GEOS-Chem Adjoint Model and the Data Assimilation Working Group

IGC6
05/06/2013

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Kevin W. Bowman, JPL, Data Assimilation WG Co-Chair
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with contributions from the entire group*

* ~50 registered adjoint users at more than 20 institutions

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...efficiently calculates gradients of a scalar model response with respect to all model parameters (emissions, rate constants, ...) at the native model resolution.

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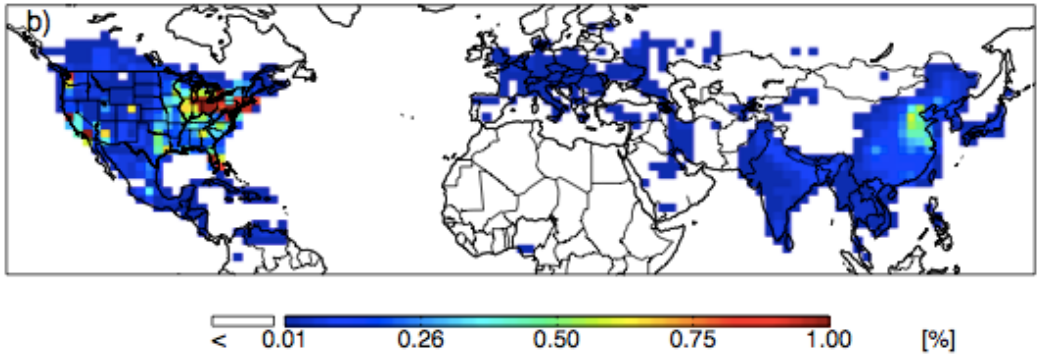

Modes response = US cumulative O3 (W126).

Adjoint calculates how sources of CO emissions anywhere in the world impact this response.

Katerya Lapina, CU Boulder

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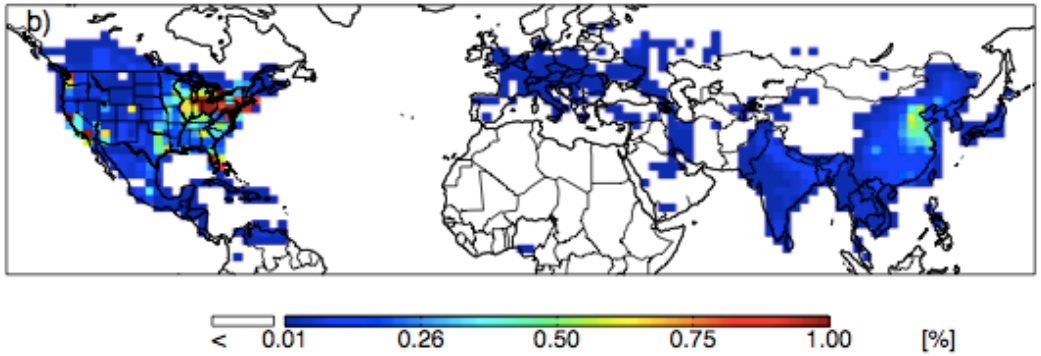

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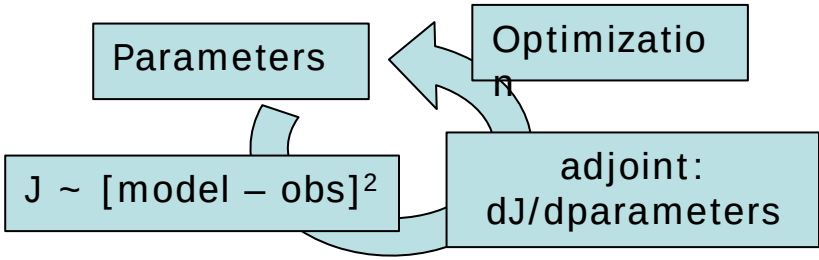
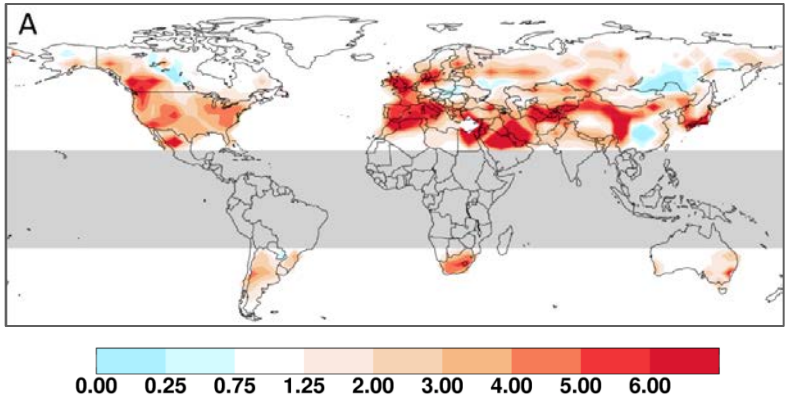
Inverse modeling / 4D-Var





top-down CH3OH emissions using TES
Kelly Wells, UM

Adjoint model: current features

Standardized code: v34i, maintained / distributed via GIT
Code base: v8-02-01 with relevant fixes / updates up to v9-01-03

Meteorology: GEOS-3, GEOS-4, GEOS-5
Simulations : full chem; offline CO, O_x, CO_2, CH_4, BC, Dust
Resolution : 4x5, 2x2.5, 0.5 x 0.667
Sensitivities : emissions, initial conditions, rate constants, stratospheric prod/loss rates

Processes: all main forward model process *excluding:*
- non-local pbl mixing scheme
- aerosol microphysics, online heterogeneous chemistry

Species: forward full chemistry model species *excluding:*
- SOA, SO4s, NITs, Br

see GC adjoint wiki page and Trello board for details

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Overview

BETA RELEASE

- Previous version: GEOS-Chem_Adjoint_v33

New: benchmarking procedures

What's new in this version

GEOS-Chem Adjoint v34 contains the following major updates and improvements.

Feature	Type	Submitted by	Committed by	Version	Status
Building Process Updated	Adjoint Update	Daven Henze (CU Boulder), Yanko Davila (CU Boulder)	Yanko Davila (CU Boulder)	v34	Approved 14 Nov 2012
Add support for GFED3 Emissions	Forward Model Update	Melissa Payer (Harvard)	Yanko Davila (CU Boulder)	v34	Approved 14 Nov 2012
Checkpoint files creation updated	Adjoint Update	Daven Henze (CU Boulder), Yanko Davila (CU Boulder)	Yanko Davila (CU Boulder)	v34	Approved 14 Nov 2012

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(FROM IGC5)

Developments: rank by priority (high, med, low) and assign point people or groups

Model development	Development group	Priority level	Readiness	Difficulty
Off-diagonal error covariance matrix	JPL	high	med	low
Inverse Hessian	Tang (Purdue), JPL	high	med	low
Methane	Wecht (Harvard), Tang (Purdue)	high	high	low
CH4 obs operators: SCIA, AIRS, TES	Harvard / Purdue	med	med	low
generalized DOAS obs operator	Bousserez (Dal)	high	high	low
generalized TES obs operator	Lee (JPL)	med	med	med
full chemistry nested	Zhe Jiang (UT)	highest	low	med
CO/CO2	Jones (UT), Bowman (JPL)	high	low	med
BC offline adjoint	Yuhao Mao, Qinbin Li (UCLA)	high	low	low
heterogeneous chemistry (RDAER)	Henze (CU Boulder)	med	med	low
GISS tracer advection adjoint	Henze (CU Boulder)	low	low	low
GCAP convection	Henze (CU Boulder)	low	low	med
Colum				
additio				
Sensiti				
Dust	Xu (UNL), Park (SNU), Li (UCLA)	high	med	low
Satellite obs operator sensitivity	Bowman, Lee (JPL)	med	med	low
Generic surface obs operator	Jones (UT)	med	med	low
Output rxn rate sensitivities	Paulot (Caltech/Harvard)	med	med	low
Joint initial condition & emissions opt	?	high	low	low
ISORROPIA adjoint	Shannon Capps (Georgia Tech)	med	med	med
Scaling factor "hooks" in forward model	work w/Bob and emissions group	high	low	low

Many high priority items implemented in the last two years.

Recent and current applications: Inverse modeling

Aerosol and aerosol precursor emissions:
- Carbonaceous PM using IMPROVE (Mao, UCLA; Egan-Pimblett, Dalhousie)
- Asia BC with OMI AAOD (Zhang, CU Boulder)
- Aerosols with MODIS (Xu, Wang, UNL)
- Aerosols with POLDER (Meland, CU Boulder/CUD)
- NH_3 using TES (Zhu, CU Boulder; Capps, US EPA)
- NH_3 using wet deposition (Paulot, Harvard)

Greenhouse gases:
- CH4 (Wecht, Turner, Harvard; Tan, Purdue)
- CO2 from GOSAT (Liu, Lee, JPL; Deng, UT; Zhu, Purdue; Shim, KEI)

Reactive gas-phase species
- CO from MOPITT (Jiang, UT) and BORTAS (Parrington, Edinburgh)
- CH3OH from TES (Wells, UMN)

Recent and current applications: Sensitivity analysis

Climate / chemistry:

- Radiative forcing (Henze, Lacey, CU Boulder; Bowman, JPL)
- Arctic O_3 and NO_y (Walker, UT) and Antartic nitrate (Lee, CU Boulder)
- CCN (Karydis, GIT)
- Adjoint of ISORROPIA aerosol thermodynamics (Capps, GIT/US EPA)

Satellite design and analysis

- GEOCAPE (Lee, JPL; Henze, CU Boulder; Wecht, Harvard)
- XCO2 sensitivity analysis (Liu, JPL)
- Column constraints (Turner, Harvard; Padmanabhan, Dalhousie)

Emissions mitigation strategies

- PM2.5 in Asia (Kharol, Dalhousie)
- O3 W126 vegetative exposure (Lapina, CU Boulder)
- PM2.5 and O3 health impacts (Lee, Dalhousie; Henze, CUB; Koo, MIT)
- N deposition (Henze, CU Boulder; Paulot, Harvard)

Research Highlights: Source attribution of $PM_{2.5}$ related mortality

What is the health-related benefit for reducing a ton of emissions, and how does this vary by location?

Recent and current applications

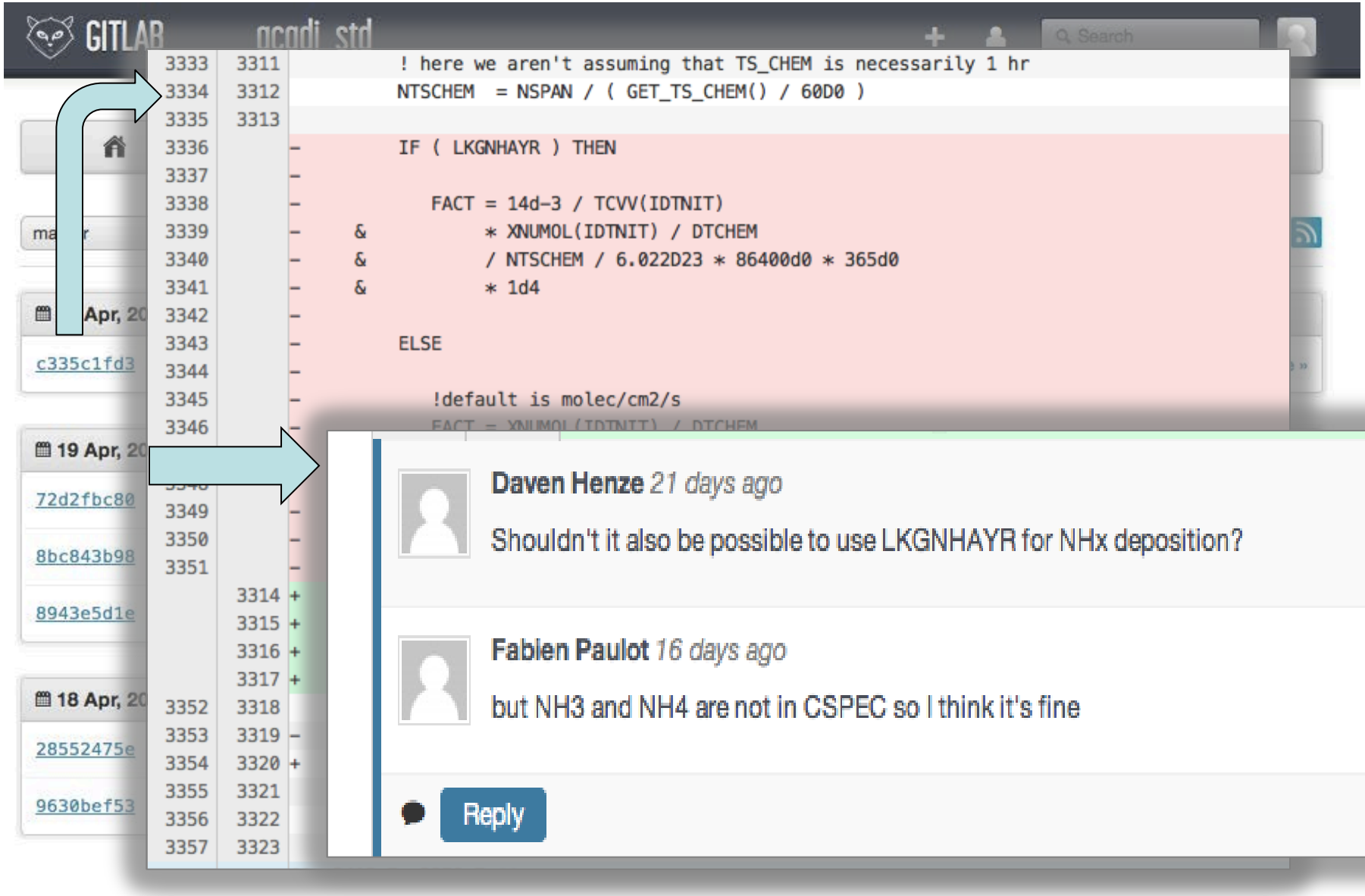
Theory
- Weak constraint 4D-Var (Keller, UT)
- Inverse Hessian (Bousserez, CU Boulder)

Other Data Assimilation activities
- 3D-Var assimilation of ozone from TES and MLS (Lee, Neu JPL)
- 3D-Var assimilation of CO2 from TES and GOSAT (Lee)
- EnKF CO2 flux estimates (Denning, CSU; Palmer, Univ Edinburgh)

Software Engineering
- pyEnsemble Manager (Perkins, UW)
- Multi-mission observation operator M2O2 (Lee, JPL)
- full-time adjoint model code support (Yanko Davila, CU Boulder)

New: code tracking with GitLab

http://adjoint.colorado.edu:8080



Future directions

- Additional adjoint model capabilities
  - Additional offline simulations (N_2O, …)
  - more sensitivity output: convection, …
  - more sophisticated optimization and DA analysis tools
  - further consolidation of observation operators (e.g., M2O2)
  - additional meteorology: MERRA, GCAP…
  - chemistry update when SMVGEAR is retired

- Keep an eye on grid-independent forward model development

- More connection/shared code with other assimilation methods (3D-Var and other sequential methods)

- Switch from quarterly to ~monthly WG telecons

- Adjoint Model Co-Scientist: assist with development, benchmarking, code maintenance and support

the end