Applications with the
Newest Multi-spectral Environmental Satellites

Lectures and Labs in Madison from 25 to 29 Mar 2013

Paul Menzel

RS Bootcamp Agenda for 25 – 29 March 2013 in Room 1411

Monday 9 – 11 am and 1 – 4 pm
Planck function, BTs in mixels, Intro to HYDRA,
reflected solar and thermal emission, 4 vs 11 um
Tuesday 9 – 11 am and 1 – 4 pm
RTE, land-ocean-atm spectral signatures in MODIS & VIIRS
Wednesday 9 – 11 am and 1 – 4 pm
Hyperspectral IR, MW Sounder,
VIIRS, CrIS, & ATMS split window estimates of low level moisture.
Thursday 1- 4 pm
Group projects on winter storm over USA on their own
Friday 9 – 11 am
Group presentations, Quiz, Summary Lecture.

Lectures am, Labs pm
180 min labs will include student presentations

Lectures and Labs

Lectures and laboratory exercises emphasize investigation of high spatial resolution visible and infrared data (from MODIS and VIIRS), high spectral resolution infrared data (from AIRS and CrIS), and microwave sounding data (AMSU and ATMS). Text for the classroom and a visualization tool for the labs are provided free; "Applications with Meteorological Satellites" is used as a resource text from ftp://ftp.ssec.wisc.edu/pub/menzel/ and HYDRA is used to interrogate and view multispectral data in the labs from http://www.ssec.wisc.edu/rink/hydra2. Homework assignments and classroom tests are administered to verify that good progress is being was made in learning and mastering the materials presented.

Lectures

Applications with Meteorological Satellites is used as a resource text

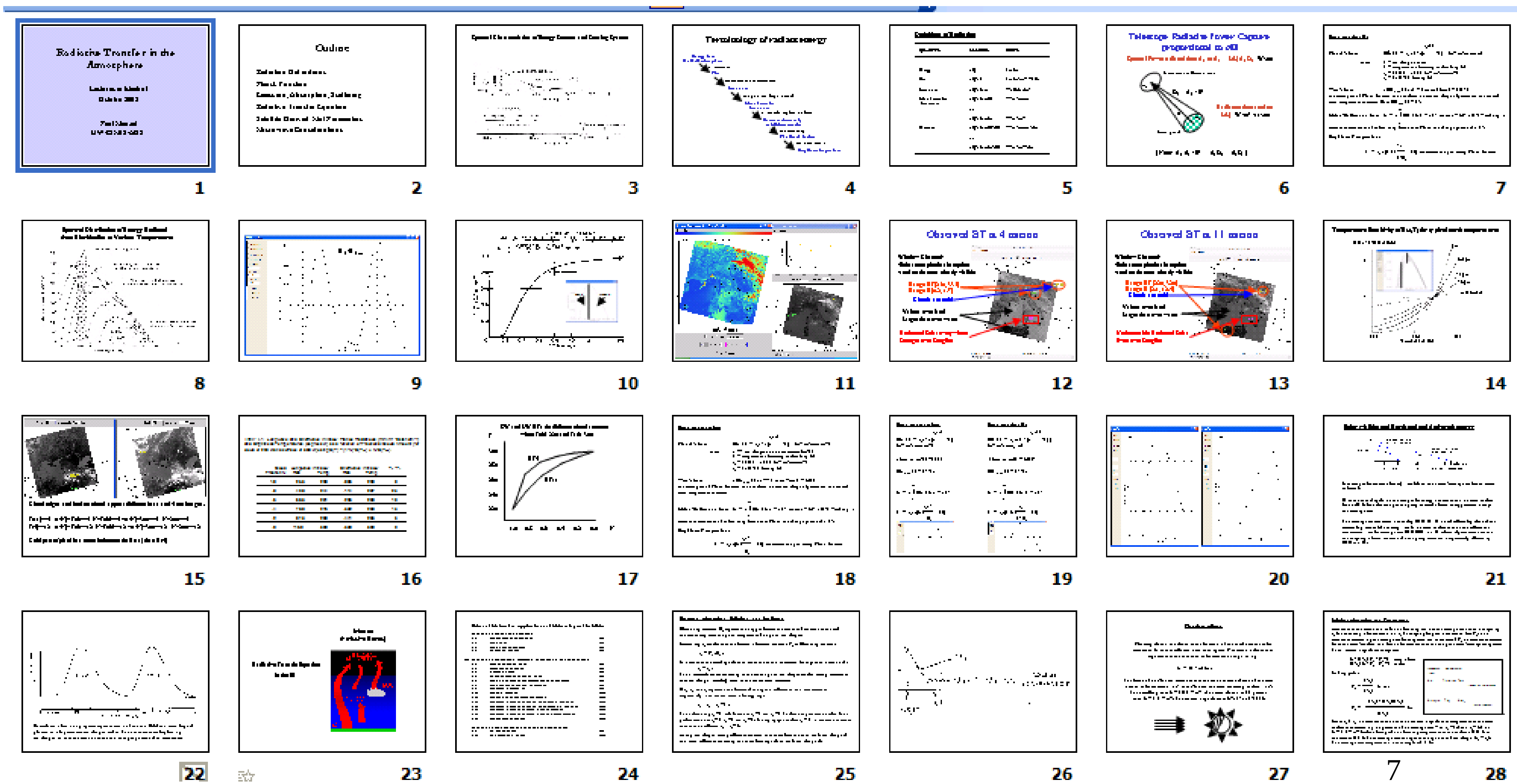
It is available for free at *ftp://ftp.ssec.wisc.edu/pub/menzel/*

* indicates chapters covered

References, problems sets, and quizzes are included in the Appendices

Agenda includes material from Chapters 2, 3, 5, 11, and 12

Lectures are given with powerpoint presentations



Material includes equations

Planck's Law $B(\lambda,T) = c_1 / \lambda^5 / [e^{c_2/\lambda T} - 1]$ $(mW/m^2/ster/cm)$

where λ = wavelengths in cm

T = temperature of emitting surface (deg K)

$c_1 = 1.191044 \times 10\text{-}5$ $(mW/m^2/ster/cm^{-4})$

$c_2 = 1.438769$ (cm deg K)

Wien's Law $dB(\lambda_{max},T) / d\lambda = 0$ where $\lambda(max) = .2897/T$

indicates peak of Planck function curve shifts to shorter wavelengths (greater wavenumbers) with temperature increase. Note $B(\lambda_{max},T) \sim T^5$.

Stefan-Boltzmann Law $E = \pi \int_{o}^{\infty} B(\lambda,T)\, d\lambda = \sigma T^4$, where $\sigma = 5.67 \times 10\text{-}8$ W/m2/deg4.

states that irradiance of a black body (area under Planck curve) is proportional to T^4 .

Brightness Temperature

$$T = c_2 / [\lambda \ln(\frac{c_1}{\lambda^5 B_\lambda} + 1)]$$ is determined by inverting Planck function

And some derivations,

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) + \sum_p \varepsilon_\lambda(\Delta p)\, B_\lambda(T(p))\, \tau_\lambda(p)$$

The emissivity of an infinitesimal layer of the atmosphere at pressure p is equal to the absorptance (one minus the transmittance of the layer). Consequently,

$$\varepsilon_\lambda(\Delta p)\, \tau_\lambda(p) = [1 - \tau_\lambda(\Delta p)]\, \tau_\lambda(p)$$

Since transmittance is an exponential function of depth of absorbing constituent,

$$\tau_\lambda(\Delta p)\, \tau_\lambda(p) = \exp [- \int_p^{p+\Delta p} k_\lambda\, q\, g^{-1}\, dp] \;*\; \exp [- \int_o^p k_\lambda\, q\, g^{-1}\, dp] = \tau_\lambda(p + \Delta p)$$

Therefore

$$\varepsilon_\lambda(\Delta p)\, \tau_\lambda(p) = \tau_\lambda(p) - \tau_\lambda(p + \Delta p) = - \Delta\tau_\lambda(p) .$$

So we can write

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \sum_p B_\lambda(T(p))\, \Delta\tau_\lambda(p) .$$

which when written in integral form reads

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \int_o^{p_s} B_\lambda(T(p))\, [\, d\tau_\lambda(p) / dp \,]\, dp .$$


Labs

HYperspectral viewer for Development of Research Applications – HYDRA2

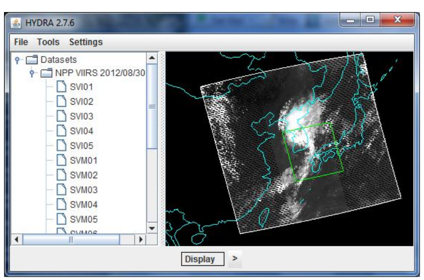
MODIS, VIIRS, CrIS, ATMS

Developed at CIMSS by
Tom Rink

With programming support from
Tommy Jasmin,
Ghansham Sangar
(ISRO)

With guidance from
Liam Gumley
Kathy Strabala
Paul Menzel

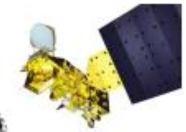
Freely available gui-driven software
For researchers and educators
Computer platform independent
Extendable to more sensors and applications
Uses Java-based technologies
Interactive, high-performance 2D/3D animations
derived from SSEC VisAD api
On-going development effort



ftp://ftp.ssec.wisc.edu/rink/HYDRA2

HYperspectral viewer for Development of Research Applications - HYDRA

MSG,
GOES



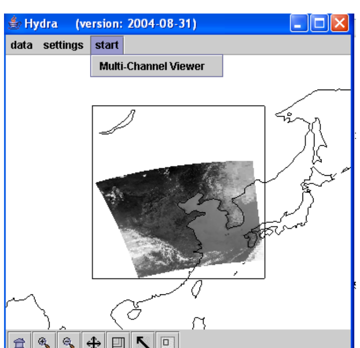
MODIS,
AIRS, IASI,
AMSU,
CALIPSO

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

Rink et al, BAMS 2007

Developed at CIMSS by
Tom Rink
Tom Whittaker
Kevin Baggett

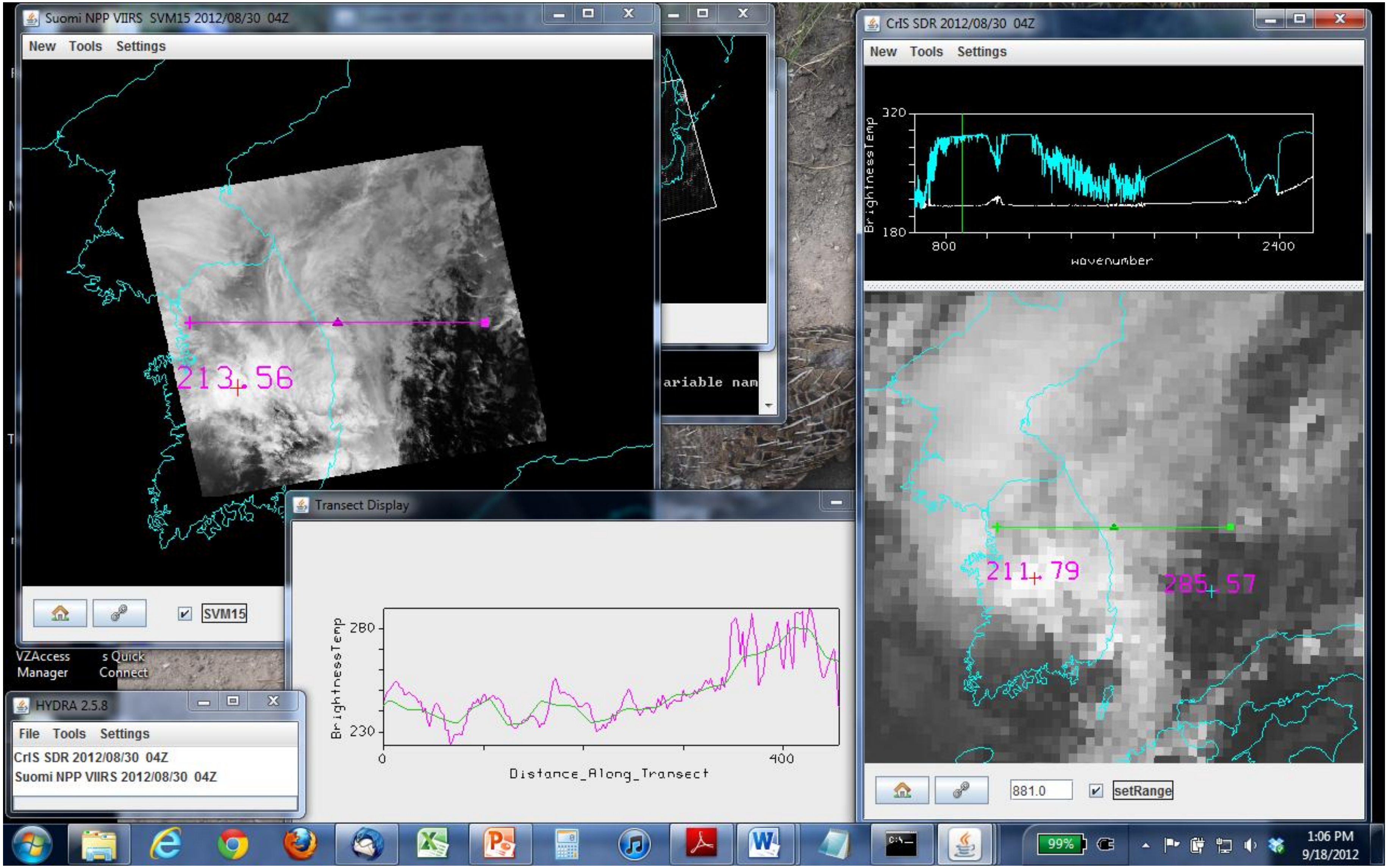
With guidance from
Paolo Antonelli
Liam Gumley
Paul Menzel
Allen Huang



CIMSS

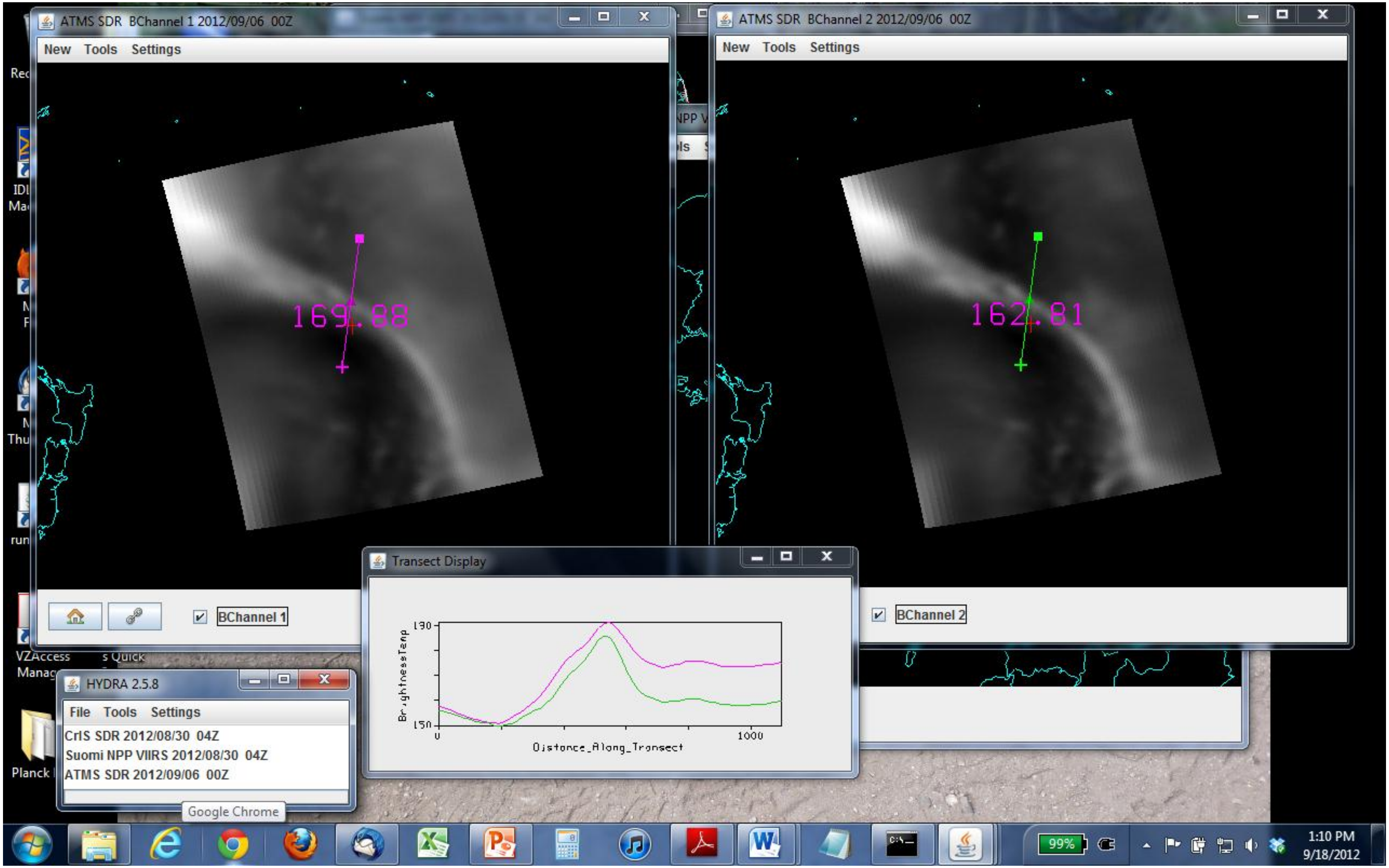
http://www.ssec.wisc.edu/hydra/

View remote sensing data with HYDRA2



VIIRS and CrIS

ATMS



ATMS SDR BChannel 1 2012/09/06 00Z
New Tools Settings
169.88
BChannel 1
ATMS SDR BChannel 2 2012/09/06 00Z
New Tools Settings
162.81
BChannel 2
Transect Display
BrightnessTemp
Distance_Along_Transect
1000
HYDRA 2.5.8
File Tools Settings
CrIS SDR 2012/08/30 04Z
Suomi NPP VIIRS 2012/08/30 04Z
ATMS SDR 2012/09/06 00Z
Google Chrome
1:10 PM
9/18/2012

Access to visualization tools and data

For hydra2 ftp://ftp.ssec.wisc.edu/rink/hydra2/

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

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

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

For VIIRS, CrIS, and ATMS data, orbit tracks, guide
http://www.nsof.class.noaa.gov
http://www.ssec.wisc.edu/datacenter/npp/
http://www.class.ncdc.noaa.gov/notification/faq_npp.htm

See tutorial "How do I order NPP data in CLASS (11/28/11)"

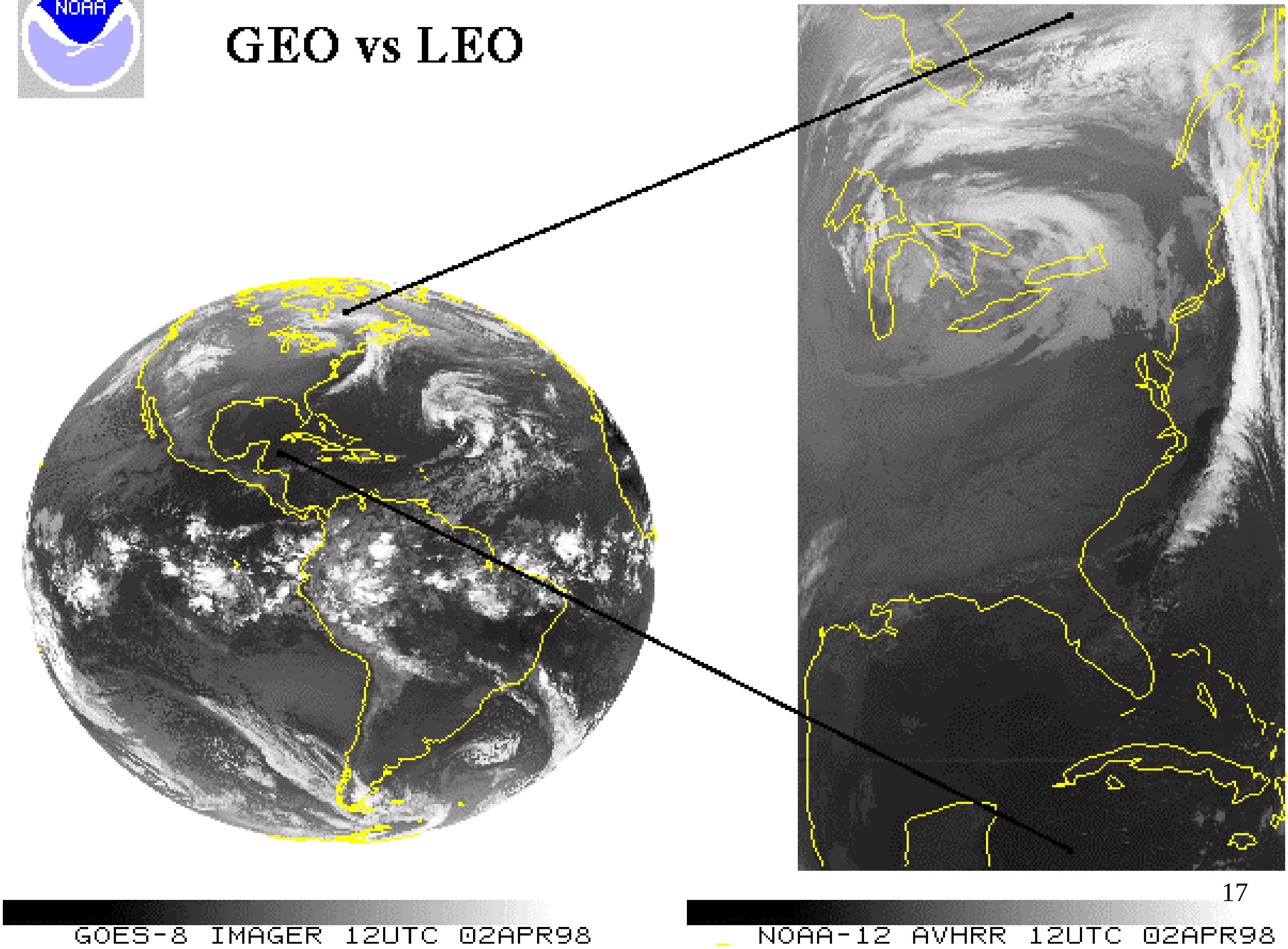
Orbits and Instruments

Lectures in Madison

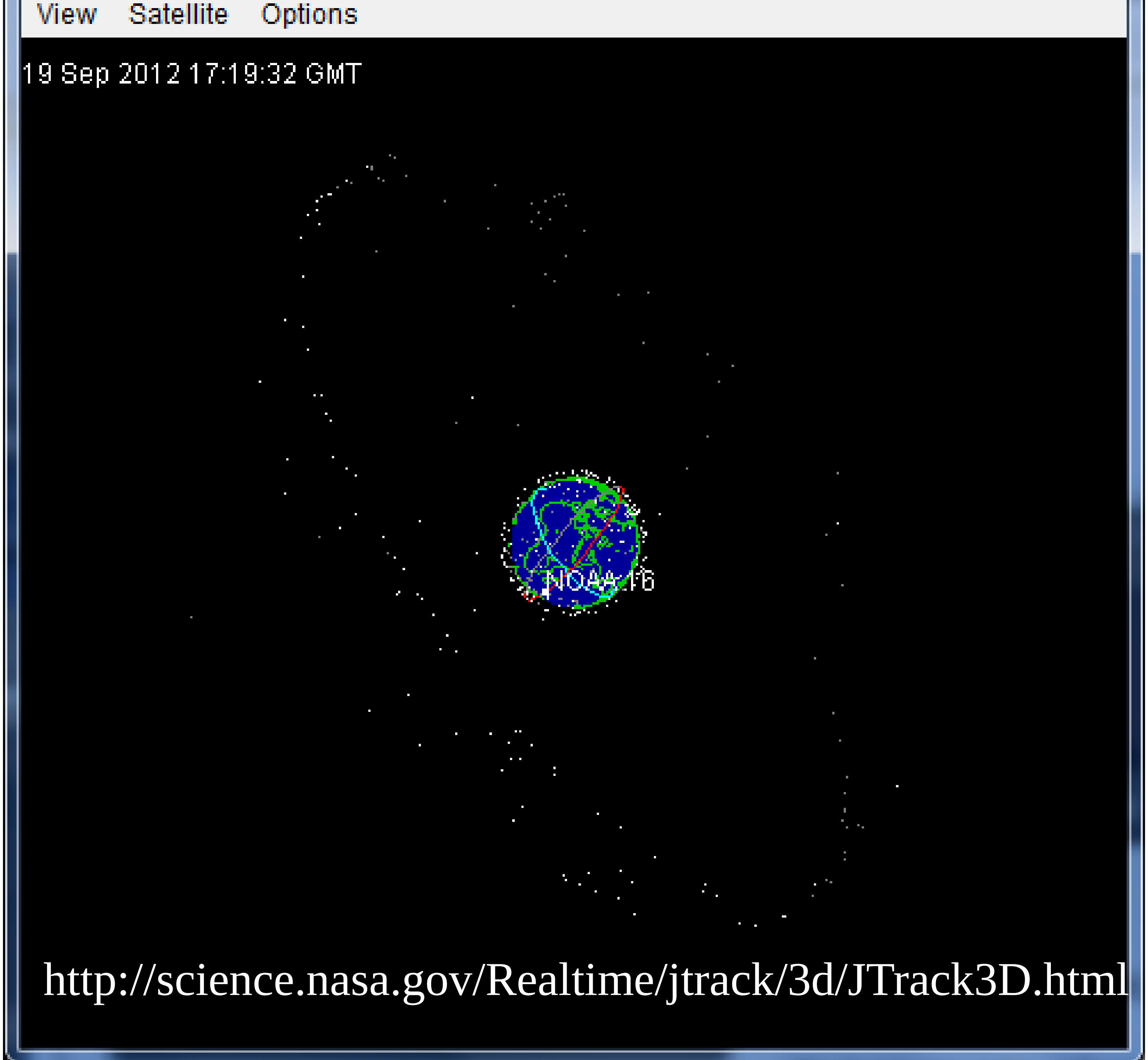
25 Mar 2013

Paul Menzel
UW/CIMSS/AOS

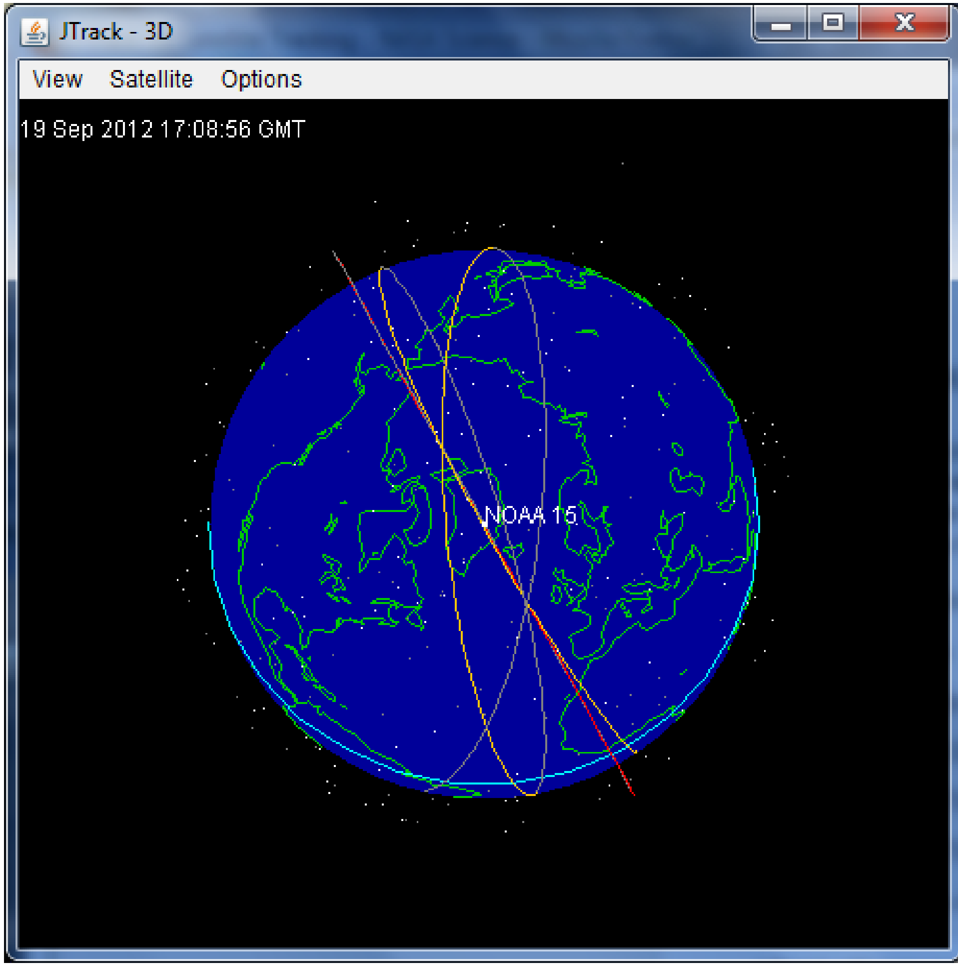
GEO vs LEO

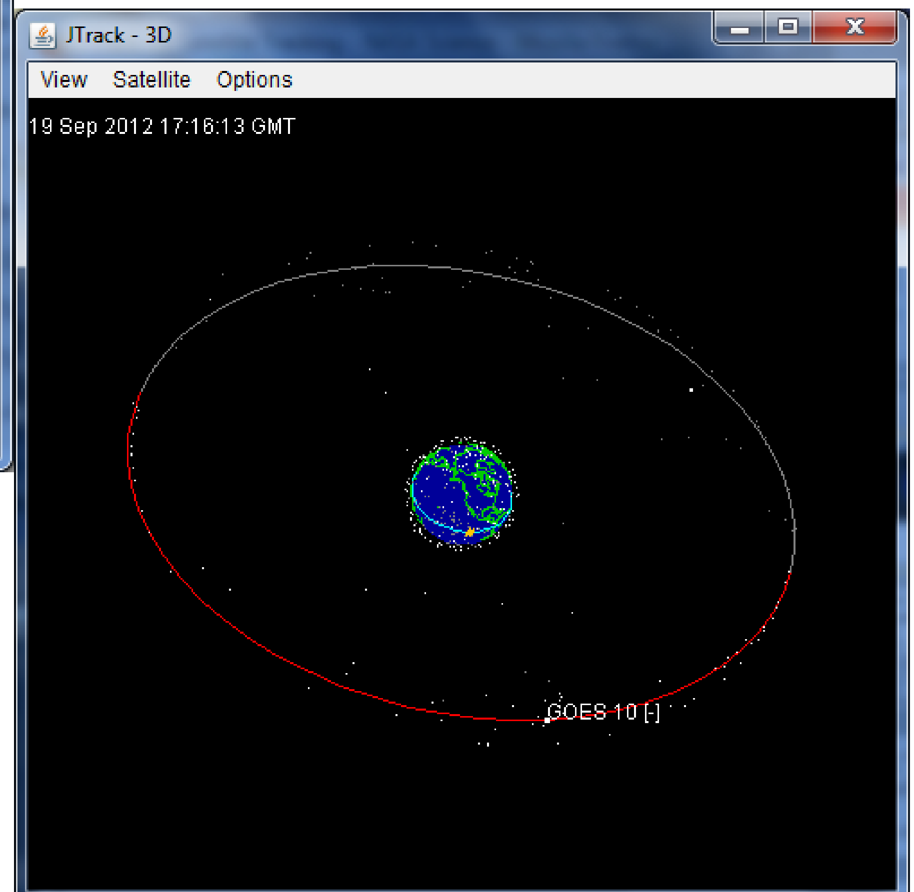


All Sats on NASA J-track

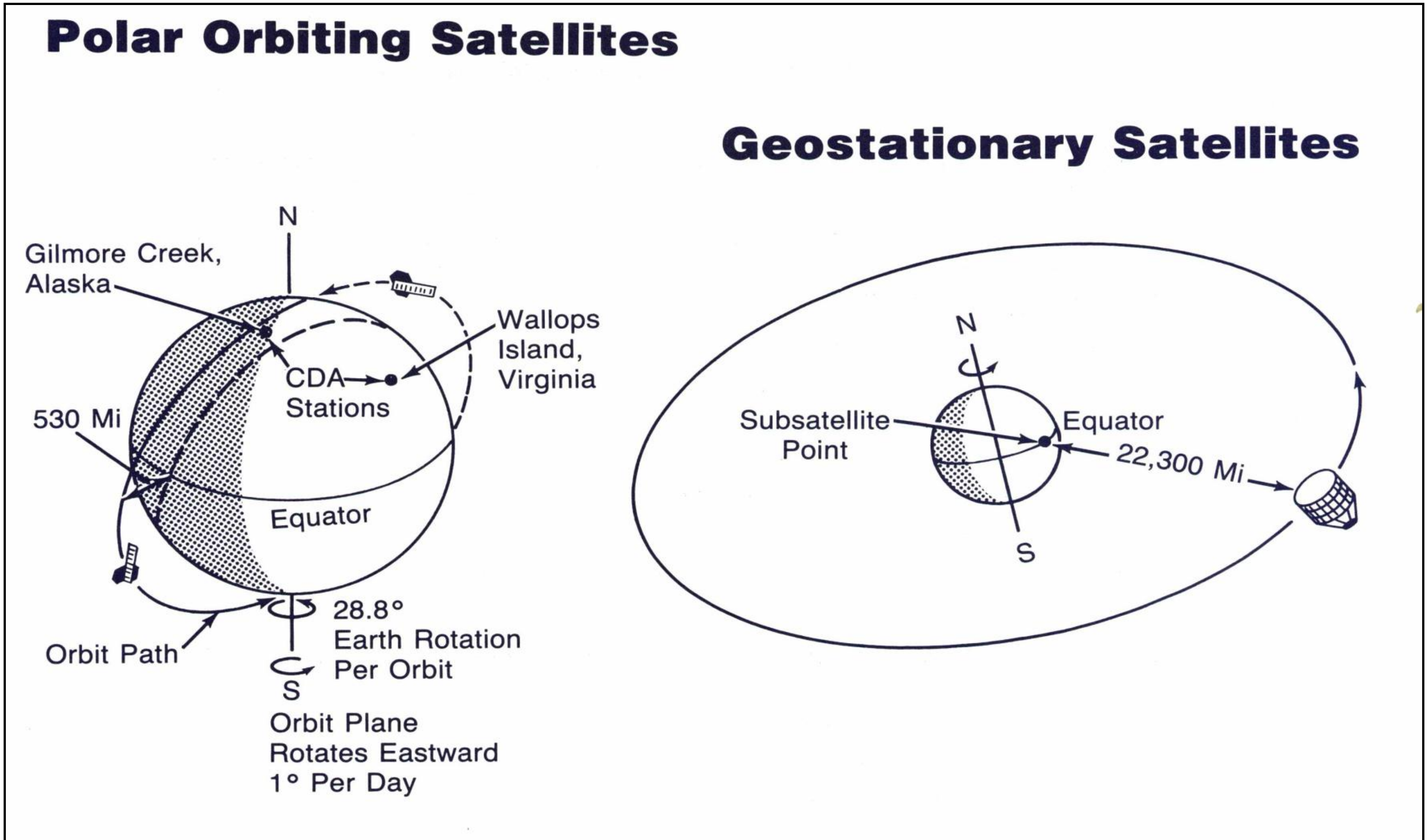


http://science.nasa.gov/Realtime/jtrack/3d/JTrack3D.html


JTrack - 3D
View Satellite Options
19 Sep 2012 17:08:56 GMT
NOAA 15


JTrack - 3D
View Satellite Options
19 Sep 2012 17:16:13 GMT
GOES 10 [-]

Polar (LEO) & Geostationary (GEO) Orbits



Geo Orbit

Let us continue our discussion of the circular orbit. Using the definition of angular velocity $\omega = 2\pi/\tau$ where τ is the period of the orbit, then

$$GMm/r^2 = m\omega^2 r$$

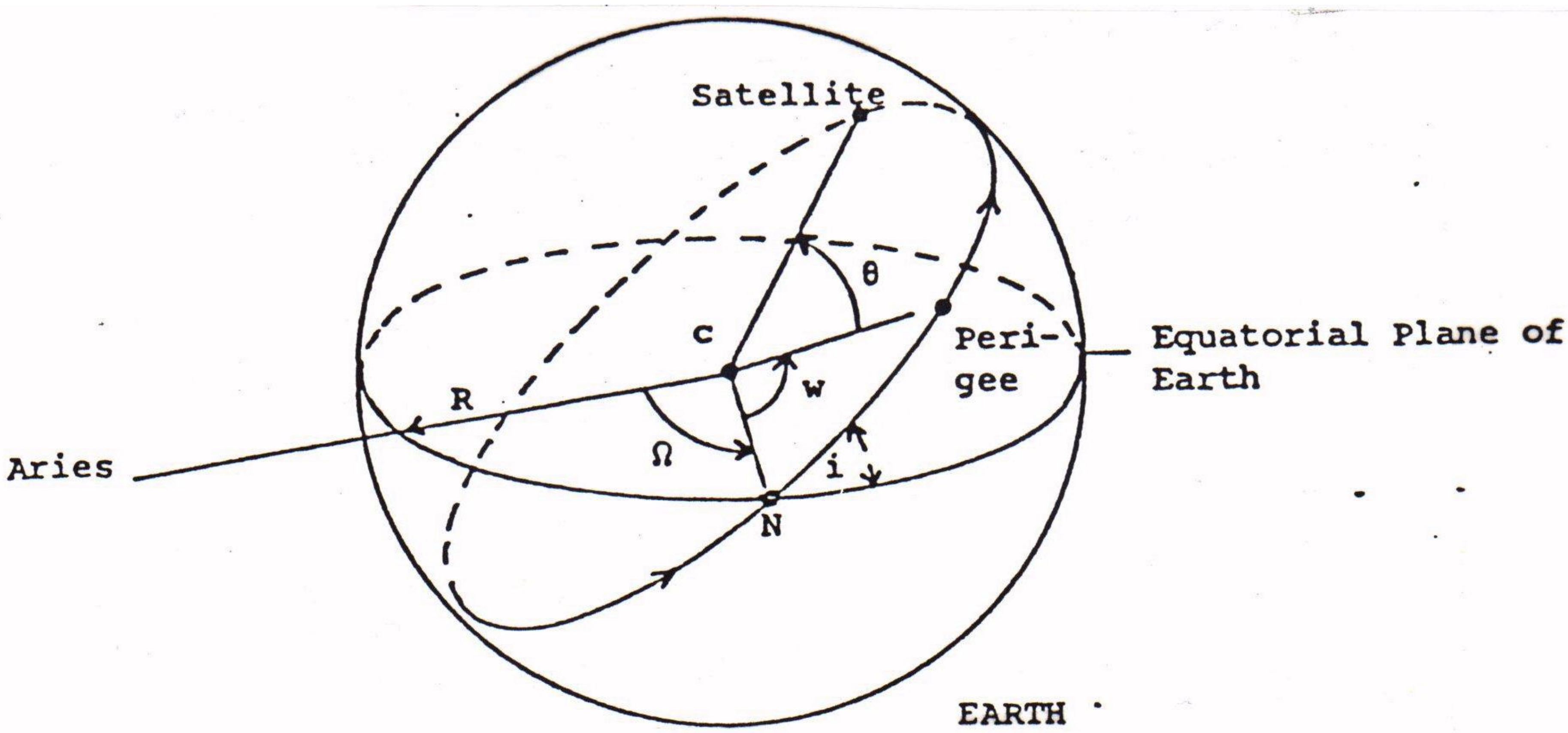
becomes

$$GM/r^3 = 4\pi^2/\tau^2 .$$

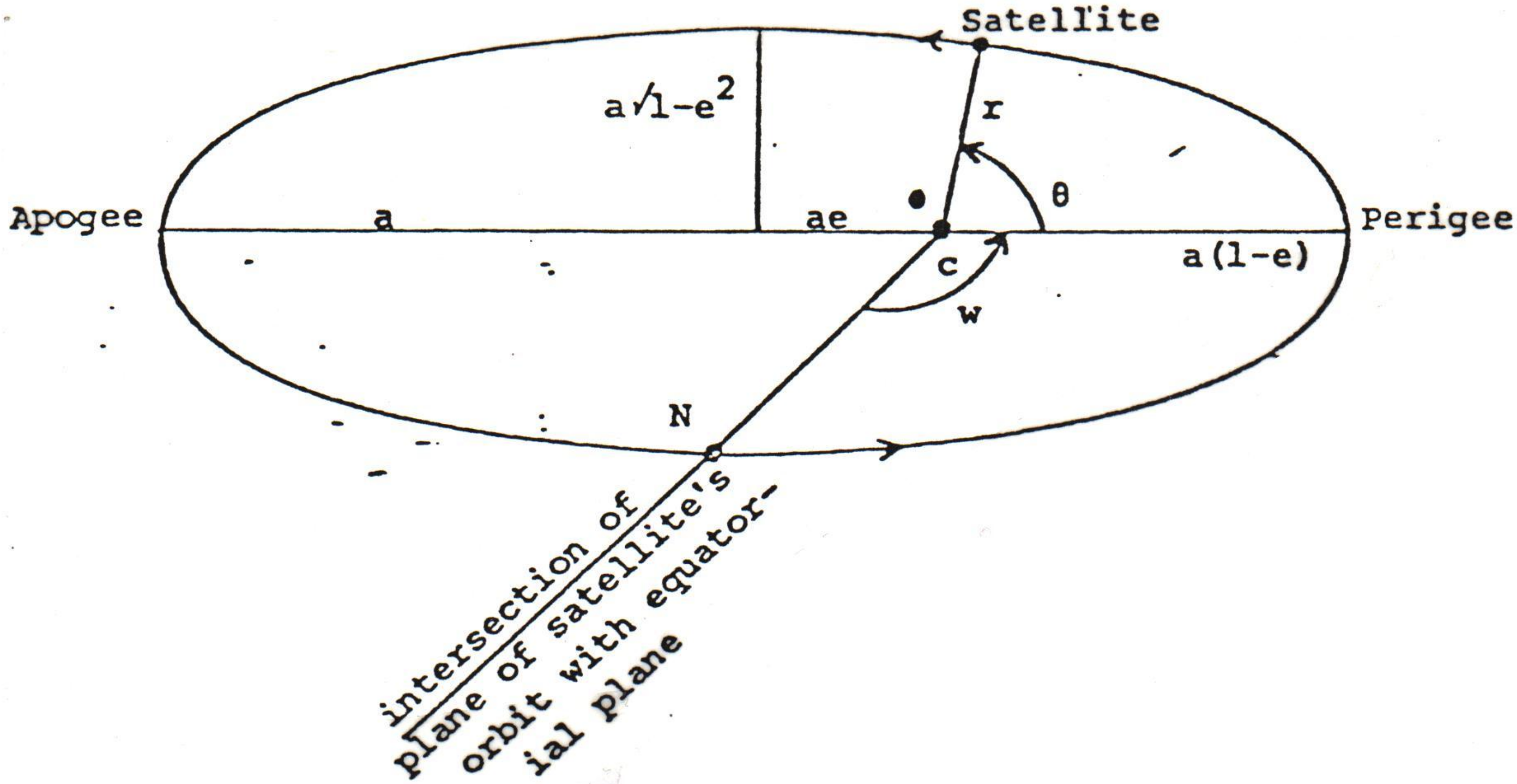
For the geostationary orbit, the period of the satellite matches the rotational period of the earth so that the satellite appears to stay in the same spot in the sky. This implies that τ = 24 hours = 8.64x10**4 seconds, and the associated radius of the orbit r = 4.24x10**7 meters or a height of about 36,000 km. The geostationary orbit is possible at only one orbit radius.

Leo Orbit

For a polar circular orbit with τ = 100 minutes = 6x10**4 seconds, we get r = 7.17x10**6 metres or a height of about 800 km. Polar orbits are not confined to a unique radius, however the type of global coverage usually suggests a range of orbit radii.



Orbital elements for an elliptical orbit showing the projection of the orbit on the surface of a spherical earth. C is the centre of the earth and R is the equatorial radius. i is the inclination of the orbit relative to the equatorial plane, Ω is the right ascension of the ascending node with respect to Aries, a is the semi-major axis of the ellipse, ε is the eccentricity, w is the argument of the perigee, and Θ is the angular position of the satellite in its orbit.



The orientation of the satellite orbit plane is described by (a) the inclination of the satellite orbit plane with respect to the earth equatorial plane denoted by I, and (b) the right ascension of the ascending node, Ω, measured eastwards relative to Aries (representing a fixed point in the heavens). The shape and size of the satellite orbit is given by (c) the semi-major axis of the ellipse denoted by a, and (d) the eccentricity of the ellipse, denoted by ε. The orientation of the orbit in the orbit plane is given by (e) the argument of the perigee or the angle between the ascending node and the perigee denoted by w. And finally (f) θ denotes the angular position of the satellite in its orbit. These are the six orbital elements that are necessary to calculate the trajectory of the satellite in its orbit

Effects of Non-spherical Earth

The earth's gravitational field is not that of a point mass, rather it is the integrated sum over the bulging earth. The potential energy for a satellite of mass m a distance r from the centre of mass of the earth is written

$$PE = - Gm \int_{earth} dM/s$$

where the integration is over the mass increment dM of the earth which is a distance s from the satellite. This integration yields a function in the form

$$PE = -GMm/r \left[1 - \sum_{n=2,...} J_n (R/r)^n P_n(\cos\theta)\right]$$

where the J_n are coefficients of the n^{th} zonal harmonics of the earths gravitational potential energy and the $P_n (\cos\theta)$ are Legendre polynomials defined by

$$P_n(x) = \frac{1}{n2^n} \frac{d^n}{dx^n} [(x^2-1)^n] .$$

The most significant departure from the spherically symmetric field comes from the n=2 term, which corrects for most of the effects of the equatorial bulge. Therefore

$$PE = -GMm/r [1 - J_2 (R/r)^2 (3\cos^2\theta - 1)/2 + ...]$$

where J_2 = 1082.64x10**-6. At the poles P_2 = 2 and at the equator P_2 = -1. The coefficients for the higher zonal harmonics are three orders of magnitude reduced from the coefficient of the second zonal harmonic.

Equatorial bulge primarily makes the angle of the ascending node vary with time.

Sun-synchronous Polar Orbit

The equatorial bulge primarily makes the angle of the ascending node vary with time. The variation is given by

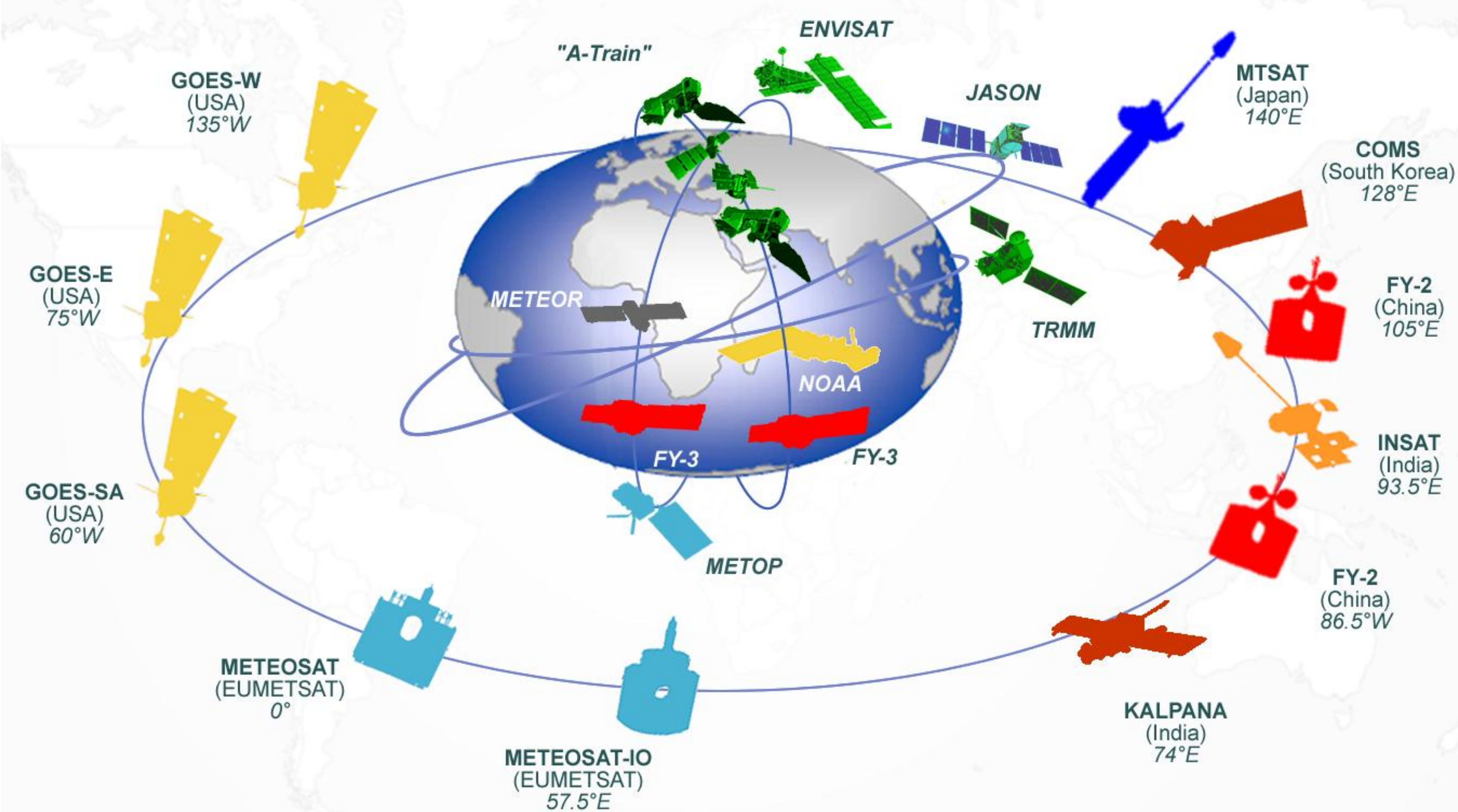
$$d\Omega/dt = -3/2\, J_2\, (GM)^{1/2}\, R^2\, a^{-7/2}\, (1-\varepsilon^2)^{-2} \cos i$$

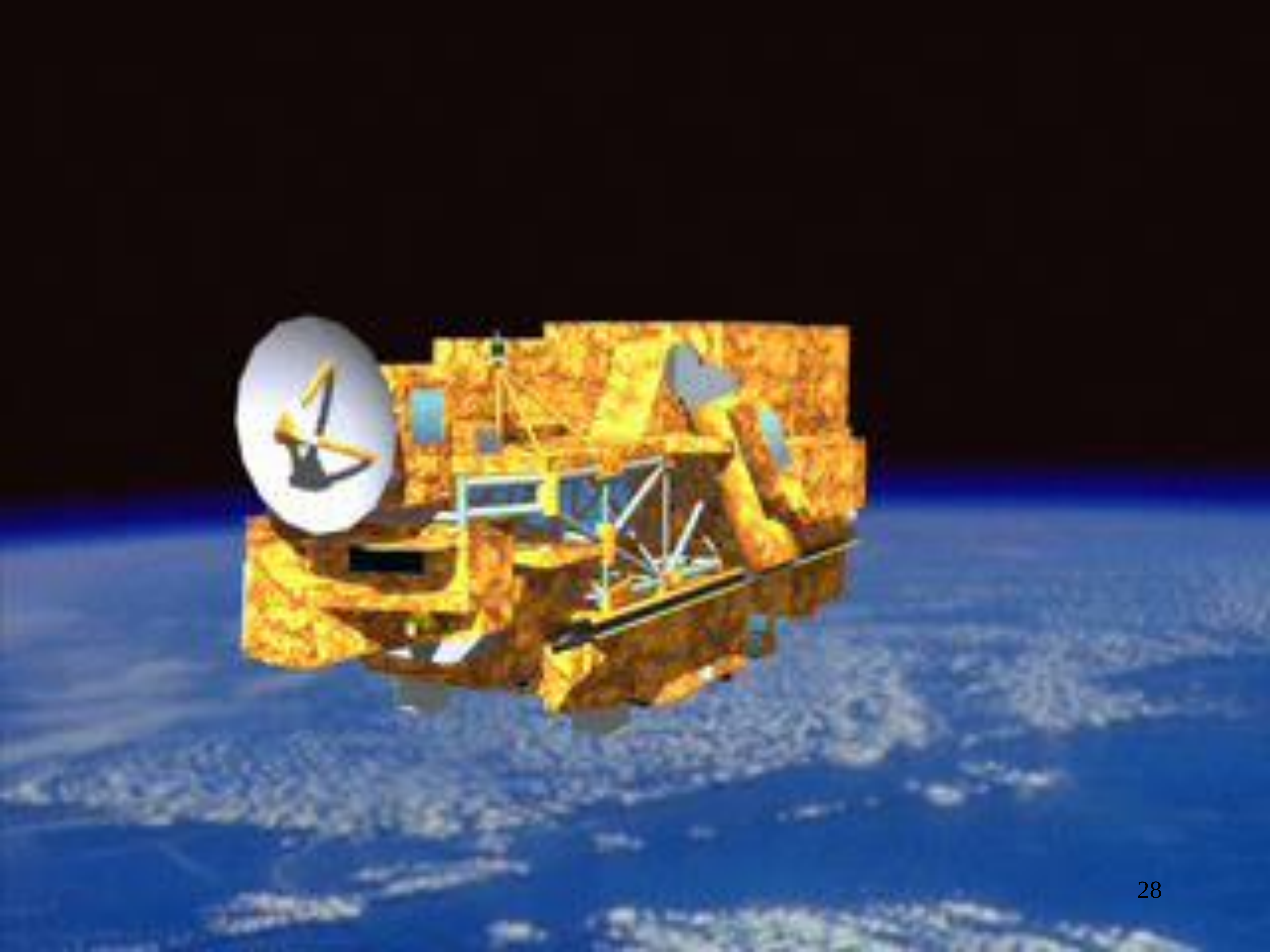
Through suitable selection of the orbital inclination i, the rotation of the orbital plane can be made to match the rotation of the earth around the sun, yielding an orbit that is sun synchronous. The negative sign indicates a retrograde orbit, one with the satellite moving opposite to the direction of the earths rotation. The rotation rate for sun synchronous orbit is given by

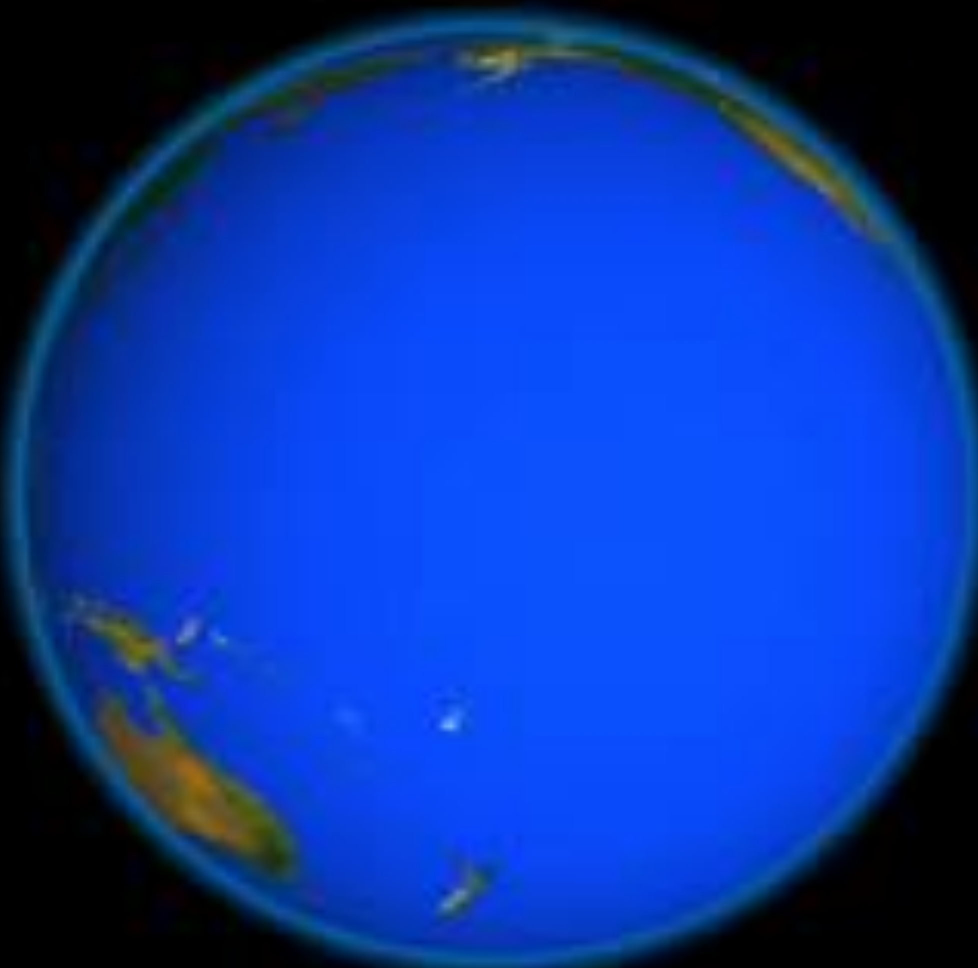
$$\Omega = 2\pi/365.24 \text{ radians/year} = 2 \times 10^{-7} \text{ rad/sec} .$$

which is approximately one degree per day. Such a rate is obtained by placing the satellite into an orbit with a suitable inclination; for a satellite at a height of 800 km (assuming the orbit is roughly circular so that $a = r$), we find $i = 98.5$ degrees which is a retrograde orbit inclined at 81.5 degrees. The inclination for sun synchronous orbits is only a weak function of satellite height; the high inclination allows the satellite to view almost the entire surface of the earth from pole to pole.

Space-based Global Observing System 2012



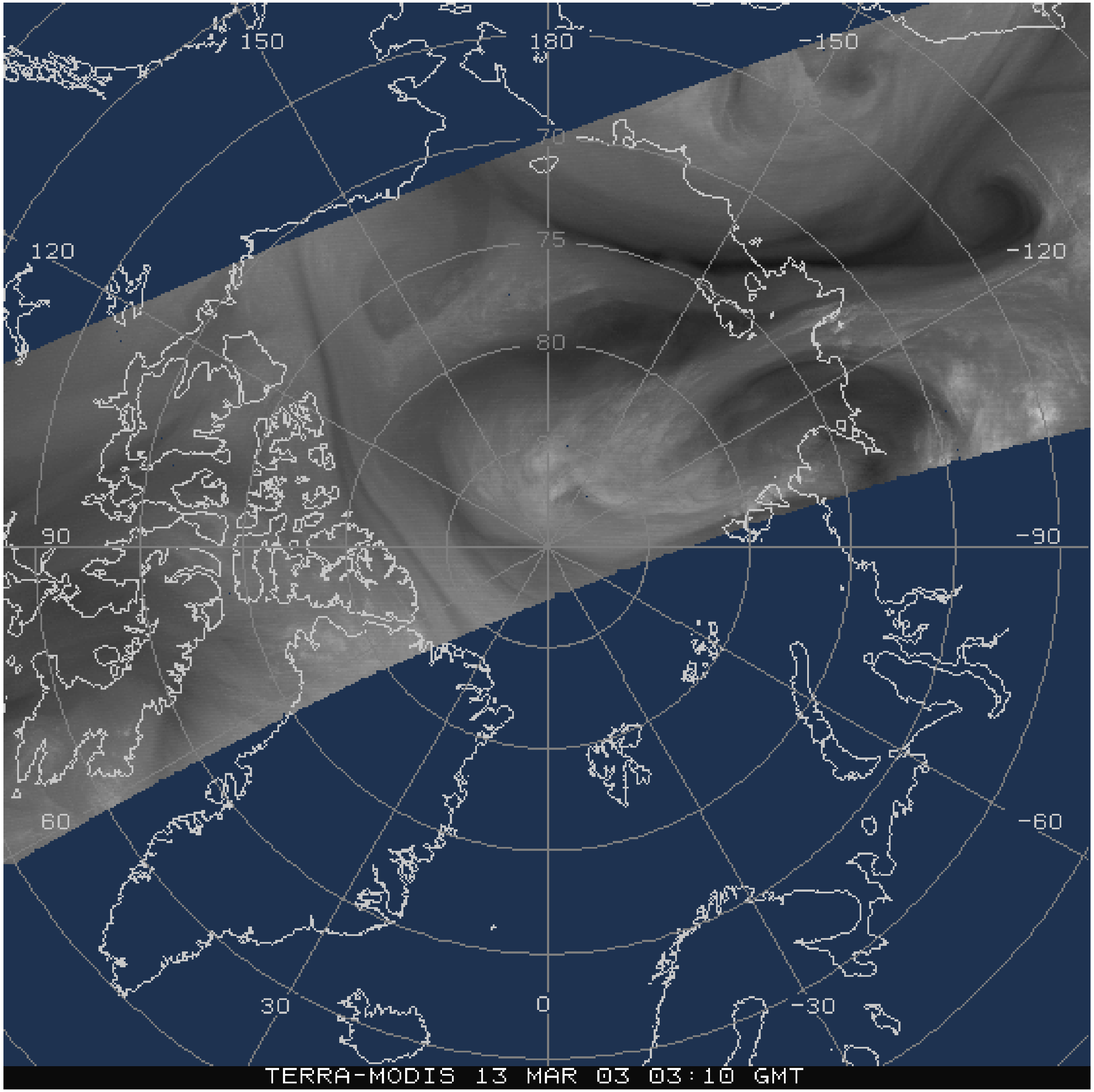




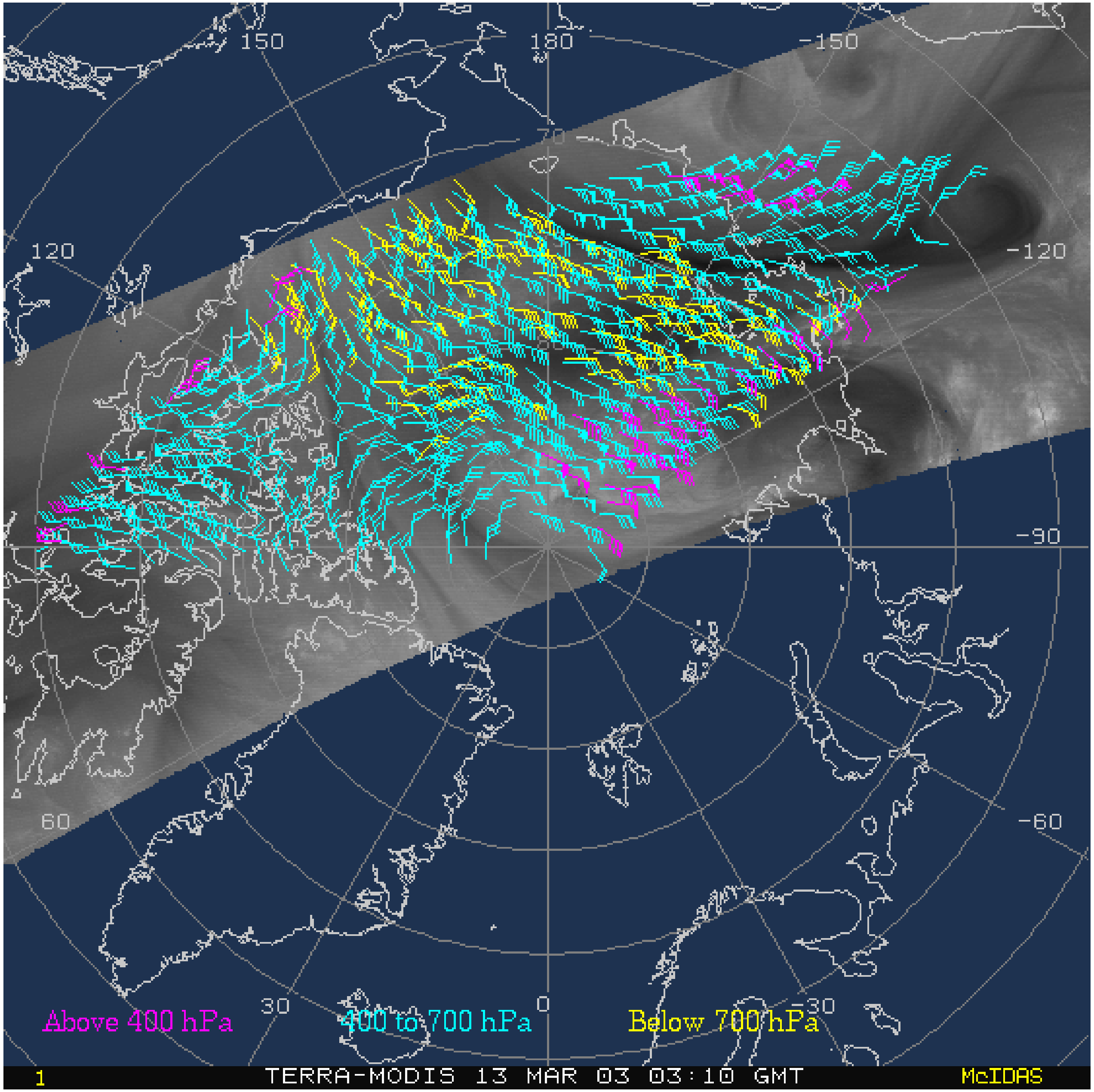
[redacted]

[redacted]

Leo coverage of poles every 100 minutes

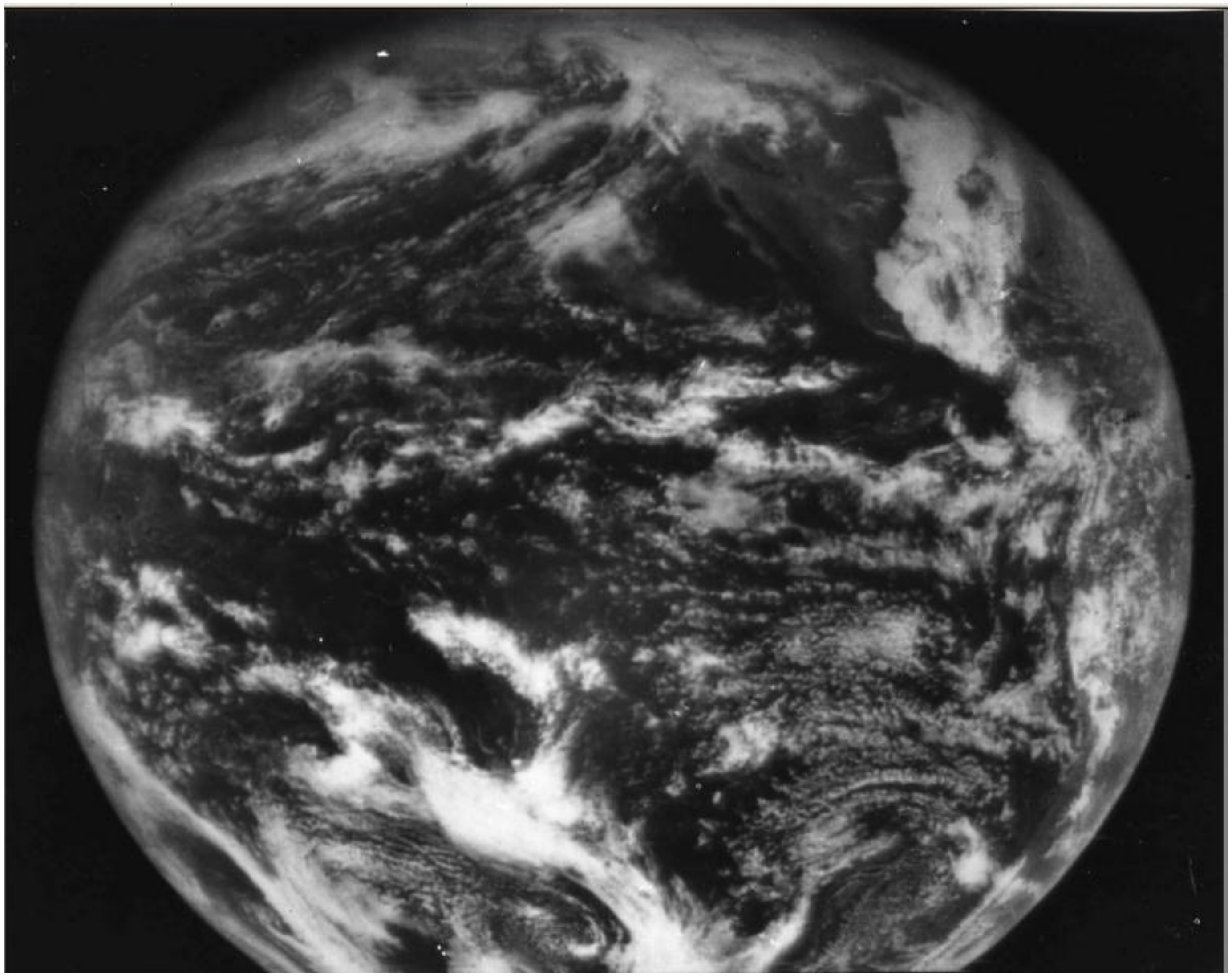


Tracking Polar Atmospheric Motion from Leo Obs



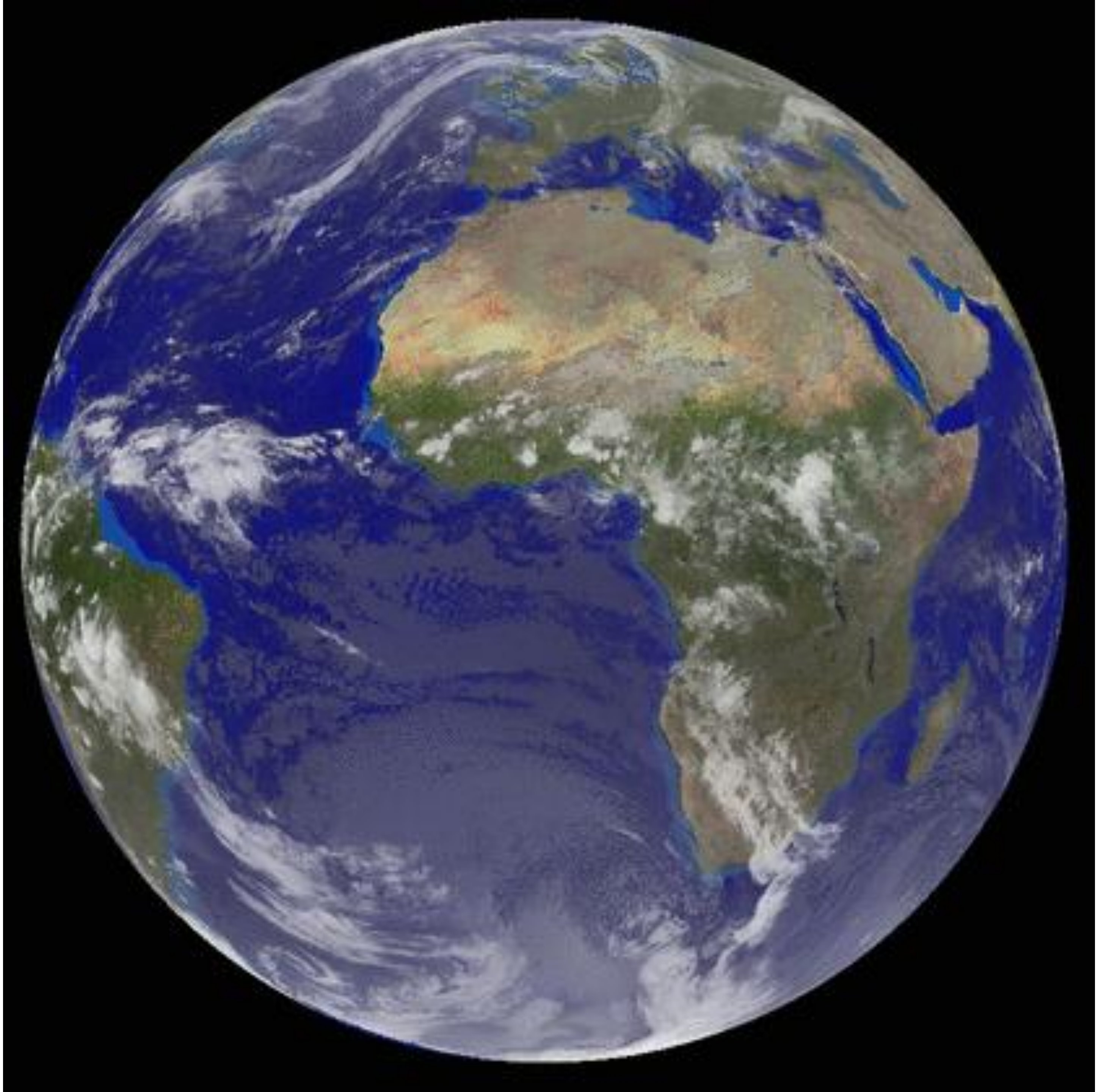
Getting to Geostationary Orbit

Observations from geostationary orbit

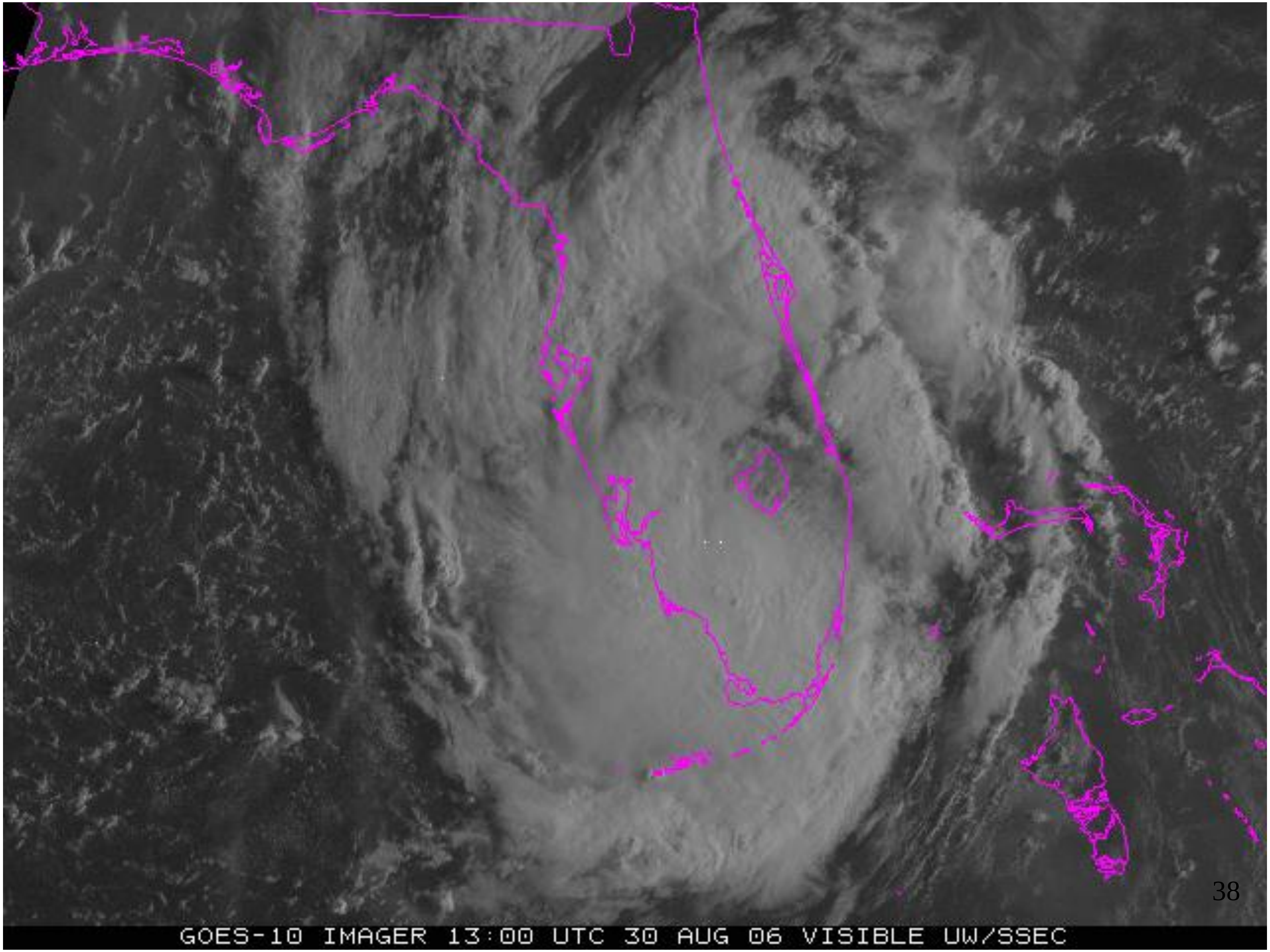


"the weather moves - not the satellite"
Verner Suomi

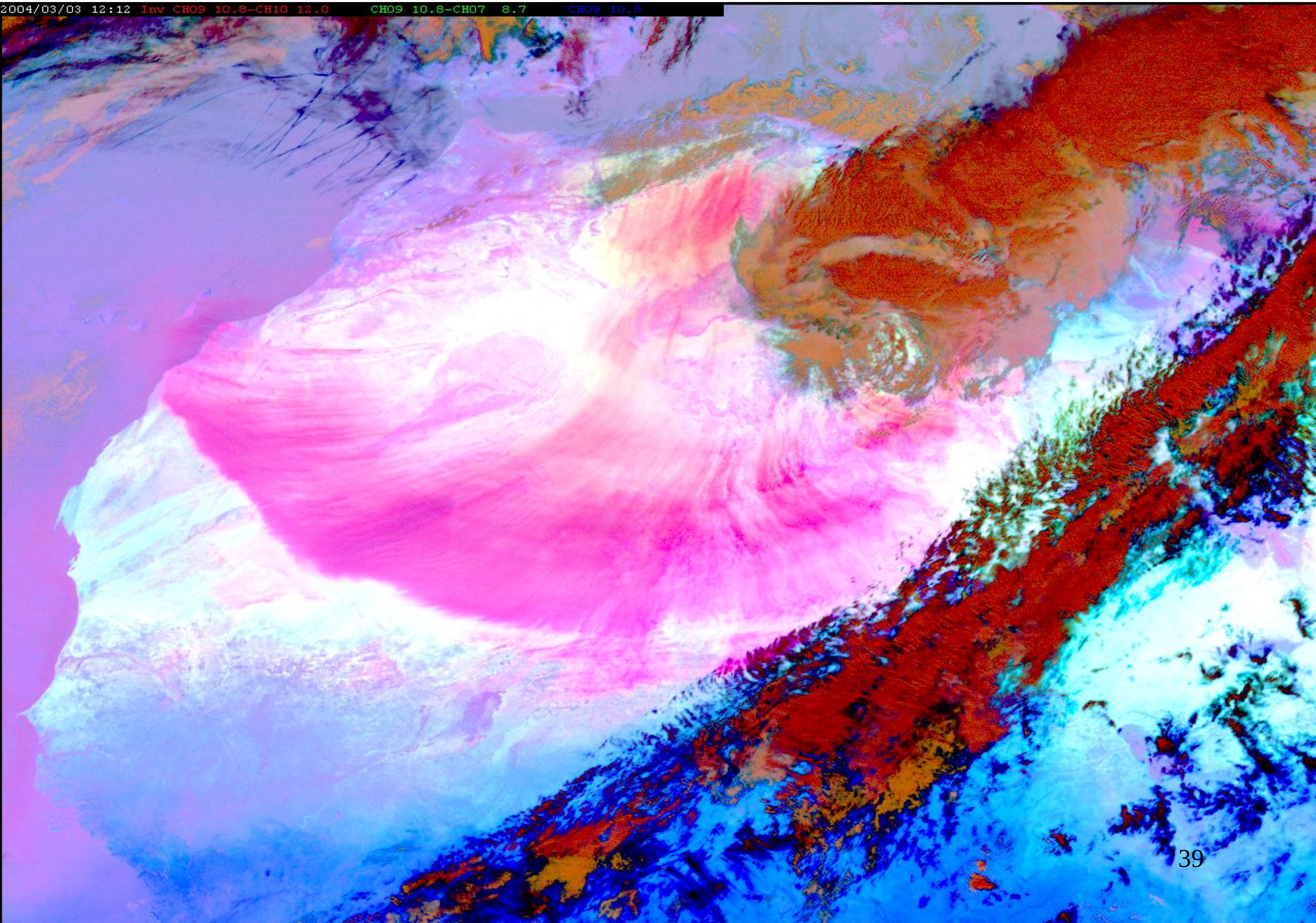
[redacted]



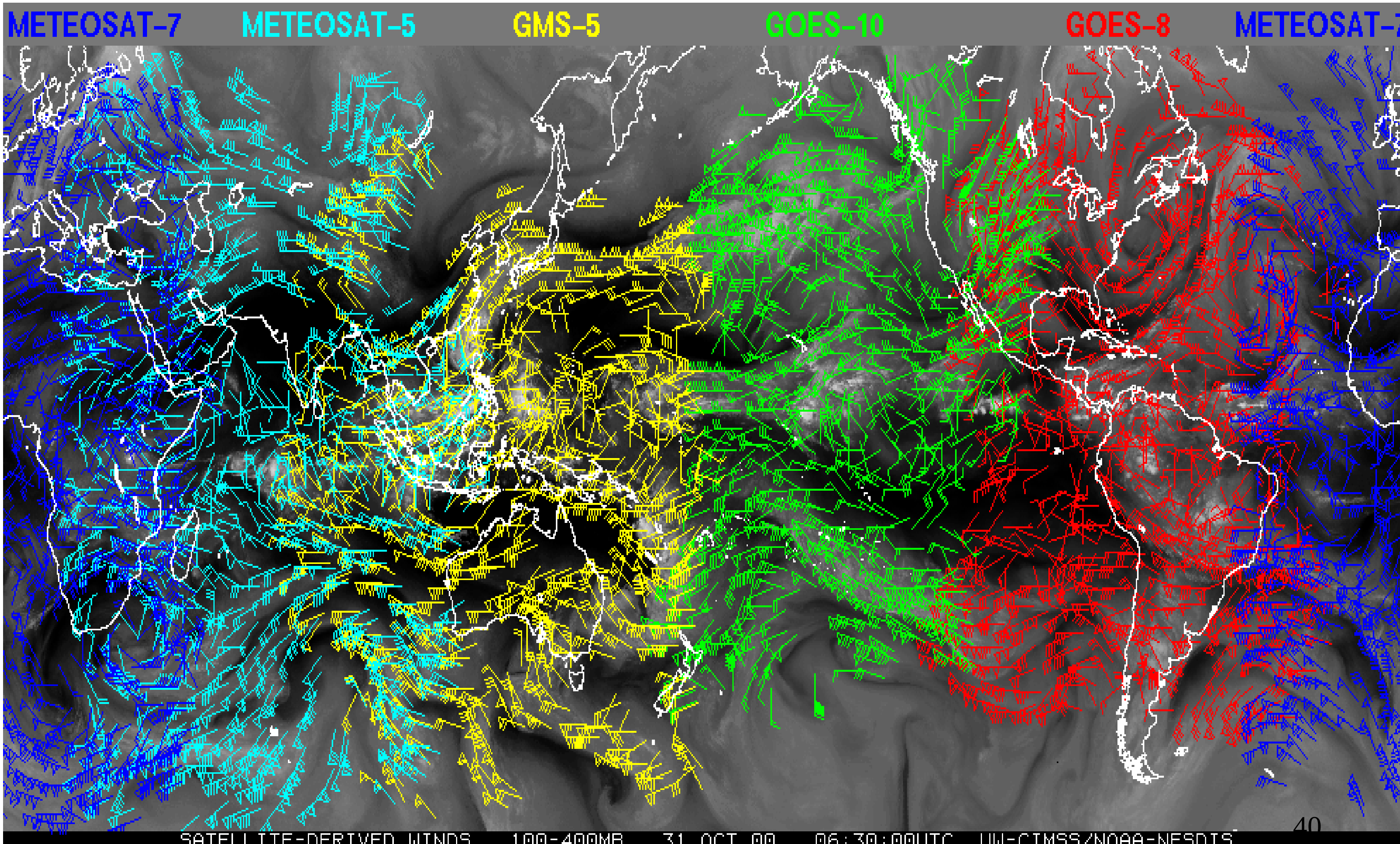
One minute imaging over Florida



SEVIRI sees dust storm over Africa



Five geos are providing global coverage for winds in tropics and mid-lats



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 ($\Delta t \leq 15$ minutes)	repeat coverage twice daily ($\Delta t = 12$ hours)
near full earth disk	global coverage
best viewing of tropics & mid-latitudes	best viewing of poles
same viewing angle	varying viewing angle
differing solar illumination	same solar illumination
visible, NIR, IR imager (1, 4 km resolution)	visible, NIR, IR imager (1, 1 km resolution)
IR only sounder (8 km resolution)	IR and microwave sounder (1, 17, 50 km resolution)
filter radiometer	filter radiometer, interferometer, and grating spectrometer
diffraction more than leo	diffraction less than geo

Leo Observations

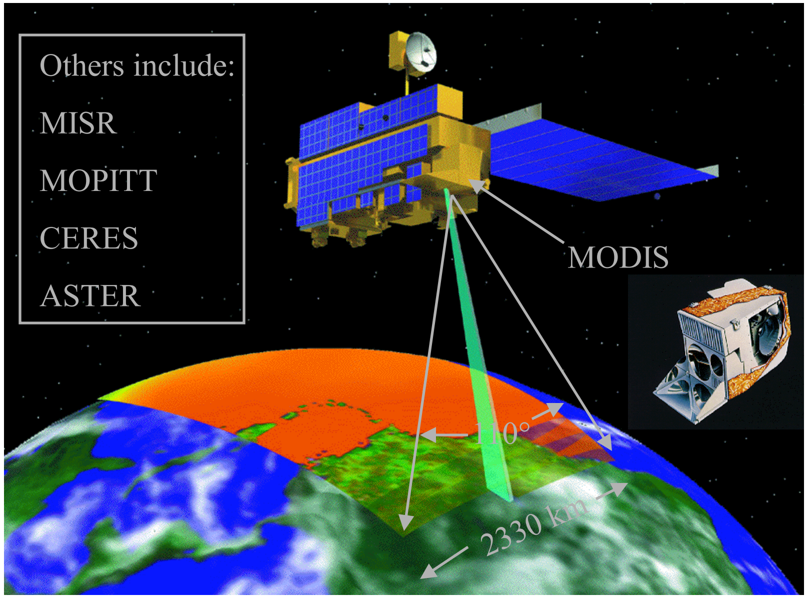
**Terra was launched in 1999
and the EOS Era began**

**MODIS, CERES, MOPITT,
ASTER, and MISR
reach polar orbit**

**Aqua and ENVISAT
followed in 2002**

**MODIS and MERIS
to be followed by VIIRS
AIRS and IASI
to be followed by CrIS
AMSU leading to ATMS**

Launch of EOS-Terra (EOS-AM) Satellite - A New Era Begins



MODIS instrument Specifications:

Bands 1-2 (0.66,0.86 μm): 250 m

Bands 3-7 (0.47, 0.55, 1.24, 1.64, 2.13 μm): 500 m

Bands 8-36: 1 km

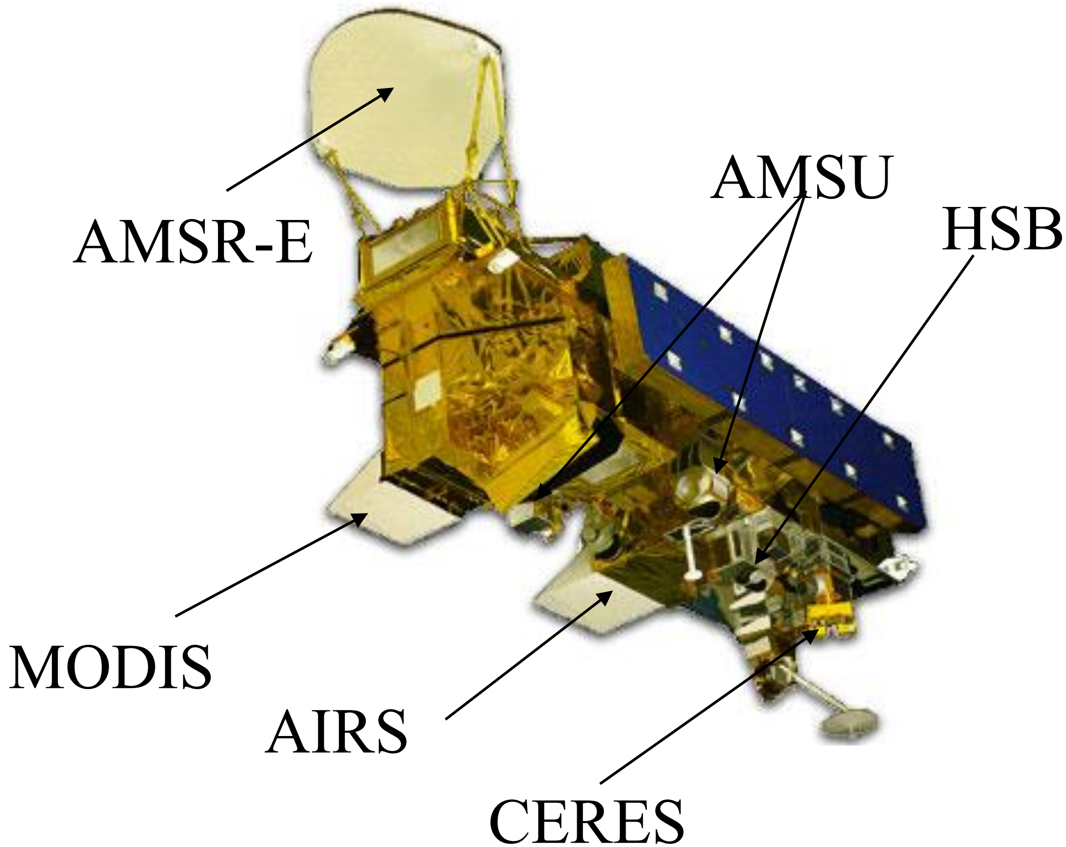
Launch date: December 18, 1999, 1:57 PT

Earth viewdoor open date: February 24, 2001

Allen Chu/NASA GSFC

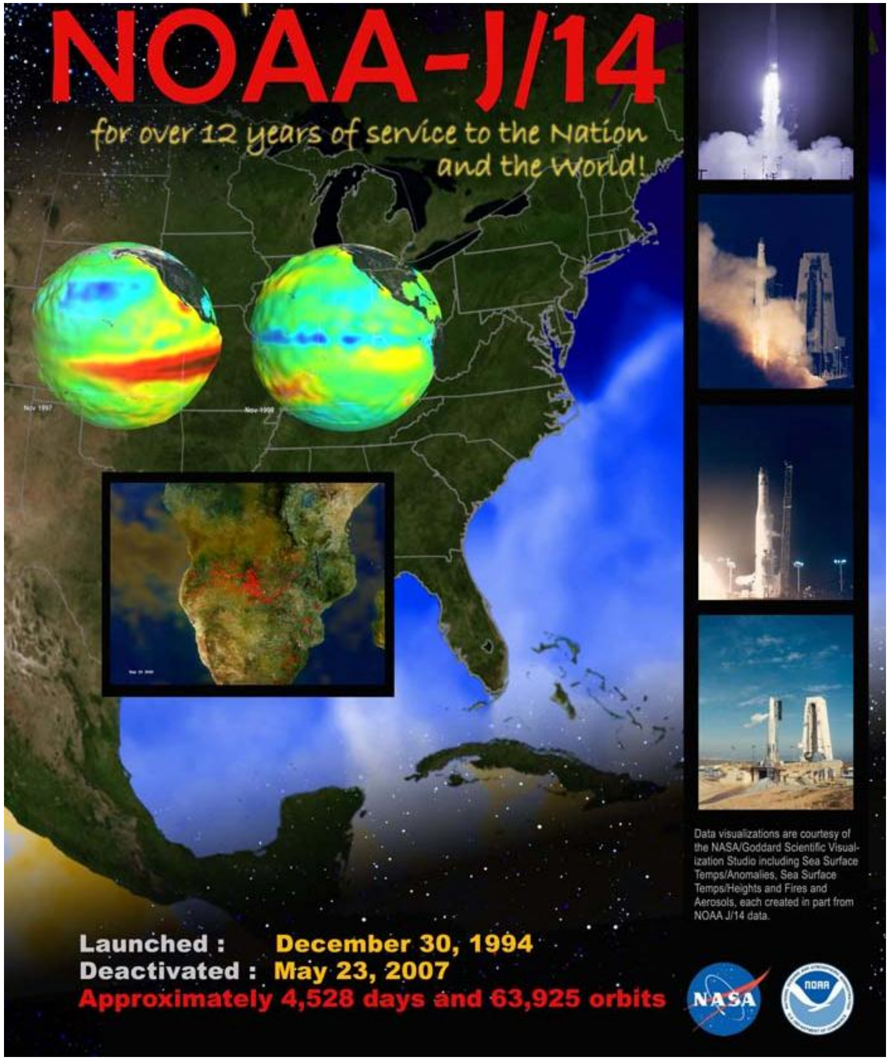
Followed by the launch of EOS-Aqua (EOS-PM) Satellite

"Thermometer in the Sky"



Launch date: May 4, 2002, 2:55 PDT
Earth view door open date: June 25, 2002

Joint Polar System

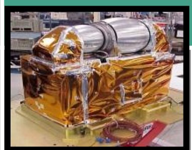
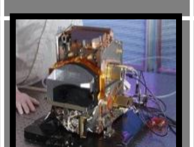


Suomi National Polar-orbiting Partnership (NPP)

launched 28 Oct 2011

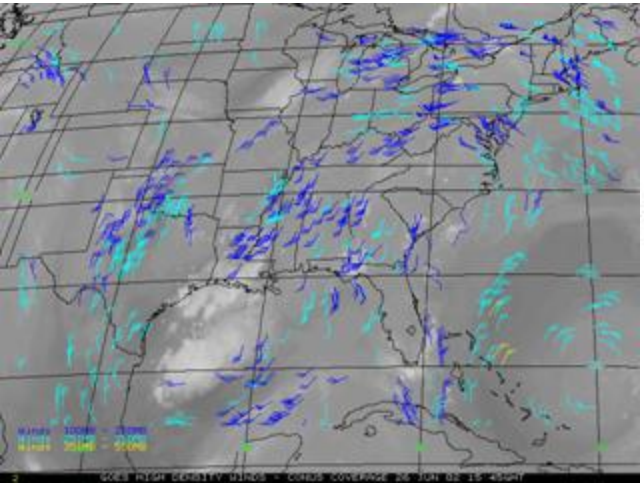
NPP was re-named Suomi NPP on 24 Jan 2012

SNPP/JPSS Instruments

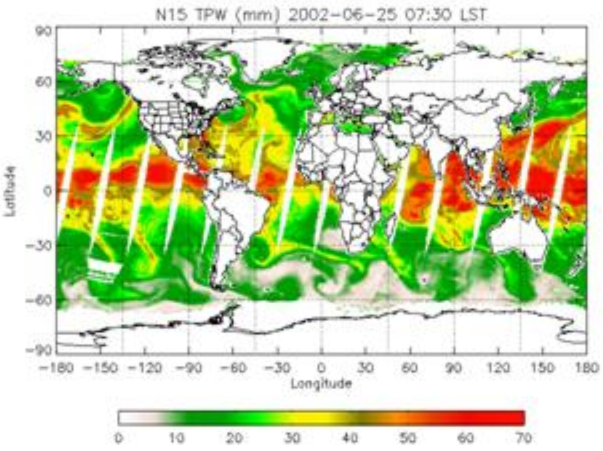
JPSS Instrument	Measurement	NOAA Heritage	NASA Heritage
 ATMS	ATMS and CrIS together provide profiles of high vertical resolution atmospheric temperature and water vapor information	AMSU	AMSU
 CrIS		HIRS	AIRS
 VIIRS	Provides daily high-resolution imagery and radiometry across the visible to long-wave infrared spectrum for a multitude of environmental assessments	AVHRR	MODIS
 OMPS	Spectrometers with UV bands for ozone total column measurements	SBUV-2	OMI
 CERES	Scanning radiometer which supports studies of Earth Radiation Budget		CERES

Atmospheric Products: Examples

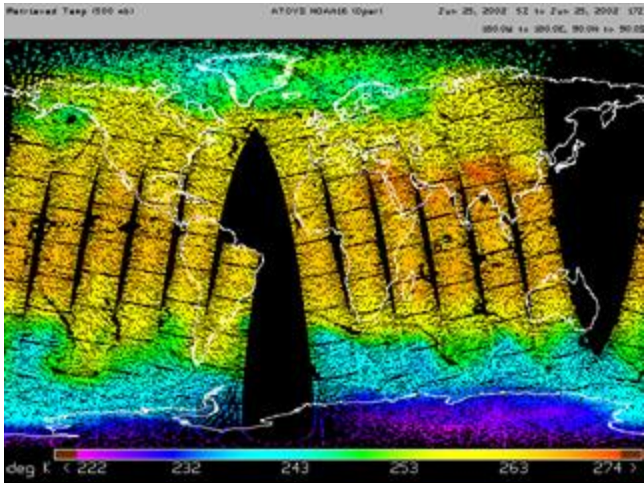
Winds



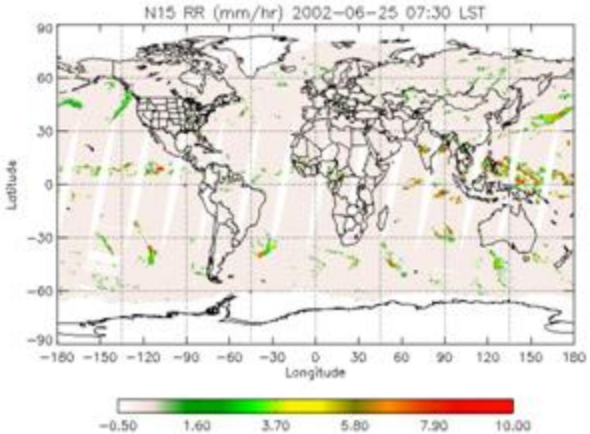
Total Water Vapor



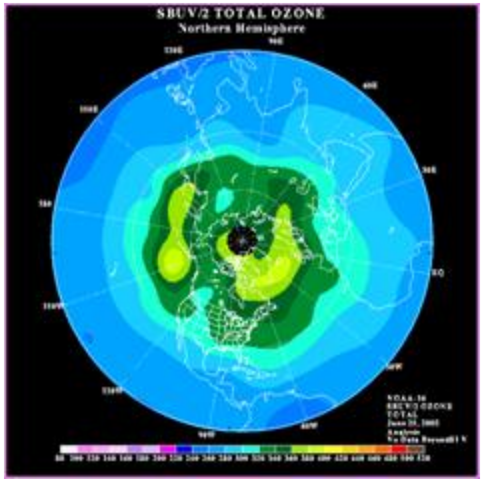
Temperature 500 mb



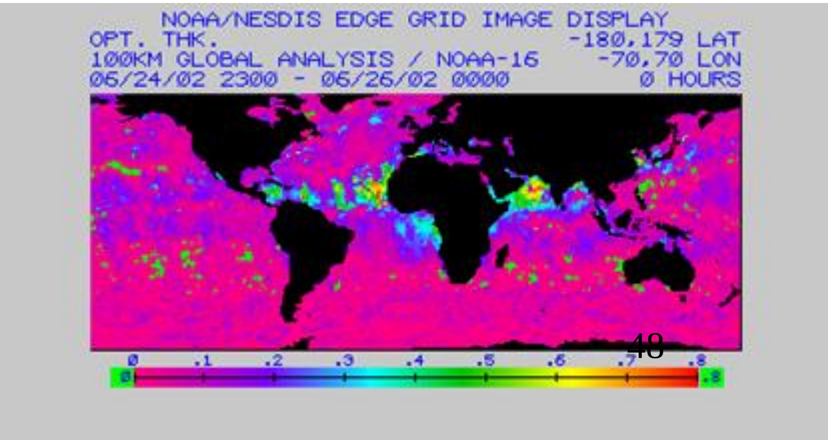
Rain Rate



Ozone

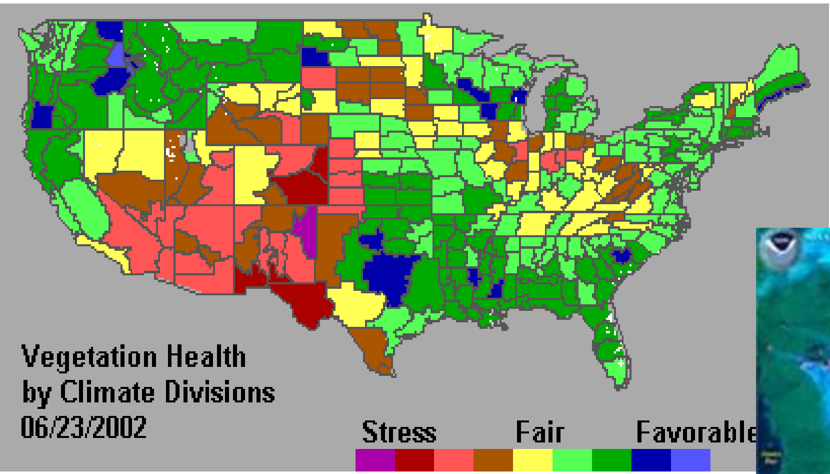


Aerosol Optical Thickness

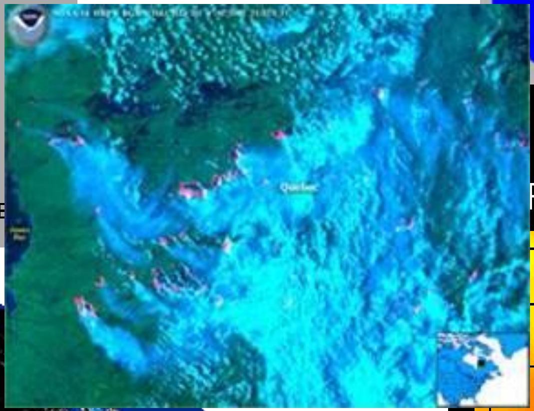


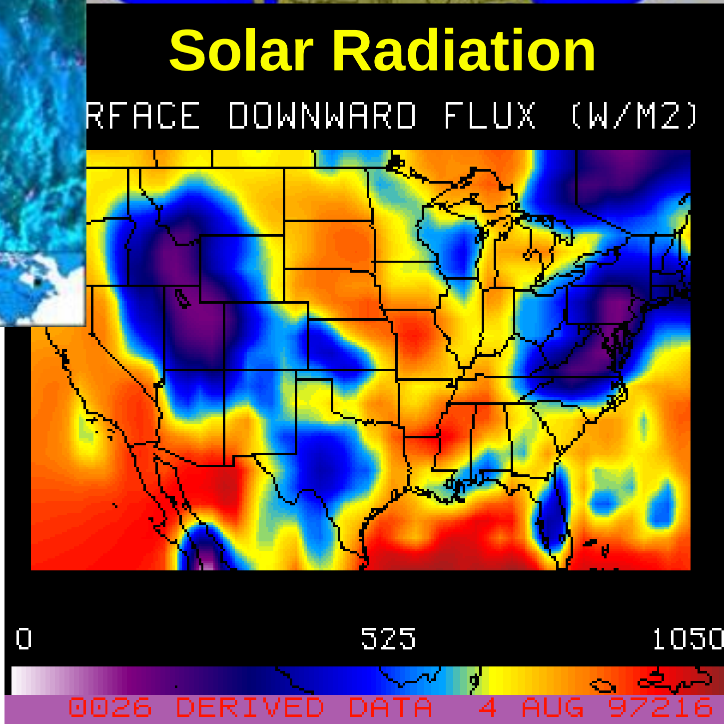
Land Surface Products: Examples

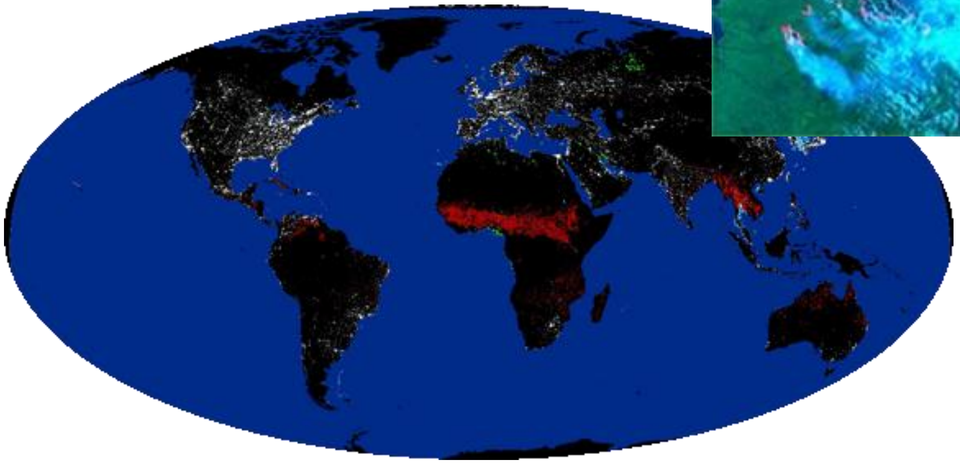
Vegetation Health



Quebec Fires/Smoke



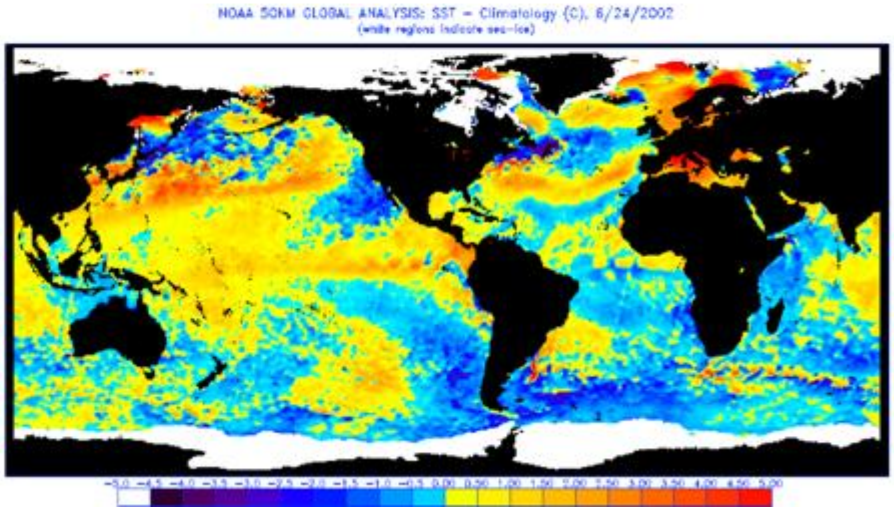




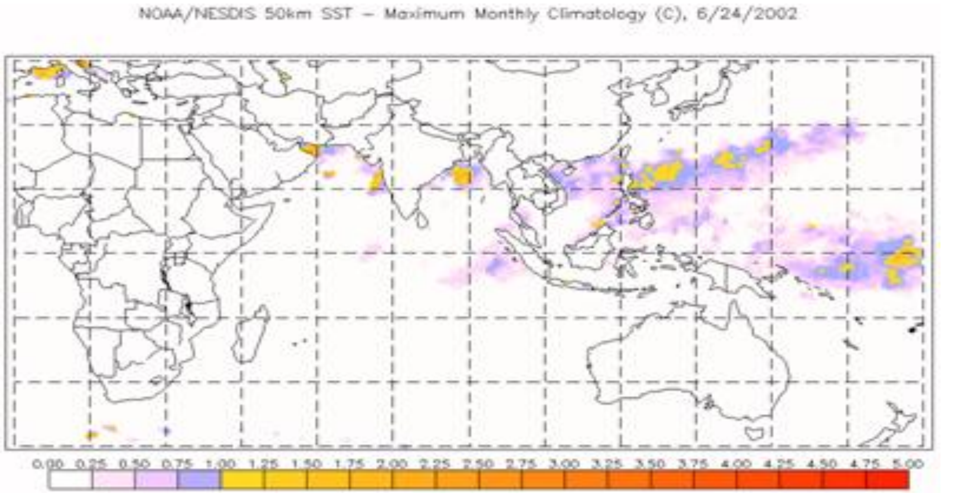
Global Lights/Fires

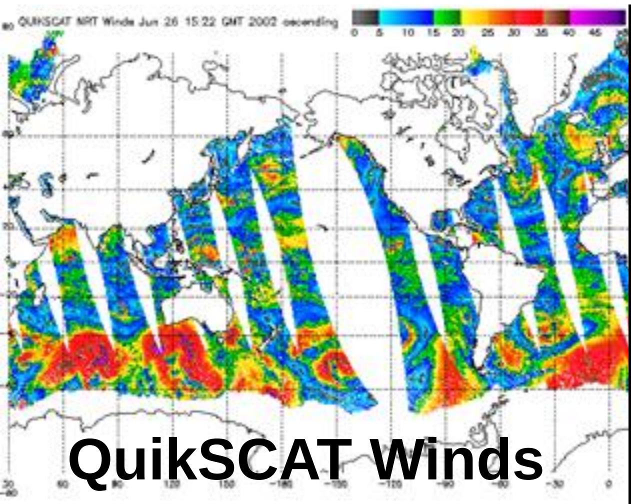
Ocean Products: Examples

SST Anomalies

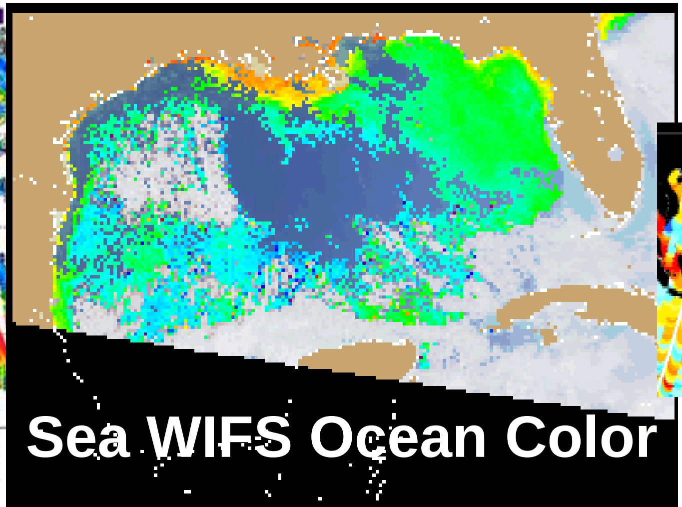


Hot Spots: Potential Coral Bleaching



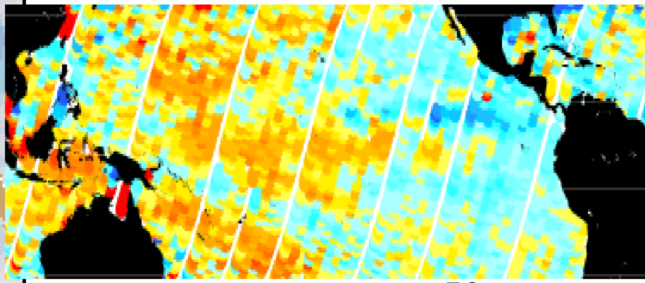


QuikSCAT Winds



Sea WIFS Ocean Color

TOPEX Sea Level



Remote Sensing Advantages

* provides a regional view

* enables one to observe & measure the causes & effects of climate & environmental changes (both natural & human-induced)

* provides repetitive geo-referenced looks at the same area

* covers a broader portion of the spectrum than the human eye

* can focus in on a very specific bandwidth in an image

* can also look at a number of bandwidths simultaneously

* operates in all seasons, at night, and in bad weather

Intro to VIS-IR Radiation

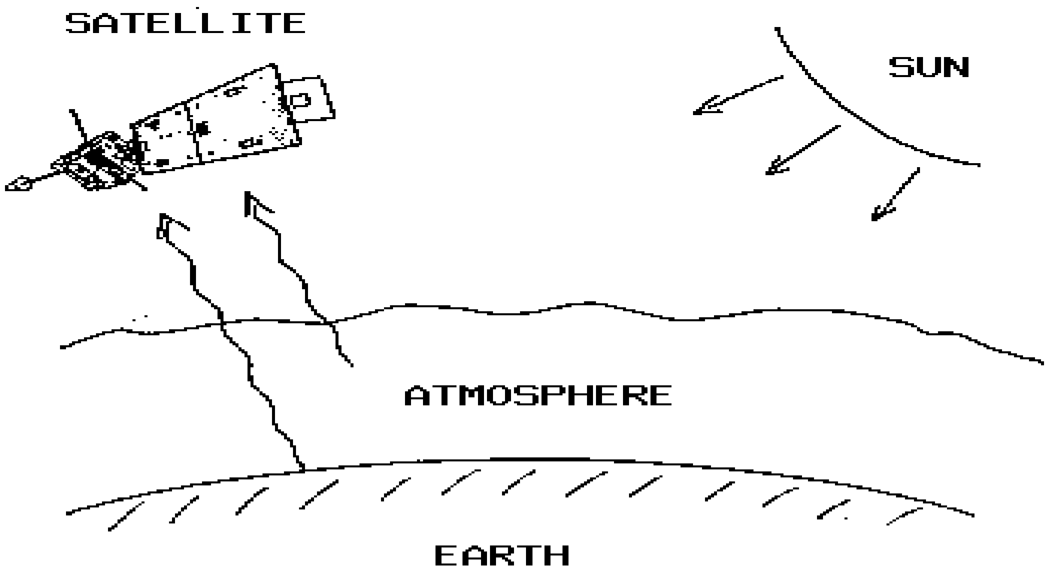
Lectures in Madison

25 March 2013

Paul Menzel
UW/CIMSS/AOS

Relevant Material in Applications of Meteorological Satellites

Satellite remote sensing of the Earth-atmosphere

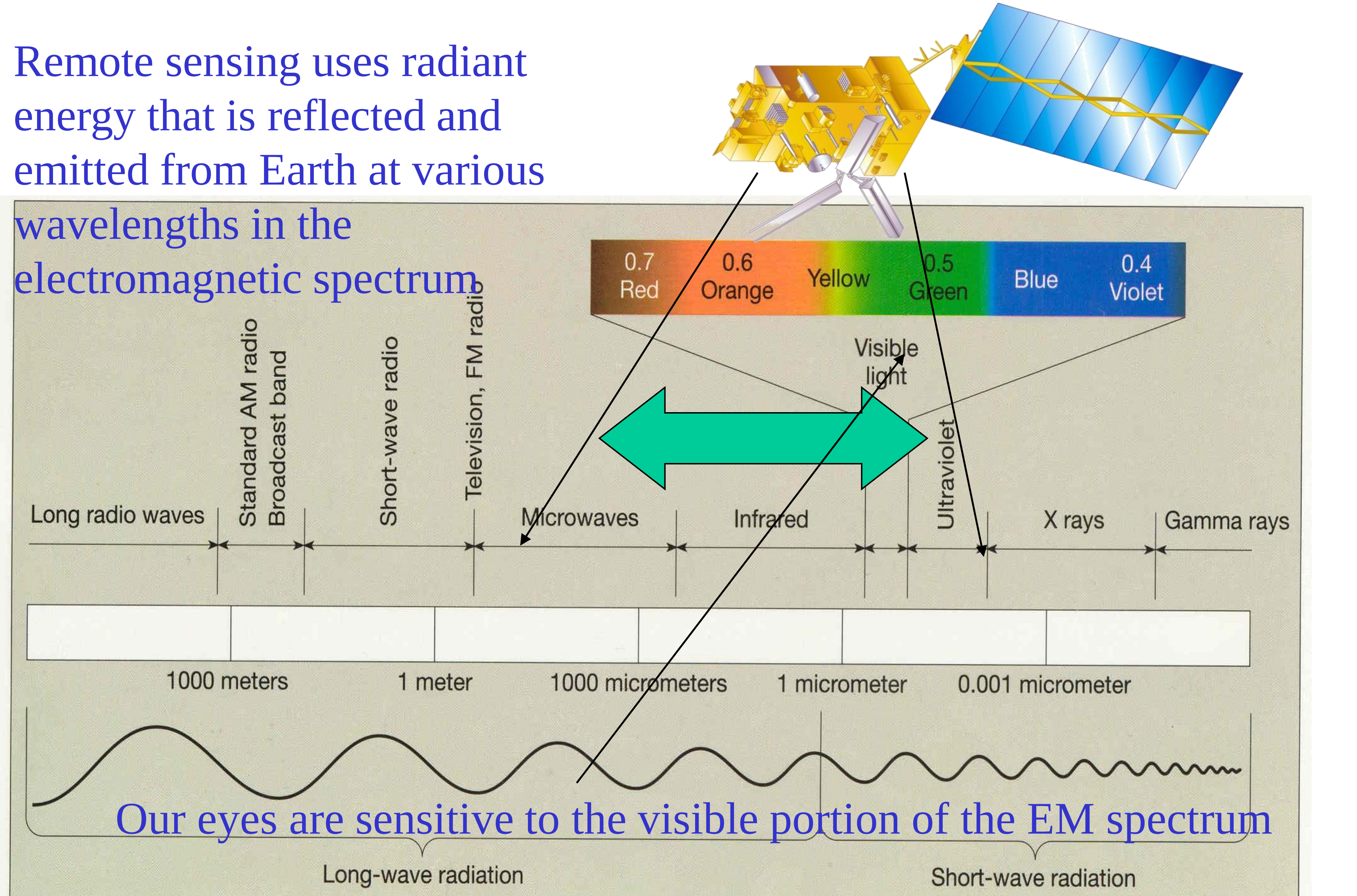


Observations depend on

telescope characteristics (resolving power, diffraction)
detector characteristics (field of view, 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)

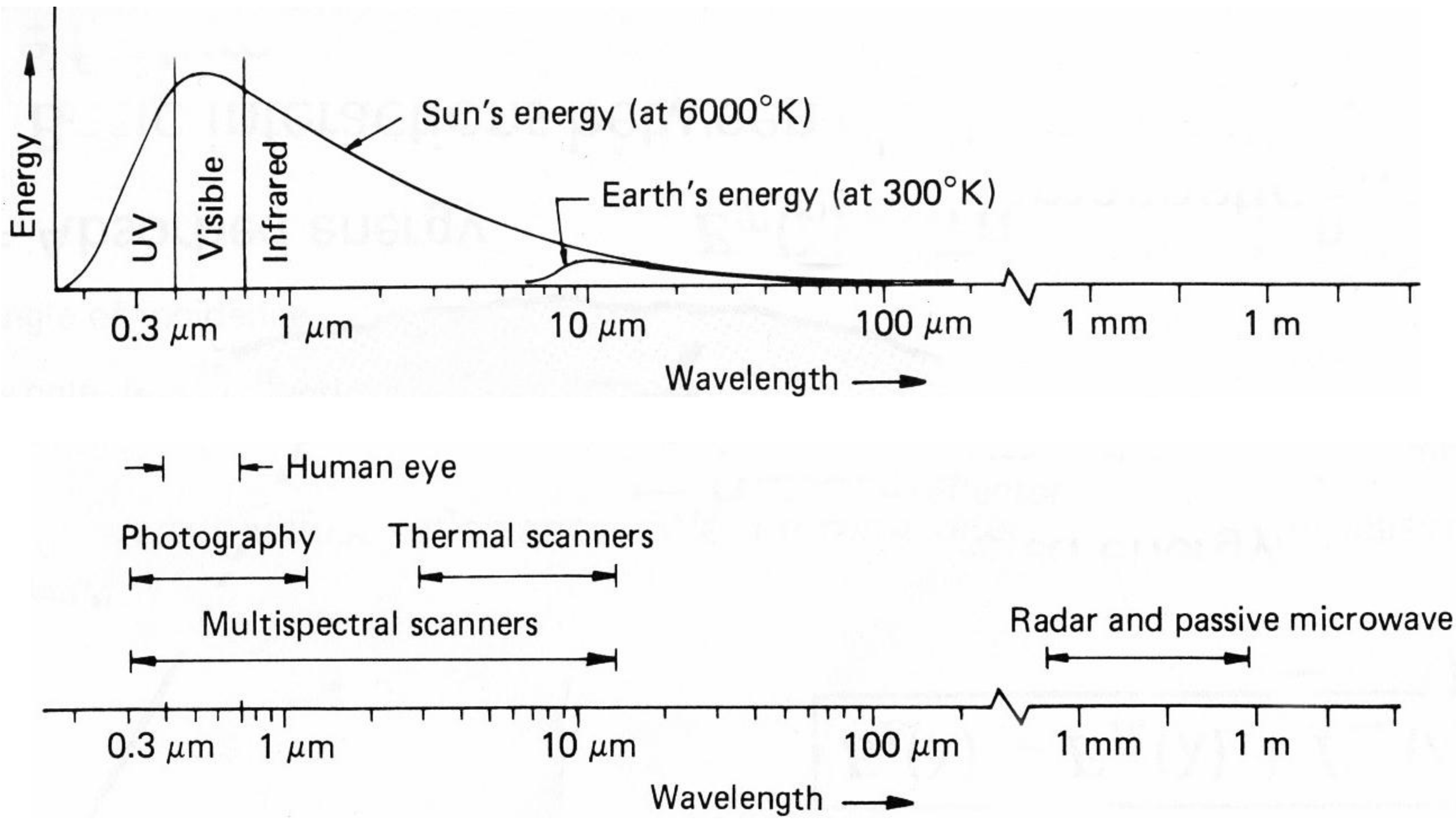
Electromagnetic spectrum

Remote sensing uses radiant energy that is reflected and emitted from Earth at various wavelengths in the electromagnetic spectrum



Our eyes are sensitive to the visible portion of the EM spectrum

Spectral Characteristics of Energy Sources and Sensing Systems



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 wavelengths

Planck's Law

$$B(\lambda,T) = c_1 / \lambda^5 / [e^{c_2/\lambda T} - 1] \quad (\mathrm{mW/m^2/ster/cm})$$

where λ = wavelengths in cm

T = temperature of emitting surface (deg K)

c_1 = 1.191044 x 10-5 ($\mathrm{mW/m^2/ster/cm^{-4}}$)

c_2 = 1.438769 (cm deg K)

Wien's Law $dB(\lambda_{max},T) / d\lambda = 0$ where $\lambda(\max) = .2897/T$

indicates peak of Planck function curve shifts to shorter wavelengths (greater wavenumbers) with temperature increase. Note $B(\lambda_{max},T) \sim T^5$.

Stefan-Boltzmann Law

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

where σ = 5.67 x 10-8 W/m2/deg4.

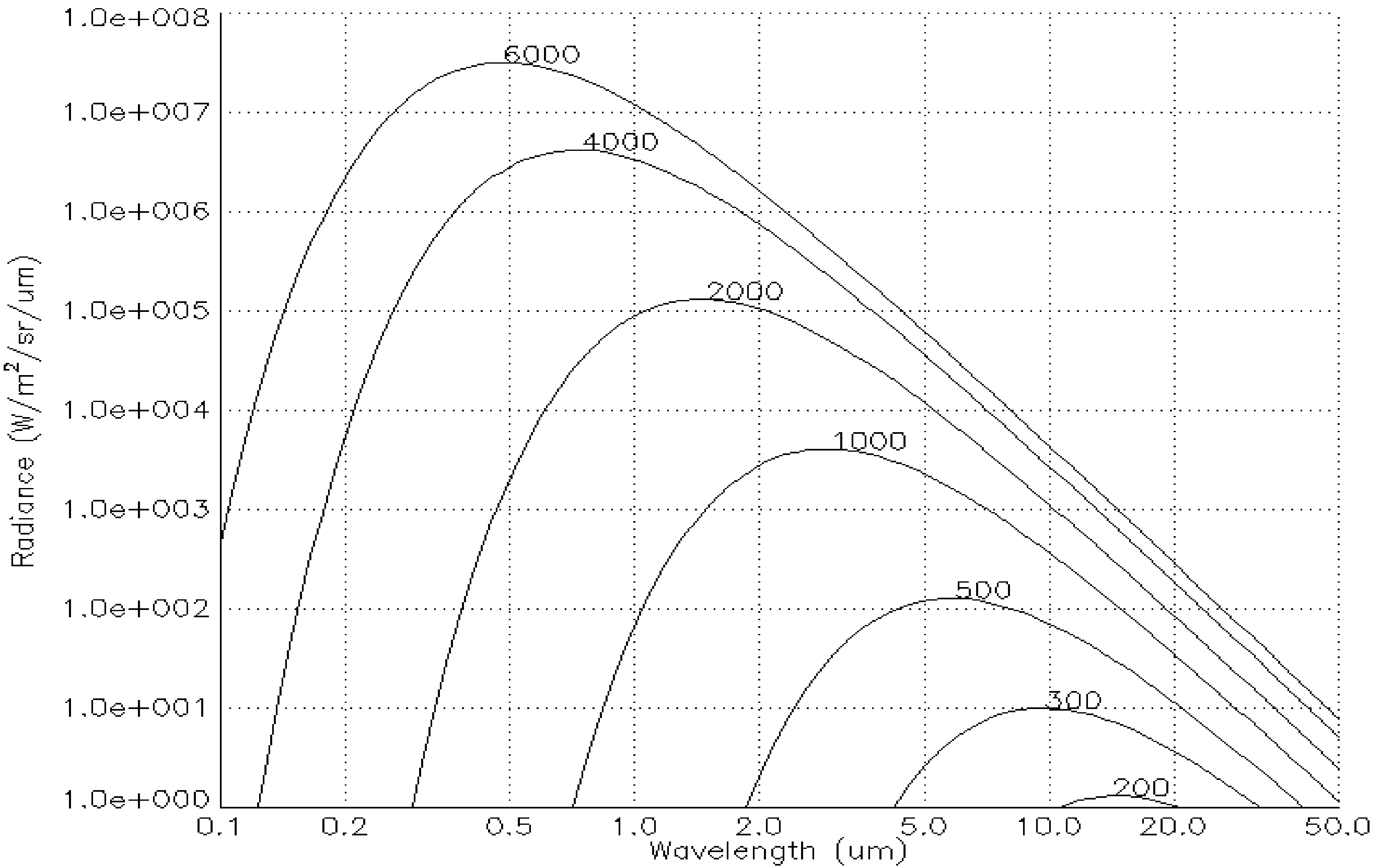
states that irradiance of a black body (area under Planck curve) is proportional to T^4 .

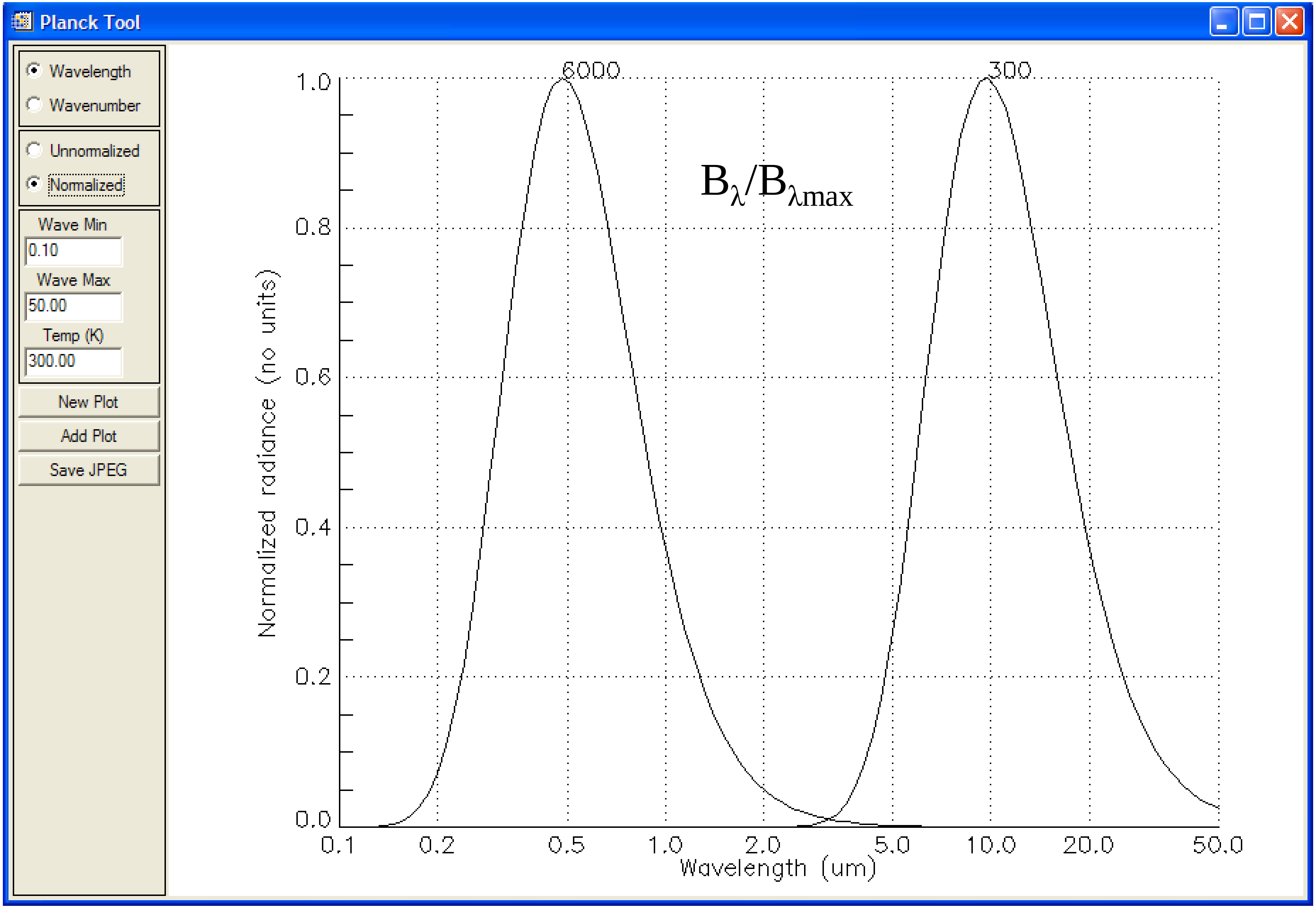
Brightness Temperature

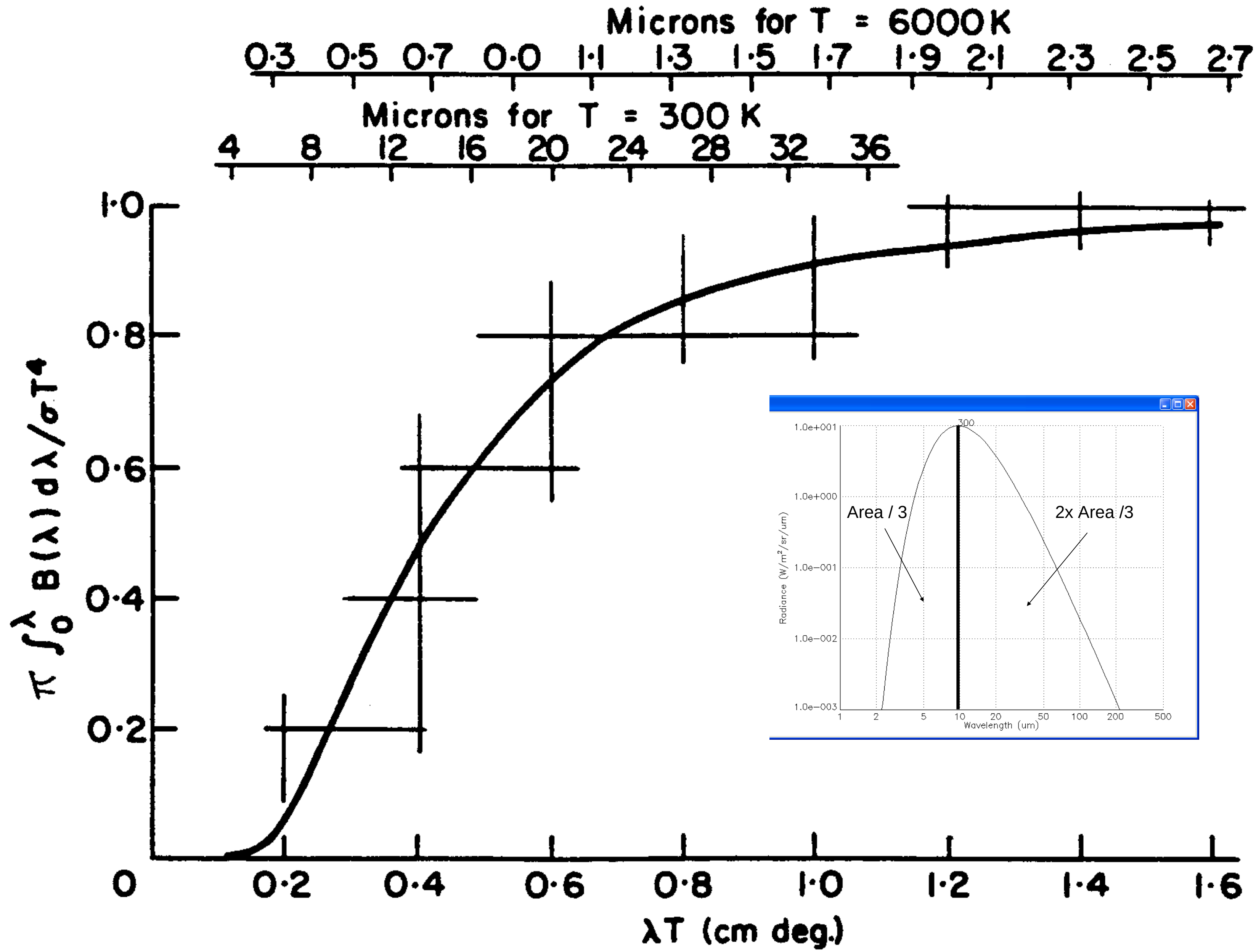
$$T = c_2 / [\lambda \ln(\frac{c_1}{\lambda^5 B_\lambda} + 1)]$$

is determined by inverting Planck function

Spectral Distribution of Energy Radiated from Blackbodies at Various Temperatures




Planck Tool
Wavelength
Wavenumber
Unnormalized
Normalized
Wave Min
0.10
Wave Max
50.00
Temp (K)
300.00
New Plot
Add Plot
Save JPEG
6000
300
$B_\lambda/B_{\lambda max}$
1.0
0.8
0.6
0.4
0.2
0.0
Normalized radiance (no units)
0.1
0.2
0.5
1.0
2.0
5.0
10.0
20.0
50.0
Wavelength (um)


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
$\pi \int_0^\lambda B(\lambda)\, d\lambda / \sigma T^4$
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.)
Area / 3
2x Area /3
300
1.0e+001
1.0e+000
1.0e−001
1.0e−002
1.0e−003
Radiance (W/m^2/sr/um)
1 2 5 10 20 50 100 200 500
Wavelength (um)

Using wavenumbers

Planck's Law $B(\nu,T) = c_1\nu^3 / [e^{c_2\nu/T} - 1]$ (mW/m^2/ster/cm^{-1})

where ν = # wavelengths in one centimeter (cm-1)

T = temperature of emitting surface (deg K)

c_1 = 1.191044 x 10-5 (mW/m^2/ster/cm^{-4})

c_2 = 1.438769 (cm deg K)

Wien's Law $dB(\nu_{max},T) / d\nu = 0$ where νmax) = 1.95T

indicates peak of Planck function curve shifts to shorter wavelengths (greater wavenumbers) with temperature increase.

Stefan-Boltzmann Law $E = \pi \int_o^\infty B(\nu,T)\, d\nu = \sigma T^4$, where σ = 5.67 x 10-8 W/m2/deg4.

states that irradiance of a black body (area under Planck curve) is proportional to T^4 .

Brightness Temperature

$$T = c_2\nu/[\ln(\frac{c_1\nu^3}{B_\nu} + 1)]$$ is determined by inverting Planck function

Using wavenumbers

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

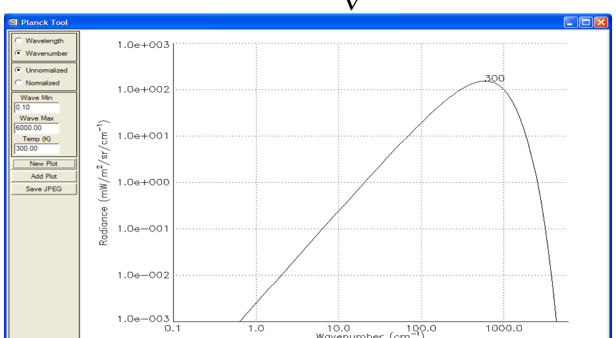
$(mW/m^2/ster/cm^{-1})$

ν(max in cm-1) = 1.95T

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

$$E = \pi \int_0^\infty B(\nu,T)\, d\nu = \sigma T^4,$$

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



Using wavelengths

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

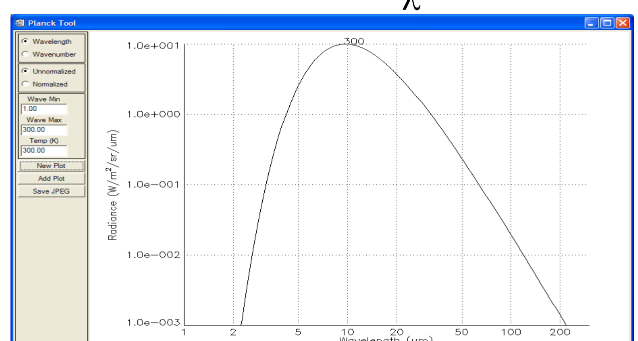
$(mW/m^2/ster/\mu m)$

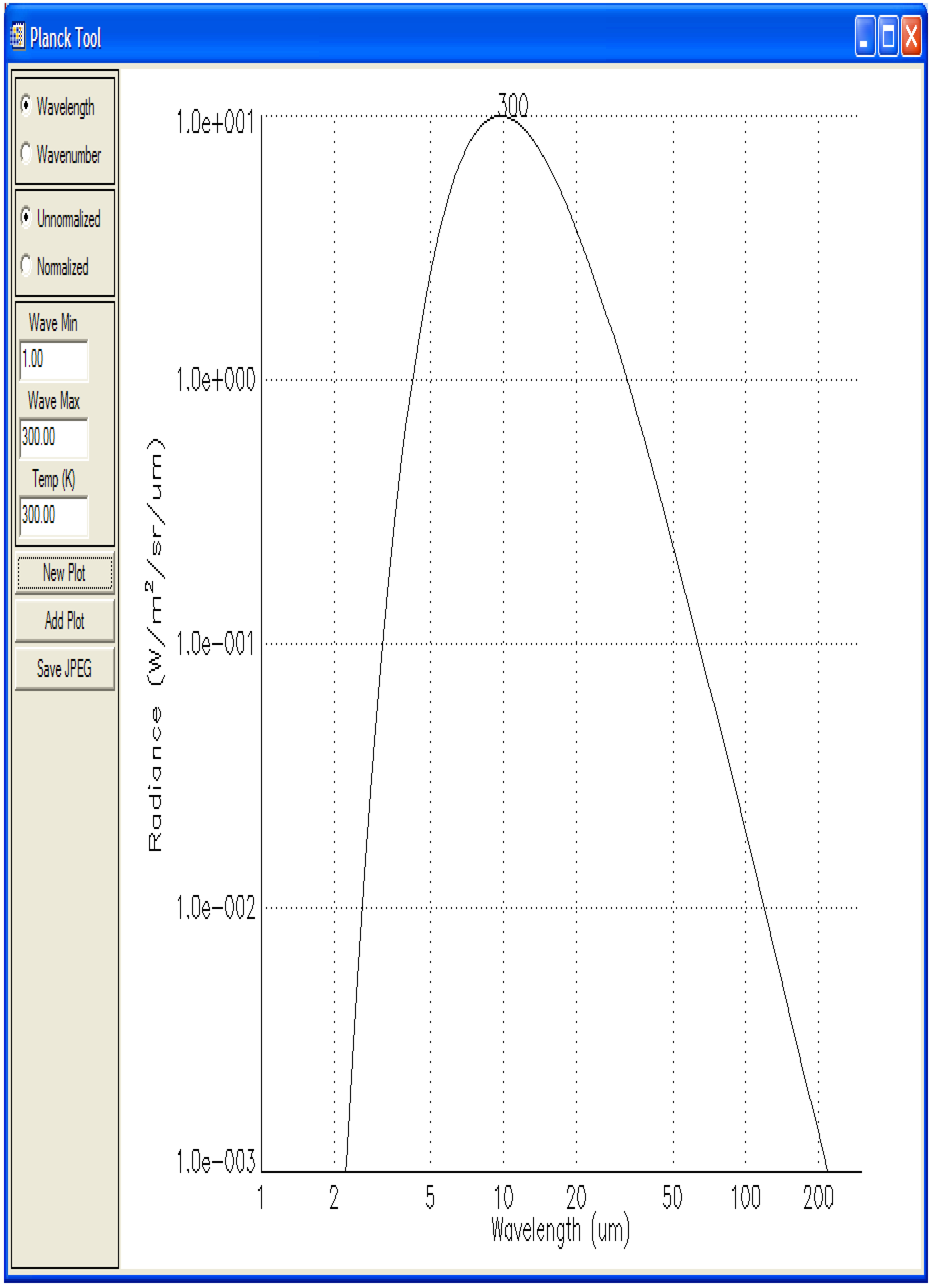
λ(max in cm)T = 0.2897

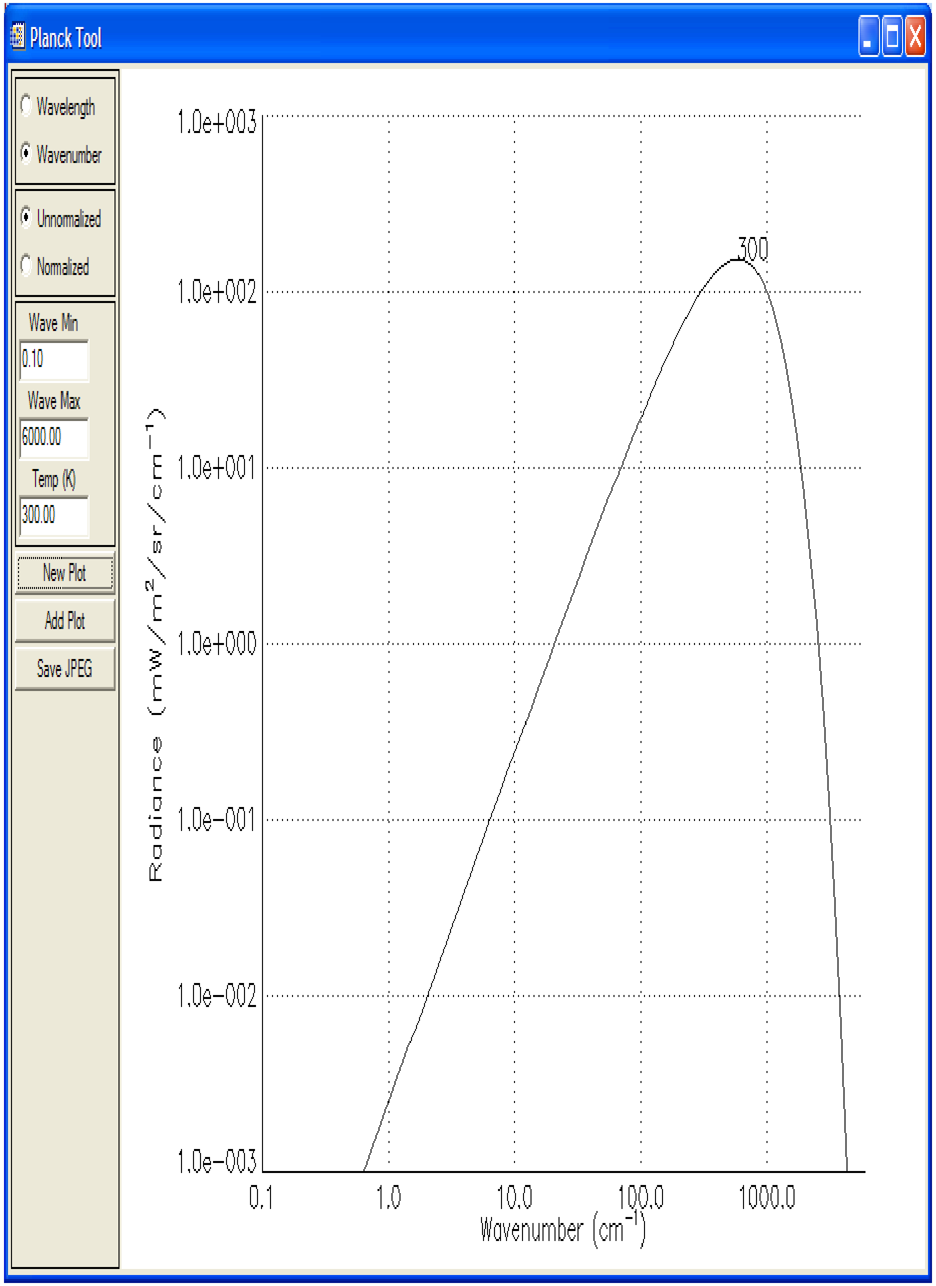
$B(\lambda_{max},T) \sim T^{**}5.$

$$E = \pi \int_0^\infty B(\lambda,T)\, d\lambda = \sigma T^4,$$

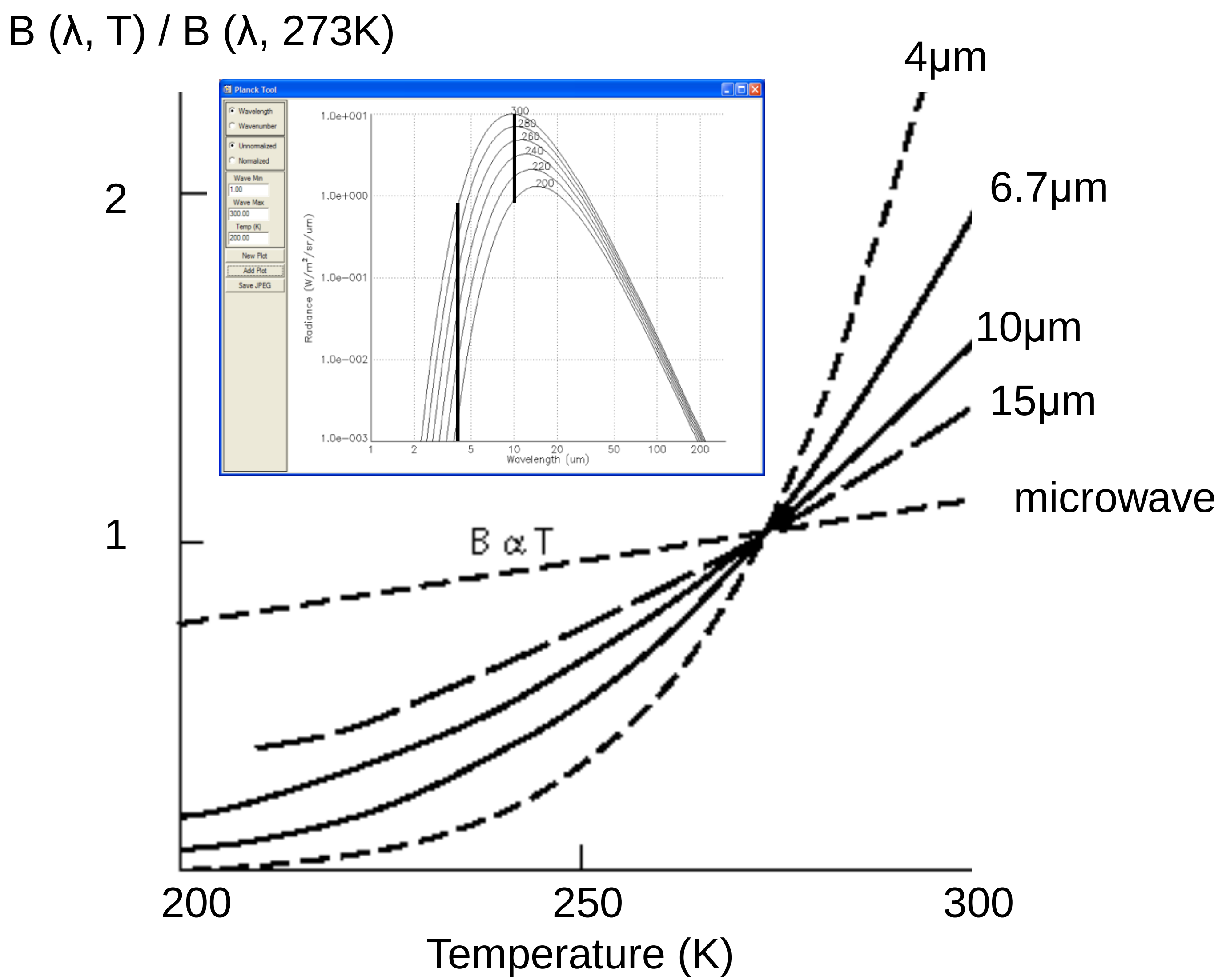
$$T = c_2/[\lambda \ln(\frac{c_1}{\lambda^5 B_\lambda} + 1)]$$




Planck Tool
Wavelength
Wavenumber
Unnormalized
Normalized
Wave Min
1.00
Wave Max
300.00
Temp (K)
300.00
New Plot
Add Plot
Save JPEG
300
1.0e+001
1.0e+000
1.0e-001
1.0e-002
1.0e-003
Radiance (W/m^2/sr/um)
1
2
5
10
20
50
100
200
Wavelength (um)


Planck Tool
Wavelength
Wavenumber
Unnormalized
Normalized
Wave Min
0.10
Wave Max
6000.00
Temp (K)
300.00
New Plot
Add Plot
Save JPEG
300
1.0e+003
1.0e+002
1.0e+001
1.0e+000
1.0e-001
1.0e-002
1.0e-003
Radiance (mW/m^2/sr/cm^{-1})
0.1
1.0
10.0
100.0
1000.0
Wavenumber (cm^{-1})

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



(Approximation of) B as function of α and T

$\Delta B/B=\alpha\ \Delta T/T$

Integrating the Temperature Sensitivity Equation Between T_{ref} and T (B_{ref} and B):

$B=B_{ref}(T/T_{ref})^{\alpha}$

Where $\alpha=c_2\nu/T_{ref}$ (in wavenumber space)

$$B=B_{ref}(T/T_{ref})^{\alpha}$$

$$\Downarrow$$

$$B=(B_{ref}/\ T_{ref}{}^{\alpha})\ T^{\ \alpha}$$

$$\Downarrow$$

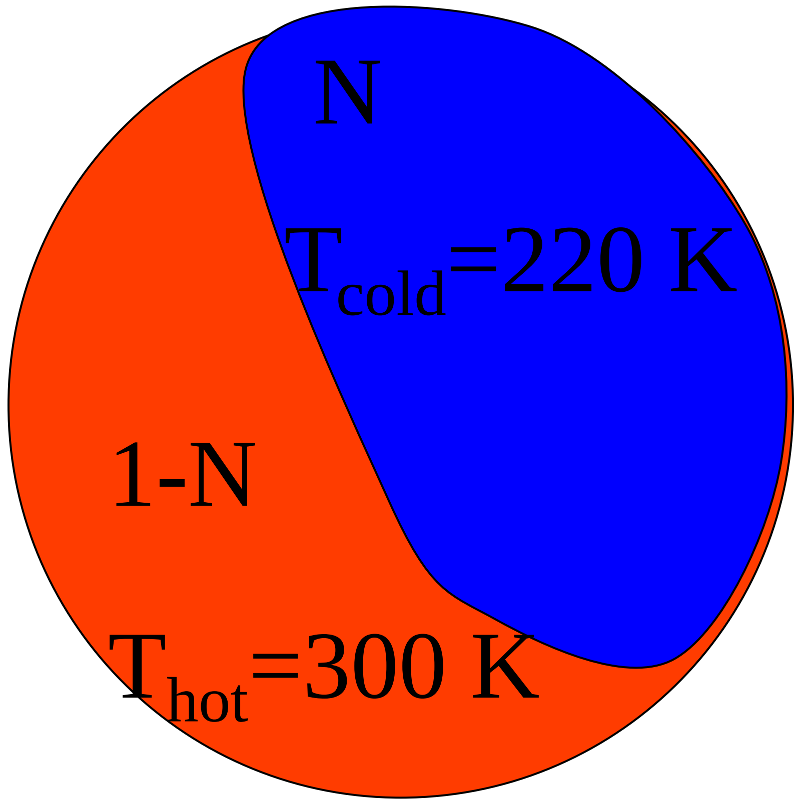
$$B \propto T^{\ \alpha}$$

The temperature sensitivity indicates the power to which the Planck radiance depends on temperature, since B proportional to T^{α} satisfies the equation. For infrared wavelengths,

$\alpha = c_2\nu/T = c_2/\lambda T.$

Wavenumber	Typical Scene Temperature	Temperature Sensitivity
900	300	4.32
2500	300	11.99

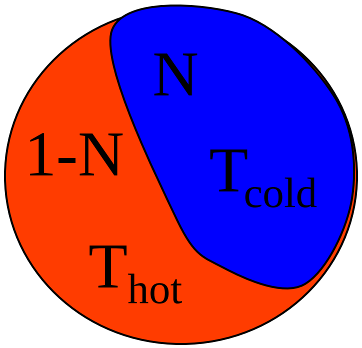
Non-Homogeneous FOV



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

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

For NON-UNIFORM FOVs:



$B_{obs}=NB_{cold}+(1\text{-}N)B_{hot}$

$B_{obs}=N\ B_{ref}(T_{cold}/T_{ref})^{\alpha}+(1\text{-}N)\ B_{ref}(T_{hot}/T_{ref})^{\alpha}$

$B_{obs}=B_{ref}(1/T_{ref})^{\alpha}\ (N\ T_{cold}{}^{\alpha}+(1\text{-}N)T_{hot}{}^{\alpha})$

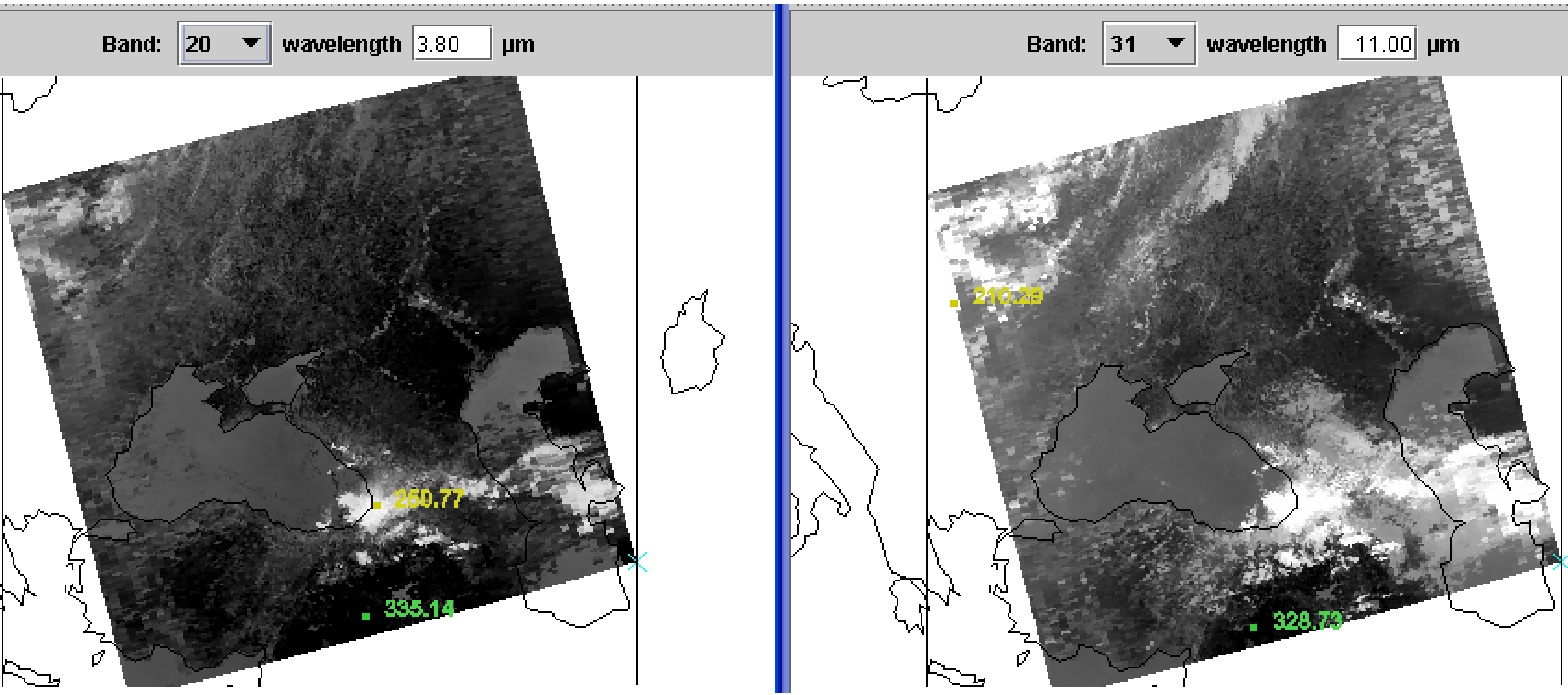
For N=.5

$B_{obs}/B_{ref}=.5\ (1/T_{ref})^{\alpha}\ (\ T_{cold}{}^{\alpha}+T_{hot}{}^{\alpha})$

$B_{obs}/B_{ref}=.5\ (1/T_{ref}T_{cold})^{\alpha}\ (1+(T_{hot}/\ T_{cold})^{\alpha})$

The greater α the more predominant the hot term

At 4 μm (α=12) the hot term more dominating than at 11 μm (α=4)



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

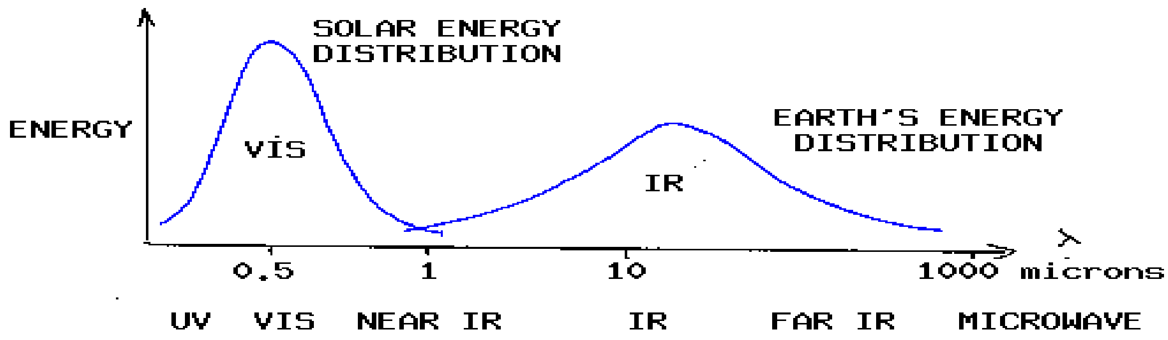
T(11)**4=(1-N)*Tclr**4+N*Tcld**4~(1-N)*300**4+N*200**4

T(4)**12=(1-N)*Tclr**12+N*Tcld**12~(1-N)*300**12+N*200**12

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

Relevant Material in Applications of Meteorological Satellites

Solar (visible) and Earth emitted (infrared) energy

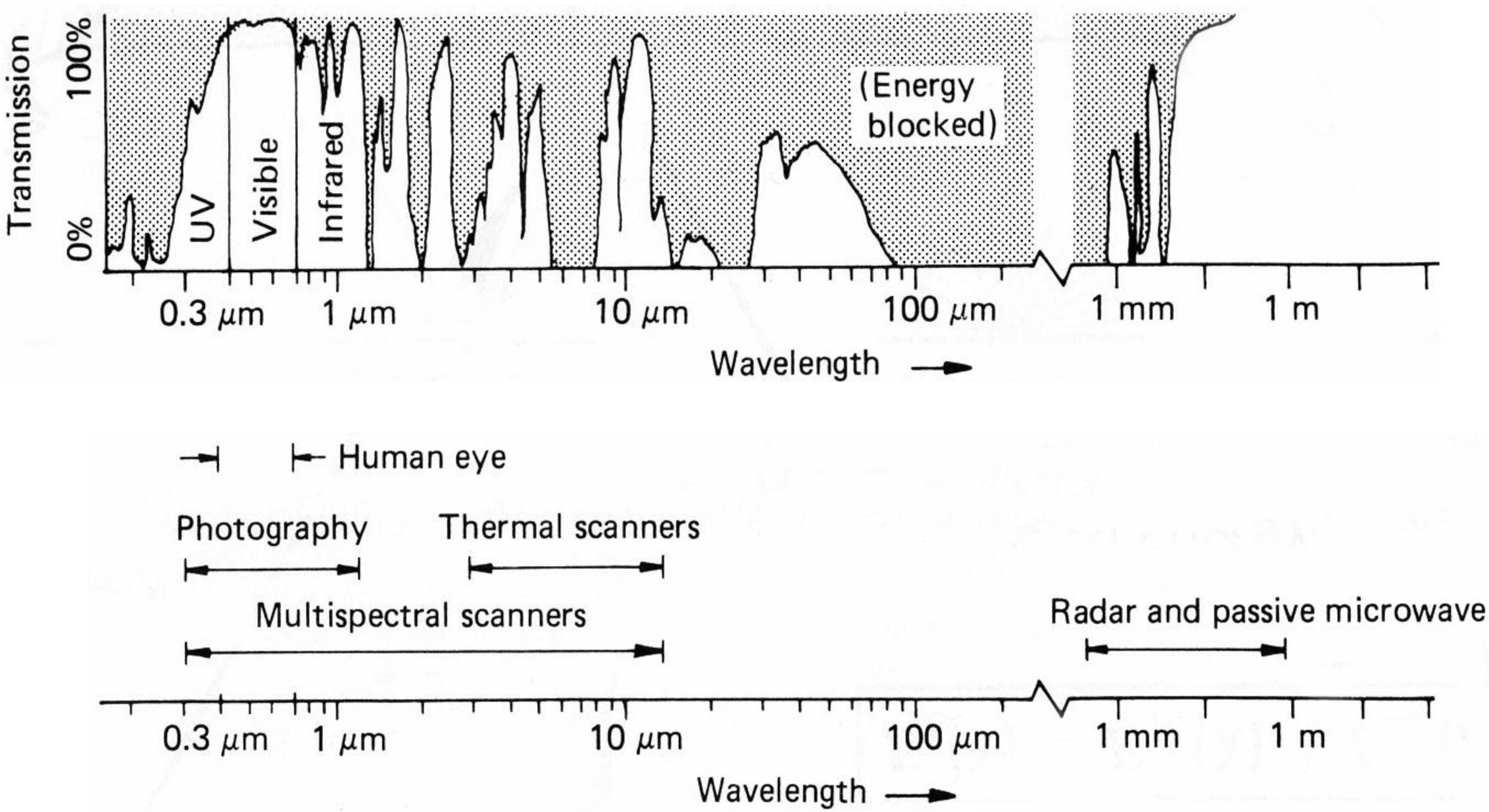


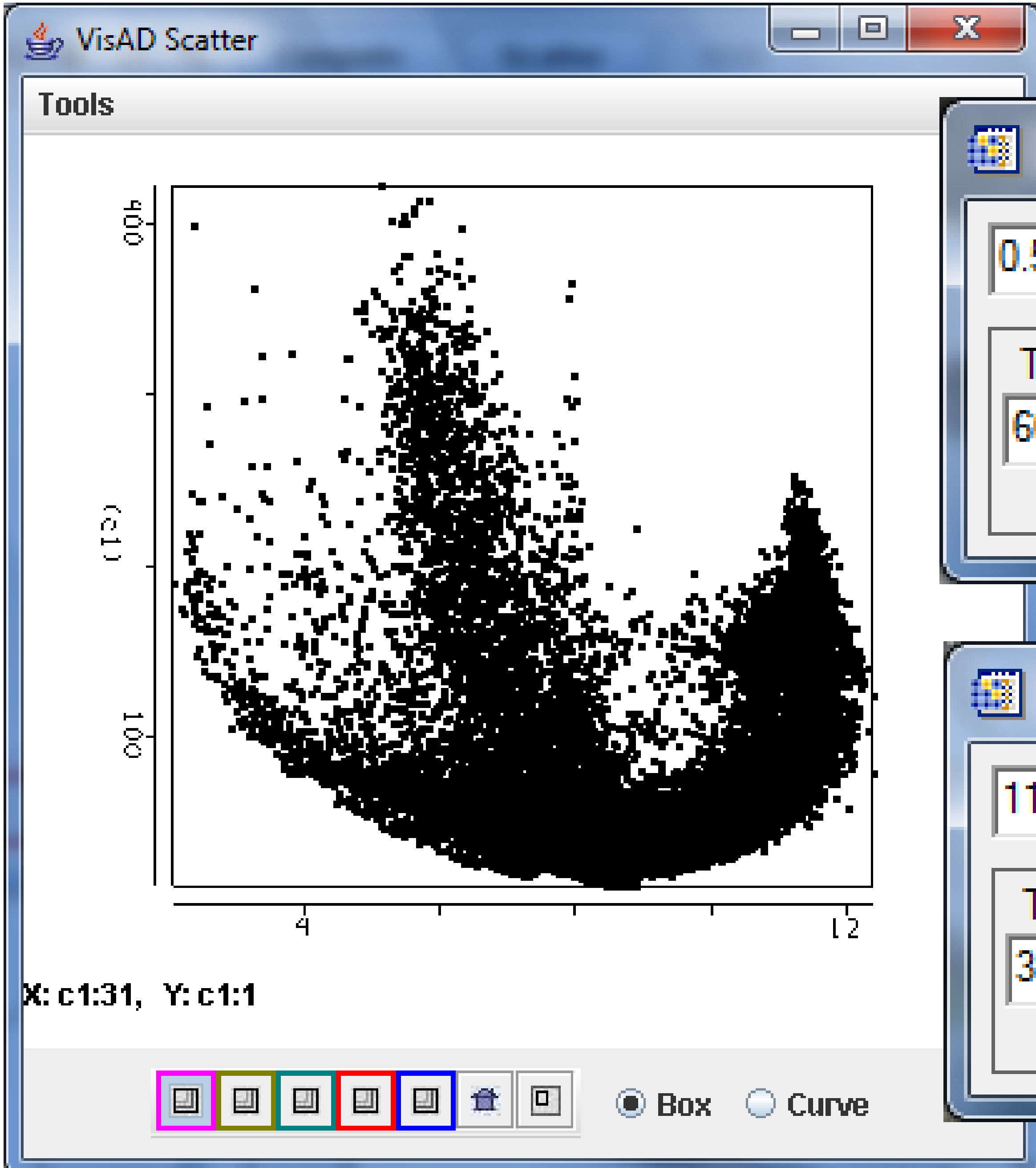
Incoming solar radiation (mostly visible) drives the earth-atmosphere (which emits infrared).

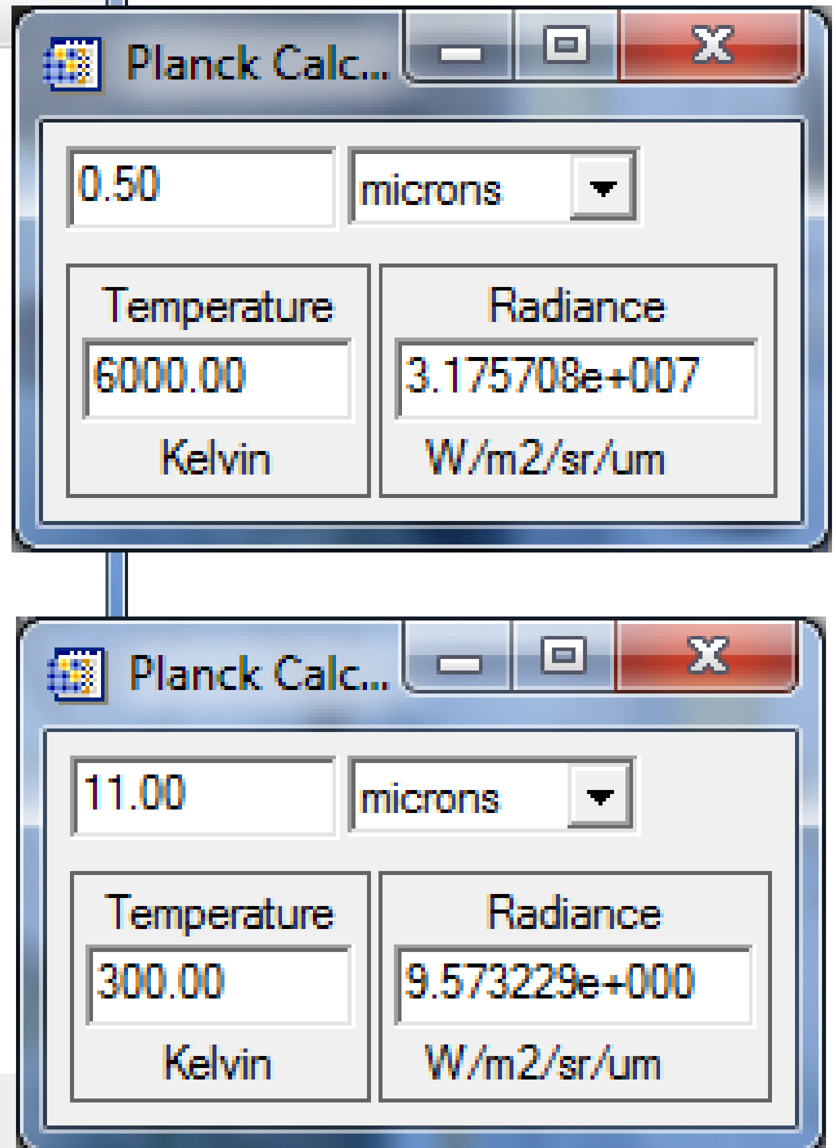
Over the annual cycle, the incoming solar energy that makes it to the earth surface (about 50 %) is balanced by the outgoing thermal infrared energy emitted through the atmosphere.

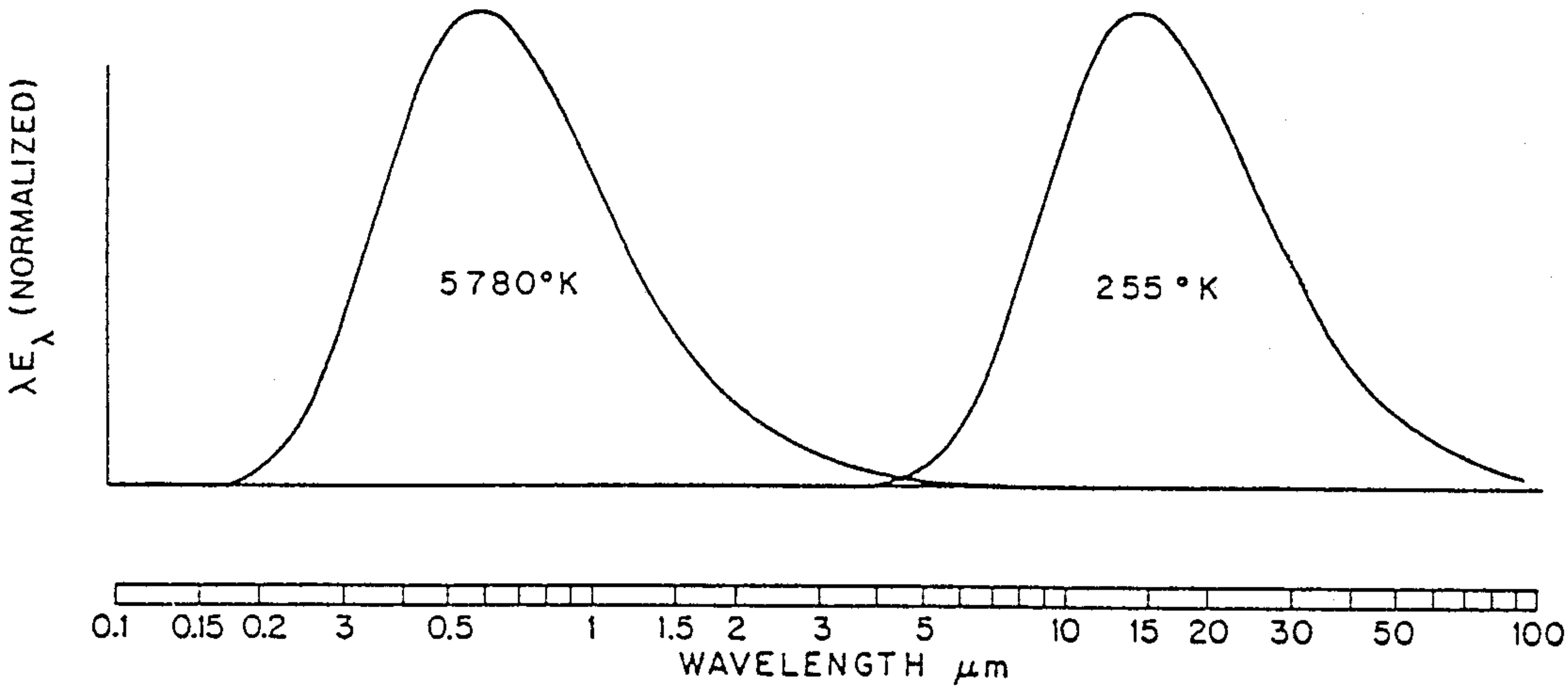
The atmosphere transmits, absorbs (by H2O, O2, O3, dust) reflects (by clouds), and scatters (by aerosols) incoming visible; the earth surface absorbs and reflects the transmitted visible. Atmospheric H2O, CO2, and O3 selectively transmit or absorb the outgoing infrared radiation. The outgoing microwave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

Spectral Characteristics of Atmospheric Transmission and Sensing Systems

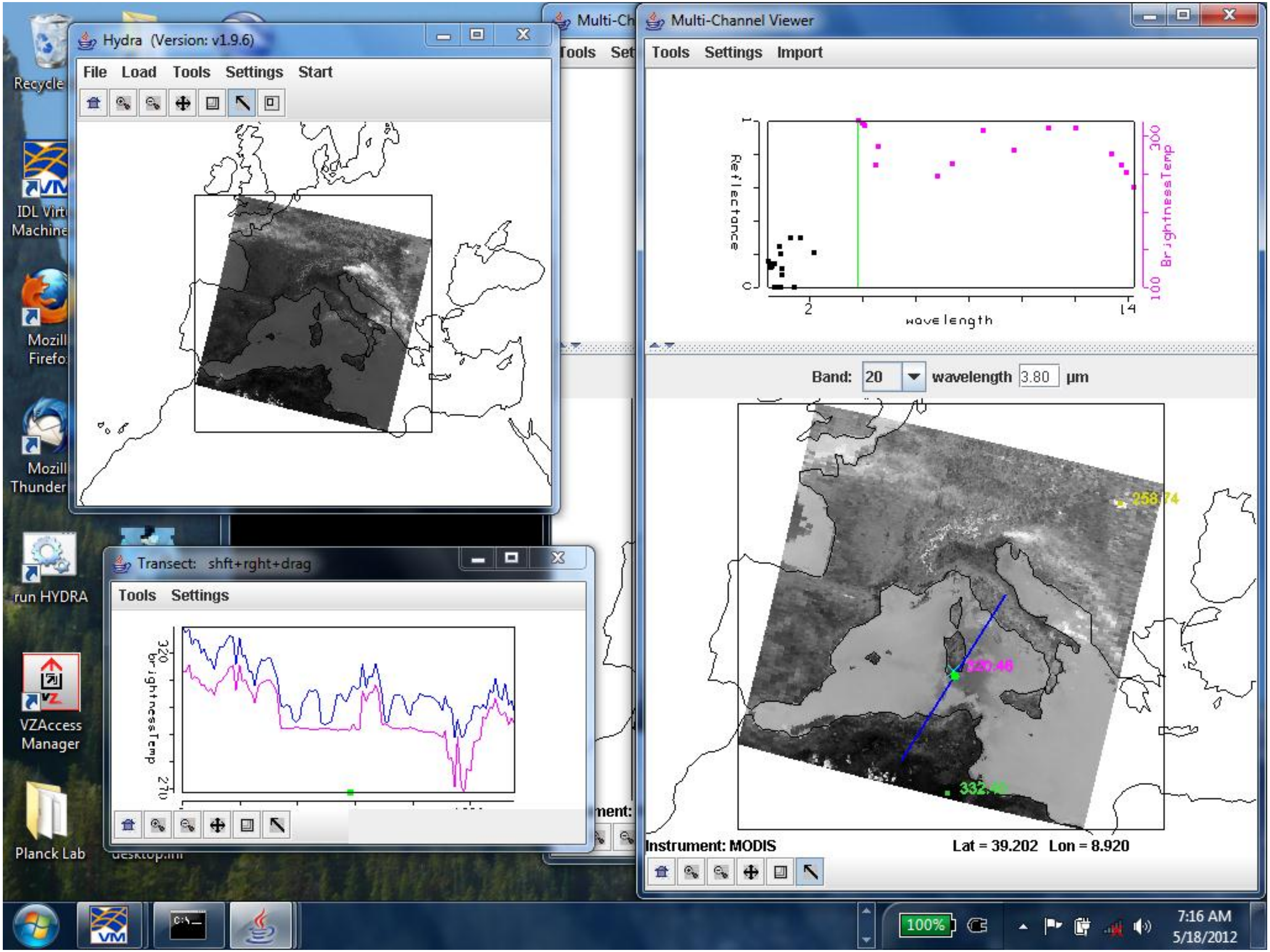



VisAD Scatter
Tools
400
100
4
12
X: c1:31, Y: c1:1
Box
Curve

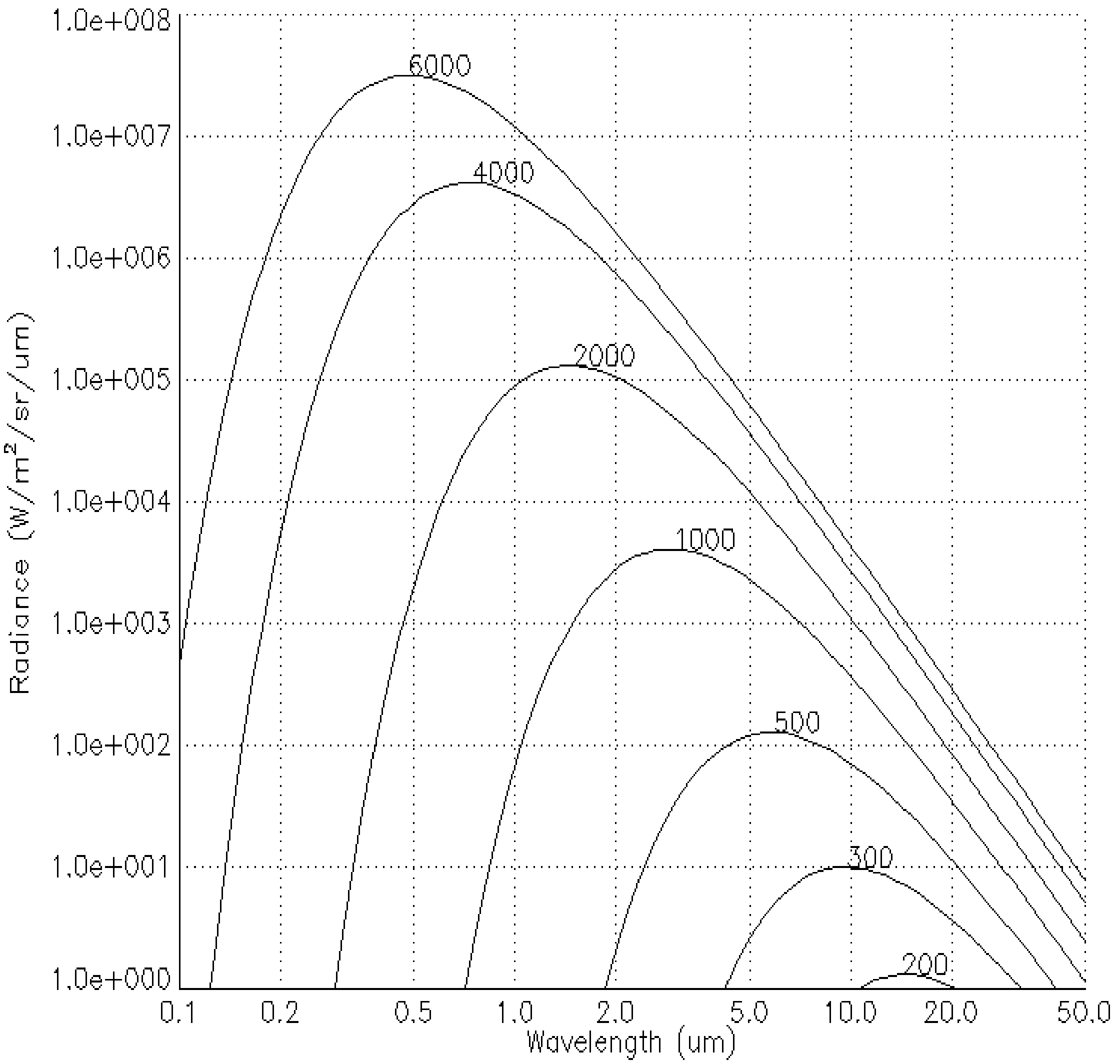

Planck Calc...
0.50
microns
Temperature
6000.00
Kelvin
Radiance
3.175708e+007
W/m2/sr/um
Planck Calc...
11.00
microns
Temperature
300.00
Kelvin
Radiance
9.573229e+000
W/m2/sr/um

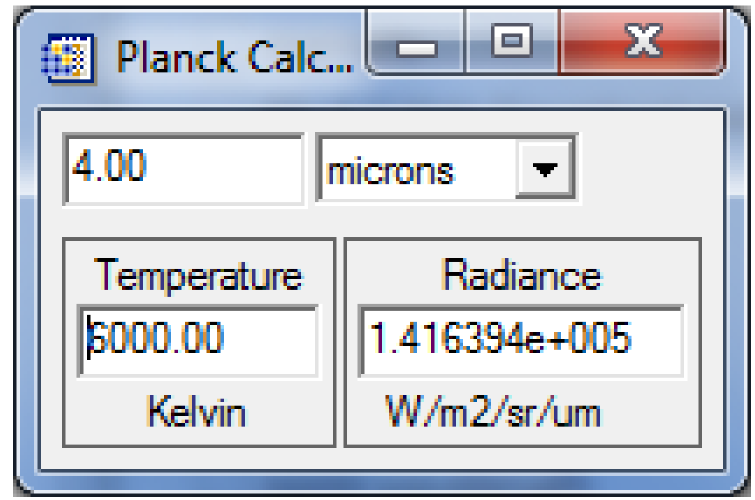


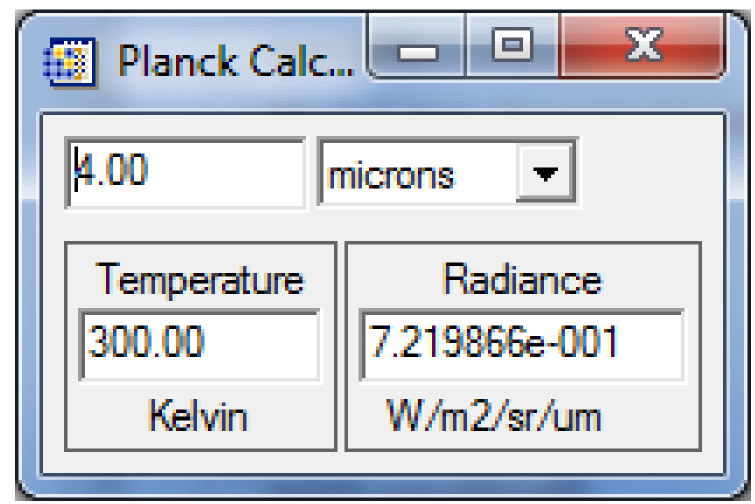
Normalized black body spectra representative of the sun (left) and earth (right), plotted on a logarithmic wavelength scale. The ordinate is multiplied by wavelength so that the area under the curves is proportional to irradiance.



Hydra (Version: v1.9.6)
File Load Tools Settings Start
Multi-Channel Viewer
Tools Settings Import
Reflectance
BrightnessTemp
wavelength
Band: 20 wavelength 3.80 µm
Instrument: MODIS
Lat = 39.202 Lon = 8.920
Transect: shft+rght+drag
Tools Settings
brightnessTemp
Recycle
IDL Virt Machine
run HYDRA
VZAccess Manager
Planck Lab
100%
7:16 AM
5/18/2012


1.0e+008
1.0e+007
1.0e+006
1.0e+005
1.0e+004
1.0e+003
1.0e+002
1.0e+001
1.0e+000
Radiance (W/m2/sr/um)
6000
4000
2000
1000
500
300
200
0.1
0.2
0.5
1.0
2.0
5.0
10.0
20.0
50.0
Wavelength (um)


Planck Calc...
4.00
microns
Temperature
6000.00
Kelvin
Radiance
1.416394e+005
W/m2/sr/um


Planck Calc...
4.00
microns
Temperature
300.00
Kelvin
Radiance
7.219866e-001
W/m2/sr/um

BT11=290K and BT4=310K.

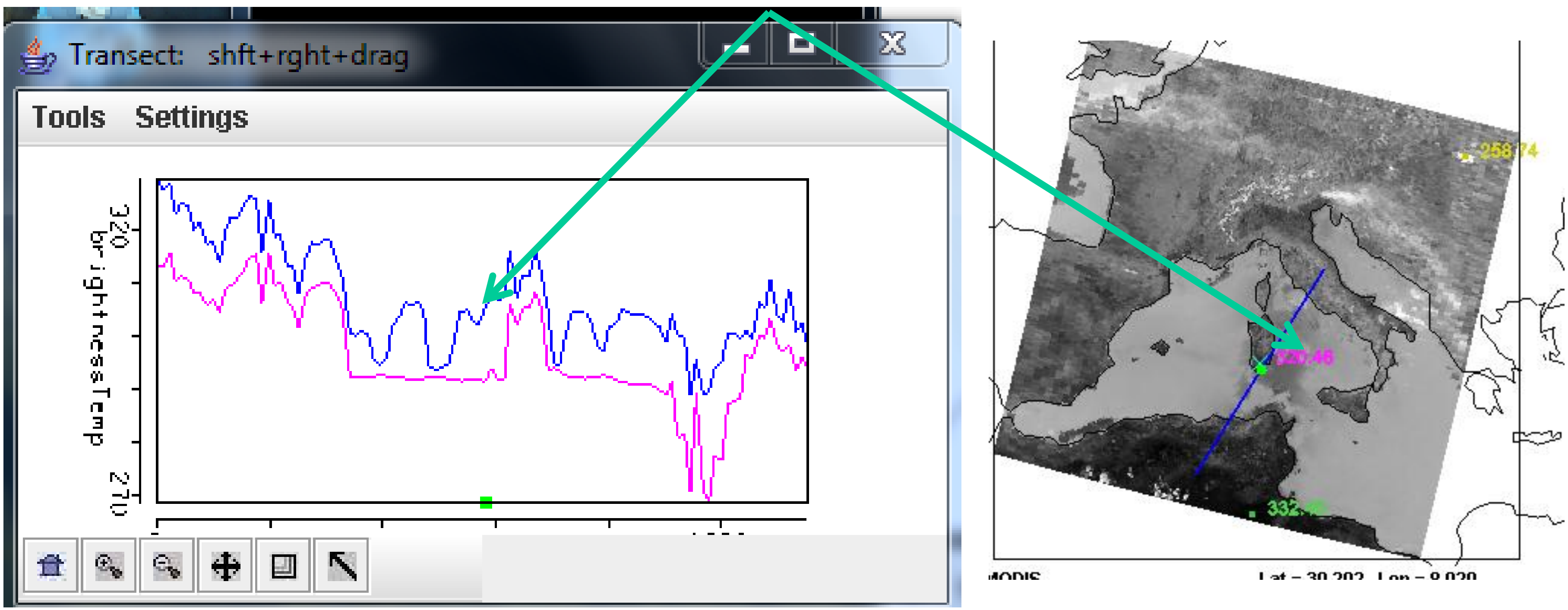
What fraction of R4 is due to reflected solar radiance?

R4 = R4 refl + R4 emiss

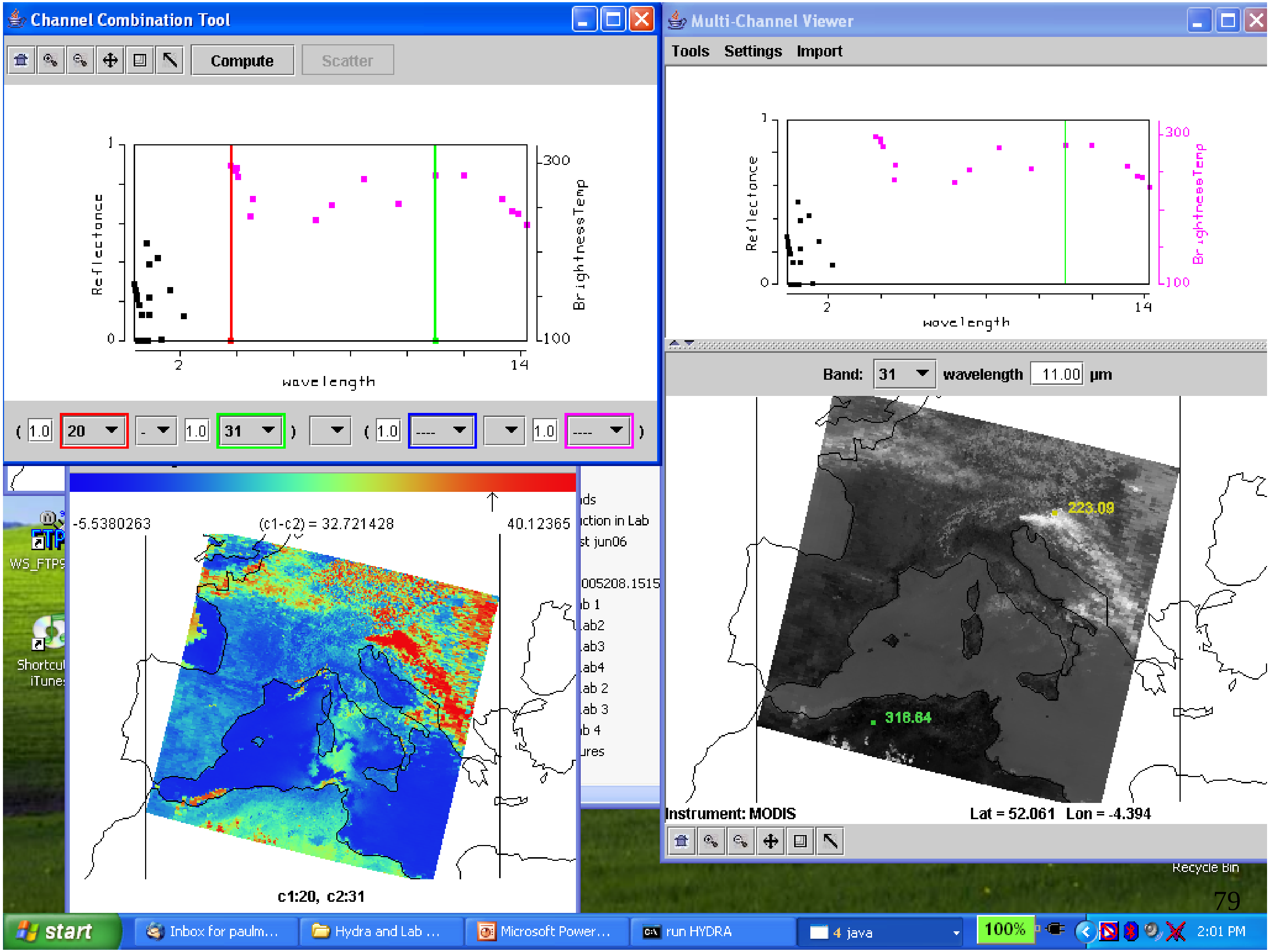
BT4 emiss = BT11

R4 ~ T**12

Fraction = [310**12 – 290**12]/ 310**12 ~ .55



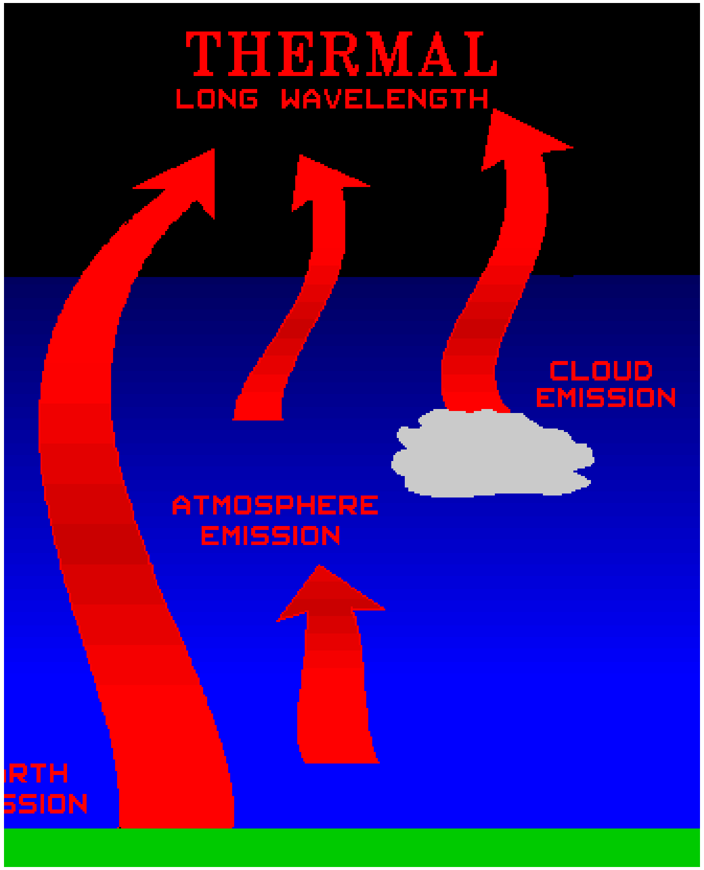
SW minus LW IRW



Radiative Transfer Equation

in the IR

Infrared
(Emissive Bands)



Emission, Absorption, Reflection, and Scattering

Blackbody radiation B_λ represents the upper limit to the amount of radiation that a real substance may emit at a given temperature for a given wavelength.

Emissivity ε_λ is defined as the fraction of emitted radiation R_λ to Blackbody radiation,

$$\varepsilon_\lambda = R_\lambda / B_\lambda \ .$$

In a medium at thermal equilibrium, what is absorbed is emitted (what goes in comes out) so

$$a_\lambda = \varepsilon_\lambda \ .$$

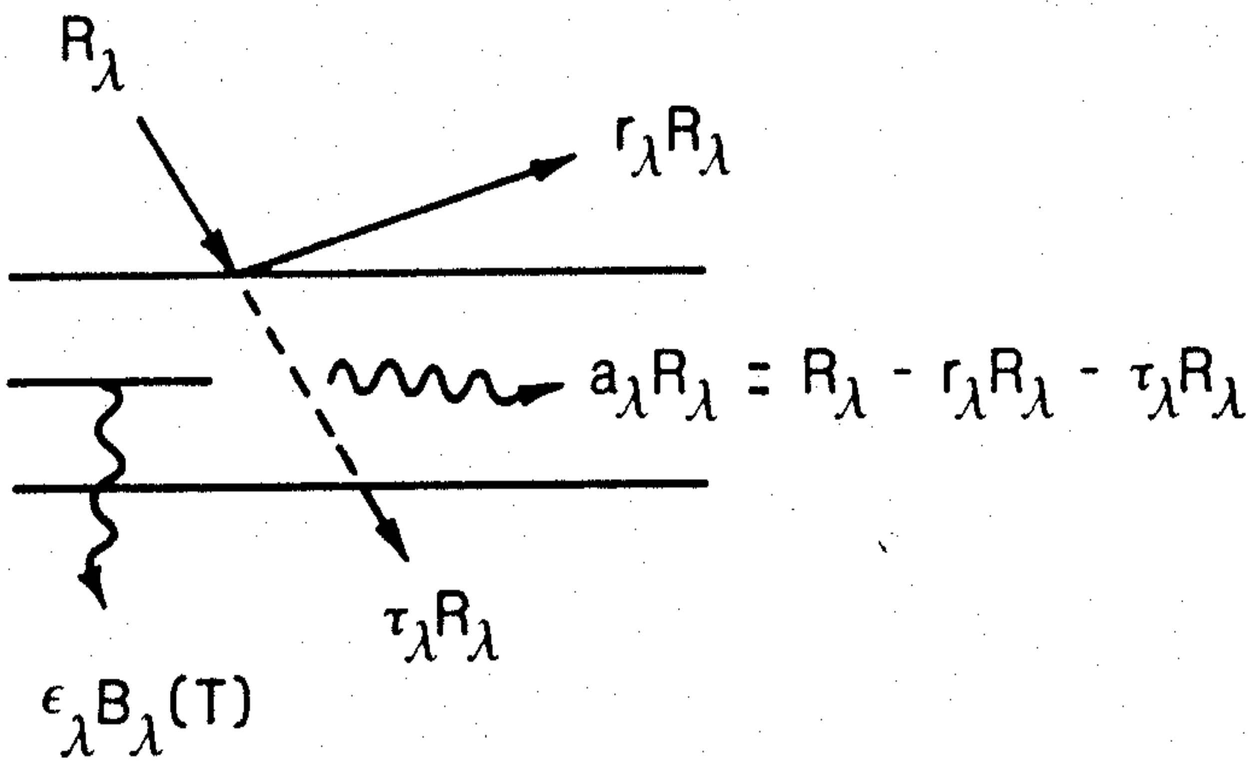
Thus, materials which are strong absorbers at a given wavelength are also strong emitters at that wavelength; similarly weak absorbers are weak emitters.

If a_λ, r_λ, and τ_λ represent the fractional absorption, reflectance, and transmittance, respectively, then conservation of energy says

$$a_\lambda + r_\lambda + \tau_\lambda = 1 \ .$$

For a blackbody $a_\lambda = 1$, it follows that $r_\lambda = 0$ and $\tau_\lambda = 0$ for blackbody radiation. Also, for a perfect window $\tau_\lambda = 1$, $a_\lambda = 0$ and $r_\lambda = 0$. For any opaque surface $\tau_\lambda = 0$, so radiation is either absorbed or reflected $a_\lambda + r_\lambda = 1$.

At any wavelength, strong reflectors are weak absorbers (i.e., snow at visible wavelengths), and weak reflectors are strong absorbers (i.e., asphalt at visible wavelengths).



"ENERGY CONSERVATION"

Transmittance

Transmission through an absorbing medium for a given wavelength is governed by the number of intervening absorbing molecules (path length u) and their absorbing power (k_λ) at that wavelength. Beer's law indicates that transmittance decays exponentially with increasing path length

$$\tau_\lambda (z \rightarrow \infty) = e^{-k_\lambda u(z)}$$

where the path length is given by $\quad u(z) = \int_z^\infty \rho \, dz$.

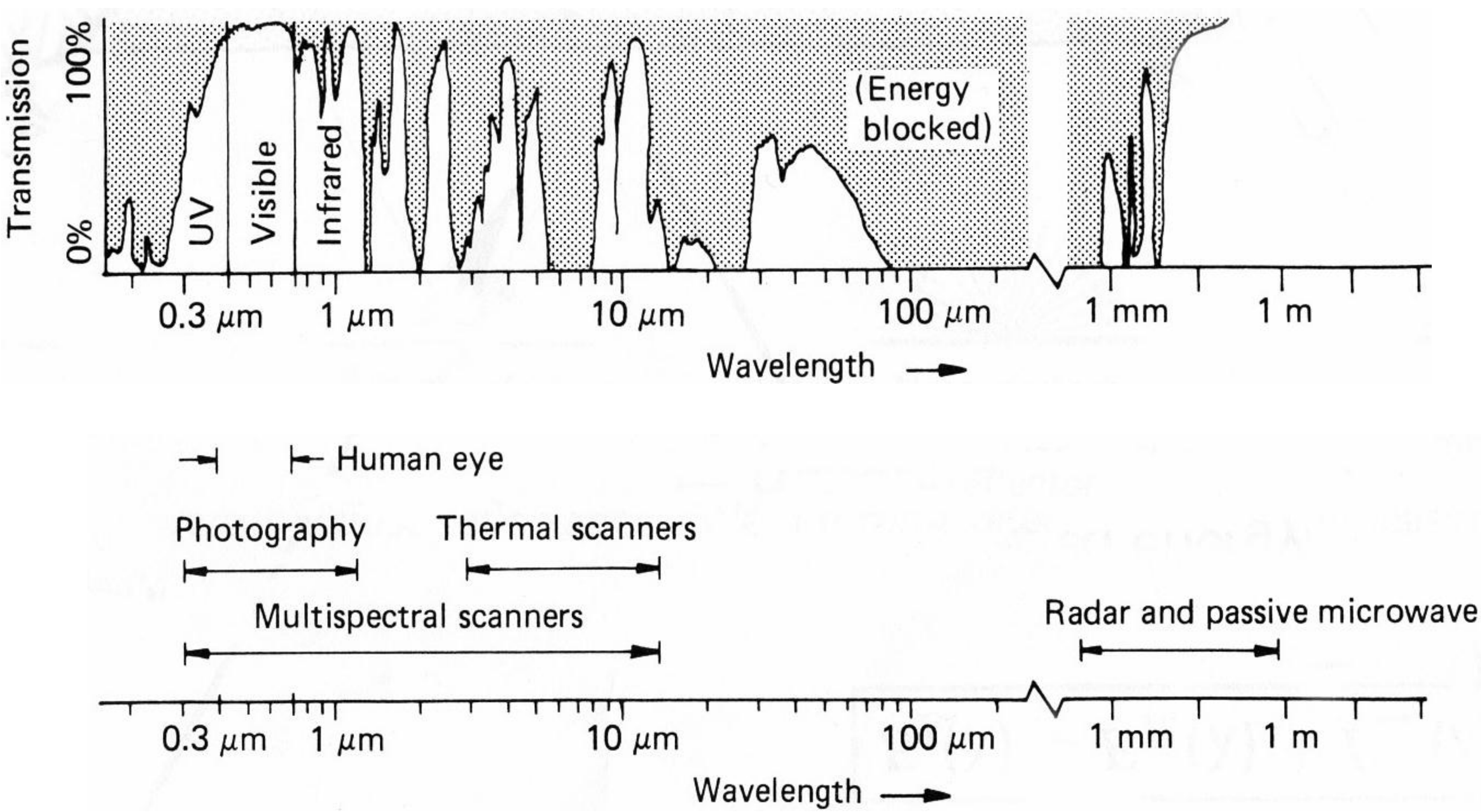
$k_\lambda u$ is a measure of the cumulative depletion that the beam of radiation has experienced as a result of its passage through the layer and is often called the optical depth σ_λ.

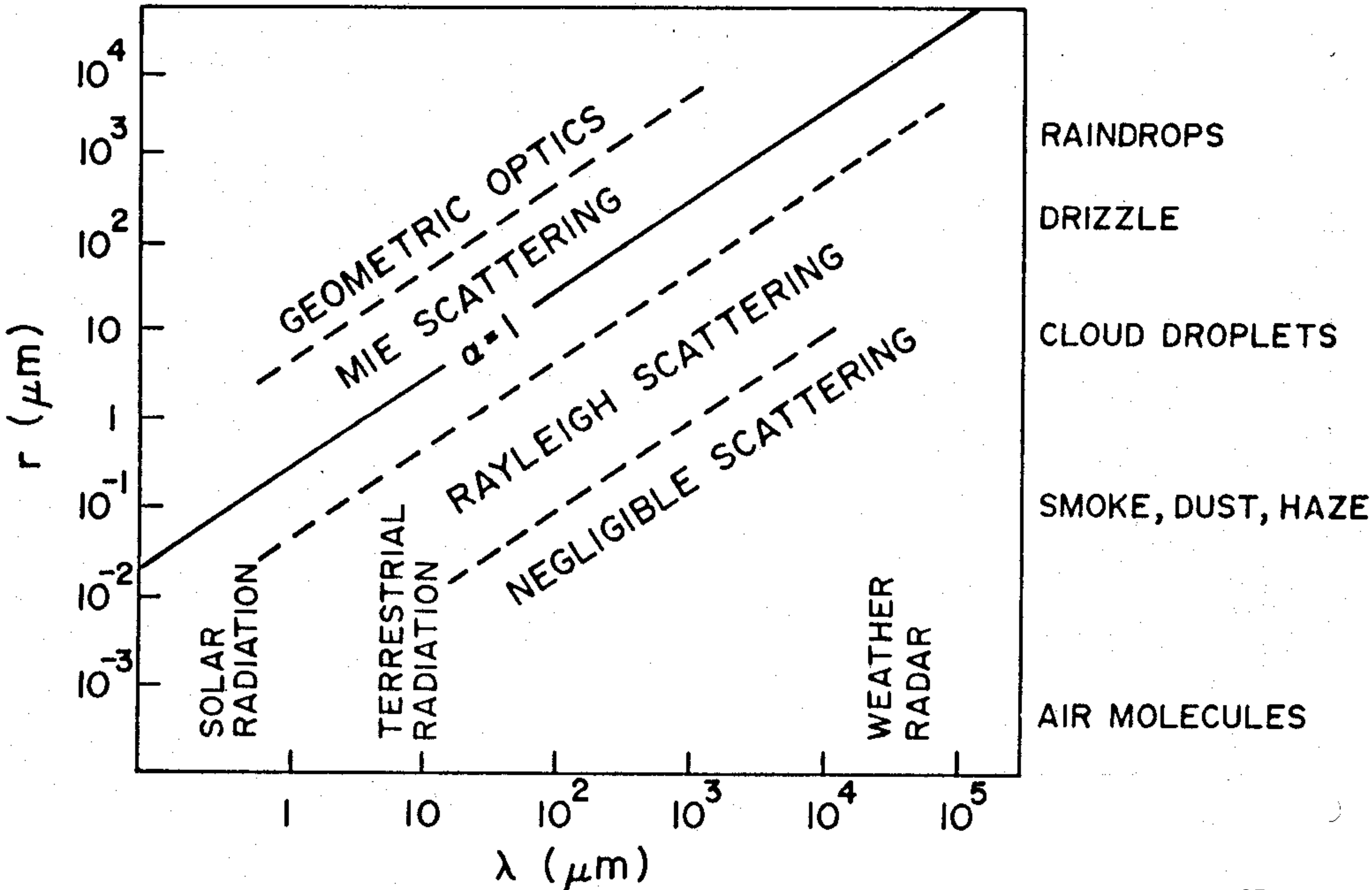
Realizing that the hydrostatic equation implies $g \rho \, dz = - q \, dp$

where q is the mixing ratio and ρ is the density of the atmosphere, then

$$u(p) = \int_o^p q \, g^{-1} \, dp \qquad \text{and} \qquad \tau_\lambda (p \rightarrow o) = e^{-k_\lambda u(p)} \ .$$

Spectral Characteristics of Atmospheric Transmission and Sensing Systems





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)

Aerosol Size Distribution

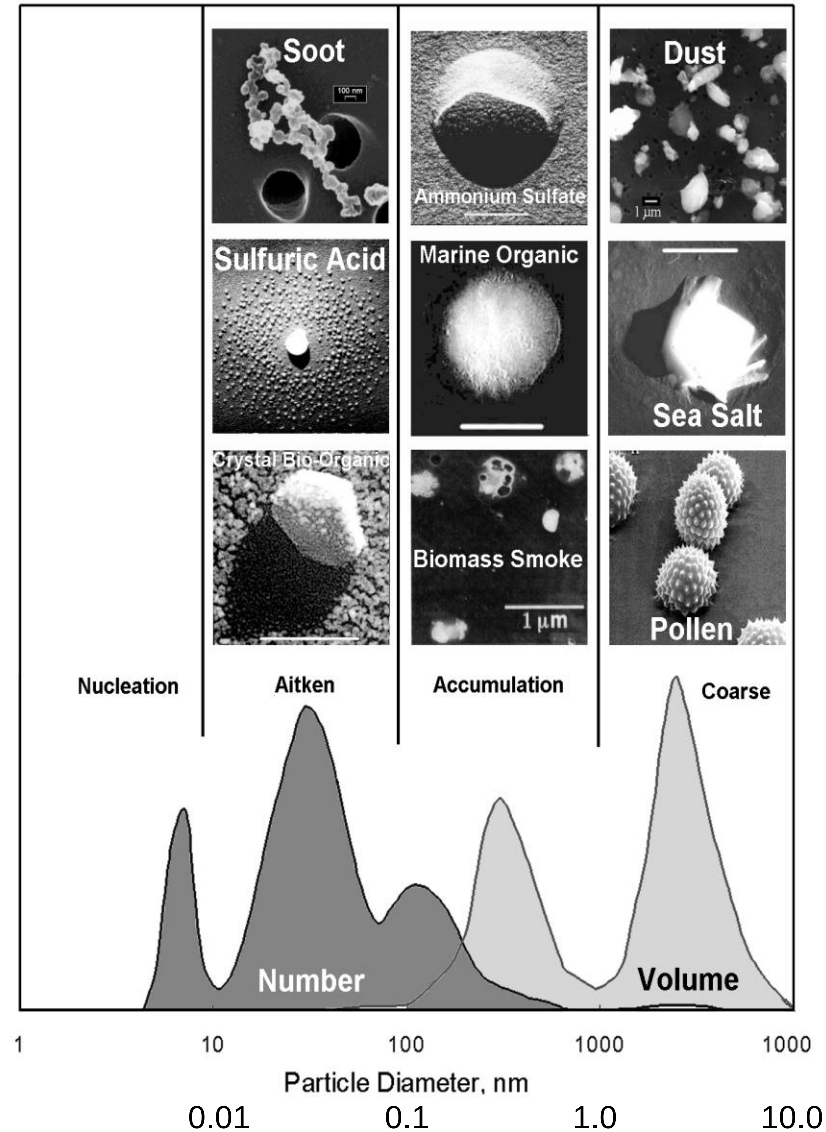
There are 3 modes :

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

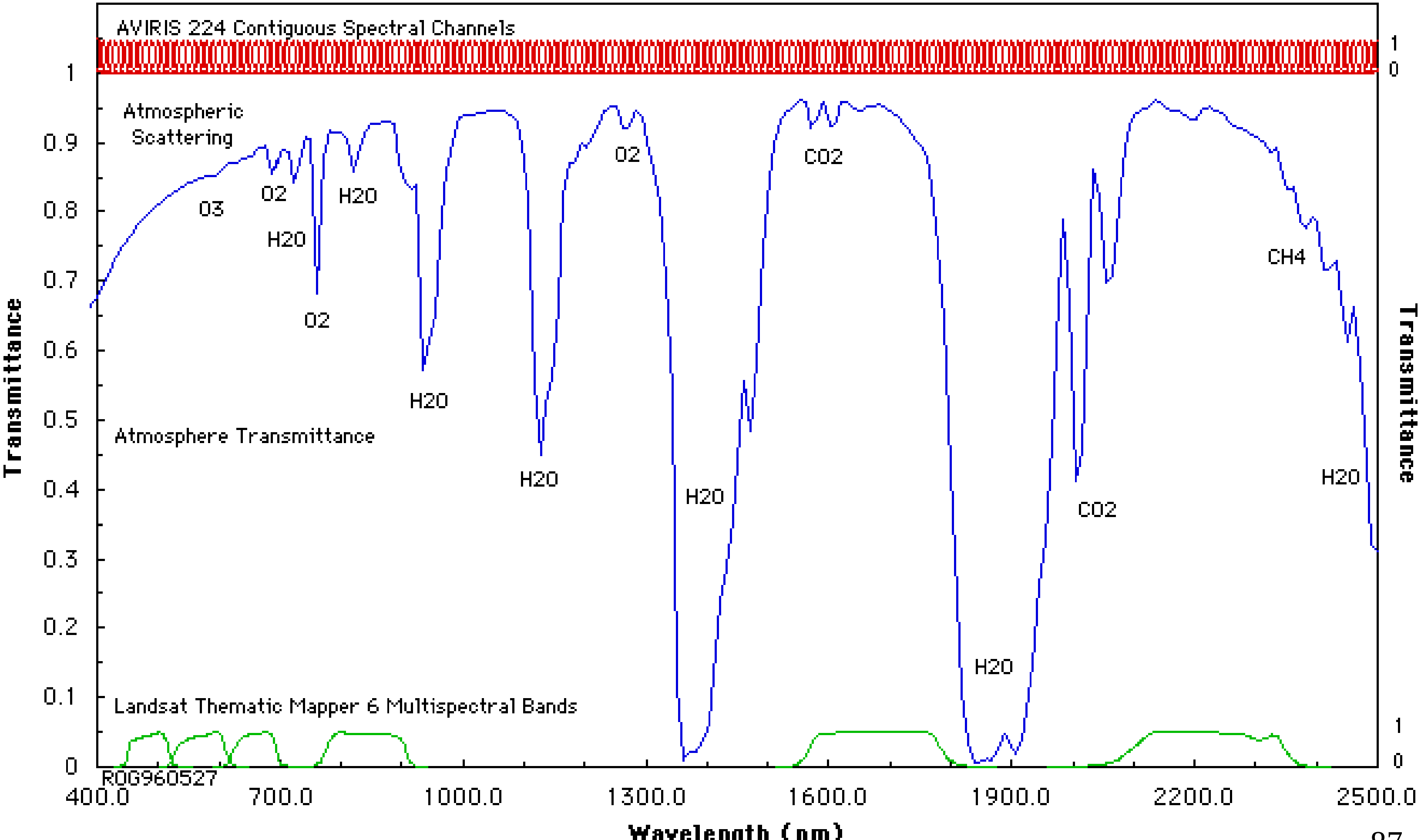
- **« accumulation »:** radius is between 0.05 µm and 0.5 µm. Coagulation processes.

- « **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.

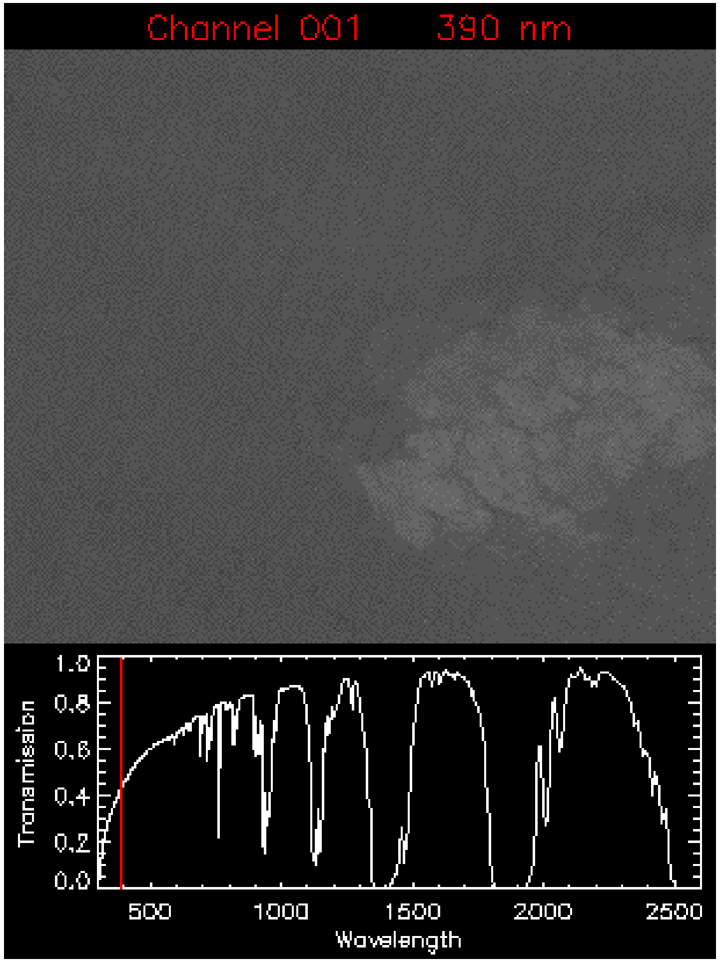


Measurements in the Solar Reflected Spectrum across the region covered by AVIRIS



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



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