Analysis of GMI simulations with a focus on ozone, using MLS, TES, and in situ data

Jennifer A. Logan
Inna Megretskaia
School of Engineering and Applied Science
Harvard University

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GMI Combo model

- Driven by the GEOS-4, GEOS-5.1 and MERRA assimilated meteorological fields

Convection schemes

- GEOS-4 – Zhang and McFarland (1995) (deep) and Hack et al. (1994) (shallow)
- GEOS-5 – a version of the Relaxed Arakawa Schubert scheme (Moorthi and Suarez, 1992) (plus many other improvements in GEOS-5)
Model runs analyzed

GEOS-5

- G5Aura - driven by GEOS-5.1 (with SYNOZ bug, no cloud optical depth)
- MERRA (without SYNOZ bug), 2004-2011
  - Various buggy versions checked out, “good” version available in late June, 2011
- Different lightning NOx (LNOx) emissions in MERRA and GEOS-5.1

GEOS-4

- Old run, aura4.light2 (local LNOx, with SYNOZ bug)
- New run, aura4.synoz (local LNOx, w/out SYNOZ bug)
- Different LNOx emissions – more on this later

Emissions were supposed to be identical in the pairs of runs, but there were small differences in e.g., CO
Outline

1. Which met. fields match the observations best, GEOS-4 vs. GEOS-5?

2. How different are the runs with the SYNOZ bug fixed?

3. How well does the new MERRA run simulate interannual variability in ozone? Preliminary analysis
   - Model evaluation using TES, MLS, and in-situ data
   - New version of MLS (v3.3) shown here

4. Why is model ozone different using GEOS-4 and GEOS-5 met. fields?
   - Analysis of dynamics, ozone budget

5. The lightning issue (nightmare?)

First discuss extra-topics, then tropics.
OLD runs: Aura4.LS2 and GEOS-5 vs. sondes, 32-75 N

- GEOS-4 > GEOS-5 in extratropics by a few ppb
- GEOS-5 agrees better with sonde and MOZAIC in mid-latitudes
- GEOS-5 matches the amplitude of annual cycle better
Ozone difference at 500 hPa in 2006, MERRA – GEOS-5

- Differences in ozone are very small in the extratropics
- Differences increase in July-Dec. in the tropics
- MERRA usually lower
Ozone difference at 500 hPa in 2006, Aura4.Synoz – Aura4.LS2

- Differences in ozone are larger in the extratropics than between the GEOS-5 runs, and the corrected run is sometimes higher.

The scale is ±14 ppb
Stratospheric profiles, GEOS-4: corrected run in red run with SYNOZ bug in blue

- Ozone is lower without the bug and
- often (not always) agrees better with data – no double counting
GEOS-5: MERRA in red, run with SYNOZ bug in blue

- Ozone is lower without the bug
- Often agrees better with data, especially in the lower tropical stratosphere
Does the MERRA run match observed IAV in extratropical ozone?

- Which data to use to evaluate the model?
- Most profile data available for Europe – analysis in paper to be submitted soon.
- New version of MLS data available since late 2010, V3.3
- Analysis of tropical data at 215 hPa in draft paper by Livesey, Logan et al., to be submitted this year
Trop. ozone data over Europe agree after ~1998

Difference between pairs of sites at ~700 hPa

- Sonde – alpine site
- MOZAIC – alpine site
- Alpine site – alpine site
Monthly anomalies in ozone
700 hPa, 1998-2008

Decreases in ozone in summer over Central Europe, 1998-2008

Aug. 2003 – heat wave
July, 2006 – heat wave
Trends in NOx emissions

These trends are not in the MERRA run, which has constant emissions for 2000 from fossil fuel use.
MERRA looks promising for simulating IAV in summertime ozone

MERRA vs. sonde and MOZAIC time series over Europe

MERRA vs. alpine site time series

More analysis needed – seasonal breakdown, anomalies, correlations with lower strat. etc
MLS V3.3 data agrees with sondes down to 146 hPa – great data set for analyzing models

MLS, Payerne w AK, w/out AK  
3 sonde stations - coherent
MLS data show that MERRA run follows observed interannual variability in the stratosphere.
MLS and MERRA at 55-65 N and 25-35 N
(zonal means, lower stratosphere)

55-65 N

25-35 N
MLS and MERRA at 5 N – 5S, 215-7 hPa

- QBO signal somewhat late
- High bias in lower strat.

Upward transport in lower strat. too slow, seen in CO tape-recorder analysis with GEOS-5
TROPICS

- Start with analysis of OLD runs – update of results presented at last GMI meeting, using new MLS version, MOZAIC, and analysis of rates and tendencies

- This analysis has not been repeated on the new runs because the lightning NOx changed so much in the GEOS-4 runs.

- Discussion point: I planned to write up the results presented here, and I will explain why the new runs complicate the issue.

- IAV in MERRA run in the tropics
TES data at 500 hPa show GEOS-4 performs better than GEOS-5.

GEOS-5 ozone > GEOS-4 in much of the tropics.
MLS (V3.3) data show GEOS-4 performs better than GEOS-5

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<th>Jan.</th>
<th>MLS</th>
<th>GEOS-4</th>
<th>G4-MLS</th>
<th>GEOS-5</th>
<th>G5-MLS</th>
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GEOS-5 ozone > GEOS-4 in much of the tropics. GEOS-4 has regions of low biases compared to MLS, and GEOS-5 has regions of high biases.
Sonde data show **GEOS-4** usually performs better in upper troposphere in the tropics.

GEOS-5 > GEOS-4 in UT (except Kuala Lumpur)

Plot shows model profiles matched to dates of sonde data, for 2005 and 2006.
GEOS-4 compares better with MOZAIC data on daily flights from Europe to Namibia in 2006.
TES ozone, 500 hPa, Jan-Dec in each box.

Remarkable fidelity in matching month-month variability of ozone

TES (minus 5 ppb)
GEOS-4
GEOS-5

GEOS-5 > GEOS-4 mid-year, mid-Pacific
GEOS-5 ≈ GEOS-4, maritime continent
MLS ozone at 215 hPa: Jan-Dec in each box.

GEOS-5 > GEOS-4 in much of the tropics
GEOS-5 ≈ GEOS-4 in maritime continent
GEOS-4 is usually closer to the MLS observations
Case study: Ozone in July

GEOS-4
AURA4,LS2 July 2006 O3(ppb) 200 hPa

GEOS-5
G5AURA July 2006 O3(ppb) 200 hPa

G5-G4
G5-G4 July 2006 O3(ppb) 200 hPa

200 hPa

GEOS-4
AURA4,LS2 July 2006 O3(ppb) 500 hPa

GEOS-5
G5AURA July 2006 O3(ppb) 500 hPa

G5-G4
G5-G4 July 2006 O3(ppb) 500 hPa

500 hPa
Vertical transport of air, July 2006

Convective mass flux (g/m²/sec)

GEOS-4

GEOS-5

Vertical mass flux: convection plus advection

Subsidence in southern sub-tropics

Red = upward flux, blue = subsidence
Lightning NOx (LNOx) emissions (kg/sec/m)

LNOx emissions have a similar vertical profile even though the mass fluxes peak at a lower altitude in GEOS-5.

GMI uses the air mass flux in their LNOx scheme

The top of the LNOx profile is determined by the top level with detrainment – an extrema
Lightning NOx in the tropics in 2006

TROPICS

LNOx in GEOS-5 is 10-20% lower than in GEOS-4 in Jan-Aug. 2006.

LNOx in 2006 is 10% less in GEOS-5 (ann. mean)

LNOx in 2005 is about the same in GEOS-4 and GEOS-5 (ann. mean)
Ozone, winds, and air mass flux, July 2006

GEOS-4

200 hPa

GEOS-5

500 hPa

White lines: air mass flux, solid=up, dotted=down; arrows are winds
Ozone (ppb)

- GEOS-4
- GEOS-5
- G5-G4

Ozone tendencies (ppb/day)

- GEOS-4
- GEOS-5
- G5-G4

NOx emissions are lower in GEOS-5, but NOx is higher

HO2 (ppt)

H2O is lower in GEOS-5

Regions analyzed with rates, tendencies etc
Water vapor at 300 hPa in July 2006

H2O (kg/kg*1000), 300 mbar, July 2006

Not all regions of convection have more H2O in GEOS-4

More H2O in GEOS-4 in SPCZ
Equatorial West Pacific: species profiles

**GEOS-4** | **GEOS-5**

Equatorial Western Pacific (1–11S, 148.75–178.75W), July 2006

- **O3 (ppb)**
- **NC (ppt)**
- **HO2 (ppt)**
- **MO2 (ppt)**
- **OH (ppm)**
- **O3 tend (ppb/day)**

Air mass flux

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**UT:** net production, (P-L) is larger in GEOS-5, as more NO “wins” over less HO₂

**LT:** net loss, (P-L) is larger (more negative) in GEOS-5, as more H₂O and more HOₓ
Rates for Production and Loss of ozone (odd-oxygen)

**GEOS-4**  
**GEOS-5**

Equatorial Western Pacific (1–11S, 148.75–178.75W), July 2006
O3 Production and Loss (ppb/day)

\[ \text{HO}_2 + \text{NO} \rightarrow \text{NO}_2 + \text{OH} \]
A digression about LNOx in GMI runs

Old runs: tropical LNOx in GEOS-5/GEOS-4 = 0.91
New runs: = 1.13

LNOx changed because the years used to scale to the satellite climatology changed – see Dale’s talk.

The ratio of LNOX in GEOS-4 to GEOS-5 (MERRA) has changed in 2006 at least.

IAV in LNOx in the tropics has changed.

Potential solution for my paper: Compare MERRA run to old Aura4.LS2 run? ~same tropical LNOx. (I am assuming SYNOZ bug has little effect on tropical trop. ozone)

I want to compare two runs with similar LNOx.
IAV in tropical flash rates

Does IAV in GMI runs have more variability than this?

LIS Tropical (23°S–N) Flash Rate

Lee Murray, Harvard
Back to MERRA run: 5 years vs. tropical sondes

Same problems as GEOS-5: too high in UT except when convection, too high over central S. Pacific in mid-year, underestimates S. tropical Atlantic in Oct-Dec. But MERRA gets a lot of things correct.
IAV in surface CO – selected (best) sites
Using TES and MLS to evaluate IAV in MERRA, 2004-2010

What is causing the upward trend in UT ozone in the model? LNOx?

More analysis to be done

TES comparison uses a uniform tropical prior
IAV in Indonesia
Driven mainly by IAV in dynamics

IAV in Middle East

Upward trend in NOx emissions?
Summary

- MERRA run looks very promising for hindcast simulations. More analysis to do.
- However, GEOS-5/MERRA vertical mixing leads to problems with tropical ozone.
- The UT is not ventilated rapidly enough, leading to excessive production of ozone in regions of subsidence.