GEOS-Chem Adjoint Model

IGC7
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with contributions from many more*

* >100 registered users at more than 23 institutions
An adjoint model...

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

Contributions to Arctic BC column concentrations (Junwei Xu et al., submitted)
Recent and current applications: Source attribution

**Climate**
- Aerosol Radiative forcing and Temperature (Lacey, CU Boulder)
- Ozone and CH\textsubscript{4} RF (Walker, JPL)
- CCN (Capps, Drexel)
- BC in the Arctic (Qi, UCLA; Xu, Dalhousie)

**Air quality**
- Background O\textsubscript{3} (JPL)
- PM\textsubscript{2.5} source attribution (Zhang, Peking)
- PM\textsubscript{2.5} health impacts (Dedoussi, MIT; Zhang, Tsinghua; Lee, Dalhousie; Lacey, CU Boulder; Koplitz, Harvard)
- O\textsubscript{3} health impacts (Henze, CU Boulder)
- NO\textsubscript{x} sensitivity to emissions (Bowman, JPL)
- GC adjoint vs HTAP multi-model source-receptor relationships (Davila, Henze, CU Boulder)

**Ecosystem impacts**
- O\textsubscript{3} vegetative exposure and crop loss (Lapina, CU Boulder)
- N deposition (Lee, CU Boulder; Zhao, Peking)

Blue = person presenting this topic at IGC8
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Inverse modeling / 4D-Var

Parameters

Optimization

$J \sim \sum \left[ \text{model} - \text{obs} \right]^2$

adjoint: $dJ/d\text{parameters}$

(a)

Jun 2004

CO emissions constrained using MOPITT (Jiang et al., 2015)
Recent and current applications:
4D-Var inverse modeling and data assimilation

**Aerosol and aerosol precursor emissions**
- Aerosol with MODIS, CALIPSO (Wang, UI; Lee, Dalhousie; Chen, CNRS)
- NH$_3$ with TES (Zhang, Peking)
- SO$_2$ and NO$_2$ with OMI (Wang, UI; Qu, CU Boulder; Cooper, Dalhousie)

**Greenhouse gases**
- CH$_4$ (Turner, Harvard/UCB; Bousserez, CU Boulder; Stanevich, UT; Tan, Purdue)
- CO$_2$ (Liu, Lee, Bowman, JPL; Deng, Jones, UT)
- N$_2$O (Wells, U. Minnesota)

**Reactive gas-phase species**
- CO from MOPITT (He, UT)
- Isoprene from OMI HCHO (Kaiser, Harvard)
- NMVOCs (Cao, Peking U.)
- CO, NO$_2$ and O$_3$ (Miyazaki, JAMSTEC/JPL; Zhang, UT)

**Method advancement and comparisons**
- Weak constraint 4D-Var (He, Stanevich, UT)
- UQ and model reduction (Bousserez, CU Boulder)
- Grid-scale vs optimal aggregation (Turner, Harvard; Wells, U Minn)
- 4D-Var and EnKF (Miyazaki, JAMSTEC/JPL; Liu, JPL)
- Mass balance vs 4D-Var (Qu, CU Boulder; Cooper, Dalhousie)
- Verification of top-down CO$_2$ flux constraints (Liu, JPL)

**Satellite design**
- GEO-CAPE (Bousserez; CU Boulder)
- CLARREO (Wang, UI)
Adjoint Application on PM$_{2.5}$ pollution over China - Data Assimilation and Source Attribution

The CNEMC Monitoring Sites

The GEOS-Chem Model and its Adjoint

Data Assimilation

Optimized Simulation

Optimized Model

Improved Source Attribution

Prior Simulation

Forward Model

GEOS-Chem adjoint major new directions: health impacts and integrated assessment

(e.g., Dedoussi, MIT; J. Lin and Q. Zhang, Peking/Tsinghua, Baublitz, Columbia; Henderson, EPA; Henze and Lacey, CUB)

**LEAP-IBC**: rapid emission and scenario assessment toolkit for UNEP

Mitigation

$\Delta$Emissions

Response

$\Delta O_3$

$\Delta PM_{2.5}$

$\Delta CH_4$

Benefits

- health
- climate
- crop yield

e.g. Lacey et al., PNAS, 2017

Impacts of atm transport vs trade on $PM_{2.5}$ mortality in China

Zhao et al., ACPD, 2017

Koplitz et al., ERL, 2016

Smoke Exposure by Contributing Province

2006

2006

2015

Singapore

Indonesia

Malaysia

$\Delta$ atmosperic transport and trade

$\Delta$ deaths

$10^3$ deaths

-55

-27

0

27

55

Population-weighted Exposure (µg m$^{-2}$)
Adjoint model: current and new features

Standardized code: v35l, maintained / distributed via GIT
Code base : v8-02-01 with relevant fixes / updates up to v10

Meteorology: GEOS-4, GEOS-5, GEOS-FP, MERRA2
Simulations : full chem; gly-chem, offline CO, O\textsubscript{x}, CO\textsubscript{2}, CH\textsubscript{4}, BC, Dust, N\textsubscript{2}O
Resolution : 4x5, 2x2.5, 0.5 x 0.667, 0.25 x 0.3125

Processes: all main forward model process excluding:
- non-local pbl mixing scheme
- aerosol microphysics
- feedback of aerosols on photolysis or heterogeneous chemistry
- UCX (in progress), HEMCO

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

Model update cycle slowed while waiting for GCHP / FlexChem...
Find out more…

Visit us at:

- manuals, instructions, publications
- code features
- current version overviews
- benchmarks

http://adjoint.colorado.edu:8080 (code GitLab)
- code distribution

https://trello.com/b/GTfHT38L/geos-chem-adjoint (pipeline)
- code development cycle / pipeline

GEOS-Chem adjoint code support:
- yanko.davila@colorado.edu

GEOS-Chem adjoint model clinic:
- Today! 5:15 – 6:00 pm, Maxwell-Dworkin 119