Constraining emission rates from geostationary orbit: Lessons learned from LEO

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**The General Inverse Problem**

**Concentration measurement** \( c(x, t) \)

**Transport chemistry deposition**

**Forward model:** chemical transport model (CTM) that solves continuity equation

\[ c(x, t) = f(e, \text{chemistry, transport, deposition}) \]

**Inverse model:** Green’s function of the CTM but requires Bayesian optimization to account for errors in CTM and in measurements

**Analytical solution:** limited to ~100 pieces of information on emissions

**Adjoint solution:** no such limitation
Adjoint vs. analytical inversion of Asian CO sources using MOPITT data

MOPITT daily CO columns (Mar-Apr 2001)

GEOS-Chem CTM and its adjoint

Correction factor to a priori sources

adjoint inversion

native CTM resolution (2°x2.5°)

Adjoint inversion reveals fine-scale variability that the analytical inversion cannot resolve

Kopacz et al. [JGR 2009]
Annual mean CO column
May 2004 - April 2005

Application of the GEOS-Chem model adjoint to optimize CO sources using multi-sensor data

Global (2°x2.5°) correlation of daily data with GEOS-Chem, May 2004 –April 2005; GEOS-Chem fields processed by averaging kernels of each instrument

Consistency between instruments and with in situ “truth”

Kopacz et al. [ACP 2010]
1. Use MOPITT, AIRS, SCIAMACHY-Bremen in adjoint inversion;

Best prior estimate from current inventories

2. Use TES and in situ data for independent evaluation of inversion results

Multi-sensor inversion; CO source optimization at 4°x5°, monthly resolution

General underestimate of emissions, but with large seasonal variation

Kopacz et al., [ACP 2010]
Underestimate of emissions from cold vehicle starts in winter?

Kopacz et al., [ACP 2010]
CO-\text{CO}_2\text{ ERROR CORRELATIONS AS CONSTRAINTS FOR CO}_2\text{ SURFACE FLUX INVERSIONS}

GEOS-Chem transport error correlation between CO and CO\textsubscript{2} columns

**Common CO-CO\textsubscript{2} source from combustion**

**Satellite observations of CO and CO\textsubscript{2}**

**GEOS-Chem simulation of CO and CO\textsubscript{2}**

**A priori error correlation**

**J\text{OINT CO-CO}_2\text{ INVERSION}

**IMPROVED OPTIMIZATION OF CO\textsubscript{2} SURFACE FLUXES**

*Wang et al., ACP 2009*
NO$_2$ AND HCHO MEASUREMENTS FROM SPACE AS CONSTRAINTS ON NO$_x$ AND REACTIVE VOC EMISSIONS

BOUNDARY LAYER ~ 2 km

Tropospheric NO$_2$ column ~ $E_{NOx}$
Tropospheric HCHO column ~ $E_{VOC}$

$h_v$ (420 nm)

1 day

Emission

$h_v$ (340 nm)

CO hours

VOC

O$_3$, RO$_2$

$\text{NO} \leftrightarrow \text{NO}_2$

Deposition

HNO$_3$

OH

Emission
ADJOINT SOLUTION FOR NO$_x$ AND VOC EMISSIONS REQUIRES FINE-SCALE INFO ON TRANSPORT, CHEMISTRY

For scales $\sim 100$ km, ignore transport:

$$E_{NO_x} = \frac{[NO_2]}{[NO_x]} \Omega_{NO_2} \tau_{NO_x}$$

$$E_{VOC} = \frac{\tau_{HCHO} \Omega_{HCHO}}{Y_{HCHO}}$$

Finer resolution requires model adjoint and confidence in model PBL dynamics, chemistry.
ISOPRENE EMISSION INFERRED FROM OMI

Mean OMI formaldehyde column (JJA 2006)

Outside of biomass burning and very polluted regions, HCHO from space is proxy for isoprene emission with uncertainty of 40% (single retrieval)

...compare to MEGAN bottom-up inventory:

Millet et al. [JGR 2008]
HCHO AS PROXY OF ISOPRENE EMISSION OVER AFRICA

Data screened against biomass burning influence using MODIS fire counts and OMI AAODs (Omar Torres)

Eloise Marais (Harvard), work in progress
GLYOXAL (CHOCHO) COLUMNS: WHAT DO THEY MEAN?

Monthly mean 10 LT glyoxal columns for Jan and Jul 2006

In model, main sources of CHOCHO are isoprene and biomass burning; SCIAMACHY data also show high values over tropical oceans. Combination of HCHO and CHOCHO data could provide improved constraints on emissions of isoprene, other VOCs, SOA formation.

Fu et al. [JGR 2008]
Diurnal variations in NO\textsubscript{x} emissions and chemical loss can be detected in OMI vs. SCIAMACHY differences.

Geostationary observations could provide quantitative assessment, test model chemistry relevant to inverting emissions.

Boersma et al. [JGR 2008]
Diurnal difference between SCIAMACHY (10 am) and OMI (1:30 pm) over Middle East in summer vs. winter

SCIAMACHY – OMI difference: DJF 2006

- maximum vehicle use in daytime would result in higher NO₂ at 13:30 than at 10:00, but this is more than compensated in summer by high chemical loss in daytime
- Need temporal averaging (here monthly) to resolve diurnal differences and reduce single-observation error (~30%)

Diurnal variation of NO₂ in Israeli cities, Mar-Nov

Boersma et al. [ACP 2009]
Aerosol optical properties assumed in satellite retrieval must be consistent with forward model for a sensible inversion.
MODIS AOD retrieval using local CTM aerosol properties and surface reflectances: application to eastern US in summer 2004.

Synthetic top-of-atmosphere reflectances

LIDORT radiative transfer model

MODIS 0.47 µm AOD (this work)

Compare to MODIS c5 operational product

MODIS 0.47 µm AOD

Product suitable for aerosol source inversion using GEOS-Chem

GEOS-Chem 0.47 µm AOD

NASA/INTEX-A DC-8 aircraft:
Aerosol chemistry
Size distribution
Optical properties

surface networks: IMPROVE (aerosol chemistry), AERONET (AOD)

EASTERN UNITED STATES (ICARTT)

Drury et al. (JGR 2010)
Geostationary orbit allows multi-angle aerosol viewing to resolve aerosol scattering phase function

- Air moves over the course of the day but this can be simulated by the CTM
- Build adjoint of radiative transfer model and invert for radiances rather than for retrieved aerosol properties
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- Spatial resolution < 10 km is undeniably valuable for cloud clearing and qualitative pinpointing of sources, but quantitative inference of emissions on that scale is challenging because of uncertainties in relevant PBL dynamics and chemistry.
- Time-averaged observations from GEO may significantly reduce model transport error relative to instantaneous observations from LEO.
- Diurnal variations in NO$_x$ emissions should be resolvable at least in a monthly mean sense; this may be more challenging for isoprene emissions.
- Need to better understand glyoxal observations.
- Potential of multi-angle (sunrise to sunset) geostationary view for better characterizing aerosols needs to be investigated.