The Walker-circulation pattern in upper tropospheric O_3 measured across three satellite instruments: a robust test of chemistry-transport models

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[2] now at Lawrence Livermore National Laboratory
This work is based on Qi Tang's dissertation research (2011)

the Walker Circulation

the fascination with longitudinal structures in the tropical troposphere goes back to G.T. Walker (1923) and R. B. Montgomery (1940) in explaining tropical meteorology.

the identification of related longitudinal structures in tropospheric ozone also has

the allure of the tropics.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. D10, PAGES 18,679–18,687, OCTOBER 20, 1991

On the Ozone Minimum Over the Equatorial Pacific Ocean

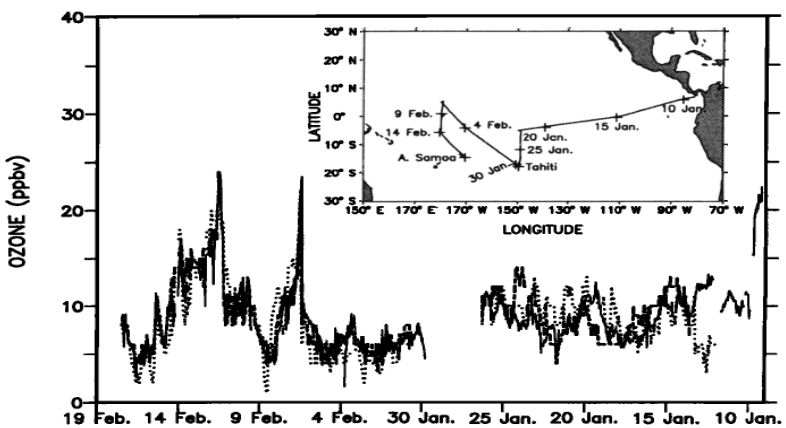
STEPHEN R. PIOTROWICZ, HUGO F. BEZDEK, GEORGE R. HARVEY, AND MARGIE SPRINGER-YOUNG

National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

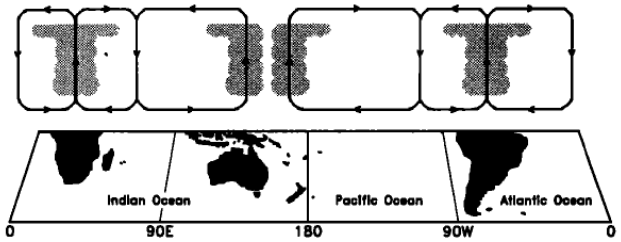
KIRBY J. HANSON

National Oceanic and Atmospheric Administration, Air Resources Laboratory, Miami, Florida

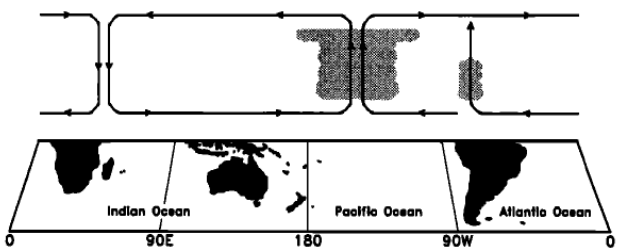
PIOTROWICZ ET AL.: OZONE OVER THE EQUATORIAL PACIFIC OCEAN



PIOTROWICZ ET AL.: OZONE OVER THE EQUATORIAL PACIFIC OCEAN



b.



Schematic of the Walker circulation during periods of (*a*) equatorial cooling and (*b*) equatorial warming

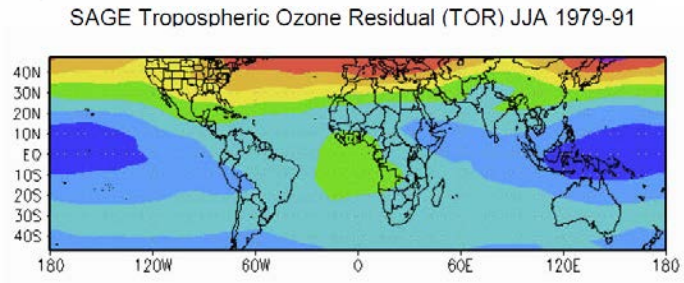
longitudinal patterns in tropospheric column O_3 (DU) are found

Atmos. Chem. Phys., 3, 893–907, 2003
www.atmos-chem-phys.org/acp/3/893/

Atmospheric Chemistry and Physics

Global distribution of tropospheric ozone from satellite measurements using the empirically corrected tropospheric ozone residual technique: Identification of the regional aspects of air pollution

J. Fishman[1], A. E. Wozniak[1,2,3], and J. K. Creilson[1,2]



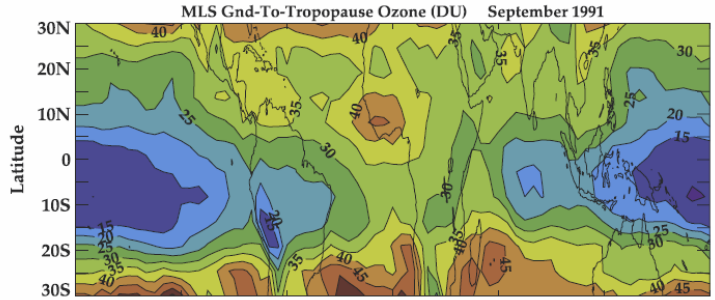
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D9, 4291, doi:10.1029/2002JD002912, 2003

Tropospheric ozone at tropical and middle latitudes derived from TOMS/MLS residual: Comparison with a global model

S. Chandra
NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

J. R. Ziemke
Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, Maryland, USA

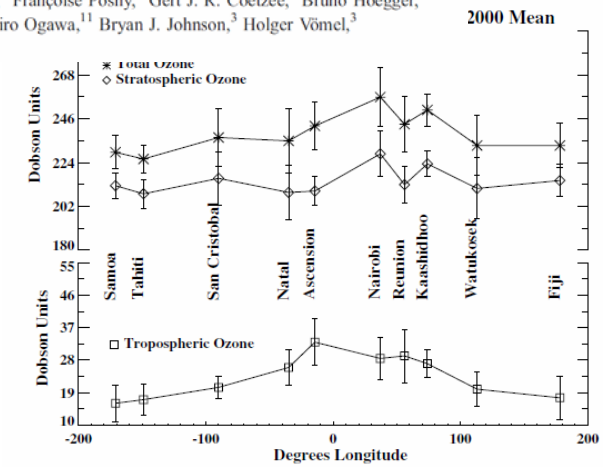
R. V. Martin[1]
Department of Earth
Massachusetts, US



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D2, 8238, doi:10.1029/2001JD000967, 2003

Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998–2000 tropical ozone climatology
1. Comparison with Total Ozone Mapping Spectrometer (TOMS) and ground-based measurements

Anne M. Thompson,[1] Jacquelyn C. Witte,[1,2] Richard D. McPeters,[1] Samuel J. Oltmans,[3] Francis J. Schmidlin,[4] Jennifer A. Logan,[5] Masatomo Fujiwara,[6] Volker W. J. H. Kirchhoff,[7] Françoise Posny,[8] Gert J. R. Coetzee,[9] Bruno Hoegger,[10] Shuji Kawakami,[11] Toshihiro Ogawa,[11] Bryan J. Johnson,[3] Holger Vömel,[3] and Gordon Labow[1,2]



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. D18, 4351, doi:10.1029/2001JD001480, 2002

Interpretation of TOMS observations of tropical tropospheric ozone with a global model and in situ observations

Randall V. Martin, Daniel J. Jacob, Jennifer A. Logan, Isabelle Bey,[1] Robert M. Yantosca, Amanda C. Staudt,[2] Qinbin Li, Arlene M. Fiore, Bryan N. Duncan,[1] and Hongyu Liu
Division of Engineering and Applied Sciences and Department of Earth and Planetary Sciences, Harvard University, Cambridge, Massachusetts, USA

Paul Ginoux[3]
School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, USA

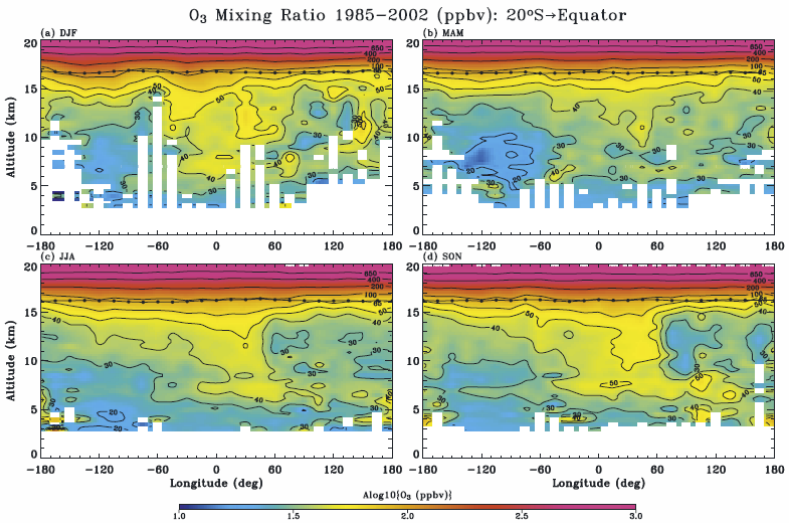
Valerie Thouret
Laboratoire d'Aérologie CNRS (UMR 5500), Toulouse, France

longitudinal patterns in tropospheric O_3 abundance (ppb) are rarer and subject to many gaps and long-period averages.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D08305, doi:10.1029/2005JD006221, 2006

Southern tropical upper tropospheric zonal ozone wave-1 from SAGE II observations (1985–2002)

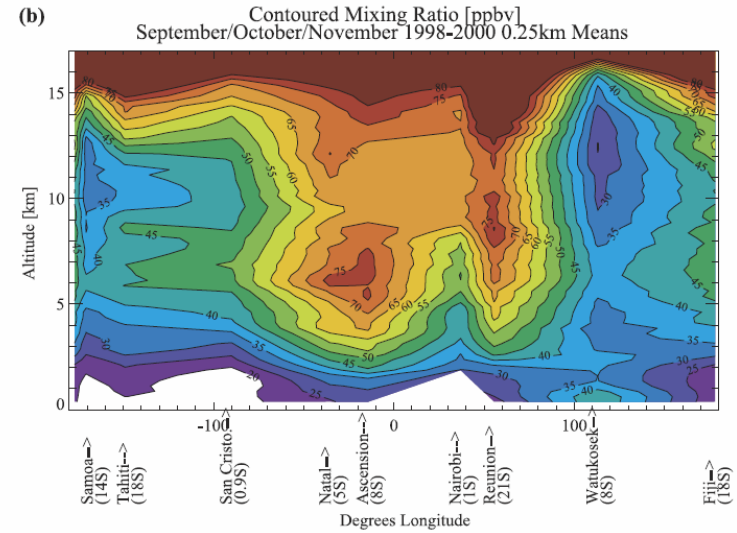
Pi-Huan Wang,[1] Jack Fishman,[2] V. Lynn Harvey,[3] and Matthew H. Hitchman[4]



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D2, 8241, doi:10.1029/2002JD002241, 2003

Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998–2000 tropical ozone climatology
2. Tropospheric variability and the zonal wave-one

Anne M. Thompson,[1] Jacquelyn C. Witte,[1,2] Samuel J. Oltmans,[3] Francis J. Schmidlin,[4] Jennifer A. Logan,[5] Masatomo Fujiwara,[6] Volker W. J. H. Kirchhoff,[7] Françoise Posny,[8] Gert J. R. Coetzee,[9] Bruno Hoegger,[10] Shuji Kawakami,[11] Toshihiro Ogawa,[11] J. P. F. Fortuin,[12] and H. M. Kelder[12,13]



GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L13706, doi:10.1029/2011GL047865, 2011

The response of tropical tropospheric ozone to ENSO

L. D. Oman,[1] J. R. Ziemke,[1,2] A. R. Douglass,[1] D. W. Waugh,[3] C. Lang,[3] J. M. Rodriguez,[1] and J. E. Nielsen[1,4]

[1] We have successfully reproduced the Ozone ENSO Index (OEI) in the Goddard Earth Observing System (GEOS) chemistry-climate model (CCM) forced by observed sea surface temperatures over a 25-year period. The vertical ozone response to ENSO is consistent with changes in the Walker circulation. We derive the sensitivity of simulated ozone to ENSO variations using linear regression analysis. The western Pacific and Indian Ocean region shows similar positive ozone sensitivities from the surface to the upper troposphere, in response to positive anomalies in the Niño 3.4 Index. The eastern and central Pacific region shows negative sensitivities with the largest sensitivity in the upper troposphere. This vertical response compares well with that derived from SHADOZ ozonesondes in each region. The OEI reveals a response of tropospheric ozone to circulation change that is nearly independent of changes in emissions and thus it is potentially useful in chemistry-climate model evaluation. **Citation:** Oman, L. D., J. R. Ziemke, A. R. Douglass, D. W. Waugh, C. Lang, J. M. Rodriguez, and J. E. Nielsen (2011), The response of tropical tropospheric ozone to ENSO, *Geophys. Res. Lett.*, *38*, L13706, doi:10.1029/2011GL047865.

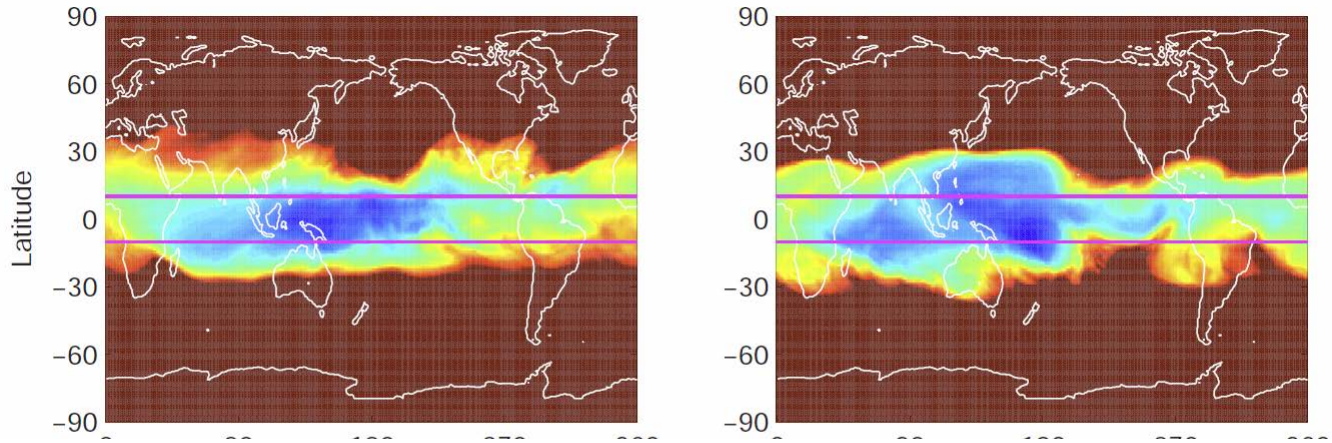
Aura has four instruments measuring ***tropical tropospheric O_3***, with HIRDLS, MLS, & TES reporting reliable measurements of the O_3 abundance in the upper tropical troposphere.

Using this data, we establish a high-resolution, low-bias upper-trop O_3 climatology that is a standard test of chemistry-climate models.

UCI CTM *(Tang & Prather, 2012 ACP, 2357–2380; 2012 ACP 10441-10452)* simulates (hindcast mode) each instrument's measurement of 10˚S-10˚N O_3 at 147 hPa, recognizing that none of the three observe at the same location and time.

Similar to Livesey et al *(2013 ACP 579-598)* we accumulate monthly statistics but with much finer longitude resolution (4˚) since the model indicates basic longitude patterns at that scale.

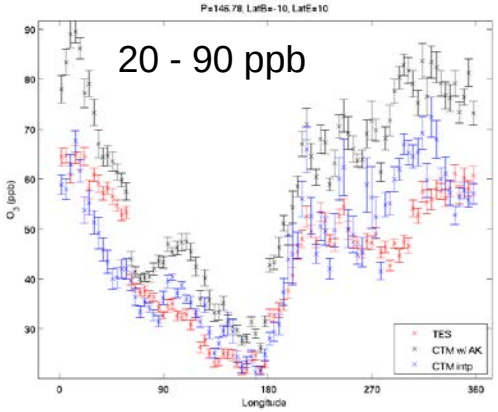
focus on 10˚S - 10˚N to avoid sub-tropical jet and fold issues



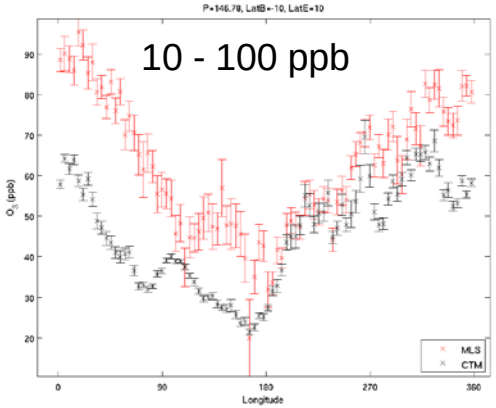
modeled ozone (ppb) at 150 hPa for July 2005 (left panel) and January 2006 (right panel)

pick 150 hPa (~13 km) to try to be clear of the tropical tropopause ‘spillover’.
resolve monthly longitudinal patterns in 90 bins (4˚).

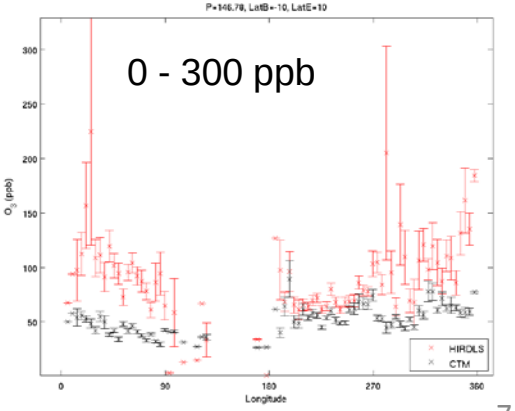
Jan 2006: **TES** vs CTM/CTM



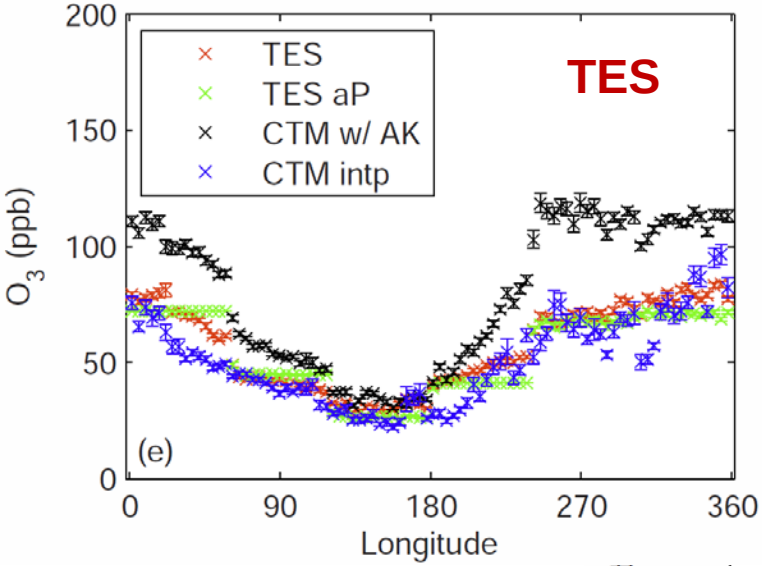
MLS vs CTM



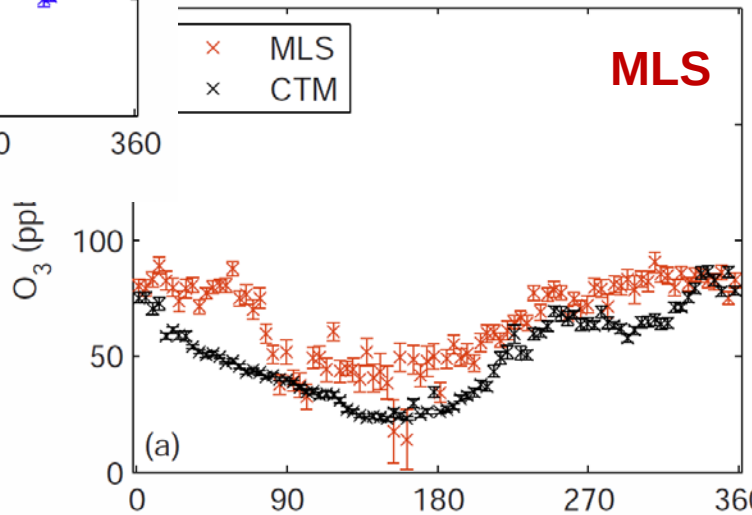
HIRDLS vs CTM

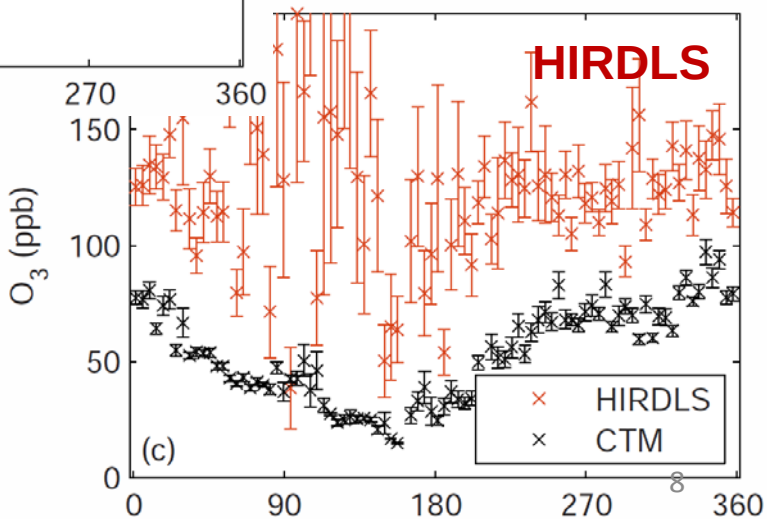


Jul 2005

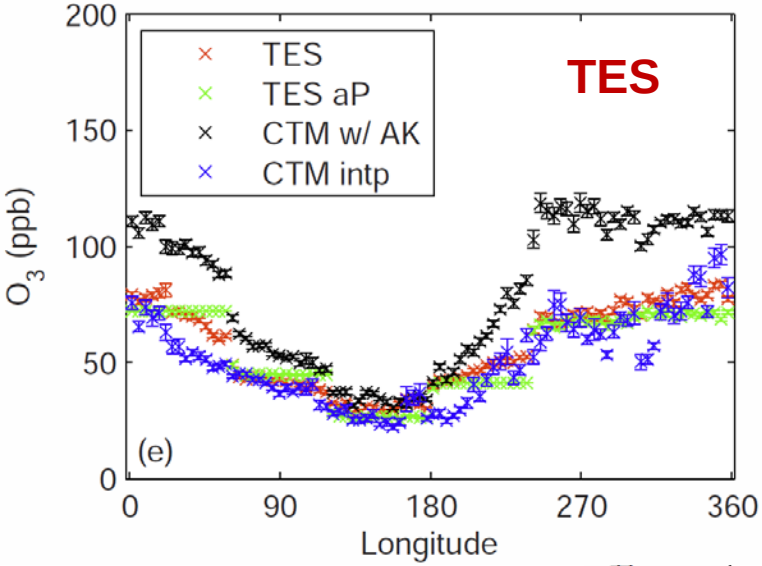


find Walker-like pattern in all 3 Aura obs.

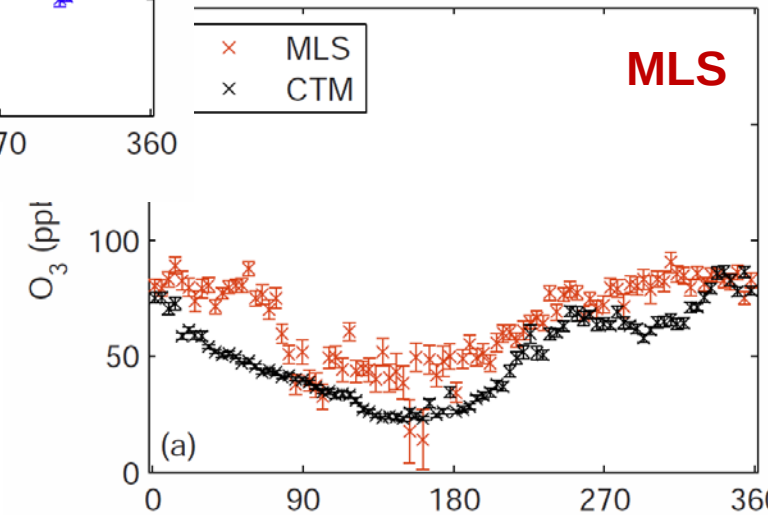


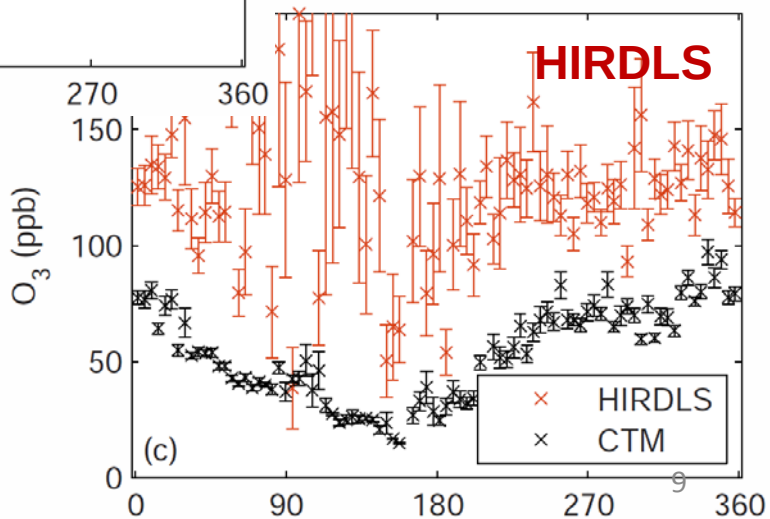


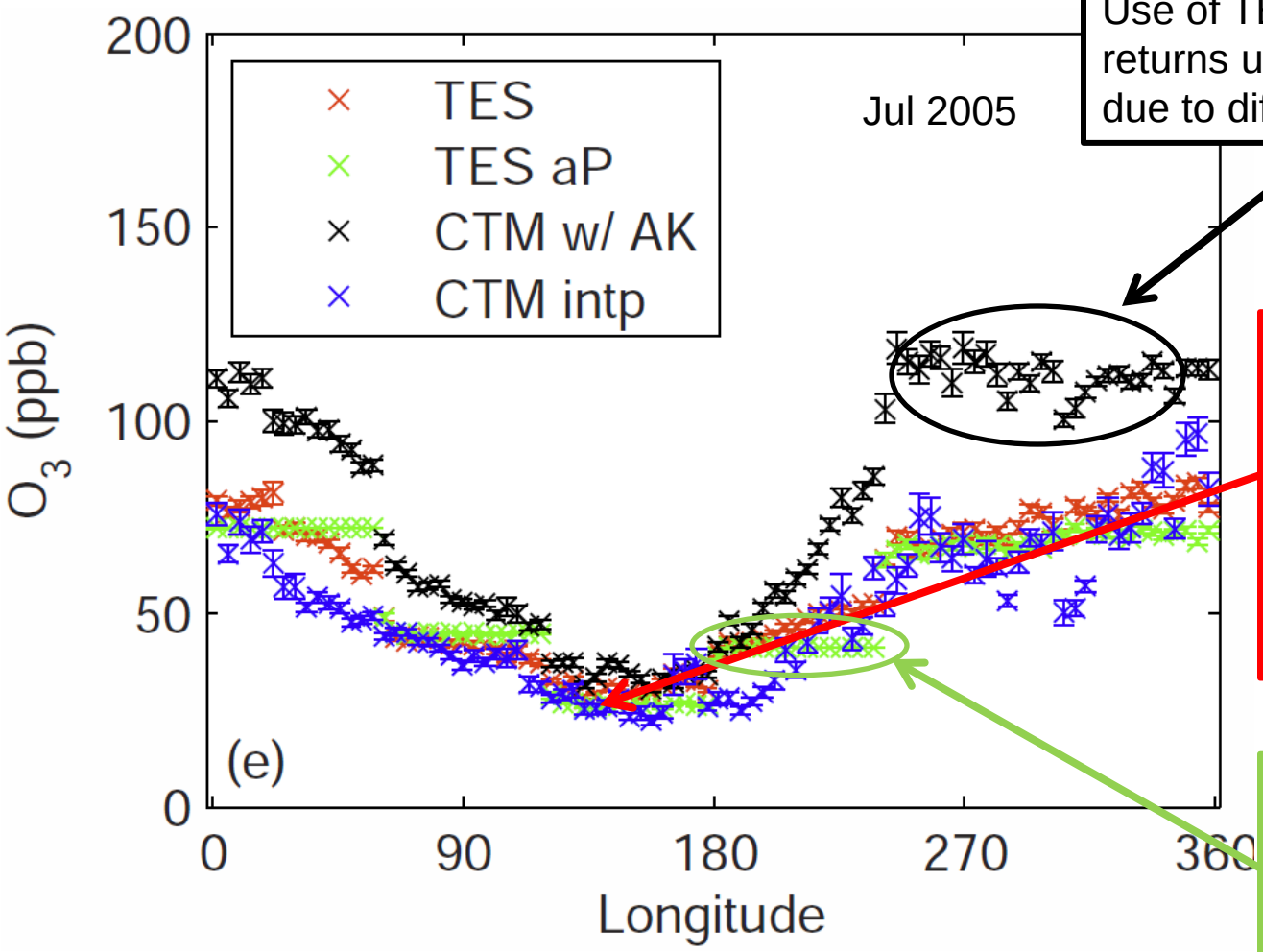
Jul 2005



find Walker-like pattern in all 3 Aura obs.







CTM+AK

Use of TES Avg Kernel with CTM: returns unphysical O_3 in trop. due to diff's in TES-CTM strat O_3.

TES

CTM

both match well and show a clear Walker-like pattern !!

but.....

TES

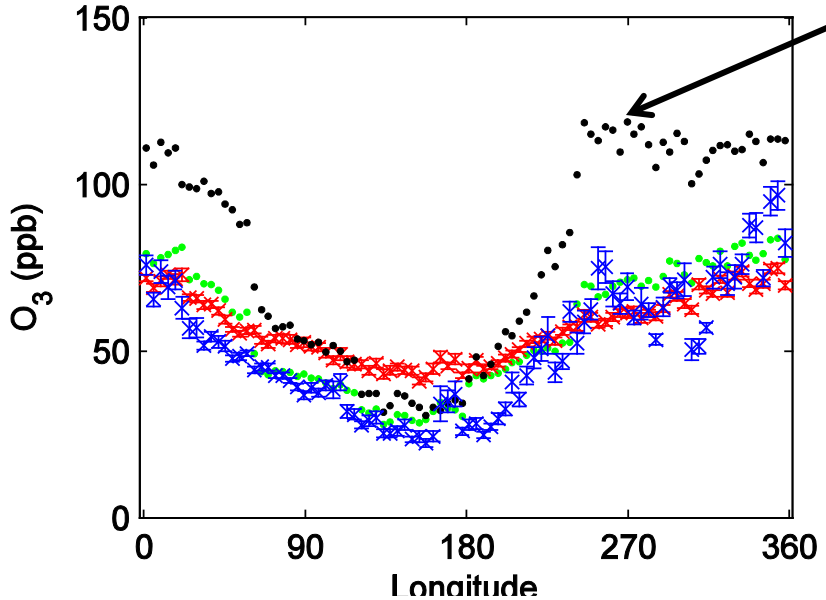
and

a priori

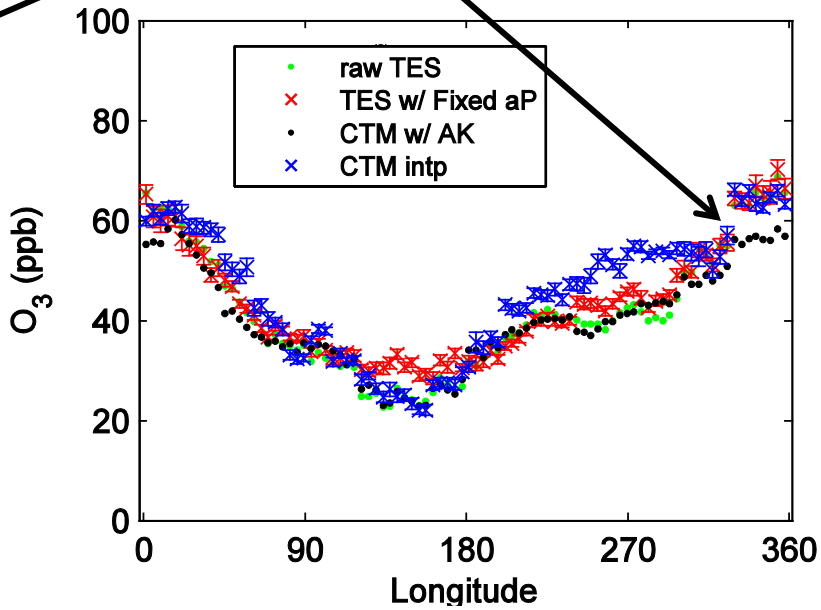
look alike. Are we just matching MOZART?

Not surprisingly, if we do this at 500 hPa, the CTM+AK is not that different from the raw CTM and is 'physical' (far enough from stratospheric differences between CTM and TES a priori.

Jul 2005: 147 hPa



511 hPa

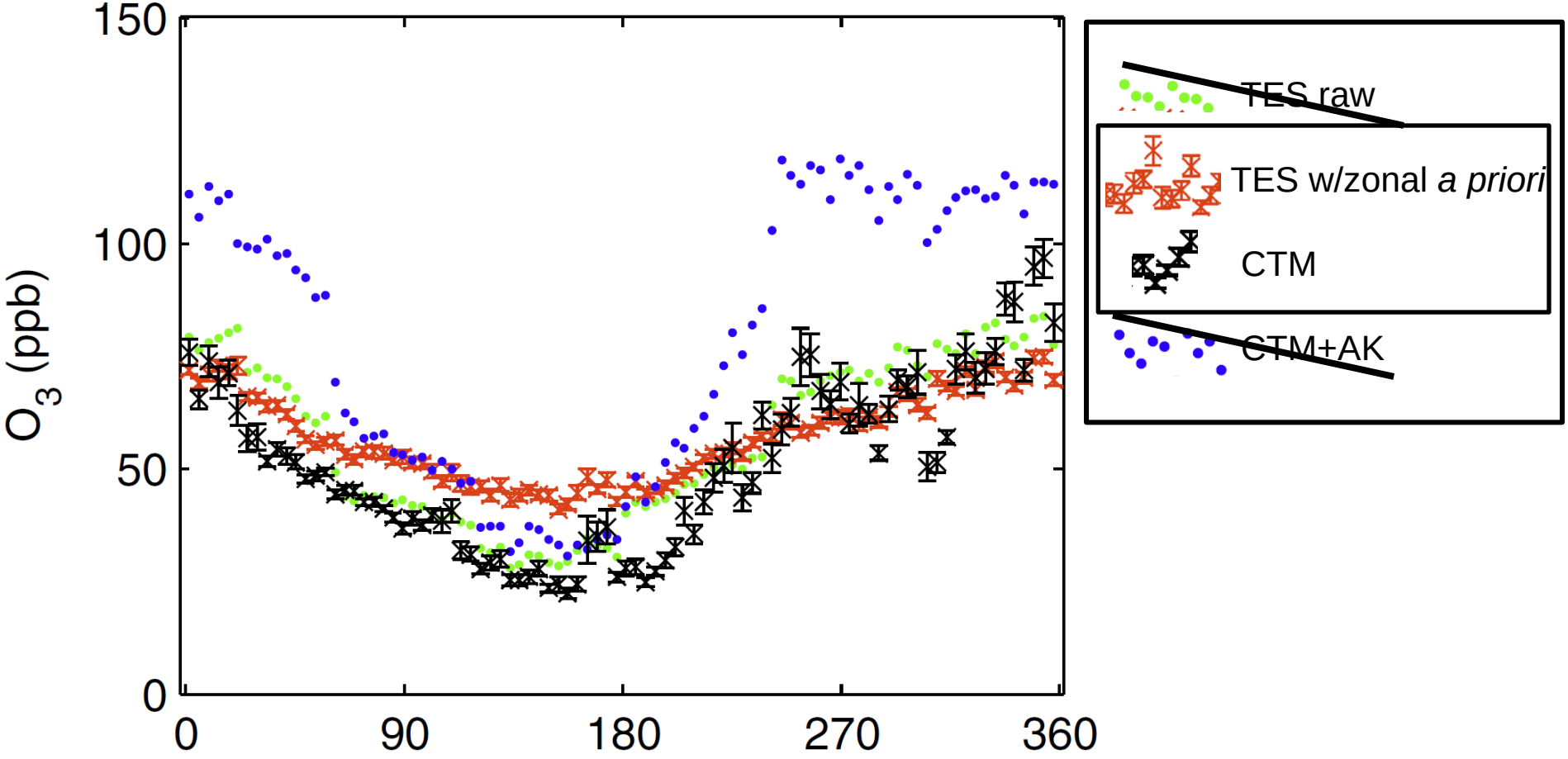


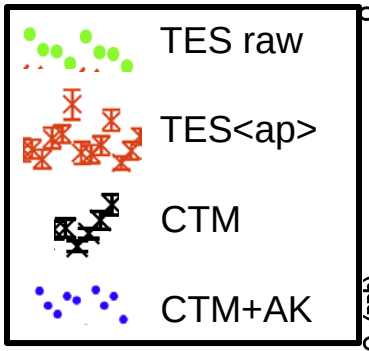
No surprise, Walker pattern seen at both 150 & 500 hPa, similar but different.

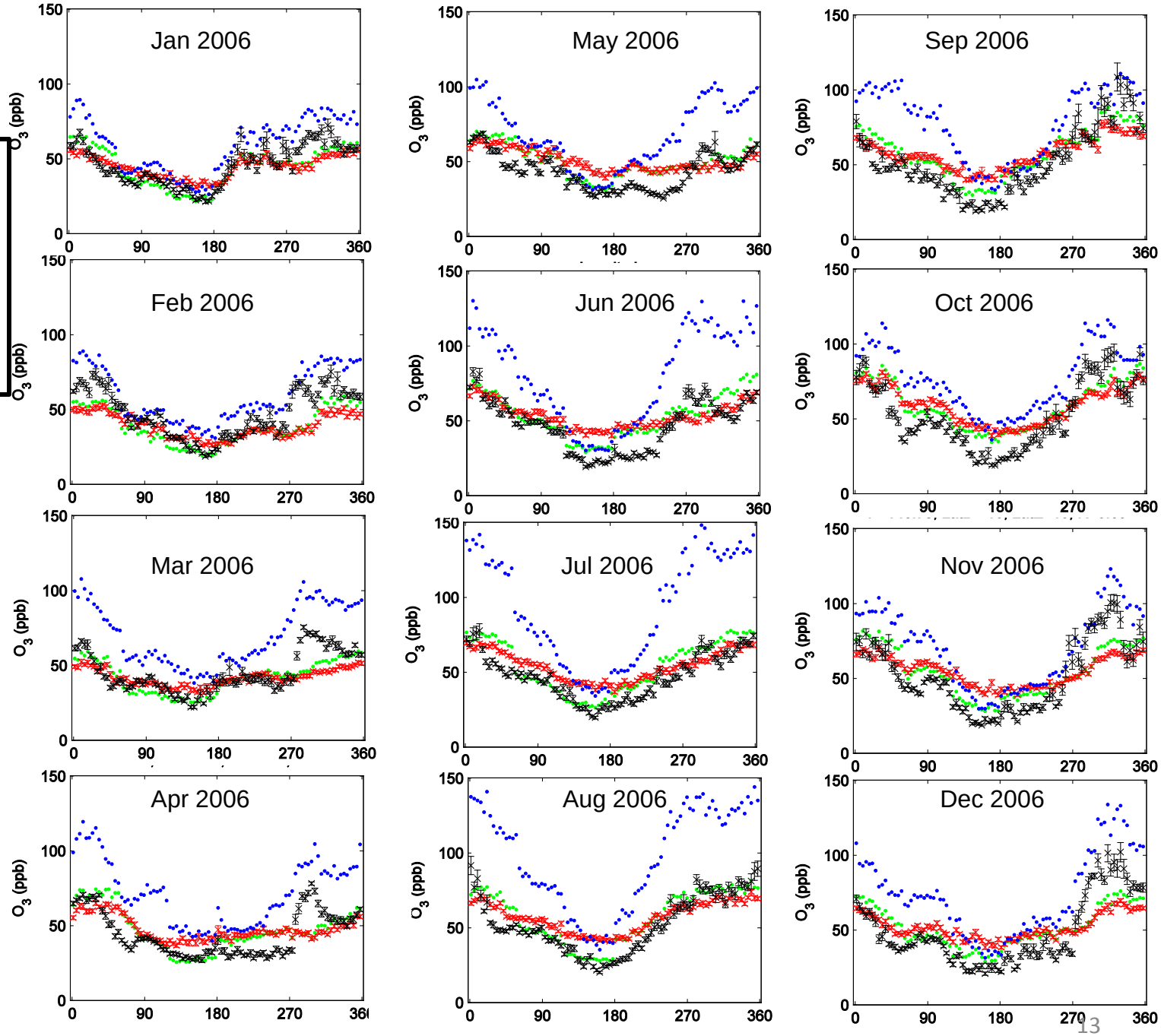
Jul 2005

OK, reprocess the TES with the zonal-mean TES *a priori.*

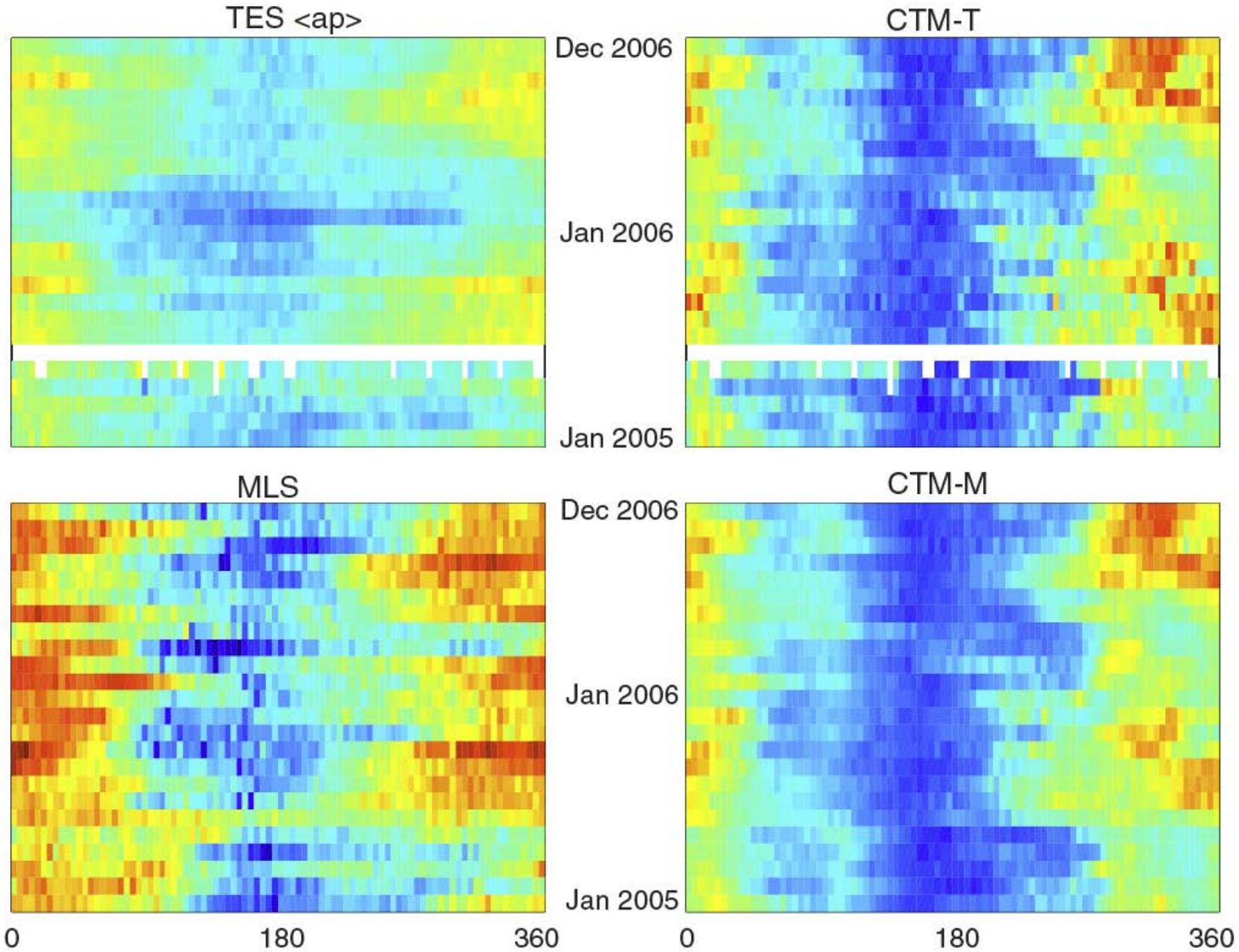
Results are not so good, but now Walker pattern in TES is real.




TES raw
TES<ap>
CTM
CTM+AK


Jan 2006
Feb 2006
Mar 2006
Apr 2006
May 2006
Jun 2006
Jul 2006
Aug 2006
Sep 2006
Oct 2006
Nov 2006
Dec 2006
O_3 (ppb)
0
50
100
150
0
90
180
270
360

Hovmöller plot shows basic agreement, some clear model biases.



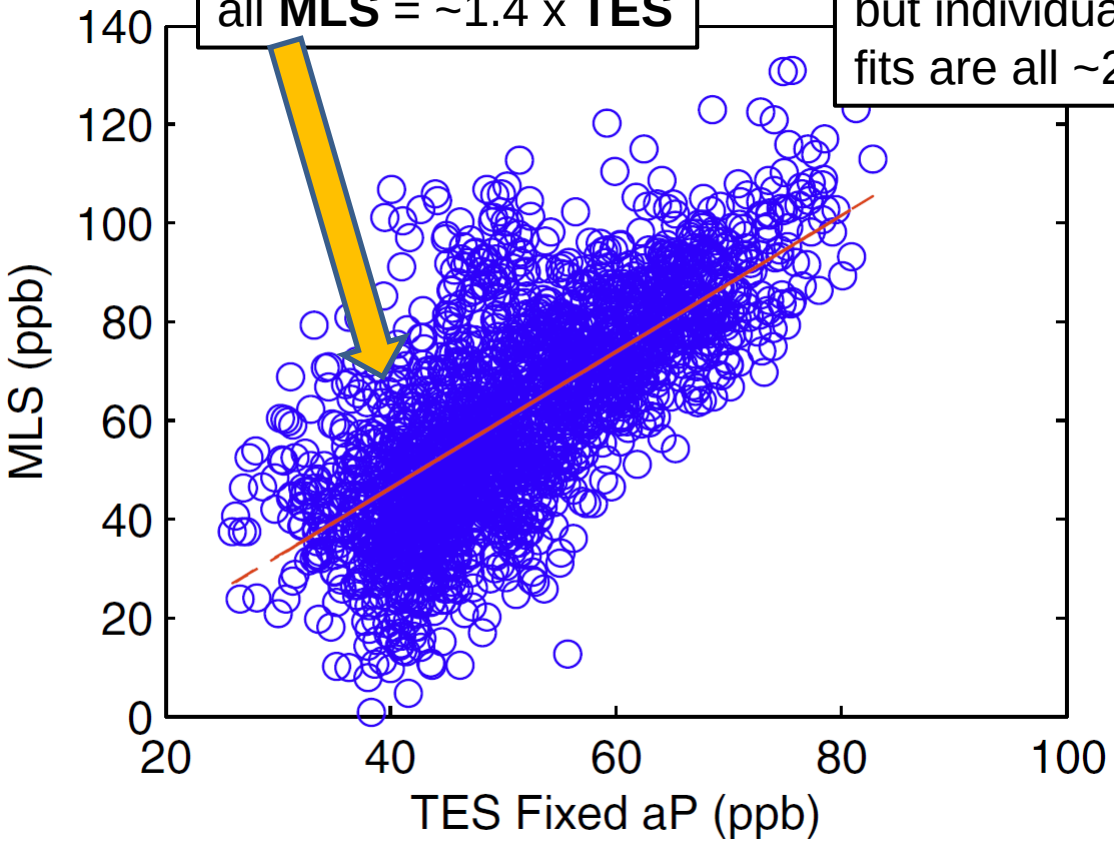
CTM-T = CTM sampled at TES obs.

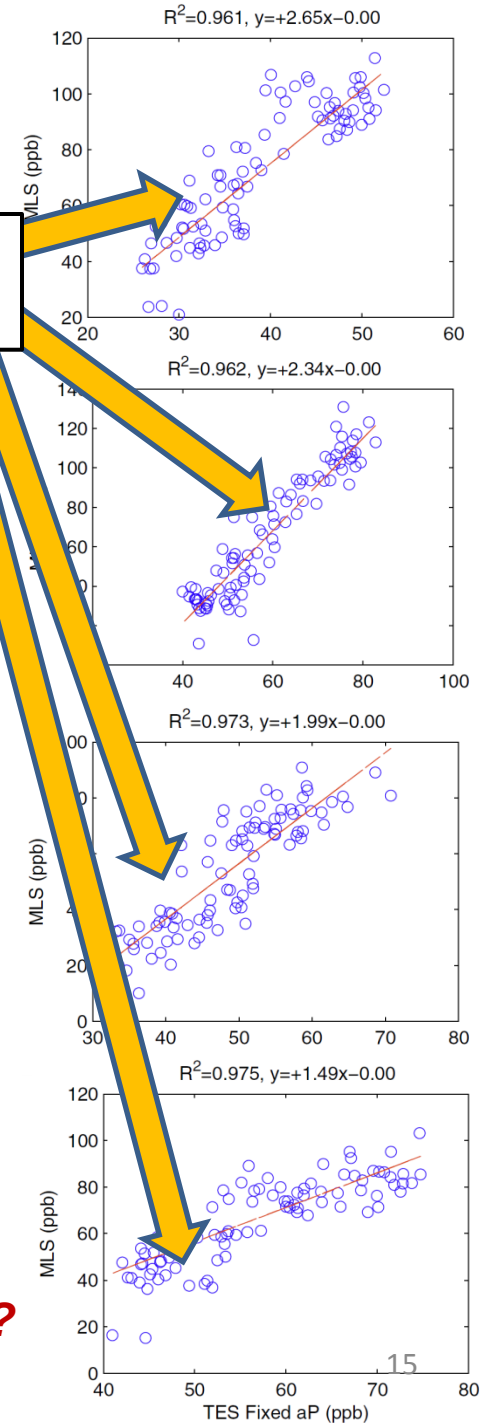
CTM-M = CTM sampled at MLS obs.

Can we identify the bias across instruments ?

all **MLS** = ~1.4 x **TES**

but individual month fits are all ~2 x **TES**





Intent: A weighted average shifts MLS & HIRDLS to mean-TES values, with longitudinal bias correction.

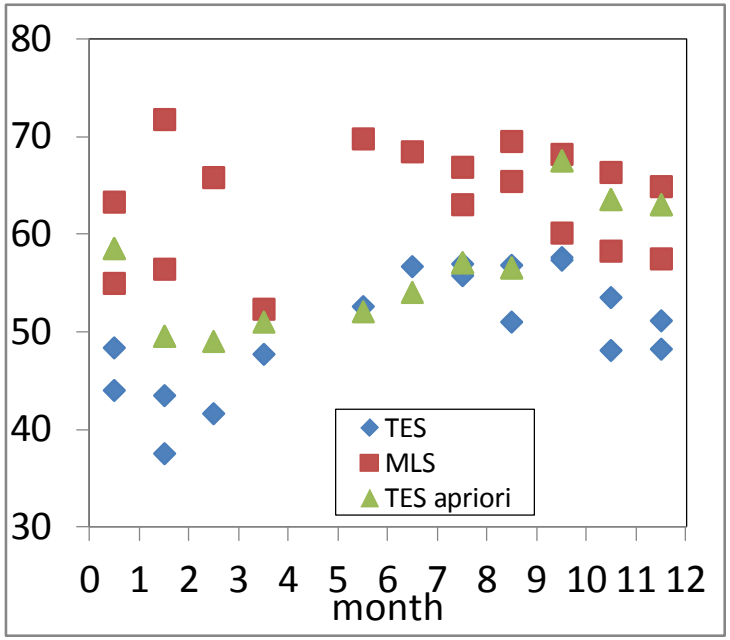
But what is going on here?

Monthly Ozone 10˚S-10˚N 150 hPa:

MLS seasonality not obvious (noisy)

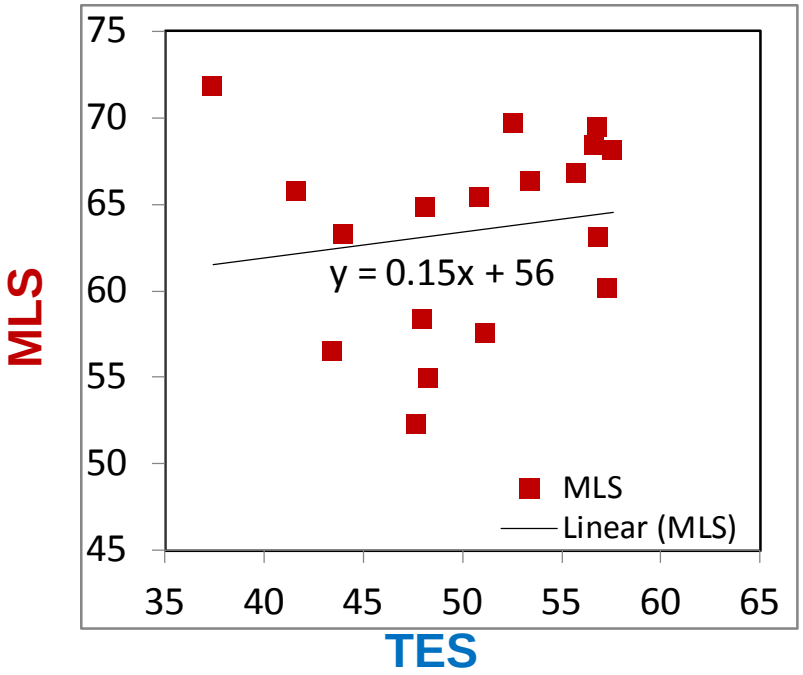
TES seasonality structured.

TES a priori seasonality structured.



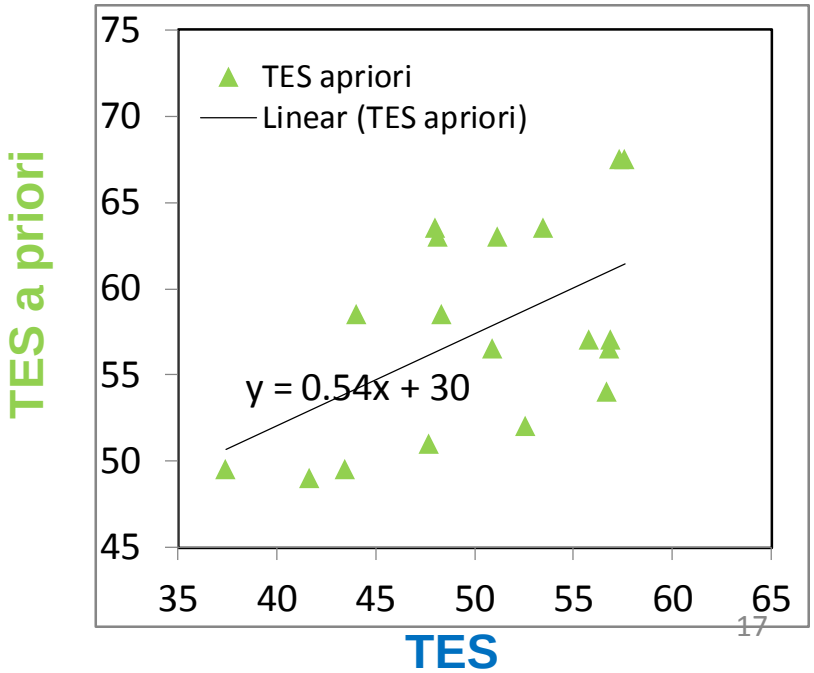
Monthly Ozone 10˚S-10˚N 150 hPa:

MLS across months shows
no linearity
but more flat bias



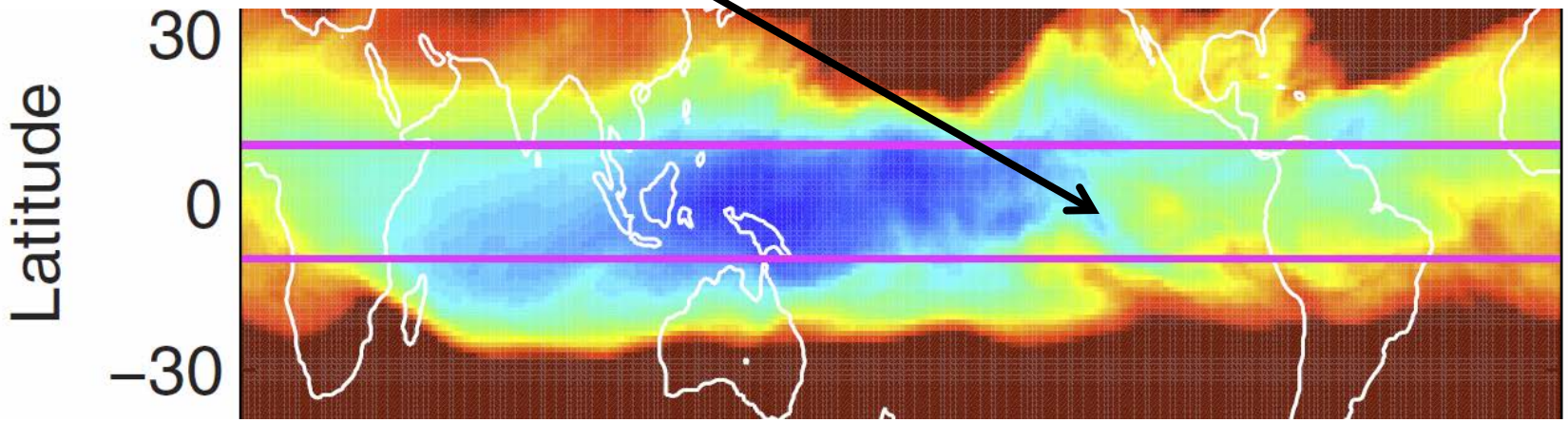
on the other hand

TES a priori is seasonal and
is linearly (not 1:1)
linked to TES

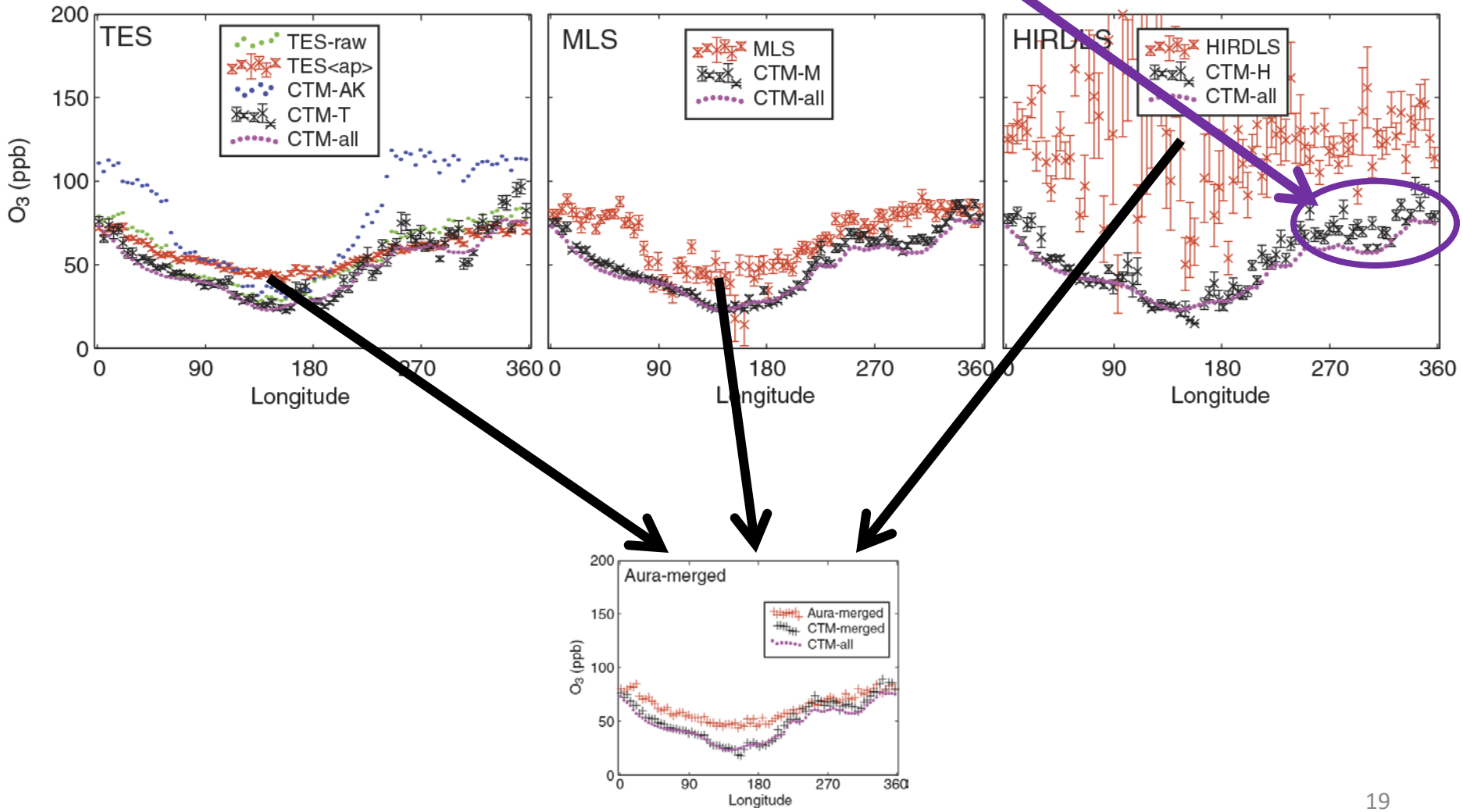


CTM used to correct sampling bias of each instrument

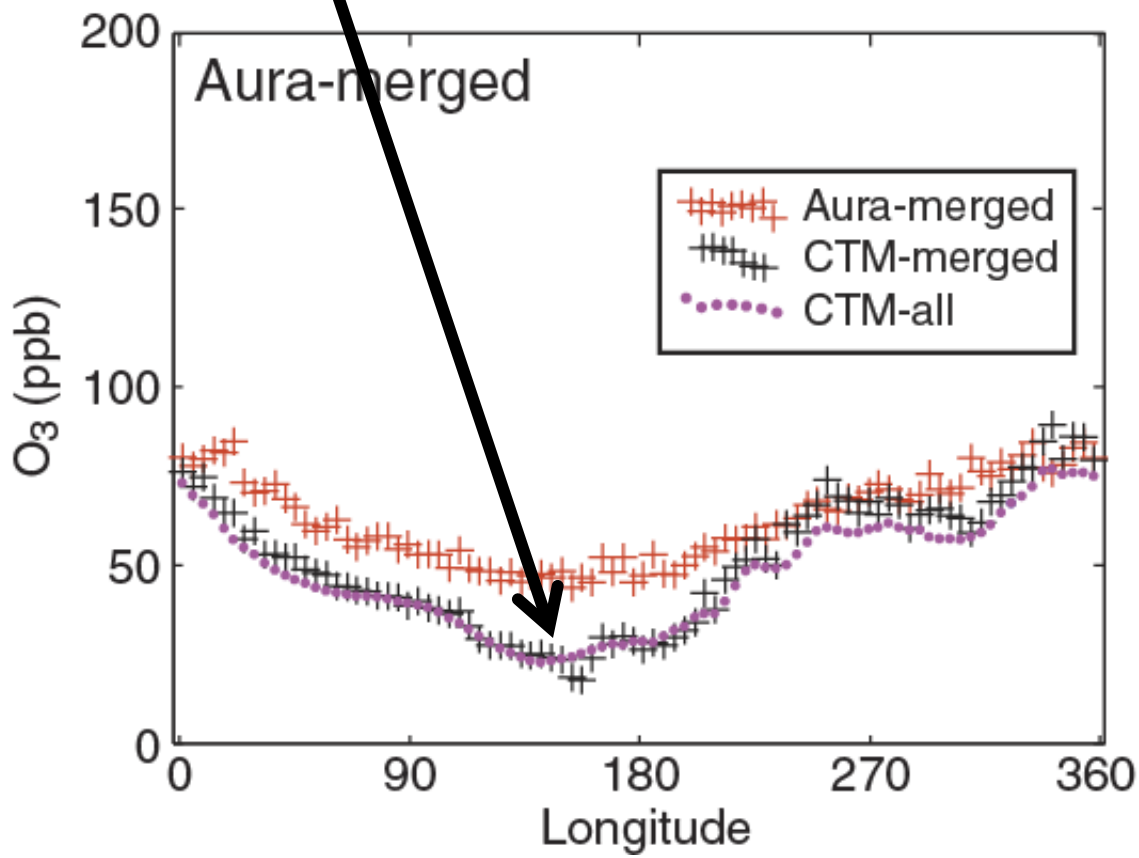
Remember that there is still structure and variability within the 10˚S-10˚N band.



Note that CTM-TES, CTM-MLS, and CTM-HIRDLS are different from one another and also different from CTM-all.



Merged file combines Aura instruments, reduces longitudinal (but not mean bias), and clearly identifies CTM errors, such as too little O_3 over Pacific.



Overall

Monthly variations of O_3 in the upper tropical troposphere (~13 km) show clear, seasonal, Walker-like patterns that are identified in all three Aura instruments.

A merged product:

(A) uses CTM to reduce monthly sampling bias in each instrument;

(B) uses linear fit MLS-TES, HIRDLS-TES to be able to add all observations (inverse weighted by std err) and thereby reduce any instrument bias across longitudes (e.g., ice, bright clouds, tpp ht).

These standing E-W patterns in upper tropospheric O_3 are one of the more robust climatologies for free-tropospheric O_3 in terms of independent instruments, number of measurements, and vertical resolution. They can be can be "almost" matched by the UCI CTM, but identify clear errors, likely in convection. This data set should become a standard test for chemistry-climate models.