# Skin SST assimilation using GEOS Atmospheric Data Assimilation System


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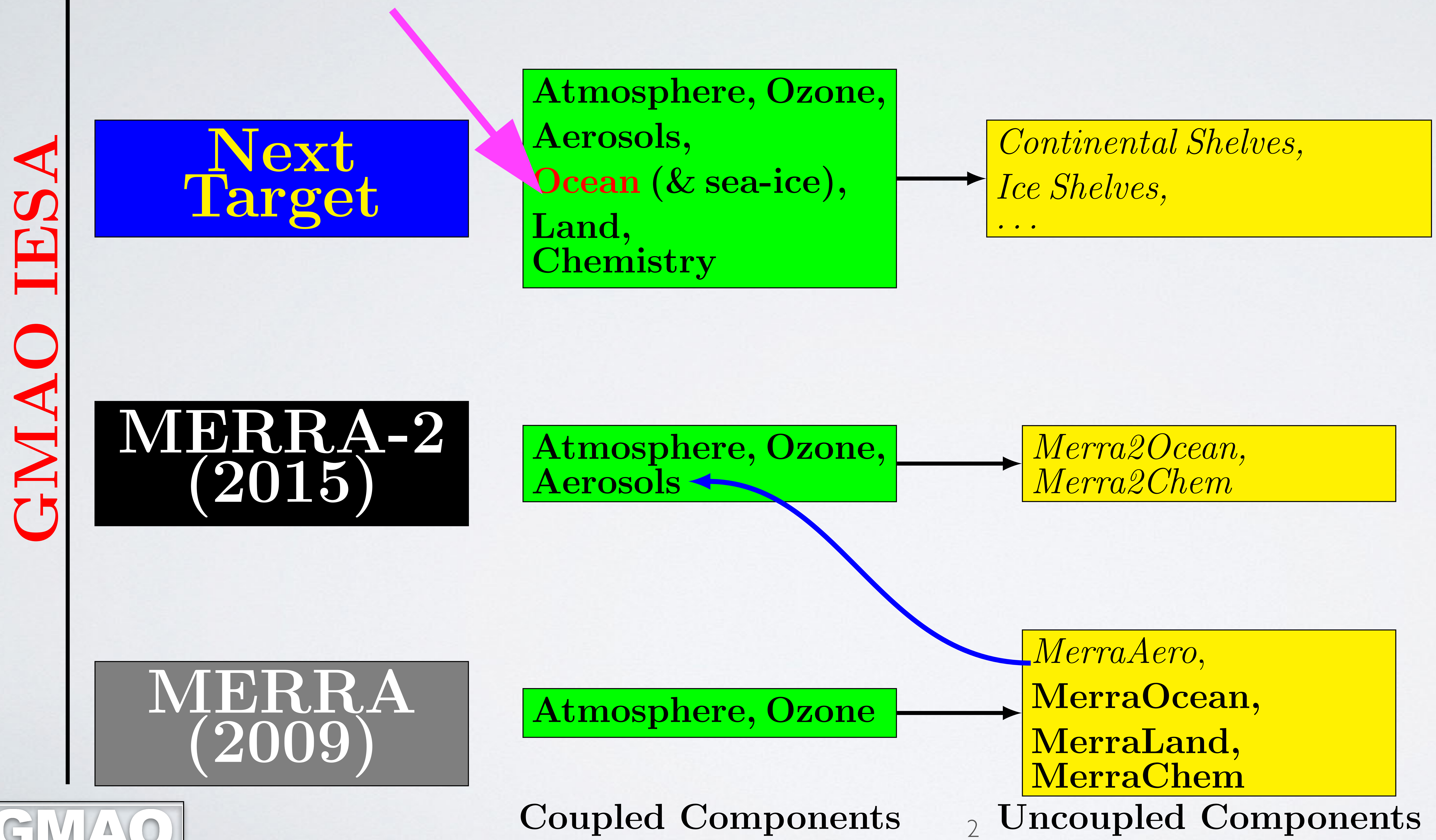
# GMAO Coupled Data Assimilation Plan: Integrated Earth System Analysis (IESA)




**Coupling**: Cross-component observational feedback in analysis/ forecast

# ATMOSPHERE-OCEAN CDA

★ Background fields— AOGCM

★ Weakly coupled analysis: separate atmosphere & ocean analyses (for e.g., separate B & H operators)

★ Strongly coupled analysis: single analysis, with B & H that are horizontally and vertically, fully-correlated

➡ an ob at ocean bottom *can* produce an increment in stratosphere!

**Why opt for weak coupling?**

- Latency of ocean obs
- Slower time-scale of (deep) ocean
- Direct assimilation of satellite radiance observations *requires* surface-ocean; *not so much* the deep ocean

# GMAO Weakly Coupled AO-CDA (*Plan*)

| Coupling | AGCM | A-ANA | OGCM | O-ANA |
|---|---|---|---|---|
| None | *Prescribed* ocean-surface | **No** analysis for skin SST | **No** diurnal cycle | • Prescribed atmosphere<br>• **Exclude** *diurnal* obs |
| Semi- | Prognostic ocean-surface | Analysis for skin SST | as above | as above |
| Weak | Prognostic ocean-surface *above* analyzed ocean | as above | • Resolve diurnal cycle<br>• Include run-off | • Analyzed atmosphere<br>• Include *diurnal* obs |

# **BACKGROUND**: SST VARIABILITY (THERMAL STRATIFICATION)

## Near-surface Temperature

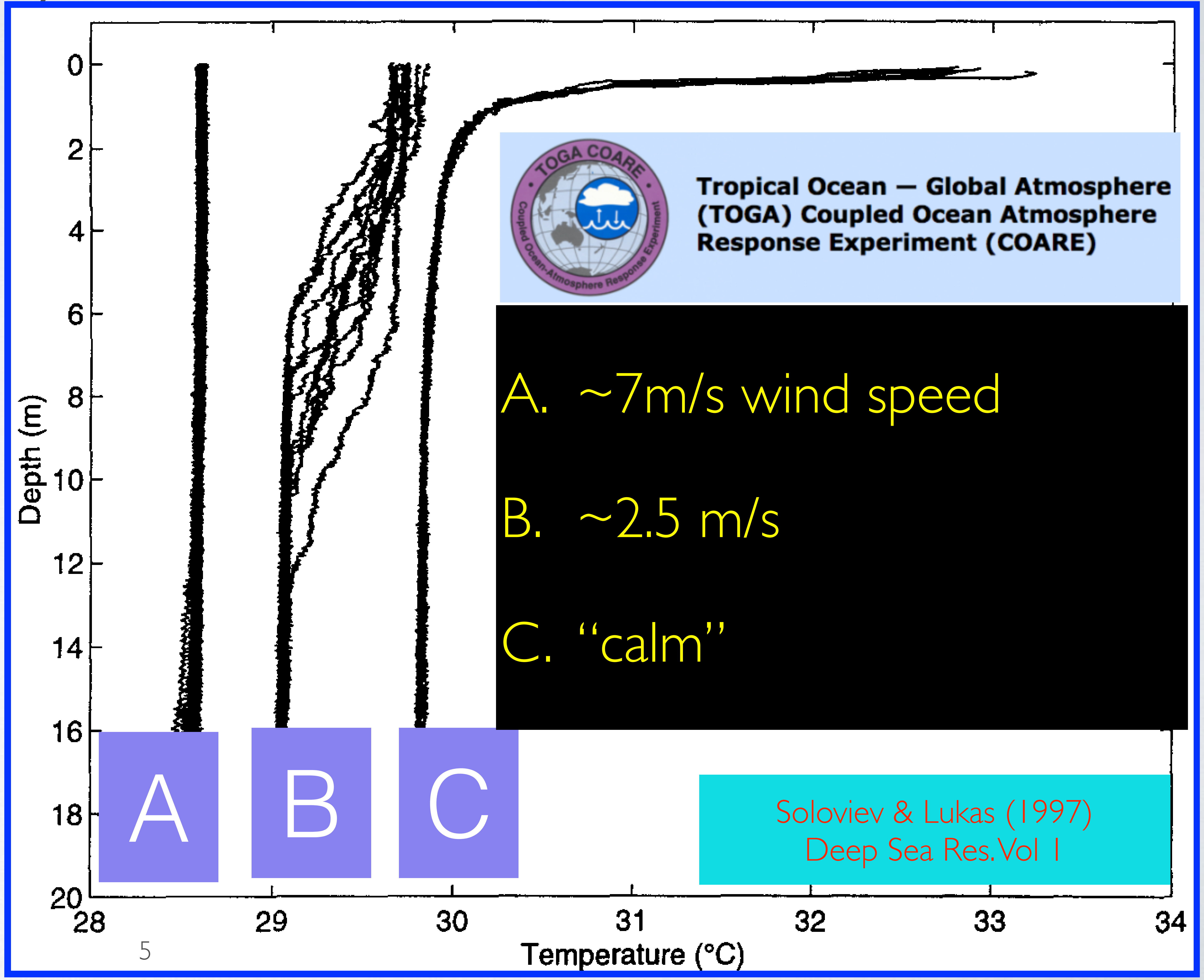
is actually T(z); T(z~0) ≈ **Skin SST**

- changes with z
- depends on the atmospheric conditions

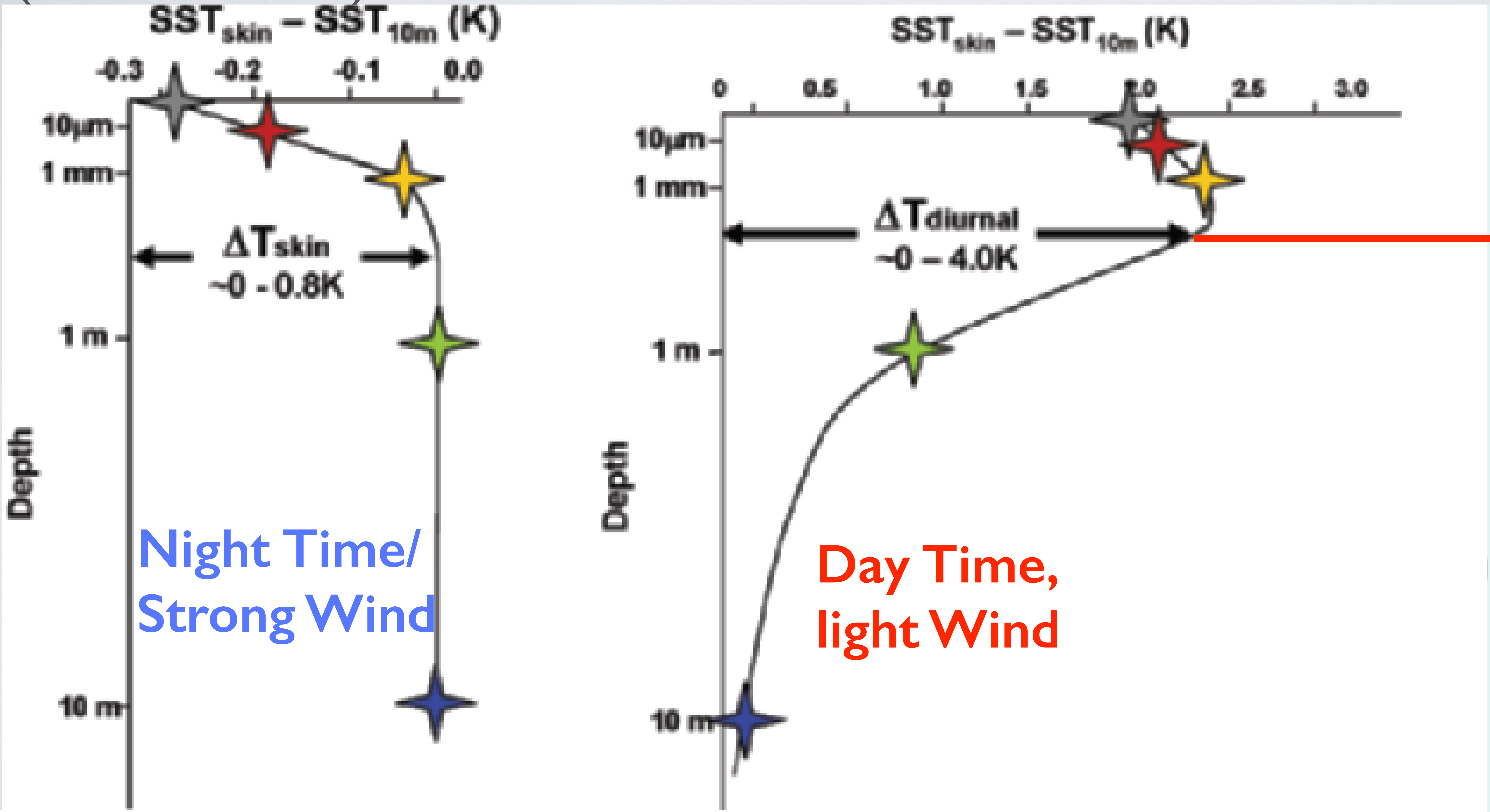
★ **Infrared** $Z_{ob}$ ~0

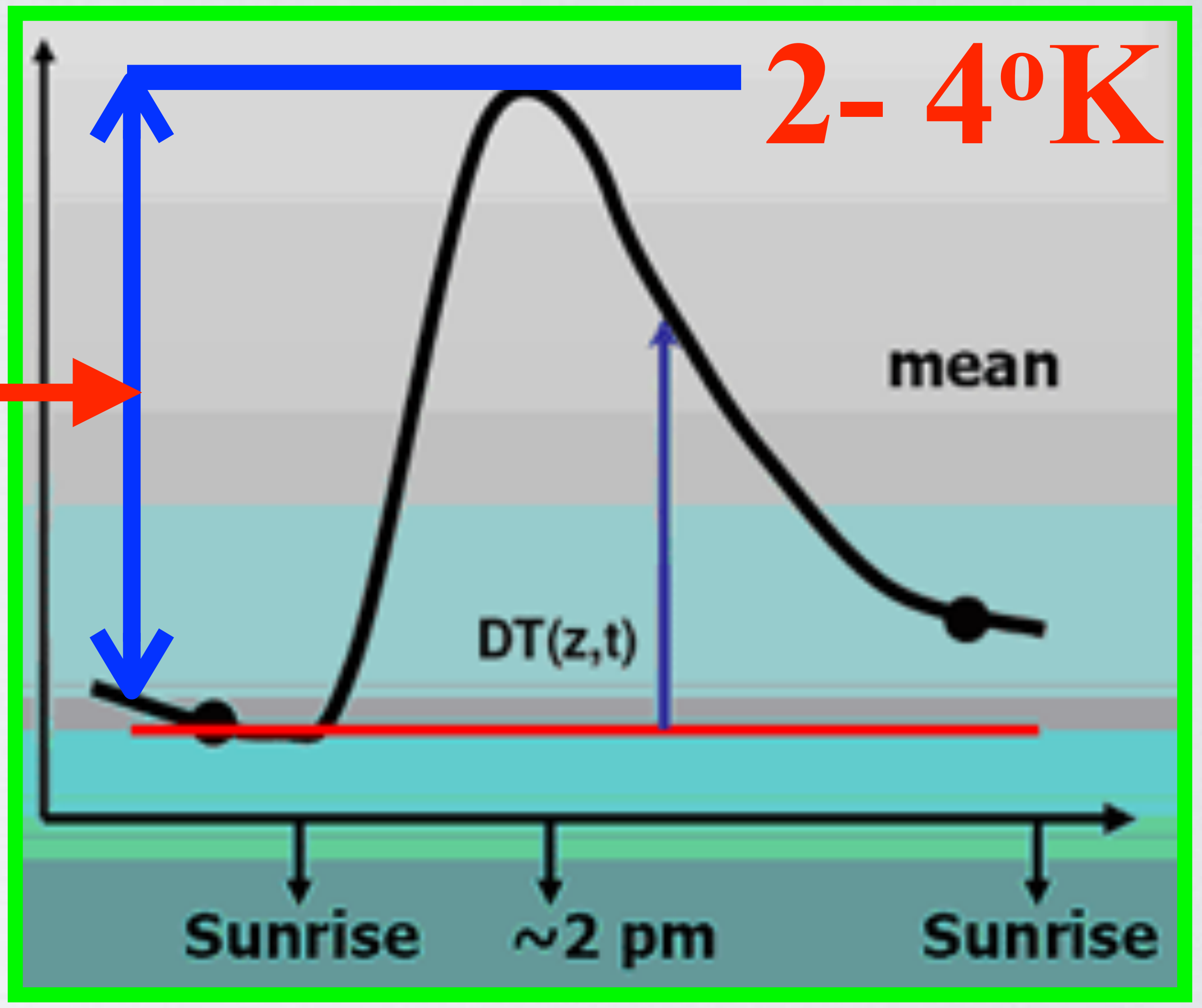
★ **Microwave** $Z_{ob}$ ~O(mm)

★ **in situ** $Z_{ob}$ ~O(cm)- O(m)



# BACKGROUND: SST VARIABILITY (DIURNAL)




**Diurnal Warming aliases on SST -Climate Implication**

# SKIN SST ($T_S$) IN GEOS ADAS

**Current Status**

- ★ $T_s$ set based on $SST_{fnd}$ (OSTIA SST)
- ★ Net Heat Flux at surface: diagnostic

| Development | Sub-system | Implements | Provides | Relevance |
|---|---|---|---|---|
| Prognostic Model for Ts | AGCM | $Ts = SST_{fnd}$ + Diurnal Warming - Cool Skin | Diurnal variability & thermal stratification | Similar to the ECMWF- IFS |
| Ts Analysis | Atmos Analysis | Analysis of IR radiances (AVHRR addition) | Fit to observations | Shared with NCEP, using CRTM |
| Ts Analysis Increment | AGCM | Analysis Feedback | Coupling of near-surface ocean temperature to atmosphere | **Direct* Radiance Assimilation for SST |

# $T_S$ MODEL

$$T(z) = \underbrace{SST_{fnd}}_{\text{OSTIA SST}} + \boxed{\Delta T_w(z)} - \boxed{\Delta T_c(z)}$$

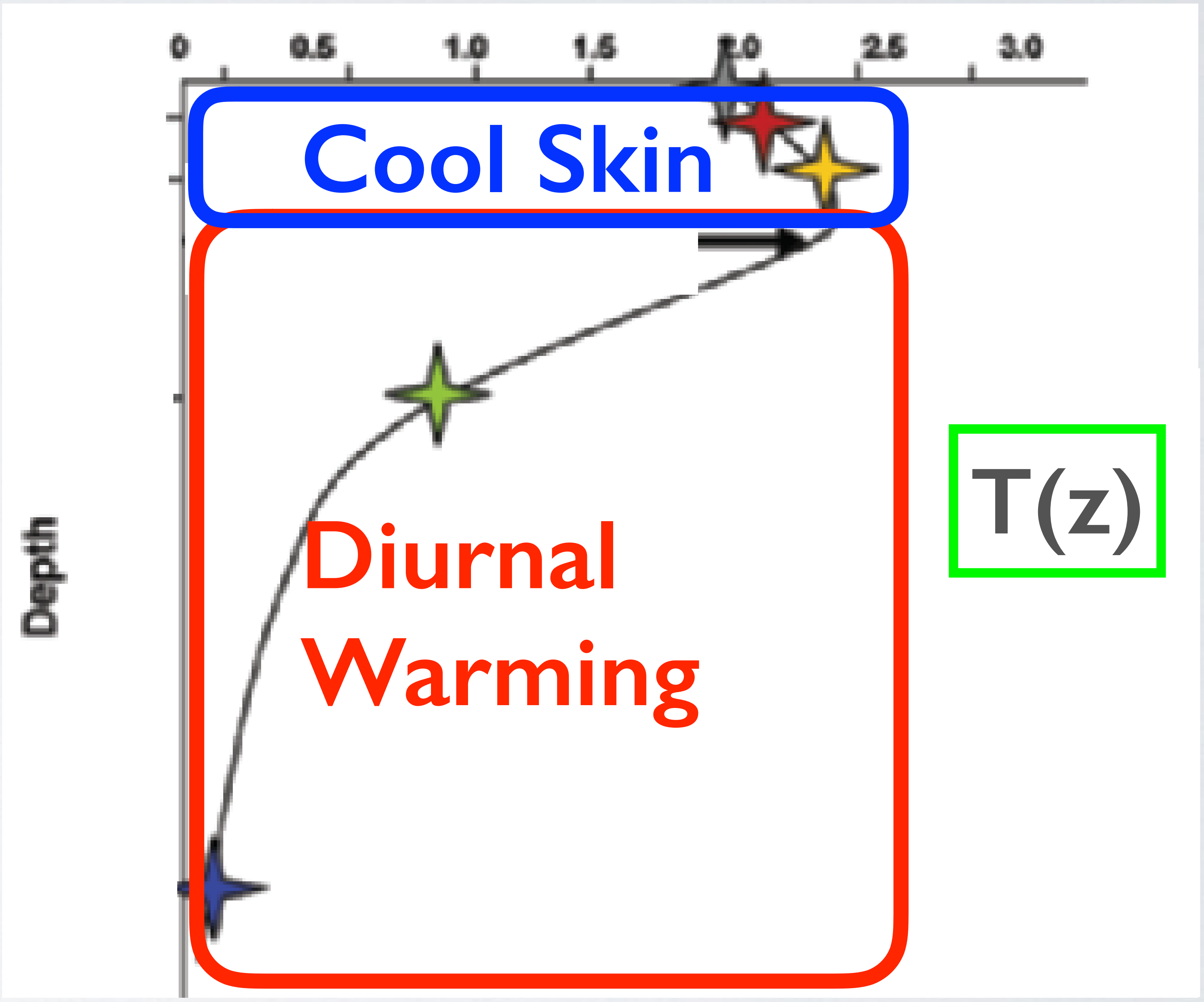
$$Skin\,SST \approx T(z=0)$$

$$\Delta T_w(z) = \boxed{\Delta T_w^{max}}[1 - (\frac{z-\delta}{d-\delta})^{\mu_s}]$$

Prognostic model

$$\Delta T_c(z) = \boxed{\Delta T_c^{max}}[1 - (\frac{z}{\delta})]$$

Diagnostic



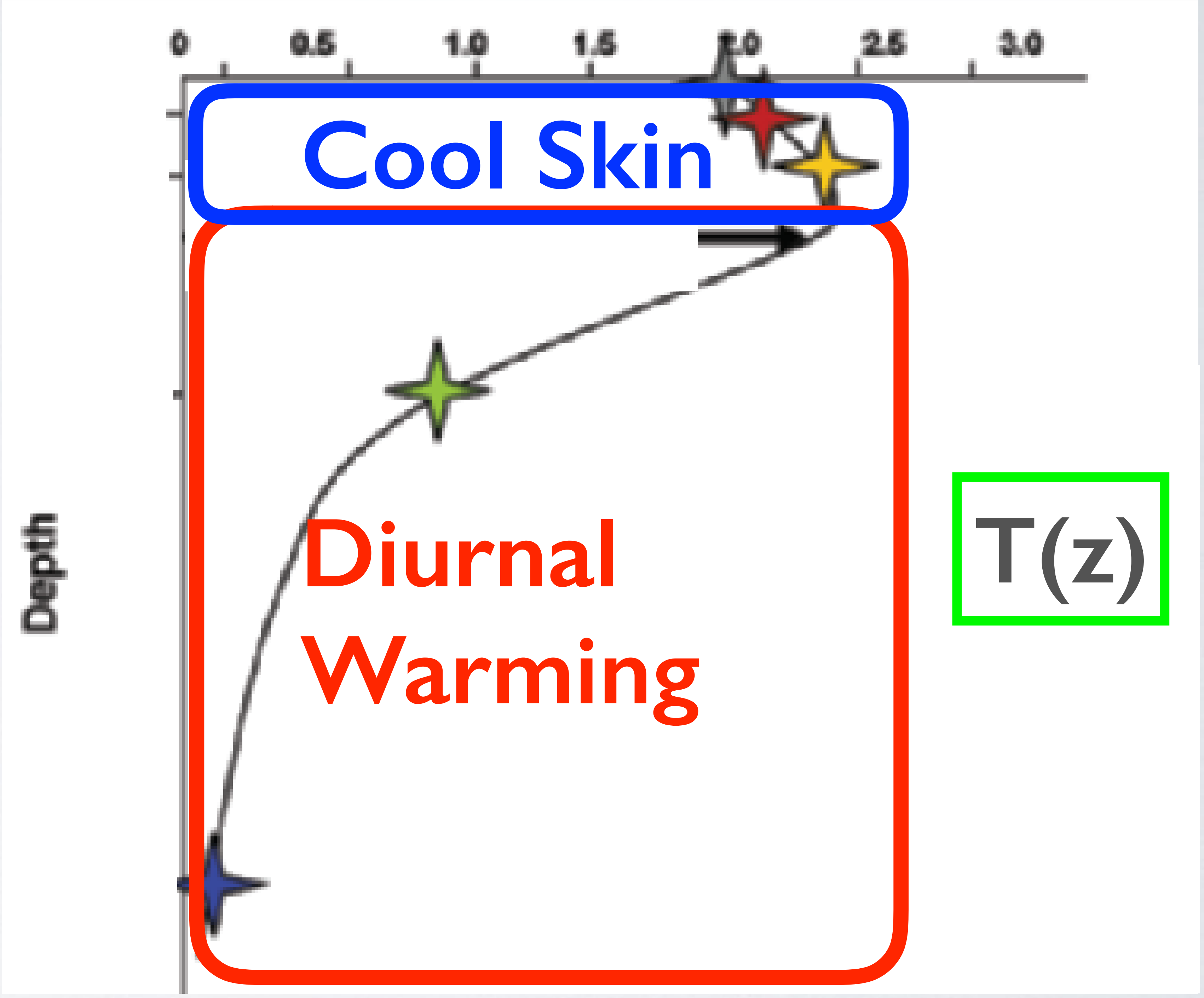

- Diurnal warming: $\delta \leq z \leq d$
- Cool skin layer: $0 \leq z \leq \delta$

# $T_S$ MODEL (DETAILS)

$$\frac{\partial \Delta T_w}{\partial t} = a\left(\mu_s, d, Q^{\downarrow}_{surf}\right) - b\left(\mu_s, d, U_{surf}, Q^{\downarrow}_{surf}\right)\Delta T_w$$

$$\Delta T_c = f(U_{surf})\ g(Q^{\downarrow}_{surf})$$

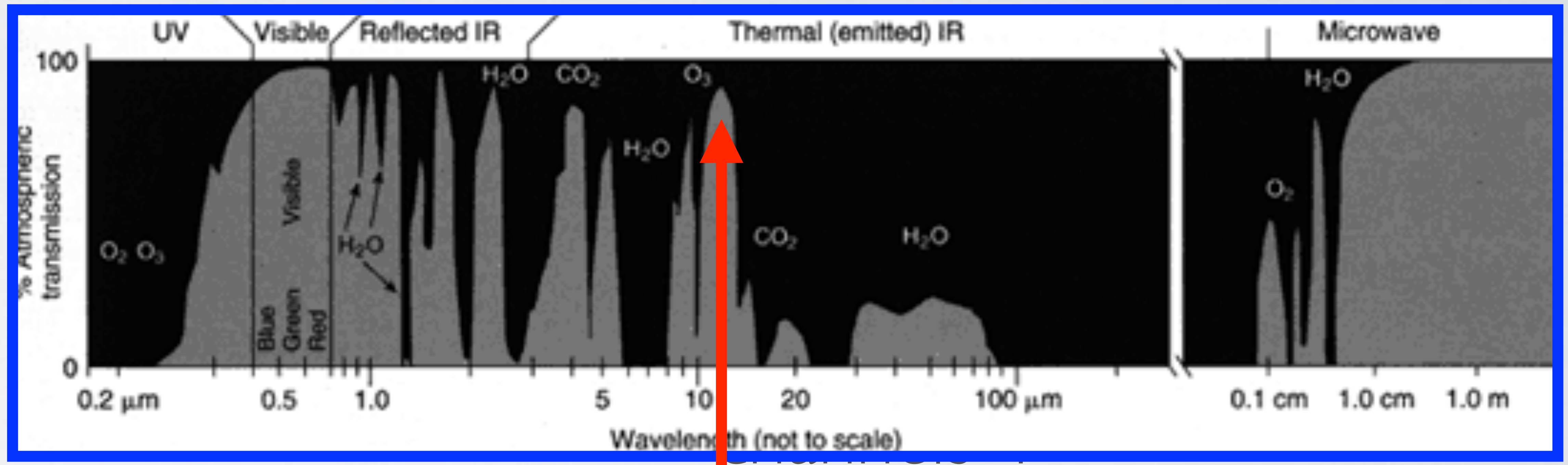
$$\boxed{\begin{aligned}\Delta T_w(z) &= \boxed{\Delta T_w^{max}}[1-(\frac{z-\delta}{d-\delta})^{\mu_s}] \\ \Delta T_c(z) &= \boxed{\Delta T_c^{max}}[1-(\frac{z}{\delta})]\end{aligned}}$$




- Diurnal warming: $\delta \leq z \leq d$
- Cool skin layer: $0 \leq z \leq \delta$

# $T_S$ ANALYSIS

1. Temperature profile: T(z) is used by the analysis to compute fit to the observations
2. Brightness temperature ($T_b$) and Jacobian ($dT_b/dT_z$) are computed using CRTM with $Z_{ob}$ :
   A. $Z_{IR}$ = 15 microns — *approximate*: $dT_z/dT_s = 1$
   B. $Z_{MW}$ = 1 mm
3. *Added* AVHRR (infrared) observations (N-18, MetOp-A)




http://earthobservatory.nasa.gov/Features/RemoteSensing/remote_04.php

➡ Items 1 & 2 impact analysis of *all* satellite radiance observations

➡ **Observations**:

- **AVHRR** is in **addition** to the existing set
- **In situ** SST (from buoys) are currently **withheld** - used for validation

➡ Ts is analyzed with the entire (upper-air) atmospheric analysis

# $T_S$ INCREMENT

AGCM has been enabled to apply the increment in

$T_s = \ (T_s^{ana} - T_s^{bkg})/(6\, hours)$

at every time step

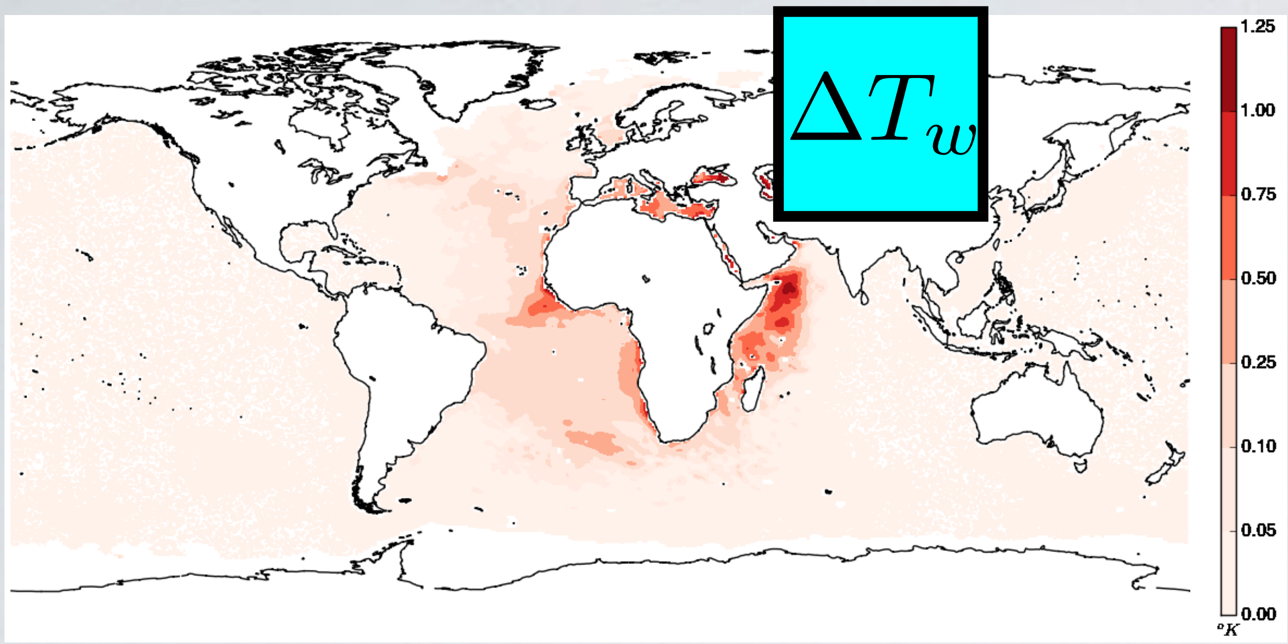
- handled like all other analysis increments
- it is applied to Ts in the air-sea interface layer

# RESULTS:

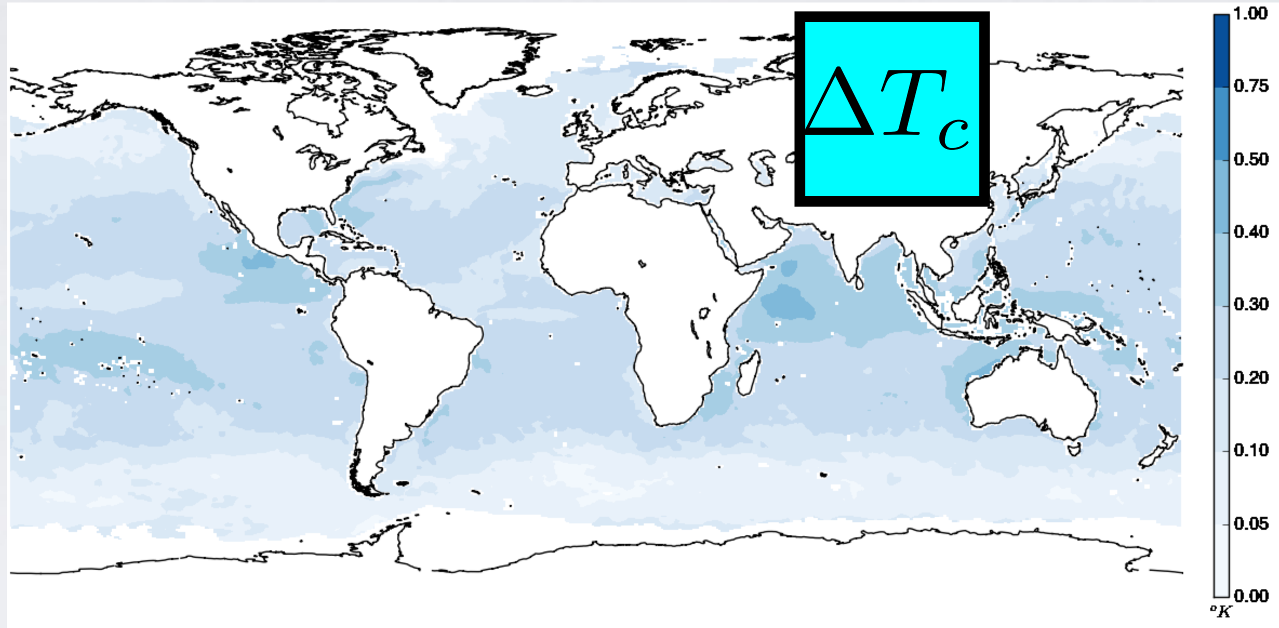
## from data assimilation cycled experiments

# DIURNAL WARMING & COOL-SKIN

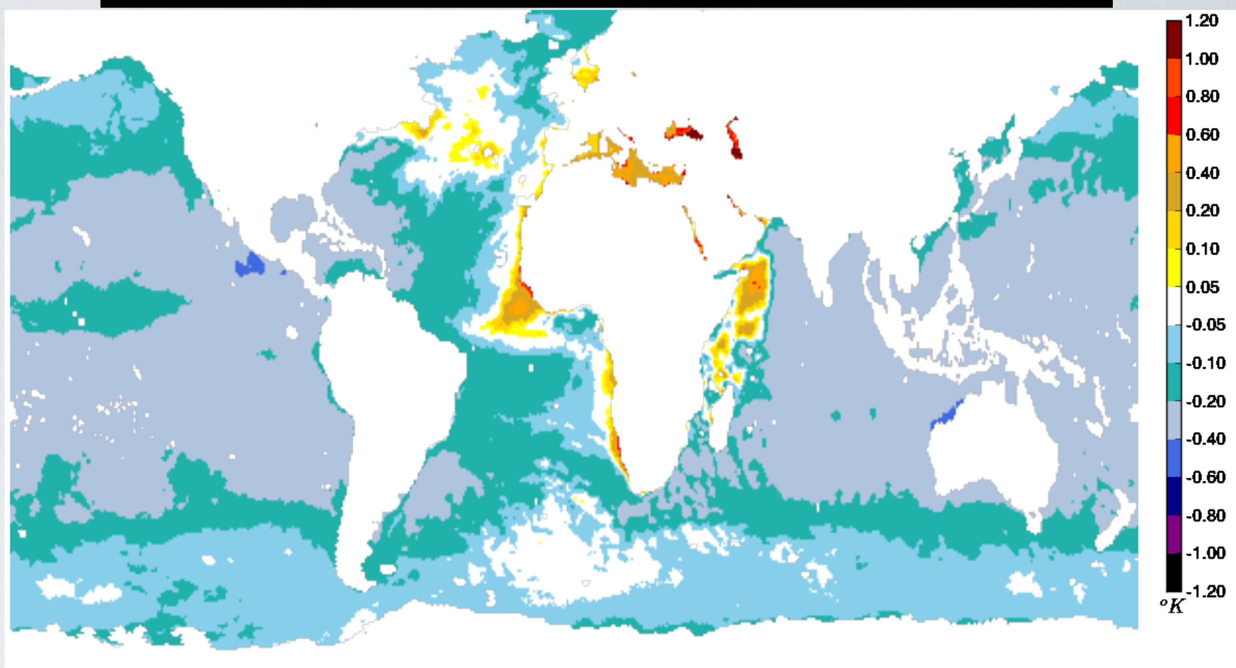
$$Skin\,SST = OSTIA\,SST + \Delta T_w - \Delta T_c$$



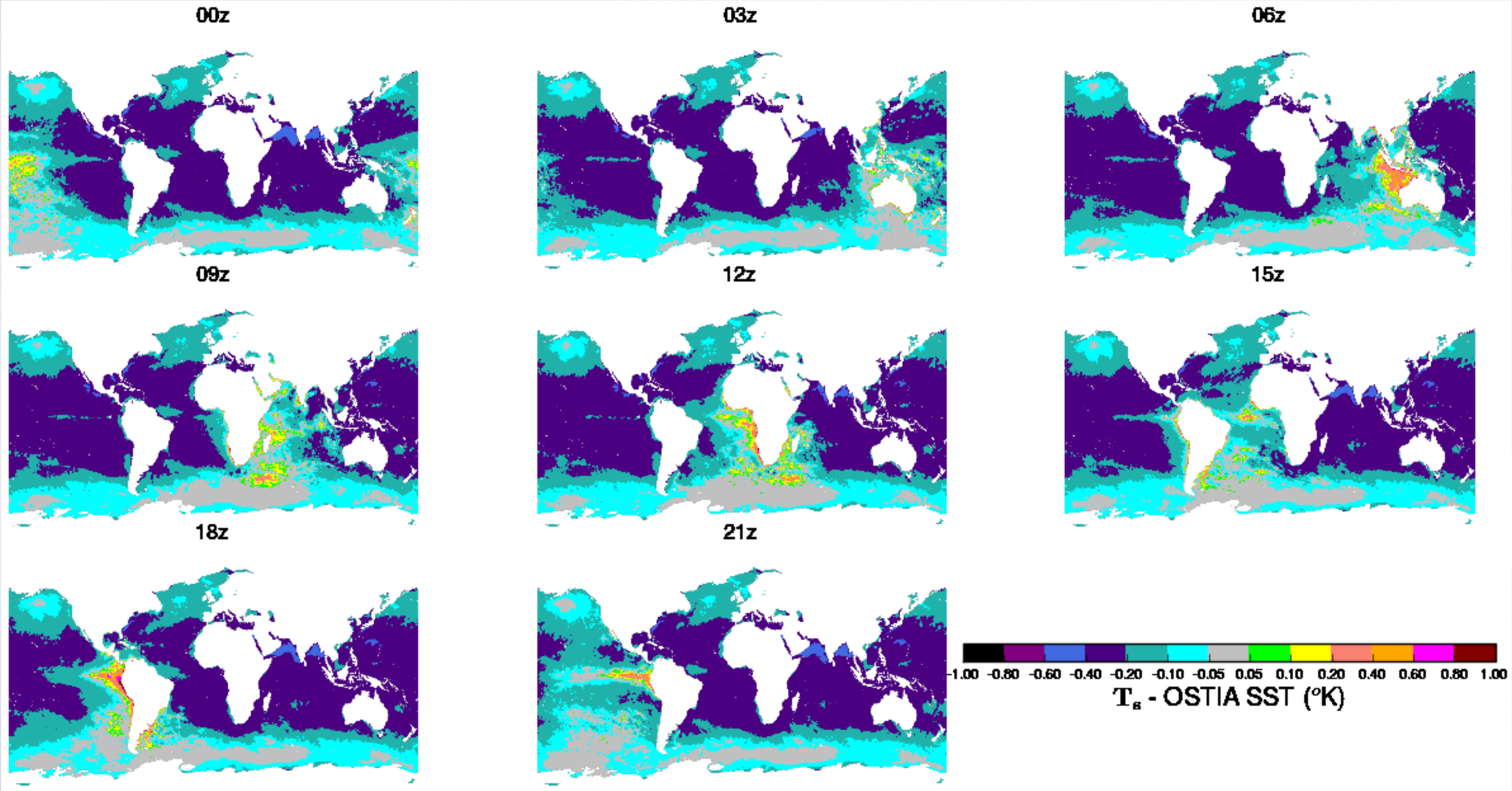

+




$Skin\,SST - OSTIA\,SST$



Apr, 2012
monthly mean




Feb, 2015
monthly mean

Skin - OSTIA SST (ºK)

# Basin Averaged Diurnal Variability

# Basin Averaged Diurnal Variability- TROPICS

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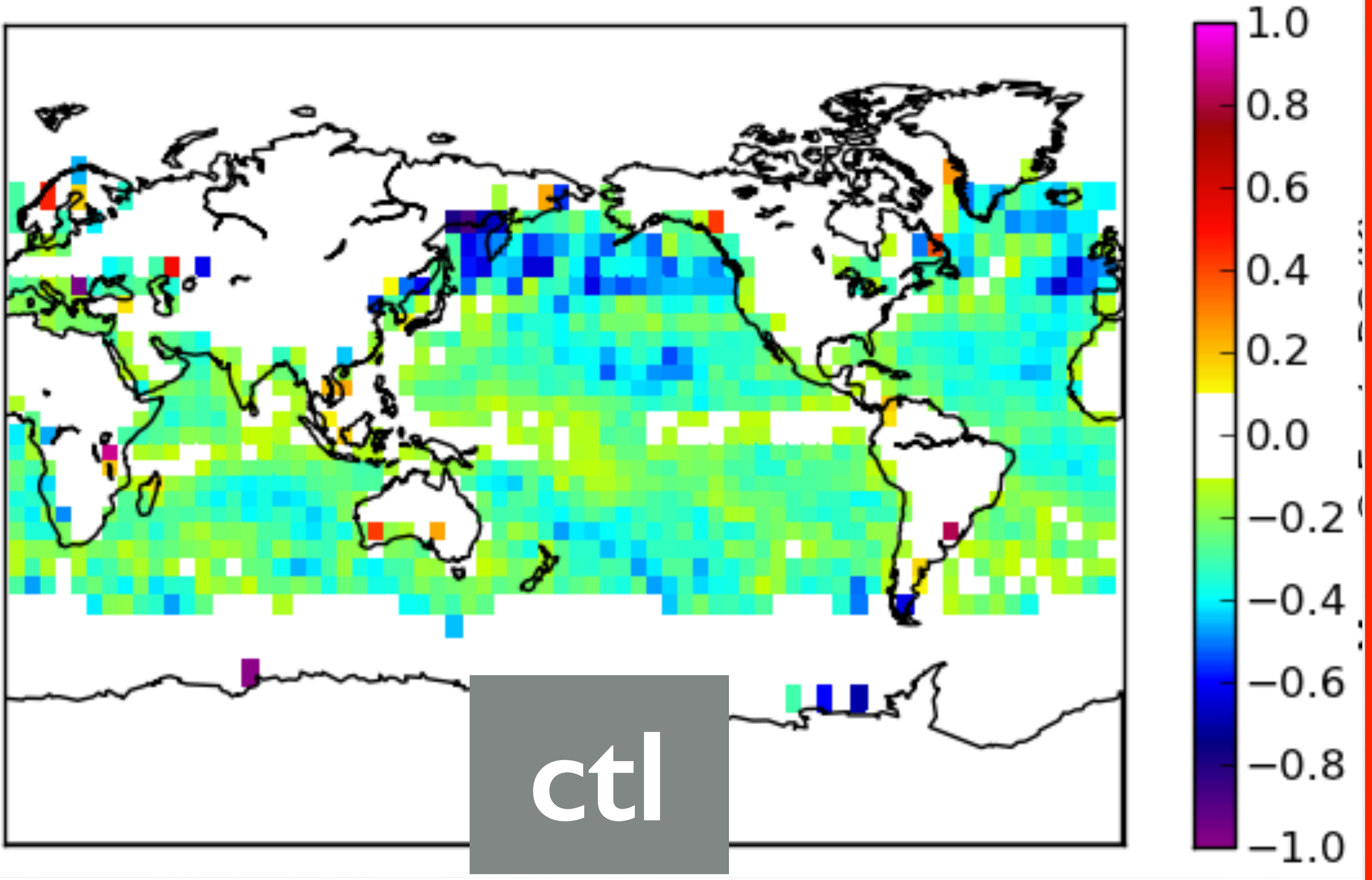
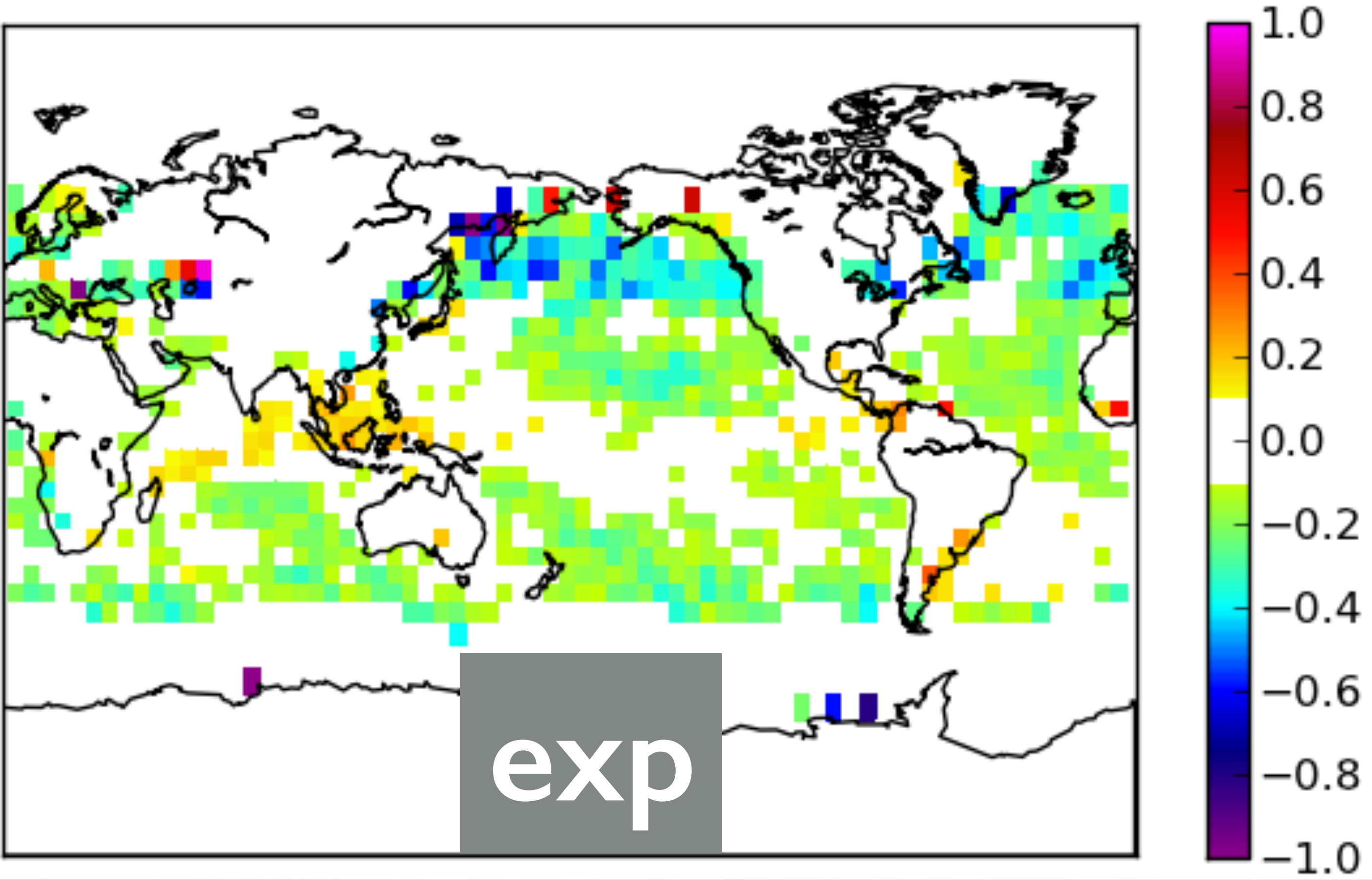
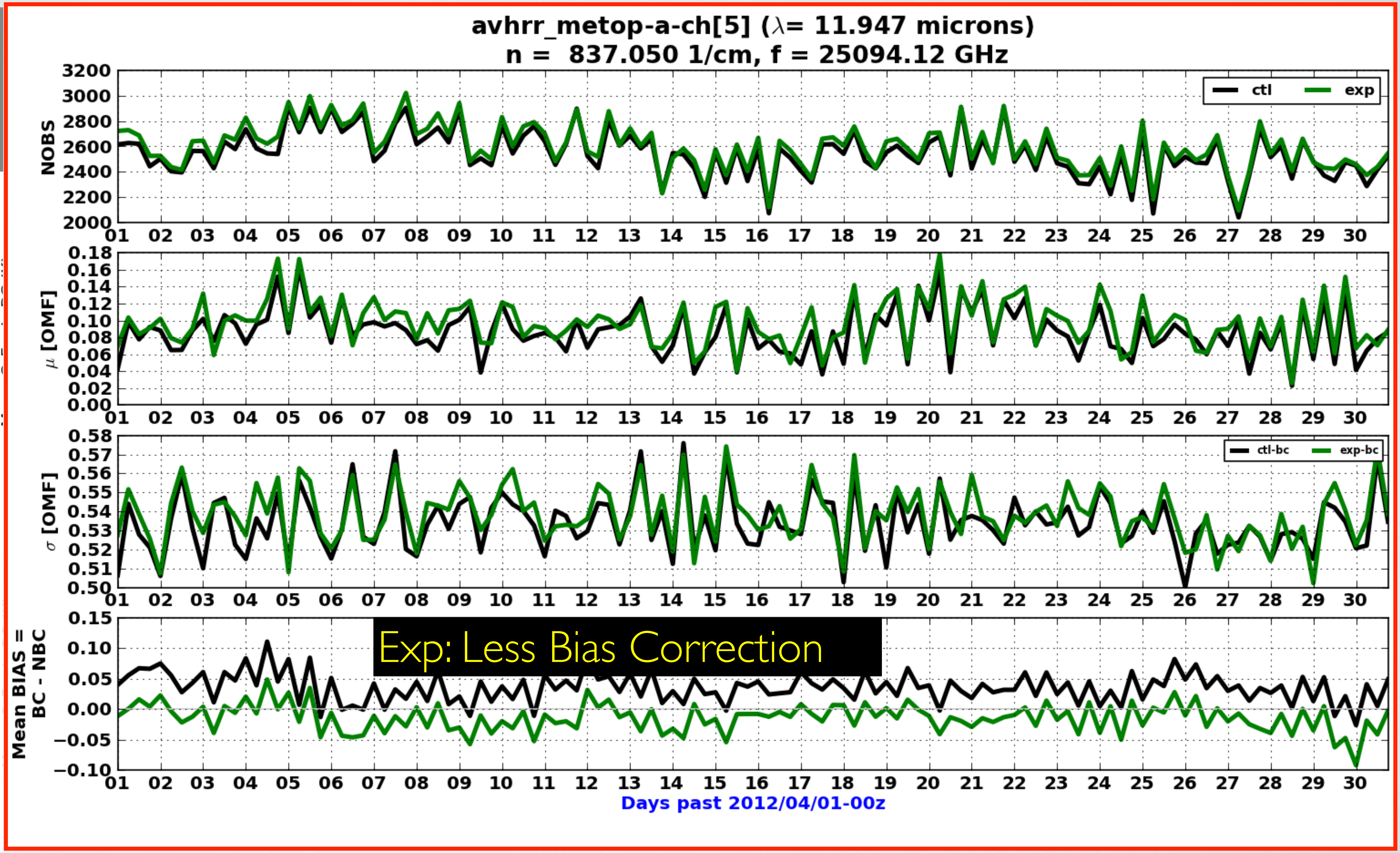
# NEAR-SURFACE THERMAL STRATIFICATION

# Analysis of AVHRR Observations

Ch3 (night time) MetOp-A
Monthly Mean O-B
(before bias correction)

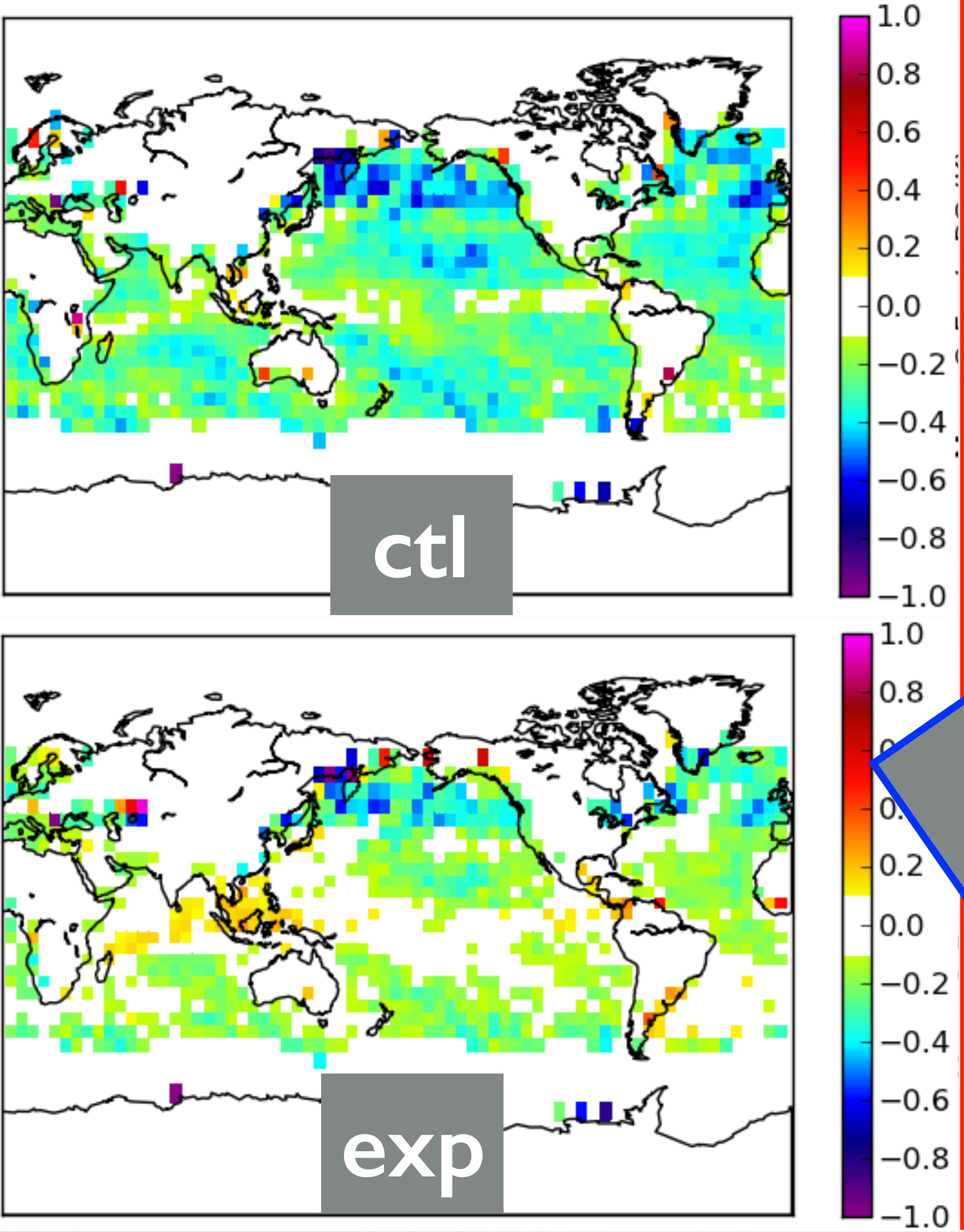


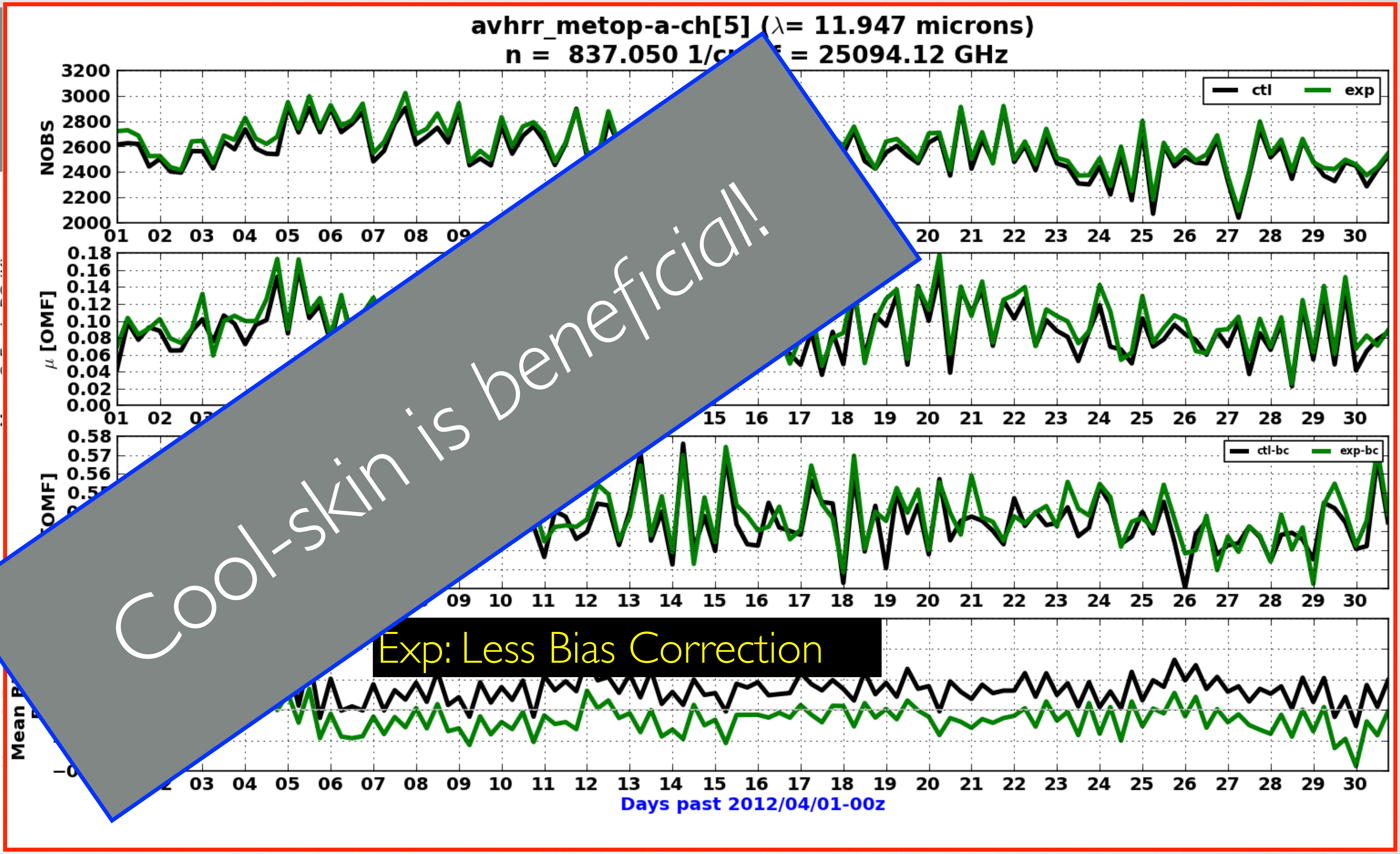



# ANALYSIS OF AVHRR OBSERVATIONS

Ch3 (night time) MetOp-A
Monthly Mean O-B
(before bias correction)



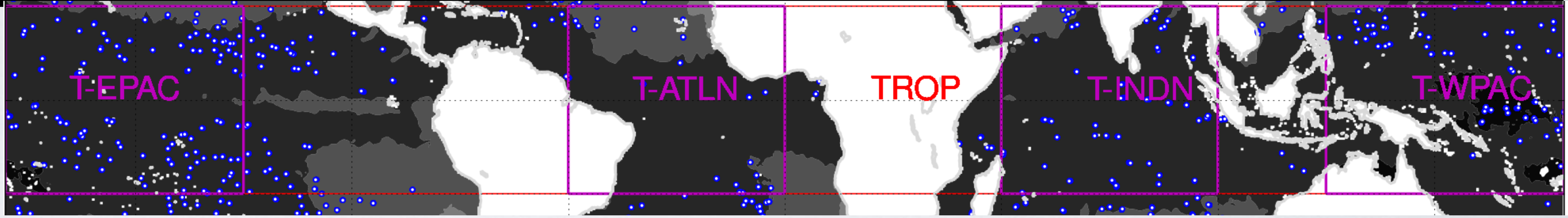

Cool-skin is beneficial!

Exp: Less Bias Correction

# Fit to In Situ Buoys (Withheld Data)

Monthly Mean Fit to
Drifting buoys
SST (Feb, 2015)

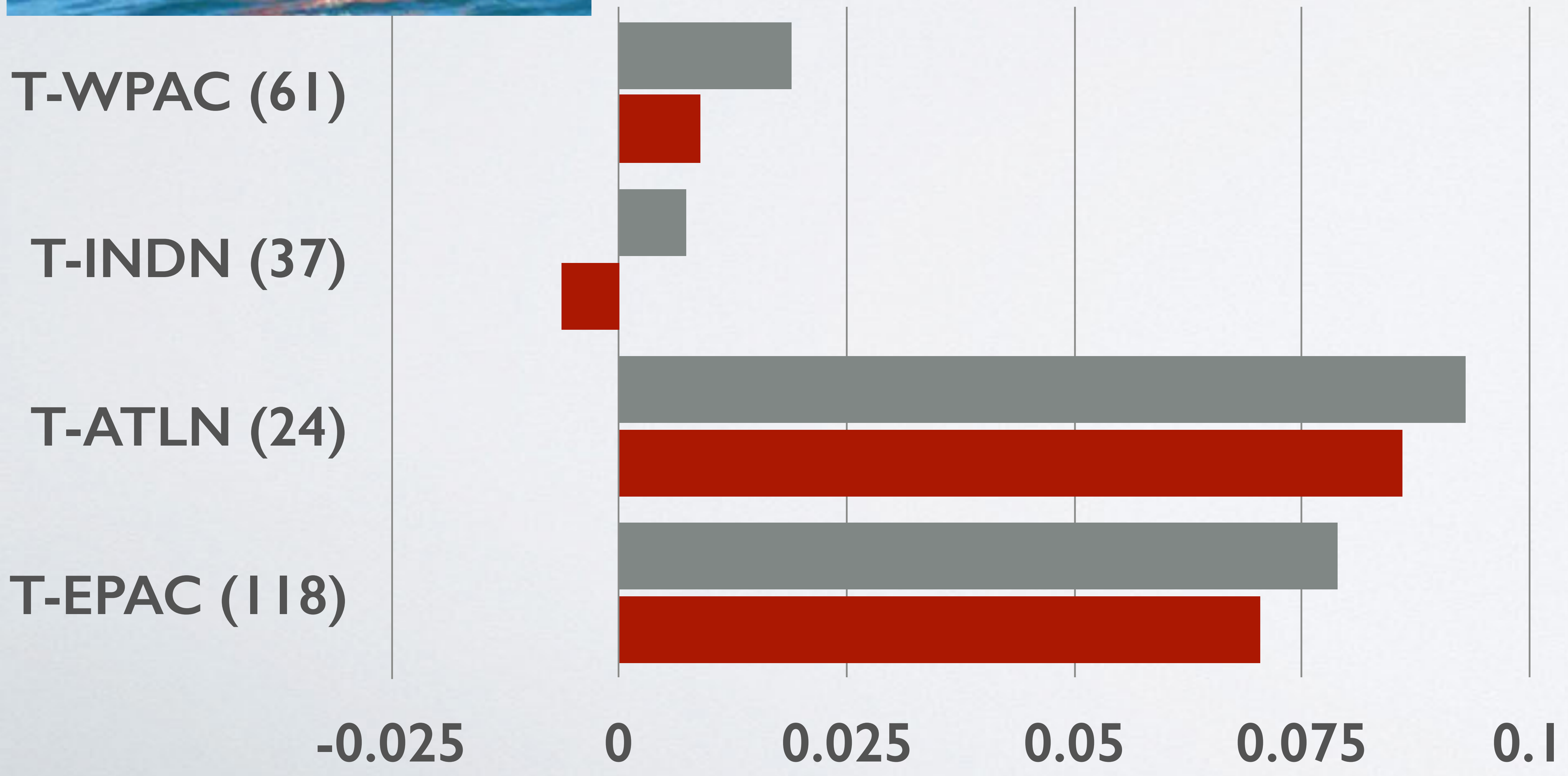
Hourly measurement of Temperature at $Z_{ob} \sim 0.2$ m



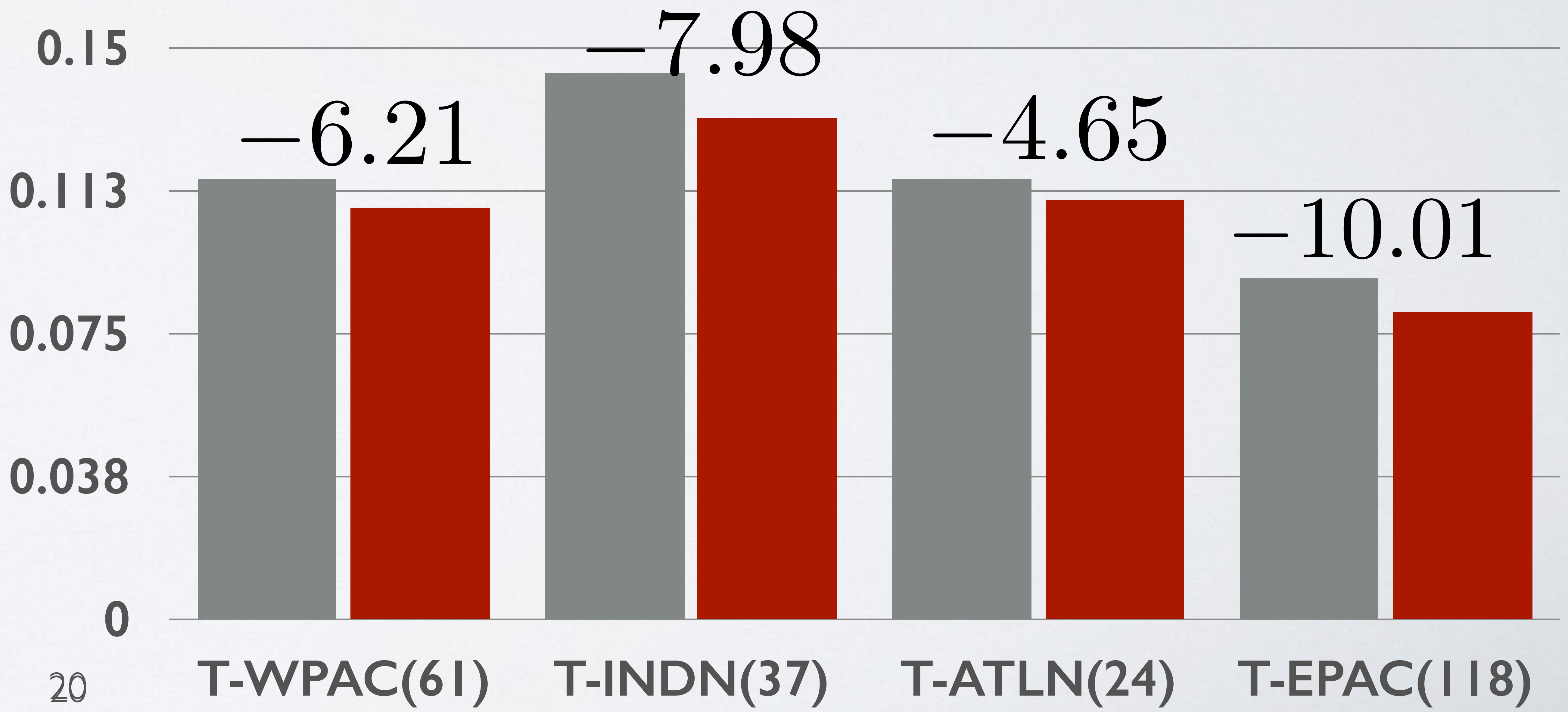

OBS-OSTIA SST
OBS - EXP T(z)

$$\frac{\sigma_{exp} - \sigma_{OSTIA}}{\sigma_{OSTIA}}(\%)$$

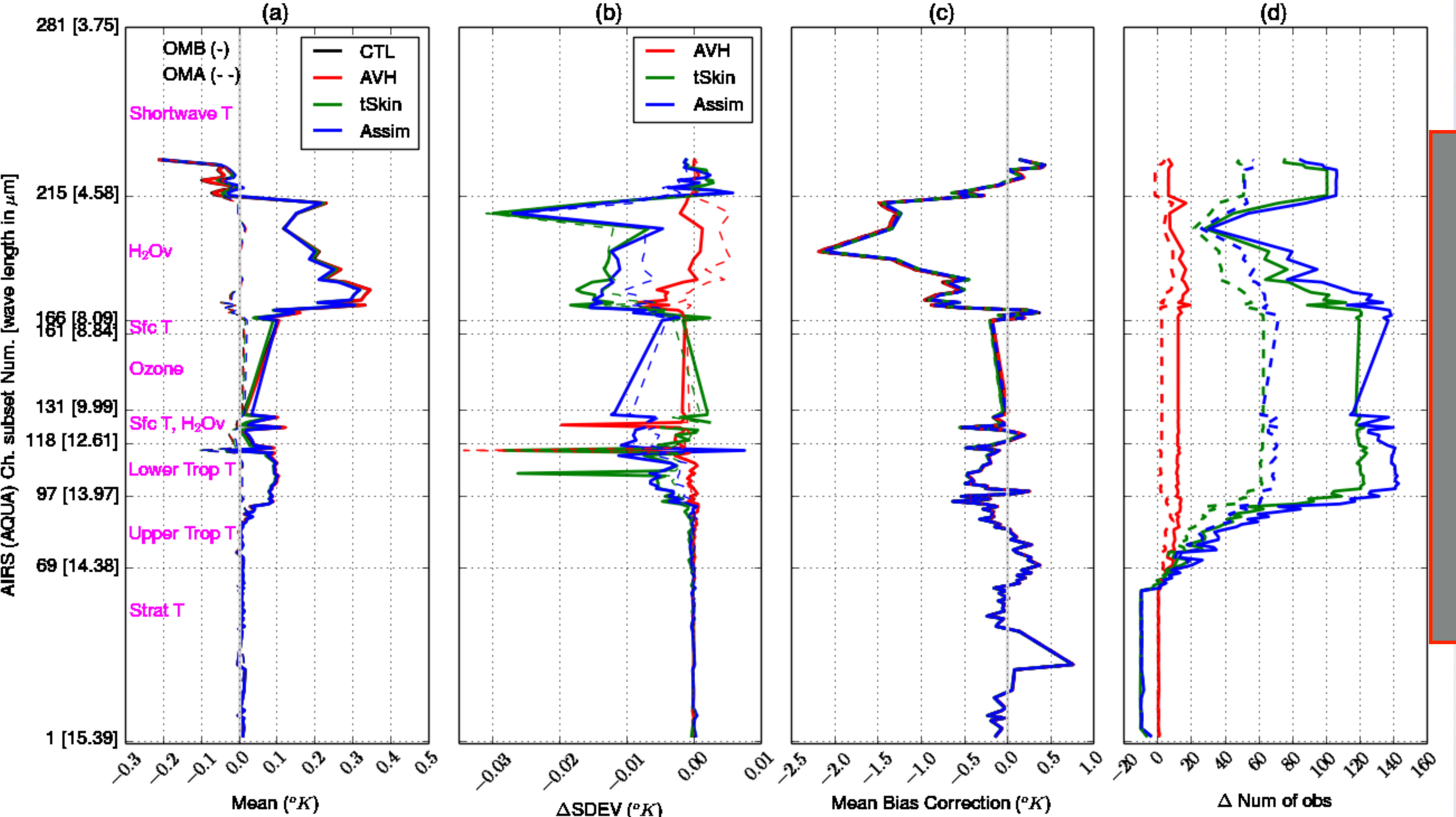
## Mean (K)




## Std Dev (K)



# Impact on IR (hyper-spectral) Obs




Similar *positive* benefit for IASI on MetOp-A

# SUMMARY- SKIN SST IN GEOS ADAS

- **Near-surface sea surface**:

☑ **thermally stratification** due to diurnal warming

☑ a thin **cool-skin layer**

Modeled

☑ **Infrared Observations** (AVHRR) measure Skin SST

Assimilated

**GEOS Atmospheric Data Assimilation System** provides:

- near-sea-surface temperature that is tightly coupled to the atmosphere
- better near-surface meteorology (improved O-B fit, forecast skill)

# CURRENT WORK (PLAN)

# GMAO Weakly Coupled AO-CDA (*Plan*)

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|---|---|---|---|---|
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| ✓ Semi- | Prognostic ocean-surface | Analysis for skin SST | as above | as above |
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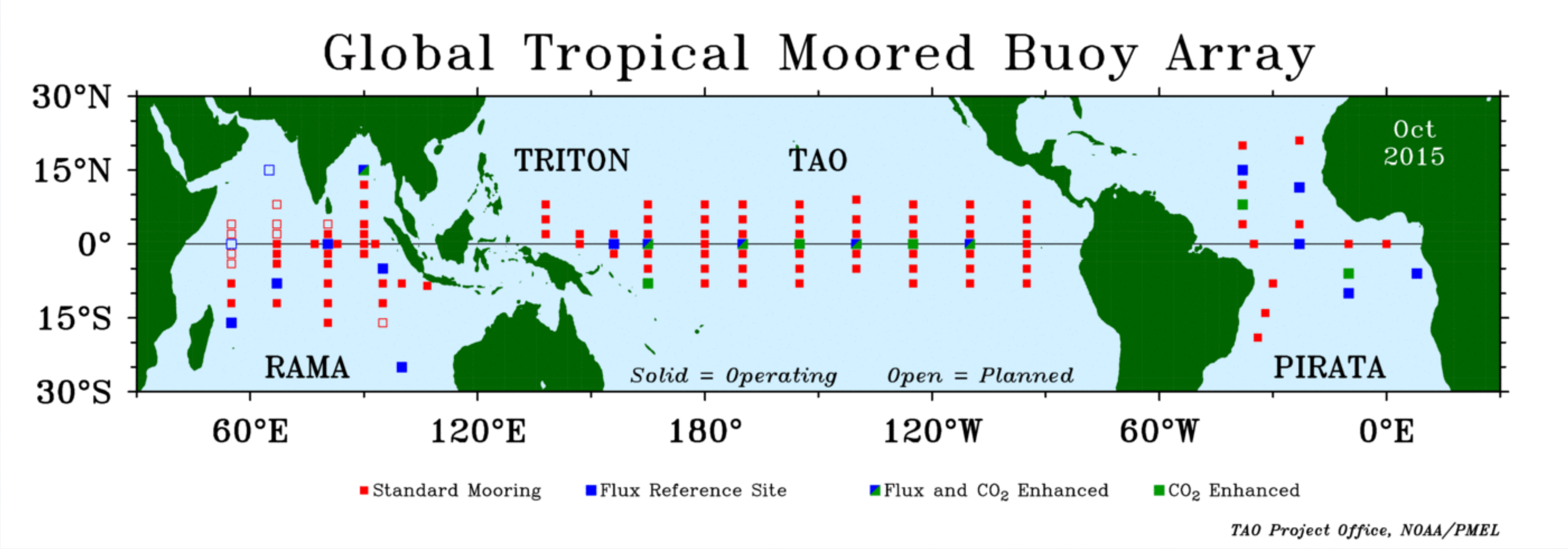
# COUPLED ASSIMILATION




## Weakly Couple Atmosphere & Ocean Data Assimilation Systems

- Using the coupled AOGCM

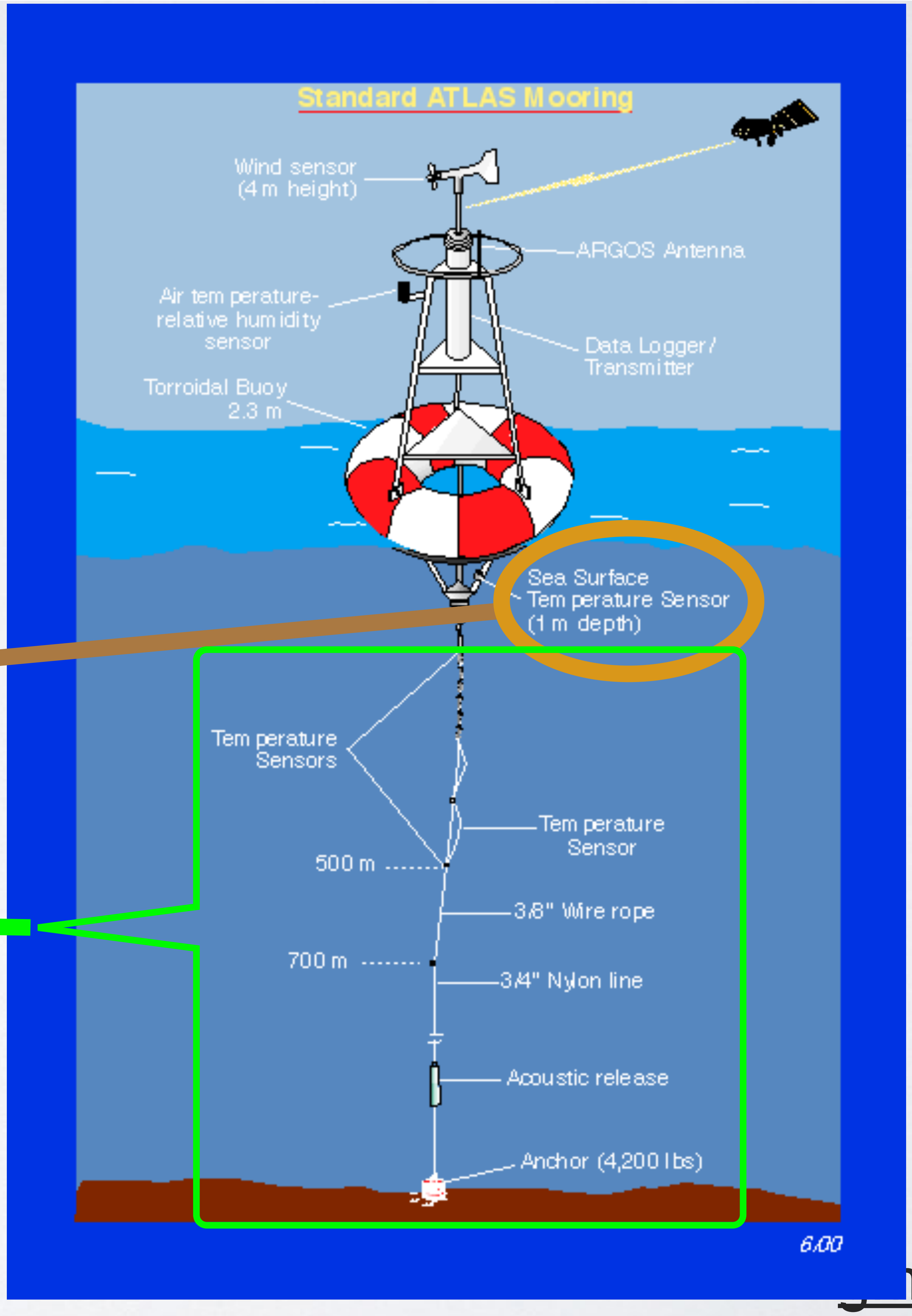
✓ T(z),$T_s$: **Atmospheric DAS**

✳ T(z), $SST_{fnd}$: **Ocean DAS**

Hourly

T(z=1 m)

T(z>2 m)



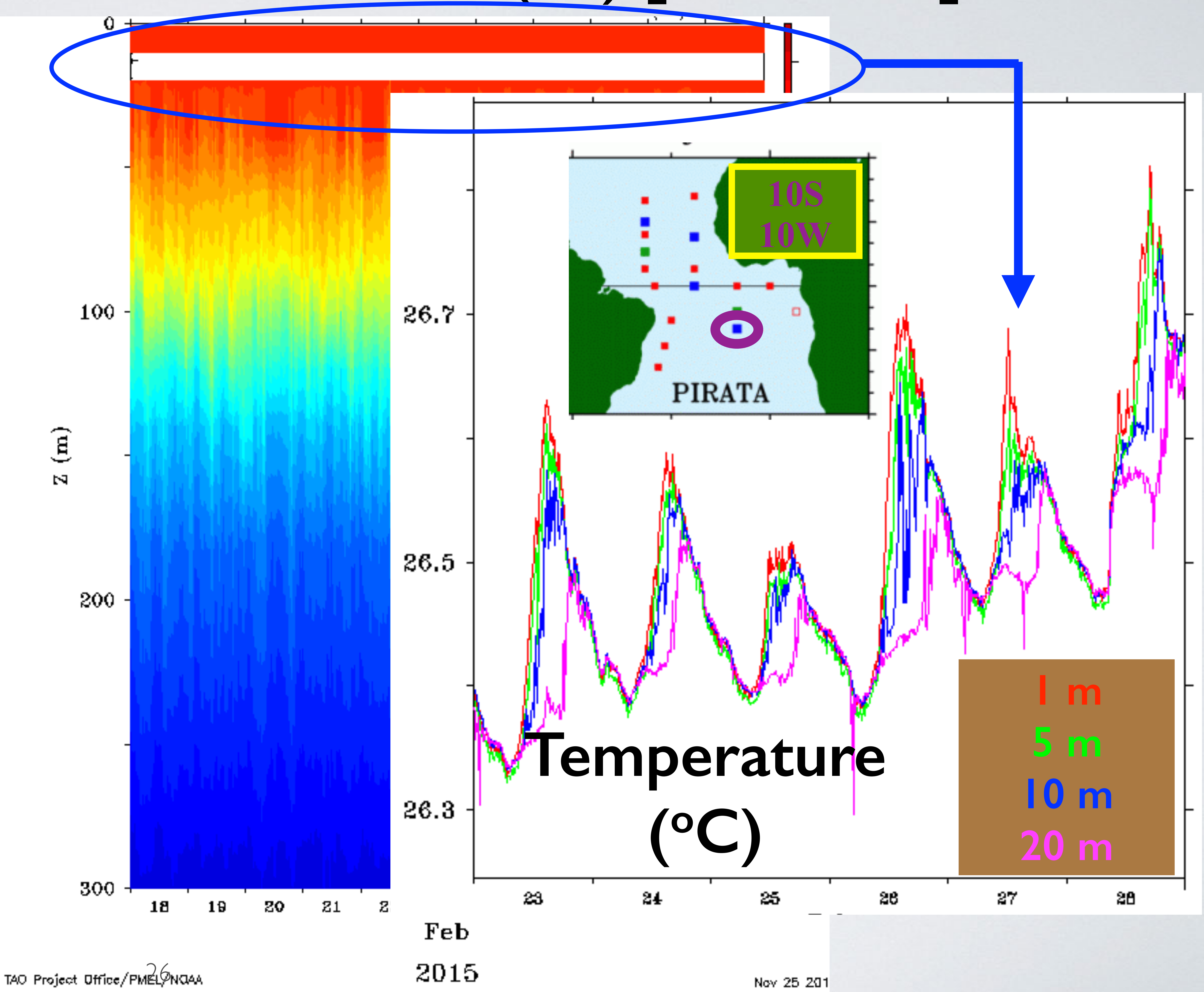

gmao.gsfc.nasa.gov

# COUPLED ASSIMILATION

**Weakly Couple Atmosphere & Ocean Data Assimilation Systems**

- Coupling feedback- Impact on:
  - ➡ Upper ocean, Mixed Layer
  - ➡ Air-sea fluxes
  - ➡ Predictability > 3 days

Isotherms (°C) [10S, 10W]



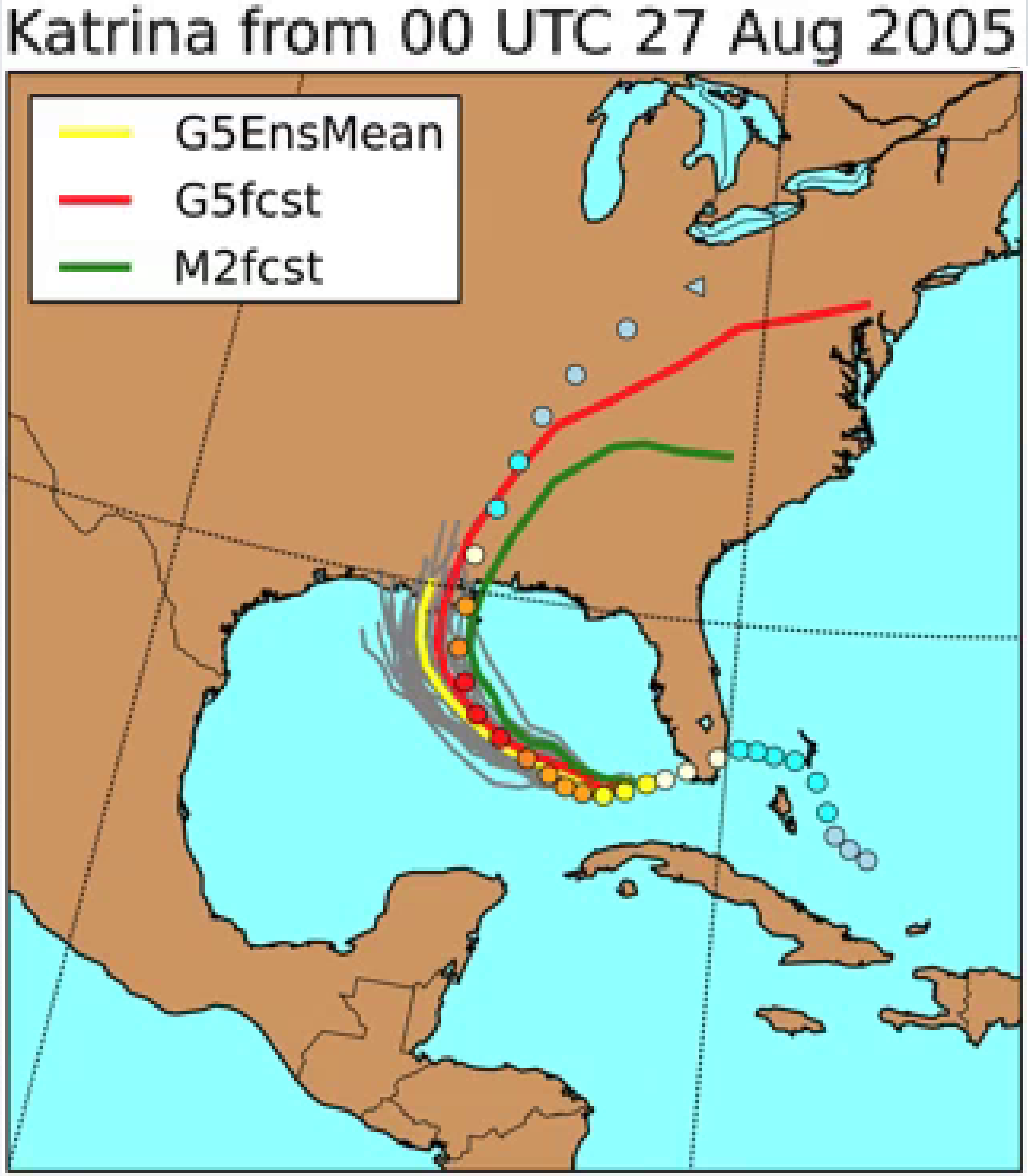
# Questions, Feedback, Suggestions
# Thank You!

# EXTRA SLIDES

# EXTENSION TO HYBRID **GEOS ADAS**

**Current** GMAO ADAS is a **Hybrid** analysis system:

- Deterministic (central) **+**
- Probabilistic (ensembles)



# HYBRID ANALYSIS FOR $T_S$

Analyze for $T_s$ using :

- ✳ Deterministic (central):

  *persistent*, large-scale errors

- ✳ Probabilistic (ensembles):

  flow dependent, small-scale errors

**Without** the $T_s$ prognostic model:

- For all ensemble members, Ts ≈ OSTIA SST

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

➡ First step: a "realistic" $B_e(T_s)$

# HYBRID ANALYSIS FOR $T_S$

Analyze for $T_s$ using :

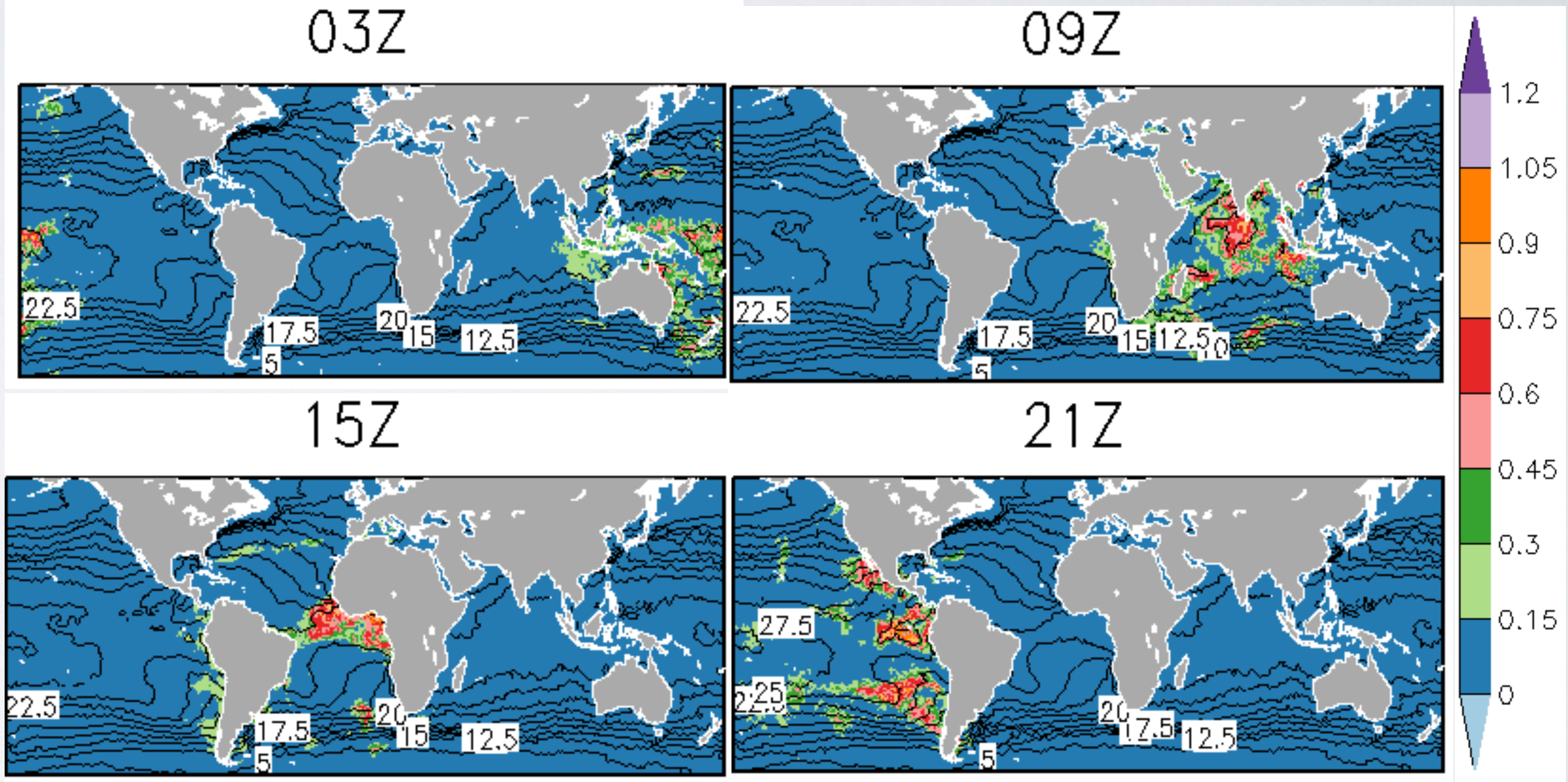
- ✳ Deterministic (central):

  *persistent*, large-scale errors

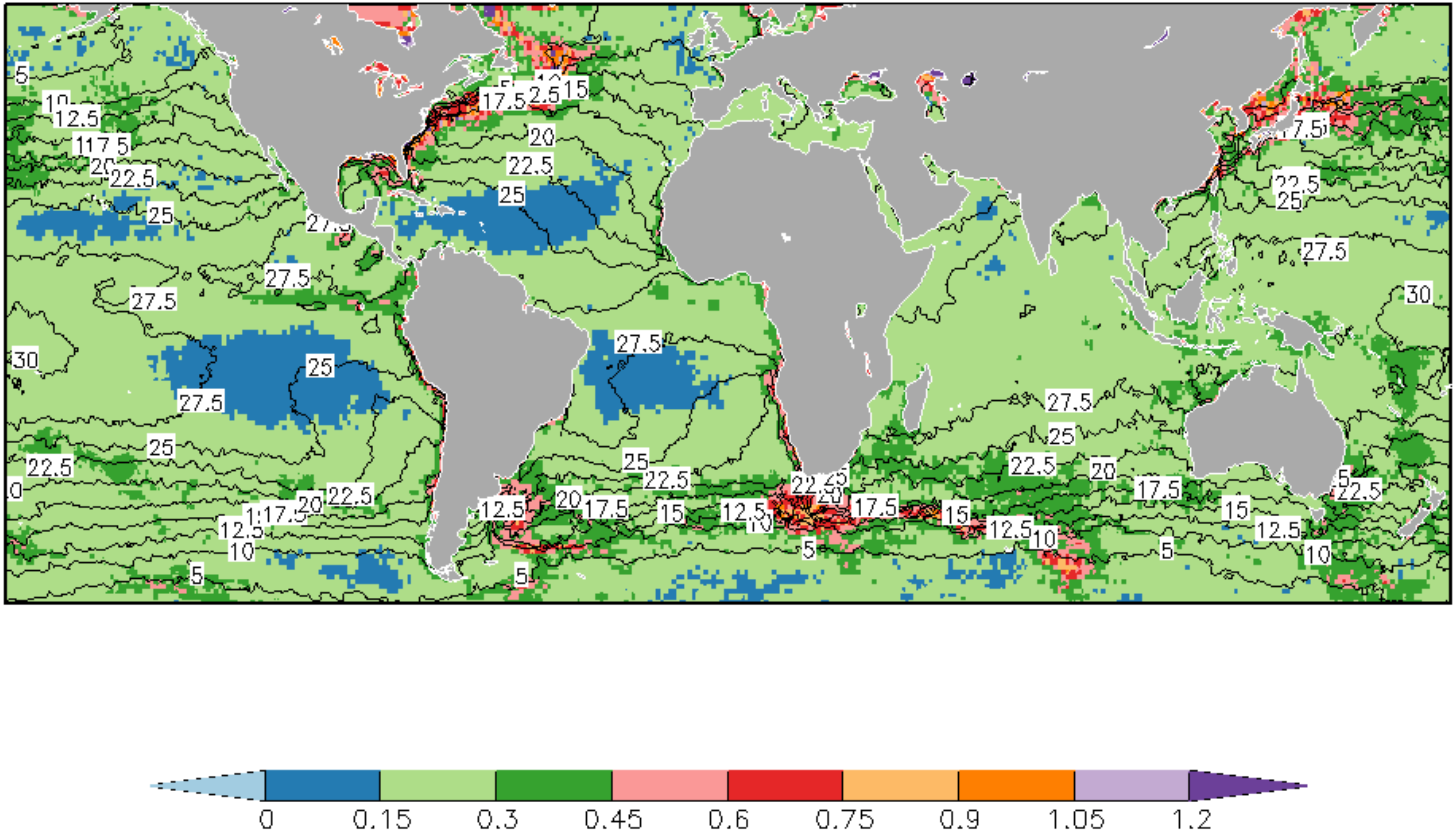
- ✳ Probabilistic (ensembles):

  flow dependent, small-scale errors

**Ensemble Mean & Std Dev $T_s$ (°C) Feb 28, 2015**




Mean (contour), Std Dev (shaded)


0
0.15
0.3
0.45
0.6
0.75
0.9
1.05
1.2

# Change in Net Surface Heat Flux

- Diurnal Warming: $\Delta H_s \sim 2 - 3W/m^2$; $\Delta H_l \sim 8 - 10W/m^2$
- Cool-Skin: $\Delta H_s \sim -4 \rightarrow -2W/m^2$; $\Delta H_l \sim -10 \rightarrow -8W/m^2$
- Similar change in $\mathbf{LW}_{net}$.