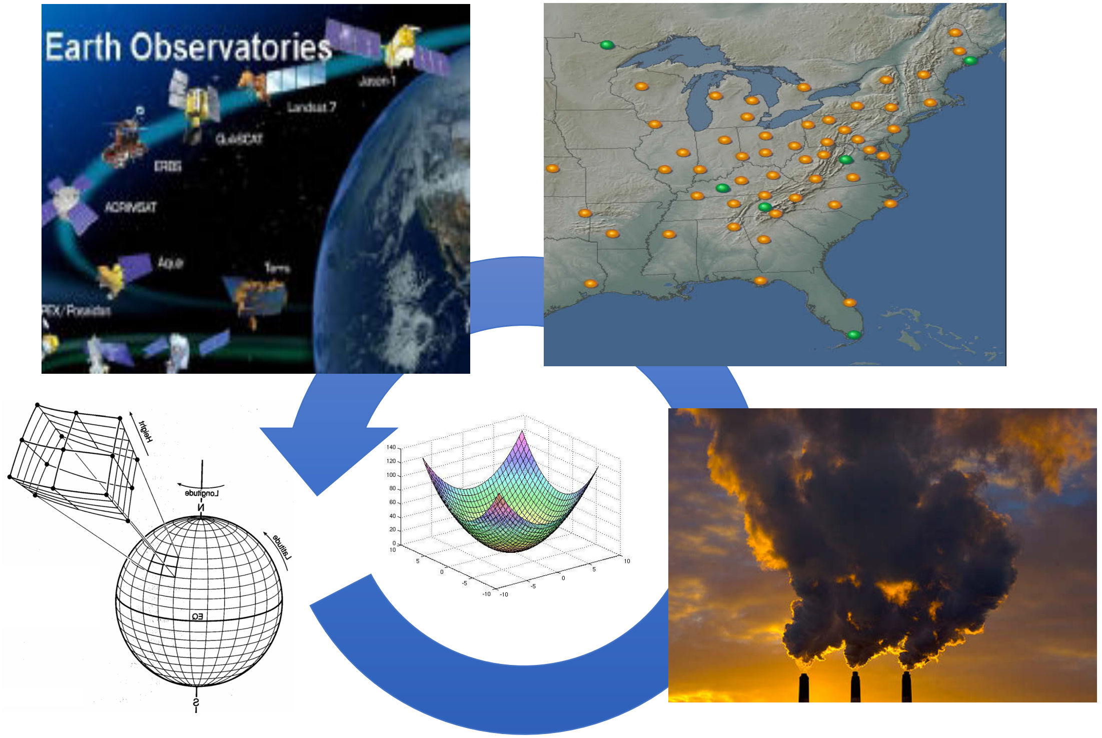
Top-down constraints on emissions of NO_2, SO_2 and NH_3

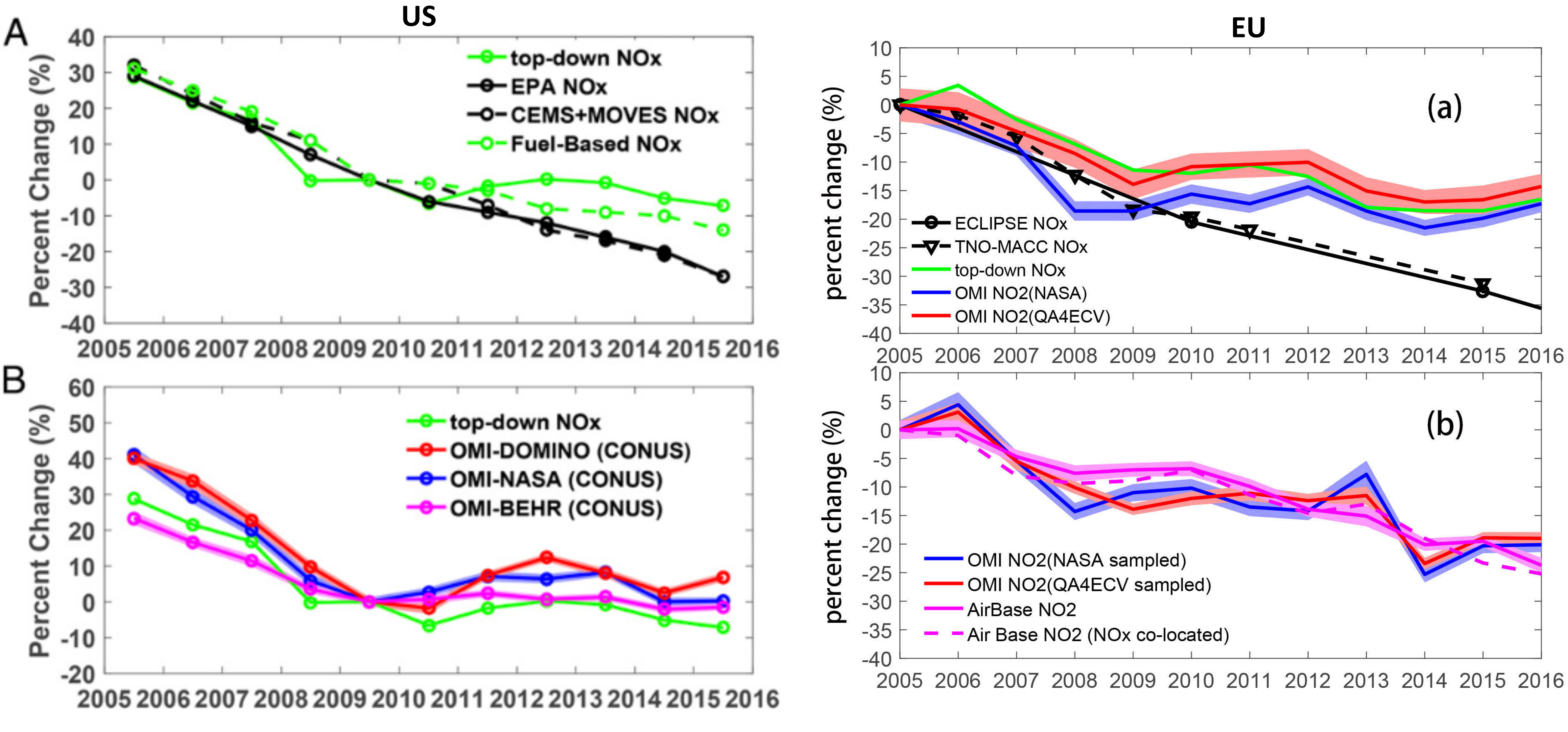


Daven K. Henze, Zhen Qu, Hansen Cao (University of Colorado, Boulder);
Zhe Jiang (USTC);

Helen Worden (NCAR); John Worden (JPL); Kazuyiki Miyazaki (JPL); Brian McDonald (NOAA); Ave Arellano (University of Arizona); Dylan B. A. Jones (University of Toronto); Emily Fischer (CSU); Liye Zhu (Sunyat-Sen U.); Folkert Boersma (KNMI); Zbigniew Klimont (IIASA); Mark Shephard (EC), Karen Cady-Pereira, Matt Alvarado, Chantelle Lonsdale (AER); Can Li (NASA Goddard); Nicolas Theys (BIRA)

Funding: NASA HAQAST, ACMAP, TASNPP

Declining trends in NOx emissions have been decreasing, in contrast to inventories



Jiang et al., PNAS, 2018

Jiang et al., in prep

Inverse modeling and data assimilation

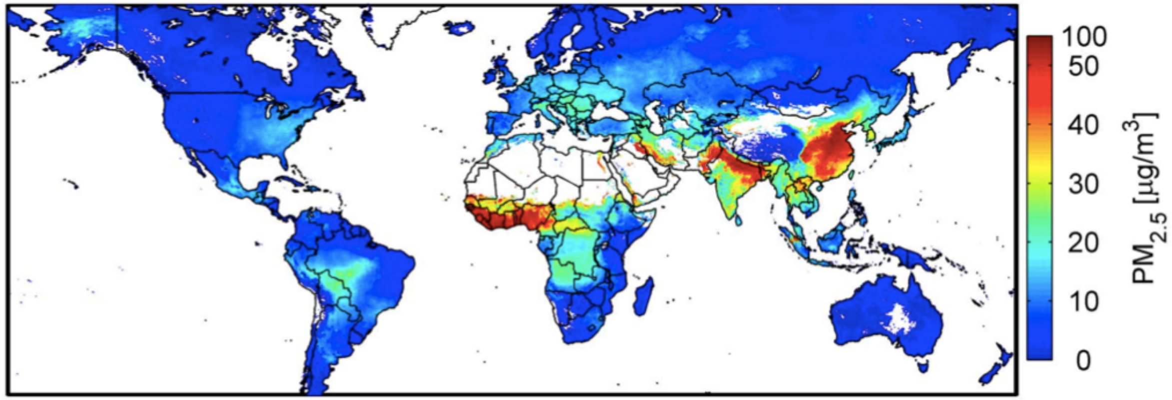
- Formally combining air quality model simulations with observational datasets
  - Plume models
  - Mass-balance
  - 3D-Var, 4D-Var, EnKF,….

- Provide a means of:
  - Updating concentration estimates (e.g., forecasting)
  - Improving emissions estimates (for forecasting, reanalysis, AQ planning)

- “4th generation”/ “instrumented models” can incorporate remote-sensing into efforts that are often entirely model-based:
  - Source attribution studies
  - Boundary conditions for regional modeling
  - Health impacts studies for species whose surface concentrations are hard to observe from satellites

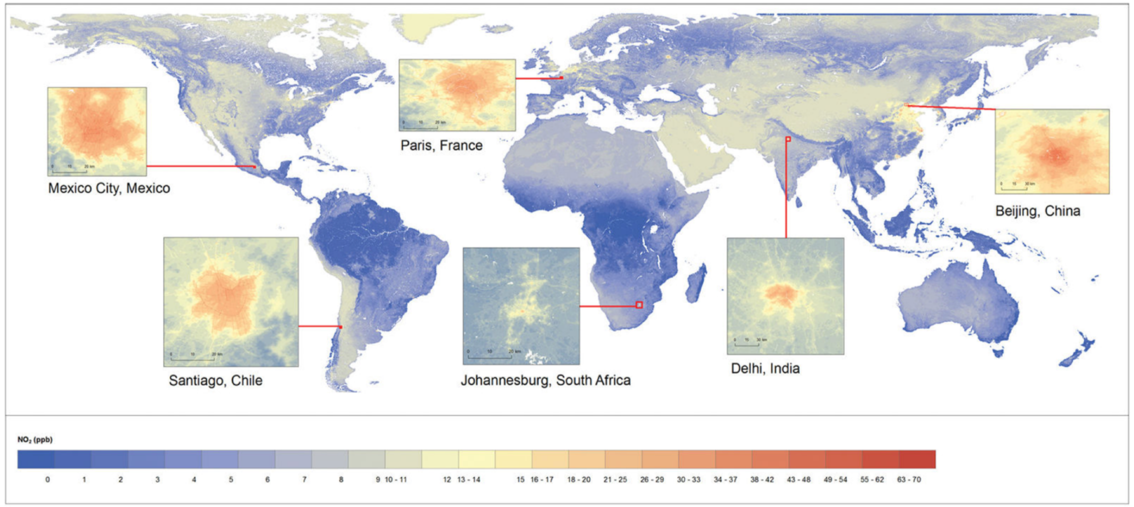
Role of chemical remote-sensing observations in health studies

$PM_{2.5}$



van Donkelaar et al., 2016: MODIS, MISR, SeaWiFS, CALIOP

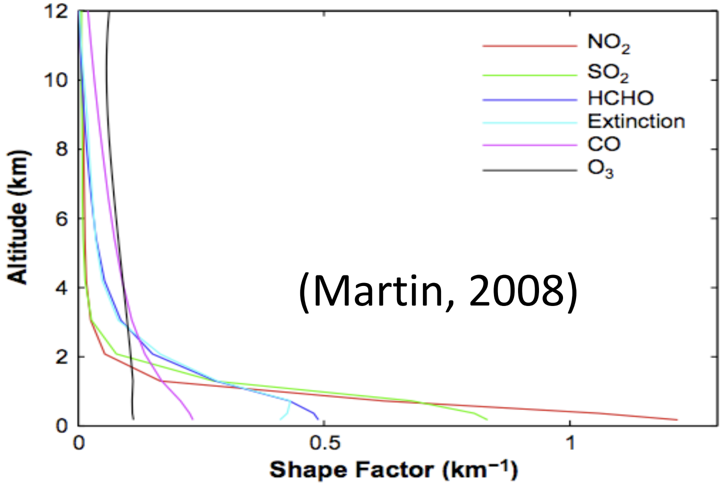
NO_2



Larkin et al., 2017: SCIAMACHY, GOME-2

- Numerous studies of health impacts of $PM_{2.5}$ and NO_2 rely on satellite-informed exposure estimates

- In contrast, O_3 health impact studies (e.g., GBD) have relied on models and surface monitoring networks



Ongoing inverse modeling efforts in our group (Zhen Qu)

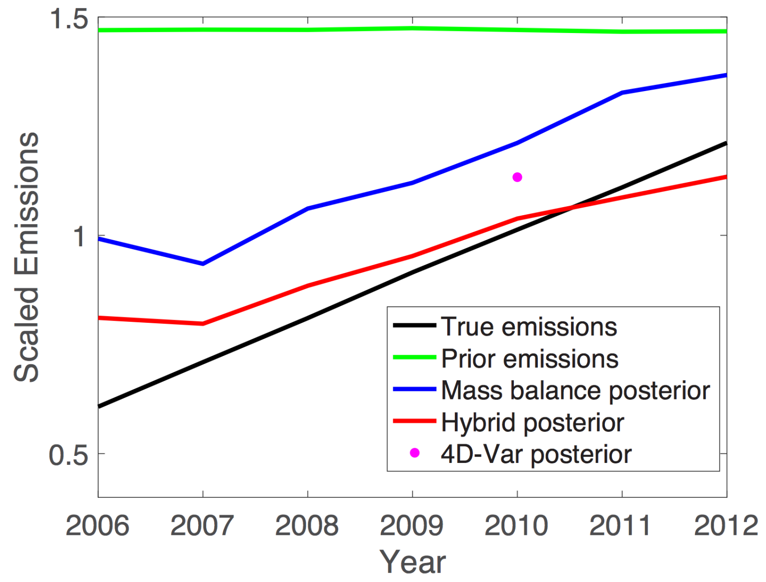
- Develop hybrid mass-balance / 4DVar
  - Computationally efficient
  - Accurate

- Application to high-resolution emissions and trends of NOx (Qu et al., 2017) and SO_2 (Qu et al., in press) using OMI satellite data

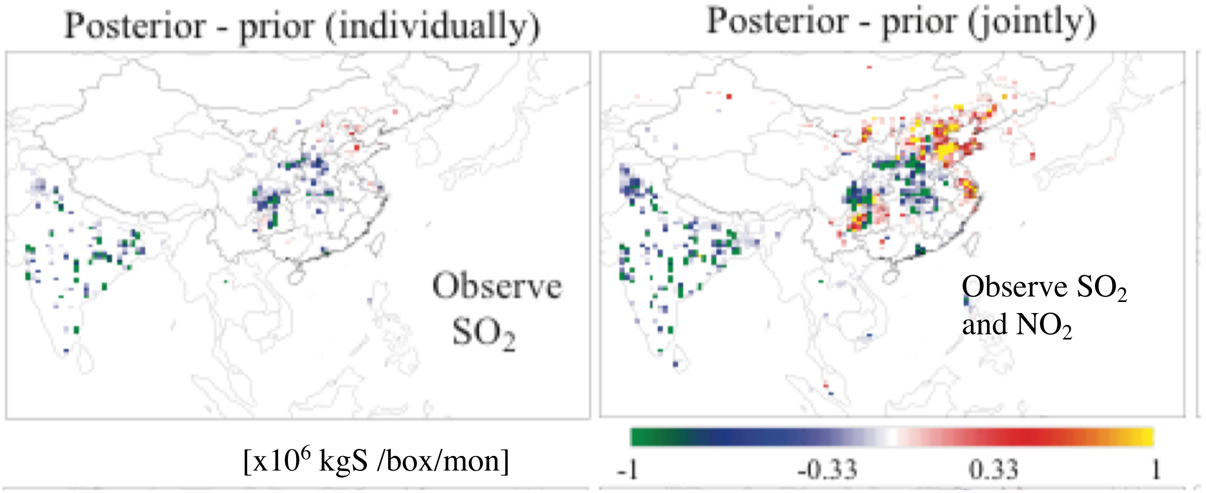
- Joint assimilation of NO_2, SO_2 (Qu et al., in press) and CO (in progress)

- Inversion method based on sectors (e.g., transportation, egu, residential, etc.) rather than species (in progress)

Testing new hybrid method with NO_2 pseudo inversion

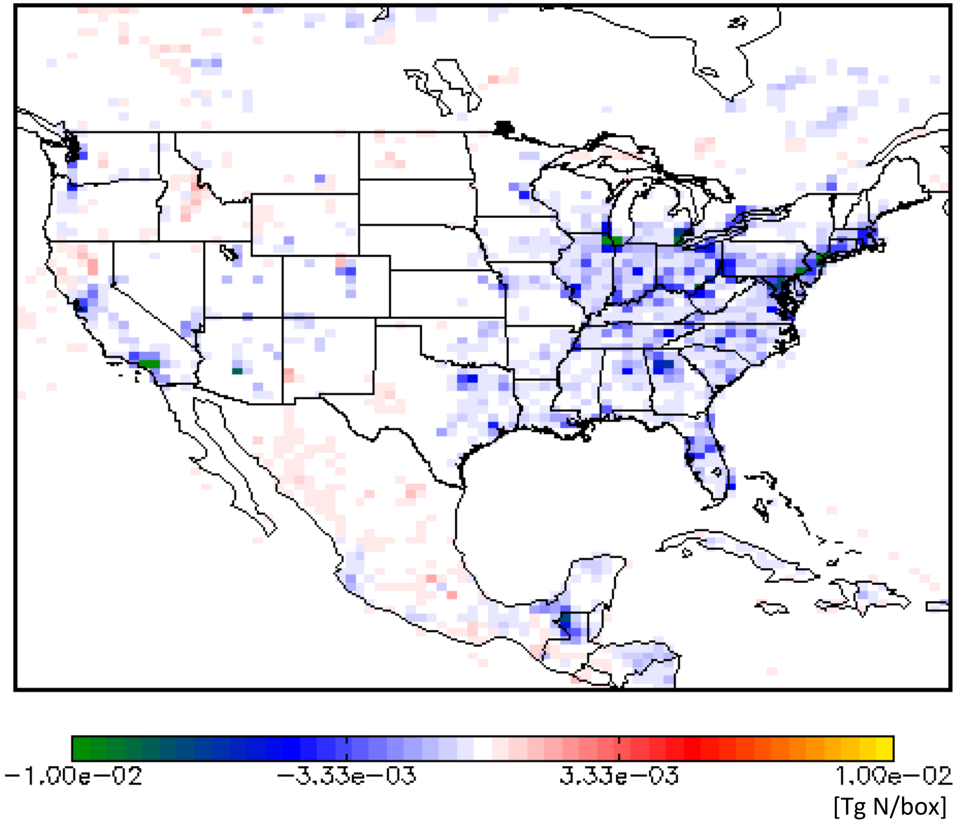


SO_2 emissions constrained by OMI SO_2 and NO_2

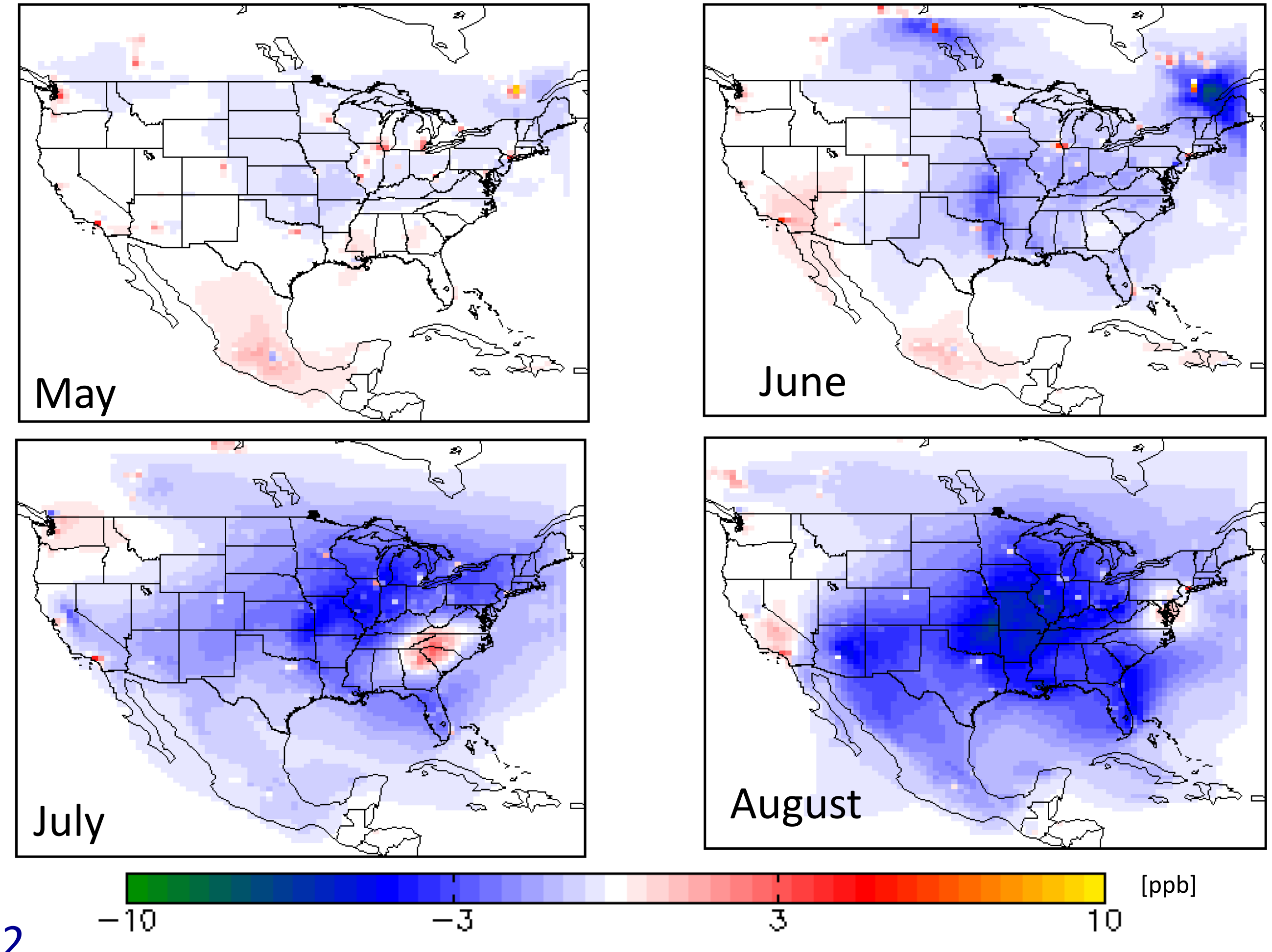


Inverse modeling of NO_x emissions in North America

2012 – 2005 annual NOx emissions



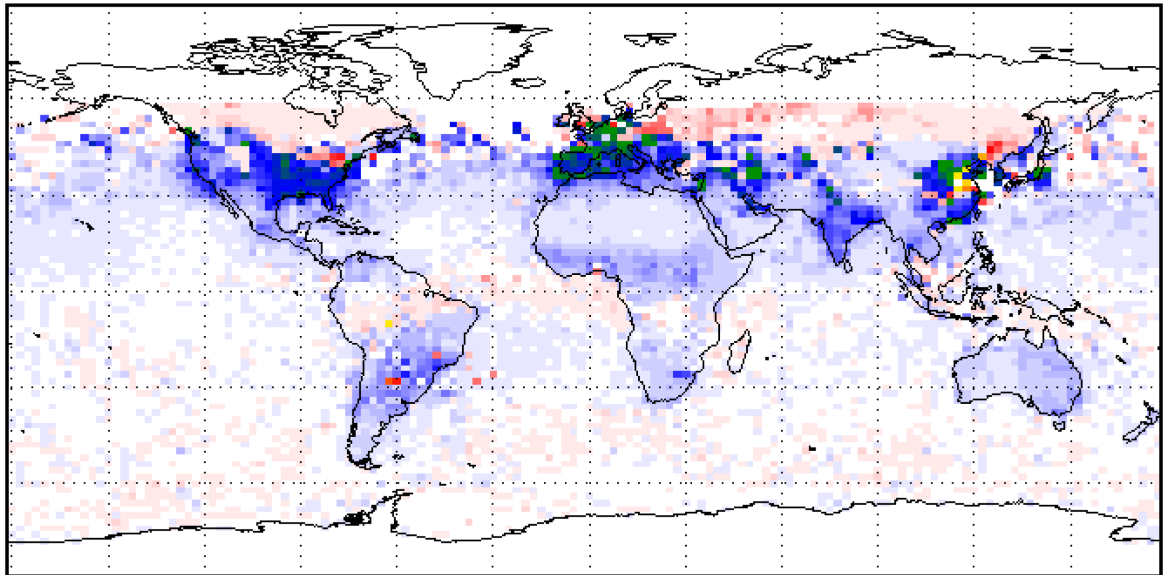
Surface 2010 O_3 concentration (posterior NO_x – prior NO_x)



- NO_x decrease by 30 - 40 % from 2005 to 2012 in EUS
- NO_x increase in Mexico by ~ 40 – 100% from 2005 - 2012
- NO_x emission overestimated in US bottom-up inventory in 2010
- Simulated O_3 are generally overestimated in US using HTAP 2010 emissions

Impact of assimilation depends on OMI NO_2 retrieval product and O_3 metric

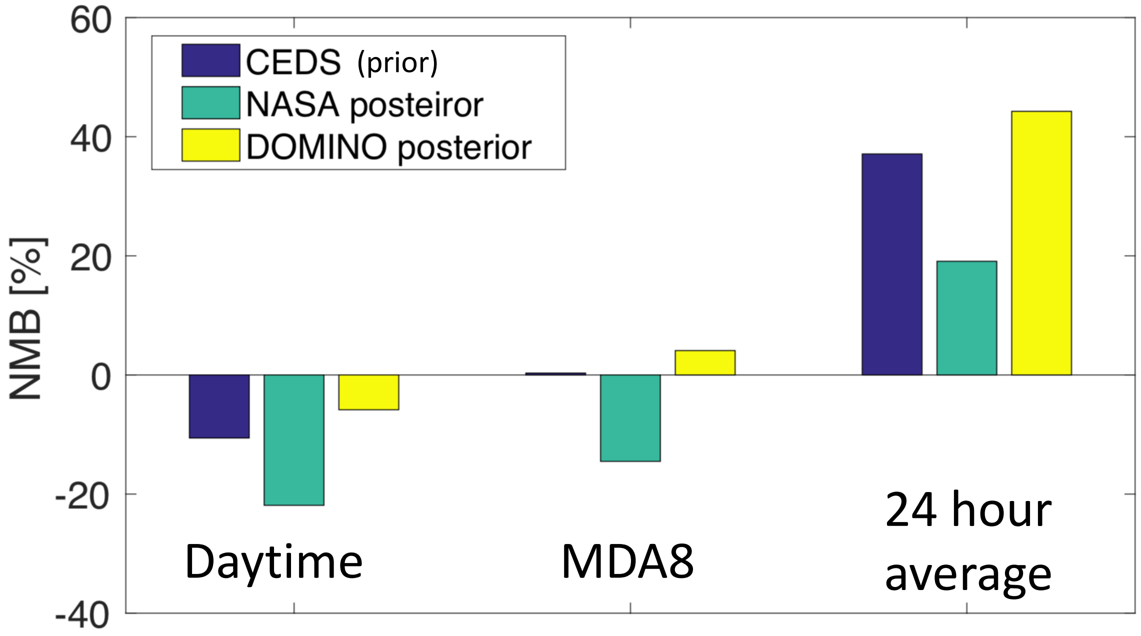
OMI VCD_{SP} - VCD_{DOMINO}, Jan 2015



NO_2 column densities from SP are ~50% smaller than that from DOMINO in densely populated and industrial regions.

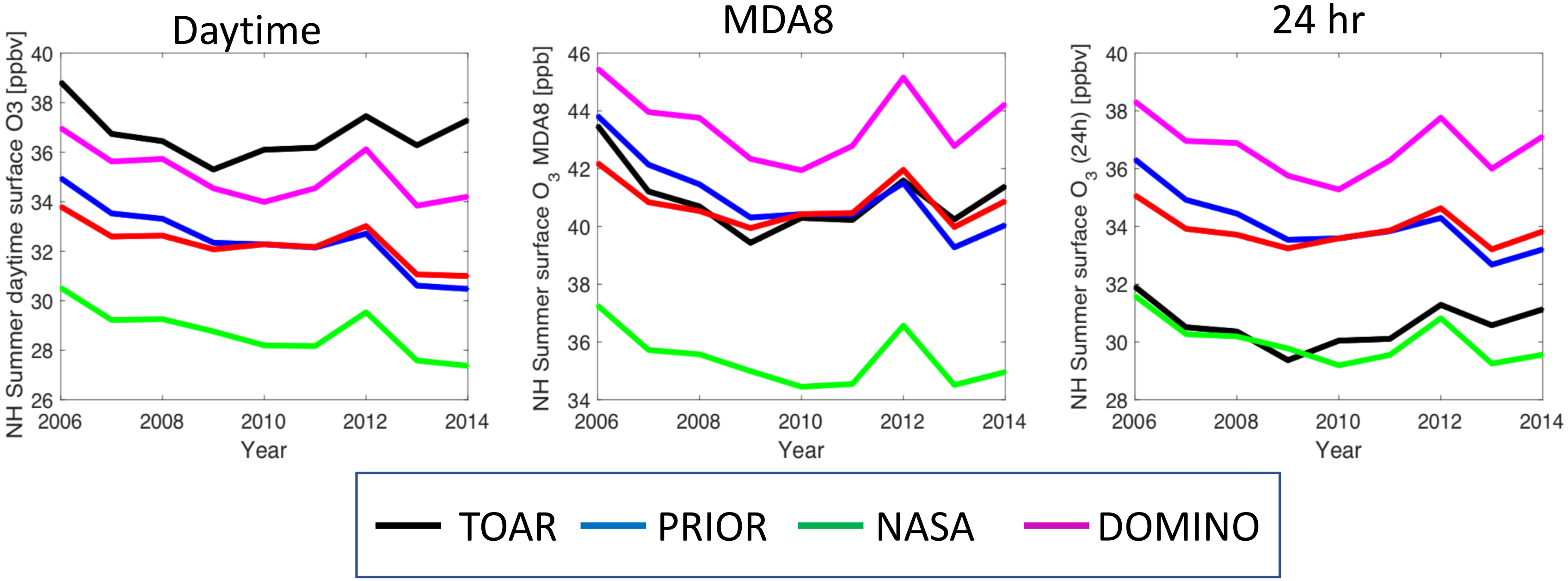
(Qu et al., 2017; Canty et al., 2015; Zheng et al., 2014)

Evaluation of global posterior emissions in GCv12 compared to O_3 (TOAR, 2019)

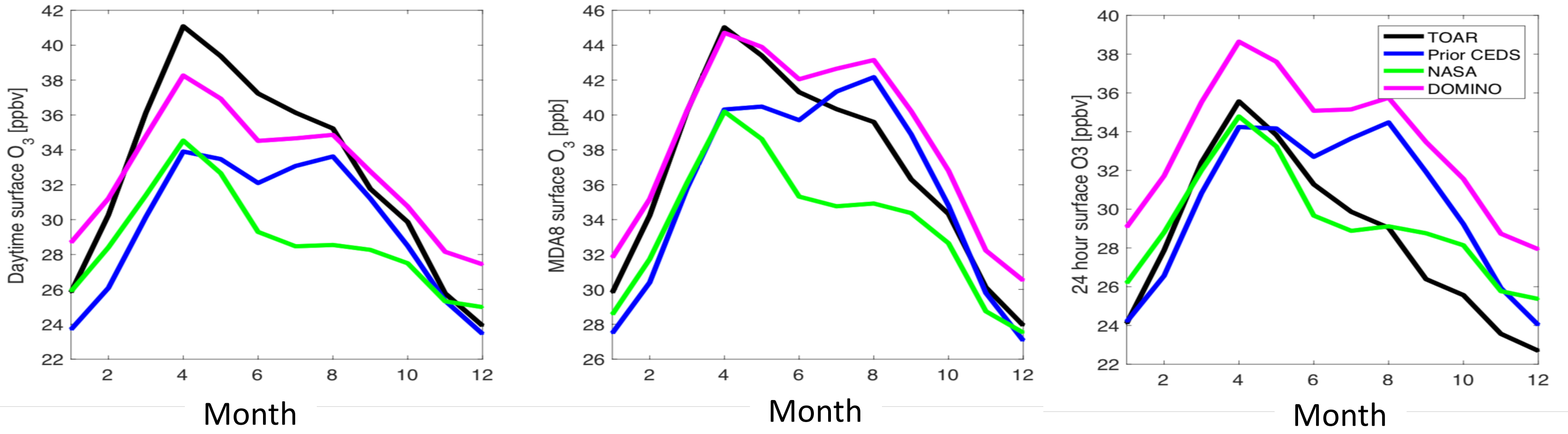


Differences across O_3 metrics highlights importance of upcoming geostationary (i.e., hourly) NO_2 satellite obs

Annual and seasonal trends are more consistently improved by OMI NO_2 inverse modeling



	Prior (CEDS)	NASA	DOMINO	
R	0.47	0.55	0.72	Daytime
R	0.81	0.85	0.89	MDA8
R	0.55	0.69	0.88	24 hr
NMB [%]	-11.57	-21.78	-4.56	Daytime
NMB [%]	0.22	-13.56	6.47	MDA8
NMB [%]	11.44	-1.85	20	24 hr



	Prior (CEDS)	NASA	DOMINO	
R	0.93	0.92	0.99	Daytime
R	0.90	0.98	0.97	MDA8
R	0.81	0.96	0.95	24 hr
NMB [%]	-9.68	-12.06	0.11	Daytime
NMB [%]	-3.25	-8.84	4.71	MDA8
NMB [%]	5.76	2.49	16.96	24 hr

Feeding Tiger Team activities

- Indicators (Anenberg)
  - trends in global O_3
  - to be included in ensemble of modeled O_3 simulations, weighted by accuracy vs surface obs, to generate O_3 exposure estimates (West)
  - will provide first satellite-informed O_3 exposures to GBD estimates of global O_3 health impacts

- Background O_3 (Neu)
  - evaluate metrics of remote, spring, Western US sites
  - provide boundary conditions for regional modeling
  - evaluate trends, source attribution in O_3 design values in Yuma (Qu et al., in prep)

- Regional Haze (Fiore)
  - evaluate role of emission trends

Year 3 Progress Update, PI Henze, Co-I's Anenberg, Kinney

Supporting health impact assessment tools using remote sensing and earth system models

- Source-receptor (SR) coefficients for $PM_{2.5}$ and O_3 to CCAC impact toolkit (LEAP-IBC)
  - $PM_{2.5}$ SR coefficients for all countries in Asia, Africa, Caribbean, Central & South America.
  - O_3 coefficients for each CCAC member nation
  - LEAP-IBC used in 25 countries, e.g. Nepal (Nakarmi et al., submitted) and Bangladesh (Kuylenstierna et al., in prep)
  - Impacts of cookstoves (Lacey et al., 2017) and fugitive diesel NOx (Anenberg et al., 2017)
- High-resolution SR calculations for urban regions
  - In progress for Africa, West Africa, South America
- Expand health impacts
  - Global air pollution and asthma (Anenberg et al., 2018), comparisons across cites with eCO2 (Anenberg et al., submitted)

Year 3: 4 papers published, 2 accepted
4 in review, 4 in prep

Tiger Team Participation

- Hi-Res $PM_{2.5}$ (**Kinney**, Freedman)
  - Health impacts of different $PM_{2.5}$ estimates (**Anenberg**)
  - Low-cost monitors deployed in NYC, Boston, SF (**Kinney**)
- Trends (Duncan, West) / Background O_3 (Neu) / Regional Haze (Fiore)
  - SO_2 and NO_x emission from OMI (Que et al., 2017; 2019; 2019; Zhang et al., PNAS, 2018)
  - O_3 source apportionment in Yuma, Az (Qu et al., in prep)
  - O_3 estimates from NOx assimilation for boundary conditions
- Fires (O'Neill, **Kinney** Co-I)
  - Health impacts of 2017 Northern CA Fires
- Indicators (**Anenberg PI)**
  - Global O_3 concentrations from OMI-NO2 assimilation results to contribute to statistically fused product (West) for GBD