Microwave radiometry for oceans and climate science

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Microwave radiometry over the ocean

- A brief review of how microwave radiometry is used by oceanographers to measure
  - Wind speed (and direction)
  - Water vapour
  - Rain
  - Ice
  - Sea surface temperature
  - salinity
- Technical challenges driven by the growing expectations of ocean science users
  - Finer spatial resolution
  - Operating closer to the coast
  - Improved sensitivity and accuracy

Physics of microwave emission

- Frequency, 1 - 200 GHz
- Wavelength, 1.5 - 300mm
- Black-body radiation
  - is given by the Plank function . . . .

$$M_\lambda = \frac{C_1}{\lambda^{-5}\left[\exp\left(\frac{C_2}{\lambda T}\right) - 1\right]}$$

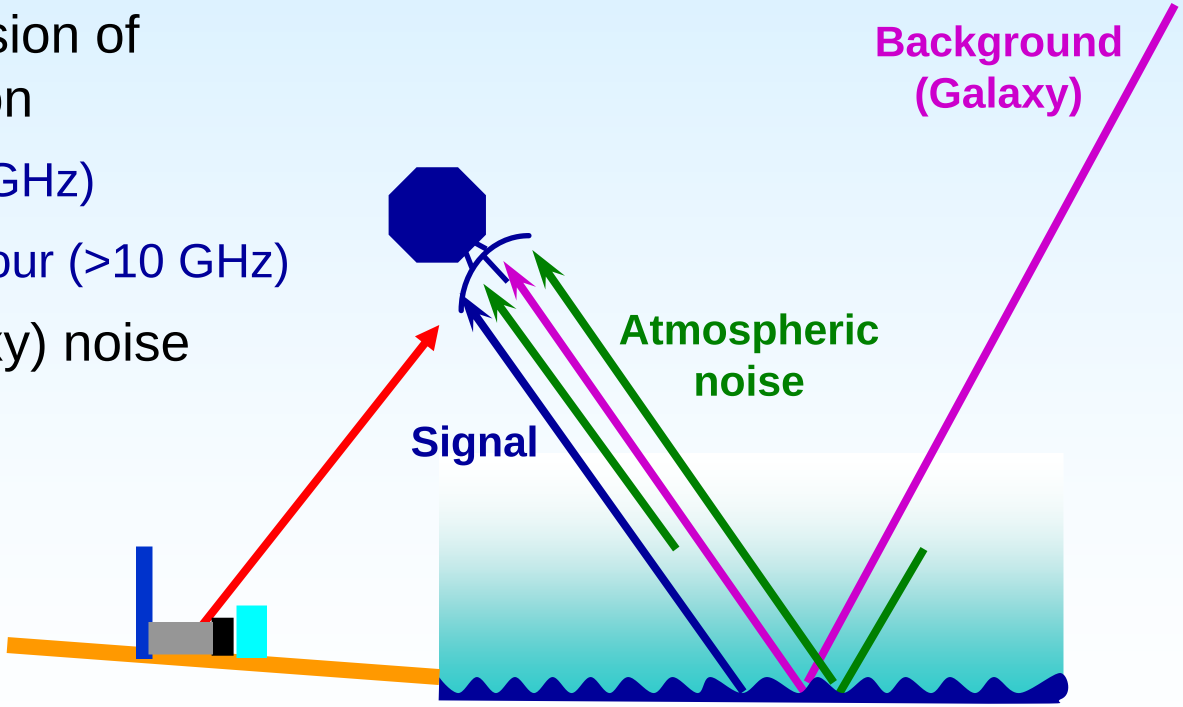
- The Rayleigh-Jeans Approximation
  - For microwaves $C_2 << \lambda T$, and Planck simplifies, in frequency units, $Wm^{-1}\ Hz^{-1}\ str^{-1}$, to . . . . . .

$$B_f = \frac{2kf^2 T\varepsilon}{c^2}$$

    - *Where k* is Boltzman's Constant, 1.38 10^{-23} JK^{-1}; *T* is temperature in K; *c* is speed of light; *f* is frequency in Hz
  - ε is the sea surface emissivity
    - M-W emissivity is ~0.4 and varies with temperature, direction etc.
  - M/W radiance referred to as "Brightness temperature"
    - The temperature of a black body emitting the measured radiation
    - Used because of the linear relation between temp and radiation

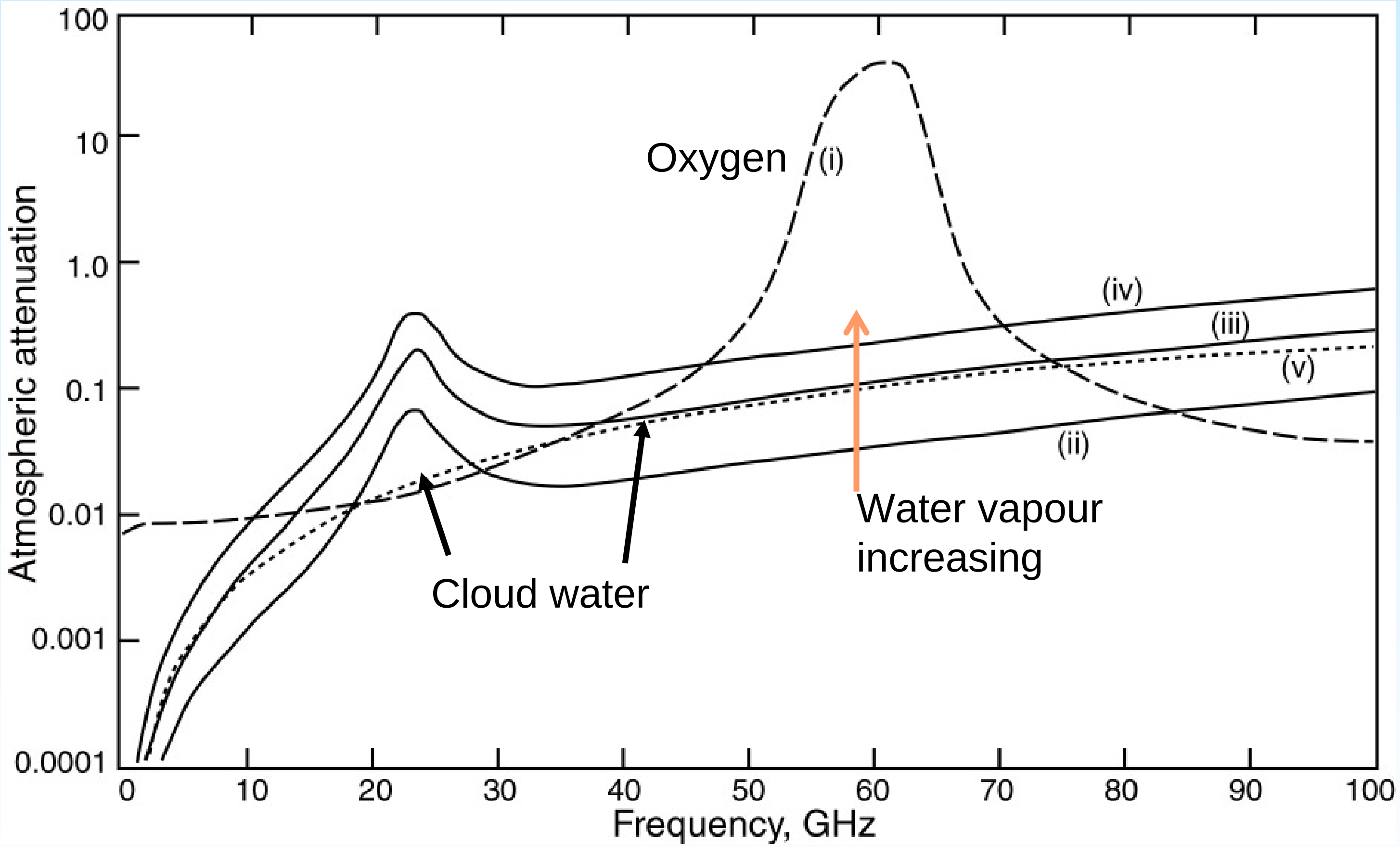
What does the microwave antenna "see"?

- T_A is composed of :-
- The water-leaving signal
  - Attenuated by atmos. absorption
- Atmospheric emission of microwave radiation
  - due to O_2 (>30 GHz)
  - due to H_2O vapour (>10 GHz)
- Background (galaxy) noise
  - (<2 GHz)
- Sidelobe noise
  - Over coasts



Reflection at sea surface is high because R (= 1 - ε) is about 50%

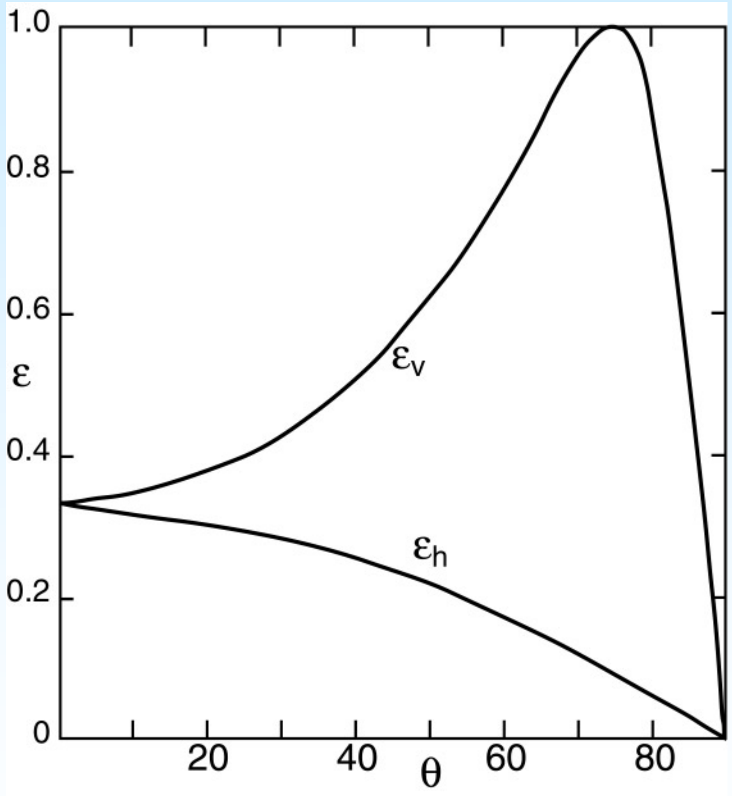
Atmospheric attenuation



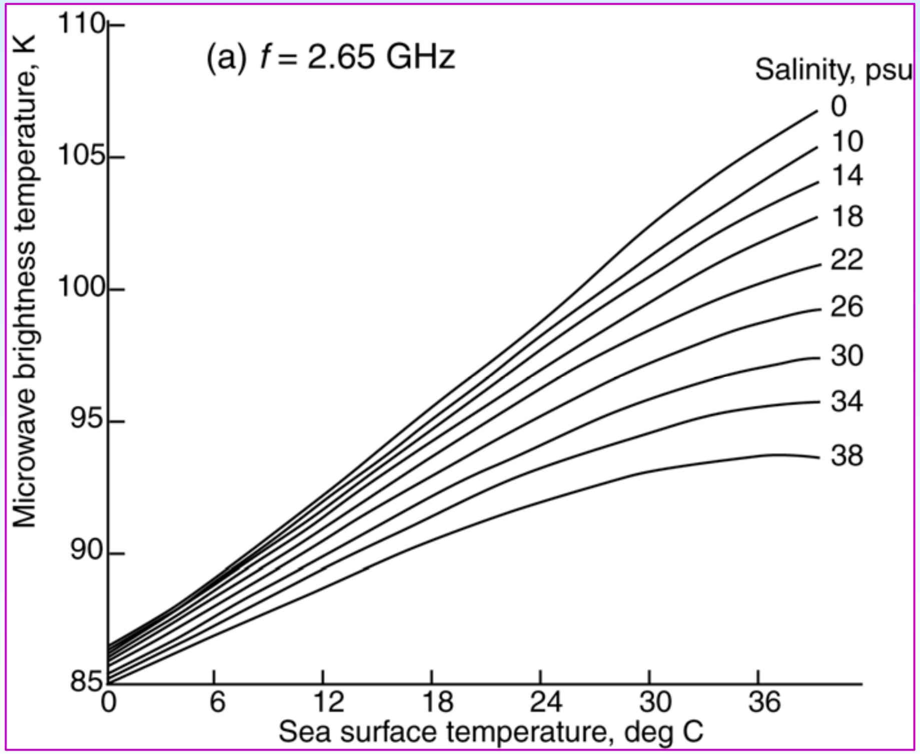
The atmospheric absorption spectrum for (i) oxygen, water vapour at (ii) 10mm, (iii) 30mm and (iv) 60mm, and (v) cloud water of 0.2 mm. (Adapted from Wentz and Meissner, 2000)

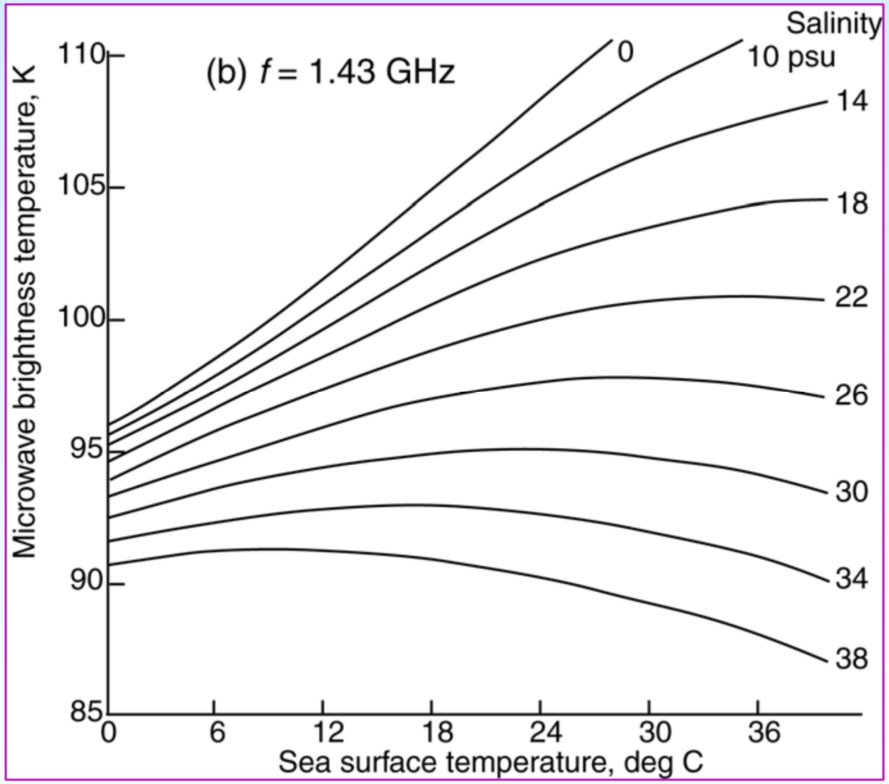
Sea surface emissivity ε

- The key to microwave radiometry
  - T_B varies as much with ε as with T
- ε varies with polarisation (h, v)
- ε varies with M-W frequency
- ε varies with ocean parameters
- Direction θ relative to the surface
  - For an area, ε depends on the integral over many facets having different θ,
  - Hence depends on the sea surface roughness governed by the **wind**
- Conductivity of surface sea water,
  - Hence depends on **temperature** and **salinity**

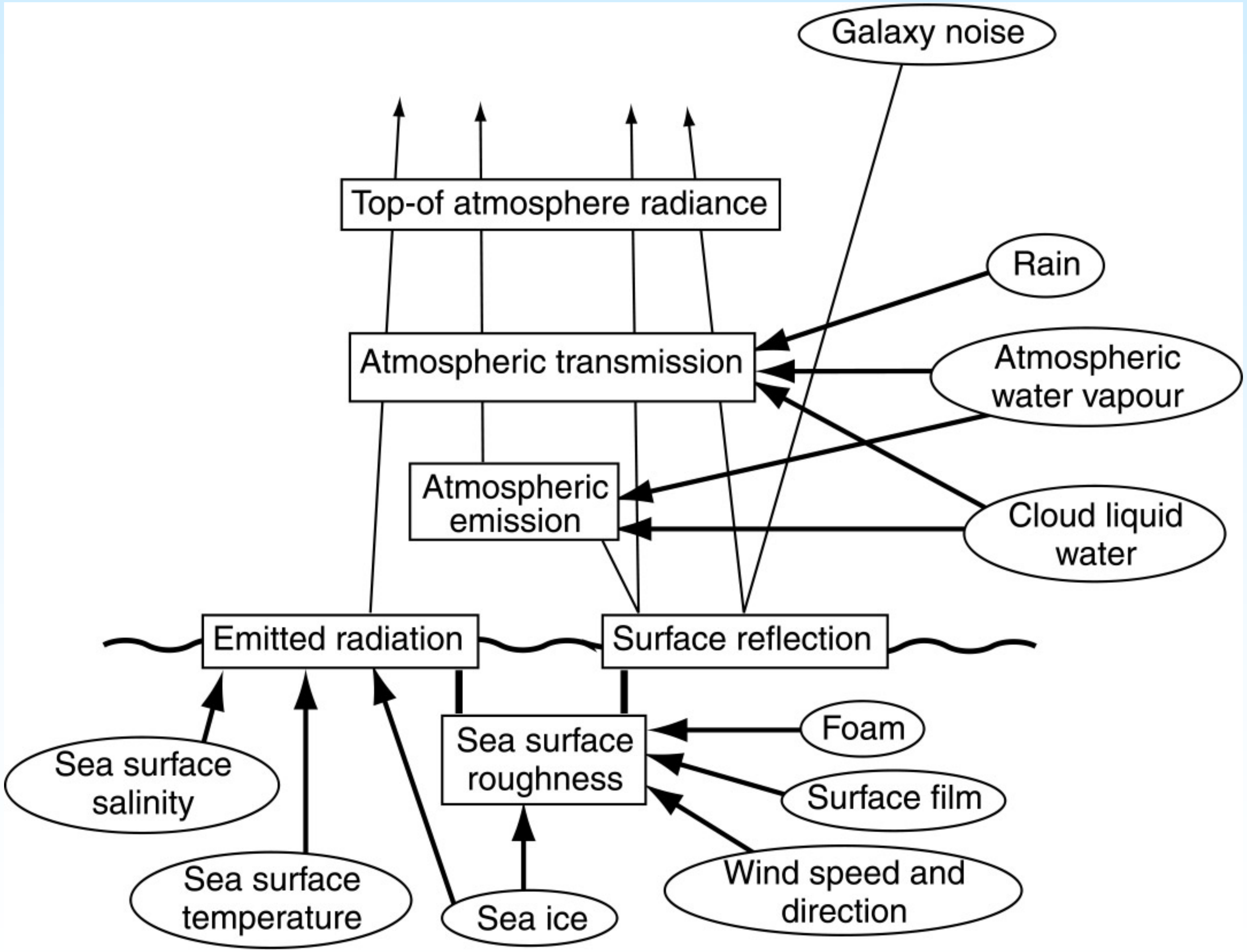


Dependence of emission on salinity and temperature





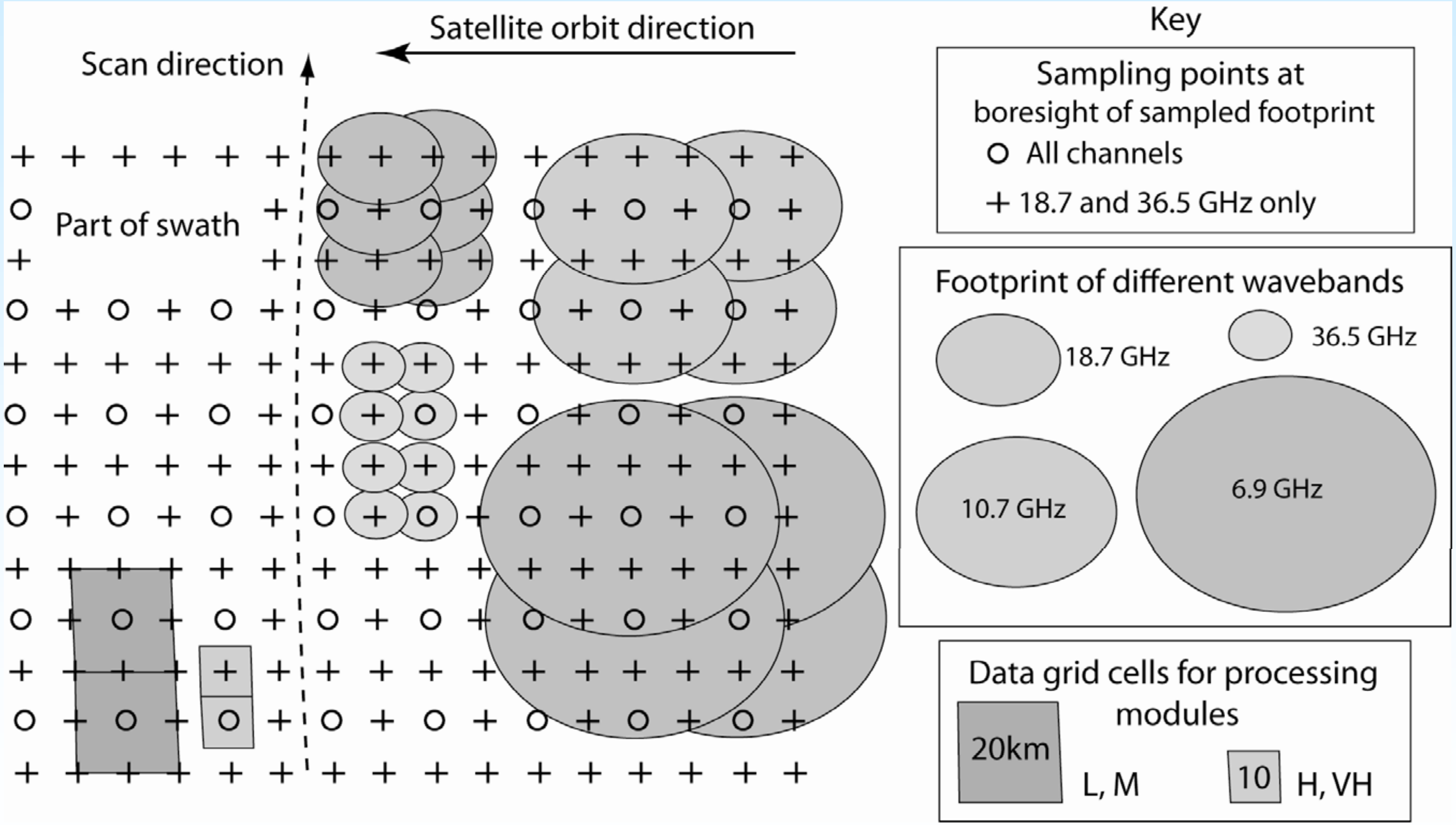
Summary of factors affecting the brightness temperature



Empirical interpretation of multichannel radiometers

- T_A influenced by many factors
  - How to distinguish their separate effects?
- Different frequencies and polarisation states are sensitive to different factors
  - Therefore measure in several channels at various frequencies, and at H and V polarisation
  - Requires at least as many independent $T_A(f,p)$ samples as the number of factors, if we are to resolve each factor
- Develop empirical algorithms using linear combinations of $T_A(f,p)$
- Estimate Temperature, Wind speed, Water vapour, Cloud liquid water

Data grid for different processing modules defined in previous figure

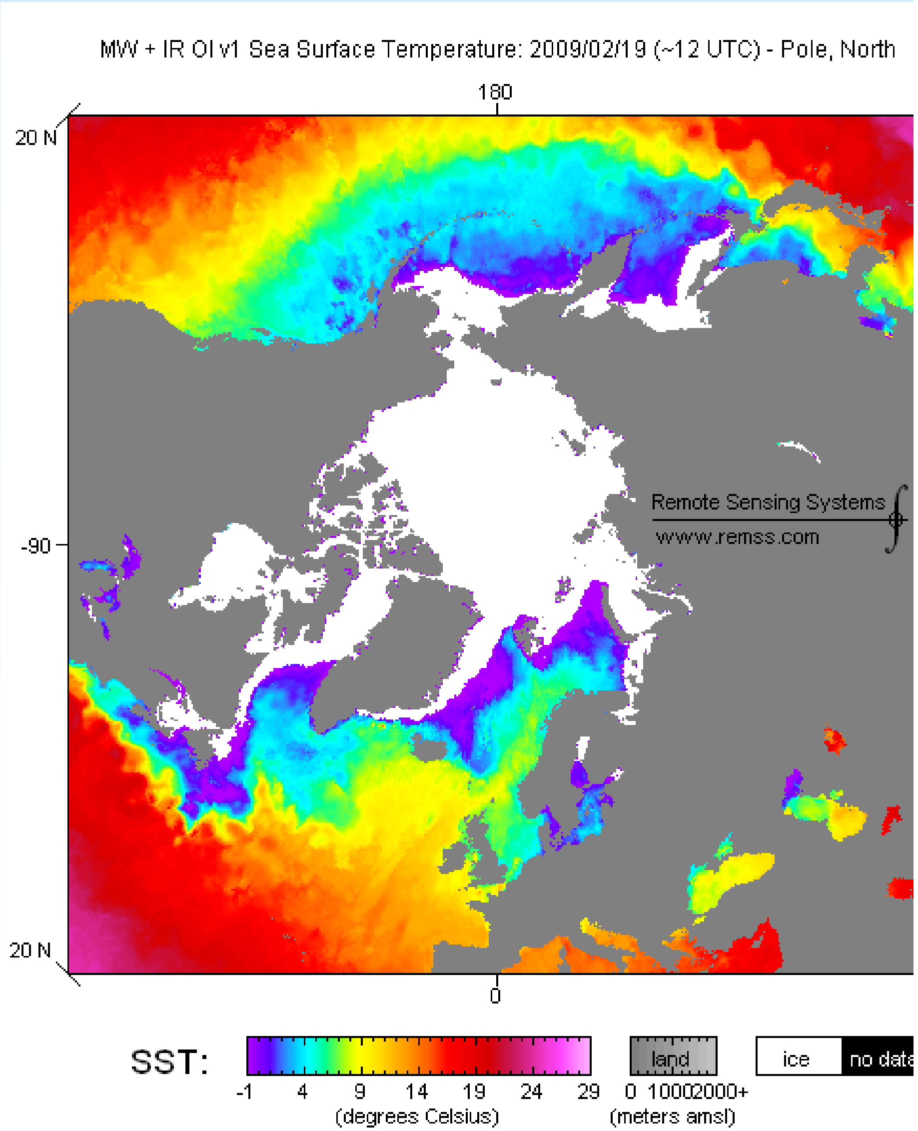


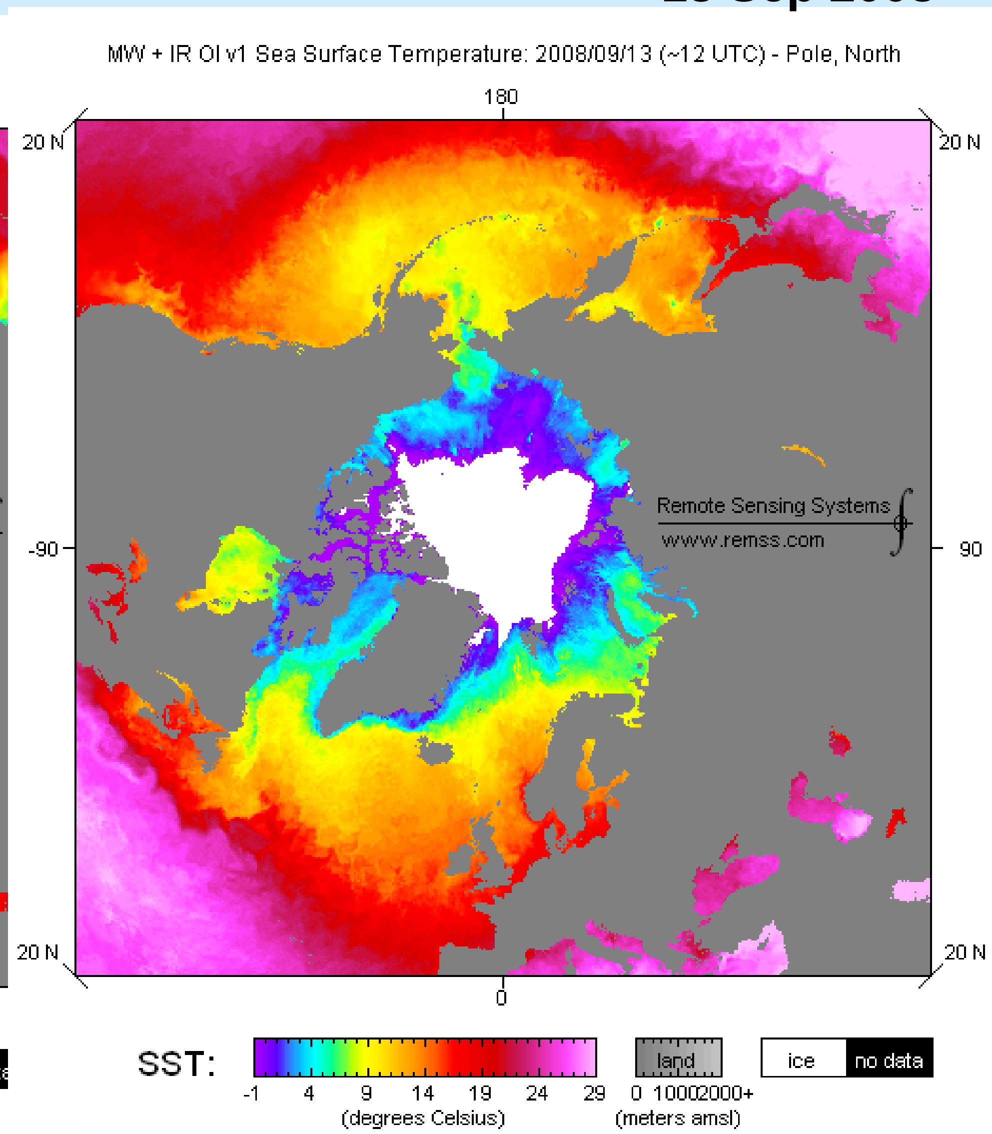
Ocean applications of microwave radiometry

- SST
  - Low latitudes from TMI (199 7) and globally from AMSR-E (2001)
  - Poor spatial and radiometric resolution c/f I-R
  - Can detect SST through clouds very well
  - Applications to study large scale structures in cloudy regions e.g. equatorial waves
  - Eventually, with improved sensors, climate SST data
  - Best used in conjunction with infrared observations
- WIND SPEED,
  - SSM/I, AMSR-E
  - Wind direction not normally retrieved
  - Wind direction measured by a polarimetric radiometer (Windsat)
- Sea Ice
  - Since 1979 on SMMR, SSM/I and AMSR-E
- SALINITY, not yet,
  - ESA SMOS mission launched Nov 2009, under test at present

Polar Sea Ice and SST from AMSR-E

19 Feb 2009 **13 Sep 2008**

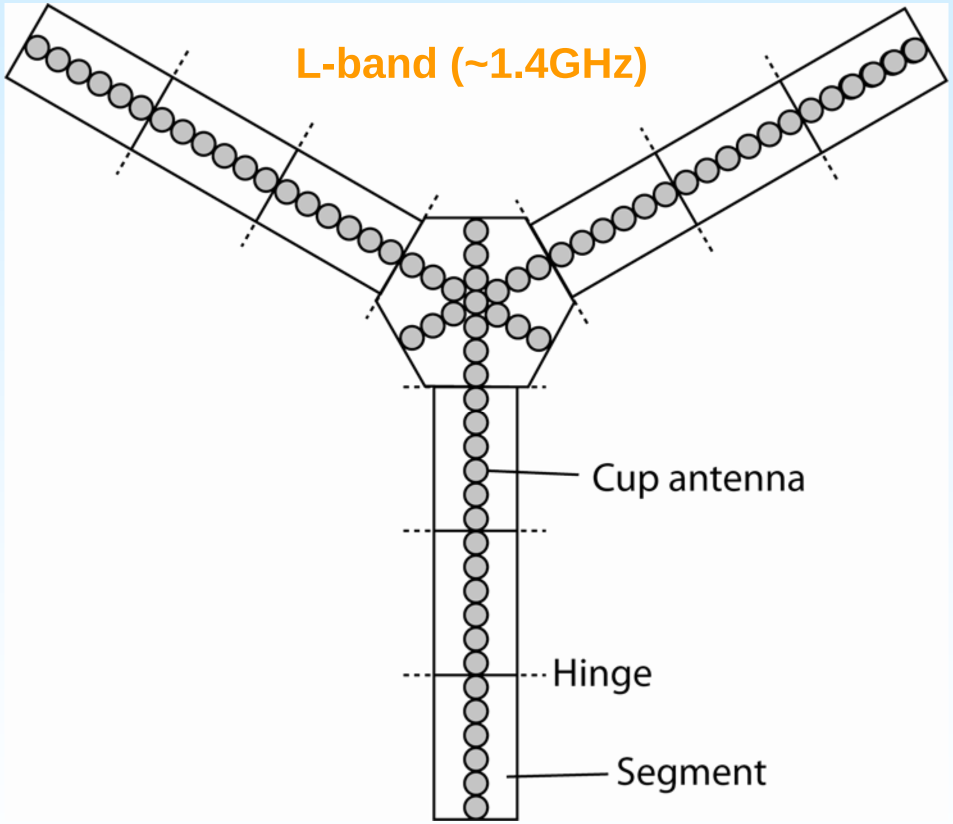




SMOS

ESA Soil Moisture & Ocean Salinity Earth Explorer Mission

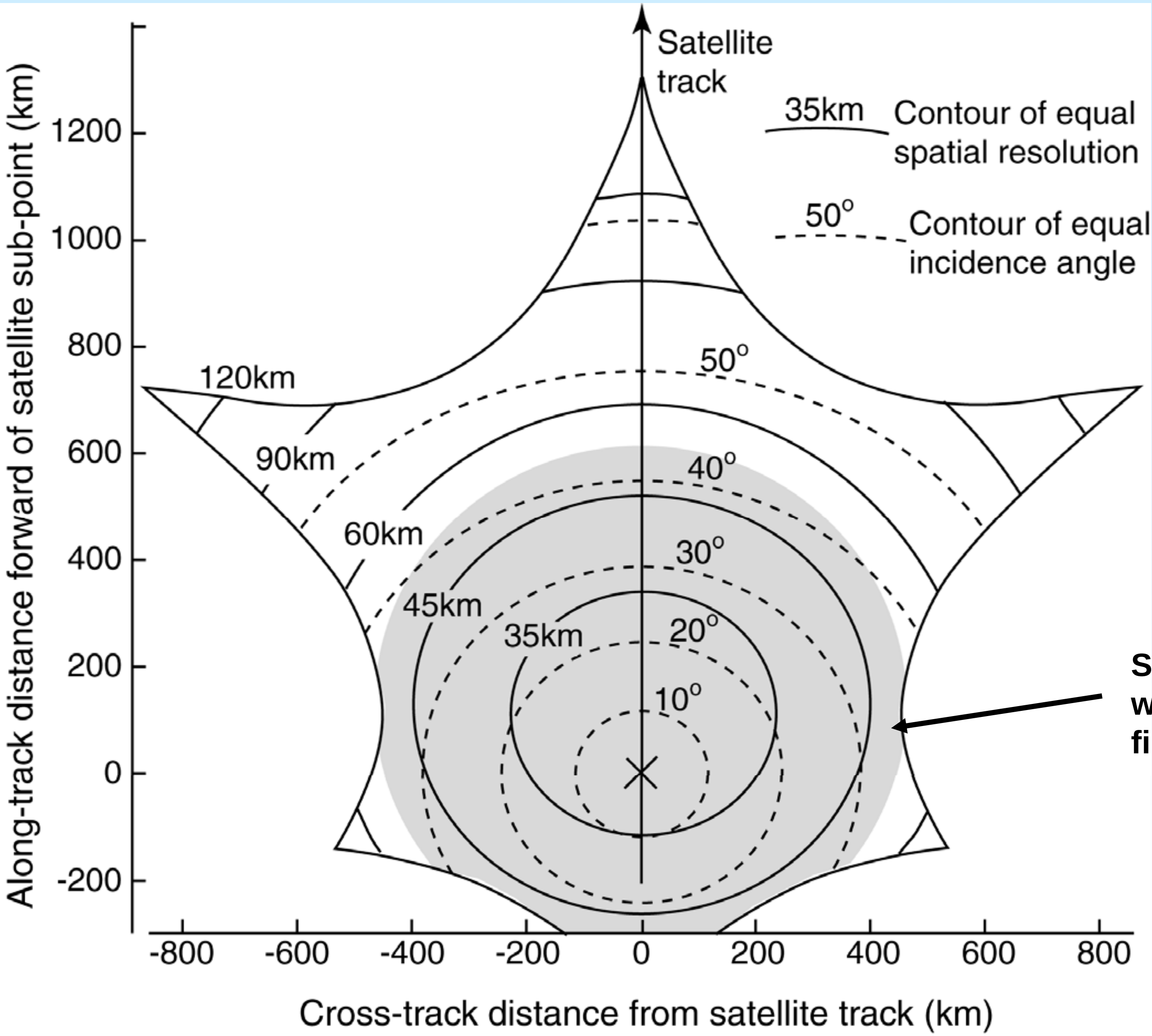
69 receiver elements. Elements are coupled together in different combinations to "point" the beam to different parts of the IFOV.



Multiple samples from each ground location are recorded during each overpass, at different incidence angles and spatial resolutions.

Microwave Imaging Radiometer using Aperture Synthesis (MIRAS)

SMOS multi-element Antenna IFOV



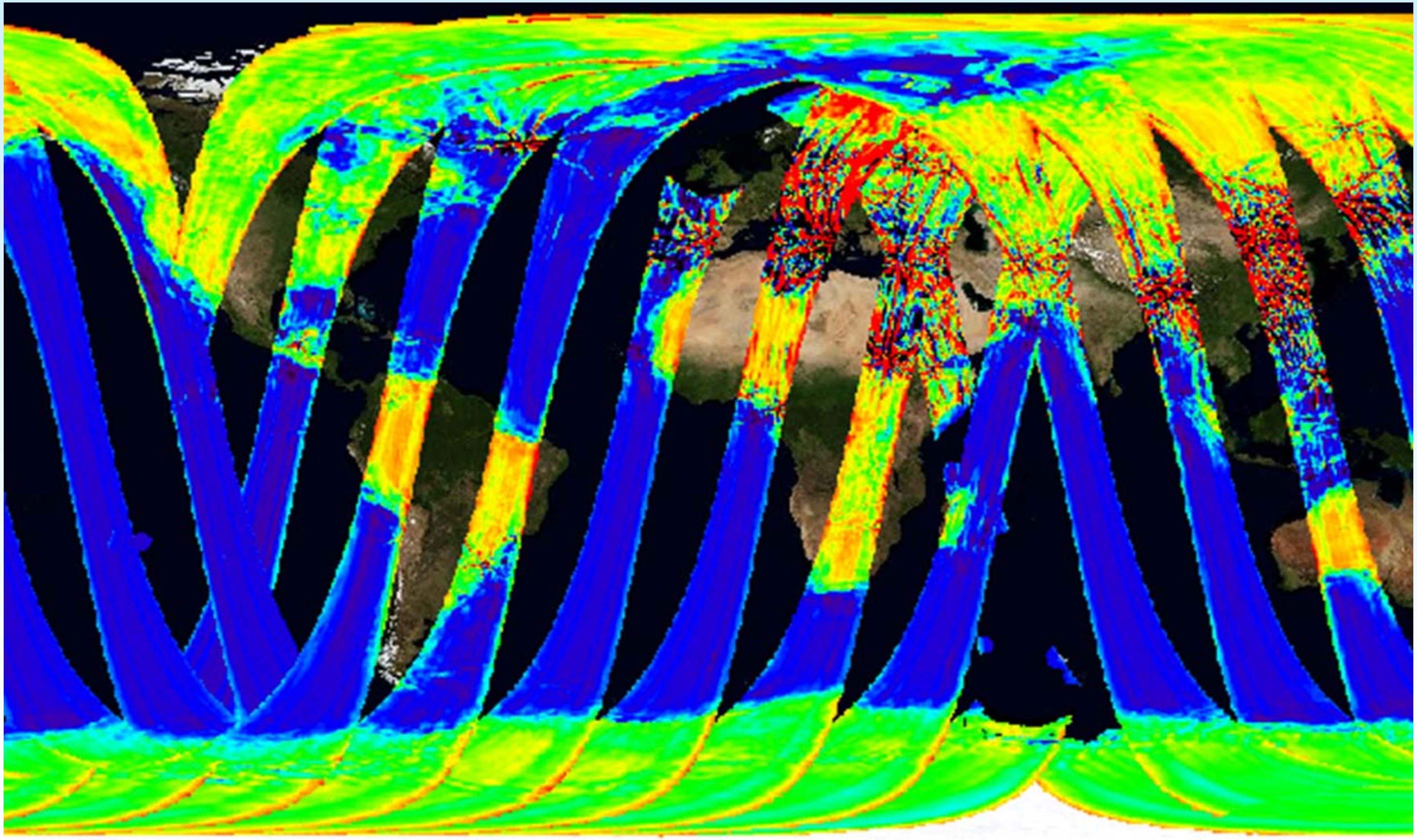
Repeat sampling of this complex IFOV as the satellite progresses allows for improved resolution (trade-off between spatial and radiometric resolution)

Requires knowledge of SST and wind speed-direction to retrieve Salinity

Shaded area is where resolution is finer than 50 km

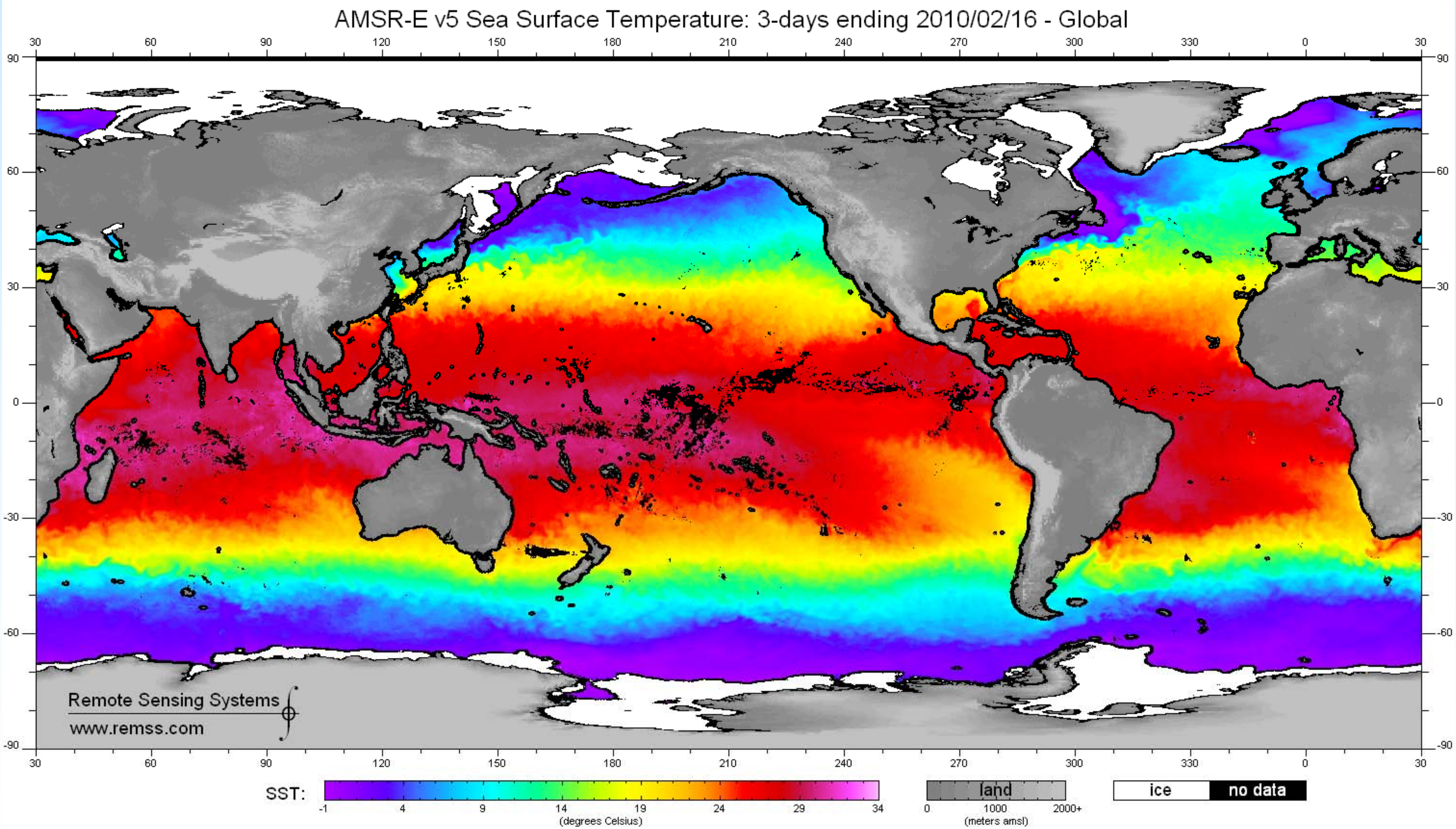
Further enhancement gained from multiple overpasses over an extended time e.g. month

First data, SMOS brightness temperature

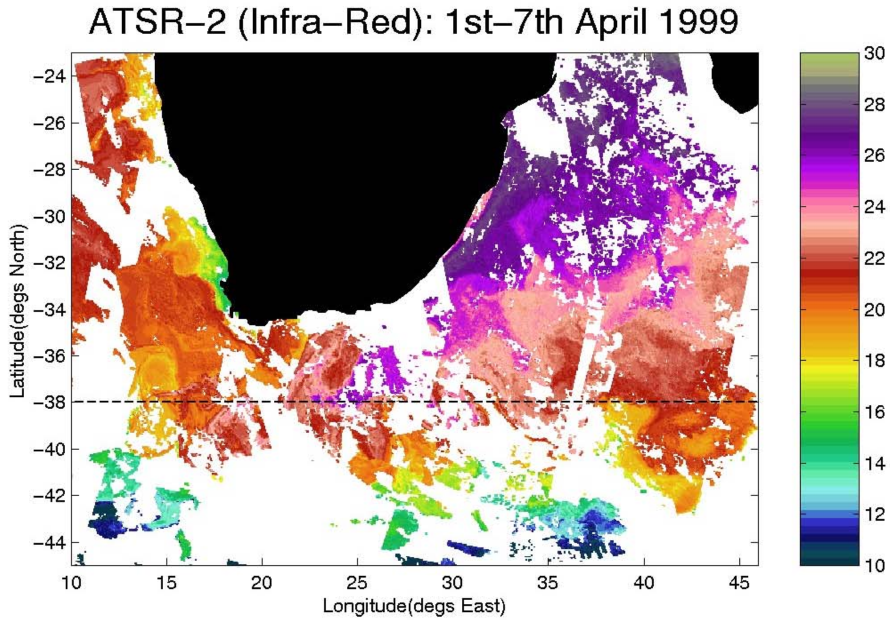


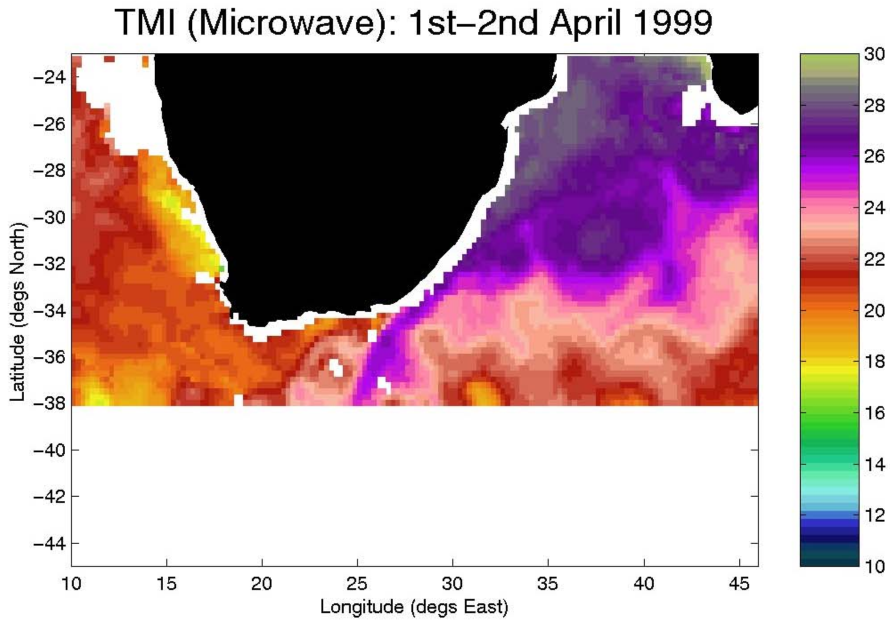
20 Nov 2009

Global SST from AMSR-E on Aqua



AMSR-E data are produced by Remote Sensing Systems and sponsored by the NASA Earth Science REASoN DISCOVER Project and the AMSR-E Science Team. Data are available at www.remss.com.



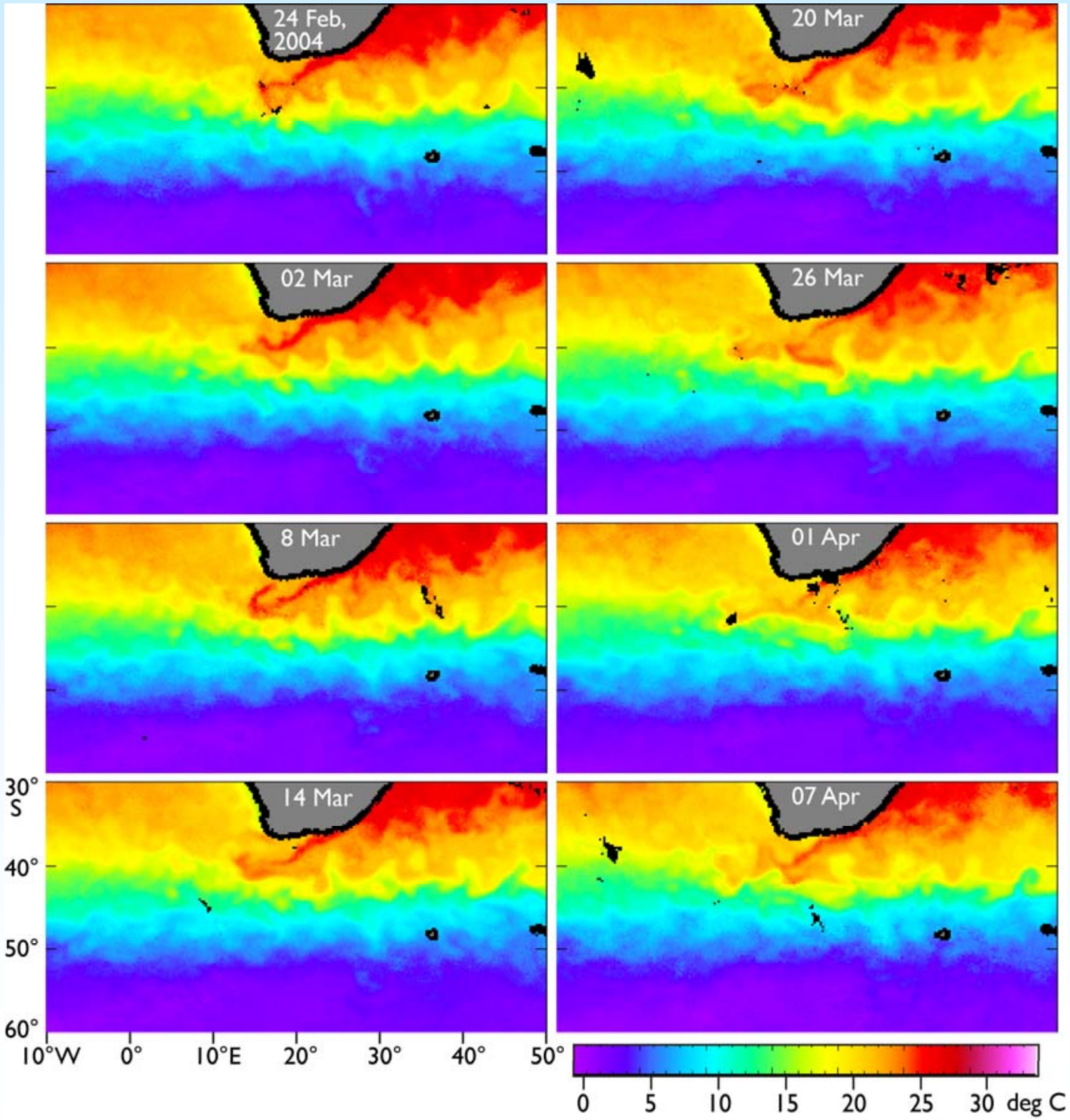


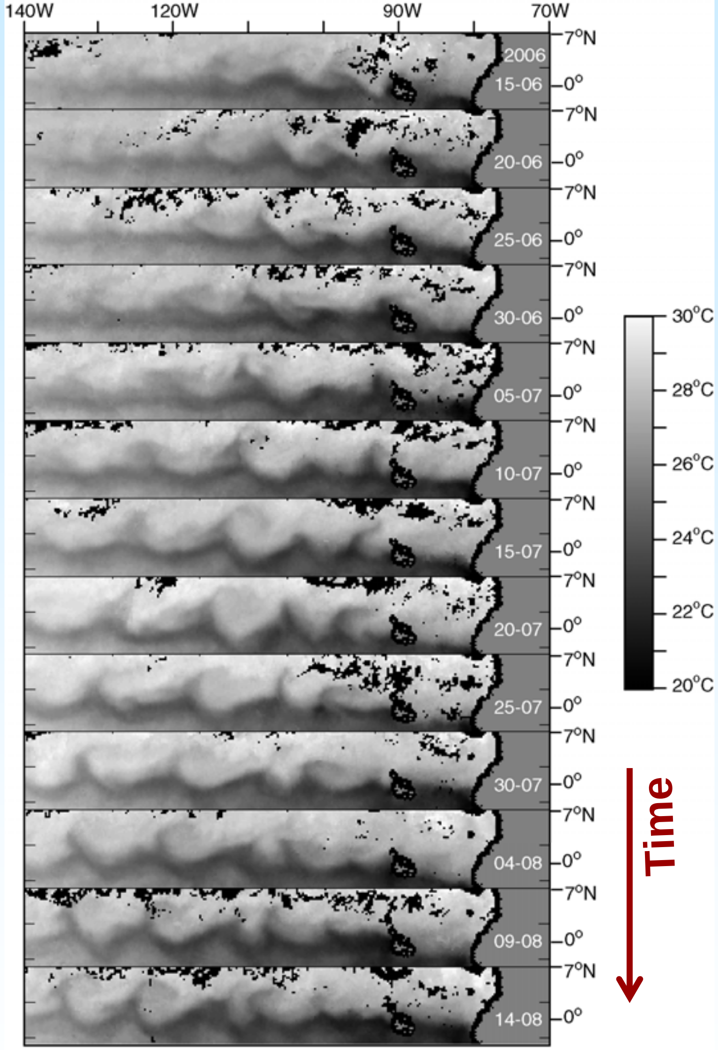
Complementarity of IR and MW radiometry

- Compare ATSR
  - 1km spatial resolution
  - 0.1 K resolution
  - Cloud dependent
  - 0.2 K accuracy
- with TRIMM Microwave Imager (TMI)
  - 0.5º spatial resolution
  - 0.25º spatial sampling
  - 0.2-0.3 K resolution
  - Independent of cloud
  - ~0.5 K accuracy

Data courtesy of G C Quartly, NOC-LSO

Microwave SST sequences reveal ocean dynamics





Low data drop-out outweighs the coarse spatial resolution

The importance of fine resolution SST

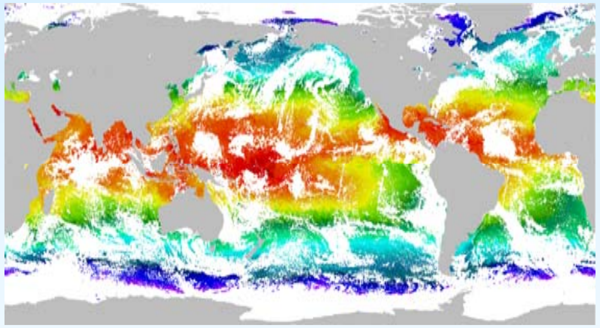
- 10 km spatial resolution essential, 5 km desirable
  - SST analyses are based on merging IR and MW products
  - In extensive cloud the resolution degrade to MW resolution
- Importance of achieving finer resolution from MW radiometry
  - Absolute accuracy can be enhanced by bias adjustment to the dual-view IR SST (AATSR)
  - Could tradeo-ff accuracy (but not radiometric resolution) for spatial resolution
- Need to get closer to the coast than 100 km
  - Can we reduce side-lobe contamination ?

- The next challenge – hi-res MW radiometry

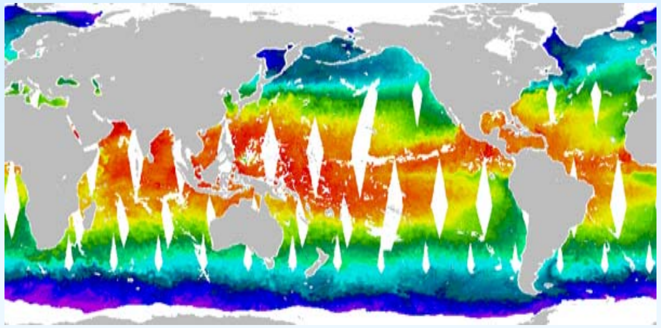
Which SST product should I use?
Different sensor types, swaths and resolutions

Daily coverage

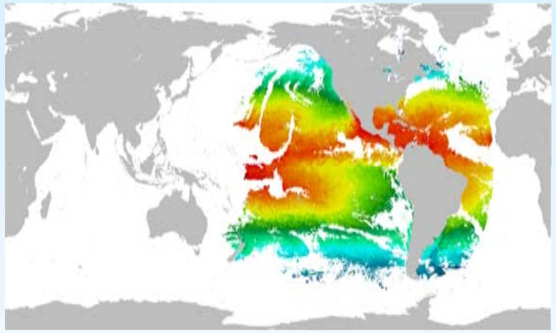
NOAA-17/18
AVHRR GAC (9km)

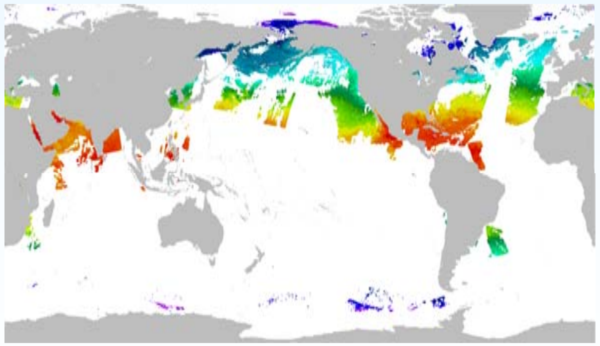


AMSRE (25/12km)

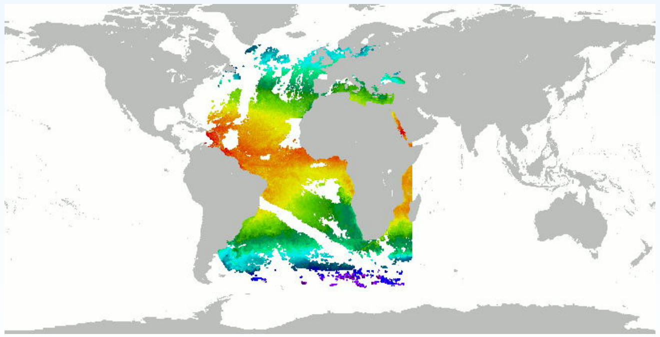


GOES-E/W (5km)

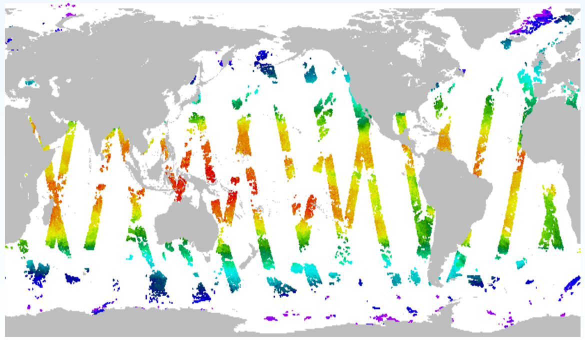




NOAA-17/18
AVHRR LAC (1km)



Meteosat Second Generation (5/10km)



AATSR (1km)

The need to merge SST data from diverse sources

- Data available from different types of sensor and different orbits provides diversity and synergy to overcome problems

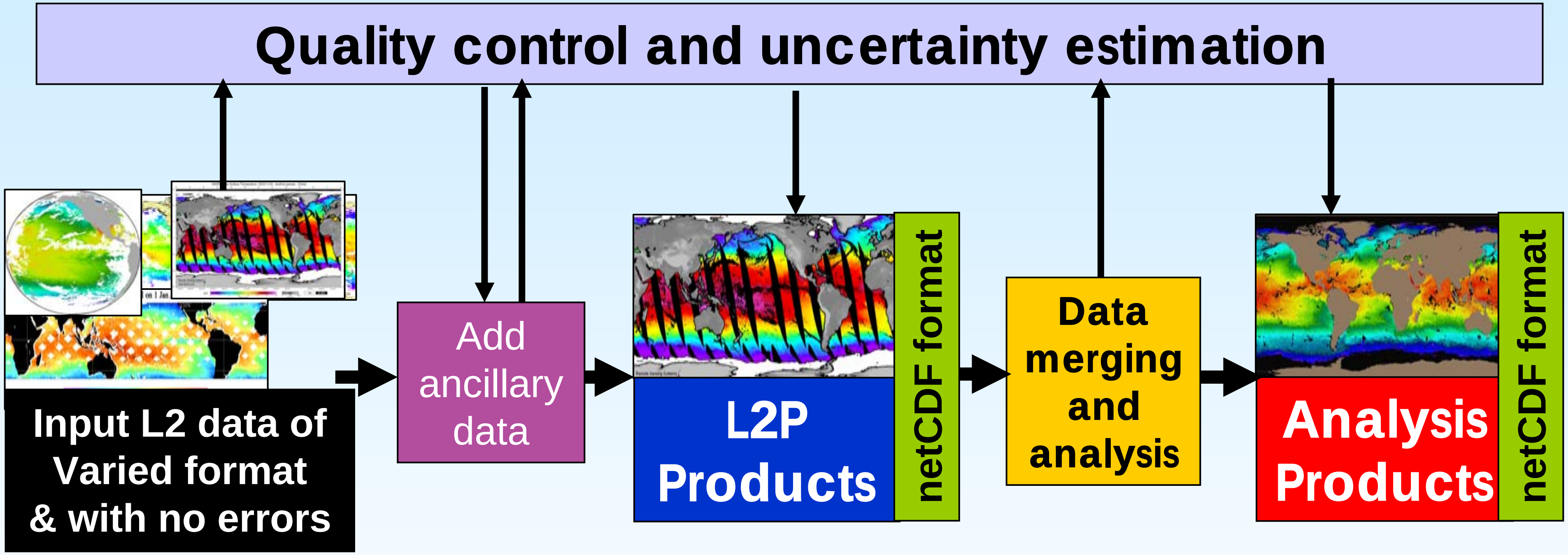
TABLE 1. Typical sampling capabilities of different types of satellite SST sensors.

Sensor type	Satellite type	Spatial resolution	Resampling interval	Absolute accuracy	Effect of cloud	Depth penetration
Infrared wide swath radiometer	Polar orbit	1–4-km, large off-nadir angles reduce resolution	12 h, global	0.4–0.6 K	Fails over cloud and in the presence of atmospheric aerosol	Skin (~10–20 μm)
Infrared dual-view radiometer	Polar orbit	1–2 km	3 days, global	0.2–0.3 K	Fails over cloud	Skin (~10–20 μm)
Infrared Earth disc radiometer	Geostationary orbit	3–10 km, large off-nadir angles reduce resolution	30 min limited field of view	0.5–0.8	Fails over cloud	Skin (~10–20 μm)
Microwave radiometer	Polar orbit	25–50 km	1–2 days, global	0.5–1 K	Affected by non-precipitating cloud	Subskin (~1–1.5 mm)

The need for hi resolution analysed SST data

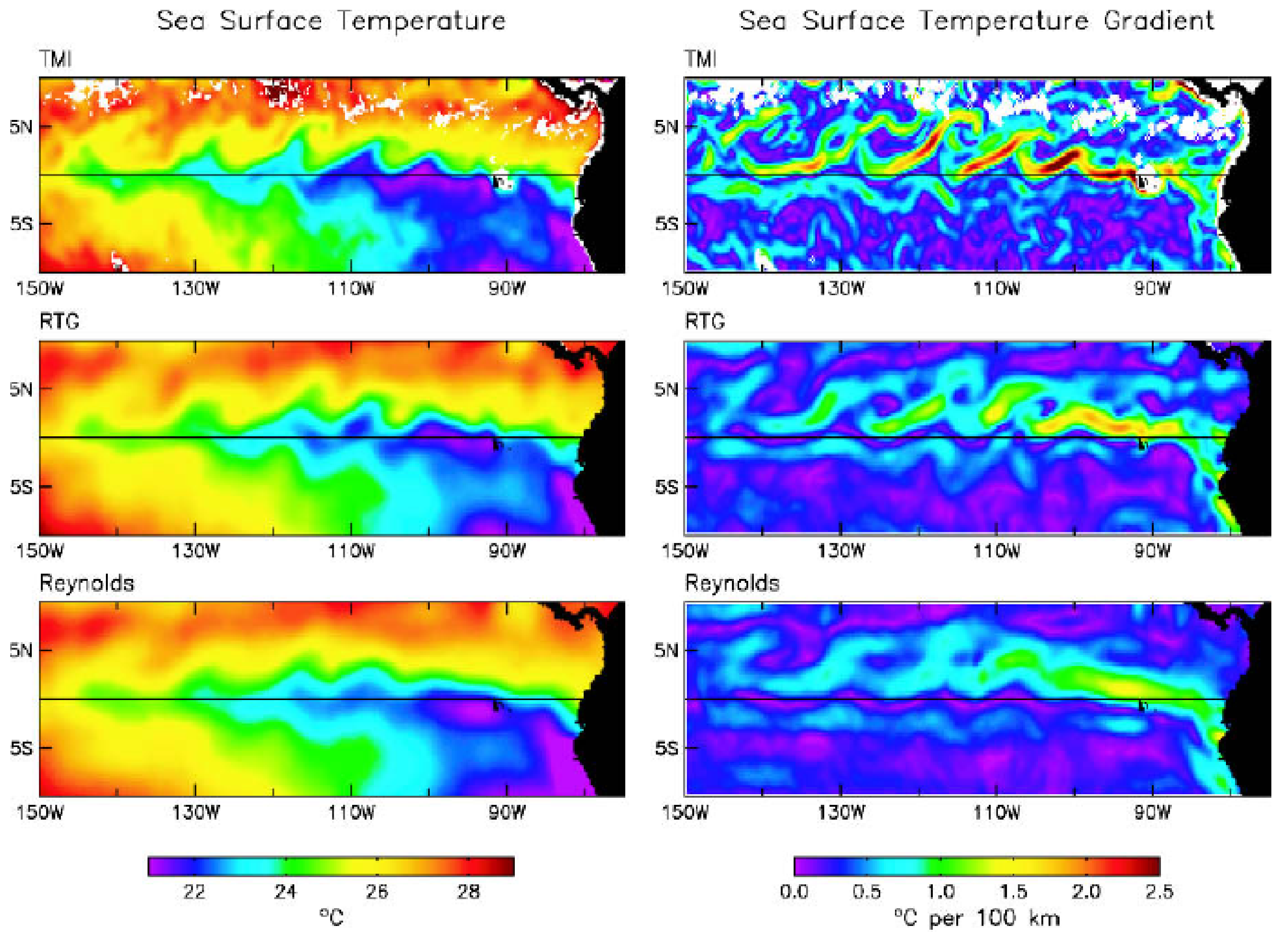
- Build merged SST datasets from all the available products
- Use complementarity of the different SST methods
- This is now achieved through the international collaborative work of GHRSST = Group for High resolution SST

The GHRSST-PP Strategy

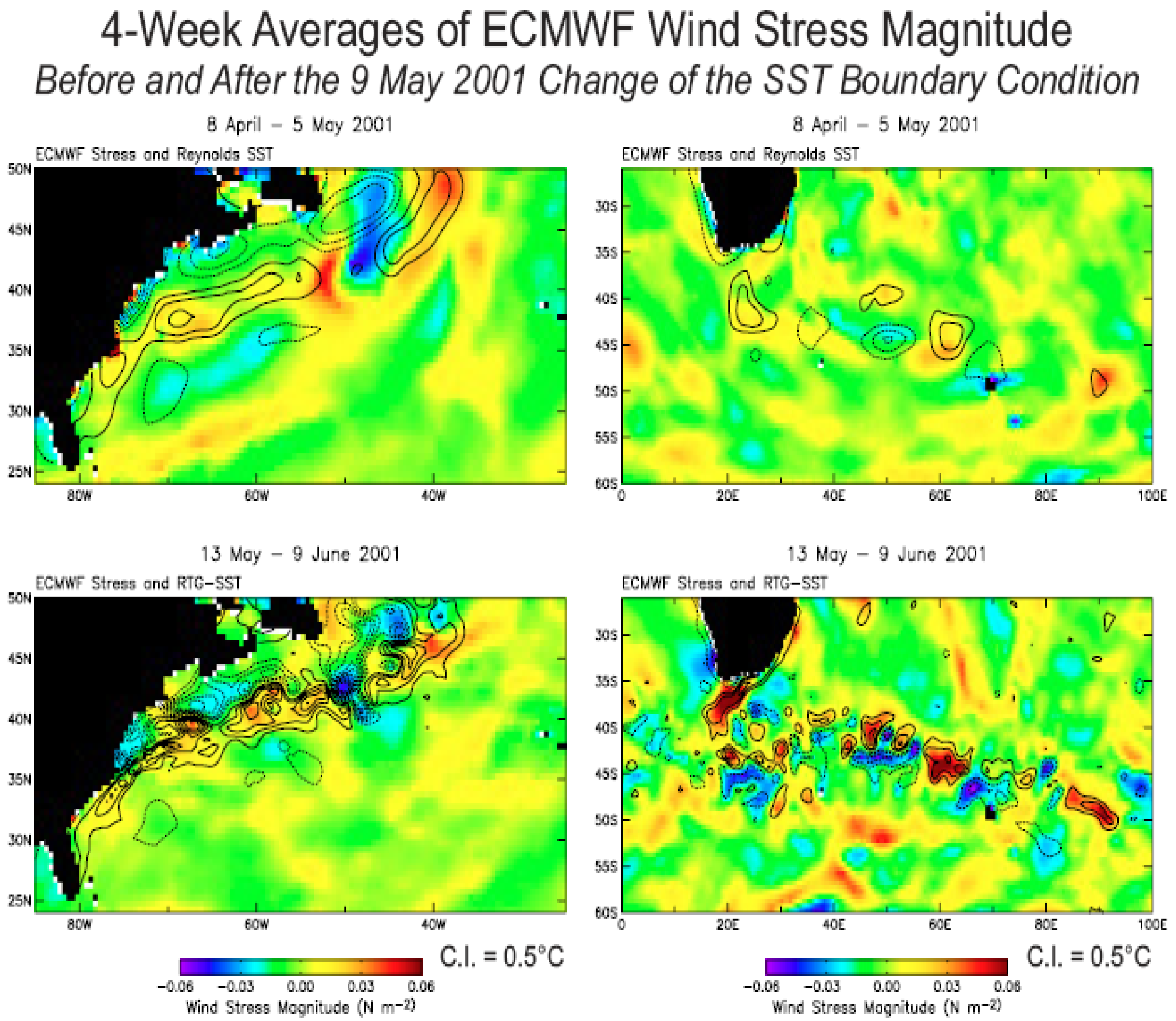


Observations → Applications

SST gradient depends on the SST product

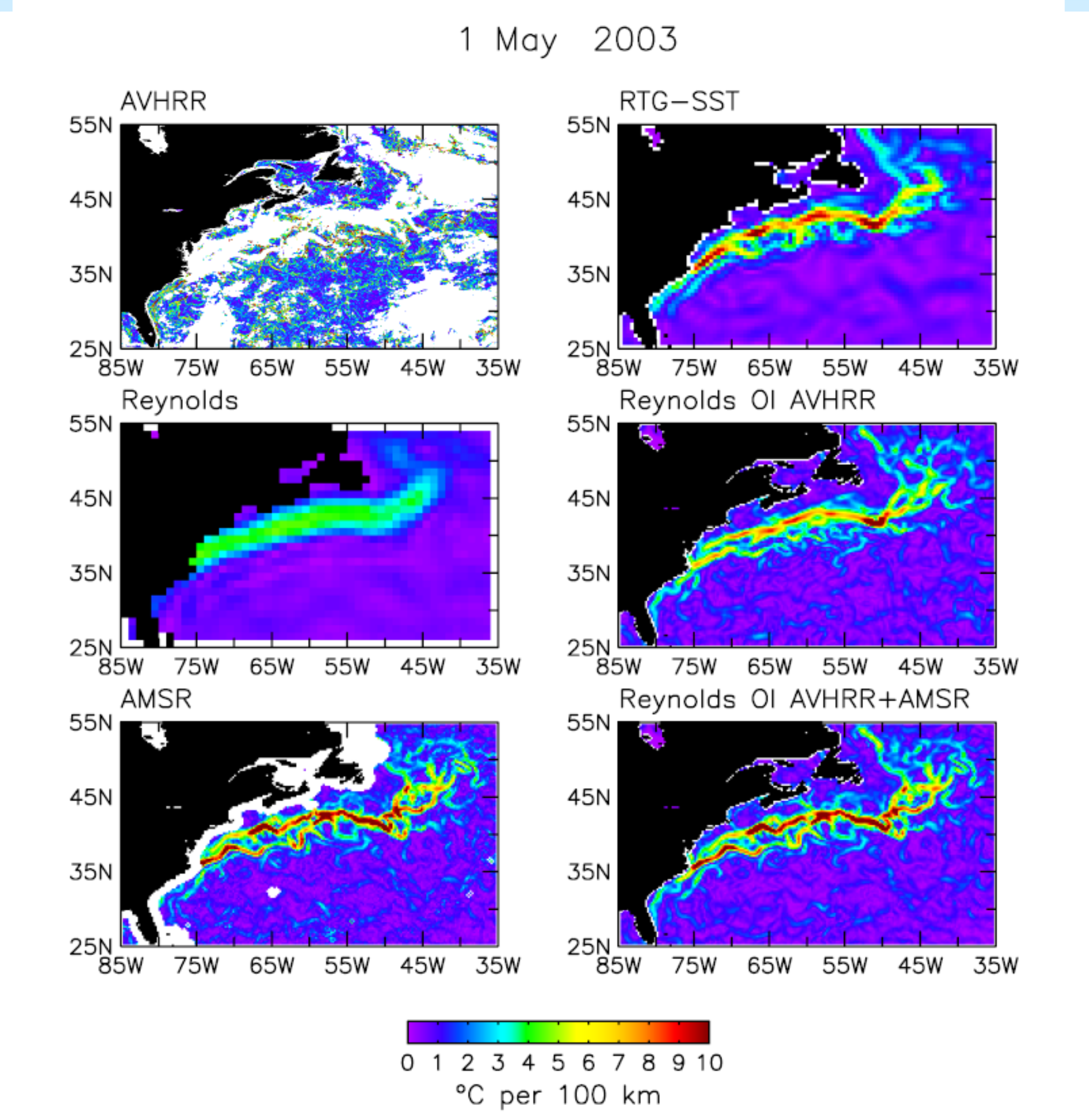


Surface winds and SST



Small-scale variability in the surface wind field increased abruptly after the 9 May 2001 change to a higher resolution SST boundary condition.

Impact of high resolution SSTs



Impact of using combined AVHRR and microwave SSTs on resolving SST gradients