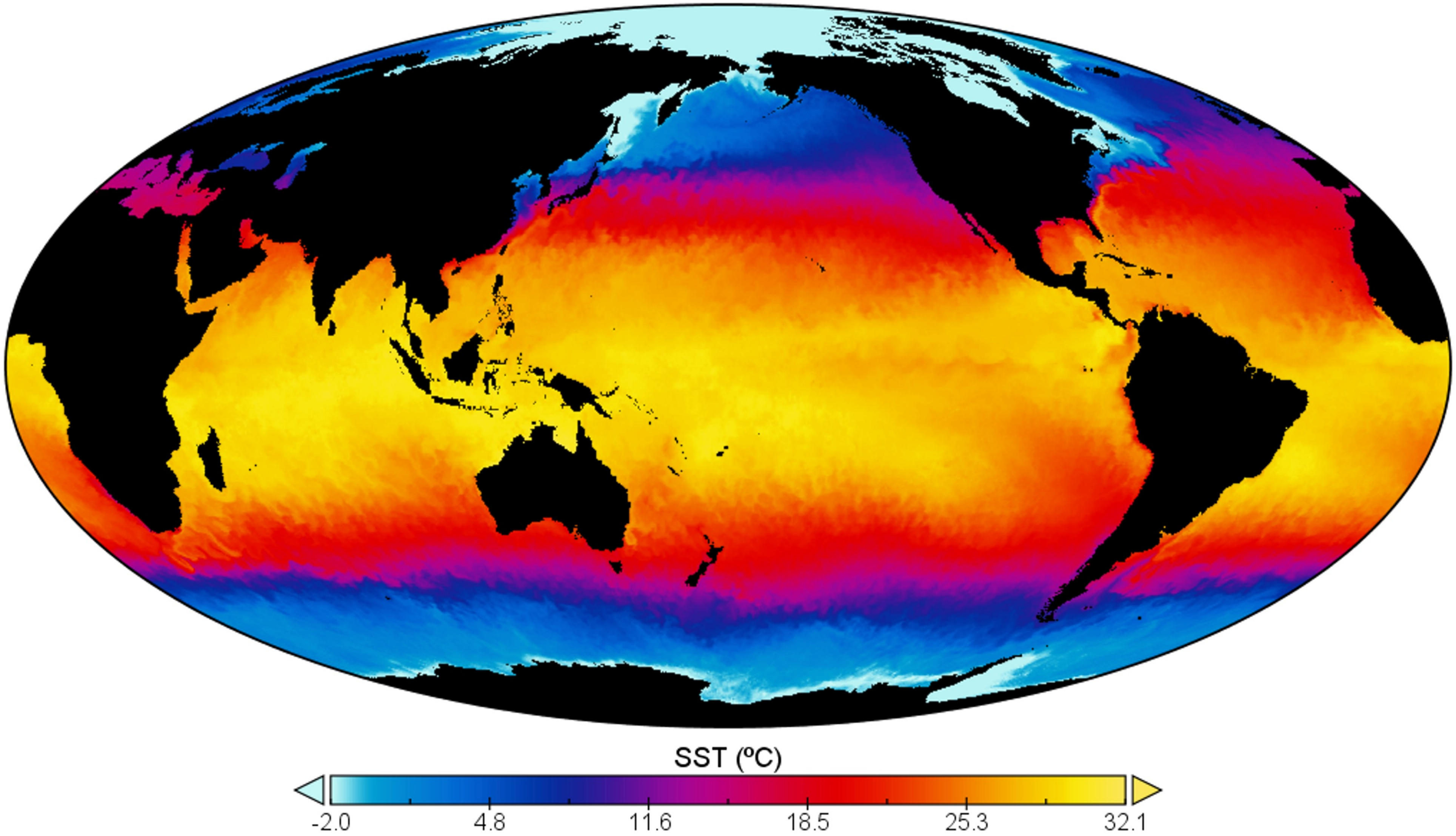
Sea Surface Temperature

NOAA CoastWatch Satellite Course

Last Updated: 8/25/2020

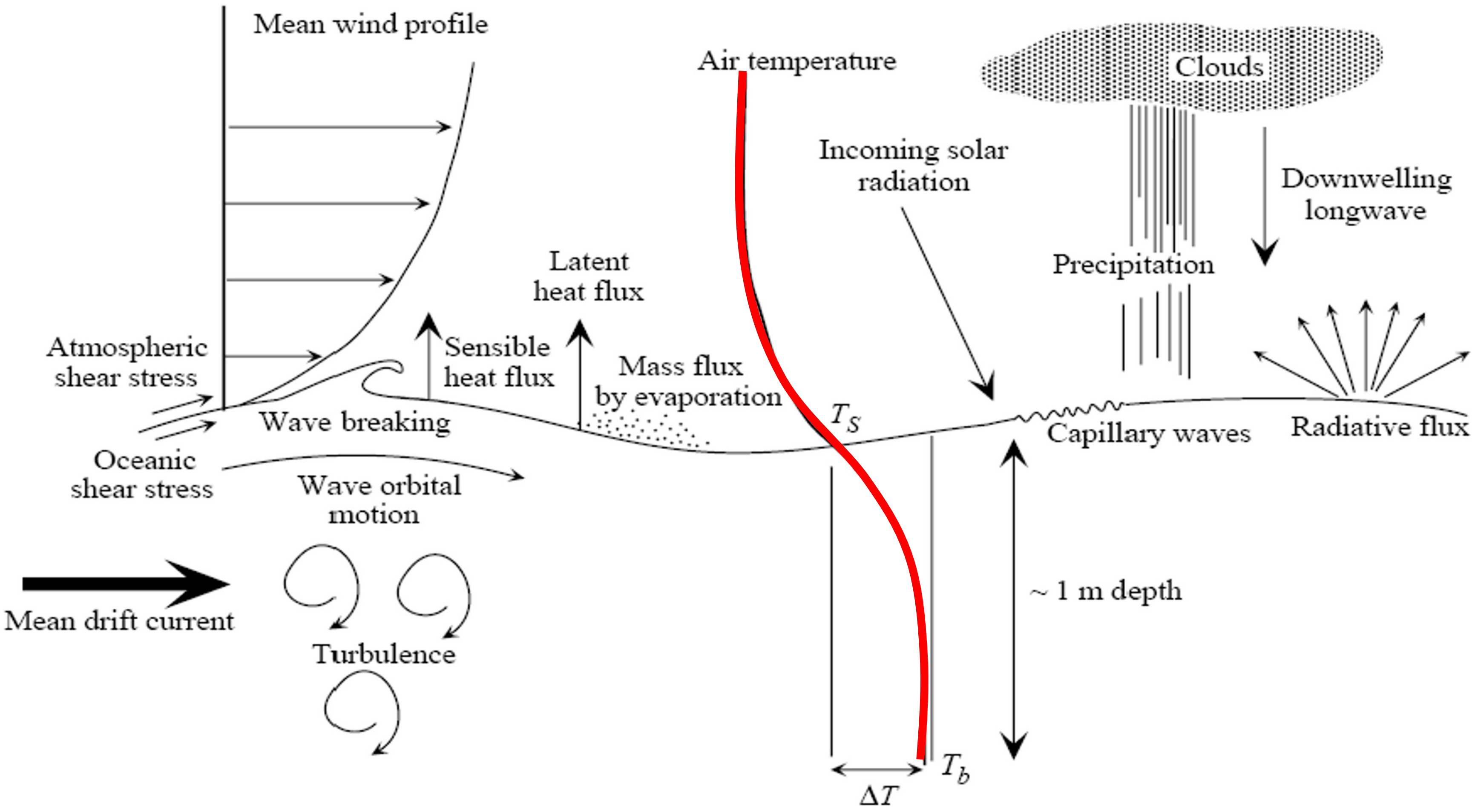
NOAA GeoPolar Blended SST – 02/25/2019



Topics covered in this presentation

- What is SST?
- Which SST is measured from space?
- Infrared vs microwave measurements
- Measurements in the infrared
- Measurements in the microwaves
- L4 Products
- A word of caution on L4 products

Defining SST is complicated by ocean surface processes



Martin 2010

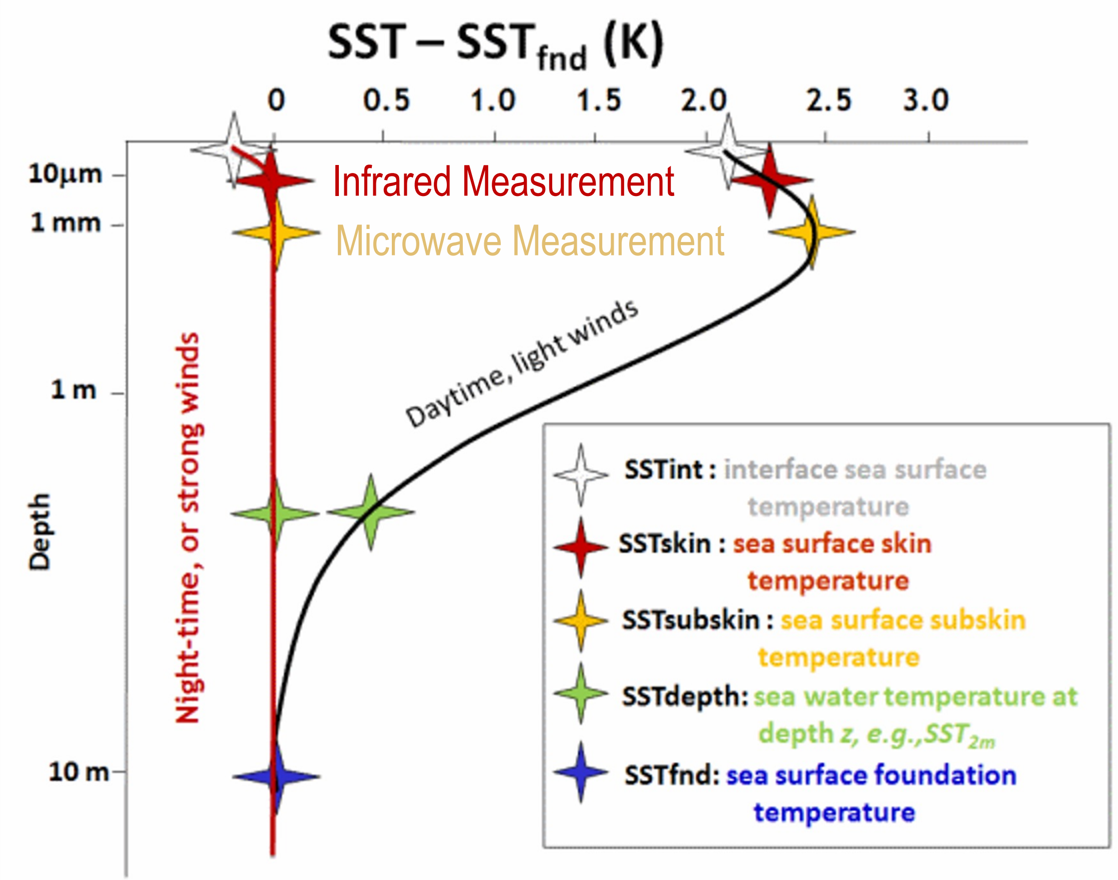
What is SST?

SST is Sea Surface Temperature

So more precisely the question is what ***surface*** (or depth) is being measured? The answer depends on the how the measurement is being made.

Infrared sensors measure the sea temperature at ~ 20 micrometers.

Microwave sensors measure the sea temperature at ~ 2 millimeters.



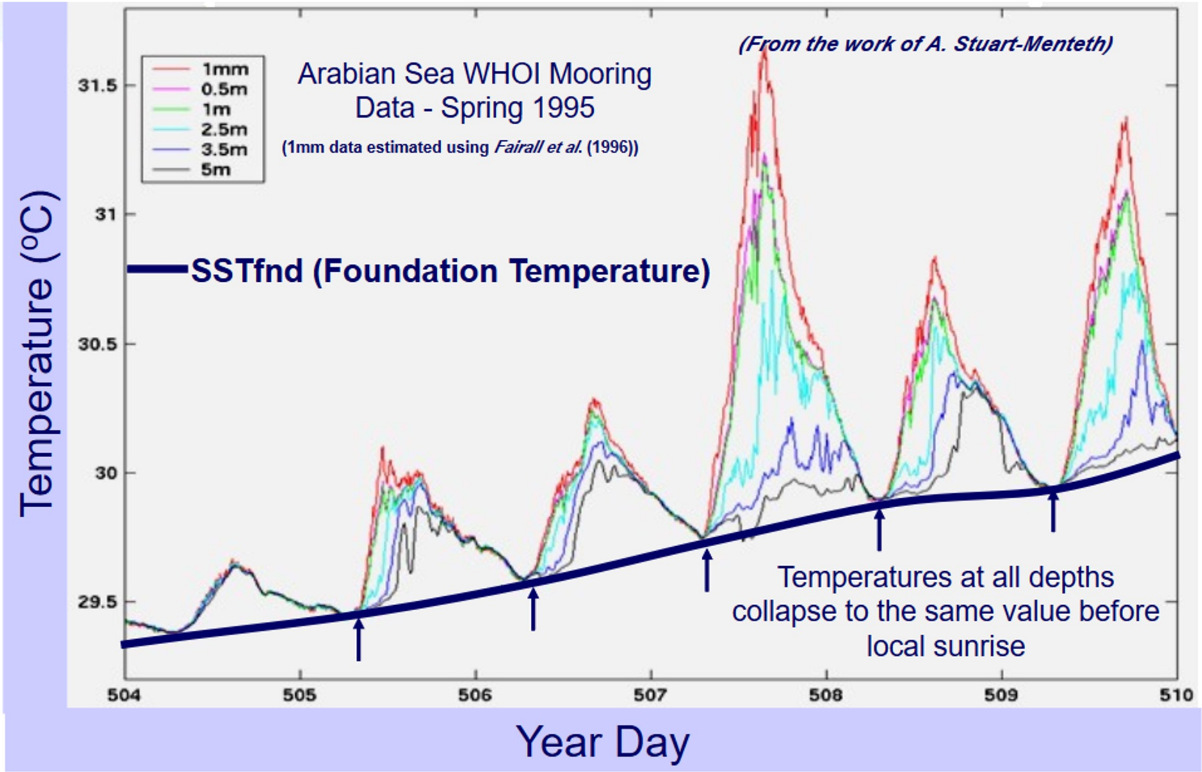
www.ghrsst.org

Foundation SST is not influenced by diurnal solar heating

Solar heating near the sea surface causes diurnal changes in SST_{skin} and $SST_{subskin}$

The **foundation SST** (SST_{fnd}) is the free of diurnal temperature variability.

- SST_{fnd} can only be measured with in-situ instruments
- Analysis procedures must be used to estimate the SST_{fnd} from satellite retrievals of SST_{skin} and $SST_{subskin}$.



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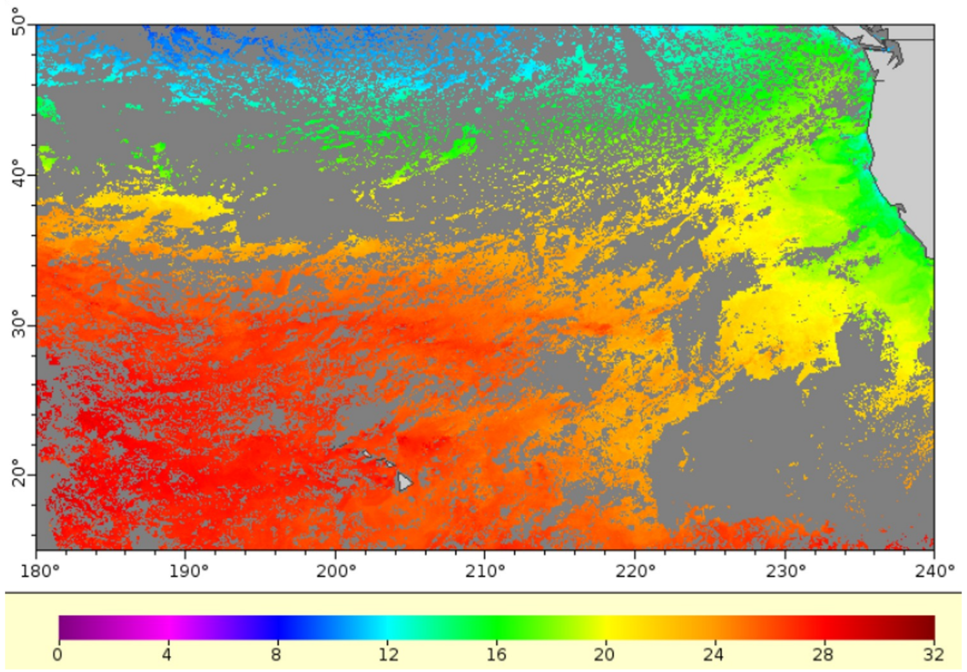
SST can be measured with infrared and microwave sensors

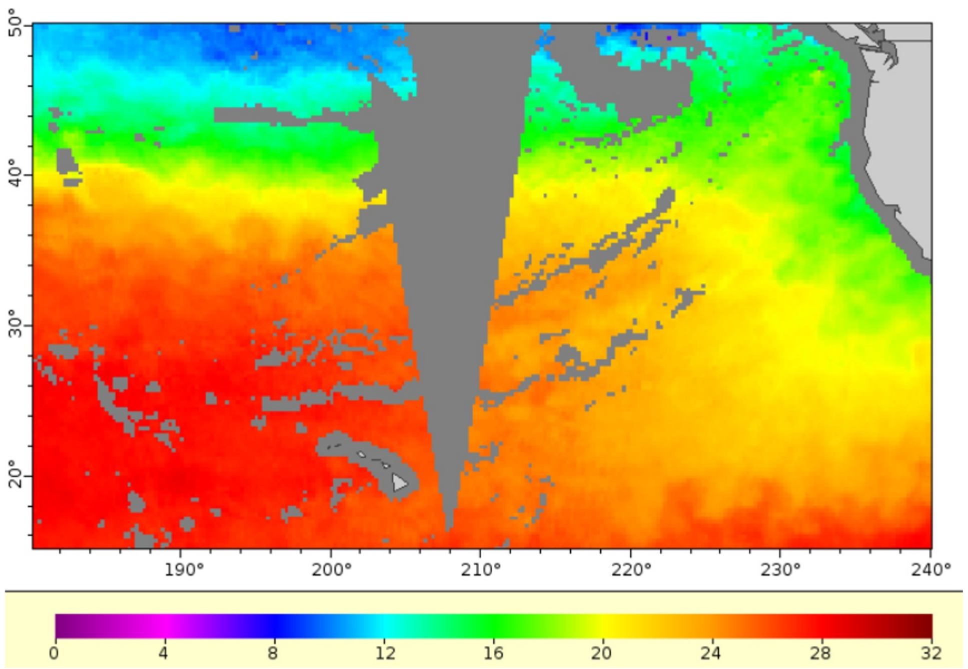
3-day Aqua MODIS (Infrared)



0.025º (~2.5 km) resolution

No data under clouds

3-day Aqua AMSR-E (Microwave)



0.25º (~25 km) resolution

Can see through most clouds

No data close to the coast

Characteristics of SST measurements

Orbit	Wavelength Band	Coverage	Spatial Resolution	Temporal Resolution	Accuracy (^{0} K)	Penetration Depth	Cloud Effect
Polar	Infrared	Global	1 - 4 km	12 hrs - 3 days	0.4-0.6	~ 20 um	Blocked
Geostationary	Infrared	Global	2 - 4 km	30 minutes	0.4-0.6	~ 20 um	Blocked
Polar	Microwave	Regional	25 - 50 km	1 - 3 days	0.4-1.0	~ 2 mm	Not Blocked except heavy rain

Adapted from Donlon et al, 20

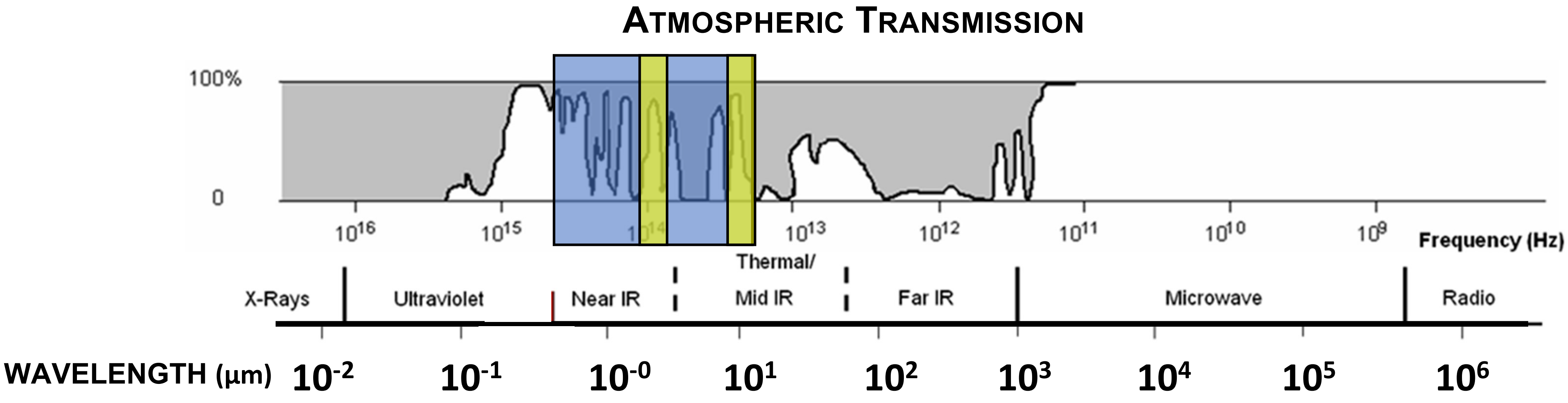
Measurements of SST in the infrared

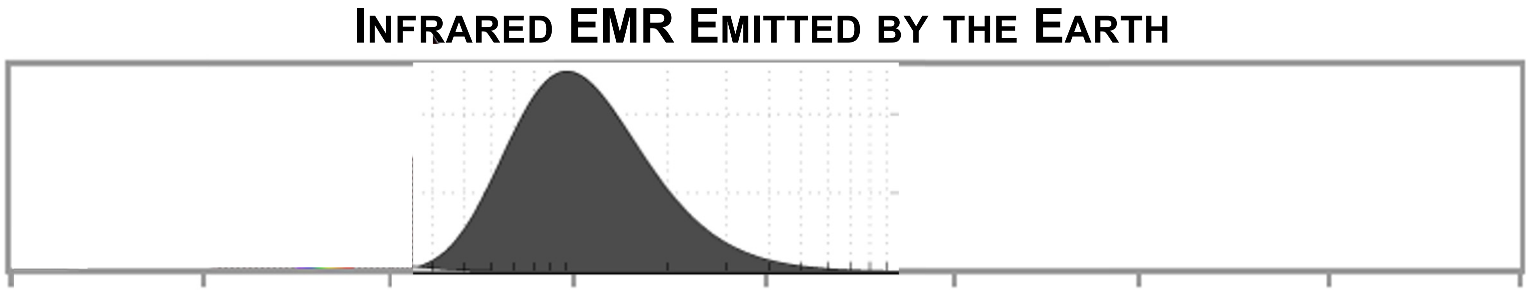
SST has been measured accurately in the infrared since 1978

Measurements are made in both polar orbit and geosynchronous orbit

Reminder: Infrared passes through narrow atmospheric windows

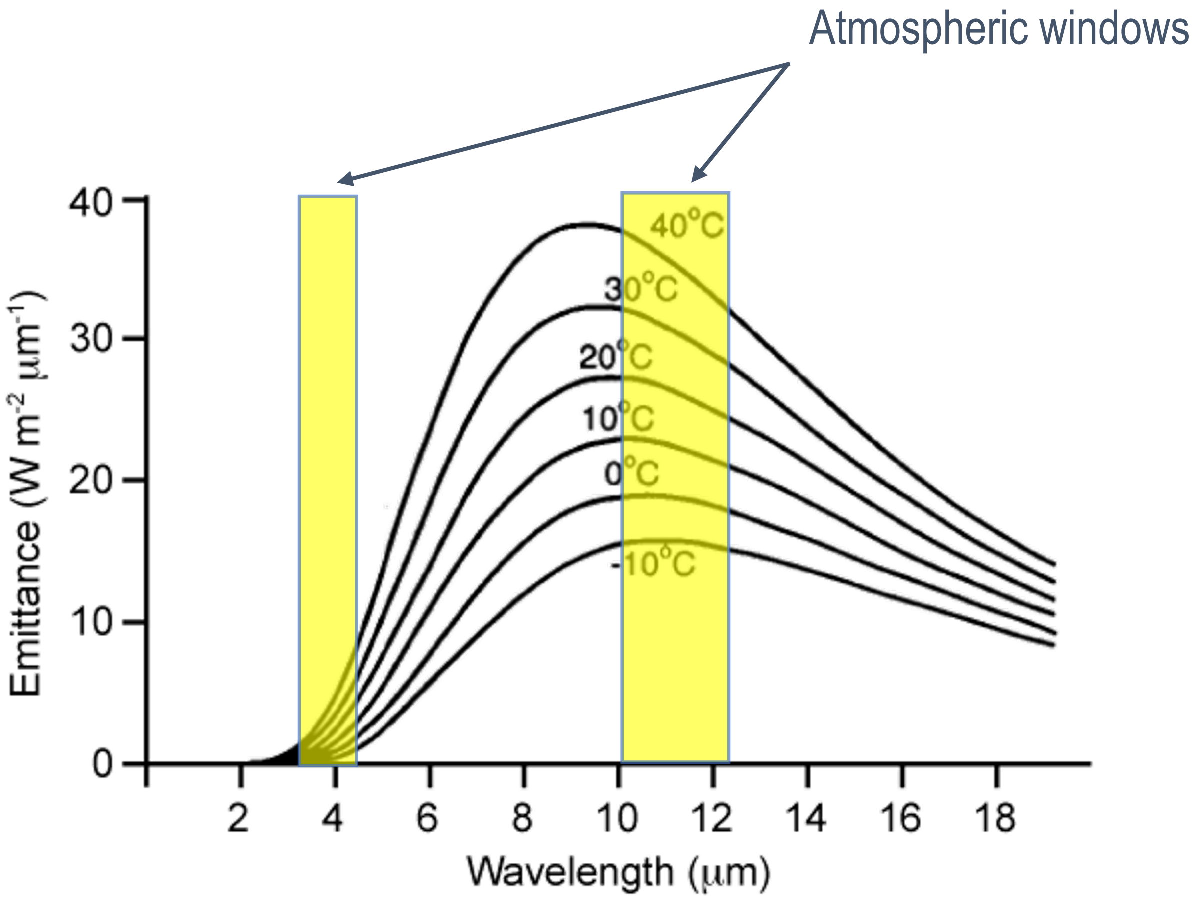
High transmittance occurs in narrow bands in the infrared.
These "optical windows" overlap the infrared emissions of the Earth.





Reminder: Black bodies

Plank's law for a blackbody emitter



The spectrum and intensity of radiation emitted an object depends on its temperature.

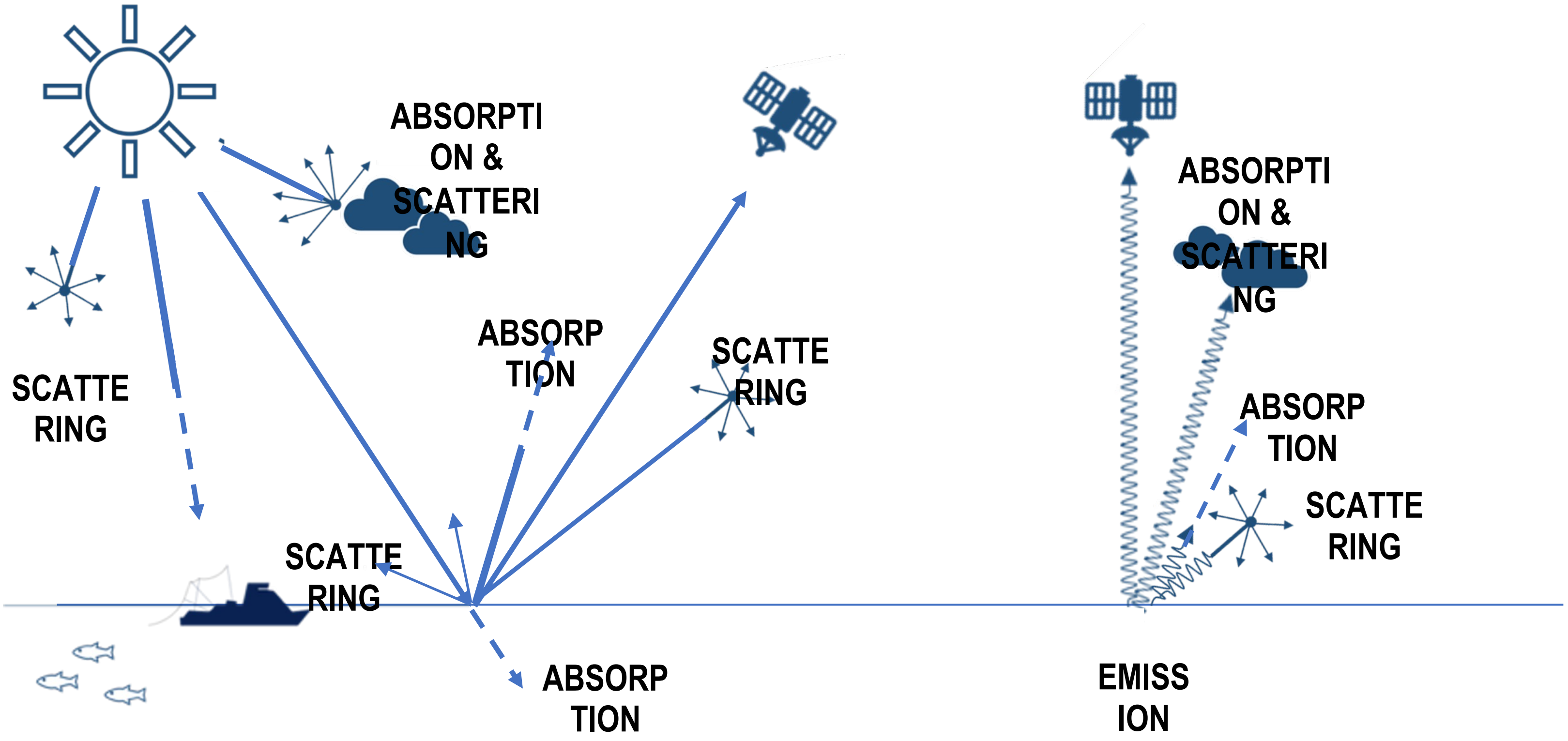
If the earth's surface is regarded as a blackbody emitter, its apparent temperature (known as the **brightness temperature**) and its emitted radiation are related by Planck's law.

The atmospheric window at 10-12 μm and higher Blackbody emissions overlap:

- The peaks of the Planck function for temperatures typical of the sea surface are close to the infrared atmospheric window.
- This is, therefore, well suited to SST measurement.

Robi n 2004

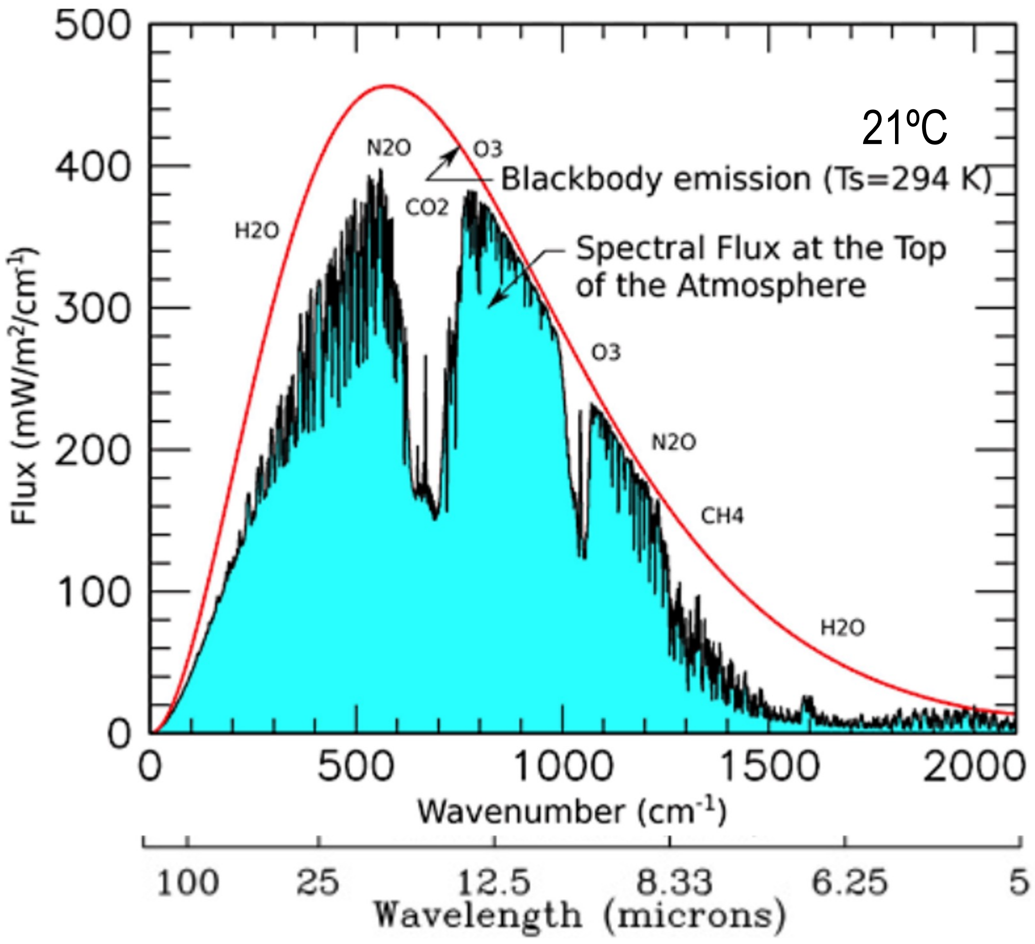
Reminder: The atmosphere alters the EMR signal



Absorption and scattering by components of the atmosphere attenuate the signal reaching the sensor.

Credit: Jan Yoshi... CI

The influence of the atmosphere on EMR attenuation



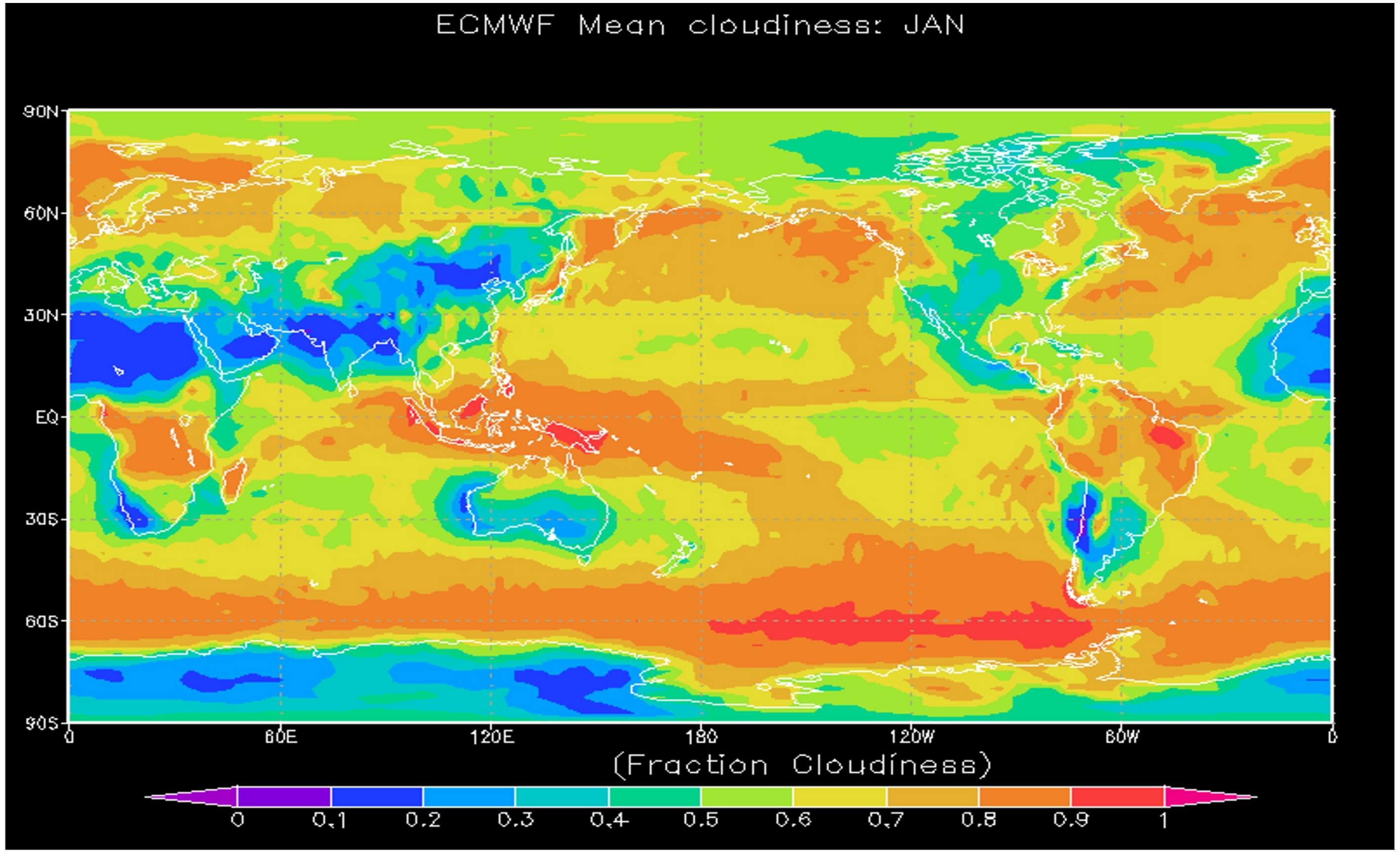
As a result, the blackbody emission from the Earth are altered when viewed through the atmosphere.

-> correction for the attenuation
by the atmosphere is needed

NASA

Clouds attenuate the infrared signal

Clouds can block the infrared signal from reaching the satellite radiometers.



Minnett 2001

Addition influence of the atmosphere in the infrared signal

Temperature Deficit

Brightness temperatures measured by a spacecraft radiometer through the clear atmosphere are **cooler** than would be measured by a similar device just above the sea surface.

- **Even with** clear skies a significant fraction of the sea surface emission is absorbed as the signal travels through the atmosphere.

- The absorbed energy is re-emitted, but at a cooler temperature that is characteristic of the height in the atmosphere.

- The resulting **temperature deficit** must be corrected for to get accurate SST measurements.

Minnett 2001

Water vapor complicates temperature deficit corrections

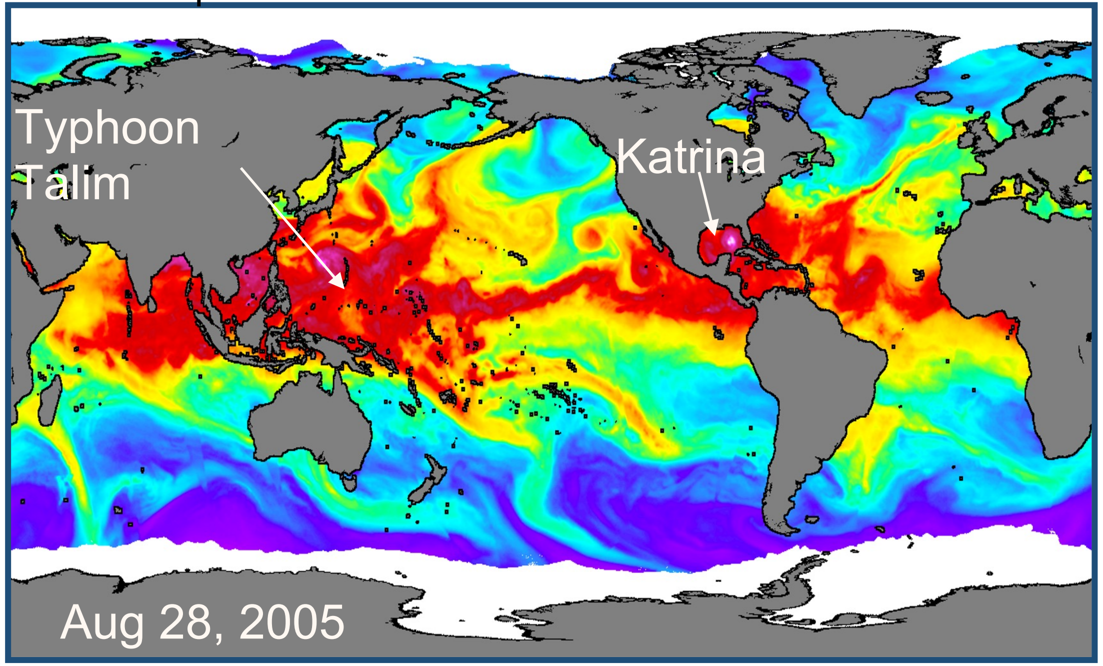
In the infrared, atmosphere **water vapor** is responsible for most of the temperature deficit.

- Water vapor concentration is variable in both space and time.

Other gases are **well mixed** throughout the atmosphere.

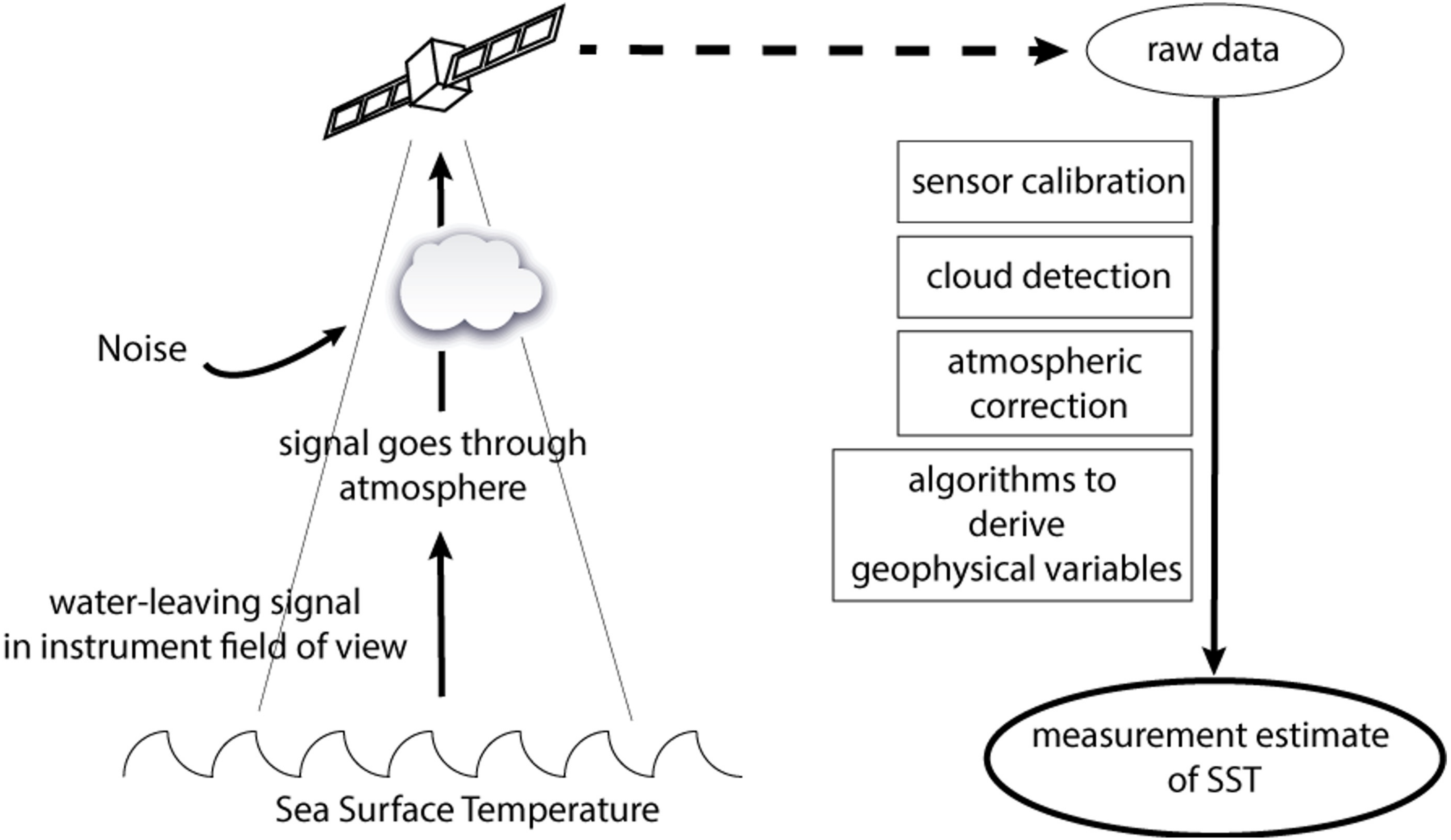
- Their contribute to the temperature deficit a relatively and is simple to correct.

Water Vapor



Minnett 2001

Measurements of SST in the infrared - summary



adapted from Robinson 2004

Instruments measuring SST using infrared sensors

Instrument	Satellite(s)	Orbit	Period of operation
AVHRR	TIROS-N, NOAA 6-19, MetOp A/B	Polar	1978-present
MODIS	Aqua, Terra	Polar	1999-present
VIIRS	SNPP, NOAA-20	Polar	2011-present
Imager	GOES 8-15	Geostationary	1994-present
ABI	GOES 16-17	Geostationary	2016-present

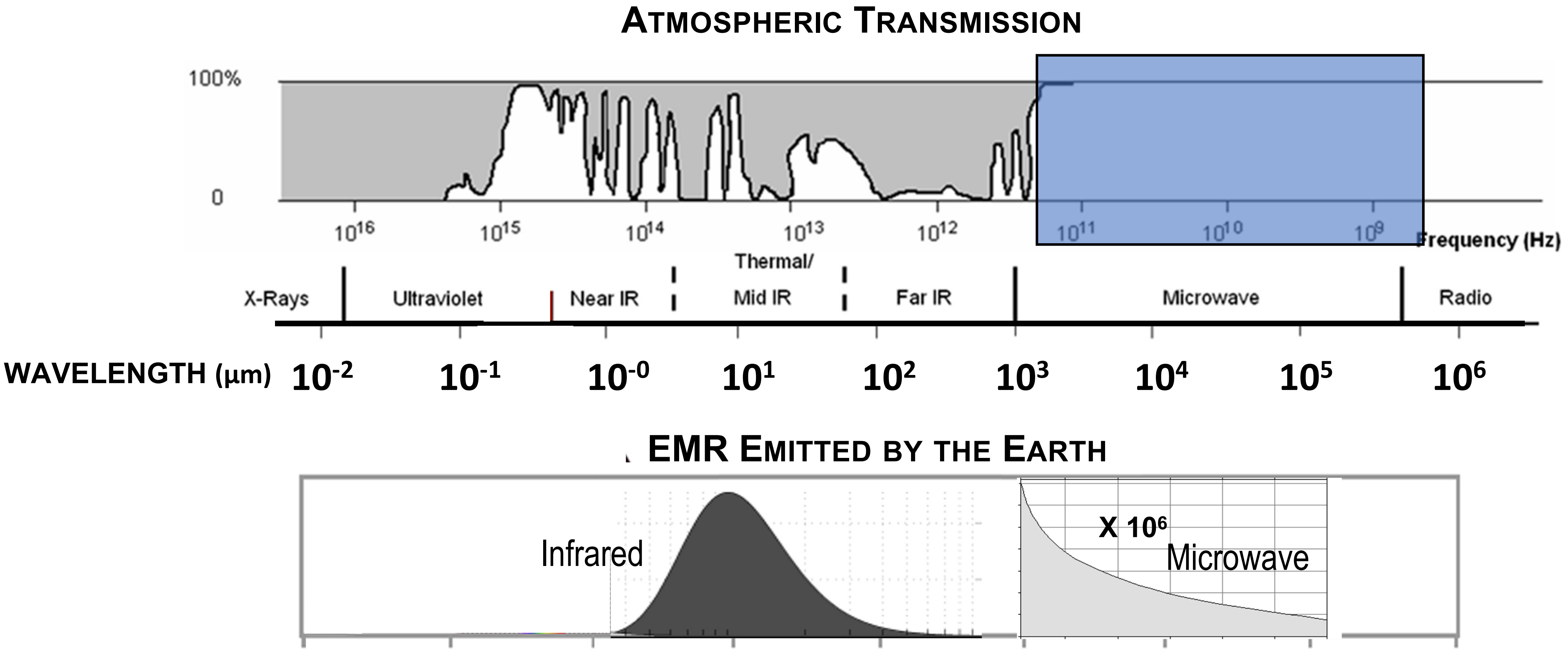
Many concurrent observations from different sensors, which can be combined into blended products.

Measurements of SST in the microwaves

Measured accurately in the tropics since 1999 (TRMM) and globally since 2002 (AMSR-E)

Reminder: Atmospheric windows

In the **microwave**, the atmosphere is almost 100% transparent but the sun and earth's radiation are weak (need large antennas to collect enough radiation)



Characteristics of microwave sensors

Low Intensity Signal:

The intensity of microwave radiation at the top of the atmosphere is low

This can be partially compensated for with larger (~m) antennae for microwave instruments.

Diffraction Limits Spatial Resolution:

The longer wavelengths give rise to diffraction effects that limit the spatial resolution

Typically resolution ranges from to 25-50 km

The precision with which thermal ocean fronts can be located is limited with microwave imagery.

Pearson et al, 2018

Characteristics of microwave sensors (continued)

The Coast Contaminates Ocean Signal

- The microwave emissivity of land and ice is significantly higher than the ocean.
- This leads to contamination of the ocean microwave signal close to the coasts and ice edges
- Accurate SST measurements are not possible in these areas.

Sees Through Clouds

- An advantage of microwave measurements is that **microwaves can penetrate non-precipitating clouds**.
- Therefore, SST can be measured in cloudy conditions with microwave sensors (not with infrared sensors).
- This is useful in persistently cloudy regions such as winter high-latitudes.

Pearson et al, 2018

Instruments measuring SST using microwave sensors

Instrument	Period of Operation	Version
TMI	1997 - 2015	V7.1
AMSR-E	2002 - 2011	V7
WindSat	2003 - present	V7.0.1
AMSR2	2012 - present	V7.1
GMI	2014 - present	V8.1

Currently only on polar-orbiting satellites.

Pearson et al, 2018

Reminder: Levels of Data

- Level 0: Raw data received from satellite, in standard binary form
- Level 1: Unprocessed data in sensor's geographic coordinates, containing calibration information
- Level 2: Derived geophysical variables atmospherically corrected and geolocated, but presented in sensor's geographic coordinates (granules).
  Also sometimes referred to as "along-track" data.
- **Level 3: Derived geophysical variables mapped on uniform space-time grid scales. Spatial and temporal composites.**
- **Level 4: Model output or results from analyses of lower-level data**
  e.g., variables derived from multiple measurements, like cloud-free product

This course focuses primarily on level 3 and level 4 data

Which data set should be used?

User's wish list:

- High-resolution
- Satellite data only
- Gap-free

Can it be done? Sure: pick any 2 from your wish list

- **High-res, satellite data only, ~~gap-free~~** ->

  L3 products, combining multiple sensors

- **Satellite data only, gap-free, ~~High-res~~** ->
  - L3 weekly or monthly composites at a spatial resolution lower than the sensor's

- **High-res, gap-free, ~~satellite data only~~** ->

  L4

  Not guaranteed to be satellite data only, i.e. because interpolation is done to fill in the gaps, users do not know which pixels come from observations and which pixels are interpolated

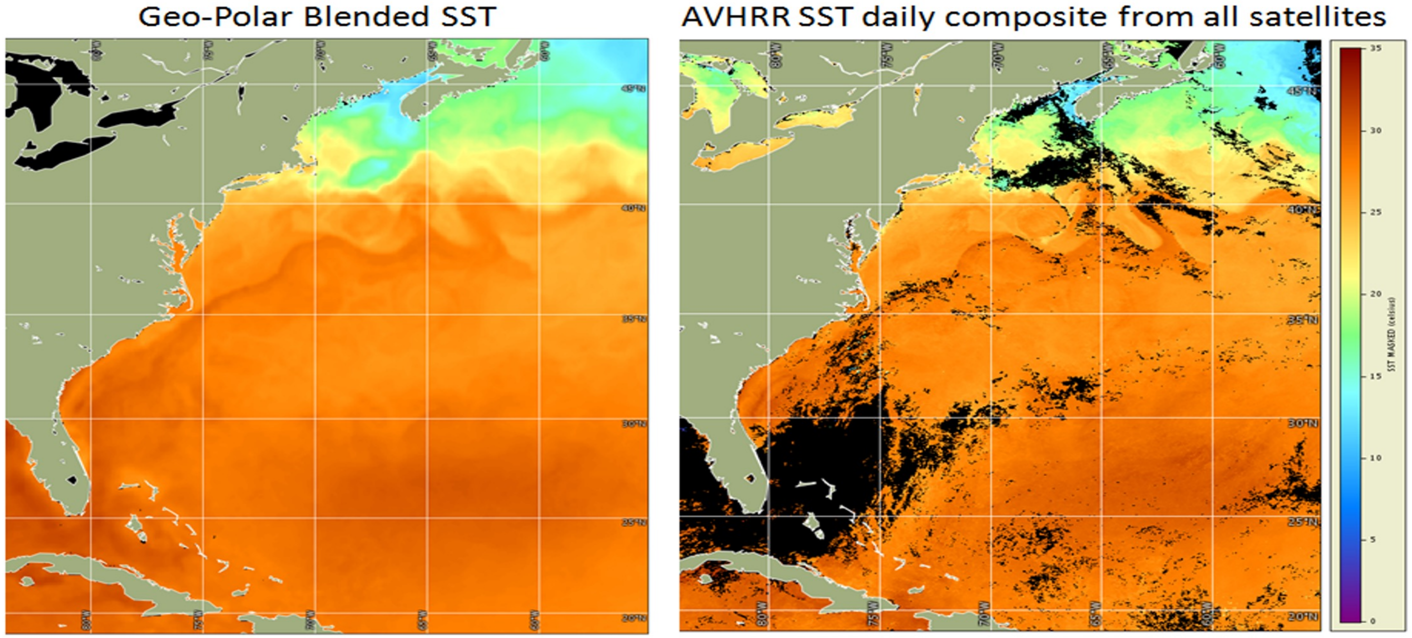
Slide from Irina Gladkova

Characteristics of some popular SST L4 products

Name	aka	Institution	spatial resolution	temporal resolution	time coverage	cloud-free
Operational Sea Surface Temperature and Sea Ice Analysis	OSTIA	Met Office	0.05º	daily	2006-present	yes
AVHRR Pathfinder Sea Surface Temperature	Pathfinder	NOAA/NASA	4km	daily	1981-june 2018	no
Multi-scale Ultra-high Resolution Sea Surface Temperature	JPL MUR	NASA	1km	daily	2002-present	yes
NOAA Geo-polar blended Sea Surface Temperature	GOES-POES	NOAA	5km	daily	2002-present	yes

NOAA Geo-Polar Blended SST

- Created by NOAA Satellite Service, Satellite Applications & Research
- 2002 – present
- Data from infrared polar & geostationary satellites, blended together
    - Optimal interpolation assimilation balances detail preservation & noise reduction
    - Near rear real-time data available on a daily basis (1 day delay)
- 5 km spatial resolution
- Estimate of nighttime SST - must consider diurnal effect

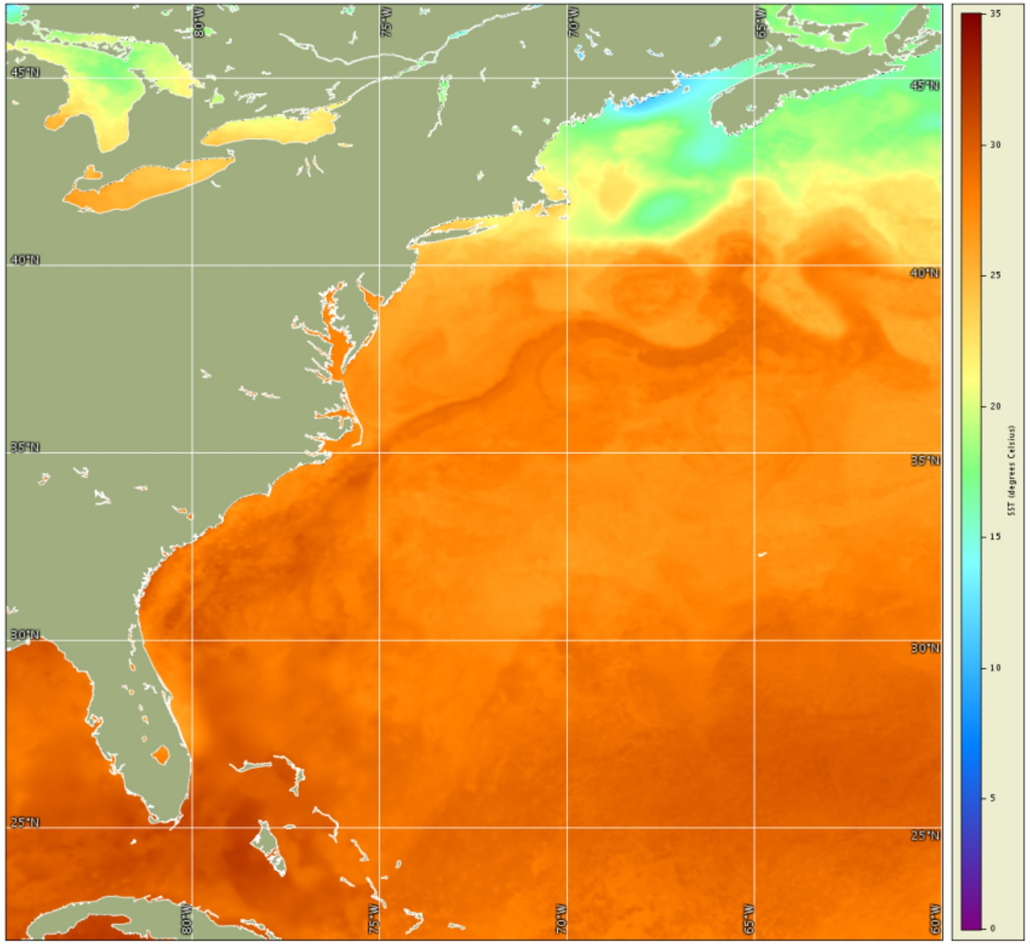


July 30, 2015

Multiscale Ultra-high Resolution (MUR) SST

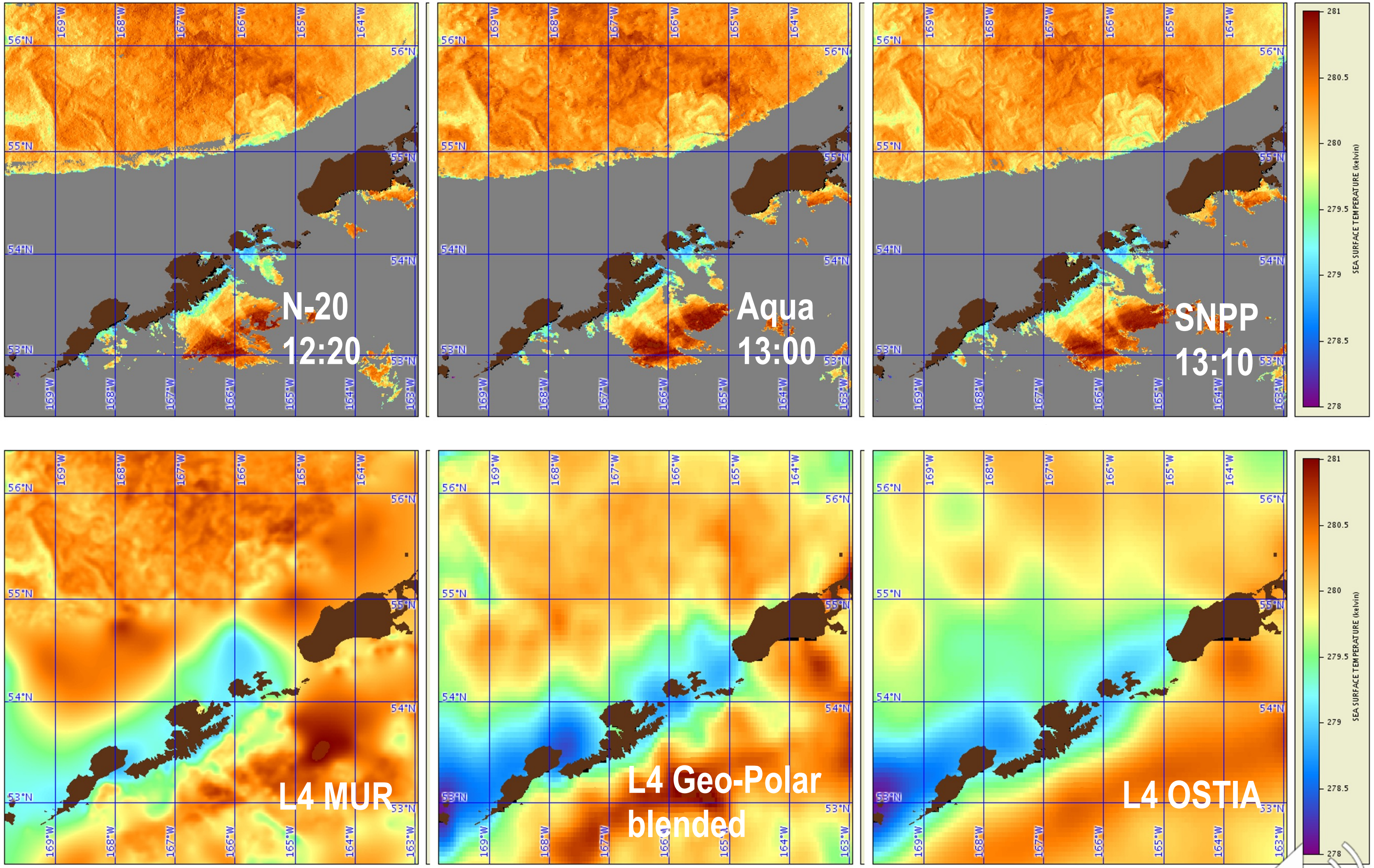
- Created by NASA Jet Propulsion Laboratory
- June 1, 2002 – present
- Daily, global, cloud-free
    - Data from polar-orbiting infrared and microwave sensors blended together
    - Data assimilated with global in-situ SST data to account for differences in the source data sets (in situ data from NOAA's iQuam database)
    - New data available on a daily basis (NRT & science quality)
- 1 km spatial resolution
- Estimate of nighttime foundation SST -must consider diurnal effect

July 30, 2015



Is gap-free more important than satellite-based?

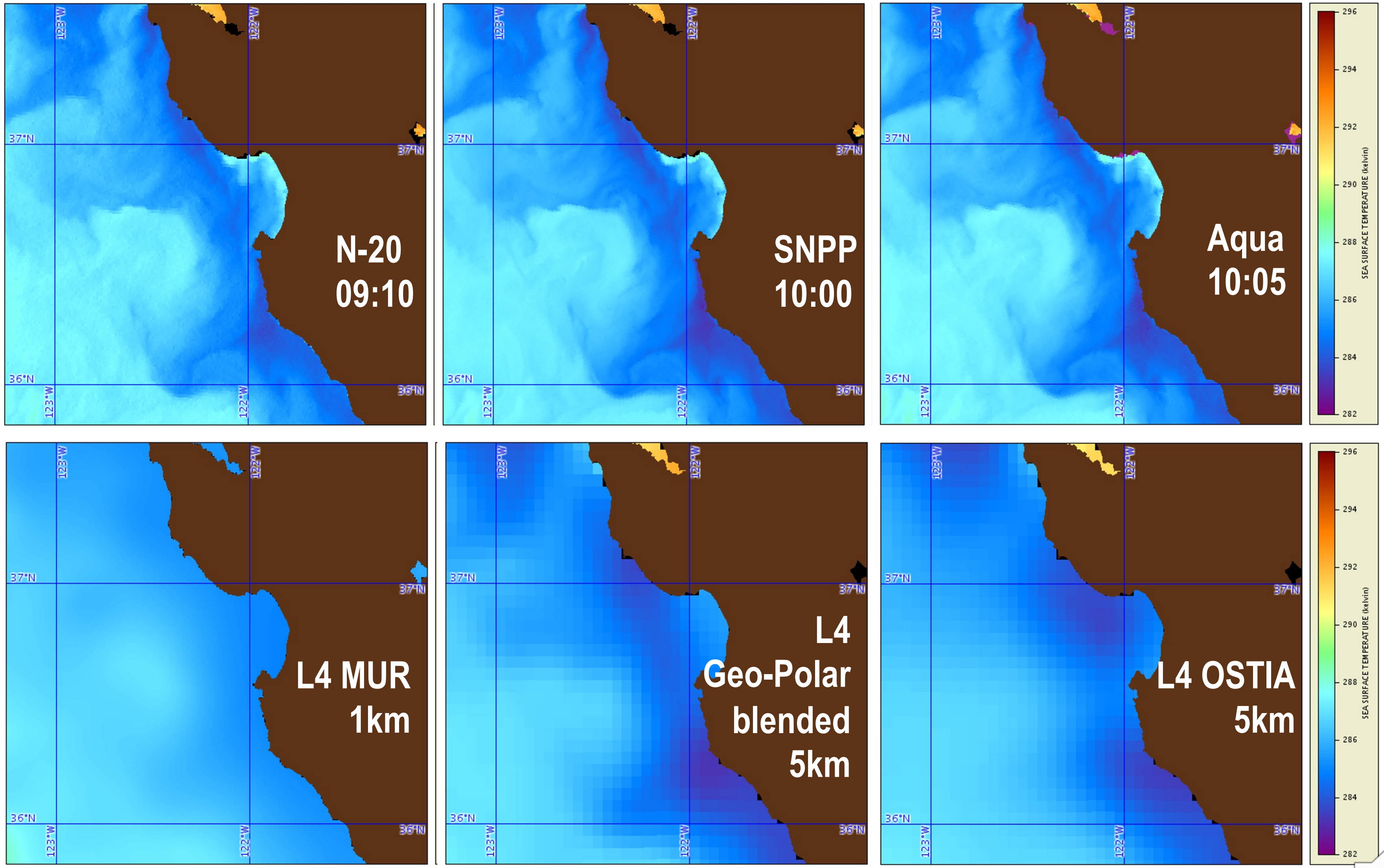
Example:
Aleutian Island
June 7, 2018



Slide from Irina Gladkova

The high resolution is not always the best choice

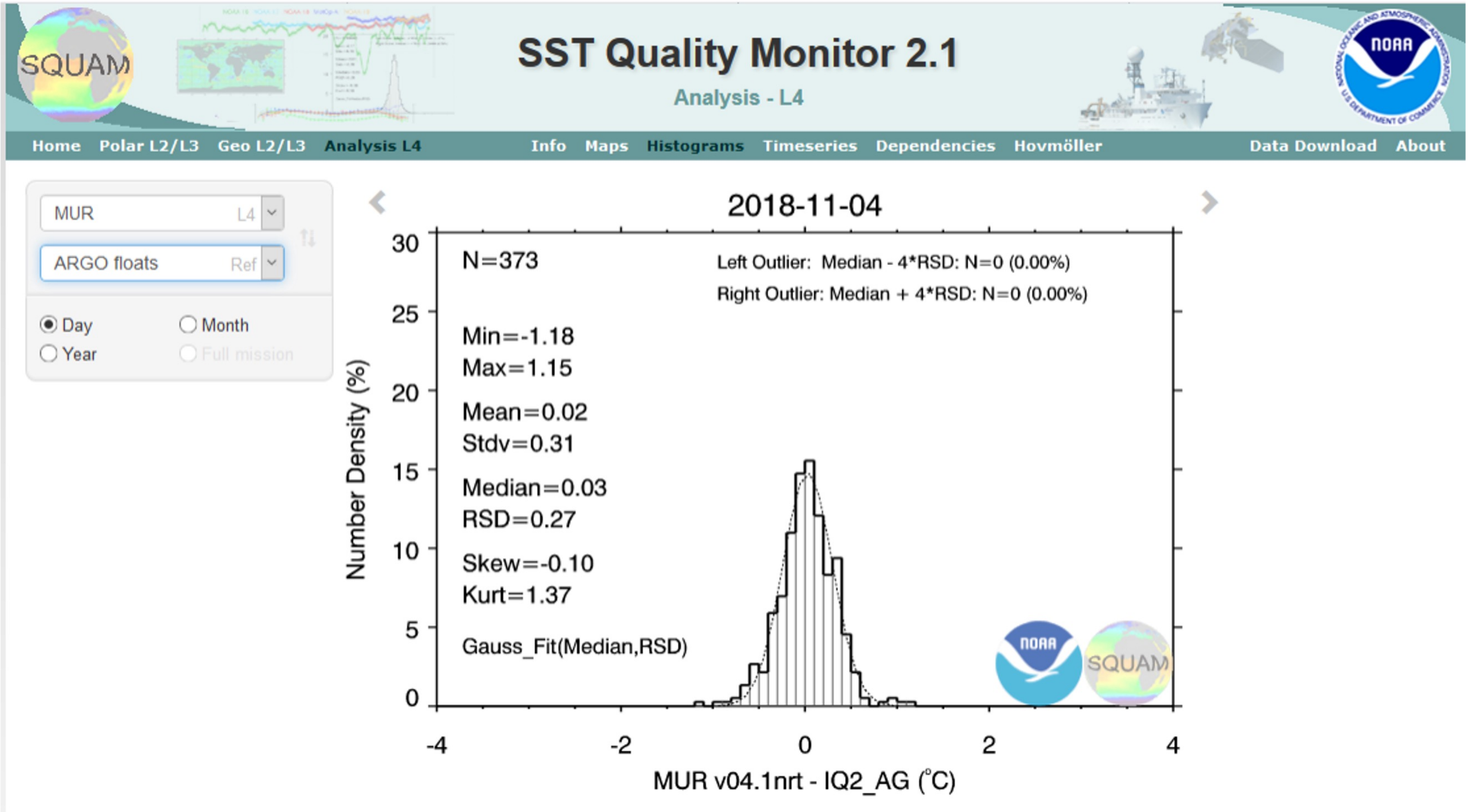
Example:
Monterey Bay
June 12, 2018



Slide from Irina Gladkova

SST Quality Monitor in available from NOAA SQUAM*

NOAA developed a tool to compare different products with each other and with in-situ data



***SQUAM** - SST Quality Monitor
https://www.star.nesdis.noaa.gov/sod/sst/squam/index.php

Review important concepts for satellite SST measurements

Infrared instruments:

- SST_{skin} – the top ~ 20 um
- High spatial resolution
- Measurements blocked by clouds
- Sensors in both polar and geo orbit

Microwave instruments:

- $SST_{subskin}$ top ~ several mm
- Reduced spatial resolution
- Sees through clouds (fuller coverage)
- No measurements close to land (50-100km)
- Sensors only in polar orbit

Blended Products:

- Data from multiple satellites and/or multiple passes of the same satellite are combined
- Often data-gaps are filled by interpellation

Products Selection

- There are many SST products to choose from
- Before picking a product, select a few and compare them for several time steps and regions.

NOAA CoastWatch Satellite Course - Narrated Presentations

- Satellite 101 – Part 1
- Satellite 101 – Part 2
- Fundamentals of Ocean Color
- **Fundamentals of Sea-Surface Temperature**
- Fundamentals of Altimetry, Wind and Salinity
- Introduction to ERDDAP
- What Dataset to Choose?
- Bringing Satellite Data into ARCGIS