Summary of Satellite Remote Sensing Concepts

Lectures in Monteponi
September 2008

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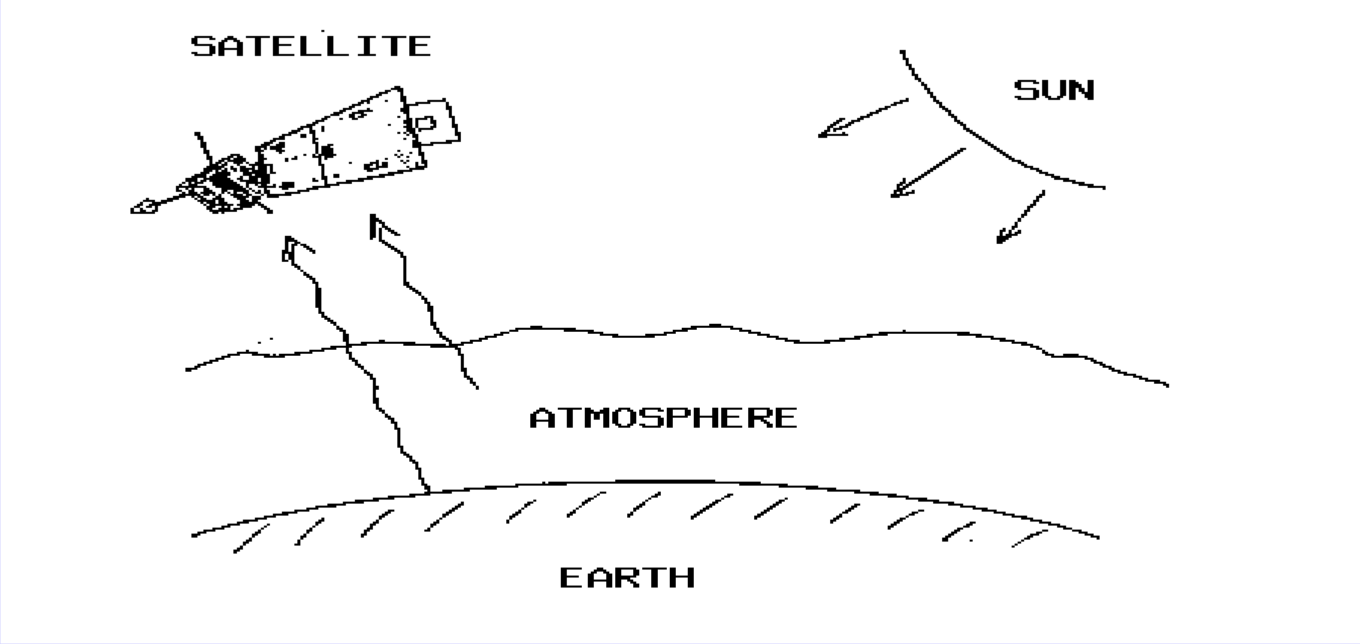
UW/CIMSS/AOS

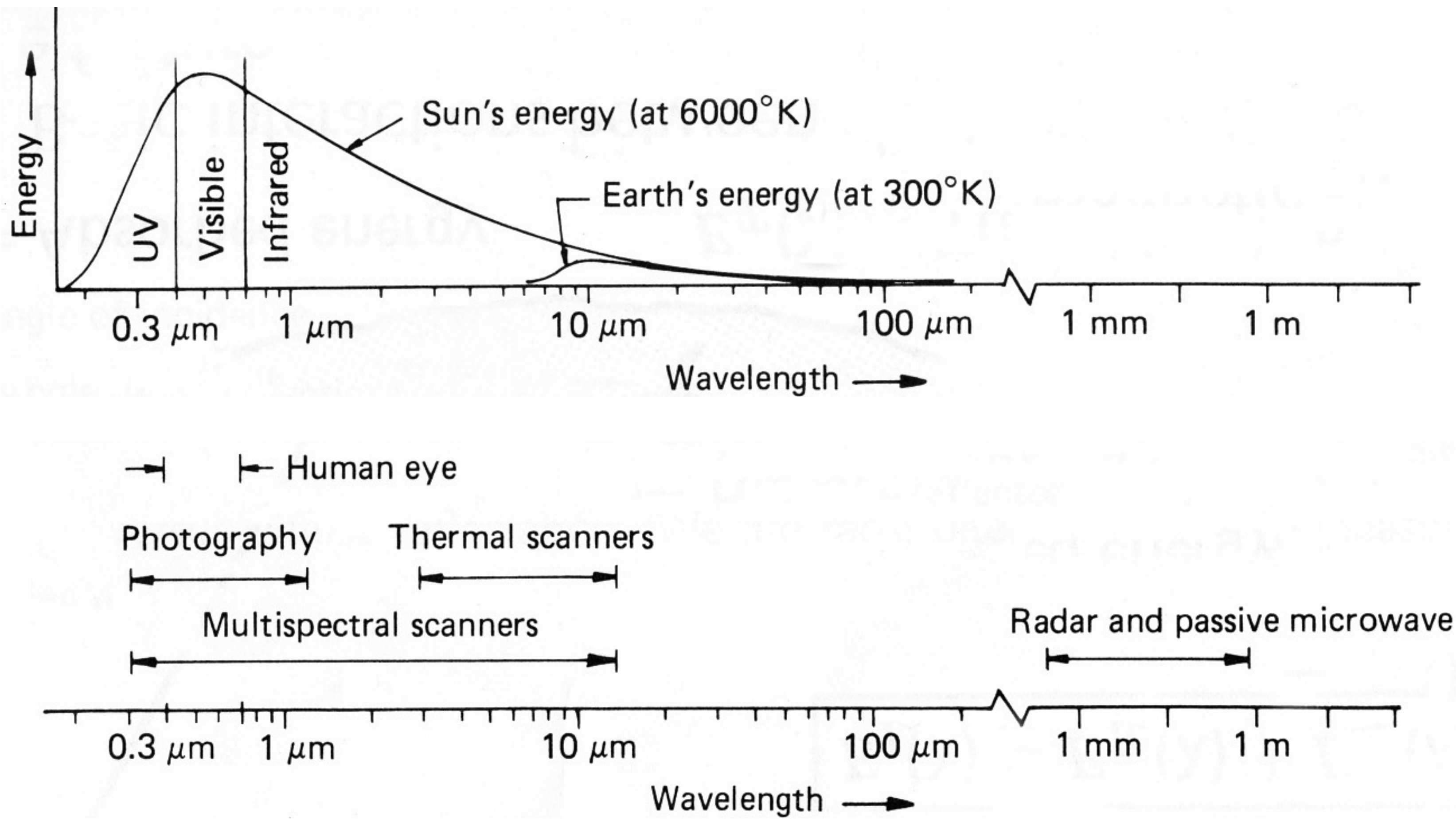
Satellite remote sensing of the Earth-atmosphere



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

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

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

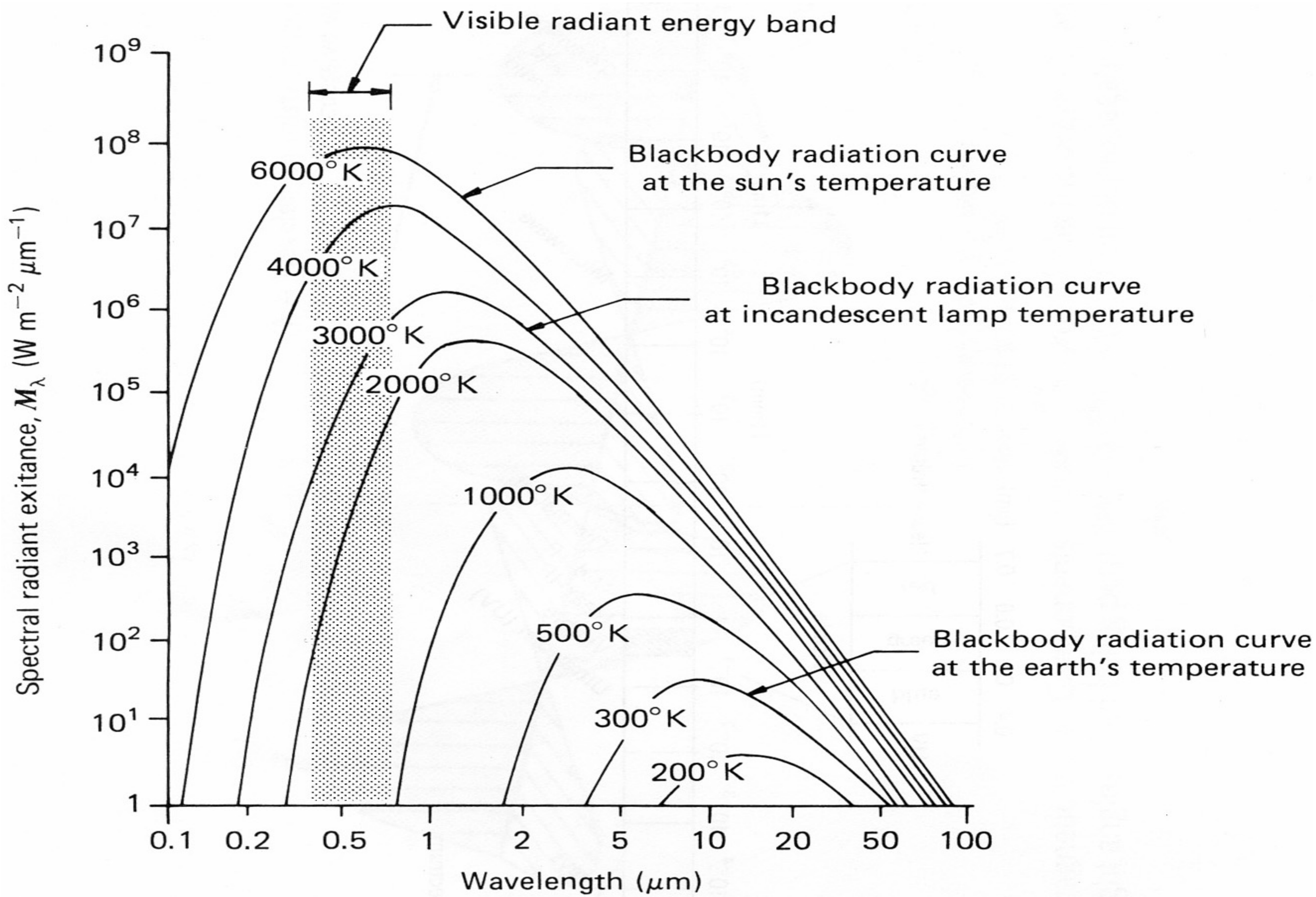
λ(max in cm)T = 0.2897

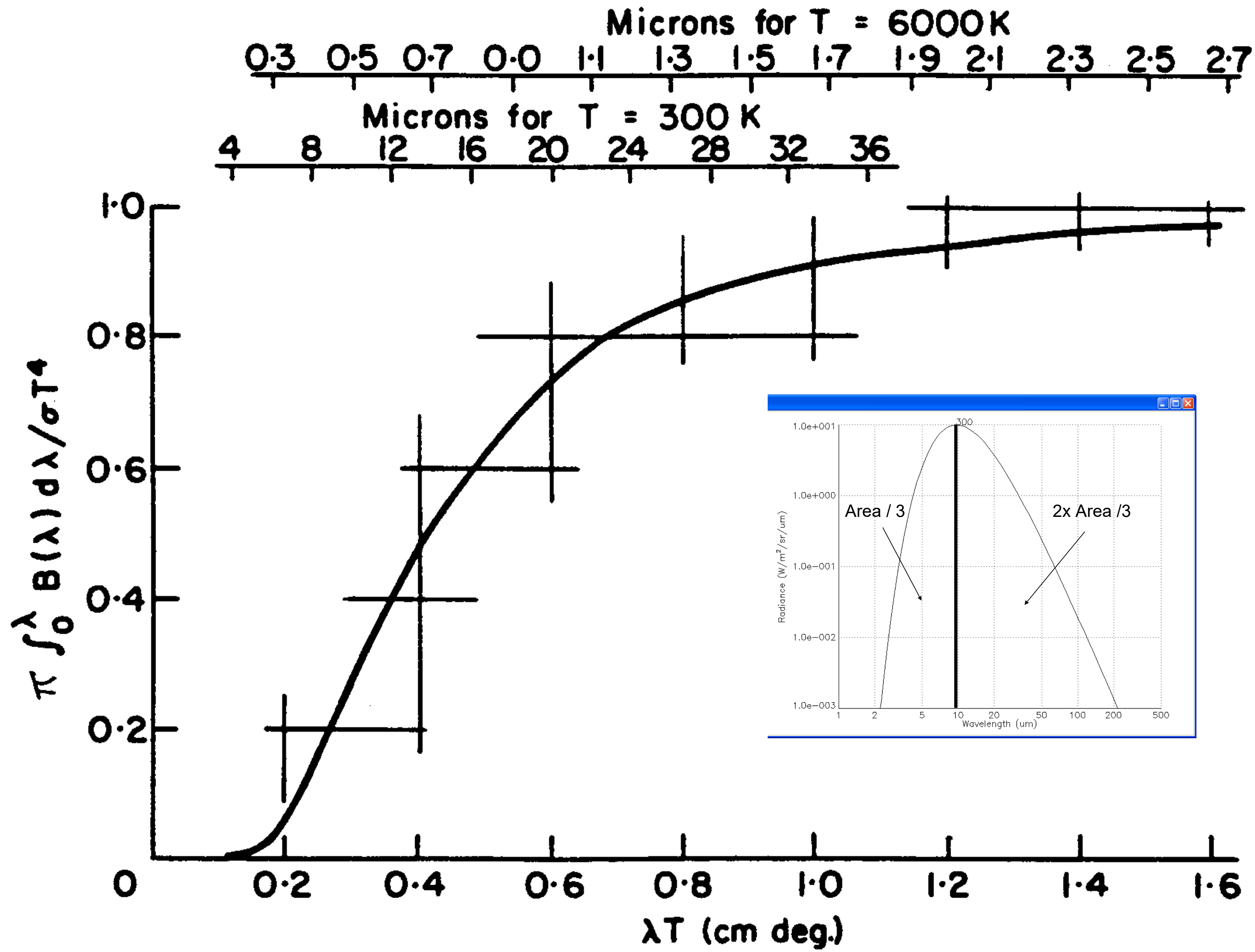
$B(\lambda_{max},T) \sim T^{**}5.$

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

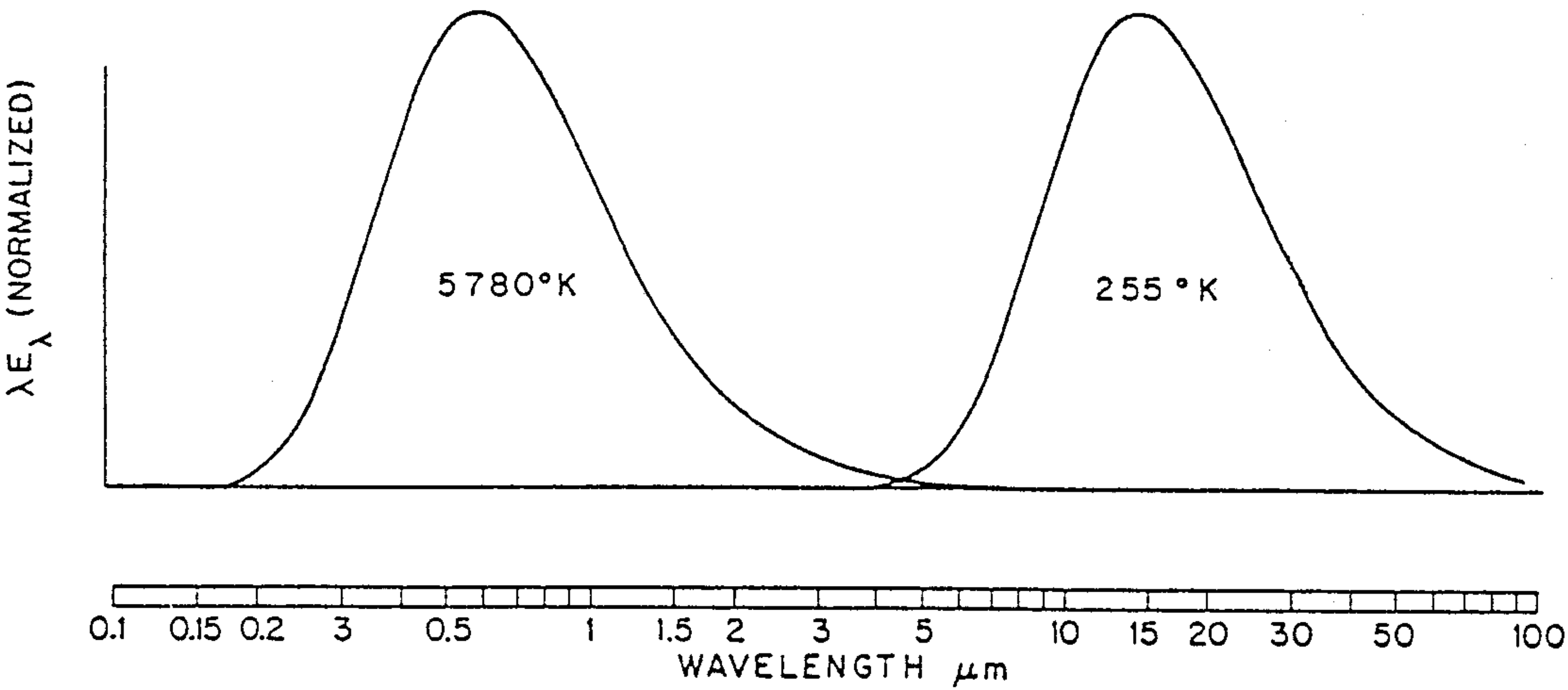
$$T = c_2 / [\lambda \ln(\frac{c_1}{\lambda^5 B_\lambda} + 1)]$$

Spectral Distribution of Energy Radiated from Blackbodies at Various Temperatures

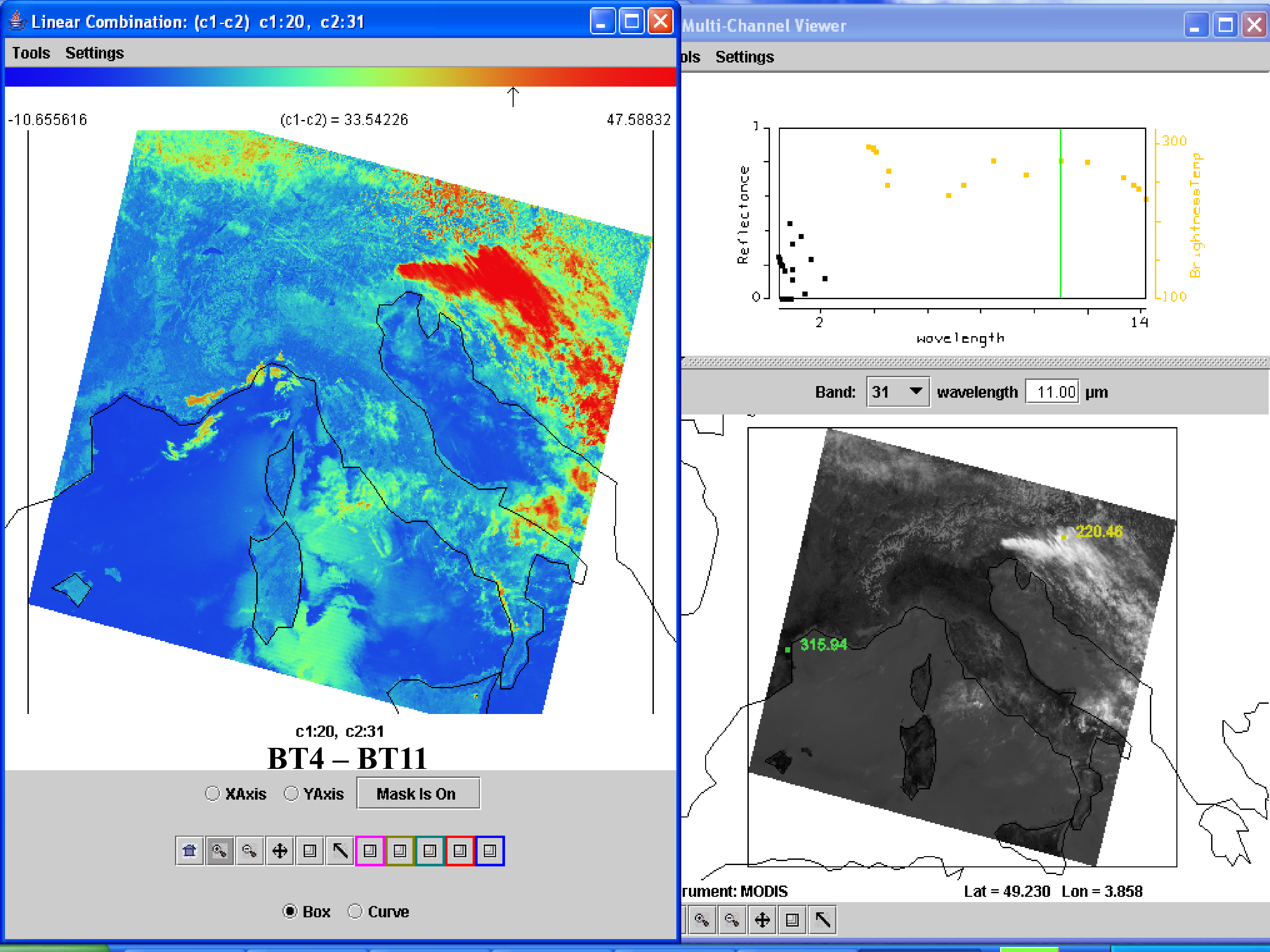




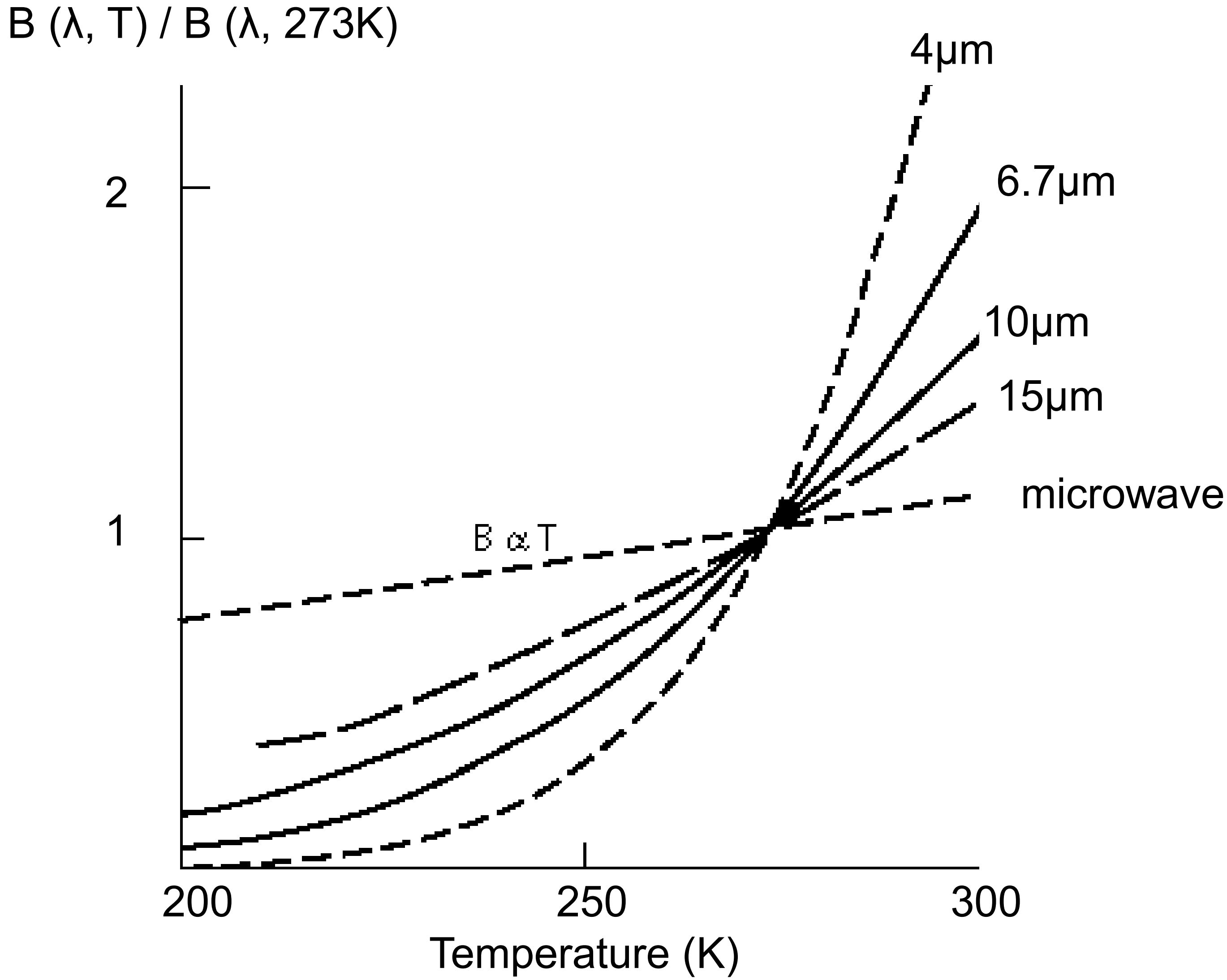
Microns for T = 6000 K
0·3 0·5 0·7 0·0 1·1 1·3 1·5 1·7 1·9 2·1 2·3 2·5 2·7
Microns for T = 300 K
4 8 12 16 20 24 28 32 36
1·0
0·8
0·6
0·4
0·2
0
0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6
λT (cm deg.)
π ∫₀^λ B(λ) dλ / σT⁴
1.0e+001
1.0e+000
1.0e−001
1.0e−002
1.0e−003
300
Area / 3
2x Area /3
Radiance (W/m²/sr/um)
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



Observed BT at 4 micron

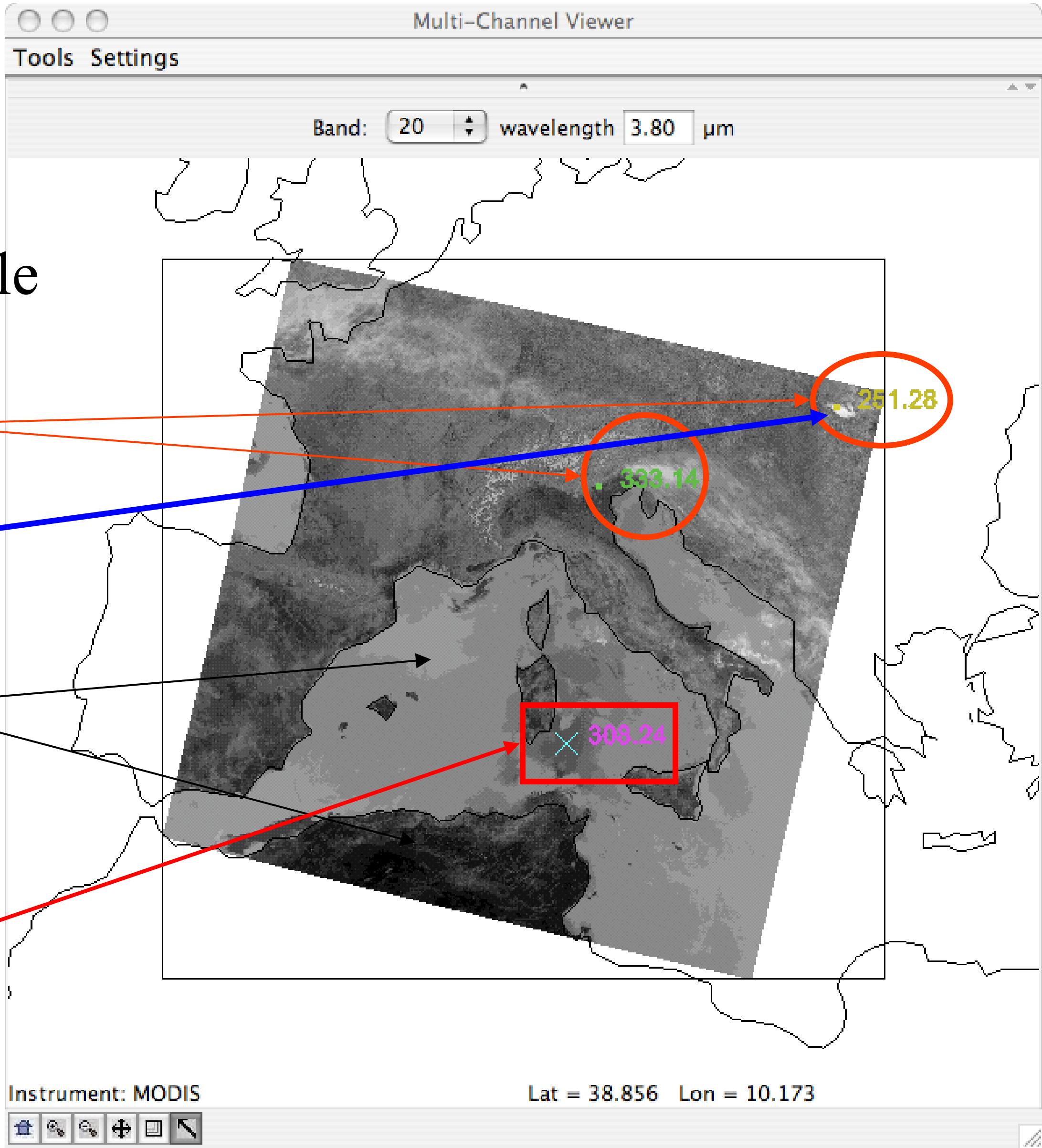
Window Channel:
•little atmospheric absorption
•surface features clearly visible

Range BT[250, 335]
Range R[0.2, 1.7]

Clouds are cold

Values over land
Larger than over water

Reflected Solar everywhere
Stronger over Sunglint



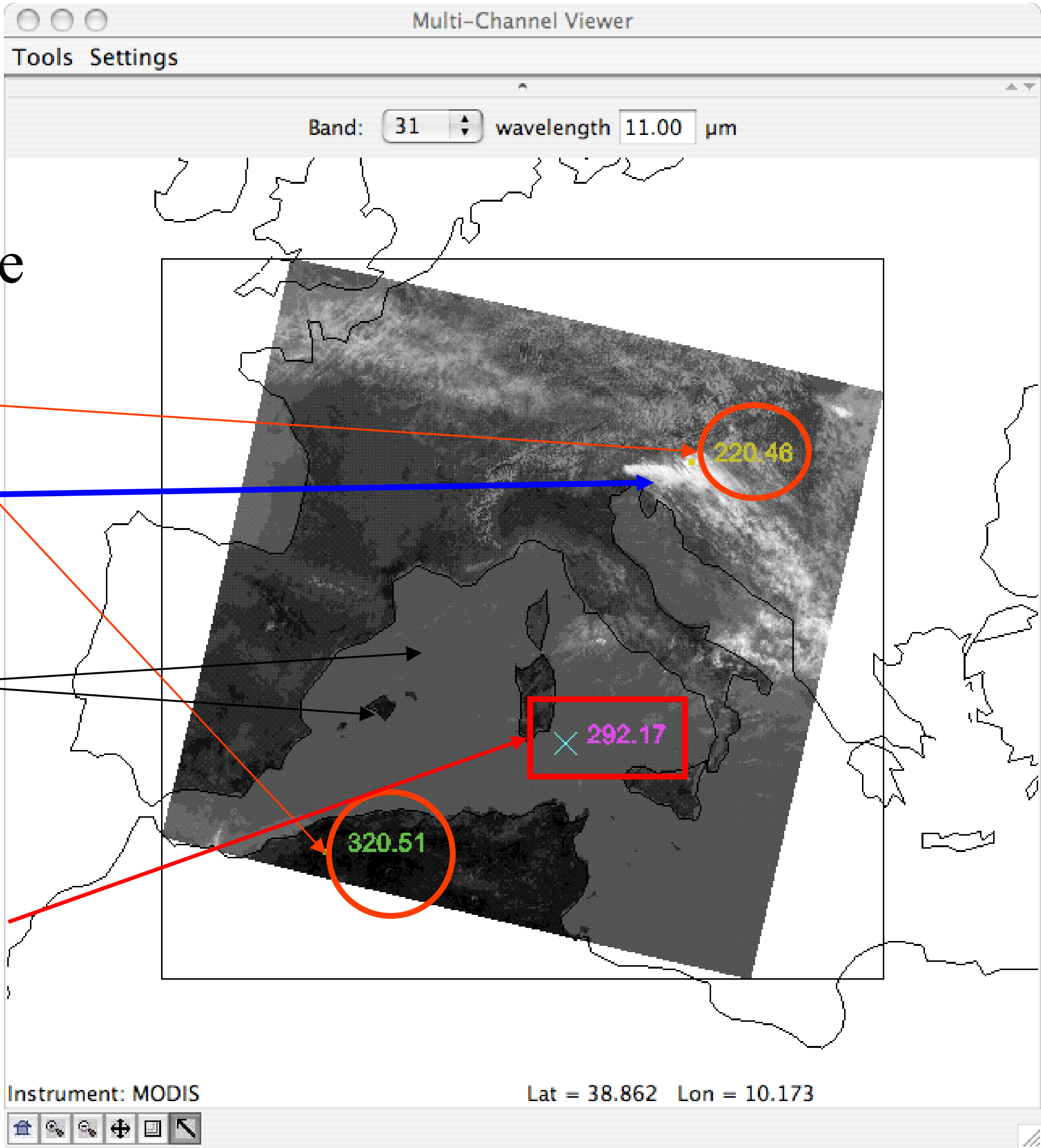
Observed BT at 11 micron

Window Channel:
- little atmospheric absorption
- surface features clearly visible

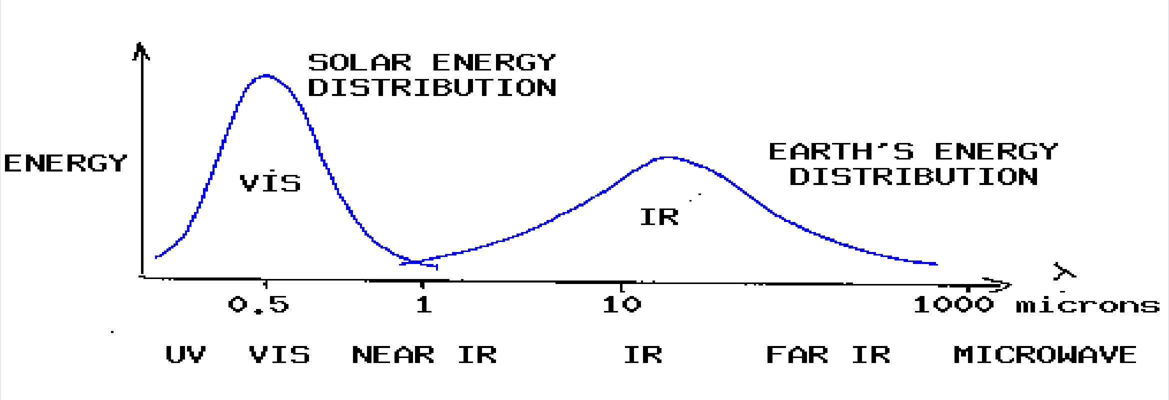
Range BT [220, 320]
Range R [2.1, 12.4]
Clouds are cold

Values over land
Larger than over water

Undetectable Reflected Solar
Even over Sunglint



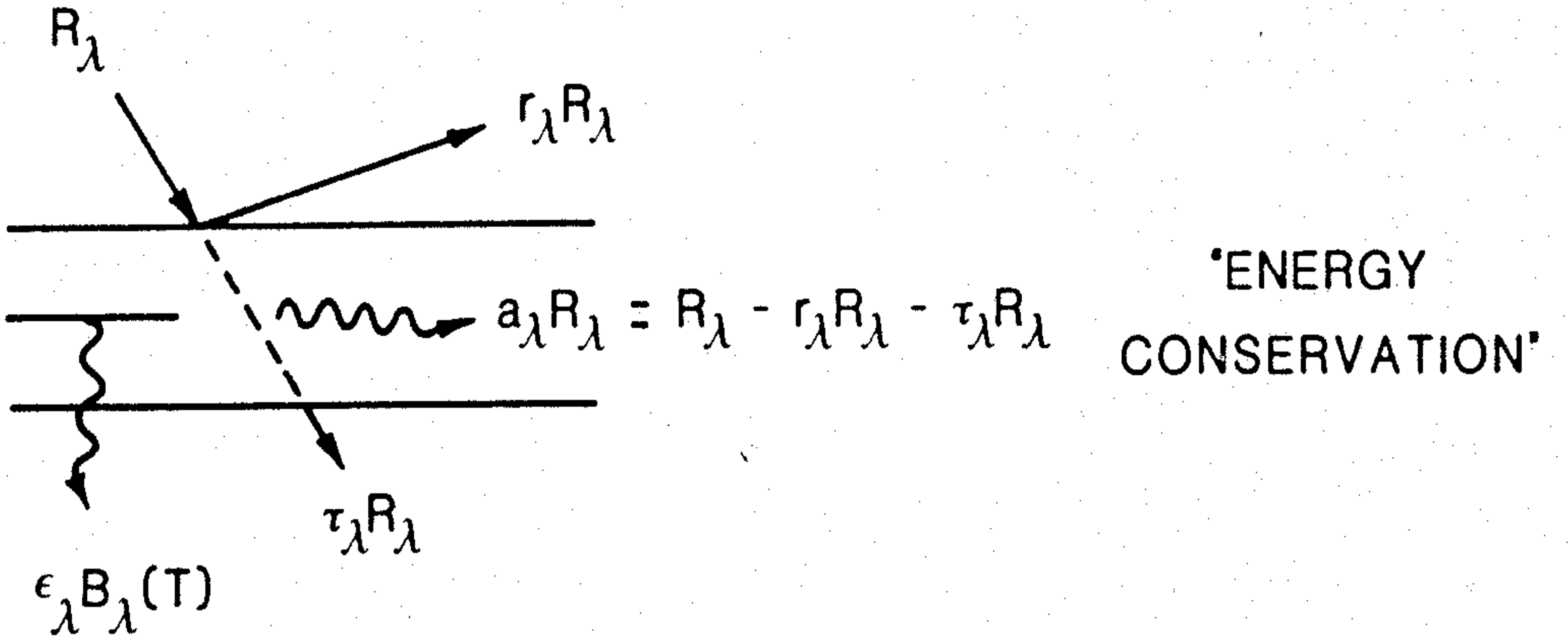
Solar (visible) and Earth emitted (infrared) energy



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.


R_λ
$r_\lambda R_\lambda$
$a_\lambda R_\lambda = R_\lambda - r_\lambda R_\lambda - \tau_\lambda R_\lambda$
'ENERGY CONSERVATION'
$\tau_\lambda R_\lambda$
$\epsilon_\lambda B_\lambda(T)$

Selective Absorption
Atmosphere transmits visible and traps infrared

Incoming solar　　Outgoing IR

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

top of the atmosphere

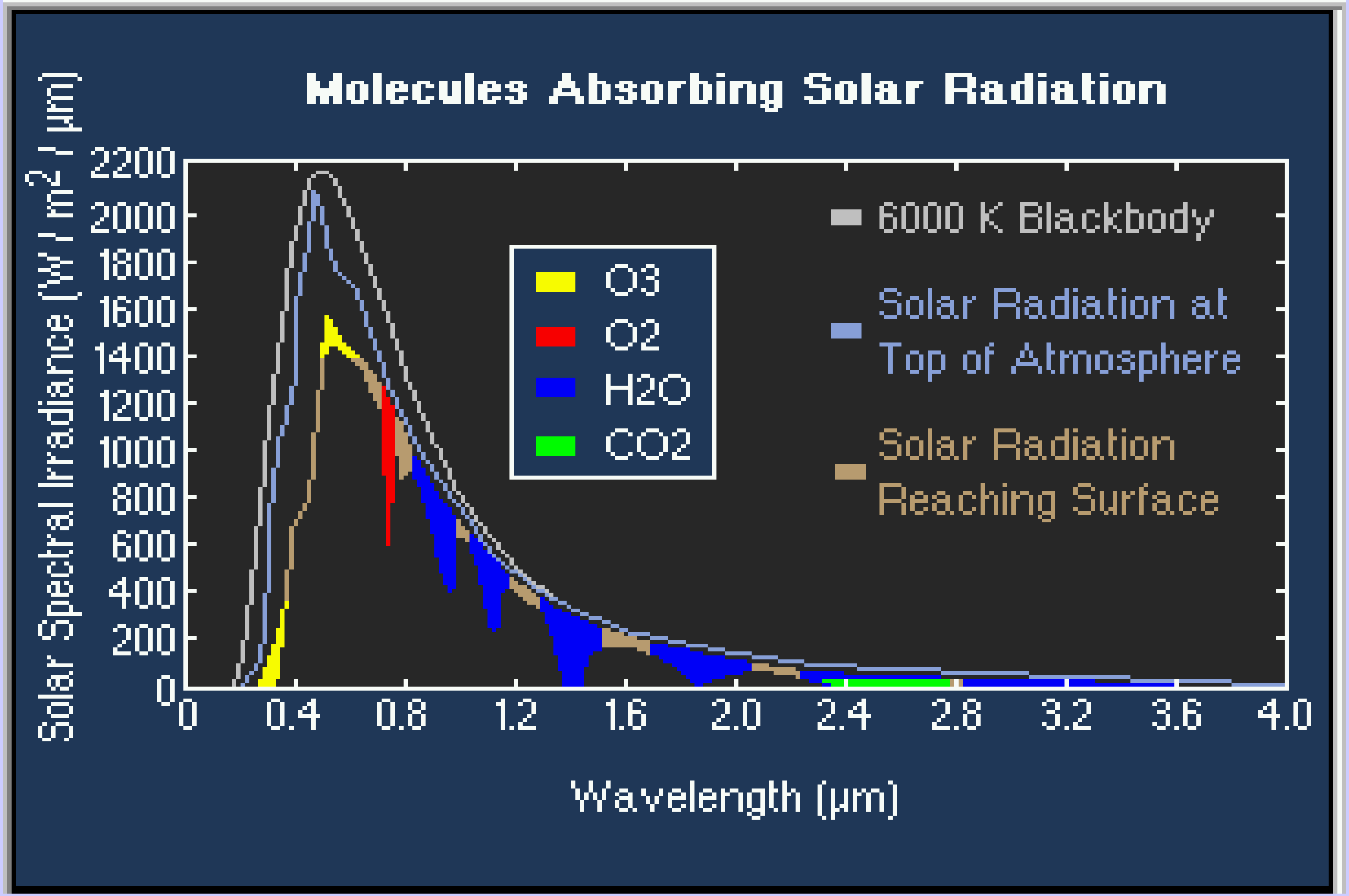
$\downarrow (1\text{-}a_s)\, E$　$\uparrow Y_{sfc}$　$\downarrow Y_a$

earth surface.

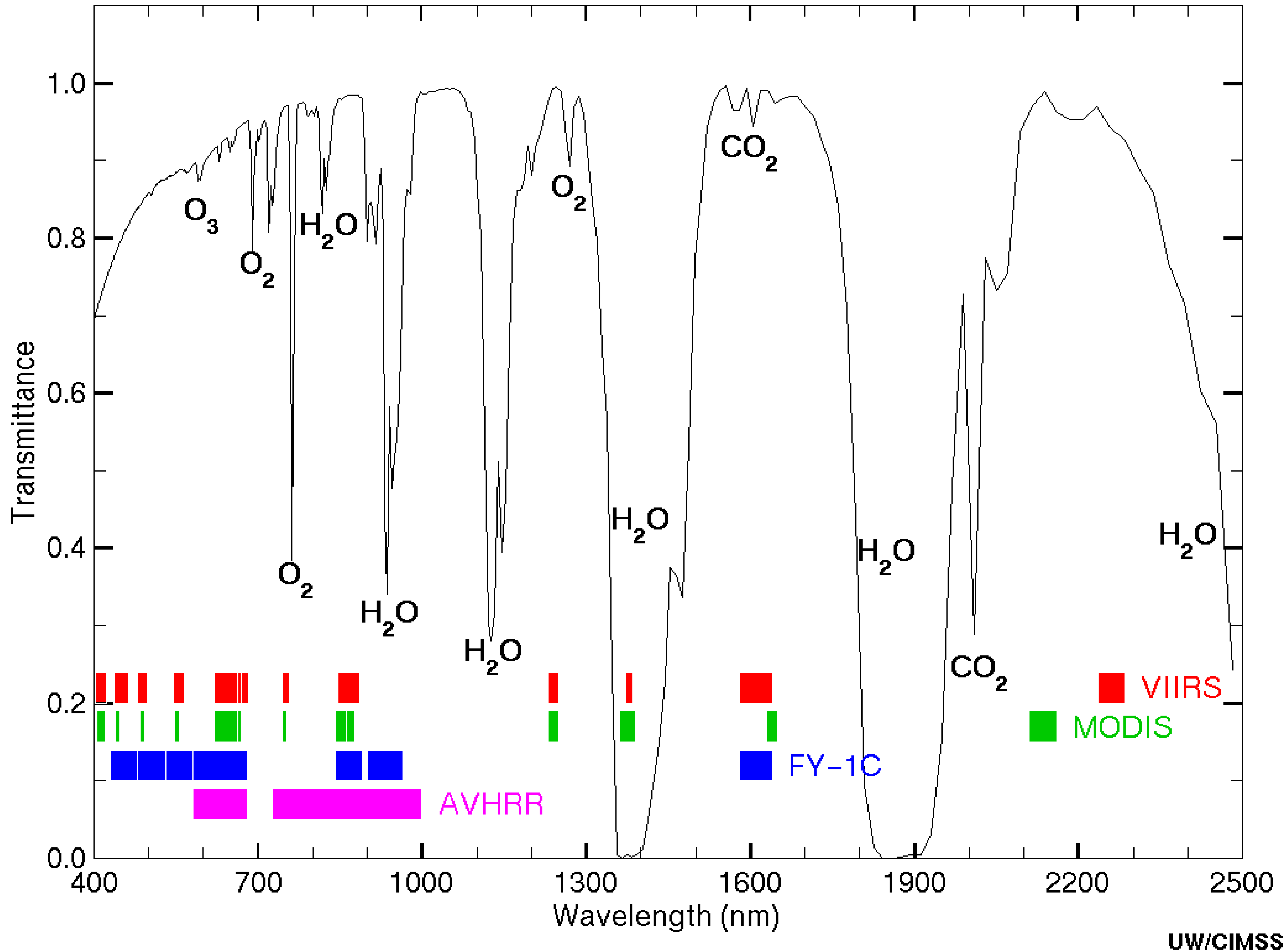
$$Y_{sfc} = \frac{(2\text{-}a_S)}{(2\text{-}a_L)} E = \sigma T_{sfc}^4$$

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

Solar Spectrum



VIIRS, MODIS, FY-1C, AVHRR



Ocean: Dark

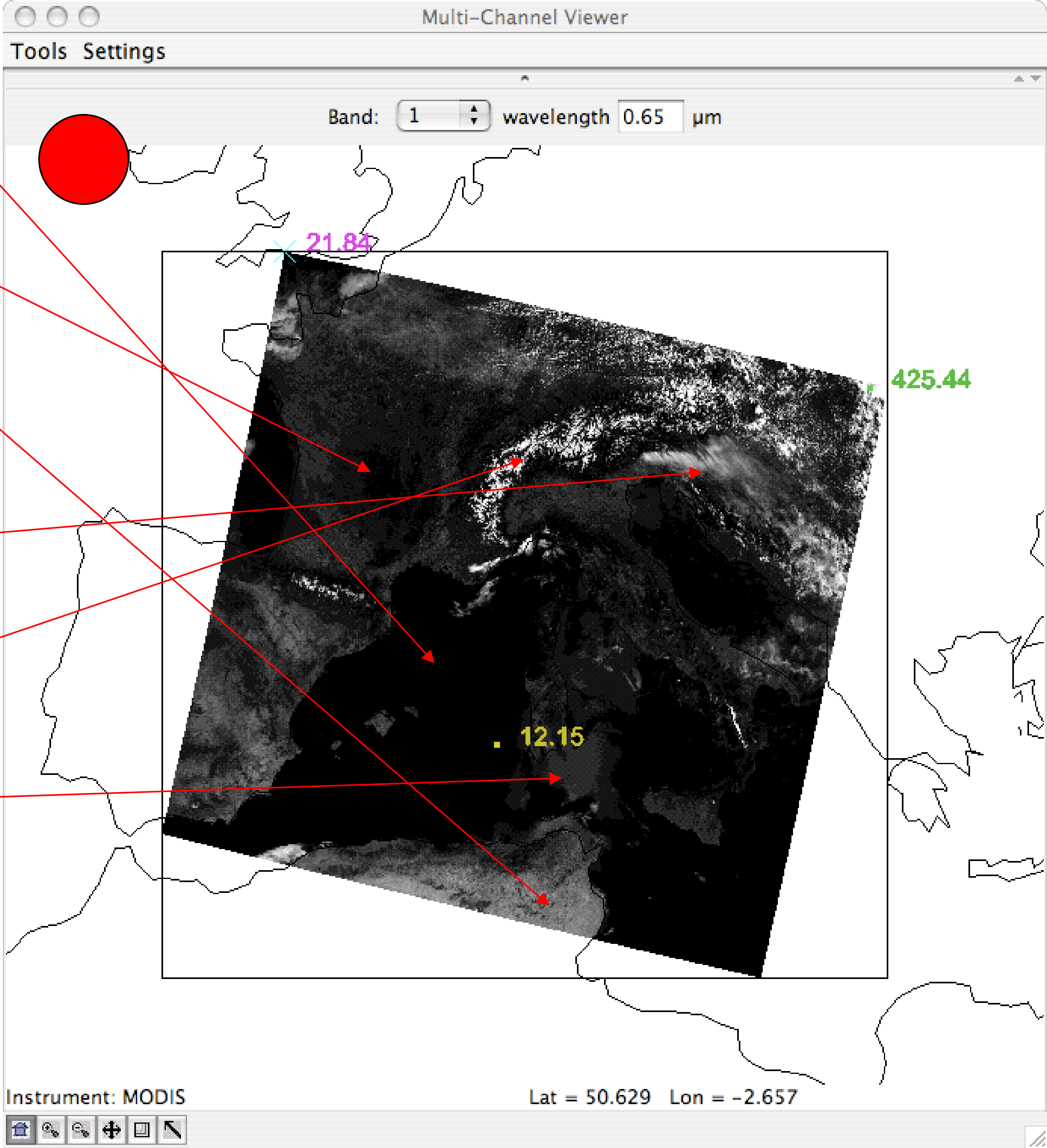
Vegetated Surface: Dark

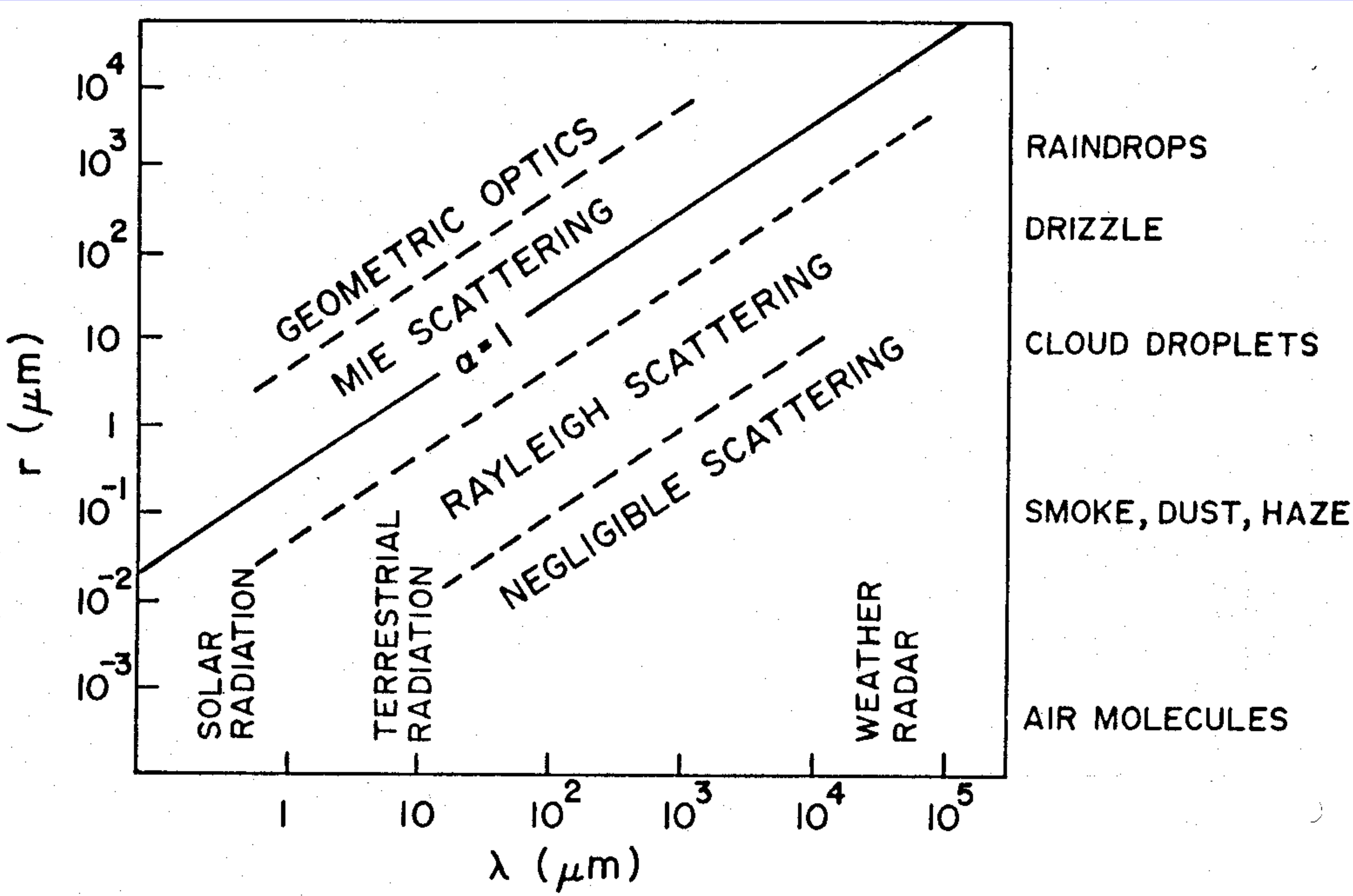
NonVegetated Surface: Brighter

Clouds: Bright

Snow: Bright

Sunglint

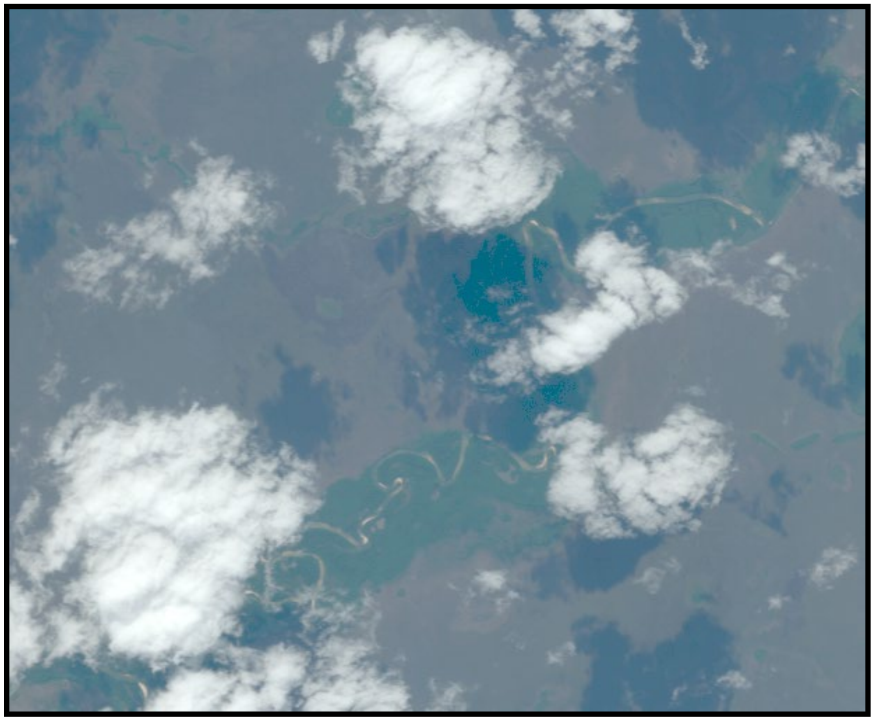


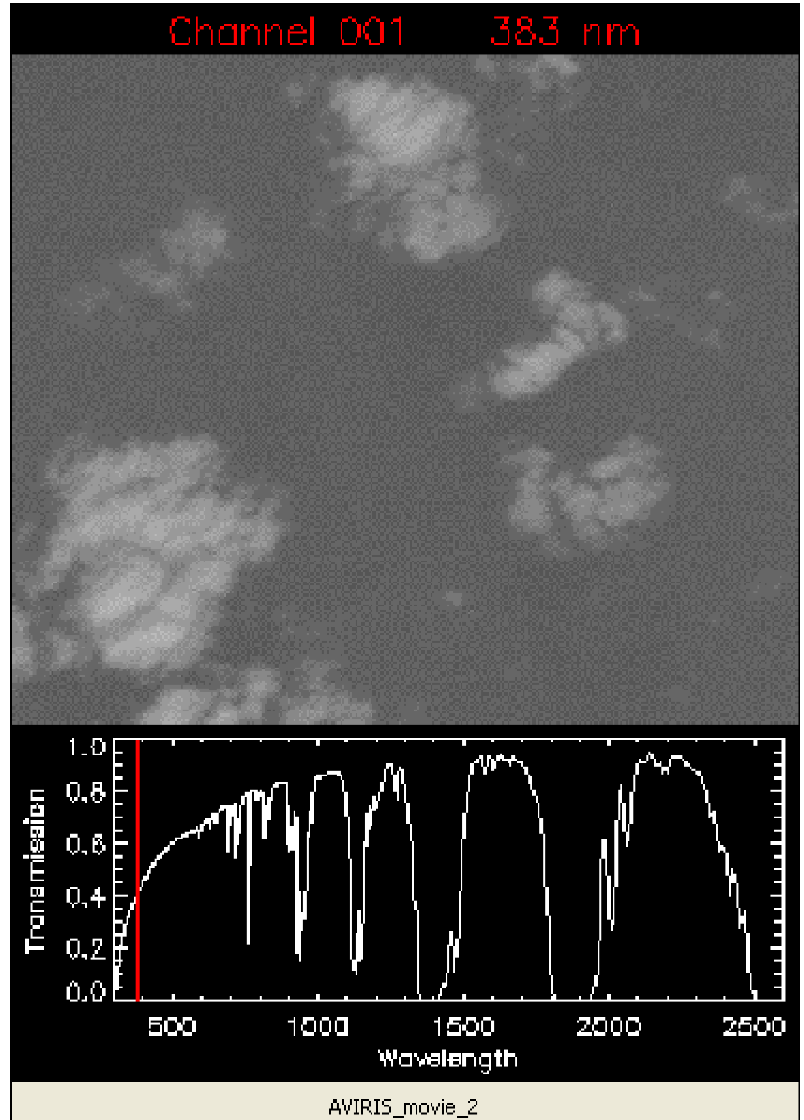


GEOMETRIC OPTICS
MIE SCATTERING
α = 1
RAYLEIGH SCATTERING
NEGLIGIBLE SCATTERING
SOLAR RADIATION
TERRESTRIAL RADIATION
WEATHER RADAR
RAINDROPS
DRIZZLE
CLOUD DROPLETS
SMOKE, DUST, HAZE
AIR MOLECULES
r (μm)
λ (μm)

AVIRIS Movie #2

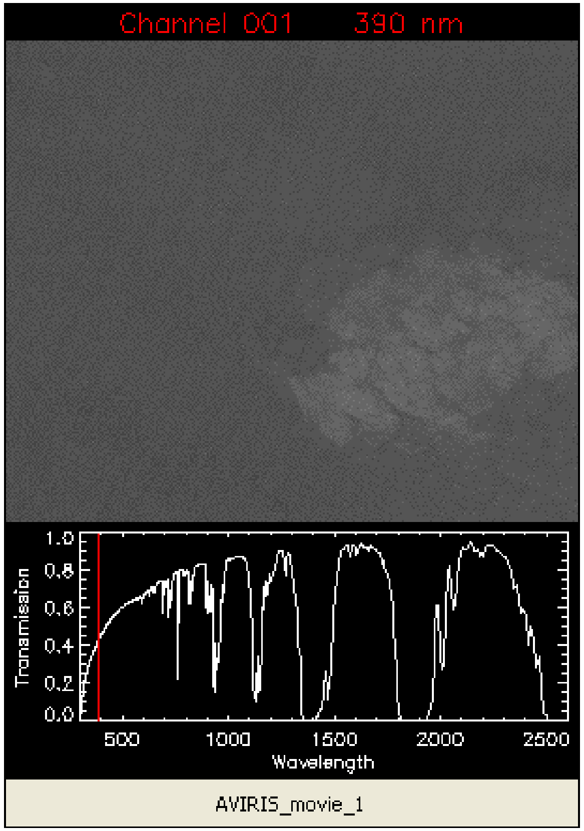
AVIRIS Image - Porto Nacional, Brazil
20-Aug-1995
224 Spectral Bands: 0.4 - 2.5 μm
Pixel: 20m x 20m   Scene: 10km x 10km





AVIRIS Movie #1

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



Aerosol Size Distribution

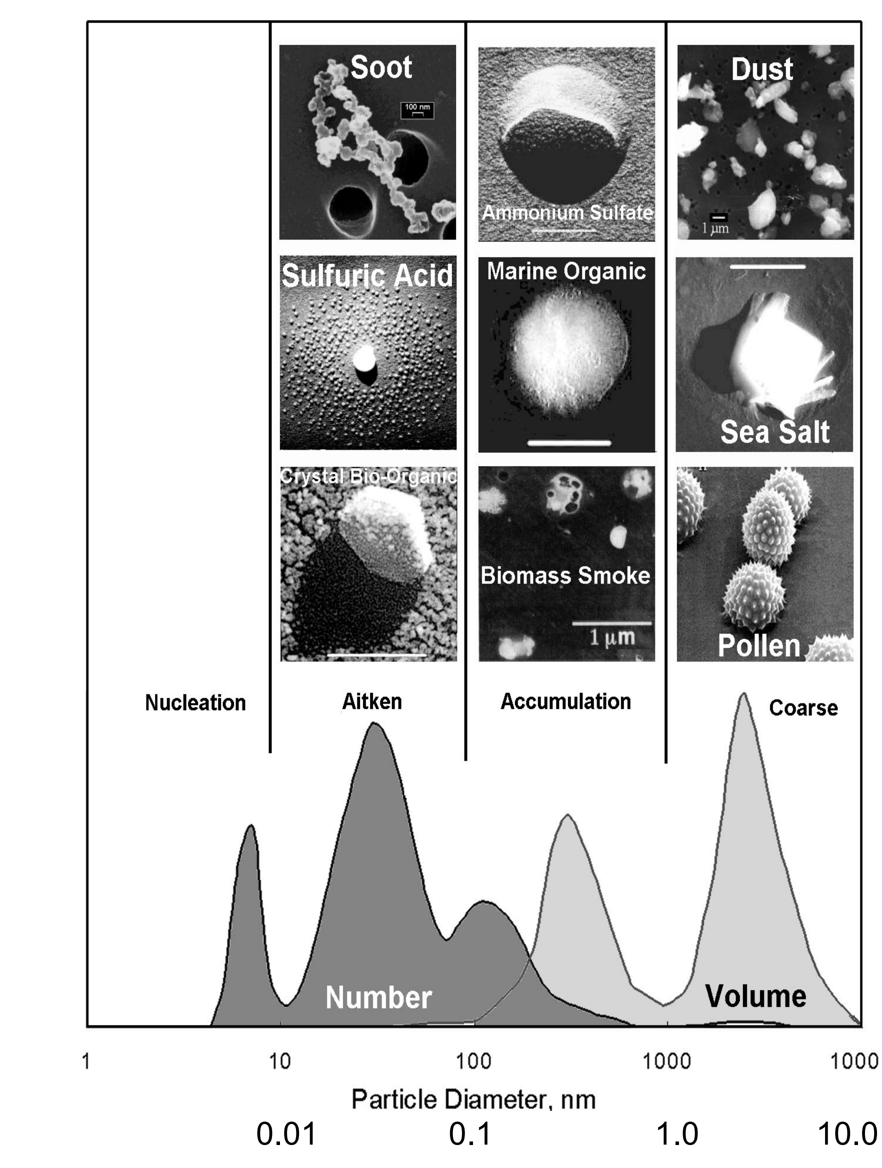
There are 3 modes :

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

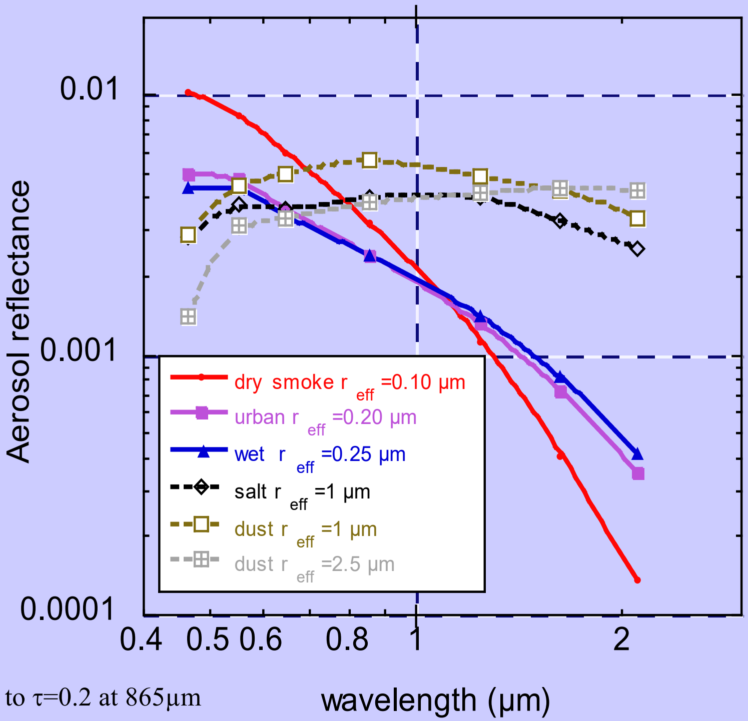
- « **accumulation »:** radius is between 0.05 µm and 0.5 µm**.** Coagulation processes.

- « **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

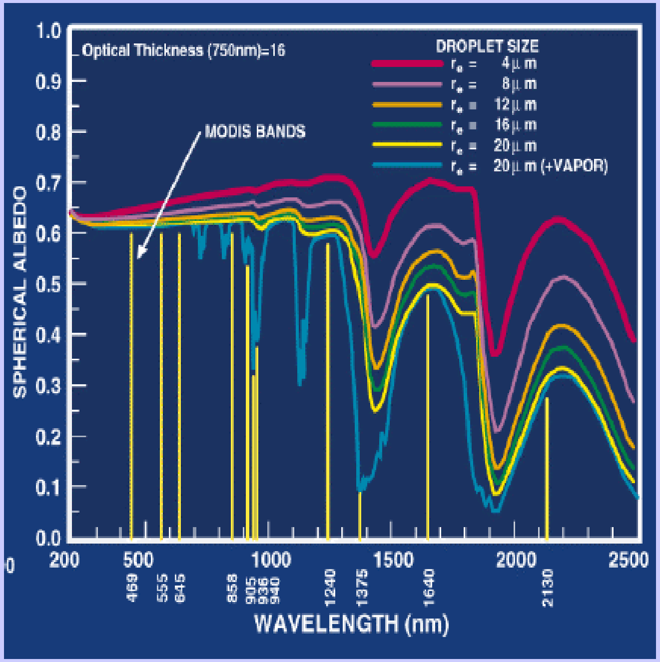


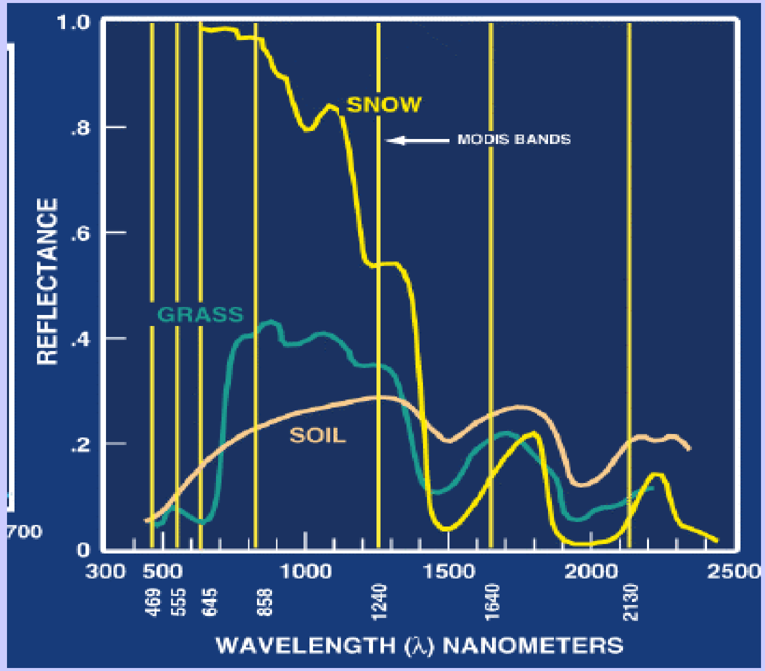
Normalized to τ=0.2 at 865μm

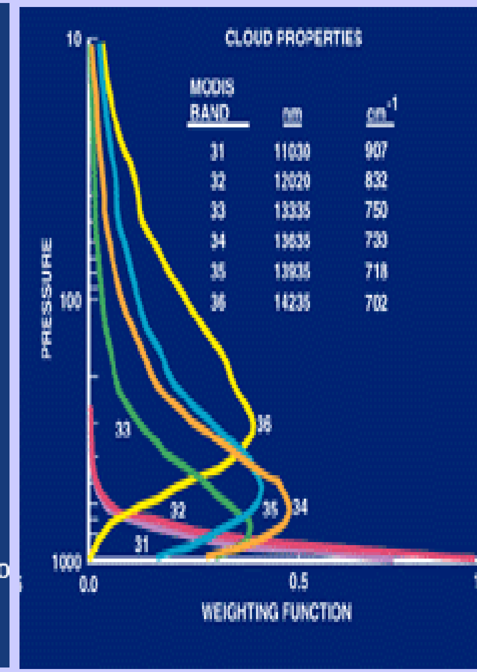
- Radiance data in 6 bands (550-2130nm).
- Spectral radiances (LUT) to derive the aerosol size distribution
- Two modes (accumulation 0.10-0.25μm; coarse1.0-2.5μm); ratio is a free parameter
- Radiance at 865μm to derive τ

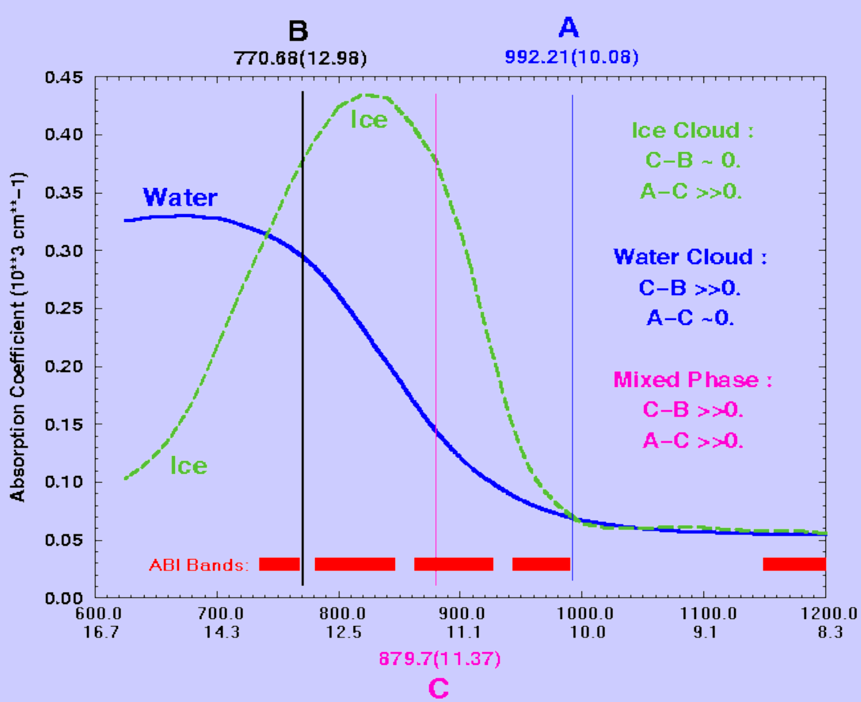
Ocean products :

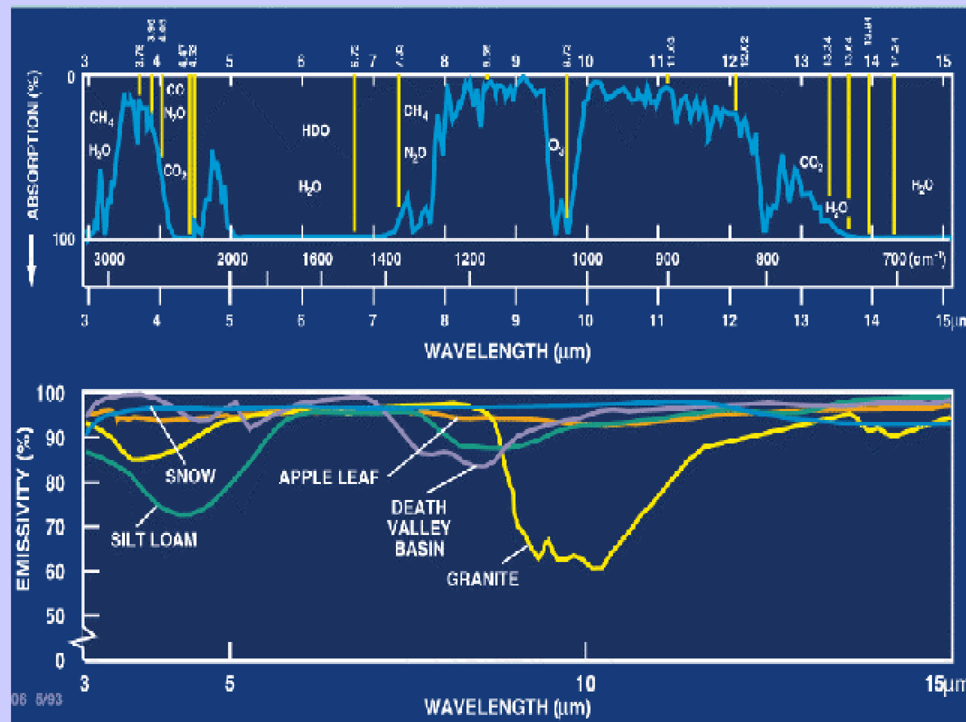
- The total Spectral Optical thickness
- The effective radius
- The optical thickness of small & large modes/ratio between the 2 modes

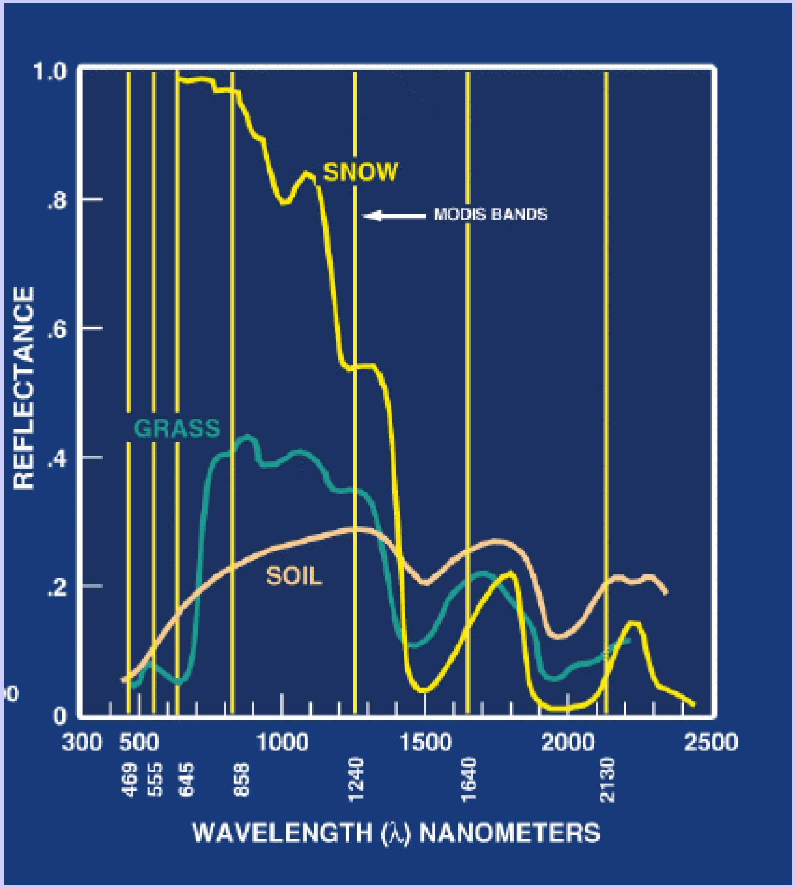

Optical Thickness (750nm)=16
DROPLET SIZE
r_e = 4 µm
r_e = 8 µm
r_e = 12 µm
r_e = 16 µm
r_e = 20 µm
r_e = 20 µm (+VAPOR)
MODIS BANDS
SPHERICAL ALBEDO
WAVELENGTH (nm)
469 555 645 858 905 936 940 1240 1375 1640 2130


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


CLOUD PROPERTIES
MODIS BAND
nm
cm^{-1}
31 11030 907
32 12020 832
33 13335 750
34 13635 733
35 13935 718
36 14235 702
PRESSURE
WEIGHTING FUNCTION


B
770.68(12.98)
A
992.21(10.08)
Ice
Water
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 (%)
CH4
H2O
CO
N2O
CO2
HDO
O3
WAVELENGTH (µm)
EMISSIVITY (%)
SNOW
APPLE LEAF
DEATH VALLEY BASIN
SILT LOAM
GRANITE
06 5/93

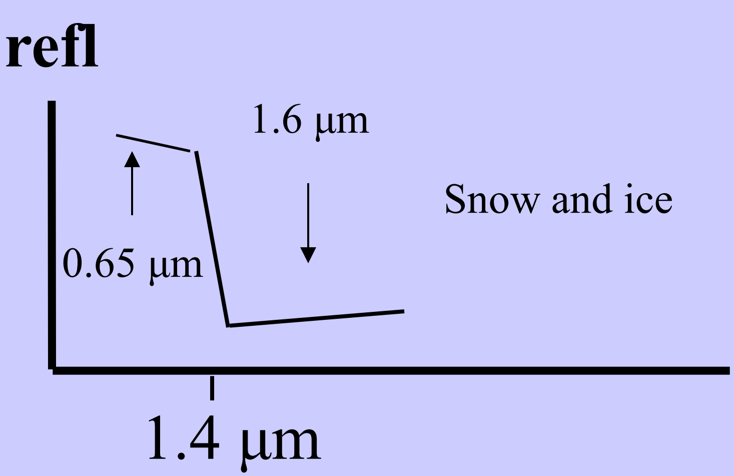


Investigating with Multi-spectral Combinations

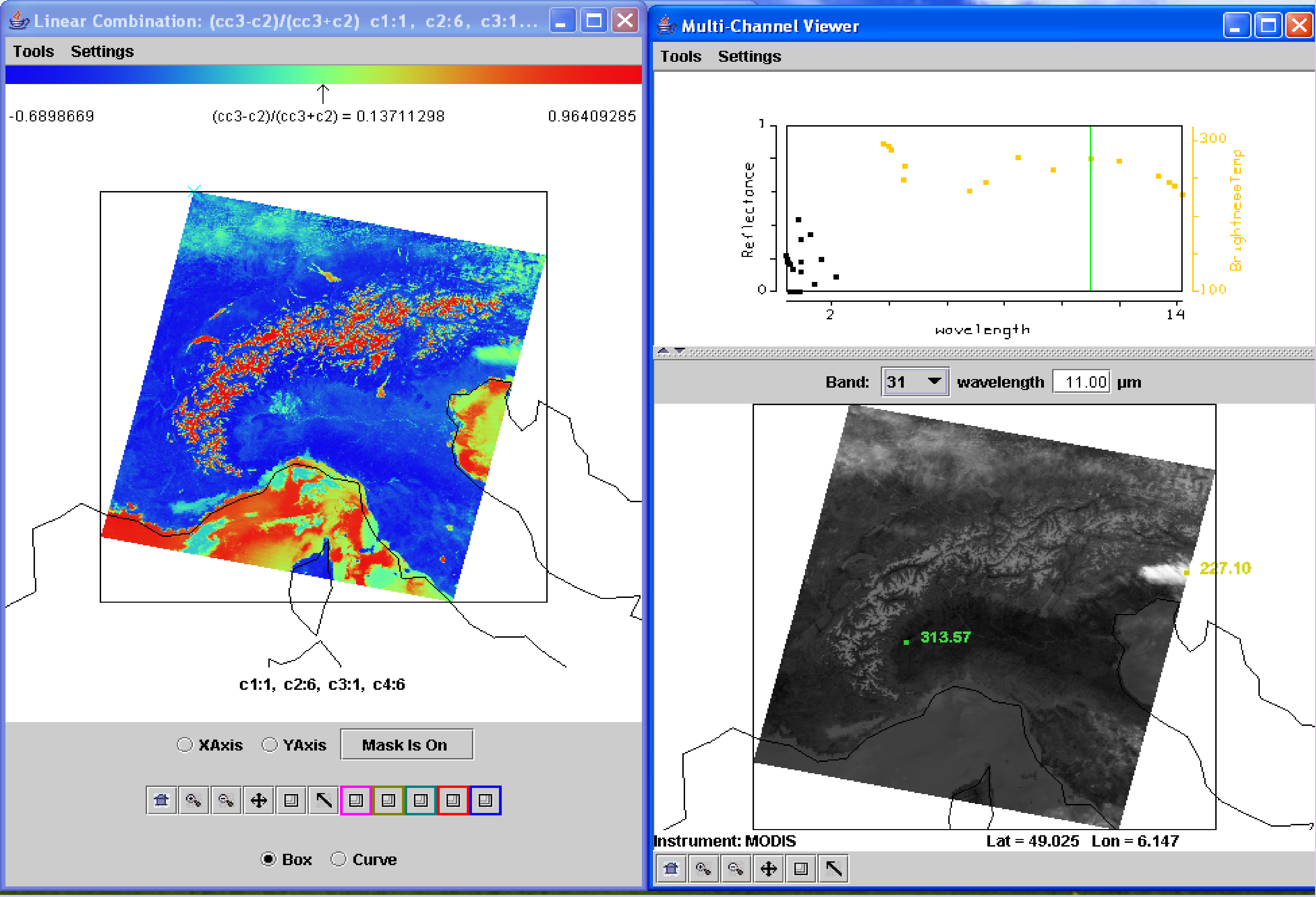
Given the spectral response of a surface or atmospheric feature

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

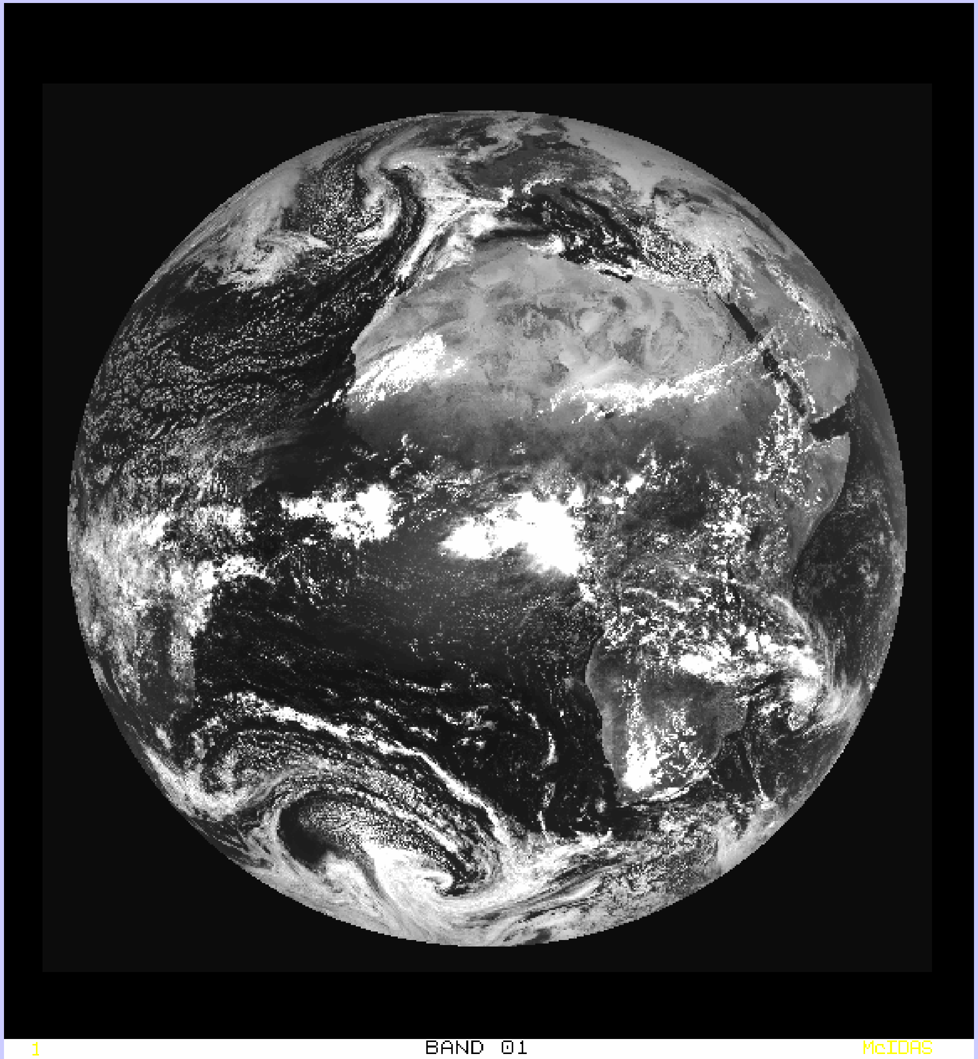


NDSI = [r0.6-r1.6]/[r0.6+r1.6] is near one in snow in Alps

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

12 channel SEVIRI

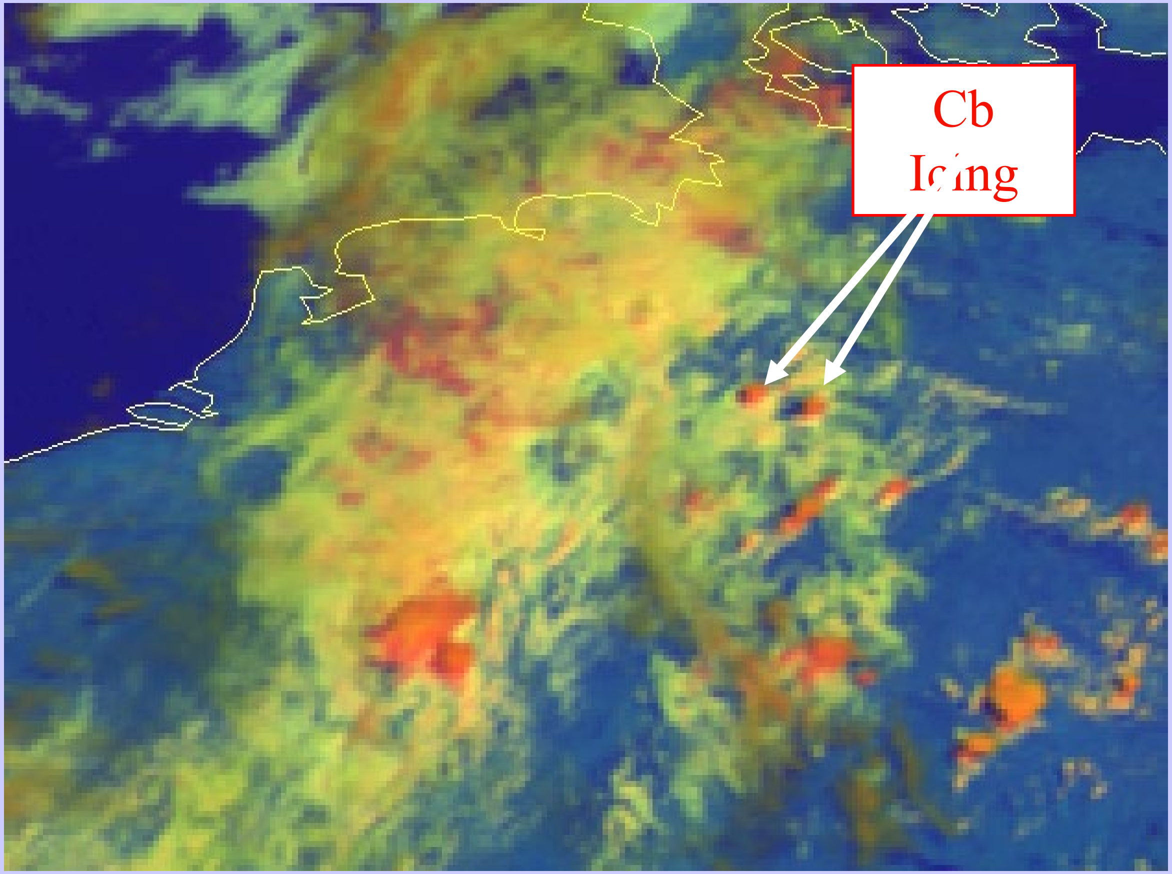


See image gallery at http://www.eumetsat.int/idcplg

Convective Initiation RGB 0.6-1.6-10.8 um

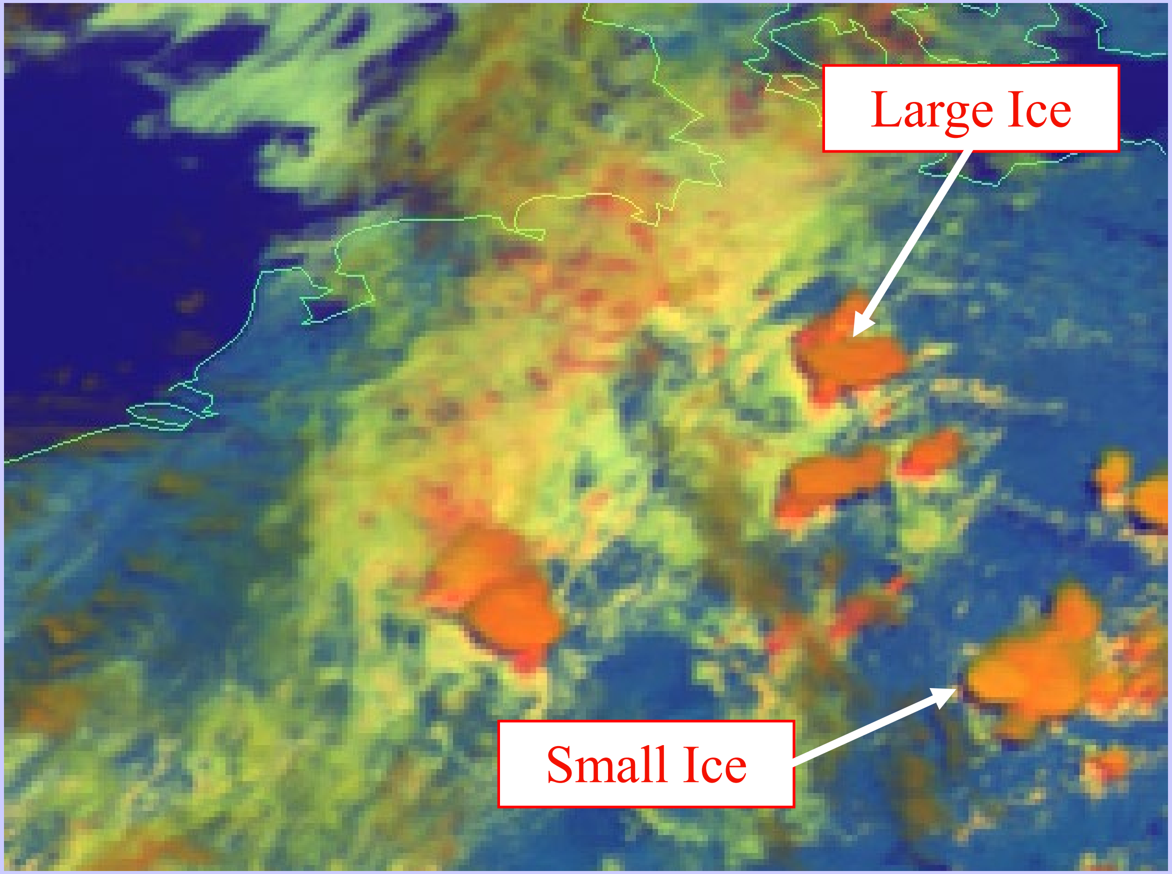
	Red VIS0.6	Green NIR1.6	Blue IR10.8	RGB
I. Very early stage	255	255	200	white-light yellow
II. First convection	255	255	100	yellow
III. First icing	255	200	0	orange
IV. Large icing	255	100	0	red-orange

First Icing



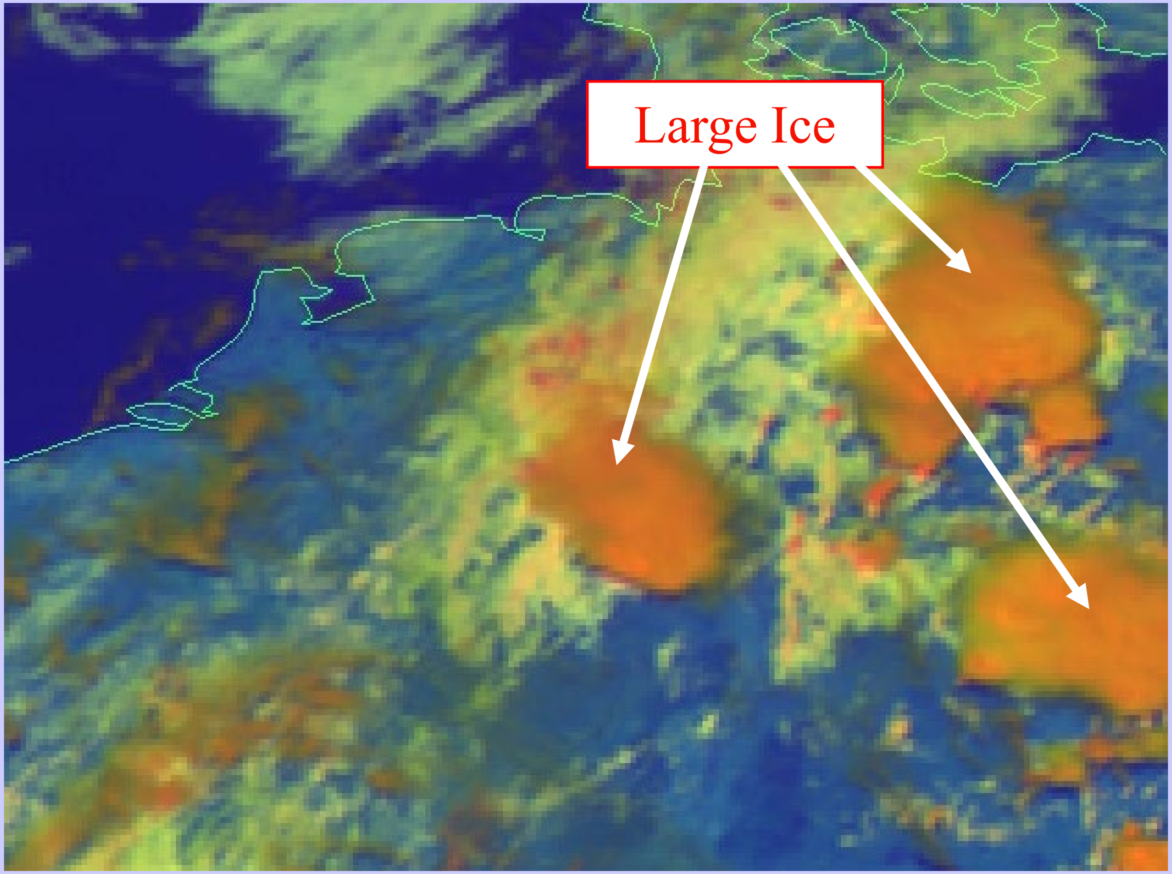
MSG-1, 5 June 2003, 10:30 UTC, RGB 01-03-09

Large Icing



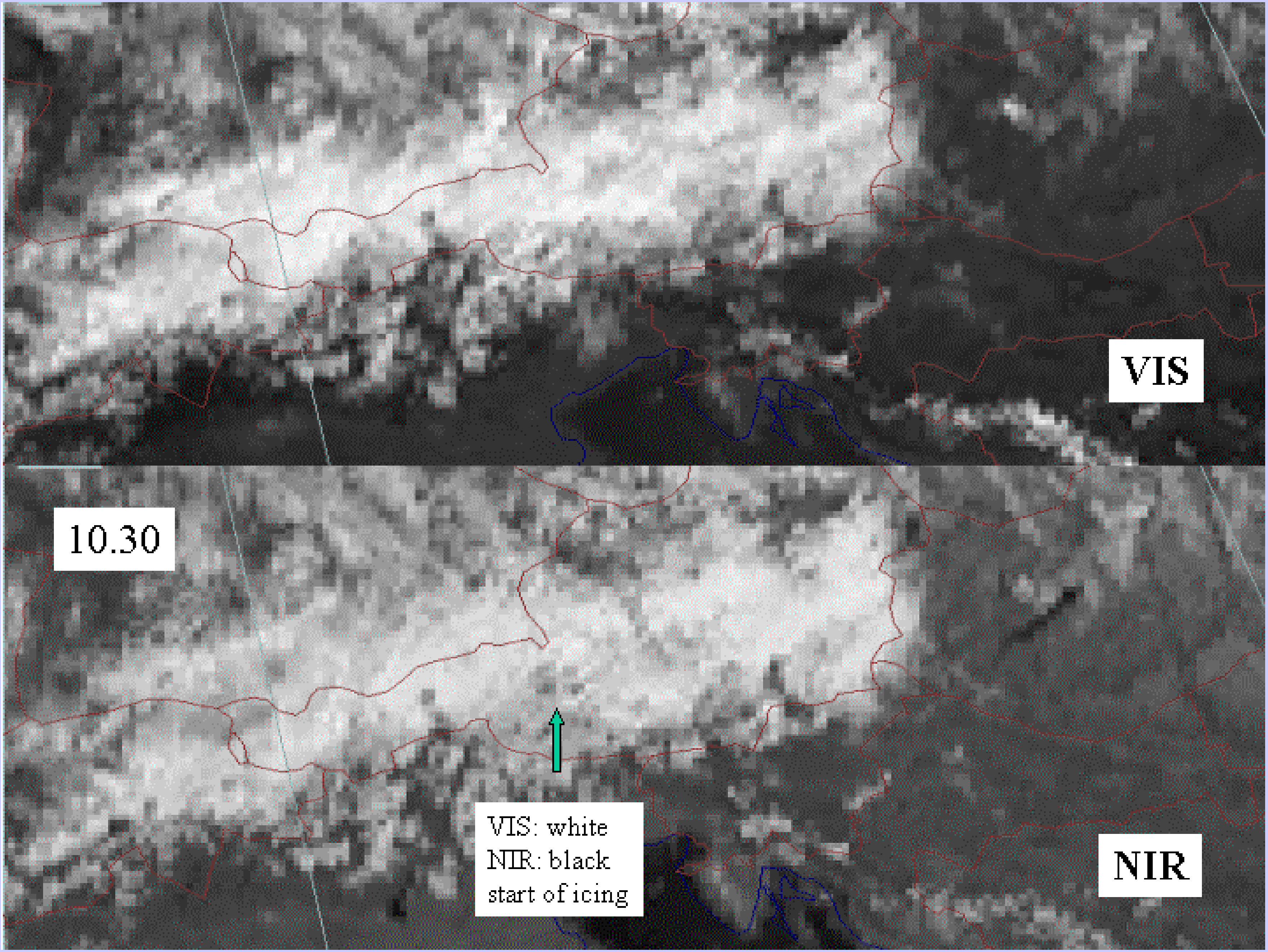
MSG-1, 5 June 2003, 11:30 UTC, RGB 01-03-09

Very Large Icing



MSG-1, 5 June 2003, 13:30 UTC, RGB 01-03-09

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



RGB example

R = BT12.0-BT10.8 G = BT 10.8-BT8.7 B = BT10.8

microphysics RGB MSG Ch 10-9, 9-7, 9
dust, clouds, contrails, fog, ash, SO2, low-level H2O

R – optical thickness of cloud, Tsfc-Tcld	-4 to +2
G – plus cloud phase	0 to +6
B – plus cloud top temp	248 to 303

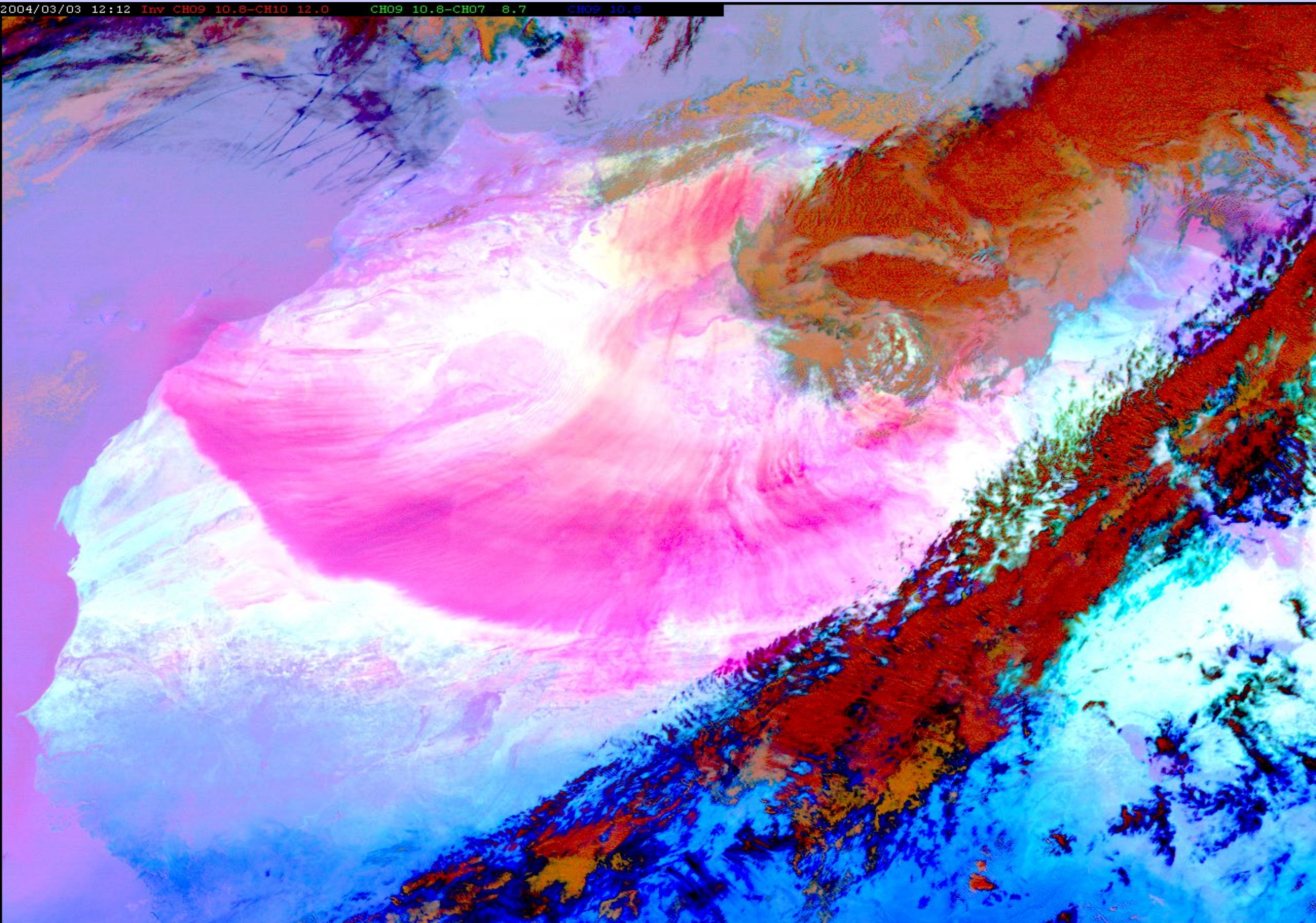
With emphasis on dust ([BT12-BT11]>0)
and thin ice clouds ([BT12-BT11]<0 & [BT11-BT8.6]>0)

R	-4 to +2
G	0 to +15
B	261 to 289

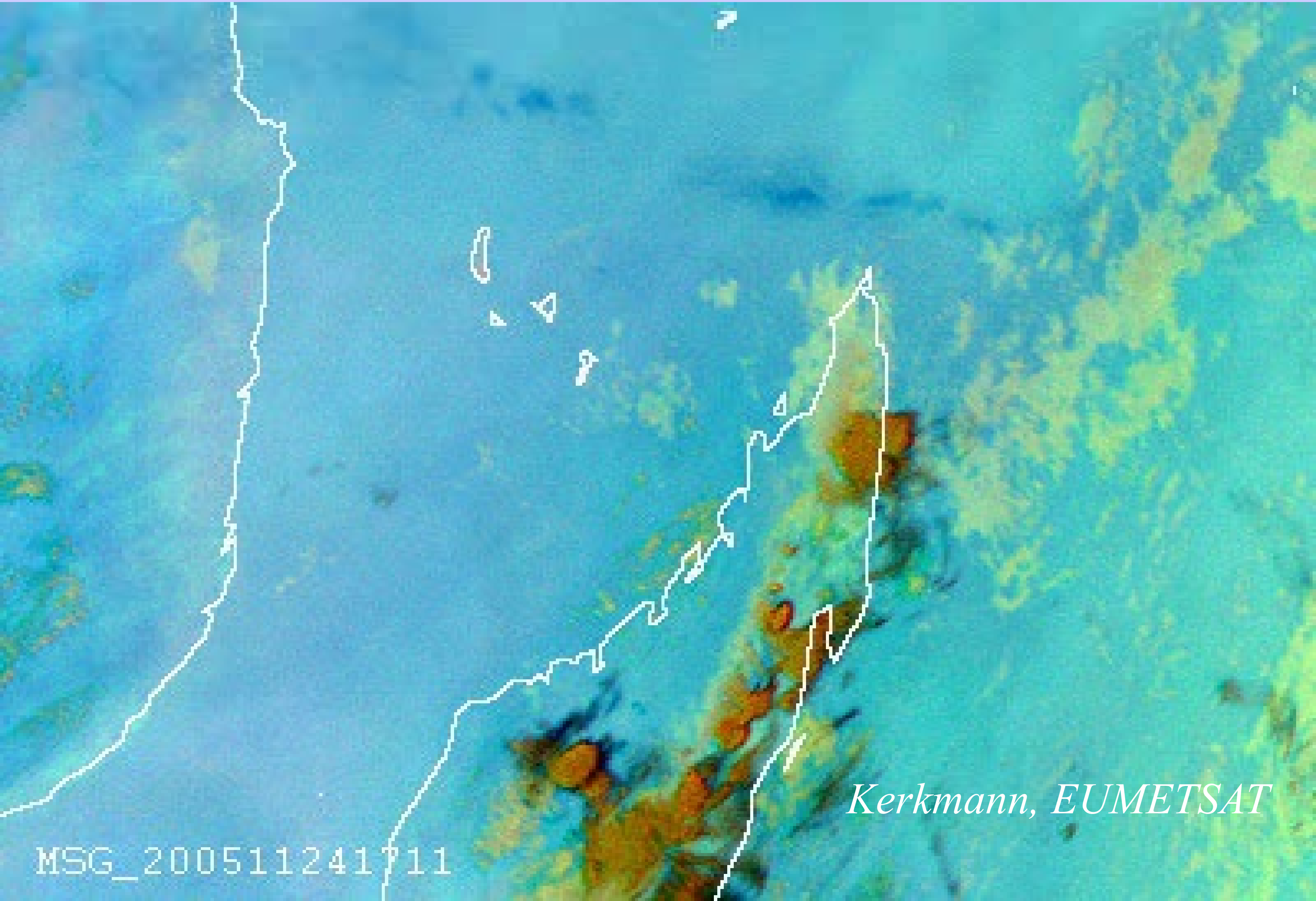
With emphasis on ash clouds ([BT12-BT11]>0)

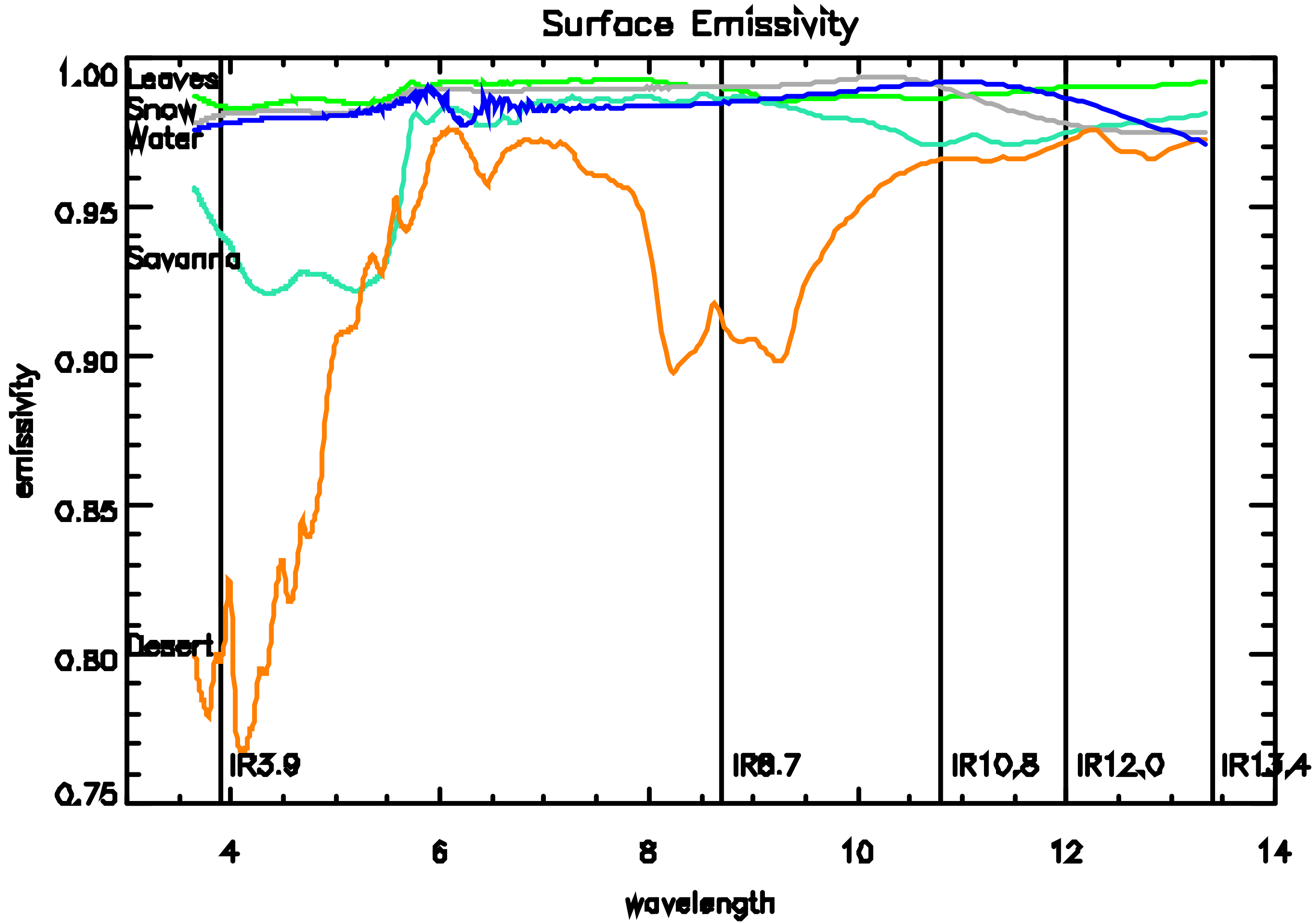
R	-4 to +2
G	-4 to +5
B	243 to 303

SEVIRI sees dust storm over Africa



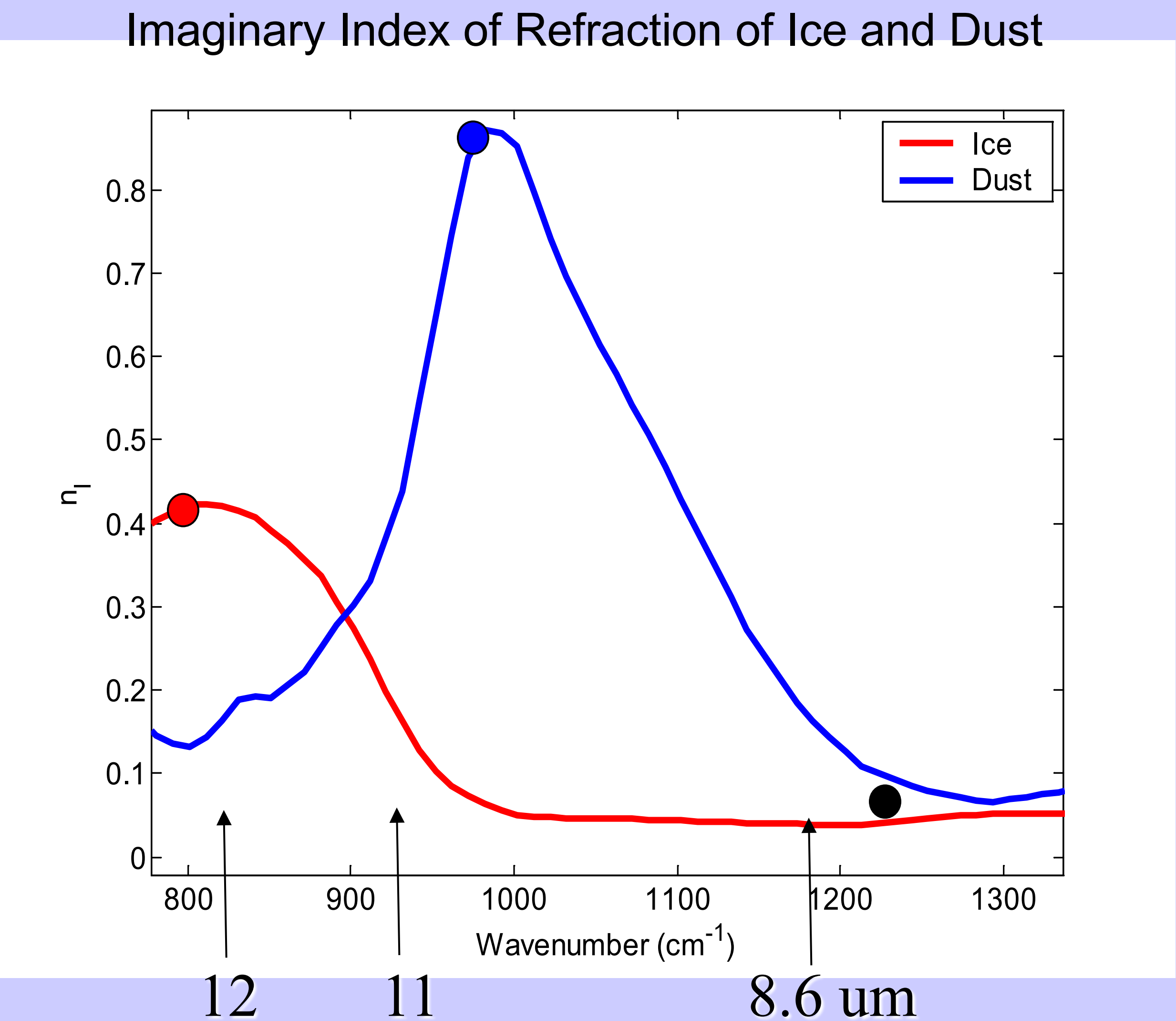
SEVIRI sees volcanic ash & SO2 and downwind inhibition of convection





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



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

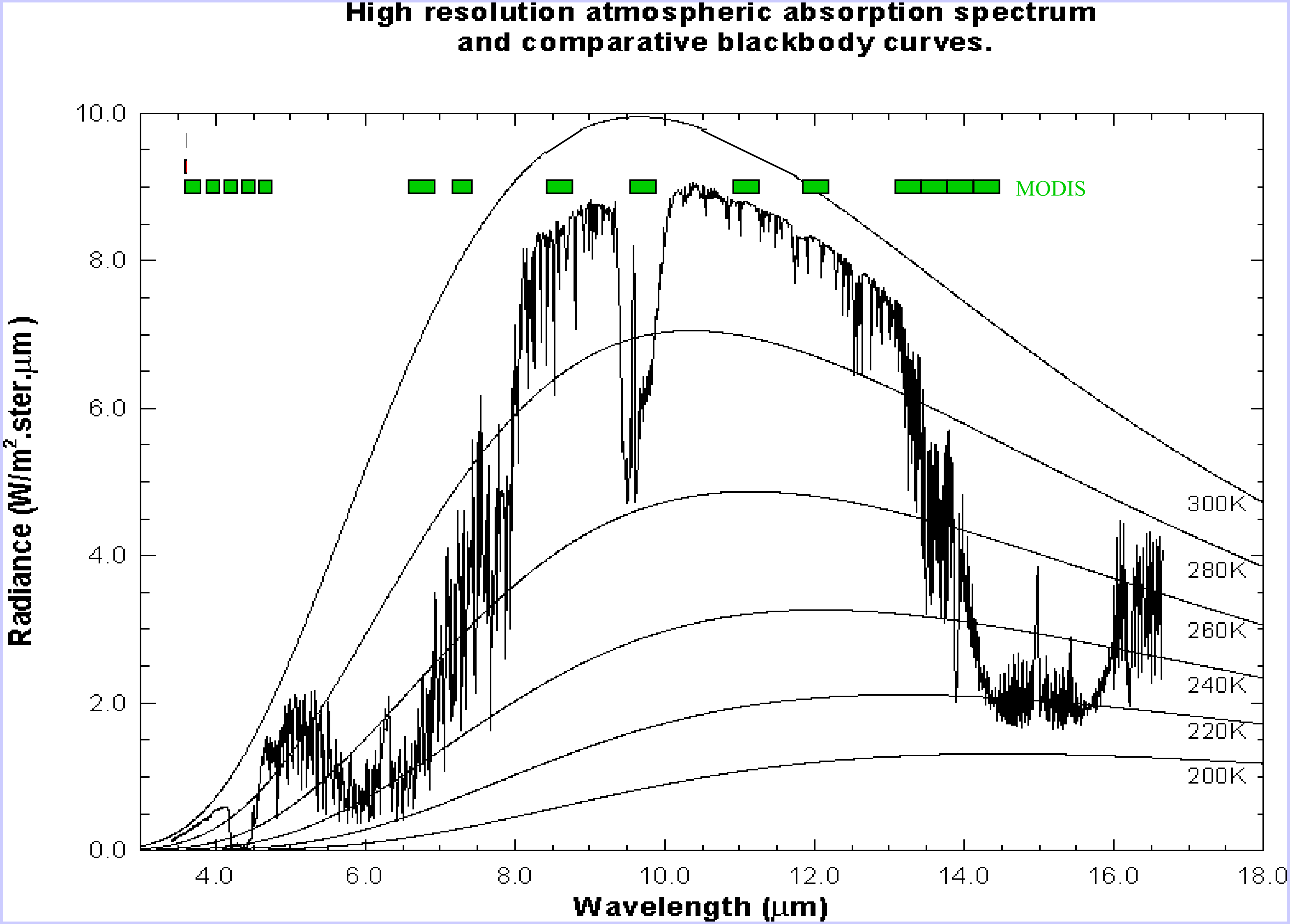
  Silicate index *increases*

  Ice index *decreases*

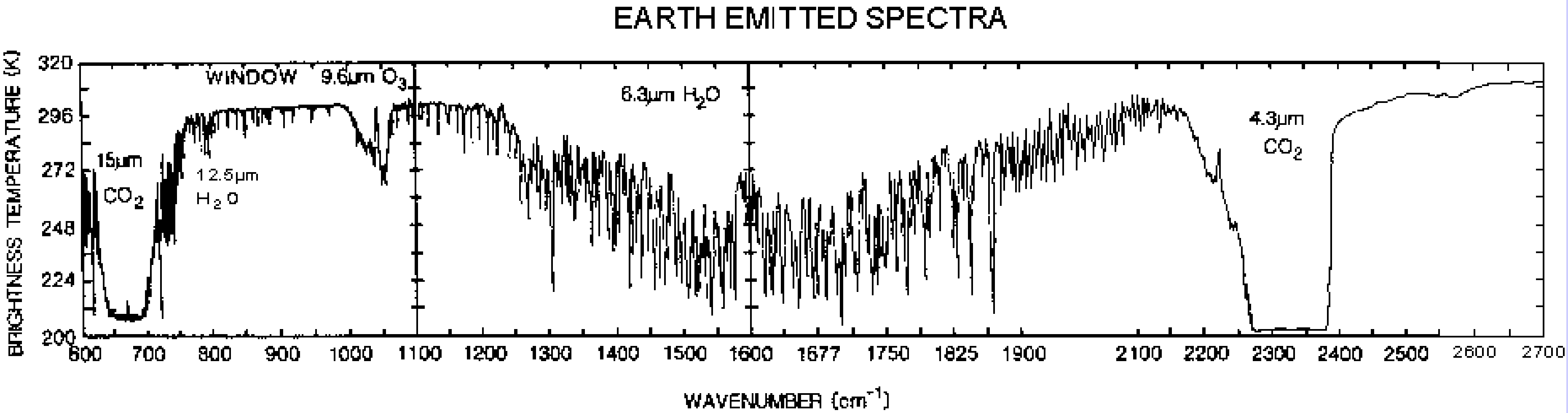
  with wavenumber

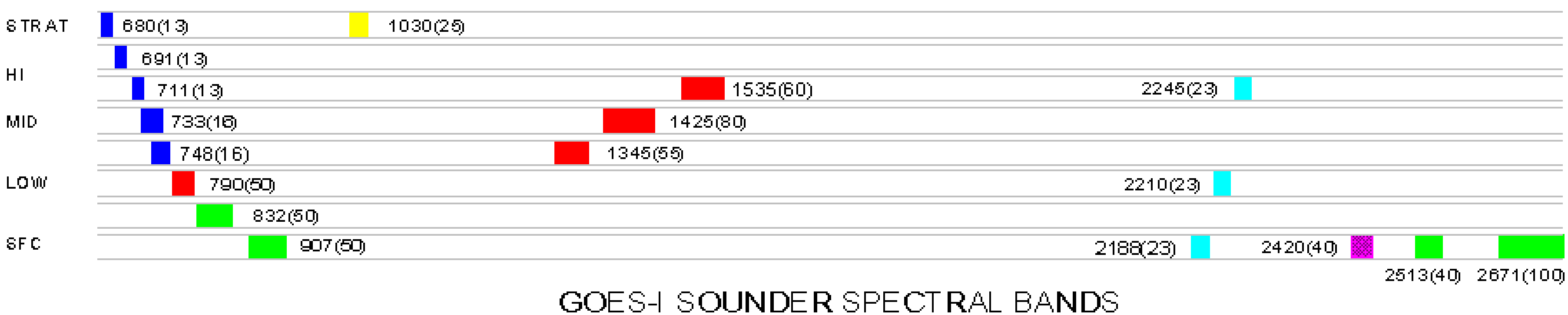
Volz, F.E. : Infrared optical constant of ammonium sulphate, Sahara Dust, volcanic pumice and flash, Appl Optics **12** 564-658 (1973)

MODIS IR Spectral Bands

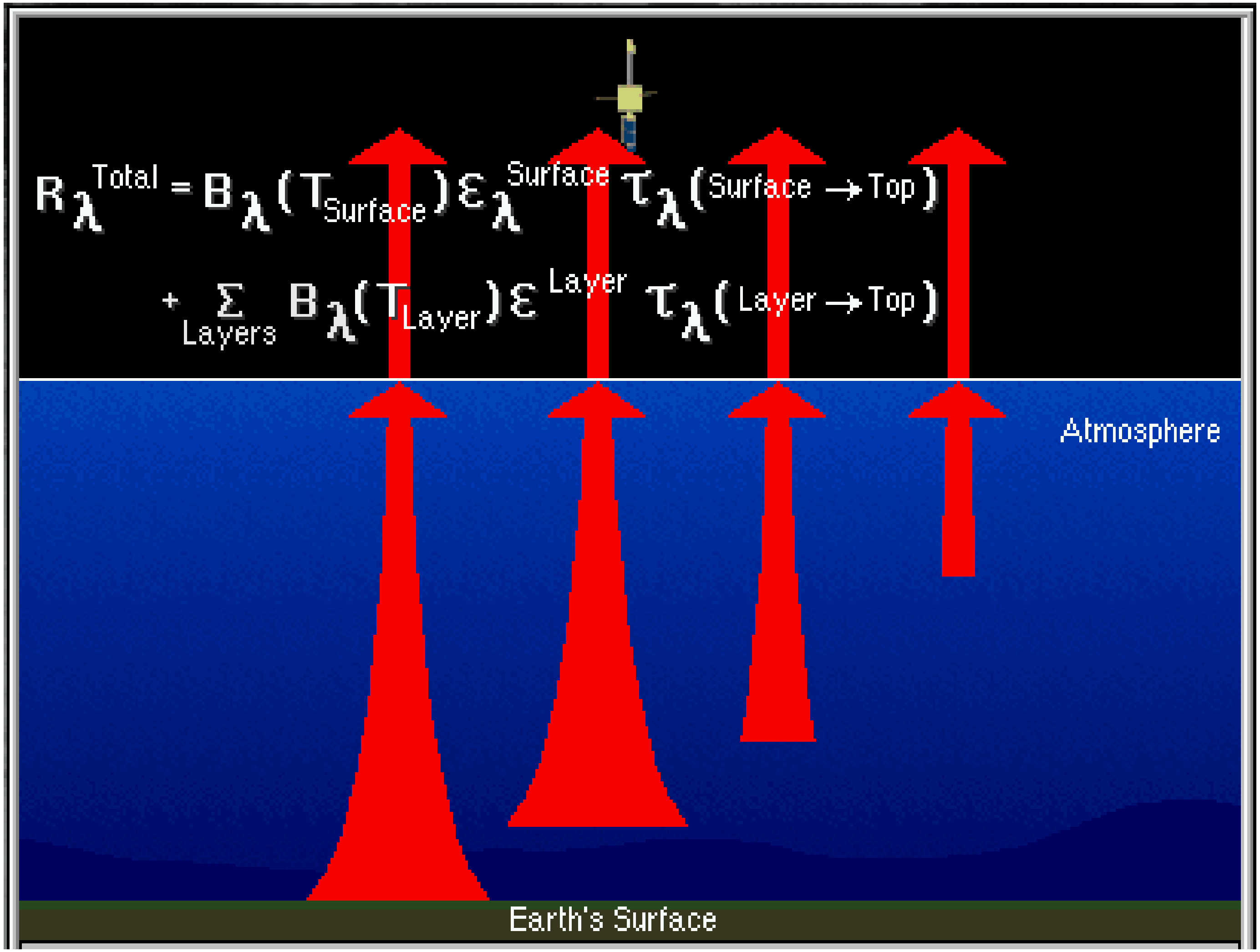


GOES Sounder Spectral Bands: 14.7 to 3.7 um and vis

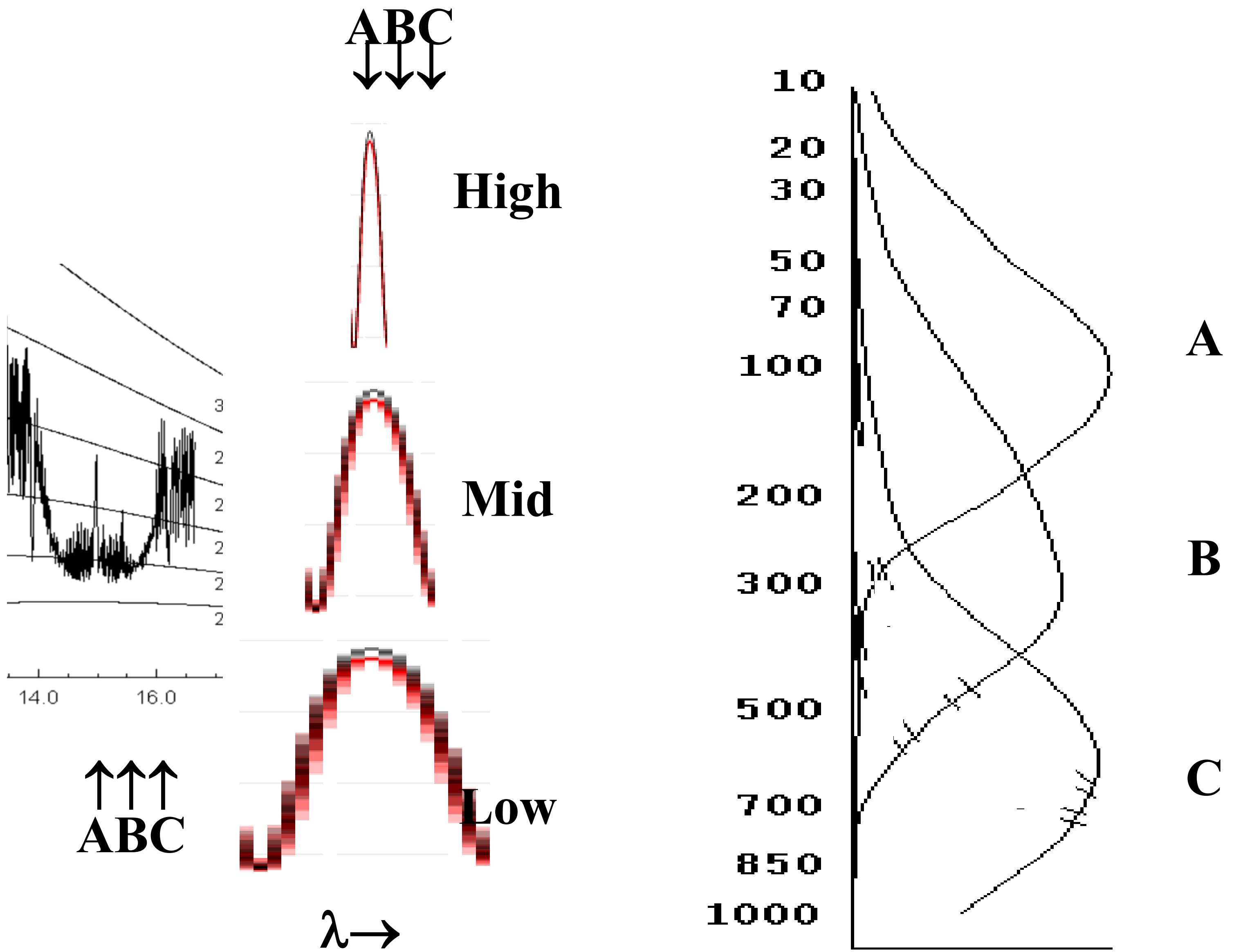


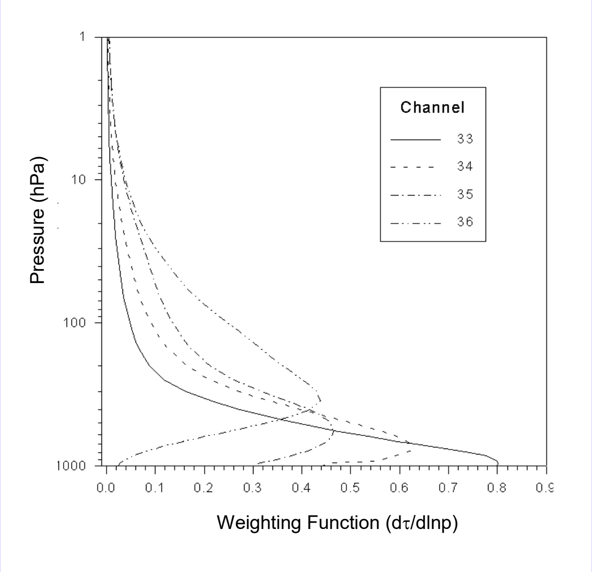


Radiative Transfer through the Atmosphere

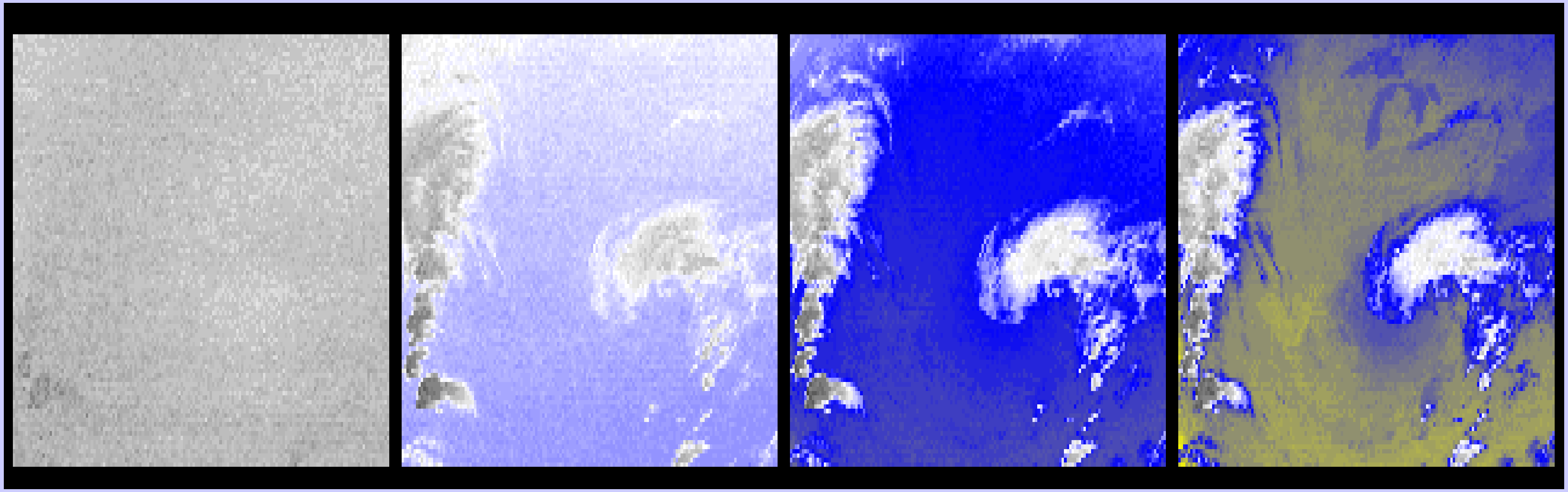


line broadening with pressure helps to explain weighting functions





CO2 channels see different layers in the atmosphere



14.2 um   13.9 um   13.6 um   13.3 um

Radiative Transfer Equation

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

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

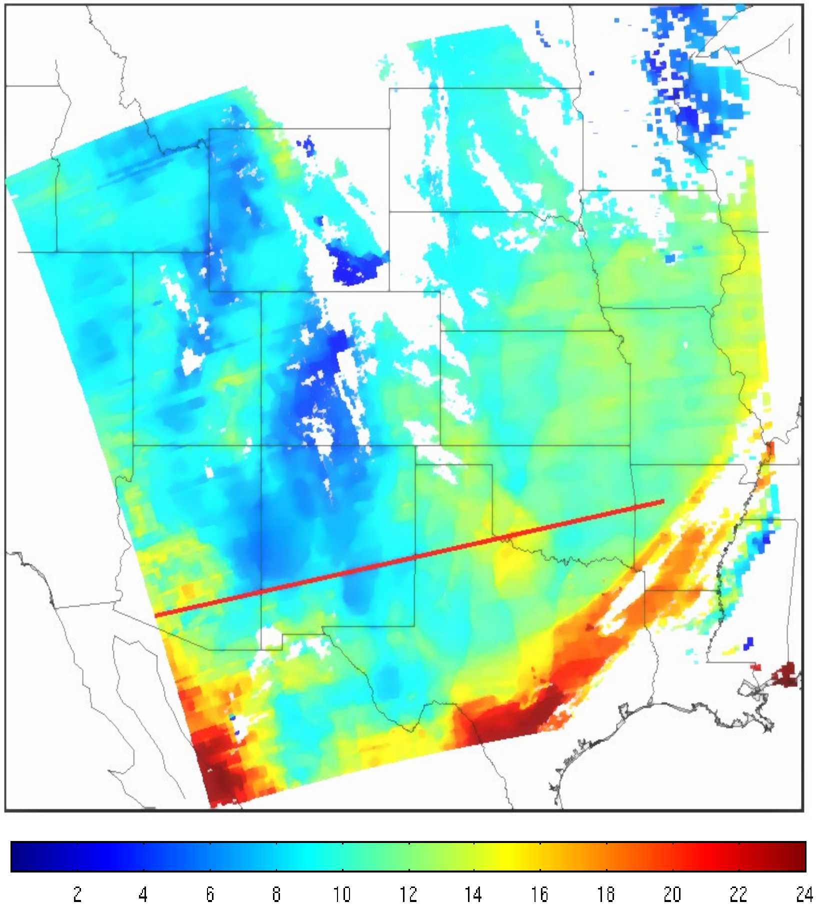
where

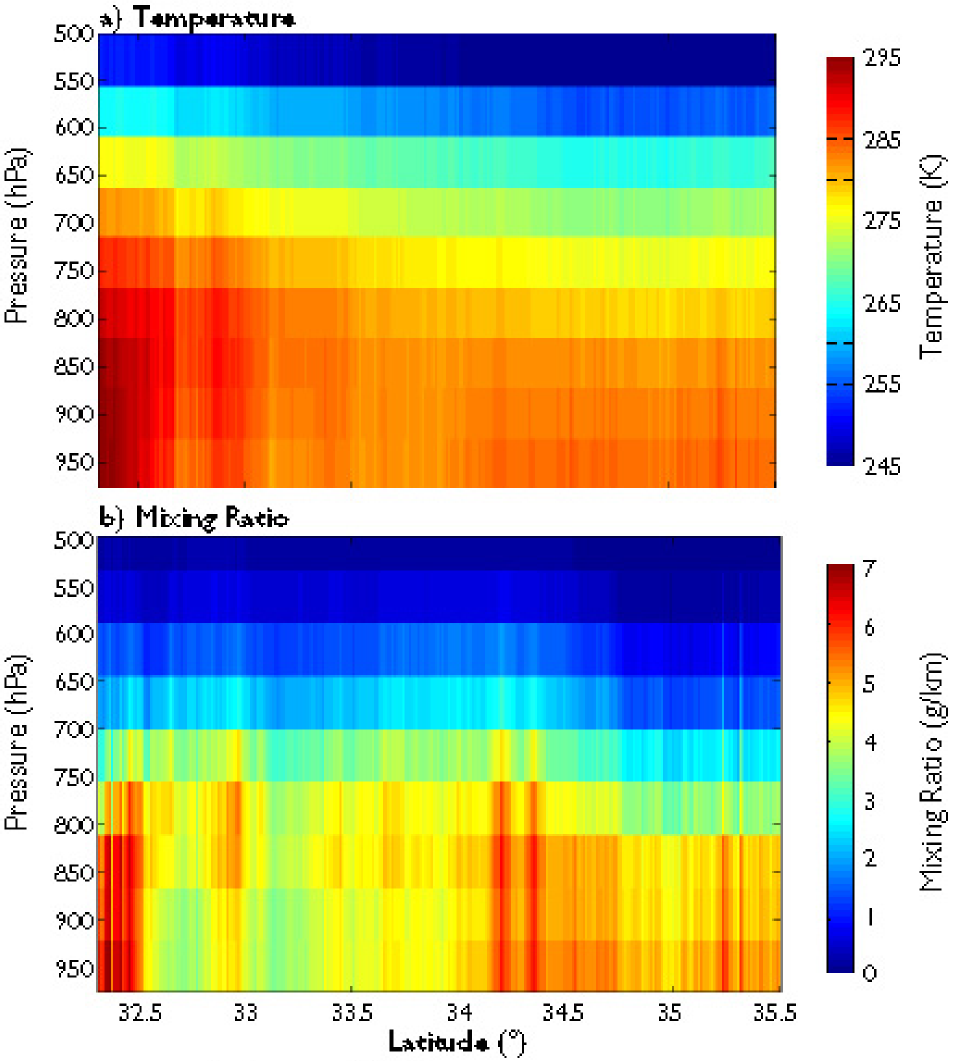
$$F_\lambda(p) = \{ 1 + (1 - \varepsilon_\lambda)\, [\tau_\lambda(p_s) / \tau_\lambda(p)]^2 \}$$

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

RTE in Cloudy Conditions

$$I_\lambda = \eta\, I^{cd}_\lambda + (1 - \eta)\, I^{c}_\lambda \quad \text{where cd = cloud, c = clear, } \eta \text{ = cloud fraction}$$

$$I^{c}_\lambda = B_\lambda(T_s)\, \tau_\lambda(p_s) + \int_{p_s}^{o} B_\lambda(T(p))\, d\tau_\lambda \,.$$

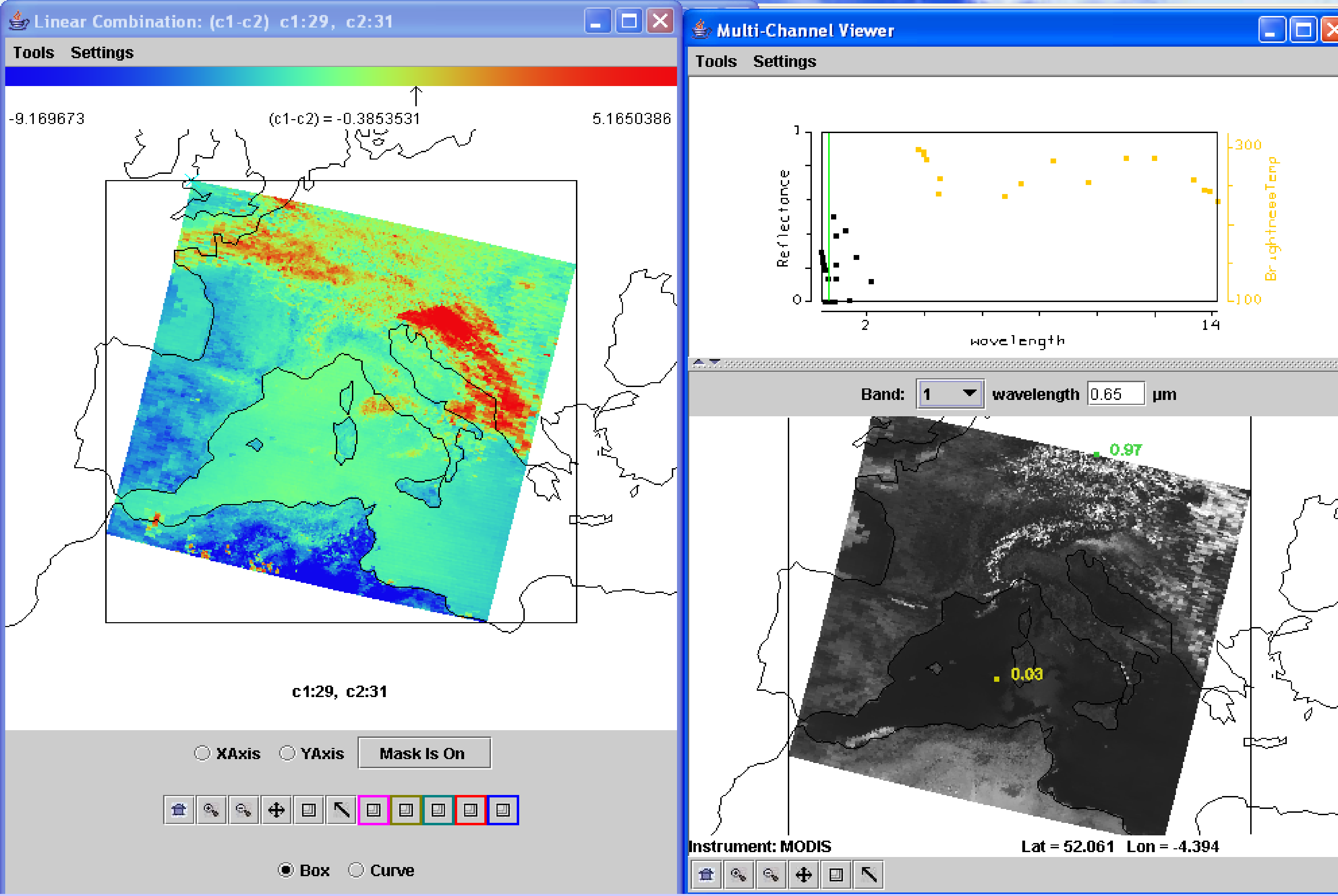
$$I^{cd}_\lambda = (1-\varepsilon_\lambda)\, B_\lambda(T_s)\, \tau_\lambda(p_s) + (1-\varepsilon_\lambda) \int_{p_s}^{p_c} B_\lambda(T(p))\, d\tau_\lambda$$

$$+ \varepsilon_\lambda\, B_\lambda(T(p_c))\, \tau_\lambda(p_c) + \int_{p_c}^{o} B_\lambda(T(p))\, d\tau_\lambda$$

ε_λ is emittance of cloud. First two terms are from below cloud, third term is cloud contribution, and fourth term is from above cloud. After rearranging

$$I_\lambda - I_\lambda^{c} = \eta\varepsilon_\lambda \int_{p_s}^{p_c} \tau(p)\, \frac{dB_\lambda}{dp}\, dp \,.$$

Techniques for dealing with clouds fall into three categories: (a) searching for cloudless fields of view, (b) specifying cloud top pressure and sounding down to cloud level as in the cloudless case, and (c) employing adjacent fields of view to determine clear sky signal from partly cloudy observations.



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

Cloud Properties

RTE for cloudy conditions indicates dependence of cloud forcing (observed minus clear sky radiance) on cloud amount ($\eta\varepsilon_\lambda$) and cloud top pressure (p_c)

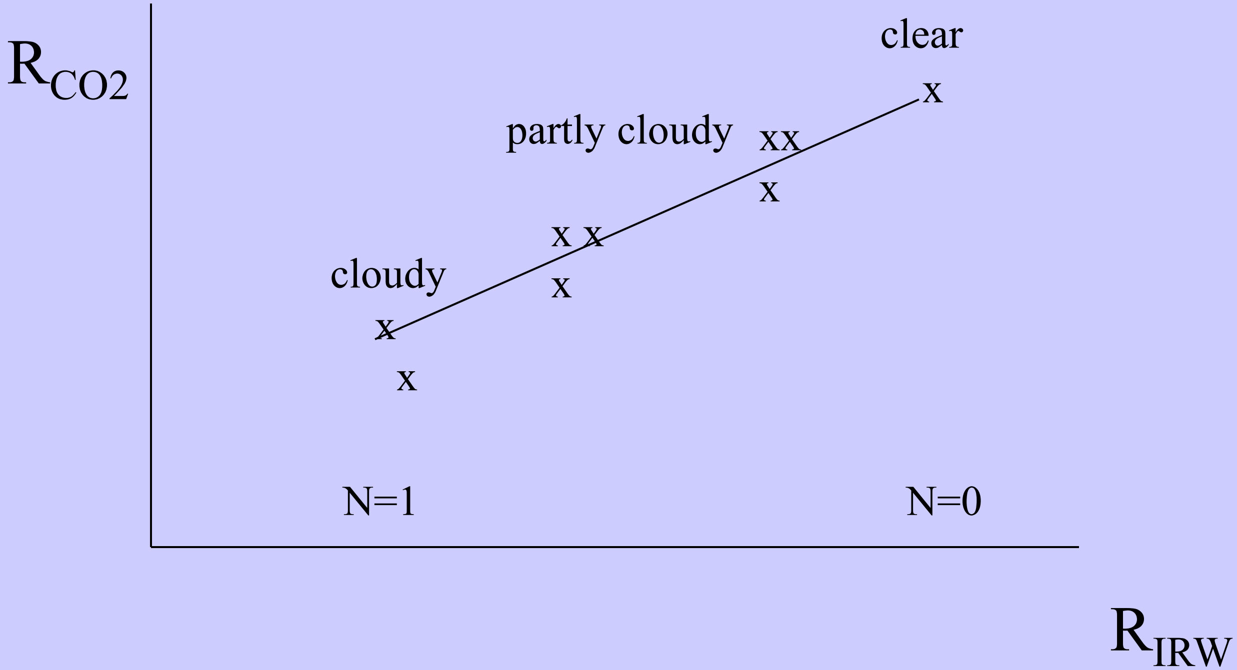
$$(I_\lambda - I_\lambda^{clr}) = \eta\varepsilon_\lambda \int_{p_s}^{p_c} \tau_\lambda \, dB_\lambda \, .$$

Higher colder cloud or greater cloud amount produces greater cloud forcing; dense low cloud can be confused for high thin cloud. Two unknowns require two equations.

p_c can be inferred from radiance measurements in two spectral bands where cloud emissivity is the same. $\eta\varepsilon_\lambda$ is derived from the infrared window, once p_c is known. This is the essence of the CO2 slicing technique.

Cloud Clearing

For a single layer of clouds, radiances in one spectral band vary linearly with those of another as cloud amount varies from one field of view (fov) to another



Clear radiances can be inferred by extrapolating to cloud free conditions.

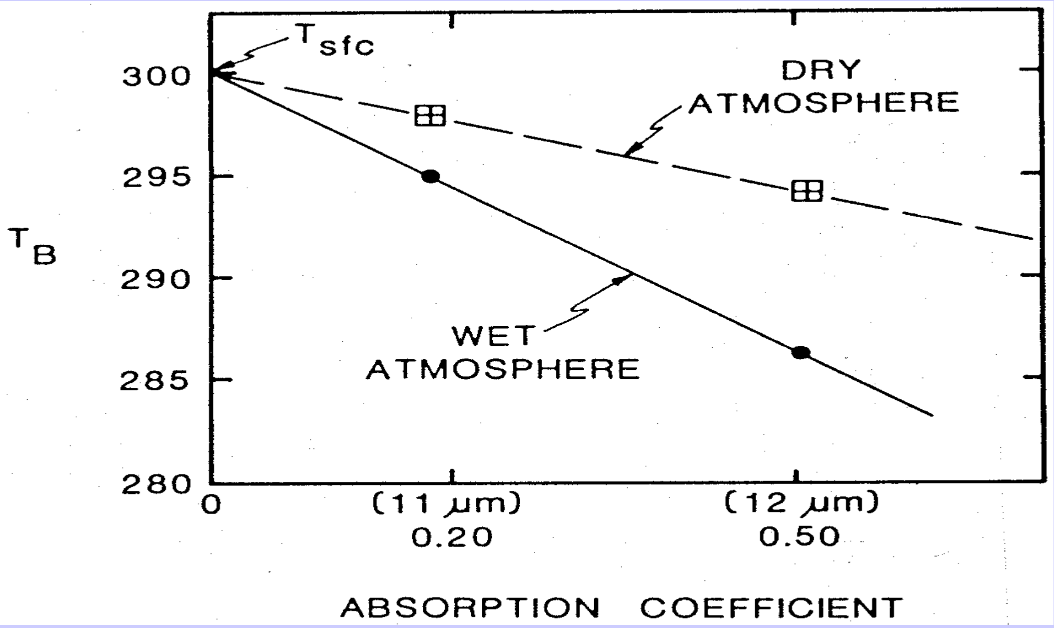
Moisture

Moisture attenuation in atmospheric windows varies linearly with optical depth.

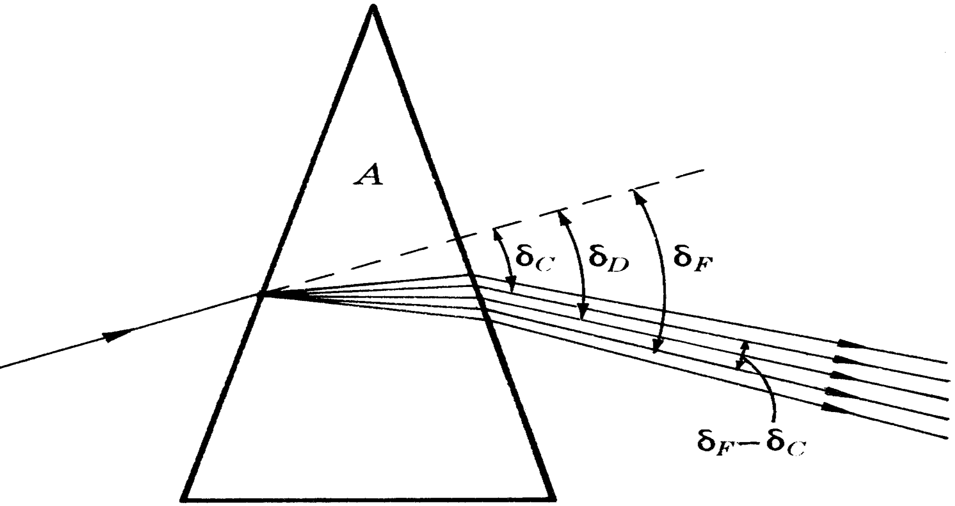
$$\tau_\lambda = e^{-k_\lambda u} = 1 - k_\lambda u$$

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

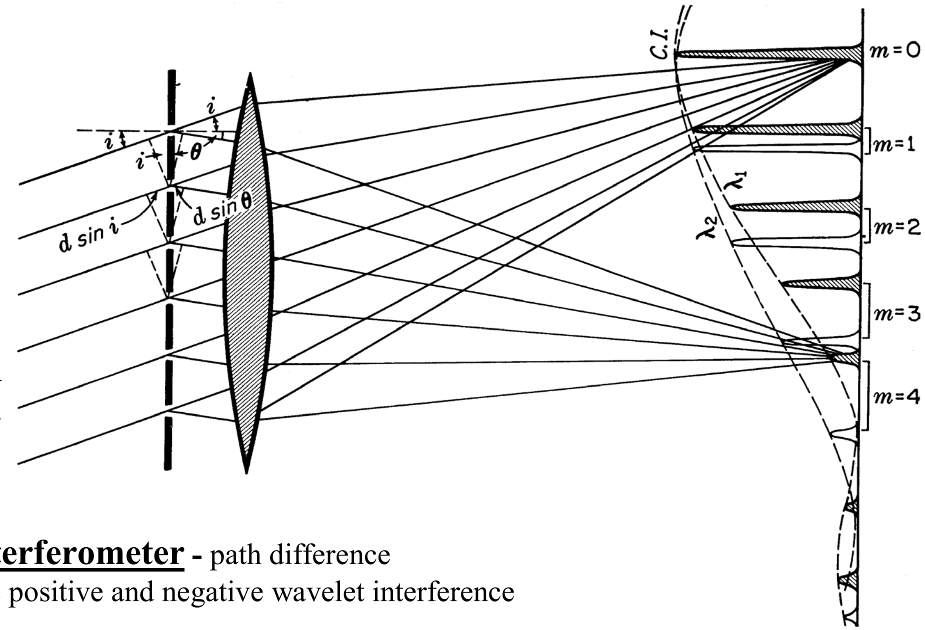
Moisture content of atmosphere inferred from slope of linear relation.



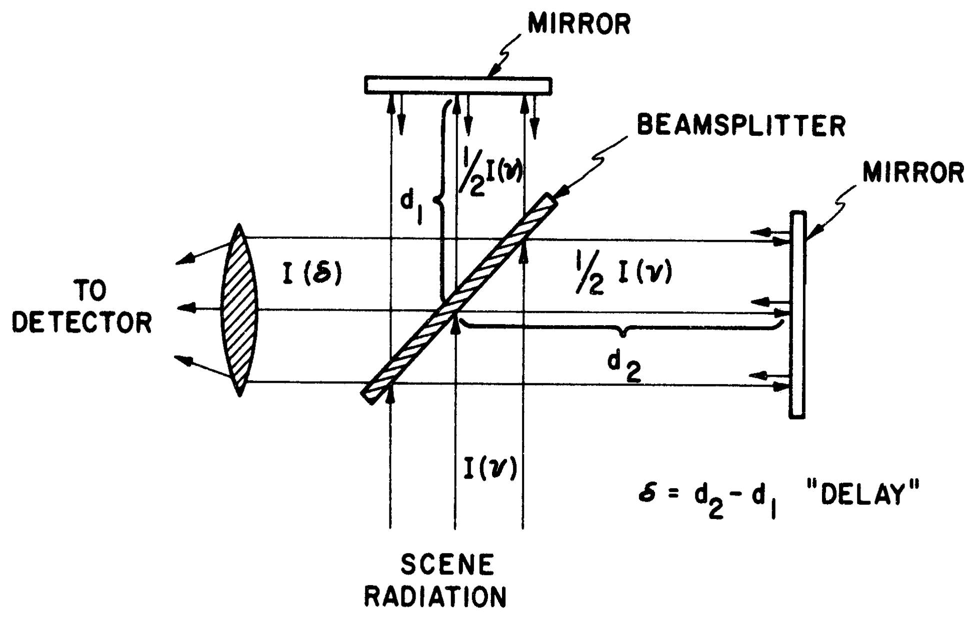
Spectral Separation with a Prism: longer wavelengths deflected less



Spectral Separation with a Grating: path difference from slits produces positive and negative wavelet interference on screen

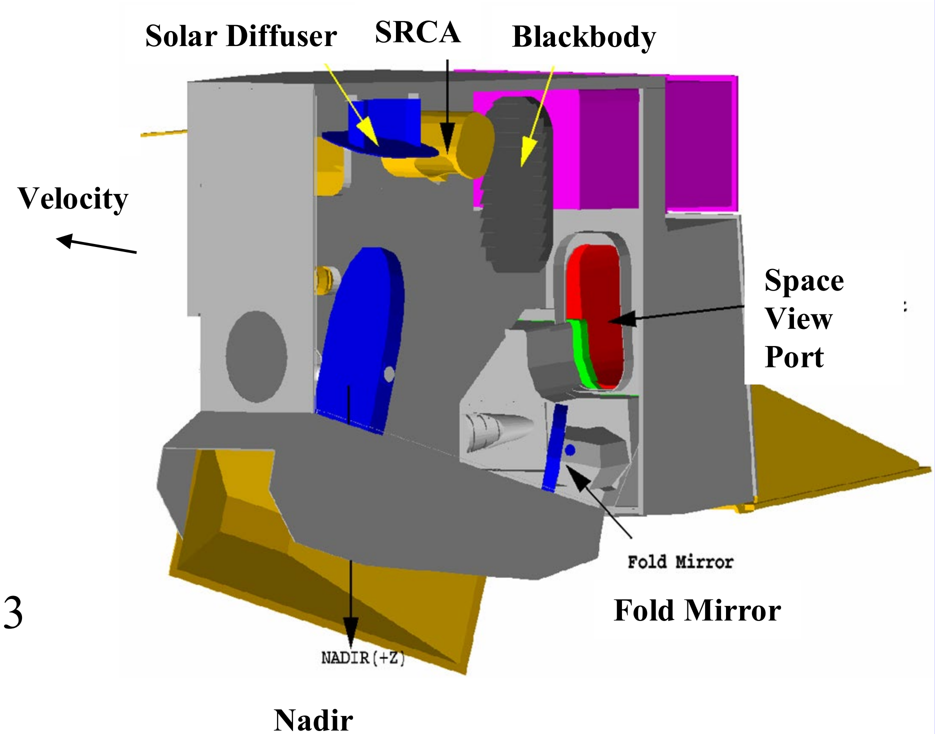


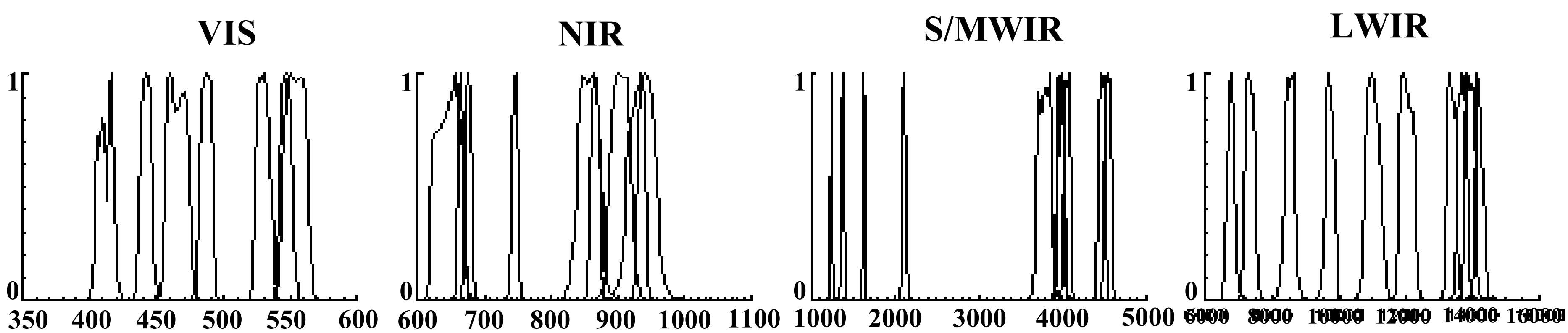
Spectral Separation with an Interferometer - path difference (or delay) from two mirrors produces positive and negative wavelet interference



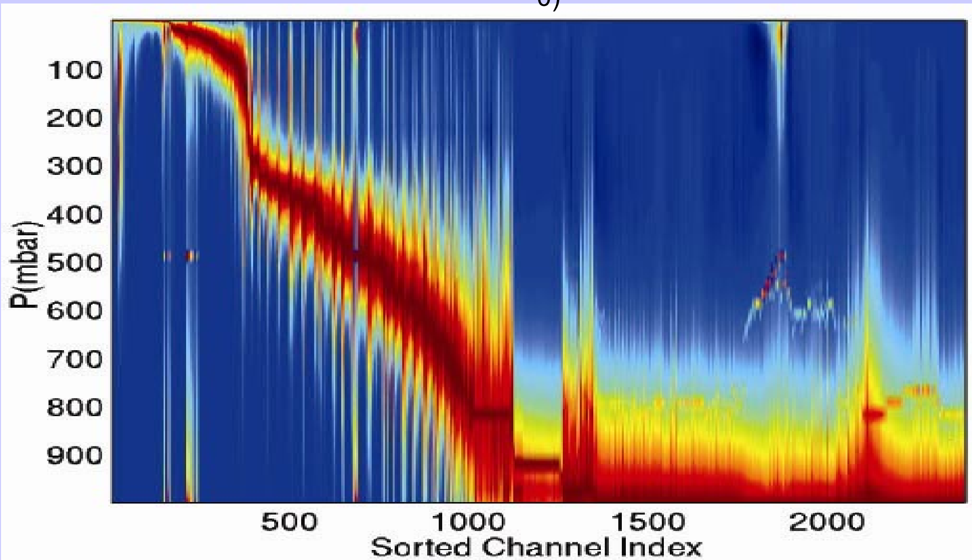
MODIS Instrument Overview

- 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)

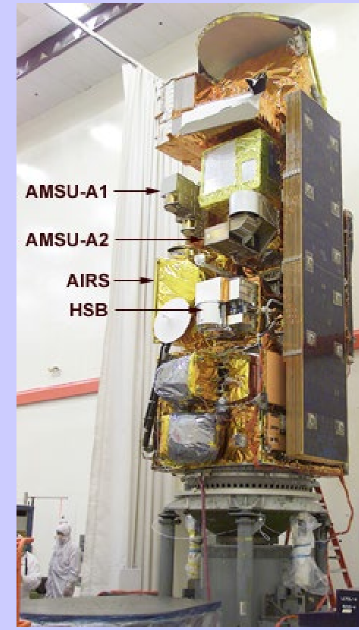




temperature weighting functions sorted by pressure of their peak (blue = 0)



AIRS On Aqua

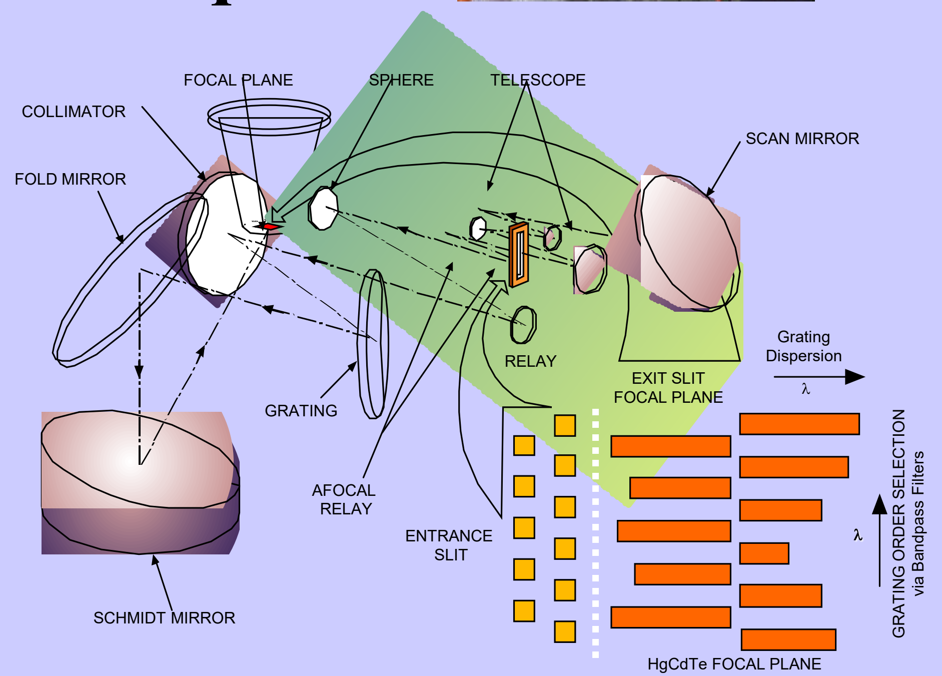


Instrument

- 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)

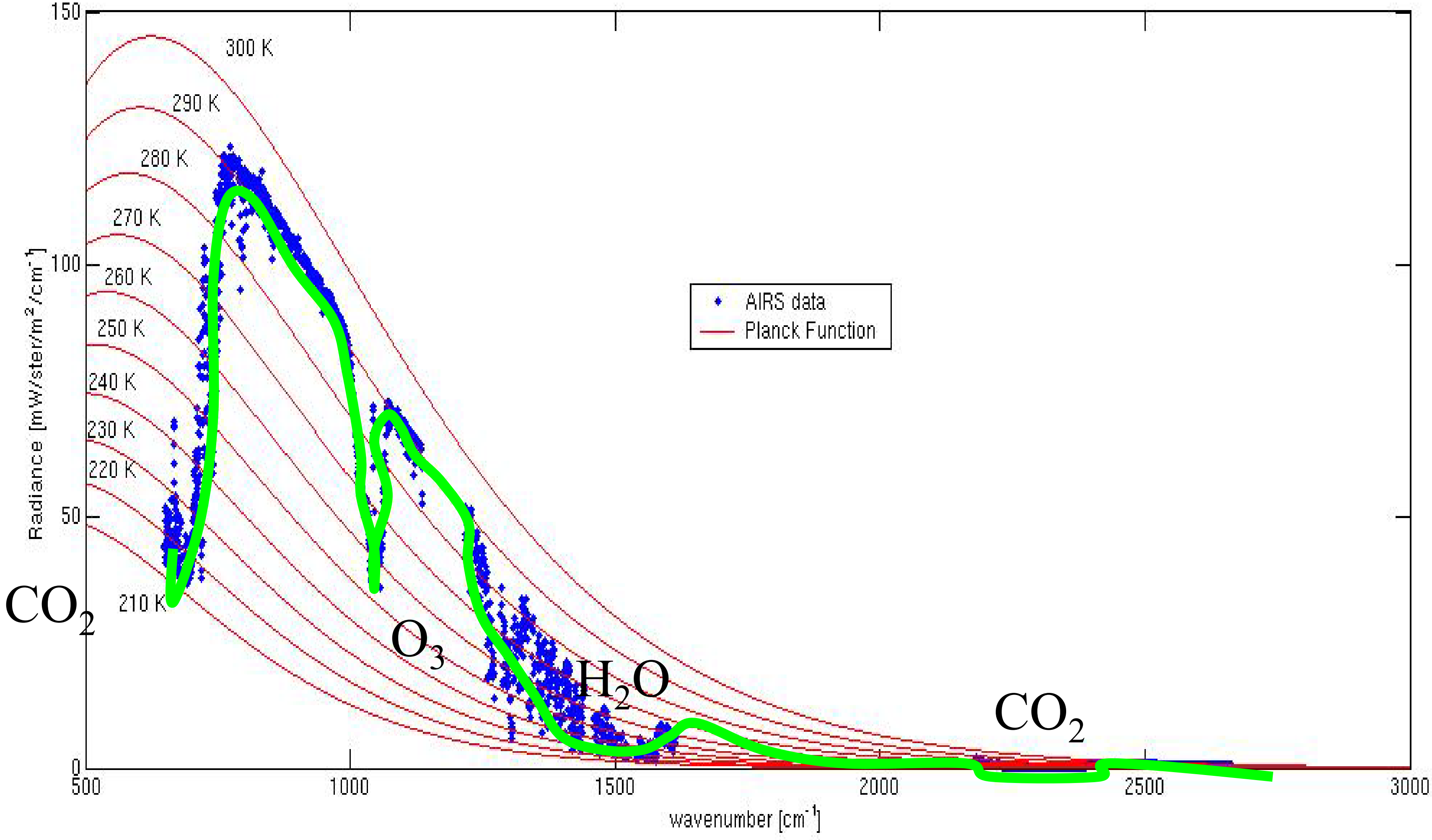
Design

- 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**

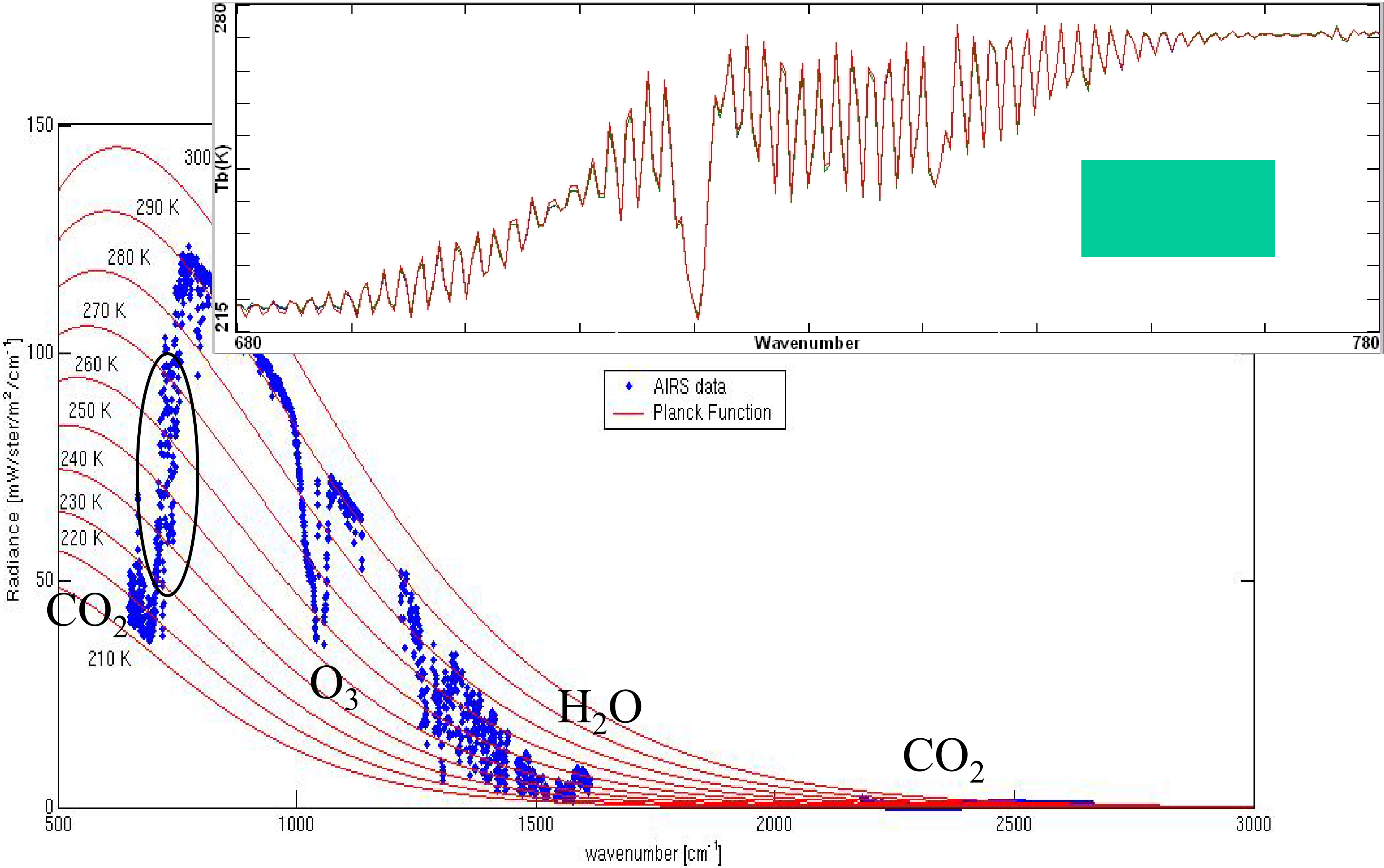


Spectral filters at each entrance slit and over each FPA array isolate color band (grating order) of interest

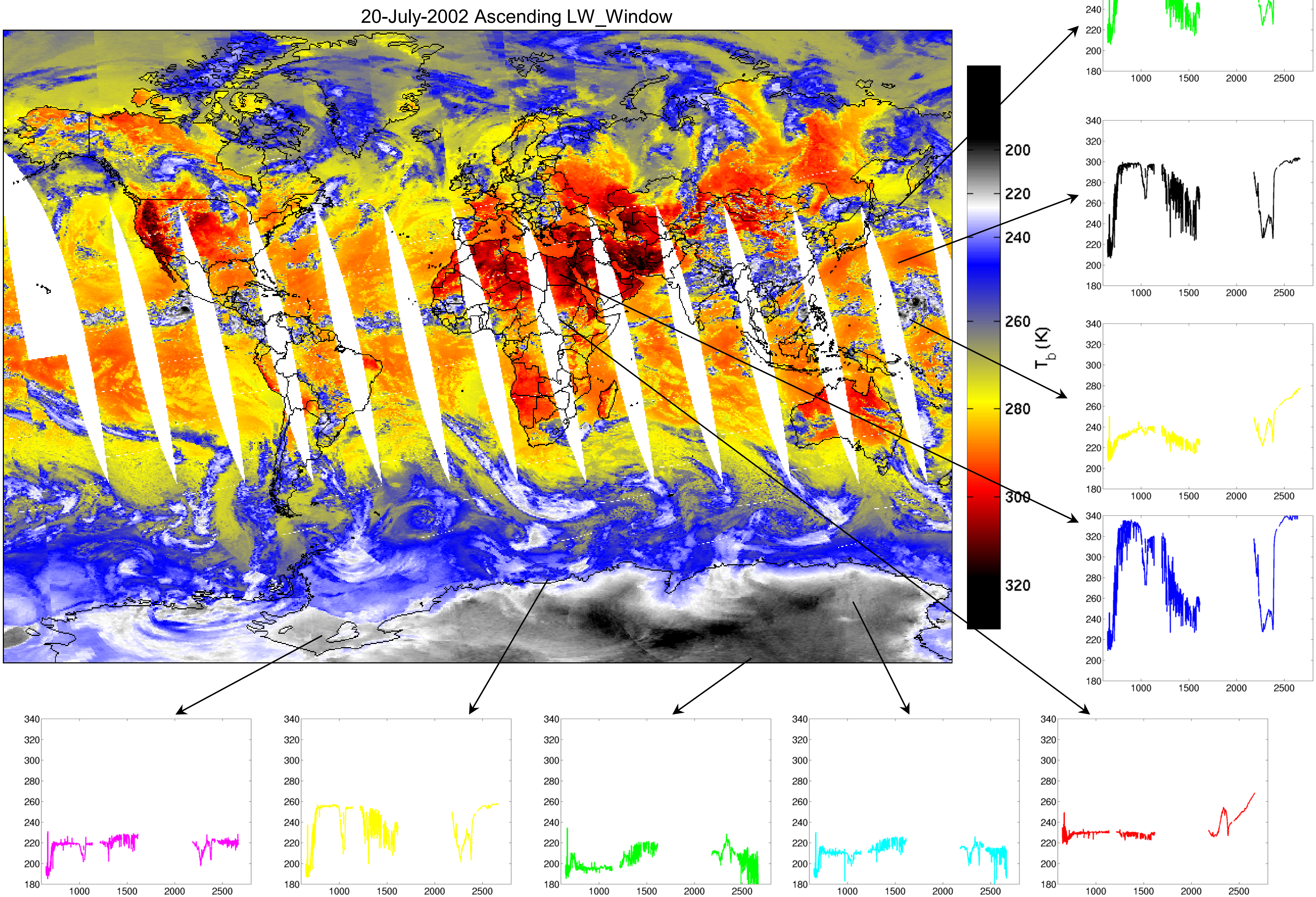
Vibrational Lines



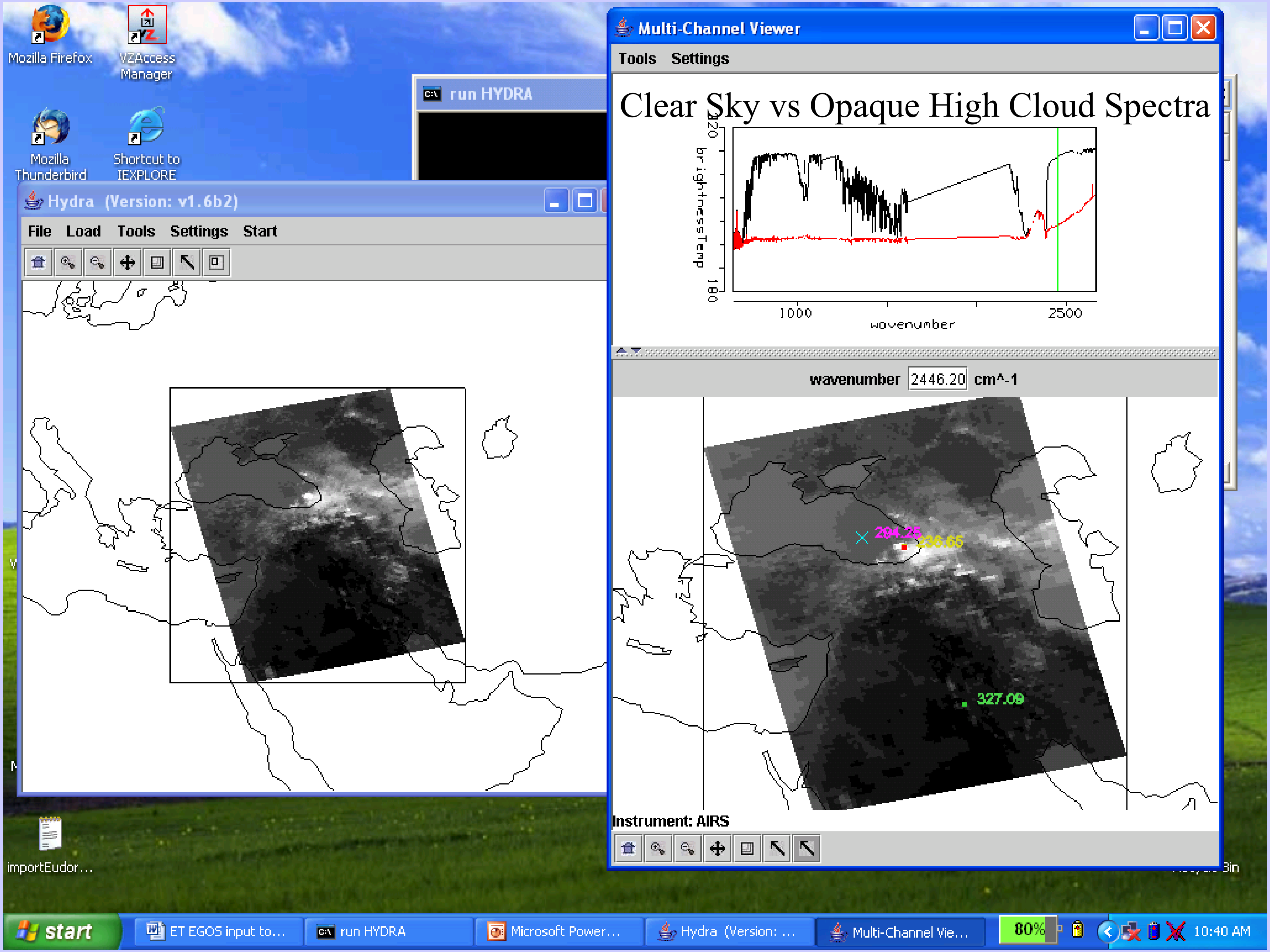
Rotational Lines

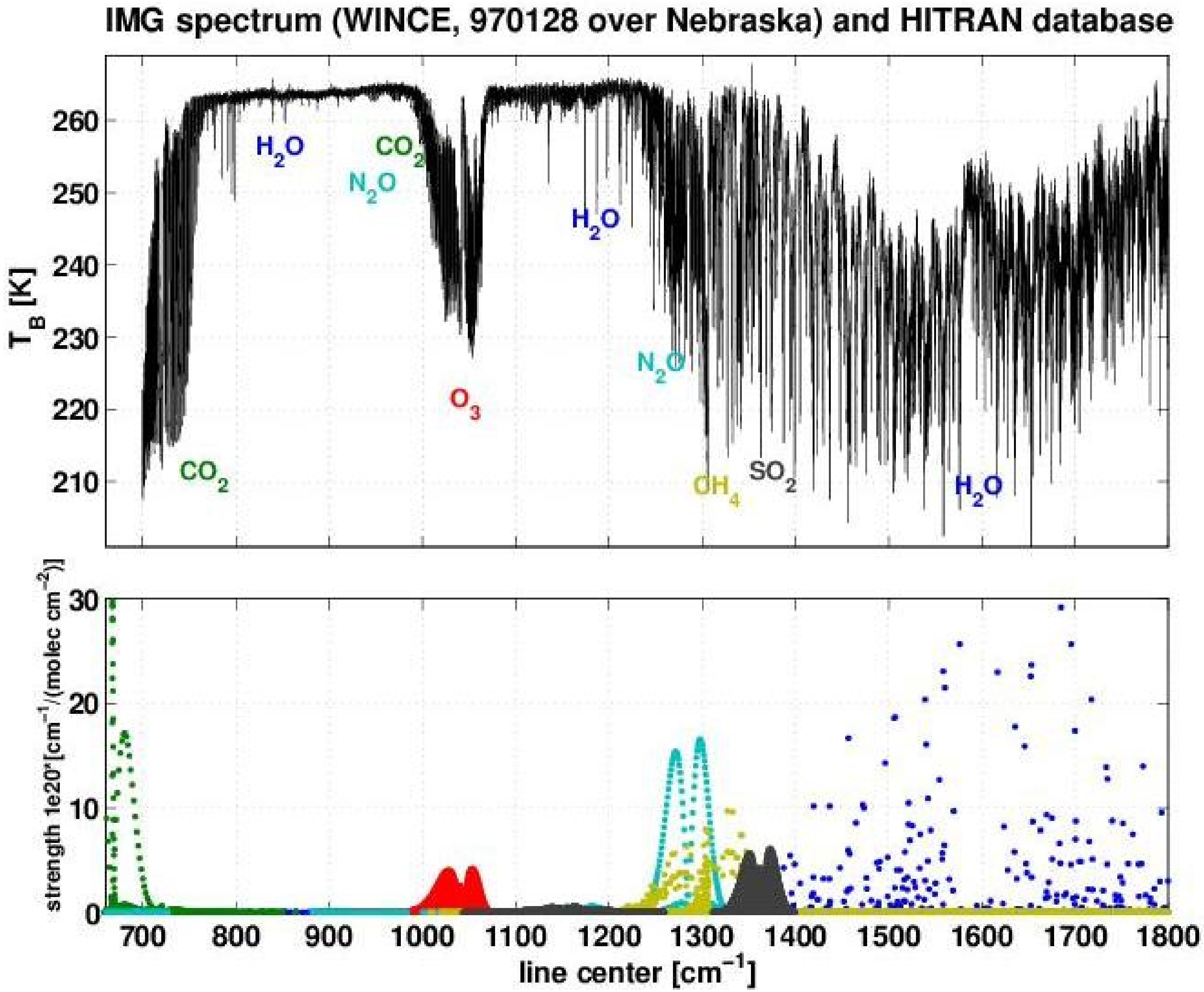


AIRS Spectra from around the Globe

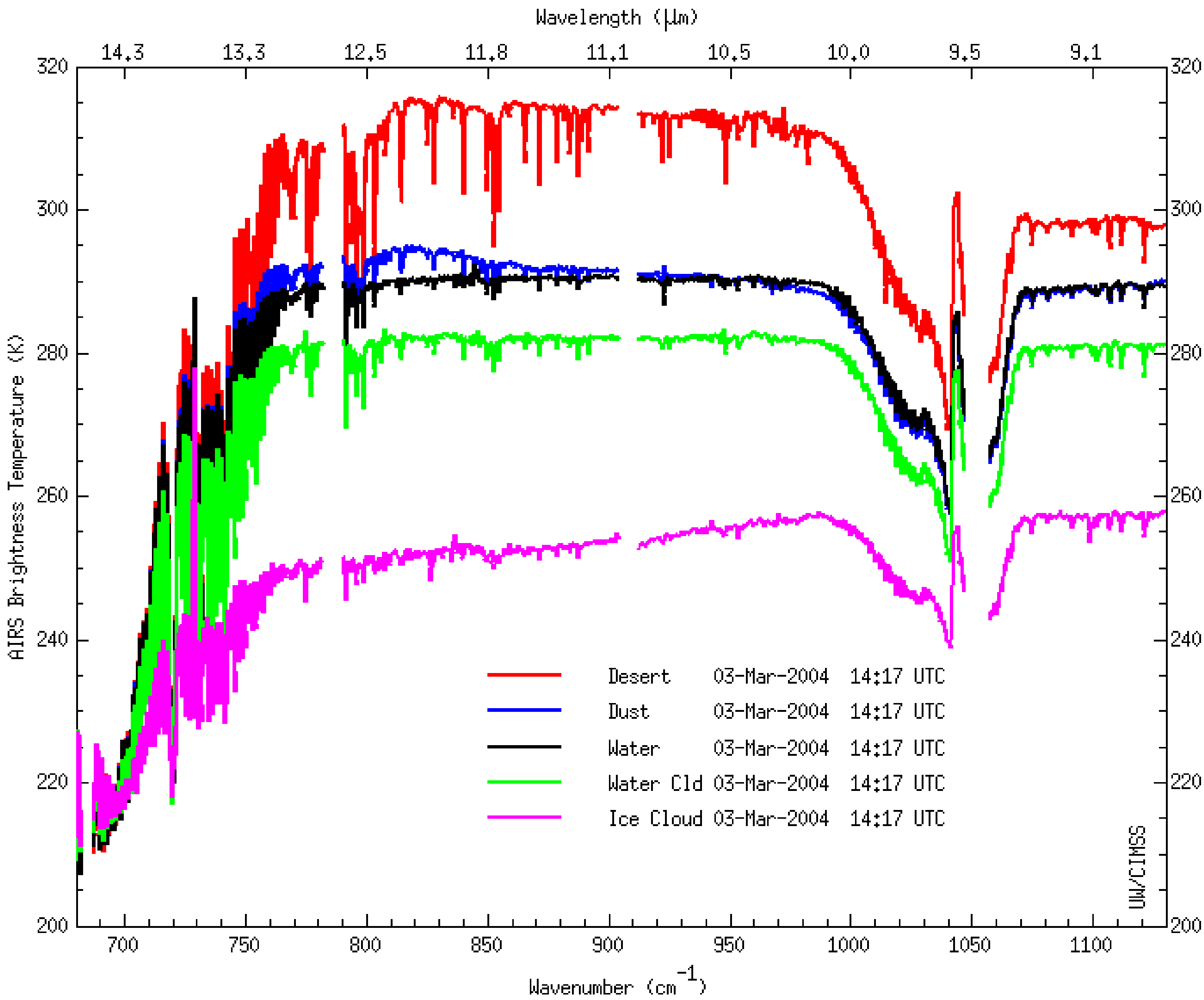


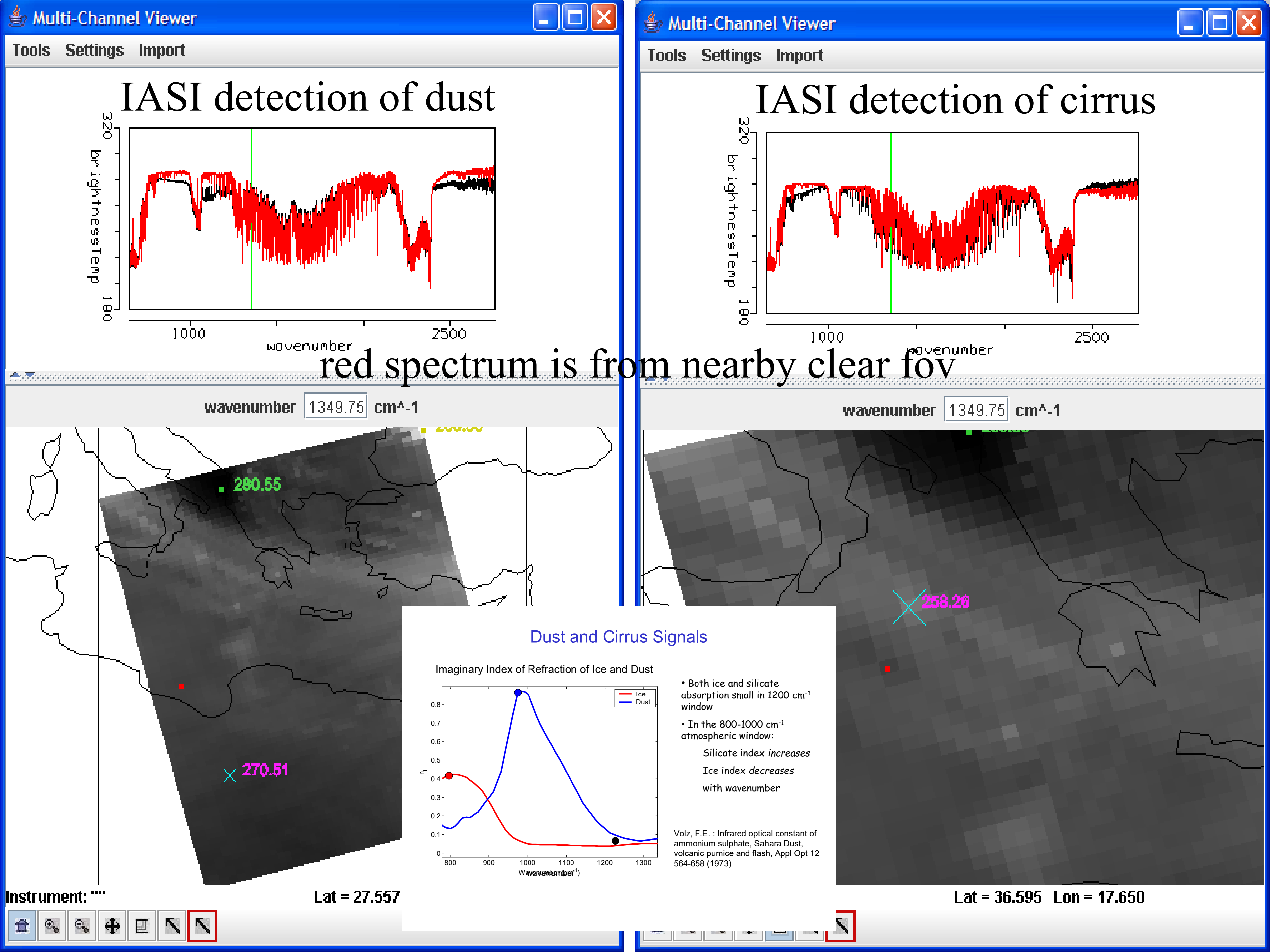
AIRS data from 28 Aug 2005





IMG spectrum (WINCE, 970128 over Nebraska) and HITRAN database
T_B [K]
260
250
240
230
220
210
H2O
CO2
N2O
H2O
N2O
O3
CO2
CH4
SO2
H2O
strength 1e20*[cm^-1/(molec cm^-2)]
30
20
10
0
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
line center [cm^-1]


Wavelength (µm)
14.3
13.3
12.5
11.8
11.1
10.5
10.0
9.5
9.1
320
300
280
260
240
220
200
AIRS Brightness Temperature (K)
700
750
800
850
900
950
1000
1050
1100
Wavenumber (cm-1)
Desert 03-Mar-2004 14:17 UTC
Dust 03-Mar-2004 14:17 UTC
Water 03-Mar-2004 14:17 UTC
Water Cld 03-Mar-2004 14:17 UTC
Ice Cloud 03-Mar-2004 14:17 UTC
UW/CIMSS

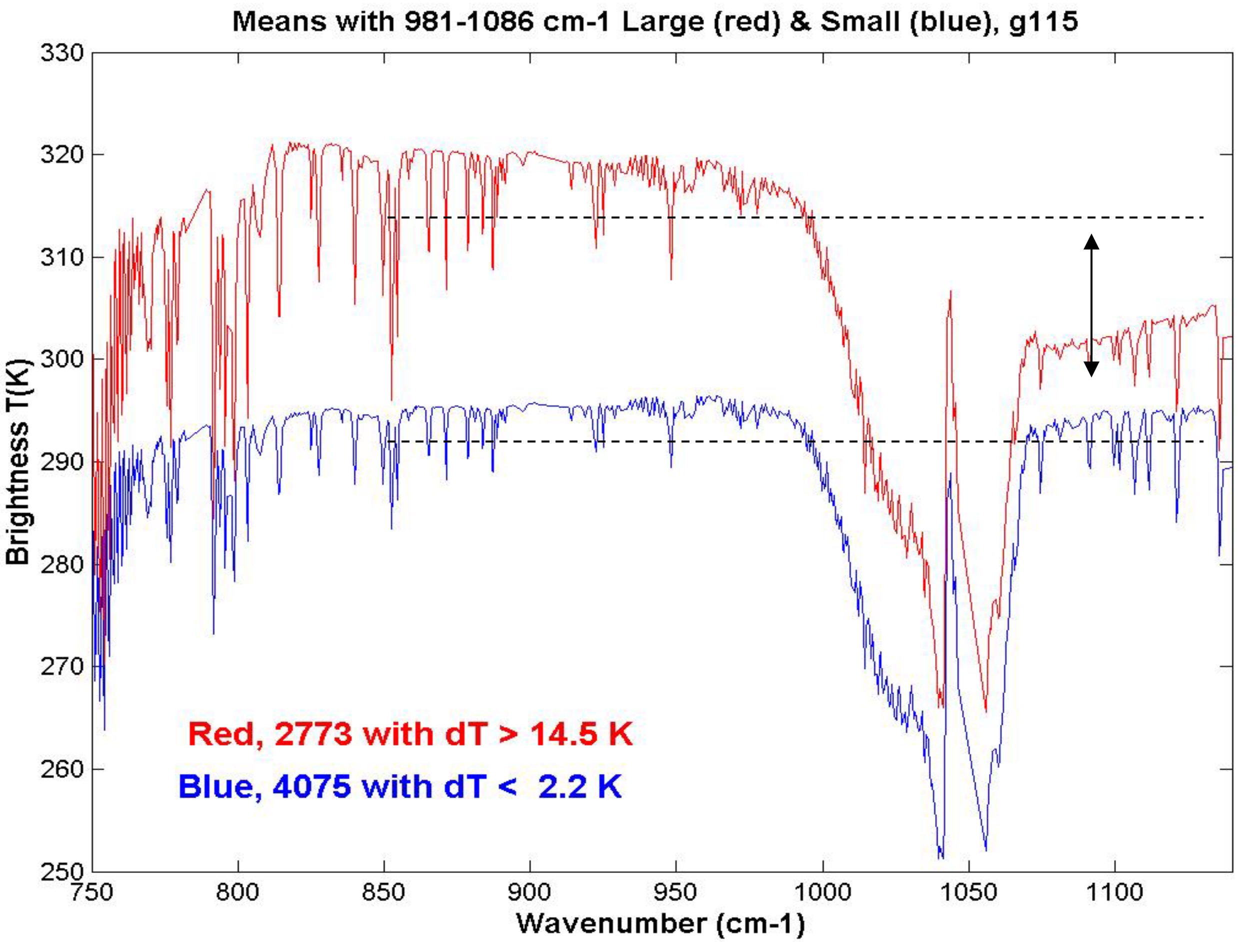


Multi-Channel Viewer
Tools Settings Import
IASI detection of dust
brightnessTemp
320
180
1000
2500
wavenumber
red spectrum is from nearby clear fov
wavenumber 1349.75 cm^-1
280.55
270.51
Instrument: ""
Lat = 27.557
Multi-Channel Viewer
Tools Settings Import
IASI detection of cirrus
brightnessTemp
320
180
1000
2500
wavenumber
wavenumber 1349.75 cm^-1
258.26
Lat = 36.595 Lon = 17.650
Dust and Cirrus Signals
Imaginary Index of Refraction of Ice and Dust
Ice
Dust
Wavenumber
• 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 Opt 12 564-658 (1973)

Inferring surface properties with AIRS high spectral resolution data

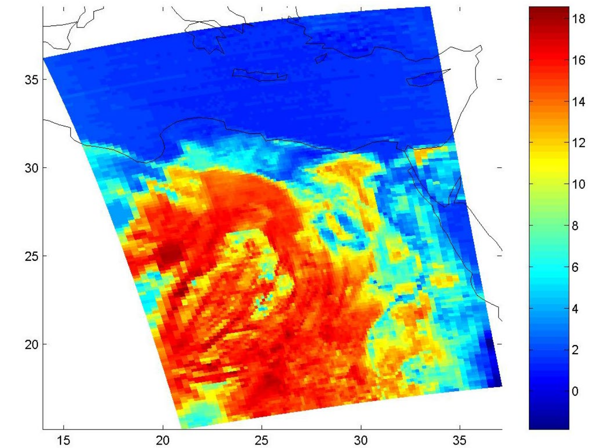
Barren region detection if T1086 < T981

Barren vs Water/Vegetated

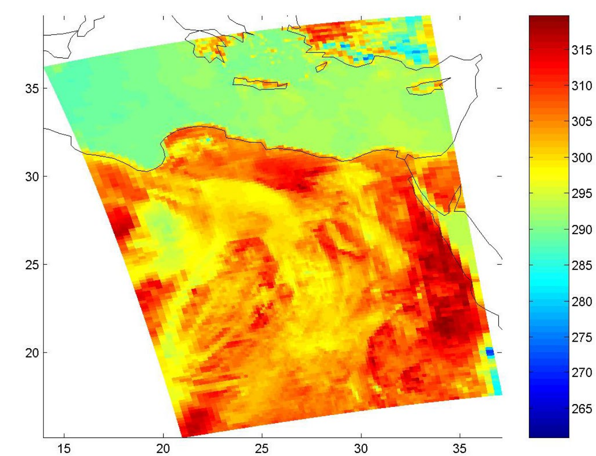


AIRS data from 14 June 2002

T(981 cm^{-1})-T(1086 cm^{-1})

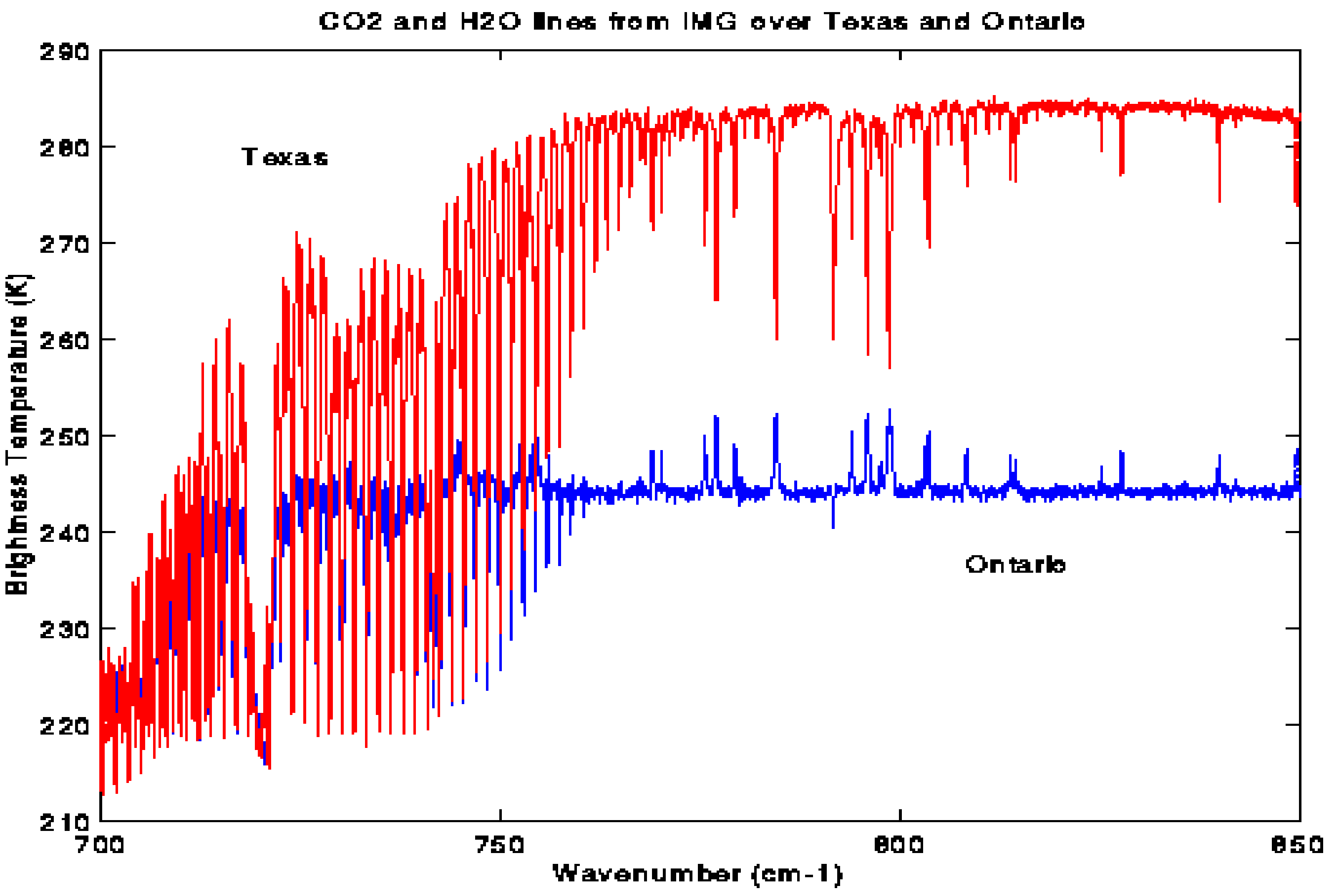


T(1086 cm^{-1})



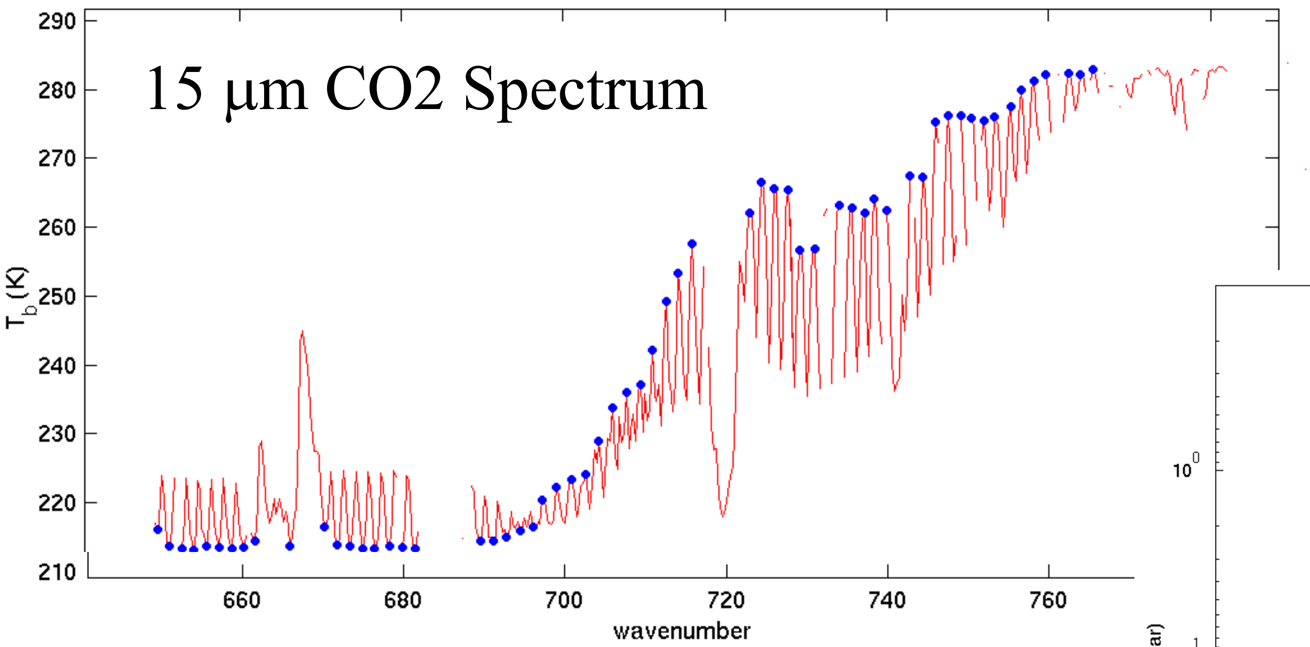
Sensitivity of High Spectral Resolution to Boundary Layer Inversions and Surface/atmospheric Temperature differences

(from IMG Data, October, December 1996)

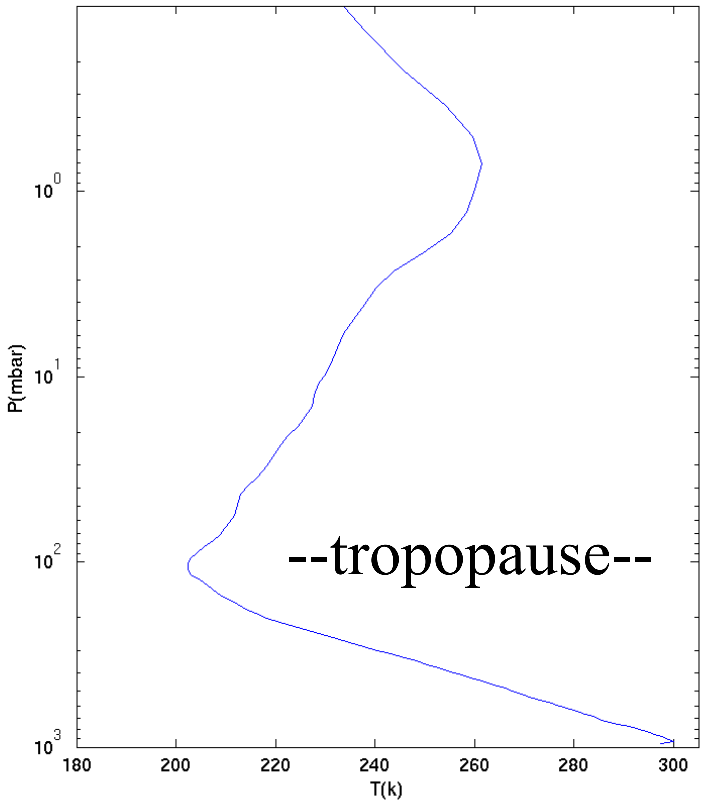


Twisted Ribbon formed by CO_2 spectrum:

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

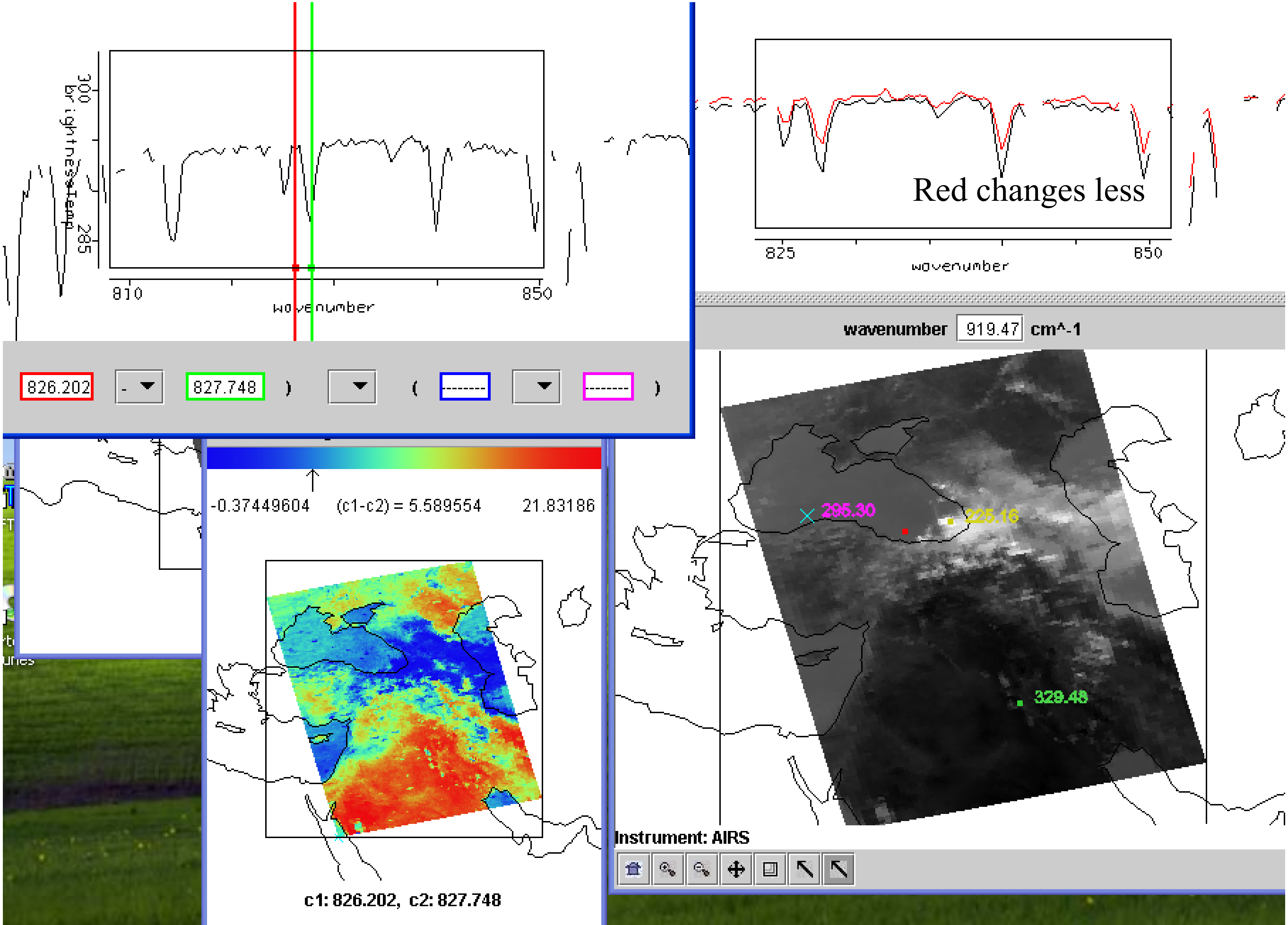


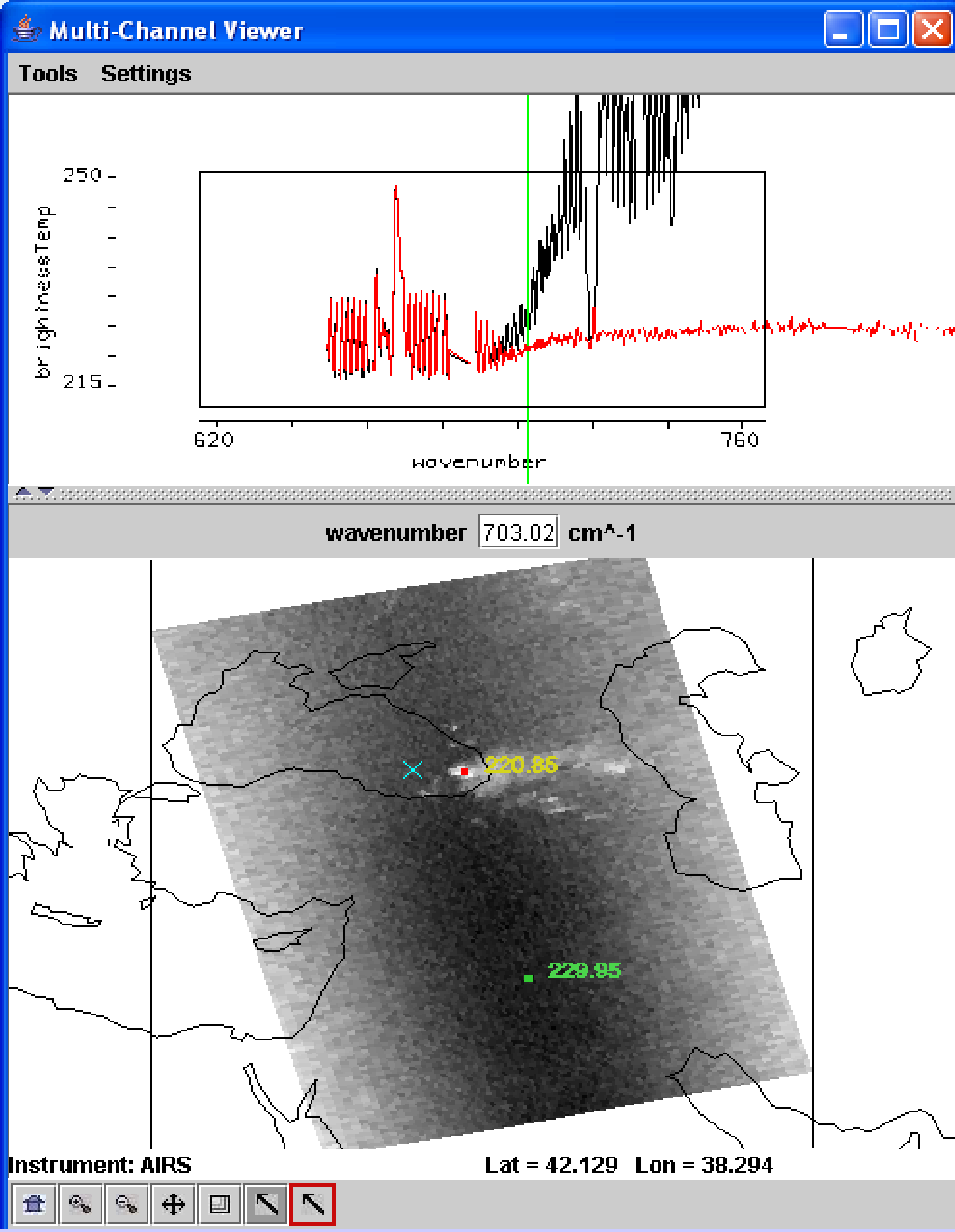
Blue between-line T_b
warmer for tropospheric channels,
colder for stratospheric channels

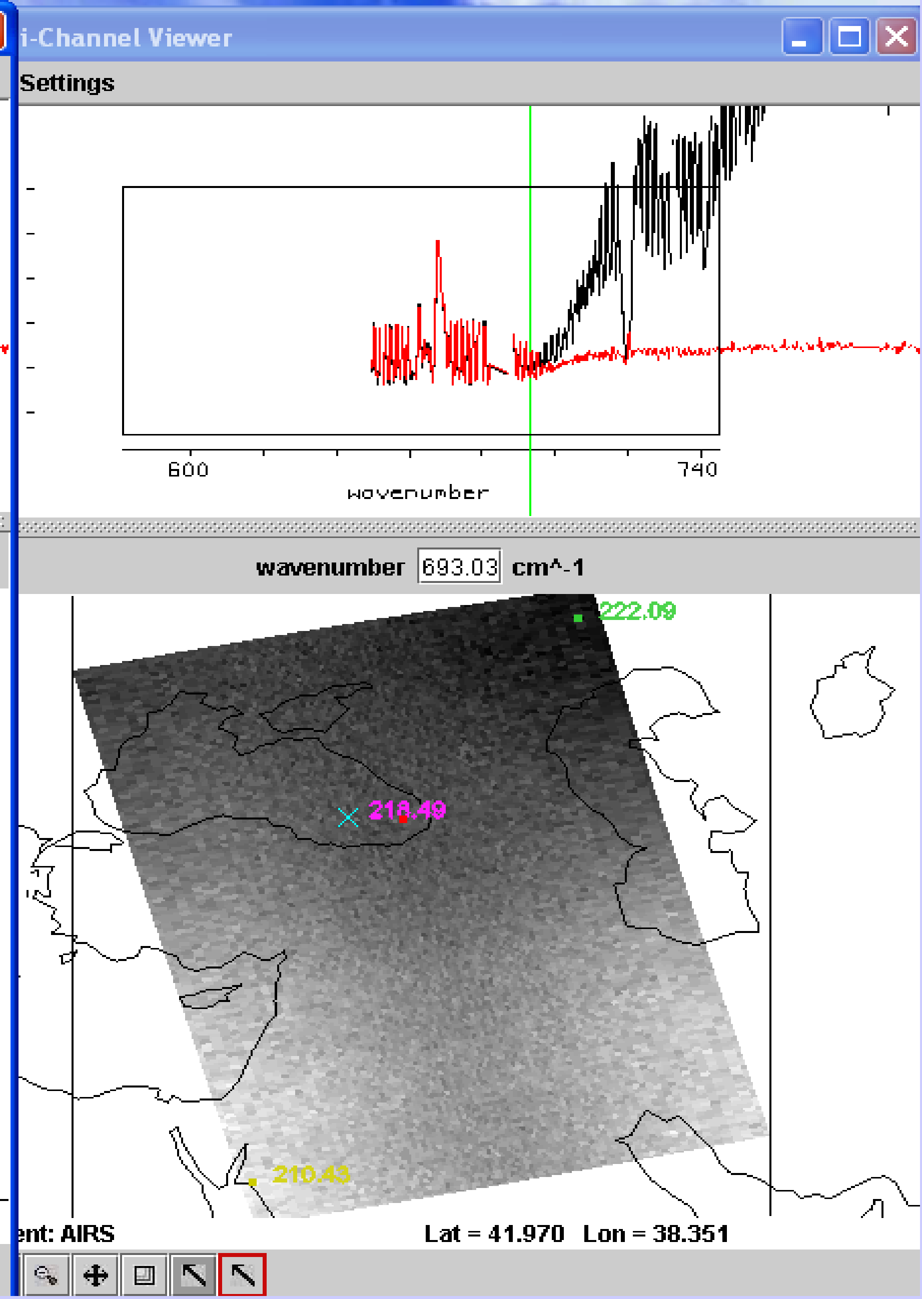


Signature not available at low resolution

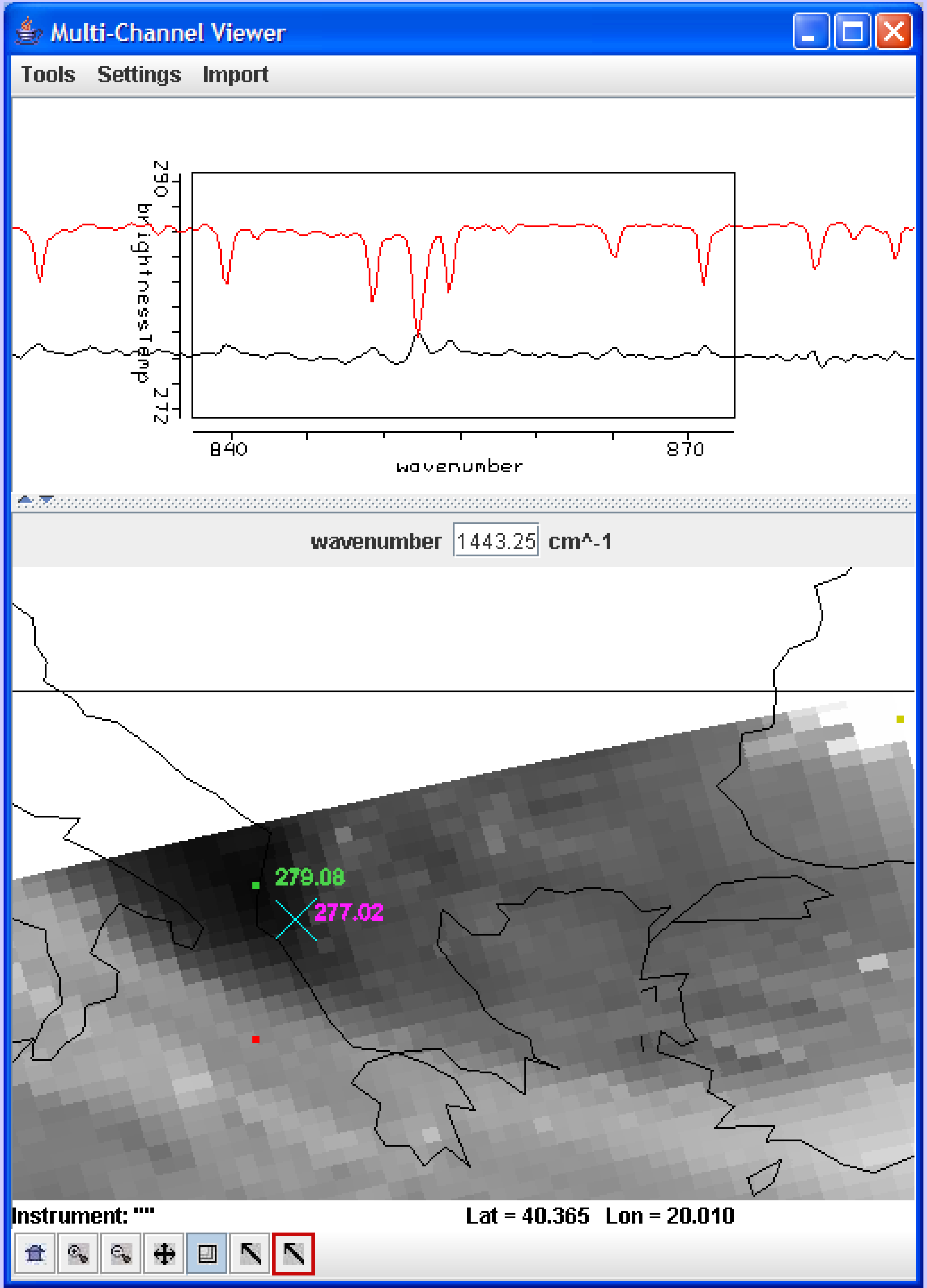
Offline-Online in LW IRW showing low level moisture



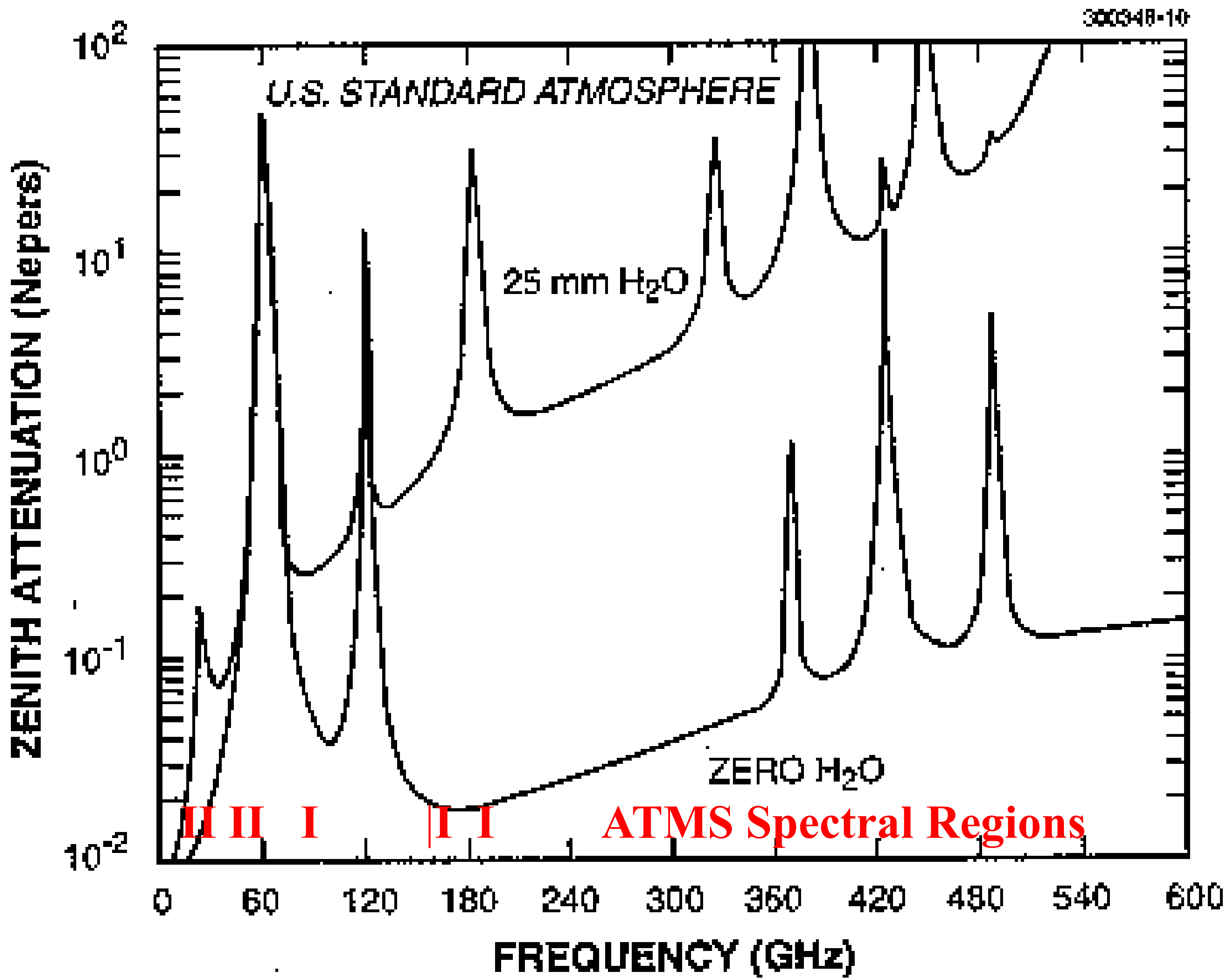




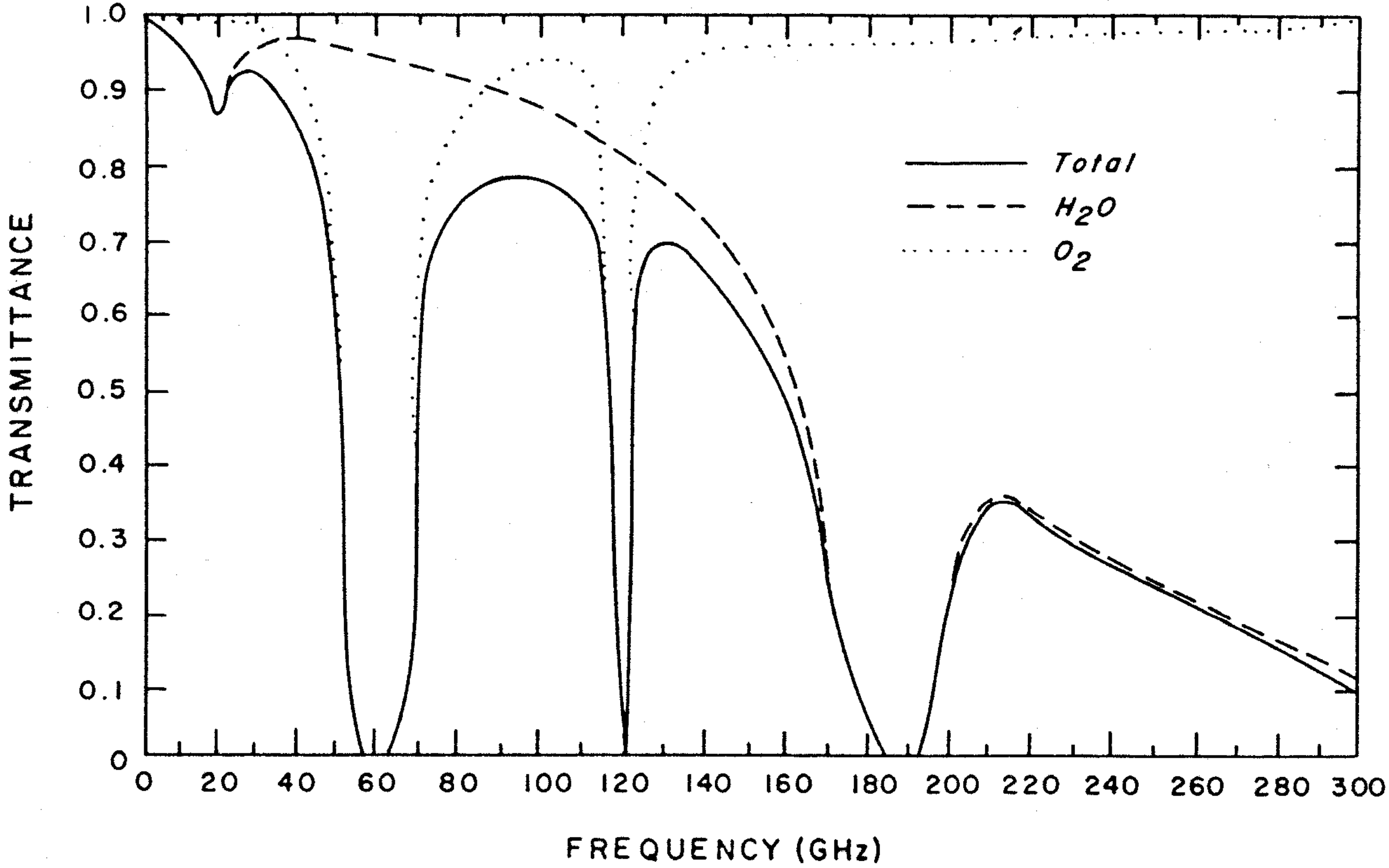
Cld and clr spectra in CO2 absorption separate when weighting functions sink to cloud level



IASI sees
low level inversion
over land



300348-10
U.S. STANDARD ATMOSPHERE
25 mm H_2O
ZERO H_2O
II II I
|I I
ATMS Spectral Regions
ZENITH ATTENUATION (Nepers)
10^2
10^1
10^0
10^{-1}
10^{-2}
0
60
120
180
240
300
360
420
480
540
600
FREQUENCY (GHz)



TRANSMITTANCE
FREQUENCY (GHz)
Total
H_2O
O_2
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

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

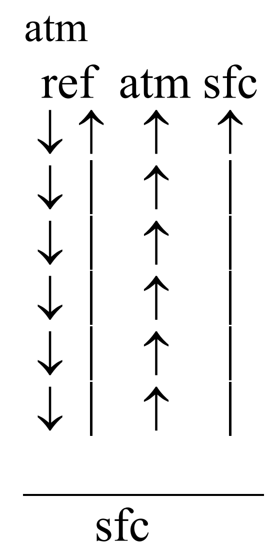
$$e^{c_2/\lambda T} = 1 + c_2/\lambda T + \text{second order}$$

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

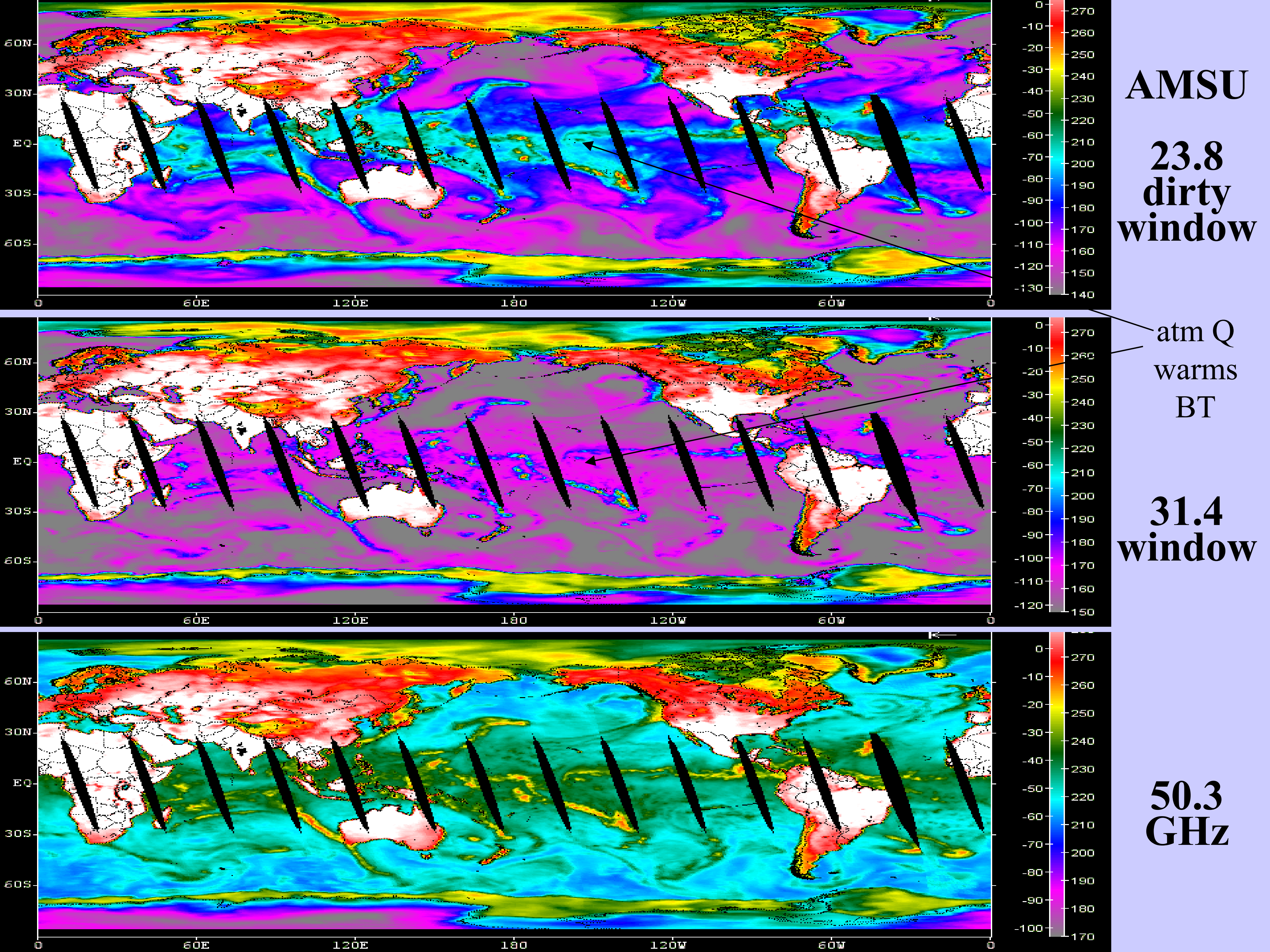
$$B_\lambda(T) \approx [c_1 / c_2]\, [T / \lambda^4]$$

So

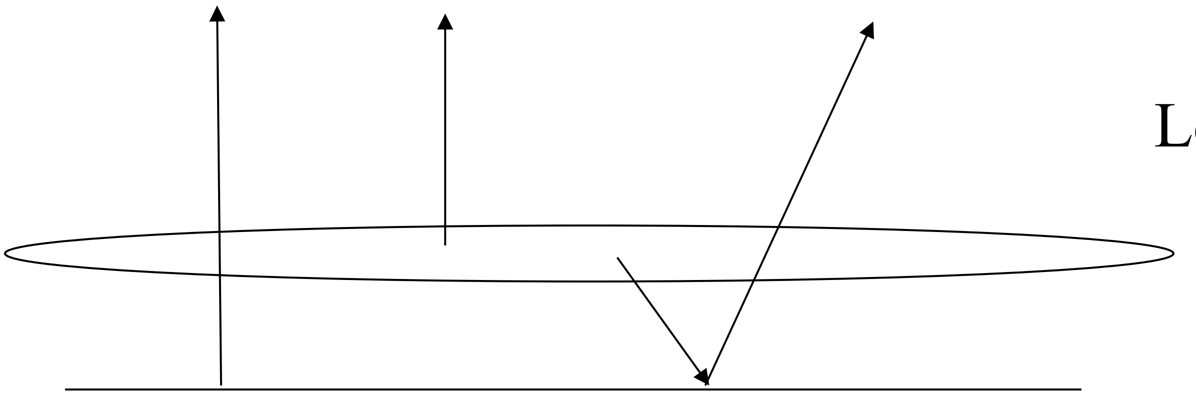
$$T_{b\lambda} = \varepsilon_\lambda T_s(p_s)\, \tau_\lambda(p_s) + \int_{p_s}^{o} T(p)\, F_\lambda(p) \frac{\partial \tau_\lambda(p)}{\partial \ln p}\, d \ln p$$

where

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



AMSU
23.8
dirty
window
atm Q
warms
BT
31.4
window
50.3
GHz



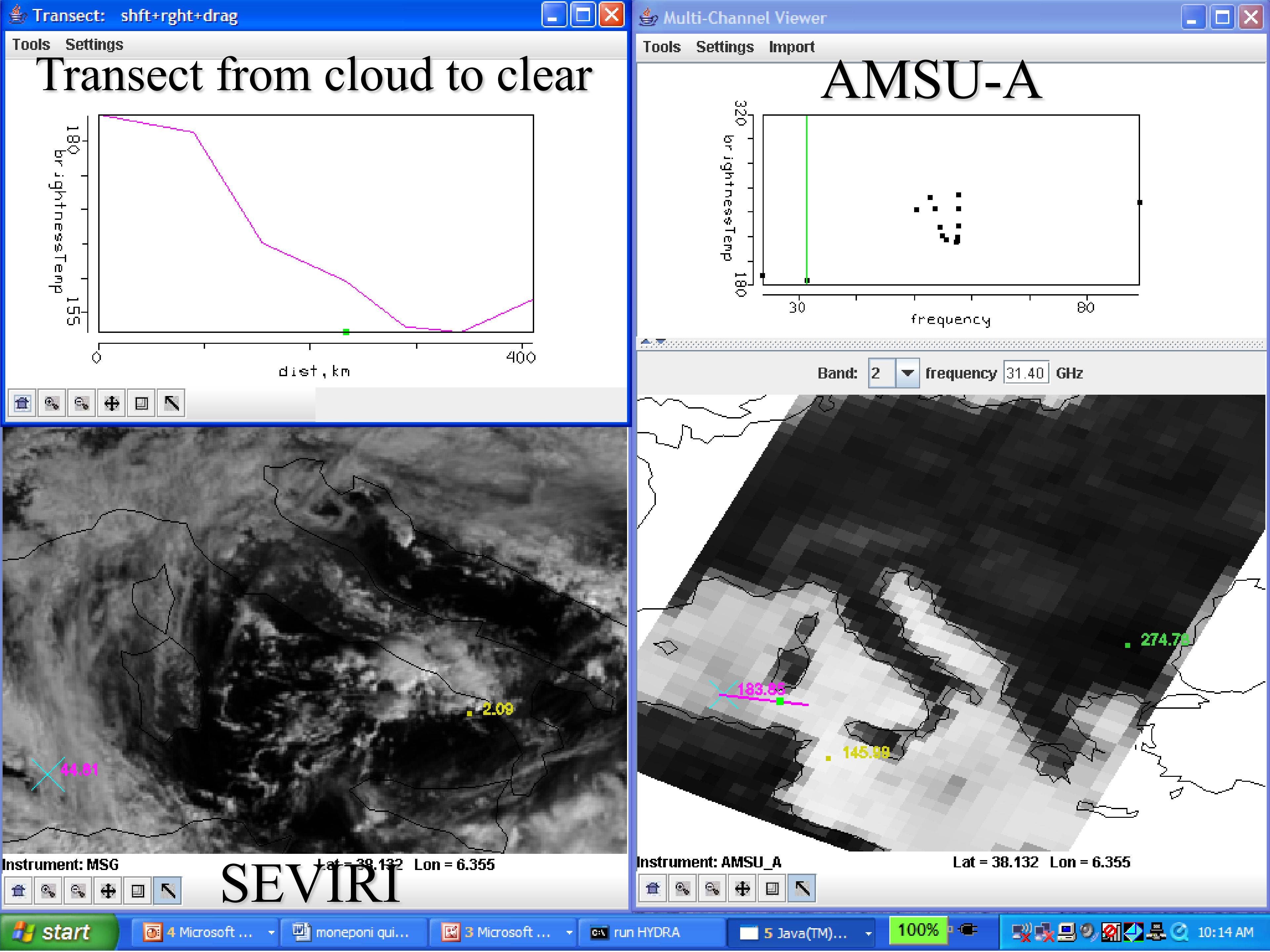
Low mist over ocean

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

So

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

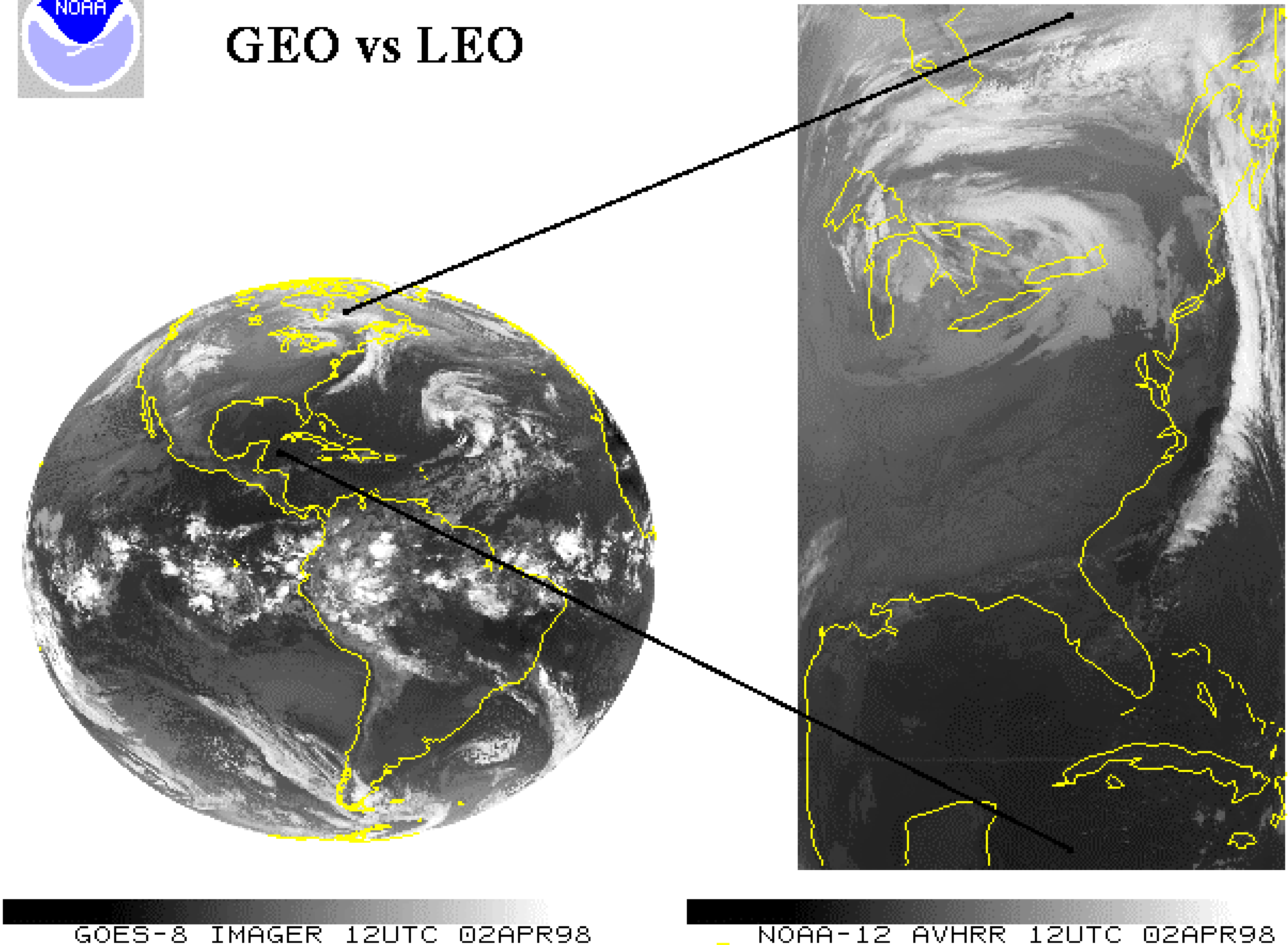
For $\varepsilon_s \sim 0.5$ and $T_s \sim T_m$ this is always positive for $0 < \sigma_m < 1$


Transect: shft+rght+drag
Tools Settings
Transect from cloud to clear
brightnessTemp
180
155
0
400
dist,km
Multi-Channel Viewer
Tools Settings Import
AMSU-A
320
180
30
80
frequency
Band: 2 frequency 31.40 GHz
274.78
183.85
145.98
Instrument: AMSU_A
Lat = 38.132 Lon = 6.355
2.09
44.81
Instrument: MSG
Lat = 38.132 Lon = 6.355
SEVIRI
start
4 Microsoft ...
moneponi qui...
3 Microsoft ...
run HYDRA
5 Java(TM)...
100%
10:14 AM

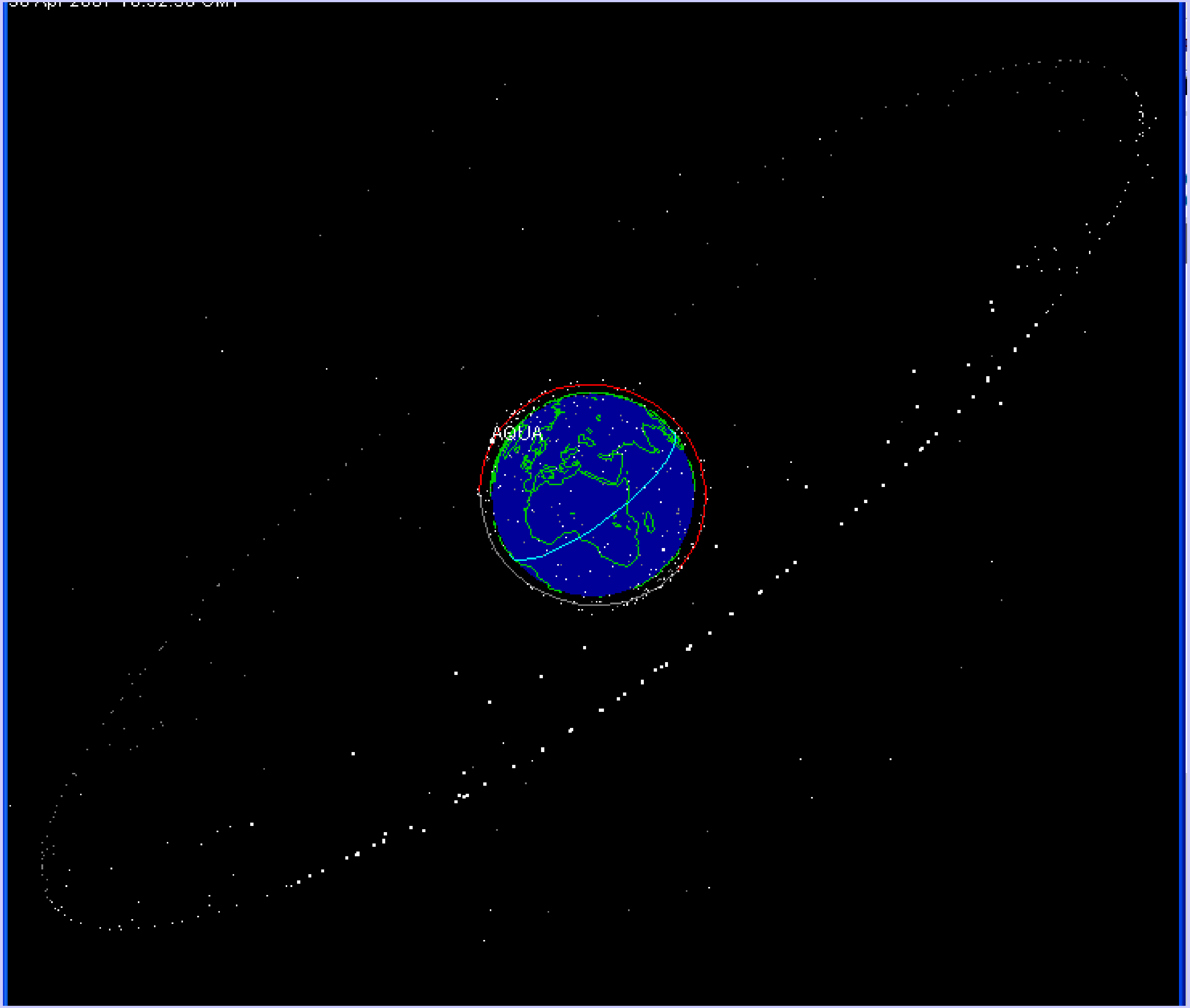
Accuracy of Satellite Derived Met Parameters

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



All Sats on NASA J-track

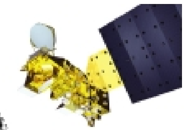


Comparison of geostationary (geo) and low earth orbiting (leo) satellite capabilities

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



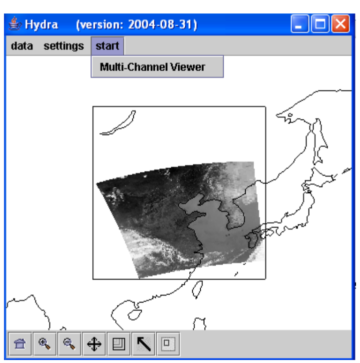
MODIS,
AIRS, IASI,
AMSU,
CALIPSO

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

Developed at CIMSS by
Tom Rink
Tom Whittaker
Kevin Baggett

With guidance from
Paolo Antonelli
Liam Gumley
Paul Menzel
Allen Huang

Rink et al, BAMS 2007



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/realtime

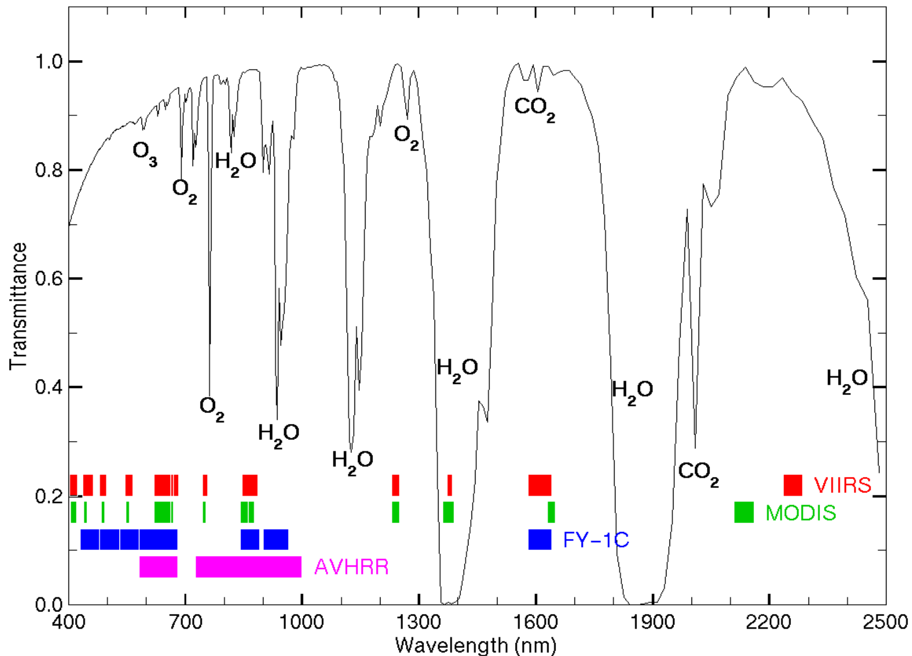
For MODIS data orders
http://ladsweb.nascom.nasa.gov/

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

Steps in downloading data

- 1) Go to http://ladsweb.nascom.nasa.gov/
- and select data and then search. Make sure that cookies are accepted by your browser (most browsers are set this way already). Under Satelllite/Instrument choose either Aqua or Terra
- 2) Under Group: Choose Aqua Level 1 Products or Terra Level 1 Products (depends on what you chose in step 1).
- 3) Under Products: Choose either 1km, 500m or 250m L1B Calibrated Radiances or you can choose all 3 if you want.
- 4) Under Start Date and Time: Use 07/10/2006 00:00:00
- 5) Under End Date and Time: 07/15/2006 23:59:59
- 6) In the Spatial Selection section choose: Latitude/Longitude
- A map should pop up. You can either outline your area of interest buy outlining a box on the map, or you can type in the North, South, East and West Limits in the boxes to the right of the images for your area of interest (Sudan). I used 0 South, 20 North, 25 West and 35 East.
- 7) Under Coverage Selection Choose:If you only want Day granules (will contain channels in the visible wavelengths) , then make sure the Night and Both boxes are not checked. I chose to only get Day granules.
- 8) Click on the Search button at the bottom. This might take a minute or two.
- 9) Eventually, I received a page that contained 6 pages of granules that met my search criteria. Under the Browse column, I could click on the image to get a quick look view of the granule.
- 10) I chose to order all of the granules that were returned from my search. I clicked on the Order Files Now button at the bottom of the window.
- 11) A page appeared that asked for my email address. I typed it in: kathy.strabala@ssec.wisc.edu
  12) I chose FTP Pull and clicked on the Order button.
- 13) It returned a window that told me some of my order is ready (alot of the data is already online). The rest of the data will be staged and I will be informed via email when it is ready.
- 14) I received an email that tells me how I can get the data.
- --
- Your Order ID is: 500143562
- The data you ordered has been staged, and you can retrieve the data through anonymous FTP using:
- ftp ladsweb.nascom.nasa.gov
- username: anonymous
- password: kathy.strabala@ssec.wisc.edu

- cd /orders/500143562
- binary
- prompt
- mget *



High resolution atmospheric absorption spectrum and comparative blackbody curves.