Summary of Satellite Remote Sensing Concepts

Lectures in Brienza
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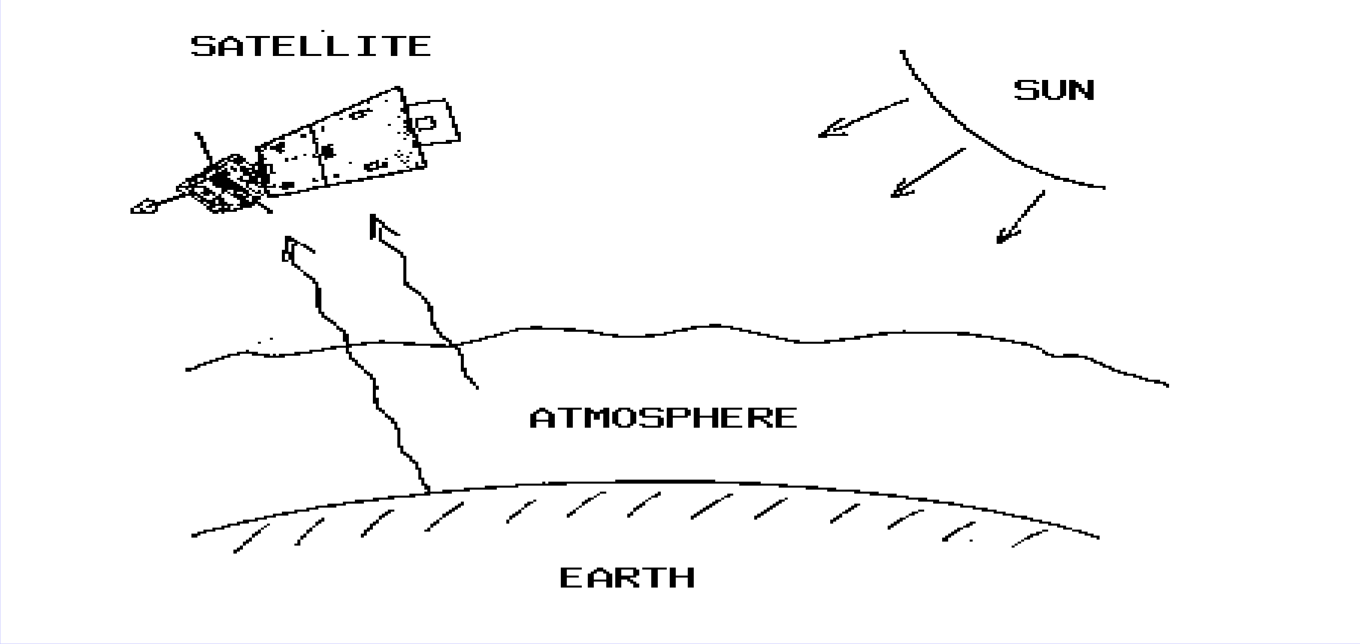
Paul Menzel
UW/CIMSS/AOS


Brienza 2011


Brienza 2011

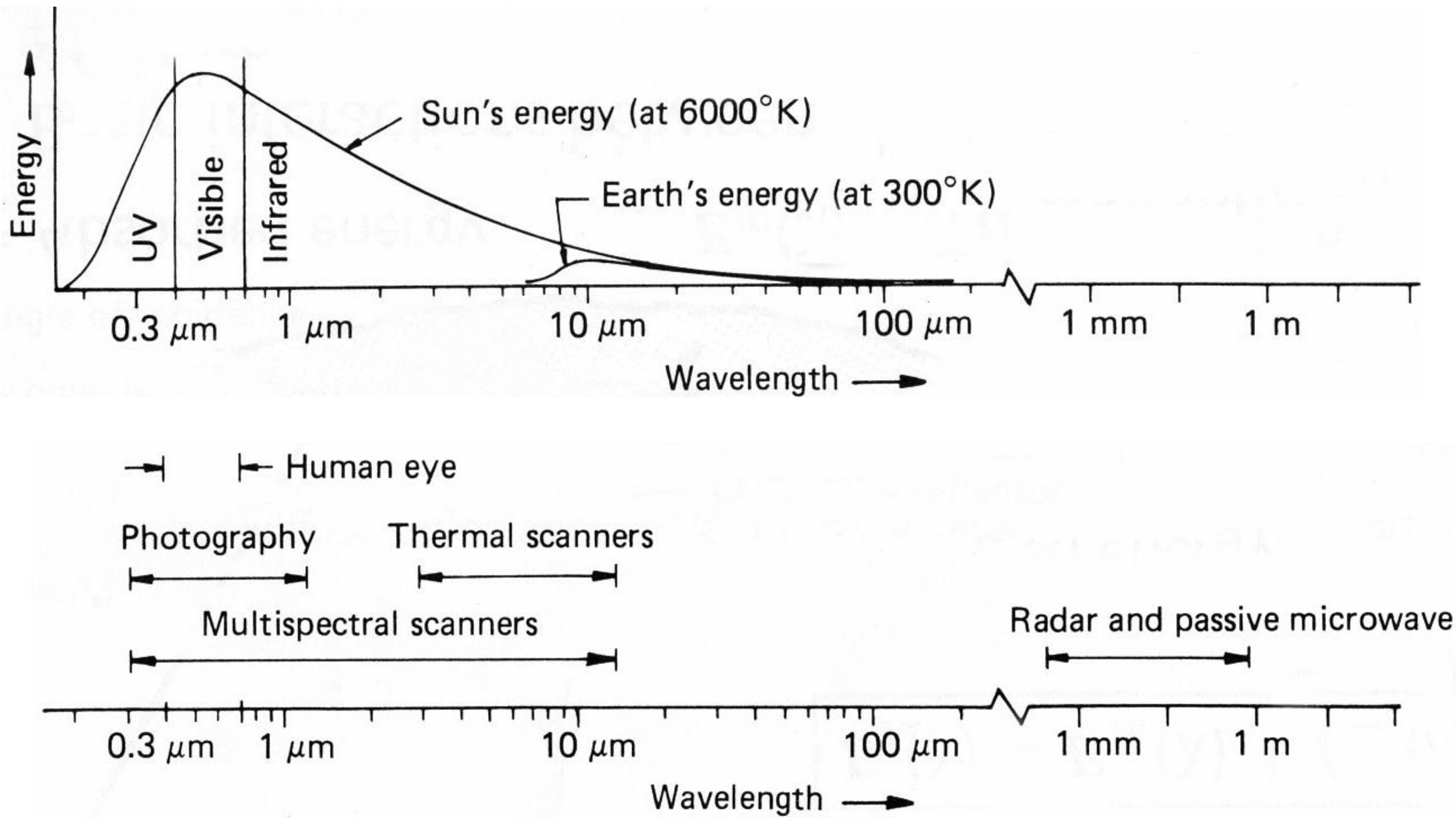
Satellite remote sensing of the Earth-atmosphere



Observations depend on

telescope characteristics (resolving power, diffraction)
detector characteristics (signal to noise)
communications bandwidth (bit depth)
spectral intervals (window, absorption band)
time of day (daylight visible)
atmospheric state (T, Q, clouds)
earth surface (Ts, vegetation cover)

Spectral Characteristics of Energy Sources and Sensing Systems



Terminology of radiant energy

Energy from the Earth Atmosphere

over time is

Flux

which strikes the detector area

Irradiance

at a given wavelength interval

Monochromatic Irradiance

over a solid angle on the Earth

Radiance observed by satellite radiometer

is described by

The Planck function

can be inverted to

Brightness temperature

Definitions of Radiation

QUANTITY	SYMBOL	UNITS
Energy	dQ	Joules
Flux	dQ/dt	Joules/sec = Watts
Irradiance	dQ/dt/dA	Watts/meter^2
Monochromatic Irradiance	dQ/dt/dA/dλ	W/m^2/micron
	or	
	dQ/dt/dA/dν	W/m^2/cm^{-1}
Radiance	dQ/dt/dA/dλ/dΩ	W/m^2/micron/ster
	or	
	dQ/dt/dA/dν/dΩ	W/m^2/cm^{-1}/ster

Using wavenumbers

$$B(\nu,T) = c_1\nu^3 / [e^{c_2\nu/T} - 1]$$

$(mW/m^2/ster/cm^{-1})$

ν(max in cm-1) = 1.95T

$B(\nu_{max},T) \sim T^{**}3.$

$$E = \pi \int_o^\infty B(\nu,T)\, d\nu = \sigma T^4,$$

$$T = c_2\nu/[\ln(\frac{c_1\nu^3}{B_\nu} + 1)]$$

Using wavelengths

$$B(\lambda,T) = c_1/\{ \lambda^5 [e^{c_2/\lambda T} - 1] \}$$

$(mW/m^2/ster/\mu m)$

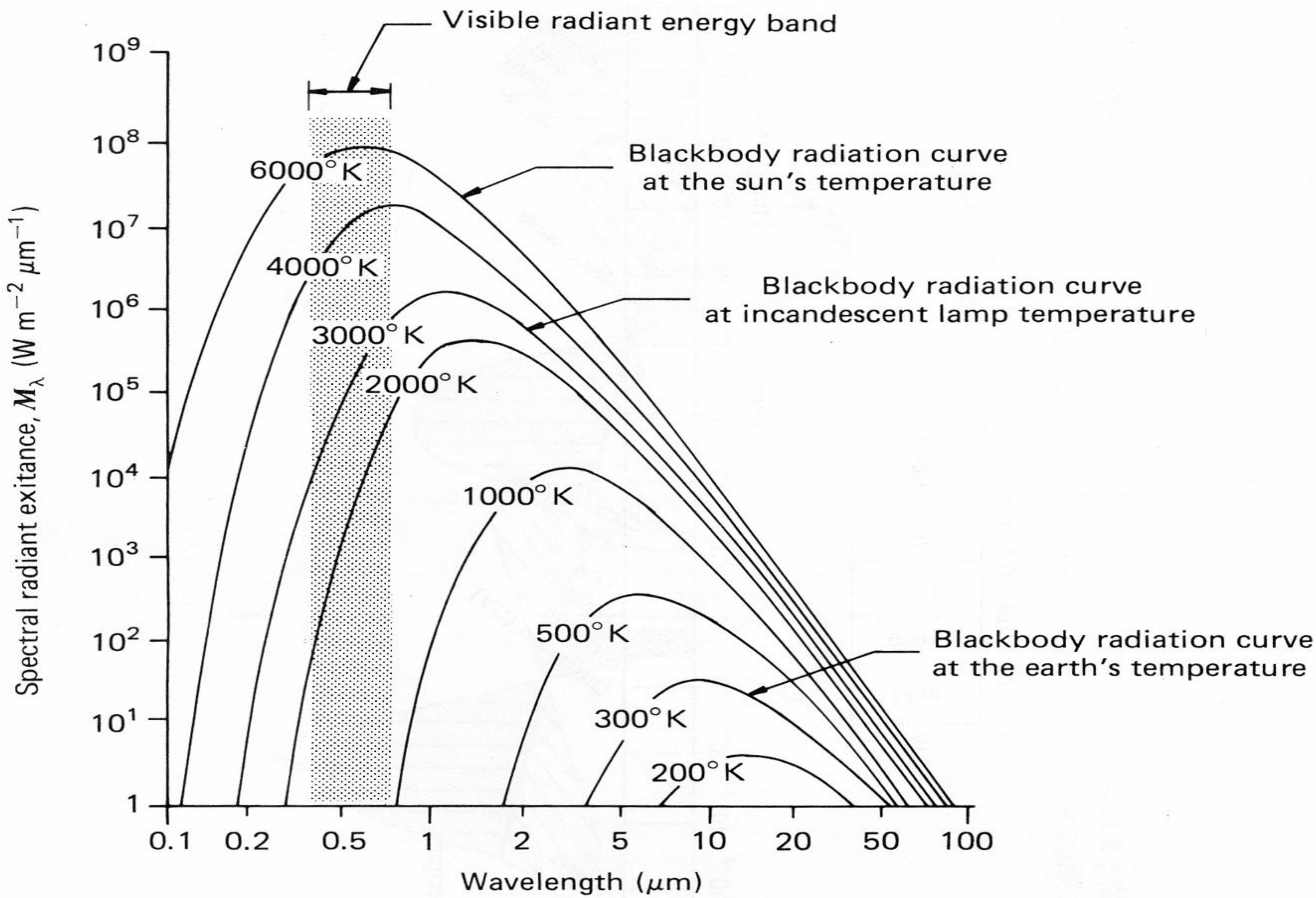
λ(max in cm)T = 0.2897

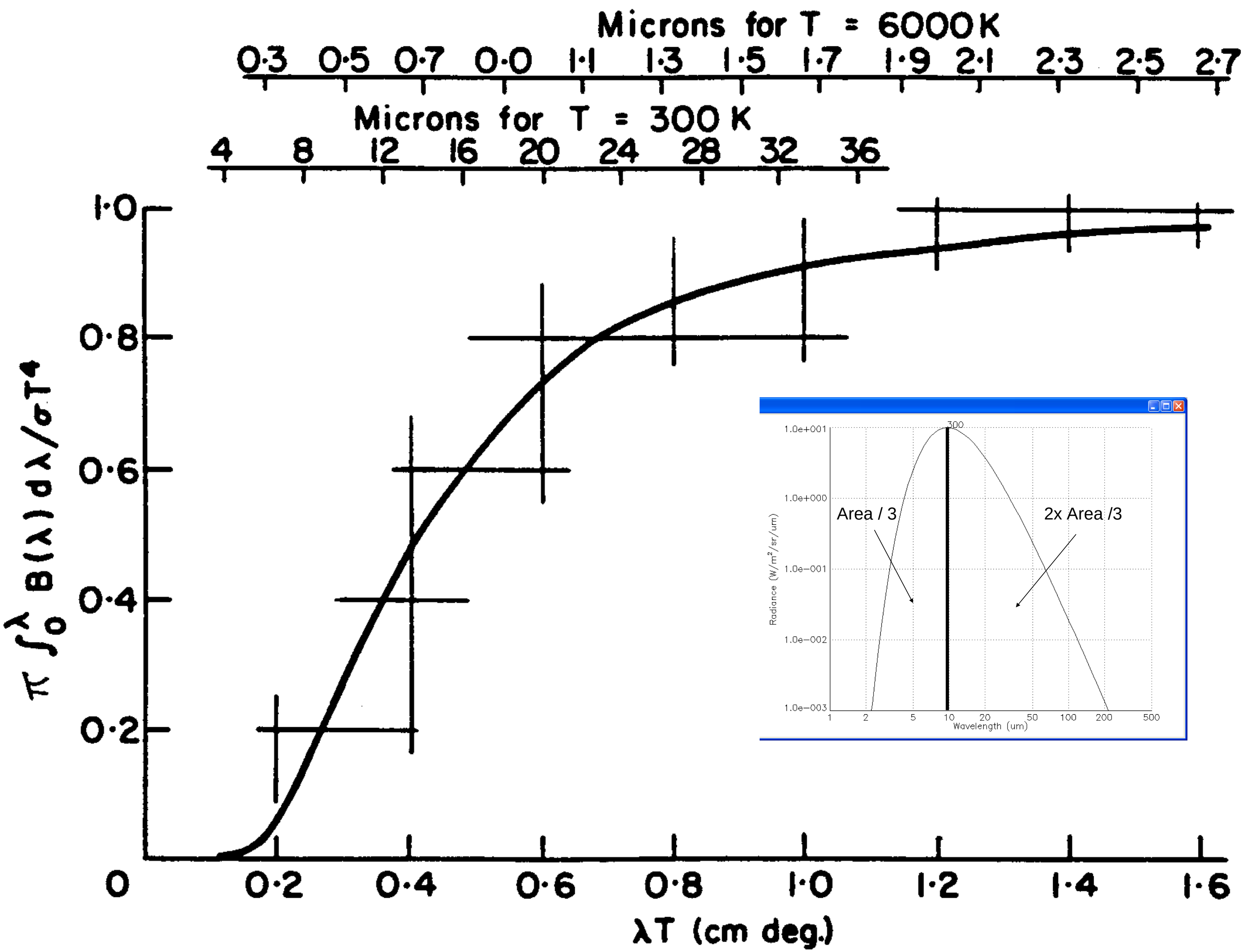
$B(\lambda_{max},T) \sim T^{**}5.$

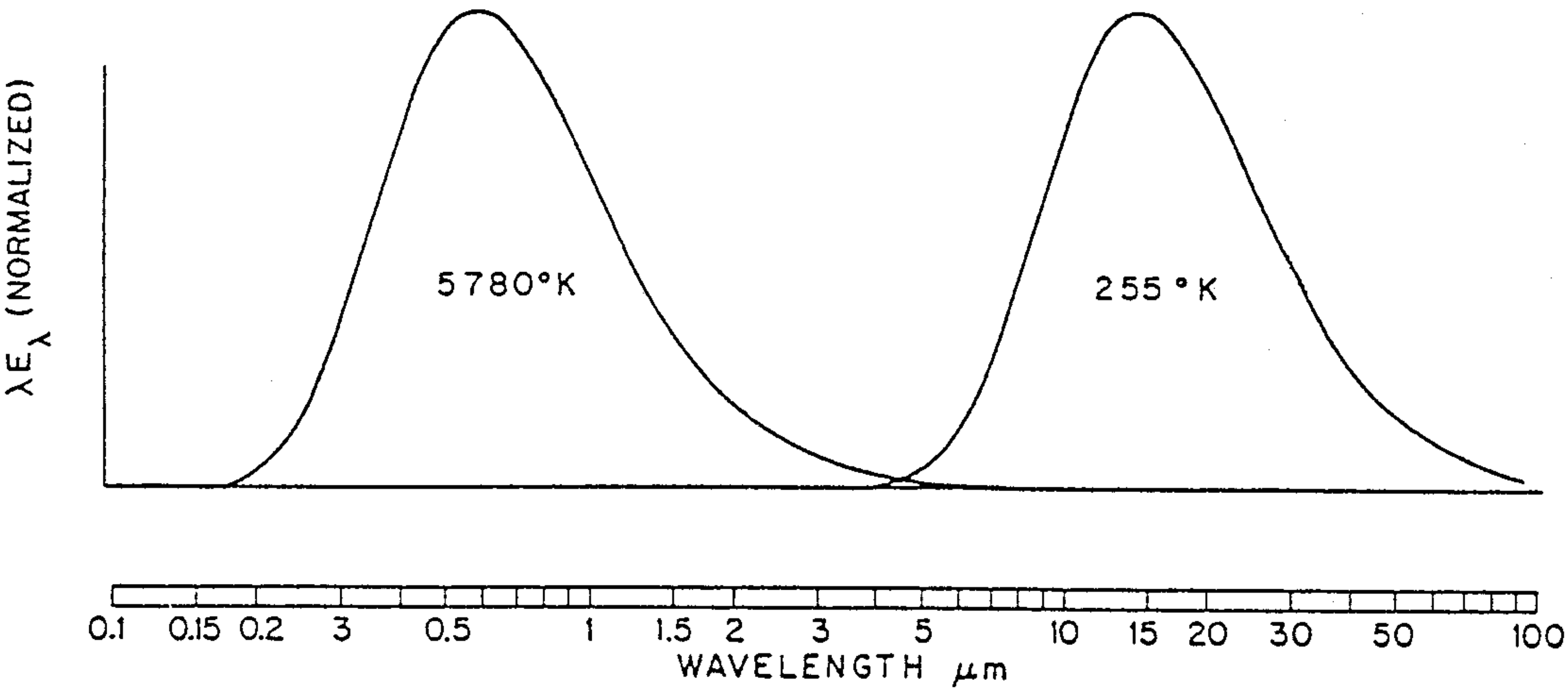
$$E = \pi \int_o^\infty B(\lambda,T)\, d\lambda = \sigma T^4,$$

$$T = c_2/[\lambda \ln(\frac{c_1}{\lambda^5 B_\lambda} + 1)]$$

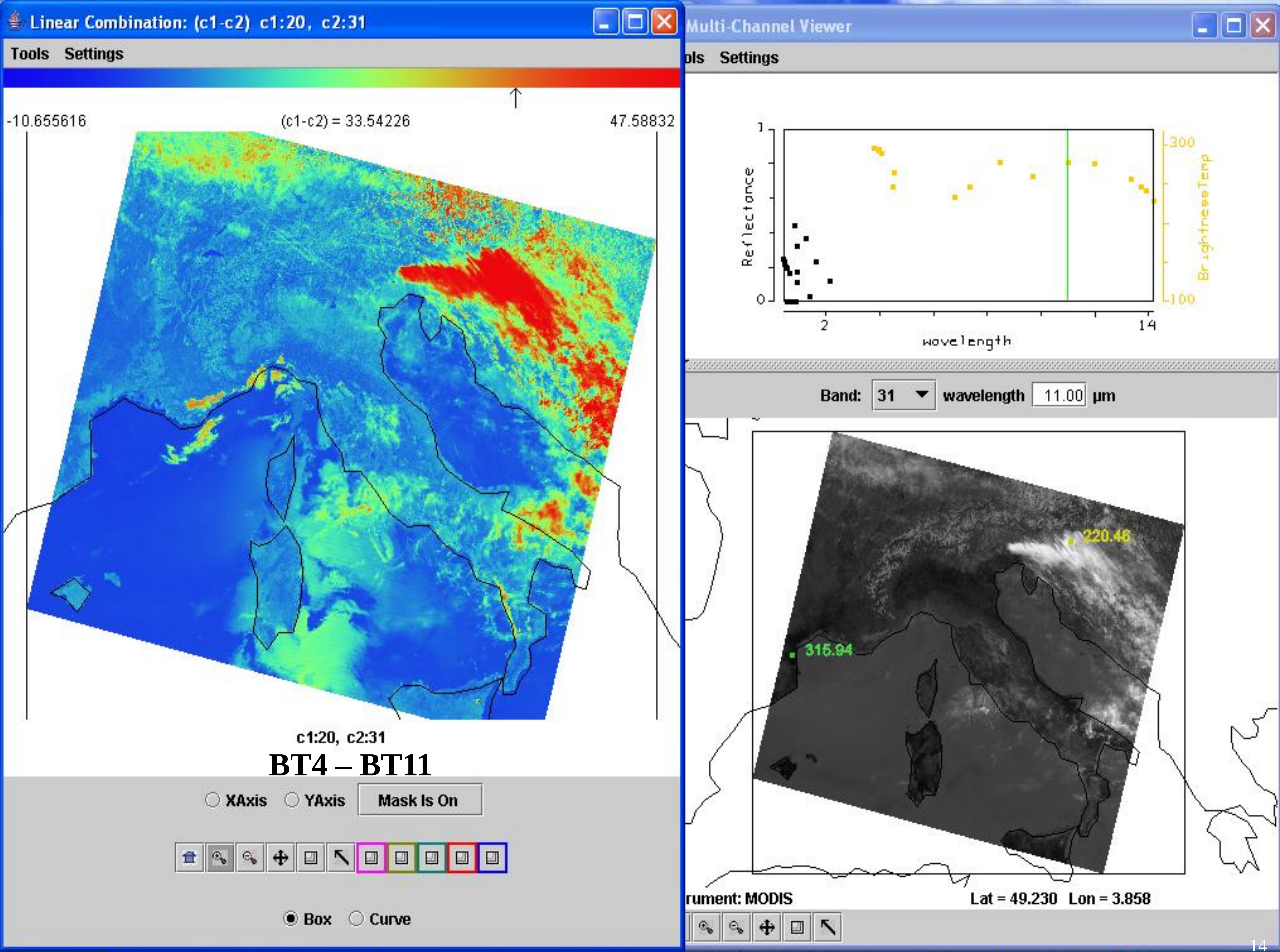
Spectral Distribution of Energy Radiated from Blackbodies at Various Temperatures



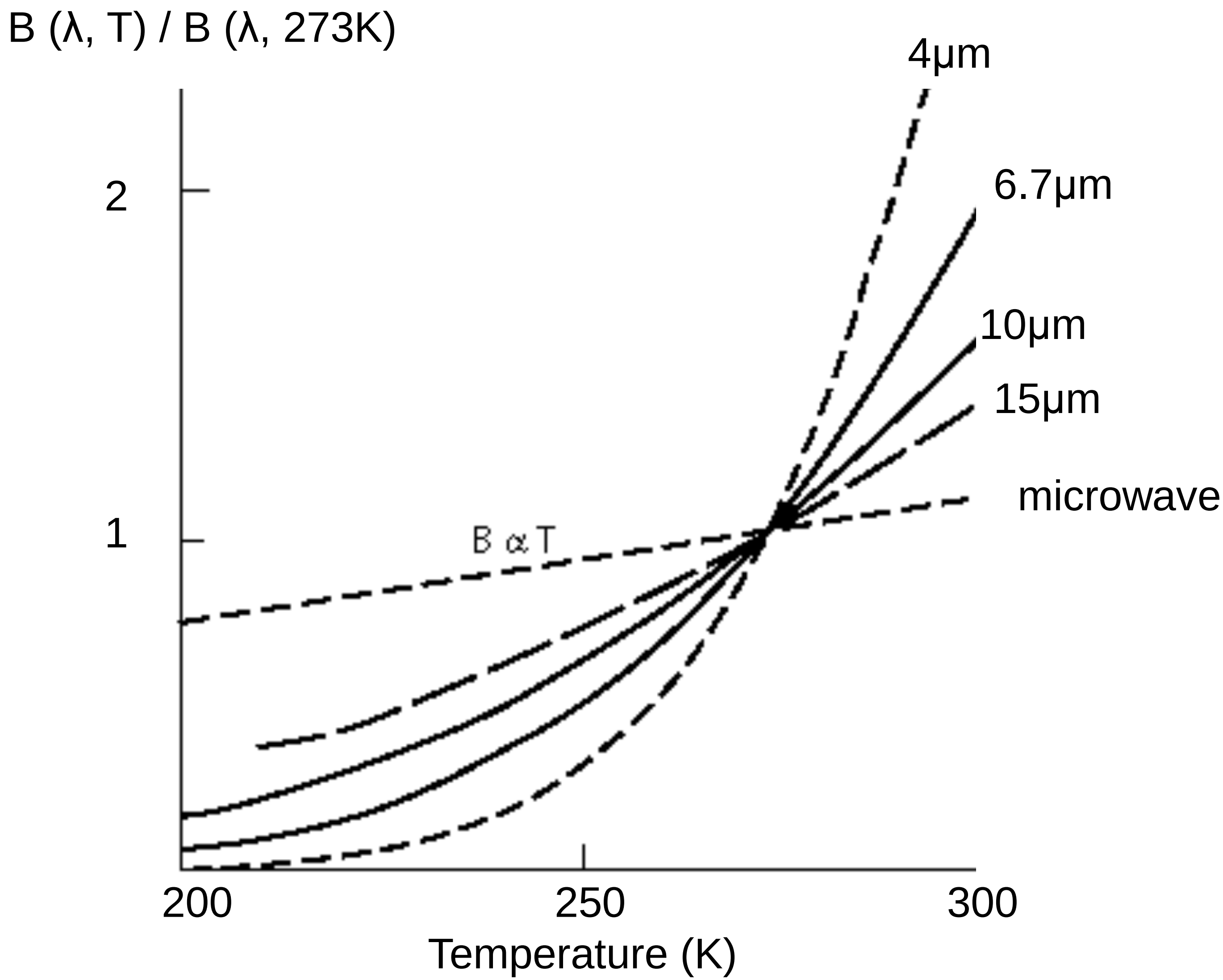

Microns for T = 6000 K
0·3 0·5 0·7 0·0 1·1 1·3 1·5 1·7 1·9 2·1 2·3 2·5 2·7
Microns for T = 300 K
4 8 12 16 20 24 28 32 36
1·0
0·8
0·6
0·4
0·2
0
$\pi \int_0^\lambda B(\lambda)\, d\lambda / \sigma T^4$
0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6
λT (cm deg.)
300
1.0e+001
1.0e+000
1.0e−001
1.0e−002
1.0e−003
Radiance (W/m²/sr/um)
Area / 3
2x Area /3
1 2 5 10 20 50 100 200 500
Wavelength (um)



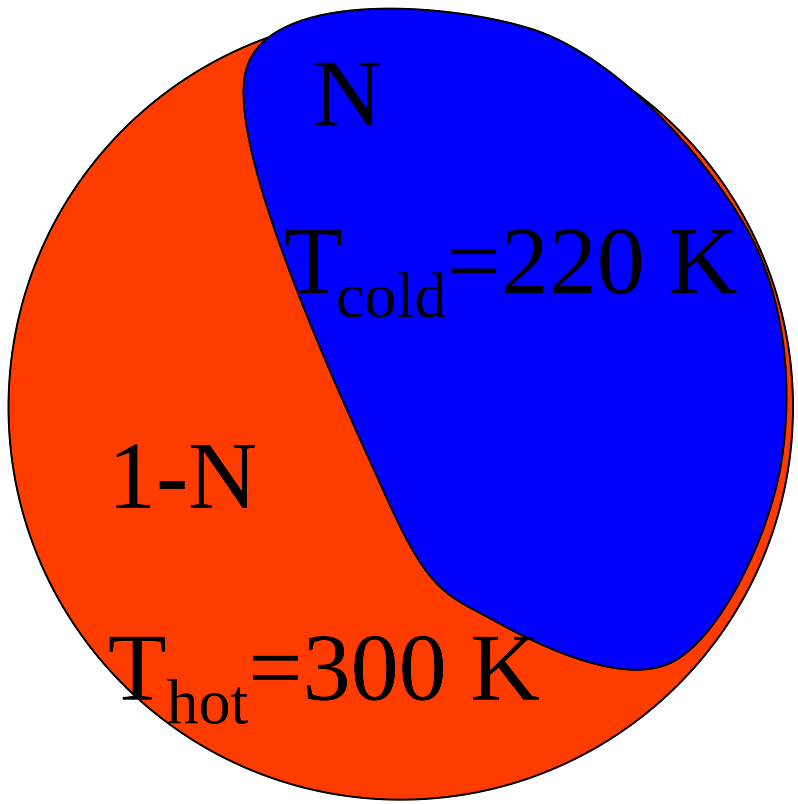
Normalized black body spectra representative of the sun (left) and earth (right), plotted on a logarithmic wavelength scale. The ordinate is multiplied by wavelength so that the area under the curves is proportional to irradiance.


Linear Combination: (c1-c2) c1:20, c2:31
Tools Settings
-10.655616
(c1-c2) = 33.54226
47.58832
c1:20, c2:31
BT4 – BT11
XAxis
YAxis
Mask Is On
Box
Curve
Multi-Channel Viewer
ols Settings
Reflectance
BrightnessTemp
300
100
1
0
2
14
wavelength
Band: 31 wavelength 11.00 µm
220.46
315.94
rument: MODIS
Lat = 49.230 Lon = 3.858

Temperature Sensitivity of B(λ,T) for typical earth temperatures

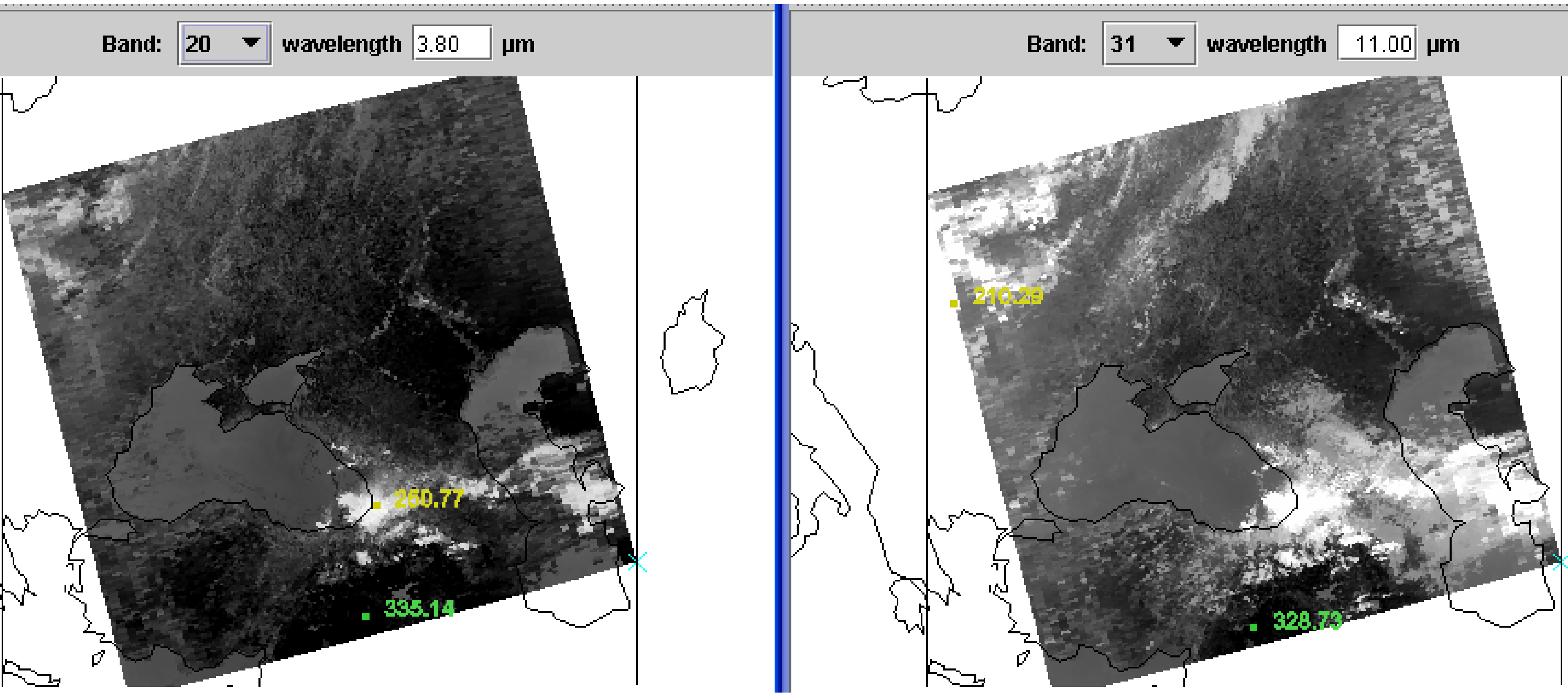


Non-Homogeneous FOV



$$B=N*B(T_{cold})+(1-N)*B(T_{hot})$$

$$BT=N*T_{cold}+(1-N)*T_{hot}$$

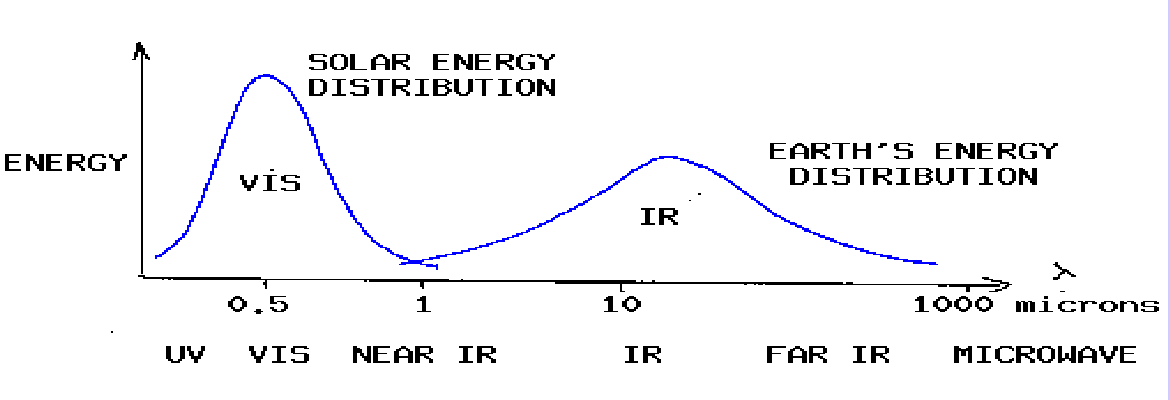


Cloud edges and broken clouds appear different in 11 and 4 um images.

$$T(11)^{4}=(1-N)*Tclr^{4}+N*Tcld^{4} \sim (1-N)*300^{4}+N*200^{4}$$
$$T(4)^{12}=(1-N)*Tclr^{12}+N*Tcld^{12} \sim (1-N)*300^{12}+N*200^{12}$$

Cold part of pixel has more influence for B(11) than B(4)

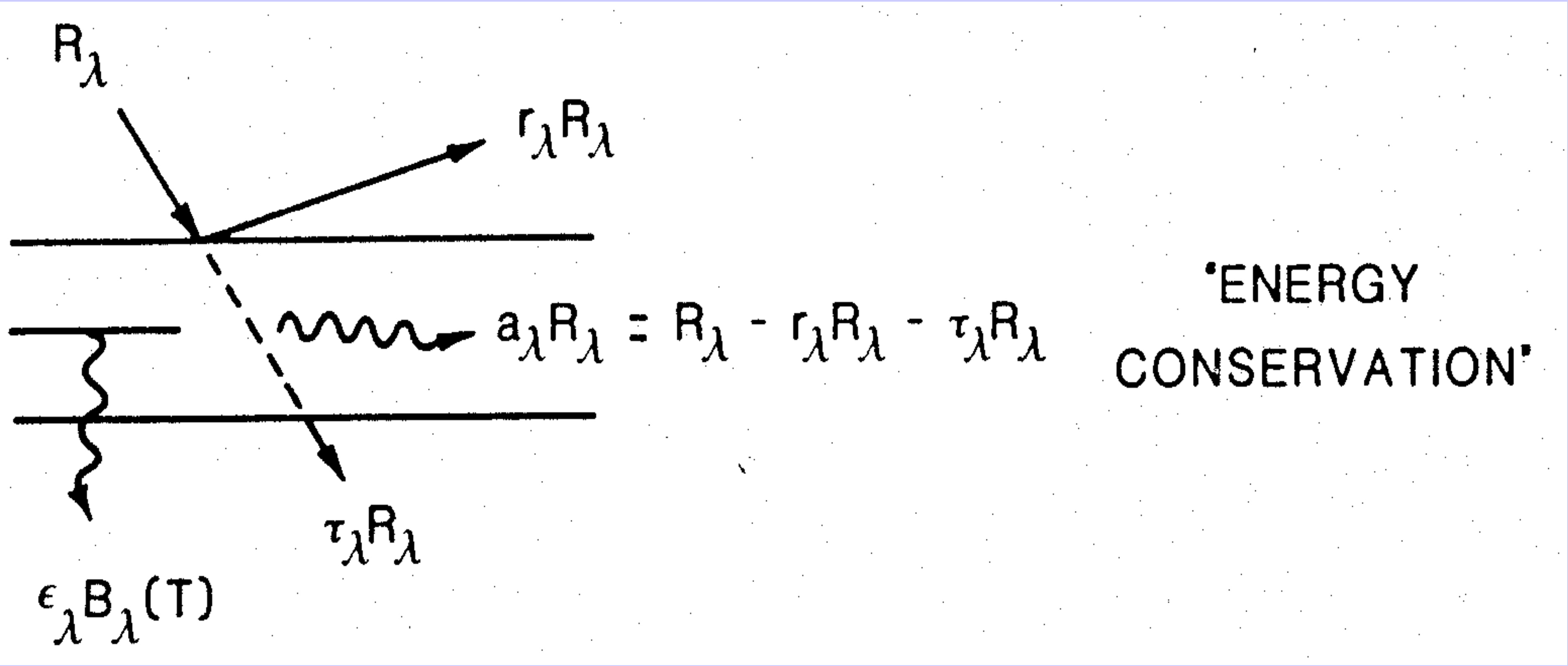
Solar (visible) and Earth emitted (infrared) energy



Incoming solar radiation (mostly visible) drives the earth-atmosphere (which emits infrared).

Over the annual cycle, the incoming solar energy that makes it to the earth surface (about 50 %) is balanced by the outgoing thermal infrared energy emitted through the atmosphere.

The atmosphere transmits, absorbs (by H2O, O2, O3, dust) reflects (by clouds), and scatters (by aerosols) incoming visible; the earth surface absorbs and reflects the transmitted visible. Atmospheric H2O, CO2, and O3 selectively transmit or absorb the outgoing infrared radiation. The outgoing microwave is primarily affected by H2O and O2.



Rλ
rλRλ
aλRλ = Rλ - rλRλ - τλRλ
'ENERGY
CONSERVATION'
τλRλ
ϵλBλ(T)

Selective Absorption
Atmosphere transmits visible and traps infrared

Incoming solar   Outgoing IR

$\downarrow E$ $\uparrow (1-a_l)\, Y_{sfc}$ $\uparrow Y_a$

______________________________ top of the atmosphere

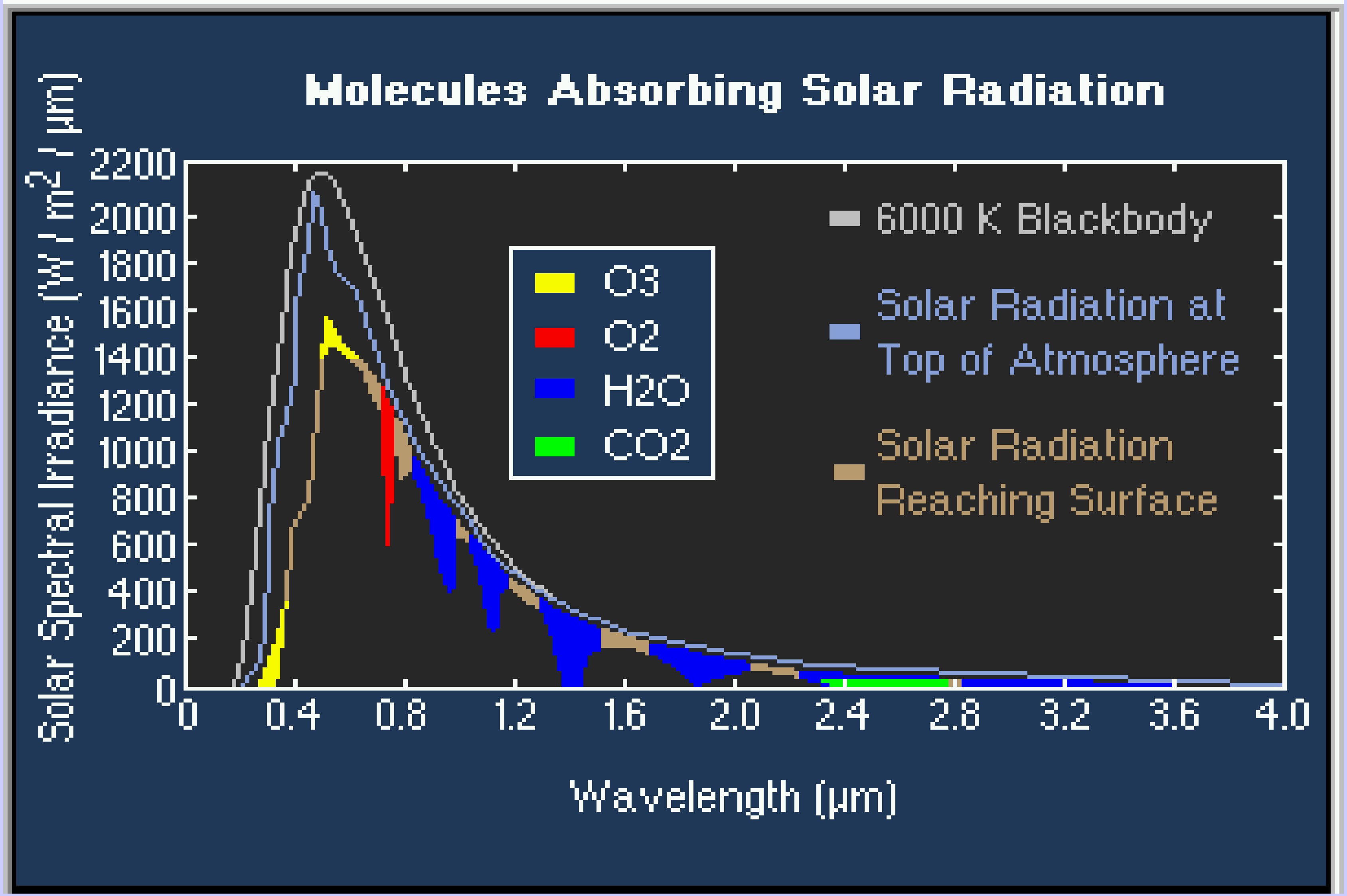
$\downarrow (1-a_s)\, E$ $\uparrow Y_{sfc}$ $\downarrow Y_a$

______________________________ earth surface.

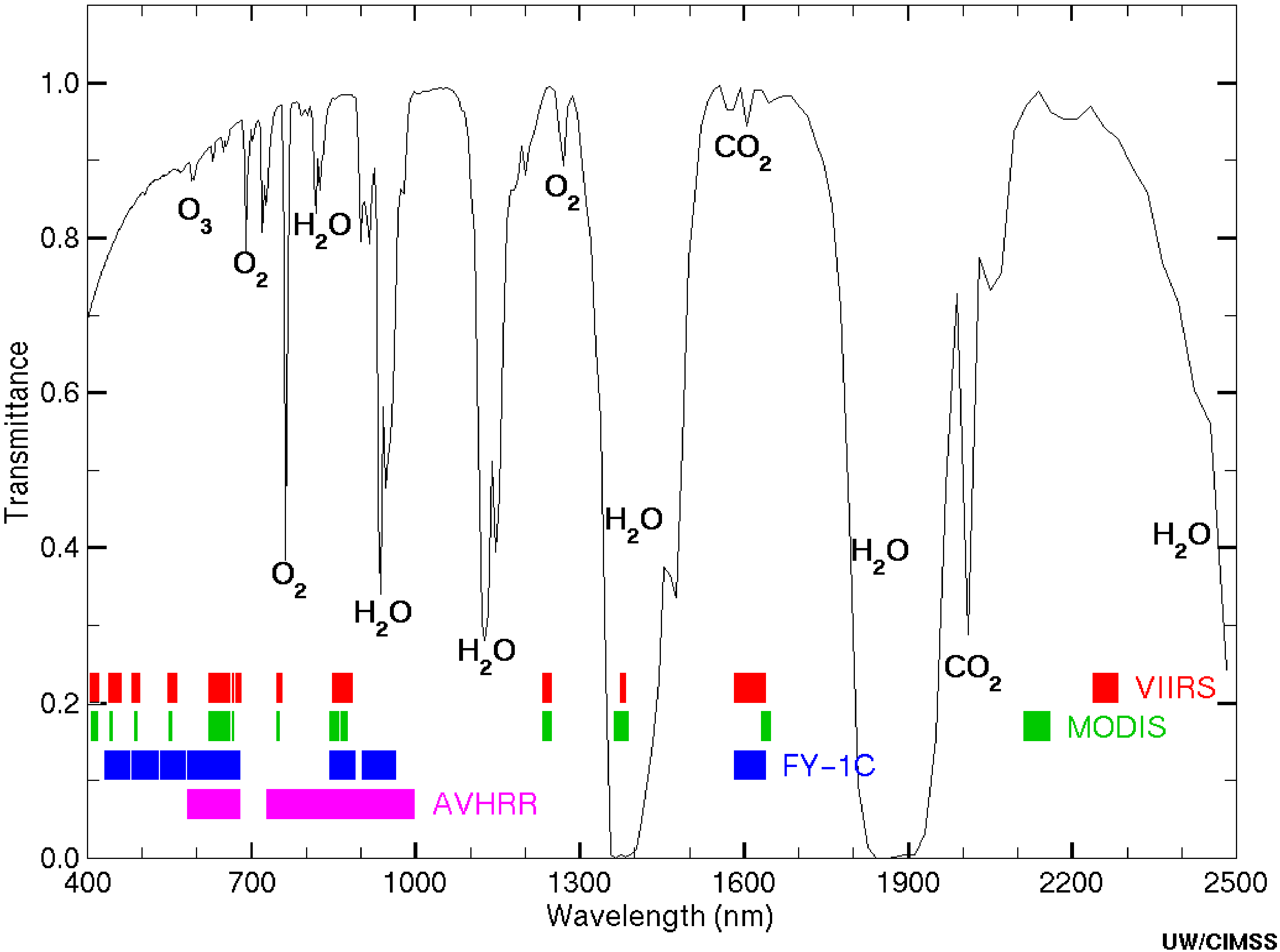
$$Y_{sfc} = \frac{(2-a_S)}{(2-a_L)} E = \sigma T_{sfc}^4$$

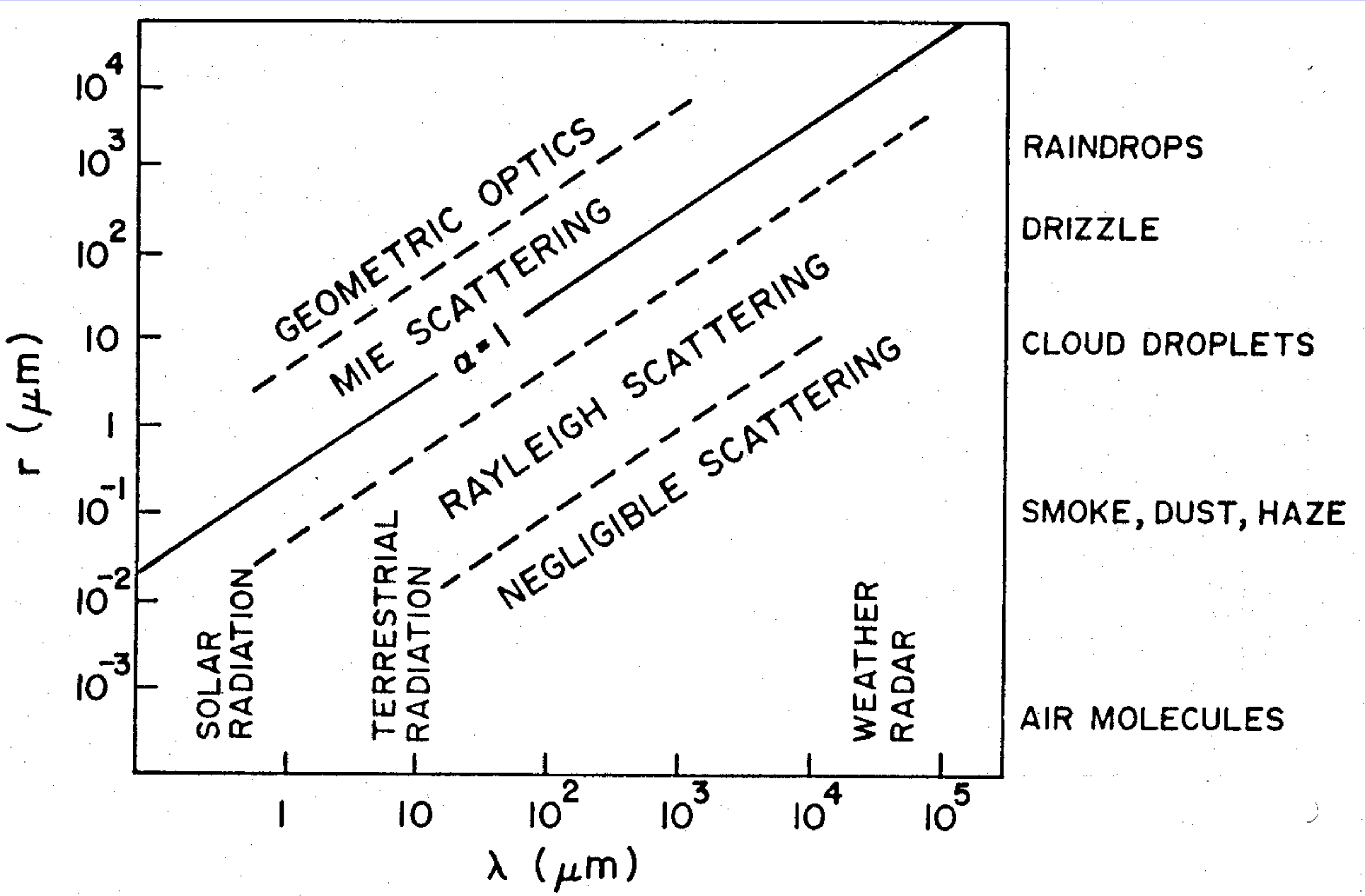
thus if $a_s < a_L$ then $Y_{sfc} > E$

Solar Spectrum



VIIRS, MODIS, FY-1C, AVHRR





GEOMETRIC OPTICS
MIE SCATTERING
α=1
RAYLEIGH SCATTERING
NEGLIGIBLE SCATTERING
SOLAR RADIATION
TERRESTRIAL RADIATION
WEATHER RADAR
r (μm)
λ (μm)
RAINDROPS
DRIZZLE
CLOUD DROPLETS
SMOKE, DUST, HAZE
AIR MOLECULES

Aerosol Size Distribution

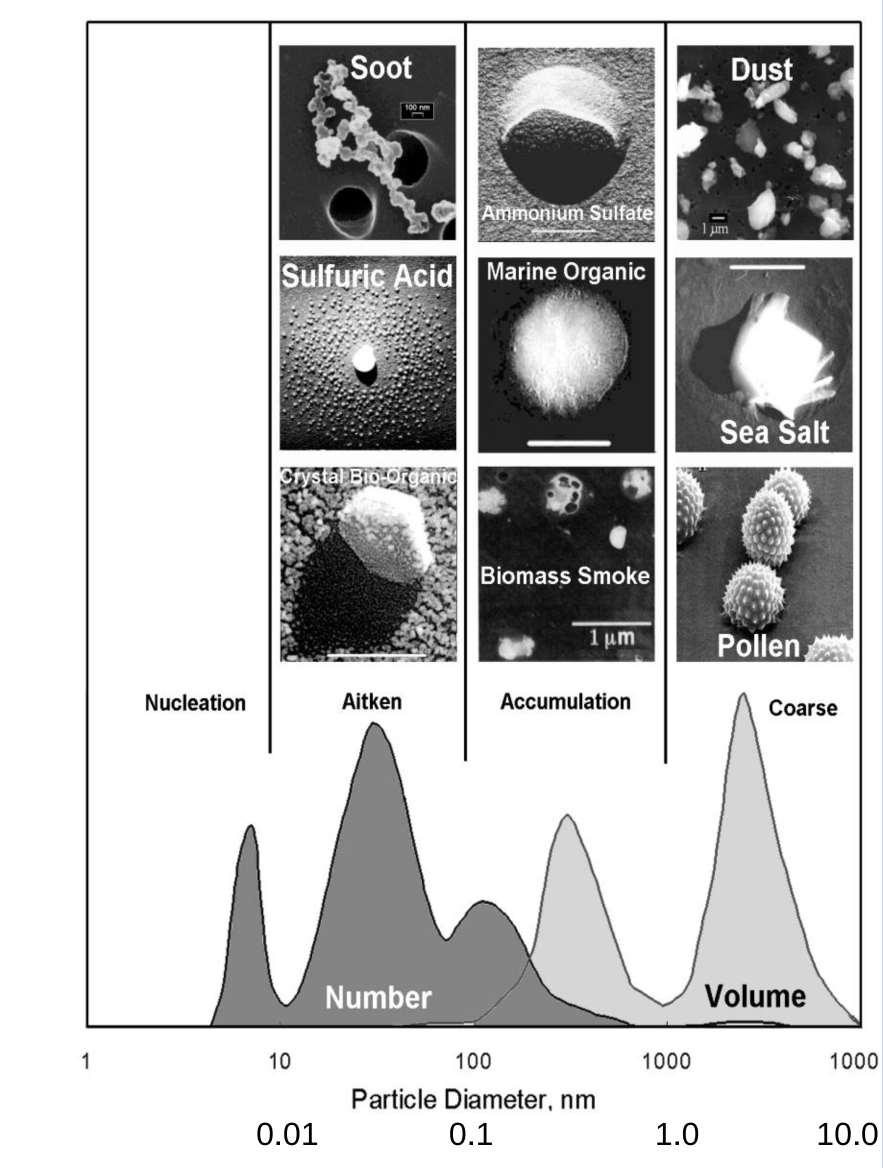
There are 3 modes :

- « **nucleation** »: radius is between 0.002 and 0.05 µm. They result from combustion processes, photo-chemical reactions, etc.

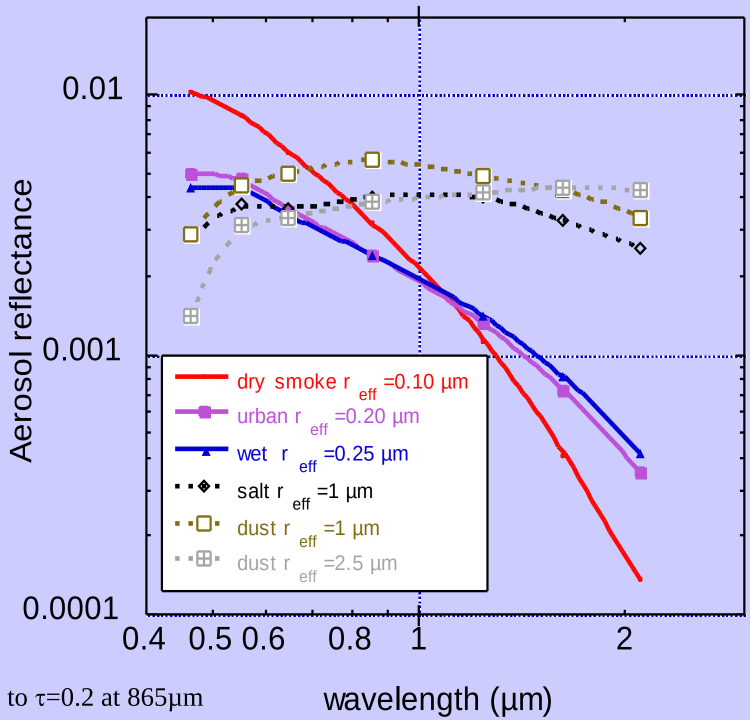
- « **accumulation »:** radius is between 0.05 µm and 0.5 µm. Coagulation processes.

- « **coarse** »: larger than 1 µm. From mechanical processes like aeolian erosion.

« fine » particles (nucleation and accumulation) result from anthropogenic activities, coarse particles come from natural processes.



Aerosols over Ocean

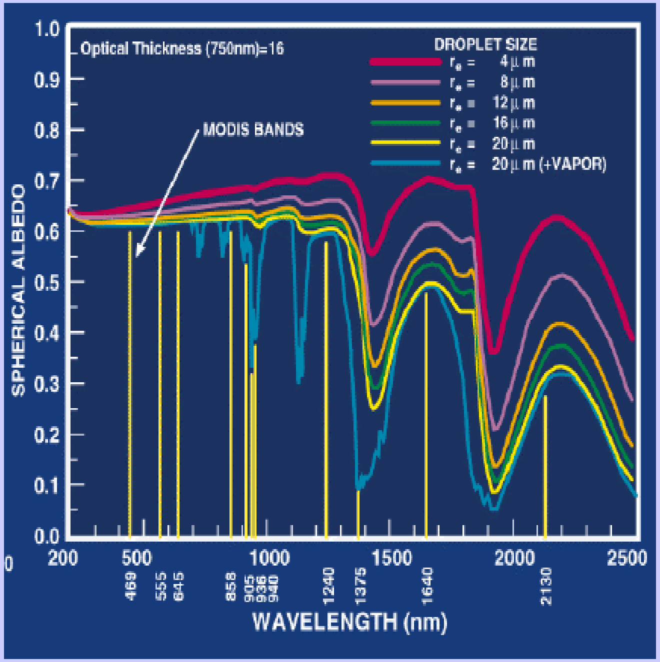


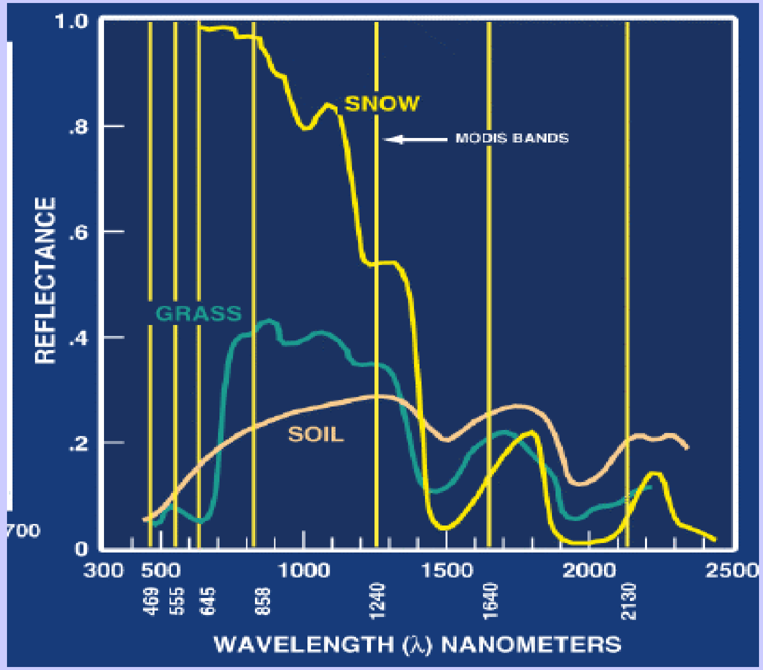
Normalized to τ=0.2 at 865µm

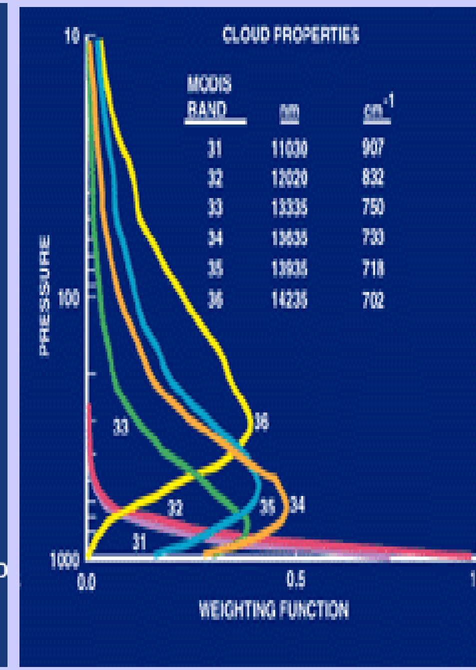
- Radiance data in 6 bands (550-2130nm).
- Spectral radiances (LUT) to derive the aerosol size distribution
- Two modes (accumulation 0.10-0.25µm; coarse1.0-2.5µm); ratio is a free parameter
- Radiance at 865µm to derive τ

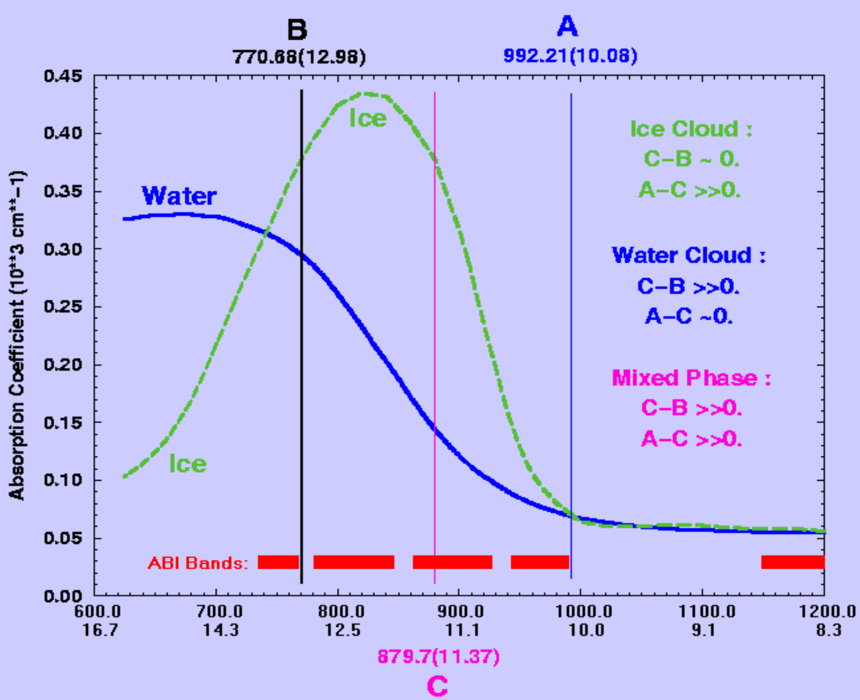
Ocean products :

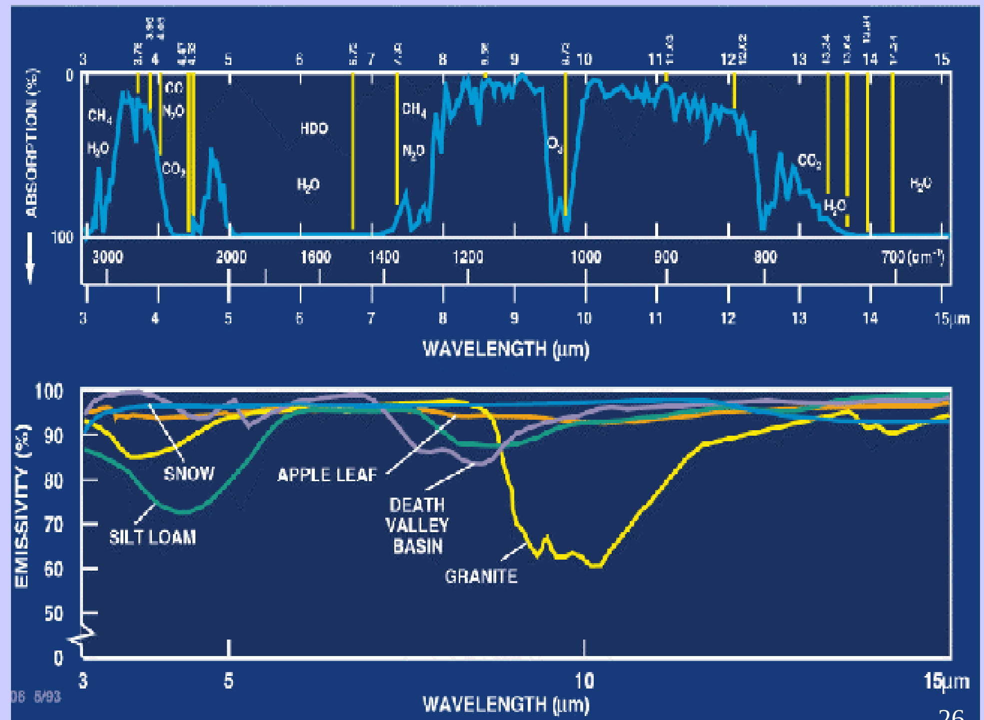
- The total Spectral Optical thickness
- The effective radius
- The optical thickness of small & large modes/ratio between the 2 modes

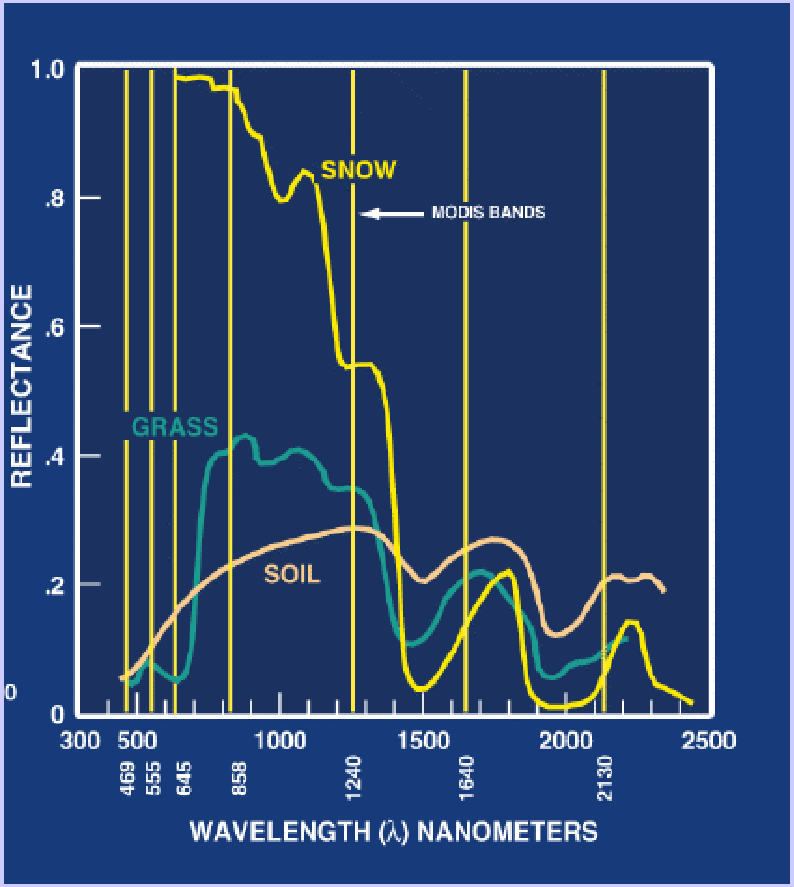

Optical Thickness (750nm)=16
DROPLET SIZE
MODIS BANDS
SPHERICAL ALBEDO
WAVELENGTH (nm)
469
555
645
858
905
936
940
1240
1375
1640
2130


SNOW
MODIS BANDS
GRASS
SOIL
REFLECTANCE
WAVELENGTH (λ) NANOMETERS
469
555
645
858
1240
1640
2130


CLOUD PROPERTIES
PRESSURE
WEIGHTING FUNCTION


B
770.66(12.98)
A
992.21(10.08)
Water
Ice
Ice Cloud :
C–B ~ 0.
A–C >>0.
Water Cloud :
C–B >>0.
A–C ~0.
Mixed Phase :
C–B >>0.
A–C >>0.
ABI Bands:
Absorption Coefficient (10**3 cm**–1)
879.7(11.37)
C


ABSORPTION (%)
HDO
WAVELENGTH (μm)
EMISSIVITY (%)
SNOW
APPLE LEAF
DEATH
VALLEY
BASIN
SILT LOAM
GRANITE
WAVELENGTH (μm)

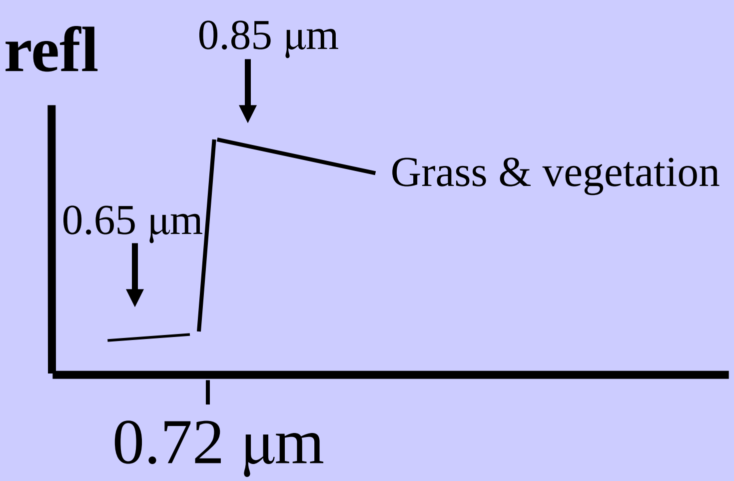


Investigating with Multi-spectral Combinations

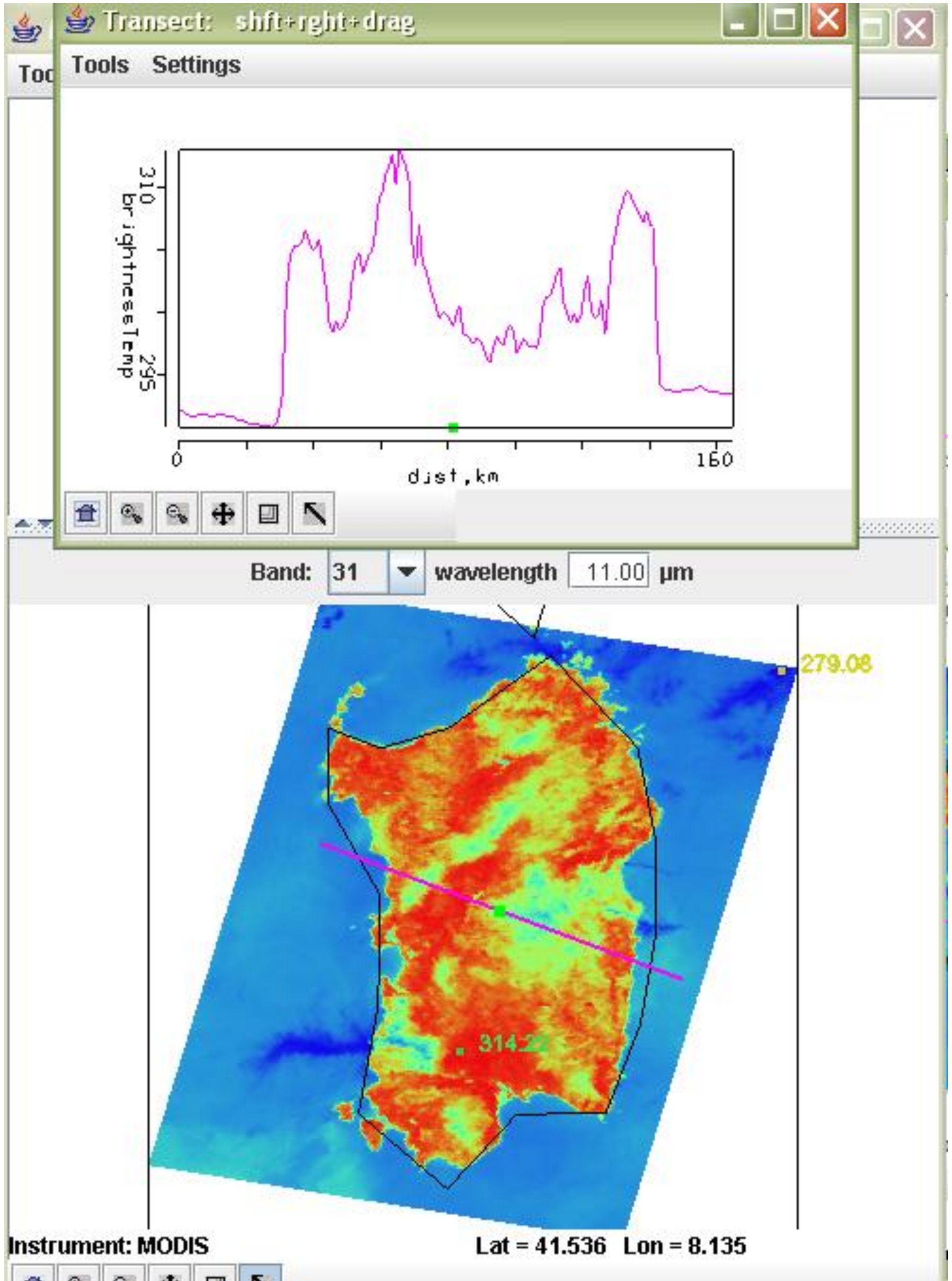
Given the spectral response of a surface or atmospheric feature

Select a part of the spectrum where the reflectance or absorption changes with wavelength

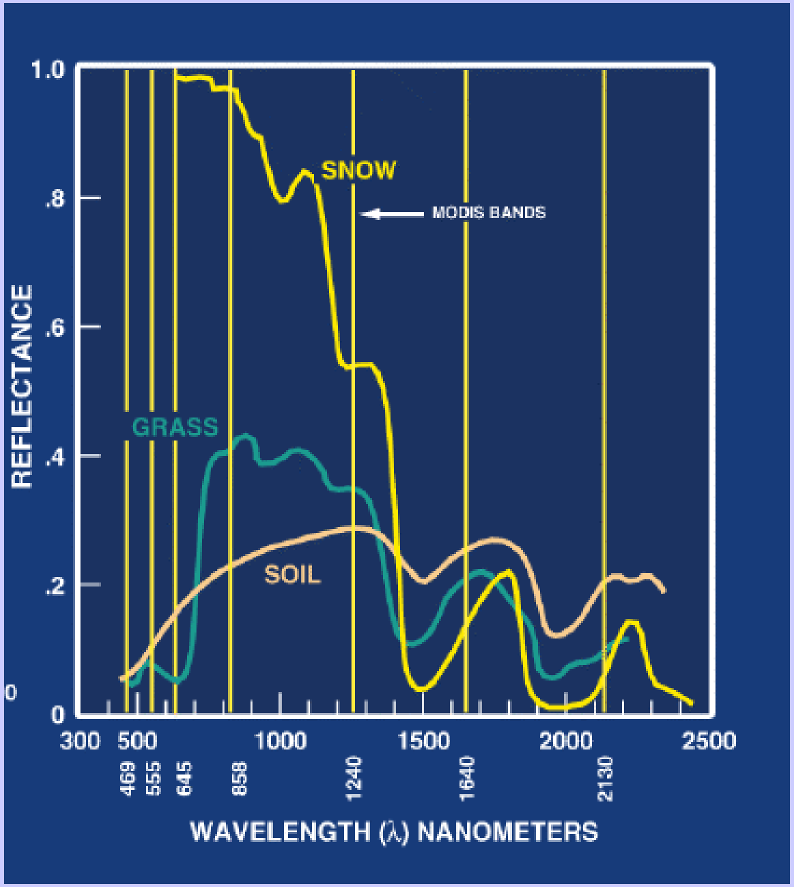
e.g. reflection from grass



If 0.65 µm and 0.85 µm channels see the same reflectance than surface viewed is not grass;
if 0.85 µm sees considerably higher reflectance than 0.65 µm then surface might be grass



NOTE: transect of BT11 through vegetated to non-vegetated areas in clear skies. – vegetated areas are warmer then the sea but cooler in BT then non-vegetated areas (displayed in RED)

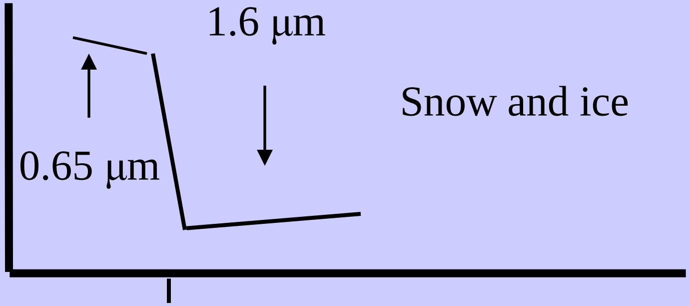


Investigating with Multi-spectral Combinations

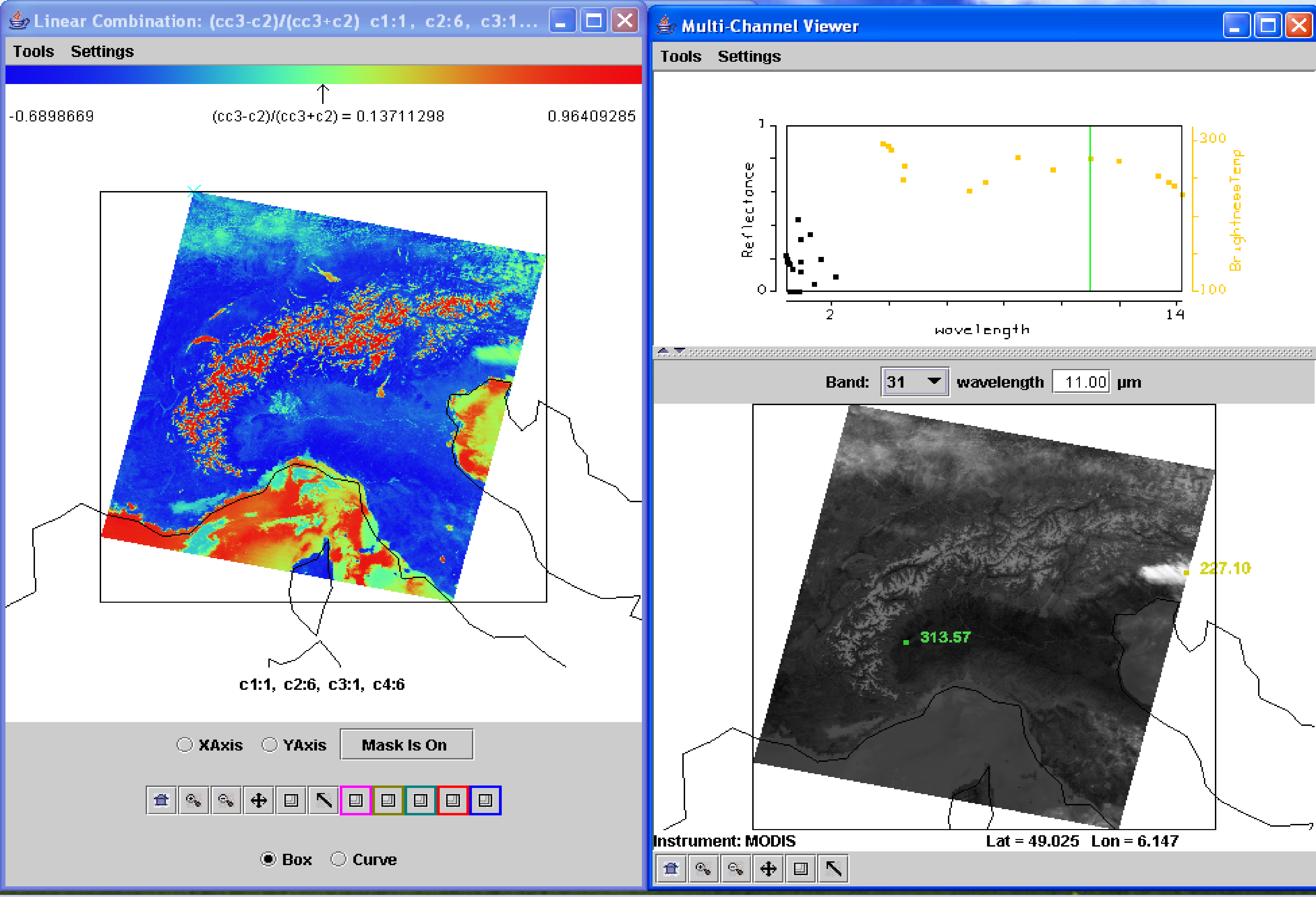
Given the spectral response of a surface or atmospheric feature

Select a part of the spectrum where the reflectance or absorption changes with wavelength

e.g. reflection from snow/ice

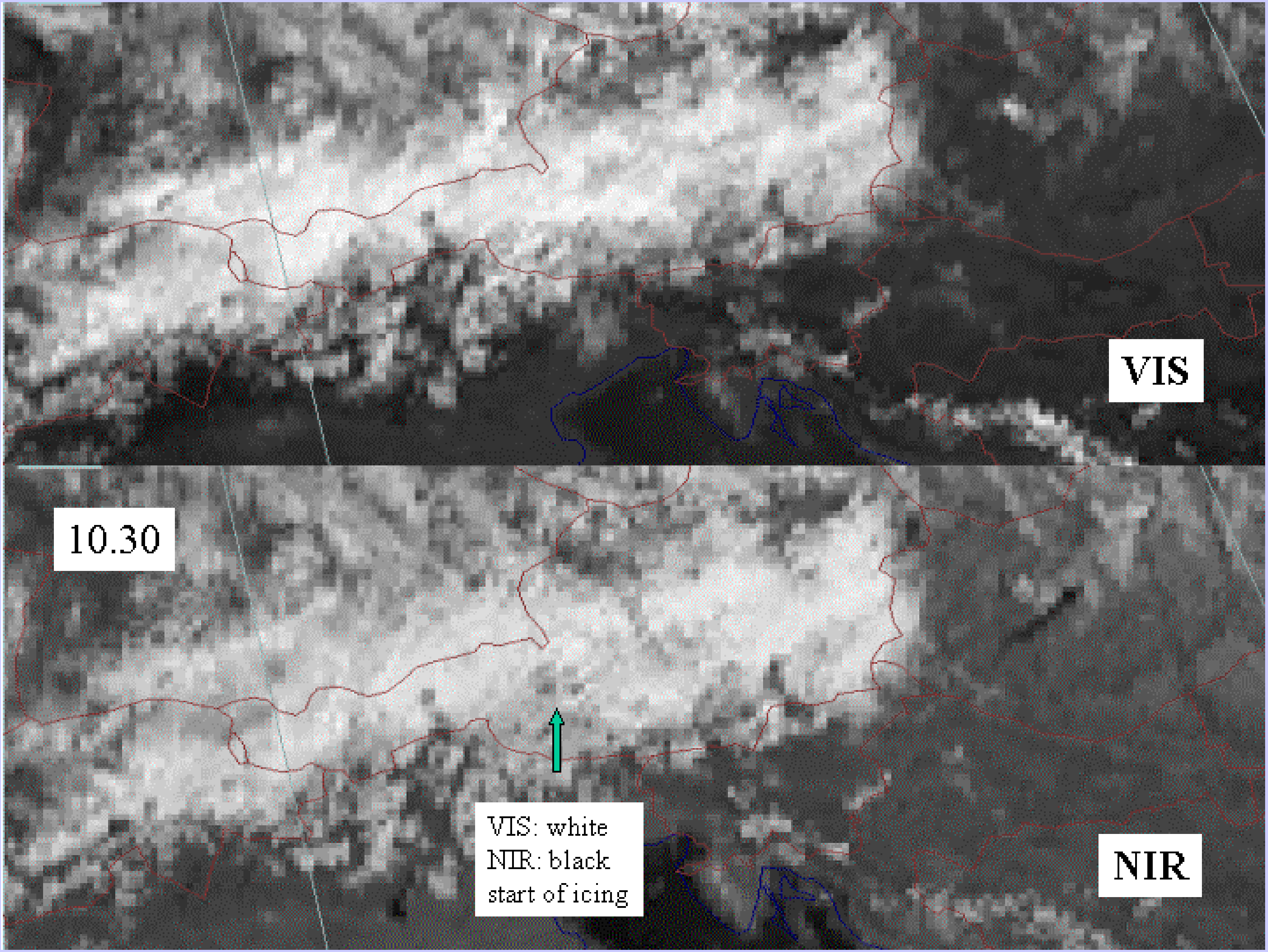


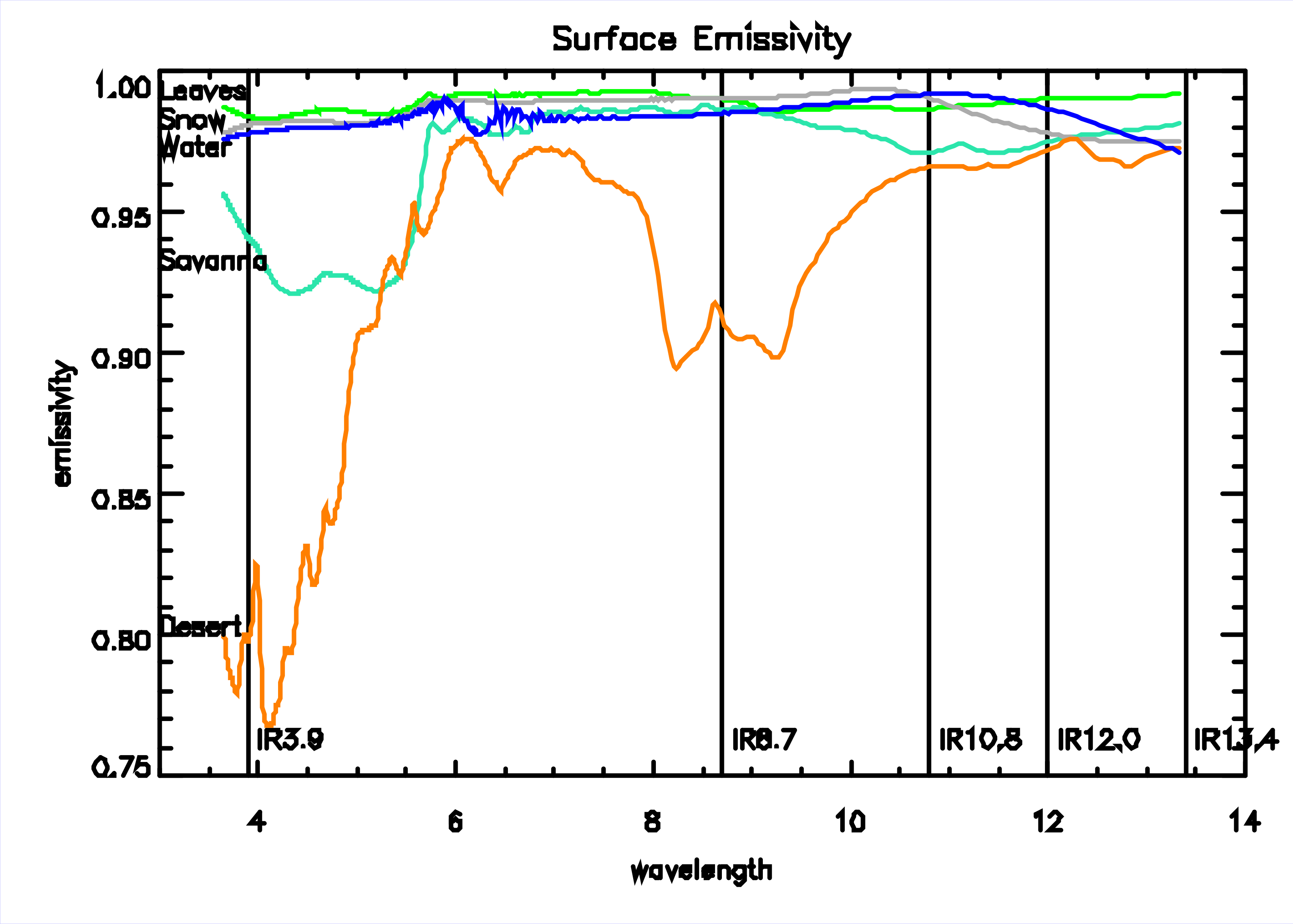
If 0.65 μm and 1.6 μm channels see the same reflectance than surface viewed is not snow;
if 1.6 μm sees considerably lower reflectance than 0.65 μm then surface might be snow



NDSI = [r0.6-r1.6]/[r0.6+r1.6] is near one in snow in Alps

Meteosat-8 sees icing in clouds (Lutz et al)

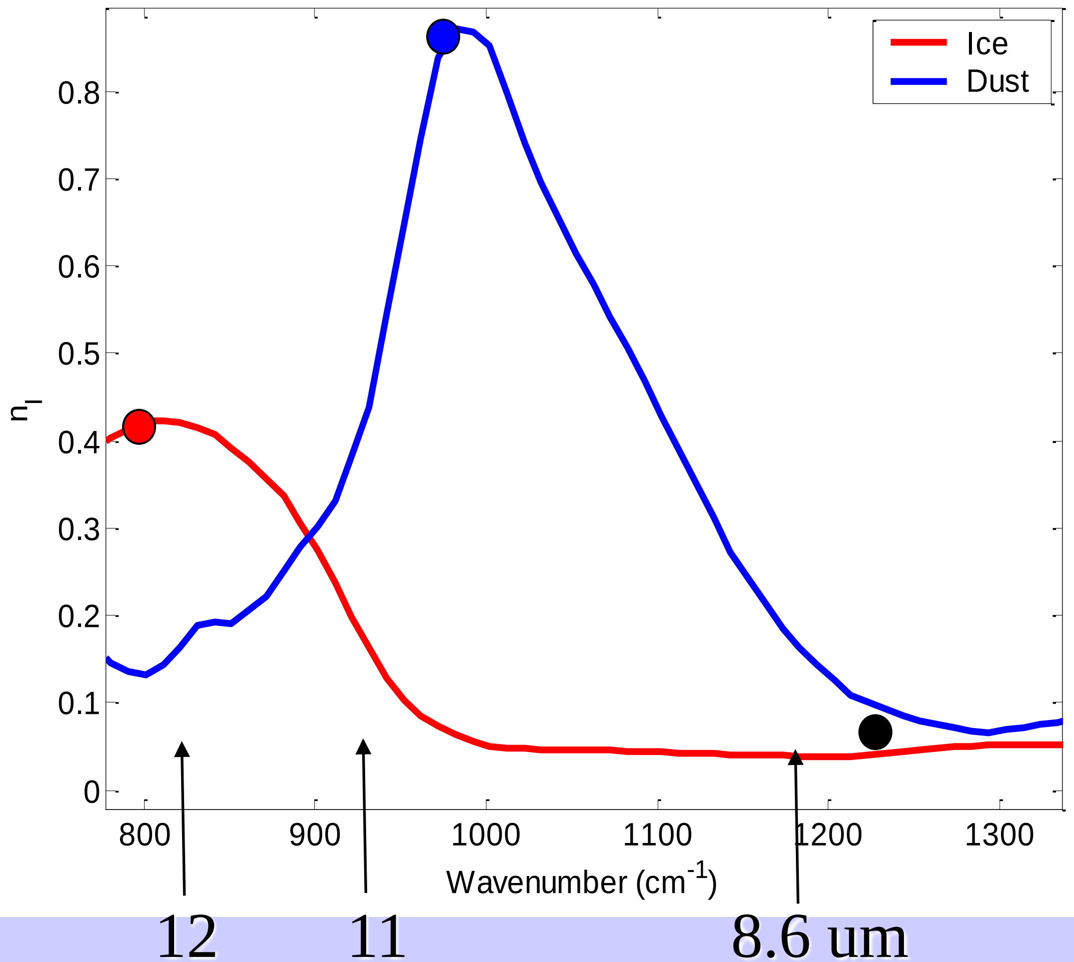




Surface Emissivity
1.00
0.95
0.90
0.85
0.80
0.75
emissivity
Leaves
Snow
Water
Savanna
Desert
IR3.9
IR8.7
IR10.8
IR12.0
IR13.4
4
6
8
10
12
14
wavelength

Dust and Cirrus Signals

Imaginary Index of Refraction of Ice and Dust



- Both ice and silicate absorption small in 1200 cm^{-1} window
- In the 800-1000 cm^{-1} atmospheric window:

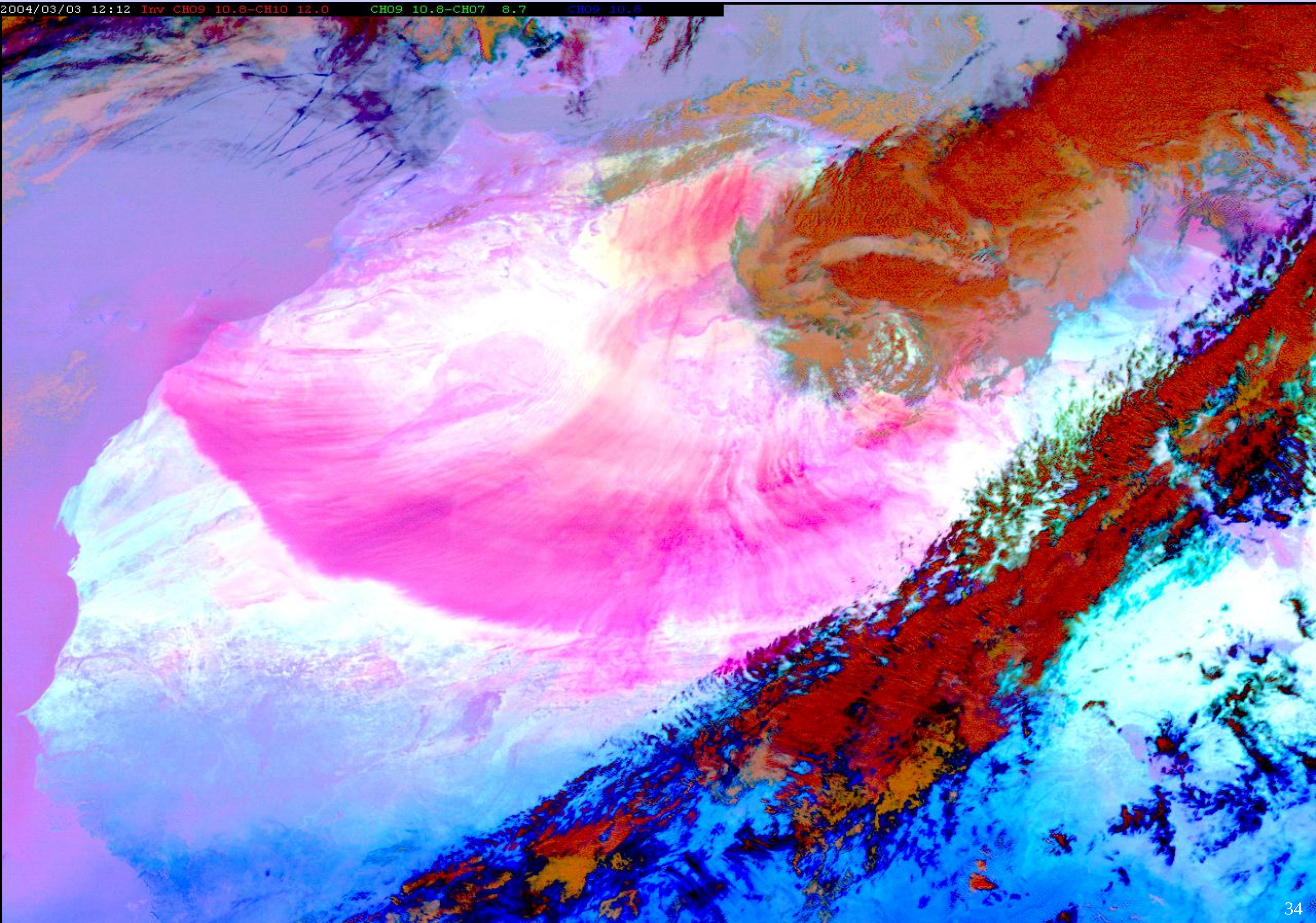
  Silicate index *increases*

  Ice index *decreases*

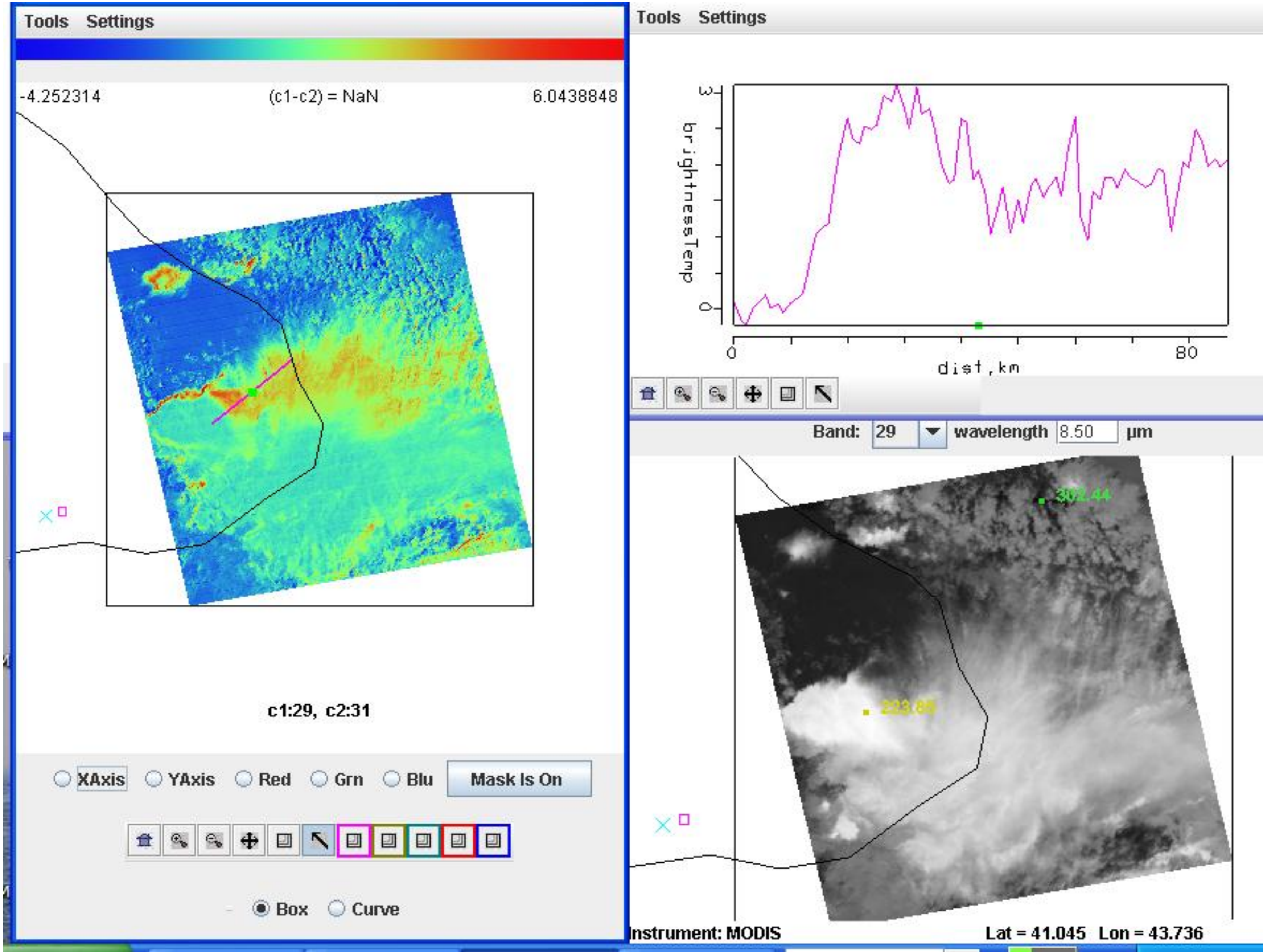
  with wavenumber

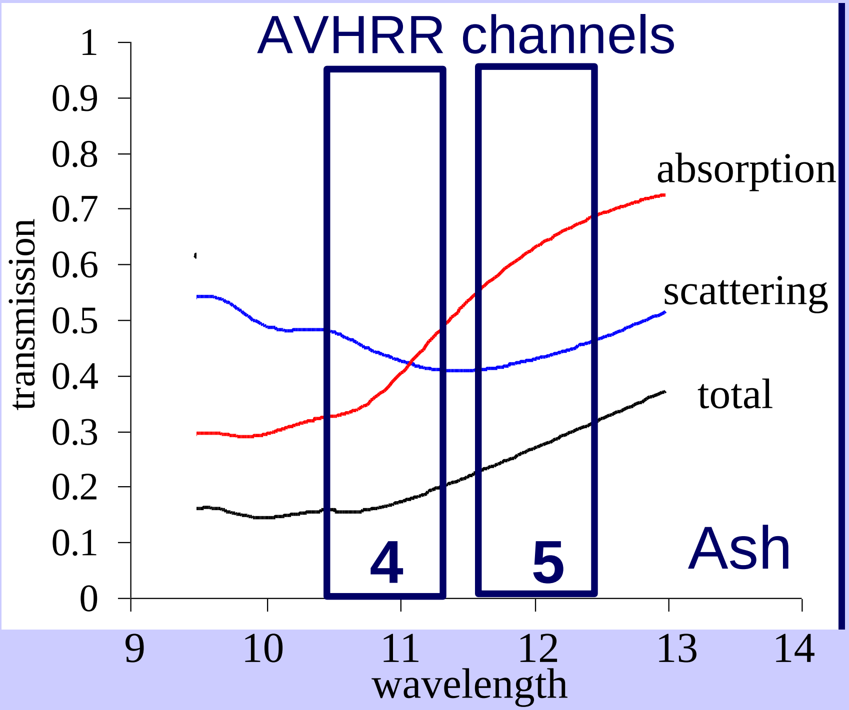
Volz, F.E. : Infrared optical constant of ammonium sulphate, Sahara Dust, volcanic pumice and flash, Appl Optics **12** 564-658 (1973)

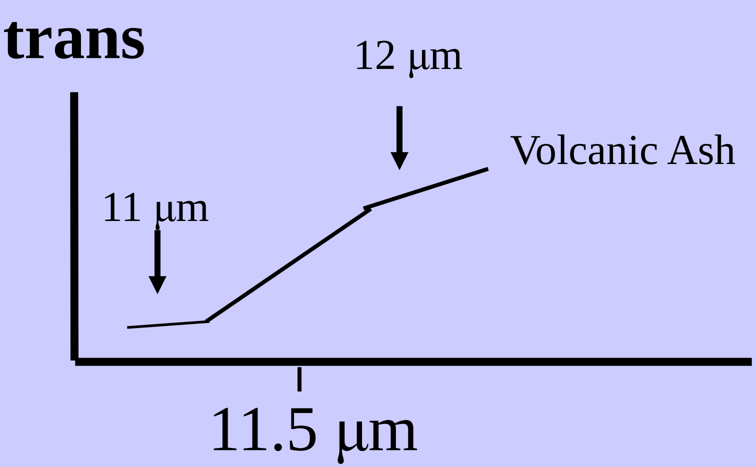
SEVIRI sees dust storm over Africa



[BT8.6-BT11] changes sign from thin (transmittting) to thick (emitting) ice cloud







Investigating with Multi-spectral Combinations

Given the spectral response of a surface or atmospheric feature

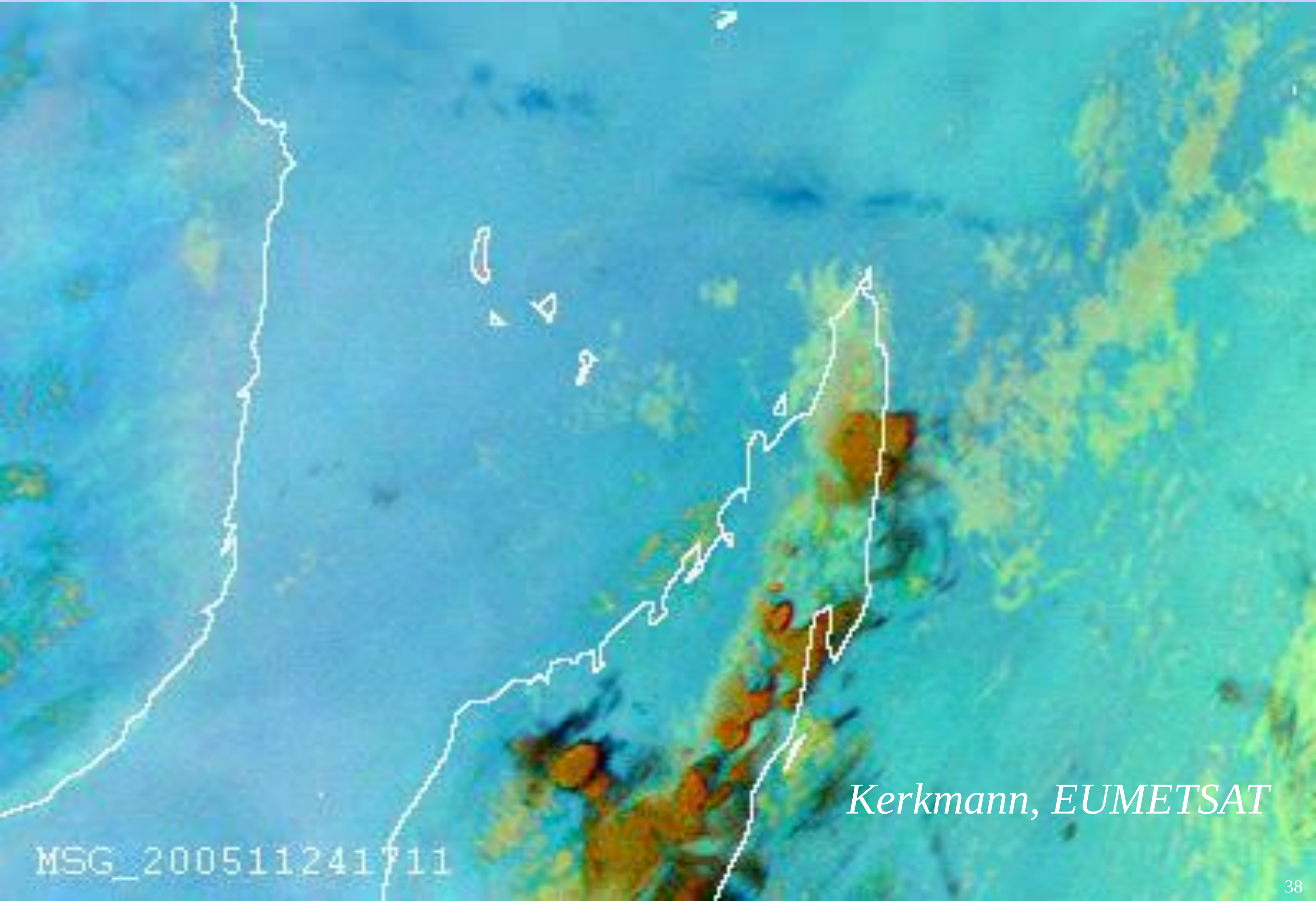
Select a part of the spectrum where the reflectance or absorption changes with wavelength

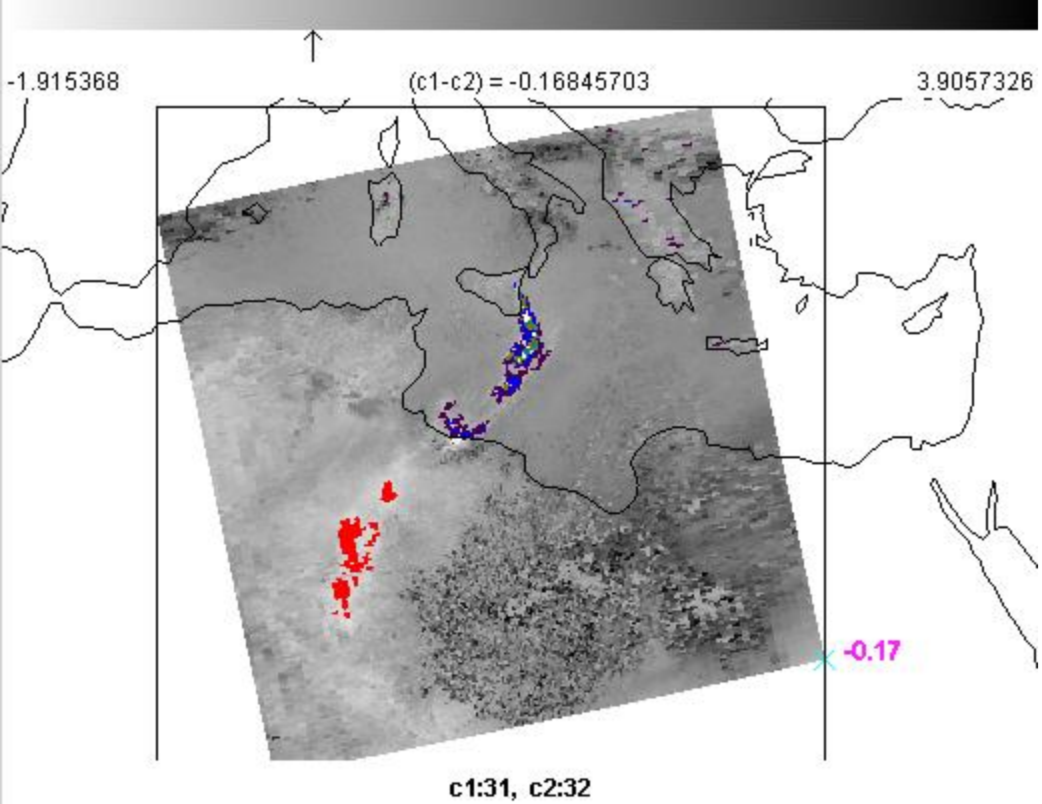
e.g. transmission through ash

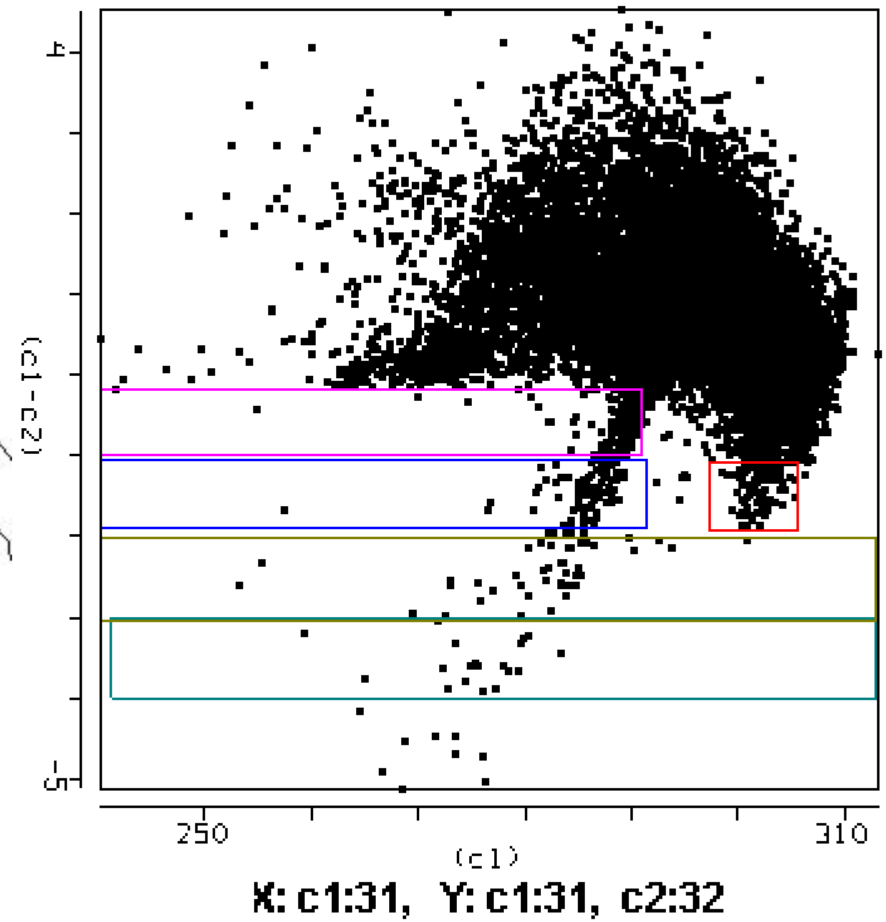
If 11 µm sees the same or higher BT than 12 µm the atmosphere viewed does not contain volcanic ash;
if 12 µm sees considerably higher BT than 11 µm then the atmosphere probably contains volcanic ash

Frank Honey, CSIRO 1980s

SEVIRI sees volcanic ash & SO2 and downwind inhibition of convection



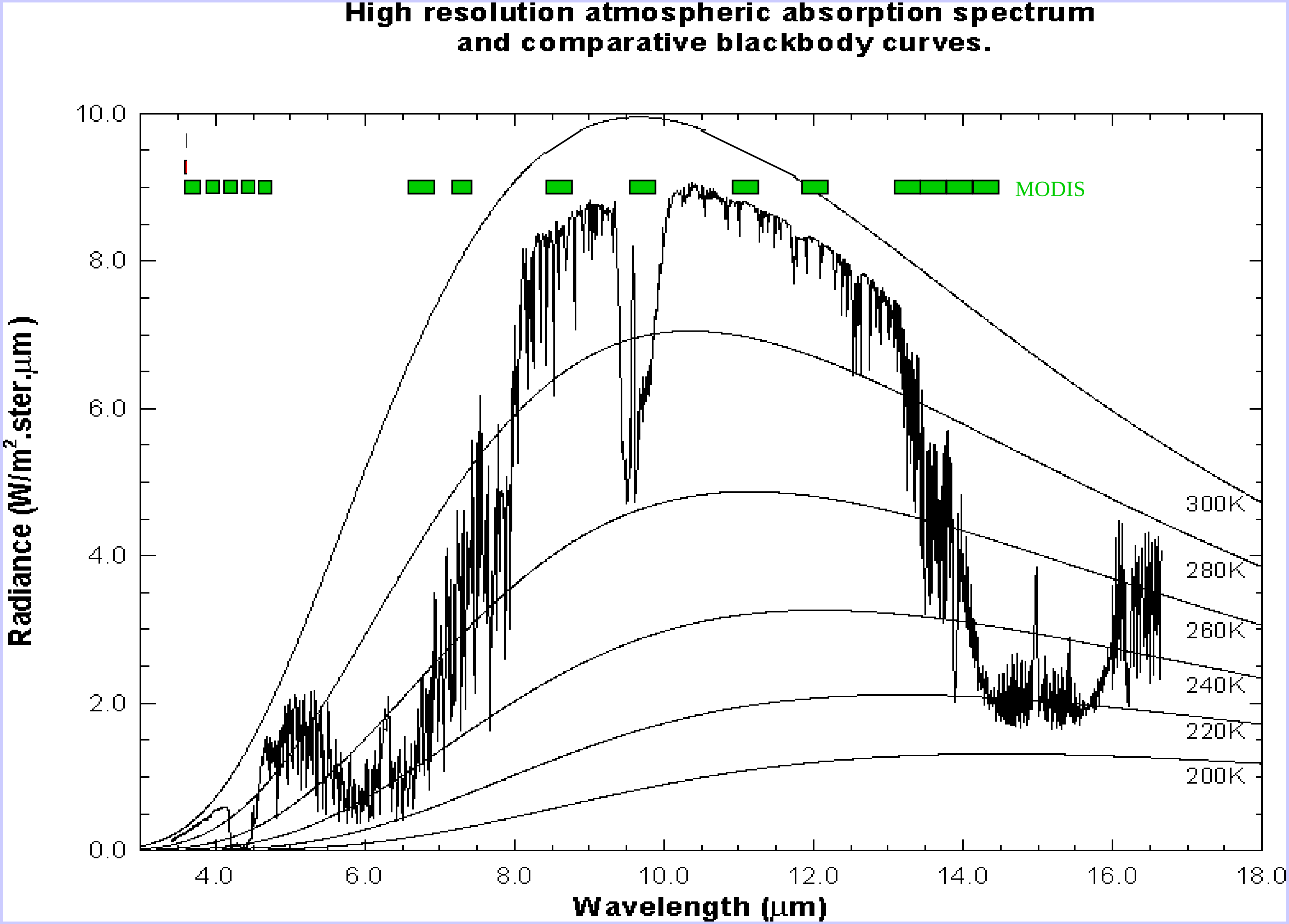




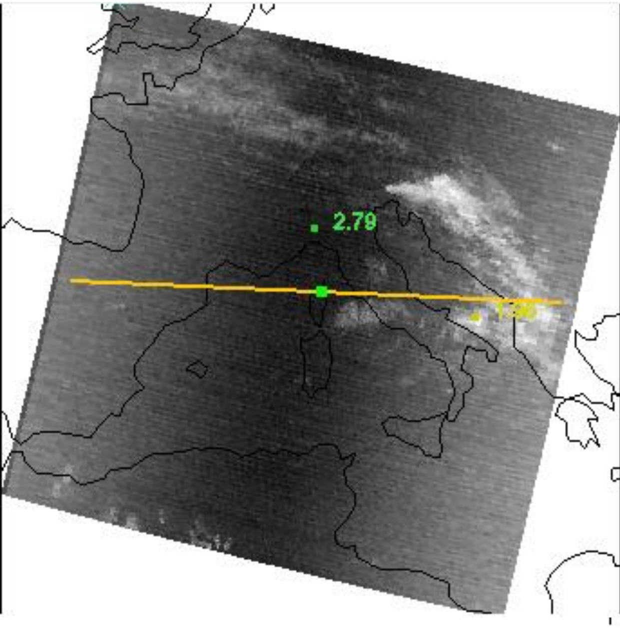
Volcanic Ash is characterised by low brightness temperatures (i.e. High in the atmosphere) and negative differences in band 31-32.

The emissivity of desert at 12 µm is higher than at 11 µm, and hence BT(12 µm) > BT(11 µm) thus negative values. The red pixels are very arid regions of the desert and are not ash clouds.

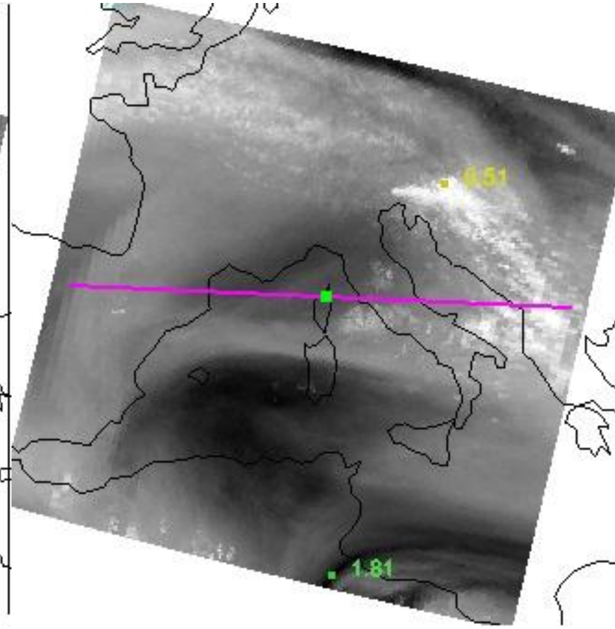
MODIS IR Spectral Bands



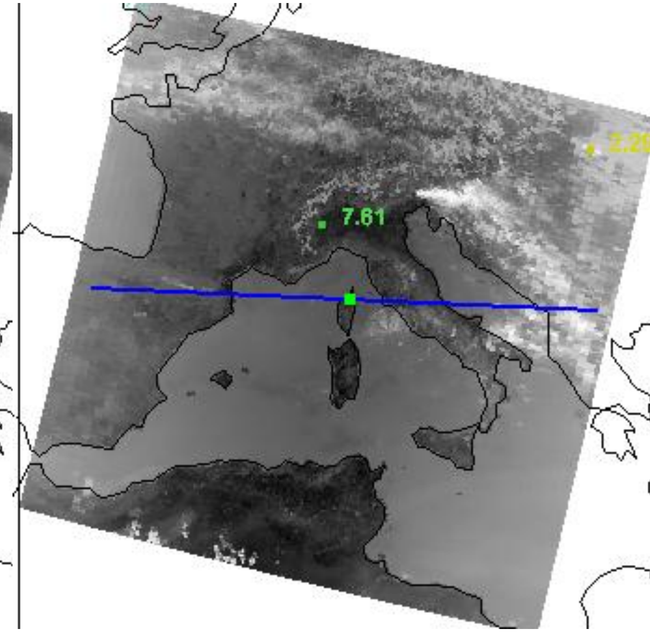
Absorption of the various atmospheric gases in the Infrared channels



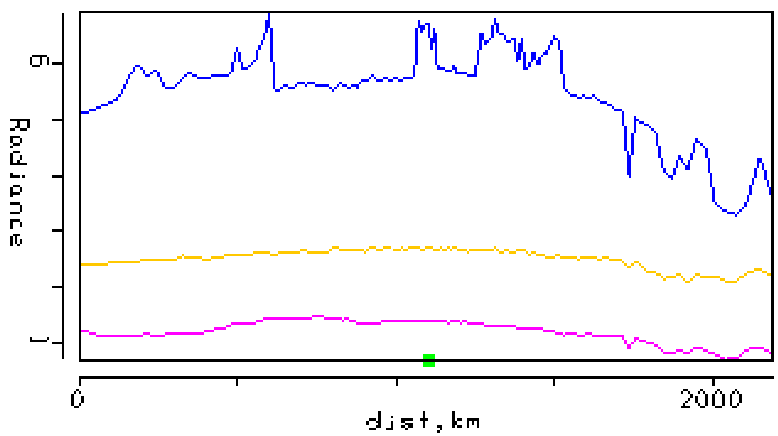
CO_2 absorption at 14.2 µm



H_2O absorption at 6.78 µm

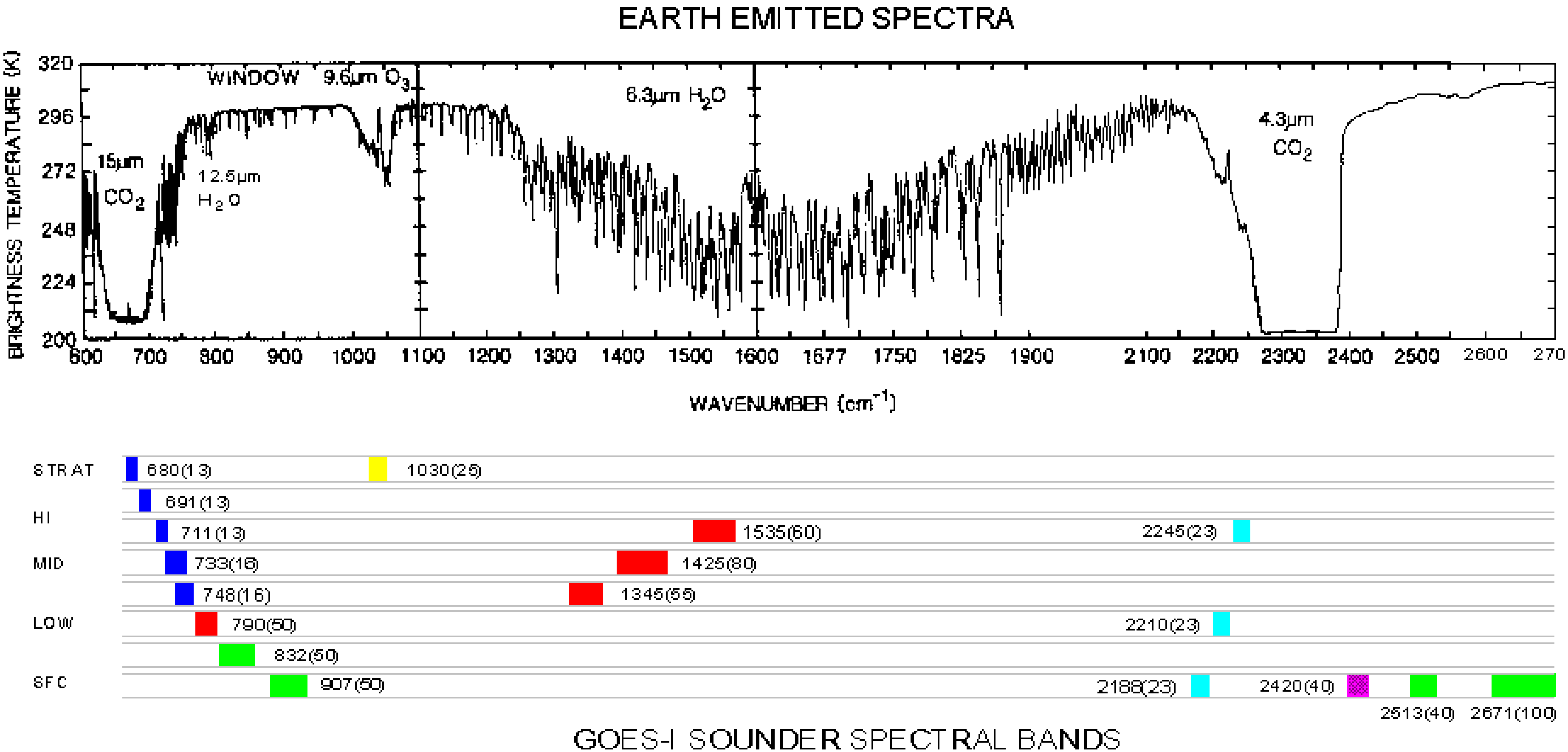


O_3 absorption at 9.70 µm

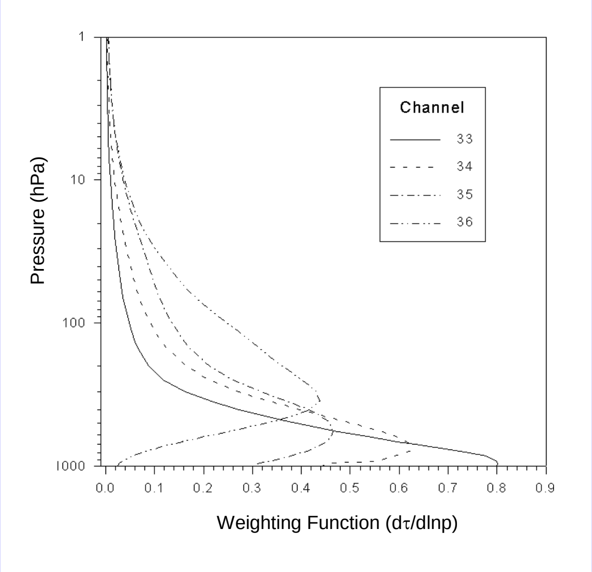


The surface features cannot be distinguished in the CO_2 and H_2O absorption band. The transect shows that the radiance for CO_2 is always higher than H_20 which states that the weighing function caused by CO_2 absorption is lower than that caused by the H_2O absorption. In other words you could look deeper into the atmosphere at 14.2 µm than at 6.78 µm. The transect also shows that absorption by O_3 is less than H_2O and CO_2 as you can "see" deeper into the atmosphere.

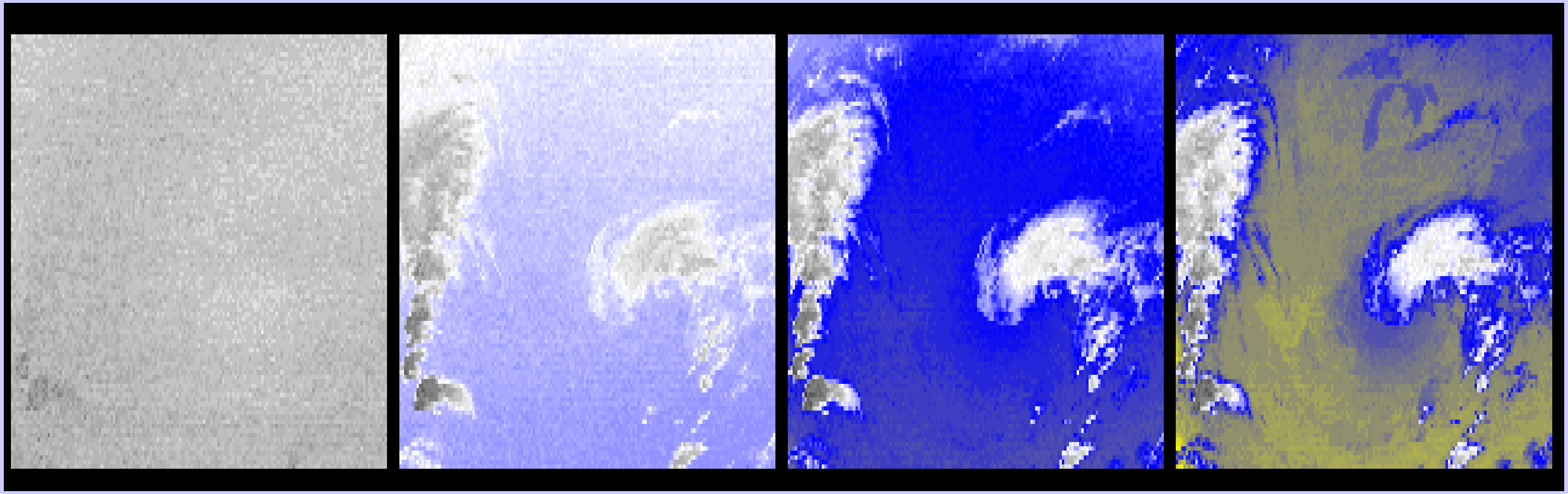
GOES Sounder Spectral Bands: 14.7 to 3.7 um and vis



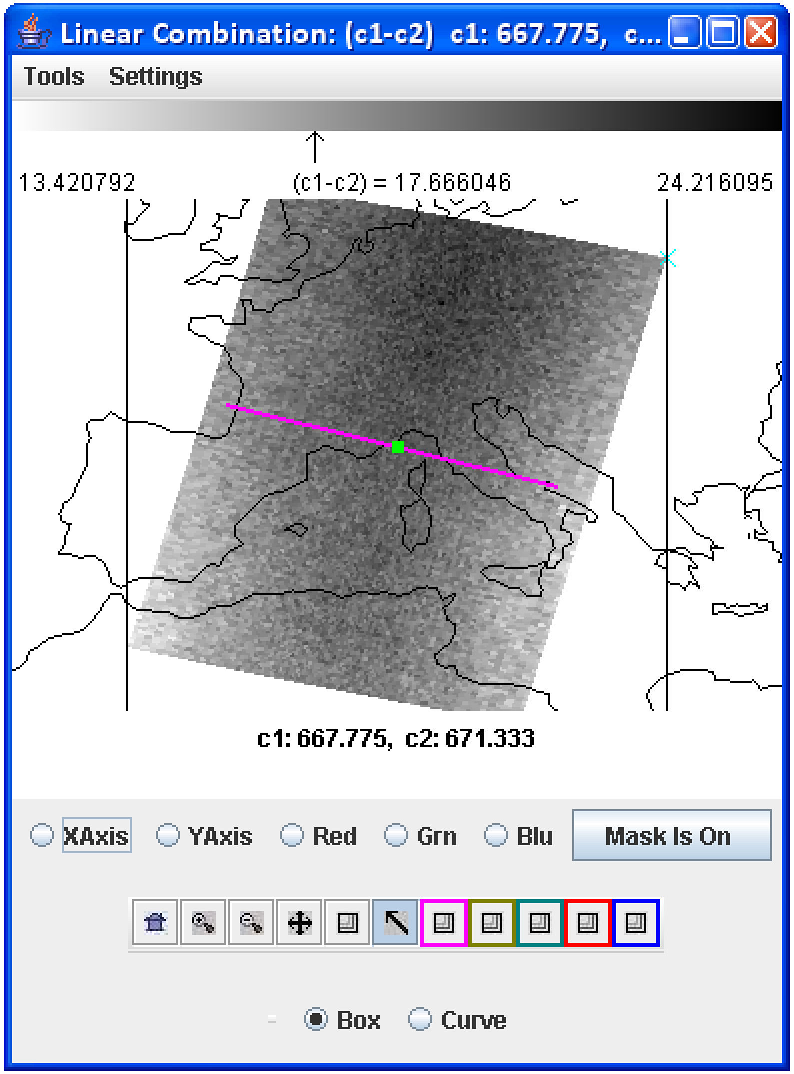
COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES



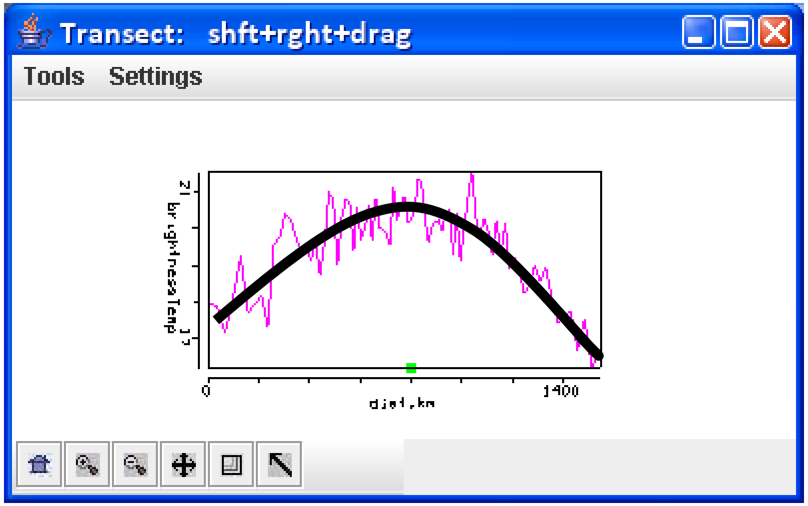
CO2 channels see different layers in the atmosphere



14.2 um 13.9 um 13.6 um 13.3 um



Perpedicular at nadir



Limb darkening

Radiative Transfer Equation

When reflection from the earth surface is also considered, the RTE for infrared radiation can be written

$$I_\lambda \;=\; \varepsilon_\lambda^{sfc}\, B_\lambda(T_s)\, \tau_\lambda(p_s) + \int_{p_s}^{o} B_\lambda(T(p))\, F_\lambda(p)\, [d\tau_\lambda(p)/\, dp]\, dp$$

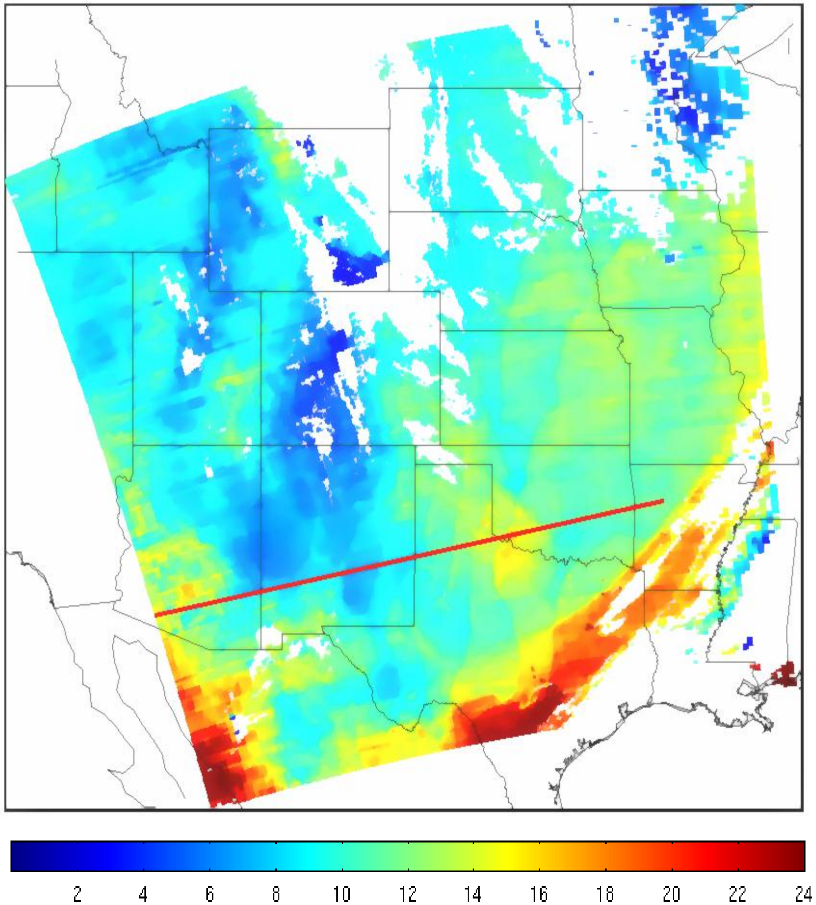
where

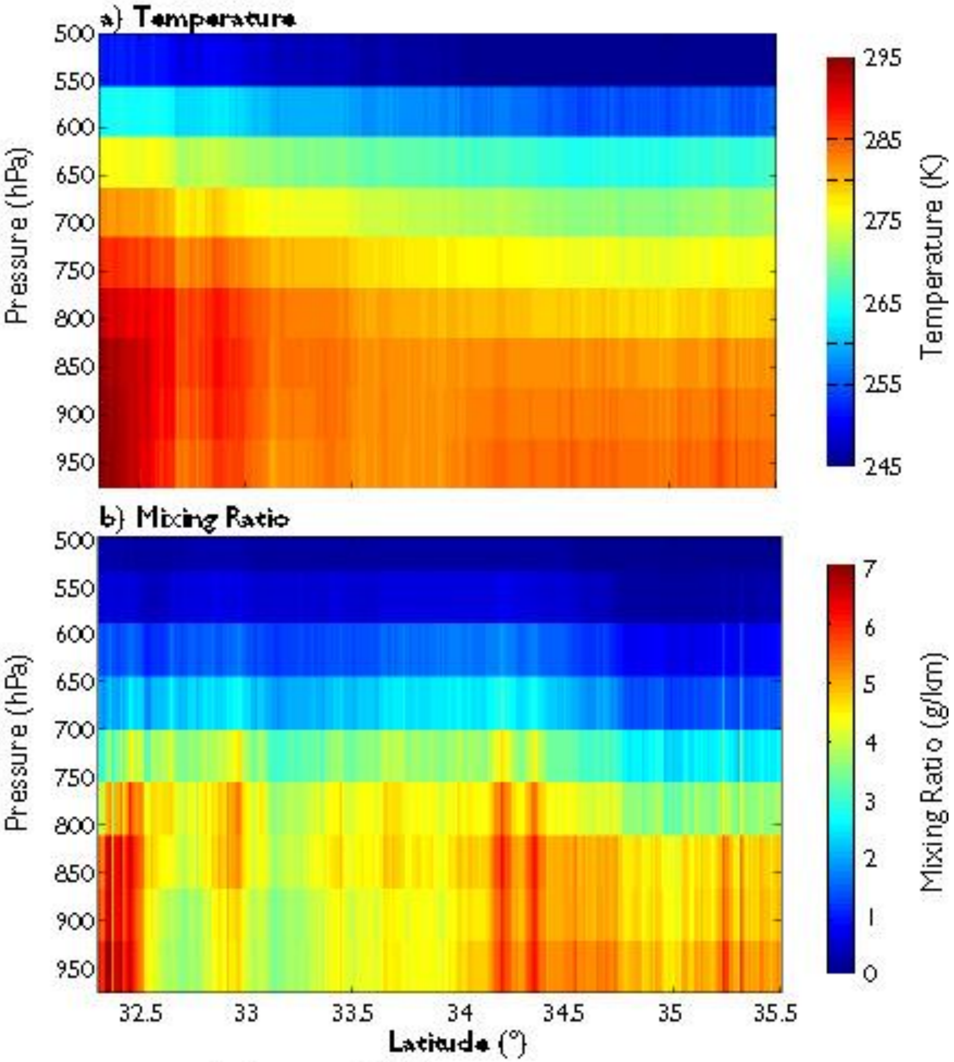
$$F_\lambda(p) \;=\; \{\, 1 + (1 - \varepsilon_\lambda)\, [\tau_\lambda(p_s) \,/\, \tau_\lambda(p)]^2 \,\}$$

The first term is the spectral radiance emitted by the surface and attenuated by the atmosphere, often called the boundary term and the second term is the spectral radiance emitted to space by the atmosphere directly or by reflection from the earth surface.

The atmospheric contribution is the weighted sum of the Planck radiance contribution from each layer, where the weighting function is [$d\tau_\lambda(p)$ / dp]. This weighting function is an indication of where in the atmosphere the majority of the radiation for a given spectral band comes from.

MODIS TPW

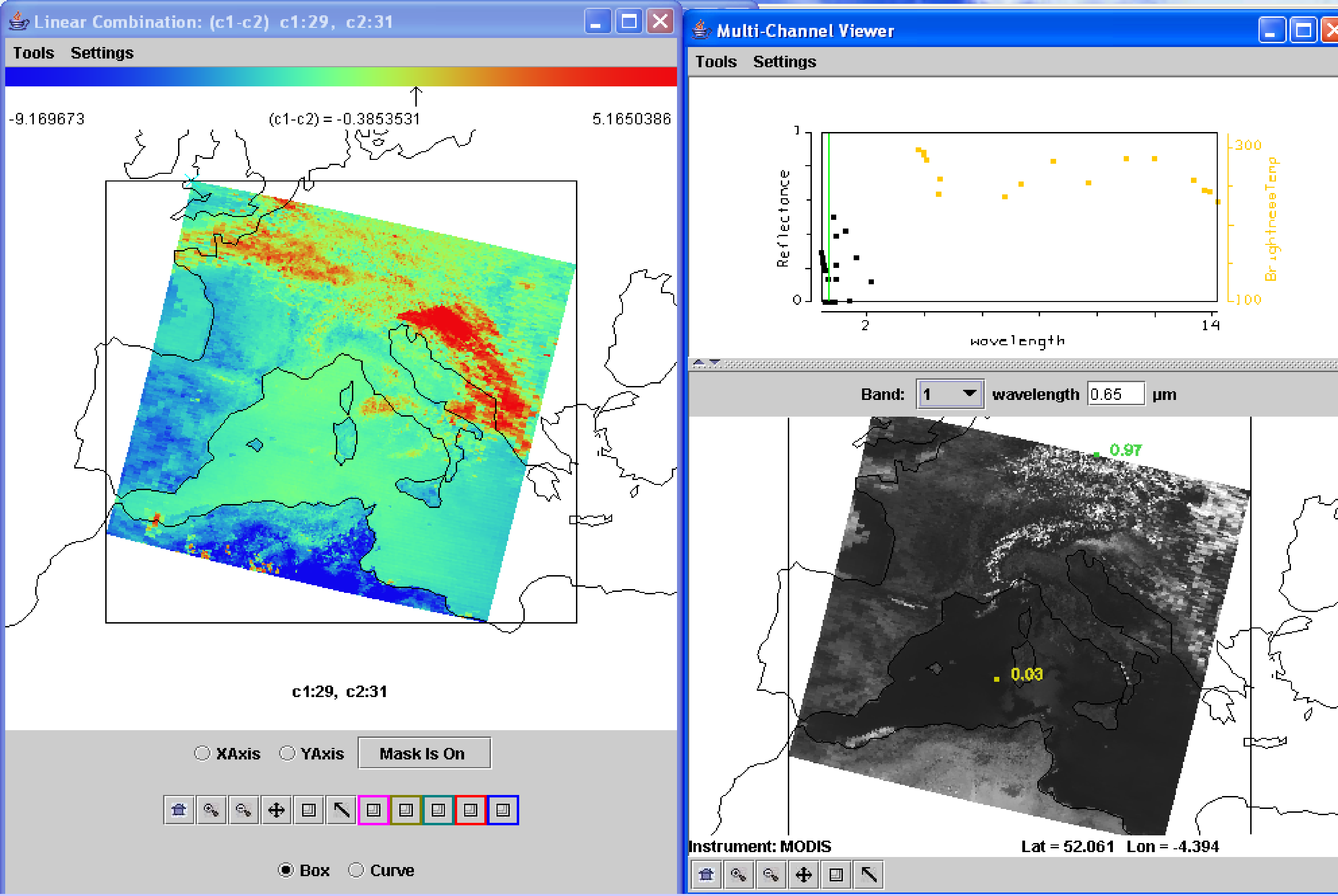




Clear sky layers of temperature and moisture on 2 June 2001

Cloud Mask Tests

• BT11	clouds over ocean
• BT13.9	high clouds
• BT6.7	high clouds
• BT3.9-BT11	broken or scattered clouds
• BT11-BT12	high clouds in tropics
• BT8.6-BT11	ice clouds
• BT6.7-BT11 or BT13.9-BT11	clouds in polar regions
• BT11+aPW(BT11-BT12)	clouds over ocean
• r0.65	clouds over land
• r0.85	clouds over ocean
• r1.38	thin cirrus
• r1.6	clouds over snow, ice cloud
• r0.85/r0.65 or NDVI	clouds over vegetation
• σ(BT11)	clouds over ocean



Ice clouds are revealed with BT8.6-BT11>0 & water clouds and fog show in r0.65

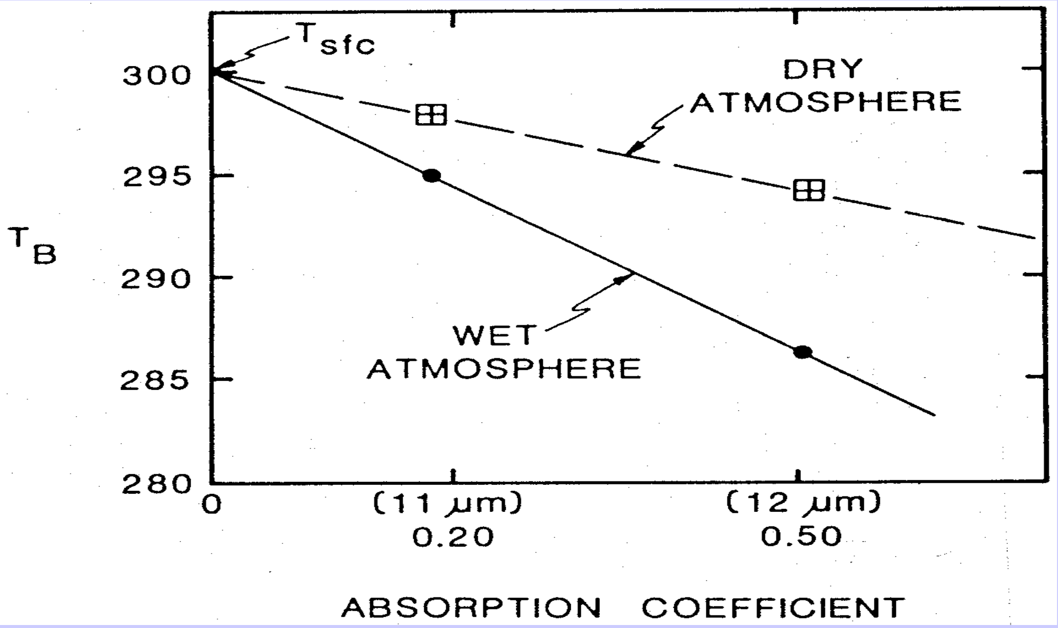
Moisture

Moisture attenuation in atmospheric windows varies linearly with optical depth.

$$\tau_\lambda = e^{-k_\lambda u} = 1 - k_\lambda u$$

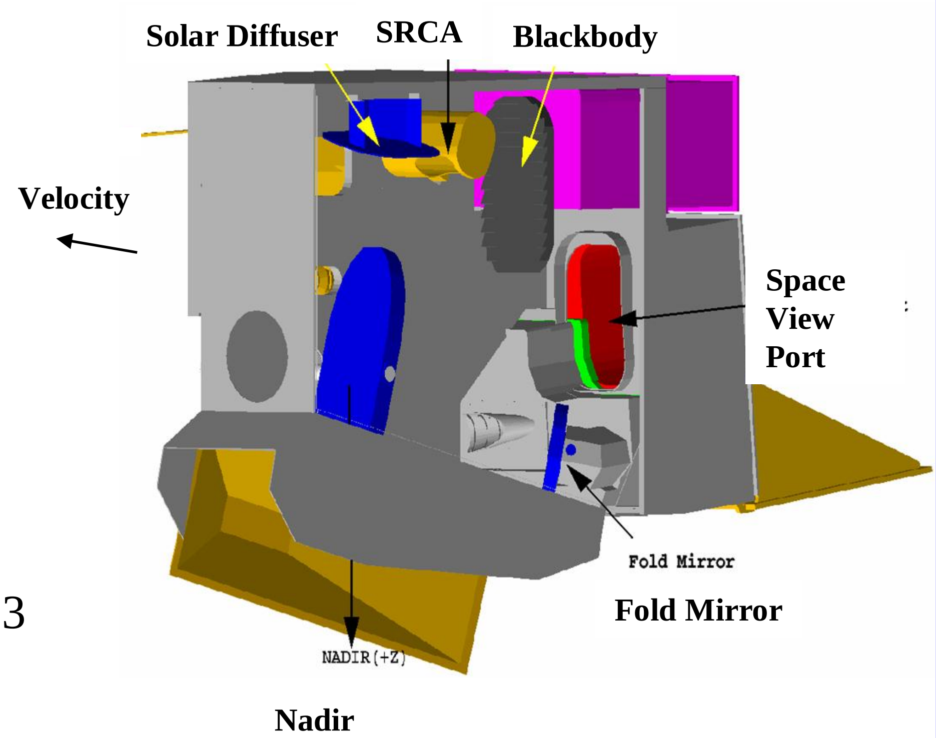
For same atmosphere, deviation of brightness temperature from surface temperature is a linear function of absorbing power. Thus moisture corrected SST can inferred by using split window measurements and extrapolating to zero k_λ

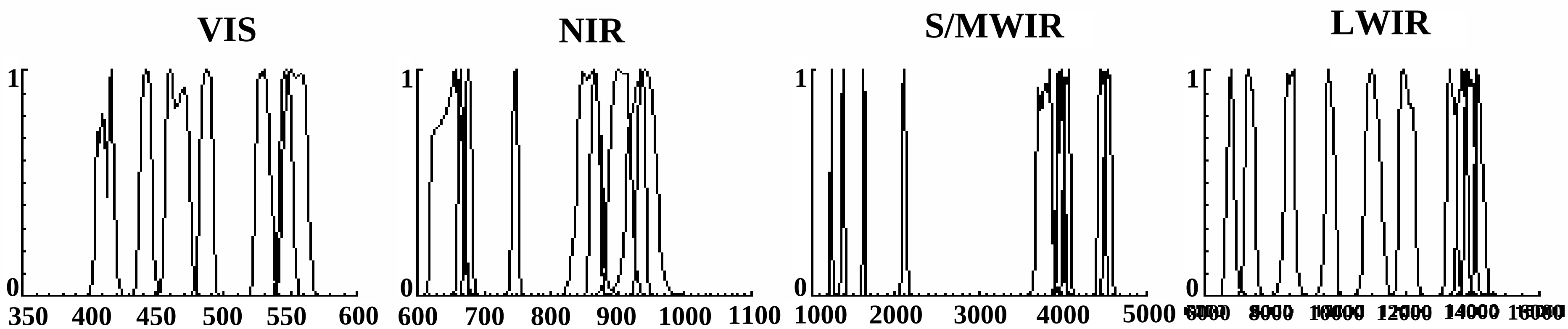
Moisture content of atmosphere inferred from slope of linear relation.



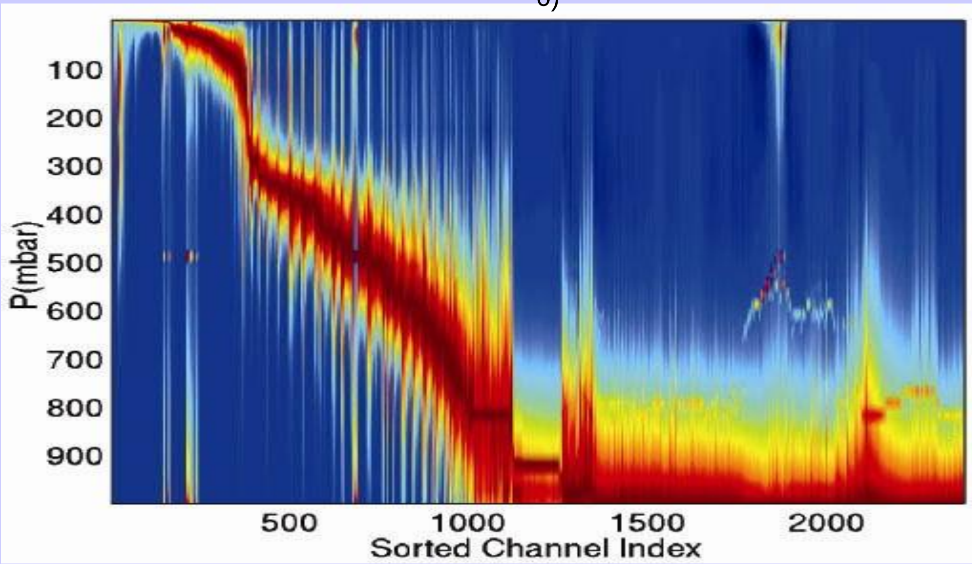
MODIS Instrument Overview

- 36 spectral bands (490 detectors) cover wavelength range from 0.4 to 14.5 μm
- Spatial resolution at nadir: 250m (2 bands), 500m (5 bands) and 1000m
- 4 FPAs: VIS, NIR, SMIR, LWIR
- On-Board Calibrators: SD/SDSM, SRCA, and BB (plus space view)
- 12 bit (0-4095) dynamic range
- 2-sided Paddle Wheel Scan Mirror scans 2330 km swath in 1.47 sec
- Day data rate = 10.6 Mbps; night data rate = 3.3 Mbps (100% duty cycle, 50% day and 50% night)

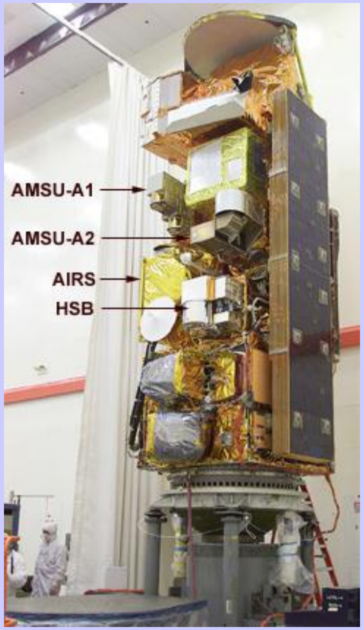




temperature weighting functions sorted by pressure of their peak (blue = 0)



AIRS On Aqua

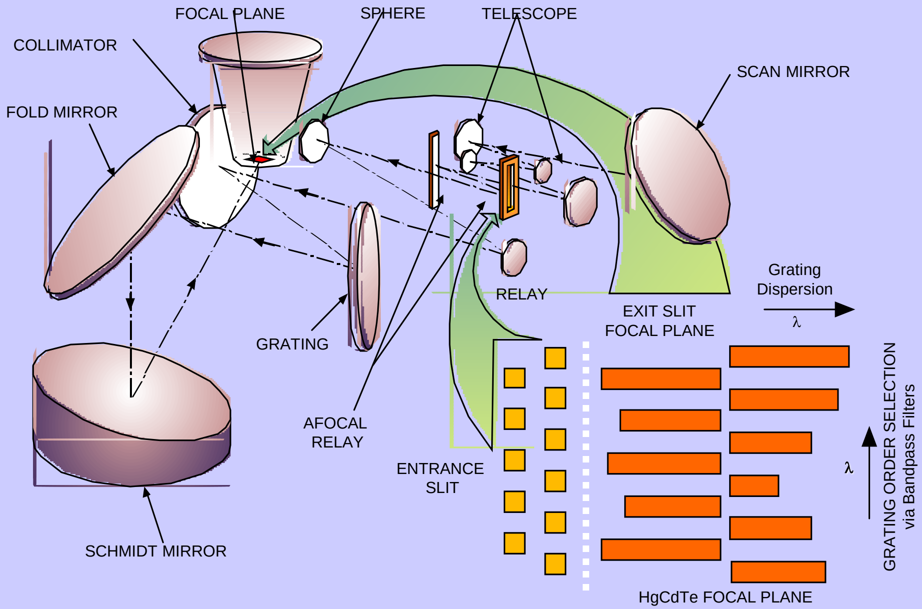


Instrument

- Hyperspectral radiometer with **resolution of 0.5 – 2 cm^{-1}**
- Extremely well calibrated pre-launch
- **Spectral range: 650 – 2700 cm^{-1}**
- Associated microwave instruments (AMSU, HSB)

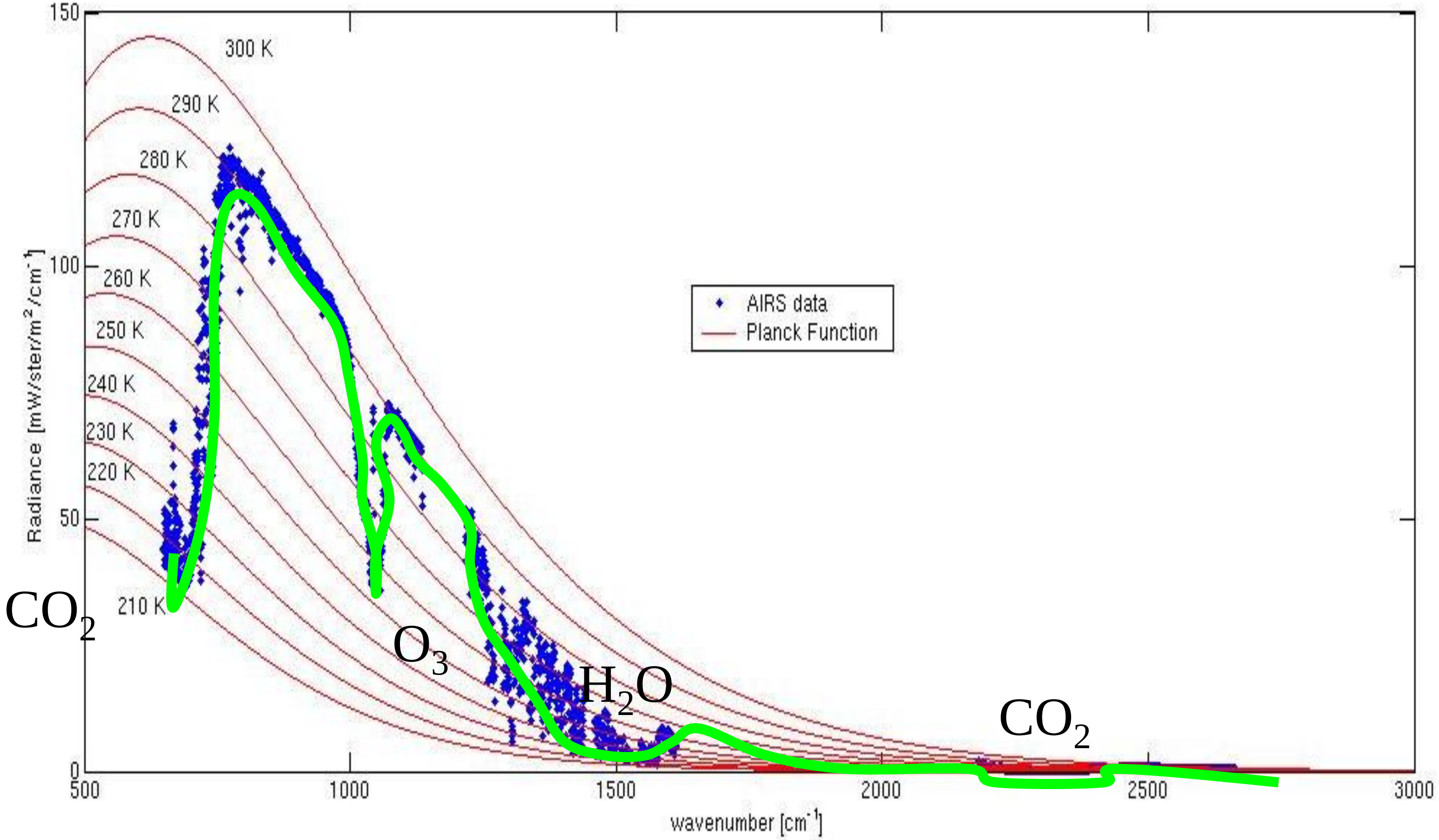
Design

- Grating Spectrometer passively cooled to 160K, stabilized to 30 mK
- **PV and PC HdCdTe focal plane cooled to 60K** with redundant active pulse tube cryogenic coolers
- **Focal plane has ~5000 detectors,** 2378 channels. PV detectors (all below 13 microns) are doubly redundant. Two channels per resolution element (n/Dn = 1200)
- 310 K Blackbody and space view provides radiometric calibration
- Paralyene coating on calibration mirror and upwelling radiation provides spectral calibration
- **NEDT (per resolution element) ranges from 0.05K to 0.5K**

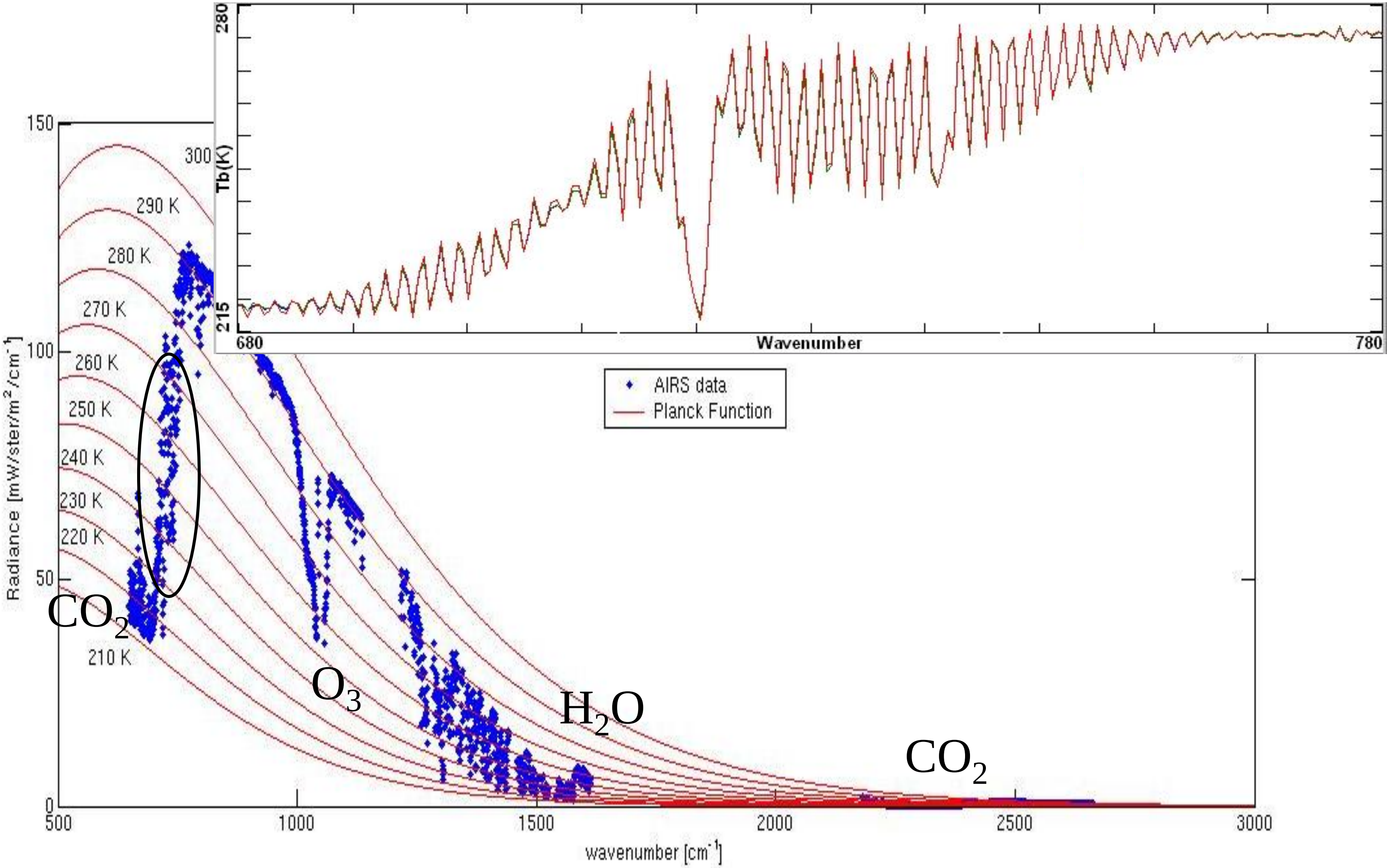


Spectral filters at each entrance slit and over each FPA array isolate color band (grating order) of interest

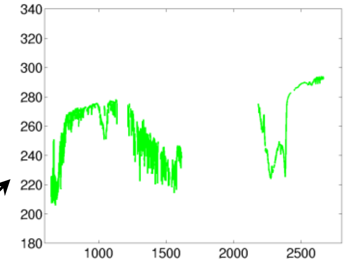
Vibrational Lines

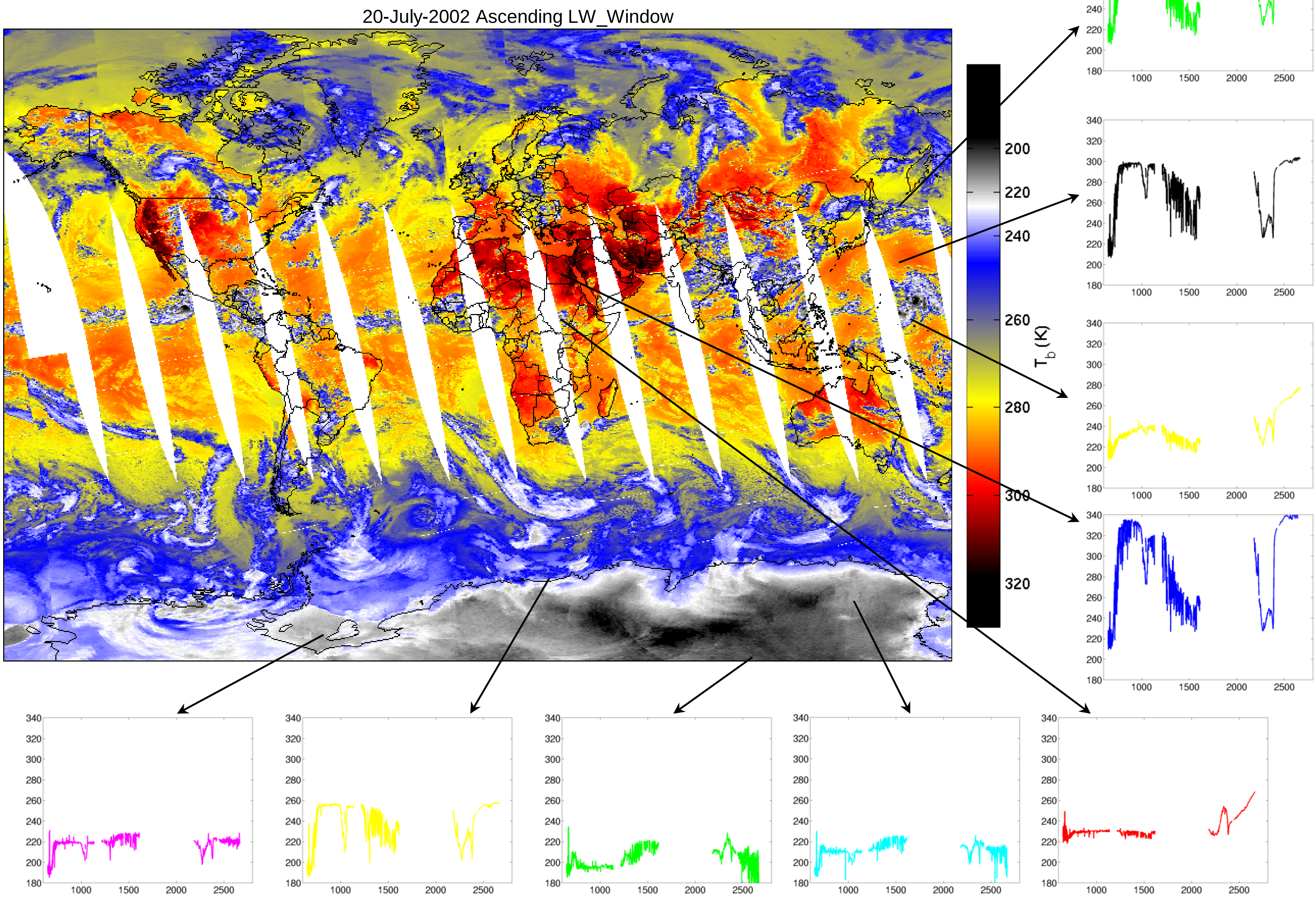


Rotational Lines

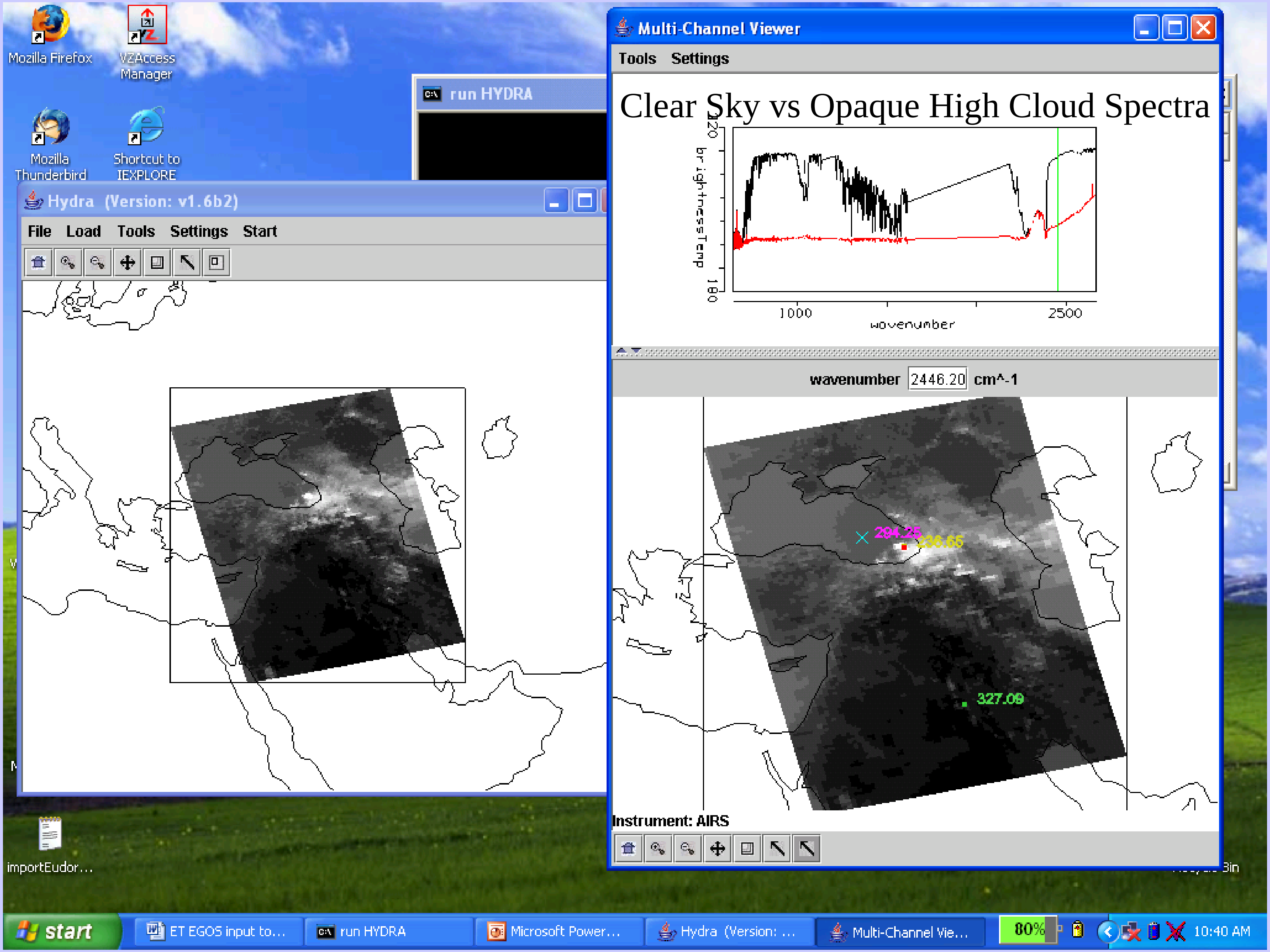


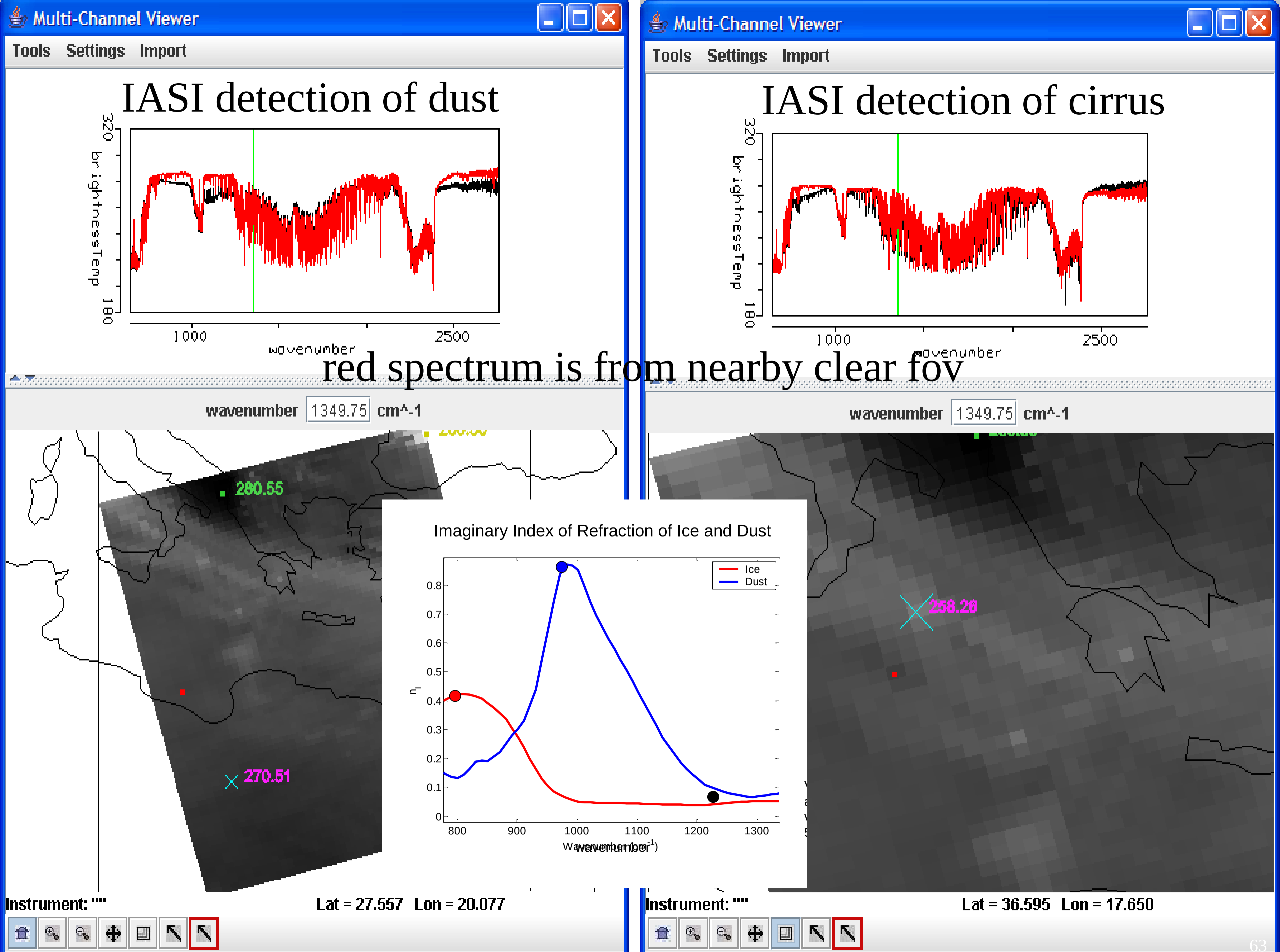
AIRS Spectra from around the Globe

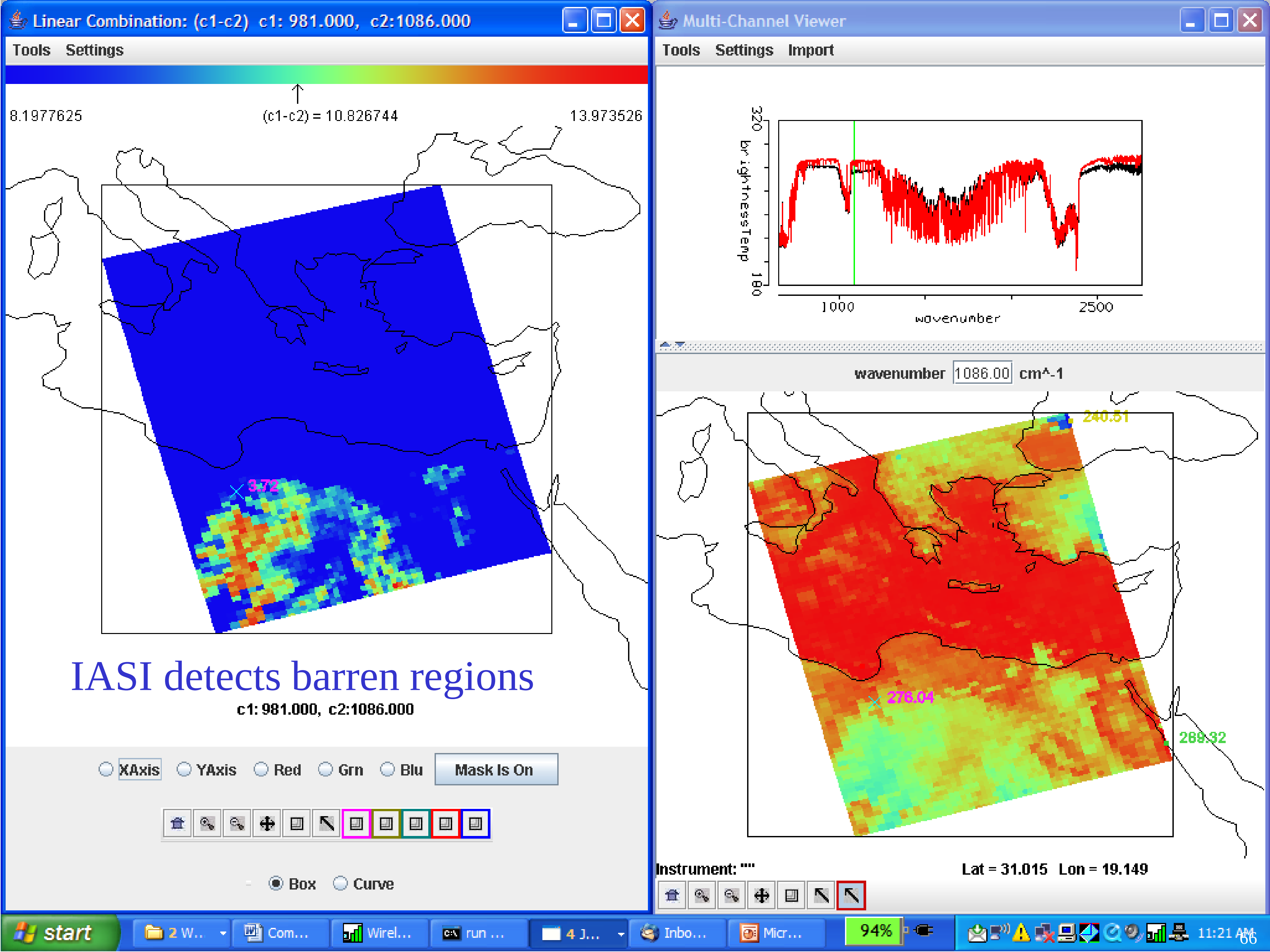




AIRS data from 28 Aug 2005



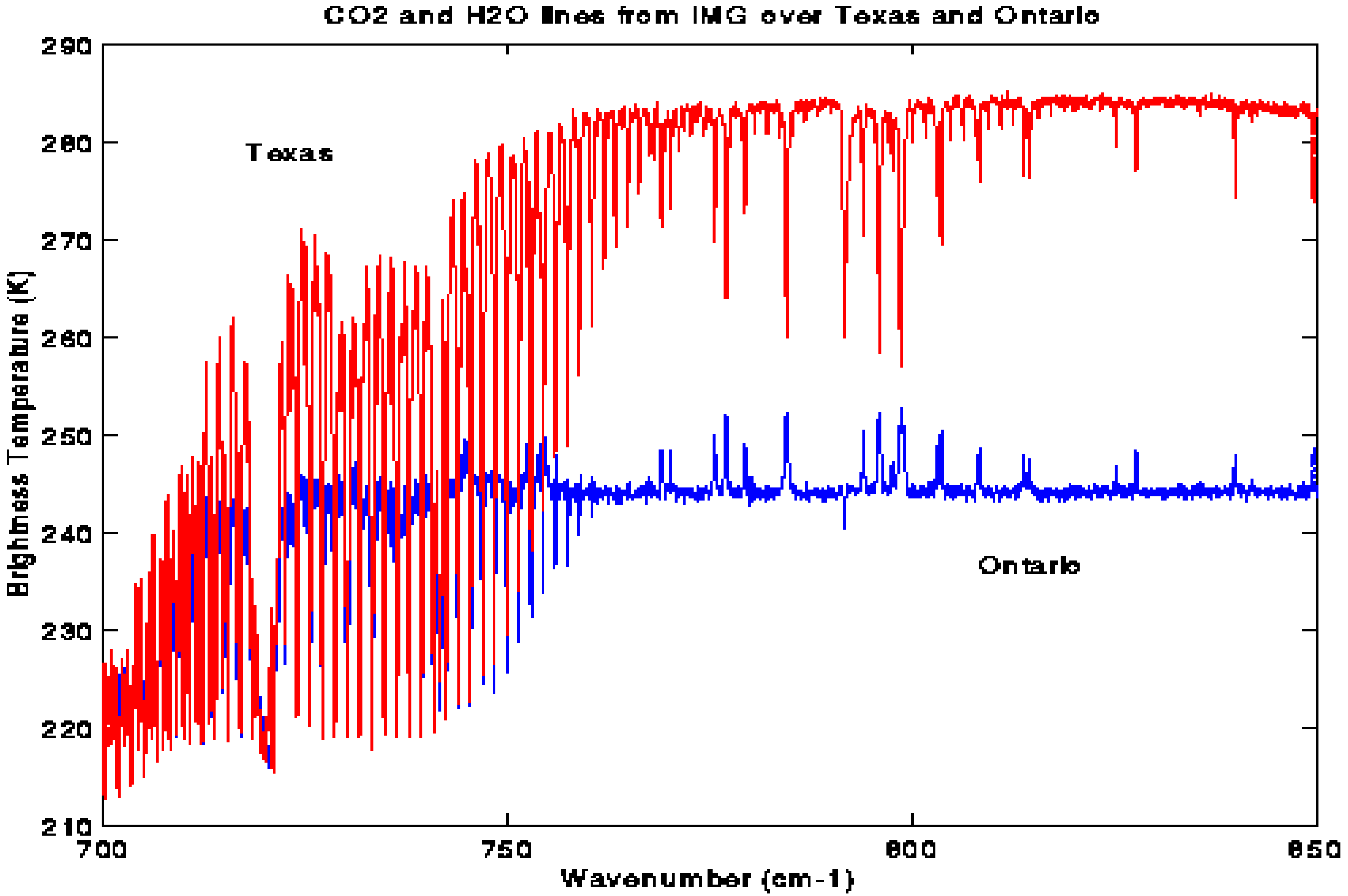

IASI detection of dust
IASI detection of cirrus
red spectrum is from nearby clear fov
Multi-Channel Viewer
Tools Settings Import
brightnessTemp
320
180
1000
2500
wavenumber
wavenumber 1349.75 cm^-1
280.55
270.51
258.26
Instrument: ""
Lat = 27.557 Lon = 20.077
Lat = 36.595 Lon = 17.650
Imaginary Index of Refraction of Ice and Dust
Ice
Dust
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
800
900
1000
1100
1200
1300
wavenumber

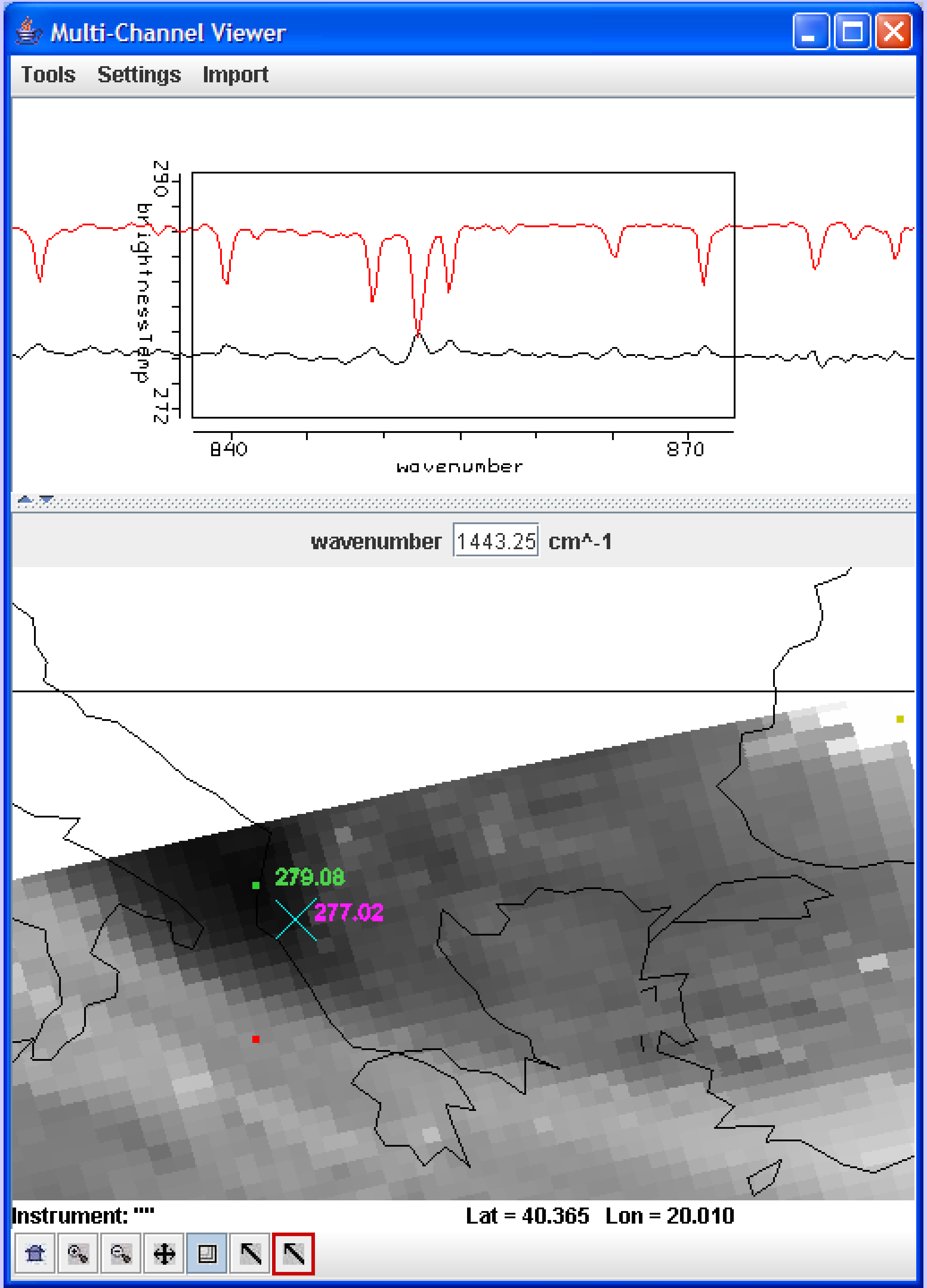


Linear Combination: (c1-c2) c1: 981.000, c2:1086.000
Tools Settings
8.1977625
(c1-c2) = 10.826744
13.973526
3.72
IASI detects barren regions
c1: 981.000, c2:1086.000
XAxis YAxis Red Grn Blu
Mask Is On
Box Curve
Multi-Channel Viewer
Tools Settings Import
brightnessTemp
320
180
1000
2500
wavenumber
wavenumber 1086.00 cm^-1
240.51
276.04
269.32
Instrument: ""
Lat = 31.015 Lon = 19.149

Sensitivity of High Spectral Resolution to Boundary Layer Inversions and Surface/atmospheric Temperature differences

(from IMG Data, October, December 1996)

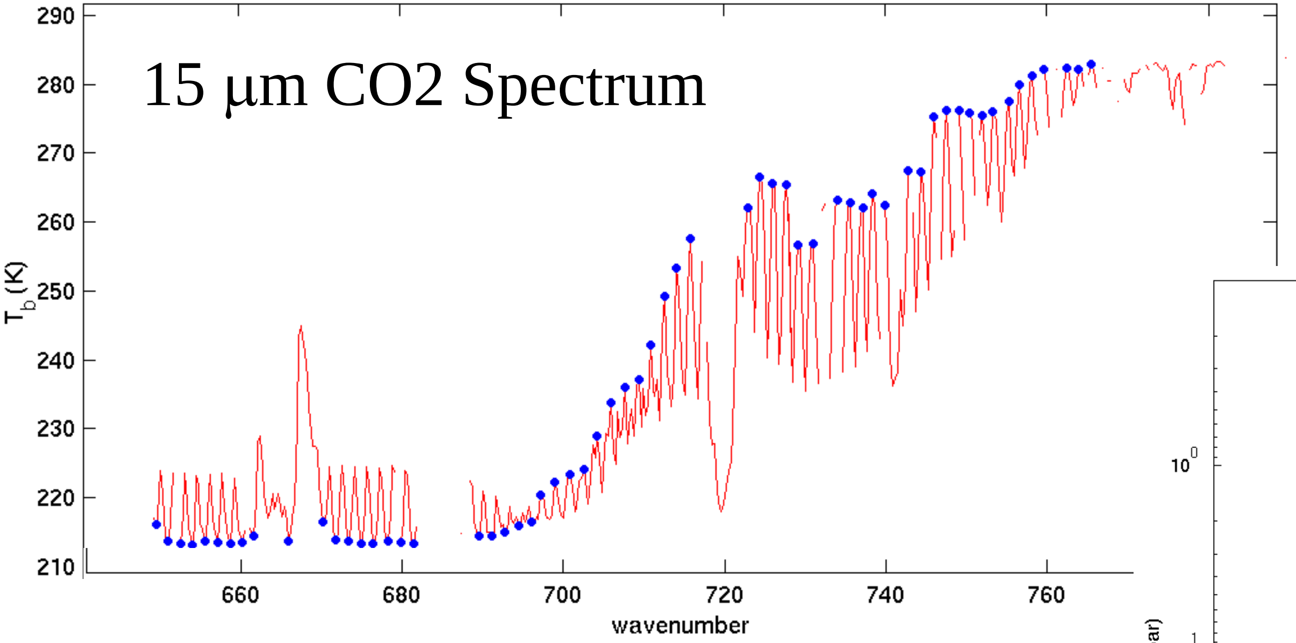




IASI sees low level inversion over land

Twisted Ribbon formed by CO_2 spectrum:

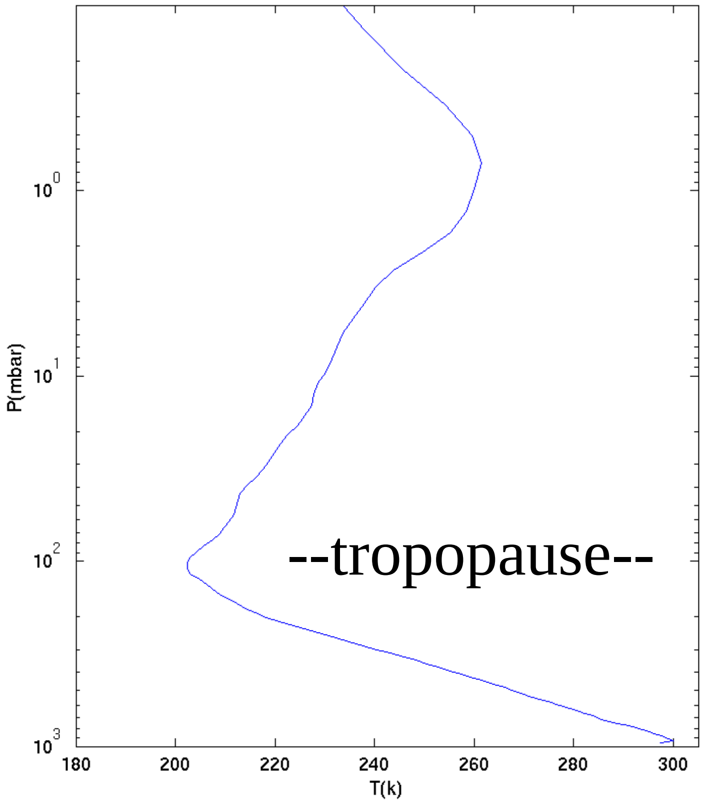
Tropopause inversion causes On-line & off-line patterns to cross



Blue between-line T_b

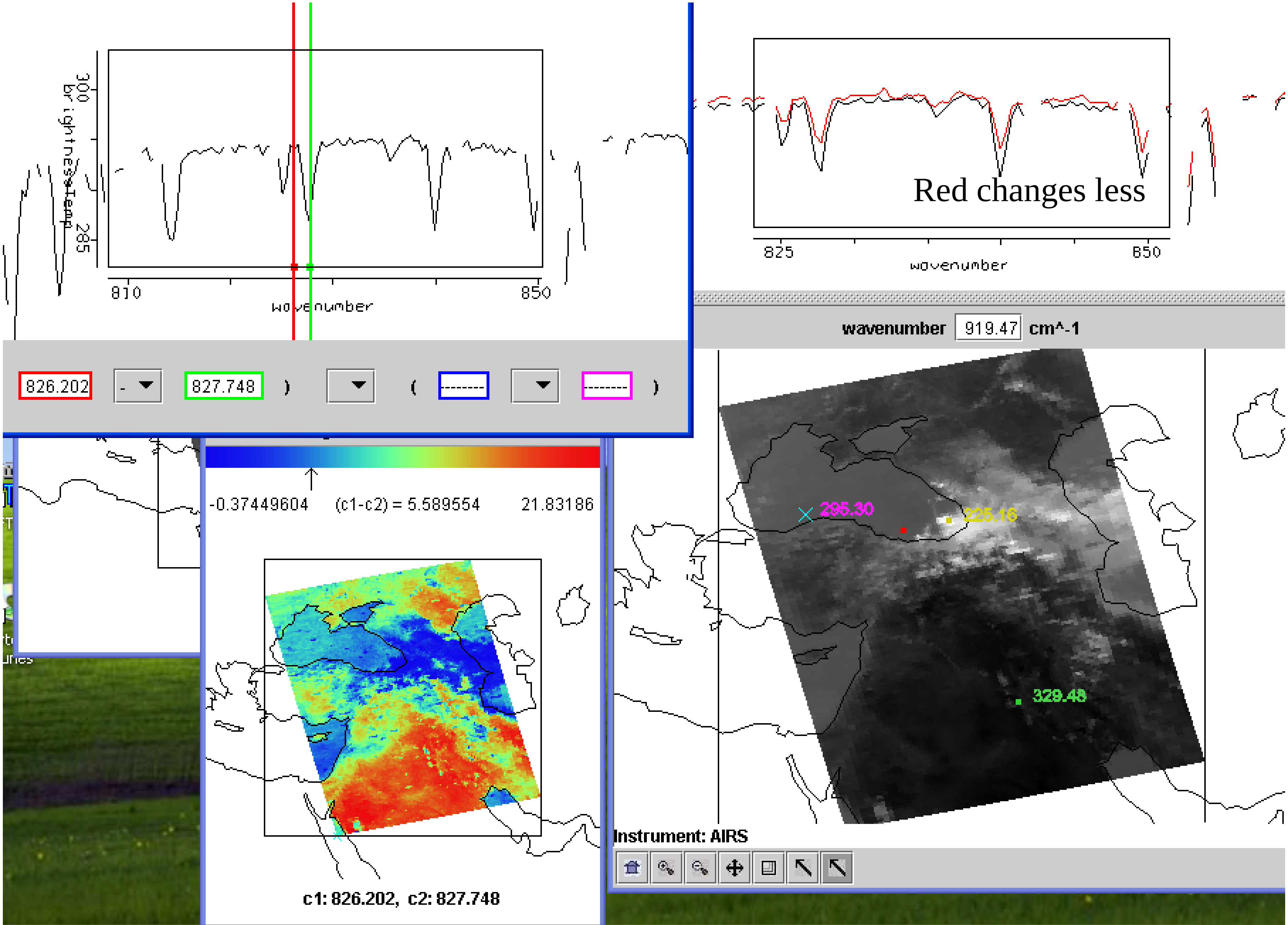
warmer for tropospheric channels,

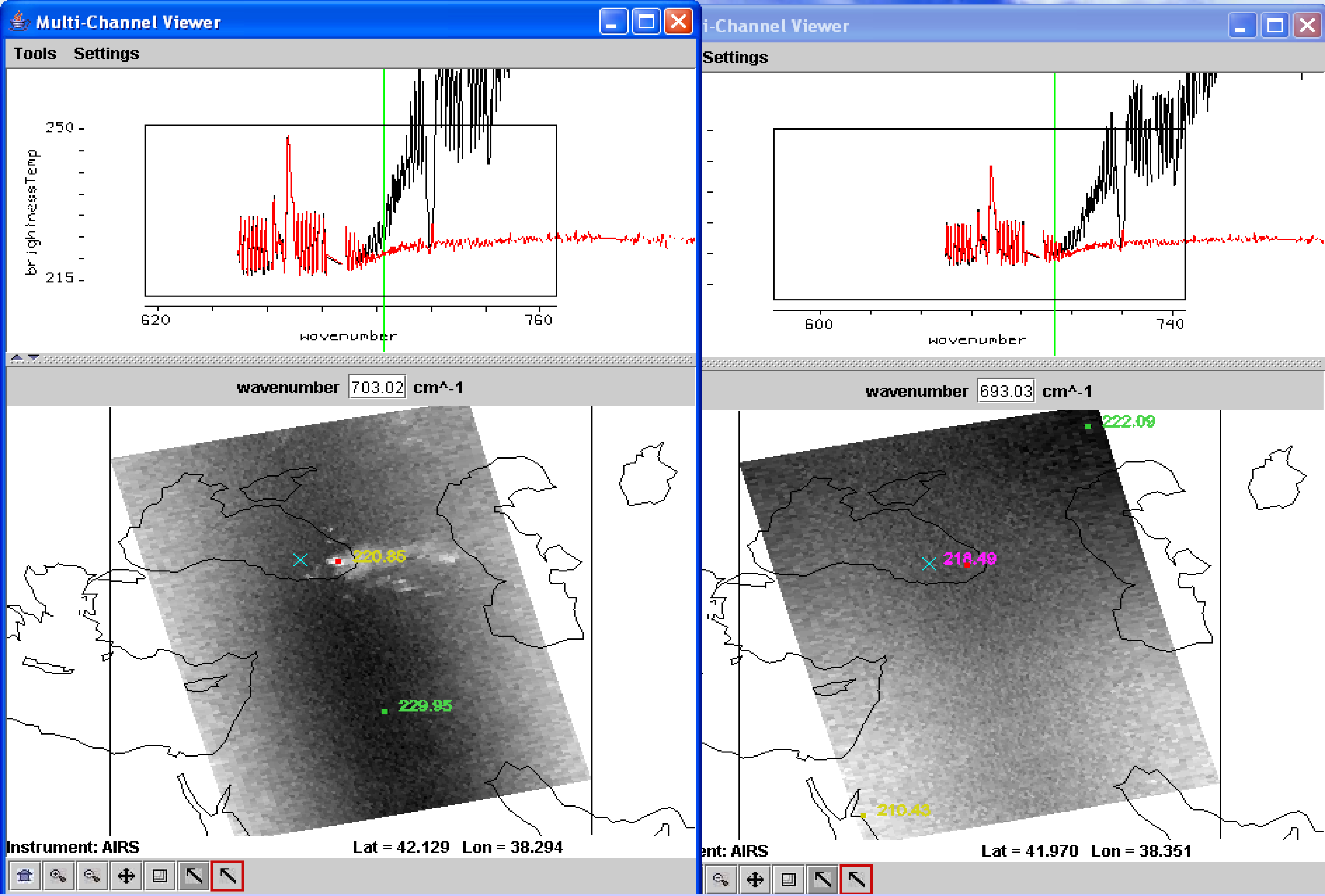
colder for stratospheric channels



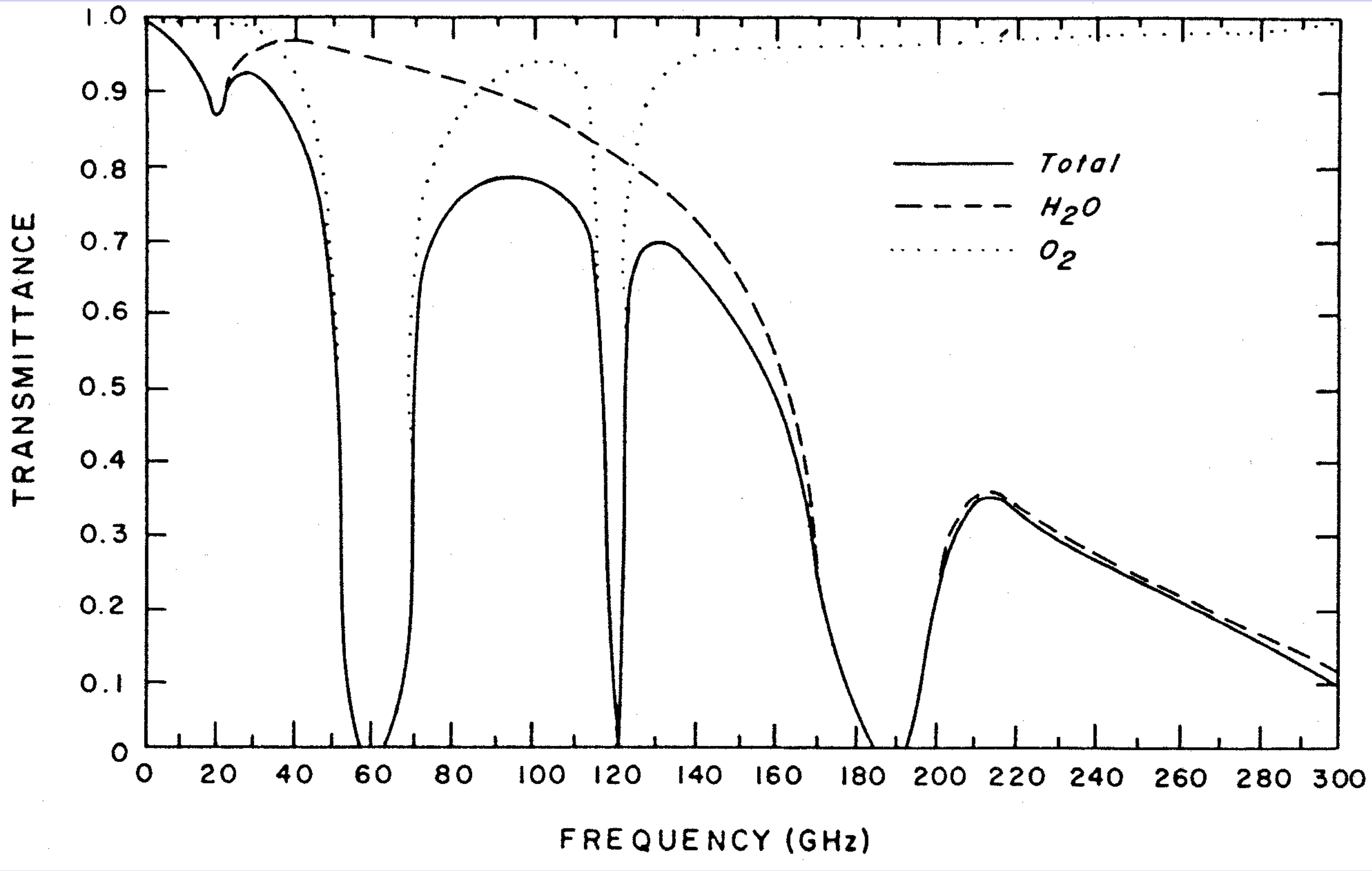
Signature not available at low resolution

Offline-Online in LW IRW showing low level moisture





Cld and clr spectra in CO2 absorption separate when weighting functions sink to cloud level


TRANSMITTANCE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
FREQUENCY (GHz)
Total
H_2O
O_2

Radiation is governed by Planck's Law

$$B(\lambda,T) = c_1 / \{ \lambda^5 [e^{c_2/\lambda T} - 1] \}$$

In microwave region $c_2/\lambda T << 1$ so that

$$e^{c_2/\lambda T} = 1 + c_2/\lambda T + \text{second order}$$

And classical Rayleigh Jeans radiation equation emerges

$$B_\lambda(T) \approx [c_1 / c_2] [T / \lambda^4]$$

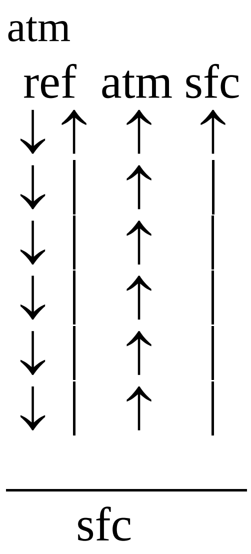
Radiance is linear function of brightness temperature.

Microwave Form of RTE

$$I^{sfc}_{\lambda} = \varepsilon_\lambda B_\lambda(T_s)\, \tau_\lambda(p_s) + (1-\varepsilon_\lambda)\, \tau_\lambda(p_s) \int_{o}^{p_s} B_\lambda(T(p))\, \frac{\partial \tau'_\lambda(p)}{\partial \ln p}\, d \ln p$$

$$I_\lambda = \varepsilon_\lambda B_\lambda(T_s)\, \tau_\lambda(p_s) + (1-\varepsilon_\lambda)\, \tau_\lambda(p_s) \int_{o}^{p_s} B_\lambda(T(p))\, \frac{\partial \tau'_\lambda(p)}{\partial \ln p}\, d \ln p$$

$$+ \int_{p_s}^{o} B_\lambda(T(p))\, \frac{\partial \tau_\lambda(p)}{\partial \ln p}\, d \ln p$$



In the microwave region $c_2/\lambda T << 1$, so the Planck radiance is linearly proportional to the temperature

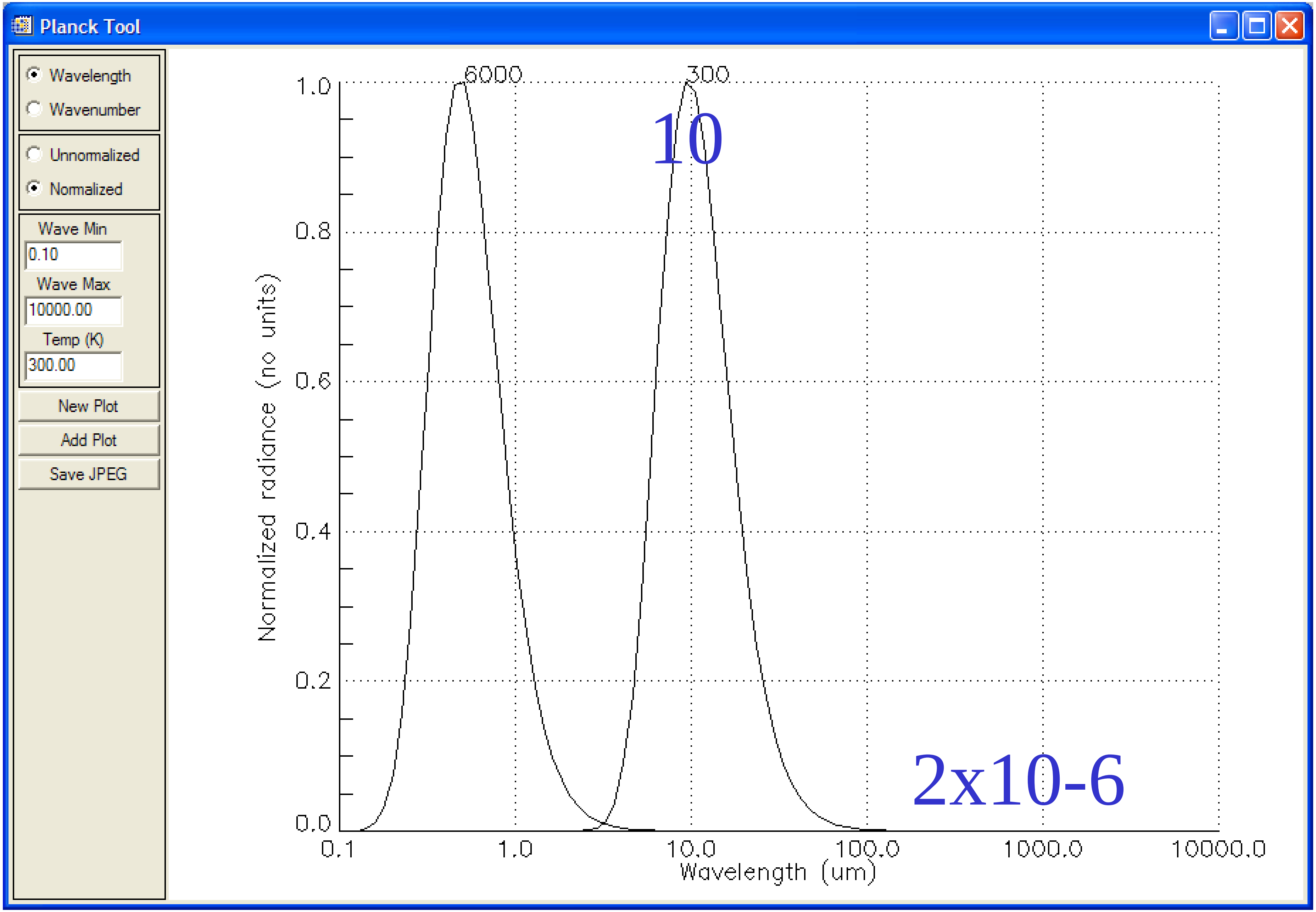
$$B_\lambda(T) \approx [c_1 / c_2]\, [T / \lambda^4]$$

So

$$T_{b\lambda} = \varepsilon_\lambda T_s(p_s)\, \tau_\lambda(p_s) + \int_{p_s}^{o} T(p)\, F_\lambda(p)\, \frac{\partial \tau_\lambda(p)}{\partial \ln p}\, d \ln p$$

where

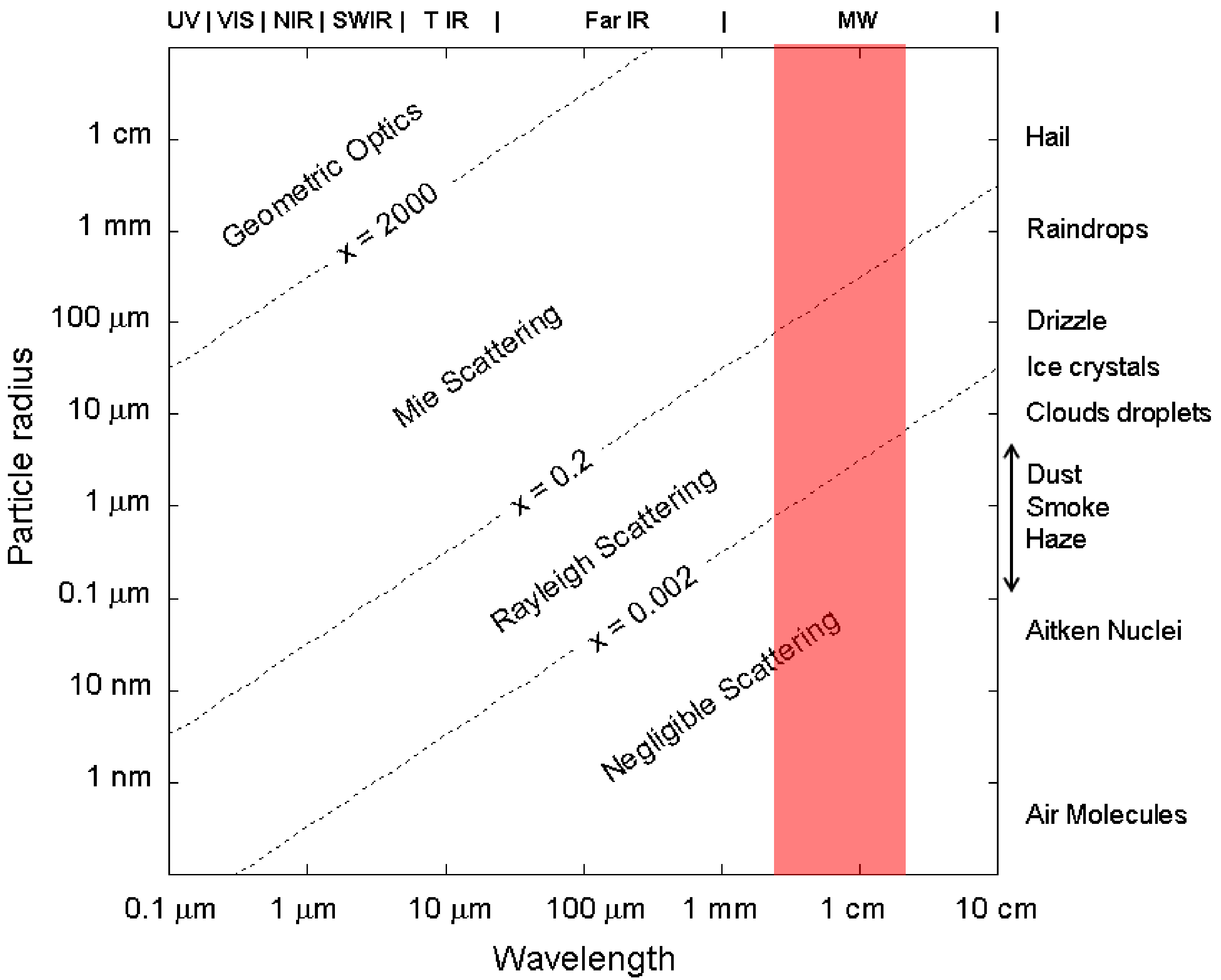
$$F_\lambda(p) = \left\{ 1 + (1 - \varepsilon_\lambda) \left[\frac{\tau_\lambda(p_s)}{\tau_\lambda(p)}\right]^2 \right\} .$$



Planck Tool
Wavelength
Wavenumber
Unnormalized
Normalized
Wave Min
0.10
Wave Max
10000.00
Temp (K)
300.00
New Plot
Add Plot
Save JPEG
6000
300
10
2x10-6
Normalized radiance (no units)
1.0
0.8
0.6
0.4
0.2
0.0
0.1
1.0
10.0
100.0
1000.0
10000.0
Wavelength (um)

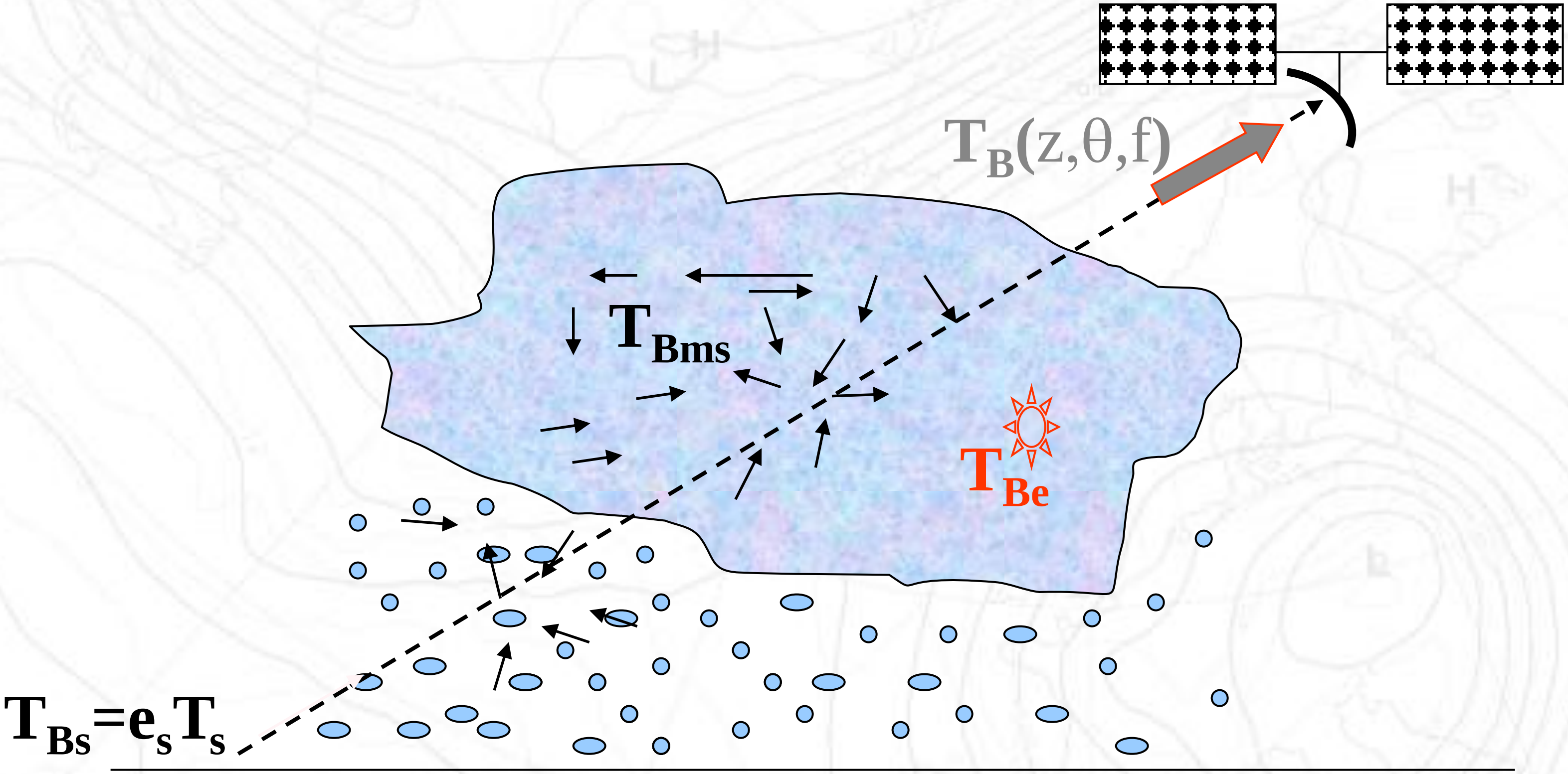
Scattering of MW radiation

- Scattering regimes



FORWARD PROBLEM
Physical basis

T_B: *brightness temperature*
f=10-160 GHz
θ=0° to 50°



e_s: *surface emissivity*
T_s:*surface temperature*

T_{Be}: *emission* T_B
T_{Bms}: *multiple scattering* T_B

FORWARD PROBLEM
Radiative transfer equation

- T_B in a plane-parallel medium: non-scattering case

$$\frac{dT_B(\tau,\Omega)}{d\tau} = \underbrace{-T_B(\tau,\Omega)}_{Extinction} + \underbrace{T(\tau)}_{Emission}$$

⇒Ordinary differential equation: linearization of F
⇒ Inverse problem as a *Fredholm integral equation* (e.g., temperature retrieval)

- TB in a plane-parallel medium: scattering case

$$\frac{dT_B(\tau,\Omega)}{d\tau} = \underbrace{-T_B(\tau,\Omega)}_{Extinction} + \underbrace{\frac{w}{4\pi}\int_{4\pi} p(\Omega,\Omega')T_B(\tau,\Omega)\,d\Omega'}_{Multiple\ scattering} + \underbrace{(1-w)T(\tau)}_{Emission}$$

=> **Integro-differential equation: strongly non-linear F (e.g., rainfall retrieval)**

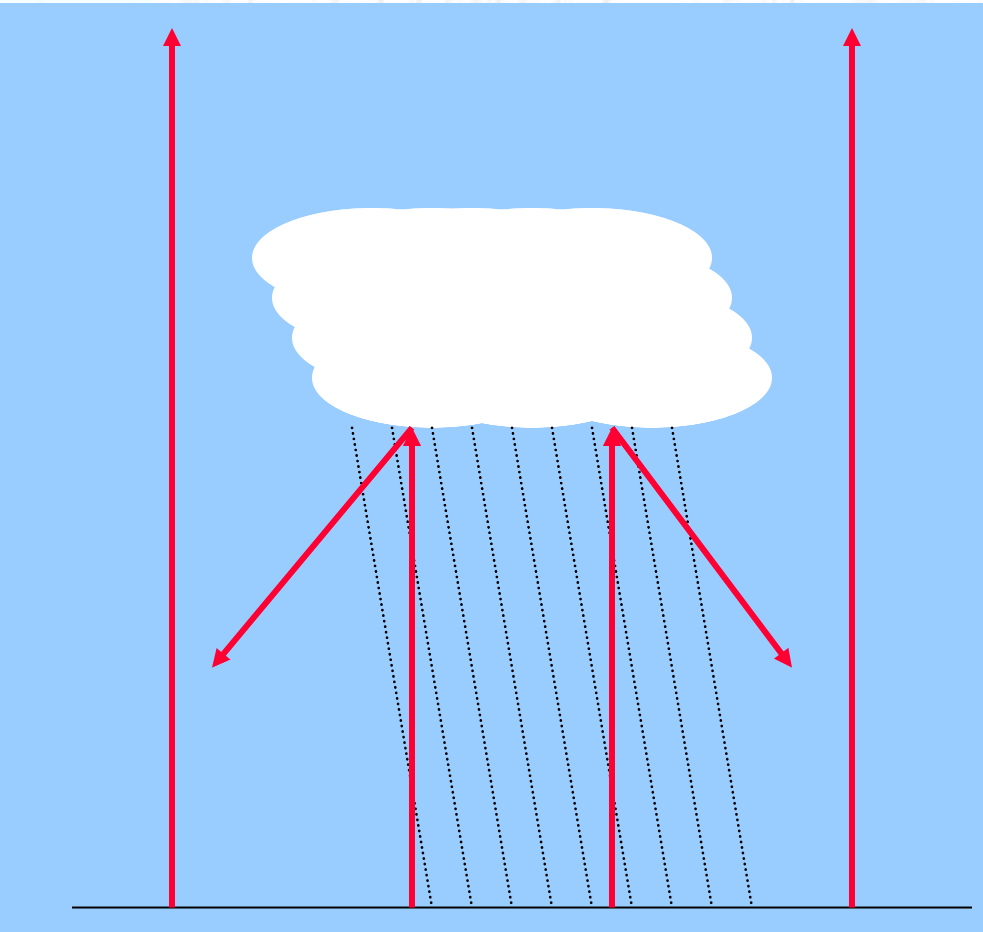
Precipitation in MW — Theory/Basis

- **Scattering signal**
  - ice in clouds scatters terrestrial radiation (cold areas over warm bckg)
    - Rainfall rates are related to the magnitude of the resulting brightness temperature depression.
    - **Strength**: can be applied to high-frequency channels: works over both land and ocean
    - **Weakness**: poor at detecting precipitation clouds with little or no ice (e.g. warm orographic clouds in the tropics)

- **Emission signal**
  - water in clouds emits radiation, (warm areas over cold bckg, e.g. ocean)
    - Rainfall rates are related to the magnitude of the resulting brightness temperature difference
    - **Strength**: sensitive to clouds with little or no ice
    - **Weakness**: must know terrestrial radiances without cloud beforehand; generally applicable over oceans but not land

Lower T_b above cloud

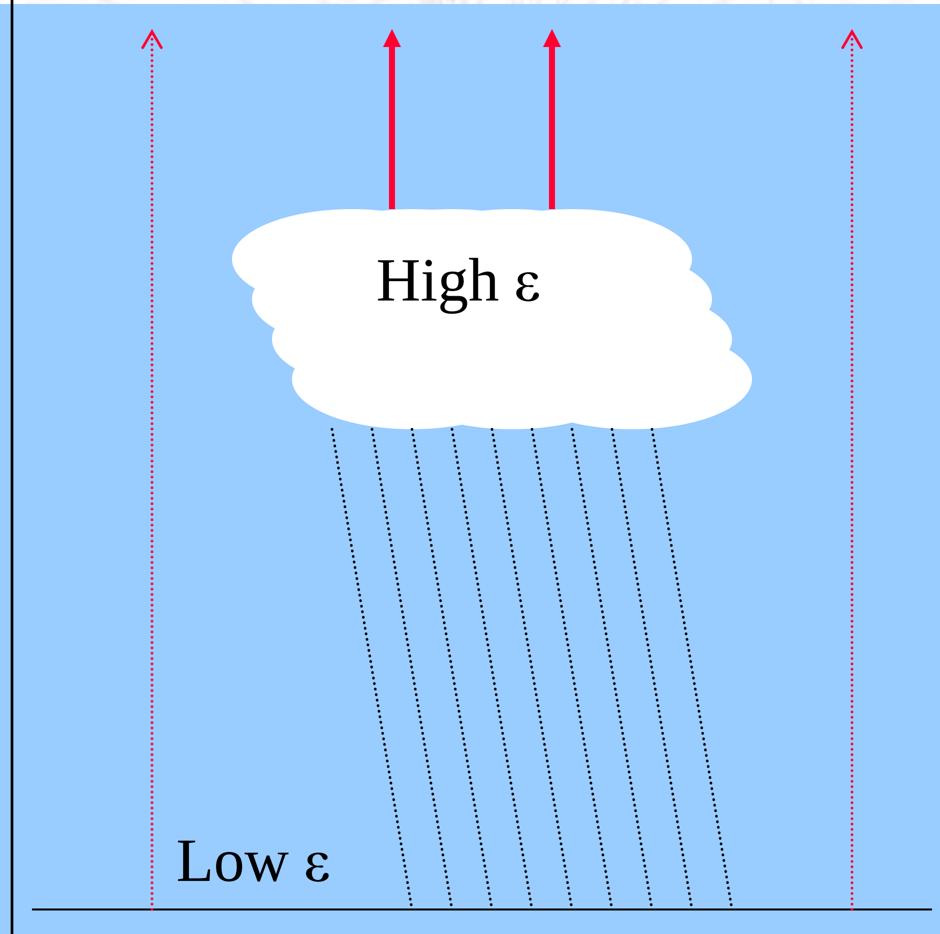
Higher T_b above clear air



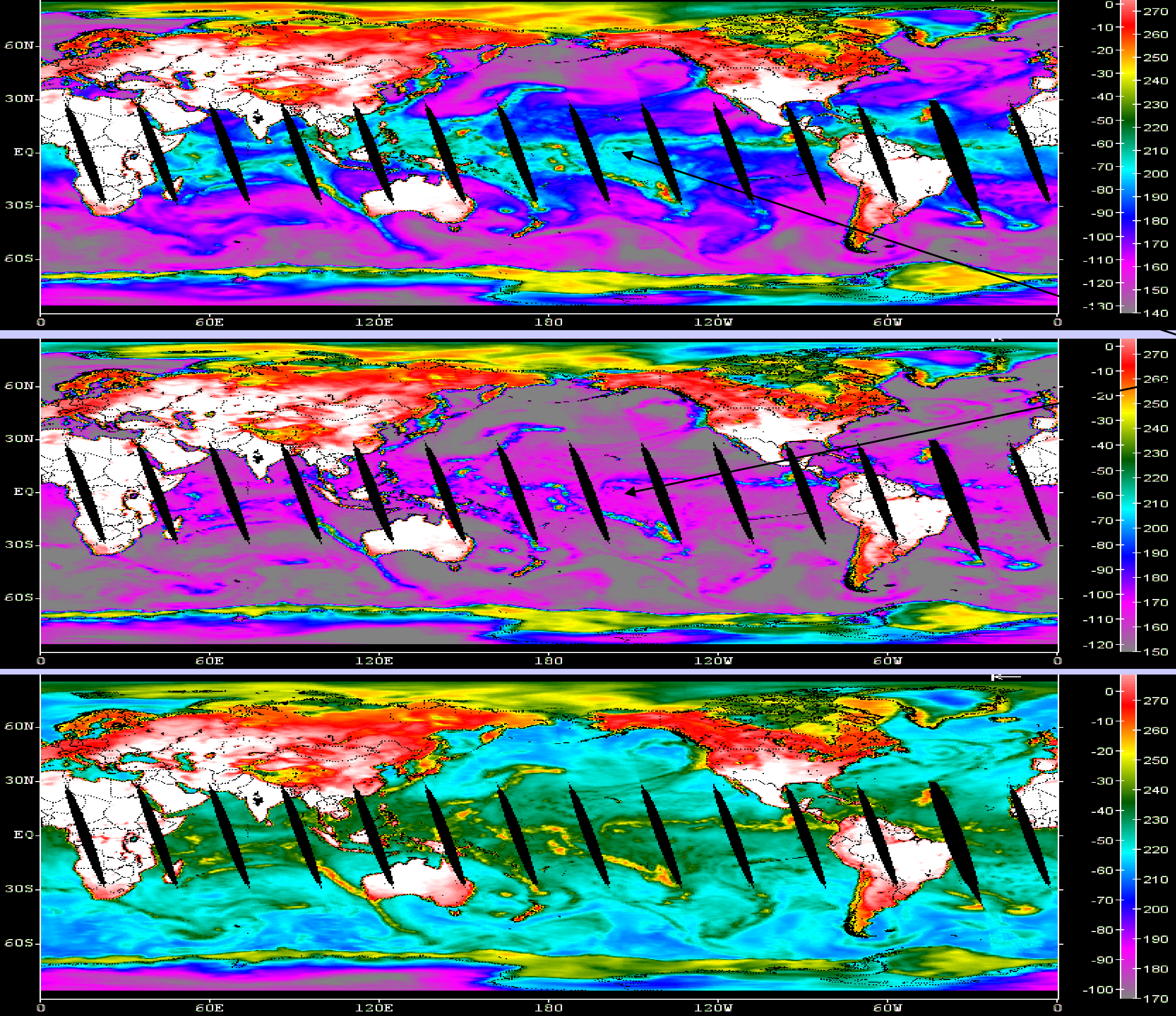
Scattering

Higher T_b above cloud

Lower T_b above clear air



Emission (over ocean)



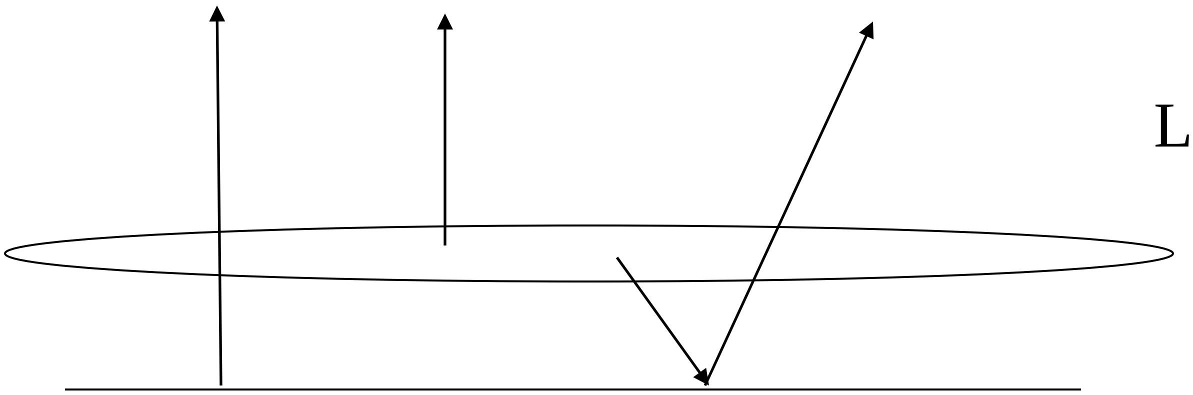
AMSU

23.8 dirty window

atm Q warms BT

31.4 window

50.3 GHz



Low mist over ocean

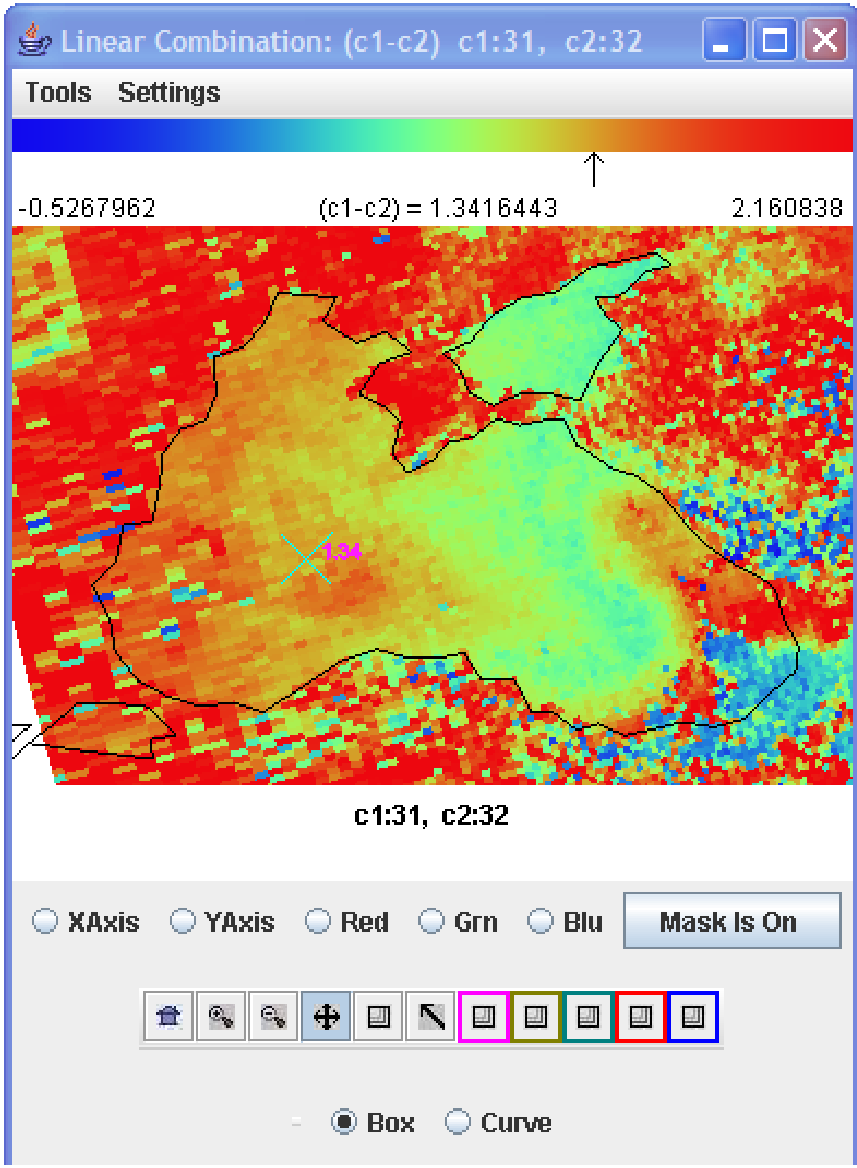
$T_b = \varepsilon_s T_s (1-\sigma_m) + \sigma_m T_m + \sigma_m (1-\varepsilon_s) (1-\sigma_m) T_m$

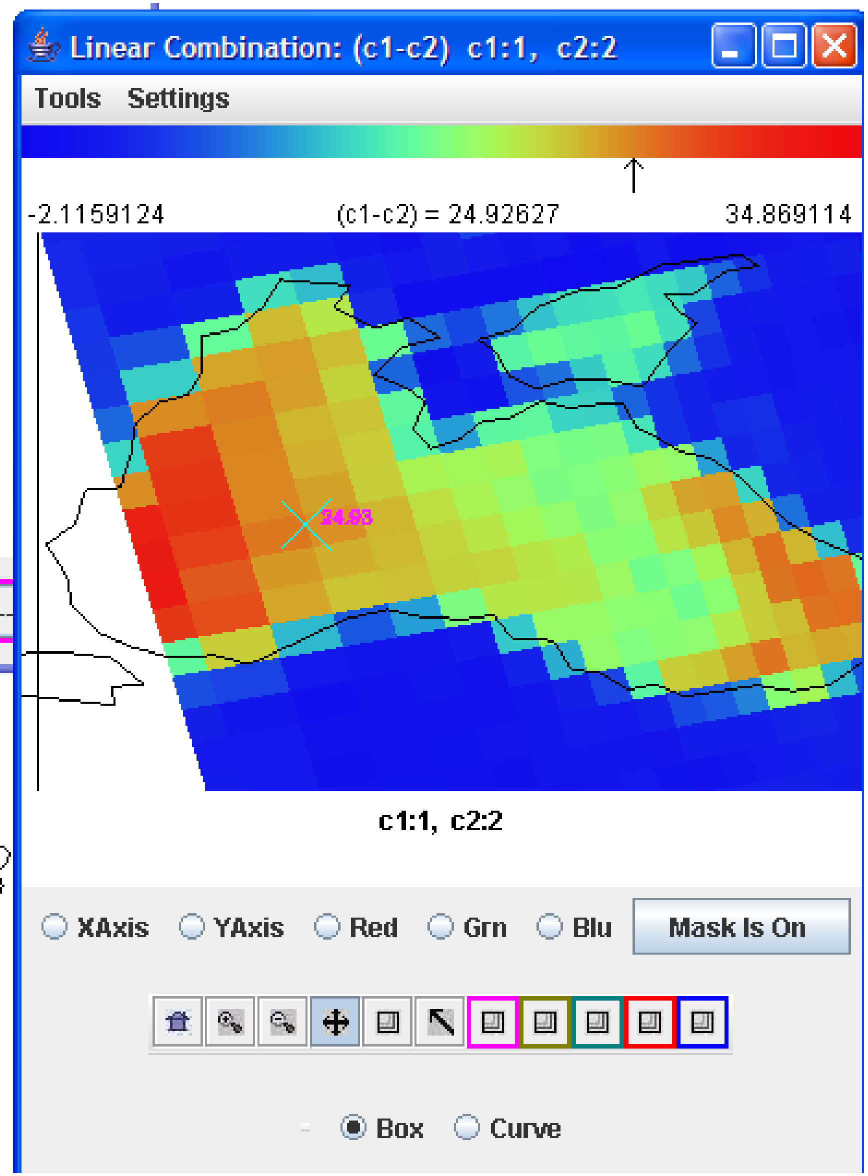
So

$\Delta T_b = - \varepsilon_s \sigma_m T_s + \sigma_m T_m + \sigma_m (1-\varepsilon_s) (1-\sigma_m) T_m$

For $\varepsilon_s \sim 0.5$ and $T_s \sim T_m$ this is always positive for $0 < \sigma_m < 1$

MW split window has larger signal for low level moisture than IR split window

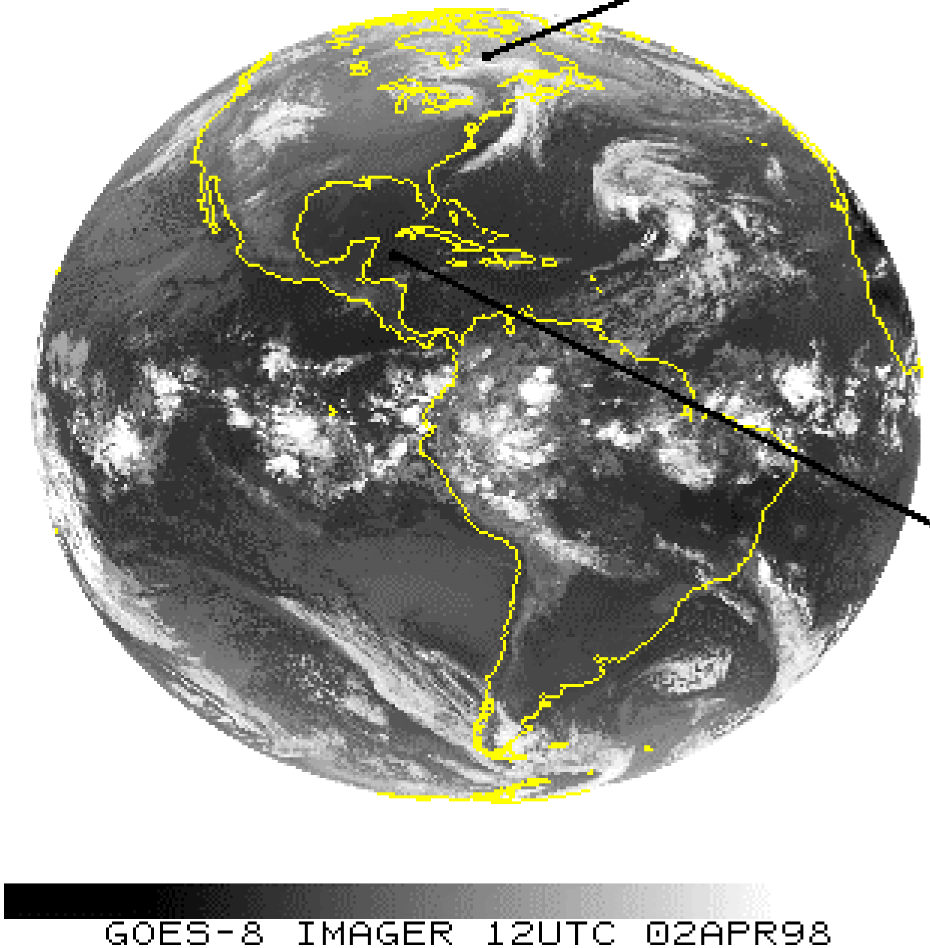


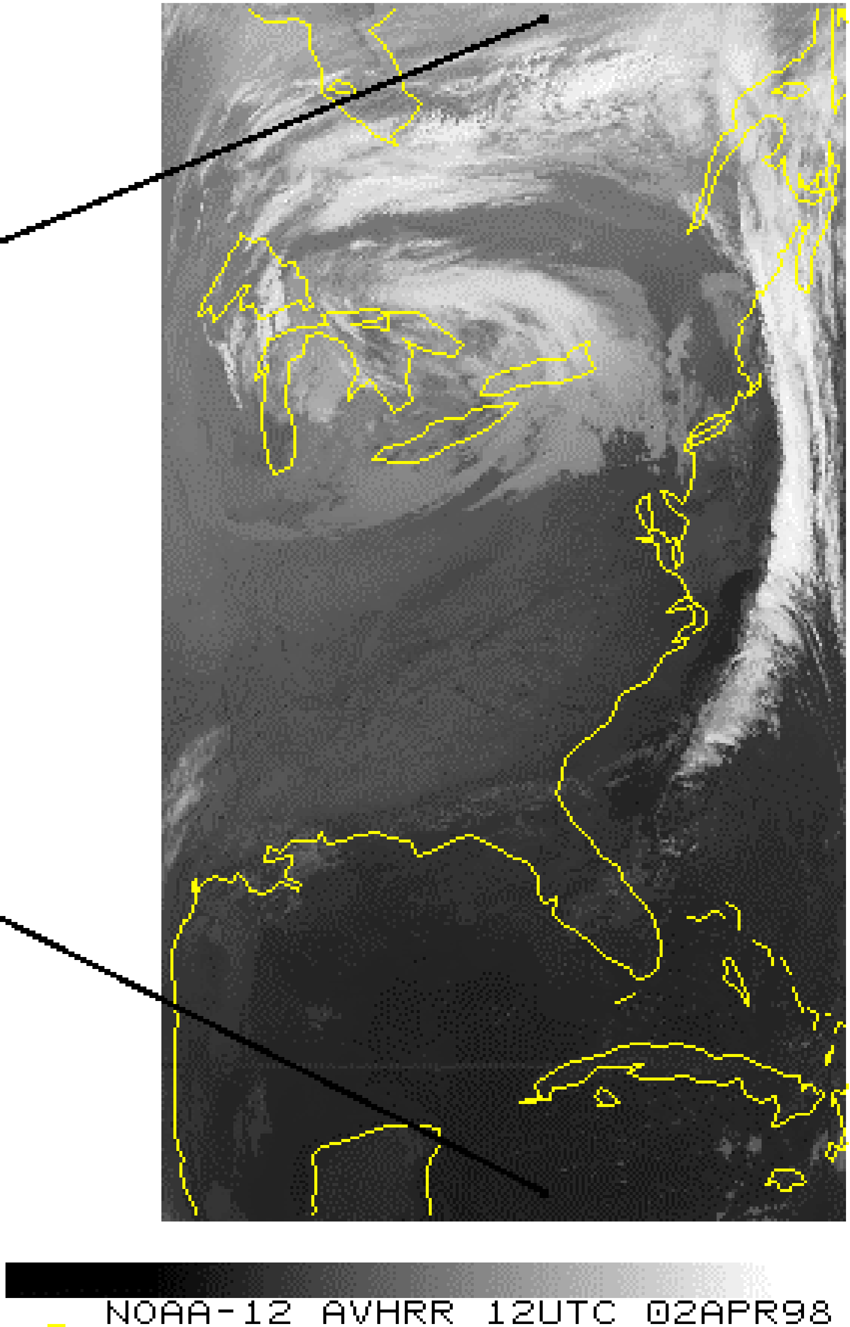


Accuracy of Satellite Derived Met Parameters

T(p) within 1.5 C of raobs for 1 km layers
SST within 0.5 C of buoys
Q(p) within 15-20% of raobs for 2 km layers
TPW with 3 mm of ground based MW
TO3 within 30 Dobsons of ozone profilers
LI adjusted 3 C lower (for better agreement with raobs)
 gradients in space and time more reliable than absolute
AMVs within 7 m/s (upper trop) and 5 m/s (lower trop)
CTPs within 50 hPa of lidar determination
Geopotential heights within 20 to 30 m
 for 500 to 300 hPa
For TC, Psfc within 6 hPa and Vmax within 10 kts
 (from MW $\Delta T250$)
Trajectory forecast 72 hour error reduction about 10%

GEO vs LEO



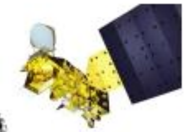


Comparison of geostationary (geo) and low earth orbiting (leo) satellite capabilities

Geo	Leo
observes process itself (motion and targets of opportunity)	observes effects of process
repeat coverage in minutes ($\Delta t \leq 30$ minutes)	repeat coverage twice daily ($\Delta t = 12$ hours)
full earth disk only	global coverage
best viewing of tropics	best viewing of poles
same viewing angle	varying viewing angle
differing solar illumination	same solar illumination
visible, IR imager (1, 4 km resolution)	visible, IR imager (1, 1 km resolution)
one visible band	multispectral in visible (veggie index)
IR only sounder (8 km resolution)	IR and microwave sounder (17, 50 km resolution)
filter radiometer	filter radiometer, interferometer, and grating spectrometer
diffraction more than leo	diffraction less than geo

HYperspectral viewer for Development of Research Applications - HYDRA

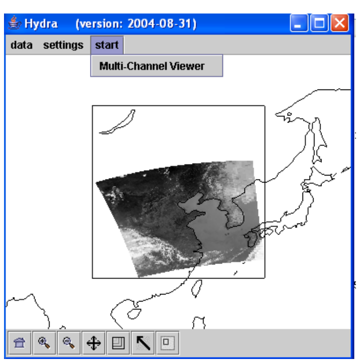
MSG,
GOES



MODIS,
AIRS, IASI,
AMSU,
CALIPSO

Freely available software
For researchers and educators
Computer platform independent
Extendable to more sensors and applications
Based in VisAD
(Visualization for Algorithm Development)
Uses Jython (Java implementation of Python)
runs on most machines
512MB main memory & 32MB graphics card suggested
on-going development effort

Rink et al, BAMS 2007



Developed at CIMSS by
Tom Rink
Tom Whittaker
Kevin Baggett

With guidance from
Paolo Antonelli
Liam Gumley
Paul Menzel
Allen Huang

CIMSS

http://www.ssec.wisc.edu/hydra/

For hydra
http://www.ssec.wisc.edu/hydra/

For MODIS data and quick browse images
http://rapidfire.sci.gsfc.nasa.gov/realtime

For MODIS data orders
http://ladsweb.nascom.nasa.gov/

For DB MODIS from SSEC (2007 onwards)
http://ge.ssec.wisc.edu/modis-today/

For AIRS data orders
http://daac.gsfc.nasa.gov/

One week is not enough

You have made a good start – continue using HYDRA, inspecting data, and asking questions – you will master remote sensing applications and help monitor the environment for weather and climate signals