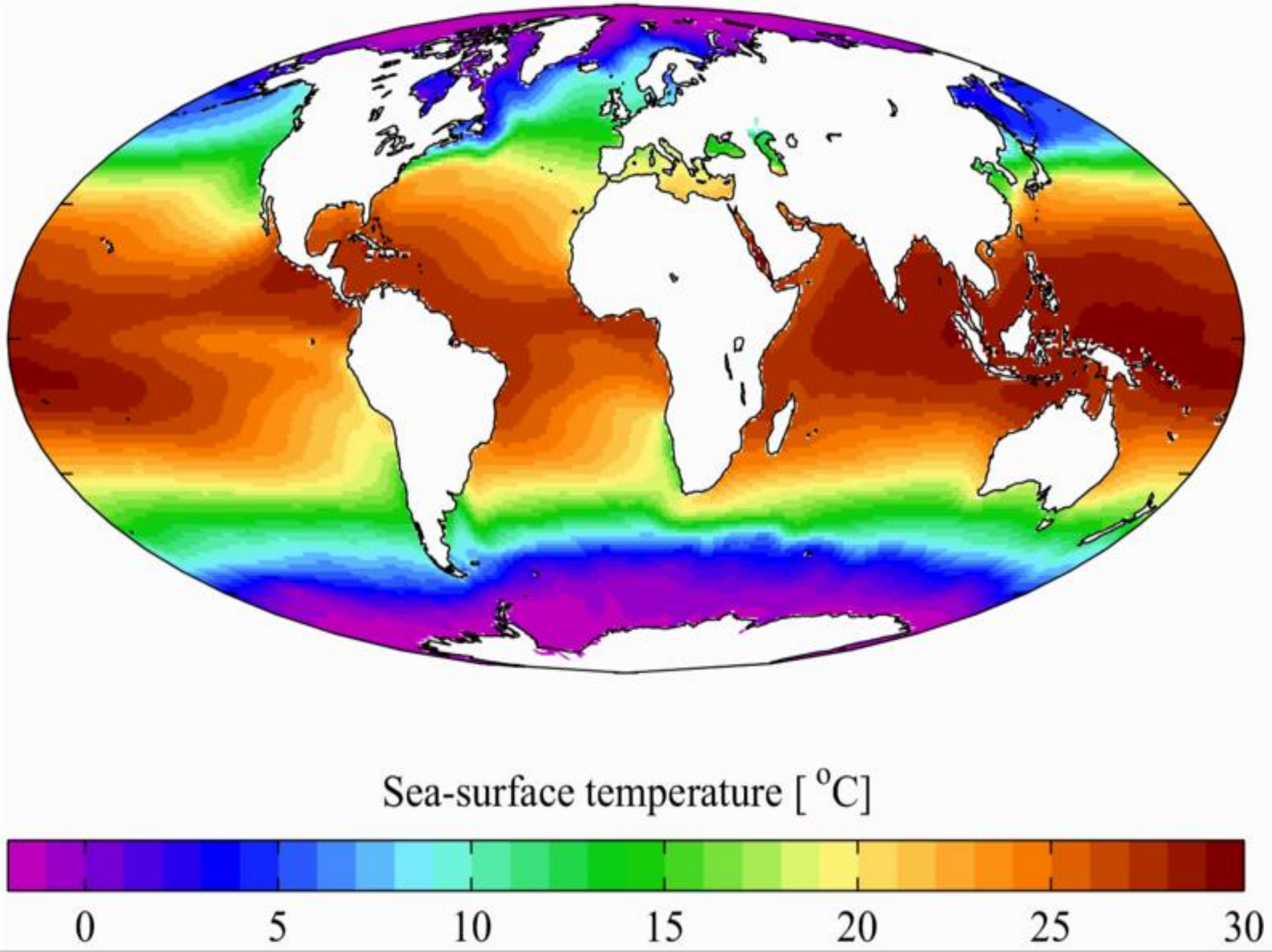
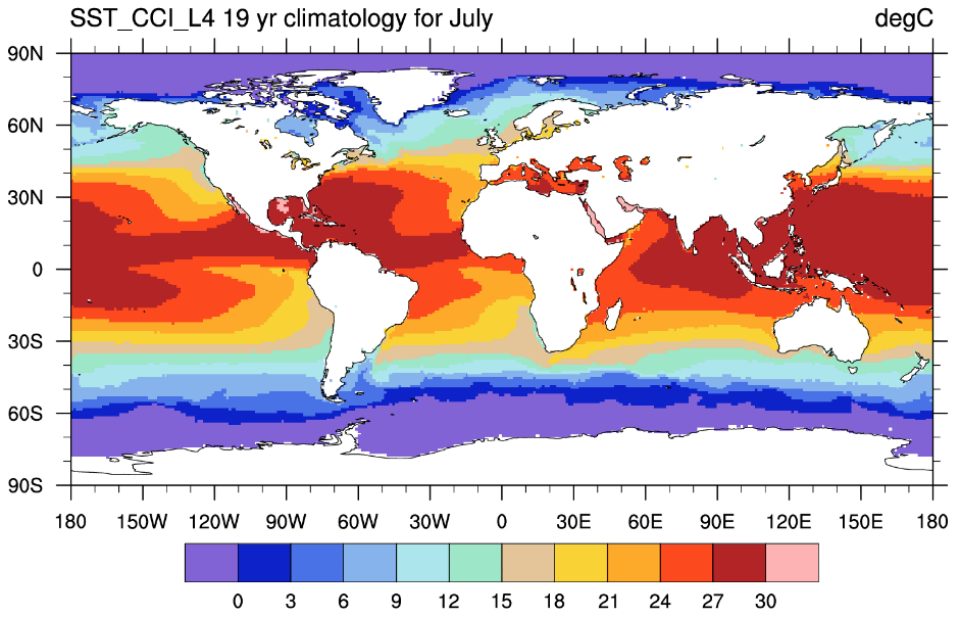
Measuring sea surface temperature from space

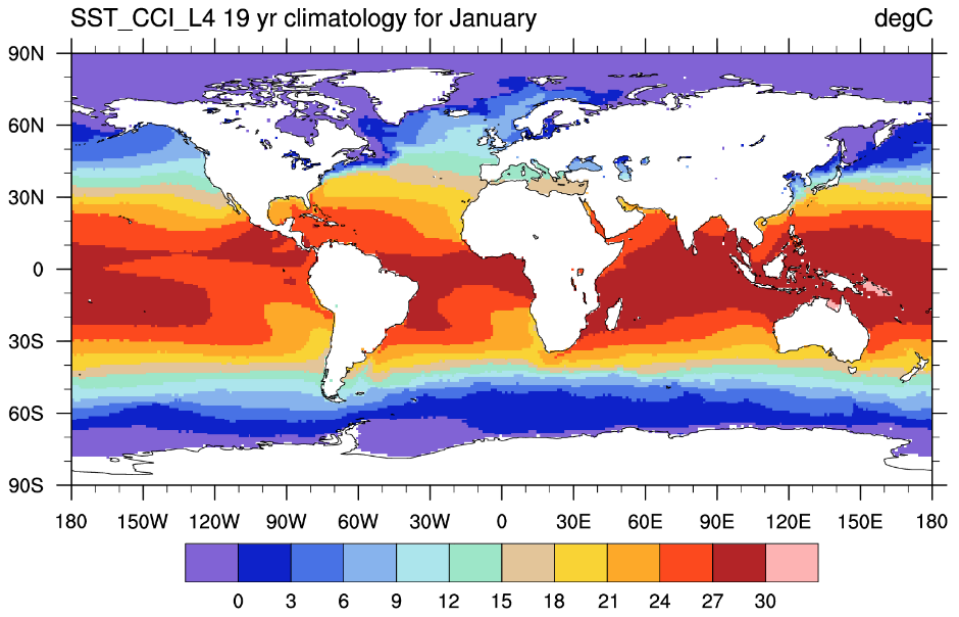
Prof. Chris Merchant
University of Reading
UK

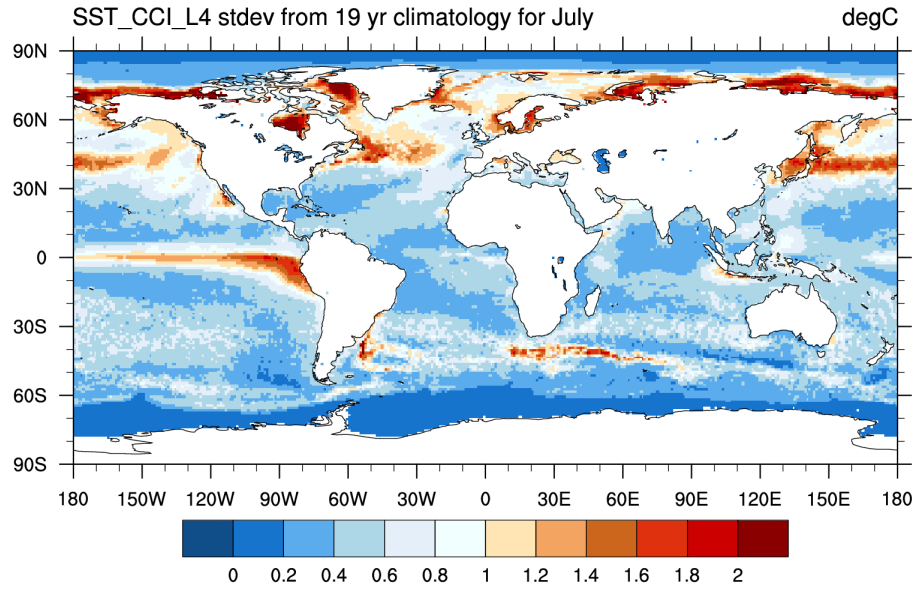
Schedule for the day

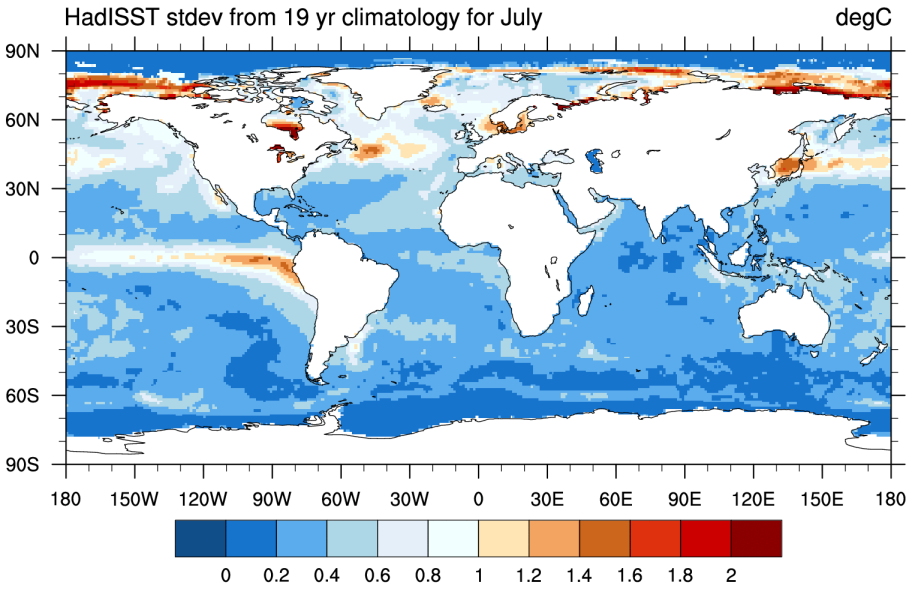
- Introduction to sea surface temperature
- Measuring SST from space
- Operational systems for SST
- *Bilko practical*
- Observing and modelling SST across scales
- *Bilko practical*
- Closing session

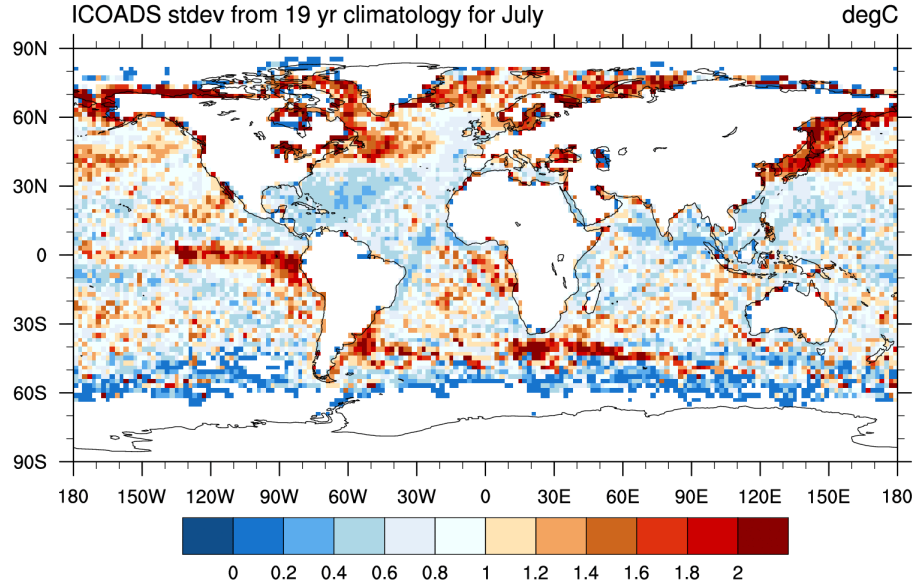

Sea-surface temperature [°C]
0
5
10
15
20
25
30

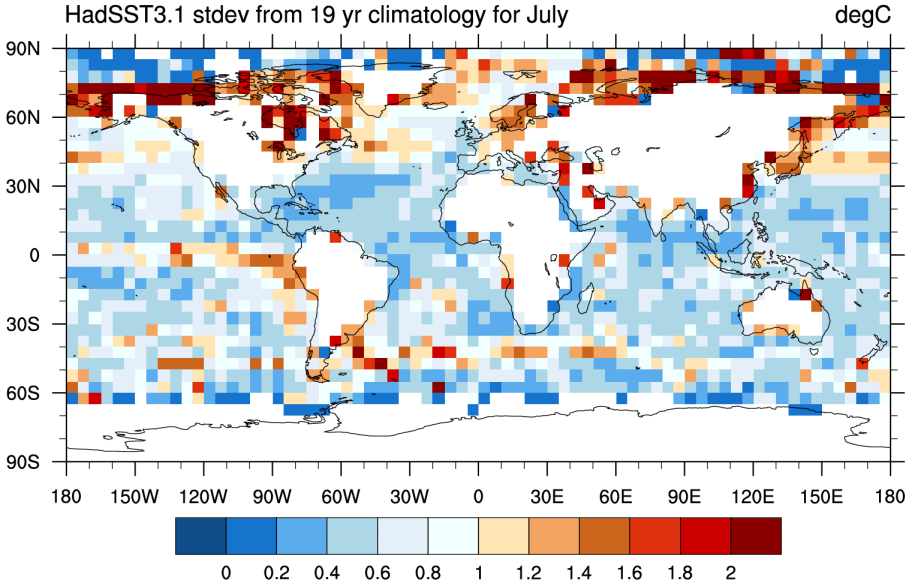

SST_CCI_L4 19 yr climatology for July
degC
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 3 6 9 12 15 18 21 24 27 30


SST_CCI_L4 19 yr climatology for January
degC
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 3 6 9 12 15 18 21 24 27 30

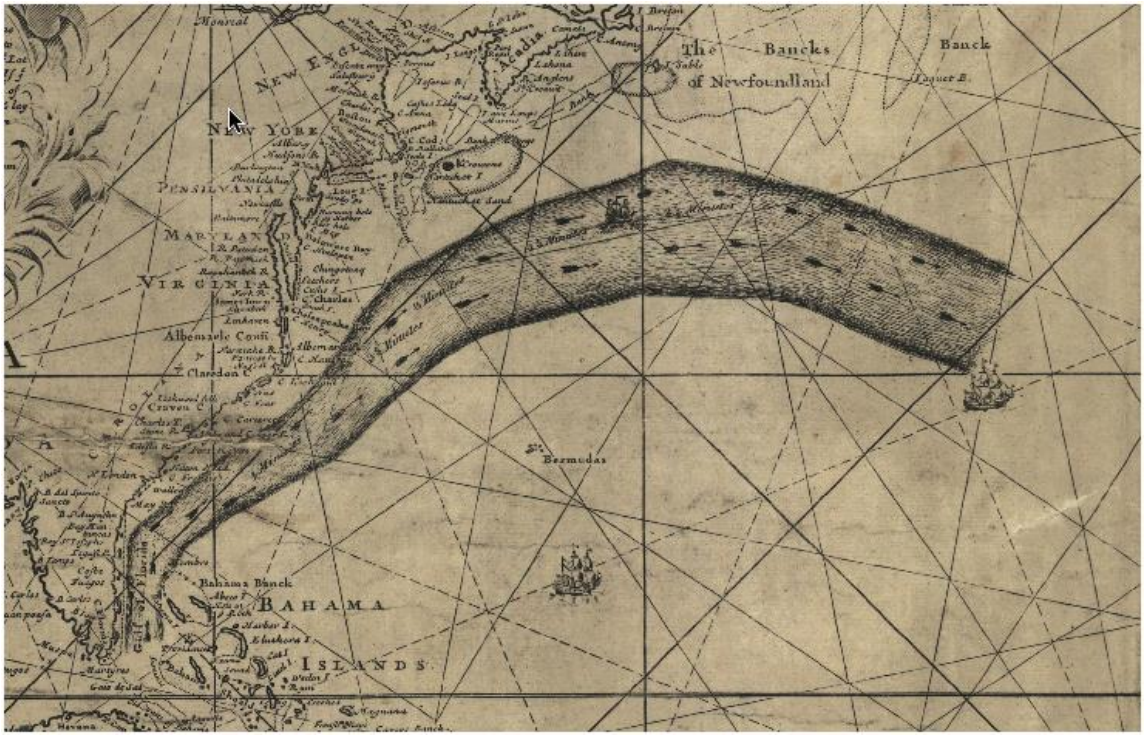

SST_CCI_L4 stdev from 19 yr climatology for July
degC
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2

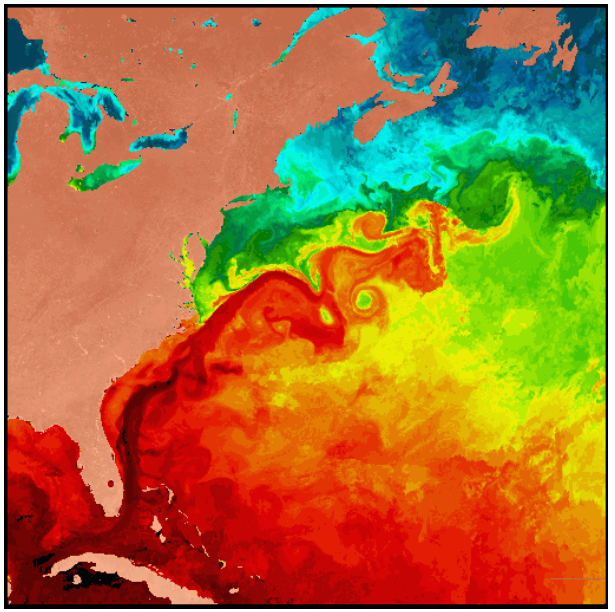

HadISST stdev from 19 yr climatology for July
degC
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2


ICOADS stdev from 19 yr climatology for July
degC
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2


HadSST3.1 stdev from 19 yr climatology for July
degC
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2

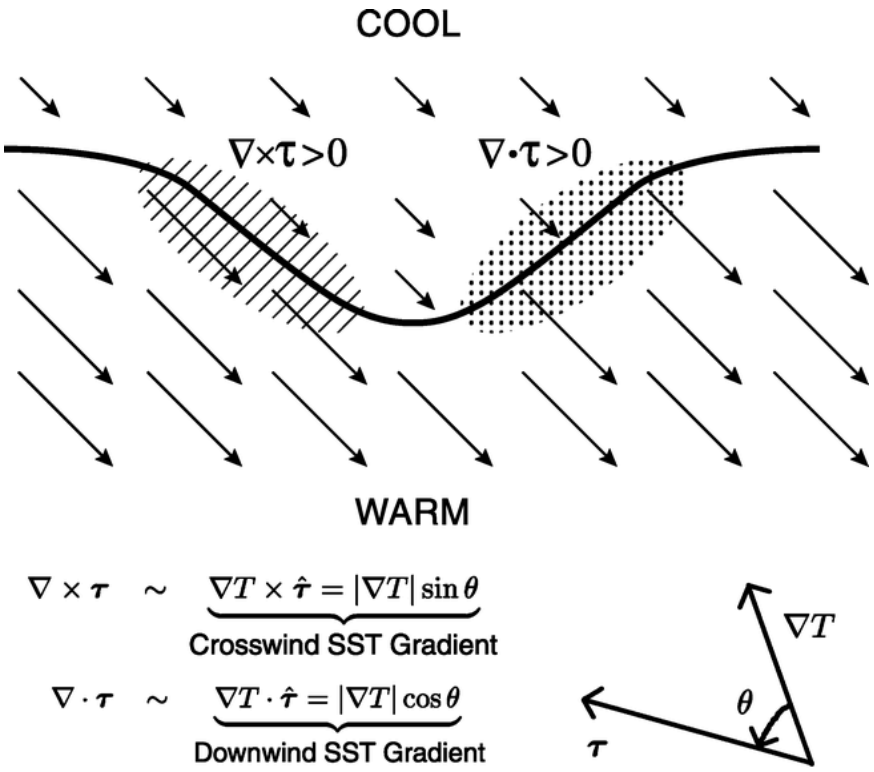
We need to observe ocean surface temperature



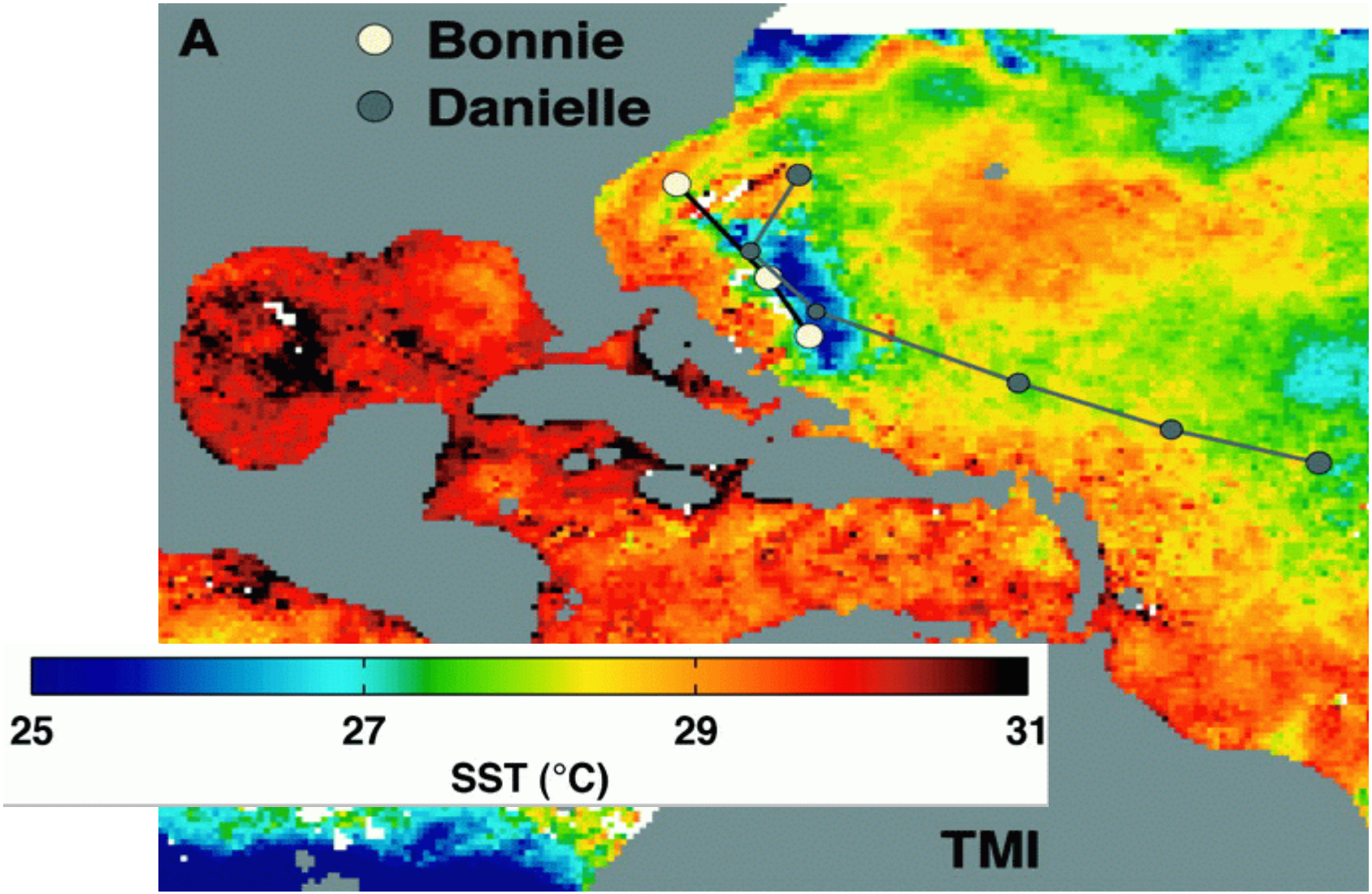


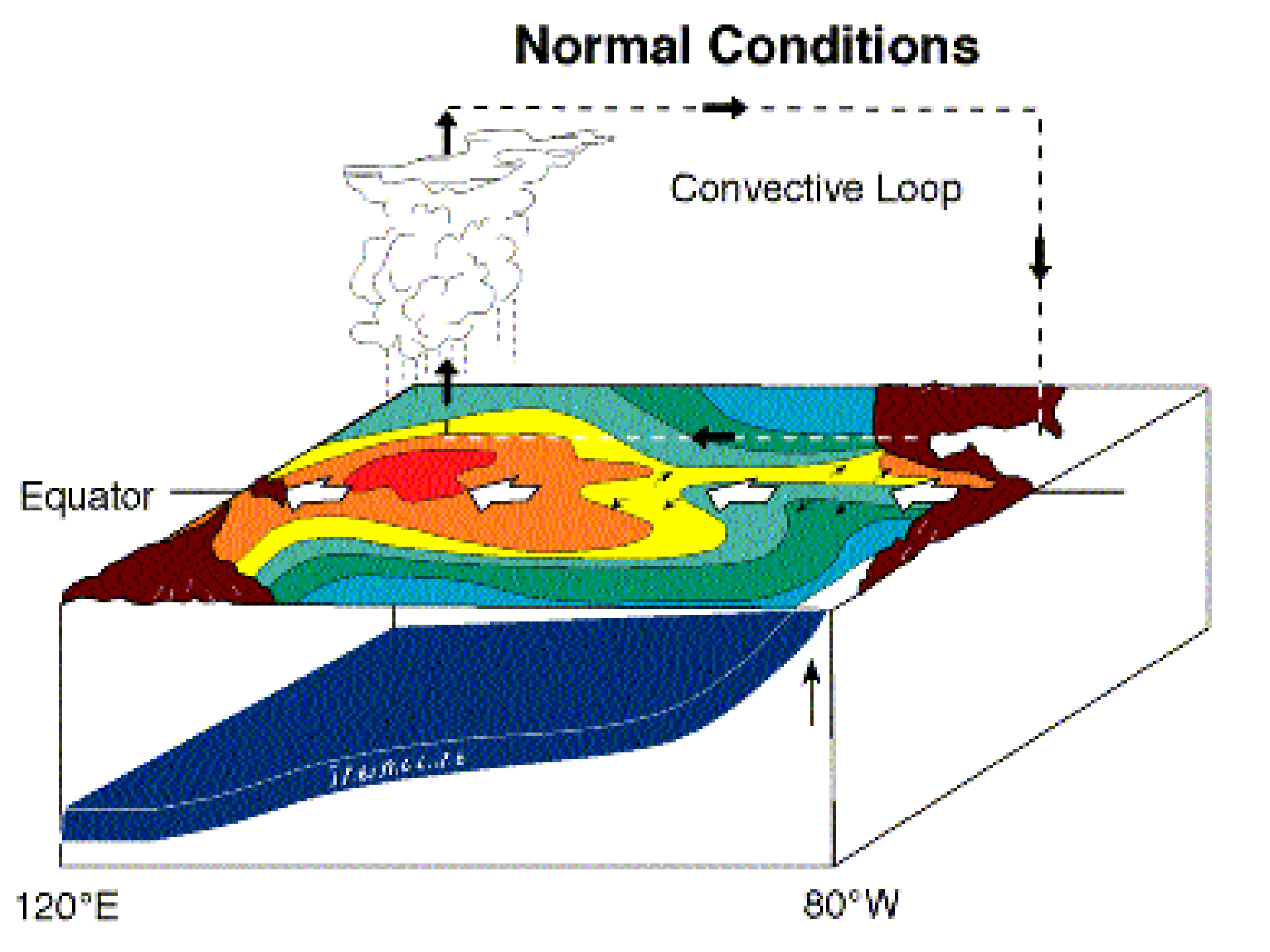
- Benjamin Franklin, 1768
- Concerned about his wine?

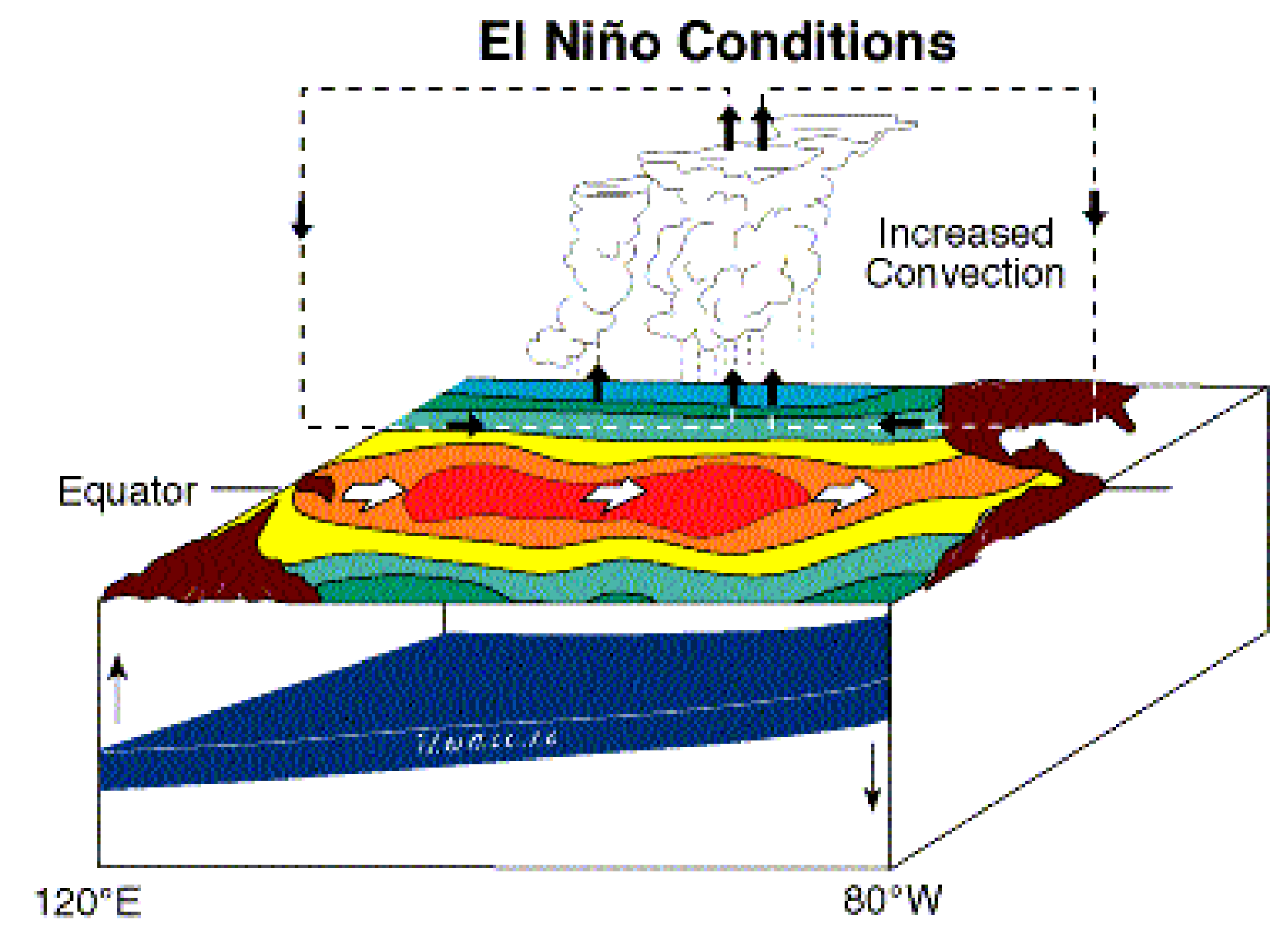
We need to observe ocean surface temperature



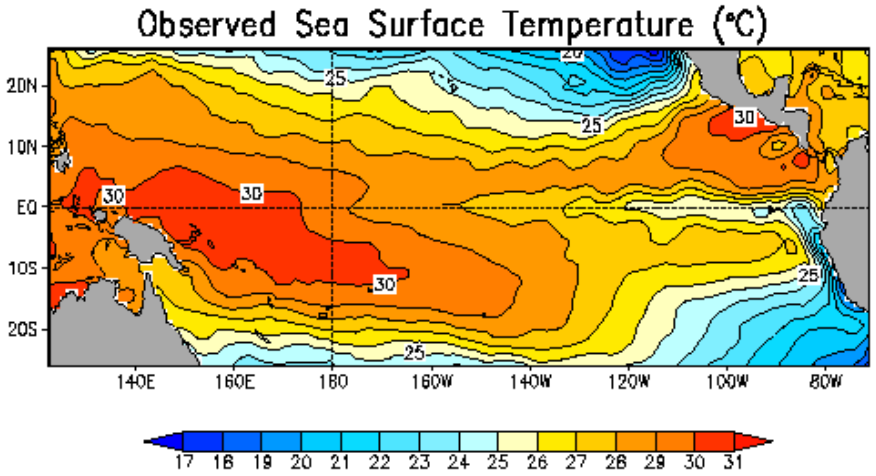
We need to observe ocean surface temperature



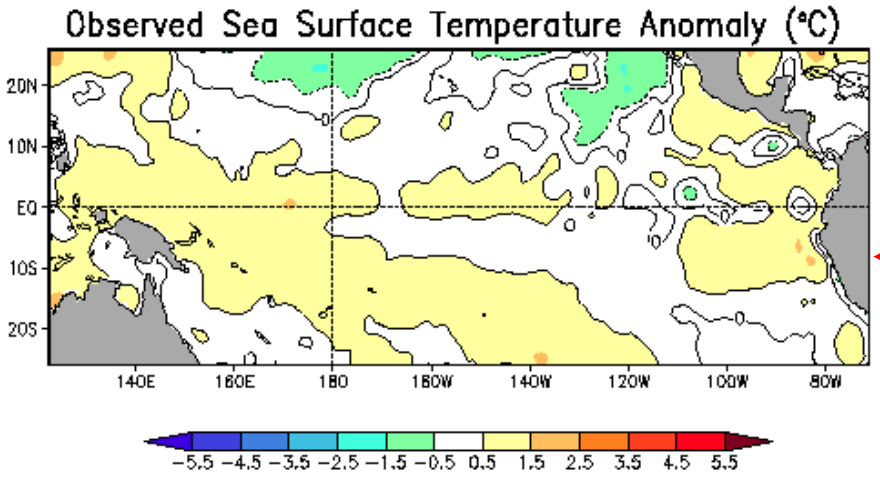

Normal Conditions
Convective Loop
Equator
120°E
80°W


El Niño Conditions
Increased
Convection
Equator
120°E
80°W

‘Anomaly’



This is a snapshot of sea surface temperature in the tropical Pacific



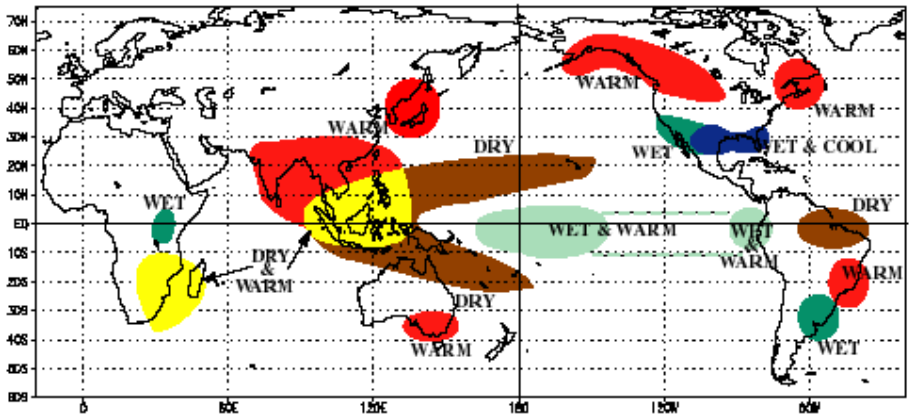
The anomaly is how it differs from average values for that time of year.

7−day Average Centered on 08 May 2002

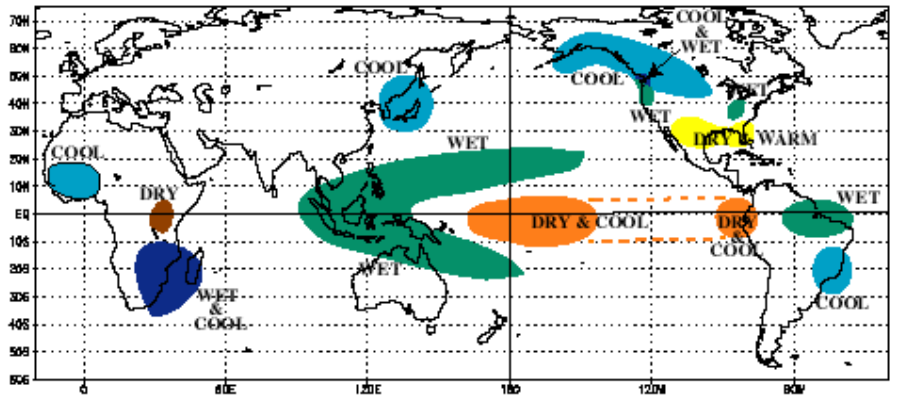
NCEP/Climate Modeling Branch

El Nino Impacts La Nina Impacts

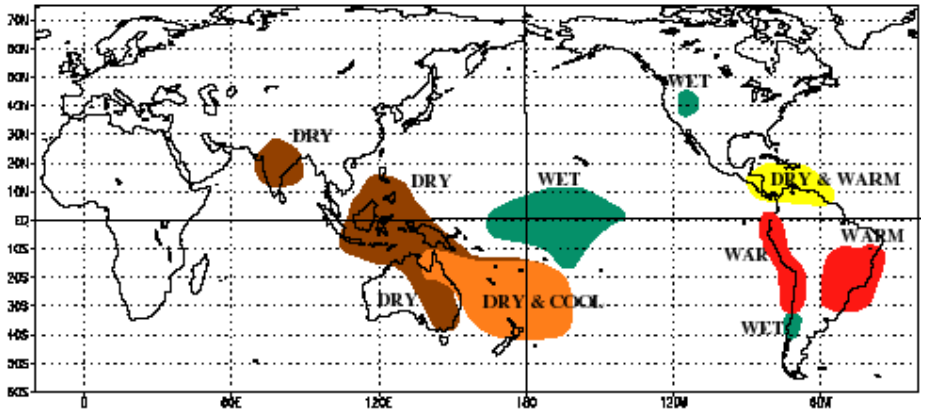
WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



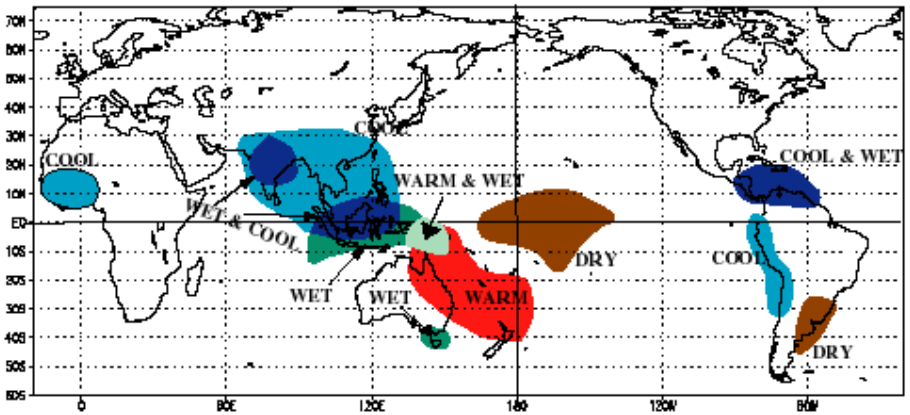
COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



WARM EPISODE RELATIONSHIPS JUNE - AUGUST

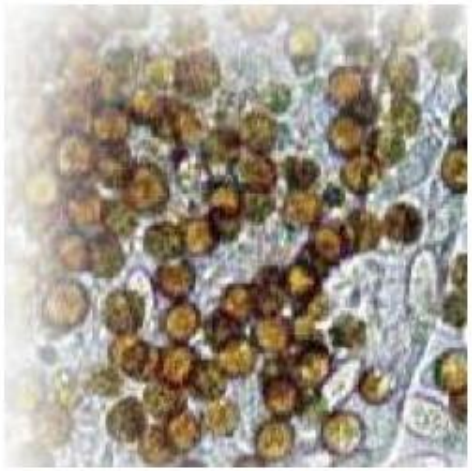


COLD EPISODE RELATIONSHIPS JUNE - AUGUST



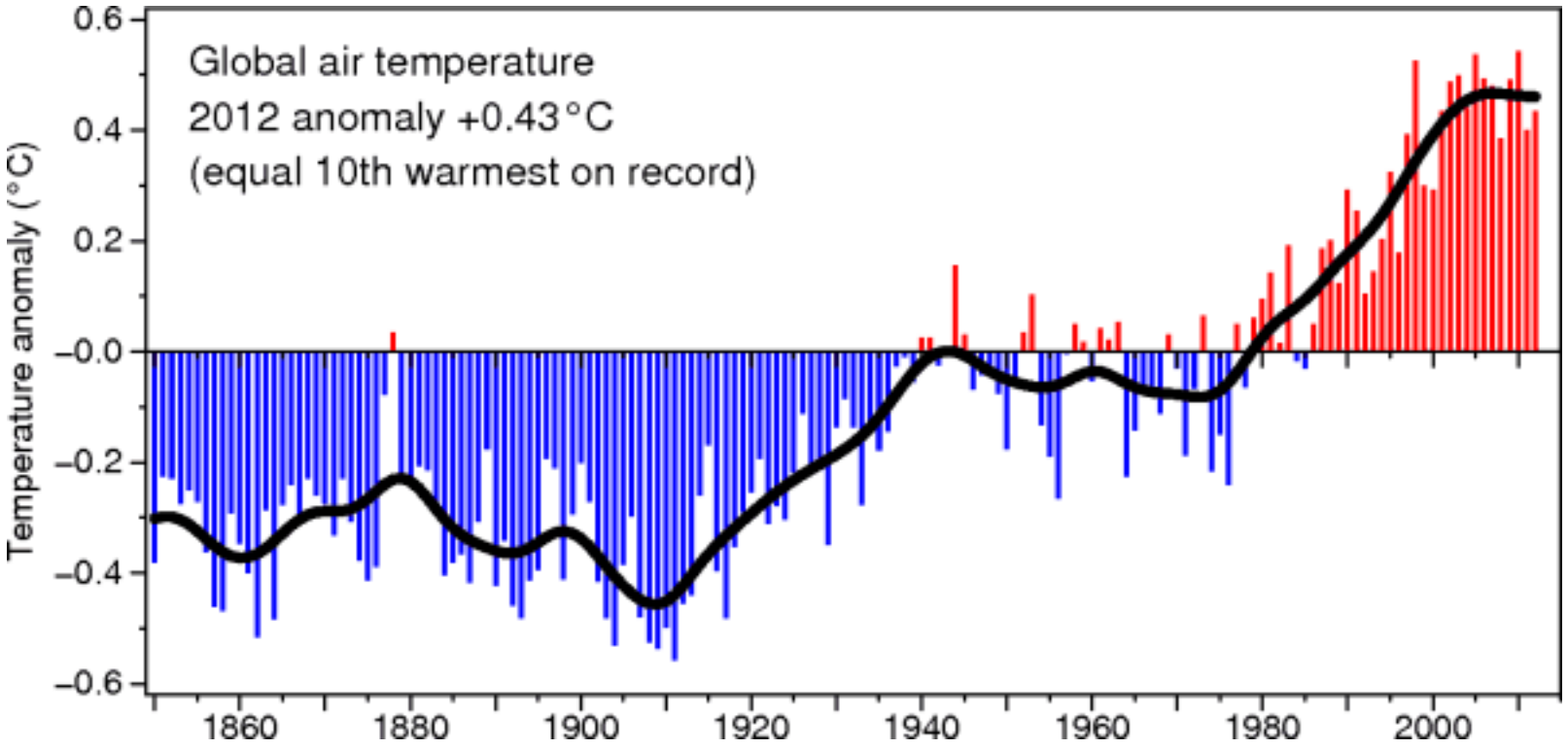
Climate Prediction Center
NCEP

Climate Prediction Center
NCEP



http://www.gbrmpa.gov.au/corp_site/info_services/science/climate_change/coral_bleaching.html

We need to observe ocean surface temperature



Climatic Research Unit

UEA

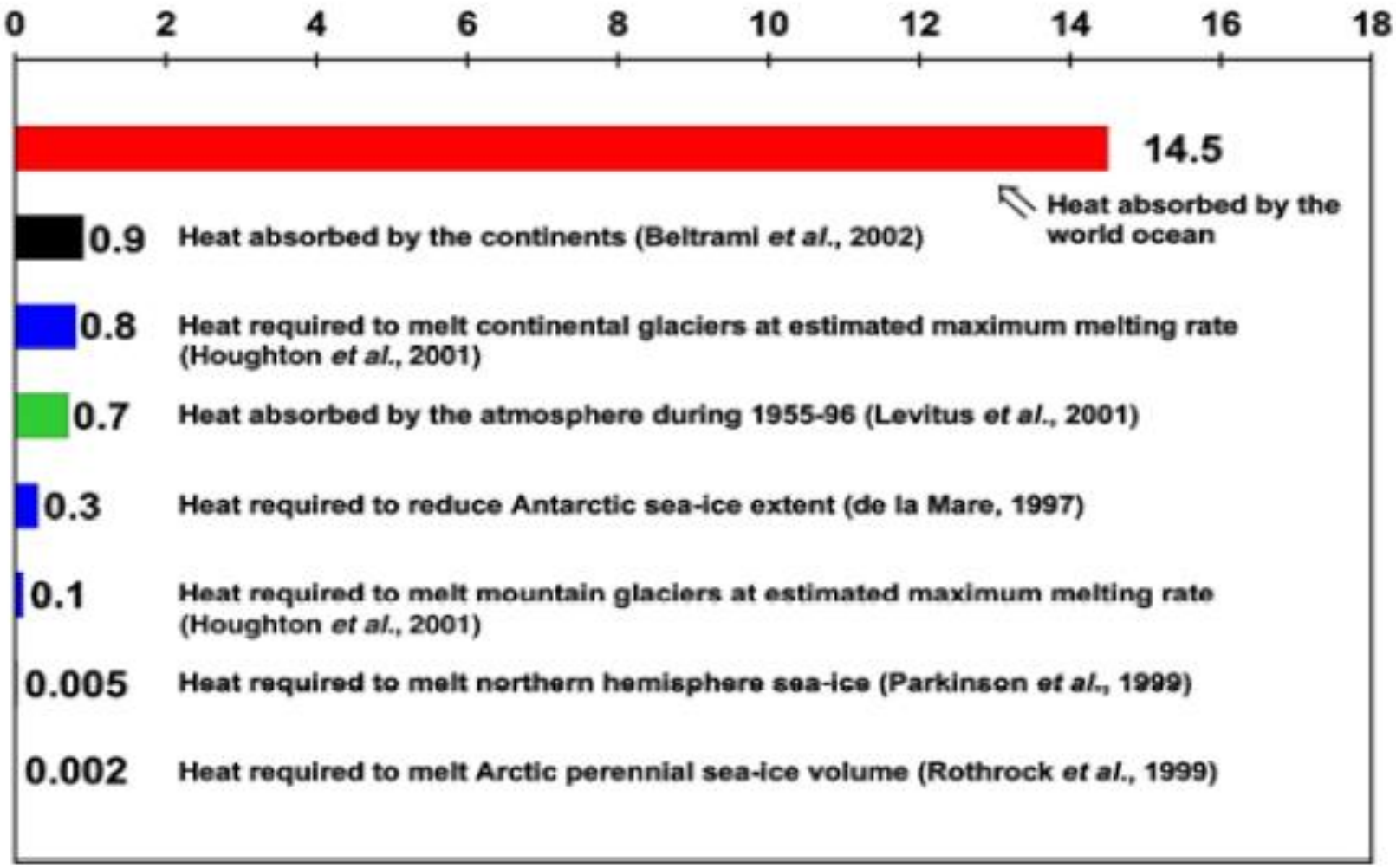
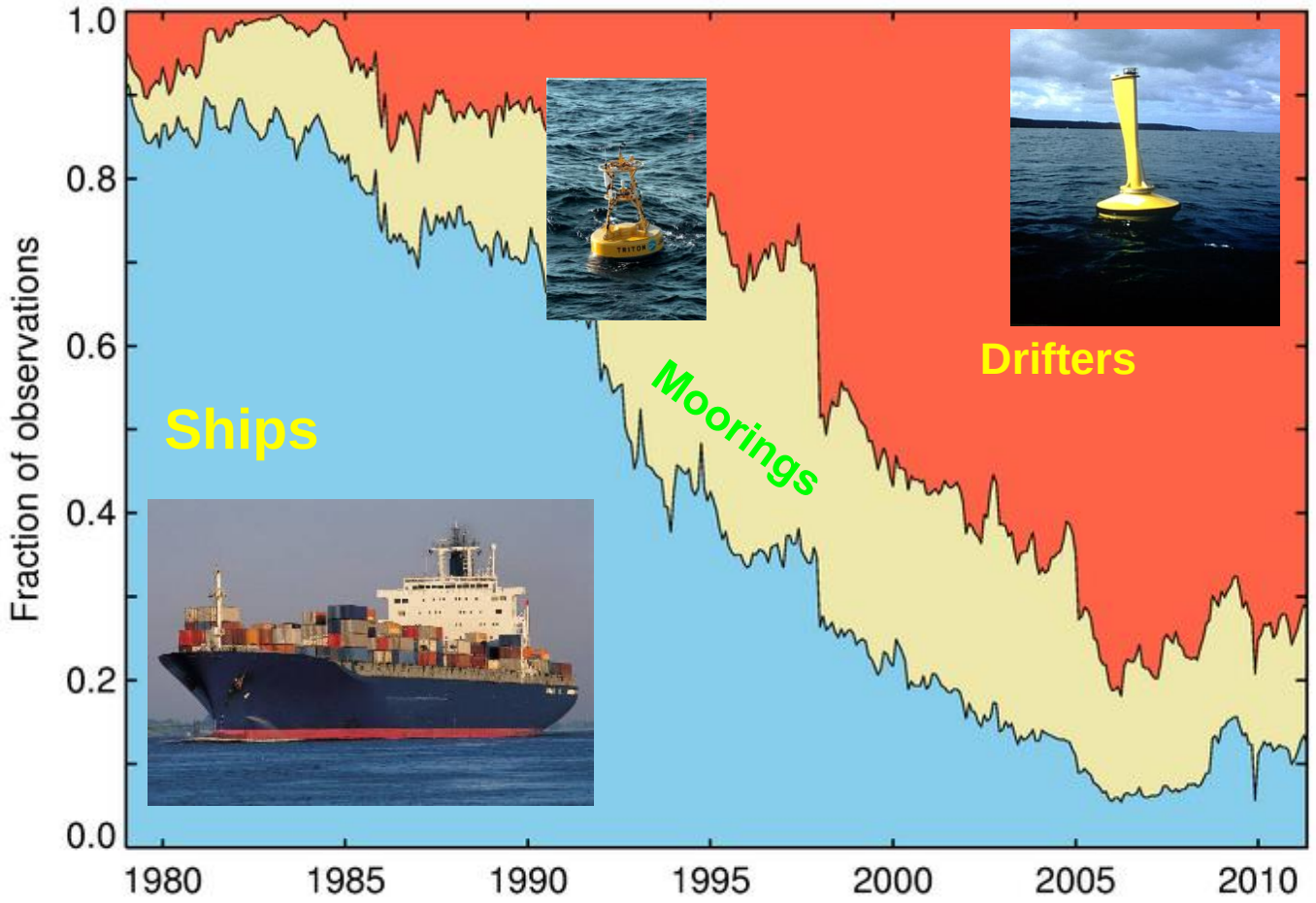
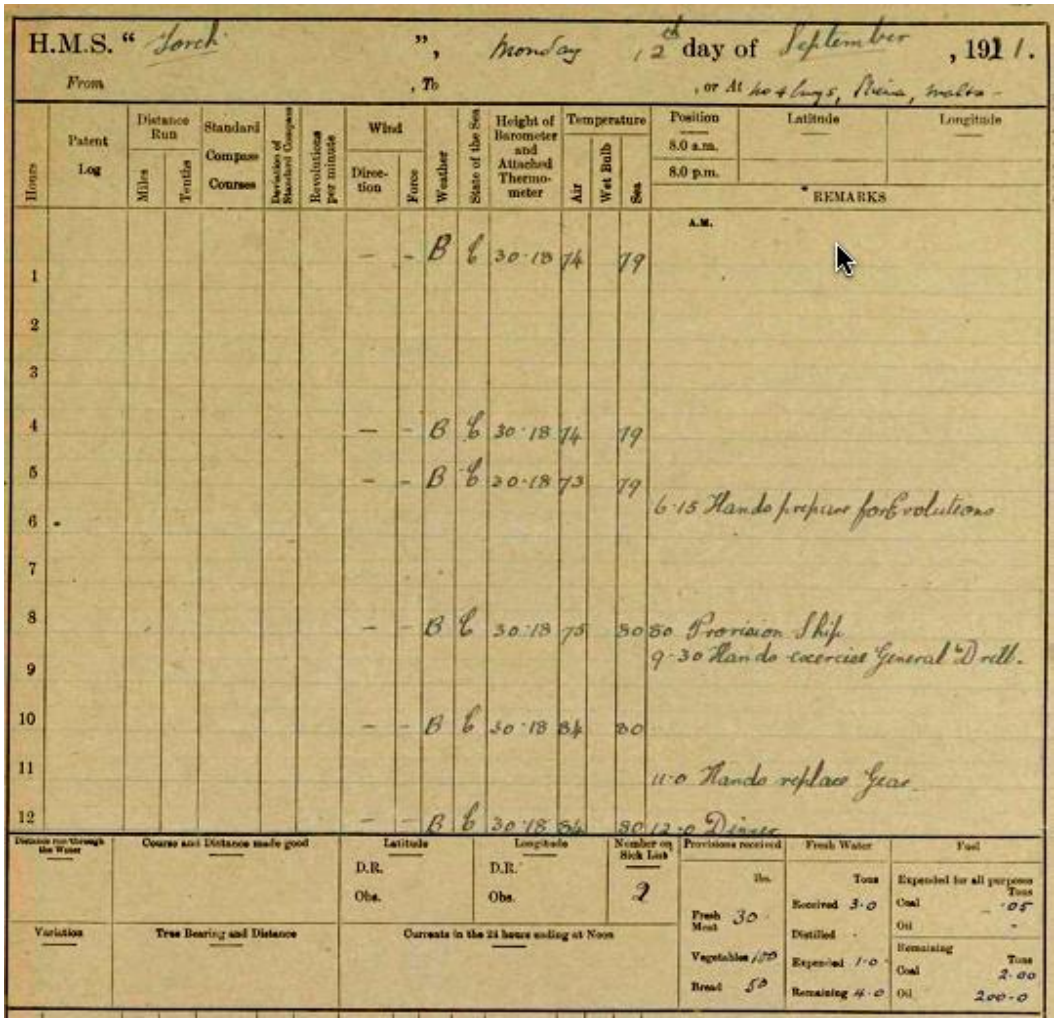


Figure 3. Estimates of Earth's heat balance components (10^{22} J) for the 1955–1998 period.

Where do in situ observations come from now?



How has SST been measured?
Routine observations by naval shipping



H.M.S. "Torch", Monday, 12th day of September, 1911.

From , To , or At Hastings, Reina, Malta -

Hours	Patent Log	Distance Run: Miles	Distance Run: Tenths	Standard Compass Courses	Deviation of Standard Compass	Revolutions per minute	Wind: Direction	Wind: Force	Weather	State of the Sea	Height of Barometer and Attached Thermometer	Temperature: Air	Temperature: Wet Bulb	Temperature: Sea	Position 8.0 a.m. / 8.0 p.m. / Latitude / Longitude / REMARKS
A.M.															
1							—	-	B	C	30·18	74		79	
2															
3															
4							—	-	B	C	30·18	74		79	
5							—	-	B	C	30·18	73		79	
6															6·15 Hands prepare for Evolutions
7															
8							—	-	B	C	30·18	75		80	8·0 Provision Ship
9															9·30 Hands exercise General Drill.
10							—	-	B	C	30·18	84		80	
11															11·0 Hands replace Gear
12							—	-	B	C	30·18	84		80	12·0 Dinner

Distance run through the Water / Course and Distance made good / Latitude D.R. Obs. / Longitude D.R. Obs. / Number on Sick List: 2

Variation / True Bearing and Distance / Currents in the 24 hours ending at Noon

Provisions received (lbs.): Fresh Meat 30 · Vegetables 150 · Bread 50

Fresh Water (Tons): Received 3·0 · Distilled - · Expended 1·0 · Remaining 4·0

Fuel: Expended for all purposes (Tons): Coal ·05 · Oil -; Remaining (Tons): Coal 2·00 · Oil 200·0

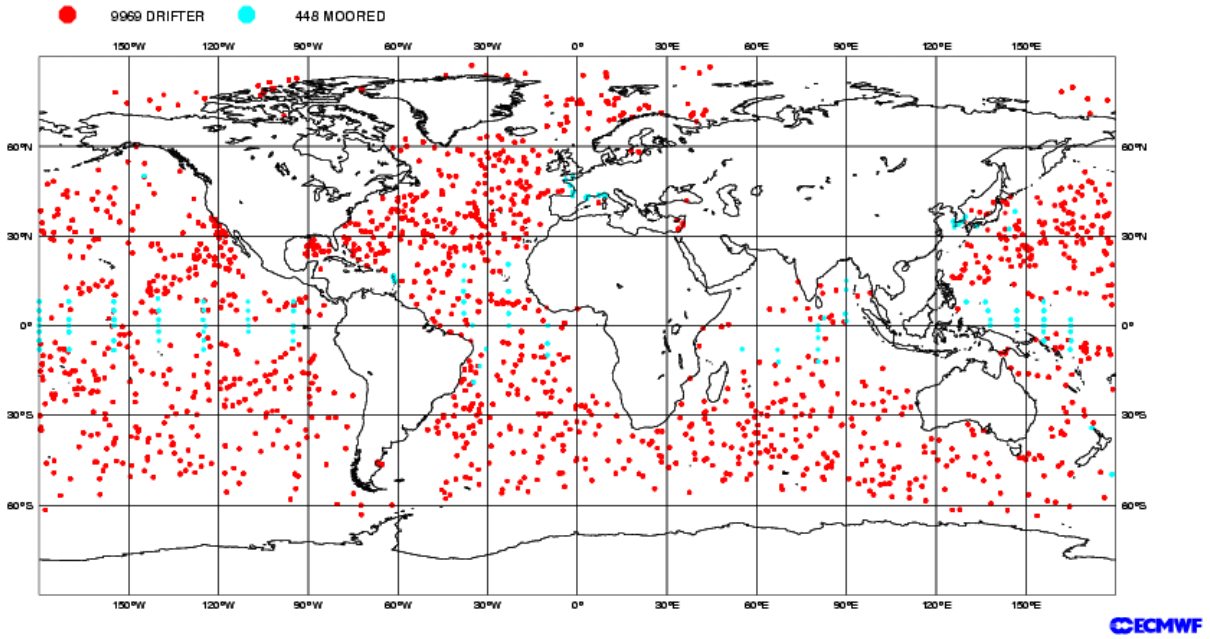
- HMS Torch (Alert class sloop)

www.oldweather.org

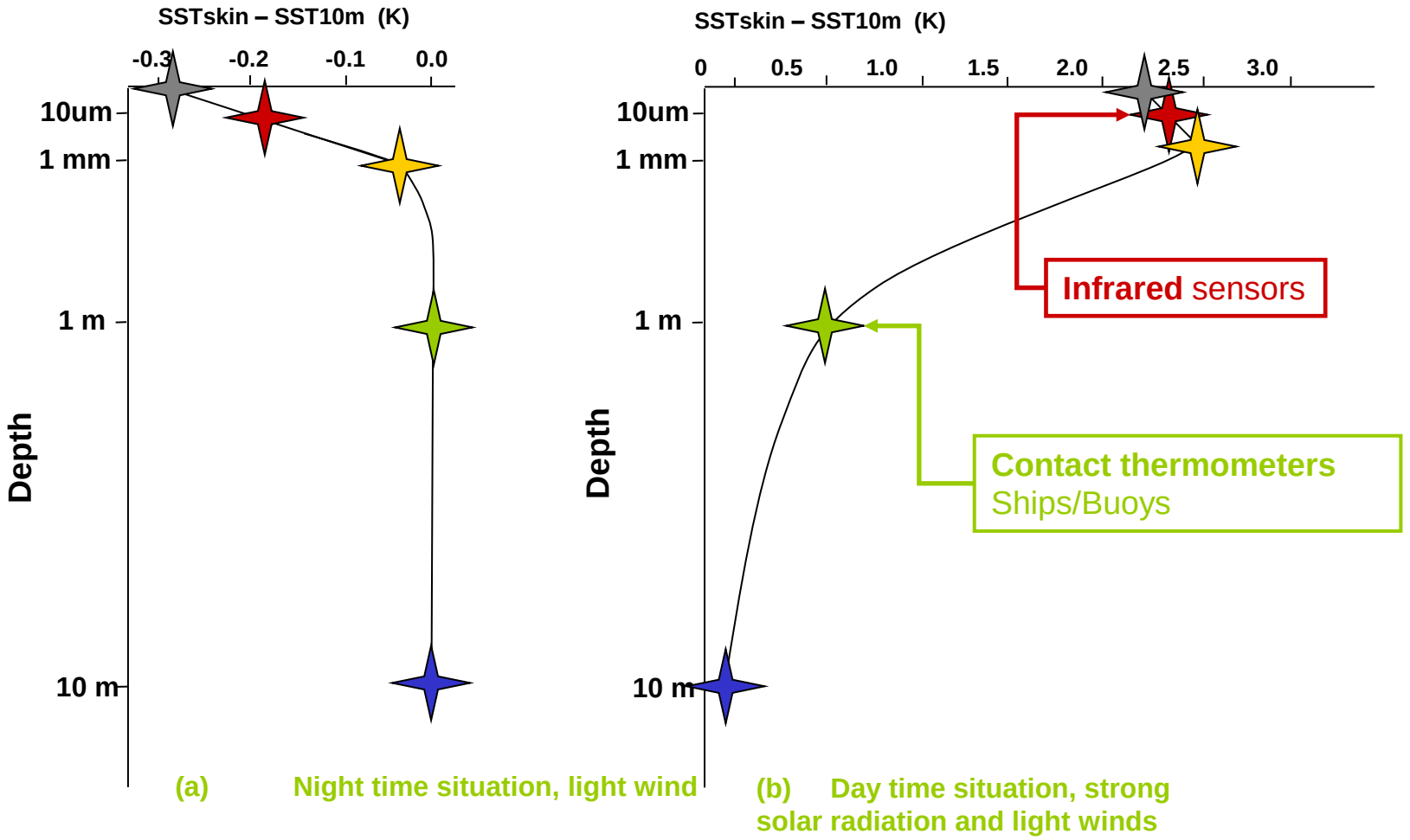
Buckets

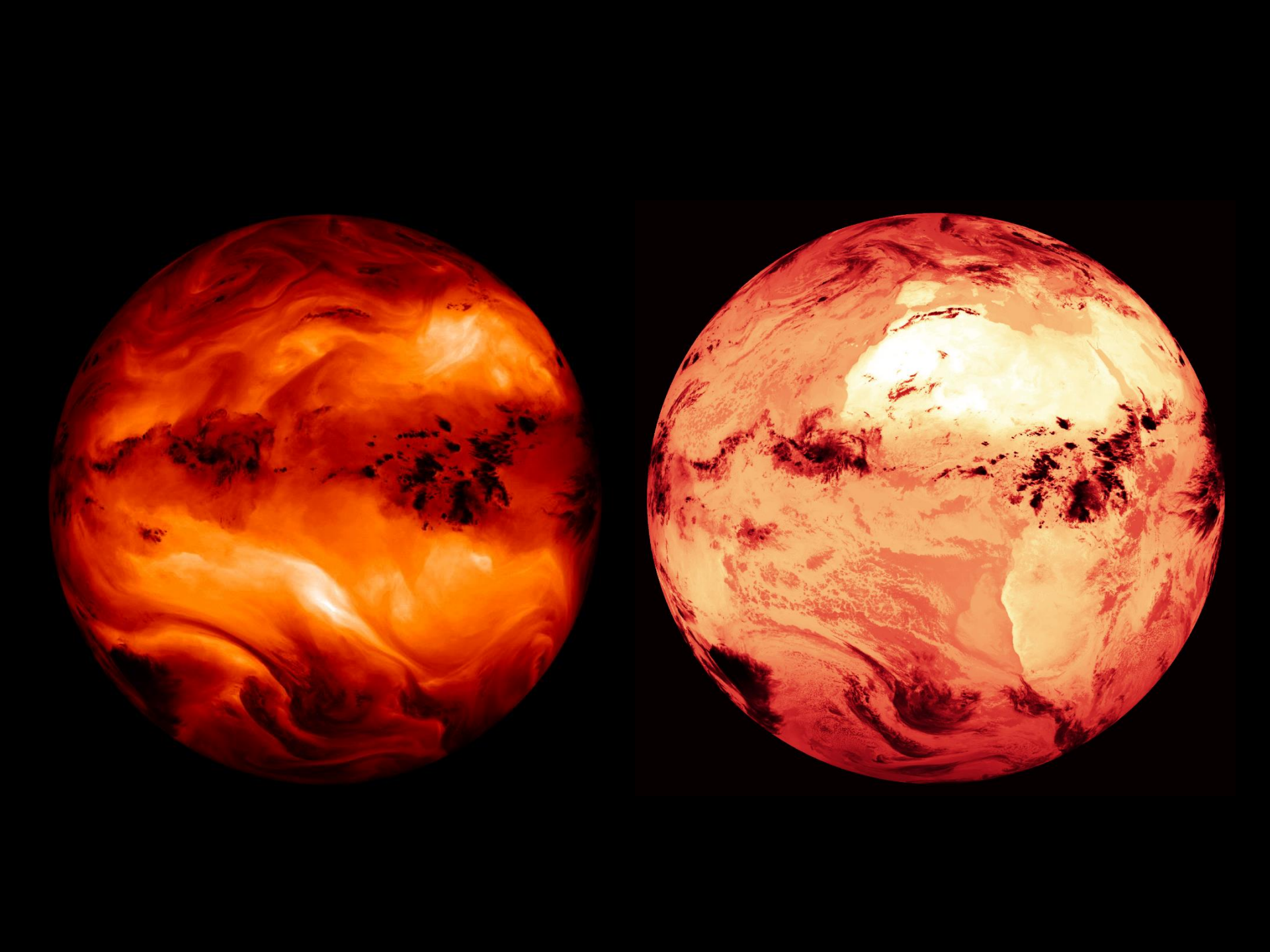

Standard Bucket (1891)
Canvas Bucket (pre-WWII)
Insulated Bucket
(Photos: David Parker)

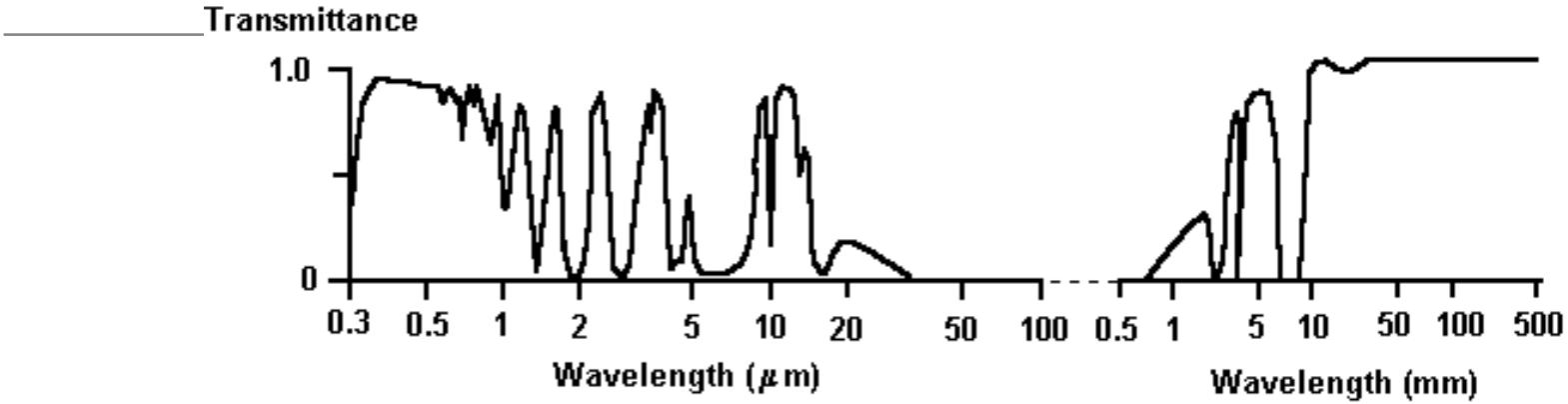
ECMWF Data Coverage (All obs DA) - BUOY
11/SEP/2010; 12 UTC
Total number of obs = 10417

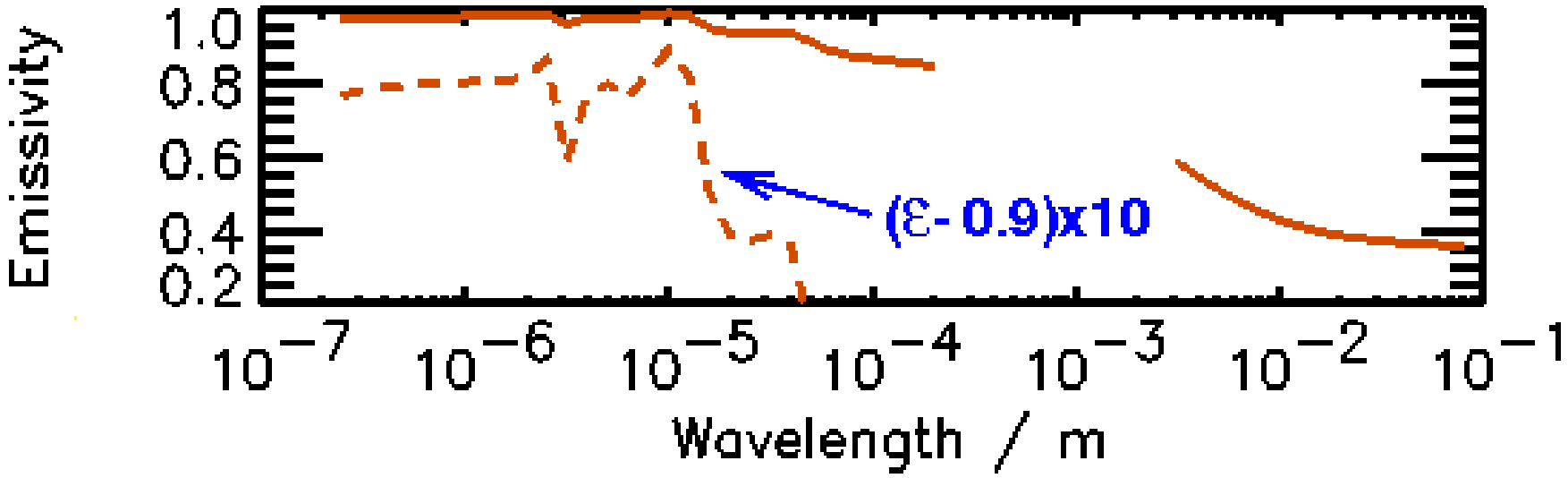


Neglected subtleties in definition of SST

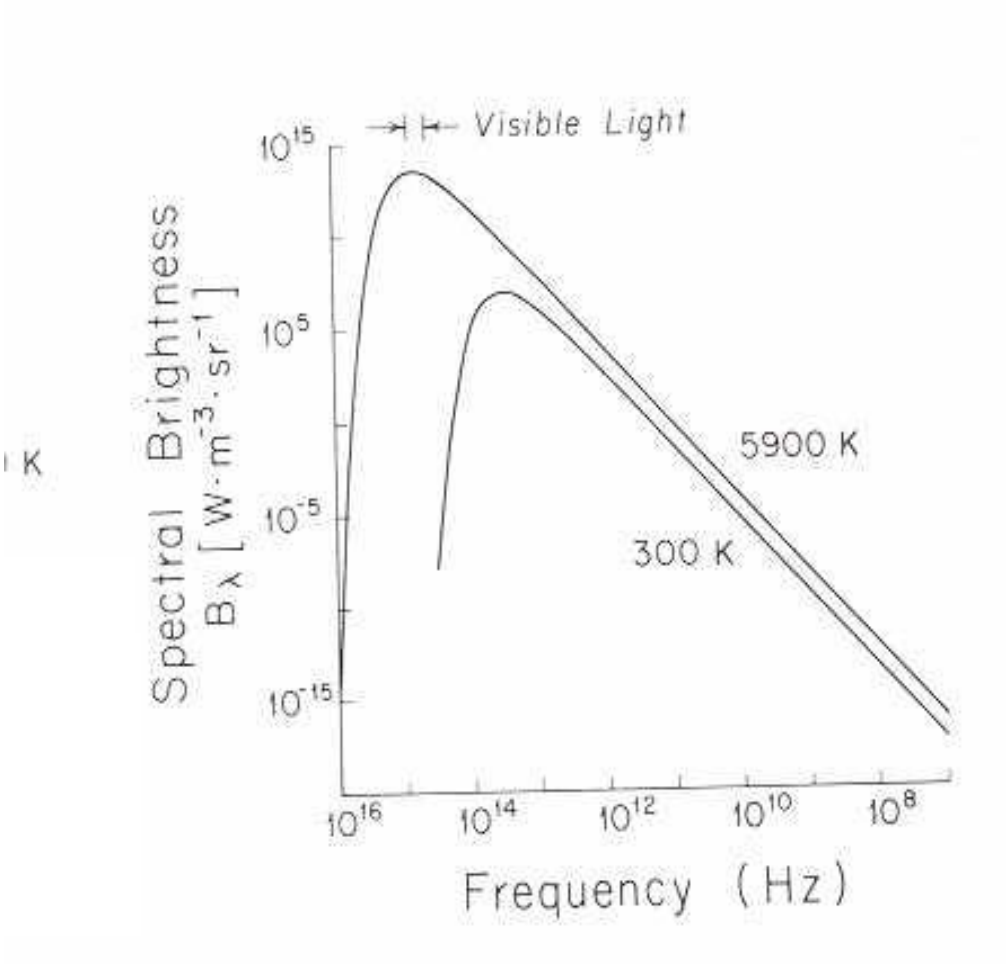




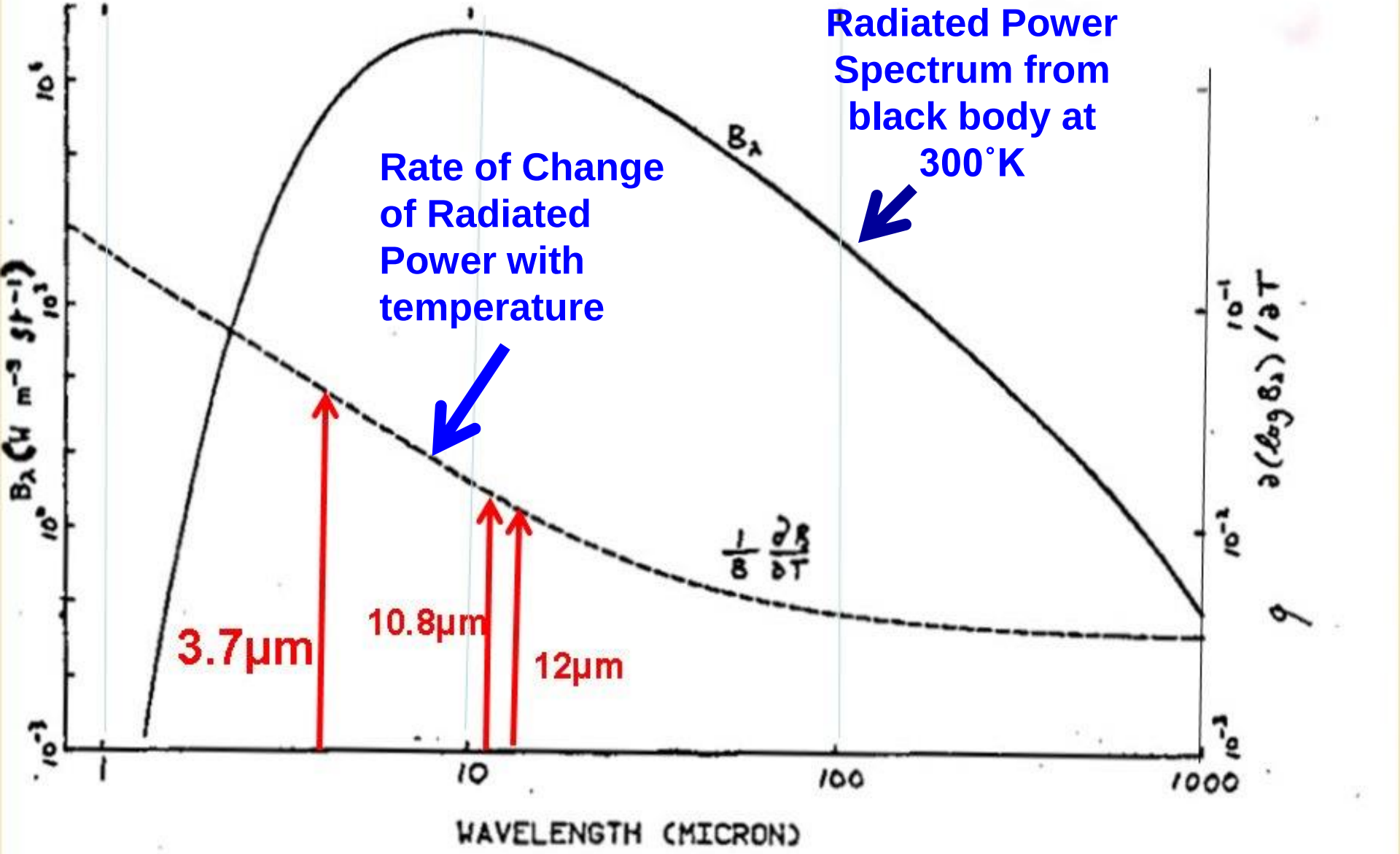

Transmittance
1.0
0
0.3
0.5
1
2
5
10
20
50
100
Wavelength (μm)
0.5
1
5
10
50
100
500
Wavelength (mm)


Emissivity
1.0
0.8
0.6
0.4
0.2
(ε - 0.9)x10
10−7
10−6
10−5
10−4
10−3
10−2
10−1
Wavelength / m

Radiometric Sensitivity
Planck's Radiation Law says it all!



Planck Function – Temperature Dependence



Satellite SSTs at a glance

Infra-red observations

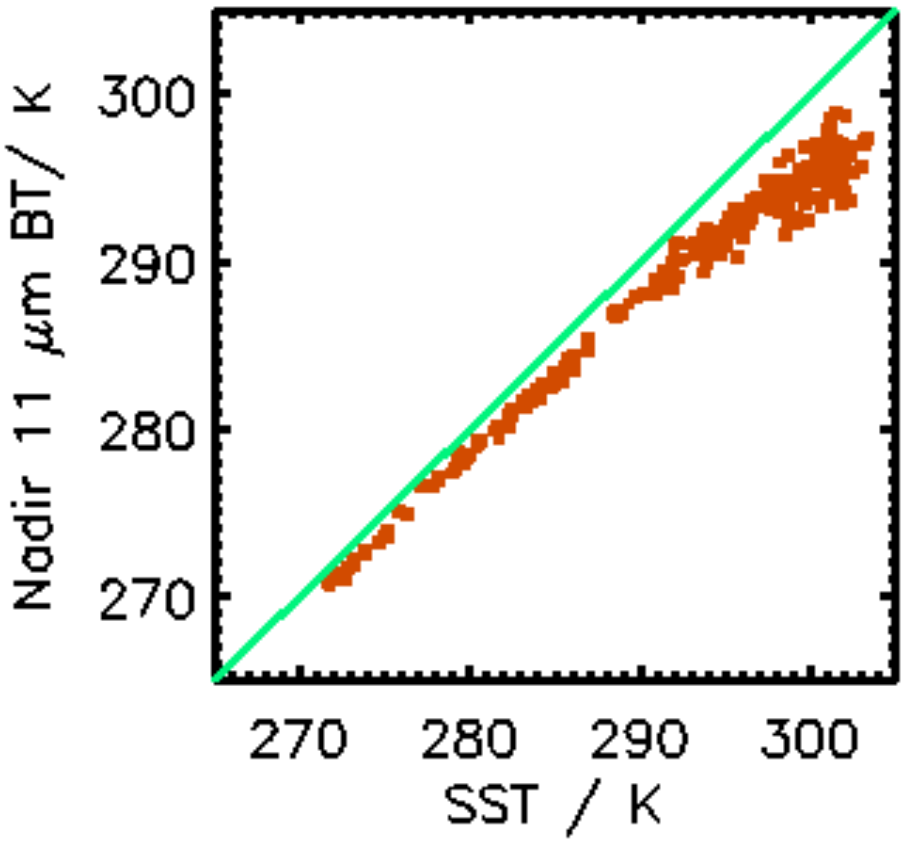
- Spatial resolution: 1 to 10 km
- Single pixel precision: 0.15 to 0.5 K
- Accuracy (bias): <0.1 K to few tenths
- Limitations: cloud cover
- Temporal resolution per sensor (not accounting for clouds): sub-hourly (geo), ~twice-daily (polar)
- Since 1981

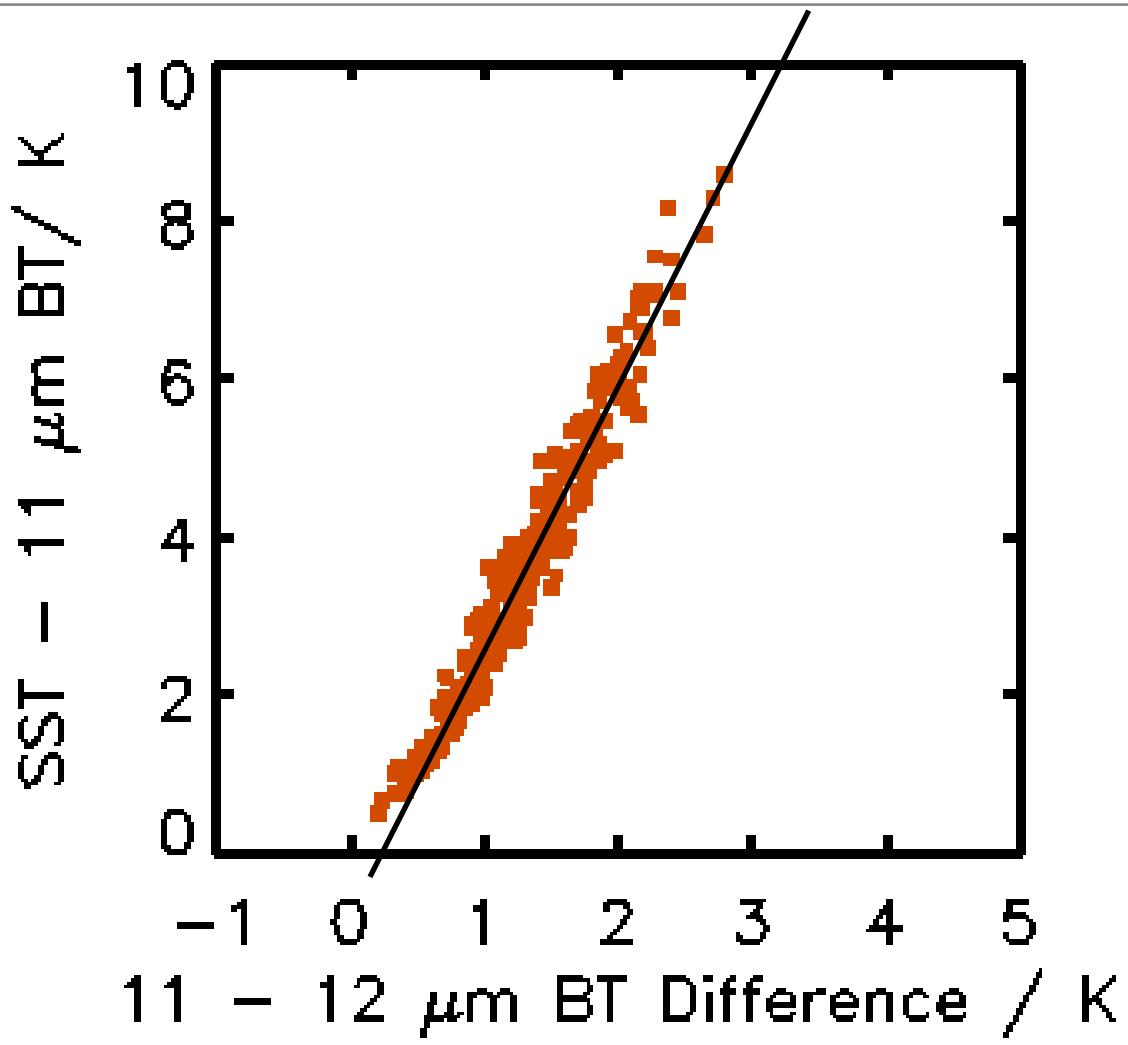
Passive microwave observations

- Spatial resolution: 50 to 100 km
- Single pixel precision: 0.5 K
- Accuracy (bias): few tenths
- Limitations: rain, 50 km margin around land and ice, radio frequency interference
- Temporal resolution per sensor (not accounting for contaminants): ~twice daily
- Since 1997

At “IR window” wavelengths …

top of atmosphere BT < SST




SST − 11 μm BT / K
10
8
6
4
2
0
−1
0
1
2
3
4
5
11 − 12 μm BT Difference / K

Split window SST equation

$$(SST - T_{11}) = m(T_{11} - T_{12}) + c$$

$$SST = T_{11} + m(T_{11} - T_{12}) + c$$

Anding and Kauth, 1970 (83 citations)

A procedure is derived for obtaining improved estimates of water surface temperature by … simultaneous radiometric measurements in two wavelength intervals … to approximately ±0.15°C.

Generalisation

$$\hat{x} = a + \mathbf{a}^T \mathbf{y}$$

Empirical regression to matched *in situ* observations

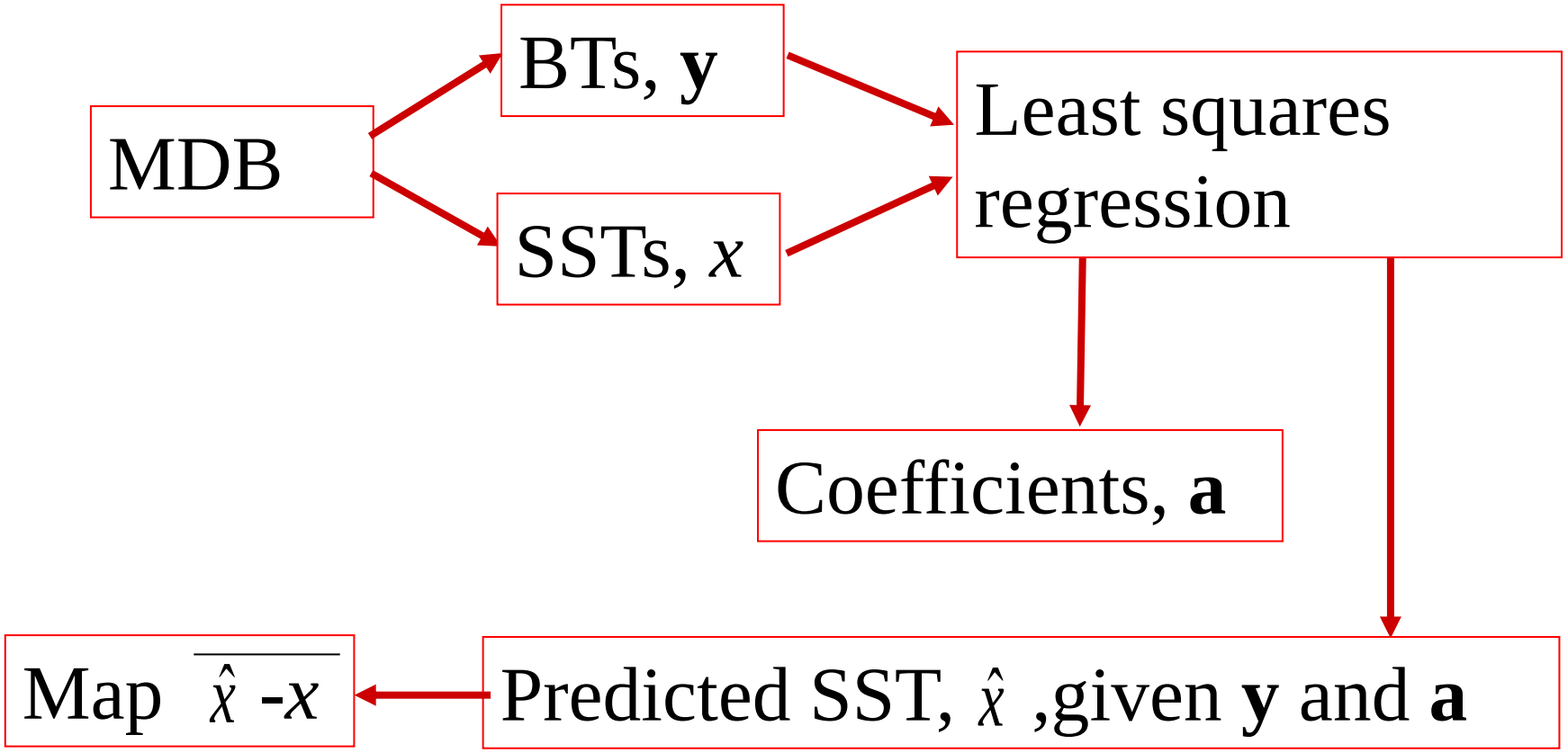
Most products except …

Regression based on radiative transfer simulations

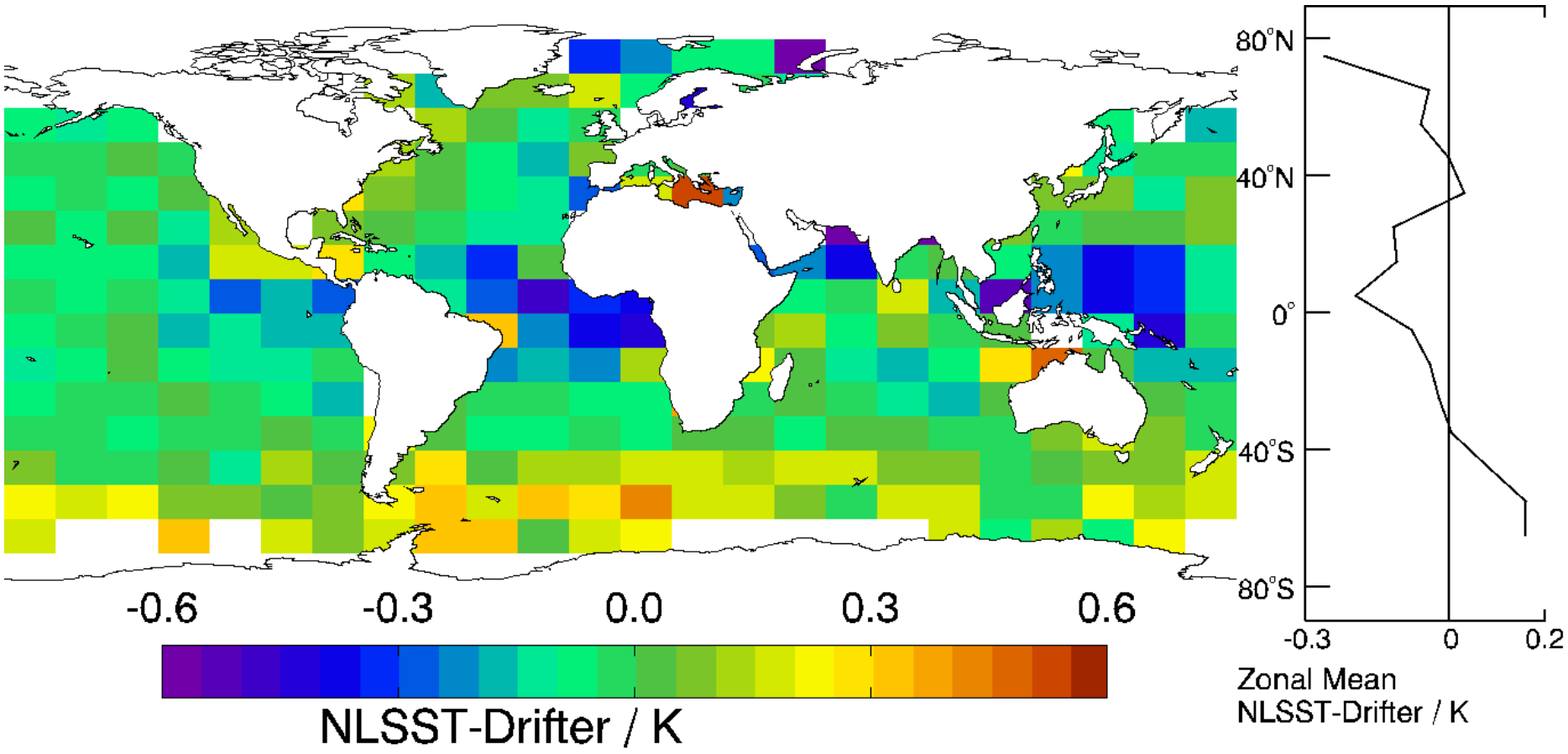
… ATSRs, Meteo-France, NOAA-GOES

Merchant C J and Le Borgne P, *J Atmos Oceanic Technology*, 22 (11) 1734-1746, **2004**.

Derive coefficients …



Regional annual biases – remote sensing is never simple!



Merchant et al., 2009, GRL (GL039843)

More modern approach

$$x = x_b + \mathbf{G(y - F(x))}$$

F is a radiative transfer model

x is the state of the ocean and atmosphere

so **F(x)** contains the BTs we expect

y contains the observed BTs

G is a gain matrix that determines how x_b is updated to give the retrieved SST

Various options for G: optimal estimation most common

Merchant C J, P Le Borgne, A Marsouin and H Roquet (2008),
Optimal estimation of sea surface temperature from split-window observations,
Rem. Sens. Env., 112 (5), 2469-2484. doi:10.1016/j.r2007.11.011

Classic Images from ATSR

The Gulf Stream

ATSR-2 Image, ƛ = 3.7µm

Review the steps to get SST using a physical retrieval

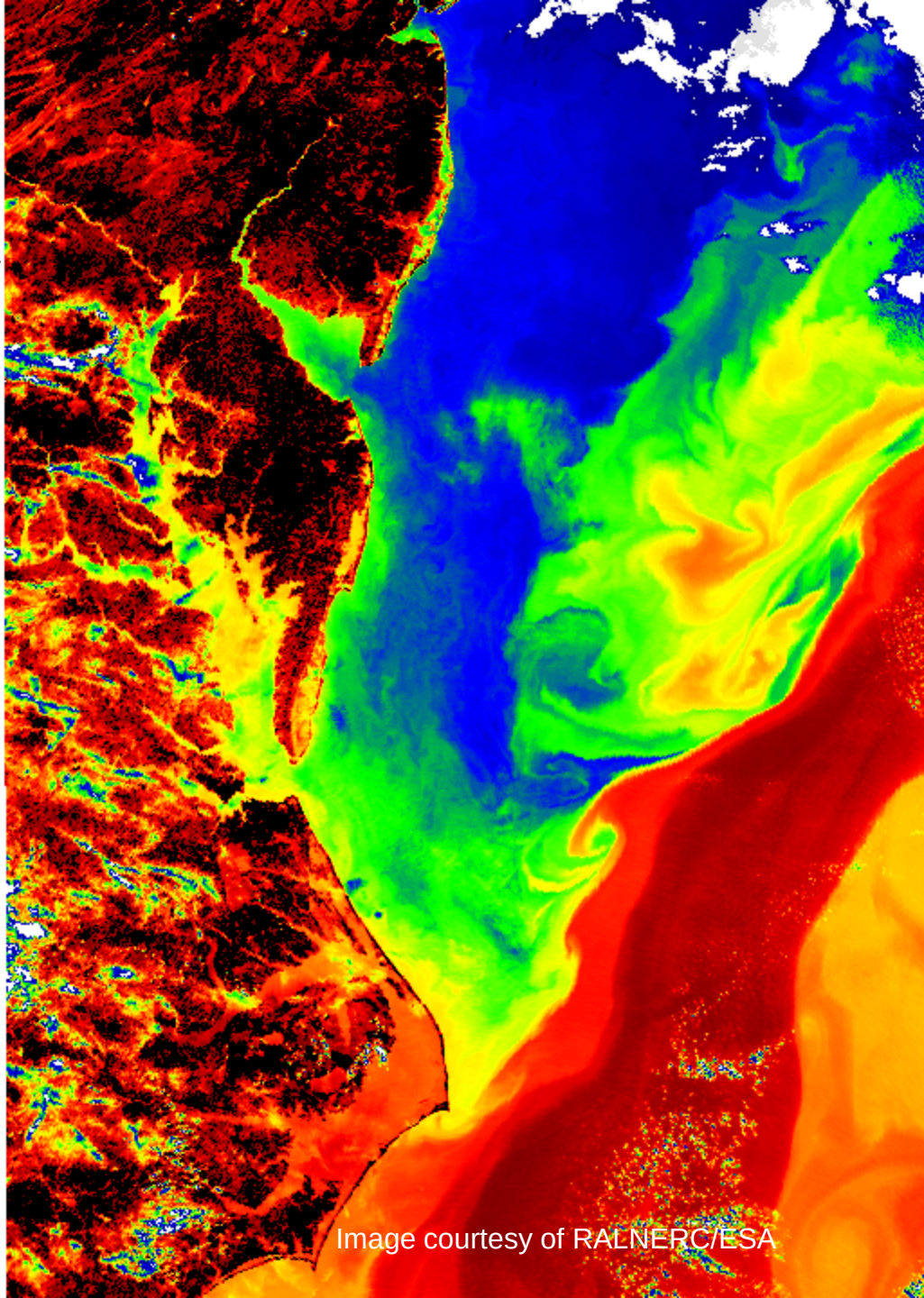


Image courtesy of RALNERC/ESA