Curso Intensivo sobre Asimilación de Datos

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Remote Sensing: Introduction

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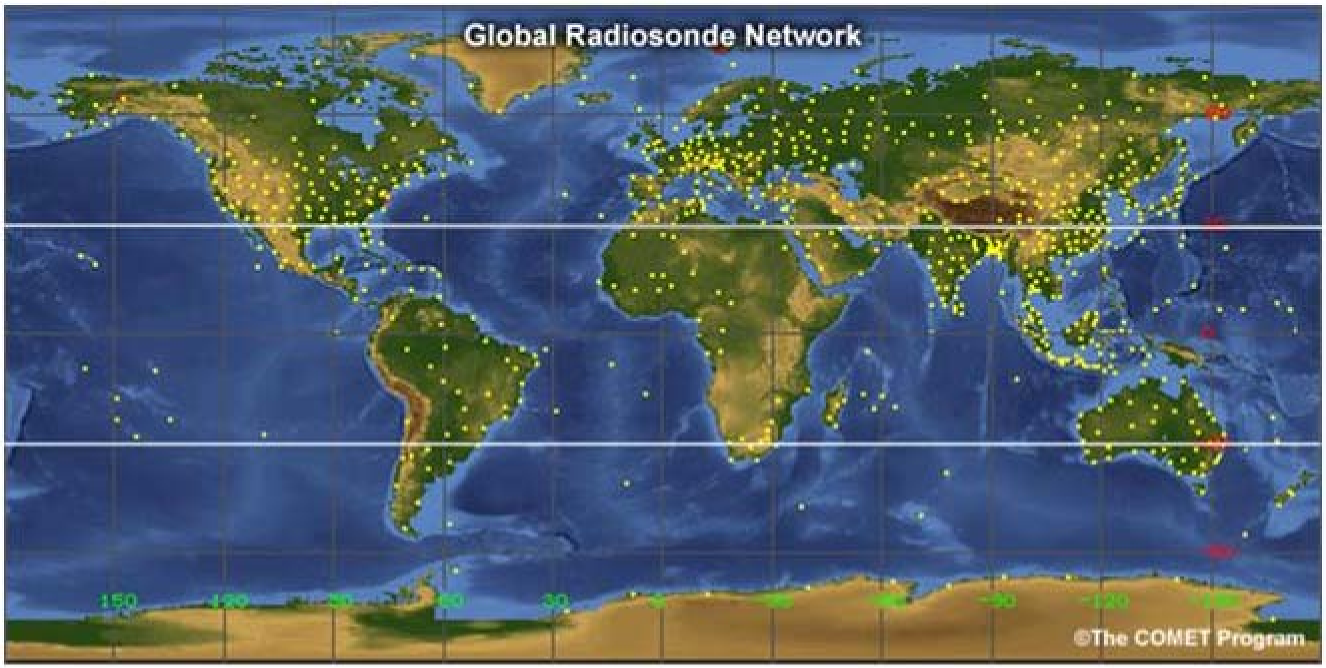
Why Remote Sensing?

Satellite remote sensing is an important complementary tool for observing Earth's atmosphere and land and ocean surfaces, especially where in-situ observations are scarce or nonexistent.

Global Radiosonde Network



Launch location of weather ballons (Radiosonde)
– Note the low density over ocean

Importance of Satellite Observations

✓ Atmospheric temperature and moisture soundings provide critical information for forecasting weather and monitoring climate and climate change.

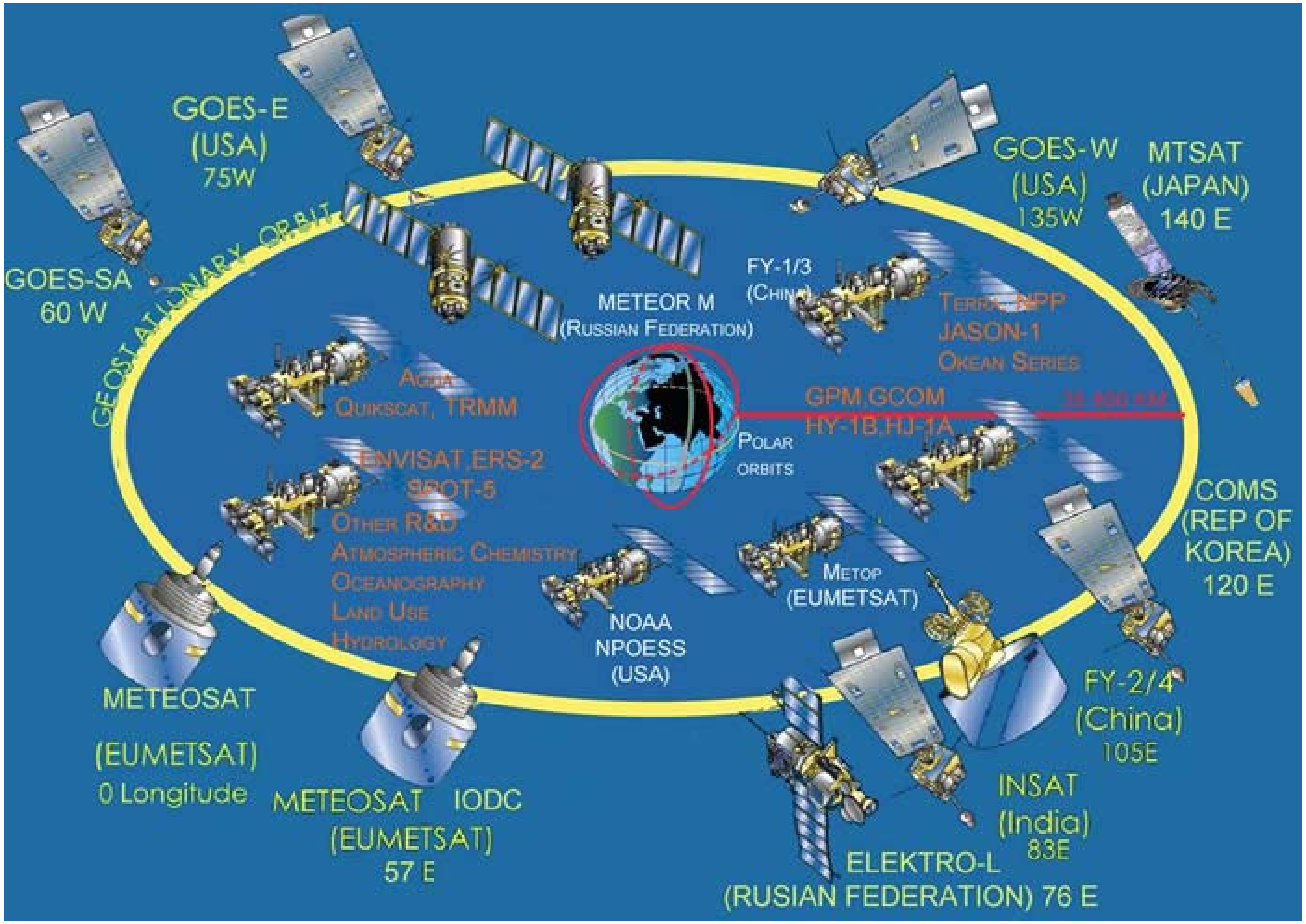
✓ Before satellites, weather balloons were the primary source of atmospheric sounding information (vertical profiles of the atmosphere)

✓ First satellite to provide soundings was Nimbus III, 1969

✓ Satellite instruments technology has improved significantly over the past decade:

- Hyperspectral IR observation for improved soundings
- Altimetry for deriving ocean height
- Scatterometry for ocean wind vectors
- L-Band microwave for soil moisture and ocean salinity

The space-based Global Observing System (GOS)



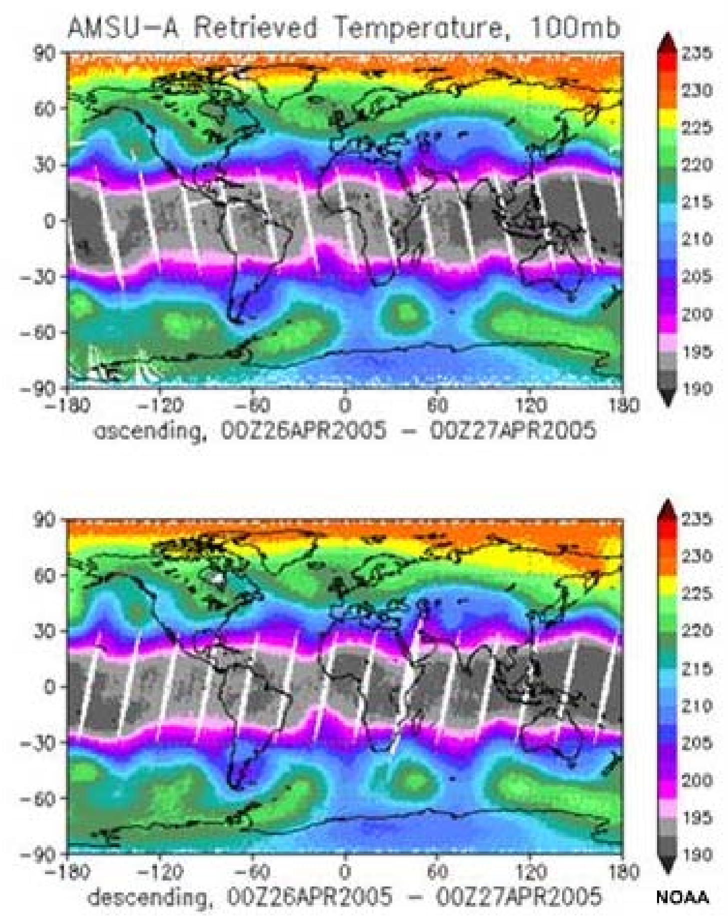
The satellite programme of each individual satellite agency participating in the GOS contribute to a globally optimized and robust observation system.

Operational Geoesatationary (Geo) satellites
Operational Low Earth Orbit (LEO) satellites
Environmental Research and Development Research (R&D) satellites

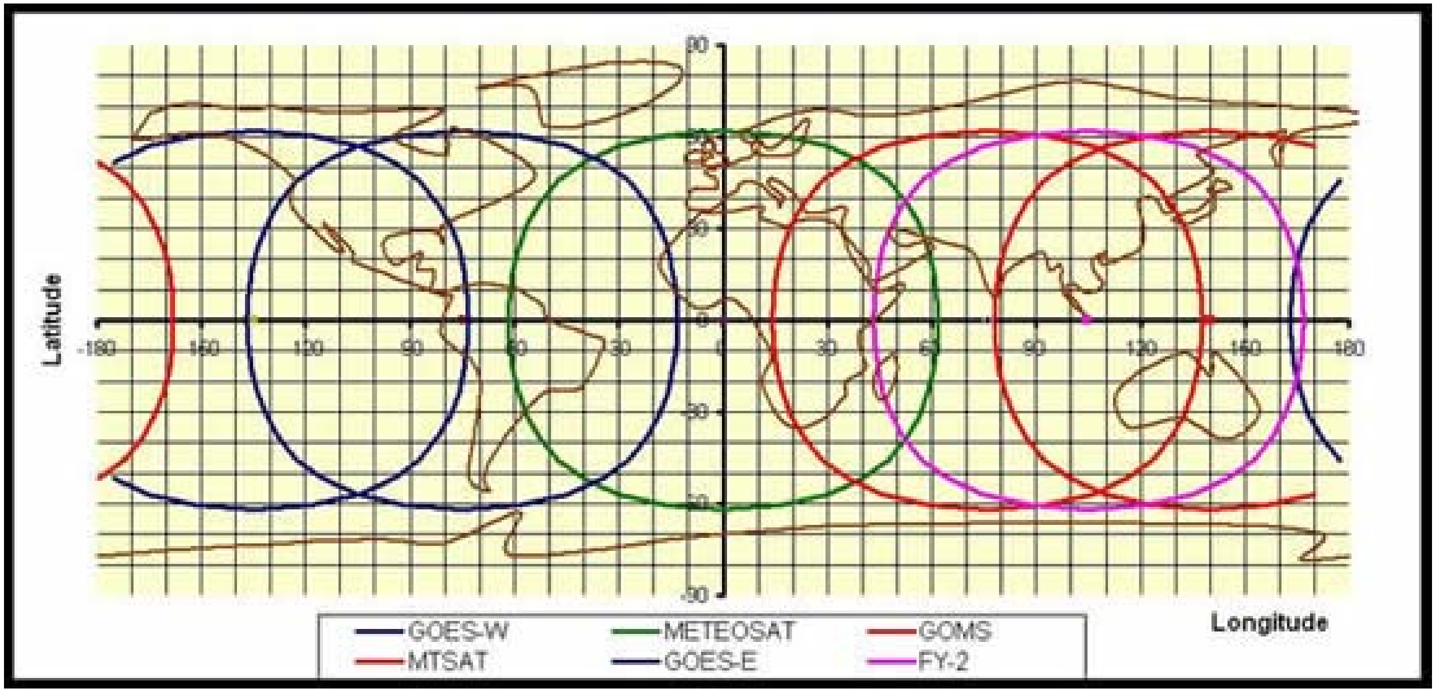
http://www.wmo.ch/pages/prog/sat/Satellites.html

Global Coverage from a Single Satellite in Polar Orbit

- Nearly complete global coverage from satellite data
- Temporal refresh range from 12 hours near the Equator and 1 – 2 hours near the poles



Global nominal planning for operational geostationary satellites



- **The nominal constellation of operational geostationary satellites includes 6 spacecraft to ensure full coverage from 50°S to 50°N with a zenith angle lower than 70°.**

Satellite Products

- **Atmosphere**
  - Temperature soundings
  - Moisture soundings
  - Winds
  - Clouds
  - Aerosols
  - Earth radiation budget
  - Precipitation
  - Ozone

- **Ocean**
  - Surface temperatures
  - Ice cover
  - Surface winds
  - Color
  - Sea level

- **Land**
  - Vegetation conditions
  - Snow pack characteristics (albedo, skin temperature, soil wetness, etc.)
  - Fire locations/Smoke Plumes

Remote Sensing Principles

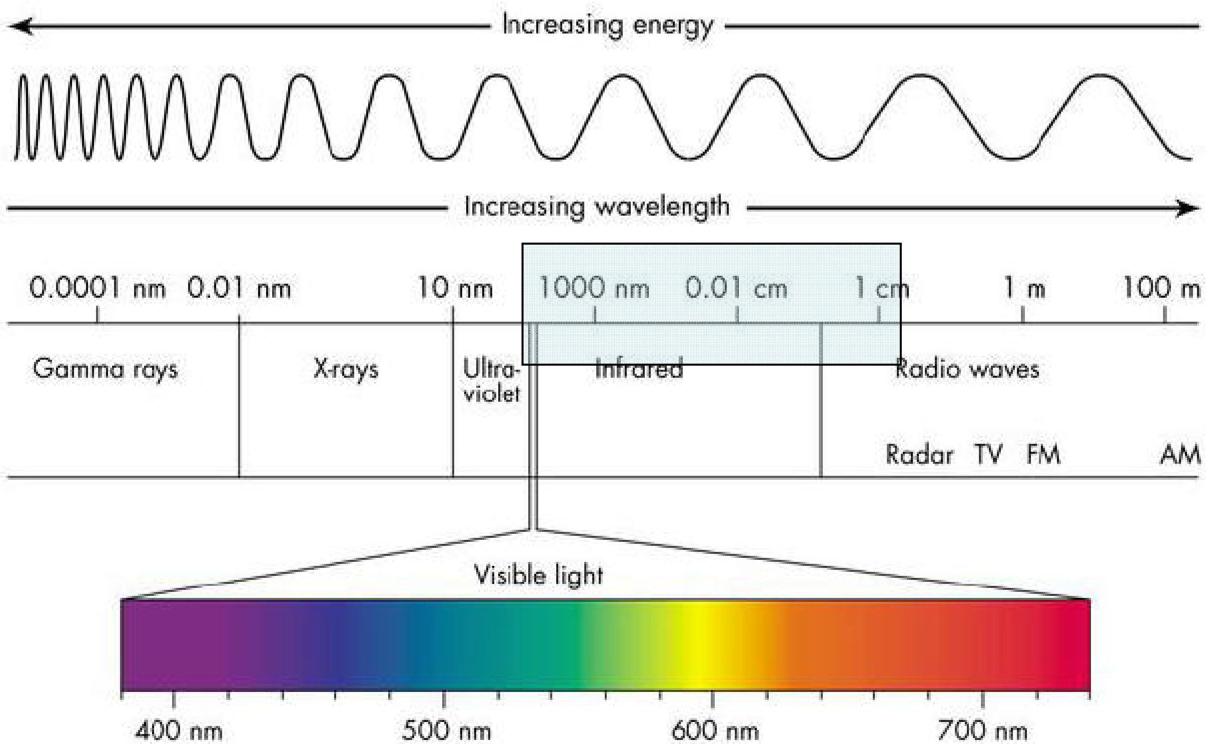
- **The term "*remote sensing*" describe the science and art of identifying, observing, and measuring a system without coming into direct contact with it.**

- **This process involves the *detection* and *measurement* of *radiation* at various *wavelengths* of the *electromagnetic spectrum.***

- ***Radiation* can be *reflected* or *emitted* from distant objects or materials, by which they may be *identified* and *categorized* by *class/type*, *substance*, and *spatial distribution*.**

http://earthobservatory.nasa.gov/Library/RemoteSensing/

Electromagnetic Spectrum



- **The entire array of electromagnetic waves comprises the electromagnetic (EM) spectrum.**

Radiation 1/2

- Unless it has a temperature of absolute zero (-273°C) an object ***reflects***, ***absorbs***, and ***emits*** energy in a unique way, and at all times.

- This energy, called ***electromagnetic radiation***, is emitted in ***waves*** that are able to transmit energy from one place to another.

- These waves originate from ***billions of vibrating electrons, atoms***, and ***molecules***, which ***emit*** and ***absorb*** electromagnetic radiation ***in unique combinations of wavelengths.***

.

- ***The amount of electromagnetic radiation an object emits depends primarily on its temperature.*** The higher the temperature of an object, the faster its electrons vibrate and the shorter its peak wavelength of emitted radiation

Radiation 2/2

The fundamental unit of electromagnetic phenomena is the quantum, the smallest possible amount of electromagnetic energy of a particular wavelength.

Quantum, move in the vacuum at the speed of light, ($c = 2{,}99793 \times 10^8\ ms^{-1}$) in the form of waves and very close to it in a real medium.

The energy of a quantum determines the frequency (and wavelength) **of radiant energy that is associated with it.**

The greater the energy of the quantum, the greater the frequency of radiant energy and vice versa.

$$\boxed{\Delta E = h\upsilon}$$

$$\boxed{c = \lambda\upsilon}$$

$$\boxed{\Delta E = hc/\lambda = hc\kappa}$$

h (Planck const.) = 6.626×10^{-34} Js

Wave Number $\kappa = 1/\lambda$

Radiative interactions

Radiation can interact with atmospheric gases in five ways:

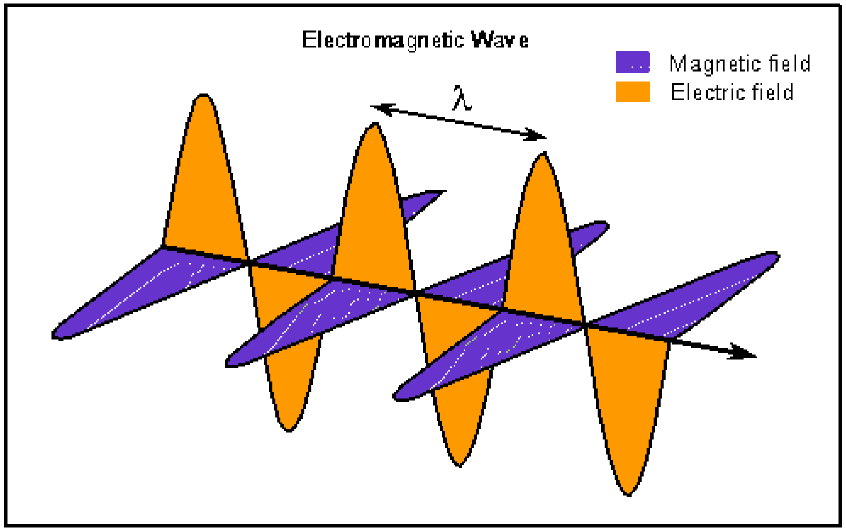
1. Ionization-dissociation interactions
2. Electronic transitions
3. Vibrational transitions
4. Rotacional transitions and
5. Forbidden transitions

Vibrational transitions occur mostly in the IR

Rotacional transitions occur in the far IR and microwave

and both can occur simultaneously

Electromagnetic Waves



The waves are called electromagnetic because they consist of combined electric and magnetic waves that result when a charged particle (electron) accelerates.

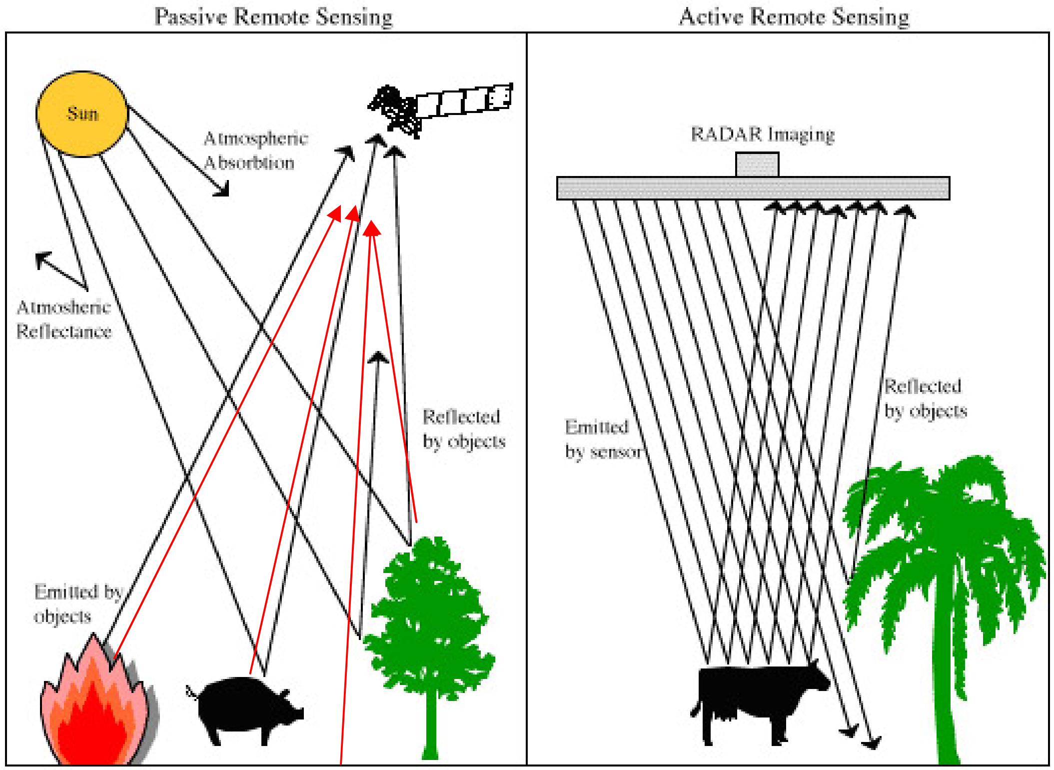
Remote sensing of the atmosphere

- The **basic principle associated with remote sensing of the atmospheric temperature and humidity structure** involves the **interpretation of radiometric measurements of electromagnetic radiation in specific spectral intervals** which are sensitive to some physical aspects of the medium.

- More specifically, at any wavenumber (or wavelength) in the infrared or microwave regions where an atmospheric constituent absorbs radiation, it also emits thermal radiation according to Kirchhoff's Law.

- **Since the radiance leaving the atmosphere is a function of the distribution of the emitting gases and of temperature throughout the atmosphere, measurements of radiance contain some information on both these quantities.**

Remote Sensing Methods

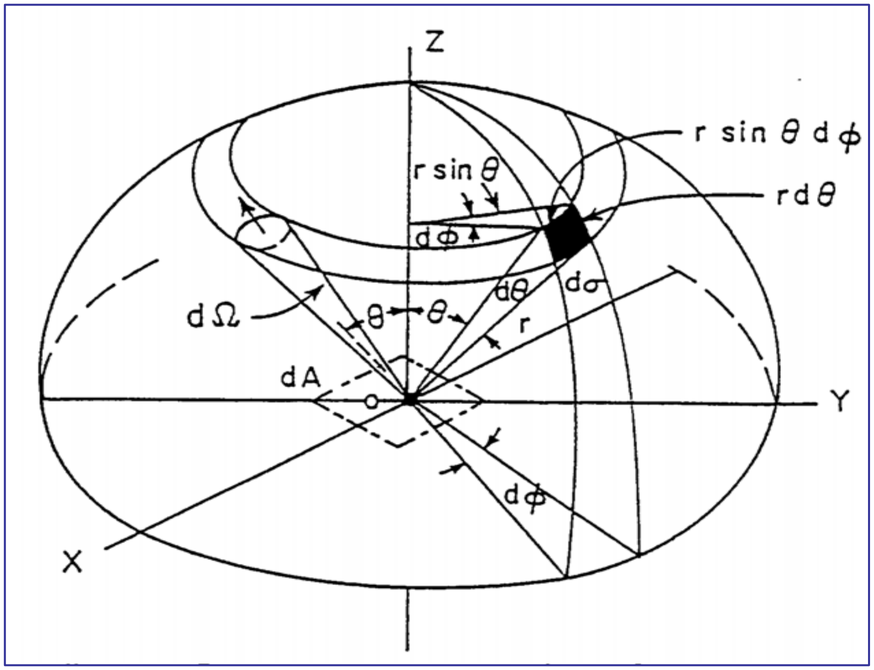


- **Passive instruments** detect natural energy that is **reflected** or **emitted** from the observed scene.

- **Active instruments** provide their own energy (electromagnetic radiation) to illuminate the object or scene they observe. They send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object.

Monochromatic radiance

The most **fundamental radiation unit for satellite meteorology** is the **monochromatic radiance.**

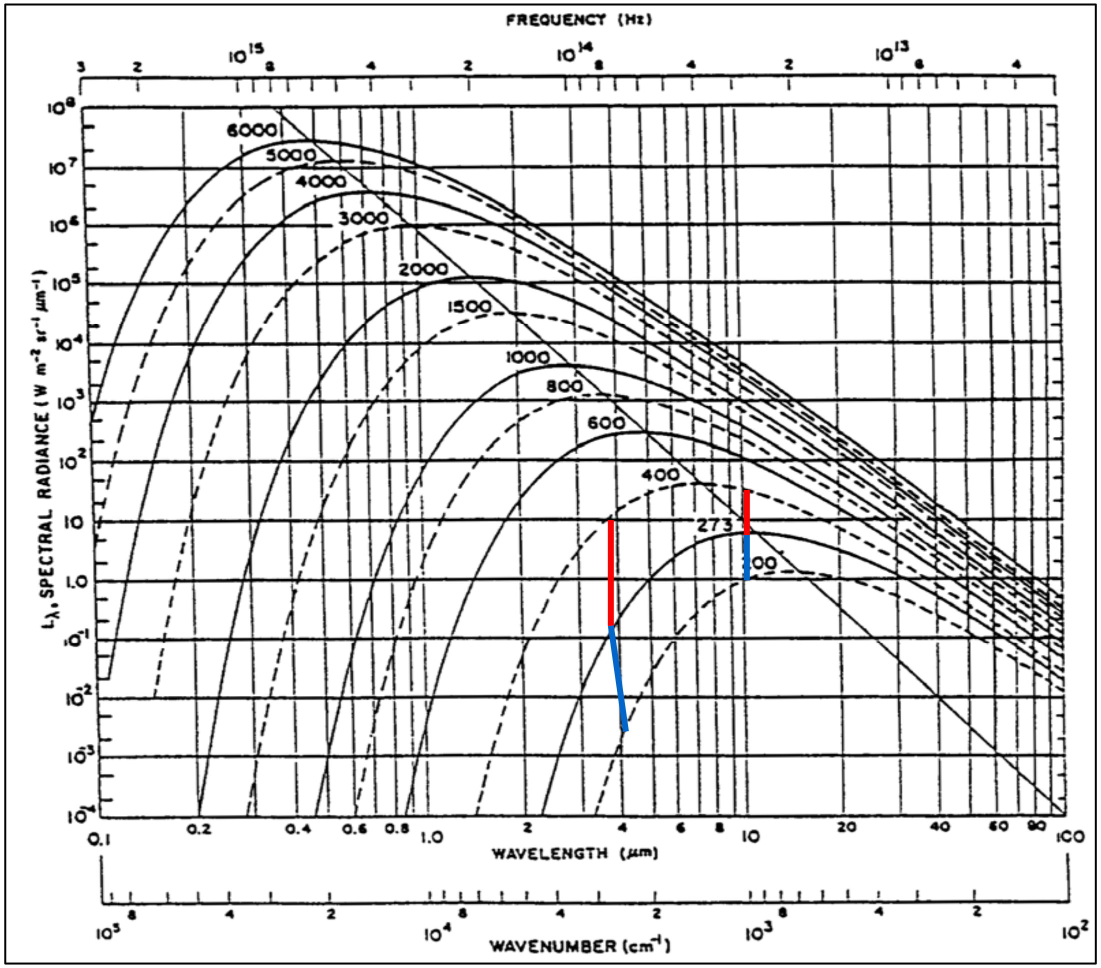


$$L_\lambda = \frac{\delta E_\lambda}{\cos\theta \, dA \, dt \, d\Omega \, d\lambda} \quad (1)$$

[Watt sr^{-1} m^{-2} μm^{-1}]

Radiance is the amount of energy crossing, in a time interval *dt,* and in the wavelength interval $d\lambda$, in a differential area *dA,* at an angle θ, to the normal to *dA,* confined to a solid angle $d\Omega$

Blackbody Radiation 1/2



The Planck Function

$$B_\lambda(T) = \frac{2hc^2}{exp(\frac{hc}{\lambda kT}) - 1}\lambda^{-5} \quad (2)$$

$$B_\lambda(T) = \frac{c_1}{exp(\frac{c_2}{\lambda T}) - 1}\lambda^{-5} \quad (3)$$

Wien Law

$$\lambda_m = \frac{2897.9\,\mu mK}{T} \quad (4)$$

K = Boltzman constant = 1.380658 x 10^{-23} J K^{-1}

c_1= 1.1910439 x 10^{-16} W m^2 sr^{-1},
c_2= 1.438769 x 10^{-2} m K.

Blackbody Radiation 2/2

- **Raleigh - Jeans approx.**

$$B_\lambda(T) = \frac{c_1}{c_2}\lambda^{-4}T \qquad (5)$$

It is good for Earth-atmosphere T, and λ (mm – cm)

- **Black Body Monochromatic Exitance**

$$M_{BB\lambda} = \pi B_\lambda(T) \qquad (6)$$

- **Black Body Total Exitance**

$$M_{BB} = \sigma T^4 \qquad (7)$$

σ: cte. de *Stefan-Boltzmann* = 5.67051 x 10-3 W m^{-2} K^{-4}

Nonblackbodies

- Emittance $$\varepsilon_\lambda = \left(\frac{emited\ radiation(\lambda)}{M_{BB}} \right)$$ (8)

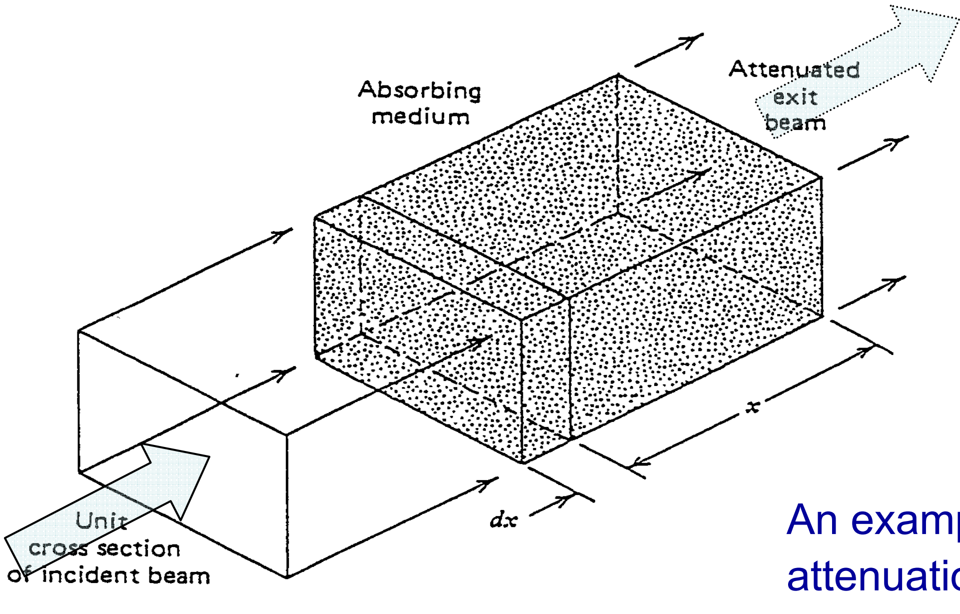
- Absorptance $$\alpha_\lambda = \frac{absorbed\ \ radiation\ \ (\lambda)}{incident\ \ radiation\ \ (\lambda)}$$ (9a)

- Reflectance $$\rho_\lambda = \frac{reflected\ radiation\ (\lambda)}{incident\ radiation\ (\lambda)}$$ (9b)

- Transmittance $$\tau_\lambda = \frac{transmitted\ radiation\ (\lambda)}{incident\ radiation\ (\lambda)}$$ (9c)

Kirchhof´s Law ⇨ $$\alpha_\lambda = \varepsilon_\lambda$$ (10)

Absortion and Transmission of Monocromathic Radiation



$$dL_\lambda / dx = -\sigma_a(\lambda) L_\lambda = -\rho\beta_a(\lambda) L_\lambda \quad (11)$$

σ_a = volume absorption coefficient
ρ = density of the medium at x
β_a = mass absorption coefficient

$$L_\lambda = L_\lambda(0)\exp(-\int_0^x \rho\,\beta_a(\lambda)\,dx) \quad (12)$$

An example of the use of Eq. (11) is the modeling of attenuation of a beam due to atmospheric constituents.

- **Optical depth**

$$\delta_\lambda = \int_0^x \rho\,\beta_a(\lambda)\,dx \quad (13)$$

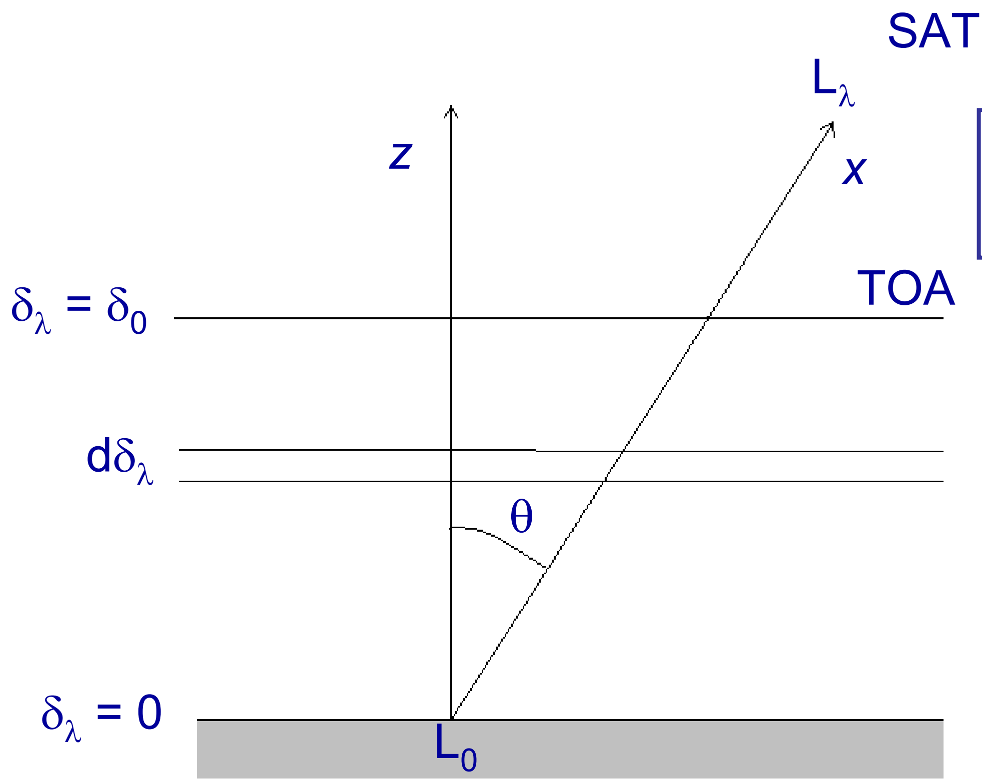
- Transmittance

$$\iota_\lambda(x,0) = \frac{L_\lambda(x)}{L_\lambda(0)} = \exp(-\int_0^x \rho\,\beta_a(\lambda)\,dx \quad (14)$$

- The transmittance, τ_λ, is a function of the distribution of the temperature and the mixing ratio of the absorbing gas with eight.

The Equation for Radiative Transfer 1/5

The Equation of energy transfer, for monochromatic radiation, upwelling through a thin atmospheric layer on its way to satellite, in which emission as well as absorption takes place, but not scattering, is expressed by:



$$\frac{dL_\lambda}{dx} = -\rho\,\beta_a(\lambda)L_\lambda(\theta,\phi) + \rho\,\beta_a(\lambda)B_\lambda(T) \quad (14)$$

L_λ: radiance reaching the satellite

L_0: radiance leaving the surface

- **Optical depth**

$$\delta_\lambda(x) = \int_0^x \rho\,\beta_a(\lambda)\,dx = \int_0^z \rho\,\beta_a(\lambda)\,dz/\cos\theta = \int_0^z \rho\,\beta_a(\lambda)\,\frac{dz}{\mu} \quad (15)$$

The Equation for Radiative Transfer 2/5

The radiative transfer equation becomes:

$$\mu \frac{dL_\lambda}{d\delta_\lambda} = -L_\lambda(\theta,\phi) + B_\lambda(T) \qquad (16)$$

which is known as ***Schwarzchild´s* equation**

The infrared (IR) radiance observed by a satellite (in the absence of scattering) can be calculated integrating *Schwarzchild´s* equation from the Earth´s surface (δ_λ.= 0) to the satellite ($\delta_\lambda = \delta_0$):

$$L_\lambda = L_0 \exp\left(-\frac{\delta_0}{\mu}\right) + \int_0^{\delta_0} \exp\left(-\frac{(\delta_0 - \delta_\lambda)}{\mu}\right) B_\lambda(T) \frac{d\delta_\lambda}{\mu} \qquad (17)$$

This equation forms the basis for sounding the atmosphere and for corrections necessary for surface parameter estimation.

The Equation for Radiative Transfer 3/5

Portion of surface radiance reaching the satellite

Contribution of the atmosphere

$$L_\lambda = L_0 \exp\left(-\frac{\delta_0}{\mu}\right) + \int_0^{\delta_0} \exp\left(-\frac{(\delta_0 - \delta_\lambda)}{\mu}\right) B_\lambda(T) \frac{d\delta_\lambda}{\mu}$$

Radiance leaving surface

Transmittance of the entire atmosphere

$$\exp\left(-\frac{\delta_0}{\mu}\right) = \tau_{\lambda 0}^{\frac{1}{\mu}}$$

Transmittance of the atmosphere between δ_λ and the satellite

$$\exp\left(-\frac{(\delta_0 - \delta_\lambda)}{\mu}\right) = \tau_{\lambda}^{\frac{1}{\mu}}$$

The product

$$\exp\left(-\frac{(\delta_0 - \delta_\lambda)}{\mu}\right) B_\lambda(T) \frac{d\delta_\lambda}{\mu}$$

Is the portion of the radiance emitted by the layer which reaches the satellite

The Equation for Radiative Transfer 3/5

$$L_\lambda = L_0 \exp\left(-\frac{\delta_0}{\mu}\right) + \int_0^{\delta_0} \exp\left(-\frac{(\delta_0 - \delta_\lambda)}{\mu}\right) B_\lambda(T) \frac{d\delta_\lambda}{\mu} \quad (17)$$

$$L_\lambda = L_0 \tau_{0\lambda}^{\frac{1}{\mu}} + \int_0^{\delta_0} \tau_\lambda^{\frac{1}{\mu}} B_\lambda(T) \frac{d\delta_\lambda}{\mu} \quad (18)$$

- Weighting function

$$\tau_\lambda^{\frac{1}{\mu}} \frac{d\delta_\lambda}{\mu} = \frac{d\tau_\lambda^{\frac{1}{\mu}}}{d\delta_\lambda} = W_\lambda(\delta_\lambda, \mu) \quad (19)$$

$$L_\lambda = L_0 \tau_{0\lambda}^{\frac{1}{\mu}} + \int_0^{\delta_0} W_\lambda(\delta_\lambda, \mu) B_\lambda(T) \frac{d\delta_\lambda}{\mu} \quad (20)$$

The Equation for Radiative Transfer 4/5

The contribution from the lower radiating surface (either land or sea) can be expressed as:

$$L_0 = \varepsilon_{s\lambda} B_\lambda(T_s) \qquad (21)$$

$\varepsilon_{s\lambda}$ is its emissivity, T_s is the *skin temperature* (the temperature of the ground itself)*;* so that finally

$$L_\lambda = \varepsilon_{s\lambda} B_\lambda(T_s)\tau_{0\lambda}^{\frac{1}{\mu}} + \int_0^{\delta_0} W_\lambda(\delta_\lambda, \mu) B_\lambda(T) \frac{d\delta_\lambda}{\mu} \qquad (22)$$

The contribution of each layer of the atmosphere, which optical depth is δ_λ centered at δ, to the integrated upward radiance L_λ emerging to space, is hence expressed by a blackbody contribution weighted according to W.

The layers for which W attains largest values are the ones who contribute most to the integral value at the top.

Equation (22) can also be expressed using *z*, *pressure*, *lnp*, or any function which is monotonic in height, as vertical coordinate

The Equation for Radiative Transfer 5/5

Water reflects as much as 60% of the **microwave radiation** incident on it.

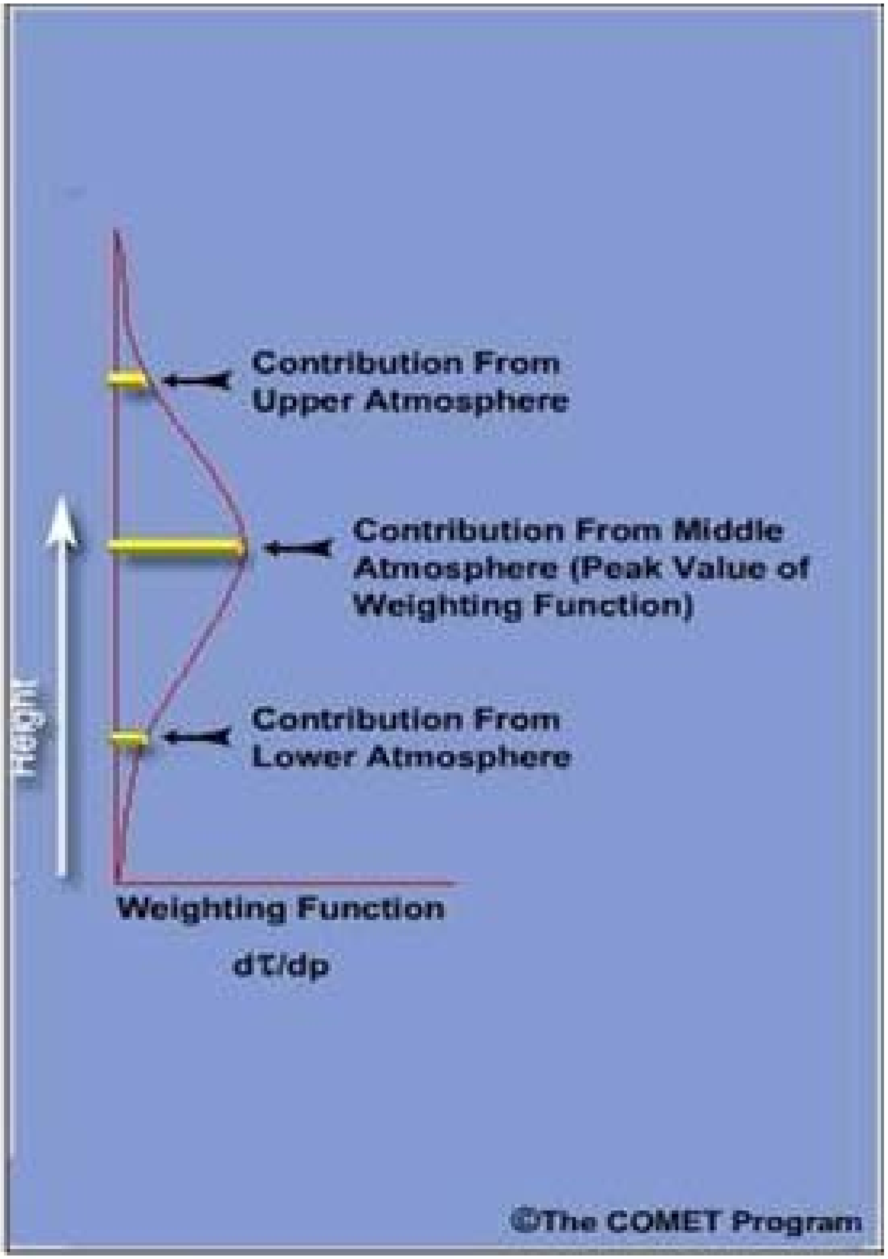
Then, the surface radiance L_0, is given by two terms,

1. the radiation emitted by the surface and
2. the reflected sky radiance:

$$L_0 = \varepsilon_{s\lambda} B_\lambda (T_s) + (1 - \varepsilon_{s\lambda}) L_{sky} \qquad (23)$$

In the microwave region of the spectrum, the weighting function must be modified for soundings made over water.

Weighting Functions

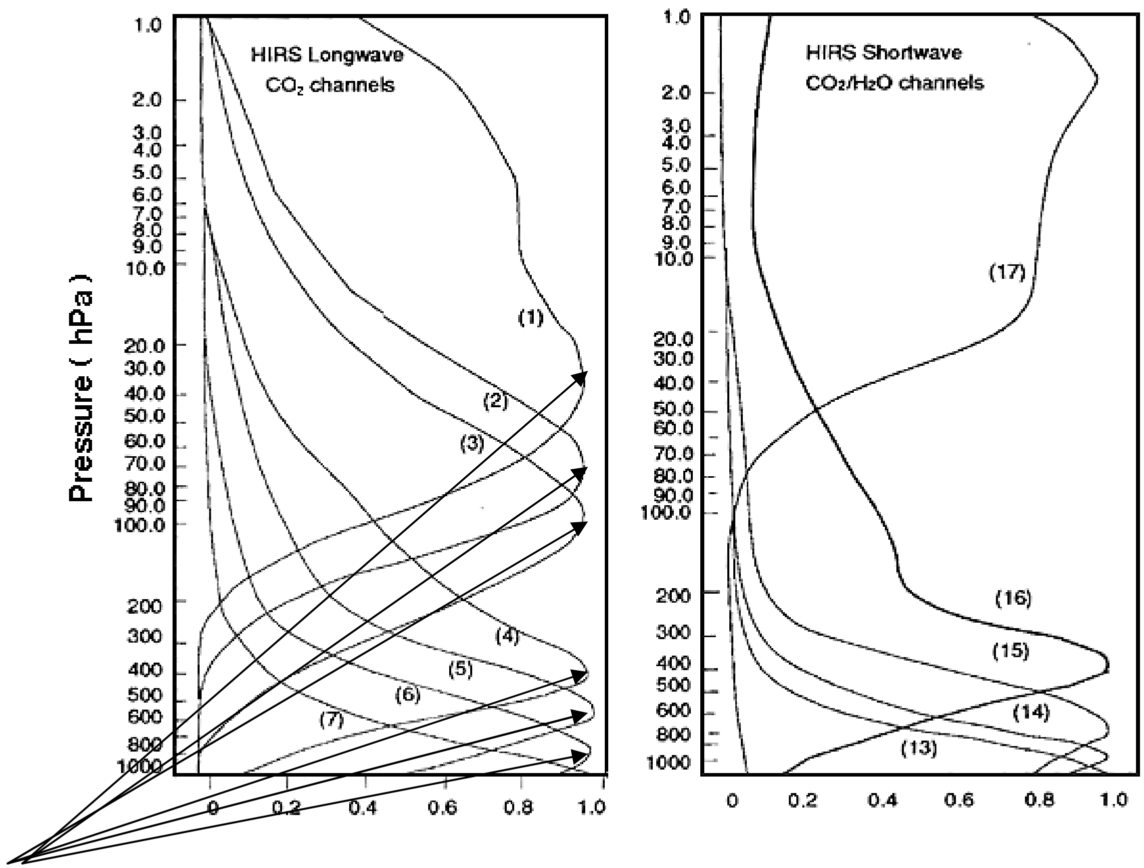


$$W_{\lambda}(p) = \left(\frac{d\tau_{\lambda}(p)}{dp} \right)$$

Many overlapping weighting functions are necessary to derive a temperature profile with high vertical resolution

Weighting Functions

Example of normalized weighting functions for the High Resolution Infrared Sounder (HIRS) on NOAA satellites.



- Each function indicates the relative contribution of the atmosphere from a given level to the radiance observed at the satellite through the numbered channel.
- A **narrower** weighting function means information comes from a **thinner** slice of the atmosphere.

The direct and inverse problems

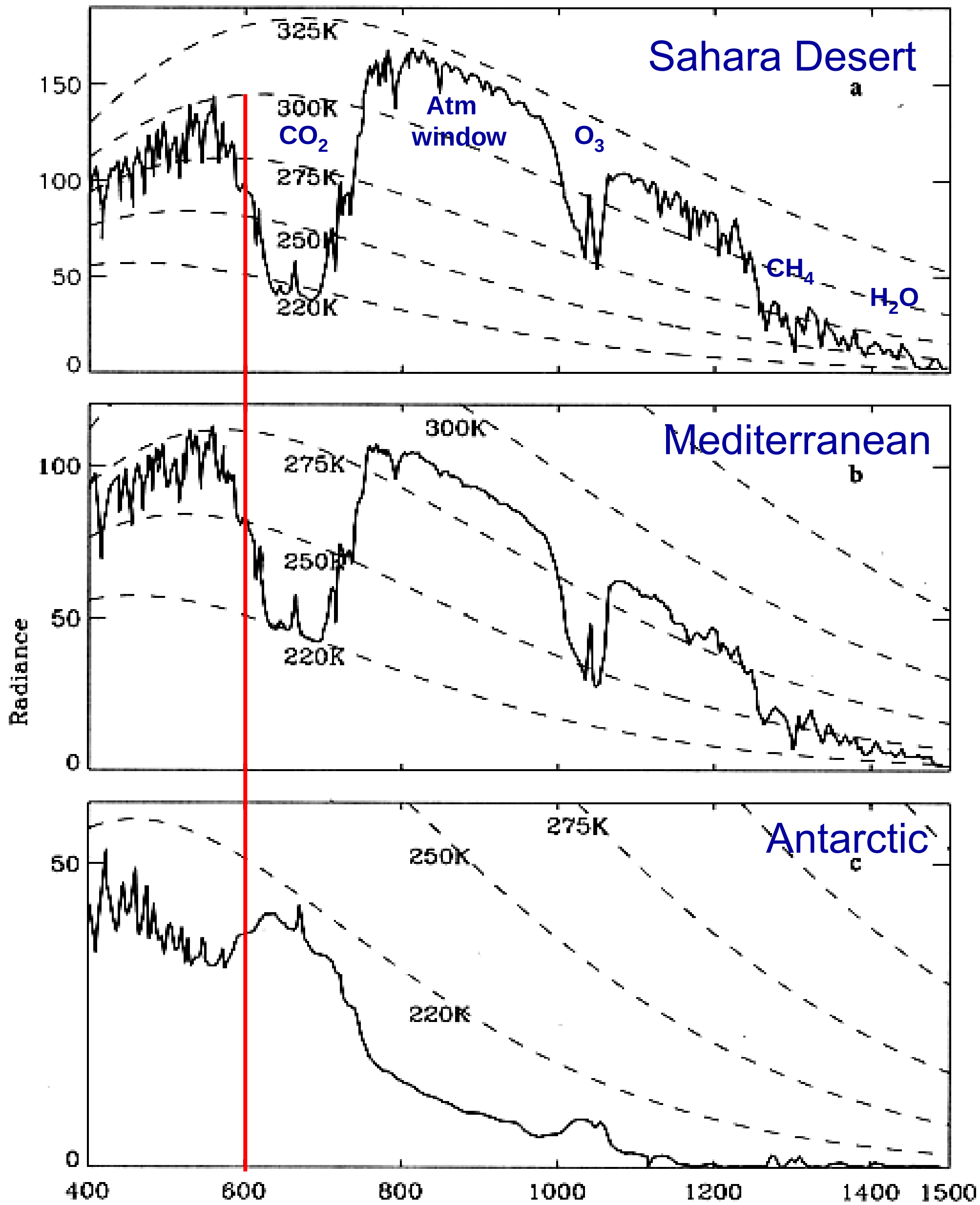
The instrument makes measurements of radiance in a number of channels.

For each channel, we can write a radiative transfer equation.

This equation expresses the DIRECT PROBLEM for the channel, i.e. given the state of the atmosphere, the solution of this equation tells us the radiance incident at the satellite in this channel.

However, when presented with **satellite measurements**, we are faced with the INVERSE PROBLEM: given the measurements (L_λ), what is the state of the atmosphere (in terms of its vertical profiles of temperature and constituents).

Spectral Distribution of Radiance Leaving the Atmosphere



- Emission spectra of the earth and atmosphere as measured from NIMBUS-4 InfraRed Interferometer Spectrometer (IRIS) from about 7 to 20 µm.
- Radiance units in milliWatts /m_2 cm^{-1} sr.
- Planck function curves for various blackbody temperatures are shown as dashed lines.
- **The spectral range shown covers an important domain used for atmospheric sounding purposes**:

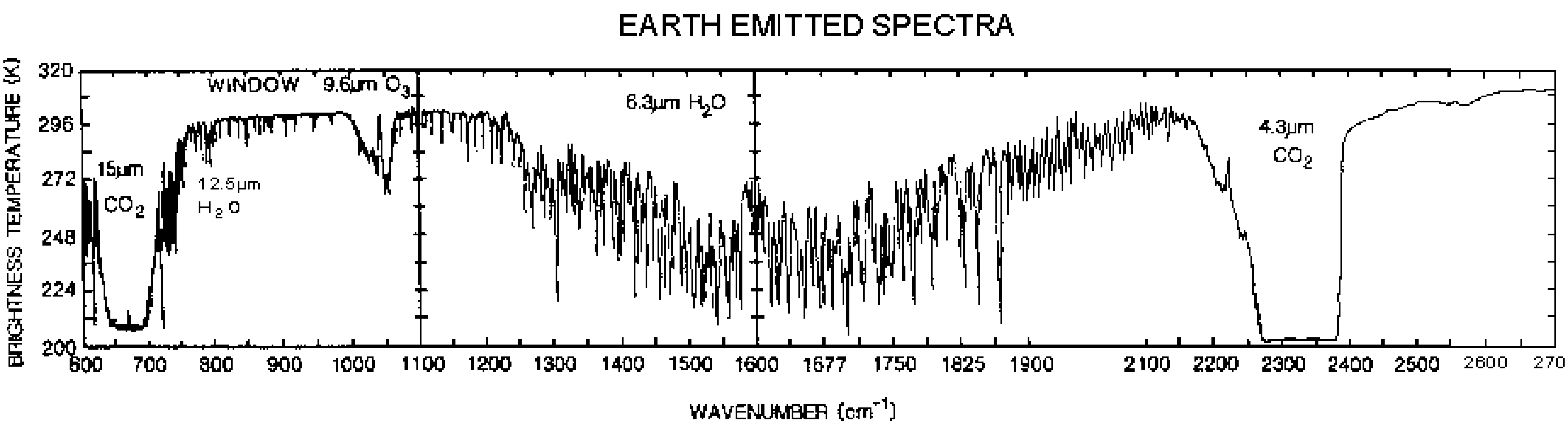
  - the CO_2 absorption band centered at 672 cm^{-1} (15 mm),

  - the window region from 1050 to 770 cm^{-1} (about 9.5 to 13 mm), and

  - the ozone absorption band around 1040 cm^{-1} (9.6 mm).

Atmospheric Sounders

- Measure upwelling thermal radiance in a number of spectral channels
- Most channels are in opaque spectral regions that do not see the surface
- Provide information about atmospheric temperature and constituent profiles
- Channels are characterized by central wavenumber (κ) and band pass $\Delta\kappa$
- Fields of view (FOV's) are roughly 15 km at nadir
- IR and microwave sounders are complementary and often fly together



High Spectral Resolution IR Sounding from Space

AIRS, IASI, soon followed by CrIS

AIRS (Atmospheric Infrared Sounder)

IASI (Infrared Atmospheric Sounding Interferometer)

CrIS (Cross-track Infrared Sounder)

Advantages of High Spectral Resolution

- High spectral resolution means absorption features due to single lines can be observed
- Many channels are observed
- Allows for selectivity of channels to be used
- Best channels are primarily sensitive to absorption by a single species
  - "Fixed" gases - CO_2, N_2O - for temperature sounding
  - H_2O, O_3, CH_4, CO for constituent profiles
  - Window (relatively transparent) channels for surface parameters
- Best channels are usually in line wings or on line centers
  - Channels in line wings have sharp W(p)
  - Channels on line centers are most sensitive to trace gas absorption
  - Channels with redundant information can be used together to reduce noise

Recent and Scheduled Future IR Sounders

HIRS2	1979 – present TIROS N NOAA 18 NOAA LEO IR sounder accompanied by MSU/AMSU 19 channel IR radiometer 667 cm^{-1} - 2750 cm^{-1} (15 μm - 3.6 μm) Spectral resolution $\Delta\kappa$ from 10 cm^{-1} - 25 cm^{-1} Spatial resolution ≈ 15 km at nadir from 824 km orbit
AIRS	Launched on Eos Aqua in May 2002 2360 channel grating detector array spectrometer 650 cm^{-1} - 2665 cm^{-1} Spectral resolution $\Delta\kappa$ from 0.5 cm^{-1} - 2.2 cm^{-1} Spatial resolution ≈ 13 km at nadir from 705 km orbit
IASI	Launched on Metop 2 in October 2006 8461 channel interferometer 645 cm^{-1} - 2760 cm^{-1} Spectral resolution $\Delta\kappa = 0.5$ cm^{-1} Spatial resolution ≈ 12 km at nadir - not contiguous
CrIS	Scheduled to fly on NPP and NPOESS Interferometer - similar spectral characteristics to AIRS

IR and Microwave Observations are Very Complementary

IR Strengths

- Best vertical resolution (accuracy) of T(p) in mid-lower troposphere
- Water vapor profile information up to the tropopause
- Best information about surface skin temperature
- Trace gas profile information

IR Limitations

- Most channel observations are strongly affected by clouds

MW Strengths

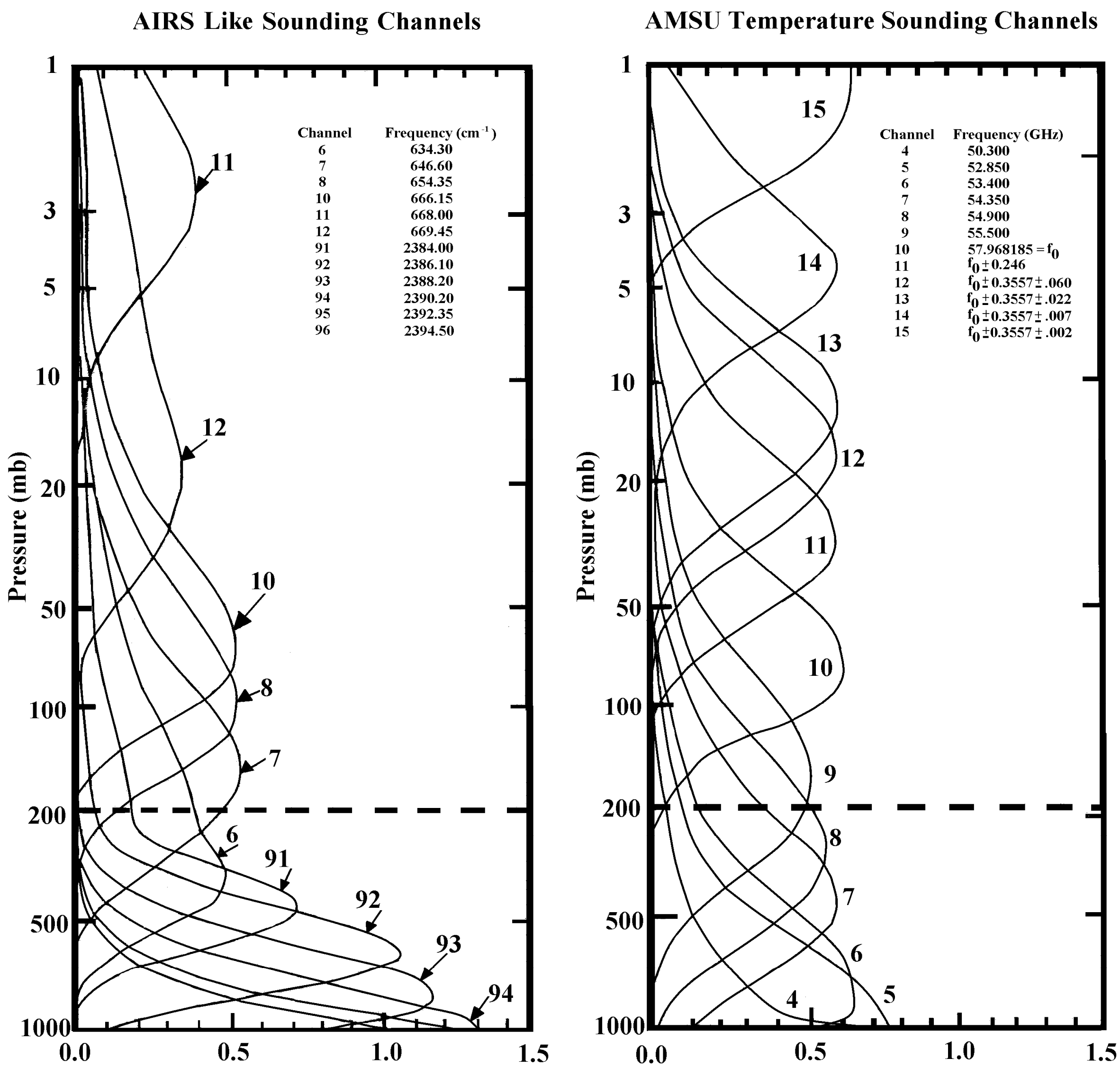
- MW observations are not affected by most clouds
- MW observations help in accounting for effects of clouds on IR observations
- Microwave soundings of T(p), q(p) can be produced in overcast conditions

MW Limitations

- Channels sensitive to lower troposphere are highly affected by variable surface emissivity

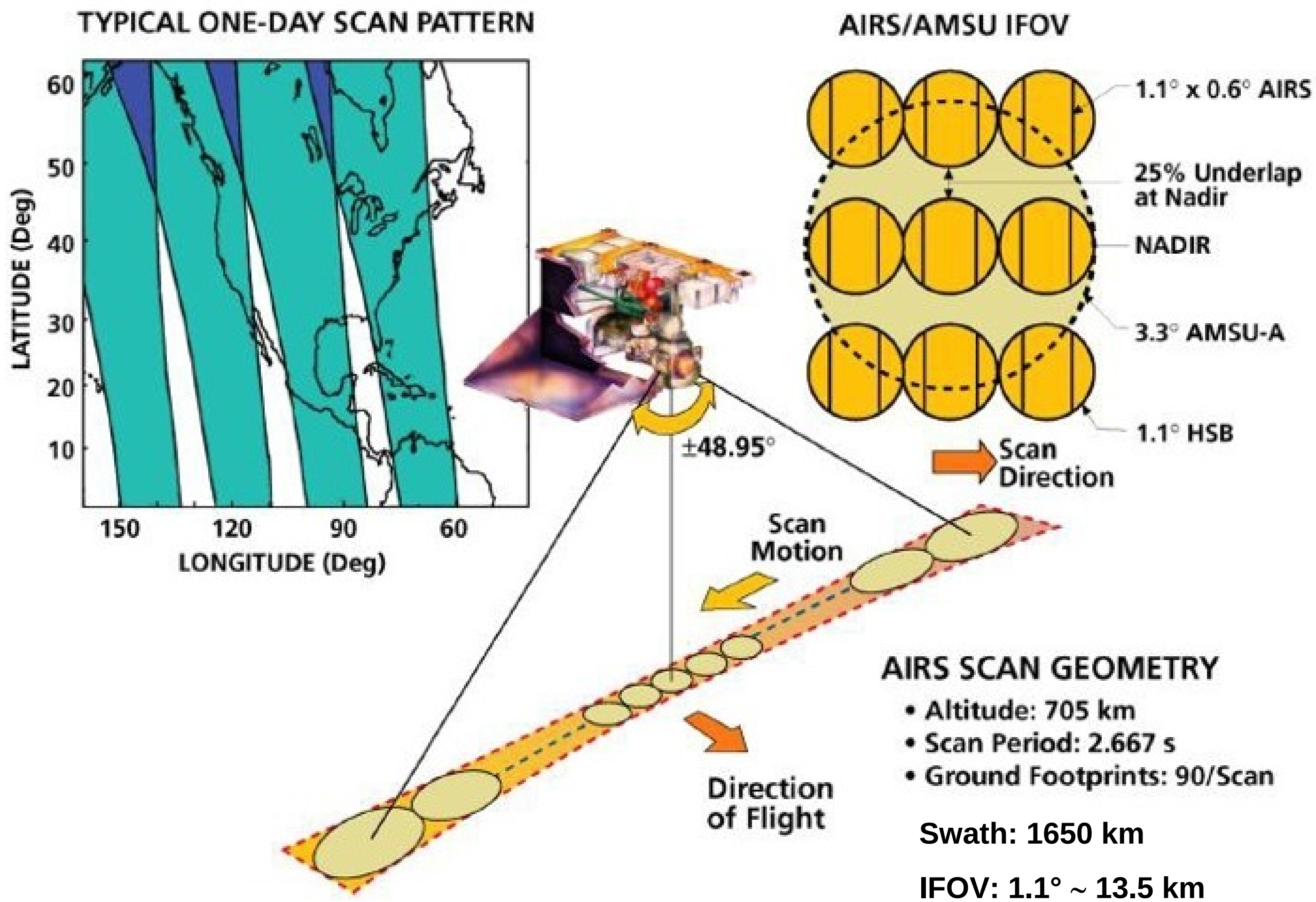
IR and Microwave Observations are Very Complementary

TEMPERATURE WEIGHTING FUNCTIONS



AIRS

▪ Scan Characteristics



Swath: 1650 km

IFOV: 1.1° ~ 13.5 km

http://airs.jpl.nasa.gov/technology/how_AIRS_works/

AIRS general characteristics

- AIRS is a high spectral resolution spectrometer with 2378 bands in the thermal infrared (3.7 - 15.4 μm) and 4 bands in the visible (0.4 - 1.0 μm).
- These ranges have been specifically selected to allow determination in the troposphere of:

  - atmospheric temperature with an accuracy of 1°C in layers 1 km thick,

  - humidity with an accuracy of 20% in layers 2 km thick

.

In the cross-track direction, a ±49.5 degree swath centered on the nadir.

- Each scan line contains 90 IR footprints, with a resolution of

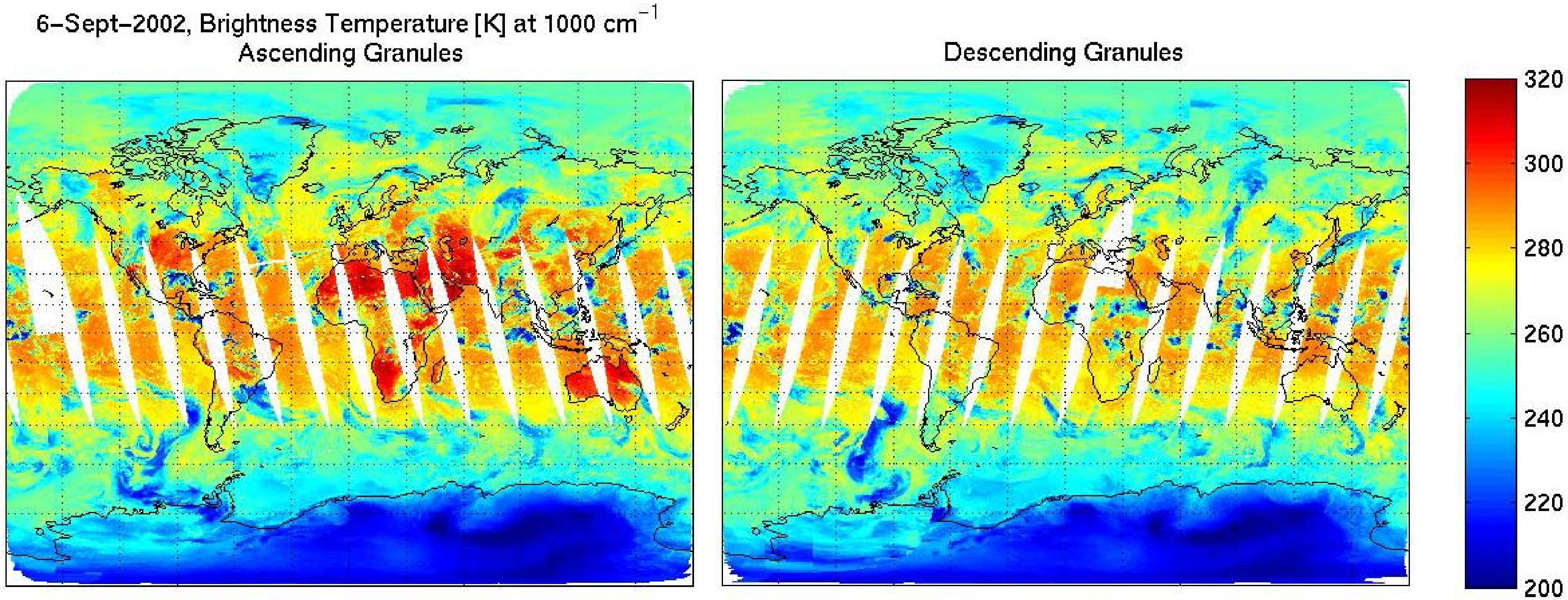
  - 13.5 km at nadir and

  - 41km x 21.4 km at the scan extremes

from nominal 705.3 km orbit.

- The Vis/NIR spatial resolution is approximately 2.3 km at nadir.

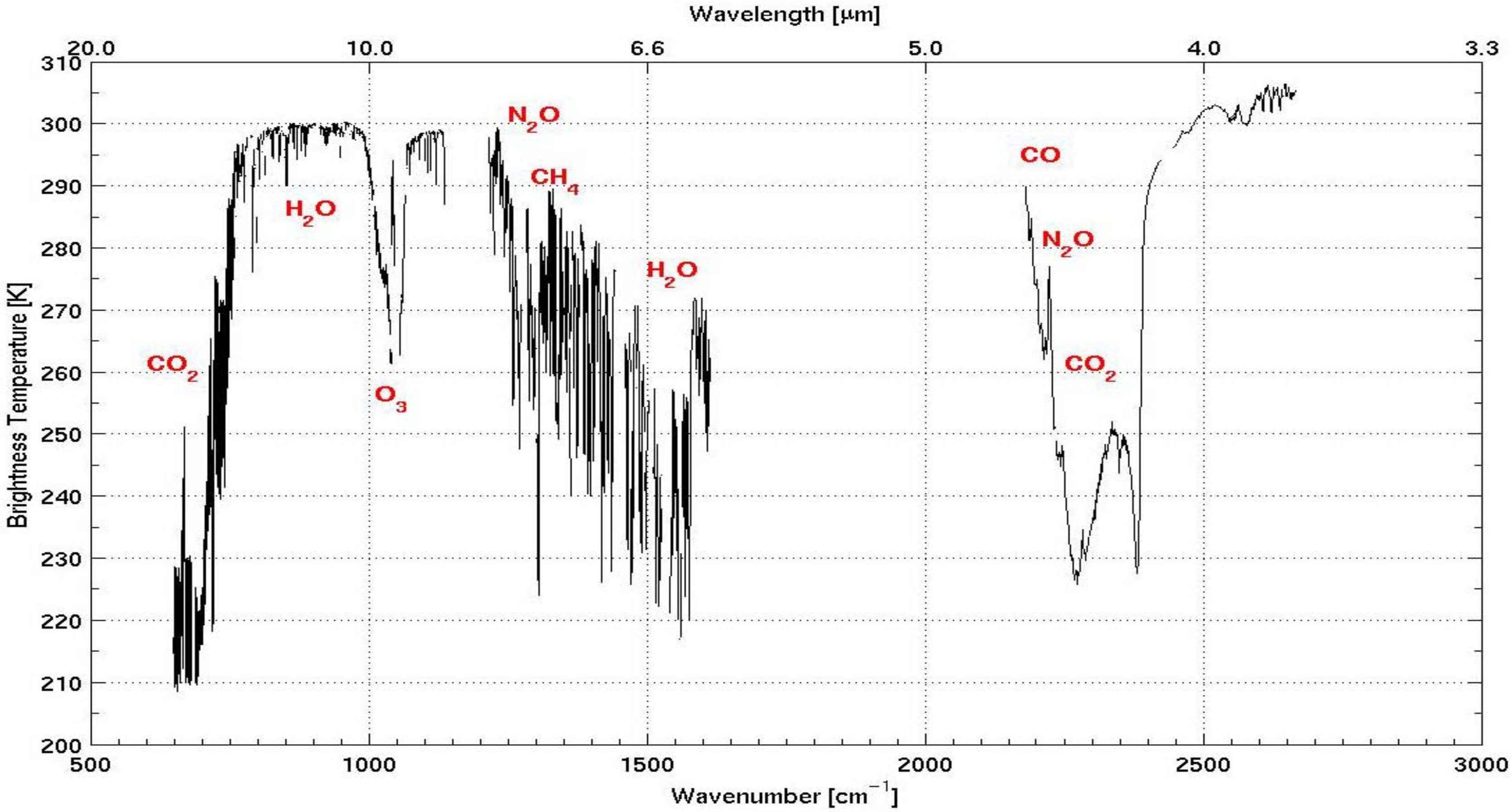
AIRS Spatial Coverage



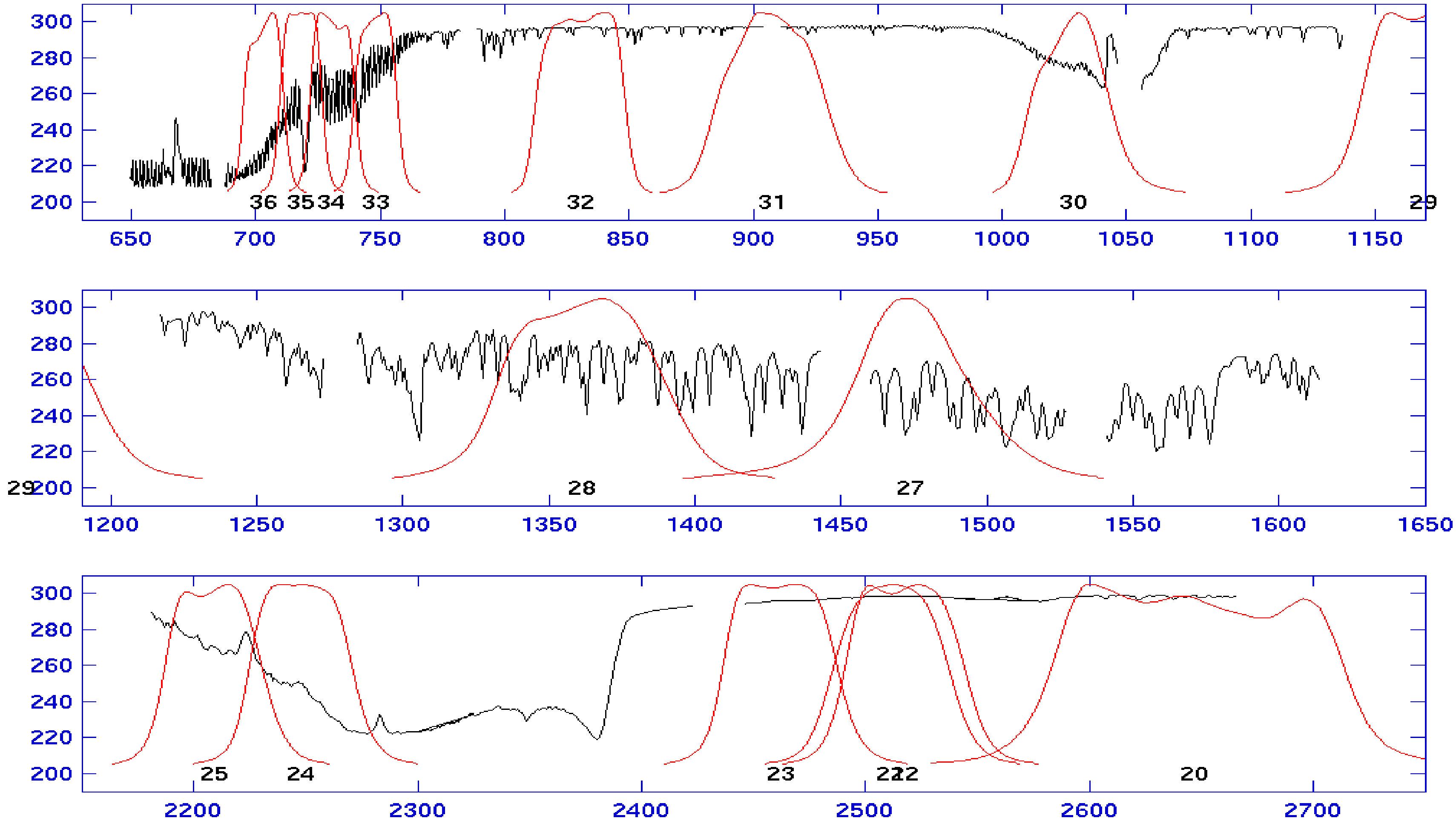
Only 5% of the globe is clear at 14 km IFOV

AIRS Spectral Coverage

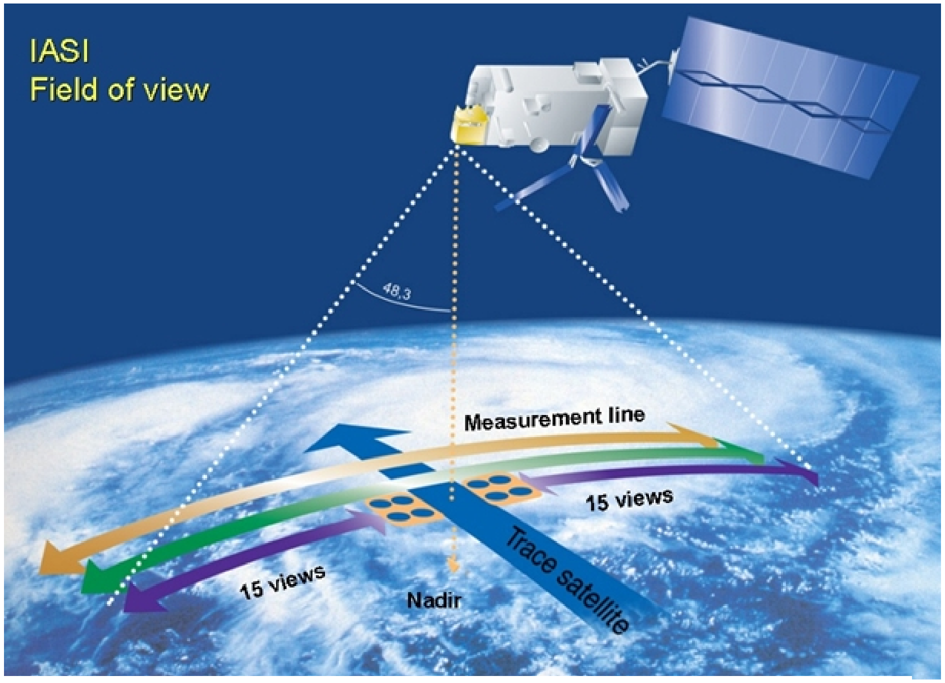
spectral ranges: 3.7 - 4.61 μm, 6.2 - 8.22 μm , 8.8 - 15.4 μm;

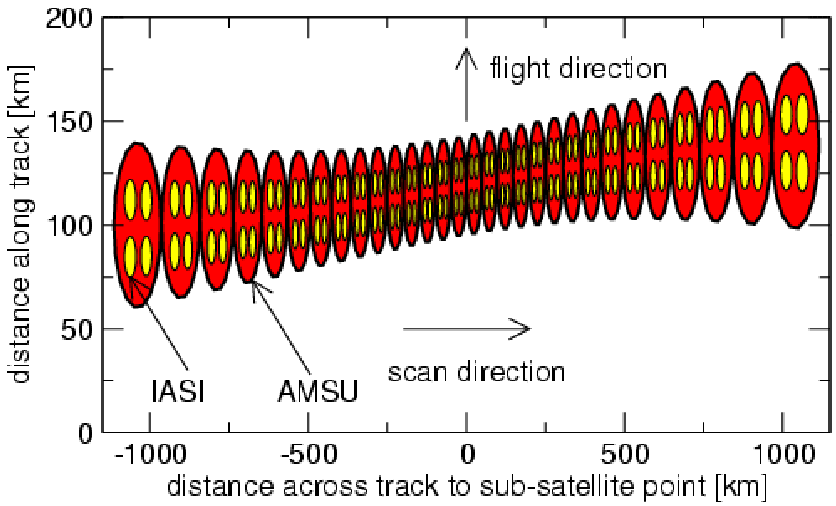


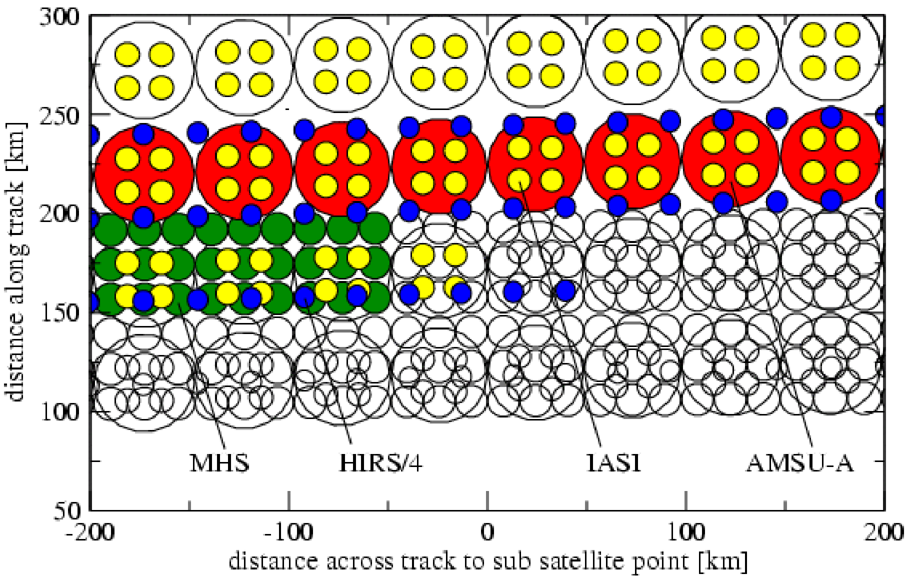
AIRS versus MODIS



IASI Scan Characteristics







EVOF consists of 2x2 matrix of IFOV

30 EFOV per scan line

IFOV size at nadir: 12 km

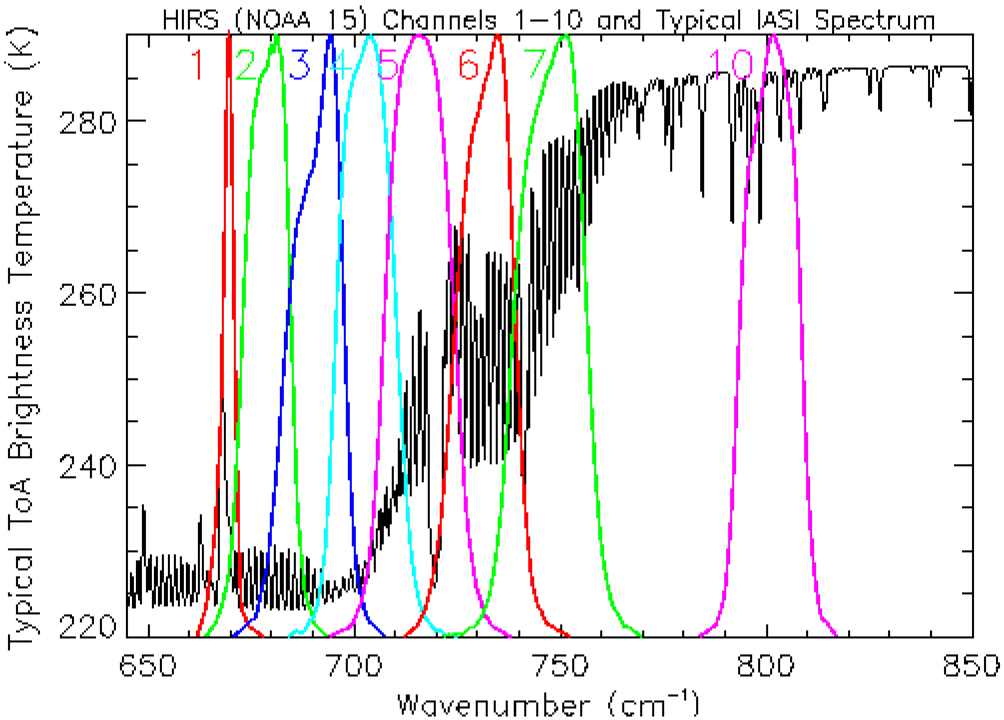
IFOV at edge across/along track: 39/20 km

Swath: ± 48.333 deg

Swath width: ± 1100 km

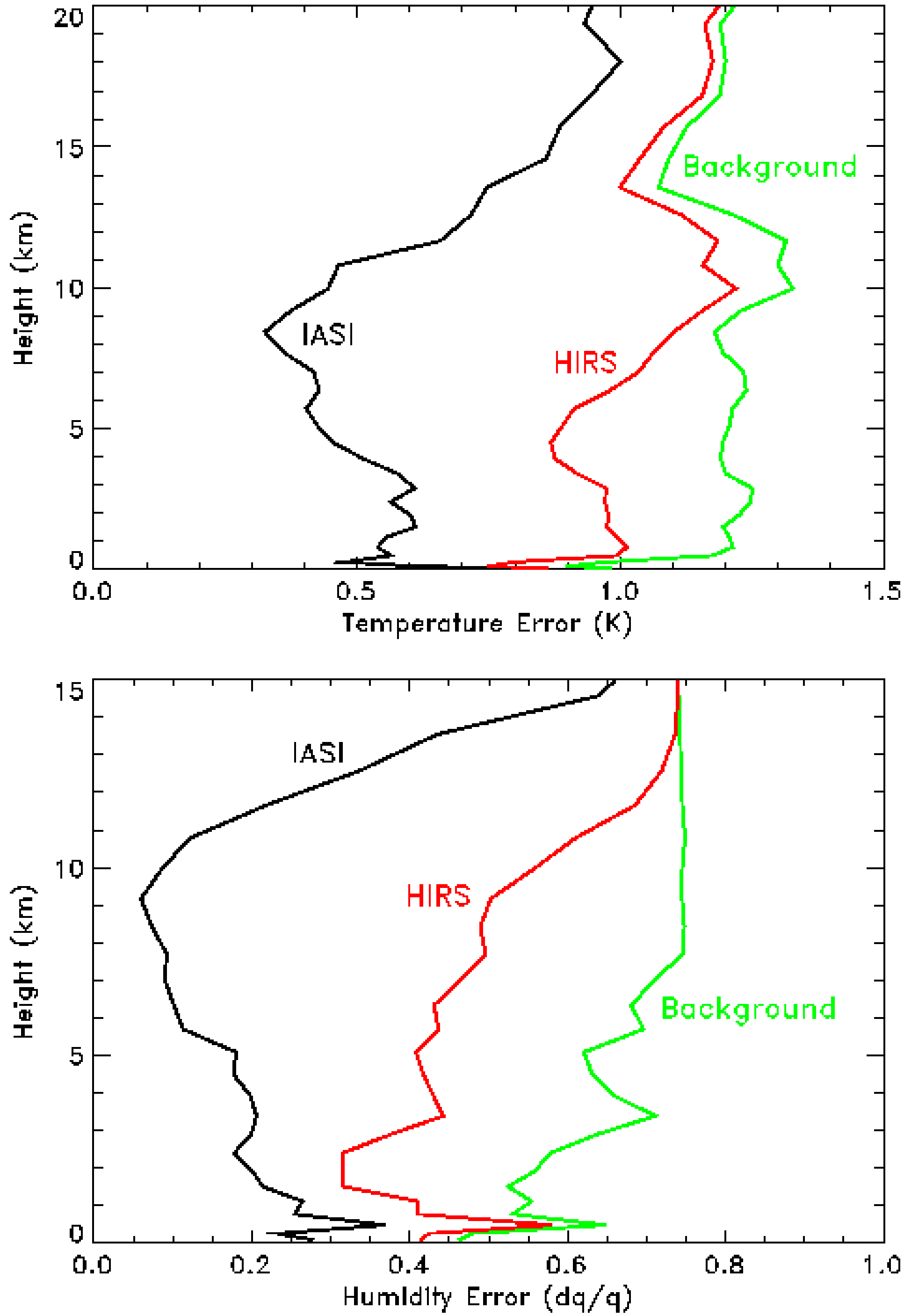
Mean Altitude approx 817 km

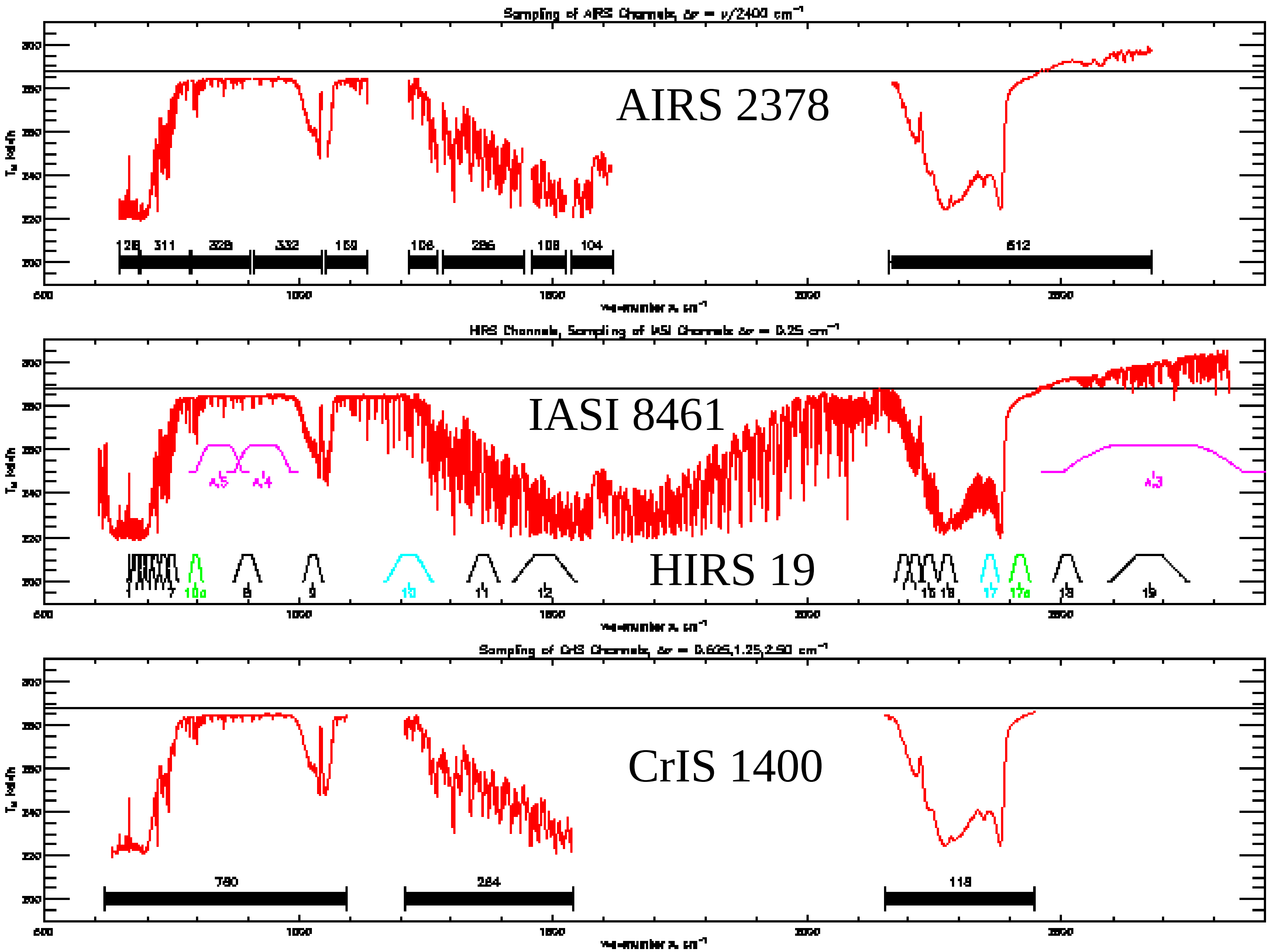
IASI versus HIRS



A comparison of a portion of a typical spectrum as would be observed by IASI with the instrument spectral response functions (ISRF) for HIRS in this region. The smoothing out of spectral features that would result from applying the HIRS ISRF is clear.

A comparison of the retrieval accuracies expected for HIRS and IASI for a mid-latitude summer profile with *a priori* information provided by a numerical weather prediction model.

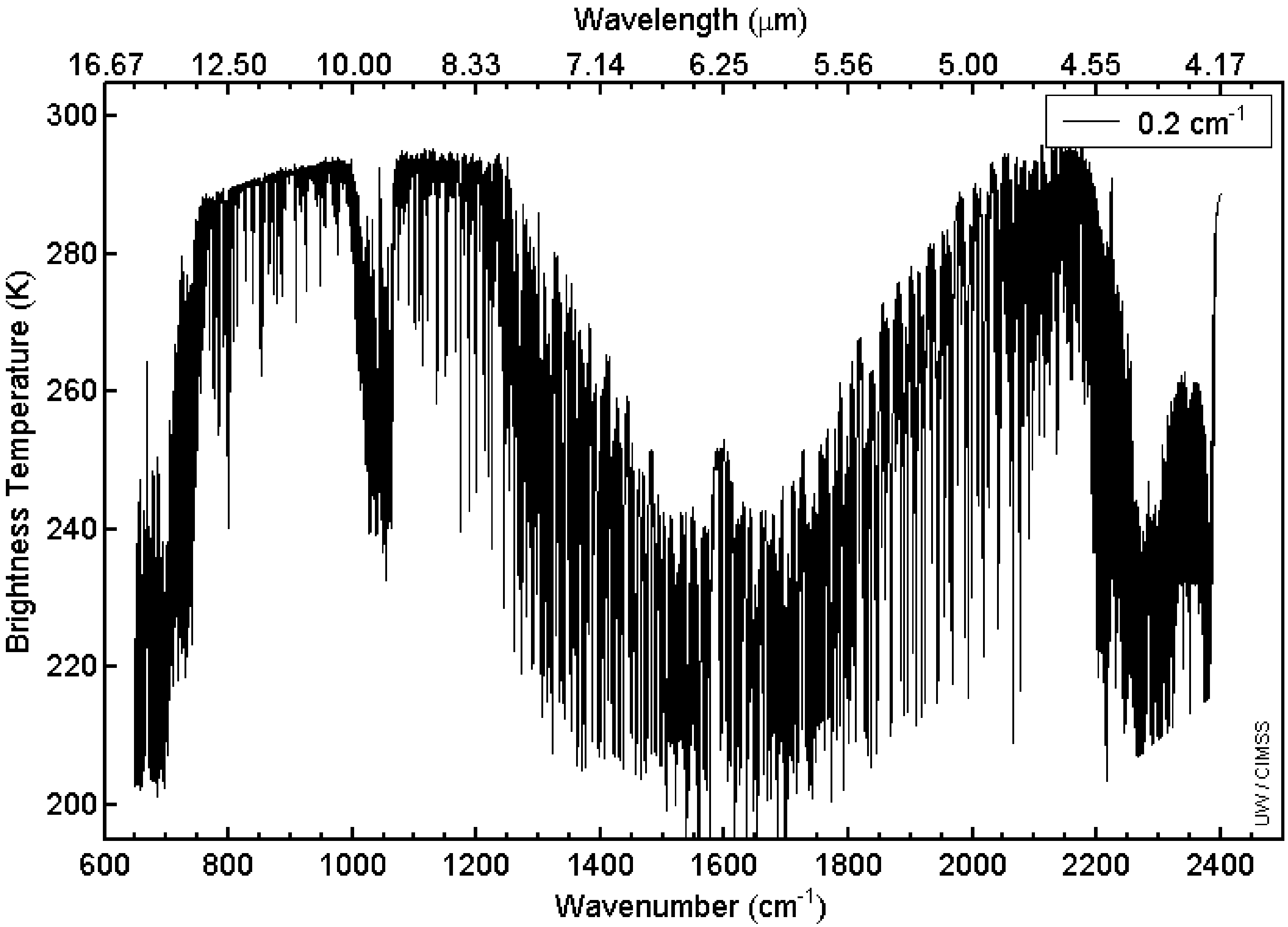



Sampling of AIRS Channels, Δν = ν/2400 cm⁻¹
AIRS 2378
128
311
328
332
150
106
286
108
104
512
Wavenumber ν, cm⁻¹
HIRS Channels, Sampling of IASI Channels Δν = 0.25 cm⁻¹
IASI 8461
HIRS 19
Wavenumber ν, cm⁻¹
Sampling of CrIS Channels, Δν = 0.625,1.25,2.50 cm⁻¹
CrIS 1400
780
284
118
Wavenumber ν, cm⁻¹

Spectral Absorption Features and Resolutions

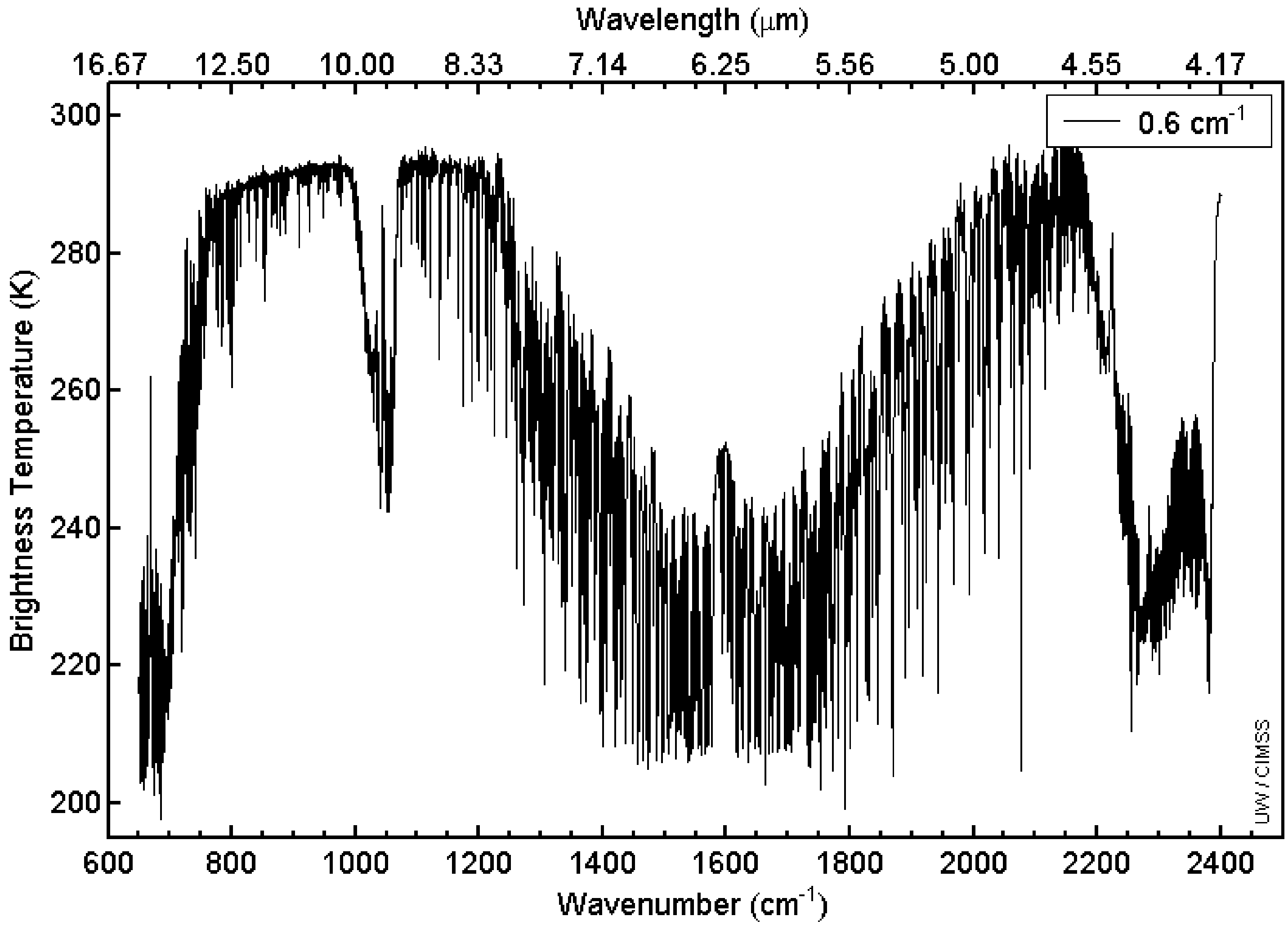
Some examples

IASI



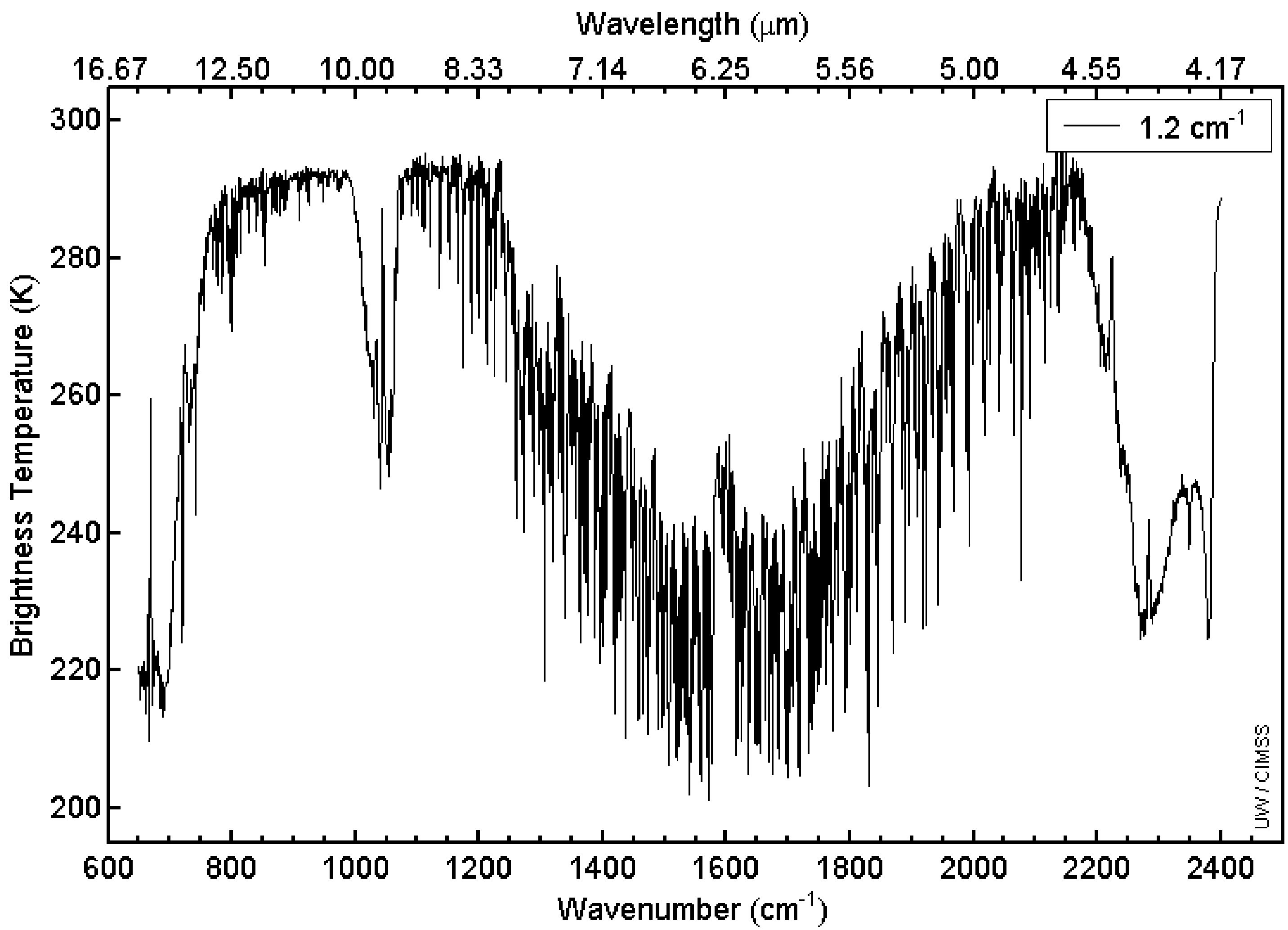
Wavelength (μm)
16.67
12.50
10.00
8.33
7.14
6.25
5.56
5.00
4.55
4.17
0.2 cm-1
Brightness Temperature (K)
300
280
260
240
220
200
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavenumber (cm-1)
UW / CIMSS

AIRS & CrIS

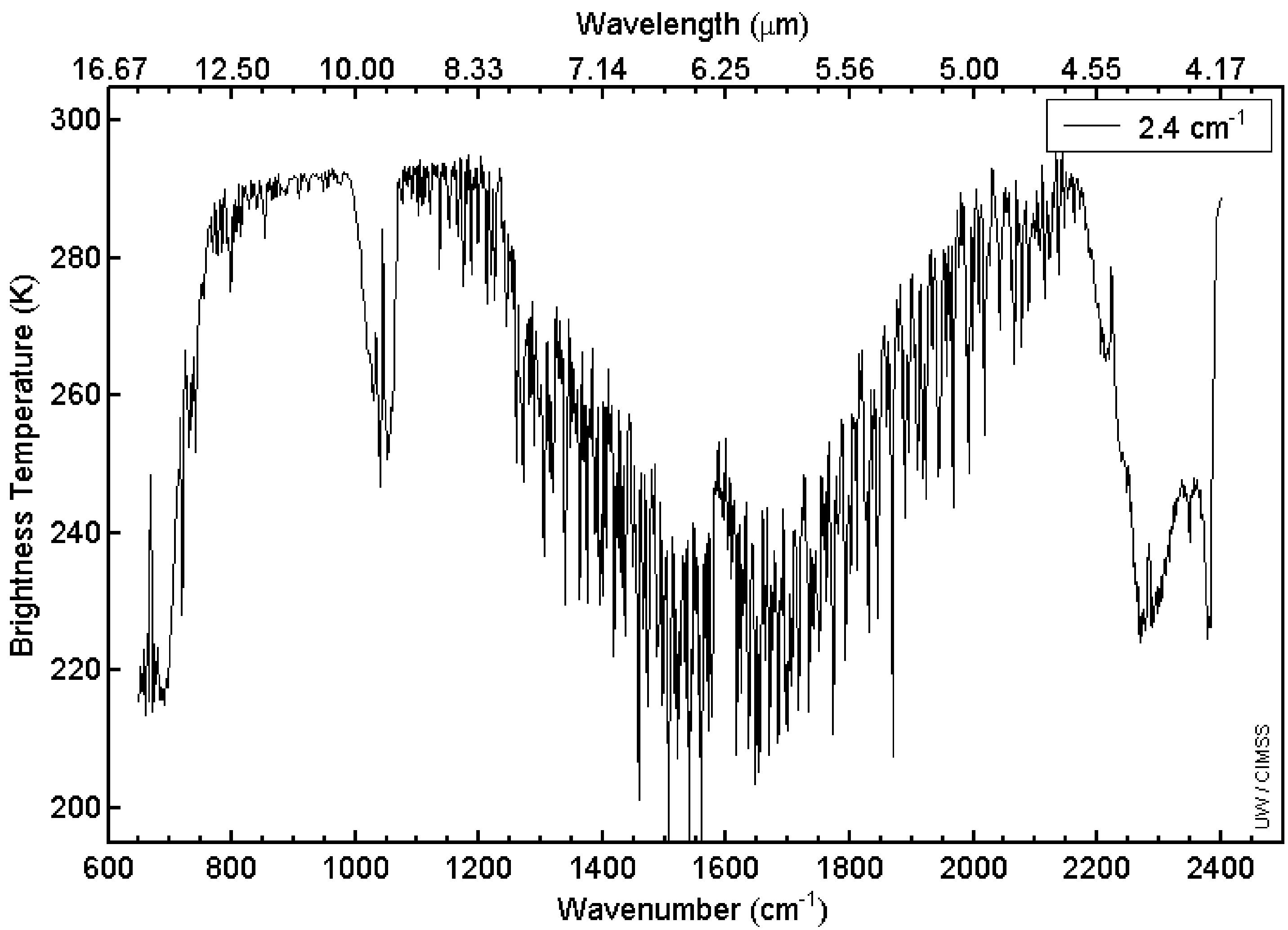


Wavelength (μm)
16.67
12.50
10.00
8.33
7.14
6.25
5.56
5.00
4.55
4.17
0.6 cm-1
Brightness Temperature (K)
300
280
260
240
220
200
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavenumber (cm-1)
UW / CIMSS

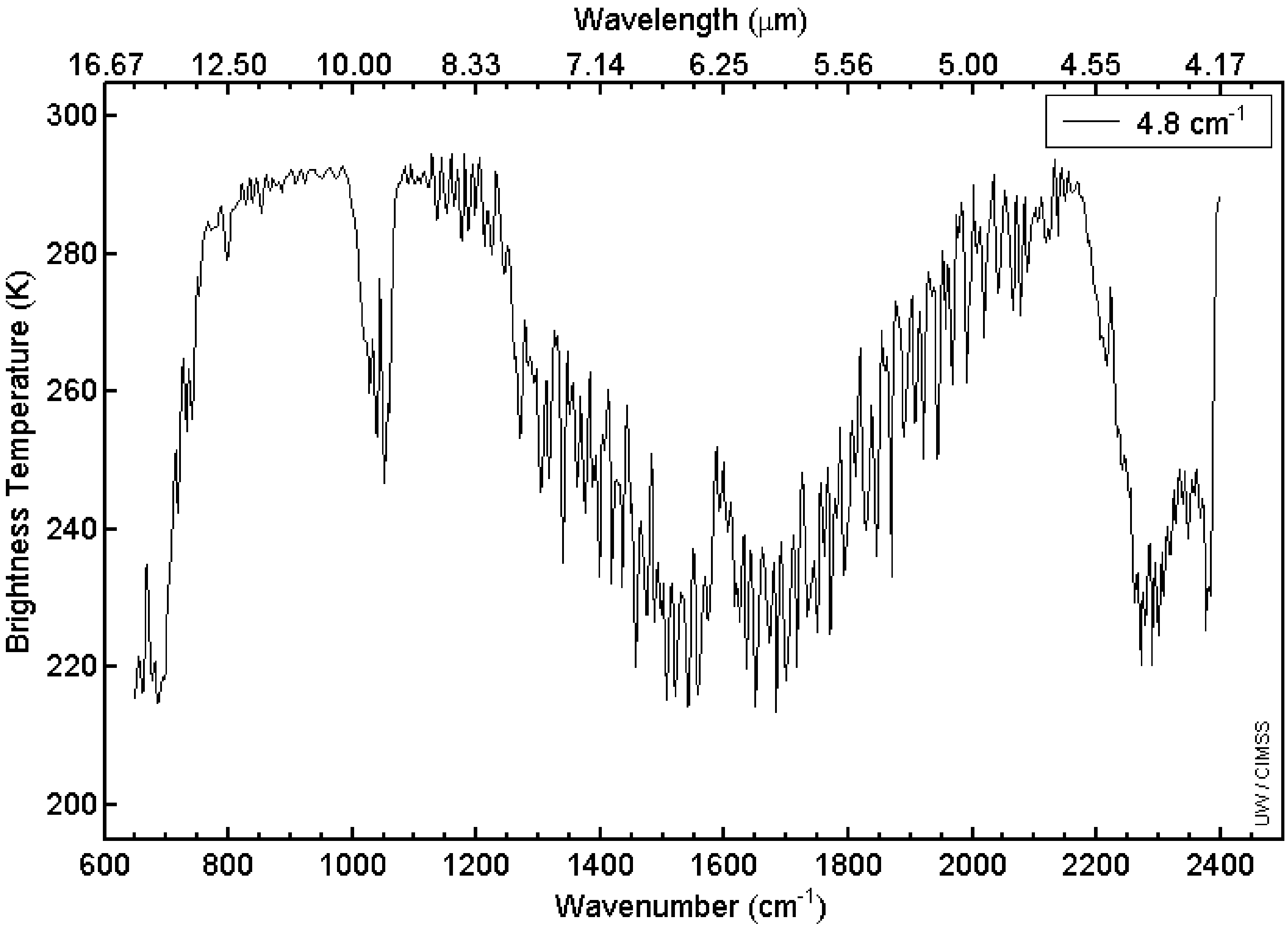
CrIS



Wavelength (μm)
16.67
12.50
10.00
8.33
7.14
6.25
5.56
5.00
4.55
4.17
1.2 cm-1
300
280
260
240
220
200
Brightness Temperature (K)
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavenumber (cm-1)
UW / CIMSS

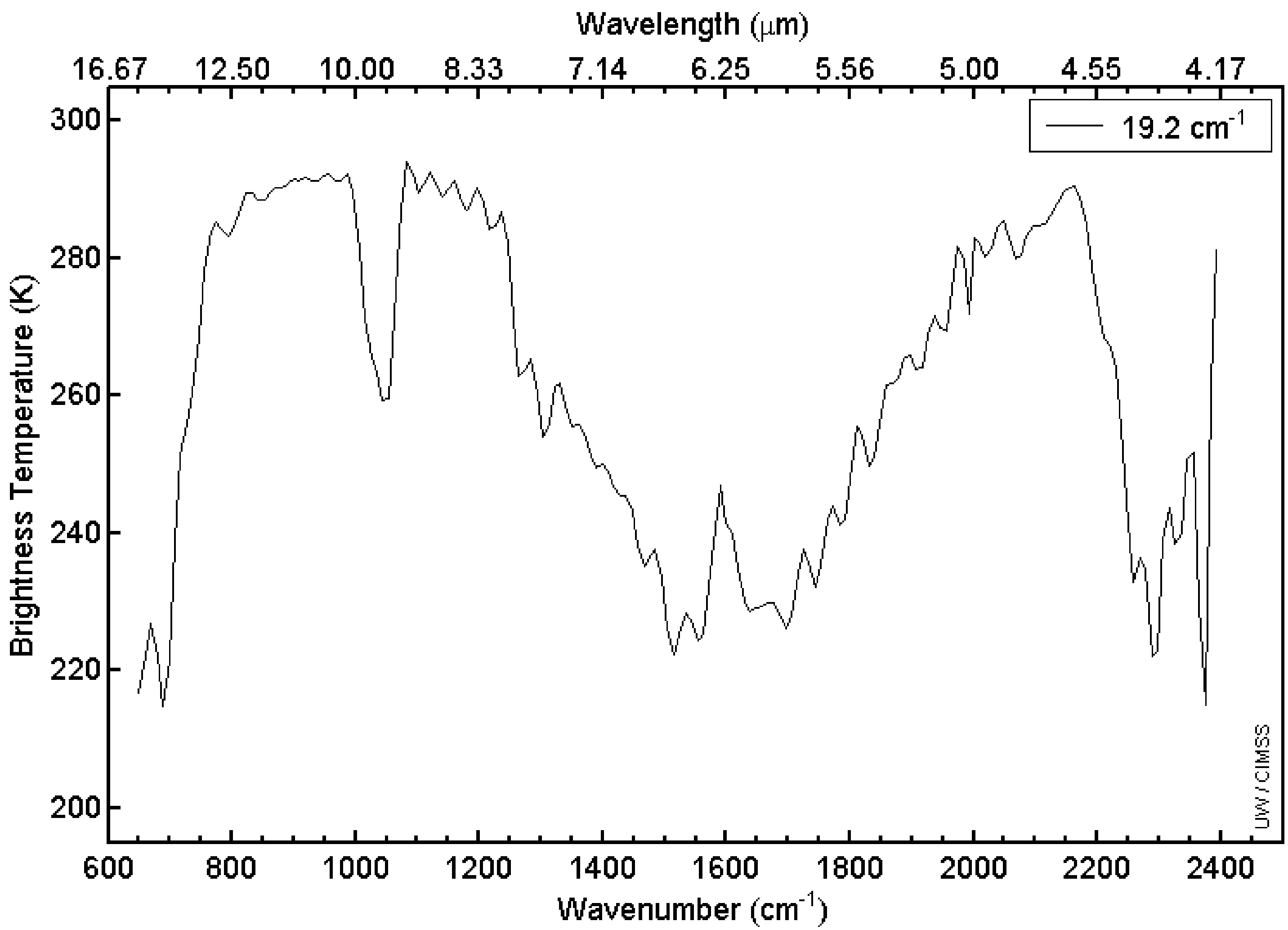


Wavelength (μm)
16.67
12.50
10.00
8.33
7.14
6.25
5.56
5.00
4.55
4.17
2.4 cm-1
300
280
260
240
220
200
Brightness Temperature (K)
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavenumber (cm-1)
UW / CIMSS



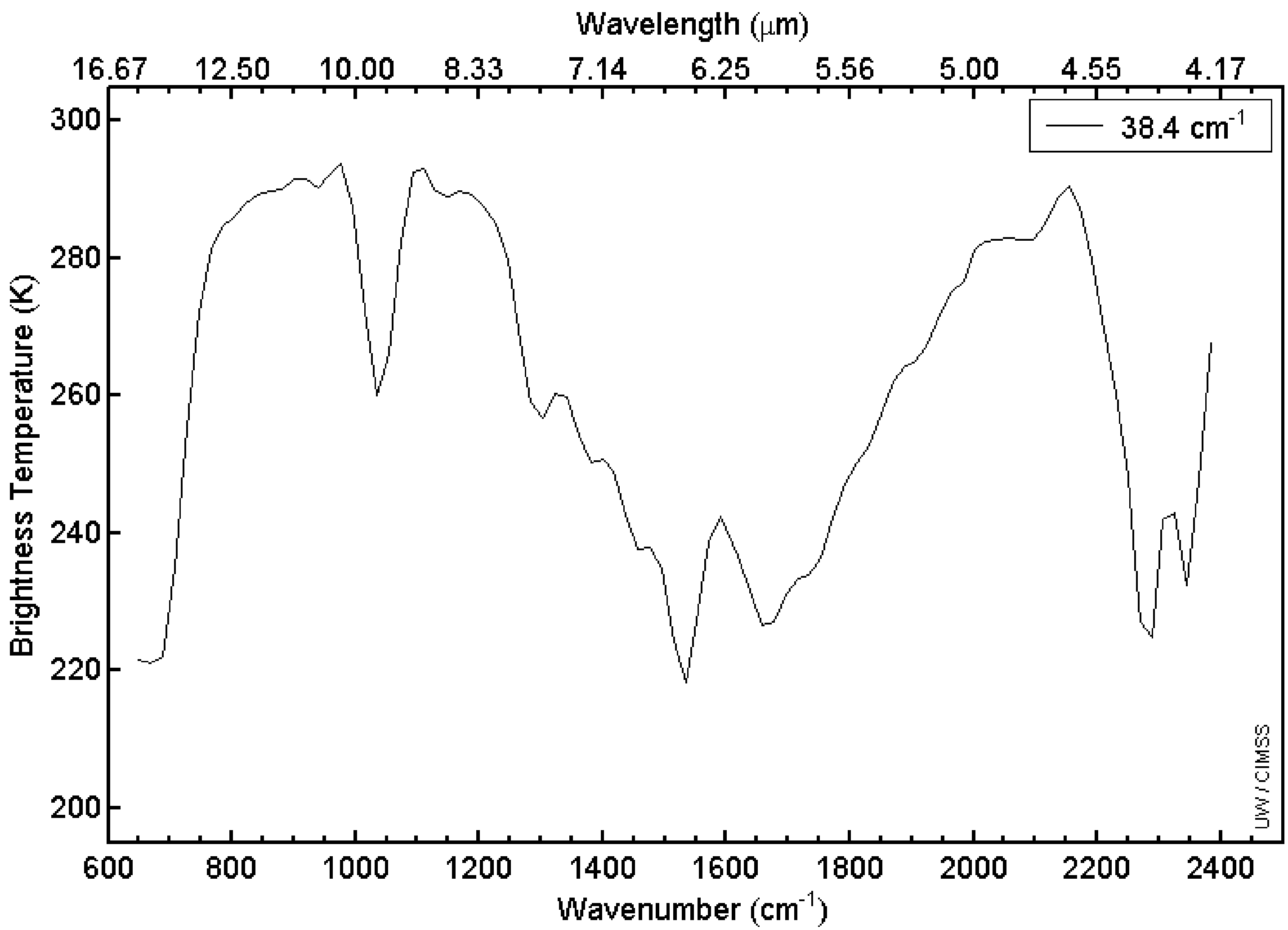
Wavelength (μm)
16.67
12.50
10.00
8.33
7.14
6.25
5.56
5.00
4.55
4.17
4.8 cm-1
300
280
260
240
220
200
Brightness Temperature (K)
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavenumber (cm-1)
UW / CIMSS

HIRS



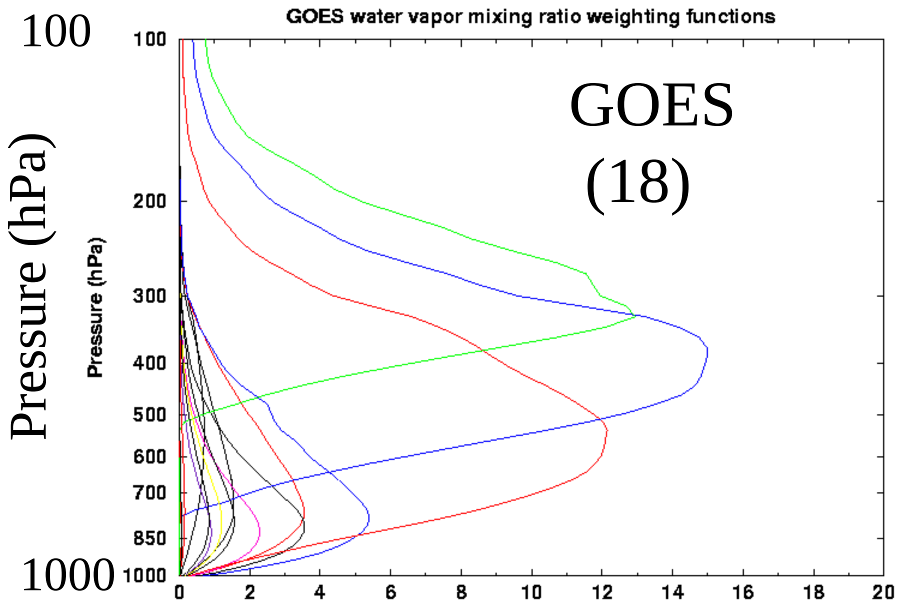
Wavelength (μm)
16.67
12.50
10.00
8.33
7.14
6.25
5.56
5.00
4.55
4.17
19.2 cm-1
Brightness Temperature (K)
300
280
260
240
220
200
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavenumber (cm-1)
UW / CIMSS

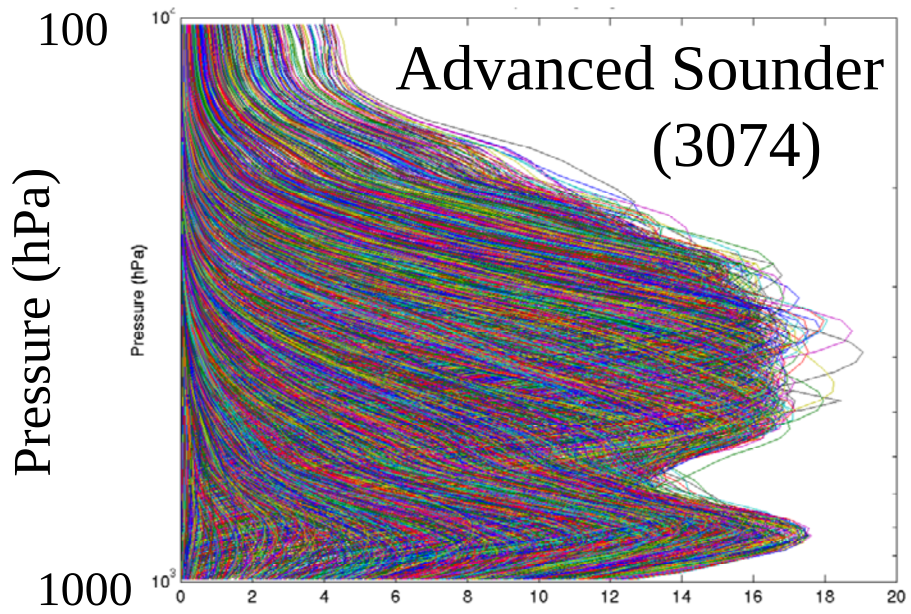
imager



Wavelength (μm)
16.67
12.50
10.00
8.33
7.14
6.25
5.56
5.00
4.55
4.17
38.4 cm-1
Brightness Temperature (K)
300
280
260
240
220
200
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavenumber (cm-1)
UW / CIMSS

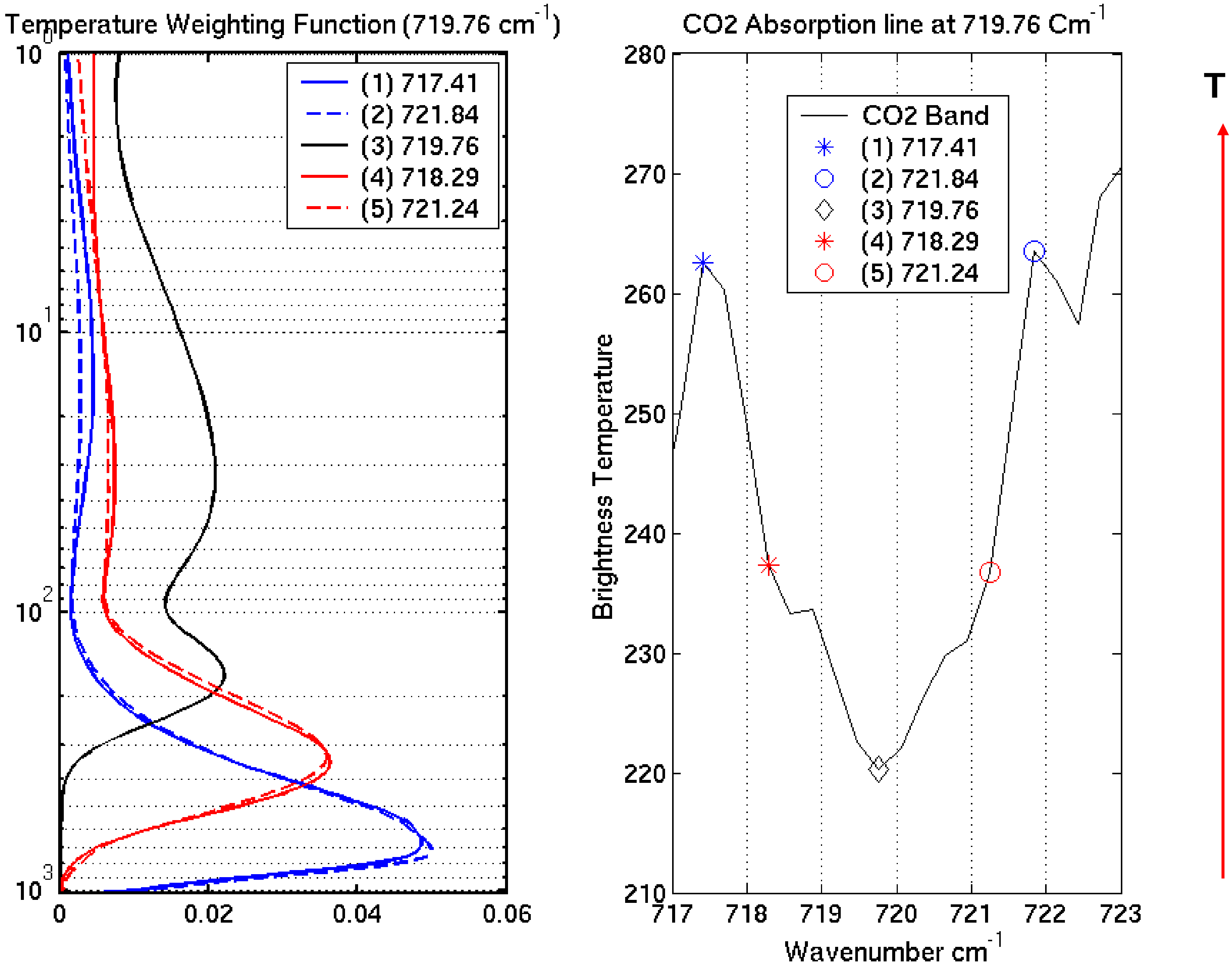
Infrared Spectral Sounding Profile



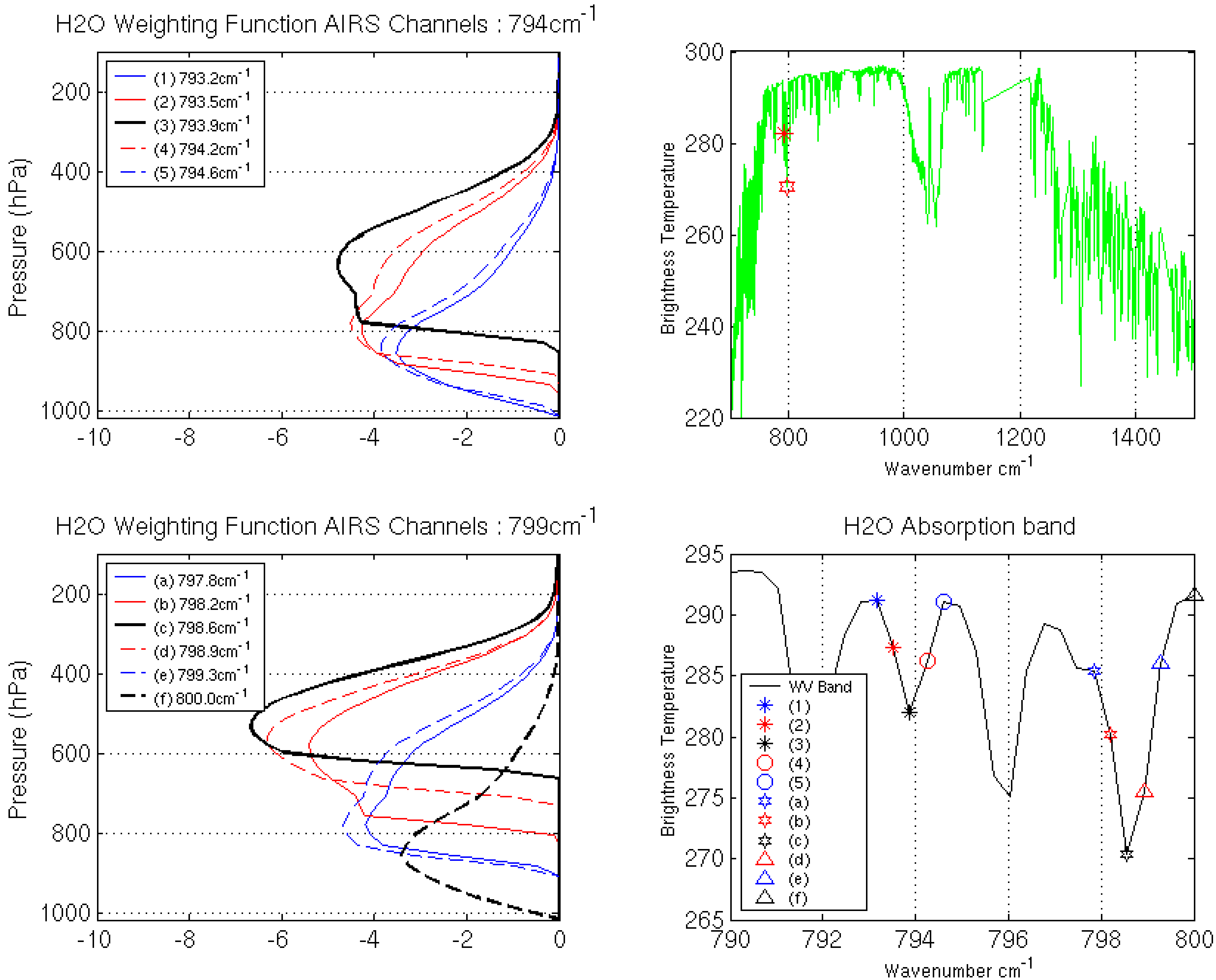


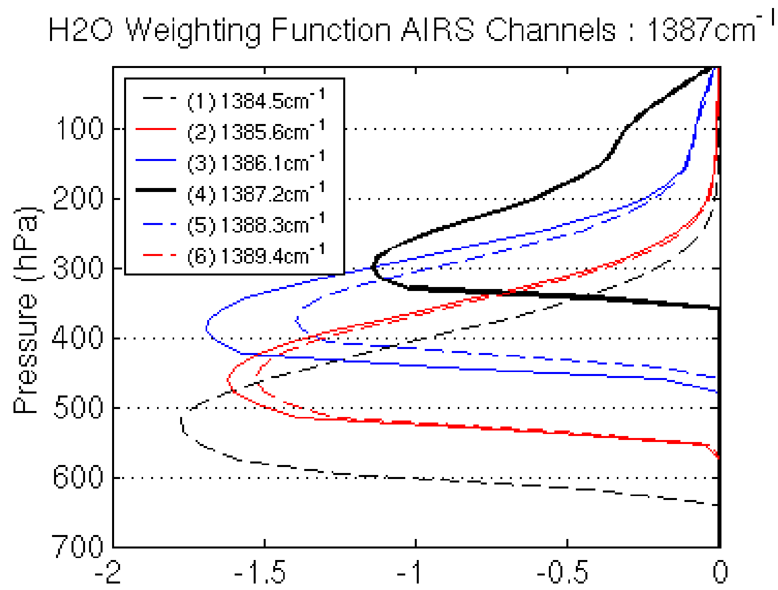
Moisture Weighting Functions

High spectral resolution advanced sounder will have more and sharper weighting functions compared to current GOES sounder. Retrievals will have better vertical resolution.

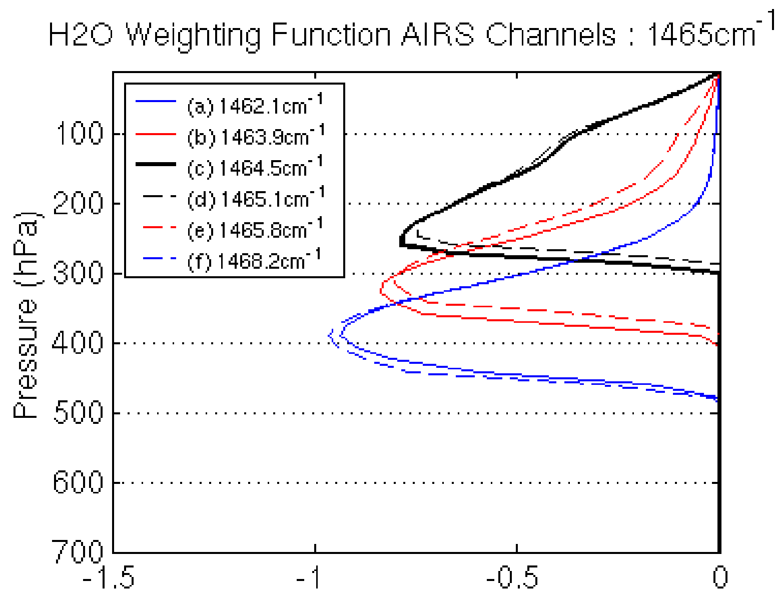


Temperature Weighting Function (719.76 cm-1)
(1) 717.41
(2) 721.84
(3) 719.76
(4) 718.29
(5) 721.24
10^0
10^1
10^2
10^3
0
0.02
0.04
0.06
CO2 Absorption line at 719.76 Cm-1
CO2 Band
(1) 717.41
(2) 721.84
(3) 719.76
(4) 718.29
(5) 721.24
Brightness Temperature
280
270
260
250
240
230
220
210
717
718
719
720
721
722
723
Wavenumber cm-1
T


H2O Weighting Function AIRS Channels : 794cm-1
Pressure (hPa)
(1) 793.2cm-1
(2) 793.5cm-1
(3) 793.9cm-1
(4) 794.2cm-1
(5) 794.6cm-1
Brightness Temperature
Wavenumber cm-1
H2O Weighting Function AIRS Channels : 799cm-1
Pressure (hPa)
(a) 797.8cm-1
(b) 798.2cm-1
(c) 798.6cm-1
(d) 798.9cm-1
(e) 799.3cm-1
(f) 800.0cm-1
H2O Absorption band
Brightness Temperature
Wavenumber cm-1
WV Band
(1)
(2)
(3)
(4)
(5)
(a)
(b)
(c)
(d)
(e)
(f)

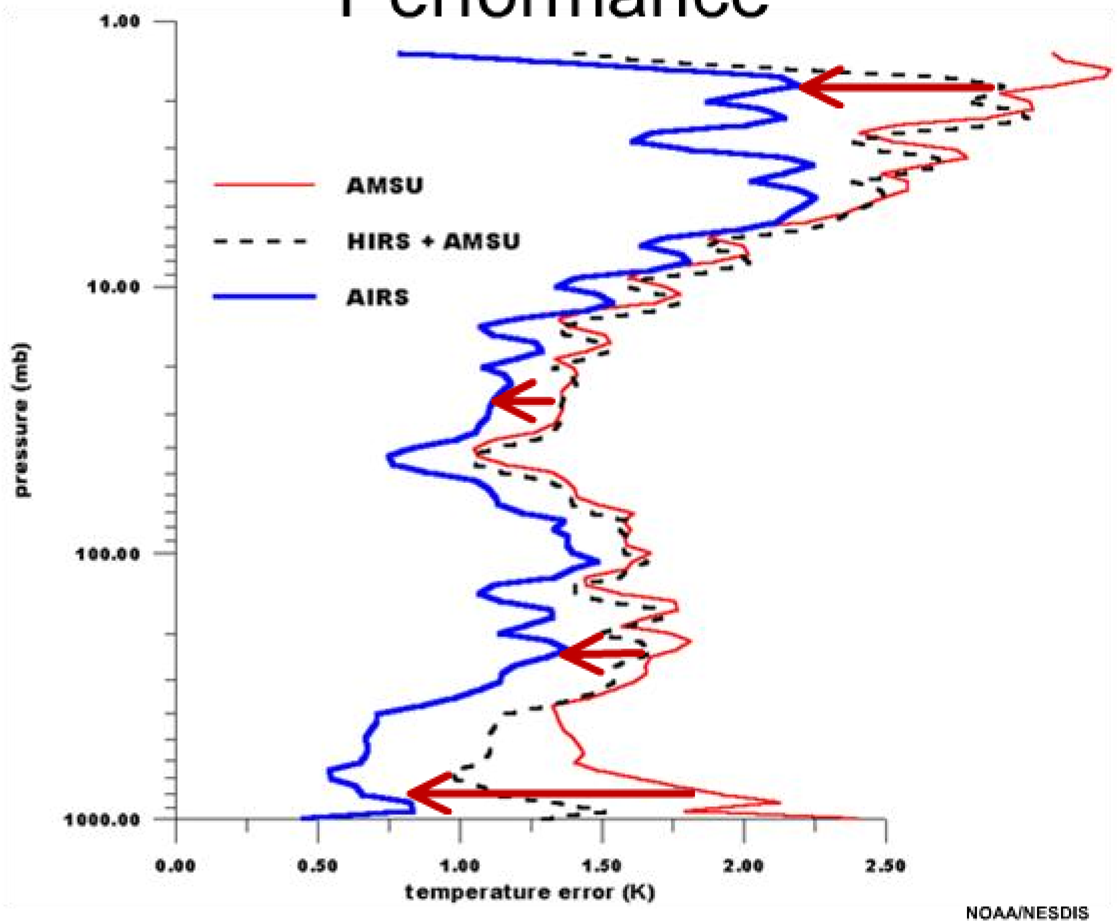


H2O Weighting Function AIRS Channels : 1387cm-1
(1) 1384.5cm-1
(2) 1385.6cm-1
(3) 1386.1cm-1
(4) 1387.2cm-1
(5) 1388.3cm-1
(6) 1389.4cm-1
Pressure (hPa)
100
200
300
400
500
600
700
-2
-1.5
-1
-0.5
0



H2O Weighting Function AIRS Channels : 1465cm-1
(a) 1462.1cm-1
(b) 1463.9cm-1
(c) 1464.5cm-1
(d) 1465.1cm-1
(e) 1465.8cm-1
(f) 1468.2cm-1
Pressure (hPa)
100
200
300
400
500
600
700
-1.5
-1
-0.5
0

Improvements in Sounding Performance



http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Why High Spectral Resolution?

- Improved spectral resolution results in:
  - Sharper weighting functions
  - "Clean" channels (e.g. temperature channels not contaminated by water vapor lines)
- Many channels with sharper weighting functions combined with low noise improves vertical resolution
- Retrieval accuracy is greatly improved
  (temperature, moisture, skin temperature, and surface emissivity)
- Resolving individual water vapor absorption lines allows detection of temperature inversions
- High spectral resolution allows the retrieval of trace gases

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Why GEO?

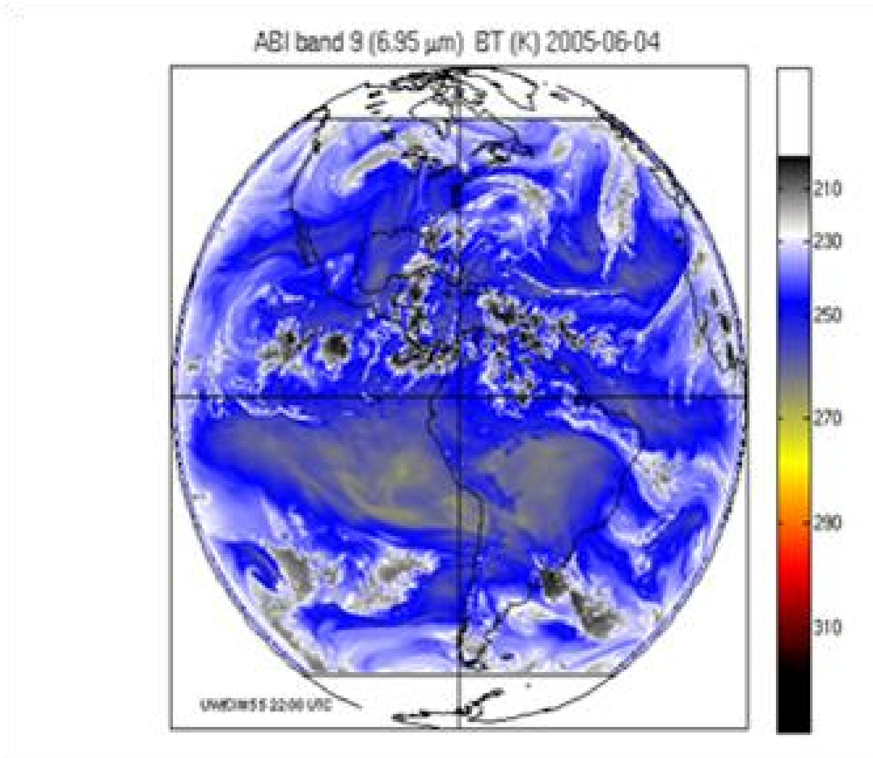
- AIRS and IASI have resulted in significant improvements in medium range global forecasts (nearly half day improvement in the 5-day forecast), however much smaller impacts in shorter range forecasts

- A GEO high spectral resolution sounder, because of high temporal refresh, is expected to significantly improve nowcasting (0 – 1 hour), and nearcasting (1 – 6 hours) and short range forecasts (6 – 48 hours)

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Benefits of High Vertical Resolution Soundings from GEO

- Provides the spatial coverage and temporal refresh to resolve the pre-convective storm environment for greatly improved prediction of severe weather
- One GEO provides hemispheric coverage with a refresh rate limited to technology
  - Nominally 1 hour hemispheric, and 5 minutes mesoscale (1000 x 1000 km area)
- One LEO provides global coverage with refresh of 12 hours
  - Cannot provide near continuous monitoring of severe weather



CIMSS

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Importance of Low-level Water Vapor Information

- **Accurate low level water vapor Information is critical because it is the fuel for deep convection**

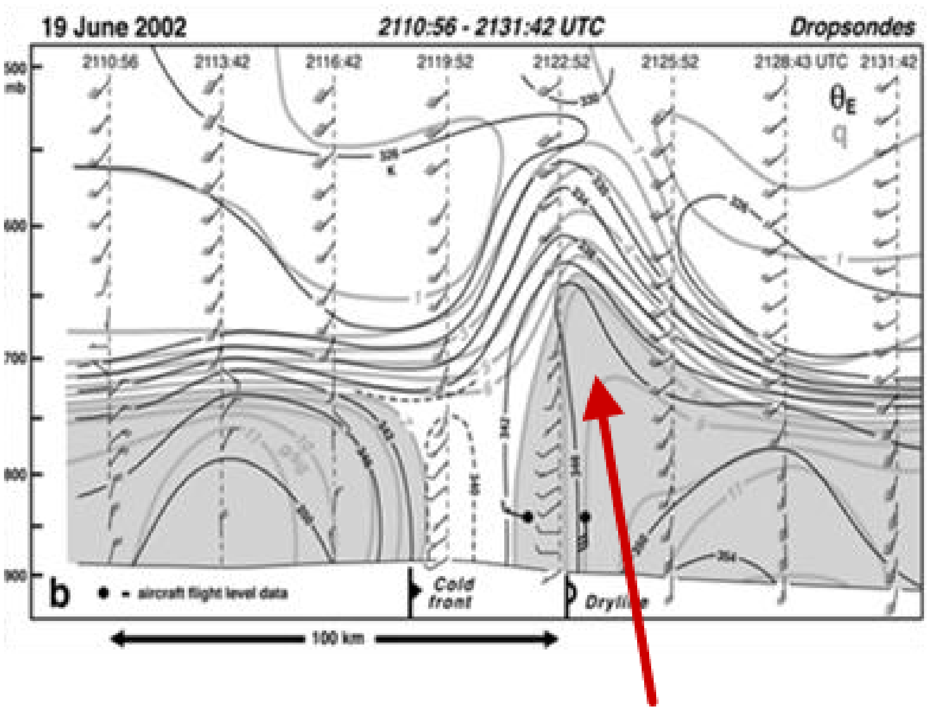
- **Large variations in the atmosphere's ability to support strong convection via low level moisture exists over scales of 25 km or less**
  - **These moisture fields evolve rapidly as circulations develop and as low level moisture is advected into a region**
  - **Numerical simulations and field experiments suggest that changes in mixing ratio as small at 1 g /kg have significant effects on the developing convection**

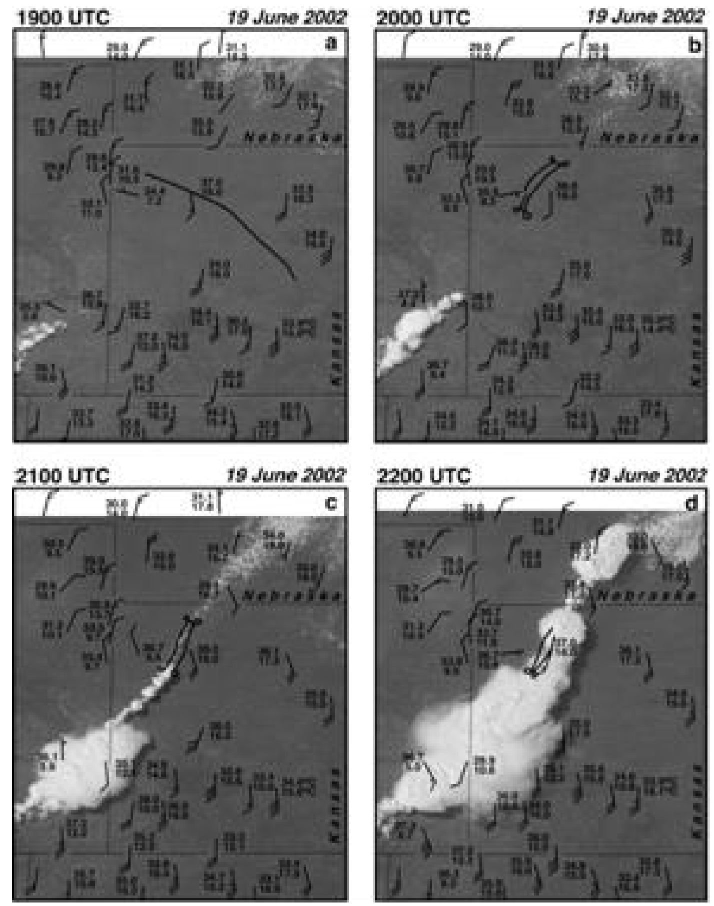
- **Geostationary satellites: capable of mapping at the required high temporal and spatial resolution the state and evolution of the convective environment on the scales necessary to observe it over large areas, accurately, on demand**

This capability requires a hyperspectral sounder in geostationary orbit!

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Importance of the Vertical Distribution of Water Vapor for Convective Development and Evolution





Numerous studies have highlighted the importance of knowing the distribution of water vapor in predicting convective development and evolution. The location where convection initiates is denoted by the upward bulge in the isopleths of mixing ratio (q) and θ_E.

All figures Murphey et al. 2006 MWR

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Non-traditional Sounding Applications

– Aerosol detection
– Volcanic ash detection
– Cirrus detection
– Trace gases (e.g. carbon products)

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Separation of Dust from Cirrus

- Both ice and silicate absorption small in 1200 cm^{-1} window
- In the 800-1000 cm^{-1} atmospheric window:
  - Silicate index *increases*
  - Ice index *decreases* with wavenumber

Imaginary Index of Refraction of Ice and Dust

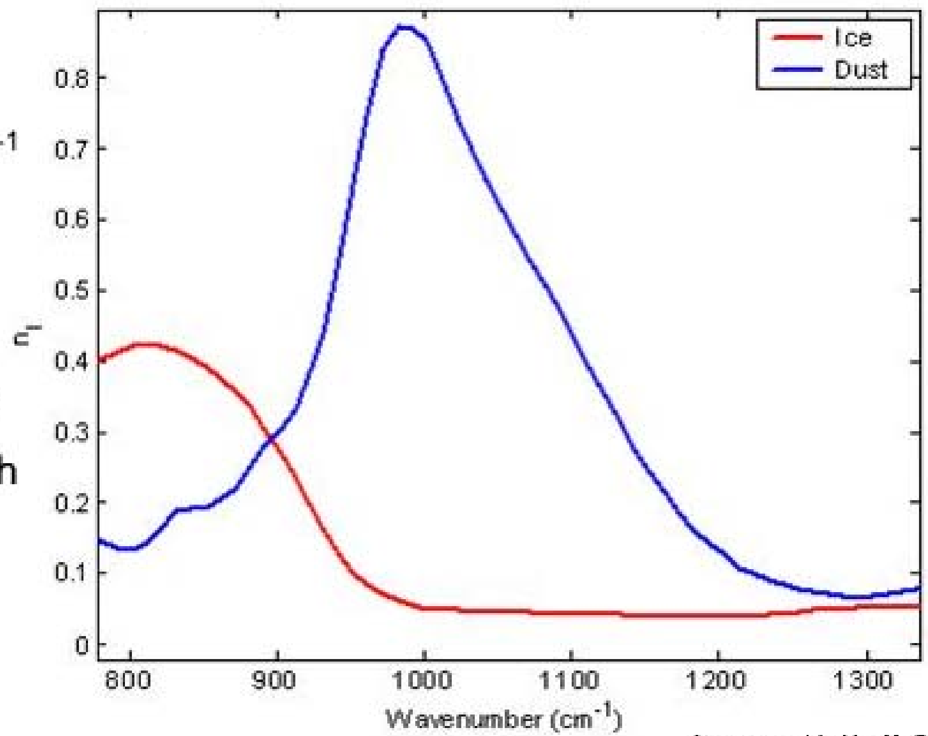


Image provided by M. Goldberg

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Summary

- Hyperspectral infrared observations improve vertical resolution and accuracy of temperature and moisture soundings and provide new products such as greenhouse gas estimates
- Microwave and/or infrared imagers need to accompany advanced infrared sounders to provide cloud-clearing capabilities
- AIRS continuity will be provided by NPOESS CrIS in the 13:30 orbit
- IASI provides hyperspectral observations in the 9:30 orbit
- All three will improve medium range weather forecasting and climate change monitoring
- An advanced sounder in geostationary orbit with significantly improved temporal sampling (minutes as opposed hours) is important for improving nowcasting and shorter range forecasts

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

COMET Module

"Advanced Satellite Sounding: The Benefits of the Hyperspectral Observation". Lecture presented by Dr. Mitch Goldberg

http://meted.ucar.edu/npoess/hyperspectral/sounding_benefits

Next Generation Geostationary Satellites
The next generation GOES will begin with GOES-R, which is currently scheduled to launch in the year 2015.

Next generation of low earth orbiting environmental satellites
The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is the next generation of low earth orbiting environmental satellites.

http://www.ipo.noaa.gov/index.php

Advanced infrared sounders
http://www.metoffice.gov.uk/research/nwp/satellite/infrared/sounders/index.html

Thanks!

Gracias!