Use of Drifting Buoy SST in Remote Sensing

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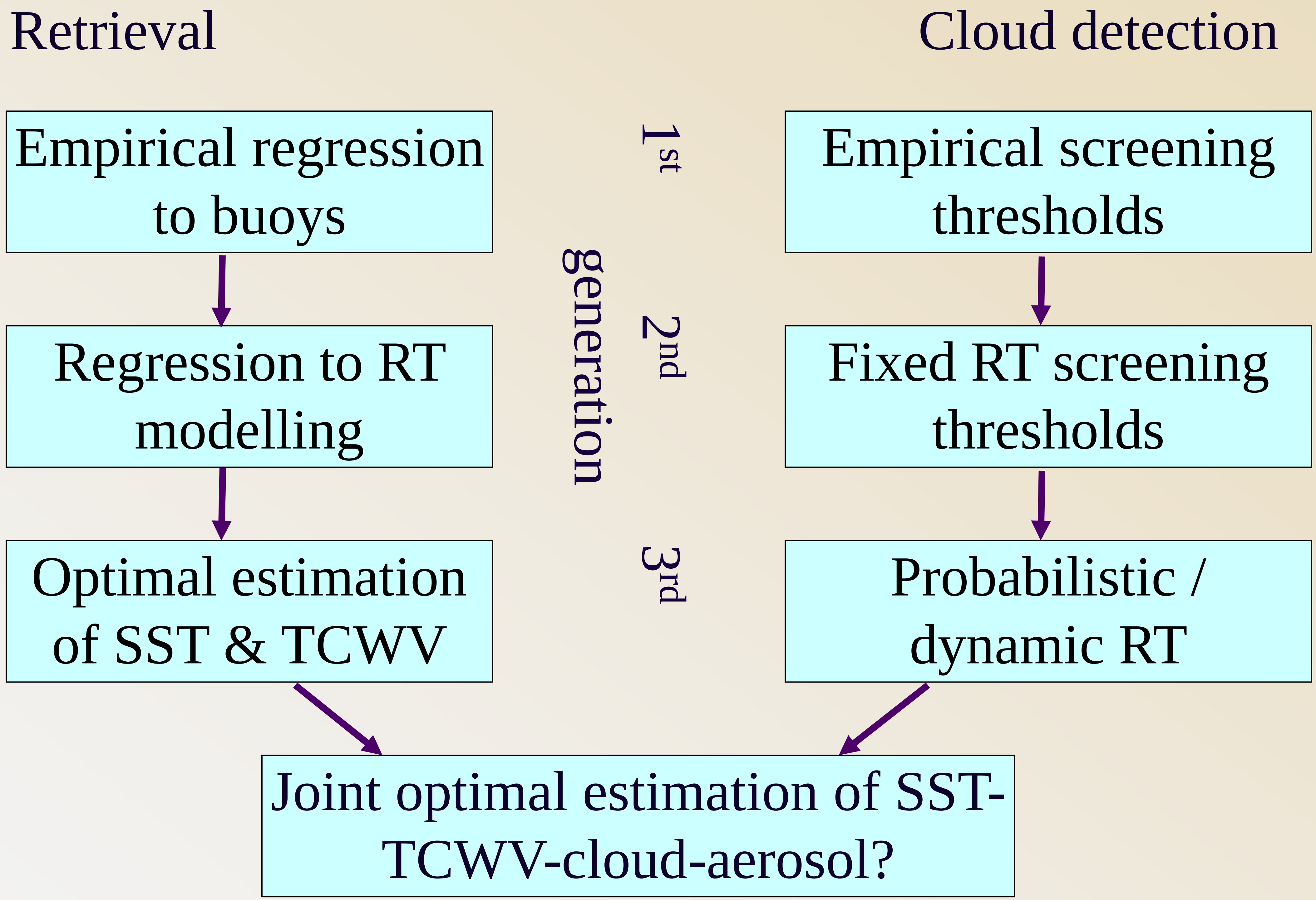
Three decades of AVHRR SST

- Empirical regression to buoy SSTs to define retrieval
- Agreement of satellite and buoy SSTs to ± 0.5 K

Times are changing ...



Benefits from third-generation techniques

- Improved techniques deliver ±0.3 K from AVHRR
  - As estimated by Standard Deviation of split window cf. drifting buoys

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Remote Sensing of Environment

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Optimal estimation of sea surface temperature from split-window observations

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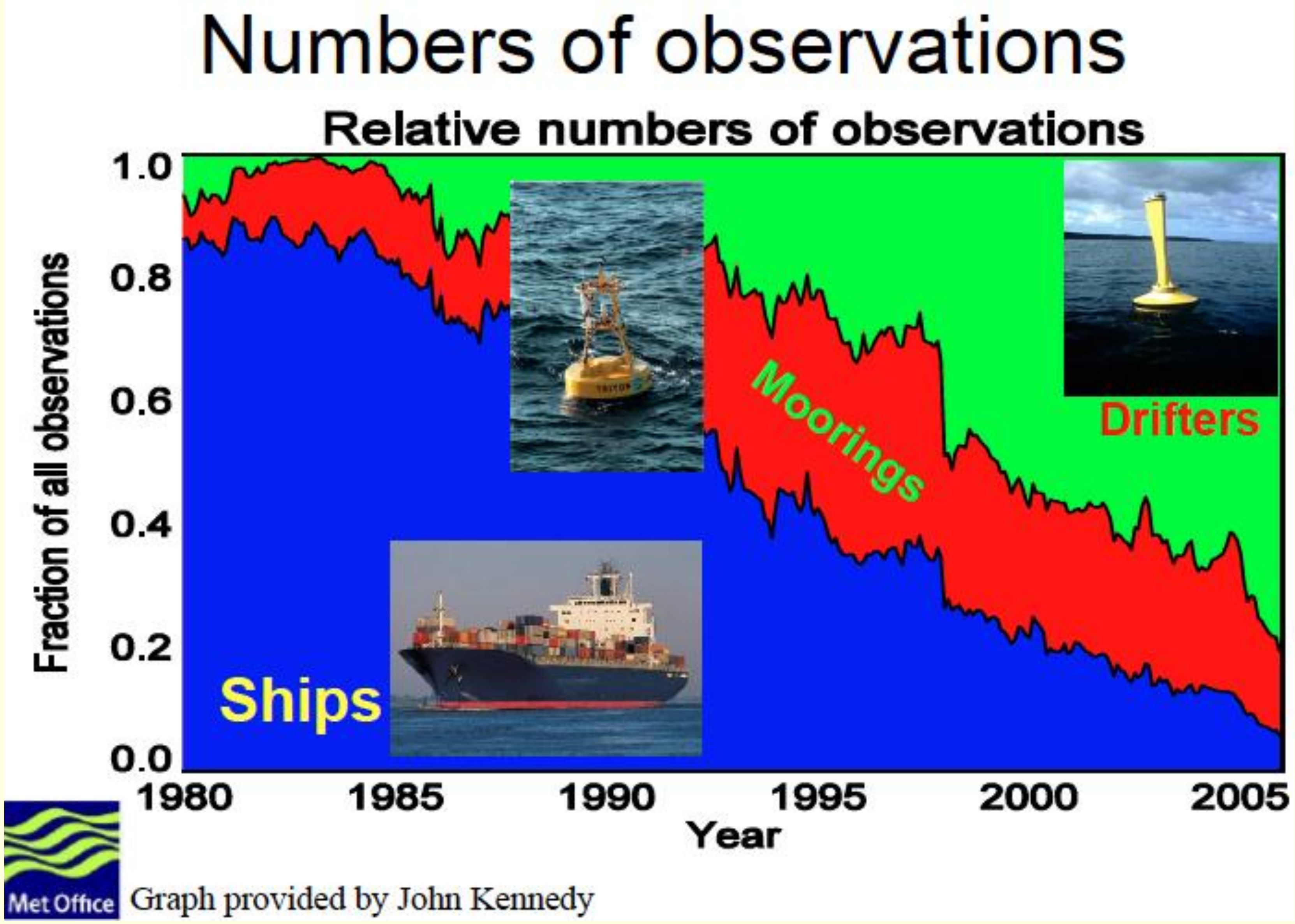
Abstract

Optimal estimation (OE) improves sea surface temperature (SST) estimated from satellite infrared imagery in the "split-window", in comparison to SST retrieved using the usual multi-channel (MCSST) or non-linear (NLSST) estimators. This is demonstrated using three months of observations of the Advanced Very High Resolution Radiometer (AVHRR) on the first Meteorological Operational satellite (Metop-A), matched in time and space to drifter SSTs collected on the global telecommunications system. There are 32,175 matches. The prior for the OE is

Satellite SST as an Essential Climate Variable

- Forthcoming ESA Climate Change Initiative
- Along-Track Scanning Radiometer Reprocessing for Climate (ARC)



ARC objectives

Independent record of ε15 years of SSTs

5 km radiometric and drifter-depth SSTs

Biases <0.1 K, regionally

Target stability δ0.05 K decade^{-1}

Comprehensive error characterization

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Deriving a sea surface temperature record suitable for climate change research from the along-track scanning radiometers

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Abstract

We describe the approach to be adopted for a major new initiative to derive a homogeneous record of sea surface temperature for 1991–2007 from the observations of the series of three along-track scanning radiometers (ATSRs). This initiative is called (A)RC: (Advanced) ATSR Re-analysis for Climate. The main objectives are to reduce regional biases in retrieved sea surface temperature (SST) to less than 0.1 K for all global oceans, while creating a very homogenous record that is stable in time to within 0.05 K decade^{-1}, with maximum independence of the record from existing analyses of SST used in climate change research. If these stringent targets are achieved, this record will enable significantly improved estimates of surface temperature trends and variability of sufficient quality to advance questions of climate change attribution, climate sensitivity and historical reconstruction of surface temperature changes. The approach includes development of new, consistent estimators for SST for each of the ATSRs, and detailed analysis of overlap periods. Novel aspects of the approach include generation of multiple versions of the record using alternative channel sets and cloud detection techniques, to assess for the first time the effect of such choices. There will be extensive effort in quality control, validation and analysis of the impact on climate SST data sets. Evidence for the plausibility of the 0.1 K target for systematic error is reviewed, as is the need for alternative cloud screening methods in this context.

Keywords: Sea surface temperature; Climate change; Radiometers; ATSR

1. Introduction

Both science and society need changes in global sea surface temperature (SST) over recent decades to be more

called (A)RC – (Advanced) along-track scanning radiometer Re-analysis for Climate.

Global SST is a major component of the observational record used to assess climate change (IPCC, 2001). Analy-

Directions for remotely sensed SST

- Away from empirical, towards physics-based
- Away from coefficients, towards formal inversion
- Sophisticated cloud detection and treatment of aerosols
- Resolve in time sub-daily variability (diurnal cycle)

- Decreasing uncertainties in satellite SST estimates - SD and regional bias
- Increasing scrutiny of drifting buoy SSTs

What satellite folks think of drifting buoy errors ...

- Three-way study
  - AATSR (IR): σ = 0.13 K
  - Drifting buoys: σ = 0.21 K
  - AMSRE (MW): σ = 0.43 K

Three-Way Error Analysis between AATSR, AMSR-E, and In Situ Sea Surface Temperature Observations

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ABSTRACT

Using collocations of three different observation types of sea surface temperatures (SSTs) gives enough information to enable the standard deviation of error on each observation type to be derived. SSTs derived from the Advanced Along-Track Scanning Radiometer (AATSR) and Advanced Microwave Scanning Radiometer for Earth Observing System (EOS; AMSR-E) instruments are used, along with SST observations from buoys. Various assumptions are made within the error theory, including that the errors are not correlated, which should be the case for three independent data sources. An attempt is made to show that this assumption is valid and that the covariances between the different observations because of representativity error are negligible. Overall, the spatially averaged nighttime AATSR dual-view three-channel bulk SST observations for 2003 are shown to have a very small standard deviation of error of 0.16 K, whereas the buoy SSTs have an error of 0.23 K and the AMSR-E SST observations have an error of 0.42 K.

1. Introduction

Sea surface temperatures (SSTs) derived from satellite-borne instruments have some advantages over traditional in situ SST measurements from buoys and ships. First, they provide a global coverage that is important in regions with sparse in situ observations. Second, some satellite instruments can give well-calibrated, accurate skin SST observations with global and temporal consistency that is not possible from in situ measurements. Satellite datasets are also beginning to span long enough periods to start being able to detect long-term changes in SST. However, it is important to understand the error characteristics of these data.

This study investigates the errors in SST observations from three different sources: infrared SSTs from the Advanced Along-Track Scanning Radiometer (AATSR), microwave SST observations from the Advanced Microwave Scanning Radiometer for Earth Observing System (EOS; AMSR-E), and in situ SST observations from drifting and moored buoys. A three-way analysis is performed in which all three SST types are collocated using data during all of 2003. Other examples of error derivation using three-way collocation include Stoffelen (1998) and Blackmore et al. (2007). These three observation types are complementary, with each having its own strengths and weaknesses.

In situ SST measurements are affected by the varying depth of measurement according to buoy type. Also, the lack of maintenance of in situ instruments, which mainly affects drifting buoys, contributes to variations in the accuracy of in situ SST observations. Additionally, there are large geographic regions not covered by the buoy network (Emery et al. 2001). Errors related to satellite-derived SST observations include cloud contamination, aerosol, and inadequacies of the retrieval process. Microwave SST retrievals can be obtained in areas that are cloudy, though not those that are precipitating, which provide a better coverage than the infrared sensors, although at generally lower spatial resolution.

An additional issue, applicable to all three observation types, is to consider the depth at which the observation is actually representative. For in situ observations, we generally assume the depth to be around 1 m, although this will vary. Infrared satellite observations retrieve the radiative skin SST, which is only 1 μm thick, whereas microwave satellite observations retrieve an SST a couple of millimeters below the skin

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Consistent with experience in ARC

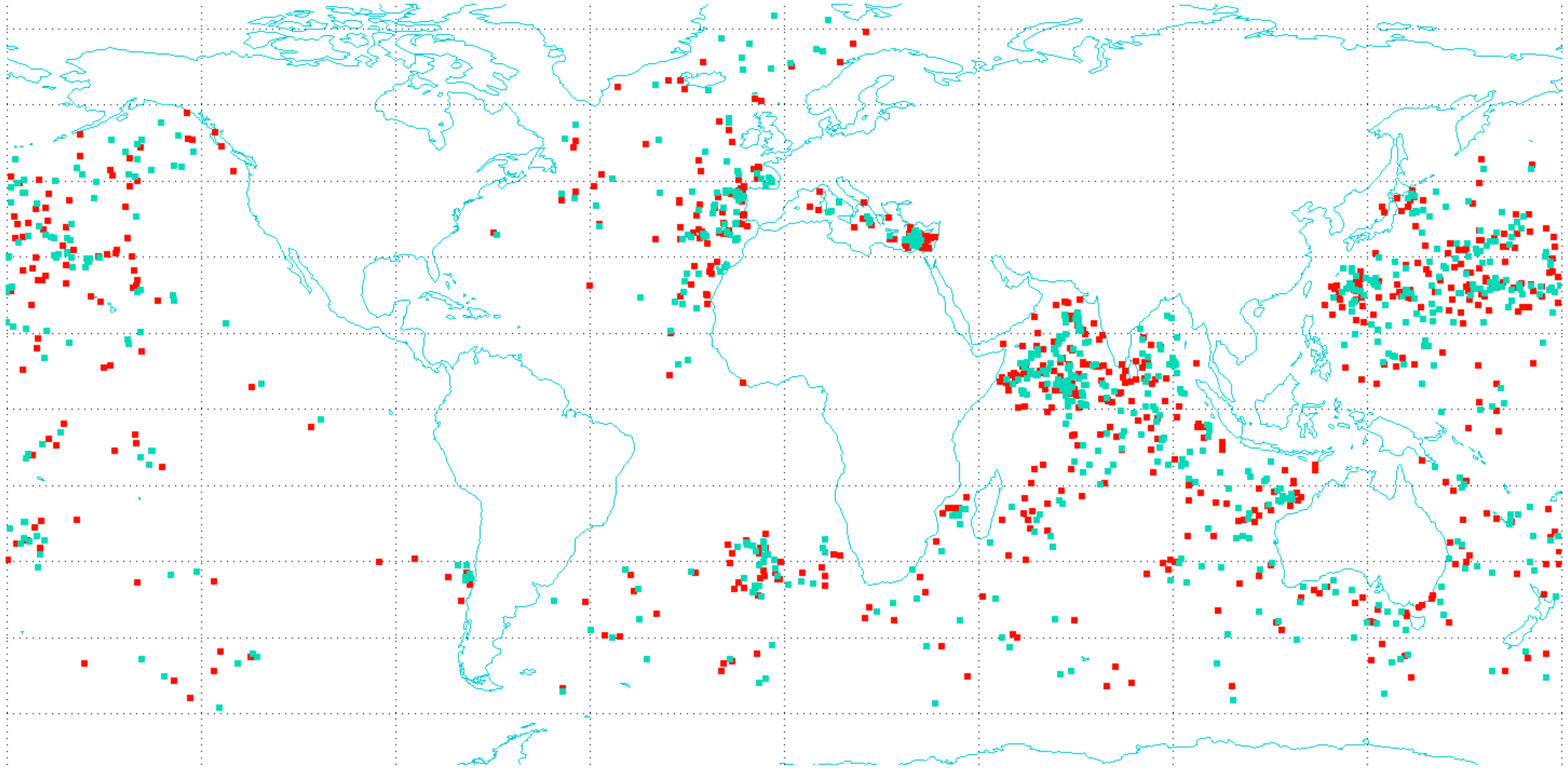
- ARC retrieval based on physics (radiative transfer simulations)
- Can simulate expected retrieval uncertainty
- Simulated value: $\sigma = 0.13$ K
- Observed SD against drifting buoys is 0.25 K
  - Outlier tolerant estimator, not exaggerated by gross failures
- Implied drifting buoy error is $\sqrt{(0.25^2 - 0.13^2)} = 0.21$ K

Relative errors of satellites and drifting buoy SST

- AATSR D3 SSTs are the “best” satellite SSTs available and are ±0.13 K
- AVHRR split window will soon give ±0.22 K operationally at M-F
- Drifting buoys (after QC or using robust statistics) seem to give ±0.21 K

- “Received wisdom”: buoy thermistors should give ±0.1 K “off the shelf”
  - Optimistic? Beginning-of-life value?
  - Rounding to 0.1 K
  - Point measured at depth being used for 1 km pixel
    - Contribution from geophysical variability?
    - Would we see any difference if buoy calibration were improved?

Argo vs. drifting buoy

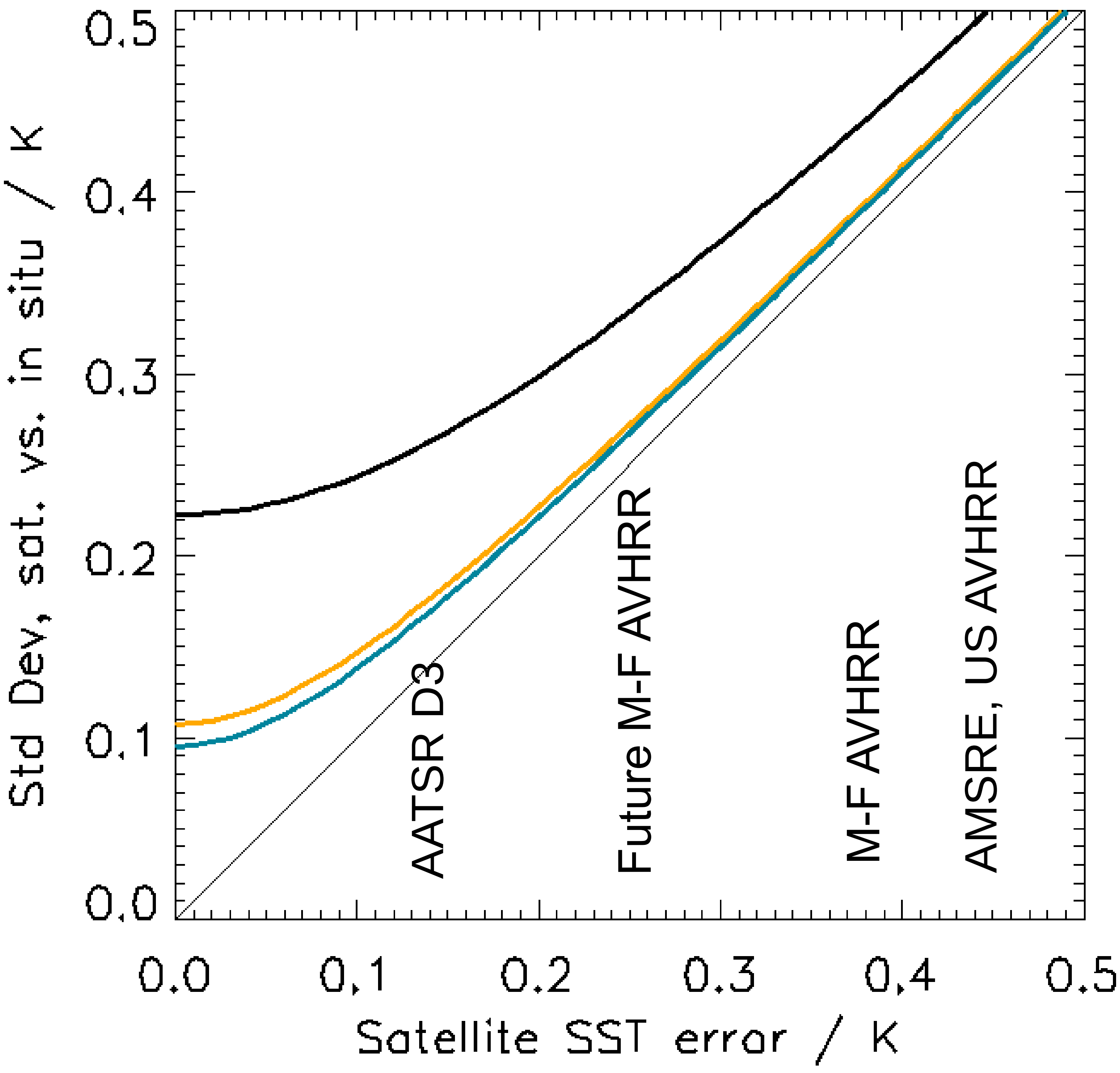


- Argo 4 m depth SST
- Accuracy: ±0.005 K
- Matched with AATSR
- Nearest (in time and space) match with drifting buoy also found
- Argo vs. AATSR: σ = ±0.15 K DB vs. AATSR: σ = ±0.25 K
- Geophysical (point to pixel) variability is ≤ ±0.095 K
- Implied DB uncertainty excluding point-to-pixel effects is ≥ ±0.20 K

Assuming DB SST $\sigma \sim \pm 0.2$ K ...

- DB uncertainty inhibits progress on satellite SST
  - Hides improvements in satellite SST uncertainty (scatter)
  - Limits ability to assess and improve bias (regional, temporal)

Apparent vs. true satellite SST uncertainty



Current drifters

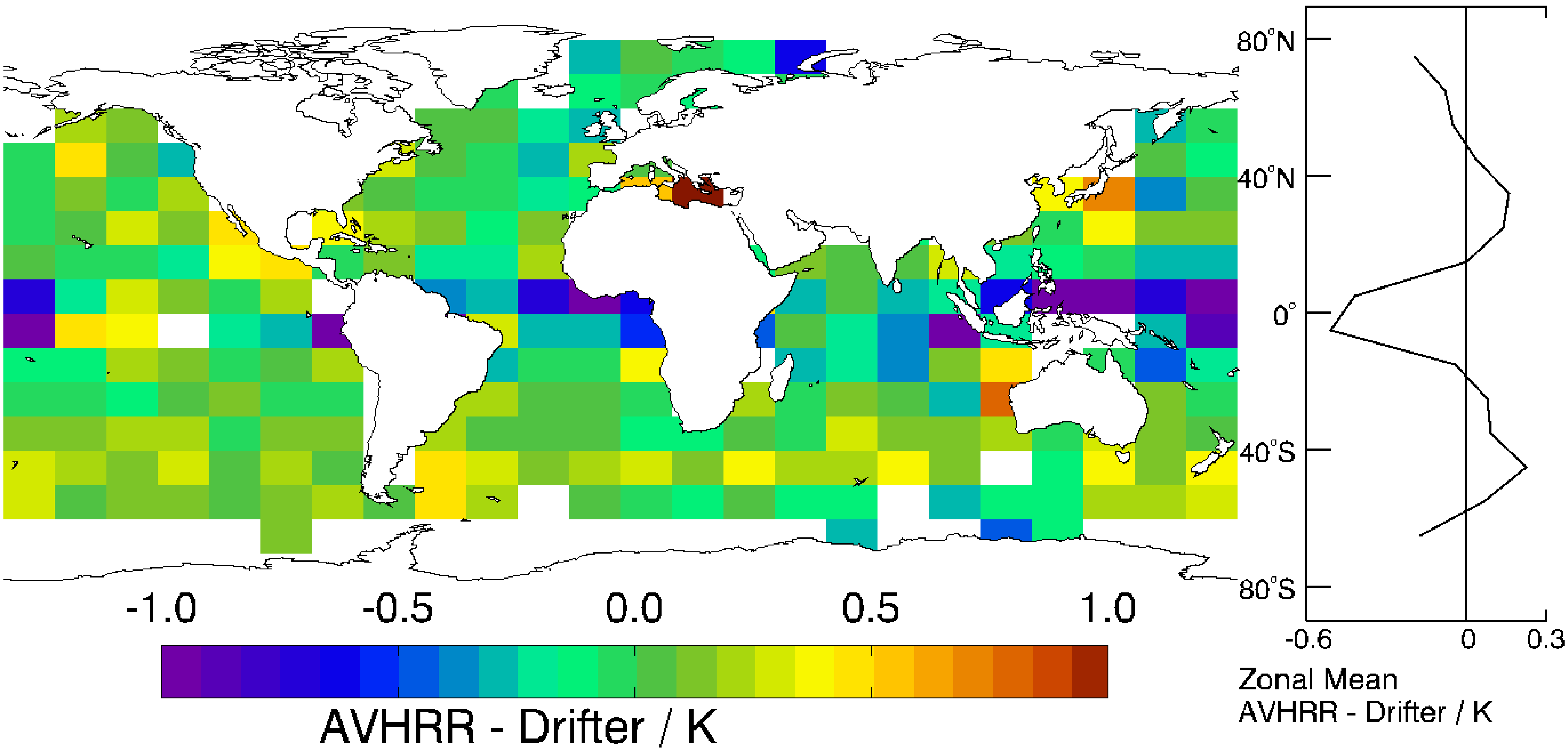
Accuracy

~ 0.05 K

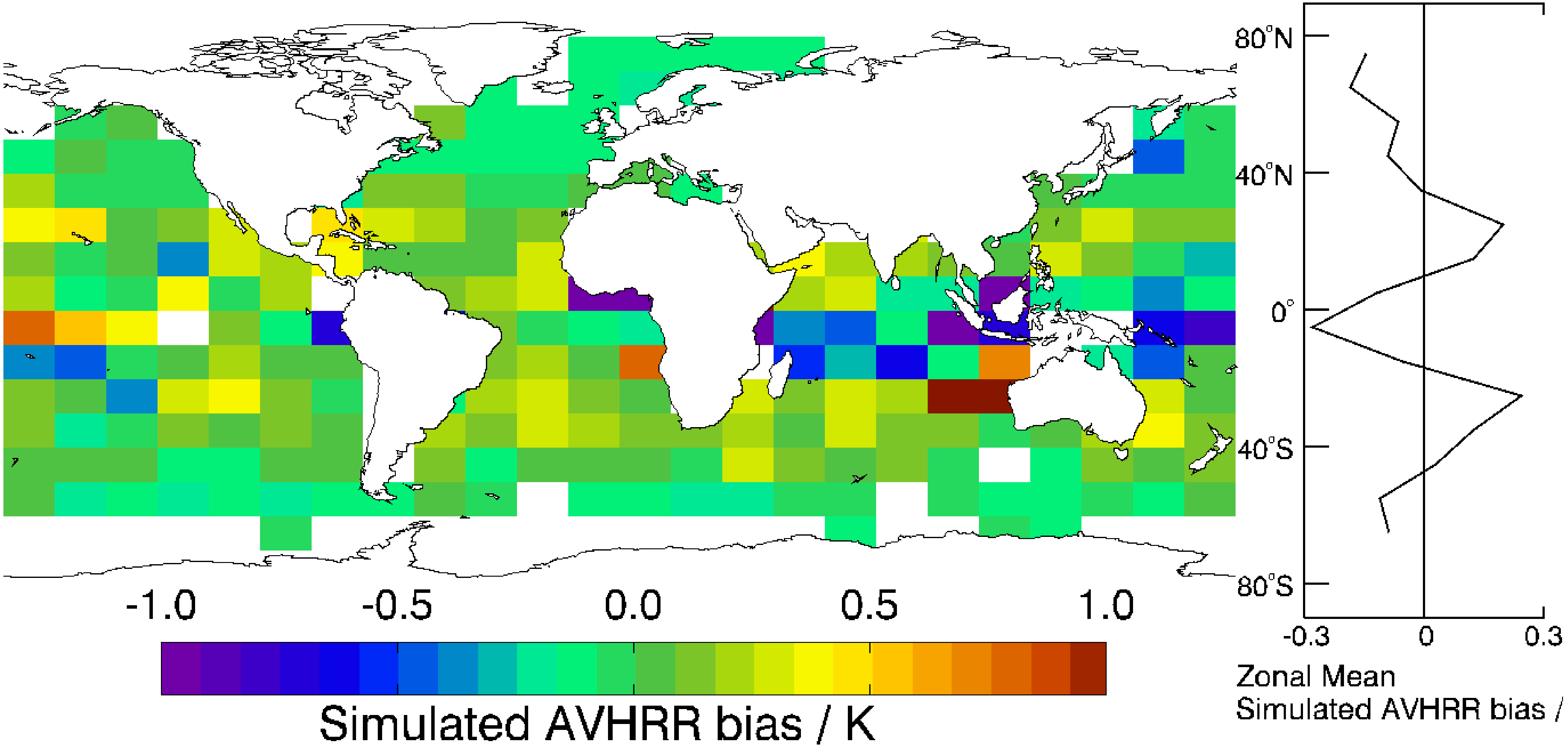
Argo

Single Sensor Error Statistics

Driving down regional biases in satellite SST

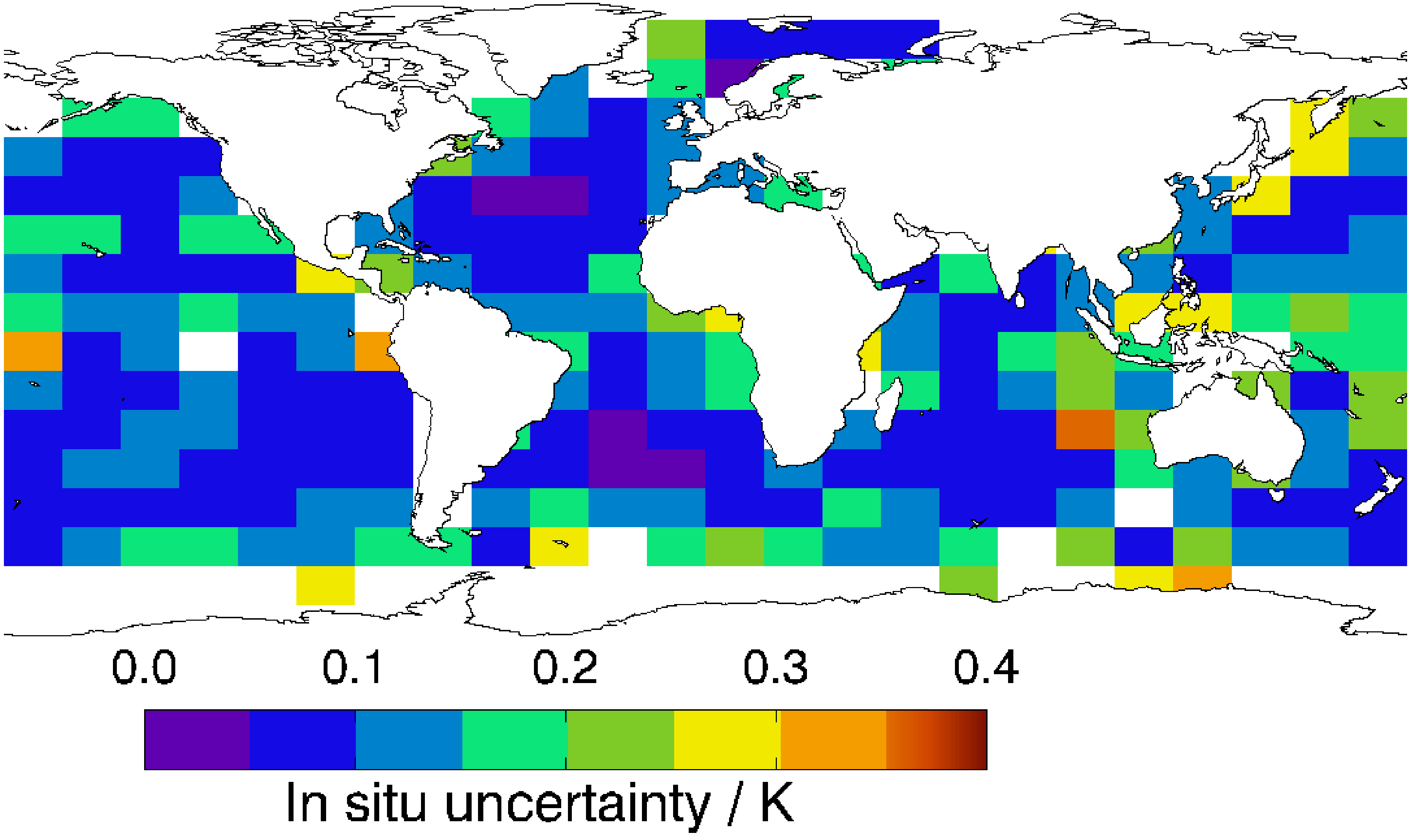


Cell-mean satellite-drifter difference, Jan 2008

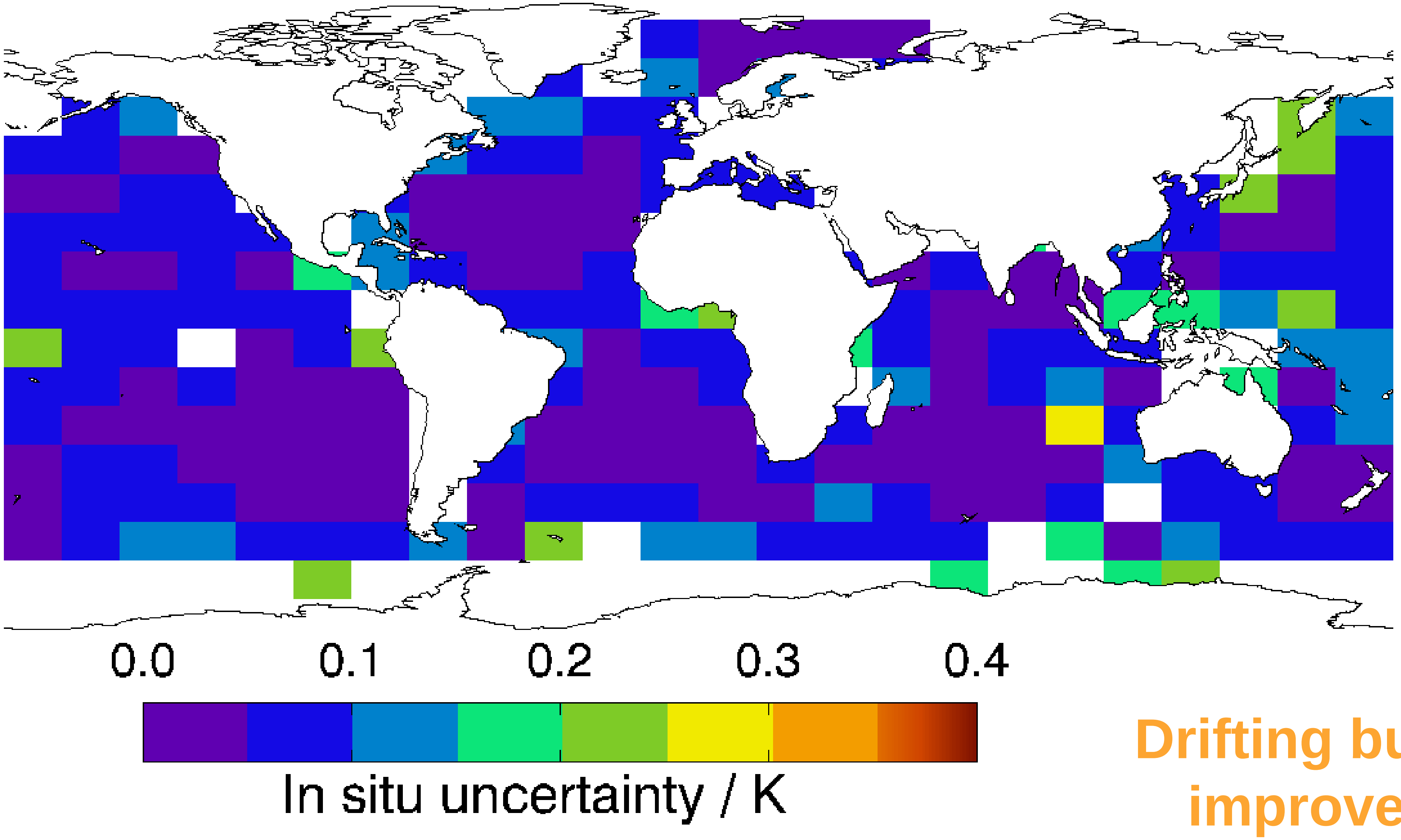


Predicted difference from matched simulations, Jan 2008

Uncertainty in cell-mean due to drifting buoy errors

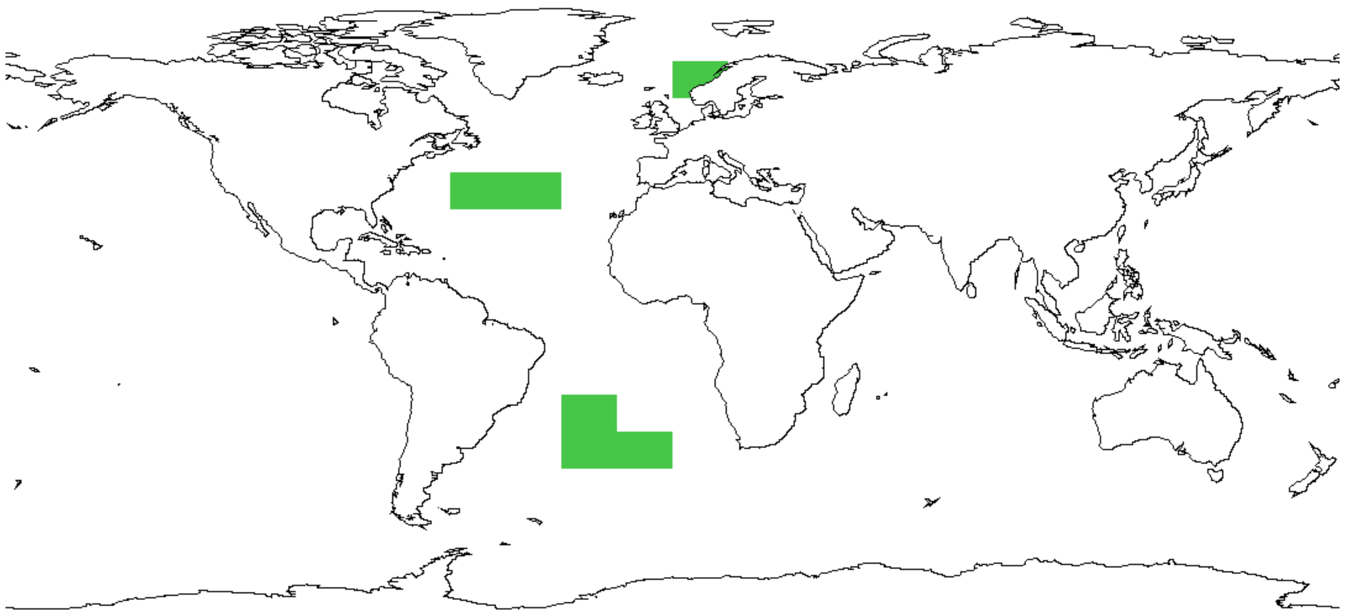


Uncertainty in cell-mean due to drifting buoy errors

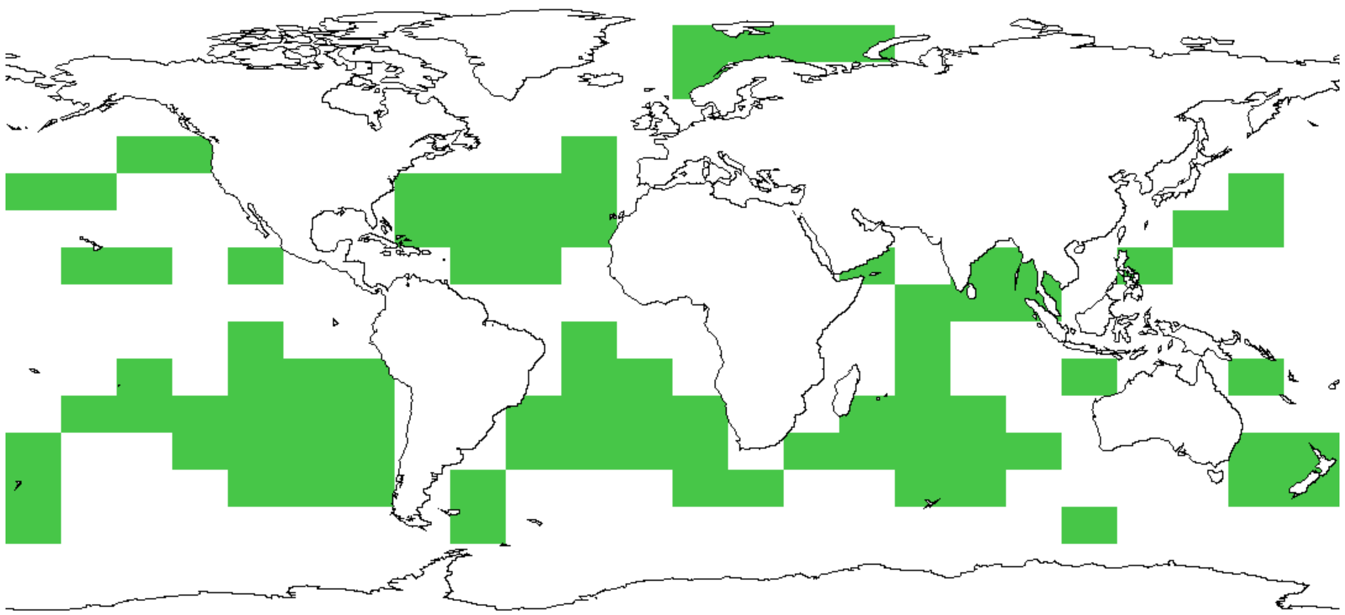


Drifting buoy accuracy improved to 0.05 K

Areas where <0.1 K bias level can be verified with 90% confidence (example: AVHRR, January 2008)

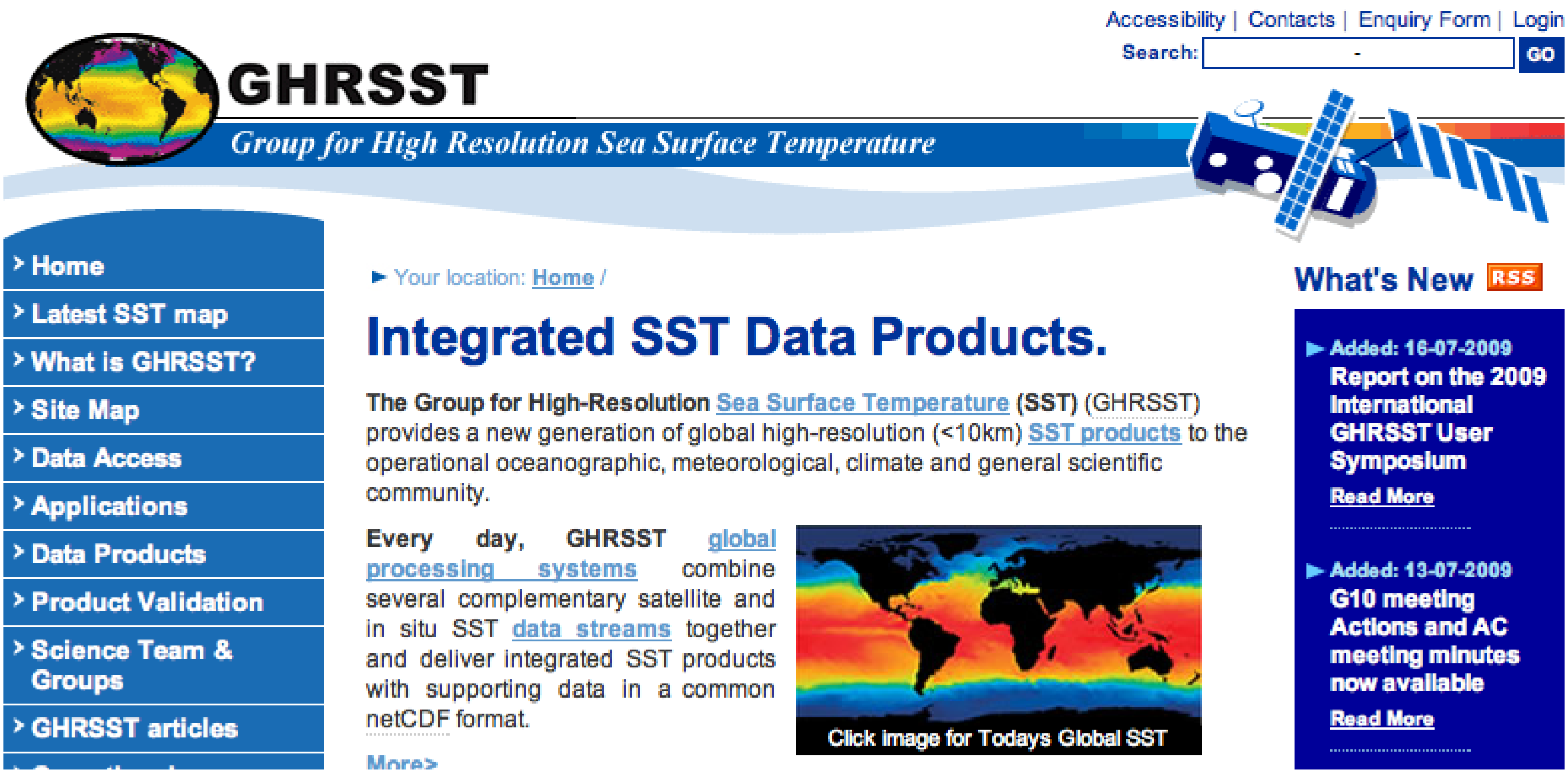


- Current



- Accuracy ~ 0.05 K

GHRSST www.ghrsst.org



International sharing of data

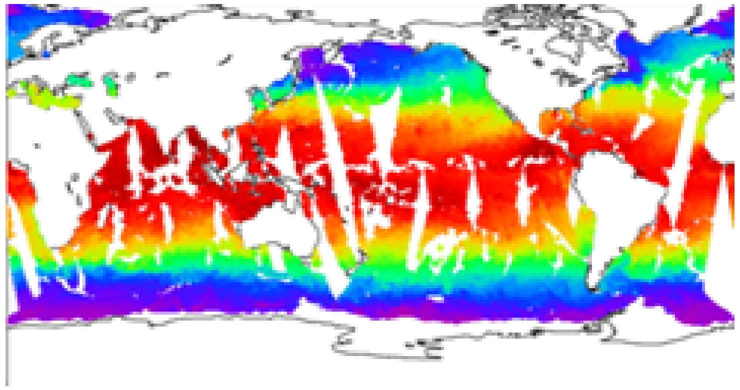
► Your location: Home / GHRSST PP Data Products

GHRSST-PP Data Product Descriptions

The GHRSST-PP has developed a set of SST Definitions that are referred to in this page. Follow the links below for a full description the GHRSST-PP data products you are interested in.

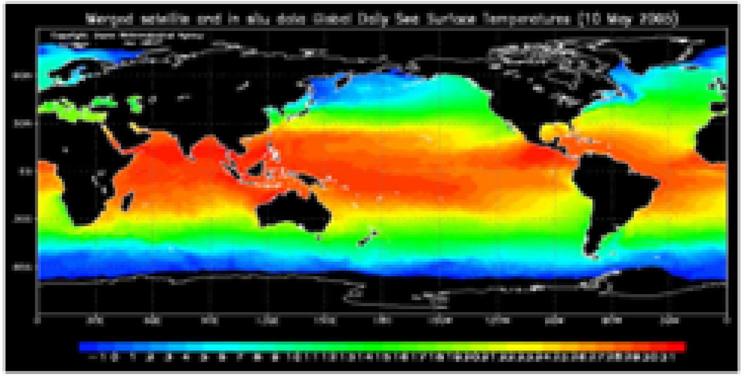
L2P Observations

L2P data products provide satellite SST observations together with a measure of uncertainty for each observation in a common netCDF format. Auxiliary fields are also provided for each pixel as dynamic flags to filter and help interpret the SST data. These data are ideal for data assimilation systems or as input to analysis systems.
More>



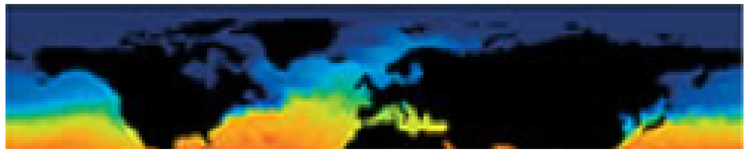
L4 Gridded SST

L4 gridded products are generated by combining complementary satellite and in situ observations within Optimal Interpolation systems. L4 gridded products are provided in GHRSST-PP netCDF format. These data are ideal for model diagnostic studies, model boundary condition specification and model initialisation.
More>



Climate Data Records

Re-analysis L4 data products are generated by combining delayed mode satellite and in situ observations in an optimal manner within the GHRSST-PP Re-Analysis



GHRSST recommendations agreed in 2008 + 1

- (1) Make hourly reporting universal
- (2) Report design depth in calm water to ±5 cm
- (3) Report of geographical location to ±0.5 km or better
- (4) SST accuracy to ±0.05 K or better, resolve 0.01 K
- (5) Use NetCDF CF-1.3
- (6) Report of the time of SST measurement to ±5 minutes
- (7) No requirement to report on or close to integer hours

- *(8) (Extra) Report estimate of absolute accuracy*

I want to persuade you that ...

- Increasing demand for high-accuracy high-resolution SST
- Recent progress in satellite SST delivering greatly improved accuracy
- Satellite SST errors can be comparable to or less than drifting buoy errors
- Drifting buoy SST accuracy is now a practical concern for remote sensers
- We see the difference when we compare against Argo
- *O*(0.01 K) accuracy would transform remote sensing of SST, and SST analysis
- Need to consider in-situ/satellite as a joint system, increase co-operation

International co-operation

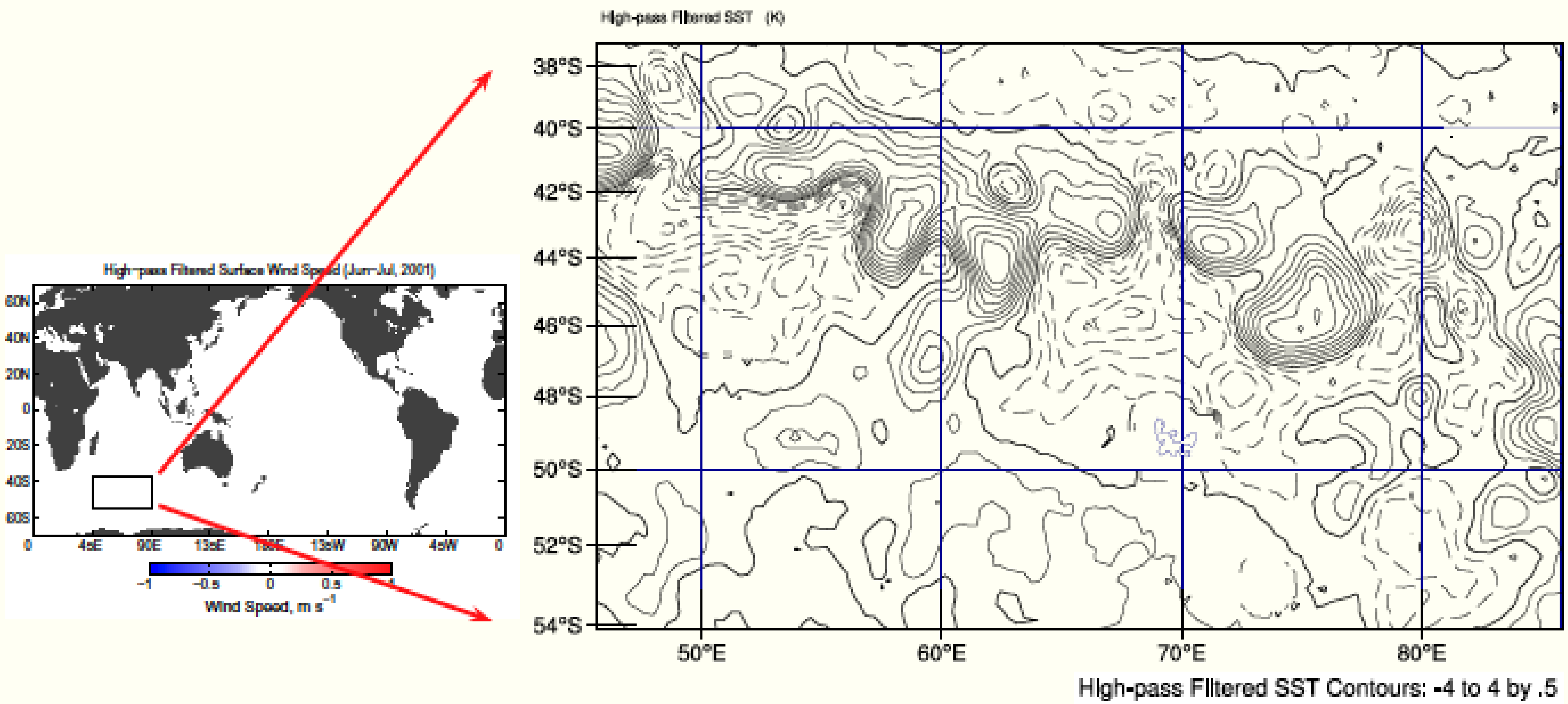
- Group for High Resolution Sea Surface Temperature (GHRSST)
  - Diurnal variability working group (Merchant)
  - SST Validation working group (Corlett)
- MyOcean -- operational oceanography services
- NEW! European Research Network for Estimation from Space of Surface Temperature (ERNESST)
- NEW! US Interim Sea Surface Temperature Science Team (ISSTST)

Demands for high space resolution

- “High” here means 0.05 deg for space, daily for time, global (OSTIA)
- Oceanography
  - Fronts, eddies, kelvin waves
- NWP
  - Hurricane wakes influence forecasting
  - High resolution SST affects wind field and atmospheric boundary layer

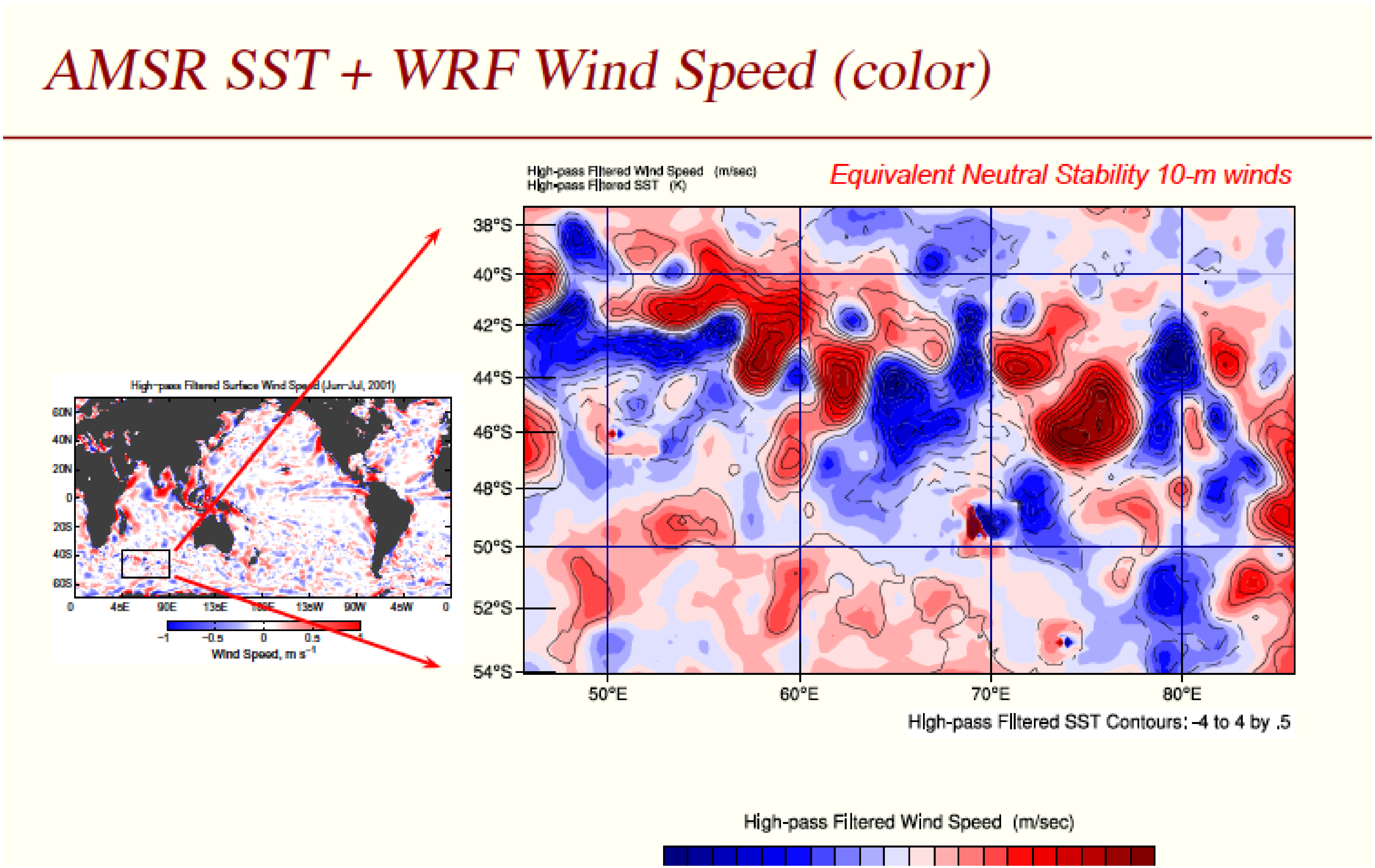
SST-wind interactions: cooler SSTs, weaker winds

AMSR SST (spatially high-pass filtered)



(July 2002)

SST-wind interactions: cooler SSTs, weaker winds



Fronts affect atmospheric boundary layer

- Wind anomalies
- Cloud albedo anomalies ~20%
- Horizontal divergence perturbations throughout troposphere, sensitive to SST resolution
- Reference:

Title: An assessment of the sea surface temperature influence on surface wind stress in numerical weather prediction and climate models
Author(s): Maloney, ED; Chelton, DB
Source: **JOURNAL OF CLIMATE** Volume: **19** Issue: **12** Pages: **2743-2762** Published: **2006**

High space-time resolution demands ...

- Use of multiple sensors and analysis ... accounting for their errors (STVAL)
  - Current GHRSST “standard” is to assess errors against drifting buoy SSTs
- Consideration of the diurnal cycle (DVWG)
- Consideration of near-surface stratification (DVWG)

... to reduce analysis errors

AATSR/buoy/AMSR-E 3 point statistics

- Bias corrected AATSR bulk D3, AMSR-E SSTs & buoy SSTs are
- co-located and the global mean differences calculated for 2003:

  - AATSR – buoy SST = 0.00K, sd 0.25K
  - AATSR – AMSR-E SST = 0.03K, sd 0.45K
  - buoy – AMSR-E SST = 0.03K, sd 0.48K

- We can say that:
- $sd^2(a,b) = (\text{error in a})^2 + (\text{error in b})^2$
- $sd^2(a,b) = (\text{error in a})^2 + (\text{error in b})^2$
- $sd^2(b,c) = (\text{error in b})^2 + (\text{error in c})^2$

- Therefore:
- $(\text{error in a})^2 = ½(sd(a,b)^2) + ½(sd(a,c)^2) – ½(sd(b,c)^2)$

Errors calculated from 3-point analysis

- Calculated error for each observation type:

- AATSR bulk D3 SST = 0.13K
- Buoy SST = 0.21K
- AMSR-E SST = 0.43K

- Similar trends are seen when in Northern and Southern hemisphere match-ups individually, using moored and drifting buoys individually, and using a 1-hour cutoff instead of 3 hours:
  - 0.13K <= error in AATSR SST <= 0.16K
  - 0.20K <= error in buoy SST <= 0.22K
  - 0.4K <= error in AMSR-E SST <= 0.49K