Observing and modelling SST variability on a range of scales

Prof. Chris Merchant

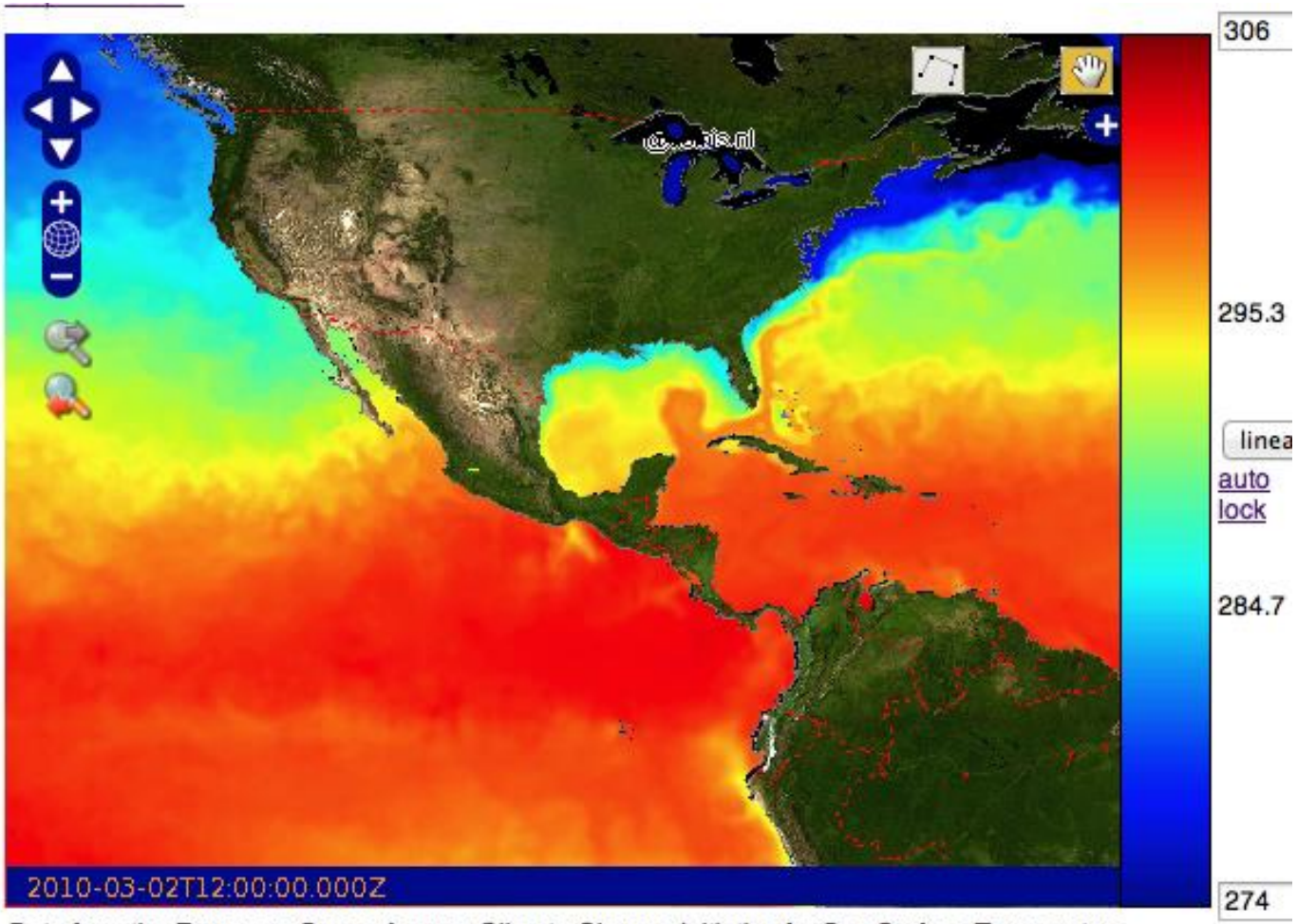
University of Reading

UK

Table 1. Selected ocean phenomena and the magnitude and scales of their SST signature. (Extracted and adapted from Robinson (2004), which provides a more complete listing.)

Phenomenon	Magnitude / K	Length scale / km	Time scale
Climatological variation across oceans	35	10^4	
El Nino and interannual variability	0.5 to 5	500 – 5000	Months to years
Tropical instability waves	0.5 to 5	200 – 2000	Months to years
Meanders and eddies on major fronts and boundary currents	1 to 8	5 to 2000	Weeks to months
Diurnal warming cycle	0.1 to 5	5 to 1000	Hours
Coral bleaching events	0.3 to 3	20 to 200	Days
Coastal wind induced phenomena	0.2 to 2	1 to 100	Hours

Kuenzer, Claudia; Dech, Stefan (Eds.) 2013, ISBN 978-94-007-6639-6



Data from the European Space Agency Climate Change Initiative for Sea Surface Temperature.

test image Open animation in Google Earth Screenshot Overlay opacity: 100%

Climate and SST

- Oceans are main thermal inertia of climate
- Prescribed runs of climate models through 20thC are an important test of atmospheric and land components of climate models
- Coupled 20thC runs test the ocean component and its air-sea interaction
- SST 'modes' affect inter-annual to decadal to centennial scales
  - ENSO, NAO, PDO etc

Climate Change Scale

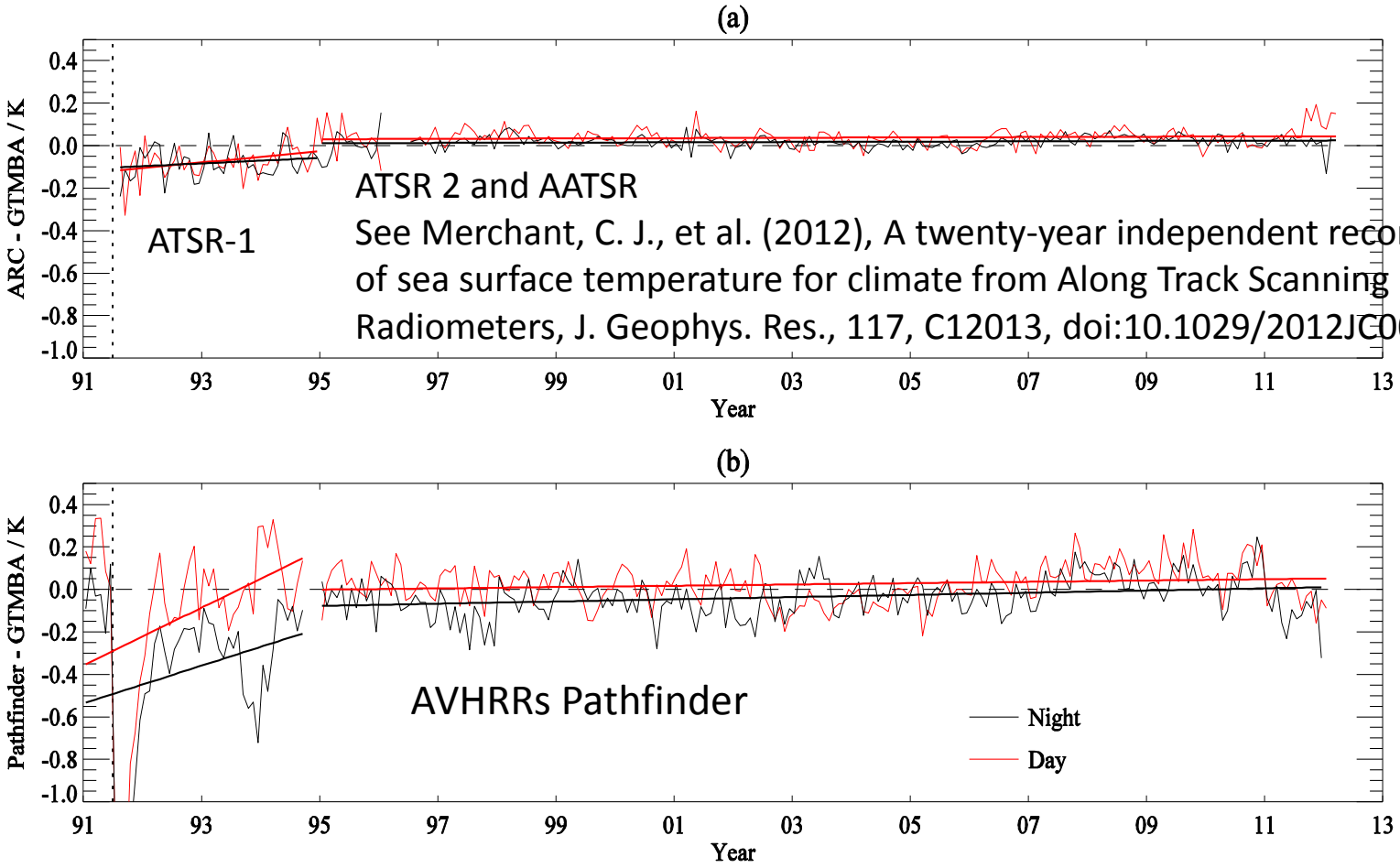
- Rate of warming O(0.1 K/decade)
- Required STABILITY of observation?

- To push observations towards “climate quality” requires specific efforts at reprocessing of data
  - learning lessons about data set
  - researching methods that maximize stability

Can we even assess stability?

- No SST long-term reference sites
- Nearest in situ data are moorings of the global tropical moored buoy array (GTMBA)
- Pre mid-1990s, can only do stability for tropical Pacific
- Pre mid-1980s, no stable data at all?

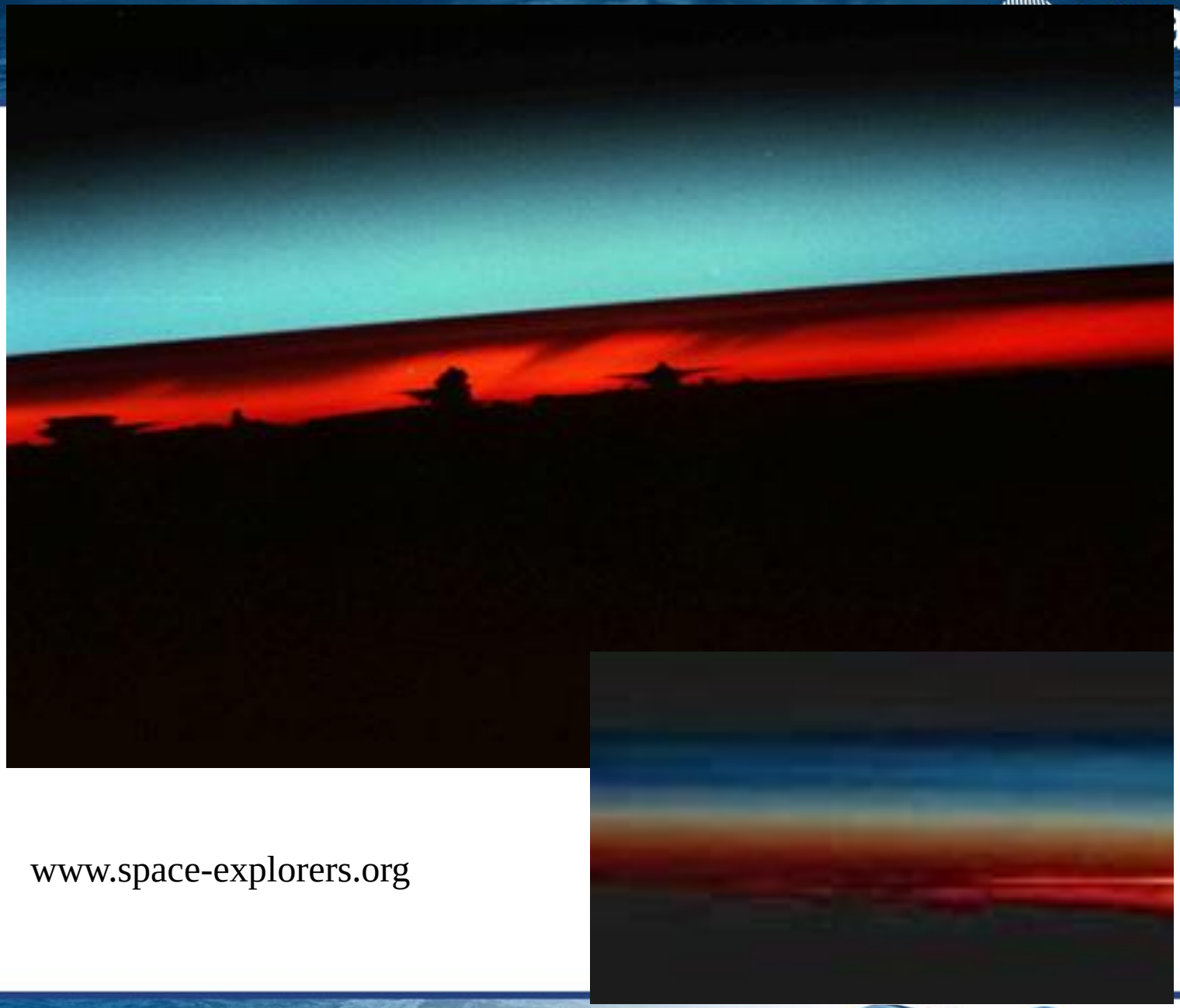
Stability assessment



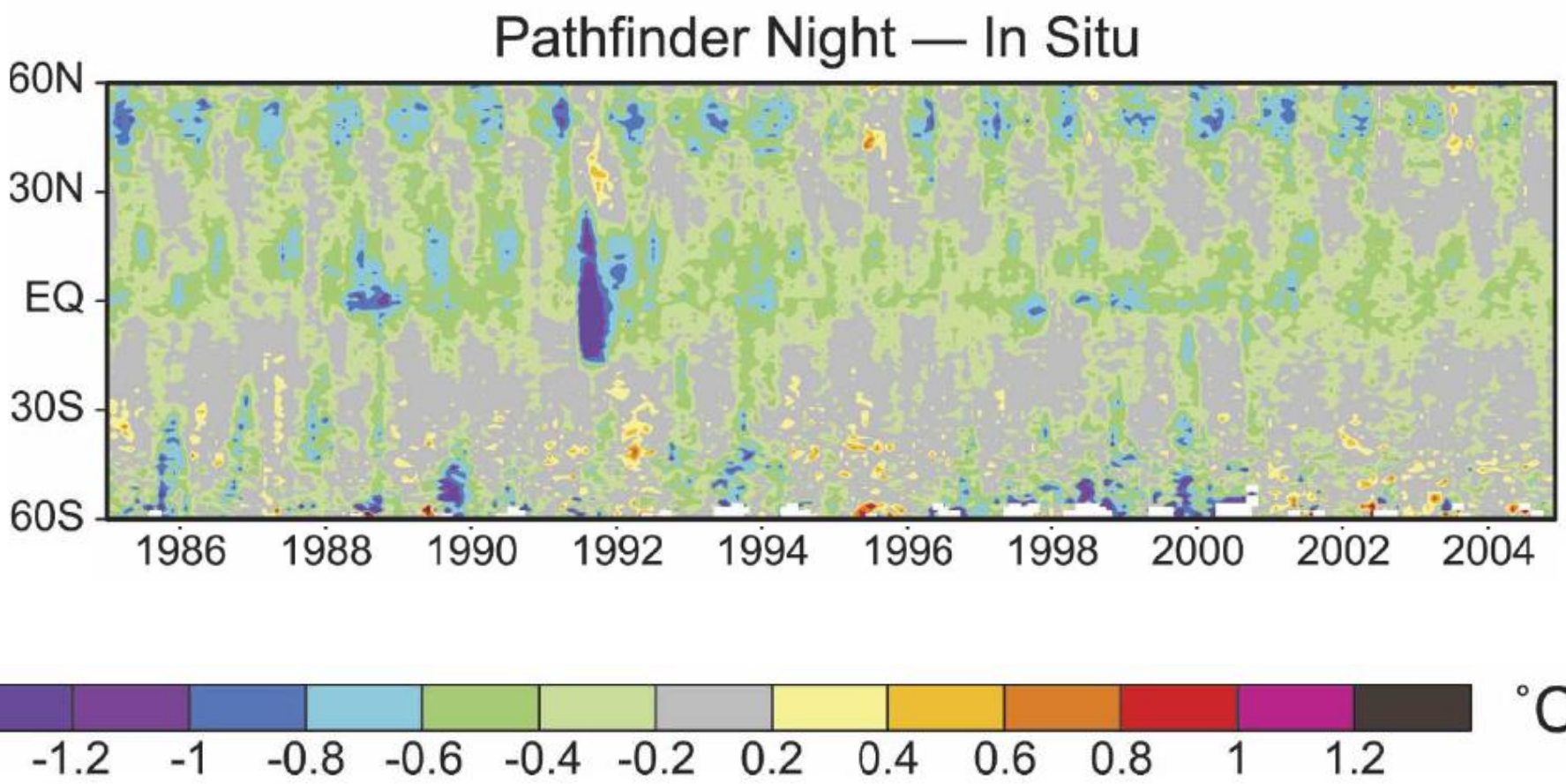
ATSR 2 and AATSR

See Merchant, C. J., et al. (2012), A twenty-year independent record of sea surface temperature for climate from Along Track Scanning Radiometers, J. Geophys. Res., 117, C12013, doi:10.1029/2012JC008400.

SST measurement challenge

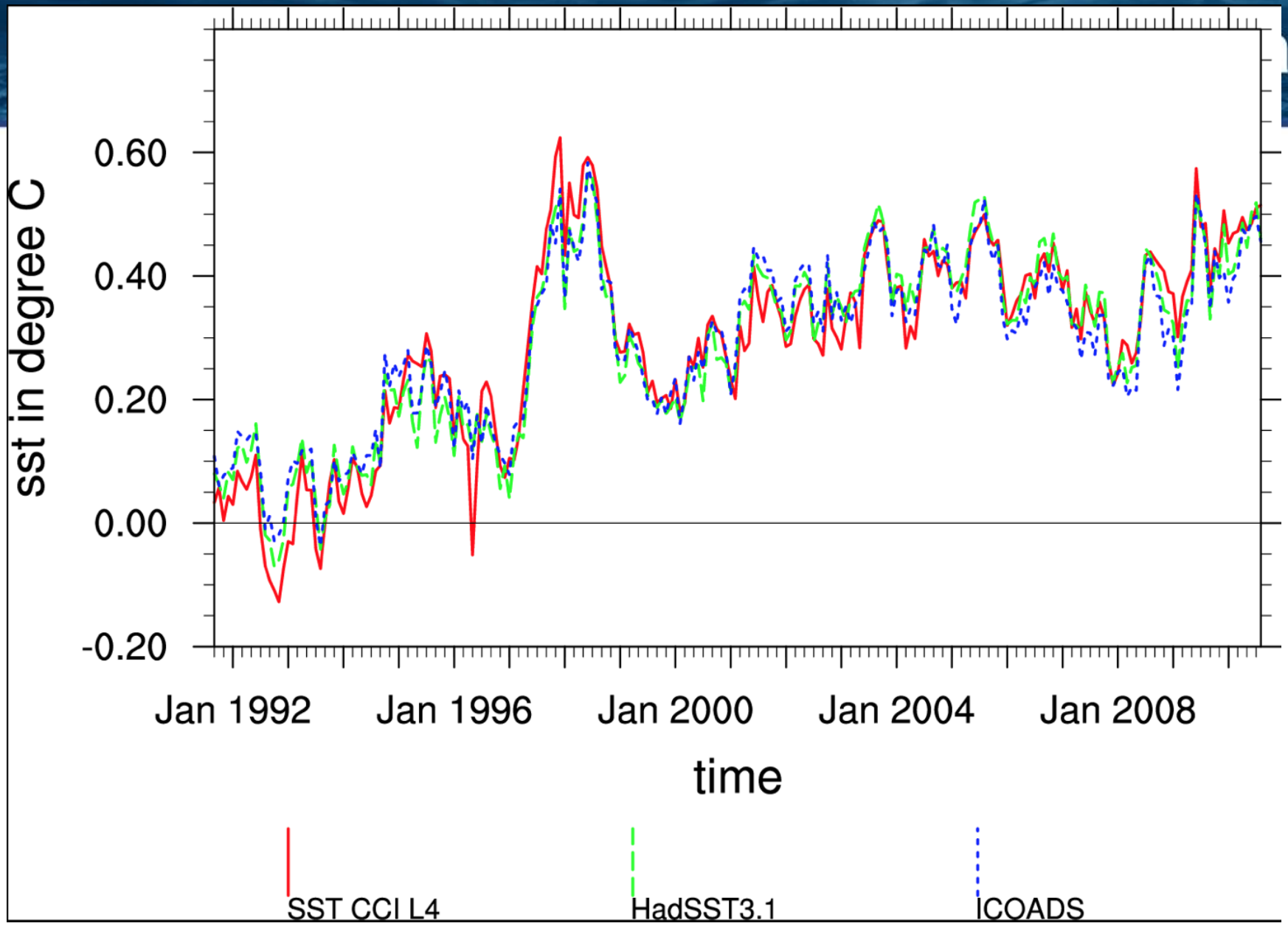


www.space-explorers.org


Pathfinder Night — In Situ
60N
30N
EQ
30S
60S
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
°C
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0.2
0.4
0.6
0.8
1
1.2

SST and Stratospheric Aerosol

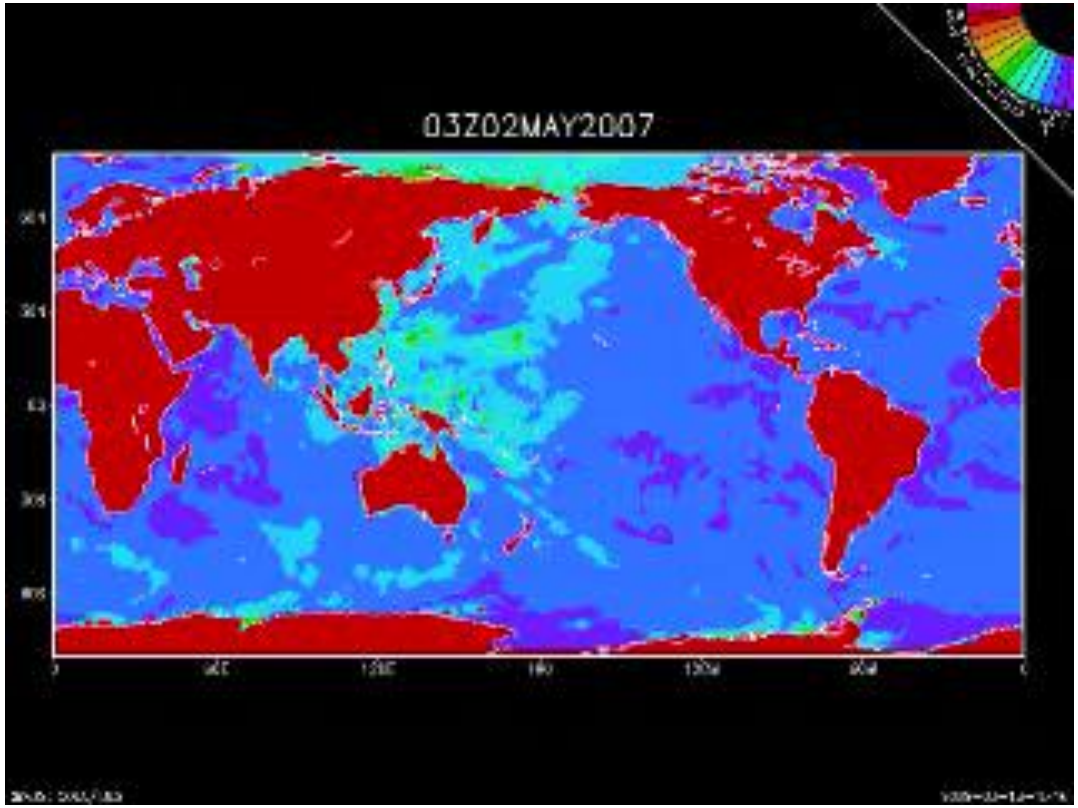
- Stratospheric aerosol cools the planet
  - Natural climate change experiment
  - Want to observe true SST changes accurate
- BUT
- Stratospheric aerosol changes window BTs
  - Causes negative SST biases
  - Less so for ATSR dual-view (robust to aerosol)
  - But not entirely solved problem (good to 0.2 K)


sst in degree C
0.60
0.40
0.20
0.00
-0.20
Jan 1992
Jan 1996
Jan 2000
Jan 2004
Jan 2008
time
SST CCI L4
HadSST3.1
ICOADS

Modelling in general

- All models are wrong, some are useful
- All models resolve some things and approximate (parameterize) others
- Useful models are generally useful for a specific purpose
- To be useful
  - Include &/or parameterize (well!) major physics
  - Represent the relevant space-time scales
- Assess modelled vs. observed mean, variability, correlations, phasing, etc

Diurnal Variability

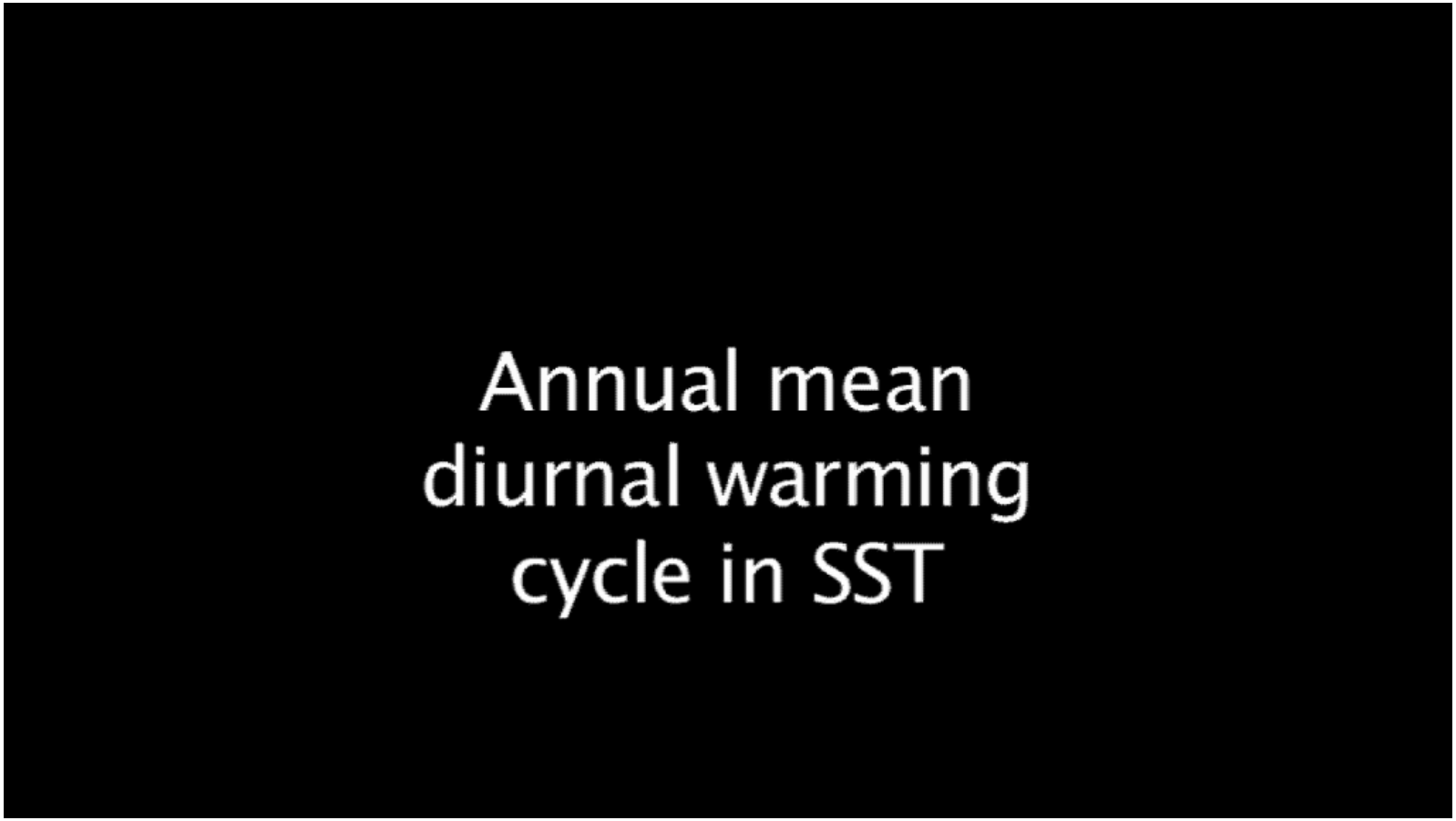


What time scale / resolution?
What space scale / resolution?

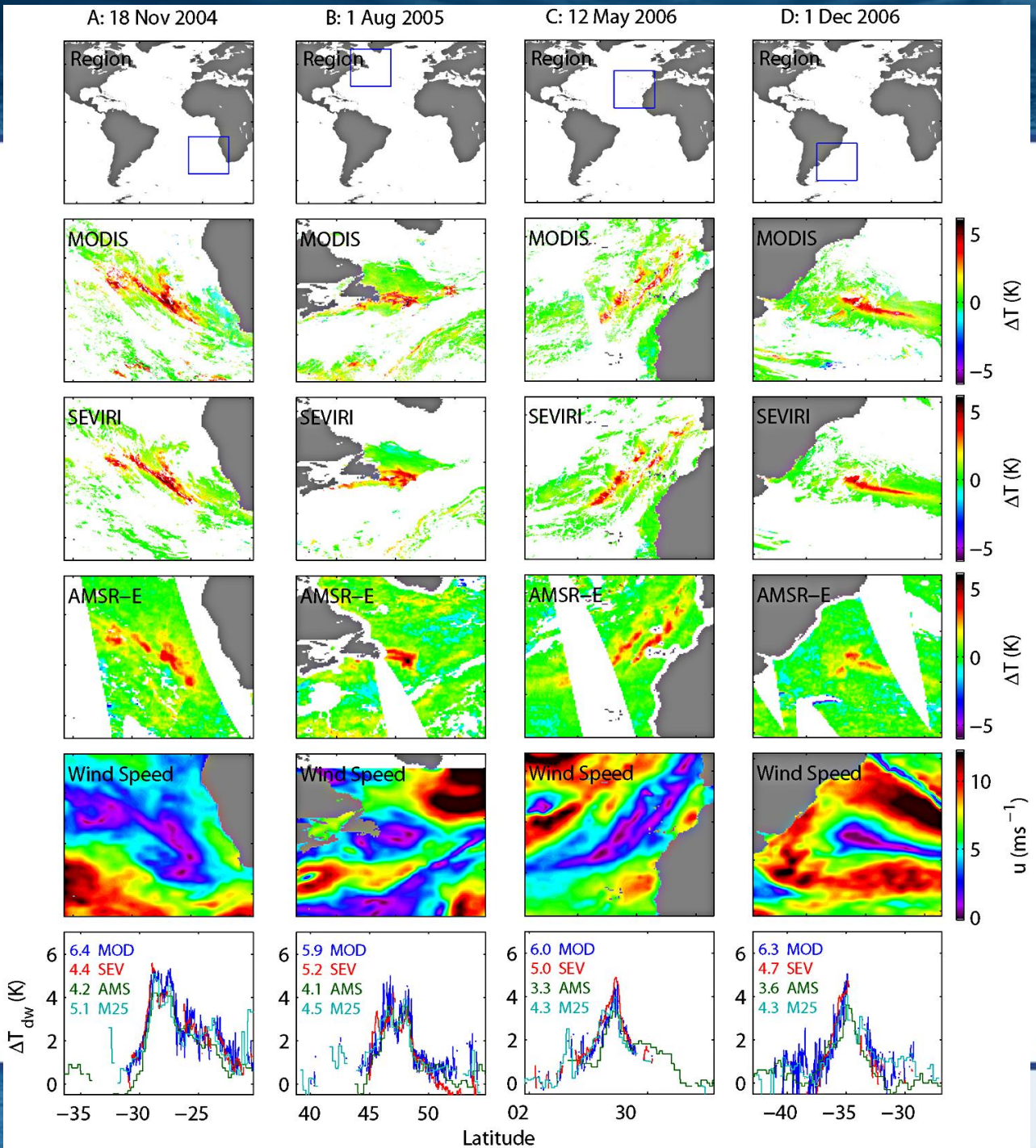
Geophysical relevance?

Mean ocean diurnal-warming cycles

SEVIRI/NWP based model, local time



0 K 1 K 2 K



What time scale / resolution?
What space scale / resolution?

Geophysical relevance?

Diurnal variability

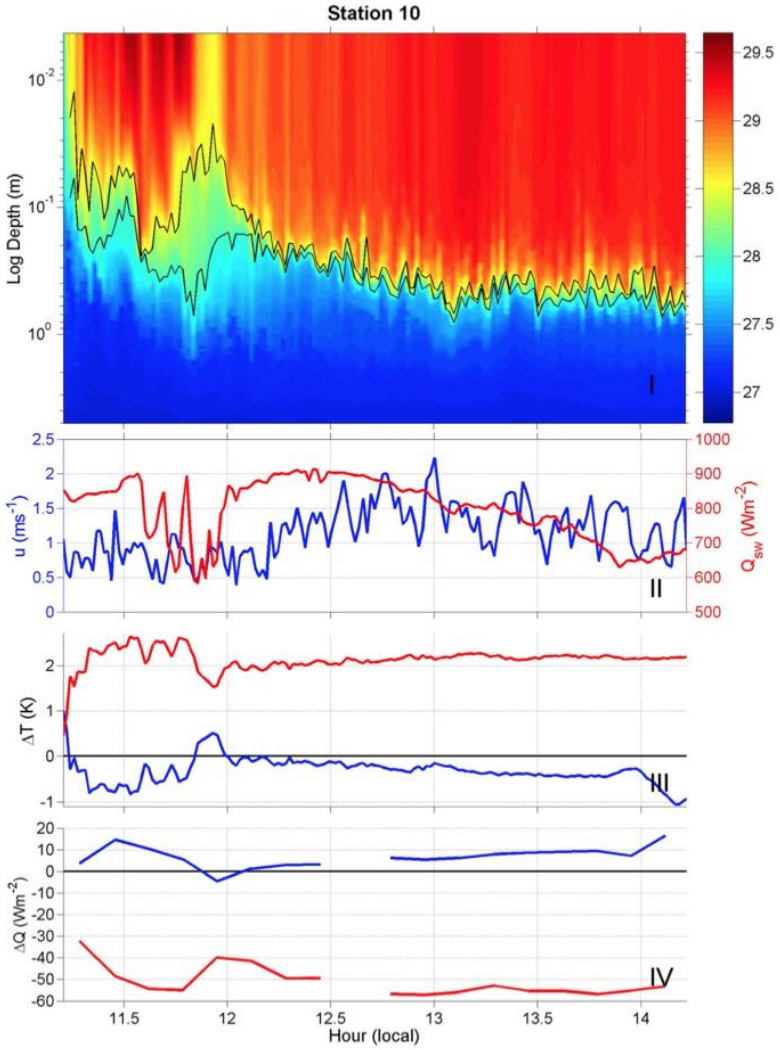


Fig. 3. Temperature-depth measurements from SkinDeEP at 22.52°N, 109.59°W on 10 Oct. 1999 (graph I). Wind speed (u) and downwelling shortwave radiation (Q_{sw}) (graph II). Temperature differences: SST_{skin}-$SST_{subskin}$ (blue) and $SST_{subskin}$-SST_{depth} (red) (graph III). Heat loss differences: $Q(SST_{skin})$-$Q(SST_{subskin})$ (blue) and $Q(SST_{subskin})$-$Q(SST_{depth})$ (red) (graph IV). $Q(SST_{skin})$, $Q(SST_{subskin})$, and $Q(SST_{depth})$ are the surface net heat flux calculated by using SST_{skin}, $SST_{subskin}$, and SST_{depth} as SST_{int}, respectively. SST_{skin} was measured with an infrared radiometer. From Ward (2006), Copyright 2006 American Geophysical Union. Reproduced by permission of American Geophysical Union.

Configuring a diurnal cycle model

- 1D is probably OK
- Need to resolve diurnal warm layer vertical
- Need time step corresponding
  - capture relevant forcing fluctuations
  - numerically stable wrt depth resolution
- Elements of model
  - Heating profile from Sun vs. wavelength
  - Equation of state (density as function of T, S)
  - Vertical turbulence
    - driven by wind (stress flux)
    - “opposed” by thermal stratification

Satellite Observations for DV

- Model can be tested against in situ thermistor chains
- But background mixing etc varies across ocean, so also need ocean-basin DV SST for comparison
- Absolute accuracy of SST is then less important than relative accuracy (across the cycle)
- E.g., same algorithm day and nigh
- E.g., full sensitivity to DV in SST – not obvious

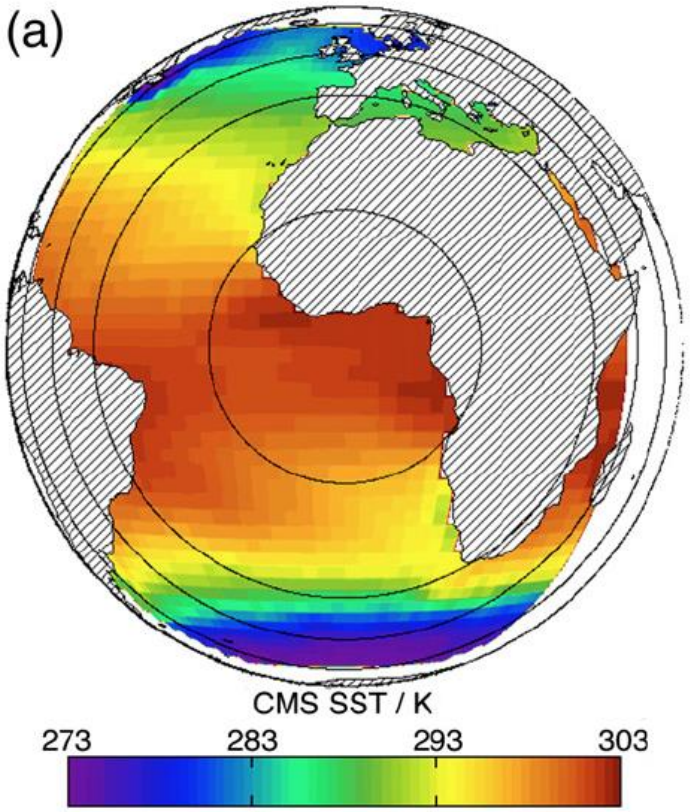
SEVIRI Sea Surface Temperature

Geostationary platform -- particularly useful for diurnal variability in SST

Want SSTs to be accurate, low noise …

… and also, have the right DV

Remote Sensing of Environment 113 (2009) 445–457



SST Sensitivity

- The degree to which the retrieved SST changes per unit change in the true SST
- Conventional SST retrieval is NLSST

$$\hat{x} = (a + bS)y_{11\mu m} + (c + dS + ex_c)\left(y_{11\mu m} - y_{12\mu m}\right) + f + gS$$
$$S = \sec\theta - 1$$

- Coefficients are defined to minimise the retrieval error variance
- This does not optimize the sensitivity, ≠1

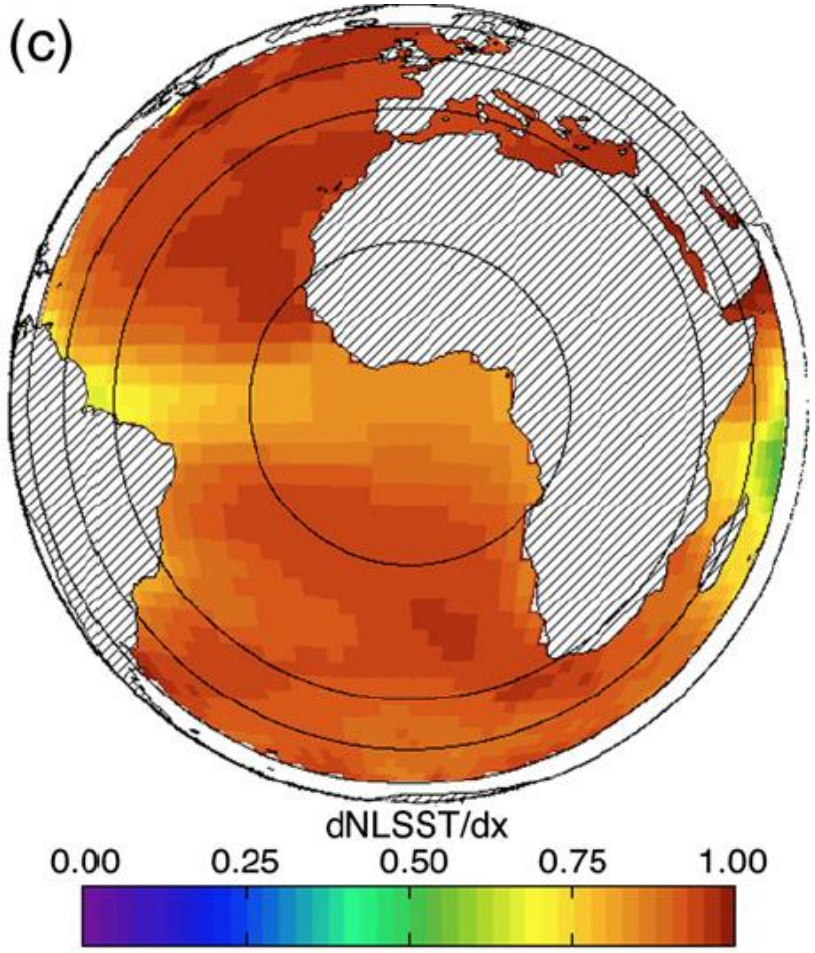
To estimate sensitivity

- Use radiative transfer simulation to find brightness temperature (BT) sensitivity to SST
- Use in derivative of the retrieval equation

$$\frac{\partial \hat{x}}{\partial x} = (a + bS)\frac{\partial y_{11um}}{\partial x} + (c + dS + ex_c)\left(\frac{\partial y_{11um}}{\partial x} - \frac{\partial y_{12um}}{\partial x}\right)$$

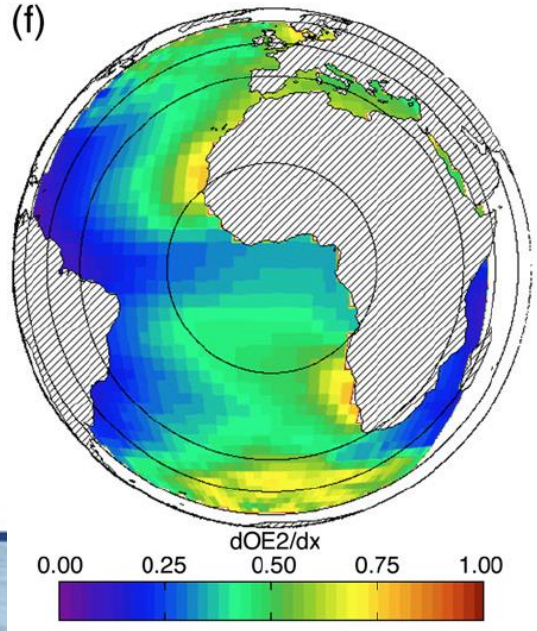
Sensitivity is not 1 for NLSST

- 3 month average of SEVIRI sensitivity using NLSST for retrieval
- SST variations in time and space are underestimated
  - Fronts
  - Diurnal variability



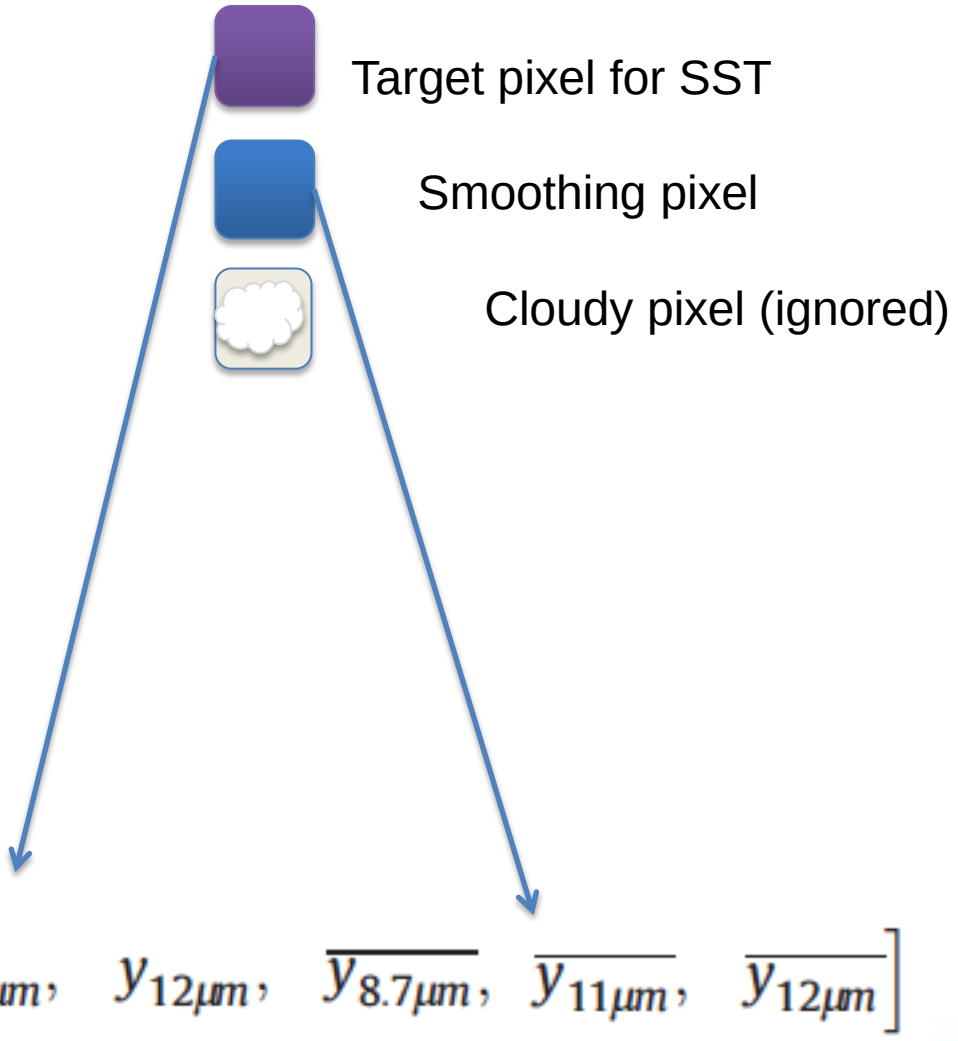
Optimal estimation of SST

- Reduced state vector approach (retrieval of SST and total column water vapour)
  - Remote Sensing of Environment 112 (2008) 2469–2484, first applied to AVHRR
- First application to SEVIRI was unconvincing in regards to the SST sensitivity
  - in OE, sensitivity is from the averaging kernel matrix which is naturally available within the retrieval framework
- Improvements:
  - include 8.7 um
  - relax prior SST uncertainty
  - **smooth OE formulation**



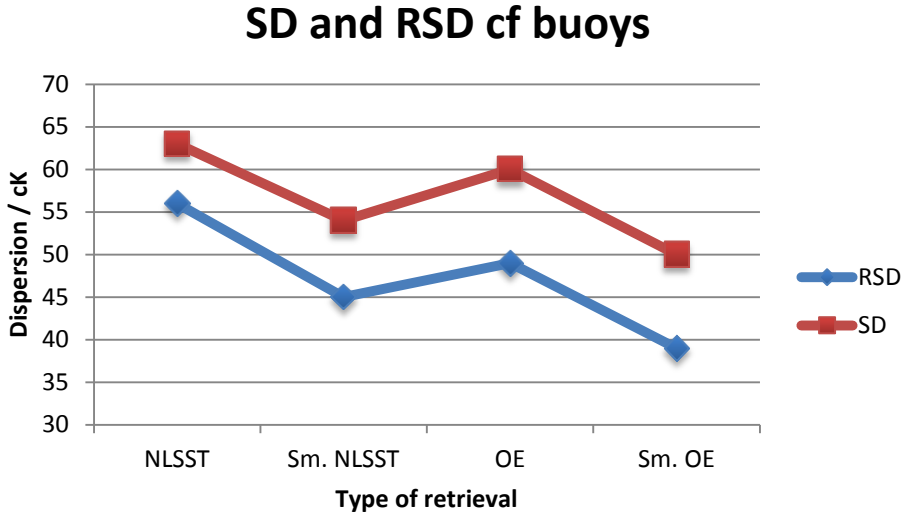
Remote Sensing of Environment 113 (2009) 445–457

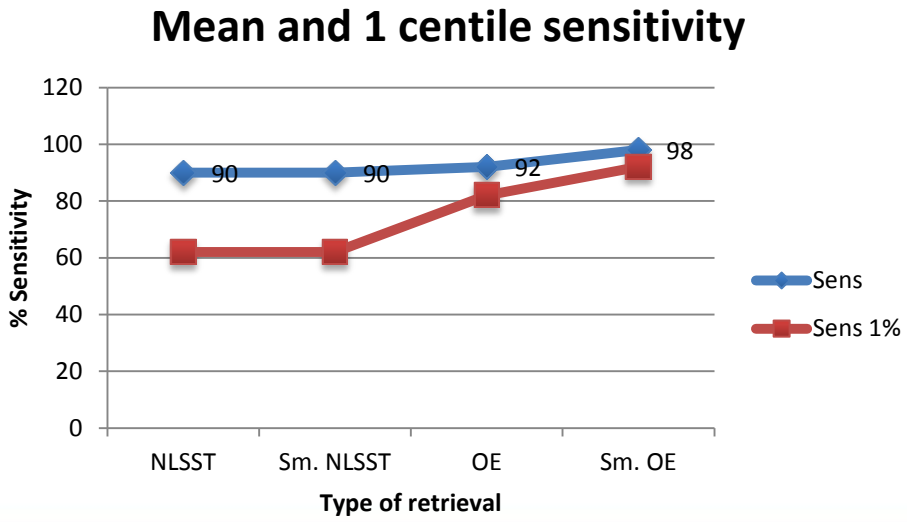
Observations used for smoothed OE

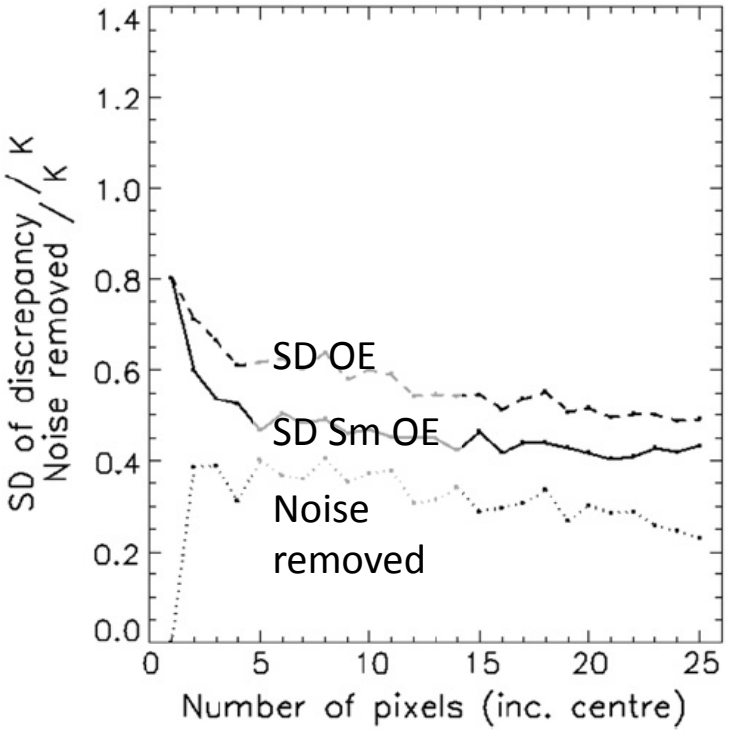


$$\mathbf{y}^{\mathrm{T}} = \left[y_{8.7\mu m},\quad y_{11\mu m},\quad y_{12\mu m},\quad \overline{y_{8.7\mu m}},\quad \overline{y_{11\mu m}},\quad \overline{y_{12\mu m}} \right]$$

Stats of discrepancy cf. validation data

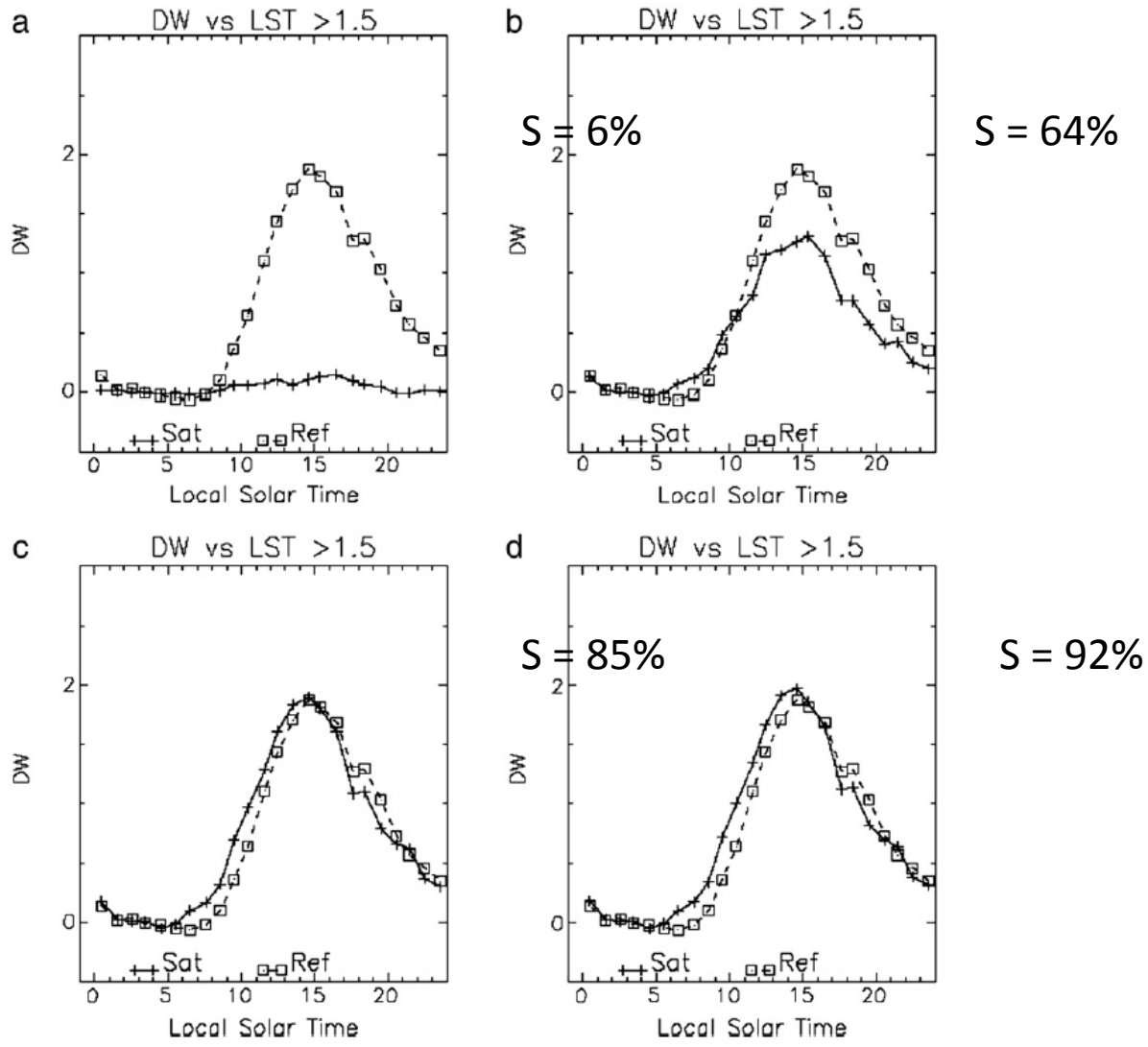






OE smoothing removes more noise than trad. atm. corr. smoothing, simultaneously increasing sensitivity

Validating the sensitivity using DV



Theoretically calculated S for different retrievals

Found cases of large DV in drifting buoy records

Retrieved SST from SEVIRI during the day for these

Shows that full amplitude is only captured by high sensitivity algorithms

Lessons from diurnal variability

- Our expectations can be wrong
  - No-one expected >5 K DV
  - Models which showed this were thought “wrong”
- Models need to represent physics
  - E.g., some sunlight absorbed v. near surface
- Observations can be right for one thing, but not for another
  - E.g., minimum error variance didn’t give S = 1 required to see DV amplitude properly

General conclusions

- Observations and models interact
  - Models can QC observations, as in assimilation
  - Observations test models
- Choose both observations and models appropriate to the phenomenon
  - There isn't a single universal SST product good for everything
  - Consider:
    - accuracy, precision, relative accuracy, stability, sampling,time resolution, space resolution, sensitivity, time period available
- No modeller should be naïve about observations!
- Observationalists need to understand modellers!

- QUESTIONS ABOUT ANYTHING COVERED TODAY?