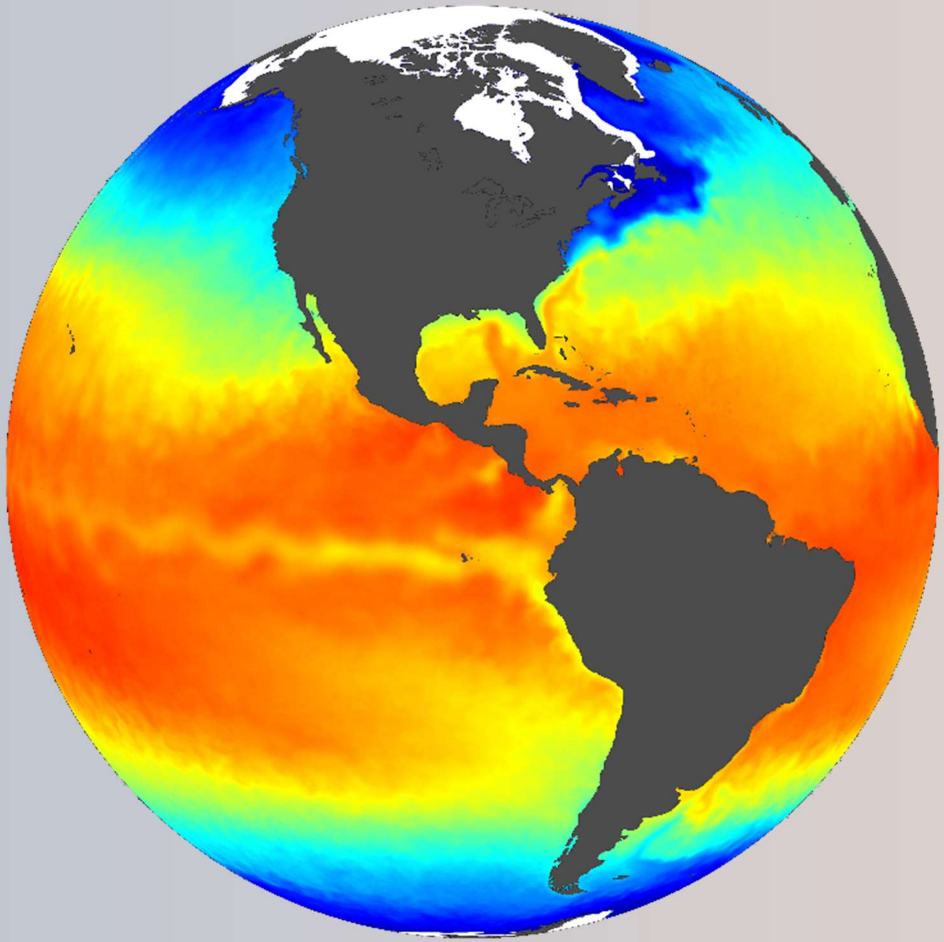


Basic concepts for sea surface temperature

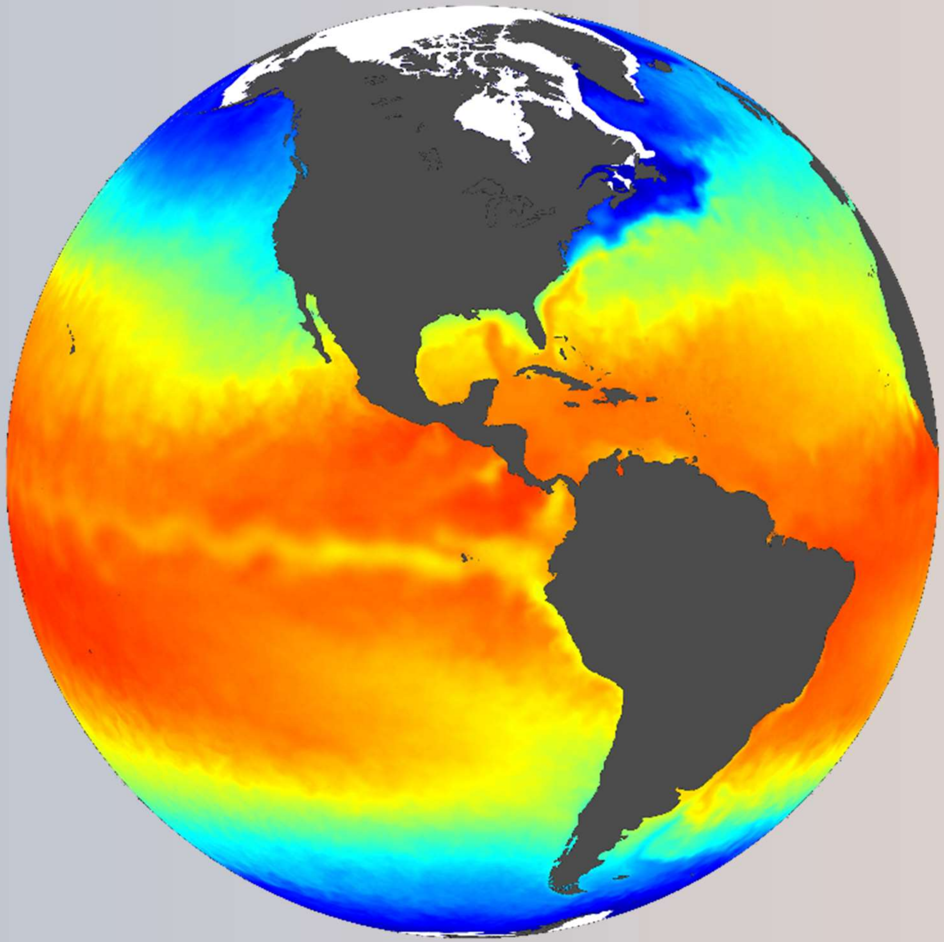
To provide operational users and the science community with the SST measured by the satellite constellation

Peter Minnett and

Chris Merchant

GHRSST
Group for High Resolution Sea Surface Temperature

CEOS
Committee on Earth Observation Satellites
Sea Surface Temperature Virtual Constellation



To provide operational users and the science community with the SST measured by the satellite constellation

Orbits and sampling

Peter Minnett

GHRSST
Group for High Resolution Sea Surface Temperature

CEOS
Committee on Earth Observation Satellites
Sea Surface Temperature Virtual Constellation

What is an orbit?

An orbit is a regular, repeating path that one object in space takes around another one. An object in an orbit is called a satellite. A satellite can be natural, like Earth or the moon, or man-made (sometimes called “artificial satellites”).

Planets, comets, asteroids and other objects in the solar system orbit the sun. Most of the objects orbiting the sun move along or close to an imaginary flat surface, called the ecliptic plane. The orbital plane of artificial satellites can be at any angle; for earth satellites, the inclination of the orbital plane is referred to the equatorial plane.

Time - the Julian Day

Following Herschel's lead astronomers adopted this system and took noon GMT -4712-01-01 (January 1st, 4713 B.C.E.) as their zero point. (Note that 4713 B.C.E. is the year -4712 according to the astronomical year numbering.) For astronomers a Julian day begins at noon and runs until the next noon (so that the nighttime falls conveniently within one "day," unless they are making their observations in a place such as Australia). Thus they defined the Julian day number of a day as the number of days (or part of a day) elapsed since noon GMT (or more exactly, UCT) on January 1st, 4713 B.C. This is the Julian Calendar.

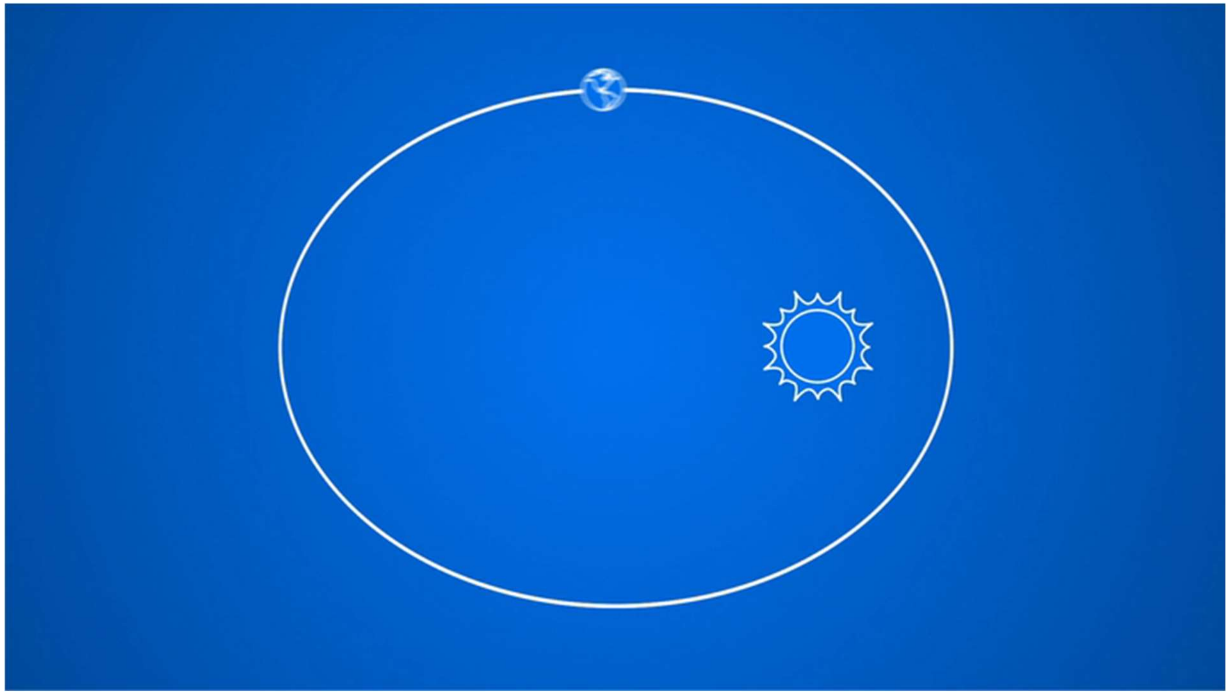
Thus, Wednesday, May 31, 2017 at 1:30:00 UTC (9:30 in Qingdao)

is JD 2457904.5625

See: http://aa.usno.navy.mil/data/docs/JulianDate.php

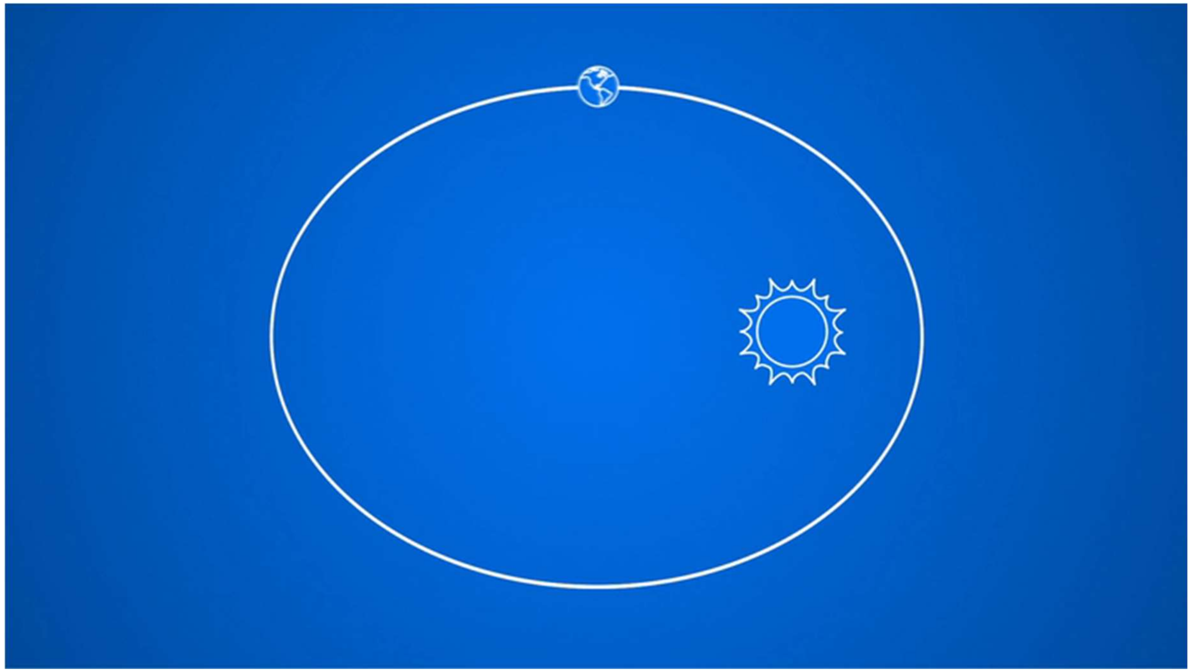
Kepler's Laws for Satellites

Law I. Within the domain of the earth's gravity field all satellites describe elliptical paths with the center of the earth at one focus.

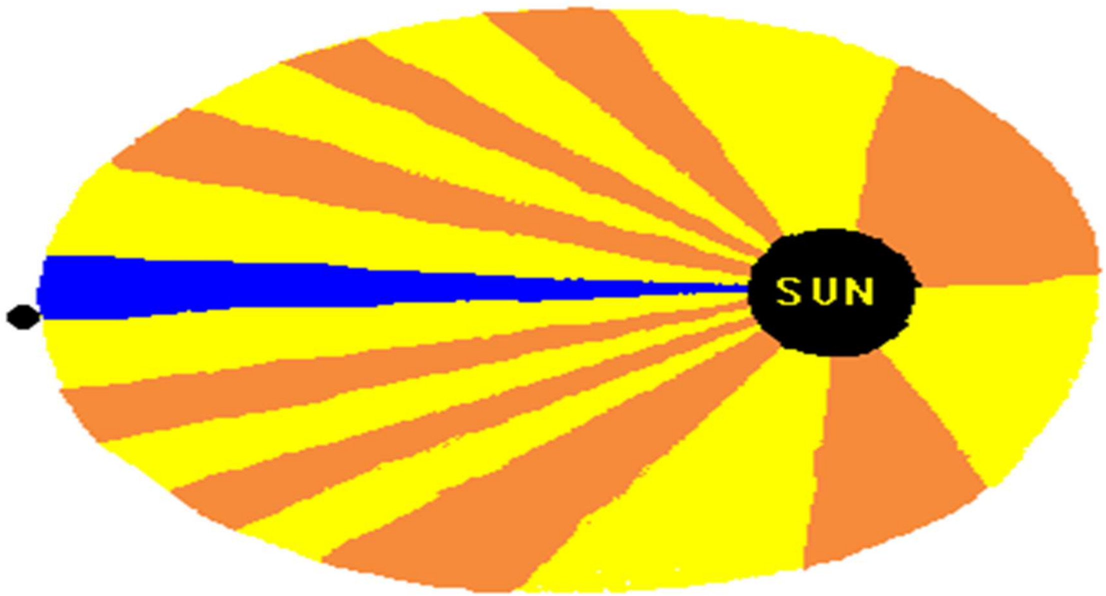


Kepler’s Laws for Satellites

Law II. The radius vector from the center of the earth to a satellite generates equal areas in equal times.



Elliptical orbits – Kepler's 2nd Law

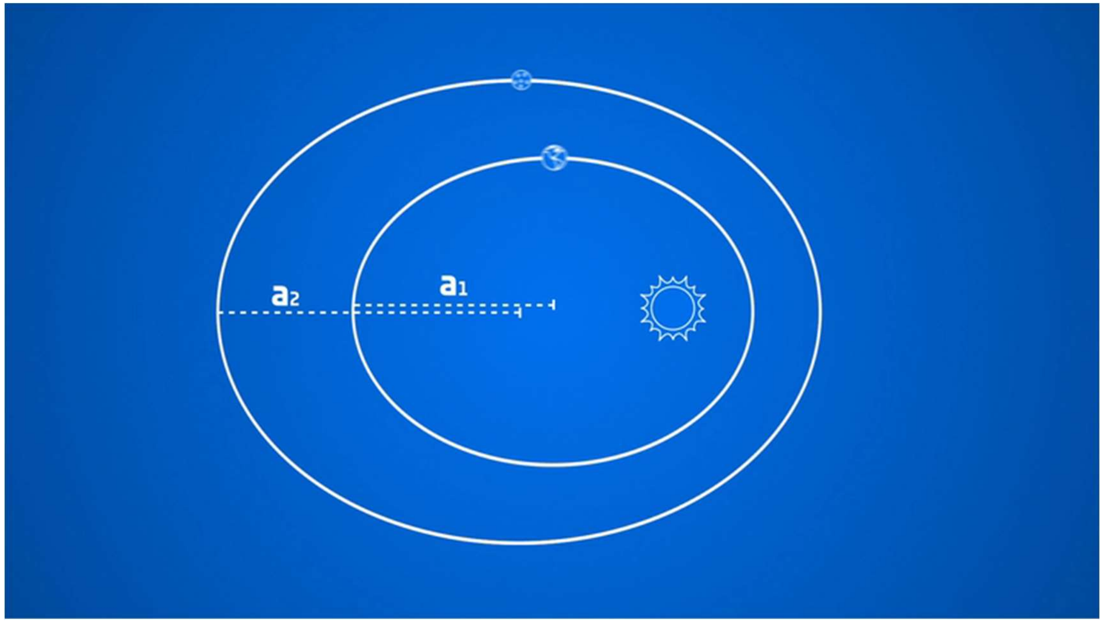


http://www.drennon.org/science/kepler.htm

Kepler's Laws for Satellites

Law III. The squares of the periods of revolution of the satellites about the center of the earth are proportional to the cubes of their mean distances from the center of the earth.

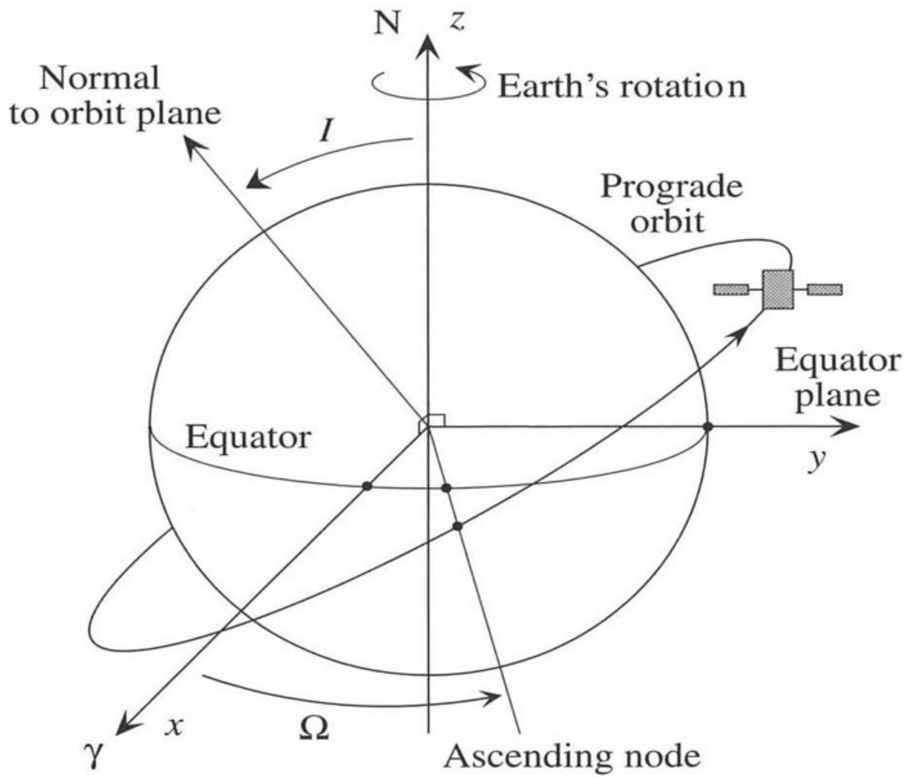
$$\text{i.e. } T = 2\pi\,(h+r_e)^{3/2} \,/\, (GM)^{1/2} \approx 9.952\ 10^{-3}\,(h+6379)^{3/2}$$



Orbital coordinate system

We want a fixed or inertial coordinate system. To define such a system we have to pick a fundamental plane (for example, the earth's equatorial plane or the ecliptic of the sun) and a principal axis, the x-axis lying in the fundamental plane. For orbits around the earth, the most common choice of coordinate system is the right ascension-declination system, where the equatorial plane is the fundamental plane and the x-axis points toward the vernal equinox (a fixed point in space, generally thought of as the constellation Aries).

The coordinates in this system are
α - the right ascension (positive is counter-clockwise)
δ - the declination or angle above the equatorial plane
r - the radial distance from the origin, the earth's center of mass



From Martin, S., An Introduction to Remote Sensing, Cambridge University Press, 2004.

Orbital Elements

Element	***Symbol***
Semimajor axis	a
Eccentricity	ε
Inclination	*i*
Argument of the perigee	ω
Right ascension of the ascending node	Ω
Mean anomaly	M or θ
Epoch time	t_o

Earth Observation Orbits

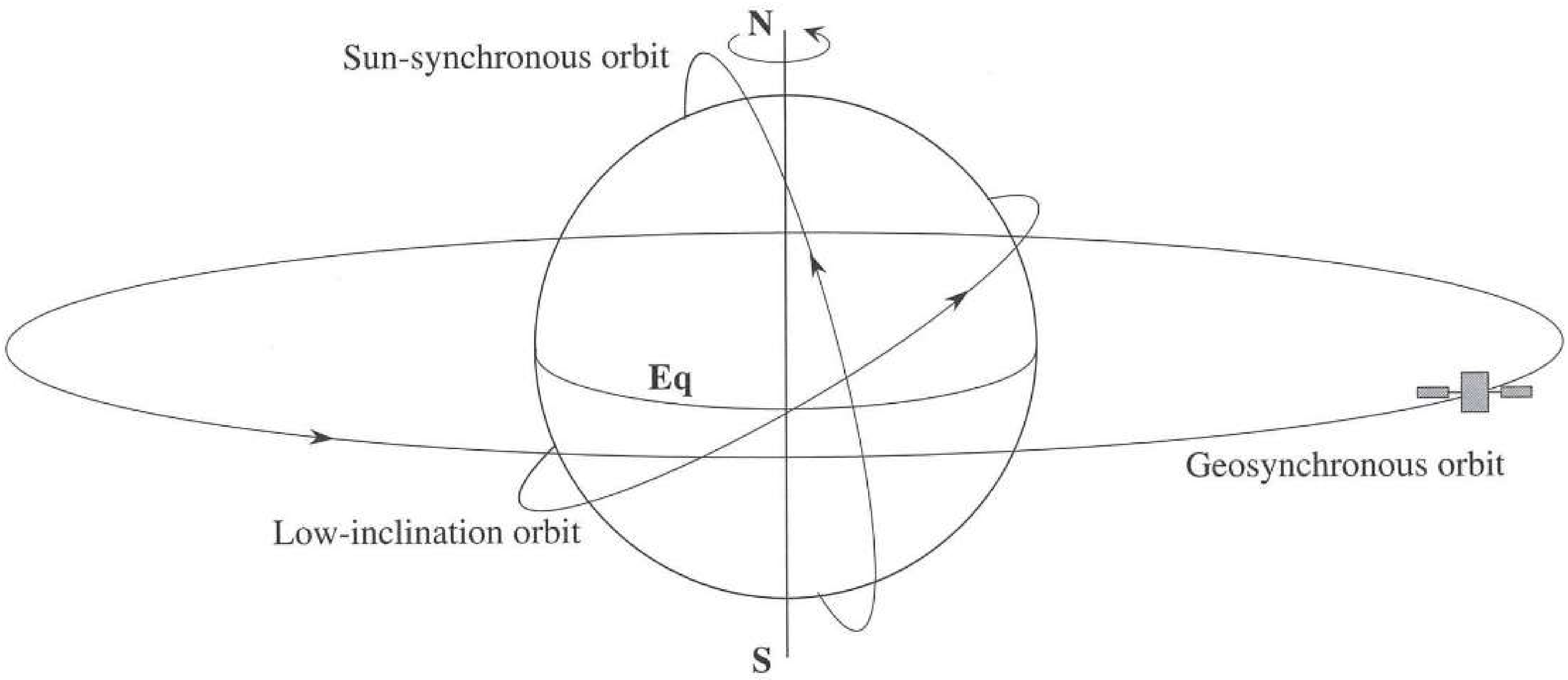
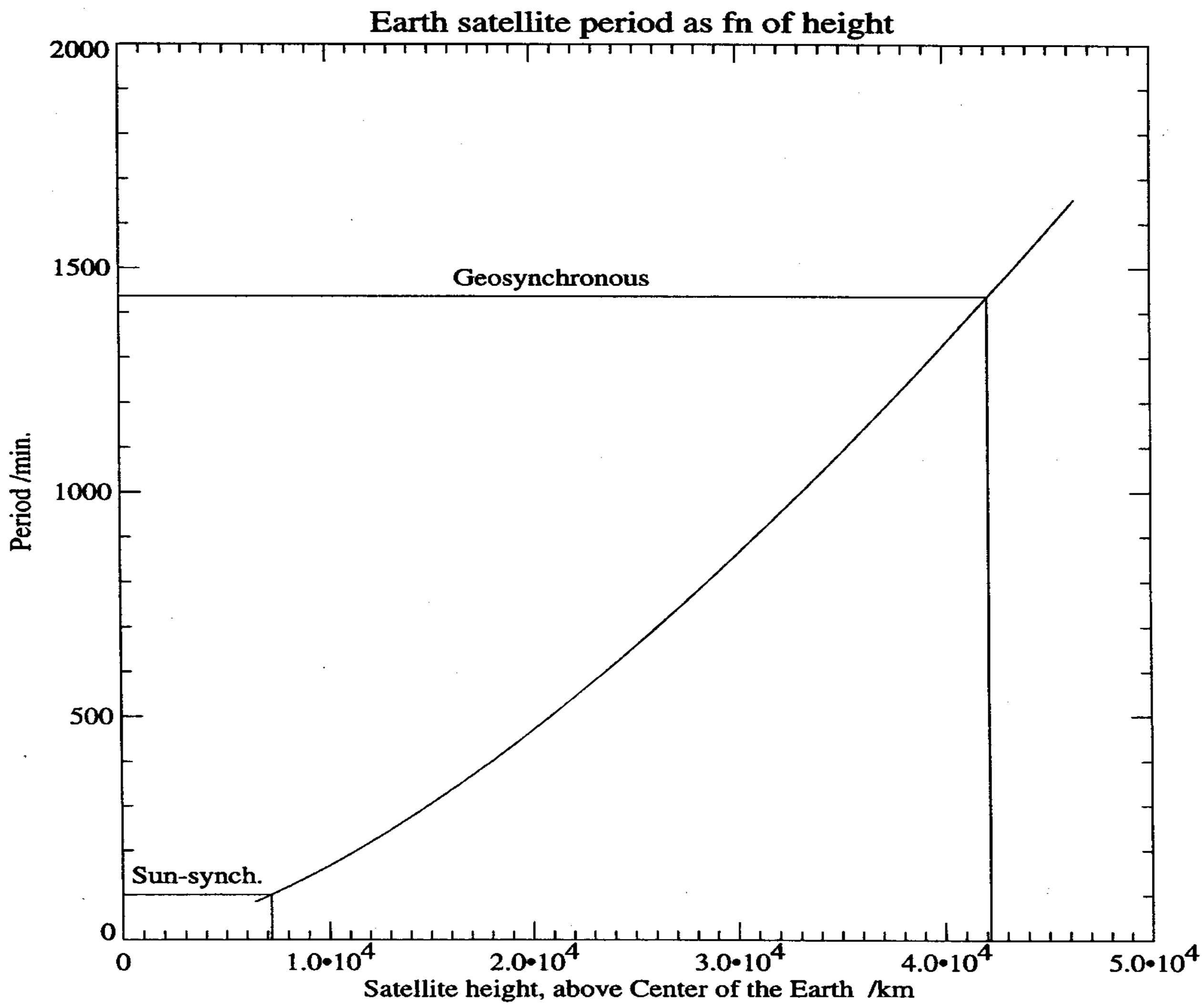


Figure 1.3. Examples of the sun-synchronous, geosynchronous and low-inclination orbits, where 'Eq' is the equator (Adapted from Asrar and Dozier, 1994, Figure 3).

From Martin, S., An Introduction to Remote Sensing, Cambridge University Press, 2004.

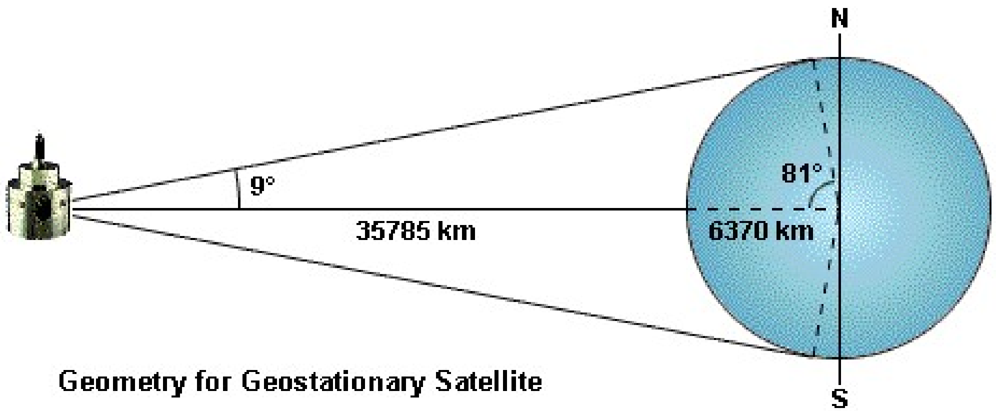
Orbital periods

Kepler's 3rd Law

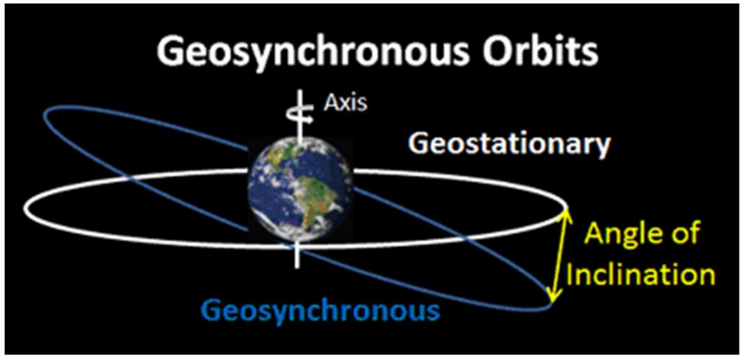


Geostationary Orbit

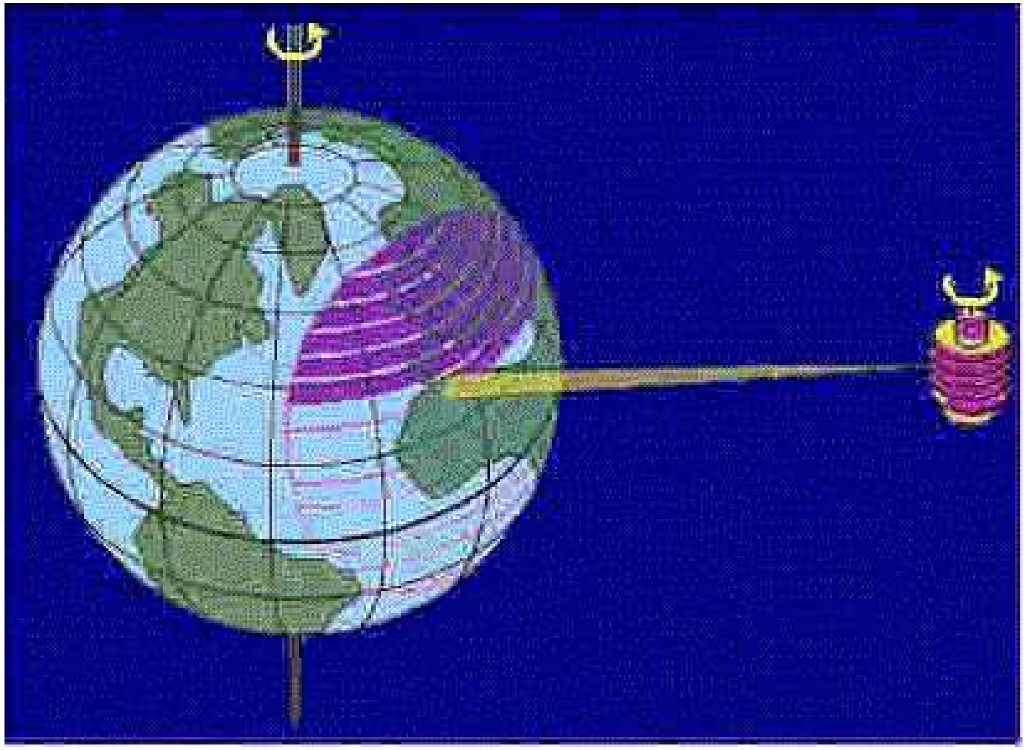
Parameter	Value
Orbital period	1 sidereal day
Height above equator	35,785 km
Orbit radius	42,155 km
Orbit circumference	264,869 km
Arc length per degree	736 km
Orbital velocity	11,066 km/h= 3.07 km/s

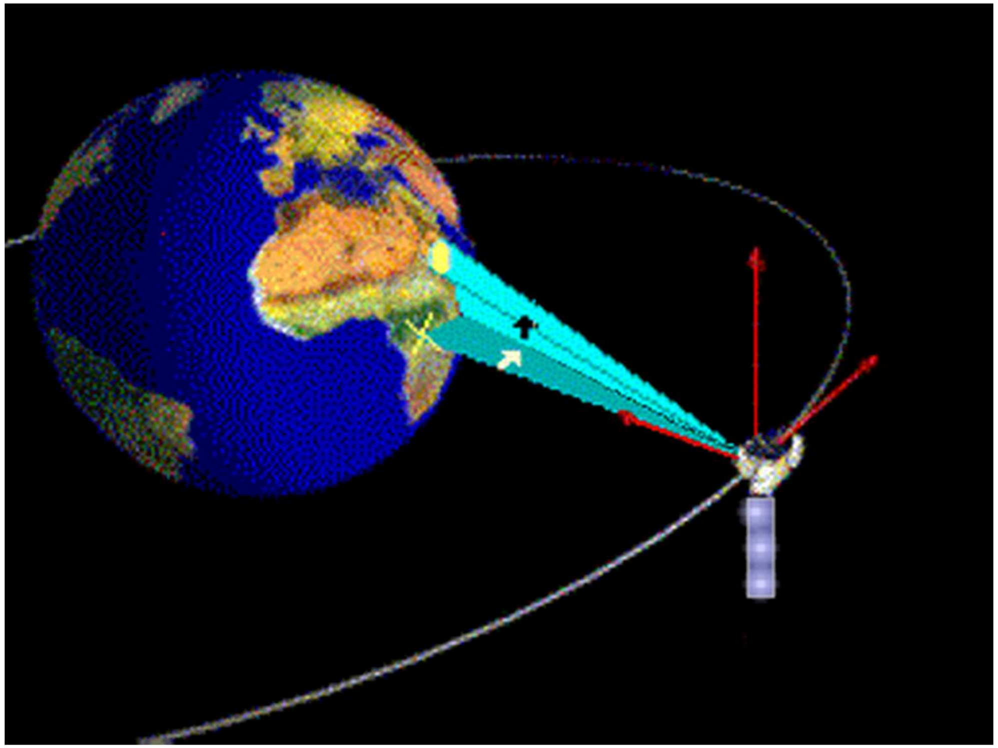


Geometry for Geostationary Satellite



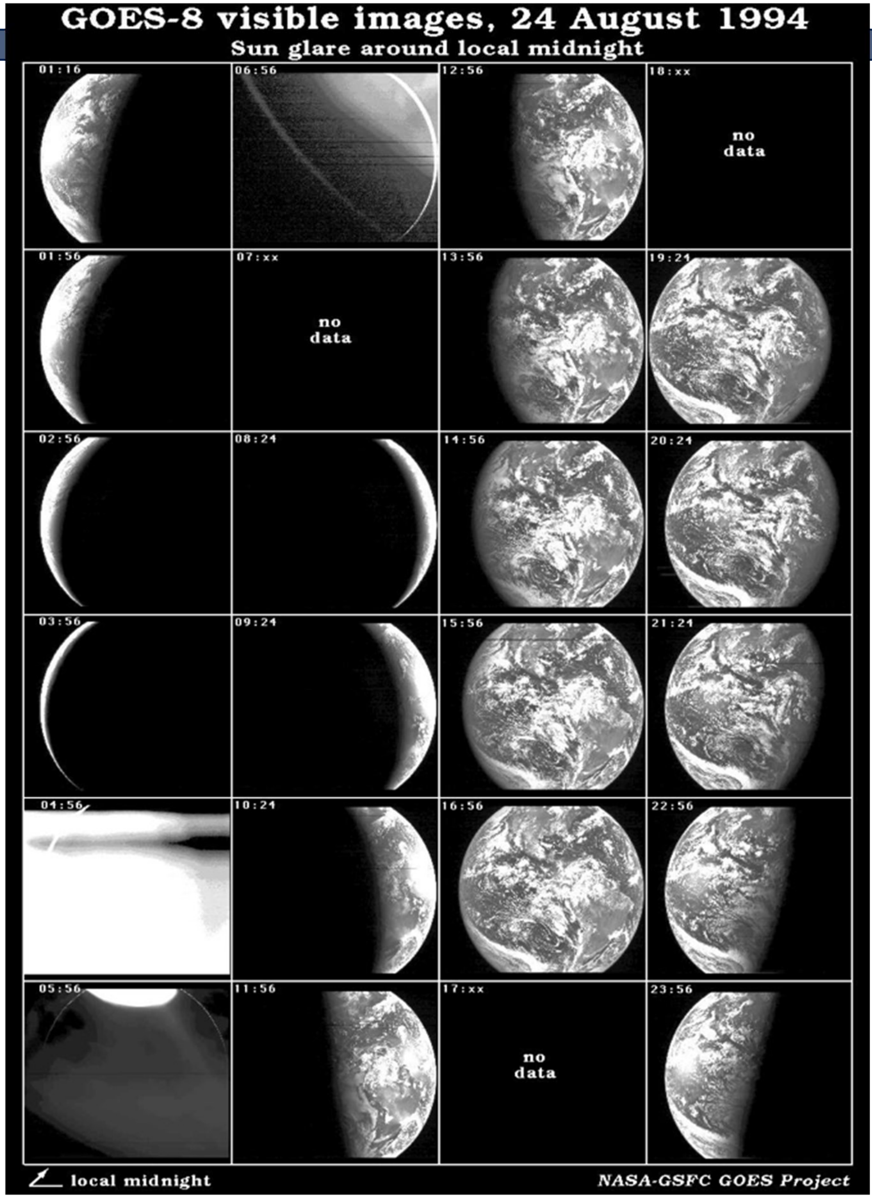
Earth scanning from geostationary orbit





Spin stabilized 3-axis stabilized

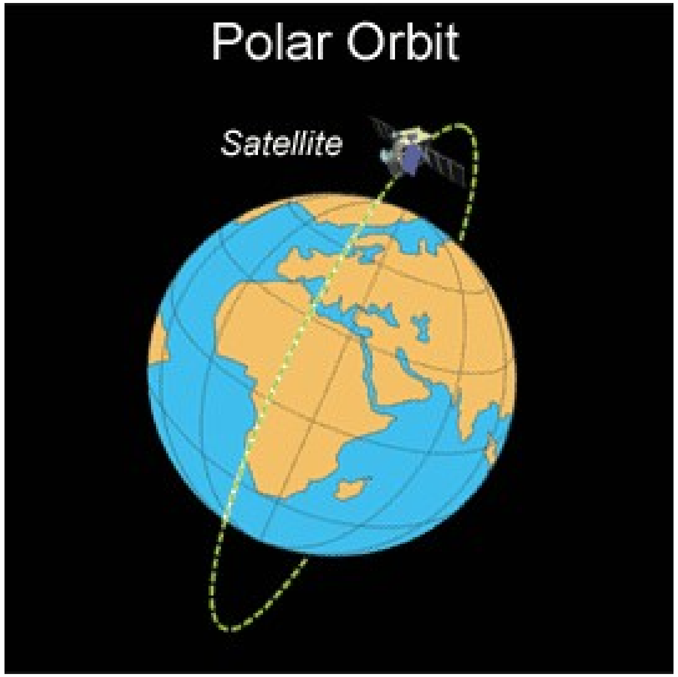
From http://www.eumetcal.org/euromet/english/satmet/s3220/s3220420.htm


GOES-8 visible images, 24 August 1994
Sun glare around local midnight
01:16
06:56
12:56
18:xx
no data
01:56
07:xx
no data
13:56
19:24
02:56
08:24
14:56
20:24
03:56
09:24
15:56
21:24
04:56
10:24
16:56
22:56
05:56
11:56
17:xx
no data
23:56
local midnight
NASA-GSFC GOES Project

Polar orbits

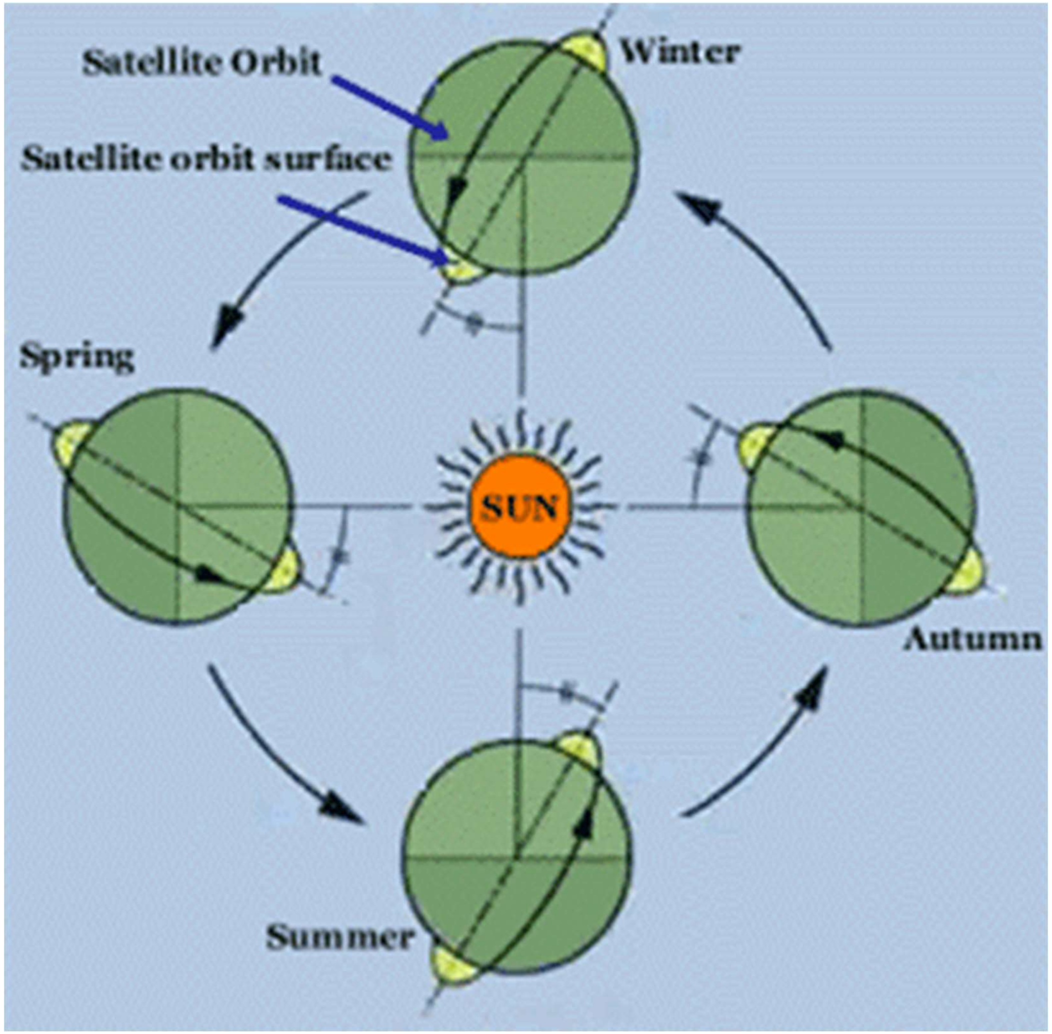
- Polar orbits are those that take the satellite **close** to the poles – not necessarily directly over the poles

- Special case: sun-synchronous - the angle between the orbit and vector to the sun is (nearly) constant
  - Altitude above the surface ~800km
  - Inclination ~98o
  - Period ~100 minutes



Sun synchronous orbit

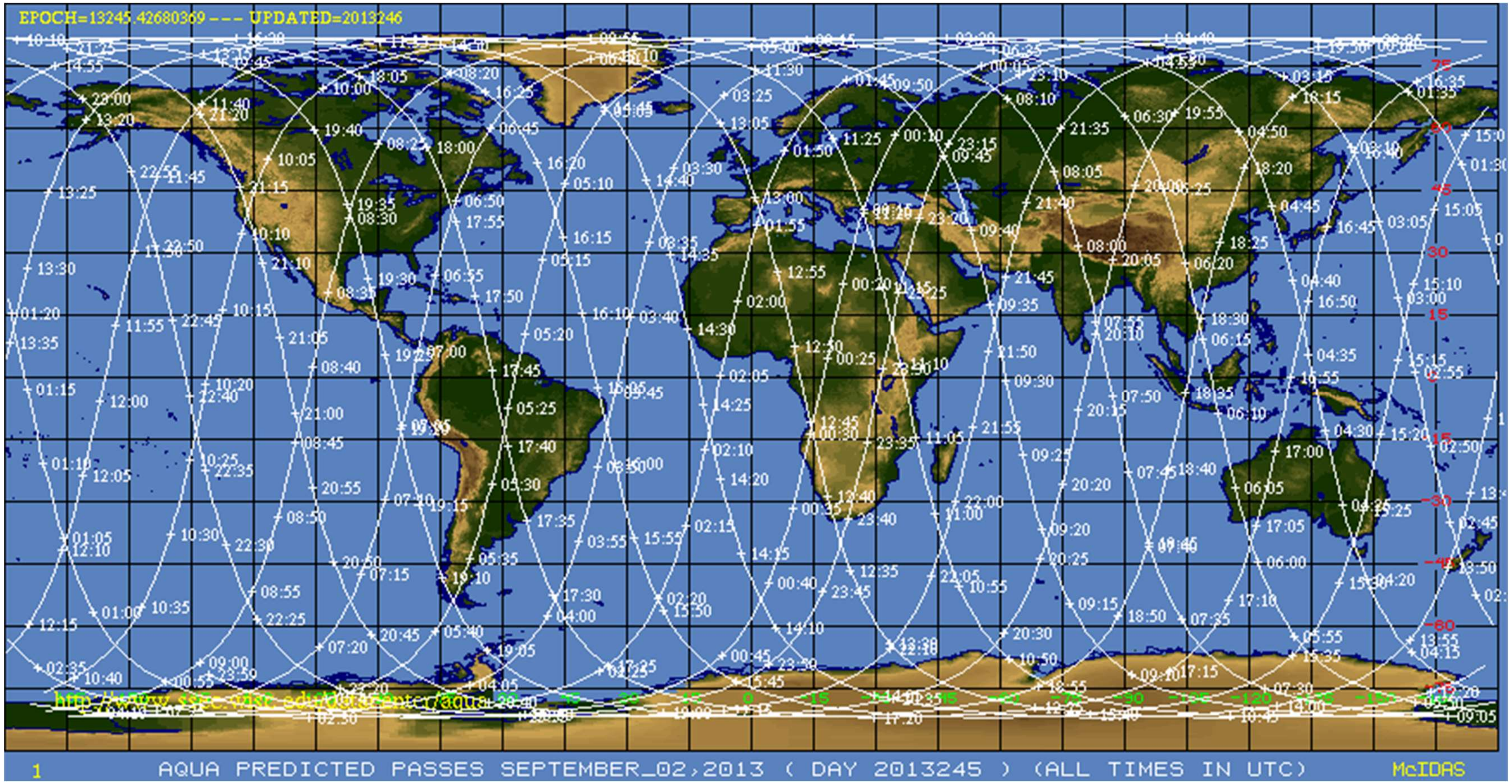
The plane of the orbit has to rotate (precess) once per year as the earth rotates about the sun.



Sun-synchronous orbit

See http://earthobservatory.nasa.gov/Features/Aqua/Aqua_animations.php

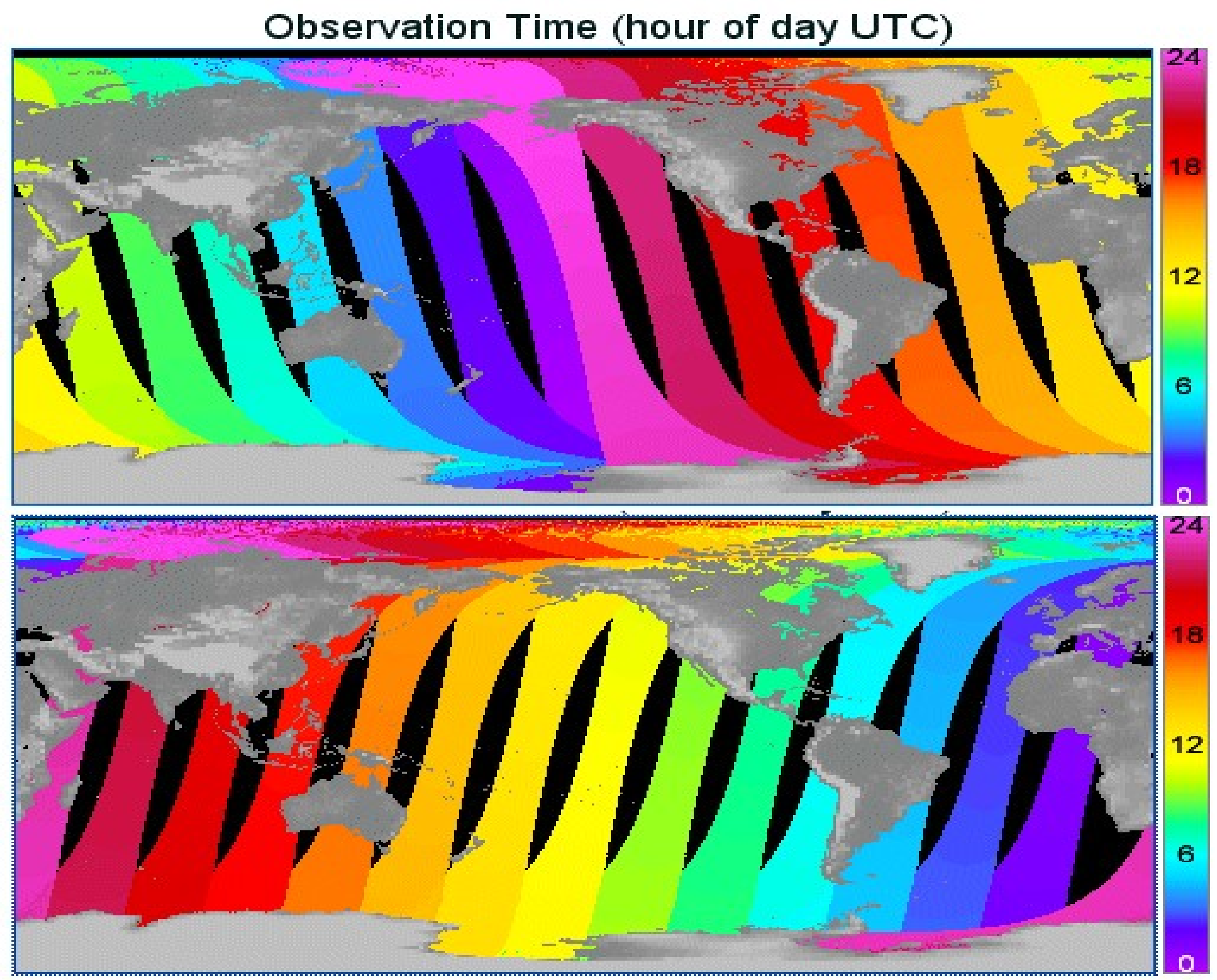
Aqua Orbits


EPOCH=13245.42680369 --- UPDATED=2013246
1
AQUA PREDICTED PASSES SEPTEMBER_02,2013 (DAY 2013245) (ALL TIMES IN UTC)
McIDAS

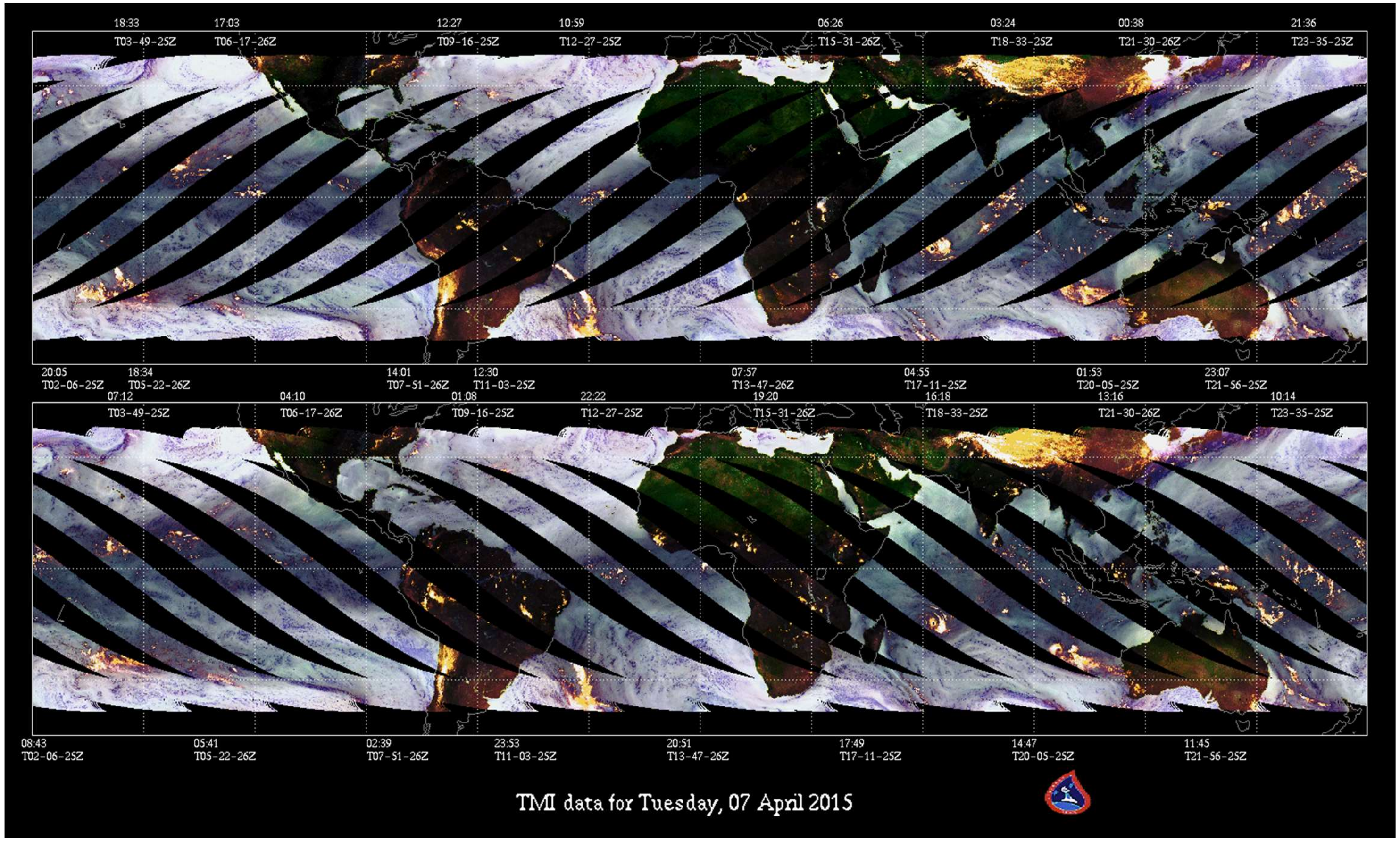
Times of measurements

- Top: Ascending arcs
- Bottom: Descending arcs

Measurements close in space are not necessarily close in time.



Low inclination drifting orbits



Geolocation

The problem is to locate a piece of remotely sensed information derived from a satellite-borne instrument in terms of an Earth-centered coordinate system (latitude and longitude).

1 - **locate the satellite in space** (the *satellite ephemeris* is the position of the satellite at a function of time), using an orbit model and appropriate orbital elements (Brouwer mean orbital elements)

$\Rightarrow$ latitude, longitude of the sub-satellite point and height above the Earth's surface as a function of time

2 - **find the orientation of the satellite** - the *spacecraft attitude* - in its own reference frame (usually the coordinate system defined by the vector to the Earth's center, the satellite velocity vector in the orbital plane, and an orthogonal vector out of the orbital plane)

$\Rightarrow$ roll, pitch and yaw angles as a function of time

3 - **find where the instrument is looking** - requires knowledge of the antenna geometry or scanning mechanism.

$\Rightarrow$ instrument dependent, but for an imaging instrument it is determined by scan-mirror angle as a function of time.

Off-nadir effects

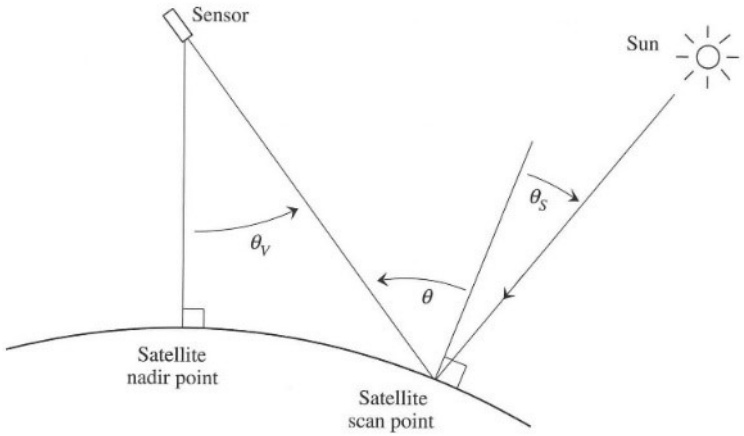


Figure 1.8. The angles used to describe the sensor view direction and the solar angle relative to a spherical Earth. The angle θ_V is the view or scan angle associated with the satellite sensor and is defined relative to satellite nadir, θ is the zenith incidence or look angle and θ_S is the solar zenith angle, both defined relative to the local vertical at the satellite scan point.

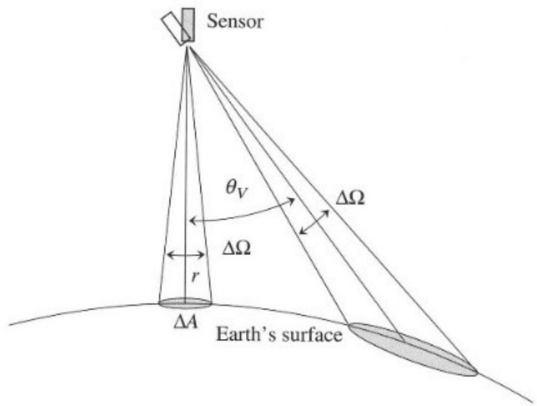


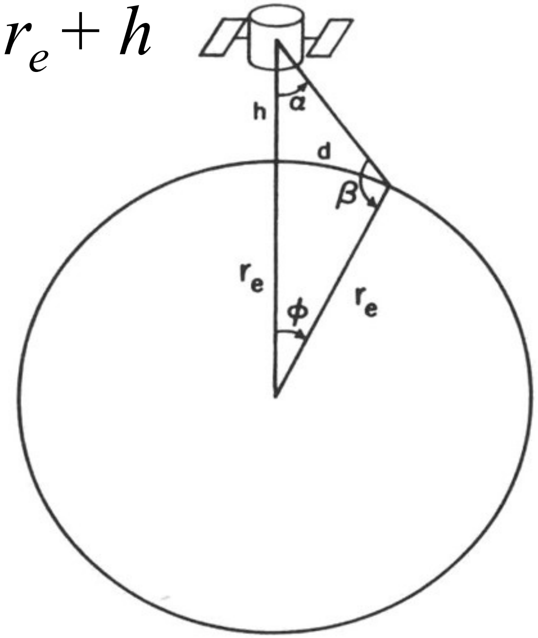
Figure 1.9. The surface area observed by an optical instrument with a constant solid angle field-of-view for nadir and off-nadir view angles.

From *An Introduction to Ocean Remote Sensing*, Seelye Martin, 2004

Scan geometry

SeaWiFS image of the Western Mediterranean Sea (NASA)

$$r_s = r_e + h$$



Determining the distance of a scan spot from the subsatellite point.

If α is the scan angle, then the law of sines gives the angle β as

$$\sin\beta = \left(\frac{r_s}{r_e}\right)\sin\alpha.$$

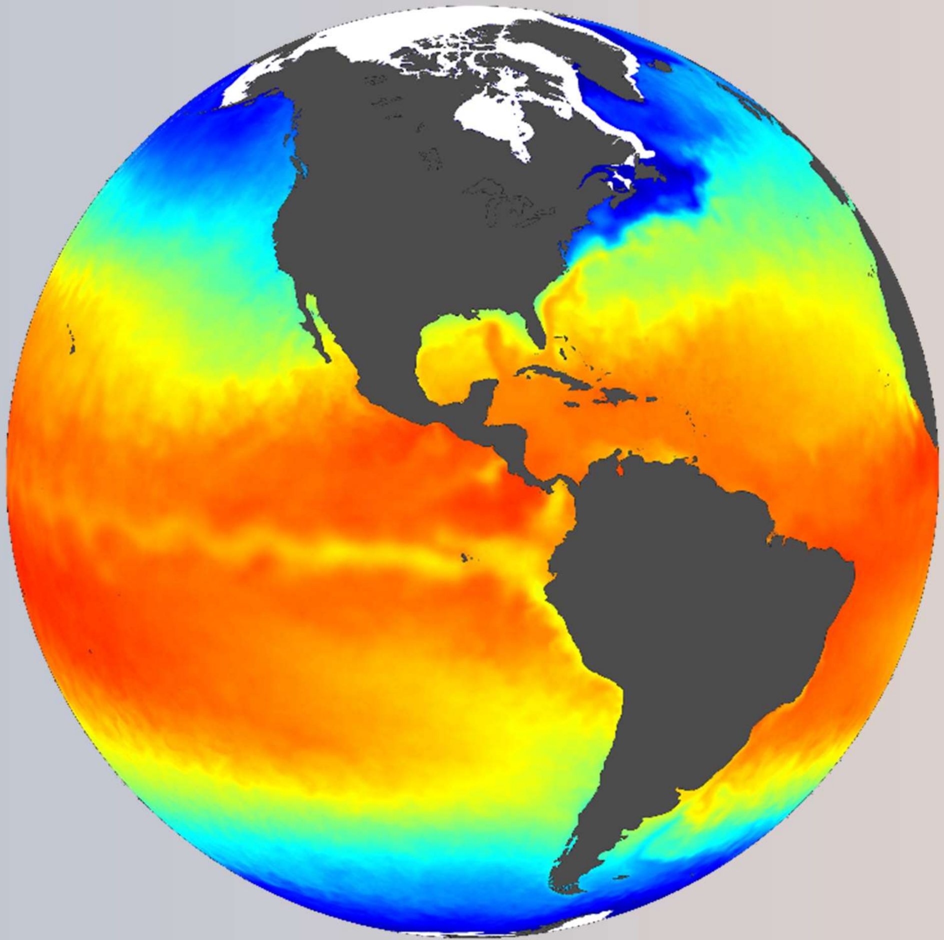
The angle measured from the center of the Earth is

$$\phi = \pi - \beta - \alpha,$$

and the distance from the subsatellite point to the scan spot is ϕr_e.

All for now….

Questions?



To provide operational users and the science community with the SST measured by the satellite constellation

What is Sea-Surface Temperature ?

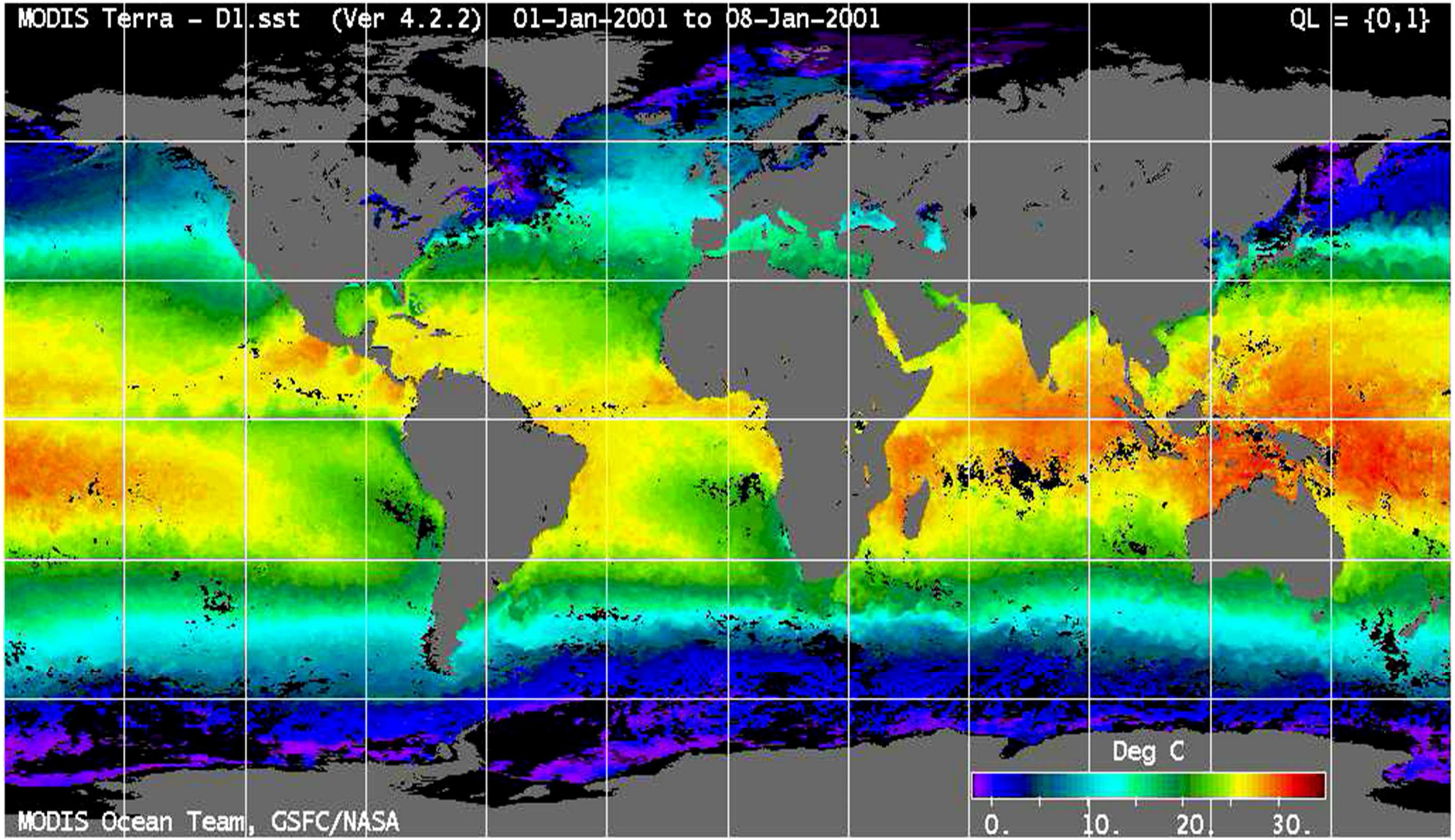
Peter Minnett

GHRSST

Group for High Resolution Sea Surface Temperature

CEOS

Committee on Earth Observation Satellites
Sea Surface Temperature Virtual Constellation


MODIS Terra - D1.sst (Ver 4.2.2) 01-Jan-2001 to 08-Jan-2001
QL = {0,1}
Deg C
0.
10.
20.
30.
MODIS Ocean Team, GSFC/NASA

What is SST?

- SST is a variable function of time and space, determined by integrated fluxes (including insolation), turbulent mixing, and advection (including upwelling).
- “SST” depends on how and where measured:
  - Heat flux between ocean and atmosphere leads to a skin layer at the ocean surface
  - Absorption of insolation can lead to surface gradients, especially in low winds.

SST & the thermal skin layer

- The skin layer exists as a consequence of heat exchange from ocean to atmosphere.
- The skin layer is a ‘bottleneck’ in the heat flow from ocean to atmosphere, and it is this flow of heat that drives evaporation and sensible heat flow.
- The skin-bulk temperature difference, can be a significant fraction of the conventional air-sea temperature difference.
- SST could be an indicator of climate change, and satellite radiometers a global thermometer.

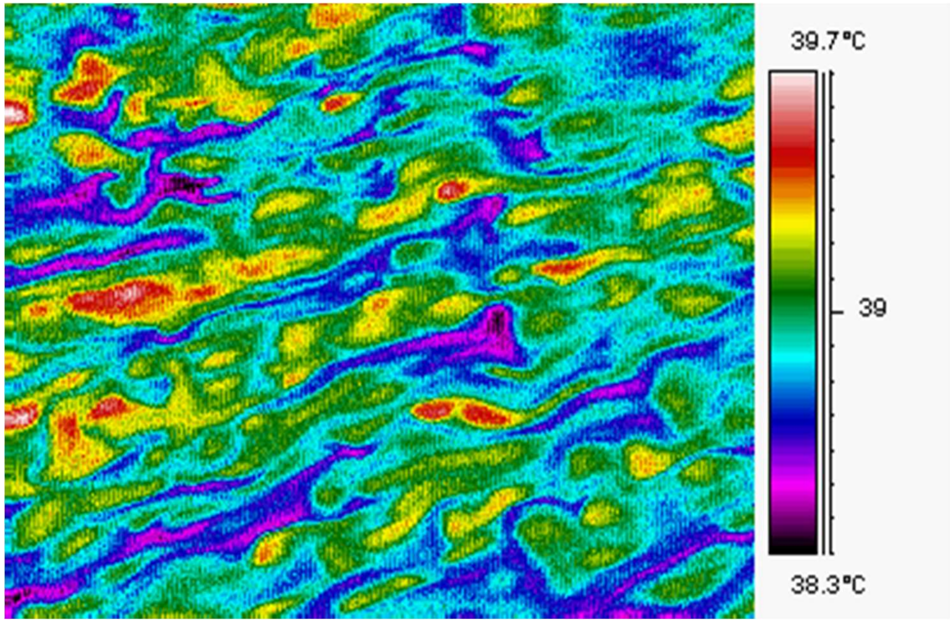
What is SST? –skin *vs.* bulk

The optical depth of sea water at infrared wavelengths is < 1mm. The **source of the infrared signal** used in remote sensing is the **skin layer** of the ocean, which is generally cooler than the subsurface layer because of heat flow from the ocean to the atmosphere.

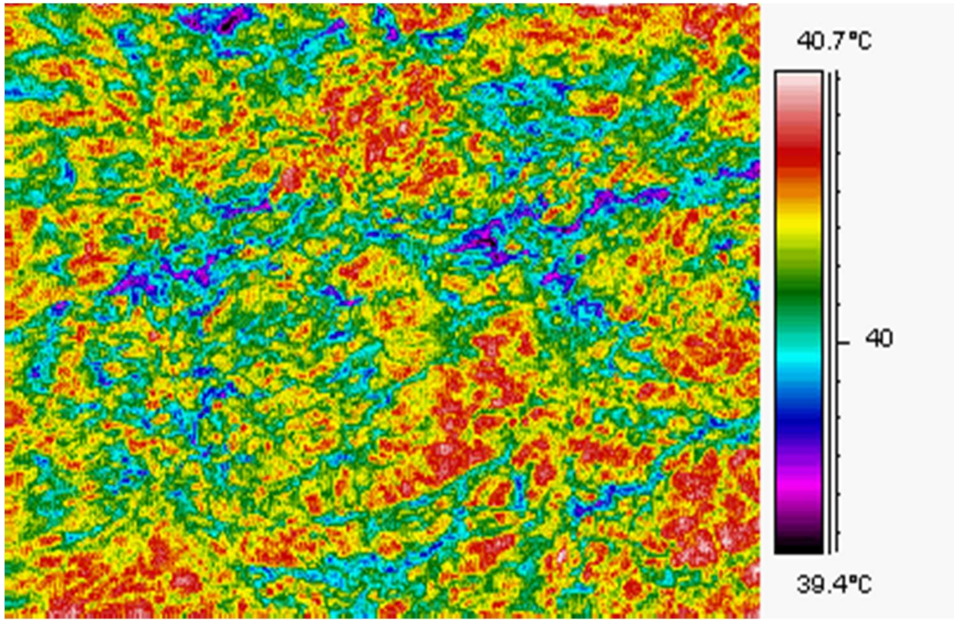
The **conventional** meaning of **SST** is the temperature measured at a **depth of a meter** or more by a contact thermometer; the so-called bulk temperature.

At the levels of accuracy at which SST can be measured from space, skin and bulk temperatures are not the same.

Small-scale structure of the skin SST

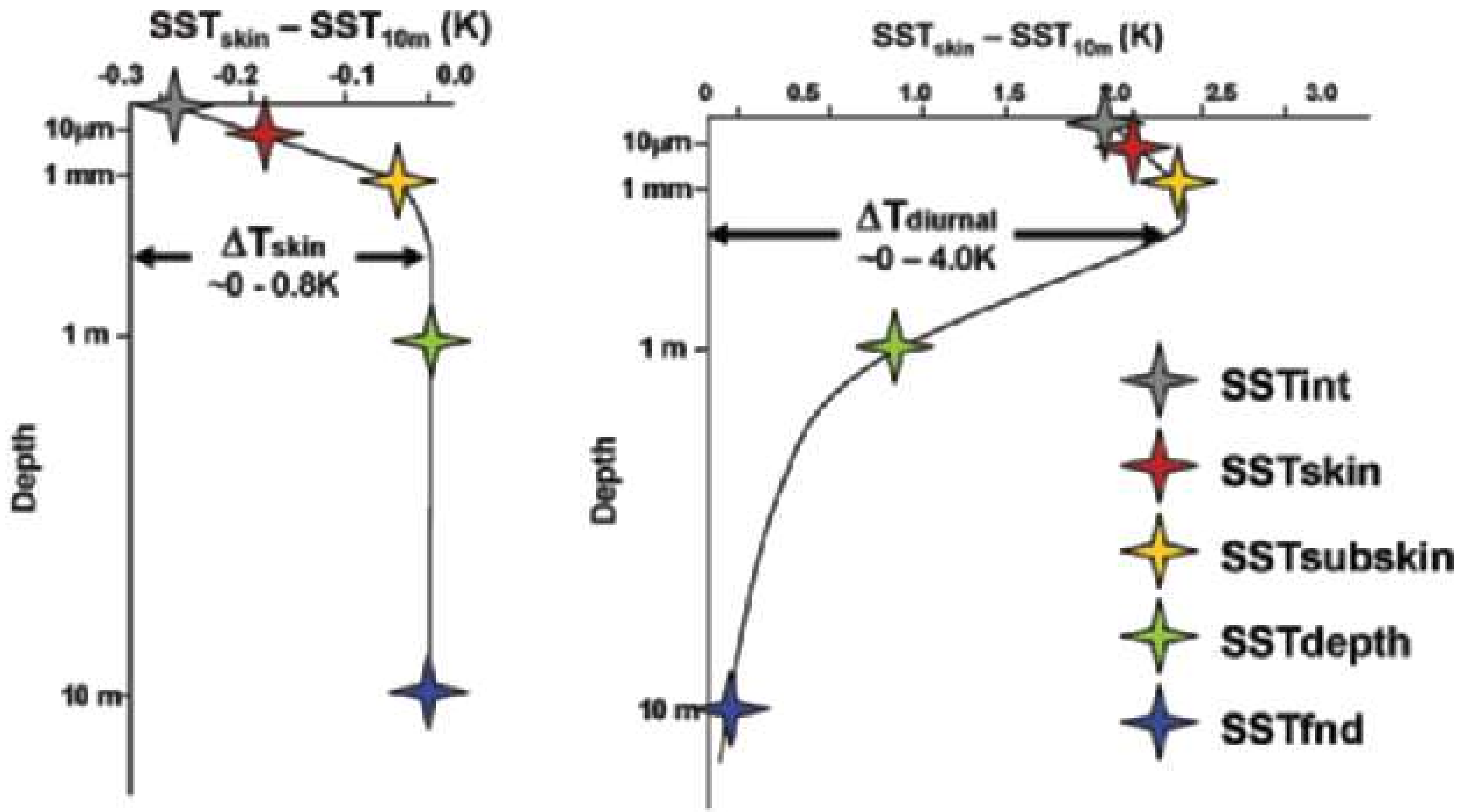


2 ms^{-1} -15K



9 ms^{-1} -15K

Schematic Temperature Profiles



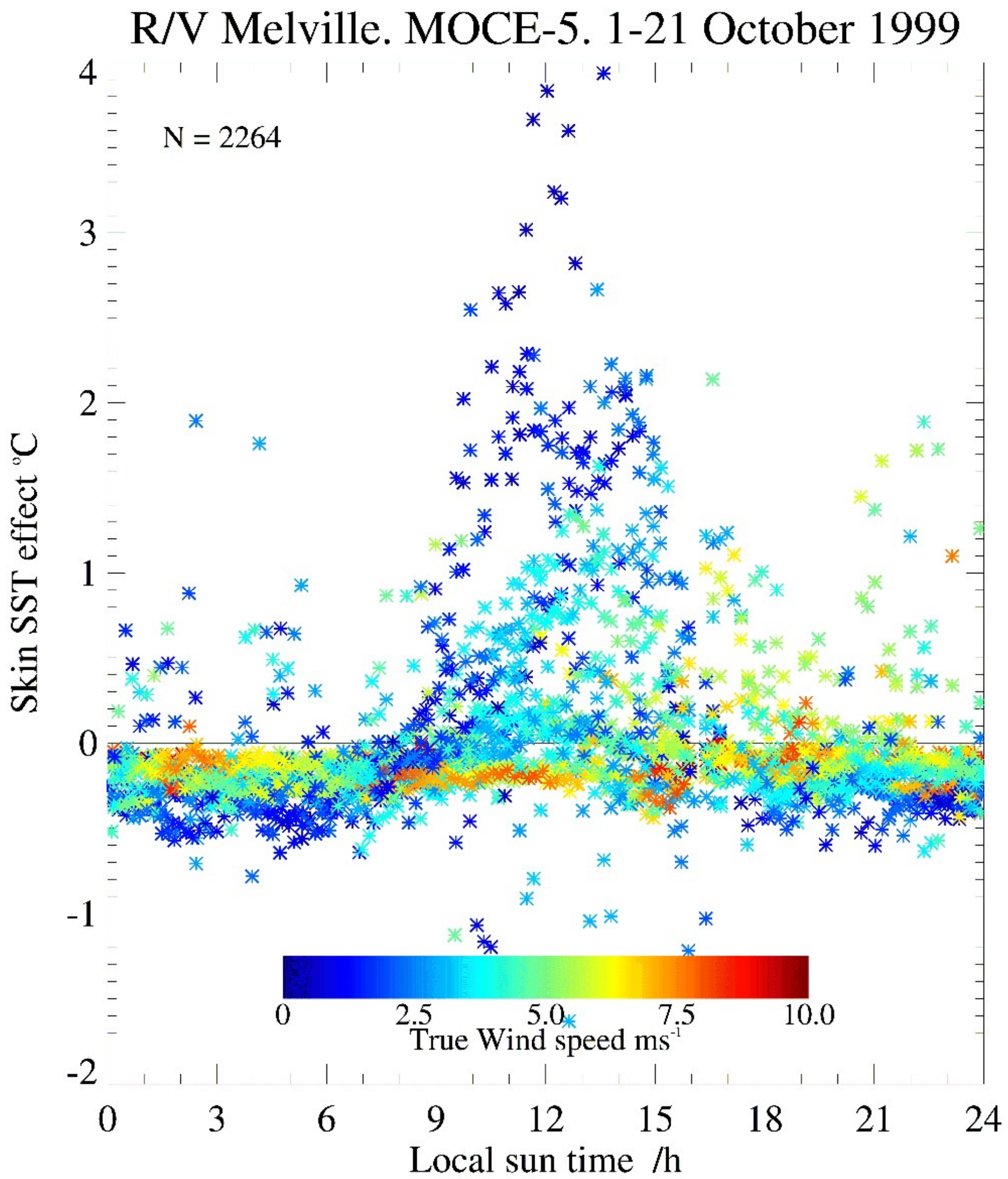
(a) Night time situation, light wind

(b) Day time situation, strong solar radiation and light winds

Donlon, et al. (2007). The Global Ocean Data Assimilation Experiment High-resolution Sea Surface Temperature Pilot Project. *Bulletin of the American Meteorological Society, 88, 1197-1213*

Wind speed dependence of diurnal & skin effects

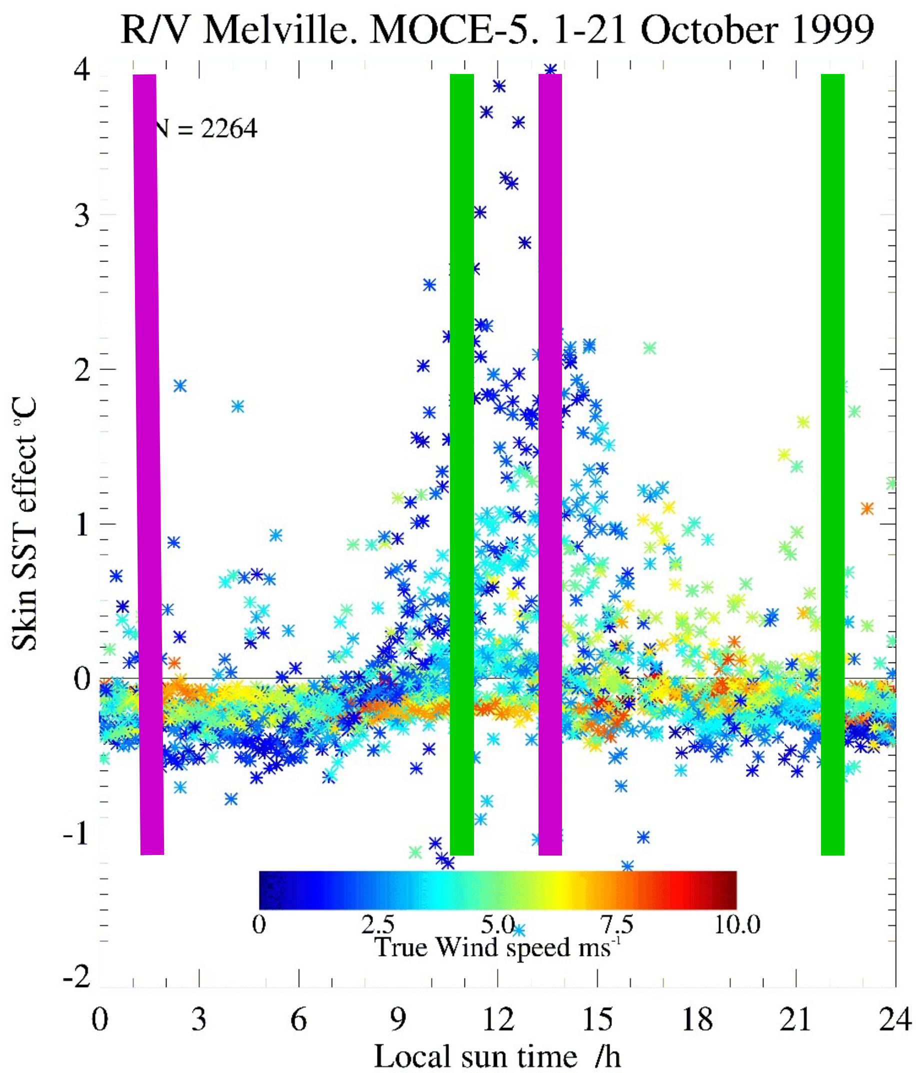
As wind speed increases, magnitude of diurnal heating decreases and peak moves to later in the afternoon.



See: Minnett, P. J. (2003). "Radiometric measurements of the sea-surface skin temperature - the competing roles of the diurnal thermocline and the cool skin." *International Journal of Remote Sensing* **24**(24): 5033-5047

Wind speed dependence of diurnal & skin effects

Terra and Aqua overpass times.

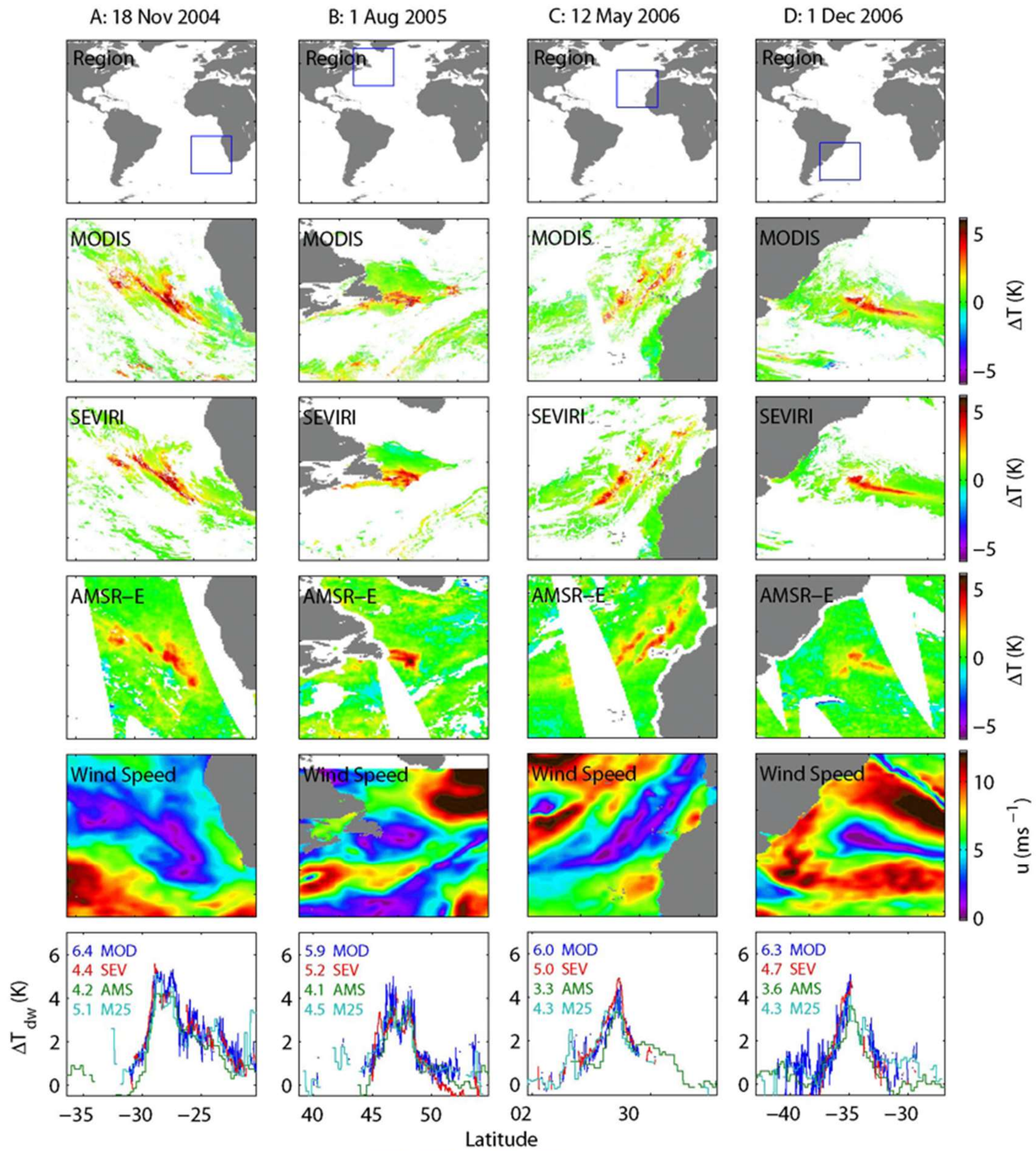


See: Minnett, P. J. (2003). "Radiometric measurements of the sea-surface skin temperature - the competing roles of the diurnal thermocline and the cool skin." *International Journal of Remote Sensing* **24**(24): 5033-5047

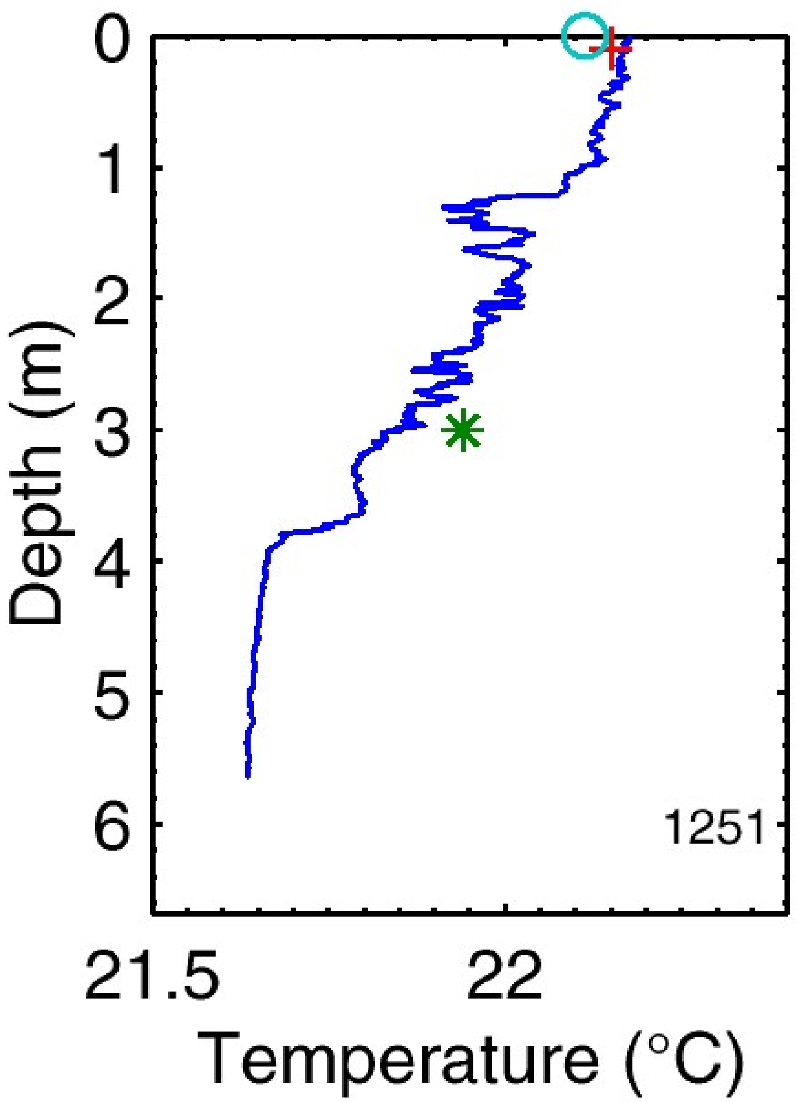
Examples of large amplitude diurnal heating

Large amplitude diurnal heating is identified in independent satellite data.

From Gentemann, C. L., P. J. Minnett, P. LeBorgne, and C. J. Merchant, 2008: Multi-satellite measurements of large diurnal warming events. *Geophysical Research Letters*, 35, L22602. doi:10.1029/2008GL035730



Near surface temperature gradients – reality



Profile measured at 12:51 local time on 4 October 1999. Off Baja California, R/V *Melville* MOCE-5 cruise.

Blue line = SkinDeEP* profile

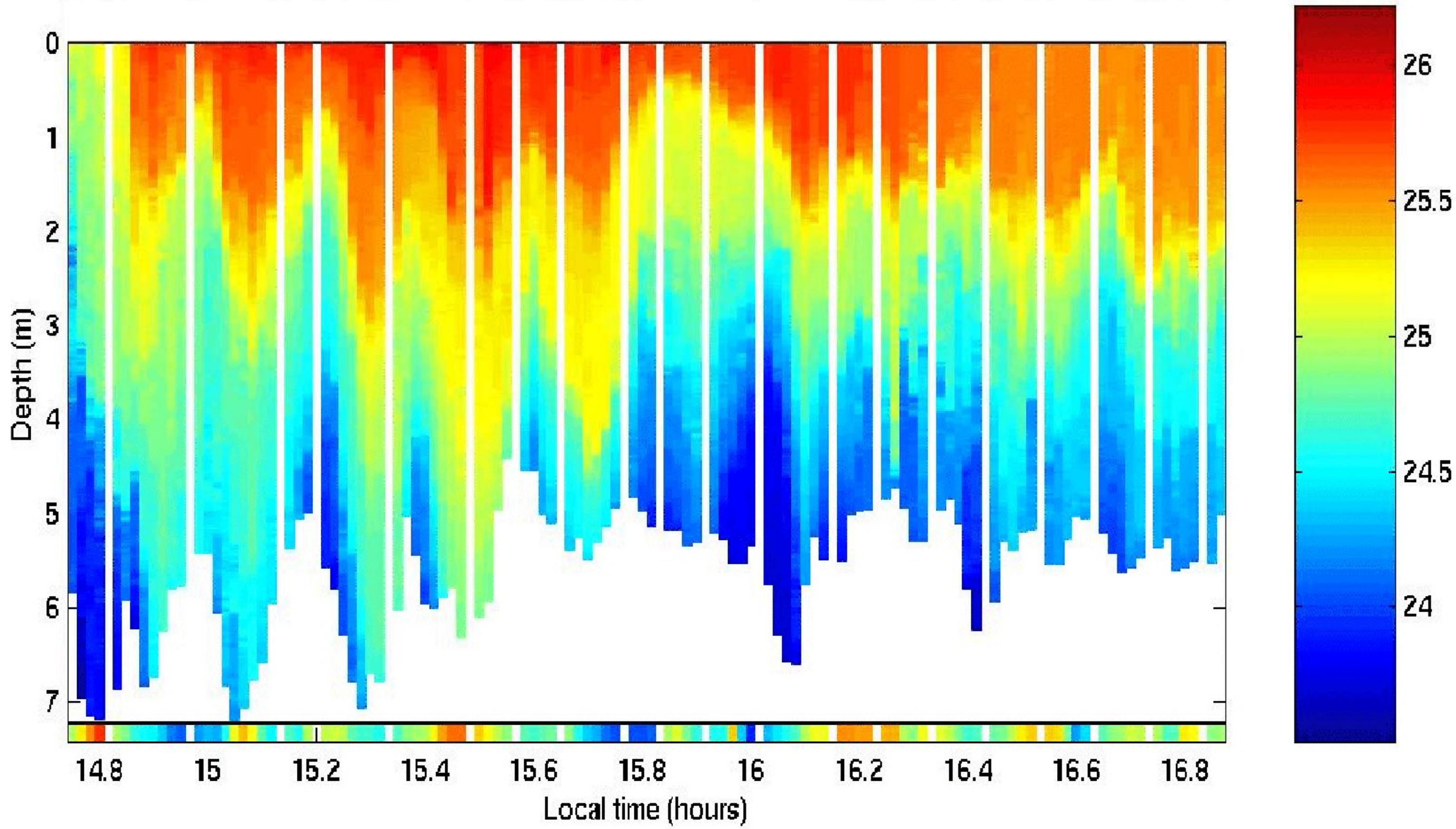
Blue circle = Radiometric (M-AERI) skin temp.

Red cross = Float bulk SST at ~0.05m

Green star = Ship thermosalinograph at ~3m

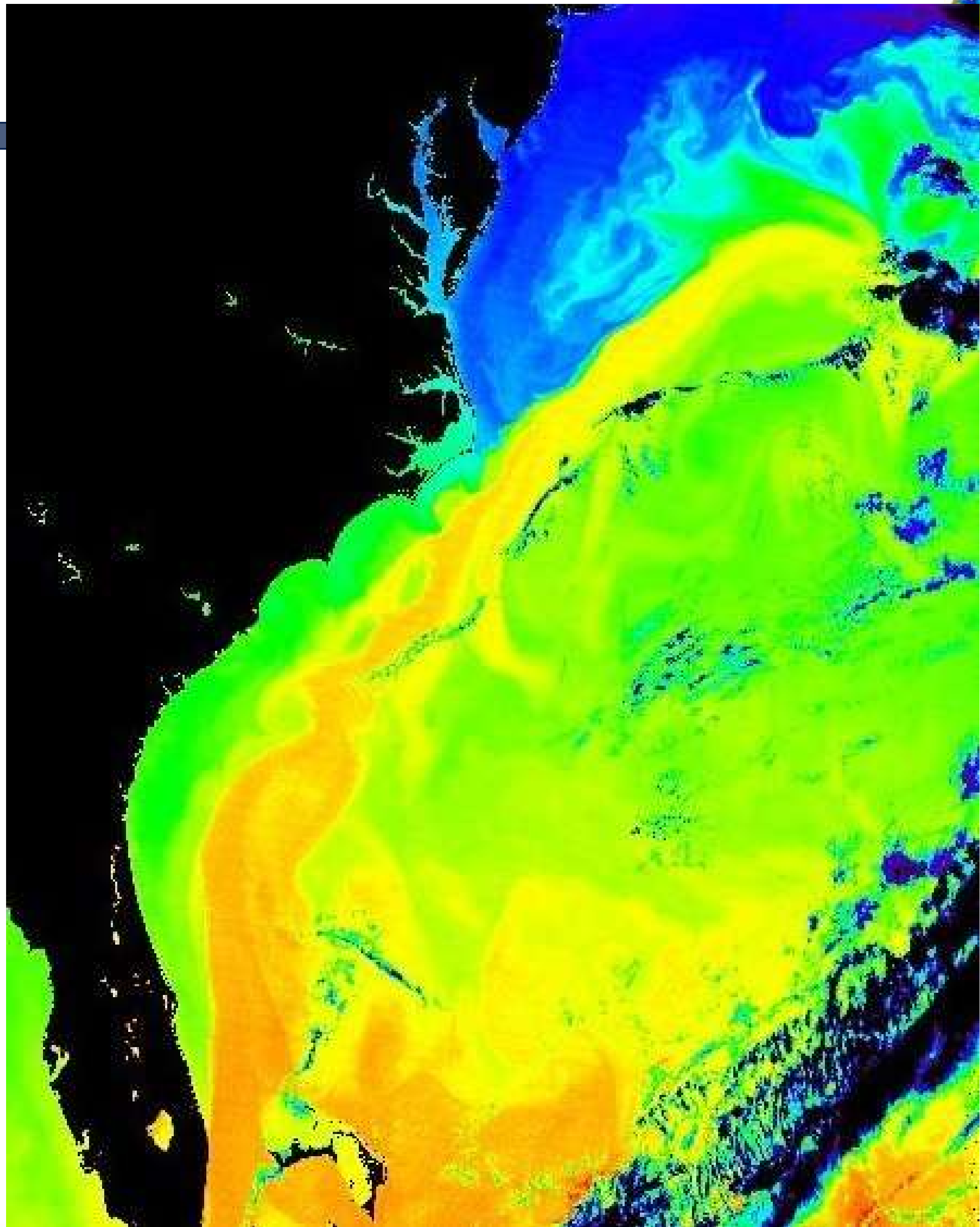
From Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. *Gas Transfer at Water Surfaces.* M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof (Eds.) *American Geophysical Union Monograph 127.* 167 - 172.

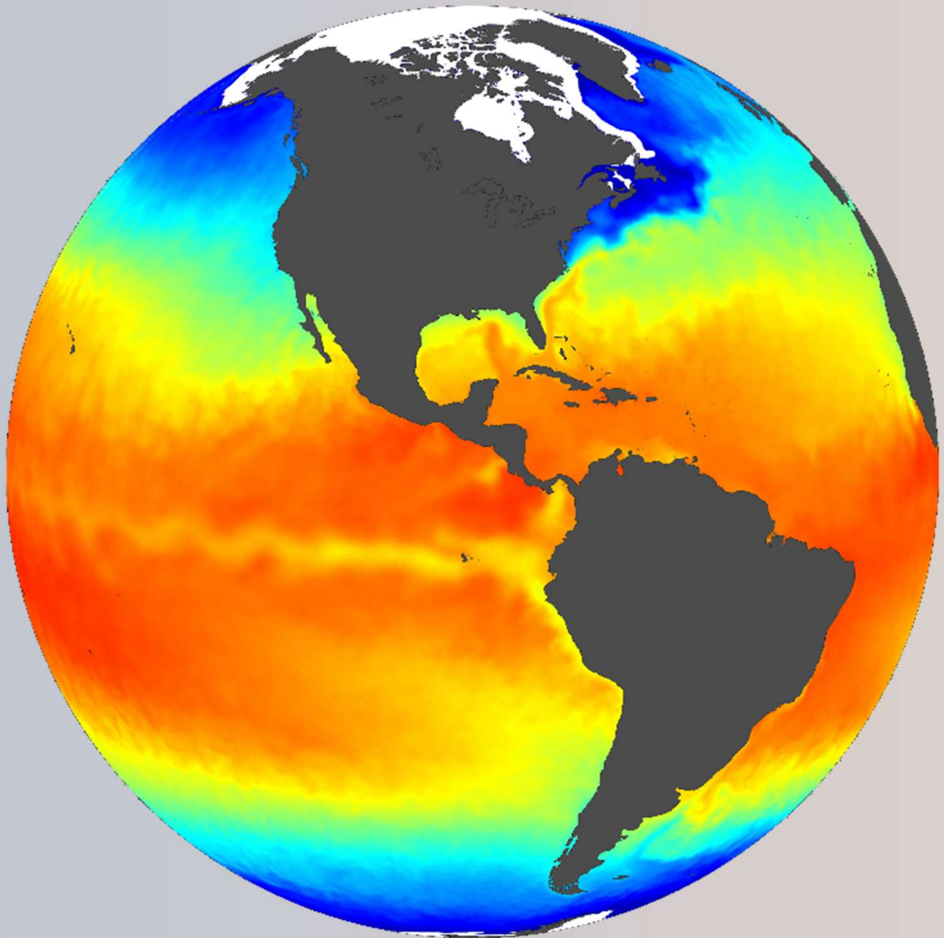
Time evolution of near-surface thermal gradients



SkinDeEP profiles on 12 October 1999. Off Baja California, R/V *Melville*.

From Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. *Gas Transfer at Water Surfaces.* M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof (Eds.) *American Geophysical Union Monograph 127.* 167 - 172.





To provide operational users and the science community with the SST measured by the satellite constellation

Some concepts in atmospheric radiation

Chris Merchant

GHRSST
Group for High Resolution Sea Surface Temperature

CEOS
Committee on Earth Observation Satellites
Sea Surface Temperature Virtual Constellation

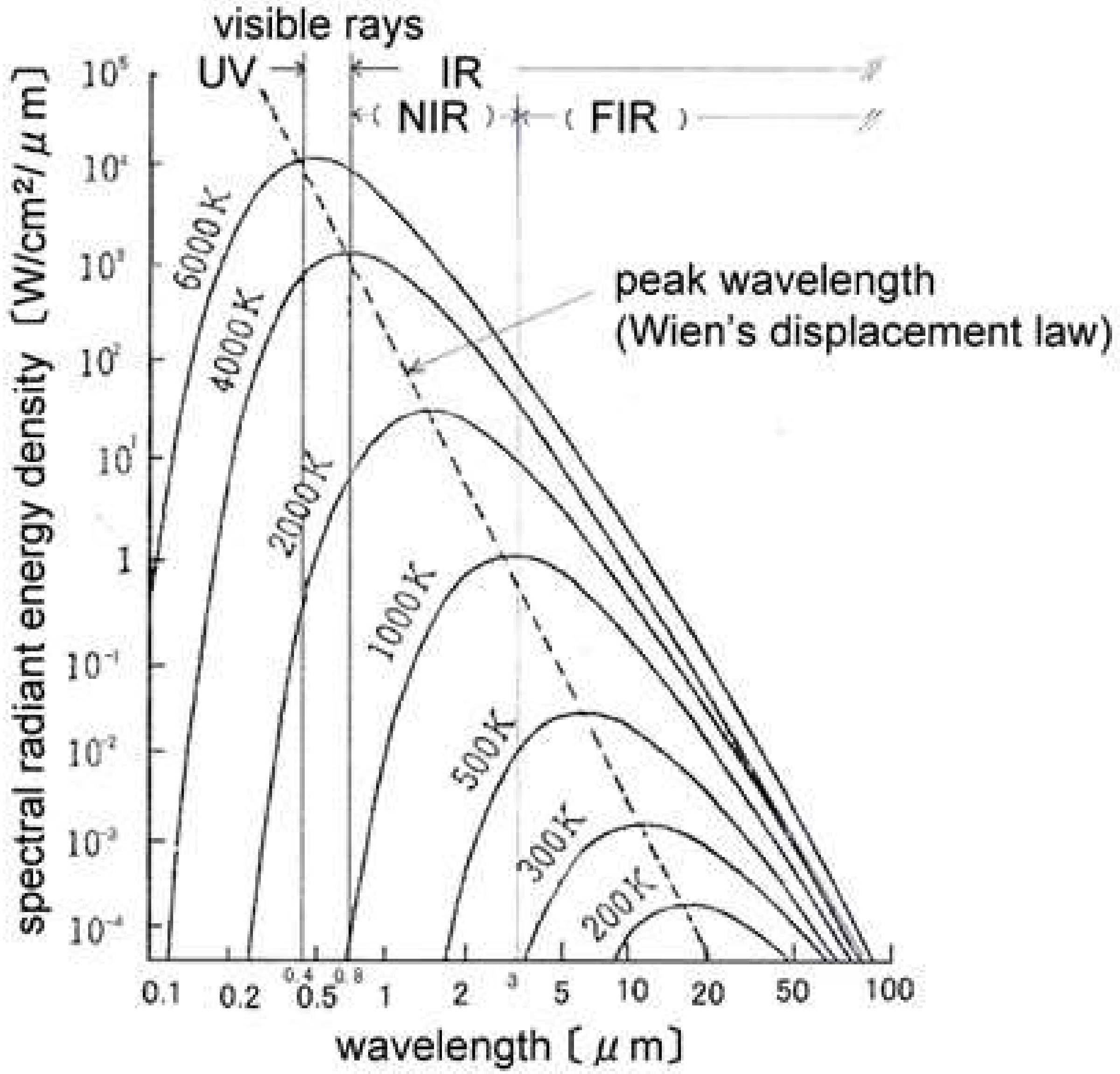
Thermal emission

- For “black-body” emission (not spectrally resolved)
- $M = \int T^4$ NB temperature in kelvin
- The radiance, B, from Planck emission is independent of angle – **isotropic**

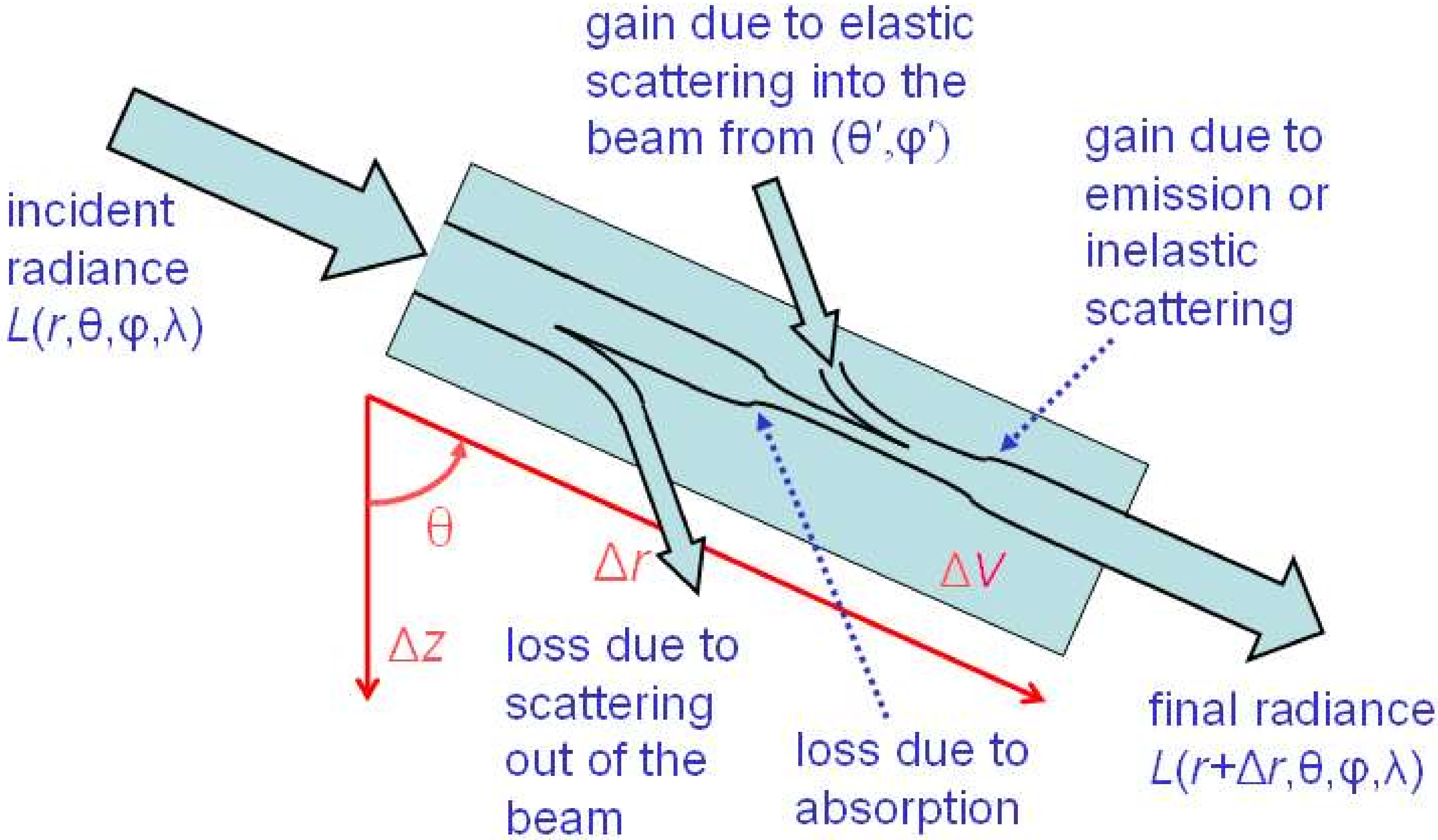
- Question: since we know M, can we calculate B?
- Yes: B = M/□
  - □ = 3.14 geometric factor that relates isotropic radiance to irradiance generally

B_L

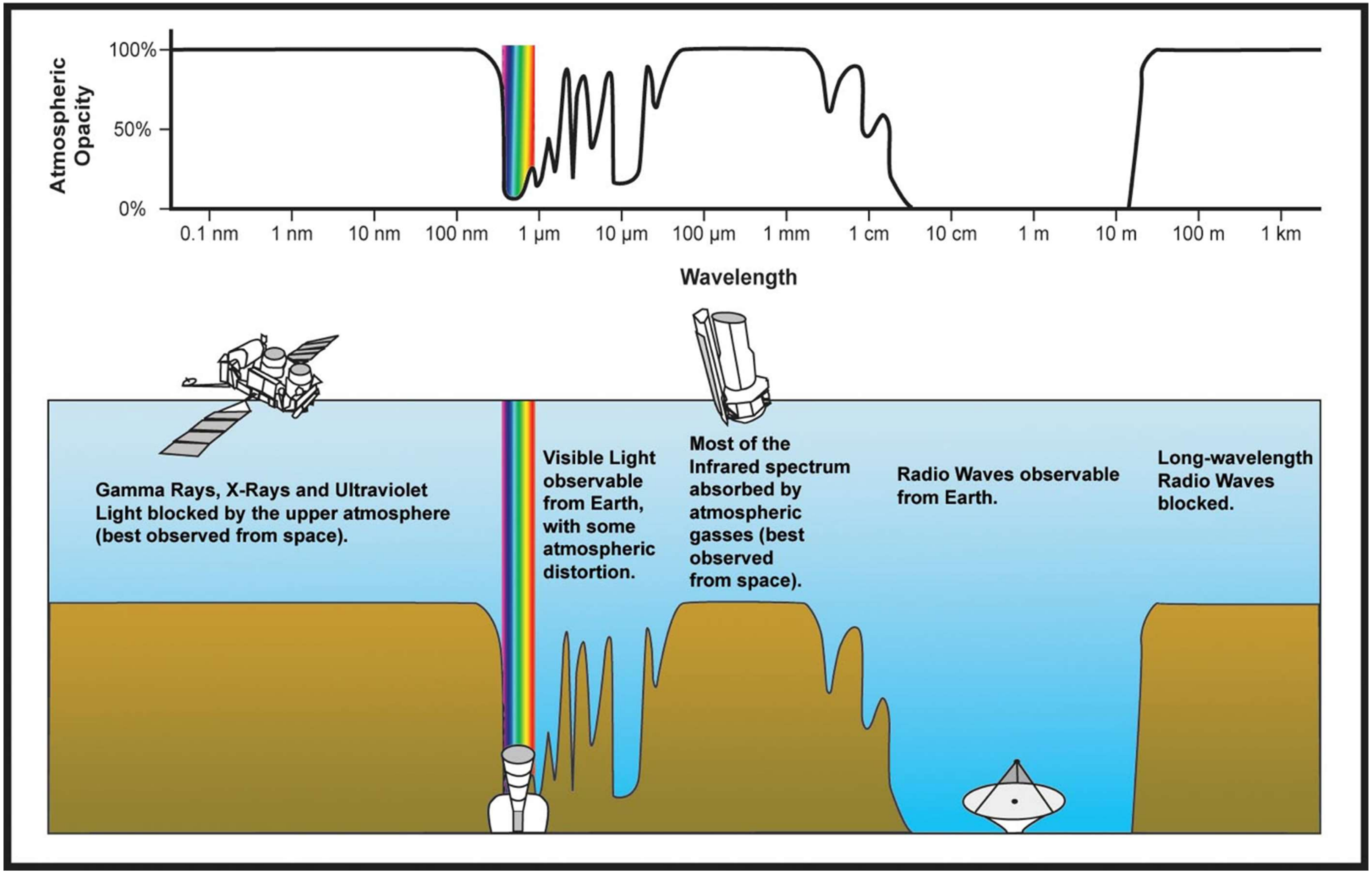
Planck (or "black-body") spectral radiance change v wavelength for various T (in K)

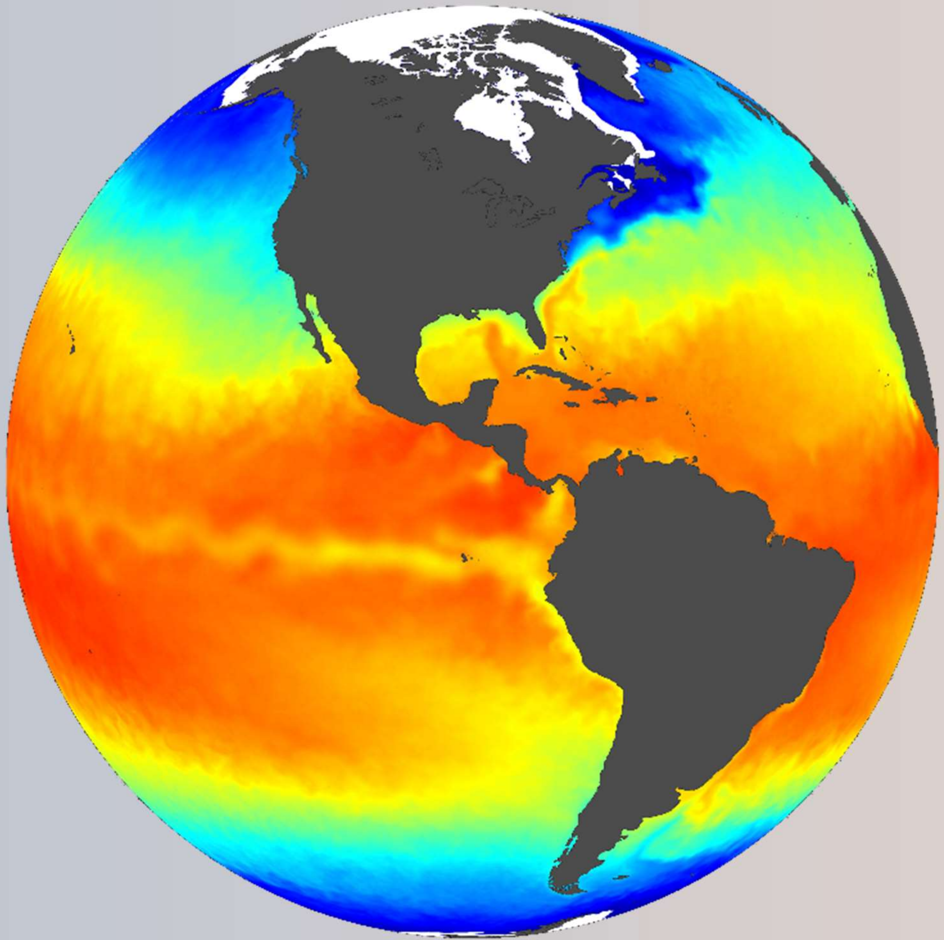


Radiation is modified by medium



Atmospheric opacity





To provide operational users and the science community with the SST measured by the satellite constellation

Examples of satellite images to discuss

Peter Minnett and

Chris Merchant

GHRSST

Group for High Resolution Sea Surface Temperature

CEOS

Committee on Earth Observation Satellites
Sea Surface Temperature Virtual Constellation