Spectral Bands And Their Applications

Lecture B of HPTE
Focus

• Major focus of Lecture B is visible, near infrared and infrared data since those are the types of data most NMHSs receive on a routine basis.

• At the end there is a section on microwave data and products as well as active sensors.
  – For in depth information concerning the microwave portion of the spectrum and its applications see the lectures in the tutorials portion of the Virtual Resource Library.
Goals

• Understand the difference between visible, near infrared and infrared radiation (channels)
  – Understand the influence of surface and atmospheric properties on what we view with a satellite sensor

• Understand the basic underlying principals behind channel selection and the factors that influence channel selection

• Understand what information can be obtained using the various satellite channels available from operational and research satellites

• Understand how to interpret data from various channels individually and in combination with other channels

• Understand the difference between multi-spectral and hyper-spectral data
Resources

• Information from Virtual Resource Library
  – Text, several tutorials and PowerPoint lectures that together cover this topic in detail
  – Links to imagery and products from the VRL as well as Sponsor and Center of Excellence sites
• Lecture notes accompanying presentation
• Hydra lab for inspection and manipulation of multispectral data
Radiance versus wavelength for blackbodies at 6000 K (sun) and 300 K (earth), notice 3.9 μm region

Today’s satellites measure energy in spectral regions ranging from the visible portion of the electromagnetic spectrum to the far infrared and into the microwave region.

At visible wavelengths, that energy is only reflected solar radiation; at far infrared wavelengths, that energy is only emitted terrestrial radiation. However for short wavelength infrared channels near 3.9 um energy measured by the satellite can be a mixture of reflected solar and earth emitted radiation during daytime.
Surface and atmospheric properties effect what we view with a satellite sensor (solar left, emitted IR right)
Today we’re digital (brought forth in Lecture A) AND MULTISPECTRAL

Each spatial element has a continuous spectrum that is used to analyze the surface and atmosphere.

224 spectral images taken simultaneously.
One advantage of digital data: Image Enhancement: Helping the eye detect Overshooting thunderstorm tops and cloud top temperature

Color bar with warm on left and cold on right
Investigating with Multi-spectral Combinations

Being digital and multispectral allows for identification of features by taking advantage of their spectral signatures.

Given the spectral response of a surface or atmospheric feature, select a part of the spectrum where the reflectance or absorption changes with wavelength.

e.g. reflection from grass and vegetation

If 0.65 μm and 0.85 μm channels see the same reflectance then surface viewed is not vegetation; if 0.85 μm sees considerably higher reflectance than 0.65 μm then surface might be vegetation.
Being digital and multispectral allows for identification of features by taking advantage of their spectral signatures. Investigating with multispectral combinations.

Given the spectral response of a surface or atmospheric feature, select a part of the spectrum where the reflectance or absorption changes with wavelength. For example, reflection from grass and vegetation.

If 0.65 μm and 0.85 μm channels see the same reflectance then surface viewed is not vegetation; if 0.85 μm sees considerably higher reflectance than 0.65 μm then surface might be vegetation.
Many satellites have channels to derive vegetation information as well as land surface characteristics. Well known are SPOT and LANDSAT. Above are shown vegetation and change maps for the area in the previous slide. To the left is a 1 km resolution vegetation map (right) and true color image (left) of the same region, taken from 12:10-12:25 UTC by Aqua’s MODIS. Note that the AVHRR and MODIS examples are not the same scale or map projection.
Investigating with Multi-spectral Infrared Combinations

Given the spectral response of a surface or atmospheric feature select a part of the spectrum where the absorption changes with wavelength

- e.g. transmission through dust cloud or volcanic ash

If 12 $\mu$m sees considerably higher BT than 11 $\mu$m then the atmosphere probably contains dust or volcanic ash; if 11 $\mu$m sees the same or higher BT than 12 $\mu$m the atmosphere viewed does not contain dust cloud or volcanic ash.
Investigating with Multi-spectral Combinations

Given the spectral response of a surface or atmospheric feature, select a part of the spectrum where the reflectance or absorption changes with wavelength.

METEOSAT movie of large dust storm over Africa

If 12 $\mu m$ sees considerably higher BT than 11 $\mu m$ then the atmosphere probably contains dust (as above) or volcanic ash; if 11 $\mu m$ sees the same or higher BT than 12 $\mu m$ the atmosphere viewed does not contain dust cloud or volcanic ash;
Spectral Information

• Now let’s look in more detail at the visible, near infrared and infrared portions of the spectrum. Our objective is to get a better understanding of their unique characteristics and how that information may be used to analyze the land, ocean and atmosphere.
The visible to near infrared portion of the spectrum
Spectral animation of a single AVIRIS scene reveals the power of being able to observe with high spectral resolution. Beginning at 400 nanometers ground features are difficult to discern, mainly due to molecular scattering which decreases at longer wavelengths. As we observe the scene at longer wavelengths, some features become distinct (land), while others become obscure (apparent decrease in smoke). Note the effect of the water vapor absorption regions on scene brightness. See also next slide.

Click on picture to start and stop animation.
AVIRIS Spectral Information from the Scene Depicting Cloud, Smoke and Active Burn Areas

AVIRIS Image - Linden CA 20-Aug-1992
224 Spectral Bands: 0.4 - 2.5 μm
Pixel: 20m x 20m  Scene: 10km x 10km

Spectral Signatures of Selected Pixels
Below, the same scene viewed with different visible to near infrared wavelength combinations.

- “true color”:
  0.646 Red, 0.547 Blue, 0.449 Green

- Non-reflective water bands:
  0.841 Red, 1.225 Blue, 1.600 Green
One might ask “why the various satellite imager channel widths and spectral locations?” The answers are complex, but basically relate back to the resolutions described earlier (Lecture A) and specifically the tradeoff between desired spectral resolutions versus the practicality of spatial resolution versus obtaining a high enough signal to noise ratio so that the instrument’s data may be used to describe the feature of interest to a desired accuracy level.
Daytime view of low cloud (water) and a thunderstorm anvil (ice) in different MODIS reflective channels
Color Combinations Aid in Cloud Type Interpretation
Now for a look at the reflection from the 1.38 micron MODIS channel in the center of a water vapor absorption region.
**Ocean Color: As illustrated by SeaWifs**

- **Instrument Bands**
  - 402-422 nm
  - 433-453 nm
  - 480-500 nm
  - 500-520 nm
  - 545-565 nm
  - 660-680 nm
  - 745-785 nm
  - 845-885 nm

- **Mission Characteristics**
  - Sun Synchronous Orbit 705 km
  - Equator Crossing 12:20 PM descending
  - Orbital Period 99 minutes
  - Swath Width 2,801 km
  - Spatial Resolution 1.1 km
  - Revisit Time 1 day
  - Digitization 10 bits
Ocean color product from MODIS showing the abundance of chlorophyll a across part of the Pacific Ocean.
MODIS estimation of aerosol optical thickness

Kaufman et al.
Daytime multispectral METEOSAT-8 image of large dust storm over Africa. This is made using a combination of images from the 0.6, 0.8 and 1.6 micron channels. Click on the image to view animation.
Earth emitted spectra overlaid on Planck function envelopes

High resolution atmospheric absorption spectrum and comparative blackbody curves.
Earth emitted spectra overlaid on Planck function envelopes

High resolution atmospheric absorption spectrum and comparative blackbody curves.

The special area in the vicinity of 3 and 4 microns
3.7 - 3.9 um Channel Imagery Applications

- Night-time Fog, Stratus & Cirrus
- Super-cooled Clouds
- Fog, Ice & Water Clouds Over Snow
- Winter Storms
- Land- and Sea-surface Temperatures
- Thin Cirrus & Multi-layered Clouds
- Urban Heat "Islands"
- Fire Detection
- Sun Glint
- Cumulus Bands at Night
- Convective Cloud Phases
- Volcanic Ash Cloud Monitoring
A close-up view around 3.9 mm, with radiance at 100%, 50% and 20% for the 6000 K source

The special area between 3 and 4 microns
Spectral Awareness, cloud phase and non-linear aspects of thermal response

Scattering from water versus ice particles at 3.9 microns

Response of 3.9 vs. 10.7 microns to Temperature variability in a FOV
Spectral Awareness, surface characteristics
Display and analysis of imagery at short 3.9 microns. Visible loop (left) and 3.9 micron reflective component loop (right) from GOES-West (aspect ratio not 1:1). Click on images to start and stop animations.
Top left: 10.7 enhanced infrared
Top right: 3.9 enhanced infrared
Bottom: fog product for same time
These are nighttime images. White is water cloud and black is ice cloud

B: water cloud with cloud top temperature (CTT) between -12 and -15°C
C: water cloud over ocean with CTT between 5 and 0°C
A: fog or stratus with CTT of 4°C
On the left is an example of the difference in temperature measured at 3.9 and 10.7 microns for a partially filled field of view (FOV) for nighttime when there is no solar reflection. In this example, the hot-area is at 500 K and the remainder of the pixel is at 300 K.
Geostationary fire coverage at frequent intervals
Pixels with fires within the field of view are red
Fires detected on October 8, 1997, using AVHRR over Borneo, and aerosols over region in mid-October 1996 versus mid-October 1997.
Fires detected by MODIS over Africa (left) and NDVI (right)
Earth emitted spectra overlaid on Planck function envelopes

High resolution atmospheric absorption spectrum and comparative blackbody curves.

The strong water vapor absorption region
High Spectral Resolution (AIRS) resolves H$_2$O Spectral Features (right). Click image to animate. This animation immediately illustrates the advantage for many applications of very high spectral resolution versus broad channels.

GOES-I/M era sounder H$_2$O Channels (above)
GOES-9 6.7 micron infrared (water vapor channel) movie loop: a broadband channel that extends from 6.47 to 7.02 microns

With GOES-12 the broadband water vapor channel spectral range was increased to span the interval 5.8 to 7.3 microns
Earth emitted spectra overlaid on Planck function envelopes

High resolution atmospheric absorption spectrum and comparative blackbody curves.

The infrared window regions and ozone absorption area
AVHRR Sea surface Temperature product produced by CoastWatch. This picture is over the Atlantic Ocean off of the East Coast of the United States. Notice the strong temperature gradient across the boundary of the Gulf Stream and warm eddies that have broken off and migrated into the colder waters.
AVHRR Sea Surface temperature Anomalies (Deg. C)
November 1996 vs November 1997
Figure 27: Thunderstorm tops over Europe from MSG on 29 July 2005 at 14:30 UTC. This case, presented by Martin Sevtak at the EUMETSAT Users’ Conference showed higher reflection from ice in the plume at thunderstorm top in 1.6 and 3.9 microns, likely due to smaller cloud particle size and related to updraft characteristics. Cold overshooting top and “V” notches are clearly shown in the 10.7 channel image, as are the plume brighter reflection from the right-most storm.
Clouds separate into classes when multispectral radiance information is viewed.

These three scatter plots illustrate how different types of clouds, snow and clear ground have different spectral signatures when plotted against 11 μm brightness temperature.
Cloud Composition

Image Over Kansas - 21 April 1996

Contrails

Ice Cloud

Contrails

Water Cloud

Infrared Temperature Difference - 8.6 μm (Band 29) - 11.0 μm (Band 31)

Infrared Temperature Difference - 11.0 μm (Band 31) - 12.0 μm (Band 32)
Visible is upper left; enhanced 10.7 micron infrared is upper right; reflective portion of 3.9 micron channel is lower left; enhanced 6.7 micron infrared water vapor is lower right.
Spectral Awareness, surface characteristics

[Graph showing emissivity as a function of wavelength for different surfaces like tree leaf, red clay, dry sand, and water.]
METEOSAT-8 (MSG) detection of large dust storm over Africa using visible to near IR (right) and IR (left) channel combinations

False color images from MSG channels. Left: 12.0-10.8 (R), 10.8-8.7 (G), 10.7 (B). Right: 1.6 (R), 0.8 (G), 0.6 (B). Click on either image to view animation.
Today’s satellites have many channels from which information may be obtained.
Products based on mathematical analysis of multi-channel images – we can do now with MODIS and MSG!
Earth emitted spectra overlaid on Planck function envelopes

High resolution atmospheric absorption spectrum and comparative blackbody curves.

The longwave CO$_2$ absorption region
The red curve shows the thermal terrestrial spectrum between 4 µm and 15 µm in terms of brightness temperatures at the top of the atmosphere calculated for a standard mid-latitude summer atmosphere and nadir view. The blue curves depict the relative spectral response functions of the GOES I-M series sounder instrument.
Detection of Temperature Inversions Possible with Hyperspectral IR

Detection of inversions is critical for severe weather forecasting. Combined with improved low-level moisture depiction, key ingredients for night-time severe storm development can be monitored.
The microwave portion of the spectrum

Earth’s microwave spectrum at the top of the atmosphere.
<table>
<thead>
<tr>
<th>Frequencies</th>
<th>Microwave Processes</th>
<th>Potential Uses</th>
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<tbody>
<tr>
<td>AMSU</td>
<td>SSM/I</td>
<td></td>
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<tr>
<td>31, 50, 89 GHz</td>
<td>19, 37, 85 GHz</td>
<td>• Large land vs. water emissivity contrast</td>
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<td></td>
<td></td>
<td>• Variable land emissivity</td>
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<td>• Variable ocean emissivity</td>
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<td>- smooth vs. rough</td>
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<td>- ice vs. water</td>
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<td>• Scattering by snow and ice</td>
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<td>• Land/water boundaries</td>
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<td>• Land surface temperature</td>
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<td>• Soil moisture/wetness</td>
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<td>• Surface vegetation</td>
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<td>• Ocean surface wind speed</td>
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<td>• Sea ice cover</td>
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### Precipitation – Cloud Water and Ice
(Key Interactions and Potential Uses)

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<td>• Absorption and emission by cloud water:</td>
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<td>50 GHz</td>
<td>37 GHz</td>
<td>• Large drops/high water content</td>
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<tr>
<td>89 GHz</td>
<td>85 GHz</td>
<td>• Medium drops/moderate water content</td>
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<td></td>
<td></td>
<td>• Small drops/low water content</td>
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<tr>
<td>89 GHz</td>
<td>85 GHz</td>
<td>• Scattering by cloud ice</td>
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<td></td>
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<td>• Oceanic cloud water and rainfall</td>
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<tr>
<td></td>
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<td>• Non-raining clouds over ocean</td>
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<td></td>
<td></td>
<td>• Land and ocean rainfall</td>
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</table>
Clicking on the movie will start or stop animation. Notice how well the tpw product depicts the ITCZ as well as shows the interaction between tropical and mid-latitude systems. (larger version on next slide)
Clicking on the product to the right will start or stop animation sequence. Notice how well the tpw product depicts the ITCZ as well as shows the interaction between tropical and mid-latitude systems.

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<td>Oceanic precipitable water</td>
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Active sensors

- Active sensors from research satellites are used to measure various sea surface properties (altimetry, wind speed and direction, ice field characteristics as well as ice berg tracking). They are also used to measure rainfall over water or land. Many of those products are available for use by NMHS'.
Altimetry

Right: Sea level anomaly over Gulf of Mexico from satellite altimetry.

To the left are maps of sea level anomaly over the equatorial Pacific showing the increase in sea level off the west Coast of South America accompanying the onset of el Nino.
Example of global wind coverage from QuikSCAT for April 1 2005. The time 20:58 UTC in the top legend indicates the most current pass in the product.
SAR Wind Speed Product

Oct 25, 1999
16:37 GMT
SAR Iceberg Tracking and monitoring of ice shelf edge and sea ice
"Three vertical cross-sections through storms on March 10, 1998"

TRMM radar cross sections, from NASA/GSFC web site.
The “A Train” formation with equator crossing times. In the formation, the satellites nominally all trace out the same ground track. Click on the bottom right to see an animation of clouds made from the formation of Terra, SAC-C and LandSat-7 (an total interval of about 40 minutes from first to last).
Active Doppler wind lidar for determination of atmospheric winds (also aerosols). Flies in a dawn/dusk orbit.
The figure at the left is From Collard and Healy (2003) showing the anticipated accuracy when GPS and hyperspectral sounding data are combined. Notice that by utilizing the two together that the answer is better than either separately.
This concludes Lecture B

• More information on spectral bands and their applications may be found by accessing the Virtual Resource Library (VRL). If you do not have a CD that contains the VRL information, using Internet go to the WMO web site and access the WMO Satellite Program to link to the Virtual Laboratory.