

Weak Constraint 4D-Var in CO Emission Estimation

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Motivation:

Data assimilation schemes like 4D-Var tacitly assume perfect transport models.

Problem: model errors are misinterpreted as parameter errors and can lead to erroneous corrections to estimated parameters

Weak Constraint 4D-Var:

Append forcing terms u_n to transport model

$$x_{n+1} = M(x_n, p) + \Gamma u_n$$

and to cost function weighted by forcing covariance matrix Q

$$J = (p - p_b)^T B^{-1} (p - p_b) + \sum_{i=1}^N (y_i - H_i x_i)^T R_i^{-1} (y_i - H_i x_i) + \sum_{j=1}^M u_j^T Q^{-1} u_j$$

Information from observations is used to estimate both parameters p and model forcing terms u_j .

Implemented in GEOS-Chem for CO-only and full chemistry simulations.

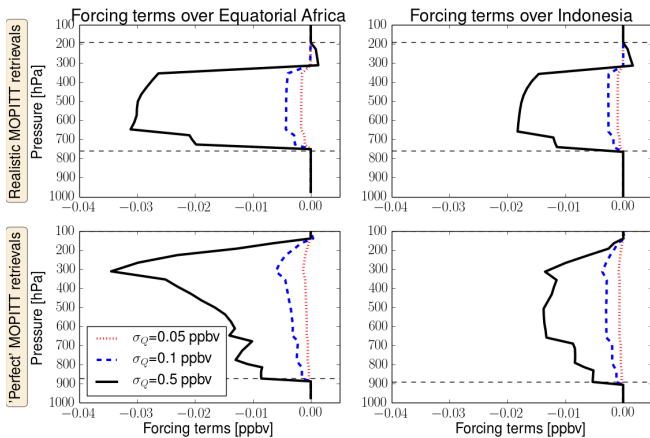
Estimated emissions using GEOS-5 from OSSEs assimilating synthetic MOPITT retrievals produced using GEOS-4 CO concentrations.

Use $Q = \sigma_Q I$ and increase a priori emissions by 50%.

	Africa	Southeast Asia	Indonesia	South America
True	111.14	194.67	92.77	59.14
A priori	166.71	292.01	139.15	88.71
Strong Constraint (normal 4D-Var)	72.59	169.14	66.47	44.39
Weak Constraint ($\sigma_Q=0.05$ ppbv)	85.35	168.33	72.12	59.07
Weak Constraint ($\sigma_Q=0.1$ ppbv)	111.19	168.71	82.88	73.45
Weak Constraint ($\sigma_Q=0.5$ ppbv)	131.09	193.74	106.72	80.91

- ▶ low σ_Q =strong penalty from forcing
emission estimates revert to strong constraint estimates
- ▶ high σ_Q =weak penalty from forcing
emission estimates revert to a priori estimates; $y_i - H_i x_i$ reduced via forcing terms, not emissions

Estimated CO forcing terms of different weak constraint 4D-Var experiments over equatorial biomass burning source regions for realistic and “perfect” MOPITT CO profile retrievals:



- ▶ design of Q controls
- ▶ magnitude of forcing terms
- ▶ vertical structure of forcing terms depends on resolution of observations

Applications for weak constraint 4D-Var:

- ▶ mitigate impact of transport model errors on estimated emissions
- ▶ study structure and physical origin of model errors from estimated forcing terms
- ▶ alternative to optimizing initial conditions in full chemistry inversions

Problems/Challenges:

- ▶ spatial & temporal sampling of observations limits ability to estimate forcing terms
- ▶ vertical resolution limits ability to accurately depict transport model errors
- ▶ ideal setup of weak constraint system hard to determine