SMALL-SCALE VARIABILITY IN MODIS AND PATHFINDER SEA SURFACE TEMPERATURES AND THEIR USE FOR DATA ERROR MODELS FOR IN SITU DATA SETS

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1. SUMMARY

SST is arguably the most visible climate variable in the public forum of climate change debate. In climate change detection and attribution studies they are usually used in the form of gridded data sets which are analyzed statistically or serve as boundary conditions for atmospheric general circulation models. Therefore it is of primary importance to ensure their optimality and reliability, including reliability of their error estimates.

Most current methods of gridding blend together satellite and in situ data and involve a mixture of optimal interpolation (successive corrections), eigenvector reconstruction, bias correction techniques, and some forms of data assimilation [*Reynolds and Smith*, 1994; *Rayner et al.*, 2003; *Kaplan et al.*, 1997,2003]. Analyses of the pre-satellite period depend on quite sparse in situ data as their inputs, but they usually try to make use of statistical information extracted from the satellite period [*Smith et al.*, 1996,1998; *Rayner et al.*, 2003; *Kaplan et al.*, 2003]. Therefore, the quality of these analyses and hence our ability to detect and properly attribute long-term climate change hinges on the quality of a priori statistical information obtained from the satellite data.

The goal of this project is to make use of the extensive satellite data in order to quantify and model in situ data errors, and thus to improve pre-satellite era climate analyses. To this end we present intercomparisons of MODIS SST products, and their comparisons with Pathfinder V5 SST and the in situ data collection ICOADS. Further, we estimate small-scale and short-term variability of SST using satellite data sets, and successfully use these estimates to model the magnitude of the the error in the binned in situ SST values.

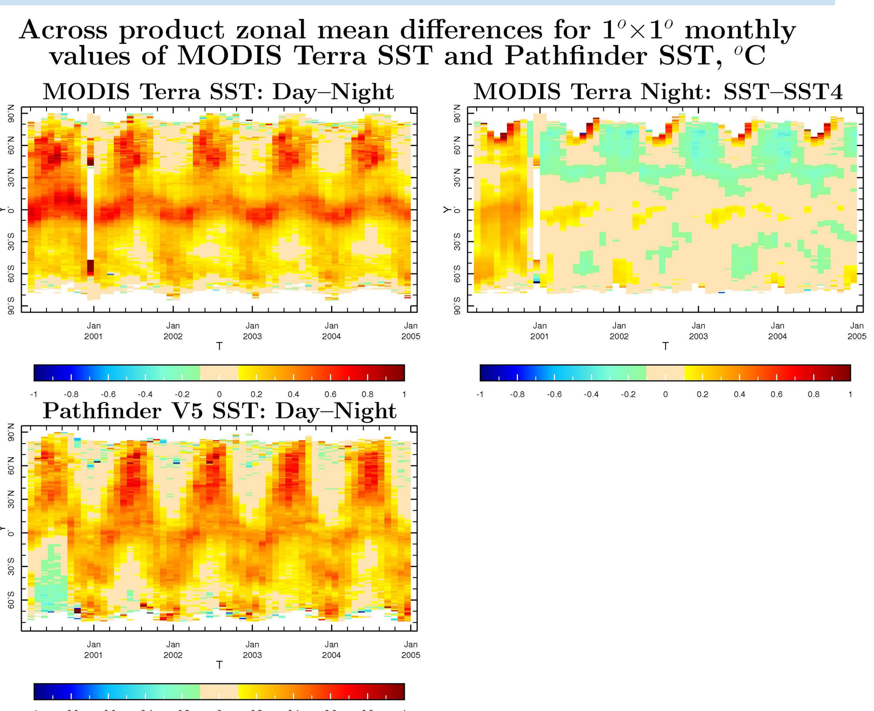

Figure 3: Zonal means of the monthly differences for SST products from MODIS Terra and Pathfinder V5. Units are ^oC.

2. RESULTS

We present spatial patterns of total RMS difference and its separation into mean bias and the error STD for many pairs of SST products. Figure 1 emphasizes the closeness of MODIS Terra SST and SST4 and presents the difference in the mean diurnal range captured by MODIS Terra observations vs Pathfinder SST. Variability estimates become significantly smaller if monthly averaging is applied (Figure 2). Apart from year 2000, time variability of zonal means shows high temporal homogeneity (Figure 3). Figure 4 and 5 compare MODIS Terra SST with Pathfinder SST directly and found the former to be slightly cooler than the latter, particularly in the midlatitudes.

We further performed the comparison of MODIS and Pathfinder temperature products with monthly $1^o\times1^o$ summaries of in situ SSTs from ICOADS, a rather complete collection of historical ship and buoy surface observations (Figure 6). The comparison covered 2000-2005 period and found in situ measurements to be on average warmer than both night and day SST products. This is surprising, because ICOADS summaries are not separated into day and time values and could be expected to fall in between day and night satellite SST products. Per work of R.Evans and P.Minnett on the MODIS Team, the errors of MODIS SST products are 0.3-0.4^{o}C, i.e. significantly smaller than most values of the STD of the SST difference shown in the right panels of Figure 6. Therefore, it is mostly the error of the in situ data that we see here, and it needs to be investigated and modeled further. The statistics of satellite to in situ comparison computed for Pathfinder SST (Figure 7) is very similar to that computed for MODIS (Figure 6).

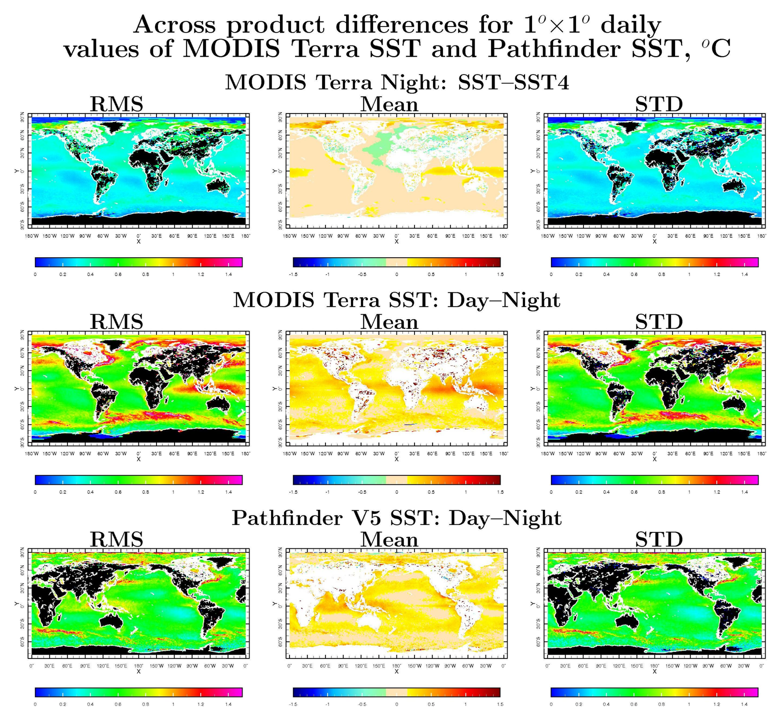

Figure 1: Across product differences for $1^o\times1^o$ monthly values of MODIS Terra SST and Pathfinder SST. Left panels show RMS difference for 2000-2005 period, central and right panels subdivide it into the mean difference and standard deviations. Calculations performed for daily values. Units are ^oC.

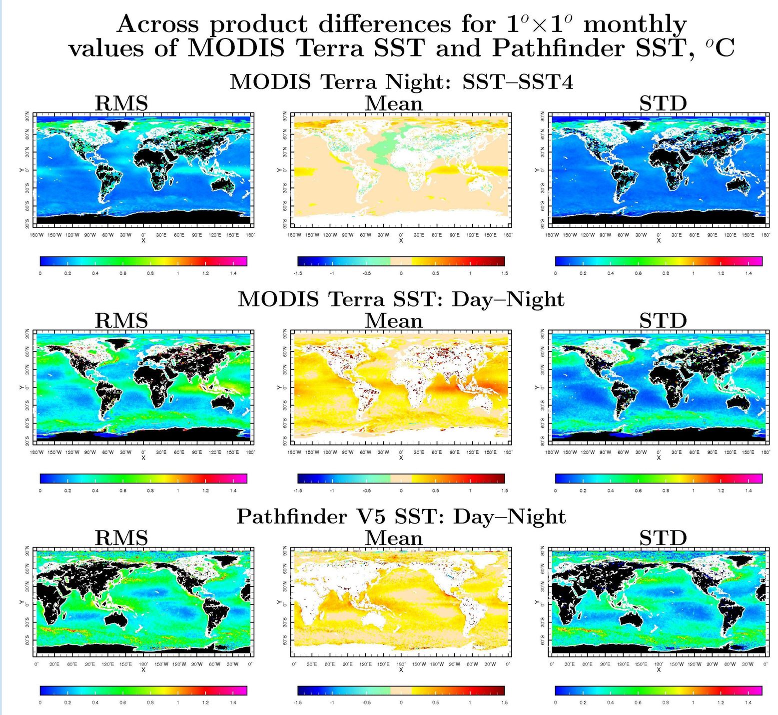

Figure 2: Across product differences for $1^o\times1^o$ monthly values of MODIS Terra SST and Pathfinder SST. Left panels show RMS difference for 2000-2005 period, central and right panels subdivide it into the mean difference and standard deviations. Daily differences were averaged into monthly bins before calculating RMS, mean, and STD. Units are ^oC.

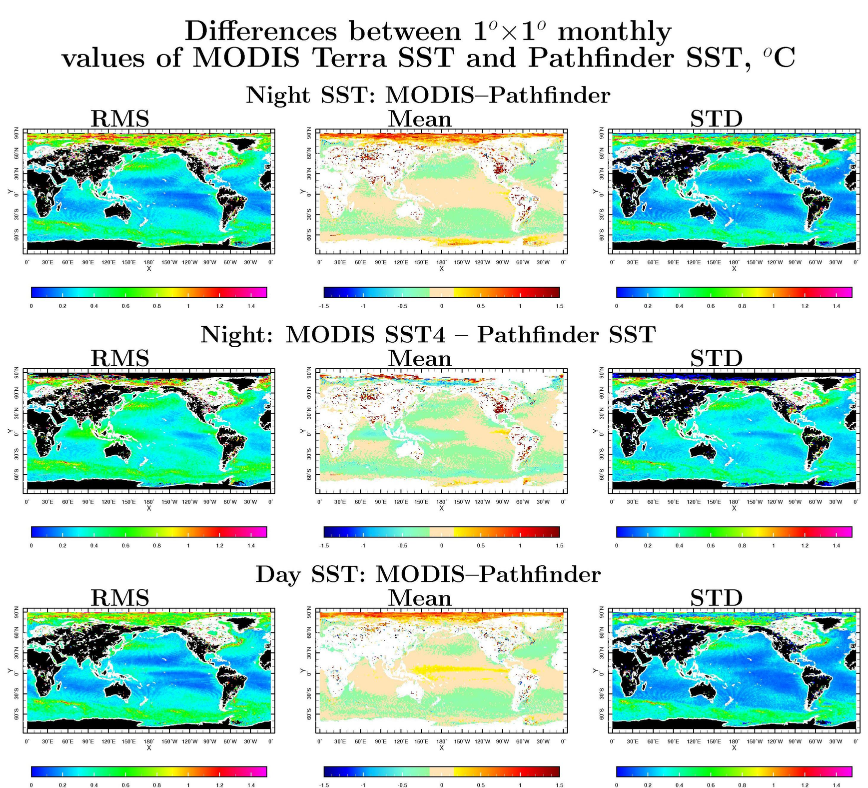

Figure 4: Differences between $1^o\times1^o$ monthly values of MODIS Terra SST and Pathfinder SST. Left panels show RMS difference for 2000-2005 period, central and right panels subdivide it into the mean difference and standard deviations. Daily differences were averaged into monthly bins before calculating RMS, mean, and STD. Units are ^oC.

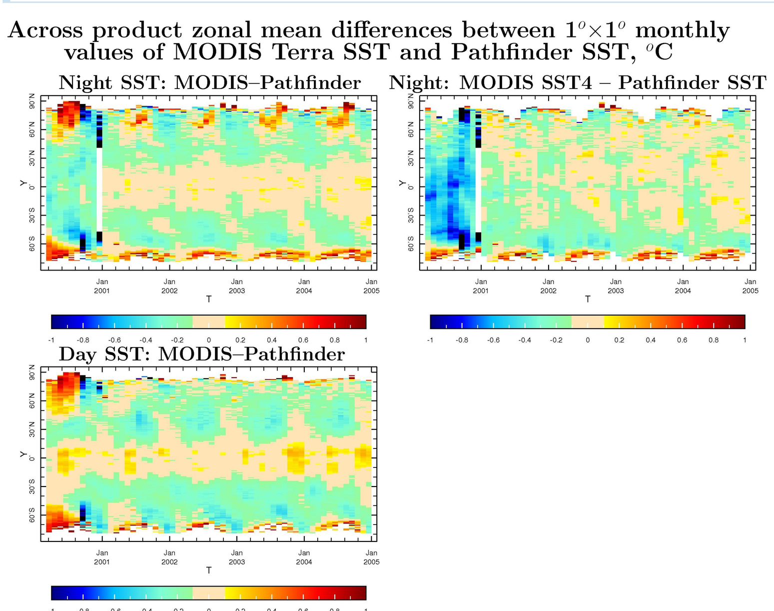

Figure 5: Zonal means of the monthly differences between SST products from MODIS Terra and Pathfinder V5. Units are ^oC.

Figure 8 shows a seasonal cycle and meridional structure in zonally averaged temperature differences. It also show a larger error of the Terra products (especially SST4) in the beginning of the record. Comparison of ICOADS with Pathfinder SSTs (Version 5) shows a similar magnitude of zonally averaged differences to those of MODIS (Figure 9).

We then use 4km Pathfinder satellite SST fields in order to estimate various components of the variability in ICOADS $1^o\times1^o$ monthly bins, and compute the total intra-bin variability estimate (Figure 10). Using this estimate σ, we can model error in ICOADS as

$$e = \sigma/\sqrt{N_{\rm obs}},$$

and then average over the period of Terra data product.

However, in situ measurement errors must be taken into account. As Figure 11 shows, the standard deviations of ICOADS data inside their $1^o\times1^o$ monthly bin are quite large, larger than space-time variability in these bins estimated from satellite data (Figure 10). With much sparser sampling of the ICOADS data, this is only possible if they are dominated by measurement error. These estimates are also consistent with the pattern of measurement error in ICOADS data estimated by Kent and Challenor [2006] (Figure 11). Adding Kent and Challenor [2006] random error estimate to the physical variability estimates for 1^o bins significantly increases our estimate of the effective error in a single in situ observation (Figure 12). As Figure 13 demonstrates, the resulting error model, that assumes independence of individual in situ observations captures major spatial features of MODIS–ICOADS STD difference.

A similar effort for 5^o bins (Figures 14 and 15) also result in a realistic pattern, albeit of a smaller range. Plausible explanation is in effective non-independence of in situ measurements for 5^o bins, due to the concentration of the observations along specific ship tracks.

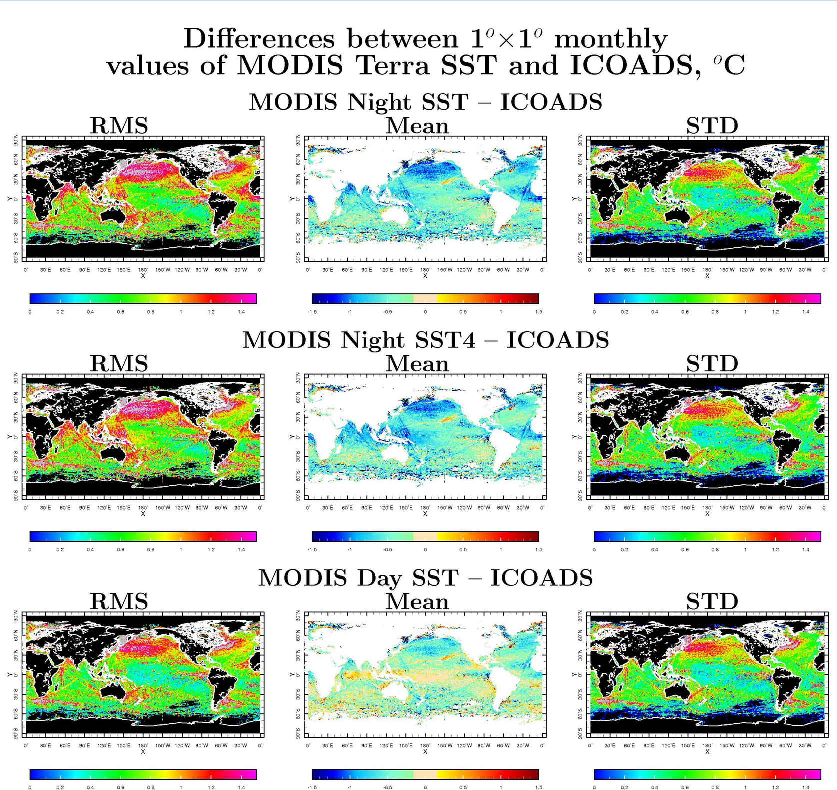

Figure 6: Difference between $1^o\times1^o$ monthly summaries of MODIS SST values and ICOADS. Left panels show RMS difference for 2000-2005 period, central and right panels subdivide it into the mean difference and standard deviations. Daily differences were averaged into monthly bins before calculating RMS, mean, and STD. Units are ^oC. ICOADS observations were not separated for day and night.

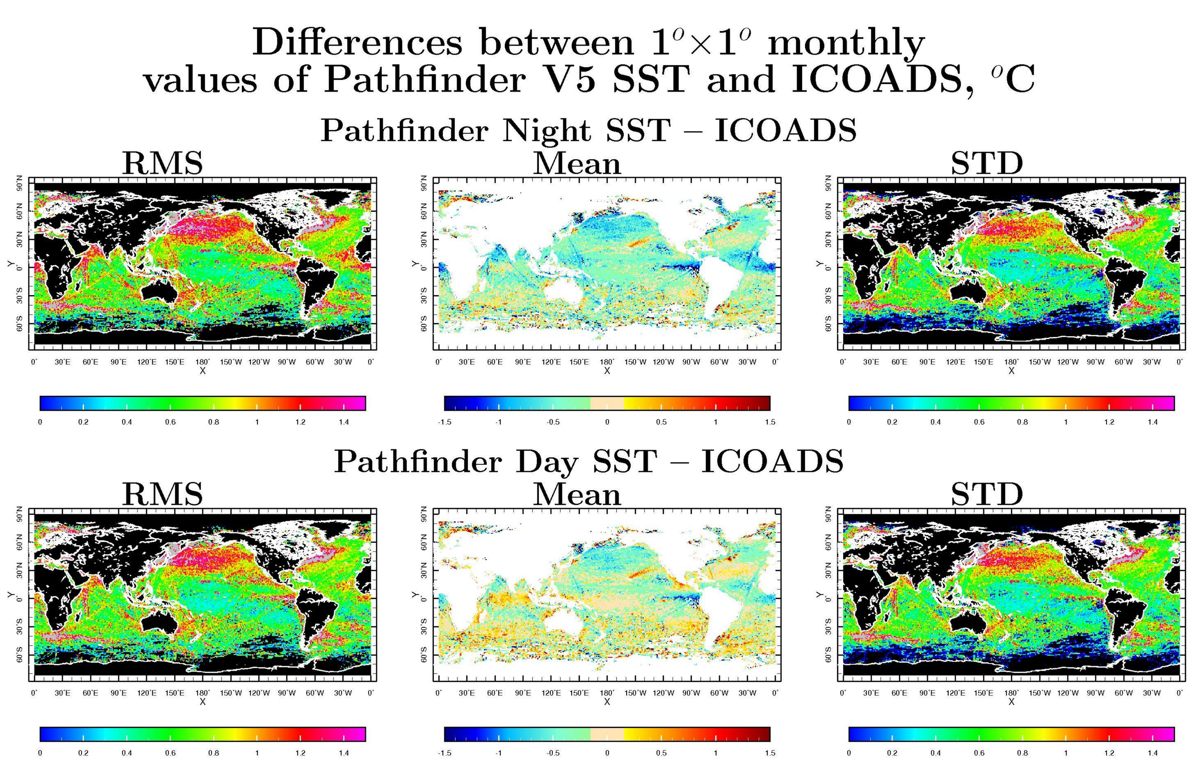

Figure 7: Difference between $1^o\times1^o$ monthly summaries of Pathfinder V5 SST values and ICOADS. Left panels show RMS difference for 2000-2005 period, central and right panels subdivide it into the mean difference and standard deviations. Daily differences were averaged into monthly bins before calculating RMS, mean, and STD. Units are ^oC. ICOADS observations were not separated for day and night.

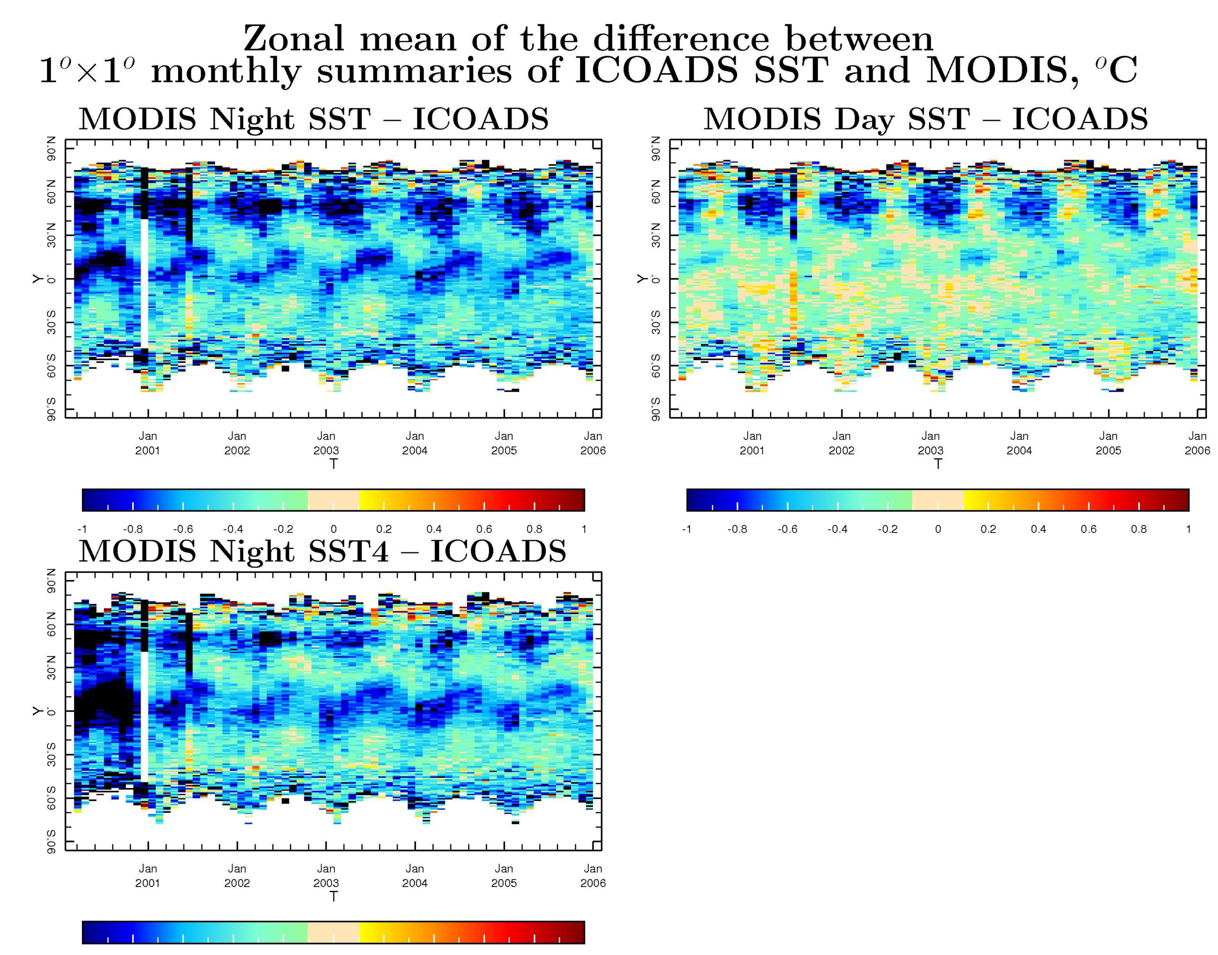

Figure 8: Zonal means of the difference between $1^o\times1^o$ monthly summaries of Terra MODIS SST and ICOADS SST values. Top panels show the difference between MODIS and ICOADS SST products, the bottom panel is the same for the night SST4. Units are ^oC.

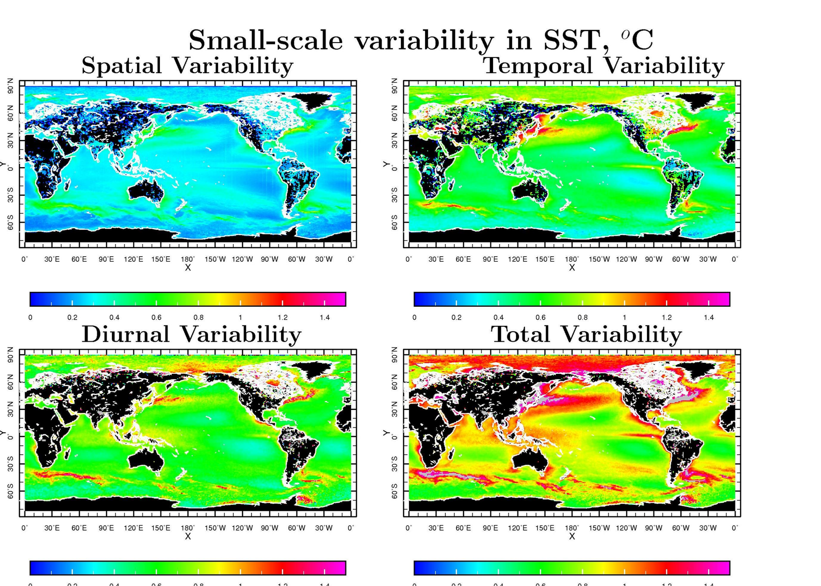

Figure 10: Estimates of standard deviation of SST variability, ^oC, estimated inside $1^o\times1^o$ monthly bins.

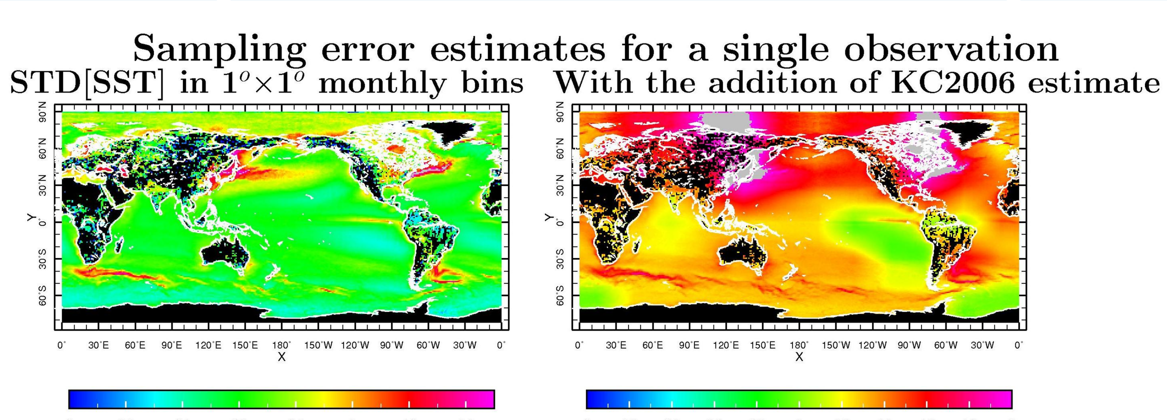

Figure 12: Adding the value of measurement error to the space×time variability in the SST measurements.

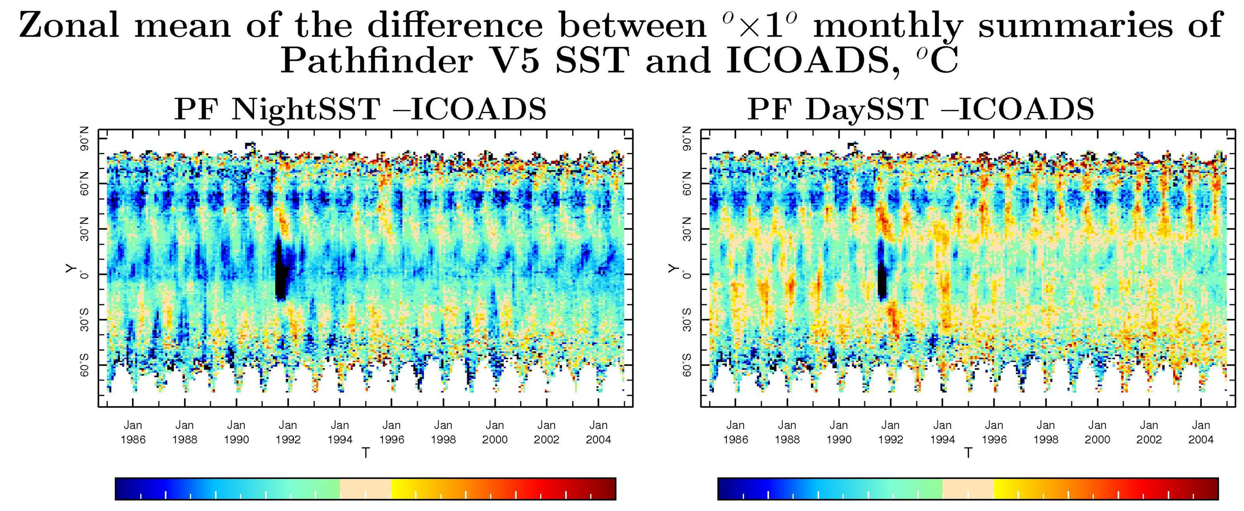

Figure 9: Same as Figure 8, but for Pathfinder V5 SST, instead of MODIS.

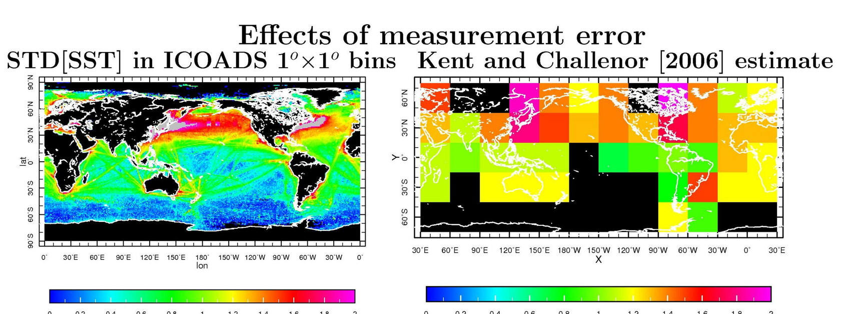

Figure 11: Effects of measurement error are seen in the field of standard deviations of SST measurements inside ICOADS $1^o\times1^o$ monthly bins (left), and are estimated by the variogram method by Kent and Challenor [2006].

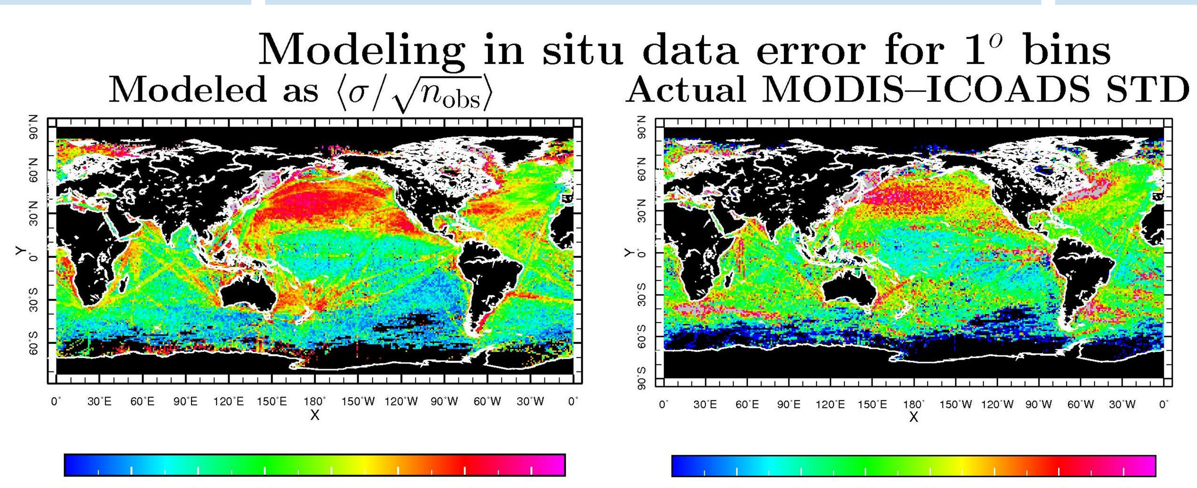

Figure 13: Modeling in situ data error as $\langle\sigma/\sqrt{n_{\rm obs}}\rangle$.

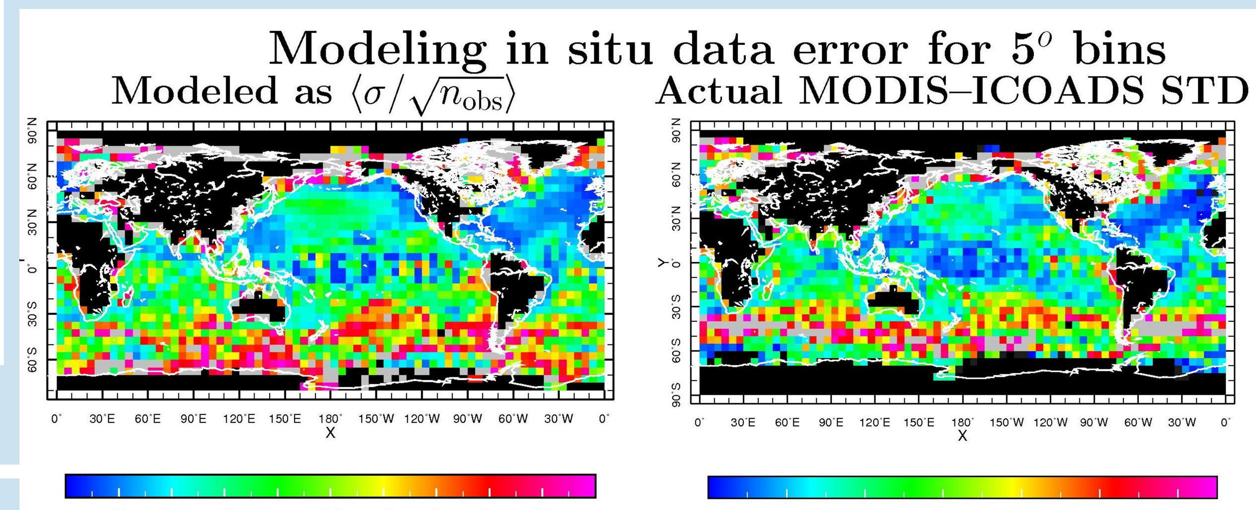

Figure 15: Modeling in situ data error as $\langle\sigma/\sqrt{n_{\rm obs}}\rangle$.

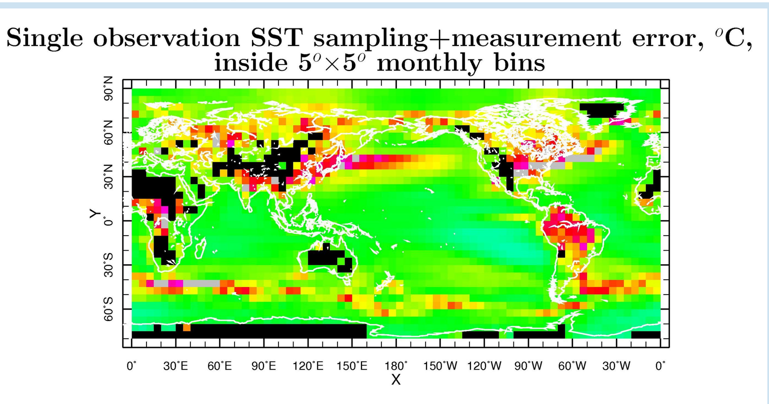

Figure 14: Single observation SST sampling+measurement error, ^oC, inside $5^o\times5^o$ monthly bins

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