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

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Model

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

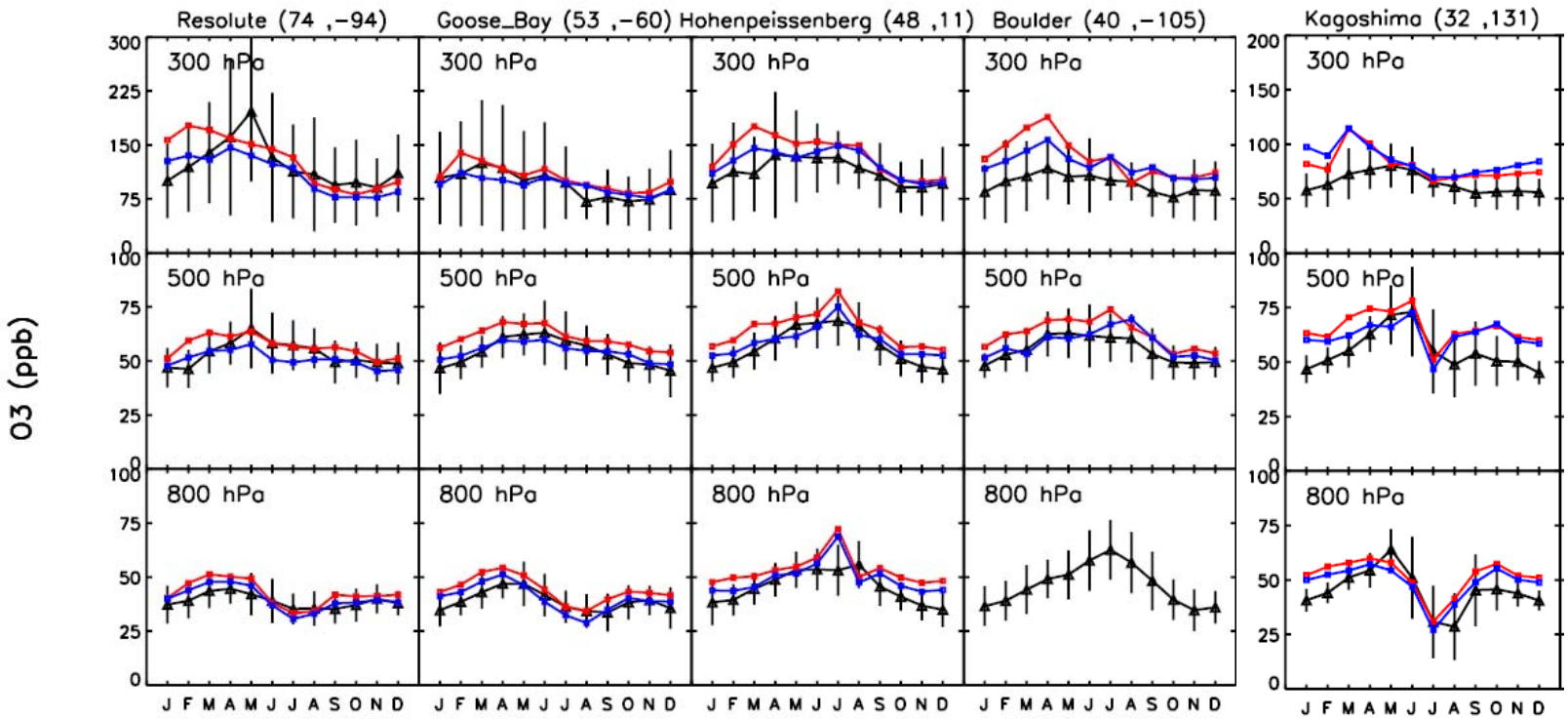
4. Why is model ozone different using GEOS-4 and GEOS-5 met. fields?

   - Analysis of dynamics, ozone budget

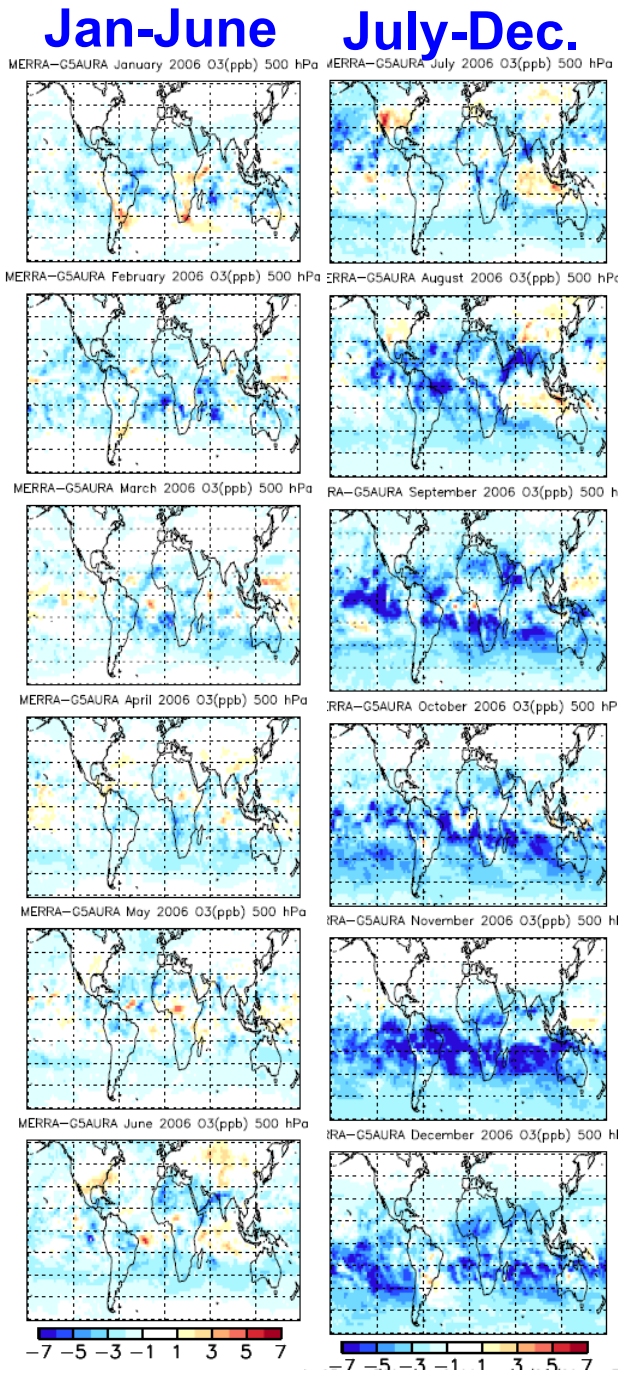
5. The lightning issue (nightmare?)

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

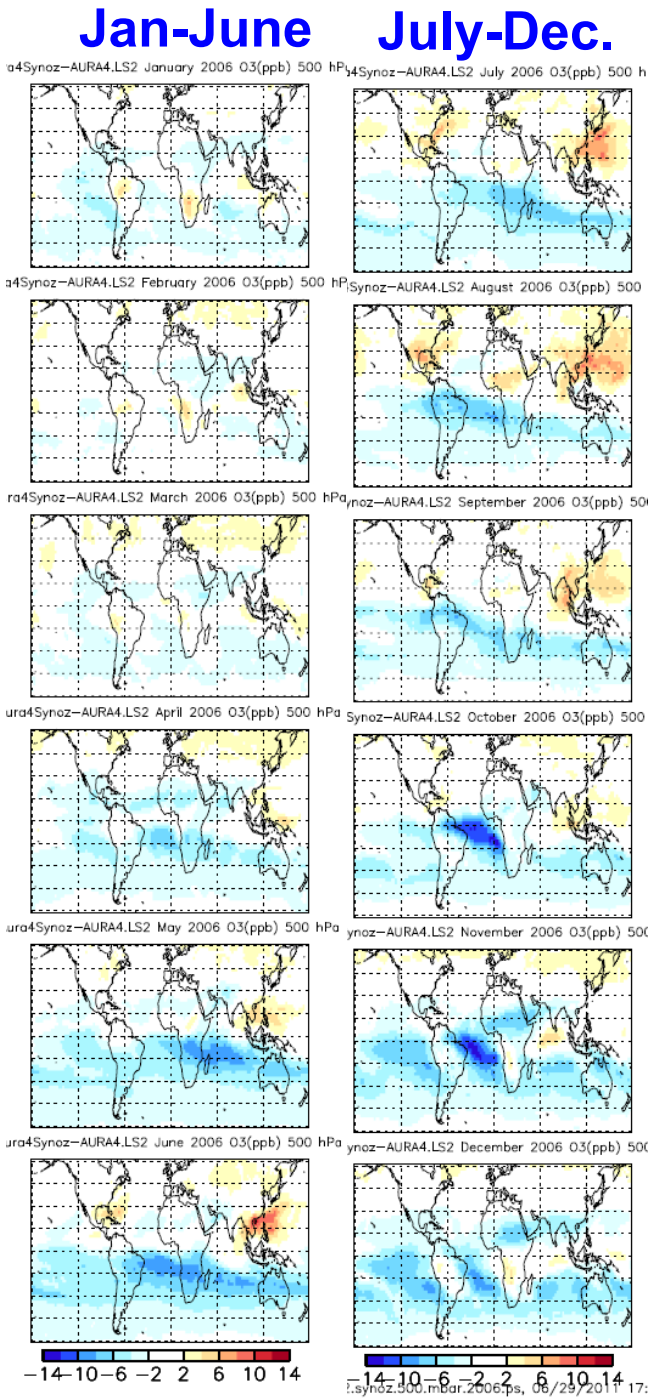


Ozone difference at 500 hPa in 2006, MERRA – GEOS-5

- **Differences in ozone are very small in the extratropics**
- **Differences increase in July-Dec. in the tropics**
- **MERRA usually lower**

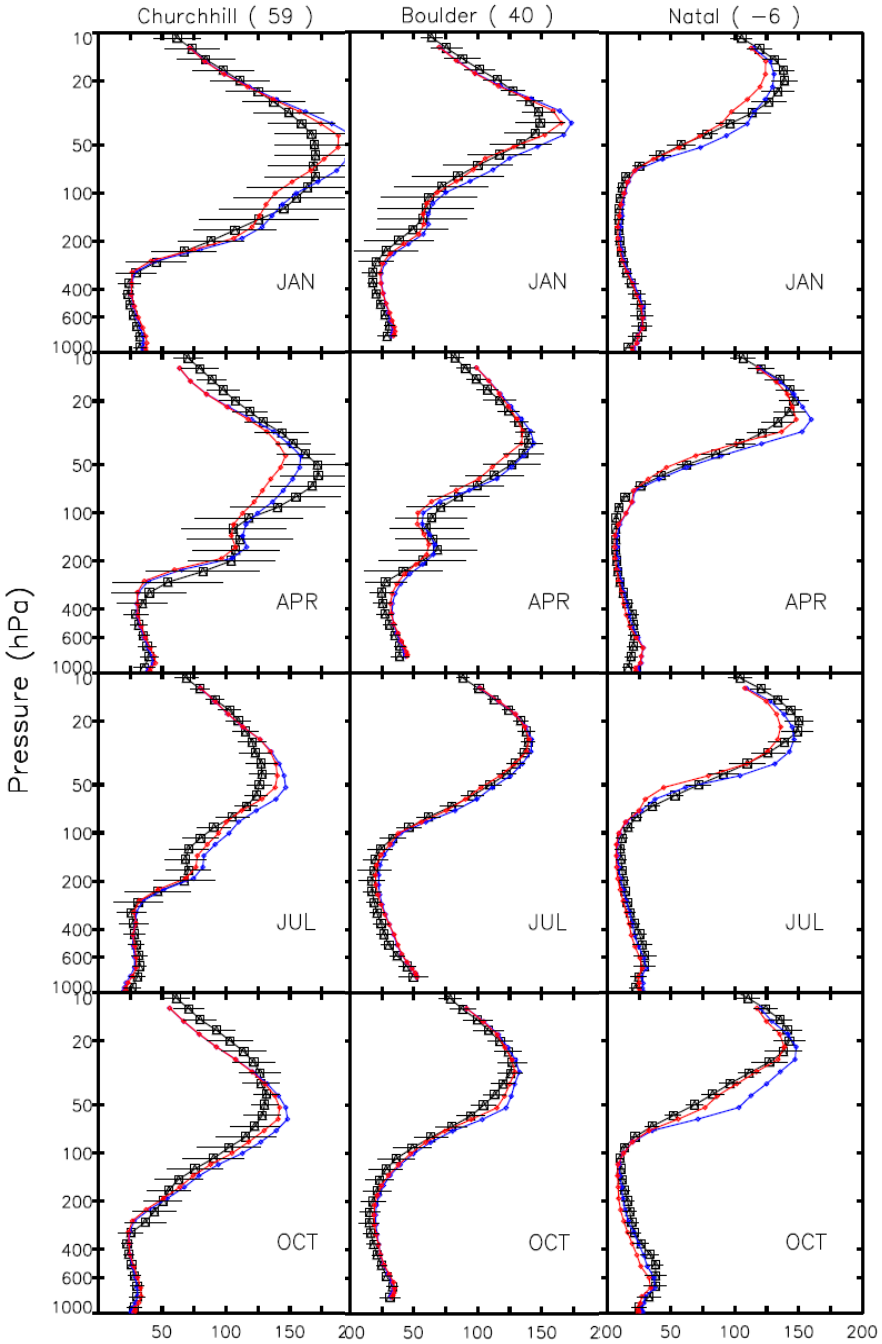
The scale is ±7 ppb

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 sometime higher.**

The scale is ±14 ppb

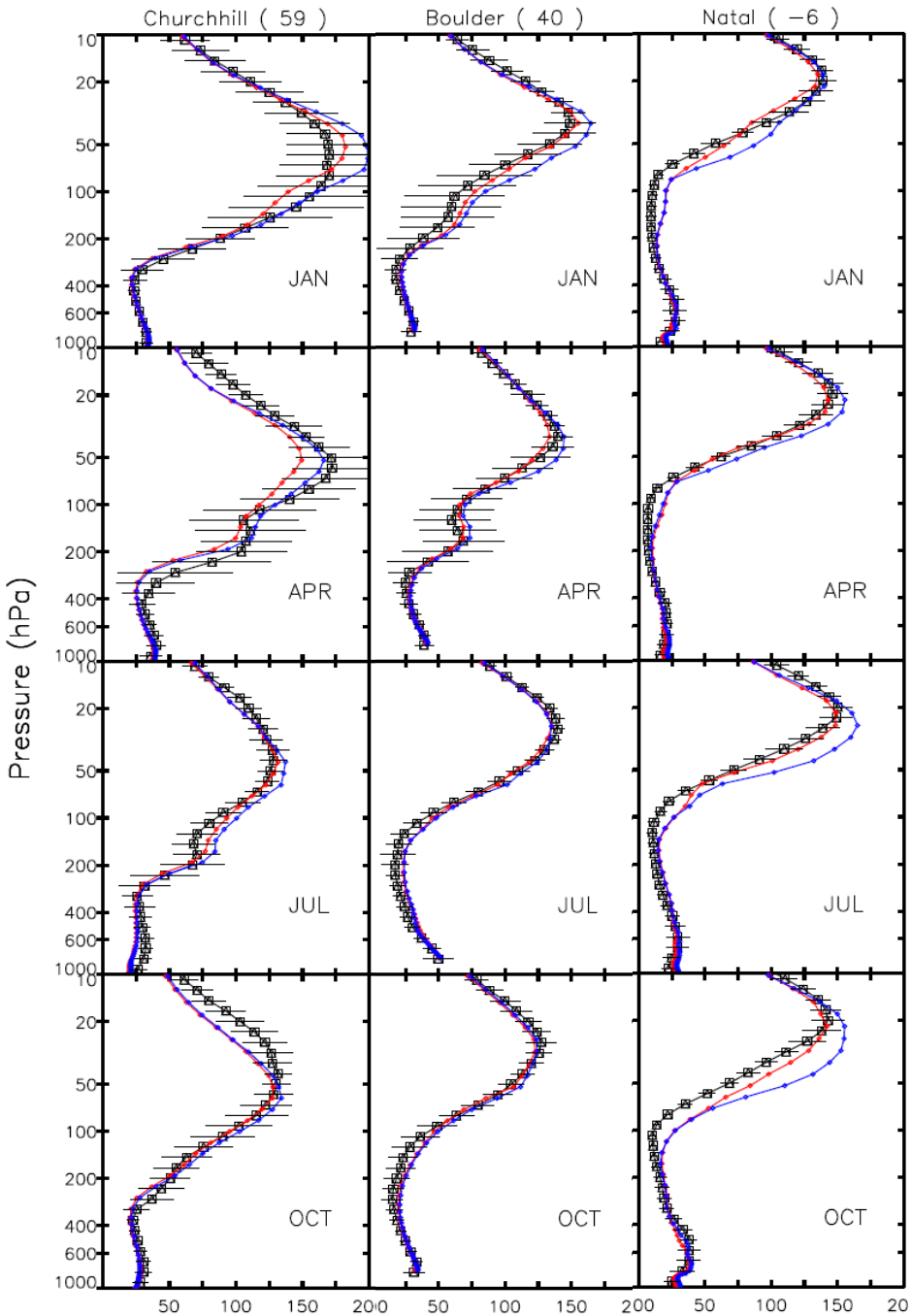


Stratospheric profiles, GEOS-4:

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

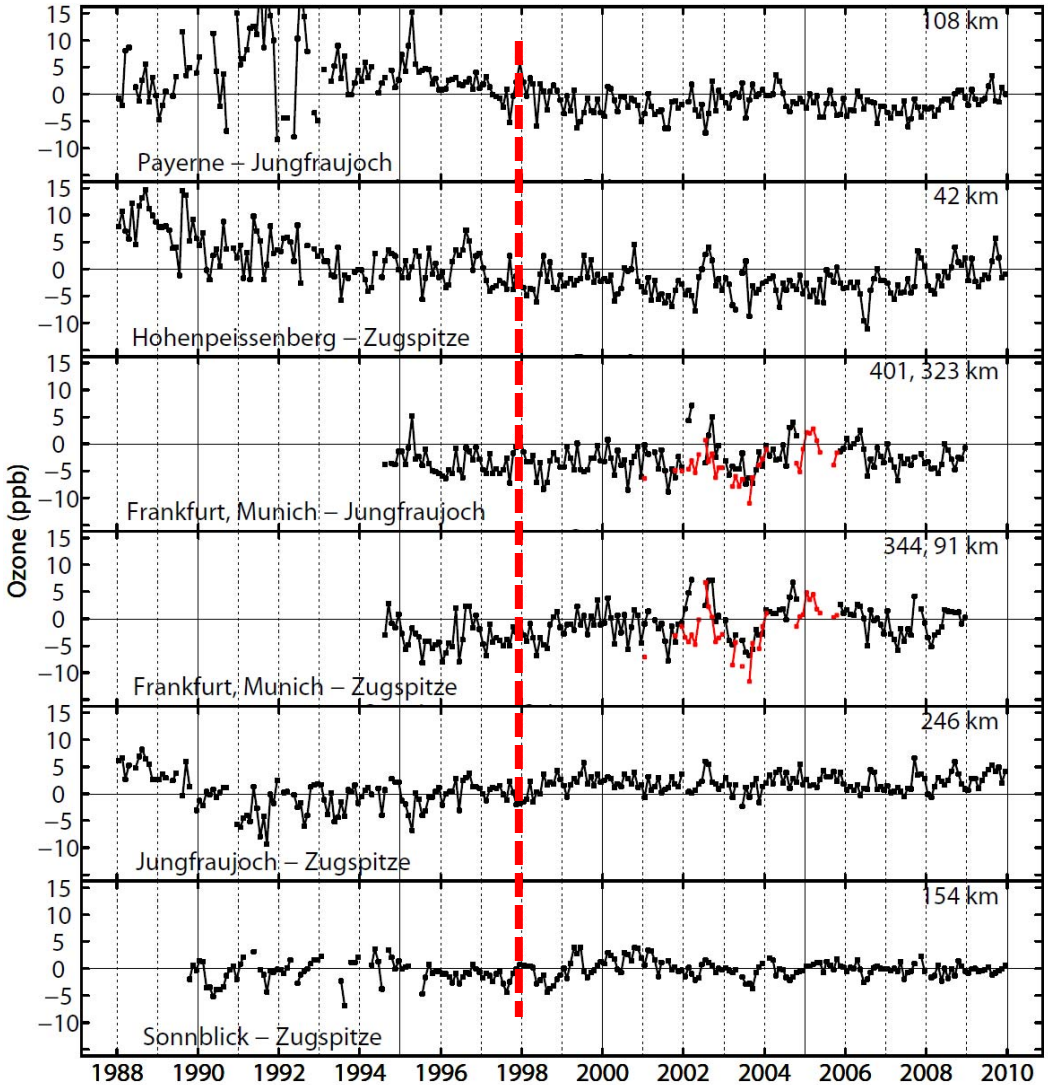
- Ozone is lower without the bug
- Often agrees better with data, especially in the lower tropical stratosphere

Does the MERRA run match observed IAV in extra-tropical 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



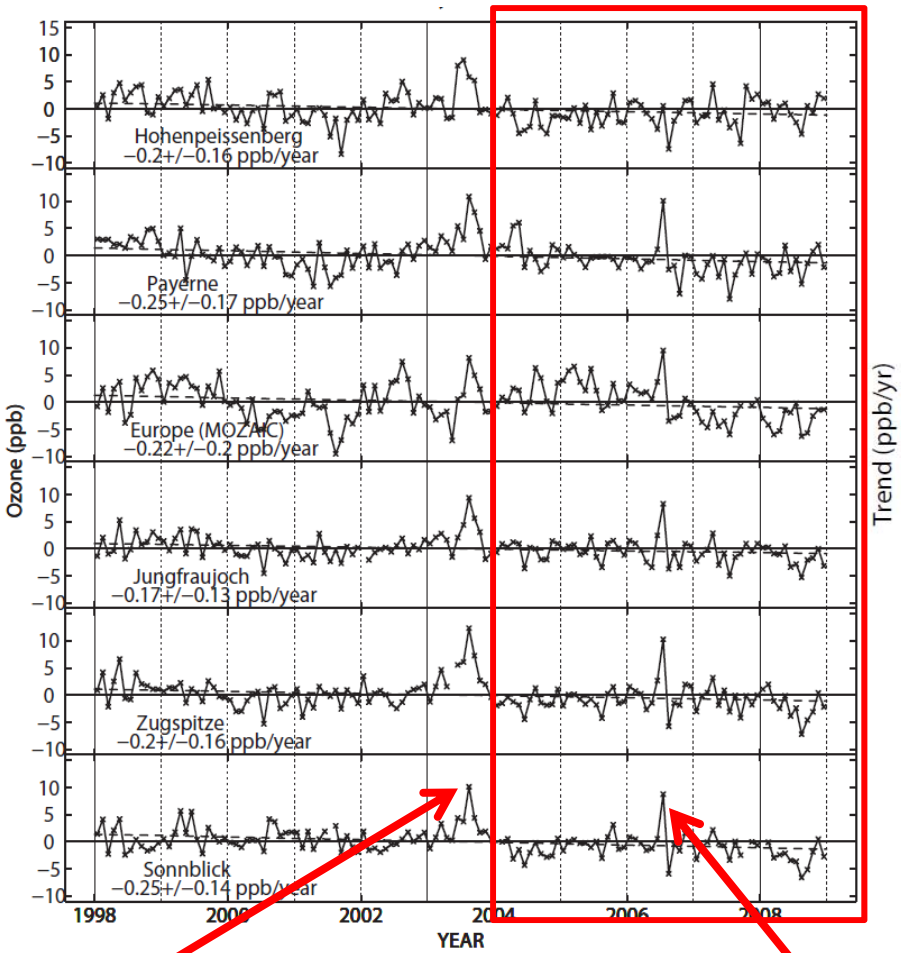
Sonde – alpine site

MOZAIC – alpine site

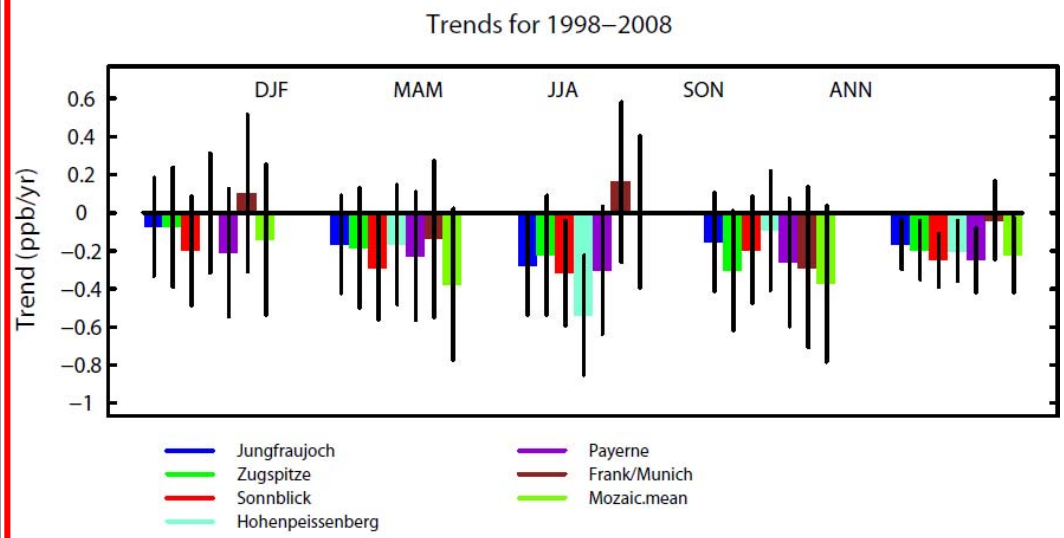
Alpine site – alpine site

Monthly anomalies in ozone 700 hPa, 1998-2008

MERRA run → 2010



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

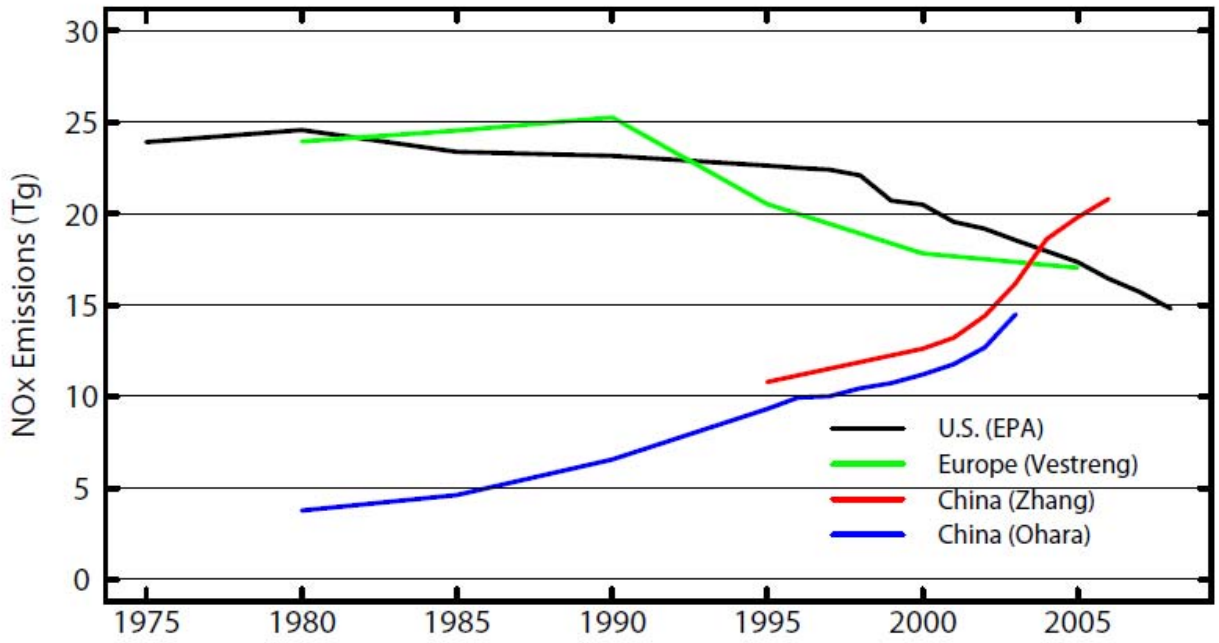


Aug. 2003 – heat wave

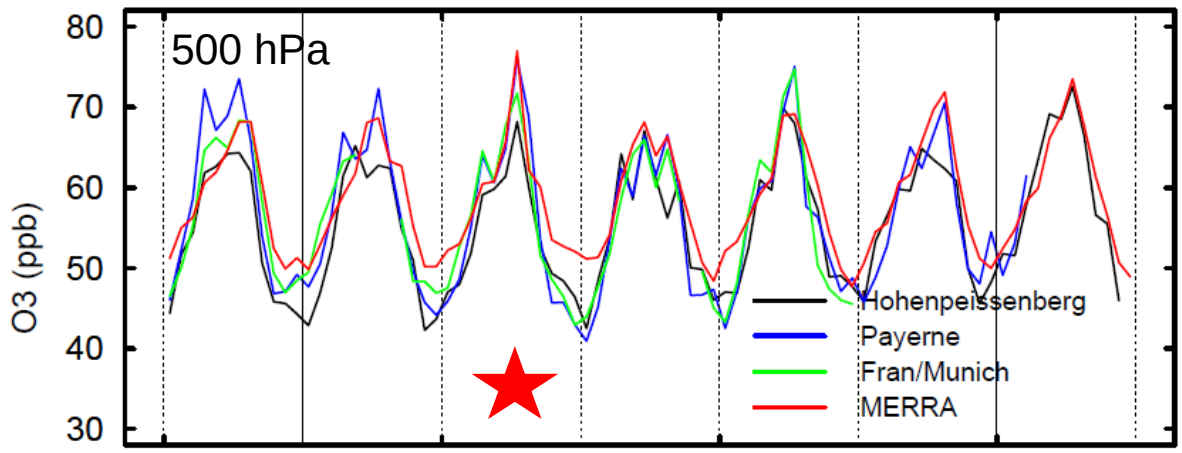
July, 2006 – heat wave

Trends in NOx emissions

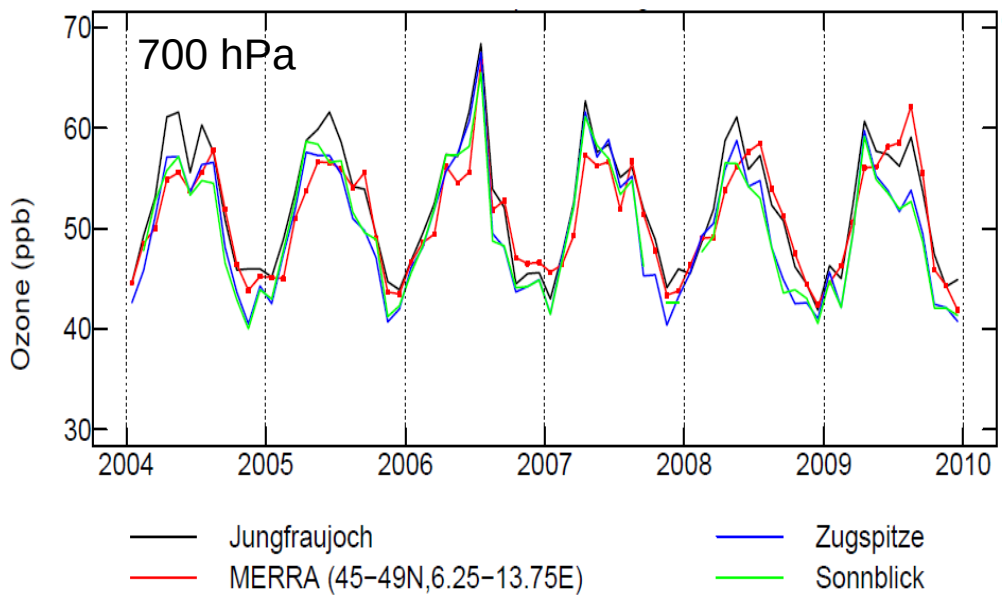
These trends are not in the MERRA run, which has constant emissions for 2000 from fossil fuel use



MERRA looks promising for simulating IAV in summertime ozone



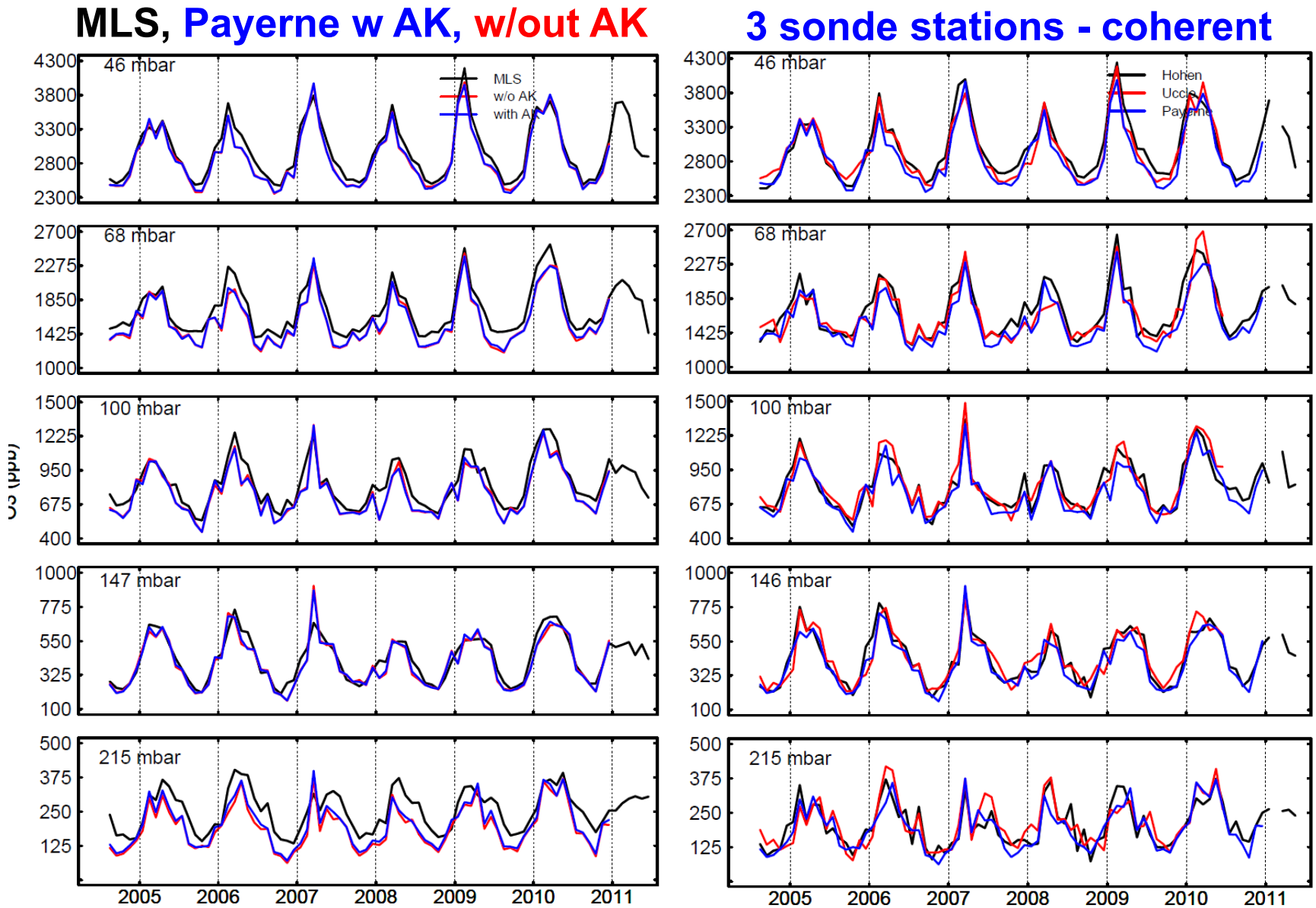
MERRA vs. sonde and MOZAIC time series over Europe



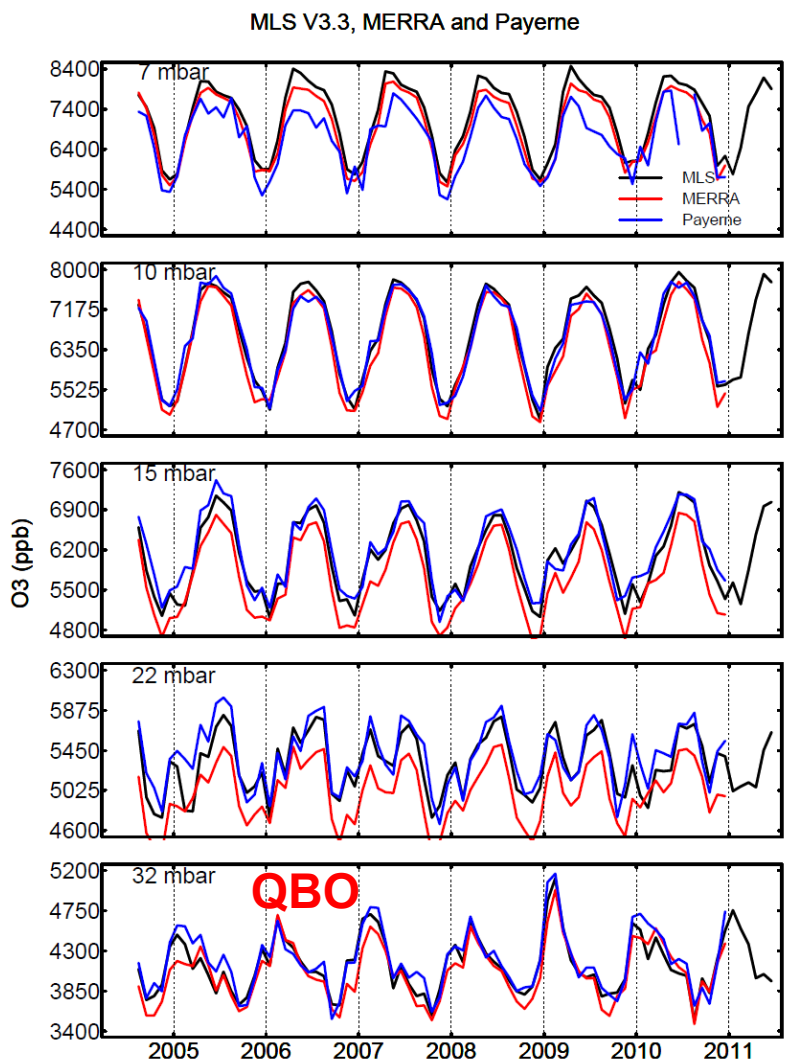
MERRA vs. alpine site time series

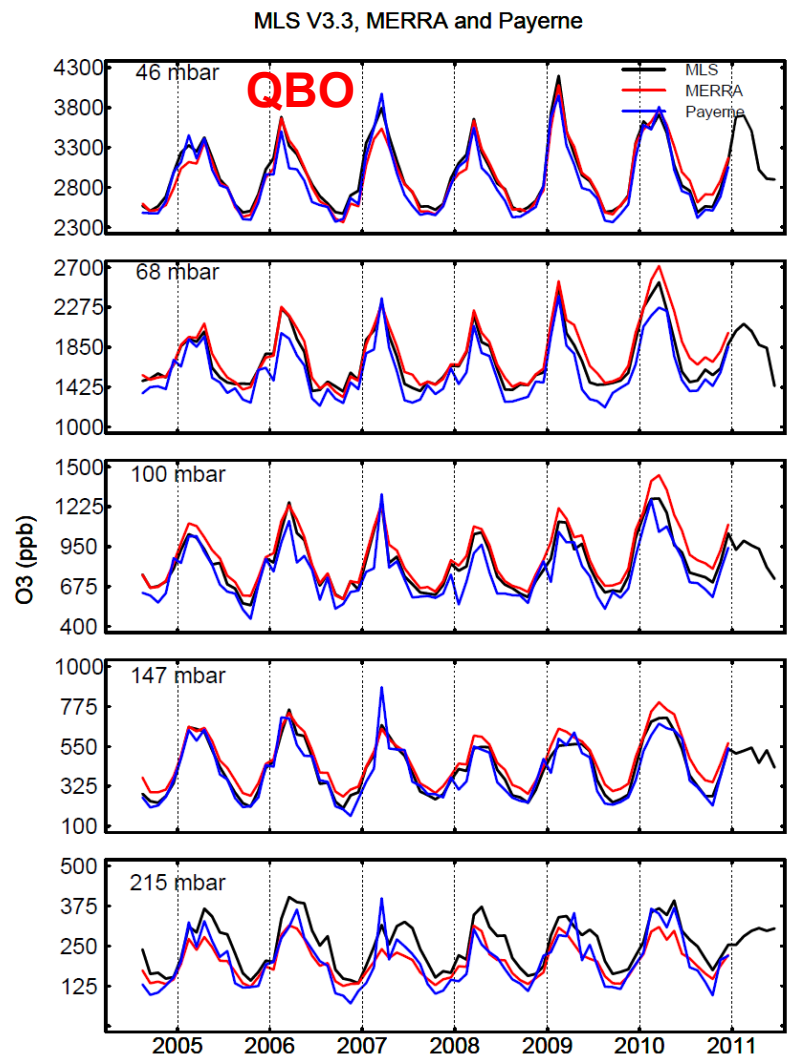
More analysis needed – seasonal breakdown, anomalies, correlations with lower strat. etc

MLS V3.3 data agrees with sondes down to 146 hPa – great data set for analyzing models



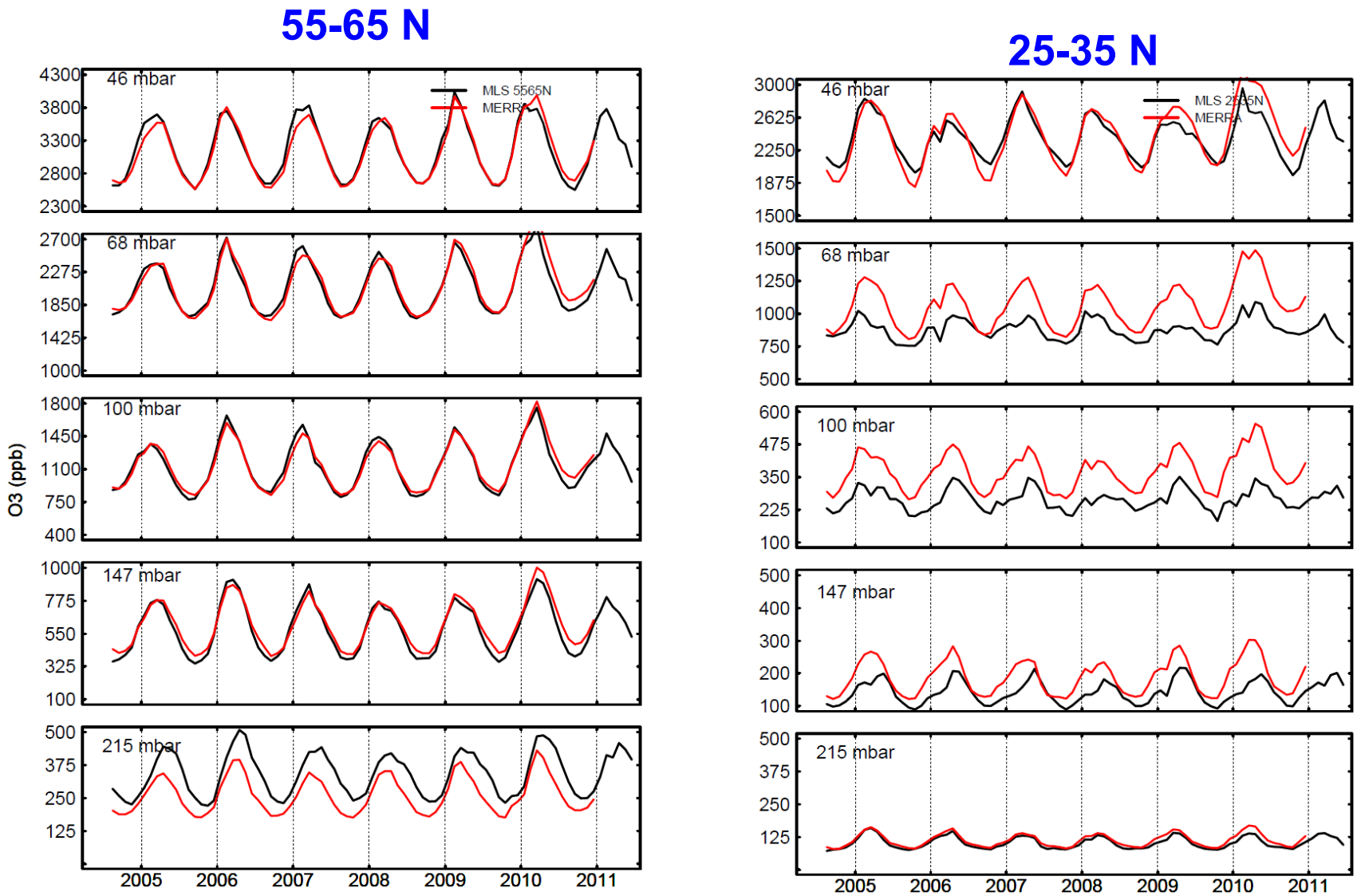
MLS data show that MERRA run follows observed interannual variability in the stratosphere





MLS and MERRA at 55-65 N and 25-35 N

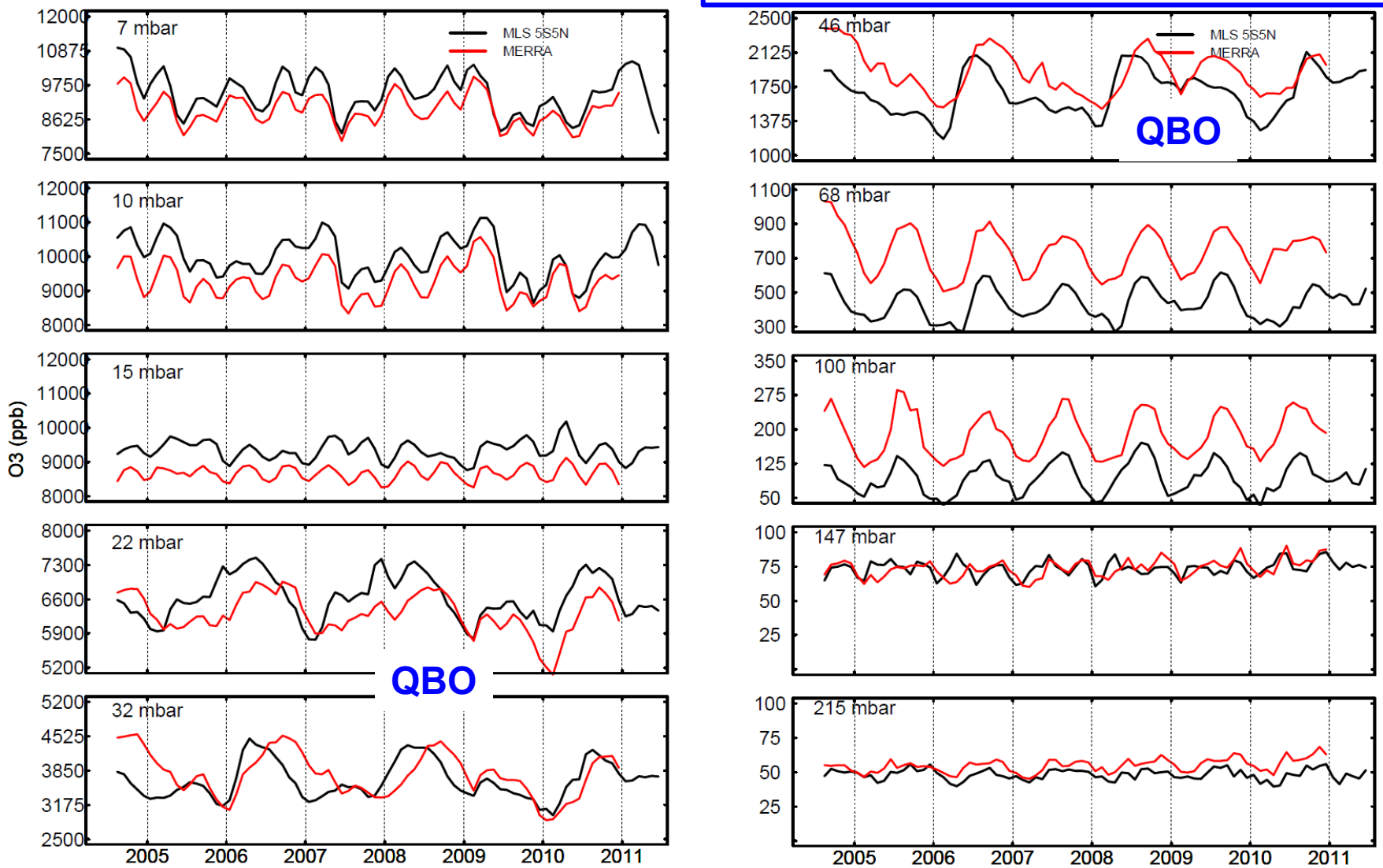
(zonal means, lower stratosphere)



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

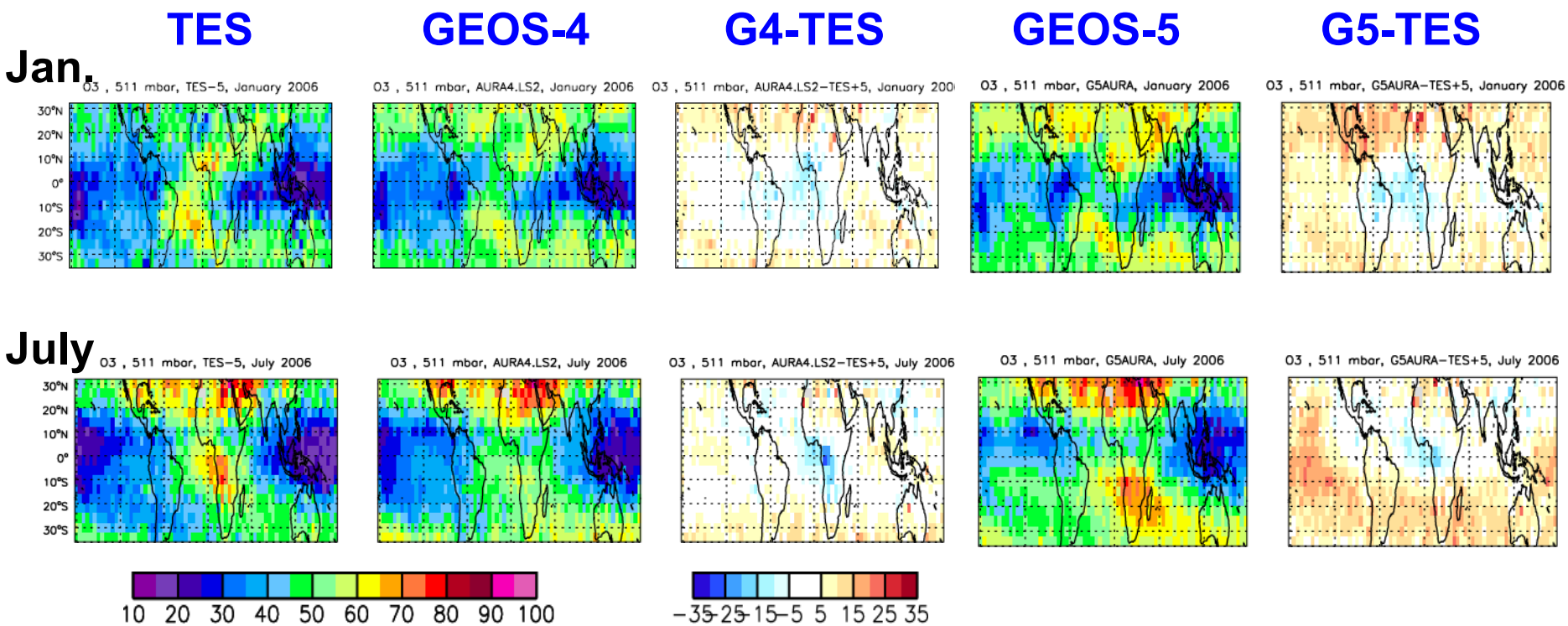
- Start with analysis of OLD runs – update of results presented at last GMI meeting, using new MLS version, MOZAIC, and analysis of rates and tendencies

- 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.

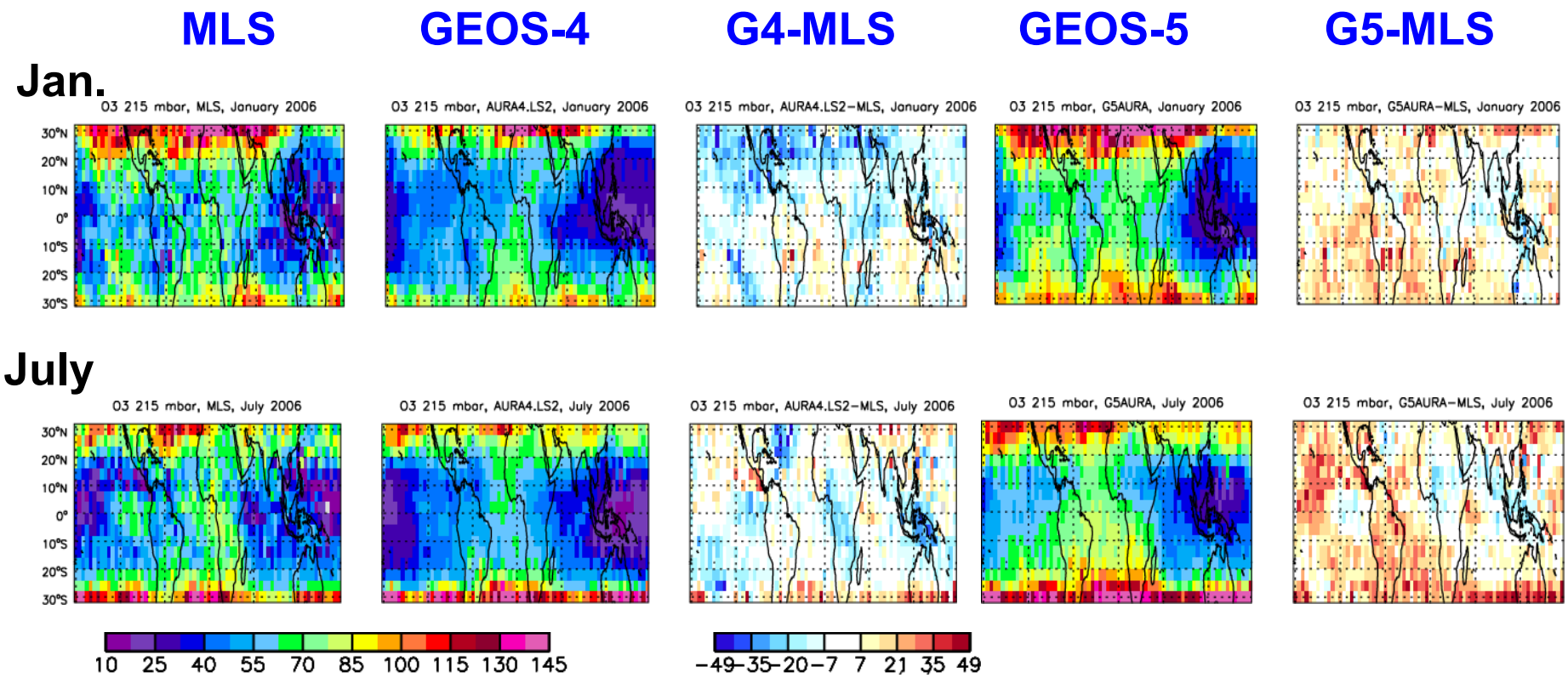
- IAV in MERRA run in the tropics

TES data at 500 hPa show GEOS-4 performs better than GEOS-5



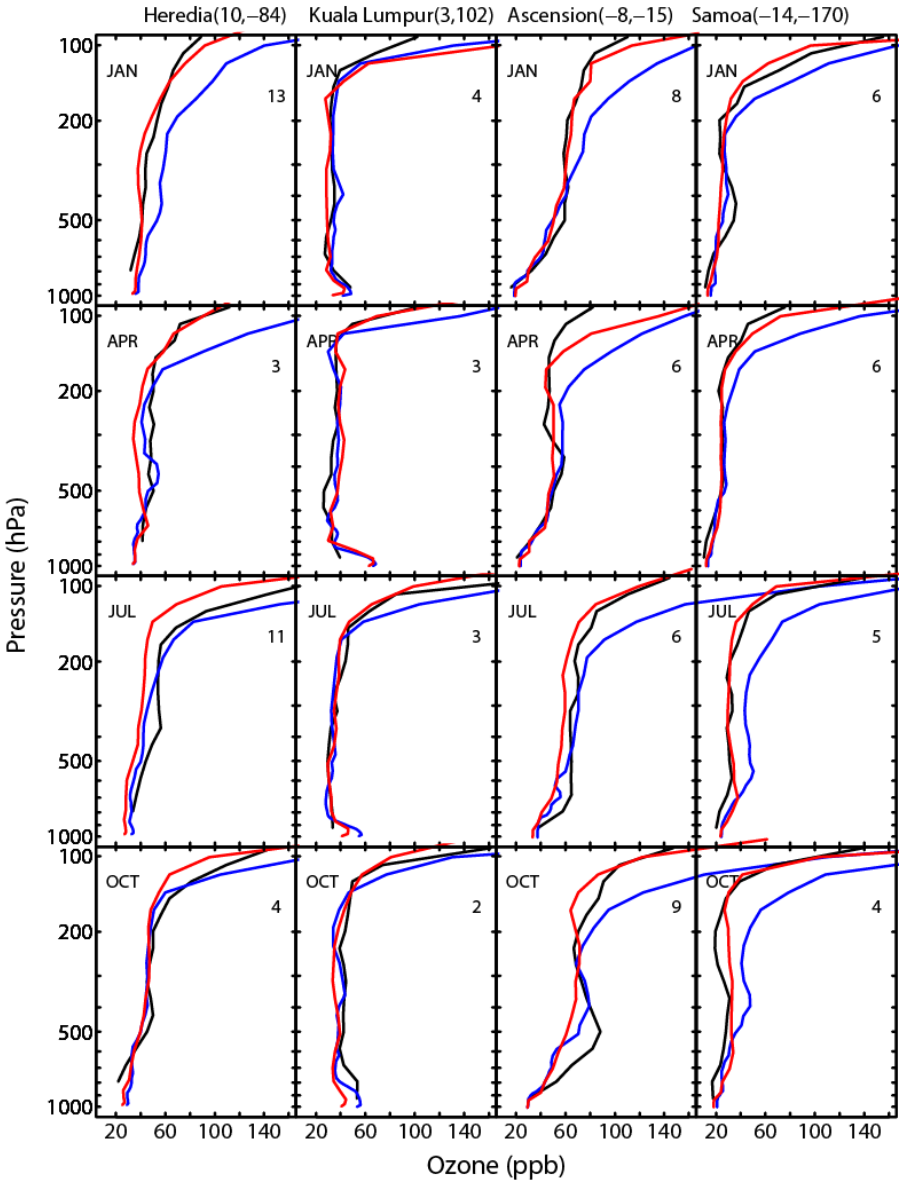
GEOS-5 ozone > GEOS-4 in much of the tropics

MLS (V3.3) data show GEOS-4 performs better than GEOS-5



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



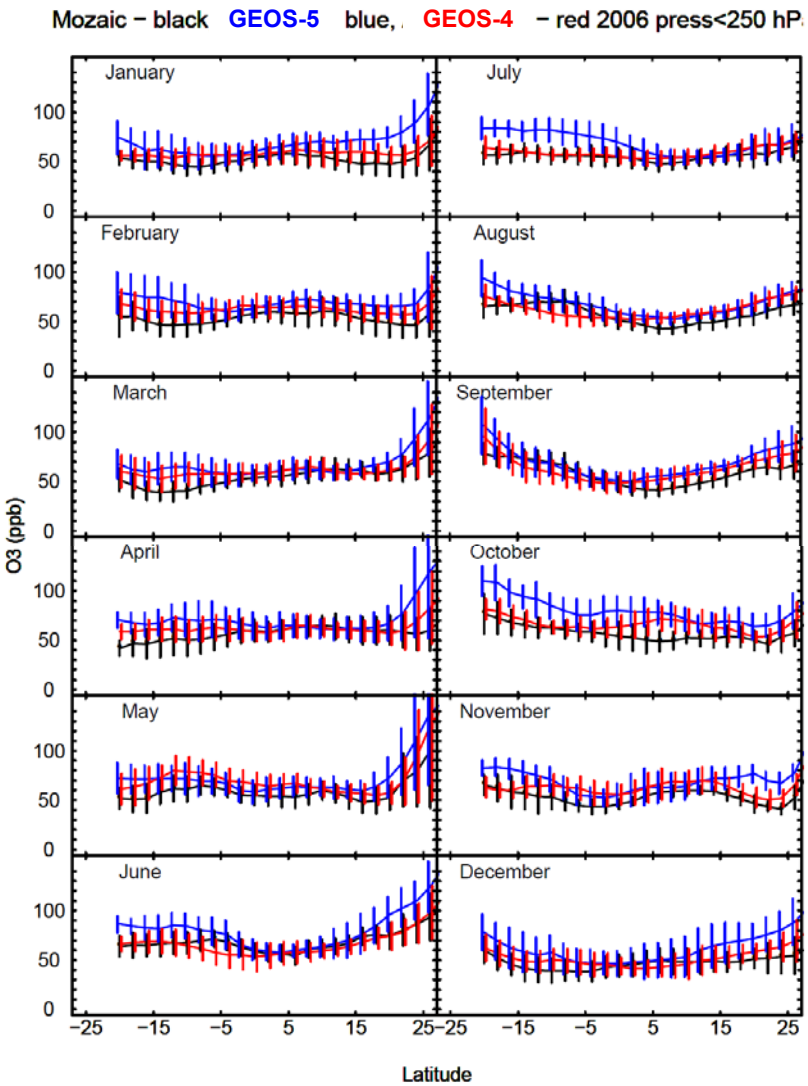
GEOS-5 > GEOS-4 in UT (except Kuala Lumpur)

Plot shows model profiles matched to dates of sonde data, for 2005 and 2006.

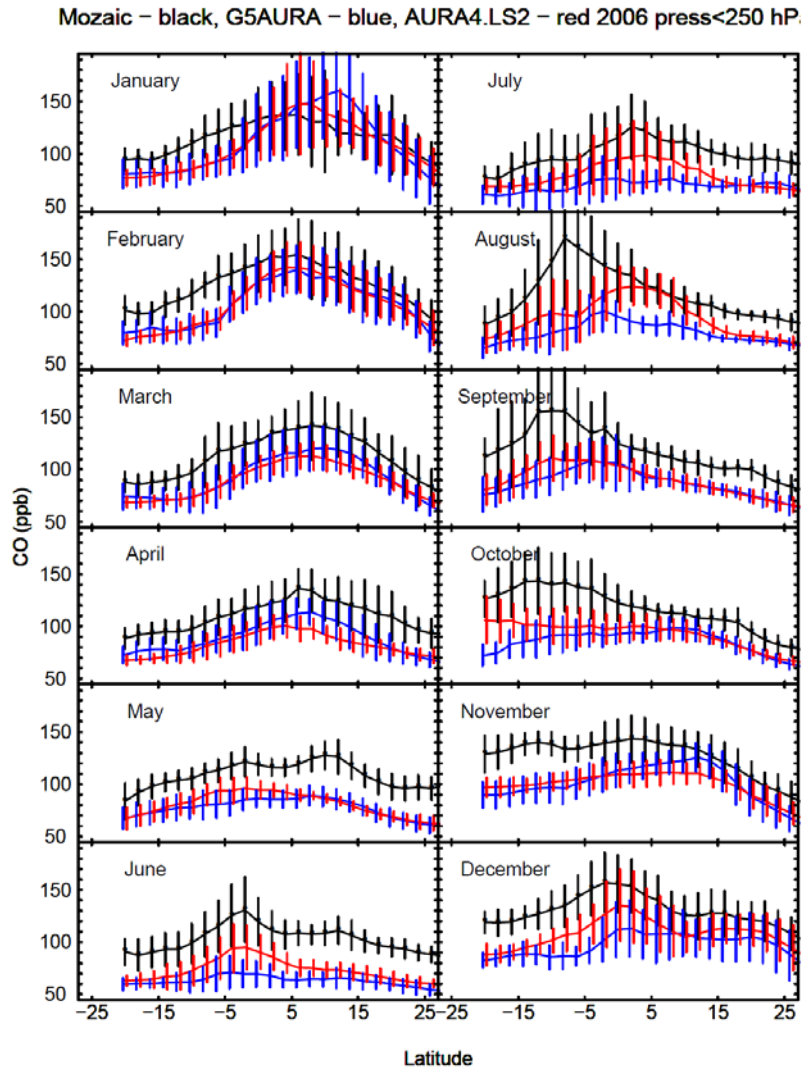
----- sonde
----- GEOS-4
----- GEOS-5

GEOS-4 compares better with MOZAIC data on daily flights from Europe to Namibia in 2006

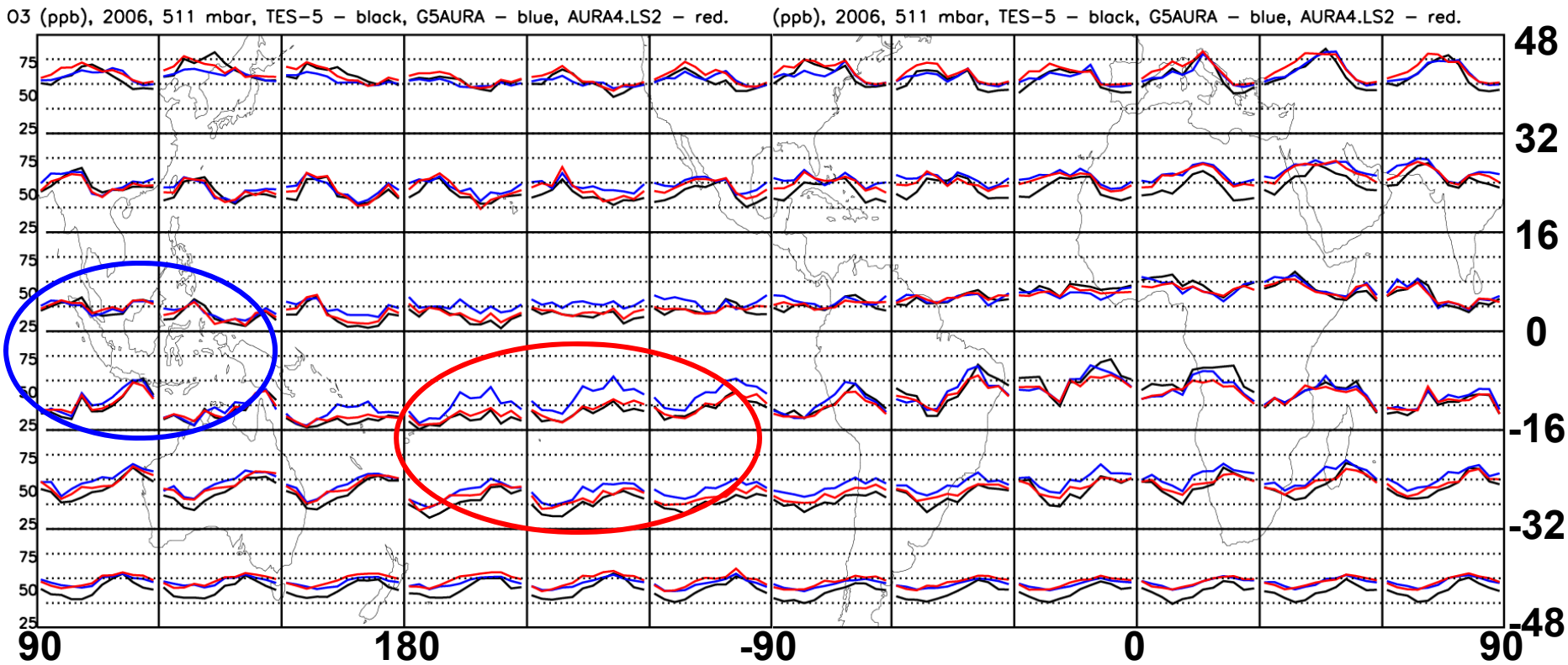
Ozone



CO



TES ozone, 500 hPa, Jan-Dec in each box.

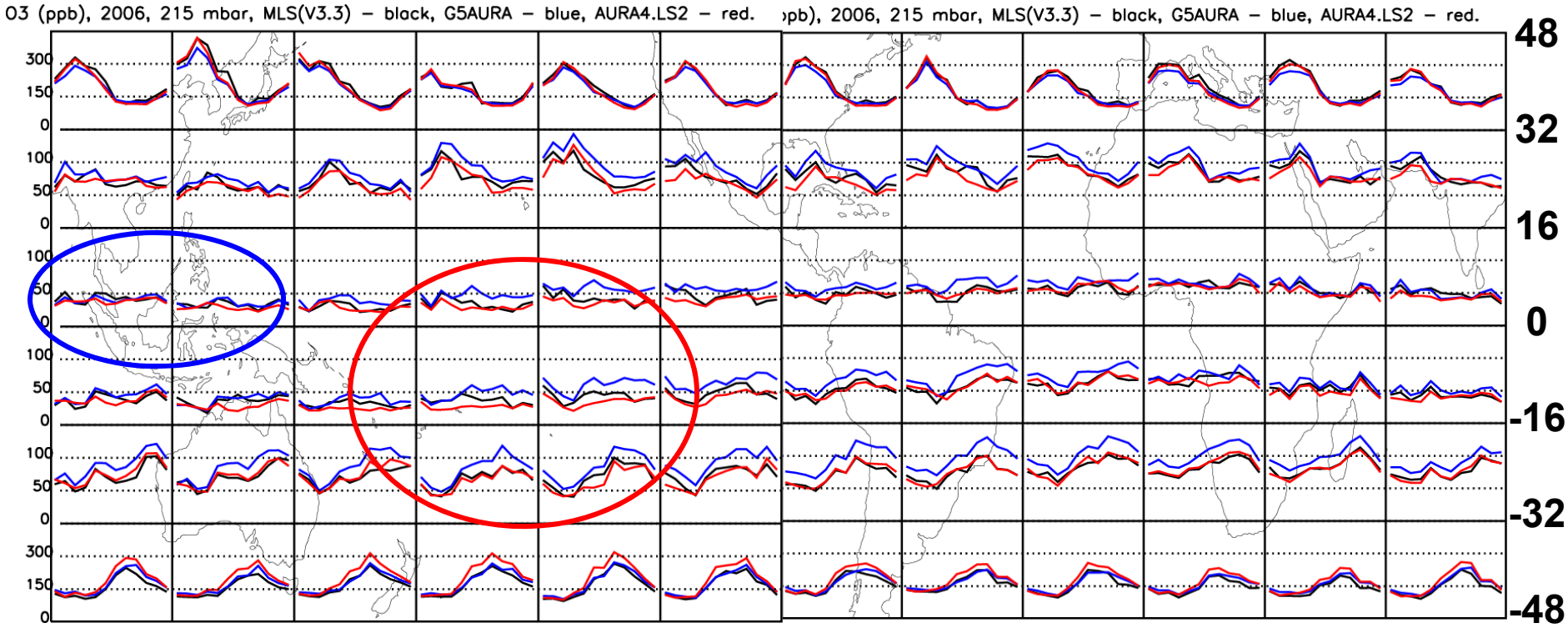


Remarkable fidelity in matching month-month variability of ozone

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

GEOS-5 > GEOS-4 mid-year, mid-Pacific
GEOS-5 ≈ GEOS-4, maritime continent

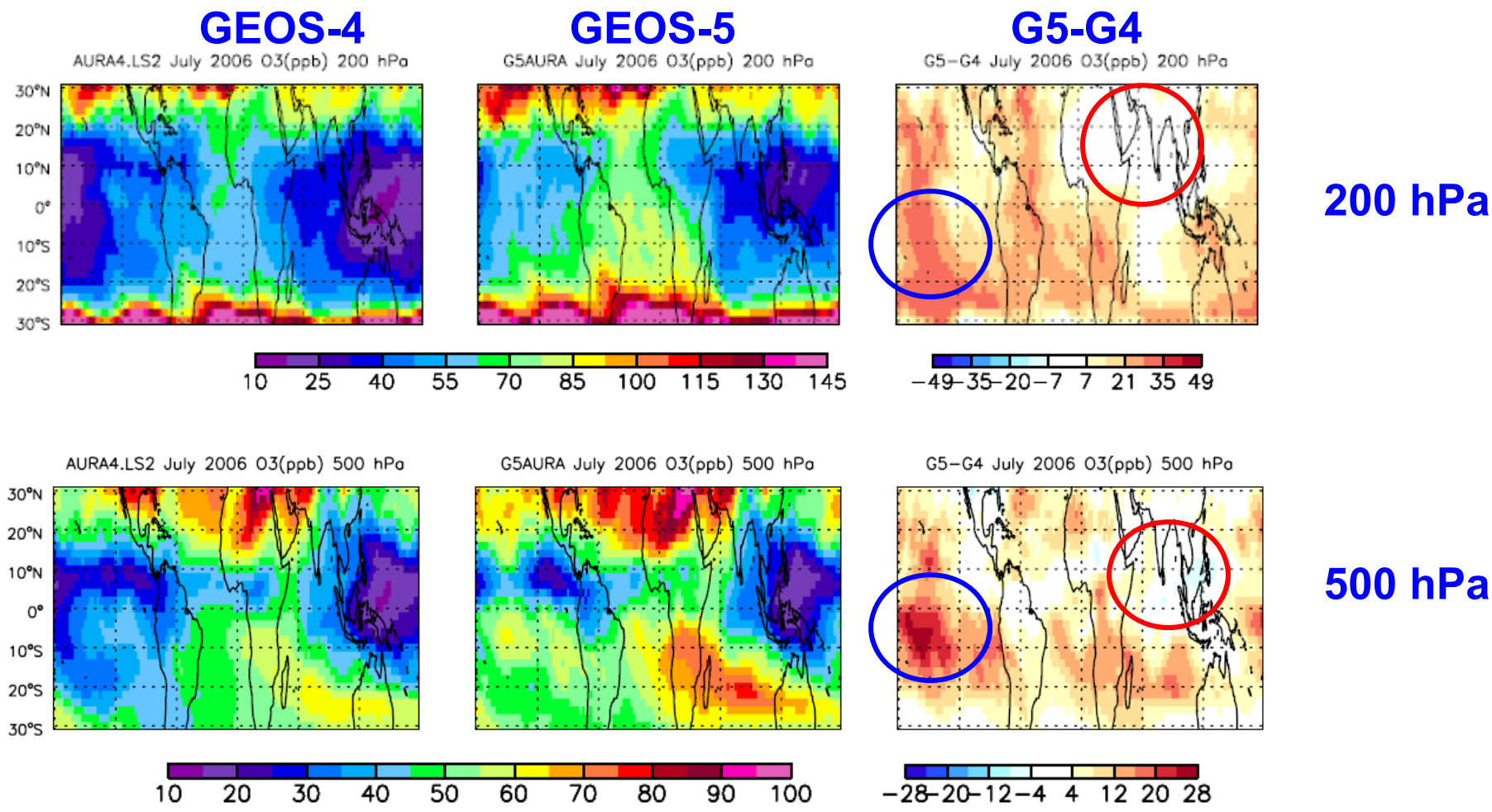
MLS ozone at 215 hPa: Jan-Dec in each box.



MLS
GEOS-4
GEOS-5

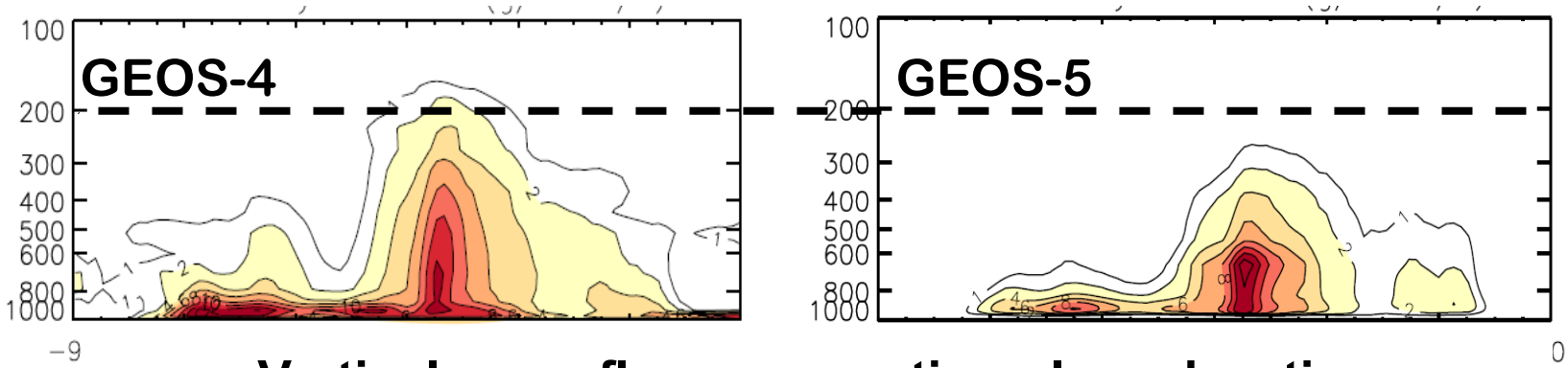
GEOS-5 > GEOS-4 in much of the tropics
GEOS-5 ≈ GEOS-4 in maritime continent
GEOS-4 is usually closer to the MLS observations

Case study: Ozone in July

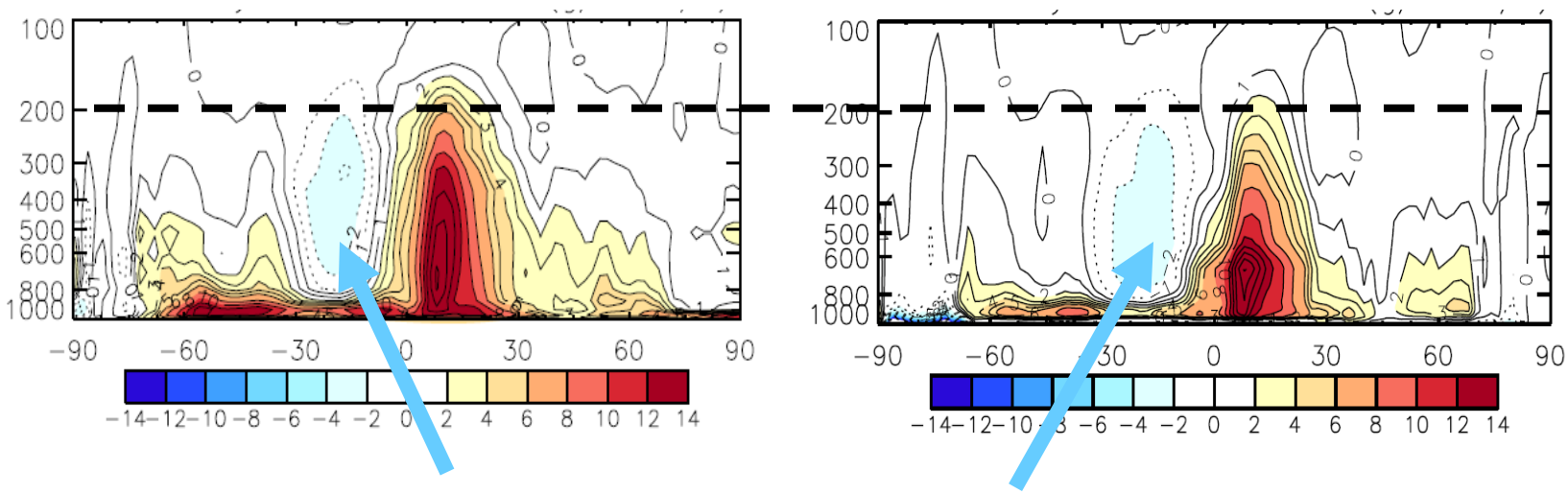


Vertical transport of air, July 2006

Convective mass flux (g/m²/sec)



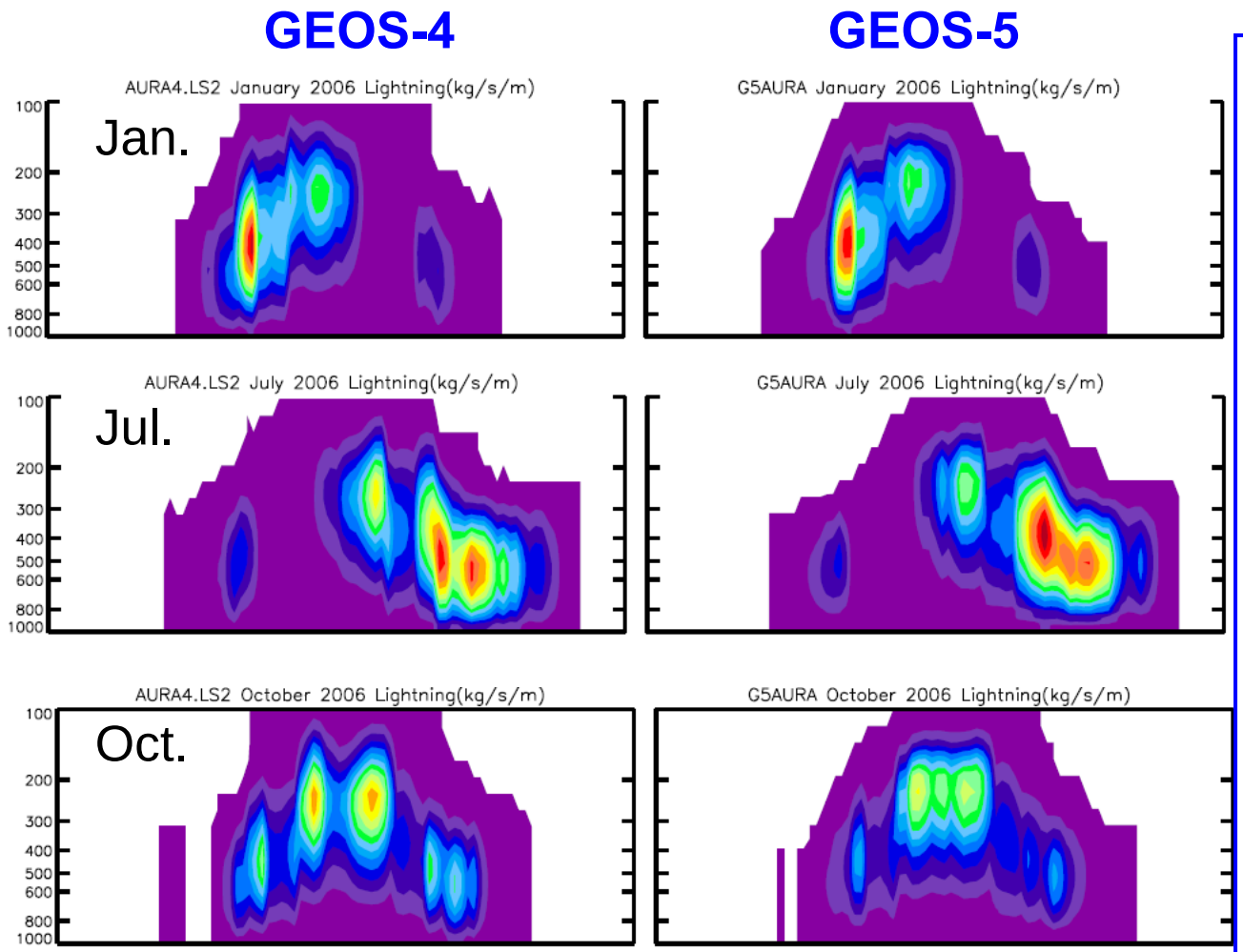
Vertical mass flux: convection plus advection



Subsidence in southern sub-tropics

Red = upward flux, blue = subsidence

Lightning NOx (LNOx) emissions (kg/sec/m)

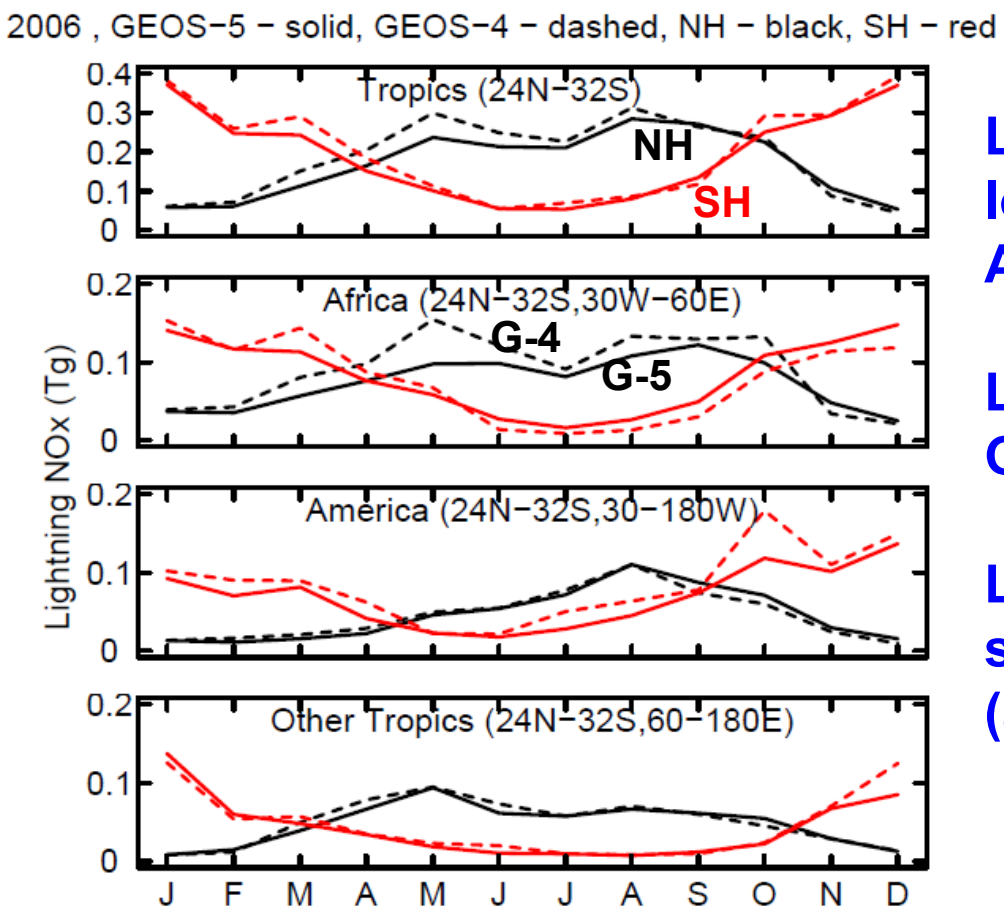


LNOx emissions have a similar vertical profile even though the mass fluxes peak at a lower altitude in GEOS-5.

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



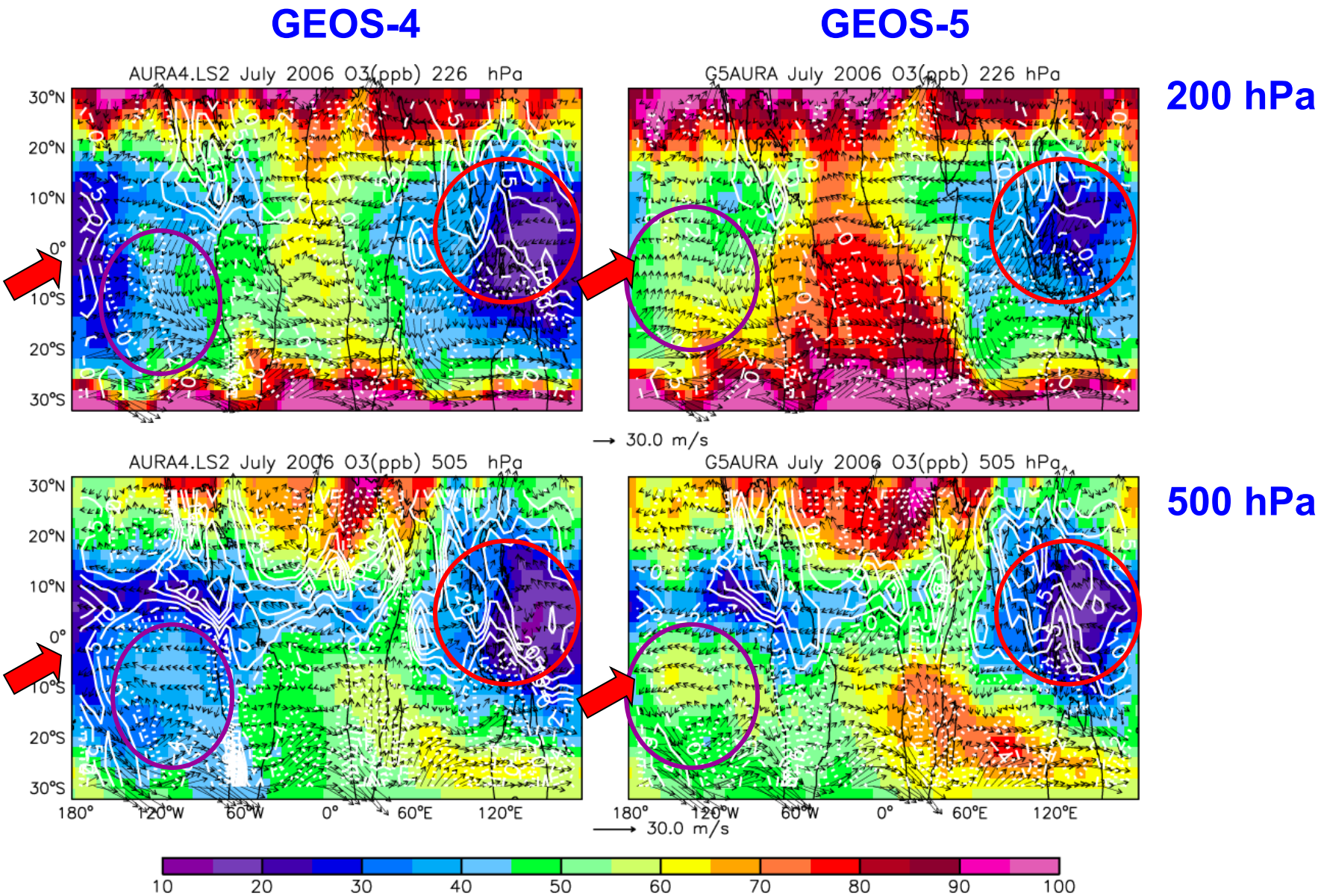
TROPICS

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)

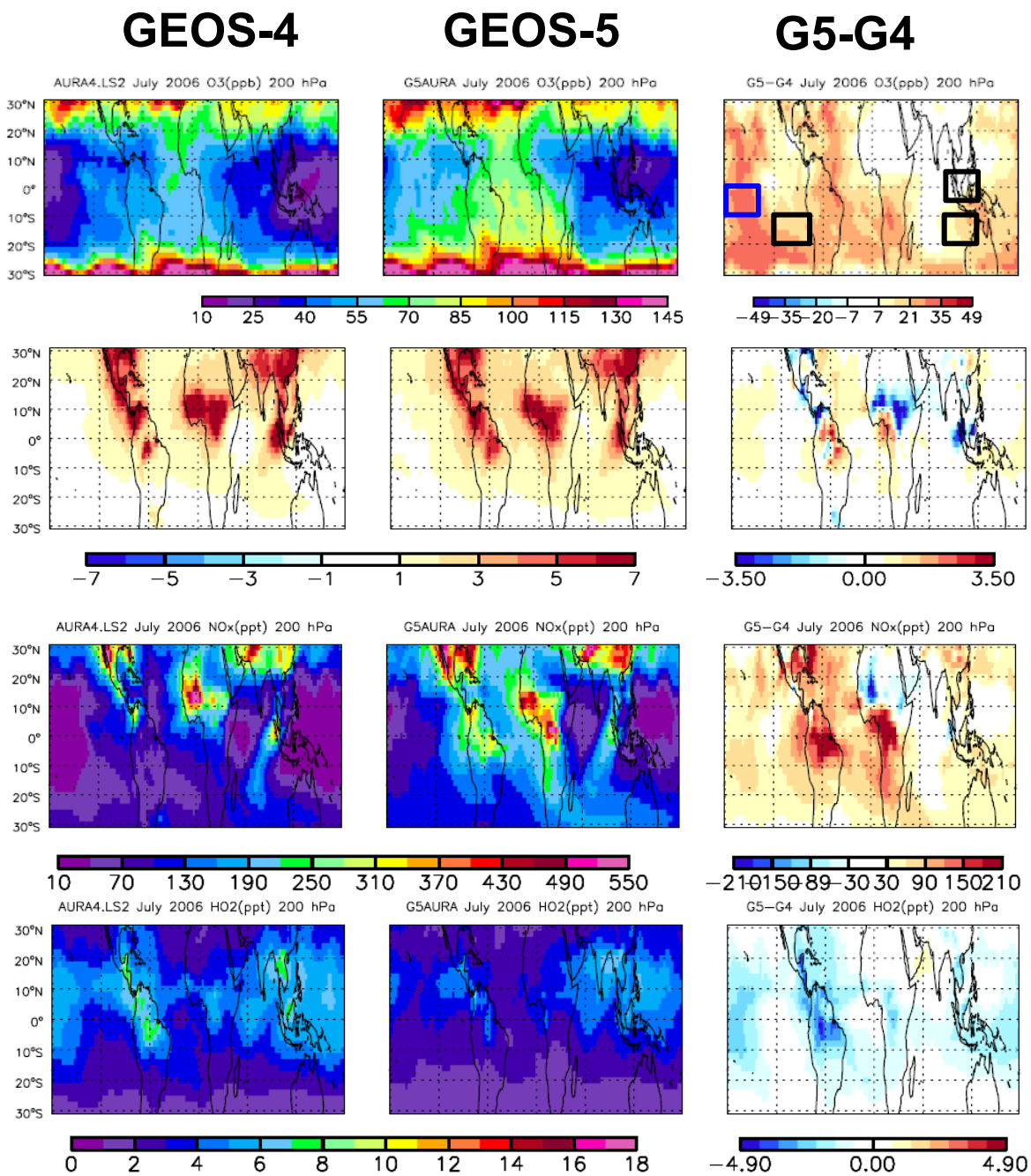
LNOx in 2005 is about the same in GEOS-4 and GEOS-5 (ann. mean)

Ozone, winds, and air mass flux, July 2006



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

July 2006, 200 hPa



Ozone (ppb)

☐ **Regions analyzed with rates, tendencies etc**

O_3 tendency (ppb/day)

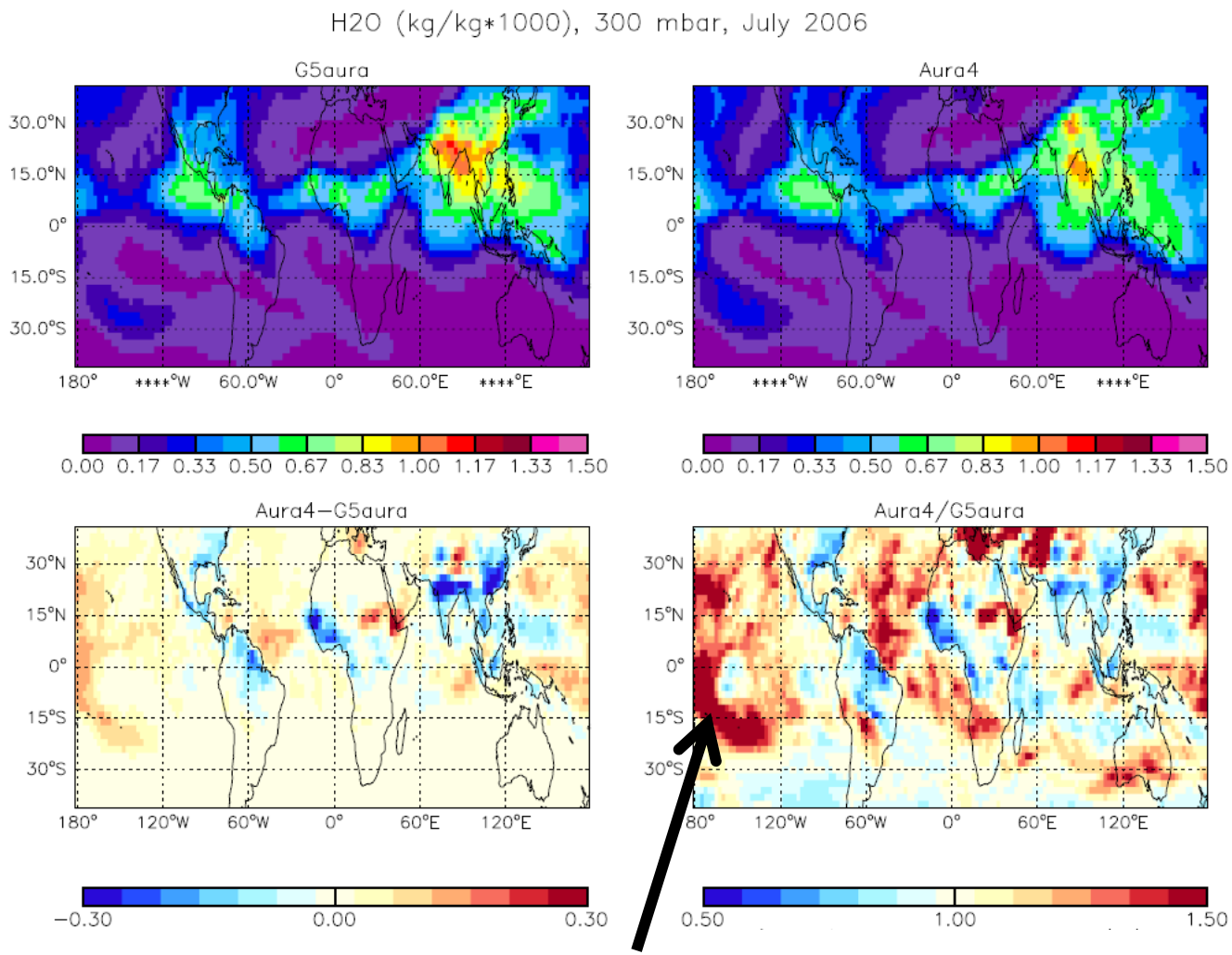
NO_x (ppt)

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

HO_2 (ppt)

H_2O is lower in GEOS-5

Water vapor at 300 hPa in July 2006

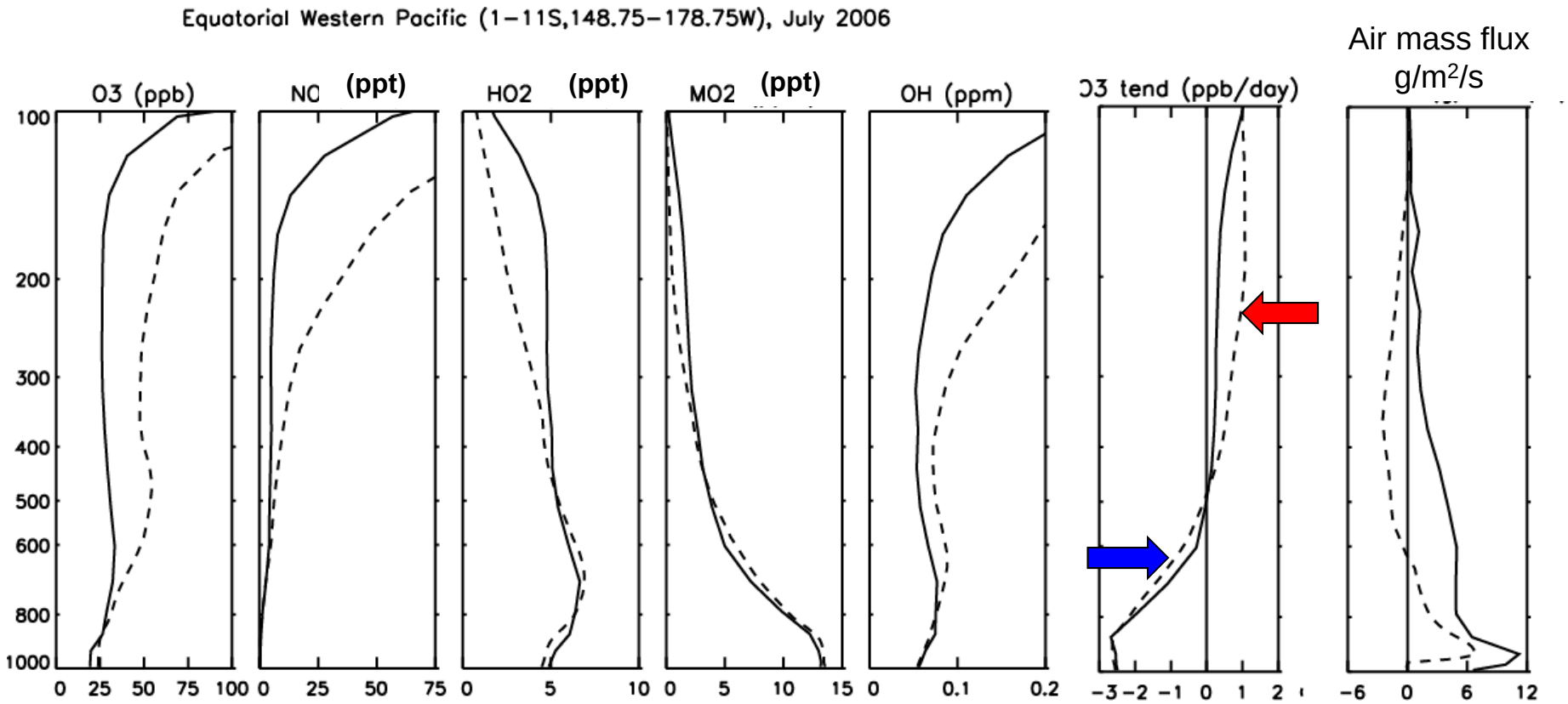


Not all regions of convection have more H_2O in GEOS-4

More H_2O in GEOS-4 in SPCZ

Equatorial West Pacific: species profiles

—— GEOS-4 ----- GEOS-5

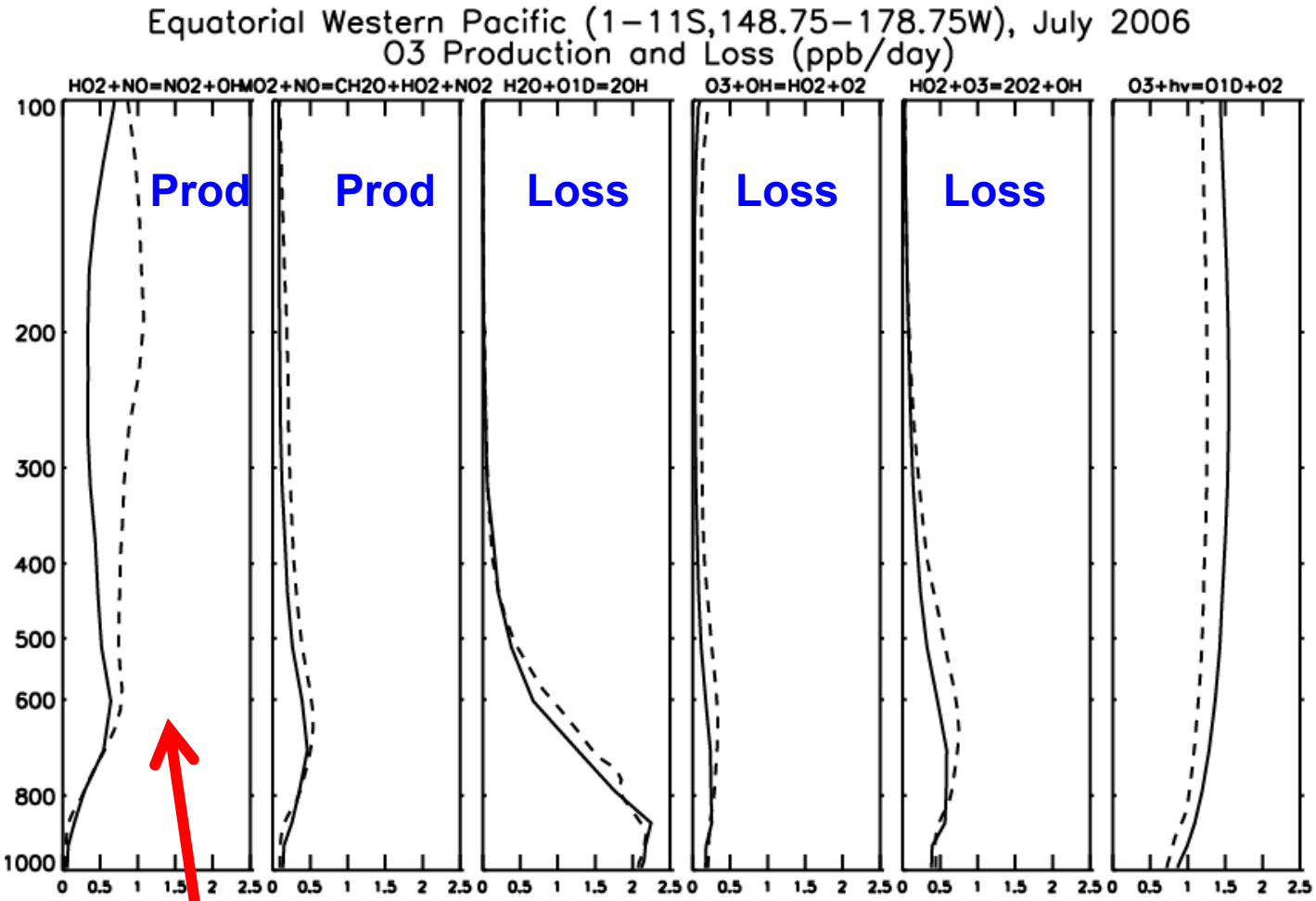


UT: net production, (P-L) is larger in GEOS-5, as more NO "wins" over less HO_2

LT: net loss, (P-L) is larger (more negative) in GEOS-5, as more H_2O and more HO_x

Rates for Production and Loss of ozone (odd-oxygen)

—— GEOS-4 ----- GEOS-5



$HO_2 + NO \rightarrow NO_2 + OH$

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.

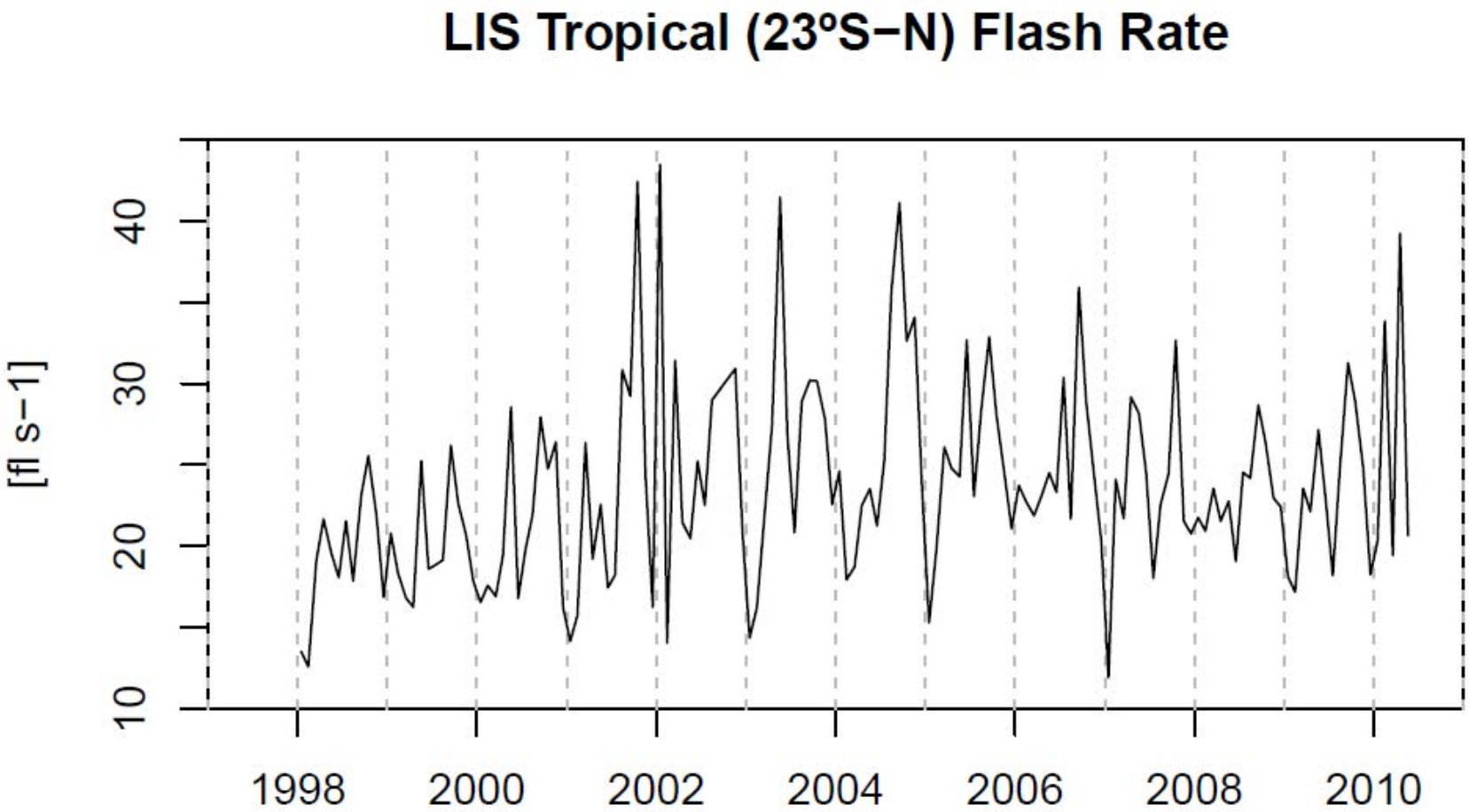
IAV in LNOx in the tropics has changed.

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

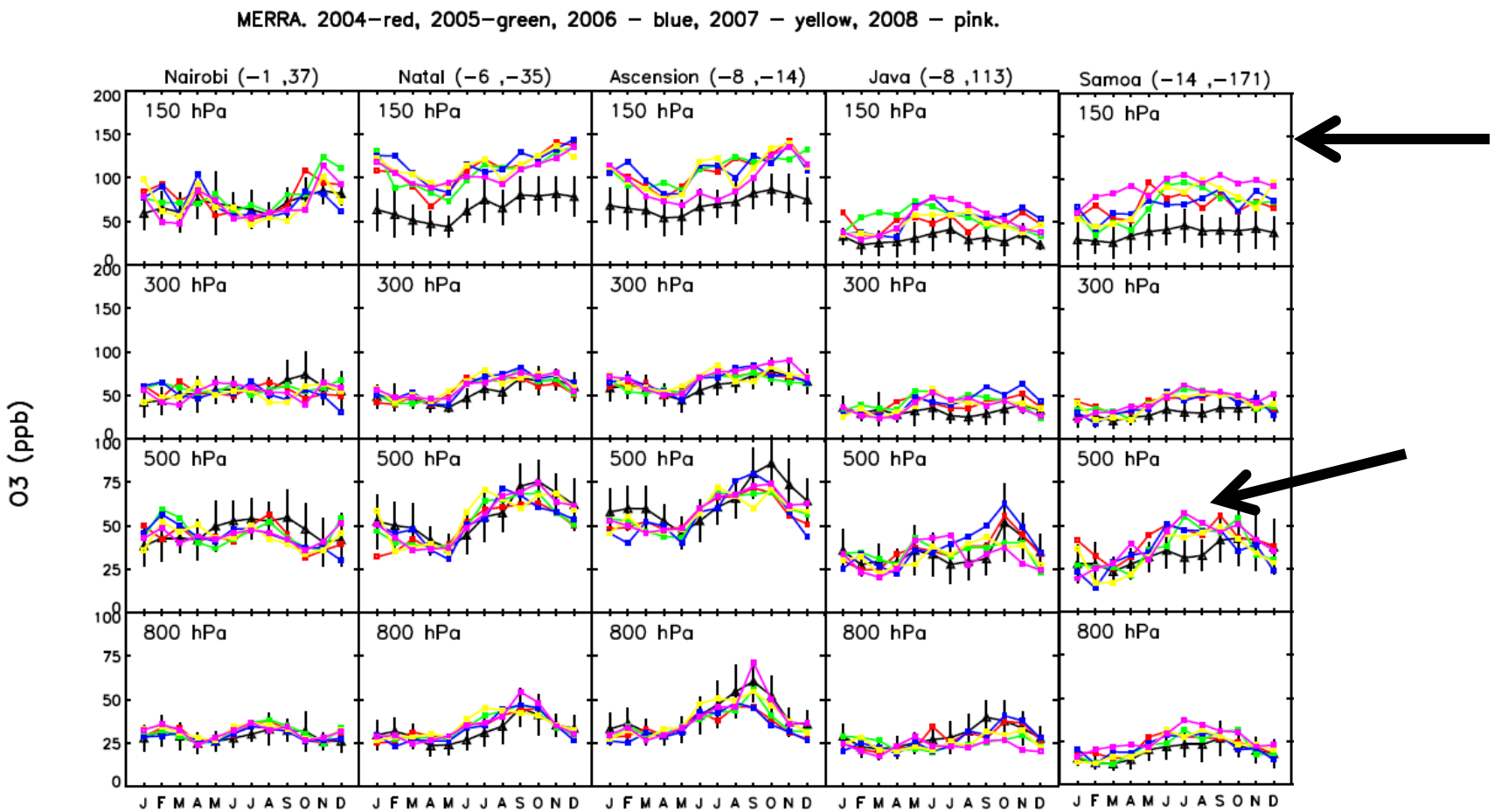
Does IAV in GMI runs have more variability than this?



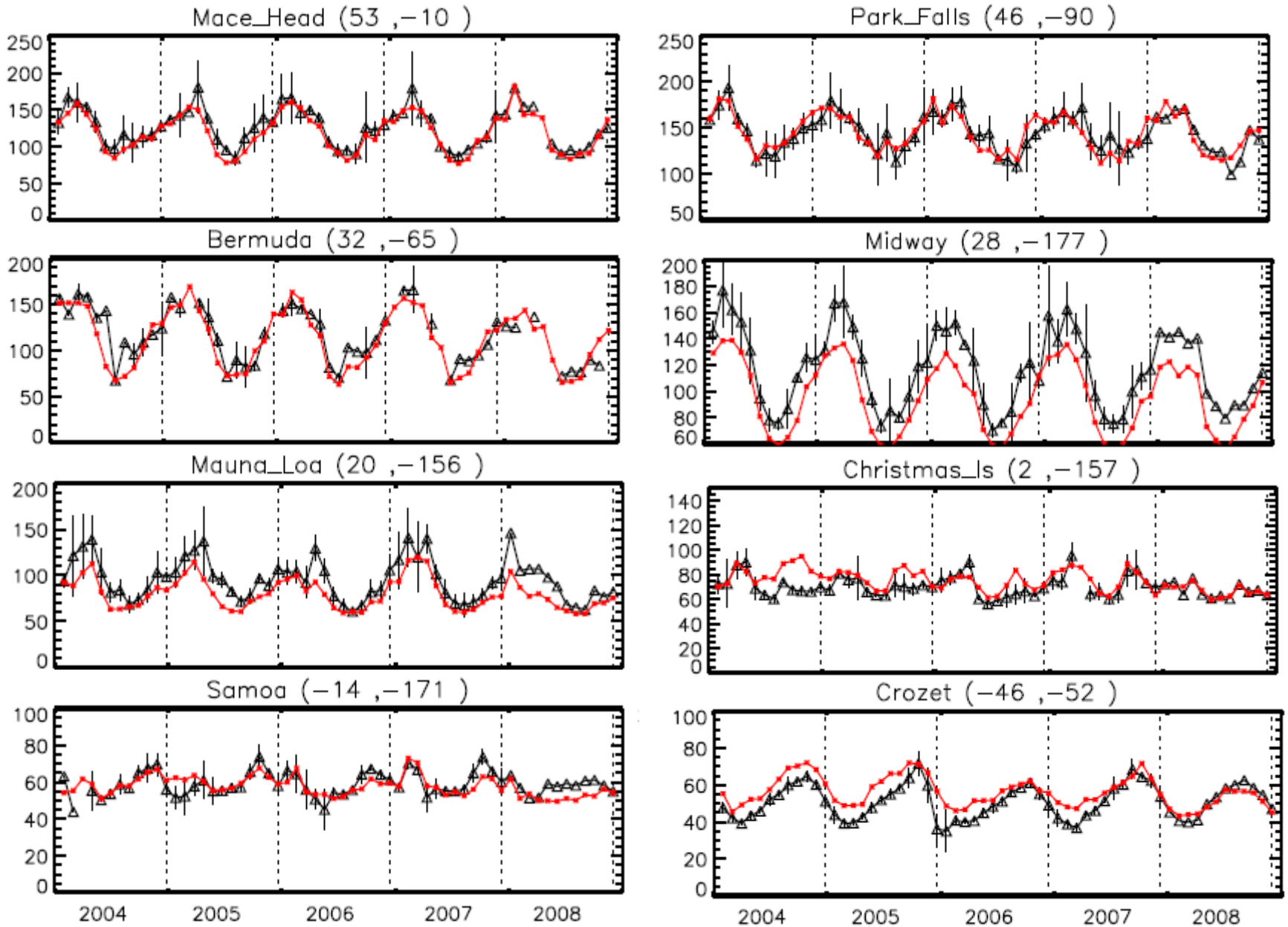
Lee Murray, Harvard

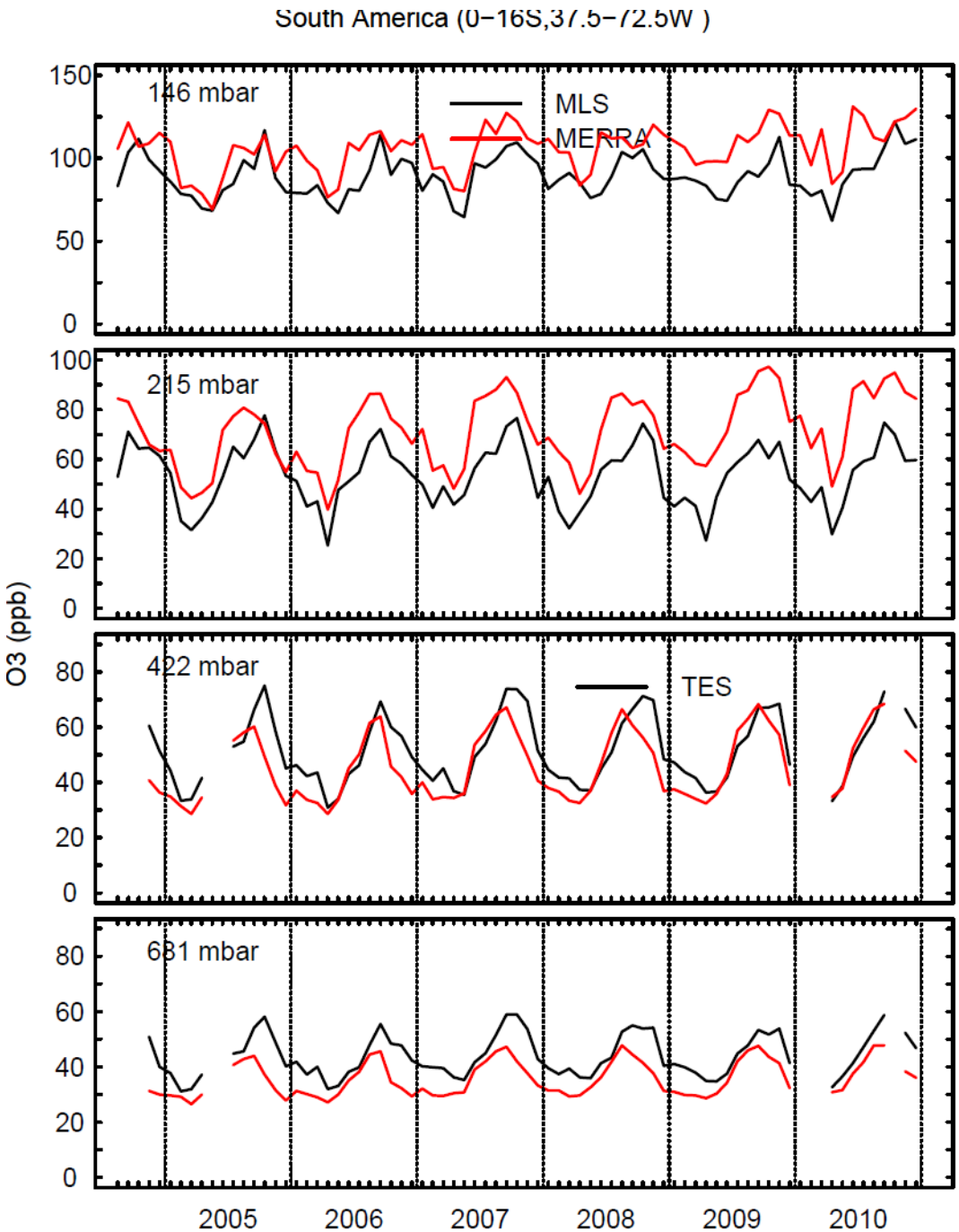
Back to MERRA run: 5 years vs. tropical sondes

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

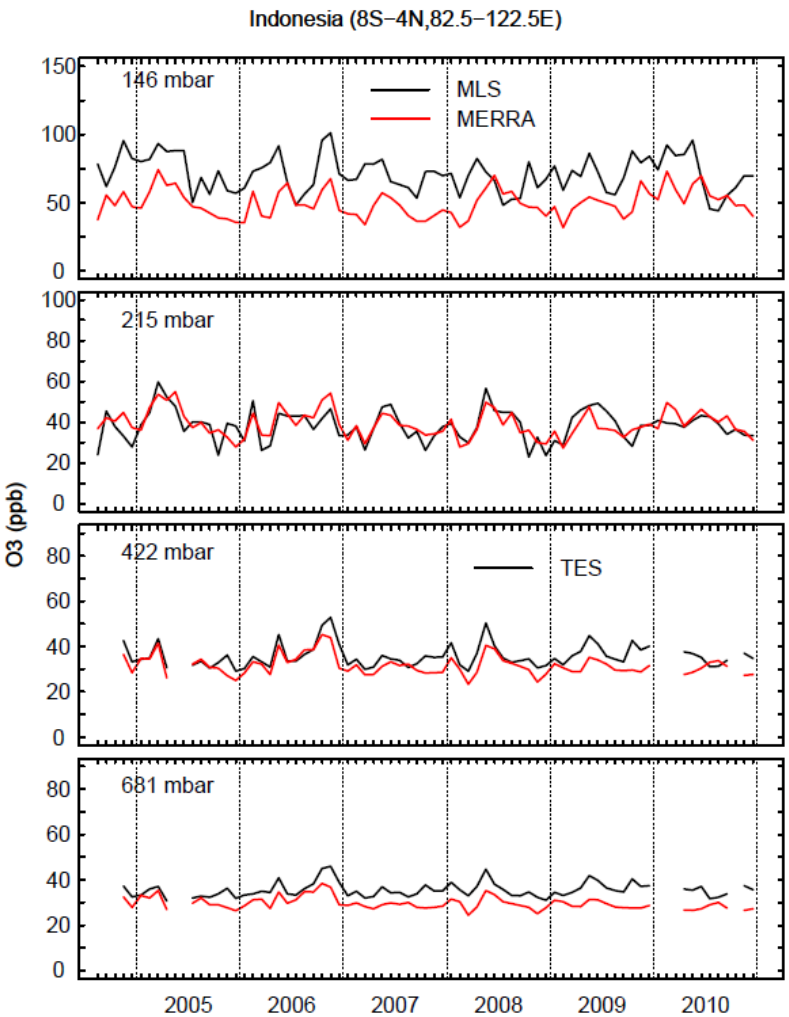
What is causing the upward trend in UT ozone in the model? LNOx?

More analysis to be done

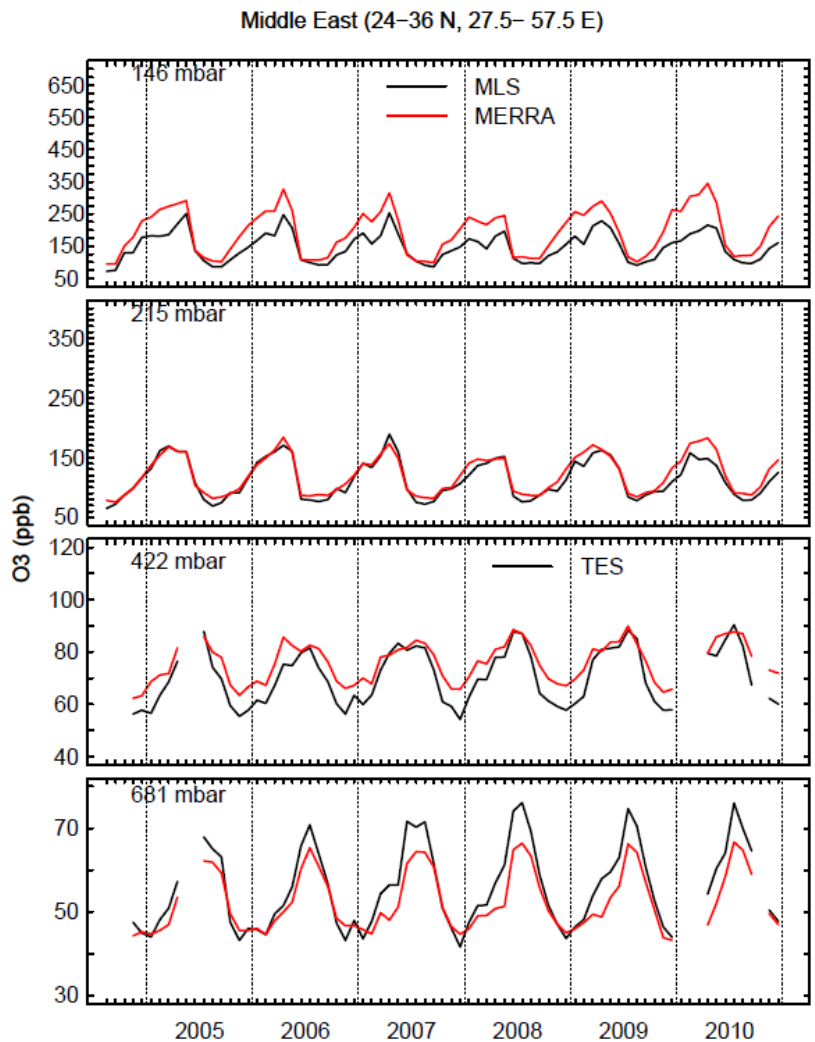
TES comparison uses a uniform tropical prior

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