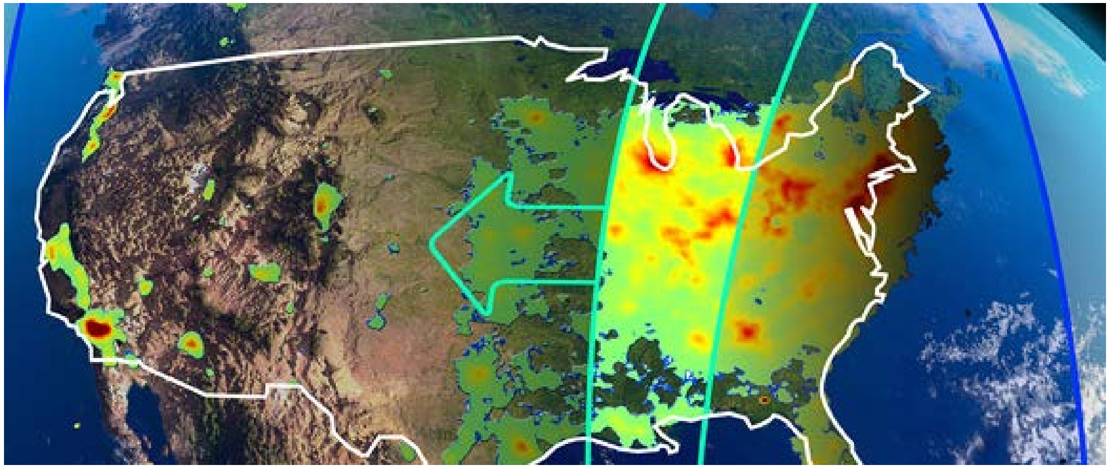
Ozone Air Quality from TEMPO: Theory, Expectations, and Subtleties



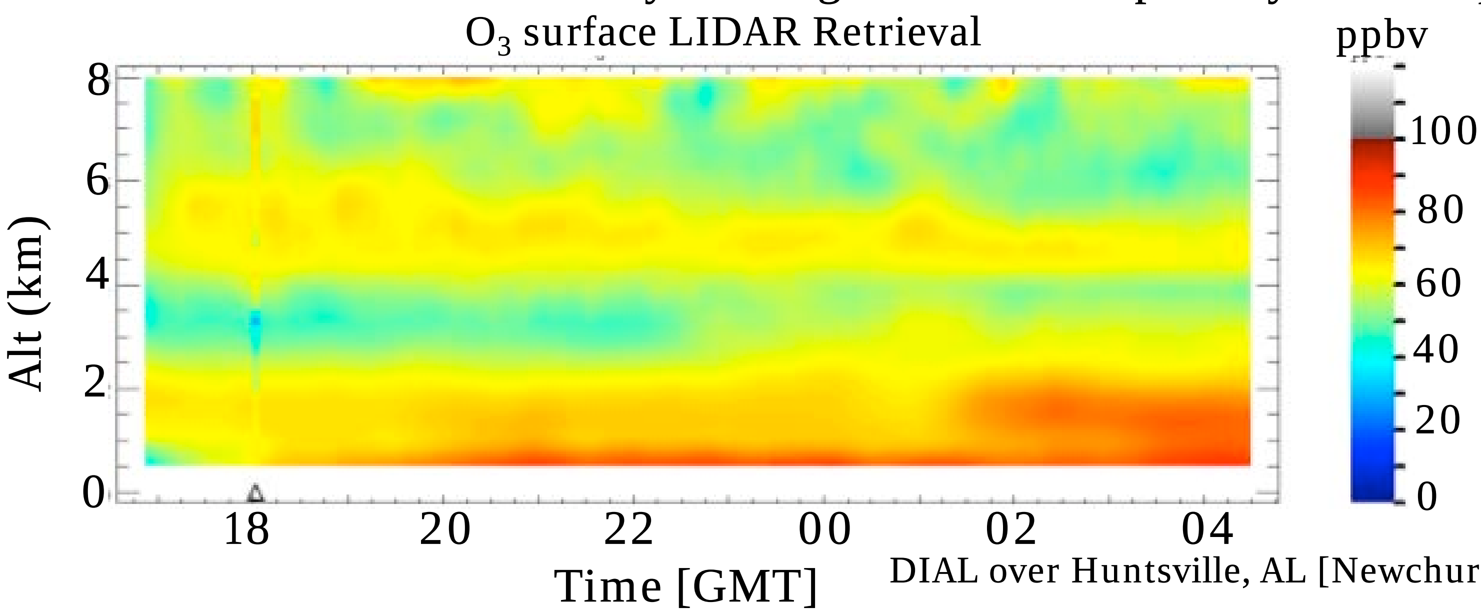
Peter Zoogman

EPS 238

April 24, 2014

The Difficulty of Ozone Air Quality from Space

- Ozone concentrations very heterogeneous both spatially and temporally

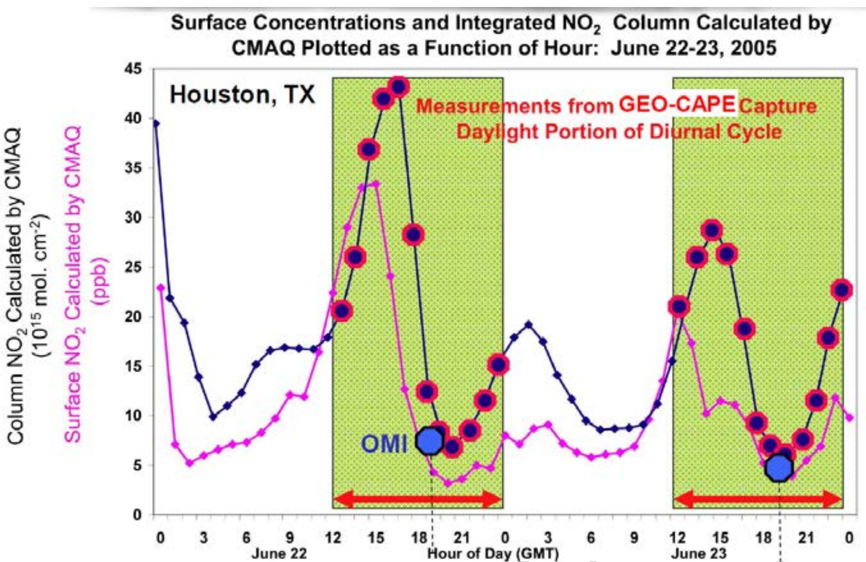


DIAL over Huntsville, AL [Newchurch et al, 2009]

Ozone chemistry complex and non-linear

Short timescales → large diurnal variation

Current network inadequate for air quality monitoring + science

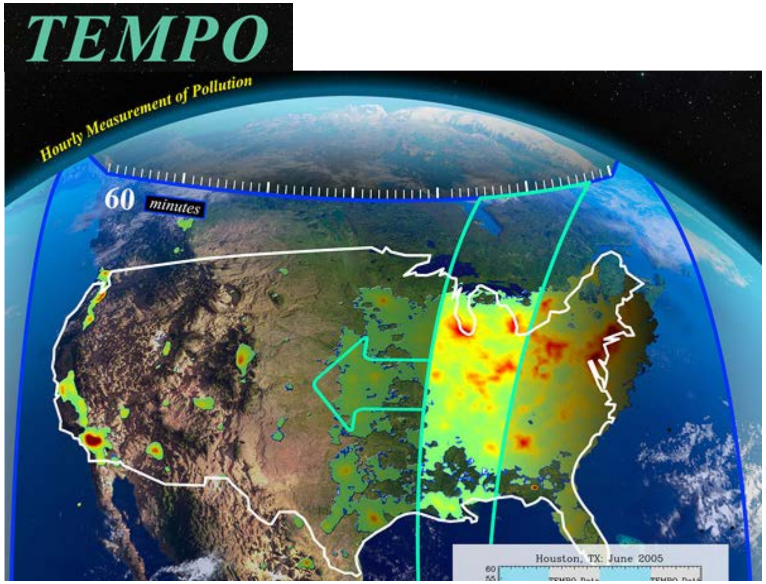


[Fishman et al. 2008]

Observations from TEMPO

Features:

- High temporal resolution
- Multispectral observations for increased vertical information

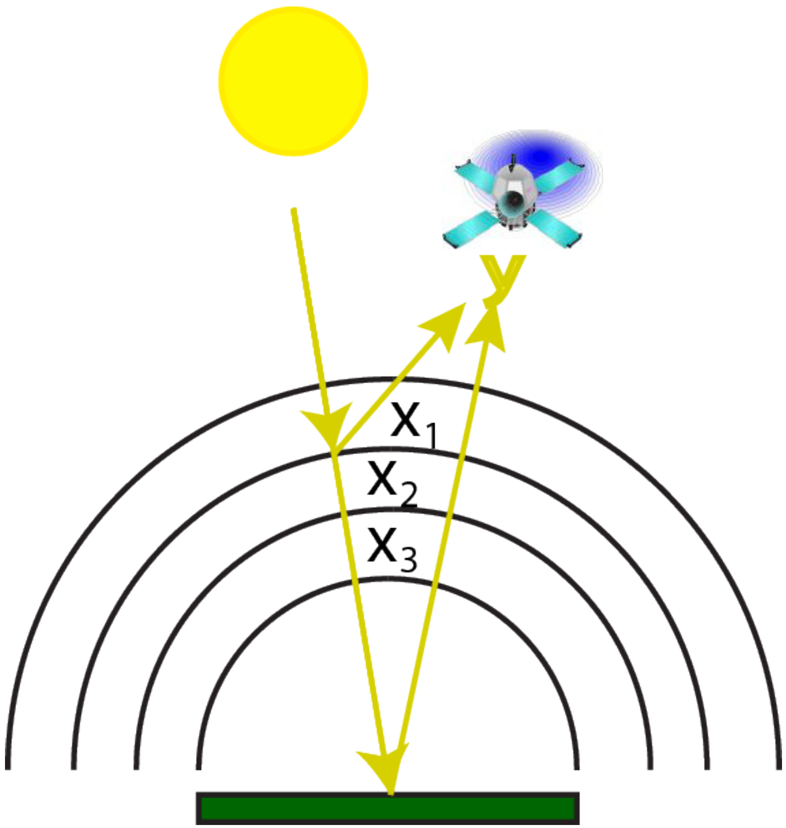


TEMPO Science Questions

1. What are the temporal and spatial variations of emissions of gases and aerosols important for air quality and climate?
2. How do physical, chemical, and dynamical processes determine tropospheric composition and air quality over scales ranging from urban to continental, diurnally to seasonally?
3. How does air pollution drive climate forcing and how does climate change affect air quality on a continental scale?
4. How can observations from space improve air quality forecasts and assessments?
5. How does intercontinental transport affect air quality?
6. How do episodic events, such as wild fires, dust outbreaks, and volcanic eruptions, affect atmospheric composition and air quality?

Use of Radiative Transfer Models In Optimal Estimation

Radiative Transfer model is necessary for satellite retrievals by optimal estimation



Forward model F relates concentrations **x** to measurements **y**

$$\mathbf{y} = F(\mathbf{x}, \mathbf{b}) + \mathbf{error}$$

Use of Radiative Transfer Models In Optimal Estimation

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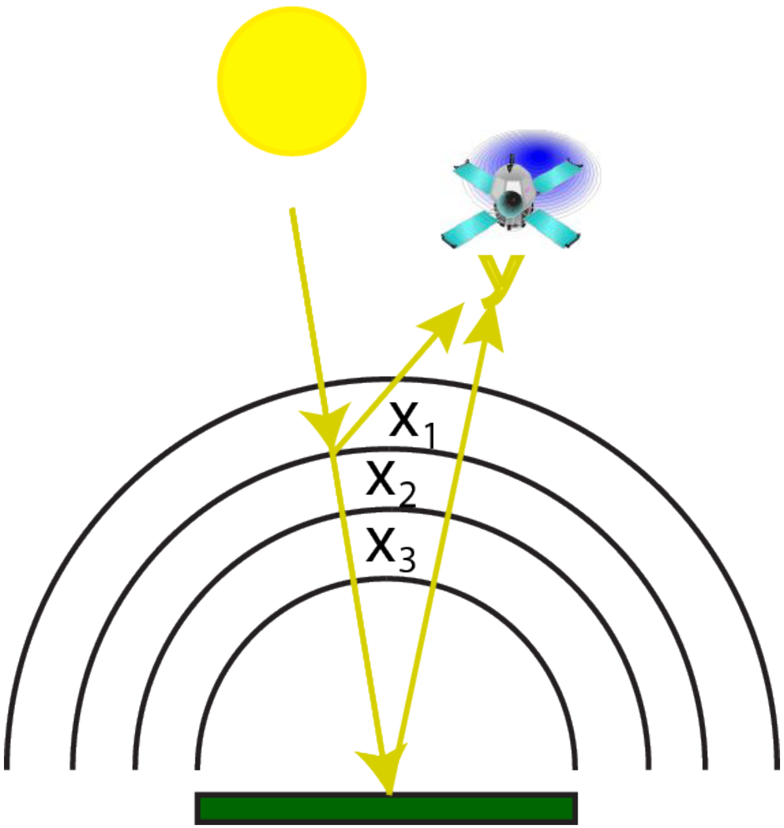

Forward model F relates concentrations **x** to measurements **y**

$$\mathbf{y} = F(\mathbf{x}, \mathbf{b}) + \mathbf{error}$$

Retrieved value $\hat{\mathbf{x}}$ minimizes the difference between measurement and computed measurement:

want minimum of: $[\boldsymbol{y} - F(\hat{\mathbf{x}}, \hat{\mathbf{b}})]$

-
-
-

$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{A}[\mathbf{x} - \mathbf{x}_a] + \mathbf{error}$$

A is the averaging kernel matrix and is a function of **F**

Information Content

Retrieved profile is a linear combination of the true profile **x** and an *a priori* guess $\mathbf{x}_a$

$$\mathbf{x}' = \mathbf{x}_{\mathbf{a}} + \mathbf{A}(\mathbf{x} - \mathbf{x}_{\mathbf{a}}) + \varepsilon$$

retrieval

a priori

true state

errors

Averaging Kernel matrix **A** quantifies the vertical information provided by a satellite retrieval

$$\mathbf{A} = \frac{\partial \mathbf{x}'}{\partial \mathbf{x}}$$

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retrieval — *a priori* — true state — errors

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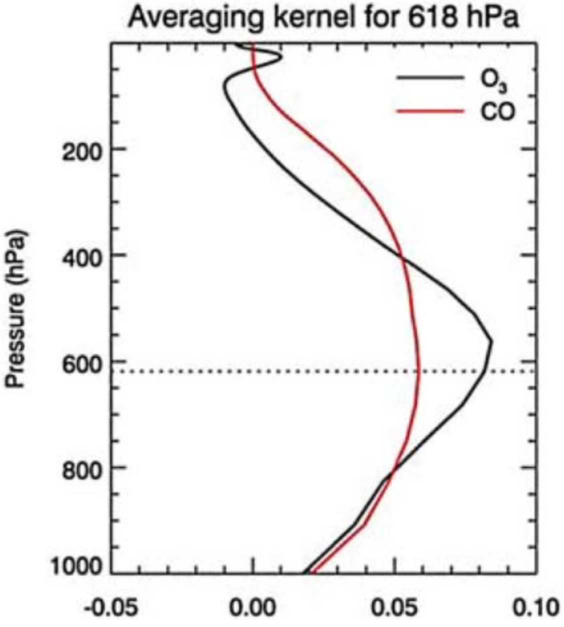

[Zhang et al. 2010]

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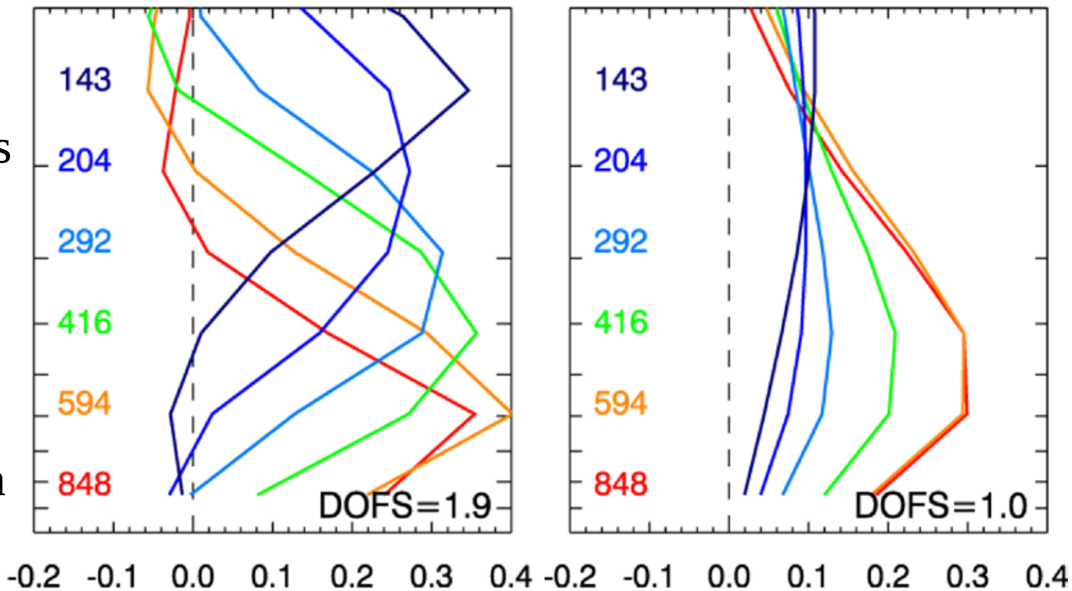

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[Zhang et al. 2010]

Simulated Retrievals

Simulated Retrievals

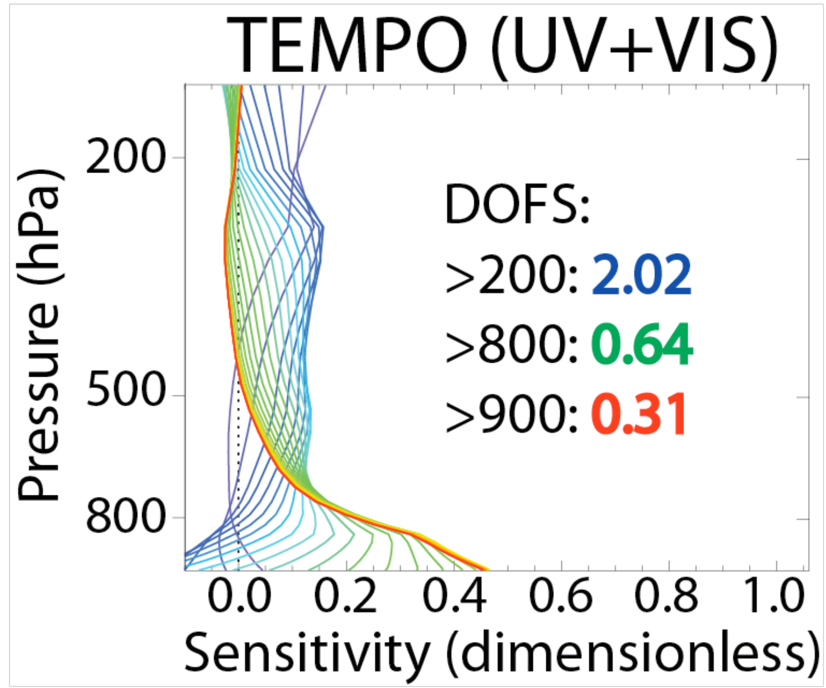
INPUTS
Profile + Surface data
Solar angle
Cross sections
Scattering
(Clouds, aerosols)

↓

Radiative Transfer run

↓

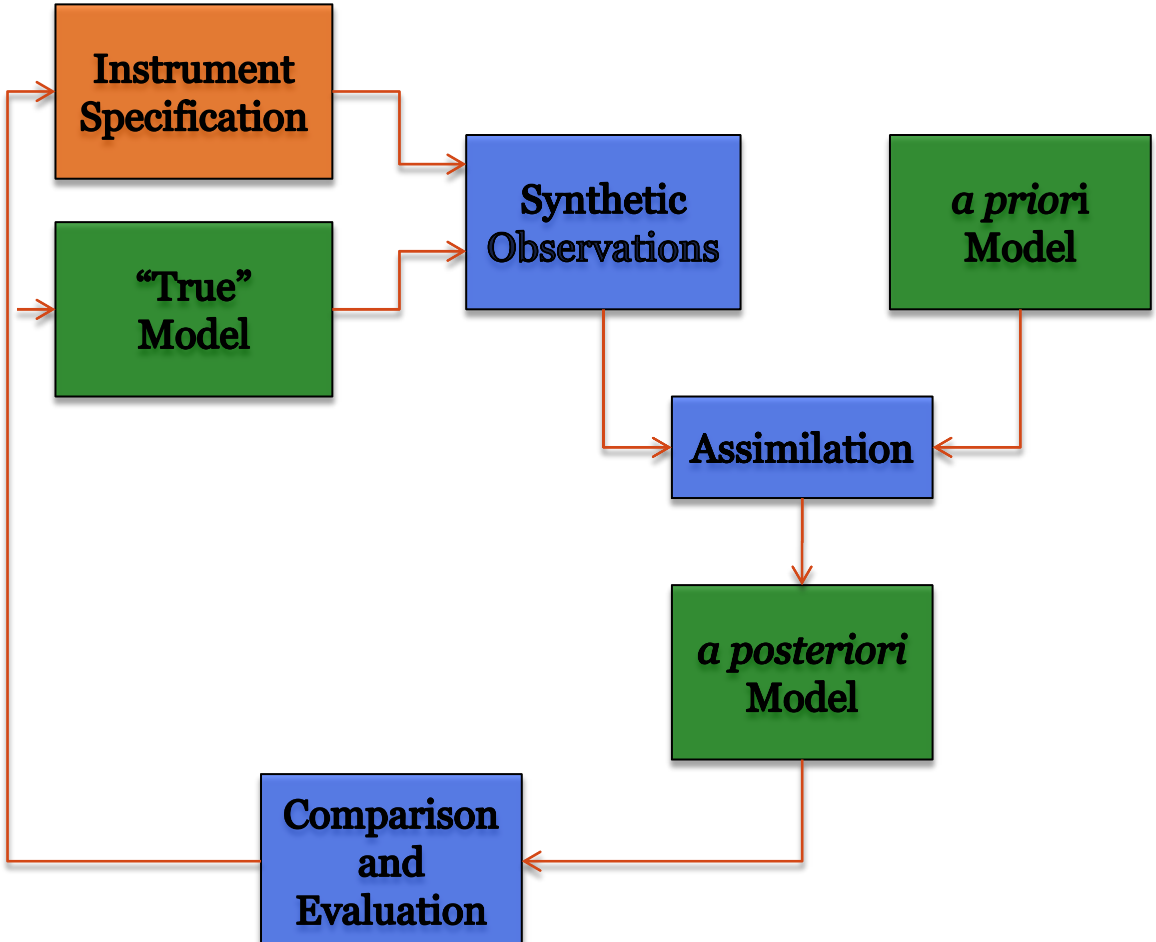
Sensitivity analysis
Information content



[Natraj et al, 2011]

Observing System Simulation Experiment

- What additional information is provided by a new instrument?



a priori = GEOS-Chem model

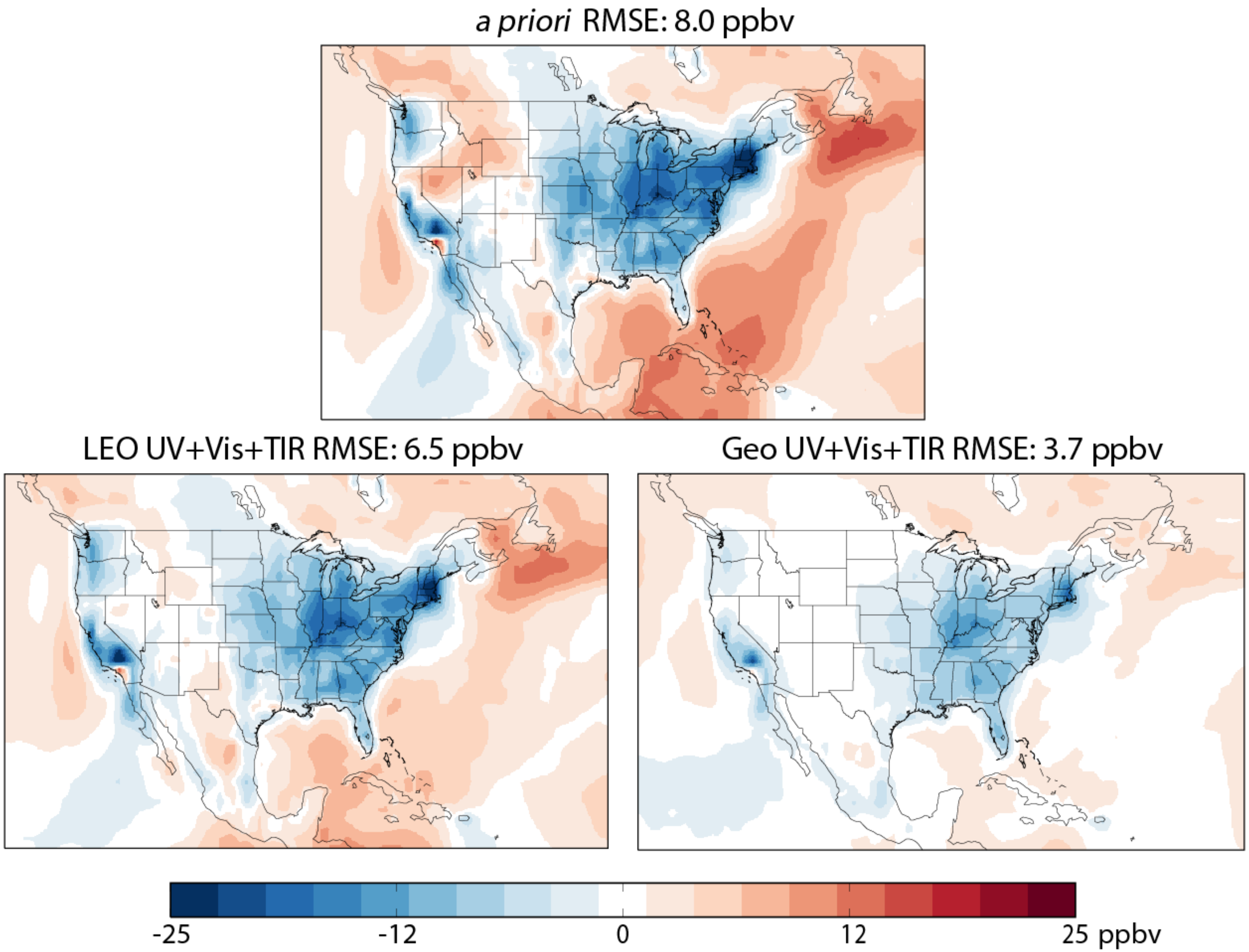
"True" = independent model

a posteriori = GEOS-Chem + assimilation of synthetic observations

→ attempt to reproduce "true" atmosphere

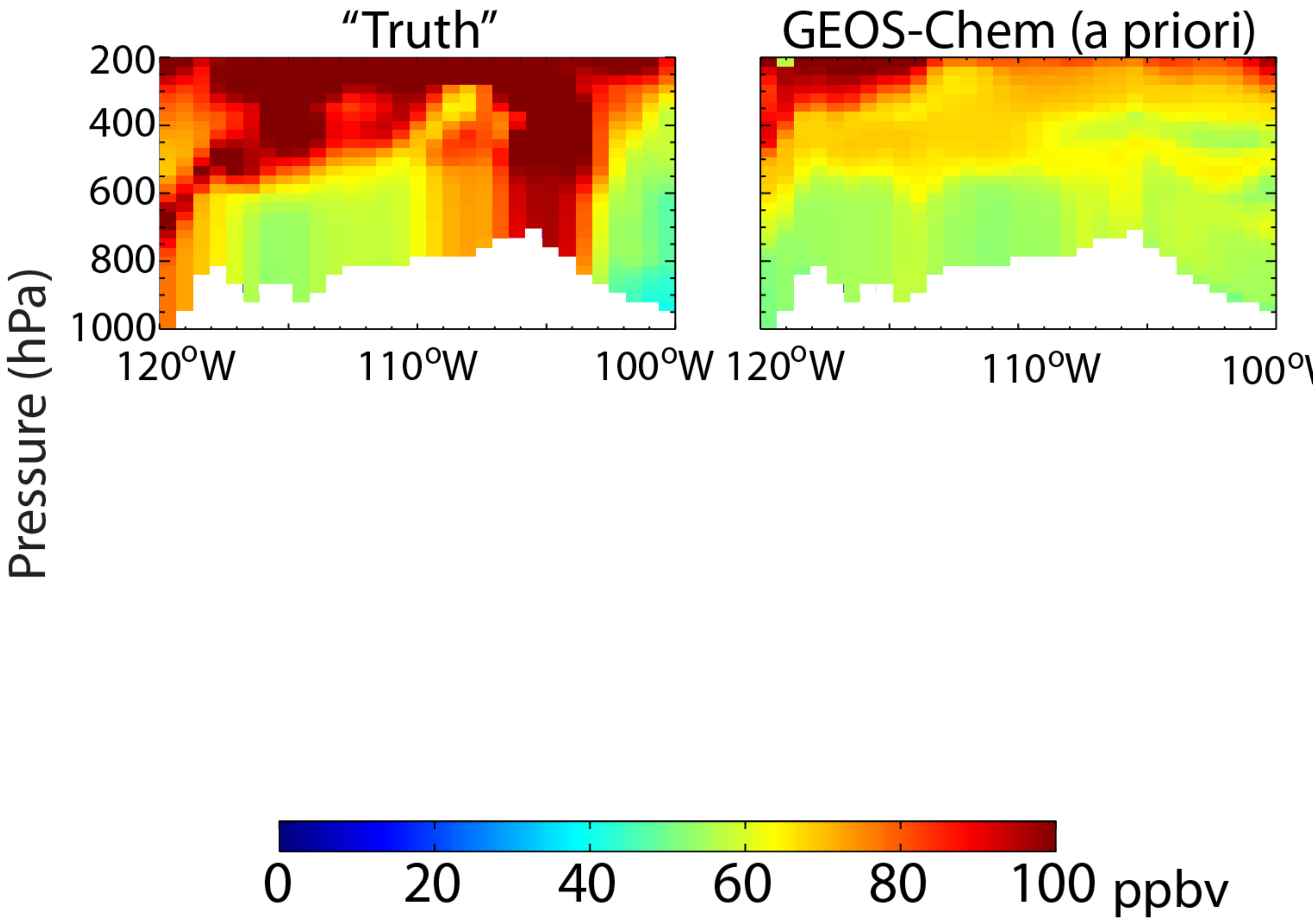
Air Quality Information from GEO

Error in Surface MDA8 Ozone averaged for July 2001

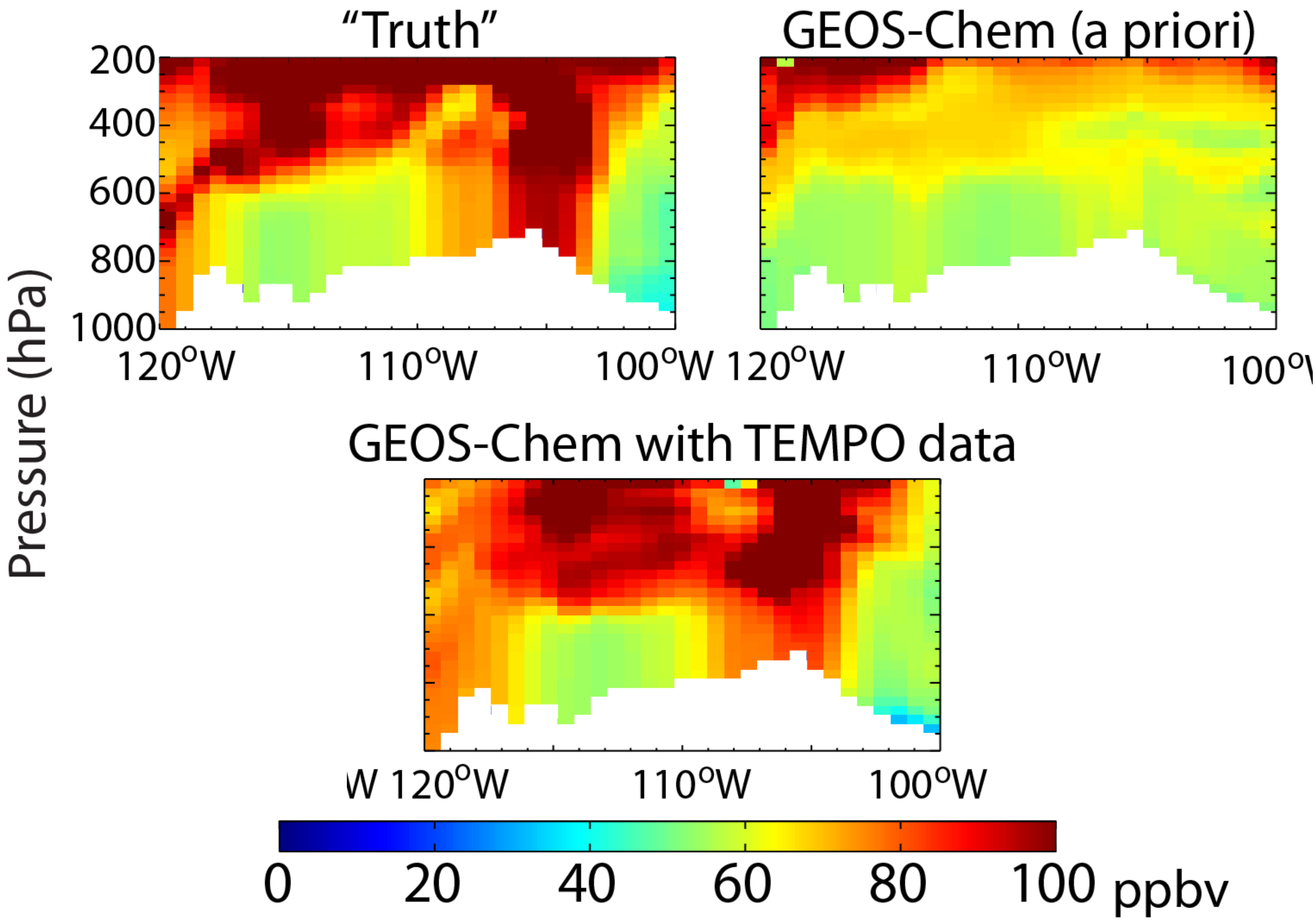


Need to combine observations in multiple spectral regions at high temporal resolution to constrain ozone air quality

Seeing a Stratospheric Intrusion



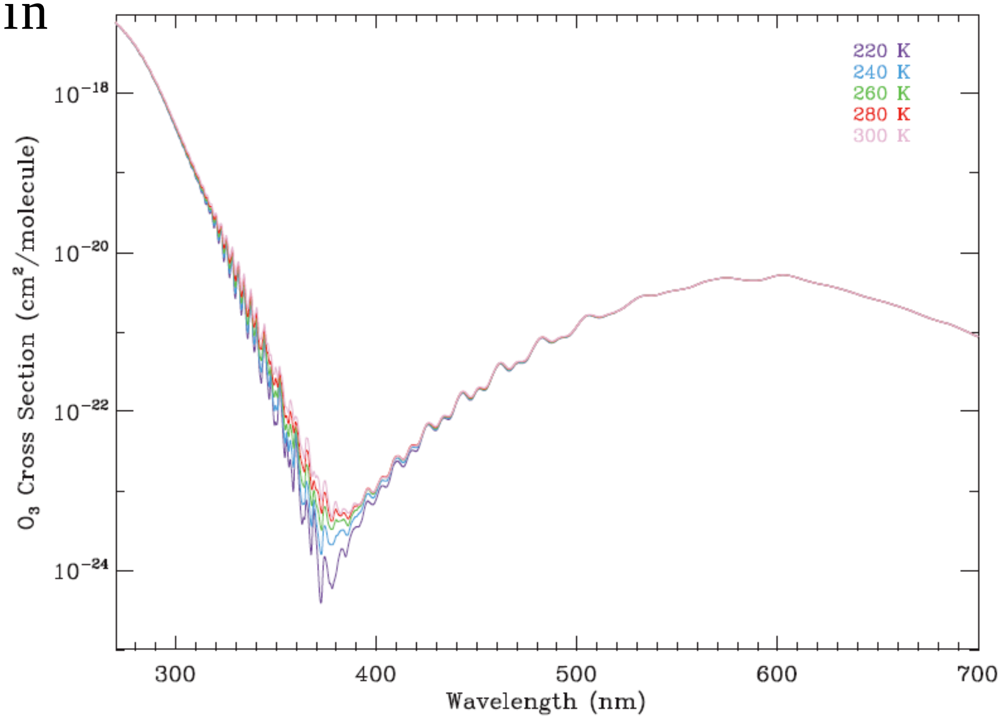
Seeing a Stratospheric Intrusion



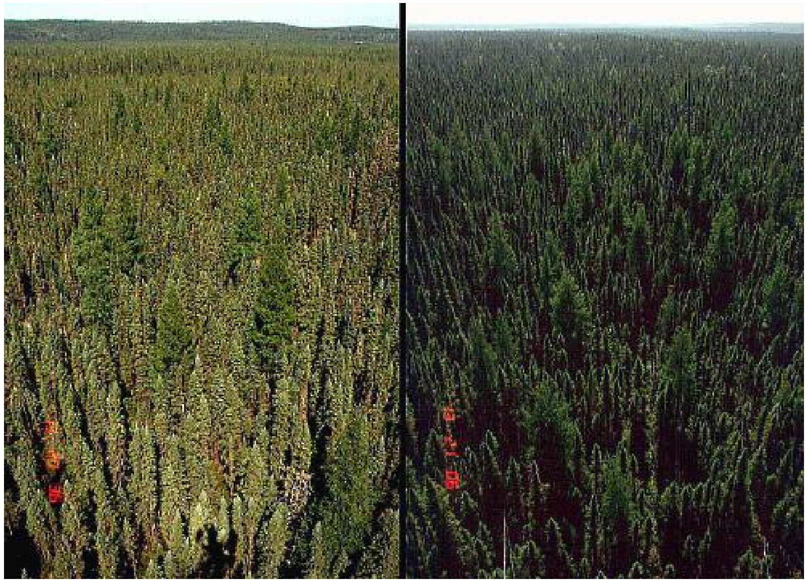
Assimilation of TEMPO observations into the GEOS-Chem model recaptures structure of stratospheric intrusion

Ozone absorption in the Visible

- Ozone has weak spectral features in the Chappuis band (~500 – 700 nm)
- Since the atmosphere is optically thin in the visible, can get information near the surface
- But retrieval is more sensitive to errors in radiative transfer model
  - Example → **surface reflectance**



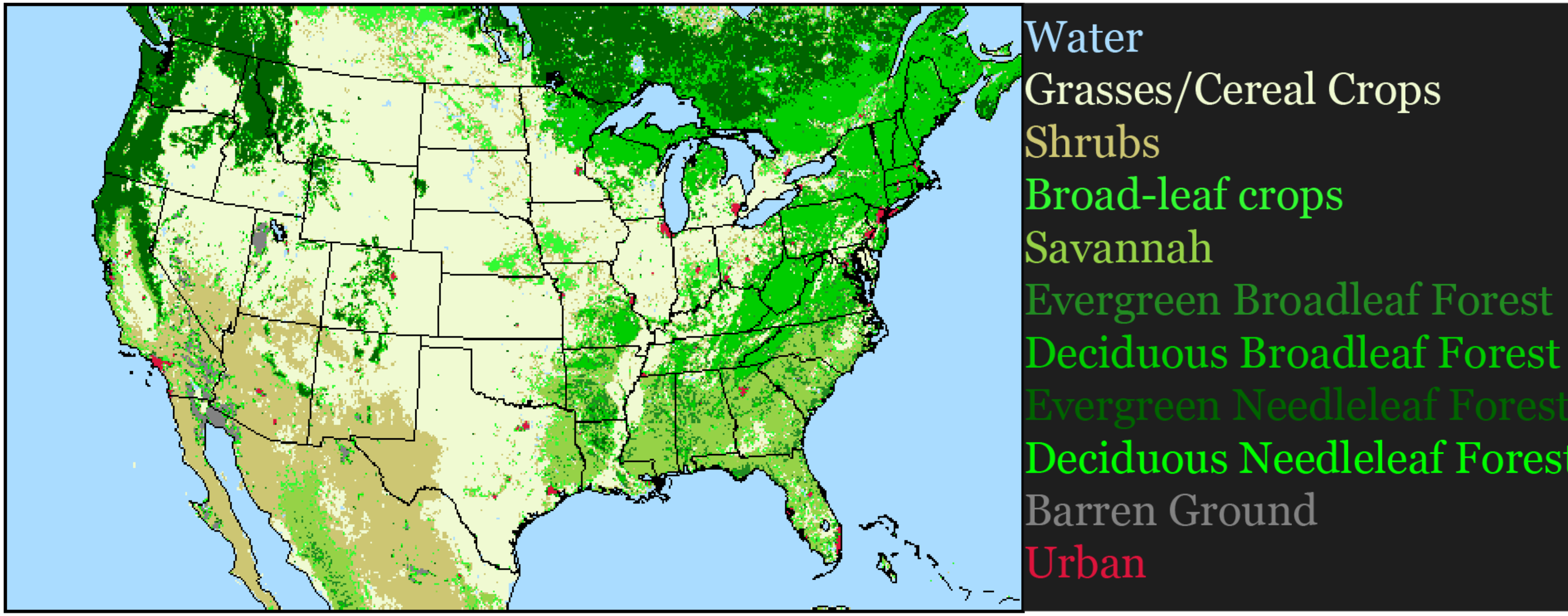
Surface Reflectance in the Visible

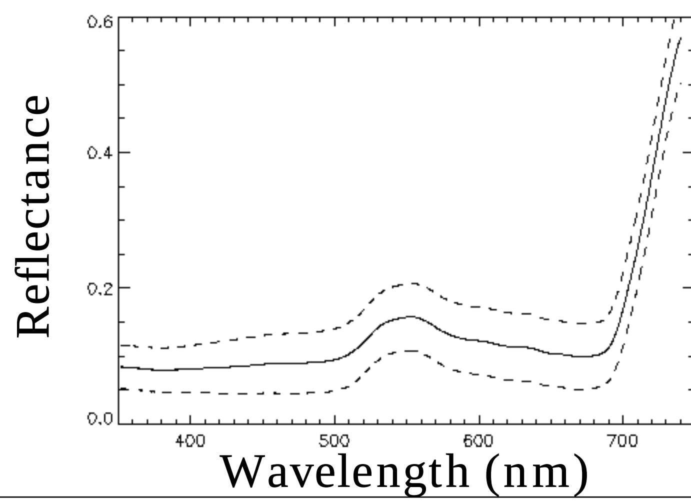


Pictures by Don Deering

- Spectral variation
- Dependence on land cover
- Changes with viewing geometry

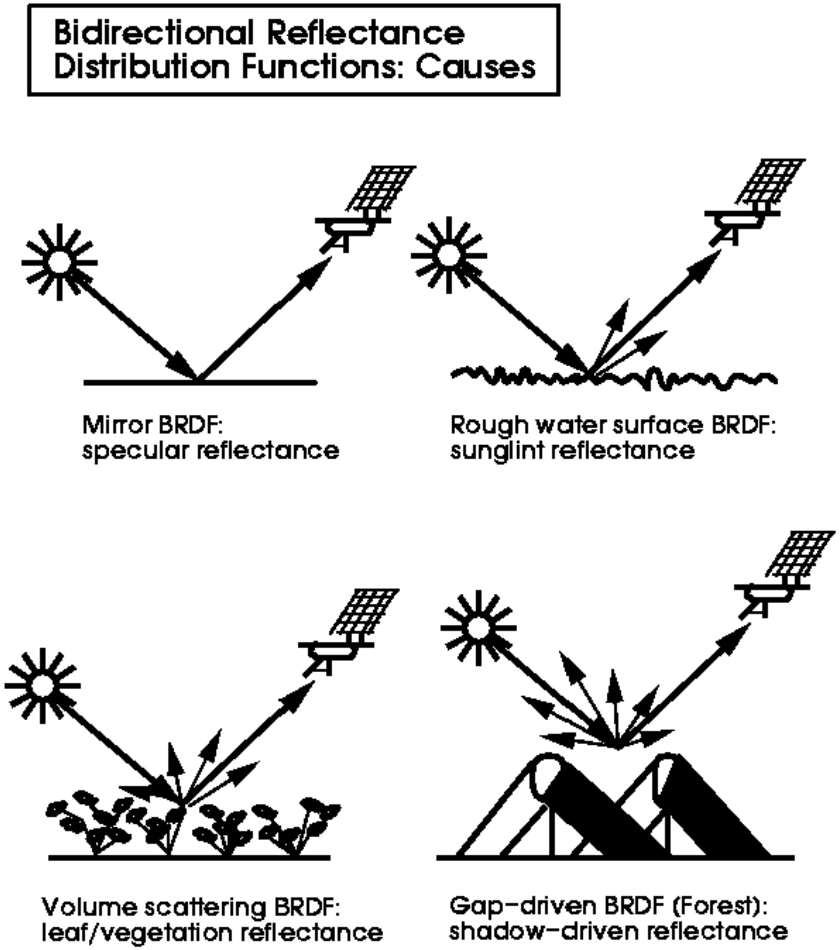
Variation by Land Cover

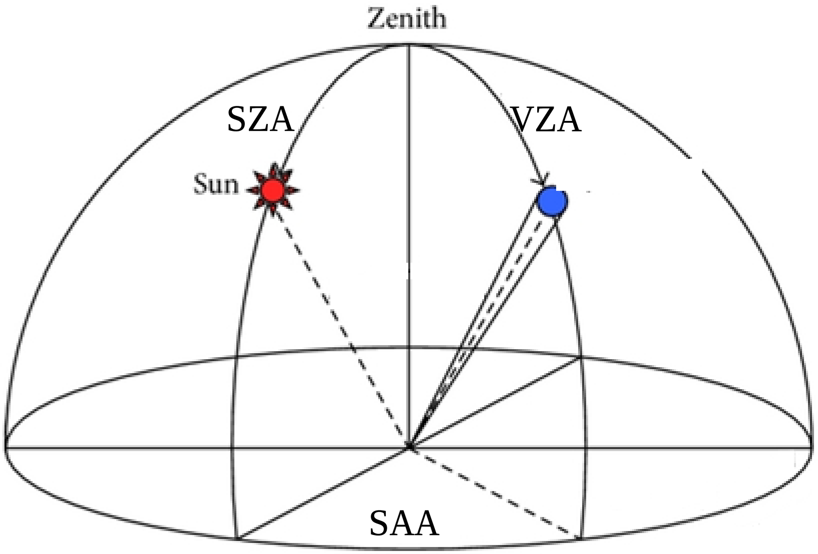




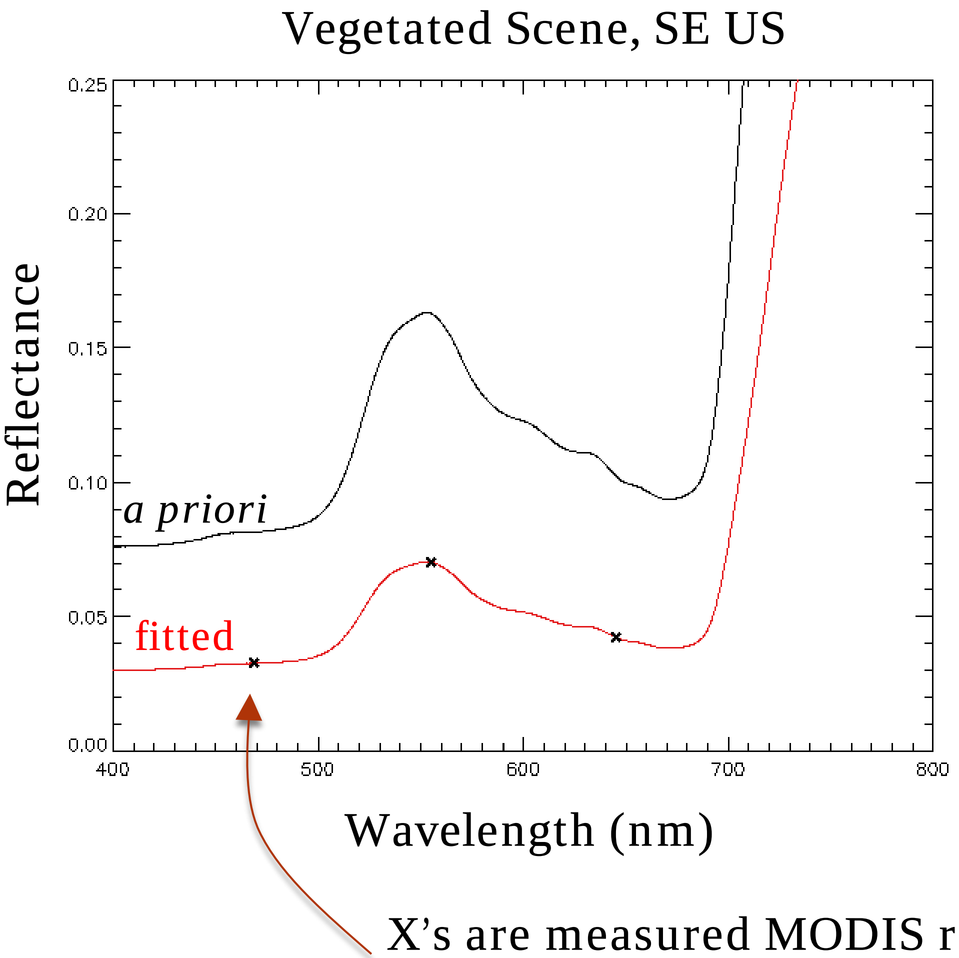
Grasses/Cereals
(51 samples)

Effect of Viewing Geometry



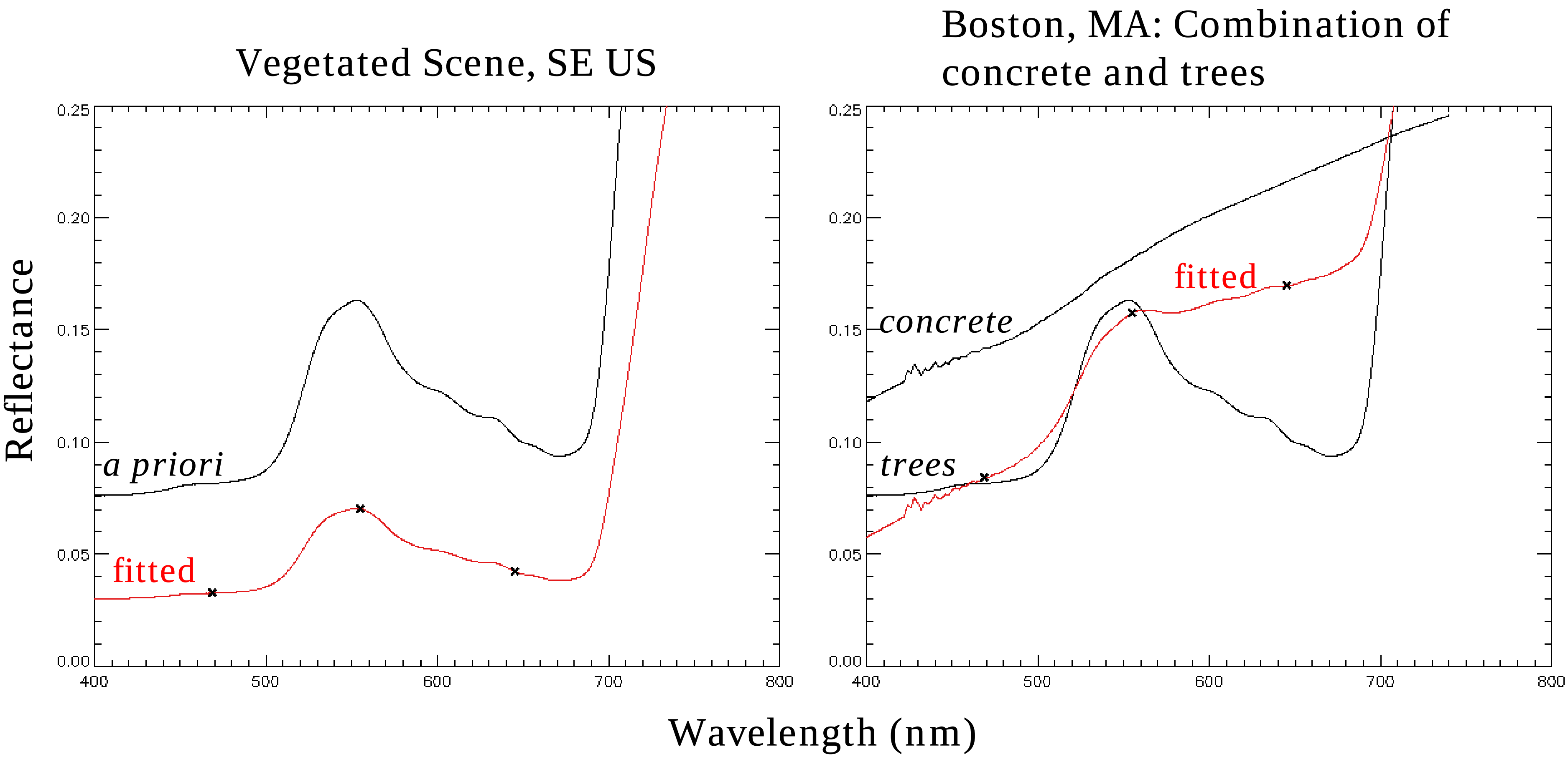


Computed surface reflectance



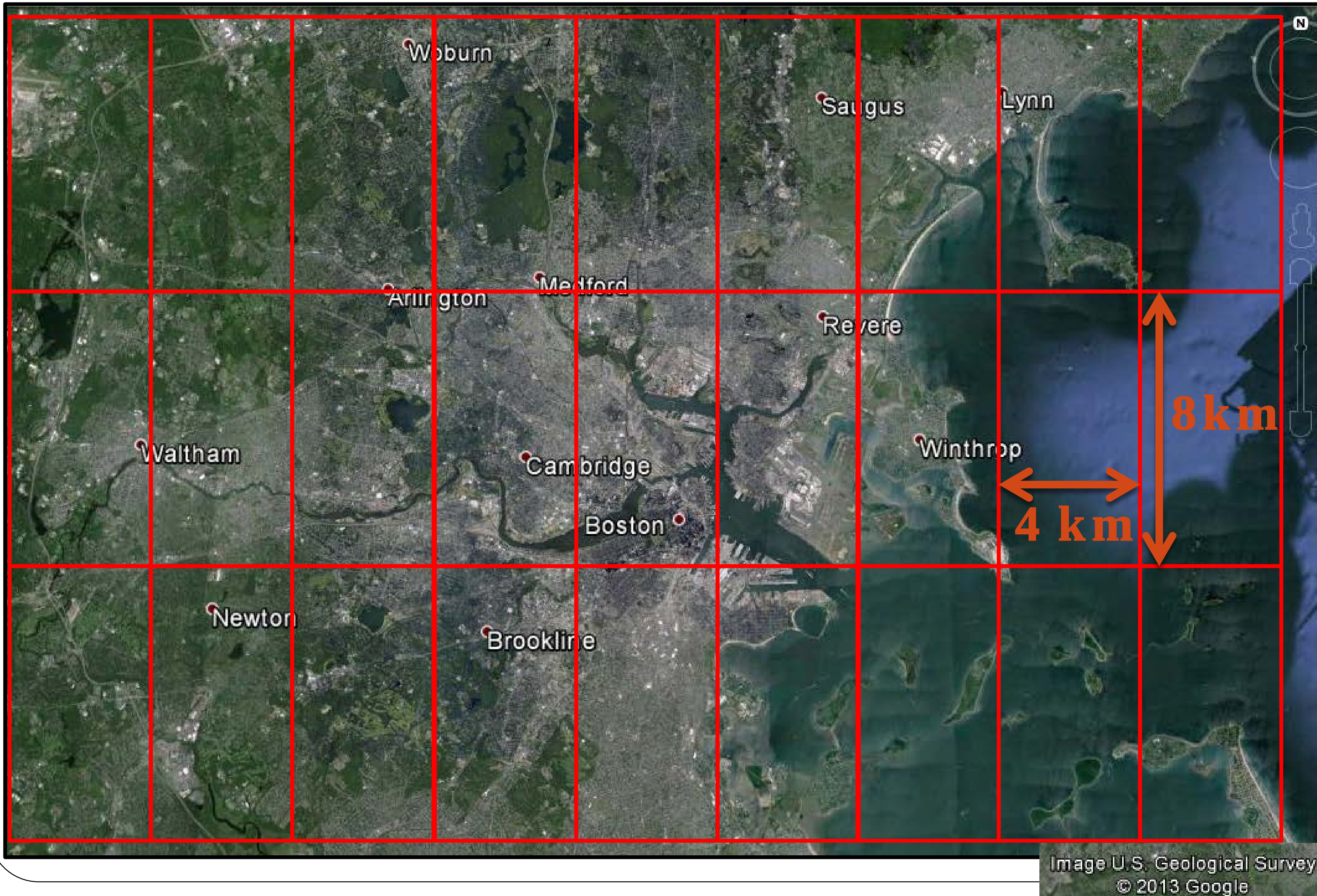
X's are measured MODIS reflectances adjusted for viewing geometry

Computed surface reflectance

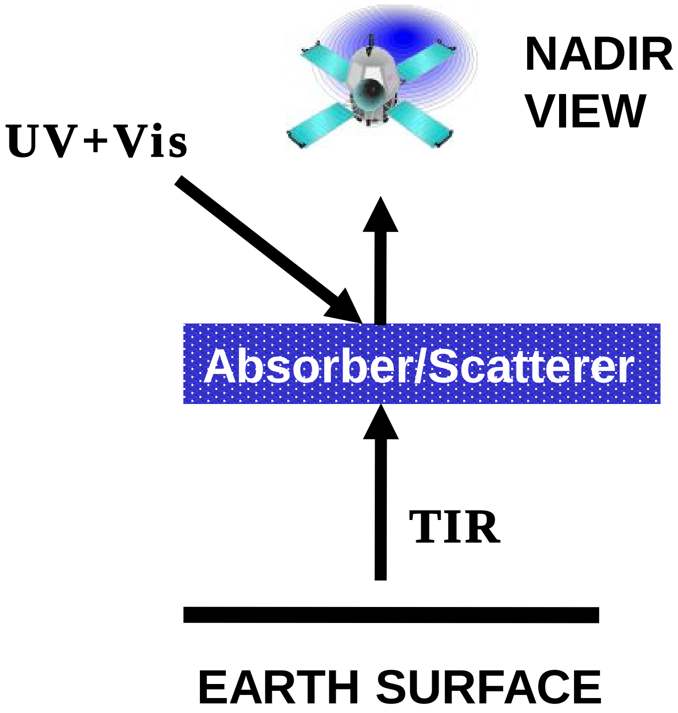


X's are measured MODIS reflectances adjusted for viewing geometry

The View from GEO



Current Satellite Observations



- High density of observations, but limited to once per day
- Satellite observe absorption features in UV, Vis, IR
  - e.g. O_3, NO_2, CO, HCHO, CH_4
- Nadir viewing geometry gives good horizontal resolution but poor vertical resolution

Air Quality Information from GEO

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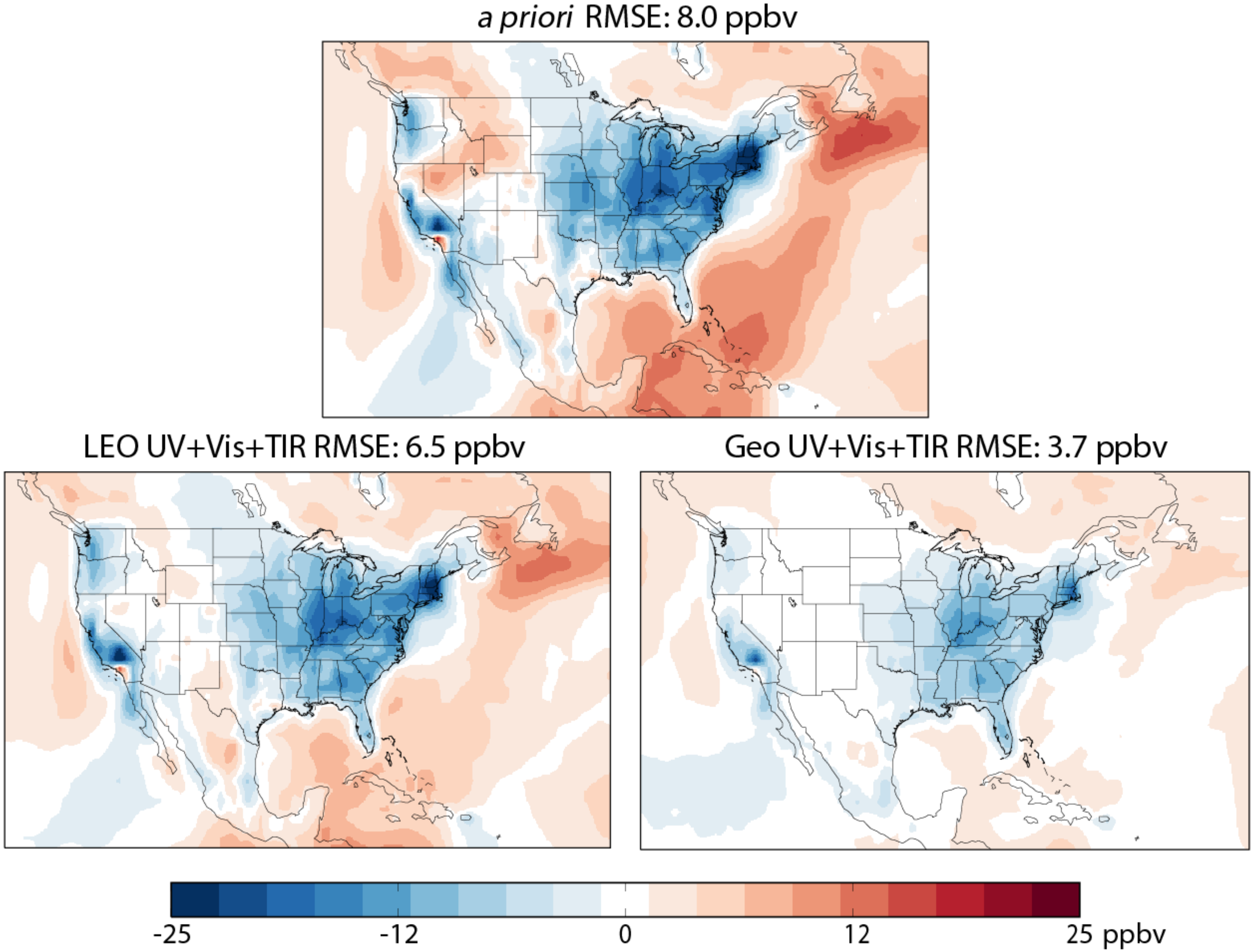
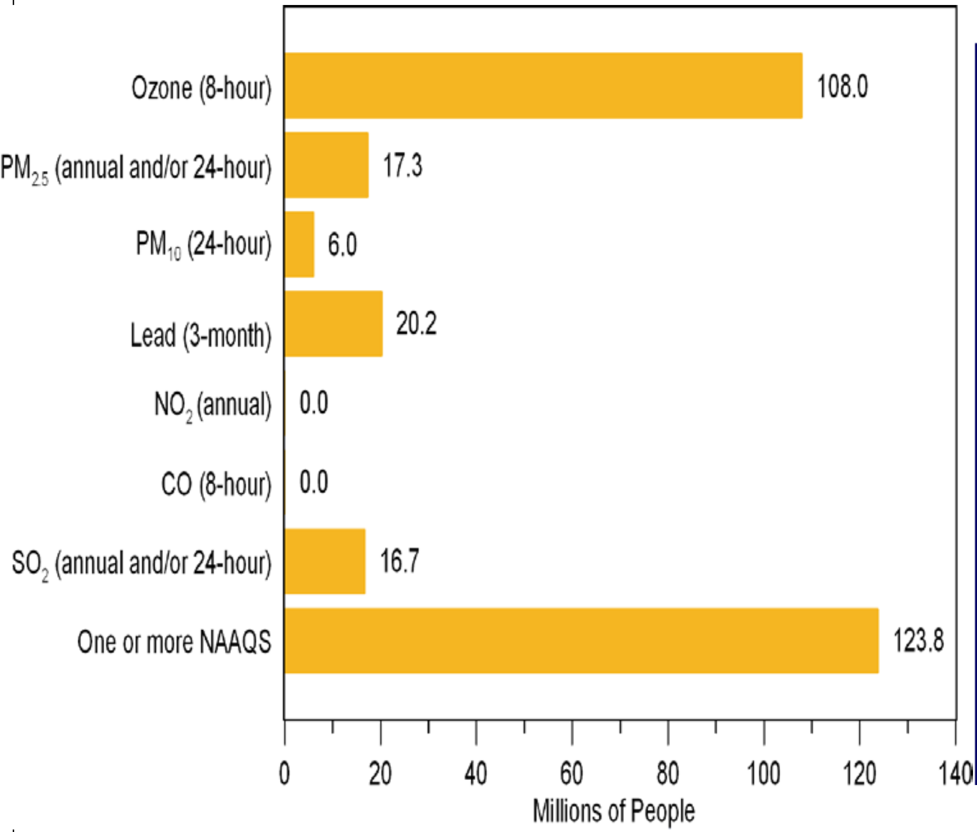
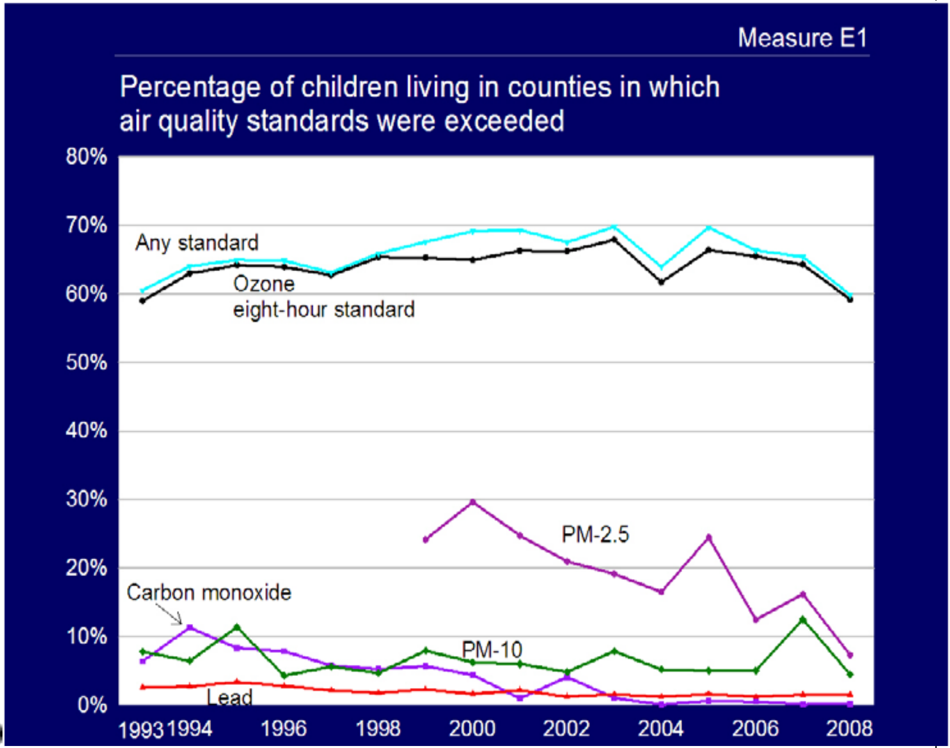


Need to combine observations in multiple spectral regions at high temporal resolution to constrain ozone air quality

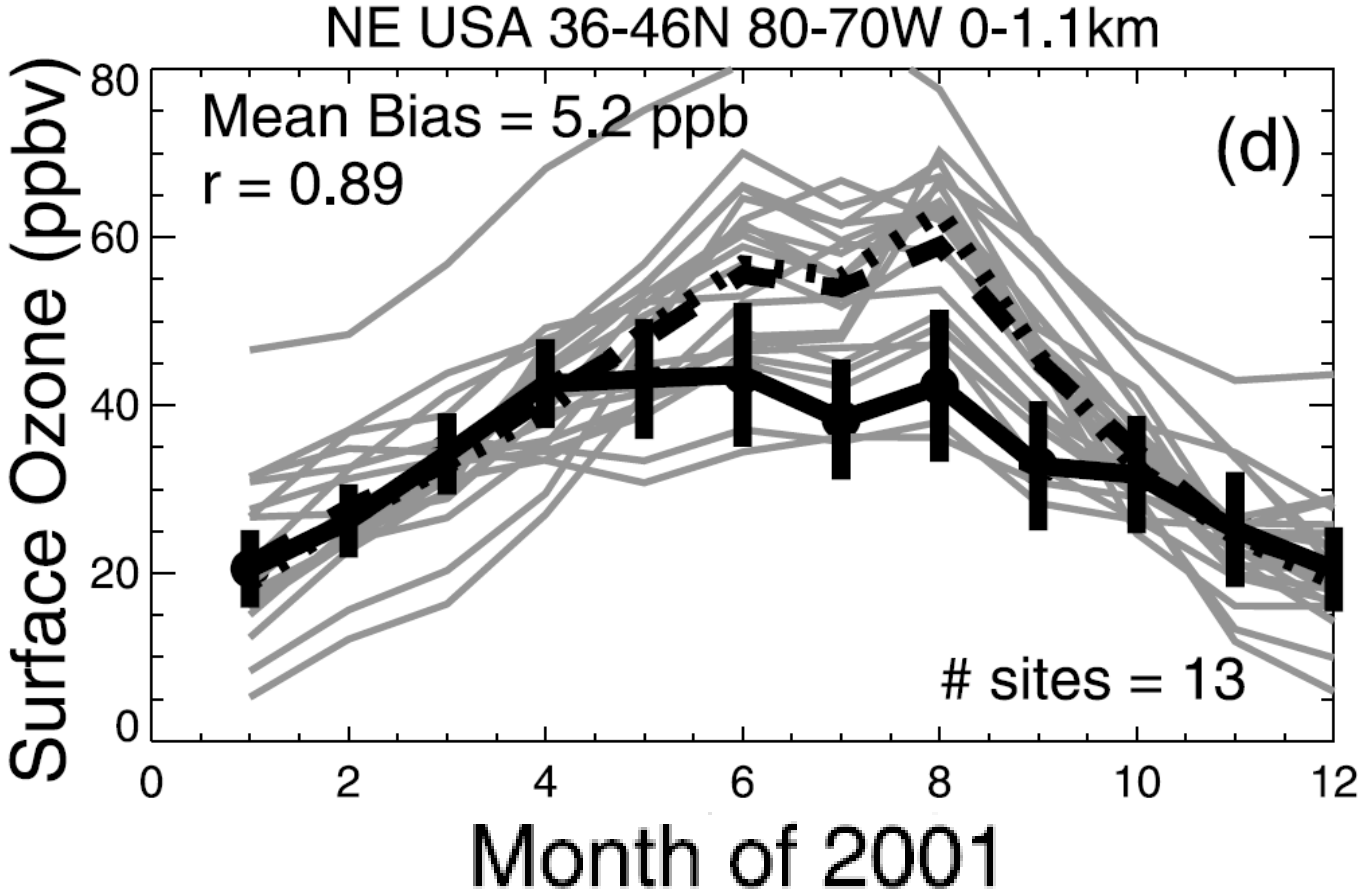
If its polluted, there's ozone





[EPA 2011]

Difficulty of Modeling Ozone



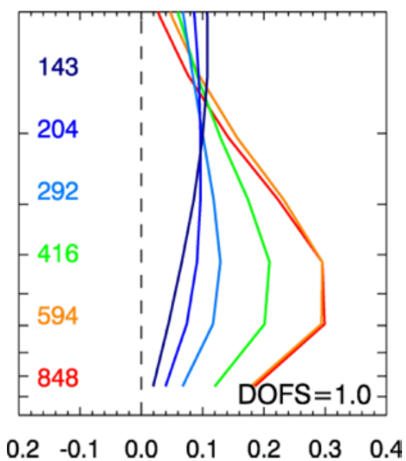
[Fiore et al. 2009]

Multispectral Satellite Observations of Ozone

Averaging Kernel matrix **A** quantifies the vertical information provided by a satellite retrieval

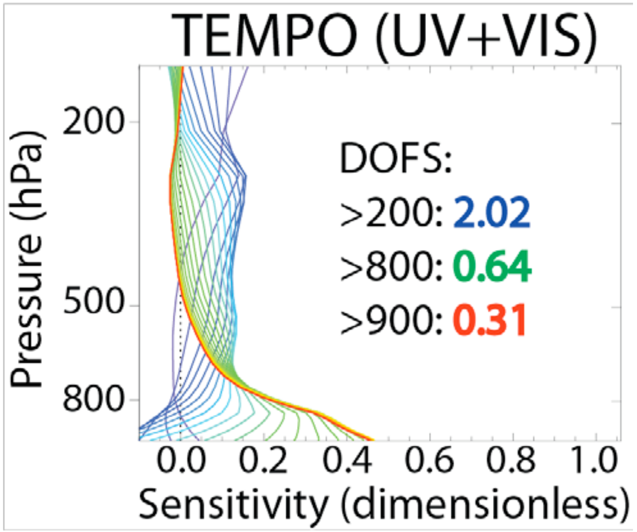
$$\mathbf{x}' = \mathbf{x_a} + \mathbf{A}(\mathbf{x} - \mathbf{x_a}) + \varepsilon \qquad \mathbf{A} = \frac{\partial \mathbf{x}'}{\partial \mathbf{x}}$$

Current ozone sensitivity, OMI (UV)

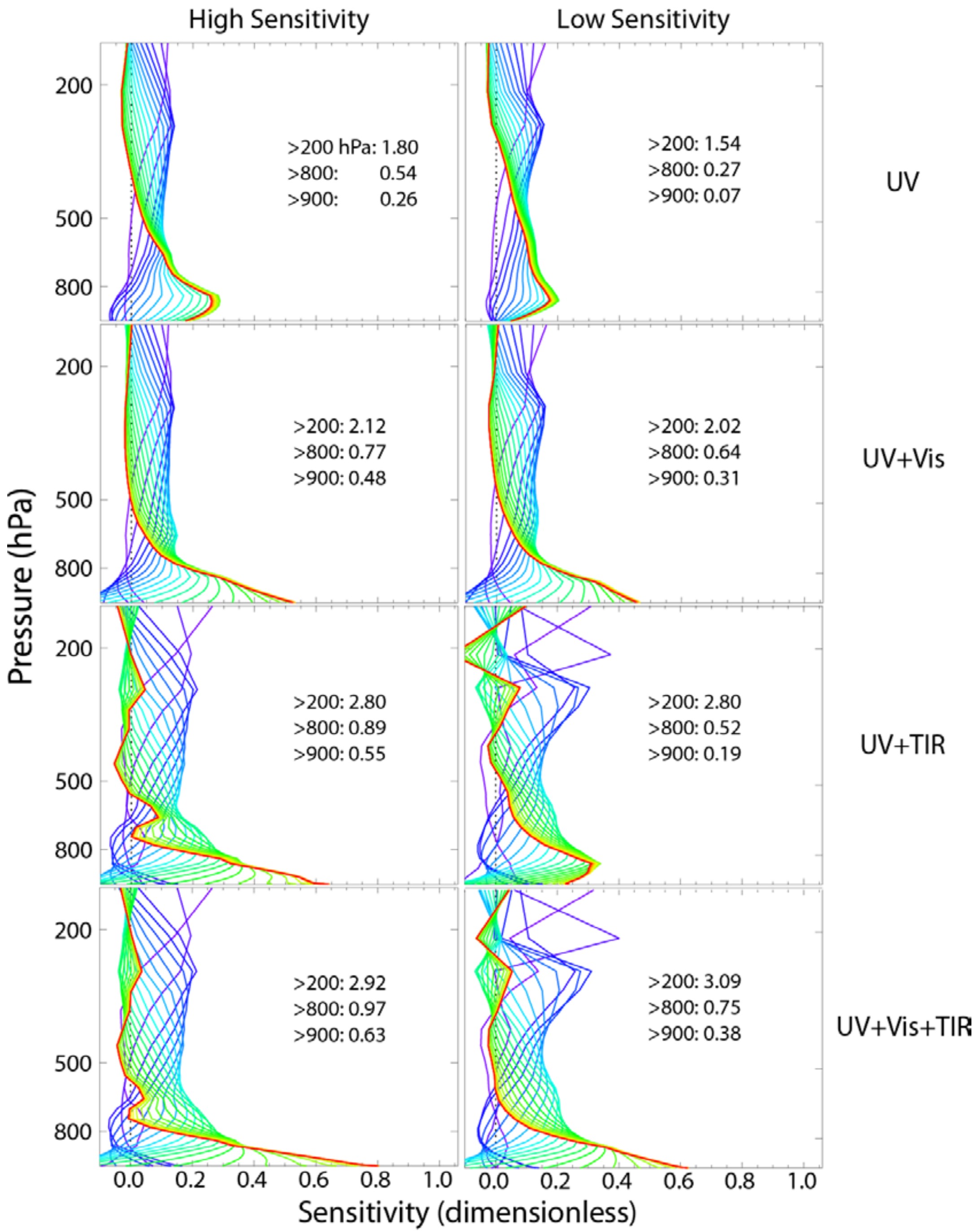


[Zhang et al. 2010]

Ozone sensitivity, future



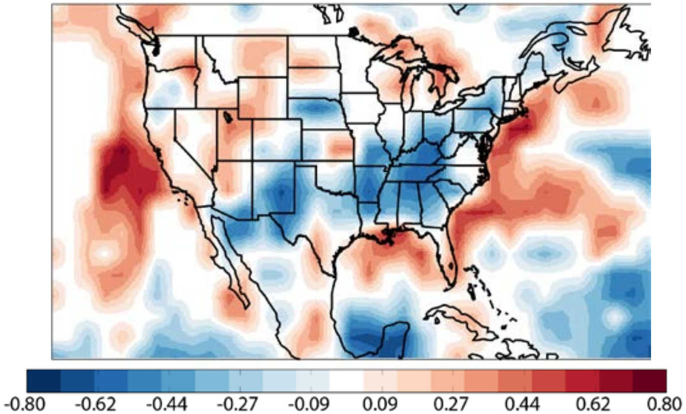
[Natraj et al, 2011]



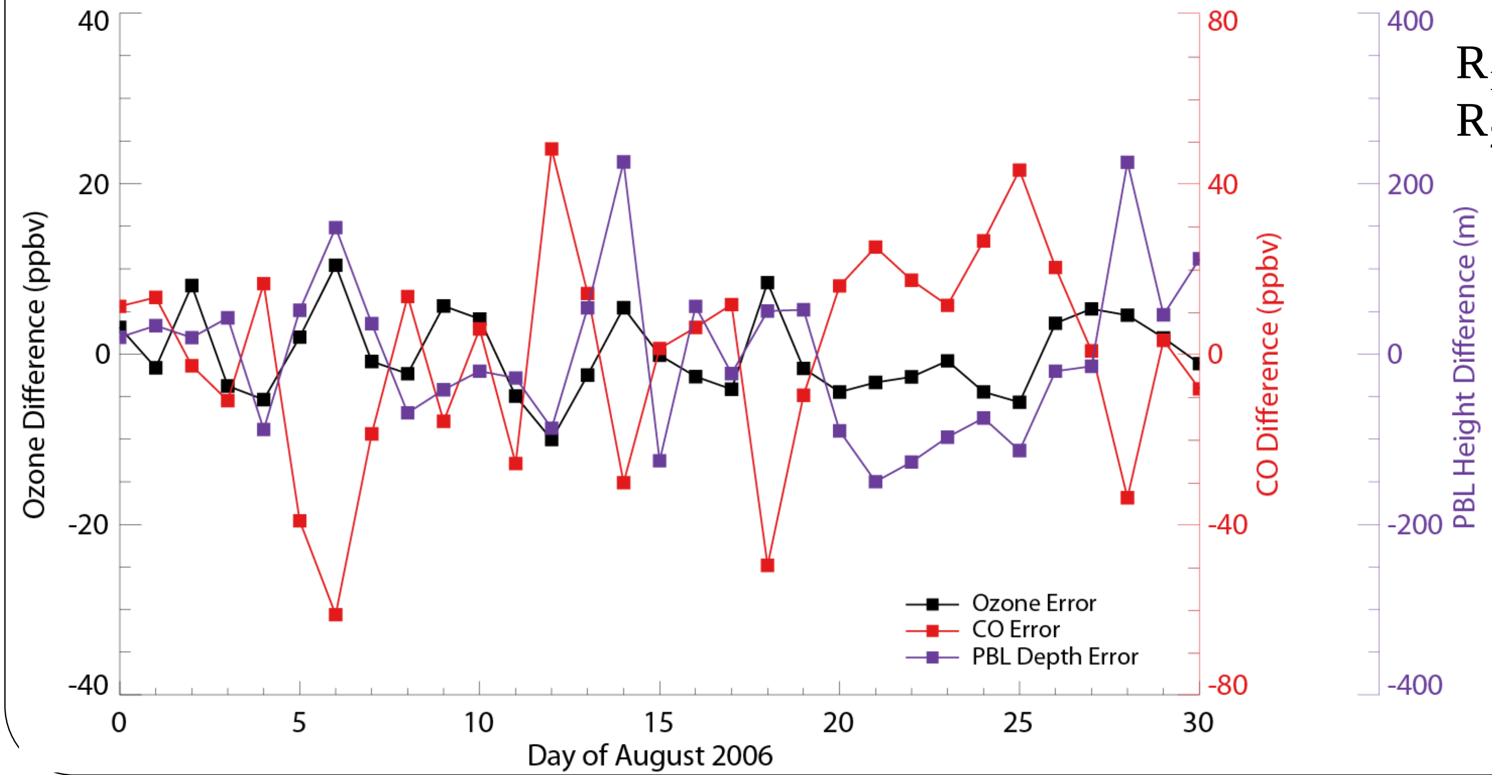
High Sensitivity
Low Sensitivity
Pressure (hPa)
200
500
800
>200 hPa: 1.80
>800: 0.54
>900: 0.26
>200: 1.54
>800: 0.27
>900: 0.07
UV
>200: 2.12
>800: 0.77
>900: 0.48
>200: 2.02
>800: 0.64
>900: 0.31
UV+Vis
>200: 2.80
>800: 0.89
>900: 0.55
>200: 2.80
>800: 0.52
>900: 0.19
UV+TIR
>200: 2.92
>800: 0.97
>900: 0.63
>200: 3.09
>800: 0.75
>900: 0.38
UV+Vis+TIR
0.0 0.2 0.4 0.6 0.8 1.0
Sensitivity (dimensionless)

Error Correlations Investigated

ozone-CO error correlations (model/model)



Negative error correlations over land driven by differences in vertical mixing



R_1 (Ozone:CO)= -.68

R_2 (PBLH:CO) = -.65