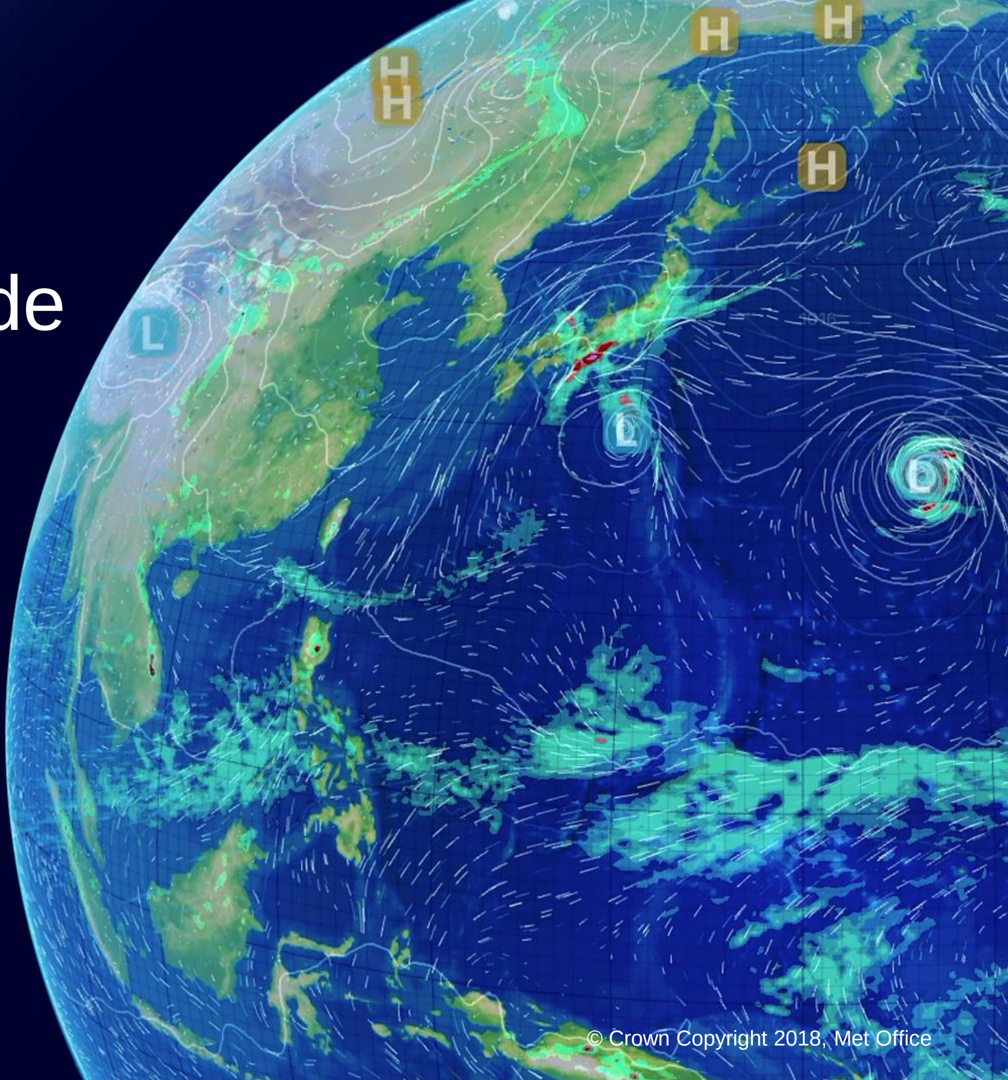
Met Office Hadley Centre

# Observations of sea-surface temperature made *in situ*: evolution, uncertainties and considerations on their use

Nick A. Rayner[1], John J. Kennedy[1], Holly Titchner[1] and Elizabeth C. Kent[2]

[1]Met Office Hadley Centre,

[2]National Oceanography Centre



# Overview

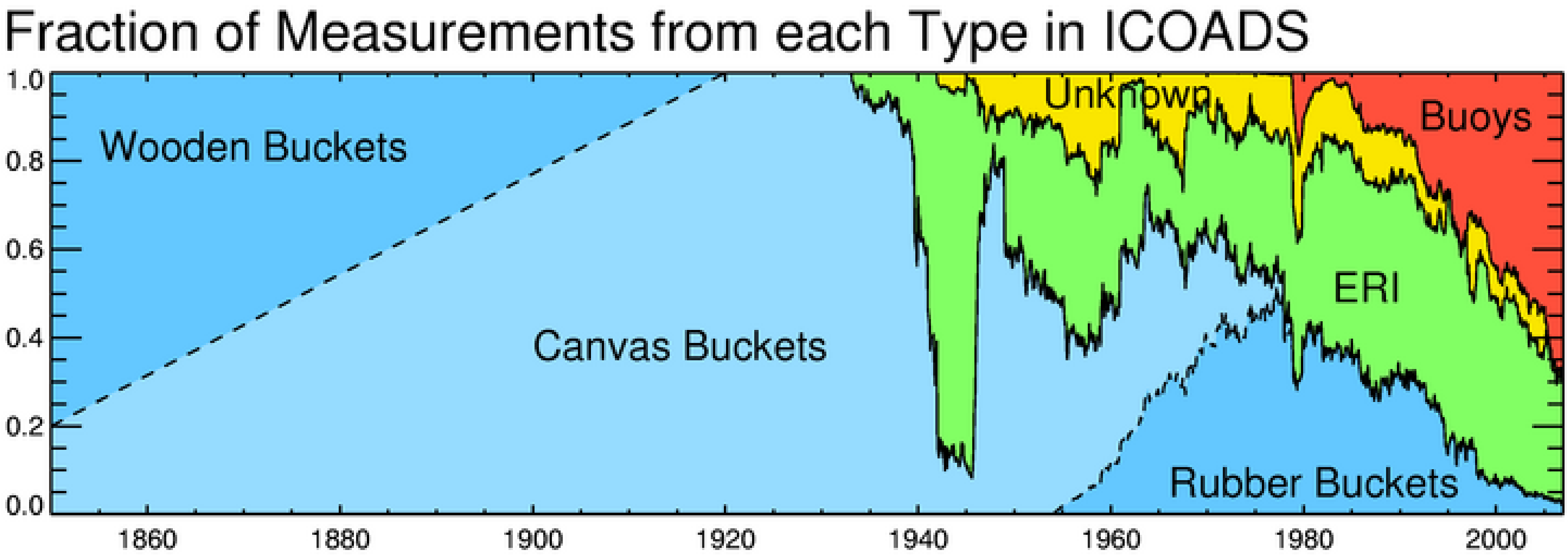
- Evolution of the *in situ* observing system
- Making a long, consistent record
- Residual uncertainties in measurements
- Blending with satellite measurements and completing the picture
- The same needs to be done for sea ice
- Summary

# Evolution of the *in situ* observing system

# Measurement Methods

Met Office
Hadley Centre

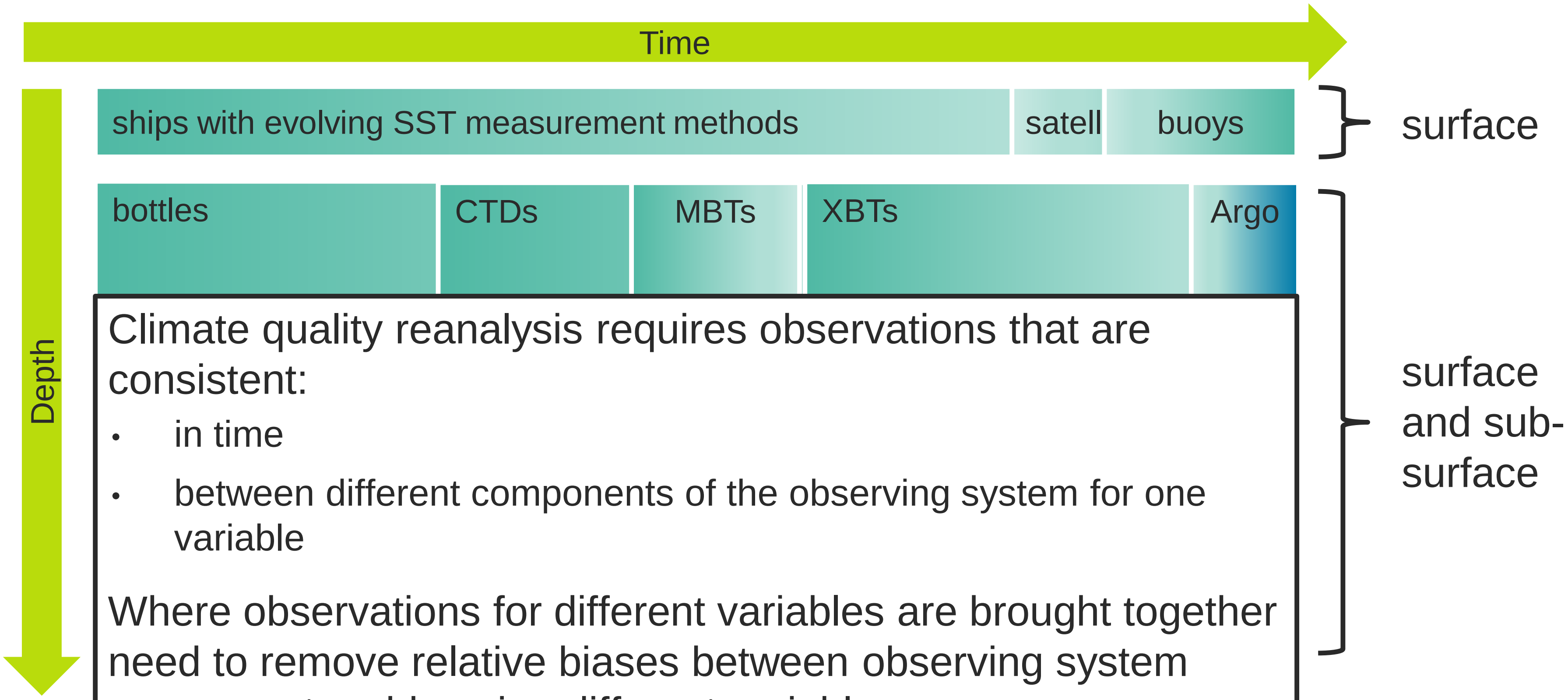
# Evolution of the observing system



# Making a long, consistent record

Met Office Hadley Centre

# Aspects of internal consistency




Climate quality reanalysis requires observations that are consistent:

- in time
- between different components of the observing system for one variable

Where observations for different variables are brought together need to remove relative biases between observing system components addressing different variables

Met Office
Hadley Centre

# In situ biases

Differences between measurement methods are large

Occasionally greater than 0.5C

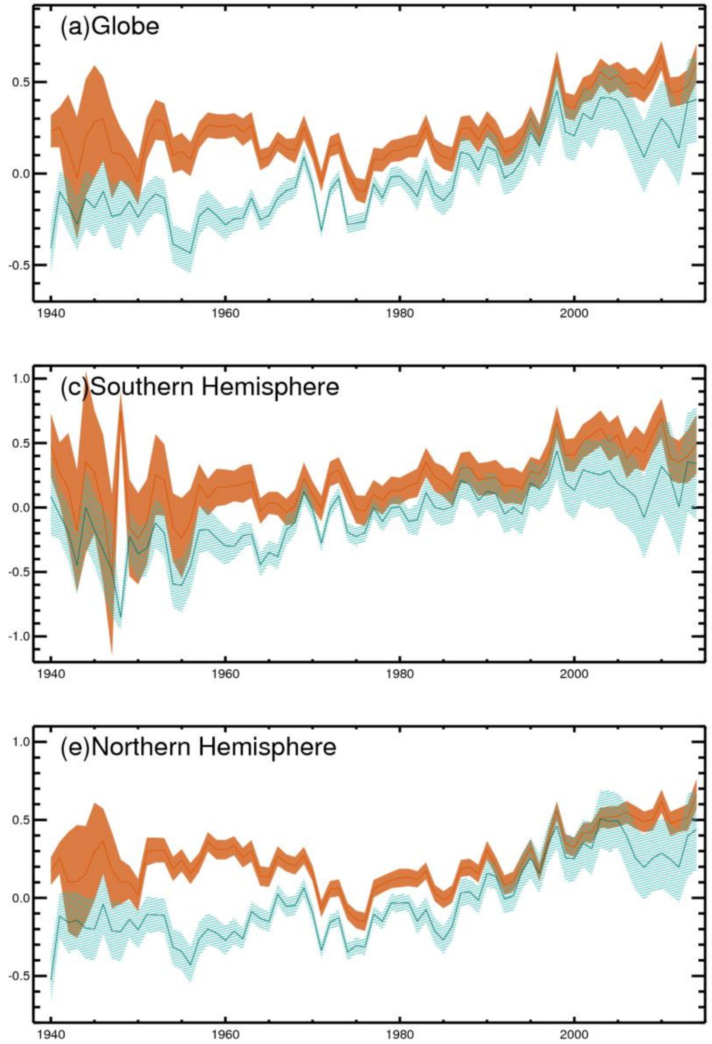
Geographically varying biases in both

Metadata assignment is not certain

Annual average unadjusted SST anomalies for collocated bucket and ERI measurements

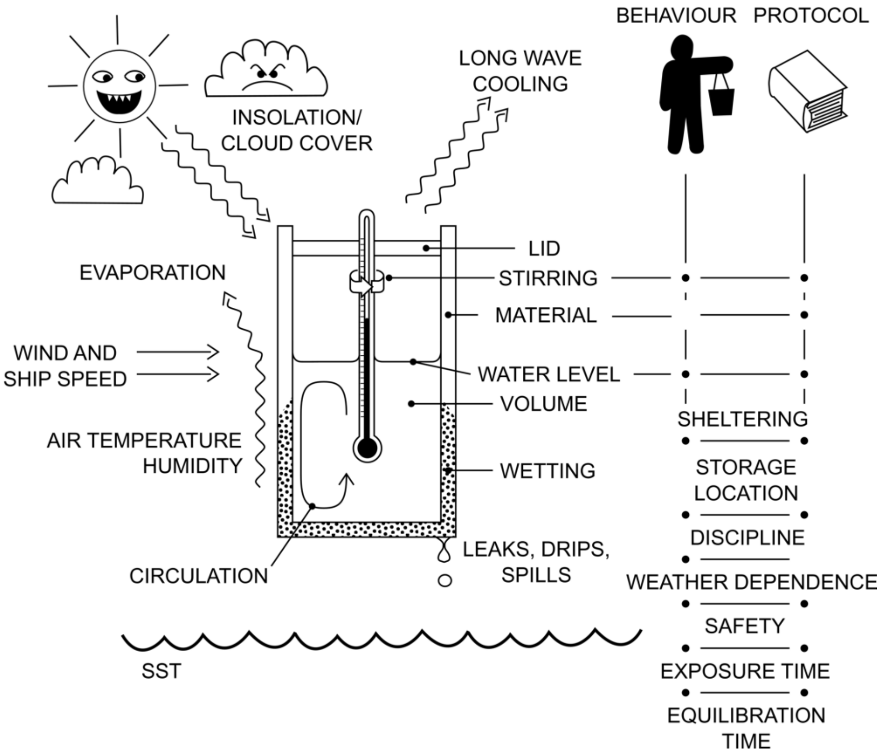
ERI

Buckets



# Ways of achieving consistency

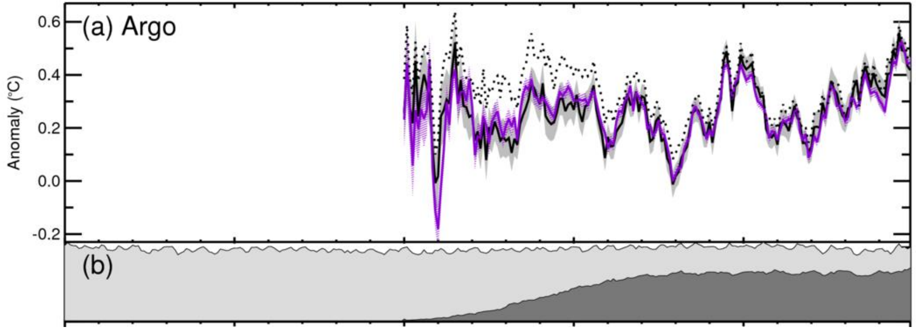
- Compare everything and develop em chosen reference
  - Risks picking the wrong reference a
- Understand each data source physica own biases




A Call for New Approaches to Quantifying Biases in Observations of Sea Surface Temperature. Kent et al. (2017) BAMS
https://doi.org/10.1175/BAMS-D-15-00251.1

# Ways of achieving consistency

- Compare everything and develop empirical corrections, relative to a chosen reference
  - Risks picking the wrong reference and biasing the whole system
- Understand each data source physically and correct according to its own biases
  - Then compare to everything else and check consistency

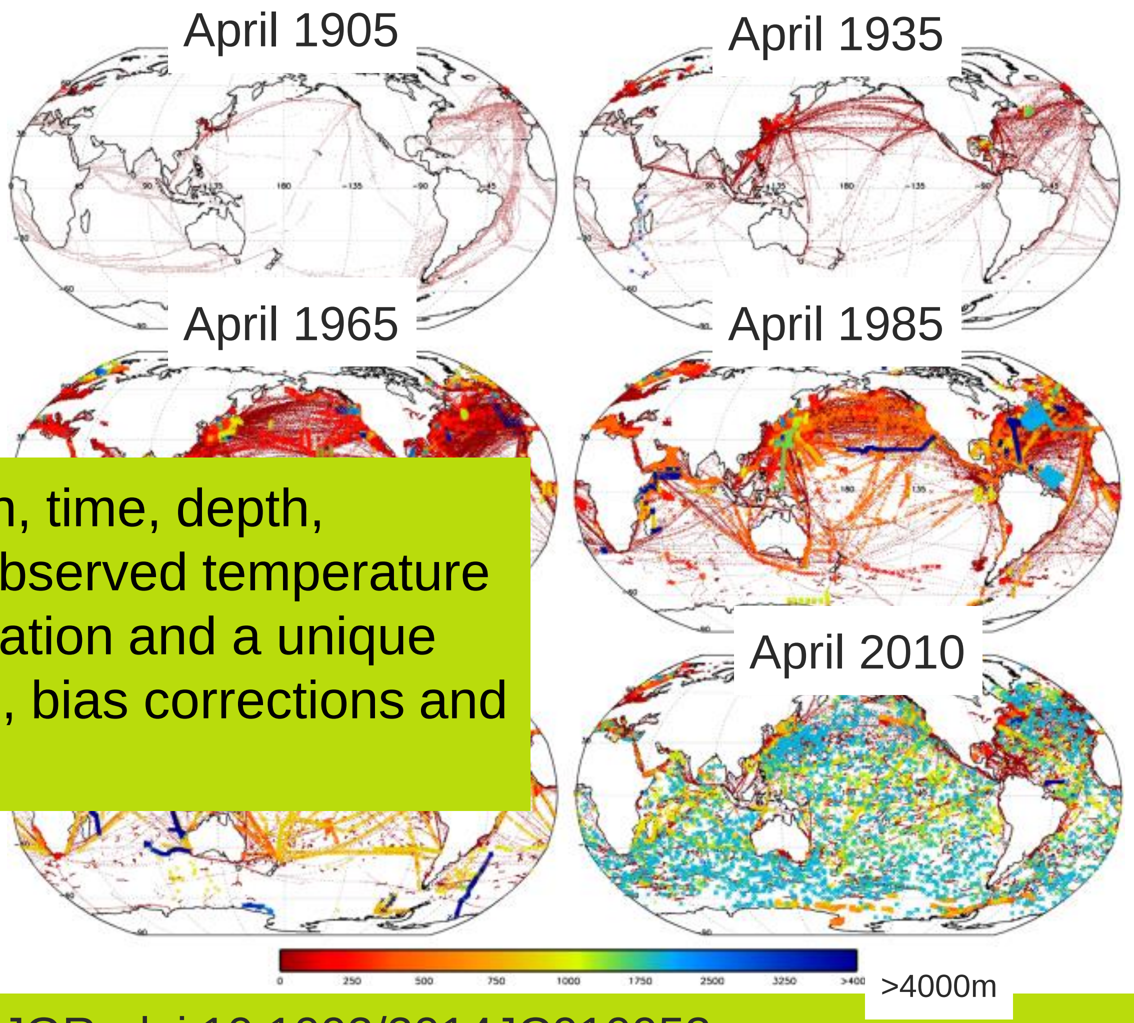


# Ways of achieving consistency

- Compare everything and develop empirical corrections, relative to a chosen reference
  - Risks picking the wrong reference and biasing the whole system
- Understand each data source physically and correct according to its own biases
  - Then compare to everything else and check consistency
  - But this requires good metadata, which is often lacking
  - However, this allows potential propagation of error structure
- Let the reanalysis handle it – still requires good understanding and metadata

# Ocean data for coupled reanalysis: HadIOD

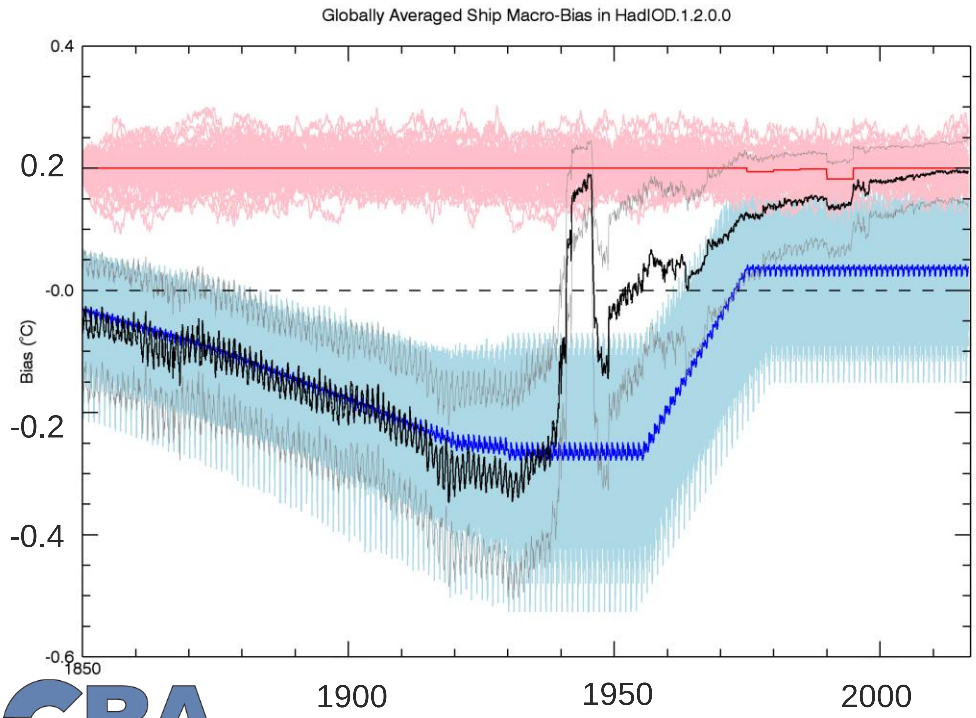
Contains platform ID, position, time, depth, platform & instrument type, observed temperature & salinity, provenance information and a unique ID, together with quality flags, bias corrections and uncertainty estimates

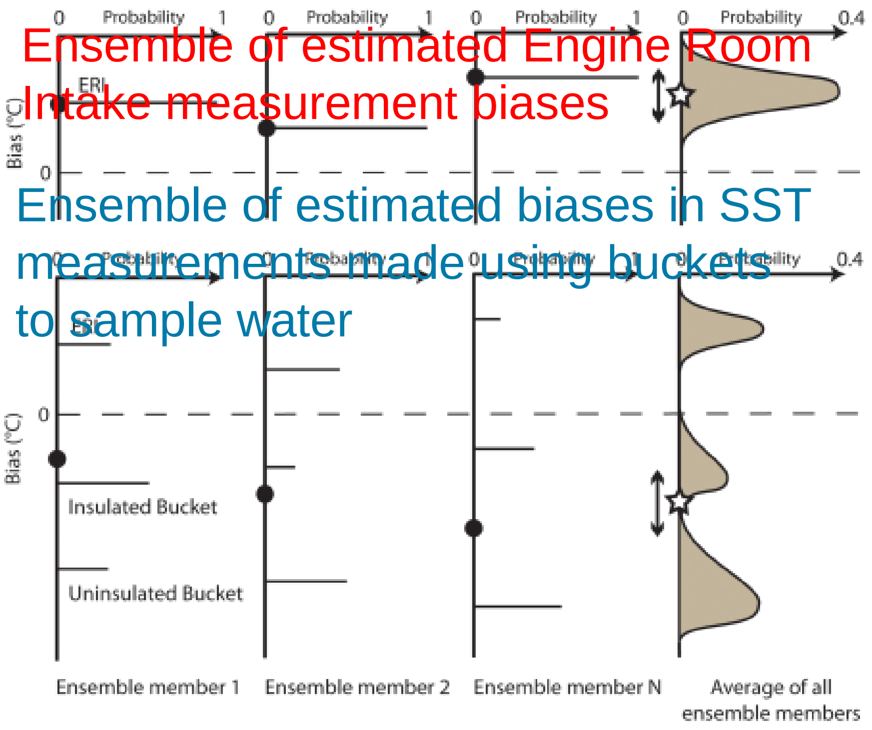




Atkinson, et al 2014: JGR, doi:10.1002/2014JC010053

# Corrections to ship SST in HadIOD

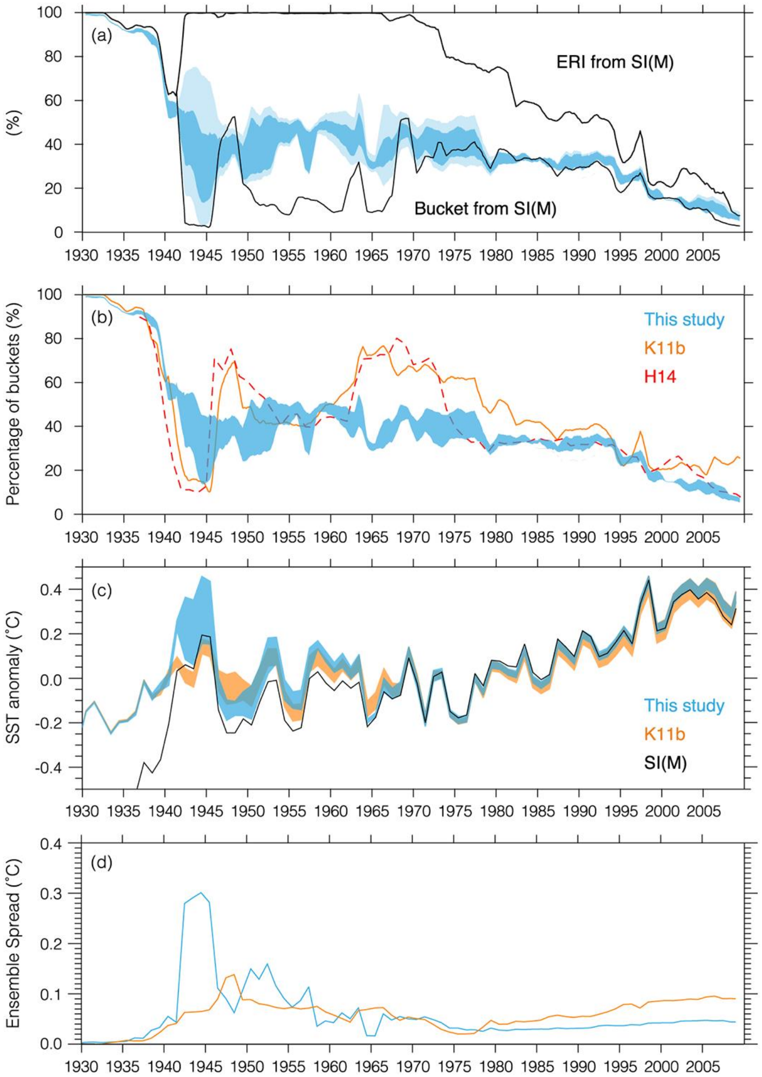


Met Office Hadley Centre

# Estimating Sea Surface Temperature Measurement Methods Using Characteristic Differences in the Diurnal Cycle

**Once metadata is sufficiently available, correction of individual bucket measurements would require knowledge of other variables, e.g. wind and cloud cover**




(a) Percentage of observations identified as ERIs and buckets from ICOADS SST method indicator or from WMO Pub 47 (SI(M), *black lines*) and in Carella et al (2018, *dark blue shading*: ensemble range (buckets: within/below; ERIs: within/above); *light blue shading*: ensemble mean percentage of the unknown measurements, randomly reassigned to ERIs and buckets).

(b) Percentage of buckets identified in Carella et al (2018, *dark blue shaded area)* in Kennedy et al 2011 (*orange solid line*, median of the ensemble) and in Hirahara et al 2014 (*red dashed line*).

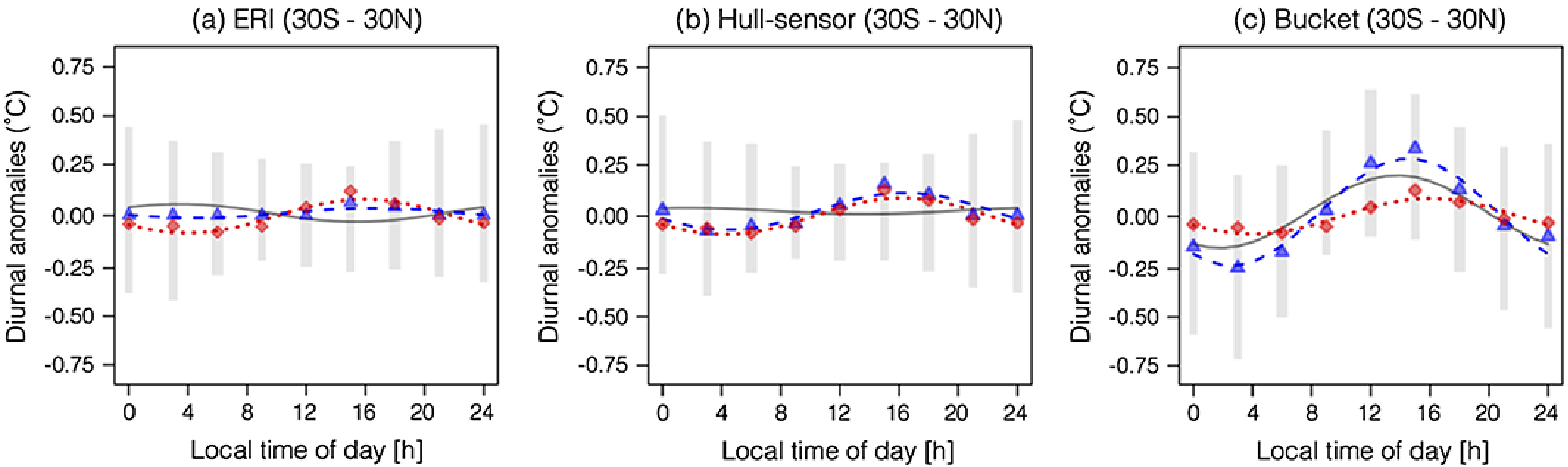
(c) SST anomaly (°C) for bias adjusted observations classified according to Carella et al (2018, *dark blue shaded area*, uncertainty given at the 95% confidence level), Kennedy et al 2011 (*orange shaded area*, uncertainty given at the 95% confidence level) and from ICOADS SST method indicator or WMO Pub 47.

(d) Ensemble spread in Carella et al (2018) and in Kennedy et al 2011.

All lines represent 12 month running means.

**Carella, G., Kennedy, J. J., Berry, D. I., Hirahara, S., Merchant, C. J., Morak-Bozzo, S., & Kent, E. C. (2018). Estimating sea surface temperature measurement methods using characteristic differences in the diurnal cycle. Geophysical Research Letters, 45.**
http://onlinelibrary.wiley.com/doi/10.1002/2017GL076475/full#grl56812-fig-0002

## Estimating Sea Surface Temperature Measurement Methods Using Characteristic Differences in the Diurnal Cycle




Carella, G., Kennedy, J. J., Berry, D. I., Hirahara, S., Merchant, C. J., Morak-Bozzo, S., & Kent, E. C. (2018). Estimating sea surface temperature measurement methods using characteristic differences in the diurnal cycle. Geophysical Research Letters, 45. http://onlinelibrary.wiley.com/doi/10.1002/2017GL076475/full#grl56812-fig-0002

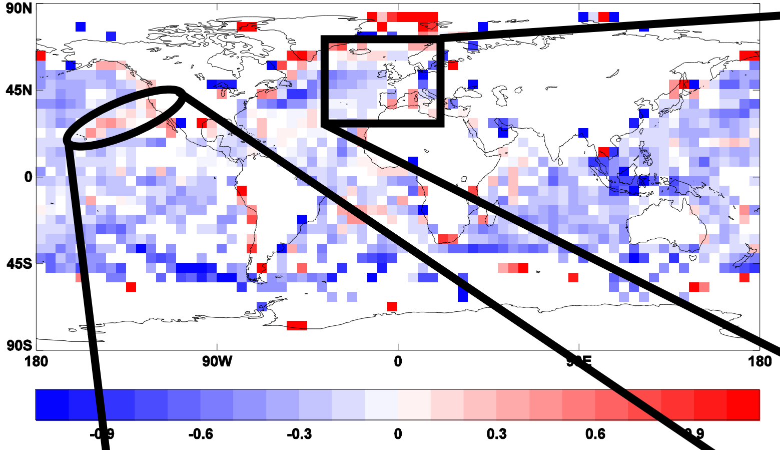
Correction of enhanced diurnal cycles in bucket measurements to bring into line with drifting buoys, etc would require detailed information on wind and cloud cover. Consider: interaction with assimilation window; impact of change in ship observation time

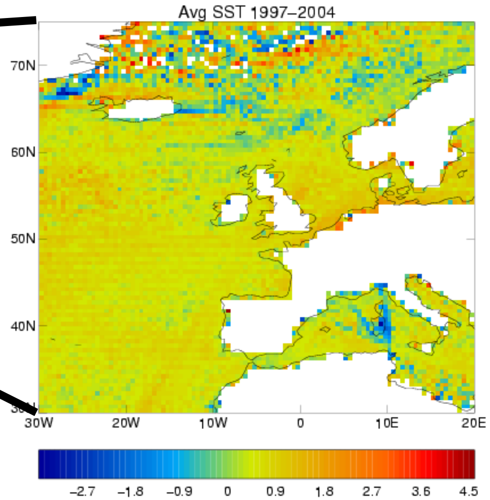
# Residual uncertainties in measurements

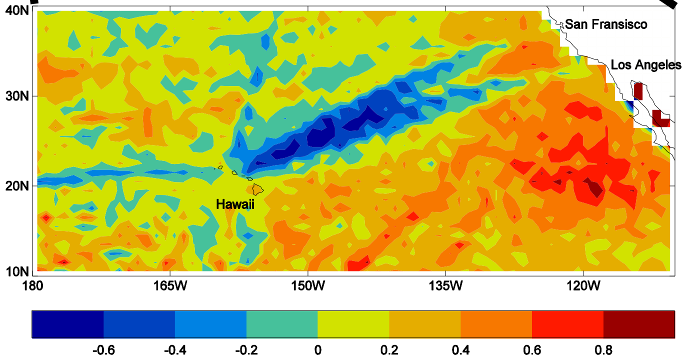
# *in situ* SST measurement uncertainties

- Once biases have been corrected, uncertainties remain.
- These arise from a number of different effects with different correlation structures:
  - Random measurement errors: found in ships and drifting and moored buoys
  - Large-scale correlated uncertainties: arising from imperfect corrections to certain types of measurements from ships
  - Errors that travel from place to place with a particular measurement platform: e.g. ships with biases different from the average.

# Localised persistent ship biases



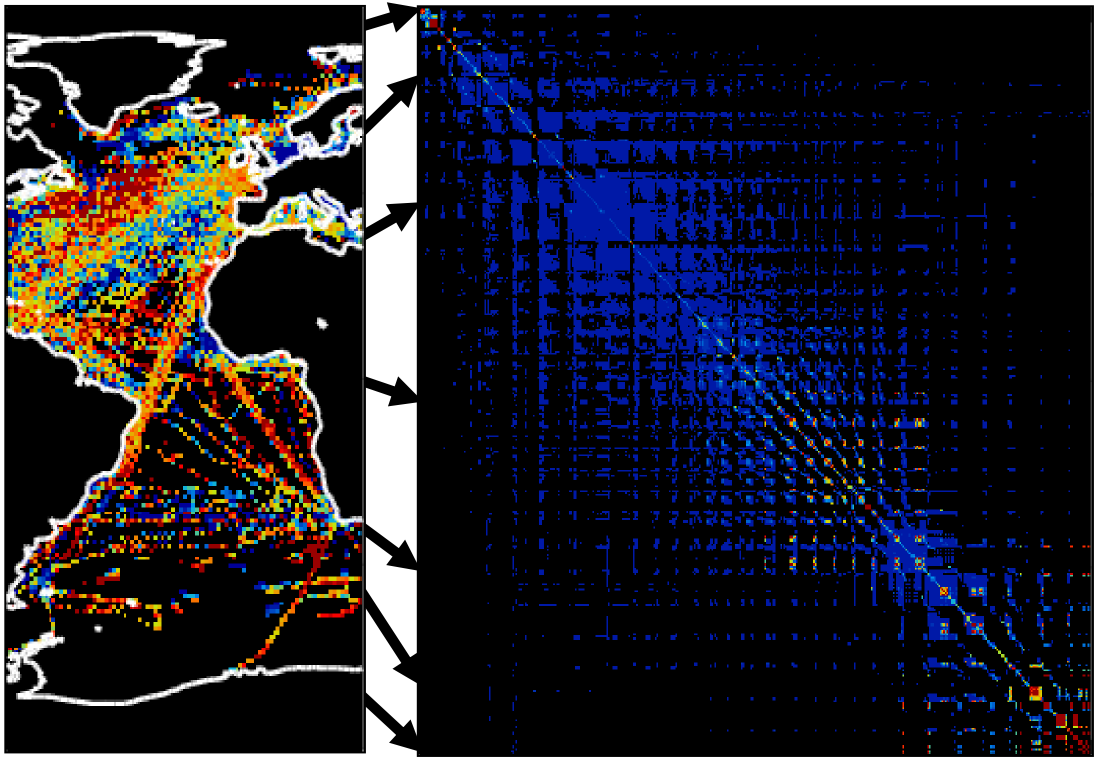




Long term averages highlight ship biases.

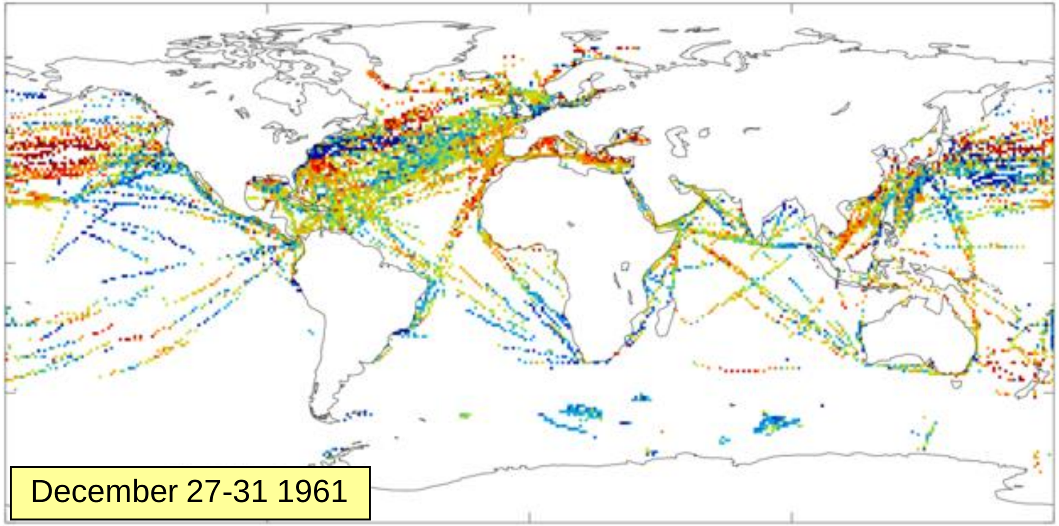
Large local biases due to ERI measurements.

“Micro-biases” (errors due to systematic effects in individual ships’ measurements) are represented in HadSST3 as error covariance matrices

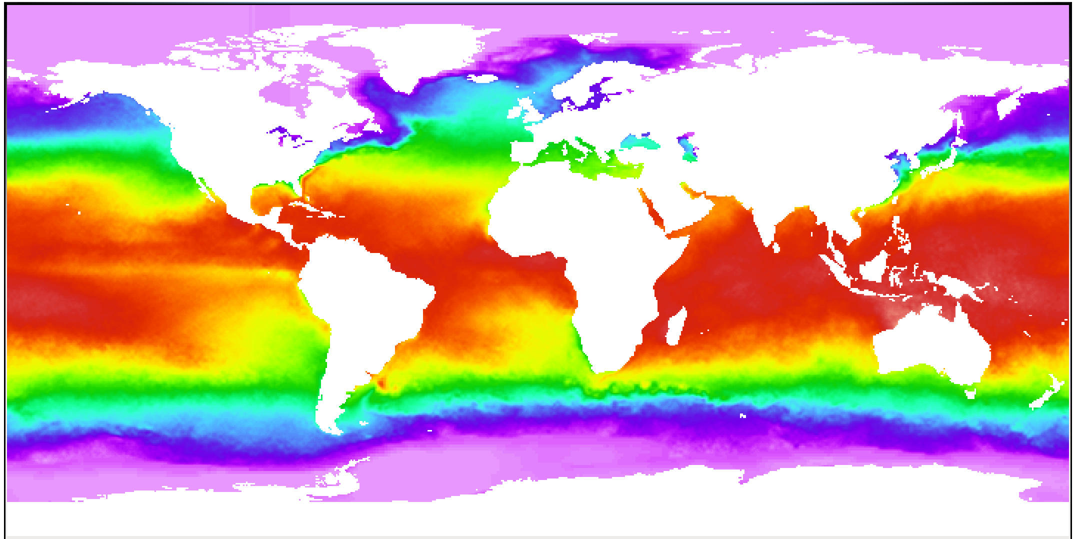


# Blending with satellite measurements and completing the picture

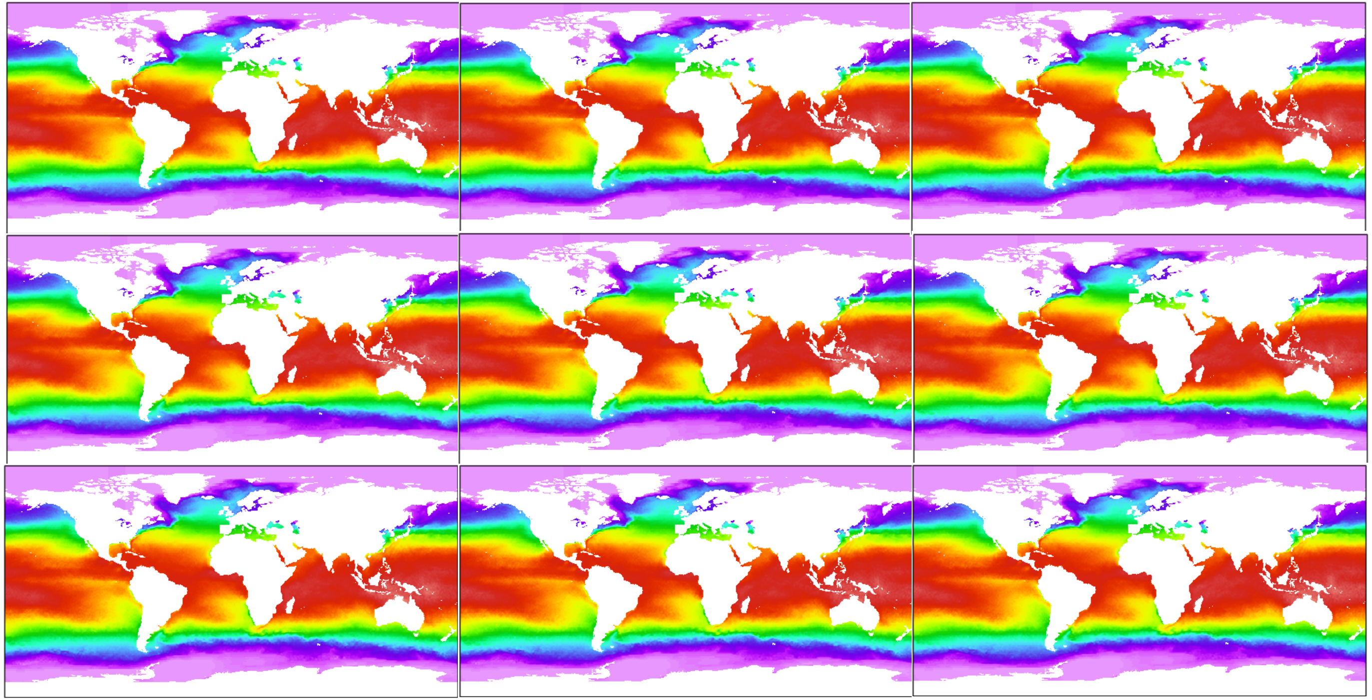
This is what we have




This is what we want

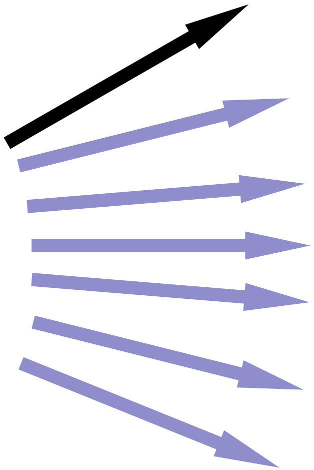


# Available observations do not uniquely define the past



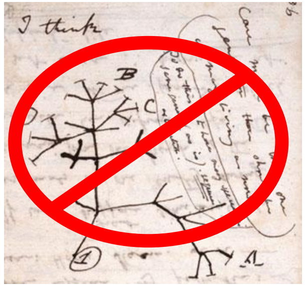
# The Ensemble Generator

First, generate a range of plausible bias adjustments to the data



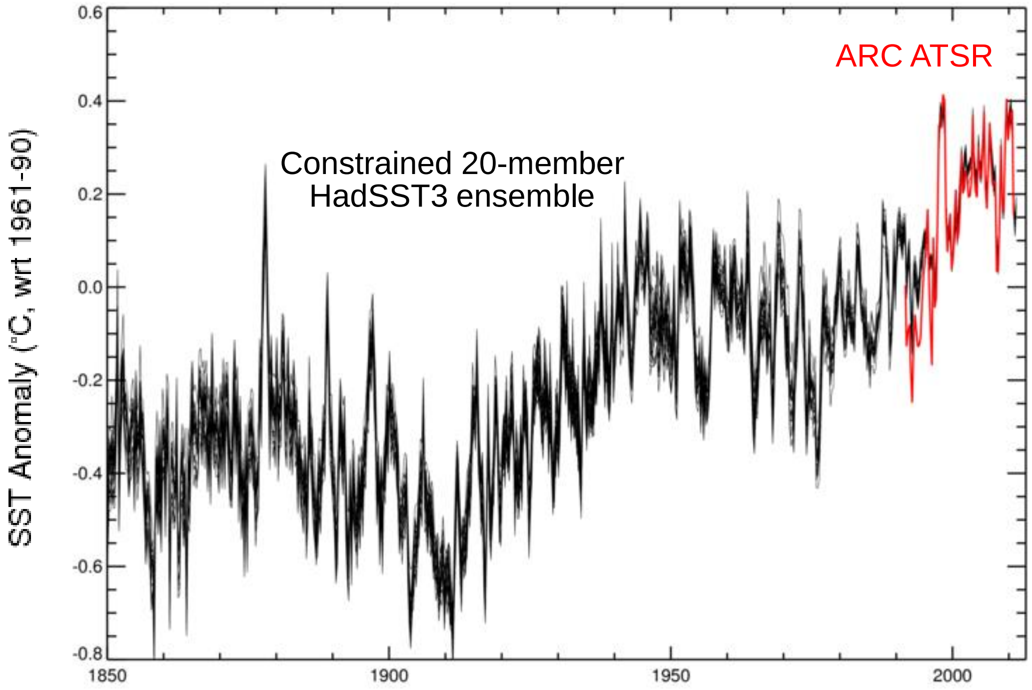
Bias adjustment

# Reject *in situ* ensemble members that disagree with ARC ATSR

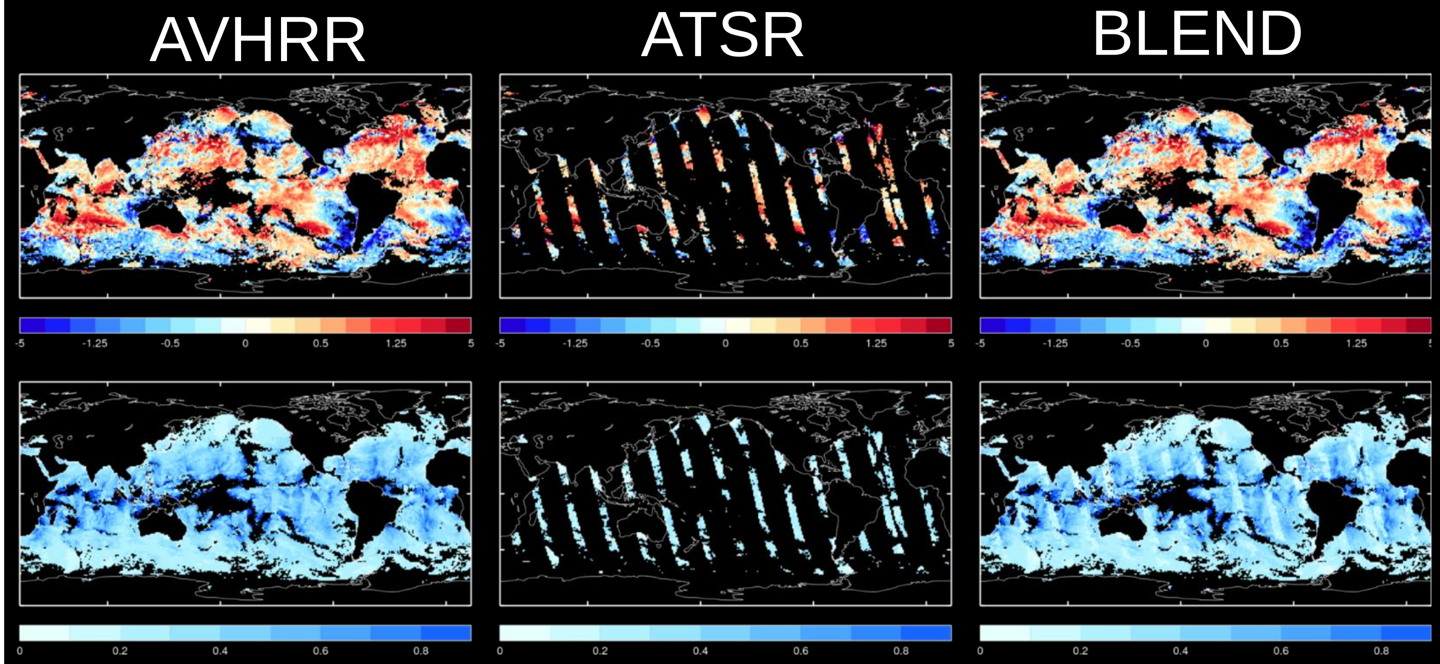


1000 member ensemble

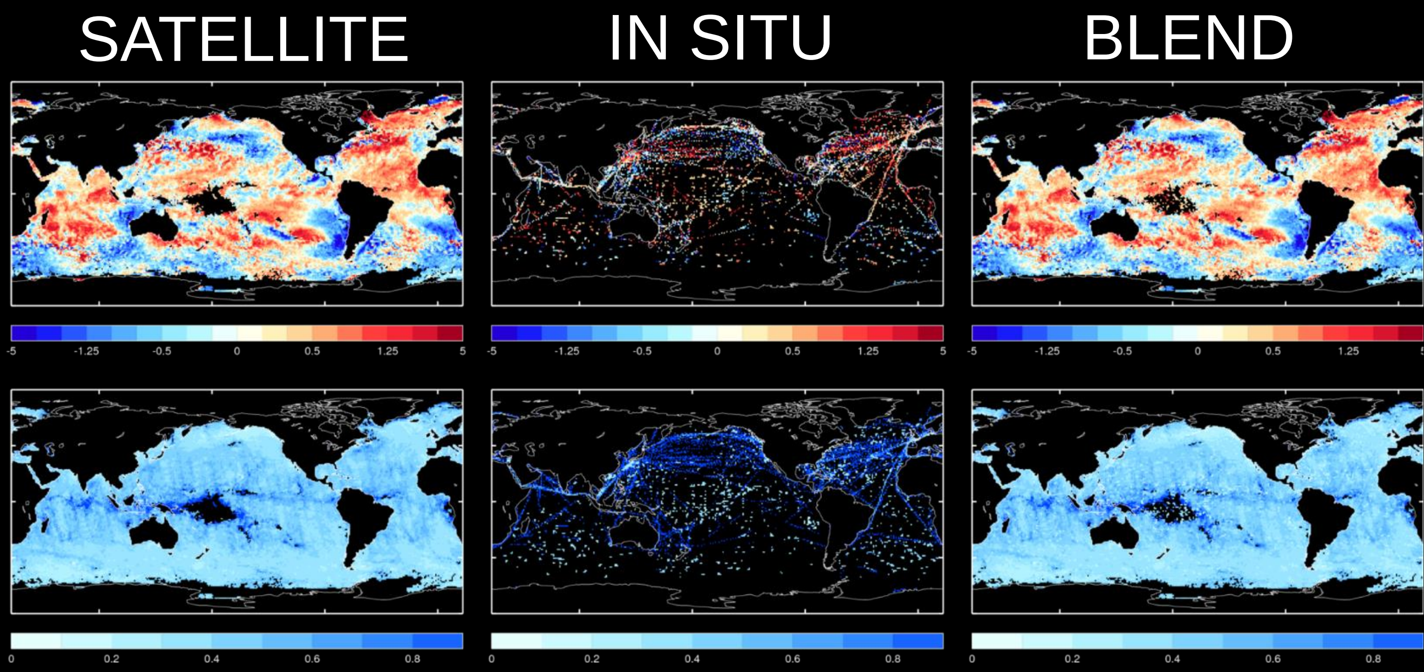
Reduced to ~10 members

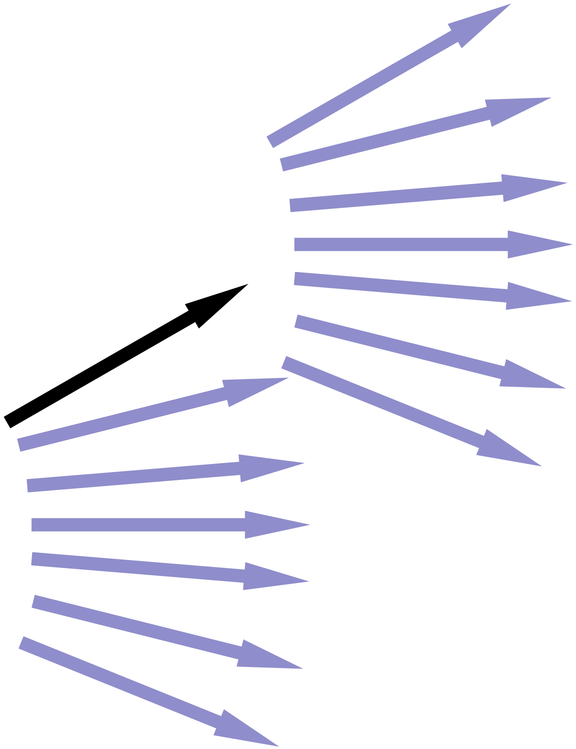


# Blending satellites - daily



# Blending satellite and in situ - pentad

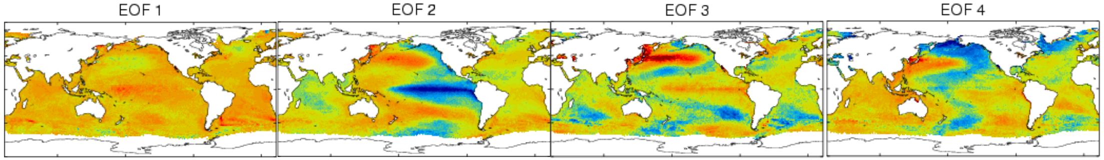




Bias adjustment

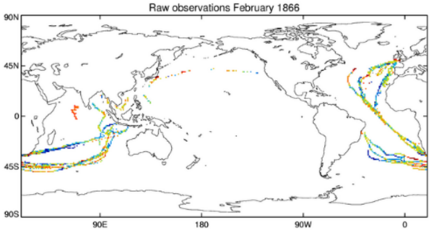
Broad-scale reconstruction

From one realisation of the in situ bias adjustments, produce 10 interchangeable realisations of the broad-scale reconstruction



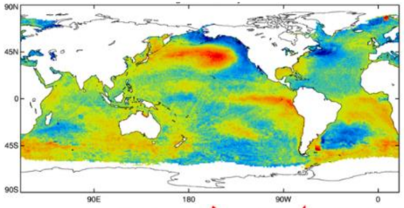

# GUESS EOFS

project on to

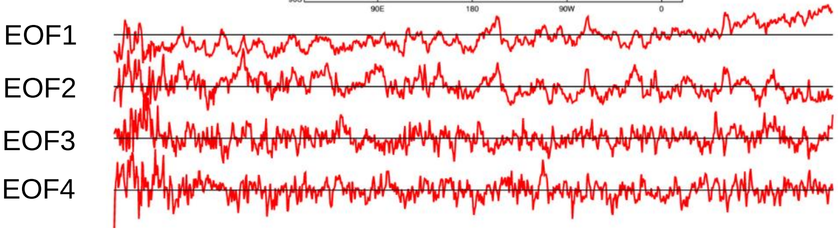



# OBSERVATIONS

**AT EACH TIME STEP**




# BROAD-SCALE RECONSTRUCTION

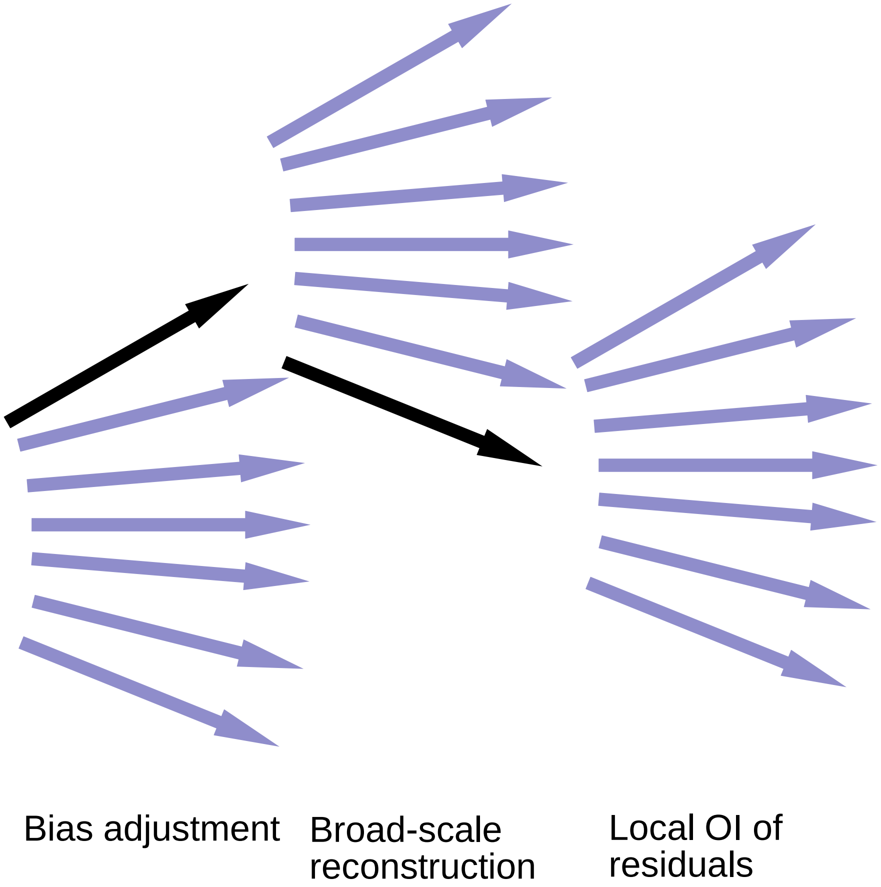



&

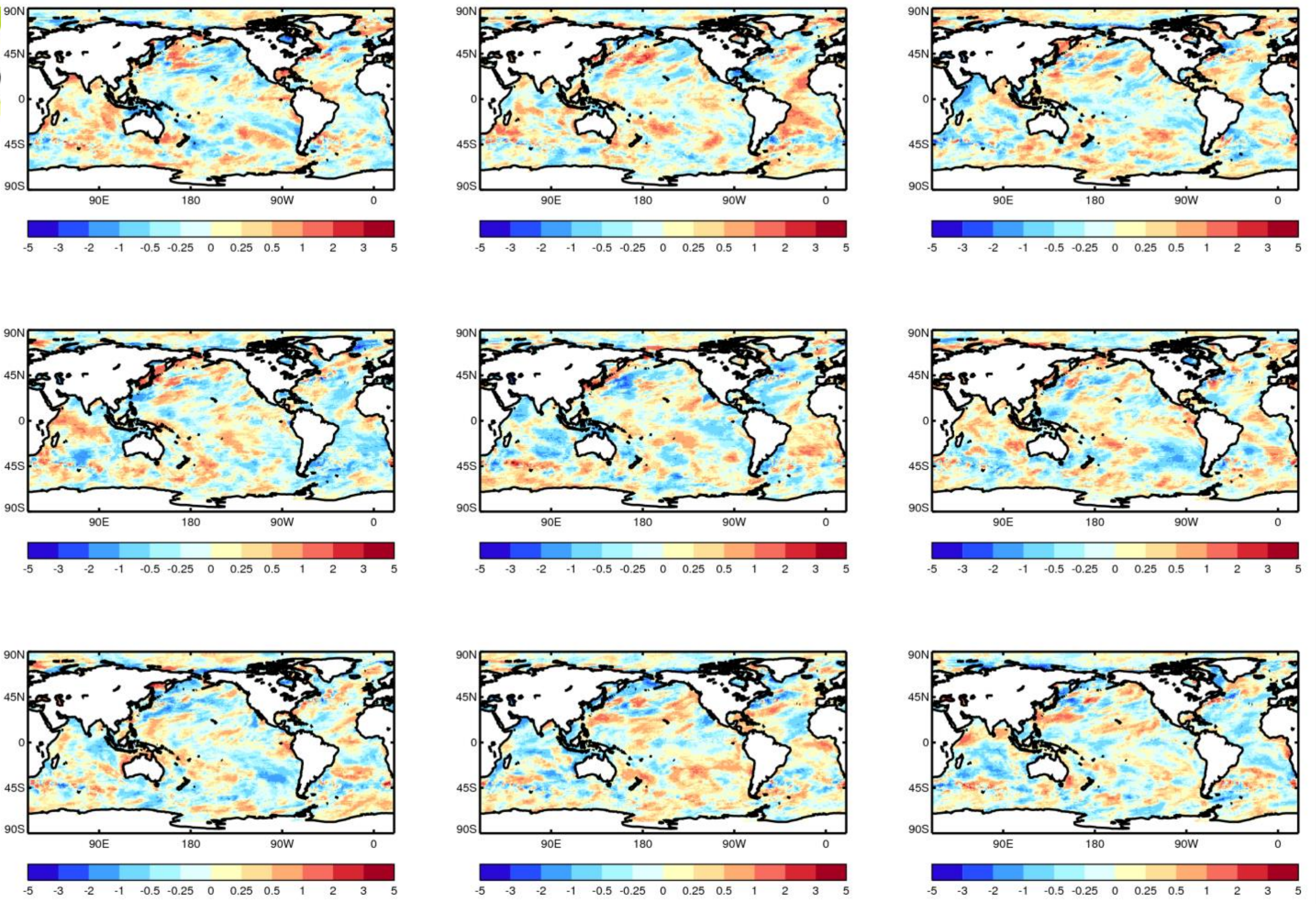
time series of weights of EOFs

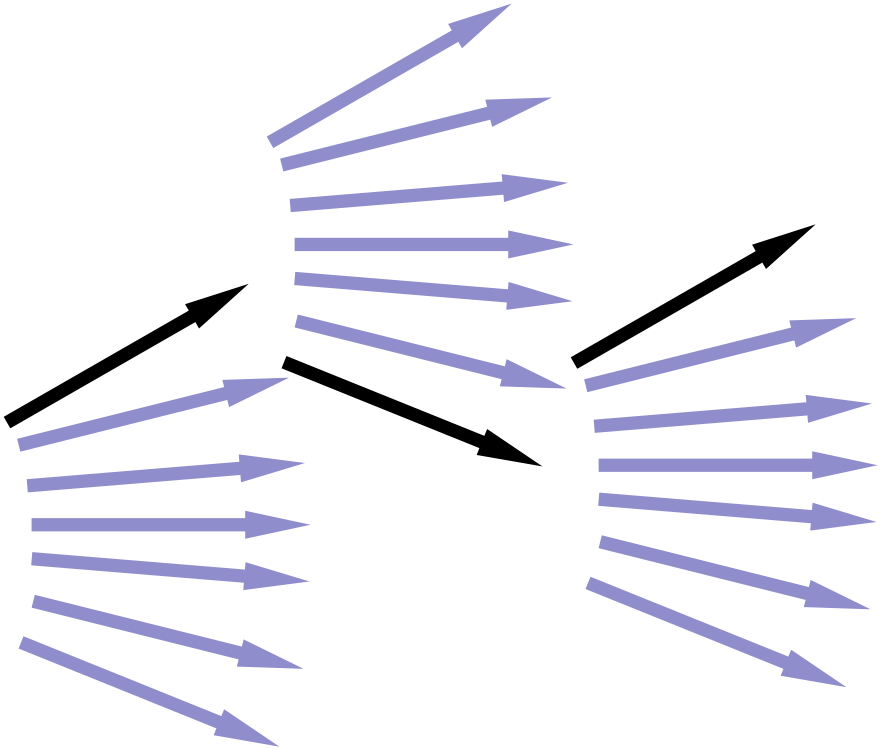
*Bayesian PCA*

Then, from each of the 10 realisations of the broad-scale reconstruction, we can create an ensemble of interchangeable local OIs of the residuals from that reconstruction



# Drawing samples from Local OI



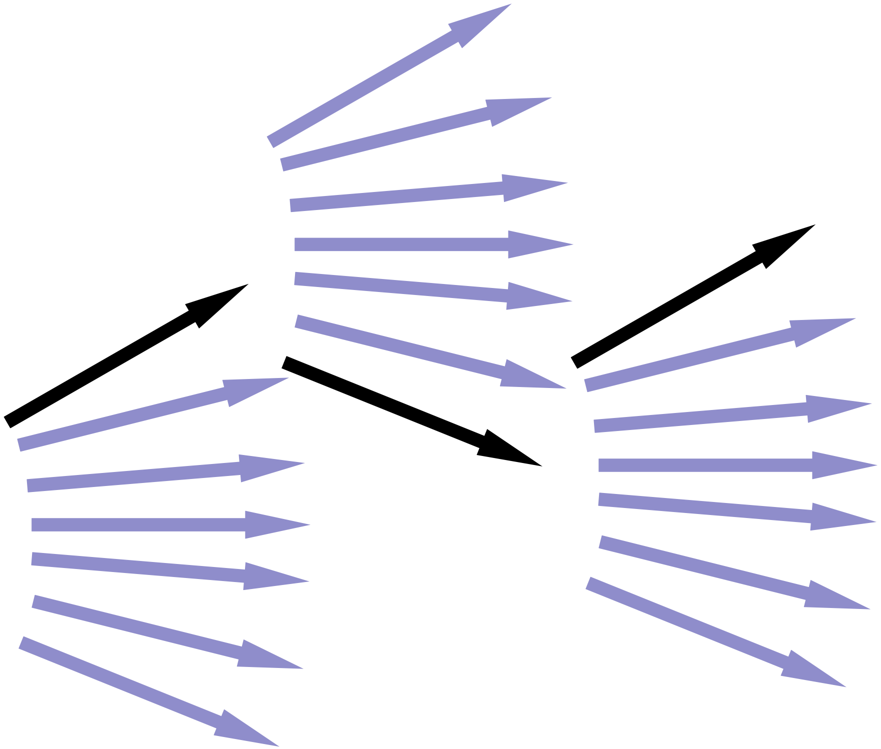


Bias adjustment

Broad-scale reconstruction

Local OI of residuals

One random selection from the analyses of the residuals gives us one of our realisations of HadISST2



Bias adjustment

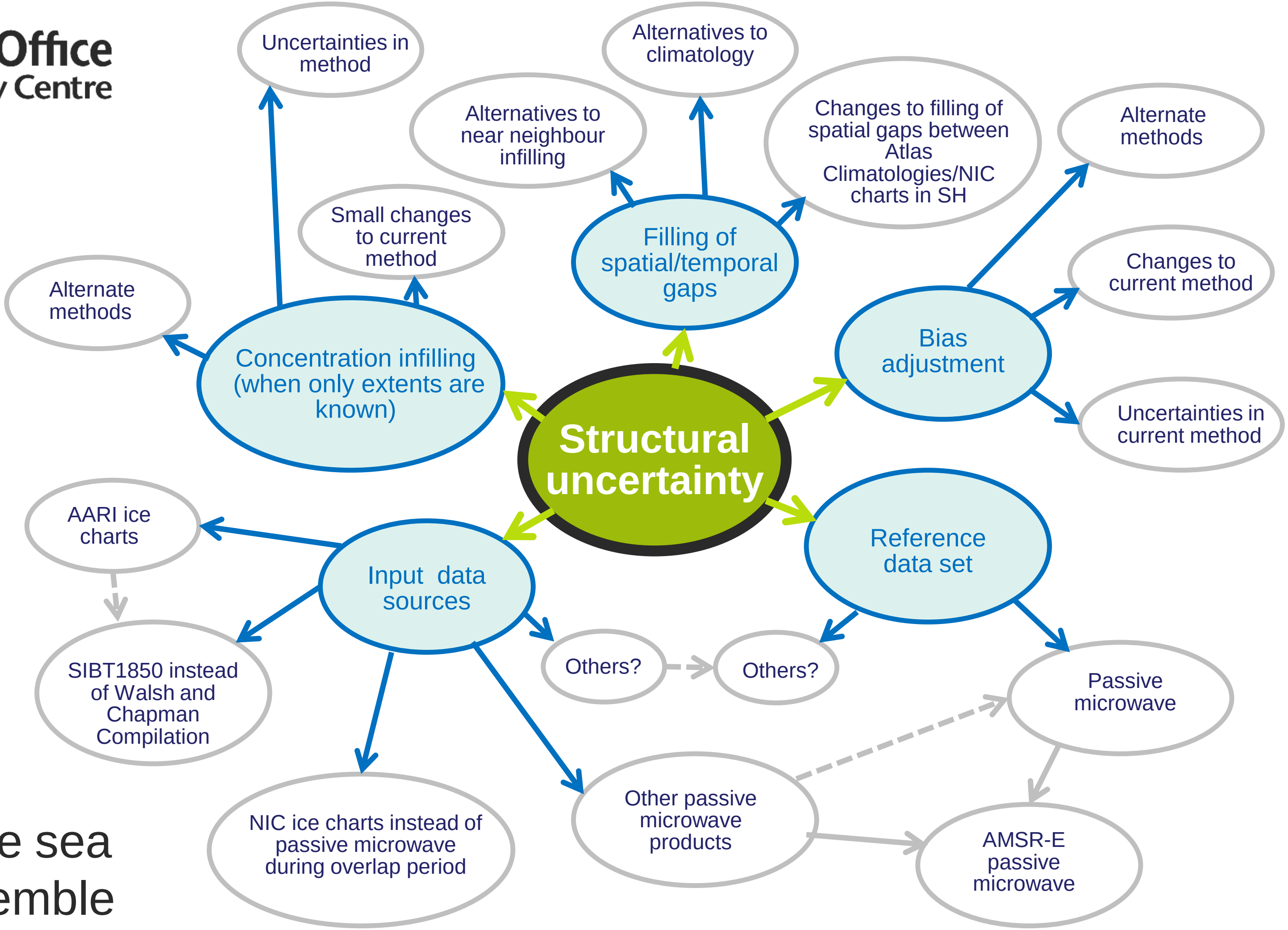
Broad-scale reconstruction

Local OI of residuals

Pick 10 such random paths to span the total uncertainty in the analysis and provide an ensemble of interchangeable versions of HadISST2

# The same needs to be done for sea ice

Met Office Hadley Centre




# Future: generate sea ice ensemble

Met Office Hadley Centre

# Summary

- Each measurement type needs to be understood to create corrections that yield a consistent record. Correcting individual observations is non-trivial and requires more metadata than we have to do it conclusively. Understanding is evolving.
- Uncertainties in SST measurements have non-trivial correlation structures that should be take into account in DA
- Ensembles allow some of these structures to be represented in analyses
- All of the above also needs to be done for sea ice
- We need to understand that as the observing system evolves, so reharmonization needs to happen – for this to be effective, adequate metadata on changes needs to be available
    - can use increased information from new observations to understand historical measurements better