ATMOSPHERE-OCEAN COUPLED DATA ASSIMILATION USING NASA-GEOS:

ESTIMATION OF AIR-SEA INTERFACE STATE VARIABLES

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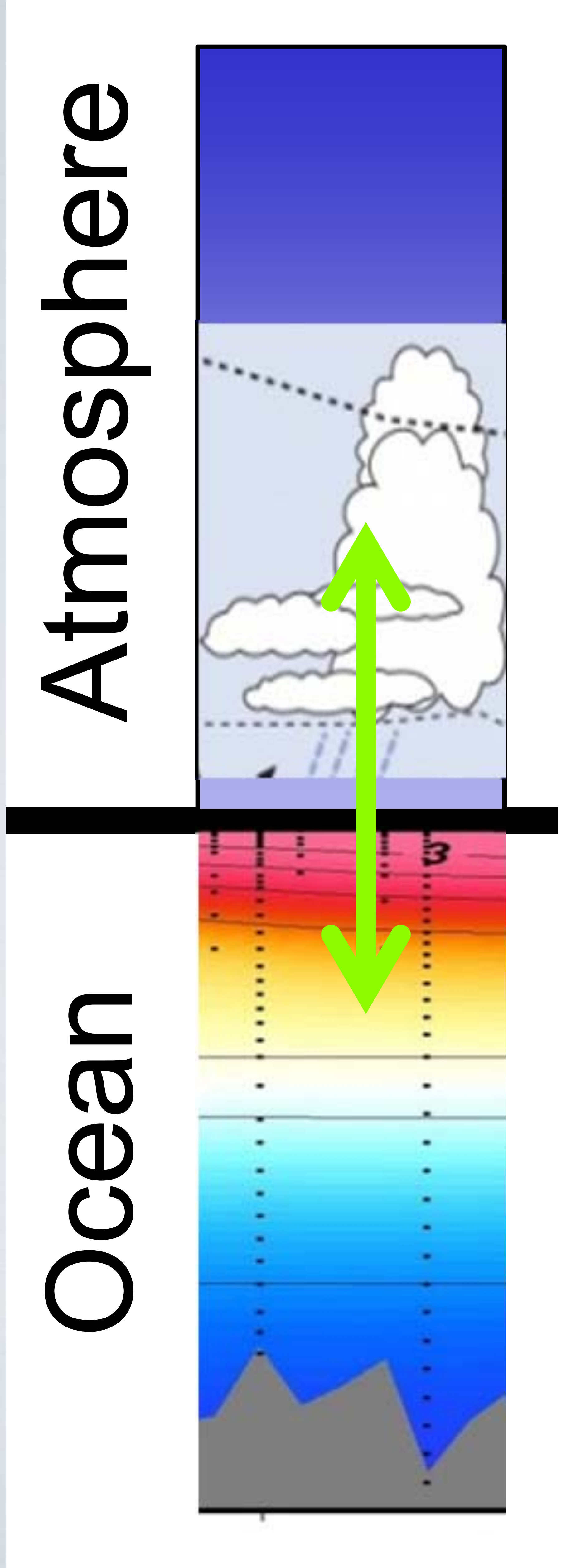
NASA GSFC - GMAO & SSAI Inc

SIAM ANN'18
(Jul 11, 2018)

Coupled Data Assimilation (I)



x_A

x_I

x_O

State Vector: $\mathrm{x} = [\mathrm{x}_A, \mathrm{x}_I, \mathrm{x}_O]^T$

Prior (background) cost:

$$J_b = \frac{1}{2}(\mathrm{x}^b - \mathrm{x})^T \mathrm{B}^{-1} (\mathrm{x}^b - \mathrm{x})$$

Likelihood (observational) cost:

$$J_{obs} = \frac{1}{2}(\mathrm{y} - H[\mathrm{x}])^T \mathrm{R}^{-1} (\mathrm{y} - H[\mathrm{x}])$$

Strongly
Coupled Analysis

$$\mathrm{x}^a = \min_{\mathrm{x}} J_b + J_{obs}$$

Coupled Data Assimilation (2)

Strongly Coupled Analysis seems simple and straightforward to implement!

Why?

1. Dimension of (3-D atm, ocn + 2-D int) $\mathbf{x}$
2. Covariance model for $\mathbf{B}$
3. Sparsity of observations (ocn, int: surface) $\mathbf{y}$

$$\mathrm{B} = \begin{bmatrix} B_{AA} & B_{AI} & B_{AO} \\ B_{IA} & B_{II} & B_{IO} \\ B_{OA} & B_{OI} & B_{OO} \end{bmatrix}$$

Alternatively (or iteratively), solve for:

- Component states (atmosphere, ocean, …) <u>separately</u>
- Use already existing analyses

▷ Different flavors of *weakly* (<u>not</u> strong!) coupled analysis

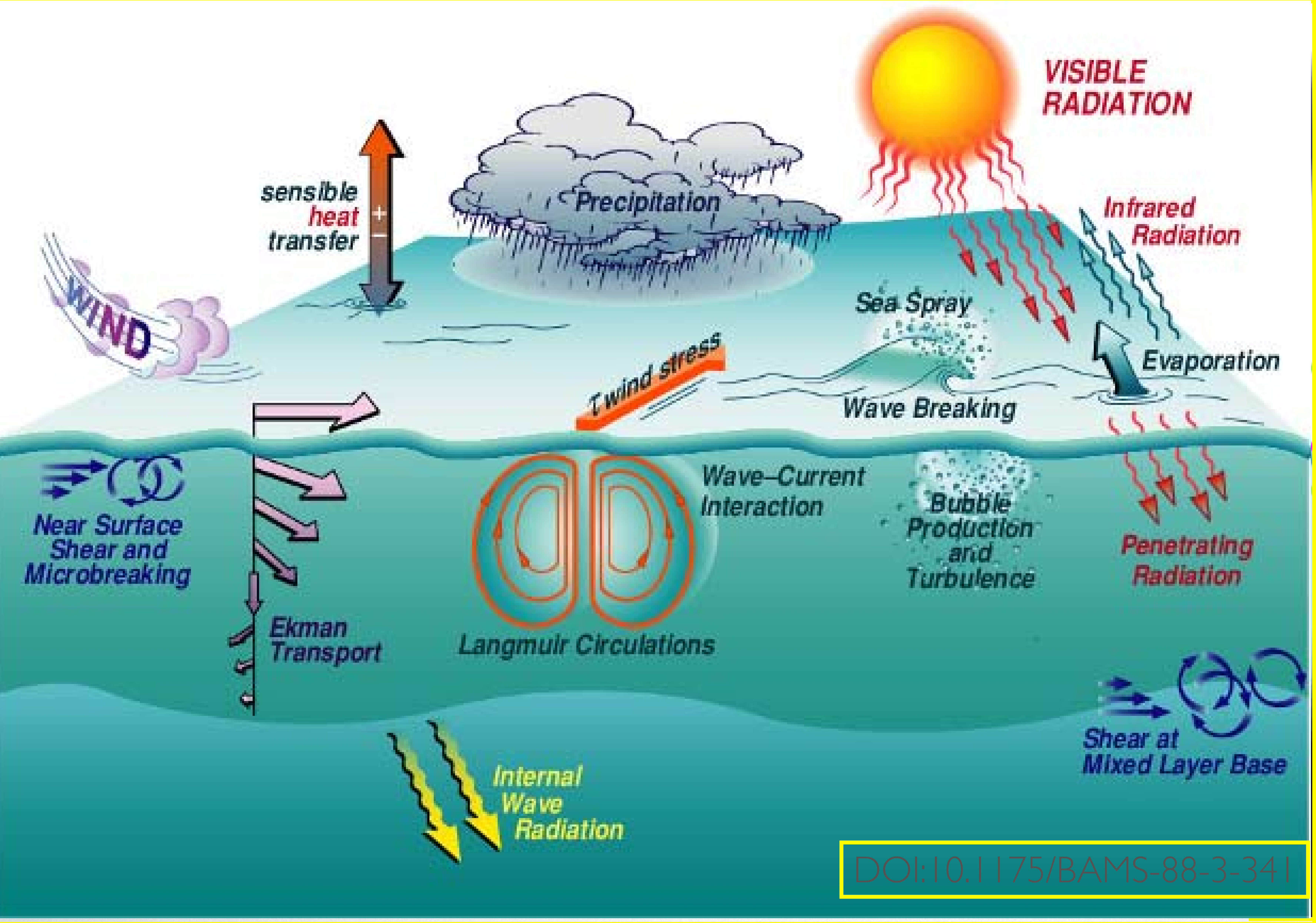
- Which component is solved 1st? Atmosphere $\mathbf{x}_A$ or Ocean $\mathbf{x}_O$?
- How is the interface state $\mathbf{x}_I$ handled?
- How realistic are the cross-correlations: B_{AO}, B_{AI}, B_{OI}; $H[\,\cdot\,]$

Coupled Data Assimilation (3)

At the GMAO, we acknowledge the (future potential/need for) Strongly Coupled Analysis…

- As a first step, our first Coupled Analysis will be (weakly) coupled via interface state variables:
  - Sea Surface Temperature (Skin SST) T_s
  - Sea Surface Salinity (Skin Salinity) S_s
  - Sea Ice, etc
- All developments will naturally carry over to the future work

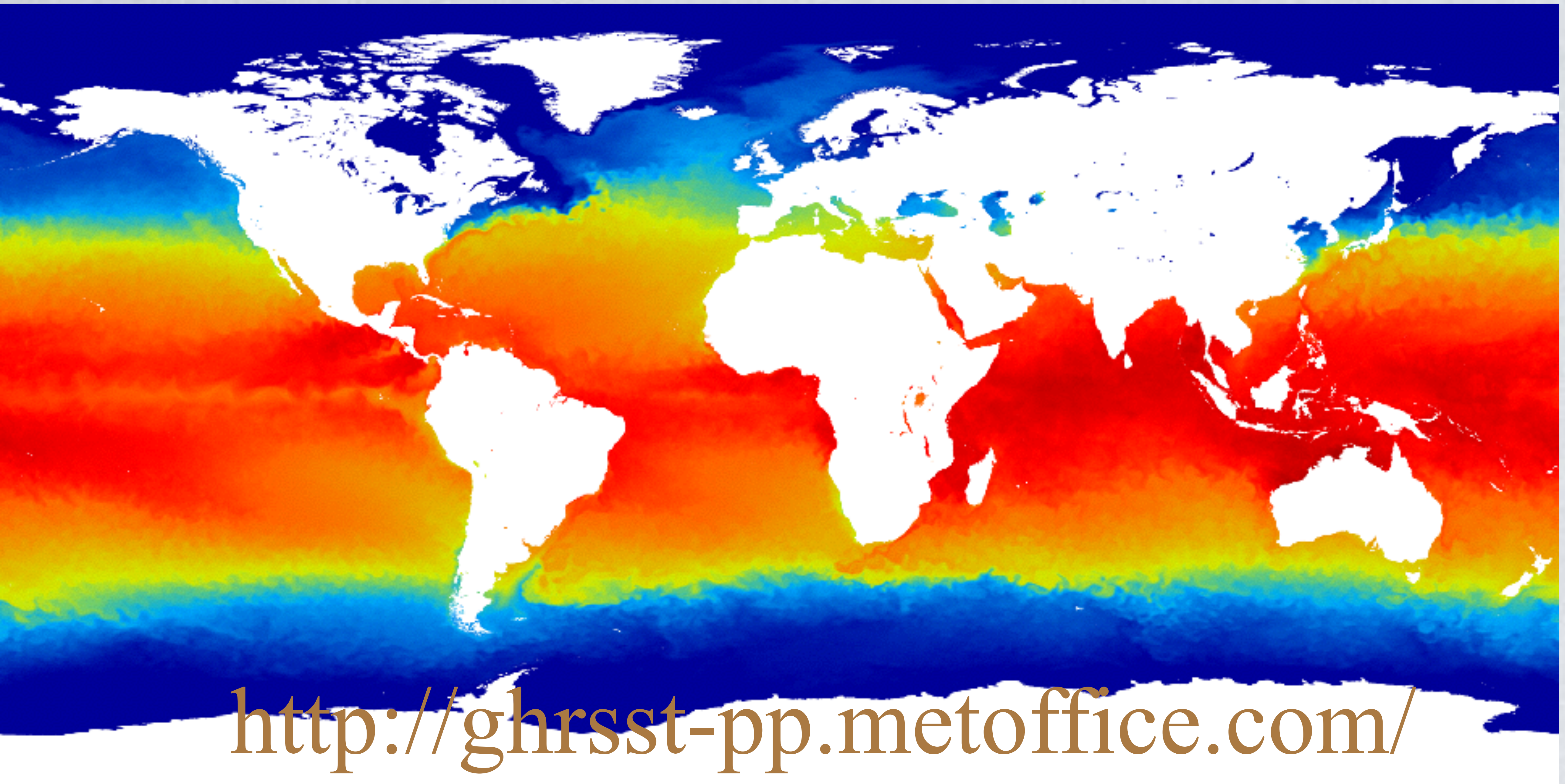
Air-sea Interface



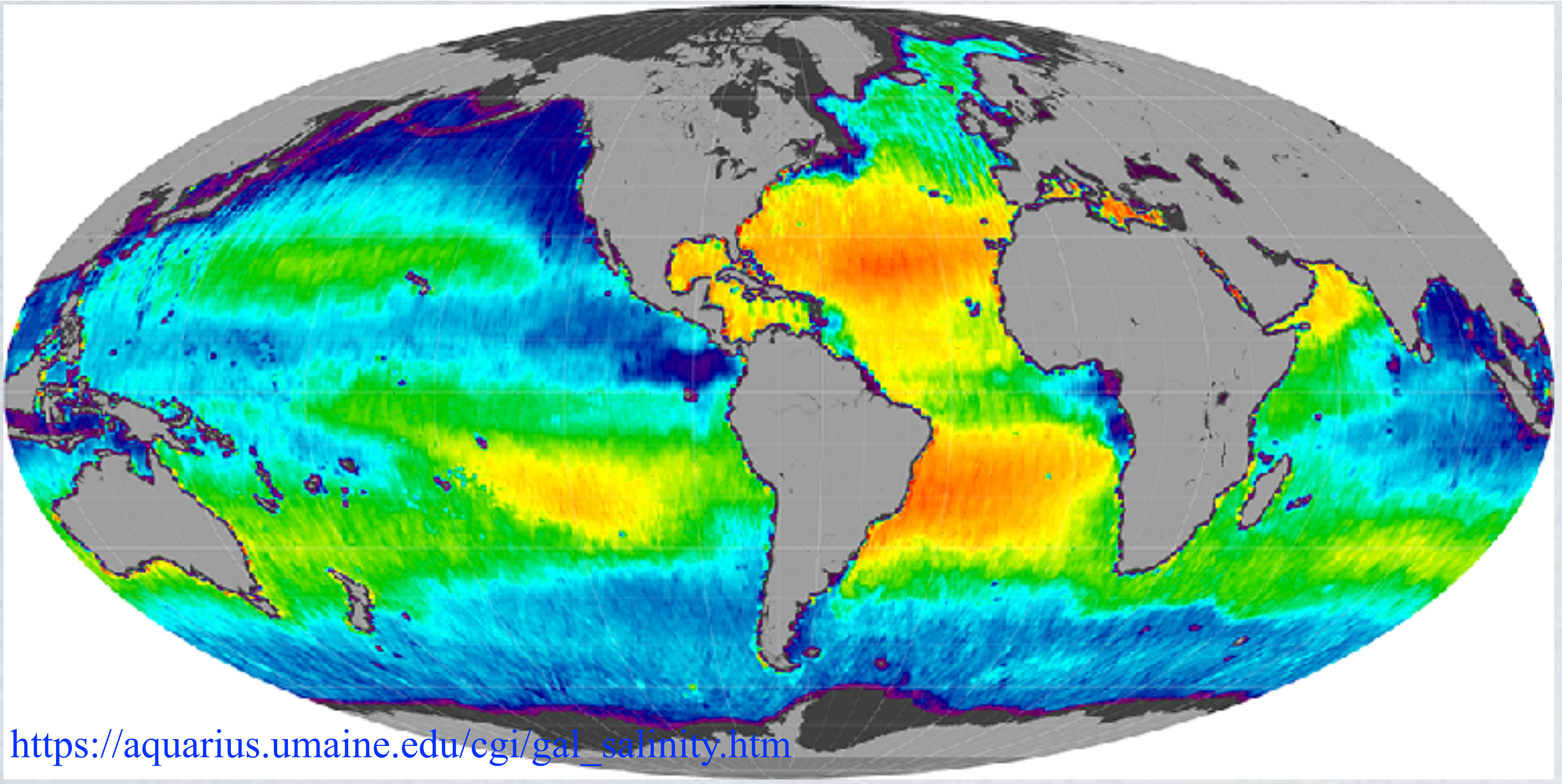
Interface is complicated!

CURRENT STATUS (I)

OSTIA SST

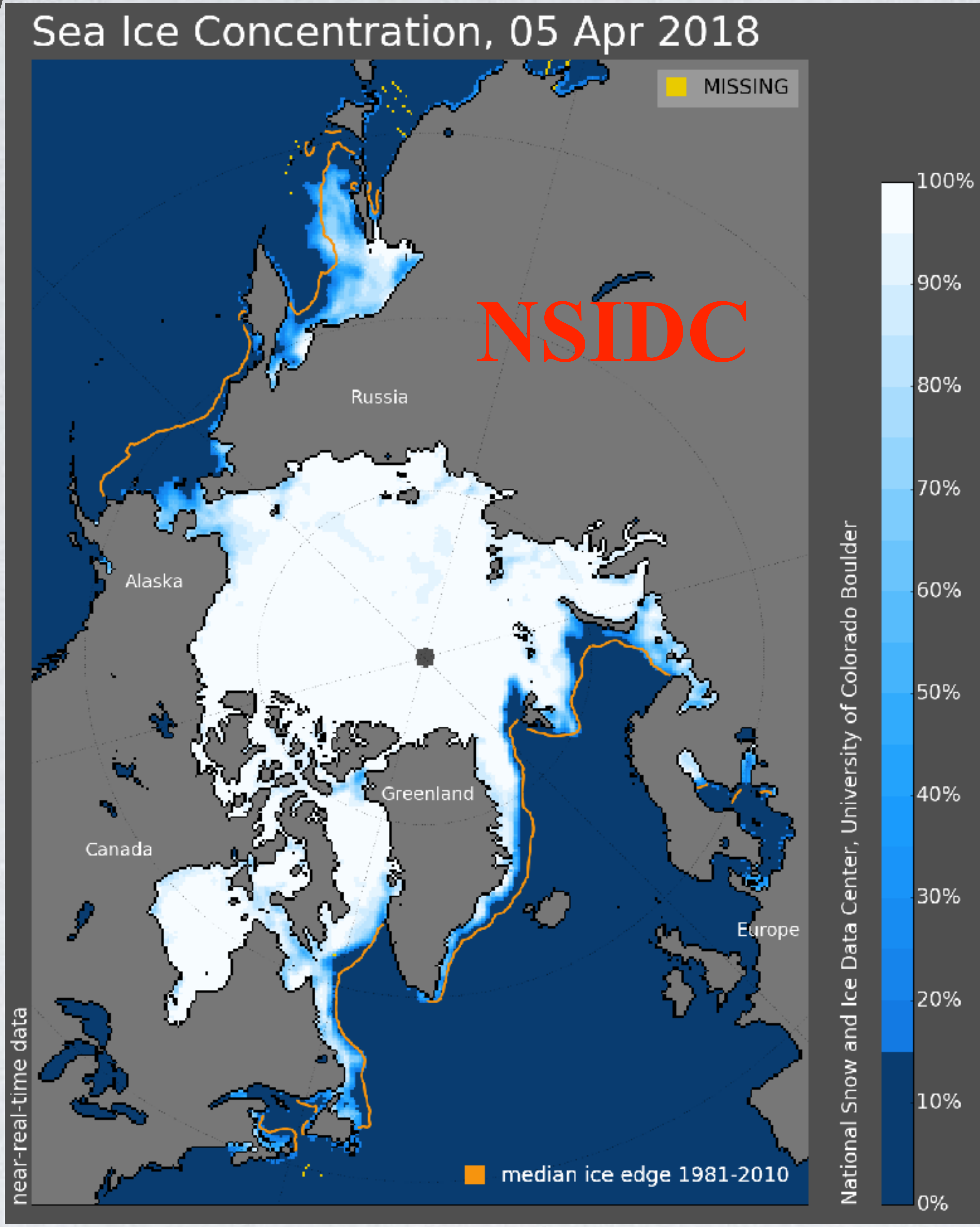


http://ghrsst-pp.metoffice.com/



https://aquarius.umaine.edu/cgi/gal_salinity.htm

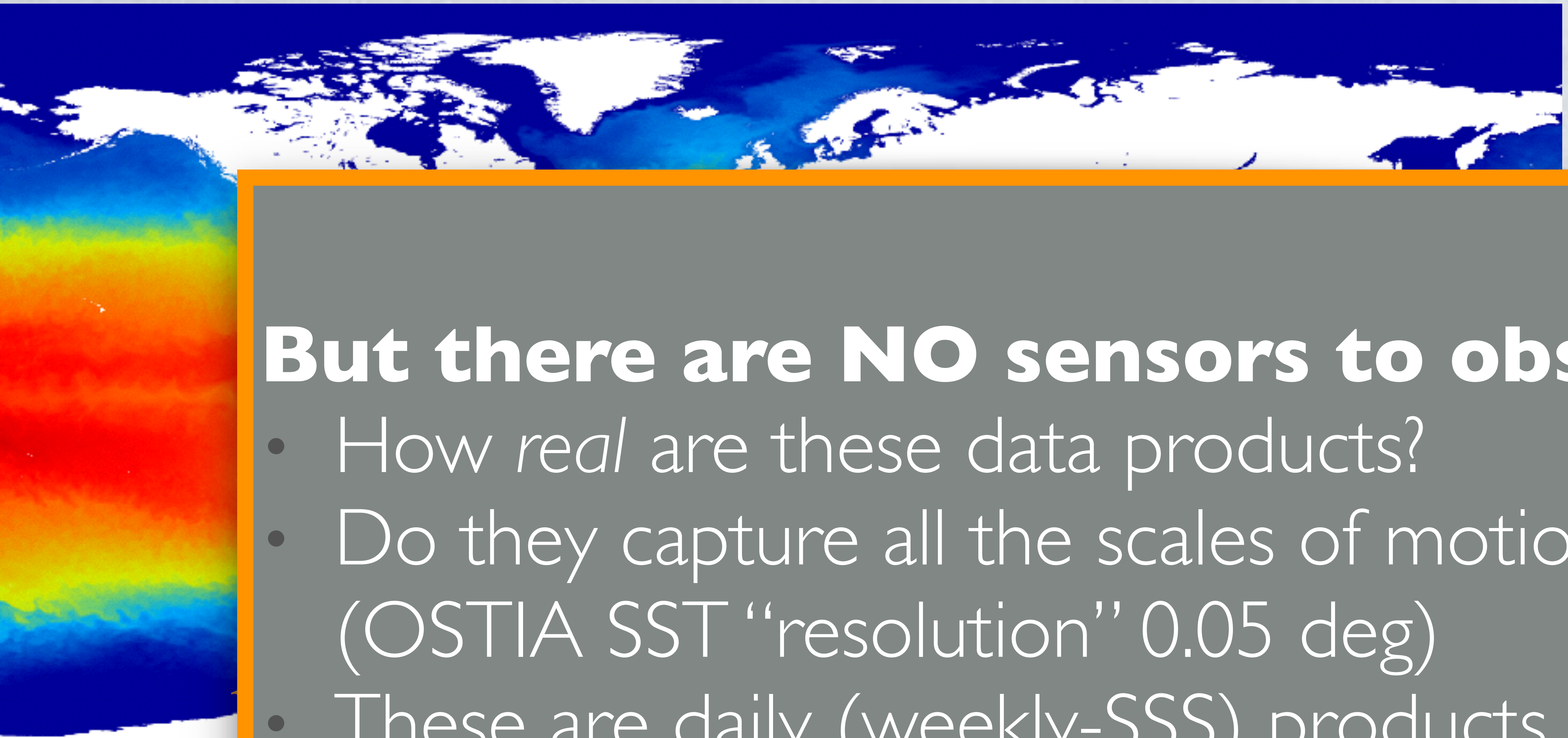
AQUARIUS SSS



NSIDC

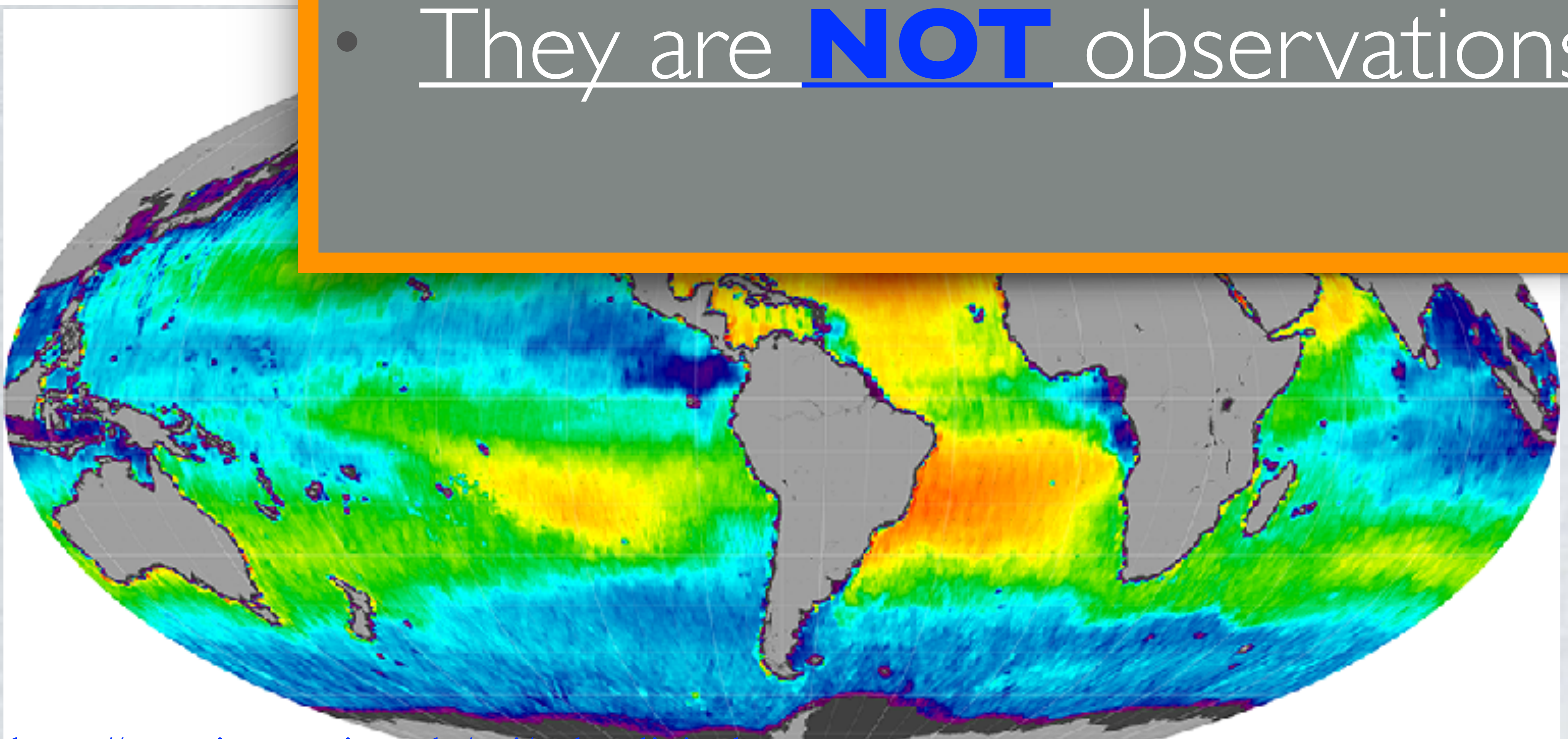
CURRENT STATUS (2)

OSTIA SST



But there are NO sensors to observe at these resolutions!

- How *real* are these data products?
- Do they capture all the scales of motion at which they are released (OSTIA SST "resolution" 0.05 deg)
- These are daily (weekly-SSS) products, but surface moves FAST!
- They are **NOT** observations!



https://aquarius.umaine.edu/cgi/gal_salinity.htm

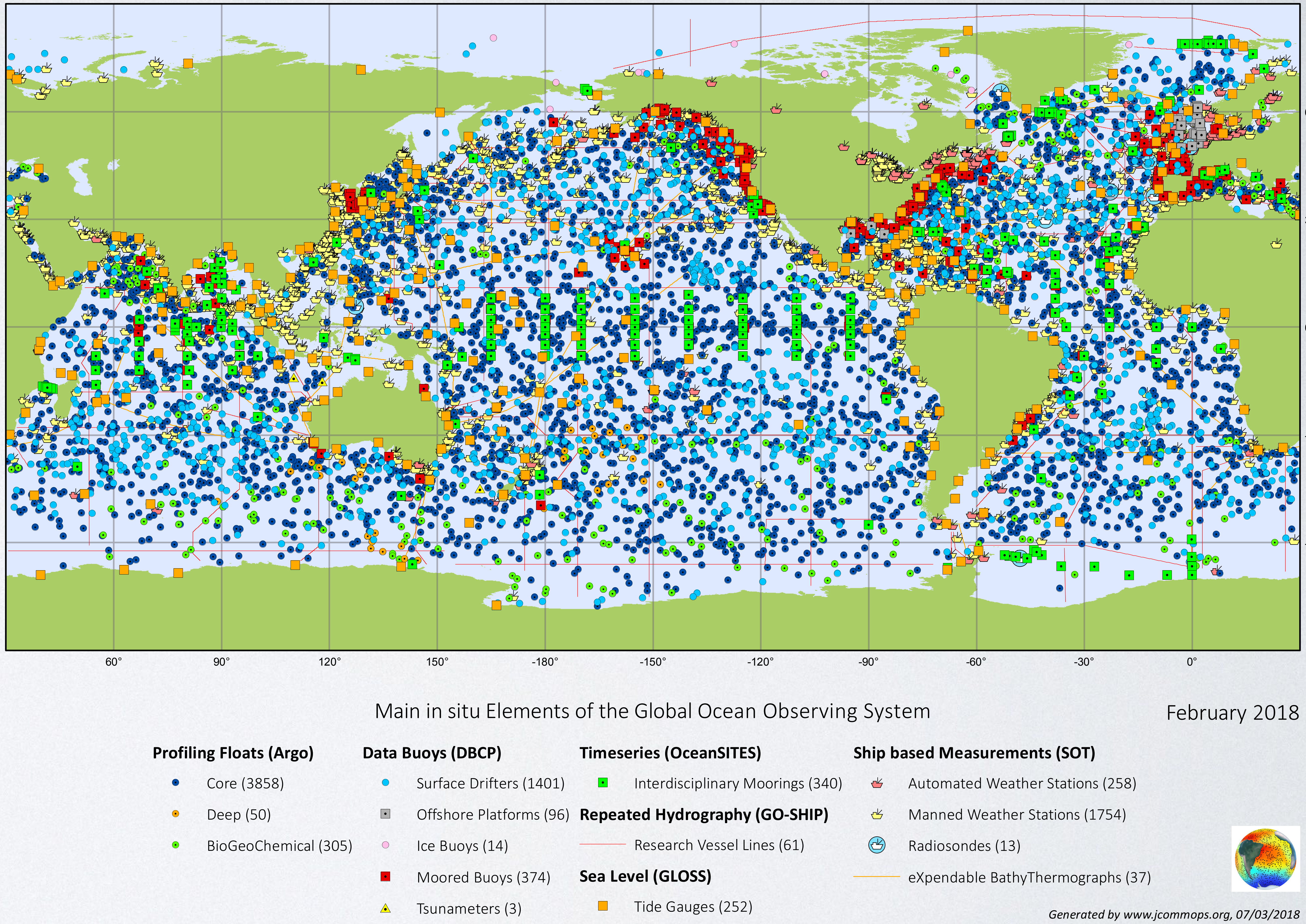
AQUARIUS SSS

SST OBSERVATIONS (I)

Spaceborne

https://earthobservatory.nasa.gov/

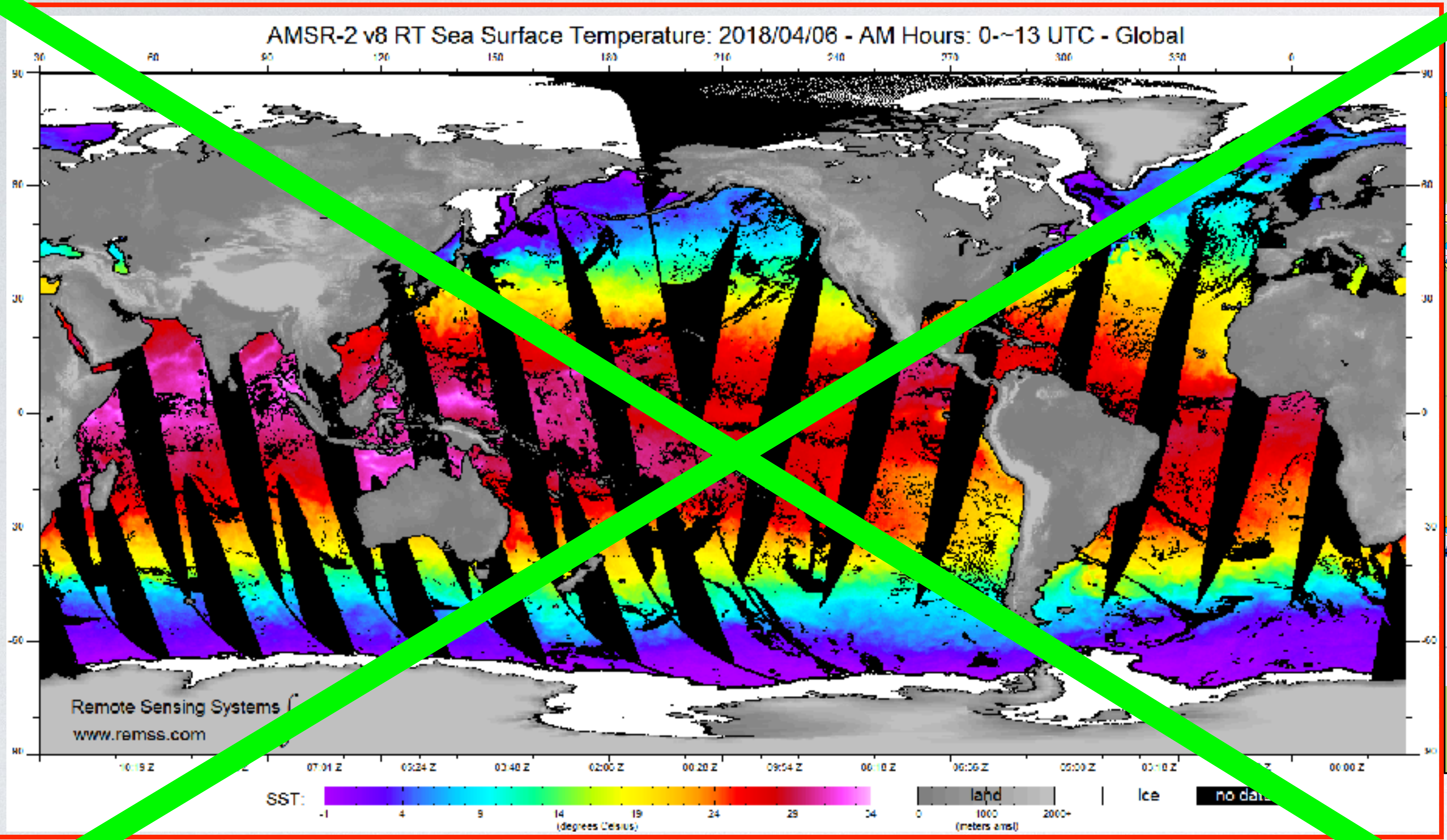
In-Situ



JCOMMOPS

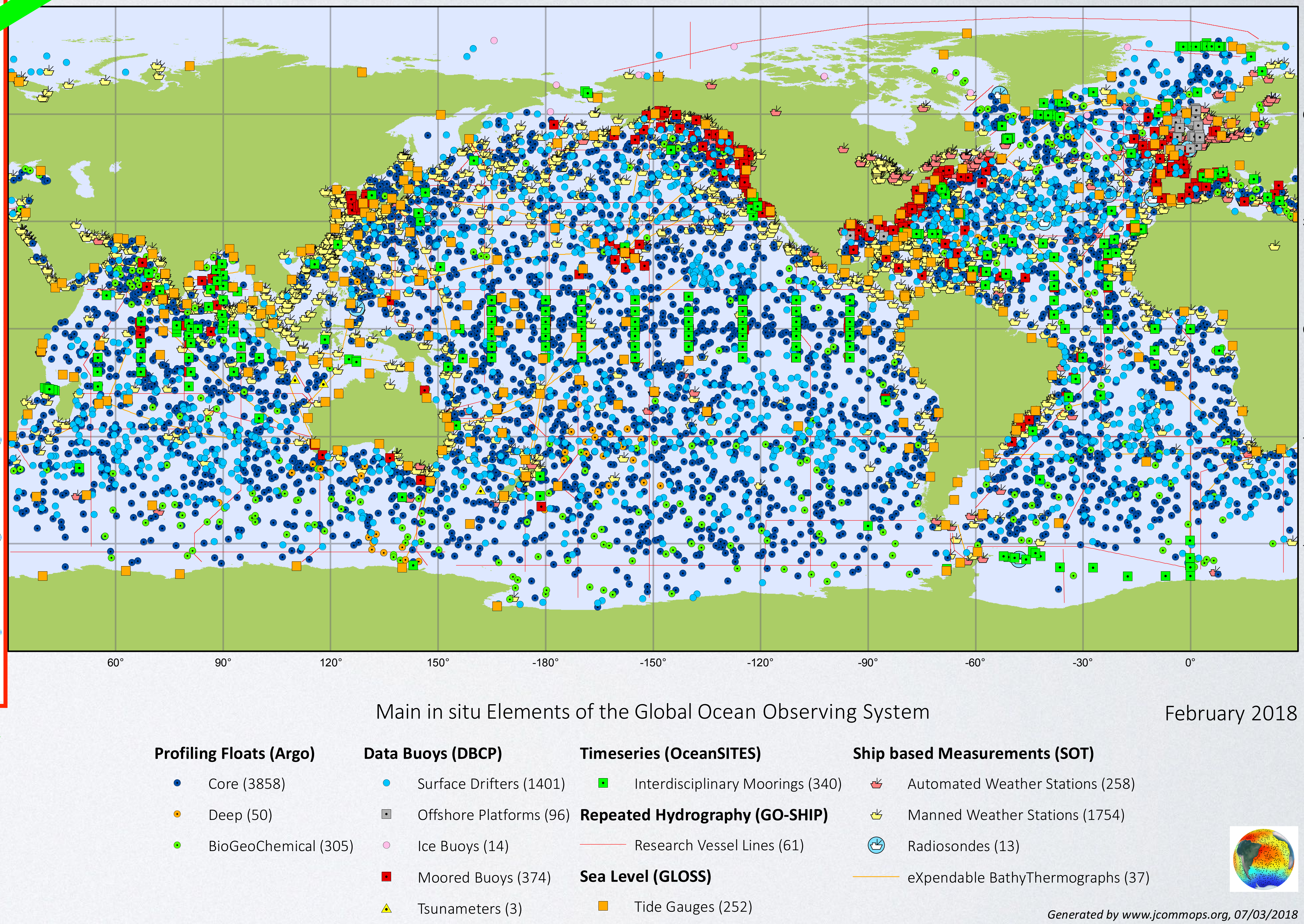
SST OBSERVATIONS (2)

Spaceborne



http://images.remss.com/amsr/amsr2_data_daily.html

In-Situ

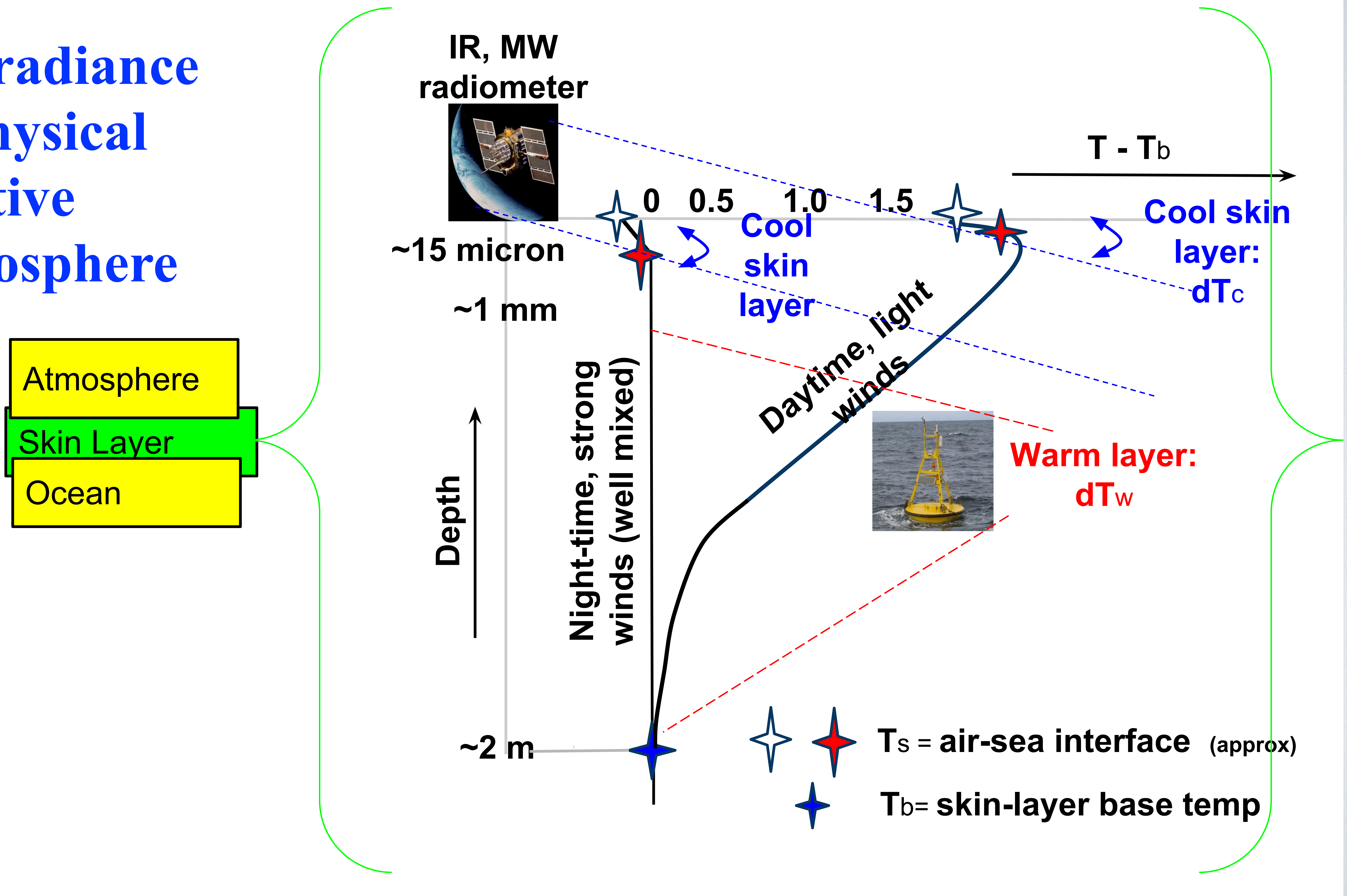


Satellites DO NOT measure SST!

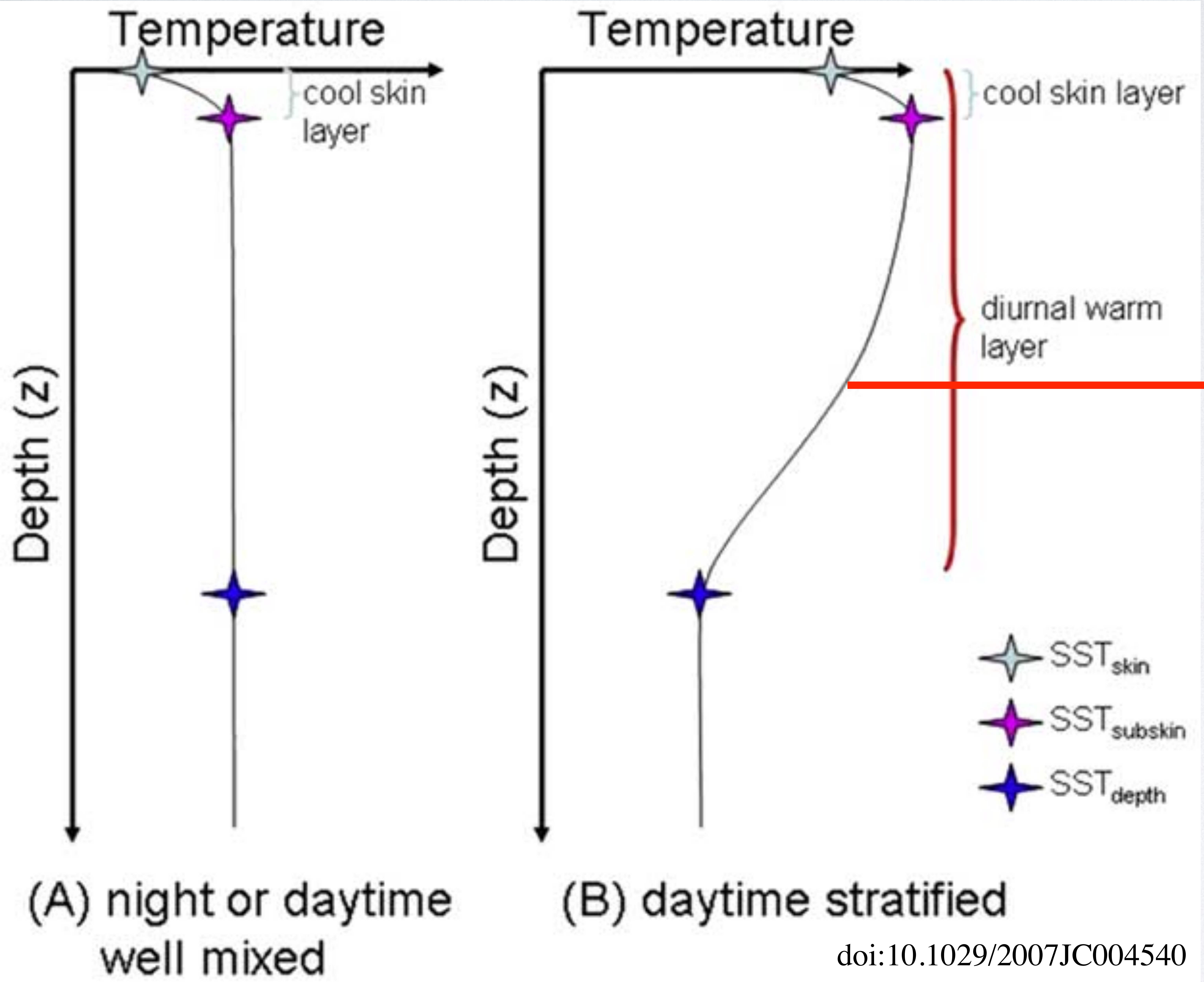
JCOMMOPS

SST OBSERVATIONS (3)

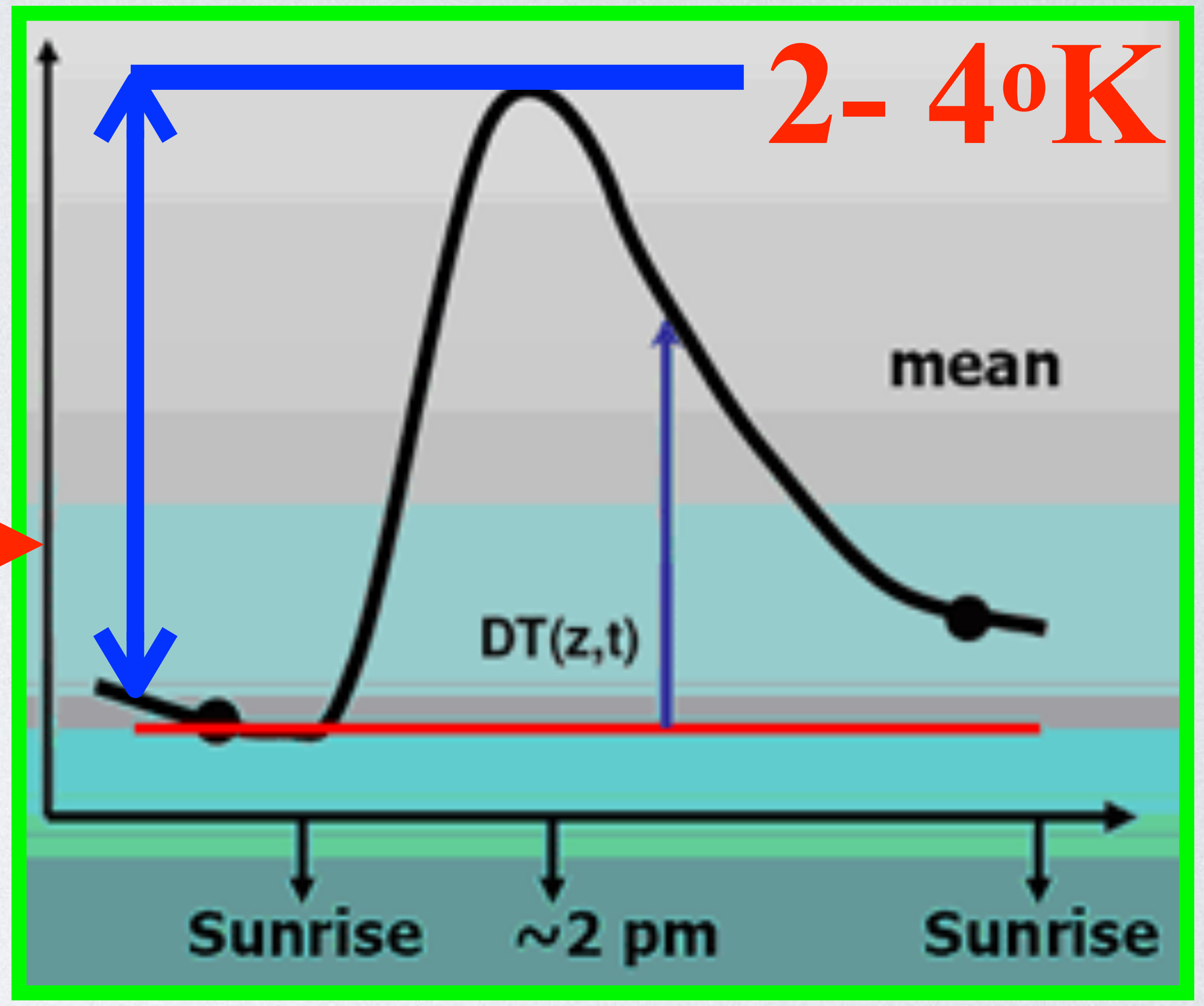
- Satellites measure radiance
- Which relates to physical variables via radiative transfer in the atmosphere H[.]



SST VARIABILITY



doi:10.1029/2007JC004540



climate Impact

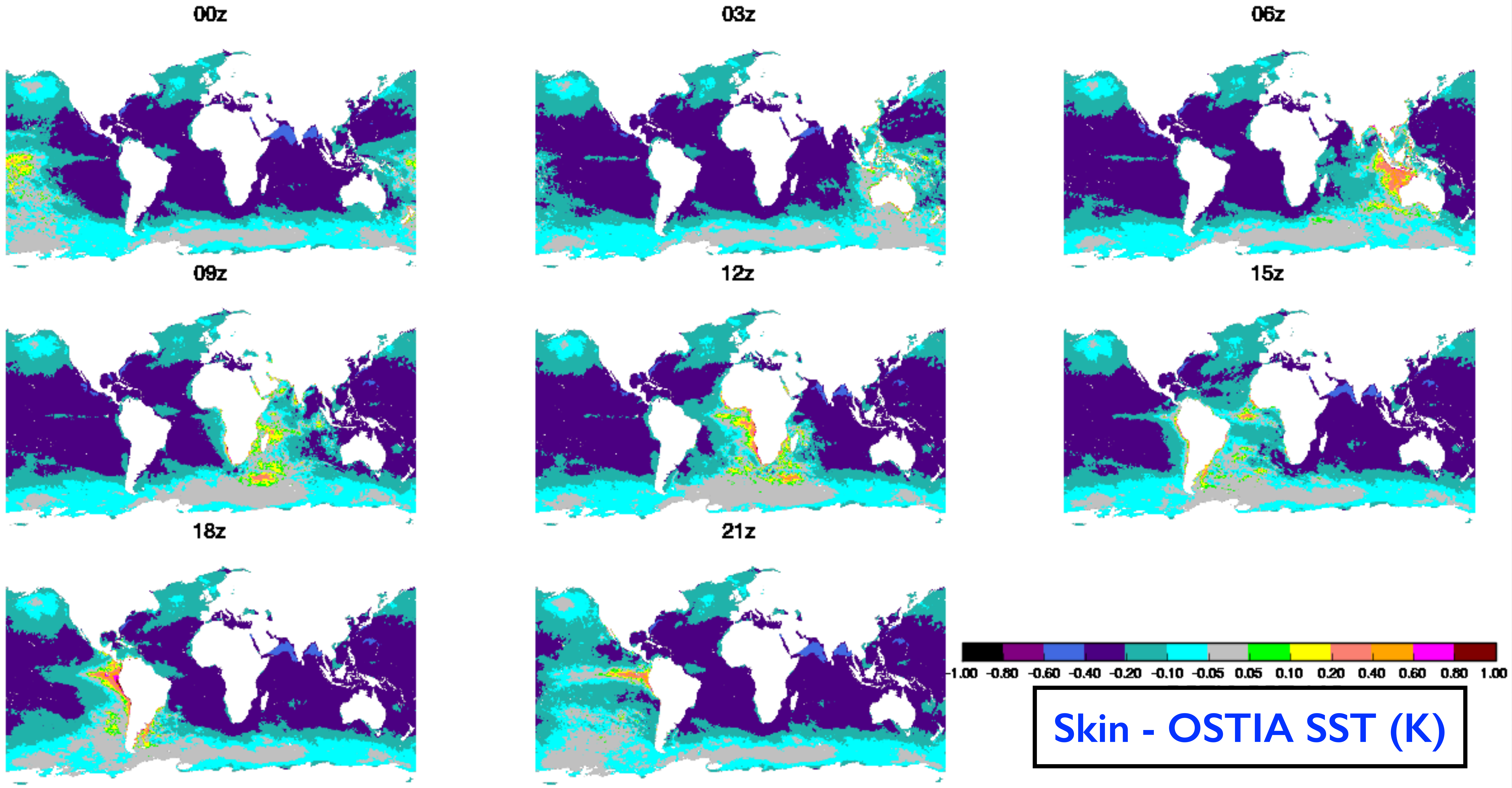
Skin SST in GEOS DAS (1)

Updates to Atmospheric Data Assimilation System (shared w/NCEP-EMC)

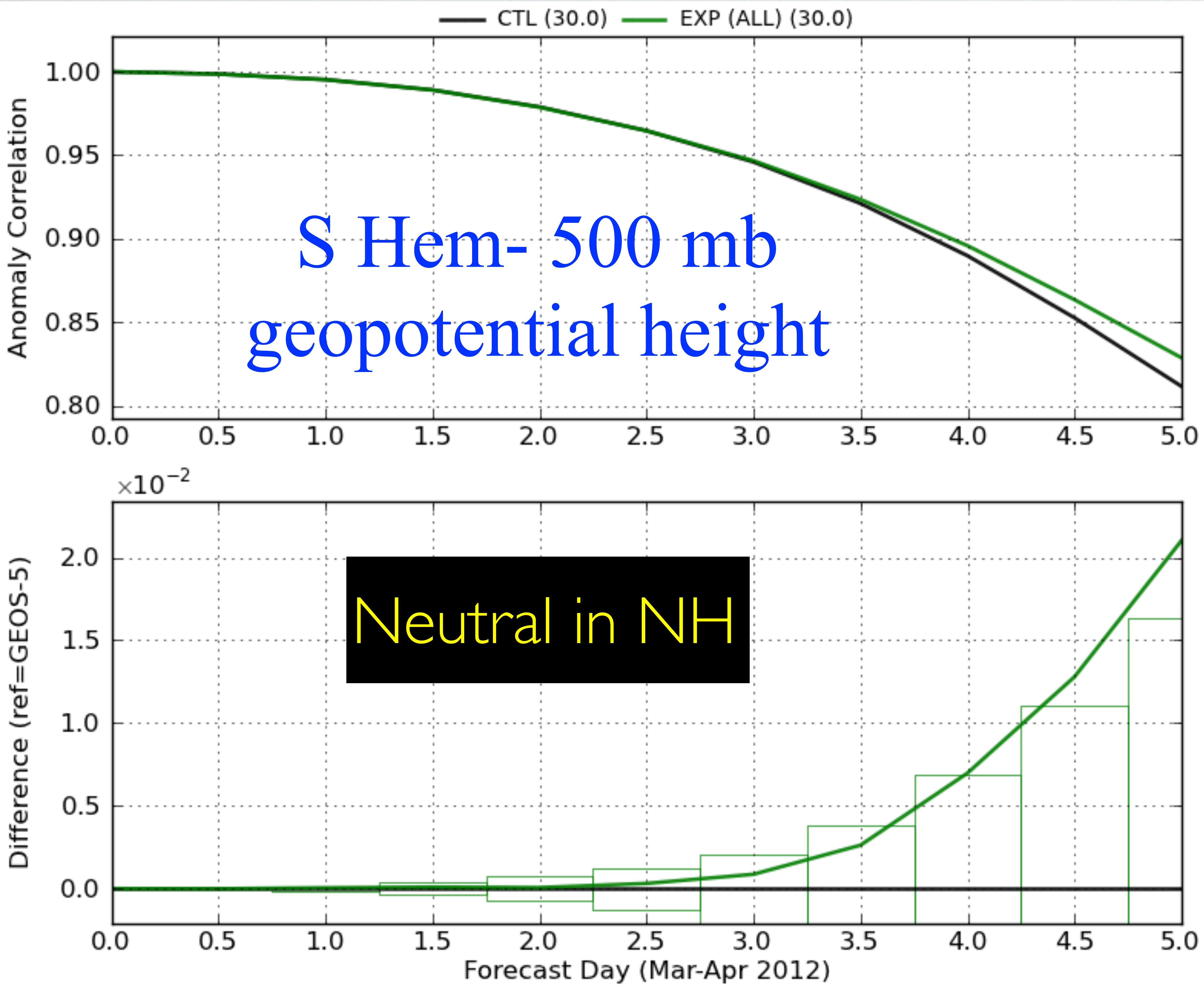
- ☑ **Model the variation of Skin SST** $= \text{OSTIA SST} + \Delta T_w - \Delta T_c$
  - thermally stratification due to diurnal warming (ΔT_w)
  - a thin cool-skin layer (ΔT_c)
- ☑ **Direct radiance assimilation for Skin SST** $H[\,\cdot\,]$
  - additional Infrared (AVHRR) satellite observations
  - using radiative transfer model
- ☑ **Operational since 01/2017**

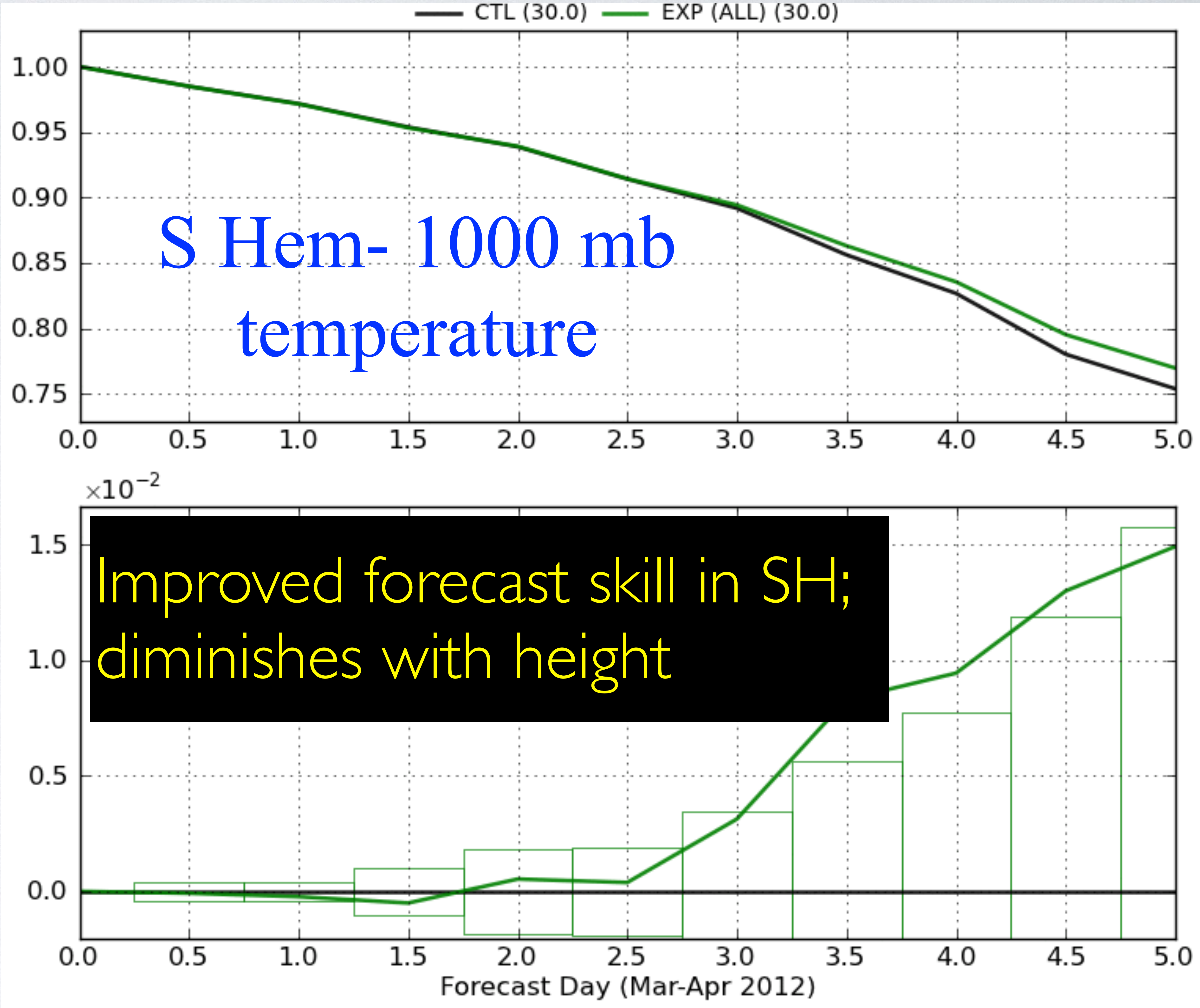
Background error details follow…

Skin SST in GEOS DAS (2)



SKIN SST IN GEOS DAS (3)





Skin SST in GEOS DAS (4)

NASA/TM–2016–104606/Vol 44

Technical Report Series on Global Modeling and Data Assimilation, Volume 44

Randal D. Koster, Editor

Estimation of the Ocean Skin Temperature using the NASA GEOS Atmospheric Data Assimilation System

Quarterly Journal of the Royal Meteorological Society Q. J. R. Meteorol. Soc. (2017) DOI:10.1002/qj.2988

RMetS Royal Meteorological Society

Assimilation for skin SST in the NASA GEOS atmospheric data assimilation system

JOURNAL OF GEOPHYSICAL RESEARCH
Oceans
AN AGU JOURNAL
JGR
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Research Article

Evaluation of NASA GEOS-ADAS Modeled Diurnal Warming Through Comparisons to SEVIRI and AMSR2 SST Observations

Current Work

BACKGROUND ERROR FOR T_s

$$B = \begin{bmatrix} B_{AA} & 0 \\ 0 & B_{II} \end{bmatrix}$$

Hybrid Analysis for T_s using :

✳ Deterministic (central):

persistent, large-scale errors

✳ Probabilistic (ensembles):

flow dependent, small-scale errors

Without the T_s model:

- For all ensemble members, $T_s = \text{OSTIA SST}$

➡ Ensemble generated covariance $B_e(T_s) \approx 0$

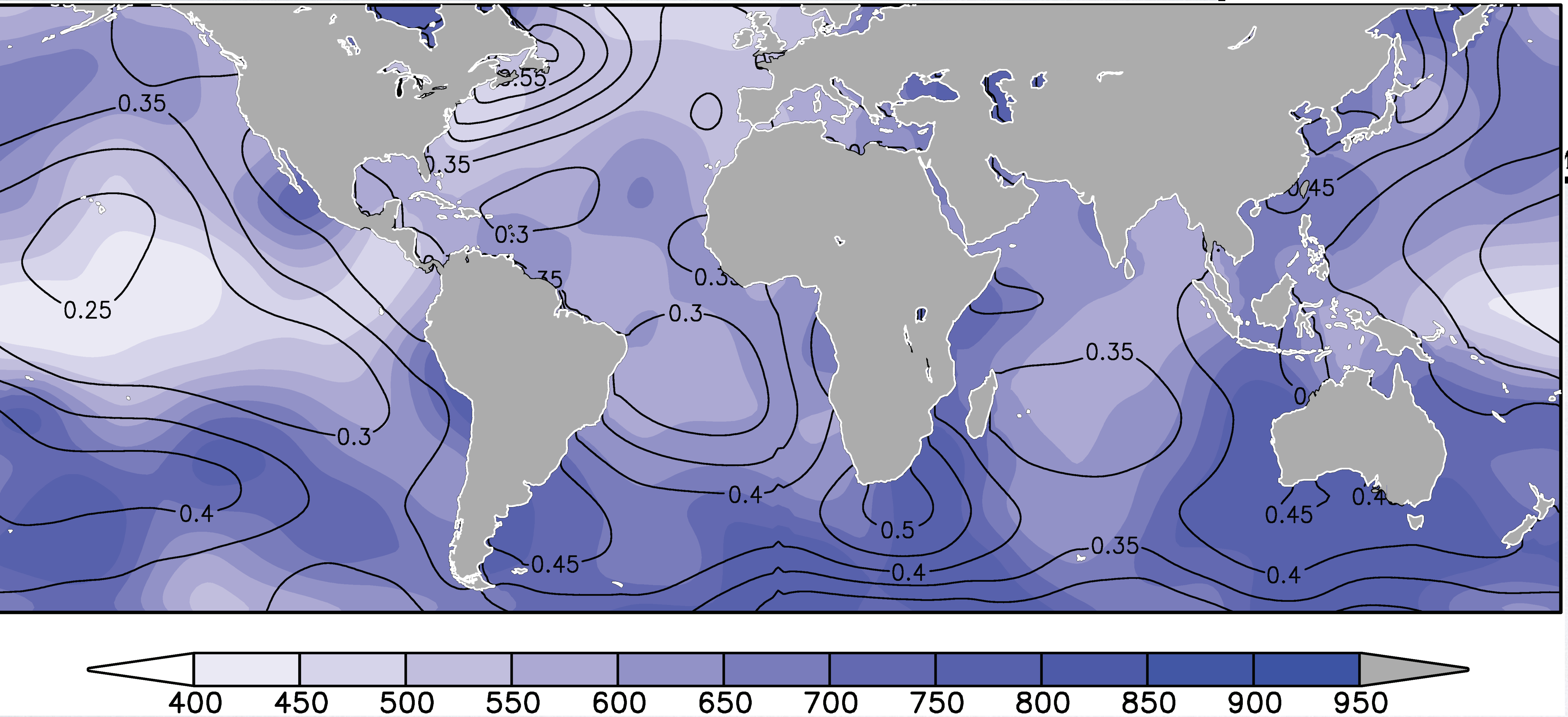
BACKGROUND ERROR FOR T_s

Improved Global Sea Surface Temperature Analyses Using Optimum Interpolation

RICHARD W. REYNOLDS AND THOMAS M. SMITH

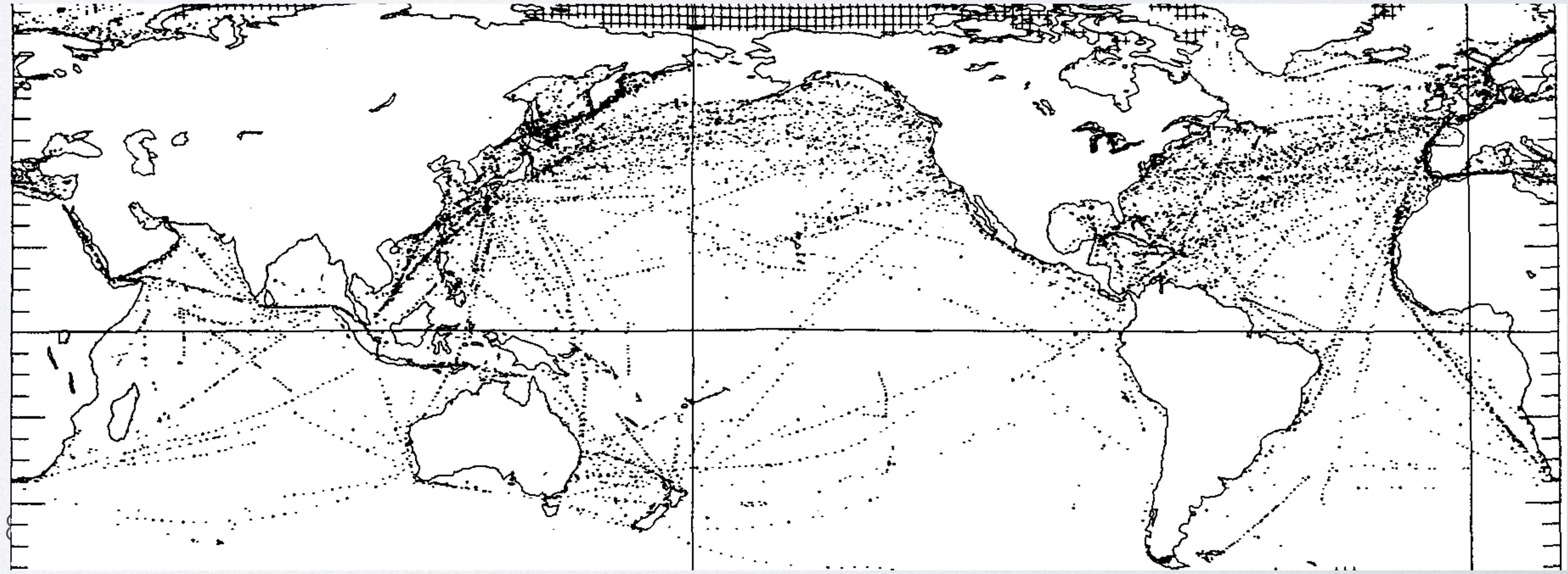
National Meteorological Center, NWS, NOAA, Washington, D.C.

(Manuscript received 10 November 1992, in final form 29 August 1993)

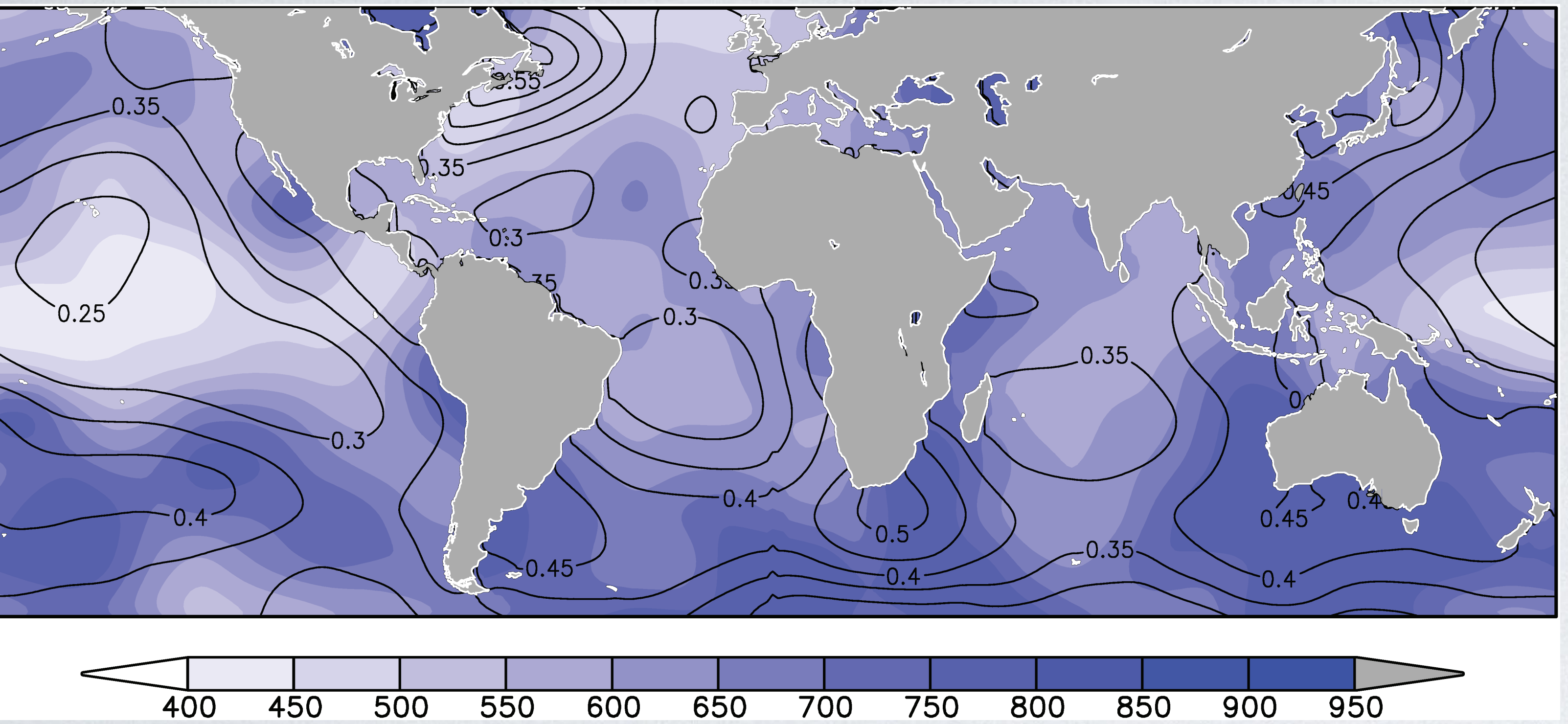


Derived ~1994 using a very-sparse SST observation network

- Long correlation length-scales (400- 950Km)
- Over-confident $\sigma_b : 0.25 - 0.6C$



HYBRID ANALYSIS FOR T_s

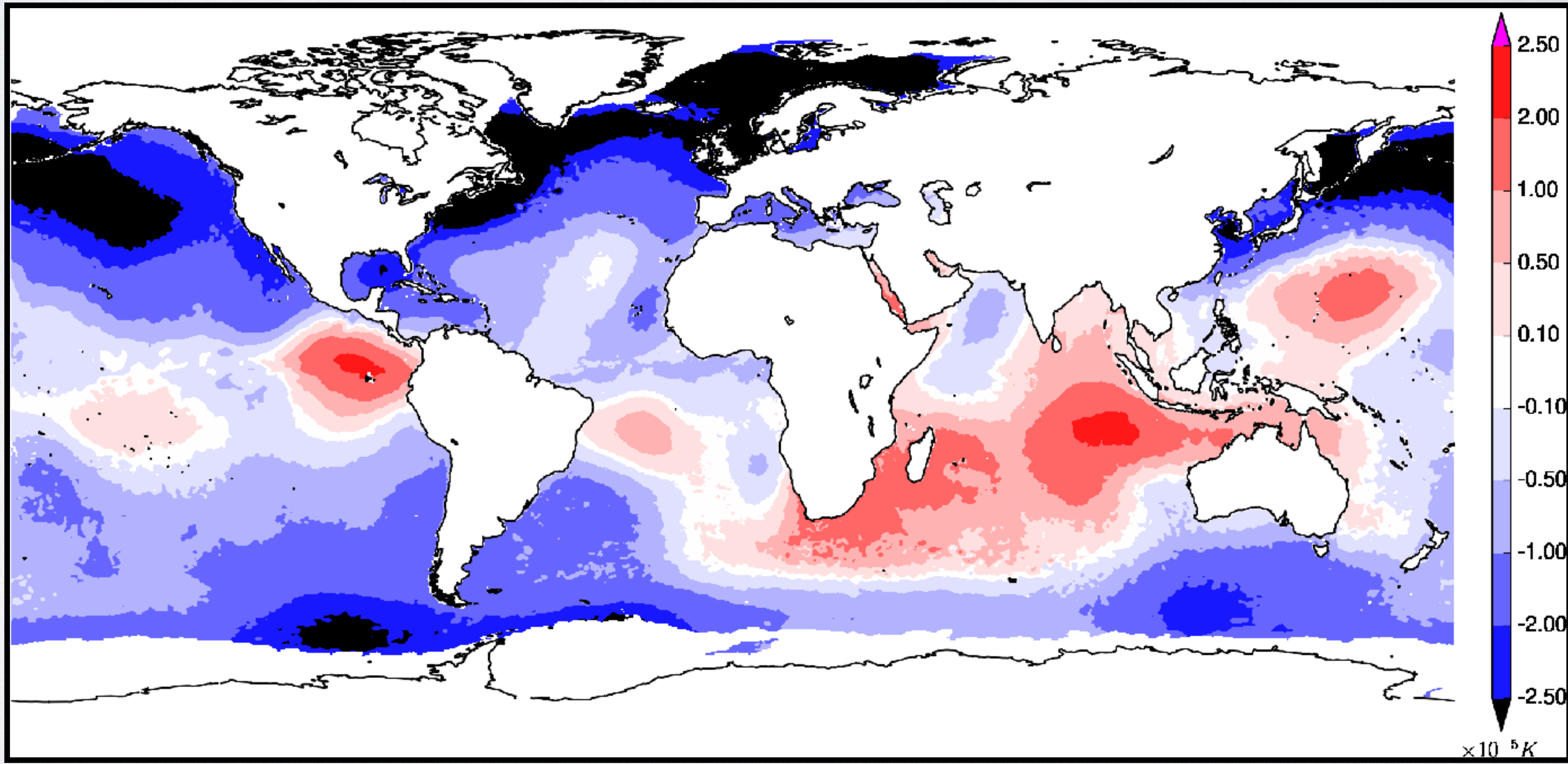


Monthly mean of increment (ANA-BKG)
12UTC (December, 2017)

Increments:

- very smooth
- Long correlations

Currently we use the deterministic analysis increment only, because…



HYBRID ANALYSIS FOR T_S

Ensemble (2018/01/31 06UTC)

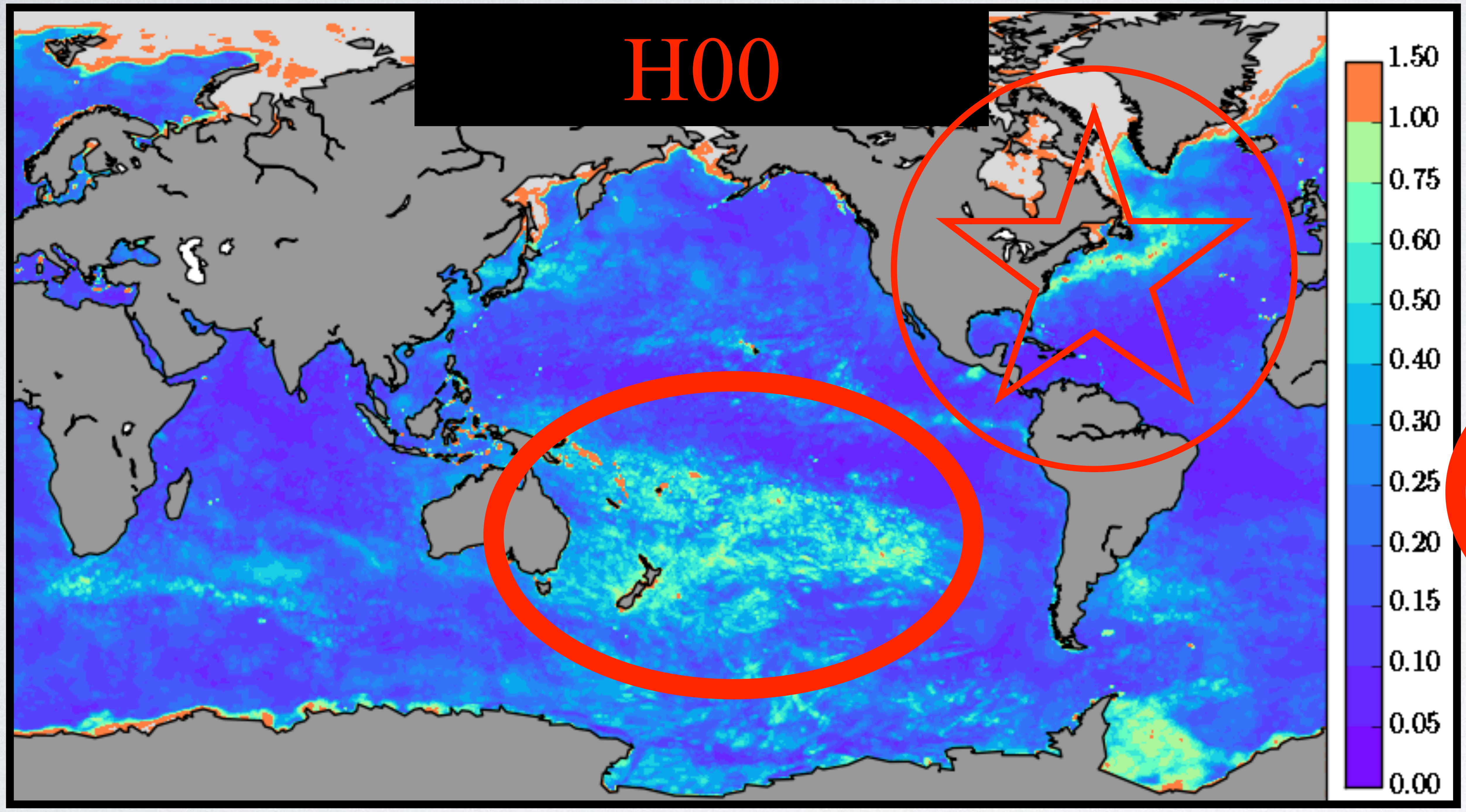
HYBRID ANALYSIS FOR T_s

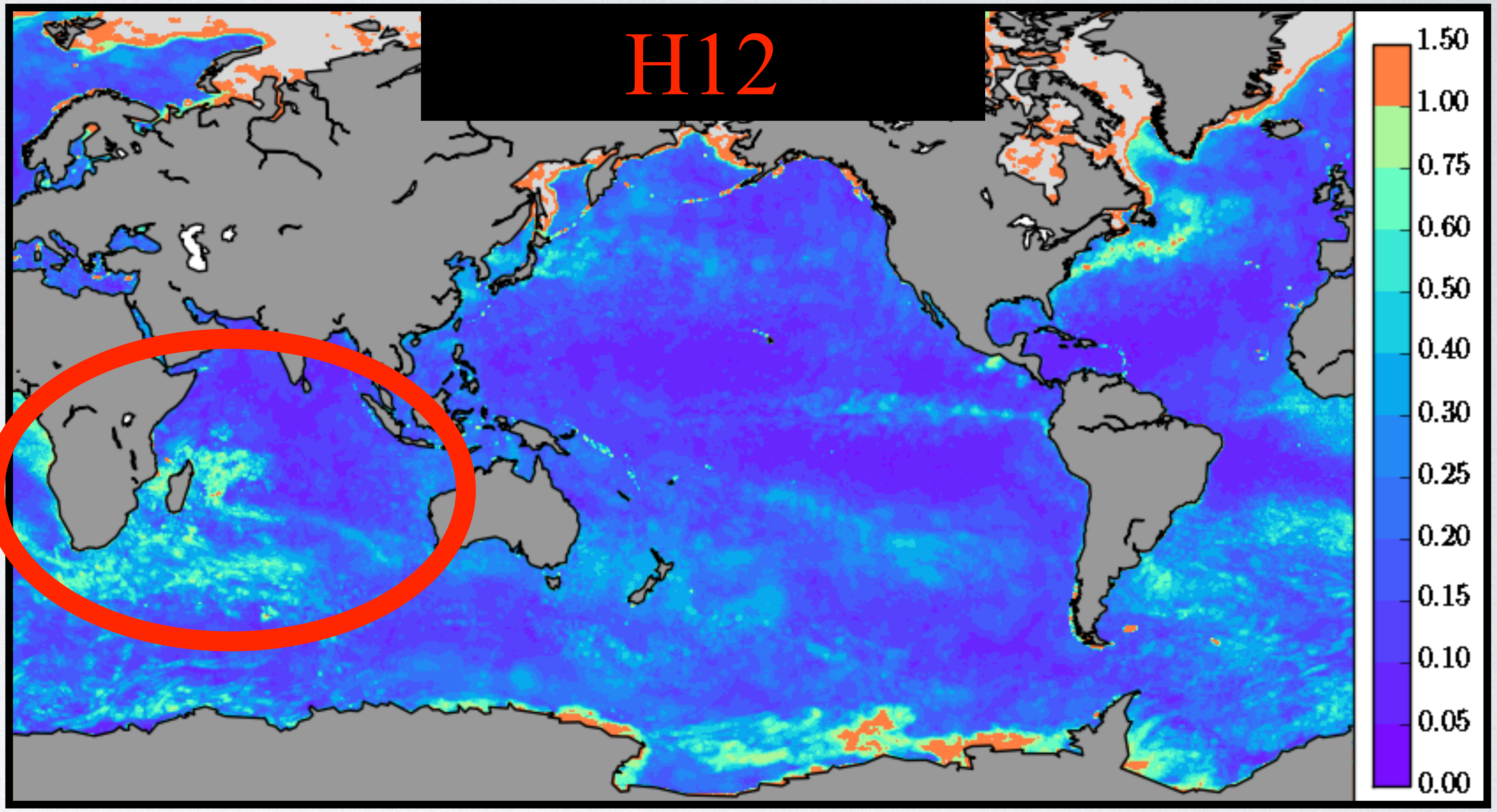
- Ensembles won’t fix this issue!
- An ensemble of analyzed ocean states (ocean model and analysis)
  - if **well** constructed and affordable (eddy-resolving)
  - could solve the problem!
- Climatological B is **needed**
  - NMC Method?
  - or, some other way…?

HYBRID ANALYSIS FOR T_s

NMC Method

01/2018 (mon mean)





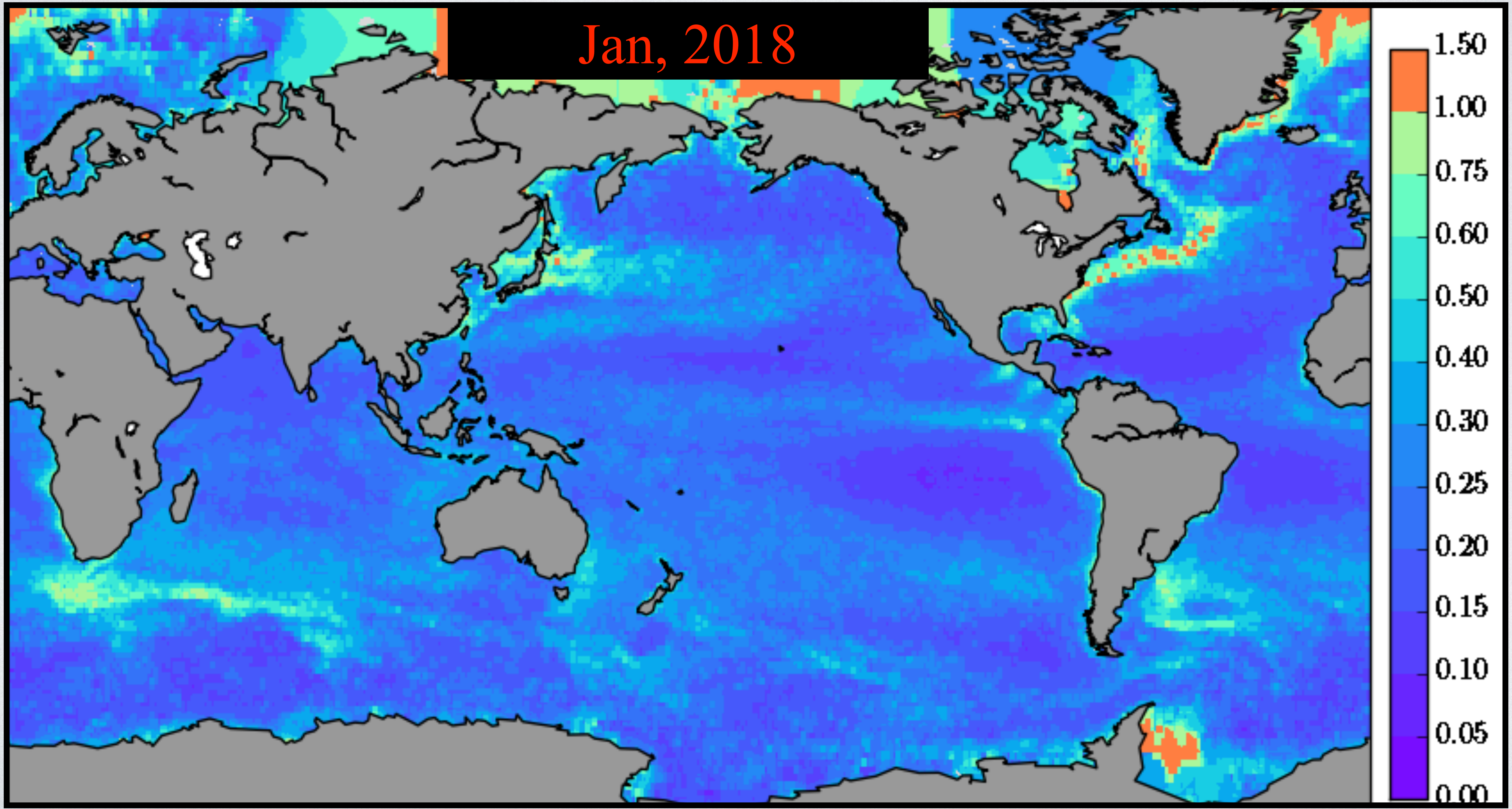
- High-variability (strong currents) is captured
- Diurnal variability is represented

48-hour forecasts
not available for 06, 18 UTC

HYBRID ANALYSIS FOR T_s

OSTIA SST OI error

01/2018 (mon mean)



Summary

- Coupled Data Assimilation
  - many challenges
  - and many possibilities (strong/weak; iterations, cross-correlations, …)
- Interface states (skin SST, Salinity, sea ice)
  - retrievals (of SST, Salinity, …) do not fully represent coupled processes
  - need internal self-consistency
  - must be part of coupled analysis
- Updates to the GEOS DAS
  - includes analysis for skin SST along with upper-air
  - the skin SST background error

Questions, Feedback, Suggestions
Thank You!