Application of Ensemble Forecast Sensitivity to Observation (EFSO) Calculations Towards Targeted Aircraft Thinning Configurations

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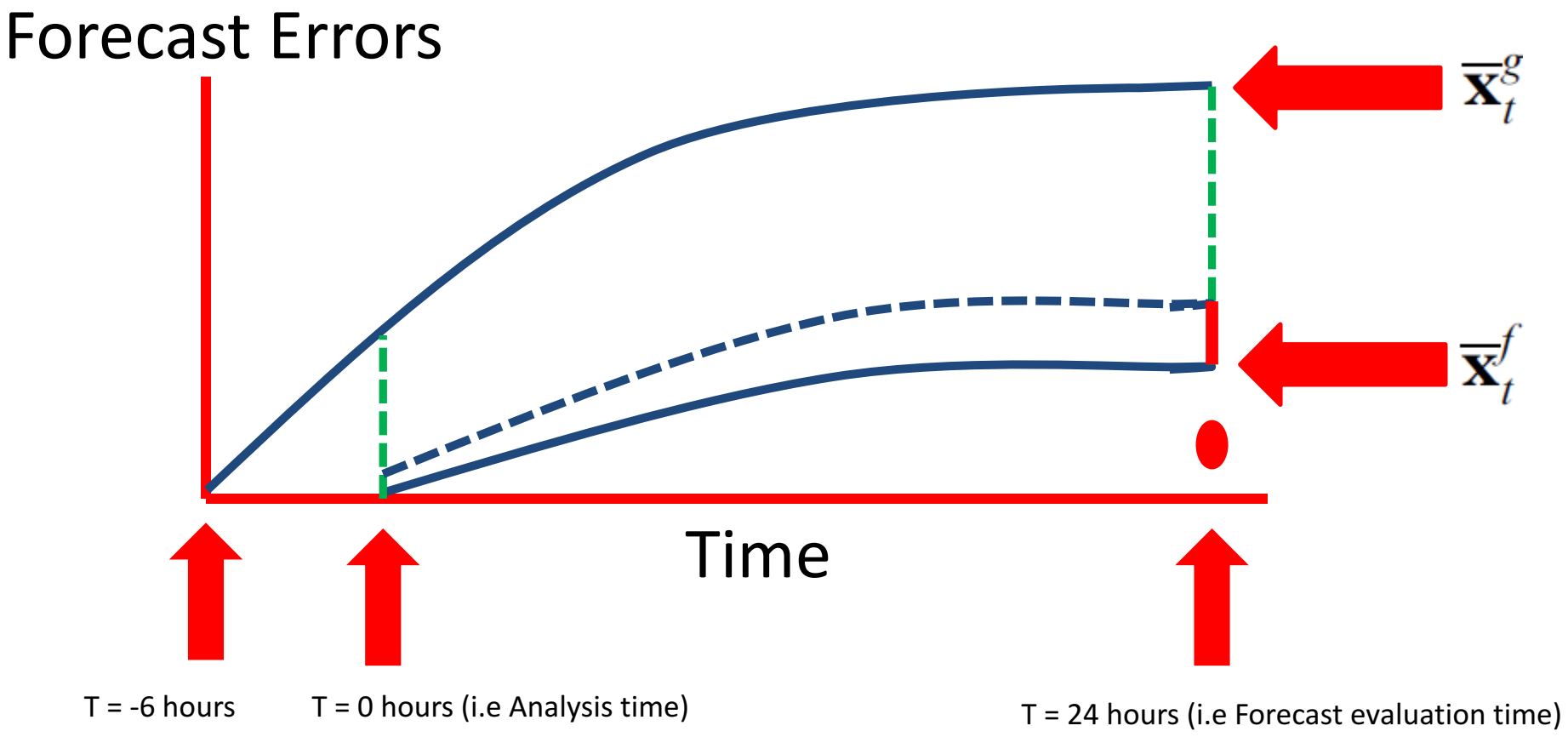
Outline

- Introduction to EFSO Concepts
- EFSO Components and Interpretation
- Preliminary EFSO Guidance Based on EnKF Products from a 4DEnVar GFS Cycling Experiment
- Summary of Preliminary Results

Introduction to EFSO Concepts

The EFSO Methodology



EFSO Related Forecast Error Definitions

Forecast Errors

$$\mathbf{e}_t^f \equiv \overline{\mathbf{x}}_t^f - \mathbf{x}_t^{\text{truth}}, \quad \mathbf{e}_t^g \equiv \overline{\mathbf{x}}_t^g - \mathbf{x}_t^{\text{truth}}$$

Quadratic Error Reduction

$$\Delta e_t^{f-g} \equiv \mathbf{e}_t^{f\mathbf{T}} C \mathbf{e}_t^f - \mathbf{e}_t^{g\mathbf{T}} C \mathbf{e}_t^g = \left(\mathbf{e}_t^f - \mathbf{e}_t^g\right)^{\mathbf{T}} C \left(\mathbf{e}_t^f + \mathbf{e}_t^g\right)$$

Forecast Error Difference

$$\mathbf{e}_t^f - \mathbf{e}_t^g = \overline{\mathbf{x}}_t^f - \overline{\mathbf{x}}_t^g$$

The EFSO Formulation

$$\Delta e_t^{f-g} \equiv \left(\mathbf{e}_t^f - \mathbf{e}_t^g\right)^{\mathbf{T}} C \left(\mathbf{e}_t^f + \mathbf{e}_t^g\right) \quad (1)$$

$$\mathbf{e}_t^f - \mathbf{e}_t^g = \overline{\mathbf{x}}_t^f - \overline{\mathbf{x}}_t^g \approx \mathbf{M}\left(\overline{\mathbf{x}}_0^a - \overline{\mathbf{x}}_0^b\right) = \mathbf{MK}\delta\mathbf{y}_{\mathrm{o}} \quad (2)$$

$$\Delta e_t^{f-g} \approx \frac{1}{(K-1)} \delta\mathbf{y}_{\mathrm{o}}^{\mathbf{T}} \mathbf{R}^{-1} \left(\mathbf{H}\mathbf{X}_0^a\right) \mathbf{X}_t^{f\mathbf{T}} C \left(\mathbf{e}_t^f + \mathbf{e}_t^g\right) \quad (3)$$

EFSO Nomenclature, Units and Typical Observation Impact Magnitude

- Positive quantities are referred to as being detrimental and negative quantities are referred to as being beneficial

- EFSO Units: (J/kg)

- Typical observation impact magnitude for most observing systems is on the order of 1E-6

EFSO Components and Interpretation

Components of the EFSO Formulation

$$\Delta e_t^{f-g} \approx \frac{1}{(K-1)} \delta \mathbf{y}_o^{\mathbf{T}} \mathbf{R}^{-1} (\mathbf{H}\mathbf{X}_0^a) \mathbf{X}_t^{f\mathbf{T}} C \left(\mathbf{e}_t^f + \mathbf{e}_t^g \right)$$

$\frac{(\mathbf{H}\mathbf{X}_0^a)\mathbf{X}_t^{f\mathbf{T}}}{(K-1)}$

Cross Covariance between analysis perturbations in observation space and forecast Perturbations at forecast time

Relates analysis perturbation directions in ob space to forecast perturbation directions

$\left(\mathbf{e}_t^f + \mathbf{e}_t^g \right)$

Sum of two forecast error realizations (before and after assimilating observations)

Provides the direction for helpful forecast perturbations

Components of the EFSO Formulation

- Sum of forecast errors provide the direction for helpful forecast perturbations

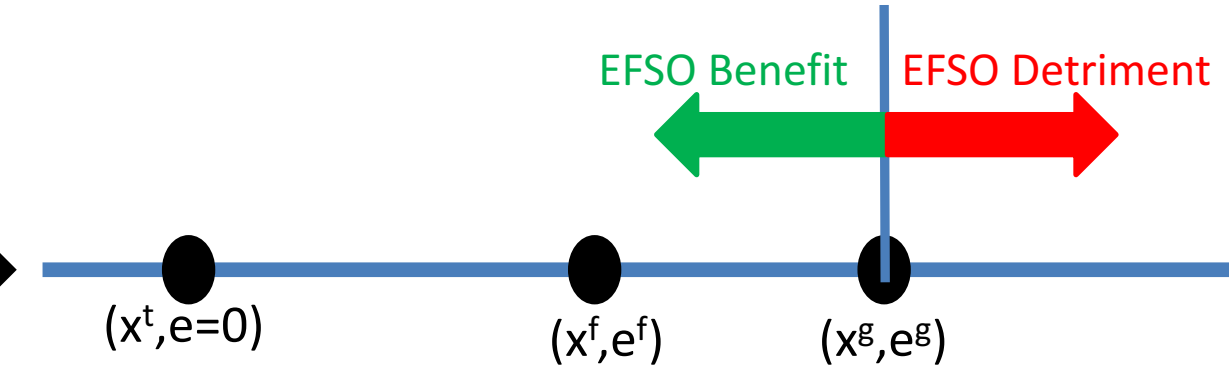
- Cross covariances between analysis perturbations in observation space and forecast perturbations in state space determine the sign of forecast perturbations for a given innovation

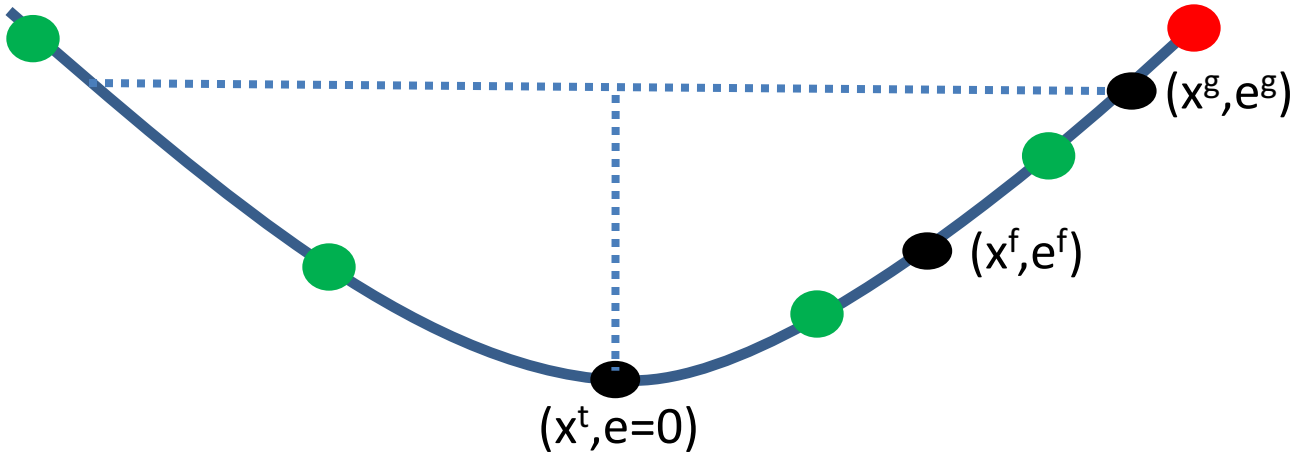
- Observation error, innovation magnitude, analysis uncertainty (analysis covariance) and sensitivity of forecast to analysis all contribute to the magnitude of observation impact in the EFSO formulation.

A Framework for Explaining EFSO Detriment and Benefit

Scenario 1: EFSO Results
(1) All relevant negative innovations are beneficial
(2) If OmA is positive and OmB is negative, EFSO is beneficial.

Locations of state realizations In observation space and EFSO indicated impact based on the relative observation position





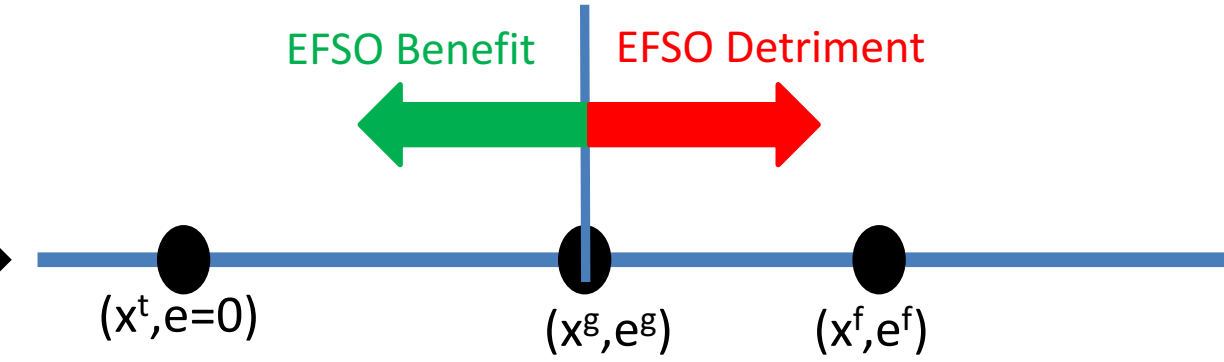
A Framework for Explaining EFSO Detriment and Benefit

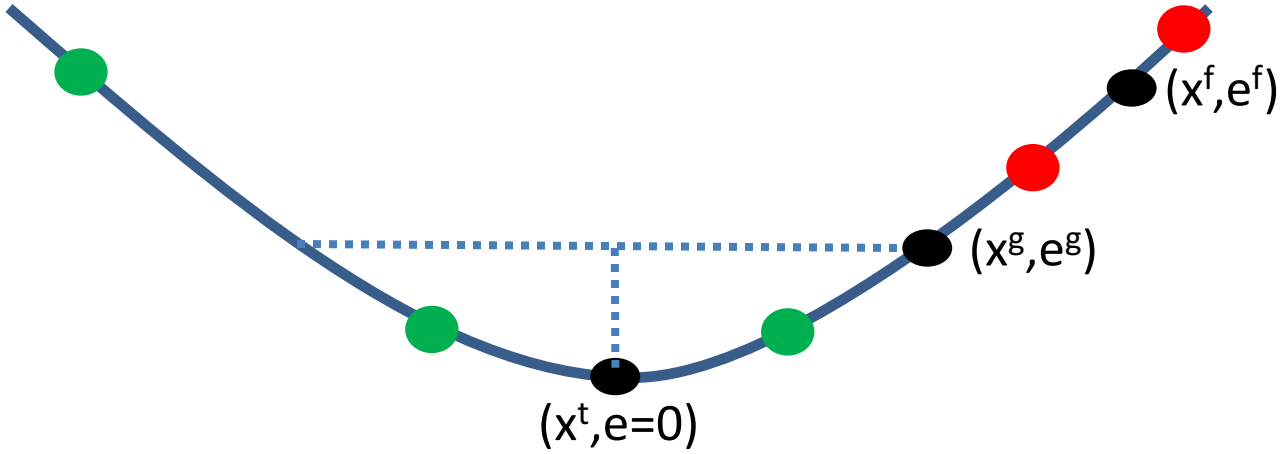
Scenario 2 EFSO Results:

(1) All relevant negative innovations are beneficial

(2) If OmB is positive and OmA is negative, assimilated innovations/obs are detrimental, but the contribution to observation "center of mass" is helpful.

Locations of state realizations In observation space and EFSO indicated impact based on the relative observation position

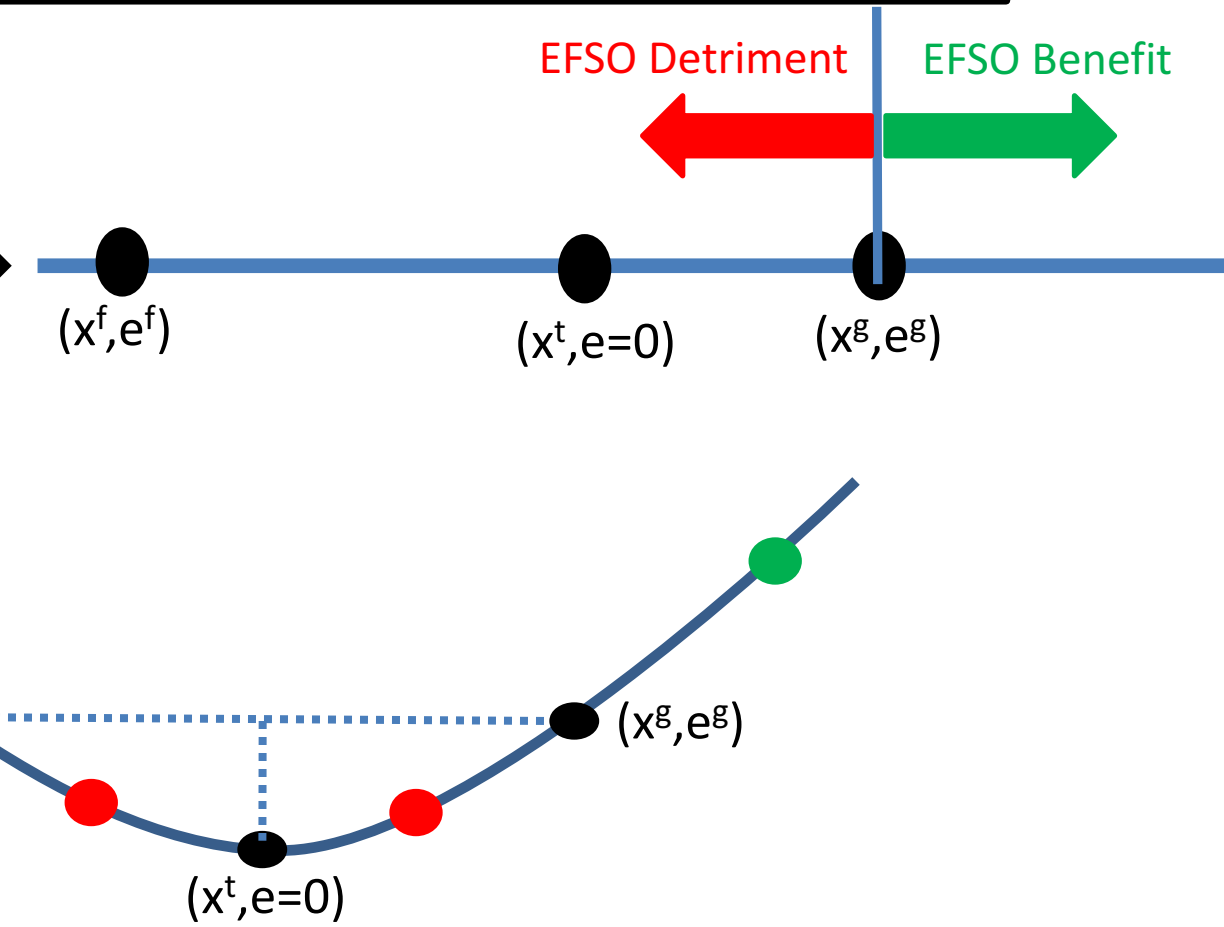




A Framework for Explaining EFSO Detriment and Benefit

Scenario 3 EFSO Results:
(1) All relevant positive innovations are beneficial.
(2) All relevant negative innovations are detrimental. However, all observations between x^g and x^f improve the observation "center of mass" and analysis.

Locations of state realizations In observation space and EFSO indicated impact based on the relative observation position



Preliminary EFSO Guidance Based on EnKF Products from a 4DEnVar GFS Cycling Experiment

Thinning Configuration and Dataset Presented

- Thinning is applied to just wind observations

  Thinning Dimensions

  - 50 km horizontal
  - 50 mb vertical
  - 1 hour intervals

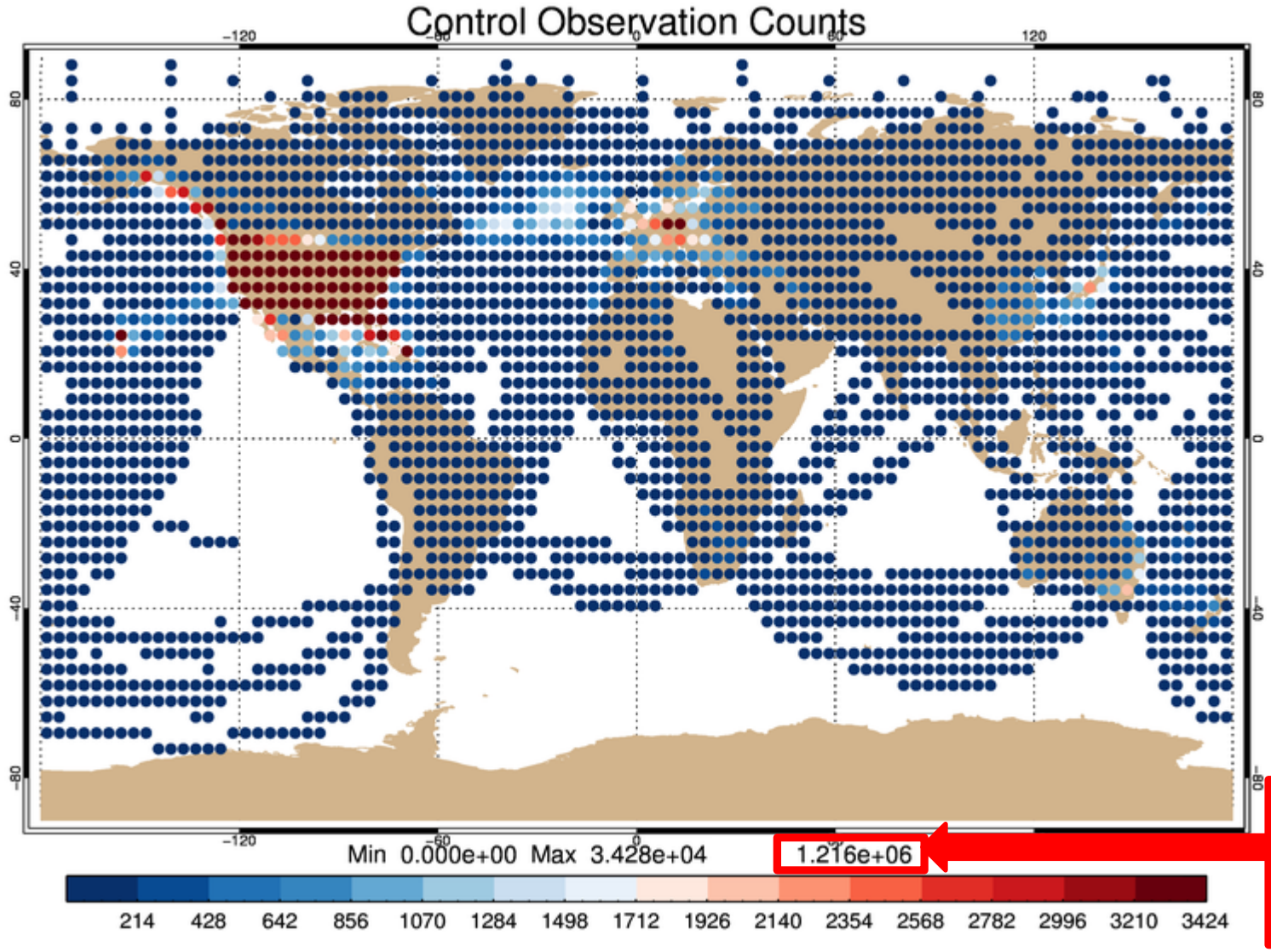
- Dataset presented: **All cycles from 2015010800 through 2015011306. This includes a total of 22 cycles.**

Simultaneity of EFSO

- Taking advantage of the simultaneity aspect of EFSO, the observation impacts are sorted by observable, horizontal location (3.75 by 3.75 composite boxes) and flight segment (i.e cruising altitude versus ascents/descents)

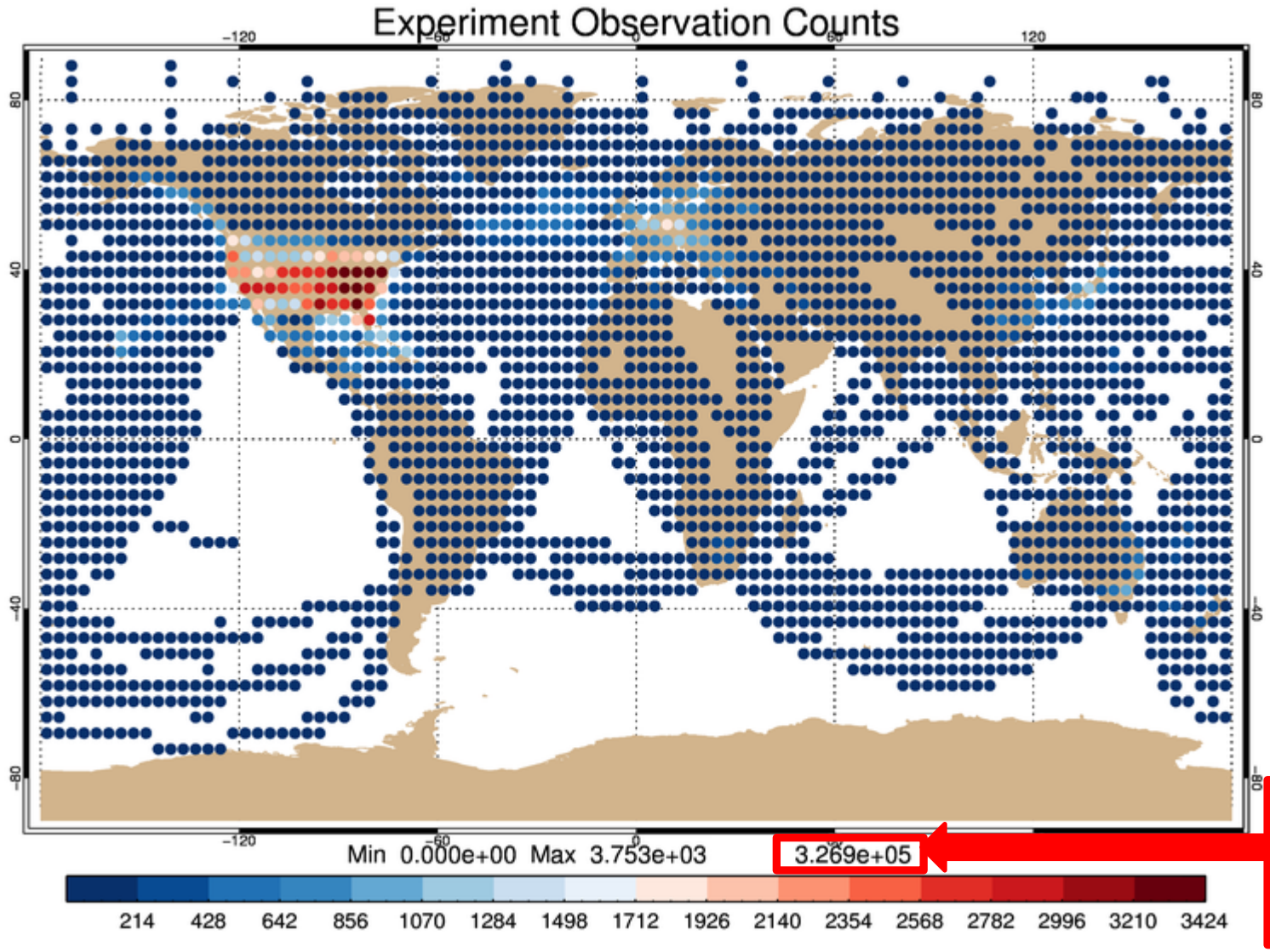
- The intent is to use EFSO to identify specific scenarios (eg. particular aspect ratios) where thinning is beneficial/detrimental

Total Control Observation Counts @ Flight Level (Zonal Wind Observations)



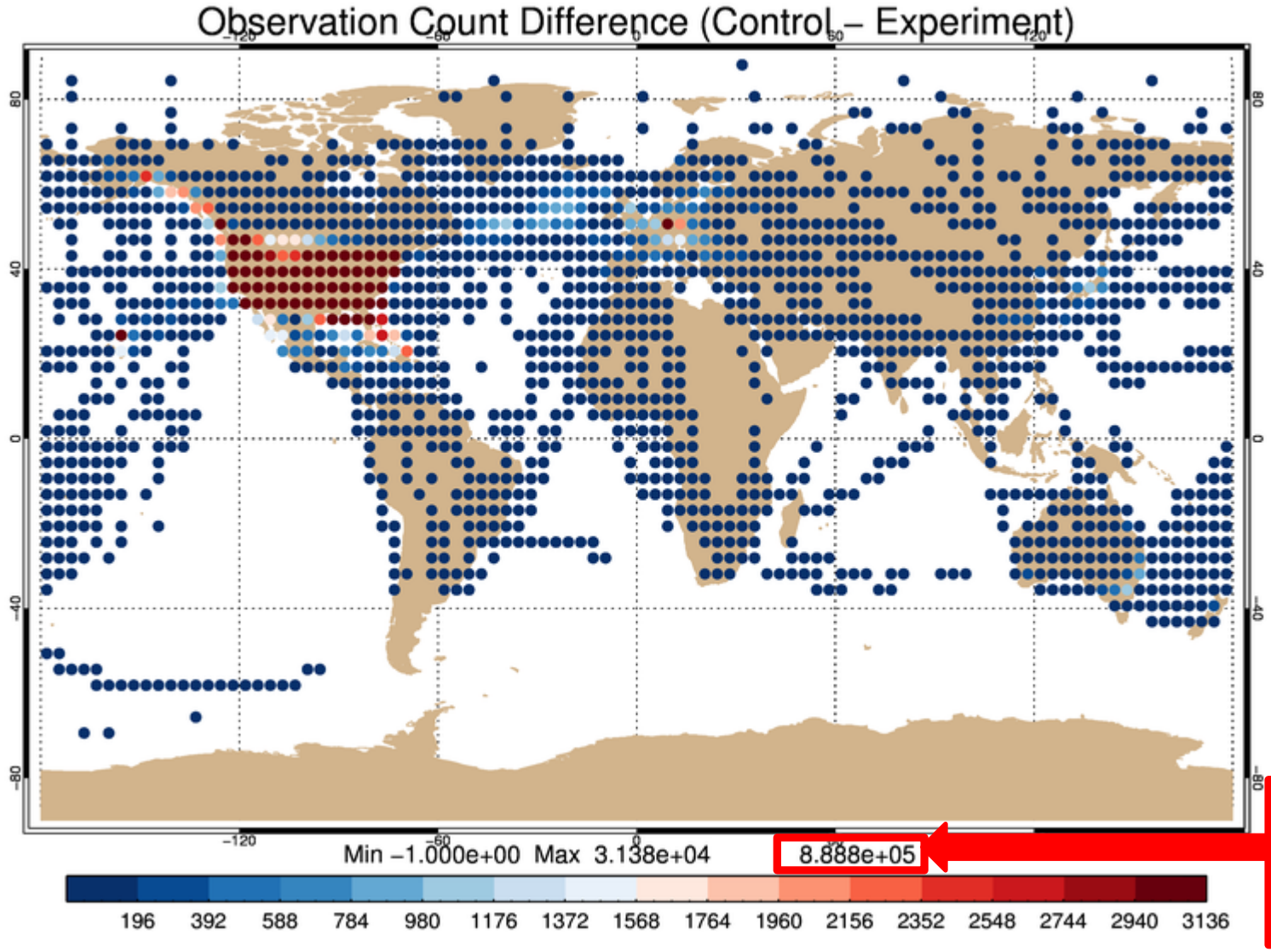
Total all 22 cycles

Total Experiment Observation Counts @ Flight Level (Zonal Wind Observations)

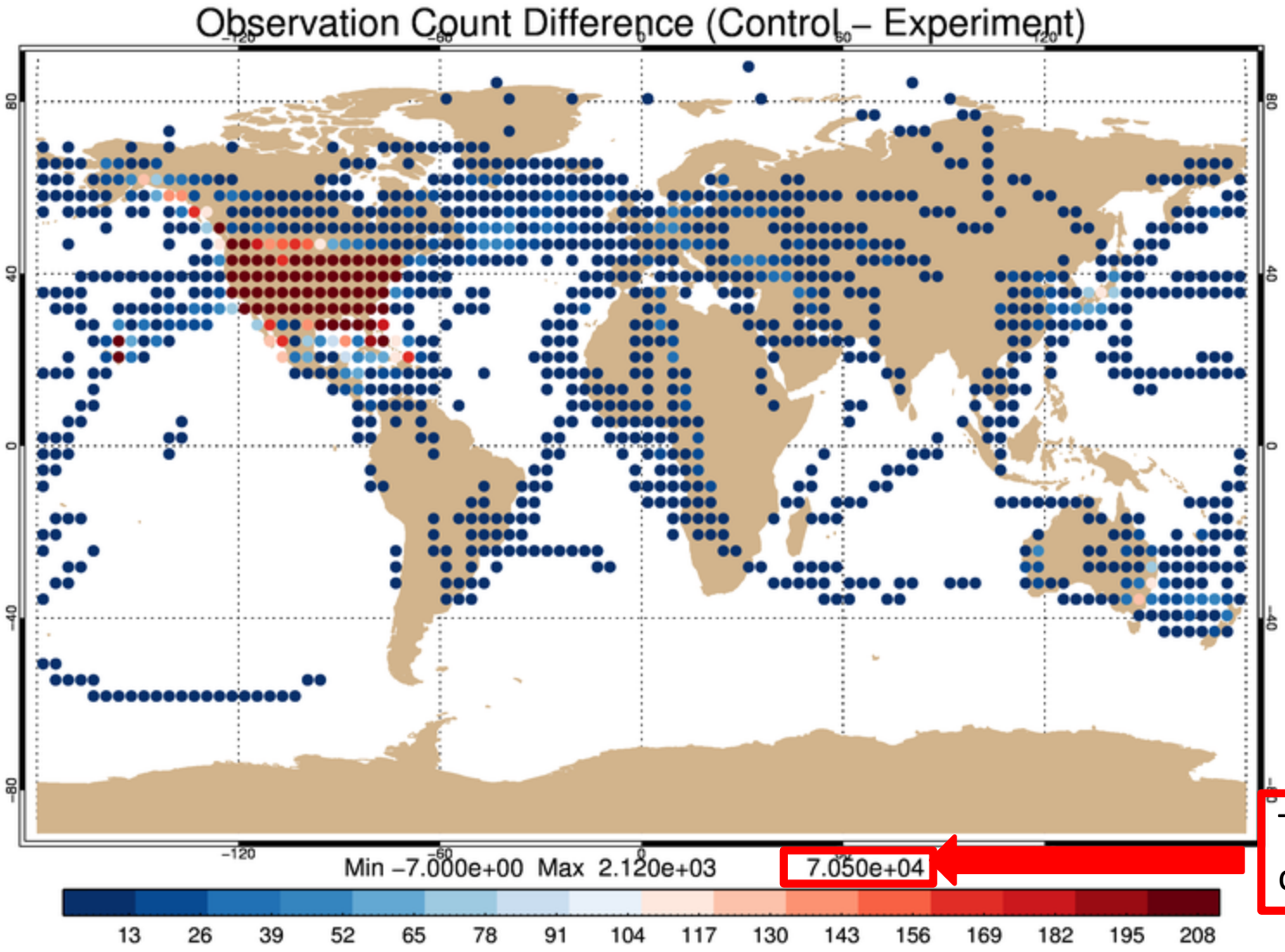


Total all 22 cycles

Total (Control – Experiment) Observation Counts @ Flight Level (Zonal Wind Observations)

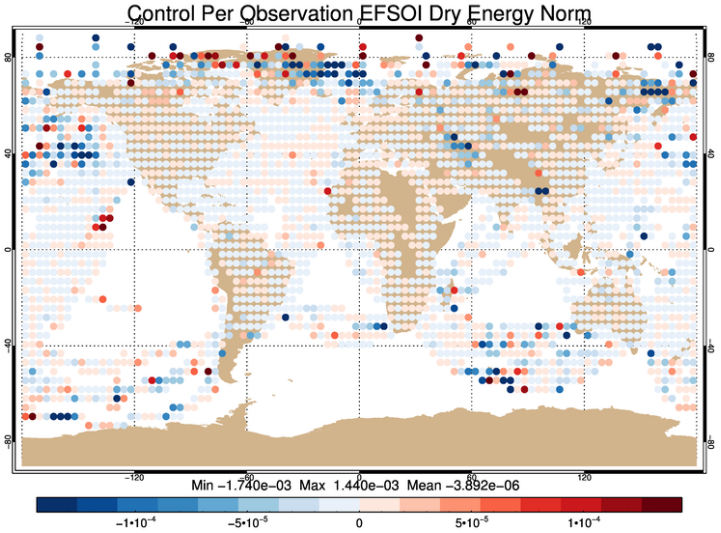


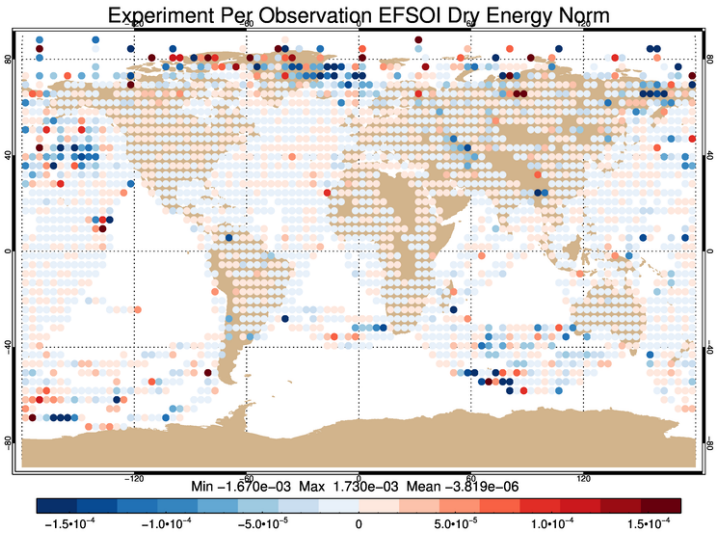
Total (Control – Experiment) Observation Counts @ Flight Level (Temperature Observations)

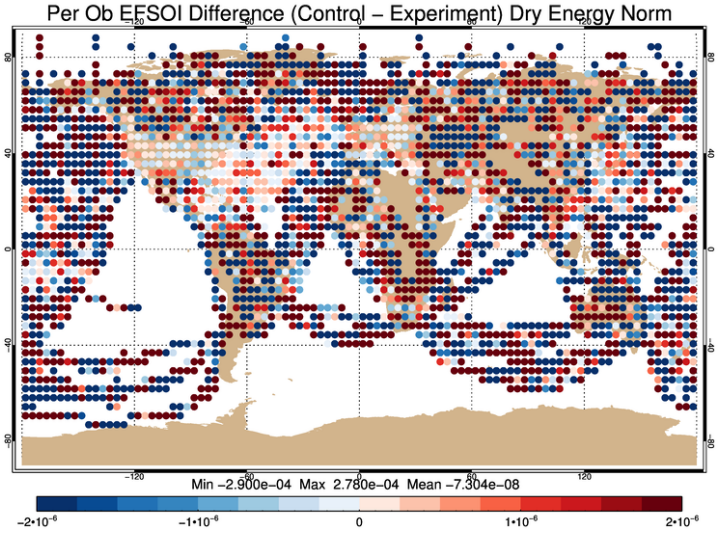


Total all 22 cycles

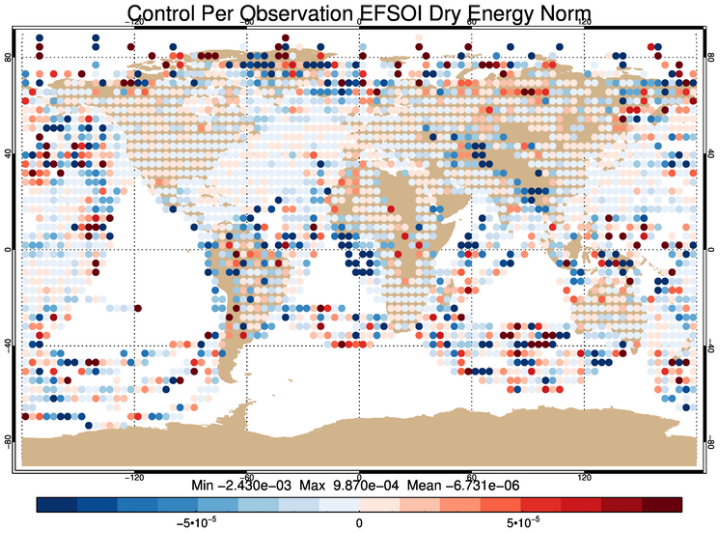
Per Observation EFSO @ Flight Level (Temperature Observations)

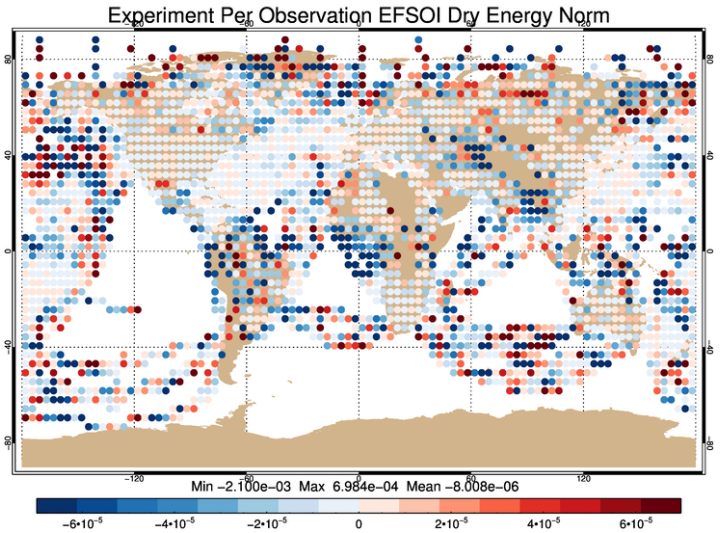


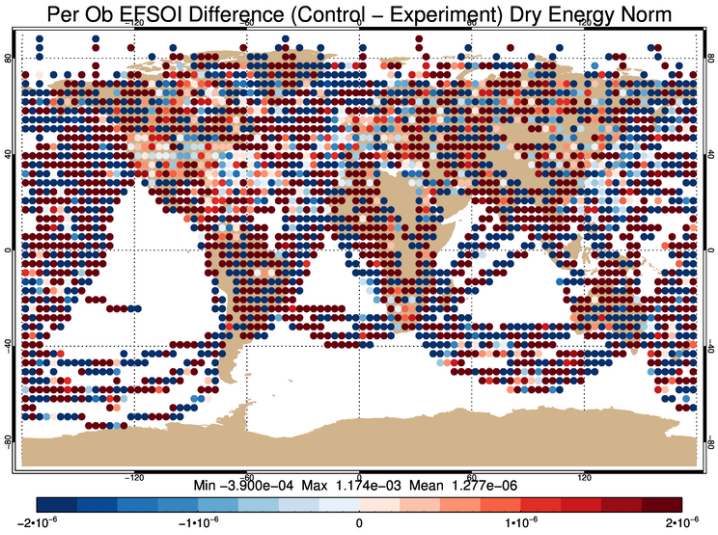




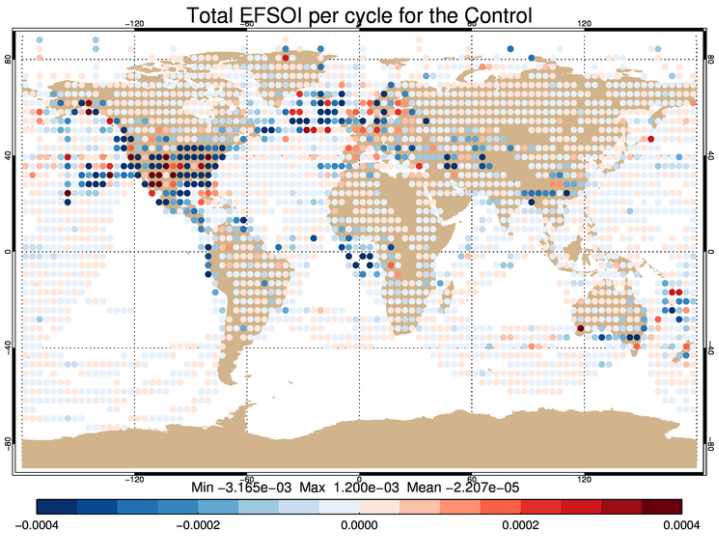
Per Observation EFSO @ Flight Level (Zonal Wind Observations)

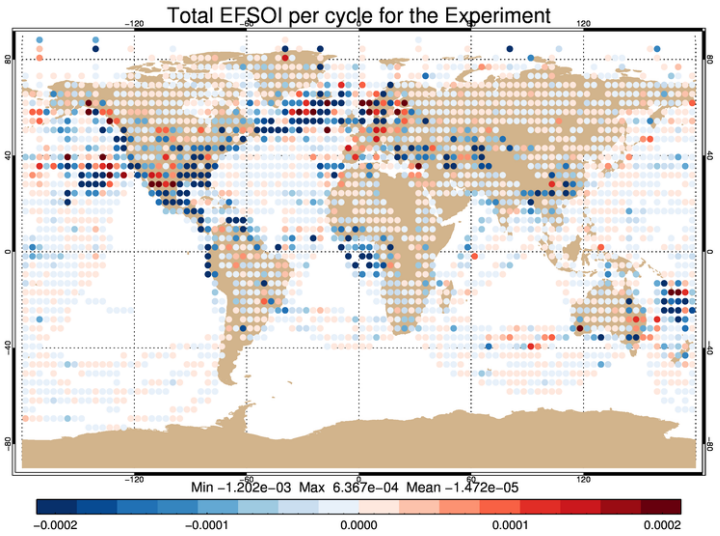


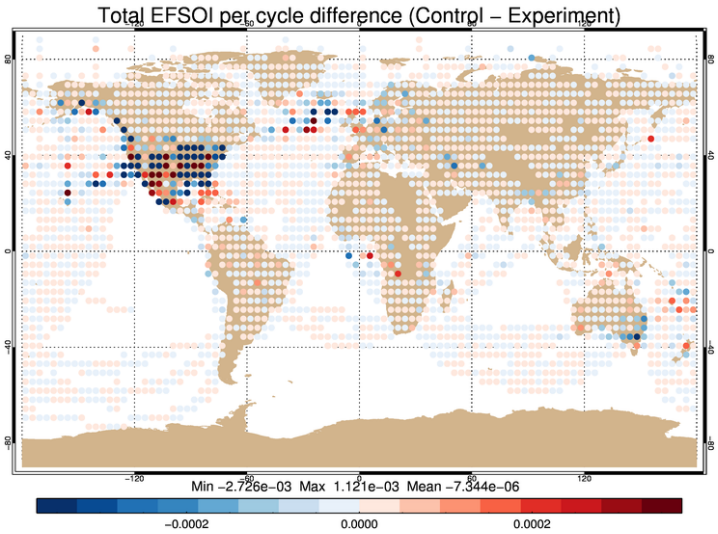




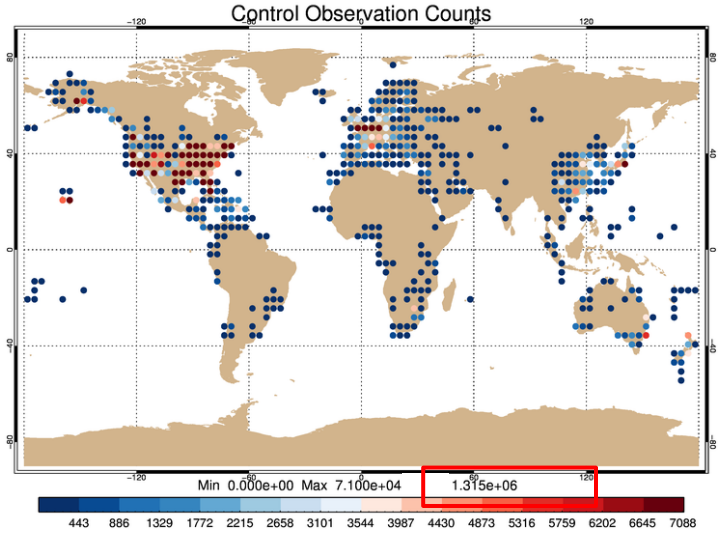
Total EFSO per cycle @ Flight Level (Zonal Wind Observations)

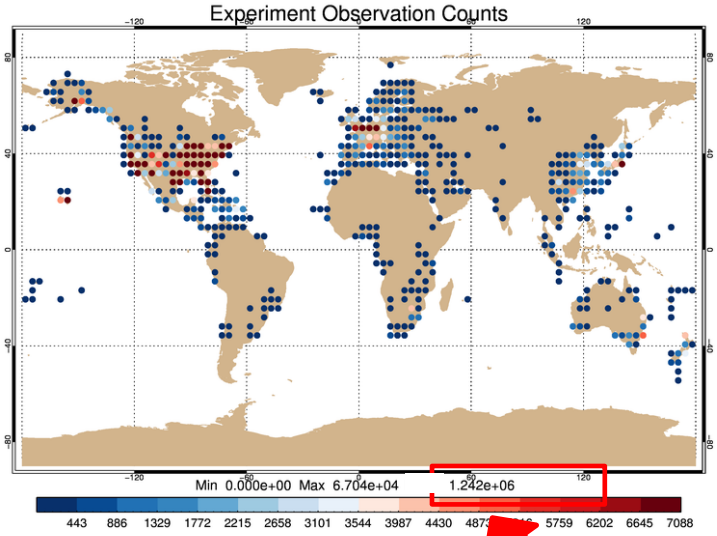


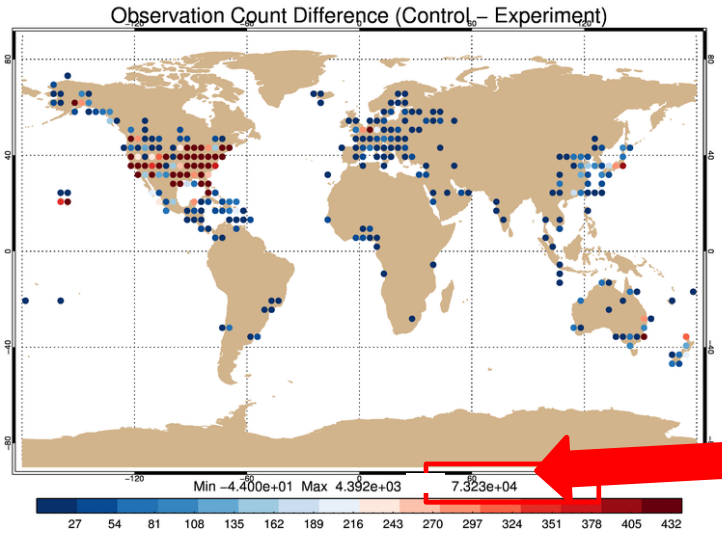




Observation Counts (Pressure > 400hPa) (Temperature Observations)

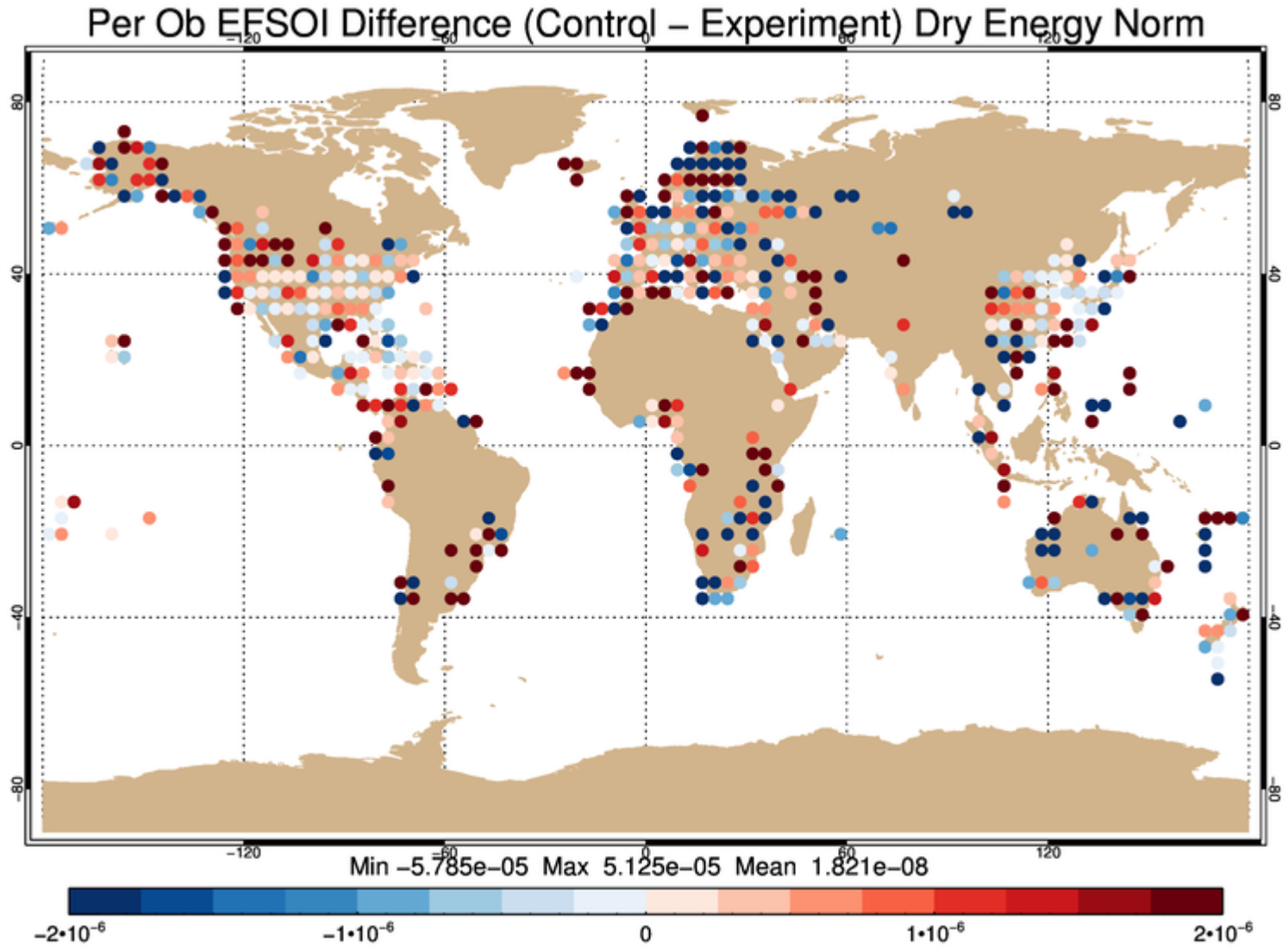




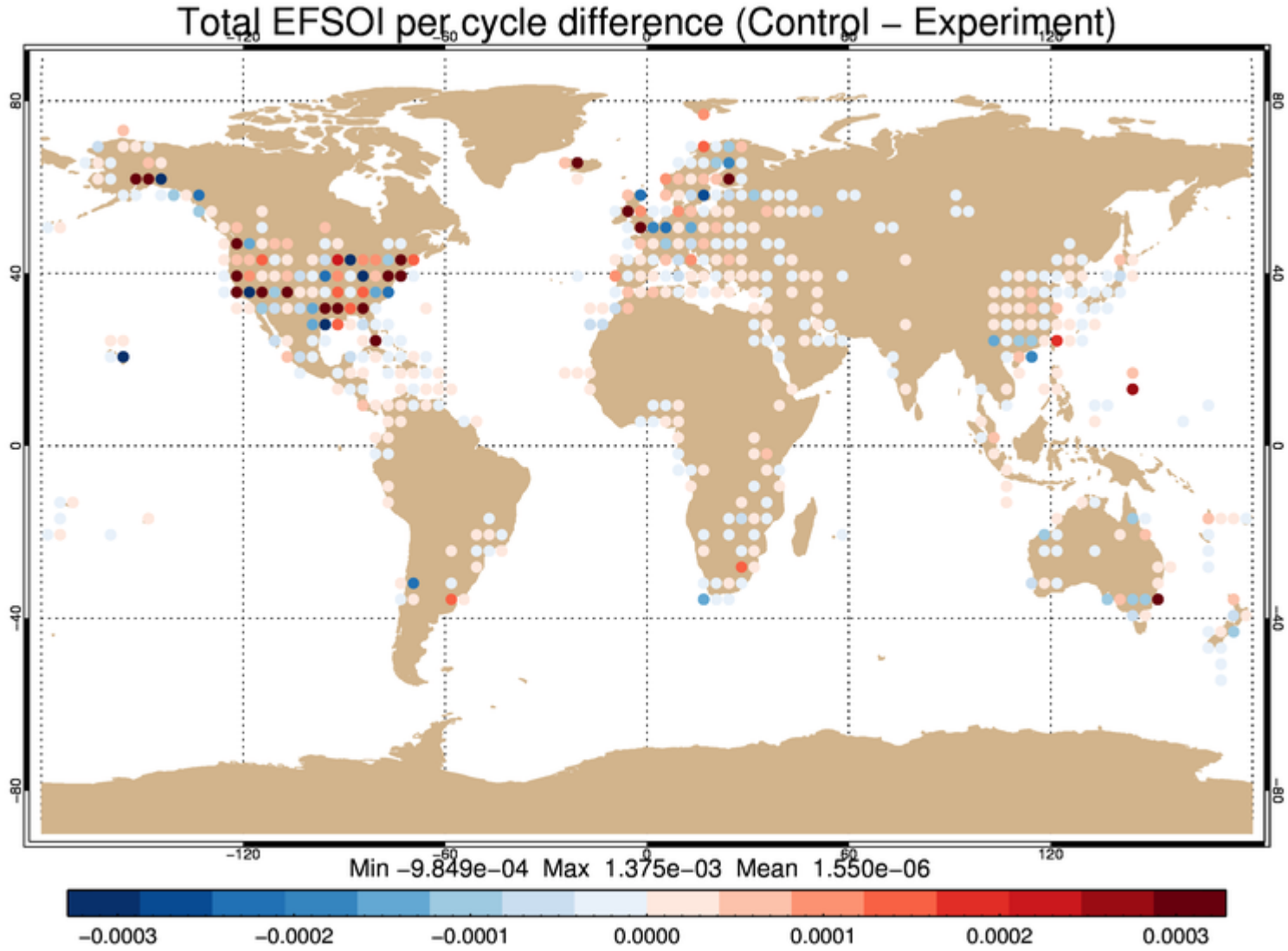


Total all 22 cycles

Per Observation EFSO
(Pressure > 400 hPa)
(Temperature Observations)



Total EFSO per cycle
(Pressure > 400 hPa)
(Temperature Observations)



Summary of Preliminary Results

- Per observation impact follows observation density. Spatial variability in the ensemble spread is tied to observation density.
- The larger total impact differences between the control and experiment are coincident with higher observation density
- EFSO calculations indicate that temperature observations for ascents/descents were more helpful (less harmful) in the experiment.
- A larger EFSO dataset is needed to further consider where new data sources may be helpful
- For the experiment, there was a ~5% reduction in assimilated temperature observations. Note that only wind observations were thinned in the experiment.