Sensitivity of CO$_2$ Flux Inversions to the Temporal and Spatial Distribution of Observations

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Introduction

Question

- How do differences in spatio-temporal observational coverage affect CO$_2$ flux estimates?

Plan

- Use GEOS-Chem adjoint model to look at sensitivity of observations to surface fluxes spatially and temporally for each season
Observing Systems

- **Surface**: Network of surface and tower sites. ObsPack PROTOTYPE package contains 190 data sets from 20 labs.

- **TCCON**: Network of >20 ground-based spectrometers which make measurements of solar spectra to retrieve XCO$_2$.

- **GOSAT**: TANSO-FTS infers XCO$_2$ from reflected insolation. Glint mode over ocean, nadir over land.

- **OCO-2**: Infers XCO$_2$ from reflected insolation. Alternates glint and nadir modes.
Observations

- Use ideal set of observations:
  - **Surface**: Prototype surface and tower observations (similar selection to CarbonTracker). Fixed observations from SON 2011 to each season so that identical observations occur for site for each season.
  - **TCCON**: Observations from years with most observations for each season at each site.
  - **GOSAT**: QF=0 (ACOS, Sept 2011 - Aug 2012)
  - **OCO-2**: WL≤10, QF=0 (ACOS, Sept 2014 - Aug 2015)

- Observations times are aggregated into 2x2.5 degree spatial grids and 1 hour time steps, such that there can only be one observation for a given grid-cell over a given time-step.
Observation Density (number per day)
Method: Calculating Sensitivities

- We relate variations in observed CO$_2$ at the locations and times of the observations by taking the derivative of the following sensitivity function with respect to the fluxes:

\[
J = \sum_{i=1}^{N} \left[ \frac{\text{CO2}_i}{\text{Air}_i} \right] \cdot 10^6 \quad \text{(ppm)}
\]

CO2 = mols of CO$_2$
Air = mols of Air
N = number observations (over a season)

- The sensitivity of an observation to surface fluxes is given by,

\[
\gamma_{i,j} = \sum_t \frac{\partial J}{\partial f_{i,j,t}}
\]

f = surface fluxes
Sensitivities

- Surface obs highest over most of northern extratropics
- OCO-2 highest in tropics and southern hemisphere
Ocean glint and H-Gain nadir have similar importance

Spatial distribution of ocean glint varies seasonally
Sensitivities: OCO-2 Observing Modes

- Ocean glint dominates
- Land glint and nadir are similar
Surface observations are sensitive to North American and European seasonal cycle

OCO-2 is sensitive to tropical seasonal cycle and northern extratropic in JJA
Conclusions

- OCO-2 has highest sensitivity for most of globe over all seasons.
  - provides the highest sensitivity to fluxes across Eurasia in JJA.
  - captures the seasonal cycle in the tropics and southern subtropics.

- Surface observations have highest sensitivity to northern hemisphere for SON, DJF, MAM.
  - captures the seasonal cycle in North America and Europe.

- Combining OCO-2 and the surface data should enable us to better capture the global seasonal cycle and the inter-hemispheric gradient in CO₂.

- The substantial sensitivity differences between observation systems means careful consideration is required in comparing inversion flux estimates.
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