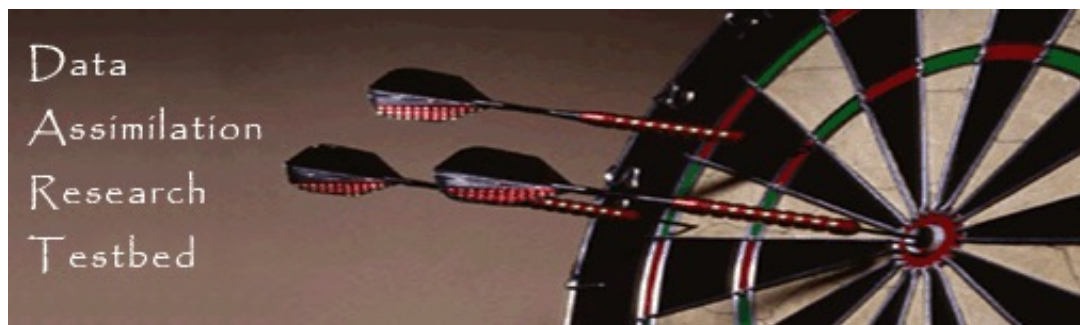


Using More Trusted Observations to Reduce Systematic Error in Less Trusted Observations using Ensemble Data Assimilation

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Outline

- 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.

Ensemble Kalman Filter Approach

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.

Ensemble Kalman Filter Approach

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.

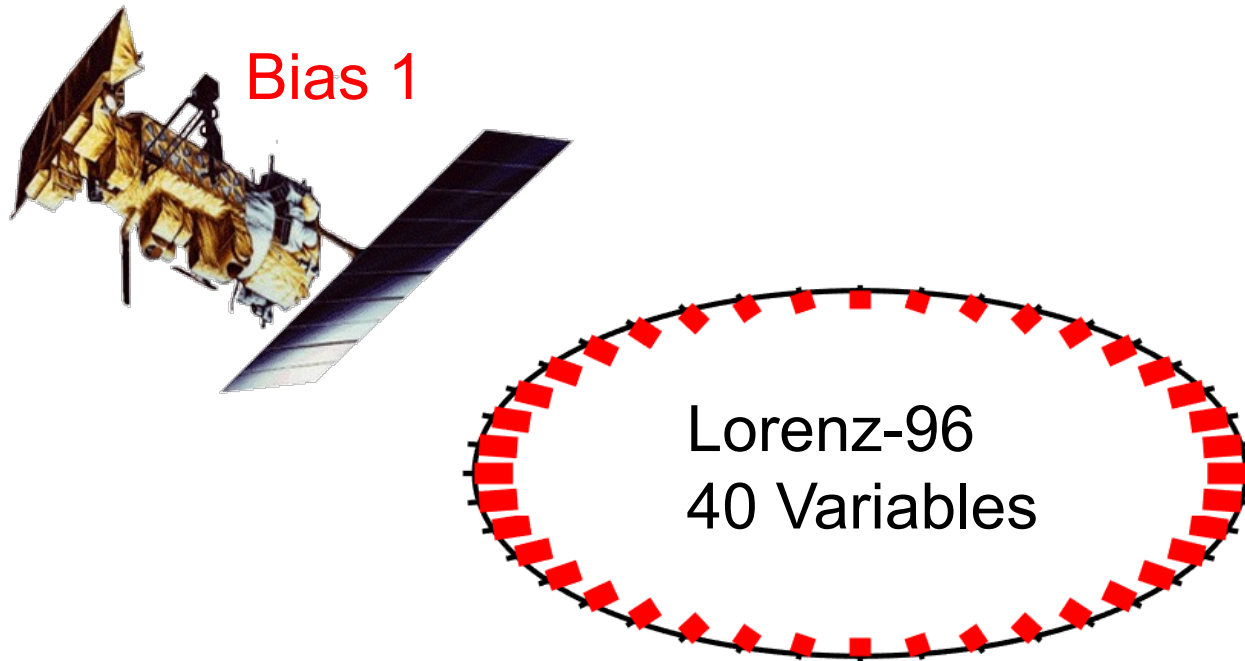
Space/time varying adaptive inflation for state and bias.

Anderson 2007, standard deviation 0.6, fixed.

1500 assimilation step spin-up.

1000 assimilation steps for results.

Observing System: Two Instrument Types



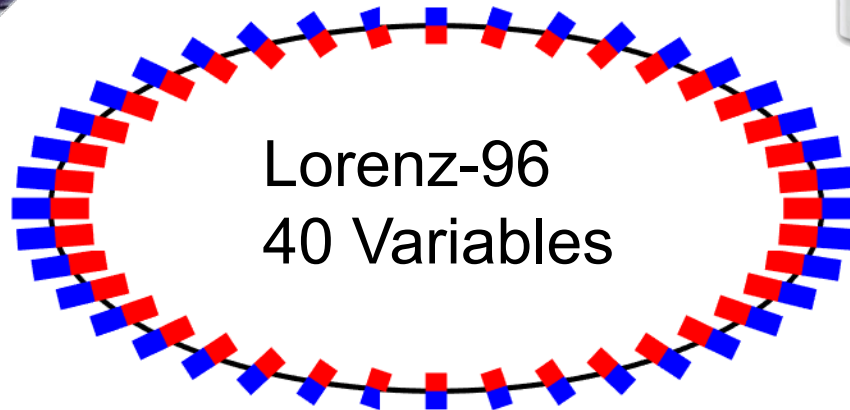
Observing System: Two Instrument Types



Bias 1



Bias 2



Lorenz-96
40 Variables

Observing System: Two Instrument Types



Unbiased
(Trusted)



Trusted instruments (green) will not have a bias estimated.

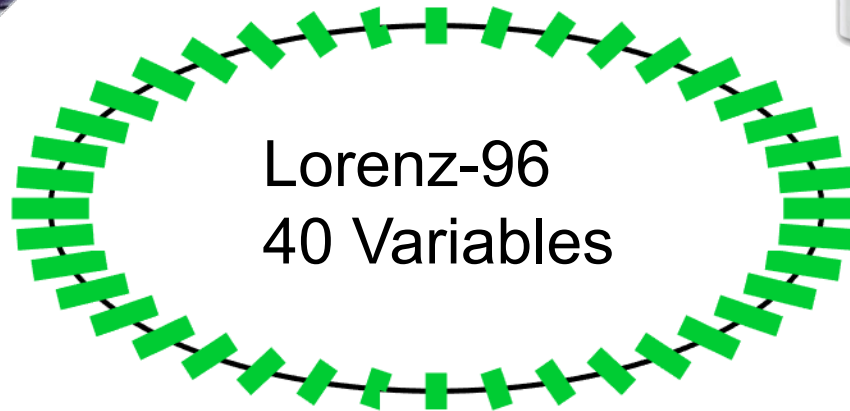
Five Cases: 1



Trusted



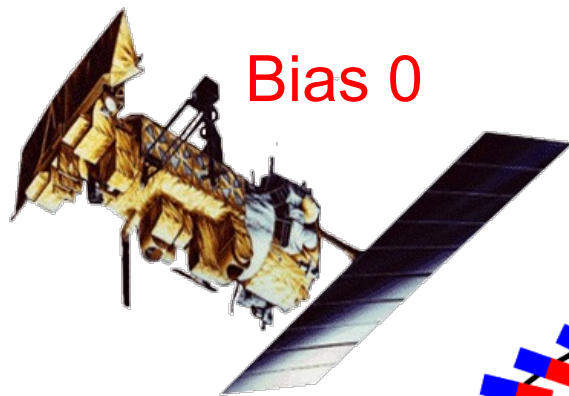
Trusted



Lorenz-96
40 Variables

Baseline: Two trusted instruments.

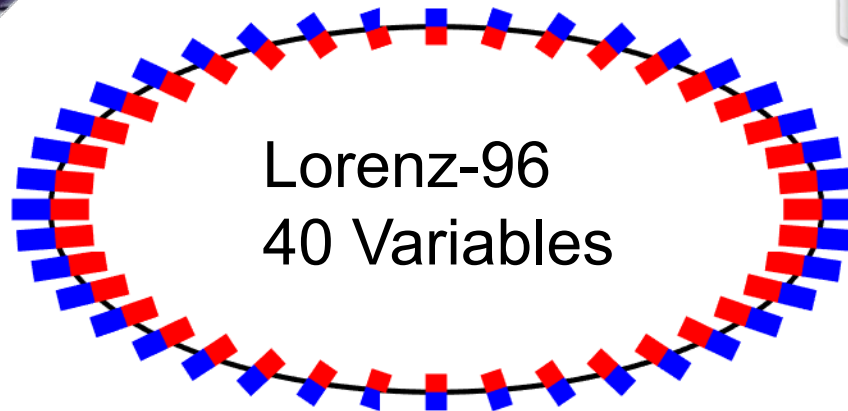
Five Cases: 2



Bias 0

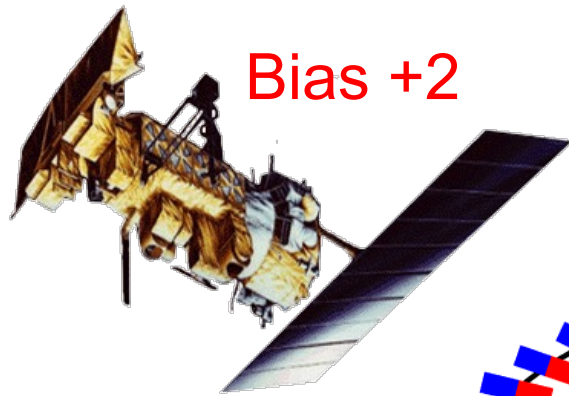


Bias 0



Two instruments with zero bias, but...
Bias is still estimated for each.

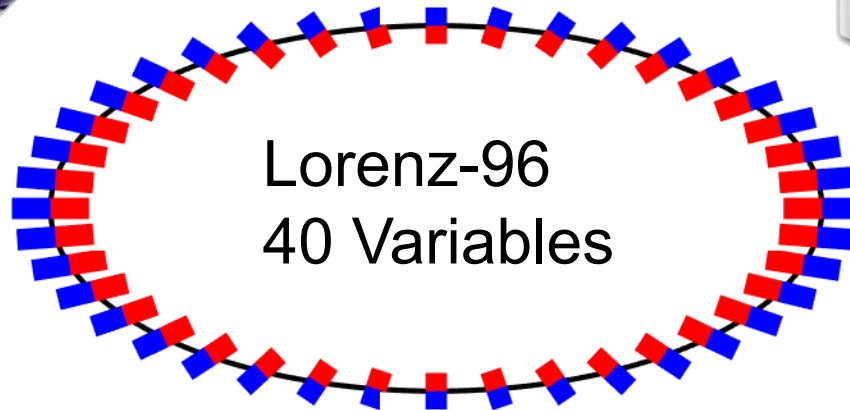
Five Cases: 3



Bias +2

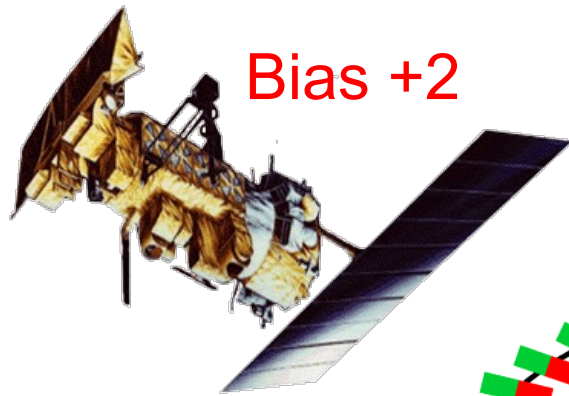


Bias +2

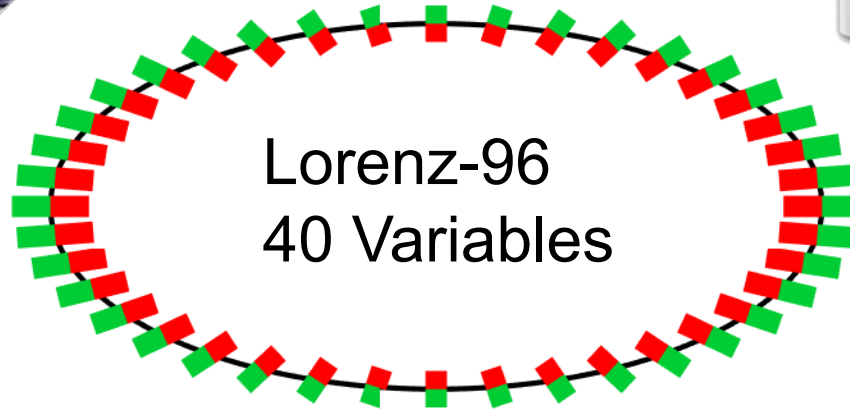


Two instruments with +2 bias.

Five Cases: 4



Bias +2



Lorenz-96
40 Variables

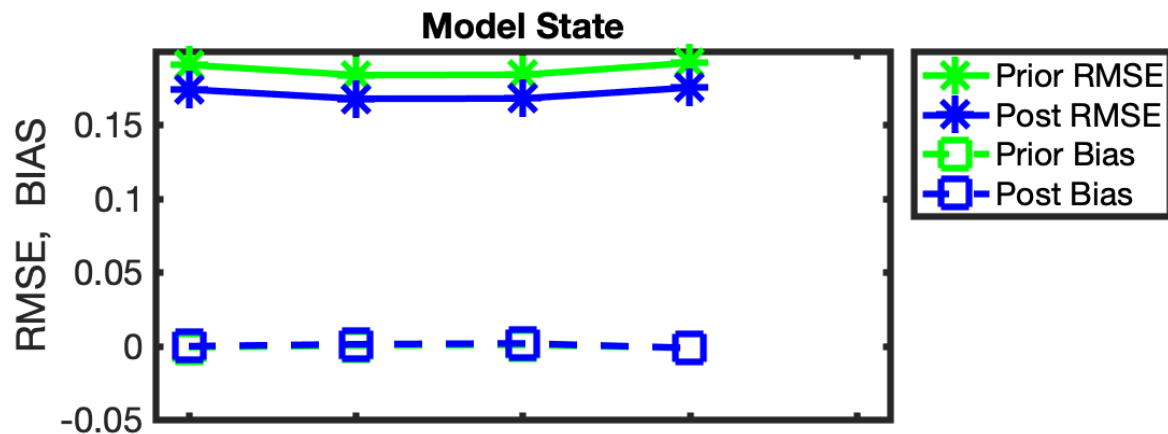


Trusted

Instrument with +2 bias.
Trusted Instrument.

Perfect Model: 40 Obs from Each Instrument

Only slight degradation for state when bias is estimated.

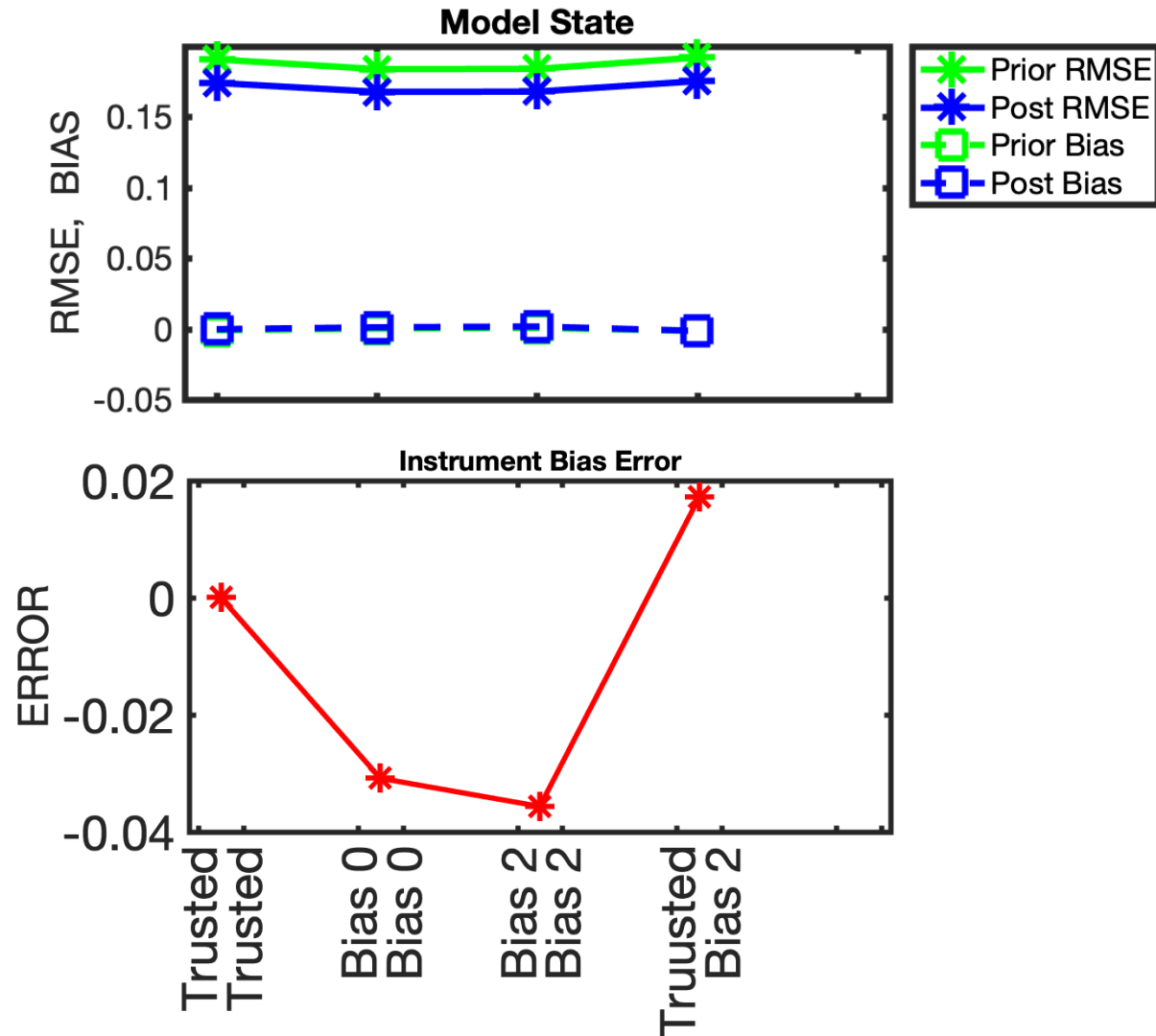


Perfect Model: 40 Obs from Each Instrument

Only slight degradation for state when bias is estimated.

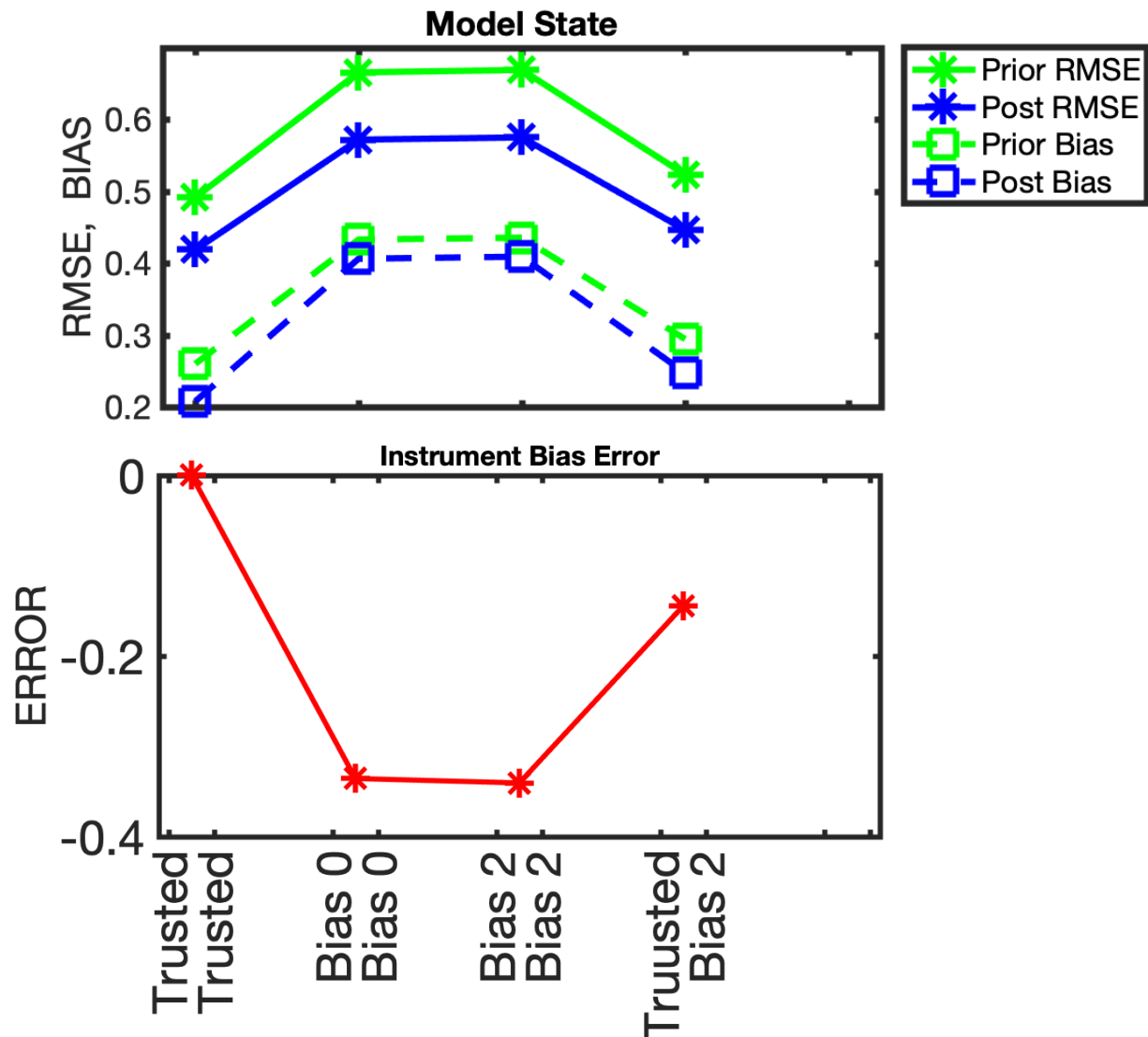
Bias estimates very accurate.

Size of bias is irrelevant.



F=10 Imperfect Model: 40 Obs from Each Instrument

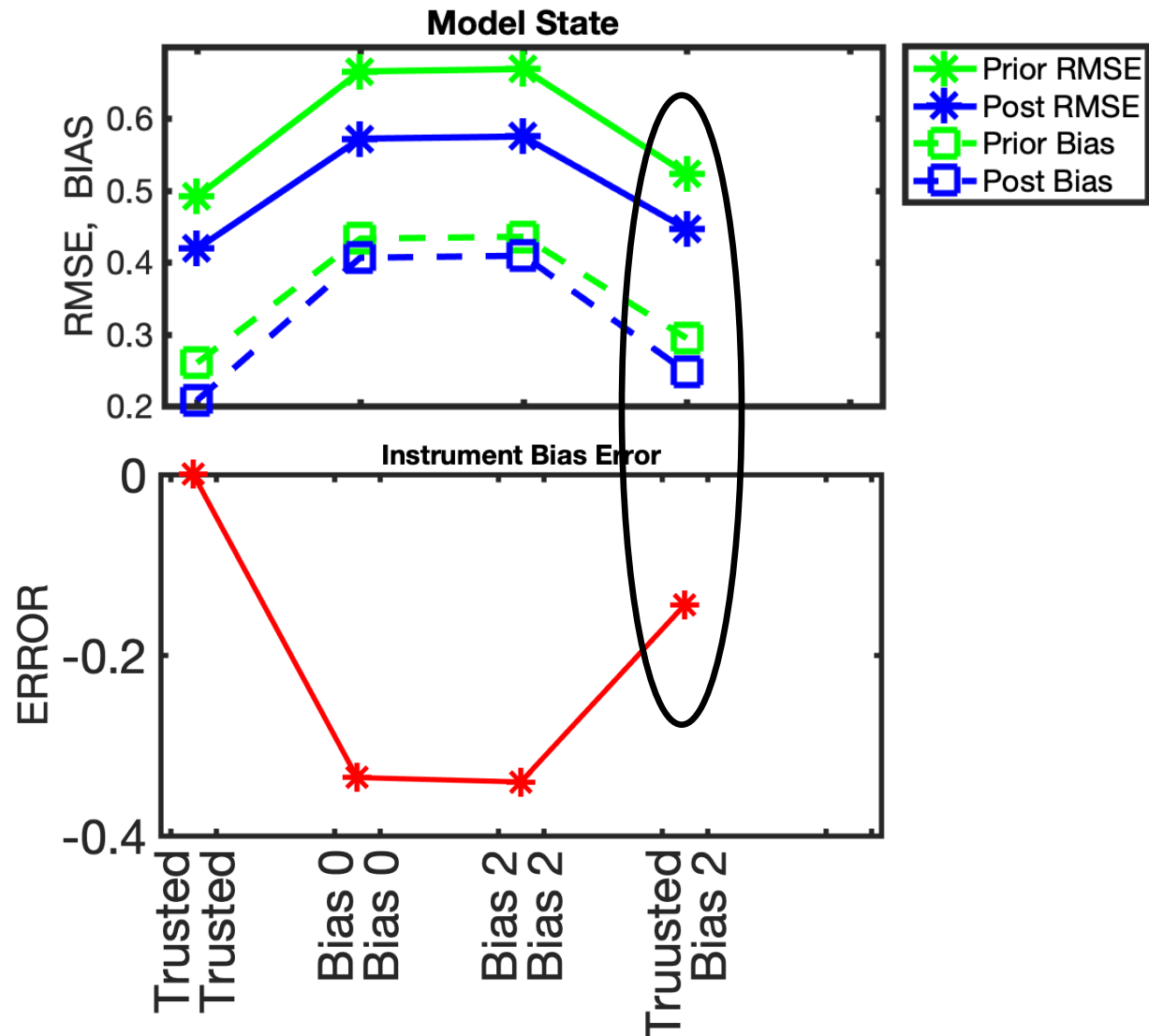
Hard to distinguish between model error and instrument bias.



F=10 Imperfect Model: 40 Obs from Each Instrument

Hard to distinguish between model error and instrument bias.

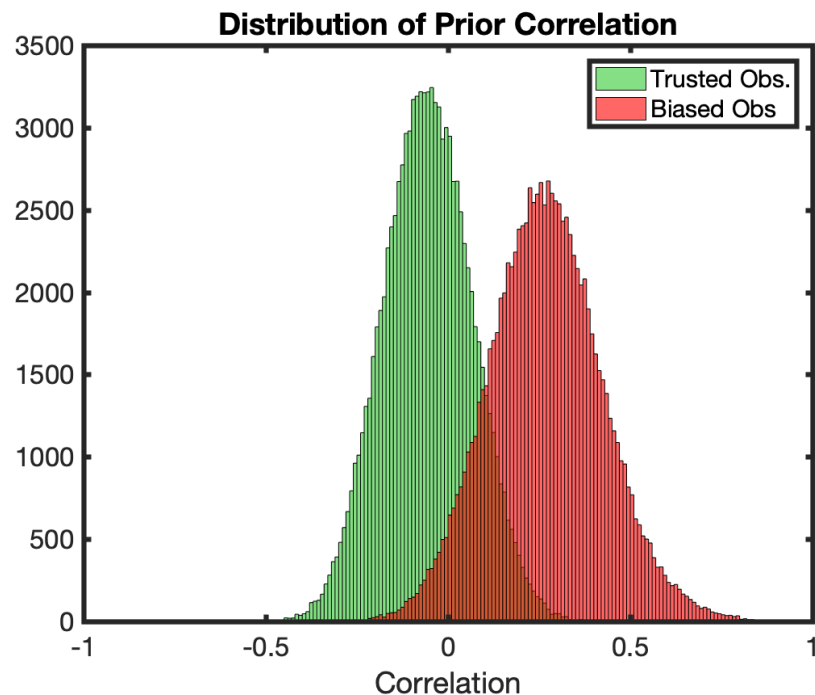
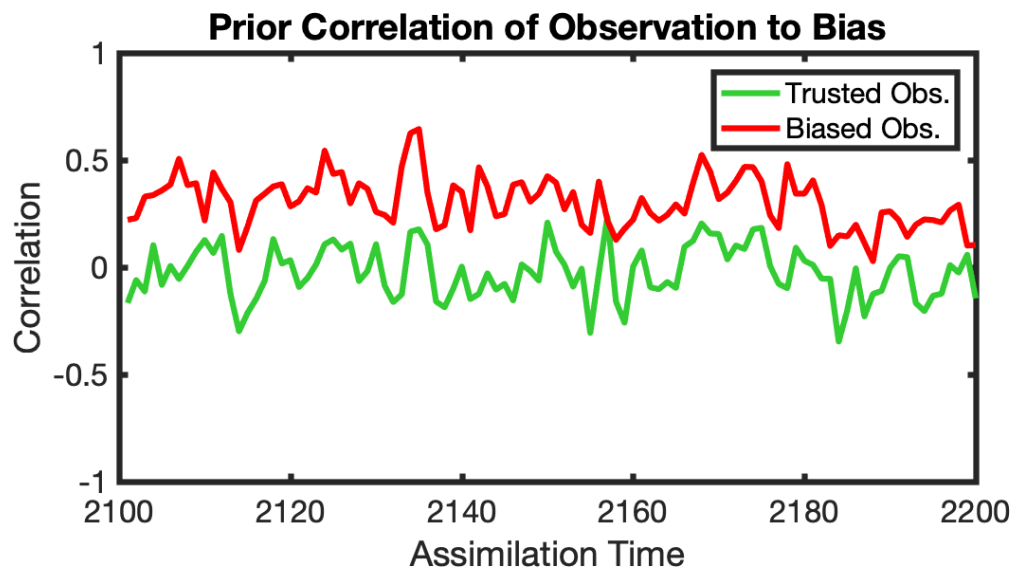
Having trusted instrument helps but cannot correct all instrument bias.



Five Cases: 5: Difference Observations

DA challenge:

Trusted obs priors weakly correlated with bias ensemble.



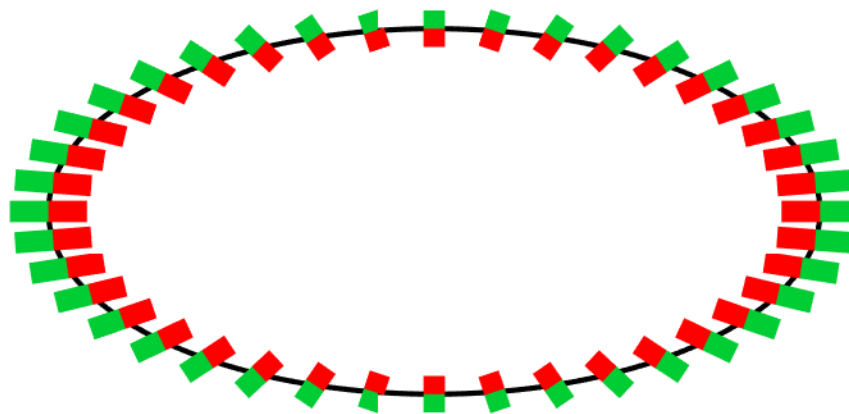
Five Cases: 5: Difference Observations

Observationalist's approach:

Why do all this messy DA?

Have collocated trusted and biased obs.

Just look at the differences at each location.



Five Cases: 5: Difference Observations

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.

Five Cases: 5: Difference Observations

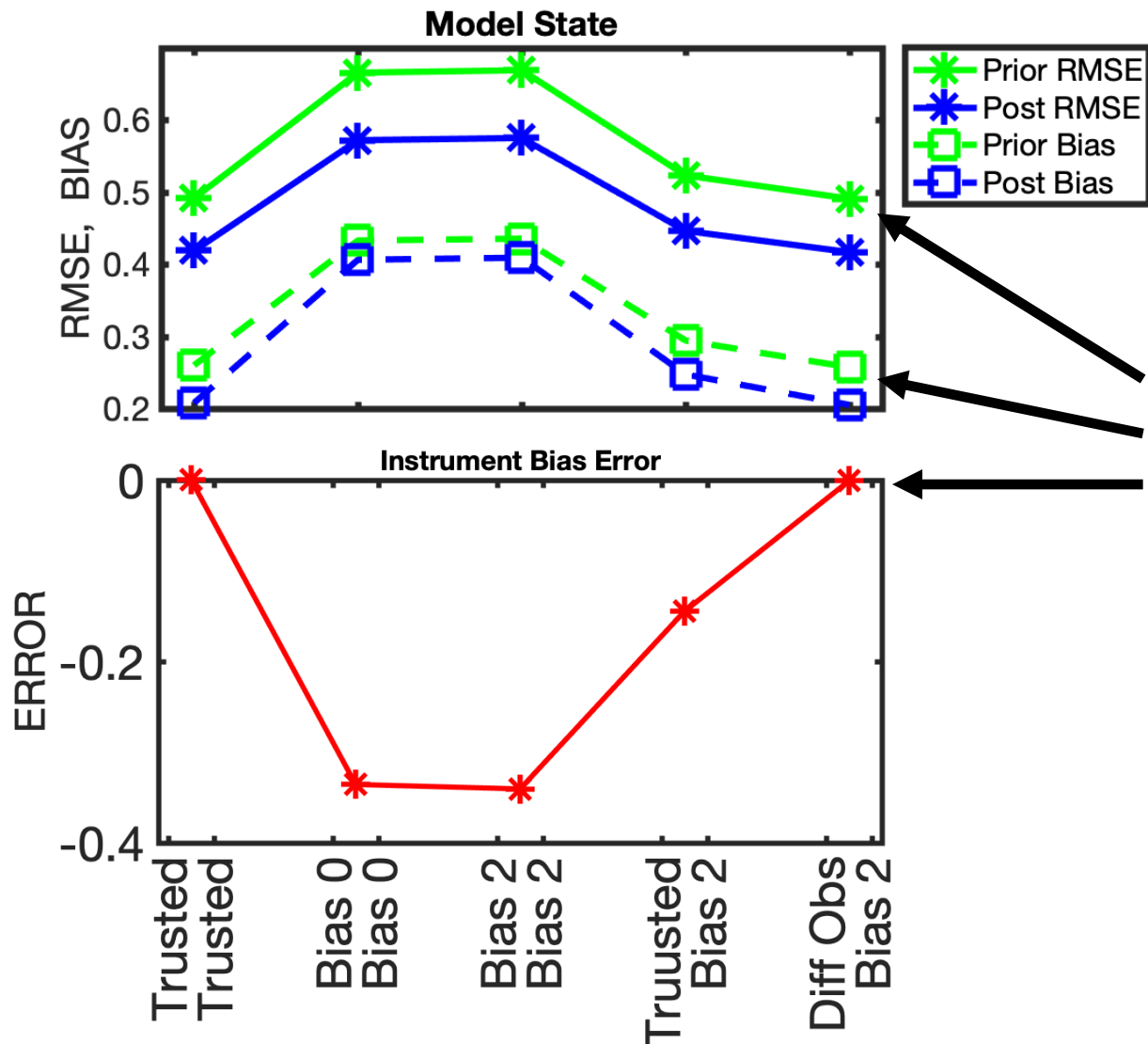
DA Solution:

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.

Five Cases: 5: Difference Observations

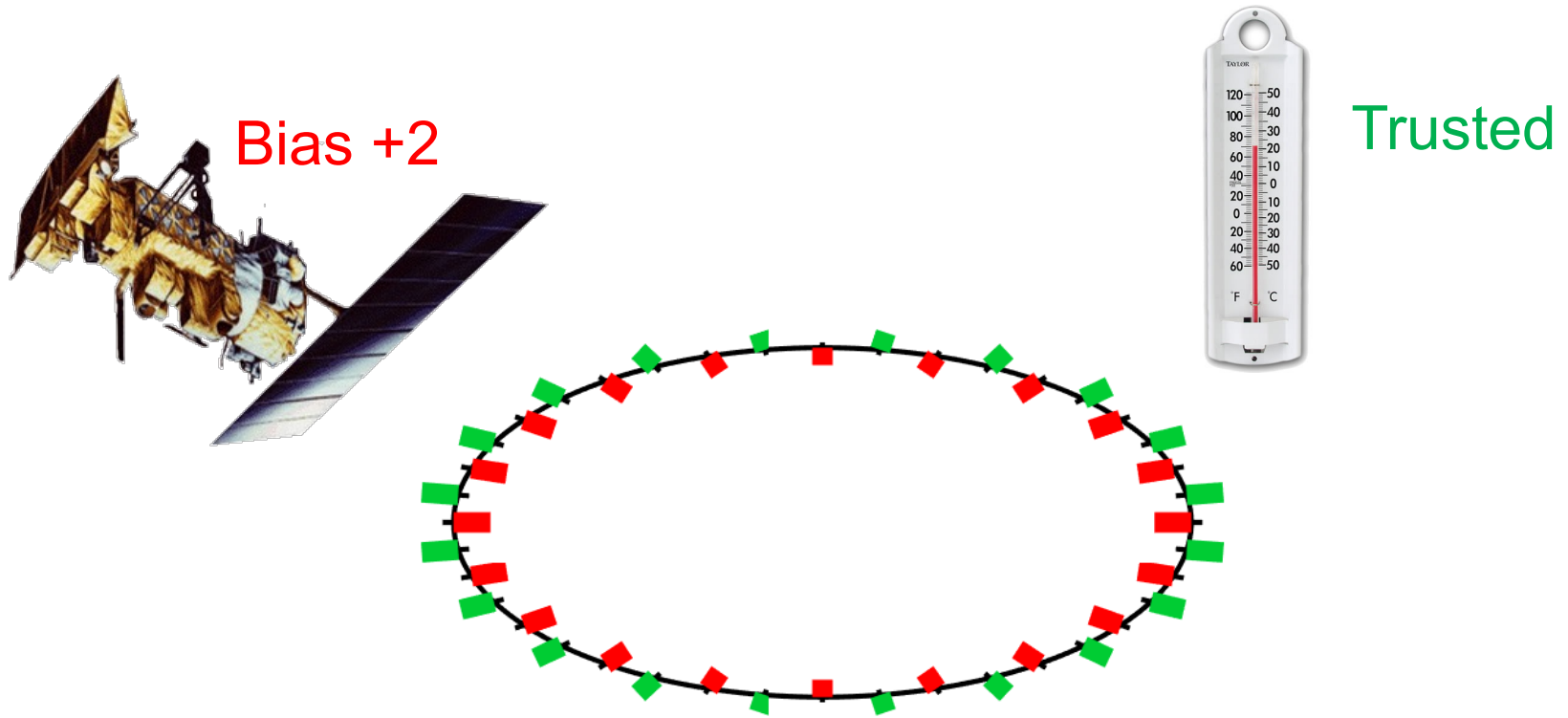
DA Solution:

Not so fast.

Used **collocated** trusted and biased obs of same type.
If we had these, could easily do things off-line.

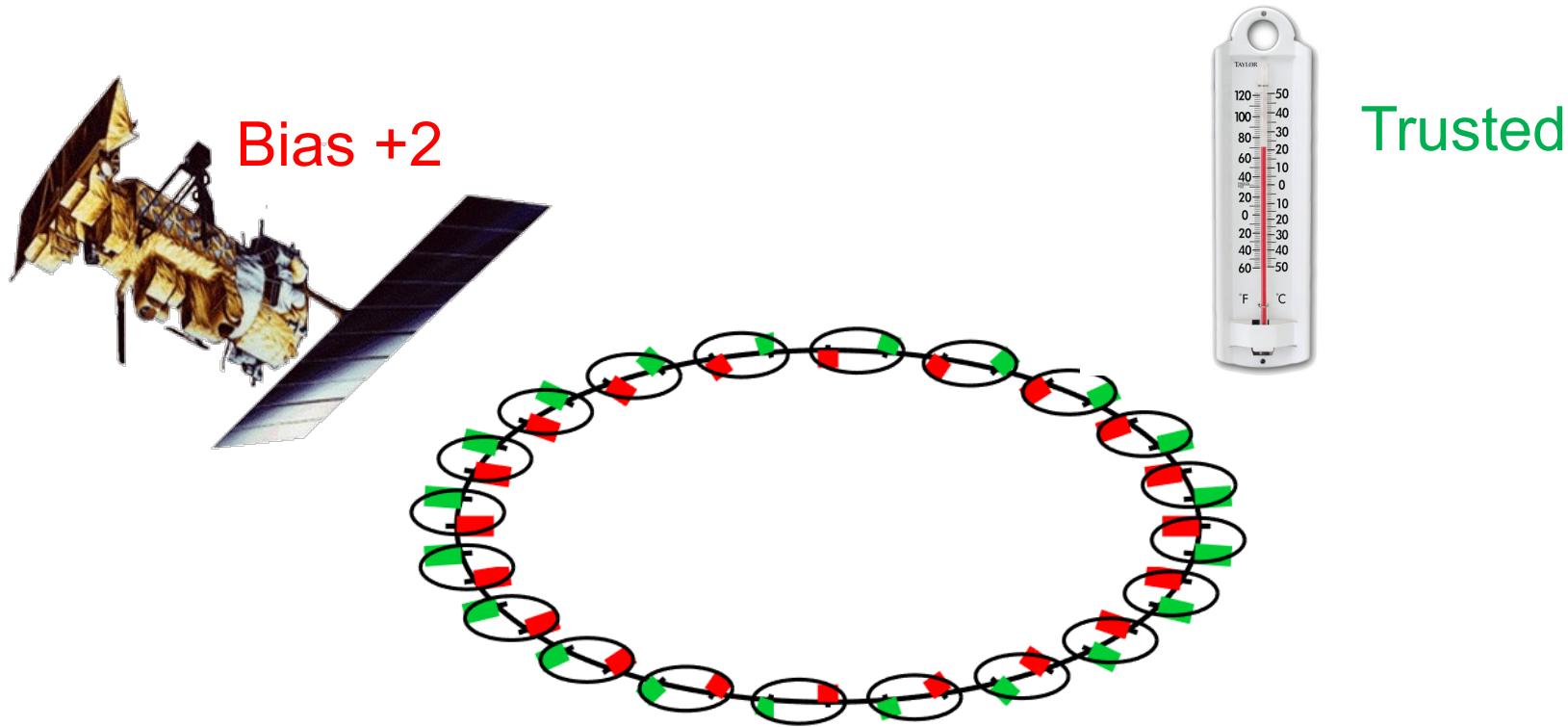
Can this work for obs with different locations, or types?

20 Offset Obs from Each Instrument



Instrument with +2 bias.
Trusted Instrument.

20 Offset Obs from Each Instrument: Difference Obs.



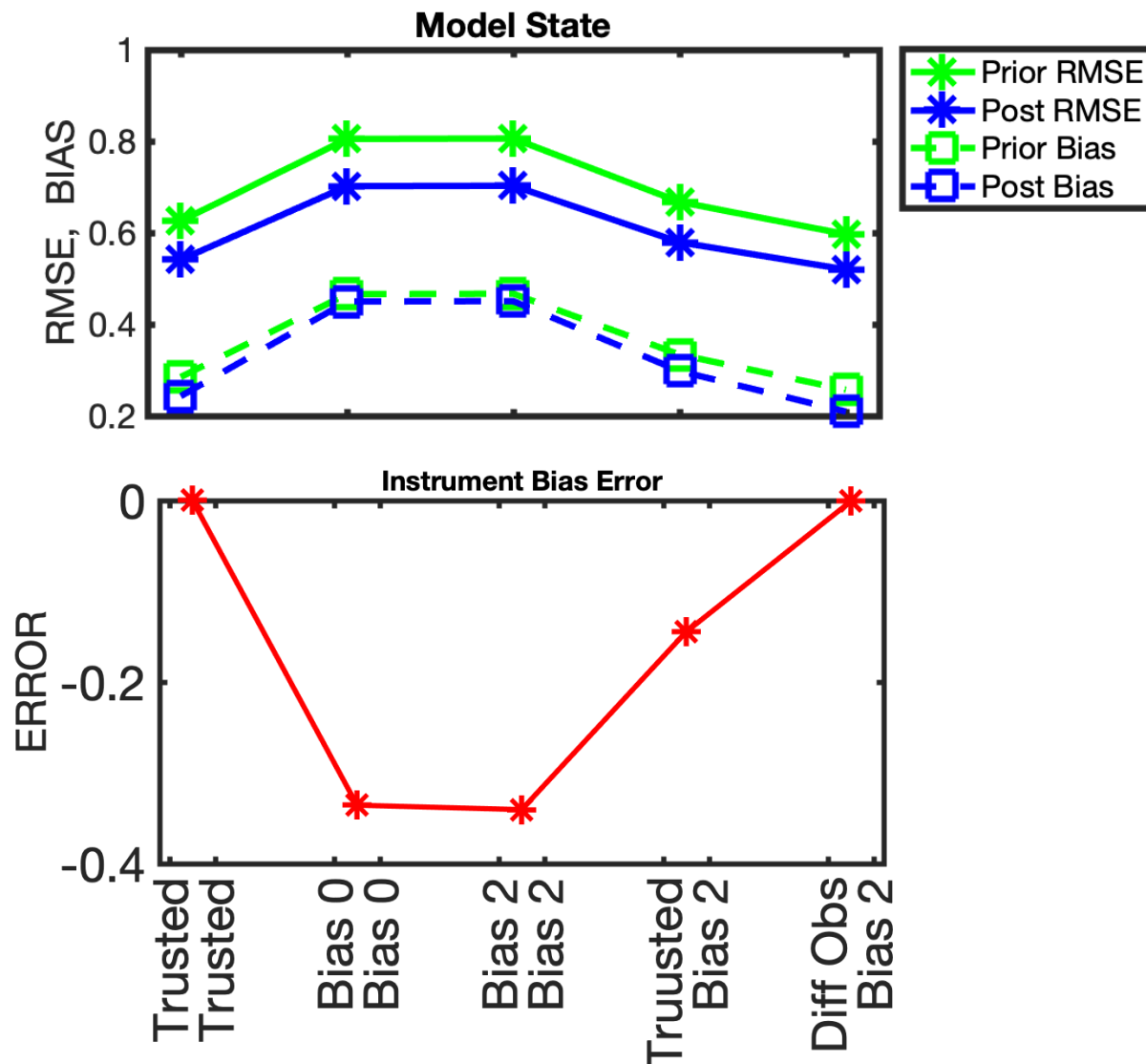
Instrument with +2 bias.
Trusted Instrument.

F=10 Imperfect Model: 20 Offset Obs from Each Instrument

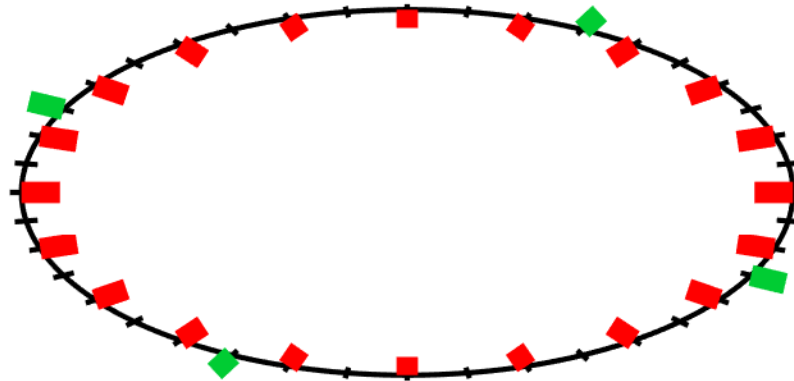
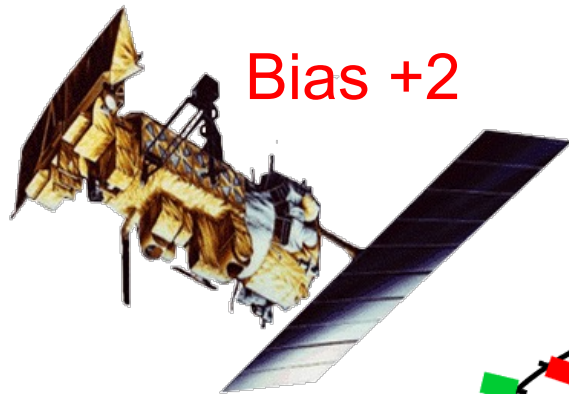
Difference obs still effective.

Uses model correlations for relation between the obs.

Errors in 2nd moment are now a concern.



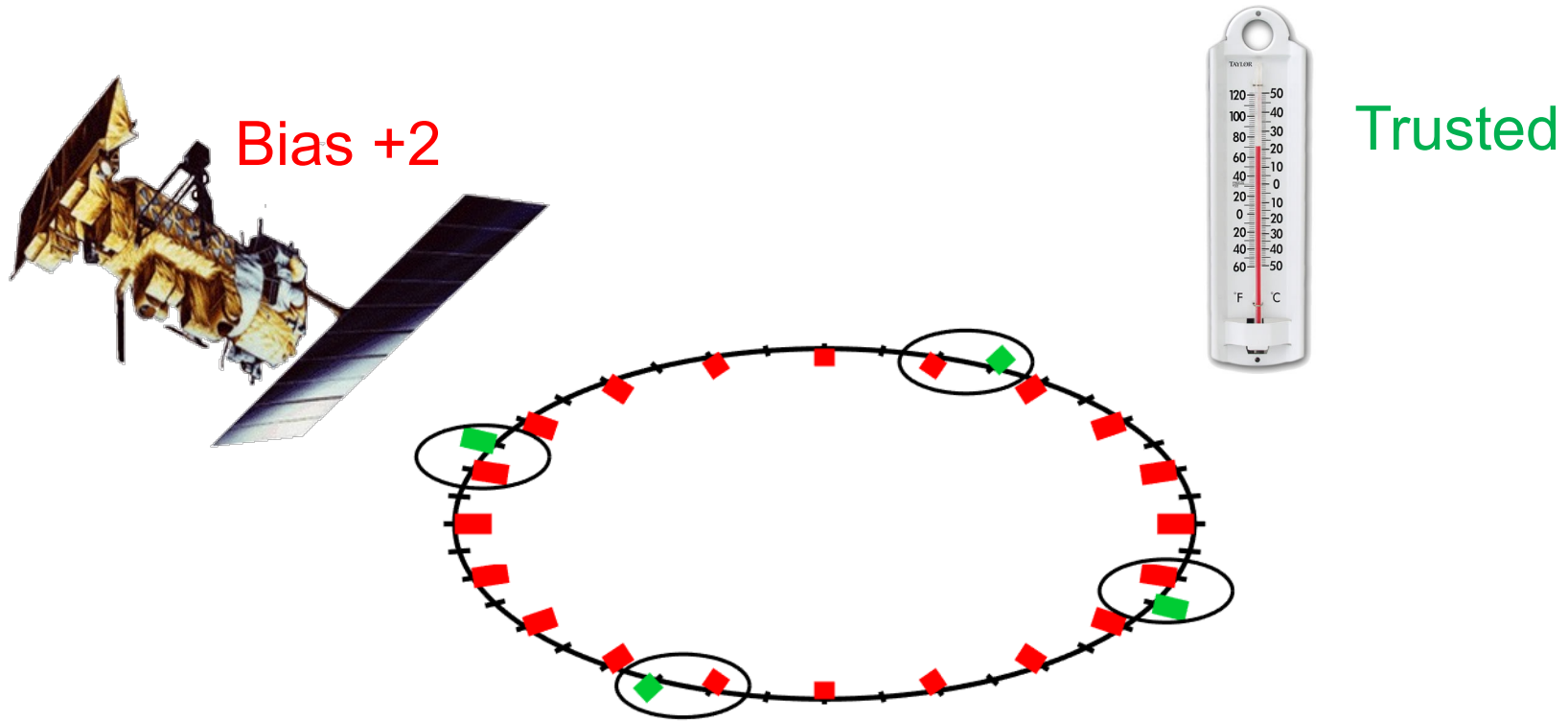
4 Trusted Obs, 20 Offset biased Obs



Trusted

Instrument with +2 bias.
Trusted Instrument.

4 Trusted Obs, 20 Offset biased Obs: Difference Obs



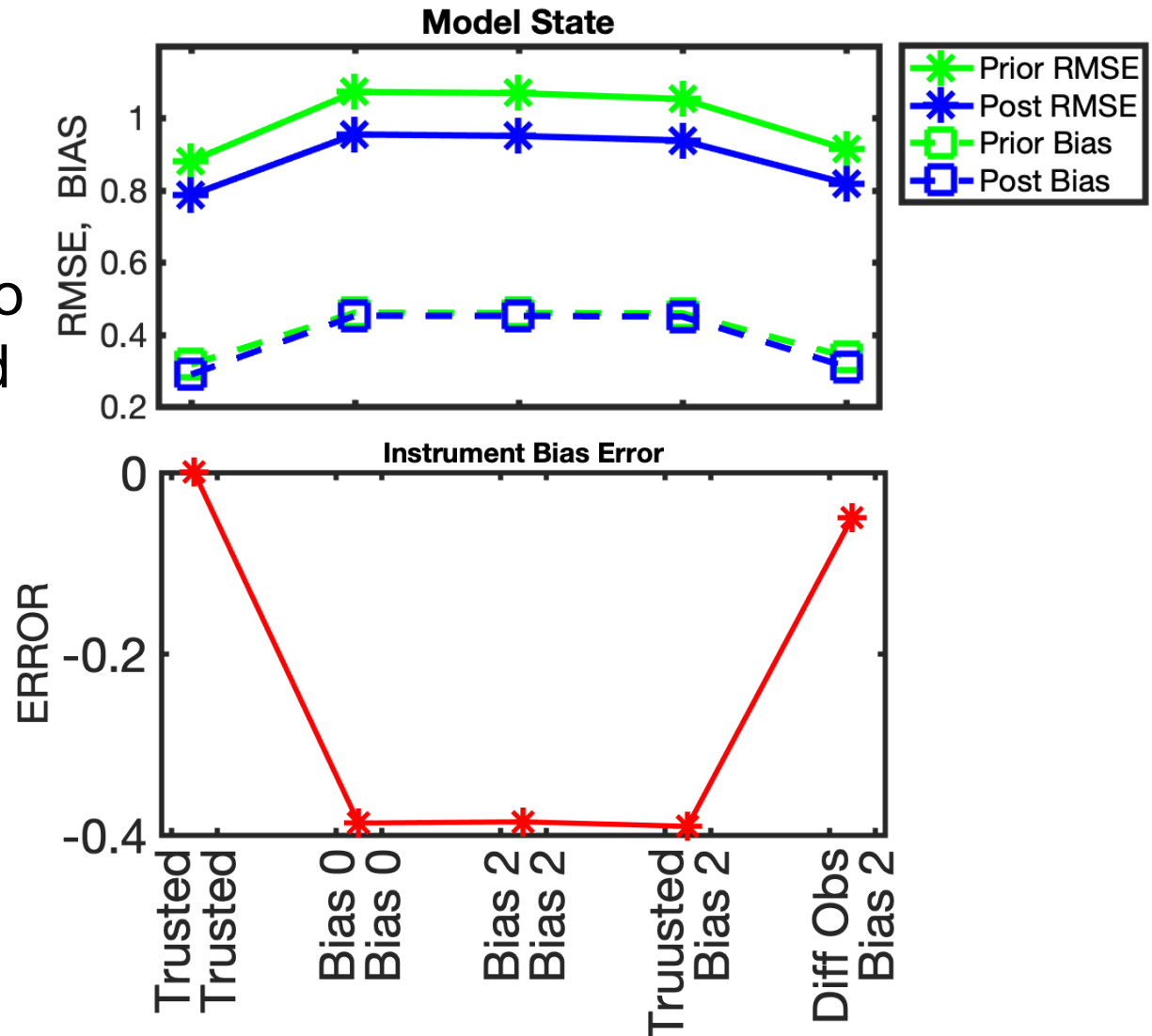
Instrument with +2 bias.
Trusted Instrument.

F=10 Imperfect Model: 4/20 Observations

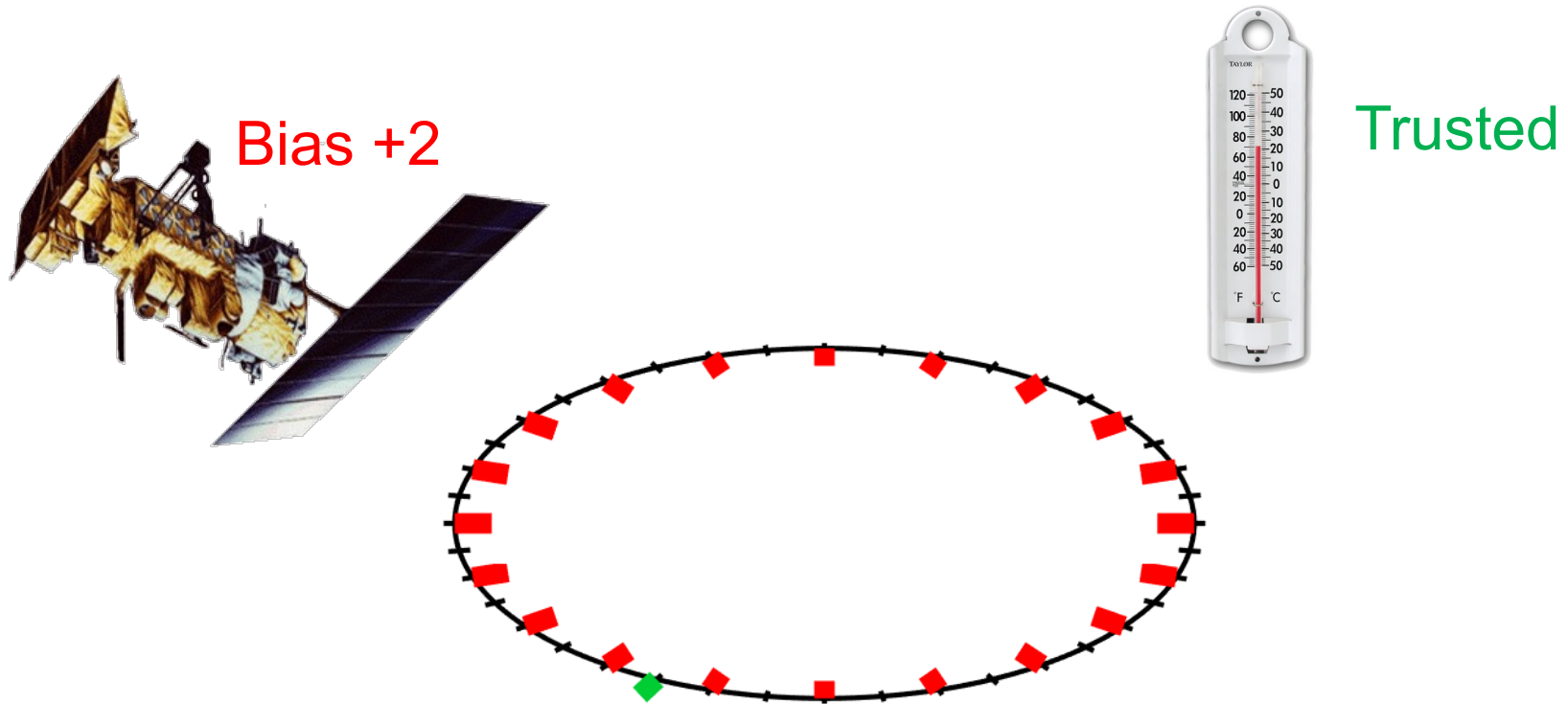
Difference obs still effective.

Only 4 compared to 20 obs from biased instrument.

Losing information?

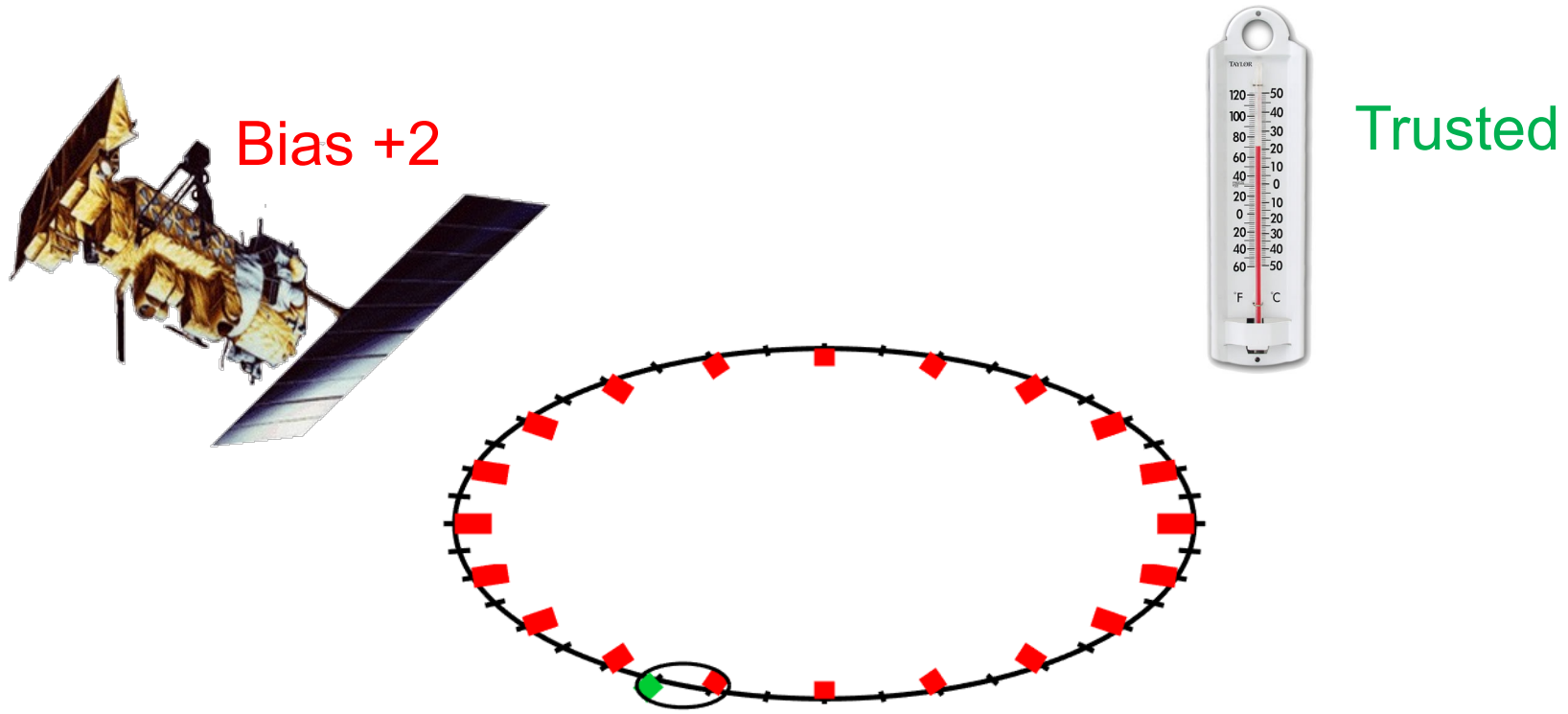


1 Trusted Obs, 20 Offset biased Obs



Instrument with +2 bias.
Trusted Instrument.

1 Trusted Obs, 20 Offset biased Obs



Instrument with +2 bias.
Trusted Instrument.

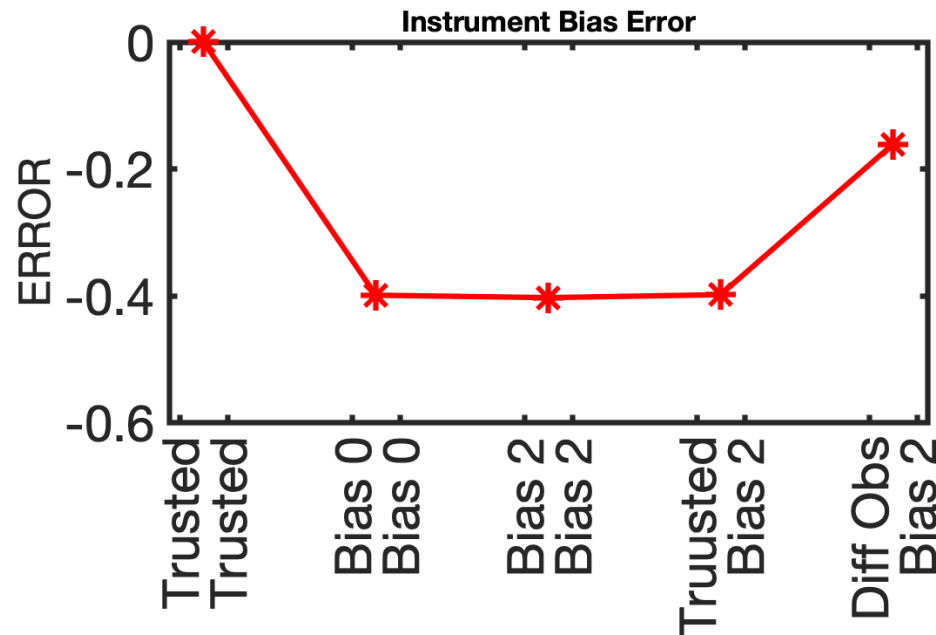
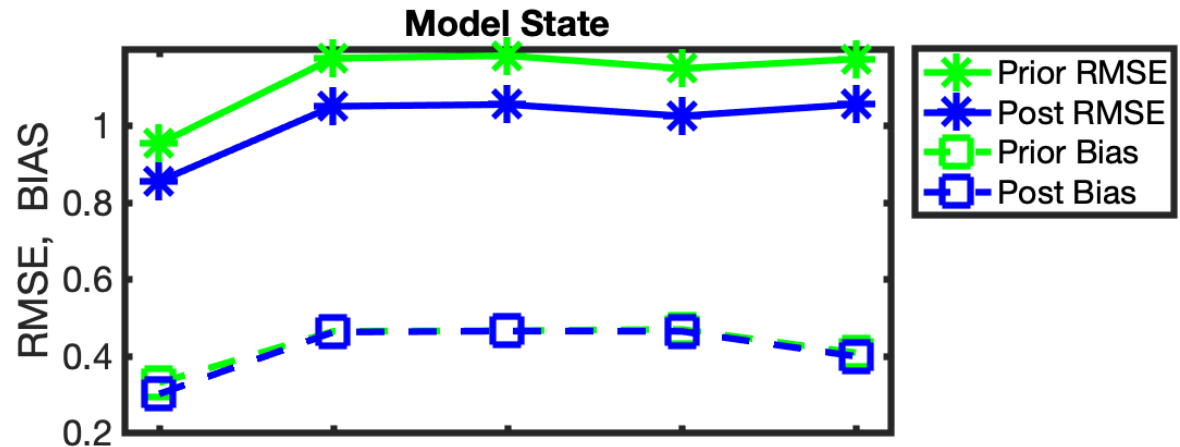
F=10 Imperfect Model: 4/20 Observations

Difference obs less effective.

Better estimate of other instruments bias.

Effect on state variables limited.

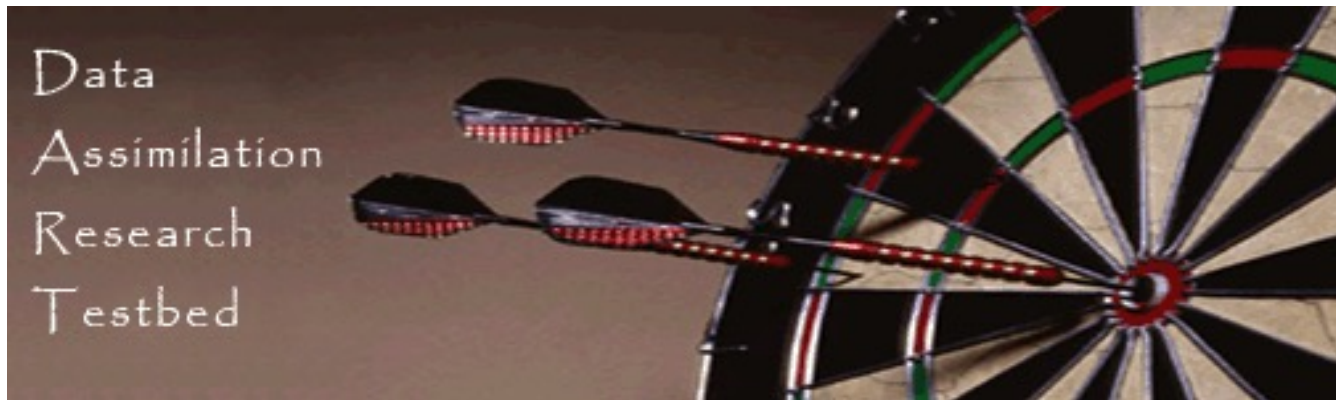
Need to use the other 19 biased obs, but correlated errors!



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

Anderson, J., Hoar, T., Raeder, K., Liu, H., Collins, N., Torn, R., Arellano, A.,
2009: *The Data Assimilation Research Testbed: A community facility.*
BAMS, **90**, 1283—1296, doi: 10.1175/2009BAMS2618.1