Uncertainties in sea-surface temperature measurements

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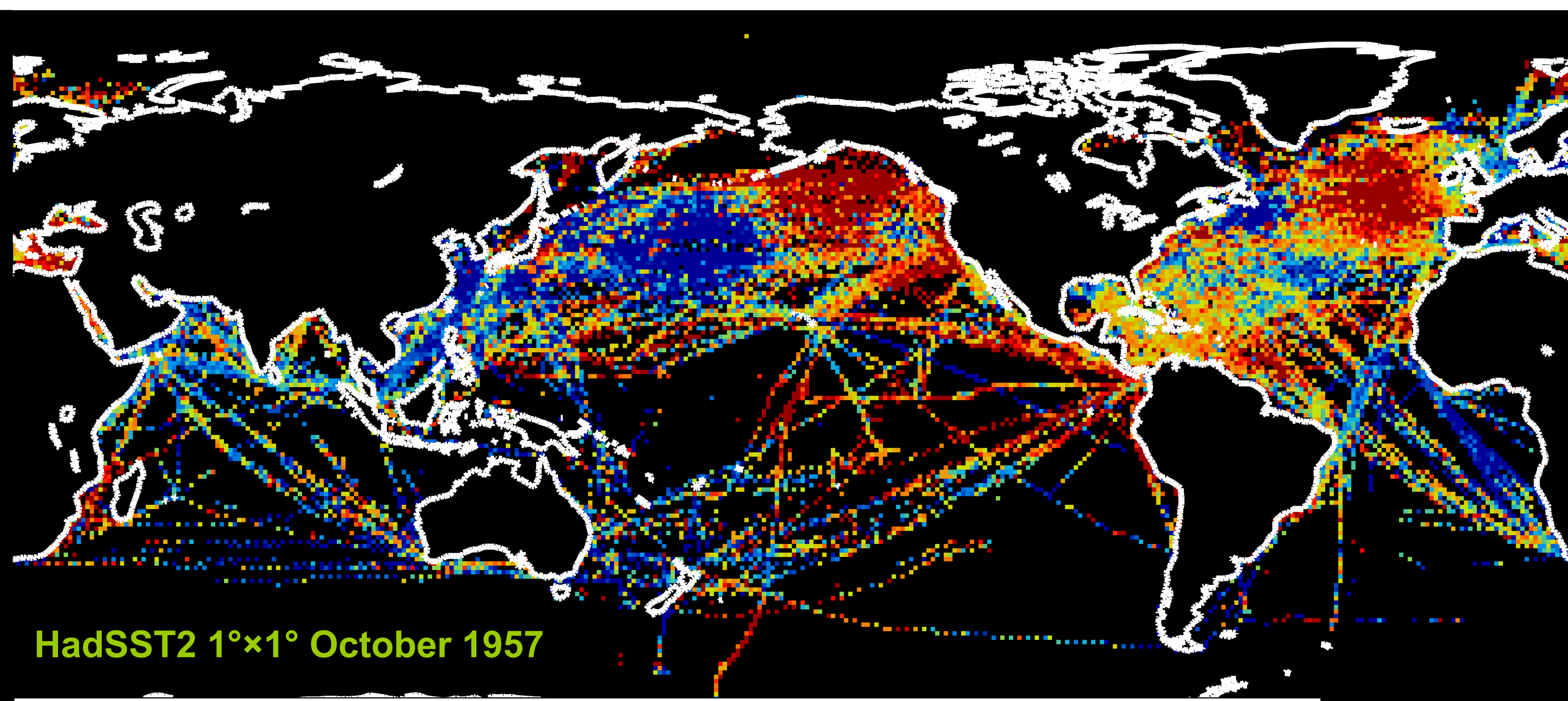
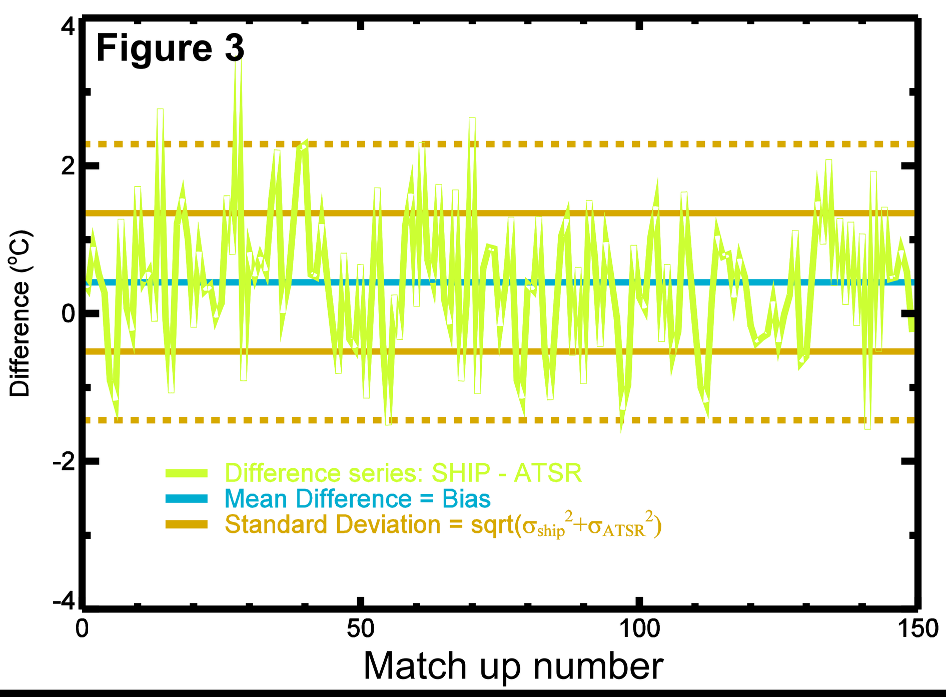
Introduction Existing estimates of sea-surface temperature uncertainties assume that uncertainties are uncorrelated. This is mathematically convenient but untrue. A new error model is being developed. It considers measurement errors as a combination of a constant offset – the bias of the measurement – which varies from ship to ship plus a random component that varies from one measurement to the next. Using this model, error estimates for in situ SST measurements have been calculated from comparisons with ATSR (Along-Track Scanning Radiometer) data. Distributions of biases and measurement errors are built up and used to estimate uncertainties on grid-box and area averages. The correlated part of the uncertainty (the bias) can lead to uncertainties that are more than twice as large as was previously assumed. The largest differences are seen in sparsely sampled regions.



Intersecting ship tracks show that there are persistent biases between ships, but formerly there was no “gold standard” against which to measure the bias.

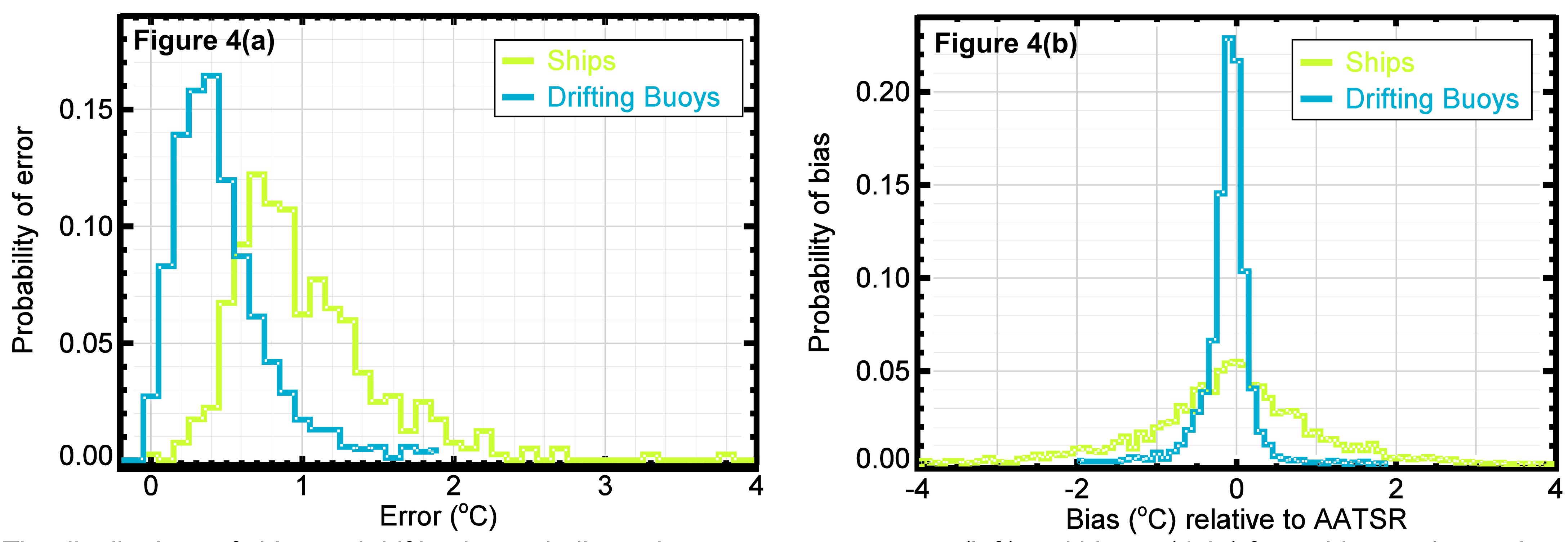
The (A)ATSR series of instruments provide a consistent baseline against which to measure SST biases.

Estimating bias and measurement errors Ship observations were matched to co-incident AATSR observations (same day and 1x1 grid box) over 2005. The mean difference (as shown in **Figure 3**) is interpreted as the bias and the variance of the difference as the sum of the measurement errors for the ship and the AATSR. Previous work (O’Carroll et al. 2008) has demonstrated that ATSR measurements have errors of ~0.16K.



The sampling error is assumed to be zero. This will act to increase the measurement error assigned to each ship.

This process is repeated for all ships and drifting buoys with more than 25 AATSR match-ups in 2005. The results are shown in **Figure 4.**



The distributions of ships and drifting buoys indicate that measurement errors (left) and biases (right) from ships are larger than for drifting buoys. The distributions change very little from year to year. These distributions can be used to estimate grid box uncertainties. Because the bias is a constant offset it introduces a correlated component to the error. This information can be incorporated into a more sophisticated error model than that used in e.g. Rayner et al. 2006.

Error model: The uncertainty on a grid-box average SST, σ_{tot}, is given by

$$\sigma_{tot}^2 = \frac{\sum_i n_i \sigma_{m_i}^2}{(\sum_i n_i)^2} + \frac{\sum_i n_i^2 \sigma_{b_i}^2}{(\sum_i n_i)^2} + \frac{\sigma_s^2(1-\bar{r})}{n}$$

where σ_{mi} is the measurement error, σ_{bi} is the bias error $\sigma_s(1-r)$ is the sampling error, n_i is the number of observations taken by ship i and the subscript i runs over each ship that took measurements in that grid box. It is instructive to consider the case where each of n_{plat} ships takes the same number of observations for a total of n_{total} observations.

$$\sigma_{tot}^2 = \frac{\sigma_m^2 + \sigma_s^2(1-\bar{r})}{n_{total}} + \frac{\sigma_b^2}{n_{plat}}.$$

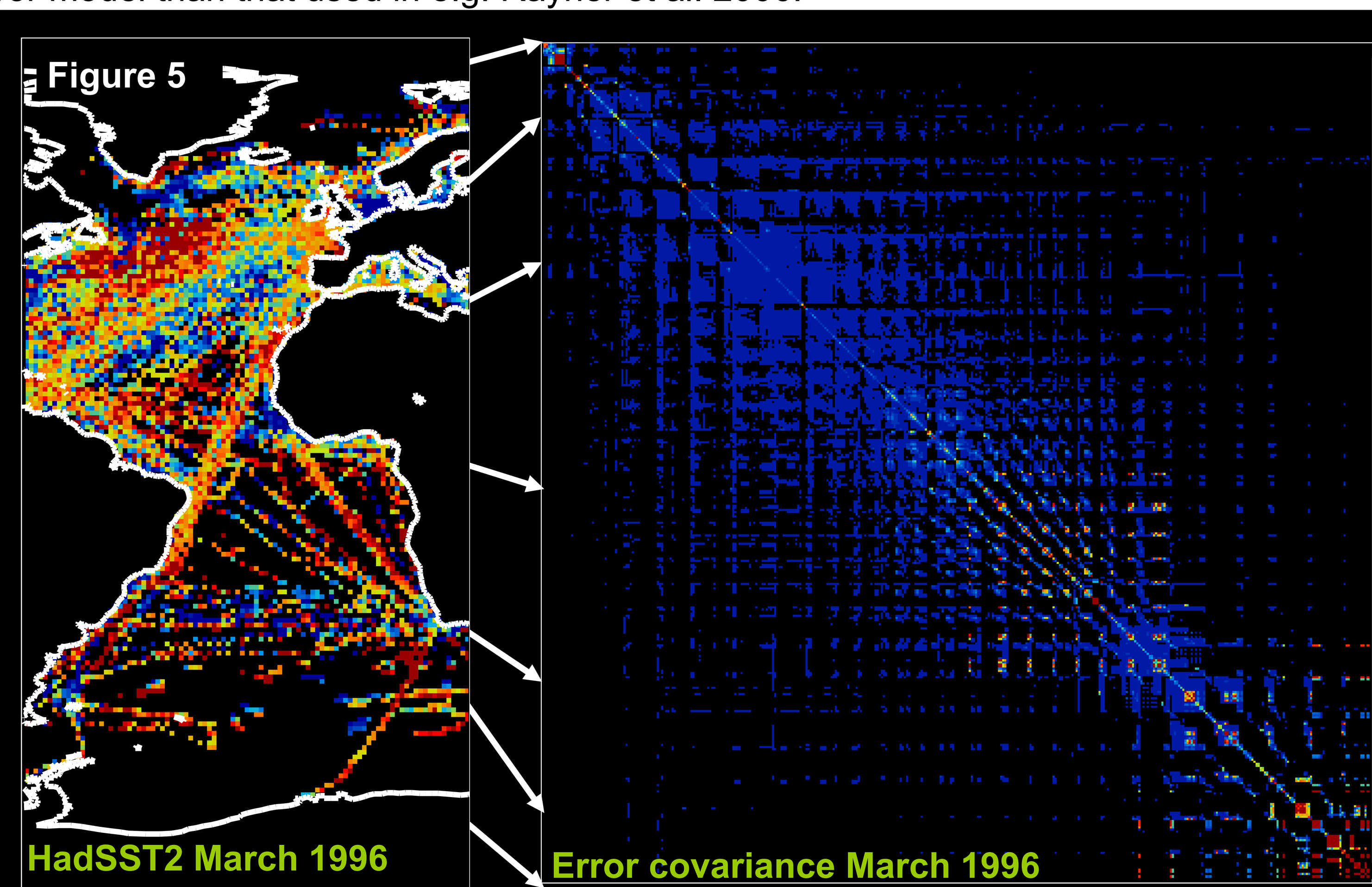
It is clear that the grid-box average error can only be reduced when the number of observations increases and the number of ships increases. The error covariance C_{ij} between two grid boxes i and j is given by

$$C_{i,j\, i \neq j} = \frac{\sum_k n_{i_k} n_{j_k} \sigma_{b_k}^2}{N_i N_j}$$

where the sum k is over all ships that made measurements in both grid boxes, n_{ik} is the number of observations made by ship k in grid box i, N_i is the total number of measurements made in grid box i. An example covariance matrix is shown in Figure 5 to the right.

Figure 5 depicts 1° latitude x 1° longitude SST anomalies for March 1996 (left) and error covariance matrix for the same data at 5°x5° resolution (right). The white arrows show roughly which latitudes correspond to which elements of the matrix.

The covariances are largest (red colours) where the observations come from a small number of ships. This is particularly obvious when looking at the bottom right hand corner of the matrix which corresponds to data in the Southern Ocean and South Atlantic.



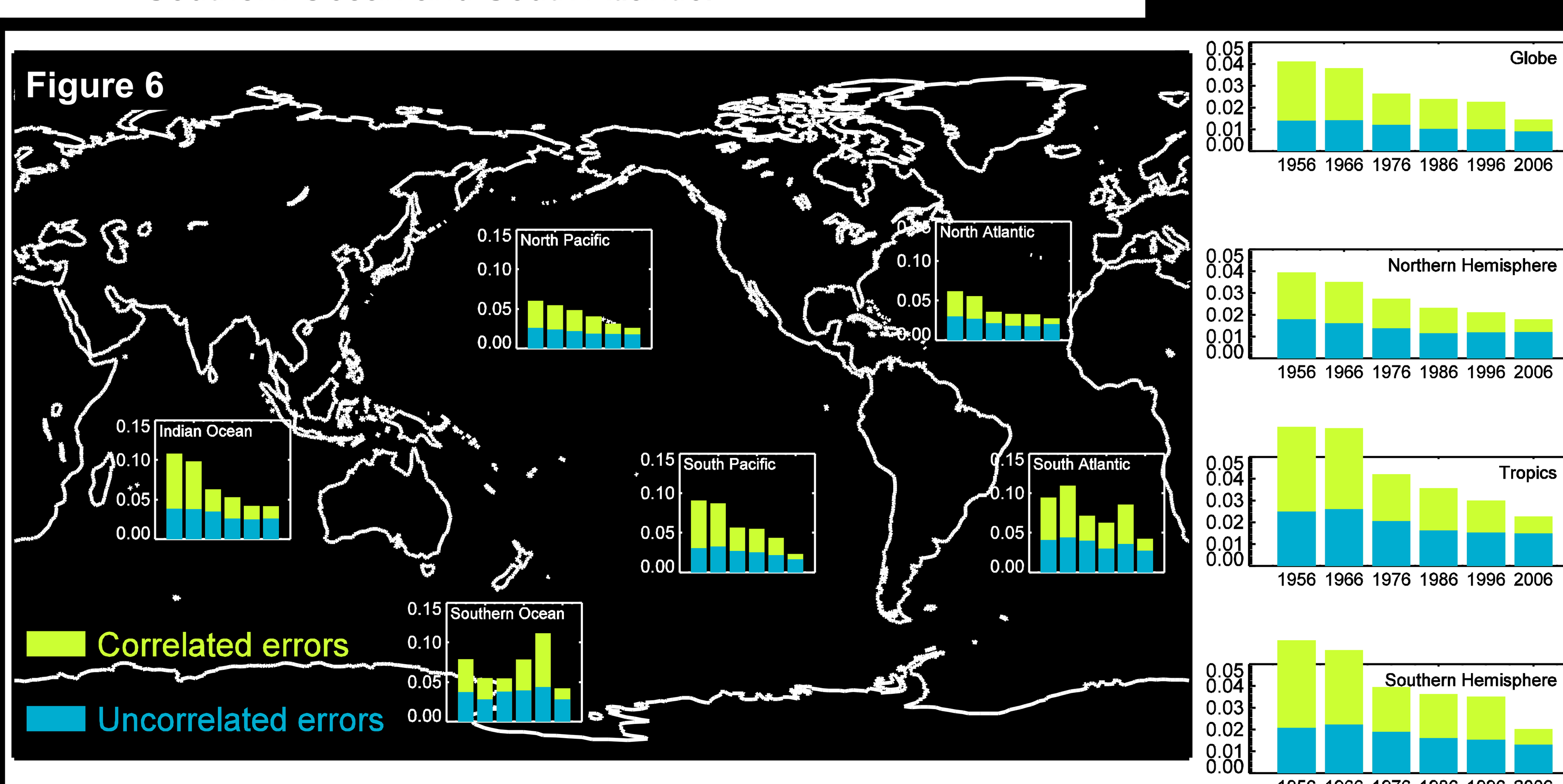
Global and regional averages Because the errors are correlated between grid boxes, the uncertainty on an average of grid boxes is also larger than in the case where the errors are uncorrelated. The error on an area average σ_f is given by

$$\sigma_f^2 = \frac{aCa^T}{(\Sigma a_l)^2}$$

where C is the error covariance matrix and a is a vector of area weights for the grid boxes and is set to zero where there are no data.

The correlation of errors tends to increase the uncertainty in the grid box and area averages. Examples for March from some select regions are shown in Figure 6.

However, certain operations on the data, for example taking the difference of two grid boxes, may have a lower uncertainty than the equivalent operation in the case where the uncertainties are uncorrelated.



The observational uncertainties on area-average March SSTs (every 10 years from 1956-2006) that arise from measurement and bias errors are shown for the case where the uncertainties are assumed to be correlated (green) and uncorrelated (blue). The uncertainties in the correlated and uncorrelated cases can differ by a factor of two or more. The drop in correlated errors in the most recent data is due to the large number of drifting buoys deployed in the southern hemisphere.

Conclusion The assumption that the errors on sea surface temperature measurements are uncorrelated is likely to be unjustified and will therefore lead to underestimates of grid-box average uncertainty. Regional average SST uncertainties will also be larger not only because individual grid box uncertainties are higher but also because the errors are correlated from one grid box to another.

In order to reduce uncertainties in SST it is necessary to have a diverse and numerous measurement fleet.

New techniques will need to be developed to adapt current interpolation schemes to account for these correlations. When the correlations are not taken into account, these schemes will tend to underestimate the uncertainties.

References

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O’Carroll A., Eyre J. and Saunders R. et al. 2008 Three-way error analysis between AATSR, AMSR-E and in situ sea surface temperature observations. In press J. Atmos. Oceanic. Tech.

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