

# *Air Force Technical Applications Center*

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## **Application of Advanced Data Assimilation Techniques to Improve Atmospheric Transport and Dispersion Predictions**



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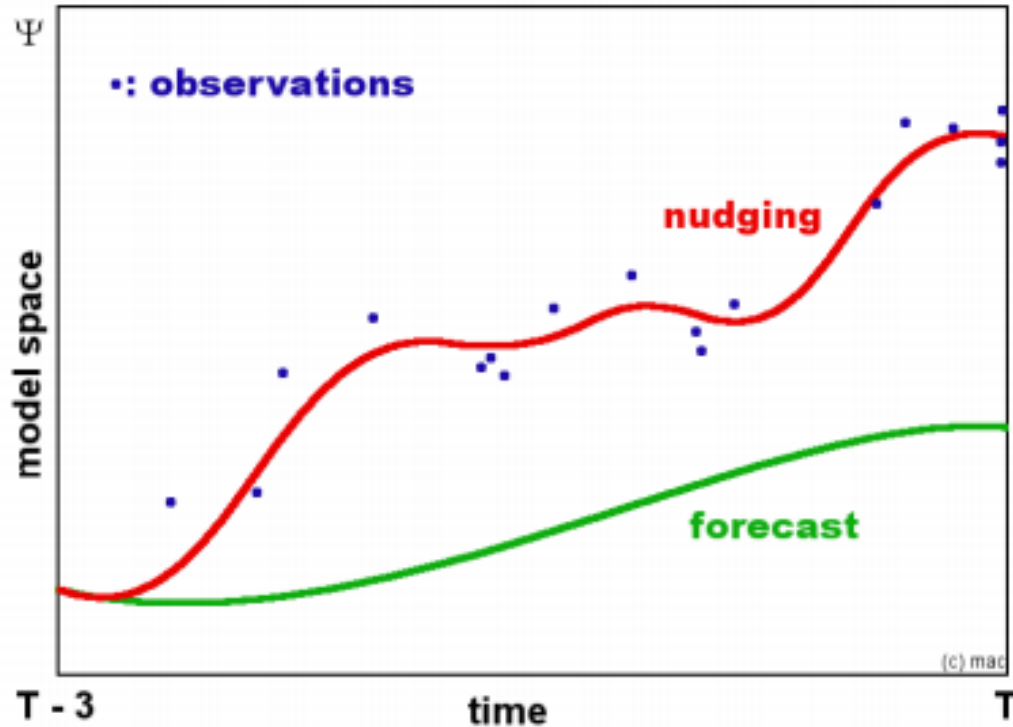
# Assimilation aids transport and dispersion predictions

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- Accurate transport and dispersion (T&D) of radionuclides relies on accurate meteorological input
- Meteorological data assimilation (DA) improves inputs used to drive T&D simulations
- In retrospective T&D, four dimensional data assimilation (“nudging”) is typically employed
- Weather forecasting uses more advanced DA techniques to initialize simulations



# Nudging



Adapted from: [https://www.cim-community.eu/dokumente/upload/Training16\\_Assimilation\\_Schraff.pdf](https://www.cim-community.eu/dokumente/upload/Training16_Assimilation_Schraff.pdf)

- Continuous assimilation over time
- Relax modeled values toward observations

# 3D Variational

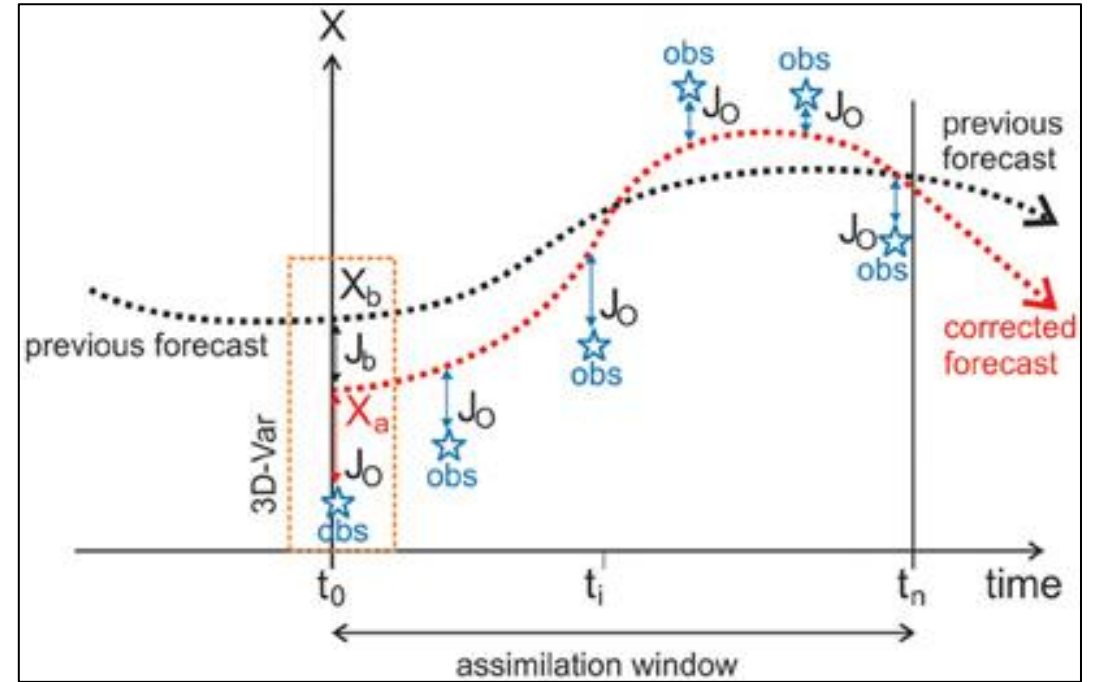


Image source: [https://www.frontiersin.org/files/Articles/88996/fenvs-02-00016-HTML/image\\_m/fenvs-02-00016-g003.jpg](https://www.frontiersin.org/files/Articles/88996/fenvs-02-00016-HTML/image_m/fenvs-02-00016-g003.jpg)

- Improves initial model state
- Allows use of remotely-sensed observations (e.g., satellite)



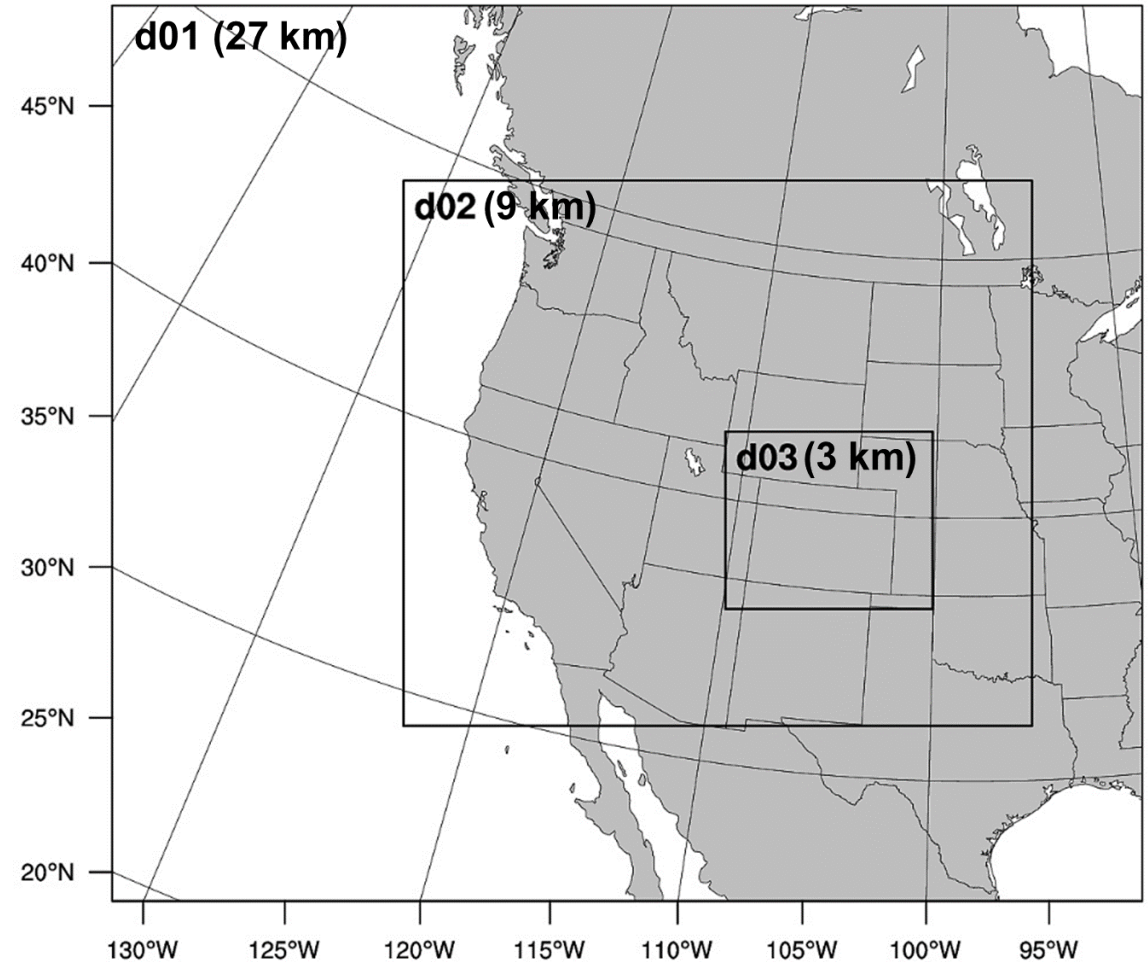
**Could more advanced meteorological DA techniques be utilized to improve T&D simulations?**



# Meteorological model setup

## Weather Research and Forecasting (WRF) model

- Simulations performed for 17 – 24 October 2010
- Three domains: 27–9–3 km
- YSU Planetary Boundary Layer (PBL)
- RRTMG radiation
- Morrison microphysics
- Kain-Fritsch cumulus





# Data assimilation experiments

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## Nudging

Analysis nudging performed on outer two domains

Observational nudging performed on all three domains

Surface variables nudged with  $\frac{1}{2}$  strength and  $\frac{1}{2}$  radius as upper-air variables

## Cycling 3DVAR

WRFDA Model

Assimilation of available observations every 6 hours on outer two domains

Each 6 h forecast brought together into a continuous time series

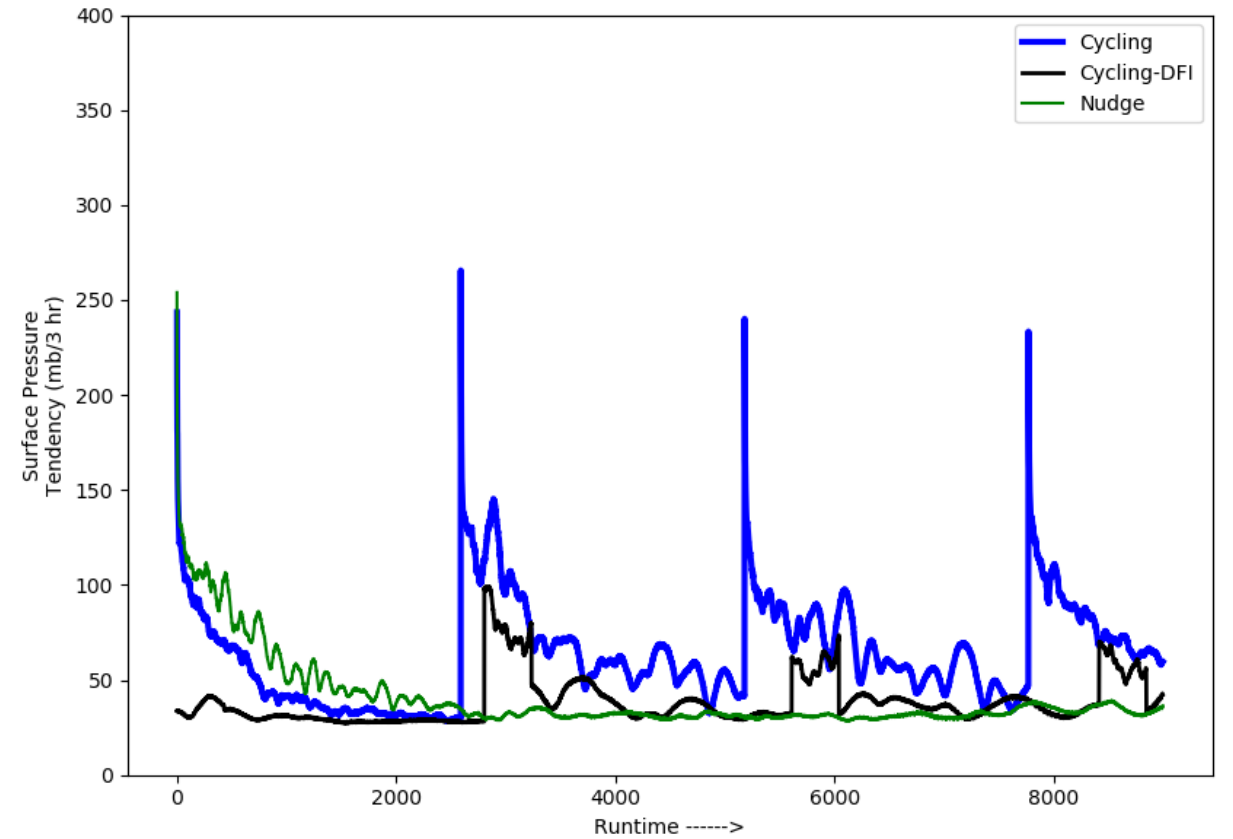
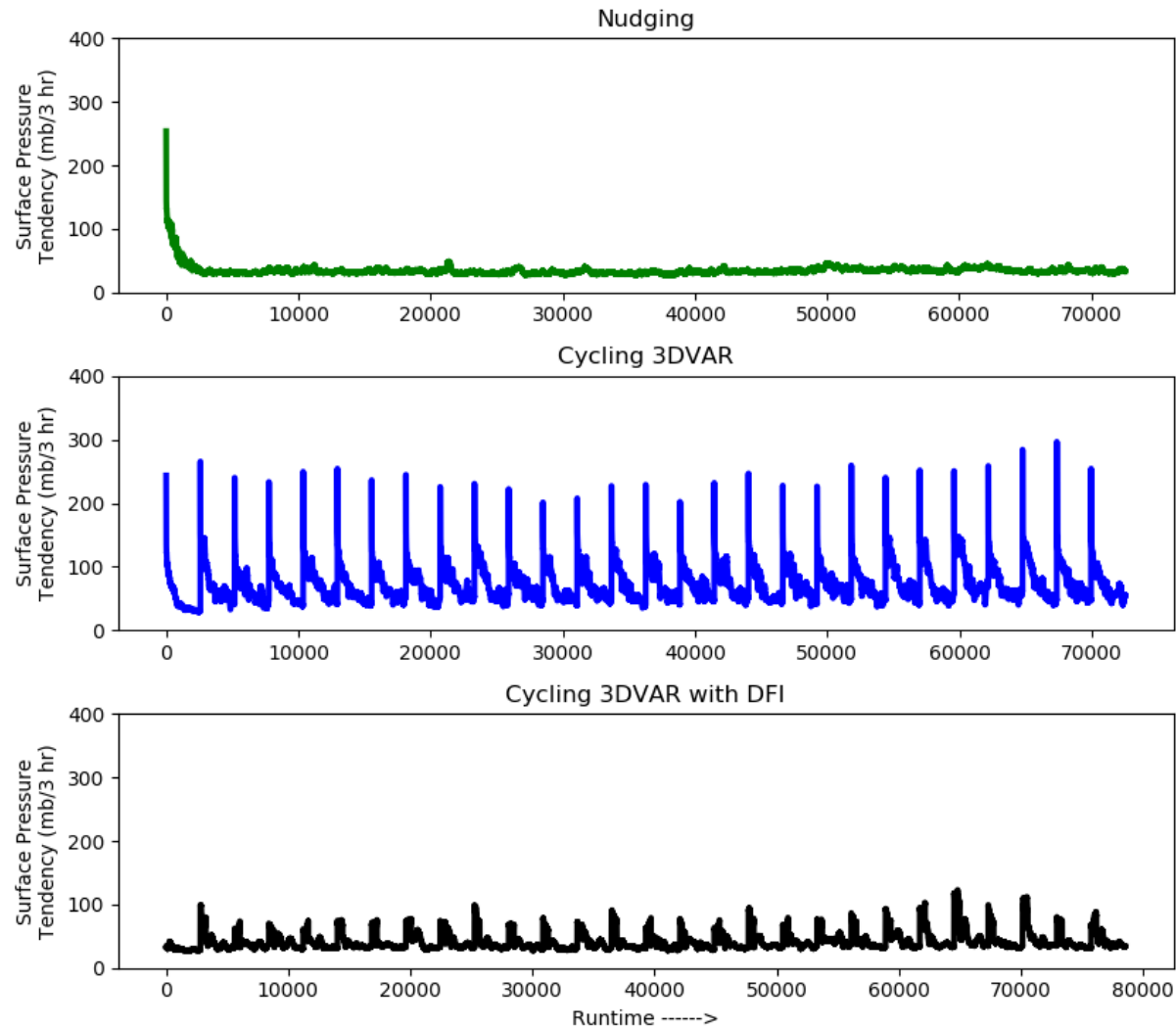
## Cycling 3DVAR with DFI

As above, but with digital filter initialization (DFI)

DFI method removes initial model imbalances



# Surface pressure tendency: *The case for nudging*





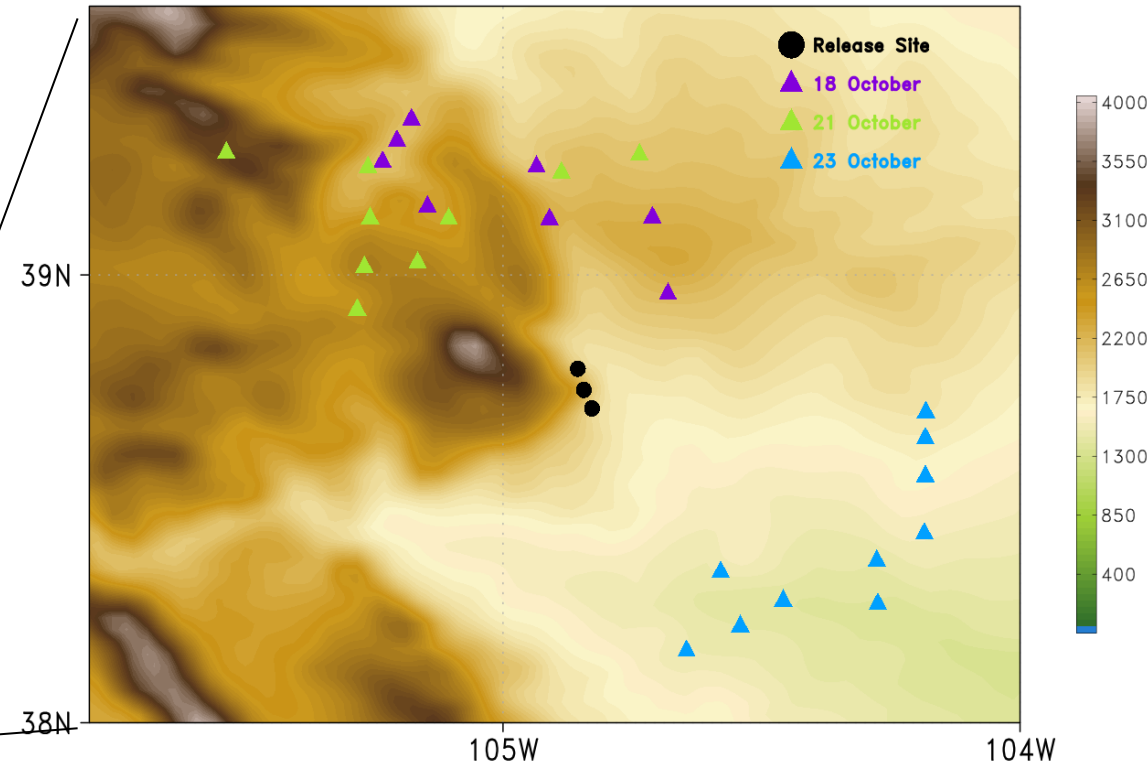
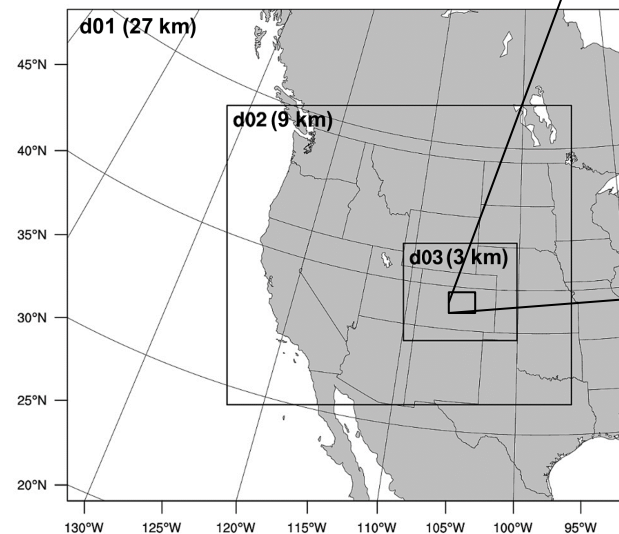
# Transport and Dispersion Simulations

## Colorado Springs Tracer Experiment

- Three release locations
- Releases on 18, 21, 23 October
- Mobile samplers based on wind direction

## Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT)

- $2.5 \times 10^6$  particles
- 30-min sampling
- $0.01 \times 0.01^\circ$  grid





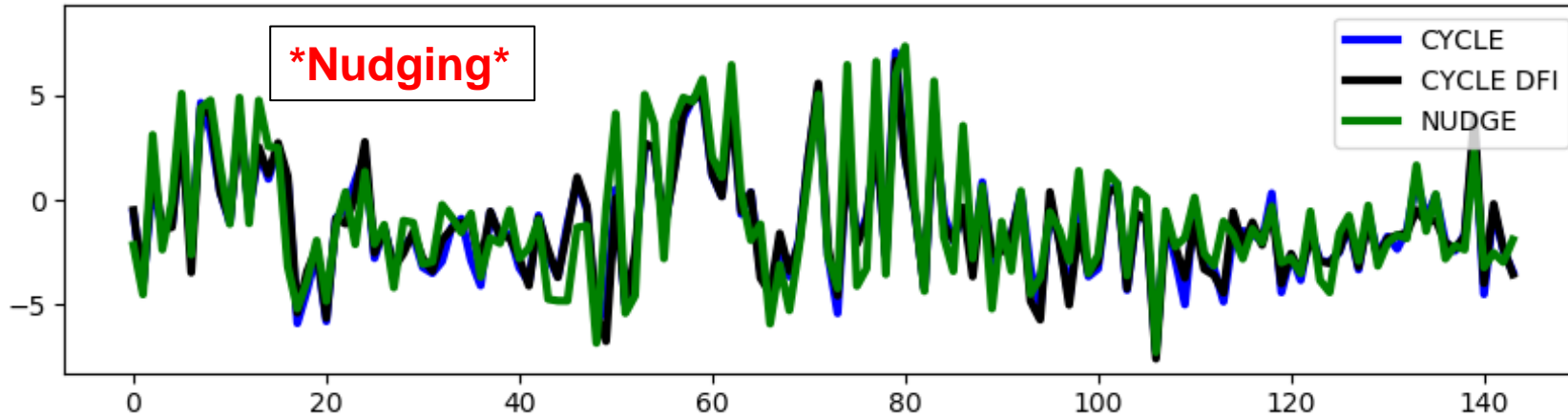
# Meteorological Evaluation



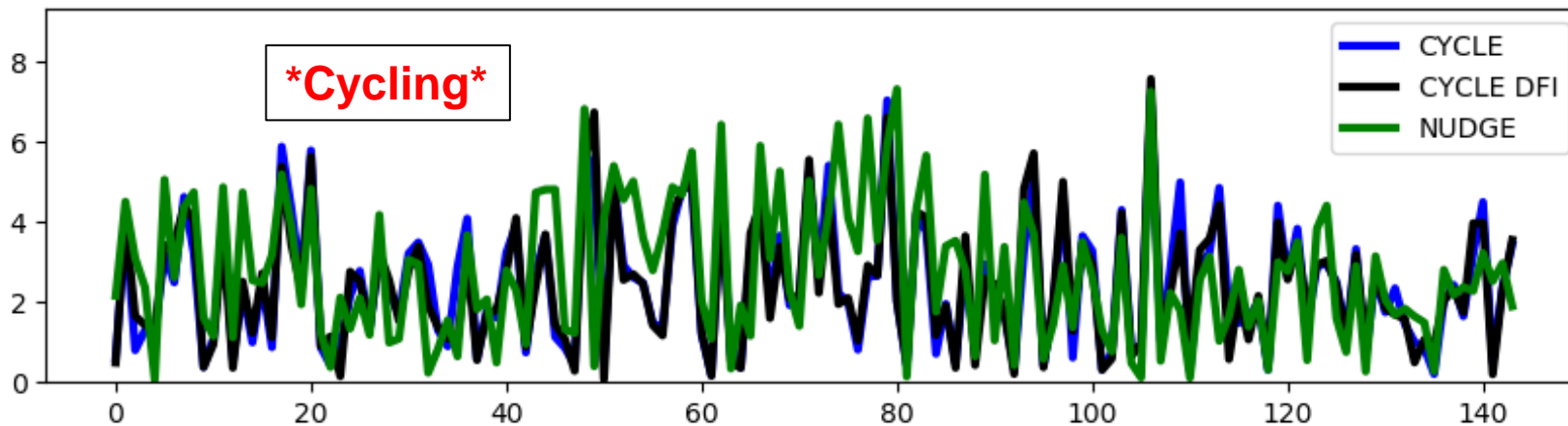
# 2-m Temperature

\* Indicates\* better performer

## Bias



## MAE

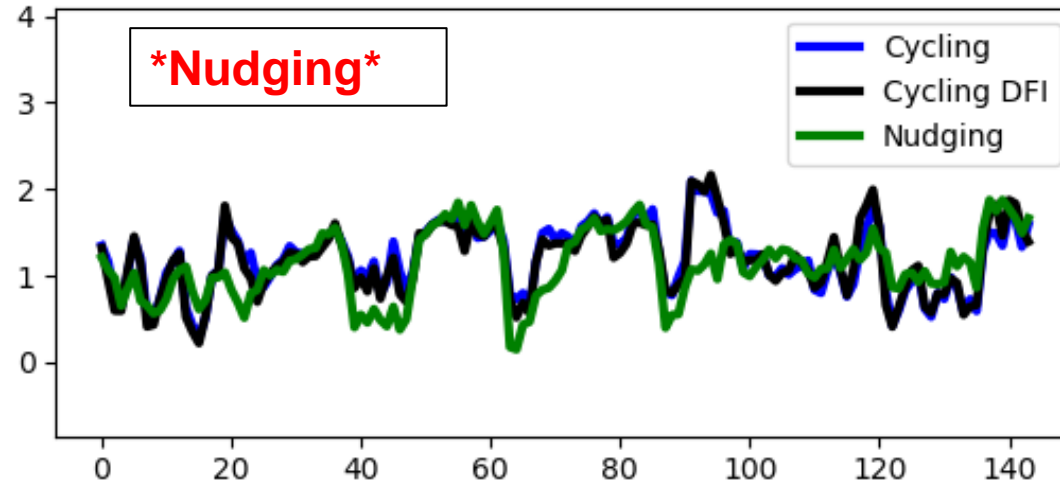




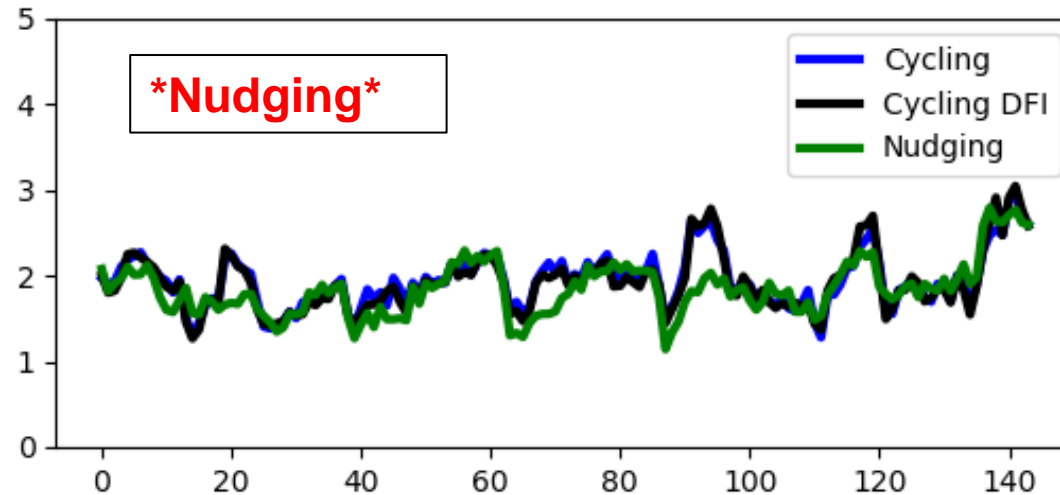
# 10-m Wind Speed

\* Indicates\* better performer

## Bias



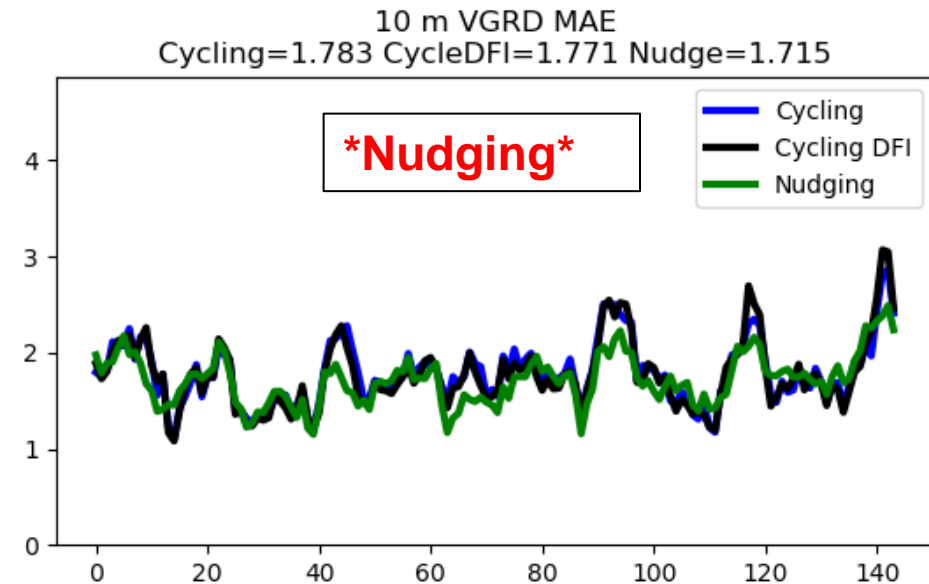
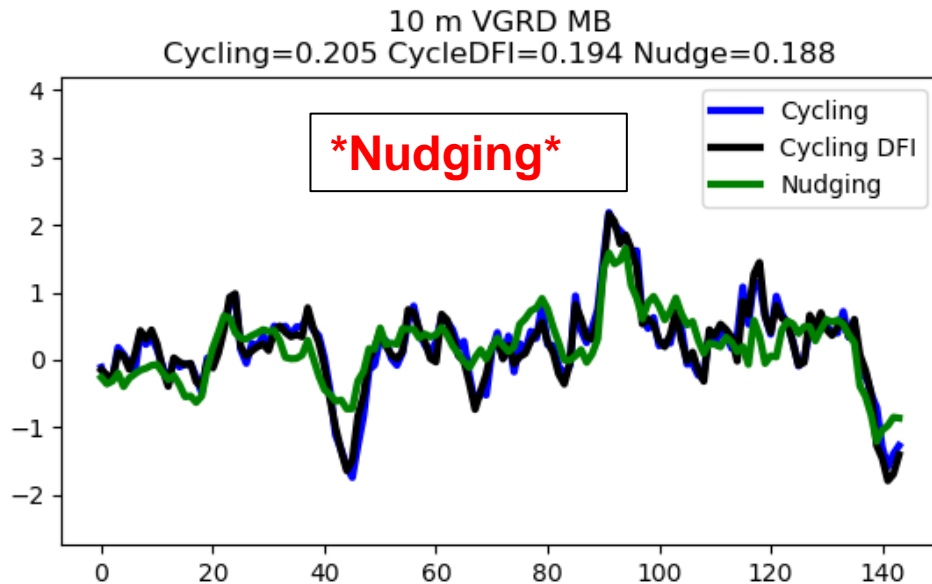
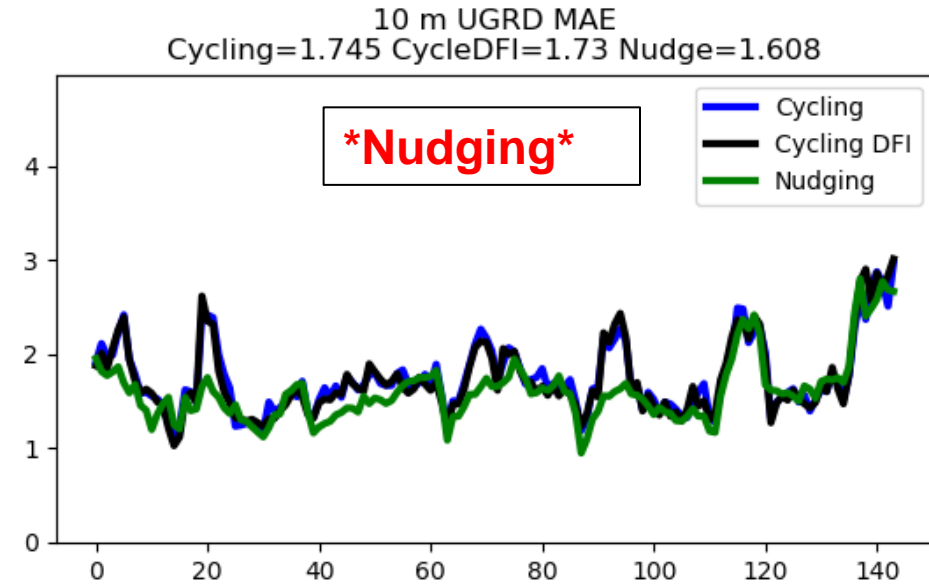
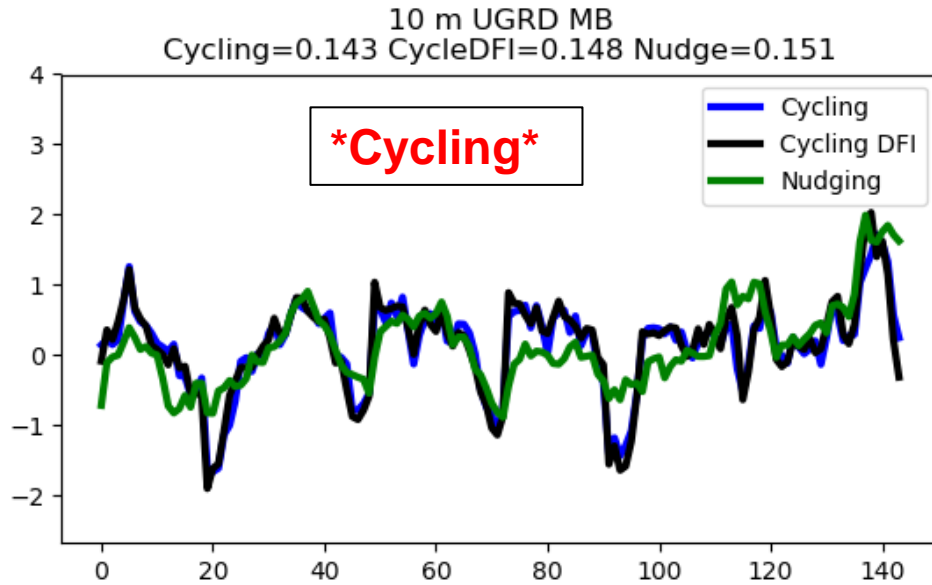
## MAE





# 10-m U & V Components

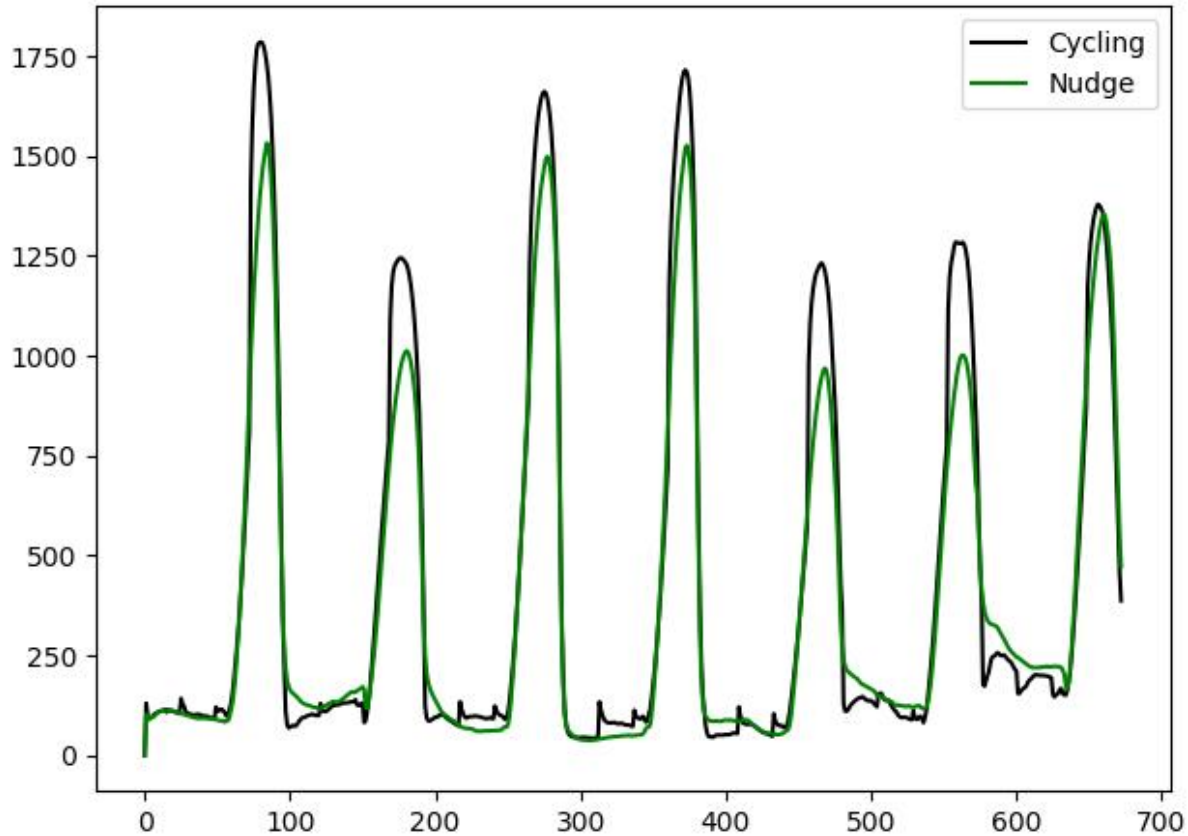
\* Indicates\*  
better  
performer



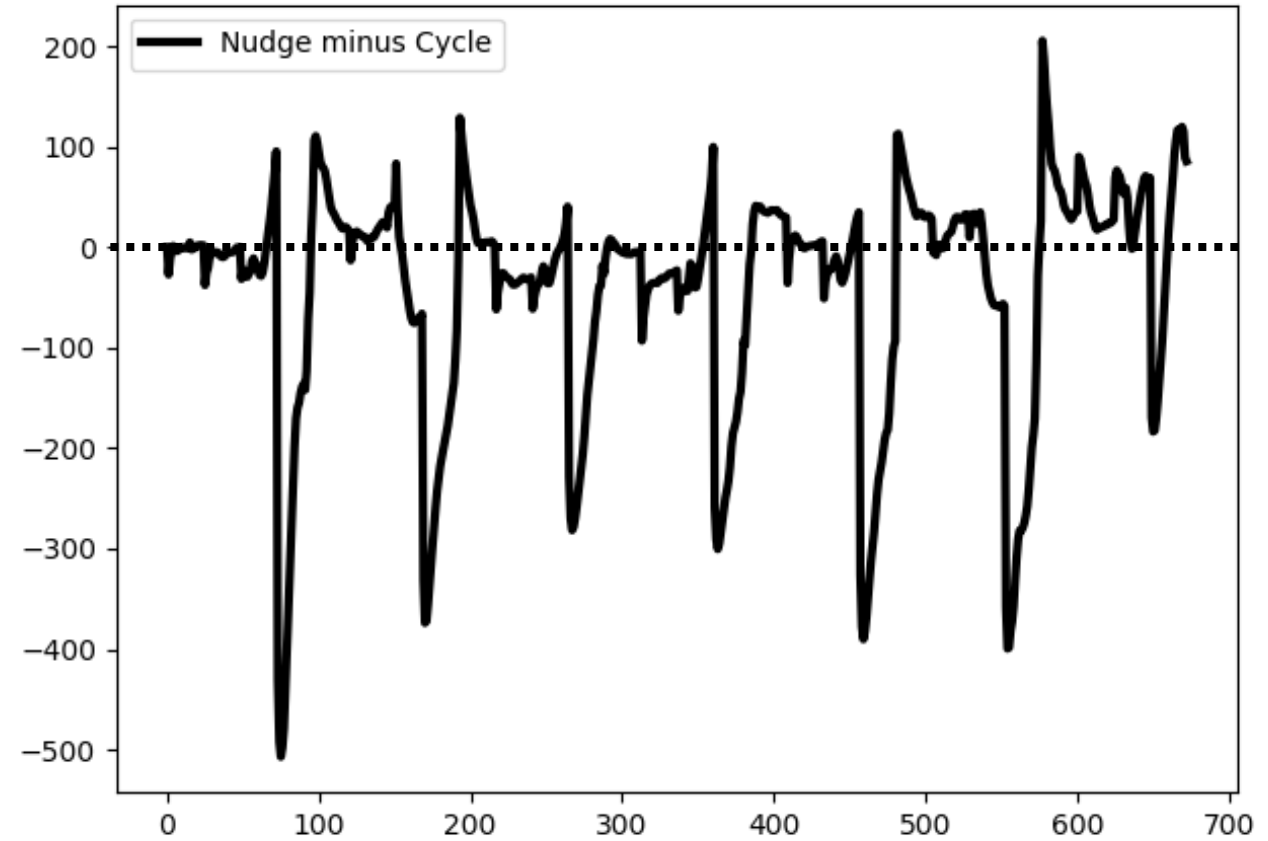


# PBL heights differ 200-500 m: Nudging run consistently shallower

## PBL Height



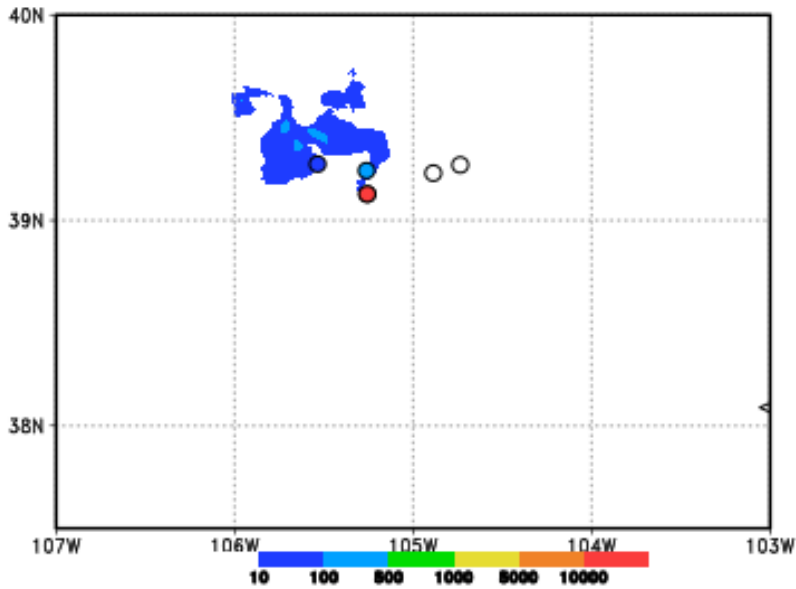
## Nudge minus Cycle



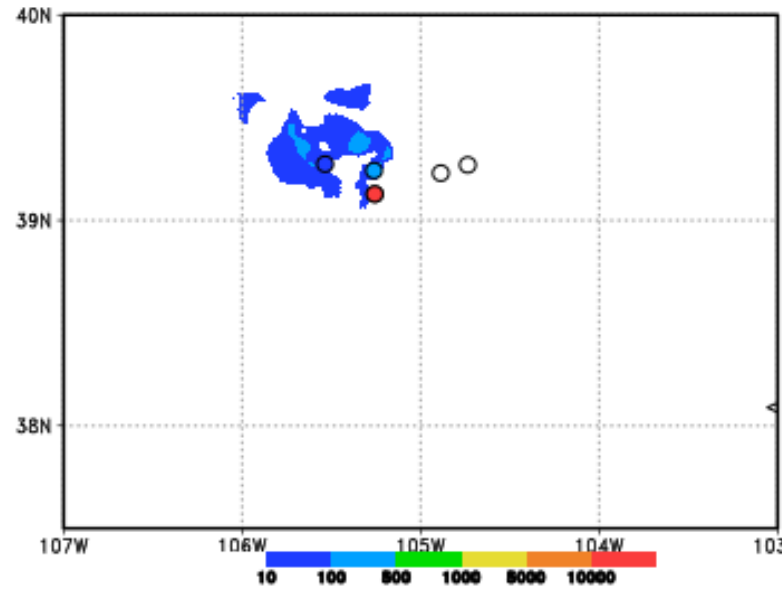


# HYSPLIT Dispersion Evaluation

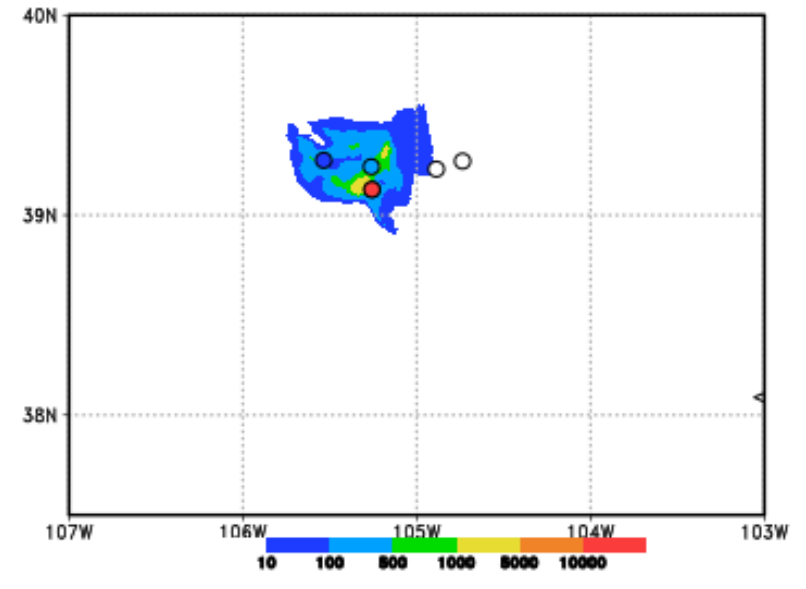
## Cycling



## Cycling DFI



## Nudging





# HYSPLIT Final Rank to measure robustness

## 0 (worst) to 4 (best)

### Correlation Coefficient (R)

scatter among predicted and observed values

### Figure of Merit in Space (FMS)

percentage overlap between observed and simulated plumes

$$\text{Final Rank} = R^2 + \left(1 - \frac{|FB|}{2}\right) + \left(\frac{FMS}{2}\right) + \left(1 - \frac{KSP}{100}\right)$$

### Fractional Bias (FB)

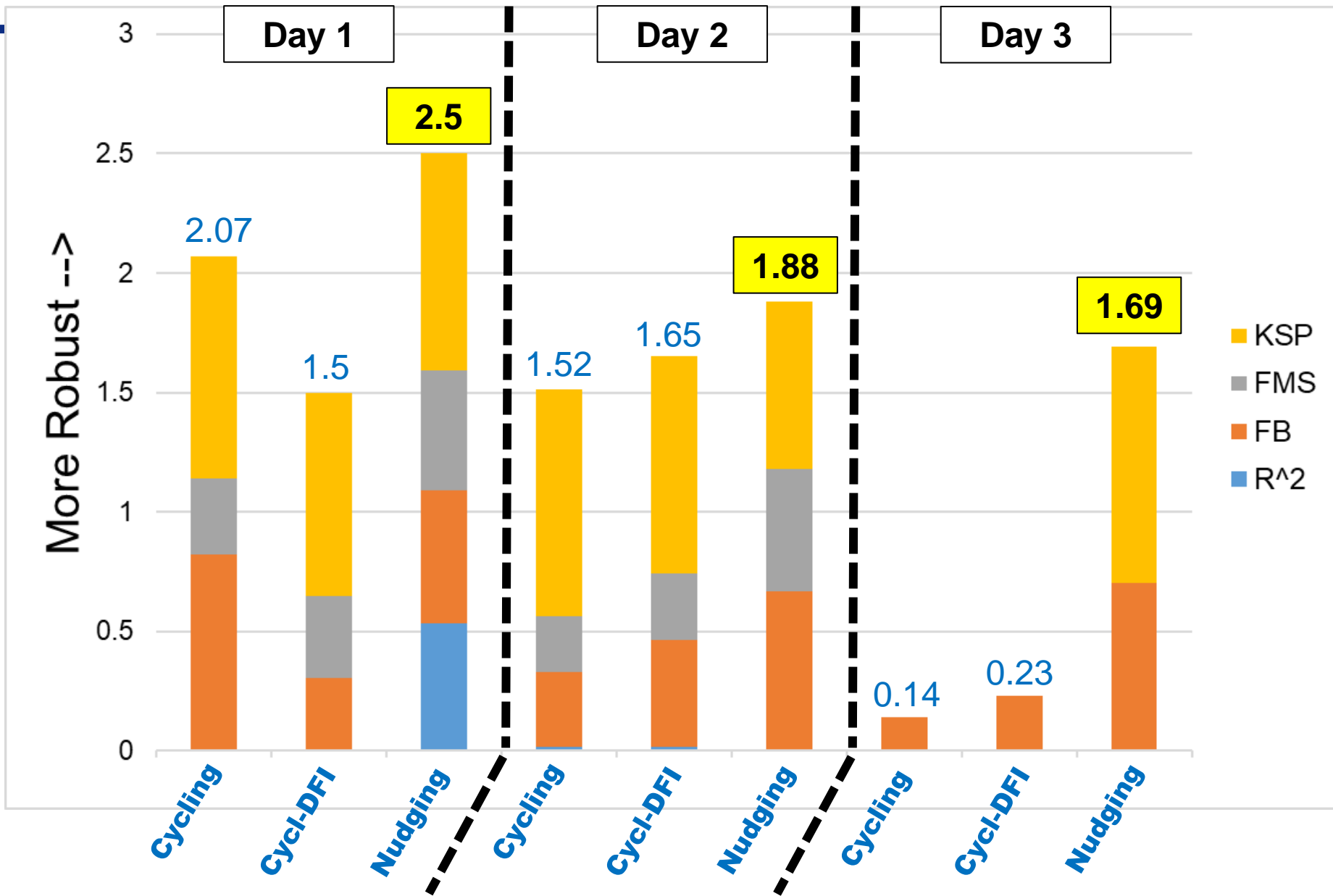
reveals systematic over/under prediction in model

### Kolmogorov-Smirnov Parameter (KSP)

measures how well model reproduced observed concentration distributions, regardless of location in time and space

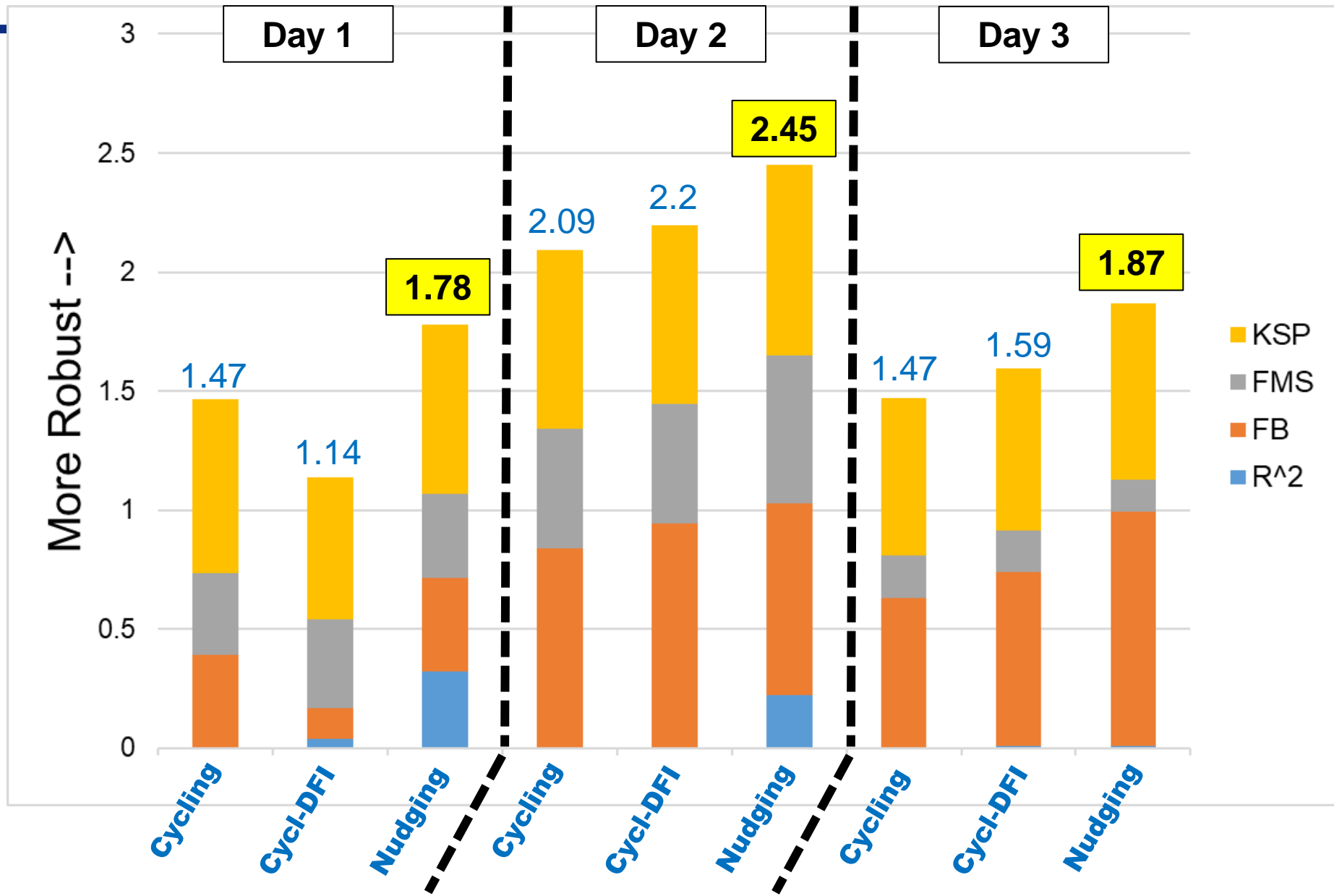


# Release Location 1 – Daily Analysis



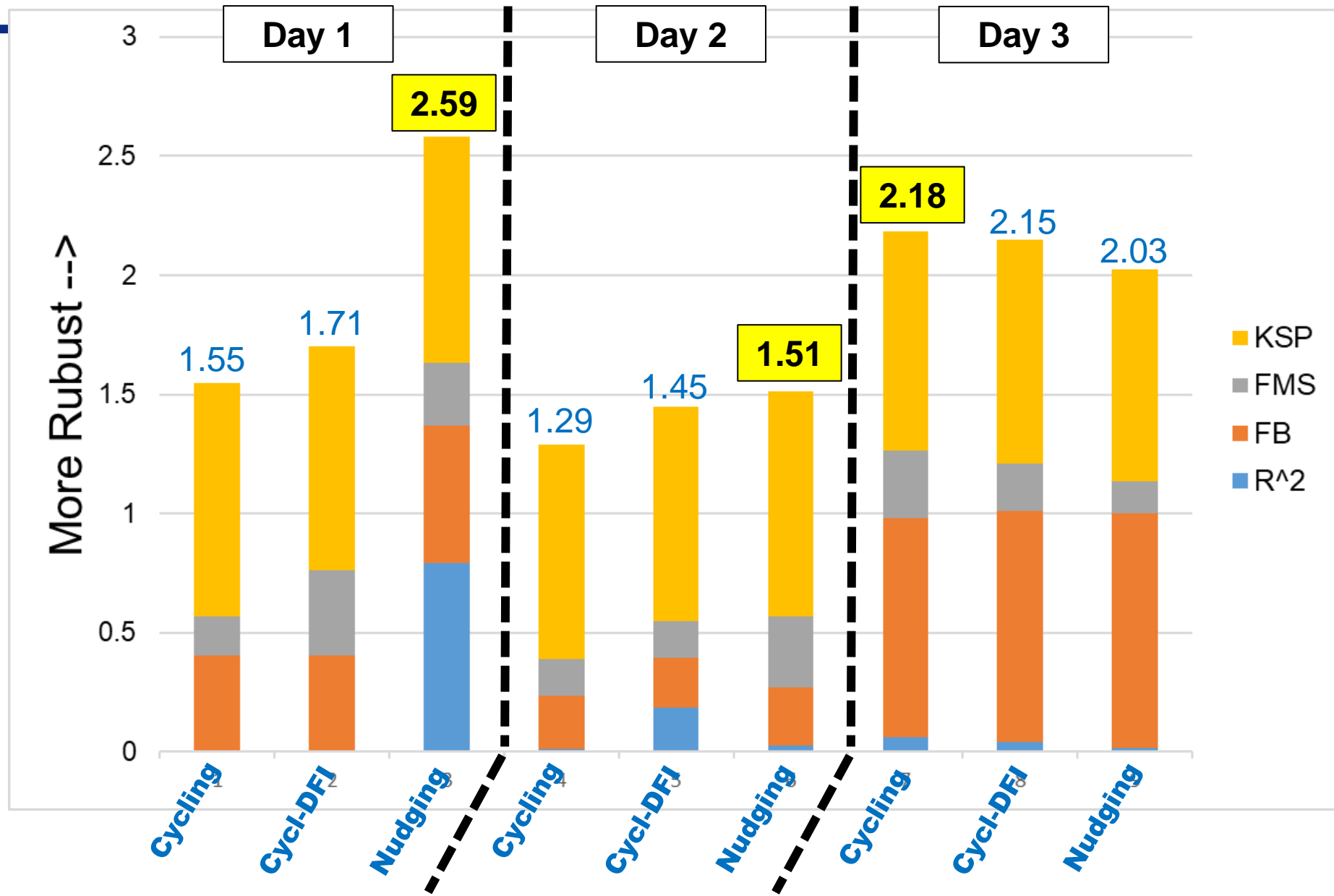


# Release Location 2 – Daily Analysis





# Release Location 3 – Daily Analysis





# Nudging consistently outperformed 3DVAR

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- Meteorological evaluation slightly better with nudging
- Dispersion results better in 8/9 releases with nudging
- Nudging provides a simple, continuous DA method for retrospective T&D
- Forecasts of T&D would likely benefit from more advanced variational techniques (future work)
- Hybrid DA techniques (e.g., hybrid nudging/variational/EnKF) might combine the best of both worlds (future work)



Thank you!  
Questions?