# NOAA's Geo-Polar Blended SST Analysis

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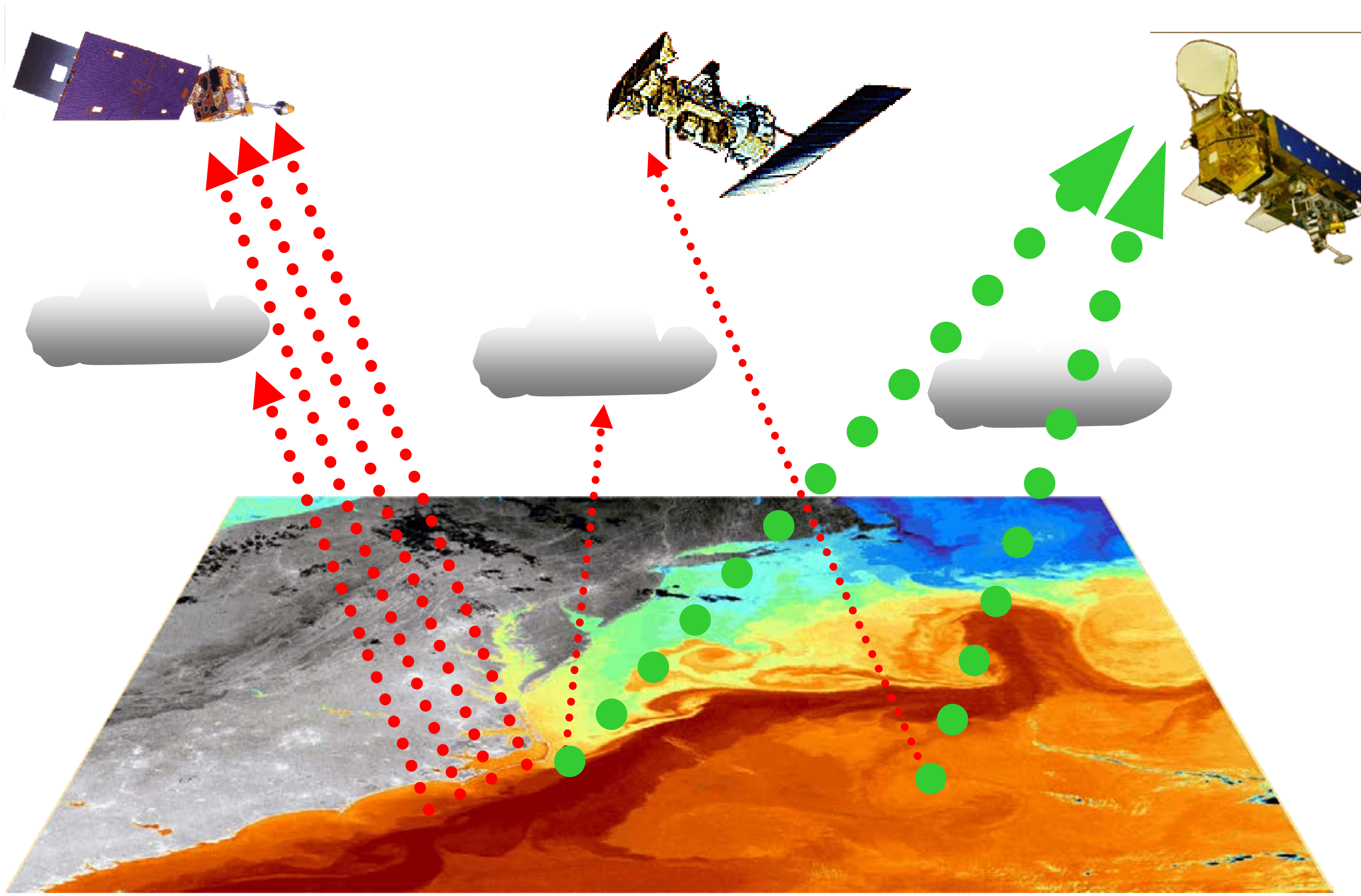
*[4]University of Reading, UK*

*[5]NOAA/NESDIS/OSPO*



JPSS Annual Meeting, 8 – 12 August, 2016

# Maximize strengths – minimize weaknesses



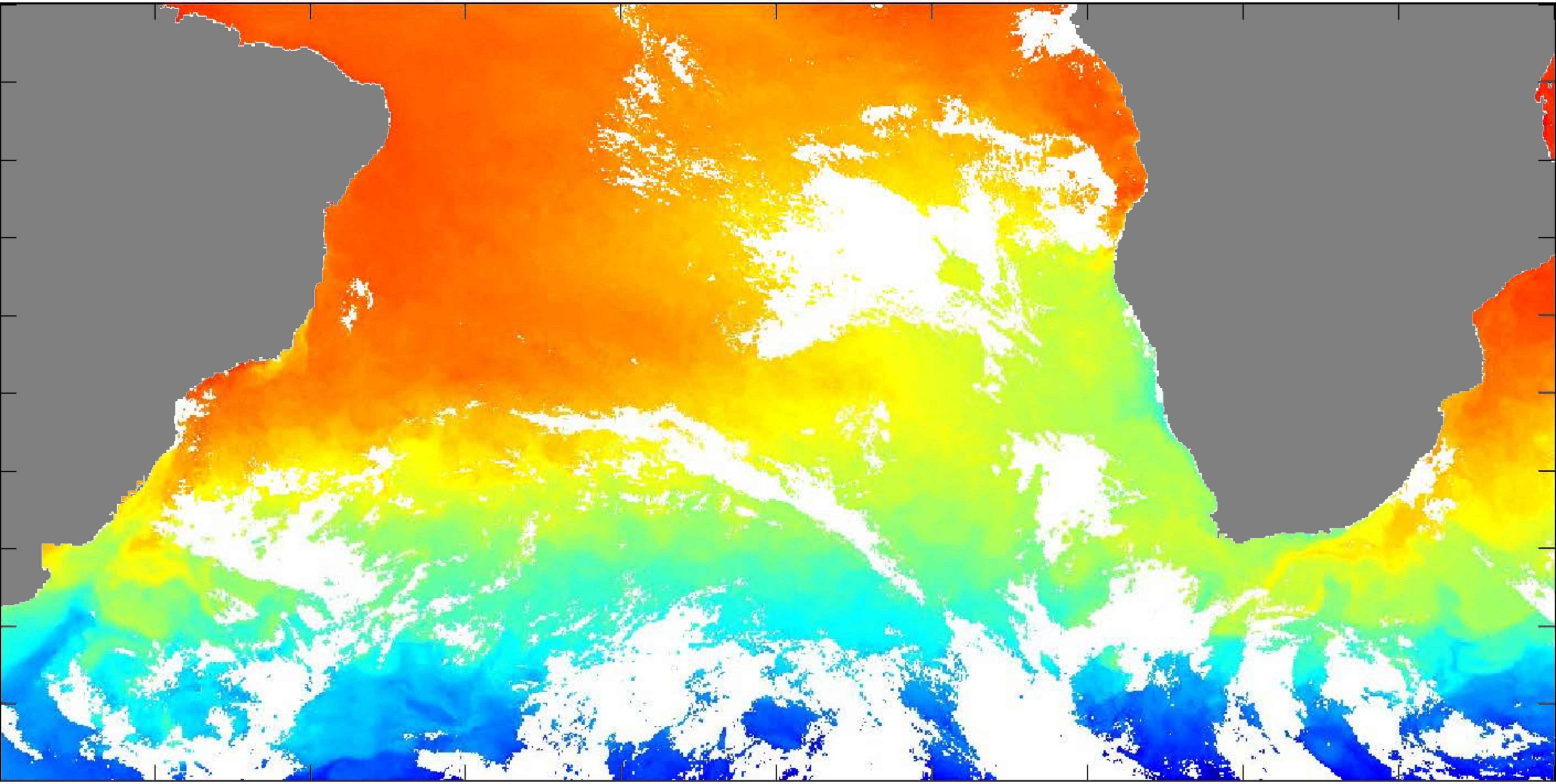
POES IR has **high spatial resolution**

GOES IR has **high temporal resolution**

Microwave has **all-weather capability**

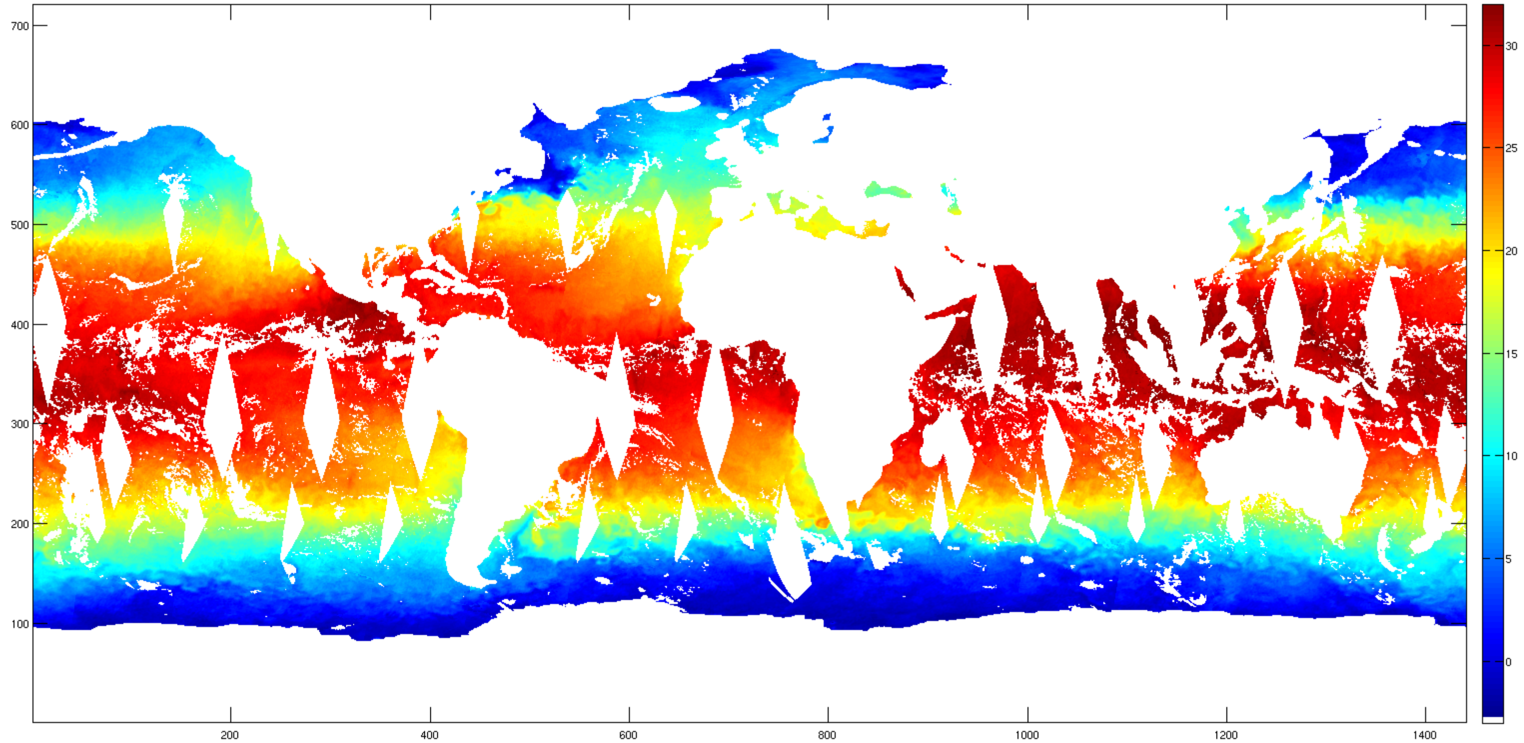
Combine to obtain the **optimal SST analysis**

# Combined coverage



**Geo-SST dominates low-to-mid latitudes**

# Data Coverage – AMSR-2



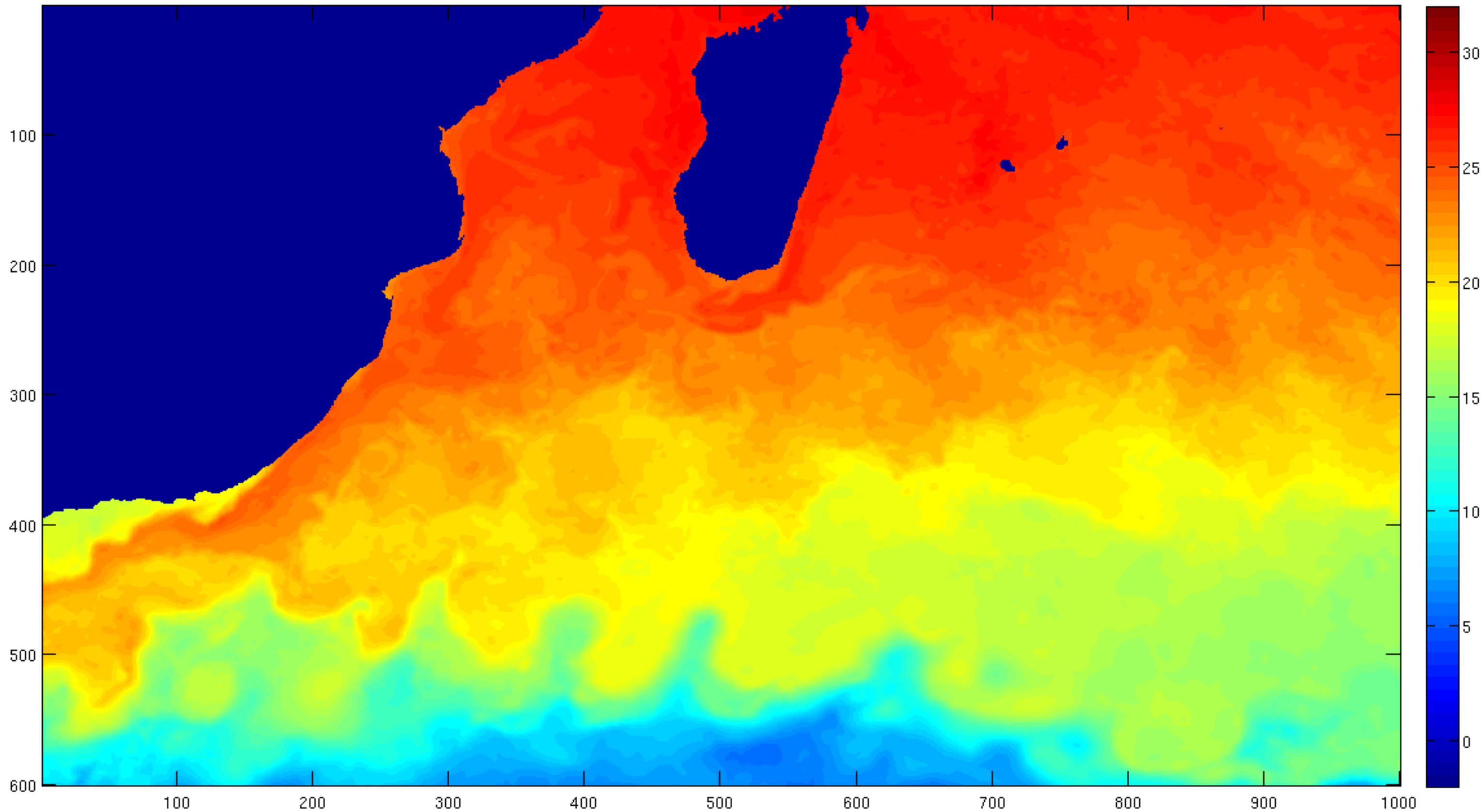

- Valid SST data coverage from AMSR-2 for 2014-05-01
  - » Improved coverage in both Tropics and High Latitudes
  - » 3 days gives almost complete coverage away from land & ice

# 5-km Blended SST Analysis

- **Produced daily from 24 hours of Polar- & Geo-SST**
  - MetOp-B
  - GOES-E/W Imager
  - Meteosat-10 SEVIRI
  - Himawari-8 Imager
  - VIIRS
  - [AMSR-2]
  - **Does <u>not</u> use buoy data**
- **Multi-scale OI**
  - Mimics Kalman Filter **(***Khellah et. al., 2005***)**
- **3 stationary priors**
  - Short, intermediate and long correlation lengths
  - Mimic non-stationary prior while preserving rigor
  - Interpolation of resultant analyses based data density
    - ➢ **<u>Allows fine resolution where possible without introducing noise</u>**

# VIIRS data

- **VIIRS successfully incorporated into Geo-Polar Blended 5-km global SST analysis**

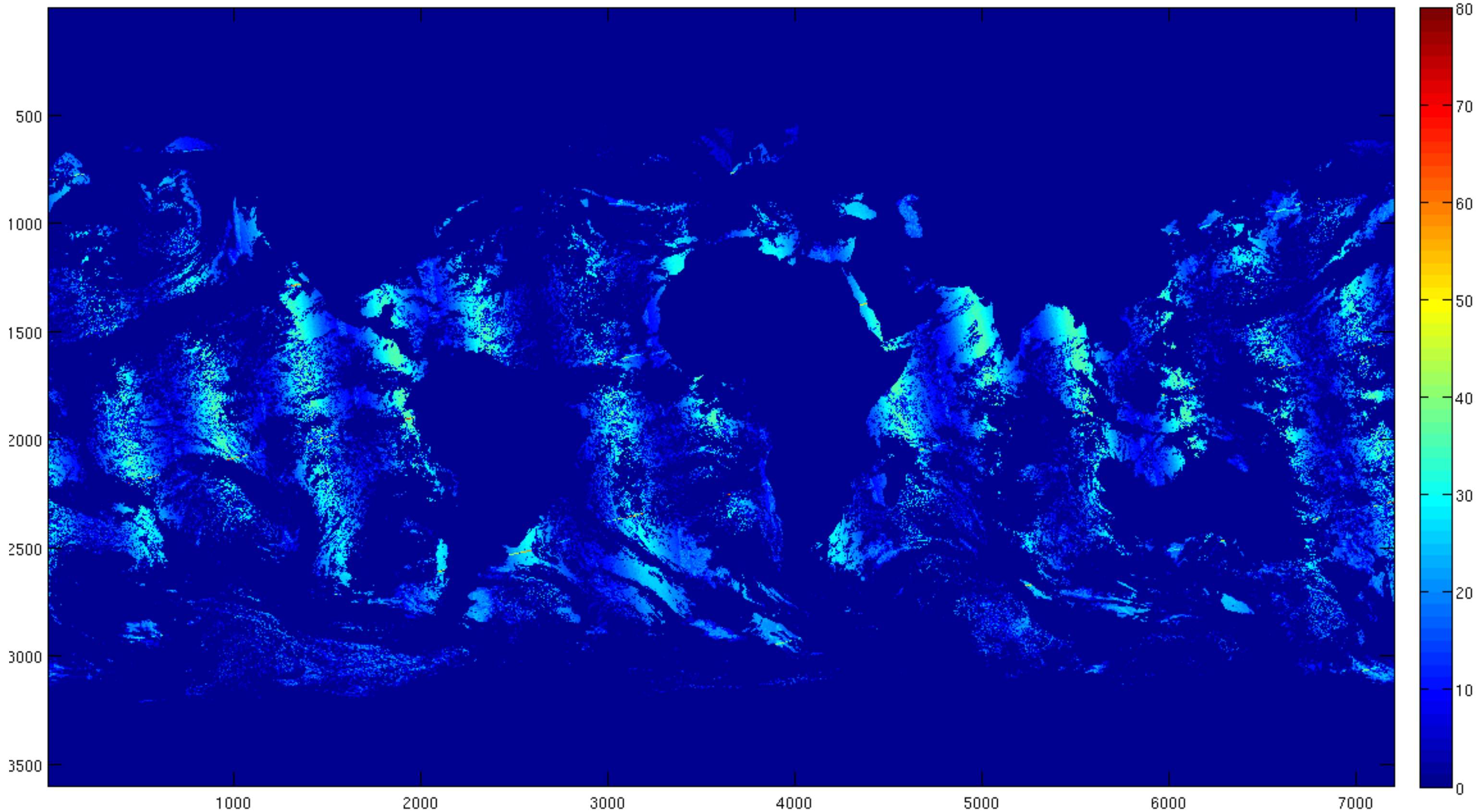



Super-Ob'd VIIRS SST data

Final analysis

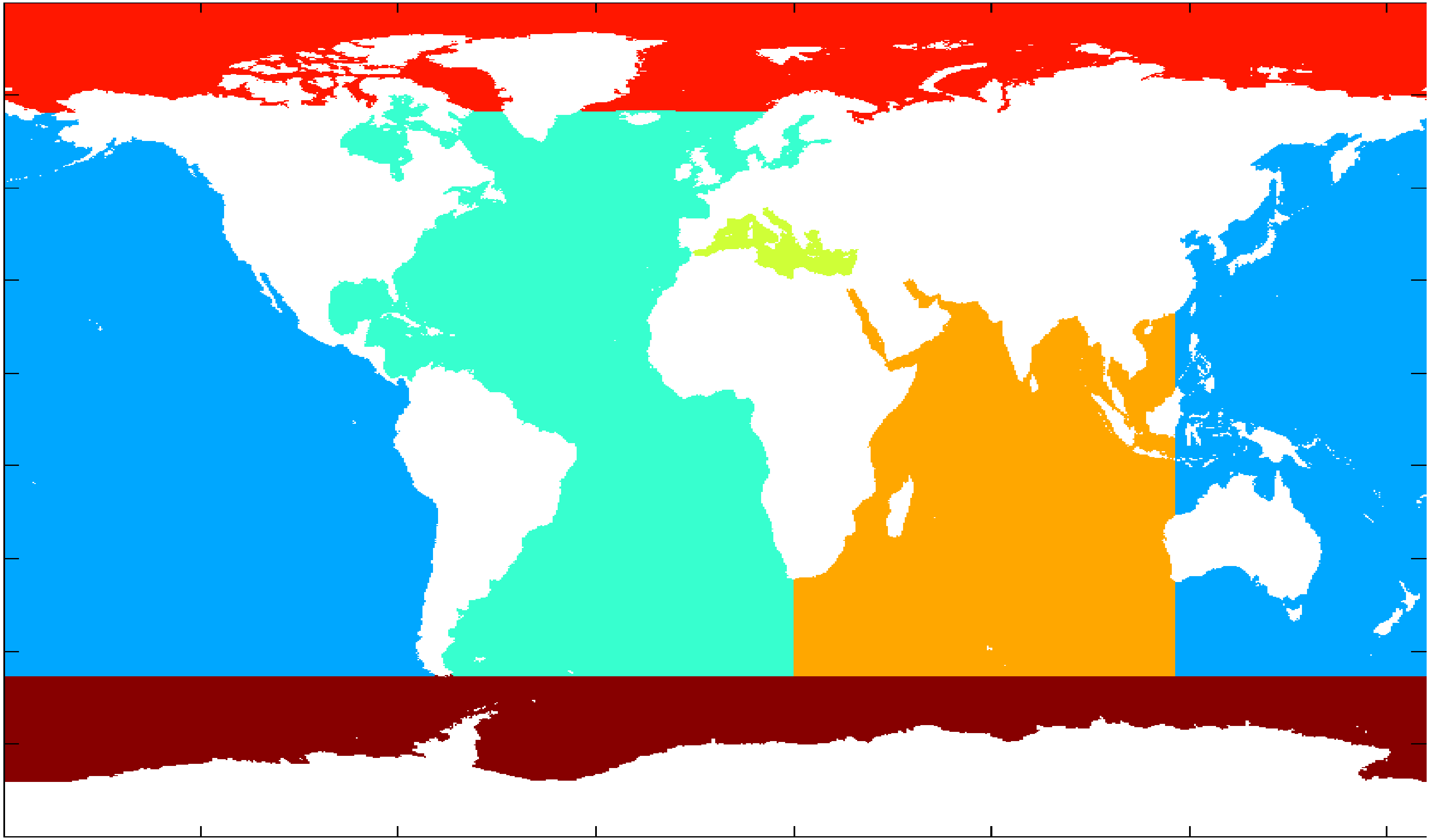
# VIIRS coverage

- **Coverage is improved w.r.t. MetOp AVHRR**

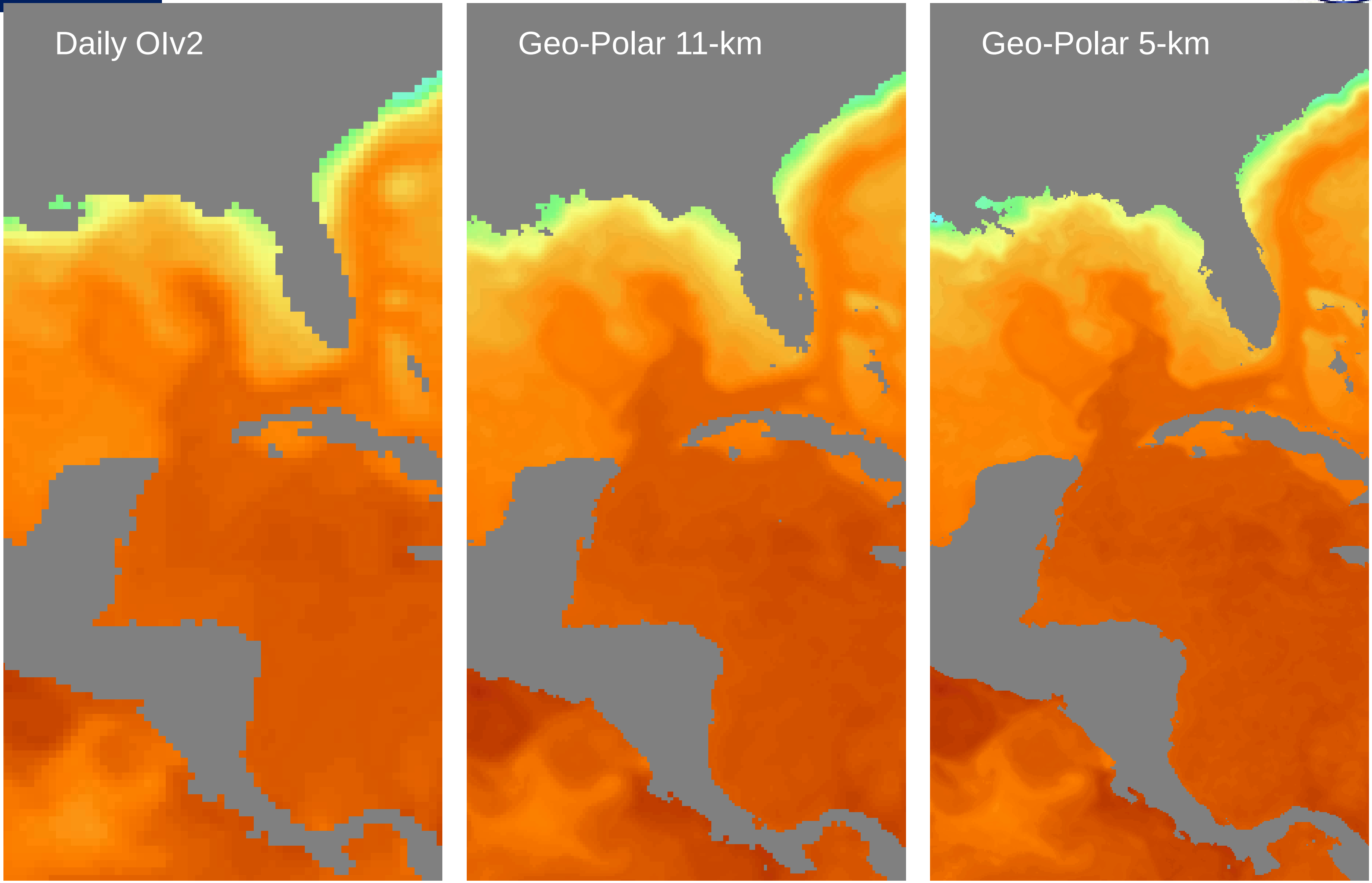



ACSPO AVHRR coverage
ACSPO VIIRS coverage

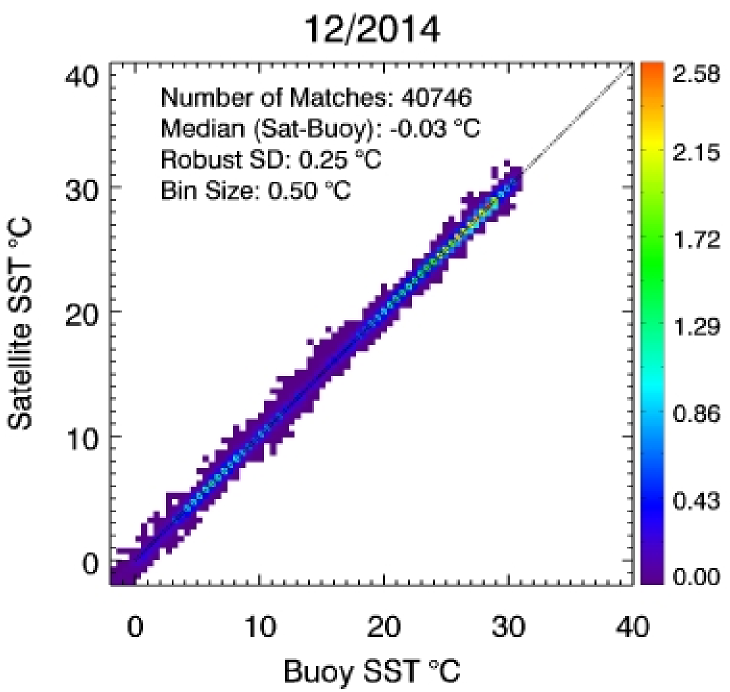
# Separate Ocean Basins

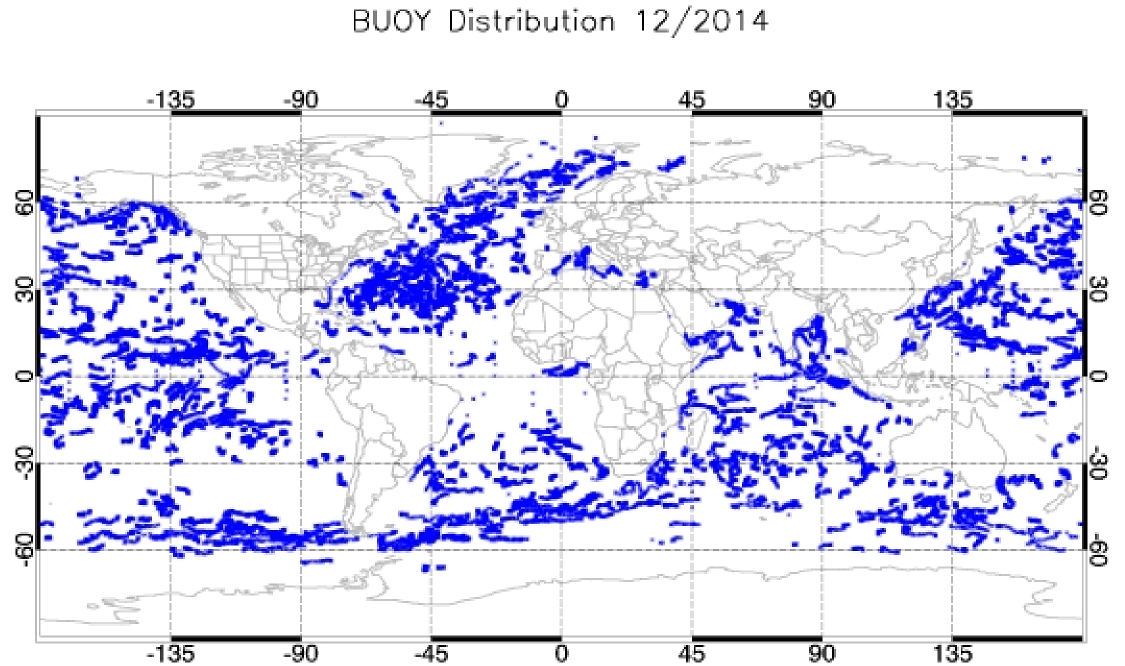


# Resolution difference



# Product Accuracy: Blended SST



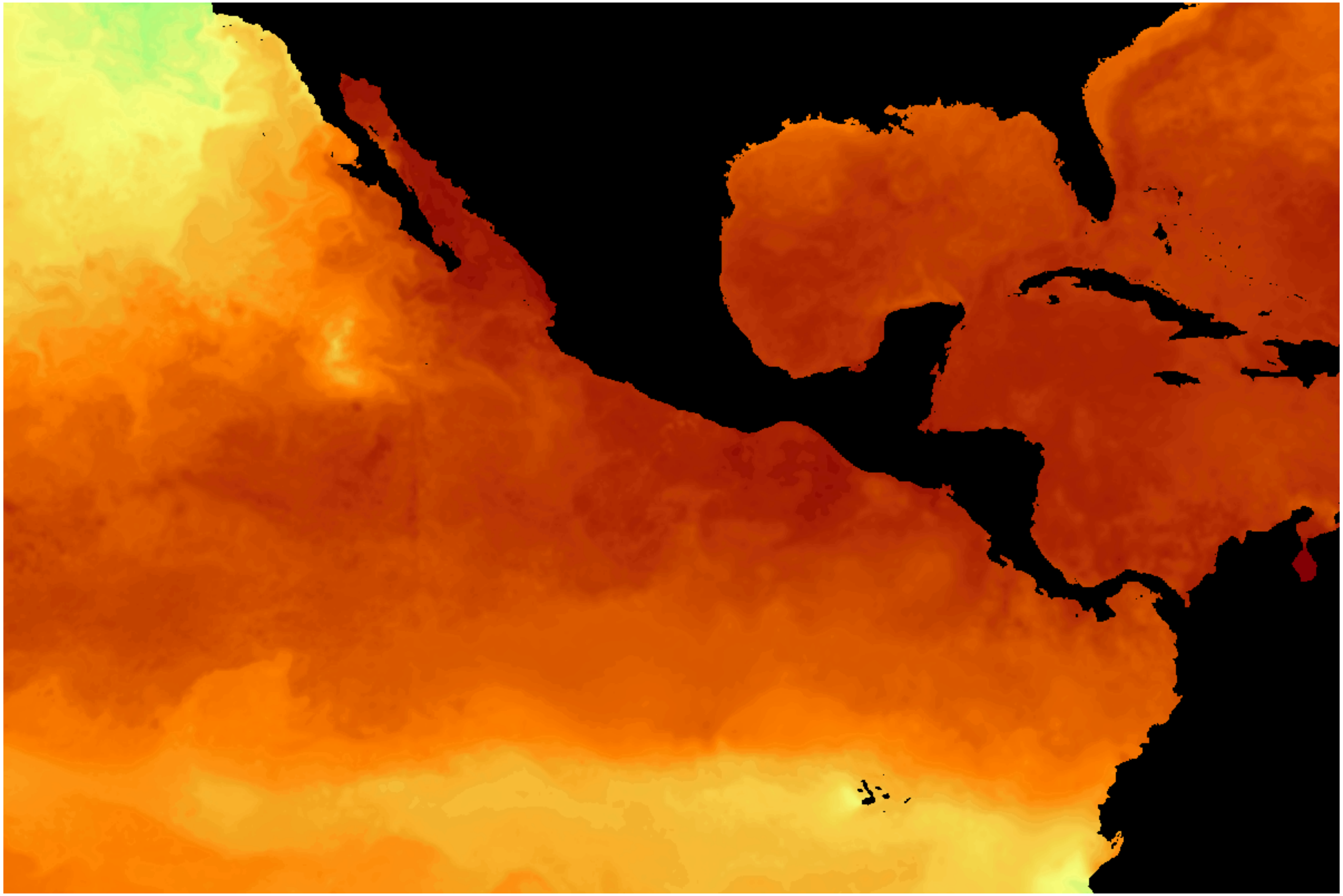




Median bias (analysis – buoy) -0.03 K

Robust Standard Deviation 0.25 K

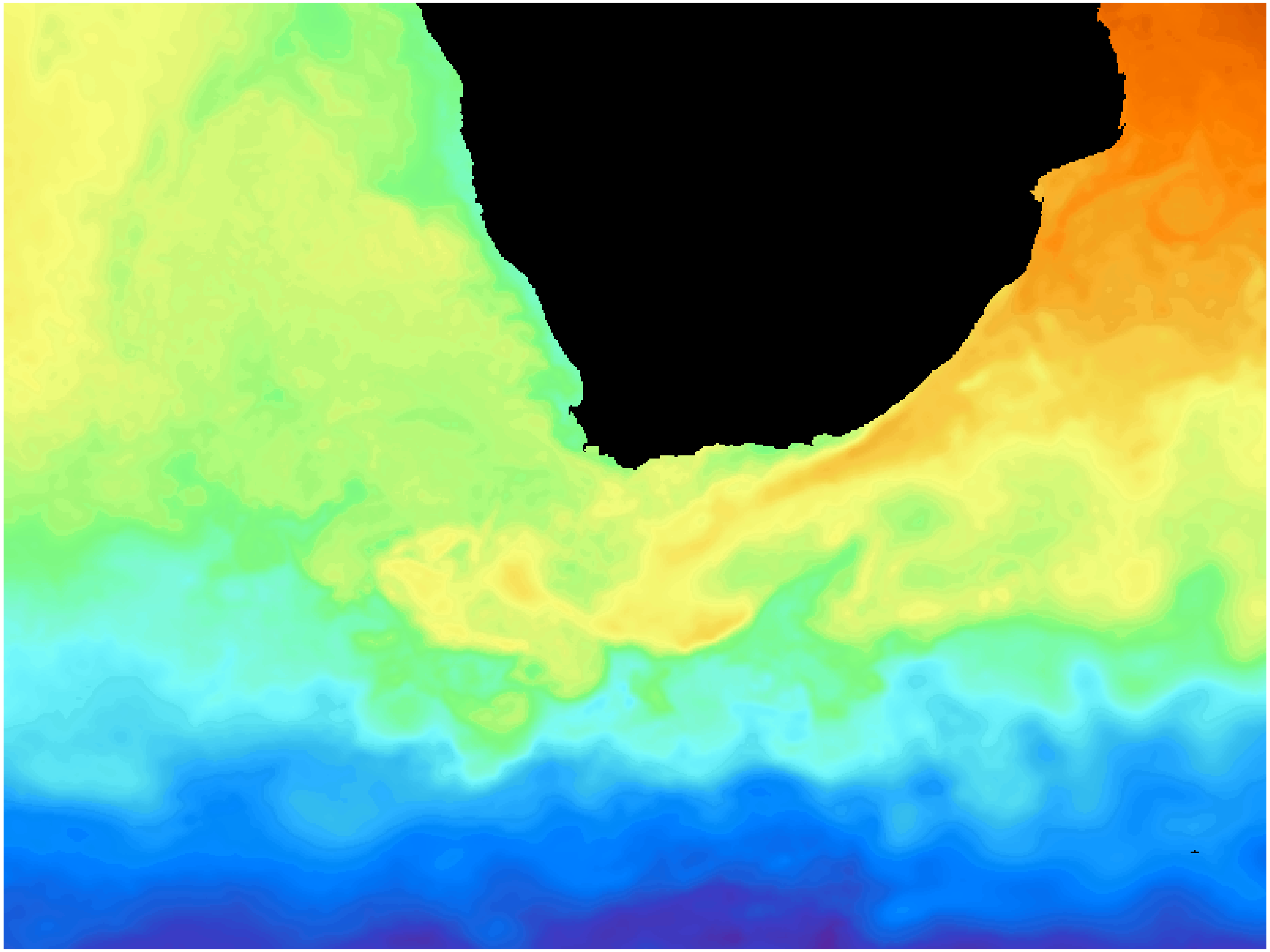
Robust Standard Deviation = (75% - 25%)/1.349

# 5-km Examples



**Day+night 5-km, Nov 1 – Dec 31, 2012**

# 5-km Examples



**Day+night 5-km, Nov 1 – Dec 31, 2012**

# NOAA Coral Reef Watch

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

DOC > NOAA > NESDIS > STAR > CRW

Coral Reef Watch

CRTF | CRCP | CREIOS | CoRIS

CRW Home

Products Overview

Near-Real-Time Data
(5-km Resolution)

Bleaching Alert Area

Degree Heating Week

HotSpot

Sea Surface Temperature

SST Anomaly

Virtual Stations/Gauges

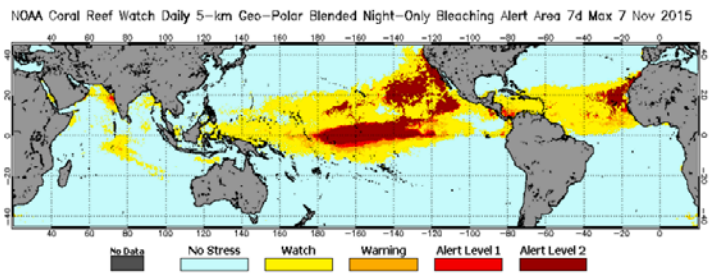
Near-Real-Time Data
(50-km Resolution)

## Coral Reef Watch Satellite Monitoring

**NOAA Coral Reef Watch is pleased to announce the release of its new Daily 5-km Satellite Coral Bleaching Thermal Stress Monitoring Product Suite. The 5-km products are accessible directly below, in the left navigation bar, and throughout this website. Access to our heritage suite of operational 50-km satellite monitoring products will still be possible for the next several months. We encourage all of our users to look over the new 5-km products and provide feedback to us at coralreefwatch@noaa.gov.**

*Click on buttons below image to change parameter; click on image to navigate to parameter's web page.*

Switch to 50-km products ►




Alerts | HotSpot | DHW | SST | Anomaly | SST Trend | Outlook | Doldrums | Virtual Stations

El Niño bleaching patterns web page

The NOAA Coral Reef Watch program's satellite data provide current reef environmental conditions to quickly identify areas at risk for coral bleaching, where corals lose the symbiotic algae that give them their distinctive colors. If a coral is severely bleached, disease and partial mortality become likely, and the entire colony may die.

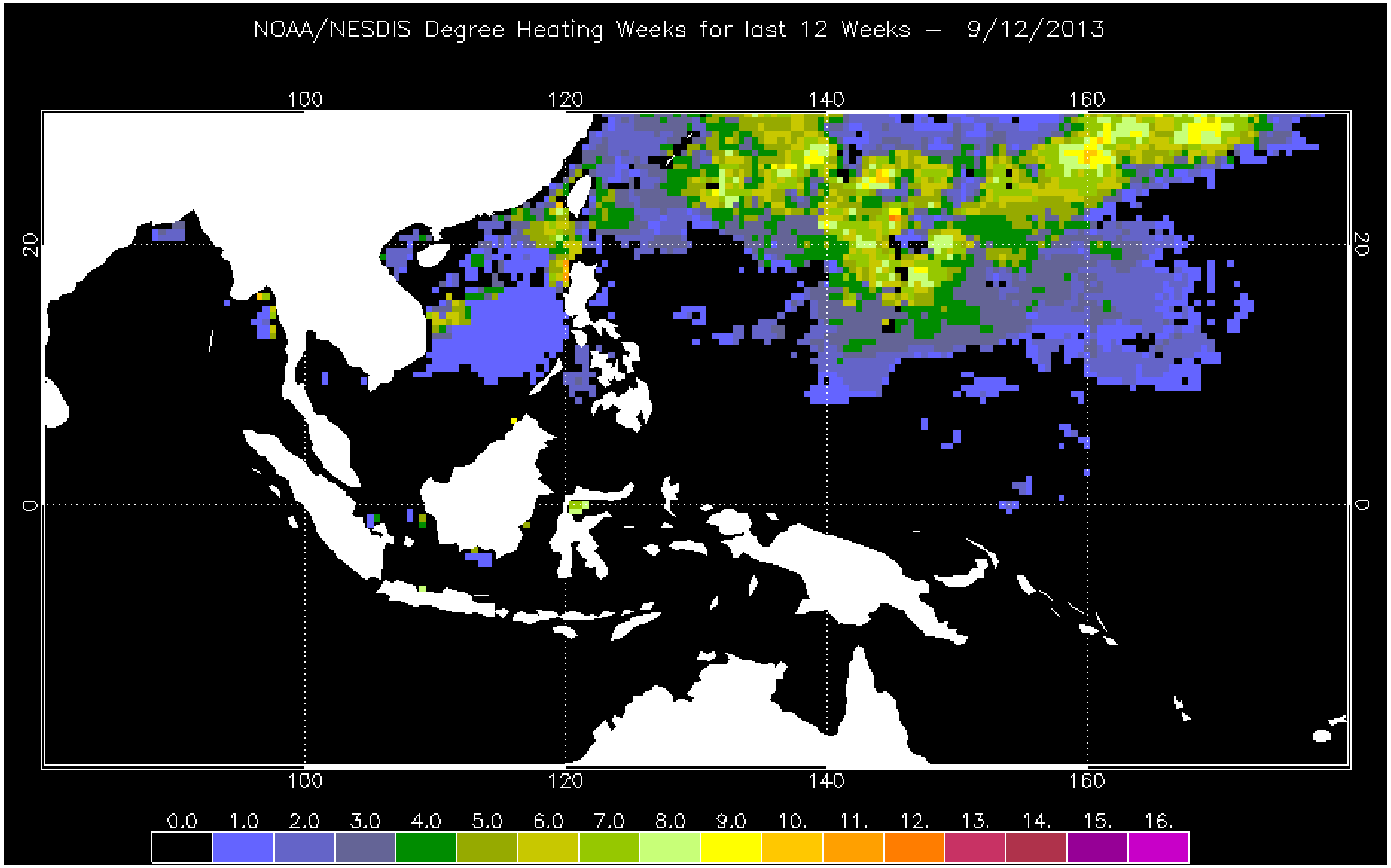
Continuous monitoring of sea surface temperature at global scales provides researchers and stakeholders with tools to understand and better manage the complex interactions leading to coral bleaching. When bleaching conditions occur, these tools can be used to trigger bleaching response plans and support appropriate management decisions.

**Announcements**

**October 8, 2015: NOAA announces third ever global coral bleaching event on record! Read the NOAA press release here.**

# Coral Reef Watch Products

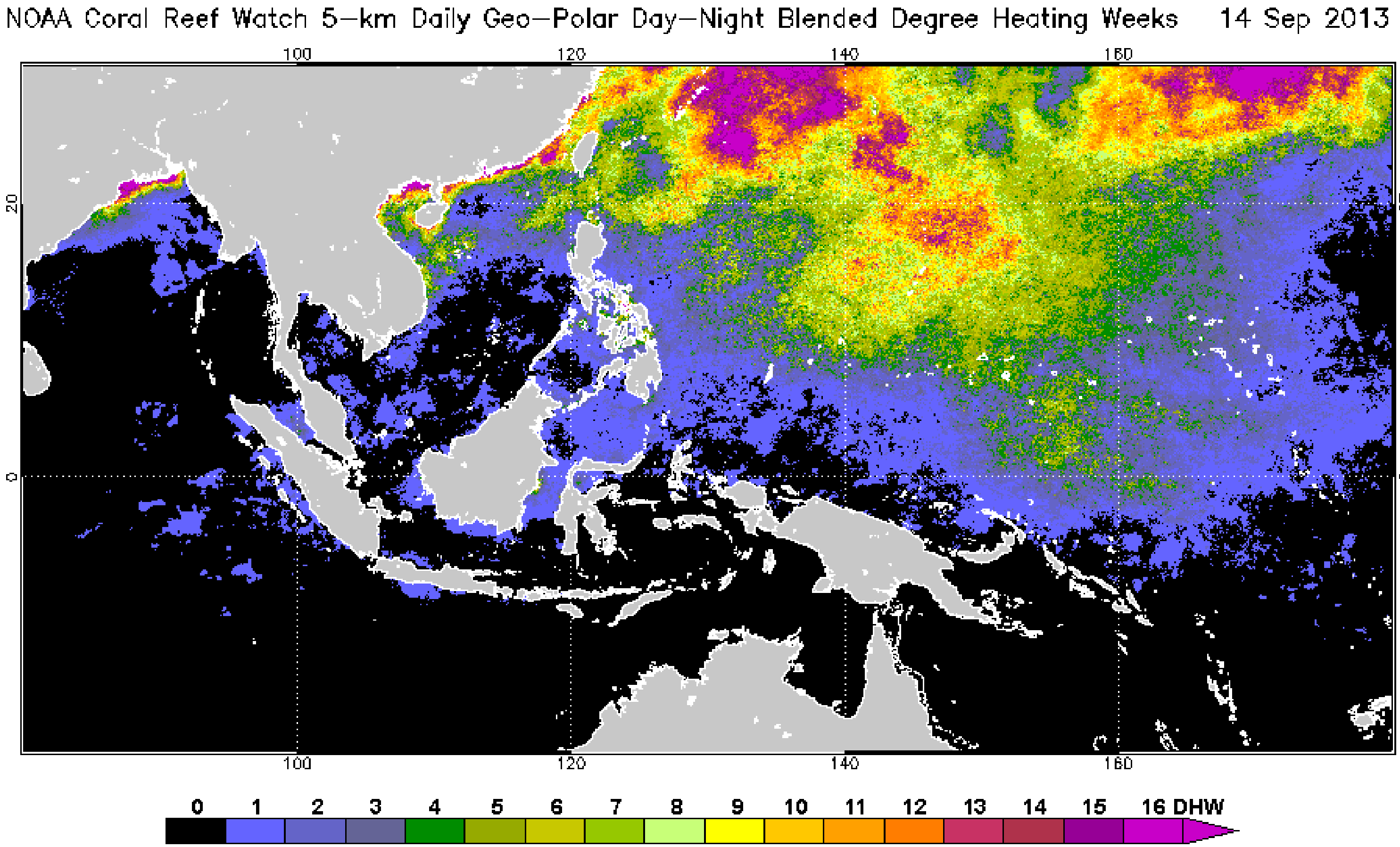
"Coral Triangle"




- **Accumulated thermal stress is predictor of bleaching risk**

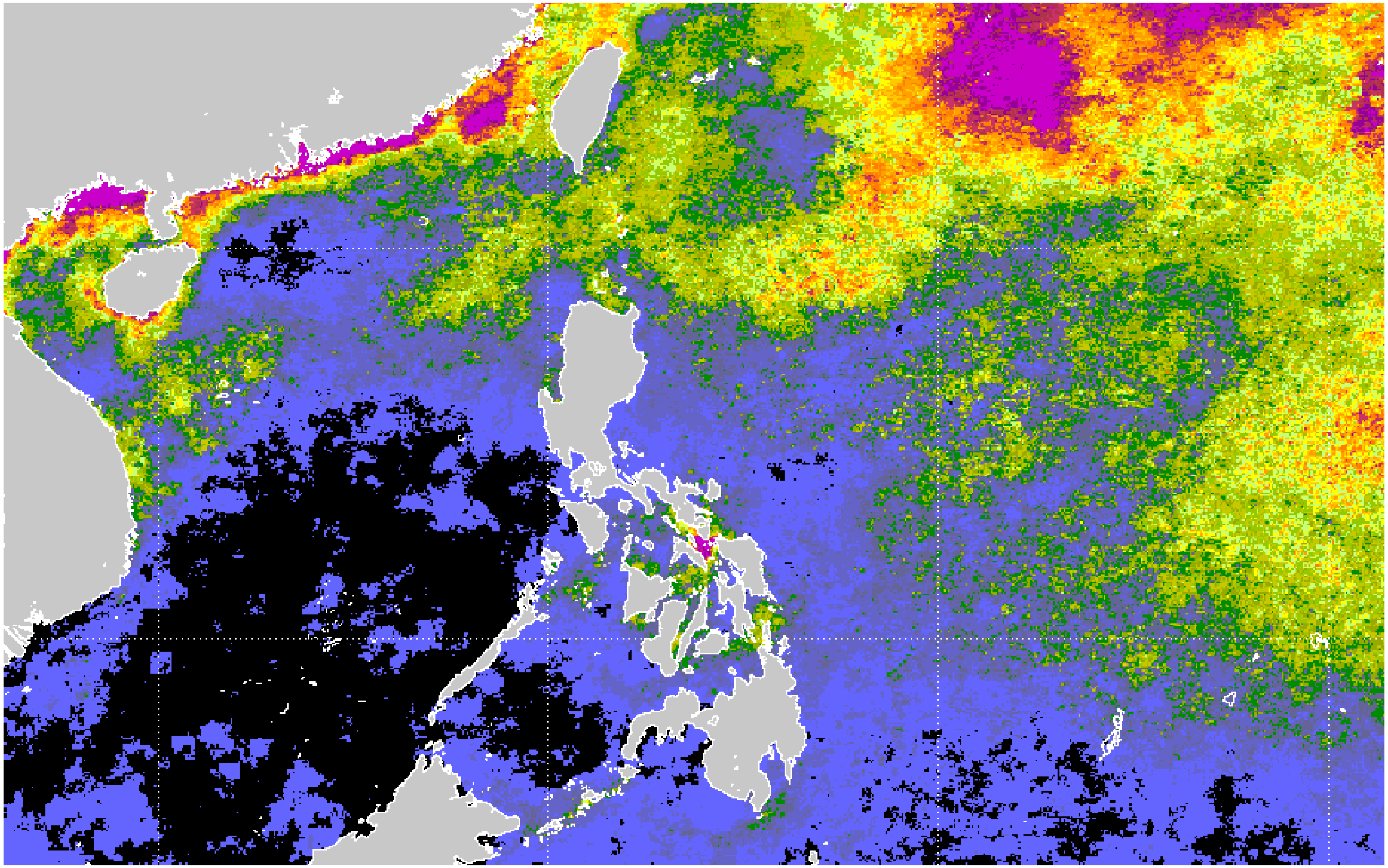
# CRW Products based on 5-km SST

"Coral Triangle"



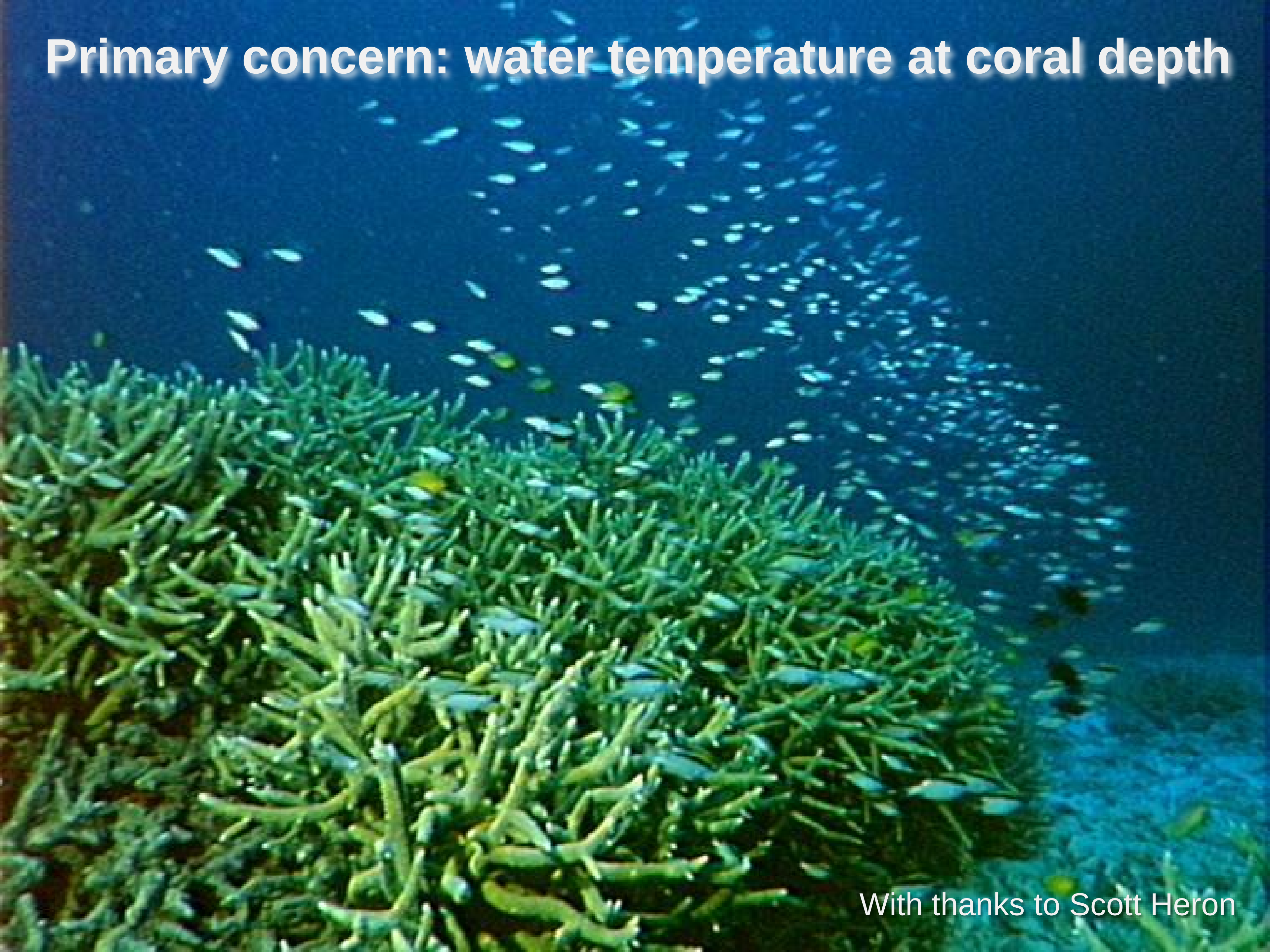
# CRW Products – 5-km detail

"Coral Triangle"



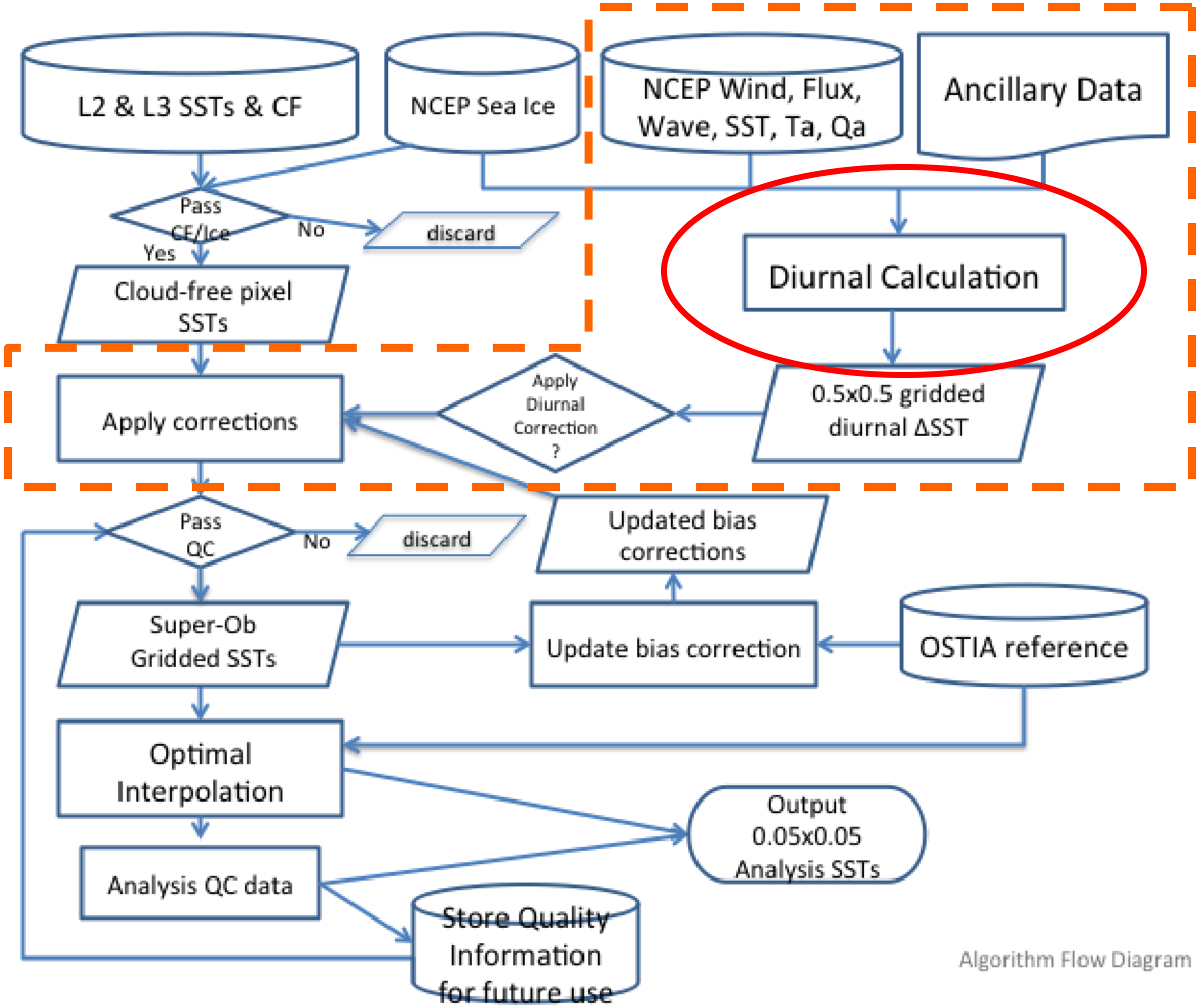
- **New analysis enables much greater precision, *e.g.* small fringing reefs**
- **However, climatology is not derived from same dataset**

# Primary concern: water temperature at coral depth



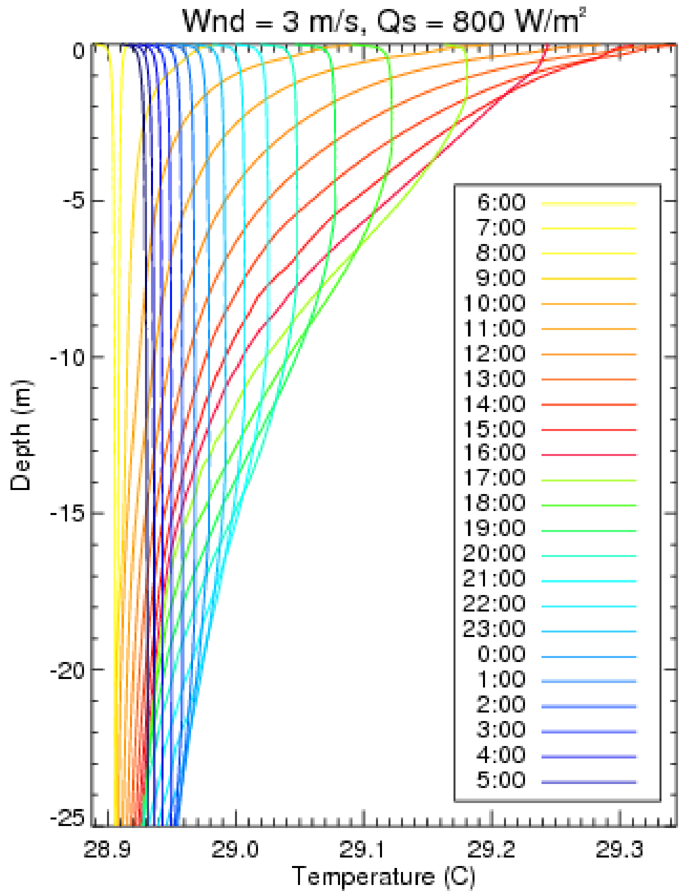
With thanks to Scott Heron

# Including diurnal warming correction in SST analysis

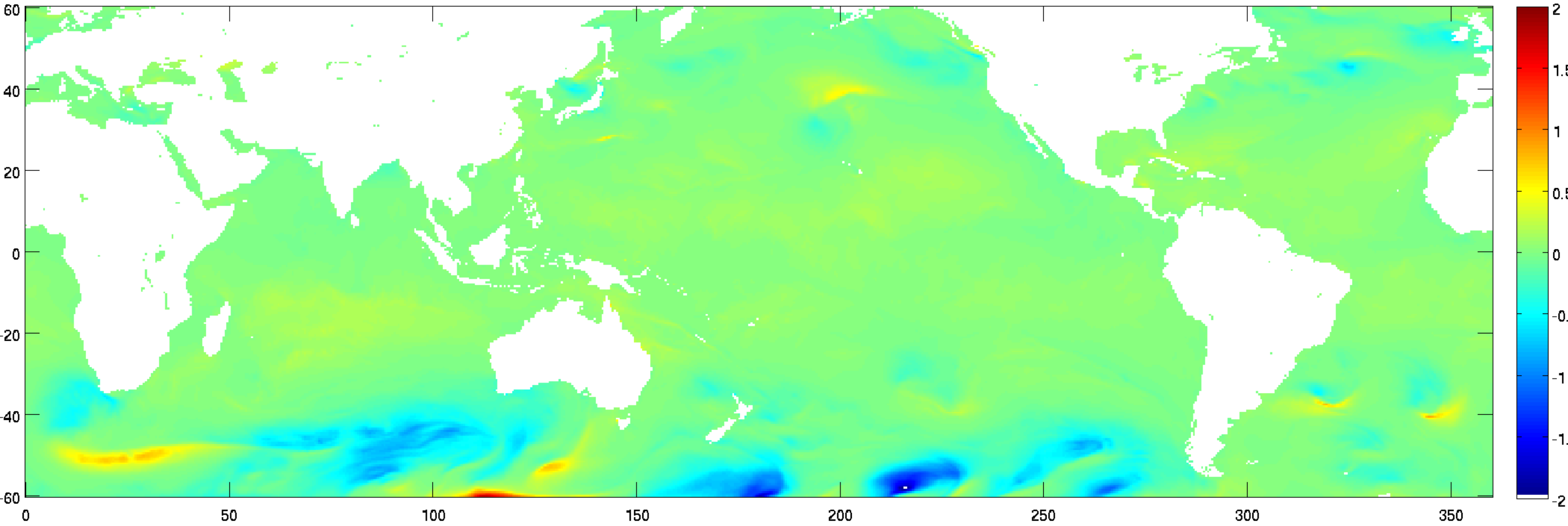


# Diurnal Warming Correction – Sample Model Profile of Warming with Depth

- **Model simulates full vertical profile of warming**
  - Enables estimation of warming at arbitrary depth
  - Model presently run to a depth of 50 m
- **Time evolution of vertical temperature profile shown here for idealized forcing with a constant wind speed of 3 m/s and a peak insolation of 800 W/m²**

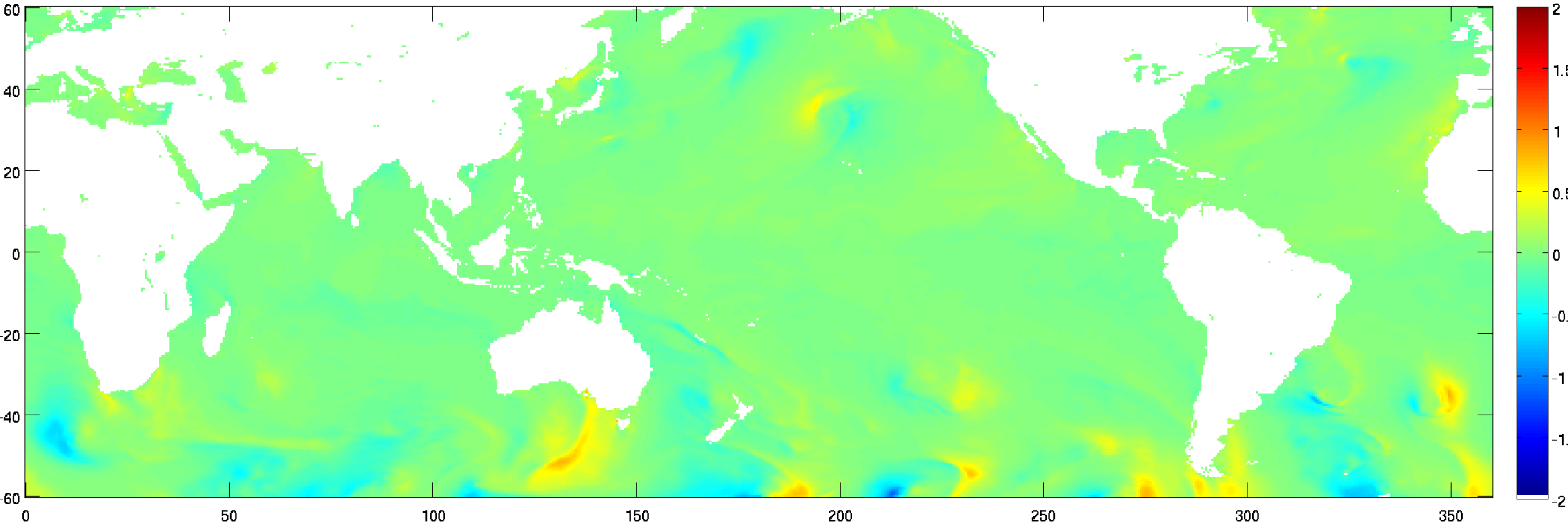


# Diurnal Warming Correction - Sample Model Forcing Fields



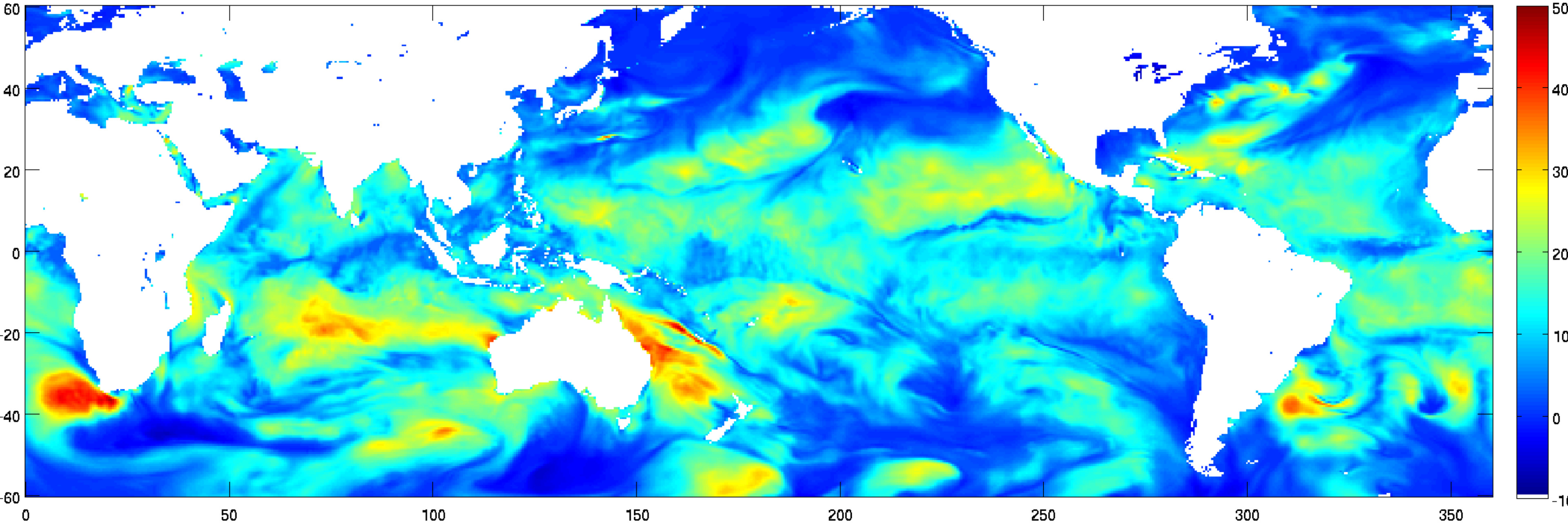

**Zonal wind stress**

# Diurnal Warming Correction - Sample Model Forcing Fields



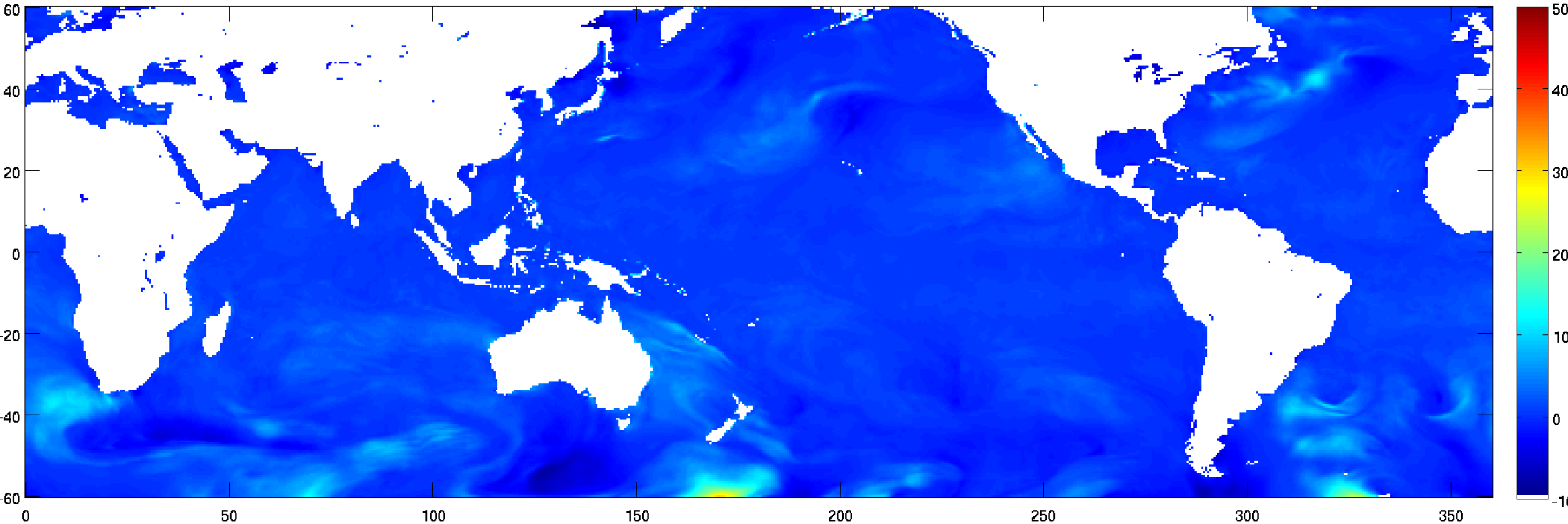

## Meridional wind stress

# Diurnal Warming Correction - Sample Model Forcing Fields



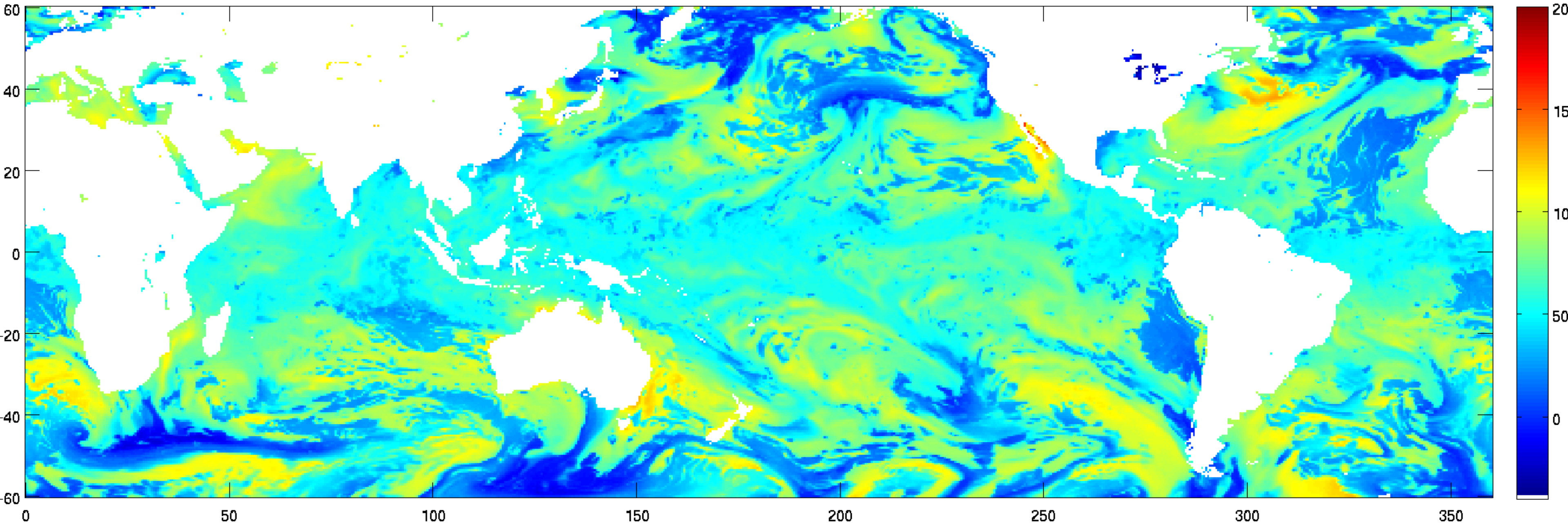

**Latent heat flux**

# Diurnal Warming Correction - Sample Model Forcing Fields



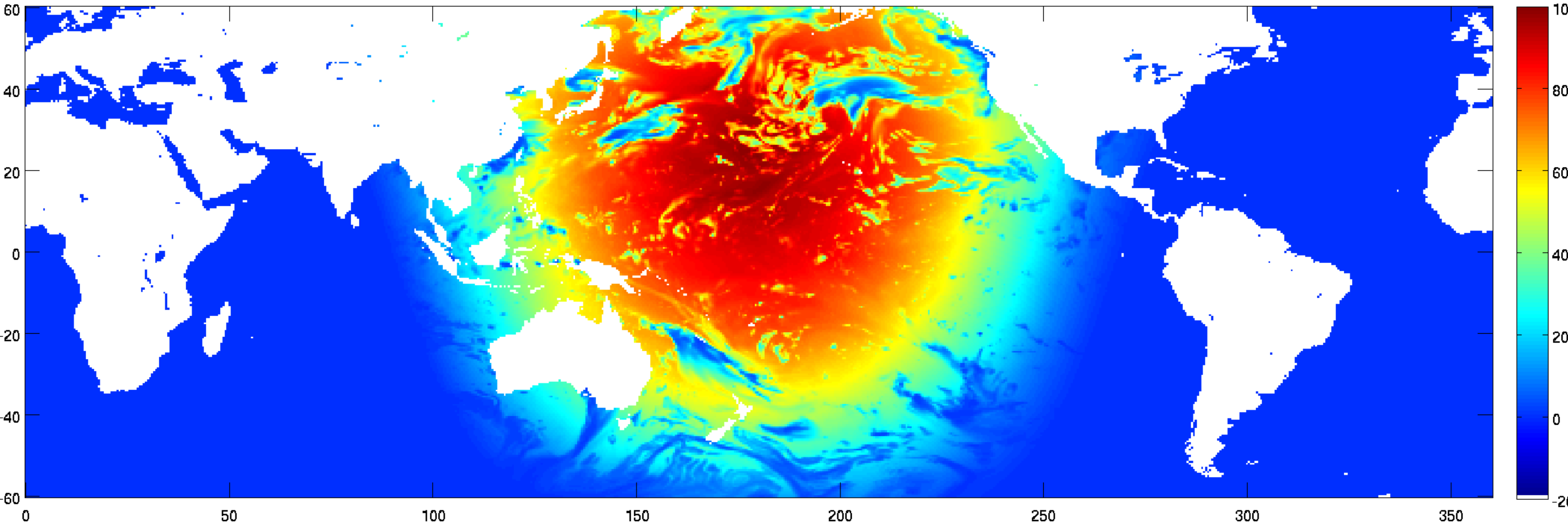

Sensible heat flux

# Diurnal Warming Correction - Sample Model Forcing Fields



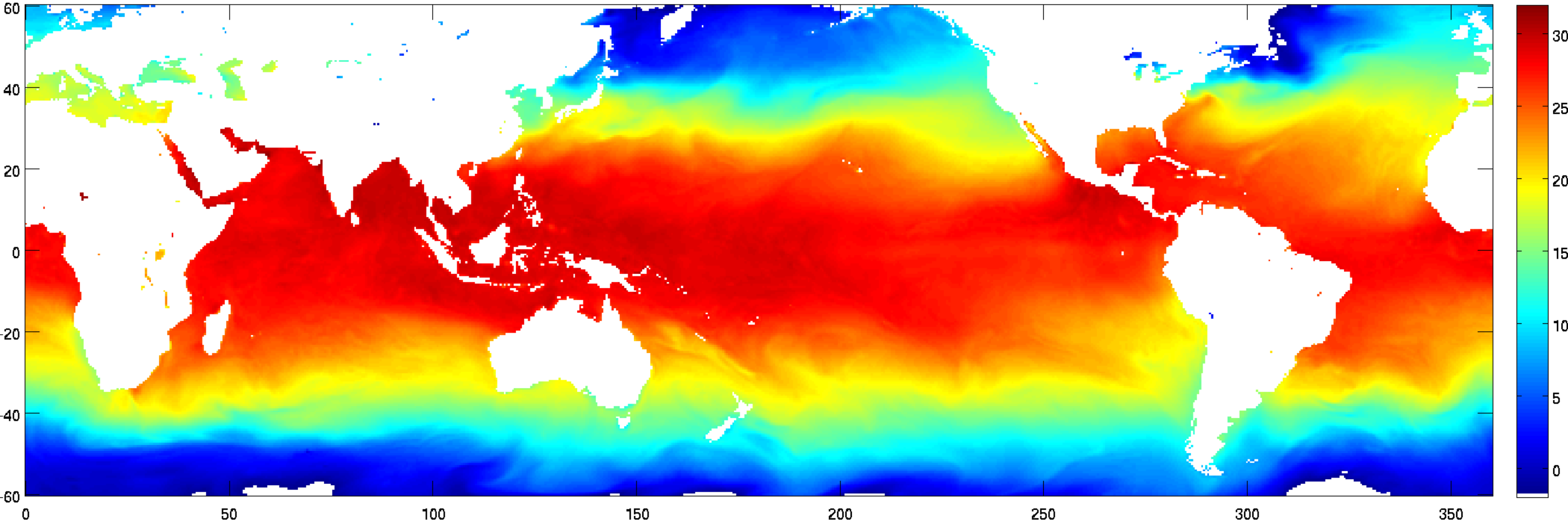

**Net longwave heat flux**

# Diurnal Warming Correction - Sample Model Forcing Fields



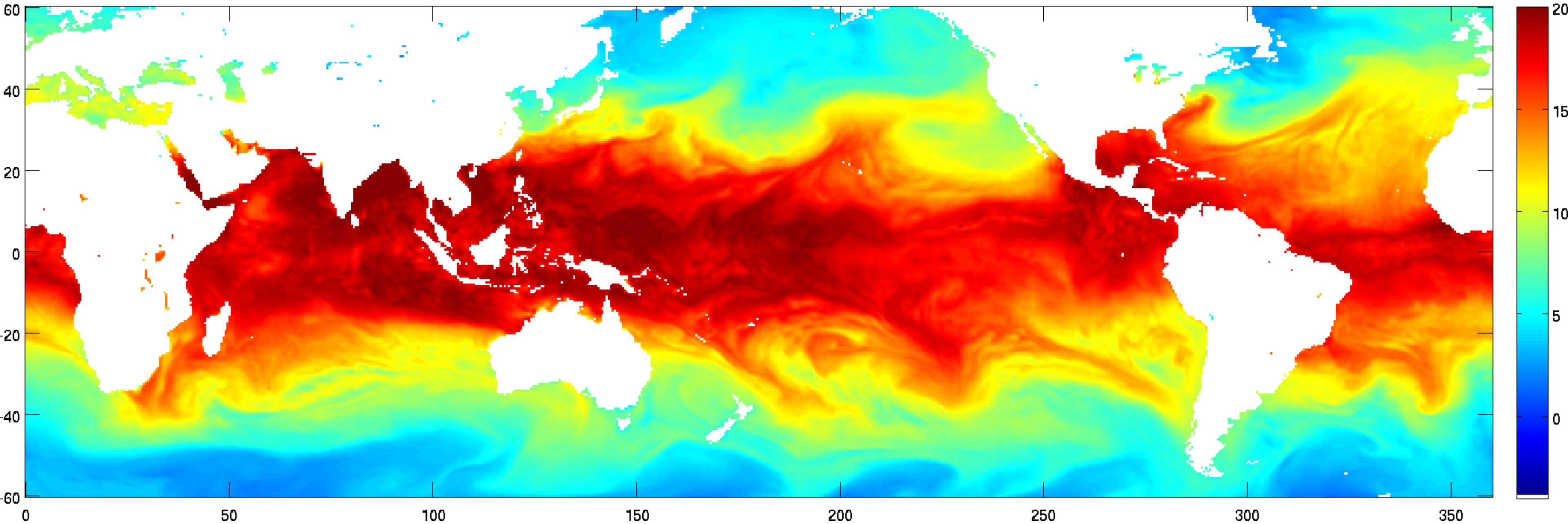

**Net shortwave heat flux**

# Diurnal Warming Correction - Sample Model Forcing Fields



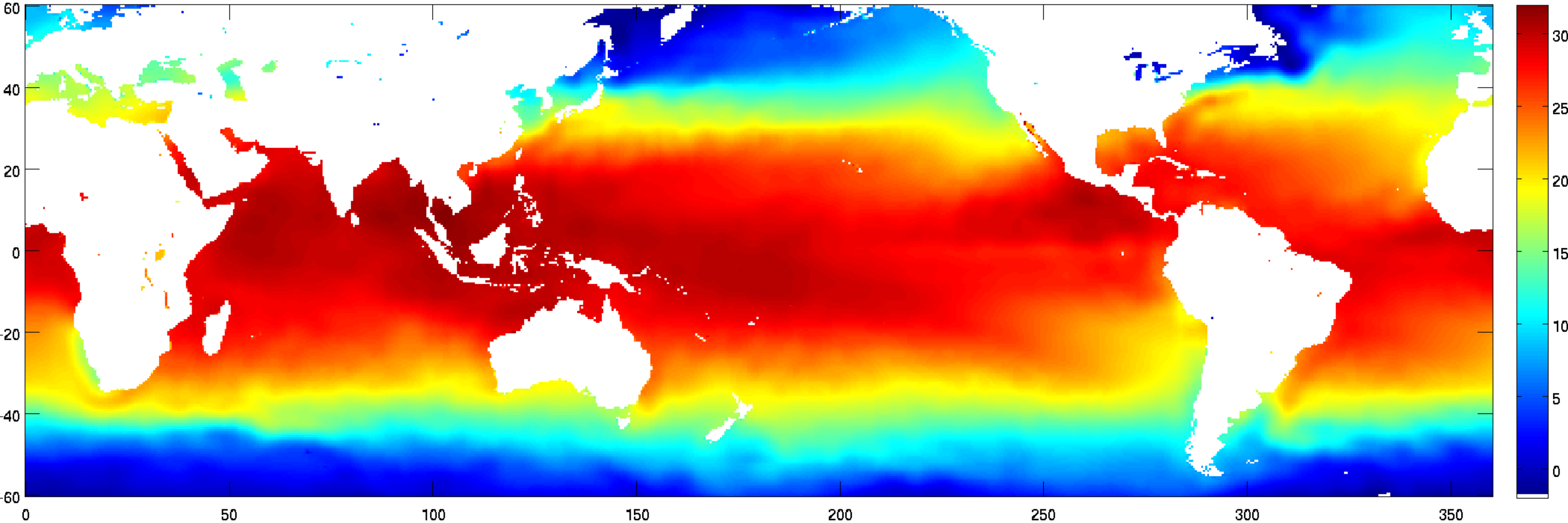

2m air temperature

# Diurnal Warming Correction - Sample Model Forcing Fields



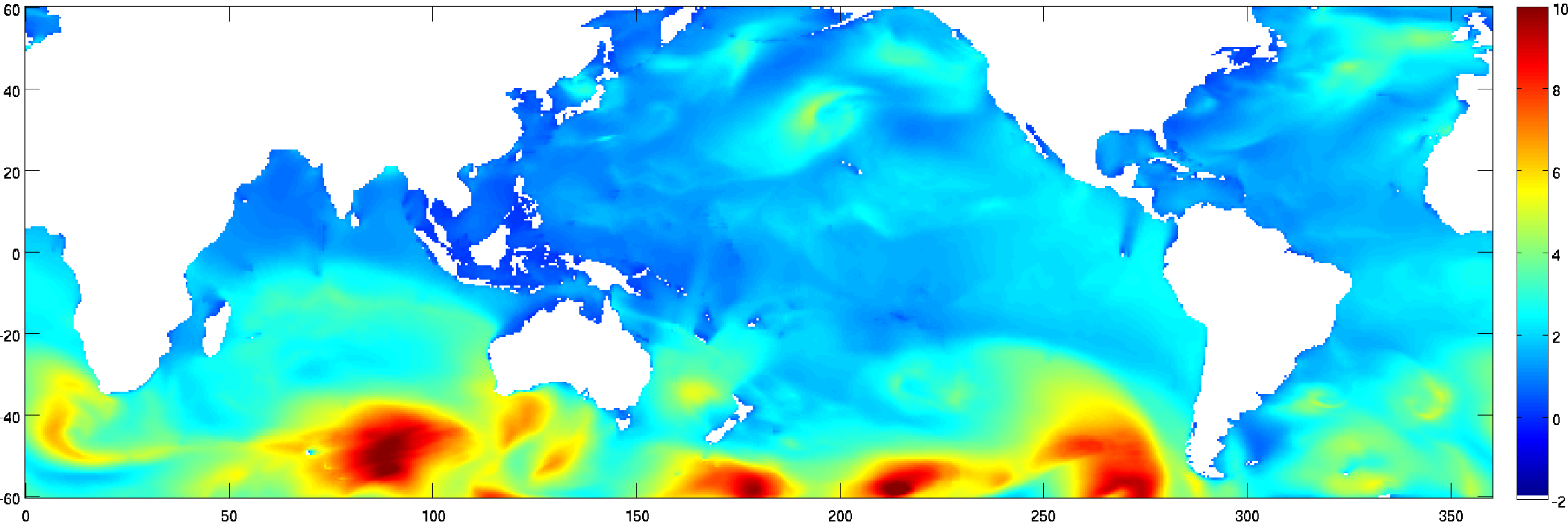

**2m specific humidity**

# Diurnal Warming Correction - Sample Model Forcing Fields



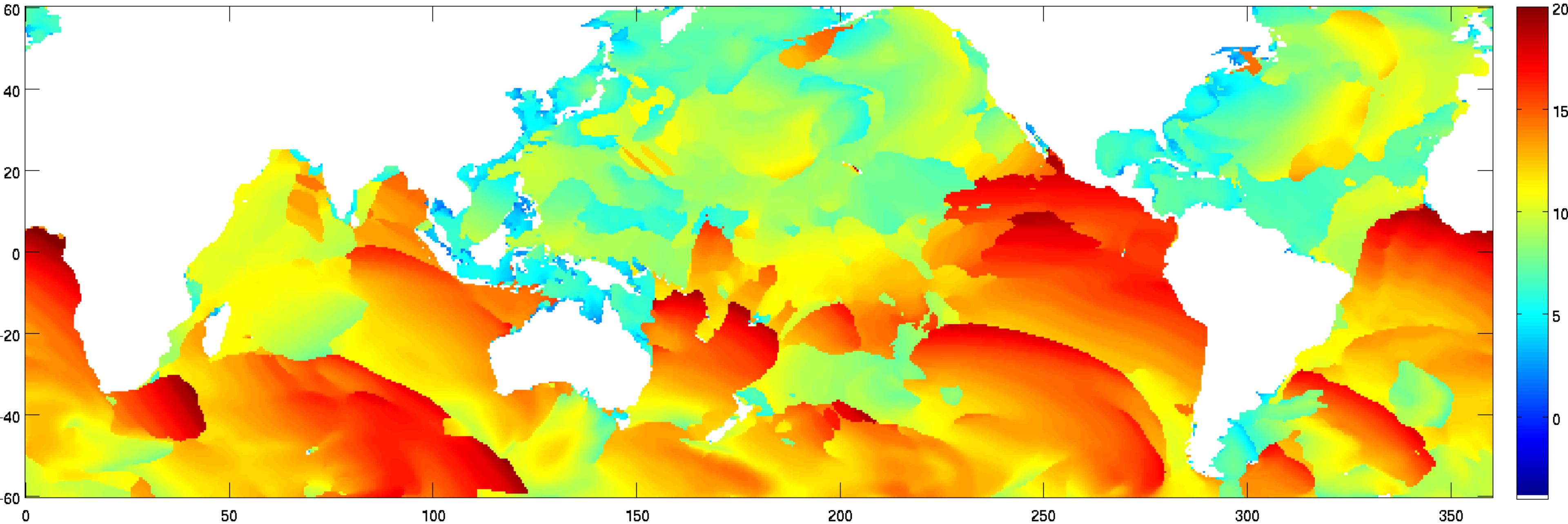

**NWP SST**

# Diurnal Warming Correction - Sample Model Forcing Fields



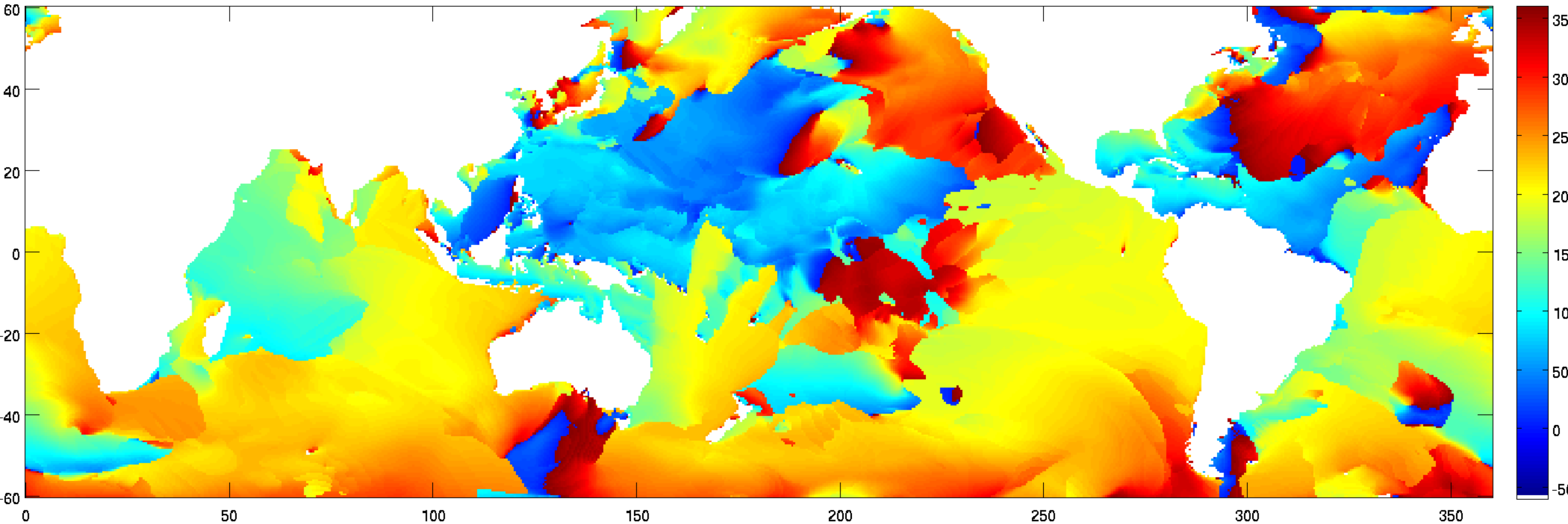

## Significant wave height

# Diurnal Warming Correction - Sample Model Forcing Fields




**Primary wave period**

# Diurnal Warming Correction - Sample Model Forcing Fields

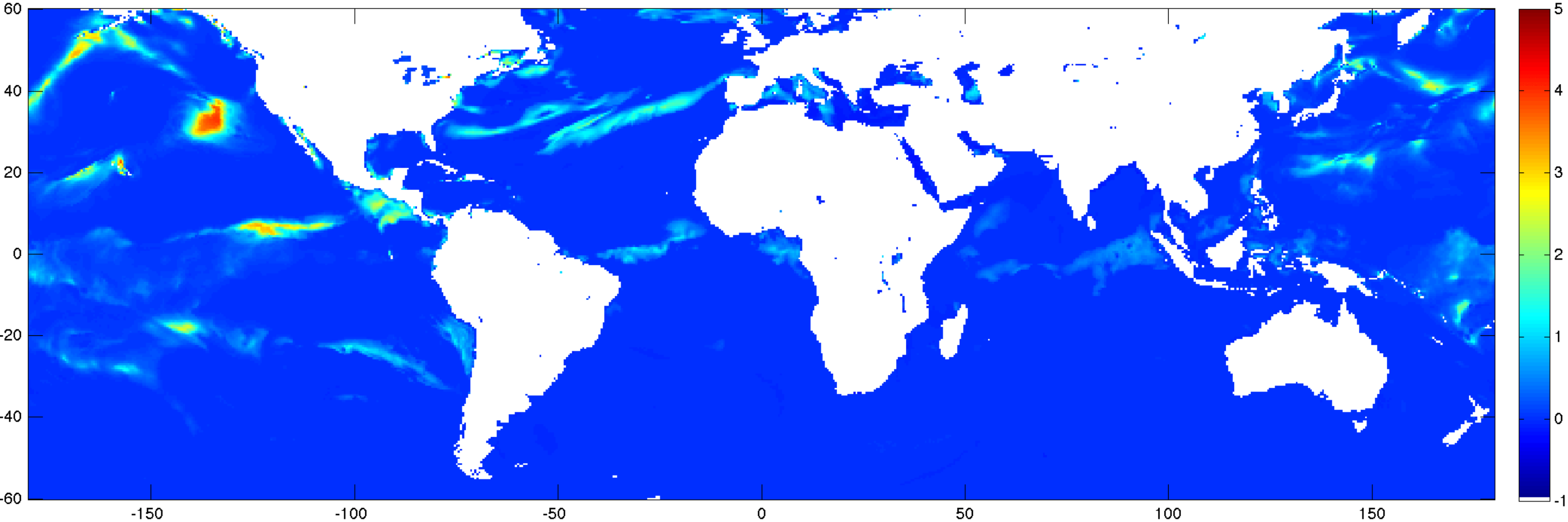



**Primary wave direction**

# Diurnal Warming – Flux Feedback Adjustment

- NCEP heat fluxes assume fixed SST
- In the presence of diurnal warming, the heat fluxes will change
- Use a simple "scaled bulk formulae" approach, e.g.:
  - » $Q_L = K_L u^*(Q_s - Q_a)$
  - » Determine $K_L$ from NCEP values of $Q_L$, $u^*$, $Q_s$ & $Q_a$
  - » Adjust $Q_L$ as $Q_s$ changes (a function of SST)
- Longwave heat flux simply changes as $\varepsilon\sigma T^4$
- Option to toggle flux feedback on/off

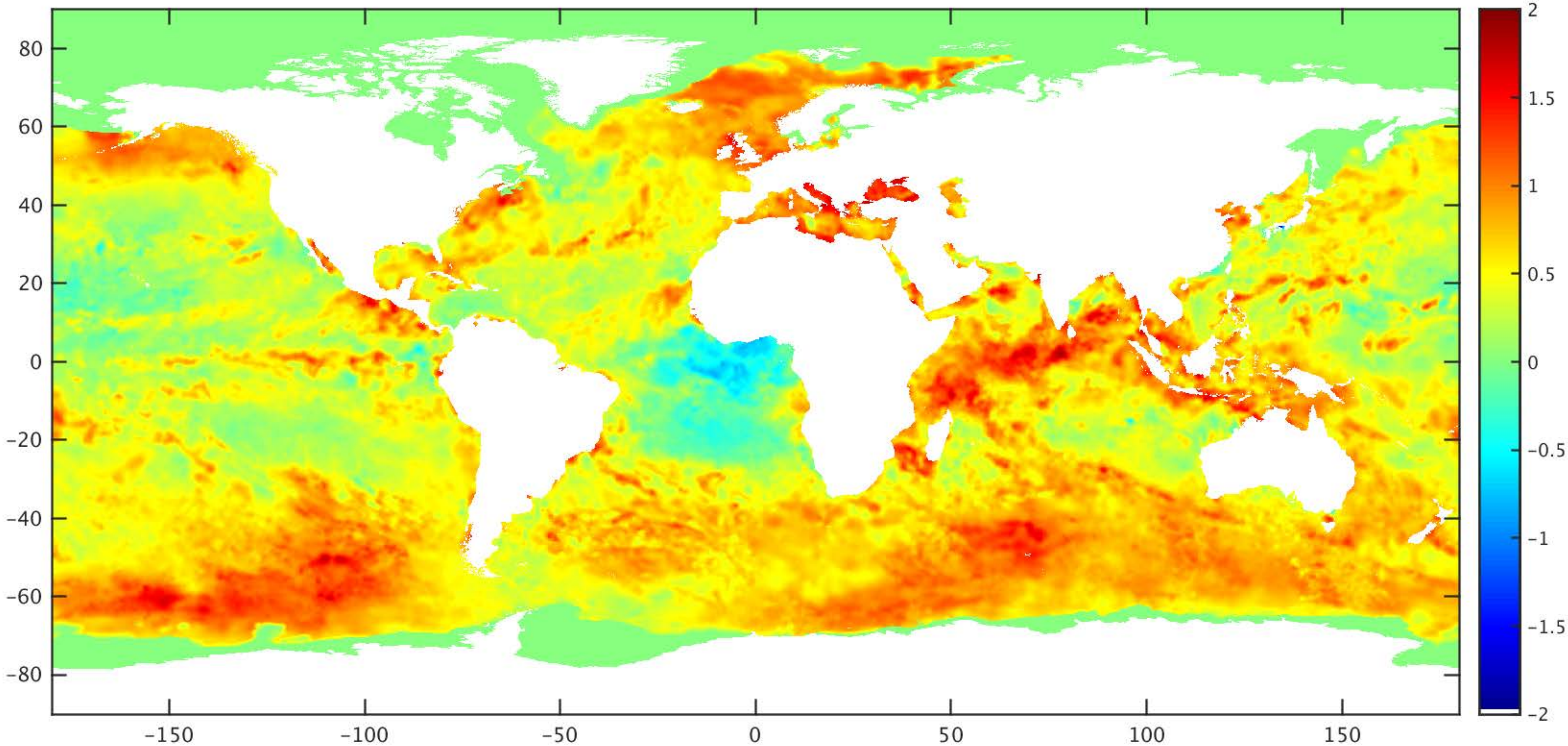
# Sample output




- Regions of >5 K warming
- Note, warming events on edge of ±60° limit

# Magnitude of warming

Example bias correction field VIIRS daytime




- **Bias correction usually <2 K**
- **Model response damped by including <u>gustiness parameterization</u>**
- **Why might the <u>observed</u> diurnal excursion be damped?**

# How sensitive is retrieved SST to true SST?

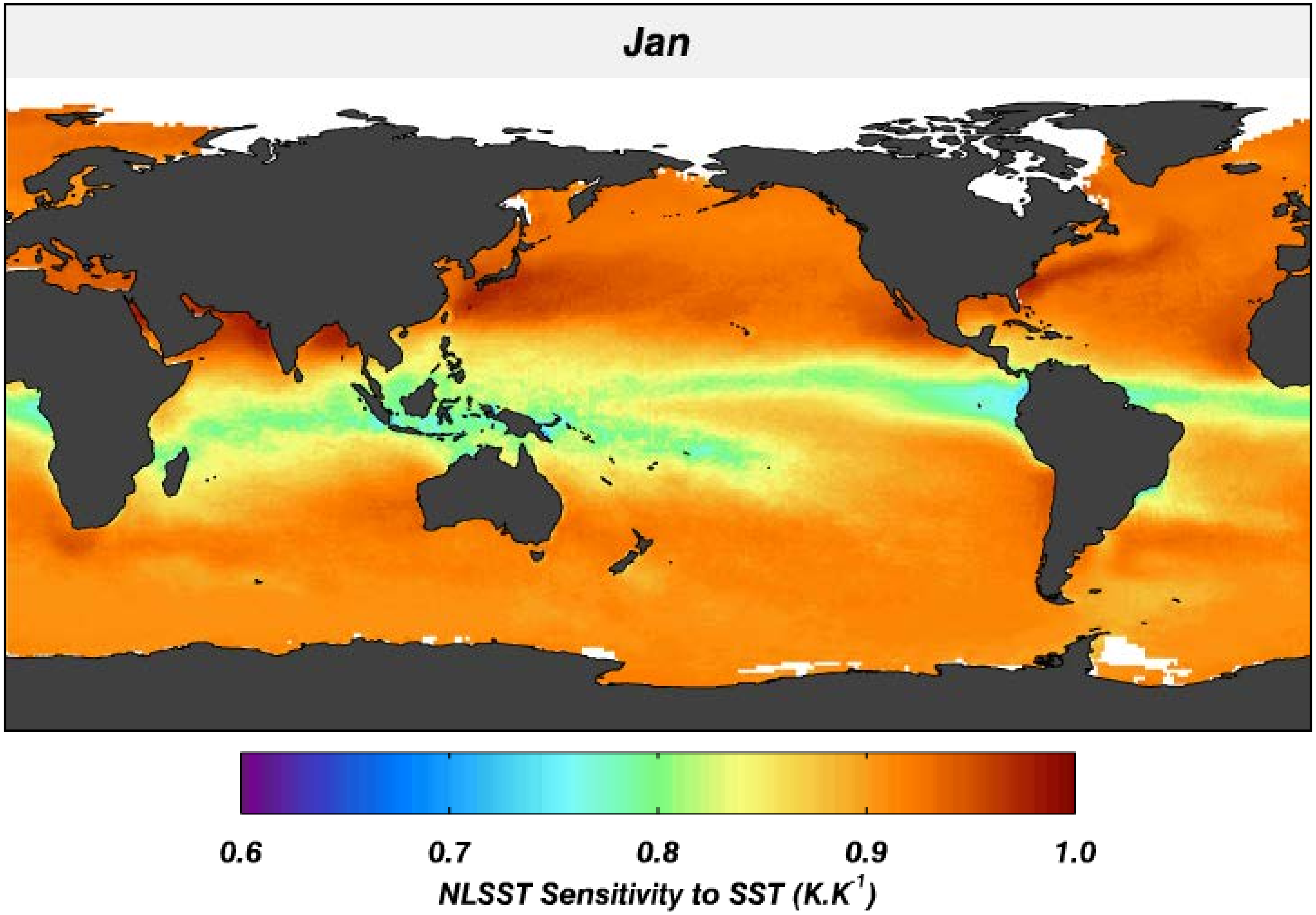
- If SST changes by 1 K, does retrieved SST change by 1 K?
- CRTM provides tangent-linear derivatives $\partial T_{11} / \partial SST_{\mathrm{true}}$ $\partial T_{12} / \partial SST_{\mathrm{true}}$

Response of **NLSST algorithm** to a change in **true SST** is…

$$\begin{aligned}\partial NLSST / \partial SST_{\mathrm{true}} = & \left(a_1 + a_2 \times SST_{bg} + a_3 \times \{\sec(ZA) - 1\}\right) \times \partial T_{11} / \partial SST_{\mathrm{true}} \\ & - \left(a_2 \times SST_{bg} + a_3 \times \{\sec(ZA) - 1\}\right) \times \partial T_{12} / \partial SST_{\mathrm{true}}\end{aligned}$$

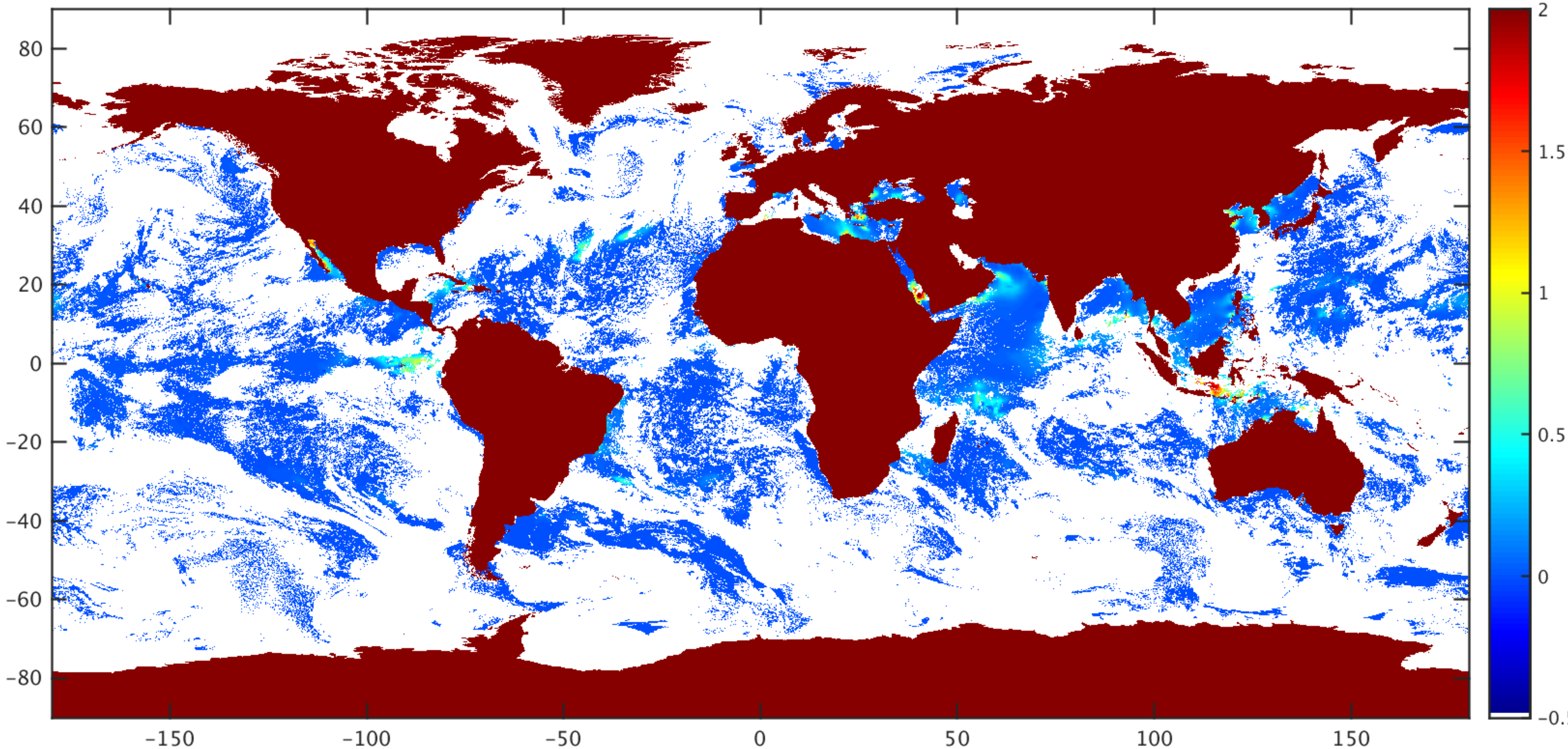
Merchant, C.J., A.R. Harris, H. Roquet and P. Le Borgne, Retrieval characteristics of non-linear sea surface temperature from the Advanced Very High Resolution Radiometer, Geophys. Res. Lett., **36**, L17604, 2009

# Sensitivity to true SST



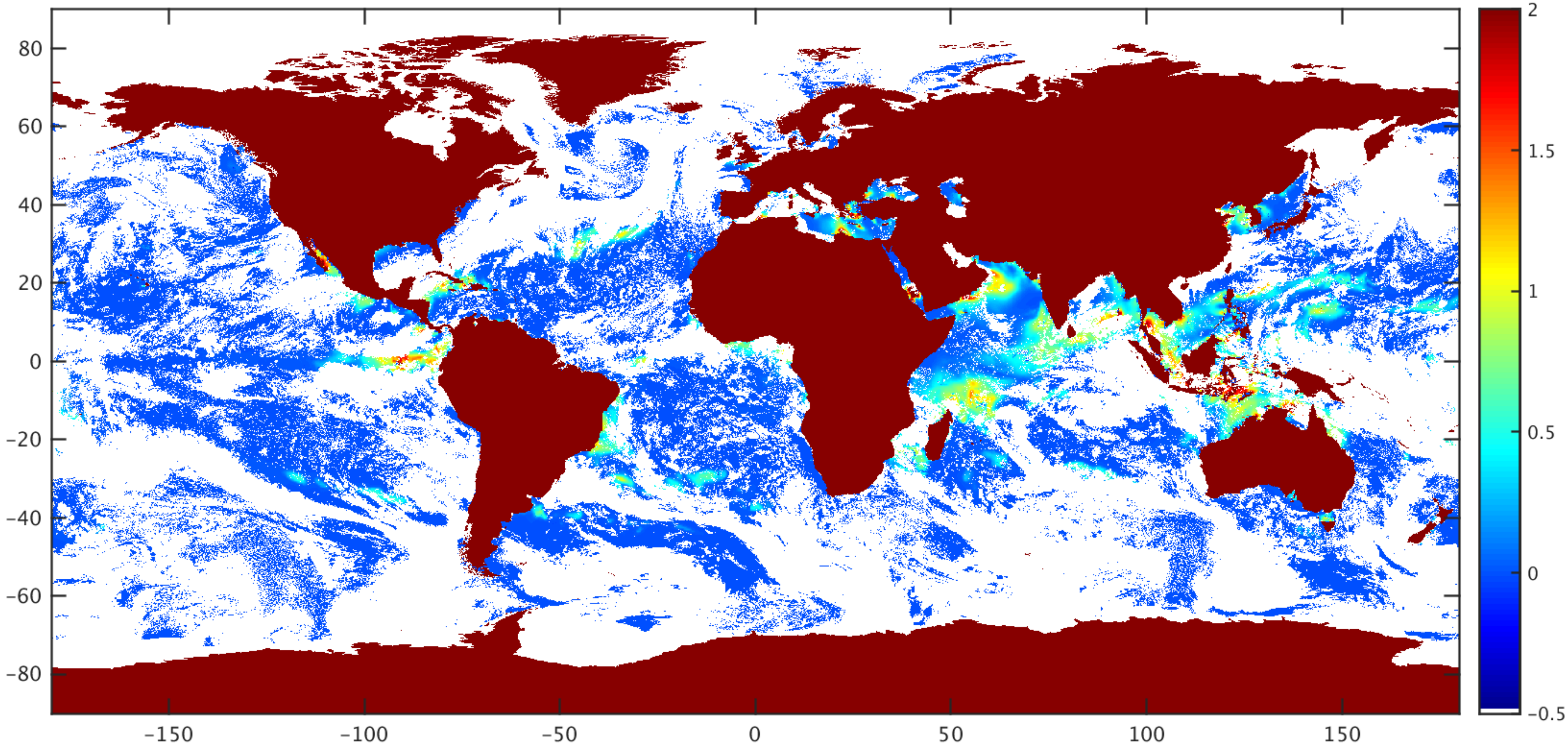

Sensitivity often <1 and changes with season

# Effect of diurnal adjustment on input data



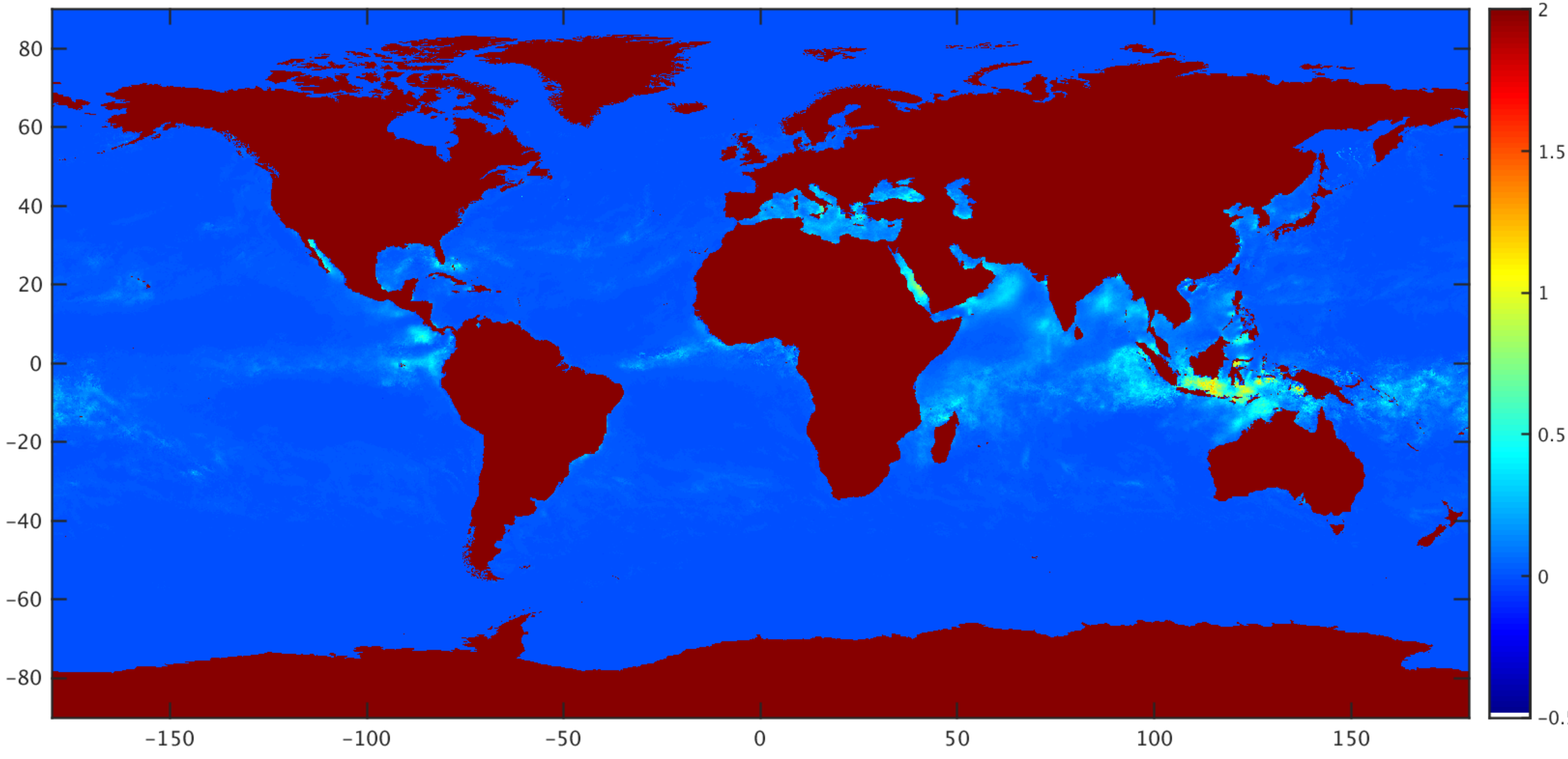

- **METOP adjustments are fairly modest**

# Effect of diurnal adjustment on input data



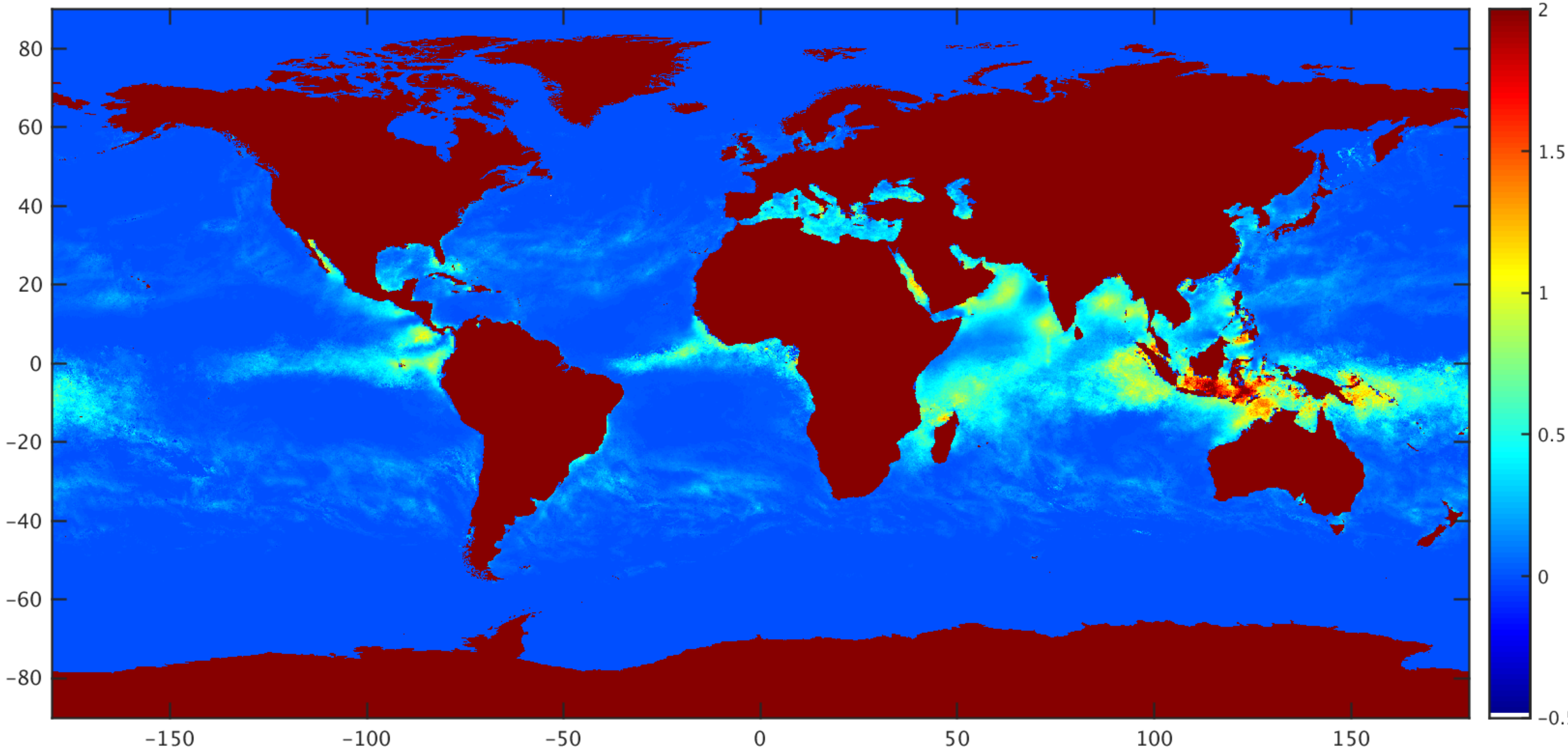

- **VIIRS adjustments are more significant**

# Effect of diurnal adjustment on input data



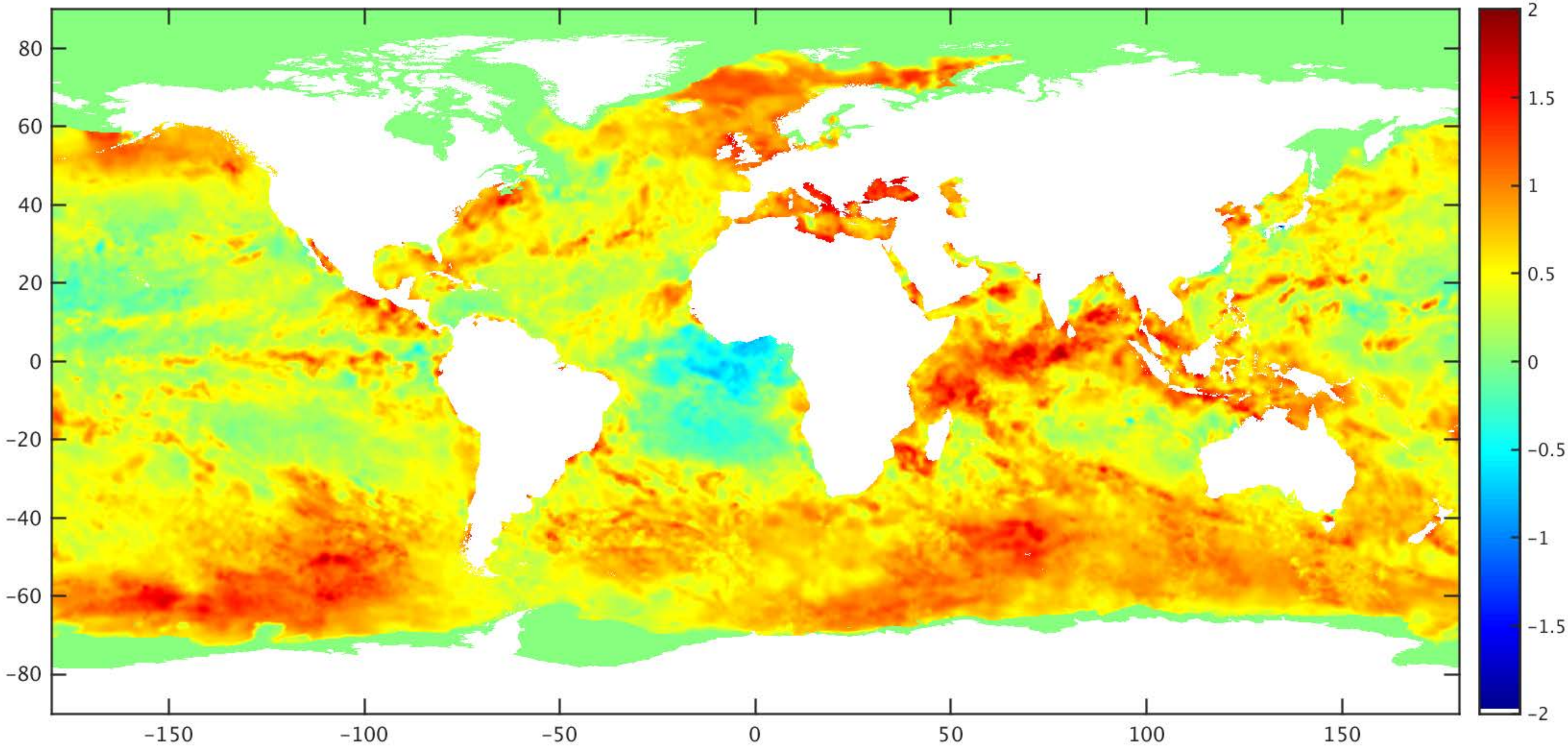

- **METOP monthly average for March 2016**

# Effect of diurnal adjustment on input data



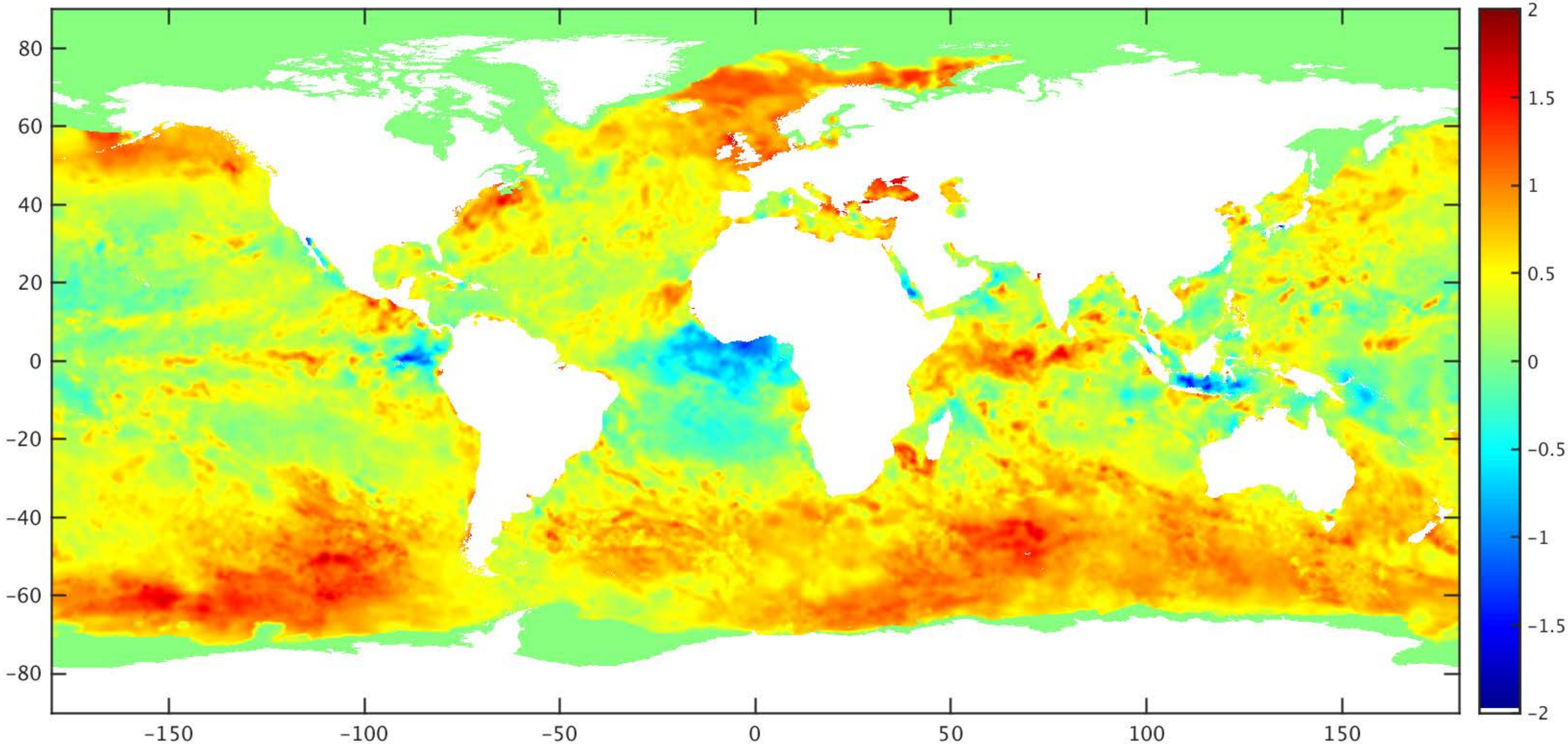

- **VIIRS monthly average for March 2016**

# Effect of diurnal adjustment on bias correction



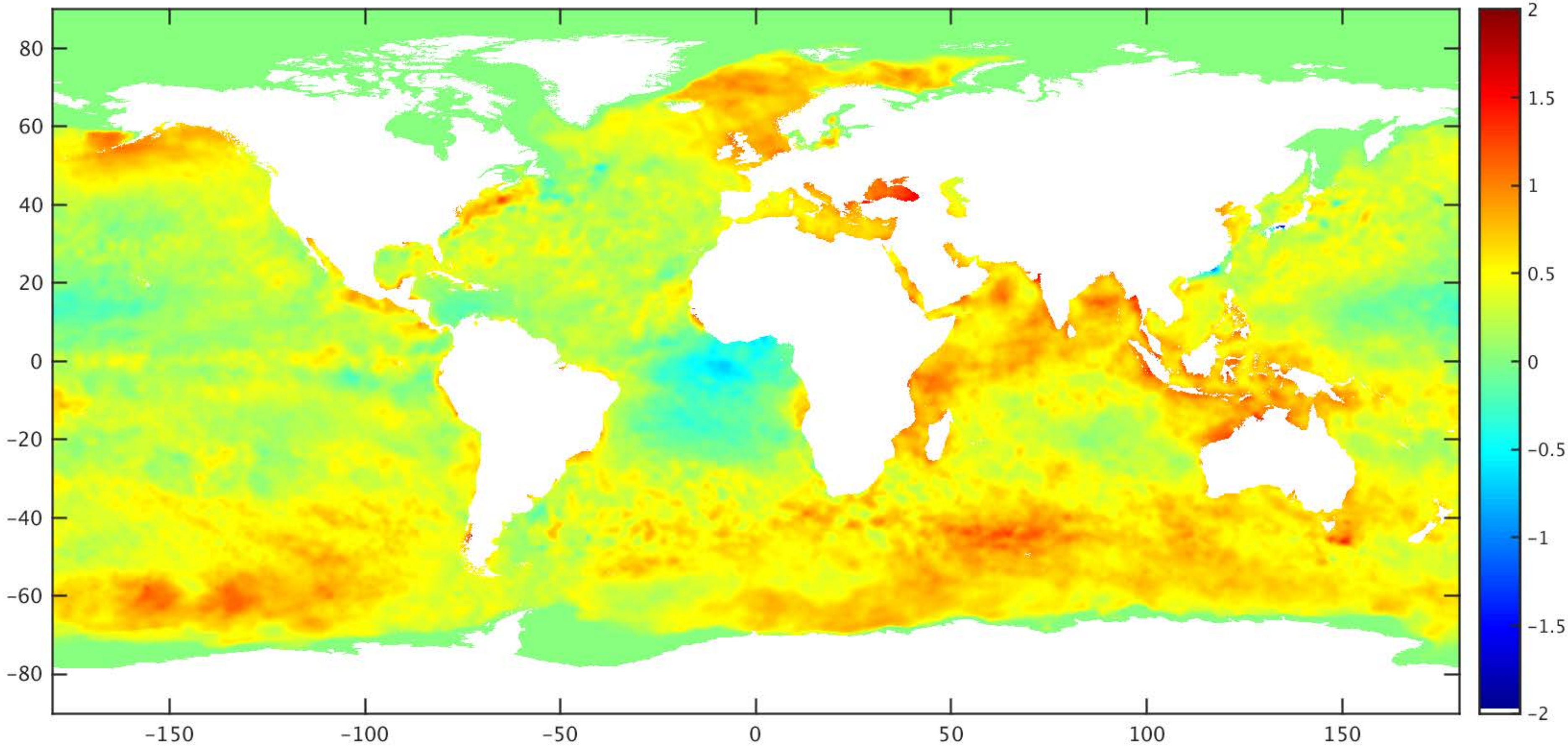

- **Unadjusted VIIRS (2016-03-21)**

# Effect of diurnal adjustment on bias correction



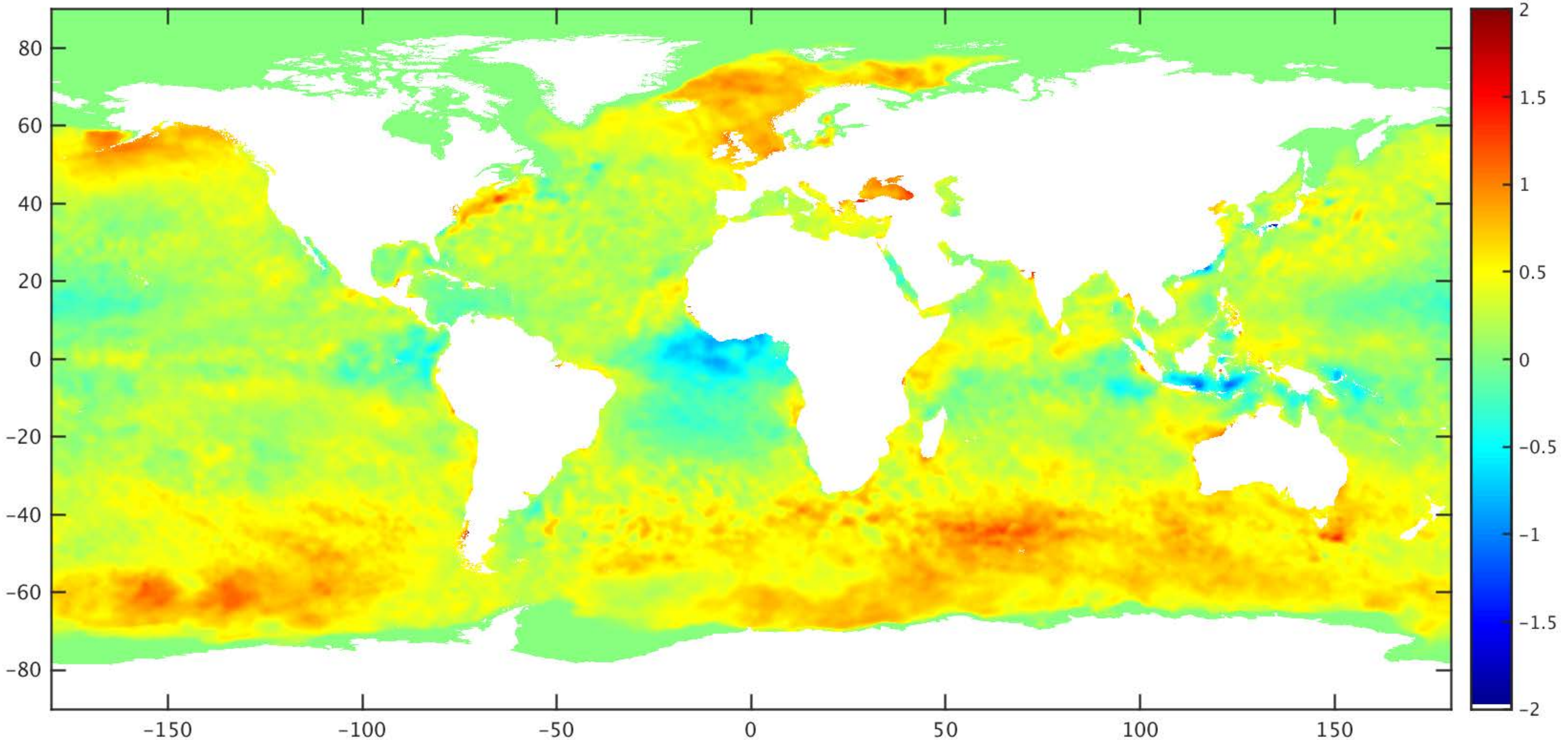

- **Diurnally adjusted VIIRS (2016-03-21)**

# Effect of diurnal adjustment on bias correction



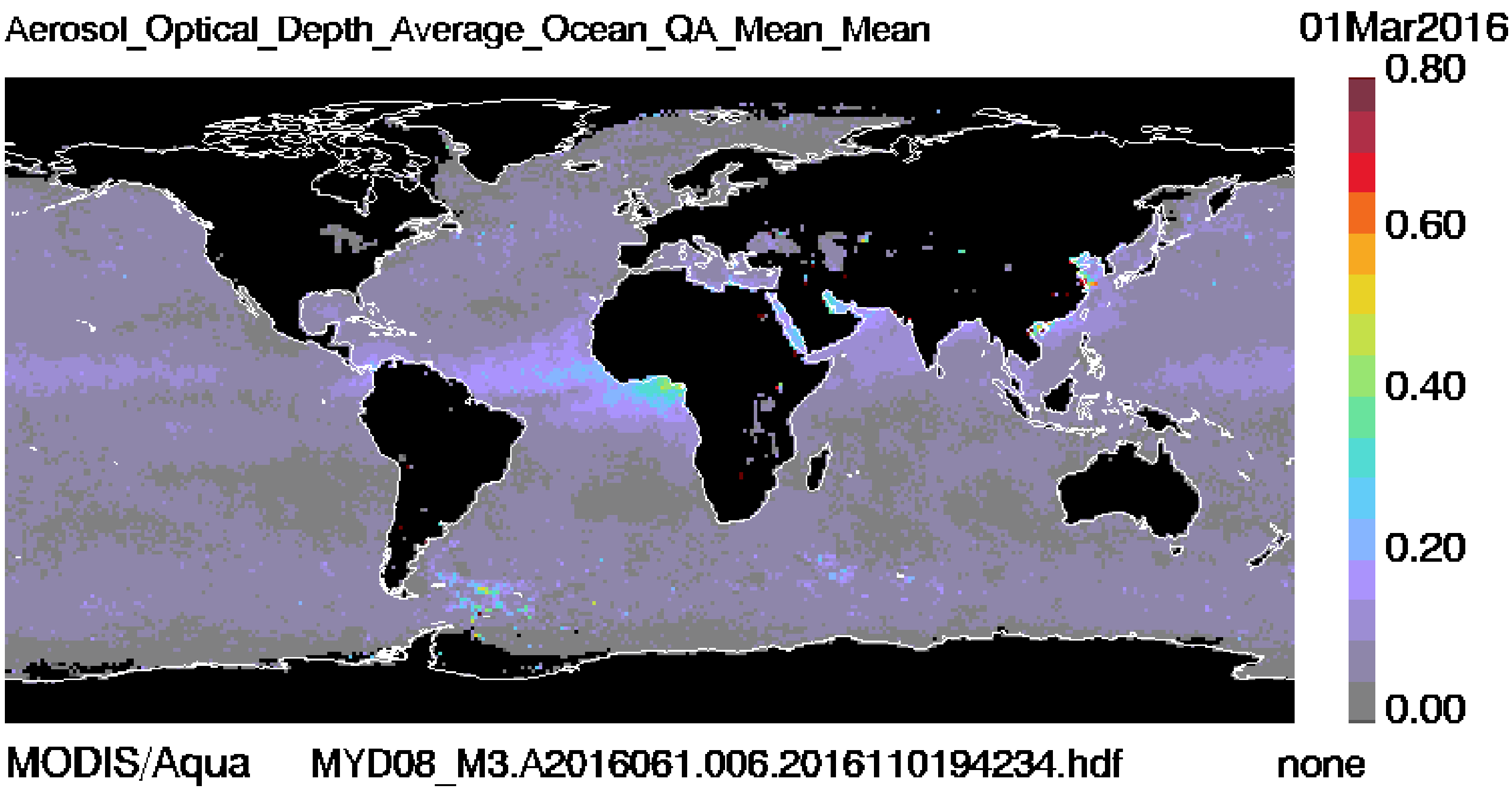

- **Unadjusted monthly average VIIRS**

# Effect of diurnal adjustment on bias correction



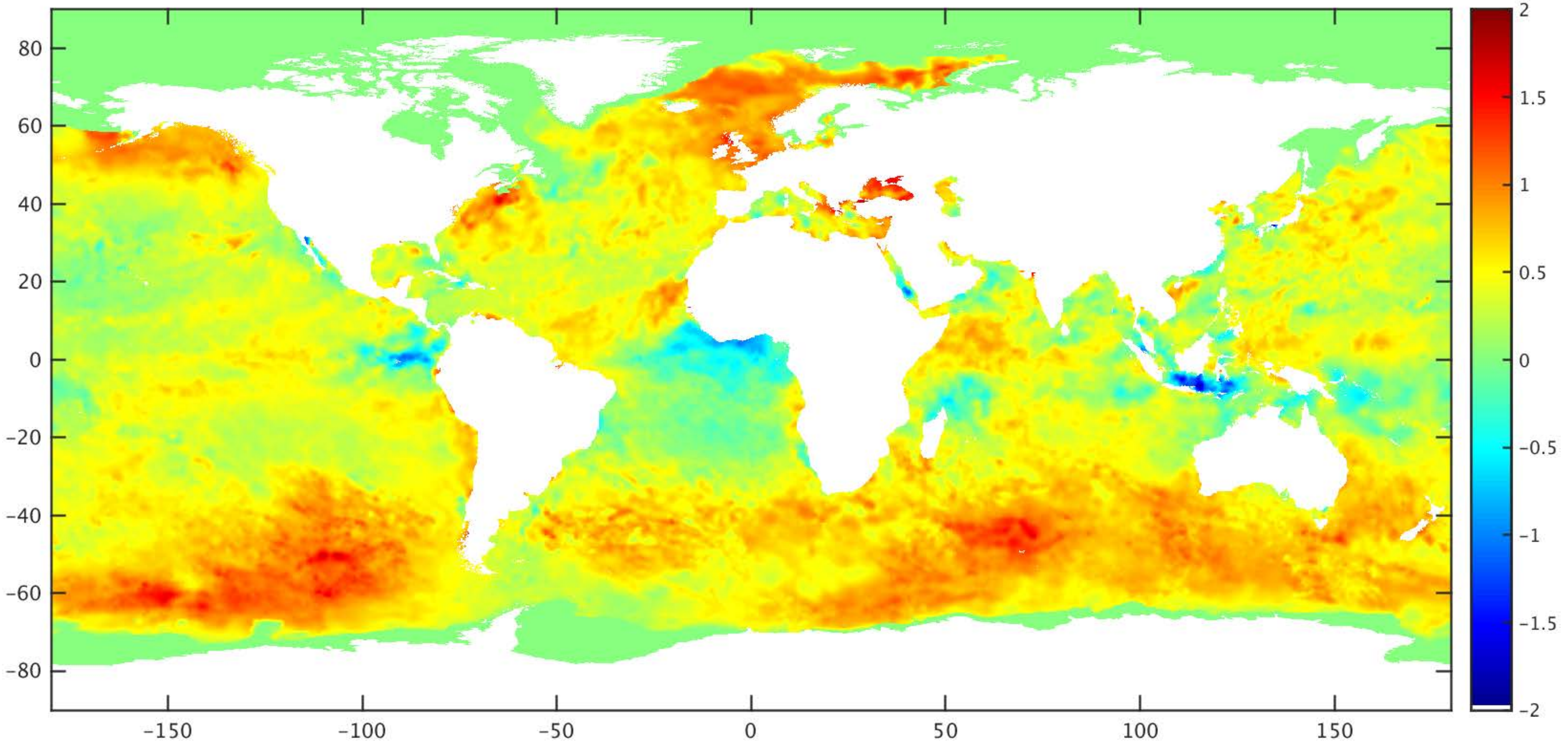

- **Diurnally adjusted monthly average VIIRS**

# Retrieval biases – aerosol?



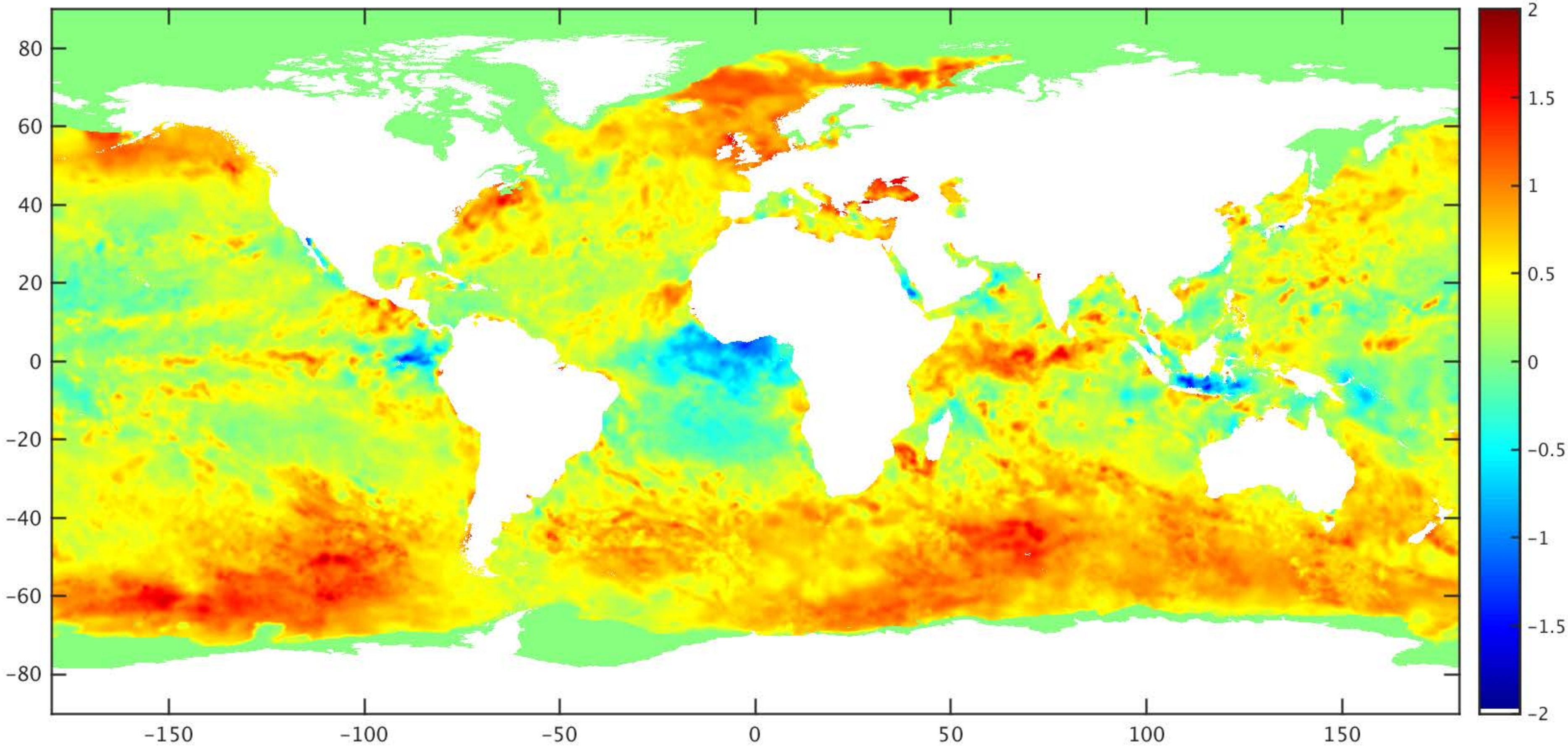

- **MODIS-A mean aerosol, Mar 2016**
- **Other atmospheric factors, *e.g.* water vapour loading**

# Effect of diurnal adjustment on bias correction



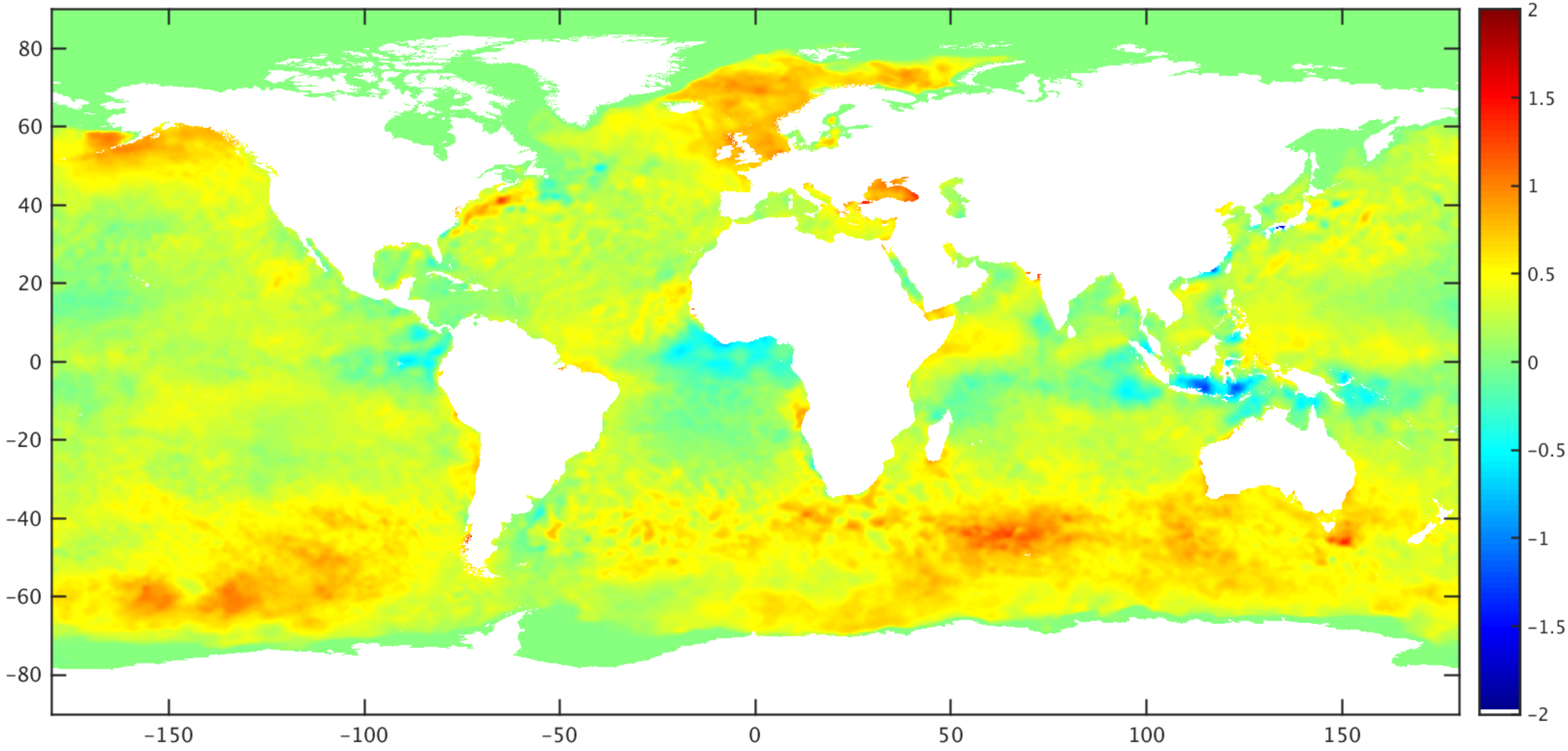

- **Diurnally adjusted VIIRS + SSES Bias (2016-03-21)**

# Effect of diurnal adjustment on bias correction



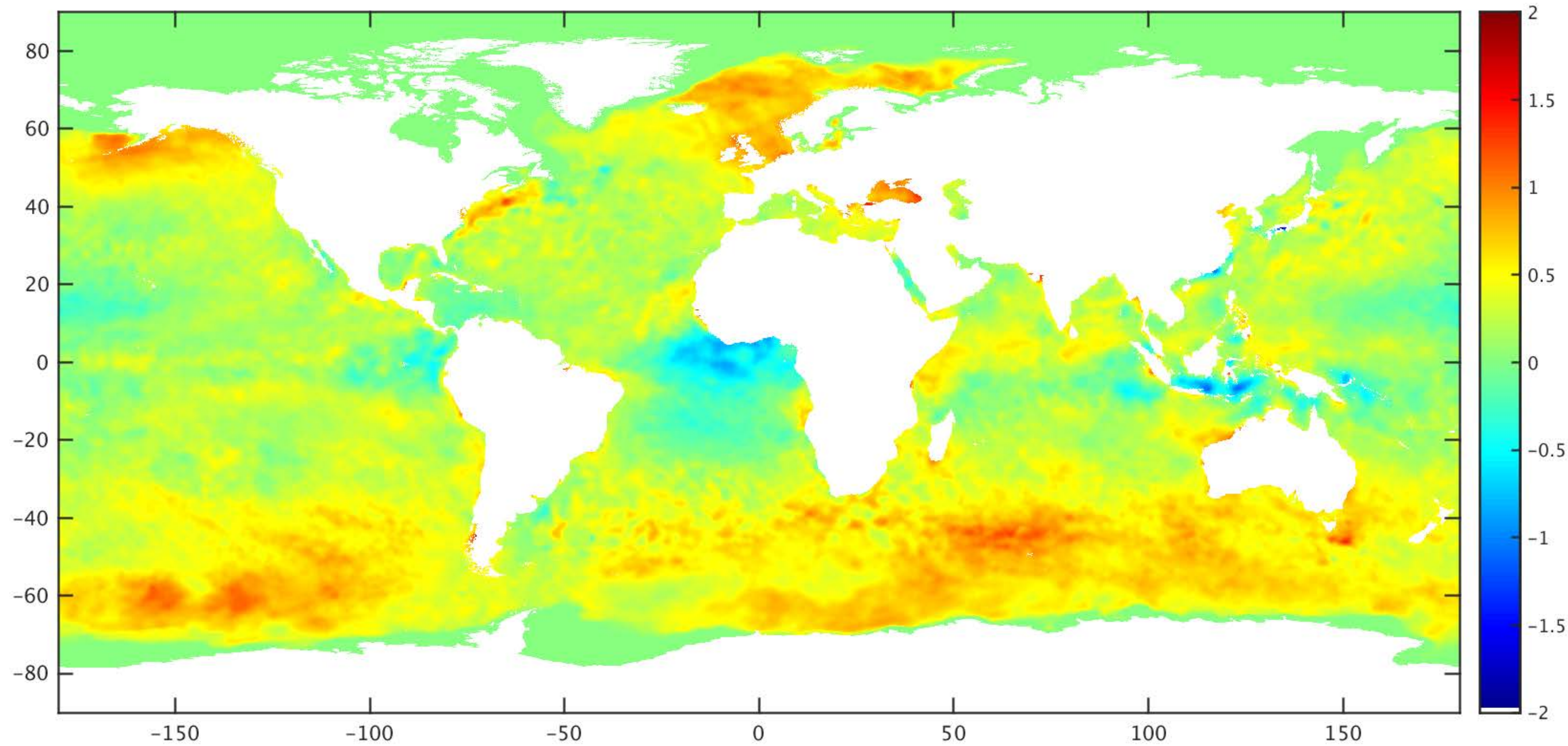

- **Diurnally adjusted VIIRS (2016-03-21)**

# Effect of diurnal adjustment on bias correction




- **Diurnally adjusted monthly average VIIRS + SSES Bias**

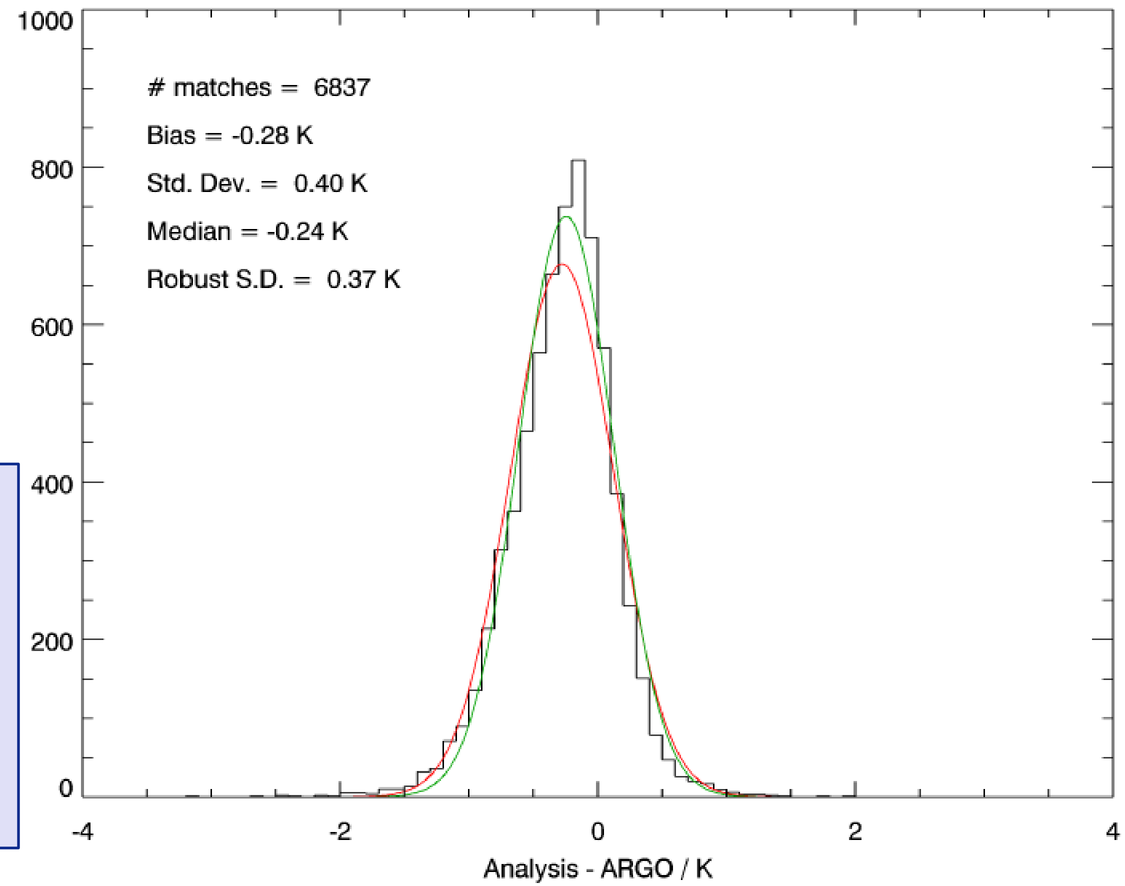
# Effect of diurnal adjustment on bias correction




- **Diurnally adjusted monthly average VIIRS**

# Validation vs ARGO

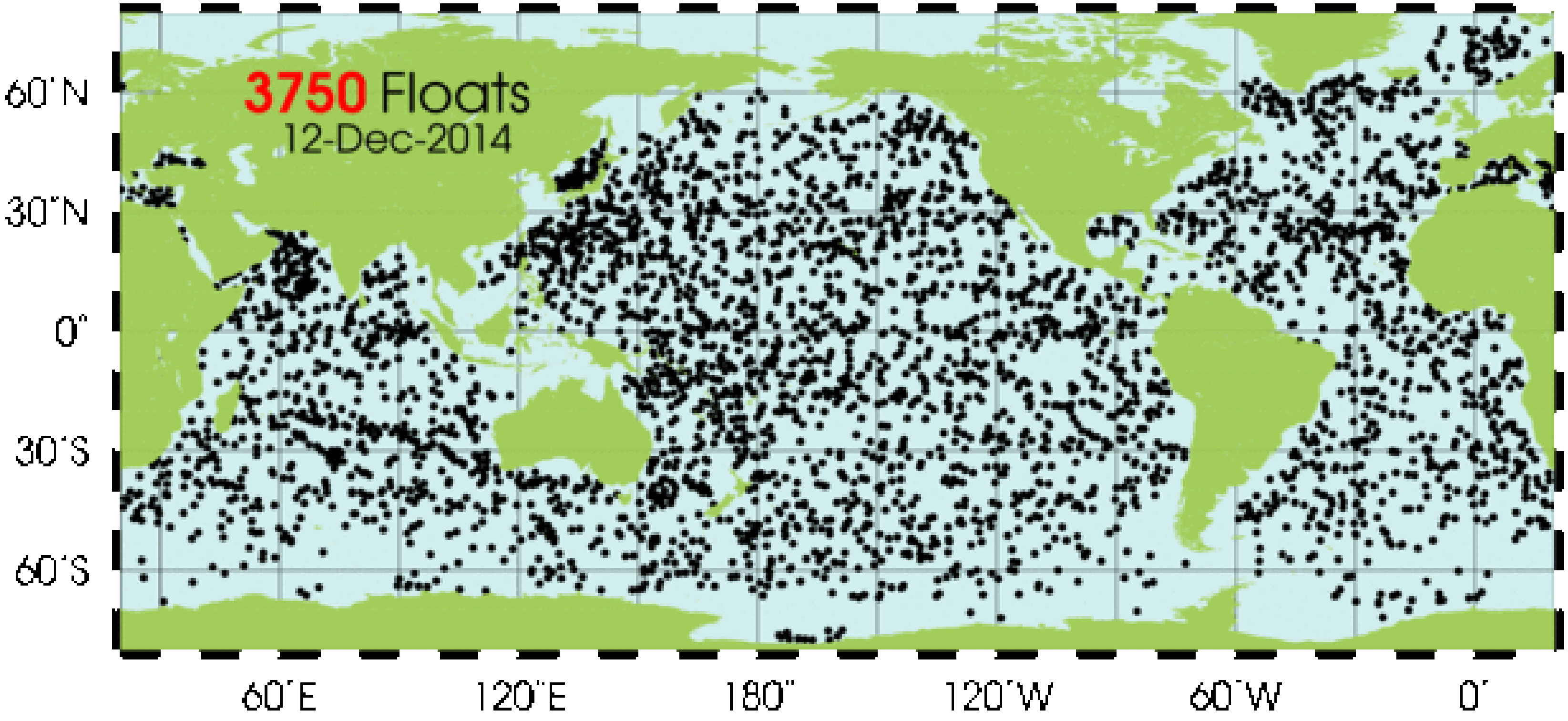
- March 2016
- iQuam QC
- 3 – 7 m depth



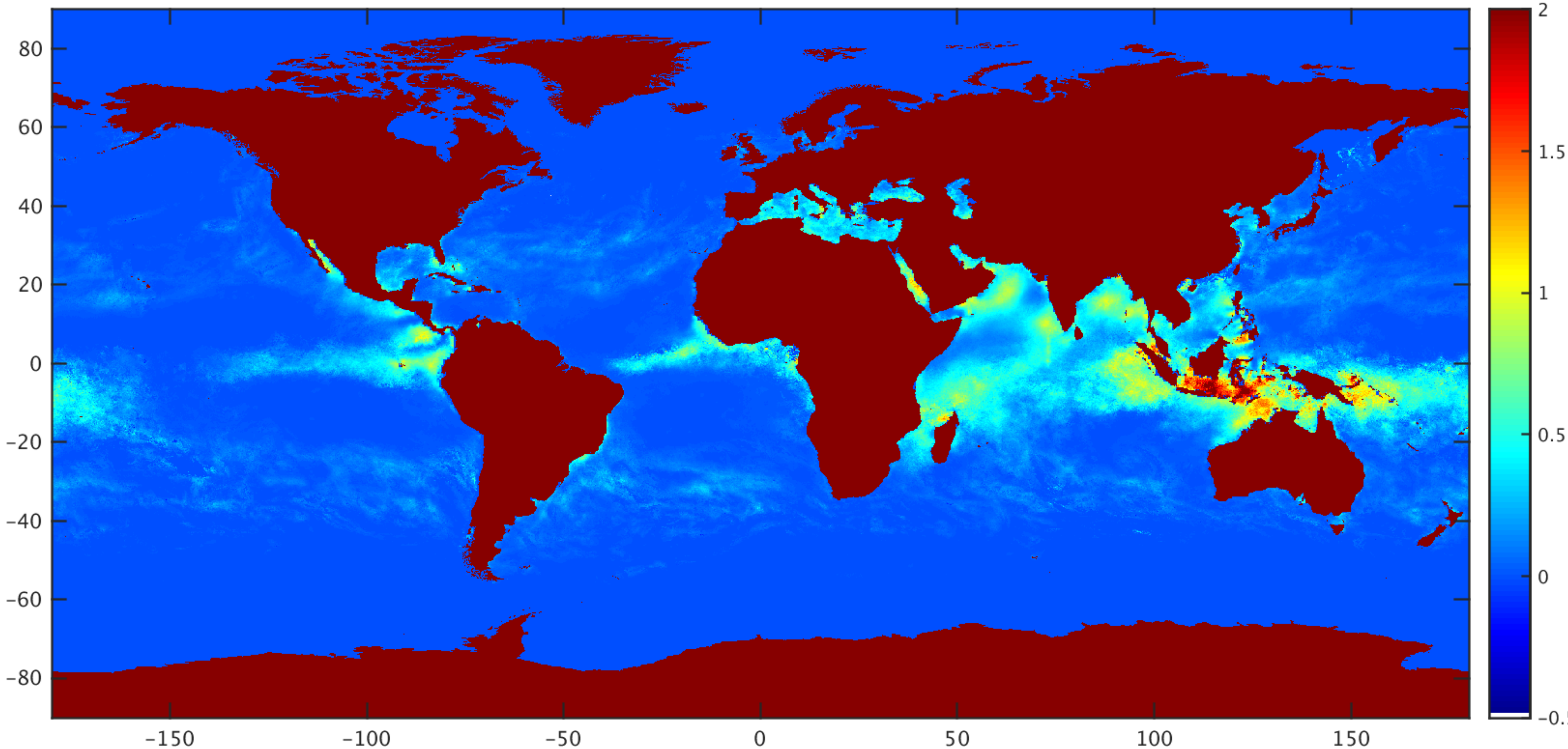

**Global: -0.28±0.40 (0.37)**
**30+°N: -0.40±0.46 (0.36)**
**<|30°|: -0.18±0.36 (0.30)**
**30+°S: -0.40±0.41 (0.37)**

***N.B.*** **Virtually identical statistics to uncorrected analysis!**

# Locations of currently active ARGO floats



# Effect of diurnal adjustment on input data




- **VIIRS monthly average for March 2016**

# Summary

- **NOAA produces all the L2 data that go into the analysis**
  - Polar data – ACSPO regression SST
  - Geostationary – Bayesian cloud + MTLS Physical retrieval
  - *N.B.* Convergence on ACSPO means Himawari-8 is ACSPO
  - AMSR-2 SST will be processed with NOAA GAASP algorithm
- **L4 SST analysis continues to be improved**
  - Data-adaptive correlation length **preserves features without introducing excessive noise**
  - 5-km noticeably better than 11-km (mesoscale oceanography)

# Summary cont'd

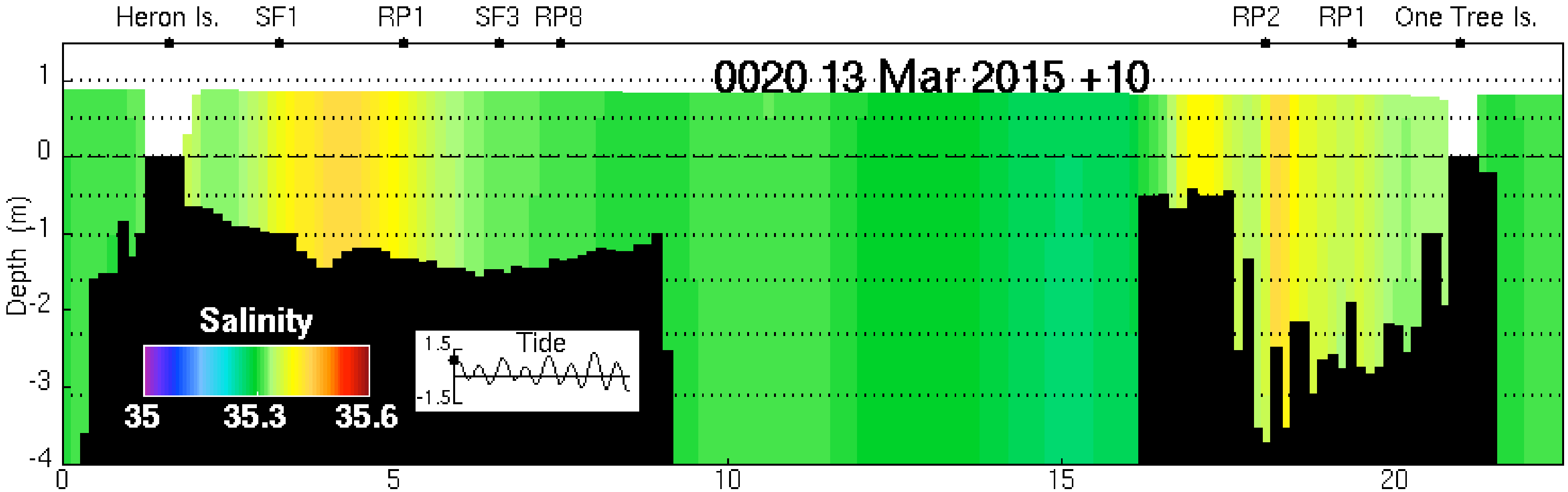
- **Diurnal correction with turbulence model & Stokes' Drift**
  - Beneficial for applications that depend on SST at depth (*e.g.* CRW)
  - Daytime SST retrieval may not see full scope of DW, especially in tropics
    - Need pixel-based estimates of algorithm sensitivity
    - Boris Petrenko has been working on this
  - Gustiness parameter damps warming (too much?)
    - Partly a work-around for above issue
  - Other regional algorithm biases
    - On balance, using SSES bias + diurnal adjustment is better
- **Validation vs ARGO**
  - Headline results are good…
  - …but diurnal adjustment has negligible impact
  - Analysis bias correction scheme due for update
    - Particularly using Sentinel-3 SLSTR

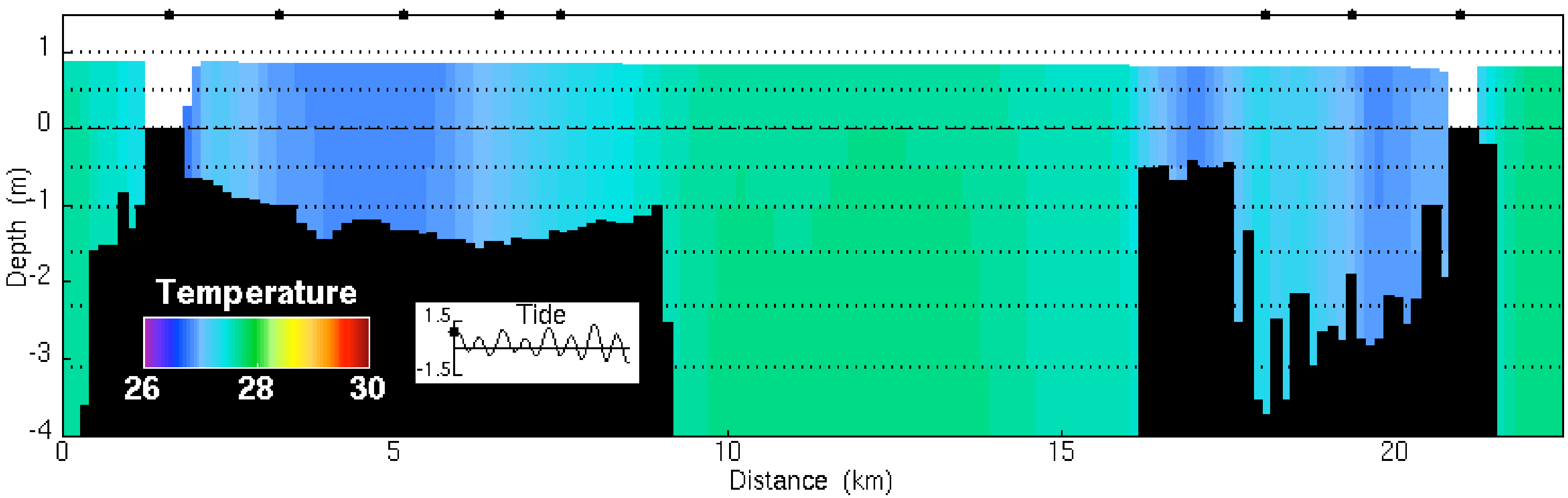
# The way ahead for corals?

- **Assimilate into hi-res model**
  - Account for tidal motion/mixing
  - Capture full diurnal behavior

# CAPRICORNIA HYDRODYNAMIC MODELLING

## Heron - One Tree Section




NRT

Last updated : 19-Mar-2015 04:35:08

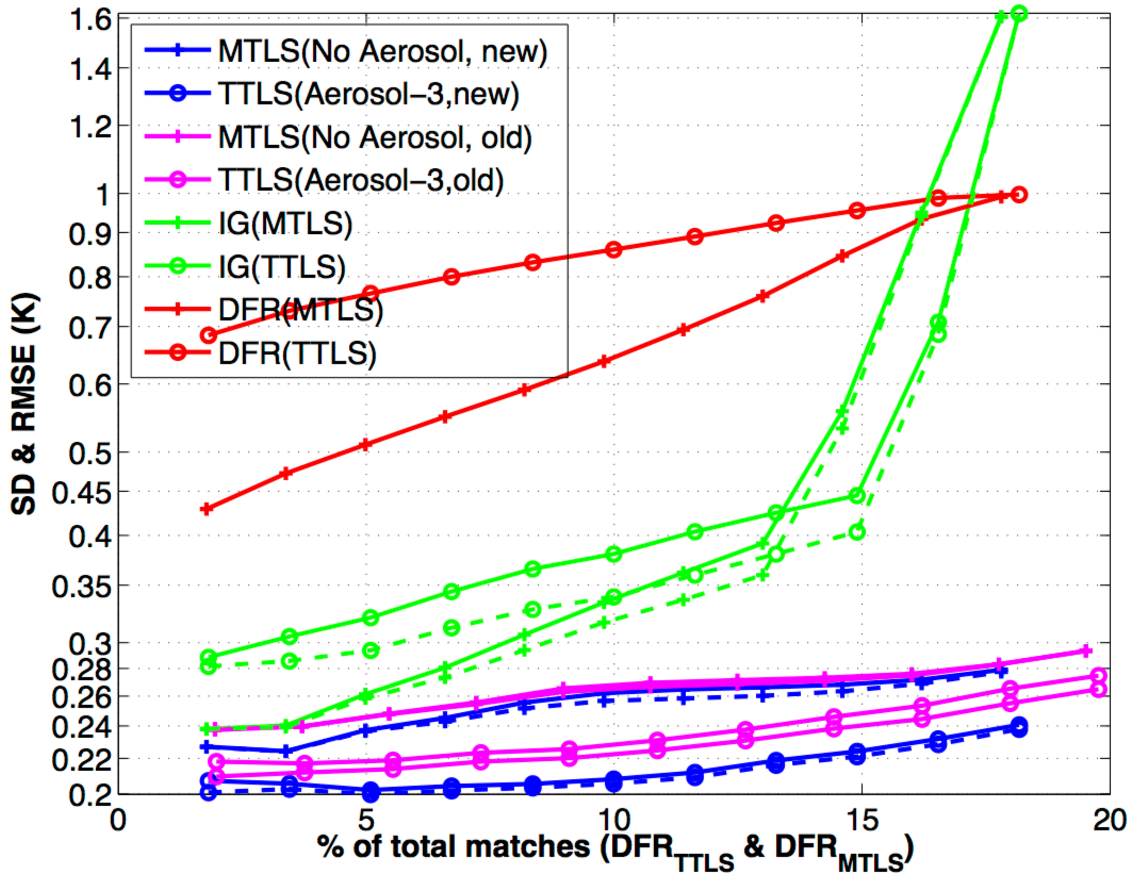
# Backup slides

# MODIS: Addition of aerosol

- **Put aerosol information in the CRTM**
  - NGAC profiles, multiple species (dust, salt, sulfate, soot)
  - Improve match of RTM to observation
  - Does this improve retrieval?
- **Put aerosol in the retrieval vector**
  - Allow Total Column Aerosol to vary
  - $\boldsymbol{x} = [\mathrm{SST}, \mathrm{WV}, \mathrm{TCA}]^T$
  - Jacobian now includes ∂T/∂TCA for each channel
  - Does this improve retrieval?
- **MTLS developed for 2-parameter retrieval**
  - Try different regularization operator since problem is now more ill-conditioned: **Truncated Total Least Squares (TTLS)**

$$|\Delta \boldsymbol{y}| \leq 1:\ \lambda = (\sigma_{end-1})^2 \qquad |\Delta \boldsymbol{y}| > 1:\ \lambda = (\sigma_{end-1}/\log(|\Delta \boldsymbol{y}|))^2$$

# Inclusion of aerosol




- **Accuracy with TTLS & joint [SST, WV, TCA] ~0.2 K**
- **Algorithm sensitivity is also improved *cf.* MTLS**

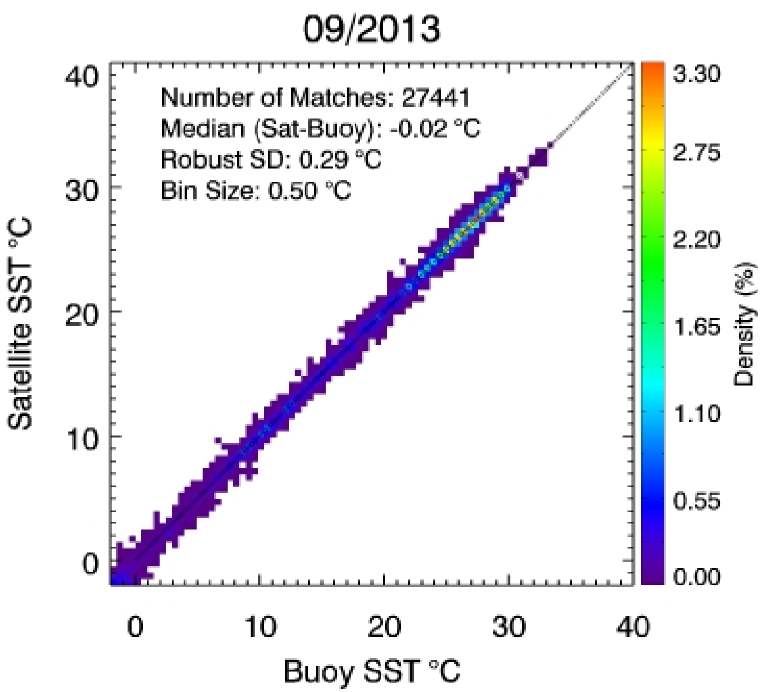
# Reprocessing

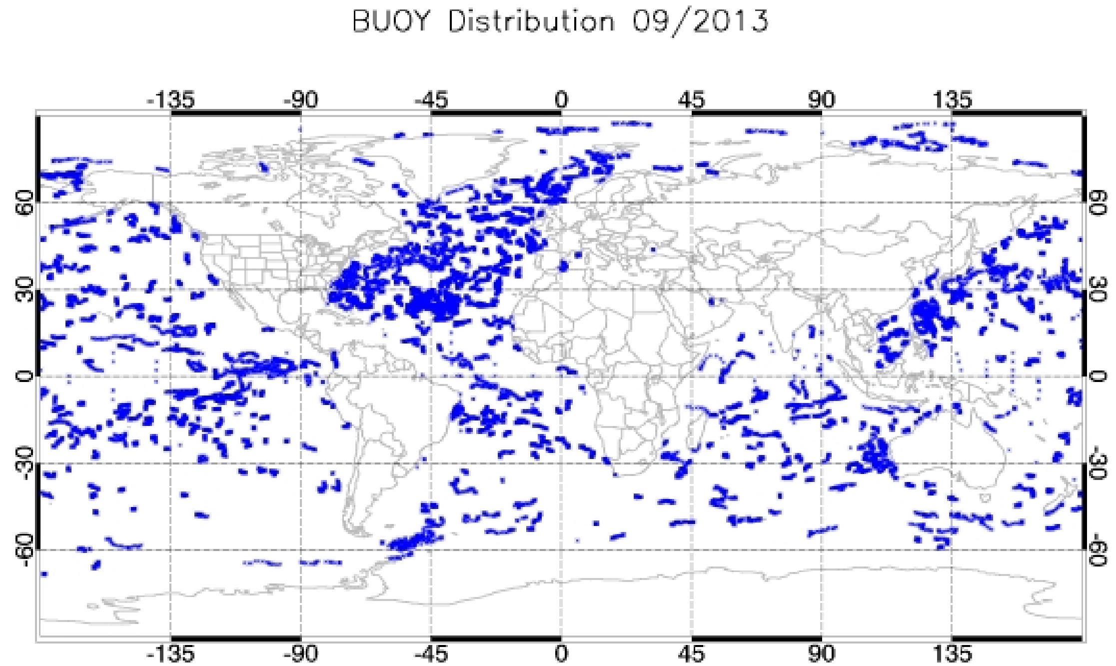
- **Some <u>operational</u> products depend on anomalies w.r.t. a baseline**
  - *E.g.* NOAA Coral Reef Watch
- **Geo-Polar SST analysis September 2004 – present**
  - Captures some major bleaching events
  - Sufficient to retune bleaching thresholds
  - **<u>Requires input data to be reprocessed as well</u>**
- **Datasets**
  - NOAA AVHRR (METOP, NOAA)
  - GOES-E/W (8, 10, 11, 12, 13, 15)
  - MTSAT-1R, MTSAT-2, GOES-9
  - Meteosat-8/9/10
  - Ancillary NWP

**~200 TB**

- **Should be complete by March 2016**

# Product Accuracy




Median bias (analysis – buoy) -0.02 K

Robust Standard Deviation 0.29 K

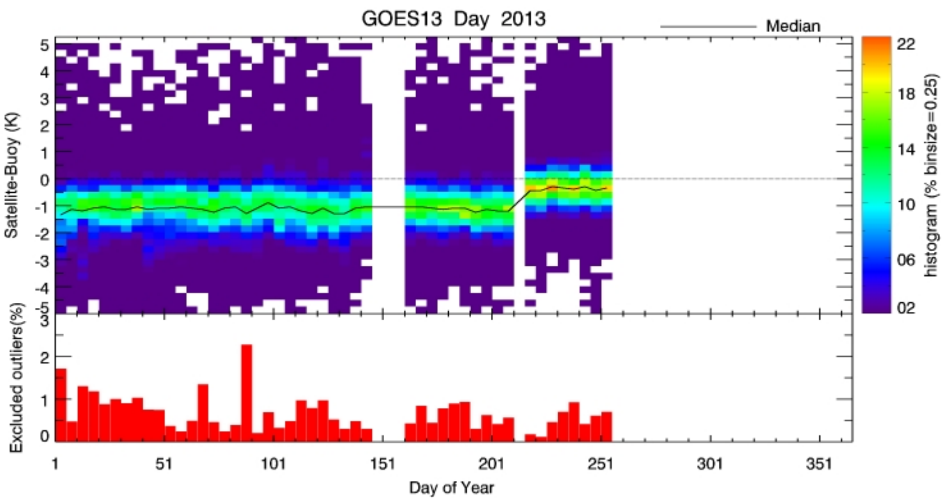
*N.B.* Robust Standard Deviation = (75% - 25%)/1.349

# Recent update to Geo-SST

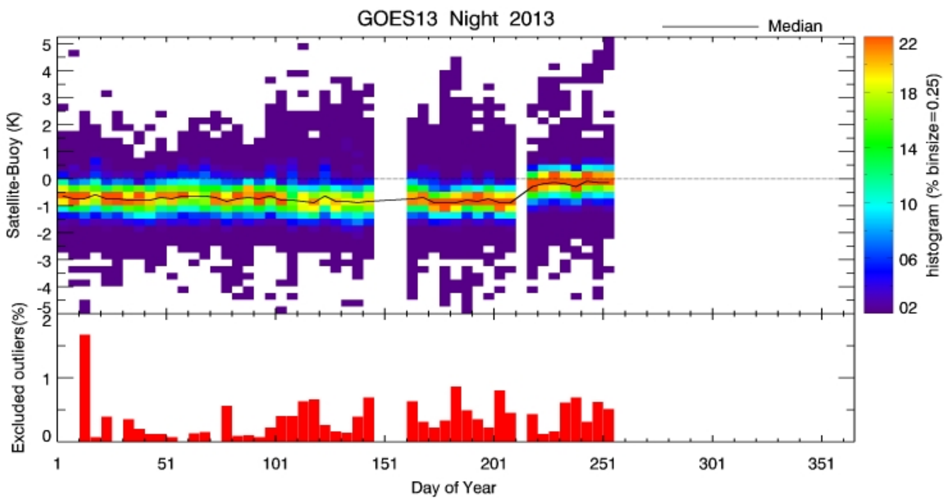
- **Physical retrieval based on Modified Total Least Squares**
- **Improved bias and scatter *cf.* previous regression-based SST retrieval**

**GOES-13**

**Daytime**



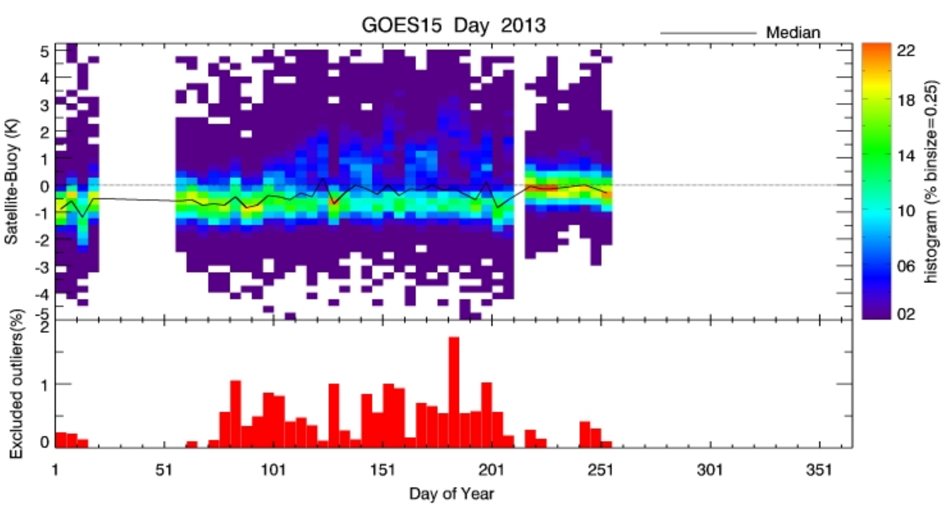

**Nighttime**

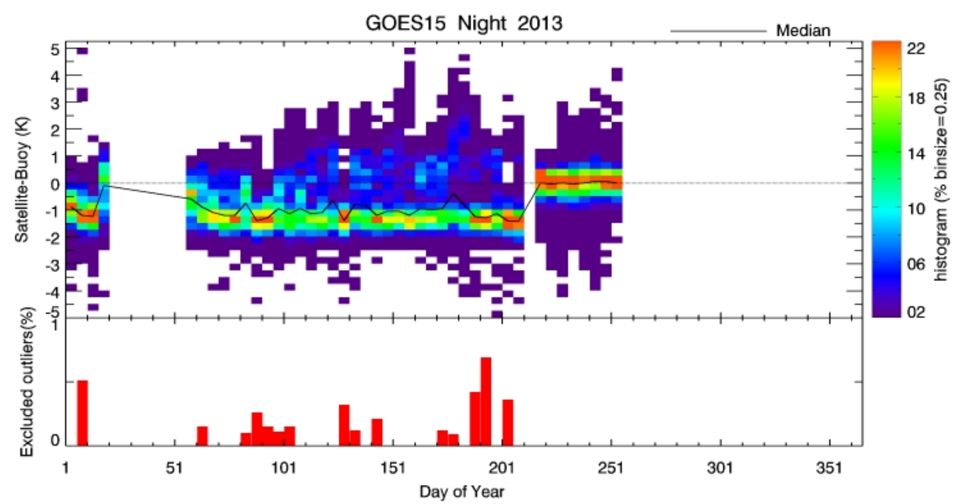


# Recent update to Geo-SST

- **Physical retrieval based on Modified Total Least Squares**
- **Improved bias and scatter *cf.* previous regression-based SST retrieval**

## GOES-15

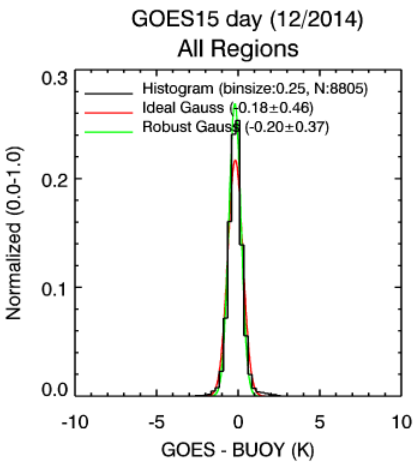


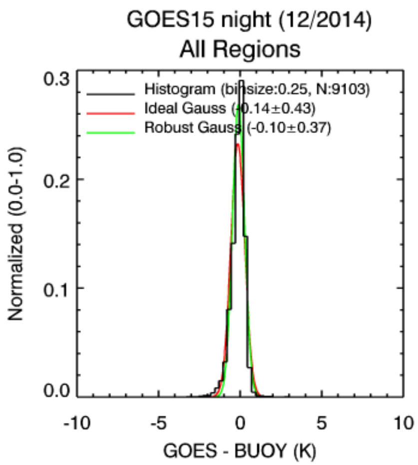

**Daytime** **Nighttime**

# Product Accuracy: Geo-SST

## GOES-15

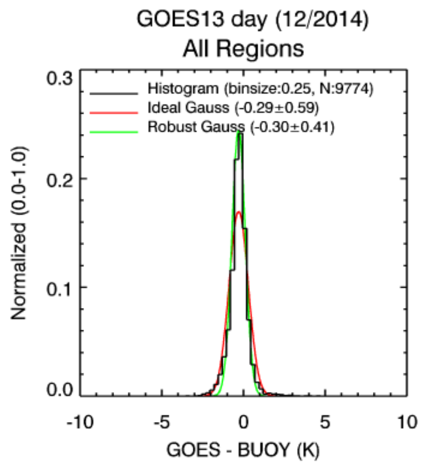



-0.18±0.46 (0.37)

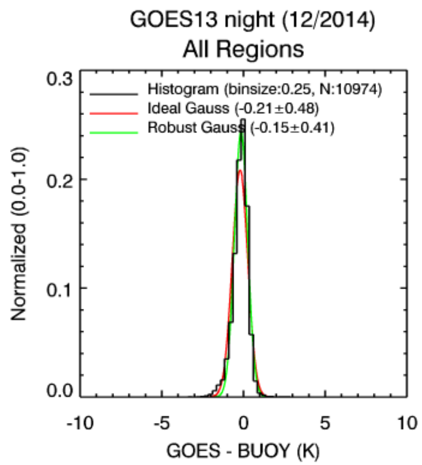



-0.14±0.43 (0.37)

## GOES-13

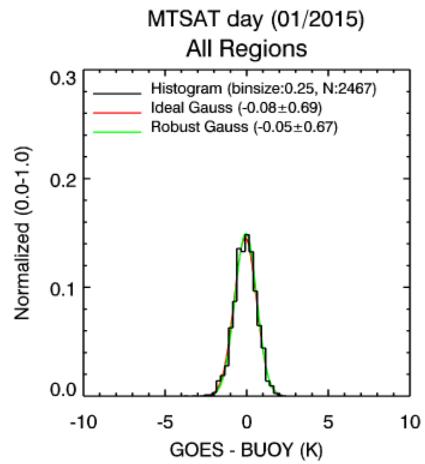



-0.29±0.59 (0.41)

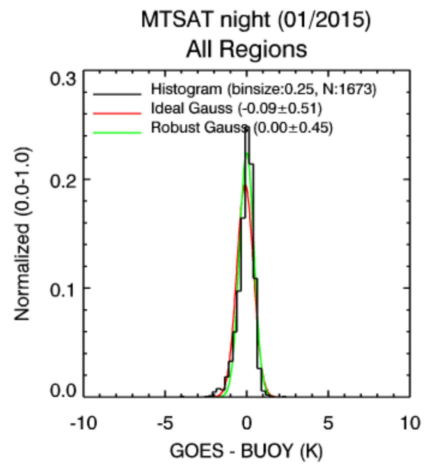



-0.21±0.48 (0.41)

## MTSAT-2

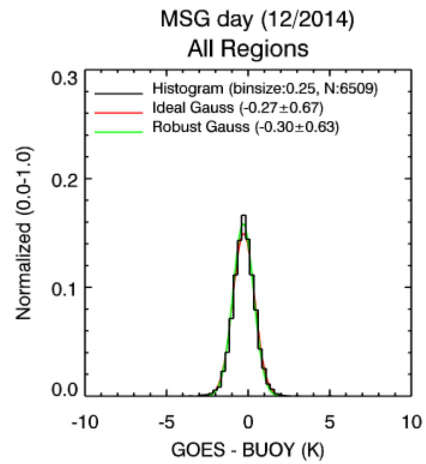



-0.08±0.69 (0.67)

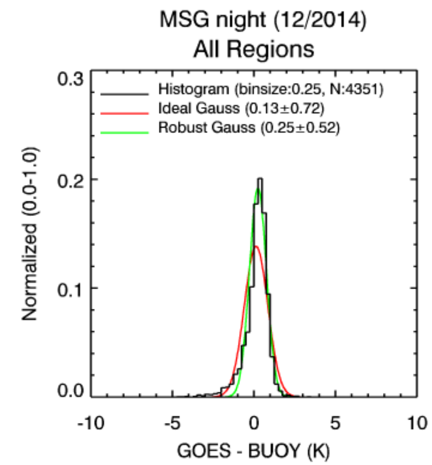



-0.09±0.51 (0.45)

## Meteosat-10



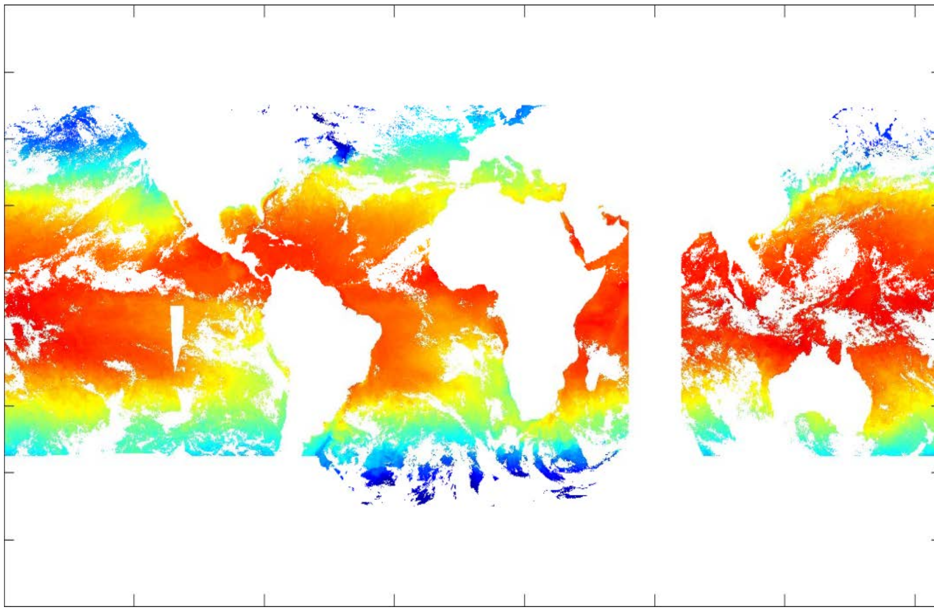

-0.27±0.67 (0.63)



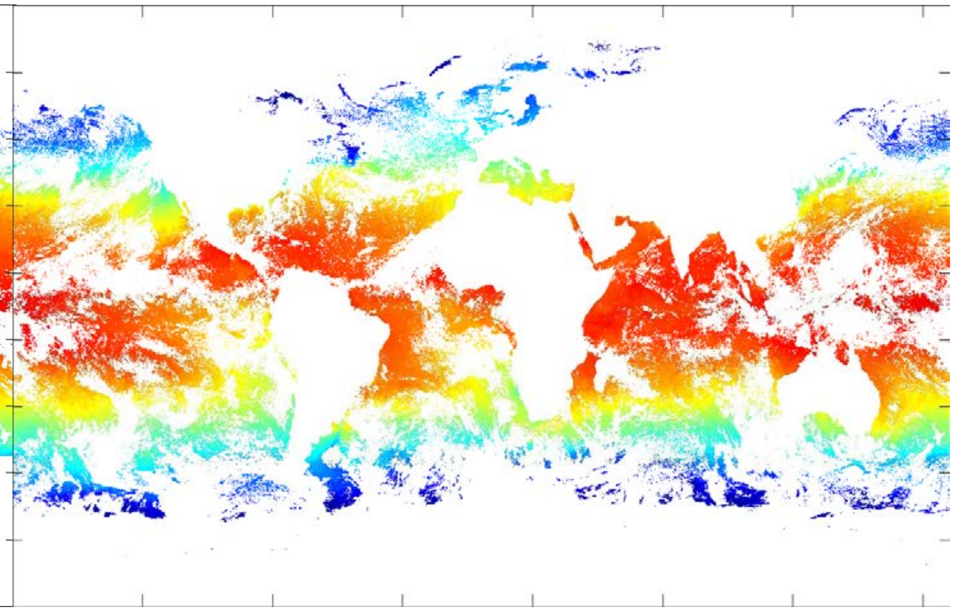

0.13±0.72 (0.52)

# Data Coverage

**Geostationary SST**



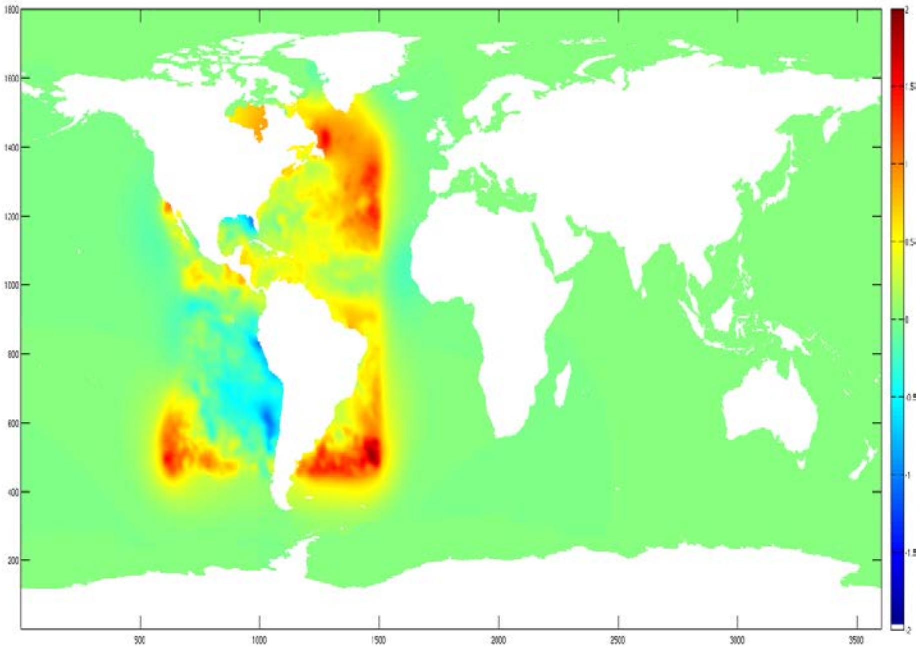
**Polar-Orbiter SST**



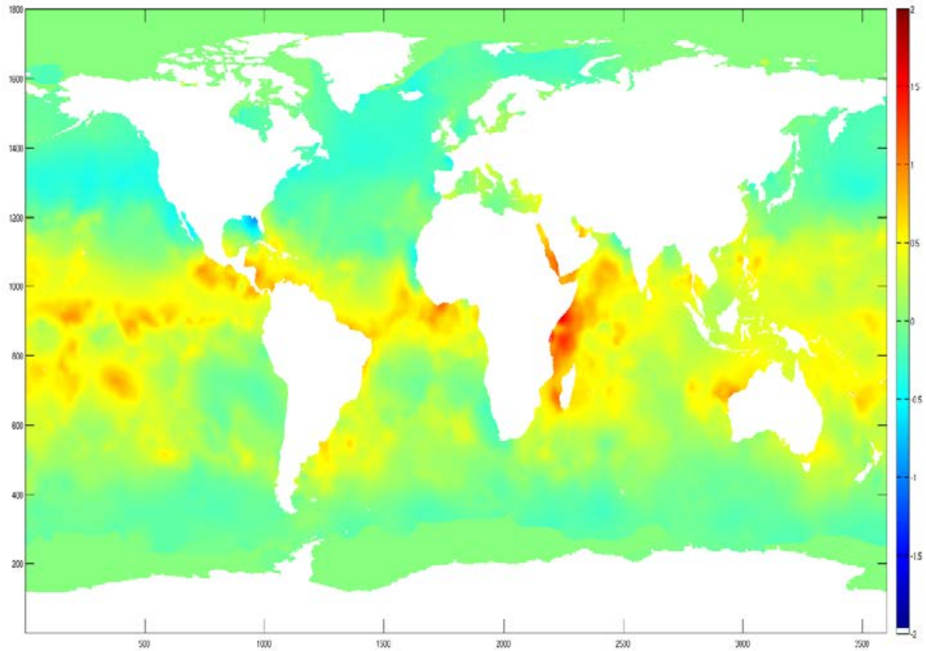
- **Geostationary data in particular provide lots of observations**
  - N.B. gap in coverage in Indian Ocean
- **Data-driven analysis**
  - Need to treat the input data “carefully”

# Bias correction

**Geostationary (GOES-13)**



**AVHRR (NOAA-19)**

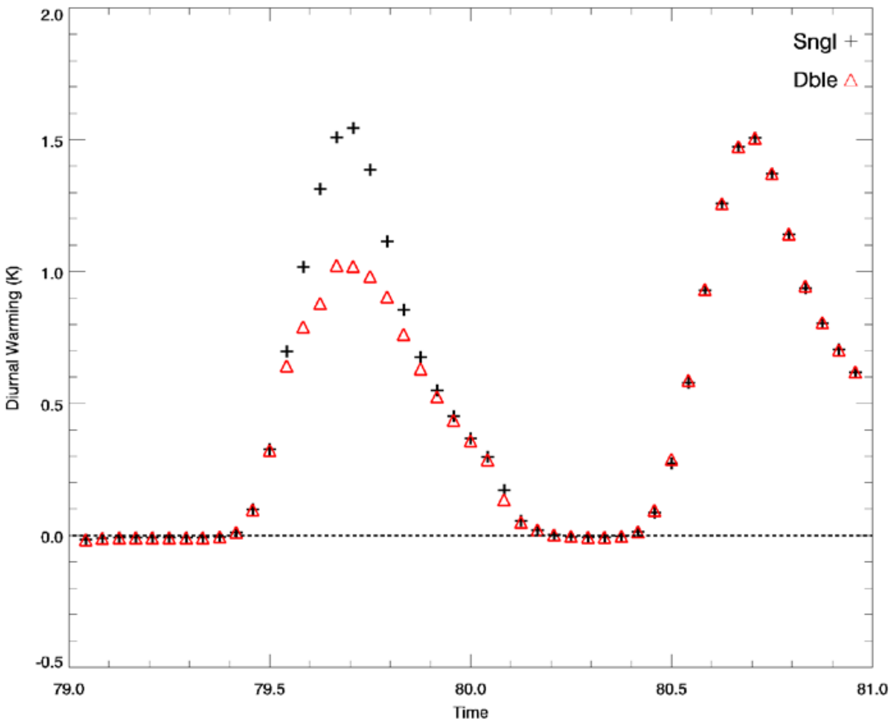


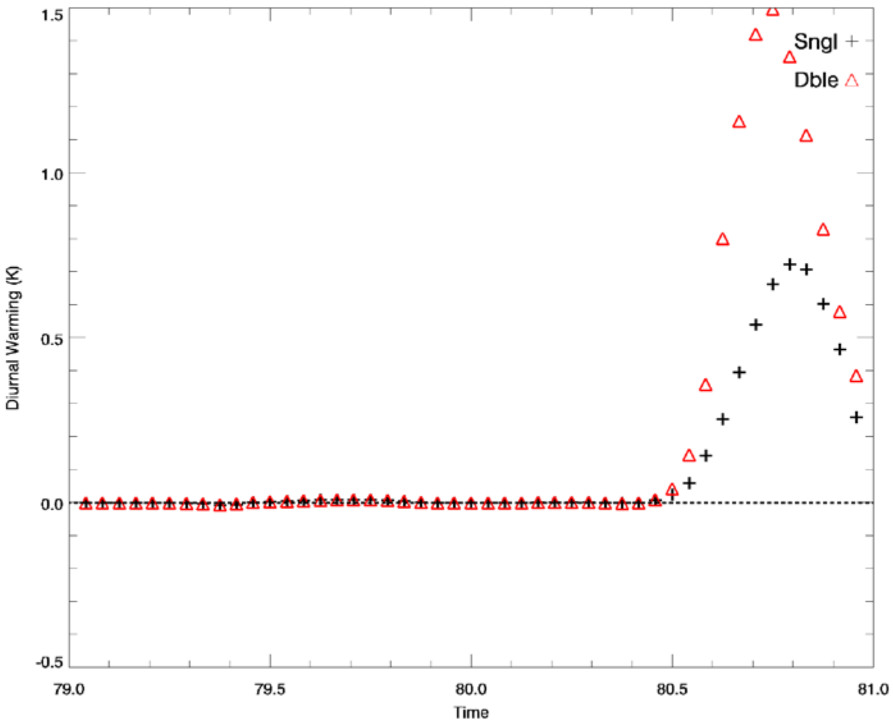
- "saddle point" nature of the bias correction field for Geo-SST data anticipated due to fixed geometry with respect to major atmospheric circulation patterns
- Warm biases evident in AVHRR for the southern hemisphere at least partially due to diurnal warming

# Status

- **All relevant routines from the research (Wick) DW code have been rewritten in F90 to NOAA/NESDIS coding standards**
- **New code runs ~ 2.5x faster than old code**
- **Code includes**
  - Wave breaking
  - Stokes drift (impact of waves)
  - Single parameter file to select modes/change behaviour
    - New code enables user to change some parameters without code modifications e.g. scaling for Langmuir/Stokes drift Q2 surface boundary condition (currently set to 1. – makes a big difference to DW)

# The effect of data precision

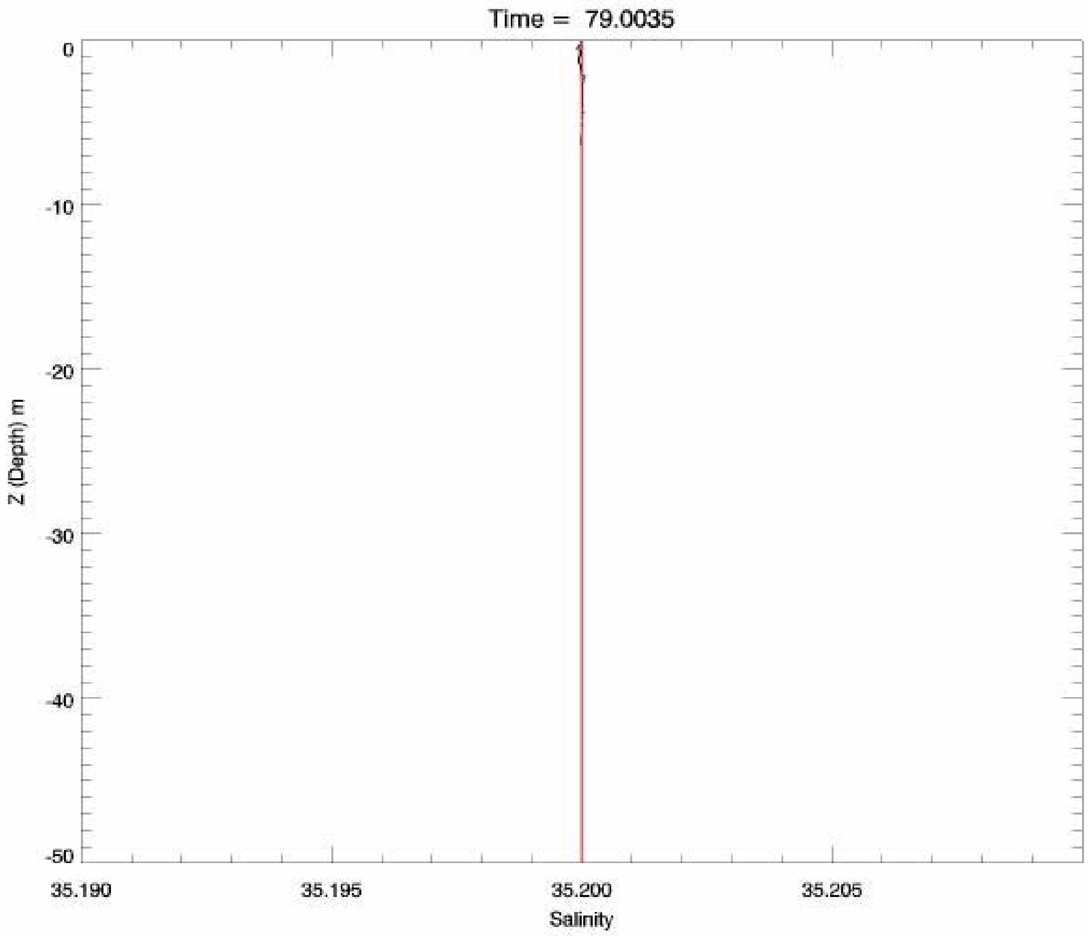



Change of precision has an impact on the result – sometimes quite large

- Change in precision a trivial exercise in new code
- Double precision version runs 28% slower
- Profile parameters are more stable in double precision

# Salinity profile– single vs double precision

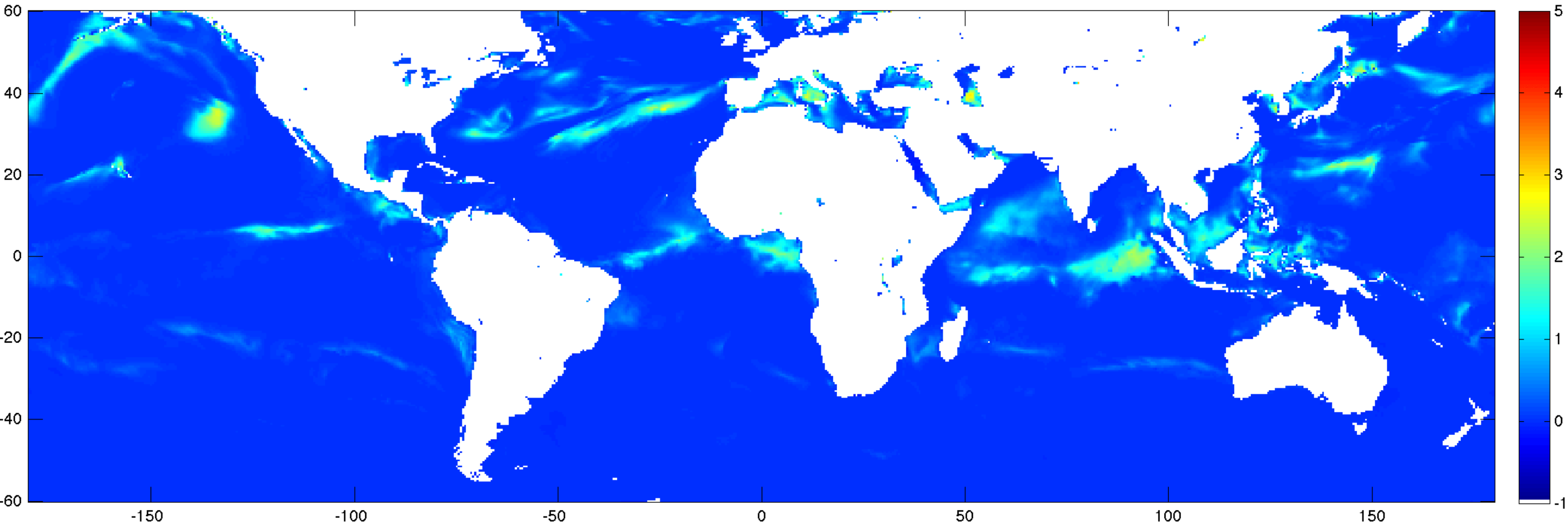



- Double precision gives the correct answer – no salinity variations expected for this run
- No evaporation/rainfall included

# Summary

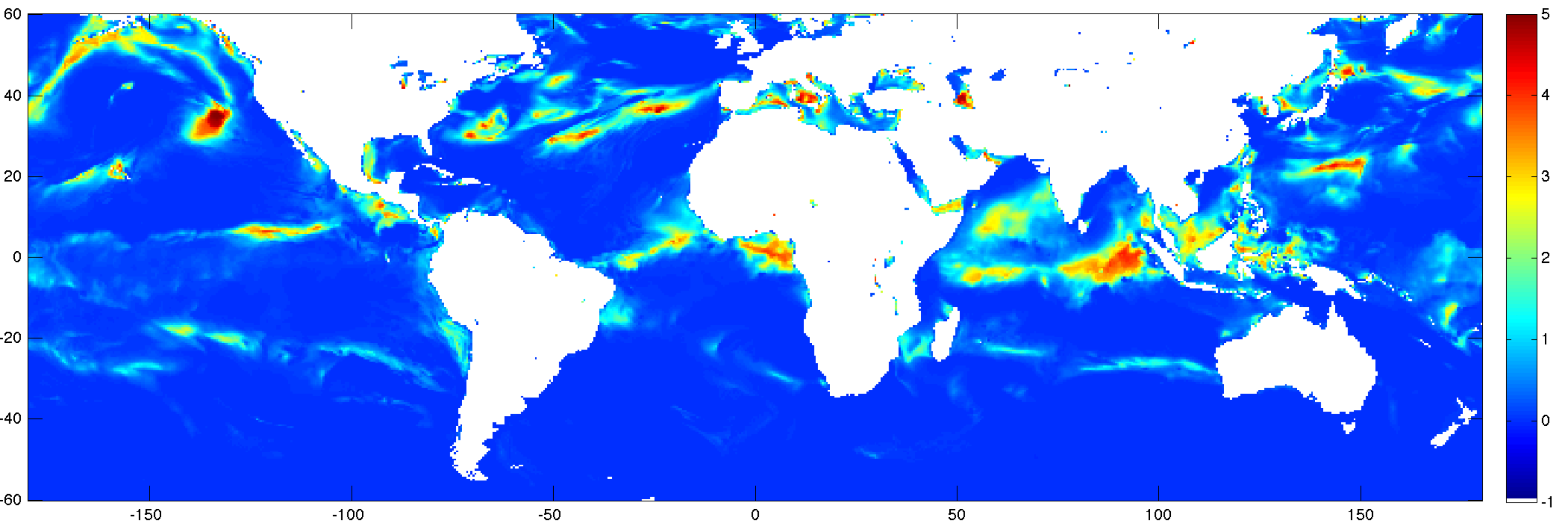
- **New code**
  - Cannot get exact agreement with original research code
  - Result can change if precision changed in new code
    - Double precision required for stability
  - Ability to 'tune' DW in parameter file if run against *in situ* cases
    - Modifications to parameter file – no recoding should be required
- **Code available from NOAA after made operational**
  - Current schedule pre-operational Oct 2014
    - Still under testing for NOAA operational systems
  - Will include involvement from Gary Wick (NOAA) via collaboration on any new developments

# Daily mean warming




- **Reasonable fraction with ≥1 K**
- **Recall that warming doesn't always disappear**

# Daily maximum warming




- **Regions with large warming may build on previous day**

# History of Inverse Model

- **Forward model:** $\mathrm{Y} = \mathrm{KX}$
- **Inverse:** $\mathbf{X} = \mathbf{K}^{-1}\mathbf{Y}$ **(measurement error)**
- **Legendre (1805) Least Squares:**

$$\mathbf{X} = \mathbf{X}_{ig} + (\mathbf{K}^{\mathrm{T}}\mathbf{K})^{-1}\mathbf{K}^{\mathrm{T}}(\mathbf{Y}_{\delta} - \mathbf{Y}_{ig})$$

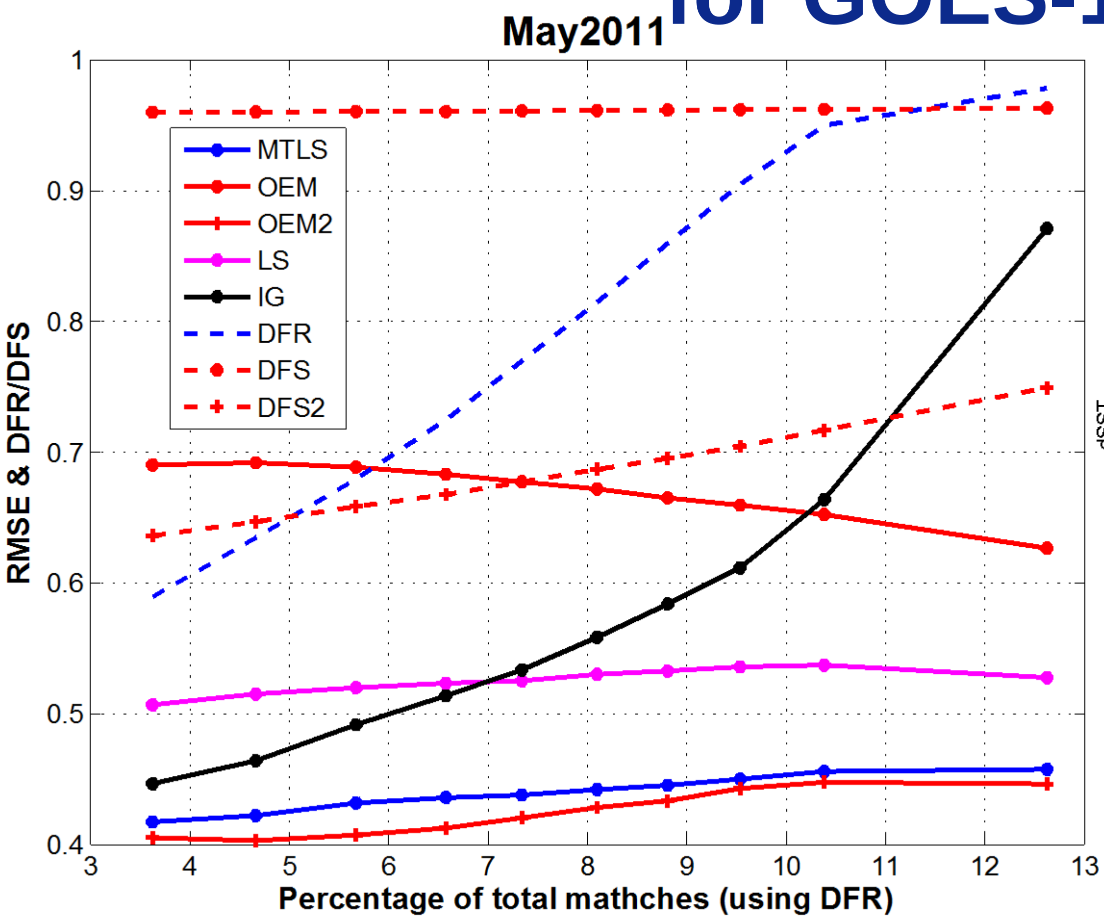
- **Last 30~40 years**

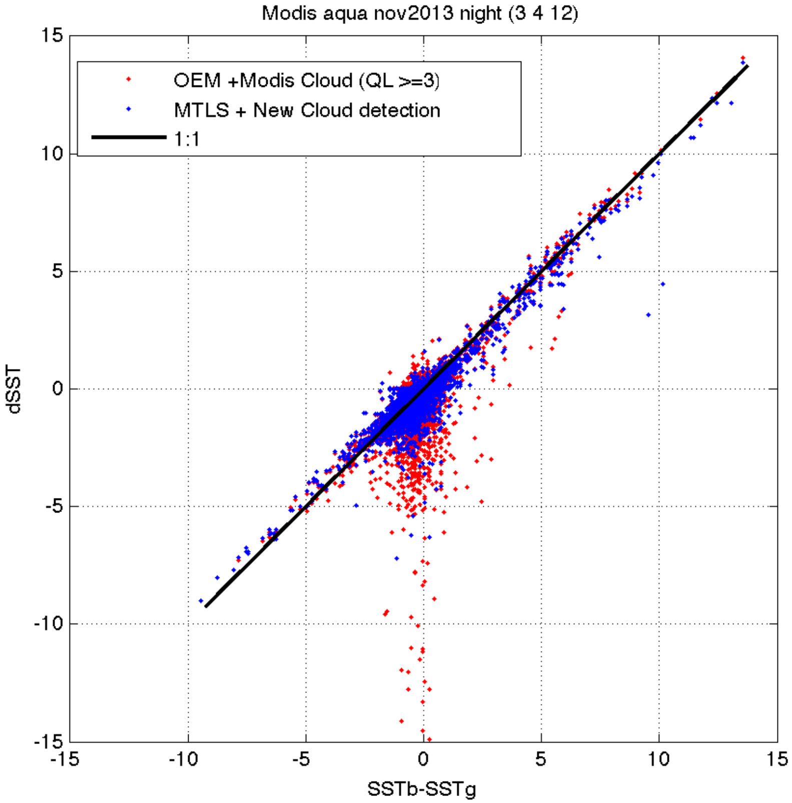
$$\delta \mathrm{X} \leq \mathrm{cond}(\mathrm{K})\,\delta E$$

- **MTLS:** $\mathbf{X} = \mathbf{X}_{ig} + (\mathbf{K}^{\mathrm{T}}\mathbf{K} + \lambda\mathbf{R})^{-1}\mathbf{K}^{\mathrm{T}}(\mathbf{Y}_{\delta} - \mathbf{Y}_{ig})$

- **OEM:** $\mathrm{X} = \mathrm{X}_{\mathrm{a}} + (\mathrm{K}^{\mathrm{T}}\mathrm{S}_{\mathrm{e}}^{-1}\mathrm{K} + \mathrm{S}_{\mathrm{a}}^{-1})^{-1}\mathrm{K}^{\mathrm{T}}\mathrm{S}_{\mathrm{e}}^{-1}(\mathrm{Y}_{\delta} - \mathrm{Y}_{\mathrm{a}})$

# DFS/DFR and Retrieval error for GOES-13




- Retrieval error of OEM higher than LS
- More than 75% OEM retrievals are degraded w.r.t. *a priori* error
- DFR of MTLS is high when *a priori* error is high
- The retrieval error of OEM is comparable when *a priori* perfectly known, but DFS of OEM is much lower than for MTLS