An Ensemble Kalman Smoother for the Coupled Greenhouse Gas and Flux estimation problem

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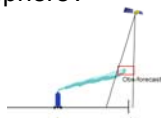
1. The problem

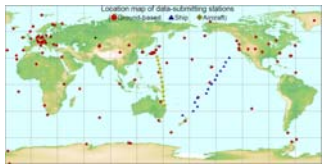
Why develop a Carbon Assimilation System (EC-CAS)?

- Monitor CO_2, CH_4 fluxes over Canada
- Address climate mitigation policies related to managed and unmanaged Canadian carbon sources and sinks
- Address adequacy of EC's network of ground-based observations

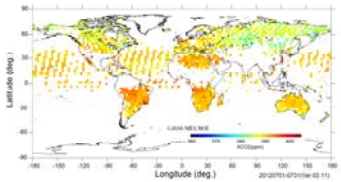
The assimilation problem:

- Given atmospheric observations over a time window, what was the flux of CO_2 between the Earth's surface and the atmosphere?
- Observations: sparse, accurate surface CO_2 sites, aircraft, GOSAT (2009), OCO2-(2014)
- Unknowns: global 2D flux of CO_2
- Background fluxes: (1) anthropogenic emissions and (2) biomass burning from inventories, and ecosystem models of (3) terrestrial biospheric fluxes, and (4) ocean fluxes.





WMO's World Data Centre for Greenhouse Gases (WDCGG)
http://ds.data.jma.go.jp/gmd/wdcgg/



GOSAT column avg CO_2 for July 2012
http://www.gosat.nies.go.jp © NIES

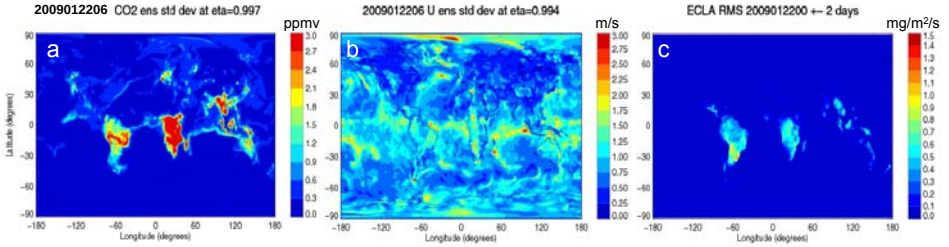
2. The assimilation system

- Operational global weather forecast model: GEM global
- Start from operational ensemble Kalman Filter (EnKF)
- Will extend control vector for constituents and fluxes
- Will extend scheme to become a fixed lag Kalman smoother
- Similar systems: Kang et al. 2012; Miyazaki et al. 2011, Tian et al. 2013
- Model issues that still need to be resolved:
  - Semi-Lagrangian advection does not conserve mass yet
  - No transport of tracers through convection yet

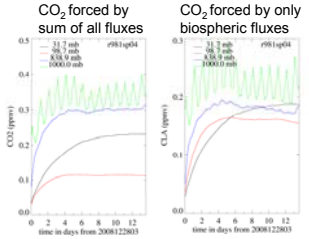
3. Current status

First step: EnKF only. No tracer assimilation, only passive advection

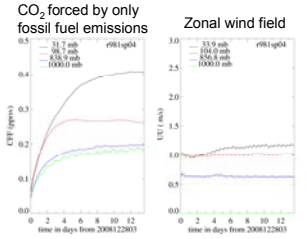
- Testing with 64 ensemble members, low 0.9° grid spacing
- Start on 28 Dec 2008. All members have same initial CO_2 and same fluxes. Spread is due to spread in winds only. How does uncertainty in winds affect CO_2 spread?



CO_2 spread (a) does not mainly resemble spread in winds (b) but rather the spatial variability of biospheric fluxes (c)



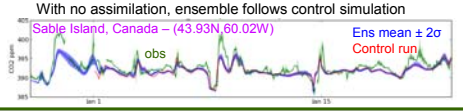
Spread in total CO_2 (left) largest near surface due to gradients created by biospheric fluxes (right)



When surface fluxes are small (left) CO_2 spread increases with height since spread in winds increases with height (right)

- CO_2 spread near surface reflects flux gradients
- Ask me about ensemble spread movies

With no assimilation, ensemble follows control simulation



4. Issues/Next steps

Ensemble perturbations

- Is the ensemble spread large enough?
- Add perturbation of parameters related to tracer transport, e.g. vertical diffusion?
- How to formulate perturbations of surface fluxes?
- Is additive (stationary) covariance needed for CO_2?

Next steps

- Study boreal summer period when biospheric fluxes are largest
- Extend EnKF control vector for constituents, add observations and operators for CO_2
- Study GOSAT, OCO-2 assimilation
- Extend to Kalman smoother
- Couple to ecosystem model with own assimilation to get biospheric fluxes

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Miyazaki, K., T. Maki, P. Patra, and T. Nakazawa (2011), *J. Geophys. Res.*, 116, D16306, doi:10.1029/2010JD015366.
Tian, X., Z. Xie, Y. Liu, Z. Cai, Y. Fu, H. Zhang and L. Feng (2013), *Atmos. Chem. Phys. Disc.*, 13, 24755-24784, doi:10.5194/acpd-13-24755-2013.
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