Data Assimilation studies with CESM

CESM Atmosphere/Whole Atmosphere/Chemistry-Climate Winter Working Group Meeting

Wednesday, 14 February 2024

Ben Gaubert[1], W. Tang[1], I. Ortega[1], L. Emmons[1], H. M. Worden[1], Amin Mirrezaei[2], A. F. Arellano Jr[2], J. L. Anderson[3], K. Raeder[3], K. McKain[4,5], C. Granier[6,7]

[1]Atmospheric Chemistry Observations Modeling Laboratory (ACOM), NSF NCAR; [2]University of Arizona; [3]Computational and Information Systems Lab (CISL) NSF NCAR; [4]CIRES, University of Colorado; [5]Global Monitoring Laboratory, NOAA; [6]Laboratoire d'Aérologie, Université de Toulouse, CNRS; [7]NOAA/Chemical Sciences Laboratory, and CIRES, University of Colorado.

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Chemical data assimilation: CAM-chem/DART

Data Assimilation Research Testbed (DART)

DART is a **community** and **open source** software for ensemble DA.

Sequential and **ensemble** DA technique.

DART provides advanced **localization** and **inflation** algorithms for efficient ensemble DA.

scientific reports

Check for updates

OPEN

A new CAM6 + DART reanalysis with surface forcing from CAM6 to other CESM models

Kevin Raeder[1,4]✉, Timothy J. Hoar[1,4], Mohamad El Gharamti[1,4], Benjamin K. Johnson[1,4], Nancy Collins[1,4], Jeffrey L. Anderson[1,5], Jeff Steward[2,4] & Mick Coady[3,5]

- **Meteorological DA setup from Raeder et al. (2021): State vector: Ps, T, U, V, Q, CLOUD**
- Ensemble Adjustment Kalman Filter analysis update
- Spatially and temporally varying adaptive multiplicative covariance inflation
- Spatial localization

J. L. Anderson et al., The Data Assimilation Research Testbed: A Community Facility Bulletin of the American Meteorological Society, 2009

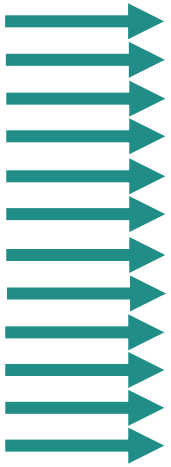
Chemical Satellite Data Assimilation: CAM-chem/DART

CAM-chem

- CESM2.2 FV09 (0.9°x1.25° and 32 vertical layers)
- Gas phase chemistry: **MOZART-TS1**
- Aerosol scheme: **MAM4 + VBS for SOA**
- Perturbation in global aerosol and nudging parameters, initial conditions and emissions:

Daily ensemble CAMS-GLOB-ANT
Gases and aerosols

Daily ensemble FINN
Gases and aerosols



Step 1: Forecast step

Ensemble: 30 member perturbed

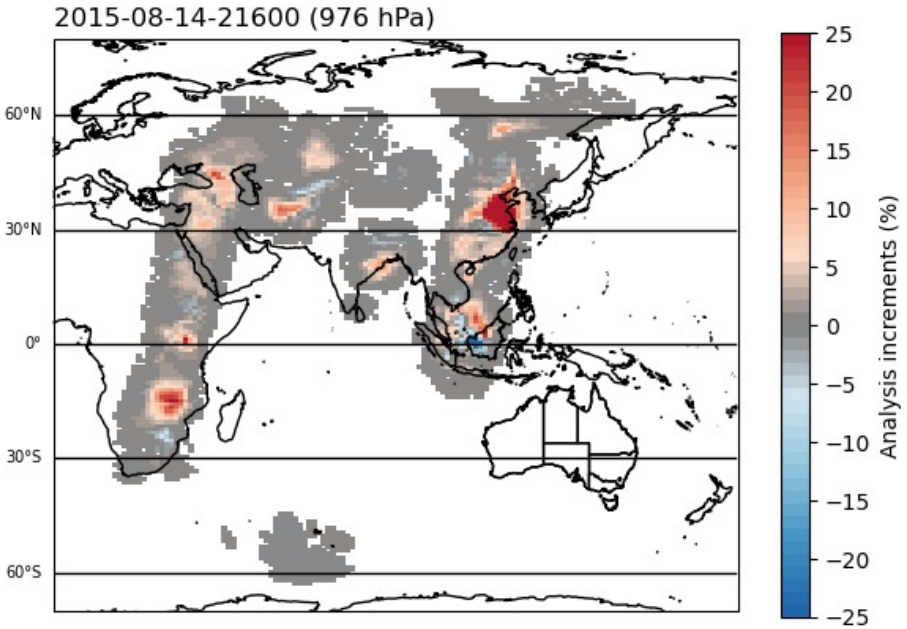
CAM-chem - 6-hour forecast

Chemical data assimilation: CAM-chem/DART

Emission update

Daily ensemble
CAMS-GLOB-ANT
Gases and aerosols

Daily ensemble FINN
Gases and aerosols



DART

- **Meteorological DA setup from Raeder et al. (2021): State vector: Ps, T, U, V, Q, CLOUD**
- Ensemble Adjustment Kalman Filter analysis update
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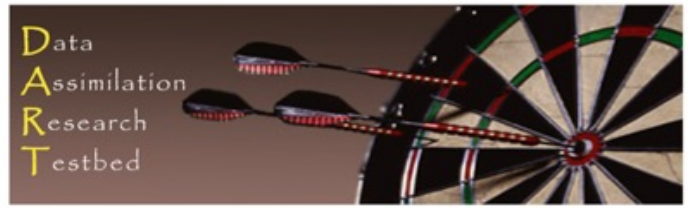
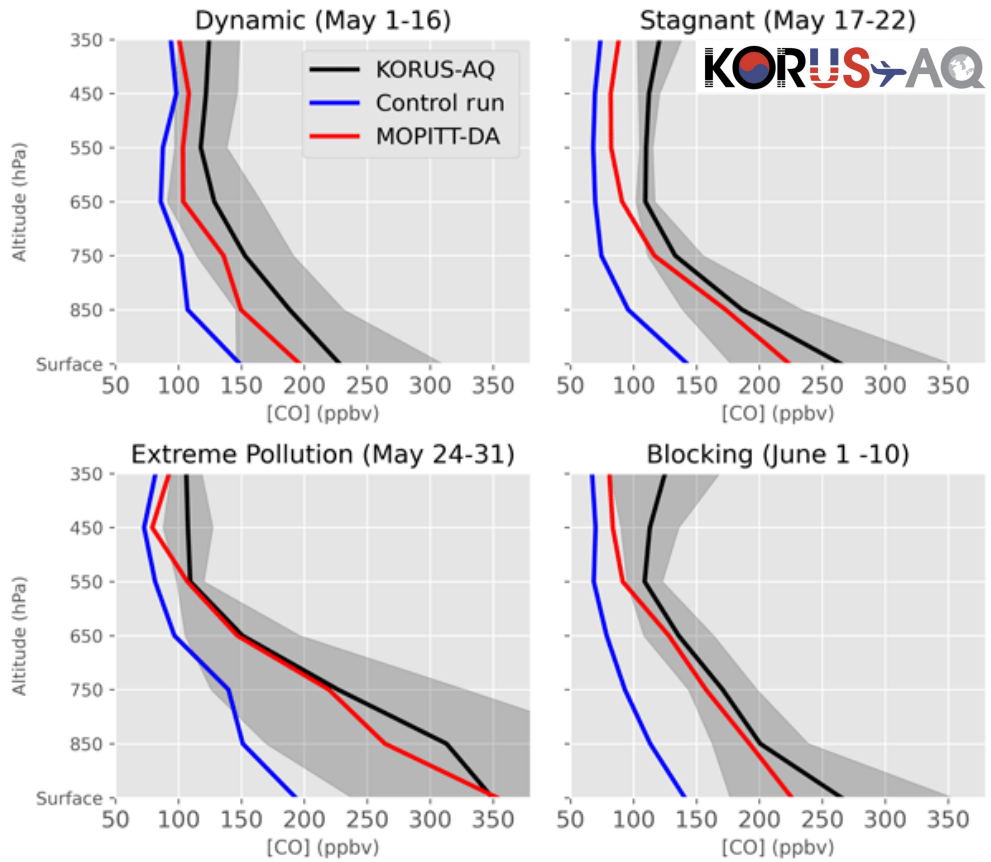
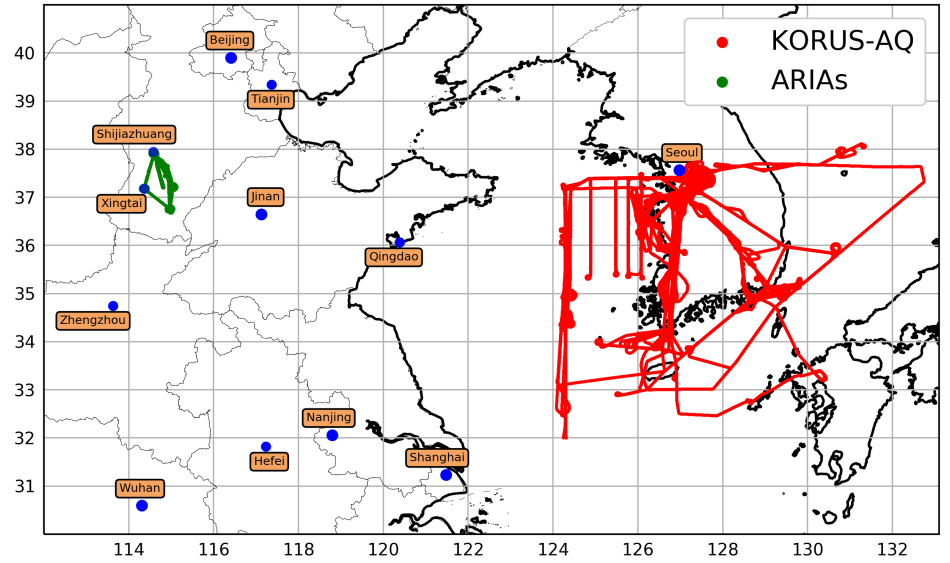
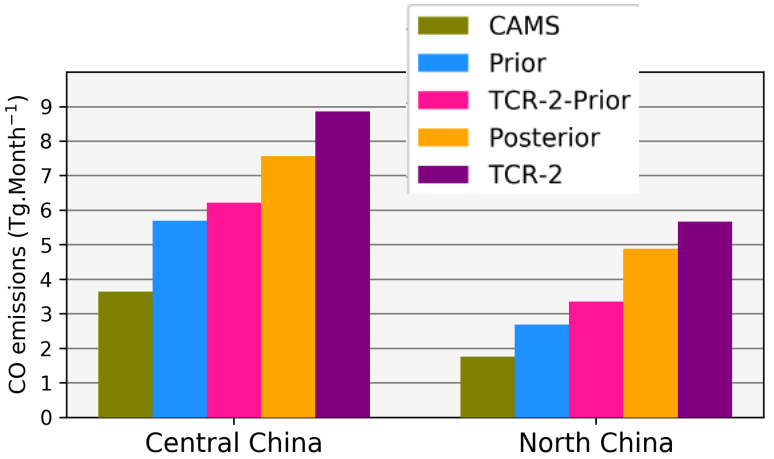
- Chemical DA
  - ✓ **CO IC**
  - ✓ **CO anthropogenic emissions**
  - ✓ **CO fire emissions**



Chemical data assimilation: MOPITT CO profiles







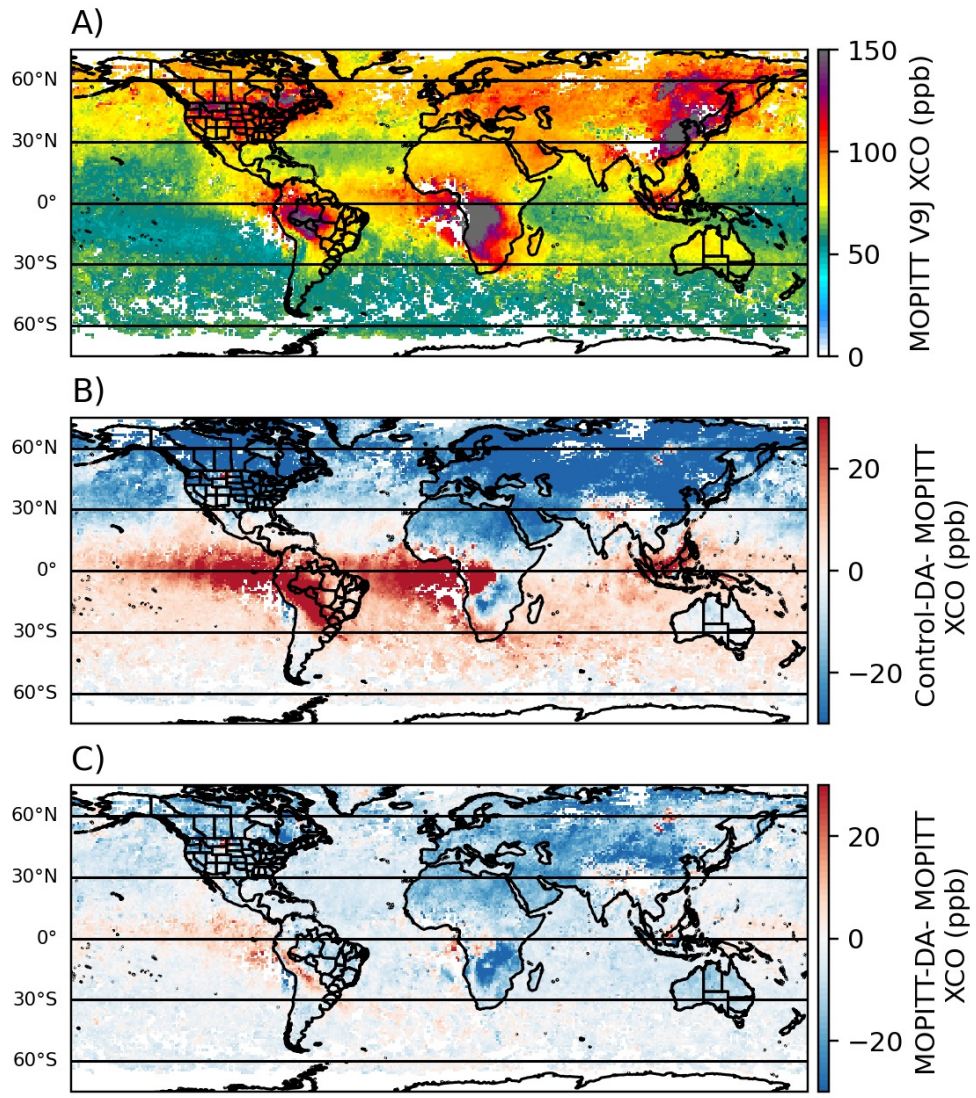
- ✓ Verification of CO vertical profiles with aircraft data
- ✓ Inversion reveal large underestimation
- ✓ Comparison of bottom-up and other chemical reanalyses reveal large uncertainties in emissions fluxes

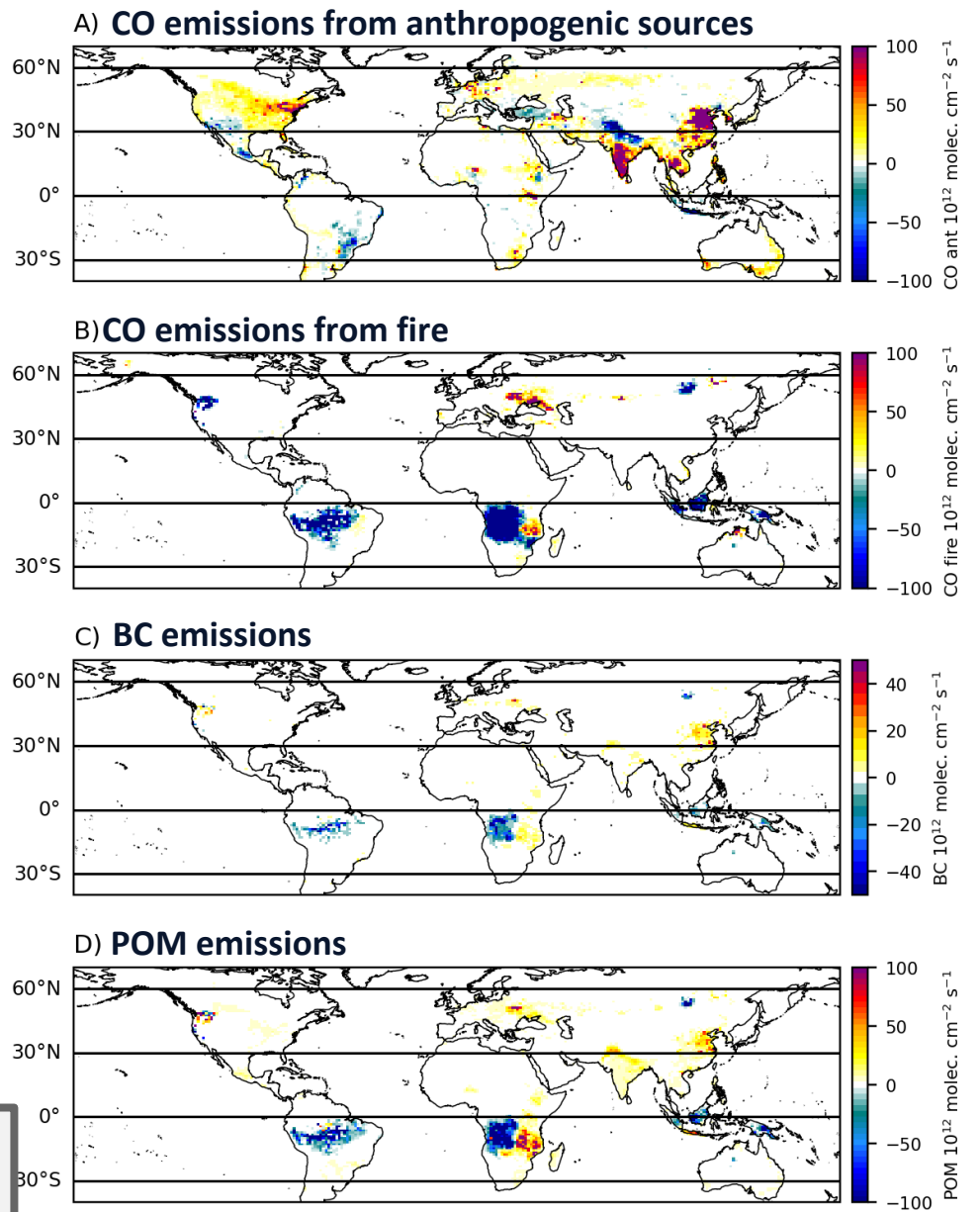
Gaubert et al., 2020

Chemical data assimilation: MOPITT CO and MODIS AOD

Northern Extratropics CO background underestimated

CO fires overestimated in the tropics



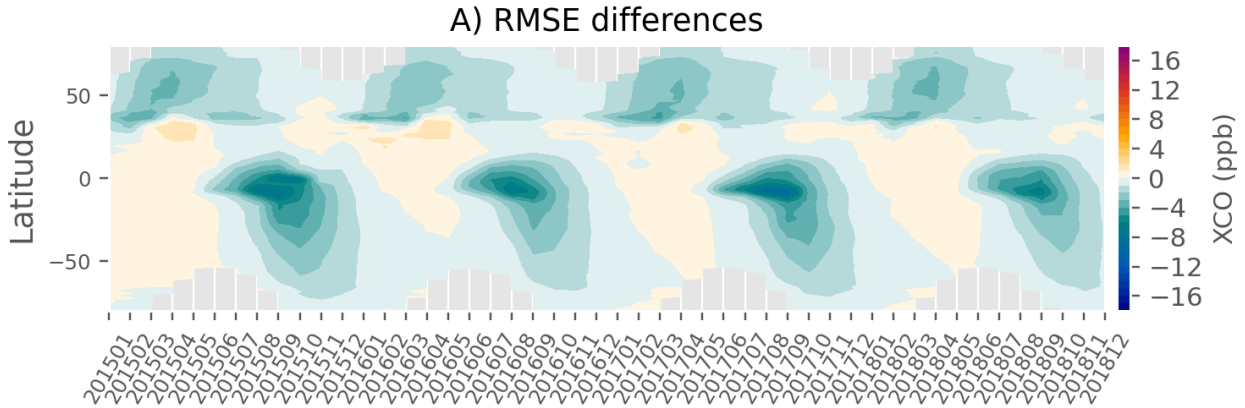


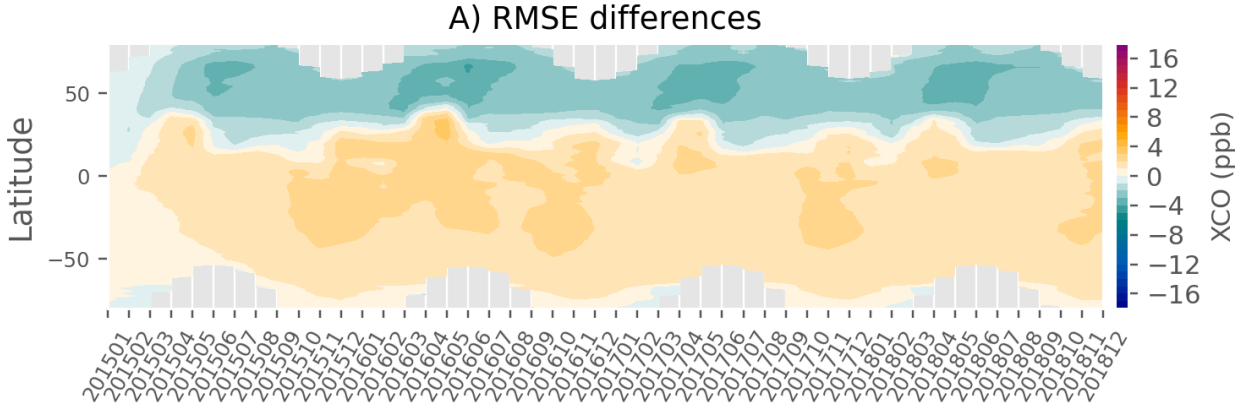
- ✓ Error patterns from emission biases
- ✓ Fires and Anthropogenic sources can be quantified

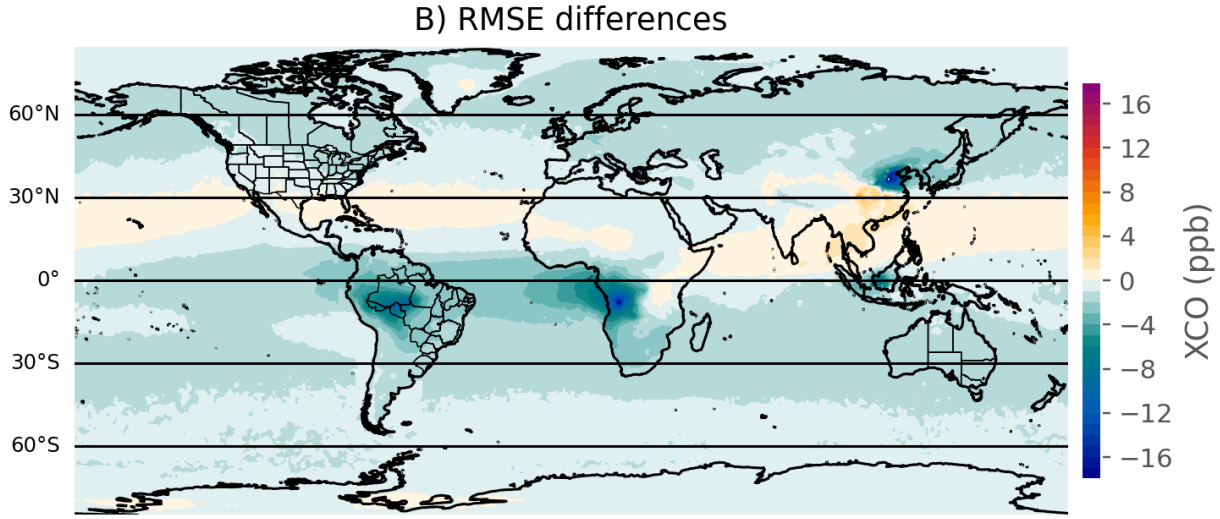
Gaubert et al., 2023

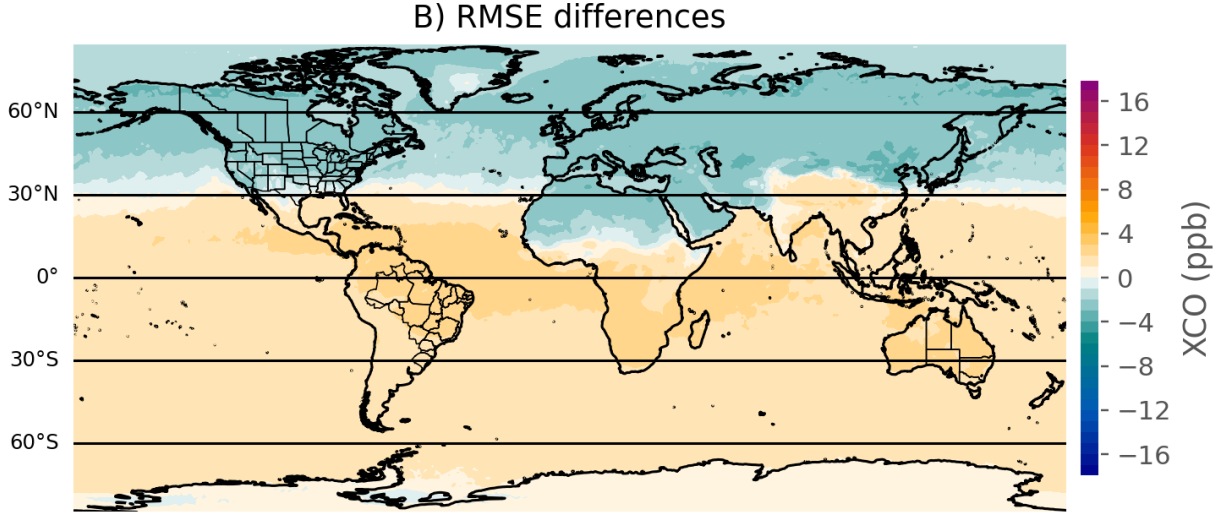
Emission inversions: Forward simulations with posterior emissions

4 years (2015-2019) CAM-chem simulations









✓ Derived posterior emissions from 1-month inversion

✓ 10 % reduction in JO^1D (direct reduction in OH source)

Posterior simulations: Comparison with NASA ATom

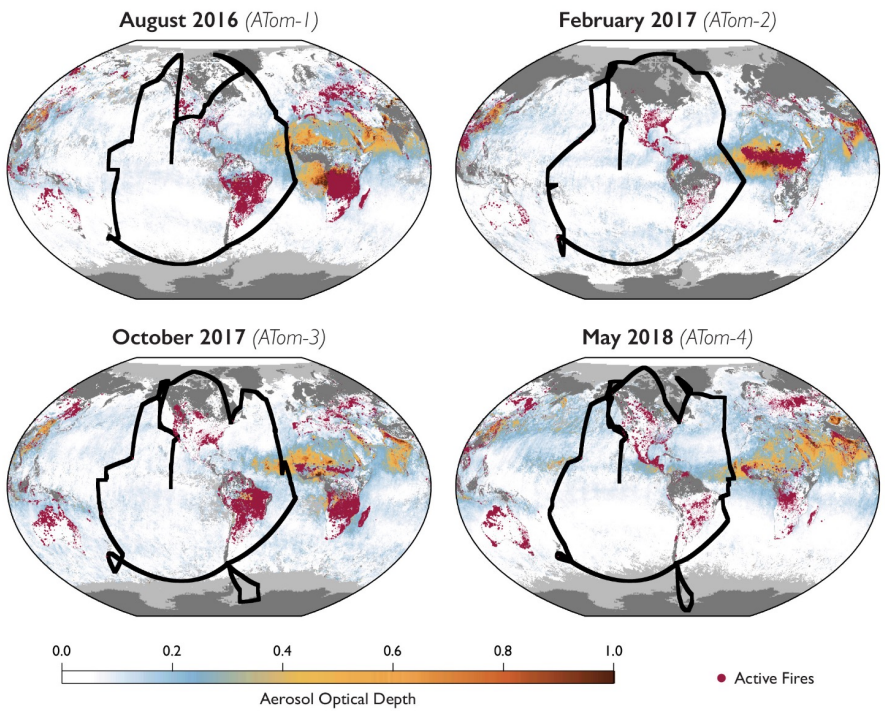
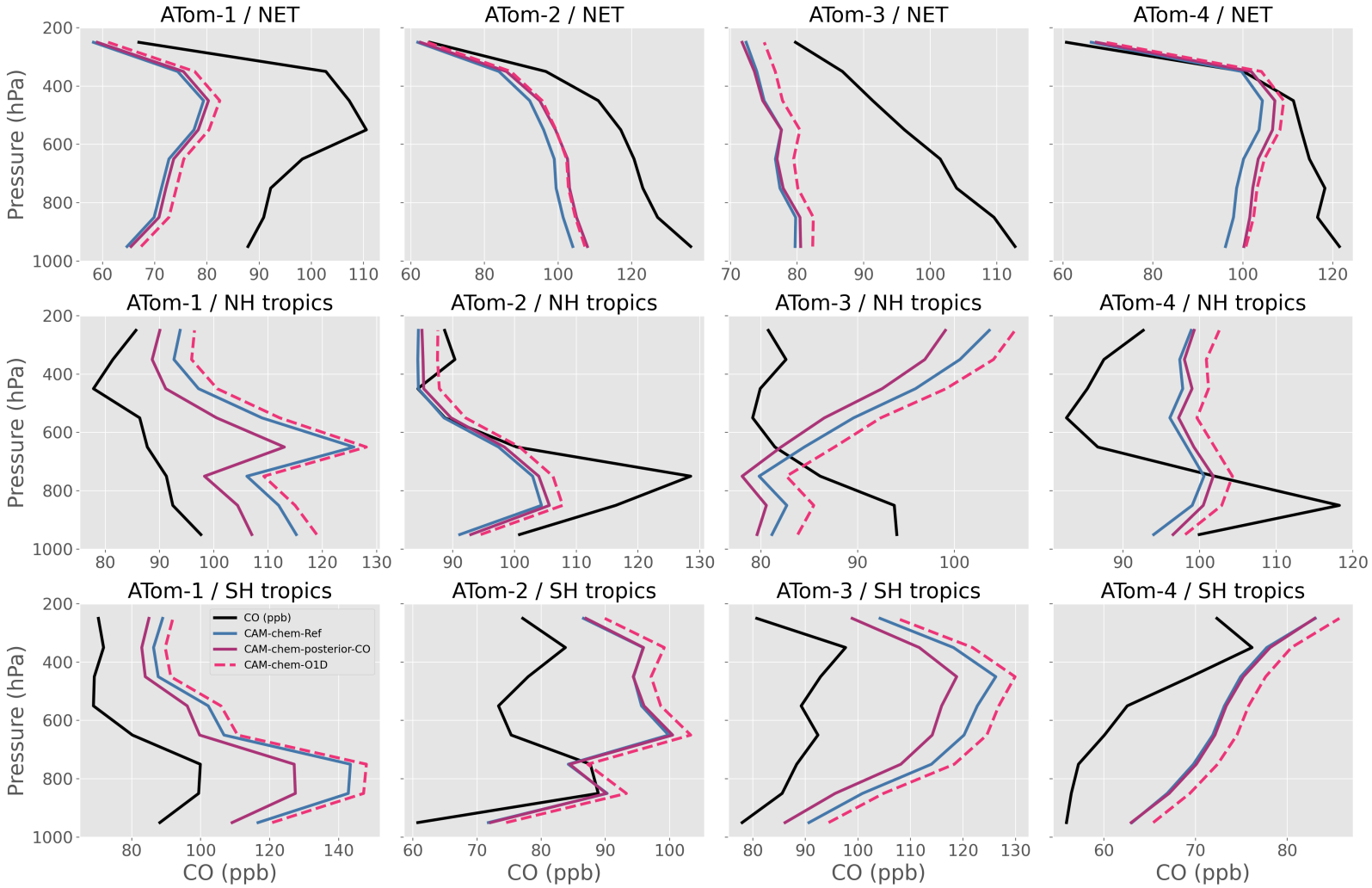


Fig. ES5. Maps of monthly average aerosol optical depth (AOD) and monthly aggregated fires during the four ATom deployments. AOD and fire location data are based on observations from the MODIS instrument on board NASA's *Terra* satellite. The ATom flight tracks are indicated by the black traces.

ATom-1: August 2016
ATom-2: February 2017
ATom-3: October 2017
ATom-4: May 2018

Northern extratropical hemisphere



Joint MOPITT and CrIS CO DA and emission estimations

1. Assessment of the joint assimilation of MOPITT and NOAA-20 Cross-track Infrared Sounder (CrIS) CO from Community Long-term Infrared Microwave Coupled Atmospheric Product System (CLIMCAPS)

2. Evaluation of Quantile-Conserving Ensemble Filter Framework (QCEFF, Anderson 2022, 2023, Monthly Weather Review)
   - An ensemble filter that deal with non Gaussian and modestly non linear distributions
   - Bounded (positive quantities) normal rank histogram (BNRH),

A Quantile-Conserving Ensemble Filter Framework. Part I: Updating an Observed Variable

JEFFREY L. ANDERSON[a]

[a] *NCAR/CISL/TDD/DAReS, Boulder, Colorado*

(Manuscript received 30 August 2021, in final form 20 January 2022)

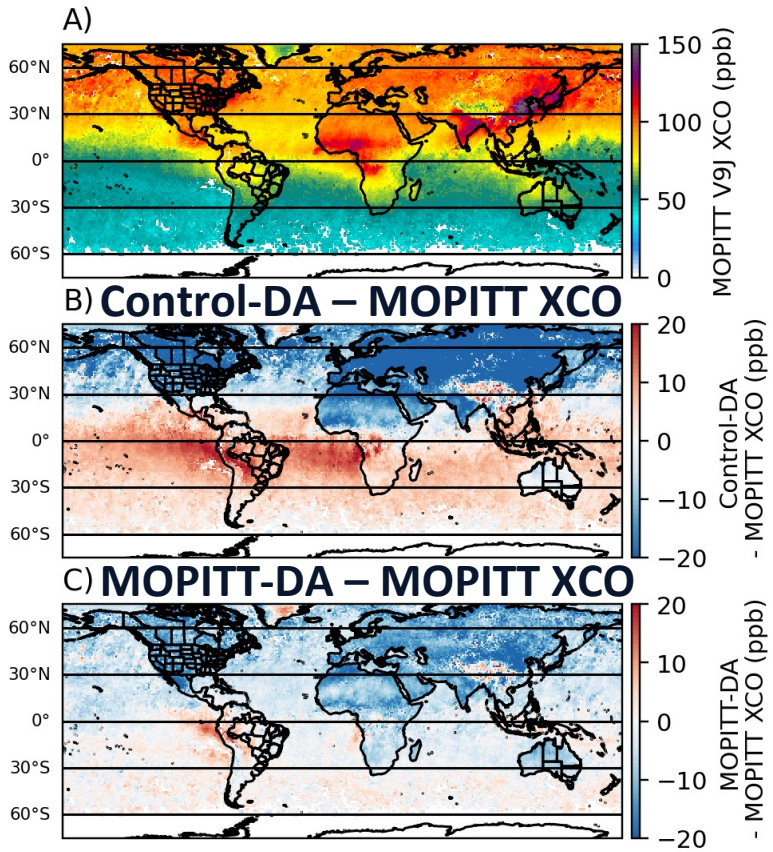
A Quantile-Conserving Ensemble Filter Framework. Part II: Regression of Observation Increments in a Probit and Probability Integral Transformed Space

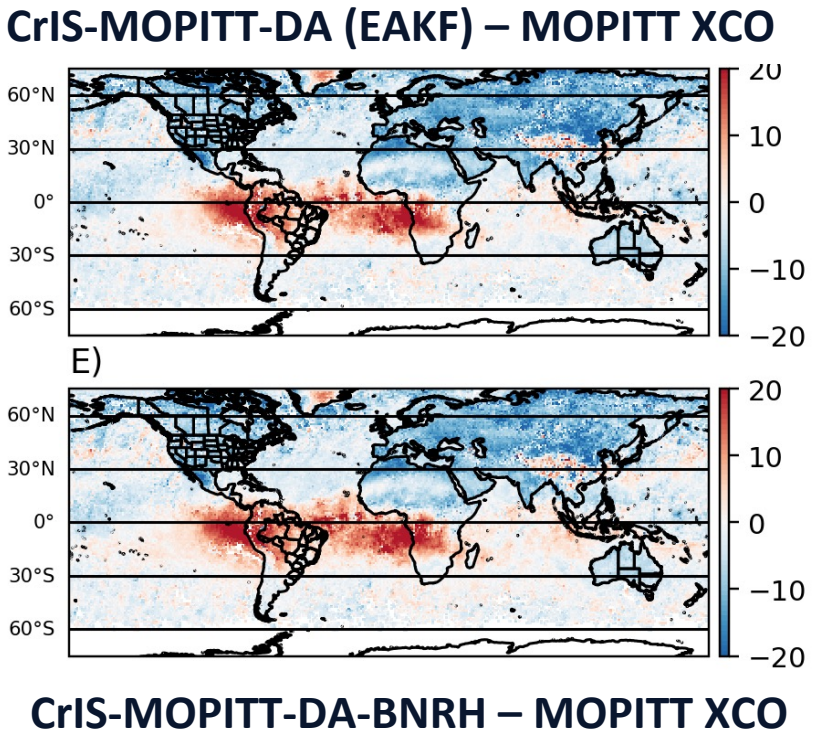
JEFFREY L. ANDERSON[a]

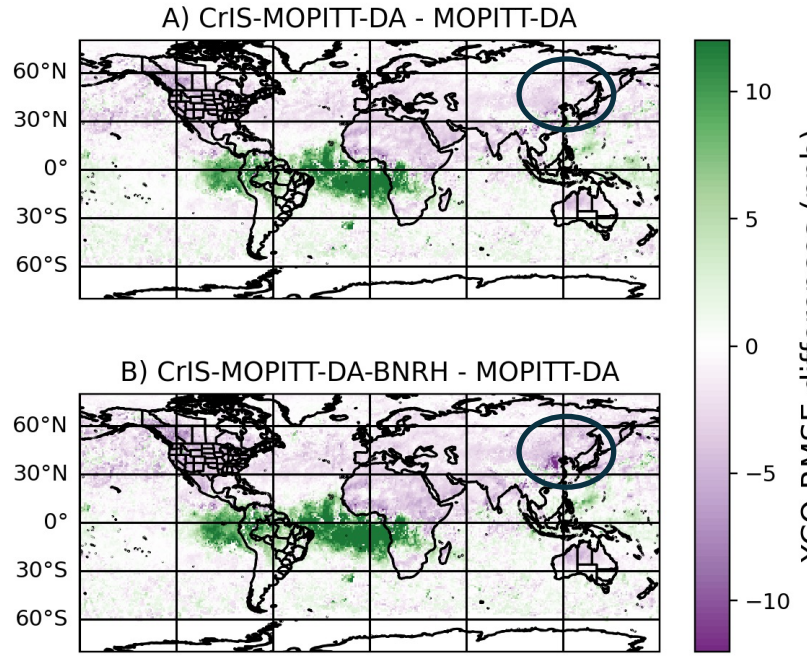
[a] *NCAR/CISL/TDD/DAReS, Boulder, Colorado*

(Manuscript received 23 March 2023, in final form 4 July 2023, accepted 12 July 2023)

Results: Comparison with MOPITT XCO





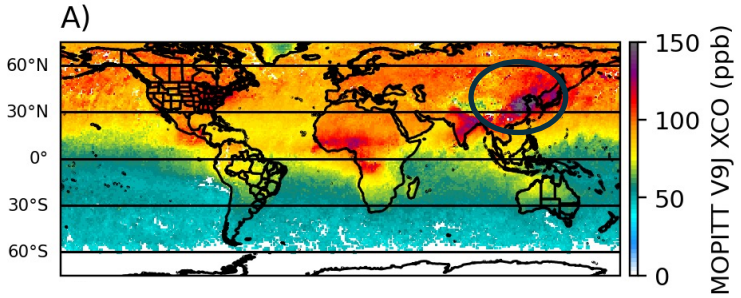


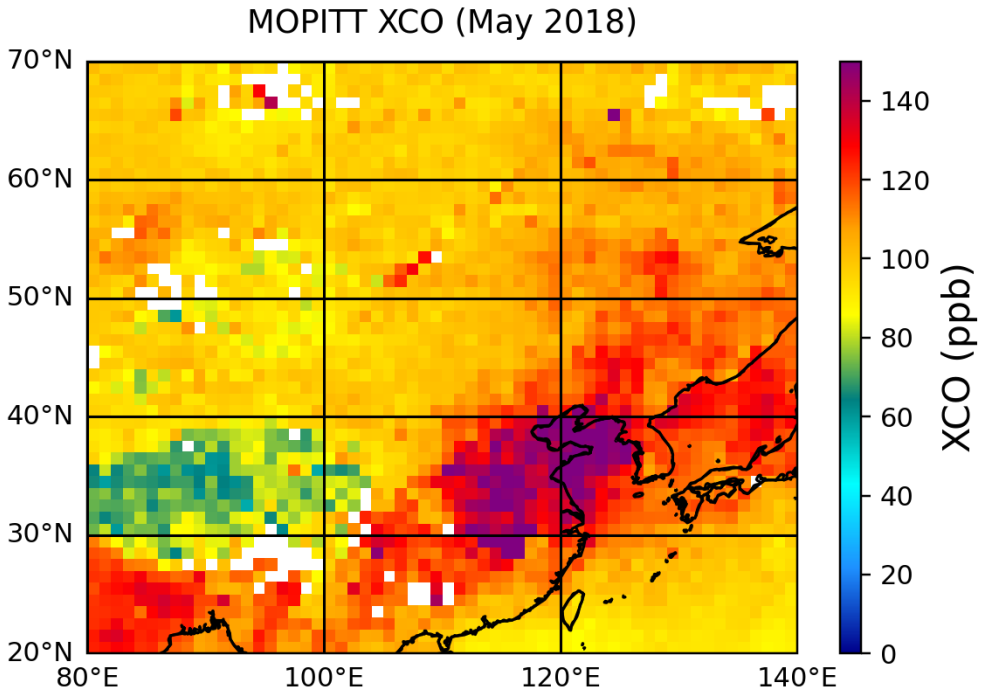
ΔRMSE vs. MOPITT-DA

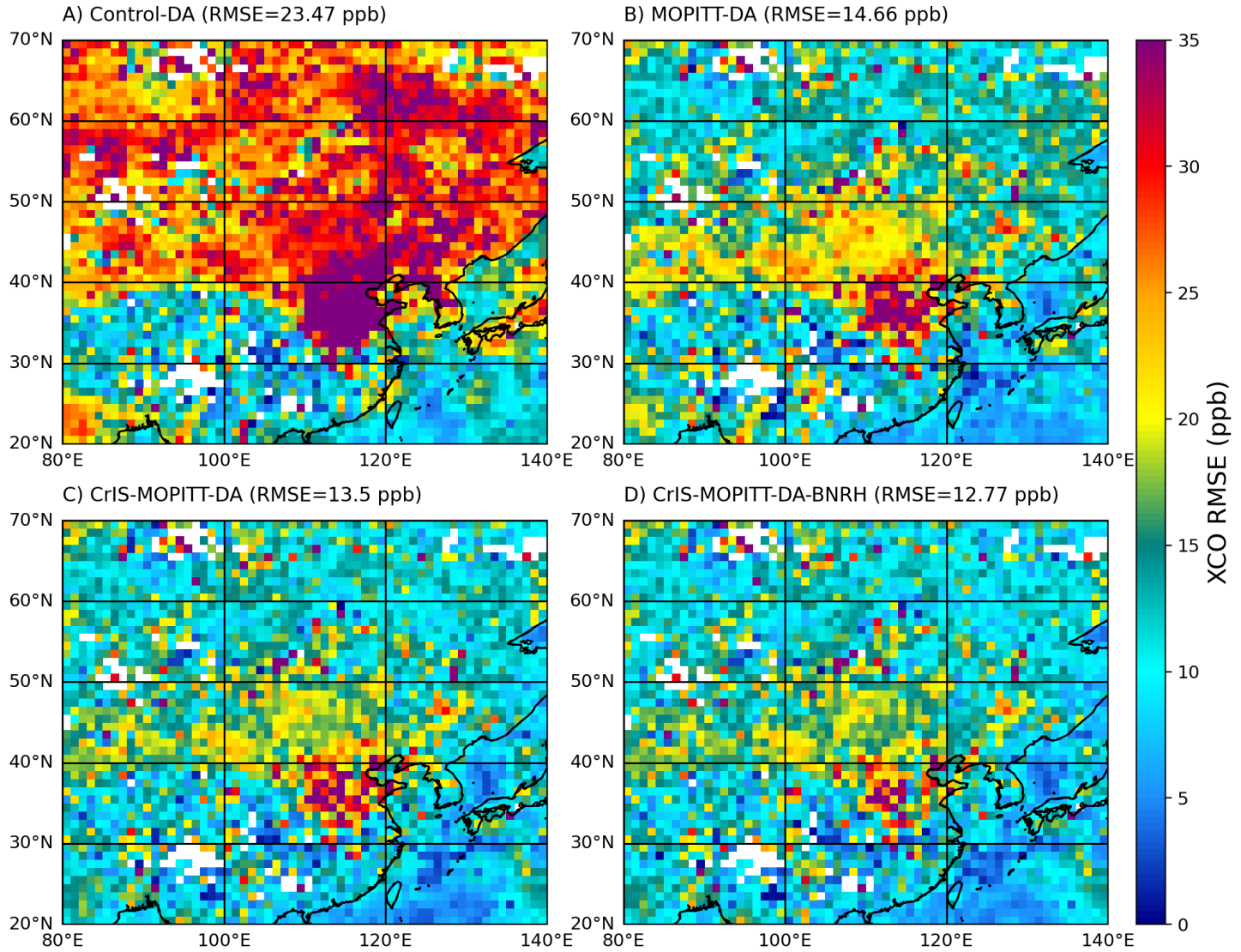
- ❖CLIMCAPS-CrIS and MOPITT-DA are biased to each others for tropical fires
- ❖Joint MOPITT-CrIS-DA improves CO fit to MOPITT, better than MOPITT-DA

Gaubert et al., in review, 2024

Results: Comparison with MOPITT XCO



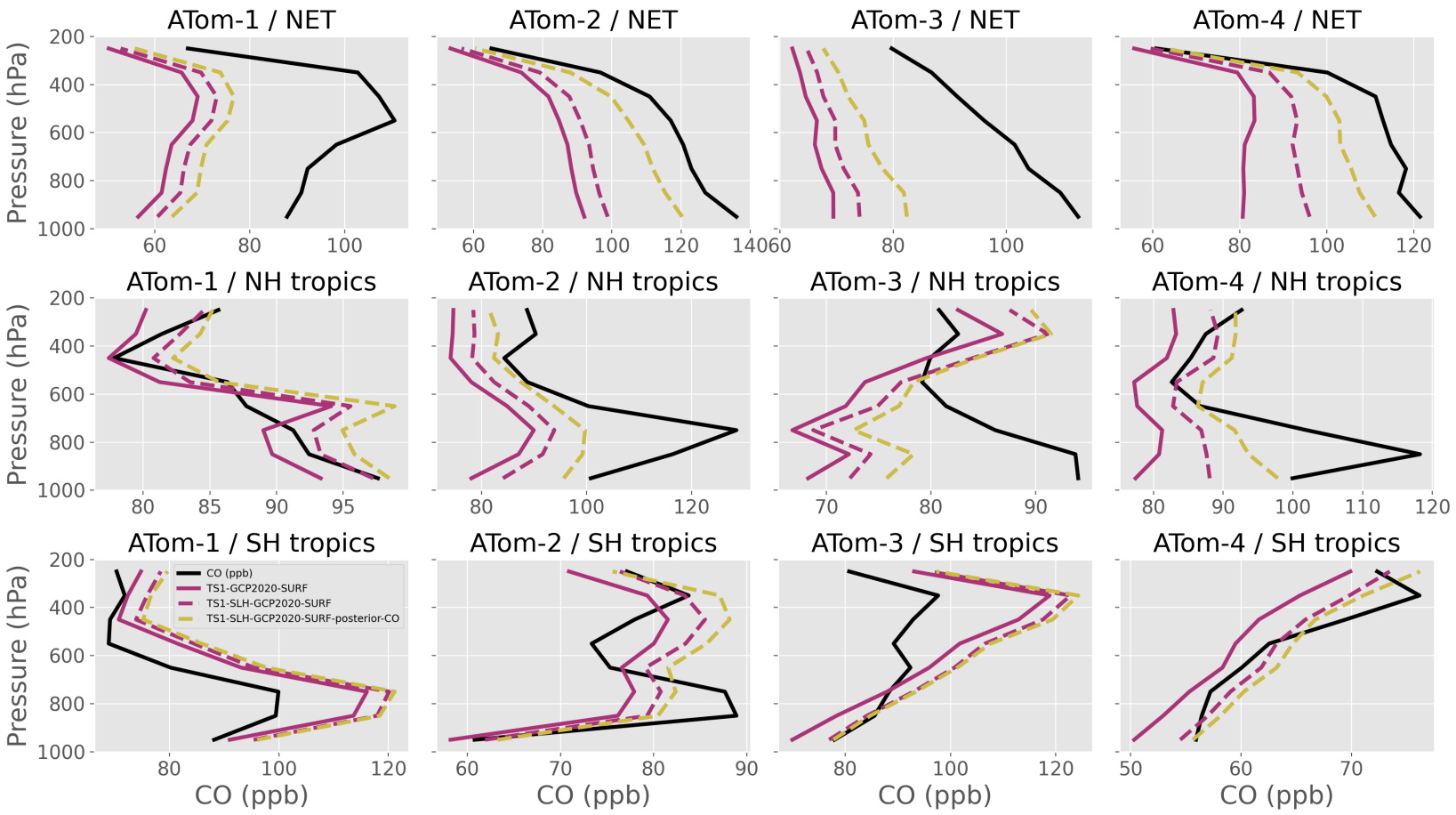


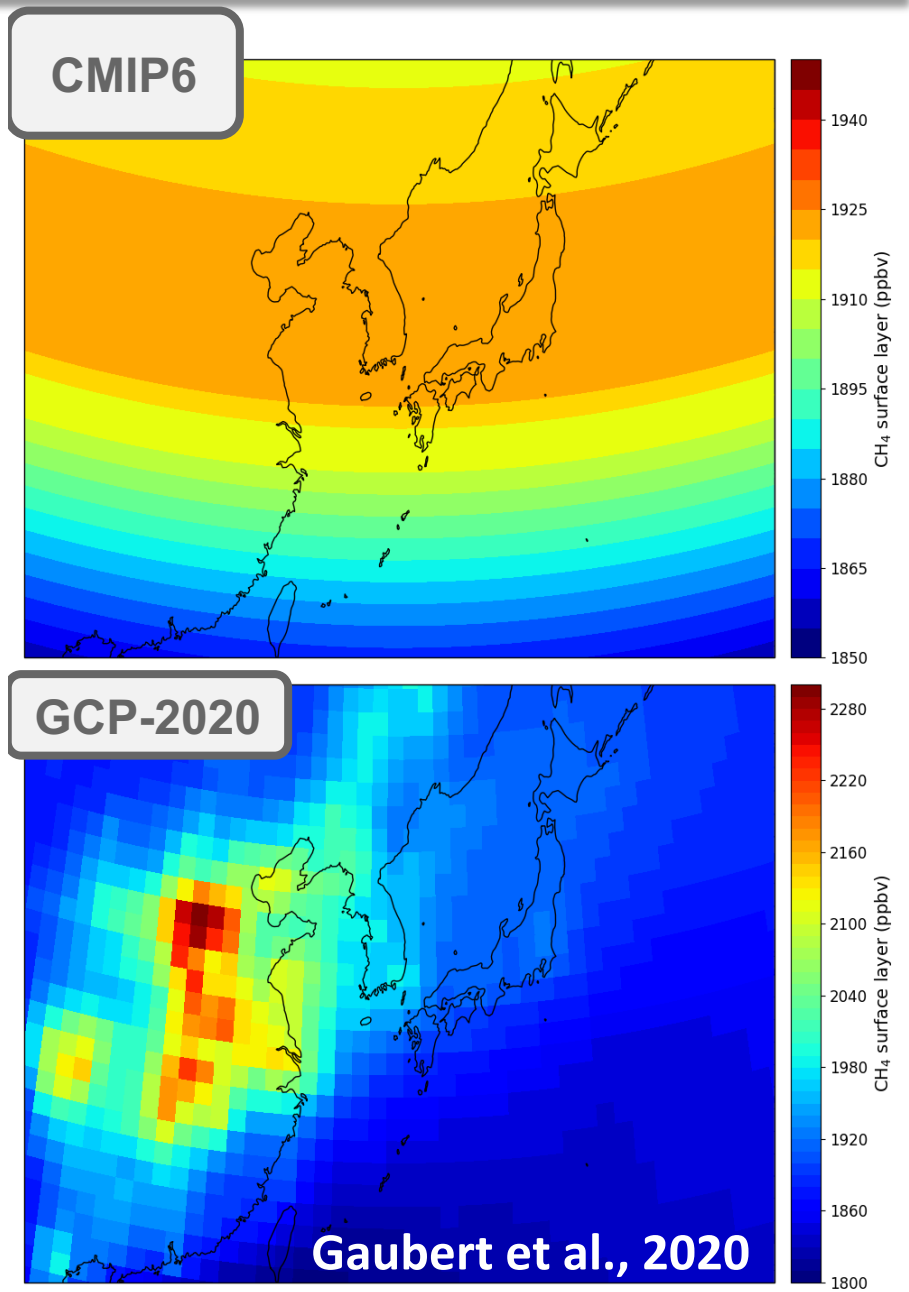


❖**BNRH improves fit to observations**

RMSE vs. MOPITT-DA

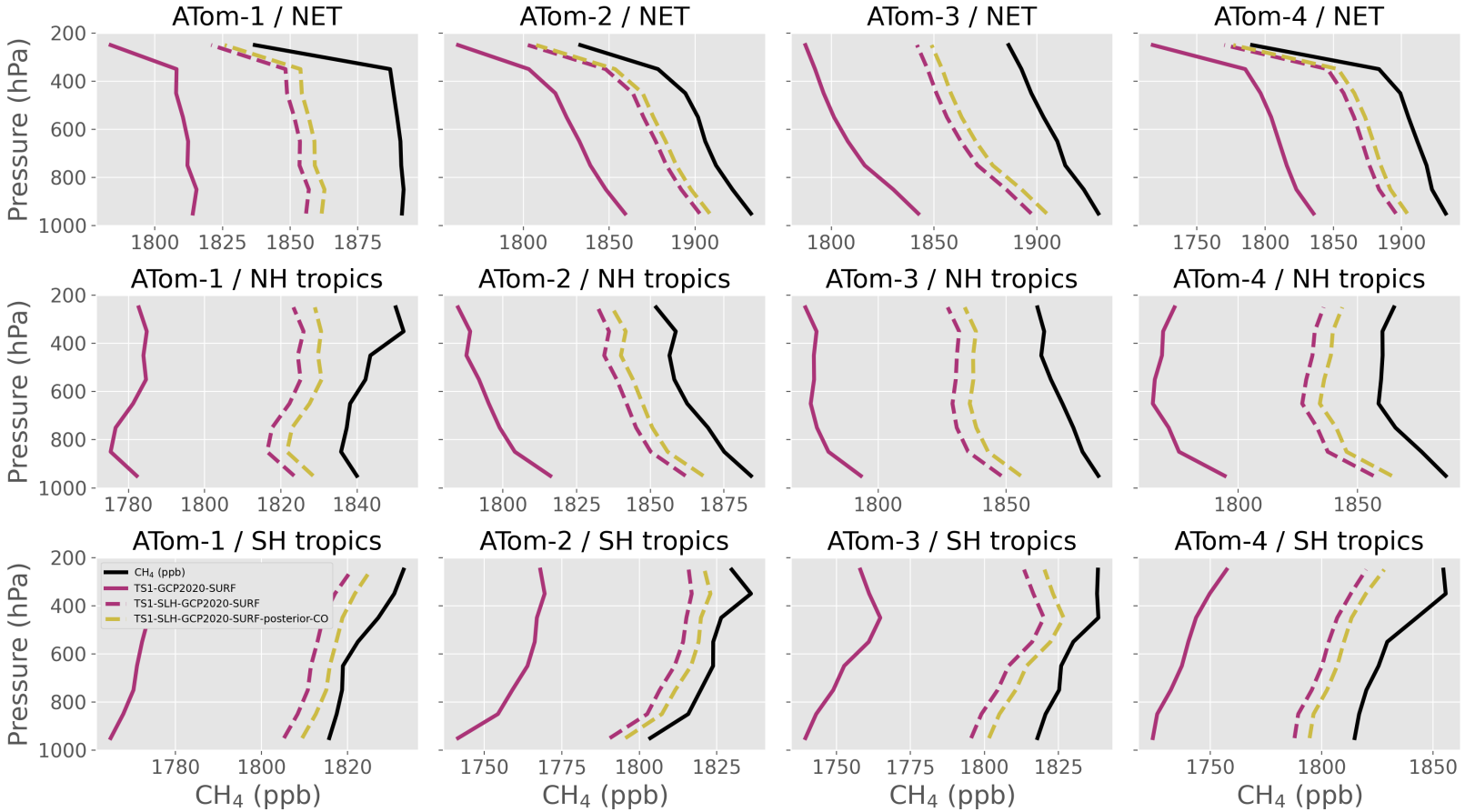
Emission-driven CH4 and halogen chemistry

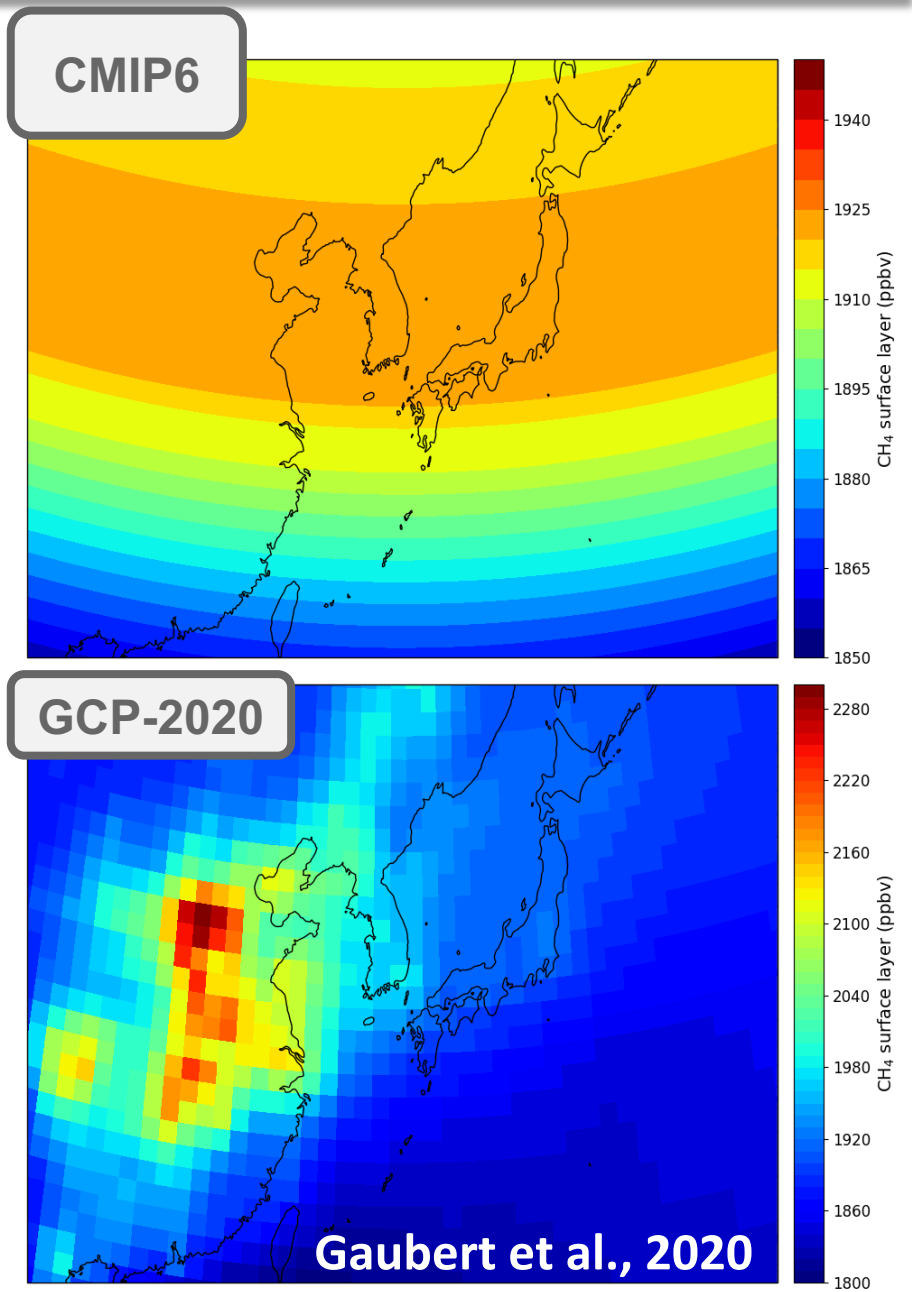




- Updated halogen representation reduces OH
- It has a larger impact on CO than an emission change
- Overall larger sensitivity to emission changes

Emission-driven CH4 and halogen chemistry





- Updated halogen representation reduces OH
- It enables emission-driven methane simulations

Comparison of satellite products

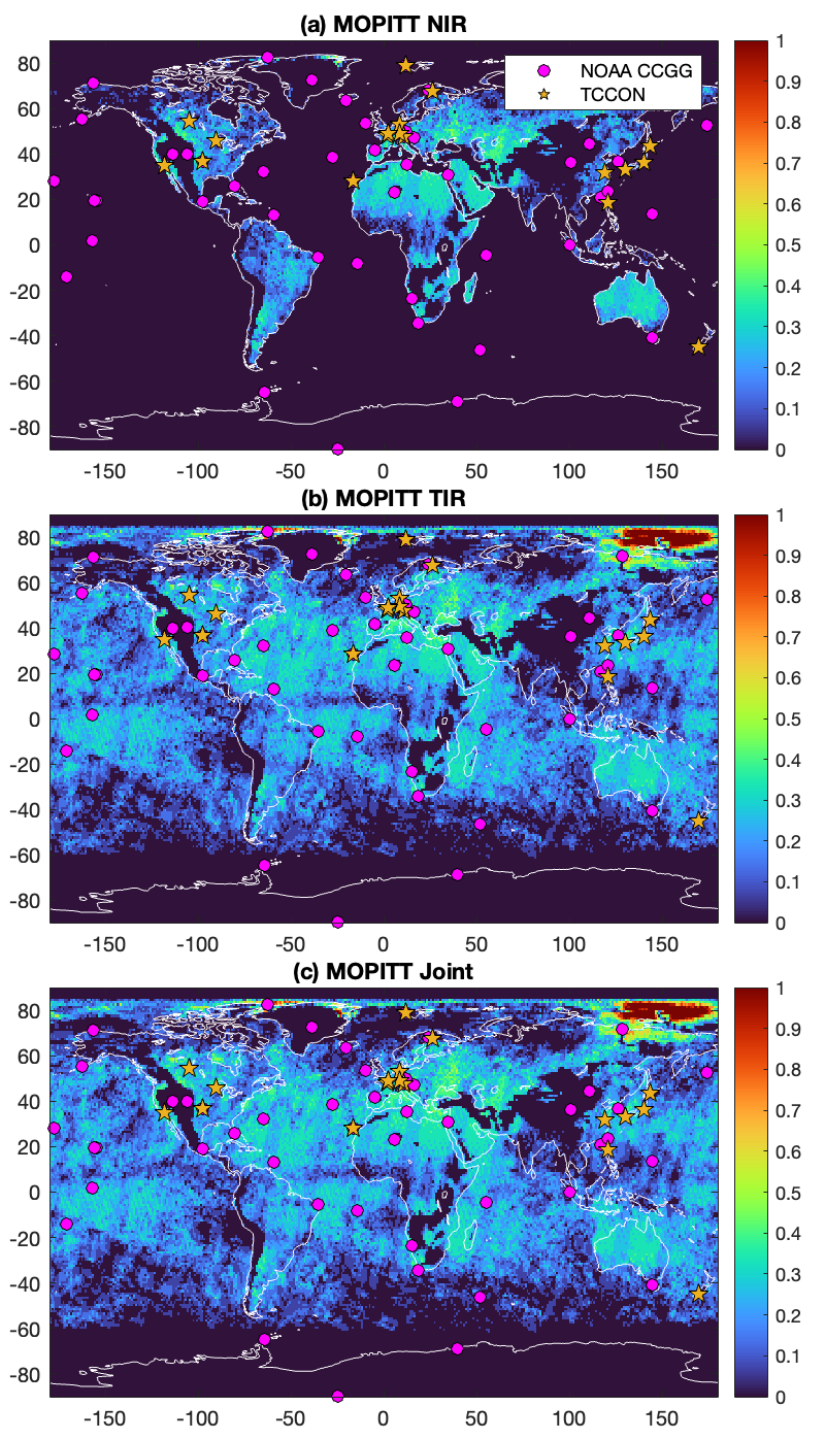
Status: a revised version of this preprint was accepted for the journal AMT.

Advantages of assimilating multi-spectral satellite retrievals of atmospheric composition: A demonstration using MOPITT CO products

Wenfu Tang, Benjamin Gaubert, Louisa Emmons, Daniel Ziskin, Debbie Mao, David Edwards, Avelino Arellano, Kevin Raeder, Jeffrey Anderson, and Helen Worden

(1) Assimilating multispectral/joint retrievals versus single-spectral products.
(2) Assimilating satellite profile products versus column products.
(3) Assimilating multispectral/joint retrievals versus assimilating individual products separately.

Data Assimilation can be used to **indirectly evaluate satellite** observations and act as a transfer functions to other datasets: surface and aircraft in-situ, ground based remote sensing, other satellite observations.



Summary

- **DART/CAM-chem** system for efficient ensemble assimilation of meteorology-aerosol-chemistry in a global interactive chemistry model.
- Emission updates allows for discrimination of **anthropogenic** and **fire** emission fluxes with characterization of systematic errors.
- With the addition of additional datasets, it allows to quantify the role of **chemistry** and **emissions** and further improve chemical predictions
- Evaluating impacts of different observation types: comparison of **MOPITT and CrIS underlines biases** between the two retrievals, but also synergies
- A novel assimilation algorithm: **Bounded Normal Rank Histogram (BNRH) provides** better results than the Ensemble Adjustment Kalman Filter (EAKF).
- Posterior anthropogenic emissions from BNRH, combined with **halogen chemistry** representation (SLH) show large improvement in background CO and will enable emission-driven CH_4 simulations