Models for remotely-sensed sea surface heights and temperatures in ocean data assimilation

Alexey Kaplan and Mark A. Cane

Lamont-Doherty Earth Observatory

of Columbia University

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The goal: to address data error modeling for data assimilation purposes, reflecting the difference in averaging of physical field by the model grid and by the observing systems.

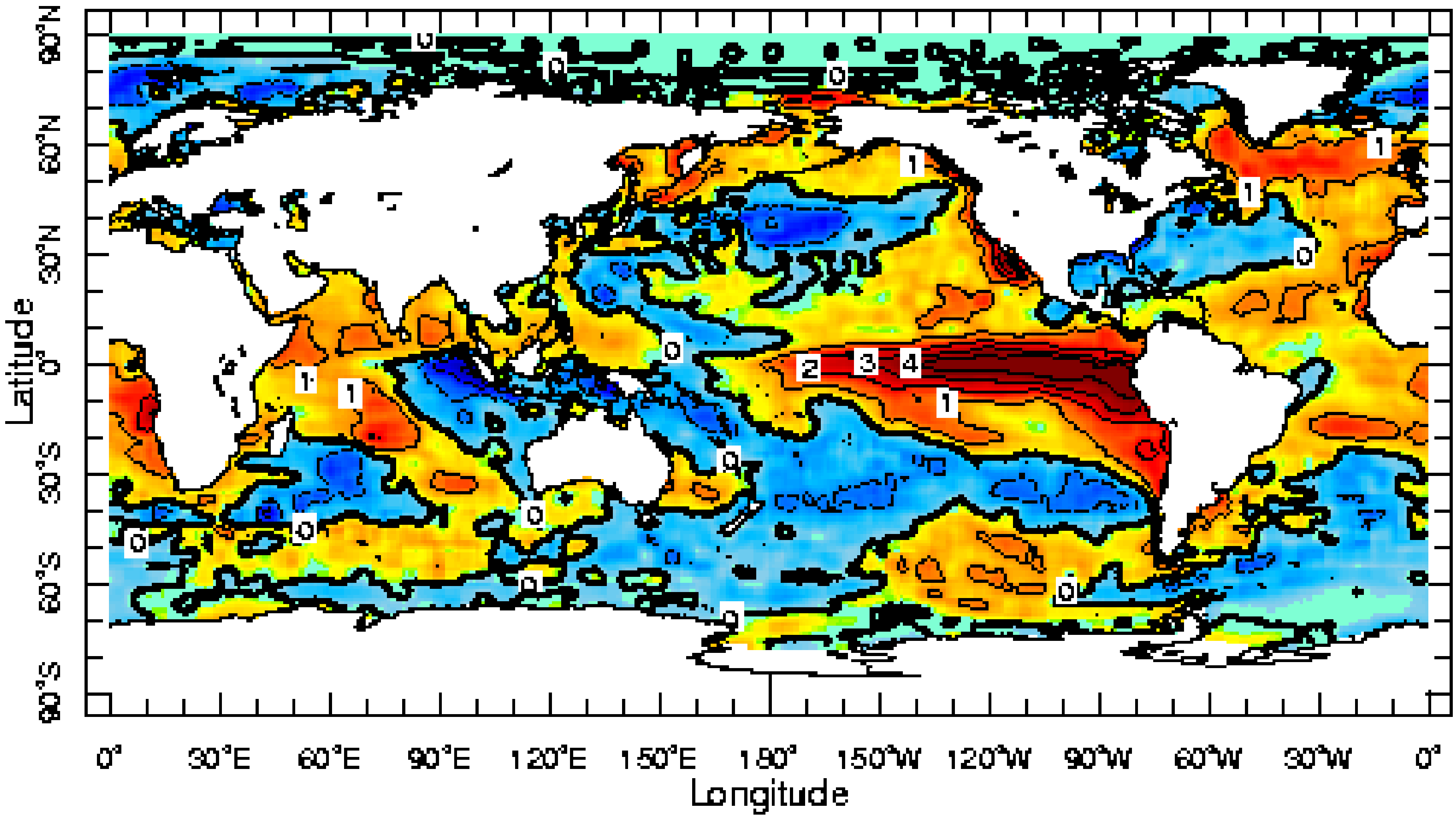
Consider a typical situation in the ocean modeling:
Model: grid resolution – 30km x 60km,
Data: Sea surface height altimetry – 7km footprint;
SST – 1-4-25km averages, depending on the product;
In situ observations – local.

What is the error of the data with regards to the model grid values?
It needs to be specified for the assimilation procedures.

In addition to measurement error of the data, we need to take into account the error due to the difference in averaging of the physical field by the model and by different types of the observing systems.
Are our error estimates consistent with each other and with data differences?

Let’s start from a very simple problem: explaining the difference between gridded versions of satellite and in situ SST data

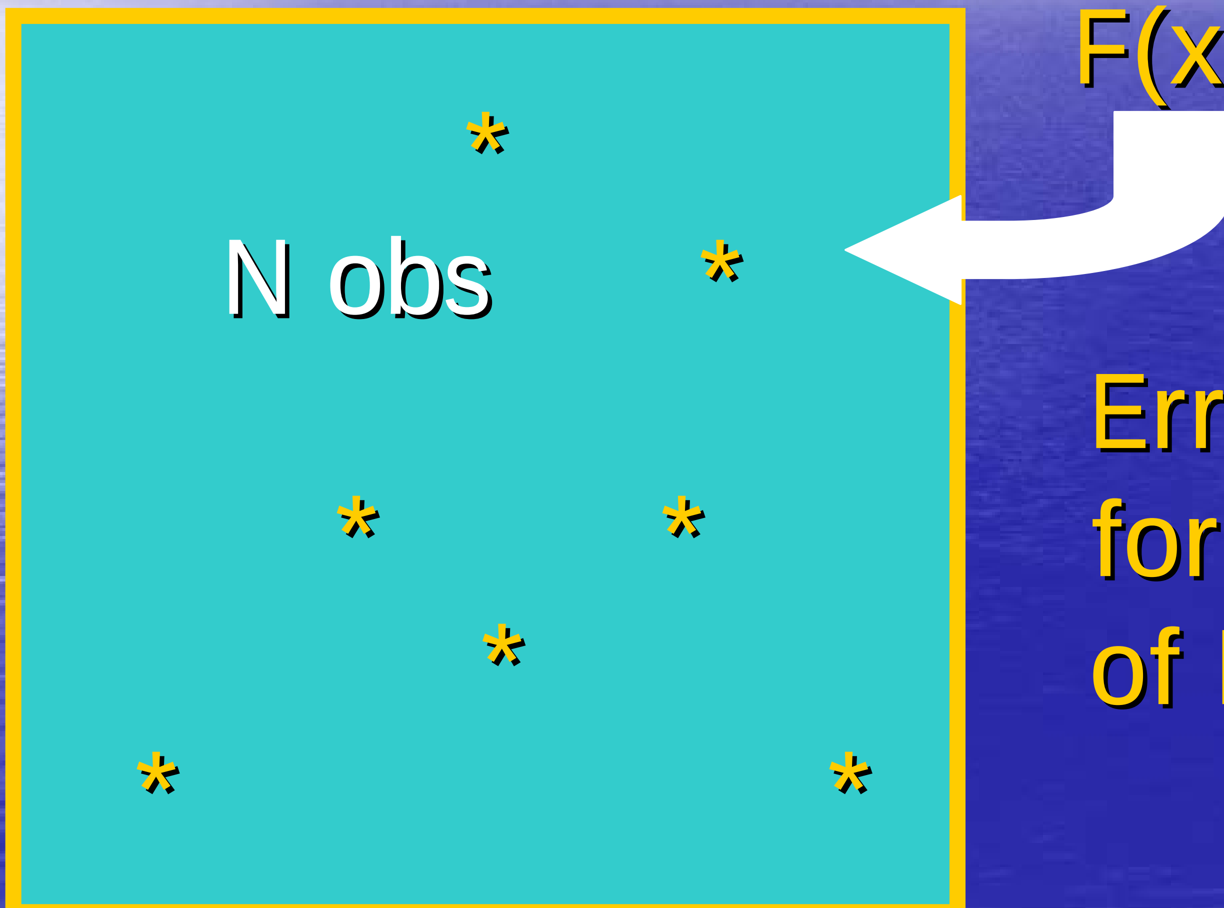
Sea Surface Temperature Anomaly (Reynolds and Smith's NCEP OI v.2)



9-15 Nov 1997

What is the error in the binned obs mean (as estimates of the “true” bin area average)?

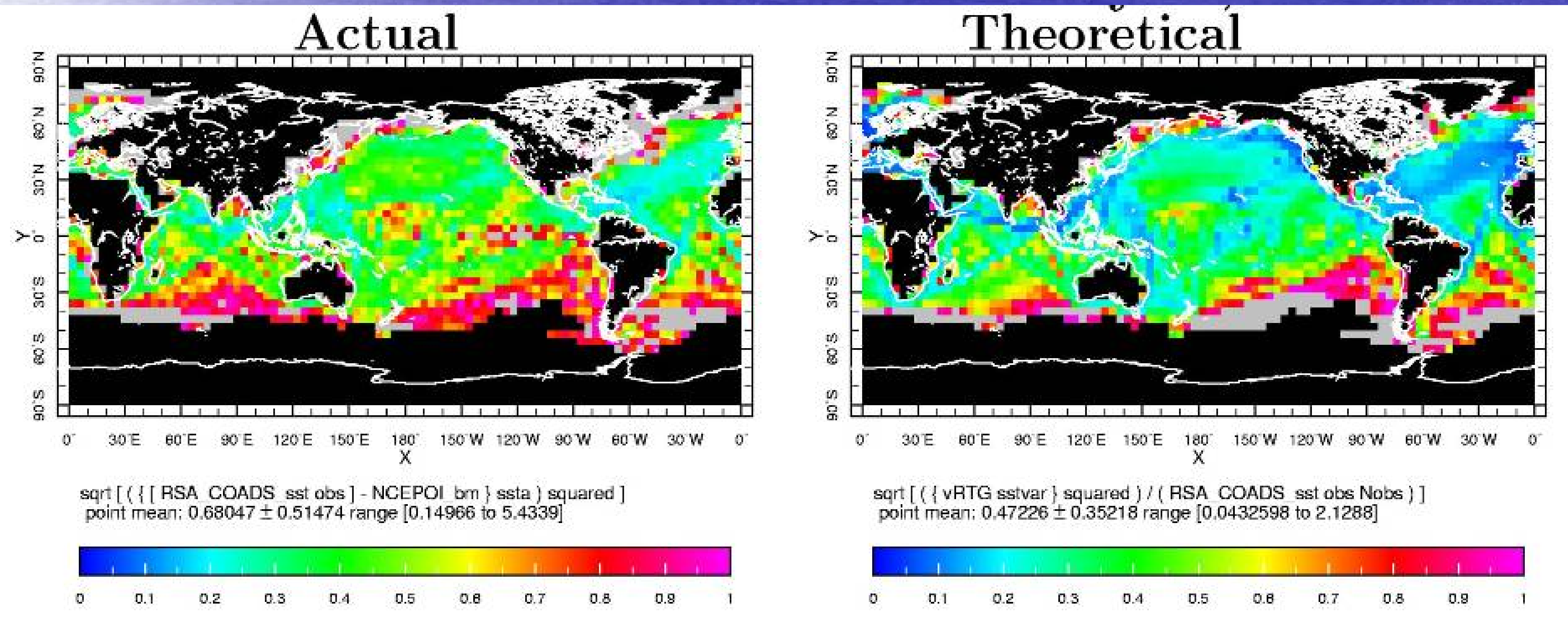
$F(x,y)$ [or $F(x,y,t)$]



Error variance for the mean of N observ is

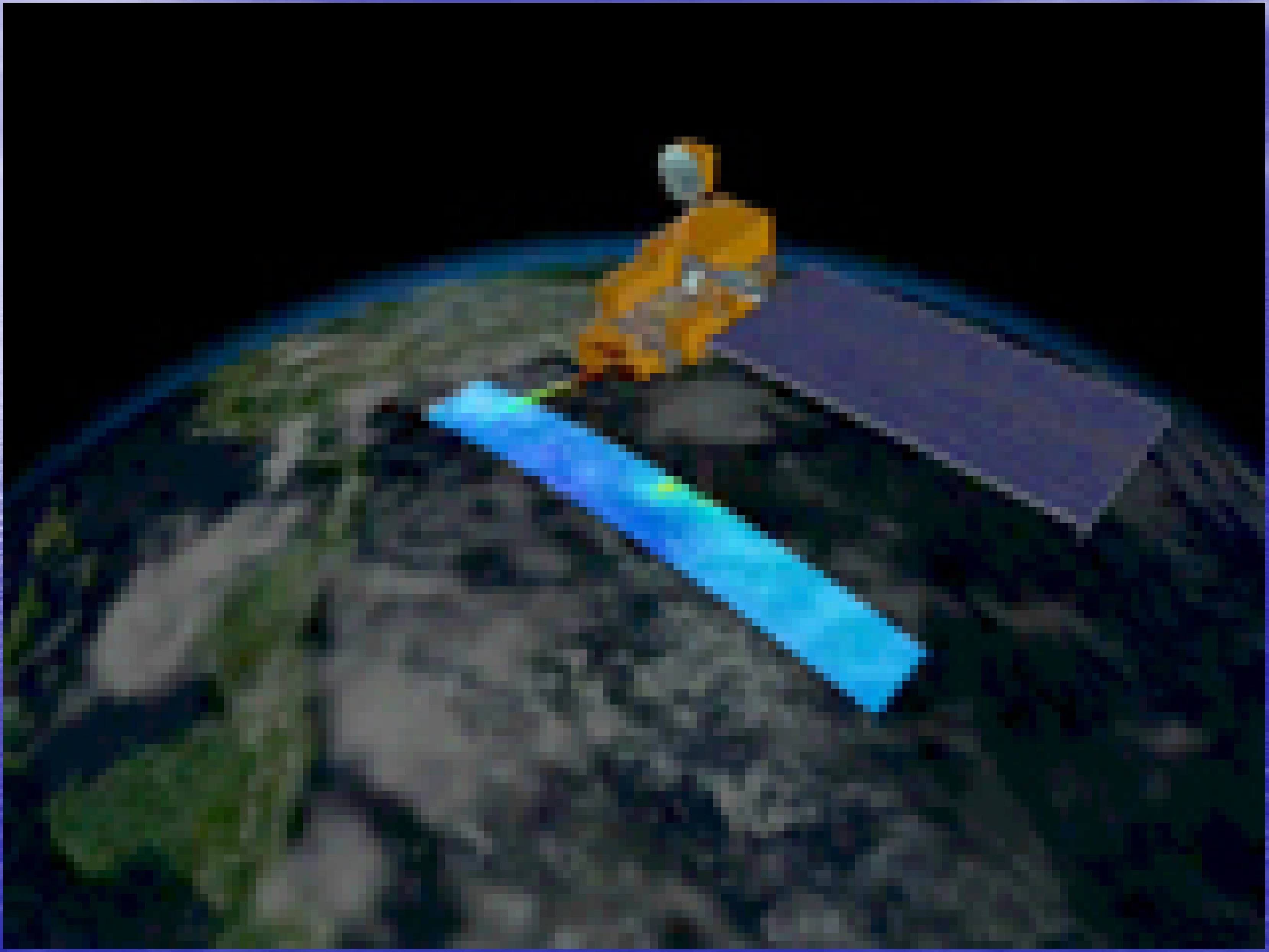
$$\sigma^2/N$$

Error in 4 degree ICOADS bins (NCEP OI analysis is used as “truth”): Actual and theoretical error variance differ by a factor of two

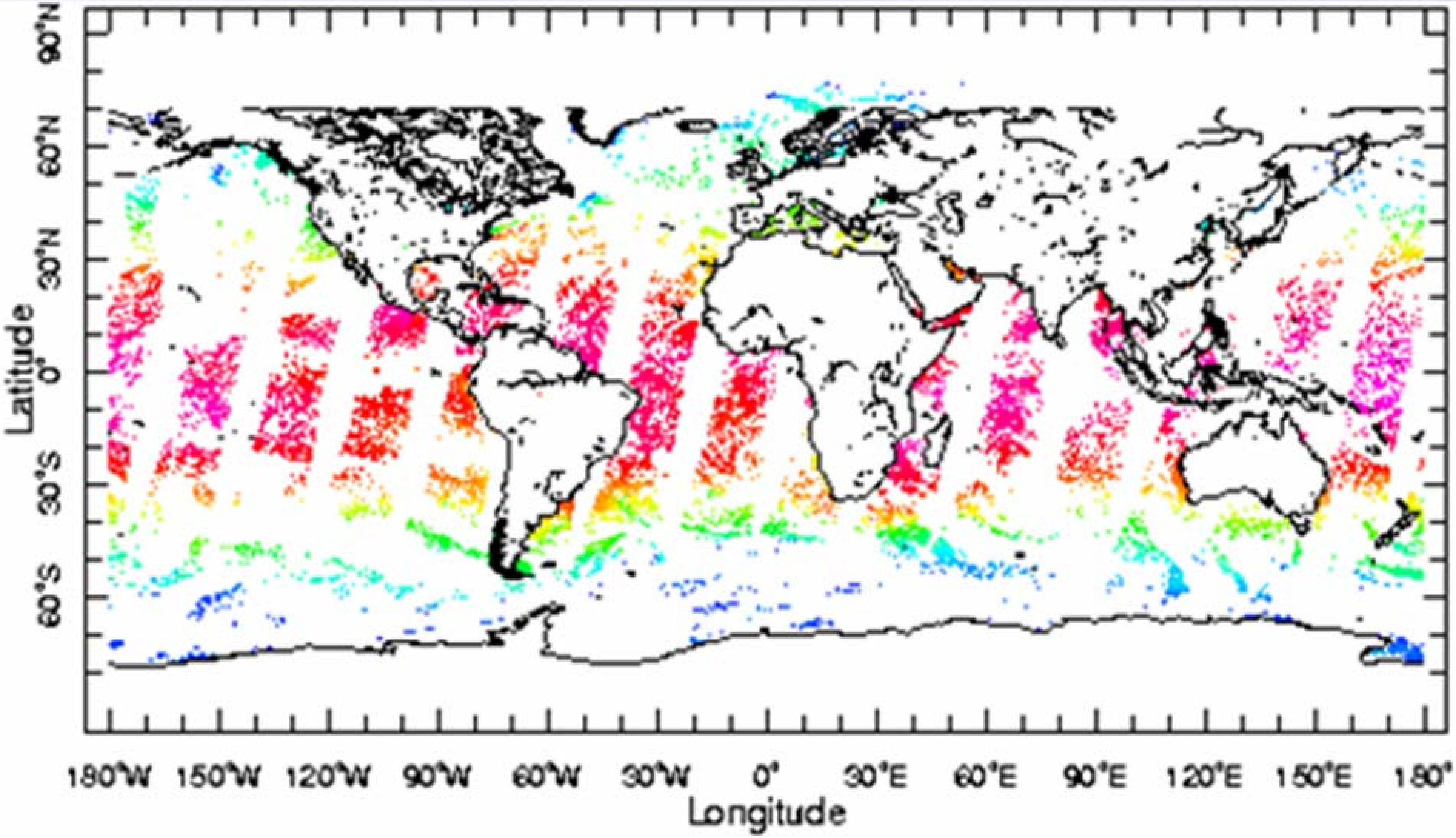


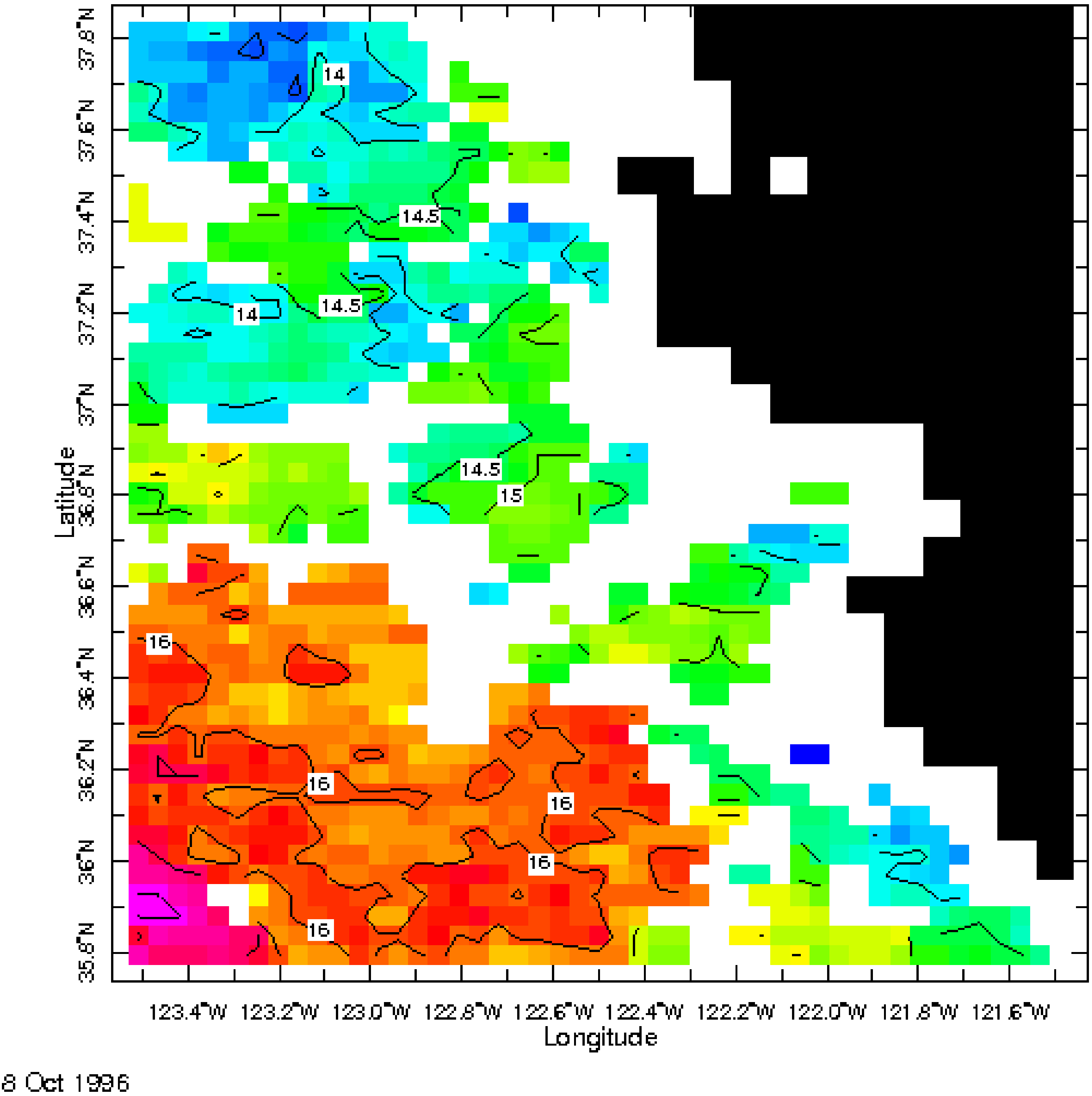
High-resolution brought in by satellite data can help pinpoint natural SST variability

MODIS Scanning Swath



Satellite Sea Surface Temperature Measurements for one day





Pathfinder SST: Monterey Bay, Oct 8, 1996 4km resolution

A few weeks of background processing of 20 years of daily 4km maps of Pathfinder AVHRR SST later

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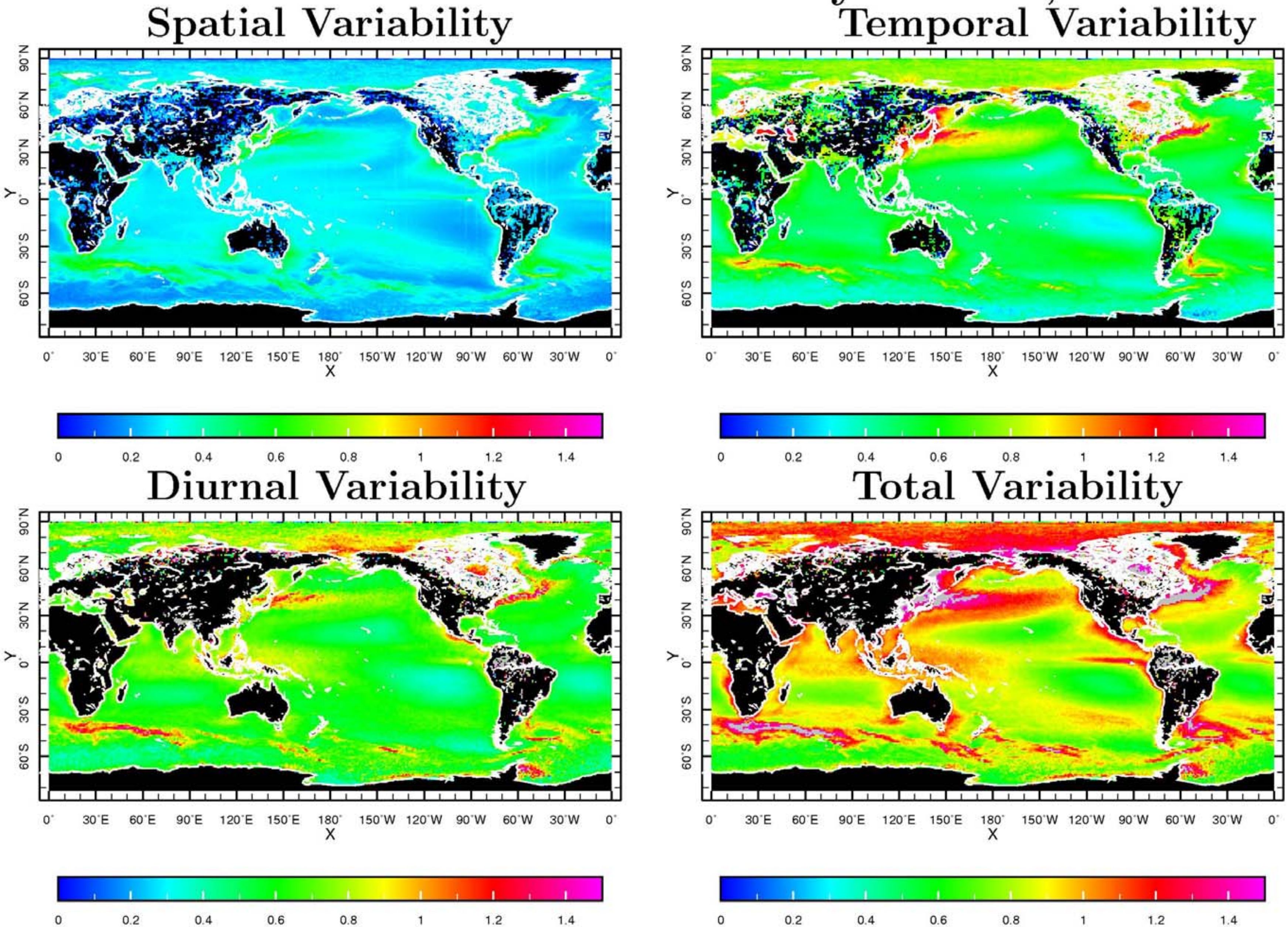
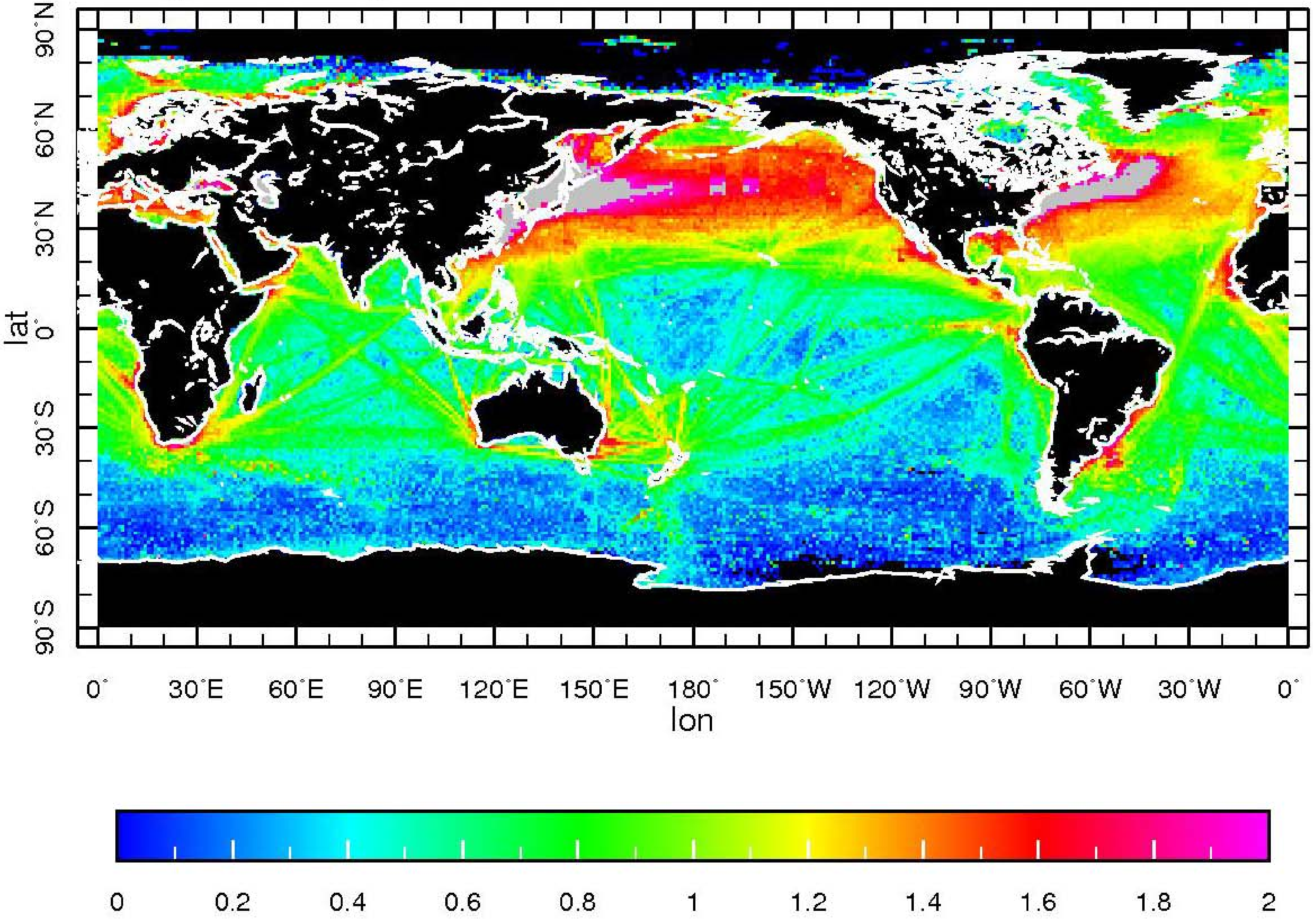
we have SST variability inside 1x1 boxes estimated...

Small-scale variability in SST, ^{o}C

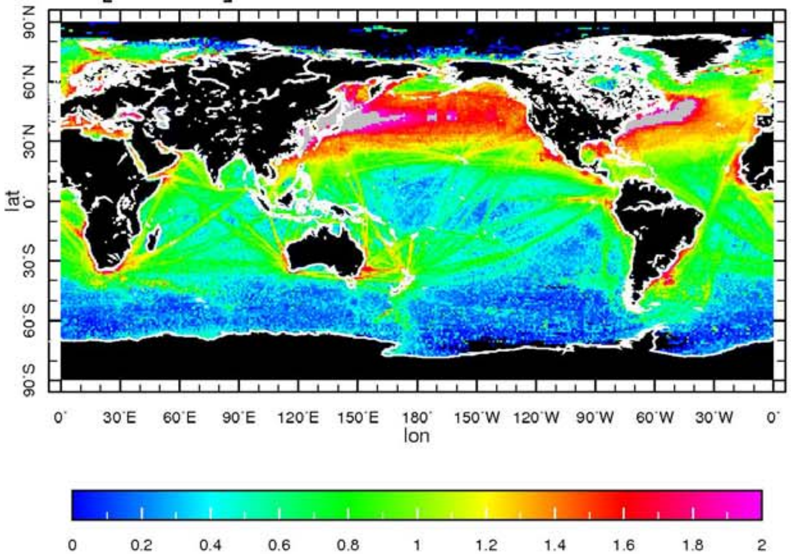


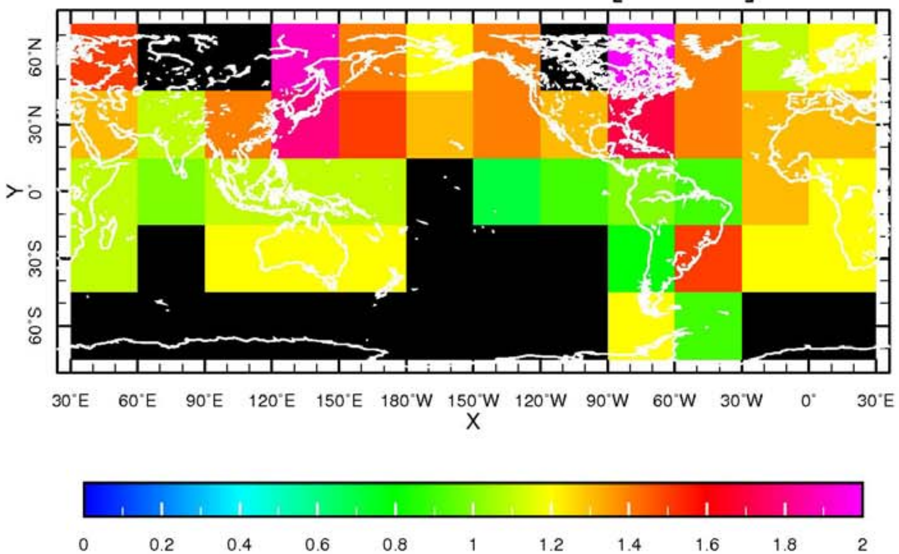
STD[SST] in ICOADS $1^o \times 1^o$ bins



Effects of measurement error

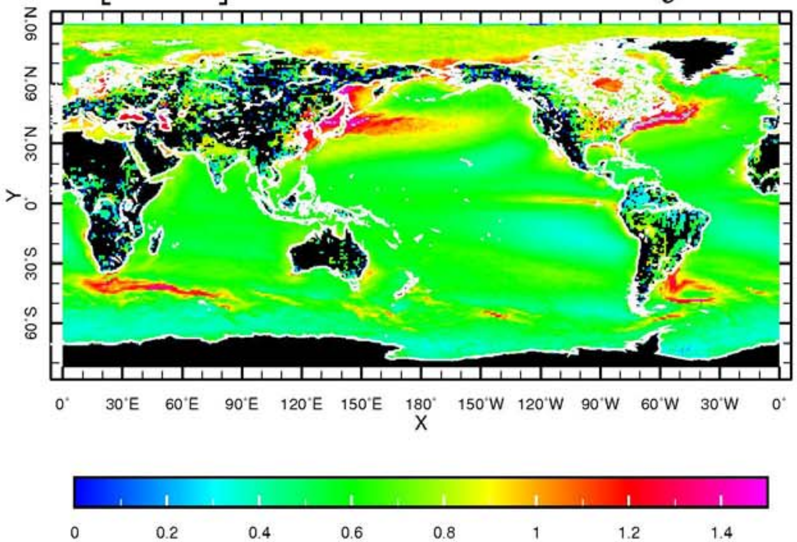
STD[SST] in ICOADS $1^o \times 1^o$ bins Kent and Challenor [2006] estimate



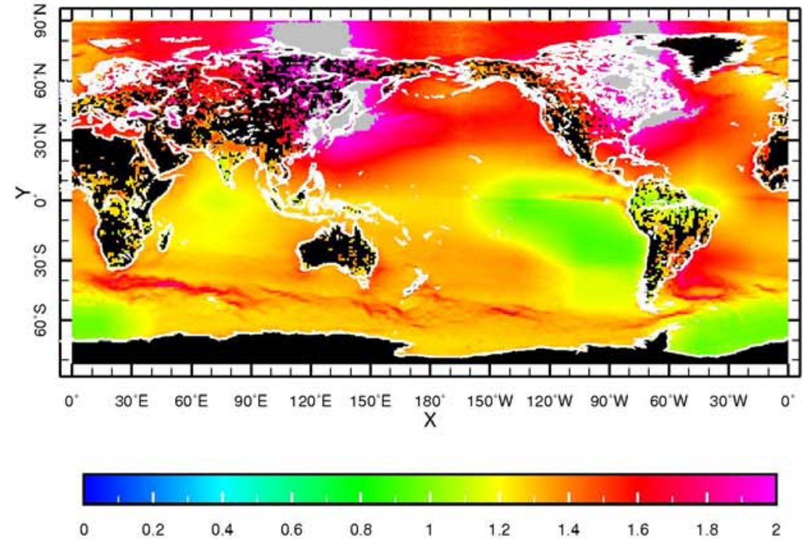


Sampling error estimates for a single observation

STD[SST] in $1^o \times 1^o$ monthly bins

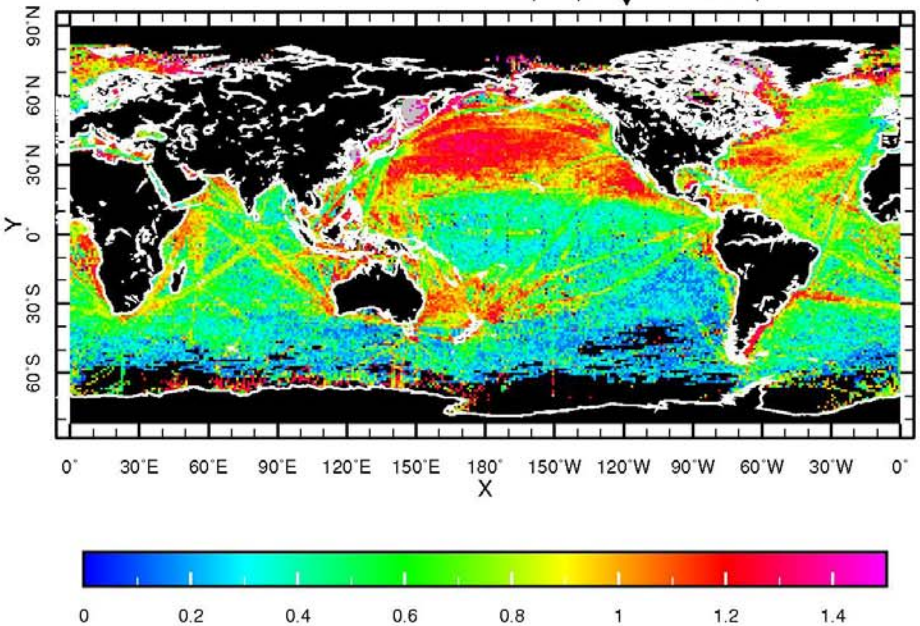


With the addition of KC2006 estimate

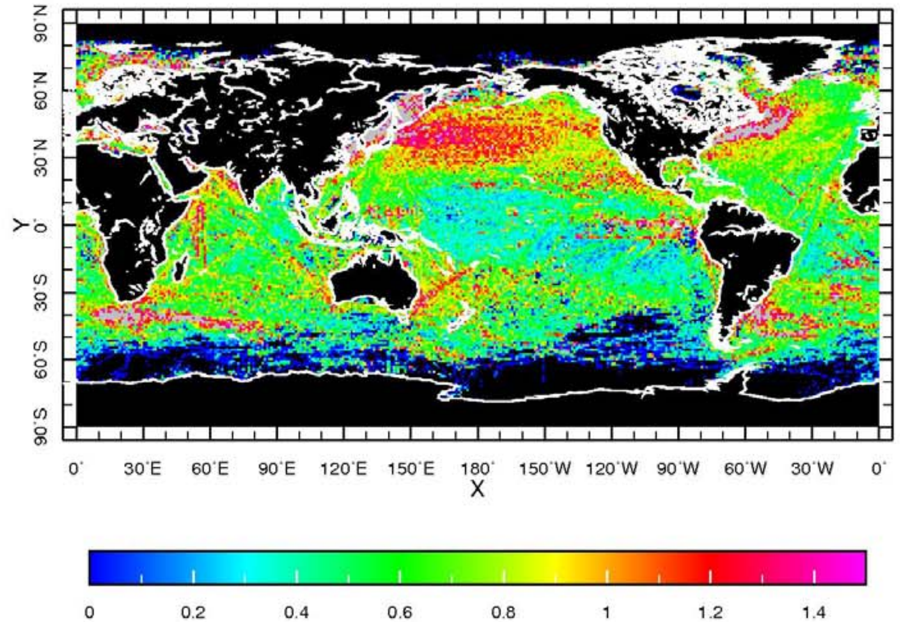


Modeling in situ data error for 1^o bins

Modeled as $\langle \sigma / \sqrt{n_{\text{obs}}} \rangle$



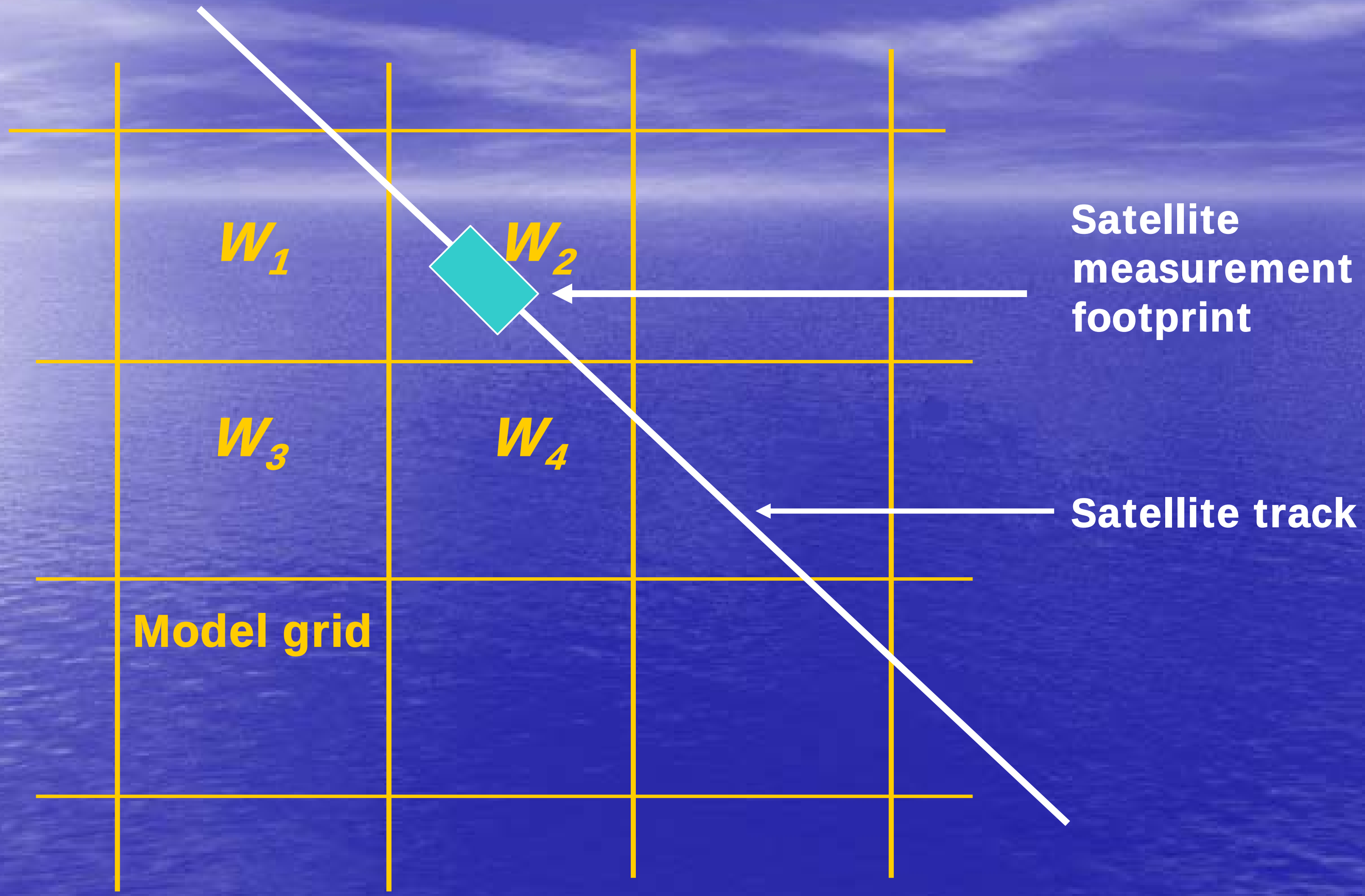
Actual MODIS–ICOADS STD



What we have learned from the SST analysis:

For representing 1degX1degX1month bins both (in situ) measurement error and natural SST variability contribute significantly into the effective observational error

Model and data values



$$S^o = Hs = W_1 s_1 + W_2 s_2 + W_3 s_3 + W_4 s_4$$

$$H s + \varepsilon = s^o$$

Spectral representation of data error

$$H s = \int W(\vec{x}) s(\vec{x}) d\vec{x}$$

$$s^o = \int W^o(\vec{x}) s(\vec{x}) d\vec{x}$$

$$\varepsilon = \int (W^o(\vec{x}) - W(\vec{x})) s(\vec{x}) d\vec{x}$$

Assume

$$s(\vec{x}) = \int f(\vec{k}) e^{i\vec{k}\vec{x}} d\vec{k},$$

then

$$\varepsilon = \int d\vec{k} f(\vec{k}) \int (W^o(\vec{x}) - W(\vec{x})) e^{i\vec{k}\vec{x}} d\vec{k} = \int w(\vec{k}) f(\vec{k}) d\vec{k},$$

where

$$w(\vec{k}) = \int (W^o(\vec{x}) - W(\vec{x})) e^{i\vec{k}\vec{x}} d\vec{k}.$$

Let $P(\vec{k})$ be a power spectrum of $s(\vec{x})$:

$$\langle f(\vec{k}) f(\vec{k}')^* \rangle = P(\vec{k}) \delta(\vec{k} - \vec{k}').$$

Then

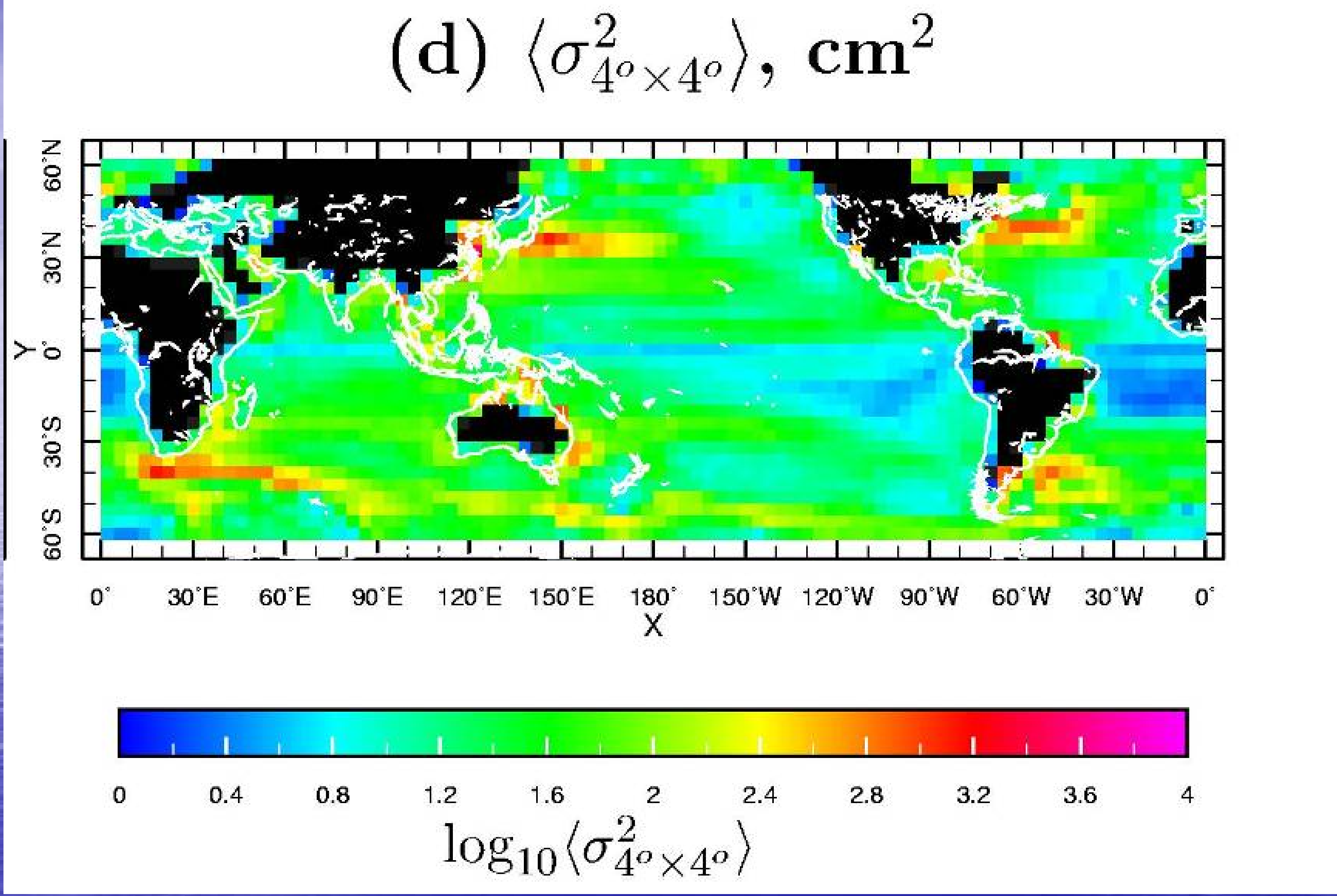
$$\langle \varepsilon^2 \rangle = \int P(\vec{k}) |w(\vec{k})|^2 d\vec{k}.$$

Rough Approximation

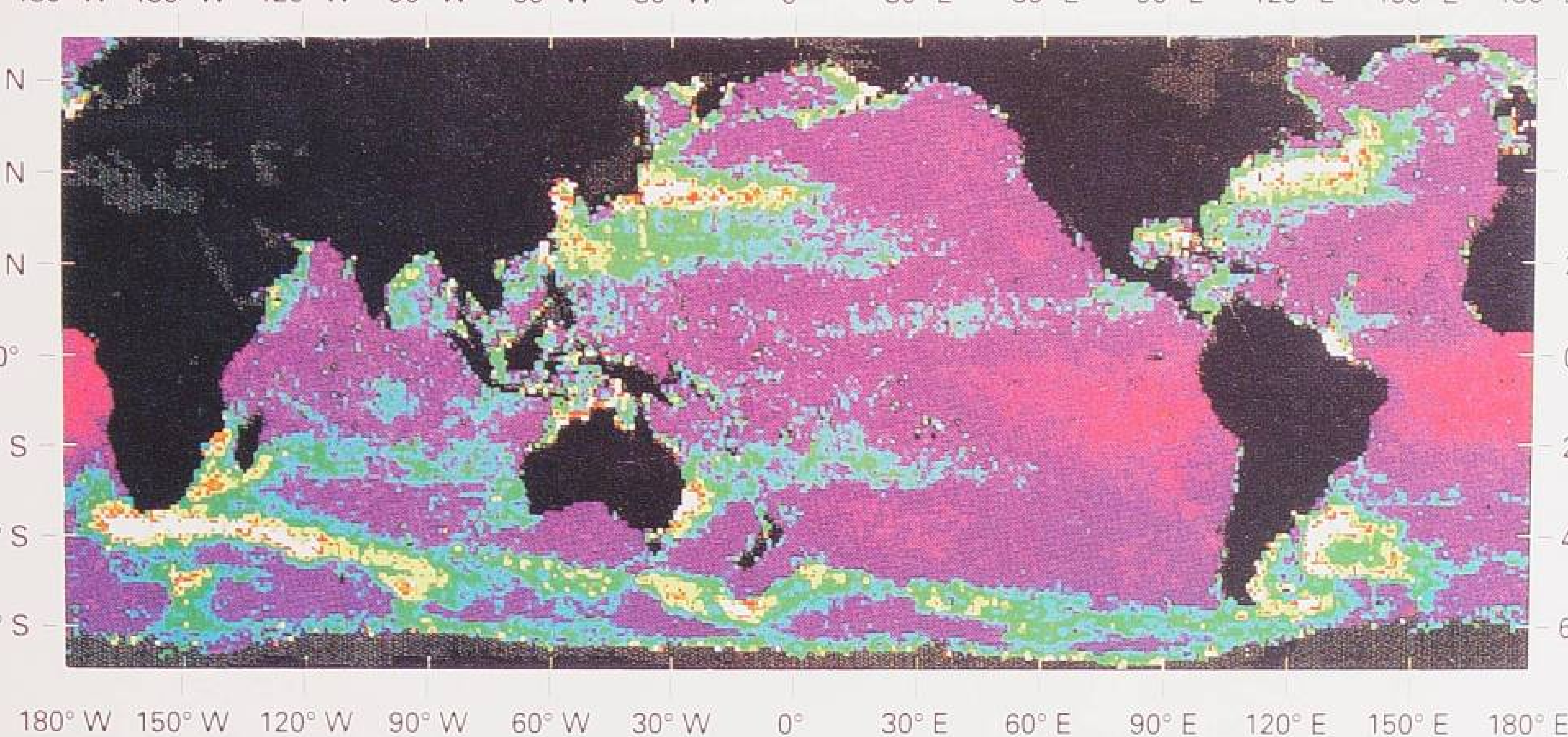
Suppose we want to use a satellite retrieval with a footprint of size l on the ocean surface for the assimilation to a model with the grid size L. By using the footprint value as an estimate for an average over the model grid box, we commit a sampling error. If a wavenumber power spectrum $P(k)$ of the physical field is isotropic and known, the expression for this error is very simple

$$\sigma^2 = \int_{2\pi/L}^{2\pi/l} P(k)dk.$$

If the field is not isotropic and a more sophisticated model-data interpolation operator is used, the formulas quickly becomes more complicated, but as long as the power spectra estimates are available, model and observing system geometries are known, the computation of sampling error variances and covariances are straightforward.



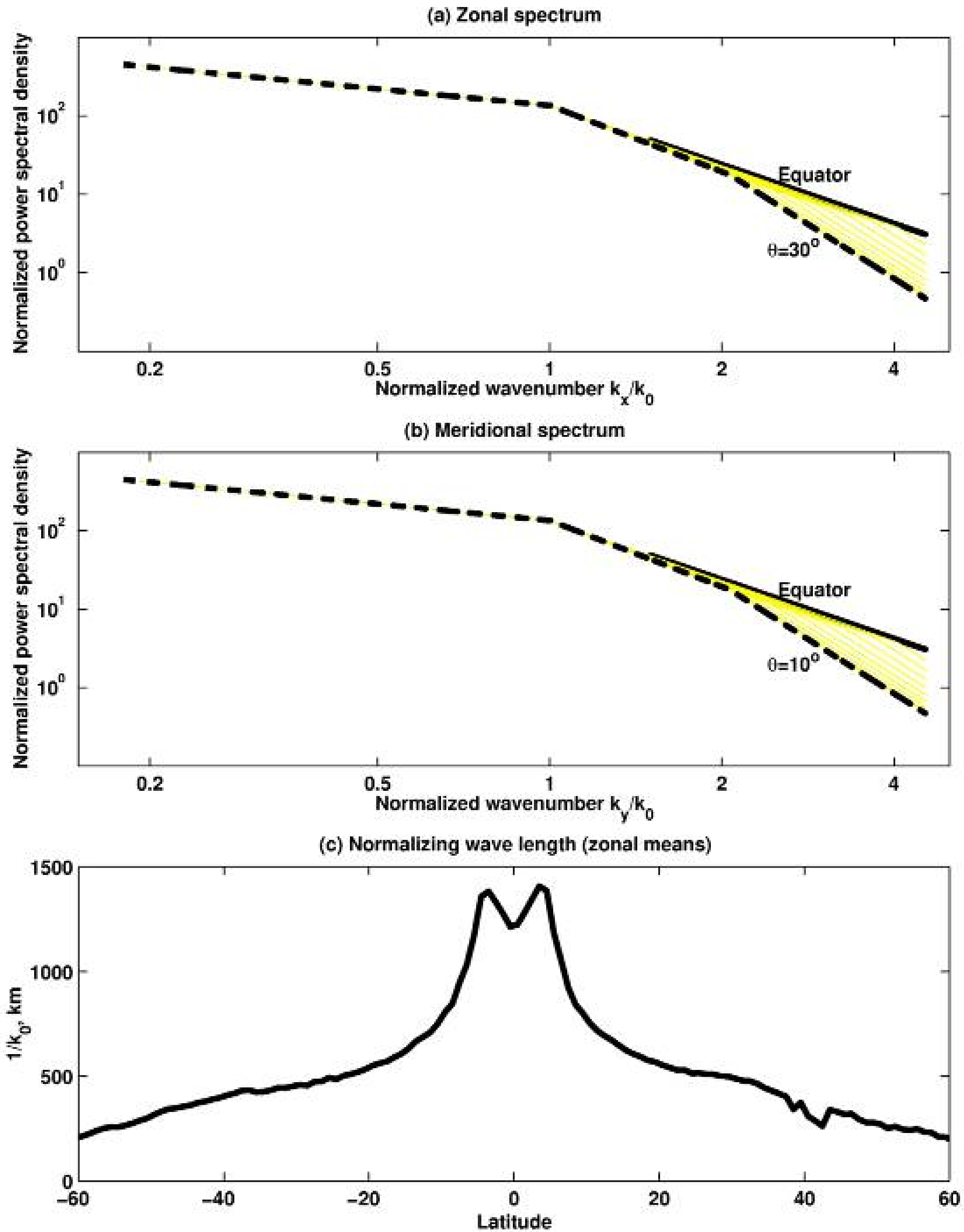
Sea surface height from 1/3 degree AVISO analyses (Ducet et al. 2000)



M. Tomczak & J.S. Godfrey book

"Regional Oceanography: an Introduction"

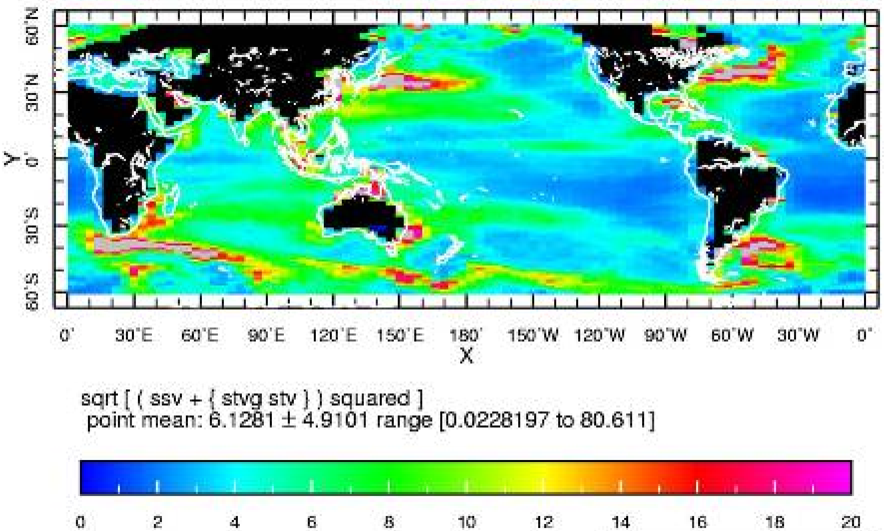
FIG. 4.8. Annual mean of eddy energy in the ocean as observed by satellite altimeter during December 1986 - November 1987. The eddies are detected by measuring the shape of the sea surface, which bulges downward in cyclonic and upwards in anticyclonic eddies as explained in Figs 2.7 and 3.3. The quantity shown is the standard deviation of observed sea level (cm) from the mean sea level over the observation period. From Fu *et al.* (1988).



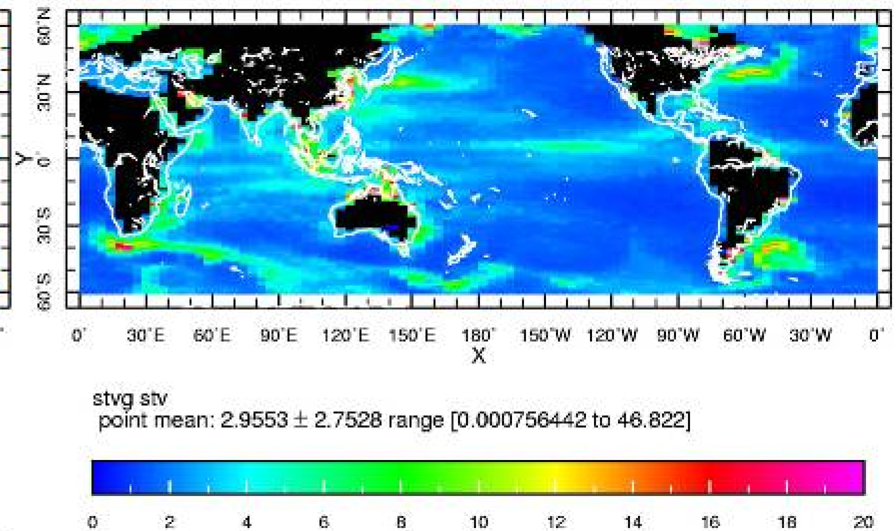
Wavenumber spectrum for sea surface heights: Combining Stammer (1997) tropical and midlatitudinal spectral forms [Rossby radius is from Chelton et al. (1998)]

TOPEX [*Ducet et al.* 2000]
Time-space separation of small-scale sea level height variability

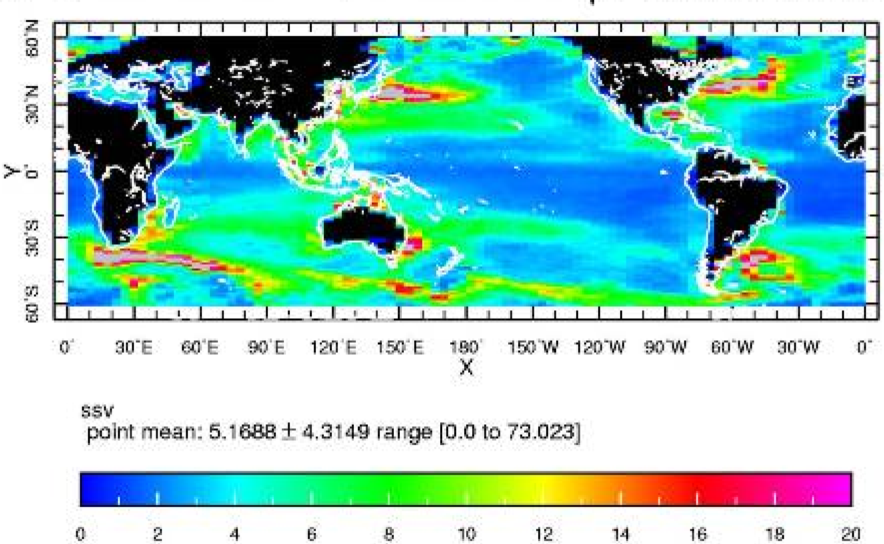
(a) Total SSV $\sigma_{4^o \times 1^o \times 1\,\mathrm{month}}(s)$



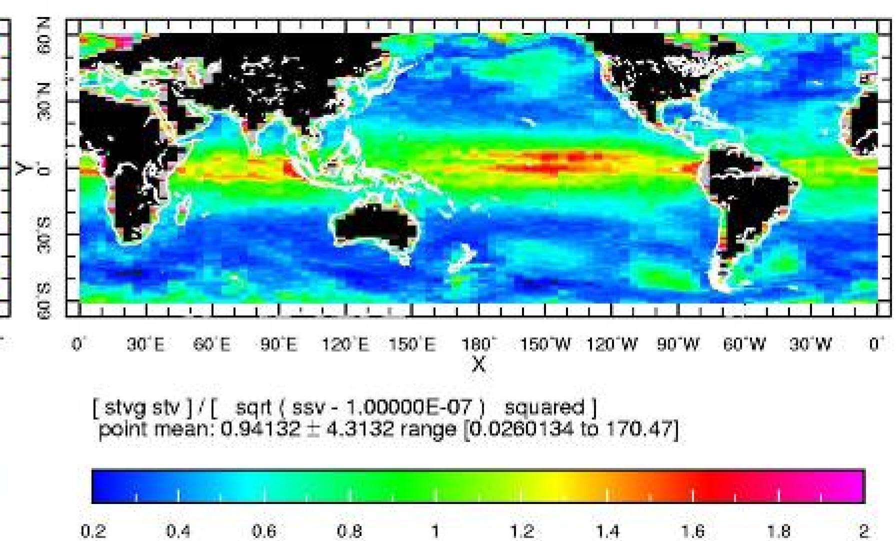
(b) Short-term temporal variability $\sigma_{1\,\mathrm{month}}([s]_{4^o \times 1^o})$



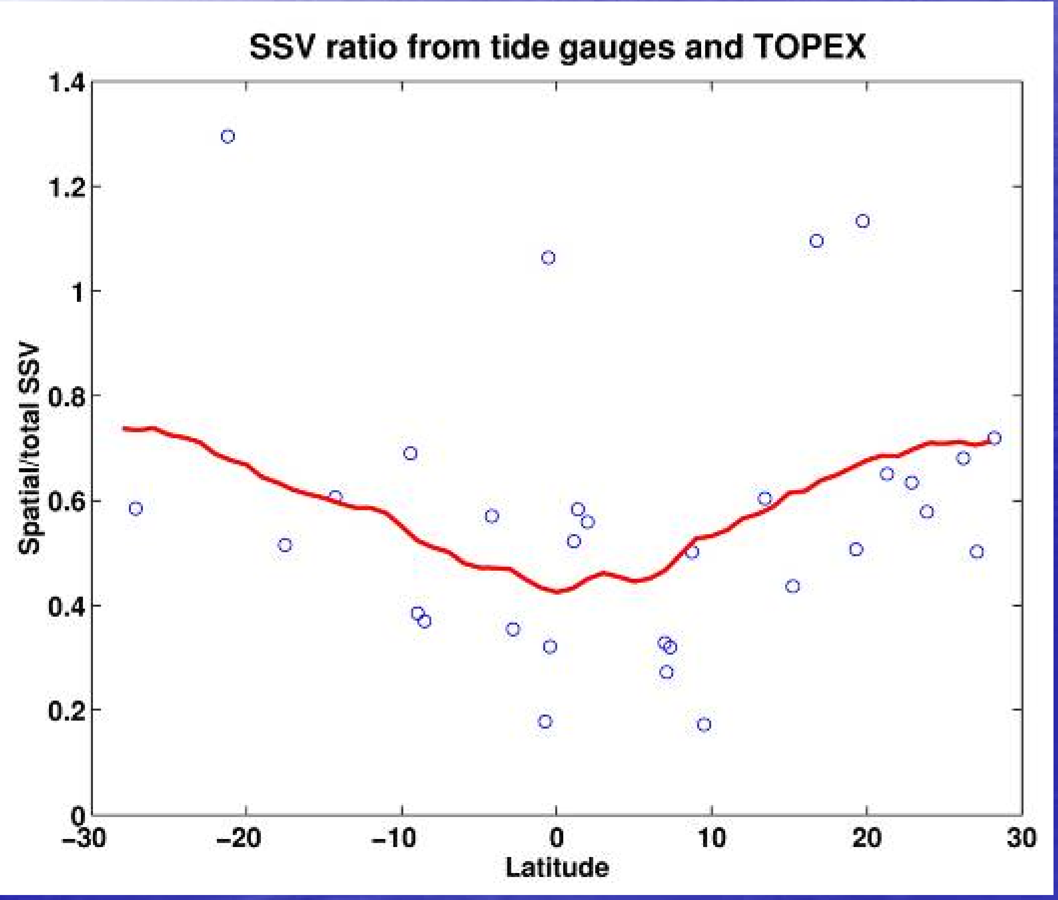
(c) Spatial variability inside bins $\sqrt{[\sigma^2_{4^o \times 1^o}(s)]_{1\,\mathrm{month}}}$

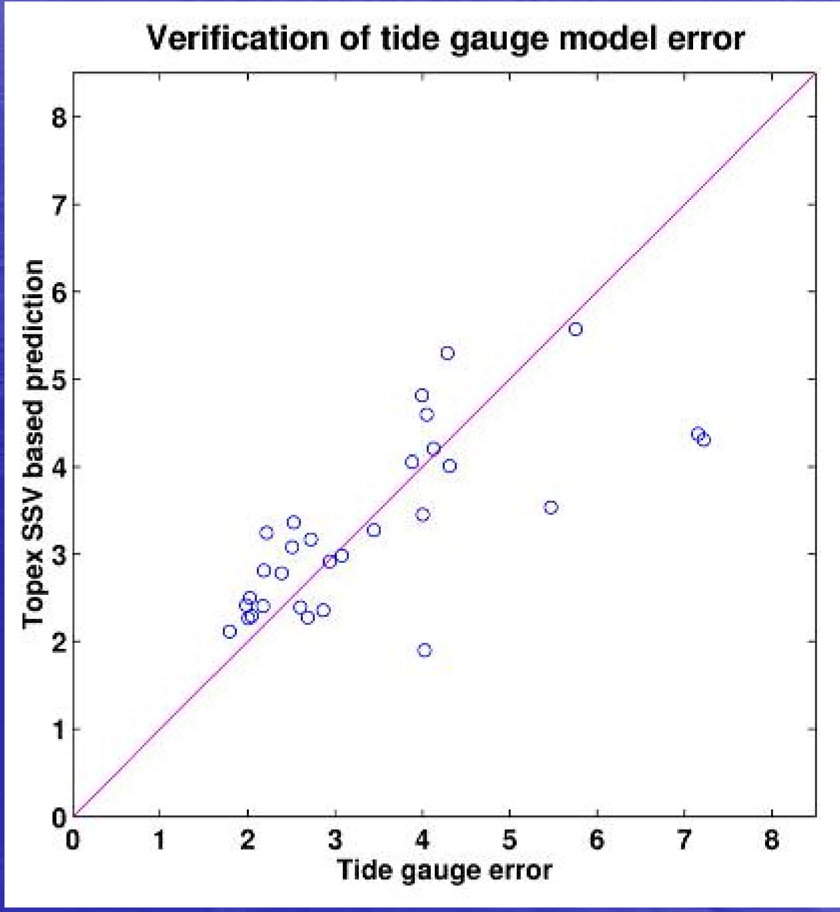


(d) Ratio γ of temporal to spatial variability



ERROR ESTIMATE VERIFICATION USING IN SITU DATA (TIDE GAUGES)





Conclusions

1. Effective data error depend on the model resolution (and averaging intrinsic in individual observations).

2. The richness of satellite data allows us to specify and use for error modeling spectral representations of assimilated fields.

3. Error due to averaging difference may exceed the nominal measurement error.

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Joint Center
for
Satellite Data Assimilation