Forecast and Analysis of Vertical Ozone Structures in the UTLS: Scale-Dependent Assimilation Schemes of Multi-Instrumental Data

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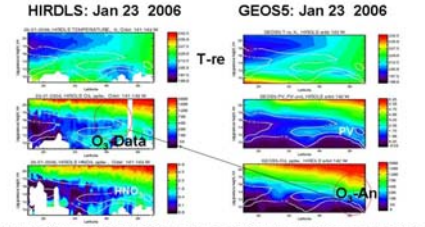
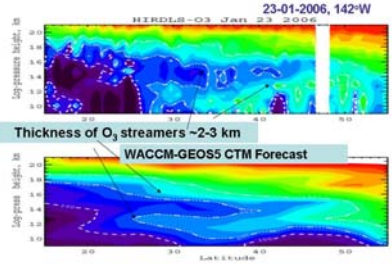
Abstract. *The paper evaluates forecasts and analyses of vertical ozone (O_3) structures in the Upper Troposphere and Lower Stratosphere (UTLS). The study was motivated by ability of HIRDLS (High Resolution Dynamics Limb Sounder) instrument to observe thin vertical layers of constituents (O_3 and HNO_3) and failures to mark these layers in the O_3 analyses. The shortcomings of analyses can be related with the inadequate treatment of vertical resolution of space-borne data (SBUV) by assimilation schemes. To overcome this problem the class of so-called scale-dependent assimilation schemes is introduced for joint analysis of data characterized by different vertical resolutions. These schemes preserve the observed thin layered structures (2-4 km) of ozone when column-based data are assimilated. For the multi-year climate studies paper discusses the adequate representation of vertical structures of analyzed O_3 and H_2O using HIRDLS and MLS data (2004-2008) in the equatorial stratosphere.*

Motivation by Aura orbital plots: HIRDLS vs GEOS5 in the UTLS

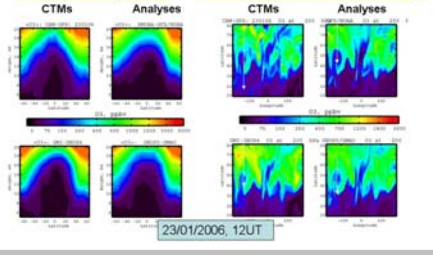


How often and why O_3 analyses fail to reproduce ozone thin layers characterized by negative vertical gradients of O_3?

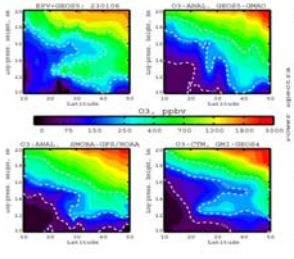
HIRDLS O_3 data and CTM O_3 forecast (comparable scales in the data analysis, $\delta h/\delta z \sim N/f$)



O_3: CTMs (CAM-GFS & GMI-GEOS4) and Analyses (NOAA-SMOBA and GMAO-GEOS5)

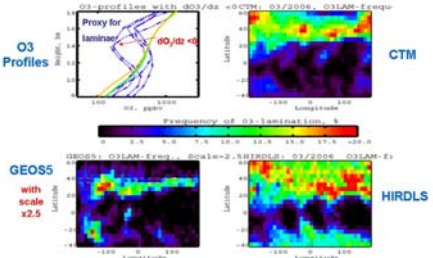


PV and O_3 Analyses and CTM, *142°W, 23/01/2006, 12 UT*



Spectra vertical oscillations of O_3

Lamination frequency reproduced by CTM, Analyses (GEOS5) and HIRDLS retrievals

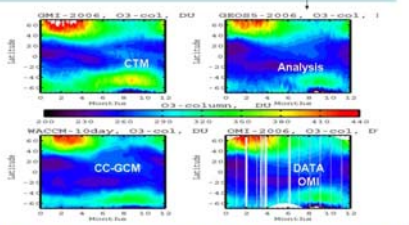


Consistent resolutions of observing systems: models and observations *(Fox-Rabinovitz & Lindzen, 1993)*

desirable $\delta z_c \sim N/f\delta h$ for the extra-tropical UTLS

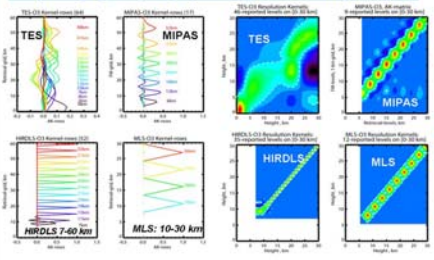
Analyses/Models, $N_x x N_y x N_z$	Types of O_3 data
• GMAO/GEOS-5.1.0 *540x360x72* δz_c ~250m vs δz_m~1 km	• ***Type-1***: **Column-based O_3 data** (OMI,TOMS, SBUV)
• NOAA/GFS-SMOBA *360x180x36* δz_c~ 500m vs δz_m~1 km	• ***Type-2***: **Vertical profiles** (limb instruments HIRDLS, MLS, MIPAS with $\delta z \sim N/f\ \delta h$ constrain dynamics)
• GMI-CTM-GEOS4 *144x 91x45* • CAM-Chem-GFS *144x 96x28* δz_c~ 1 km vs δz_m~1 km	• ***Type-3***: **Smoothed profiles** (nadir sensors => layer-averaged data AIRS, TES, METOP.... with $\delta h/\delta z \sim\ \delta h/Hp$ ~1-5 =/= N/f)
• WACCM3-SST/QBO *72x 45x76* δz_c~ 2 km vs δz_m~2 km • WACCM3-CTM-GEOS5 *180x 91x72* • WACCM3-CTM-with DAS δz_c~ 1 km vs δz_m~1 km	• ***Type-4***: **in-situ vertical profile data** (no horizontal sampling, sondes, SHADOZ and WOUDC)

Type I Data: Comparing O_3-colums (DU): CTM, WACCM-climate, GEOS5 (2006),OMI (2006)

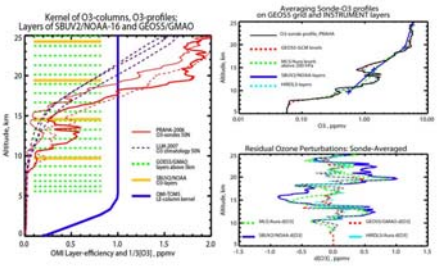


OMI O3-columns are reproduced by models and analysis

Types II-III: Characterization of O_3 profiles by Resolution Kernel matrices: Rows and Images (Averaging, *Sharpness, Symmetry, Values and Properties*)



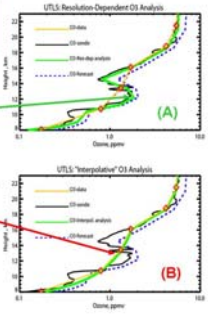
Data/Instrument and Analysis/Model grids: *resolved (visible) and invisible (Nyquist) scales*



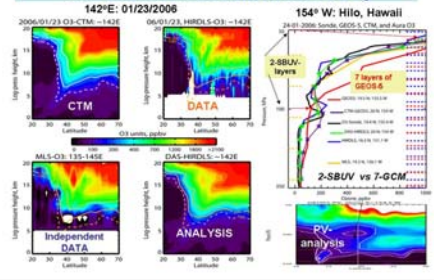
Resolution-dependent analyses schemes

- A) *Preserving vertical O_3 short-wave components by resolution-dependent scheme that adjust only "visible" scales.*
- B) *Treating "layer-averaged" data as a "point-wise" data => "backward" interpolation from the data space to the analysis grid*

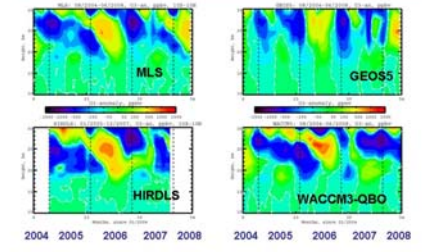
Compare the (A)- *and* (B)- *"green" analysis curves*



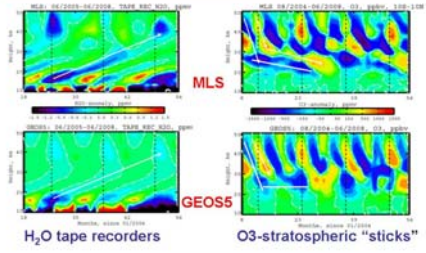
Examples: Assimilating LS intrusions in UT with vertical resolution of HIRDLS-O_3



Equatorial O_3-anomaly (10°S-10°N, 2004-2008): data, analysis, and model simulations



Equator: H_2O and O_3 stratospheric analyses GEOS5 and MLS (HIRDLS-H_2O, future data versions)



Conclusions

- *Nadir sensors with $\delta h/\delta z \sim 1\text{-}5 << N/f$ ($\delta z \sim H_p$)* report the smoothed profiles that are still column-based data.
- *Limb sensors deliver profile-based data with $\delta h/\delta z \sim N/f$* consistent with model dynamics and monitoring transport of ozone in thin layers of the UTLS (*MLS and HIRDLS*).
- To advance multi-instrumental O_3 products (analyses, retrievals) along with characterization of data by resolution kernels the *scale-dependent assimilation schemes should be developed.* Erroneous treatment of column-based measurements as the point-wise data may degrade analyzed fields.
- ***Message for Assimilation:*** *Don't blend incomparable vertical scales of observations and forecasts, constrain only scales visible to the instrument, preserving short-scale structures of models.*

- ***Acknowledgements to*** Aura Instrument Science Teams, GFS/NOAA, GEOS/GMAO, and GMI/GSFC, SHADOZ groups for data and simulations.