Constraining the Earth System with EOS-Aura Observations

Steven Pawson

Global Modeling and Assimilation Office, NASA GSFC

Objective: to give an overview of how EOS-Aura has impacted GMAO's ability to provide complete Earth System analysis and prediction capabilities and how EOS-Aura observations will continue to impact us in the future

Overview

Main results show:

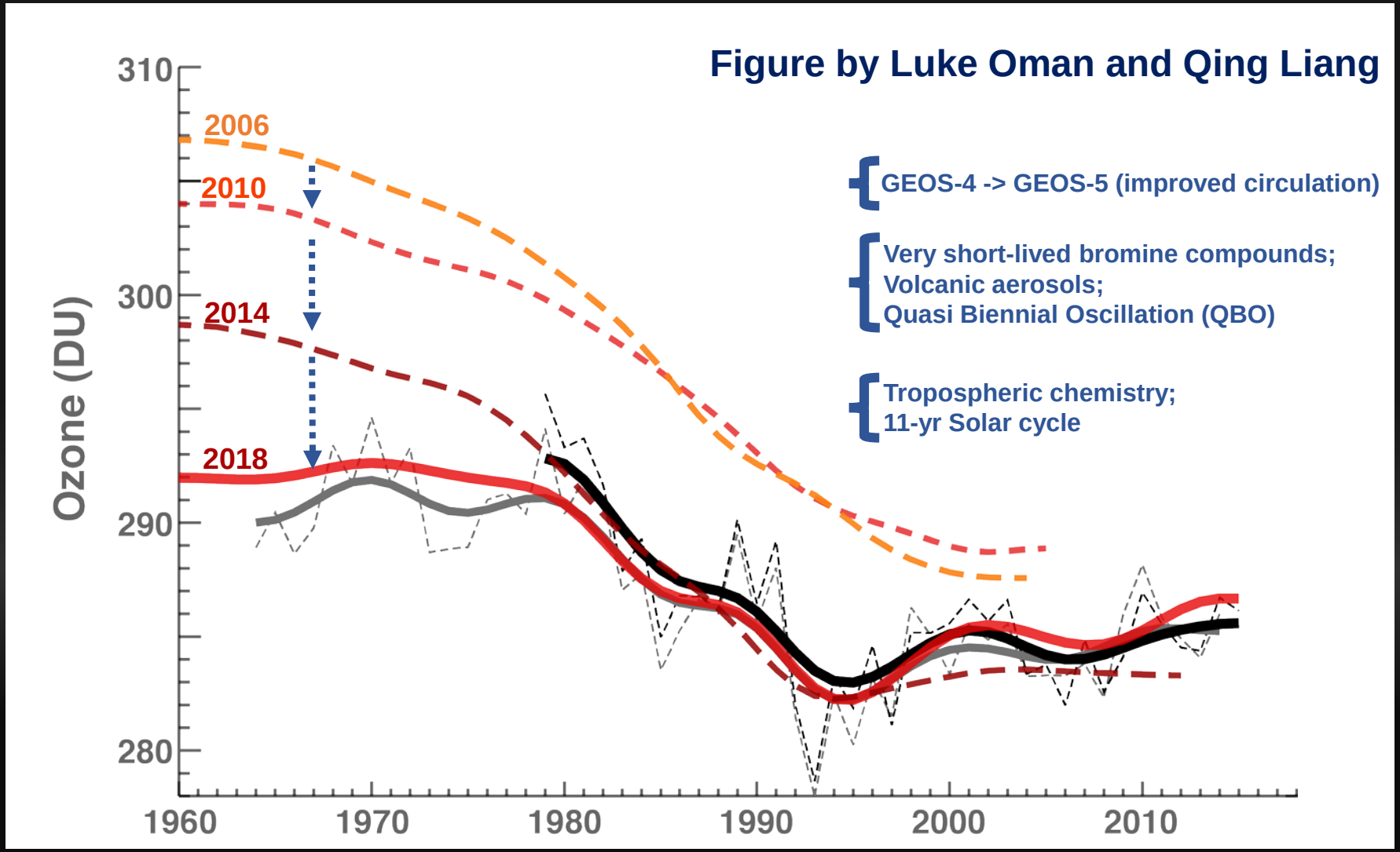
- Increased capabilities of the GEOS system over time
- Beneficial impacts of MLS+OMI ozone in GEOS reanalysis (MERRA-2)
- Move to troposphere-stratosphere chemistry mechanism in future reanalyses
- Progress and remaining challenges in tropospheric constituent assimilation

Two notes:

- Tighter coupling of processes as time advances – a slow process
- Configuring the GEOS system to suit the focus of the work

Total Column Ozone in the GEOS Chemistry-Climate Model

- Successive changes in GEOS CCM have led to very realistic representation of total global ozone evolution
- Significant involvement in WMO's ozone assessments reveals GEOS CCM is among the most realistic models
- A significant part of this success has been proximity to NASA's Earth Observation, especially the Aura team (Anne Douglass's group's work)

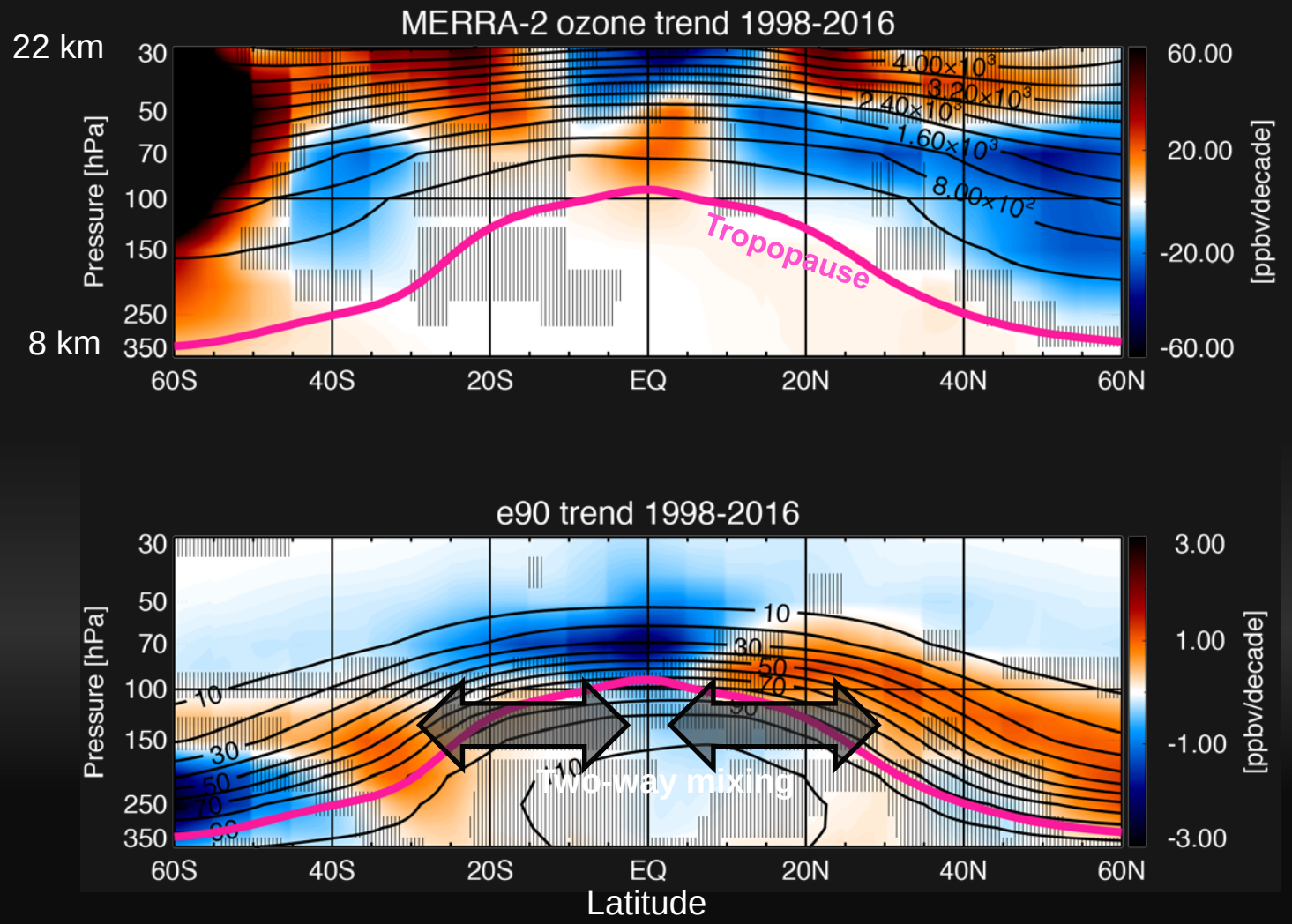


Main Focus: Assimilation of Aura Data into GEOS Systems

Some major landmarks for GEOS systems:

- 2015: MERRA-2 reanalysis (1980 onwards) assimilated:
  - MODIS 550nm AOD (OMI is a validation dataset)
  - OMI total-column and MLS ozone profiles, replacing SBUV after 2004
  - MLS temperature in the upper stratosphere
- Circa 2020-2021: proposed atmospheric reanalysis for EOS era (2000 on):
  - High-resolution atmosphere with land/ice/upper ocean connections
  - Troposphere-stratosphere composition assimilation
- Circa 2022: planned MERRA-2 replacement, focus on coupled Earth System

Use of MERRA-2 to compute ozone trends in the lower stratosphere

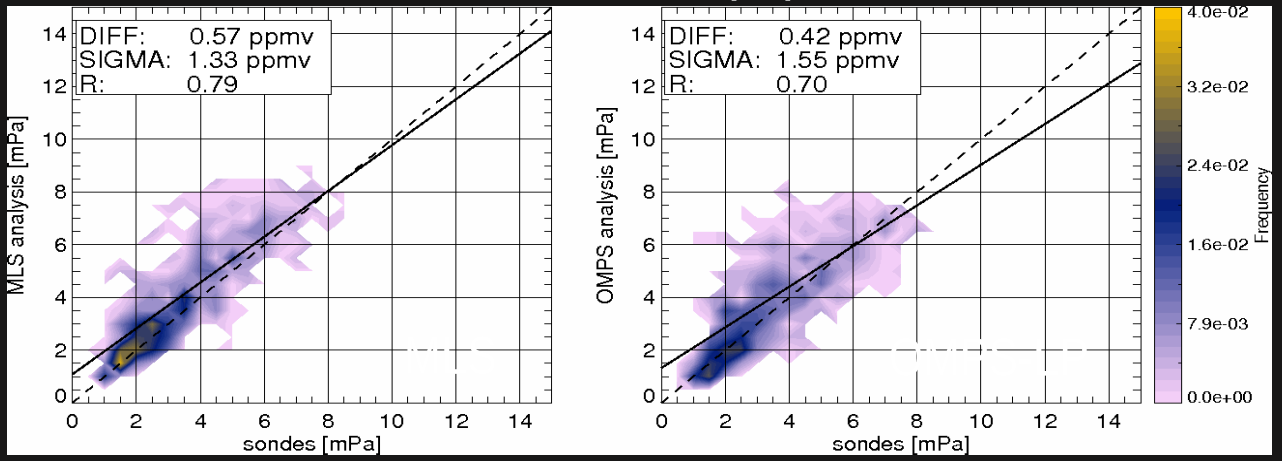


- Atmospheric ozone concentrations are increasing after 1998 because of the Montreal Protocol.
- MERRA-2 ozone just above the tropopause has continued to decline (blue shading in top panel).
- Idealized tracer experiment reveals enhanced tropical-extratropical mixing between 1998 and 2016 (bottom panel).
- Implies that transport changes between 1998 and 2016 caused ozone in the extratropical lower stratosphere to decline. Either long-term variations or a systematic change in mixing are to blame.

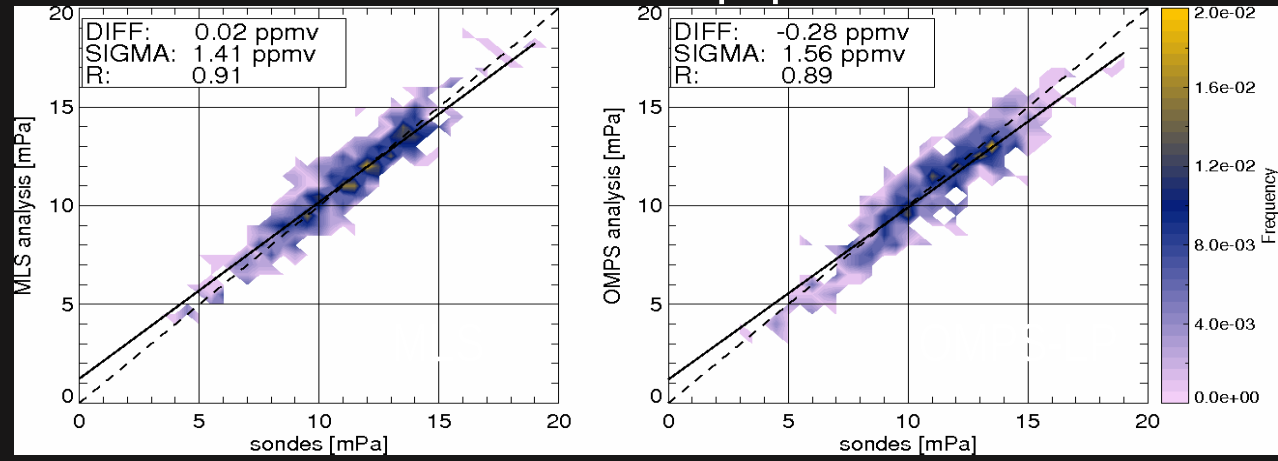
Wargan et al., 2018, *GRL*

Ozone in Future Reanalyses: Can OMPS-LP Replace MLS?

1 km above the tropopause



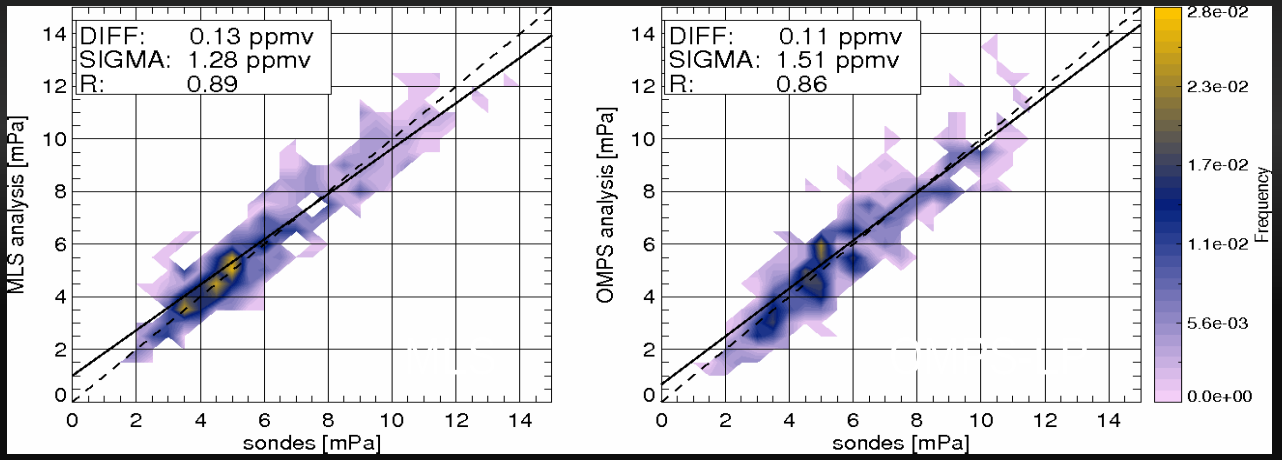
8 km above the tropopause



Ozonesondes

Ozonesondes

3 km above the tropopause



Ozonesondes

Ozonesondes

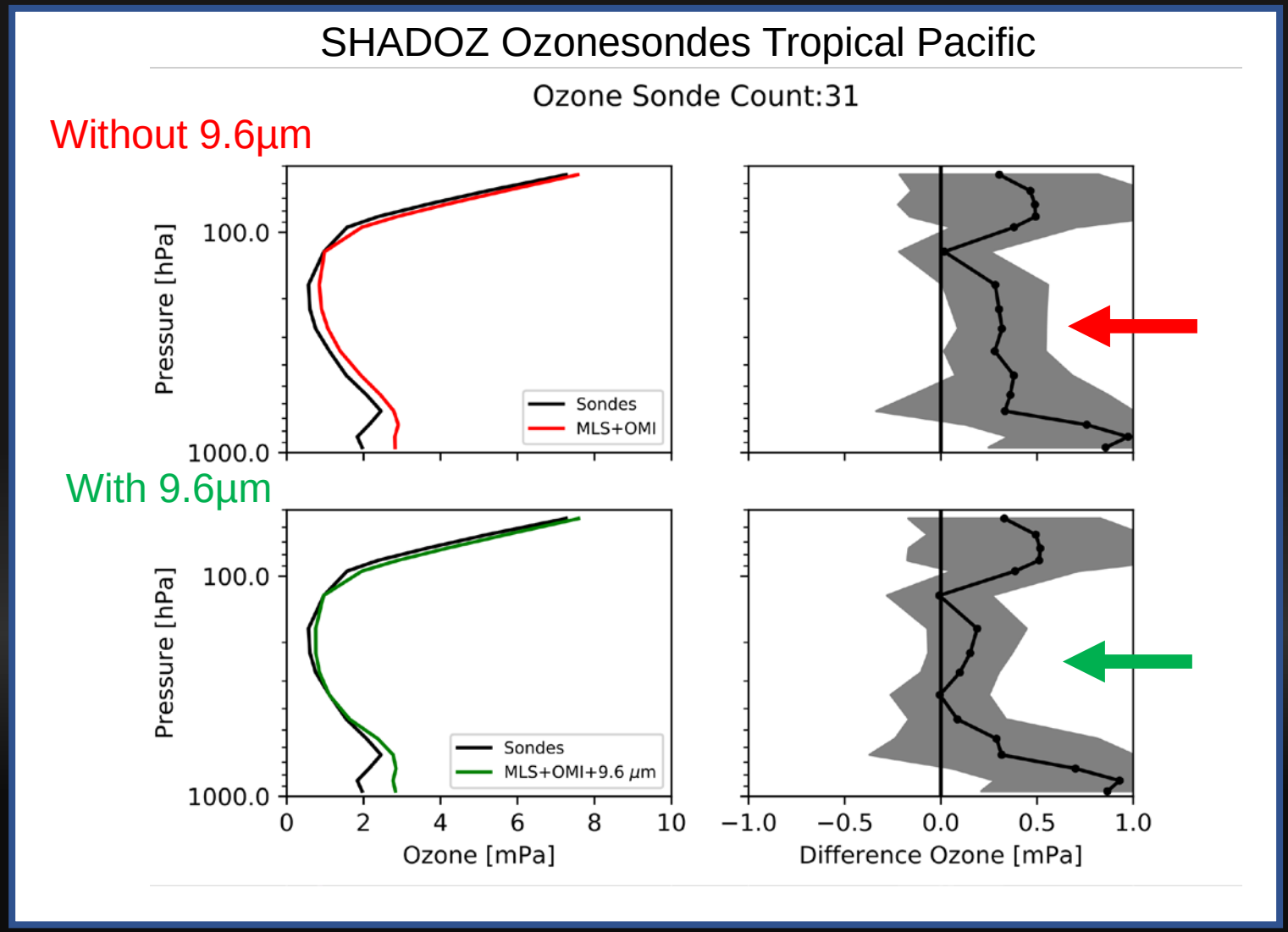
Remarkably good agreement with ozonesondes, except very close to the tropopause where ozone variability is high.

Very similar performance of MLS and OMPS-LP analyses in terms of variability.

Wargan et al., recent research

Ozone in Future Reanalyses: Added Value of 9.6-micron Radiances

- Radiances are assimilated in the 9.6μm band for hyperspectral instruments AIRS, IASI, CrIS
- Added to system including MLS and OMI
- Improvements to the ozone analysis in the upper troposphere: verified against 31 ozone sondes in the tropical Pacific
- Future question: can we exploit this result for periods when UTLS ozone profiles are not available?



Karpowicz et al., recent research

Ozone in Future Reanalyses: Towards Stratosphere-Troposphere Chemistry

Ongoing collaboration between Harvard University and GMAO has led to successful implementation of the GEOS-Chem chemistry mechanism as an option for configuration of the GEOS model:

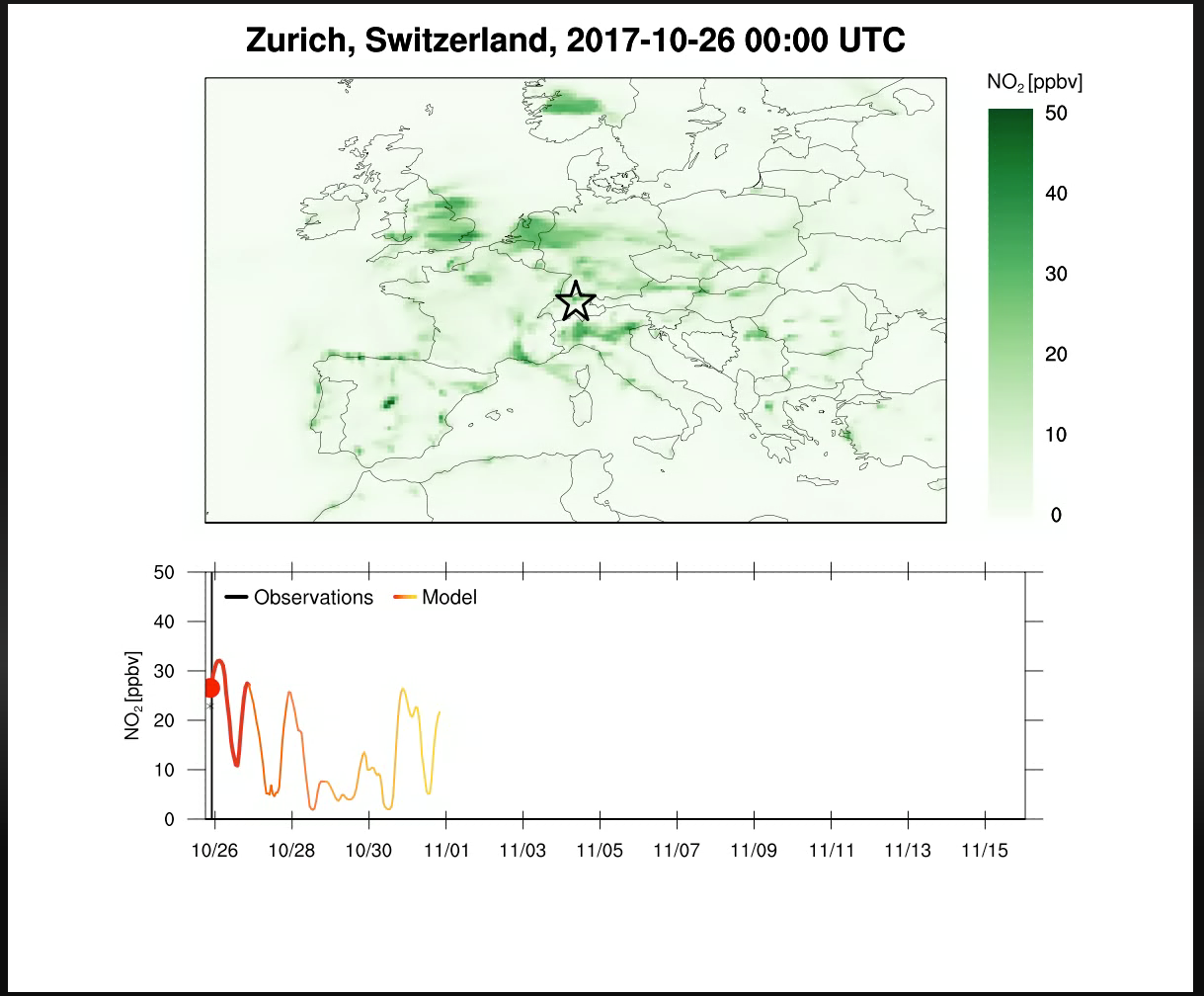
- Viable option for future GEOS CCM systems
- Already used as a GMAO production system: GEOS Composition Forecasting
- GEOS CF does not yet assimilate tropospheric constituents
- Need to reconcile aerosol mechanisms (GOCART is used for physical impacts)
- Reduced chemical mechanisms will lead to faster/viable forecast systems for operational centers

GEOS CF (Composition Forecasting) System

Towards a stratosphere-troposphere composition assimilation

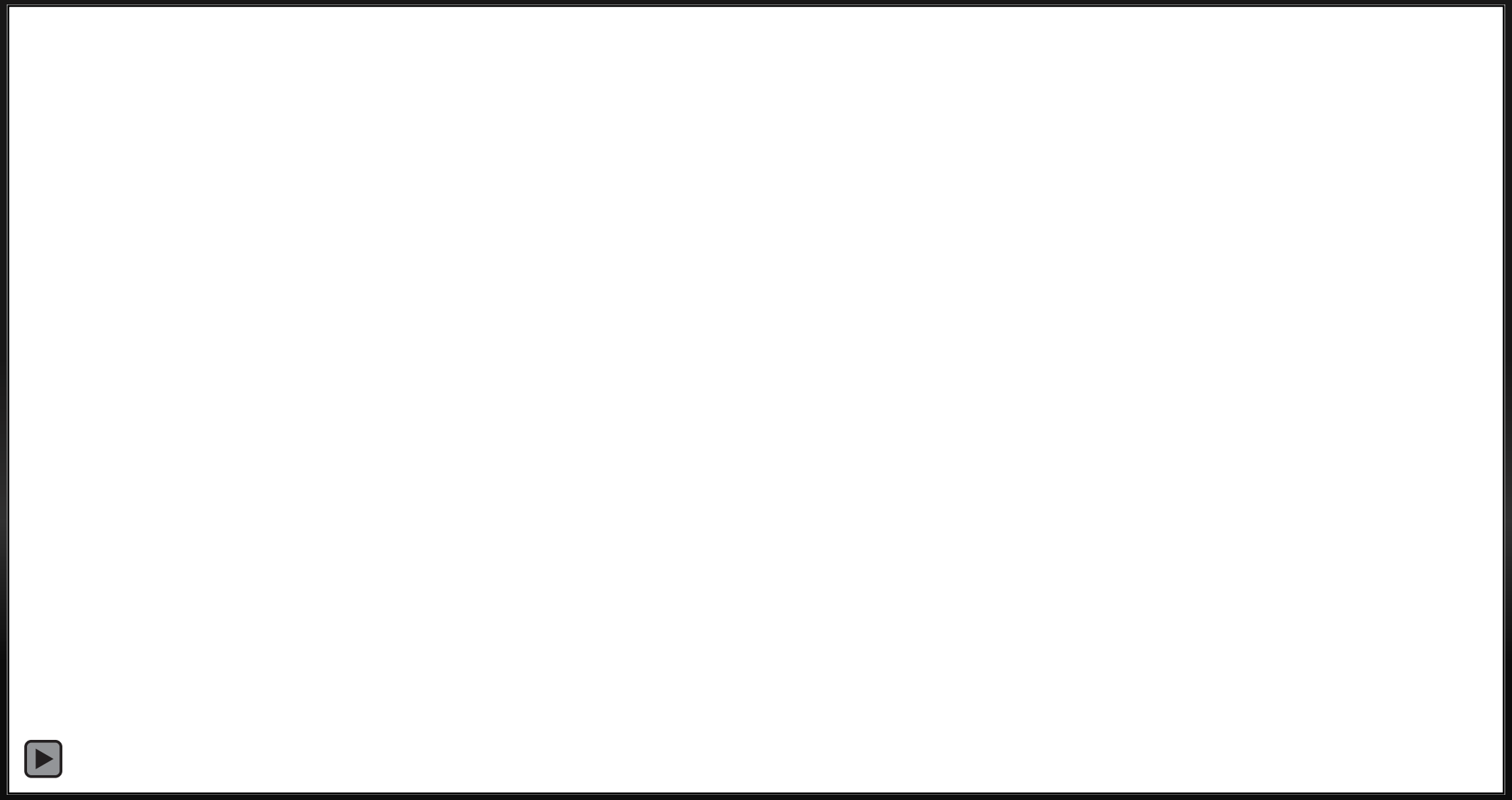
Real-time analysis and forecasting system for atmospheric composition:

- Based on GEOS meteorological analyses, using REPLAY technique
- Emissions and reactive chemistry based on GEOS-Chem
- No assimilation of constituents (for now)
- Resolution: c360L72, or ~25km globally
- One five-day forecast each day

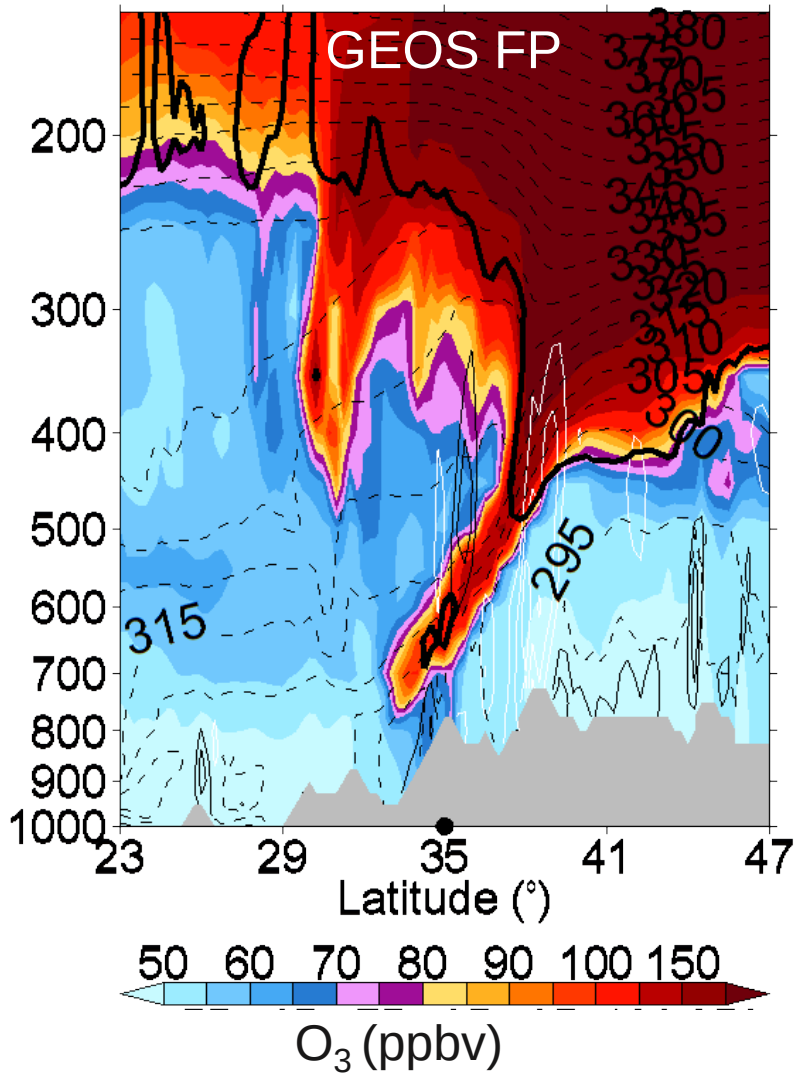


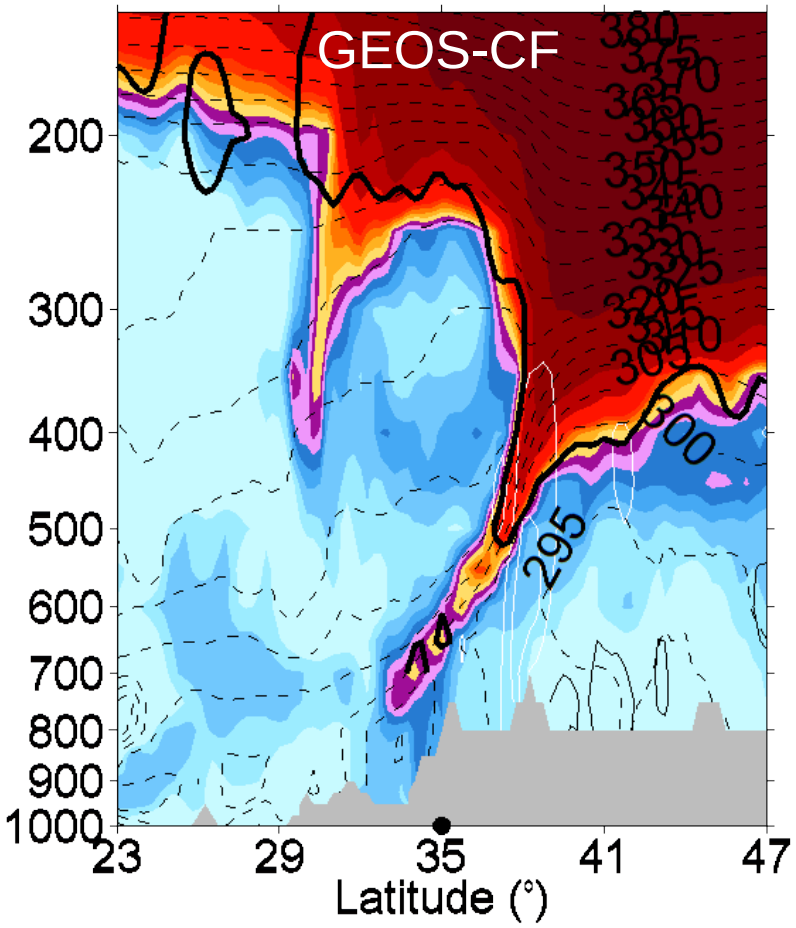
Keller, Knowland, et al.

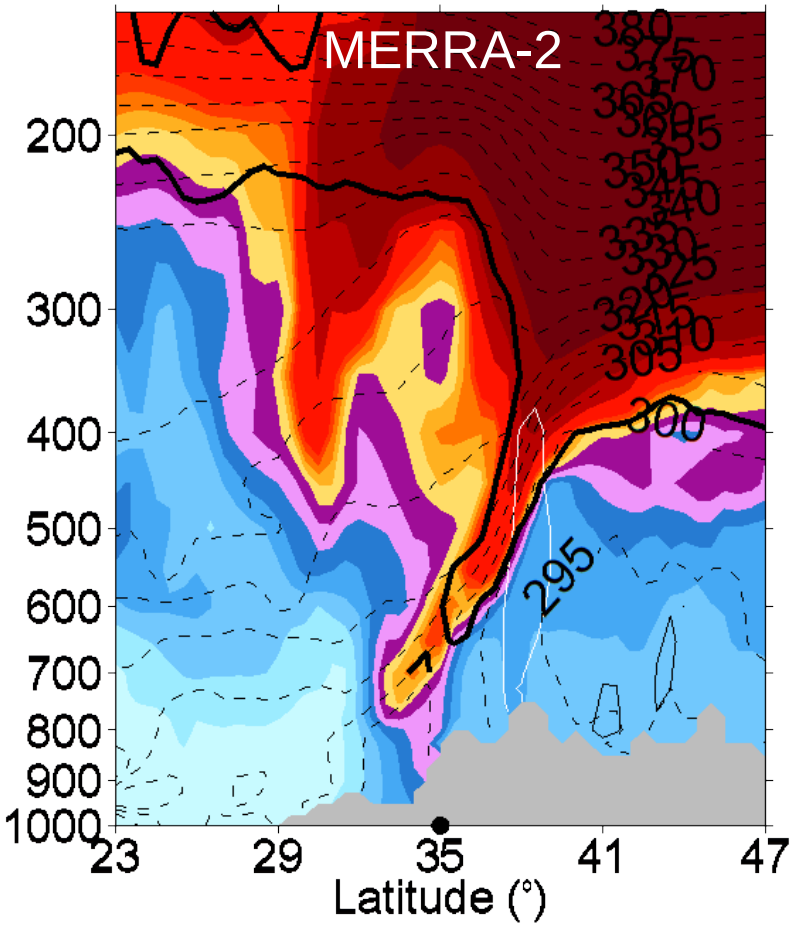
Example output: GEOS-CF surface ozone “analysis”



An ozone intrusion event in MERRA-2, GEOS-FP and GEOS-CF







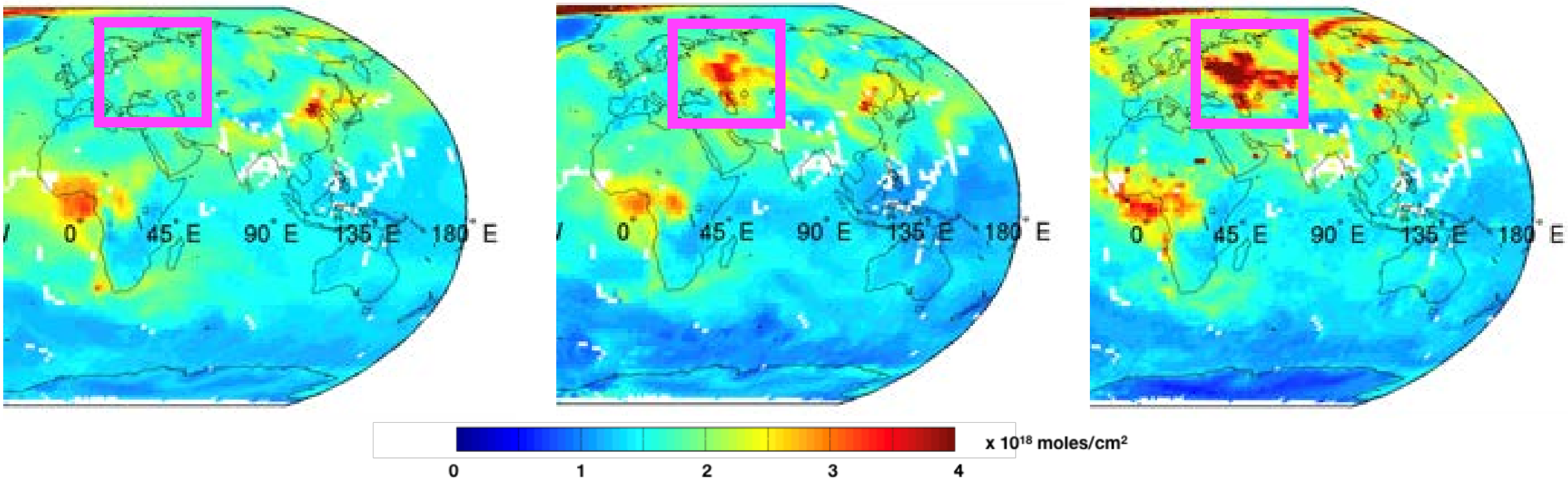
Flagstaff, Arizona, USA 17 April 2018 18UTC

Assimilation of MOPPIT CO: August 2010 Russian Wildfires

GEOS: CO Simulation

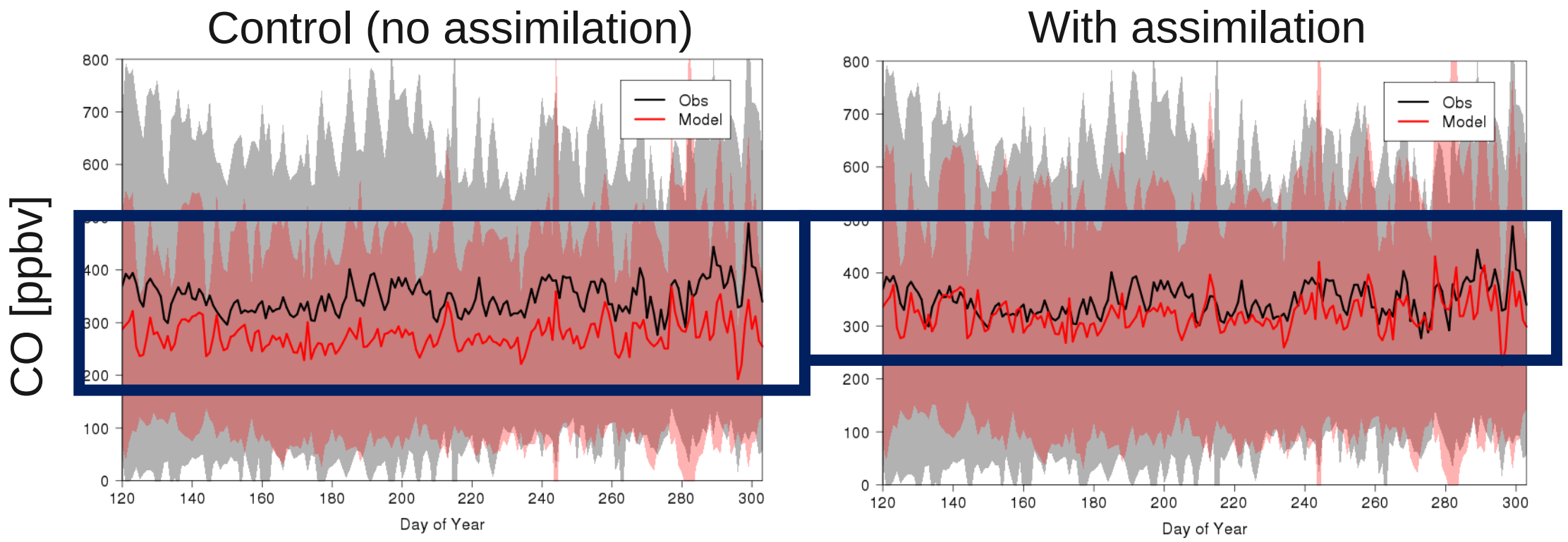
GEOS: MOPPIT CO Assimilated

IASI CO Retrievals



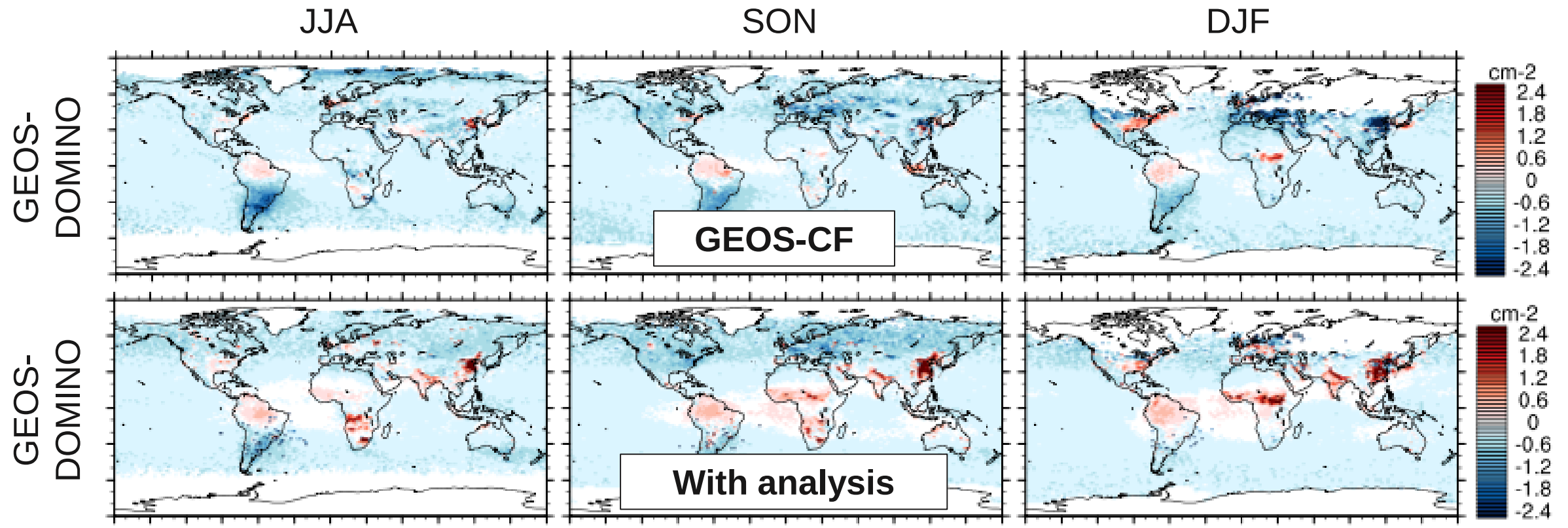
Beneficial impact of assimilating MOPPIT CO information on regional CO distributions

Assimilating MOPPIT CO: Reduced Low Bias Compared to Surface Observations



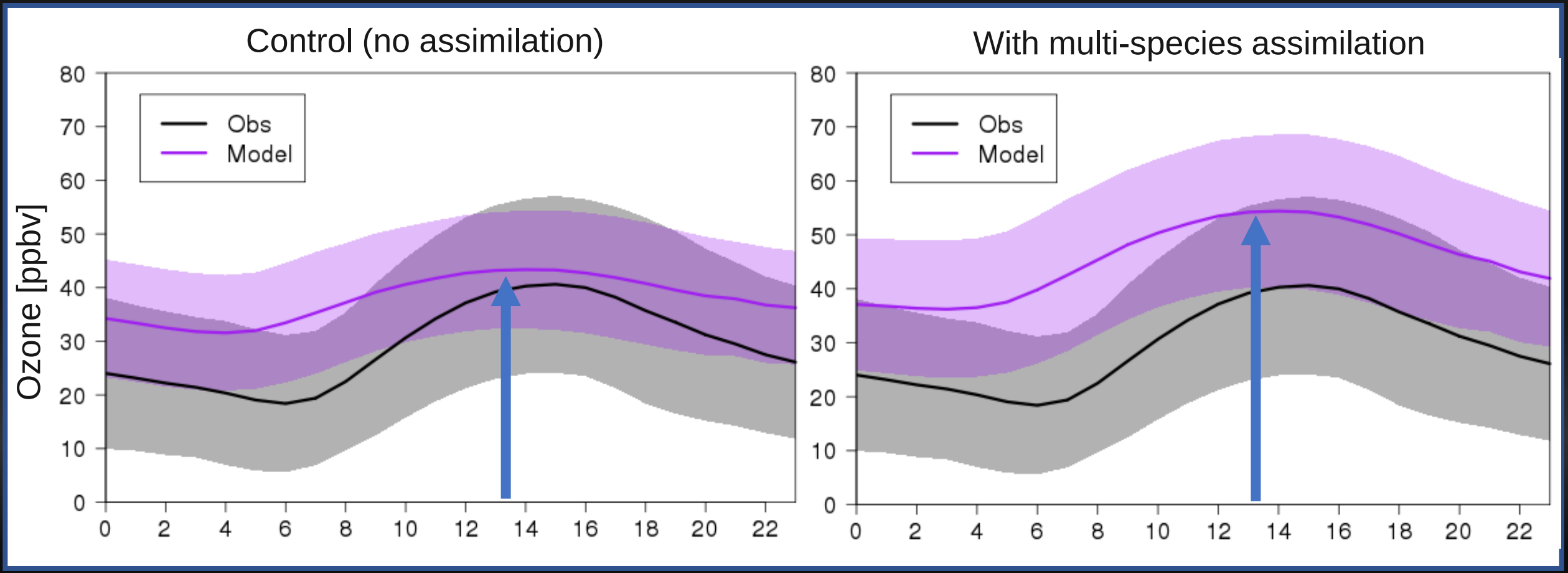
- Implies significant (~20%) underestimation of CO emissions (?)
- Alternatively: CO lifetime too short (→ OH)

Impacts of assimilating OMI NO_x into GEOS CF System



Assimilate tropospheric NO:NO_2 ratio at 1:30pm.
NO_x assimilation increases background NO_2 which is thought to be too low
Comparison with DOMINO dataset

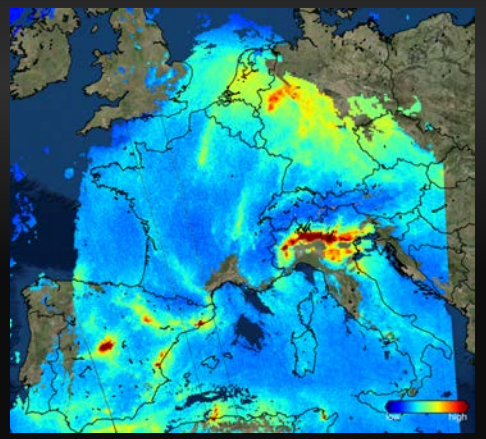
Assimilating CO and NO_x: Improved Diurnal Cycle but Exacerbated Tropospheric Ozone Bias!

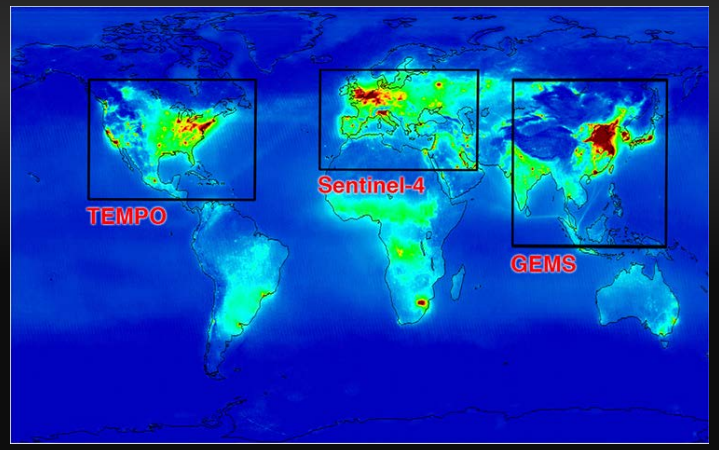


- Improved diurnal cycle most likely due to improved afternoon NO_2

Multi-constituent Assimilation and Future Reanalyses

- Impacts of joint assimilation of O_3, NO_2 and CO:
  - ✓ Reduction of CO bias
  - ✓ Better spatiotemporal representation of NO_2
  - ✗ Further increase of tropospheric ozone
- Weak observational constraint in current configuration
- Current system designed to fix the effects rather than the cause





Summary

EOS Observations have been, and will continue to be, central to GMAO's work on analysis and prediction of the complete Earth System:

- Demonstrable impacts on the UTLS and stratosphere in MERRA-2
- Impacts on tropospheric composition – some benefits, but not yet a clear story
- Stratospheric constituent assimilation underway (Wargan talk, yesterday)

Overall, for atmospheric composition assimilation in GMAO:

- Aligning work on aerosols and gaseous composition (challenges are different)
- The full GEOS-Chem mechanism is likely too expensive for sustained forecasts
- Benefits of initialization of ozone on seasonal forecasts are not yet exploited
- Need to explore synergies with other NASA data: e.g. surface hydrology/vegetation