משרד החינוך
המזכירות הפדגוגית
אגף א' מדעים
הפיקוח על הוראת מדעי כד"א

המחלקה להוראת המדעים

המרכז הארצי
להוראת מדעי כדה"א

מינהלת מל"מ
המרכז הישראלי לחינוך מדעי-טכנולוגי
ע"ש עמוס דה-שליט

אטמוספירה פלנטרית

אוגדן חומרי הוראה לתכנית
מדעי כדה"א בחטיבה העליונה

האטמוספרה של כדור הארץ מהחלל

הפרויקט בוצע על פי מכרז מס' 09/07.13 עבור המזכירות הפדגוגית, משרד החינוך

הקדמה

תכנית הלימודים במגמת מדעי כדור הארץ בחטיבה העליונה, מבוססת על גישת מערכות כדור הארץ. לפי גישה זו מורכב כדור הארץ מארבע תת-מערכות שמקיימות ביניהן קשרי גומלין של מעברי חומר ואנרגיה: הגיאוספרה, ההידרוספרה האטמוספרה והביוספרה.

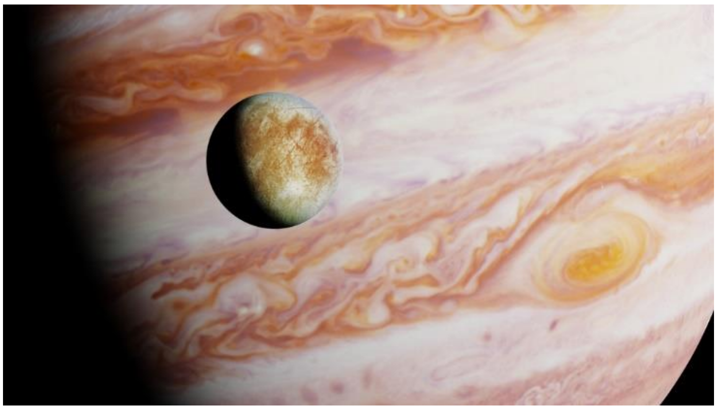
בשל המקום המרכזי שתופסת האטמוספרה באתגרים הגדולים הניצבים כיום בפני האנושות (דוגמת שינויי האקלים וההתחממות הגלובלית), יש חשיבות עצומה להבנת מקומה ותפקידיה של האטמוספרה ושל מערכת קשרי הגומלין שמתקיימים בינה לבין תת-המערכות האחרות. רק הבנה עמוקה של המערכת תאפשר לאנושות להתמודד כראוי עם האתגרים.

חומר הלימוד הקיים כיום לתלמידים בתחום האטמוספירה הוא ראשוני מאד ומתמקד במחזור הפחמן. כדי להביא להבנה מערכתית עמוקה של מקומה של האטמוספרה והתהליכים המתרחשים בה, יש צורך בתוספת משמעותית לפעילויות הקיימות ובעיקר בהיבט האטמוספרה בכדור הארץ בהיבט המערכתי הרחב של מערכת השמש. לדוגמה, הכרת והבנת תופעות אטמוספריות בכדור הארץ ופלנטות אחרות של מערכת השמש; אינטראקציה עם כוכבים כמו השמש וכוכבים מחוץ למערכת השמש. לימוד האטמוספירה בהיבט מערכת השמש הוא חלק המקשר בין הפלנטה לחלל החיצון מבחינת מעברי חומר ואנרגיה. לימוד הנושא בדגש האינטראקציה שבין האטמוספירה לבין החלל החיצון יאפשר מעבר הדרגתי מהמוחשי למופשט. בחוברת זו נאספו חומרים ופעילויות החקר הקיימות (בארץ ובעיקר בעולם) בנושאי האטמוספרה וקשרי הגומלין שבינה לבן שאר מערכות כדור הארץ והחלל, אשר ניתן להתאימם לרמת בית ספר התיכון. חומרים אלו יעזרו בהמחשה והמשגה של תופעות אטמוספריות כגון הזוהר הצפוני (אינטראקציה בין הרוח הסולרית לבין שדה מגנטי של פלנטה האטמוספרה שלה).

לחוברת שני חלקים:

חלק א': מערכי שיעור מלאים, שמקורם ממחלקות חינוך של סוכנויות חלל של מדינות שונות. לחלק מהמערכים נלווים מאמרים מדעיים הדנים בתופעה הנלמדת.

חלק ב': מאמרים מדעיים על תופעות אטמוספריות בכוכבי לכת שונים וסקירה שמטרתה לפשט ולהנגיש את הכתיבה המדעית.



הירח אירופה על רקע הסערות באטמוספירה של צדק

תוכן עניינים

הקדמה

חלק א': מערכי שיעור מלאים

נערכו על ידי מחלקות חינוך של סוכנויות חלל שונות בעולם (כולל הישראלית). לחלק מהמערכים נלווים מאמרים מדעיים הדנים בתופעה הנלמדת.

1. **הלווין ונוס** – לימוד חישה מרחוק בדגש על הלווין ונוס של התעשיה האוירית בשיתוף עם סוכנות החלל הצרפתית ***(סוכנות החלל הישראלית)***
2. **Survivor Earth** - גישת מערכות כדור הארץ בדגש על תפקיד האטמוספרה ומחזור המים, איסוף נתונים וניתוחם כולל שימוש בנתוני לווינים (***NASA***)
3. **מערך מעשי - INFRARED WEBCAM HACK-** השמשת מצלמת המחשב הנייד כחיישן אינפרה אדום **(סוכנות החלל האירופית)**
4. **אטמוספרה פלאנטרית –** יחידת האטמוספרה המופיעה כחלק מתכנית לימודים הכוללת היכרות עם כלל התופעות הגיאולוגיות והאטמוספריות של פלנטות וגופים אחרים במערכת השמש ***(NASA)***
5. **הזוהר הצפוני -** מיקום הזוהר הצפוני, מקורותיו, השלכות על חיי היום יום (***NASA***)
6. **האטמוספרה של טיטאן –** שימוש בספקטרוסקופיה להבנת הרכב אטמוספרי **(סוכנות החלל האירופית)**

חלק ב': הצעות לפיתוח מערכים עתידיים

מאמרים על תופעות אטמוספריות בכוכבי לכת שונים, המשלבים מאמרים מדעיים עם סקירות המפשטות מעט את המידע.

1. מערכות עננים על נוגה כסמן לפני השטח ***(סוכנות החלל האירופית)***
2. זוהר צפוני של קרני X על צדק ***(סוכנות החלל האירופית)***
3. חימום האטמוספרה של צדק ע"י רוח השמש **(NASA)**
4. הזוהר הצפוני של צדק – מאמר מקור מ- **Nature (2002)**
5. חימום האטמוספרה של צדק ע"י רוח השמש – מאמר מקור מ- **Nature (2019) Astronomy**

חלק א': מערכי שיעור מלאים

חלק זה מכיל מערכי שיעור שפותחו במחלקות חינוך של סוכנויות החלל הישראלית, האמריקאית (NASA) והאירופית (ESA).

למערכי השיעור מצורפים קבצים דיגיטליים שונים, כולל מצגות, הנמצאים על הדיסק המצורף, מחולקים לתת- תיקיות לפי שמות המערכים השונים.

משרד המדע והטכנולוגיה

ISA
סוכנות החלל הישראלית
משרד המדע והטכנולוגיה

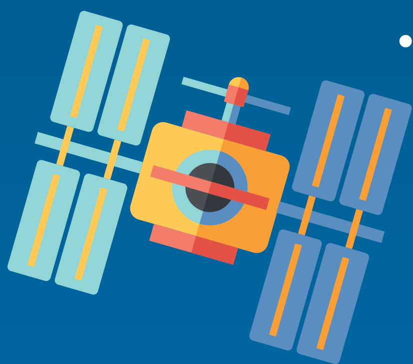
היכרות עם הלוויין ונוס וניתוח תצלומיו

גיל התלמידים: חט"ב

מספר תלמידים מומלץ: עד 25

משך השיעור: 90 דקות

כותבות המערך: ד"ר שמרית ממן וד"ר סיון איזיקסון מהמעבדה לחישה מרחוק והדמאה פלנטרית באוניברסיטת בן גוריון בנגב.



יש להדפיס את דפי העבודה והתמונות המצורפות בצבע ובאיכות גבוהה ככל האפשר. לחלופין מומלץ לקיים את השיעור בכיתת מחשבים. בדפי העבודה יש שאלות בונוס המצריכות שימוש בתוכנה החינמית Google earth. מומלץ מאוד להתקינה.

VENµS

רציונל למורה

- שיעור זה עוסק בתרומתו הייחודית של הלוויין ונוס ובתכונותיו של לוויין זה ותכונותיהם של לווייני חישה מרחוק בכלל.

מטרות (ידע ומיומנויות)

- התלמידים יכירו ויבינו את המושג החישה מרחוק ואת חקר כדה"א באמצעות הדמאות לוויין.
- התלמידים ילמדו על עקרונות בסיסיים במחקר סביבתי בניתוח הדמאות לוויין (ארבע הרזולוציות).
- התלמידים יכירו את תכונותיו ויתרונותיו של הלוויין ונוס.
- התלמידים יתנסו בניתוח הדמאות שהתקבלו מהלוויין ונוס, בחילוץ מידע ובהשוואה ללוויינים אחרים.

מושגים עיקריים

- חישה מרחוק, רזולוציה, רזולוציה מרחבית, רזולוציה רדיומטרית, רזולוציה ספקטראלית, רזולוציה עיתית, ניטור שינויים בזמן, מולטי־ספקטראליוּת, צילום אינפרה־אדום

מקורות מידע ותוכנות

- מידע על הלוויין ונוס באתר סוכנות החלל הישראלית
- Google Earth (מומלץ)

רקע למורה ומושגים

חישה מרחוק

חקר כדה"א מהחלל הוא תחום טכנולוגי־גאוגרפי שהחל להתפתח לפני כחמישים שנה עם שליחת לווייני הריגול הראשונים (לווייני תצפית, חישה מרחוק). כיום קיימים עשרות לווייני צילום, הן מחקריים והן מסחריים, ולכל לוויין תכונות משלו, בהתאם למשימה שלשמה שוגר.

כבר שנים רבות יש למדינת ישראל נציגות מכובדת של לווייני תקשורת ולווייני חישה מרחוק בחלל. **בשנת 2017 בלטה בהישגיה הלוויינות הישראלית בתחום החישה מרחוק**. בשנה זו שוגרו בהצלחה שני לווייני תצפית ישראליים. הראשון - ננו־לוויין BGUSAT, לוויין של אוניברסיטת בן־גוריון בנגב בשיתוף עם התעשייה האווירית וסוכנות החלל הישראלית. השני - הלוויין ונוס VENμS , פרי שיתוף פעולה של סוכנות החלל הישראלית וזו הצרפתית. הלוויינים הללו עדיין שוהים בחלל, מצלמים אתרים נבחרים על פני כדה"א ומשדרים את התמונות אל תחנות הקרקע.

הדמאות לוויין

לתיאור צילומי לוויין אנו משתמשים במונח הדמאה (Image), ולא הדמיה (Simulation).

הלוויין ונוס

ונוס, ששמו נכתב בלועזית VENμS (ראשי תיבות של Vegetation and Environment on a New Micro Satellite), הוא לוויין חישה מרחוק שנבנה ומופעל בשיתוף פעולה של סוכנות החלל הישראלית והצרפתית. הלוויין שוגר באוגוסט 2017 והדמאות שלו כבר משמשות חוקרים ברחבי העולם במגוון נושאי סביבה וחקלאות.

כאן בלינק אפשר לעקוב ולראות היכן נמצא הלוויין ונוס בכל רגע.

רזולוציה

משמעות המילה רזולוציה היא כושר הפרדה או כושר הבחנה. בהקשר של הדמאות לוויין ושל תמונות בכלל, המושג רזולוציה מציין את היכולת שלנו להפריד ולהבחין בין עצמים בתמונה. יכולת זו תלויה במאפיינים שונים של התמונה, וכל מאפיין הוא כשלעצמו סוג של רזולוציה, כפי שיפורט להלן.

רזולוציה מרחבית

רזולוציה מרחבית עניינה **גודלו של** העצם הקטן ביותר שניתן לזהות בתמונה. היא מתבטאת בגודל הפיקסל בתמונה - כמה שטח במציאות מייצג כל פיקסל. גודל הפיקסל תלוי ביכולות החיישן (סנסור) ובמרחק שלו מהאובייקט המצולם. בצילומים של אובייקטים על פני הקרקע במצלמה רגילה, ייתכן גודל פיקסל של 1 מ"מ עד 1 ס"מ. בהדמאות לוויין גודל הפיקסל יהיה לרוב בין מטרים אחדים לאלף מטרים.

הרזולוציה המרחבית של ונוס: גודל הפיקסל של ונוס הוא 5~ מטר לפיקסל. זוהי רזולוציה מרחבית הנחשבת גבוהה לחיישנים לוויינים (HSR – High Spatial Resolution). לשם ההשוואה, לווייני מזג אוויר מצלמים ברזולוציה של כ-1,000 מטר לפיקסל, ולעומת זאת יש היום לוויינים המצלמים ברזולוציה של 1 מטר לפיקסל ואף פחות, ונחשבים בעלי רזולוציה מרחבית גבוהה מאוד (VHSR - Very High Spatial Resolution). בעתיד מתוכנן הלוויין ונוס לשנות מסלול קרוב יותר אל כדה"א ולשפר את הרזולוציה המרחבית שלו: להגיע ל-2.7 מטר לפיקסל.

רזולוציה רדיומטרית

רזולוציה רדיומטרית עניינה כמות **הגוונים** שכל פיקסל יכול לייצג (מספר גווני אפור). ככל שמתועדים בתמונה יותר גוונים, כך גדלה יכולת ההבחנה בין אובייקטים שהגוונים שלהם כמעט זהים. הרזולוציה הרדיומטרית מבוטאת בשיטה הבינארית לביטוי מספרים ועל כן נמדדת בביט, וכמות הגוונים מחושבות בחזקות על בסיס 2.

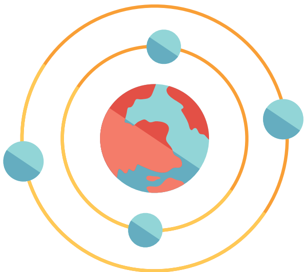
הרזולוציה הרדיומטרית של ונוס: הרזולוציה הרדיומטרית של הלוויין ונוס היא 10 ביט, כלומר 1024 גווני צבע אפשריים בכל אחד מהערוצים.

צילום מולטי־ספקטראלי (רב־ערוצי)

מצלמות רגילות מצלמות בתחום הנראה לעין בשלושה ערוצים: כחול, ירוק ואדום. התמונה המתקבלת ממצלמות צבעוניות היא השילוב של הצבעים הללו בעוצמות שונות של בהירות.

מצלמות מולטי־ספקטראליות המשמשות במחקר יכולות לצלם בתחומים נוספים **של הספקטרום האלקטרומגנטי**. למעשה הן "רואות" קרינה במגוון אורכי גל. מצלמות מולטי־ספקטראליות מותקנות על לוויינים רבים ועל מטוסים ורחפנים. תמונות הלוויין ותצלומי האוויר משמשים לשלל מטרות: מחקרים אקולוגיים, מיפוי גאולוגי, שימושים חקלאיים ועוד.

רזולוציה ספקטראלית



רזולוציה ספקטראלית היא מידת יכולותו של החיישן להבחין בין **אורכי הגל** השונים, הן בתחום הנראה והן בתחומים נוספים כמו אולטרה־סגול, אינפרה־אדום, תֶּרְמִי וכד'. ככל שהתמונה כוללת יותר תחומים בספקטרום האלקטרומגנטי וככל שיכולת ההבחנה בין אורכי הגל גדלה, כך מתקבל יותר מידע על האובייקטים המצולמים בהדמאה.

רזולוציה ספקטראלית של ונוס: המצלמה המותקנת על הלוויין מורכבת מ-12 ערוצים בתחום האור הנראה והאינפרה־אדום הקרוב. ריבוי הערוצים בתחום זה (ערוצים יחסית צרים) ותכונותיהם מקנים ללוויין רזולוציה ספקטראלית גבוהה בתחום הרגיש לניטור ומחקר צומח.

צילום באינפרה־אדום קרוב לשם מחקר חקלאי ואקולוגי

שילוב התחום הנראה והאינפרה־אדום בהדמאות לוויין מספק מידע חשוב על מצב הצמח והקרקע. בעזרת עיבוד התמונות ניתן לאתר מחלות או יובש בצמחים (עקת יובש), להעריך את טיב היבול בשלב מוקדם ובכך לסייע בתכנון יעיל וניהול נכון של השדות החקלאיים.

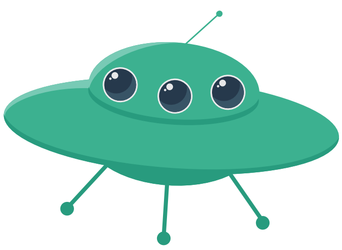
רזולוציה עיתית

רזולוציה עיתית בלוויין עניינה **הזמן** שחלף בין תיעוד אחד של נקודה על פני כדה"א למשנהו. התיעוד של כדה"א לאורך זמן בצילומי לוויין מאפשר השוואה של תופעות בקנה מידה נרחב.

רזולוציה עיתית של ונוס: זמן החזרה של ונוס הוא יומיים בלבד. זהו זמן חזרה הנחשב גבוה והוא מאפשר מעקב אחר שינויים מהירים למדי, כמו תגובה לשרפות, פגעים בחקלאות, תגובת צמחים לזיהום ממוקד ועוד. לצורך השוואה, זמן החזרה של לוויני התצפית האמריקאים מסדרת LANDSAT, סדרה גדולה ומוצלחת, הוא 16-18 יום! בטווח זמן זה אנו עשויים להחמיץ אירועים קריטיים כמו שרפות או שיטפונות בזק, ואין אפשרות לעקוב כראוי אחר גידולים חקלאיים מהירי צימוח כגון תירס.

סיכום נושא רזולוציות הדמאות הלוויין ונוס:

אף על פי שיש כיום לוויינים בעלי רזולוציה מרחבית, רדיומטרית, ספקטראלית או עיתית גבוהה מזו של הלוויין ונוס, יש לבחון כל לוויין על פי מכלול הרזולוציות שלו. לרוב רזולוציה אחת באה על חשבון אחרת. ונוס נחשב לוויין ייחודי ומוביל ביכולות המחקר שהוא מאפשר, בשל שילוב כלל התכונות שלו ובעיקר בזכות ריבוי ערוצים יחסי בתחום האור הנראה והאינפרה־אדום הקרוב ובזכות תדירות הצילום הגבוהה. ריבוי הערוצים מספק מידע רב על מצב הצמחייה והקרקע, ותדירות הצילום הגבוהה מאפשרת ניטור של שינויים מהירים בסביבת המחקר.



מהלך השיעור

תקציר השיעור:

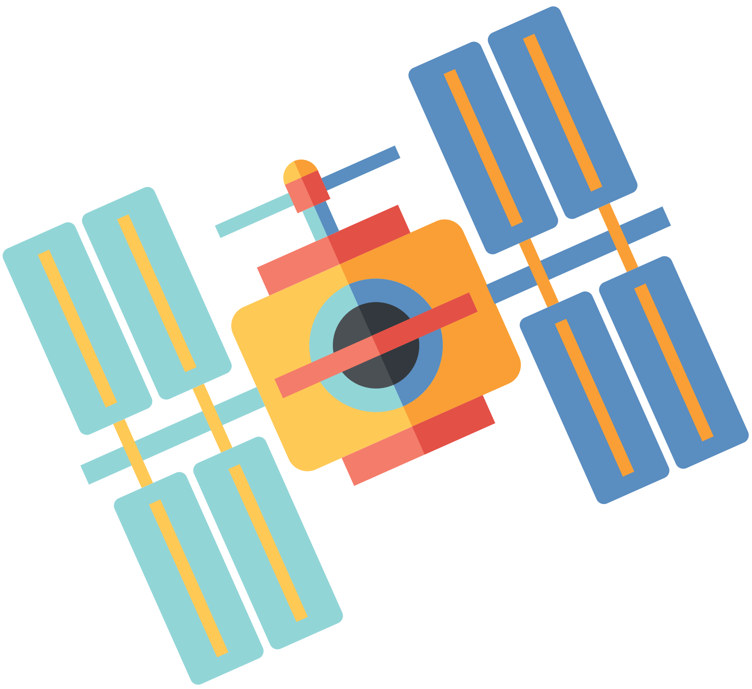
מבוא המסביר על לוויינים וחישה מרחוק בכלל ועל הלוויין ונוס בפרט > פרק מבוא: מהי רזולוציה > פרק על רזולוציה מרחבית > פרק על רזולוציה רדיומטרית > פרק על רזולוציה ספקטראלית > פרק על רזולוציה עיתית.

עבור כל אחד מן הפרקים על הרזולוציות מצורף דף עבודה לתלמידים בליווי הדמאות לוויין. מומלץ לפנות לדף העבודה בתום כל פרק במצגת, אך ניתן גם לרכז את דפי העבודה לסיום המצגת כולה.

רצף מומלץ לשיעור

הנושא	מס' שקופית	הנחיות למורה
שימו לב: בחלק מהשקופיות יש הערות הבהרה ודגשים למורה בתוך המצגת.		
מבוא	9-2	• שקפים אלה נועדו ליצור עניין בתלמידים ולהציג להם את נושא הלוויינות והחישה מרחוק בהקשר של הלוויין הישראלי־צרפתי החדש, ונוס. • כדאי להתעכב ולהגדיר על הלוח, עם התלמידים, מהי חישה מרחוק. • *בחיי היום־יום אנו כבר רגילים לראות על מסך הטלוויזיה שלנו ובאתרי אינטרנט את השימוש הרחב בהדמאות לוויין. בפעם הבאה שתצפו בחדשות, למשל, שימו לב שהמפות המוצגות הן למעשה הדמאות לוויין.
מהי רזולוציה	16-10	• הסבר על רזולוציה, מושג שהתלמידים ודאי שמעו בעבר אך יתקשו להגדיר. נסו לתת לתלמידים להגדיר את המושג בעצמם בתחילה, או לומר מה הם יודעים עליו, באיזה הקשר שמעו את המושג וכו'.
רזולוציה מרחבית	24-17	• הסבר והדגמה על רזולוציה מרחבית. • שימת דגש על כך שרזולוציות שונות מתאימות למשימות מחקר שונות. • אם מתפתח דיון ניתן לציין גם את החסרונות של רזולוציות גבוהות, לדוגמה גודל הקובץ. ככל שיש יותר פיקסלים בתמונה נתונה, כל פיקסל מייצג שטח קטן יותר במציאות. זוהי רזולוציה מרחבית גבוהה יותר, ופירושו של דבר קובץ כבד יותר (והדבר נכון לעוד סוגי רזולוציות). • למשימות רבות יש צורך ברזולוציה מרחבית גבוהה, למשל למחקרים העוסקים באוכלוסייה ובמבנים בשטח עירוני, או למשימות ריגול וליישומים צבאיים.
רזולוציה רדיומטרית	26-25	• פרק קצר על רזולוציה רדיומטרית. גם דוגמת החתול בתחילת המצגת היא רזולוציה רדיומטרית. לפרק זה אין תרגיל התנסות. • מטרת הפרק להמחיש שוב שכל פיקסל בתמונה מקבל ערך, כלומר צבע, וכך נבנית התמונה.

הנושא	מס' שקופית	הנחיות למורה
רזולוציה ספקטראלית	39-27	• חשובה לפרק זה ההבנה שתמונה דיגיטלית (ממצלמת סמארטפון או ממצלמה לוויינית) היא למעשה שילוב של שלוש תמונות בצבעים שונים. • נדרש הסבר קצר על הספקטרום האלקטרומגנטי ועל הקרינה באורכי גל שונים. כאשר אנו מסתכלים "מעבר לחושינו", כלומר מעבר לתחום הנראה, אנו מקבלים מידע חדש על שטח המחקר. למשל, אם נסתכל על אצטדיון בתחום הנראה בלבד, לא נוכל לדעת אם הדשא אמיתי או סינתטי: לשניהם צבע ירוק. אולם אם נצלם את האצטדיון בתחום האינפרה־אדום הקרוב, ההבדל יהיה מובהק. * כדי שנוכל לראות מעבר לחושינו (מעבר לתחום הנראה בעין האנושית) אנו משתמשים בחיישנים מיוחדים כגון מצלמות תרמיות ומצלמות חישה מרחוק המותקנות על לוויינים. יש בעלי חיים המסוגלים לראות בתחומים אלו ללא חיישנים. דבורים, למשל, רואות בתחום האולטרה־סגול וכמה מסוגי הנחשים רואים בתחום האינפרה־אדום, כלומר ראייה תרמית.
רזולוציה עיתית	43-40	• התמקדות באחת התכונות החשובות של הלוויין - זמן חזרה. • כדאי להגדיר עם התלמידים מהו זמן חזרה, ולדון בחשיבותו של זמן חזרה קצר כמו של ונוס (יומיים) ובסוגיות מחקר סביבתיות שהלוויין יאפשר לחקור (דוגמאות בהערות לשקופיות במצגת). * זמן חזרה, כפי שהוזכר לעיל, הוא קריטי בחקר תופעות פתאומיות כגון אסונות טבע (הוריקנים, התפרצות הרי געש, שיטפונות וכד'). בחקר תהליכים הדרגתיים יותר, זמן חזרה קצר משפר את מידת הדיוק ואת איכותם של הנתונים המתקבלים (לדוגמה, השפעת התפשטות מחלה בשדה חקלאי).
סיכום	44	• תרומתו האפשרית של הלוויין ונוס למחקר סביבתי. • לאחר שהתלמידים הבינו את יכולות הלוויין יתקיים דיון ובו הם יתבקשו להעלות רעיונות: מה יאפשר הלווין לחקור ולמצוא ובאילו תחומים.



הפעילות לתלמיד

רזולוציה מרחבית

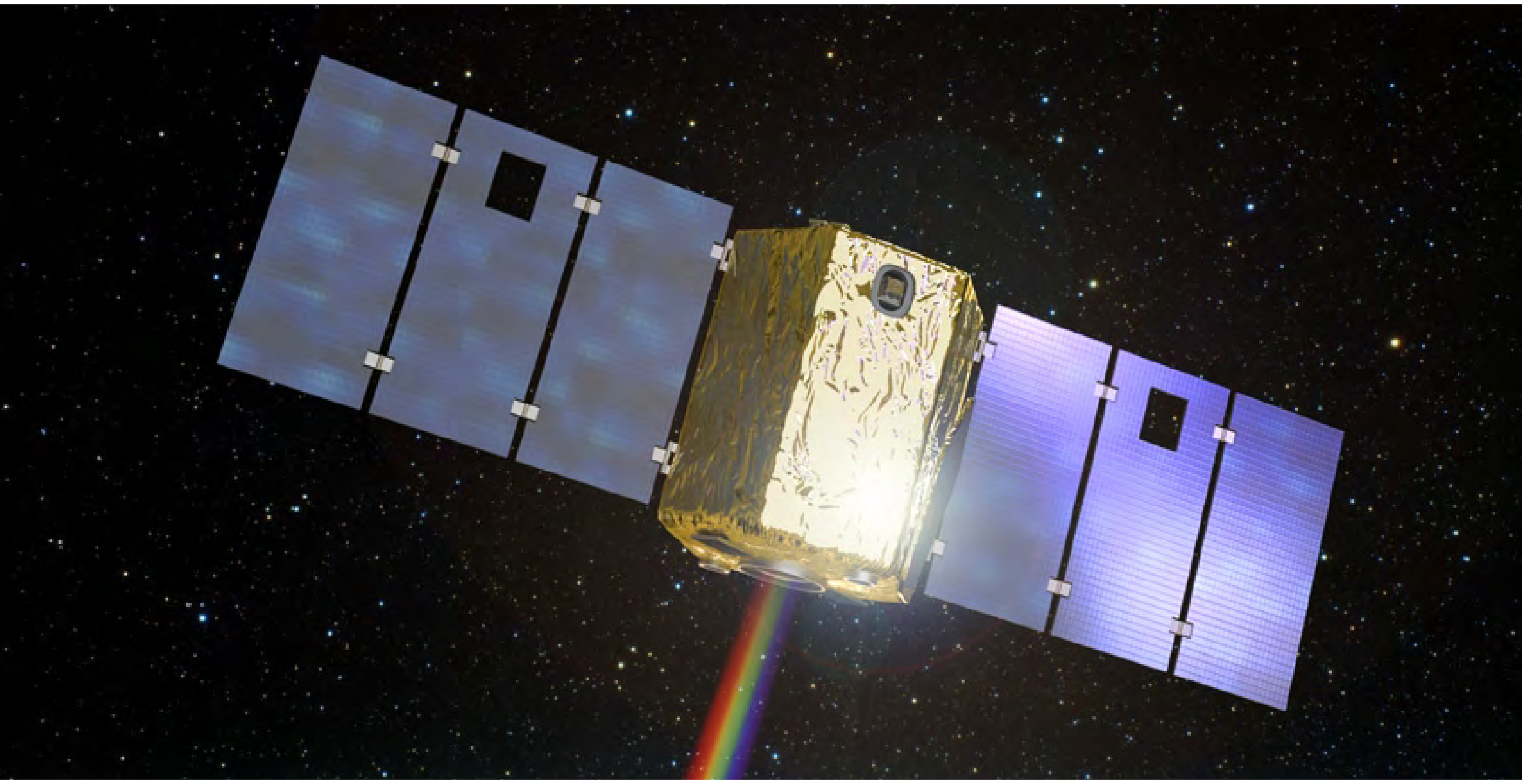
מטרת המטלה היא להמחיש לתלמידים את המשמעות של גודל הפיקסל הנחוץ לזיהוי העצמים בתמונה.

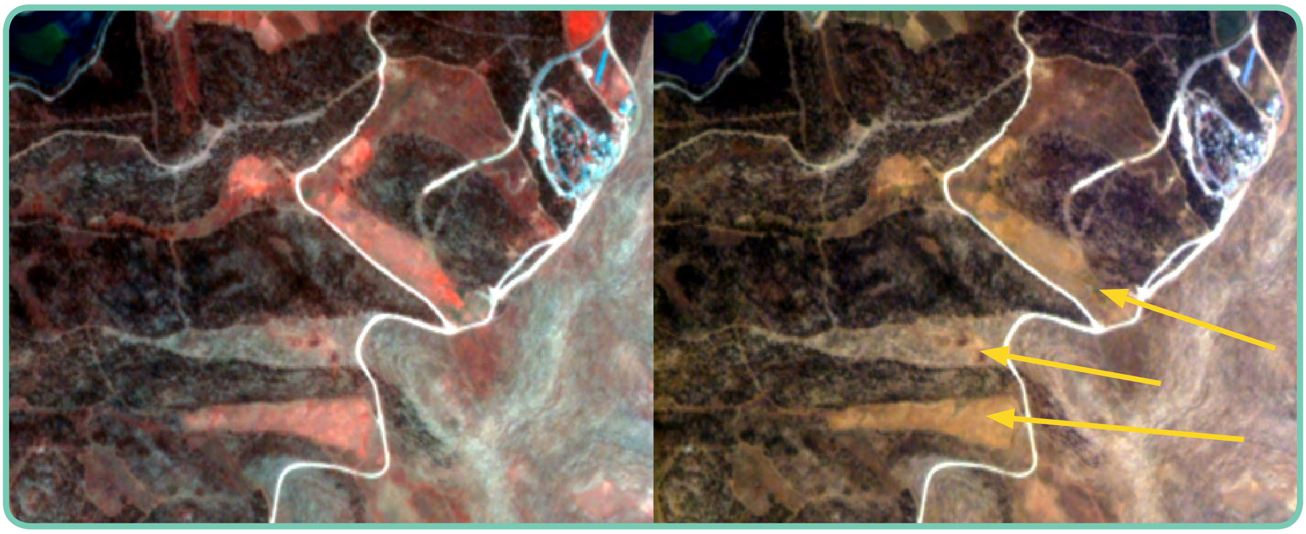
1. פרטים שלא ניתן להבחין בהם ברזולוציה של 30 מטר: שבילים קטנים, מבנים, שדות קטנים, פרטים בקו החוף וכד'. הנחו את התלמידים למצוא פרטים רבים ככל האפשר ולסמנם על ההדמאה המודפסת, או הקרינו על לוח מחיק וסמנו עם התלמידים את הפרטים.
2. מובן שיש אינסוף פריטים שאיננו יכולים לראות ברזולוציה של 5 מטרים: מכוניות, אנשים, עצים וכד'.
3. שאלת בונוס: **יש לשים לב להבדל בין הדמאות לוויין של Google earth לבין תצוגת רחוב (Street view)** הרזולוציה המרחבית בתצוגת הרחוב היא אומנם גבוהה מאוד וניתן לראות פרטים שאי אפשר לראות מהלוויין, אבל החיסרון של תצוגת הרחוב הוא הרזולוציה העיתית והכיסוי המרחבי. תצוגת רחוב מצולמת אחת לכמה שנים ולכן אינה עדכנית.

רזולוציה ספקטראלית

מטרת המטלה היא להמחיש לתלמידים ששימוש בתחום שמעבר לאור הנראה (מעבר לחושינו), מאפשר קבלת מידע חדש.

1. מה רואים כאשר בוחנים את יער יתיר באור אינפרה־אדום קרוב (מיוצג בהדמאה בצבע אדום):
   - **השדות החקלאיים** בולטים לעין לעומת היער, בשל צפיפות הצומח בשדות החקלאיים (ניתן לראות ב-Google earth שהיער דליל מאוד ולכן כל פיקסל ביער מכיל גם צמחייה אך גם הרבה קרקע).
   - **ערוצי הנחלים** בסביבה המדברית מסביב ליער, שבתמונת הצבע הרגיל לא ברור אם יש בהם צמחייה, נראים אדומים בתמונת האינפרה־אדום הקרוב, ודבר זה מלמד על נוכחות צמחייה.
2. דוגמה לאזורים שנראים דומים זה לזה בתמונת האור הנראה: שימו לב לשלושת הוואדיות ממזרח ליער (בצורת משולשים; מסומנים בחיצים צהובים בתמונה מימין). הגוון שלהם נראה דומה, אך כשבוחנים את השטח באור באינפרה־אדום קרוב הוואדי האמצעי נראה אדום פחות. מתברר אפוא שיש בו פחות צמחייה.





איור 1: מימין הדמאה של יער יתיר באור הנראה. משמאל אותו אזור בצילום אינפרה־אדום קרוב (צבוע באדום).

רזולוציה עיתית

מטרת המטלה היא להמחיש לתלמידים את השינויים הרבים המתרחשים באזור חקלאי ואת ניטורם באמצעות הלוויין.

1. אסונות טבע וכן גידולים חקלאיים הם דברים שחל בהם שינוי בטווח זמן של יומיים, ולכן הלוויין ונוס רלוונטי מאוד למחקרים שעוסקים בהם. לעומתם, בתהליכים ארוכי טווח הקשורים באקלים העולמי, כמו התחממות גלובלית, המסת קרחונים, מִדבּוּר, הם תהליכים שאי אפשר להבחין בשינוי בהם בטווח של יומיים.
2. השינויים שקל להבחין בהם יהיו בשטחים החקלאיים. אזורים שלא השתנו הם לרוב האזורים הטבעיים, כמו הר תבור עצמו, וכן האזורים הבנויים.

משרד החינוך
המזכירות הפדגוגית
אגף א' מדעים
הפיקוח על הוראת מדעי כד"א
הפיקוח על הוראת מדעי כדור הארץ
מכון ויצמן למדע
המחלקה להוראת המדעים
המרכז הארצי
להוראת מדעי כדה"א
מינהלת מל"מ
המרכז הישראלי לחינוך מדעי-טכנולוגי
ע"ש עמוס דה-שליט

Survivor: Earth in 10 Lessons

A Collaboration between Montgomery County Public Schools Outdoor Environmental Education Program and the Global Precipitation Measurement Mission

The following lessons have been developed to teach students about local and global water issues. They are based on NASA's Global Precipitation Measurement (GPM) Mission (http://pmm.nasa.gov/gpm/) and an instructional module designed for Montgomery County Public Schools Outdoor Environmental Education Program (http://www.montgomeryschoolsmd.org/curriculum/outdoored/). The lessons connect with both the Next Generation Science Standards as well as the Common Core Curriculum and involve STEM topics. They are hands on activities that are done largely outdoors, and which include scientific data collection and analysis and integrate technology. Many of the lessons involve data collected based on protocols from the GLOBE Program (www.globe.gov). Each lesson is designed to take one hour. The lessons build on each other, but can also be used independently. Each lesson topic includes a lesson plan, PowerPoint presentation, student capture sheet and capture sheet answer guide.

1. Connecting the Spheres: Earth Systems: Students will investigate Earth systems by making observations in nature and identifying systems in the natural world. Ultimately, the students will understand how the four spheres/systems on Earth (biosphere, hydrosphere, geosphere, and atmosphere) are interconnected.
2. Earth's Water: Students will gain an understanding of Earth's water – how much, what it's like and where it is found. Students participate in a demonstration showing the distribution and composition of water on earth. Students also create a map showing where freshwater is located on earth.
3. The Water Cycle: Students will investigate the water cycle by participating in a webquest, then building a mini model of the water cycle to observe how water moves through Earth's four systems. Students will use what they've learned to draw and label a diagram of the water cycle.
4. Water in the Hydrosphere: Students will investigate the hydrosphere by going outside and using scientific equipment to measure temperature, pH, and transparency of a body of water. They will use this qualitative and quantitative data to understand how it is important to know about the condition of freshwater sources in many places in the natural environment and how these places are connected in the water cycle.
5. Water in the Geosphere: Students will investigate water in the geosphere by going outside and using scientific equipment to measure soil moisture, temperature, color and consistence. Students will use this qualitative and quantitative data to understand how water is found in many places in the natural environment and how these places are connected in the water cycle.
6. Water in the Biosphere: Students will investigate water in the biosphere by going outside and observing plants and land cover as an indication of amount of water in the biosphere. Students will use this qualitative data to understand how water is found in many places in the natural environment and how these places are connected in the water cycle.
7. Water in the Atmosphere: Students will investigate water in the atmosphere by going outside and using scientific equipment to collect atmospheric moisture data (temperature, relative humidity, precipitation, and cloud cover). Students will use this qualitative and quantitative data to understand how water is found in the atmosphere, how the atmosphere determines weather and climate, and how Earth's spheres are connected through the water cycle.

8. Measuring Precipitation: Students are given an engineering problem (measuring precipitation), easily obtainable materials and tools and time to design their device. Students will simulate rain to test the device and compare their results. The comparison of results leads to a discussion about the need for a standardized calibration system to be used to get precise measurements that are reliable. Students are then introduced to the Global Precipitation Measurement mission and learn how this mission will set the new calibration standard for measuring precipitation across the world.
9. Water Conservation: Students will think about the many ways that people use freshwater, and how we can conserve this precious and fundamental natural resource. Students will watch a short documentary describing issues related to clean water availability, analyze water use data, and start to think about how they consume and can conserve water. This background knowledge will lead to students collecting data about their own water use and finding areas in their lives to conserve water.
10. The Global Precipitation Measurement Mission (GPM): To help students learn about the Global Precipitation Measurement Mission, they will watch a short video summarizing the purpose of the mission, learn about the parts of the satellite and their functions, and build and edible model of the satellite.

Connect the Spheres: Earth Systems Interactions Teacher Guide

Lesson Overview:

This activity was developed as an introductory experience to a series of lessons about water resources on Earth. Students will investigate Earth systems by making observations in nature and identifying systems in the natural world. Ultimately, the students will understand how the four spheres/systems on Earth (biosphere, hydrosphere, geosphere and atmosphere) are interconnected.

Learning Objectives:

- Identify processes in Earth systems
- Describe connections between Earth systems

National Standards:

Core Idea ESS2.A: Earth Materials and Systems

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produces chemical and physical changes in Earth's materials and living organisms. (MS-ESS2-b) (MS-ESS2-c)

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability and responses to natural disasters. The Global Precipitation Measurement (GPM) mission, launching in 2014, will help scientist to better understand how much rain and snow falls around the world.

Water cycles through all parts of Earth's systems. Before students can study water availability, they must first have an understanding of Earth systems and how they are connected. This lesson helps students make observations of processes in nature and relate the observations to Earth systems.

This lesson is based on the Elementary GLOBE Earth Systems Learning Activity titled "We're All Connected: Earth System Interactions." http://www.globe.gov/documents/348830/350113/ElementaryGLOBE_EarthSystemsActivity2_en.pdf

Materials:
Pencils
Clipboards
Masking tape
Copies of "Connect the Spheres" student capture sheets, including partner capture sheets
Pictures for "beat the clock" (in the "Connect the Spheres" PowerPoint)

Engage:

Give each student a pencil, capture sheet and clipboard. Explain that they are going outside on a short nature walk (Slide 2). As they walk, students will record their observations. Some questions to think about as they walk and observe could include: What do you see? What's going on outside these days/today? What do you see happening in nature? Have you noticed any changes in nature around your home or school? The observations can seem simple, but they will all be important later on. Walk for about 5-10 minutes and ask students to record a minimum of 5 observations. If the students seem to struggle, point out a few things along the way to get their minds working: the ground is covered with leaves, a small plant is growing, a bird flew from bush to bush, etc.

Explore:

Gather students back together in the classroom, or outdoor classroom. Show them the diagram of the components of Earth systems from the PowerPoint: Water, Soil, Air, Living Things, Sun (Slide 3). Ask students to write which system category each observation falls into. They can write this in the left column next to each observation on the capture sheet.

Now that they have categorized their observations, ask them to find a partner. As a pair, they will choose one of their observations to consider in more detail and describe the interactions between the systems. As you explain the task, model this process for the students (Slide 4). Hand out partner capture sheets. The pairs will write the observation and circle the picture of the system it belongs to. Then, draw arrows showing the connections between parts based on that observation. Students should write notes along the arrows to explain that connection. They should make as many connections as they can. Which group/observation will have the most connections? If they finish early, they can try another observation to see if they can get more interactions. If they seem to struggle finding many connections, show them Slide 5.

Depending on time, ask a few groups to present their observations and connections to the class. Another great technique would be to have students to post their paper around the room and do a quick gallery walk so students can see what other groups produced. Can anyone else find more connections in these examples?

Explain:

Ask the students: From what they saw/heard, what overall message can they see? What are some conclusions they can make? What is this showing us? (Slide 6) Guide students to understand that all of Earth's systems are connected in some way. Each part cannot be on its own for anything to work or survive in nature.

Evaluate:

Give the four scientific terms for each sphere and ask them to match them to the pictures as best as they can. Hint: use the prefixes to help!

Beat the clock! Show students a picture and ask them to write down as many connections between spheres as they can in 30 seconds.

Elaborate/Extend:

- Conduct this same lesson in different seasons and compare the observations and interactions.
- Play a "Find that Observation" Game. Randomly give students an interaction pair (like sun-soil) and they must find one observation that illustrates that interaction. The observation can be from their list or from a set of cards made by the teacher.
- "Earth System in a Bottle" lesson from Elementary GLOBE – students create terrariums to learn about the four spheres. http://www.globe.gov/documents/348830/350113/ElementaryGLOBE_EarthSystemsActivity1_en.pdf
- Create a play to show what they have learned about Earth's systems. http://www.globe.gov/documents/348830/350113/ElementaryGLOBE_EarthSystemsActivity3_en.pdf

Teacher Notes:

As the first lesson introducing a series of more detailed lessons, focus should be on allowing the students to make observations and think about connections in nature. It is recommended to provide vocabulary, more content and context at the end of the lesson, after students have developed their own understanding of connections between Earth systems.

Additional Resources:

- Elementary GLOBE Earth Systems Story Book
  http://www.globe.gov/documents/348830/350113/ElementaryGLOBE_EarthSystems_en.pdf
- Precipitation Education Earth Systems Resources
  http://pmm.nasa.gov/education/subtopics/earth-systems
- NASA Expedition Earth and Beyond "Spheres of Earth" lesson materials
  http://ares.jsc.nasa.gov/ares/eeab/SOE.cfm
- Series of lessons/labs about Earth System Science from the Science Education Research Center at Carleton College
  http://pmm.nasa.gov/education/lesson-plans/earth-system-science

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"Connect the Spheres: Earth's Systems Interactions"
Student Capture Sheet

<u>Guiding Questions</u>

What "systems" are found on Earth?

How dÏ Earth's systems interact?

<u>Engage</u> - Nature Walk Observations – make at least 5

	Observation
	1.
	2.
	3.
	4.
	5.
	6.
	7.

<u>Explain</u>

After seeing many examples, what conclusions about Earth's systems can you make?

Evaluate

Match these vocabulary words to the systems: water, earth materials, air, living things

Hydrosphere =

Biosphere =

Atmosphere =

Geosphere =

Beat the clock! When the teacher shows you a picture, write as many interactions between Earth's systems as you can before the timer runs out!

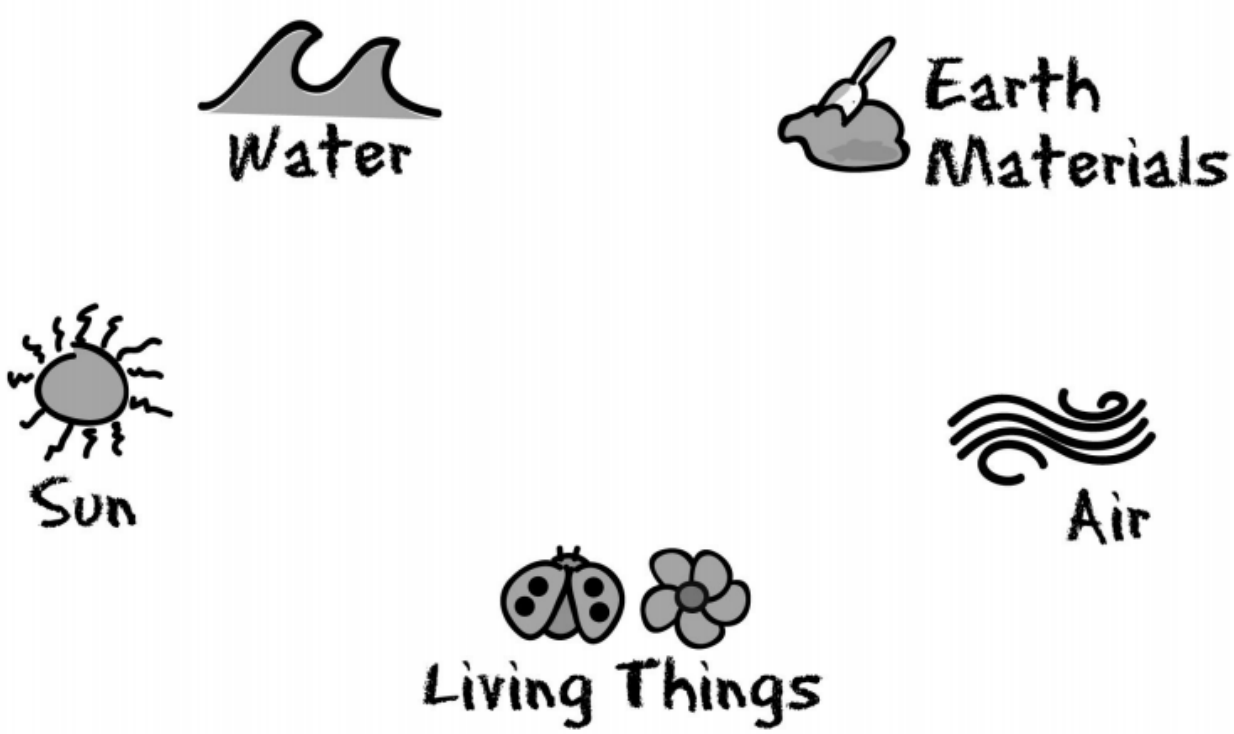
Picture	Interactions

Partner Names:

"Connect the Spheres: Earth's Systems Interactions"
Partner Capture Sheet

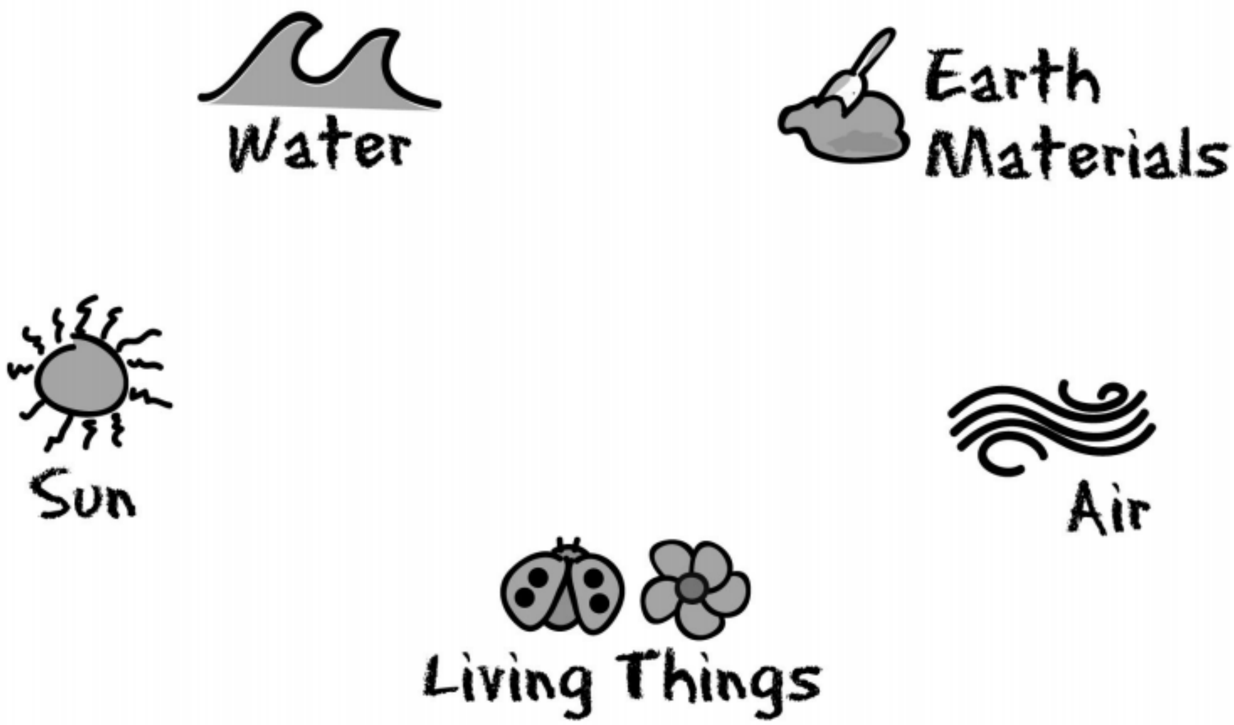
Observation: ____

1. Circle which system the observation belongs with.
2. Draw arrows to make connections between that system/observation and they other systems. Make as many as you can!
3. Along each arrow, write details about what that interaction is.



Observation: ____

1. Circle which system the observation belongs with.
2. Draw arrows to make connections between that system/observation and they other systems. Make as many as you can!
3. Along each arrow, write details about what that interaction is.



Earth's Water Teacher Guide

Lesson Overview:

This activity was developed to give participants an understanding of Earth's water – how much exists, what it's like and where it is found. n this oned hourd long activity, students participate in a demonstration showing the distribution and composition of water on Earth. Students also create a map showing where freshwater is located on Earth (in streams, ice packs, wetlands, etc.).

Learning Objectives:

- Explain how much water is on Earth
- Describe the forms and locations of water on Earth
- Explain why it is important to know about our water resources

National Standards:

Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes

- Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land. (MS-ESS-4)

Core Idea ESS2.A: Earth Materials and Systems

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produces chemical and physical changes in Earth's materials and living organisms. (MS-ESS2-b) (MS-ESS2-c)

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability and responses to natural disasters. The Global Precipitation Measurement (GPM) mission, launching in 2014, will help scientist to better understand how much rain and snow falls around the world.

Materials:
Copies of "Earth's Water" student capture sheets
Crayons – red, blue, green, gray
5 gallon bucket
Measuring cup (1/2 cup and 2 cup sizes)
Ice cube tray
Water dropper
Globes or color maps of Earth

Engage:

Use the "Earth's Water" PowerPoint and ask students to answer three riddles. (Slide 2
What do the answers all have in common? WATER!

Show the students a picture of Earth from space. (Slide 3) Ask the students how much of Earth's surface is covered with water? (About 70%). Ask the students to list what they know about water and what they would like to learn on the KWL chart. Where is water? What kinds of water exist in, on, or around Earth? Why is water important?

Share answers with the class.

Explore:

Demonstration: Amounts of water on Earth

(adapted from http://ecosystems.psu.edu/youth/sftrc/lesson-plans/water/6-8/everywhere)

Show the students a 5-gallon bucket filled with water. This represents all the water on Earth. Ask students to make a prediction: of the 5 gallons of water, how much do you think is available to humans? (If desired, review with students what "available water" would be: fresh, liquid able to be accessed from surface water or aquifers.) (Slide 4)

Using the 5 gallon bucket of water, ask a student to come up and remove 2 cups of water. The bucket water represents salt water (97%) and the 2 cups represent fresh water (3%) Move the bucket to the side and focus on the cups of freshwater. Ask another student to remove ½ cup of water from one of the 2 cups. Pour the other 1 ½ cups into an ice cube tray. The 1½ cups of water represents freshwater that is stored as ice in glaciers and polar ice caps and is therefore not available for our use. The ½ cup of water is liquid water in the ground, surface water (rivers, lakes), and water vapor in the atmosphere. Although it is all freshwater, it is not all clean and usable by humans. Pull out an eye dropper and ask a third student to come up and hold her his/her hand. Drop one drop of water into the hand – this one drop represents the amount of freshwater that is clean, and accessible to humans.

Explain:

Summarize this information on the student capture sheet. (Slide 5)

Explore:

World Water Distribution

Divide students in groups of four. Give each group a globe or map of the Earth. Give them about five minutes to observe the Earth and distinguish between water and land. Discuss the observations as a class. (Slide 6) Show Slide 7 and discuss where we find water on Earth.

Load the National Geographic fresh water interactive map (Slide 8
http://ngm.nationalgeographic.com/2010/04/water/water-animation
on a computer or projector for the class. Ask students to color and shade their world map outlines according to where the water is located. First, quickly shade or color oceans (salt water) red. We cannot use this water. Next, from the NG map, color the permafrost areas gray. (Permafrost is ground that remains below freezing for several years. There is water in the soil but it remains frozen.) Also color the glacial and ice areas gray. Along with permafrost, all of this water is frozen. Notice the glaciated area and ice sheets as outlines along mountain tops. Next, color the wetland areas green. Prominent wetland areas typically occur along large river systems or where land stays saturated with water for long periods of time. Finally, shade blue over the general river and lake areas.

What other water is on Earth that we haven't labeled? Answer: Water vapor in the atmosphere.

Remind students that although there is a lot of green and blue colored on our map (liquid fresh surface water), less than 1% of all the water on Earth is available for our use.

Evaluate:

Discuss with students: (Slide 9) Why is Earth's nickname "the water planet" both appropriate and misleading? Answer: 70% of Earth is water so it is appropriate. However only about 3% is freshwater and less than 1% is freshwater that is available for animals and humans to use. Also, we cannot create more water, so it is misleading because there is not an unlimited amount of water available to us.
List at least five things you learned to complete the KWL chart we started at the beginning of class.

Elaborate/Extend:

- Give students the numbers to create their own pie chart or bar graph of global water distribution. (Slide 10) http://ga.water.usgs.gov/edu/earthhowmuch.html
  Examples: http://ga.water.usgs.gov
  http://pacificwater.org/pages.cfm/water-services/water-demand-management/water-distribution/

Teacher Notes:

There are many ways to represent the amount of water on Earth and divide it up into smaller amounts to show the amount of available fresh water. Here we have demonstrated using water from a 5-gallon bucket. Another method is to use 100 small objects and reduce them by percentages according to the estimate of water distribution on Earth. This lesson from EPA has several examples http://www.epa.gov/region1/students/pdfs/ww_intro.pdf

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/
- GPM freshwater availability classroom lesson http://pmm.nasa.gov/education/lesson-plans/freshwater-availability-classroom-activity
- An Apple as the Planet http://nasawavelength.org/resource/nwd 000d 000d 002d 889/
- EPA lesson "All the water in the world" with various levels for grades K-6 http://www.epa.gov/region1/students/pdfs/ww_intro.pdf
- USGS information about how much water is on Earth http://ga.water.usgs.gov/edu/earthhowmuch.html
- Penn State "Water, Water Everywhere" Lesson http://ecosystems.psu.edu/youth/sftrc/lesson-plans/water/6-8/everywhere

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Earth's Water Student Capture Sheet

Guiding Questions

How much water is on Earth?
Where is water found and what forms is it in?
Why is it important to know about our water resources?

Engage

1. Riddle me this:
    a. What runs and never gets tired?
    b. What runs but has n feet, roars but has n mouth?
    c. What lives in winter, dies in summer, and grows with its root upward?

2. Water on Earth

What I KNOW	What I WANT to know	What I LEARNED

Explore

Predict: Of the 5 gallons of water representing all of Earth's water, how much do you think is available to humans? ____________

Explain

97% of Earth's water is ____________________________

2.5 % of Earth's water is ____________________________

98.7% of *fresh* water is ____________________________

1.3% of *fresh* water is ____________________________

In summary: What percent of Earth's water is available to humans? ________________

Explore

Shade salt water (oceans) red.
Color frozen fresh water gray.
Color wetlands green.
Shade rivers and lake areas blue.

Evaluate

1. Why is Earth's nickname "the water planet" both appropriate and misleading?

____

____

____

____

____

2. List at least things you learned to complete the KWL chart we started at the beginning of class.

The Water Cycle Teacher Guide

Lesson Overview:

This activity was developed to give participants an understanding of Earth's water cycle. In this one-hour long activity, students participate in a webquest to learn about the water cycle, and then build a mini model of the water cycle to observe how water moves through Earth's four systems.

Learning Objectives:

- Describe the processes that a droplet of water goes through as it moves through Earth's four systems
- Identify the four Earth systems on a diagram of the water cycle

National Standards:

- *Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes*
  Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land.
    - MS-ESS2-4: Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity. [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [*Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.*]

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability and responses to natural disasters. The Global Precipitation Measurement (GPM) mission, launching in 2014, will help scientist to better understand how much rain and snow falls around the world.

Precipitation is a vital component of how water moves through Earth's water cycle. The water cycle connects all four of Earth's spheres: the hydrosphere, geosphere, atmosphere and biosphere. Water evaporates from the surface of land and oceans, rises and cools, condenses into rain or snow, and falls again to the surface as precipitation. The water falling on land collects in rivers and lakes as well as soil, and much of it flows back into the oceans. Water also transpires from plants into the atmosphere. All living things need water to survive.

This lesson is adapted from GPM's "Water Cycle Webquest" and from the Monroe County (NY) Water Authority.
http://pmm.nasa.gov/education/interactive/water-cycle-webquest
http://www.mcwa.com/MyWater/KidsWaterFun.aspx#cycle

Materials:
Computers with internet access
Copies of "The Water Cycle" student capture sheet
Large metal or plastic bowl
Bucket of water
Plastic wrap
Dry coffee mug
Long piece of string or large rubber band

Engage:

Show "The Water Cycle" presentation and ask students where the water that they drink comes from and generate a discussion about how we get the water that we use in our daily lives. (Slide 2) Inquire about how water resources are used in our daily lives (i.e. drinking, watering crops, generating power, etc.) At this point, don't worry about giving the students the answers, but rather generate curiosity and get a feel for their pre- existing background knowledge.

Explore:

Make a model of the water cycle (Slide 3)

First, set up the water cycle model by following the instructions on "The Water Cycle" student capture sheet. Move on to the next sections of the lesson while the water droplets form on the plastic wrap. Then, return to the model to make observations.

Adapted from http://www.mcwa.com/MyWater/KidsWaterFun.aspx#cycle

Explain:

Webquest (Slides 4 and 5)

(adapted from http://pmm.nasa.gov/education/interactive/water-cycle-webquest)

Tell the students that they will complete a webquest using different websites and data sets to give them some background about the water cycle. They will record their answers on a student capture sheet.

As a result of interacting with the material in this webquest, students will learn how much water on Earth is actually freshwater, how water moves through Earth's water cycle, the importance of the oceans to our water cycle, the interactions of Earth's systems as water changes state and moves through them, how the average person in the U.S. uses freshwater resources, how clouds form, and why understanding the water cycle is vital to knowing about weather, climate and natural resources.

Explain:

Return to the water cycle models. Students should record their observations and answer the questions on the capture sheet. (Slide 6)

Water from the "ocean" of water in the bowl evaporated. It condensed to form misty "clouds" on the plastic wrap. When the droplets grow large enough and become too heavy to stay up, it "rained" into the mug!

Evaluate:

Ask students to use what they've learned to draw a picture of the water cycle – it can have words, pictures, arrows, etc. (Slide 7)

Elaborate/Extend:

Ask students to add four vocabulary words to their diagram: hydrosphere, atmosphere, geosphere, biosphere.. Discuss the words, roots, and definitions if desired.

Use Slide 8 in "The Water Cycle" presentation and ask them if they can identify the parts of the water cycle labeled with letters. http://ga.water.usgs.gov/edu/watercycleguess.html Students can also build a more "real" model of the watershed with rocks, plants, etc. Use the steps from Learning Activity 2 from the following site. This can be taken home for more long-term observations. http://www.thirteen.org/h2o/educators_lesson2b.html Complete the entire water cycle webquest.

Teacher Notes:

The webquest can be completed on individual computers, as groups on computers, or as a class using the PowerPoint.

The water cycle webquest used to develop this lesson has many more sections to it. There are also many useful websites with more information about the water cycle.

It is recommended to try the mini water cycle model before doing it with students. This will help determine how much time it will take for the different water phases to occur.

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/
- Water Cycle article: http://earthobservatory.nasa.gov/Features/Water/
- EPA water cycle animation http://www.epa.gov/safewater/kids/flash/flash_watercycle.html
- Water cycle lesson plans:
  - http://www.thirteen.org/h2o/educators_lesson2b.html
  - http://learn.fi.edu/guide/hongell/lessonplans.html
- USGS Water Cycle article with diagram to label at the bottom http://ga.water.usgs.gov/edu/watercycleprecipitation.html

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The Water Cycle Student Capture Sheet

Guiding Questions

What processes does a droplet of water go through as it moves through Earth's four systems?

Engage

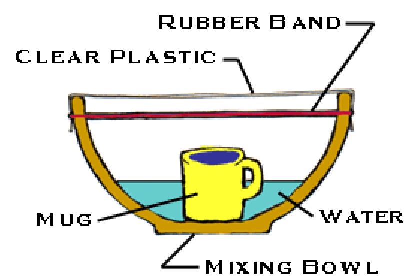
1. Where does our drinking water come from?

2. How do we use water in our daily lives?

Explore – Model Water Cycle

Materials: large metal or plastic bowl, bucket of water, plastic wrap, dry coffee mug, large rubber band or piece of string

1. Put the bowl in a sunny place outside.
2. Using the pitcher or bucket, pour water into the bowl until it is about ¼ full.
3. Place the mug in the center of the bowl. Be careful not to splash any water into it.
4. Cover the top of the bowl tightly with the plastic wrap.
5. Tie the string around the bowl to hold the plastic wrap in place.
6. Let the model sit in the sun outside while you complete the next section of the lesson.



Explain – Webquest

1. Let's begin by following molecule of water as it makes its way through the water cycle in this short animation. http://pmm.nasa.gov/education/videos/tour-water-cycle

• Is there a specific beginning or end in the water cycle? Why or why not?

• What "powers" the water cycle?

2. Let's learn more about the water cycle and the importance of water to life on Earth.
http://gpm.nasa.gov/education/videos/water-water-everywhere

- What drives water evaporation?

- Why is water vapor fresh water when it rises from the ocean?

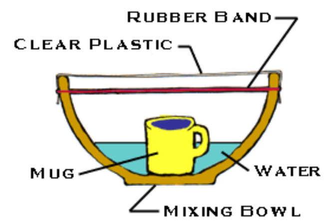
- Why might freshwater in the form of snow take longer to enter the water cycle again than liquid precipitation?

- What is an aquifer?

- What role do people play in the water cycle?

Explain – Model Water Cycle

What do you observe? After the mist starts to drip into the mug, peel back the plastic and record what you see in the mug.



What does the water in the bowl represent? What does the plastic wrap represent?

Evaluate

Draw a picture of the water cycle in the space below. Add arrows and words to label as needed.

Extend Try defining these terms in your own words: hydrosphere, atmosphere, geosphere, biosphere. Add the words to your water cycle diagram.

Water in Earth's Hydrosphere Teacher Guide

Lesson Overview:

This is an activity that was developed to give participants an understanding of the hydrosphere. In this one-hour long activity, participants learn about the hydrosphere by making observations and taking measurements. They will go outside and use scientific equipment to investigate temperature, pH and transparency of a body of water. They will use this qualitative and quantitative data to understand why it is important to know about the condition of freshwater sources in many places in the natural environment and how these places are connected in the water cycle. The data collection is based on protocols from the GLOBE program, www.globe.gov.

Learning Objectives:

- Describe Earth's hydrosphere using qualitative (words) and quantitative (numbers) data
- Interpret data to assess the condition of water in the hydrosphere
- Explain why it is important to know about the condition of our freshwater resources

National Standards:

Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes

- Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land. (MS-ESS-4)

Core Idea ESS2.A: Earth Materials and Systems

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produces chemical and physical changes in Earth's materials and living organisms. (MS-ESS2-b) (MS-ESS2-c)

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability and responses to natural disasters. The Global Precipitation Measurement

(GPM) mission, launching in 2014, will help scientists to better understand how much rain and snow falls around the world.

Water is continuously cycling through all Earth systems (the water cycle). The hydrosphere includes all Earth's water. Water is found in oceans, streams, lakes glaciers, soil and air. The hydrosphere interacts with all of Earth's spheres, and water is found in all spheres.

This lesson adapts protocols from the GLOBE Program (www.globe.gov) to help students get hands-on experience collecting scientific data about our hydrosphere so they can better understand the water cycle and why it is important to know the distribution, quantity and quality of water on Earth.

Many background facts can be found in the notes on the PowerPoint slides. These websites and resources may prove useful to get more detailed information. There are additional resources at the end of this lesson plan.

The introduction to the Hydrology Guide from The GLOBE Program
http://www.globe.gov/documents/11865/354409/hydro_chapintro.pdf

Materials:
Copies of "Hydrosphere" Student Capture Sheet
Stream picture (optional)
thermometer
pH paper
clear collection jar

Engage:

Divide the class into workgroups of 4 students. Give each group a picture of a stream (from a nearby stream if possible) or show the picture on the "Hydrosphere" PowerPoint. Present the scenario (Slide 2): You walk by this stream on your way home from school every day However, today you notice something different – there are many dead fish in the water. You wonder… what could have caused this? Ask the groups to brainstorm a list of reasons the fish might be dying on their capture sheets. Share ideas as a class.

Show students the introductory slide about the hydrosphere (Slide 3). The hydrosphere is all of Earth's water – in streams, oceans, the ground, the atmosphere, and even frozen water. Water connects all parts of Earth (all spheres) and the water cycle describes this connection and how water moves (Slide 4). Discuss why water is so important (Slide 5). Unfortunately, it is rare to find completely unpolluted water. However, even water that's not completely polluted can support life. You might lead a discussion of what the students think the definition of "polluted" water might be. Lead them to understand that when people add chemicals and other pollutants to the water, it can affect the health of the watershed. You might point out that we can't tell if water is polluted simply by looking at it. Thus scientists run tests to gather data to help them determine the health of a body of water. Today our focus is on the condition of a local water body on which living things rely. Our mission is to determine what condition the water is in and understand why it's important to collect this information.

Explore:

Present our scientific question: "How much water is present in the hydrosphere today?" Ask the students if they can identify which components of the water cycle involve the hydrosphere. Let them discuss ideas or share as a class. Then show the animation of the water cycle and narrate the animation as needed to describe the geosphere connection.

Prepare the students to go outside and test the water (Slide 6). Give them the testing equipment and review how to use and care for it. Also, review how and where to collect data (see capture sheet and data collection instructions). Finally, inform the students about how to find their study site and give them a time to return and a time---keeping device. If they finish early, they could test another site with a different land use.

Explain:

Gather the groups together (Slide 7) to share and analyze their results. Based on the data collected, have them answer the scientific question, "What is the condition of the water in the hydrosphere today?" using both qualitative and quantitative data. Students should discuss with their group and record their thoughts on the capture sheet. Use the "did you know" sections on the data collection instruction sheet to help interpret data. Remind the students that this data is just for today. They would need to collect this data over many days to get a complete idea of the condition of the water.

Evaluate:

Discuss the following with the students: list factors that would make a pond in healthy to support fish (Slide 8). Ask the students why it is important to study bodies of water (Slide 9). All the water on Earth is connected though the water cycle. We need to understand our natural waters and have data about how conditions change over time to make better decisions about how we use, manage, and enjoy water resources. Also, water is a limited resource, and we can't simply make more water. The water we have now is the same water that has been on Earth for several billion years, and it is continuously recycled through the water cycle. Therefore, it is vital that we know where and how much rain and snow falls to Earth all over the globe.

Wrap up by sharing a little about NASA's GPM Mission and satellite (Slide 10). Also share the video "Water, Water Everywhere" (Slide 11).

Elaborate/Extend:

- Show students the video "Water, Water Everywhere." http://pmm.nasa.gov/education/videos/water-water-everywhere
- Compare hydrosphere data in several different bodies of water or locations along the same body of water.
- Conduct other water quality tests from the GLOBE hydrology protocol, like nitrates, phosphates, salinity, dissolved oxygen, etc. http://www.globe.gov/documents/11865/354448/hydro_ds_invest.pdf
- Conduct a macroinvertebrate study in your water body. http://www.iwla.org/index.php?ht=a/GetDocumentAction/i/1182
- Make a secchi disk to test transparency in a more scientific way. http://des.nh.gov/organization/divisions/water/wmb/vlap/documents/secchi.pdf
- Use a map to discover how your local stream or water body is connected to others in your local watershed.

Teacher Notes:

This lesson provides students with background information about the hydrosphere, and allows students to go outside and take actual measurements to learn about the condition of the water. The data collection can happen with or without the background information

Choose locations for groups to visit where they can easily access a body of water, preferably freshwater. Groups can all test in the same area, or you can send groups to different locations and compare data.

The data collection is based on GLOBE Program protocols. The GLOBE Program has many training opportunities and offers a wide variety of different opportunities for students to collect authentic data and share it with other students around the world! Go to http://www.globe.gov and click "join" to learn more.

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/ http://www.nasa.gov/mission_pages/GPM/overview/index.html
- Background information about the hydrosphere and water cycle http://www.sciencelearn.org.nz/Contexts/H2O-On-the-Go/Science-Ideas-and-Concepts/The-water-cycle http://www4.uwsp.edu/geo/faculty/ritter/geog101/textbook/hydrosphere/hydrosphere.html http://www.geography4kids.com/files/water_intro.html

Name--- Date--- Period--

Water in Earth's Hydrosphere Student Capture Sheet

Guiding Questions

What is the hydrosphere?
What is the condition of water in the hydrosphere right now? How do you know?
Why is it important to study the condition of the surface waters?

Engage

1. As you walk by the stream in your neighborhood, you notice several dead fish floating in the water. What could be some reasons for this?

____

____

____

2. The hydrosphere is ____

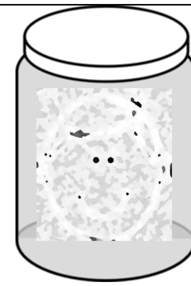
____

3. Prediction: Water is in ____________________(good condition, somewhat good condition, poor condition) in your local hydrosphere today.

Explore

Record your data below. Remember to include units!

	Data	**Notes**
Water Temperature		
pH		

Transparency		
		
D **Very Transparent**	D **Somewhat Transparent**	D **Not Transparent**
Good Quality		Lower Quality

Explain

Based on the data you collected, water is _________________________(good condition, somewhat good condition, poor condition) today. Provide evidence to support your answer. Hint: Use the "Did You Know" information on the instruction sheet to help you understand your data.

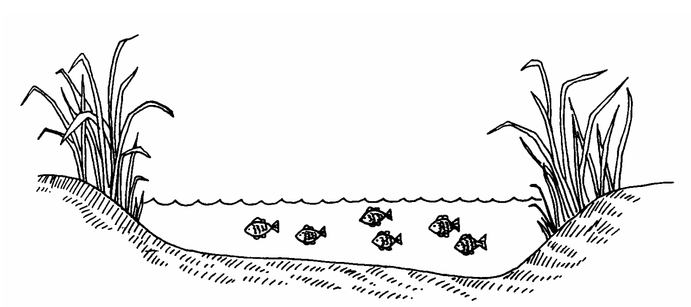
___

___

___

Evaluate

On the drawing below, label or add at least 3 factors that make the pond considered "in good condition."



Why is it important to study the surface water in your neighborhood?

___

___

Hydrosphere Data Collection

Water Temperature

1. Hold the thermometer at least 6 centimeters into the water for at least 2 minutes.
2. Record the temperature in degrees Celsius.

Did You Know: Warmer water usually allows more organisms to live in the water, however if the water gets too warm, they can grow too much or die, which pollutes the water. If the water gets too cold, organisms cannot survive.

pH

1. Dip the pH strip into the water and immediately pull it out.
2. Compare the color on the strip to the color chart on the container and record your data.

Did You Know: pH scale goes from 0 – 14 and measures the level of acid in the water, which can determine if it's safe to drink. Pure water has a pH of 7. The lower the number the more acidic; the higher the number the more basic or alkaline. A healthy stream is between 5.5 and 8.

Transparency

1. Fill the jar with water.
2. Hold the jar up in front of your group member's face. Observe how clearly you can see their face through the water. Use the chart to determine the approximate transparency.

Did You Know: Transparency refers to how far light can travel through the water. The clearer the water, the better. That means fewer particles in the water, which allows lighter so plants can grow.

Remember!!!

Gather all of your equipment before you leave!

Empty the water from the jar.

Keep the used pH strip out of the jar so it does not contaminate the others. Keep the unused pH strips dry and the container sealed tightly.

Water in the Geosphere Teacher Guide

Lesson Overview:

This is an activity that was developed to give participants an understanding of the geosphere. In this one-hour long activity, participants learn about the geosphere by making observations and taking measurements. They will go outside and use scientific equipment to investigate water in the soil by measuring soil moisture, temperature, color, and consistency. Students will use this qualitative and quantitative data to understand how water is found in many places in the natural environment and how these places are connected in the water cycle. The data collection is based on protocols from the GLOBE program, [www.globe.gov.](http://www.globe.gov)

Learning Objectives:

- Describe Earth's geosphere using qualitative (words) and quantitative (numbers) data
- Interpret data to assess the state of moisture in the geosphere
- Explain why the geosphere is an important part of the water cycle

National Standards:

Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes
- Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land. (MS-ESS-4)

Core Idea ESS2.A: Earth Materials and Systems
- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produces chemical and physical changes in Earth's materials and living organisms. (MS---ESS2-b) (MS-ESS2-c)

  - **5-ESS2-2.** Describe and graph the amounts and percentages of water and fresh water in various reservoirs to provide evidence about the distribution of water on Earth. [Assessment Boundary: Assessment is limited to oceans, lakes, rivers, glaciers, ground water, and polar ice caps, and does not include the atmosphere.]
  - **MS-ESS2-1.** Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.] [Assessment Boundary: Assessment does not include the identification and naming of minerals.]

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability and responses to natural disasters. The Global Precipitation Measurement (GPM) mission, launching in 2014, will help scientist to better understand how much rain and snow falls around the world.

Water is continuously cycling through all Earth systems (the water cycle). The geosphere includes Earth's materials, such as rocks, minerals, and soil extending from Earth's core to its surface. The geosphere is an important part of the water cycle because it filters and stores water so animals, plants and humans can use it.

This lesson adapts protocols from the GLOBE Program (www.globe.gov) to help students get hands-on experience collecting scientific data about our geosphere so they can better understand the water cycle and why it is important to know the distribution, quantity, and quality of water on Earth.

Many background facts can be found in the notes on the PowerPoint slides. These websites and resources may prove useful to get more detailed information. There are additional resources at the end of this lesson plan.

The Soils Guide from The GLOBE Program
http://www.globe.gov/documents/352961/353237/soil_intro.pdf

Materials:
Various samples of soil, sand, rocks (you can dig up some samples from around your home, school, or buy potting soil, rocks, or sand from the store)
Copies of "Geosphere" student capture sheets including data collection instructions
Soil moisture meter (Indoor/outdoor moisture sensor meter made by Niagara, available at www.amazon.com)
Pencils
Spoons
Soil thermometer (Taylor classic instant read pocket thermometer, or use the Taylor digital waterproof max/min thermometer – both available from www.amazon.com)

Engage:

Divide the class into workgroups of four students. Place soil samples in front of each group of students. (Slide 2) Ask them to brainstorm a list of observations about the soil as a group and record the ideas on their capture sheets. They can use all their senses (except taste). Then, ask them to brainstorm a list of things they would like to know about the soil if they had more equipment. Share ideas as a class.

Show students the introductory slide about the geosphere. (Slide 3) The geosphere includes Earth's materials, such as rocks, minerals, and soil from Earth's core to its surface. Today our focus is on the soil material on the Earth's surface. Our mission is to determine how much water is in the geosphere and how it contributes to the water cycle.

Explore:

Present our scientific question: "How much water is present in the geosphere today?" (Slide 4) Ask the students if they can identify which components of the water cycle involve the geosphere. Let them discuss ideas or share as a class. Then show the animation of the water cycle and talk with the animation to describe the geosphere connection (Slide 5).

Prepare the students to go outside and explore the geosphere and test for water (Slide 6). Give them the testing equipment and review how to use and care for it. Also, review how and where to collect data (see capture sheet and data collection instructions). Finally, tell the students how to find their geosphere study site and give them a time to return and a time---keeping device. If they finish early, they could test another site with a different land use.

Explain:

Gather the groups together (Slide 7) to share and analyze their results. Based on the data collected, have them answer the scientific question, "How much water is present in the geosphere today?" using both qualitative and quantitative data. Students should discuss the answer with their group and record their thoughts on the capture sheet. High soil moisture readings indicate more water. Soils that are more loose and friable hold and filter more water, while more firm/compact soils do not let water infiltrate. Also, darker soils have more organic matter, which has more water. Remind the students that this data is just for today. We would need to collect this data over many days to get a complete idea of how much water is in the geosphere in this location.

Evaluate:

Discuss the following with the students: Which parts of the water cycle involve the geosphere? How is the geosphere an important part of the water cycle? (Slide 8)

Wrap up by sharing a little about NASA's GPM Mission and satellite. (Slide 9). Also share the video "Too Much, Too Little" (4:44) (Slide 10).

Elaborate/Extend:

- Compare geosphere data in several different habitats and land use areas (near a stream, on top of a hill, in the forest, next to a building, etc.).

- Study soil particle size in more detail by demonstrating how different soils (silt, clay, sand) settle in water. https://www.soils.org/files/s4t/texture.pdf
- Challenge the students to consider how soil and water availability differ from place to place and therefore measurements of soil moisture and soil type can be much different in a humid climate compared to a desert or urban setting.
- Make (and eat!) some edible dirt. http://agpa.uakron.edu/p16/lessons/pdf/soil_recipe.pdf

Teacher Notes:

This lesson provides students with background information about the geosphere and allows students to go outside and take actual measurements about water in the geosphere. This data collection can happen with or without the background information.

Choose locations for groups to visit where they can easily access soil. Groups can all test in the same area, or you can send groups to different locations and compare water in the soil from these different land uses (near a water source, high on a hill, in a forest, in a yard, etc.). If you are not able to access soil, either because it's not easily available or because you cannot go outside, you can bring soil samples into the classroom. Dig soil in advance from around your school or home, ask students to bring in samples from their home, or use potting soil from a garden store.

The data collection is based on GLOBE Program protocols. The GLOBE Program has many training opportunities and offers a wide variety of different opportunities for students to collect authentic data and share it with other students around the world! Go to http://www.globe.gov and click "join" to learn more.

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/ http://www.nasa.gov/mission_pages/GPM/overview/index.html
- Background information about the geosphere and water cycle http://www.sciencelearn.org.nz/Contexts/H2O-On-the-Go/Science-Ideas-and-Concepts/The-water-cycle http://www.miamisci.org/ecolinks/geosphere.html

Name- Date- Period-

Geosphere Student Capture Sheet

Guiding Questions

What is the geosphere?
Is there water in the geosphere right now? How do you know?
How is the geosphere an important part of the water cycle?
How does soil consistency affect the water cycle?

Engage

1. Observe the soil samples and brainstorm with your group

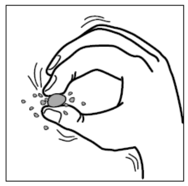
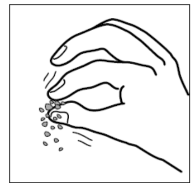
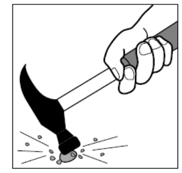
Observations of Soil Samples and What you know about soil	What you would like to know about soil if you had more time and equipment

2. The geosphere is ____
____

3. Prediction: water is ______________________ (not present, somewhat present, highly present) in the geosphere today.

Explore Record your data below. Remember to include units!

	Data	Notes
Soil Moisture		
Soil Temperature		

Soil Consistence			
 ☐ **Loose –** falls through fingers	 ☐ **Friable –** breaks a little	 ☐ **Firm –** breaks a little	 ☐ **Extremely Firm –** does not break (you won't use a hammer!)
Easier for water to move	→	→	More difficult for water to move

Soil Color			
☐ **Black** – lots of organic (living) material and more water	☐ **Brown** – some organic material and some water	☐ **Reddish** – contains minerals like iron	☐ **Gray** – light color means dryer soil
More water	→	→	Less water

Explain

Based on the data you collected, water is __________________________ (not present, somewhat present, highly present) in the geosphere today. Hint: Use information in the data tables to help you find evidence.

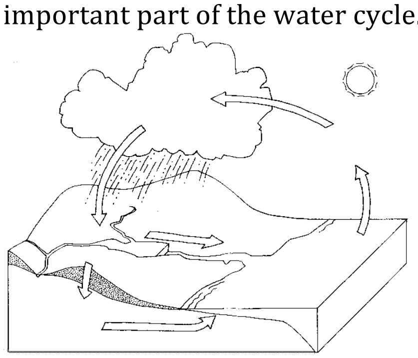
____

____

____

Evaluate

Label the parts of the water cycle that involve the geosphere and describe how the geosphere is an important part of the water cycle.



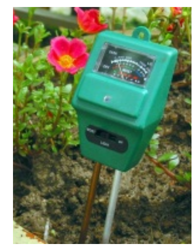
Geosphere Data Collection

Prepare the study area

1. Clear the leaves and debris from a small area (about 1 to 2-foot square) on the ground so the soil is exposed.
2. Use the spoon to loosen and dig up a small amount of soil.

Soil Moisture

1. Create a hole in the soil with the pencil.
2. Insert the probe into the hole and gently press the tip into the soil.
3. Record your data.



Soil Temperature

1. Using the hole you created with the pencil for soil moisture, insert the soil thermometer and wait at least 2 minutes.
2. Record the temperature in degrees Celsius.

Use the soil you loosened with the spoon for the following tests.

Soil Consistency – Hold a chunk of dirt between your thumb and index finger. Use the scale on the capture sheet to rate the firmness of the soil.

Soil Color – Compare the soil color to the chart on the capture sheet and record which color it is most close to.

Remember!!!

Return your test area to the way it looked when you arrived by putting the soil and leaves back to their original locations.

Gather your equipment before you leave!

Water in the Biosphere Teacher Guide

Lesson Overview:

This is an activity that was developed to give participants an understanding of the biosphere. In this one-hour long activity, participants learn about the biosphere by making observations and taking measurements. They will go outside and use a dichotomous key to investigate plants and land cover as an indication of amount of water in the biosphere. Students will use this qualitative data to understand how water is found in many places in the natural environment and how these places are connected in the water cycle. The data collection is based on protocols from the GLOBE program: www.globe.gov.

Learning Objectives:

- Describe Earth's biosphere using qualitative (words) data
- Interpret data to assess the state of moisture in the biosphere
- Explain why the biosphere is an important part of the water cycle

National Standards:

Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes

- Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land. (MS-ESS-4)

Core Idea ESS2.A: Earth Materials and Systems

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produces chemical and physical changes in Earth's materials and living organisms. (MS-ESS2-b) (MS-ESS2-c)

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability and responses to natural disasters. The Global Precipitation Measurement (GPM) mission, launching in 2014, will help scientist to better understand how much rain and snow falls around the world.

Water is continuously cycling through all Earth systems (the water cycle). The biosphere is all of the living things on Earth. The biosphere is an important part of the water cycle because it is where all the spheres interact and work together. Livings things depend on all of the other spheres. Especially important is when plants transpire, putting water vapor into the atmosphere.

This lesson adapts protocols from the GLOBE Program (www.globe.gov) to help students get hands-on experience collecting scientific data about our biosphere so they can better understand the water cycle and why it is important to know the distribution, quantity and quality of water on Earth. For the most part, this lesson uses the MUC protocols.
http://www.globe.gov/documents/10157/334459/MUC_guide.pdf

Many background facts can be found in the notes on the PowerPoint slides. These websites and resources may prove useful to get more detailed information. There are additional resources at the end of this lesson plan.

The Land Cover/Biology Guide from The GLOBE Program
http://www.globe.gov/documents/355050/355095/land_chapintro.pdf

Materials:
Copies of "Biosphere" Student Capture Sheets, including the Land Cover Key
Pencils

Engage:

Take the students outside. Tell them you will set the timer for one minute and they need to look for as many livings things as they can. Then, give students a few minutes to record their observations. After this time, share answers. How many students wrote plants? Animals? All of these living things, whether big or small, in the ground or in the air, plants or animals, are all part of the biosphere (Slide 2).

Show students the introductory slide about the biosphere (Slide 3). The biosphere is all the livings things on Earth. It extends anywhere there is life. The biotic components of an ecosystem are those that are living or were living at one time. All life relies on water. Animals can move around to find their own water. Plants and trees are stationary organisms so they rely on the water that is available in their habitat. Land and habitat types are often named by the types of plants that grow in the area. Different plants requir different amounts of water.

Explore:

Present our scientific question: "How much water is present in the biosphere today?" (Slide 4) Ask the students if they can identify which components of the water cycle involve the biosphere. Let them discuss ideas or share as a class. Then show the animation of the water cycle and talk over the animation to describe the biosphere connection (Slide 5).

Prepare the students to go outside and explore the biosphere and test for water (Slide 6). Give them the land cover classification key and review how to use it and how to record the data. Also, instruct them to record other living things or signs of life they see. Finally, inform the students of how to find their biosphere study site and give them a time to return and a time-keeping device. If they finish early, they could visit another site.

Explain:

Gather the groups together (Slide 7) to share and analyze their results. Based on the data collected, have them answer the scientific question, "How much water is present in the biosphere today?" Students should discuss this question with their group and record their thoughts on the capture sheet. All plants require water to survive. So, unless the area has no vegetation or is very urban, there is water. Deciduous trees tend to live in moister environments than evergreen trees. Cultivated areas, like farms, lawns and sports fields require a lot of water to live.

Evaluate:

Discuss the following with the students: Which parts of the water cycle involve the biosphere? How is the biosphere an important part of the water cycle? (Slide 8)

Wrap up by sharing a little about NASA's GPM Mission and satellite (Slide 9). Also share the video (Slide 10).

Elaborate/Extend:

- Take pictures of the different land covers in your area and compare them.
- Identify some species of trees and plants in your area so you know exactly what is living there.
- Go on a scavenger hunt for animals or signs of animal life. http://www.nwf.org/kids/family-fun/outdoor-activities/backyard-scavenger-hunt.aspx
- Make a terrarium or tabletop biosphere to investigate how all the spheres work together and how the living things help them interact
  http://www.instructorweb.com/lesson/maketerrarium.asp
  http://www.apartmenttherapy.com/diy-tabletop-biosphere-89370

Teacher Notes:

This lesson provides students with background information about the biosphere and allows students to go outside and explore the biosphere. The data collection can happen with our without the background information.

Choose locations for groups to visit where there is a variety of land cover types. Groups can all test in the same area, or you can send groups to different locations and compare land covers.

The data collection is based on GLOBE Program protocols. The GLOBE Program has many training opportunities and offers a wide variety of different opportunities for students to collect authentic data and share it with other students around the world! Go to http://www.globe.gov and click "join" to learn more.

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/ http://www.nasa.gov/mission_pages/GPM/overview/index.html
- Background information about the biosphere and water cycle http://www.sciencelearn.org.nz/Contexts/H2O-On-the-Go/Science-Ideas-and-Concepts/The-water-cycle http://www.miamisci.org/ecolinks/biosphere.html http://www.geography4kids.com/files/land_intro.html

Name- Date- Period-

Water in the Biosphere Student Capture Sheet

Guiding Questions

What is the biosphere?
Is there water in the biosphere right now? How do you know?
How is the biosphere an important part of the water cycle?

Engage

1. Record how many living things you can observe in one minute.

2. The biosphere is ____
____

3. Prediction: Water is ____________________ (not present, somewhat present, highly present) in the biosphere today.

Explore Circle the land cover you determined based on the classification key.

General Water Requirements for Plants

High	Medium	Low	Very Low
Cultivated Agriculture Cultivated Non-Agriculture Wetland	Deciduous Forest Deciduous Shrubland Grassland Forb Community	Evergreen Forest Evergreen Shrubland	Urban Barren Land Open Water

Other Observations of Signs of Life


Tracks


Scat


Fur, feathers, bones


Animal homes


Nests

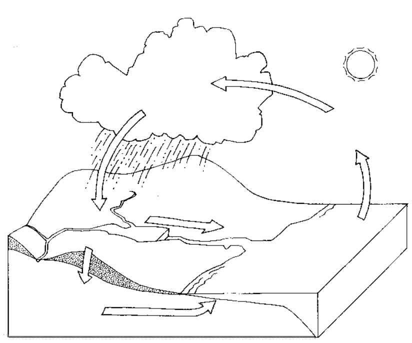
More signs:

Explain

Based on the data you collected, water is ____________________ (not present, somewhat present, highly present) in the biosphere today.

Evaluate

Label the parts of the water cycle that involve the biosphere and describe how the biosphere is an important part of the water cycle.

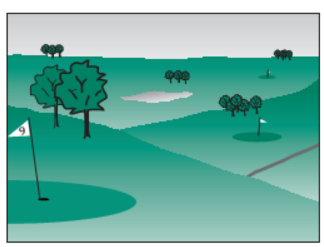


Land Cover Classification Key

(adapted from the GLOBE Program's MUC Field Guide)

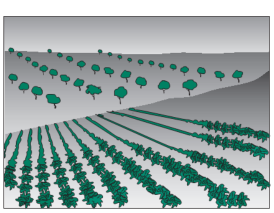
1a. Site is Developed (used by humans for buildings, farms, sports fields, etc.)	Go to 2
1b. Site is Natural – not used by humans (forest, pond, meadow, etc.)	Go to 4
2a. Site has been built on with homes, stores, roads, etc. more than 40%	**Urban**
2b. Plants, grass, crops cover more than 60%	Go to 3
3a. Fields of crops, orchard trees or sod for grass	**Cultivated Agriculture**
3b. Sports, field, golf courses, parks	**Cultivated Non-Agriculture**
4a. There is little or no vegetation (plants)- may be no growth or surface water	Go to 5
4b. Vegetation is present	Go to 6
5a. Site is land with little vegetation	**Barren Land**
5b. Site has water like a river, lake or pond	**Open Water**
6a. Land is saturated with water some or most of the year	**Wetland**
6b. Land is not saturated with water some or most of the year	Go to 7
7a. More than 60% is woody vegetation (with bark like trees or shrubs)	Go to 8
7b. More than 60% ground cover is herbaceous (plants have no bark like grasses and flowers)	Go to 11

Urban

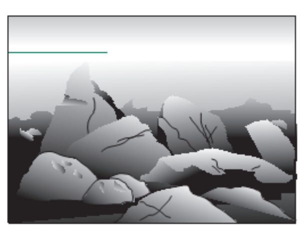


Cultivated Non-Agriculture

Cultivated Agriculture



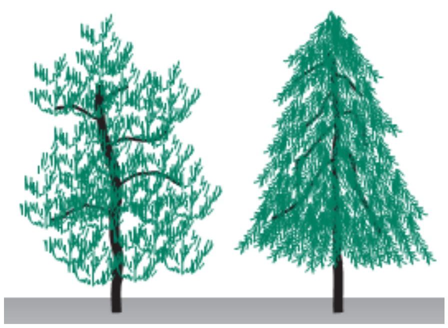
Barren Lnd



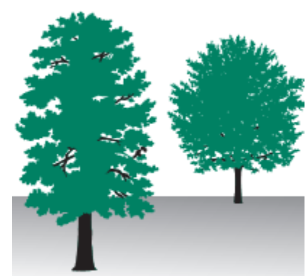
Open Water

8a. Trees taller than 5 meters cover more than 40% of the sky	Go to 9
8b. Trees shorter than 5 meters cover more than 40% of the ground	Go to 10
9a. More than 50% of the trees are evergreen (keep leaves or needles all year)	**Evergreen Forest**
9b. More than 50% of the trees are deciduous (lose their leaves in the fall)	**Deciduous Forest**
10a. More than 50% of the shrubs are evergreen (keep leaves or needles all year)	**Evergreen Shrubland**
10b. More than 50% of the shrubs are deciduous (lose their leaves in the fall)	**Deciduous Shrubland**
11a. Plants are more than 60% grasses (grass, sedges, cattails)	**Grassland**
11b. Plants are more than 60% broad-leaved plants like clovers, ferns, flowers	**Forb Community**

Examples of Evergreen Shrubs and Trees

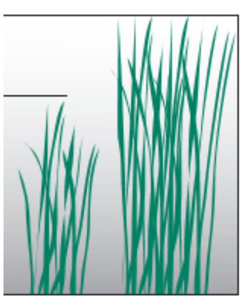


Examples of Deciduous Shrubs and Trees

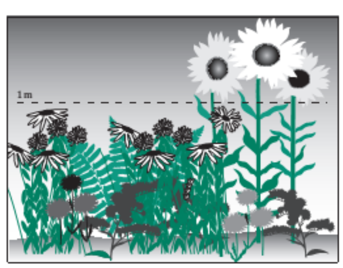


Herbaceous Vegetation

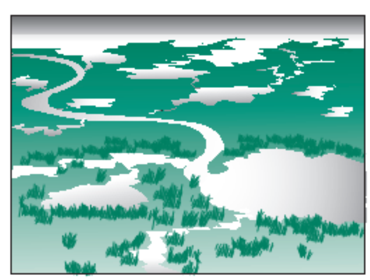
Grassland



Forb Communities



Wetland



Water in the Atmosphere Teacher Guide

Lesson Overview:

This is an activity that was developed to give participants an understanding of the atmosphere. In this one---hour long activity, participants learn about the atmosphere by making observations and taking measurements. They will go outside and use scientific equipment to collect atmospheric moisture data (temperature, relative humidity precipitation and cloud cover). Students will use this qualitative and quantitative data to understand how water is found in the atmosphere, how the atmosphere determines weather and climate, and how Earth's spheres are connected through the water cycle. The data collection is based on protocols from the GLOBE program: www.globe.gov.

Learning Objectives:

- Describe Earth's atmosphere using qualitative (words) and quantitative (numbers) information
- Interpret data to assess the state of moisture in the atmosphere
- Explain why the atmosphere is an important part of the water cycle

National Standards:

Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes

- Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land. (MS--ESS--4)

Core Idea ESS2.A: Earth Materials and Systems

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produces chemical and physical changes in Earth's materials and living organisms. (MS--ESS2--b) (MS--ESS2--c)

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability, and responses to natural disasters. Since rainfall and snowfall vary greatly from place to place, satellites can provide more uniform observations of rain and snow around the globe than ground instruments, especially in areas where surface measurements are difficult. In 2014, NASA will launch the Global Precipitation Measurement (GPM) satellite to collect precipitation data, improving the ability to know where and when rain is occurring. This lesson adapts protocols from the GLOBE Program (www.globe.gov) to help students get hands--on experience collecting scientific data about our atmosphere so they can better understand weather and the water cycle.

Many background facts can be found in the notes on the PowerPoint slides. These websites and resources may prove useful to get more detailed information. There are additional resources at the end of this lesson plan.

The Atmosphere Guide from The GLOBE Program
http://www.globe.gov/web/atmosphere-climate/overview

NASA's "The Air We Breathe" story book (PDF)
http://www.nasa.gov/pdf/62452main_The_Air_We_Breathe.pdf

USGS Water Science School
http://ga.water.usgs.gov/edu/watercycleatmosphere.html

Materials:

To set up at least 24 hours in advance outside:

- Rain gauge http://www.ambientweather.com/strgloteprra.html
  (Note: If you do not have a rain gauge, you can still do this lesson by making a rain gauge. You can find directions for making your own rain gauge at this URL: http://www.crh.noaa.gov/abr/?n=raingauge.php)
- Thermometer – Taylor digital waterproof max/min thermometer (available at amazon.com) or any outdoor thermometer

To give to each group – in a bag for easy carrying

- pH paper strips – amazon.com
- sling psychrometer – amazon.com

To bring out to use for all groups

- container to pour rain water into and measure pH

To have inside

- an apple cut in half

Copies of the "Atmosphere" student capture sheets

Engage:

Give students the student capture sheet. Show the students the picture from the "Water in the Atmosphere" PowerPoint, either on the screen or print copies for groups to share, and an apple cut in half. Ask if they can determine what these represent. Have them explain why they think that a blanket is sometimes used to describe Earth's atmosphere. Record their ideas on the capture sheet then discuss in groups and as a class. Be careful however – scientists believe that having students think of the Earth's atmosphere exactly like a blanket can lead to misconceptions. The blanket represents the atmosphere that surrounds Earth and we can compare the size of the atmosphere around Earth to the thickness of the skin of an apple. However, the atmosphere does not act precisely like a blanket, which works by trapping air near the surface of your body and allowing it to warm by conduction. The atmosphere keeps the Earth's surface warm primarily by radiation. Help them to remember what they have learned about radiation, and be sure that they understand that most of Earth's heat comes from the Sun's heat energy, which is transferred through radiation. For more information, please see http://bit.ly/1jUKITu and http://bit.ly/1npI2Bg. (Slide 2)

Assess students' prior knowledge about the atmosphere. Provide students with background facts about the atmosphere (using PowerPoint slides with notes, animations and video). Stress the connection to the water cycle and precipitation. (Slides 3, 4, 5, 6) Have students answer the engage questions on the capture sheet.

Ask the students how they think scientists measure water in the atmosphere. Gather their ideas and then show them the pictures or actual items that we will use to collect atmospheric data today. (Slide 7)

Explore:

Present our scientific question: "How much water is present in the atmosphere today?"

Divide students into groups of 3-4 and give each group pH paper and a sling psychrometer. The rest of the equipment should already be placed outside. Remind them to bring their capture sheets to record data, or at least one from the group. Bring the container to pour the rainwater into. Walk outside to the weather station and help the groups collect data. Students often need help understanding the units on the rain gauge (the numbers are millimeters) and will need help with the sling psychrometer, unless they've practiced this in advance. After all groups have recorded the rainfall in the rain gauge, pour the rain water into the container and let each group measure the pH of this water.

Explain:

Gather groups together (Slide 8) to analyze their results. Based on the data collected, have them answer the scientific question, "How much water is present in the atmosphere today?" using both qualitative and quantitative data. Students should discuss with their group and record their thoughts on the capture sheet. High humidity, high rainfall, and low, water filled clouds indicate a lot of water on that day. High wispy clouds, no rain, low humidity can mean less water. Remind the students that this data is just for today. We would need to collect this data over many days to get an idea of our weather patterns. Emphasize that we would need to collect data over a long period of time to gather information about the climate of an area.

Evaluate:

Discuss the following with the students: How is the atmosphere an important part of the water cycle? (Slide 9)

Elaborate/Extend:

- Hands-on activity to practice estimating cloud cover http://www.globe.gov/documents/348614/353086/atla---cloudcover.pdf
- "Measuring Precipitation" Lesson
- Weather and Climate IQuest
- Make your own sling psychrometer (also has a chart for determining relative humidity) http://www.teachervision.fen.com/tv/printables/TCR/0743936671_020---022.pdf
- Learn ALL of the cloud types http://www.globe.gov/documents/348614/351665/atmo_ds_clouds1.pdf http://science-edu.larc.nasa.gov/cloud_chart/
- Collect more atmosphere data or report your data to The GLOBE Program's Atmosphere Group http://www.globe.gov/web/atmosphere---climate/overview
- Water pollution is greatly affected by air pollution http://www.chesapeakebay.net/issues/issue/air_pollution#inline

Teacher Notes:

This lesson provides students with background information about the atmosphere and allows students to go outside and take actual measurements about water in the atmosphere. The data collection can happen with or without the background information.

For the best data collection experience, set the thermometer and rain gauge outside at least 24 hours in advance. Also, consider demonstrating use of the equipment before collecting the data in the field. The cloud---cover data has been simplified and only asks students to decide between four major types of clouds and generalize their water content. Teachers can use the GLOBE Program cloud data sheet if they want their students to learn about all the types of clouds as categorized by scientists. The GLOBE Program has many training opportunities and offers a wide variety of different opportunities for students to collect authentic data and share it with other students around the world! Go to http://www.globe.gov and click "join" to learn more.

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/
- This 1:58 minute video segment provides an overview of Earth's atmosphere and discusses atmospheric pressure and how it changes as astronauts enter space. http://www.nasa.gov/mov/217388main_080_Earth_Atmosphere.mov
- Precipitation module/lesson from the "Investigating the Climate System" series http://www.nasa.gov/pdf/62321main_ICS_Precipitation.pdf
- Clouds module/lesson from the "Investigating the Climate System" series http://www.nasa.gov/pdf/62317main_ICS_Clouds.pdf
- Weather and climate basics from the National Center for Atmospheric Research http://www.eo.ucar.edu/basics/wx_2.html

Last update: 5/21/2014

Name- Date- Period-

Atmosphere Student Capture Sheet

Guiding Questions

What is the atmosphere and why is it important?
Is there water in the atmosphere right now? How do you know?
How is the atmosphere an important part of Earth's water cycle?

Engage

1. The atmosphere is

2. What is the difference between weather and climate?

3. Prediction: Water is ______________________ (not present, somewhat present, highly present) in the atmosphere today.

Explore

Record your data below. Remember to include units!

	Data	Notes
Current Air Temperature		
Amount of Rainfall		
pH of Rain Water		
Relative Humidity		

Cloud Type			
☐ **Cirrus:** High wispy clouds; contain ice crystals 	☐ **Cumulus:** Low to middle white puffy clouds; contain water drops 	☐ **Stratus:** Low layered clouds cover most of the sky; contain water drops 	☐ **Nimbostratus:** Low layered clouds with rain falling 
Low moisture →			**Higher Moisture**

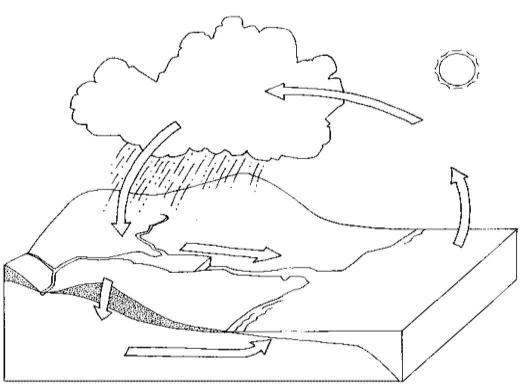
Cloud Cover					
					
No Clouds	*Clear*	*Isolated*	*Scattered*	*Broken*	*Overcast*
❑ 0%-No Clouds	❑ <10% Clouds	❑ 10-25% Clouds	❑ 25-50% Clouds	❑ 50-90% Clouds	❑ >90%

Explain

Based on the data you collected, water is ________________________ (not present, somewhat present, highly present) in the atmosphere today. Provide evidence to support your answer.

Evaluate

Label the parts of the water cycle that involve the atmosphere and describe how the atmosphere is an important part of the water cycle.

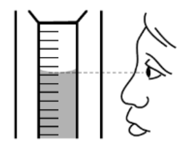


Atmosphere Data Collection

Temperature

Use the thermometer to record the current air temperature in degrees Celsius.

Amount of Rainfall and pH of Rain Water



1. Read the level of the water in the rain gauge; your eyes should be as close to the level of the water in the tube as possible.
2. Record the rainfall to the nearest millimeter. If there is no water in the rain gauge record 0.0 mm. If there is less than 0.5mm, record T for trace. If some spills, record M or missing. Then, circle the points that relate to your rainfall measurement.
3. If there is water in the rain gauge, carefully pour it into your collection container and replace all parts of the rain gauge.
4. Dip the pH strip into the water and immediately pull it out.
5. Compare the color on the strip to the color chart on the container and record your data.

Relative Humidity

1. Stand in the shade if possible and far enough away from other people so you will not hit anything with the psychrometer. Also, do not let your body heat affect the thermometers.
2. Record the dry bulb temperature to the nearest 0.5°C using the thermometer with no wick attached.
3. On the thermometer with the wick, check that the wick is wet and then sling the psychrometer for 3 minutes. Let it stop whirling on its own (don't stop it with your hand), and record the wet bulb temperature to the nearest 0.5°C.
4. Use the slide scale on the psychrometer to determine the relative humidity and record it on your data sheet.

Clouds

1. Observe the clouds in the sky – look in all directions, including directly overhead. Be careful not to look directly at the sun!
2. Check all of the cloud type(s) you see on the data sheet. If there are no clouds, write "none visible."

Measuring Precipitation Teacher Guide

Lesson Overview:

This is an inquiry-based, hands-on activity that has been created to engage students in designing and testing a rain gauge. Throughout this one-hour lesson, students are given an engineering problem (measuring precipitation), easily obtainable materials and tools, and time to design and test their rain gauges. Students will simulate rain to test the gauge and compare their results. The comparison of results leads to a discussion about the need for a standardized calibration system to be used to get precise measurements that are reliable. Students are then introduced to the Global Precipitation Measurement (GPM) mission and learn how GPM will measure precipitation around the globe in new ways.

Learning Objectives:

- Explain the need to measure precipitation
- Use provided materials and tools to solve an engineering problem
- Realize the necessity of having a calibrated rain gauge that uses an agreed upon unit of measurement and a standardized design to ensure the reliability and validity of data collection

National Standards:

Core Idea ETS1: Engineering Design

ETS1.A: DEFINING AND DELIMITING AN ENGINEERING PROBLEM
What is a design for? What are the criteria and constraints of a successful solution?
The engineering design process begins with

- Identification of a problem to solve
- Specification of clear goals, or criteria for final product or system

ETS1.B: DEVELOPING POSSIBLE SOLUTIONS
What is the process for developing potential design solutions?

Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes

- Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land. (MS-ESS-4)

Background Information:

The Science: NASA is partnering with the Japan Aerospace Exploration Agency to develop and launch a core satellite a satellite designed to measure rain and snow from space. This international satellite mission will unite data from the GPM Core Satellite with precipitation information from a network of other domestic and international satellites that together will provide observations of rain and snow worldwide every three hours- http://pmm.nasa.gov/GPM. One of the reasons that it is important to know how much rain and snow are falling worldwide is because we only have a very small amount of freshwater available to meet society's needs. Earth is widely known as the "Water Planet", but onl about 1 percent of all of Earth's water is available to us to meet our needs - http://pmm.nasa.gov/science.

The Methodology: This lesson purposely uses an open-inquiry approach. The goal here is not for the students to make accurate rain gauges that have correct calibration on their first attempt, but rather to allow them to attempt to design a rain gauge and then test it out. This familiarizes them with the many factors that must be taken into account when designing a tool for a specific purpose. It is important that the students are allowed to make mistakes, such as not using a ruler and making measurements from the top down, in order for them to have the experience of designing and trying out a tool, and then realizing that there are certain design criteria that must be taken into account.

Materials:

A wide assortment of plastic containers for students to select from (1 for every pair of students: empty water bottles, soda bottles, etc. It is fine if they are not all clear and they should not all be the same size or shape for this particular activity)
Scissors, tape
Both metric and standard rulers
Measuring tape
Plastic graduated cylinders of different sizes
Watering can
Copies of "Measuring Precipitation" student capture sheets

Engage:

Show students the precipitation forecast map in the PowerPoint (Slide 2) and ask "what is precipitation?" (Refer them back to water cycle lessons – product of water vapor condensing in the atmosphere and falls quickly out of a cloud) and "how do meteorologists measure precipitation?" Do not answer this for them, rather share this question as an engineering problem.

Then, pull up the current rainfall data from the Tropical Rainfall Measuring Mission (TRMM) website http://trmm.gsfc.nasa.gov/affinity/affinity_3hrly_rain.html or giv students a copy of recent data to examine. Ask them to spend some time looking at the data and then record at least three things this data shows us. Discuss as a class.

Show students the "Fresh(water) Connection" Video (1:24) (Slide 3) which describes how the GPM mission will help advance our understanding of Earth's water and energy cycles, improve the forecasting of extreme events that cause natural disasters, and extend current capabilities of using satellite precipitation information to directly benefit society. You will need internet access to show this video. If you don't have internet access, you can download it ahead of time by going to the link.

Explore:

Tell the students that they will design instruments that can measure how much rain is falling. Ideally students should work in pairs. (Slide 4) Show them the available materials and tools. Ask them to spend 5-10 minutes designing their instrument on paper. Be sure to consider size an the materials that they will use. Remember, their rain gauge must collect precipitation and be able to measure how much precipitation fell during a certain time period. Ask them to show you the design before they begin constructing. Give students about 20 minutes to construct their design. Take the instruments outside and use a watering can to simulate rain. (Slide 5) The goal is not to create a perfect instrument the first time, but to get them thinking about the engineering and science behind measuring precipitation.

Throughout the process, encourage the students to think creatively and do not guide them too much. During the testing, they may get frustrated if it does not work well. Remind them that it is a first step, and that trial and error is part of the scientific and engineering process.

Explain:

Summarize their experience on the student capture sheet.

Evaluate:

Answer the questions on the student capture sheets. (Slide 6)

Show the students an actual rain gauge and discuss similarities and differences to their designs. How is the rain gauge calibrated? The tube measures millimeters, but it looks like inches, why? How do we make sure all of the rain gauges in use over the world measure rain the same way?

Show the students the short video (2:01) "For Good Measure" to show why scientists will use satellites to measure rainfall. http://pmm.nasa.gov/education/videos/for-good-measure

Elaborate/Extend:

- Give students another class period (or take their instruments home) to re-work the instrument and test again.
- Design an instrument to measure precipitation in the form of snow.
- Put up a rain gauge at your school. These are very inexpensive (~$30) and you can report the data and compare data across the country. Go to the CoCoRaHS site below to learn more! http://www.cocorahs.org/Content.aspx?page=CoCoRaHS_Schools

Teacher Notes:

Consider introducing this lesson the day before and asking students to bring their own materials and tools in for the lesson.

The creative process of developing a new design to solve a problem is a central element of engineering:

- Open-ended generation of ideas
- Specification of solutions that meet criteria and constraints
- Communicated through various representations, including models
- Data from models and experiments can be analyzed to make decisions about a design.

This is a very well-written article that explains the importance of including engineering practices in the National Science Education framework-
http://www.nsta.org/about/standardsupdate/resources/201201_Framework-Sneider.pdf

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education website: http://pmm.nasa.gov/education/
- Tropical Rainforest Measuring Mission information and data http://trmm.gsfc.nasa.gov/
- How to make a rain gauge http://www.wikihow.com/Build-a-Rain-Gauge
- Precipitation background from USGS and National Geographic http://ga.water.usgs.gov/edu/watercycleprecipitation.html and

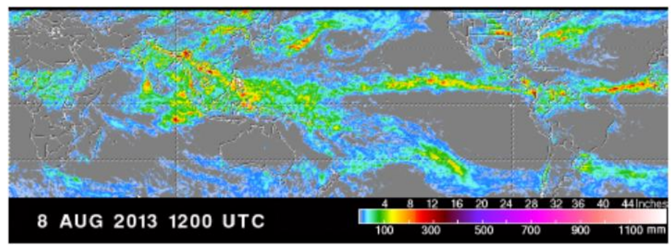
http://education.nationalgeographic.com/education/encyclopedia/precipitation/?ar_a=1
- NOAA Weather Service precipitation predictions and maps http://water.weather.gov/precip/
- Become a GLOBE school and share your rainfall data with other students around the world. www.globe.gov

Name- Date- Period-

Measuring Precipitation Student Capture Sheet

Guiding Questions

Why do we measure precipitation?
How do you solve an engineering problem?
Why is it important to have standardized ways to measure precipitation?



Engage

1. What is precipitation?

2. How do we measure precipitation?

3. What is this data showing us? Write at least 3 things.

Explore

1. Work with your partner to sketch and label the design for your device that will measure rain. Show it to your teacher before you start construction.

Explain –

After you have poured water on your device, answer the following questions:

1. How much rain did you collect in your device?
2. Record at least 3 notes or observations about your device as it collected the rain.

Evaluate

1. What did you find difficult about this task?
2. Which design did you think would be the most effective for measuring precipitation? Why?
3. What are some design factors that you think need to be consistent for the rain gauges? Why?
4. What could you do to improve your rain gauge?

Water Conservation Teacher Guide

Lesson Overview:

This activity was developed to get students thinking about the many ways that people use freshwater, and how we can conserve this precious and fundamental natural resource. In this one-hour-long activity, students will watch a short documentary describing issues related to clean water availability, analyze water-use data and start to think about how they consume and can conserve water. This background knowledge will lead to students collecting data about their own water use and finding areas in their lives to conserve water.

Learning Objectives:

- Analyze freshwater usage data to describe ways humans use water
- Explain why it is important to conserve freshwater
- List ways we can conserve freshwater resources

National Standards:

- *Core Idea ESS2.C: The Roles of Water in Earth's Surface Processes*
  Water continuously cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, and crystallization, and precipitation, as well as downhill flows on land.
  - MS-ESS2-4: Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity. [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [*Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.*]
- *Core Idea ESS3.A: Natural Resources*
  Humans depend on Earth's land, ocean, atmosphere and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.
  - MS- ESS3-4: Construct an argument supported by evidence for how increases in human population and per-capital consumption of natural resources impact Earth's systems. [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.]

Background Information:

Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability and responses to natural disasters. The Global Precipitation Measurement (GPM) mission, launching in 2014, will help scientist to better understand how much rain and snow falls around the world.

Most of the freshwater we use is from surface sources (such as rivers and lakes), and those bodies of water are replenished by rain. Although the Earth's surface has more than 70 percent water, only about 3 percent is fresh water and less than 1 percent is available for consumption. Therefore, freshwater is a scarce and valuable resource. Humans use it for almost everything – agriculture, power generation, and personal needs. In the United States, we often take it for granted that we can turn on the faucet and have easy access to safe, clean water. However, many people in the world are not so lucky. Conserving our freshwater resources and monitoring our freshwater distribution are becoming very important issues.

Materials:

Copies of "Water Conservation" Student capture sheets
Copies of the water diary http://www.thirteen.org/h2o/print/p_educators_lesson4_h2.html
Internet access for showing documentary
Copies of graphs cut for each group

Engage:

Ask students to list ways they use water. Share answers aloud and/or make a list on the board. (See PowerPoint) (Slide 2) Remind students that we use only freshwater. Most of the water on Earth is salt water. Discuss the difference between fresh and salt water, as well as the availability of each. (See background above and Earth's Water lesson for more details.)

Explore/Explain:

Part 1: Safe Water Documentary: Show the students the short documentary "Overview" from the safe drinking water website. Ask them to record answers to the questions as they watch. Review the answers as a class. http://www.drinking-water.org (Slide 3)

Part 2: Analyze the Data: Divide students into groups of 4. Give each group a graph of water--use data. Ask them to discuss the data with their group and record three facts they learned. Give each group a turn to share answers with the class. Ask the students what surprised them about the data (graphs are found at the end of the student capture sheet). (Slide 4)

Evaluate:

Ask the students to list ways they use water again. Has their list expanded or become more thoughtful? Then, ask them to list ways they can conserve water. This will lead into the extension activity which can be done as homework for a few weeks. (Slide 5)

Elaborate/Extend:
Give students the Water Diary from Planet H20 and ask them to complete it for one week. (http://www.thirteen.org/h2o/print/p_educators_lesson4_h2.html) After they have collected data for the week, have them share their results. Students can even make graphs to represent their data. (Slide 6)

After they have examined their own use, ask them to choose one or two things they will do to conserve water. Give them another copy of the water diary to complete for a week after pledging to reduce. Share results after that week. Were they successful? Will they continue it or hopefully add more ways to conserve water? How will they encourage their families to conserve water?

If you have more time, or want to give students something fun to do at home, www.discoverwater.org is an interactive website for students to learn more about water issues and ways they can conserve.

Watch the Sources and Distribution Documentaries on http://www.drinking-water.org

Teacher Notes:

This lesson should provide students with an overview of current freshwater issues on Earth. It is meant to make them aware of these issues and think about ways they can help. Then data collection on personal water use can go on as long as you would like and students can hopefully communicate the lesson to other friends and family members. Consider making it a challenge, pledge, or competition for your class to encourage as much participation as possible. A great prize would be a reusable water bottle!

Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/
- GPM freshwater availability classroom lesson http://pmm.nasa.gov/education/lesson-plans/freshwater-availability-classroom-activity
- Penn State Water Lessons http://ecosystmes.psu.edu/youth/sftrc/lesson-plans/water/6-8
- Project WET http://www.projectwet.org/
- USGS information about water use in the United States http://water.usgs.gov/watuse/
- USGS Water Science School http://ga.water.usgs.gov/edu/
- EPA Water Sense Program http://www.epa.gov/watersense/

Name - Date- Period-

Water Conservation Student Capture Sheet

Guiding Questions

What are the various ways humans use water?
Why is it important to conserve water?
What are some ways we can conserve water?

Engage

List at least 6 ways you use water in your daily life.

Explore and Explain

Part 1: Safe Water Documentary: While you watch the short documentary, answer the following questions:

1. Give at least two reasons why safe freshwater is not available to many people around the world.

2. Why is having safe freshwater a big concern?

3. What are some solutions to this problem?

Part 2: Analyze the Data: Discuss the data with your group and record three facts you learned from this data. You will share these with the class.

Evaluate

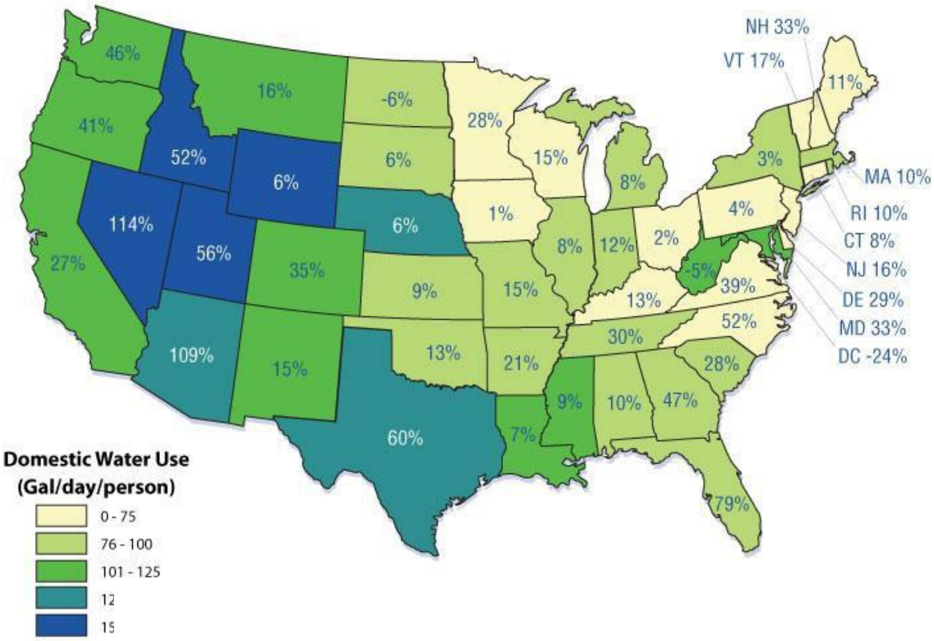
1. Review your original list of ways you use water (Engage). List more ways you use freshwater that you didn't think of before this lesson.

2. What are some ways you can conserve freshwater in your daily life?

GPM.NASA.GOV / EDUCATION

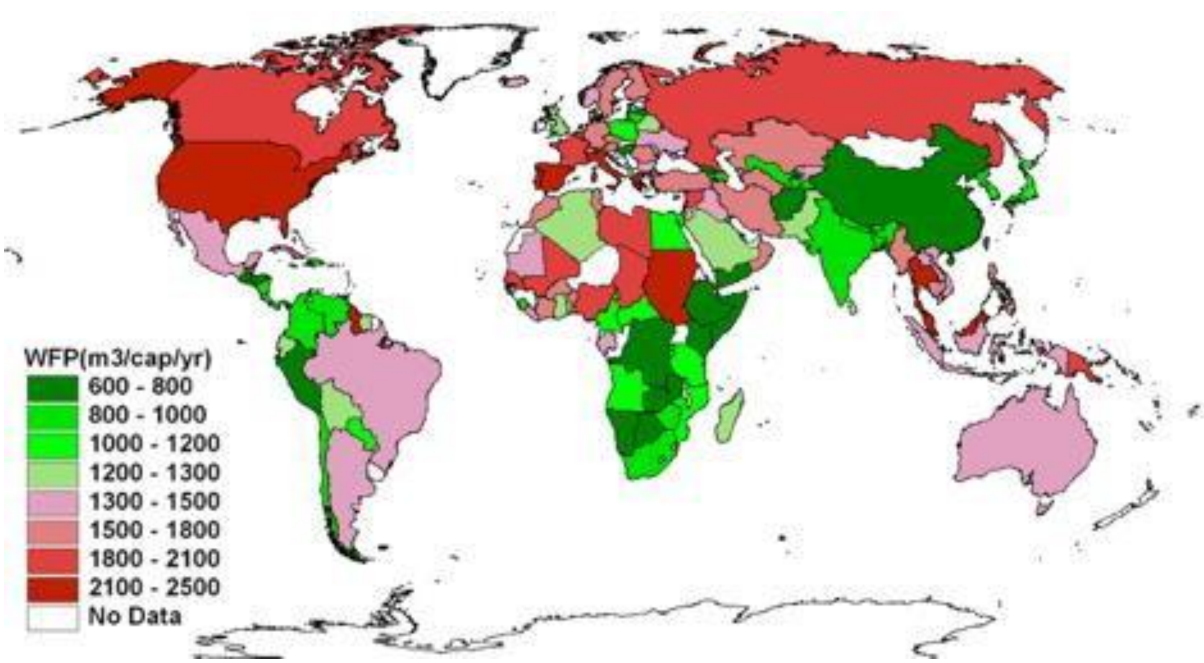
Source: epa.gov

Domestic Water Use in Gallons per Day per Person and Projected Percent population Change by 2030

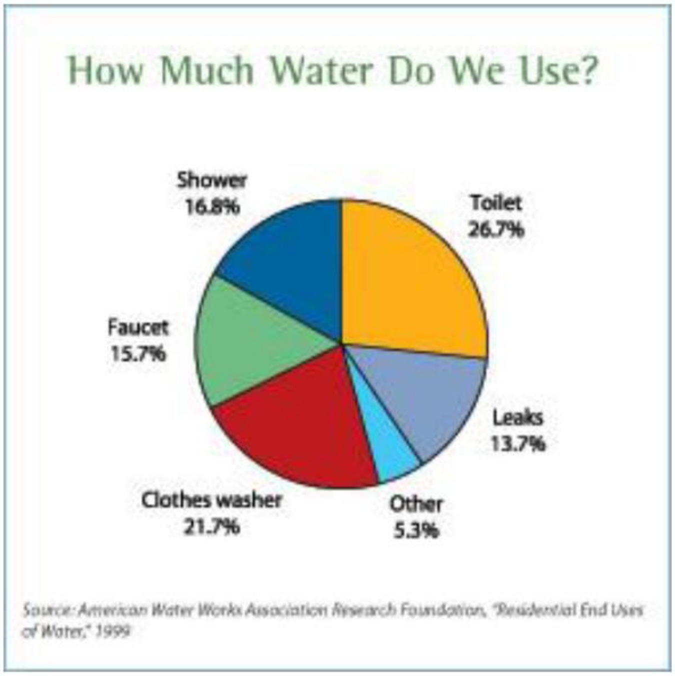


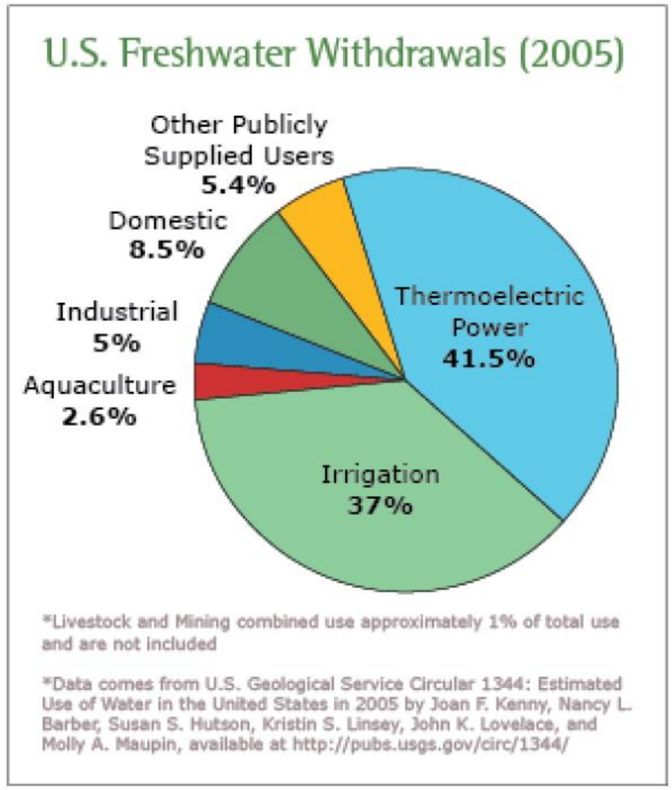
Global Water Use per Person per Year

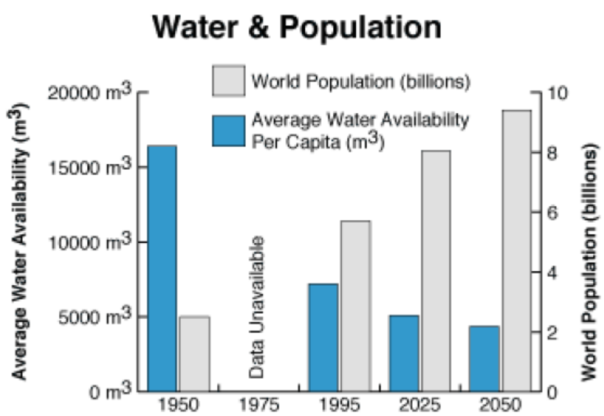
Source: waterfootprint.org

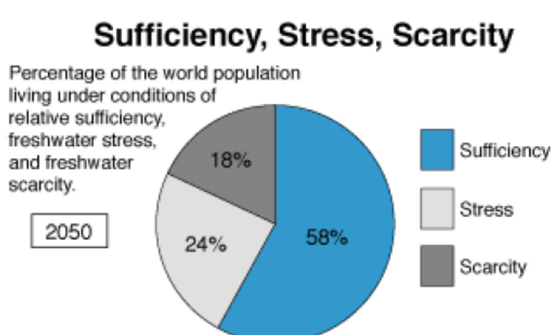


Note: Units are cubic meters per person per year, but most important to look at is the comparison between countries – red means more water use, green means less.









Source: discoveryeducation.com

The Global Precipitation Measurement Mission

Teacher Guide

Lesson Overview:

This activity was developed to teach students about the Global Precipitation Measurement Mission. In this one-hour long activity, students will watch a short video summarizing the purpose of the mission, learn about the parts of the satellite and their functions, and build an edible model of the satellite.

Learning Objectives:

- Describe the purpose of the GPM Mission
- Name at least four parts of the GPM satellite and describe their functions

National Standards:

Core Idea ETS2.A Interdependence of Science, Engineering, and Technology

- Engineering advances have led to important discoveries in virtually every field of science. These discoveries have in turn increased the need for more sophisticated technologies to solve even more complex science problems. Scientific development has led to the development of entire industries and engineered systems.

Core Idea PS4.C Information Technologies and Instrumentation

- Understanding waves and their interactions with matter has been used to design technologies and instruments that greatly extend the range of phenomena that can investigated by science (e.g., telescopes, microscopes) and have many useful applications in the world.

Background Information:

In 2014, NASA will launch the Global Precipitation Measurement (GPM) satellite to collect precipitation data. Water is fundamental to life on Earth. Knowing where and how much rain or snow falls globally is vital to understanding how weather and climate impact both our environment and Earth's water and energy cycles, including effects on agriculture, fresh water availability, and responses to natural disasters. Since rainfall and snowfall vary greatly from place to place, satellites can provide more uniform observations of rain and snow around the globe than ground instruments, especially in areas where surfaces measurements are difficult.

Materials:

Copies of “GPM” student capture sheets including GPM reading
Food for edible model (suggestions are: pretzel sticks, graham crackers, marshmallows, frosting, skittles)
Knives for spreading frosting
Napkins, paper towels or paper plates to build model on

Engage:

Show students the short video “Our Wet Wide World” (4:06) which is linked in the “GPM” PowerPoint. (Slide 2) Ask them to answer the questions on their capture sheets. Tell them they will learn more about the GPM satellite today.

Explore/Explain

Ask the students to read the background information (found at the end of the student capture sheet) about GPM. Or, read it as a class or in groups. (Slide 3) Then, complete the following tasks:

Part 1: Parts of the Satellite and their Functions: (Slide 4)
Ask students to find a partner. They will work with their partner to label the parts of the satellite. They can check their answers with the teacher’s key (Slide 5), then complete the matching section to match the part of the satellite with its function. (Slide 6) The reading should provide some information to help them. Share answers as a class, and make sure students have the correct answers. (Slide 7) The answer key is found in the PowerPoint.

Part 2: Build an Edible Model: (Slide 8)
Show students the options of food ingredients you have. Ask them to use their labeled diagram to create a model of the satellite using the food items. Be sure to check for any food allergies before deciding which materials to use. Put the models on display on the desks and let the students do a gallery walk to see what others have created. Once they have shared their work let them eat it! (A suggested edible model is shown in the teacher notes section.)

Evaluate:

Ask the students to write a short letter to a younger student to share what they’ve learned about GPM. (Slide 9)

Elaborate/Extend:

- Show students the GPM Launch Animation Video (2:03) (Slide 10) that shows how scientists plan to get the satellite into orbit. http://pmm.nasa.gov/education/videos/gpm-launch-animation
- Learn more about the science behind GPM at http://pmm.nasa.gov/GPM.
- Create an anime or superhero character for GPM. GPM had a challenge recently and selected two main Anime characters to use in their upcoming Anime comic books. Students can make their own GPM characters or write a story that involve the two GPM Anime characters. http://pmm.nasa.gov/education/anime
- Ask students to choose another satellite to research. A list of current missions can be found at http://www.nasa.gov/content/earth-missions-list/

Teacher Notes:

Here is one way to make an edible model using graham crackers, frosting, pretzel sticks, and marshmallows:


Additional Resources:

- Helpful information, background, and resources about the GPM mission and Precipitation Education http://pmm.nasa.gov/education/ http://pmm.nasa.gov/GPM
- GPM's predecessor is TRMM – Tropical Rainfall Measuring Mission http://pmm.nasa.gov/TRMM
- Information about using edible models in science classes http://www.teachervision.fen.com/science/activity/5634.html
- Information about microwaves and how they are used to measure precipitation

  http://science.hq.nasa.gov/kids/imagers/ems/micro.html

  and http://missionscience.nasa.gov/ems/06_microwaves.html

Name- Date- Period-

GPM Student Capture Sheet

Guiding Questions

What is the purpose of the GPM Mission?
What are the components of the satellites and their functions?

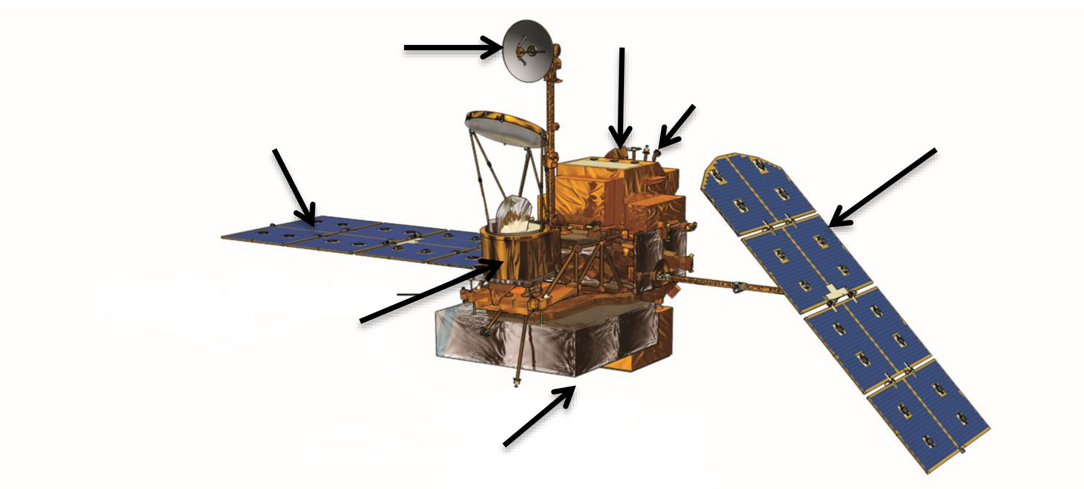
Engage

Answer the following questions while watching the video "Our Wet Wide World."

1. How much of Earth's water is freshwater? How much of this freshwater is usable?
2. What are some issues we can learn more about using GPM?
3. What will GPM measure and how often?
4. How many other satellites will work with GPM?

Explore and Explain Label the parts of the satellite:

Star-field finder Control System Solar Panel High gain data-relay antenna
GPM Microwave Imager (GMI) Dual-frequency Precipitation Radar (DPR)



Explore and Explain Match the part of the satellite with its function.

Function Word Bank

power	type of precipitation
navigation	3-D information about particles
communication	

1. High gain data-relay antenna ______________________
2. Star-field finder ______________________
3. Solar Panels ______________________
4. GPM Microwave Imager (GMI) ______________________
5. Dual-frequency Precipitation Radar (DPR) ______________________

Evaluate

Write a short letter (1 or 2 paragraphs) about GPM to a 4th grade student. Be sure to explain what GPM is, what it will be used for, why it is important, and some of the parts of the satellite.

GPM: Global Precipitation Measurement

When is it going to rain? How much will it rain? We always want to know about precipitation to plan day-to-day events, but it also helps us make decisions about bigger issues, such as safety, transportation, and jobs. Precipitation significantly affects our food and water supply. Therefore, it is important to accurately measure rain and snowfall.

There are many ways to measure precipitation. Rain gauges can collect and measure rainfall in a location over a period of time. However that only measures rain in one specific spot. Radars can be set up on land and cover more ground. Radar sends out a signal and measures how much of the signal is scattered by rain or snow. However, they are only available in certain locations, and are only used on land, therefore missing rainfall data over our oceans. We can't cover the entire Earth with instruments to measure rain, so we look to the sky!

The Global Precipitation Measurement mission (GPM) is an international network of satellites (Figure 1) that are all looking down on Earth and measuring precipitation from above. The GPM concept centers on the deployment of a "core" satellite carrying an advanced radar/radiometer system to measure precipitation from space every three hours. Not only will this data give us a better picture of global precipitation, it will help advance our understanding of Earth's water and energy cycle and improve forecasting of extreme events that cause natural hazards and disasters.

Figure 1: Illustration of the GPM satellite constellation

The GPM Core Observatory (Figure 2) will carry two instruments that measure precipitation from space. The data from these two instruments serves as a reference standard to unify precipitation measurements made by an international network of partner satellites. The design and sampling technique of the Core Observatory builds on the concept of the Tropical Rainfall Measuring Mission (TRMM), which was launched in 1997.

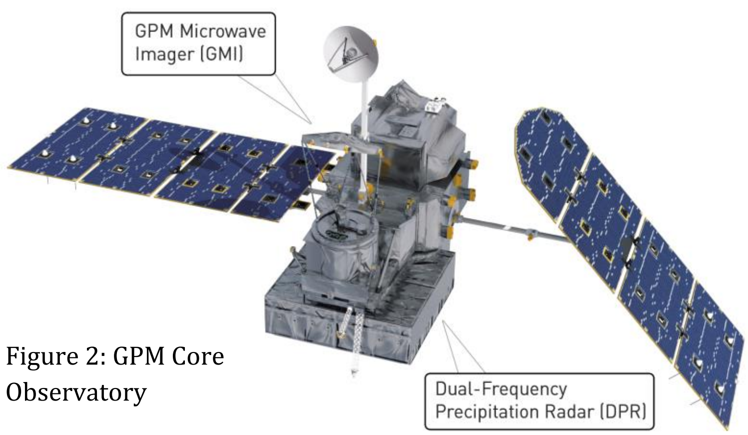


Figure 2: GPM Core Observatory

The two main instruments on the Core Observatory are the Dual-Frequency Precipitation Radar (DPR) and the GPM Microwave Imager (GMI). The DPR (Figure 3) provides three-dimensional information about precipitation particles in the different layers of clouds. It sends energy at two frequencies (Ku and Ka) into the cloud and observes the energy that is reflected from different heights in the cloud. It is an active radar instrument since it actually sends out energy. The GMI is a passive radiometer – it just observes and measures energy that is emitted by precipitation within clouds. Different types of precipitation, like heavy rain and light snow, emit different wavelengths of energy. The GMI measures these wavelengths which can tell us what kind of precipitation is in the cloud.

Other components of the satellite include the solar panels to provide power, a high gain data-relay antenna for communication, a star-field finder for navigation, and a control system to manage the satellite.

Figure 3: The Dual-Frequency Precipitation Radar (DPR) is the two boxes on the bottom of the Core Observatory – the small one is the Ka frequency radar and the larger flat box is the Ku frequency radar

Figure 4: GPM Microwave Imager (GMI) is a passive radiometer with an antenna above.

The GPM mission is co-led by NASA and the Japan Aerospace Exploration Agency (JAXA). The GPM Core Observatory is scheduled for launch in early 2014.

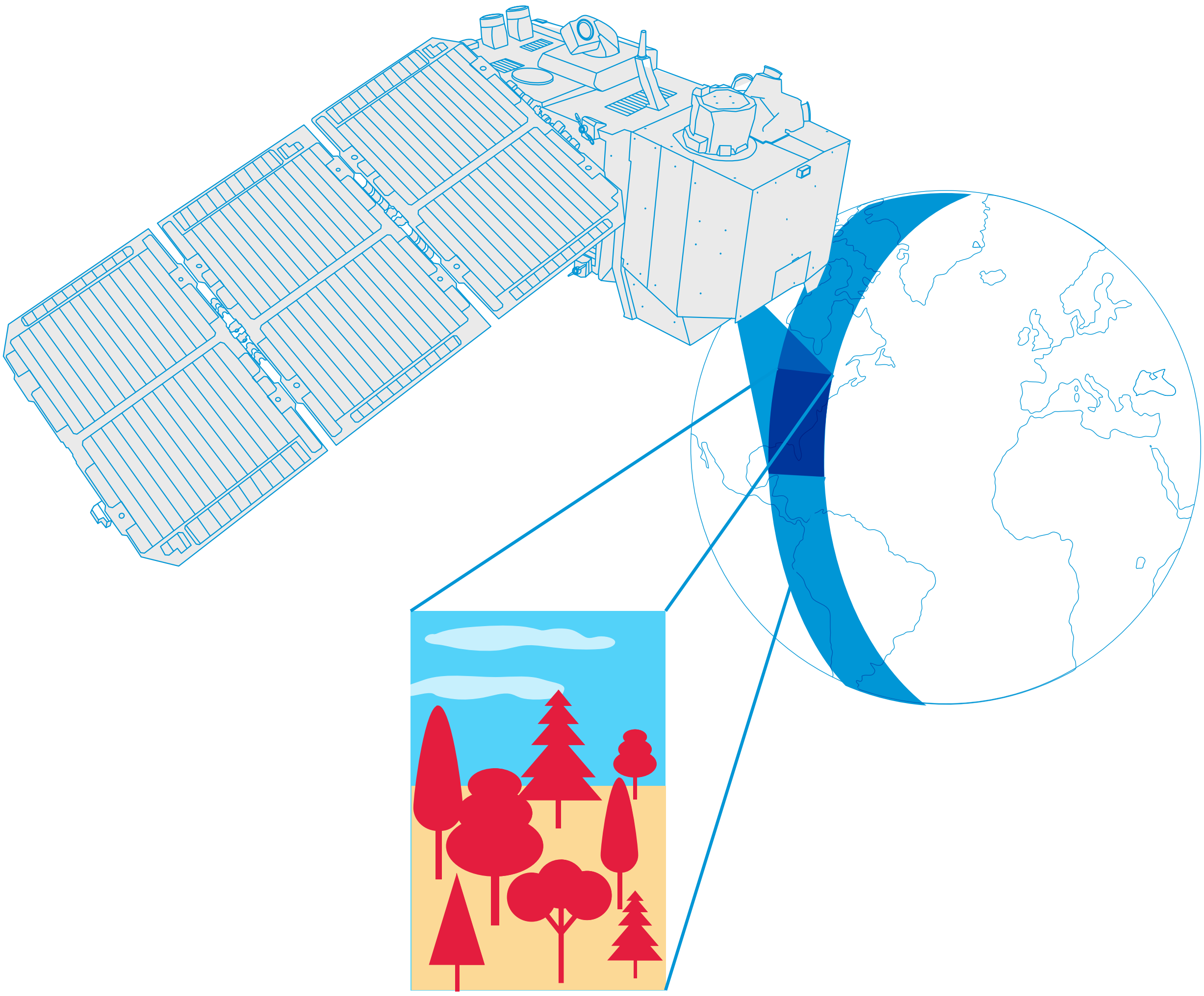
For more information visit http://pmm.nasa.gov/GPM and http://pmm.nasa.gov/education/

physics | P15

teach with space

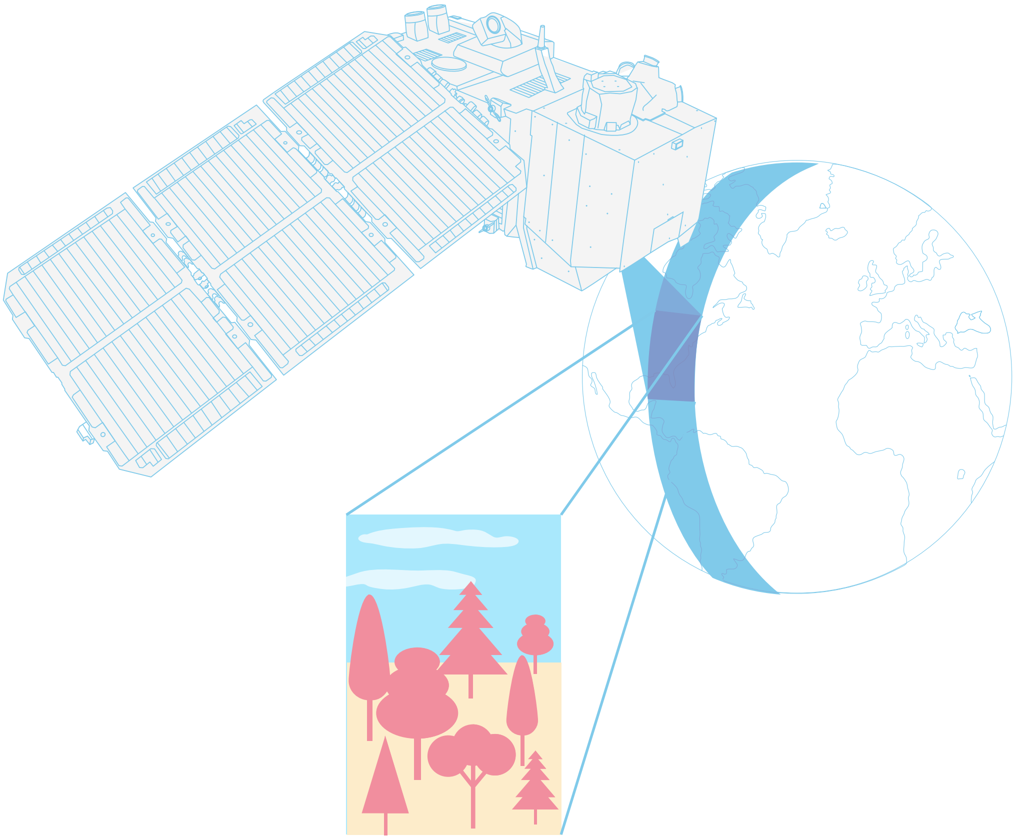
→ INFRARED WEBCAM HACK

Using infrared light to observe the world in a new way



teacher guide & student worksheets

European Space Agency



Teacher guide

teach with space – infrared webcam hack | P15a
www.esa.int/education

The ESA Education Office welcomes feedback and comments
teachers@esa.int

Activity concept developed for ESA by the National Space Academy (NSA), UK

An ESA Education production

→ INFRARED WEBCAM HACK

Using infrared light to observe the world in a new way

Fast facts

Subject: Physics, Geography

Age range: 12-16 years old

Complexity: medium

Lesson time required: 30 minutes per activity

Cost: medium (10-30 euros per group)

Location: any indoor space with daylight

Includes the use of: webcam and computer

Keywords: Earth observation, Infrared light, Satellite imagery, Physics, Geography.

Brief description

This set of three activities will enable students to understand the electromagnetic spectrum and observe infrared radiation through the modification of a cheap webcam. It will enable discussion of how infrared radiation can be used to obtain information that is not available using visible light. Students will also analyse satellite images providing them with a context to understand why it is useful to "see" in infrared.

Learning objectives

- Identify the different types of electromagnetic radiation.
- Describe different applications of infrared light.
- Use tools available on the internet to collect and analyse satellite data.
- Understand how infrared light can be used to monitor the health of vegetation.
- Identify false colour and true colour satellite images.

→ Summary of activities

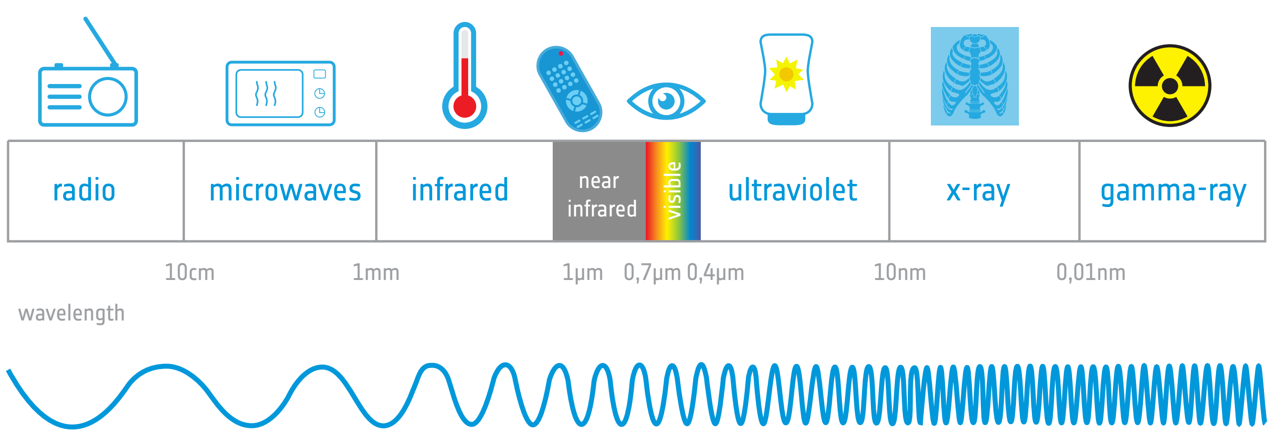
Summary of activities					
	Title	Description	Outcome	Requirements	Time
1	Hacking the webcam	To modify a webcam so that it sees in near-infrared light rather than in visible light.	An Infrared webcam	None	30 minutes
2	Looking at objects with an infrared camera	To look at different types of objects, observing each in both visible and near-infrared light.	To identify different applications of infrared light and understand how infrared light can be used to find out information that is not available using visible light.	Completion of Activity 1	30 minutes
3	Looking at the Earth in infrared light	To analyse true colour satellite images and compare them to false colour images that visualise near-infrared light.	To understand how infrared light can be used to monitor the health of vegetation and why it is useful to "see" in infrared.	None	30 minutes

➔ Introduction

The electromagnetic spectrum categorises the electromagnetic radiation that exists, including infrared radiation(Figure 1). Most electromagnetic radiation emitted by the Sun is reflected or absorbed by Earth's atmosphere. However, some radiation like visible radiation, radio waves, and part of infrared can pass through the atmosphere.

Objects with different surface features reflect and absorb the Sun's radiation in different ways. The reflected radiation contains information about the surface of the object, and enables us to see the colour and form of the object. The human eye can only see a very limited range of the spectrum, the visible light. However we can use different instruments to see what is invisible to us. Earth observation satellites, for example, carry scientific instruments that can see in the visible and the infrared range, as well as other ranges of the electromagnetic spectrum.

Figure 1



↑The electromagnetic spectrum categorises different types of radiation, from the longest (radio) to the shortest (gamma ray) wavelengths.

In this resource, we will focus on the near-infrared and visible parts of the spectrum. Infrared radiation is divided into different parts, just like visible light is divided into different colours. Near-infrared radiation, with its slightly longer wavelengths than visible light,is reflected by vegetation, delivering detailed information about plants on Earth. That is why this part of the electromagnetic spectrum is used in Earth bservation satellites to monitor Earth's vegetation.

Figure 2

↑ The European Sentinel-2 satellite carries an high-resolution multispectral imager with 13 spectral bands for a new perspective of our land and vegetation.

→ Background

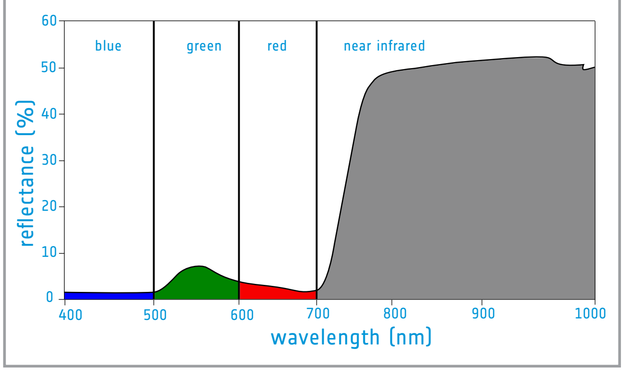
Vegetation monitoring

Plants have a particular way of reflecting electromagnetic radiation. The chlorophyll in the plants absorbs light to get energy for the photosynthesis process. But only the red and blue part of the visible light are needed. The green light is reflected, which explains why leaves appear green to us. The near-infrared light is not needed for the photosynthesis, therefore most of the light is reflected by the cell structure of the leaf.

Figure 3 shows the percentage of reflected radiation, also called reflectance, for a healthy plant. The blue light is absorbed almost completely by the chlorophyll, about 10% of the green light is reflected, and the red light is absorbed almost completely. Moving to slightly longer wavelengths, about 50% of the near-infrared light is reflected. The combination of low visible reflectance and high near-infrared reflectance is a characteristic of most plant types.

When a plant becomes less healthy, for example due to water scarcity, it reflects more of the visible red light and less of the near-infrared light. This can also be seen in autumn when leaves turn yellow and red, due to phenology. The bigger the difference between the reflected red and near-infrared light, the healthier a plant is. This fact is used in Earth observation to calculate indices which help us obtain information about the health of plants on a large scale.

Figure 3



↑ Percentage of radiation reflected by a healthy plant for the wavelengths of visible light and near-infrared light.

True colour and false colour images

A way to visualise reflected near-infrared light is to create false colour images, making use of the fact that cameras carried by satellites can 'see' more than just the visible part of light. A false colour image uses at least one wavelength outside the visible range, and as a result the colours in the final image may not be what we expect them to be. For example, grass is not always green! A true colour image combines actual measurements of reflected red, green, and blue light. The result looks like the world as we are used to seeing it.

In the figures below, we can see a true colour image(Figure 4) and a false colour image (Figure 5) of the town of Birkerød in Denmark. The false colour image shows reflected near-infrared light as red, red light as green, and green light as blue. Since plants reflect more near-infrared than green, vegetation areas will appear red. The brighter and richer red indicates a higher reflectance in the near-infrared, therefore indicating more and healthier vegetation. In the true colour image, the vegetation appears green, like we are used to seeing it.

Overall, the reflectance in the visible light is much lower than the one in the near-infrared, and the image is darker. This makes it harder to identify water bodies in the real colour image, because the reflectance is also very low. In the false colour image, the water bodies can be clearly identified due to the high difference in reflectance for water and the surrounding vegetation (high reflectance). Water absorbs most of the incoming light– near-infrared, red, and green – and therefore has a very low reflectance.

Figure 4

↑ True colour image of the town of Birkerød in Denmark.

Figure 5

↑ False colour image of the town of Birkerød in Denmark.

→ Activity 1 – Hacking the webcam

In this activity, students will modify a webcam so that it sees in near-infrared light rather than in visible light.

Equipment (for each infrared camera)

Figure 6

↑ Infrared webcam hack video. See links section.

- 1 webcam with manual focus ring on the front
- 1 drawing pin or a similar pin
- Two pieces of exposed photographic film or a polarising filter large enough to cover the lens
- Clear tape
- Scissors
- Computer

Exercise

Instructions for hacking the webcam are provided in the student activity sheet. Cheap webcams are usually easier to disassemble than more expensive models. The example used in the student activity sheet is a Trust 17405. Refer to the Infrared Webcam Hack video for a video guide of how to set up and carry out the experiment. Students can work in small groups. Alternatively, the webcams can be modified in advance, and students can run Activities 2 and 3. The principal modification to be performed is to remove the infrared filter. Depending on the conditions of light it may be necessary to add a visible light filter.

Filters work by blocking light within a specific wavelength range. Two polarised filters are required to block visible light. This is because the wave may be moving up and down, or side to side (this single-plane oscillation is called polarisation). Two filters ensure that all the visible radiation is blocked.

Most webcams are “plug and play” – the software required to run them is already on the camera. However, depending on the webcam you use, there is a small chance that it may be necessary to install the operating software before the webcam is plugged into a computer.

Teachers should make sure that students understand that the hacked camera is a near-infrared camera, not a thermal imaging camera!

The sensors used in digital cameras are sensitive to light with wavelengths up to around 1 µm (near-infrared). Thermal imaging cameras use infrared at longer wavelengths. These cameras are sensitive to the infrared radiation which is emitted by all objects with a temperature above absolute zero and not visible to our eyes. The higher the temperature of an object, the shorter the wavelength of the emitted radiation will be. When the temperature of an object is high enough, the radiation emitted can be imaged using near-infrared cameras or our very own eyes. We can see this in our kitchen: when a toaster reaches very high temperatures, it turns red!

→ Activity 2: Looking at objects with an infrared camera

In this activity, students will look at different types of objects, observing each in both visible with their eyes and near-infrared light with the modify webcam.

Equipment

- Infrared camera (from activity 1)
- Remote control
- Led light
- Candle
- Healthy plant and fake plastic plant

Exercise

Daylight is necessary for the experiment with the plants. The experiment should always be tested in the classroom before doing it with the students. Depending on the light conditions in the room it may be necessary to block the visible light and to put the polarising filter/exposed film in front of the lens.

Students should observe the different objects and fill the table in the student activity sheet, where they describe how they see each object in both types of light, and then give an interpretation for their observations.

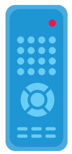
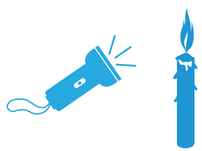
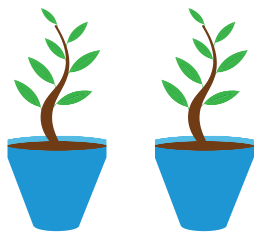
Results

See the table on the next page.

Discussion

The remote control, the candle and the LED light send out (emit) infrared radiation. With the help of the hacked webcam, students can 'see' infrared light, e.g. emitted from the remote control. Looking at light sources from daily life, like the LED light and the candle, the infrared camera allows us to investigate which one emits less infrared light and is therefore more energy-efficient.

Looking at the plants with the hacked webcam, what we see is reflected daylight. As the real plant reflects a lot of near infrared light and this is related to a healthy plant structure, we can understand how healthy a plant is when looking at it in infrared light.

Objects	Describe your observations		Explain your observations
	Visible light	Infrared light	
Remote control 	When pressing a button and looking at the infrared sender, nothing can be seen, (except sometimes a faint light when the wavelength used by the remote control is very close to the visible wavelengths).	Looking at the remote control through the webcam and pressing the buttons, a bright light signal from the infrared sender can be seen. Tip: This is also visible with the camera of some smartphones!	Remote controls are used to control from a distance some devices like televisions. How does the receiver (e.g. the television) know which button on the remote control has been pressed? Each button sends out on-off signals at a certain wavelengths of the infrared light. The pattern of the signal is related to one button on the remote. For this reason, we can see the signal emitted by the remote with the infrared camera.
LED vs. candle 	The LED light and the candle both emit light. The colours look different. The candle has a warmer light, whereas the LED light is whiter.	Looking through the webcam, the candle appears much brighter than the LED light.	The candle not only emits visible light but also heat which can be visible in the infrared, and for this reason the candle appears brighter with the infrared camera. The LED light does not emit a lot of light in the infrared like the candle, but it appears brighter in the visible.
Living vs. fake plants 	Both plants are green when looking at them. Tip: If there are any yellow or brown leaves, they can be compared to the healthy, green leaves.	Looking at both plants with the infrared webcam, the green leaves of the living plant appear much brighter than those of the fake plant. Yellow or brown leaves are much darker than the green leaves.	In visible light both plants look green and real. In the infrared camera the living plant looks much brighter than the fake one. The living plant reflects a lot of radiation in the infrared, as this part of the light is not needed for photosynthesis. High reflectance of infrared light is caused by the spongy mesophyll. This can be related to a healthy plant structure. The plant structure of the yellow or brown leaves is already destroyed, so the reflectance of the infrared light is much lower.

→ Activity 3: Looking at the Earth in infrared light

In this activity students will analyse satellite images. The activity introduces true colour images and compares them to false colour images that visualise near-infrared radiation. It provides students with a context so that they understand why it is useful to "see" in near-infrared.

Exercise

The satellite images were downloaded from the EO Browser, an online application where you can access ready-to-use satellite images in true colour, false colour showing near-infrared, and many more products! You can explore this tool and start by showing the students their hometown in the summer and the winter with true and false colour images. Students can also research their own examples.

Figure 7

↑ Screenshot of the EO Browser online tool (08.08.2018).

1. **Observe the true colour image below taken by the Sentinel-2 satellite (Northern Germany, 28.11.2016). Which of the following features can you identify?**
   o Agriculture fields
   ~~o Snow~~
   o Forest
   ~~o Clouds~~
   o River
   o Lakes
   o Streets
   ~~o Cars~~
   o Buildings
   ~~o People~~

   Teachers can ask students why there are no cars or people visible in the image. The reason is the spatial resolution of the satellite image. The spatial resolution is the area on Earth that is represented by one pixel of the satellite image. The satellite image in this exercise has a spatial resolution of 10m, therefore a pixel represents 10m x 10m on Earth. At this resolution, people and cars cannot be identified.

2. **Observe the false colour image.**
   a. **Try to find the features you previously observed. Can you also identify new features?**

      All features can be identified. Water bodies, especially the ones in the forest, can now be distinguished much more easily.

   b. **What surface type/feature appears red in the false colour image? Distinguish between bright red and dark red.**

      Vegetation/plants appear red. The fields are bright red and the forest is dark red. The structure of the forest can be identified due to the shadow of the treetops.

3. **Describe the differences and similarities between the true colour image in Exercise 1 and the false colour image in Exercise 2.**

   In the true colour image, the vegetation (grass and forest) appears in very dark green, and the bare soil in brown. Buildings and roads are grey. In the false colour images, the grass and forest appear in red.

   Water bodies (lakes and rivers) are very dark in both images, and large buildings that could represent industrial areas are very bright/white in the true and false colour images.

4. **Discuss the advantages and disadvantages of the true colour and false colour images showing near-infrared light.**

   Overall the reflectance displayed in the true colour image is much lower than the one in the false colour image, and the image is darker. This makes it harder to identify water bodies in the real colour image, because the reflectance is also very low. In the false colour image, the water bodies can be clearly identified due to the difference in reflectance values for water (very low reflectance) and the surrounding vegetation (high reflectance).

   In the false colour images, more details of the vegetation can be identified. The reason is the high reflectance in combination with the shadows that occur due to the structure of the treetops. The angle of incidence of the Sun has to be taken into account when discussing shadows: the image was taken in November, meaning that the angle of incidence is lower than in the summer, therefore the shadows are bigger and rough surfaces appear darker.

→ General discussion

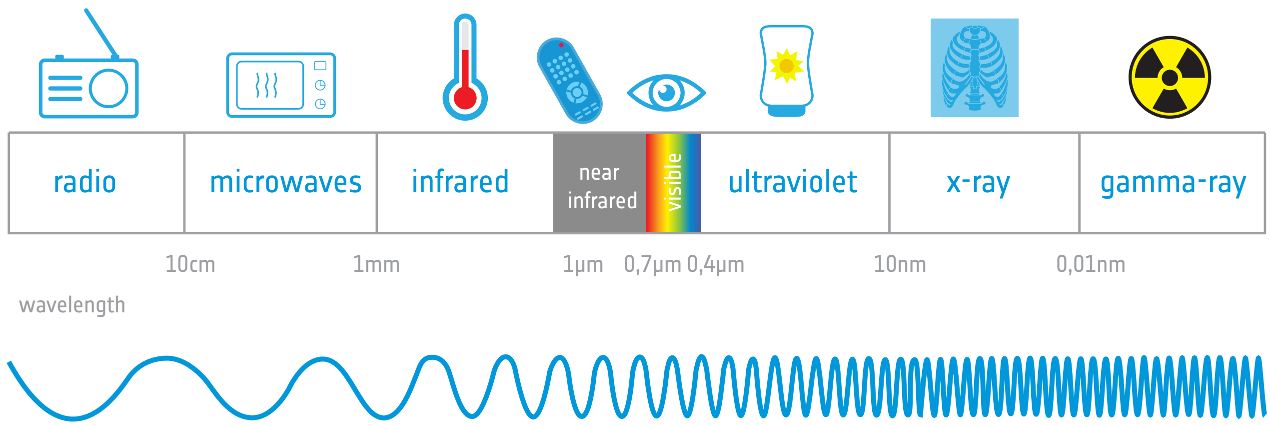
These practical activities can be used to discuss the electromagnetic spectrum, Earth observation applications, and the monitoring of vegetation on our planet. The activities also provide a setting for the discussion of the impact of space technology on our future and on our everyday lives.

→ INFRARED WEBCAM HACK

Using infrared light to observe the world in a new way

Our eyes can't see infrared light, but we can use an infrared camera to see this 'invisible' light. The light we can see – visible light – is only a very small part of the electromagnetic spectrum. Figure A1 shows the different types of radiation and their wavelengths on the electromagnetic spectrum and gives examples of what certain wavelengths are used for.

Figure A1

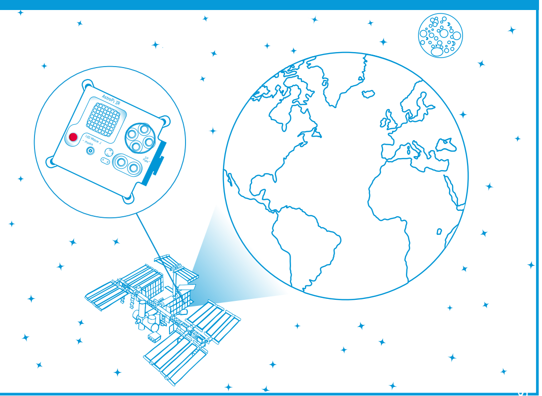


↑The electromagnetic spectrum categorises different types of radiation in order of wavelength, from the longest (radio) to the shortest (gamma-ray)

Infrared light is divided into different parts, just like visible light is divided into different colours. Near-infrared light, the part closest to red light, can be easily detected by the sensors used in digital cameras. Also Earth observation satellites carry scientific instruments designed to detect electromagnetic emissions from constituents of the Earth's surface and atmosphere allowing us to observe our planet in a new way.

Did you know?

Onboard the International Space Station (ISS) there is a very special infrared camera that can be used to take great pictures of Earth! The infrared camera is part of Astro Pi, a small computer with a set of sensors and gadgets that can be used to run great scientific experiments. Teams of students can program this small computer by participating in the European Astro Pi Challenge and use the Astro Pi's near-infrared camera to measure, fot example, the health and density of vegetation on Earth.



→ Activity 1: Hacking the webcam

In this activity you are going to make an infrared camera by hacking a normal webcam. Usually, in all digital cameras and webcams there is an infrared filter behind the lens that filters out all infrared light in order to mostly capture visible light. This filter needs to be removed. Here you find simple instructions on how to hack your webcam to be able to see in near-infrared.

Equipment

- 1 webcam with a manual focus ring on the front
- 1 pin or scalpel
- 2 pieces of exposed photographic film or polarising filter
- Clear tape
- Scissors

Exercise

1. Disassemble the camera

Unscrew the focus ring in an anticlockwise direction until the whole lens can be pulled out.

2. Remove the infrared filter

On the inside of the lens there is a small piece of plastic with a red/green tint (see the left lens in Figure A2). This is the infrared filter. Using a pin or a scalpel, remove the filter. Be careful: this should be done very gently, as the filter can break if too much pressure is used.

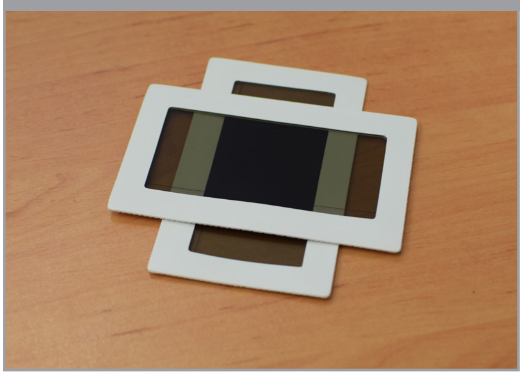
3. Assemble the camera

Screw the lens back onto the webcam and plug the webcam into a computer. It may be necessary to open video software to view an image through the webcam. Use the focus ring to adjust the focus until you have a clear image of the object that you wish to look at.

Figure A2

↑ How to make an infrared camera.

Figure A3



↑ Polarising filters.

The infrared webcam is now ready to be used!

Tip: If your image appears very bright on the screen, there is too much visible light which needs to be filtered out. For this, two pieces of polarising filter or exposed photographic film have to be put in front of the lens. Make sure the two pieces are put on one another perpendicularly. The filters can also be fixed with clear tape.

→ Activity 2: Looking at objects with an infrared camera

In this activity, you will use the hacked infrared webcam to make your own experiment about how objects look like when seen with visible and infrared light.

Equipment

- Infrared camera (from activity 1)
- Remote control
- Led light
- Candle
- Healthy plant and fake plastic plant

Exercise

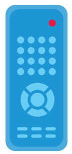
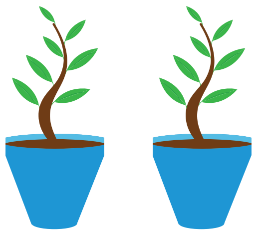
1. Look at the different objects firstly with your eyes (visible light) and then through the webcam (infrared light).
2. Fill in the table on the next page with your observations.

Discussion

Taking into consideration the results from your experiment, discuss with other students how infrared light can help us better understand what we see. Summarise your conclusions below.

Did you know?

The European Space Agency (ESA) has helped develop lots of satellites that use different types of cameras for looking at Earth. A group of missions called the Sentinels aim to improve our understanding and management of the Earth's environment. One of the missions is called Sentinel-2 and consists of two twin satellites. The cameras onboard the satellites take images in visible as well as in infrared light, and they cover the whole planet every five days! Sentinel-2 can be used to monitor plant growth, map changes in land cover, and monitor the world's forests.

Objects	Describe your observations		Explain your observations
	Visible light	Infrared light	
Remote control 			
LED vs. candle 			
Living vs. fake plants 			

→ Activity 3: Looking at Earth in infrared light

Infrared cameras are used in Earth observation satellites. With the help of computers, we can then visualise the light we cannot see with our own eyes. What comes out is a 'false colour image'. If we display the light visible to human eyes, we call it a 'true colour image'. A true colour image combines actual measurements of reflected red, green, and blue light, and shows the world as we see it. A false colour image uses at least one wavelength outside the visible range. As a result, the colours in the final image may not be what we expect them to be. For example, grass is not always green!

In this activity you will analyse satellite images and compare true colour images with false colour images. Will you be able to find the differences?

Exercise

1. Observe the true colour image below taken by the Sentinel-2 satellite (Northern Germany, 28.11.2016). Which of the following features can you identify?

- Agriculture fields
- Snow
- Forest
- Clouds
- River
- Lakes
- Streets
- Cars
- Buildings
- People

Figure A4

↑ True colour image taken by the Sentinel-2 satellite. Contains modified Copernicus Sentinel data [2017] processed by Sentinel Hub.

2. Observe the false colour image taken by the Sentinel-2 satellite (Northern Germany, 28.11.2016).

Note: The false colour image shows reflected near-infrared light as red.

a. Try to find the features you previously observed. Can you also identify new features?

____

____

____

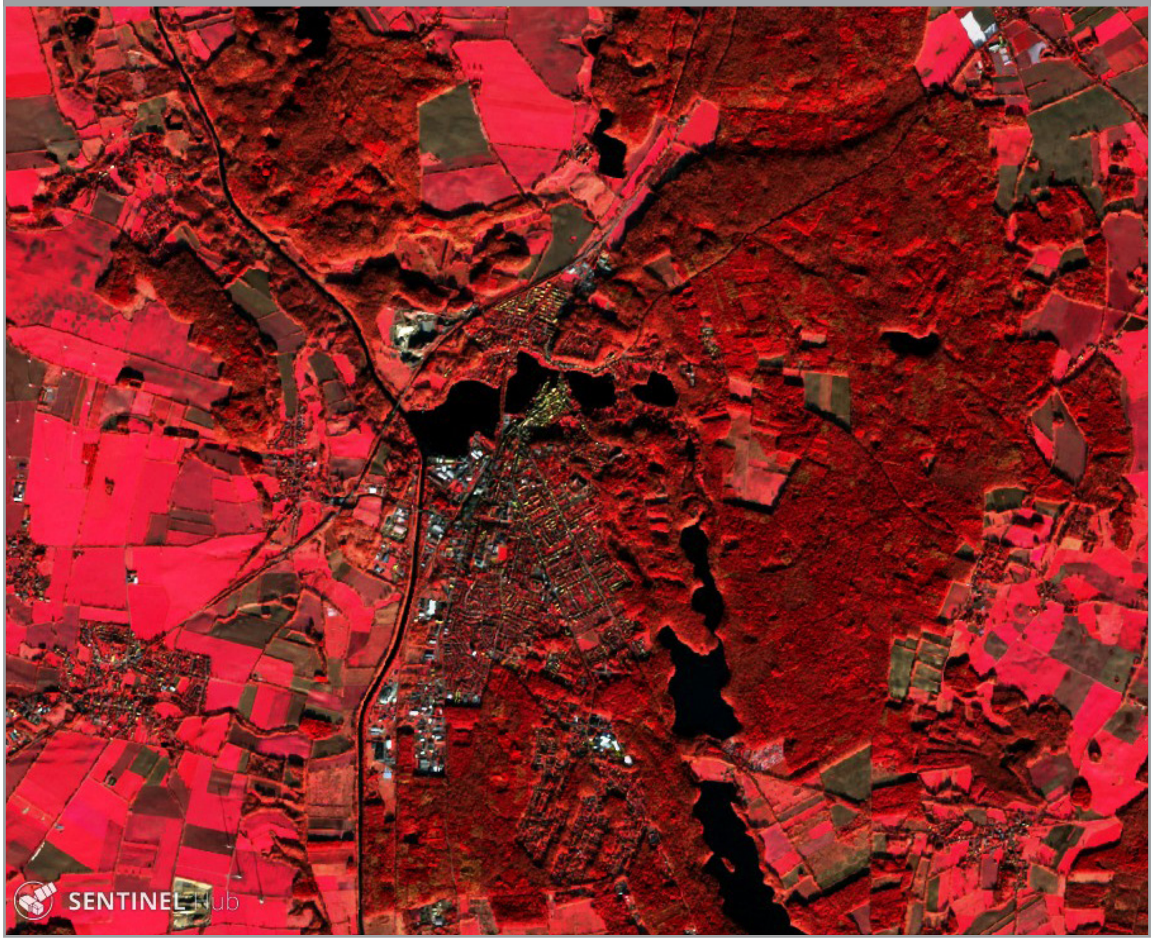
b. What surface type/feature appears red in the false colour image? Distinguish between bright red and dark red.

____

____

____

Figure A5



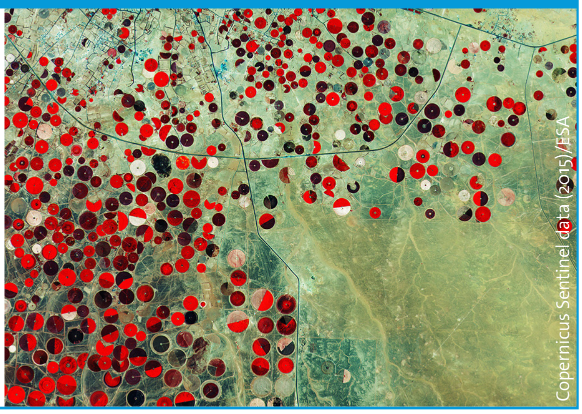
↑ False colour image taken by the Sentinel-2 satellite. Contains modified Copernicus Sentinel data [2017] processed by Sentinel Hub.

3. Describe the differences and similarities between the true colour image in Exercise 1 and the false colour image in Exercise 2.

4. Discuss the advantages and disadvantages of the true colour images and the false colour images showing near-infrared light.

Did you know?

This image from the Sentinel-2A satellite shows how Saudi Arabia's desert is being used for agriculture. The circles come from an irrigation system, where the long water pipe rotates around a well at the centre. It is a false colour image and the near-infrared is displayed in red. Plants reflect most of this light. These high reflection values explain the bright red of the irrigated fields. Near-infrared light is often used to monitor vegetation from space.



→ Links

ESA resources

ESA teach with space – infrared webcam hack video | VP15:
esa.int/spaceinvideos/Videos/2017/06/Infrared_webcam_hack_-_using_an_infrared_webcam_to_observe_the_world_in_a_new_way_-_classroom_demonstration_video_VC15

ESA classroom resources:
esa.int/Education/Classroom_resources

ESA space projects

ESA's Earth Observation missions
www.esa.int/Our_Activities/Observing_the_Earth/ESA_for_Earth

Sentinel -2
www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2

Extra information

Online platform to access satellite imagery
https://apps.sentinel-hub.com/eo-browser

Video Sentinel-2: an introduction
esa.int/spaceinvideos/Videos/2015/07/Sentinel-2_an_introduction

ESA Earth Observation Image of the Week
esa.int/spaceinimages/Sets/Earth_observation_image_of_the_week

Introduction to Planetary Atmospheres

Earth is not unique in possessing an atmosphere. Venus, Mars, Pluto, and two of the satellites of the outer planets—Titan (a moon of Saturn) and Triton (a moon of Neptune) have atmospheres that envelop their surfaces. In addition, the giant planets of the outer solar system—Jupiter, Saturn, Uranus, and Neptune—are composed predominantly of gases. Other bodies in the solar system possess extremely thin atmospheres. Such bodies are the Moon (sodium gas), Mercury (sodium gas), Europa (oxygen) and Io (sulfur).

The compositions of planetary atmospheres are different, for a variety of reasons. First, surface gravity, the force that holds down an atmosphere, differs significantly among the planets. For example, the large gravitational force of the giant planet Jupiter is able to retain light gases such as hydrogen and helium that escape from lower gravity objects. Second, the distance from the sun determines the energy available to heat atmospheric gas to a planet's escape velocity, the speed at which gas molecules overcome a planet's gravitational grasp. Thus, the distant and cold Titan, Triton, and Pluto are able to retain their atmospheres despite relatively low gravities. Finally, we know that the chemistry and geologic history are different for each planet. Because atmospheric makeup is generally related to chemistry and temperature during planetary formation and the subsequent escape of interior gases, the constituents and total pressures of planetary atmospheres are likely to be different. Moreover, on Earth, atmospheric composition is largely governed by the by-products of the very life that it sustains.

From the perspective of the planetary geologist, atmospheres are important in the ways they shape planetary surfaces. Wind can transport particles, both eroding the surface and leaving deposits. Frost and precipitation can leave direct and indirect marks on a planetary surface. Climate changes can influence a planet's geological history. Conversely, studying surface geology leads to an understanding of the atmosphere and climate of a planet—both its present state and its past.

Coriolis Effect

Instructor Notes

Suggested Correlation of Topics

Air and its movements, atmospheres, circulation of air or sea, meteorology, ocean currents, physics: forces and mechanics, planetary rotation

Purpose

The objective of this exercise is to demonstrate that an object which moves in latitude over the surface of a rotating planet experiences the Coriolis effect, an apparent deflection of its path from a straight line. Upon completion of this exercise the student should understand the concept of the Coriolis effect and be able to understand viewing an event from different frames of reference.

Materials

Suggested: lazy susan type turntable (must be able to be rotated clockwise and counterclockwise), paper, tape, markers (3 colors)

Background

The Coriolis effect is caused by an "imaginary" force but has very real effects on the weather of Earth and other planets. On Earth, which spins counterclockwise as viewed from above its north pole, objects are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This deflection is only apparent, however, as an observer watching from space would see the object's path as a straight line. It is because we are viewing in the frame of reference of the rotating Earth that we see the apparent deflection.

This exercise demonstrates the Coriolis effect by using a rotating turntable. Students will draw straight lines while spinning the turntable in different directions. To their surprise the resultant lines will be curves on the paper covering the turntable. This apparent deflection, the Coriolis effect, only occurs in the frame of reference of the turntable. The students, in a different frame of reference, know that the path of the marker used to draw the line was straight. On the sphere of the Earth, we occupy the same reference frame as the motion, so we "see" the Coriolis effect in action. To an outside observer, who is occupying another reference frame, there is no deflection and the motion is a straight line.

This concept has important implications for the motion of ocean currents, storms on Earth, and even missiles, but is unimportant at smaller scales. In combination with pressure effects, the Coriolis deflection gives rise to a counterclockwise rotation of large storms, such as hurricanes, in the northern hemisphere, and clockwise rotation in the southern hemisphere. This could be illustrated to students through pictures of hurricanes or other large storms found in newspapers, magazines, or elsewhere in this lab manual.

Students should work in pairs, one spinning the turntable at a constant speed and the other marking the line. Instructors should note that the spinning of the Earth once a day on its axis is called rotation. Students can experiment with rotating their turntable faster or slower to see the effect on the drawn lines. A faster spin will result in greater deflection. If time or materials are a problem, this exercise can be done as a demonstration by the instructor.

Vector motion of the surface of a sphere is complex. The magnitude of the Coriolis effect is controlled by rotation about the vertical axis. On Earth the vertical axis of rotation is a line connecting the geographic north and south poles. On a rotating sphere, the maximum rotation is at the poles; there is no rotation about the vertical axis at the equator. To visualize this, imagine two flat disks glued onto the surface of a sphere, one at the north pole and one at the equator. As the sphere rotates, the disk at the north pole rotates around the vertical rotation axis of the sphere. The vertical axis of the sphere is also the axis of rotation of the disk. If viewed from above, the disk spins in one spot, just as the sphere does. The surface of the disk at the equator is parallel to the vertical rotation axis of the sphere. When the sphere rotates, this disk revolves around the axis. There is no spin or rotation of the disk at the equator. The magnitude of the Coriolis effect increases from the equator where it has no effect to the poles. The turntable is equivalent to the disk at the pole of the sphere, and illustrates the maximum Coriolis effect.

The Coriolis effect operates on Mars in a similar way as on Earth. Because Mars rotates at about the same rate and in the same sense as Earth, Mars has large-scale weather systems just like on the Earth. Students might try to predict the direction that the Coriolis effect would deflect objects on Venus or Uranus, which spin clockwise as viewed from "above" (north of) the solar system. Advanced students and upper grades can answer the optional starred (*) question, which applies their observations to more complex situations.

Science Standards

- Earth and Space Science
  - Origin and evolution of the Earth system

Answer Key

1. The line is straight.
2. Unlike the real Earth, this model is not rotating.
3. The line was deflected to the right.
4. Counterclockwise.
5. It would be deflected to the right.
6. It was deflected to the left.
7. Clockwise.
8. It would be deflected to the left. [The direction of travel does not matter in the deflection, all directions of travel are deflected to the right in the northern hemisphere and to the left in the southern hemisphere.]
9. Objects in the northern hemisphere are deflected to the right, while those in the southern hemisphere deflect to the left.
10. The streaks form a curved path.
11. The streaks are curved because there is a Coriolis effect on Mars.
12. Yes; for there to be a Coriolis effect on Mars, the planet must rotate.
13. The wind blew from the north.
14. The wind is being deflected to the left.
15. Deflection to the left indicates we are looking at the southern hemisphere of Mars.

*16. The Coriolis "force" is an imaginary force because objects affected by it are really following a straight path. It is an apparent deflection we see from the vantage point (frame of reference) of the rotating Earth.

Name ______________________________

Coriolis Effect

Purpose

By tracing an object as it moves across the surface of a rotating and a non-rotating model, you will demonstrate the true and apparent motions of objects as they move across the real Earth. This apparent motion is known as the **Coriolis effect**.

Materials

For each student group: Turntable which can be spun both ways, paper, tape, colored markers (3)

Introduction

The Coriolis effect is the name given to the imaginary force that deflects objects, such as rockets or large storms, which move over the surface of some planets. It is important in causing the swirling motion of storms, including hurricanes. The Coriolis effect occurs on Earth and other planets because the planets rotate.

Questions

Cover the turntable with the paper, taping it to the edges of the turntable. Use one of the markers to draw a straight line all the way across the turntable. This shows the path of clouds or objects moving on a non-rotating planet.

1. Observe and describe the shape of the line you drew. Looking down on your line, is it straight or curved?

2. What is wrong with (missing from) this model of the Earth that might affect how objects truly move over the Earth's surface?

Now spin the turntable counterclockwise. This is the direction that the Earth turns (or rotates), when viewed from the north pole. The turntable is modeling the northern hemisphere of the Earth. Draw a straight line across the turntable using a different colored marker, while spinning it at a constant speed. Be sure to watch that your marker follows a straight path! Label the beginning of the line you drew with an arrow pointing in the direction the marker moved. Note that the line you drew is a curve.

3. With the starting point of the line directly in front of you, in which direction was line deflected? (Which way does the arrow point—right or left?)

4. Which direction does the line curve (clockwise or counterclockwise)?

5. If you were in an airplane that takes off from Miami, Florida and is flying to Toronto, Canada, would your plane be deflected to the left or to the right as it flew?

Now spin the turntable clockwise. This is the direction that the Earth turns (or rotates), when viewed from the south pole. The turntable is modeling the southern hemisphere of the Earth. Draw a straight line across the turntable using a different colored marker, while spinning it at a constant speed. Be sure to watch that your marker follows a straight path! Label the beginning of the line you drew with an arrow pointing in the direction the marker moved. Note that the line you drew is again a curve.

6. With the starting point of the line directly in front of you, in which direction was line deflected? (Which way does the arrow point—right or left?)

7. Which direction does the line curve (clockwise or counterclockwise)?

8. If you were in a cruise ship that set sail from Cape Town, South Africa and was sailing for Rio de Janeiro, Brazil, would your ship be deflected to the left or to the right as it traveled?

9. What is the difference between the way objects move over the Earth in the northern hemisphere compared with those in the southern hemisphere?

Examine Figure 7.1, which shows part of Mars. The bright streaks associated with some craters can be used as wind direction indicators. They are deposits of dust that can form downwind from craters.

10. Does the group of streaks form a straight or a curved path (as a whole group)?

11. What does the shape of the wind streaks indicate about the existence of a Coriolis effect on Mars?

12. Does Mars rotate? How do you know?

13. From which way did the wind blow to make the streaks in Figure 7.1?

14. Imagine you are on the part of Mars shown in this figure, standing with the wind to your back. Which way is the wind being deflected, to your left or your right?

15. If Mars rotates in the same direction as the Earth (from west to east), is this a picture of the northern or southern hemisphere of Mars?

Optional Question

*16. Why is the Coriolis "force," which causes objects to deflect from a straight path on a rotating planet, sometimes called an imaginary force?

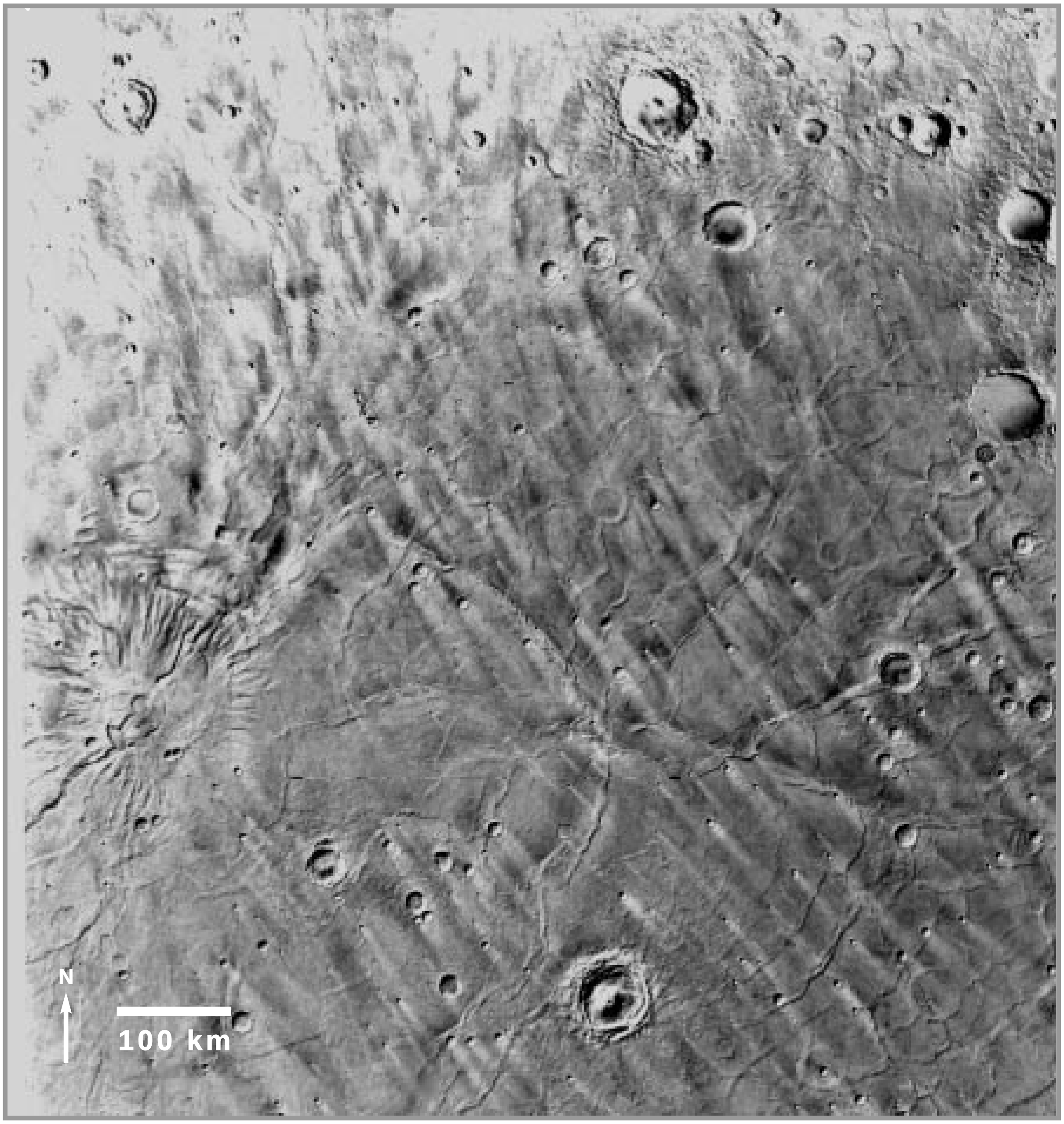


Figure 7.1. *Centered at 20˚, 250˚W, this mosaic is of a region on Mars called Hesperia Planum, site of much aeolian (wind) activity. Note the bright streaks associated with some of the craters; they can be used as wind direction indicators. North is to the top. Viking Orbiter mosaic 211-5478.*

Exercise Seven is suggested as an introductory exercise.

■ ★ 1.0 hours

Storm Systems

Instructor Notes

Suggested Correlation of Topics

Air and its movements, air masses, atmospheres, Coriolis effect, cyclonic storms, geography, meteorology, rotation of planets, weather forecasting, weather satellites, winds

Purpose

The objective of this exercise is to demonstrate the fundamentals of atmospheric circulation as they apply to Earth and other planets. Upon completion of this exercise the student should understand the fundamental controls on atmospheric circulation, especially planetary rotation and the Coriolis effect. In addition, the student will be able to make simple weather predictions based on satellite photographs.

Materials

World map

Background

Earth's weather patterns are complex, but some basic meteorological concepts can be understood by examining photographs of the Earth taken from space. Furthermore, comparing Earth's cloud patterns to those of other planets which have very different atmospheres—Mars, Venus, and Jupiter—sheds light on some basic principles of atmospheric circulation.

A fundamental concept of this exercise is that air moves from areas of high pressure toward areas of lower pressure. An analogy can be made to water flowing from a high pressure hose, or dye dissipating in water.

The simple Hadley cell circulation model of Figure 8.1 introduces atmospheric circulation. The pattern is driven by solar energy, which heats the equatorial regions. As the planetary comparisons of this lab indicate, rapid planetary rotation disrupts this simple pattern into multiple circulation cells and turbulent eddies. This occurs on Earth giving rise to cyclonic storms, which are low pressure centers that result in inclement weather. The tilt of a planet can also affect the atmospheric circulation pattern, because the region of maximum solar heating will change with the season of the year. Venus rotates very slowly (once in 243 Earth days) and is tilted only 3° with respect to the plane of its orbit. Thus, Venus has a relatively simple pattern of atmospheric circulation which approximates a Hadley cell.

The Coriolis effect, introduced in the previous laboratory exercise, is an imaginary force that causes deflection of air parcels due to a planet's rotation (Figure 8.2). On a planet rotating toward the east (such as the Earth and most other planets), this causes rightward deflection and counterclockwise rotation of winds in the northern hemisphere, and the opposite effect in the southern hemisphere (Figure 8.3). The slow rotation of Venus makes the Coriolis effect unimportant there. However, like Earth, Mars has a 24 hour rotation period and the Coriolis effect is important.

To some students it will be readily apparent which way a storm is spiraling. Others may first want to sketch the spiraling clouds. If your pencil moves clockwise as it moves in toward the center of the spiral, then the clouds spiral clockwise, and vice versa. This exercise calls on students to locate and predict the weather in various cities around the world. Using a world map to locate the cities and then finding them on the Earth photo is a good lesson in geography. Additional cities can be added by the instructor if time permits.

Jupiter is a giant gas planet that has no solid surface; instead its atmosphere gets progressively denser with depth. At great depth within the atmosphere the pressure is so tremendous that the gases of the atmosphere are compressed into a liquid, and below this is the solid core of the planet. Jupiter rotates very rapidly, once in about 9 hours 55 minutes; Jupiter also has a large supply of internal heat. These factors contribute to complex, turbulent flow in the atmosphere. Neighboring bands in Jupiter's atmosphere typically have winds that blow in opposite directions. Vortices (spots) in the atmosphere are generally not Coriolis-induced; instead they develop along boundaries between bands as a result of the opposing winds. Imagining that a storm rotates like a pinwheel can help to reveal the directions that winds to either side are blowing. Most of Jupiter's spots are temporary features, appearing and disappearing as winds and eddies shift slightly. The Great Red Spot of Jupiter, observed from Earth for more than 300 years, is a notable exception.

Science Standards

- Earth and Space Science
  - Energy in the Earth system
  - Origin and evolution of the Earth system

Answer Key

1. **a.** It spirals counterclockwise.

   b. The Coriolis effect deflects any northern hemisphere storm into a counterclockwise spiral.

2. **a.** They spiral clockwise.

   b. The Coriolis effect deflects any southern hemisphere storm into a clockwise spiral.

3. The feature is a storm front, usually associated with precipitation, wind, and cooler temperatures.

4. **a.** Continued clouds and showers; cool.

   b. Continued clear and warm.

   c. Partly cloudy and hot.

   d. Increasing clouds with rain likely; cooler.

   e. Continued clear and cool.

5. The air pressure will decrease as the cyclonic storm over the eastern United States, a center of low pressure, passes through.

6. **a.** It is a cyclonic storm.

   b. It must be in the northern hemisphere because the clouds spiral counterclockwise.

7. **a.** No.

   b. Venus has a more simple circulation pattern.

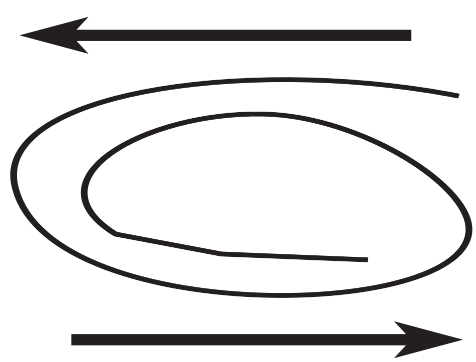
   c. Venus must rotate more slowly than the Earth, because it does not show evidence for Coriolis–induced storms. Also, its simple cloud banding reflects a single equator-to-pole circulation cell.

8. **a.** Jupiter rotates quickly. It shows well-defined banding and a turbulent, complex pattern of atmospheric circulation.

   b. The GRS lies in Jupiter's southern hemisphere.

   c. Counterclockwise.

   d. No; the rotation is incorrect.

9. 

Name ______________________

Storm Systems

Purpose

By examining photographs of Earth, Mars, Venus, and Jupiter, you will recognize wind circulation patterns and the influence of **rotation** and the **Coriolis effect** on planetary atmospheres.

Materials

World map.

Introduction

Our lives are affected every day by the weather—on some days more than others! Being able to predict the weather is a convenience, but being able to predict severe weather is important to public safety. Furthermore, understanding the Earth's weather patterns is critical to agriculture, transportation, and the military. To gain insight into Earth's weather and circulation patterns, it is useful to examine the atmospheres of other planets, comparing them to each other and to Earth.

Atmospheric circulation is caused by differences in heating, primarily between the poles and equator. On an ideal non-rotating planet (Figure 8.1), warm air would rise over the equatorial regions, lowering the air pressure there. Air in each hemisphere would then circulate to the cool polar regions where it would sink, increasing air pressure there. To complete the cycle, the cold high-pressure air would travel at ground level back toward the equator. This simplified pattern of circulation is called a Hadley cell, named after the British scientist who first proposed the model. On a real planet, the pattern of atmospheric circulation is complicated by rotation, which breaks the circulation into several cells from pole to equator and results in an ever-changing pattern of turbulent swirling clouds, called **eddies.** Also, if a planet is tilted with respect to its orbit around the Sun, the latitude of maximum solar heating changes as the planet goes through its yearly cycle of seasons.

Air moves from regions of high pressure to regions of low pressure. The pressure difference, or gradient, is

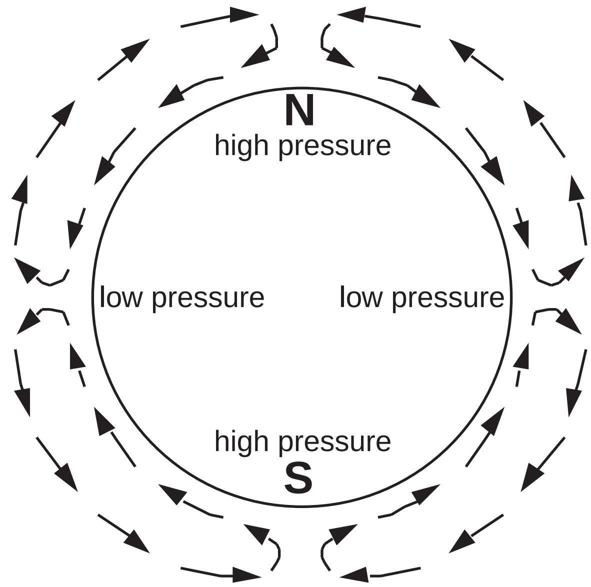


Figure 8.1. *The idealized Hadley cell model of atmospheric circulation. Although unrealistically simplified, this pattern of airflow would develop on a planet if it were spinning very slowly and if the axis were at right angles to the orbital plane (that is, if there were no seasons). The Sun would always heat the planet most strongly at the equator. Air would rise along the equator and lower the pressure locally. Colder, dense air would sink at the poles, raising the air pressure there. This air would return toward the equator along the ground. Rapid planetary rotation breaks up this circulation pattern into several cells and produces turbulent eddies.*

the driving force for atmospheric circulation. However, other effects prevent the direct motion of a given air mass from high to low pressure. Friction between the ground and the atmosphere modifies air motion, as does the presence of mountains or other topography. Furthermore, the Coriolis effect deflects air masses as they move. On a planet that rotates in the normal sense (toward the east), a parcel of air is deflected to the right of its direction of motion in the northern hemisphere and to the left in the southern hemisphere. Figure 8.2 shows this effect.

Cyclonic storms are the fundamental mechanism for turbulent, inclement weather on Earth. These are huge, well-organized centers of low pressure which develop along the boundaries between air masses. As a cyclone intensifies, so does weather activity along the boundary, or **front.** In addition to its clouds, a storm front commonly brings with it precipitation, wind, and cooler temperatures.

The motion of air parcels on Earth generates such low pressure centers. Air parcels can approach low pressure cells from all directions. Because of the Coriolis deflection, a circulation of winds is set up around the low pressure centers (Figure 8.3). The result is a counterclockwise spiral of air into a low center in the northern hemisphere, and a clockwise spiral in the southern hemisphere.

Procedure and Questions

Examine Figure 8.4, using the world map to help identify the land masses that are visible.

1. Notice the well-defined spiral pattern of clouds southwest of the Baja peninsula, Mexico.

   a. Which way is this cloud pattern spiraling, clockwise or counterclockwise?

   b. Why?

2. Now examine the two cloud spirals over the southern Pacific Ocean.

   a. Which way are these clouds spiraling, clockwise or counterclockwise?

   b. Why?

3. Notice the long line of clouds stretching over the southern Pacific Ocean. What is this feature and what kind of weather is likely associated with it?

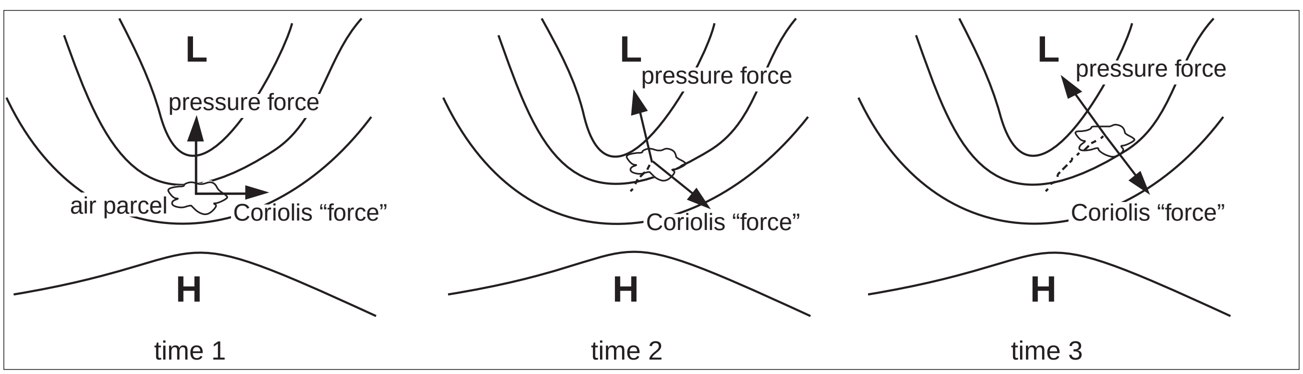


Figure 8.2. *As a small mass of air, called an air parcel, moves under the influence of a pressure gradient, its path is not a direct one from high to low pressure. The curved lines around the low pressure centers (L) are contours of equal pressure, or isobars. The low pressure center can be considered a "well" or sink for air, and the high pressure center (H) can be considered a "ridge" or source of air. If you were riding along an air parcel in the northern hemisphere, you would be deflected to the right of your direction of motion as the air parcel drifts from high pressure toward lower pressure. Thus, the final motion is nearly parallel to the isobars, rather than across them. In the southern hemisphere, the mirror image of the diagram is observed, with the Coriolis "force" causing air parcels to deflect toward their left.*

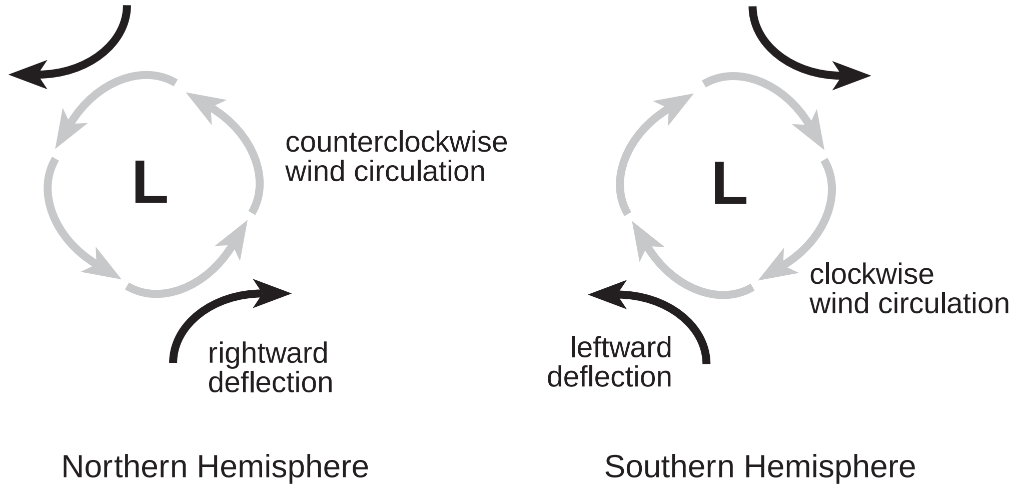


Figure 8.3. *A simplified illustration of how low pressure cells (cyclones) develop. Air parcels heading toward lows are deflected by the Coriolis effect to set up a counterclockwise circulation pattern in the northern hemisphere, and a clockwise pattern in the southern hemisphere.*

4. As Earth rotates from west to east, frictional drag pulls the atmosphere along more slowly in the same direction. Assuming that the storm system off of southern Chile will reach the coast by tomorrow, and noting that this photo was taken in September, determine a likely weather forecast (temperature, clouds, and precipitation) for the next 24 hours in each of the following locations:

   a. Indianapolis (40°N, 86°W)

   b. El Paso (32°N, 106°W)

   c. The Galápagos Islands (0°N, 91°W)

   d. Tierra del Fuego (54°S, 68°W)

   e. Buenos Aires (34°S, 58°W)

5. Will the air pressure become higher or lower in Bermuda during the next 24 hours? Explain.

6. Look at Figure 8.5, taken by a spacecraft in orbit over Mars. Like Earth, Mars rotates west to east.

   a. What do you think this cloud feature is?

   b. In what hemisphere is the feature? How do you know?

7. Examine the atmosphere of Venus as seen in Figure 8.6.

   a. Can you identify any obvious spiraling clouds that might be due to the Coriolis Effect?

   b. Compare the photos of Venus and Earth, and recall the simple Hadley cell circulation model of Figure 8.1. Does Venus appear to have a more simple or more complex pattern of atmospheric circulation than Earth?

   c. How does the circulation pattern support the proposition that Venus rotates slowly?

Jupiter is a gaseous planet, having no solid surface (but likely possessing a solid core). Although the planet is composed mostly of hydrogen and some helium, its visible clouds probably consist of ammonia (NH_4), ammonium hydrosulfide (NH_4HS), and water (H_2O). The Great Red Spot (GRS) is a great storm in the clouds of Jupiter.

8. Base your answers to the following questions on the Voyager photos of Jupiter shown in Figures 8.7 and 8.8.

   a. Does Jupiter rotate quickly or slowly? Justify your answer.

   b. Does the GRS lie in the northern or southern hemisphere of Jupiter?

   c. In which direction do winds around the GRS rotate?

   d. Is the GRS a Coriolis-induced storm? Support your answer.

9. The winds of Jupiter commonly blow in opposite directions in neighboring bands. That is, winds blow to the east in one band and to the west in the neighboring band. These opposing winds can act to create swirling eddies and storms. Draw a sketch of the GRS. Indicate with arrows the directions that winds along its northern and southern edges are blowing.

Sketch area

Figure 8.4. *Earth as seen from the Geostationary Operational Environmental Satellite, GOES-7. The picture was taken at 6 p.m. Greenwich Mean Time on September 25, 1994, soon after the start of northern hemisphere autumn. The north pole is toward the top.*

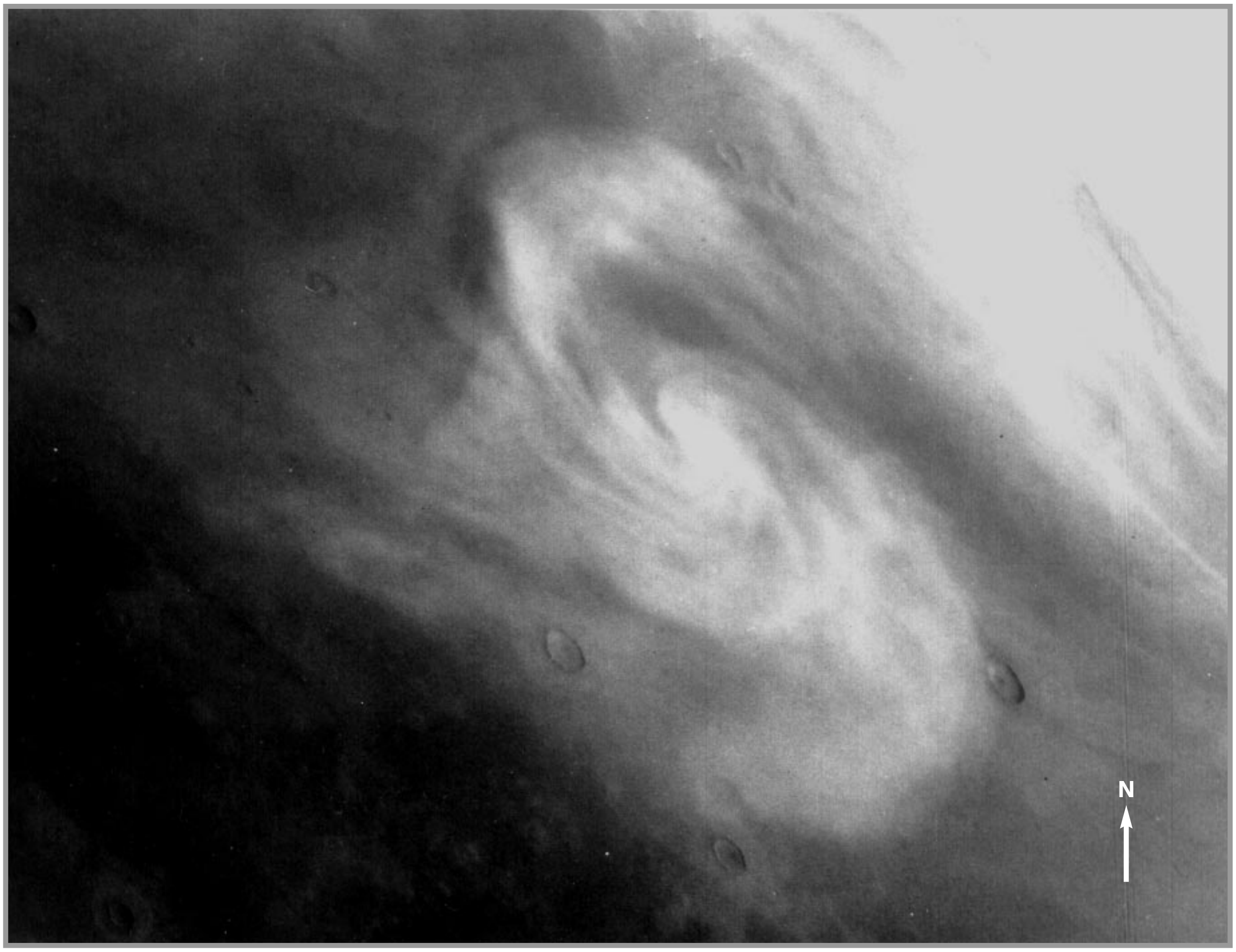


Figure 8.5. *Viking Orbiter image 78A42, showing a water frost cloud pattern over the surface of Mars. North is toward the top.*

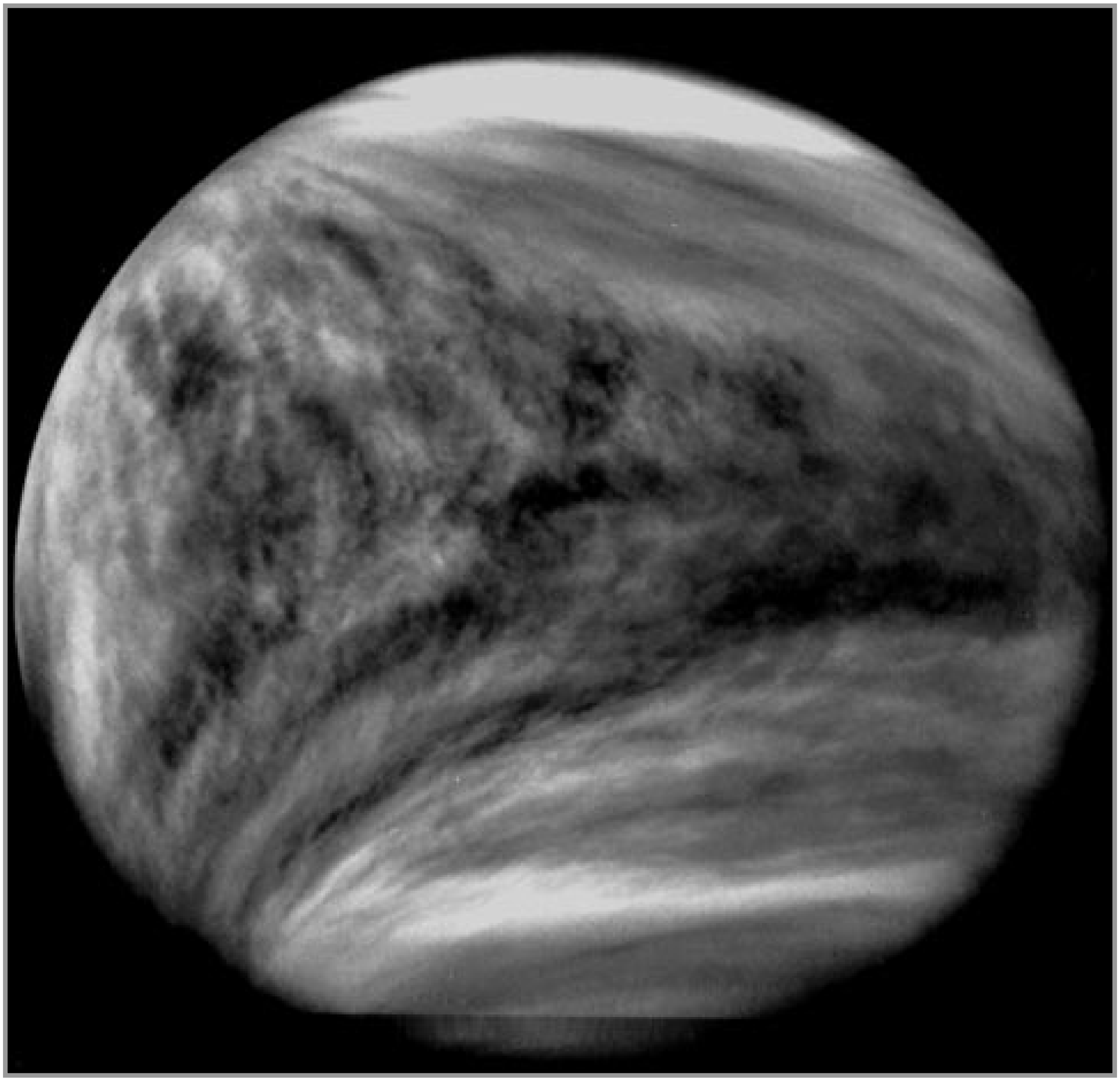


Figure 8.6. *Patterns of cloud motion on Venus are revealed in this ultraviolet image, taken by the Pioneer Venus orbiter in 1979. Venus is unusual in that the planet and its atmosphere rotate from east to west. The surface of Venus cannot be seen through the thick clouds. North is toward the top; the horizontal black line is missing data. Pioneer Venus image 0202-79-046-0830, courtesy of Larry Travis.*

Figure 8.7. *Jupiter as seen by the Voyager 1 spacecraft from a distance of 54 million km (34 million miles), as it approached the planet on January 9, 1979. The Great Red Spot (GRS) is a large vortex just below center. North is toward the top.*

Figure 8.8. *Closeup of the Great Red Spot (GRS) seen by Voyager 1 on February 25, 1979 from a distance of 9.2 million km (5.7 million miles). The spot is about 25,000 km (16,000 miles) across, and could hold two Earths side-by-side. White ovals and turbulent, swirling eddies are also visible.*

■ ★ 1.0 hours

Aeolian Processes

Instructor Notes

Suggested Correlation of Topics

Aerodynamics, air and its movements, arid lands, climate, deserts, environments, erosion, landforms, meteorology, weather, wind and its effects

Purpose

The objective of this exercise is to demonstrate the process of wind erosion and deposition around surface features such as hills and craters.

Materials

- 3-speed fan
- 6-foot-long table (or longer)
- chair
- drop cloth
- sugar (5-pound bag); very fine sand can be substituted
- small ball (tennis or racquet ball)
- drinking glass
- metric ruler
- pencil
- tape
- ribbon or string (approximately 15 cm-long)
- 3 to 5 obstacles, different sizes and types; rocks, ruler, key, etc.

This exercise works well for groups of students. In addition, it can be a demonstration by the instructor. This exercise is only a general simulation of the complex interaction of the wind and a planetary surface. The wind produced by the fan has a "spin" to it because of the fan blades. For increased simulation accuracy, the wind can be stabilized by removing the "spin". To stabilize the wind, an open gridwork, such as toilet paper tubes glued together, must be placed between the fan and the experiment. Because the gridwork will slow the wind, as well as stabilize it, higher fan speeds will be necessary for material movement. Commercial three speed fans may not have sufficient wind velocities. Sugar is much easier than sand to move with the wind velocities produced by a commercial fan. Both materials are messy to work with, so have a dust pan and broom on hand.

For more accurate simulation of the effects of wind on planetary surfaces, it is recommended that a wind tunnel be constructed. The directions for constructing a wind tunnel are included here. The construction of the wind tunnel is time consuming, but can be used for quantitative experiments, or for science-fair projects.

Wind Tunnel

Materials:

1. Wardrobe box from a moving company
2. 3-speed 50 cm box fan
3. Wind stabilizer (open ended milk cartons or cardboard tubes glued together along their lengths)
4. Base for inside box, approximately 15 cm high and 50 cm wide
5. Masking tape
6. Clear plastic wrap (for the side 'windows')
7. Sand collection tray (such as a kitty litter box)
8. Dark-colored posterboard

Construction:

Figure 9.1 shows the set-up for the wind tunnel. Moving company wardrobe box (or similar size box 61 cm x 50 cm x 122 cm) is kept intact (do not remove the flaps). Three windows are cut out, one on each side and one on the top. The two side windows are sealed with clear plastic wrap (or clear acrylic panels) and taped from the inside. The width of the plastic wrap determines the height of the window. A convenient length is 40 cm. The top window is left unsealed so that you can look more closely at the sand crater and perhaps take pictures during different stages of the experiment. A base is placed on the floor of the wind tunnel in order to raise the floor area to nearer the center of the fan. Fifteen centimeters above the floor is sufficient. The base should fit snugly within the tunnel, to help stabilize the box and to prevent the base from being moved by the wind from the fan. The sand collection tray is placed behind the base to catch some of the sand or sugar. The posterboard is placed on top of the base and should be taped down along the sides to prevent it from becoming airborne during the experiment. The wind stabilizer is placed directly against the base within the tunnel and the fan is placed immediately behind the wind stabilizer. The fan should be within the flaps at one end of the box, and directed to blow into the tunnel.

Science Standards

- Earth and Space Science
  - Energy in the Earth system
  - Origin and evolution of the Earth system

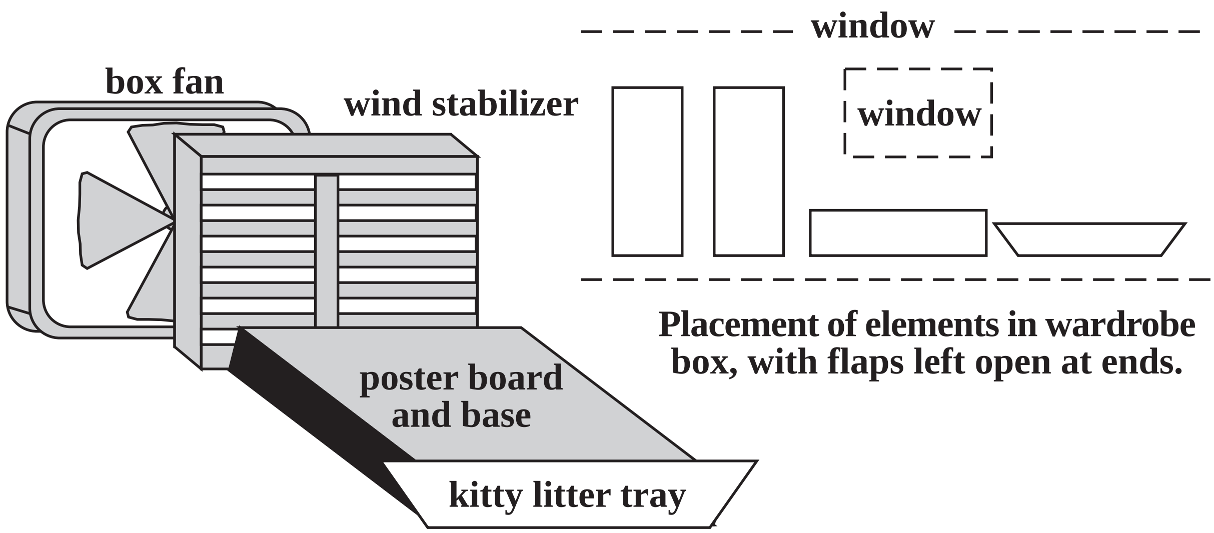


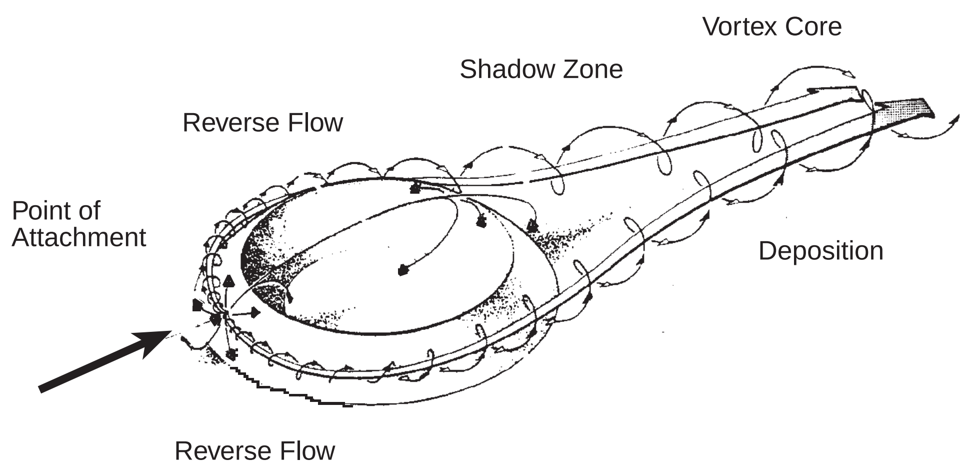
Figure 9.1. *Diagram of wind tunnel construction.*

Answer Key

1. Sketch of cone
2. Answers will vary, depending on fan speed and material (sugar or sand) used. Usually travels entire distance of table and beyond (a meter or more).
3. Answers will vary, but may see a sheet of sugar/sand with ripple-like features developing perpendicular to the wind direction.
4. Answers will vary, depending on fan speed and material used. Usually 1/3 to 1/2 meter for the initial bounce. The second one is shorter (less energy).
5. Answers will vary, depending on fan speed and material used. Usually a few centimeters.
6. Sketch (NOTE: sketches are not provided within this answer key, as the variation in fan velocities will control the speed of erosion and deposition).
7. Sketch
8. Erosion occurs at the front and sides of the cone.
9. Deposition occurs behind the cone.
10. The sketch below represents the aerodynamic characteristics of a crater when wind blows across it from left to right. Experiments to visualize this model were done at the NASA Ames Research Center. For a cone, the reverse flow (seen within the crater) does not occur.
11. Sketch
12. Depending on the shape and positioning of the obstacles, sugar will initially pile up against the obstacle (on the front and sides), some sugar will also be deposited behind each obstacle. With time the sugar will be removed from the front and sides, but will remain in the lee of (behind) each obstacle. For discussion, talk about windbreaks, such as snow fences, and other obstacles man puts in the path of the wind to control drifting sand and snow.
13. Sketch
14. Sketches, see answer 10 above for wind movement arrows.
15. Students should see sugar within the crater moving from the back of the crater towards the front (reverse flow). Once the back rim of the crater has been removed by erosion this motion will decrease dramatically and may not be observed by the student.
16. Sketches, see answer 10 above for wind movement arrows.
17. Answers will vary, should be the same for both crater shapes.
18. **a.** Answers will vary, but should have produced something similar to the windstreaks seen in the figure (most likely during Part Two).

    b. The average prevailing wind has come from the east (from right to left).

    c. The bright crater tails are most likely depositional zones of bright surface materials.



Name ______________________________

Aeolian Processes

Purpose

In this experiment you will investigate the process of wind erosion and deposition around features such as craters and hills.

Materials

For each student group: 3 speed oscillating fan, long table, chair, drop cloth, sugar, small ball (tennis or racquet ball), drinking glass, metric ruler, pencil, tape, ribbon or string (~15 cm long), 3 to 5 obstacles (small rocks, keys, ruler, eraser, etc.).

Introduction

Wind is an important agent of gradation in many arid and coastal regions of the Earth and on Mars and Venus. During wind erosion, small particles are moved in **suspension, saltation, or traction**. Very small particles can be carried by the wind without touching the ground until the wind slows or stops and drops the particles. This is termed suspension. Most sand (and sugar) sized particles are bounced along the surface. This is termed saltation. Particles too large to be picked up by the wind or bounced along the surface may be pushed along the surface by the wind or by the impact of particles in saltation. This is termed traction. Eventually the particles are deposited by the wind in some new location. Wind erosion and deposition of particles result in distinctive landforms, such as dunes and windstreaks. Venus and Mars have wind related features similar to those seen on Earth.

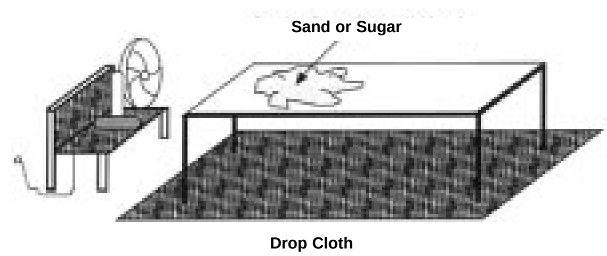


Figure 9.2. *Diagram of the experimental set-up.*

Procedure and Questions

Place the fan on the chair, centered at the end of the table. Make sure the center of the fan is even with the surface of the table (see Figure 9.2). Direct the wind by tilting the fan towards the surface of the table at an angle of 15 to 20 degrees from vertical. Tape a piece of ribbon or string on the end of a pencil. Turn the fan on medium speed. Holding the pencil perpendicular to the surface of the table with the string along the table, move the pencil around the table to locate the "dead spots" produced by the fan. Locate the area near the fan where the air movement is greatest; this spot is where all sand piles should initially be placed.

Part One

Form a 5 centimeter high cone of sugar in the identified spot. Make an initial sketch of the top view and side view of the cone in the space provided.

1. Initial Sketch (use Sketch Area A):

   Turn on the fan at a speed (usually medium) that results in moderate movement of material. Leave the fan on for three minutes. Answer the following questions while the fan is blowing.

2. How far down the table surface has the sugar traveled after one minute?

Sketch Area A

3. Describe the pattern the sugar has formed at the far end of the table after 2 minutes.

4. What is the average length of the bounce of a sugar grain leaving the cone of sugar? Is the second bounce of a sugar grain longer or shorter than the first bounce?

5. How high above the table does the sugar rise (in centimeters).

After three minutes turn off the fan and make a sketch of the cone. Include both a top and side view.

6. Second Sketch (use Sketch Area A):

Turn the fan back on for another two minutes. Be sure to note the saltation of the sugar grains at the far end of the table. Sugar from the cone will hit sugar grains on the table and make them move along in saltation or traction. After two minutes turn the fan off and make a final sketch of the top and side views of what remains of the cone of sugar.

7. Final Sketch (use Sketch Area A):

Compare your previous two sketches with the final one.

8. From where has most of the sugar been eroded on the cone?

9. Has any sugar been deposited around the cone? If so, where?

10. Based on your three sketches of the sugar cone, diagram the effect the cone has on the wind movement. Do this by imagining you can see the wind. Draw arrows to show how you think the wind moves around the cone.

Part Two

Clean up all the sugar on the table. Form another 5 cm high cone of sugar in the spot of greatest wind movement. Place obstacles (keys, small rocks, eraser, etc.) at different locations on the table downwind of the cone of sugar. Place the obstacles at different orientations to the wind. For example, with a long side parallel, perpendicular or at an angle to the wind; flat or on its side. Turn on the fan at the same speed as in part one. After three minutes turn the fan off and observe the deposition and erosion of sugar around the obstacles.

11. Make a sketch (include both a top and side view) of each obstacle and the sugar surrounding it. Add arrows to indicate the movement of the wind around each obstacle. (use Sketch Area B).

Sketch Area B

12. Where does most of the deposition occur at the obstacle? Where does most of the erosion occur?

Part Three

Remove the obstacles and clean up all the sugar on the table. Form a thin (few grains thick) layer of sugar 20 cm by 20 cm in size and make a 3 cm high cone of sugar in the center. Make sure the cone is in the spot of maximum wind. Use the ball to form a bowl-shaped crater on the pile. Remove the ball and make an initial sketch of the crater. Include a top and side view.

13. Initial Sketch (use Sketch Area C):

    In this part of the activity, you will be turning the fan on and off for three one-minute intervals to monitor the progress of erosion of the crater. Turn on the fan at the same speed used previously, producing moderate movement of the sugar. After one minute, turn off the fan and observe what changes have occurred to the crater and the surrounding area. Sketch what you observed. Include a top and side view, as well as arrows indicating the wind movement over and around the crater.

14. a. Sketch after first one-minute interval (use Sketch Area C):

    b. Sketch after second one-minute interval (use Sketch Area C):

    c. Sketch after final one-minute interval (use Sketch Area C):

15. How is the movement of the wind around the crater different from the movement of the wind around the cone in Part One?

Sketch Area C

Part Four

Clean up all the sugar on the table. Form another thin layer of sugar 20 cm by 20 cm in size and make a 3 cm high cone of sugar in the center. Make sure the cone is in the spot of maximum wind. Use the bottom of the drinking glass to form a flat-bottomed crater that goes all the way down to the table surface. Make an initial sketch of the crater and its surroundings. Turn the fan on and off for three, one-minute intervals and sketch what you observe. Include top and side view, as well as arrows indicating the wind movement over and around the crater. (Use Sketch Area D, placing two sets of sketches in each box provided.)

16. **a.** Initial Sketch (use Sketch Area D):

    b. Sketch after first one-minute interval (use Sketch Area D):

    c. Sketch after second one-minute interval (use Sketch Area D):

    d. Sketch after final one-minute interval (use Sketch Area D):

17. Based on your observations and sketches, are there any differences in erosion and deposition of sugar between the bowl-shaped crater and the flat-bottomed crater? If yes, explain.

The wind is at work on other planetary surfaces besides Earth. Examine the photograph of Mars (Figure 9.3).

18. **a.** Do you see anything similar to what you produced on the table?

b. From which direction do you think the wind was blowing?

c. Are the light areas behind the craters zones of erosion or deposition? Recall the obstacles in Part Two.

Sketch area D

Figure 9.3. *Wind streaks on Mars located on plains between Tartarus Montes and Orcus Patera. The picture center is approximately 19°N, 183° W. North is to the top. Viking Orbiter photograph 545A52.*

Aeolian: Pertaining to wind.

Albedo: The ratio of the radiation reflected by a body to the amount incident upon it, often expressed as a percentage, as, the albedo of the Earth is 34%.

Angle of illumination: The angle that a ray of electromagnetic energy makes with the plane of a surface (light from directly overhead is at 90°).

Atmosphere: The body of gases surrounding or comprising any planet or other celestial body, held there by gravity.

Caldera: Large, circular to subcircular depression associated with a volcanic vent. Calderas result from collapse, explosion, or erosion.

Cinder cone: A volcanic, conical hill formed by the accumulation of cinders and other pyroclastic materials; slopes are usually greater than 10°.

Contact: A plane or irregular surface between two types or ages of rock.

Coriolis effect: The acceleration which a body in motion experiences when observed in a rotating frame. This force acts at right angles to the direction of the angular velocity.

Corona: Elliptical, tectonically deformed terrains found on Venus and Miranda.

Crater: Circular depression on a surface.

Cyclonic storm: Atmospheric disturbance with circulation of winds in a counterclockwise direction in the northern hemisphere and in a clockwise direction in the southern hemisphere.

Datum plane: A surface of widespread extent used as a reference for stratigraphic determinations.

Density: Measure of the concentration of matter in a substance; mass per unit volume.

Deposition: The accumulation of material by physical or chemical sedimentation.

Dip: The angle that a surface makes with the horizontal (measured perpendicular to the strike of the surface).

Dune: Mound of fine-grained material formed by wind or water

Eddy: A temporary current, usually formed at a point at which a current passes some obstruction, or between two adjacent currents flowing in opposite directions, or at the edge of a permanent current.

Ejecta: The deposit surrounding an impact crater composed of material (rock fragments, glass) thrown from the crater during its formation.

Electromagnetic spectrum: Energy in the form of radiation, all sharing the same speed of propagation (c - speed of light) but varying in frequency and wavelength.

Embayment: A low area containing rocks that extend into the terrain of other rocks (lap over or up against other rock units).

Equilibrium (cratered surface): A state of “balance”, in which craters of a given size are formed and obliterated at the same rate.

Erosion: Process whereby materials are loosened, dissolved, or worn away, and moved from one place to another by natural agencies. Includes weathering, solution, corrosion, and transportation.

Fault: A fracture or zone of fractures along which the sides are displaced relative to one another.

Fault, normal: Fault in which the rocks have been shifted vertically by extensional forces.

Fault, reverse: Fault in which the rocks have been shifted vertically by compressional forces.

Fault, strike-slip: Fault in which the rocks have been shifted horizontally past each other along the strike of the fault.

Force: That which tends to put a stationary body in motion or to change the direction or speed of a moving body.

Fracture: General term for any break in a rock or rock unit due to mechanical failure by stress (includes cracks and joints).

Front (storm): The contact at a planet's surface between two different air masses, commonly cold and warm.

Geologic map: A graphic record of the distribution, nature, and age relations of rock units and structural features (such as faults) in an area.

Geomorphic: Pertaining to the surface morphology (landforms) of a planet.

Graben: An elongate crustal depression bounded by normal faults on its long sides.

Gradation: Geological process involving the weathering, erosion, transportation, and deposition of planetary materials by the agents of wind, water, ice, and gravity.

Hadley cell: A thermally driven unit of atmospheric circulation that extends in both directions from the equator. Air rises at the equator, flows poleward, descends, and then flows back toward the equator.

Ice: Solid formed of volatile materials, particularly water, methane, ammonia, and nitrogen.

Impact: In planetology, the collision of objects ranging in size from tiny micrometeoroids to planetesimals.

Impact cratering: Process involving impact of objects with a planetary surface.

Kinetic energy: Energy of motion; $KE = 1/2\ (\text{mass})\ (\text{velocity})^2$

Landform: Any feature of a surface having a distinct shape and origin.

Lava: Magma (molten rock or liquid material) that reaches the surface of a planet or satellite.

Leeward: The side located away from the wind; the sheltered side.

Limb: The edge of the apparent disk of a planetary body.

Linea: Elongate markings on a planetary surface.

Lithosphere: The stiff upper layer of a planetary body; the solid outer part of a planet; on Earth, it includes the crust and the upper part of the mantle and is about 100 km thick.

Macula: A dark spot.

Magma: Melted or fluid rock material.

Mare (pl., maria): An area on the moon that appears darker and smoother than its surroundings; composed primarily of basaltic lava flows.

Mass wasting: The movement of rock and soil downslope caused by gravity.

Meteor: A "shooting star"—the streak of light in the sky produced by the transit of a meteoroid through the Earth's atmosphere; also the glowing meteoroid itself. The term "fireball" is sometimes used for a very bright meteor.

Meteorite: Extraterrestrial material which survives to a planetary surface as a recoverable object.

Meteoroid: A small particle in space.

Morphology: The external structure, form, and arrangement of rocks and solid materials in relation to the development of landforms.

Periglacial: Processes, areas, and climates at the immediate margins of former and existing glaciers and ice sheets, and influenced by the cold temperature of the ice.

Pit crater: An impact crater containing a central depression.

Plate tectonics: The theory of planetary dynamics in which the lithosphere is broken into individual plates that are moved by convection of the upper mantle.

Radar: (1) A method, system, or technique of using beamed, reflected, and timed radio waves for detecting, locating, or tracking objects (such as rockets) , for measuring altitude, etc., in any of various activities, such as air traffic control or guidance. (2) The electronic equipment or apparatus used to generate, transmit, receive, and , usually, to display radio scanning or locating waves; a radar set.

Rays: Long, thin deposits of ejecta thrown out radial to young impact craters.

Regio: A large area on a planetary surface having distinctive albedo markings.

Rift zone: A belt of strike-slip or normal faults in close proximity to each other.

Rille: Trench or crack-like valleys, up to several hundred kilometers long and 1 to 2 kilometers wide. May be sinuous in form.

Rotation: Turning of a body about an internal axis, as a rotation of Earth.

Saltation: A mode of sediment transport in which the particles are moved progressively forward in a series of short intermittent leaps, jumps, hops, or bounces.

Satellite: An attendant body that revolves about another body, the primary.

Scarp: Cliff produced by tectonic, impact, or erosion processes.

Secondary crater: Crater formed by ejecta thrown from a "primary" crater.

Shield volcano: A volcanic mountain in the shape of a broad, flattened dome.

Sinuous rille: see *Rille*

Slip face: The steeply sloping surface on the lee side of a dune, standing at or near the angle of repose of loose sand, and advancing downwind by a succession of slides wherever that angle is exceeded.

Strata: layers of rock (singular = stratum)

Stratigraphic column: Diagram that shows the relative ages of units within an area (oldest at the bottom, youngest at the top)

Stratigraphic relations: see *Stratigraphy*

Stratigraphy: Science of rock strata; concerned with the original succession and age relations of rock strata as well as their form, distribution and composition.

Strike: The azimuth or trend taken by a rock layer or structural surface.

Superposition (principle of): The principle that, in a series of strata that has not been overturned, the oldest rocks are at the bottom and the youngest are at the top.

Suspension: A mode of sediment transport in which the upward currents in eddies of turbulent flow are capable of supporting the weight of sediment particles and keeping them indefinitely held in the surrounding fluid (air or water).

Tectonic: Refers to deformation of planetary materials, as in faulting of Earth's crust.

Tectonism: Process involving movement of the lithosphere.

Terminator: The line of sunrise or sunset on a planet or satellite.

Terrain: A region of a surface sharing common characteristics (as in “mountainous terrain”).

Terrestrial: Of or pertaining to Earth or earthlike.

Tidal heating: The process of frictional heating of a planetary object by the alternate growth and decay of a tide in its lithosphere.

Topography: The general configuration of a surface, including its relief and the position of features.

Traction: A mode of sediment transport in which the particles are swept along, on, near, or immediately above and parallel to a bottom surface by rolling, sliding, pushing, or impact of saltating grains.

Unit: Three-dimensional body of rock with uniform characteristics and formed within a specific period of time.

Vertical exaggeration: The apparent increase in relief as seen in a stereoscopic image.

Volcanism: The process by which magma and its associated gases rise into the crust, and are extruded onto the surface and into the atmosphere.

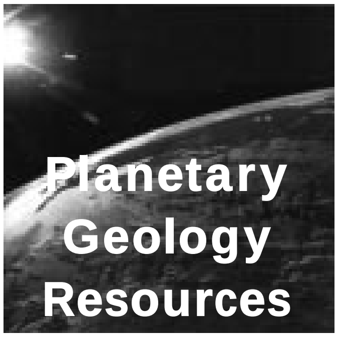
Vortices: Revolving motions within fluid flow.

Wavelength: The distance between successive wavecrests, or other equivalent points, in a series of harmonic waves.

Weathering: Chemical and physical alteration of materials exposed to the environment on or near the surface of a planetary object.

Wind streak: Zone where sediments have been preferentially deposited, eroded, or protected from wind erosion. Often form “tails” on the lee side of obstacles.

Windward: The side located toward the direction form which the wind is blowing; facing the wind.



1.1 Undergraduate geology textbooks.

There are dozens of college freshman textbooks that introduce geology. Most are similarly organized and cover the same basic material. Any college or university which teaches geology or earth science will carry one or more of these in their bookstore.

1.2 Planetary science textbooks.

These publications cover general planetary science and typically include chapters on each planet and planetary system. Most of these books assume a fundamental background in the sciences.

Beatty, J. K., and Chaikin, A., eds. (1990). *The New Solar System,* Cambridge, MA: Sky Publishing Corp. and Cambridge University Press, 326 pp.

Carr, M.H., Saunders, R.S., Strom, R.G., and Wilhelms, D.E. (1984). *The Geology of the Terrestrial Planets,* Washington, DC: National Aeronautics and Space Administration, 317 pp.

Christiansen, E.H. and Hamblin, W.K. (1995). *Exploring the Planets*. Englewood Cliffs, New Jersey: Prentice Hall, 500 pp.

Francis, Peter (1981). *The Planets,* New York: Penguin Books, 411 pp.

Greeley, Ronald (1994). *Planetary Landscapes,* New York: Chapman and Hall, 286 pp.

Guest, J.E. (1979). *Planetary Geology,* London: David and Charles (Publ.) , 208 pp.

Hamblin, W.K., and Christiansen, E.H. (1990). *Exploring the Planets,* New York: Macmillan Publishing Co., 451 pp.

Hartmann, William K. (1983). *Moons and Planets,* 2nd ed., Belmont, CA: Wadsworth Publishing Co., 509 pp.

Morrison, D., and Owen, T. (1988). *The Planetary System,* Reading, MA: Addison-Wesley Publishing Co., 519 pp.

Murray, B., Malin, M.C., and Greeley, R. (1981). *Earthlike Planets: Surfaces of Mercury, Venus, Earth, Moon, Mars,* San Francisco, CA: W.H. Freeman and Co., 387 pp.

1.3 Reference books.

These publications are collections of review papers or deal with focused topics. They serve as research resources at a professional level. Some can be used in advanced classes.

Atreya, S.K., Pollack, J.B., and Matthews, M.S., (1989). *Origin and Evolution of Planetary and Satellite Atmospheres,* Tucson, AZ: The University of Arizona Press, 881 pp.

Barnes, C. W. (1980). *Earth, Time, and Life – An Introduction to Geology,* New York, NY: John Wiley & Sons, Inc., 583 pp.

Barsukov, V.L., et al., eds. (1992). *Venus Geology, Geochemistry, and Geophysics: Research Results from the Soviet Union,* Tucson, AZ: The University of Arizona Press, 421 pp.

Bergstralh, J. T., Miner, E. D. and Matthews, M. S., eds. (1991). *Uranus,* Tucson, AZ: The University of Arizona Press, 1076 pp.

Binzel, R. P., Gehrels, T., and Matthews, M. S., eds. (1990). *Asteroids II,* Tucson, AZ: The University of Arizona Press, 1258 pp.

Bullard, F. M. (1976). *Volcanoes of the Earth,* Austin, TX: University of Texas Press, 579 pp.

Burns, J. W., ed. (1977). *Planetary Satellites,* Tucson, AZ: The University of Arizona Press, 598 pp.

Burns, J. A., and Matthews, M. S., eds. (1986). *Satellites,* Tucson: University of Arizona Press, 1021 pp.

Carr, M. H. (1981). *The Surface of Mars,* New Haven, CT: Yale University, 232 pp.

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Christianson, N. B. (1989). *Earth Has a Cold Heart,* Glendale, AZ: Ne-do Press, 202 pp.

Cox, A.N., Livingston, W.C. and Matthews, M.S., eds. (1992). *Solar Interior and Atmosphere,* Tucson, AZ: The University of Arizona Press, 1416 pp.

Frazier, K. (1985). *Solar System: Planet Earth,* Alexandria, VA: Time-Life Books, 176 pp.

Gallant, R. (1964). *Bombarded Earth,* London, England: John Bkaer Publishers, Ltd., 256 pp.

Gehrels, T., and Matthews, M. S., eds. (1984). *Saturn,* Tucson, AZ: The University of Arizona Press, 968 pp.

Gehrels, T., ed. (1976). *Jupiter,* Tucson, AZ: The University of Arizona Press, 1254 pp.

Greeley, R., and Batson, R. (1997). *The NASA Atlas of the Solar System.* Cambridge, England: Cambridge University Press, 369 pp.

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Glass, B.P. (1982). *Introduction to Planetary Geology,* New York, NY: Press Syndicate of the University of Cambridge, 469 pp.

Hamblin, W. K. (1975). *The Earth's Dynamic Systems,* Minneapolis, MN: Burgess Publishing Company, 578 pp.

Hartmann, W. K., (1983). *Moons and Planets,* Belmont, CA: Wadsworth Publishing Company, 509 pp.

Hunten, D.M., Colin, L., Donahue, T.M., and Moroz, V.I., eds.(1991). *Venus,* Tucson, AZ: The University of Arizona Press, 1143 pp.

Kieffer, H.H., Jakosky, B.M., Snyder, C.W., and Matthews, M.S., eds. (1992). *Mars,* Tucson, AZ: The University of Arizona Press, 1498 pp.

Mark, K., ed. (1987). *Meteorite Craters,* Tucson, AZ: The University of Arizona Press, 288 pp.

Miller, P., Beer, D., Brown, A. H. (1985). *Atlas of North America,* Washington, DC: National Geographic Society, 264 pp.

Miller, V. C., Miller, C. F. (1961). *Photogeology,* New York, NY: McGraw-Hill Book Company, Inc., 243 pp.

Morrison, D., ed. (1982). *Satellites of Jupiter,* Tucson, AZ: The University of Arizona Press, 972 pp.

Newsom, H. E., Jones, J. H. (1990). *Origin of the Earth,* New York, NY: Oxford University Press, 378 pp.

Palmer, A. R. (1992). *The Geology of North America Series,* Boulder, CO: The Geological Society of America.

Péwé, T. L., ed. (1981). *Desert Dust: Origin, Characteristics, and Effect on Man,* Boulder, CO: The Geological Society of America, Inc., 303 pp.

Roberts, J. L. (1982). *Introduction to Geological Maps and Structures,* Elmsford, NY: Pergamon Press, Ltd., 332 pp.

Roddy, D. J., Pepin, R. O., Merrill, R. B., eds. (1976). *Impact and Explosion Cratering: Planetary and Terrestrial Implications,* Elmsford, NY: Pergamon Press, 1301 pp.

Rothery, D.A., (1992). *Satellites of the Outer Planets: Worlds in their Own Right,* Oxford, England: Clarendon, 208 pp.

Scientific American (1983). *The Planets,* San Francisco, CA: W. H. Freeman and Company, 132 pp.

Shupe, J. F., et al., (1992). *Atlas of the World: Revised Sixth Edition,* Washington, DC: National Geographic Society, 136 pp.

Sonett, C.P., Giampapa, M.S. and Matthews, M.S., eds. (1992). *The Sun in Time,* Tucson: University of Arizona Press, 990 pp.

Walls, J. (1980). *Land, Man, and Sand,* New York, NY: MacMillan Publishing Co., Inc., 336 pp.

Tilling, R. I., ed. (1988). *How Volcanoes Work,* Washington, DC: American Geophysical Union, 14,880 pp.

Vilas, F., Chapman, C.R., Matthews, M.S., eds. (1988). *Mercury,* Tucson, AZ: The University of Arizona Press, 794 pp.

Walls, J. (1980). *Land, Man, and Sand,* New York, NY: MacMillan Publishing Co., Inc., 336 pp.

Wilhelms, D.E. (1987). *The Geologic History of the Moon,* U.S. Geological Survey Professional Paper 1348, Washington, DC: U.S. Govt. Printing Office, 328 pp.

1.4 NASA publications.

NASA publishes a wide variety of books dealing with missions, mission results, and planetary exploration, as well as planetary map atlases. Although many of these are no longer available, copies are usually contained in libraries which carry U.S. Government publications.

Object	Year	Serial	Title	Notes
Earth	1980	SP-403	*Volcanic Features of Hawaii: A Basis for Comparison with Mars*	
Moon	1964	SP-61	*Ranger VII photograph of the Moon,* Part I, Camera A series	
Moon	1965	SP-62	*Ranger VII photographs of the Moon,* Camera B series	Photographic collection
Moon	1965	SP-63	*Ranger VII photographs of the Moon,* Camera P series	Photographic collection
Moon	1966	SP-111	*Ranger VIII photographs of the Moon,* Cameras A, B, P	Photographic collection
Moon	1966	SP-112	*Ranger IX photographs of the Moon*	Photographic collections
Moon	1966	SP-126	*Surveyor I: a preliminary report*	
Moon	1966	JPL-TR 32-800	*Ranger VIII and IX experimenters' analysis and interpretations*	Mission description and science results
Moon	1969	SP-184	*Surveyor: program results*	
Moon	1969	SP-214	*Apollo 11 preliminary science report*	Mission description with photographs; includes descriptions and results from various experiments on board the command module and/or lander spacecraft
Moon	1969	SP-201	*Apollo 8, photography and visual observations*	
Moon	1970	SP-242	*Guide to Lunar orbiter photographs*	Explains camera system and gives footprints
Moon	1970	SP-200	*The Moon as viewed by Lunar orbiter*	Mission description and photographs; includes descriptions and results from various experiments on board the command module and/or lander spacecraft

Object	Year	Serial	Title	Notes
Moon	1971	SP-241	*Atlas and gazeteer of the near side of the Moon*	Lunar orbiter photographs with place names
Moon	1971	SP-206	*Lunar orbiter photographic atlas of the Moon*	Photographic collection
Moon	1971	SP-232	*Apollo 10, photography and visual observations*	Mission description with photographs; includes descriptions and results from various experiments on board the command module and/or lander spacecraft
Moon	1971	SP-238	*Apollo 11 mission report*	
Moon	1971	SP-272	*Apollo 14 preliminary science report*	
Moon	1971	SP-246	*Lunar photographs from Apollo 8, 10, 11*	
Moon	1972	SP-315	*Apollo 16 preliminary science report*	
Moon	1972	SP-289	*Apollo 15 preliminary science report*	
Moon	1972	SP-284	*Analysis of Surveyor 3 material and photographs returned by Apollo 12*	
Moon	1972	SP-306	*Compositions of major and minor minerals in five Apollo 12 crystalline rocks*	Description of samples
Moon	1973	SP-330	*Apollo 17 preliminary science report*	Mission description with photographs; includes descriptions and results from various experiments on board the command module and/or lander spacecraft
Moon	1974	EP-100	*Apollo*	Public information booklet
Moon	1973	SP-341	*Atlas of Surveyor 5 television data*	Photographs with short captions
Moon	1975	SP-350	*Apollo expedition to the Moon*	Mission description with photographs; general public
Moon	1978	SP-362	*Apollo over the Moon*	Summary of Apollo missions to the Moon; color photographs and science discussions

Object	Year	Serial	Title	Notes
Mars	1968	SP-179	*The book of Mars*	
Mars	1971	SP-263	*The Mariner 6 and 7 missions to Mars*	Mission description and photographic collection
Mars	1974	SP-334	*The Viking mission to Mars*	
Mars	1974	SP-329	*Mars as viewed by Mariner 9*	Photographs with science
Mars	1974	SP-337	*The new Mars, the discovery of Mariner 9*	Photographs with science
Mars	1975	SP-425	*The Martian landscape*	Mission description and photographs for Viking
Mars	1979	SP-438	*Atlas of Mars, the 1:5000000 map series*	Map and photomosaic collection
Mars	1980	SP-444	*Images of Mars – the Viking extended mission*	Photograph collection
Mars	1980	SP-441	*Viking orbiter views of Mars*	Photograph collection with science
Mars	1980	CR-3326	*The mosaics of Mars as seen by the Viking lander cameras*	Photomosaics based on Mars charts; gives frame locations
Mars	1981	SP-429	*Viking site selection and certification*	
Mars	1982	CR-3568	*Viking lander atlas of Mars*	Lander photographs and maps
Mars	1983	RP-1093	*A catalog of selected Viking orbiter images*	Photomosaics based on Mars charts; gives frame locations
Mars	1984	SP-4212	*On Mars, exploration of the red planet 1958–1978*	History of missions and explorations
Mercury	1978	SP-423	*Atlas of Mercury*	Synopsis of Mariner 10 results; collection of photographs and USGS charts
Mercury	1978	SP-424	*The voyage of Mariner 10*	Mission description
Venus	1975	SP-382	*The atmosphere of Venus*	
Venus	1983	SP-461	*Pioneer Venus*	Popularized account of mission with discussion of science results

Object	Year	Serial	Title	Notes
Jupiter	1971	SP-268	*The Pioneer mission to Jupiter*	
Jupiter	1974	SP-349	*Pioneer Odyssey – encounter with a giant*	Mission description and photographic collection
Jupiter	1980	SP-439	*Voyage to Jupiter*	Popularized account of mission with discussion
Jupiter	1989	SP-494	*Time-variable phenomena in the jovian system*	
Jupiter/ Saturn	1977	SP-420	*Voyager to Jupiter and Saturn*	
Jupiter/ Saturn	1980	SP-446	*Pioneer: first to Jupiter, Saturn, and beyond*	
Saturn	1974	SP-340	*The atmosphere of Titan*	
Saturn	1974	SP-343	*The rings of Saturn*	
Saturn	1980	JPL-400-100	*Voyager I encounters with Saturn*	Public information booklet
Saturn	1982	SP-451	*Voyages to Saturn*	Popularized account of mission with discussion of science results
Saturn	1984	SP-474	*Voyager I and II atlas of six saturnian satellites*	
Saturn	1978	CP-2068	*The Saturn System*	Conference proceedings
general	1971	SP-267	*Physical studies of the minor planets*	
general	1976	SP-345	*Evolution of the Solar System*	
general	1981	EP-177	*A meeting with the universe*	Popularized account of Solar System exploration
general	1984	SP-469	*The geology of the terrestrial planets*	An introduction to Mercury, Venus, Earth, Moon, and Mars, and a chapter on asteroids, comets, and planet formation
general	1997		*The NASA atlas of the Solar System*	Cambridge Univerity Press

Planet	Mission	Journal
Mercury	Mariner 10	*Science,* 1974, **185,** no. 4146
Mercury	Mariner 10	*J. Geophys. Res.,* 1975, **80,** no. 17
Mercury	Mariner 10	*Phys. Earth Planet. Int.,* 1977, **15,** nos. 2 and 3
Mercury	Mariner 10	*Icarus,* 1976, **28,** no. 4
Venus	Mariner 10	*Science,* 1974, **183,** no. 4131
Venus	Pioneer	*Science,* 1979, **203,** no. 4382
Venus	Pioneer	*Science,* 1979, **205,** no. 4401
Venus	Pioneer	*J. Geophys. Res.,* 1980, **85,** no. A13
Venus	general	*Icarus,* 1982, **51,** no. 2
Venus	general	Icarus, 1982, **52,** no. 2
Venus	Vega	***Science,*** 1986, **231,** no. 4744
Venus	Magellan	*Science,* 1991, **252,** no. 5003
Venus	Magellan	*J. Geophys. Res.,* 1992, **97**, nos. E8 and E9
Moon	Apollo II	*Science,* 1970, **167,** no. 3918
Moon	Apollo	*The Moon,* 1974, **9**
Moon	general	*Rev. Geophys. Space Phys.,* 1974, **12,** no. 1
Moon	general	*The Moon,* 1975, **13,** nos. 1,2 and 3
Moon	Galileo	*Science,* 1992, **255,** no. 5044
Mars	Mariner 6 and 7	*J. Geophys. Res.,* 1971, **76,** no. 2
Mars	Mariner 9	*Icarus,* 1972, **17,** no. 2
Mars	Mariner 9	*Icarus,* 1973, **18,** no. 1
Mars	Mariner 9	*J. Geophys. Res.,* 1973, **78,** no. 20
Mars	Mariner 9	*Icarus,* 1974, **22,** no. 3
Mars	Viking 1	*Science,* 1976, **193,** no. 4255
Mars	Viking 1 and 2	*Science,* 1976, **194,** no. 4260
Mars	Viking	*J. Geophys. Res.,* 1977, **82,** no. 28
Mars	Viking	*Icarus,* 1978, **34,** no. 3
Mars	general	*J. Geophys. Res.,* 1979, **84,** no. B14
Mars	general	*Icarus,* 1981, **45,** nos. 1 and 2
Mars	general	*Icarus,* 1982, **50,** nos. 2 and 3
Mars	general	*J. Geophys. Res.,* 1982, **87,** no. B12
Mars	general	*J. Geophys. Res.,* 1990, **95,** no. B9
Jupiter	Pioneer 11	*Science,* 1975, **188,** no. 4187
Jupiter	Voyager 1	*Nature,* 1979, **280,** no. 5725
Jupiter	Voyager 1	*Science,* 1979, **204,** no. 4396
Jupiter	Voyager 2	*Science,* 1979, **206,** no. 4421
Jupiter	Voyager	*J. Geophys. Res.,* 1981, **86,** no. A10
Saturn	Pioneer 11	*Science,* 1980, **207,** no. 4429
Saturn	Voyager 1	*Nature,* 1981, **292,** no. 5825
Saturn	Voyager 1	*Science,* 1981, **212,** no. 4491
Saturn	Voyager 2	*Science,* 1982, **215,** no. 4532
Saturn	Voyager	*Icarus,* 1983, **53,** no. 2
Uranus	Voyager 2	*Science,* 1986, **233,** no. 4739
Neptune	Voyager 2	*Science,* 1989, **246,** no. 4936
Neptune	Voyager 2	*J. Geophys. Res.,* 1991, **96,** supplement
Neptune-Triton	Voyager 2	*Science,* 1990, **250,** no. 4979
Comet Halley	5 missions	*Nature,* 1986

1.6 Regional Planetary Image Facilities.

In a quarter century of solar system exploration, nearly a million images have been obtained of the planets and their satellites. Some 17 facilities exist worldwide which contain archives of planetary images. These facilities are open to the public for aid in finding specific images. They do not, however, provide copies of photographs (see Section 1.8).

Arizona State University, SPL, Department of Geology, Box 871404, Tempe, AZ 85287-1404

University of Arizona, RPIF, Lunar and Planetary Lab, Tucson, AZ 85721

Brown University, RPIF, Box 1846, Department of Geological Sciences, Providence, RI 02912

Cornell University, SPIF, 317 Space Sciences Building, Ithaca, NY 14885

Deutsche Forschungsanstalt fuer Luftund Raumfahrt e.V. (DLR) , Regional Planetary Image Facility, Institute for Planetary Exploration, Rudower Chaussee 5, 0-1199 Berlin, Germany

University of Hawaii, RPIF, Hawaii Institute of Geophysics, Planetary Geoscience Division, Honolulu, HI 96822

Institute of Space and Astronomical Sciences, Regional Planetary Image Facility, 3-1-1 Yoshinodai, Sagamihara-shi, Kanagawa 229, Japan

Israeli Regional Planetary Image Facility, Ben-Gurion University of the Negev, P.O. Box 653, Beer-Sheva, 84105, Israel.

Jet Propulsion Laboratory, RPIF, MS 202-101, 4800 Oak Grove Drive, Pasadena, CA 91109

University of London Observatory, Regional Planetary Image Facility, 33/35 Daws Lane, Observatory Annexe, London, NW7 4SD, England

Lunar and Planetary Institute, Center for Information Research Services, 3600 Bay Area Blvd., Houston, TX 77058

University of Paris-Sud, Phototheque Plantaire de'Orsay, Laboratoire de Geologie Dynamique de la Terre et des Plantes, Department des Sciences de la Terre, Batiment 509, F-91, 405 Orsay Cedex, France

University of Oulu, Regional Planetary Image Facility, Department of Astronomy, 90570 Oulu, Finland

Southern Europe Regional Planetary Image Facility, CNR Institutio Astrofisica Spaziale, Reparto di Planetologia, Viale Dell' Universita, 11, 00185 Roma, Italy

Smithsonian Institution, RPIF, Room 3773, National Air and Space Museum, Washington, DC 20560

U.S. Geological Survey, RPIF, Branch of Astrogeologic Studies, 2255 N. Gemini Drive, Flagstaff, AZ 86001

Washington University, RPIF, Box 1169, Department of Earth and Planetary Sciences, One Brookings Drive, St. Louis, MO 63130-4899

1.7 Videos

The following sources have video and/or films on planetary science topics. Most will provide catalogs or lists on request.

1. Instructional Video
   P.O. Box 21
   Maumee, Ohio 43537

2. The Planetary Society
   65 North Catalina Ave
   Pasadena, CA 91106
   (818) 793-5100

3. Michigan Technological University
   Video Marketing
   1400 Townsend Drive
   Houghton, MI 49931-1295
   (906) 487-2585

4. Gould Media, Inc.
   44 Parkway West
   Mt. Vernon, NY 10552-1194
   (914) 664-3285
   FAX (914) 664-0312

5. Finley-Holiday Film Corp.
   12607 E. Philadelphia St.
   P.O. Box 619
   Whittier, CA 90601
   (310) 945-3325

6. NASA CORE
   Lorain County Joint Vocational School
   15181 Route 58 South
   Oberlin, OH 44074
   (440) 774-1051 ext. 293/249

7. National Air and Space Museum
   Smithsonian Institution
   Educational Resource Center, MRC 305
   Washington, DC 20560
   (202) 786-2109

8. Films for the Humanities & Sciences
   P. O. Box 2053
   Princeton, NJ 08543-2053

9. Astronomical Society of the Pacific
   390 Ashton Avenue
   San Francisco, CA 94112
   (800) 335-2624

10. Instructional Video
    P. O. Box 21
    Maumee, OH 43537
    (419) 865-7670
    FAX (419) 867-3813

11. JLM Visuals
    1208 Bridge Street
    Grafton, WI 53024-1946
    (414) 377-7775

12. Sky Publishing Corporation
    P. O. Box 9111
    Belmont, MA 02178-9111
    (800) 253-9245

13. Crystal Productions
    Box 2159
    Glenview, IL 60025
    (800) 255-8629
    FAX (708) 657-8149

1.8 CD-ROMs

1. Hopkins Technology
   421 Hazel Lane
   Suite 700
   Hopkins, Minnesota 55343-7116

2. National Space Science Data Center
   Code 633
   Goddard Space Flight Center
   Greenbelt, MD 20771
   (301) 286-6695

3. Astronomical Society of the Pacific
   390 Ashton Avenue
   San Francisco, CA 94112
   (800) 335-2624

4. Sky Publishing Corporation
   P. O. Box 9111
   Belmont, MA 02178-9111
   (800) 253-9245

5. Crystal Productions
   Box 2159
   Glenview, IL 60025
   (800) 255-8629
   FAX (708) 657-8149

1.9 Slide sets

1. Astronomical Society of the Pacific
   390 Ashton Ave
   San Francisco, CA 94112
   (800) 335-2624

2. Finley-Holiday Film Corp.
   12607 E. Philadelphia St.
   P.O. Box 619
   Whittier, CA 90601
   (310) 945-3325

3. Lunar and Planetary Institute
   3600 Bay Area Blvd.
   Houston, TX 77058
   (713) 486-2100

4. Gould Media, Inc.
   44 Parkway West
   Mt. Vernon, NY 10552-1194
   (914) 664-3285
   FAX (914) 664-0312

5. American Geophysical Union
   2000 Florida Avenue, N.W.
   Washington, DC 20009
   (800) 966-2481 (North America only)
   (202) 462-6900

6. NESTA/MESTA Publications
   c/o Lisa Bouda
   28815 Ironwood
   Warren, MI 48093

7. National Association of Geology Teachers
   P. O. Box 5443
   Bellingham, WA 98227-5443

8. Sky Publishing Corporation
   P. O. Box 9111
   Belmont, MA 02178-9111
   (800) 253-9245

9. Crystal Productions
   Box 2159
   Glenview, IL 60025
   (800) 255-8629
   FAX (708) 657-8149

1.10Maps

1. Earth Science Information Center
   U. S. Geological Survey
   507 National Center
   Reston, VA 22092
   (703) 860-6045

2. Map Link
   25 Eat Mason
   Santa Barbara, CA 93101
   (805) 965-4402

3. National Space Science Data Center (NSSDC)
   Code 633
   Goddard Space Flight Center
   Greenbelt, MD 20771
   (301) 286-6695

4. U. S. Geological Survey
   Distribution Branch
   Box 25286 Federal Center
   Denver, CO 80225
   (303) 234-3832

1.11 Miscellaneous Products (globes, posters, equipment)

1. Crystal Productions
   Box 2159
   Glenview, IL 60025
   (800) 255-8629
   FAX (708) 657-8149

2. Sky Publishing Corporation
   P. O. Box 9111
   Belmont, MA 02178-9111
   (800) 253-9245

3. Astronomical Society of the Pacific
   390 Ashton Ave
   San Francisco, CA 94112
   (800) 335-2624

4. The Planetary Society
   65 North Catalina Ave
   Pasadena, CA 91106
   (818) 793-5100

5. Lunar Sample Curator (Apollo lunar samples for Colleges/Universities only)
   SN2 NASA/Johnson Space Center
   Houston, TX 77058-3698
   FAX (713) 483-2911

A Note About Photographs

An essential part of Planetary Geology is the use of spacecraft photographs. Ideally each student-team should have access to glossy photographic prints for use during the laboratory exercises. Photocopies of the pictures in this book (such as Xerox copies) generally lack sufficient detail to be useful. Offset printing is slightly better, but again this process is at least three generations removed from the original product.

Glossy prints or copy negatives can be obtained for a nominal cost (in some cases for no charge) from various sources. Each spacecraft photograph caption in this book contains the necessary picture identification numbers to help you in obtaining the photos. Usually the mission name (Apollo, Viking, etc.) and frame number is sufficient identification.

Listed below are sources of space photography. Instructions for ordering photography will be provided upon written request. Be sure to include your name, title, the fact that the photographs will be used at a non-profit educational institution, and specific photograph numbers.

For planetary mission photography:

National Space Science Data Center
Code 633
Goddard Space Flight Center
Greenbelt, MD 20771

For Earth photography:

EROS Data Center
U.S. Geological Survey
Sioux Falls, SD 57198

For photographs indicating Arizona State University as their source, contact:

Arizona State University
Space Photography Laboratory
Department of Geology
Box 871404
Tempe, AZ 85287-1404

Aurora

. . . fabled glowing lights of the Sun-Earth connection

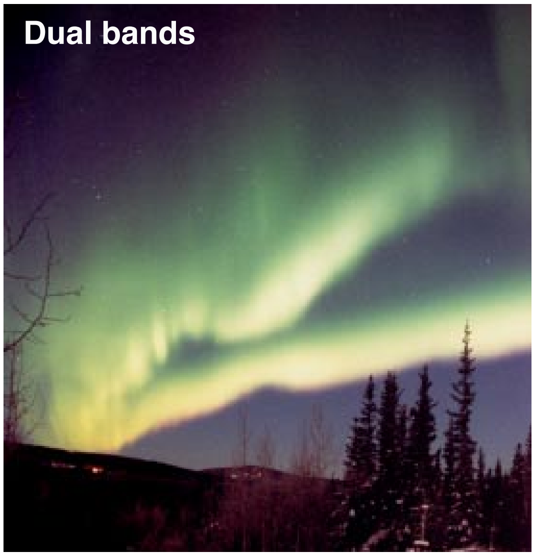
Photo credits: Jan Curtis

What is the aurora?

Named for the Roman goddess of dawn, the aurora is a mysterious and unpredictable display of light in the night sky. The **aurora borealis** and **aurora australis** – often called the northern lights and southern lights – are common occurrences at high northern and southern latitudes, less frequent at mid-latitudes, and seldom seen near the equator. While usually a milky greenish color, auroras can also show red, blue, violet, pink, and white. These colors appear in a variety of continuously changing shapes. Sometimes the aurora is so dim and scattered as to be mistaken for clouds or the Milky Way; sometimes it is bright enough to read by.

Jan Curtis

Auroras are a spectacular sign that our planet is electrically connected to the Sun. These light shows are provoked by energy from the Sun and fueled by electrically charged particles trapped in Earth's magnetic field. While beautiful to behold, they can be a nuisance to those who depend on modern technology.



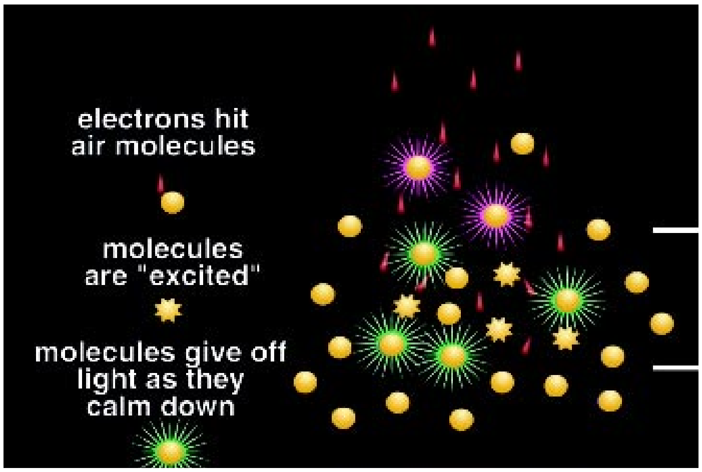
Jan Curtis

What does an aurora look like?

Auroras can appear as long, narrow **arcs** of light, often extending east to west from horizon to horizon. At other times they stretch across the night sky in **bands** that kink, fold, and swirl, or even ruffle like curtains. They can spread out in multi-colored **rays**, like vertical shafts of light that stretch far up into space. And sometimes they engulf the sky in a thin cloud or veil. As aurora expert Robert Eather once wrote: "Like snowflakes, no two are ever quite the same."

Dramatically different auroras can appear in the course of a single night, and all of the forms can vary in intensity. The late evening auroras are usually long diffuse arcs, which slowly evolve into rayed arcs or bands that show increasing activity. As the night progresses, the bands and arcs become rippled and folded, eventually breaking into rays and -- if the viewer is lucky -- a **corona**. The corona is considered the most spectacular form of a rayed aurora, appearing overhead with all shafts converging to a center point. **Patches**–fluffy clouds of light–and flickering auroras are generally seen later in the night.

Jan Curtis



What causes the aurora?

The typical aurora is caused by collisions between fast-moving electrons from space with the oxygen and nitrogen in Earth's upper atmosphere. The electrons—which come from the Earth's **magnetosphere**, the region of space controlled by Earth's magnetic field —transfer their energy to the oxygen and nitrogen atoms and molecules, making them "excited". As the gases return to their normal state, they emit photons, small bursts of energy in the form of light. When a large number of electrons come from the magnetosphere to bombard the atmosphere, the oxygen and nitrogen can emit enough light for the eye to detect, giving us beautiful auroral displays. This ghostly light originates at altitudes of 100 to more than 400 km (60 to more than 250 miles).

Why do auroras come in different colors and shapes?

The color of the aurora depends on which gas — oxygen or nitrogen — is being excited by the electrons, and on how excited it becomes. The color also depends upon how fast the electrons are moving, or how much energy they have at the time of their collisions. High energy electrons cause oxygen to emit green light (the most familiar color of the aurora), while low energy electrons cause a red light. Nitrogen generally gives off a blue light. The blending of these colors can also lead to purples, pinks, and whites. The oxygen and nitrogen also emit ultraviolet light, which can be detected by special cameras on satellites.

The different shapes of auroras are a mystery that scientists are still trying to unravel. The shape seems to depend on where in the magnetosphere the electrons originate, what causes them to gain their energy, and why they dive into the atmosphere.

Jan Curtis

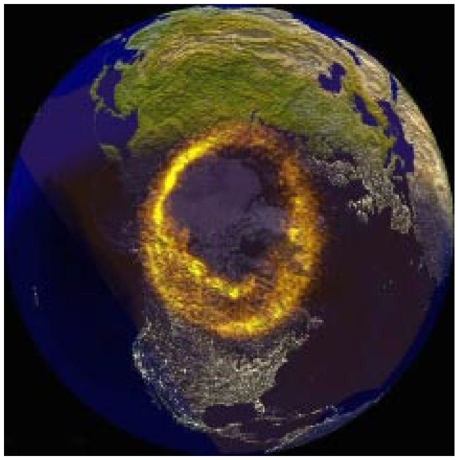
Jan Curtis

Where can you see an aurora?

Auroras usually occur in ring-shaped areas about 4,000 km (2,500 miles) in diameter around the magnetic poles of the Earth. These rings are known as **auroral ovals**. The northern oval traces a path across central Alaska and Canada, Greenland, and northern Scandinavia and Russia. In the southern hemisphere, the auroral oval hovers mostly over the oceans circling Antarctica, but it can occasionally reach the far edges of New Zealand, Chile, and Australia. There is a common misconception that auroras can only be seen near the poles of the Earth, but auroras are actually quite rare at the geographic and geomagnetic poles. In fact, if you made an expedition to the north coast of Alaska, you would usually have to look south to see an aurora.

The auroral ovals expand and contract with the level of auroral activity, sometimes extending to lower latitudes to cover much of North America or Europe when the space around Earth is most disturbed.

The complete auroral ovals in the north and south are nearly mirror reflections of each other, or **conjugate**. But it wasn't until the Space Age, when satellites could gather images of the entire Earth, that scientists were able to see the large-scale auroras around both poles at the same time.

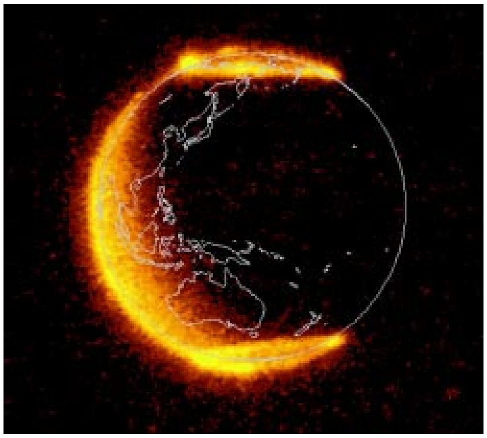


UV image of auroral oval superimposed on a figure of partly sunlit Earth

When can you see an aurora?

Low levels of auroral activity occur day and night, every day, in the northern and southern **auroral ovals**. Since the aurora is much dimmer than sunlight (a million times), it cannot be seen from the ground in the daytime. The best displays tend to occur in the few hours before midnight.

Light pollution caused by city lights makes it difficult to see auroras except in dark rural areas. Perhaps the best chance to see an aurora is during a high-latitude airplane flight at night. But when a really bright aurora occurs, you can see it from the city and even through thin clouds.



Polar spacecraft

Auroral ovals in UV light from far above the equator. The arc of light (left) is sunlight.

In Alaska and central Canada, the aurora can be a nightly occurrence. Go a little further south and you might see an aurora ten times a year. Auroras are much more likely to occur during periods of high sunspot numbers, at the peak of the Sun's eleven-year **sunspot cycle**. Then you might see an aurora once or twice a year in regions as far south as Texas or Florida. In the rarest events, auroras are observed near the equator, as when in 1909 the most potent geomagnetic storm on record brought an aurora to Singapore.

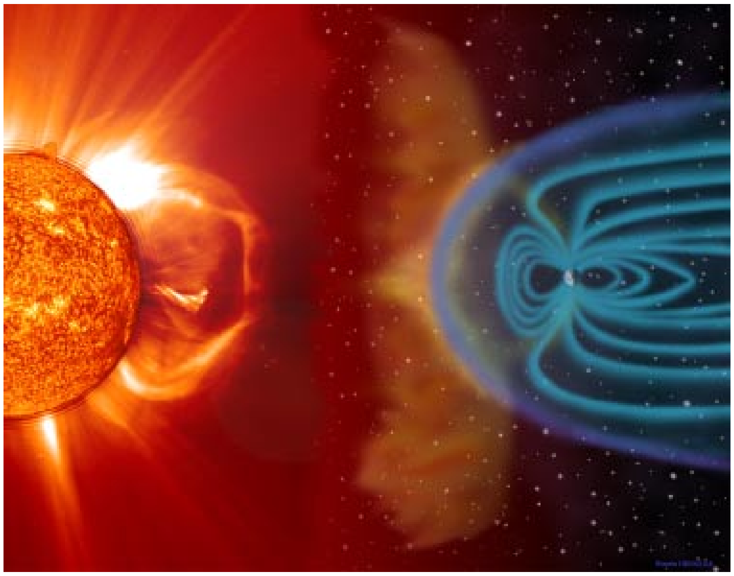
Auroras are easier to see in the wintertime because it is dark for longer periods of the day. And clear winter nights tend to be better for observing the sky due to less haze and water vapor in the air.

How is the aurora related to the Sun?

Auroras are a sign that Sun and Earth are connected by more than sunlight. They indicate that something electric is happening in space.

The Sun provides the energy for the aurora, but particles in the aurora come from Earth's own neighborhood in space. The Sun's energy is carried toward the Earth in the **solar wind**, a stream of electrically charged particles (mostly protons and electrons) flowing out from the Sun in all directions. As these particles approach Earth, they interact with our planet's magnetic field. This field deflects most of the particles, creating a huge cavity in the solar wind–the magnetosphere. This region stretches about 60,000 km (40,000 miles) toward the Sun and several hundred thousand kilometers in a long tail on the night side, away from the Sun.

Variations in the properties of the solar wind control the amount of energy that can leak into the magnetosphere. Here the energy is converted into electric currents and electromagnetic energy and temporarily stored in the magnetosphere, especially in its tail. When this influx of energy is relatively large, the magnetosphere loses its equilibrium, or balance. To become stable again, the excess energy is released suddenly, with much of the energy going into the acceleration of electrons.

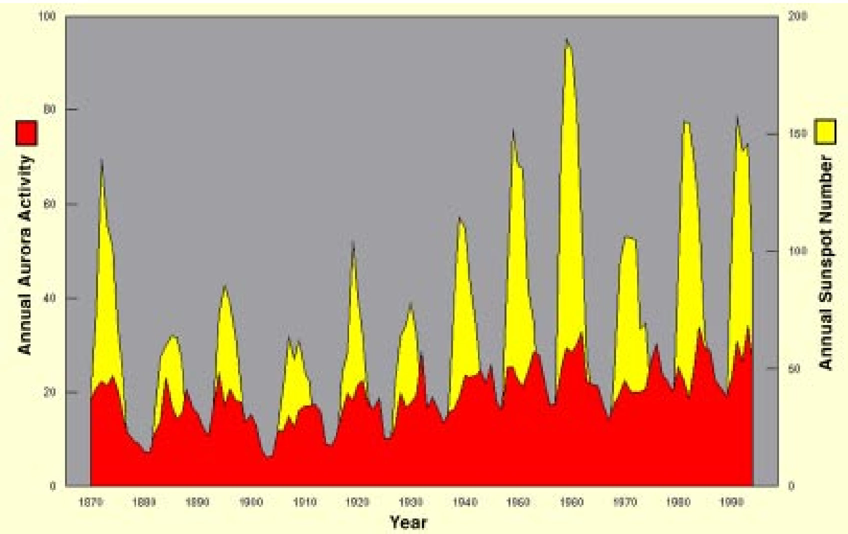


Steele Hill, NASA

A solar storm blasts out from the Sun and heads towards Earth's protective shield, the magnetosphere (sizes not to scale)

The aurora primarily occurs where the magnetic field guides the electrons from the tail of the magnetosphere into the atmosphere where they produce the aurora. Because the tail is on the night side of the Earth (away from the Sun), the more intense, dynamic and beautiful auroras occur near midnight.

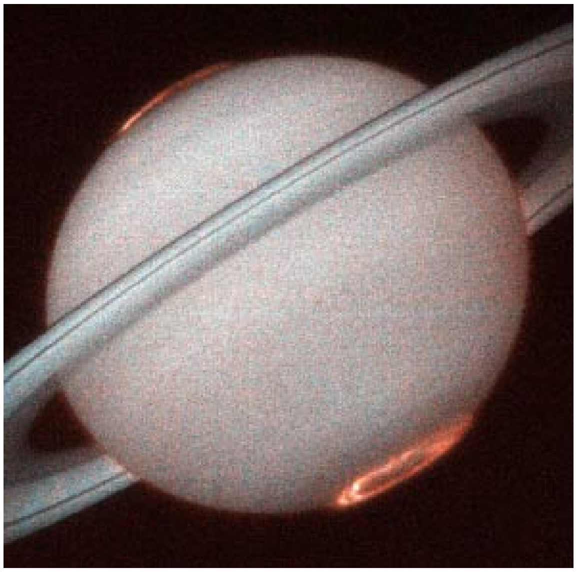
For many years, it was thought that the particles in the aurora came directly from the Sun because great auroral displays often occurred a few days after large eruptions on the Sun. But particles coming directly from the Sun would lose their energy at much higher altitudes than where we find the aurora. And due to the deflection of solar wind particles by the magnetosphere, particles straight from the Sun can gain access to the atmosphere only near the Poles, so they would not form the auroral ovals that we see lying a couple of thousand kilometers out from the Poles.



Historical record of linkage between sunspots and auroral activity

Do other planets have auroras?

Auroras have been observed on Jupiter, Saturn, and Uranus, but not on Mars, Venus, or Mercury. Any planet with a magnetic field and an atmosphere should likely have auroras (Mars and Venus have no global magnetosphere; Mercury has almost no atmosphere). Since an aurora indicates the presence of an atmosphere, we might be able use the presence of auroras to find planets beyond our solar system that could support life.



J.T. Trauger/JPL and NASA

Conjugate auroras on Saturn

Does the aurora make a sound?

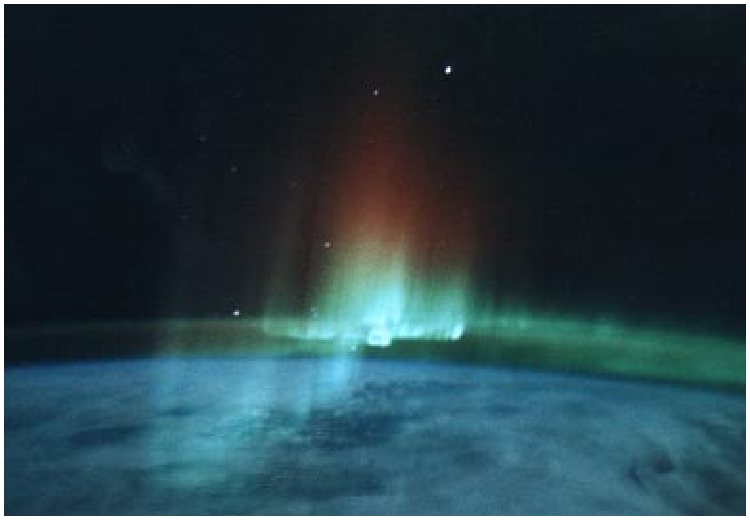
Observers have speculated about this for hundreds of years, noting that they have heard crackling, swishing, and hissing sounds while they watched the aurora dance in the sky. But scientific experimenters have been unable to detect any audible sound from the northern lights, and most scientists cannot find a reason why the lights should make a sound. The air in the upper part of the atmosphere where auroras are formed is too thin to conduct audible sound any distance. So if sounds are heard, they must come from some other phenomenon occurring at the same time.

Photo: Dick Hutchinson

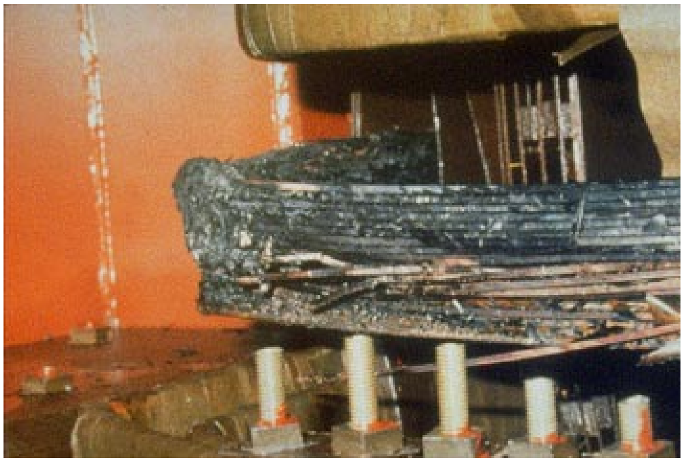
Why do we care about auroras?

Before telegraphs and telephones, rockets and radio, people were not affected by auroras. Solar activity and the resulting auroral light shows were curiosities of nature. But then humans started to harness the power of electromagnetism, developing networks of electrical power and communications systems. It was soon learned that the aurora could affect those systems.

The electrons spiraling down the Earth's magnetic field to produce the aurora are themselves an intense electric current. The rapidly changing current can cause unwanted electrical currents to flow through long communication lines, power lines and pipelines, producing disruptions in communication, electrical outages, brownouts, and fuel leaks. At the same time, the upper atmosphere, or **ionosphere**, becomes rippled like a piece of corrugated cardboard. Radio signals are refracted (bent) differently than expected or even absorbed, making it difficult to communicate at certain frequencies. Electrons accelerated to high energies in the tail of the magnetosphere can raise havoc with satellites, damaging electronics and creating false commands.

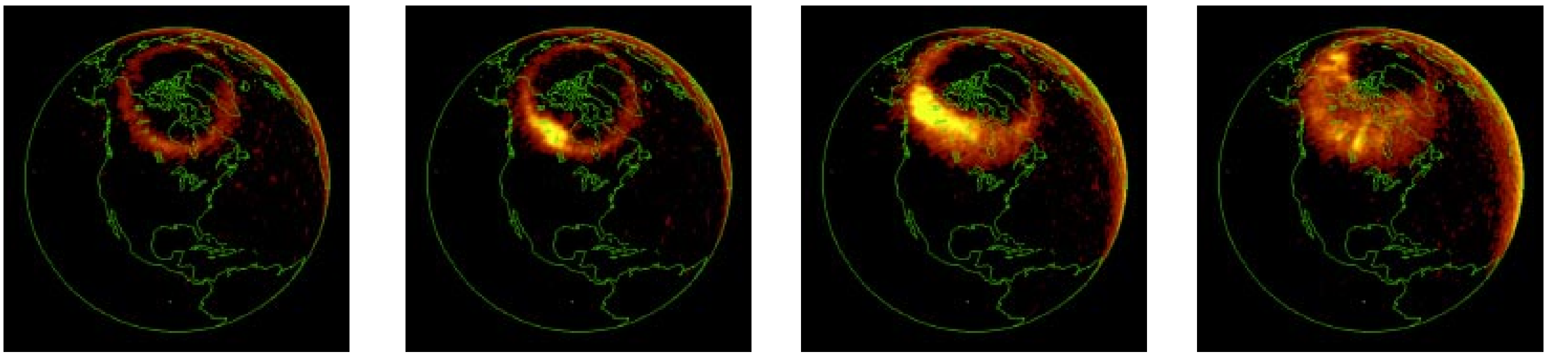


Aurora australis (Southern Lights) from a space shuttle



Courtesy: John Kappenman

Large transformer damaged by 1989 geomagnetic storm at NJ power plant



Polar spacecraft

An auroral oval seen from space as it increases in intensity and area over several hours (seen in UV light)

Who has helped us understand the aurora?

Some of the brightest minds in history have puzzled over the aurora. In the **4th century B.C.** Aristotle made one of the first truly scientific accounts of the aurora borealis, describing "glowing clouds" and a light that resembled flames of burning gas.

Courtesy: Danish Meteorological Institute

A Finnish oil painting of the aurora

The real advances in auroral science began when scientists started connecting auroras to magnetism. In the **late 16th century**, William Gilbert conducted experiments that led him to propose that the Earth itself was a giant magnet, with a North and South Pole as if a great bar magnet had been buried inside.

In the **17th century** Anders Celsius proposed that the lights were caused by moonlight reflected by ice and water in the air. Rene Descartes (France) and other scientists asserted that the refraction of moonlight and the reflection of colored rays by ice crystals in the atmosphere somehow caused the aurora. Some of these misconceptions survive even today.

In **1739,** a London watchmaker, George Graham, noticed that on some days, a compass needle made irregular motions from true north that he could not explain. That same year in Sweden, Anders Celsius detected the same phenomenon and noted that it seemed to occur when auroras danced in the sky.

Benjamin Franklin wrongly attributed the lights to a sort of lightning or electric discharge from clouds above the polar regions.

An important discovery of the link between solar activity and the aurora occurred in England in **1859** when astronomer Richard Carrington and amateur sun-watcher Richard Hodgson independently noticed bright patches of white light coming from around some sunspots. These were the first reported observations of a solar flare. About 18 hours after the flare, the magnetic instruments at the Kew Observatory in London measured large variations in the Earth's magnetic field. Across the Atlantic, Elias Loomis, a Yale professor, noted a day later that the auroral light show was "one of the most remarkable ever recorded in the United States."

It wasn't until the **late 1800s and early 1900s** that spectroscopic measurements of auroral light identified oxygen and nitrogen as the color sources for the aurora.

Around the **turn of the 20th century,** Norwegian physicist Kristian Birkeland revived Gilbert's experiments. He placed a spherical magnet inside a vacuum chamber and shot an electron beam at it. He found that the beam was guided by the magnetic field to hit the sphere near the poles. He reasoned that the Sun must shoot beams of corpuscles (now called electrons) toward Earth, where the planet's magnetic field guides them in near the Poles. His view of the aurora was close to the truth, except that the corpuscles originate in our magnetosphere, not from the Sun.

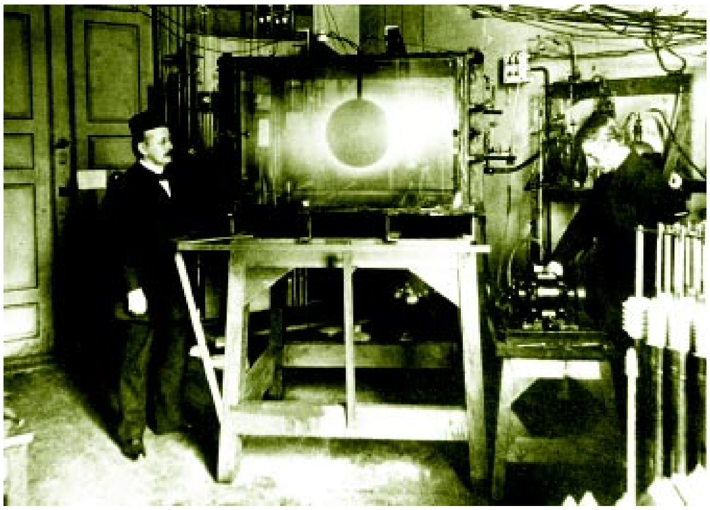


Photo: Fra Birkeland

Birkeland in his lab testing his theories on what causes aurora

In the **1930s**, Sydney Chapman and Vincent Ferraro proposed that clouds of electrically charged particles ejected from the Sun fly across empty space and envelope the Earth to cause auroras; we now call this mixture of electrons and protons plasma, the fourth state of matter. Since these clouds would be excellent conductors of electricity, they would generate currents and distort Earth's magnetic field.

Following the launch of the Sputnik satellites by the Soviet Union and the Explorer satellites by the United States, centuries of scientific theories, remote observations and wild speculations were put to the test by first-hand observations. Scientists such as James Van Allen and Sergei Vernov discovered that the space around Earth was filled with high-energy particles, trapped by the Earth's magnetic field into doughnut shaped rings around the Earth, called the **radiation belts**. Russian and American space probes proved the existence of the solar wind and a series of US satellites mapped out the shape of the magnetosphere. Satellites in the tail of the magnetosphere found it unstable, and low altitude polar satellites measured the electrons producing the aurora.

Today scientists understand much about the transfer of energy from the Sun, its temporary storage in the magnetosphere, and its release into electrons that crash into the atoms and molecules of the atmosphere to produce the awesome auroral light shows. But the aurora still keeps hidden a number of mysteries about why and how it appears as such wondrous displays.

How do different cultures react to the aurora?

"These northern lights have this peculiar nature, that the darker the night is, the brighter they seem, and they always appear at night but never by day…. In appearance, they resemble a vast flame of fire viewed from a great distance. It also looks as if sharp points were shot from this flame up into the sky." -- Written in A.D. 1230 by an anonymous Norwegian author

Photo: Michel Tournay

Dancing aurora taken near Quebec, Canada

To the dispassionate, objective viewer, auroras can appear as colorful, wispy curtains of light ruffling in the night sky. But legend and lore across the ages and around the world tell of more in the heavens than just a brilliant, ghostly light show.

Ancient folklore from China and Europe describes auroras as great dragons or serpents in the skies. In Scandinavia, Iceland, and Greenland, an aurora was often seen as the great bridge Bifrost, the burning archway by which the gods traveled from heaven to Earth.

Some Native American tribes pictured spirits carrying lanterns as they sought the souls of dead hunters, while Eskimos saw souls at play, using a walrus head as a ball. One legend from the Inuit describes the aurora this way: "The sky is a huge dome of hard material arched over the flat Earth. On the outside there is light. In the dome, there are a large number of small holes, and through these holes you can see the light from the outside when it is dark. And through these holes the spirits of the dead can pass into the heavenly regions. The way to heaven leads over a narrow bridge that spans an enormous abyss. The spirits that were already in heaven light torches to guide the feet of the new arrivals."

In Norway, the aurora is to be viewed with awe. There is to be no waving, whistling, staring, or any other form of "defiance". If you wave at the aurora, according to myth, it will increase in activity and reach down and touch you, with apparently unwelcome results.

Those who did not see supernatural beings often interpreted the aurora as a predictor of the weather. Snow and bitter cold were often thought to follow bright auroral displays in Scandinavia, while the Eskimos saw just the opposite: the spirits were bringing favorable weather.

1893 Fridtjof Nansen woodcut of aurora

"And the skies of night were alive with light, with a throbbing, thrilling flame;
Amber and rose and violet, opal and gold it came.
It swept the sky like a giant scythe, it quivered back to a wedge;
Argently bright, it cleft the night with a wavy golden edge.
Pennants of silver waved and streamed, lazy banners unfurled;
Sudden splendors of sabres gleamed, lightning javelins were hurled.
There in awe we crouched and saw with our wild, uplifted eyes
Charge and retire the hosts of fire in the battlefield of the skies."

— Robert Service, from "The Ballad of the Northern Lights," published in 1908

For more information on the web

The Exploration of the Earth's Magnetosphere
http://www.phy6.org/Education/Intro.html

The Aurora Explained
http://www.alaskascience.com/aurora.html

Windows to the Universe
http://www.windows.ucar .edu/spaceweather/

Sun-Earth Day 2003
http://sunearth.gsfc.nasa.gov/sunearthday/2003/

LESSON: Planning a trip to see the aurora

Objectives: The student will identify the range of latitude with the highest probability of seeing an aurora and choose a location to visit to view them.

List of Materials: 1 cm x 1 cm graph paper, colored pencils (4 different colors)

Background: The location of aurora sightings around the world is not random. There is a pattern to the number of sightings found in different locations around the Earth. What do you think it is?

Directions:

1. Looking at an atlas, a world map, or a web site (http://www.getty.edu/research/tools/vocabulary/tgn/ is a good one), research and record the latitude and longitude for each location in the chart that is blank.

Location	*Geographic Latitude*	*Geographic Longitude*	*Number of days per year with auroral sightings**
San Diego, California, USA			0
Tokyo, Japan (*Tokyo, Nihon*)			0
Athens, Greece (*Athínai, Ellás*)			0
Rome, Italy (*Roma, Italia*)			1
Paris, France			2
London, England			3
Moscow, Russia (*Moskva, Rossiya*)			5
Toronto, Ontario, Canada			10
Calgary, Alberta, Canada			20
Thule, Greenland (*Thule, Grønland*)			50
Peary Land, Greenland			60
North Pole	90º 0' N	---	65
Alert, Nunavut, Canada	82º 30' N	62º 18' E	70
Ny-Alesund, Svalbard	78º 55' N	11º 56' E	75
Anchorage, Alaska, USA			90
Reykjavik, Iceland			280
Murmansk, Russia (*Murmansk, Rossiya*)			280
Barrow, Alaska, USA			300

**Auroras can't be seen well in the summertime in the northern hemisphere, but they still occur. These numbers include summer auroras.*

2. Using the geographic data and sightings from the table, place a small "x" of the proper color on each of the locations on the world map.

Number of auroral sightings	**Mark on the map**
0-49	blue
50-99	green
100-149	yellow
150 or more	red

3. Create a graph large enough to fill most of a sheet of graph paper following these directions:
   a. Label the x-axis "Latitude in degrees". The range of that axis should be the same as the latitude range in the table in 1.: approximately 30-90 degrees.
   b. Label the y-axis "Number of sightings". The range for this axis is in the table in 2.: 0 - 300.
   c. From the table in 1., average the number of auroral sightings per year for each 10 degrees of latitude (30-39 degrees, 40-49 degrees, etc.). Plot the points on your graph to compare the average number at different latitudes. Use the colors from 2. Give your graph a title.

Data analysis: Looking at both the map and the graph, answer the following questions:

a. Which latitudes have the most sightings?
b. Does the number of sightings change as you get closer to the North Pole?
c. What can you conclude about where the aurora is most likely to be seen?
d. Read the "Where can you see an aurora?" section on this poster. Do your results agree with the scientific research? Explain.

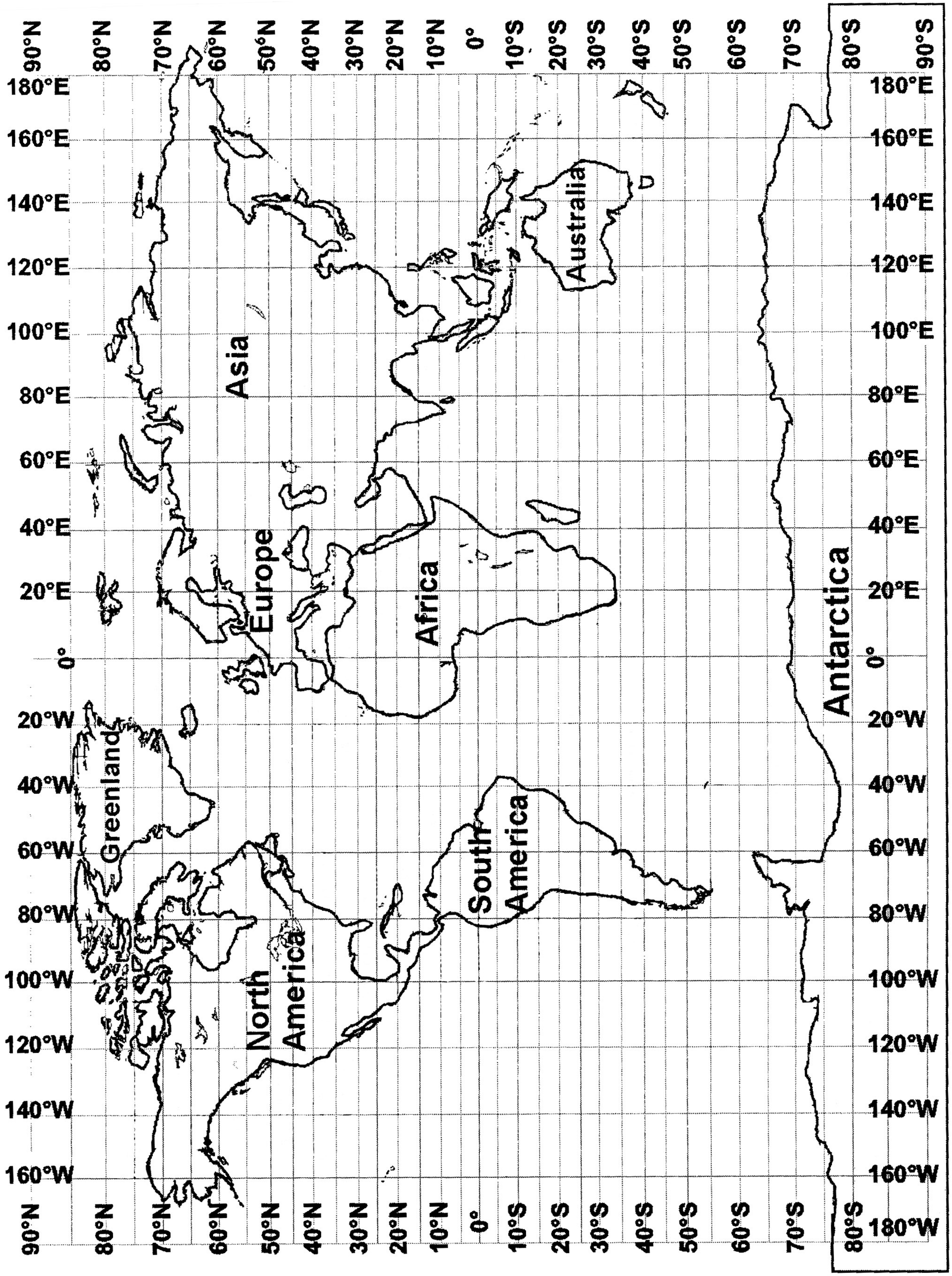
Science journal: Write in your journal:

a. What can you predict about the probability of seeing an aurora in your town?
b. Discuss the advantages and disadvantages of visiting the locations with high probabilities. What other conditions should you consider in selecting a location?
c. Why can't you see a summertime aurora well in the northern hemisphere?

Extension: The Earth's magnetic poles do not line up with its geographic poles and in fact have changed location over time (see http://www.geolab.nrcan.gc.ca/geomag/e_nmpole.html). Do you think the location of the magnetic poles affects the location of auroral sightings?

(Answer key is at http://sunearth.gsfc.nasa.gov/sunearthday/2003/poster.html)

***Education Standards**–Poster: NSES Science Content Standards B, D, F (Grades 5-8). Lesson: NCTM Math Standards Data Analysis and Probability, Connections, Representation (Grades 6-8); NCGE Geography Standards 1,4*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Physical sciences / Life and earth sciences
4. Messages in light

Worksheet 1

Links with the school curriculum

- Physical / chemical sciences (age 15-16-17) – Concepts: Messages in light. The transformation of matter.

Answers to questions

Here is a list of suggested answers to the questions on the information sheet *Spectrum of the atmosphere of Titan.*

- **Question 1.** It is an emission spectrum.
- **Question 2.** Observations have been made in the infrared because this is the wavelength range in which cold objects (such as planets and natural satellites) re-emit part of the energy which they receive. This is also the wavelength range in which emission lines from several organic compounds can be detected.
- **Question 3.** Cyanhydric acid (HCN); cyanogen (C_2N_2); cyanoacetylene (HC_3N).
- **Question 4.** Hydrocarbons are molecules containing only hydrogen (H) and carbon (C) atoms
- **Question 5.** Since hydrocarbons are fuels and oxygen is an oxidant, they would create the conditions for combustion. We would still, however, need a heat source to initiate combustion.

Supplementary questions

- **Question 1.** Look up the name of each of the molecules present in the spectrum.
- **Question 2.** Determine the stoichiometric numbers which allow the elements of carbon and hydrogen to be conserved in equations corresponding to the combustion of different hydrocarbons present in Titan's atmosphere in the presence of dioxygen.

Then... 2

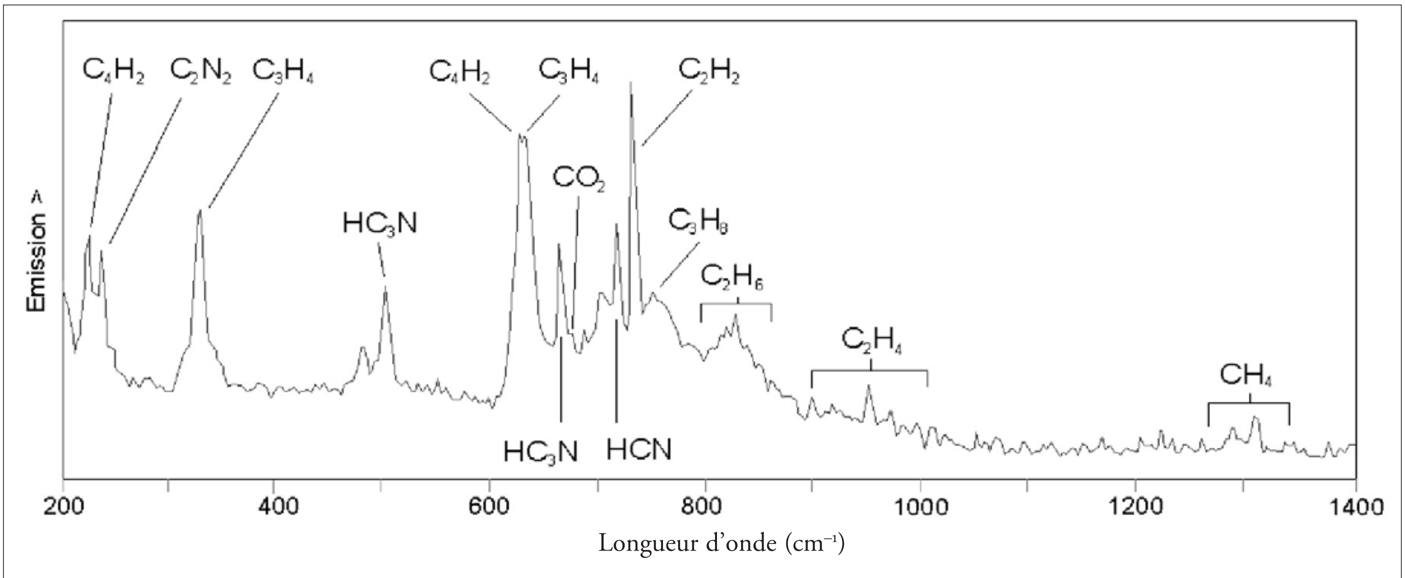
Web links

- ESA missions per wavelength (in English): http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=34990
- Seeing the invisible (in French): www.cite-sciences.fr/francais/ala_cite/act_educ/education/ressources/parcours/voirinvisible_lycee.doc
- The atmosphere of Titan (in French): http://www.lisa.univ-paris12.fr/GPCOS/Pc/Titan.htm
- Atmosphere of Titan (in English): http://www.esa.int/SPECIALS/Cassini-Huygens/SEMU76HHZTD_0.html
- Spitzer space telescope: http://www.cite-sciences.fr/francais/ala_cite/science_actualites/sitesactu/magazine/article.php?id_mag=1&lang=fr&id_article=1866
- What became of Voyager 1?: http://www.cidehom.com/article.php?_a_id=795

Document

Spectrum of the atmosphere of Titan

Passing near Titan in 1980, the Voyager 1 probe gathered infrared radiation from this satellite of Saturn and broke it down into a spectrum. The observation was performed in infrared because this is the wavelength in which cold objects (such as planets and satellites) re-emit part of the energy which they receive from the Sun. This spectrum provided evidence of a number of organic compounds, which was the reason behind the Huygens mission, due to land on Titan on 14 January 2005.



Test yourself

1 Is this an emission spectrum or an absorption spectrum?

2 Why was the spectrum obtained in infrared?

3 Pick out the lines of cyanhydric acid, cyanogen and cyanoacetylene in this spectrum.

4 What allows you to detect the presence of several hydrocarbons?

5 What might happen if you introduced oxygen into this kind of atmosphere?

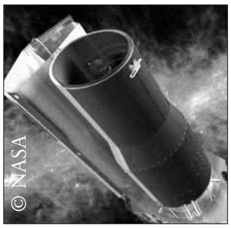
Comprehension

Observation of the Universe by wavelength

The electromagnetic spectrum is made up of all wavelength domains in which an electromagnetic wave can be found. Classified from longest to shortest wavelengths, we can distinguish between the radio domain, infrared, the visible domain (which our eyes are capable of detecting), ultraviolet, the X domain and the gamma domain. Visible light constitutes only a very small part of the electromagnetic spectrum. The most spectacular phenomena in the Universe (the explosion of supernovae) and the most fundamental (birth of stars) happen to emit exactly those wavelengths, which our senses cannot detect. Here are some of the instruments, which allow us to explore the Universe on all wavelengths.

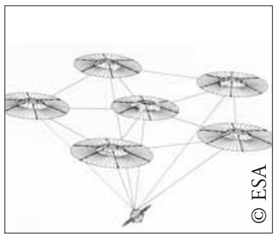
The Arecibo radiotelescope in the United States, located on the island of Puerto Rico.

The Arecibo radiotelescope picks up radiation emitted by radio sources in the Universe. This radiation passes through the atmosphere without difficulty, but an increasing number of man-made parasitic signals (e.g. from mobile phones) adversely affect the quality of observations.



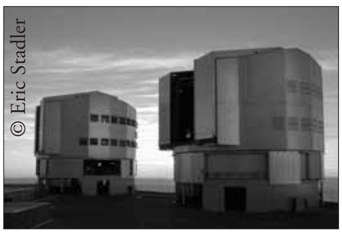
The Spitzer infrared telescope (United States).

The Spitzer satellite observes the Universe in far infrared, a form of radiation to which Earth's atmosphere is completely opaque. This makes it possible to observe regions such as stellar nurseries, where gas and dust accumulate before creating new suns.



The Darwin space telescopes (Europe).

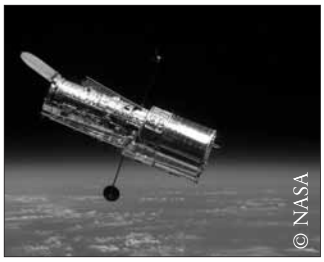
A "formation flying" space telescope project, capable of analysing light emitted from planets orbiting other suns. Darwin will observe in infrared, a wavelength, which allows us to observe cold objects such as dust or planets reflecting the light of their sun.



The VLT (Europe, located in Chile).

The VLT (*Very Large Telescope*) is a group of four giant terrestrial telescopes, each 8.2 metres in diameter. The VLT allows us to observe in the visible spectrum but also in near infrared, which can pass through the atmosphere.

The Hubble space telescope (United States, Europe).



The Hubble space telescope is able to make observations in the infrared and ultraviolet, but it makes most of its observations in the visible domain. It is due to be replaced in 2011 by the James Webb telescope, which is optimised for infrared. This characteristic allows it to observe the birth of stars and extrasolar planets, objects with very low luminosity.

The Corot satellite (France, Europe).

European satellite which will search for rocky planets orbiting other suns, scheduled to be launched in 2006. Corot will observe the reduction in luminosity of stars caused by the passage of a possible planet in front of the star disc being observed. It is able to detect planets five time larger than the Earth.

The SOHO satellite (United States, Europe).

SOHO is a solar space observatory which is capable of observing our star (the Sun) in the visible and the ultraviolet. SOHO can access different depths of the solar atmosphere depending on the wavelength used.

The FUSE satellite (United States).

Space telescope dedicated to the observation of ultraviolet radiation. It observes hot plasmas inside distant galaxies.

The XMM satellite (Europe).

XMM-Newton is a satellite dedicated to the observation of X radiation.
It detects X radiation emitted by sources with a temperature exceeding one million degrees, such as supernovae, cataclysmic explosions which signal the end of the life of giant stars. The Earth's atmosphere completely blocks X-rays from passing through.

The INTEGRAL satellite (Europe).

Satellite dedicated to the study of gamma radiation, which makes it ideal for observing areas where particularly violent phenomena occur, such as the environment of black holes or the active nuclei of galaxies.

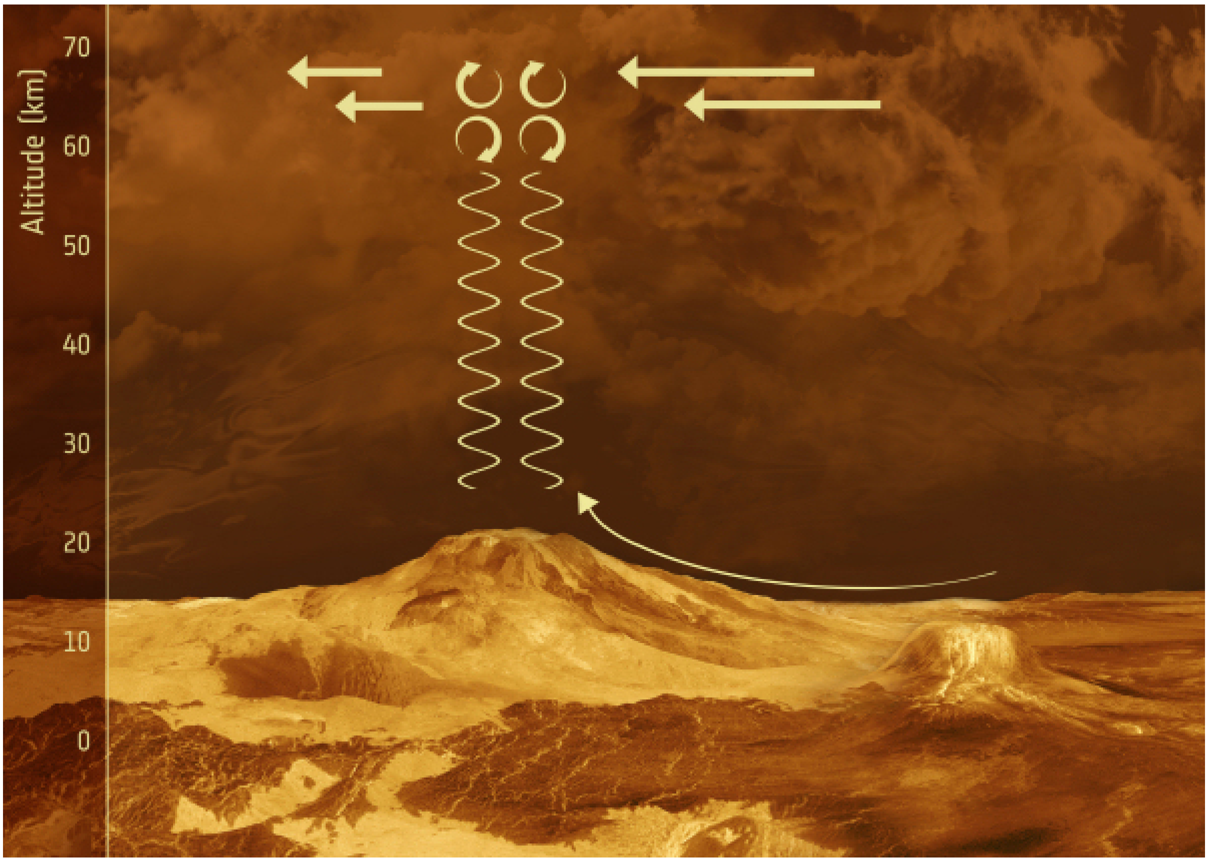
esa science & technology
European Space Agency

News 24-June-2019 19:30:13

What lies beneath: Venus' surface revealed through the clouds

18 July 2016

Using observations from ESA's Venus Express satellite, scientists have shown for the first time how weather patterns seen in Venus' thick cloud layers are directly linked to the topography of the surface below. Rather than acting as a barrier to our observations, Venus' clouds may offer insight into what lies beneath.



Gravity waves on Venus. *Credit: ESA*

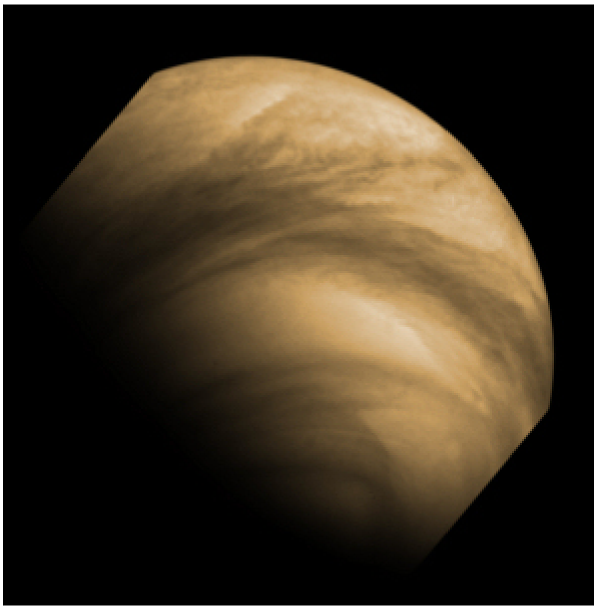
Venus is famously hot, due to an extreme greenhouse effect which heats its surface to temperatures as high as 450 degrees Celsius. The climate at the surface is oppressive; as well as being hot, the surface environment is dimly lit, due to a thick blanket of cloud which completely envelops the planet. Ground-level winds are slow, pushing their way across the planet at painstaking speeds of about 1 metre per second – no faster than a gentle stroll.

However, that is not what we see when we observe our sister planet from above. Instead, we spy a smooth, bright covering of cloud. This cloud forms a 20-km-thick layer that sits between 50 and 70 km above the surface and is thus far colder than below, with typical temperatures of about -70 degrees Celsius – similar to temperatures found at the cloud-tops of Earth. The upper cloud layer also hosts more extreme weather, with winds that blow hundreds of times faster than those on the surface (and faster than Venus itself rotates, a phenomenon dubbed 'super-rotation').

While these clouds have traditionally blocked our view of Venus' surface, meaning we can only peer beneath using radar or infrared light, they may actually hold the key to exploring some of Venus' secrets. Scientists suspected the weather patterns rippling across the cloud-tops to be influenced by the topography of the terrain below. They have found hints of this in the past, but did not have a complete picture of how this may work – until now.

Scientists using observations from ESA's Venus Express satellite have now greatly improved our climate map of Venus by exploring three aspects of the planet's cloudy weather: how quickly winds on Venus circulate, how much water is locked up within the clouds, and how bright these clouds are across the spectrum (specifically in ultraviolet light).

"*Our results showed that all of these aspects – the winds, the water content, and the cloud composition – are somehow connected to the properties of Venus' surface itself,*" says Jean-Loup Bertaux of LATMOS (Laboratoire Atmosphères, Milieux, Observations Spatiales) near Versailles, France, and lead author of the new Venus Express study. "*We used observations from Venus Express spanning a period of six years, from 2006 to 2012, which allowed us to study the planet's longer-term weather patterns*."



Venus cloud tops. *Credit: ESA/MPS/DLR/IDA*

Although Venus is very dry by Earth standards, its atmosphere does contain some water in the form of vapour, particularly beneath its cloud layer. Bertaux and colleagues studied Venus' cloud-tops in the infrared part of the spectrum, allowing them to pick up on the absorption of sunlight by water vapour and detect how much was present in each location at cloud-top level (70 km altitude).

They found one particular area of cloud, near Venus' equator, to be hoarding more water vapour than its surroundings. This 'damp' region was located just above a 4500-metre-altitude mountain range named Aphrodite Terra. This phenomenon appears to be caused by water-rich air from the lower atmosphere being forced upwards above the Aphrodite Terra mountains, leading researchers to nickname this feature the 'fountain of Aphrodite'.

"*This 'fountain' was locked up within a swirl of clouds that were flowing downstream, moving from east to west across Venus,*" says co-author Wojciech Markiewicz of the Max-Planck Institute for Solar System Research in Göttingen, Germany. "*Our first question was, 'Why?' Why is all this water locked up in this one spot?*"

In parallel, the scientists used Venus Express to observe the clouds in ultraviolet light, and to track their speeds. They found the clouds downstream of the 'fountain' to reflect less ultraviolet light than elsewhere, and the winds above the mountainous Aphrodite Terra region to be some 18 per cent slower than in surrounding regions.

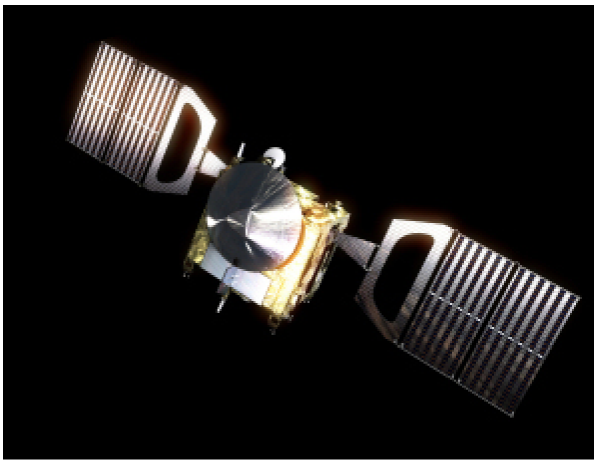
All three of these factors can be explained by one single mechanism caused by Venus' thick atmosphere, propose Bertaux and colleagues.

"*When winds push their way slowly across the mountainous slopes on the surface they generate something known as gravity waves,*" adds Bertaux. "*Despite the name, these have nothing to do with gravitational waves, which are ripples in space-time – instead, gravity waves are an atmospheric phenomenon we often see in mountainous parts of Earth's surface. Crudely speaking, they form when air ripples over bumpy surfaces. The waves then propagate vertically upwards, growing larger and larger in amplitude until they break just below the cloud-top, like sea waves on a shoreline.*"

As the waves break, they push back against the fast-moving high-altitude winds and slow them down, meaning that winds above Venus' Aphrodite highlands are persistently slower than elsewhere.

However, these winds re-accelerate to their usual speeds downstream of Aphrodite Terra – and this motion acts as an air pump. The wind circulation creates an upwards motion in Venus' atmosphere that carries water-rich air and ultraviolet-dark material up from below the cloud-tops, bringing it to the surface of the cloud layer and creating both the observed 'fountain' and an extended downwind plume of vapour.

"*We've known for decades that Venus' atmosphere contains a mysterious ultraviolet absorber, but we still don't know its identity,*" says Bertaux. "*This finding helps us understand a bit more about it and its behaviour – for example, that it's produced beneath the cloud-tops, and that ultraviolet-dark material is forced upwards through Venus' cloud-tops by wind circulation.*"



Venus Express spacecraft. *Credit: ESA*

Scientists already suspected that there were ascending motions in Venus' atmosphere all along the equator, caused by the higher levels of solar heating. This finding reveals that the amount of water and ultraviolet-dark material found in Venus' clouds is also strongly enhanced at particular places around the planet's equator. "*This is caused by the mountains way down on Venus' surface, which trigger rising waves and circulating winds that dredge up material from below,*" says Markiewicz.

As well as helping us understand more about Venus, the finding that surface topography can significantly affect atmospheric circulation has consequences for our understanding of planetary super-rotation, and of climate in general.

"*This certainly challenges our current General Circulation Models,*" says Håkan Svedhem, ESA Project Scientist for Venus Express. "*While our models do acknowledge a connection between topography and climate, they don't usually produce persistent weather patterns connected to topographical surface features. This is the first time that this connection has been shown clearly on Venus – it's a major result.*"

Venus Express was in operation at Venus from 2006 until 2014, when its mission concluded and the spacecraft began its descent through Venus' atmosphere.

The study by Bertaux and colleagues made use of several years of Venus Express observations gathered by the Venus Monitoring Camera (VMC) – to explore the wind speeds and ultraviolet brightness of the clouds – and by the SPICAV spectrometer (Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus) – to study the amount of water vapour contained within the clouds.

"*This research wouldn't have been possible without Venus Express' reliable and long-term monitoring of the planet across multiple parts of the spectrum. The data used in this study were collected over many years,*" adds Svedhem. "*Crucially, knowing more about Venus' circulation patterns may help us to constrain the identity of the planet's mysterious ultraviolet absorber, so we can understand more about the planet's atmosphere and climate as a whole.*"

Notes for editors

"Influence of Venus topography on the zonal wind and UV albedo at cloud top level: the role of stationary gravity waves", by J.-L. Bertaux et al., is published in the *Journal of Geophysical Research: Planets*. doi: 10.1002/2015JE004958

The study is based on data from Venus Express' VMC (Venus Monitoring Camera) and SPICAV spectrometer (Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus).

ESA's Venus Express was launched in 2005, arrived at Venus in 2006, and spent eight years exploring the planet from orbit. The mission ended in December 2014 after the spacecraft ran out of orbit-raising propellant and entered the atmosphere. Some science highlights from Venus Express can be found here.

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Images And Videos

- Gravity waves on Venus (http://sci.esa.int/jump.cfm?oid=58088)
- Venus cloud tops (http://sci.esa.int/jump.cfm?oid=51938)
- Venus Express Spacecraft (http://sci.esa.int/jump.cfm?oid=38273)

See Also

- Venus mountains create wave trains (http://sci.esa.int/jump.cfm?oid=53597)

Related Publications

- Bertaux, J.-L., et al. [2016] (http://sci.esa.int/jump.cfm?oid=58086)
- Fedorova, A., et al. [2016] (http://sci.esa.int/jump.cfm?oid=58087)

esa united space in europe

European Space Agency

SURPRISINGLY ERRATIC X-RAY AURORAS DISCOVERED AT JUPITER

30 October 2017
ESA and NASA space telescopes have revealed that, unlike Earth's polar lights, the intense auroras seen at Jupiter's poles unexpectedly behave independently of one another.

Aurora at Jupiter

Auroras have been seen in many places, from planets and moons to stars, brown dwarfs and a variety of other cosmic bodies. These beautiful displays are caused by streams of electrically charged atomic particles – electrons and ions – colliding with the atmospheric layers surrounding a planet, moon or star. Earth's polar lights tend to mirror one another: when they brighten at the North pole, they generally brighten at the South pole, too.

The same was expected of auroras elsewhere, but a new study, published today in Nature Astronomy, reveals that those at the gas giant Jupiter are much less coordinated.

The study used ESA's XMM-Newton and NASA's Chandra X-ray space observatories to observe the high-energy X-rays produced by the auroras at Jupiter's poles. While the southern auroras were found to pulse consistently every 11 minutes, those at the planet's north pole flared chaotically.

"These auroras don't seem to act in unison like those that we're often familiar with here on Earth," says lead author William Dunn of University College London's Mullard Space Science Laboratory, UK, and Harvard-Smithsonian Center for Astrophysics, USA.

"We thought the activity would be coordinated through Jupiter's magnetic field, but the behaviour we found is really puzzling.

Aurora over northern Canada

"It's stranger still considering that Saturn – another gas giant planet – doesn't produce any X-ray auroras that we can detect, so this throws up a couple of questions that we're currently unsure how to answer.

"Firstly, how does Jupiter produce bright and energetic X-ray auroras at all when its neighbour doesn't, and secondly, how does it do so independently at each pole?"

With the data at hand, William and colleagues identified and mapped X-ray hot spots at Jupiter's poles. Each hot spot covers an area half the size of Earth's surface.

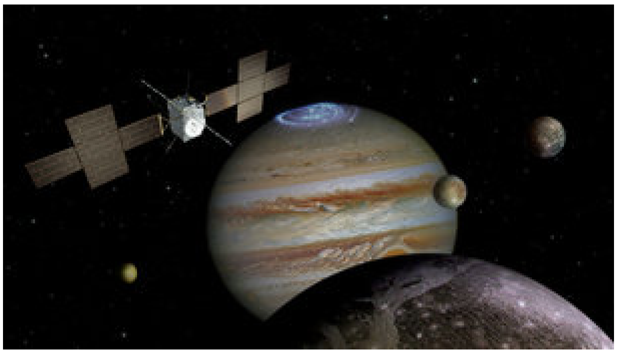
As well as raising questions about how auroras are produced throughout the cosmos, Jupiter's independently pulsing auroras suggest that there is far more to understand about how the planet itself produces some of its most energetic emissions.

Jupiter's magnetic influence is colossal; the region of space over which the Jovian magnetic field dominates – the magnetosphere – is some 40 times larger than Earth's, and filled with high-energy plasma. In the outer edges of this region, charged particles ultimately from volcanic eruptions on Jupiter's moon, Io, interact with the magnetic boundary between the magnetosphere and interplanetary space. These interactions create intense phenomena, including auroras.

"Charged particles have to hit Jupiter's atmosphere at exceptionally fast speeds in order to generate the X-ray pulses that we've seen. We don't yet understand what processes cause this, but these observations tell us that they act independently in the northern and southern hemispheres," adds Licia Ray, from Lancaster University, UK, and a co-author.

The asymmetry in Jupiter's northern and southern lights also suggests that many cosmic bodies that are known to experience auroras – exoplanets, neutron stars, brown dwarfs and other rapidly-rotating bodies – might produce a very different aurora at each pole.

Further studies of Jupiter's auroras will help to form a clearer picture of the phenomena produced at Jupiter; auroral observing campaigns are planned for the next two years, with X-ray monitoring by XMM-Newton and Chandra and simultaneous observations from NASA's Juno, a spacecraft that started orbiting Jupiter in mid-2016.


Juice at Jupiter

ESA's Juice will arrive at the planet by 2029, to investigate Jupiter's atmosphere and magnetosphere. It, too, will observe the auroras and in particular the effect on them of the Galilean moons.

"This is a breakthrough finding, and it couldn't have been done without ESA's XMM-Newton," adds Norbert Schartel, ESA project scientist for XMM-Newton.

"The space observatory was critical to this study, providing detailed data at a high spectral resolution such that the team could explore the vibrant colours of the auroras and figure out details about the particles involved: if they're moving fast, whether they're an oxygen or sulphur ion, and so on.

"Coordinated observations like these, with telescopes such as XMM-Newton, Chandra and Juno working together, are key in exploring and further understanding environments and phenomena across the Universe, and the processes that produce them."

Notes for Editors

The research is presented in a paper entitled "The Independent Pulsations of Jupiter's Northern and Southern X-ray Auroras," by W.R. Dunn et al., published in the journal Nature Astronomy on 30 October 2017. The lead author is supported by an ESA Network/Partnering Initiative fellowship.

More information about ESA's XMM-Newton space telescope can be found here.

ESA's Cluster mission studied in-situ aurora acceleration processes at Earth in 2008 and 2009, and the joint ESA–China Smile mission will observe Earth's aurora starting in 2022.

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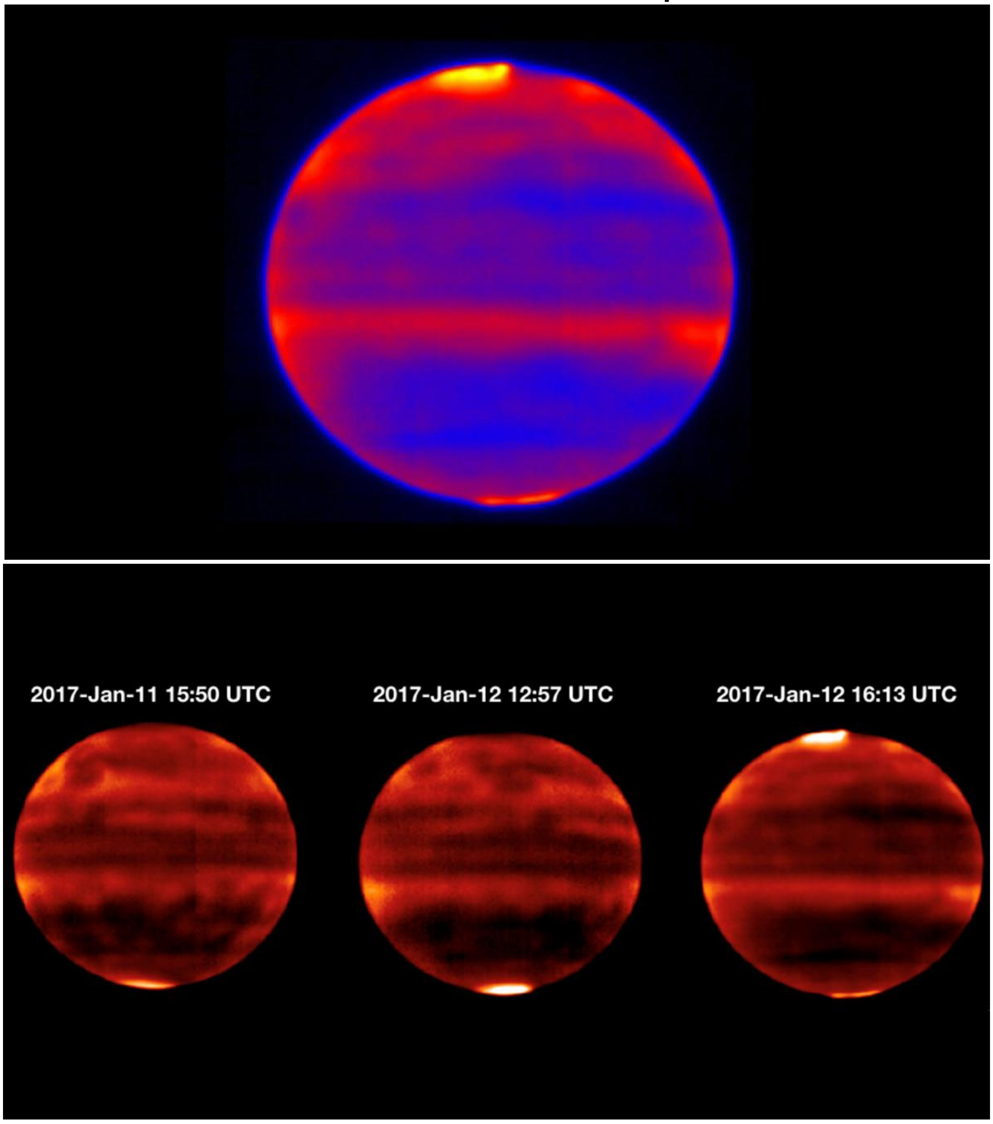
http://sci.esa.int/science-e/www/area/index.cfm?fareaid=23

חלק ב': הצעות לפיתוח מערכים עתידיים

1. חימום האטמוספרה של צדק ע"י רוח השמש



Sensitive to Jupiter's stratospheric temperatures, these infrared images were recorded by the Cooled Mid-Infrared Camera and Spectrograph (COMICS) at the Subaru Telescope on the summit of Mauna Kea, Hawaii. Areas of the atmosphere that are more yellow and red indicate the hotter regions. Aurora produce enhanced and variable heating at Jupiter's poles. The heating occurs when the magnetosphere and the solar wind interact and deposit energy into Jupiter's atmosphere. Images were captured less than a day apart, from Jan. 11-12, 2017, and illustrate how quickly the atmosphere varied in response to the solar wind.

This work was supported by a NASA Keck PI Data Award, administered by the NASA Exoplanet Science Institute.

New Earth-based telescope observations show that auroras at Jupiter's poles are heating the planet's atmosphere to a greater depth than previously thought - and that it is a rapid response to the solar wind.

"The solar wind impact at Jupiter is an extreme example of space weather," said James Sinclair of NASA's Jet Propulsion Laboratory in Pasadena, California, who led new research published April 8 in Nature Astronomy. "We're seeing the solar wind having an effect deeper than is normally seen."

Auroras at Earth's poles (known as the aurora borealis at the North Pole and aurora australis at the South Pole) occur when the energetic particles blown out from the Sun (the solar wind) interact with and heat up the gases in the upper atmosphere. The same thing happens at Jupiter, but the new observations show the heating goes two or three times deeper down into its atmosphere than on Earth, into the lower level of Jupiter's upper atmosphere, or stratosphere.

Understanding how the Sun's constant outpouring of solar wind interacts with planetary environments is key to better understanding the very nature of how planets and their atmospheres evolve.

"What is startling about the results is that we were able to associate for the first time the variations in solar wind and the response in the stratosphere - and that the response to these variations is so quick for such a large area," said JPL's Glenn Orton, co-author and part of the observing team.

Within a day of the solar wind hitting Jupiter, the chemistry in its atmosphere changed and its temperature rose, the team found. An infrared image captured during their observing campaign in January, February and May of 2017 clearly shows hot spots near the poles, where Jupiter's auroras are. The scientists based their findings on observations by the Subaru Telescope, atop the summit of Mauna Kea in Hawaii, which is operated by the National Astronomical Observatory of Japan.

The telescope's Cooled Mid-Infrared Camera and Spectograph (COMICS) recorded thermal images - which capture areas of higher or lower temperatures - of Jupiter's stratosphere.

"Such heating and chemical reactions may tell us something about other planets with harsh environments, and even early Earth," said Yasumasa Kasaba of Tohoku University, who also worked on the observing team.

מקור:

אתר האינטרנט של JPL (המעבדה להנעה סילונית) של נאס"א

A pulsating auroral X-ray hot spot on Jupiter

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Jupiter's X-ray aurora has been thought to be excited by energetic sulphur and oxygen ions precipitating from the inner magnetosphere into the planet's polar regions[1–3]. Here we report high-spatial-resolution observations that demonstrate that most of Jupiter's northern auroral X-rays come from a 'hot spot' located significantly poleward of the latitudes connected to the inner magnetosphere. The hot spot seems to be fixed in magnetic latitude and longitude and occurs in a region where anomalous infrared[4–7] and ultraviolet[8] emissions have also been observed. We infer from the data that the particles that excite the aurora originate in the outer magnetosphere. The hot spot X-rays pulsate with an approximately 45-min period, a period similar to that reported for high-latitude radio and energetic electron bursts observed by near-Jupiter spacecraft[9,10]. These results invalidate the idea that jovian auroral X-ray emissions are mainly excited by steady precipitation of energetic heavy ions from the inner magnetosphere. Instead, the X-rays seem to result from currently unexplained processes in the outer magnetosphere that produce highly localized and highly variable emissions over an extremely wide range of wavelengths.

Observations were made with the high-resolution camera (HRC) of the Chandra X-ray Observatory on 18 December 2000 for an entire 10-h Jupiter rotation (from 10–20 UT) in support of the Cassini fly-by of Jupiter. These observations show strong auroral emissions from high latitudes (Fig. 1) as well as a rather featureless disk that probably results from a combination of reflected and fluoresced solar X-rays[11]. The Chandra data are time-tagged and thus can be mapped into jovian latitude and system III longitude coordinates (system III longitudes are based on the 9.925-hour rotation period of Jupiter's magnetic field). Comparison of the resulting X-ray emission map with simultaneous far-ultraviolet images obtained by the Hubble Space Telescope imaging spectrograph (HST-STIS) shows that the northern auroral X-rays are concentrated in a 'hot spot' within the main ultraviolet auroral oval at high magnetic latitudes (Fig. 2).

The hot spot is located roughly at 60–70° north latitude and 160–180° system III longitude; no similar hot spot is seen in the south, but this is almost certainly due to the poor viewing geometry for the southern polar cap. We note that this same hot-spot region is the site of enhanced infrared emissions from CH_4 (ref. 4), C_2H_2 (ref. 5), C_2H_4 (ref. 6) and C_2H_6 (ref. 7), as well as highly variable H_2 emissions at far-ultraviolet wavelengths[8], and a 'dark spot' in the sunlight reflected from Jupiter at mid-ultraviolet wavelengths[12].

Jupiter's main auroral oval lies at latitudes that map magnetically to radial distances near 30 jovian radii, R_J (refs 13–15); the location of the hot spot at latitudes poleward of the main oval indicates that the bulk of the jovian X-ray emissions must connect along magnetic field lines to regions in the jovian magnetosphere well in excess of $30R_J$ from the planet. The Chandra HRC observations therefore call into question earlier views that attribute the X-ray auroral emissions to energetic particles diffusing planetward from the outer regions of the Io plasma torus and precipitating in the atmosphere at latitudes

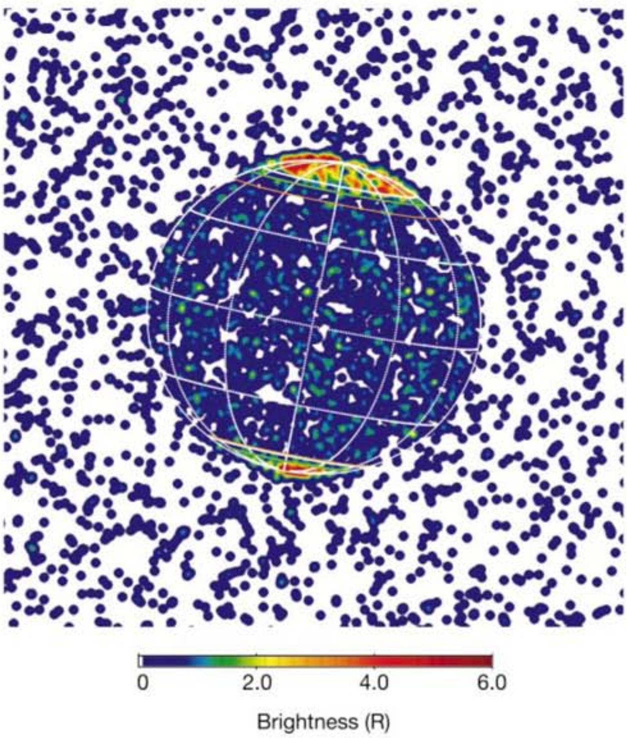

Figure 1 Chandra X-ray Observatory image of Jupiter on 18 December 2000. False colour brightnesses are indicated in rayleighs (*R*). The observation lasted 10 h (10–20 UT) and each X-ray photon has been smeared by double the 0.4-arcsecond full-width half-maximum point-spread-function of the high-resolution camera. A jovicentric graticule with 30° intervals is overplotted, along with the maximum equatorward extent of the $L = 5.9$ (orange lines) and $L = 30$ (green lines) footprints of the VIP4 model[16] magnetosphere. The auroral emissions are located at much higher latitudes than we expected on the basis of previous X-ray observations and indicate a connection with Jupiter's outer magnetosphere. An animation showing the time dependence of these observations may be viewed at http://pluto.space.swri.edu/yosemite/jupiter/ chandra_hrc.html.

below those of the main oval[3]. On the other hand, our magnetic mapping of the hot spot to distances greater than $30R_J$ means that the source of the precipitating particles is unclear, because at such large distances from Jupiter there are insufficient S and O ions (B. H. Mauk, personal communication) to account for the hot-spot emissions. Another ion source or excitation mechanism (such as electron bremsstrahlung) must be considered.

Further evidence that some process other than energetic ion precipitation from the inner magnetosphere is responsible for the bulk of the observed auroral X-rays is provided by the lack of expected correlation between the X-ray emission morphology and the surface magnetic field strength (that is, the magnetic field strength at $1R_J$) as determined with the VIP4 model[16] (Fig. 2). That is, for the nominal mechanism of generation by energetic ion precipitation, the brightest X-ray emissions would be expected where the eastward drifting (that is, toward lower longitude) ions encounter the most steeply decreasing surface magnetic field strength along their L-shell footprint (that is, the locus of intersection of their magnetic field lines with the surface of Jupiter) and only if the field strength is lower than in the conjugate hemisphere[17,18]. Thus, although we would expect emissions at slightly higher latitudes than the $L = 5.9$ footprint of the Io plasma torus, at system III longitudes of 0–60° in the north and 120–260° in the south, we found minor clusters of X-rays near the $L = 5.9$ footprint near 140° in the north and 80–120° in the south.

A result even more puzzling than the high-latitude location of the X-ray hot spot is revealed when the X-ray counts are plotted as a function of time. The resulting light curve and power spectrum (Fig. 3) show a very strong ~45-min oscillation in the emitted X-rays. One of the primary goals of the Chandra and HST campaigns supporting the Cassini fly-by was to search for transient auroral variations that might be related to the interaction of the solar wind with Jupiter's magnetosphere. However, correlative Cassini solar-wind data acquired upstream at about $200R_J$ show no comparable periodicity, even accounting for the 5–10-h delay time for the propagation from the spacecraft to the planet. Likewise, no 45-min periodicities were seen in Galileo and Cassini energetic-particle and plasma-wave measurements at the time of the Chandra observations, although such periodicities are seen at other times (W. S. Kurth, personal communication). Forty-minute oscillations have been seen before in energetic particles in the outer magnetosphere and in radio waves[9,10]. Following the Ulysses fly-by of Jupiter, intermittent bursts of 1–200-kHz radio emissions with an approximately 40-min period were observed for several months originating from high southern-jovian latitudes; these bursts were correlated with Ulysses measurements of solar-wind velocity and both relativistic (>8 MeV) and lower (~50 keV) energy electrons from Jupiter[9]. However, the origin of these quasi-periodic radio bursts has not been explained.

As there is no apparent correlation between the auroral X-rays and the solar-wind parameters measured by Cassini before and during the Chandra observations, it seems most likely that the oscillations arise from processes internal to the jovian magnetosphere. Global ultra-low-frequency (ULF) oscillations of the magnetic field and of the density of high-energy ions are ubiquitous in the jovian magnetosphere and are generally found to have periods in the 10–20-min range[19,20]. Certain models of the ULF oscillations as standing waves along magnetic field lines indicate that spacecraft motion affects the measured periods so that they are closer to one hour in a reference frame that corotates with Jupiter[19]. The observed ULF oscillations may arise in a resonance with the bounce periods of the energetic particles (that is, the period for a magnetically trapped ion to repeat its north–south motion along a field line). Scattering of some portion of this particle population into the loss cone could

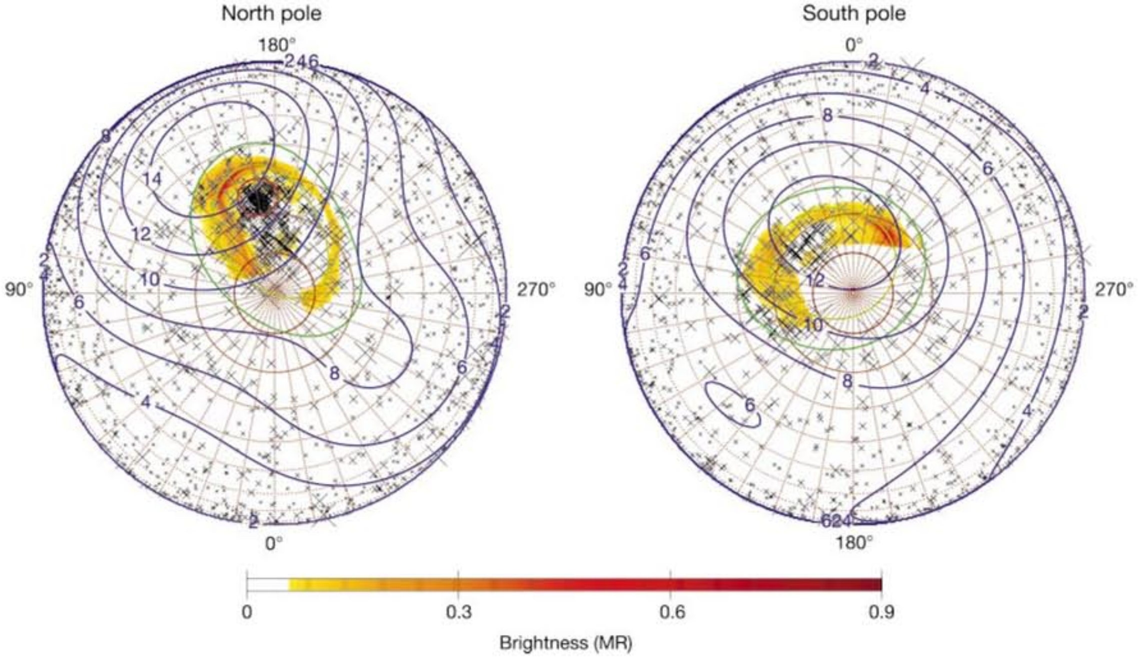

Figure 2 Polar projections of X-rays seen by Chandra and simultaneous far-ultraviolet images obtained by the Hubble Space Telescope. The mapped locations of individual X-ray photons (crosses) are overlaid on averages of several northern (left) and southern (right) auroral images made with the Hubble Space Telescope imaging spectrograph (HST-STIS) during 10–20 UT on 18 December 2000. The mapping assumes that the X-ray and ultraviolet auroras peak in emission at 240 km above the 1-bar pressure level. The size of each cross gives an approximate indication of the uncertainty in location of the corresponding X-ray photon, and only photons with emission angles of <85° are shown. The HST-STIS images made with the 25MAMA filter are displayed in false colour with auroral H_2 emission brightnesses in megarayleighs (MR) as indicated by the colour bar. Surface VIP4 model[16] magnetic field strength contours are shown for comparison (dark blue). The $L = 5.9$ and $L = 30$ footprints of the VIP4 model magnetosphere are also included (outer and inner green ovals, respectively), and a 10° graticule (brown dotted lines) with system III longitudes labelled. Most of the northern auroral X-rays are unexpectedly located well within the main far-ultraviolet oval and are coincident with the polar-cap far-ultraviolet emissions. The red circle in the northern auroral plot (left) shows the region defined for the hot spot used in the timing analysis. The apparent increase in X-rays toward the equator is an artefact of the polar projection.

result in quasi-periodic precipitation that would account for the periodicity observed in the X-ray emissions. However, bounce periods vary with particle energy, distance from Jupiter, and pitch angle, and it is unclear what would cause a narrow range of periods to dominate this resonance over much of the magnetosphere.

It is difficult to estimate the power in the emitted X-rays, because the Chandra HRC responds over a broad energy range (0.1–10 keV) with a variable sensitivity that peaks near an energy of 1.1 keV. We currently have no knowledge of the details of the emitted spectrum, so we can only make very rough estimates of the emitted power. Assuming a photon energy of 574 eV (corresponding to an O^{6+} emission feature expected to be bright in ion auroras or solar-wind charge exchange[21,22]), the estimated X-ray luminosities of the disk of Jupiter and its northern and southern auroras are about 2.3, 1.0 and 0.4 GW, respectively. These results are consistent with previous observations made with low spatial resolution[1,2].

As we note above, it is difficult to account for the ion flux needed to produce the estimated luminosities with a source region located in the outer magnetosphere. If the emissions are indeed generated by heavy-ion precipitation, one possibility is high-latitude reconnection of the planetary and solar-wind magnetic fields, with the subsequent entry of the highly ionized (but low energy) heavy-ion component of the solar wind. The captured solar-wind ions could be accelerated to MeV energies by the field-aligned currents present in the outer magnetosphere[22–24]. Such particles could also be consistent with the observed plasma waves. For example, the bounce period of 20 MeV oxygen ions on a dipole field line at $L = 120R_J$ with an equatorial pitch angle of 30° is about 38 minutes. Although outer magnetospheric field lines are not dipolar[25], they are close enough for this simple calculation to be informative. We wondered whether electron bremsstrahlung, originally rejected primarily on energetic grounds, should be reconsidered as an explanation for the X-rays. The energetics argument still holds: the power needed to produce the brightest far-ultraviolet 'flares' seen in the same polar-cap region as the X-ray hot spot is a few tens of TW (ref. 8), much less than the estimated power of a few PW (ref. 1) needed to produce the observed X-rays by electron bremsstrahlung. Thus, explaining the observed hot-spot X-rays with electron bremsstrahlung still seems unpromising. Whatever ultimate source is determined for the hot-spot X-rays, it should probably also account for the far-ultraviolet flare emissions, the various hydrocarbon infrared emissions, and possibly the mid-ultraviolet dark spot, as it is unlikely that these various phenomena occur in the same area of the upper atmosphere of Jupiter and yet are unrelated to one another. □

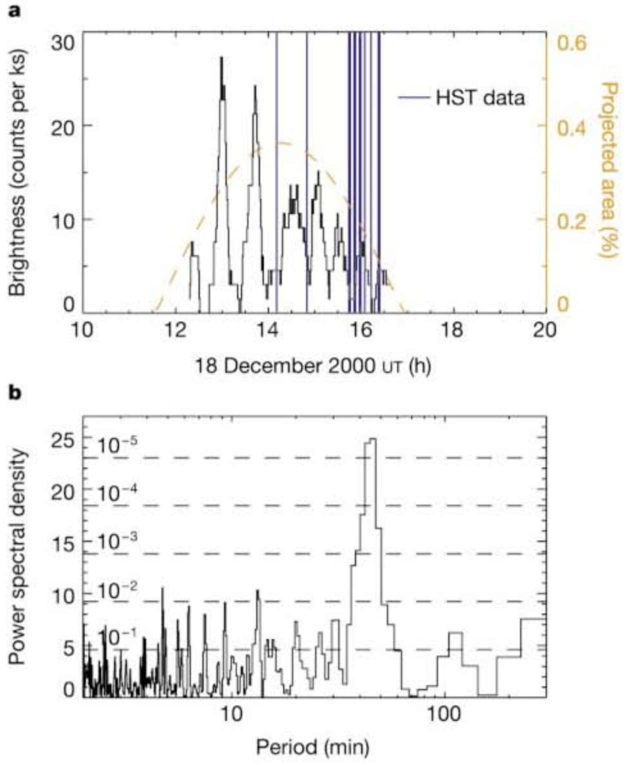

Figure 3 Light-curve and power-spectrum data for the auroral hot spot. **a**, Light curve showing the X-ray count rate measured by Chandra as a function of time for the auroral hot spot. Here we defined the hot spot region to include only those X-rays emitted within a 5°-radius circle centred on a latitude of 65° and a system III longitude of 170° (as shown by the red circle in Fig. 2). The total number of X-rays emitted from this region is 113, and the plot shows an 11-min boxcar smoothing of a 1-min binning of the data. The orange dashed line shows the projected area of the hot spot (as a percentage of the projected area of Jupiter). The times of the HST-STIS northern auroral region images shown in Fig. 2 are indicated by vertical purple lines. Unfortunately, no images were obtained during any of the bright X-ray pulses. **b**, Power spectrum of the hot spot signal, normalized so that, if the photons were randomly distributed over the visibility period, the mean power spectral density of any particular frequency bin would be expected to have a value of 2 (ref. 26). The peak at a period of approximately 45 min is clearly seen. The peak at 300 min is associated with the approximately 600-min rotation period of Jupiter. The dashed lines are labelled with the probability of a random signal exceeding that level in a particular frequency bin (for example, the 45-min period peak has a 4×10^{-6} likelihood of having been attained at random).

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LETTERS

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A brightening of Jupiter's auroral 7.8-μm CH_4 emission during a solar-wind compression

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Enhanced mid-infrared emission from CH_4 and other stratospheric hydrocarbons has been observed coincident with Jupiter's ultraviolet auroral emission[1–3]. This suggests that auroral processes and the neutral stratosphere of Jupiter are coupled; however, the exact nature of this coupling is unknown. Here we present a time series of Subaru-COMICS images of Jupiter measured at a wavelength of 7.80 μm on 11–14 January, 4–5 February and 17–20 May 2017. These data show that both the morphology and magnitude of the auroral CH_4 emission vary on daily timescales in relation to external solar-wind conditions. The southern auroral CH_4 emission increased in brightness temperature by about 3.8 K between 15:50 UT, 11 January and 12:57 UT, 12 January, during a predicted solar-wind compression. During the same compression, the northern auroral emission exhibited a duskside brightening, which mimics the morphology observed in the ultraviolet auroral emission during periods of enhanced solar-wind pressure[4,5]. These results suggest that changes in external solar-wind conditions perturb the Jovian magnetosphere in such a way that energetic particles are accelerated into the planet's atmosphere, deposit their energy as deep as the neutral stratosphere, and modify the thermal structure, the abundance of CH_4 or the population of energy states of CH_4. We also find that the northern and southern auroral CH_4 emission evolved independently between the January, February and May images, as has been observed at X-ray wavelengths over shorter timescales[6] and at mid-infrared wavelengths over longer timescales[7].

Images at 7.80-μm were obtained using Subaru-COMICS (Cooled Mid-Infrared Camera and Spectrograph) on 11–14 January, 4–5 February and 17–20 May 2017 (UT). A subset of these images is shown in Figs. 1 and 2, which respectively show southern and northern polar projections at times when the southern auroral region (SAR; 330°–60° W in system III longitude) and northern auroral region (NAR; centred at 180° W in system III longitude) were visible on the disk of Jupiter. These images demonstrate variability of both the magnitude and morphology of the 7.80-μm CH_4 emission over timescales of days to months. Further details of the measurements and processing are provided in the Methods and Supplementary Information.

In terms of the morphology, the strongest 7.80-μm emission in both auroral regions appears enclosed inside the statistical mean of the ultraviolet emissions of the main oval[8]. Figure 3 shows the results of ionosphere-to-magnetosphere mapping model calculations (see Methods) and demonstrates that the positions of strongest CH_4 emission in the auroral regions predominantly correspond to radial distances of more than 95 Jupiter radii (R_J); beyond the dayside magnetopause[9] and potentially on open field lines. The exception is the morphology of the emission in the NAR at 16:13 UT on 12 January (Fig. 2a), when a poleward, duskside feature of stronger emission parallel to the eastern boundary of the statistical oval was observed. This feature was not present less than 24 h later (Fig. 2b) and we have ruled out variable atmospheric seeing conditions between these two nights as the source of this intermittent morphology (see Supplementary Fig. 2). A similar morphology for the ultraviolet auroral emission, described as the 'duskside-active region', has also been observed during periods of enhanced solar-wind pressure, and has been attributed to duskside/nightside reconnection associated with the Vasyliunas or Dungey cycles or velocity shears caused by changing flows on the nightside magnetospheric flank[4,5,10]. Ionosphere-to-magnetosphere mapping calculations map 73° N, 155° W (an example location covered by the duskside feature) to roughly $100R_J$ at a local time of 19.0 h. Unlike the NAR, the SAR does not appear to exhibit any smaller-scale morphology, although its position at a comparably higher latitude than the NAR reduces the effective spatial resolution and thus the ability to resolve smaller-scale features. In contrast to previous studies[7,11], we find no obvious movement in the longitudinal position of the southern auroral CH_4 emission.

To quantify temporal changes in the magnitude of the auroral emission and its relation to solar-wind conditions, we calculated the residual radiance between each auroral region and a lower-latitude zonal mean, henceforth named the auroral–quiescent residual ΔT_b (see Methods). Figure 4 compares the auroral–quiescent residual and uncertainty for both auroral regions and the results of a solar-wind propagation model (see Methods). The solar-wind propagation model predicts the arrival of a solar-wind compression at Jupiter at approximately 22:00 UT on 11 January, when the dynamical pressure was predicted to have increased from less than 0.1 nPa to 0.7 nPa. The auroral–quiescent residual increased from $\Delta T_b = 8.0 \pm 0.3$ K at

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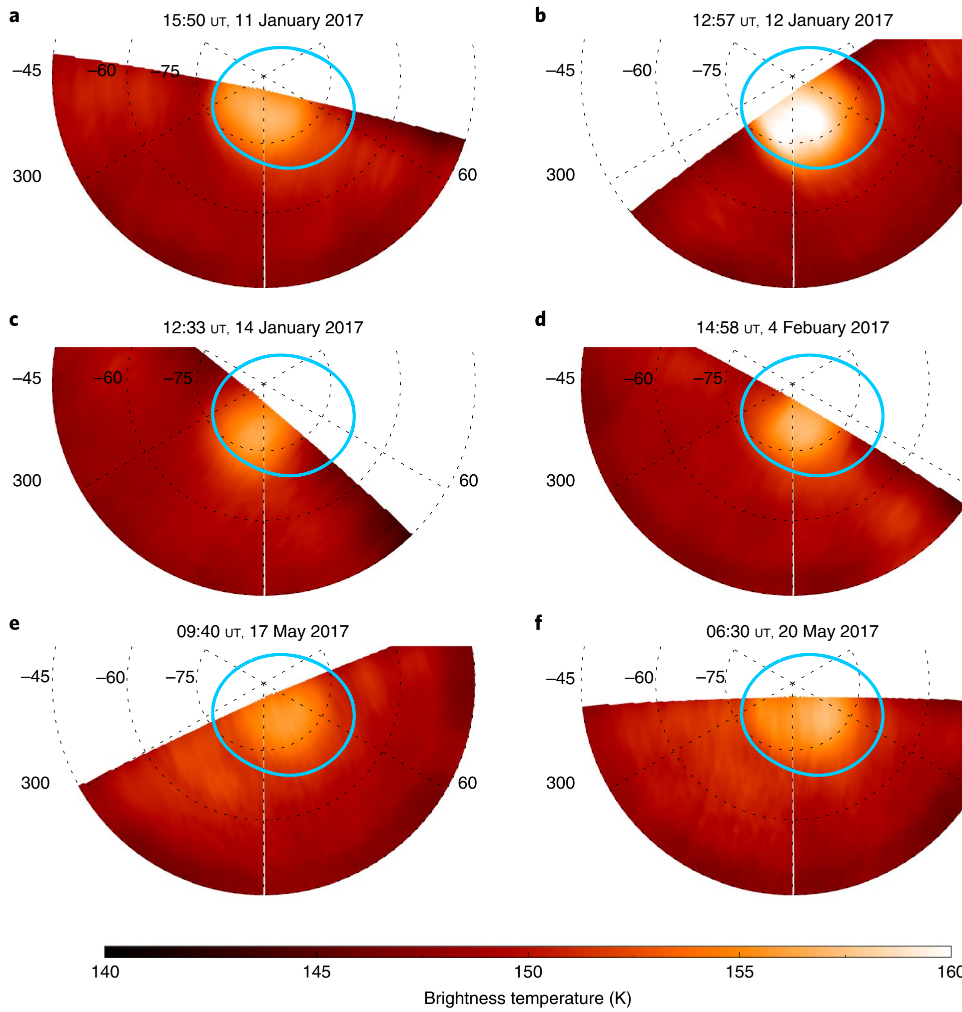

Fig. 1 | Southern polar projections of Jupiter's 7.80-µm CH_4 emission. a–f, Images were recorded by Subaru-COMICS on 11 January (**a**), 12 January (**b**), 14 January (**c**), 4 February (**d**), 17 May (**e**) and 20 May (**f**) 2017. These are a subset of the observations shown in Supplementary Fig. 1, when the SAR (330°–60° W, system III) was fully or partially visible on the disk. The colour scale indicates the brightness temperature. Solid light-blue lines represent the statistical-mean position of the ultraviolet auroral main oval emission[8]. For consistency with the Juno science team and the community supporting the Juno mission, increasing system III longitude is shown anticlockwise. All latitudes and longitudes are in degrees and are planetocentric and System III, respectively.

15:50 UT 11 January to $\Delta T_b = 11.8 \pm 0.5$ K at 12:57 UT 12 January—a net increase of 3.8 ± 0.6 K in brightness temperature T_b or a roughly 25% increase in radiance. Although the viewing geometries of the SAR differ between these two images, forward-model calculations of the 7.80-µm emission (see Methods) at these two geometries differ by only 0.7 K in T_b and thus cannot explain all of the observed change. From 12:57 UT 12 January to 12:33 UT 14 January, the SAR returned to a brightness similar to that observed pre-compression; this brightness then remained roughly constant in all subsequent measurements (although variability between these measurements cannot be ruled out).

The NAR was not visible on the disk of Jupiter in the images taken on 11 January (before the solar-wind compression) and so we do not know whether it also brightened during the same solar-wind compression. However, the aforementioned duskside-active emission captured by COMICS at 16:13 UT on 12 January (Fig. 2a) occurred shortly after the solar-wind compression, which reiterates that this morphology is probably driven by enhanced solar-wind conditions and their perturbing effect on the nightside magnetosphere. From 16:13 UT 12 January to 12:30 UT 13 January, the auroral–quiescent residual of the NAR was constant in time within uncertainty and subsequently decreased significantly to 1.2 ± 1.1 K. Similarly, measurements in May show the NAR emission to be weak and comparable with, if not weaker than, lower-latitude regions. From 18 May to 19 May, there was a marginal increase in the emission in the NAR during a small solar-wind compression (about 0.2 nPa); however, the change in emission was not significant with respect to measurement uncertainty. Without measurements between 13 January, 5 February and 18 May, it is uncertain whether the NAR emission was consistently weaker in time or whether it exhibited short-term (daily or weekly) variability and the measurements by chance captured periods of weaker emission. We favour the latter possibility given that the measurements on 5 February and 17 May were preceded by at least seven days of steady, low-pressure (less than 0.05 nPa) solar-wind conditions. We note the results of a recent study[12], which showed that the total auroral power during a solar-wind compression exhibited a positive correlation with the duration of steady, quiescent solar-wind conditions preceding the compression. We also note that the northern auroral C_2H_6 emission was shown in previous work to weaken during periods of low solar activity, which similarly suggests a connection with solar-wind conditions on longer timescales[13].

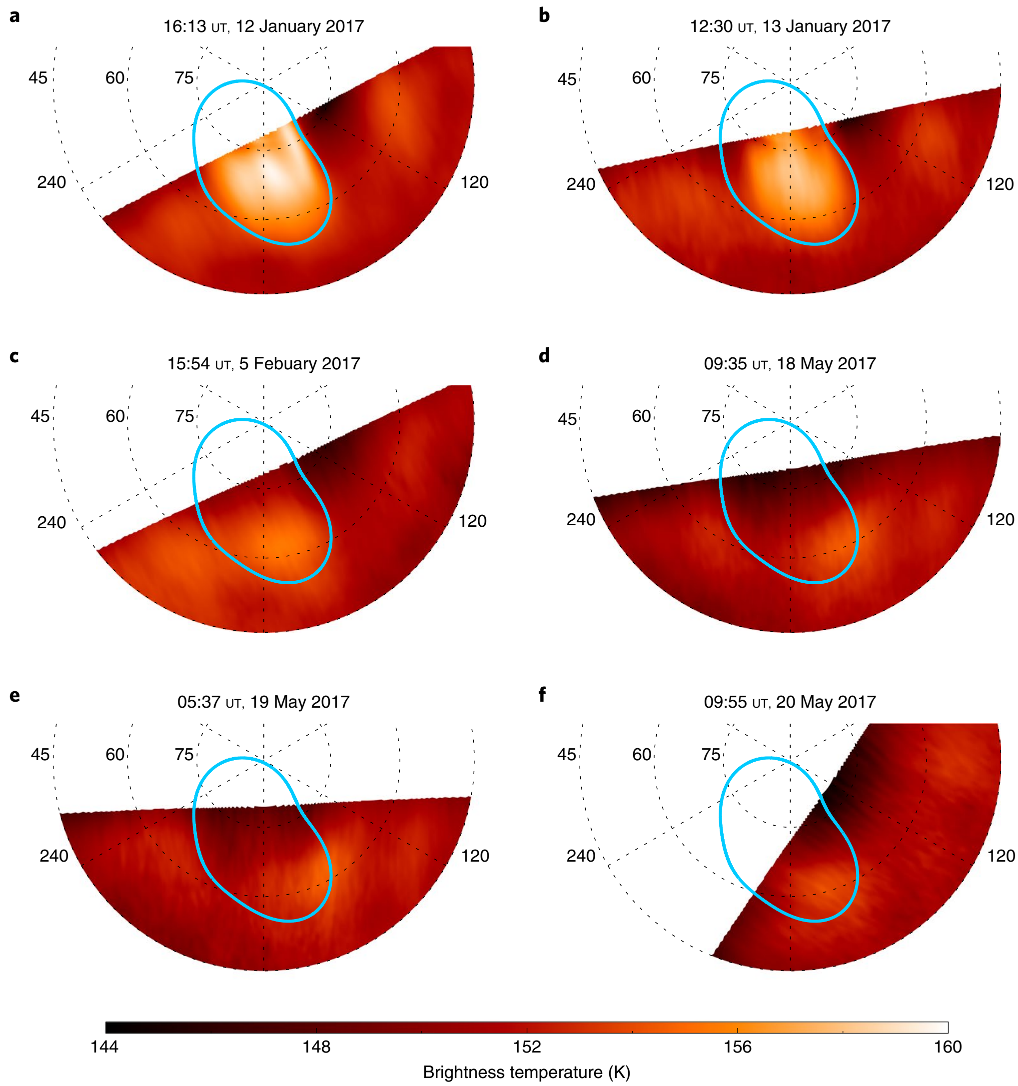

Fig. 2 | Northern polar projections of Jupiter's 7.80-µm CH_4 emission. a–f, Images were recorded by Subaru-COMICS on 12 January (**a**), 13 January (**b**), 5 February (**c**) 18 May (**d**), 19 May (**e**) and 20 May (**f**) 2017. These are a subset of the observations shown in Supplementary Fig. 1, when the NAR (centred at 180° W, system III) was fully or partially visible on the disk. The colour scale indicates the brightness temperature. Solid light-blue lines represent the statistical-mean position of the ultraviolet auroral main oval emission[8]. All latitudes and longitudes are in degrees and are planetocentric and System III, respectively.

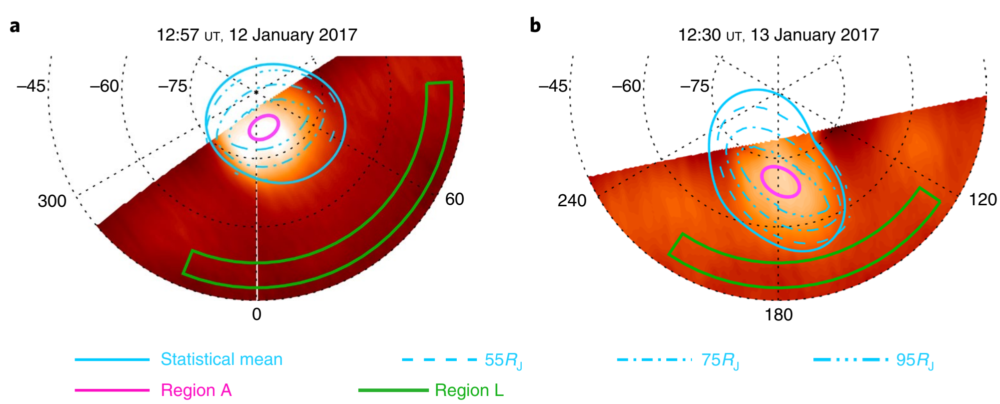

Fig. 3 | Polar projections and regions chosen for analysis. a,b, Subaru-COMICS 7.80-µm images recorded at 12:57 UT, 12 January 2017 (**a**; shown in the south) and 12:30 UT, 13 January 2017 (**b**; shown in the north), as in Figs. 1 and 2, shown again here for comparison with the ultraviolet main oval statistical mean[8] and contours that map to different distances in the magnetosphere of Jupiter, as indicated in the legend. The region enclosed within the 95R_J contour is interpreted to map to the outer magnetosphere/magnetopause. Regions A and L (enclosed within the magenta and green regions) were chosen to represent the auroral and non-auroral regions, respectively, for calculations of the relative radiance and its variability, as detailed in the Methods. All latitudes and longitudes are in degrees and are planetocentric and System III, respectively.

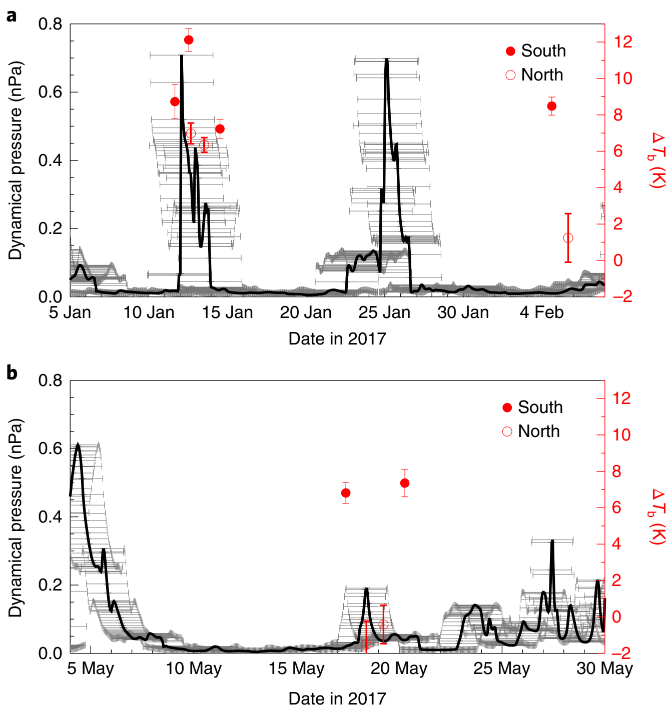

Fig. 4 | Auroral–quiescent residual over time. a,b, The residual 7.80-µm brightness temperature ΔT_b (left axis) between region A and region L, as described in the text and Methods, are shown as red circles with error bars. Results are shown for January 2017 (**a**) and May 2017 (**b**). Predicted solar-wind dynamical pressure at Jupiter (right axis; see Methods) is shown as the solid black line, with horizontal error bars showing the potential time error. The data suggest a brightening of Jupiter's southern auroral CH_4 emission in response to a solar-wind compression at approximately 22:00 UT on 11 January 2017.

The daily variability of the southern auroral CH_4 emission suggests that the source of the variability is in the upper stratosphere/mesophere to thermosphere region (10–1 µbar), where the thermal inertial timescales are much shorter (around four weeks at 1 µbar)[14] compared to the lower stratosphere (around 30 weeks at 1 mbar)[14]. We suggest that the observed changes in CH_4 emission result from: (1) variable auroral-related heating of the 10- to 1-µbar level, (2) auroral-driven changes in the vertical CH_4 profile near its homopause at roughly 1 µbar, (3) variable non-local thermodynamic equilibrium (non-LTE) effects that modify the population of energy states of CH_4 or (4) some combination of (1)–(3). To explore the first two possibilities and to determine what magnitude and type of change in the vertical temperature or CH_4 profiles could yield an increase in T_b of 3–4 K at 7.80 µm, we performed a series of radiative-transfer calculations using NEMESIS (see Methods).

As shown in Supplementary Fig. 5a,b, assuming the CH_4 abundance is held fixed, a 3-4-K change in T_b would require either: (1) the pressure level of the mesosphere–thermosphere transition to move deeper in the atmosphere by approximately a pressure-scale height or (2) the lapse rate in the thermosphere to increase by a factor of 2. The former corresponds to a total, atmospheric temperature increase of more than 100 K at the 0.5-µbar level, assuming a thermospheric lapse rate similar to that measured during Galileo's descent[15], whereas the latter corresponds to a total, atmospheric temperature increase of about 20 K at 0.5 µbar. In steady state, thermospheric general circulation models show that the mesosphere-to-thermosphere transition pressure is deeper in the auroral regions compared to the non-auroral regions[16,17]. Yates et al.[18] performed time-dependent thermospheric circulation modelling to investigate the response of the thermospheric structure and circulation to solar-wind compressions and expansion events. Between steady and compressed solar-wind conditions, the model predicted a warming of around 20 K and an increase in lapse rate near 70°N due to increased rates of joule heating at pressures lower than 1 µbar (with the lower model boundary set at 2 µbar). This is consistent with the two-fold increase of the thermospheric lapse rate required to brighten the 7.80-µm emission by 3–4 K, as detailed above.

As shown in Supplementary Fig. 5c, assuming a fixed vertical temperature profile, increasing the altitude of the CH_4 homopause (with respect to the Moses et al.[19] model A CH_4 profile) by greater than a pressure-scale height would yield a 3–4-K increase in T_b at 7.80 µm. At the 0.2-µbar level, this would correspond to an increase in the volume mixing ratio of the order of 10^{-4}. In solving the vertical continuity equation assuming that the change in volume mixing ratio is driven entirely by advection and not a chemical source (that is $w = (-\Delta X/\Delta t)/(\Delta X/\Delta z)$, where w is the vertical velocity, X is the volume mixing ratio, t is time and z is height), a change in vertical wind of 2.7 cm s^{-1} with respect to the steady state would be required. The Bougher et al. thermospheric model[16] predicts vertical winds near 70°S of approximately 50 cm s^{-1} at the 0.2-µbar level in steady state, and thus a change in vertical wind of 2.7 cm s^{-1} is reasonable. A higher-altitude homopause of CH_4 (and other hydrocarbons) in Jupiter's auroral regions was also found to optimize the consistency between Juno and Hisaki measurements[20].

Non-LTE effects are likely to be important at the altitudes where the source of variability has been inferred or could itself be the driver of the observed variability. In the absence of a strong radiation source, classical non-LTE effects become non-negligible at pressures below 0.1 mbar, where collisional timescales become longer than the spontaneous radiative lifetime[21–23]. Without a sufficient number of thermal collisions, the population of rotational and vibrational energies deviates from the translational energy population and thus can no longer be described as a Boltzmann distribution. In comparison to non-auroral regions, the upper-stratospheric heating present in Jupiter's auroral regions[7,24,25] also yields a larger contribution of photons at mid-infrared wavelengths from pressure levels where classical non-LTE processes become non-negligible. In addition, currents of electrons and ions in Jupiter's auroral regions and the resulting charged-particle collisions and dissociative recombinations may induce a non-Boltzmann population of the excited energy states of CH_4. A further process might be 'H_3^+ shine', whereby the downward flux of H_3^+ emission in lines in the 3–4 µm range 'pump' overlapping CH_4 ν_3 lines, exciting the vibrational modes and thereby modifying the population of lines responsible for the ν_4 band at approximately 7.80 µm (ref. [26]). Modelling of the aforementioned non-LTE processes will be the subject of future work.

We cannot distinguish between temperature, CH_4 abundance and non-LTE effects driving the variable CH_4 emission observed between 11 and 12 January 2017. Nevertheless, all of these processes describe a direct coupling of the neutral stratosphere in Jupiter's auroral regions to the external magnetosphere of Jupiter and solar-wind environment. Although daily variability of the northern auroral C_2H_4 and C_2H_6 emission has been observed in previous studies[27,28], we believe that the results presented here represent a substantial advance in the understanding of this phenomenon. First, the availability of solar-wind measurements and their modelled propagation to Jupiter's orbit allow the variability of the CH_4 emission to be tentatively linked to external solar-wind changes and their perturbing effect on the magnetosphere. Second, COMICS imaging at high-diffraction-limited spatial resolution allows the morphology of the CH_4 emission and its variability to be resolved at finer spatial details and mapped to the outer magnetosphere/magnetopause using ionosphere-to-magnetosphere mapping calculations. Auroral-related heating and chemistry dominate the forcing of the thermal structure and composition at Jupiter's poles[7,24,25]; our results suggest that these processes are directly connected to the external magnetosphere. This phenomenon could therefore be ubiquitous for rapidly rotating Jupiter-like exoplanets with an internal plasma source around a magnetically active star[29]. In particular, magnetohydrodynamic simulations of a hot Jupiter at a close orbital separation of 0.05 AU from its host star predict auroral powers several orders of magnitude larger than on Earth, affecting both polar and equatorial regions[30]. The coupling of the neutral stratosphere and magnetosphere of Jupiter presented here may therefore be important in the near-future characterization of Jupiter-like exoplanets from the James Webb Space Telescope and of directly imaged planets whose atmospheres are sensed predominantly at higher latitudes.

Methods

COMICS 7.8-µm images. The COMICS[31,32] instrument is mounted at the Cassegrain focus of the Subaru Telescope, which is located at the Mauna Kea Observatory (approximately 4.2 km above sea level). Subaru's 8.2-m primary aperture provides a diffraction-limited spatial resolution of approximately 0.24″ at 7.8 µm, which corresponds to a latitude–longitude footprint of approximately 2.5° × 2° at ±70° latitude. COMICS provides both imaging and spectroscopic capabilities over a spectral range of approximately 7–25 µm. Images are measured on a 320 × 240 array of Si:As blocked impurity band pixels each with a scale of 0.13″, which provides a total field of view of 42″ × 32″. Images can be measured over a number of discrete filters in both the N band (7–13 µm) and Q band (17–25 µm). We focus on images obtained in the 7.80-µm filter, which is sensitive to Jupiter's stratospheric CH_4 emission (Supplementary Fig. 3). Images were measured on 11–14 January, 4–5 February and 17–20 May 2017. Measurements were performed during periods when Jupiter was available at airmasses lower than 3. The full disk of Jupiter (with equatorial diameters of approximately 36″ in January, 39″ in February and 42″ in May) could not be measured in a single image by the COMICS field of view. In the January and February measurements, the full disk of Jupiter was measured using a 2 × 1 mosaic of individual images centred at Jupiter's mid-northern and mid-southern latitudes. In May, a 2 × 2 mosaic was conducted owing to Jupiter's larger size during this time period. For each individual image, A-frames (of Jupiter) and B-frames (dark sky 60″ north of Jupiter) were continuously recorded over a total exposure time of 20 s. Further details of the measurements presented here are provided in Supplementary Table 1.

Imaging processing, calibration and error handling. Images were processed and calibrated using the Data Reduction Manager. A − B subtraction was performed to remove telluric sky emission. The resulting images were then divided by a 'bad pixel mask' that accounts for corrupted pixels (due to cosmic ray damage, bright star saturation, manufacturer flaws, and so on) and by a flatfield to remove variations in pixel-to-pixel sensitivity across the detector. A limb-fitting procedure was used to assign latitudes, longitudes and local zenith angles to each pixel on the disk of Jupiter, using the known sub-observer latitude and longitudes at the time of each exposure. The absolute radiometric calibration of the images and correction for telluric absorption was conducted by scaling the observed lower-latitude zonal-mean brightness to those measured by Cassini's CIRS[33] instrument during the 2001 flyby. This procedure is described in greater detail in Fletcher et al.[34]. We chose this method of calibration because experience with past mid-infrared images of Jupiter and Saturn has demonstrated that the radiometric calibration using a standard star provides inconsistency between datasets obtained on different nights[34,35]. As detailed further in the Auroral–quiescent residual calculations section of Methods, our analysis of the images involved comparing the relative brightness of the auroral regions with a lower-latitude region over time, which negates errors introduced by offsets in the absolute calibration between nights. The reduced and radiometrically calibrated images are shown in Supplementary Fig. 1 in units of brightness temperature (T_b) at 7.80 µm. Portions of the image within 6 pixels (or approximately 0.8″) of the assigned limb were removed as a conservative means of removing the effects of seeing and diffraction in blurring dark sky together with emission from Jupiter. The noise-equivalent spectral radiance was calculated by finding the standard-deviation emission of dark-sky pixels more than 1.5″ (approximately 12 pixels) away from the planet. This was calculated for each image to capture changes in sensitivity due to variations in airmass and telluric atmospheric conditions between measurements. A centre-to-limb variation correction in the longitudinal direction was applied to correct for the foreshortening and limb-brightening, such that longitudes at different viewing geometries on different nights could be more readily compared. A power-law fit, of the form $\log R = a \log \mu + b$, where R is radiance, $\mu = \cos\theta$ and θ is the zenith emission angle, was performed in each latitude band to derive a centre-to-limb correction factor. For the January and February measurements, we performed the power-law correction using the image from 15:50 UT 11 January (Supplementary Fig. 1a) in the northern hemisphere and the image from 12:30 UT 13 January (Supplementary Fig. 1d) in the southern hemisphere. For the May measurements, the images from 09:40 UT 17 May and 09:35 UT 18 May (Supplementary Fig. 1i,j) were similarly chosen to perform the power-law correction in the northern and southern hemispheres, respectively. These specific images were chosen because they best capture non-auroral longitudes in each hemisphere.

Ionosphere-to-magnetosphere mapping. We adopted the ionosphere-to-magnetosphere mapping calculation by Vogt et al.[36,37] to map a location on the planet in planetocentric latitude and system III longitude to its position in radial distance and local time in the Jovian magnetosphere. The calculation is performed by imposing magnetic flux equivalence of a specified region at the equator to the area at which it maps in the ionosphere assuming a given internal field model. We adopted the VIPAL (Voyager Io Pioneer Anomaly Longitude) internal field model[38] owing to its validity in both the northern and southern hemispheres and to larger (roughly $95R_J$) radial distances. Stepping through latitude and longitude in increments of 1° polewards of ±45° latitude, the ionosphere-to-magnetosphere mapping calculation was performed to derive the local time and distance within the magnetosphere at each location. Regions enclosed within the statistical ultraviolet oval for which the calculation did not produce a real value were interpreted as mapping beyond the $95R_J$ limit of the model, which also marks the estimated position of the dayside magnetopause[9]. This calculation was used to derive the contours of distance shown in Fig. 3.

Auroral–quiescent residual calculations. Figure 3 demonstrates the areas denoted by region A and region L at high northern and high southern latitudes. Region A was chosen as a subregion of the auroral regions that mapped to the outer magnetosphere and was commonly sampled by all measurements presented in Figs. 1 and 2. Region L was chosen as a lower-latitude region away from the area of auroral influence, which is sampled at $\mu = \cos(\theta_{emm})$ (where θ_{emm} is the zenith emission angle on Jupiter) in the range $0.4 < \mu < 1$ in each image. By calculating the residual between region A and region L, any inconsistencies in the radiometric calibration from one night to the next are effectively removed, which would otherwise affect a comparison of the absolute radiance in time. The mean radiances within region A and region L were calculated. The 1σ uncertainty on the mean radiance in each region was chosen to be the larger of: (1) the noise-equivalent spectral radiance of each image (see the Imaging processing, calibration and error handling section of Methods) scaled by $1/\sqrt{n_p}$, where n_p is the number of pixels averaged, and (2) the standard deviation of the mean radiance in the region. The radiances and uncertainties were then converted to brightness-temperature units and the brightness-temperature residual and uncertainty were calculated.

Solar-wind propagation model. The Juno spacecraft continues to provide information on the magnetic and charged-particle fields while performing 53.5-day orbits inside Jupiter's magnetosphere. However, the Juno spacecraft cannot provide in situ measurements of the external solar-wind conditions outside Jupiter's magnetosphere. In the absence of such measurements, we look to modelling results. A solar-wind propagation model[39] was adopted to calculate the solar-wind dynamical pressure ($p_{dyn} = \rho v^2$, where ρ is the density and v is the velocity of the solar wind) impinging on Jupiter's magnetosphere. This model is used extensively for the magnetospheres of the outer planets[40–42] in the absence of in situ measurements of the solar-wind conditions. The model adopts hourly measurements of the solar wind and magnetic field at the nose of Earth's bow shock from OMNI[43] as input and then performs 1D magnetohydrodynamic (MHD) calculations to model the solar-wind flow out to Jupiter's bow shock. The 1D model prediction of a 3D problem can introduce uncertainties on the arrival time and magnitude of the dynamical pressure of solar-wind compressions. When the magnitude of the Earth–Sun–Jupiter angle is less than 50°, the uncertainty of the arrival time of the solar-wind shock is less than ±20 h and that of the maximum dynamic pressure is 38% (ref. [12]). Given the Earth–Sun–Jupiter angles were between 80° and 120° in during January–February 2017, we adopted a 48-h time error on the results of the solar-wind propagation model. In May 2017, the Earth–Sun–Jupiter angle was approximately 18° and thus we assumed a time error of 20 h for May 2017. These values also seem to be commensurate with a statistical comparison of 1D MHD predictions and solar-wind data measured by several spacecraft[44]. These errors are shown in Fig. 4.

Nemesis forward-model calculations. A single, broadband measurement of the CH_4 emission does not provide sufficient information to invert or retrieve atmospheric parameters and determine at what altitudes they vary. Nevertheless, we computed synthetic or forward-model spectra for a range of vertical temperature and CH_4 profiles to explore what changes in those atmospheric parameters could yield the observed 7.80-µm brightening of 3–4 K of the SAR. The NEMESIS forward model and retrieval tool[45] was adopted to compute forward-model spectra of the radiance in the COMICS 7.80-µm bandpass. Forward-model spectra were computed using the line-by-line method using the sources of line information for CH_4, CH_3D and $^{13}CH_4$, C_2H_2, C_2H_6, NH_3 and PH_3 detailed in table 4 of Fletcher et al.[46]. Calculations were performed using a square instrument function with a width of 0.04 cm^{-1} (chosen on the basis of a balance of a sufficiently high spectral resolution to resolve both weak and strong emission lines while minimizing computational expense) and subsequently convolved with the COMICS 7.80-µm bandpass and the telluric transmission spectrum (see Supplementary Fig. 2). The vertical temperature and CH_4 profiles were varied as detailed below. The remaining parameters of our model atmosphere, including the vertical C_2H_2, C_2H_4, C_2H_6, NH_3 and PH_3 profiles, were held constant because they have negligible effect on the spectrum in the 7.80-μm bandpass. Further details of the model atmosphere are provided in Sinclair et al.[24]. Note that the current NEMESIS forward model assumes LTE conditions, whereas conditions in the auroral regions may have departed from LTE, as discussed in the main text.

First, we kept the vertical CH_4 profile and its isotopologues fixed to the 'model A' vertical profile from Moses et al.[19]. Starting from the temperature profile shown in Supplementary Fig. 4a, we modified the vertical temperature profile in the range 0.1 mbar to 1 μbar, which includes the transition from the upper stratosphere/mesosphere to the thermosphere. The vertical temperature gradient (or lapse rate) in thermosphere was fixed and the pressure level of the mesosphere–thermosphere transition was varied as shown in Supplementary Fig. 5a. For each profile, a forward model was computed at the same viewing angle ($\mu = \cos(\theta_{emm}) = 0.205$) as region A in the SAR at 12:57 UT 12 January (during the solar-wind compression). The synthetic spectrum was convolved with the 7.80-μm bandpass (as detailed above) and converted to T_b. These T_b values are shown in the legend in Supplementary Fig. 5a. Further sets of forward models and brightness temperatures were similarly computed, where the pressure level of the mesosphere–thermosphere transition was fixed at 0.2 μbar and the vertical temperature gradient (or lapse rate) was varied, as shown in Supplementary Fig. 5b.

Second, we fixed the vertical temperature profile as shown in Supplementary Fig. 4a. Starting from the vertical CH_4 profile derived from model A of Moses et al.[19], the pressure level of the methane homopause was varied as shown in Supplementary Fig. 5c, and a forward-model radiance in the 7.80-μm bandpass was calculated and converted to T_b. These values are shown as the legend of Supplementary Fig. 5c.

Data availability

The COMICS images presented here are publicly available on the SMOKA (Subaru Mitaka Okayama-Kiso Archive) system (https://smoka.nao.ac.jp/). Reduced and calibrated images may be requested from J.A.S. The Data Reduction Manager is a suite of IDL software designed for reduction and processing of planetary images and is available in compressed format from G.S.O. on request (glenn.s.orton@jpl.nasa.gov). The ionosphere-to-magnetosphere mapping calculation is also written in IDL and is available from M.F.V. on request (mvogt@bu.edu). Results of the solar-wind propagation model in a specific time period may be requested from C.T. (chihiro.tao@nict.go.jp). The NEMESIS forward model and retrieval tool is written in Fortran and is available as a GitHub repository; a user account for this repository may be requested from P.G.J.I. (patrick.irwin@physics.ox.ac.uk).

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Author contributions

J.A.S. led the analysis of the observations and the preparation of this Letter. G.S.O. and Y.K. were principal investigators of the awarded telescope time. J.A.S., G.S.O., Y.K., T.M.S. and T.F. participated in the measurements at the Subaru Telescope. J.F. performed the reduction and calibration of the images. C.T. and M.F.V. provided model output for the interpretation of the results. P.G.J.I. is the lead developer of the NEMESIS code. All remaining authors contributed to the interpretation of the results and the preparation of the Letter.

Competing interests

The authors declare no competing interests.

Additional information

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