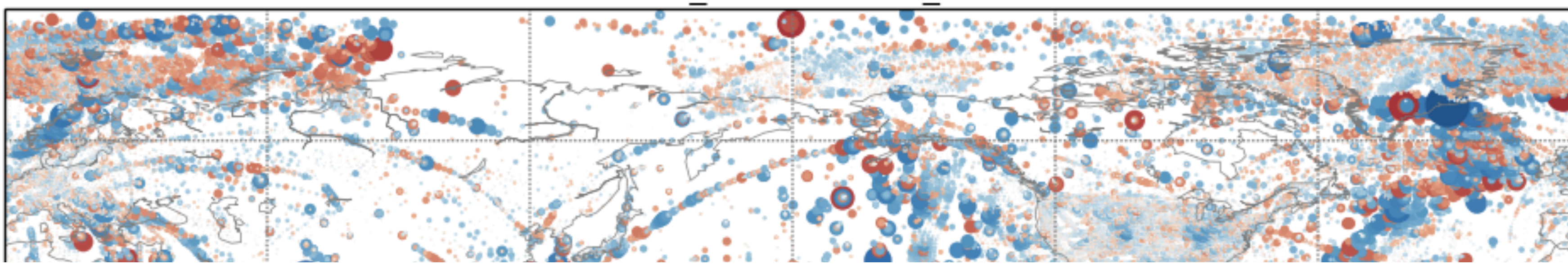
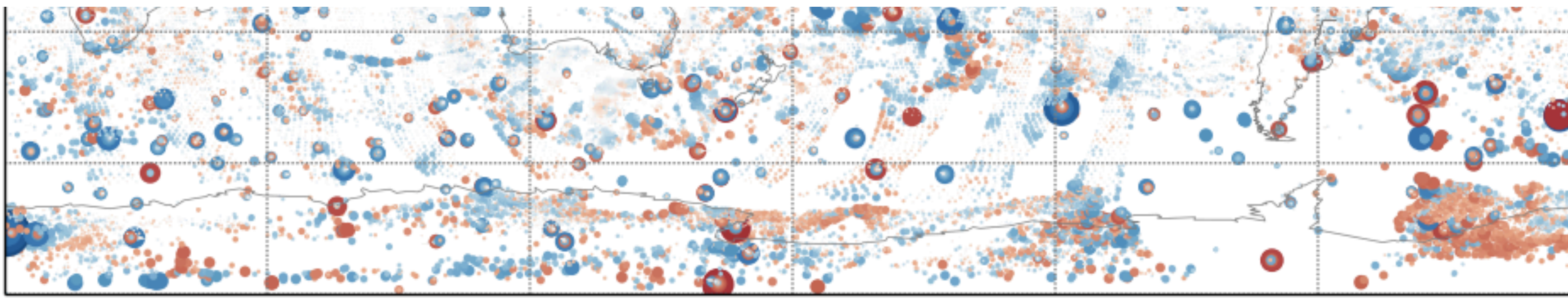


Proactive Quality Control to Improve NWP, Reanalysis, and Observations



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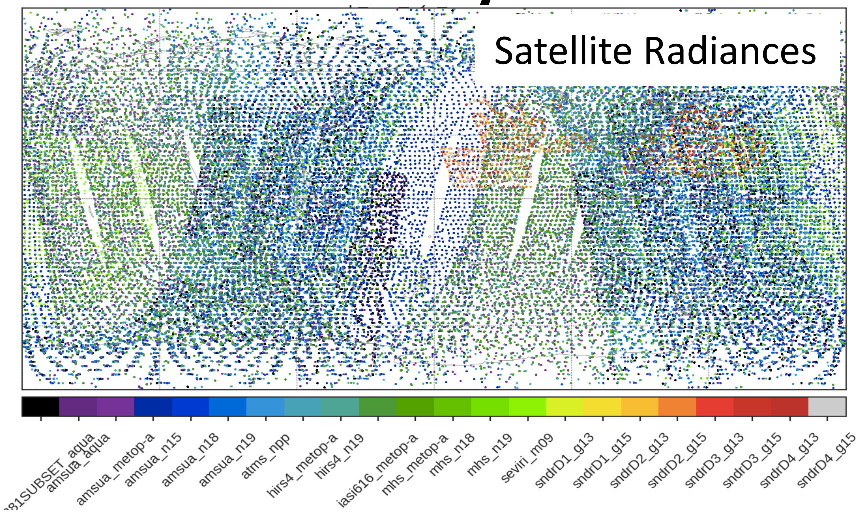
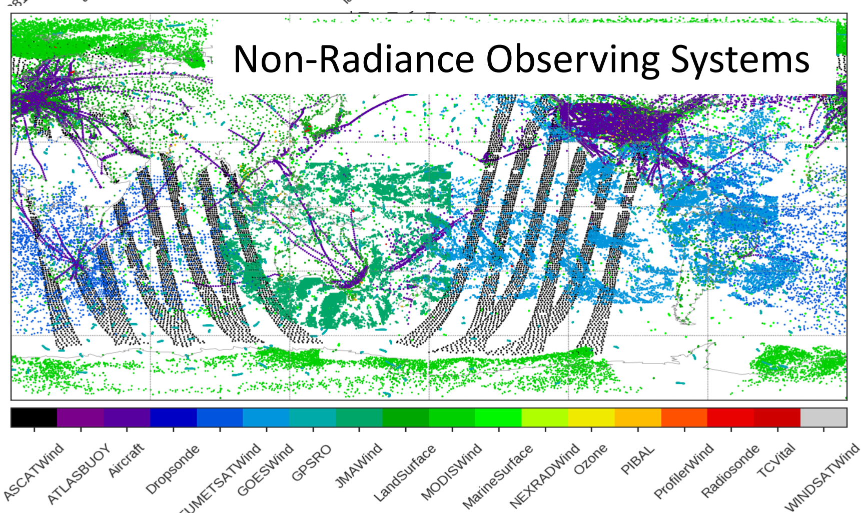
University of Maryland

Acknowledgements to Daisuke Hotta, Jim Jung, Daryl Kleist, Guo-Yuan Lien, Yoichiro Ota, Cheng Da, Takemasa Miyoshi, David Santek, Brett Hoover, Alpert Jordan and Krishna Kumar.

Massive Amount of Observations

More than 10^6 of observations assimilated every 6 hours





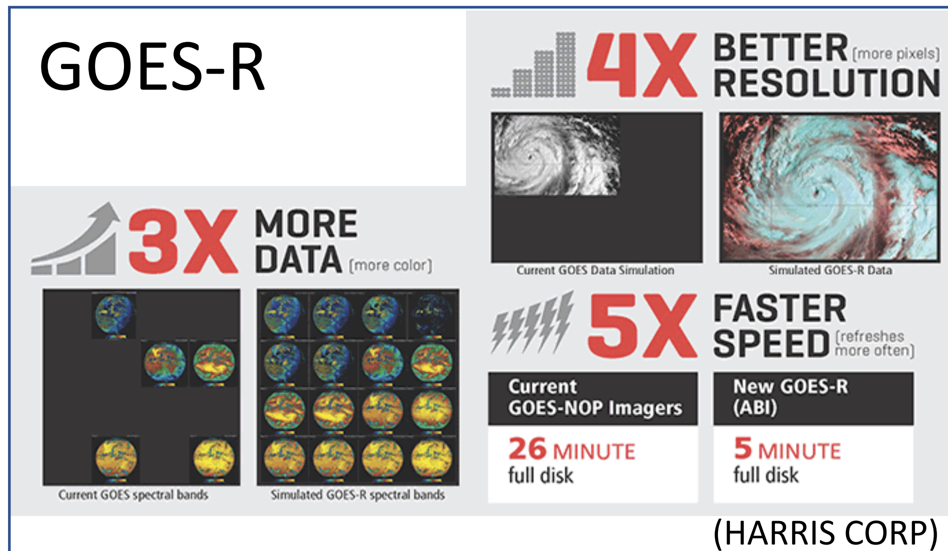
and more on the way….

Next generation satellites

- **50X** more data
- GOES R, S, T, U and Himawari 8, 9

Phase array radar

- **60X** more data
- USA, Japan



How to efficiently evaluate the impacts of all of them?

Evaluating Observation Impact

Observing System Experiments (OSEs):

- Comparing forecasts w/ and w/o a set of observations
- Direct approach to evaluate the observational impact
- Low discernibility, Computationally expensive

Forecast Sensitivity to Observations (FSO):

- Langland and Baker (2004)
- Computationally economical
- Require adjoint model (inconsistent in representing moist processes.)

Ensemble FSO (EFSO):

- Kalnay et al. (2012)
- Estimates impact of each observation all at once
- Computationally **economical**, Free of adjoint model
- Require advection of localization

EFSO Formulation

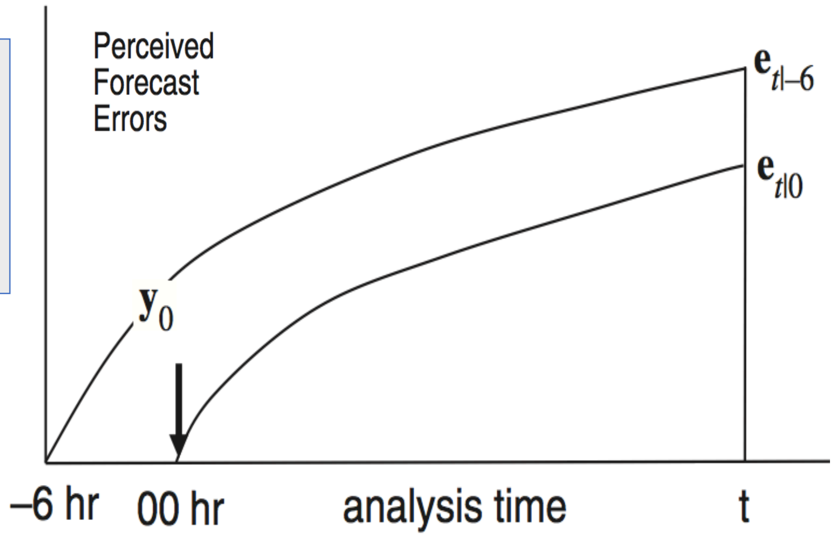
$$\Delta e^2 = \mathbf{e}_{t|0}^T C \mathbf{e}_{t|0} - \mathbf{e}_{t|-6}^T C \mathbf{e}_{t|-6}$$
$$\approx \frac{1}{K-1} \delta \mathbf{y}_0^T \mathbf{R}^{-1} \mathbf{Y}_0^a \mathbf{X}_{t|0}^{fT} C(\mathbf{e}_{t|0} + \mathbf{e}_{t|-6})$$

O-B of the ens. mean

Forecast perturbation

Analysis perturbation in obs. space

(Kalnay et al., 2012)

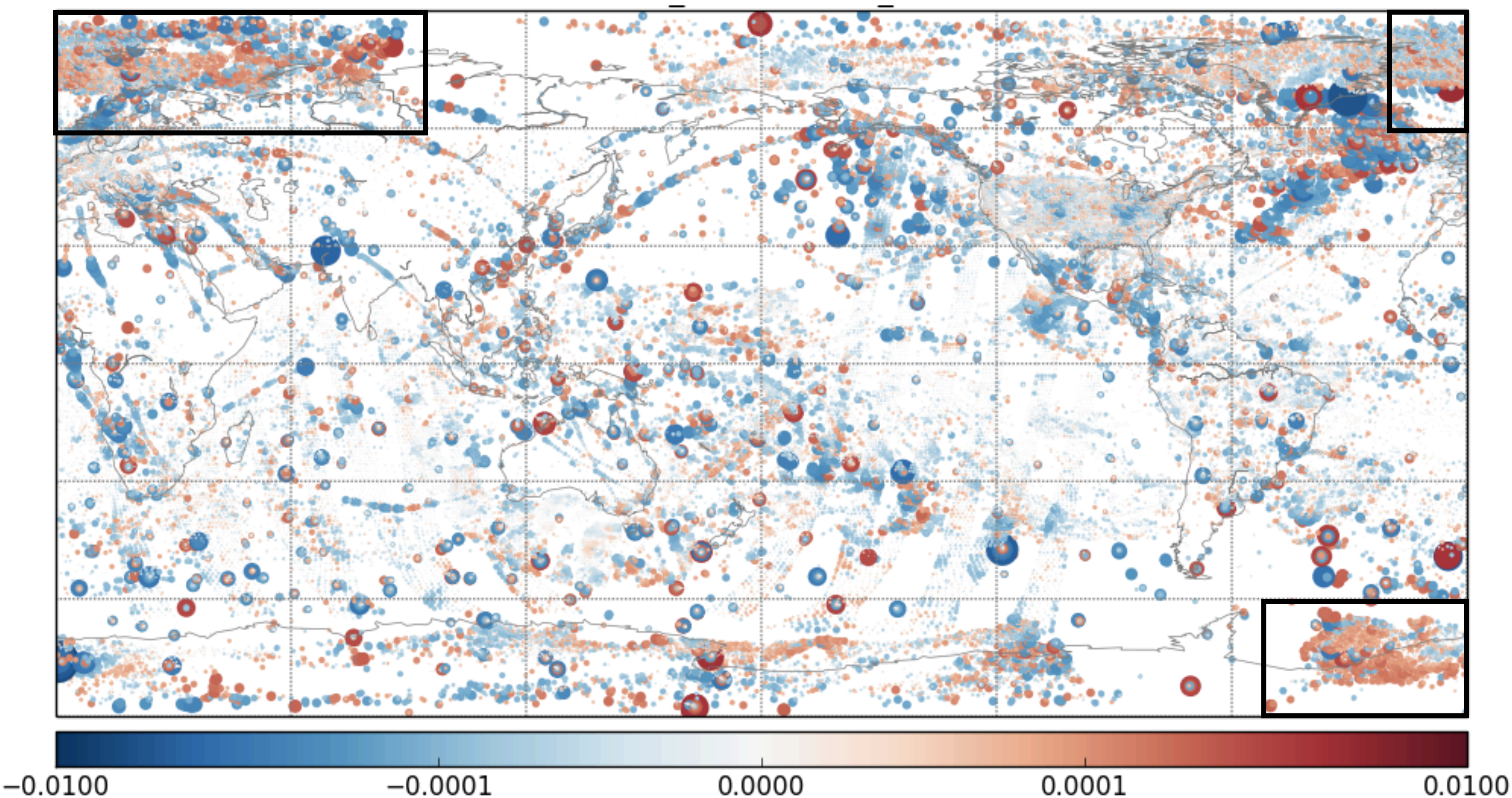


- **Quantifies** how much **each observation** improves or degrades model forecasts.
- A **linear mapping** from error changes to each observations.
- **Negative value**: error reduction/ **beneficial** observation
- **Positive value**: error growth/ **detrimental** observation

Experimental Setup

Period (1 month)	Jan/10/2012 00Z – Feb/09/2012 18Z
Model	GFS T254/T126 L64
DA	LETKF/3D-Var Hybrid GSI v2012
Localization cut-off length	2000 km/ 2 scale heights
Error norm	Moist total energy (MTE) $MTE = \frac{1}{2}\frac{1}{\|S\|}\int_S \int_0^1 \{(u'^2 + v'^2) + \frac{C_p}{T_r}T'^2 + \frac{R_d T_r}{P_r^2}p_s'^2 + w_q \frac{L^2}{C_p T_r} q'^2\} d\sigma dS$

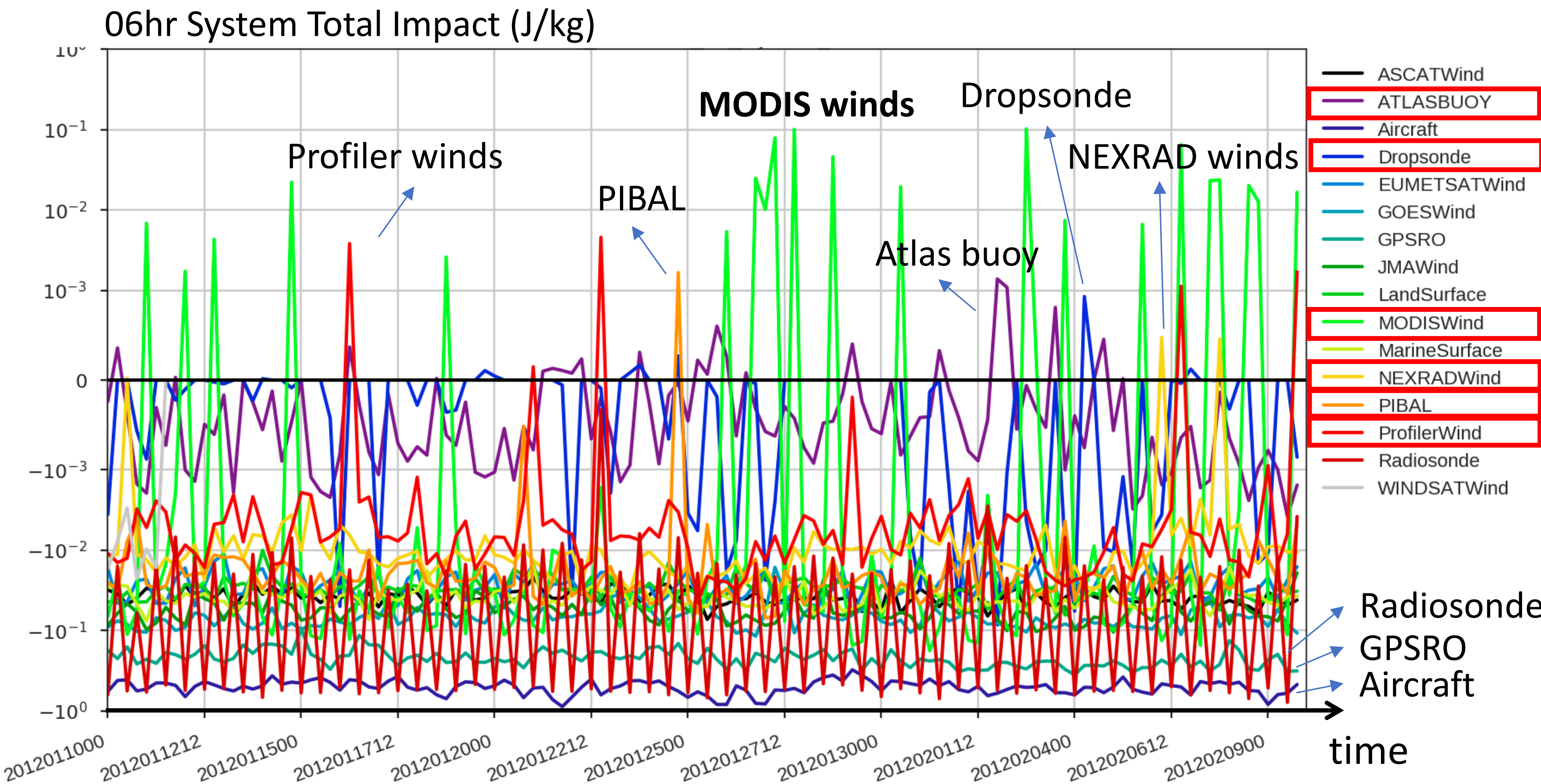
Clustered Detrimental Observations



Regions (black boxes) with clusters of **detrimental (red)** observations.

Case: Feb/06/2012 18Z
Color: 06hr MTE impact (J/kg)
Size: Magnitude of impact

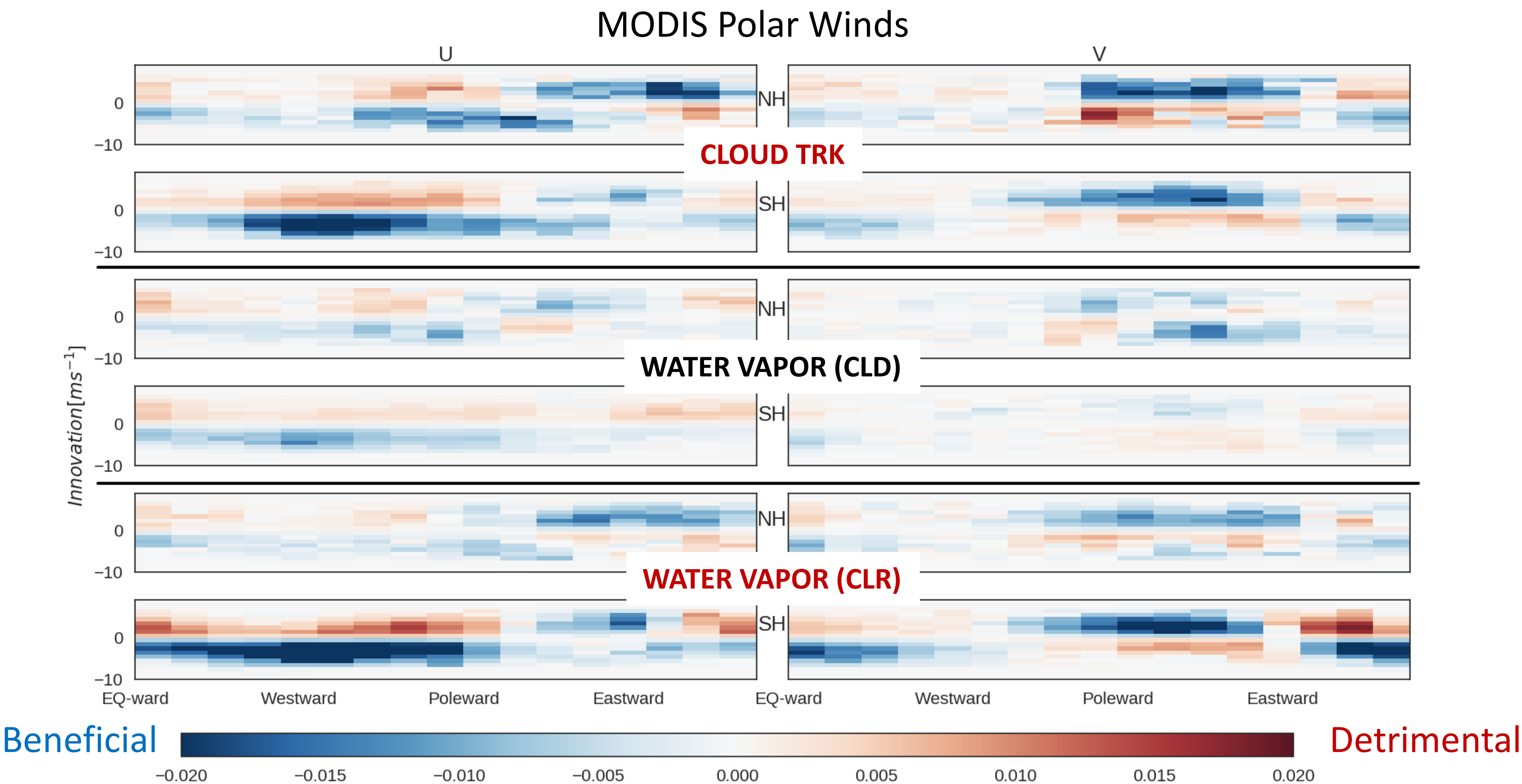
Detrimental Episodes



Detrimental episodes in some observing systems.

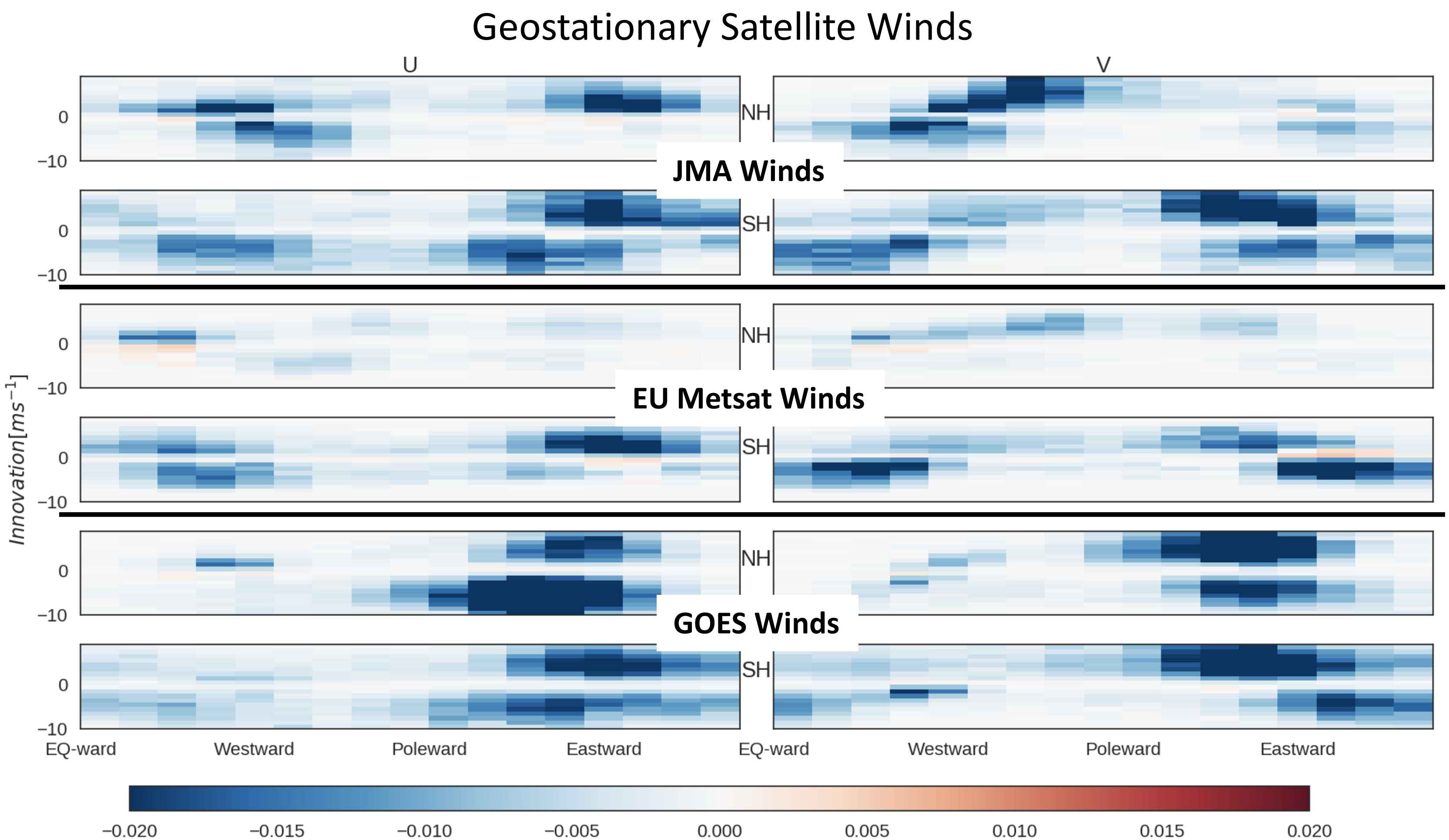
MODIS polar winds is one of the contributors.

Biases: Innovation and Wind Direction



- Prevailing **positive innovation bias** in U comp.
- Cloud tracking winds (top) and Water vapor tracking (bottom) resemble each other in both hemisphere

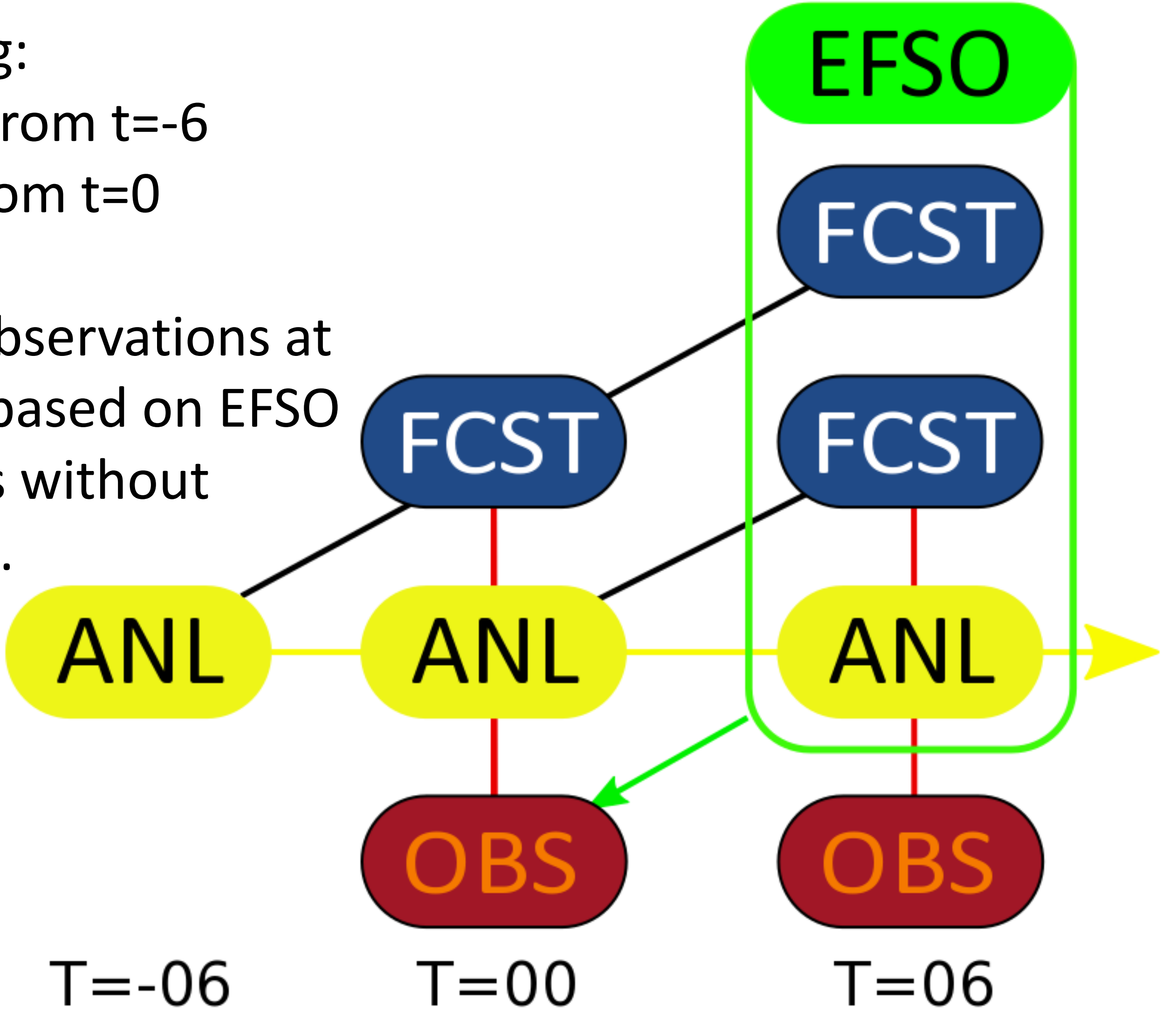
Biases: Innovation and Wind Direction



- No such biases for Geostationary Satellite Winds

PQC Algorithm

1. Perform EFSO using:
    1. 12-hr forecast from t=-6
    2. 6-hr forecast from t=0
    3. analysis at t=6
2. Determine set of observations at t=0 to be rejected based on EFSO
3. Repeat the analysis without those observations.



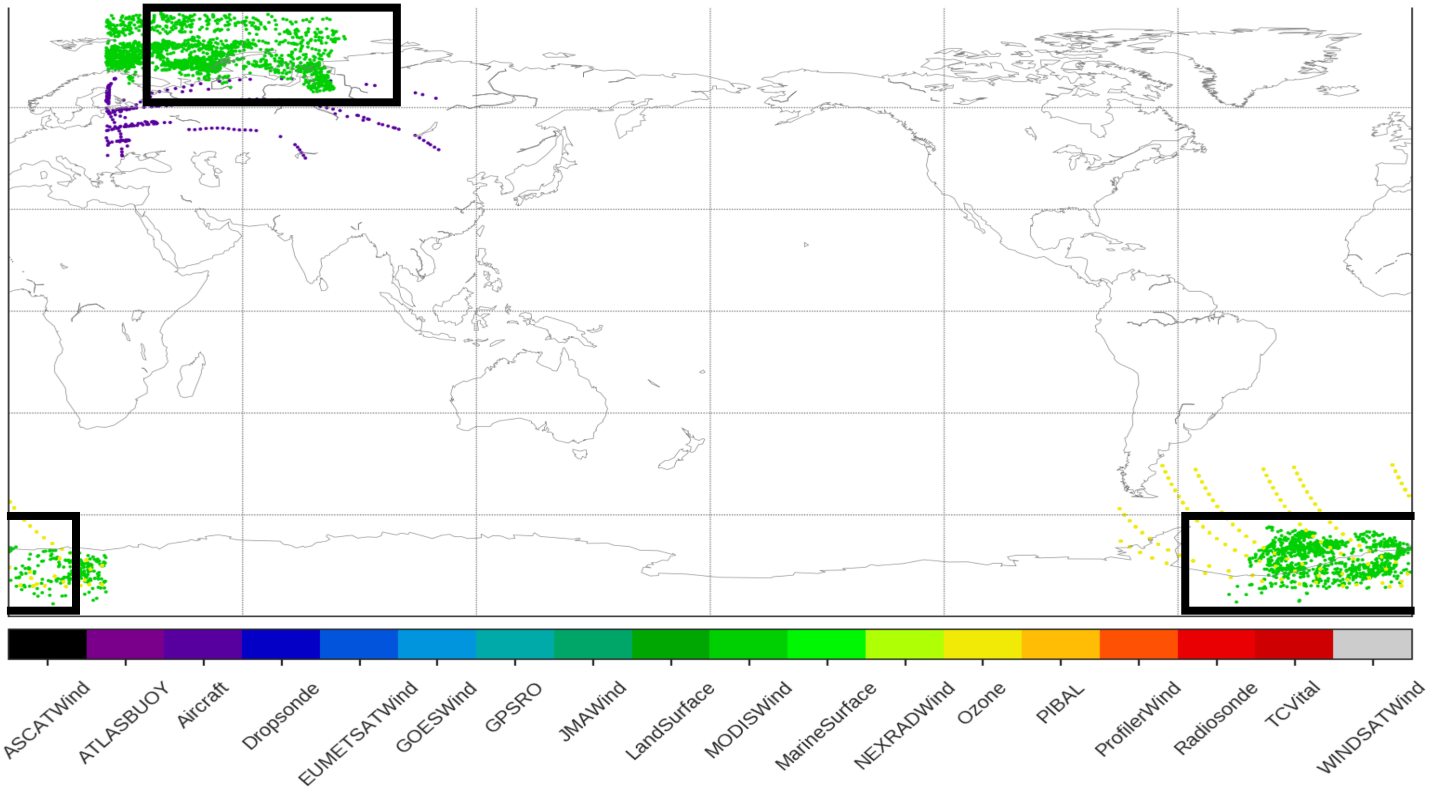
Adapted from Hotta (2017)

Three Data Denial Experiment Methods

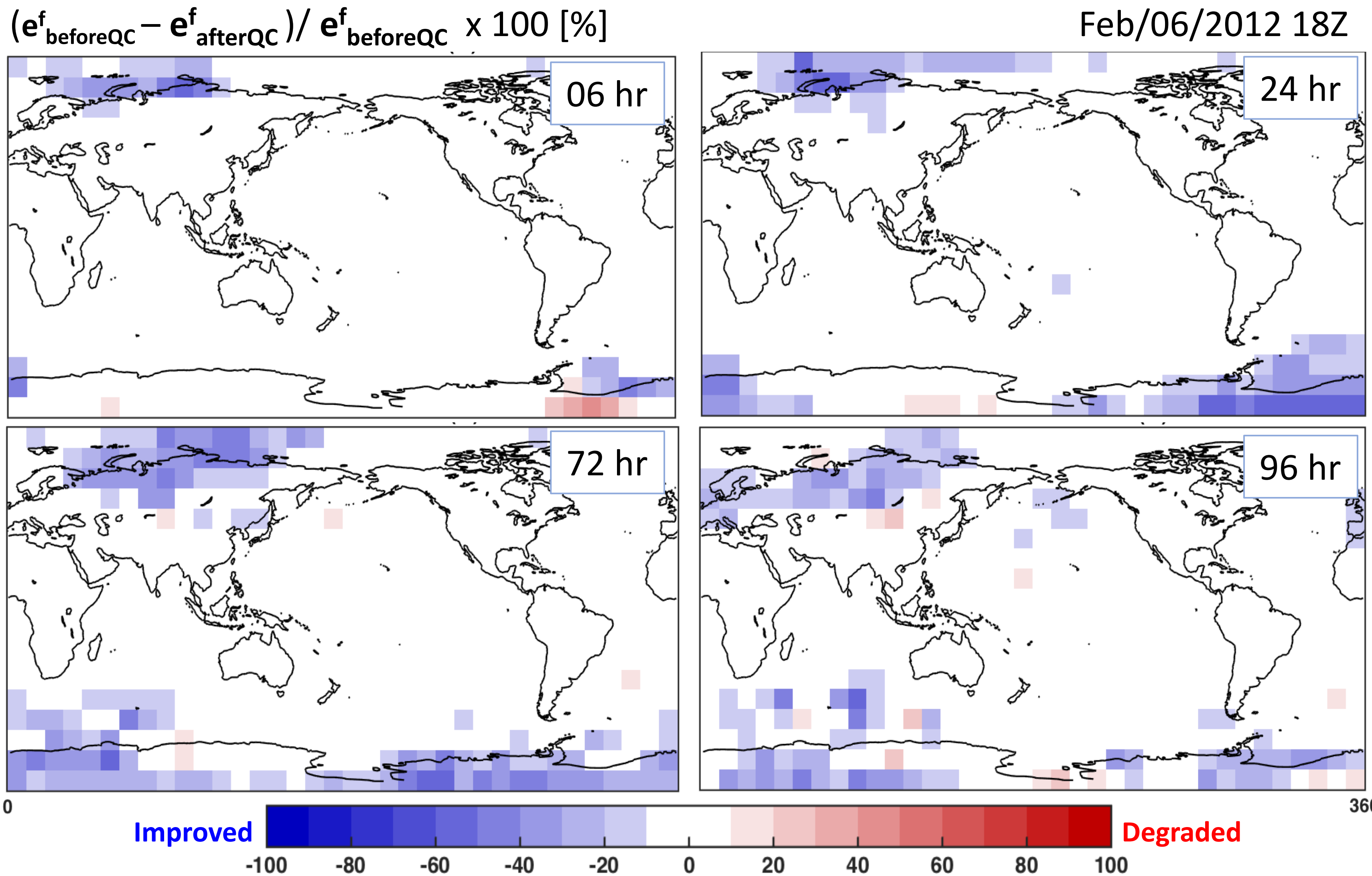
1. Hotta (from Hotta 2017 and Ota 2013)

- Identify **forecast error degradation regions**
- Perform EFSO w.r.t. those regions for 6-hr impact
- Reject detrimental observations only from the systems that have net detrimental impact.

Case: Feb/06/2012 18Z



1. Hotta Method: Impact on the Forecasts



Improved regions **strengthen** and **propagate** with weather system

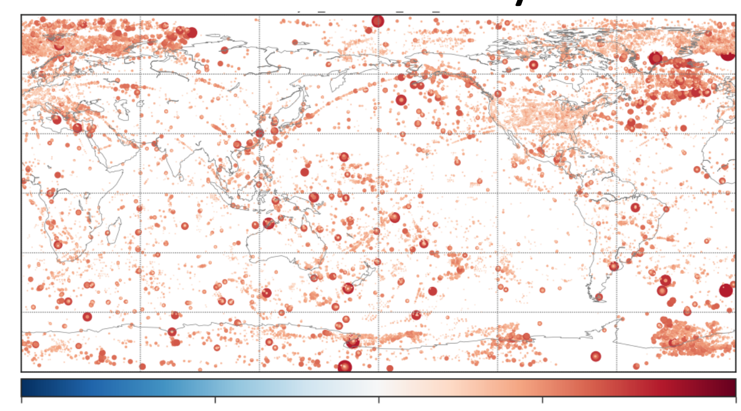
Three Data Denial Experiment Methods

2. **Threshold** (THR)

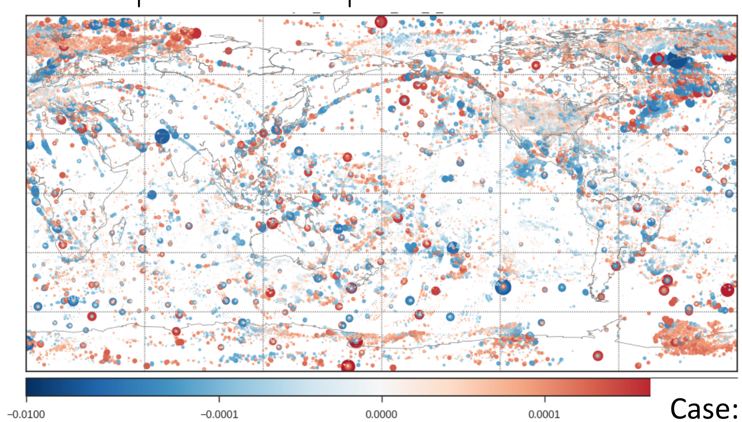
- Compute global EFSO for 06-hr impact of each observation
- Reject detrimental observations with a positive (detrimental) impact larger than a 10^-5 (J/kg) threshold.

3. **Beneficial Growing Mode** (BGM; reanalysis)

- Inspired by Trevisan (2010):
  Assimilation in Unstable Subspace (AUS)
- Compute the global EFSO for 06, 24-hr impact
- Assimilate only when: $\Delta e^2_{24|0} < \Delta e^2_{6|0} < 0$



Threshold: 37951 rejected

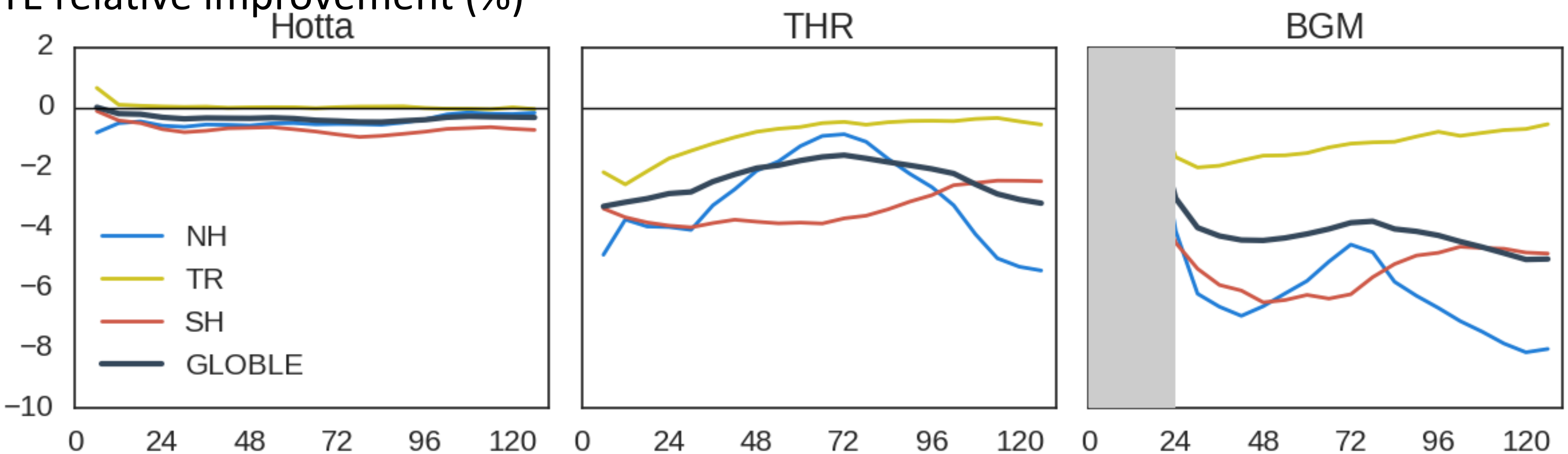


BGM: 287289 rejected

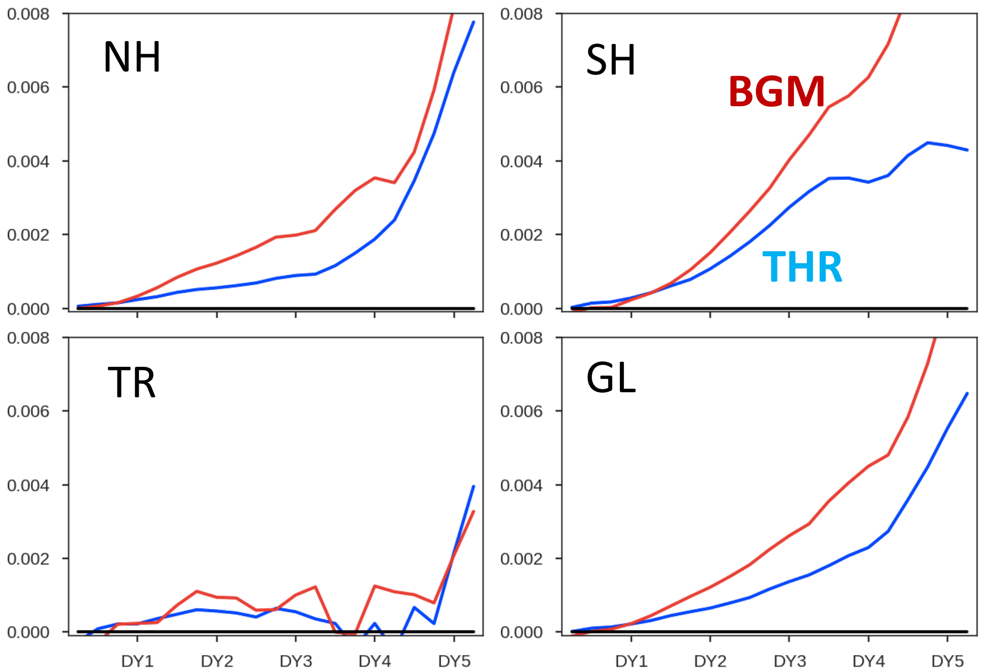
Case: Feb/06/2012 18Z
Color: 06hr MTE impact (J/kg)
Size: Magnitude of impact

Offline Experiment: 18 cases

MTE relative improvement (%)



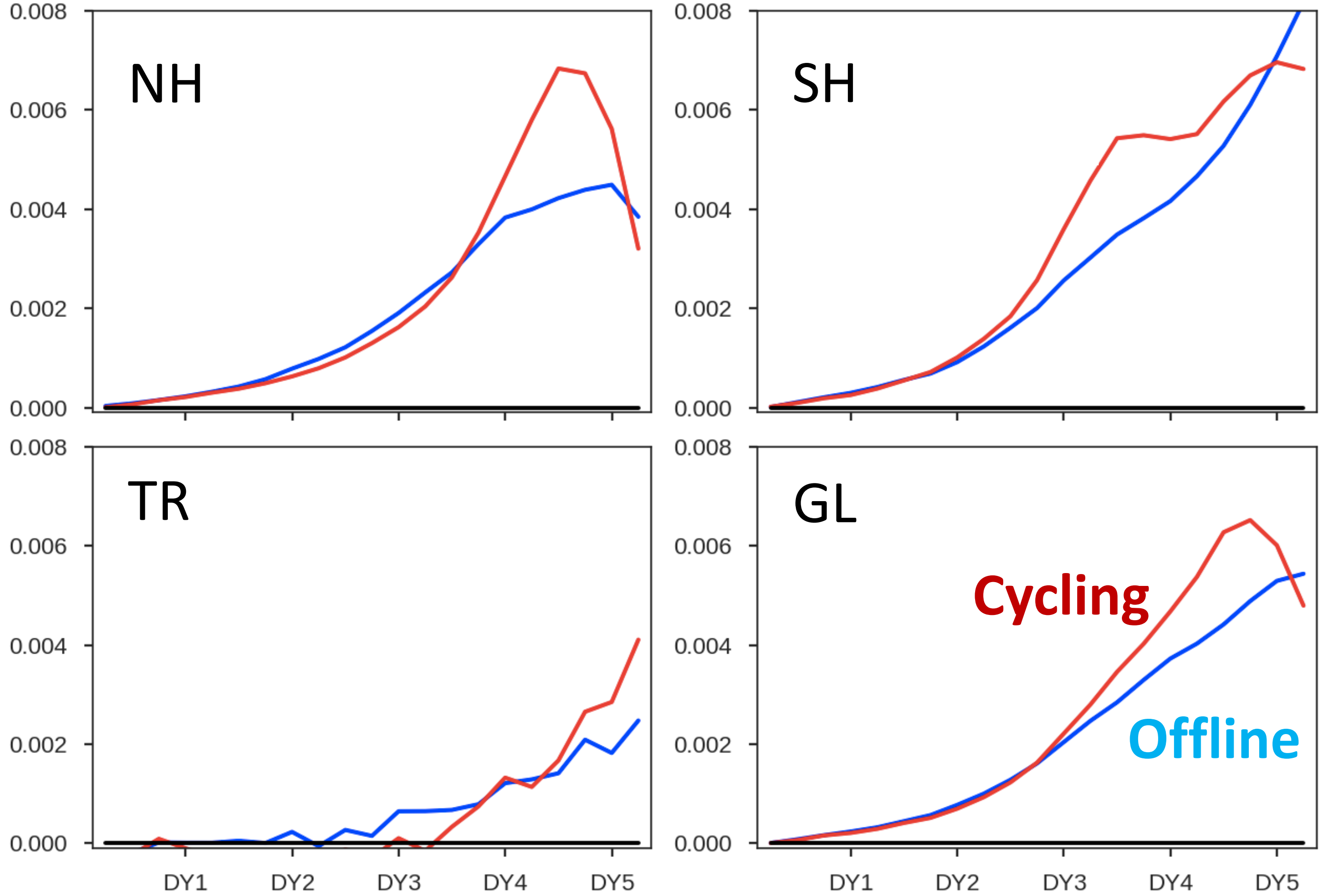
Z500 ACC Improvement: THR(blue) v.s. BGM(red):



- PQC corrects analysis and the subsequent forecast.
- All three methods improve model forecasts on average.
- The **BGM** and **THR** method have forecast improvements larger than **Hotta** method.

Cycling PQC Experiment: 40 cycles

Z500 ACC Improvement: Offline-THR(blue) v.s. Cycling-THR(red)



Improvement by **cycling PQC** maximizes around 3-5 day forecasts by accumulated beneficial effect of past PQCs.

Necessary Redoing Analysis?

Estimated PQC correction using **same Kalman gain K:**

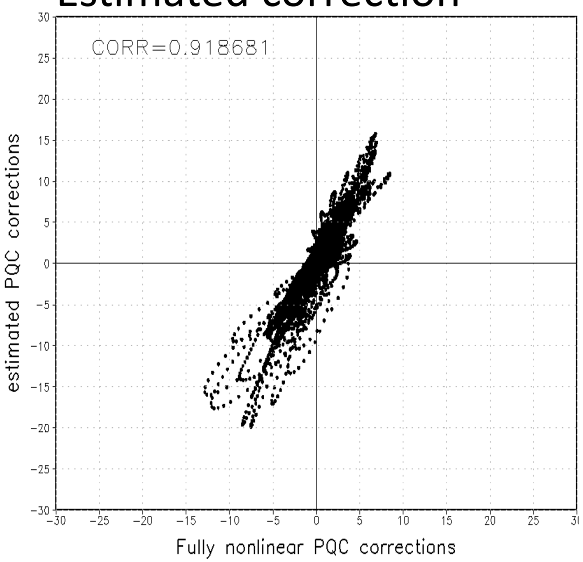
- K is actually depending on H, which is determined by observations

$$\bar{\mathbf{x}}_0^{a,\text{deny}} - \bar{\mathbf{x}}_0^{a} \approx -\mathbf{K}\delta\bar{\mathbf{y}}_0^{ob,\text{deny}}$$

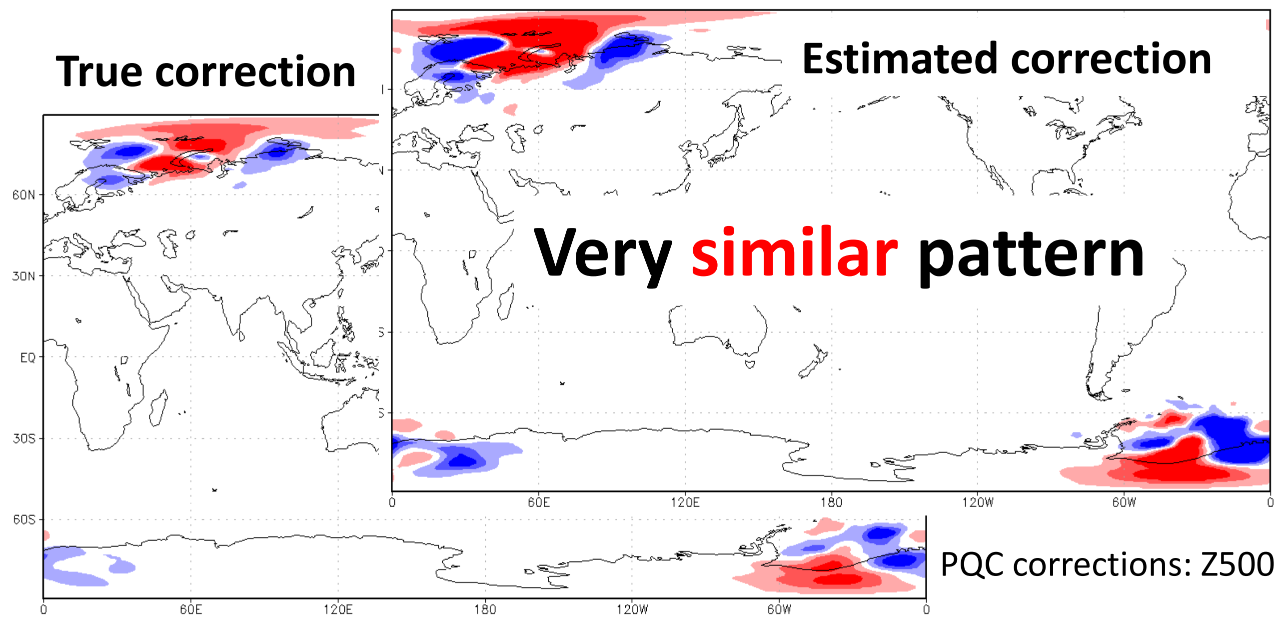
$$\mathbf{K} \approx \frac{1}{K-1}\mathbf{X}_0^{a}\mathbf{X}_0^{aT}\mathbf{H}^{T}\mathbf{R}^{-1} \approx \frac{1}{K-1}\mathbf{X}_0^{a}\mathbf{Y}_0^{aT}\mathbf{R}^{-1}$$

(Hotta, 2017)

True correction v.s.
Estimated correction



True correction



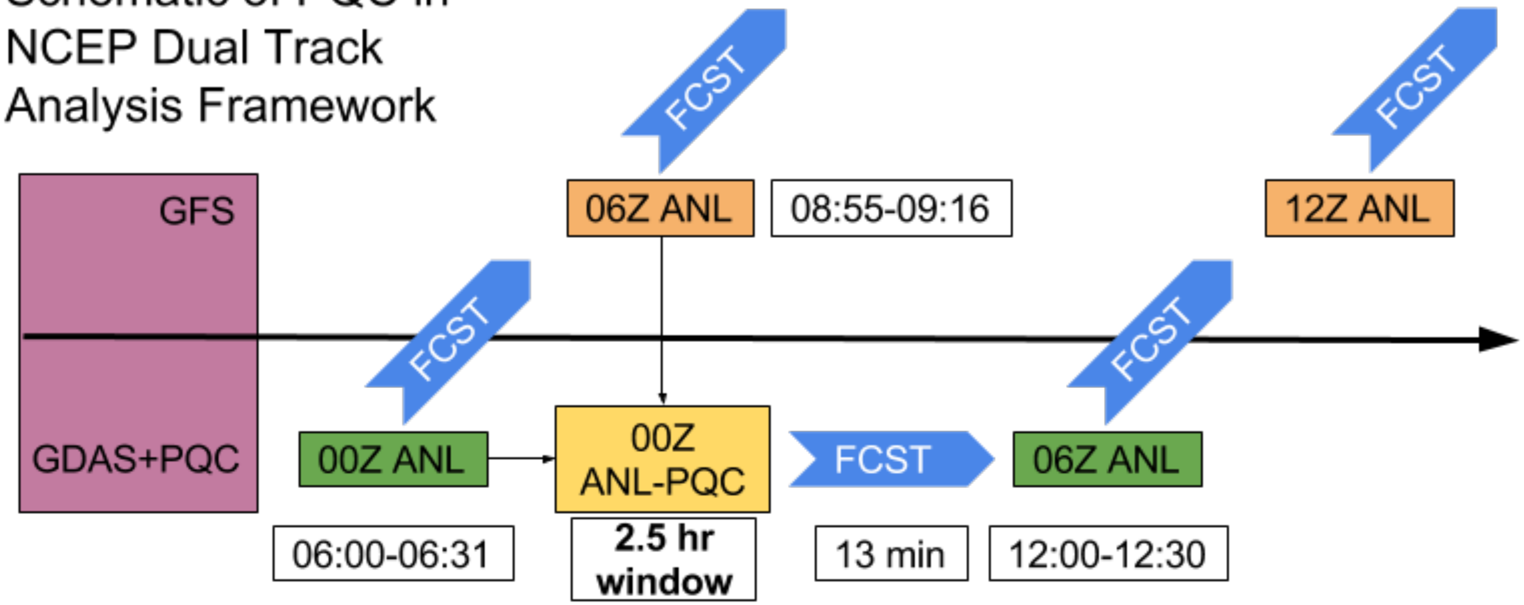
PQC corrections: Z500

PQC in NCEP Dual Track Analysis

Using **GFS-analysis** saves 3 hours of waiting

- PQC provides better **GDAS-analysis** product.
- The real-time **GFS-forecast** benefits from the PQC done **12** hours ago and the beneficial impact **accumulates** over each cycle.

Schematic of PQC in NCEP Dual Track Analysis Framework



Adapted from Hotta (2017)

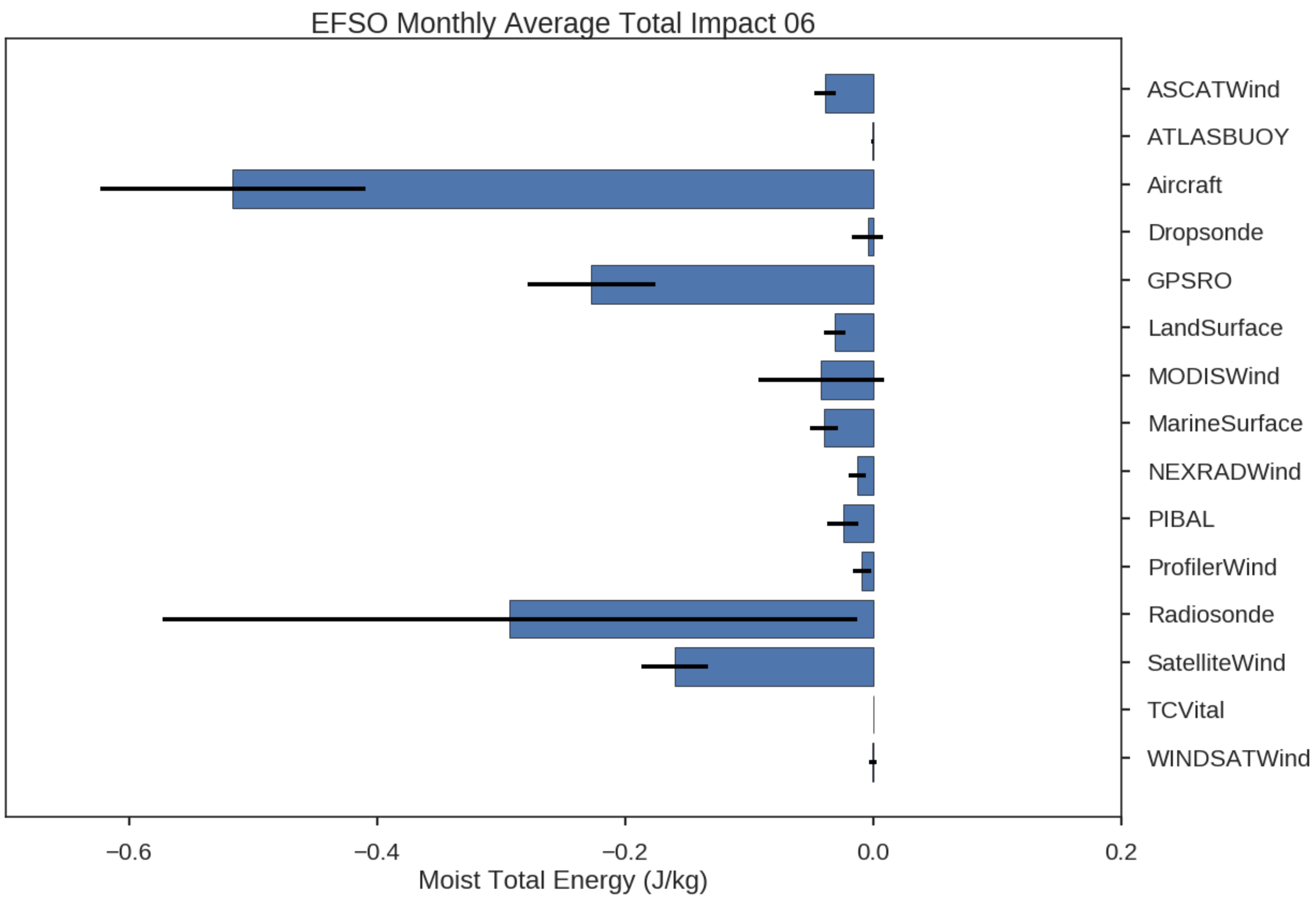
Summary

- EFSO is an efficient tool for:
  - Identifying detrimental observations
  - Online monitoring the impact on model forecast of assimilating each observation.
- PQC, affordable in operation, improves analysis and the subsequent forecast for up to 5 days.
- PQC-BGM allows doing assimilation within beneficial growing mode in reanalysis.

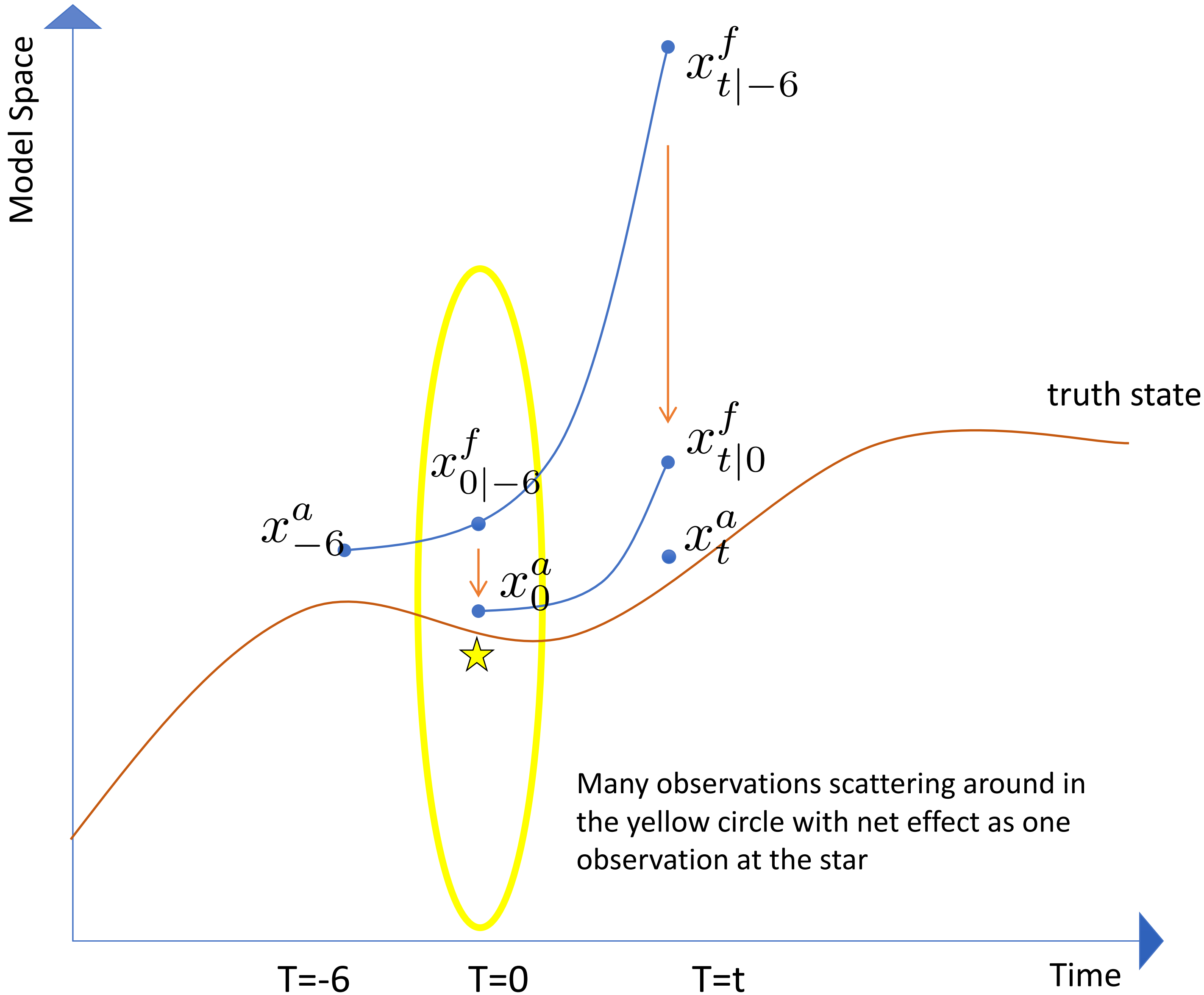
Thank you very much for your attention

Backup Slides

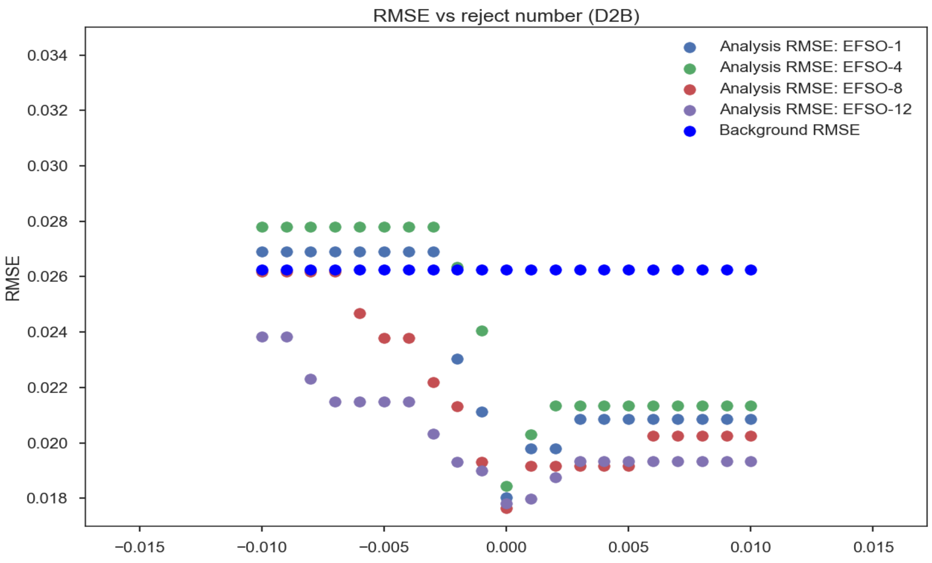
Total impact of each observing system

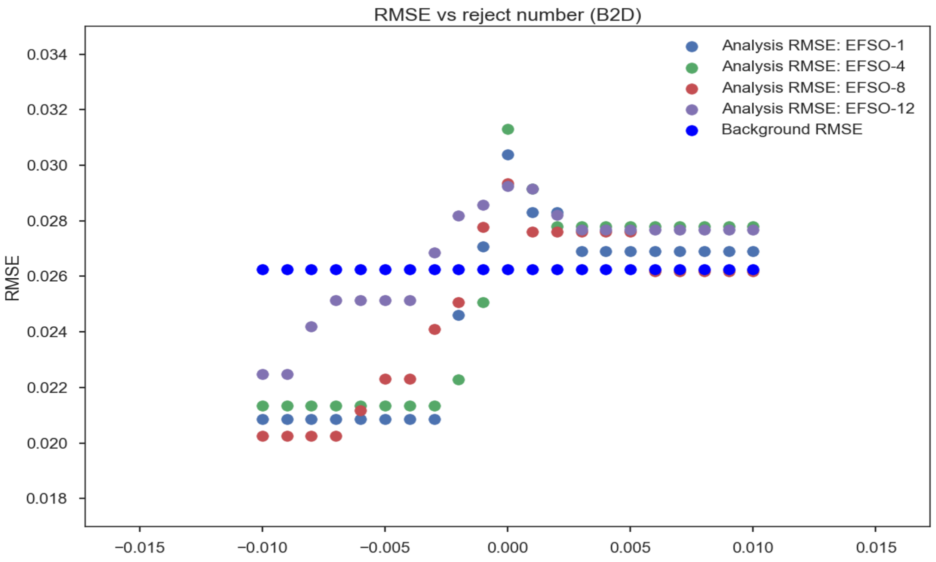


What is EFSO measuring?



PQC: reject-threshold





PQC: reject-number of obs.