Using More Trusted Observations to Reduce Systematic Error in Less Trusted Observations using Ensemble Data Assimilation

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• Instruments have systematic errors (bias).
• Correcting this bias can improve analyses and forecasts.
• Can estimate the bias as part of ensemble DA.
• Treating instruments with small bias as trusted (no bias):
  Can help estimate bias of other instruments,
  Can improve analyses and forecasts.
• Assimilating difference of trusted and biased obs is useful.
State augmentation: Instrument bias is a state variable.  
Each ensemble has its own estimate of bias.  
Bias variable is ‘global’:  
Has no location, hence no localization of obs impact.  
Adaptive inflation to maintain spread.  
No model of bias time variation (for now).
Can learn a lot with linear error growth models: 
Kalman Filter is optimal solution, 
Even with bias estimation.

Won’t show those results here.
Traditional 40-variable configuration for truth, $F=8$.

Two assimilating models explored:

1. Perfect, same as truth,
2. Enhanced forcing, $F=10$.

Note: Explored other types of model error. Results robust.
Filter details:

All forward operators are identity. Observation error variance is 1 for all observations. Assimilate every 0.05 non-dimensional time units. 80-member ensemble. Localization for state variables, GC halfwidth 20% of domain. Space/time varying adaptive inflation for state and bias. Anderson 2007, standard deviation 0.6, fixed. 1500 assimilation step spin-up. 1000 assimilation steps for results.
Observing System: Two Instrument Types

Bias 1

Lorenz-96
40 Variables
Bayes’ Rule
Observing System: Two Instrument Types

Bias 1

Bias 2

Lorenz-96
40 Variables
Trusted instruments (green) will not have a bias estimated.
Five Cases: 1

Baseline: Two trusted instruments.

Lorenz-96
40 Variables
Two instruments with zero bias, but…
Bias is still estimated for each.
Five Cases: 3

Bias +2

Lorenz-96
40 Variables

Bias +2

Two instruments with +2 bias.
Bayes' Rule

Five Cases: 4

Instrument with +2 bias.
Trusted Instrument.

Lorenz-96
40 Variables

Trusted
Only slight degradation for state when bias is estimated.
Only slight degradation for state when bias is estimated.

Bias estimates very accurate.

Size of bias is irrelevant.
Hard to distinguish between model error and instrument bias.
Hard to distinguish between model error and instrument bias.

Having trusted instrument helps but cannot correct all instrument bias.
DA challenge:
Trusted obs priors weakly correlated with bias ensemble.
Observationalist’s approach:
Why do all this messy DA?
Have collocated trusted and biased obs.
Just look at the differences at each location.
DA Solution:
Assimilate difference of collocated trusted and biased obs. The priors have a correlation of 1 with bias ensemble! These have uncorrelated observation errors by definition.

Assimilate the original observations for state ensemble.
DA Solution:
Assimilate difference of collocated trusted and biased obs. The priors have a correlation of 1 with bias ensemble! These have uncorrelated observation errors by definition.

Assimilate the original observations for state ensemble.

This is essentially a rotation of the forward operator matrix. Wouldn’t change the answer for a Kalman Filter. But reduces sampling error in ensemble filter.
F=10 Imperfect Model: 40 Obs from Each Instrument

Trusted difference obs work well even with combined model error and instrument bias.
DA Solution:
Not so fast.
Used collocated trusted and biased obs of same type. If we had these, could easily do things off-line.

Can this work for obs with different locations, or types?
20 Offset Obs from Each Instrument

Bayes' Rule

20 Offset Obs from Each Instrument: Difference Obs.

Bias +2

Instrument with +2 bias.

Trusted Instrument.
Difference obs still effective.

Uses model correlations for relation between the obs.

Errors in 2nd moment are now a concern.
4 Trusted Obs, 20 Offset biased Obs

Difference obs still effective.

Only 4 compared to 20 obs from biased instrument.

Losing information?
Instrument with +2 bias.

Trusted Instrument.
Instrument with +2 bias.
Trusted Instrument.
Bayes’ Rule

F=10 Imperfect Model: 4/20 Observations

Difference obs less effective.

Better estimate of other instruments bias.

Effect on state variables limited.

Need to use the other 19 biased obs, but correlated errors!
Conclusions

1. Ensemble filters can estimate instrument bias.
2. Model error and instrument bias hard to distinguish.
3. Using trusted observations can help.
4. Could extend to use ‘more/less’ trusted instruments.
5. Difference observations can reduce sampling error.
6. This is just a rotation of the forward operator matrix.
7. This technique might have more general applications.
All results here with DARTLAB tools freely available in DART.

www.image.ucar.edu/DARes/DART