Assessing Biases in Recent *in situ* SST and Marine Air Temperature

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- **Introduction**
- **Analysis of VOS SST**

  Bucket and Engine Room Intake SST accuracy

  Analysis of biases - errors and correlations

- **Analysis of VOS Air Temperature**

  Variations by country

  Effect of solar radiation

- **Conclusions**

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Data Set

- Blend of COADS with UK Meteorological Office Marine Data Bank for period 1980 - 1997.
- Metadata from WMO Report No. 47 merged onto individual COADS reports to give, for example, SST and air temperature measurement methods and sensor heights
- Analysis of pairs of night-time data (one ship using bucket, one ERI) within 50km and at same reporting hour for North Atlantic.

Determining small mean biases in noisy data with correlated errors

Possible errors:

- The engine intake SST may be biased
  cool: due to the larger measurement depth
  or
  warm: due to contamination by heat from the ship

- The bucket SST may be too *cool:*
  due to sensible or latent heat loss after leaving the sea,
  if thermometer is removed to read ('Wet-bulb' effect).

- The bucket SST may be too *warm :*
  if the sample is warmed by direct solar radiation
  if a warm bucket was not allowed to equilibrate

Hypothetical model

- Consider nighttime data at moderate wind speeds.
- assume that the bucket SST reports (SST_{bucket}) are in error by an amount which depends linearly on the air sea temperature difference.
- assume that the engine intake SST reports (SST_{eri}) may, on average, have a constant bias.

hence...

$$SST_{bucket} - SST_{eri} = \alpha (T_{air} - SST_{eri}) + \beta$$

i.e. $y = \alpha x + \beta$

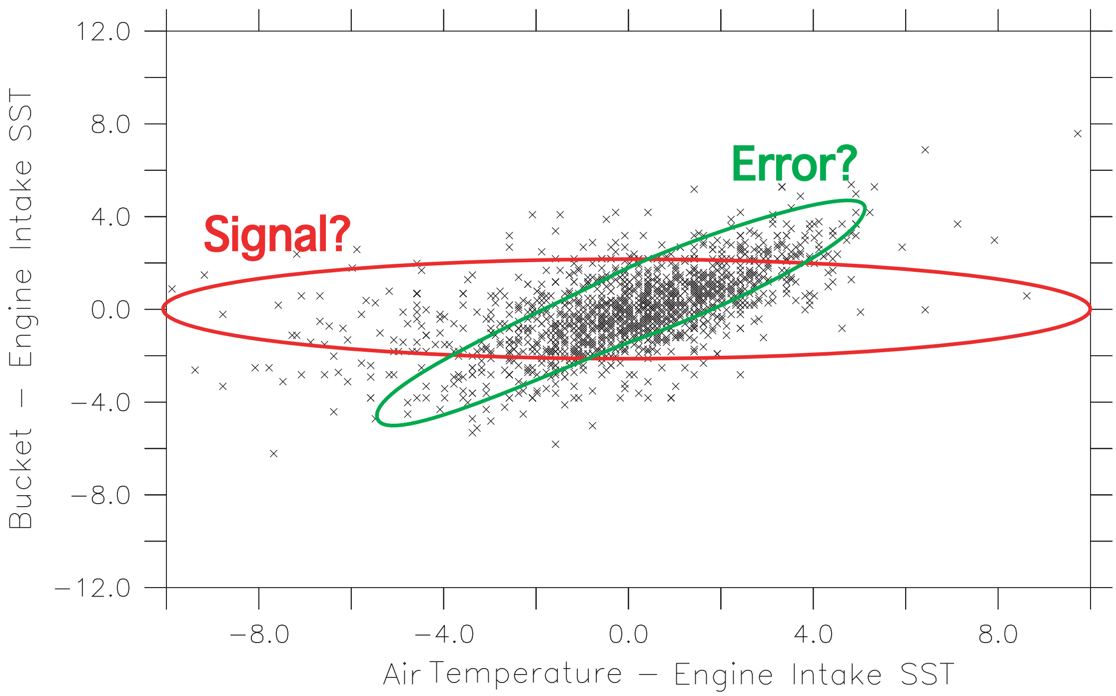
where:

$$y = SST_{bucket} - SST_{eri}$$

$$x = T_{air} - SST_{eri}$$

Example plot:

$$SST_{bucket} - SST_{eri} = \alpha\,(T_{air} - SST_{eri}) + \beta$$



- errors in SST_{eri} will cause a spurious correlation along the green ellipse which masks the expected dependence (red ellipse)
- To properly determine α and β we must transform data so that:
  (1) x and y are uncorrelated
  (2) random errors in x and y are equal

Analysis Method

(1) using the semi-variogram technique find values for the variances... $(\sigma_{air})^2$, $(\sigma_{eri})^2$, $(\sigma_{bucket})^2$.

(2) Transform x and y by multiplying by the square root of the correlation matrix:

$$C = \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \end{bmatrix} \begin{bmatrix} \varepsilon_x & \varepsilon_y \end{bmatrix} = \begin{bmatrix} \langle \varepsilon_x \varepsilon_x \rangle & \langle \varepsilon_x \varepsilon_y \rangle \\ \langle \varepsilon_y \varepsilon_x \rangle & \langle \varepsilon_y \varepsilon_y \rangle \end{bmatrix}$$

where:

$$\langle \varepsilon_x \varepsilon_x \rangle = \sigma^2_{air} + \sigma^2_{eri}$$

$$\langle \varepsilon_x \varepsilon_y \rangle = \langle \varepsilon_y \varepsilon_x \rangle = \sigma^2_{eri}$$

$$\langle \varepsilon_y \varepsilon_y \rangle = \sigma^2_{bucket} + \sigma^2_{eri}$$

to give new variables which are uncorrelated and have unit random errors.

(3) Perform orthogonal regression on transformed data.

(4) Transform regression parameters back to give α and β in the 'real world'.

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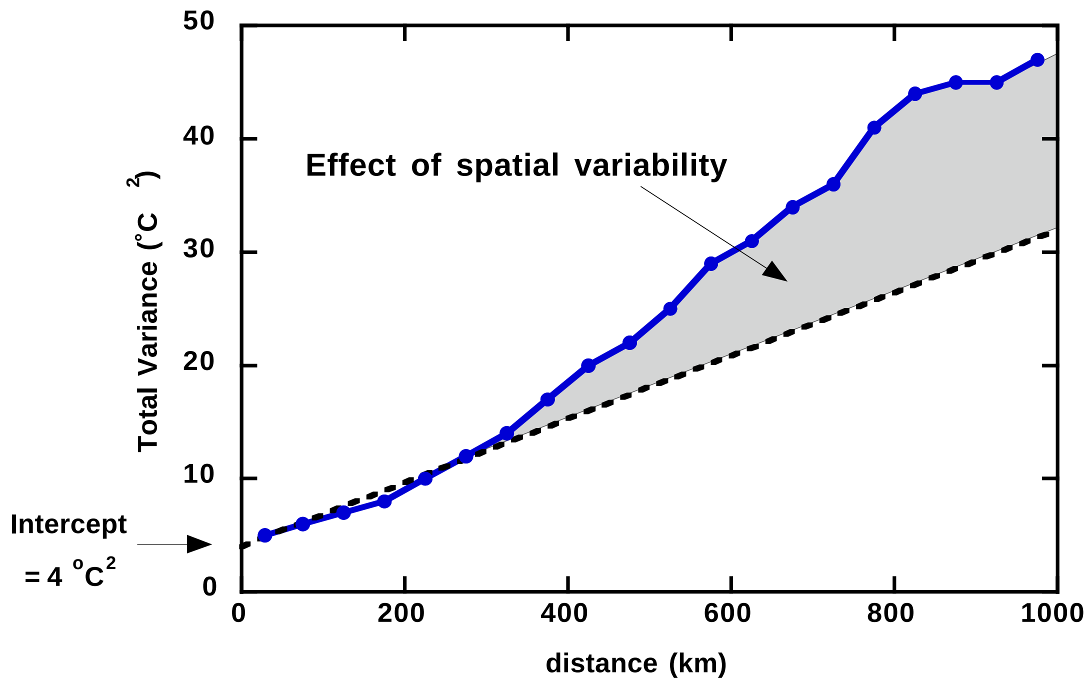
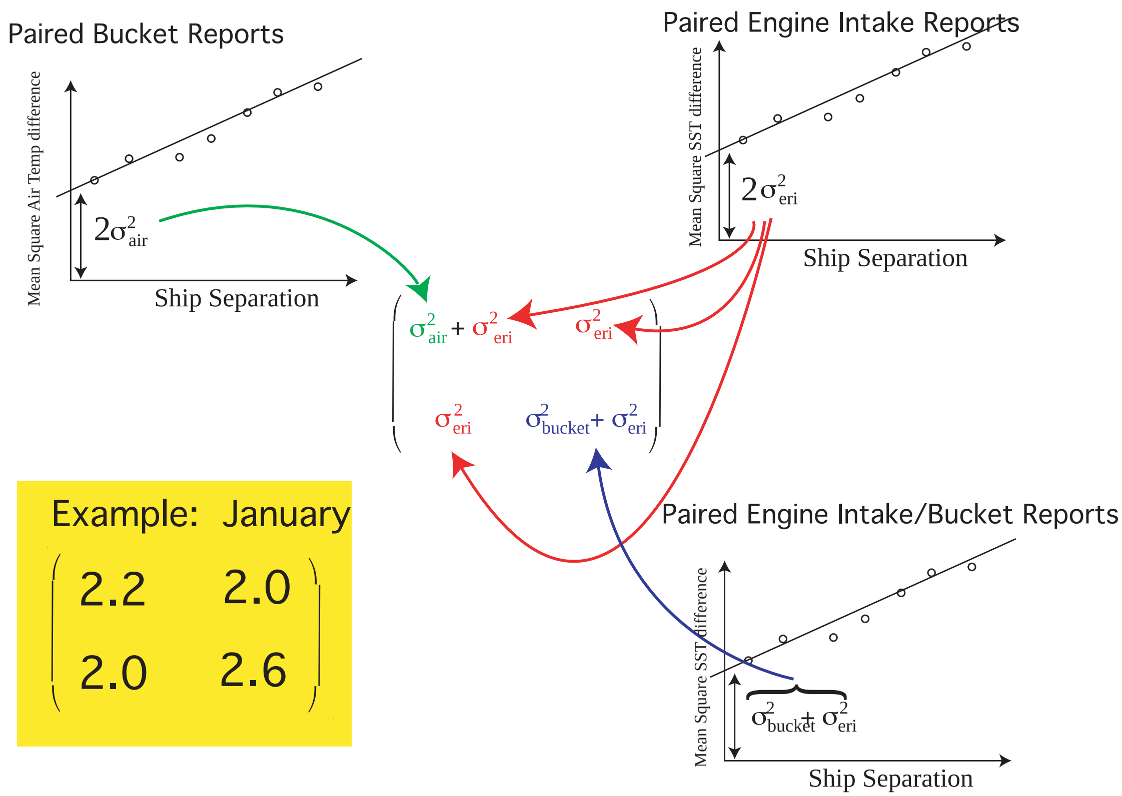
Determining random errors...
the semi-variogram technique



- plot the mean square difference between pairs of ships as a function of separation and extrapolate to zero separation
- the intercept is twice the variance, in this example:

  $\sigma = \sqrt{(4 / 2)} = 1.4^{\circ}C$

Calculating the Correlation Matrix



Example: January

$$\begin{pmatrix} 2.2 & 2.0 \\ 2.0 & 2.6 \end{pmatrix}$$

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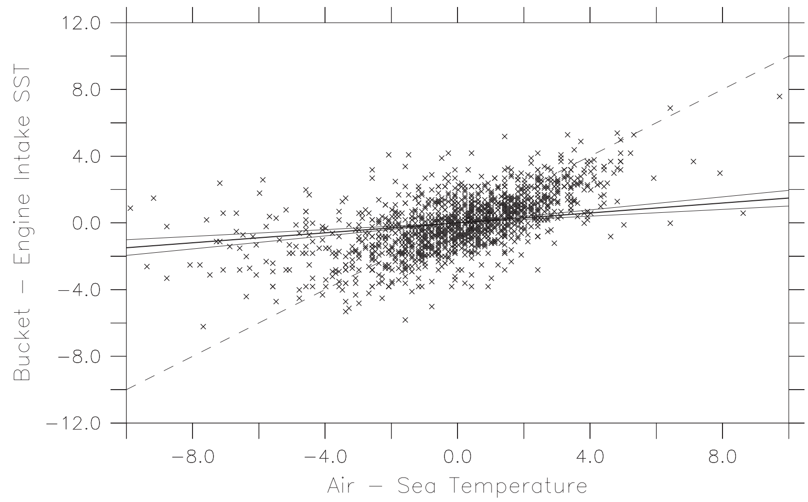
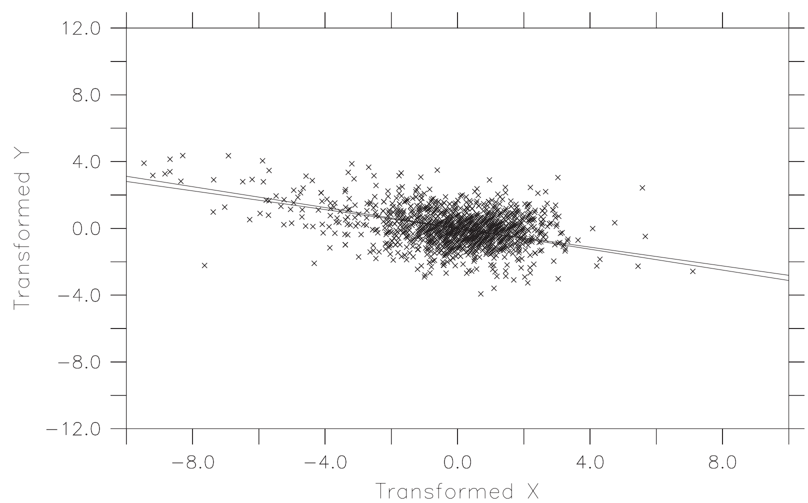
$$SST_{bucket} - SST_{eri} = \alpha\,(T_{air} - SST_{eri}) + \beta$$

... example for January data

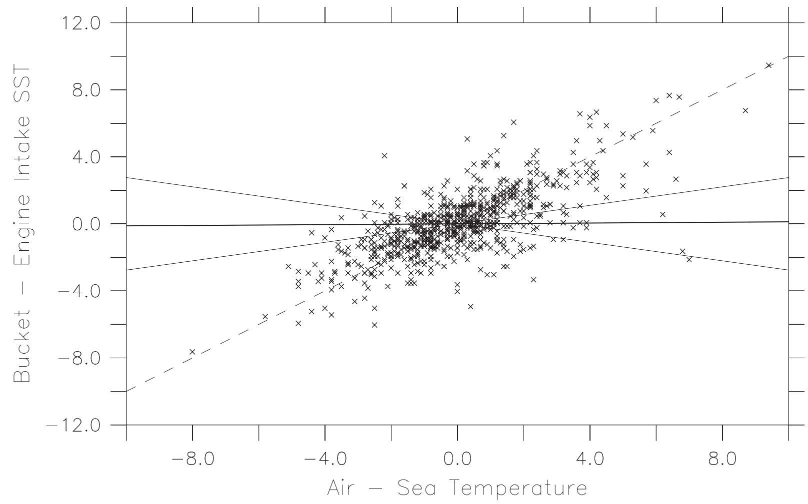


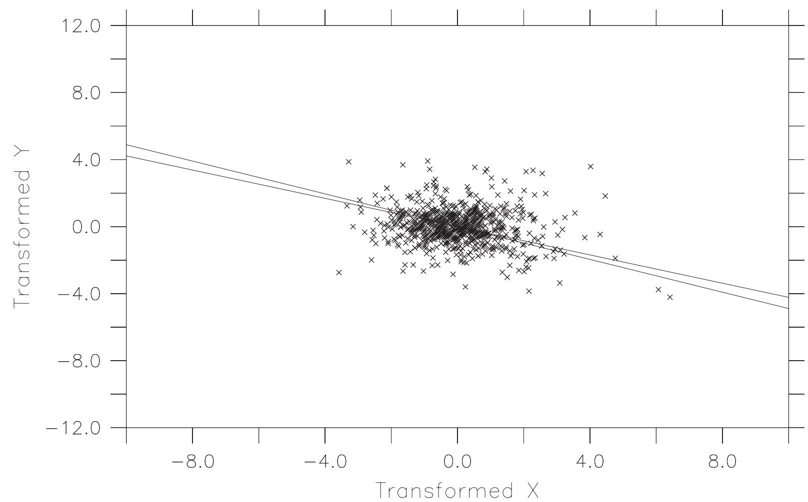


- the regression is well defined in the transformed variable space (this was not so in summer)

$$SST_{bucket} - SST_{eri} = \alpha\ (T_{air} - SST_{eri}) + \beta$$

... example for July data

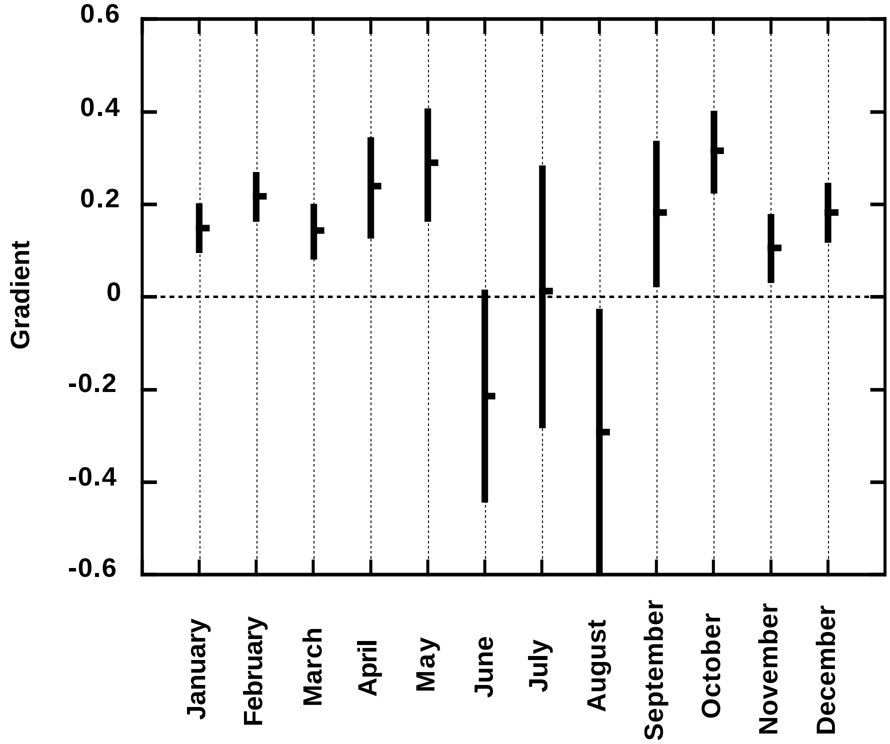




- the regression is poorly defined in the transformed variable space resulting in large uncertainty in determining α and β.

$$SST_{bucket} - SST_{eri} = \alpha\,(T_{air} - SST_{eri}) + \beta$$

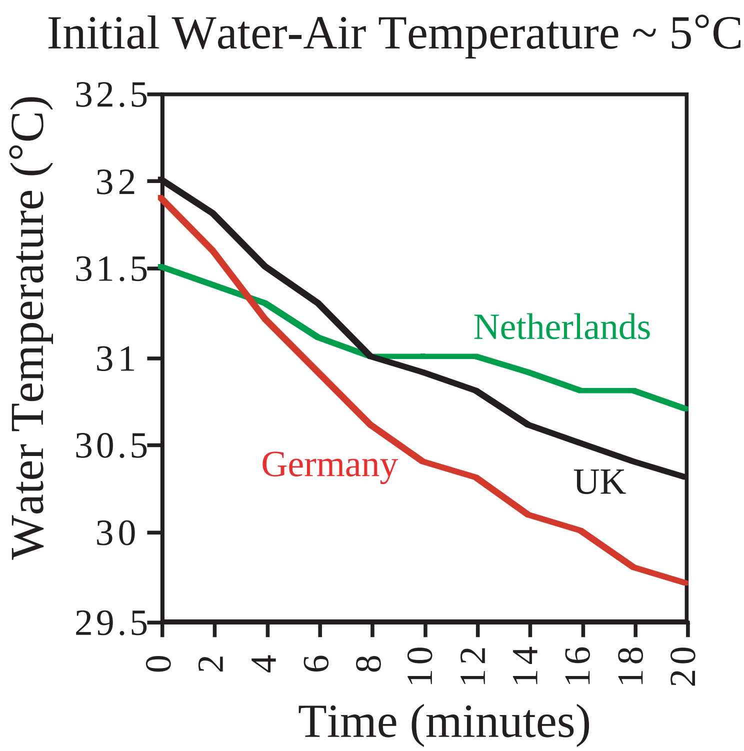
...monthly values for α ....



- except in the summer months (when the relationship was poorly defined) $\alpha \approx 0.2 \pm 0.1$
- typically the bias, β, was not significantly different from zero
- the typical North Atlantic air - sea temperature difference is about -1.5˚C suggesting an average cold bias in the bucket reports of 0.3˚C

Bucket SST Measurement

- We looked at heat loss in still air from typical SST buckets (from the UK, Germany and the Netherlands).



- The cooling rate is different for the different buckets.
- BUT: Remember that the SSTs from buckets are more reliable than those from engine intakes.

Summary of SST results

- random errors:
  for bucket SST data less than those for ERI SST data.

- bucket SST data may have a cold bias when the air is significantly colder than the sea.

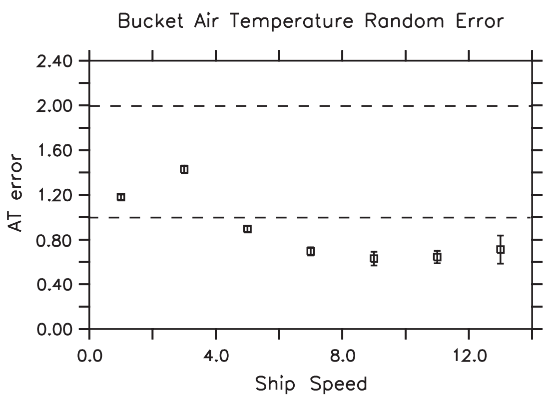
- contrary to previous studies, ERI data does not appear to have a significant warm bias
  - this needs to be confirmed.

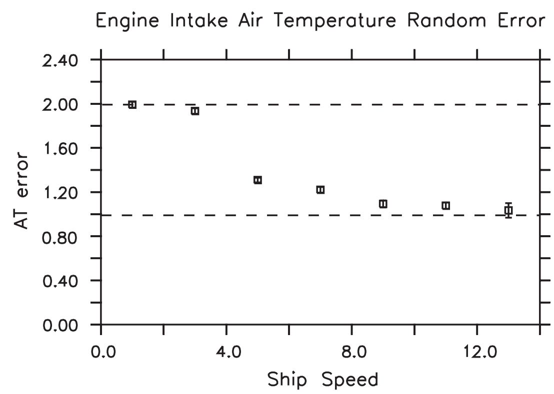
- reliable determination of random and systematic errors in ship's meteorological data requires careful analysis

- so far we have excluded daytime measurements and those taken at low and at very high wind speeds. We would like to extend the analysis to look at this data.

Nighttime VOS Air Temperature Measurement

- Ships that use engine intake thermometers to measure the SST are more likely to report poor quality air temperature measurements than those which use a bucket to measure the SST.

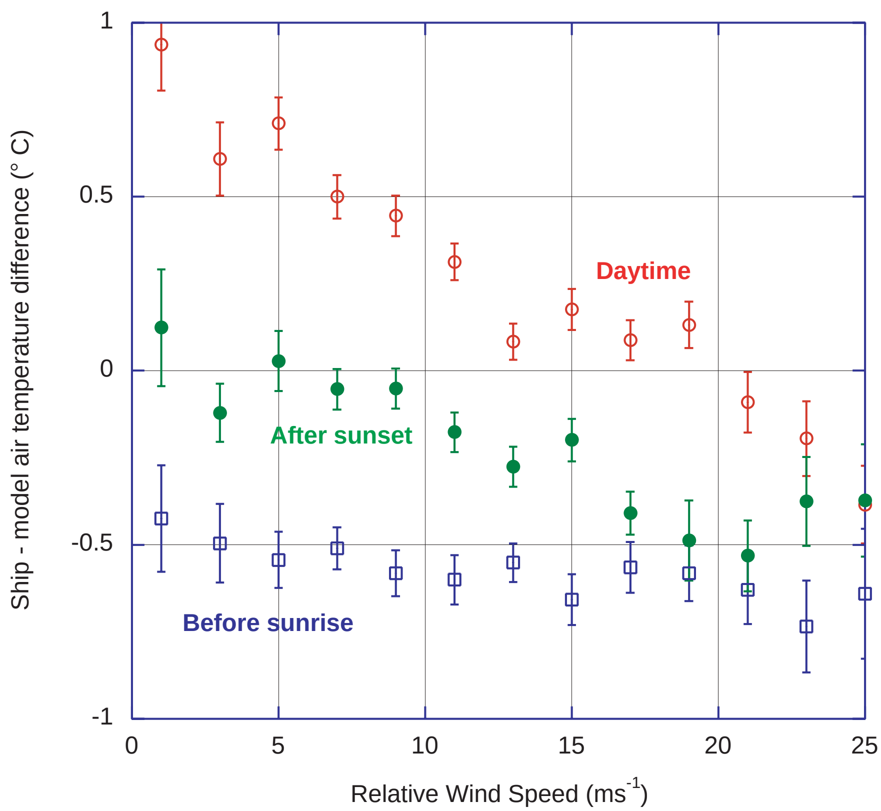




- The quality of air temperature measurements improves as the ship moves faster.
- The dependence of air temperature report quality on SST measurement method is much stronger than any dependence on the method of air temperature measurement.

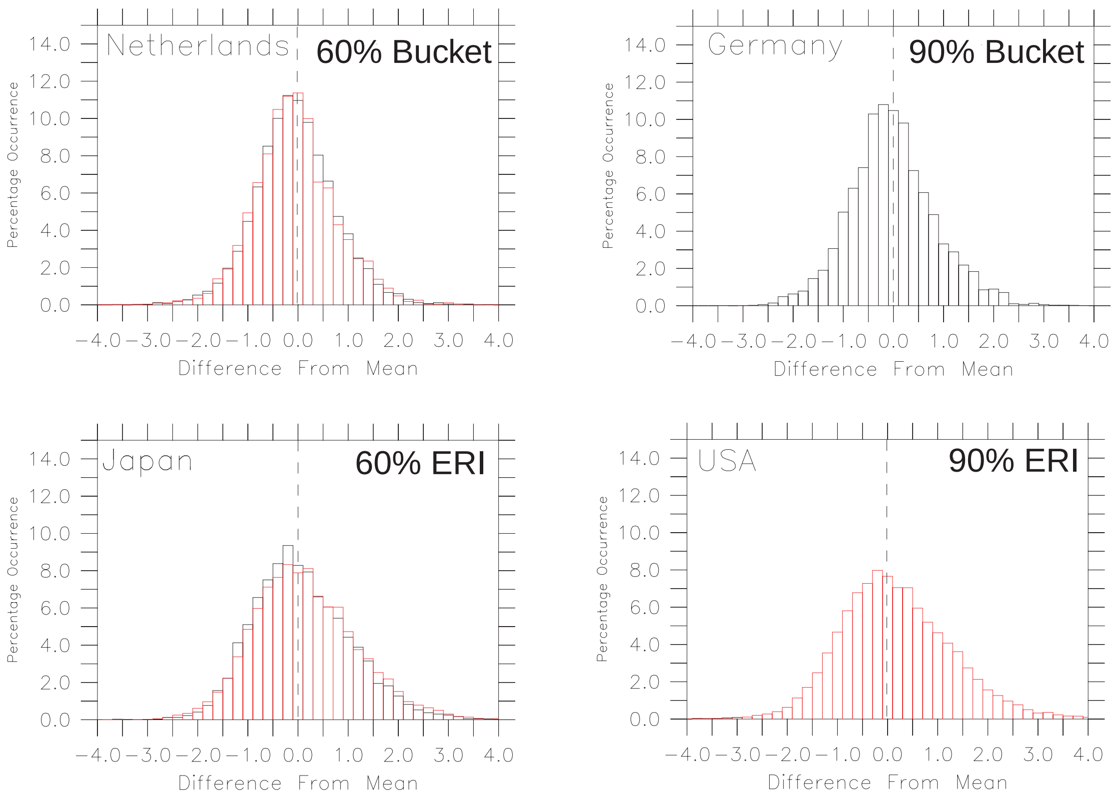
Air temperature differences depend on sensor ventilation

- Data from the VSOP-NA (VOS Special Observing Project - North Atlantic).
- Analysis method used differences between ship observations and co-located model output from the UK Met. Office Fine Mesh Model.



Air temperature differences depend on recruiting country

- histograms of normalised nighttime July air temperature difference from the mean for the surrounding 10˚ area for ships reporting bucket SST (black) and ERI SST (red):



- histograms for Japan & USA ships are less peaked (data more scattered) and skewed warm.

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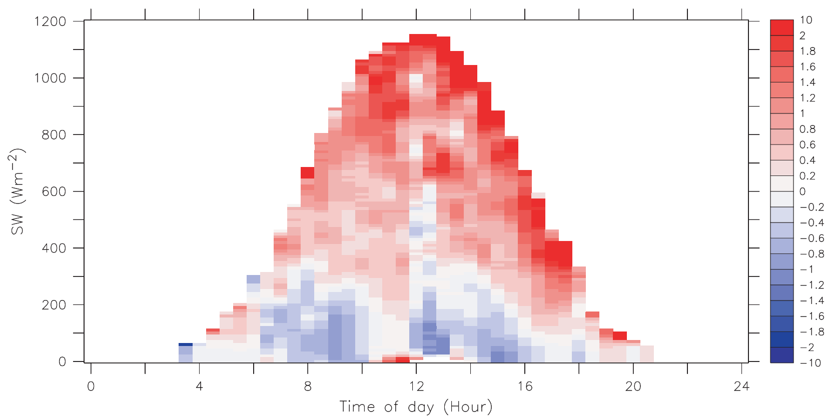
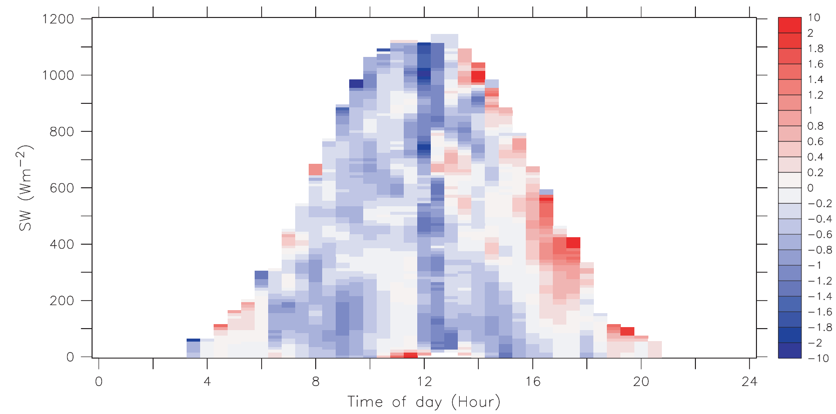
Daytime VOS Air Temperature Measurement

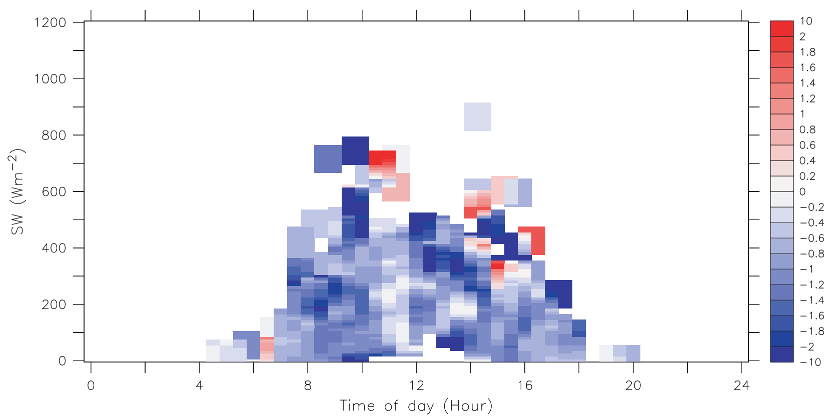
- Data from the VSOP-NA are being reanalysed to look more closely at how solar radiation affects the air temperature measurement.
- Initially a correction was suggested that depended on the incoming solar radiation and the relative wind speed over the ship.
- This correction can be improved by also allowing for the "heat-island" effect of the ship.



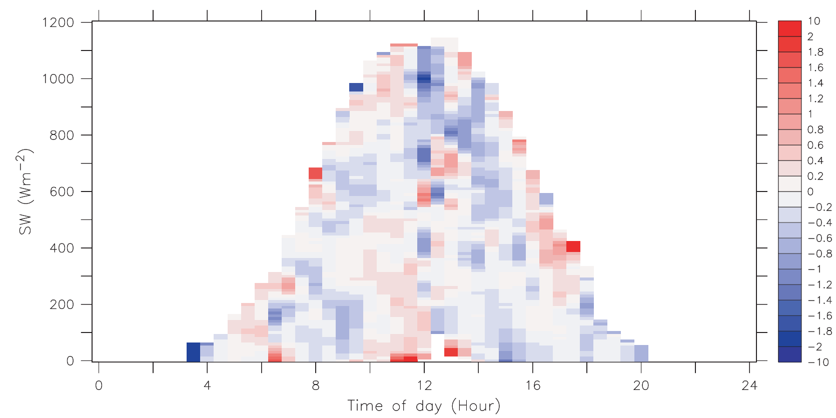
Uncorrected



Corrected (using correction of Kent et al., 1993)



Corrected (Precip only)(using correction of Kent et al., 1993)



Corrected, no precip or poorly exp. sensors (using new correction)

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Summary of Air Temperature Results

- The accuracy of air temperature measurement depends more on the country that recruited the ship than on the method of measurement.
- Ships that use buckets to measure the SST are more likely to report better quality air temperature measurements - better exposure of the temperature sensors?
- Marine air temperatures need to be corrected for the effects of both instantaneous solar radiation and the "heat island" effect.
- Poorly ventilated air temperature sensors are still biased warm after sunset.
- Need to make sure we don't overcorrect when its raining.

Conclusions

- The VOS can provide good values for marine meteorological parameters if measurements are taken with care.
- Buckets give much more reliable SSTs than engine intakes, but may be biased when the air-sea temperature difference or surface fluxes are large.
- Poorly exposed air temperature sensors degrade our knowledge of the air temperature over the ocean both during the day and during the night.
- It should be possible to correct the errors in some of the data where we have information about instrumentation.
- We may be able to improve the quality of climatological fields derived from the recent data within COADS by excluding or down-weighting data expected to be of poor quality using information about measurement method, recruiting country or environmental conditions.