Distinguishing Local From Non-local Sources Of Pollution: The Role Of LEO Sounders In The CEOS Air-quality Constellation

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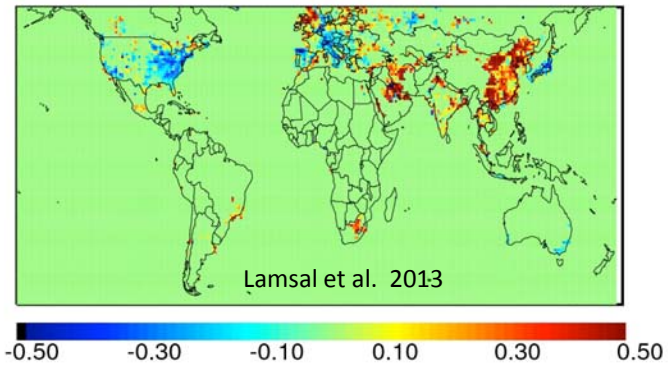
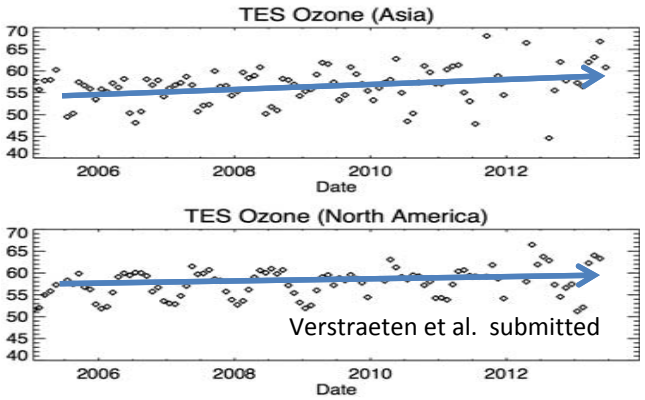
What is the role of remote sources on local air quality in the context of changing global emissions?

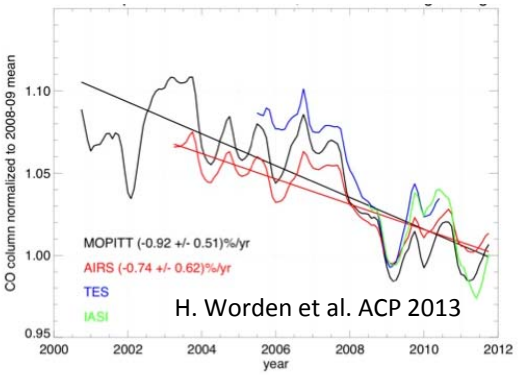
OMI NO_2



TES Ozone



MOPITT, TES, AIRS, IASI Carbon Monoxide

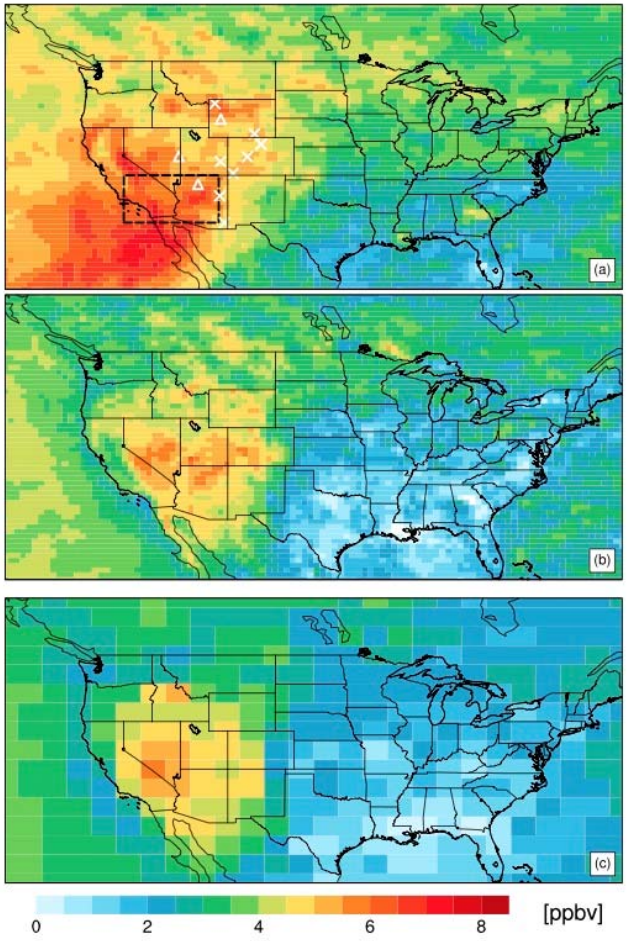


Ozone pre-cursor emissions have dramatically changed over the last decade with substantial consequences for background ozone levels and its role on air quality

Source / Receptor Relationships: Asian Emissions and Western USA Ozone

Free-tropospheric (top) and surface ozone (bottom) due to Asian emissions

Lin et al, JGR 2012; Fiore et al., JGR 2009(HTAP)



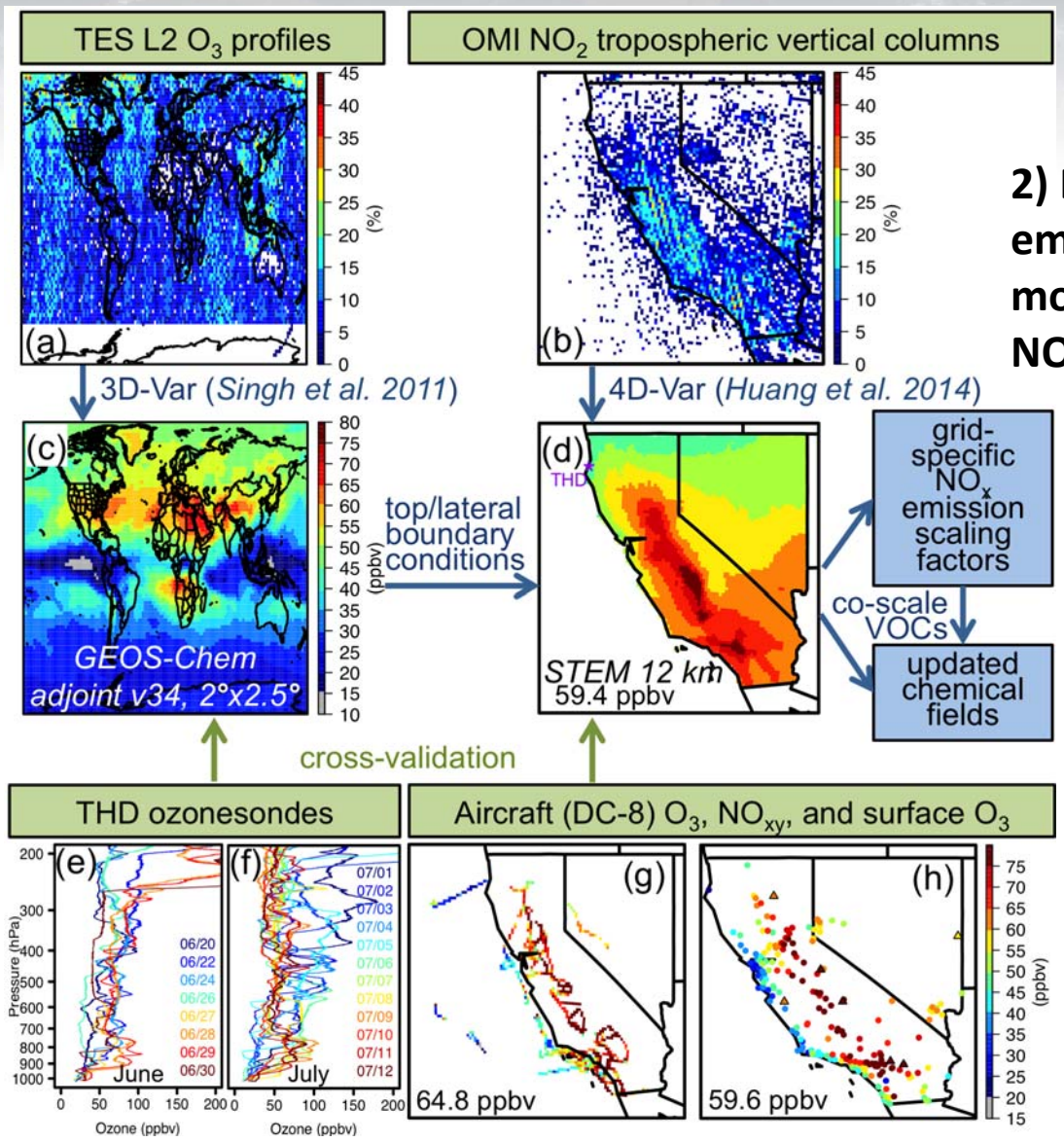
- **State-of-the-art model studies show that ozone in western free-troposphere depends on Asian surface emissions.**
- **Up to 8 ppb of the surface ozone in mountain states due to Asian emissions.**
- **Challenging to unequivocally attribute local ozone increases to remote sources using data despite wealth of aircraft and ground measurements**

Simplify the problem:
What is role of background ozone on local air quality?

Huang, Bowman et al., JGR, 2015

2) Assimilate Aura TES tropospheric ozone profile measurements into a GEOS-Chem to provide constraint on background ozone for regional model

3-4)Validate assimilated ozone and estimated NO2 with aircraft and ground measurements



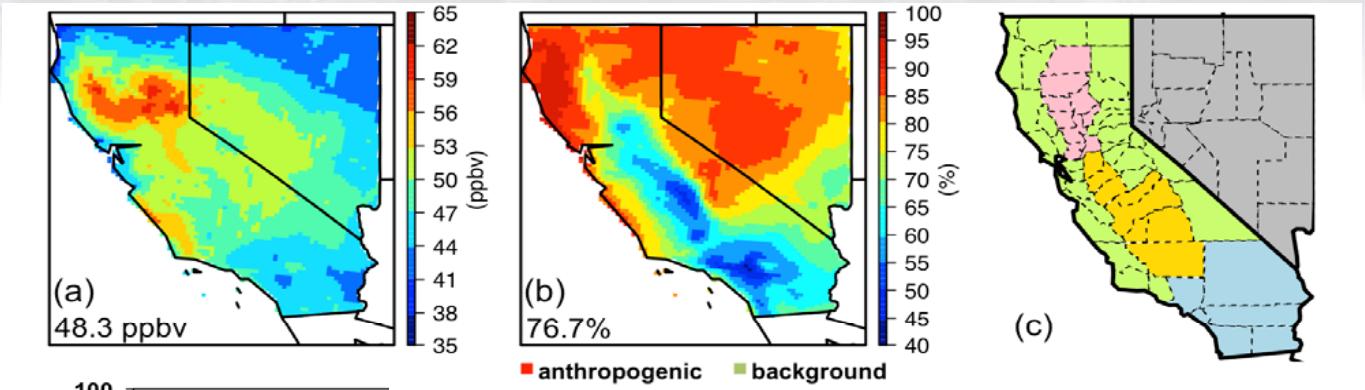
2) Estimate NOx emissions in regional model with OMI NO_2 data

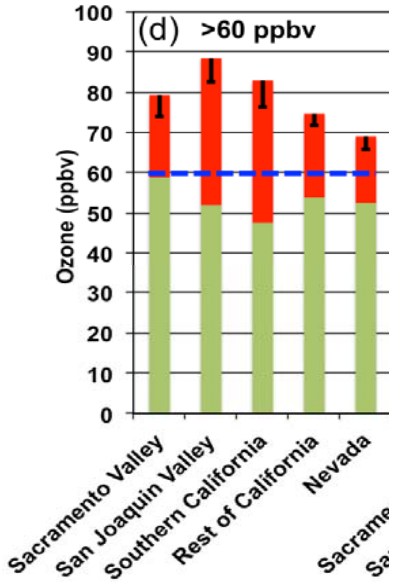
5) Turn off California Surface NOx emissions and look at effect on surface ozone

Case study: JJA 2008

Simplify the problem:
What is role of background ozone on local air quality?

Huang, Bowman et al., JGR, 2015





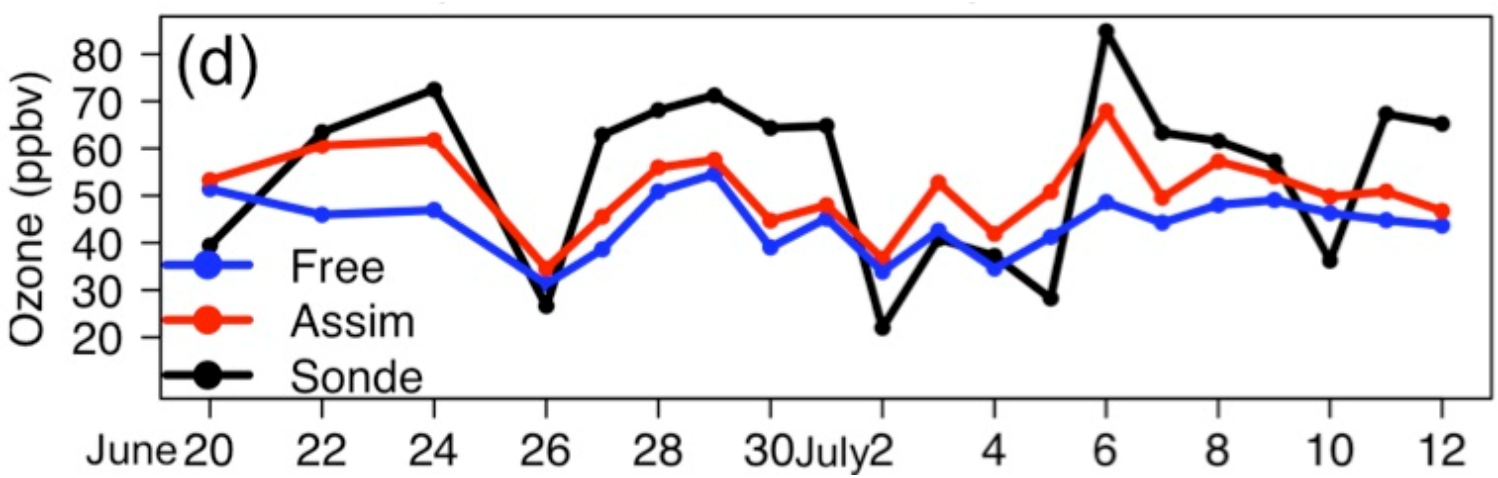
Result

Surprisingly, background ozone was a large fraction of total surface ozone and exceeded upcoming EPA regulations of 60 ppb in some regions

Simplify the problem:
What is role of background ozone on local air quality?

Huang, Bowman et al., JGR, 2015

Comparison between posterior model results and background air at Trinidad Head



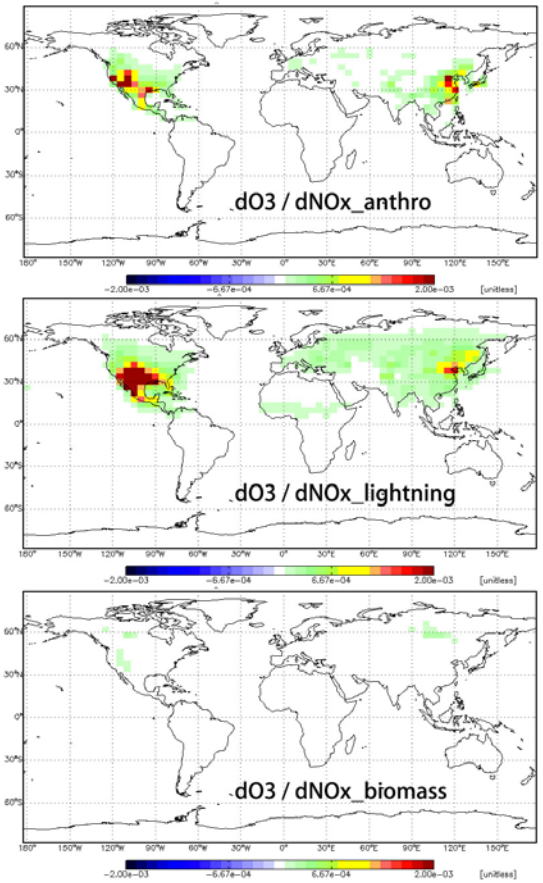
Residual errors between updated model and data are likely due to

1) **Insufficient sampling of background ozone and its pre-cursors result in substantial model/data mismatch → Need constraints on background ozone**
2) **Insufficient sampling of NOx sources → Need GEOCAPE sampling!**

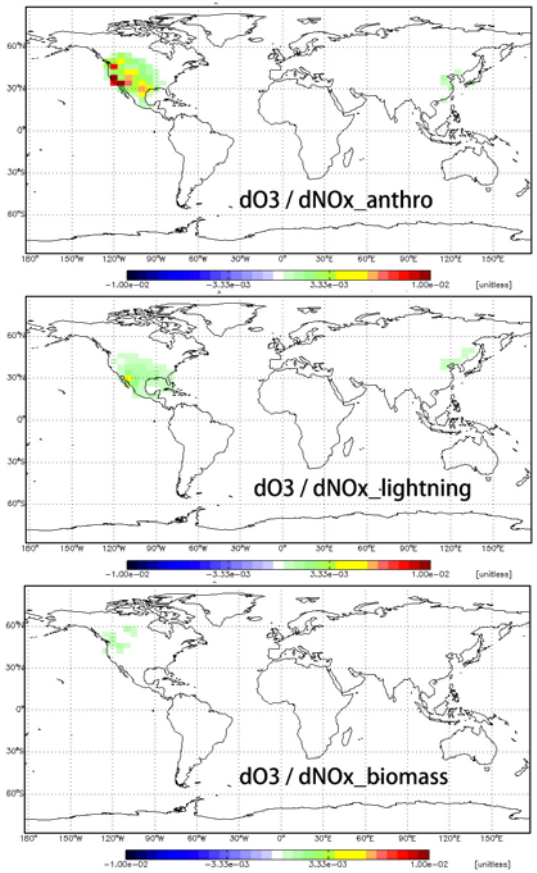
Where does the background ozone originate?

Background ozone depends on remote sources, strat/trop exchange, regional sources, and local production/loss mechanisms

Free Troposphere

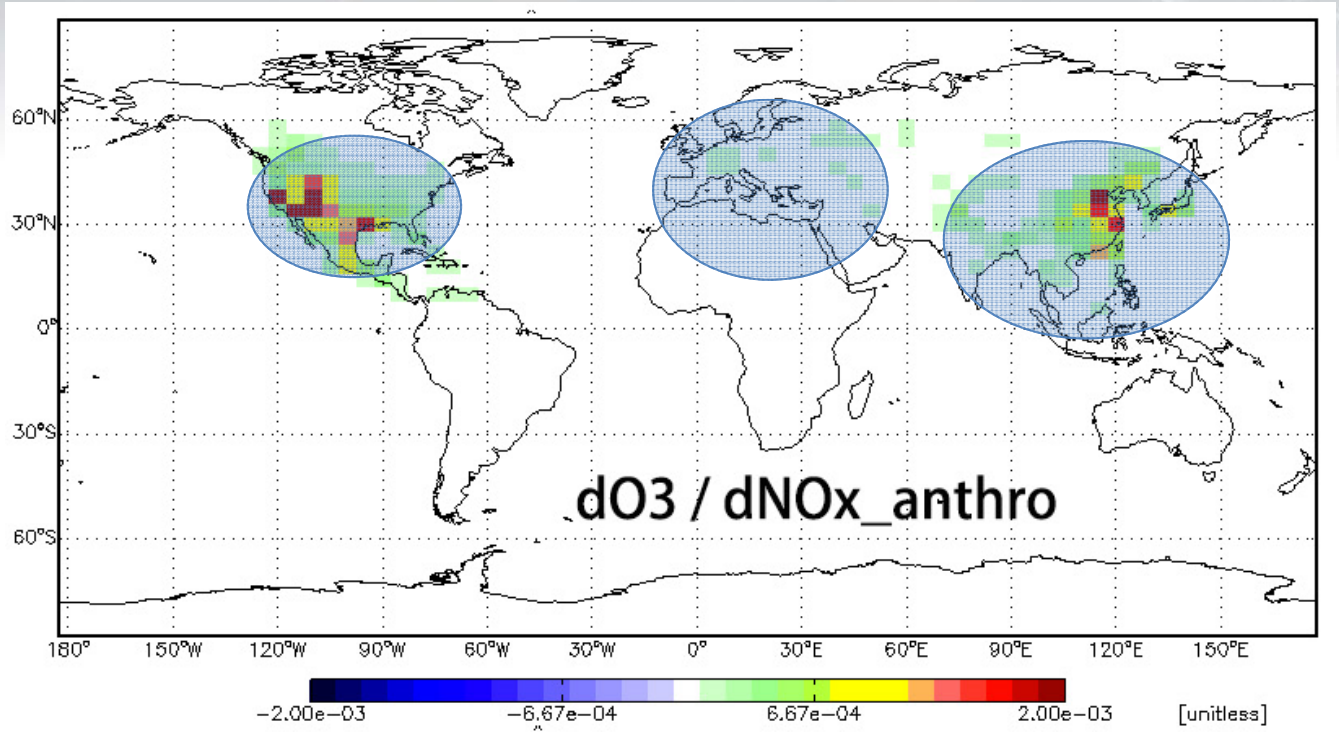


Lower Troposphere



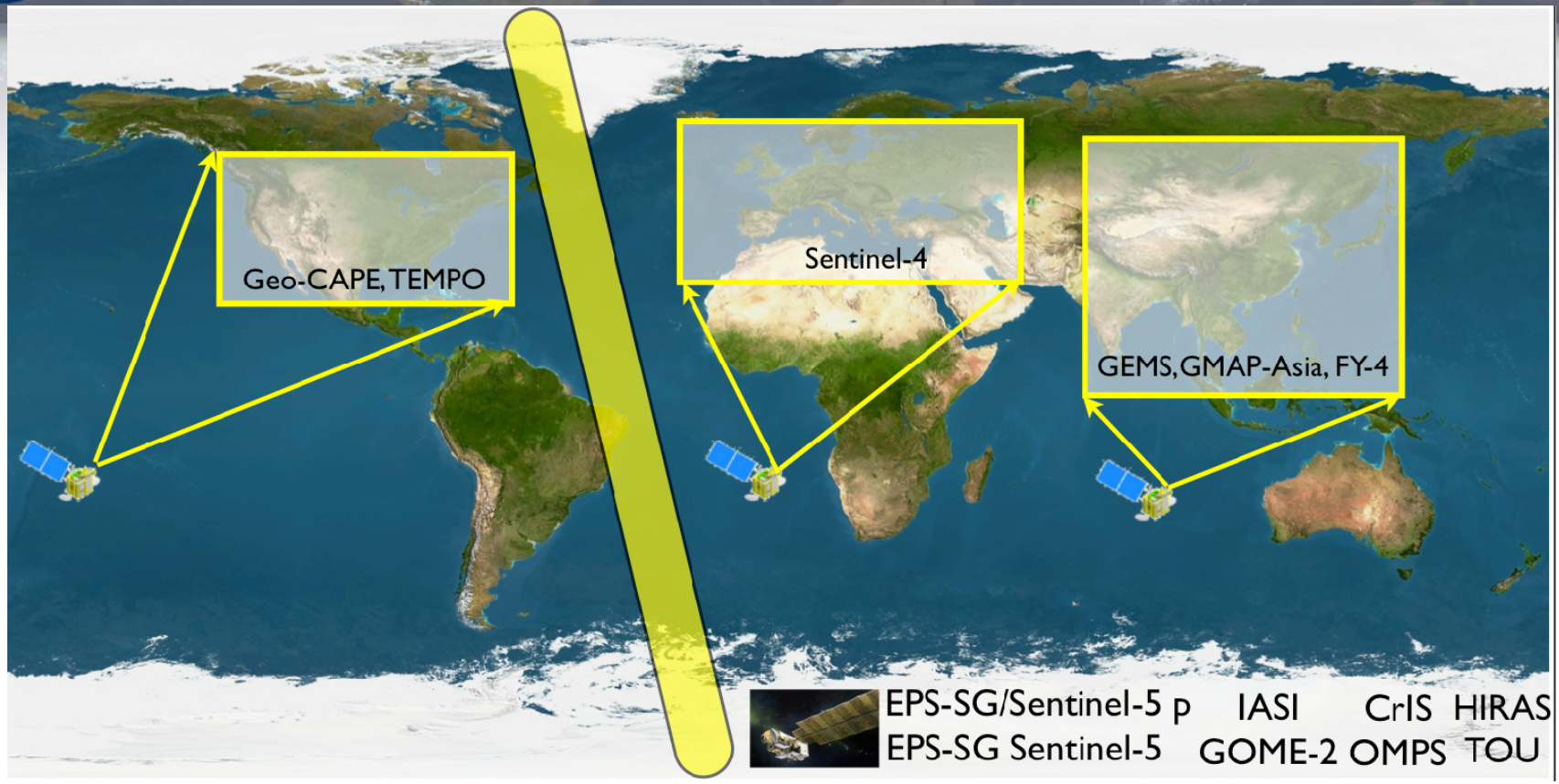
Sensitivity of free-tropospheric and lower tropospheric ozone over Western N. America to global NOx sources using adjoint of the GEOS-Chem model (July 2008)

How can we address this problem?



Attribution of surface ozone concentrations to emissions requires sampling of emissions in key regions

A GEO / LEO Constellation For Characterizing Source/Receptor Relationships

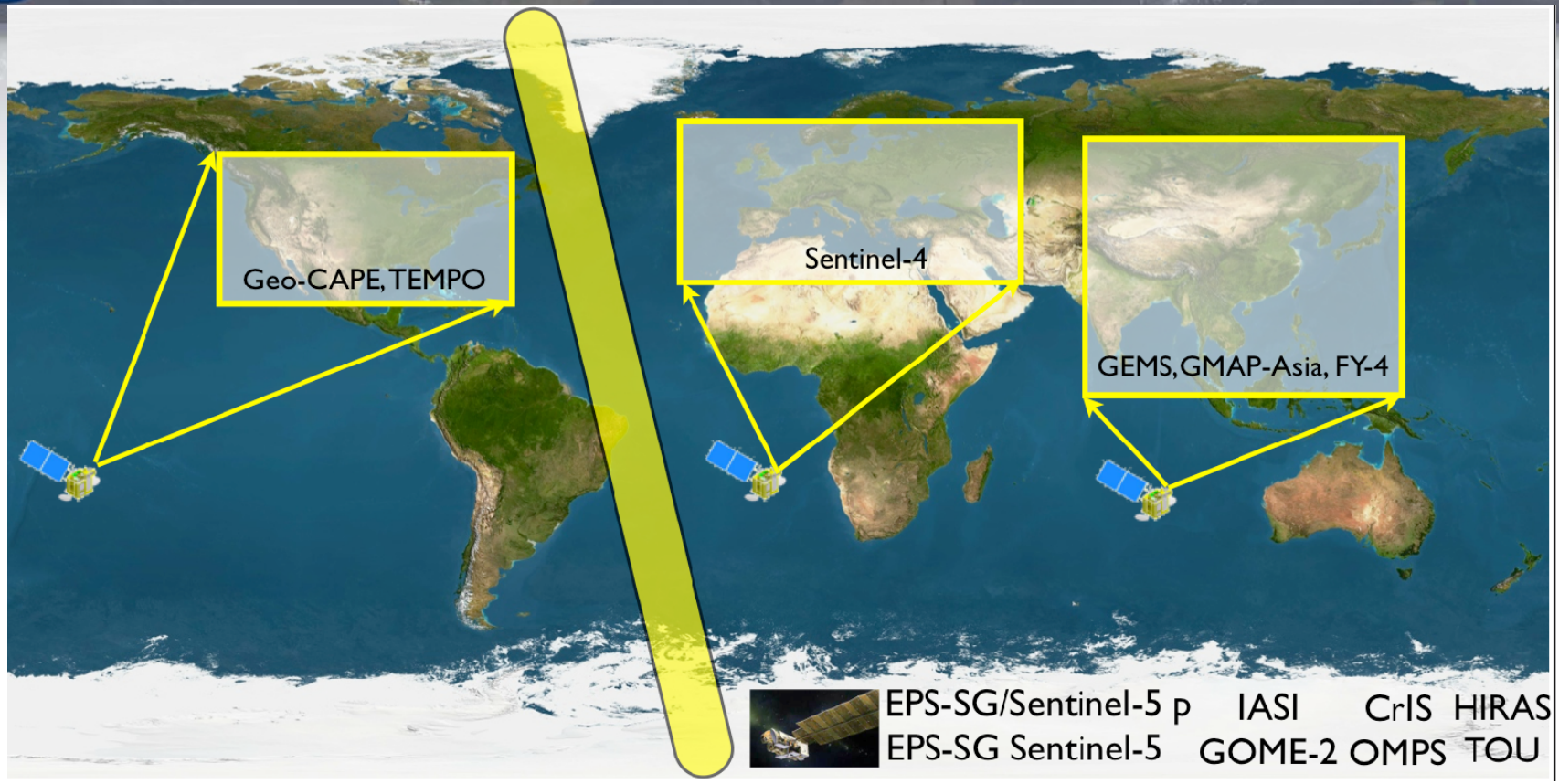


Bowman, *Atm. Env.* 2013

Geostationary sounders including TEMPO, Sentinel-4, and GEMS will provide an unprecedented number of composition observations at high spatial resolution.

A GEO / LEO Constellation For Characterizing Source/Receptor Relationships

Bowman, *Atm. Env.* 2013



We need LEO measurements of ozone profiles and its pre-cursors (e.g., CO, PAN, and VOC's) to link remote ozone pre-cursor sources to local air pollution

(why profiles?) Lifetime of ozone and its pre-cursors (e.g., NOx, PAN, CO, VOC's) depend on temperature / altitude

Transport of ozone and its pre-cursors depend on temperature and altitude

Current and Future LEO Sounders

- Aura TES (special observations only) ~ Can profile lower troposphere / upper troposphere using high spectral resolution thermal IR measurements. Global record from 2005 to 2010

- EUMETSAT IASI Can resolve middle troposphere → Production code being implemented

Combining UV + Thermal IR can increase vertical resolution of ozone profile soundings (e.g., Worden et al., 2007; Fu et al., 2013; Cuesta et al., 2013)

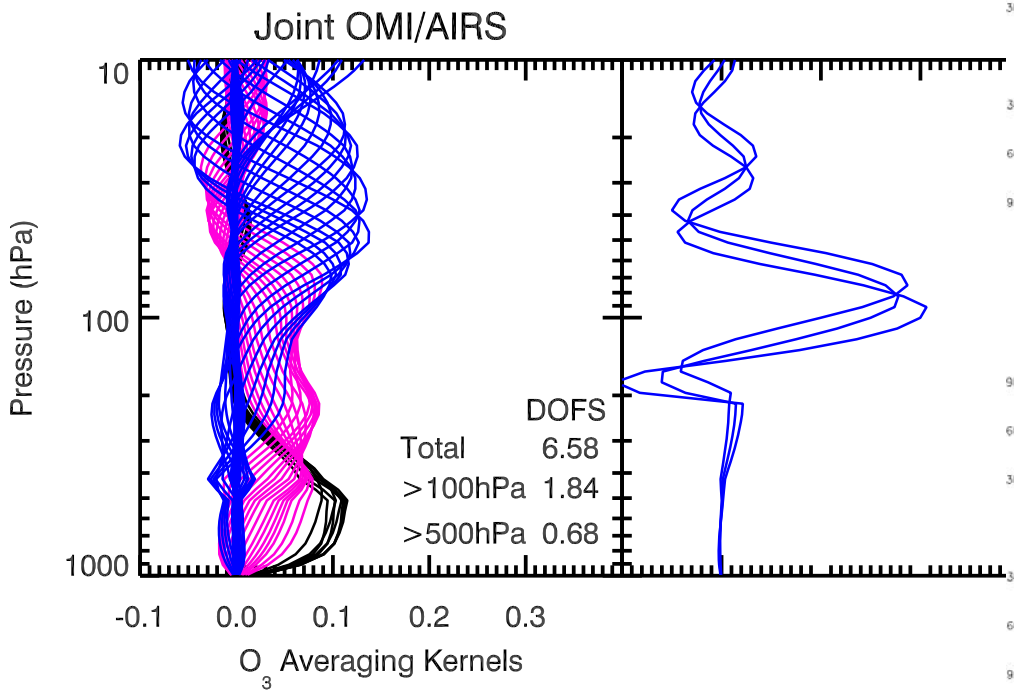
- NASA Terra AIRS + Aura OMI

(Funded by NASA ROSES call to use AIRS / OMI to fill TES observation gaps

- NASA CRIS + OMPS

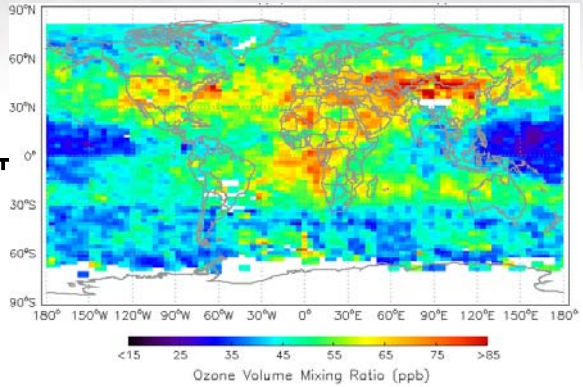
(need to extend record started by TES and answer source/transport/background ozone / receptor questions)

Joint OMI/AIRS Ozone Retrievals

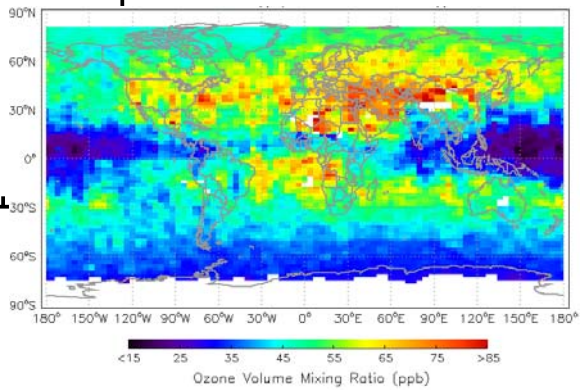


AIRS / OMI ozone retrievals can resolve lower and upper troposphere
Similar vertical resolution as Aura TES

AIRS /OMI Ozone 680 hPa (Aug 2006)



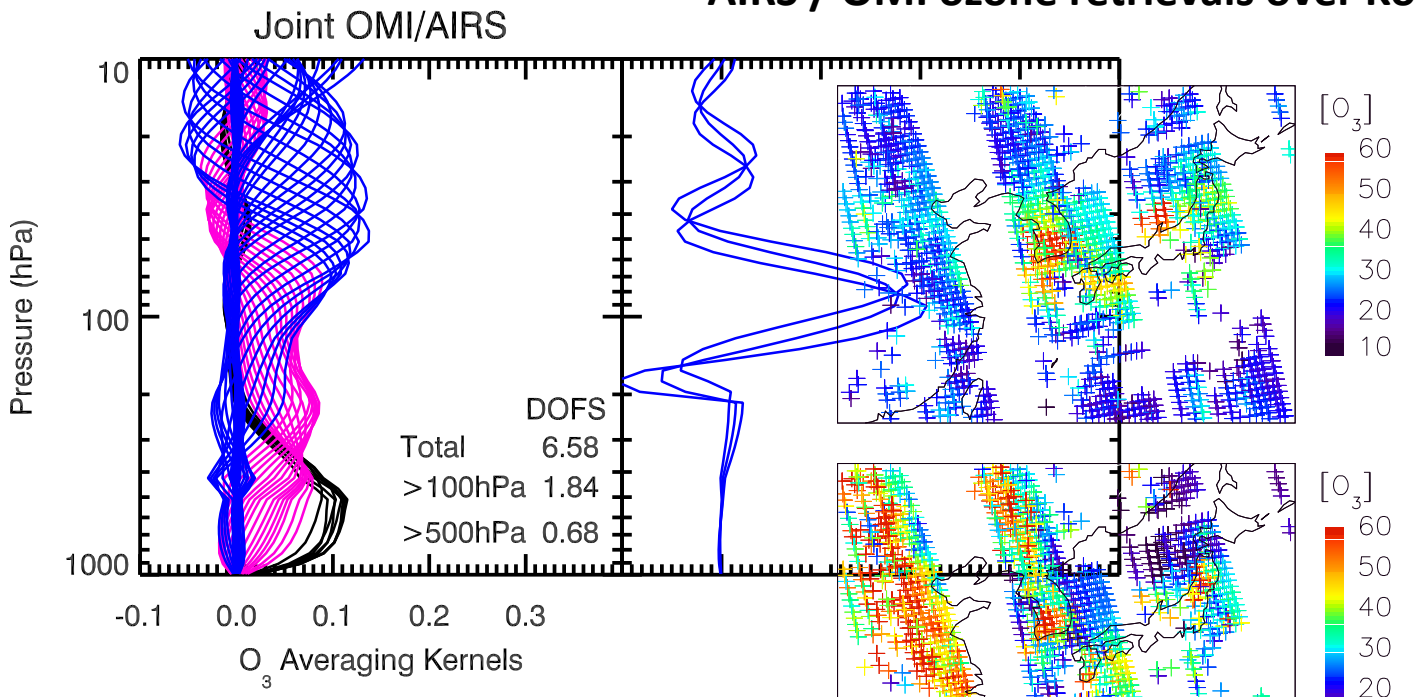
Aura TES Ozone 680 hPa



AIRS / OMI ozone retrievals consistent with TES

Joint OMI/AIRS Ozone Retrievals

Mapping Capability of AIRS / OMI ozone possible for limited scenes



AIRS / OMI ozone retrievals over Korea

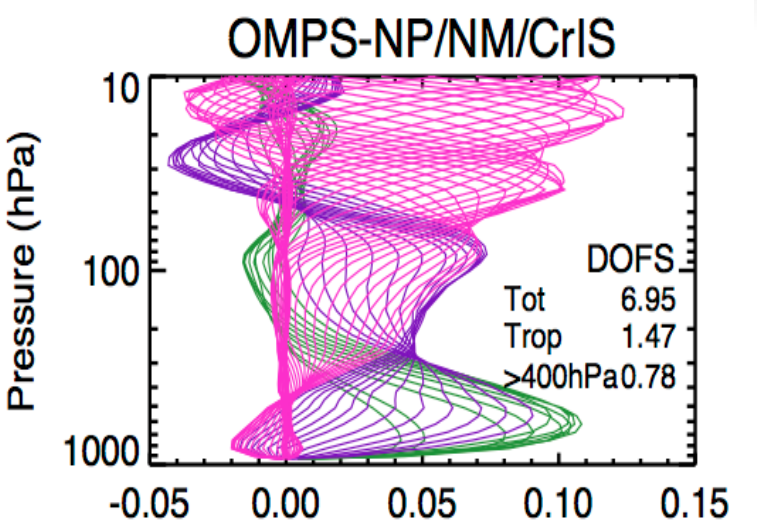
~350 hPa

~700 hPa

AIRS / OMI ozone retrievals can resolve lower and upper troposphere

Similar vertical resolution as Aura TES

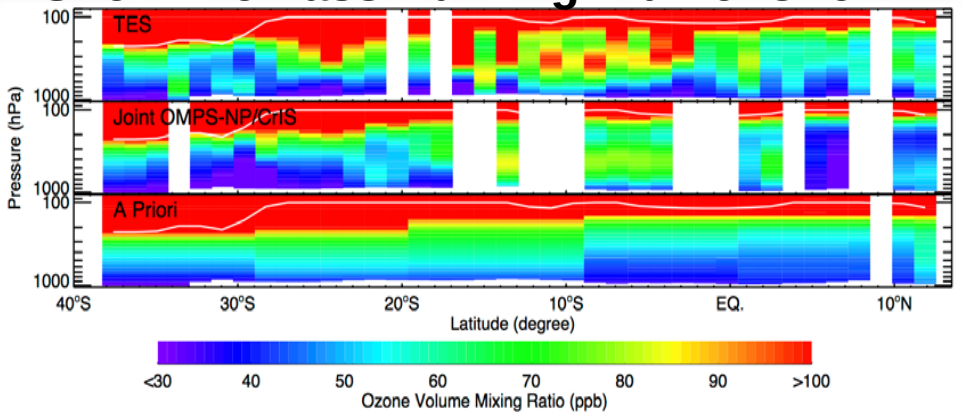
Ozone Profile Retrievals using CrIS and OMPS



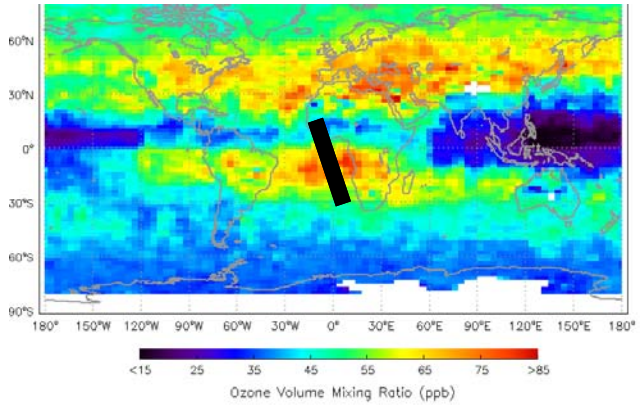
AIRS / OMI ozone retrievals can profile tropospheric ozone

Less vertical resolution than TES but better sampling than AIRS / OMI

Ozone Profiles From Joint CRIS/OMPS Retrievals Show Biomass Burning Plume Over Africa



TES Ozone During Summer Biomass Burning Season



Summary and Future Directions

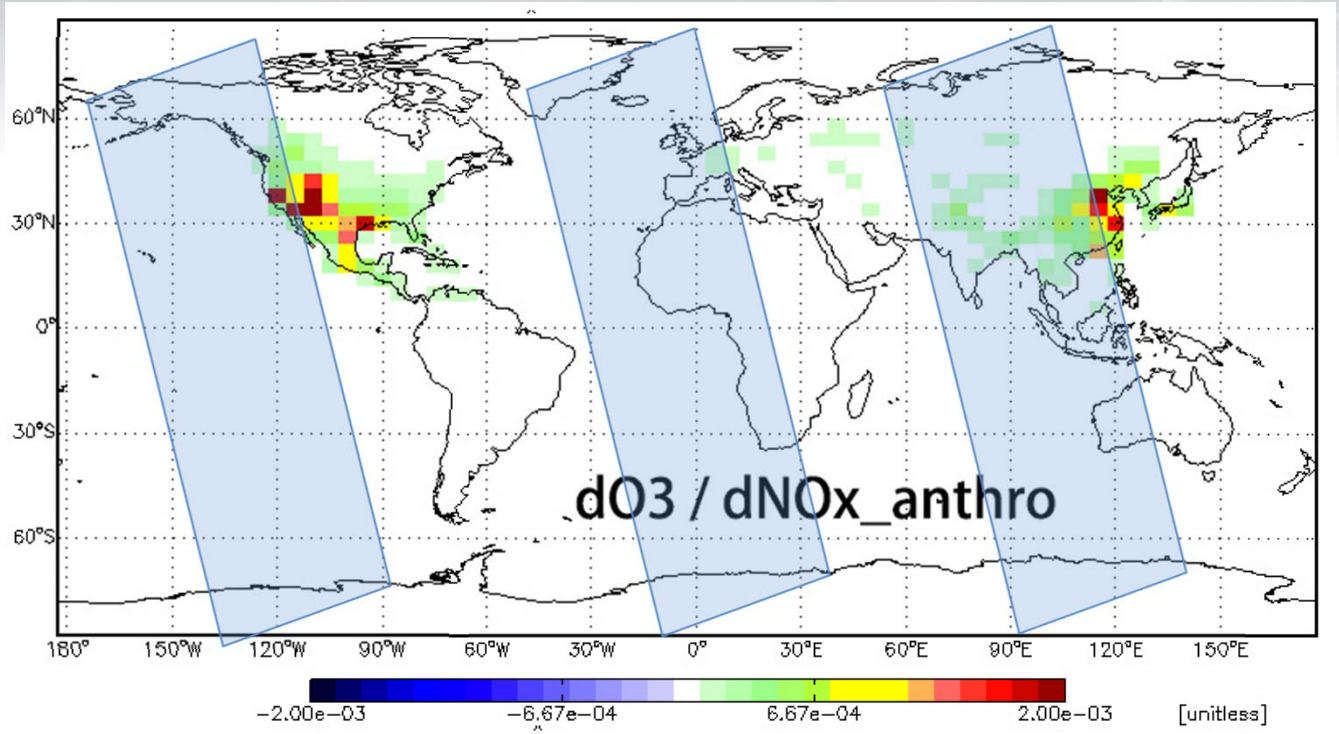
- **The trajectory of ozone as a pollutant and greenhouse gas is highly uncertain because of rapidly changing ozone pre-cursor emissions and because the partitioning of local, regional, and remote ozone pre-cursors emissions on ozone is still not well understood.**

- **GEO-Sounders will enable quantification of ozone pre-cursor emissions and their perturbation to column ozone with unprecedented spatio-temporal resolution**

- **Multi-spectral / Multi-instrument LEO measurements of ozone profiles and its pre-cursors (e.g. CO and PAN) can connect Geo-based measurements for quantifying the role of remote sources and background ozone on local air quality**

- **A programmatic framework needs to be put in place to systematically process the LEO-based data such as from AIRS/OMI, CRIS/OMPS, and IASI.**

So… How can we address this problem?



Characterizing transport of ozone and its pre-cursors requires vertically resolved profiles of ozone and its pre-cursors globally

Lifetime of ozone and its pre-cursors (e.g., Nox, PAN, CO, VOC's) depend on temperature / altitude

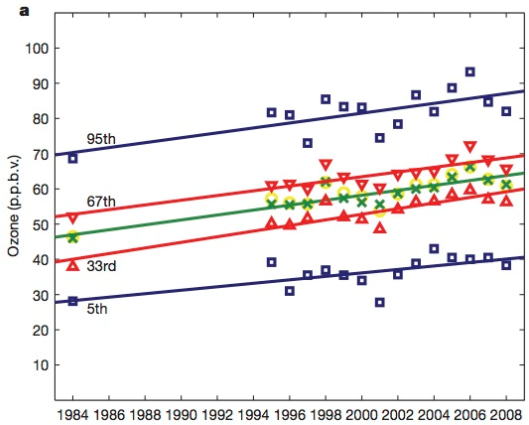
➔ Transport of ozone and its pre-cursors depend on temperature and altitude

How Does Tropospheric Ozone Respond to Anthropogenic Emissions?

TES Tropospheric Emission Spectrometer

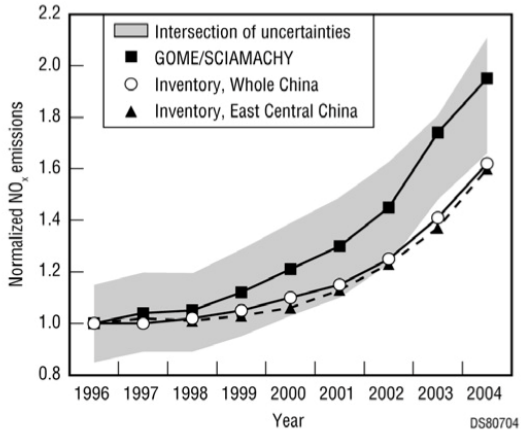
Ozone-Sondes over the Western USA show increasing spring-time free-tropospheric ozone
Cooper et al., Nature, 2010 infers that this increasing ozone is linked to increasing Asian emissions

Free-Tropospheric Ozone Over Western USA from Ozone-Sondes



~5PPB in Ozone over Western USA Between 1994 and 2004
Cooper et al. Nature 2010

Change in NO_x over Eastern China



~70% change in NO_2 between 1996 and 2004
Zhang et al., JGR 2007

Change in NO_2 from 1996 - 2006

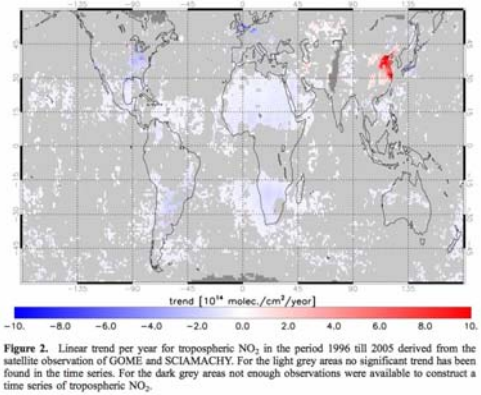


Figure 2. Linear trend per year for tropospheric NO_2 in the period 1996 till 2005 derived from the satellite observation of GOME and SCIAMACHY. For the light grey areas no significant trend has been found in the time series. For the dark grey areas not enough observations were available to construct a time series of tropospheric NO_2.

Likely decrease in NO_2 over USA since 1996 supports explanation that increasing ozone concentrations over USA are from rising Asian Emissions
Van Der A, JGR, 2008

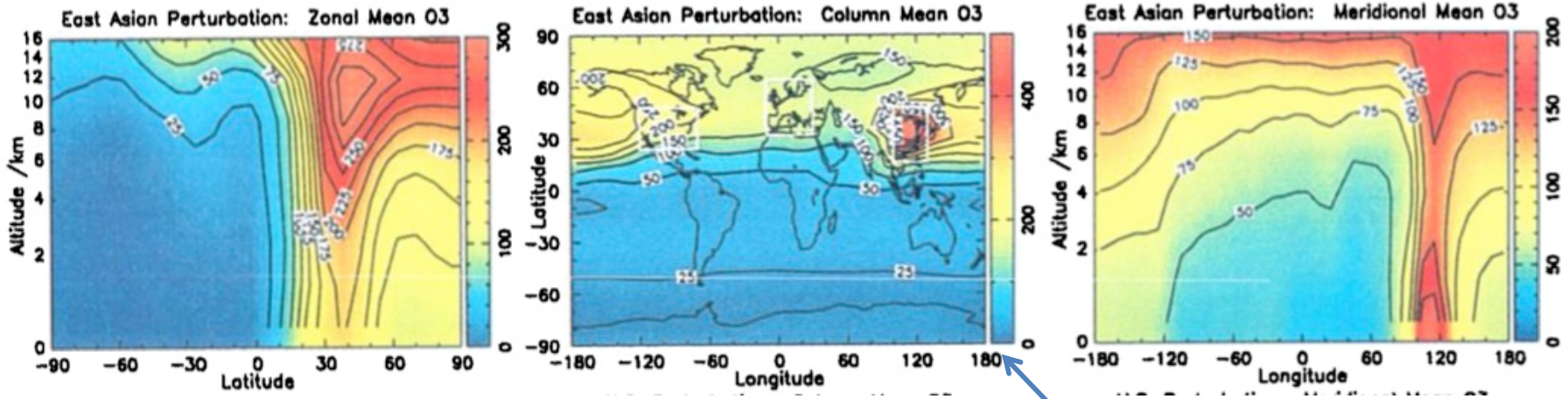
Assuming attribution of increase in ozone is correct and ozone production is limited by NOx then
~10% increase in Asian emissions → 0.7 ppb over USA

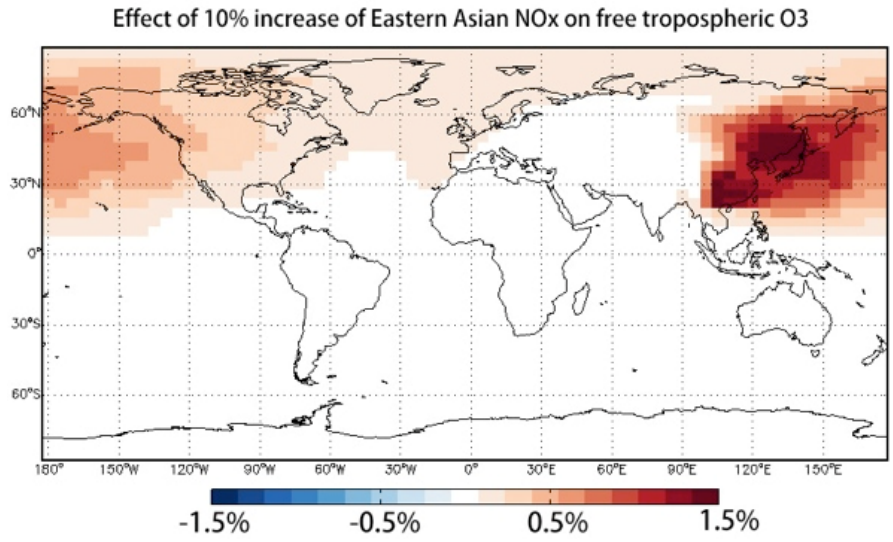
How Does Tropospheric Ozone Respond to Anthropogenic Emissions?

Model and Data Provide Conflicting Results!

Data (from previous slide) suggest 10% increase in NO_x → 0.7 ppb increase over USA

Models show that 10% increase in NO_x → 0.2 ppb increase over USA





10% increase in East Asian NOx

→ ~0.2 PPB over USA

→ ~0.4 PPB over Ea. Asia

Using UCI model

Wild and Akimoto, JGR, 2001; Fiore et al. 2009

10% increase in East Asian NOx

→ 0.3% or ~0.2 PPB over USA

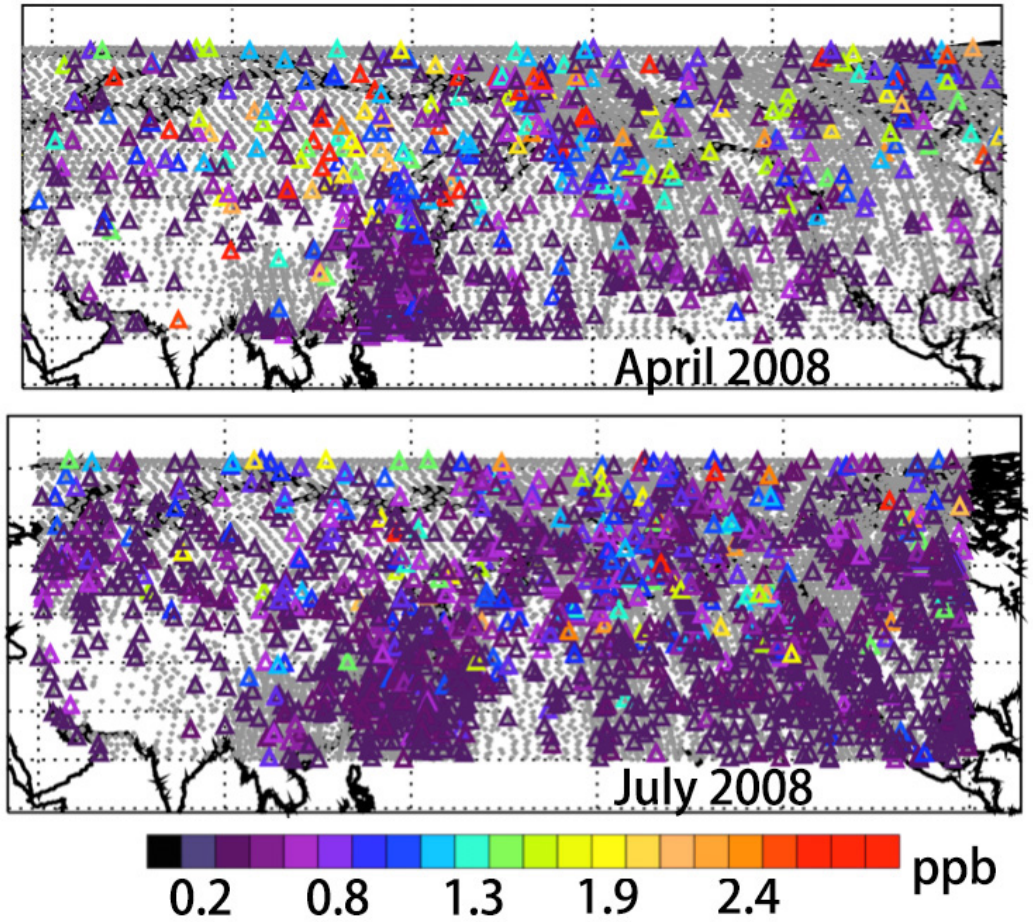
→ 1.0% or ~0.6 PPB over E. Asia

from GEOS-Chem

Jiang et al., in prep

New Aura TES PAN Data Places Constraints on Asian Pollution Transport

In contrast to the free-troposphere over Europe, PAN over Asia peaks in the summertime due to fast convective transport of PAN and its pre-cursors into the free-troposphere
Fischer et al., 2014, Deolal et al., 2014



Data and model show that transport of ozone and ozone production from Asia emissions to N. America peaks in the spring-time

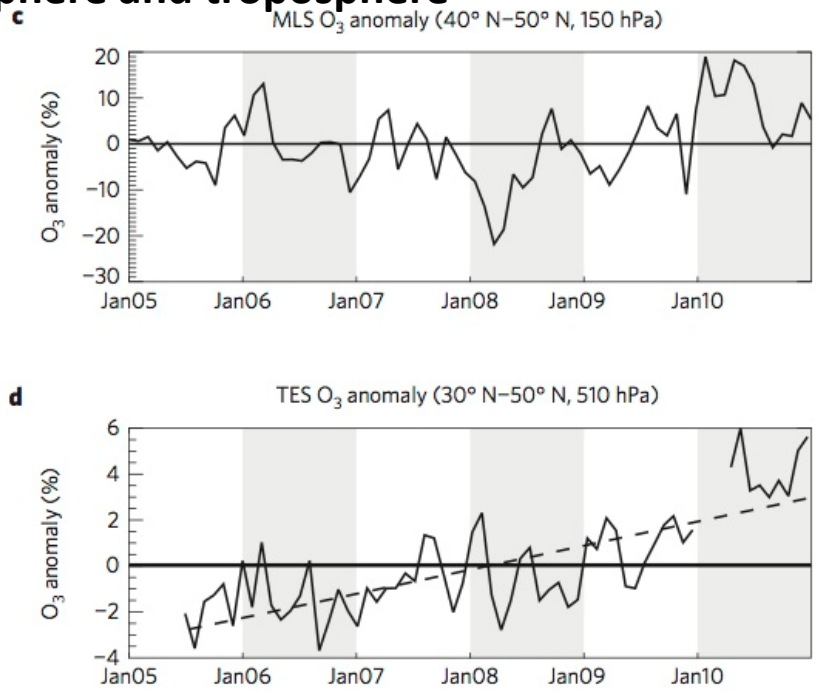
However, Contribution of Asian PAN to ozone production over N. America peaks in the summer with ~50% more ozone produced by PAN in the summer relative to spring.

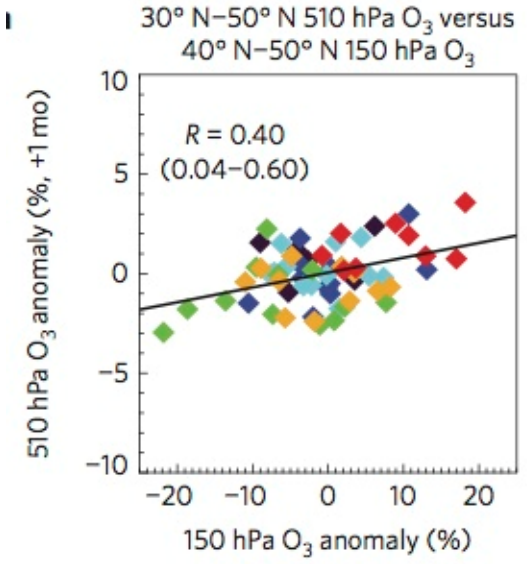
Jiang et al., GRL, submitted

Increased Stratosphere to Troposphere Exchange?

From *Neu et al., Nature Geoscience*, 2014

At the hemispheric scale: No obvious increase in exchange of ozone between the stratosphere and troposphere

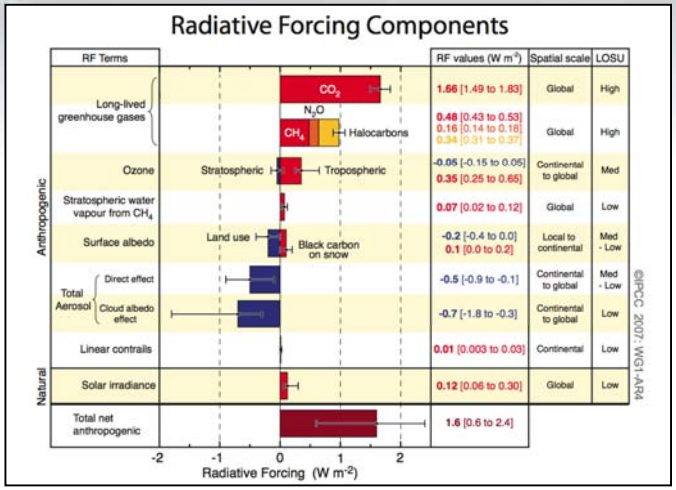




- **Stratospheric mid-latitude inter-annual variability is correlated with tropospheric variability (with 1 month shift).**
- **There is no observed trend in the lower mid-latitude stratospheric ozone or in the stratospheric circulation for this time period**

Tropospheric Ozone is the Third Most Important Greenhouse Gas and an Air Pollutant

TES Tropospheric Emission Spectrometer



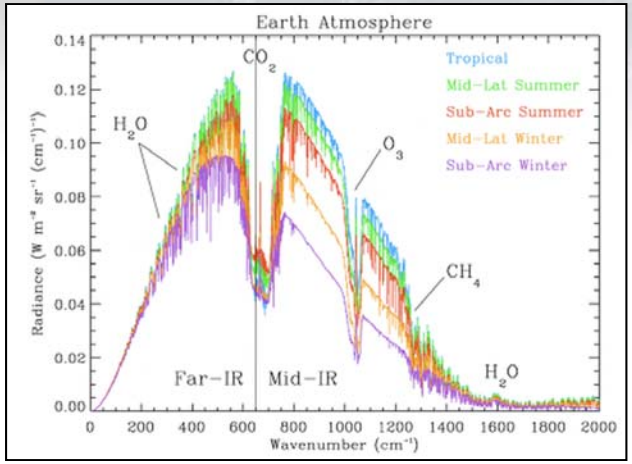


Fig. courtesy M. Mlynzcack (LaRC)

Ozone affects air-quality and plant health

Reduced CO_2 uptake from damaged plants also strongly affects climate

Regional Distribution of the EPA09 Ozone Sensitivity

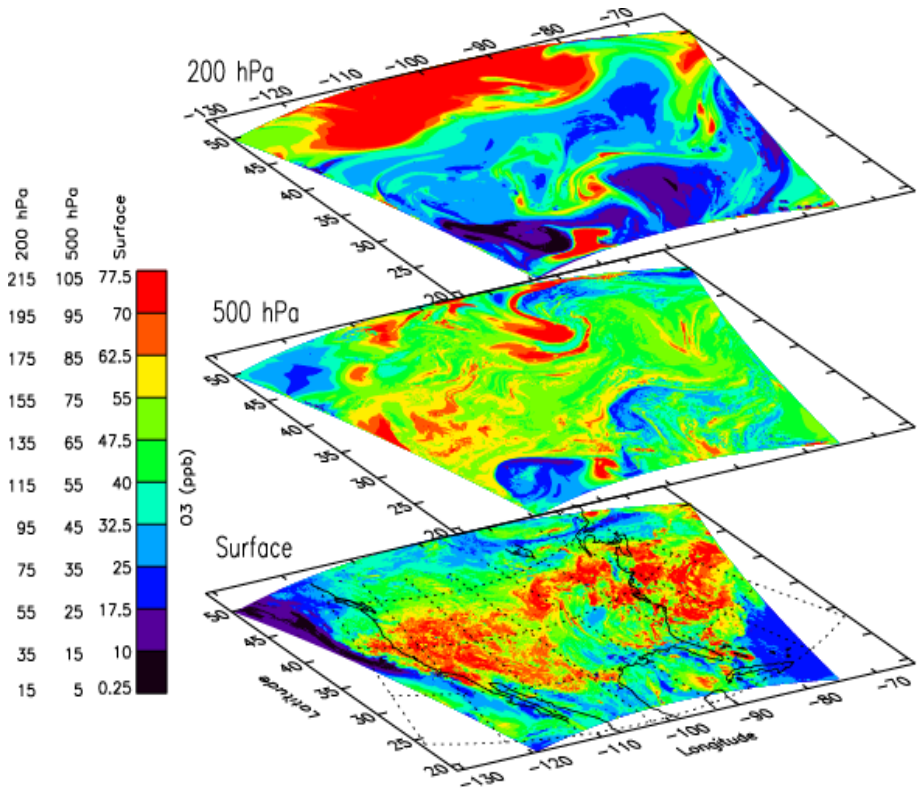
$\sum_{Region} \delta J/\delta \ln E \; / \; \sum_{Globe} \delta J/\delta \ln E$

- Reductions in OMI-constrained NOx emission estimates from 2005-2009 decreased mean surface ozone by 0.9% relative to all NOx emission contributions
- Increases in Chinese NOx emissions in 2005-2010 largely offset local EPA09 emission contributions to mean surface ozone.
- China emission changes contributed more to mean column ozone than EPA09 emissions in 2005-2009.
- SE Asia emission changes contributed more to mean column ozone than extra-EPA09 regional emissions 2005-2009.

GACM: How Will Tropospheric Ozone Respond to Continued Industrialization, Land-use, Policy, and Climate Change; How Will Ozone Affect Climate and Air Quality?

TES Tropospheric Emission Spectrometer

Need To Connect Ozone In UTLS, Mid-troposphere And Boundary Layer To Its Pre-cursors



Upper Troposphere Length scales
100-500 km horizontal
1-3 km vertical

Middle Troposphere Length scales
10-100 km horizontal
3-6 km vertical

Boundary Layer Length scales
1-10 km horizontal
1-2 km vertical

IIP, ROSES, and Terra / Aura Senior Review funded research show that coordinated, multi-viewing, multi-radiance measurements are required to increase sensitivity to trace gas composition in the upper troposphere and boundary layer.