CO and biomass burning aerosols emission inversions with CAM-Chem and DART

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• **Model:** CAM-Chem (CESM122, CAM4 MOZART4 and BAM)

• **Emissions:** HTAP for anthropogenic; FINN for BB; MEGAN for biogenic

• **Data assimilation:** DART EnKF with an ensemble of 30 members and a 6 hourly assimilation window

• “State augmentations/localizations”: Choice of which state variables are constrained from the satellite data

• For example: Departures between CO MOPITT and CAM-Chem can be used to constrain CO 3D fields but also CO emissions and additionally related aerosols e.g. OC and BC.
Motivations - Methodology

CAM-Chem (or any CTM)

Atmosph.  M(X)

Surf. Flux.  SF(X)

Anth  Fires  Volc  Biog

Prior emissions inv/ Bottom up estimates

Data Assimilation

increments every 6 hours

Remote Sensing

Emission Tool

Selectively infer emission inventories and propagate increments over time
Perturbations - Methodology

\[
q(x_1, y_1)q(x_2, y_2) = \Delta k c^2 \sum_{l,p} e^{-2(k_l^2 + \gamma_p^2)/\sigma^2} e^{i[k_l(x_1-x_2) + \gamma_p(y_1-y_2)]}.
\]

- Perturbation code can be used to set different length scales and correlate/de-correlate emissions variables and types: the user can build his own background covariance matrix making “good” apriori assumptions.

**Perturbations coefs on one member**

- **Burning perturbation structure**: \(L_s=200\text{km}, \ L_t=3\text{days}\)
- **Anthropogenic perturbation structure**: \(L_s=1000\text{km}, \ L_t=1\text{month}\)
- **Biogenic perturbation structure**: \(L_s=2000\text{km}, \ L_t=1\text{month}\)
CO increments - Methodology

• First tests: After a month of MOPITT CO inversion

• Impacts on different types of emissions are clearly different
The Washington State fires of summer 2015:
- **Total fires:** 1,541
- **Total area:** 1,005,423 acres
- **Cost:** $253 million

Haze over Denver 08/27/15
Model and data assimilation setup

- **Model:** CAM-Chem (CESM122, CAM4 with MOZART4 and BAM) at 1 degree horizontal resolution with 56 vertical levels from the surface to 1 hPa; driven by GEOS-5 analyses
- Experiments run for August 2015: from 1\textsuperscript{st} - 20\textsuperscript{th} as spin-up, and from 20\textsuperscript{th} - 31\textsuperscript{st} as the period of interest
- Emissions: HTAP for anthropogenic; FINN for BB; MEGAN for biogenic
- **Data assimilation:** DART EnKF with an ensemble of 30 members and a 6 hourly assimilation window
- Choice of whether 3D fields or emissions are constrained from the satellite data
- The emission types (anthropogenic, BB, biogenic) are perturbed independently allowing the EnKF to invert separately for the different emission types
- **Emissions experiment:**
  - Invert the MODIS AOD data to update the FINN BB emission sources for black and organic carbon (BC+OC) in the model
  - Assumption that these species dominate the wildfire plume
Smoke and aerosol

Time averaged map of Deep Blue aerosol optical depth at 0.55 microns for land (corrected): Mean of daily mean monthly 1 deg. [MODIS-Terra MOD08_M3 v6] Aug 2015

MODIS plumes of smoke across Washington on Aug. 25, 2015
Updated OC+BC emissions estimates

Emission totals from 20-31 Aug. 2015: **Factor 3.7 increase**

- But AOD is a column quantity; no direct information about near-surface aerosol for AQ applications
- However, fires co-emit both carbon monoxide (CO) and carbon aerosol (OC+BC) as primary pollutants
- What do the satellite CO data look like?
- Is there any information on the vertical distribution of pollutants?

Thanks to Pablo Saide (NCAR) & Ed Hyer (NRL) for help with gridded MODIS AOD
MOPITT V5J multispectral retrievals of CO from MOPITT provide profile information that distinguishes fire source regions from free troposphere long range transport of pollution. 20-27 August 2015

Note different scales

MODIS Fire Counts 19-28 August 2015 showing the WA north-central Okanogan Complex
Updated CO emissions estimates

Emission totals from 20-31 Aug. 2015: **Factor 3.3 increase**

Control CO | Total 0.604Tg
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MOPITT CO Inversion | Total 1.976Tg

Average CO changes across N.America: Surface-200hPa average
CO assimilation

CO profile changes from Control Run where BB tracer >10ppb, 1000 km from source

Combined MODIS inversion & MOPITT assimilation experiment:
- Use the updated emissions estimates for BC+OC from the MODIS AOD inversion
- ... then assimilate the MOPITT CO profile data and use this to constrain the aerosol profile in the model
Combined AOD inversion/CO assimilation

OC+BC profile changes from Control Run where BB tracer >10ppb, 1000 km from source

Enhanced near-surface concentrations close to fires

3000-4000 km from source

Greater high-altitude concentrations downwind

CCWG 2017
Combined AOD inversion/CO assimilation

Average OC+BC changes across N.America from 20-31 Aug. 2015 relative average difference compared to Control Run

Enhanced near-surface concentrations just downwind of fires

Reduced high-altitude concentrations close to fires; correction of vertical transport

Elevated plume aerosol down-wind
Combined AOD inversion/CO assimilation

Average OC+BC changes across N.America from 20-31 Aug. 2015 relative average difference compared to Control Run

(MODIS Inversion) - (Control Run)

(MODIS Inversion + MOPITT Assimilation) - (MODIS Inversion)
Combined AOD inversion/CO assimilation

Average OC+BC changes across N.America from 20-31 Aug. 2015 relative average difference compared to Control Run
Summary and Next steps

- Developed an online emission tool for ensemble methods
- Inversion of MODIS AOD and MOPITT CO data change FINN model a priori emissions estimates for the WA fires by a factor of about 3.5
- Presents an opportunity to explore and explain the differences between the bottom-up and top-down emissions estimate approaches
- Subsequent assimilation of the MOPITT CO profile can be used to constrain the aerosol profile
- This elevates near-surface aerosol down-wind of the plume and decreases higher altitude aerosol concentrations closer to the fires; essentially correcting plume vertical transport
- Currently evaluating near-surface aerosol analysis results with ground-based PM2.5 measurements
- Release the emission tool for the community (GMD in prep.)
Thank you!
CO Multi-Spectral Remote Sensing

Radiance (W/cm²/sr/cm⁻¹)

- Solar Reflection
  - CO (2.3 μm)
- Terrestrial Emission
  - CO (4.6 μm)

**Wavelength (μm)**

- 2.3 μm solar reflection
- 4.6 μm surface emission

- Provides column information
- Provides free troposphere profile information

Atmospheric emission

\[
\frac{\Delta y}{\Delta X_{CO}}
\]
Combined AOD inversion/CO assimilation

Average OC+BC and CO BB tracer across N.America from 20-31 Aug. 2015 relative average difference compared to Control Run
MISR AOT August 2015 average
CHRONOS Proposal to NASA EVI-4

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