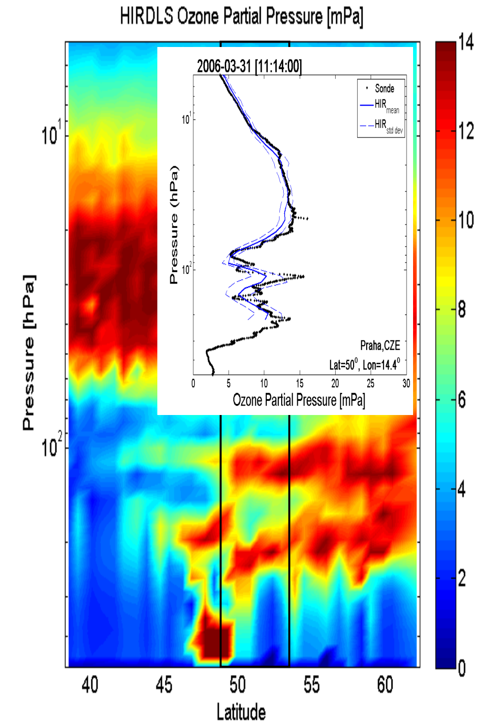
Chemical Data Assimilation: Ozone and Tracers in WACCM4/CESM-GEOS5

- **The recent chemical DA in the WACCM (Whole Atmosphere Chemistry Climate Model of CESM-1.03, top lid ~140 km).**
- **Overview of several O_3 analyses**, zooming on O_3 Vertical Structures (VS).
- **Needs for the Resolution-Dependent Analysis (RDA)**. Inverse mapping of OmF that constrain only visible structures, preserving scales unresolved by data.
- **Value of limb data (MLS and HIRDLS) in the O_3 analysis** and current efforts implementing multi-sensor (nadir + limb) RDA in the WACCM/GEOS5 research systems: OMI-MLS-HIRDLS.
- **Resolution kernels, when they add information and QC for data**
- **Benefits to assimilate the research satellite data into "whole" atmosphere models with "Full" chemistry & RDA mapping.**



Valery Yudin [1], Douglas Kinnison [1], Steven Pawson [2], Meta Sienkiewicz [2], John Gille [1], James Hannigan[2], Francis Vitt[2] and Nathaniel Livesey [3]

[1] NCAR/NESL, [2] NASA/GSFC, GMAO, [3] NASA/JPL

WACCM-GEOS5, forecast/analysis system

- Chemistry-climate model with physics. radiation of CESM, non-LTE, non-oro GWD,ion-e chem-ry to simulate MLT..

- VR of GEOS-5 + extra 16 lev. in 75-140 km;
- HR – (144x96 ~ 2.5^{o}x1.9^o)

- 125-species chemical mechanism (MA + troposphere, surf. emissions, year-to-year variations, monthly, daily by scaling to match locations of MODIS fire counts).

- Coupling with GEOS-5 through tendency:

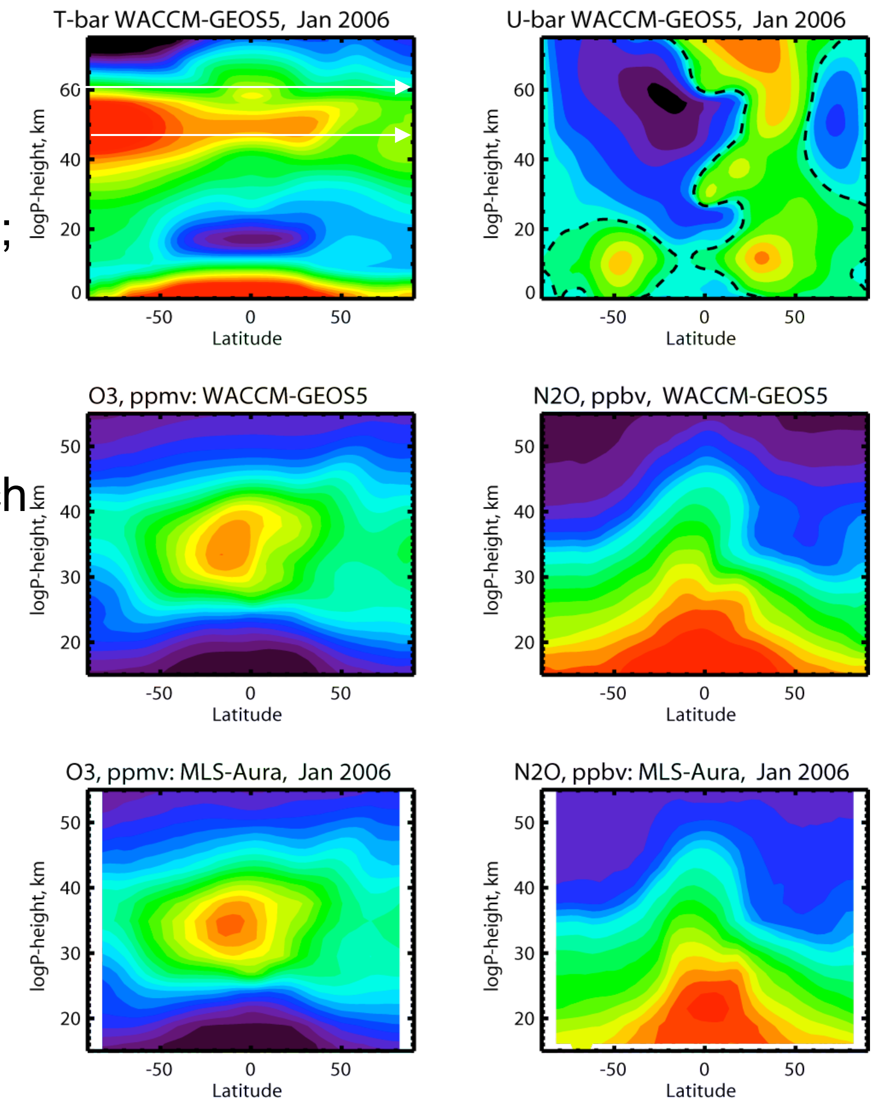
dX/dt= (Xwac- Xgeos)/50hr

[surf -:-~50 km]

dX/dt = 0, above 60 km;

transition zone. 50-60 km

(*X=U, V, T, Ps*)



Data analysis package in WACCM-GEOS5

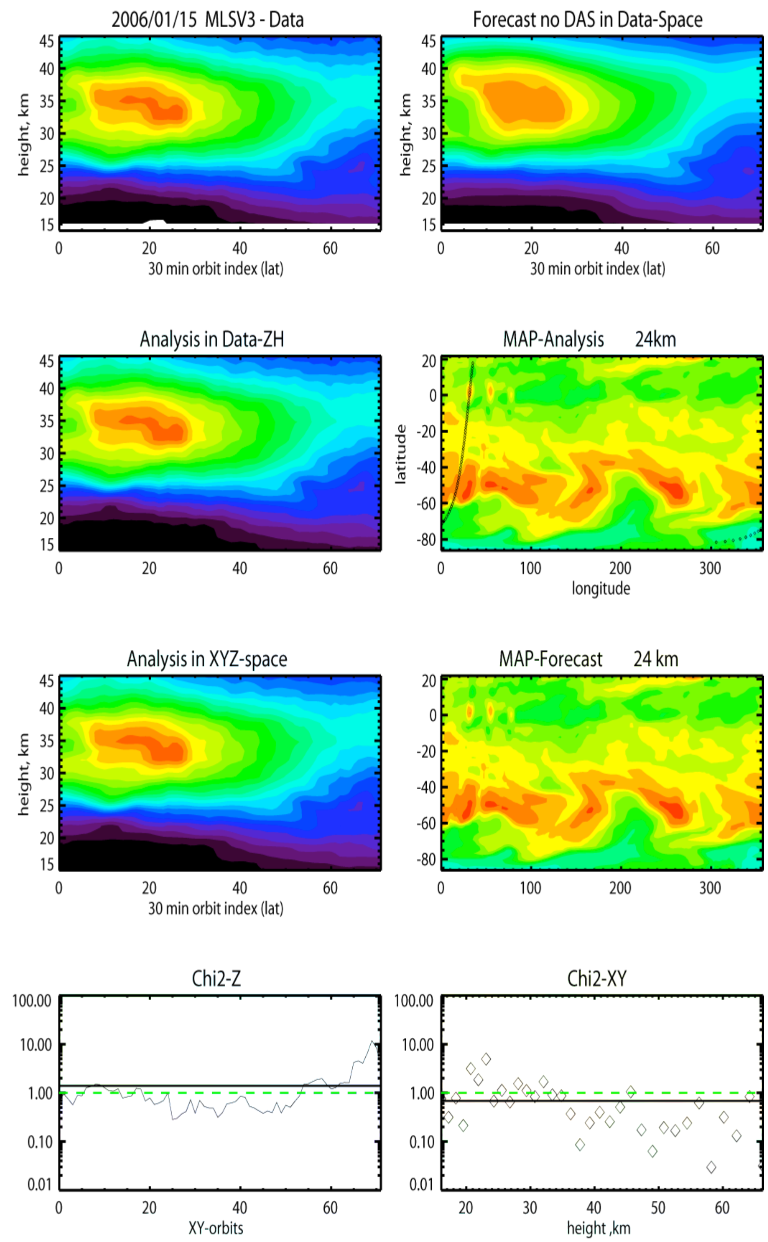
- Oriented on Aura/A-train chemicals and T.
- Current setup for O3, CO, N2O and T-re.

- **Interface for 4-data classes (VR):**
- ***Conv+Limb***
- ***Nadir-columns***;
- ***Nadir-partial columns***;
- **MOPITT-CO ..radiances**.

- Analysis interval – time step (30 min), only **linear incerements** (<25%).

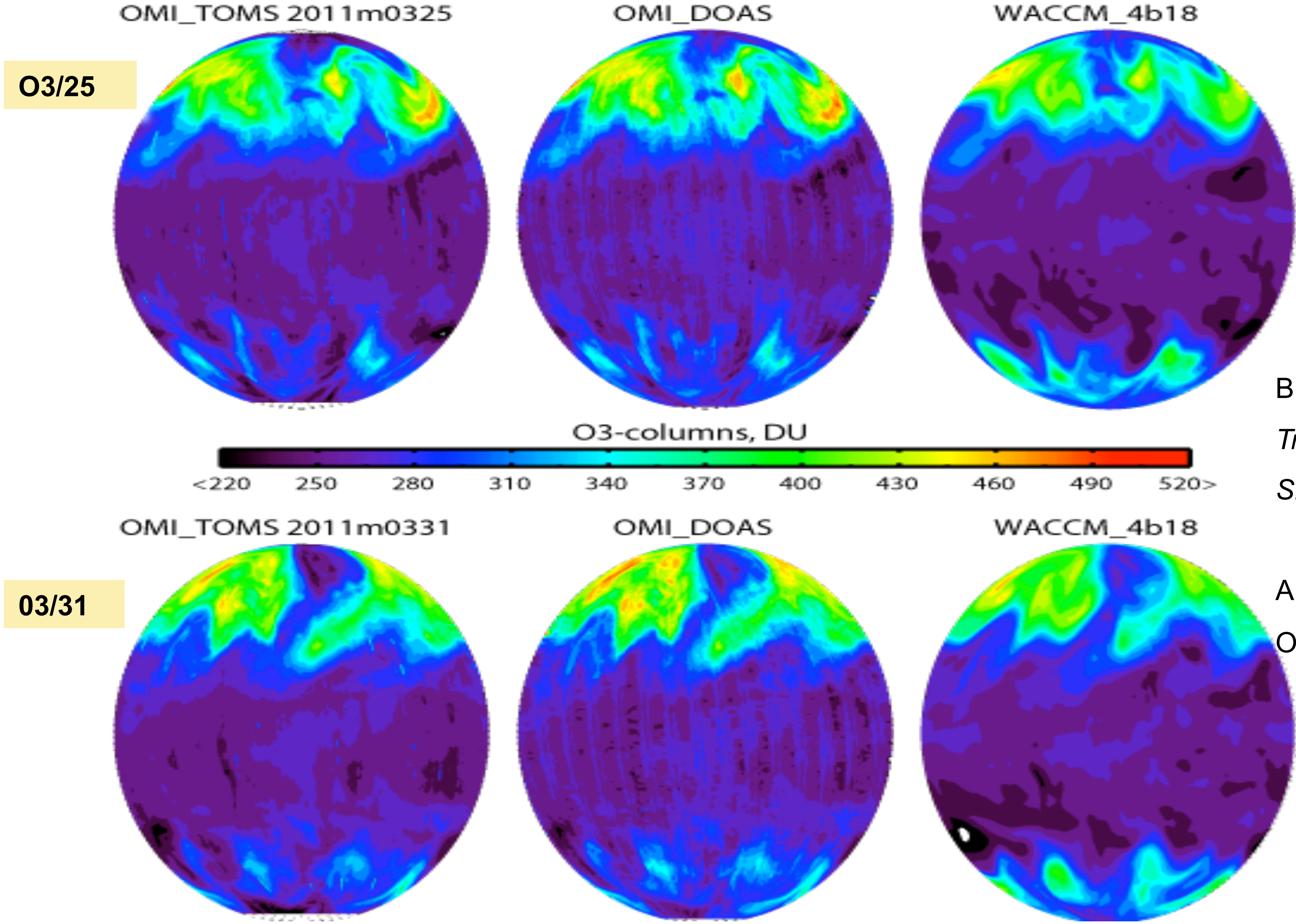
- **PV-tracer corr-ns and Resolution Kernels** => extra-Quality Controls (for retrievals)
- **Directional splitting (Vert/Hor)** in filter implementations, **transport of the variance**.

- **Resolution dependent aspects** in
  (a) reduction of variance and
  (b) adequate <B>H^T –math for columns and low-DFS profiles.



WACCM-GEOS5 no data insertion

March 2011: OMI vs WACCM-GEOS5



Biases

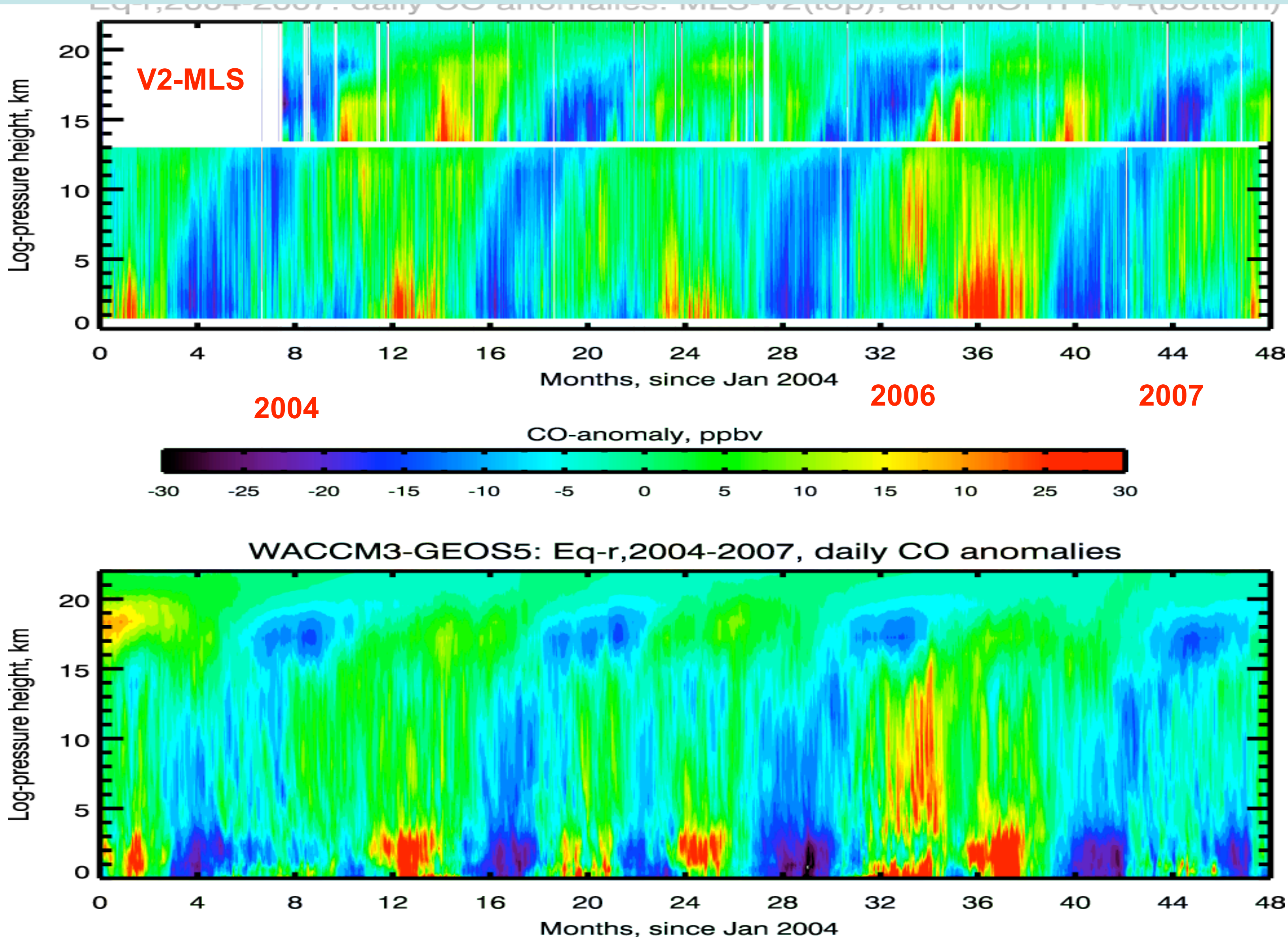
Tropics

SH-Antarctic

Arctic Dep->

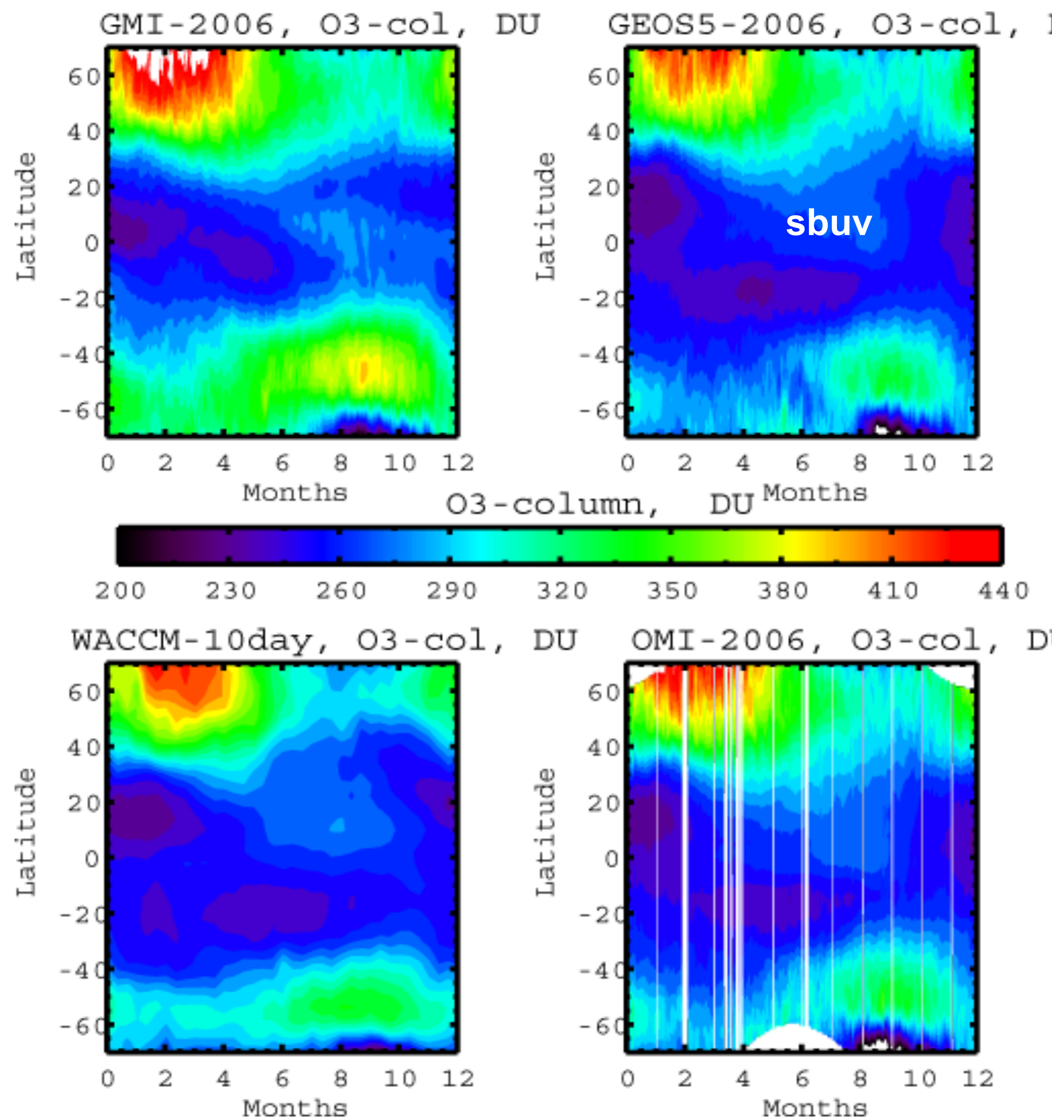
OMI-DOAS

2004-2007 CO Equatorial "Tape Recorders": MOPITT-v4 + MLS-V2 (top), WACCM-GEOS5 (bottom)

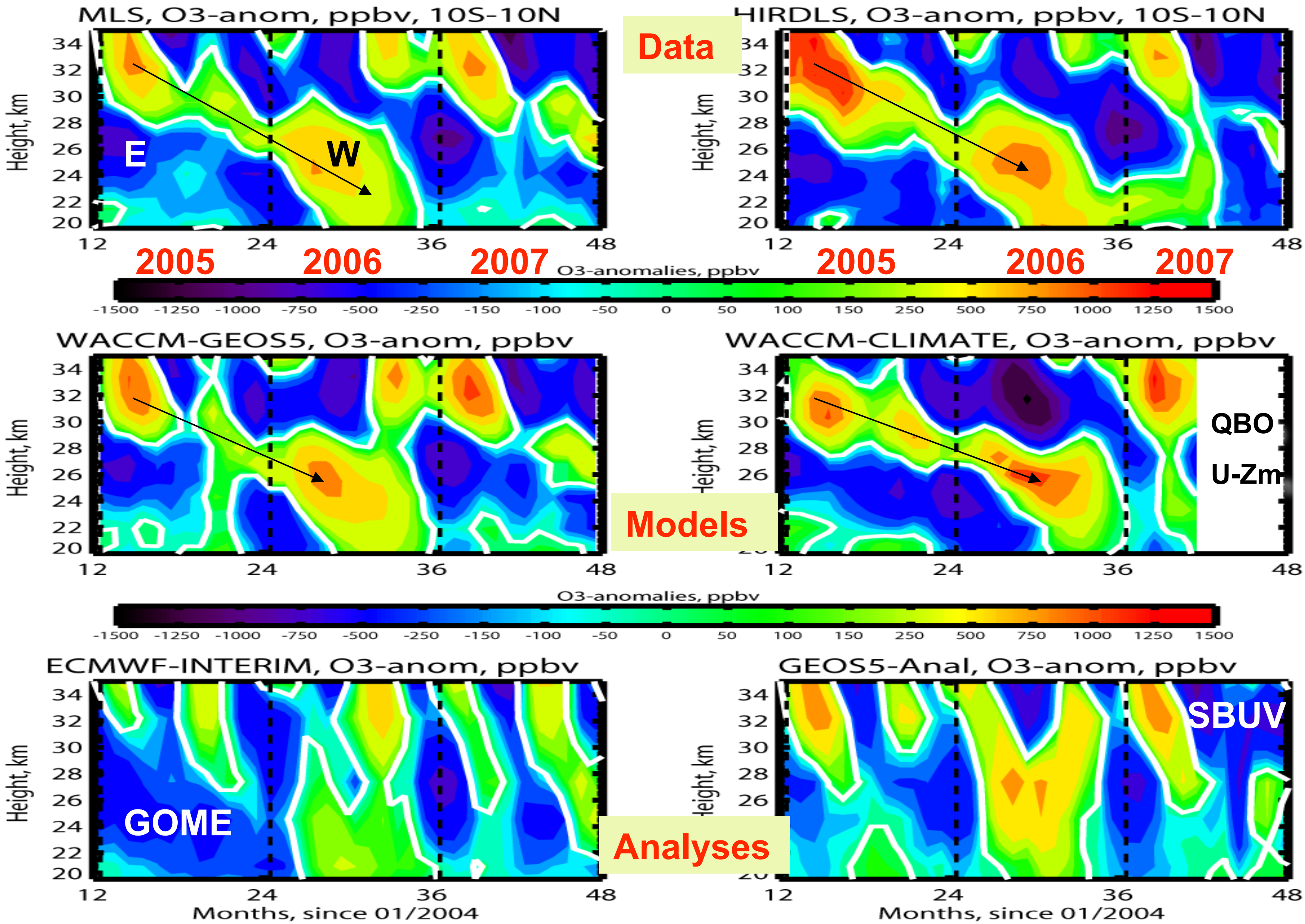


Evaluation of O_3 simulations and analyses

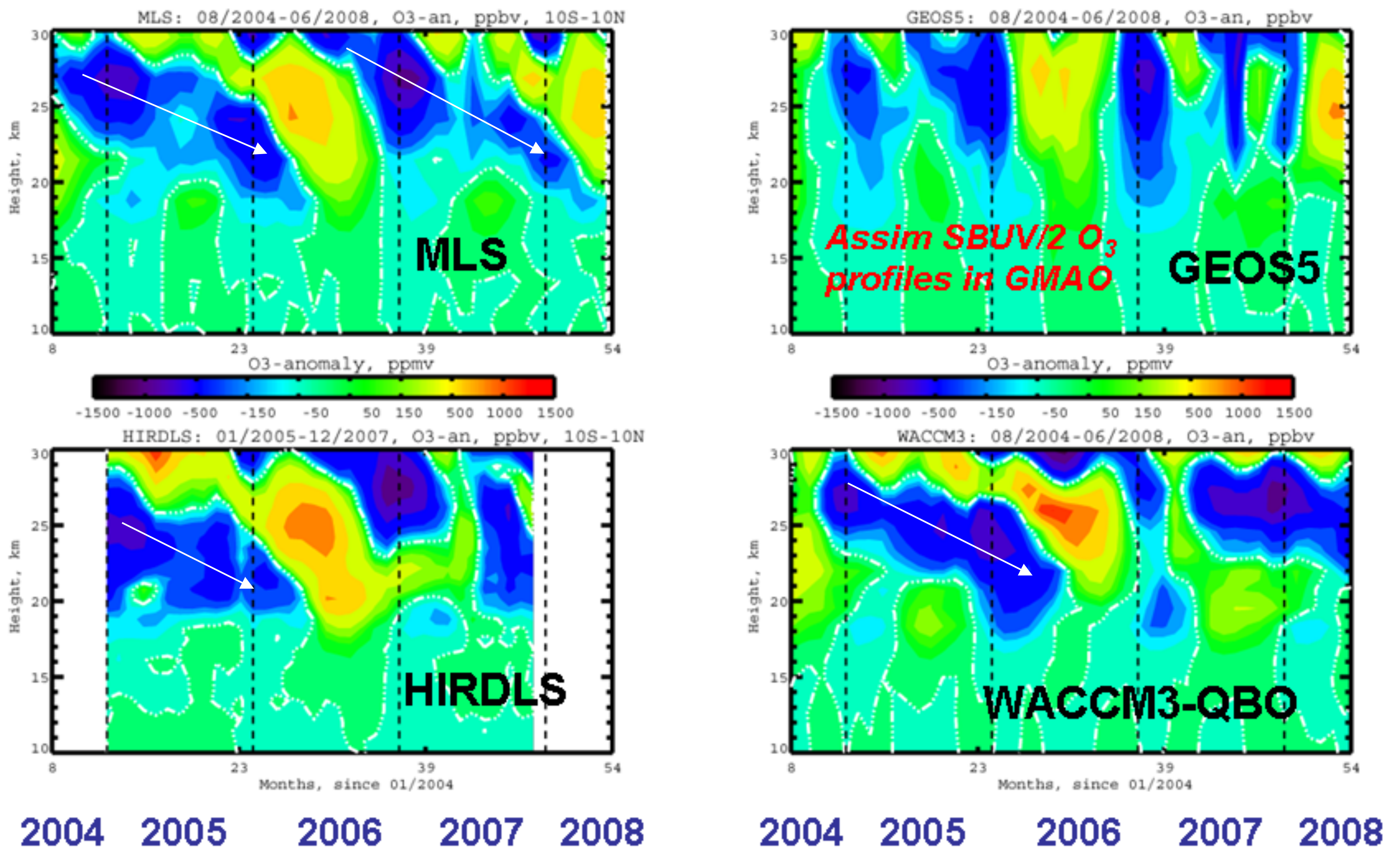
- Traditional – against high quality independent data (sondes)
- Global evaluation: against independent data, monthly composites (MLS/HIRDLS/OMI)
- Inter-comparisons of analyses, (GFS, GMAO, ECMWF) performing OSSE-studies (“ECMW-data” in GEOS-5, NH winter 2006).
- Performing sensitivity studies: impact of data in the observing system (O3: SBUV/MLS/OMI)



Tropics:QBO ozone anomalies



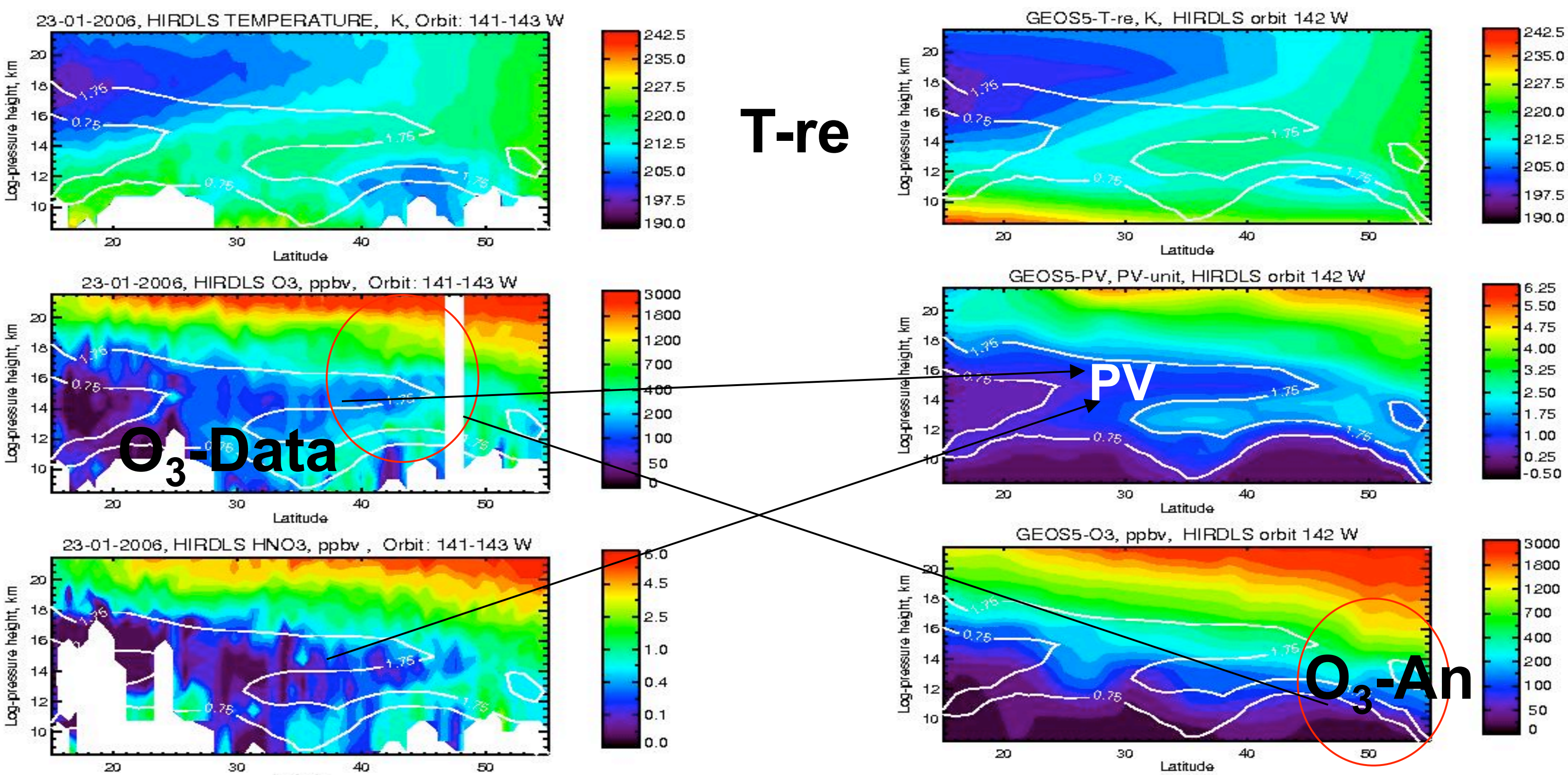
Equatorial O_3-anomaly (10°S-10°N): limb data, analysis, and climate model simulations



Reproducing Vertical Structures in Ozone Analyses and Retrievals

Motivation to zoom at VS of O3 analyses by MLS and HIRDLS orbital plots in the UTLS

HIRDLS: Jan 23 2006 **GEOS-5: Jan 23 2006**



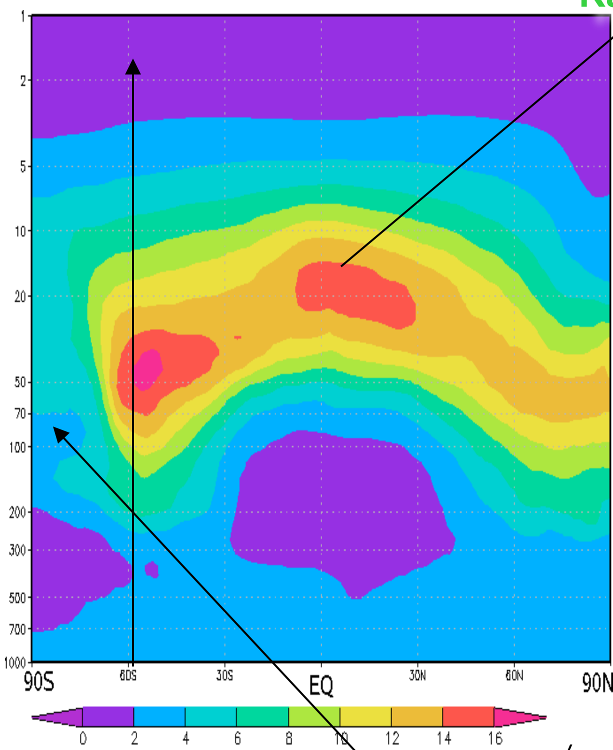
1) How frequently analyses fail to reproduce observed O_3 thin layers ?

2) Can models reproduce observed laminas ?

3) How severe DA can degrade polar ozone depletions ?

South Pole, Sep 30/2005: Two types of O3-DAS SBUV/2 (operational) and MLS (research) in GEOS5-3dVar

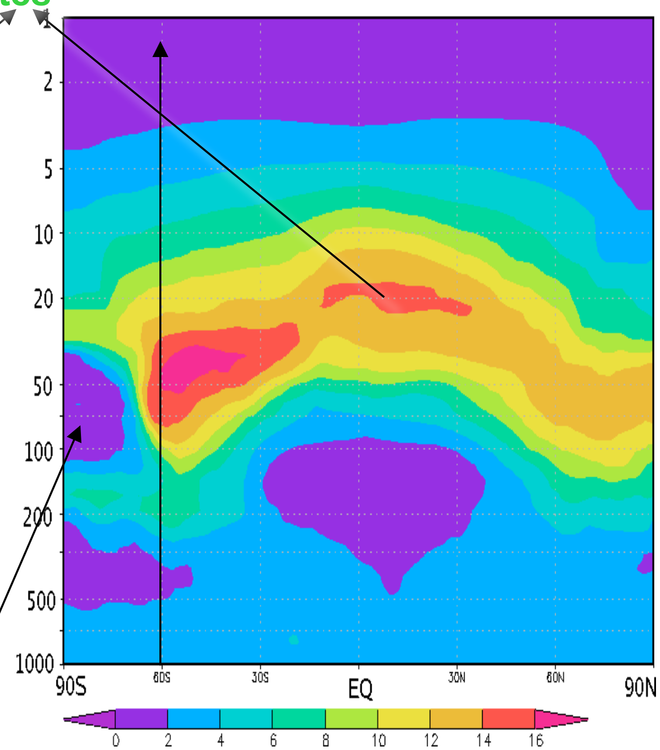
SBUV/2 assimilation



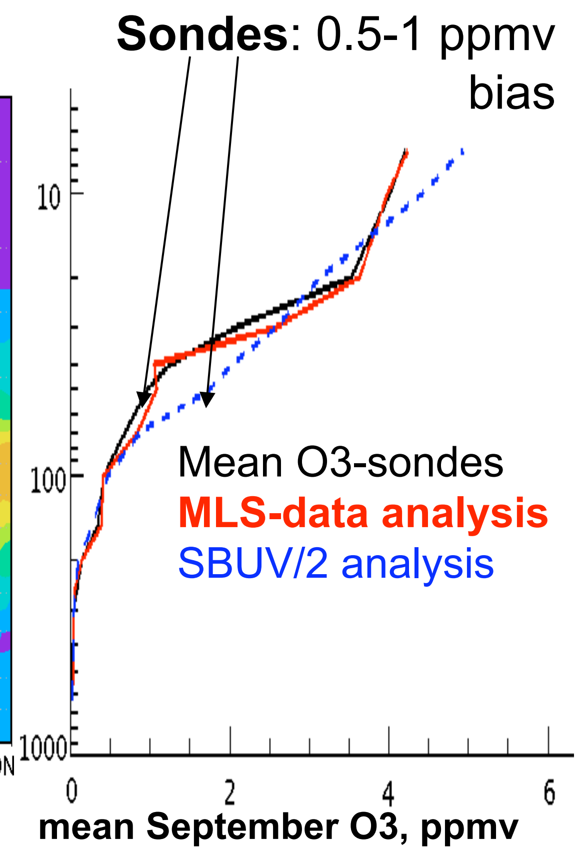
Ozone partial pressure (mPa)

Heaing Rates

MLS assimilation



Ozone partial pressure (mPa)

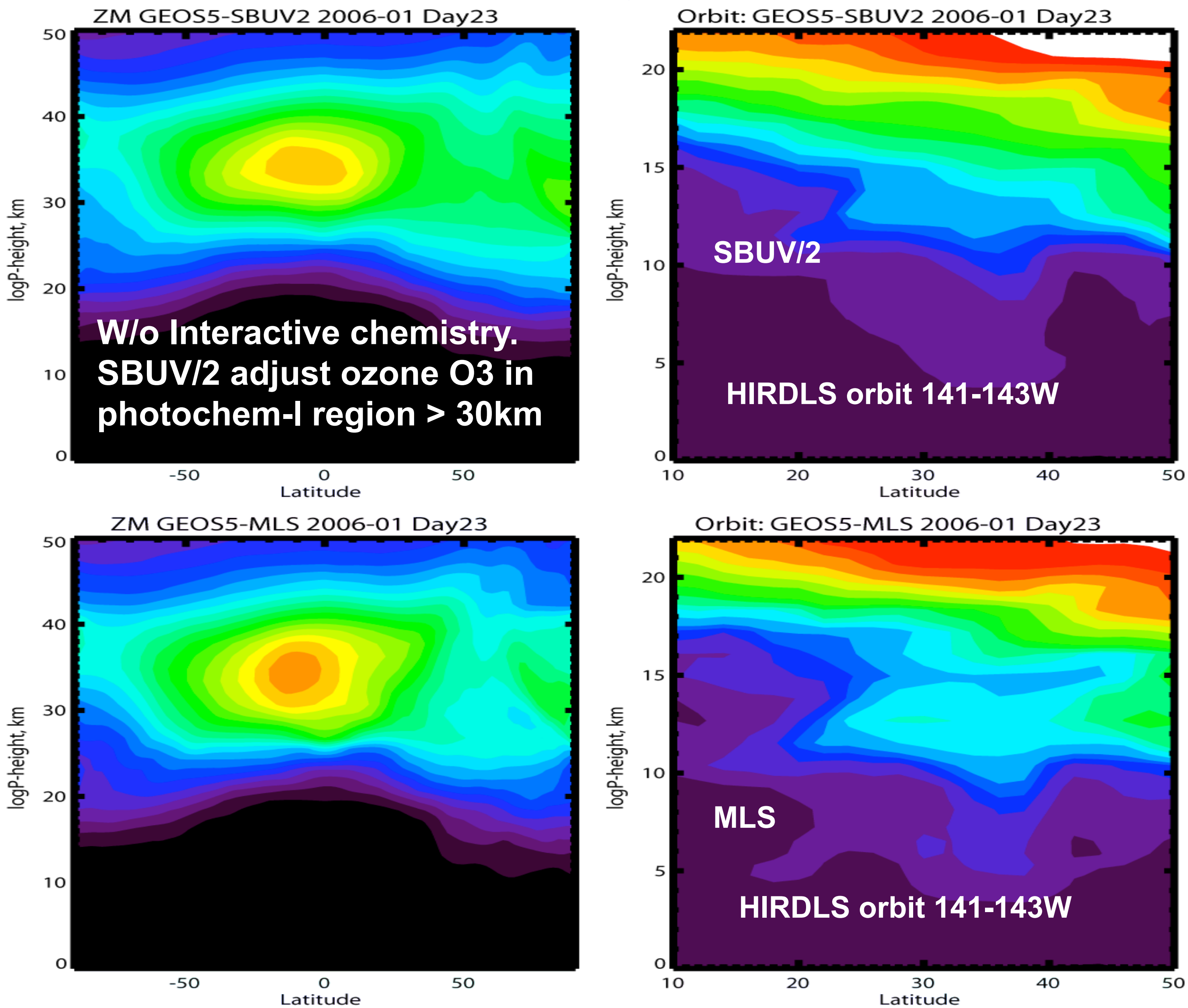


Replacement of data sets in GEOS-5 =>

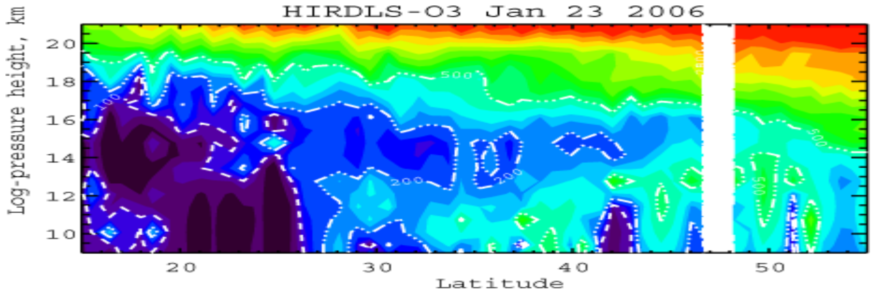
Ozone hole structures in the MLS DAS highlights the negative impact of SBUV/2 data insertion over the South Pole.

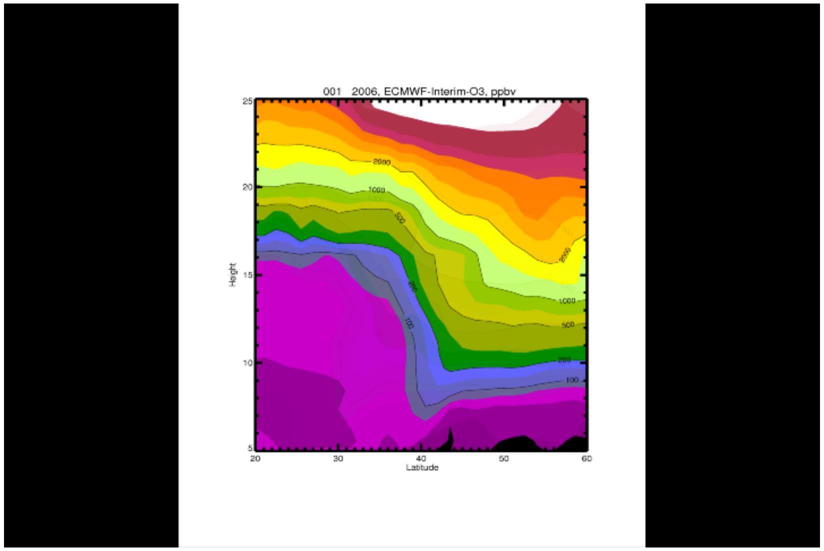
Meta Sienkiewicz

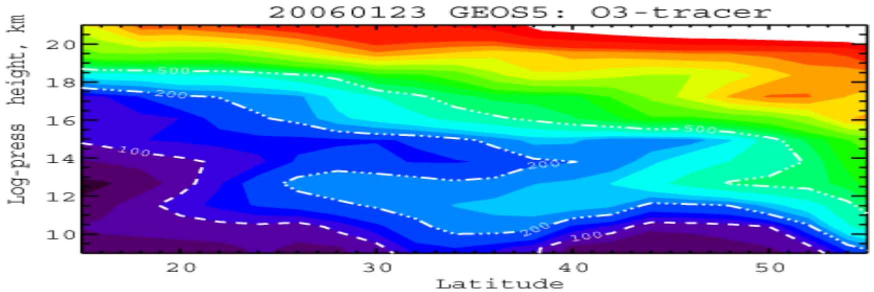
GEOS-5: Taking out SBUV/2, adding MLS => restore O3 laminas, O3-PV correlations

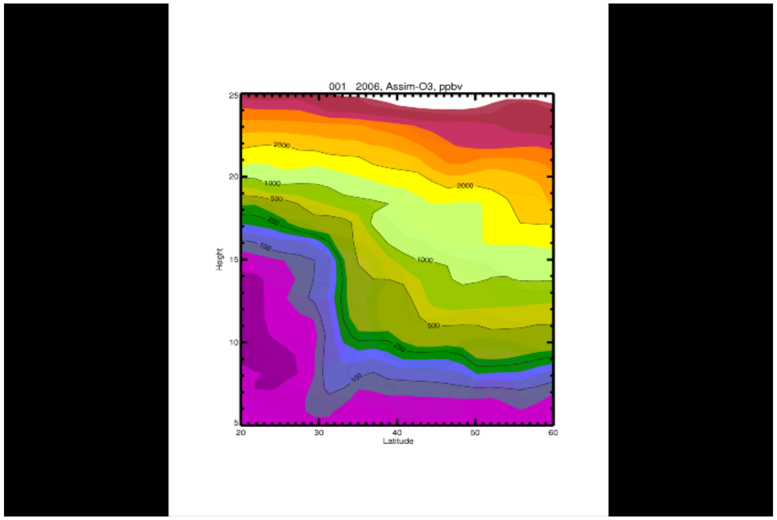


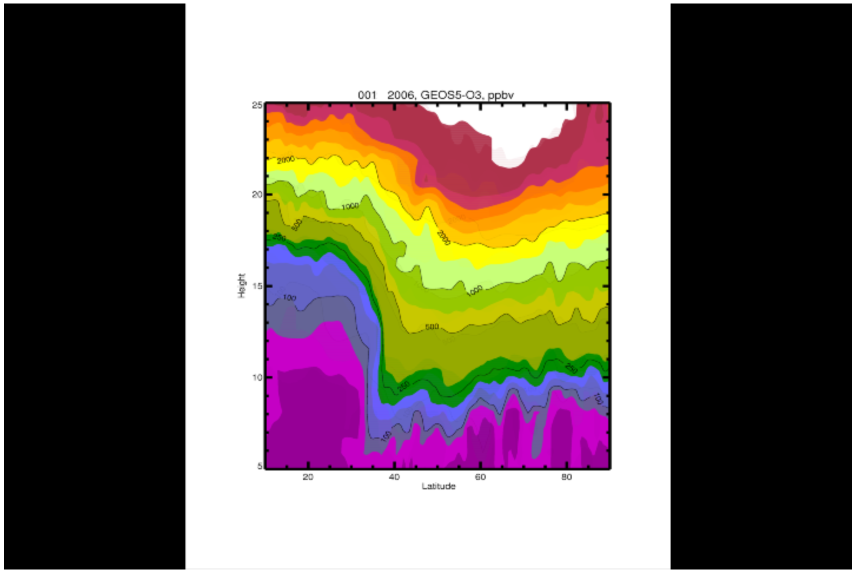
Ozone Laminas Jan 1- Feb 15 2006











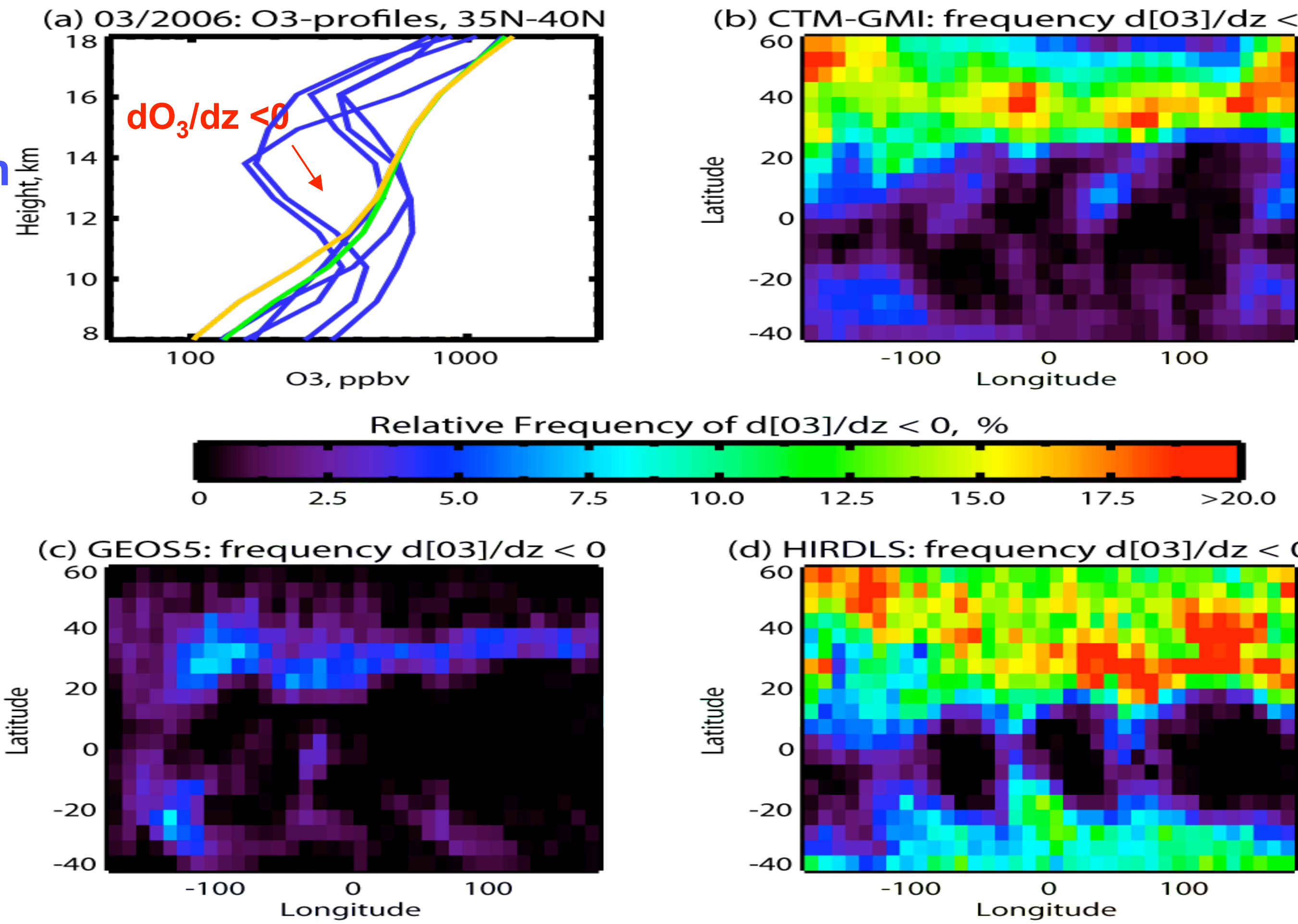
Mar/2006: Monthly frequencies (%) of O3 laminas: CTM, Analysis,and HIRDLS retrievals

Counting laminas

-50 ppvb/km

in O3 Profiles

CTM-GEOS5



HIRDLS

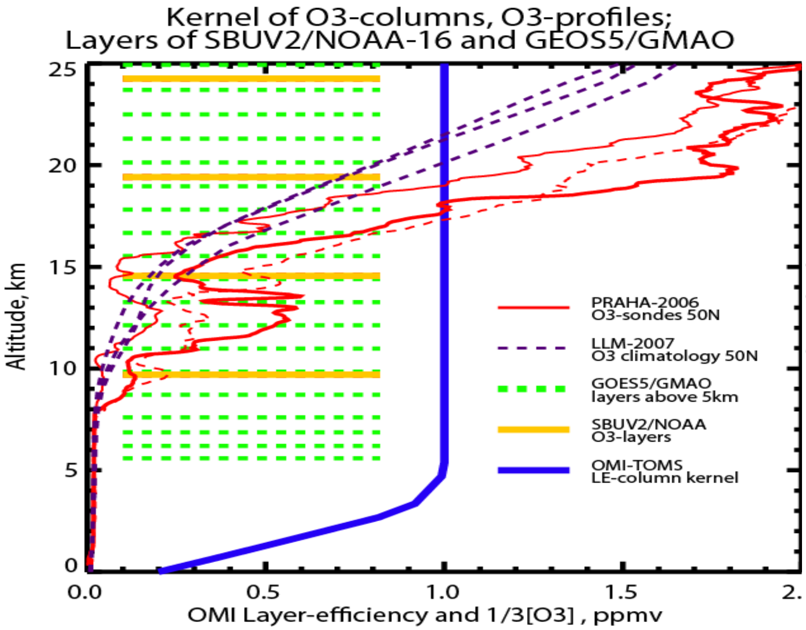
GEOS-5

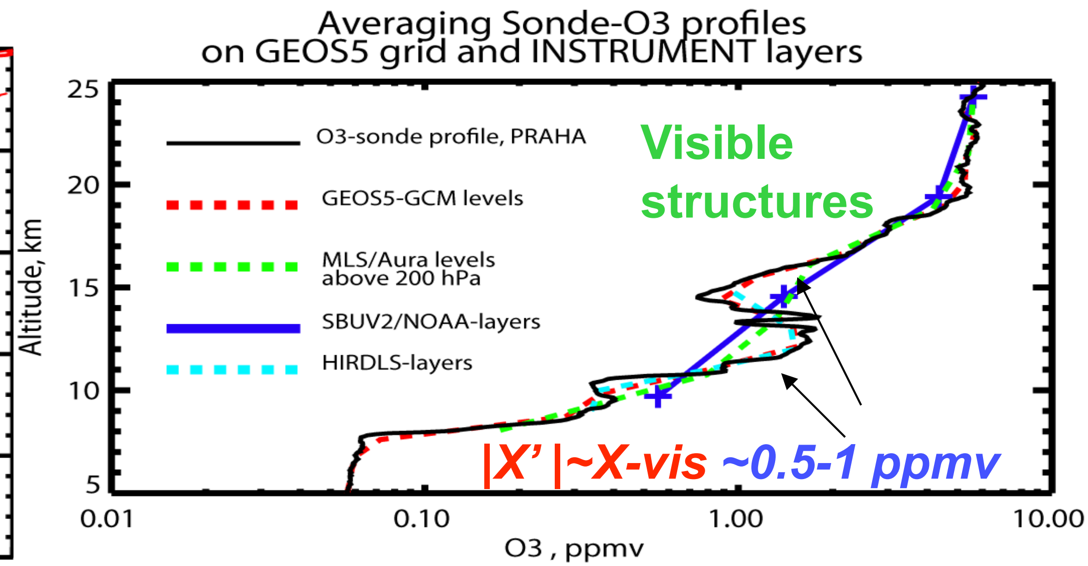
SBUV/2

Analysis of SBUV/2 O_3 partial columns degrades frequency of ozone laminas => polar ozone losses, negative impact of data analysis on vertical structures.

Vertical resolutions: data and analysis grids,

resolved (visible) structures and unresolved (Nyquist) scales





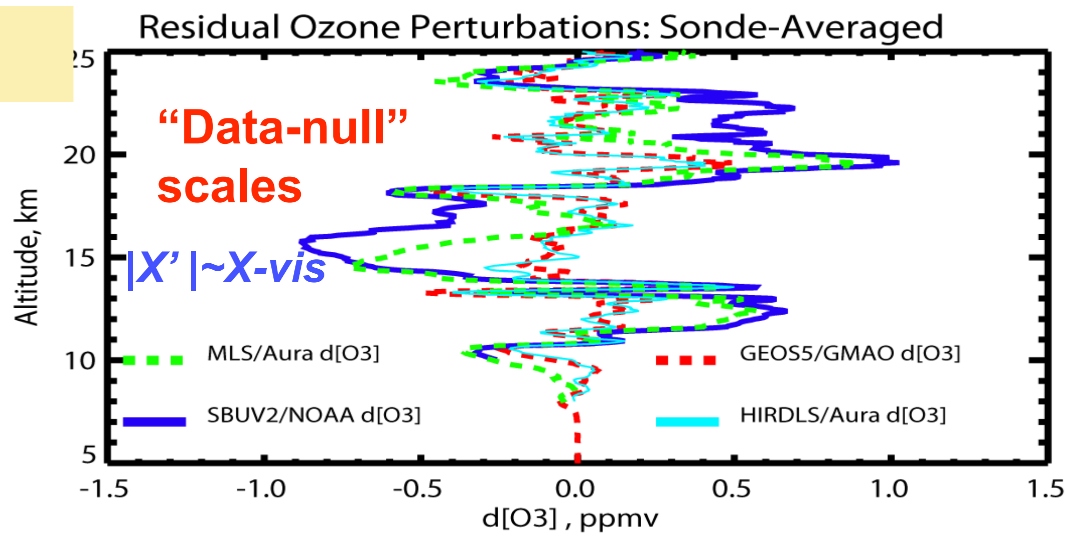
X = X-vis + X'-(data-null)

In the UTLS *:*

When |X' | ~ X-vis and

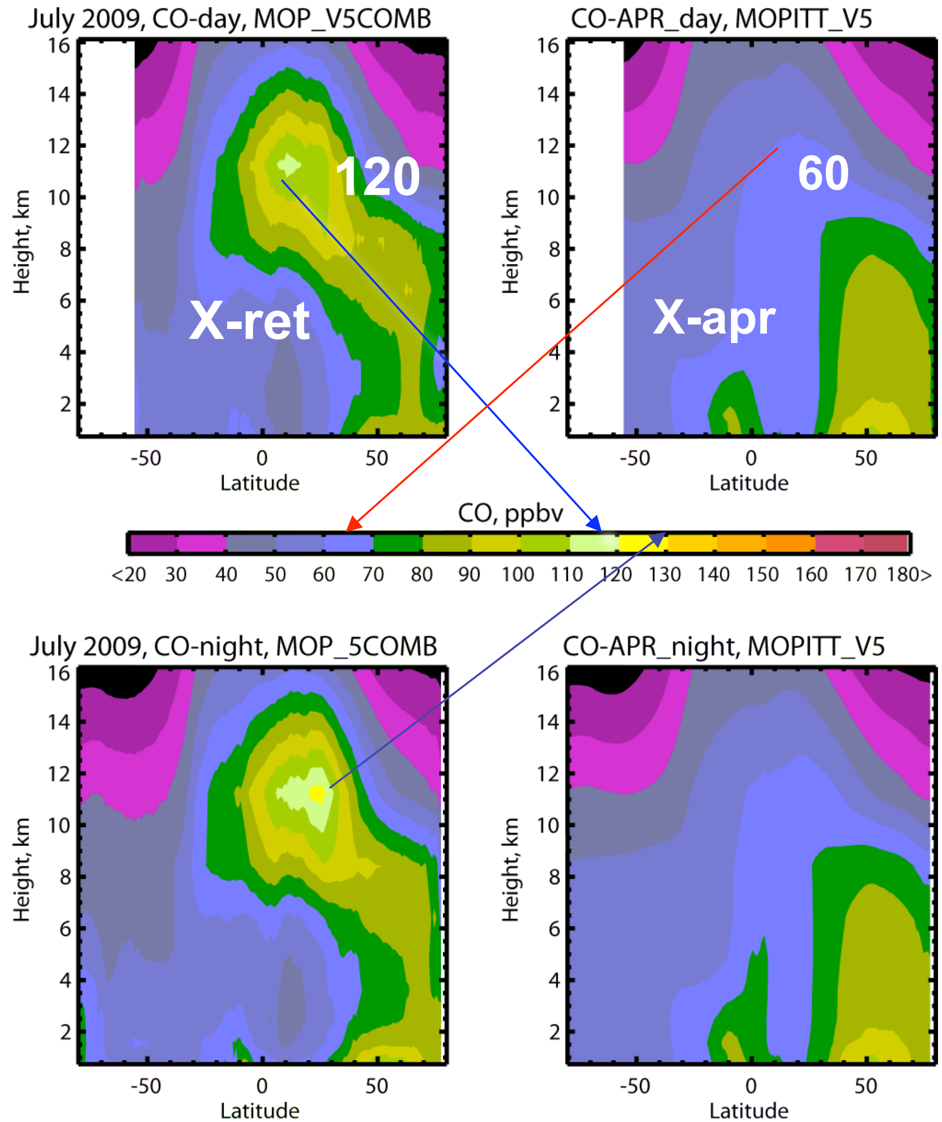
DFS << N (analysis layers)

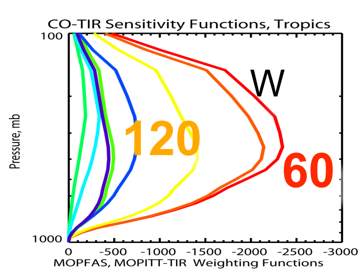
analysis of layer-averaged data needs extra-work in assimilation

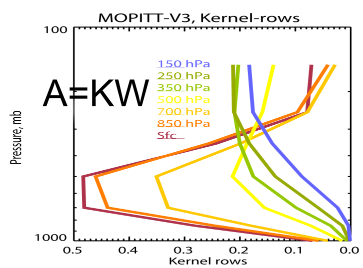


Linear characterization of data resolution: a priori (X_a) and resolution ($A=KH$) kernels

- $X_r = X_a + A(X_t - X_a)$
- $X_r = (I-A)X_a + AX_t = X'_a + X_{vis}$
- $|X'_a| \ll X_{vis}$ => Linear char-n
- $|X'_a| \sim X_{vis}$ => **Non-Linear ch-n**
- To keep linearity for low-dfs or low VR => analysis of columns (T) for which: $|T_t - T_a| \ll T_a$







Numerics of RDA for retrievals with low-DFS:

1)Kernels (A_z) and a priori (X_a); 2) SVD(AH-operator) -> selection of visible scales;
**) Errors (B-forecast and R-data) are scale-dependant; **) Vertical Mapping: BH^T*

***)** $[C]^{-1}$ =/= $[B]^{-1} + H^T[R^{-1}]H$

~1-3 km ~7-15km

****)** **BH^T - vertical projector for DFS ~1-2**

- **H => A_zH_h** (**A_z** resolution kernels)

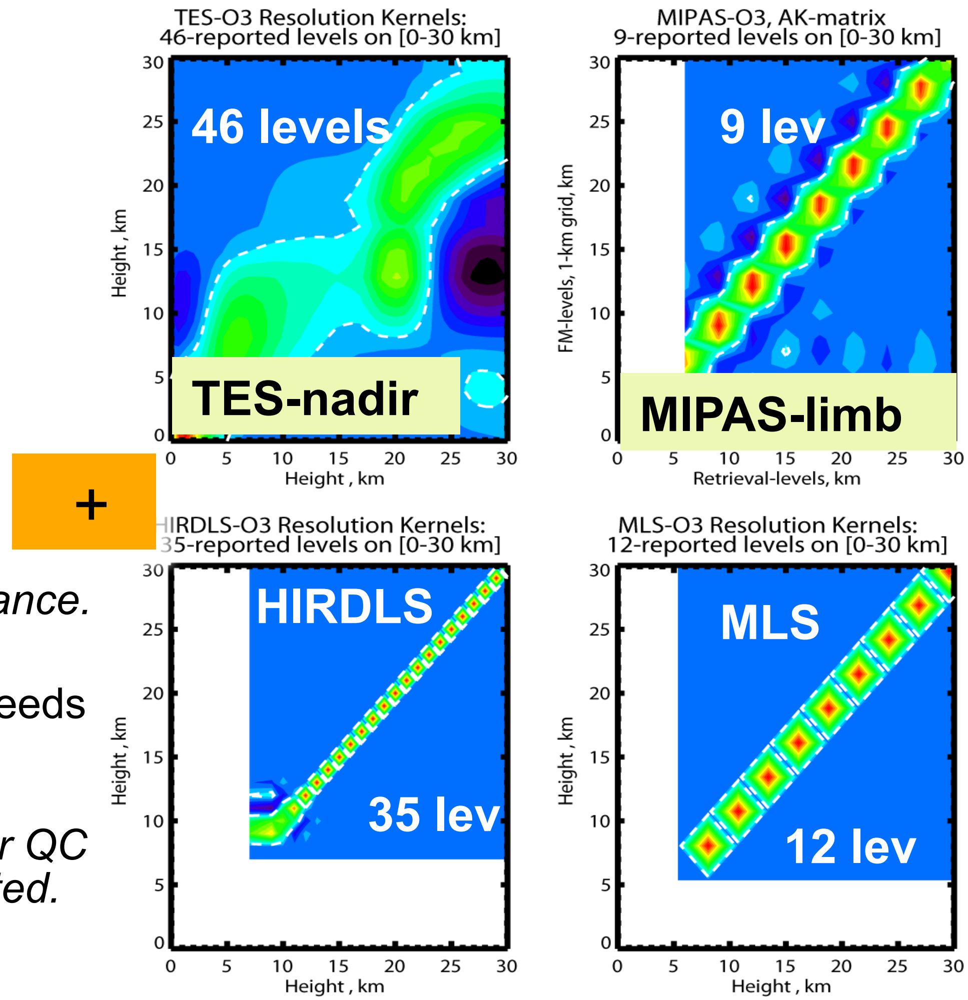
Inv Mapping: **SVD(H) => $H\delta X = \delta Y$**

(a) selection of visible components

(b) error reduction for observable scales only
data with 7km res-n =./=> 1-3 km mod. variance.

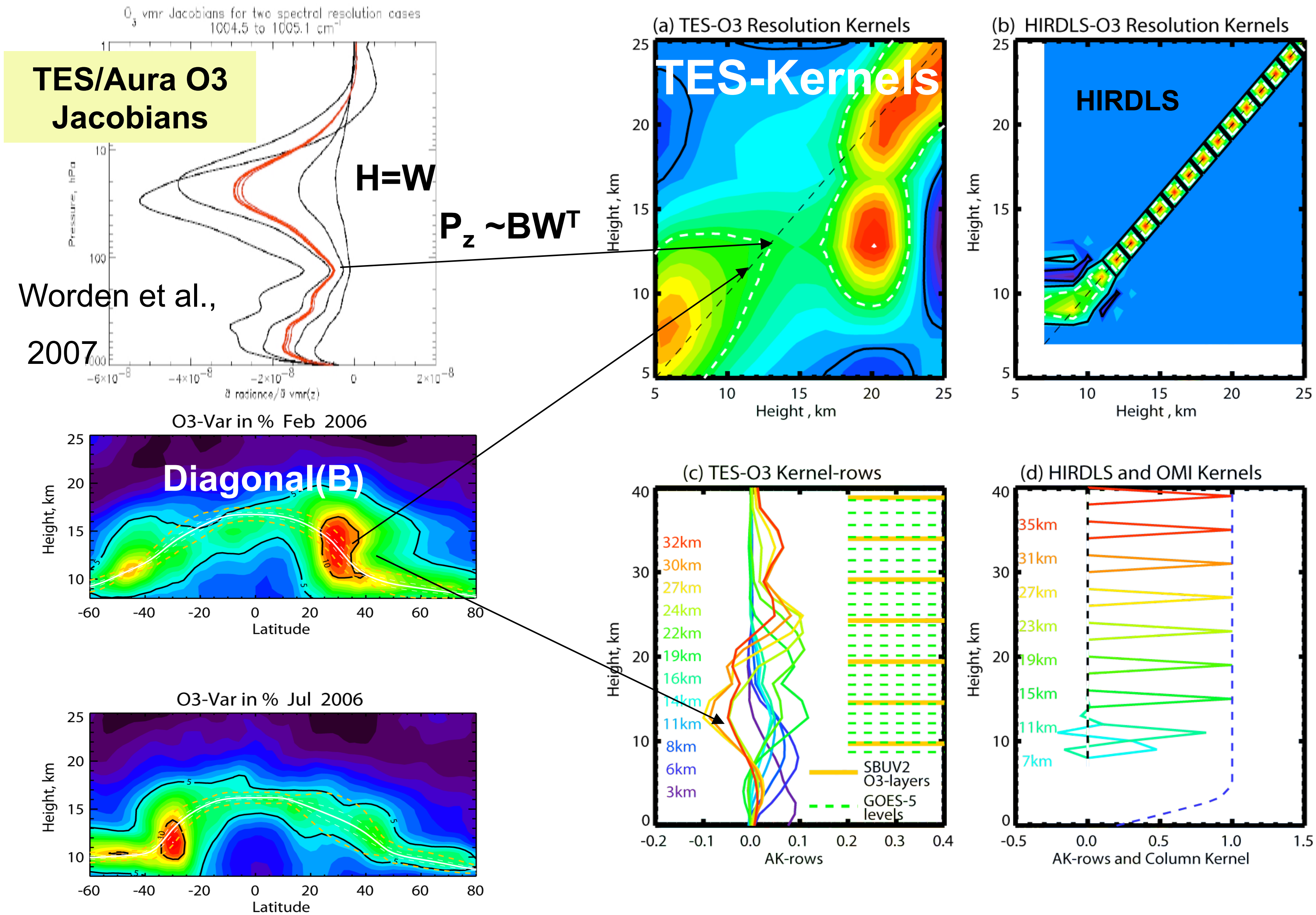
(c) handling **BH^T** in the minimization loops (needs practical solutions for EV-truncations)

Kernels and X_a provide powerful extra-info for QC showing when the linearity can be accepted.

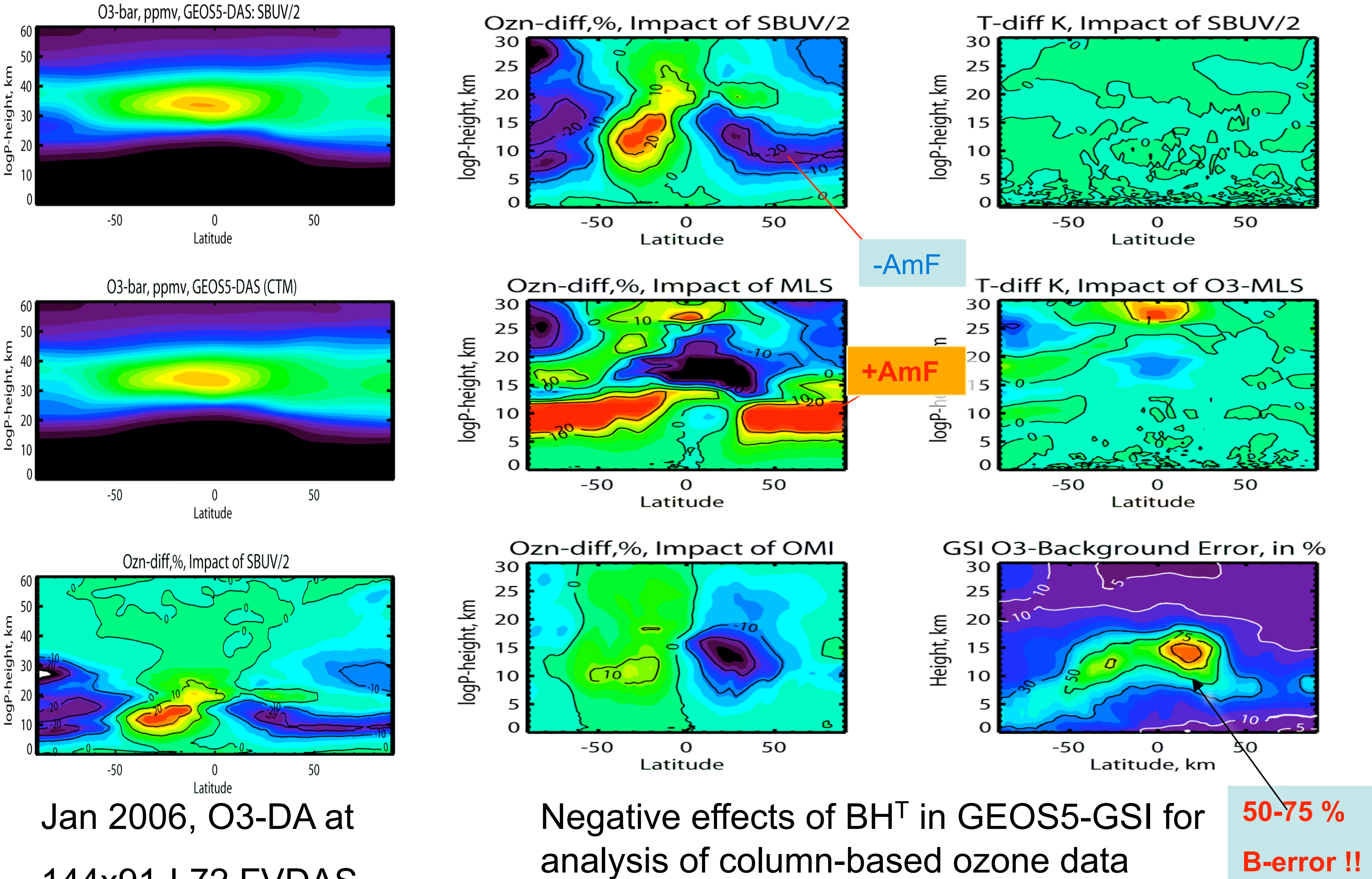


Resolution Kernel A_z-matrices

Ozone Jacobians and Kernels: TES and HIRDLS, QC by images of kernels



Multi-sensors in GEOS-5: Impacts of SBUV/2, MLS & OMI



Jan 2006, O3-DA at

144x91-L72 FVDAS

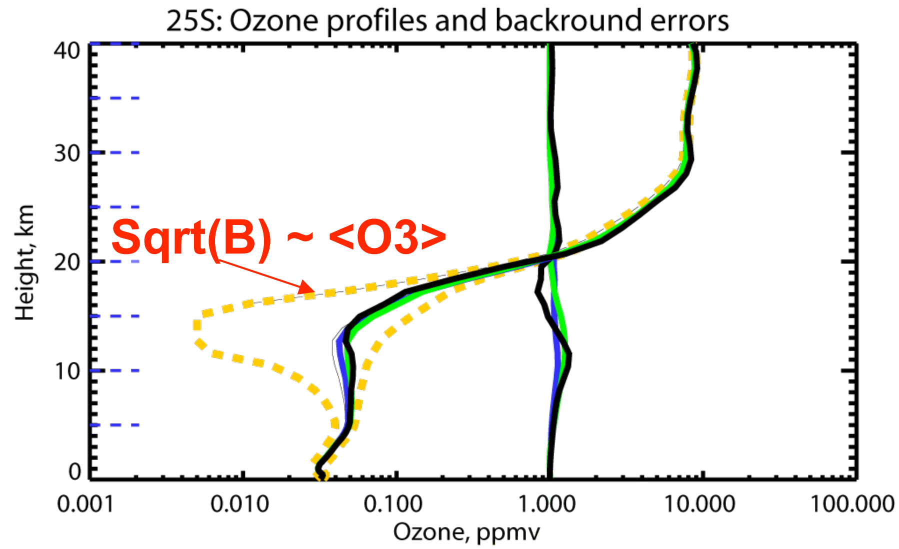
Negative effects of BH^T in GEOS5-GSI for analysis of column-based ozone data

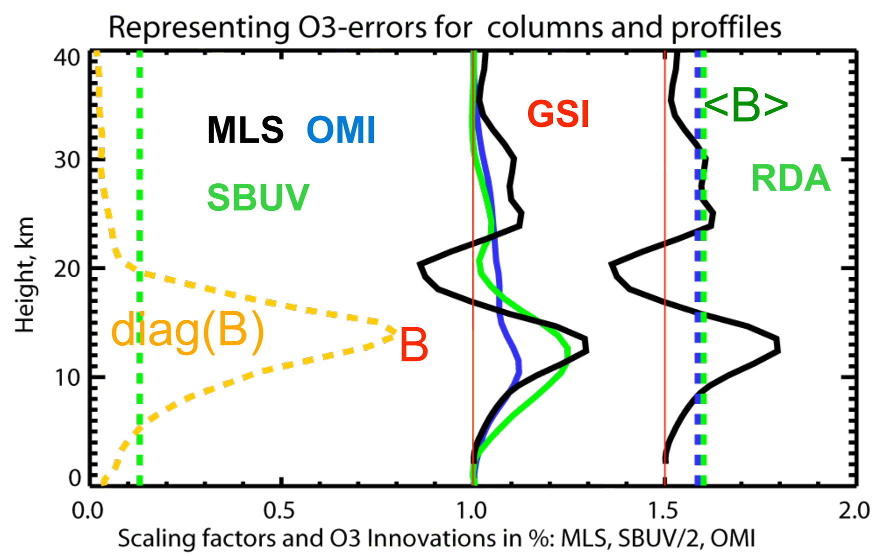
$\color{red}{B}H^T$ => $\color{green}{\langle B \rangle}$ H^T
Scaling O_3 profiles in DA of O_3 columns

- B-across the tropopause at model layers is up-scaled to uncertainties of columns <B>
- **<B>** => a scalar for columns and radiances when DFS ~ 1-4

- H^T for columns => scaling profiles along A-kernels
  H^T for radiances => scaling along Jacobians

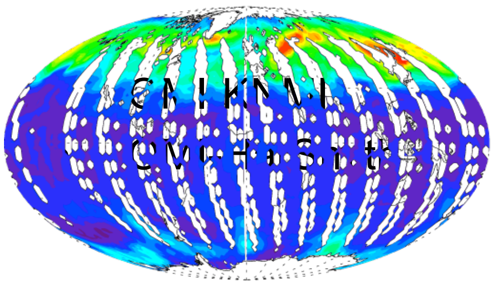
- Requirements for profiling of **H(p) and A(p)** => specification at model layers, to ensure precise accuracy (*11 layers of OMI-TOMS is not enough*)



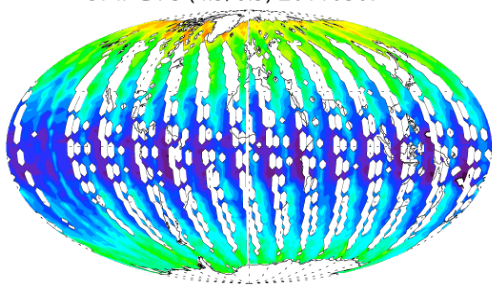


OMI-profiles ~ 50,000 per day

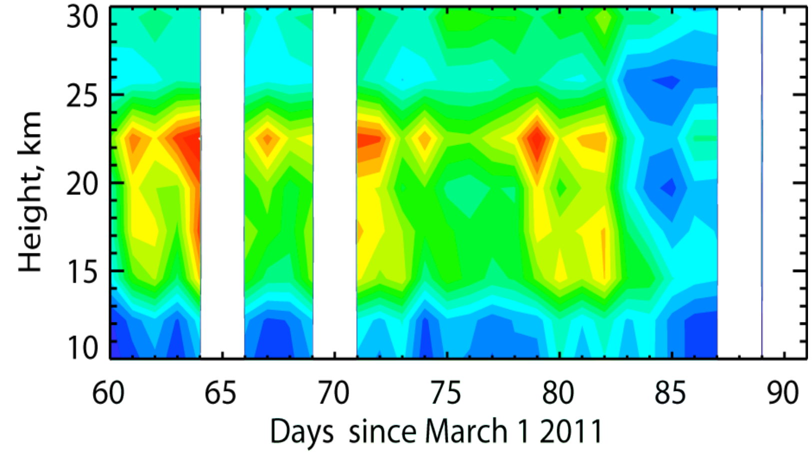
OMI-COLUMN 20110307



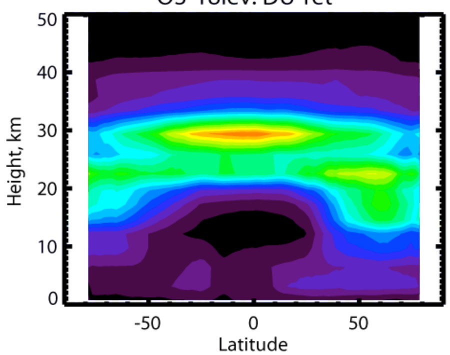
OMI- DFS (4.5/6.5) 20110307



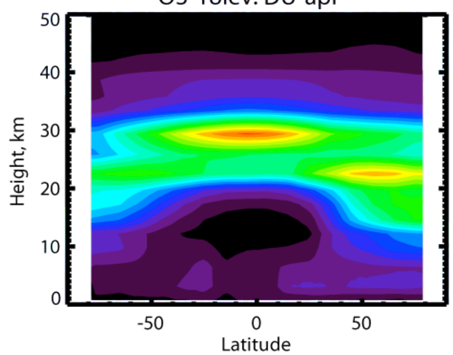
Ozone, DU, DOAS-KNMI at 67 N



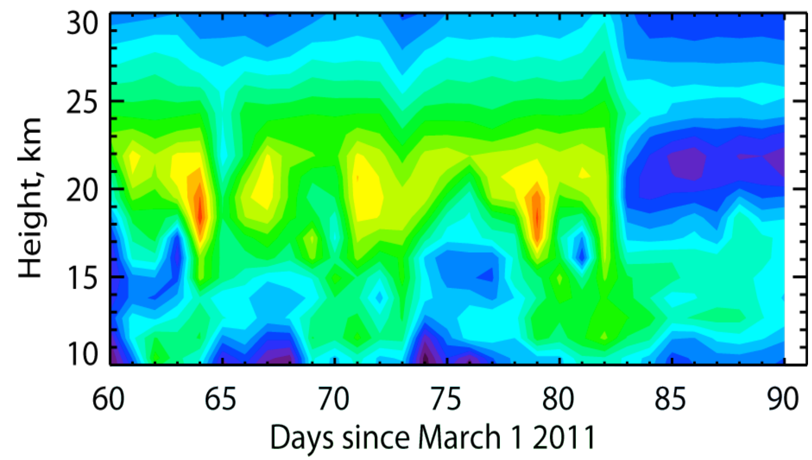
O3-18lev: DU-ret



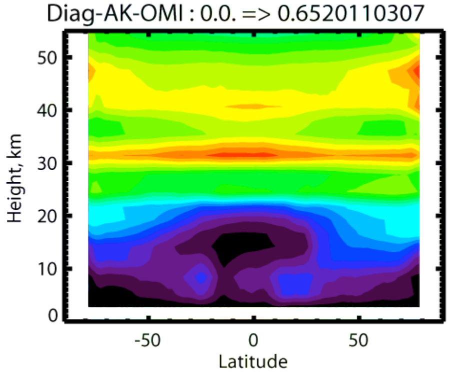
O3-18lev: DU-apr



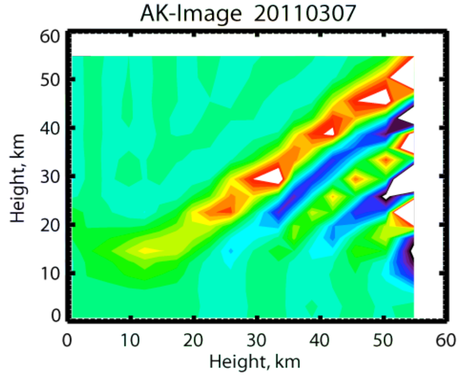
Ozone DAS-WACCM4 at 67 N



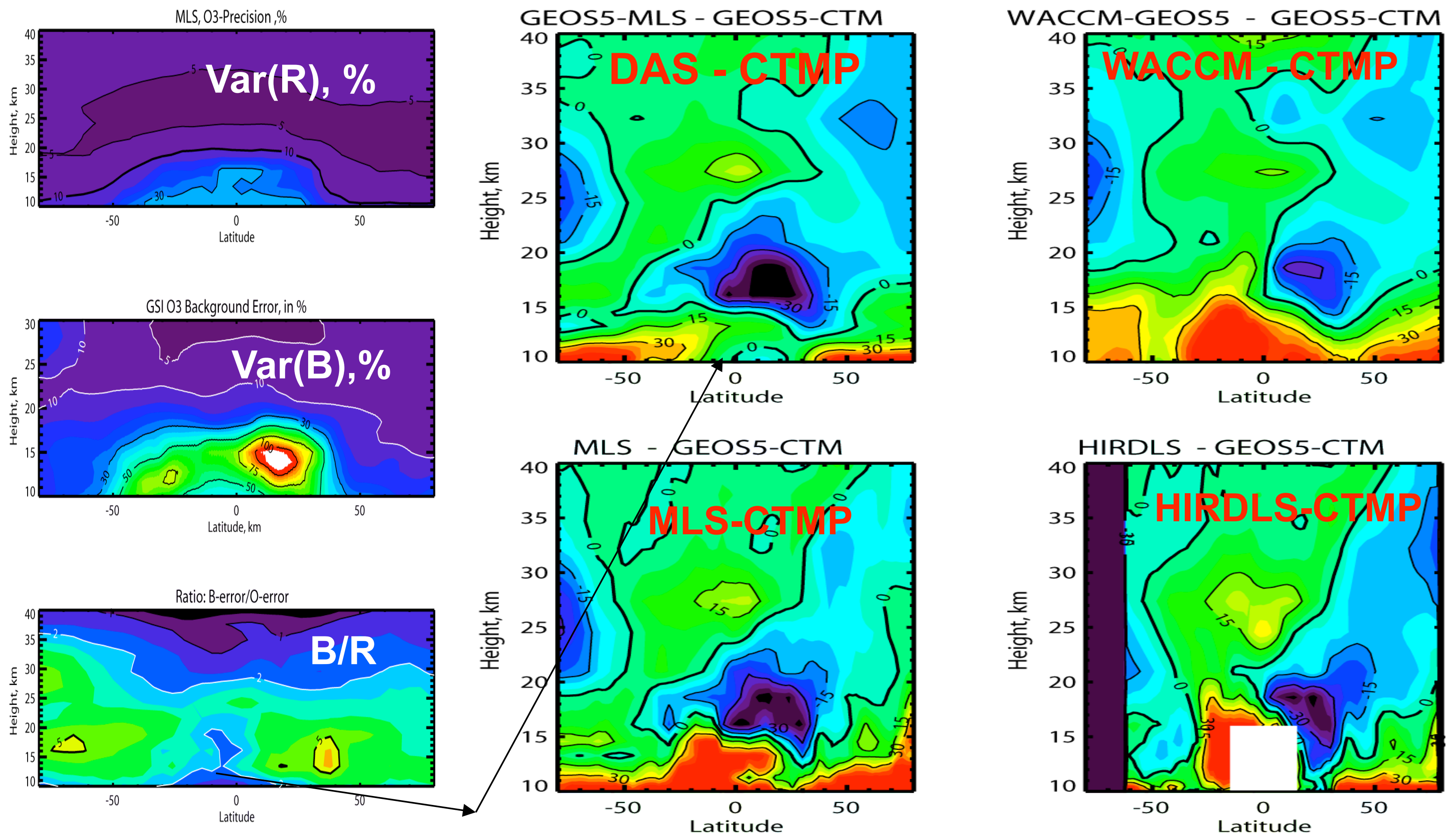
Diag-AK-OMI : 0.0. => 0.6520110307



AK-Image 20110307



Jan 2006: De-biasing GEOS-5 O3 forecast by analysis of MLS O_3 in the stratosphere

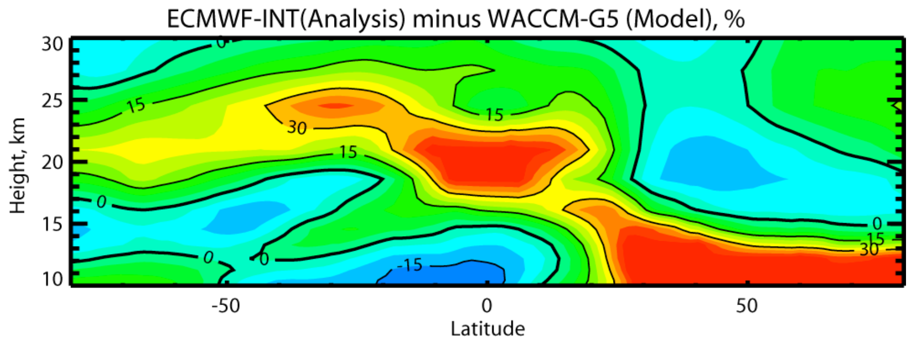


O_3-differences in %, relative to GEOS-CTMP O_3 predictions

Jan 2006: Analyses - Model, Analysis-Analysis Differences (in %),

ECMWF-Interim (E-I):

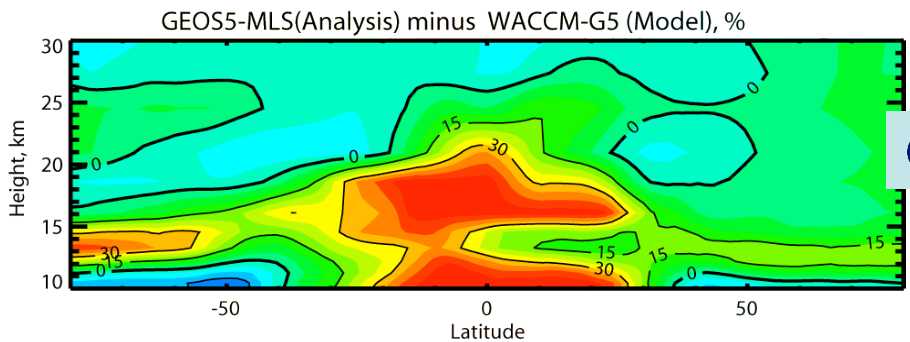
GOME O3-profiles



E-I m WAC5

GEOS5-MLS: **(G5-MLS)**

MLS-O3 profiles



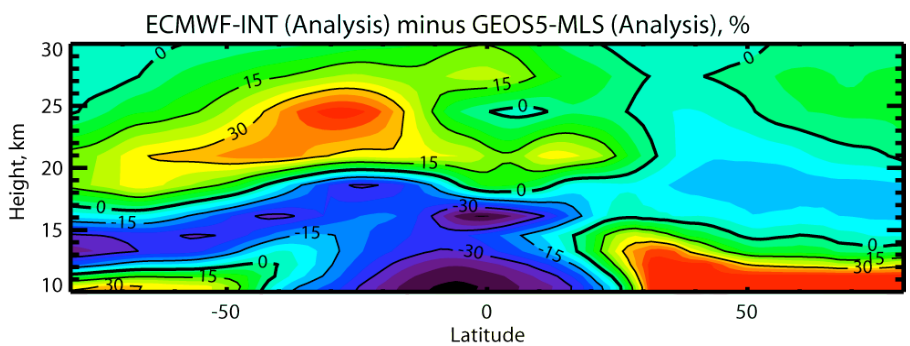
G5-MLS m WAC5

WACCM-GEOS5: (WAC5)

NCAR/NESL Community

Climate Chemistry Model driven by GEOS-5/Aura analysis system

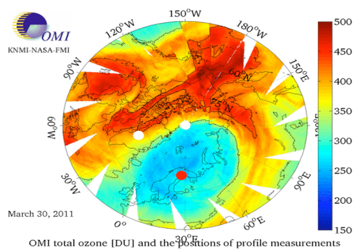
MLS ⇔ WACCM-G5

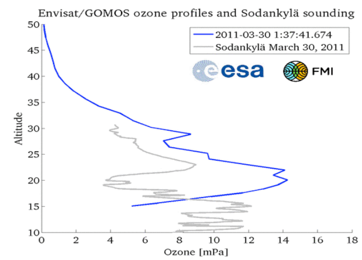


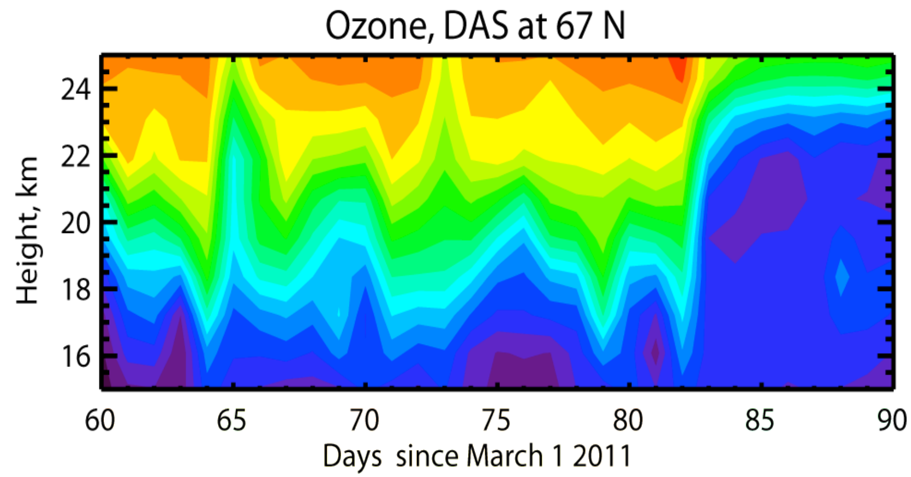
E-I m G5-MLS

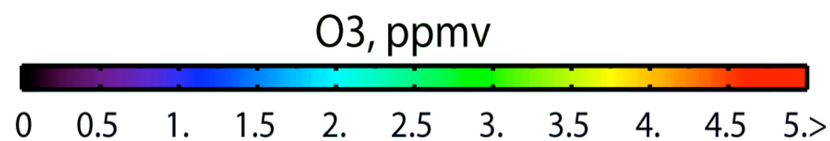
Arctic Spring 2011

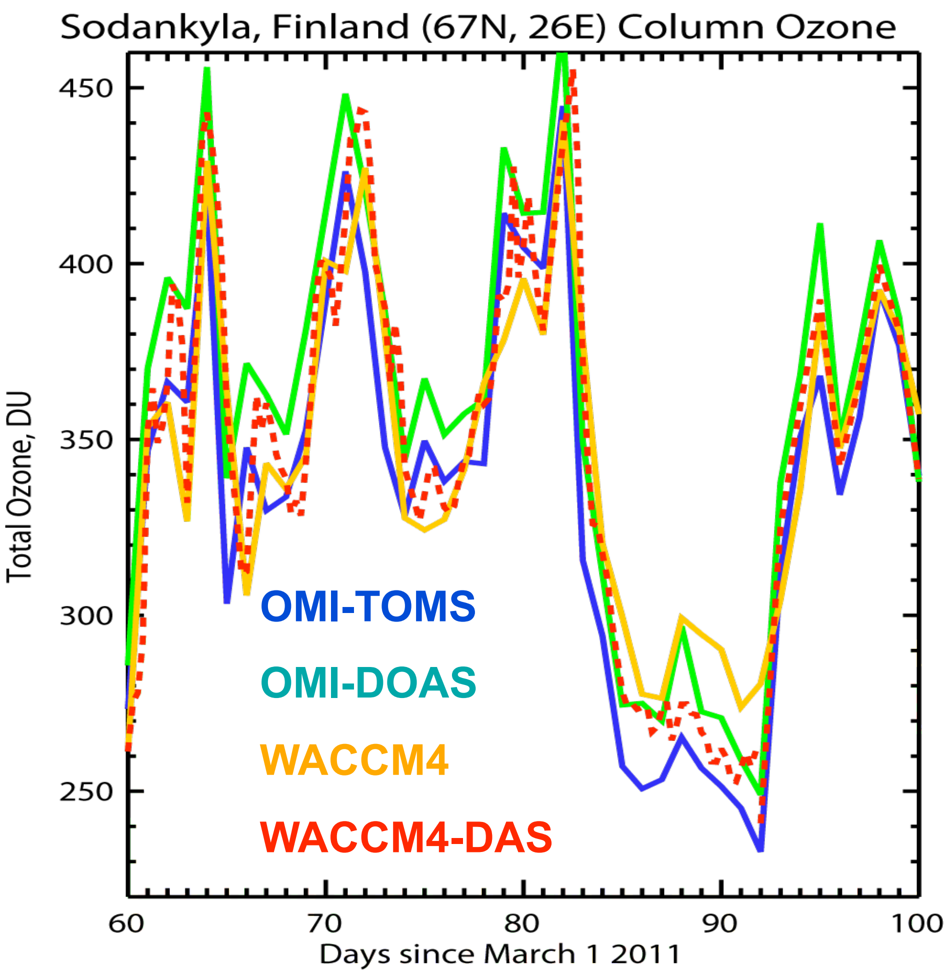
2011:March Ozone at Sodankyla, 67N

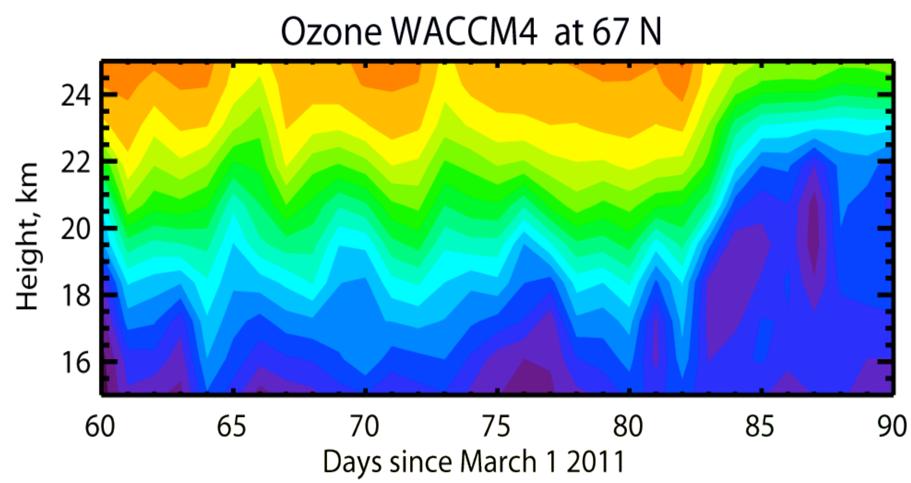




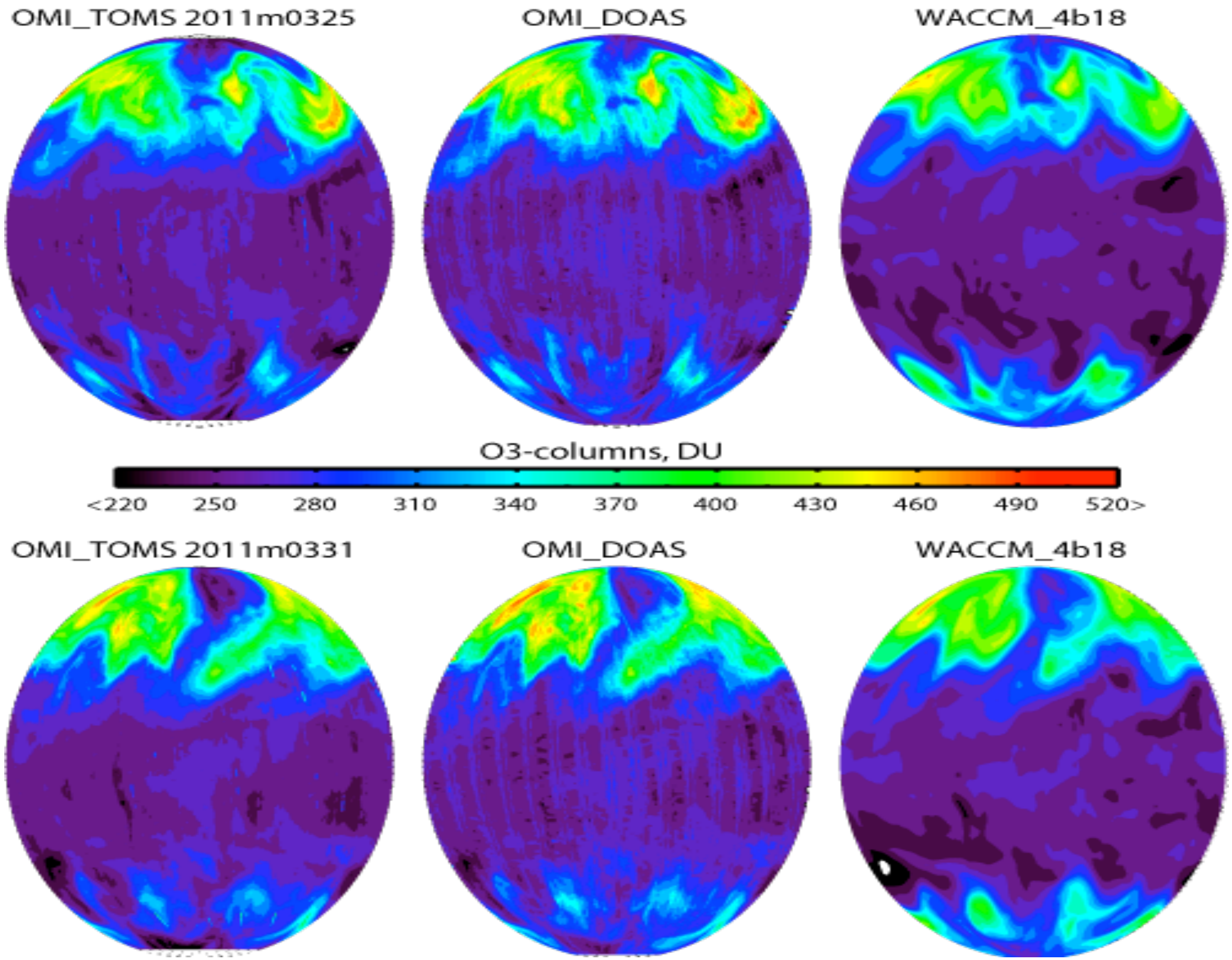




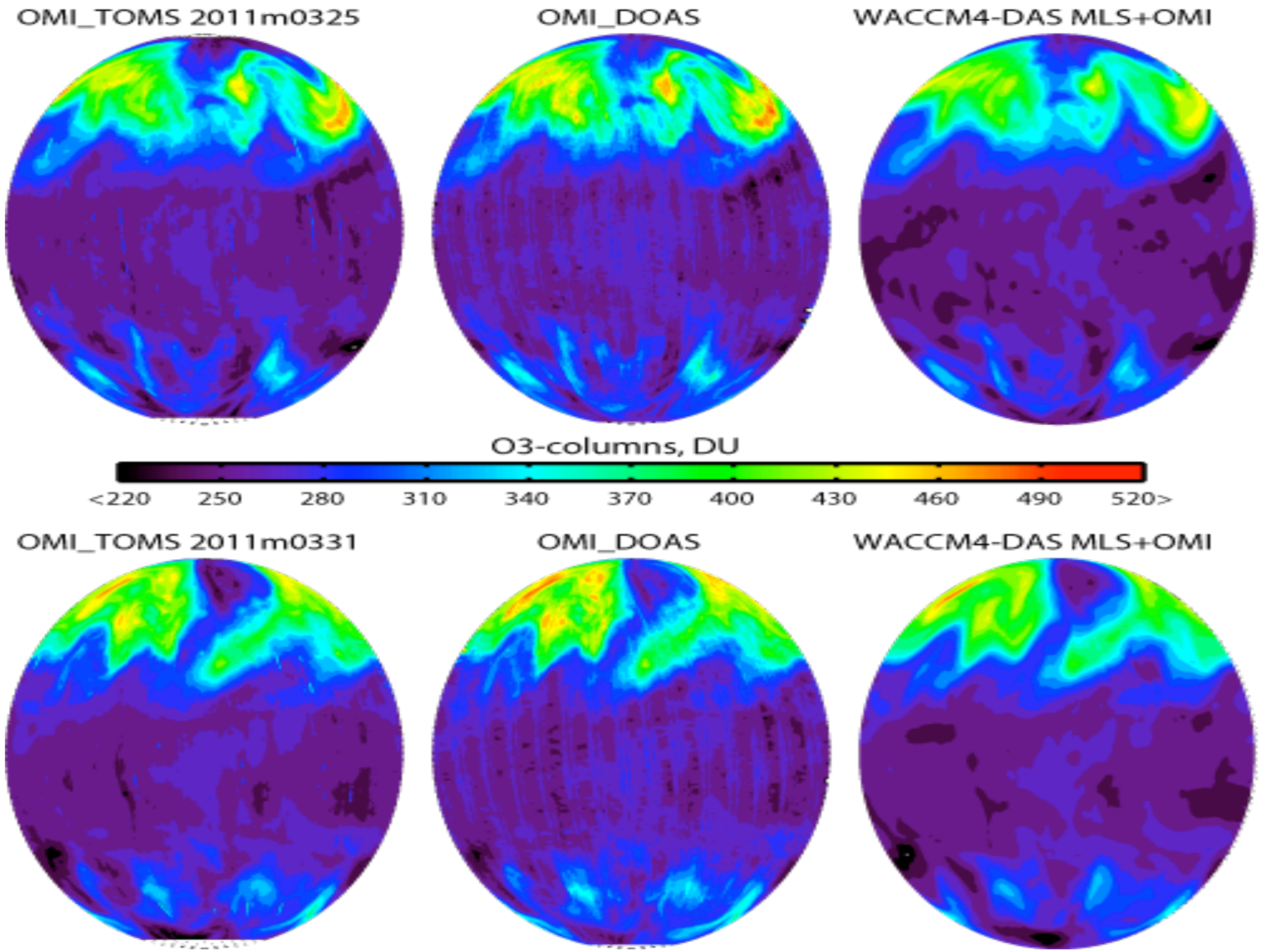


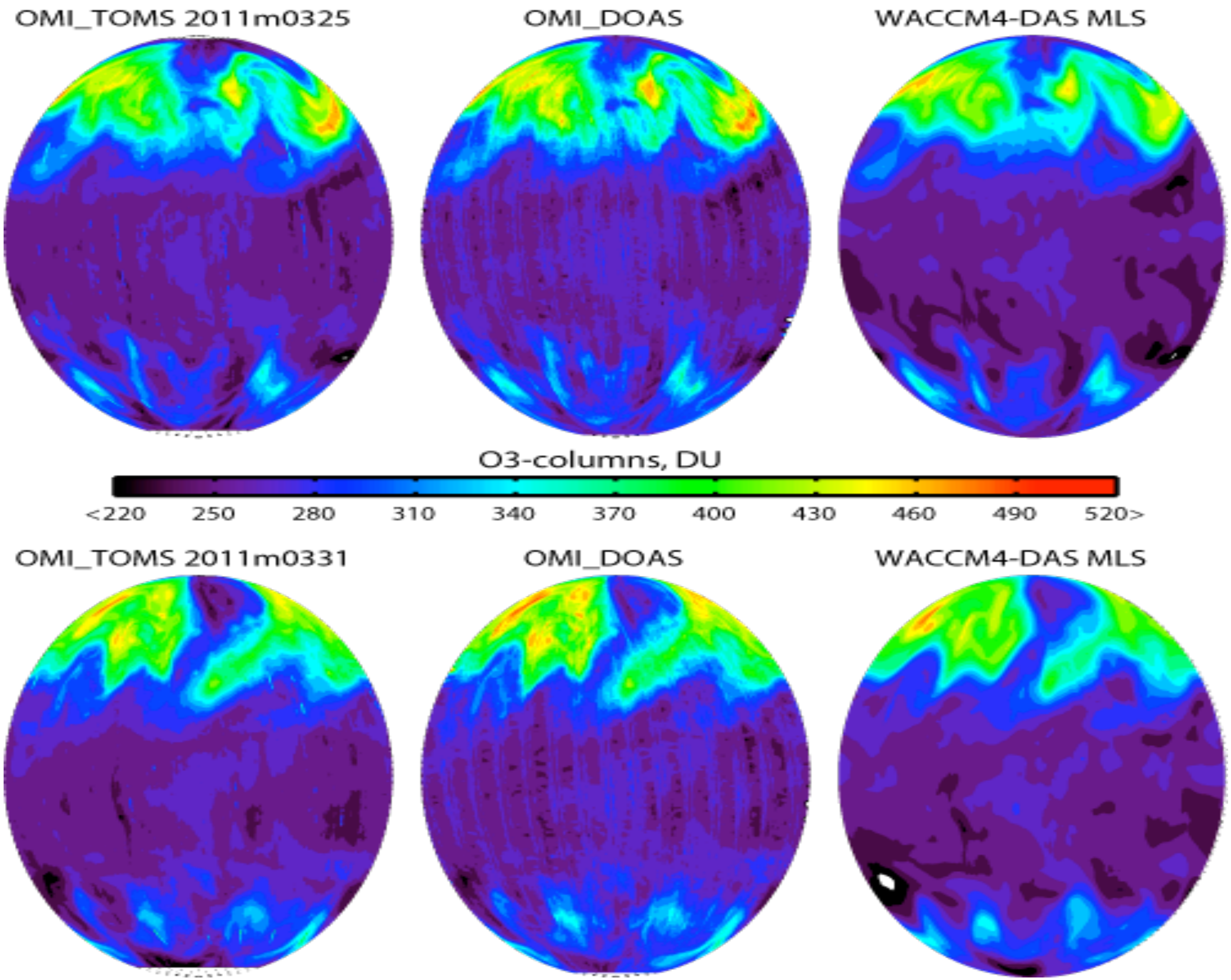


March 2011: OMI vs WACCM-GEOS5

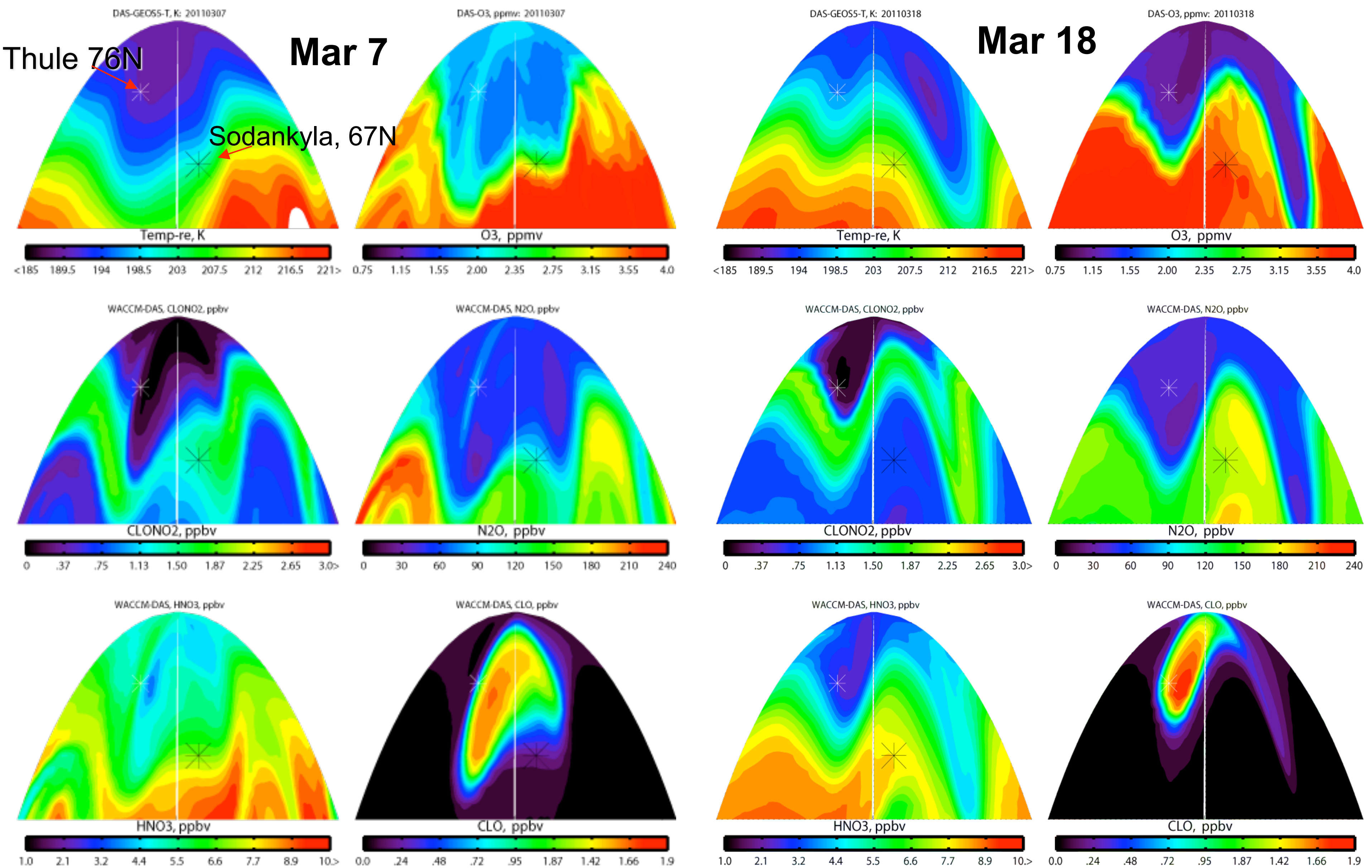


March 2011: OMI and WACCM4-DAS

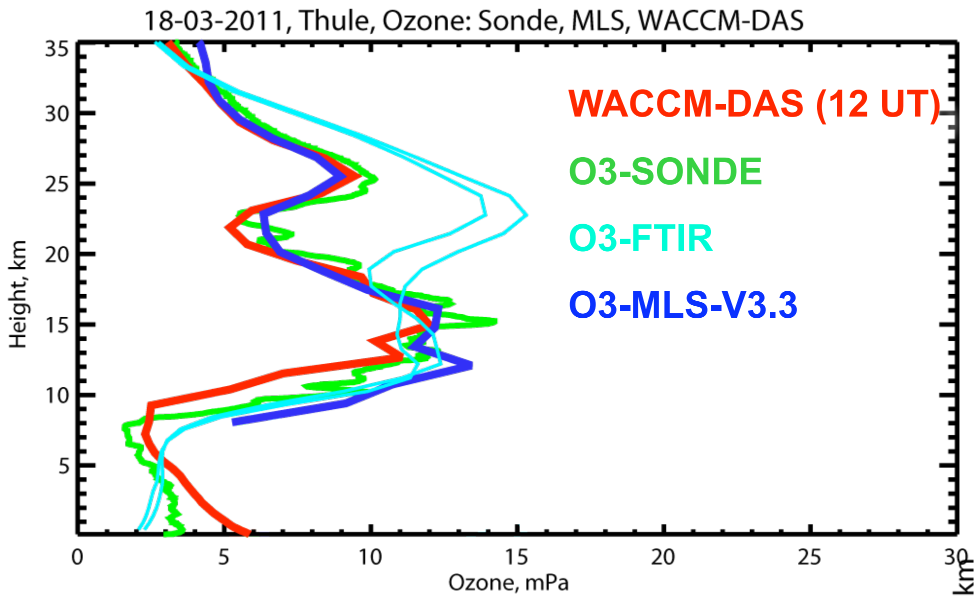


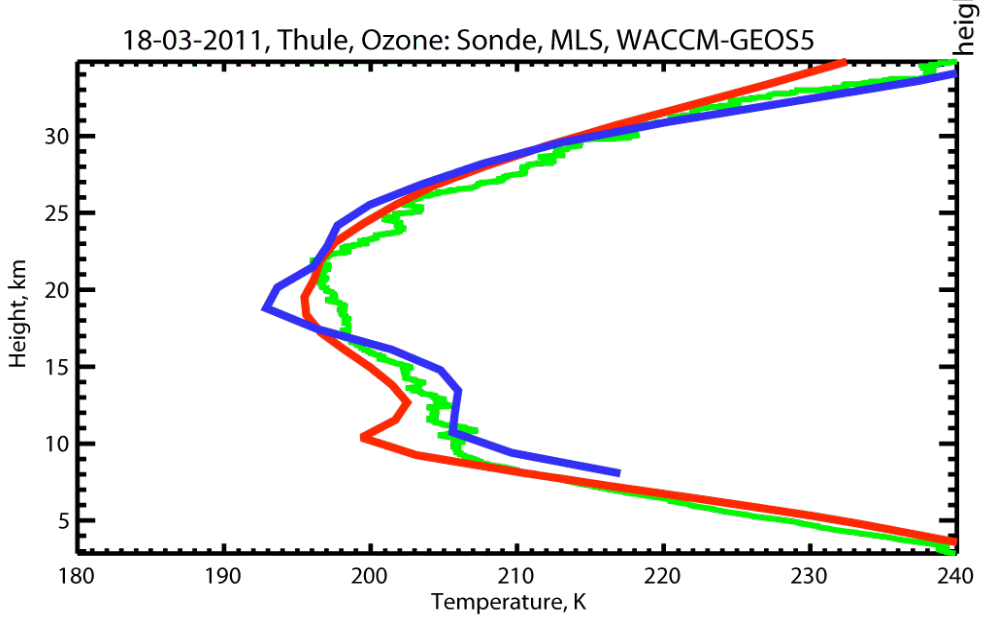

OMI_TOMS 2011m0325
OMI_DOAS
WACCM4-DAS MLS
O3-columns, DU
<220
250
280
310
340
370
400
430
460
490
520>
OMI_TOMS 2011m0331
OMI_DOAS
WACCM4-DAS MLS

Arctic Spring 2011: March 7 and 18, P=50hPa

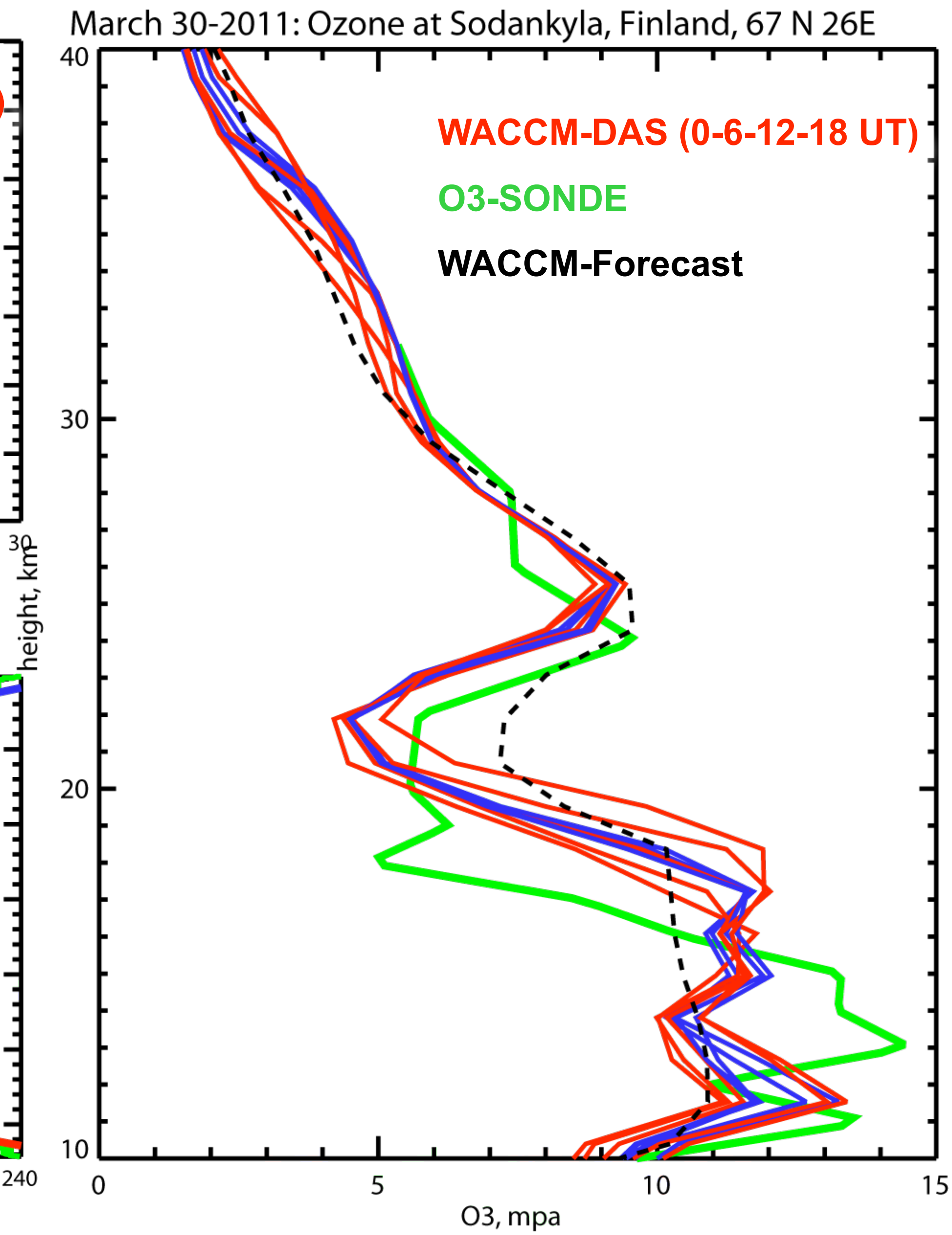


Thule 76ºN, March 18-2011

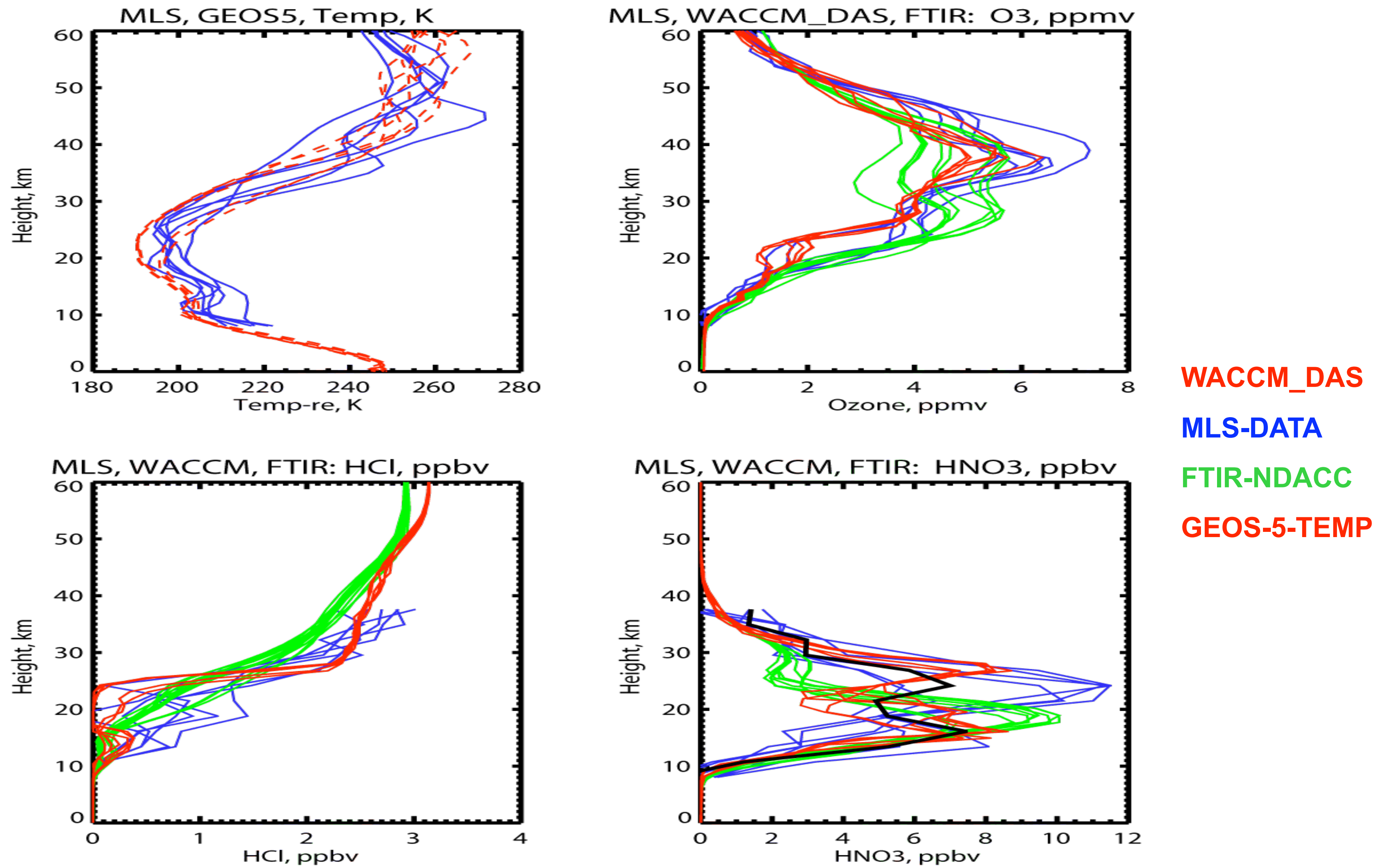




Sodankyla 67ºN, March 30



Thule 76°N: March 7,8,9, 15,16, 18

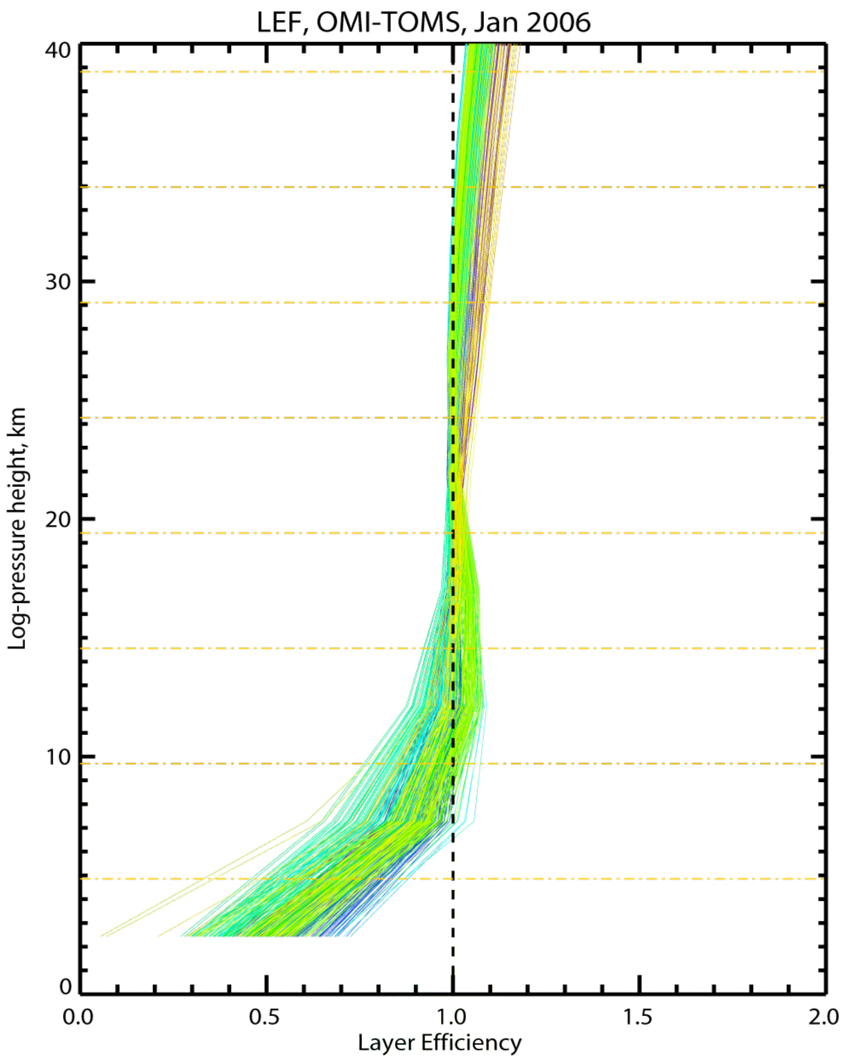


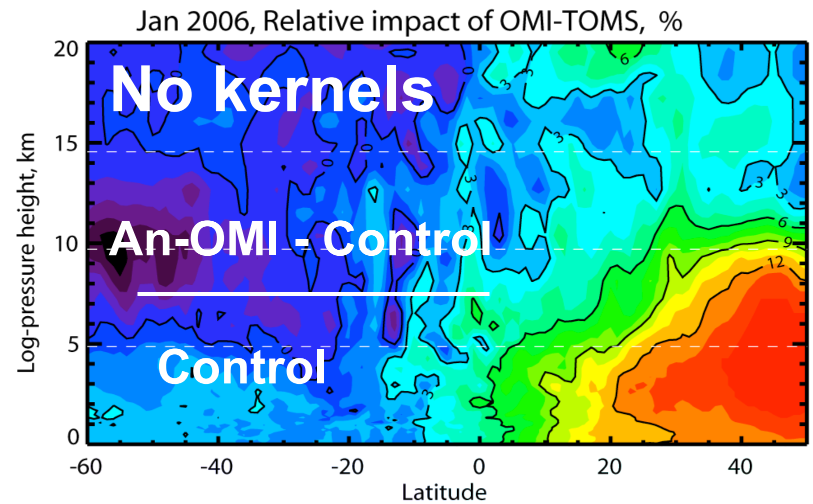
Concluding Remarks and *Outlook*

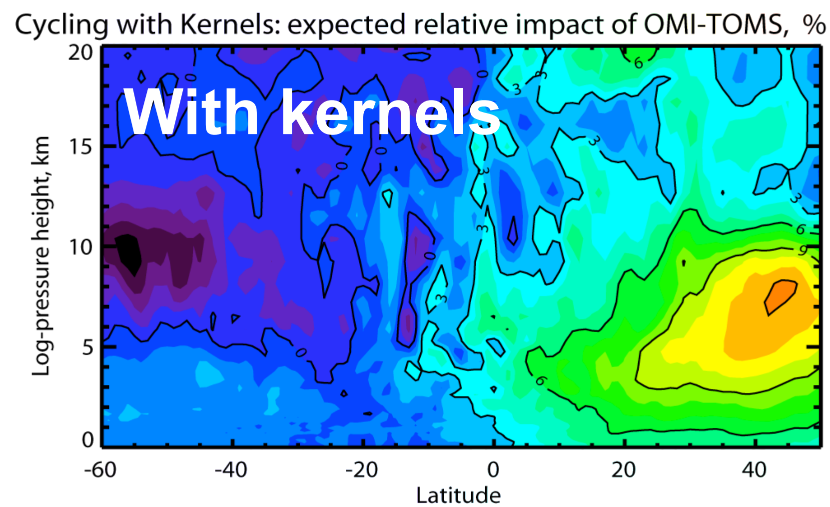
- **Ozone analysis schemes should properly acknowledge separation of visible and data-null scales**.
- **WACCM-GEOS5 system effectively utilizes the OMI and MLS/Aura O_3 data**.
- **WACCM (2004-2011) simulations with GEOS5 analyzed winds demonstrate a good quality for the ozone dynamics in the UTLS.**
- ***Current work: Implementation of RDA-schemes** for both nadir+limb data **with resolution kernels** => OMI, MLS, and HIRDLS*.
- ***Other possible implementations of RDA:** the radiance data analysis (AMSU-A channels in upper stratosphere) and CO/CO2 data analysis*
- *Need to communicate with data providers…..Kernels, Linear Char-n, A priori*

Intermediate solution => analyze only total columns, with column Kernels.

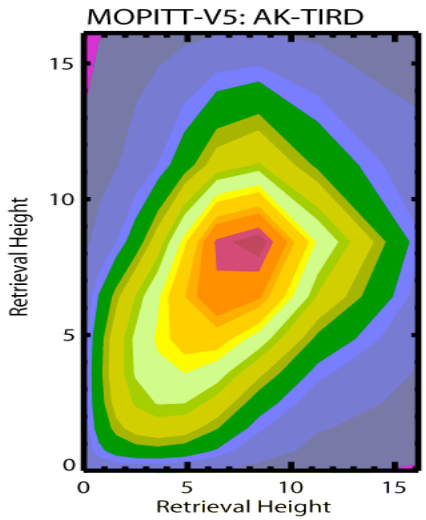
(example: analysis OMI columns in GEOS-5 with and w/o LEFs)

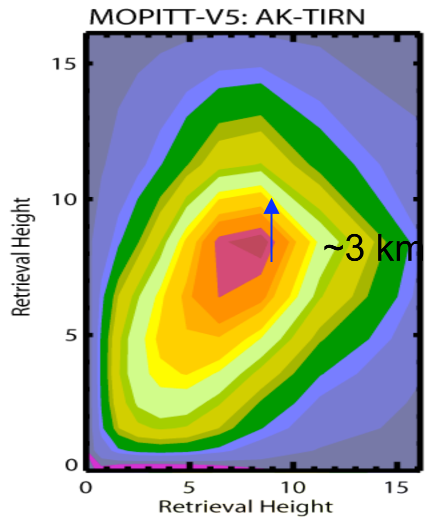






MOPITT CO: V3-V4-V5 kernels and RDA





Danger to put nadir

column-based data as a grid-wise measurements

Inverse mapping =>

Localization of vertical sensitivity in AK, compared to the RDA mapping by SVD-schemes