UCIrvine

Models, Measurements & Error Analysis in predicting Atmospheric Composition: Applications for GMI and key MAP Components

*Michael Prather, Xin Zhu, Juno Hsu, Qi Tang, (Jessica Neu), Chris Holmes**
UC Irvine

UCI – GMI Proposed TASKS:

(i) Optimized fast-JX based photolysis & solar heating module

(ii) Precipitation scavenging module focusing on NOy

(iii) Acquire independent, multi-year met fields (EC/Oslo)

(iv) Implement optional tracer-advection code for GMI

(v) Strat-chem module (O_3 & NOy) for long-term climate runs (Linoz)

(vi) Resolution error analysis / correction schemes (also NSF)

(vii) Participate in international community projects (SPARC CCMVal, EU QUANTIFY) to incorporate new findings in MAP/GMI

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In search of the tropopause: photochemistry, age-of-air, uncertainties, met fields and numerical issues

*Michael Prather, Xin Zhu, Juno Hsu, Qi Tang, Jessica Neu, Chris Holmes**
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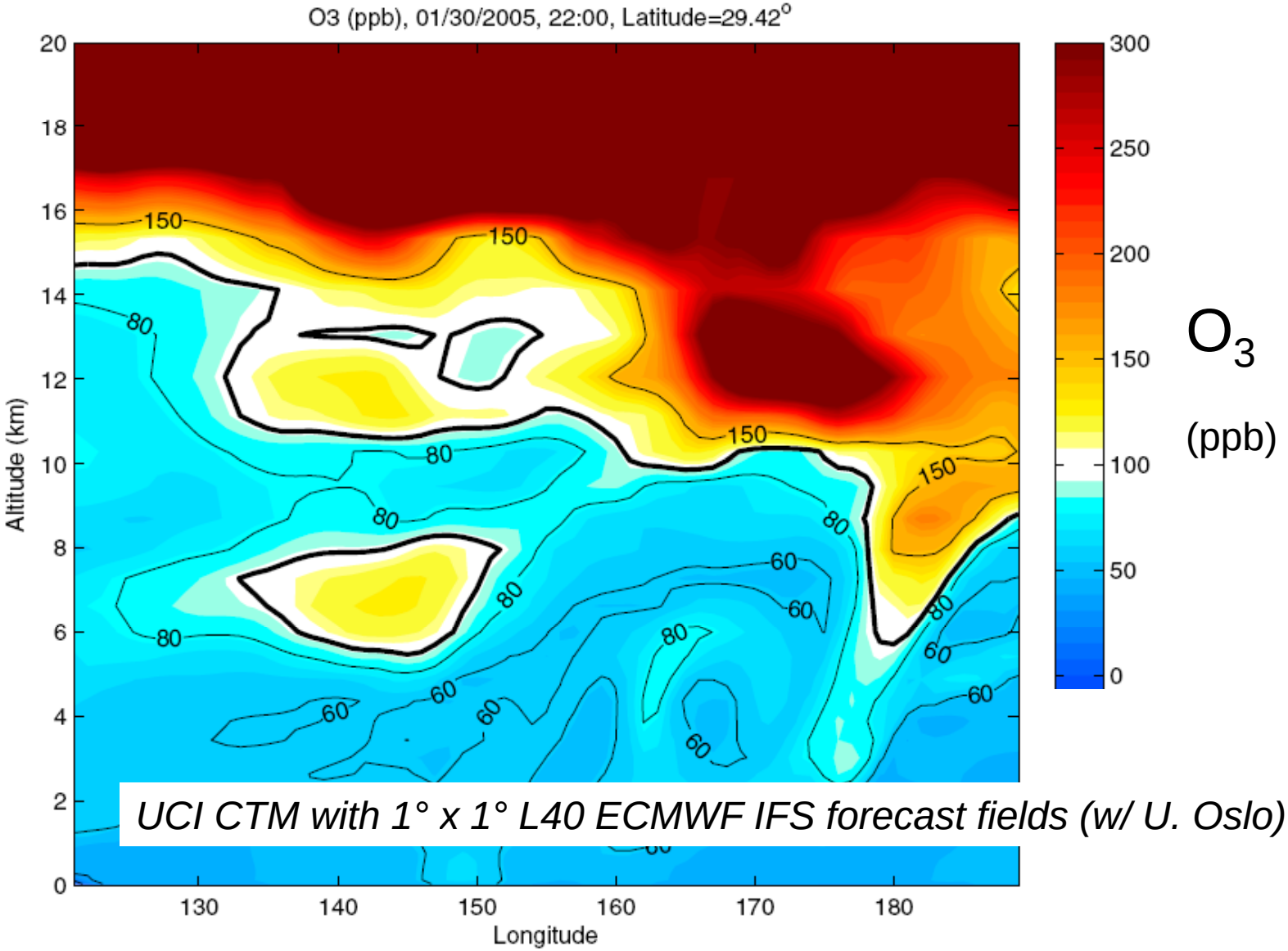
Delineating the boundary between troposphere and stratosphere in a chemistry-transport model requires a state variable for each air mass that maps out the ever shifting 3-D boundary every time step. An artificial tracer, ***e90*****,** with surface sources and 90-day decay time, is found to simulate the 1-D temperature lapse-rate definition of the tropopause as well as reproduce the seasonal variation of ozone at this boundary. This approach works from equator to pole, unlike other methods such as potential vorticity. By focusing on the time scales that separate stratosphere from troposphere, we find the probable cause of ozone seasonality (photochemistry), the oldest air in the troposphere (winter descent in the subtropics), and a north-south bias in the age-of-air of the lower stratosphere. A tracer like *e90* is invaluable in 3-D modeling, readily separating stratosphere from troposphere based on mixing times, and giving quantitative measure of the effective distance from the tropopause.

Premise:

The ***tropopause*** (tpp) is a somewhat fuzzy boundary between two chemically distinct regions: the stratosphere and the troposphere.



UCI CTM with 1° x 1° L40 ECMWF IFS forecast fields (w/ U. Oslo)

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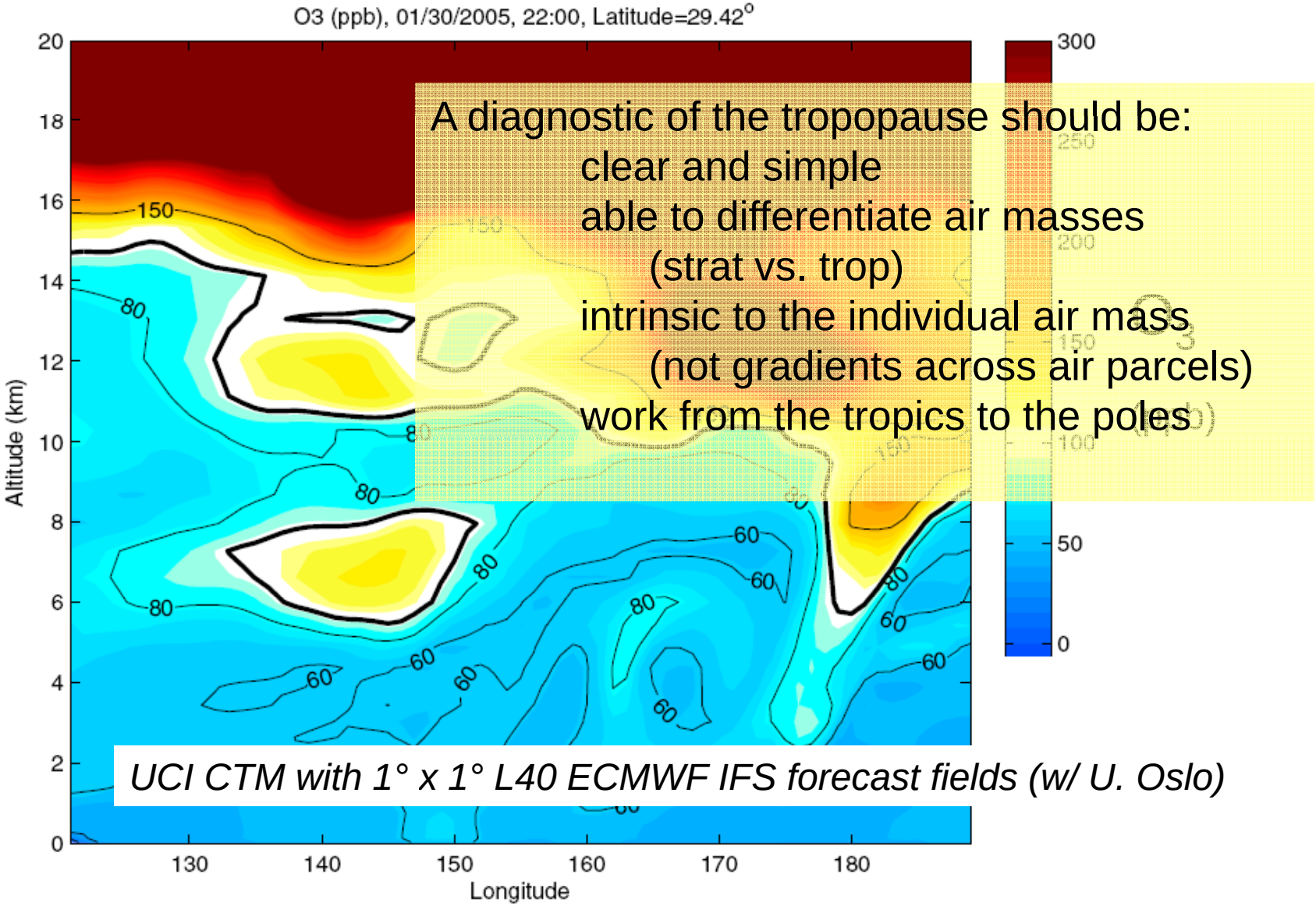


A diagnostic of the tropopause should be:

clear and simple

able to differentiate air masses

(strat vs. trop)

intrinsic to the individual air mass

(not gradients across air parcels)

work from the tropics to the poles

UCI CTM with 1° x 1° L40 ECMWF IFS forecast fields (w/ U. Oslo)

Rejecting the traditional definitions of the tropopause (*lapse rate or PV*) as unusable in a global 3-D global framework, we experiment with a definition based on the mean age since contact with the surface:

tracer 'e90'

uniform surface emissions (90S - 90N)
90-day uniform e-fold
global average ≡ 100 ppb
troposphere average ~ 125 ppb
tropopause e90 = 89 ppb (83 ± ½ % in troposphere)

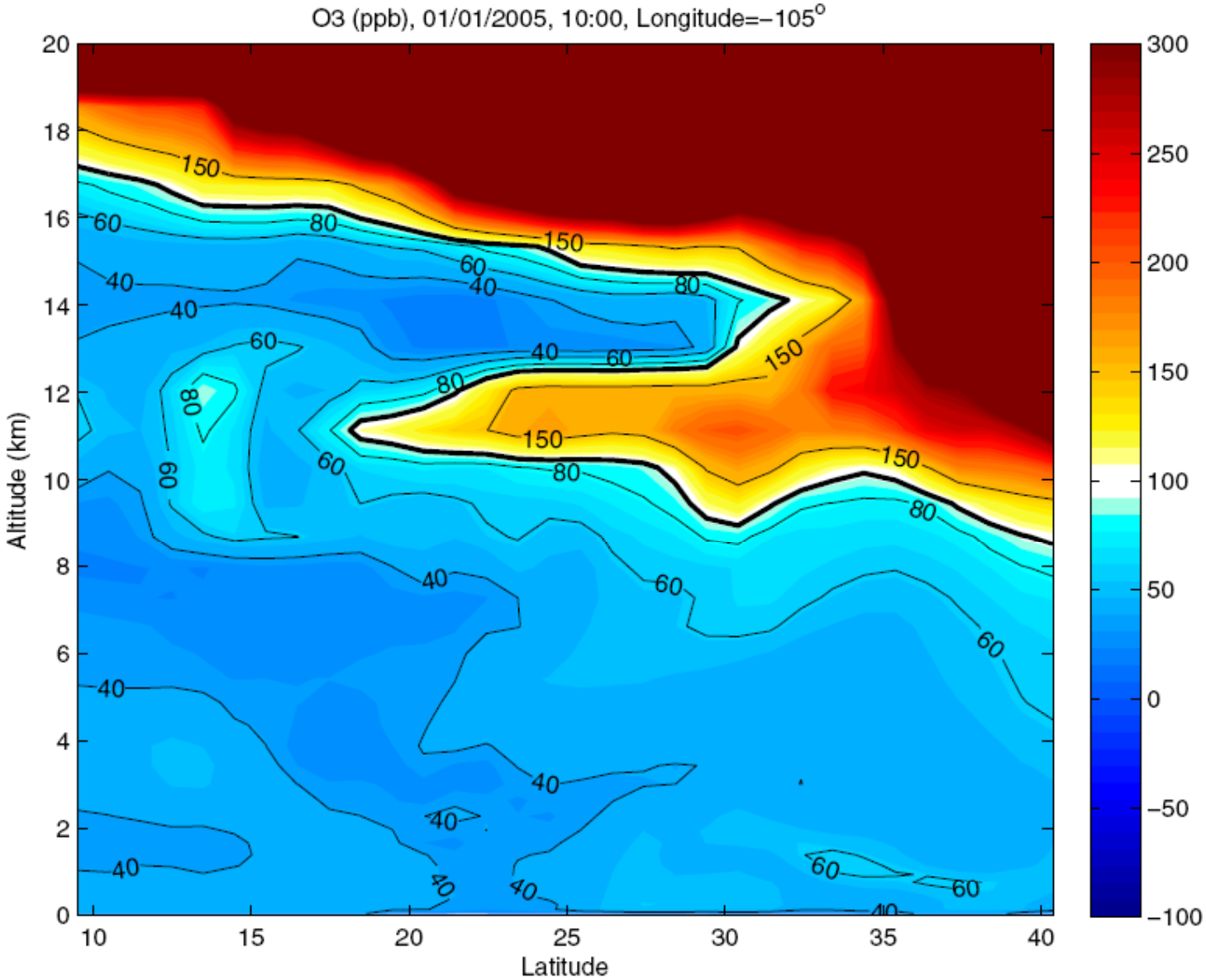
The ***tracer e90*** gives us a very useful diagnostic for distance from the tropopause in terms of transport, which works well around the jet and folds. This new approach ***should*** accurately

reproduce the sonde tropopause heights

and

match/explain seasonal variations in tropopause O_3

Why use ***e90*** to define the tropopause ?



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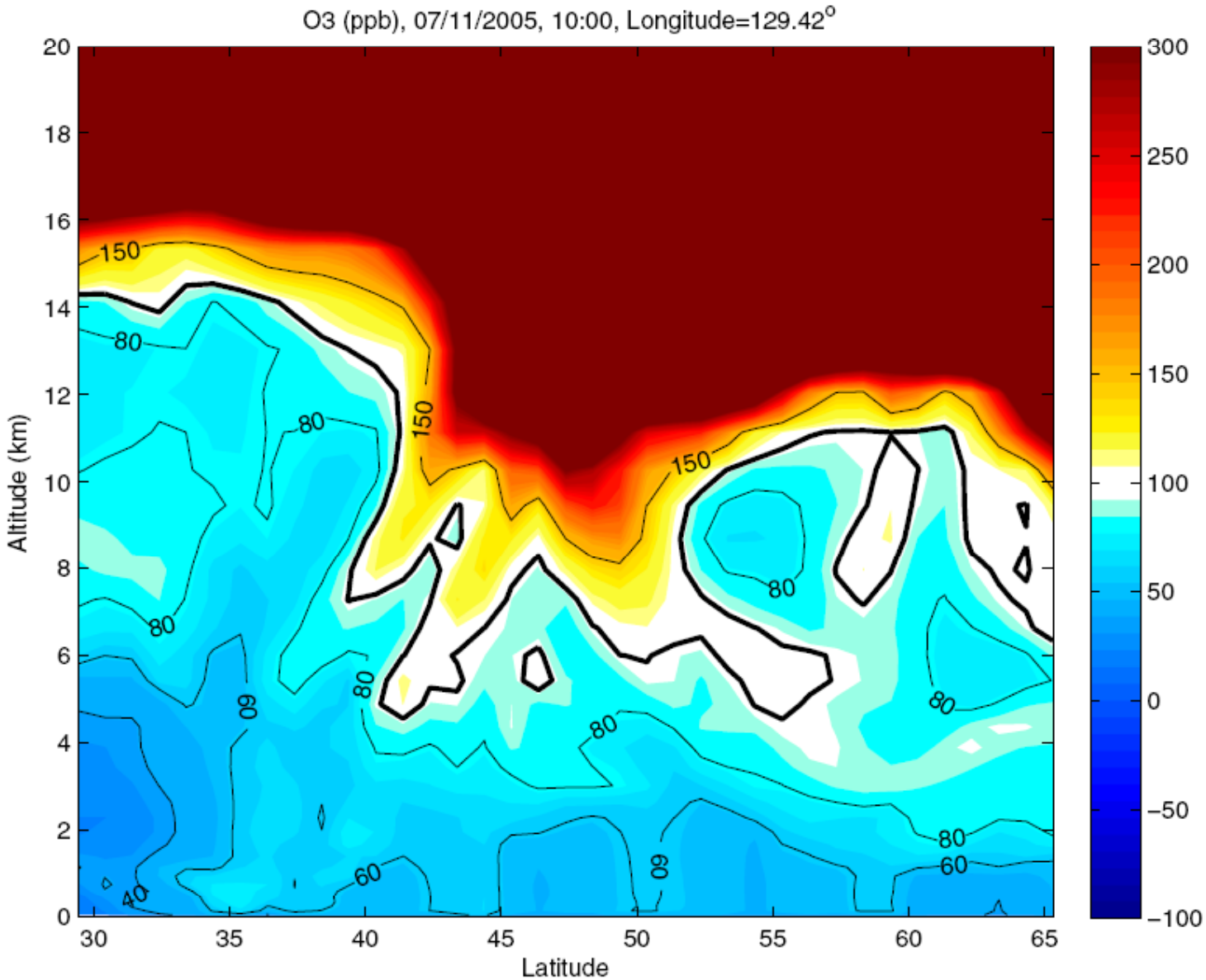

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Atmos. Chem. Phys., 8, 2365–2385, 2008
www.atmos-chem-phys.net/8/2365/2008/
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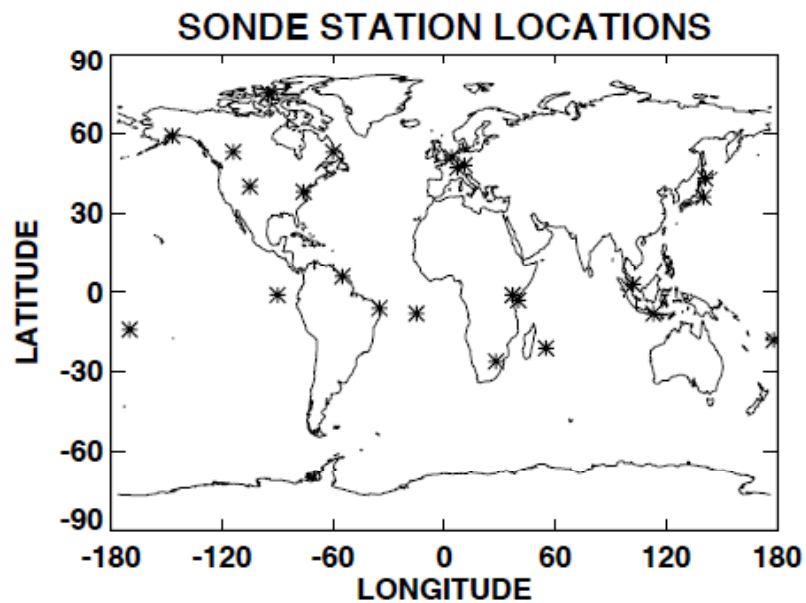
Atmospheric Chemistry and Physics

modeling tropopause O_3 accurately is not easy

Evaluation of near-tropopause ozone distributions in the Global Modeling Initiative combined stratosphere/troposphere model with ozonesonde data

D. B. Considine[1], J. A. Logan[2], and M. A. Olsen[3]

[1]NASA Langley Research Center, Hampton, Virginia, USA
[2]Harvard University, Cambridge, Massachusetts, USA
[3]Goddard Earth Sciences and Technology Center, University of Maryland, Balti



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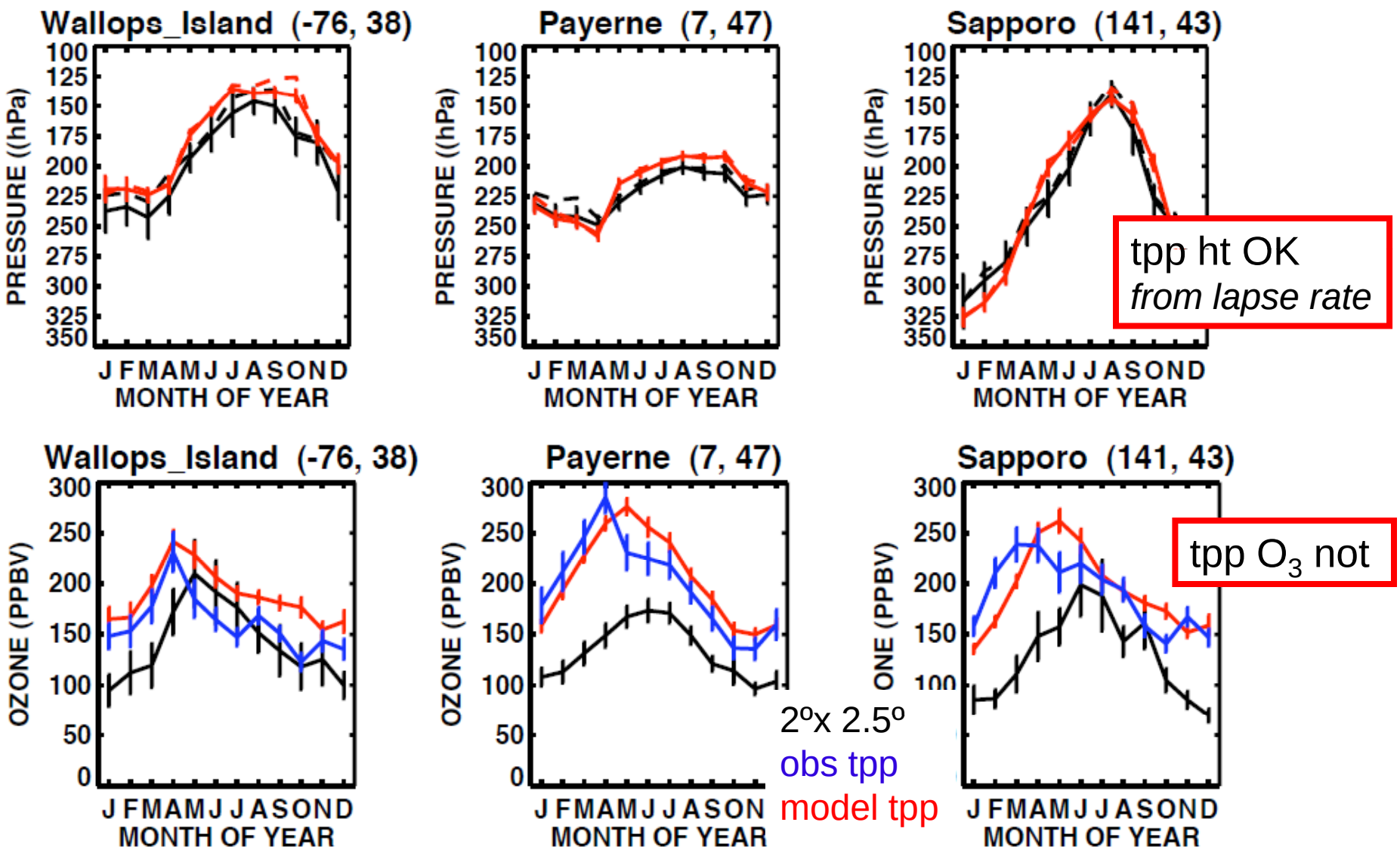
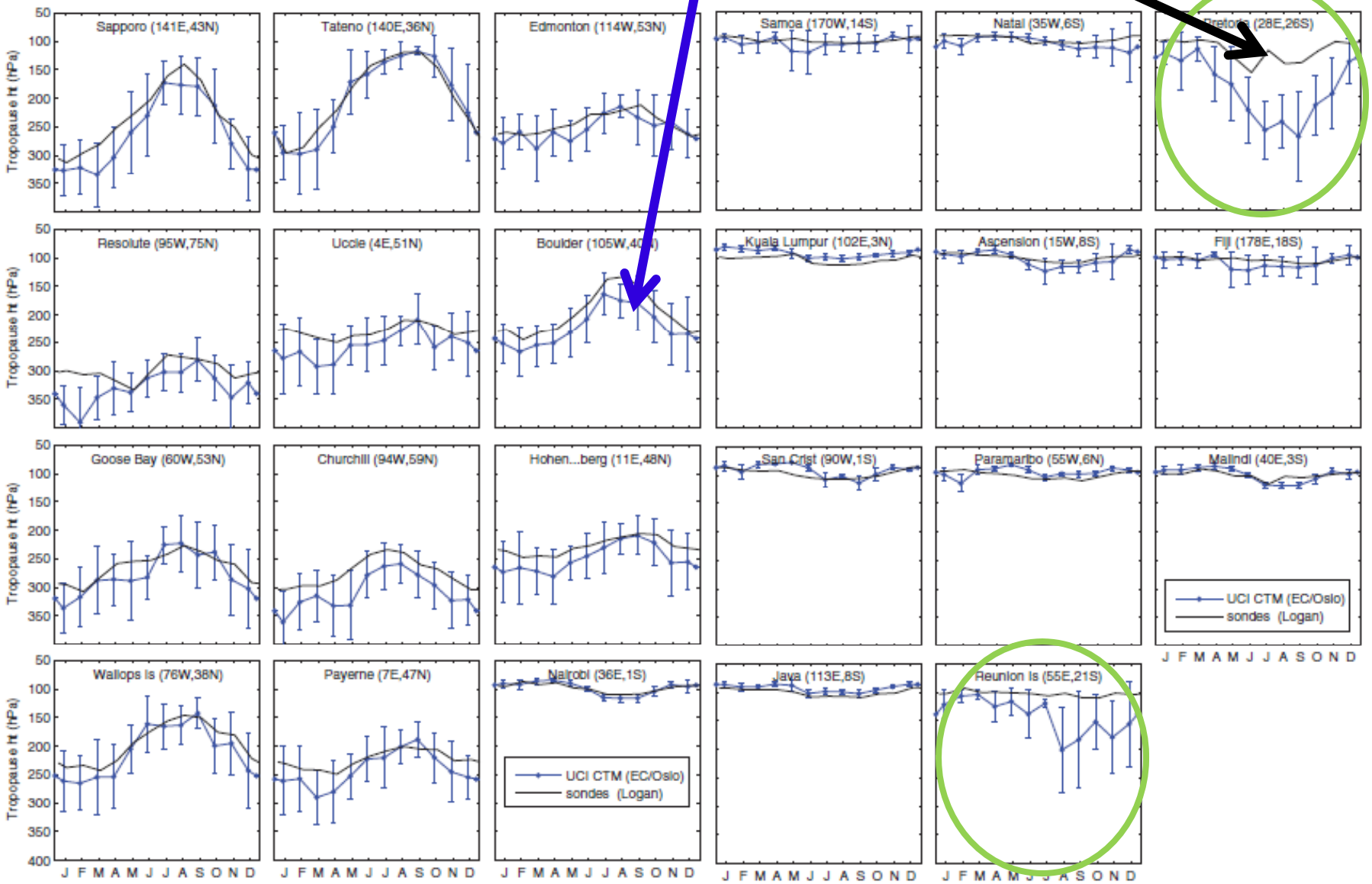


UCI: tropopause height (hPa) from ***e90*** matches ***sondes*** (using -2K/km)

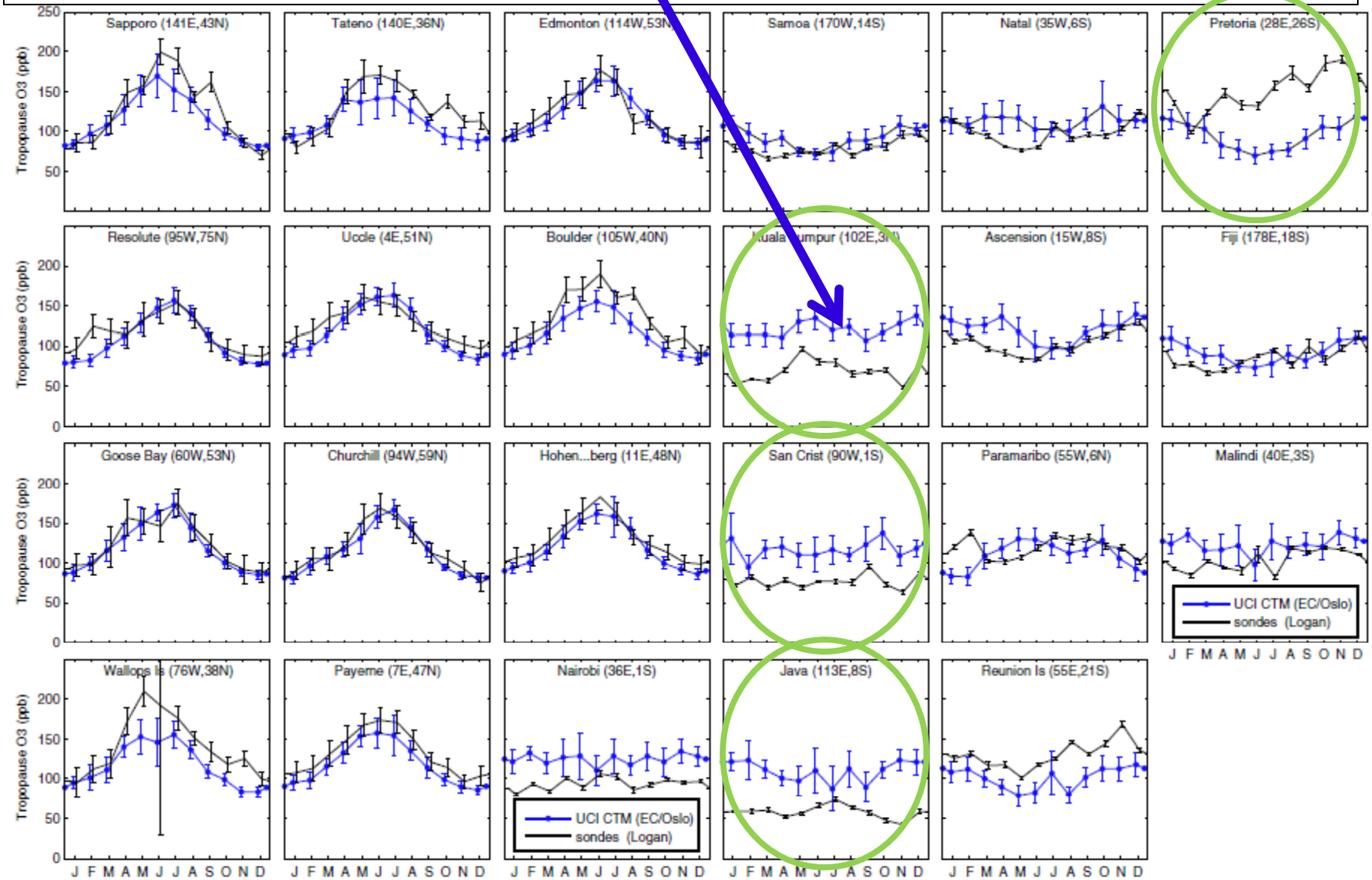
except in some tropical stations



UCI CTM with T42L60 ECMWF IFS forecast fields (w/ U. Oslo)

UCI: *tropopause O_3* (ppb) from ***e90*** matches ***sondes***,

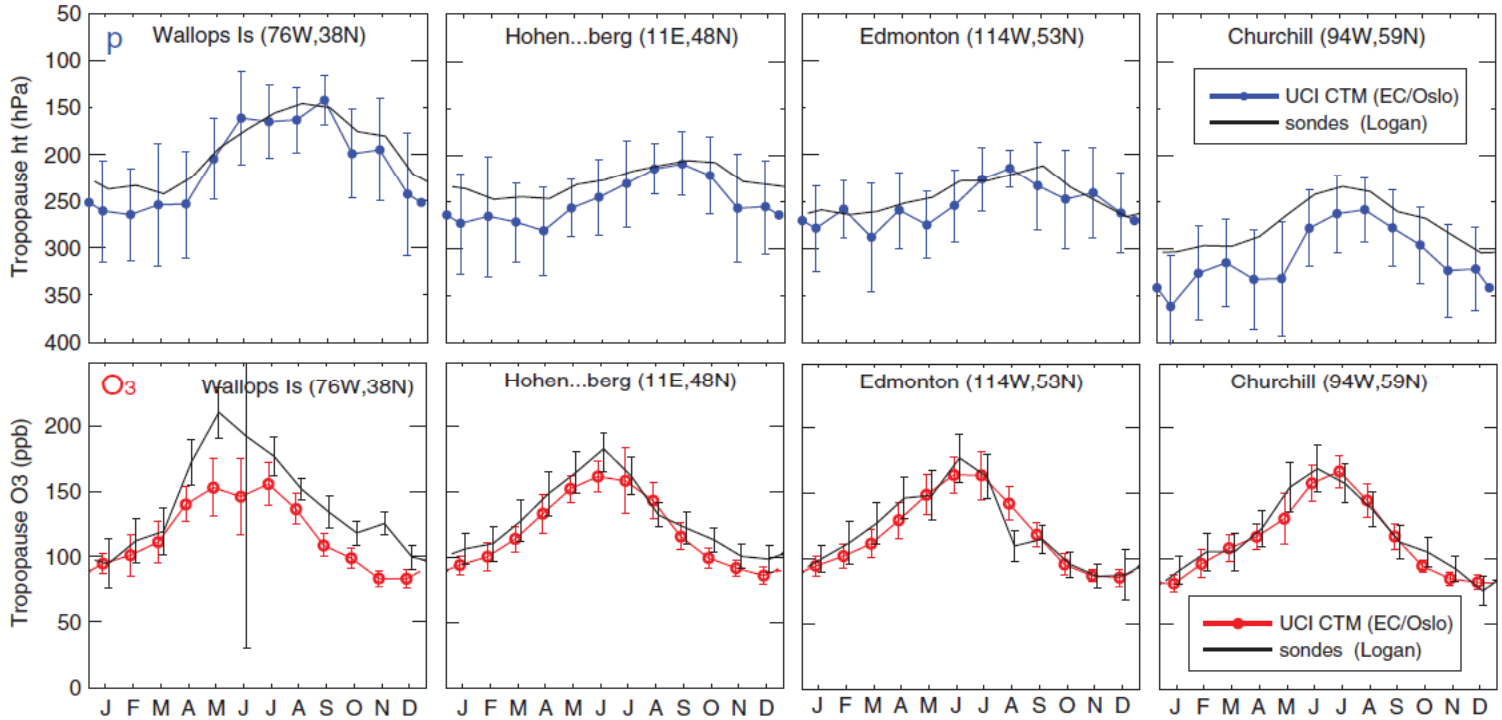
except in <u>some</u> tropical stations



UCI CTM with T42L60 ECMWF IFS forecast fields (w/ U. Oslo)

e90: ***matches the observed seasonal nature of O_3 at the tropopause***

from ~100 ppb in winter to ~200 ppb in summer in NH mid-lats



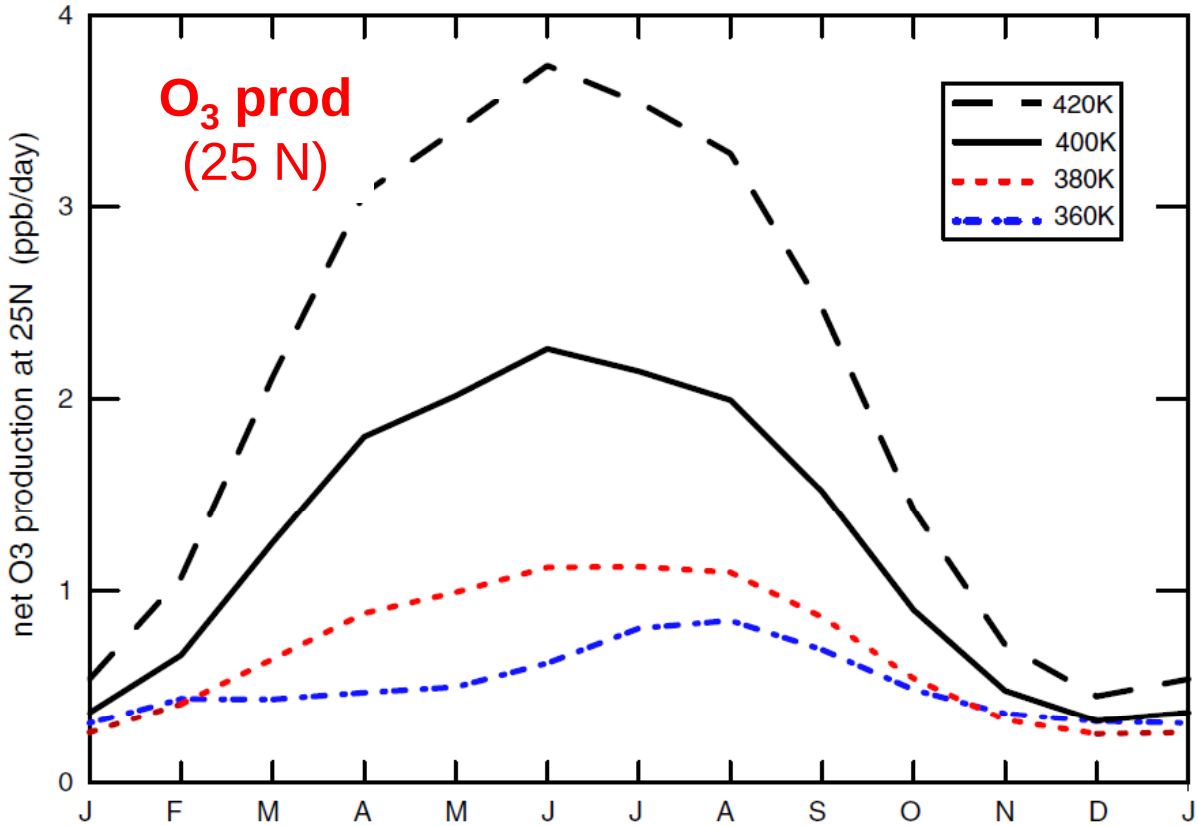
Why?

>>Stratospheric Chemistry (more O_3 production in summer)<<

O_3 chemistry in lower strat. (360-380K) at 40N-60N is far too slow (<10 ppb/month) to change O_3 by >50 ppb in a season,

but

O_3 production in sub-tropics at 400K peaks in June at +60 ppb/month, if transported to mid-lats, can explain seasonality.



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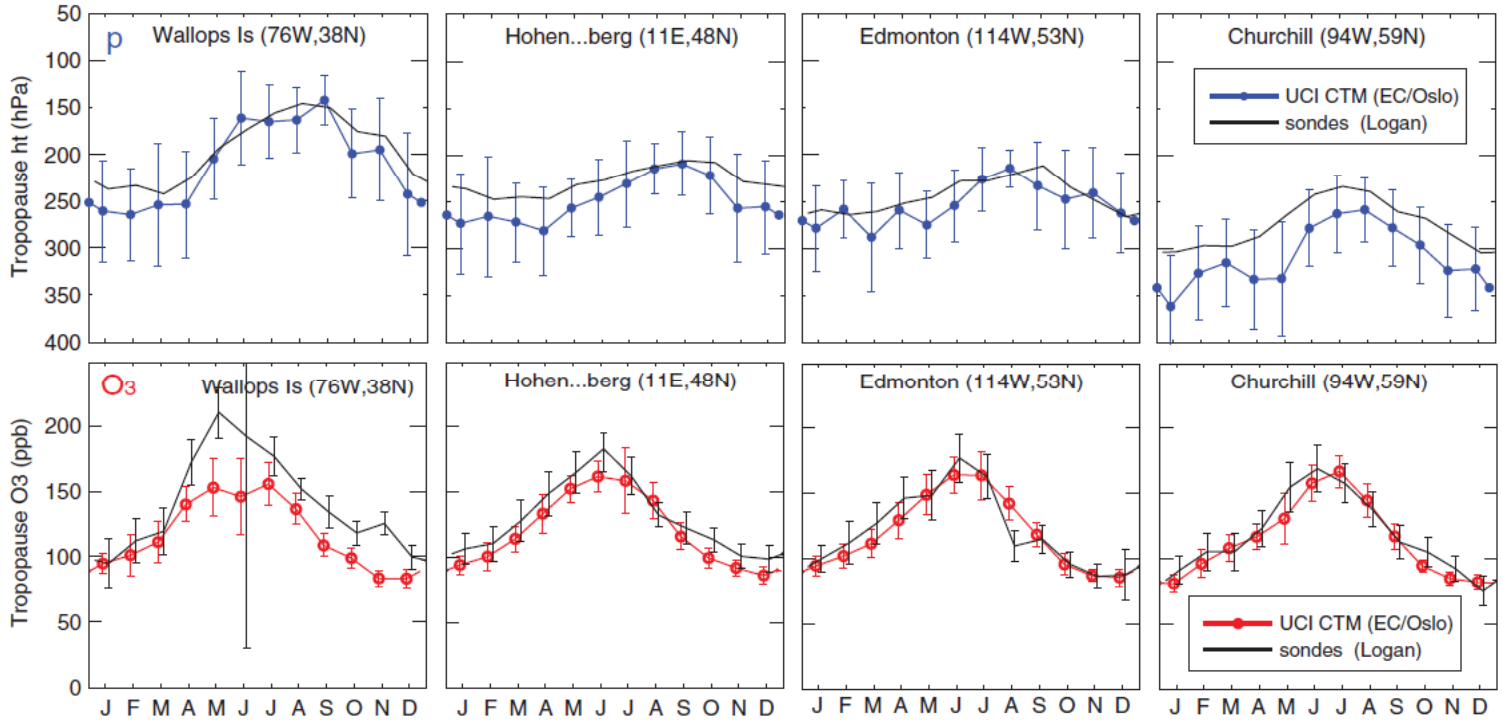
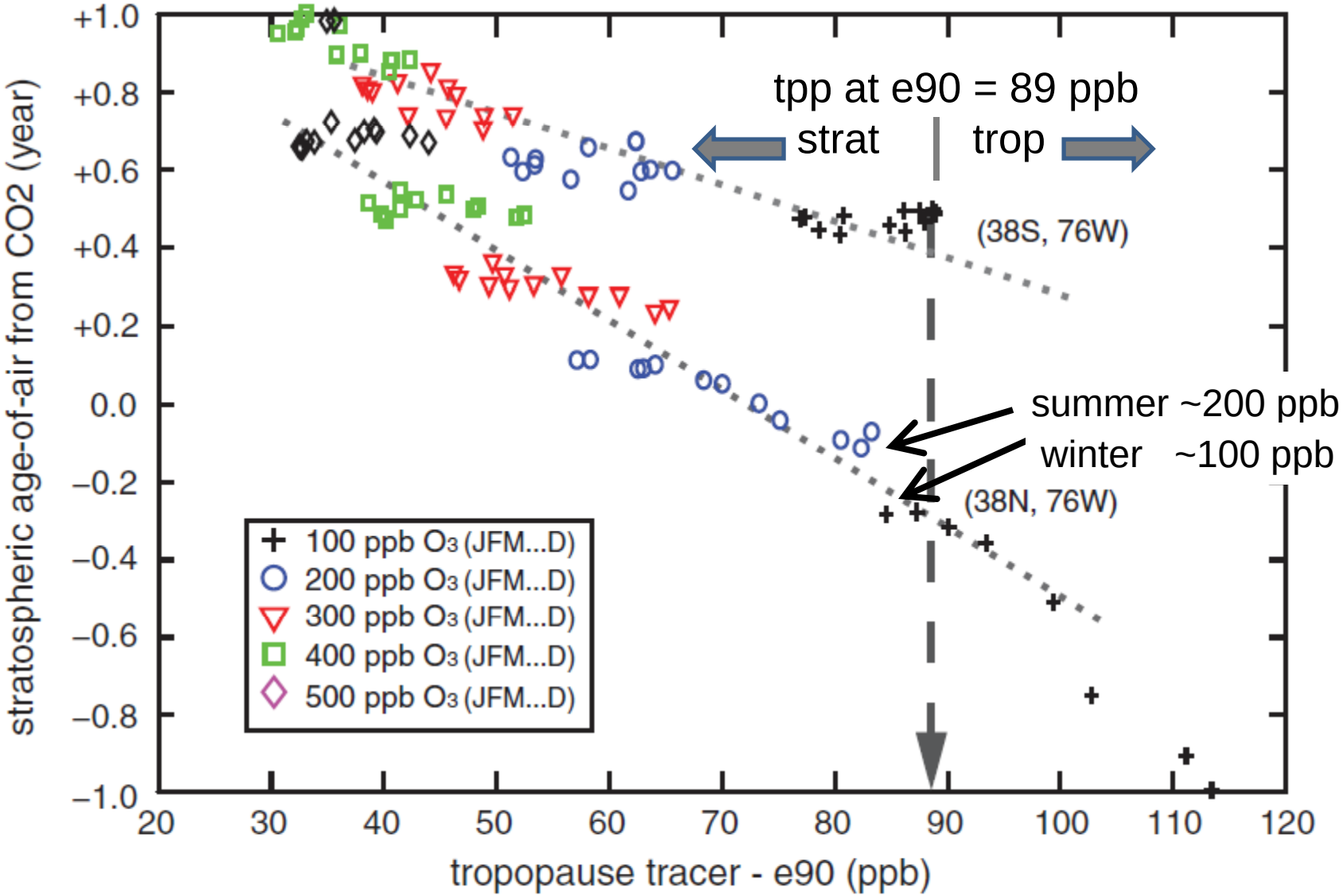


Why not the obvious ? Dynamics !

tropopause moves 'higher' into the stratosphere during summer)

stratospheric age-of-air *vs.* **e90** at Wallops I. (38N) and 38S

+ = 12 months of 100 ppb O3; O = 200; ▽ = 300 ppb; □ = 400 ppb



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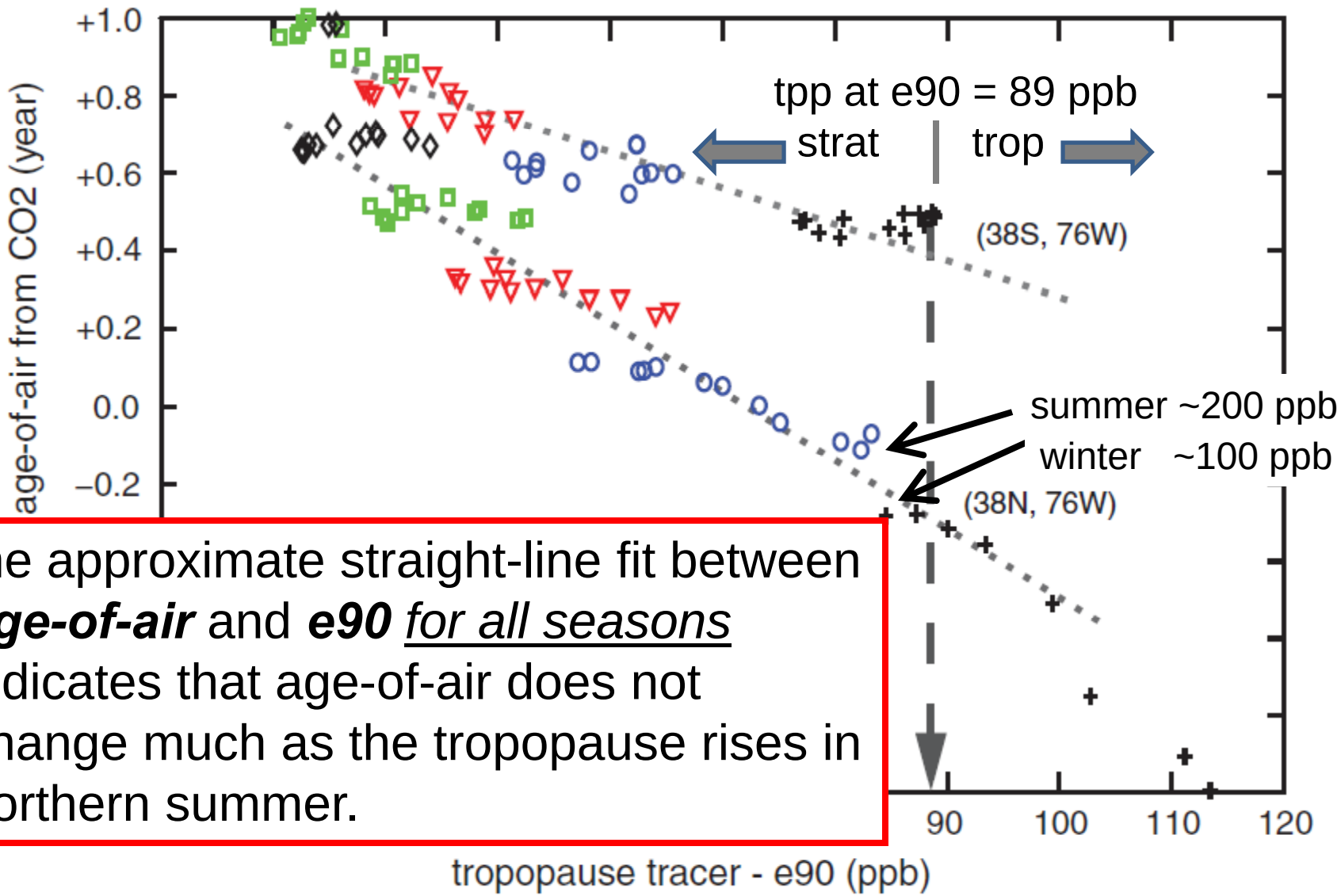
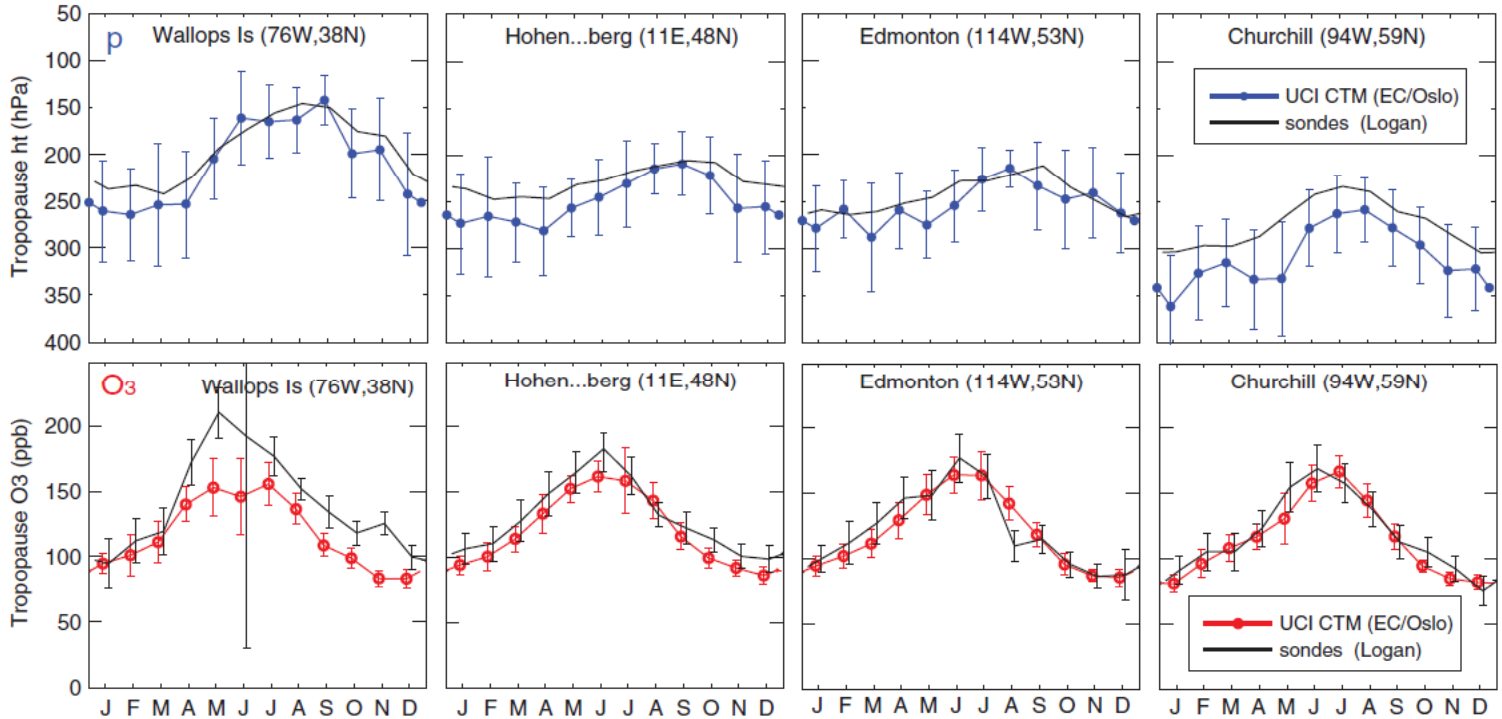


the approximate straight-line fit between ***age-of-air*** and ***e90*** *for all seasons* indicates that age-of-air does not change much as the tropopause rises in northern summer.

e90: ***matches the observed seasonal nature of O_3 at the tropopause***

from ~100 ppb in winter to ~200 ppb in summer in NH mid-lats



Why not the obvious ? Driven by tropospheric O_3 !

although trop O_3 has the same phase, the amplitude in ppb is more than a factor of 2 smaller, and cannot see how it could be amplified.

The ***tracer e90*** gives us a very useful diagnostic for distance from the tropopause in terms of transport, which works well around the jet and folds. This new approach accurately

reproduces the sonde tropopause heights

and

match/explain seasonal variations in tropopause O_3

what are the additional payoffs ?

(1) Find large, systematic bias in use of measurements and models to define the stratospheric age-of-air.

(2) Identify the oldest air in the troposphere.

(3) Accurately match Aura OMI tropospheric column ozone (TCO) on a swath-by-swath basis at 100-km resolution.

stratospheric age-of-air *vs.* **e90** at Wallops I. (38N) and 38S

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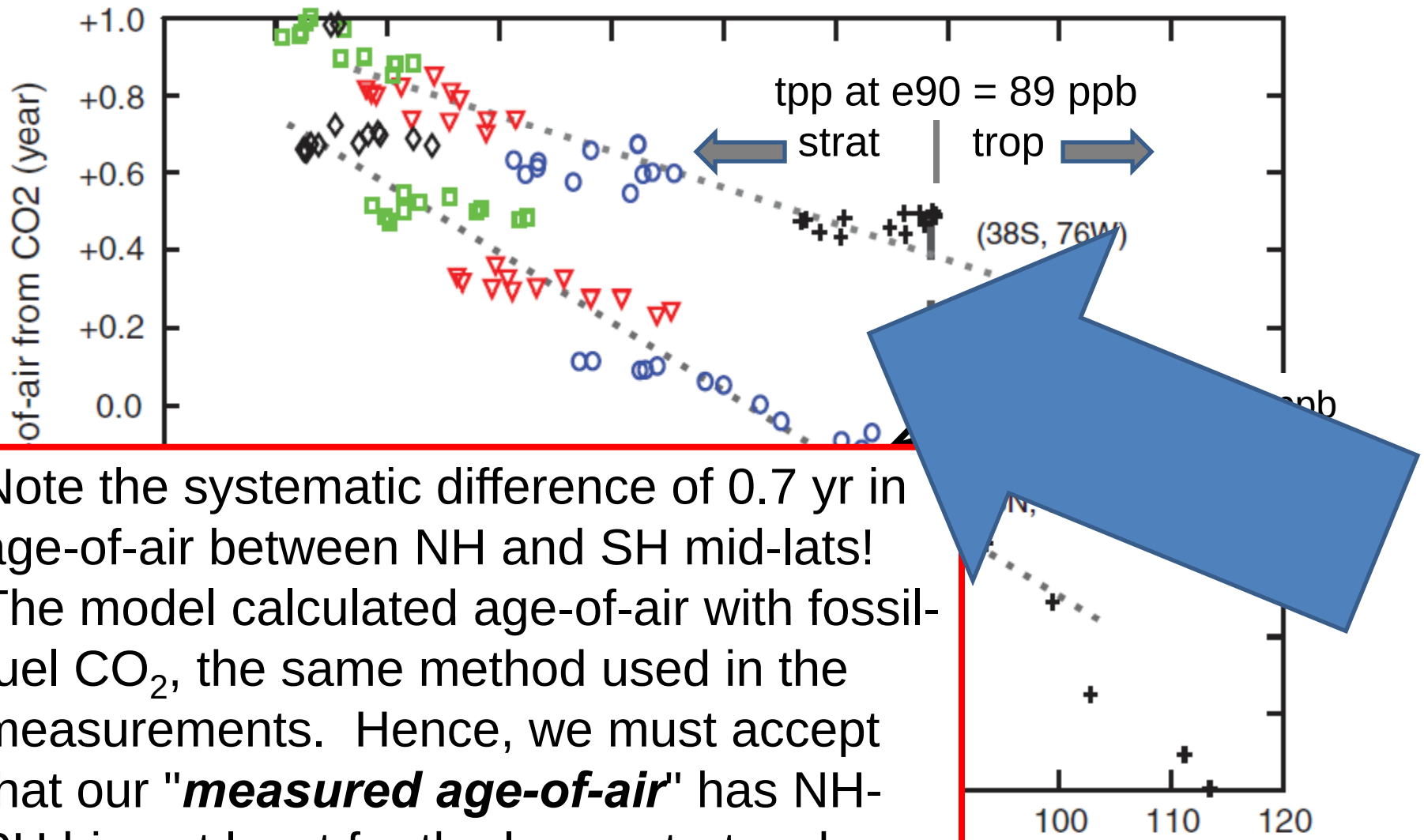

Note the systematic difference of 0.7 yr in age-of-air between NH and SH mid-lats! The model calculated age-of-air with fossil-fuel CO_2, the same method used in the measurements. Hence, we must accept that our "***measured age-of-air***" has NH-SH bias at least for the lower stratosphere.

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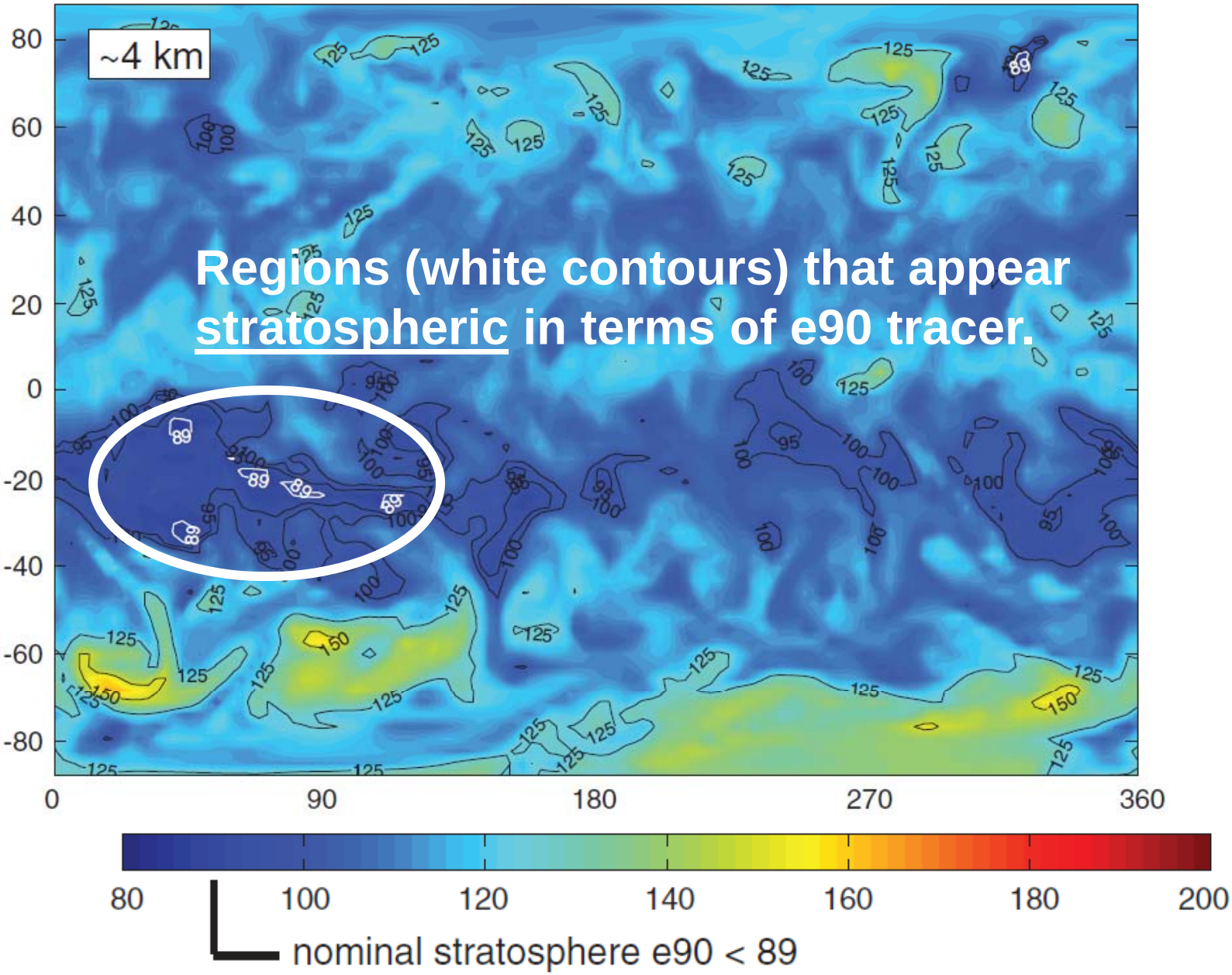
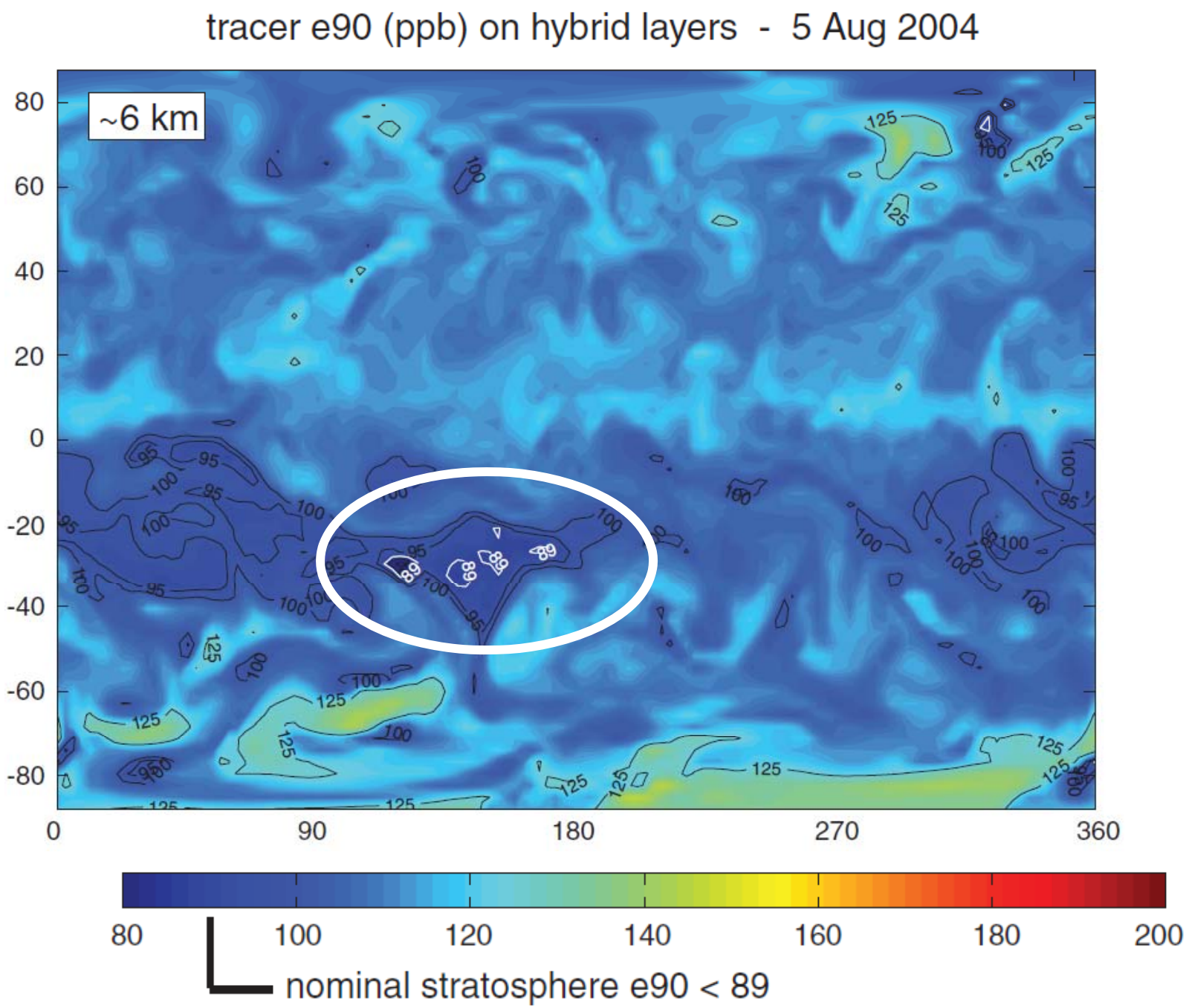
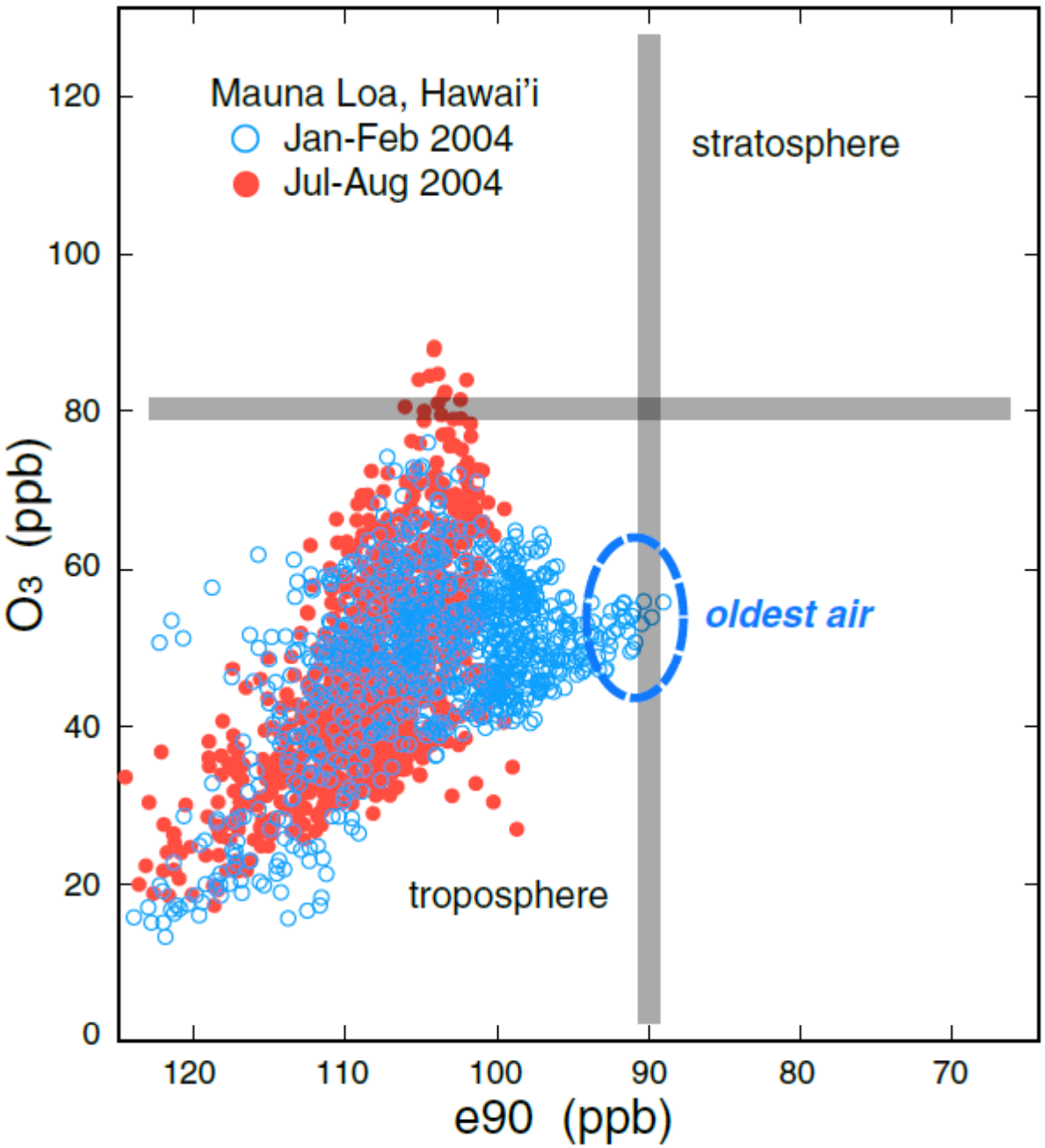
tracer e90 (ppb) on hybrid layers - 5 Aug 2004




tracer e90 (ppb) on hybrid layers - 5 Aug 2004
~6 km
80
60
40
20
0
-20
-40
-60
-80
0
90
180
270
360
80
100
120
140
160
180
200
nominal stratosphere e90 < 89


Mauna Loa, Hawai'i
Jan-Feb 2004
Jul-Aug 2004
stratosphere
oldest air
troposphere
O3 (ppb)
e90 (ppb)
0
20
40
60
80
100
120
120
110
100
90
80
70

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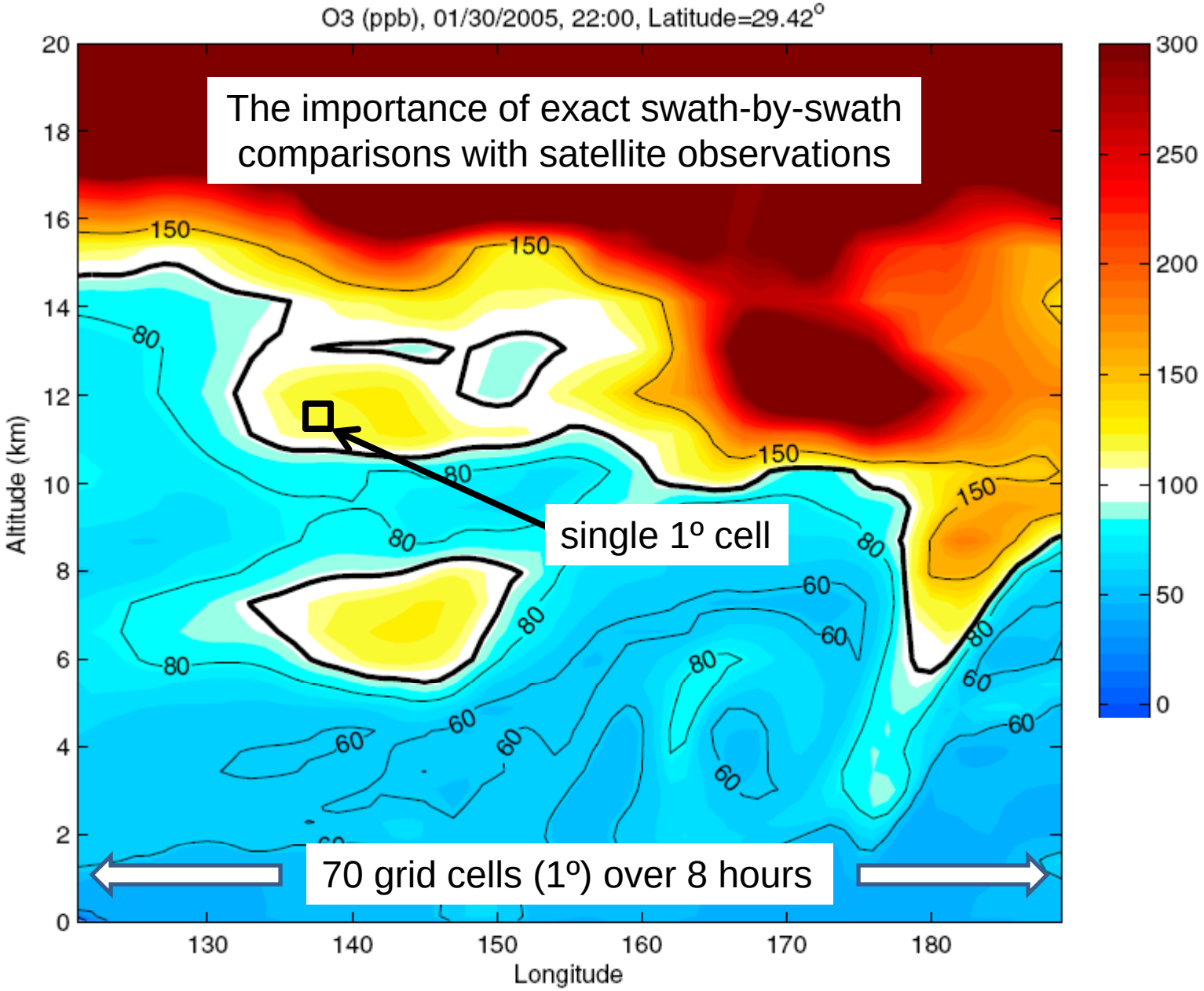

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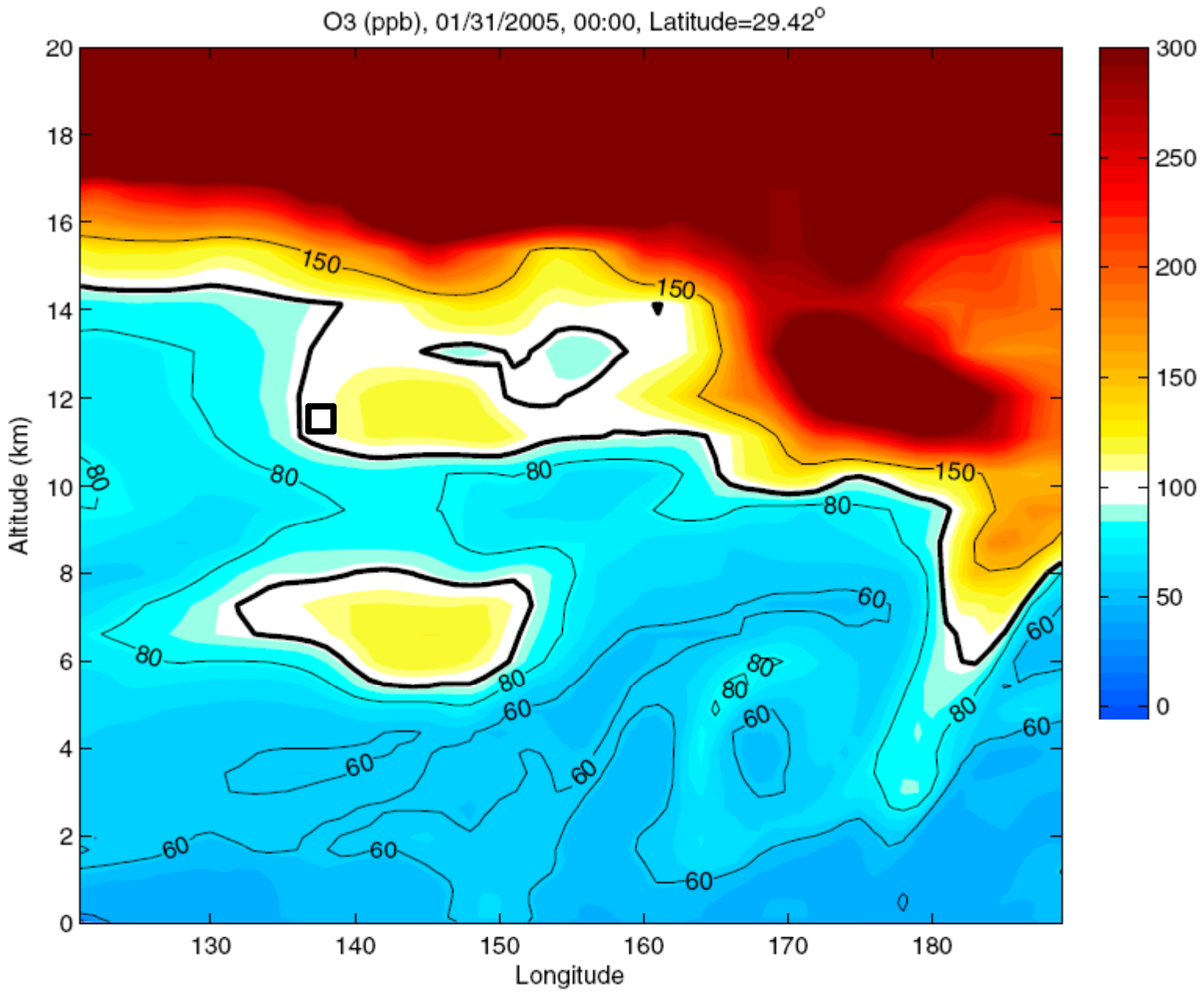

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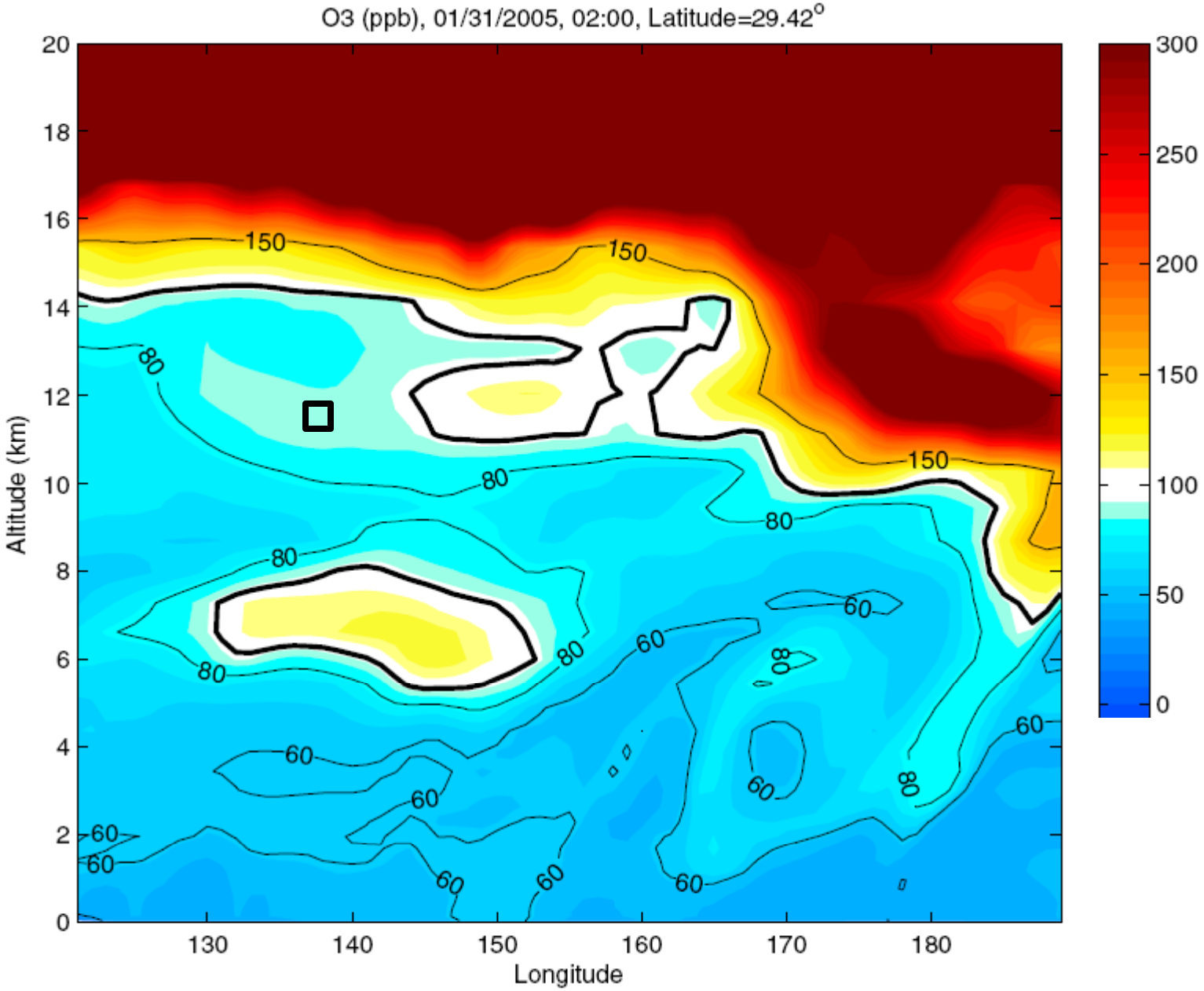

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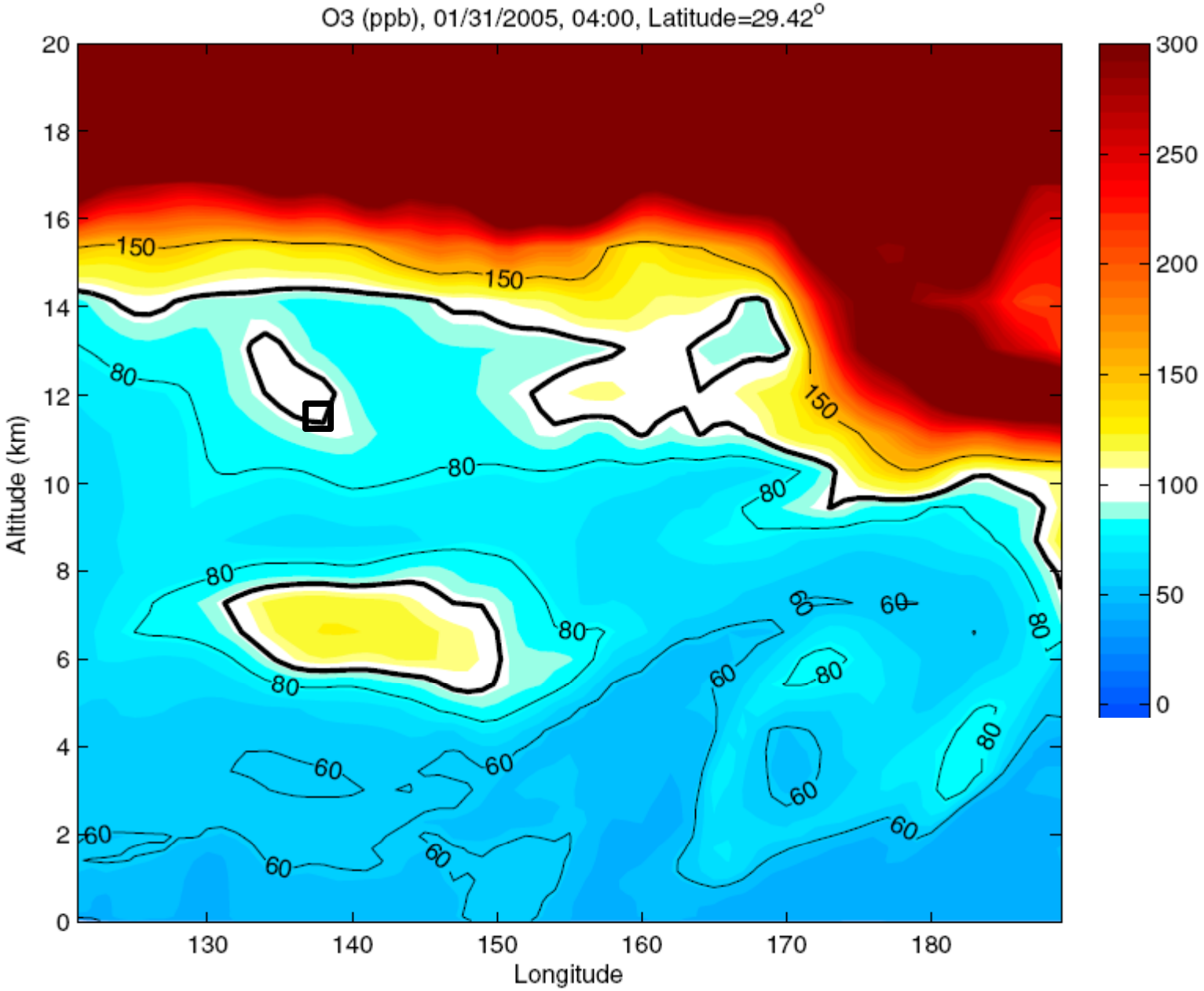

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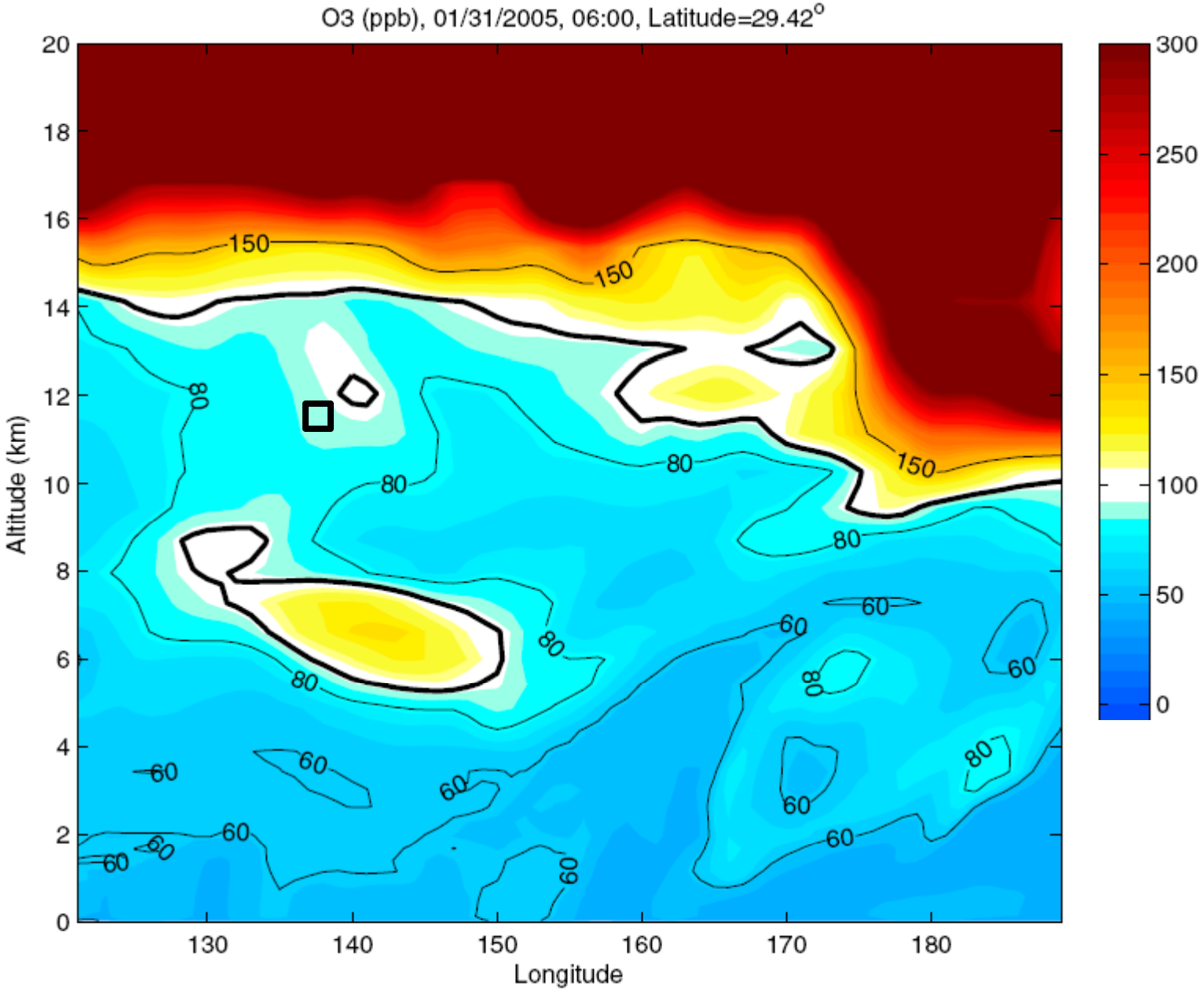

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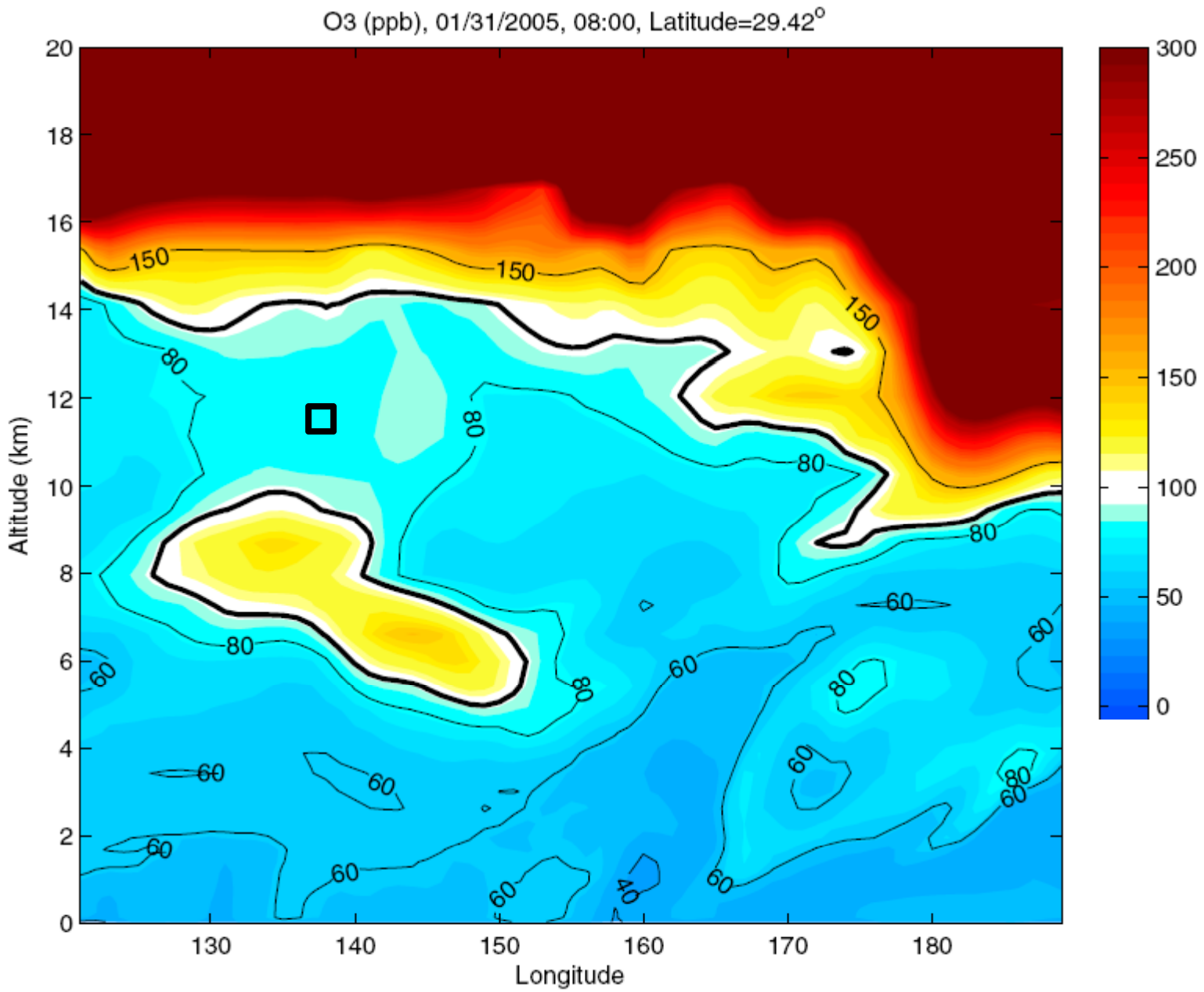

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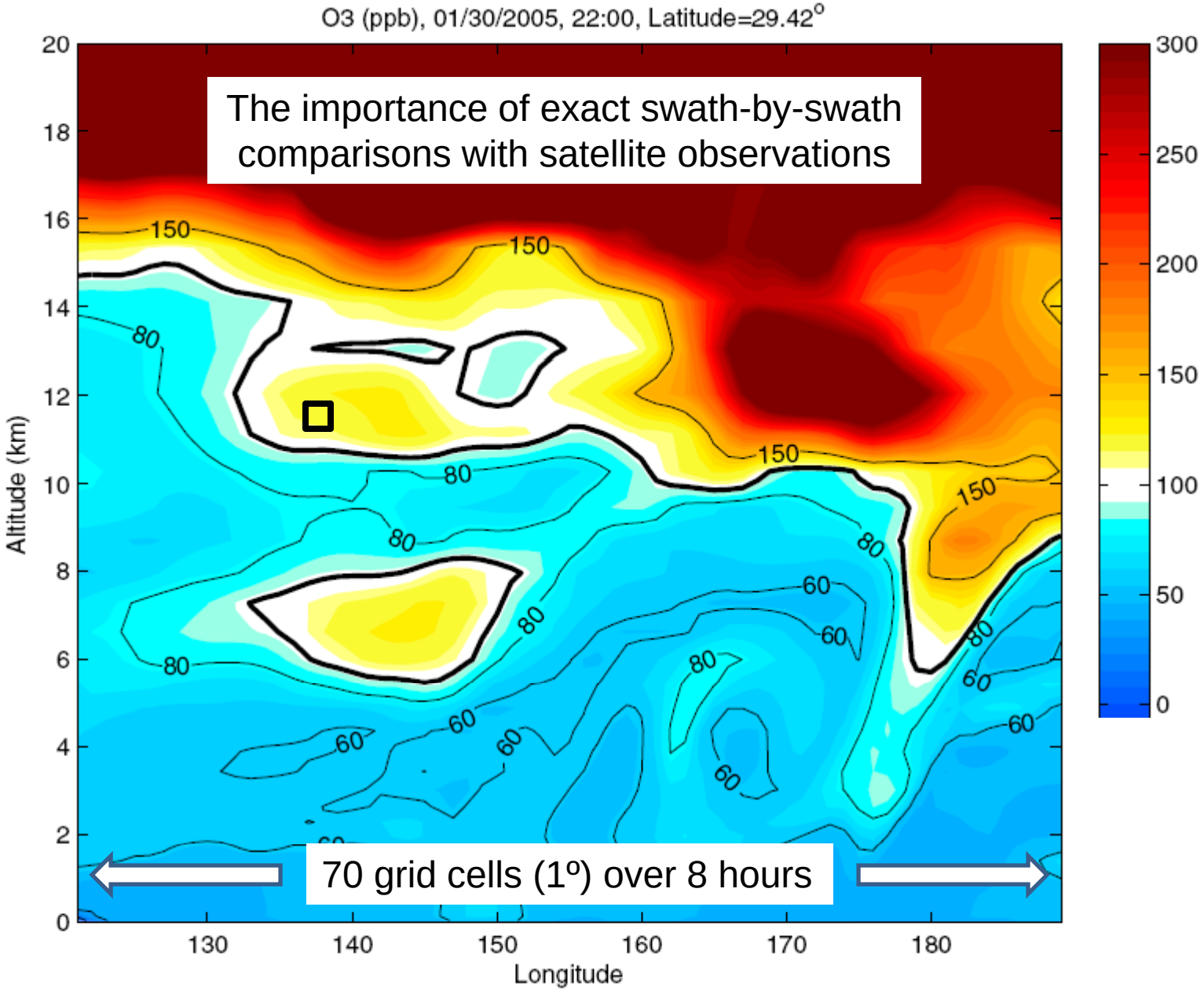

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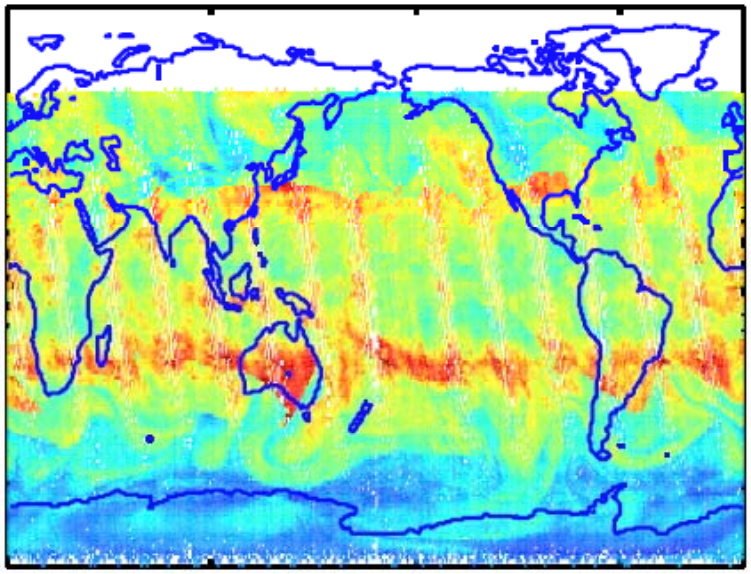
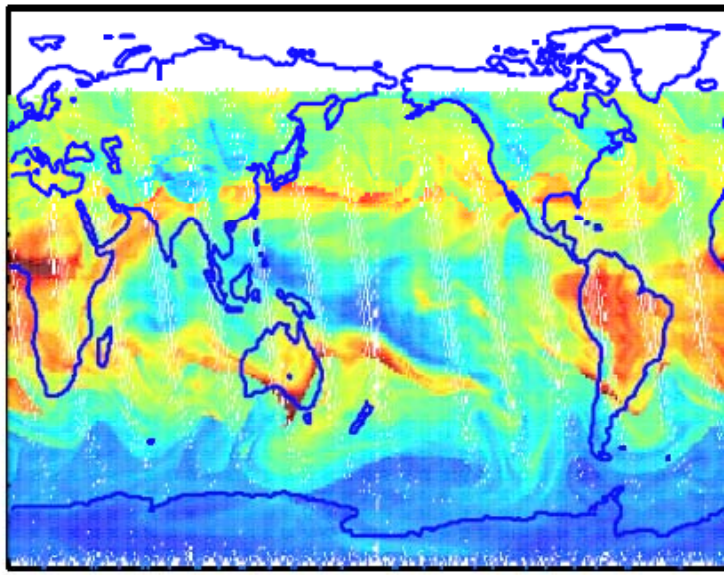
Swath-by-swath comparison of CTM with OMI profile data
using e90 to define the tropopause
shows remarkable agreement and identifies folds
(but not biomass burning or pollution in lower troposphere)

OMI TCO (DU)



CTM TCO (DU)



Tropospheric Ozone Column (DU) for 25 hr begin 00 UTC 3 Dec 2005

The tropopause is really a mixing barrier and hence best diagnosed in 3-D models with a tracer that works globally rather than static stability or PV.

A tropopause tracer (e90) is an ***intrinsic*** property of each air mass and is not based on derivatives across neighboring air masses.

Use of the e90 tropopause generates the seasonality of O_3 in the lower stratosphere, and combined with stratospheric age-of-air, can help explain it.

A clean diagnostic of the tropopause allows for more consistent diagnosis of tropospheric ozone budgets and columns, and for matching of satellite observations.

LA and HOLLYWOOD sign from UCIrvine 7 Mar 2010 1147h

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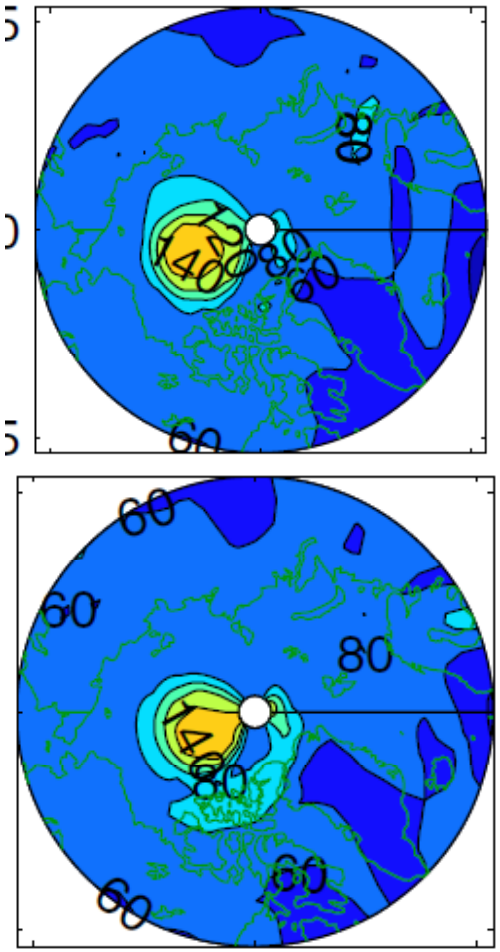
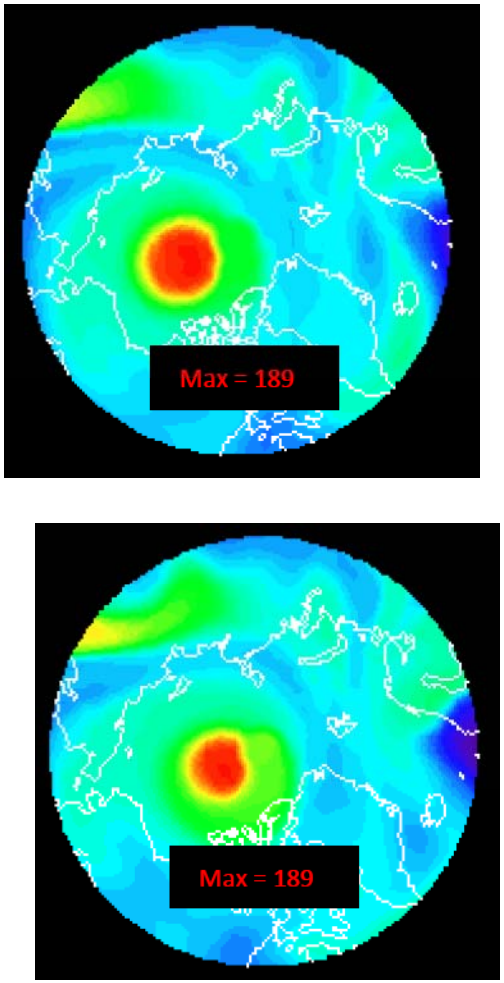
The famous April 2005 blob of N_2O at 750K

UCI CTM ran the 2005 winter through April with T42L60 ECMWF IFS met fields and got a similar result, but lower peak N_2O

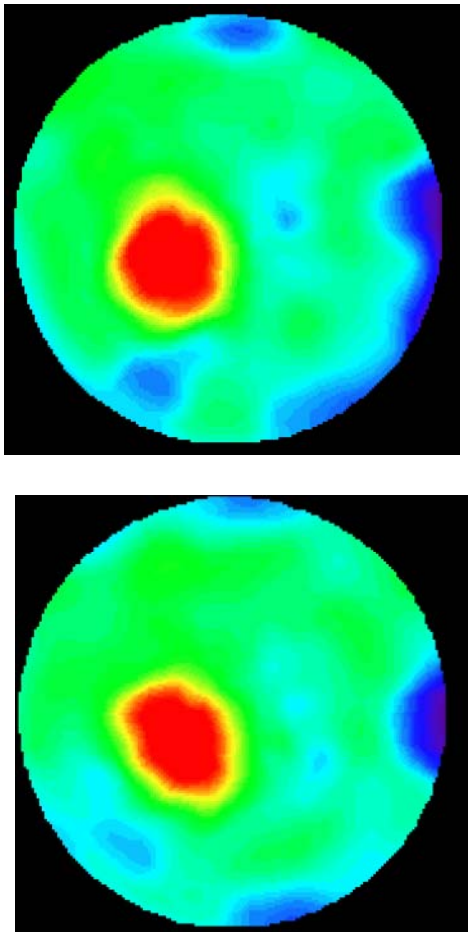
April 8

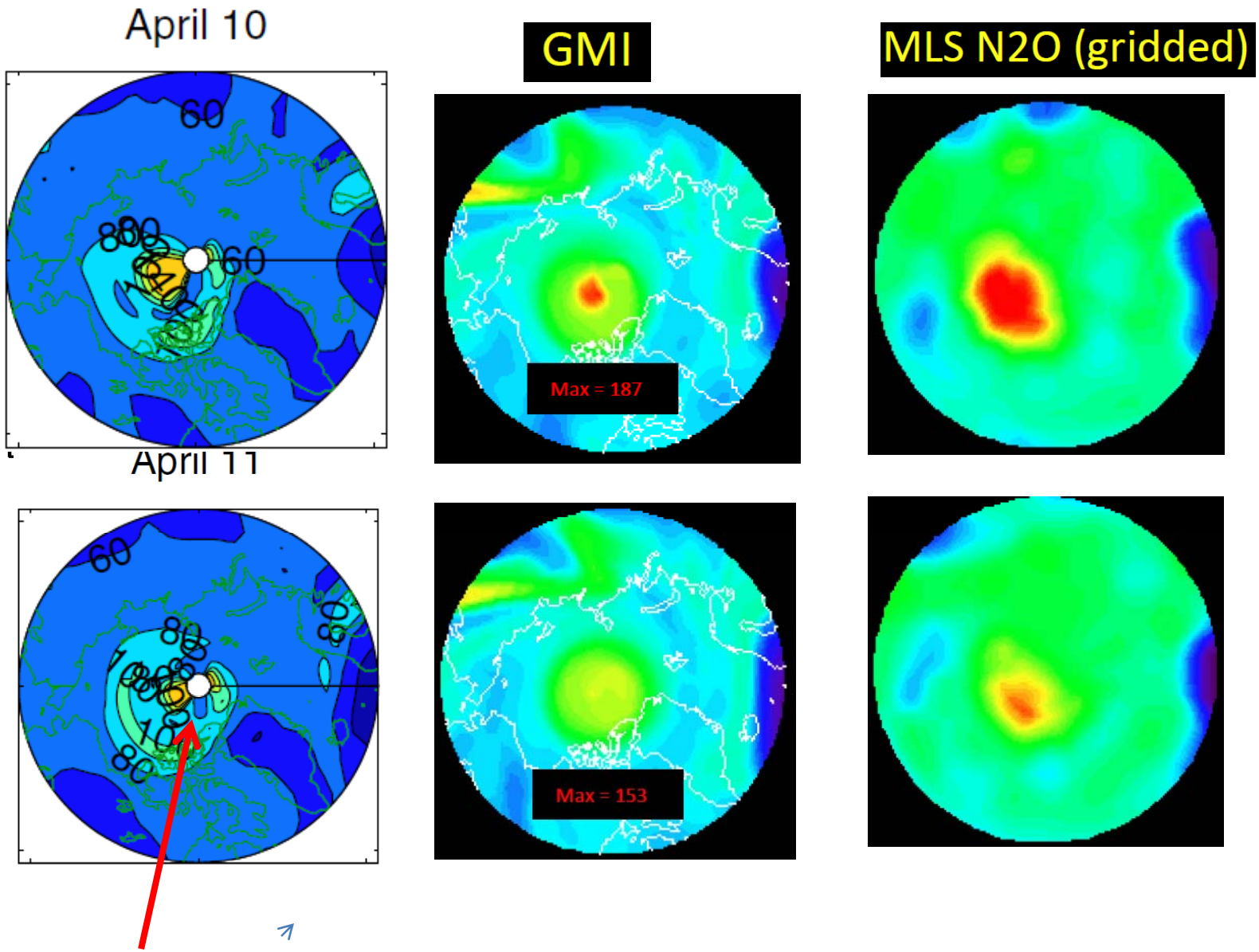


GMI



MLS N2O (gridded)





UCI CTM cross-polar flow still not great.

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(iv) Implement optional tracer-advection code for GMI

UCI CTM ver 5.6 delivered to GMI – SIVO a month ago
has stratospheric Linoz chemistry, e90 t-pause, …
Code is clean and optimized, but OpenMP, not yet MPI
uses ~6.5 out of 8 cpus
T42 full UCI chemistry (16 hrs/yr on 1 $4K board)

UCI CTM ver 6.0 timings : 1x1xL40: **1 day = 22.7 min (**6.4 / 8 cpu)

process	*fraction of time*	
chemistry+J-values	59.4%	
ASAD		46%
fast-JX		13%
advection+convection	22.3%	
OMP (budget & matrix ops)	8.7%	
budgets (3-D tendenies)	3.1%	
winds (read, setup)	1.8%	
diagnostics (avgs, restarts, ...)	1.2%	
scavenging	1.1%	
PBL+dry-dep	0.9%	
Linoz	0.4%	
emissions	0.1%	
remainder	1.0%	

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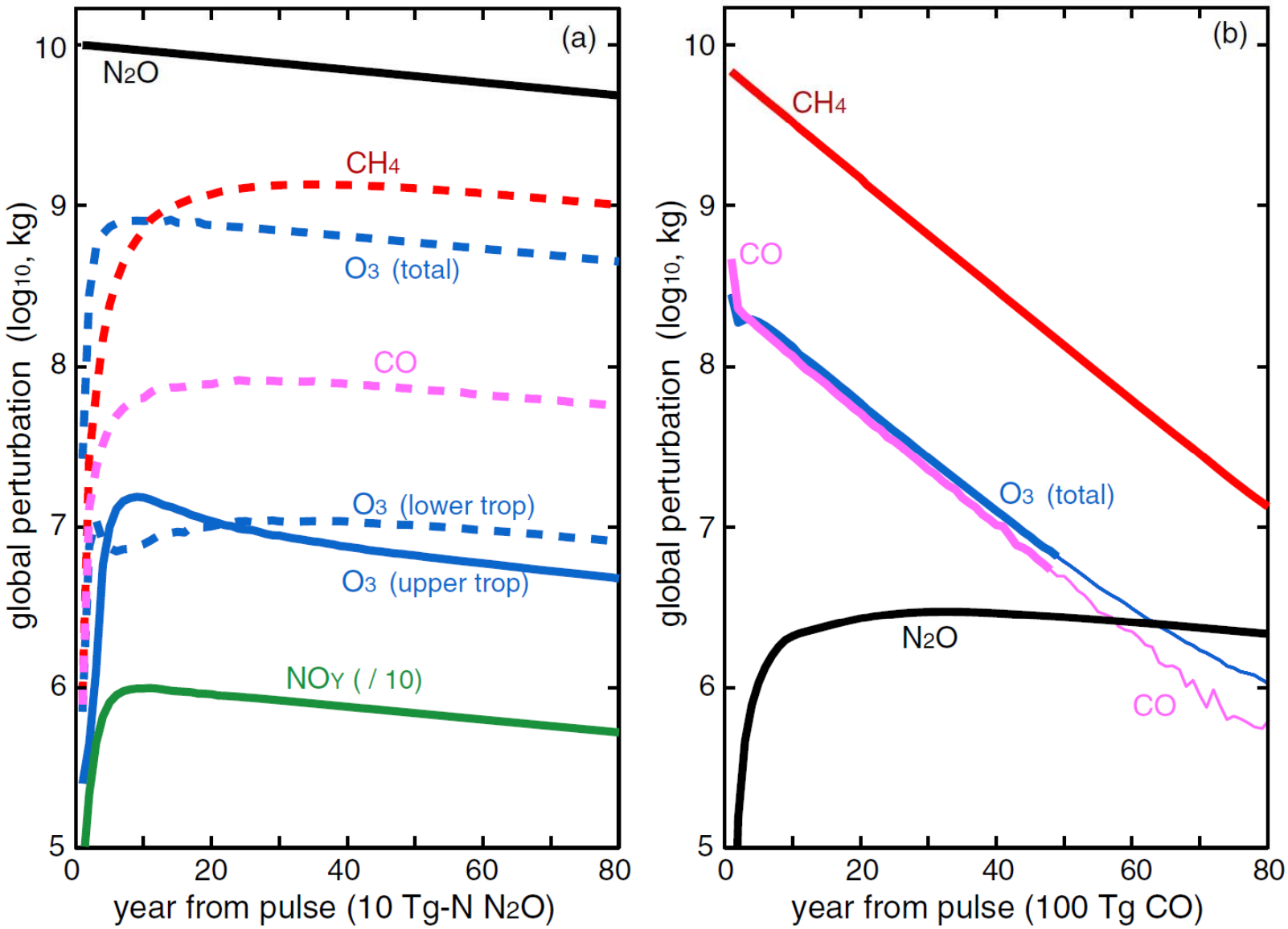
Coupling of Nitrous Oxide and Methane by Global Atmospheric Chemistry

modes with T42L60 full chemistry!



ipcc
INTERGOVERNMENTAL PANEL ON climate change
Working Group I (WG I) – The Physical Science Basis

IPCC AR5 WGI Chapters involving Atmospheric Chemistry?

Chapter 2: Observations: Atmosphere and Surface

Chapter 5: Information from Paleoclimate Archives

Chapter 6: Carbon and Other Biogeochemical Cycles

Chapter 7: Clouds and Aerosols

Chapter 8: Anthropogenic and Natural Radiative Forcing

Chapter 9: Evaluation of Climate Models

~~Chapter 10: Detection and Attribution of Climate Change: from Global to Regional~~

Chapter 11: Near-term Climate Change: Projections and Predictability

Chapter 12: Long-term Climate Change: Projections, Commitments and Irreversibility

ACU5: Atmospheric Composition with Uncertainty for AR5

At a very-preliminary scoping meeting of the AR5's Synthesis Report, Pierre Friedlingstein (for CO_2) and I got concurrence from Tom Stocker that we should try to develop a WGI Appendix that summarizes the RCP scenarios: *emissions, atmospheric abundances, and radiative forcings of the relevant gases and aerosols*. Such an appendix would include global, and possibly regional, values as well as uncertainty ranges. It would be used extensively in WGI and WGII. What goes into AR5, however, is the collective decision and efforts of the CLAs and LAs involved. Inclusion of an AR5 appendix depends on consensus by the chapters who would use/create such a cross-cutting appendix, *and also timely delivery of the science by the community.*

Deadlines:

- **2010 Oct - have plan, identify the diverse working groups**
- **2010 Nov - present to WG1 LA1 meeting**
- **2011 Jan - present to WG2 LA1 meeting**
- **2012 Jan - ACU5 workshop (after results in), i.e. how to do uncertainties.**
- **2012 Jul - cut off date for "submitted" papers (in press by early 2013)**

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As many of you will remember, the community put together our "best values" for 21st century atmospheric composition and radiative forcing for the IPCC SRES scenarios and published them in the *2001 TAR WG1 Appendix*. These have been used extensively over the past decade, including in the 2007 AR4, which did not re-evaluate the SRES. Now in the AR5, with the new RCPs being used to force the climate models, we will again have a set of emissions scenarios from the Integrated Assessment Models (much better and already gridded!) that need to be evaluated by our community. A preliminary set of greenhouse gas abundances to match the RCP emissions has been prepared by M. Meinshausen, S. Smith et al. ("The RCP GHG concentrations and their extension from 1765 to 2500", tbd, Climatic Change, see http://www.iiasa.ac.at/web-apps/tnt/RcpDb/dsd?Action=htmlpage&page=welcome). This effort is a good starting point, but we need the broader community to evaluate the best current methods for mapping emissions of greenhouse gases, aerosols, ozone precursors and other key environmental species into atmospheric abundances, radiative forcing and possibly deposition.

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I think we should treat the RCP emissions as fixed with no uncertainty for the four scenarios. The conversion to atmospheric abundance and radiative forcing must include uncertainty ranges. In the uncertainty analysis we need to be able to separate emission changes from climate change for each RCP scenario.

Current calculation of RCP GHG concentrations:
http://www.iiasa.ac.at/web-apps/tnt/RcpDb/dsd?Action=htmlpage&page=welcome

The final emissions for all RCPs are at:
ftp://ftp-ipcc.fz-juelich.de/pub/emissions/gridded_netcdf/tarfiles/

The CMIP5 site describing the scenarios and data protocols:
http://pcmdi-cmip.llnl.gov/cmip5/output_req.html

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CO_2: (from Friedlingstein), the community intends to runs the different CO_2 abundance scenarios from the AOGCM CMIP5 runs (including climate change) to infer emissions and then compare them with the RCPs as a measure of uncertainty.

IGAC AC&C activities. Evaluation of the atmospheric composition resulting from the AOGCMs running the RCPs (Lamarque and Shindell) is a very important activity, but cannot readily address questions such as "what is the best value for CH_4 in 2050 under RCP 4.5?" or "what is the uncertainty range in that estimate?"

AeroCom is currently submitting updated results that will help us evaluate the sensitivity/uncertainty in projecting aerosol composition and radiative forcing.

HTAP results are complete and written. We can use these to contrain uncertainties.

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Proposal: Use the IGAC and HTAP and AeroCom results, and then design several to many focused studies that address uncertainties in key processes. These studies should be specific and focused on the objective of quantifying the RCPs in terms of atmospheric composition and radiative forcing with probability distributions of the range. Individual studies are focused on producing one or two publications and bringing together a subset of our community (***not*** being as exhaustive as HTAP or AeroCom).

Overall, we need a diverse range of working groups (3-5 PIs per group) that address different aspects of uncertainty and write up their consensus (e.g., what happens to lightning NOx in future climate?) Some recent examples of the type of investigations that assess key sensitivities include Wild 2007 (ACP 7, 2643–2660), Stevenson & Derwent 2009 (GRL 36, L17810).

For a data archive, we could possible use the PCMDI CMIP5 setup, providing we conform to the standards (need to check it is available).

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GOAL: deliver the equivalent of the tables in the 2001 TAR appendix with uncertainties, so that we can use them in the many chapters of the AR5, including the impacts sections in WGII.

NEXT STEPS:
Outline the overall approach in greater detail (i.e., for each species to be projected).
Identify the likely individual studies (with their leads and possible teams) to evaluate the key uncertainties and write up the papers.
Prepare detailed outline to first Lead Author meetings of WGI and WGII (? WGIII)

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