# Atmospheric $CO_2$ Flux and Transport Model Evaluation

S. R. Kawa, G. J. Collatz, Z. Tao, J. S. Wang, L. E. Ott, Y. Liu
(NASA Goddard Space Flight Center)
A. E. Andrews, C. Sweeney
(NOAA Earth System Research Laboratory)

- Global Model Overview
- Upgrade to MERRA-2 Meteorology
- Comparisons with NU-WRF
- Summary

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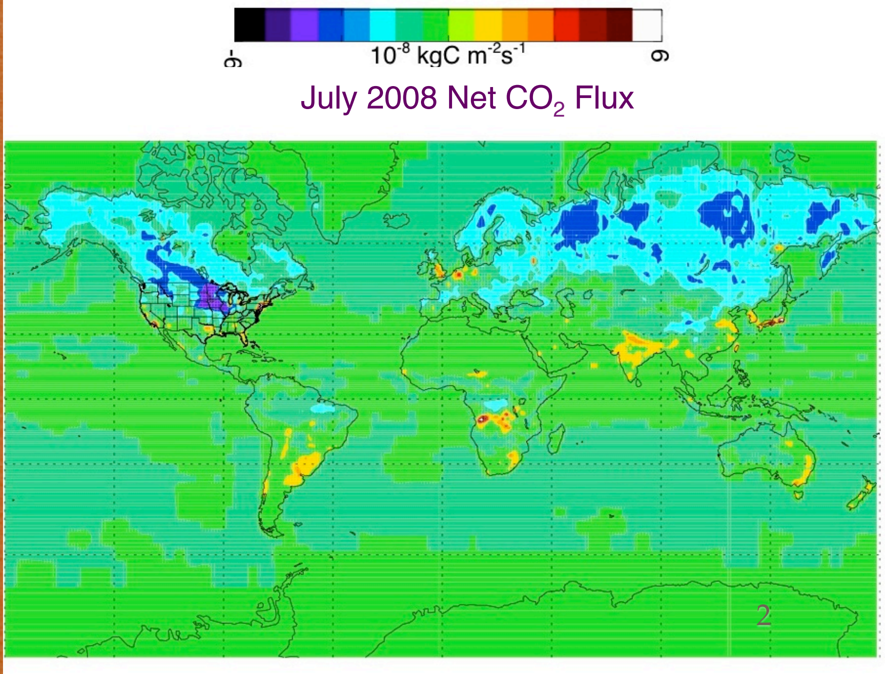
# Global $CO_2$ Model Framework (PCTM)

- Met fields from the Goddard GEOS-5/MERRA reanalysis.
    - 3-hour average fields used in off-line transport for 2005-2015
    - Model Grid: 1° x 1.25° x 56 levels to 0.4 mbar, hybrid terrain-following coordinate, output hourly

- CASA monthly global biosphere fluxes at 1x1° using mean GEOS analyzed meteorology and monthly NDVI/FPAR.
    - Biomass burning from GFED3 included in CASA fluxes.
    - 3-hourly CASA net fluxes from analyzed radiation and temperature
    - Annual mean near-balance

- Fossil Fuel emissions from CDIAC annually

- Ocean fluxes from pCO2 observations (Takahashi et al.)



# Assessment of Carbon Cycle Understanding

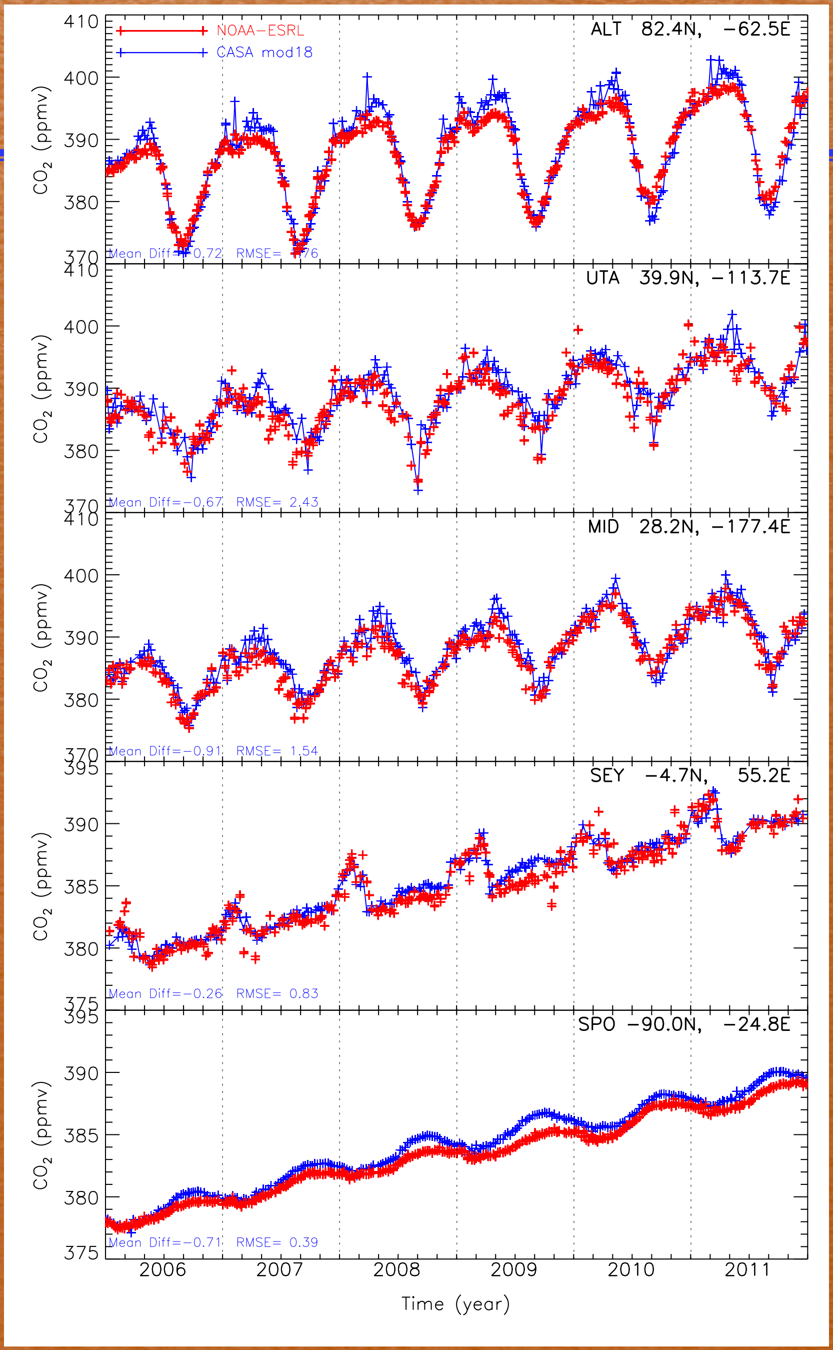
- Current best-effort models capture much of observed variability of global CO2

-> we know a lot about the problem

- Remaining uncertainties, though key, are difficult to address with heritage data

- Satellite data hold great promise, but so far no new discovery

- New measurements and modeling/ analysis systems must have have sufficient fidelity to address small deviations



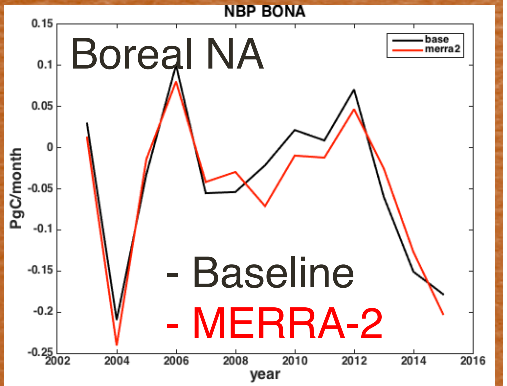
# GEOS-5 MERRA-2 vs MERRA

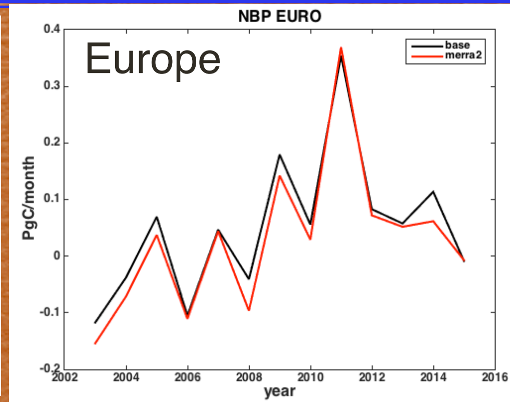
- Changes in physical parameterizations lead to improvements in the mean climate state (Molod et al., 2015).
- Data assimilation includes approximately 1M more observations per 6-hour period after 2007.
- Dry air mass conserved, and changes in surface pressure and moisture more realistically represented over both short and multi-year timescales.
- Observation-corrected precipitation used to force the land surface model.
- Includes assimilation of aerosol optical depth alongside traditional meteorological variables.
- Changes in the representation of the diurnal cycle of boundary layer mixing (McGrath-Spangler et al., 2015).
- Wind fields and transport are computed using a cubed-sphere grid.

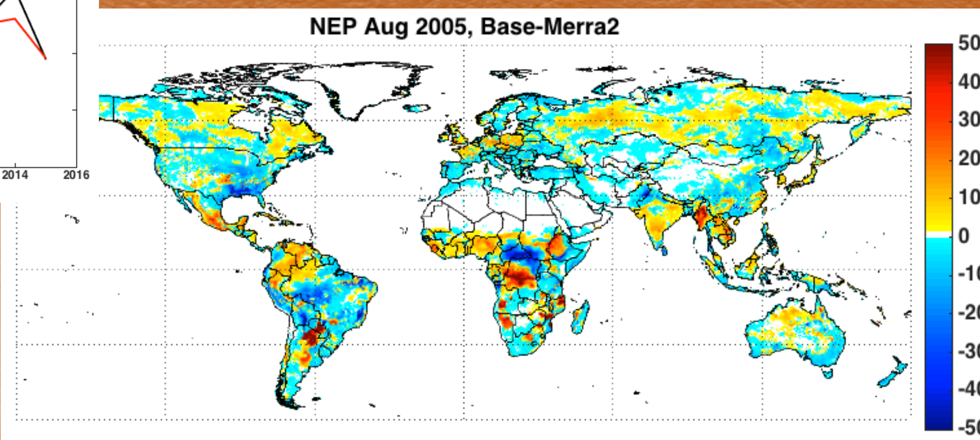
# Other PCTM Changes

- CASA-GFED Monthly Fluxes at 0.5°
- Transport Model Grid: 0.5° x 0.625°
- CDIAC Monthly FF fluxes
- Takahashi 2009 Ocean fluxes

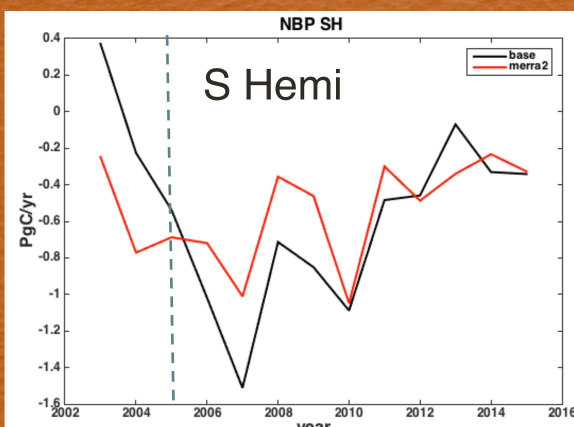
# CASA-GFED Flux Changes

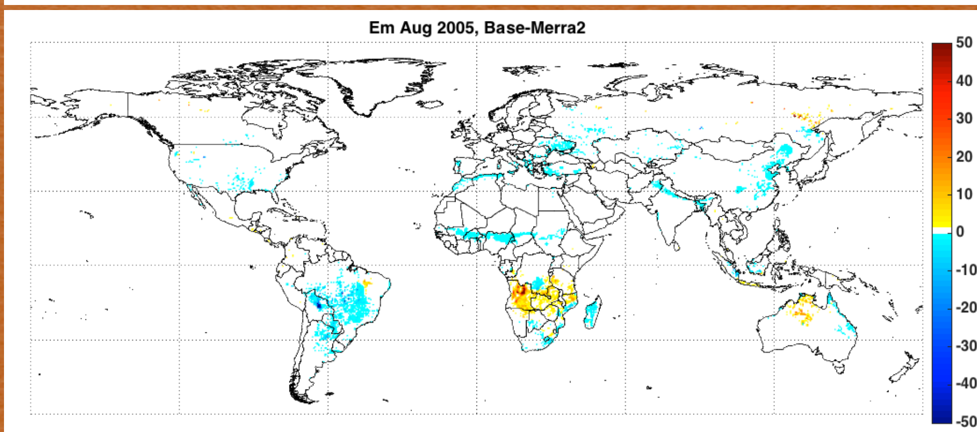



- Flux differences (NBP) in extra tropics, Australia are small

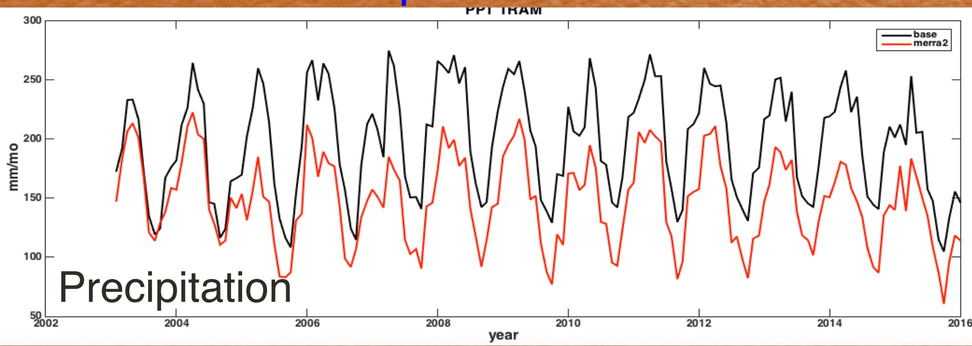


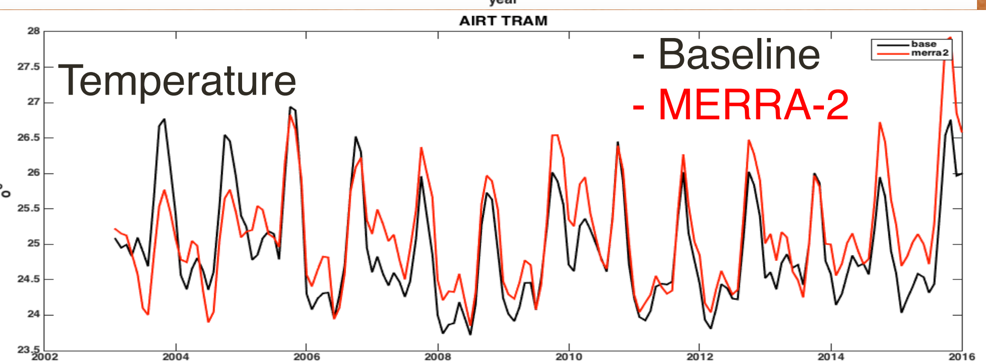




- Largest flux differences in tropical America, temperate SA, N & S Africa

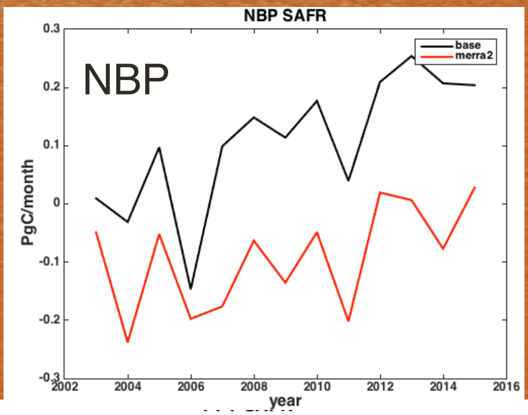
# Met Drivers

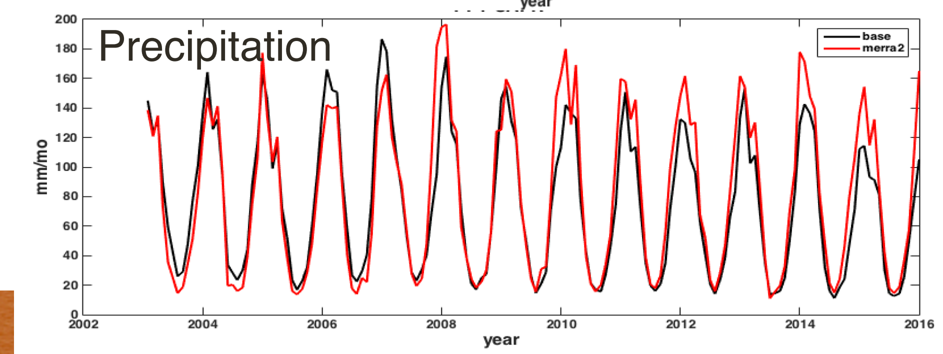
## Tropical America

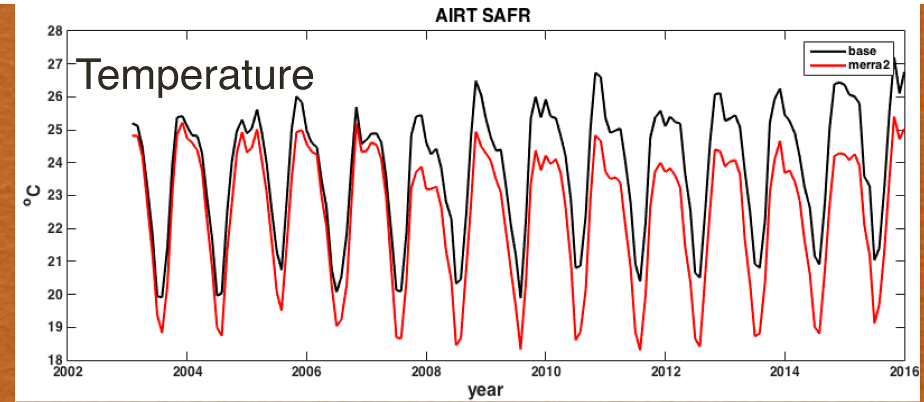



## South Africa

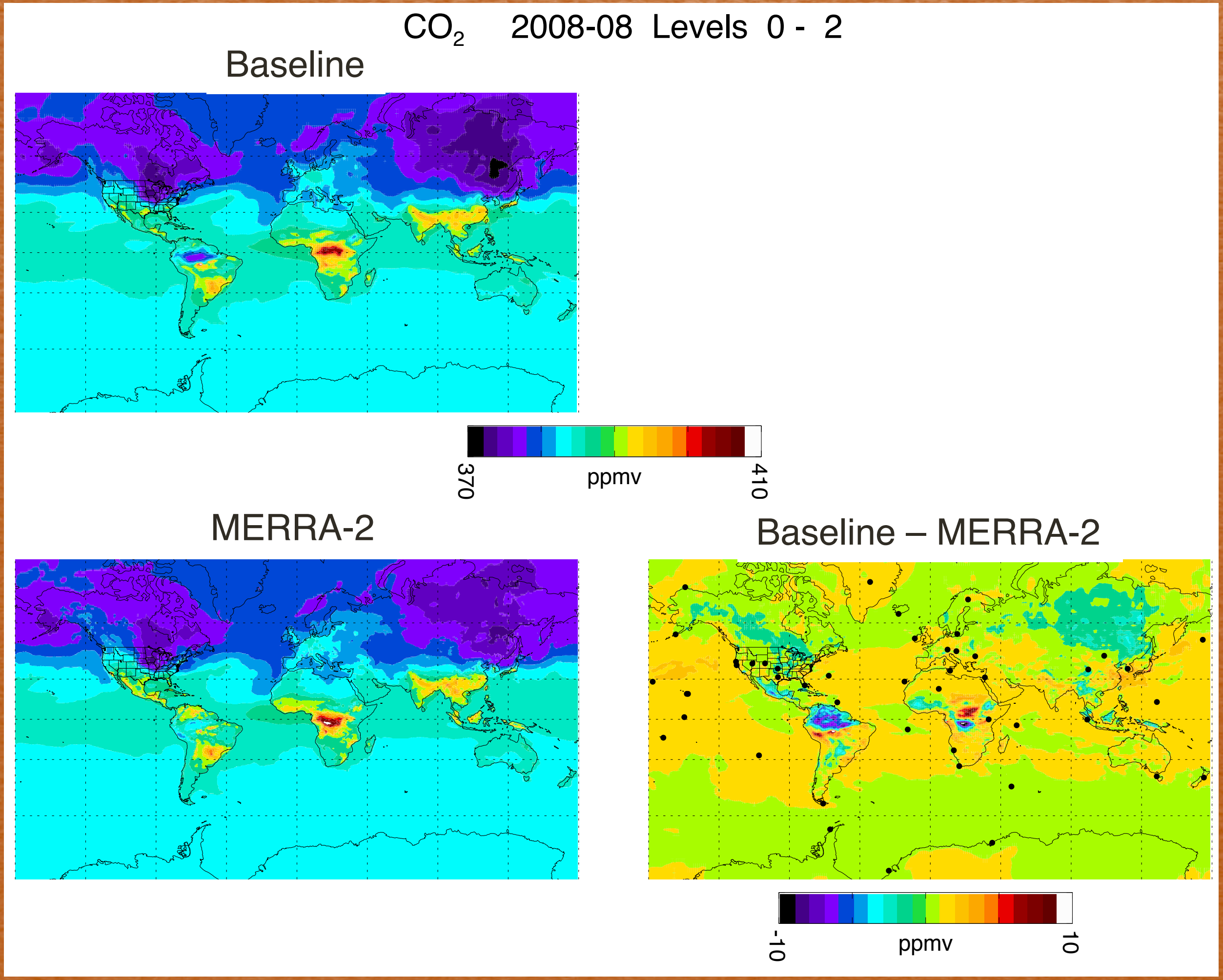



- Substantial physiological flux differences in tropics are driven by changes in meteorology.

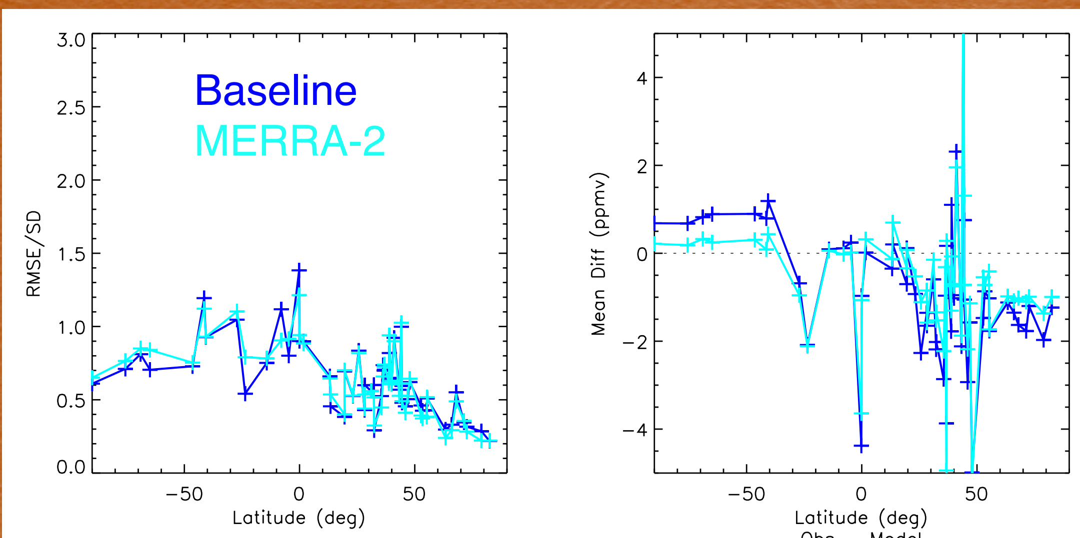
# Global $CO_2$ Change

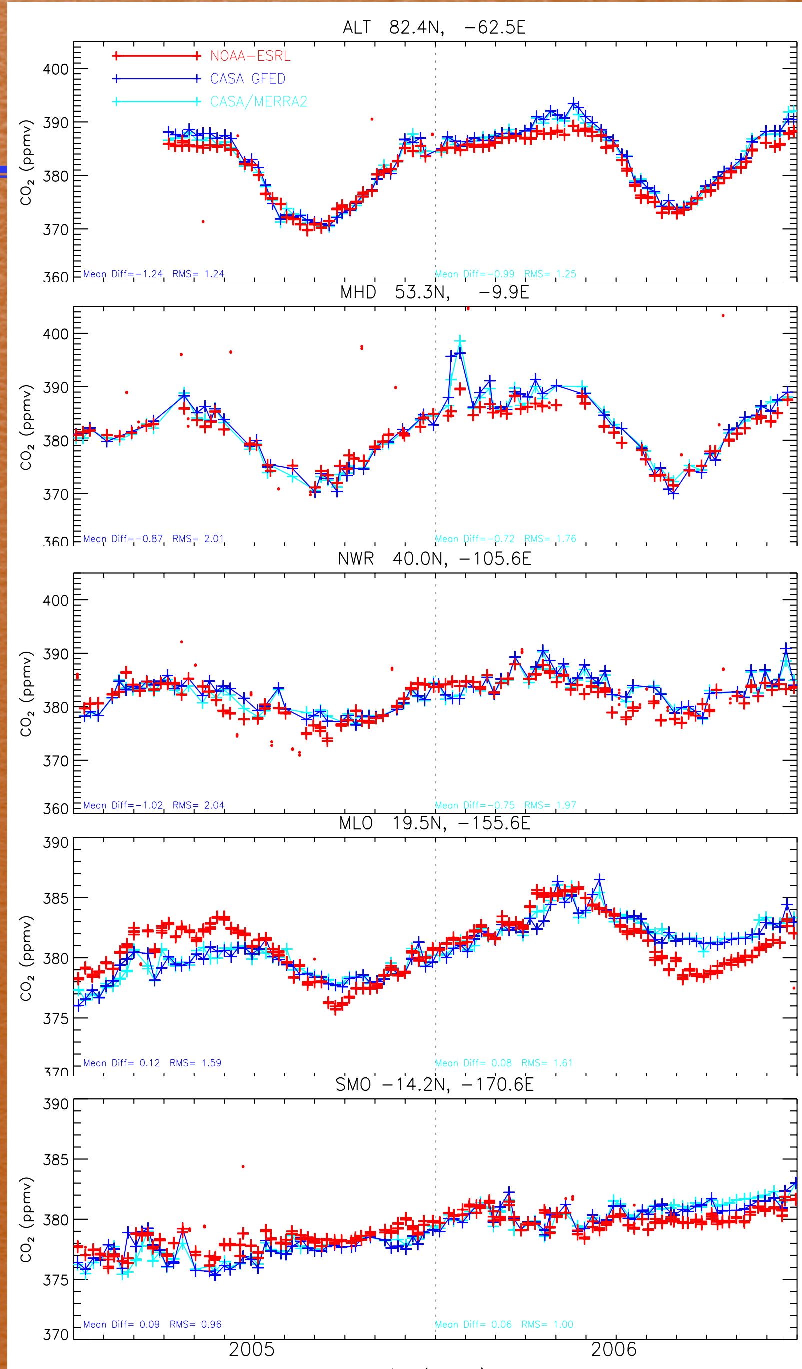



- Relatively minor changes in atmospheric $CO_2$ outside tropics.
- Large differences in tropics

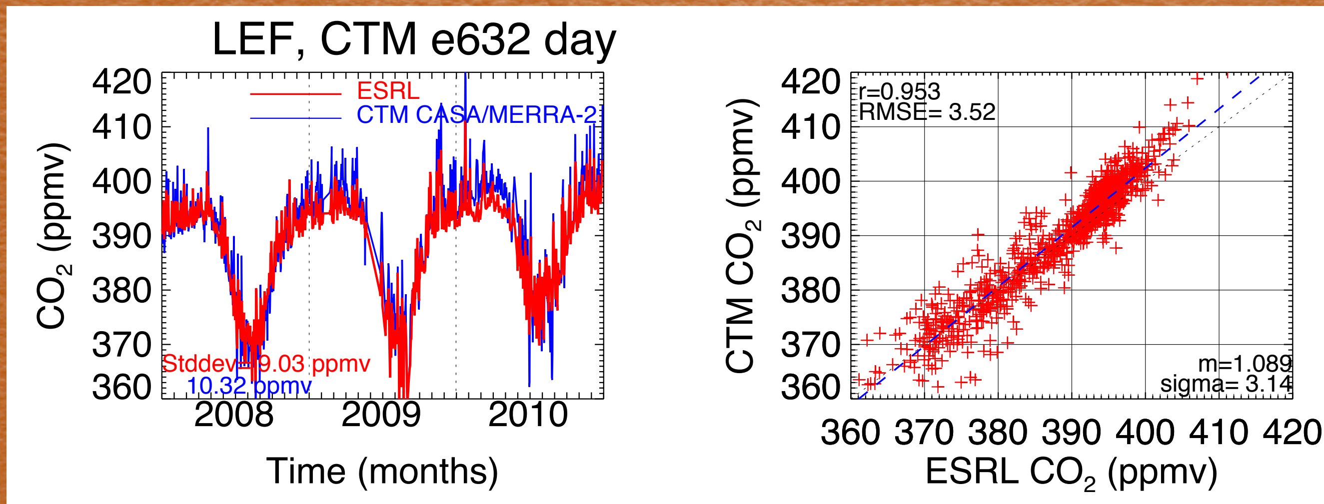
# Flask Data

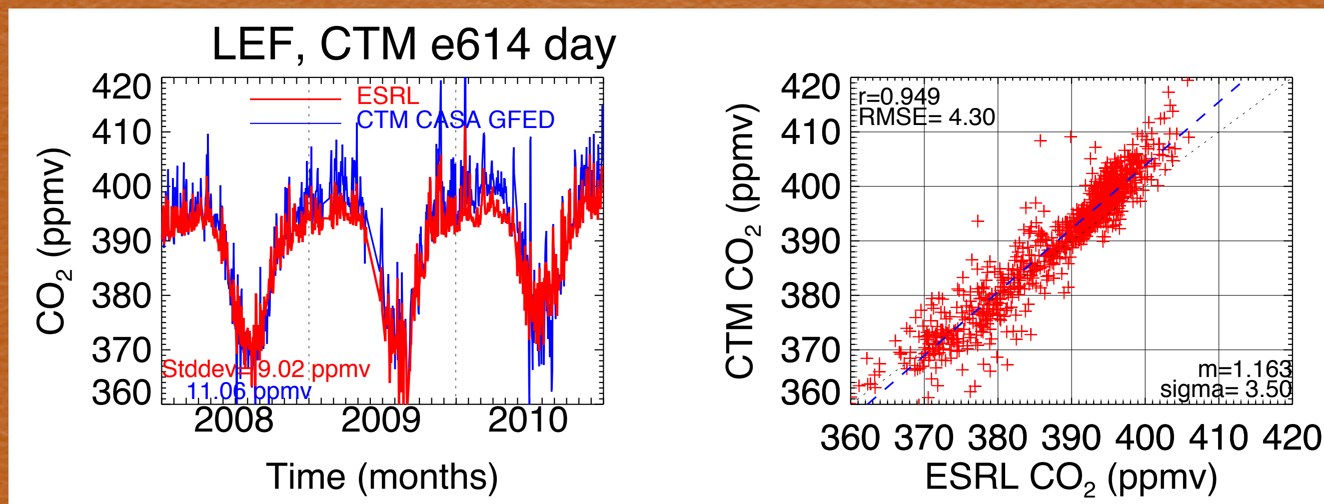
- Minor changes in $CO_2$ comparisons with flask data, perhaps favoring MERRA-2.
  - decreased hemispheric gradient: transport + ocean flux



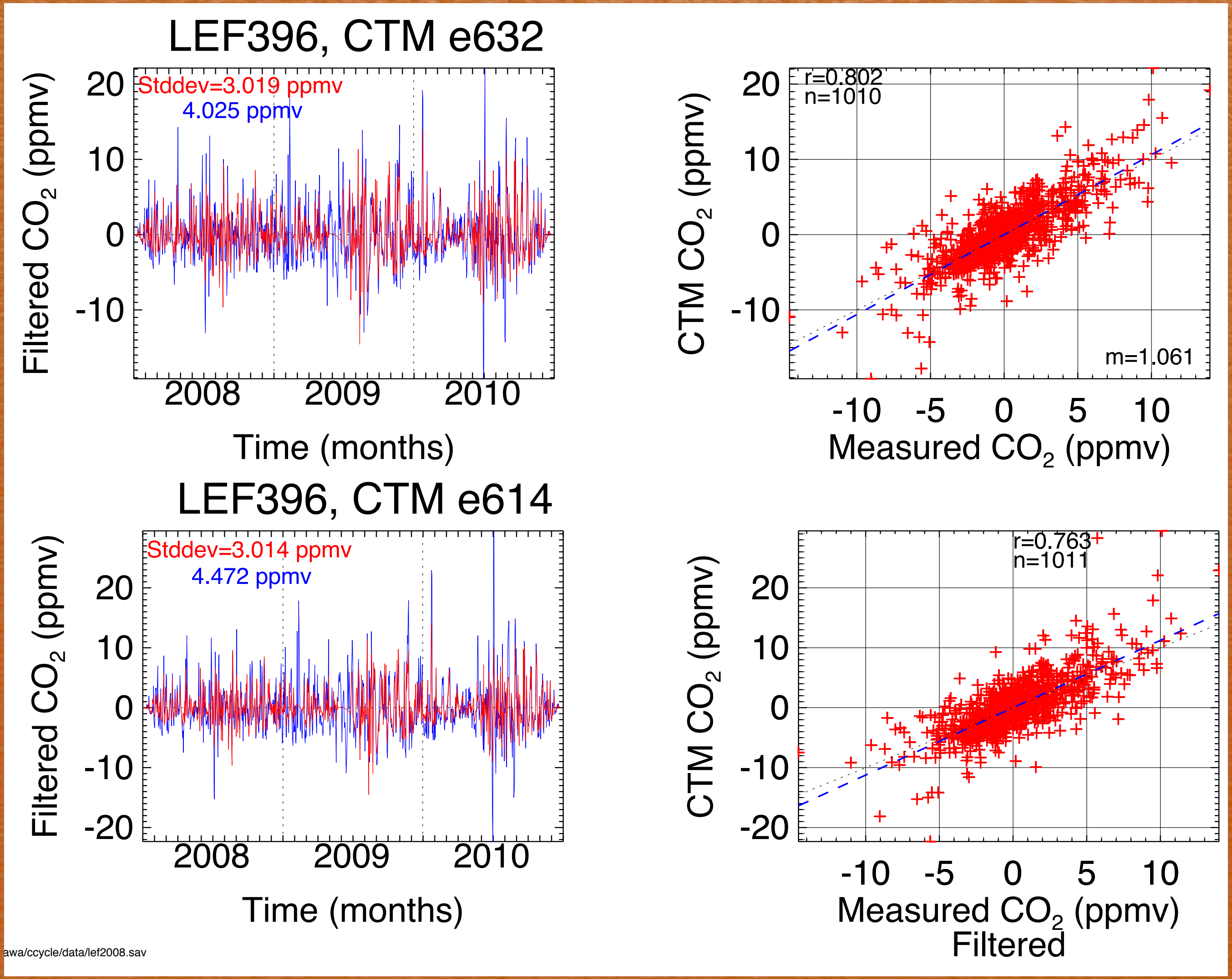
# Continuous Data




- MERRA-2 better correlated with data at most sites
  - horizontal resolution?

# Synoptic Variability

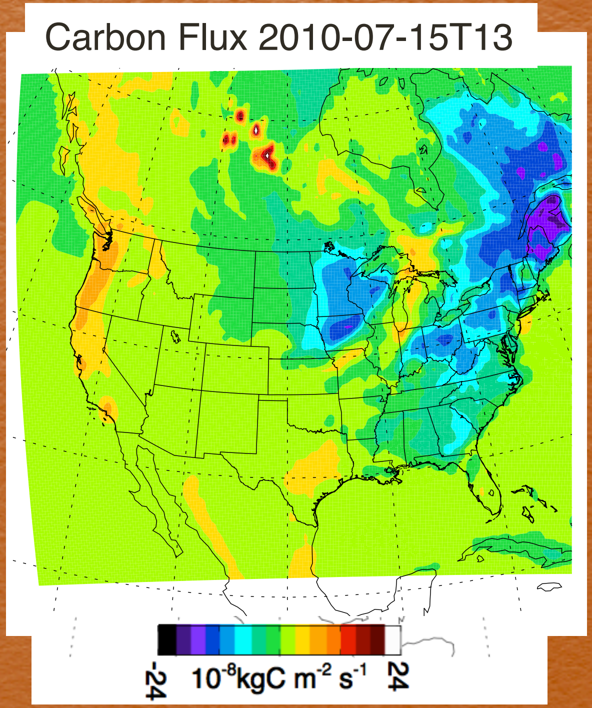


# Diagnostic $CO_2$ Flux and Transport Modeling in NU-WRF and GEOS-5

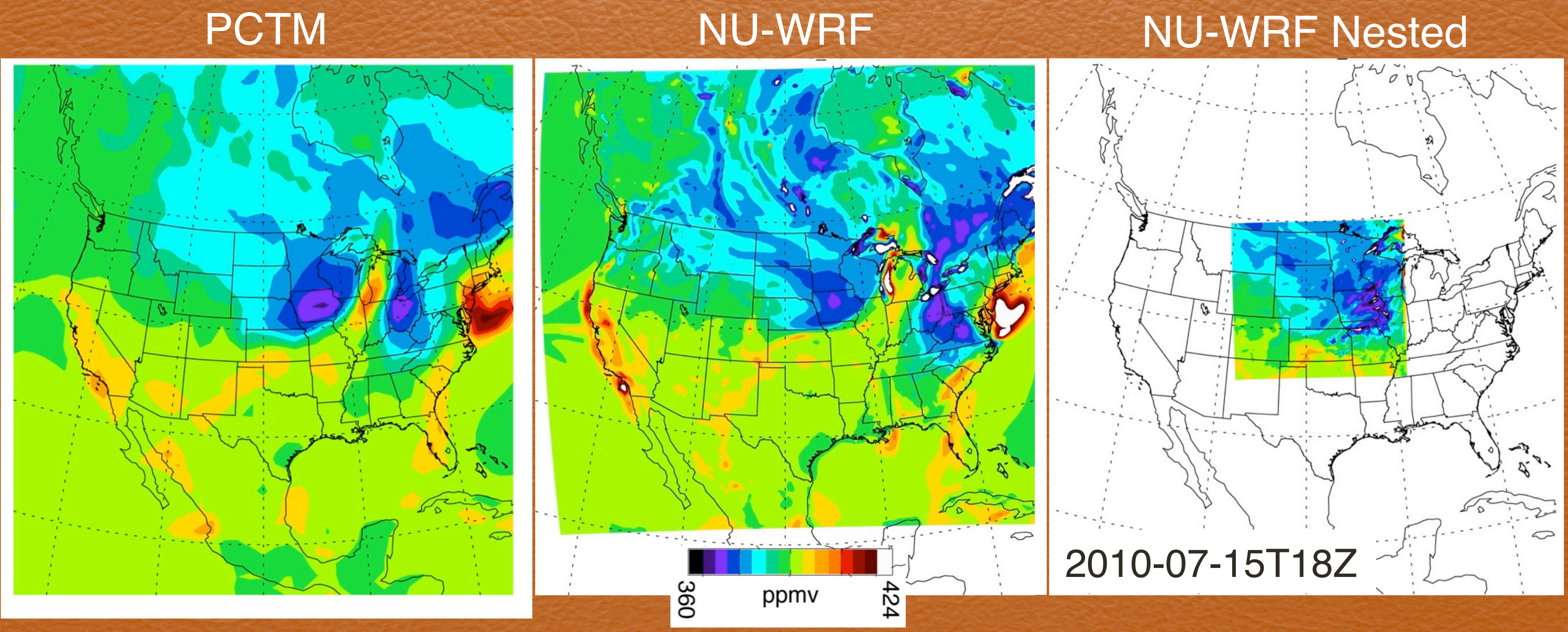
- Model Overview
- In Situ Data Comparisons
  - flask, tower, aircraft
  - model diagnostics
- Satellite Data Comparison

# Regional Modeling Overview

- Global PCTM (1 x 1.25° x 56 levels)
  - GEOS-5 MERRA met data
- Regional NU-WRF (~(27 km)$^2$ x 40 levels)
  - nudged with NARR
  - boundary conditions from global model
  - YSU PBL, Grell Convection schemes
- Surface Fluxes (0.5°, 3-hrly)
  - CASA GFED vegetation physiology and biomass burning
  - CDIAC Annual Fossil Fuel
  - Takahashi Ocean Flux
- $CO_2$ for 2010 output hourly

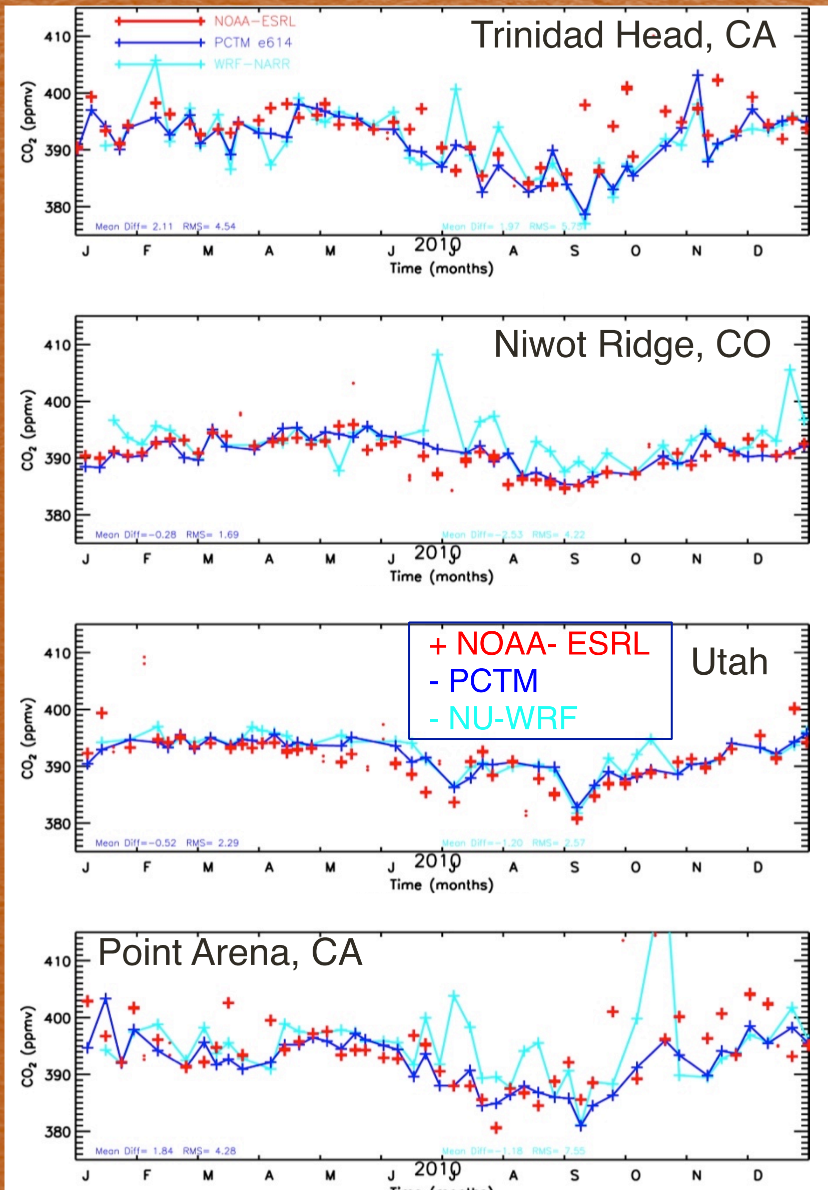


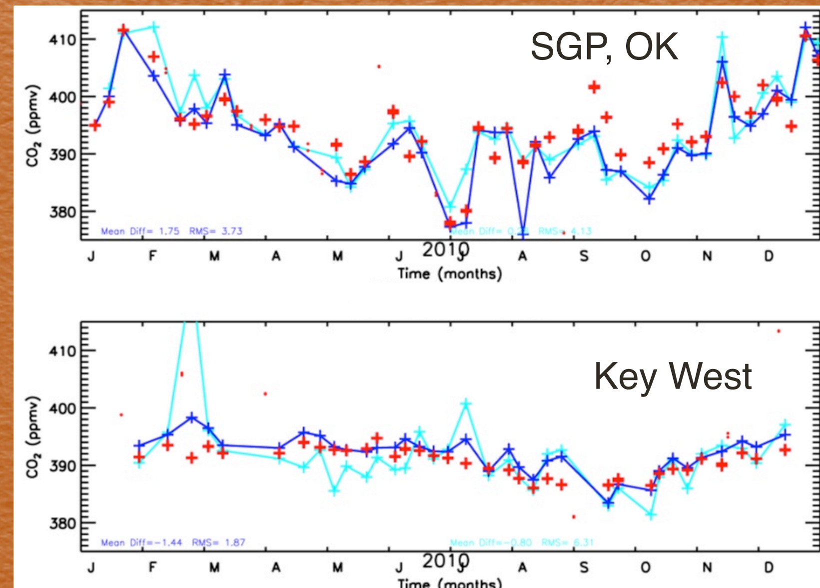
# Model $CO_2$ Near Surface




- Higher resolution transport models produce increasingly more structure in atmospheric $CO_2$

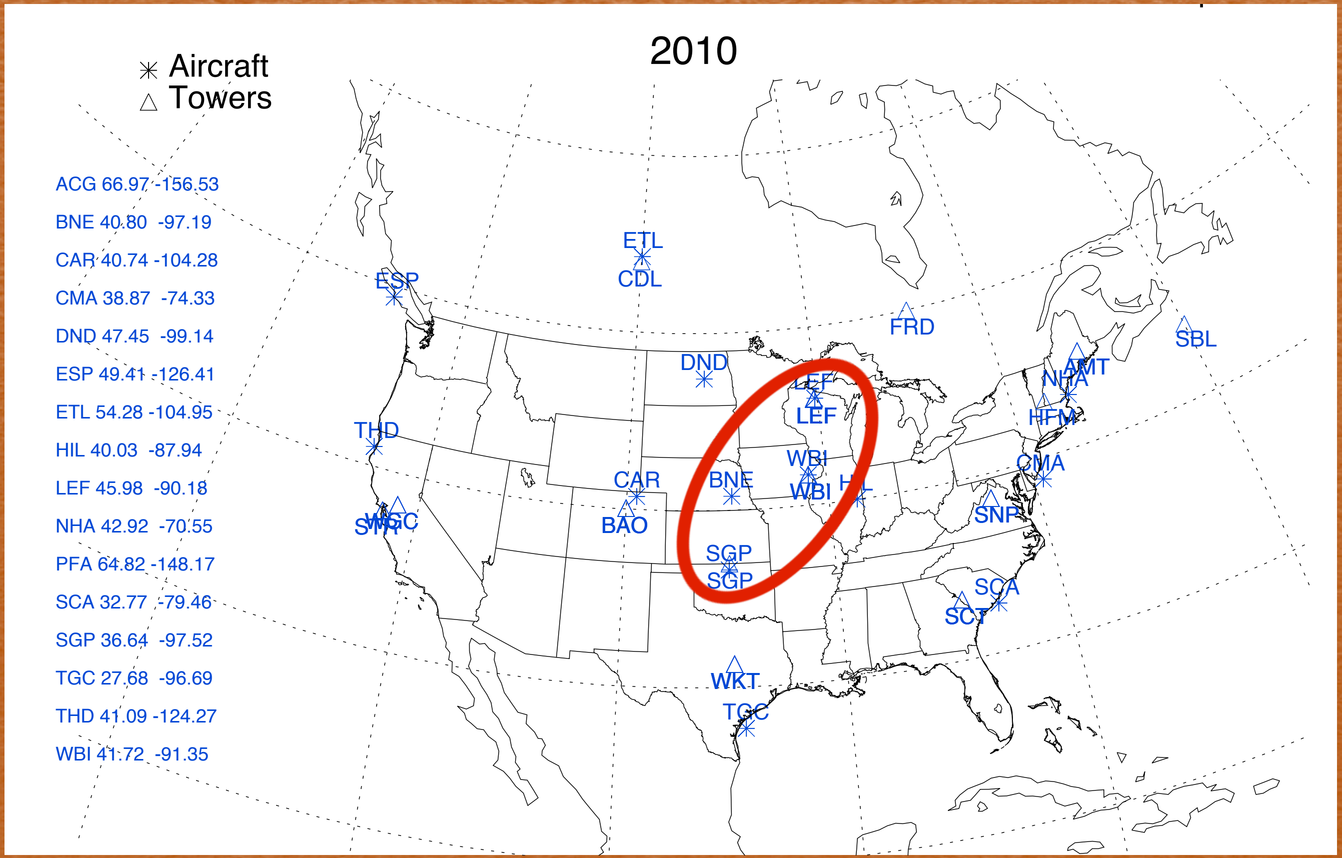
# Flask Sample Data Comparison



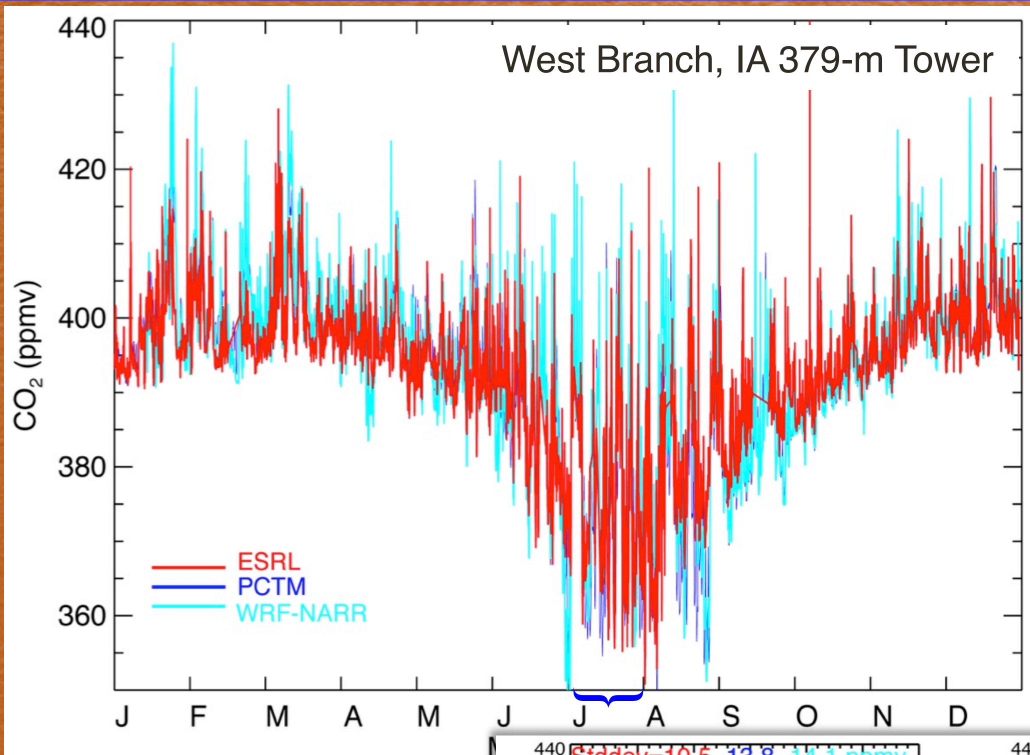

- Models capture much of seasonal and synoptic variability as expected
- NU-WRF more variable than PCTM as expected
- NU-WRF more variable than observations and less correlated at some sites – unexpected

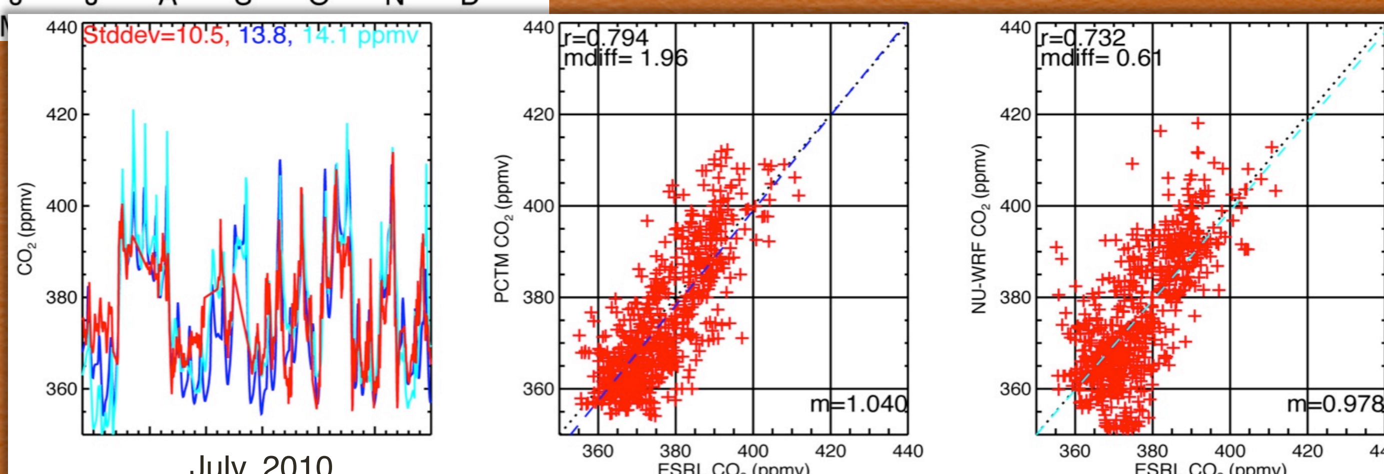
# Tower and Profile Data




- NOAA ESRL GMD

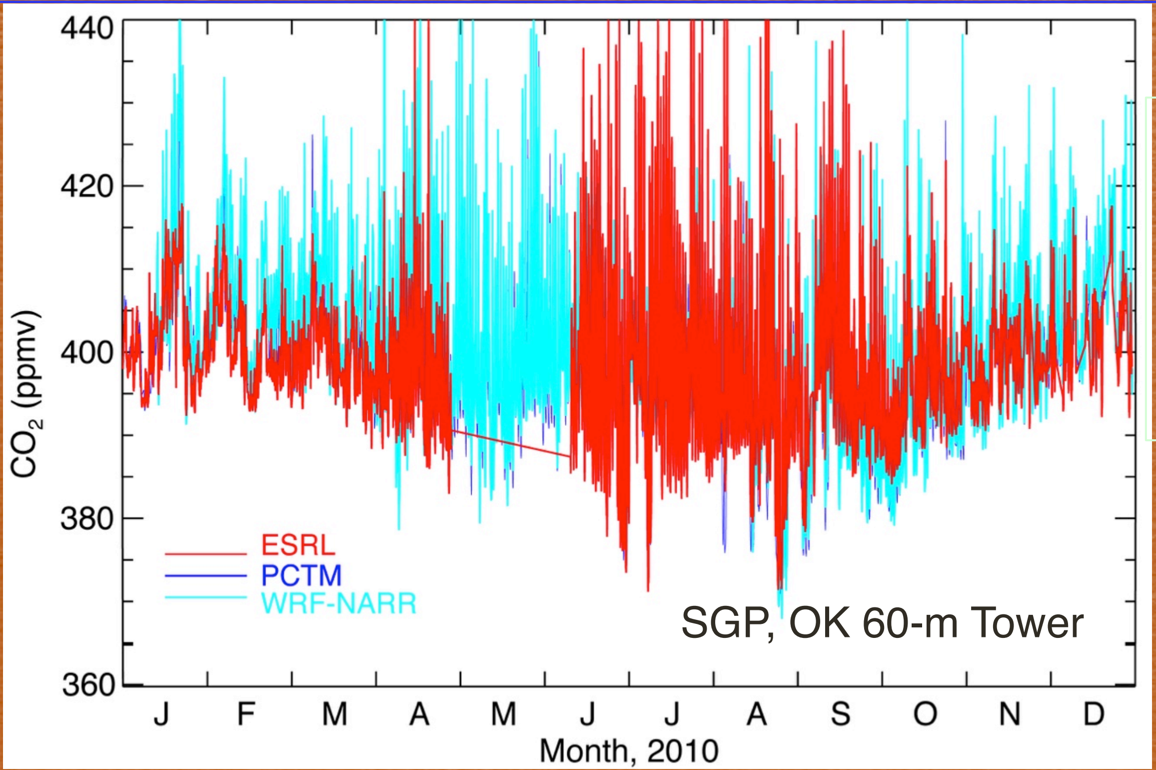
# Tower Data Time Series



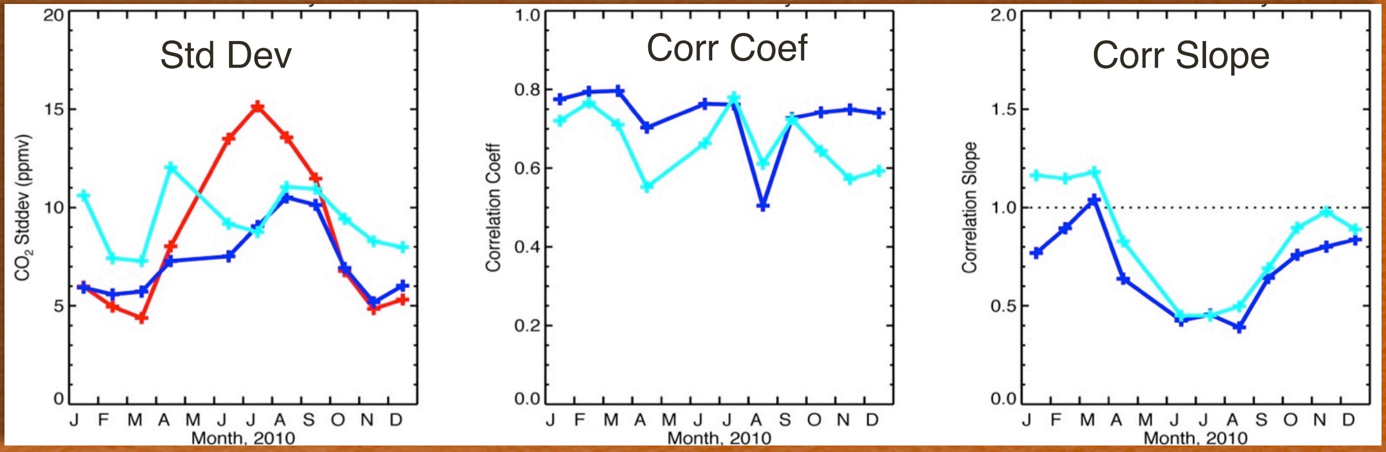




- Hourly data comparisons at tall towers show large variability, good correlation for both models
- PCTM correlation slightly better than NU-WRF

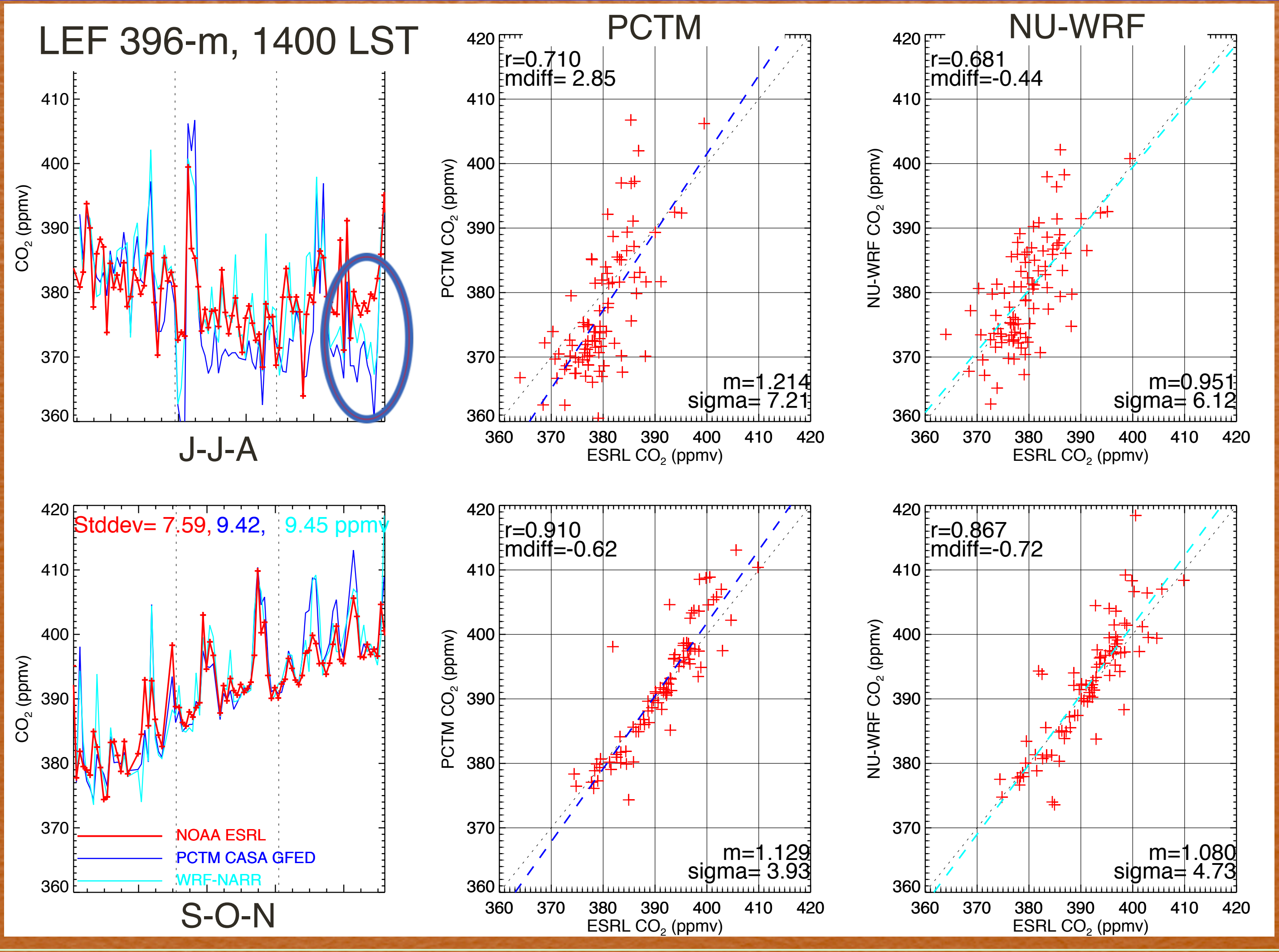
# Low-level Tower Data




- Hourly data from relatively low tower levels dominated by diurnal cycle, which models don't handle well; NU-WRF often worse.

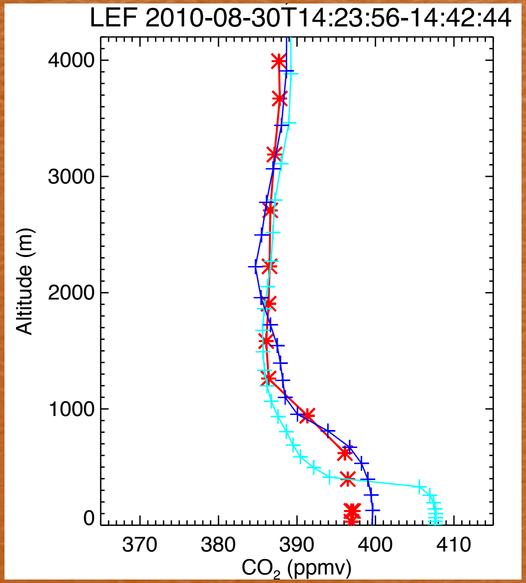


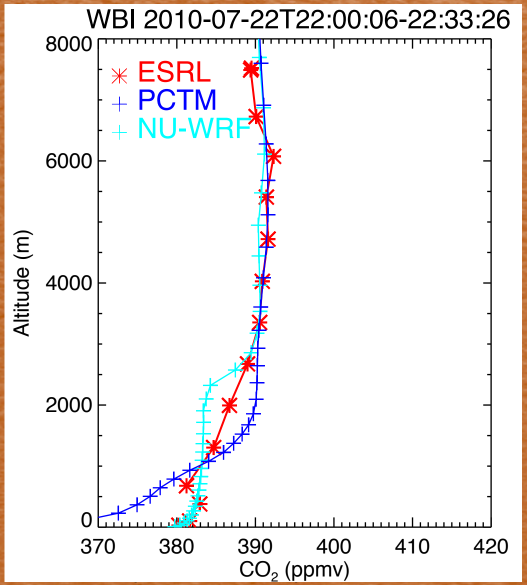
# Tower Data Time Sample



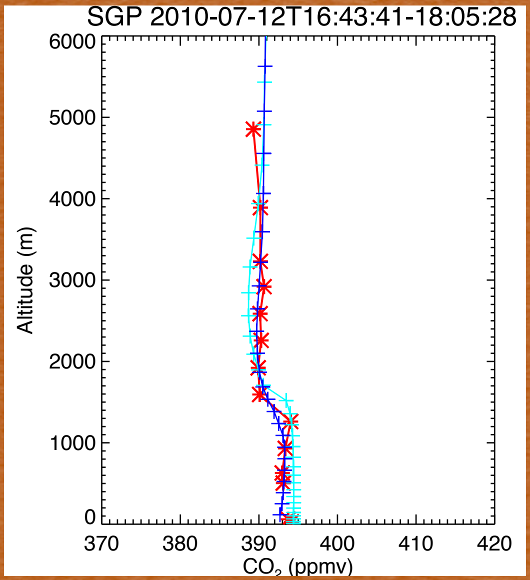

- Midday sample data comparisons show both models capture most of observed variability, but NU-WRF not clearly better.

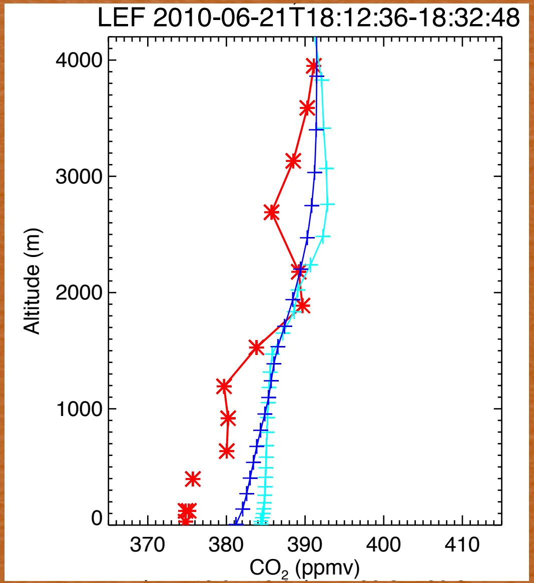
# Vertical Profile Data Comparisons



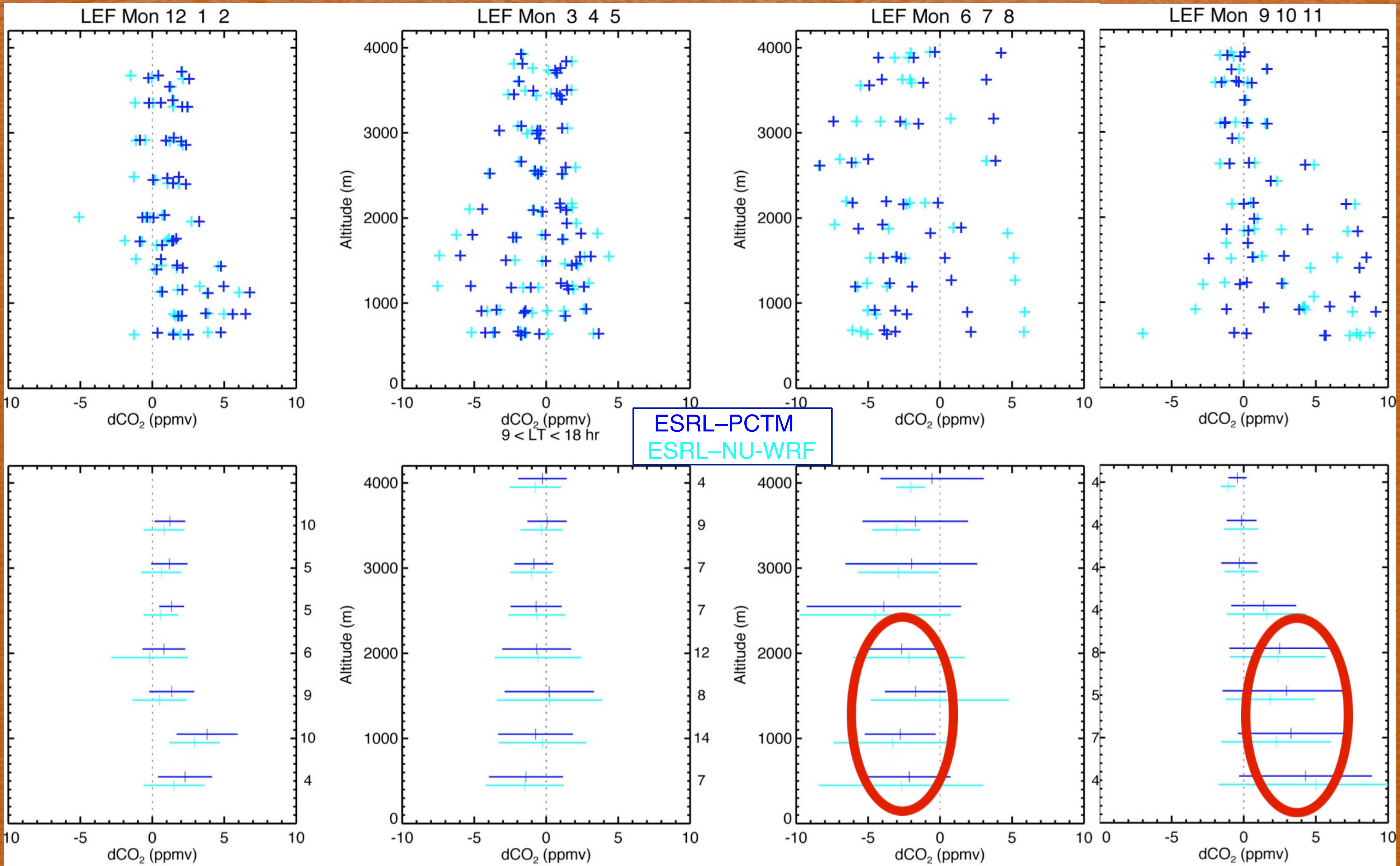




- Profile $CO_2$ data show varying degrees of model agreement
- Model mixing depths often differ
- Need to generalize across sites, seasons, times of day, weather

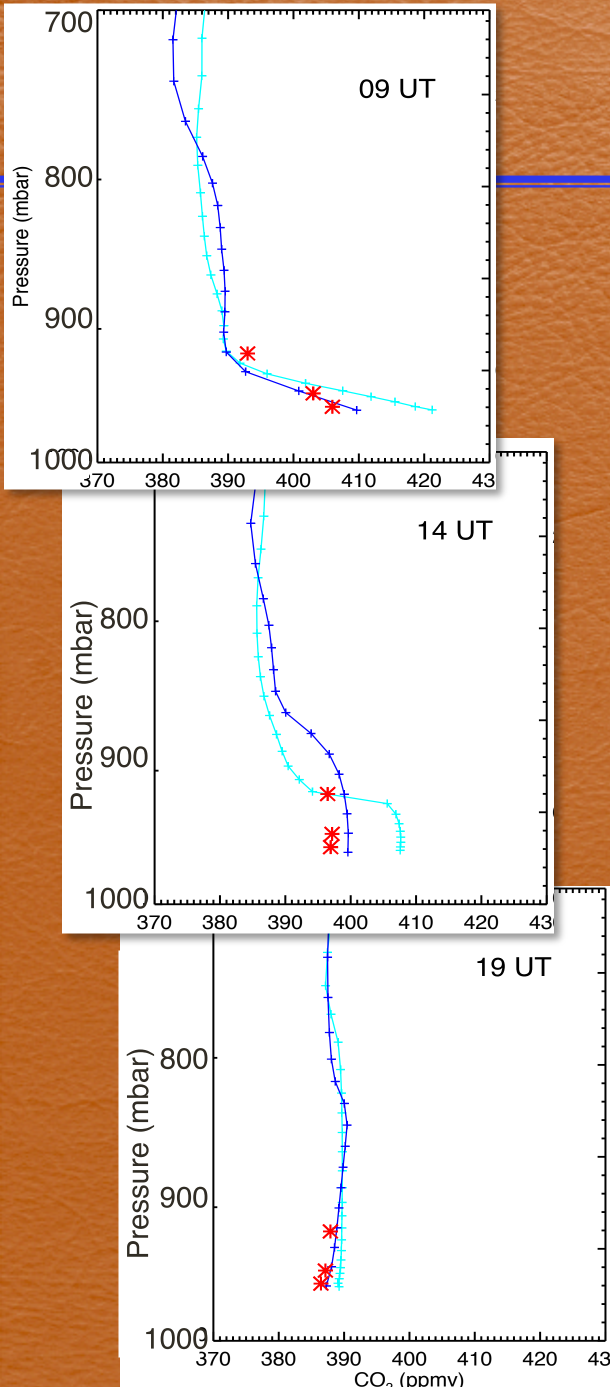


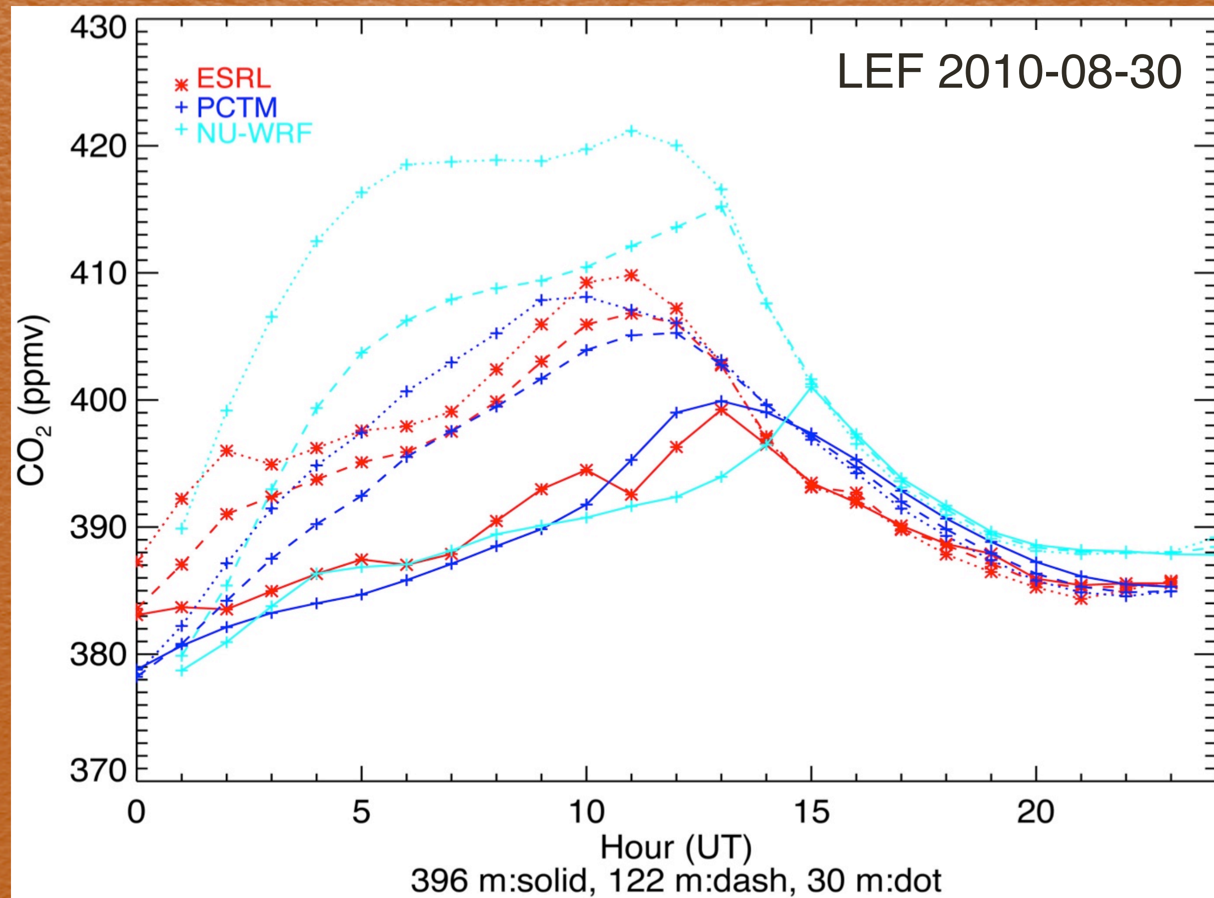



# Seasonal Difference Composites



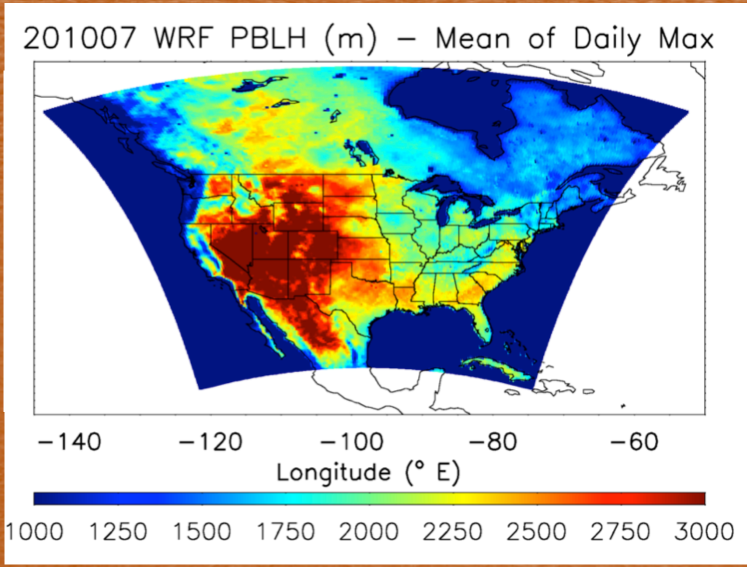
# Tower Profile Comparisons

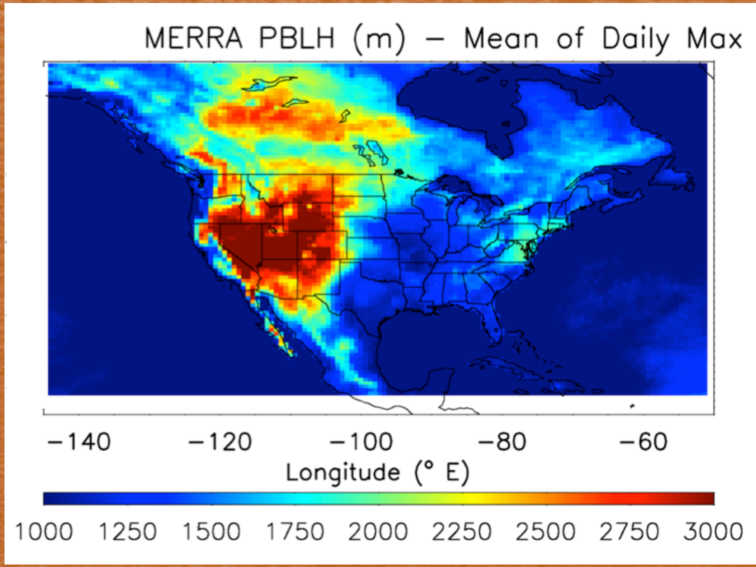


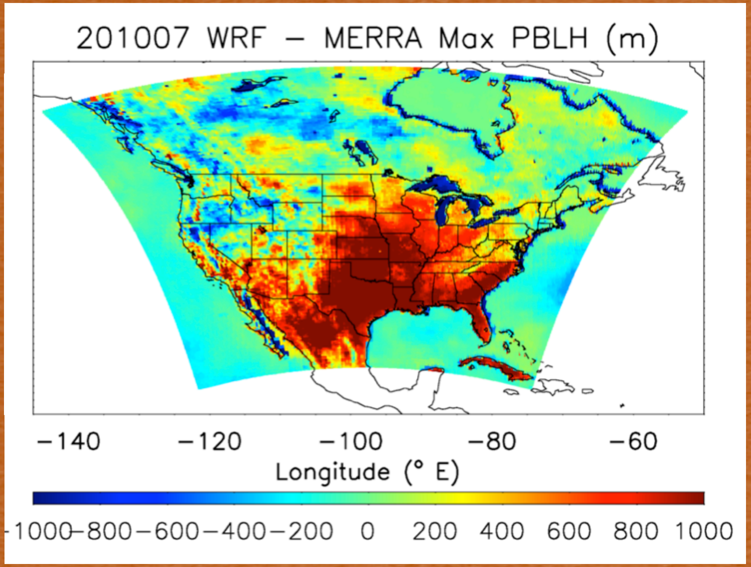




- Data comparisons show tendency for NU-WRF to exaggerate vertical gradient near surface when stable but have deeper mixing height.

# Model Diagnostics

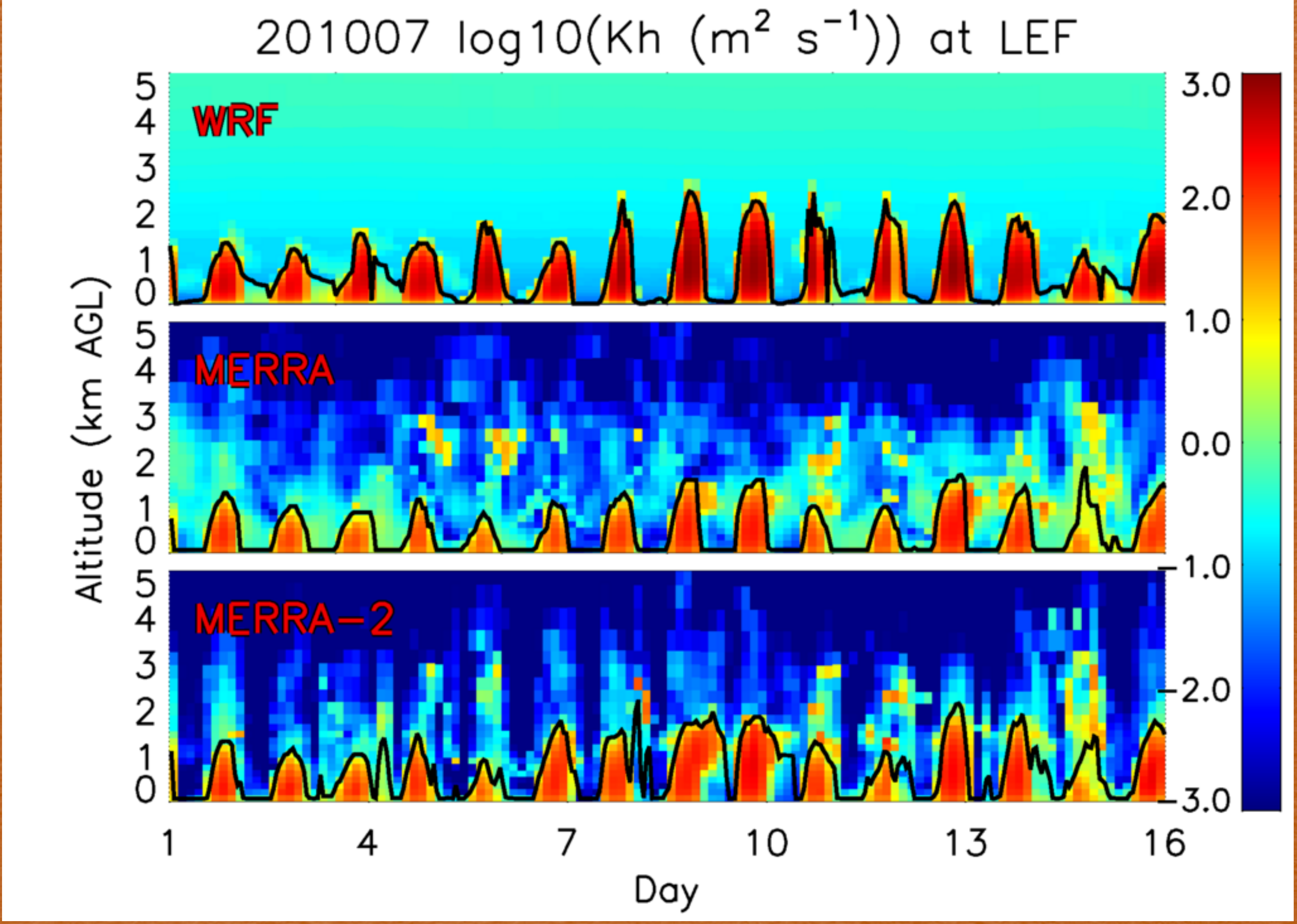


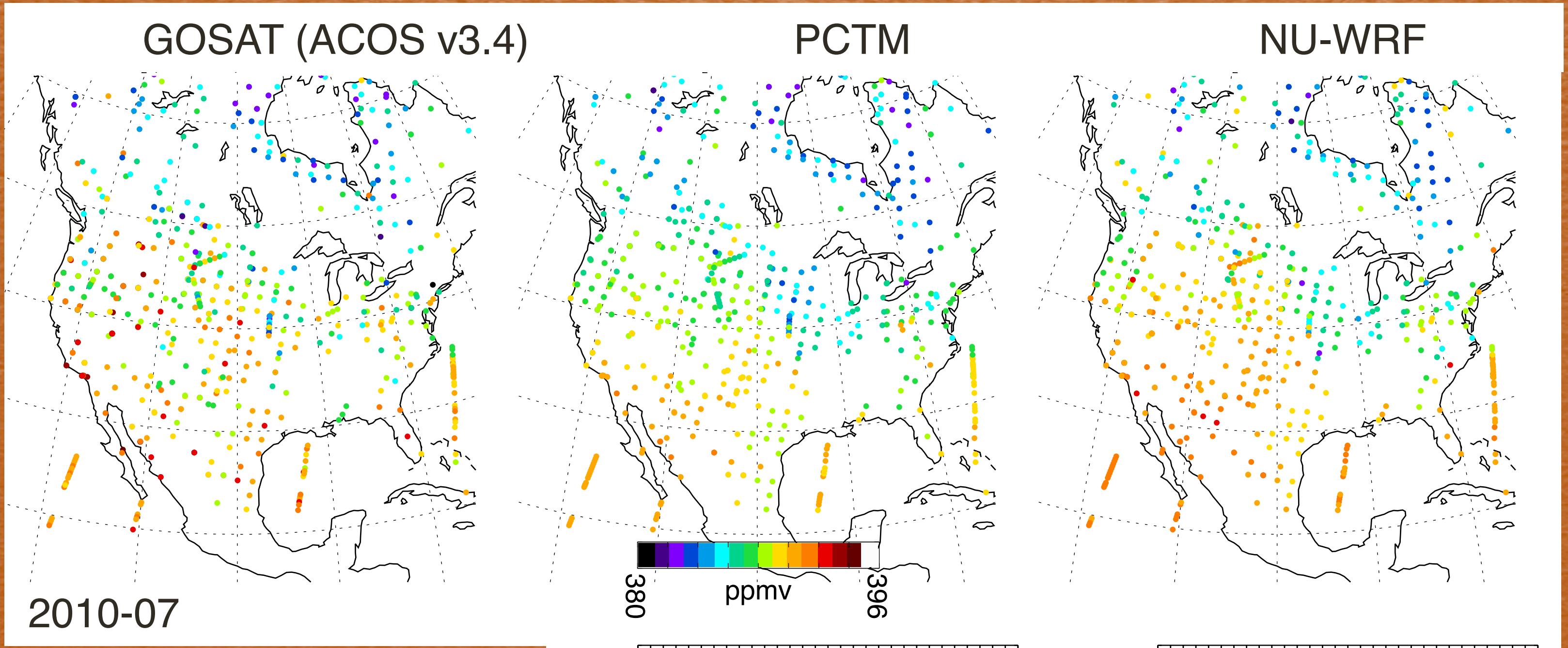




- Substantial differences in PBL height between models in some regions.
- Test of alternate PBL scheme in NU-WRF (MYJ) proved slightly worse for $CO_2$ comparisons.

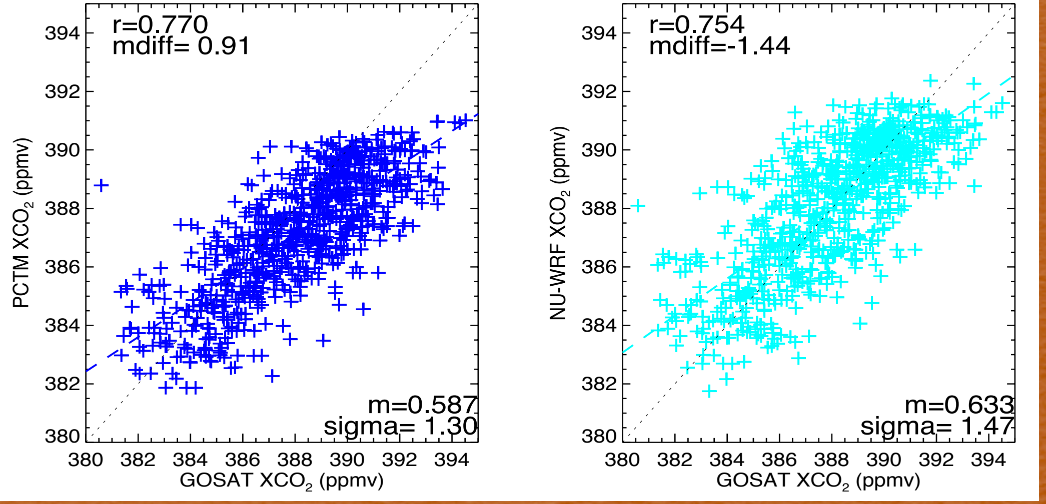
# Model Diagnostics



# Satellite Column Data




- Less susceptible to BL height uncertainty
- Model correlations with GOSAT similar to in situ



# Summary/Conclusions

- Global $CO_2$ flux and transport driven by MERRA-2 look as good or better then prior generation simulations
  - significant differences in tropics
  - generally minor improvements elsewhere

- Substantial variability across model/data $CO_2$ comparisons results from transport and mixing differences.

- WRF model (here) is not uniformly better for tracer transport than global model despite better resolution.
  - other model physics characteristics cause larger differences

- Neither model handles nighttime BL and low tower data well
  - need continued work on physics, diagnostics
  - caution in using data

# Acknowledgements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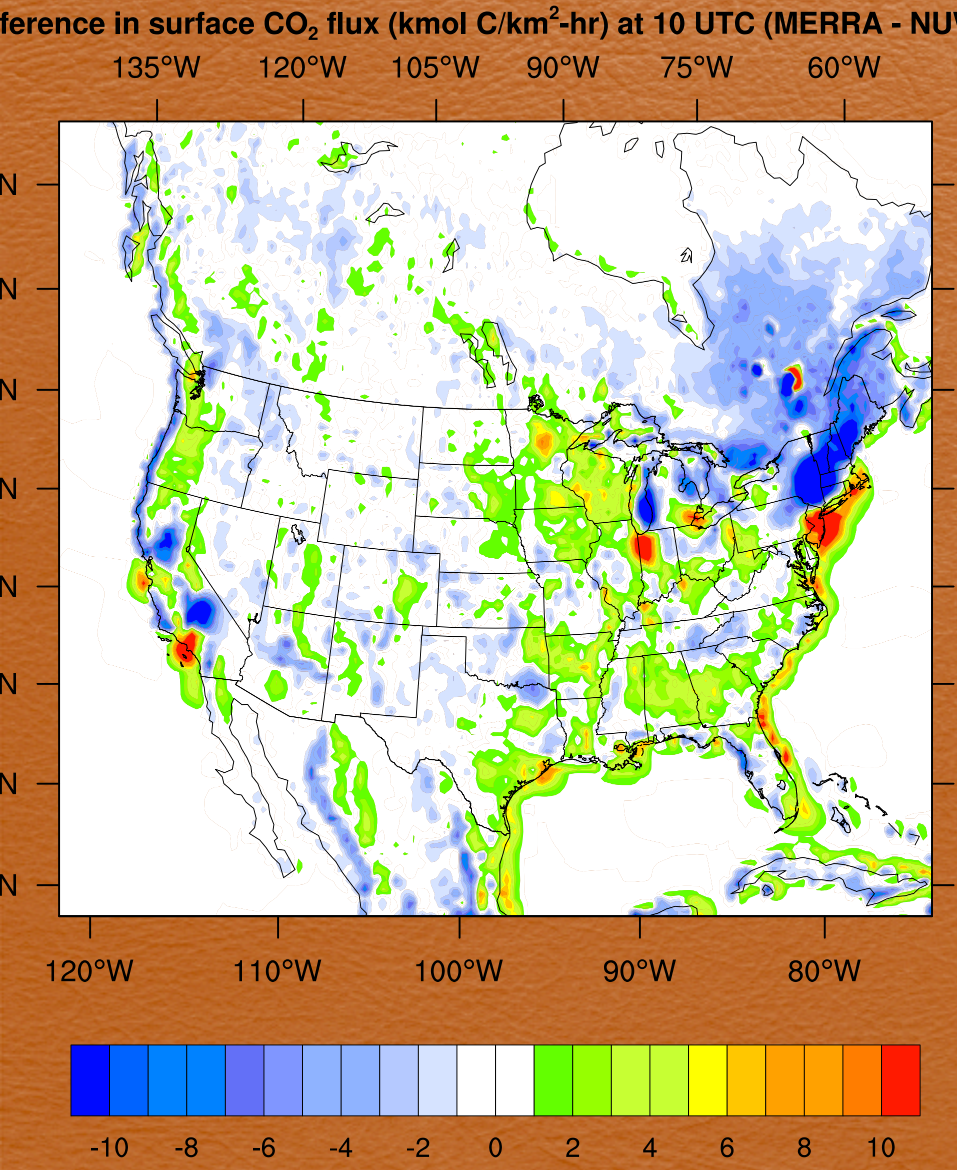
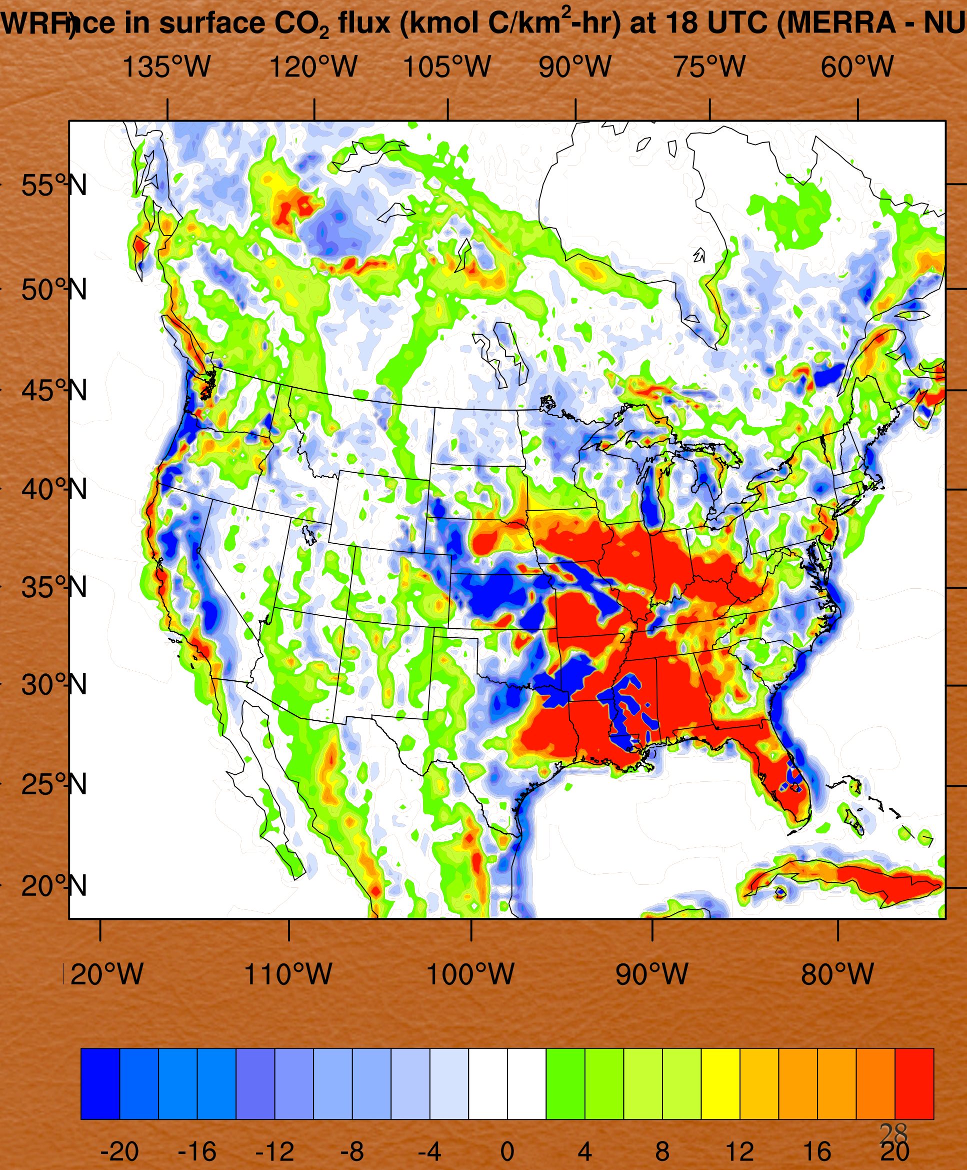
- S. Biraud, DOE LBNL ARM Program
- GOSAT Data, NASA ACOS Project
- D. B. Considine – NASA HQ, Modeling and Analysis Program

# Fluxes Driven by NU-WRF



# Model Diagnostics