Joint Assimilation of Tropospheric Emission Spectrometer and Microwave Limb Sounder Ozone Measurements in the GEOS-Chem Chemistry Transport Model

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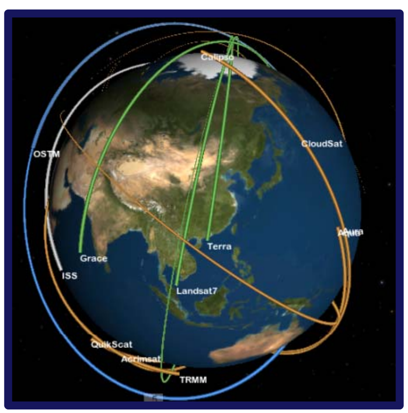
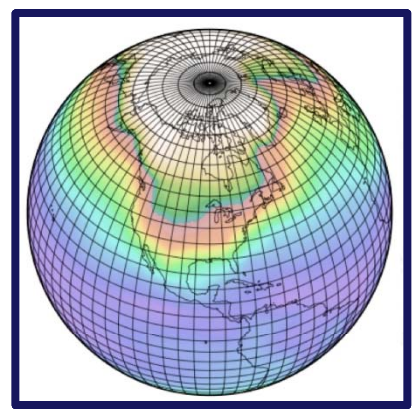
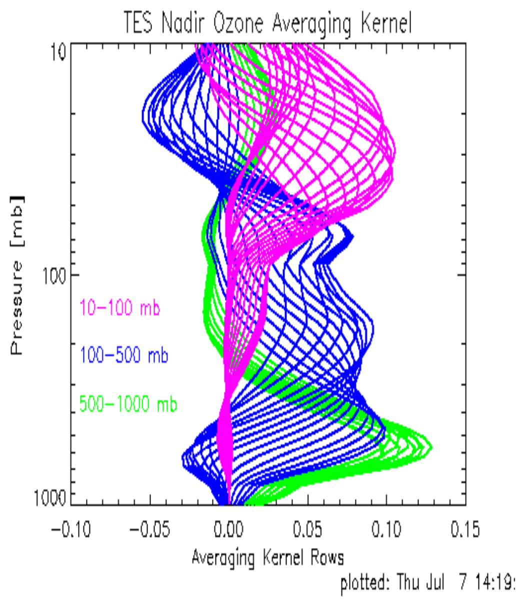
JPL/Caltech





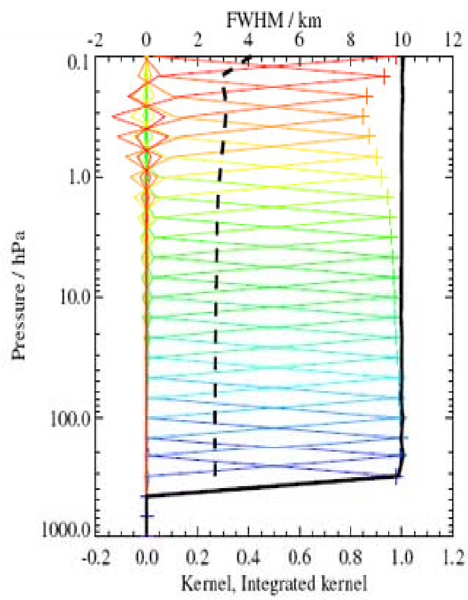
TES and MLS Measurements

TES



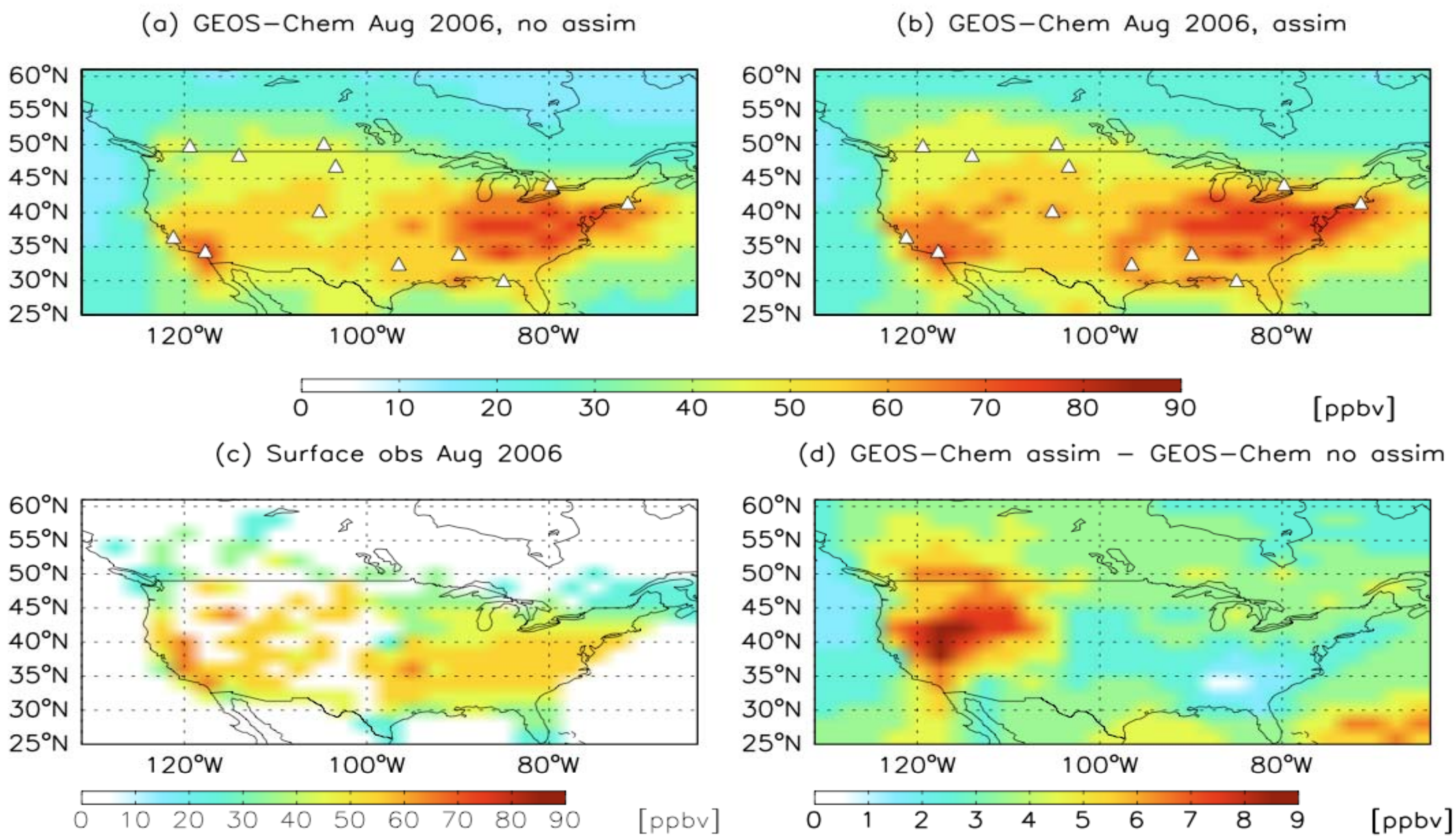
- Nadir sounder, measures in TIR
- Focused on tropospheric composition
- Broad averaging kernels, effective vertical resolution ~6-7 km for O_3
- Sensitivity falls off above ~50 hPa

MLS



- Limb sounder, measures in microwave
- Focused on stratospheric composition
- Narrow averaging kernels, effective vertical resolution ~2-3 km for O_3
- Sensitivity falls off below 215 hPa for V2.2

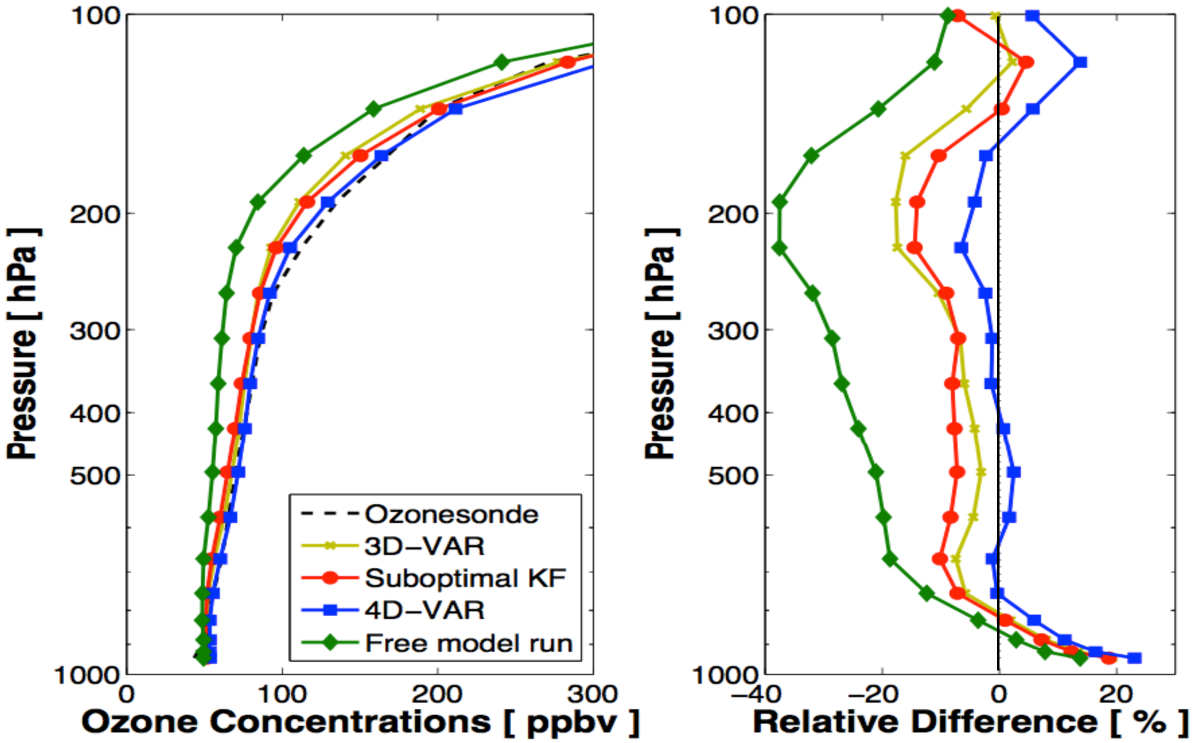
Parrington et al., 2009: Impact of TES assimilation on surface ozone



- Assimilated TES data into GEOS-Chem using sequential sub-optimal Kalman Filter
- Assimilation corrected large negative biases in model background in the free troposphere, which increased O_3 flux into the boundary layer
- Improved agreement with surface sites in W US, but exacerbated positive bias in SE

Singh et al., 2012: 3D-Var, 4-D Var, and sub-optimal Kalman Filter assimilation of TES measurments

Comparison to IONS Sondes, Aug 2006

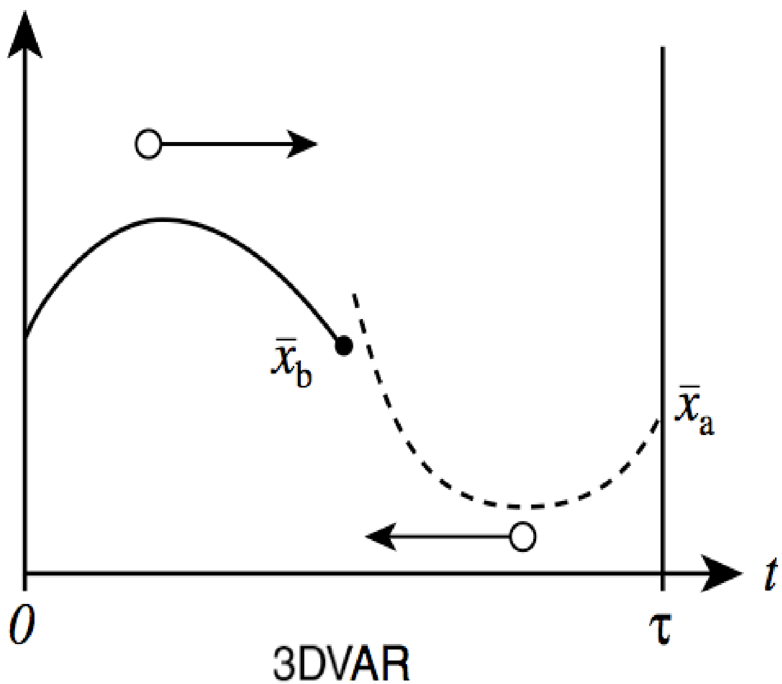


- Extended the work of Parrington, et al. (2009)
- Compared KF to 3D-Var and 4D-Var assimilation
- Found mean improvement relative to sondes, especially in mid-troposphere

3-D Var Assimilation of TES and MLS

$$\min_{\mathbf{x}_0} C(\mathbf{x}) = \left\{ \sum_i (\mathbf{y}_i - \mathbf{F}_i(\mathbf{x}))^\top (\mathbf{S}_n^i)^{-1} (\mathbf{y}_i - \mathbf{F}_i(\mathbf{x})) + (\mathbf{x}_0 - \mathbf{x}_a)^\top \mathbf{S}_a^{-1} (\mathbf{x}_0 - \mathbf{x}_a) \right\}$$

$$\text{subject to } \mathbf{x}_{i+1} = \mathbf{M}_i(\mathbf{x}_i, \mathbf{p}_i)$$

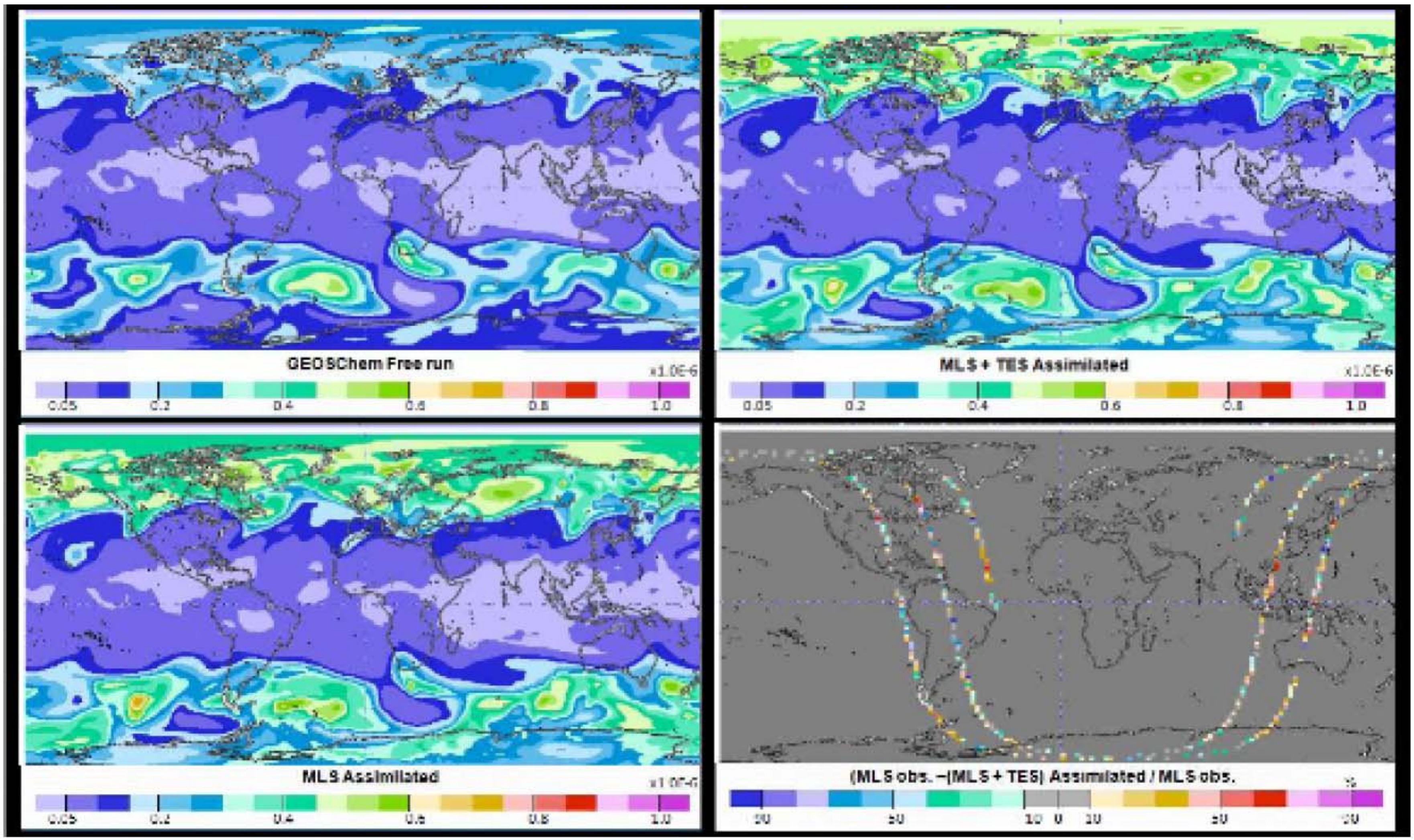


Courtesy E. Holm, ECMWF

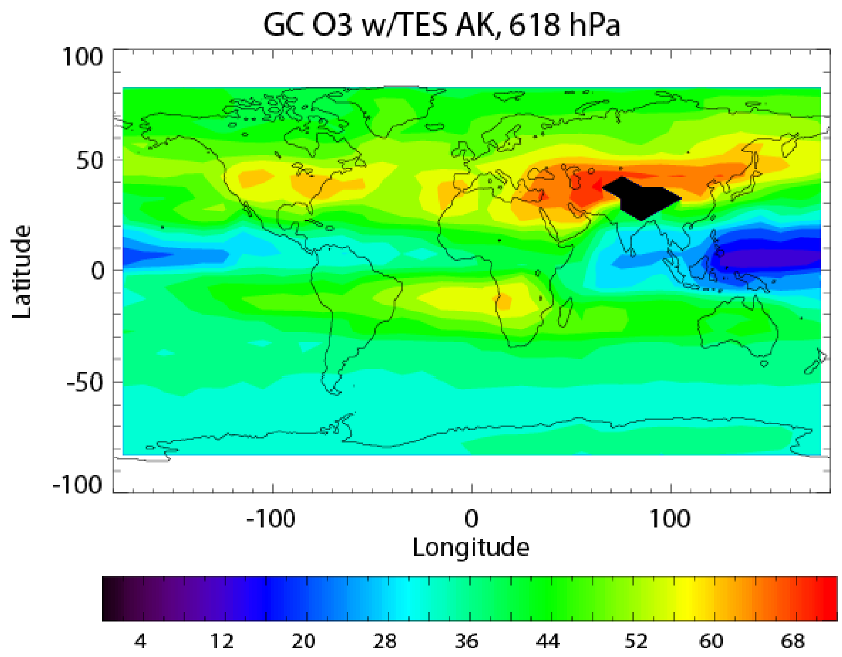
- **GEOS-Chem version 8-2-1 with GEOS-5 meteorological fields at 2º x 2.5º resolution and 47 vertical levels**
- **Comprehensive tropospheric chemistry, linearized stratospheric ozone chemistry (LINOZ)**
- **Model time step: ½ hour; Assimilation time step: 4 hours**
- **Assimilation of TES and MLS L2 ozone measurements for Jul-Aug 2006**
- **MLS v2.2, 215-0.1 hPa, TES v4, 908-0.1 hPa**

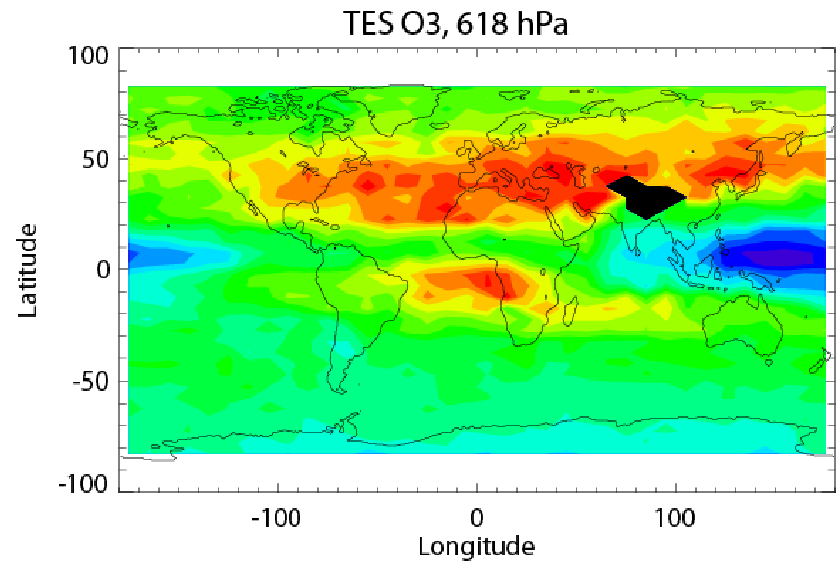
Assimilation of TES and MLS in GEOS-Chem

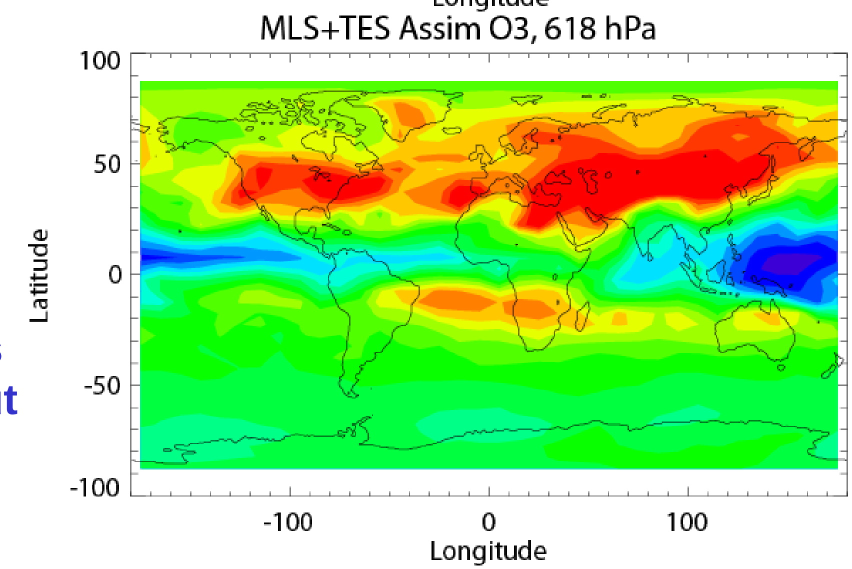
Snapshot from 200 hPa, 7/31/2006



GEOS-Chem vs TES, 618 hPa
August 2006

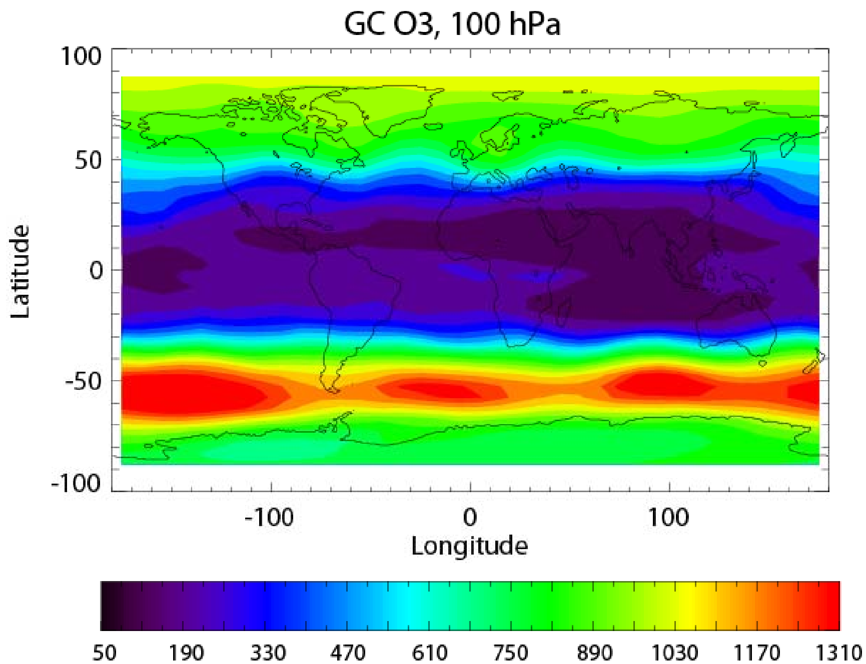


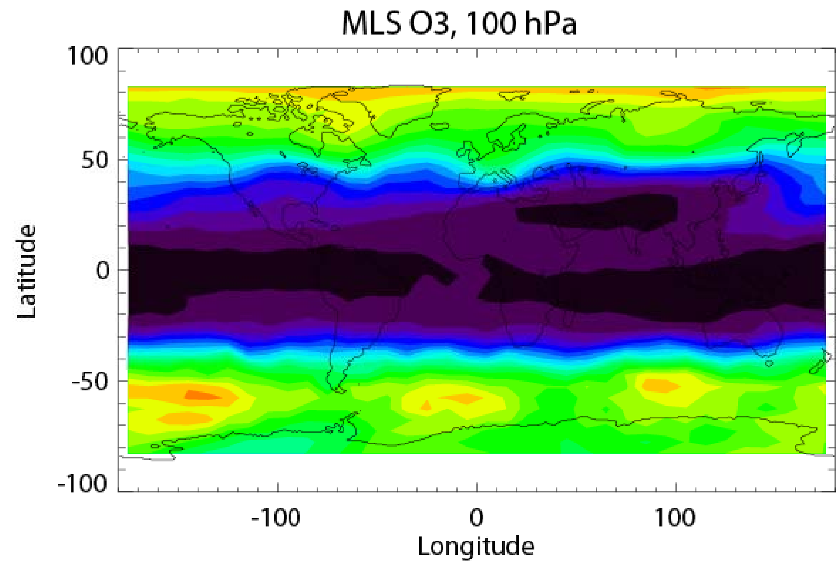


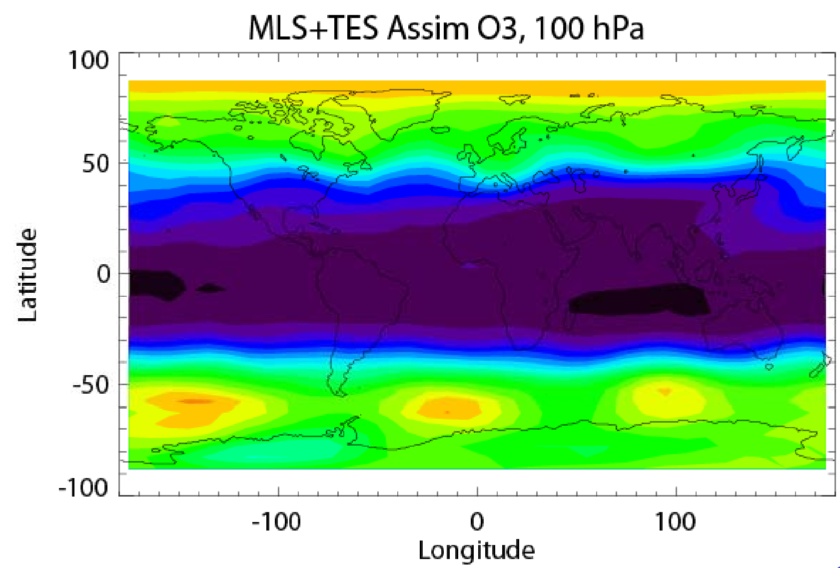


- GEOS-Chem underestimates O_3 in the mid-troposphere with respect to TES.
- The assimilation shows large enhancements over the NH continents as well as throughout the SH.

GEOS-Chem vs MLS, 100 hPa
August 2006

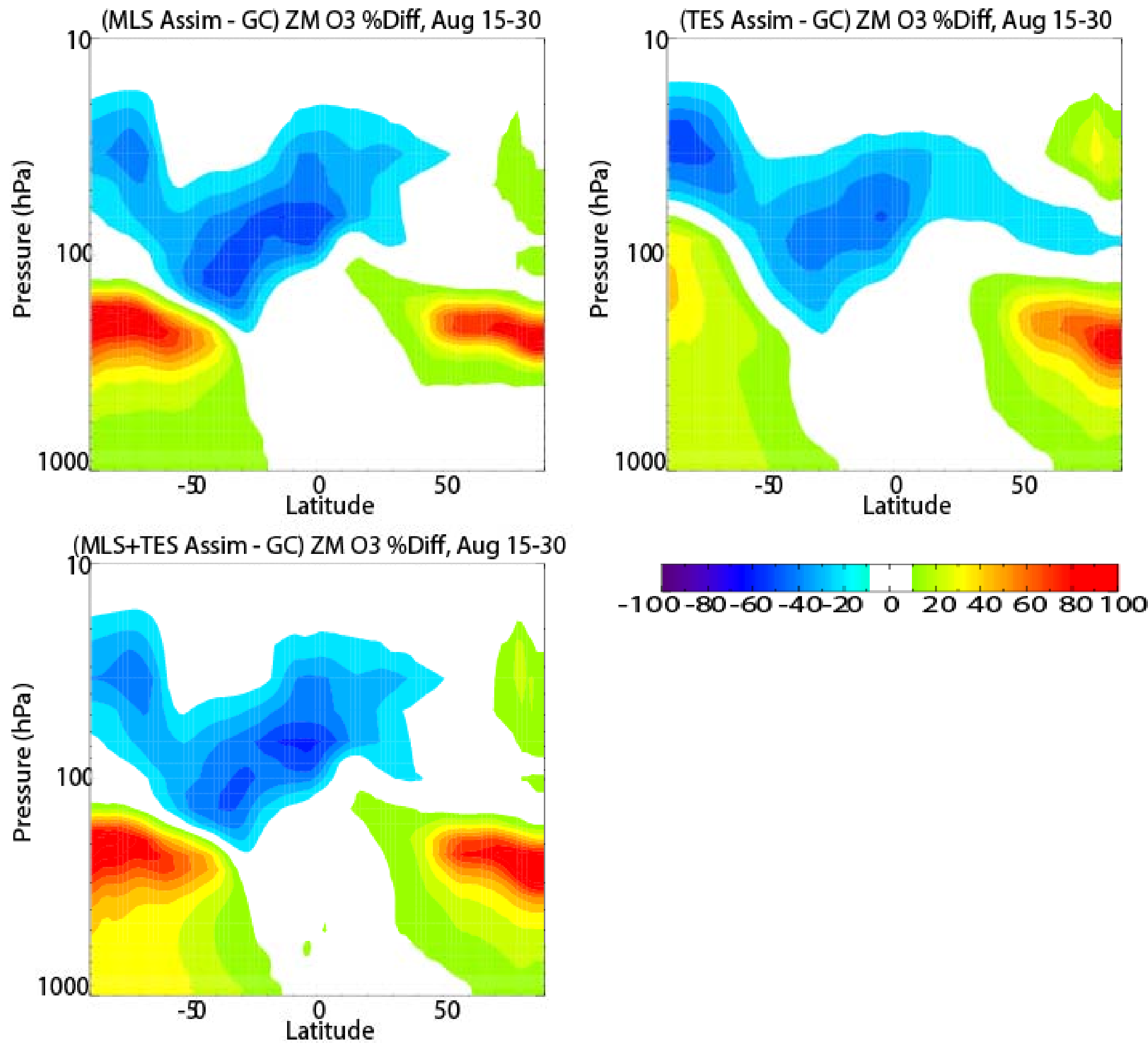






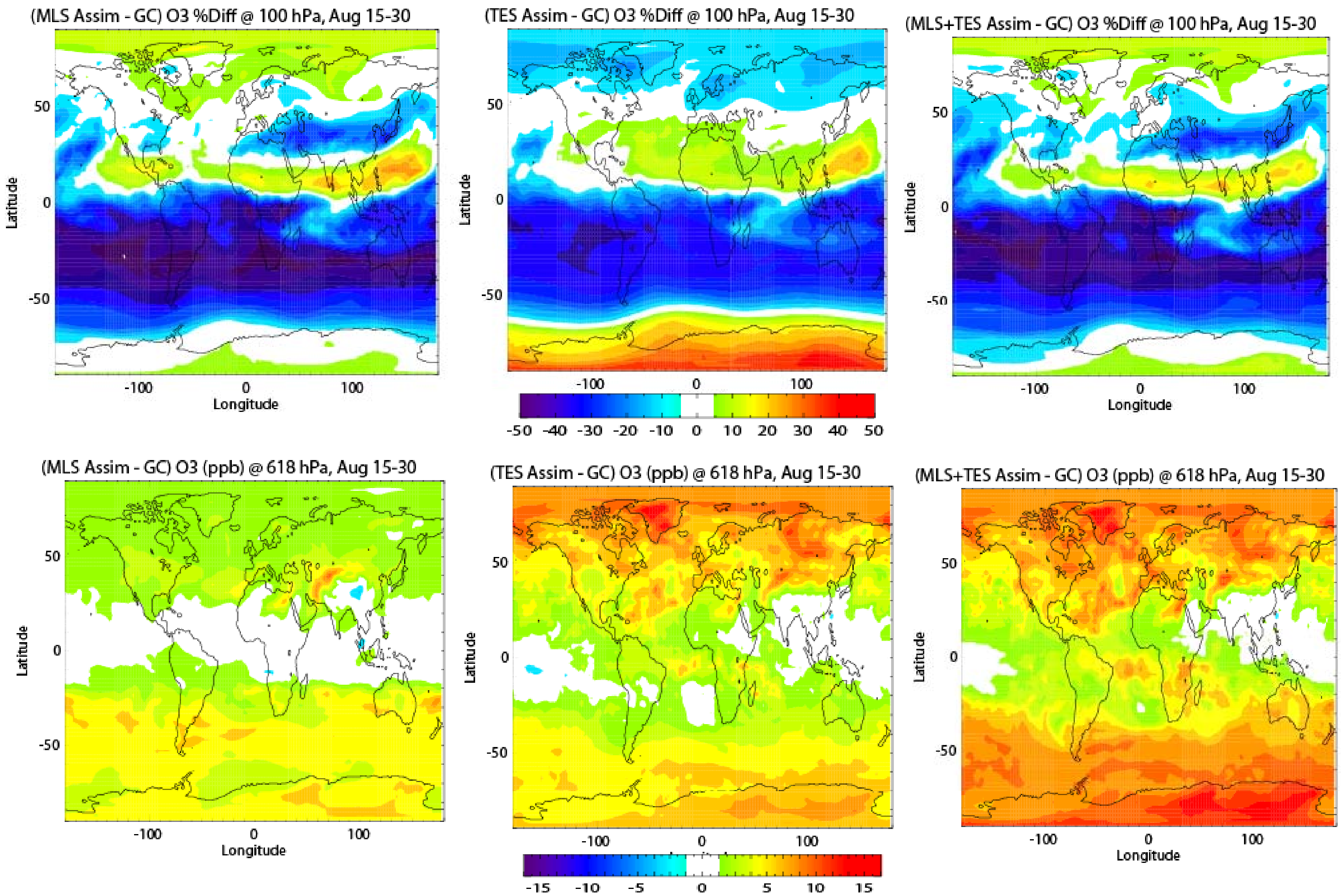
- **GEOS-Chem overestimates O_3 in the lower stratosphere with respect to MLS.**
- **The assimilation shows reductions in O_3 throughout the tropics and in the midlatitude SH**

Zonal Mean Impact of Assimilation Aug 15-30, 2006



- GEOS-Chem has a large positive bias throughout most of the stratosphere and a large negative bias in the mid- and high latitude upper troposphere
- The MLS+TES assimilation decreases the mean stratospheric O_3 column by 5% and increases the tropospheric column by 4%. The ratio of TCO to SCO increases by ~10%
- SH surface and free troposphere enhancements are particularly strong when TES and MLS are assimilated jointly

Impact of Assimilation
100 and 618 hPa
Aug 15-30, 2006



Impact of Assimilation
100 and 618 hPa
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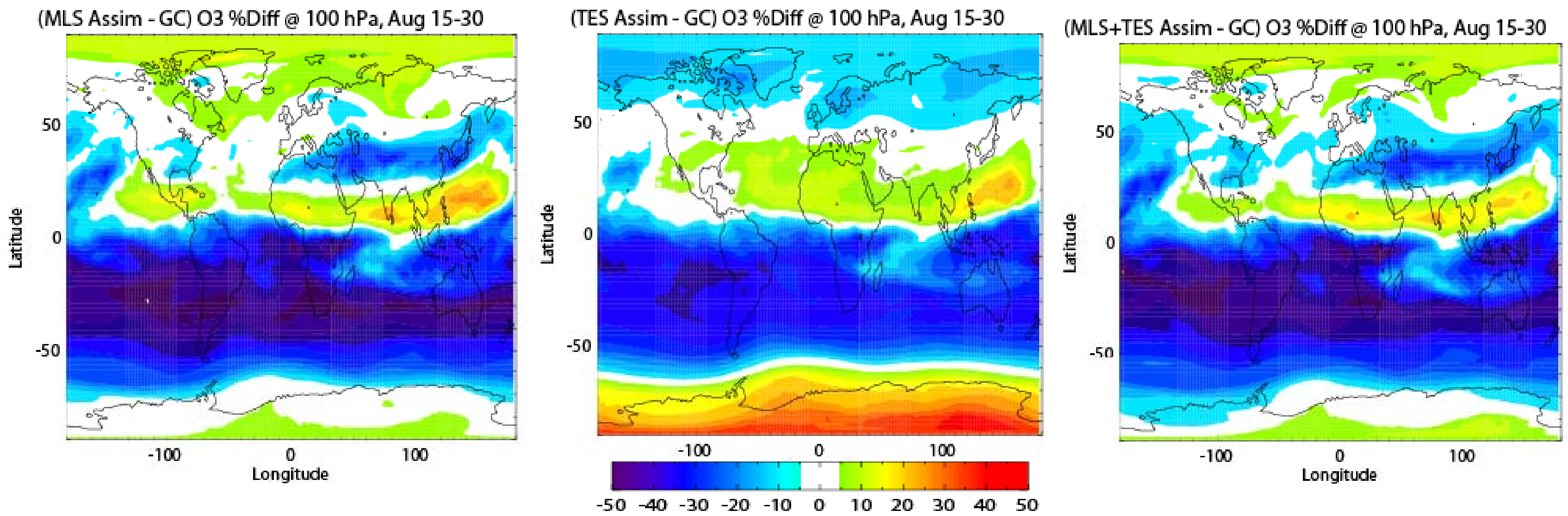
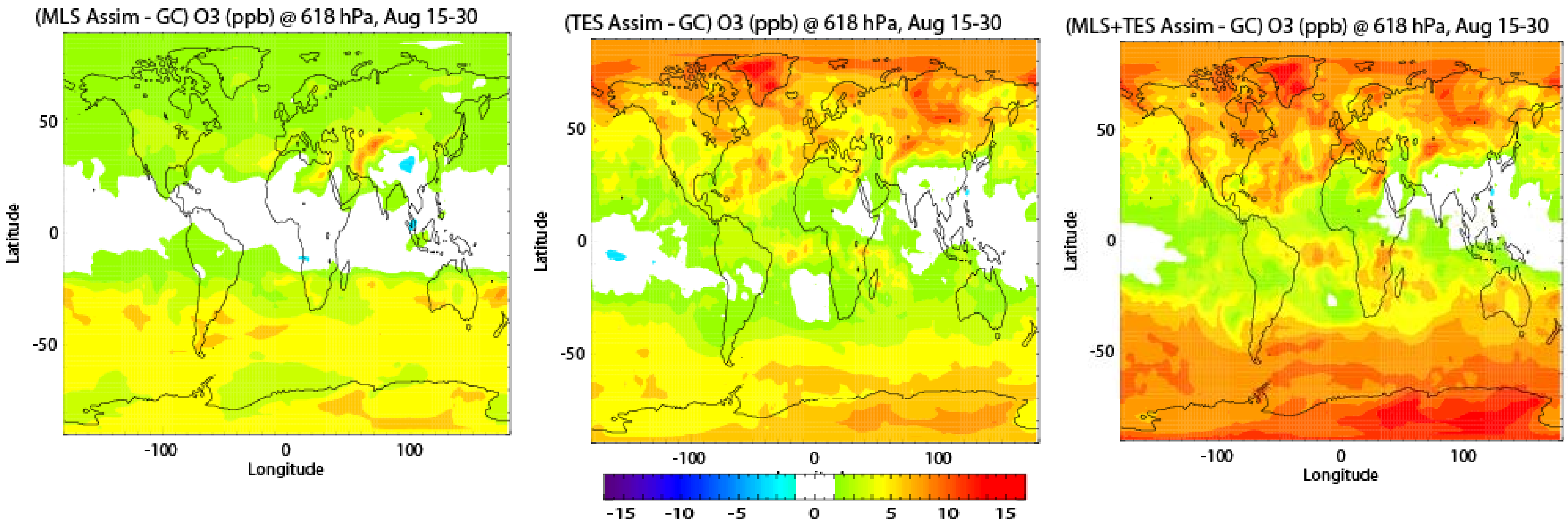


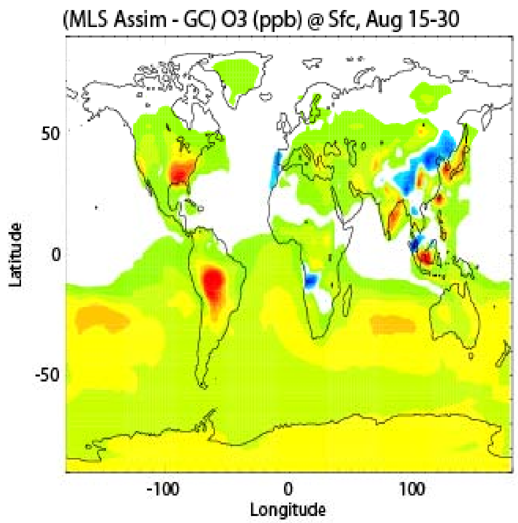
- **TES and MLS provide similar corrections in the tropics, where TES has the highest sensitivity in the stratosphere.**
- **At high latitudes, TES has less sensitivity and the joint assimilation is dominated by MLS.**

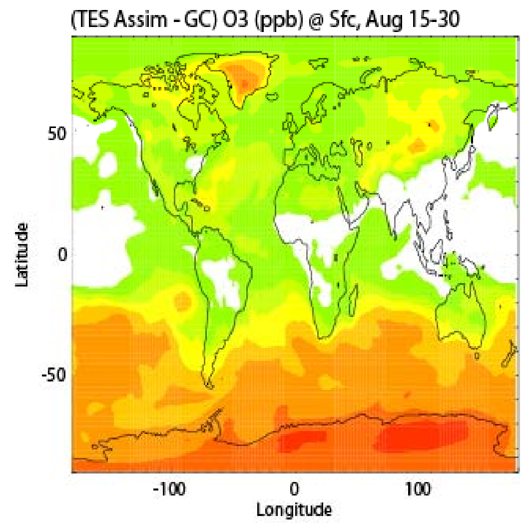
Impact of Assimilation
100 and 618 hPa
Aug 15-30, 2006

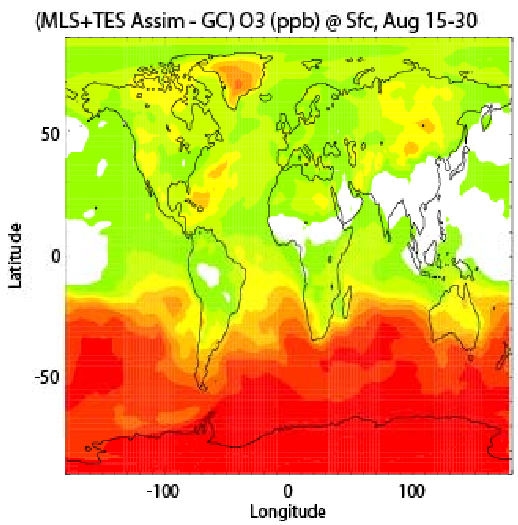
- MLS increases background O_3 throughout the mid-troposphere. TES has much higher spatial variability.
- The joint assimilation primarily reflects TES in the NH, but has large additive enhancements in the SH

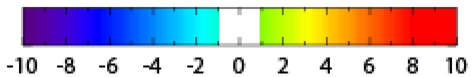


Impact of Assimilation
Surface
Aug 15-30, 2006



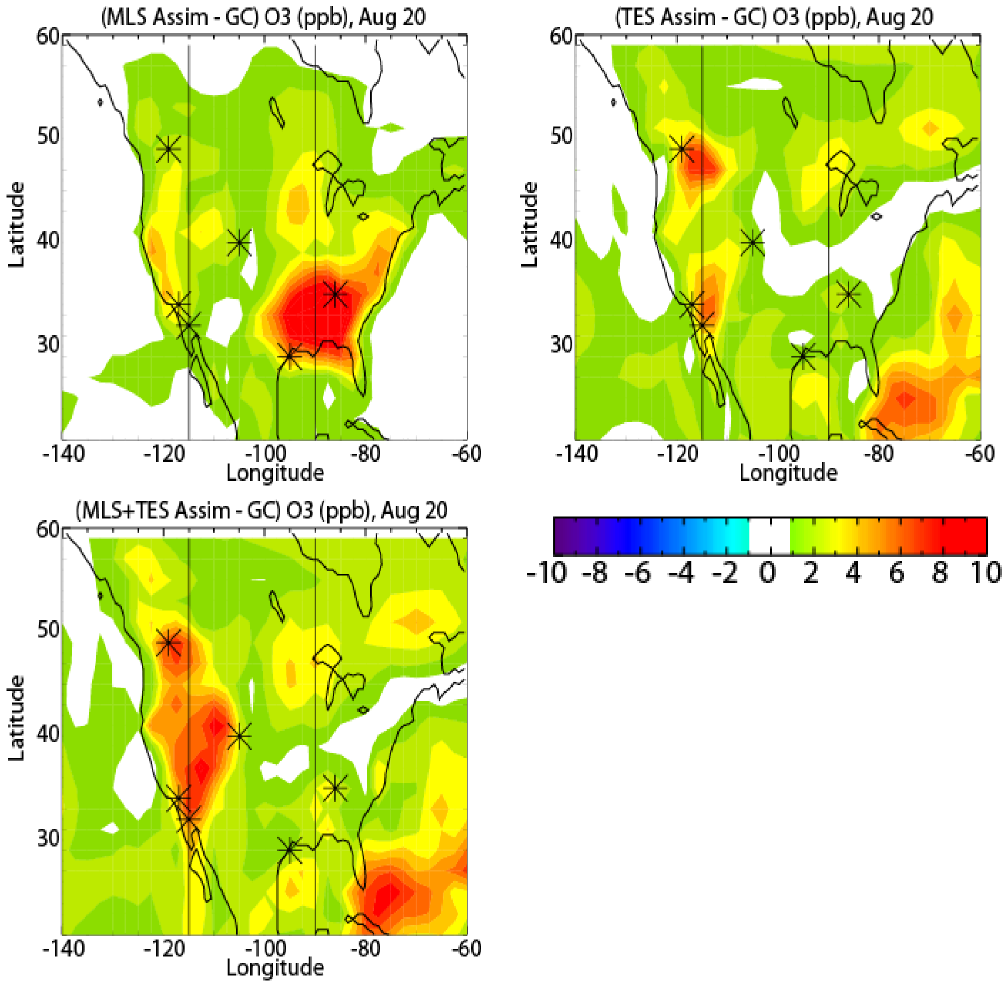






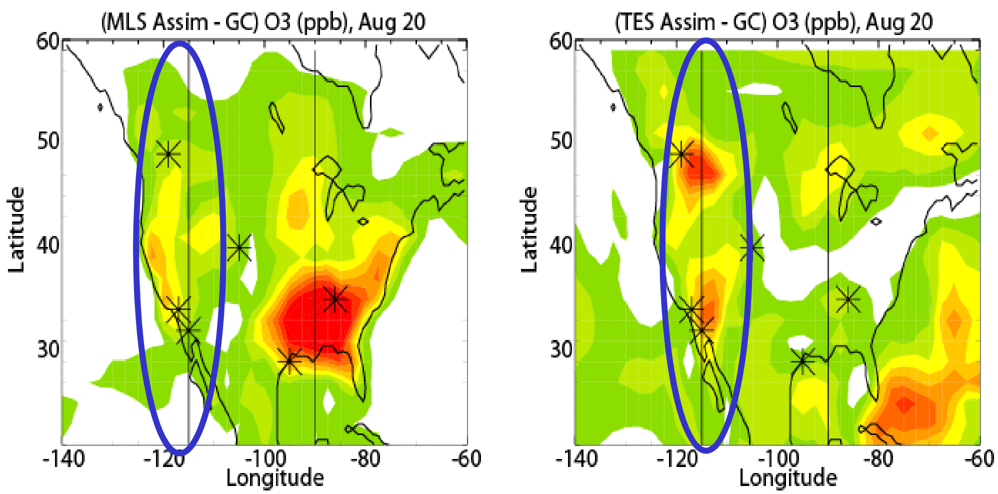
- **Assimilation of MLS observations results in a distinctive pattern on surface O_3 enhancements even though it is assimilated only above 215 hPa.**
- **The impact of TES assimilation has less spatial variability at the surface than in the mid-troposphere**

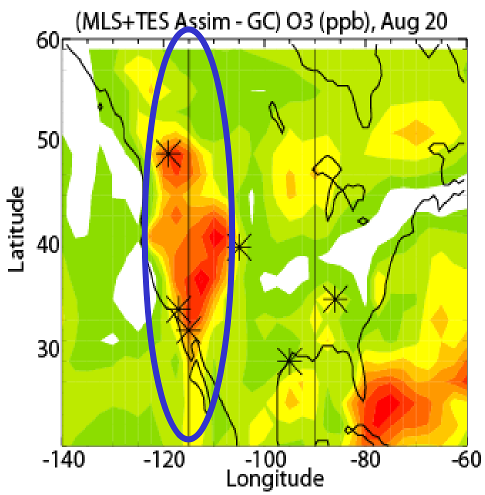
Impact of Assimilation
Western U.S.
Aug 20, 2006

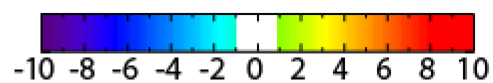


MLS and TES assimilation show very different surface patterns. MLS results in surface O_3 enhancements in the SE US while TES results in the largest enhacements in the W US.

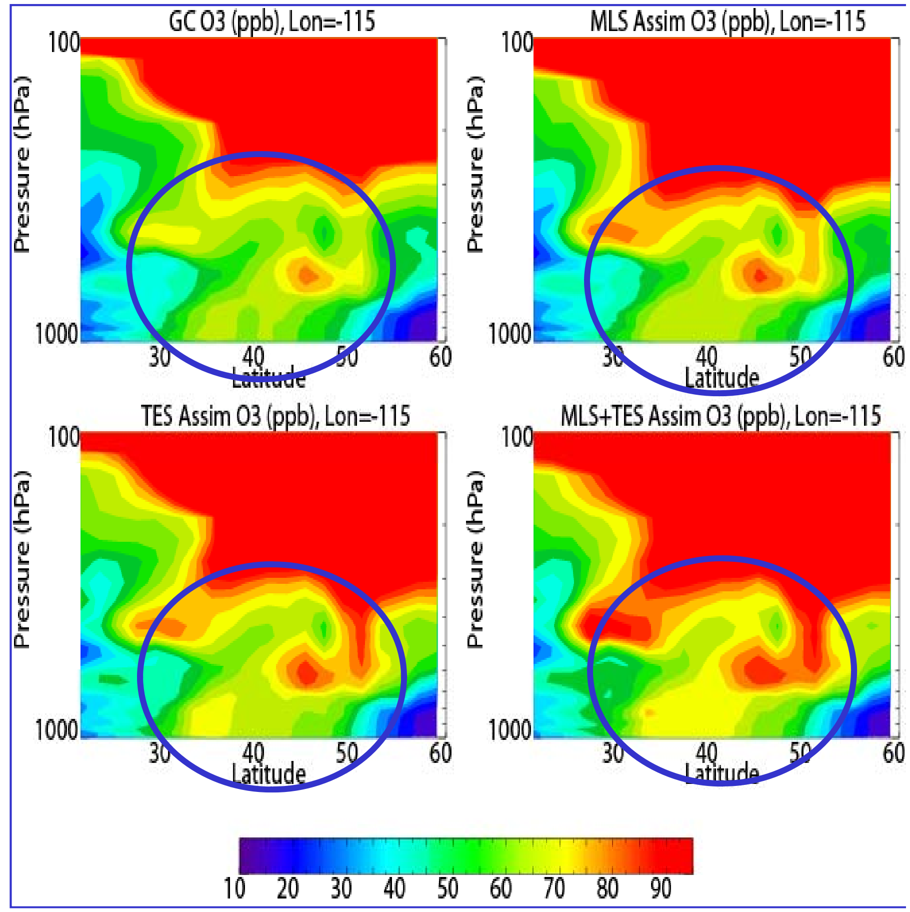
Impact of Assimilation
Western U.S.
Aug 20, 2006



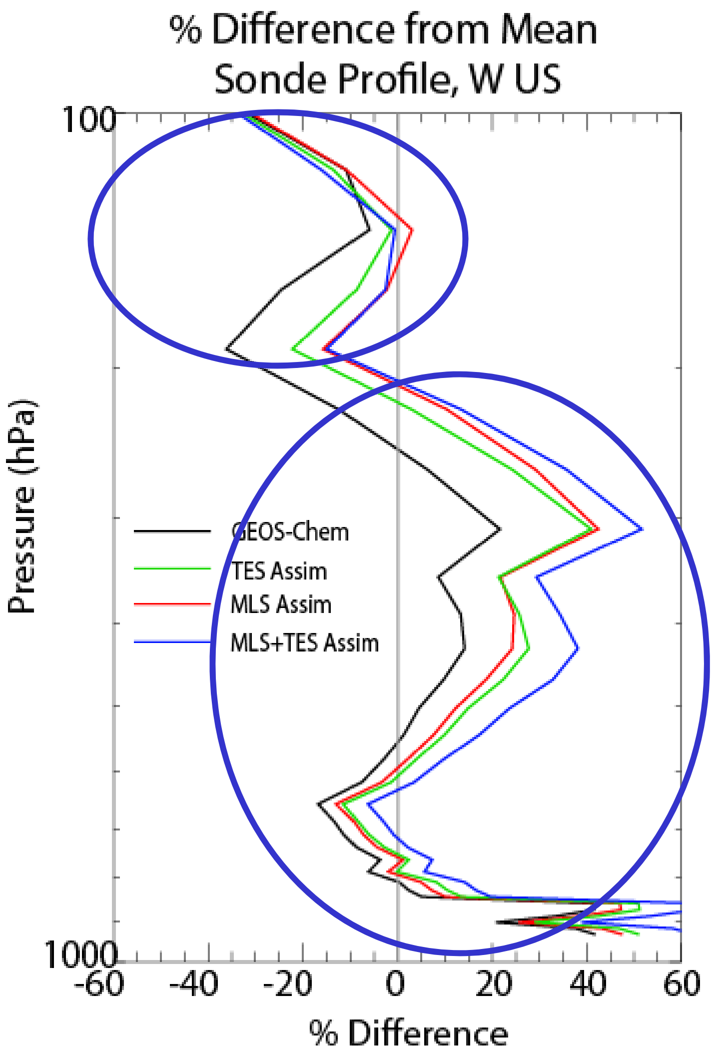


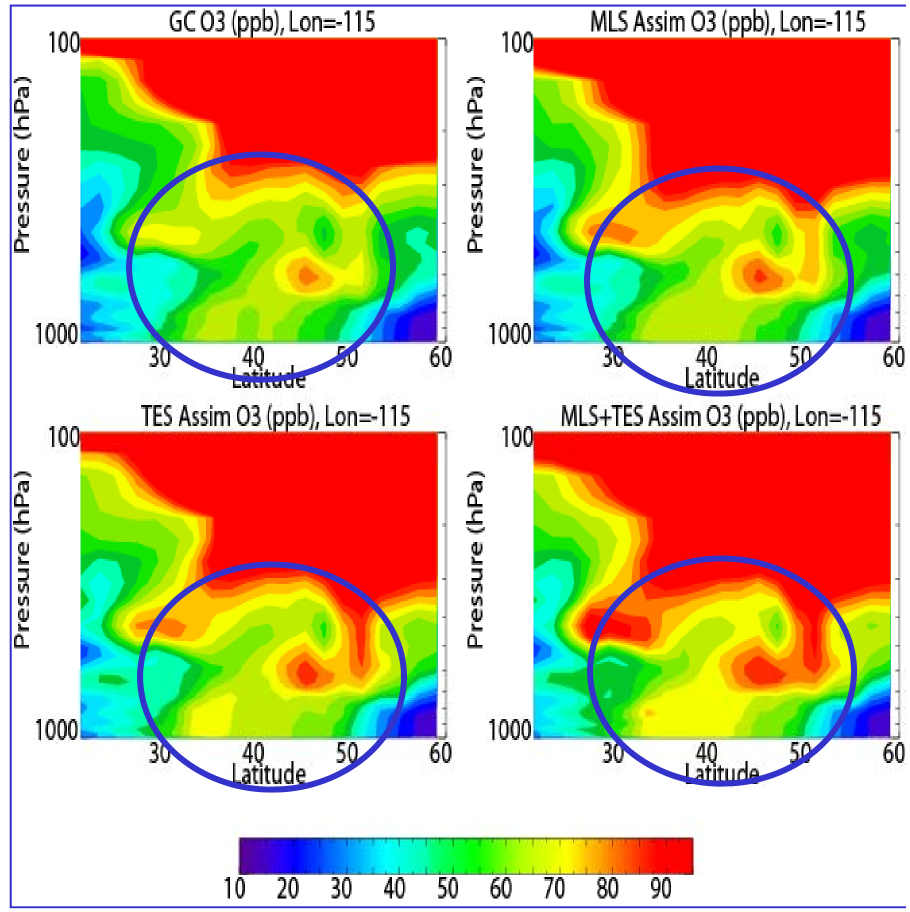


TES and MLS both enhance UT and MT O_3 relative to GEOS-Chem. TES and MLS+TES also have large surface signal

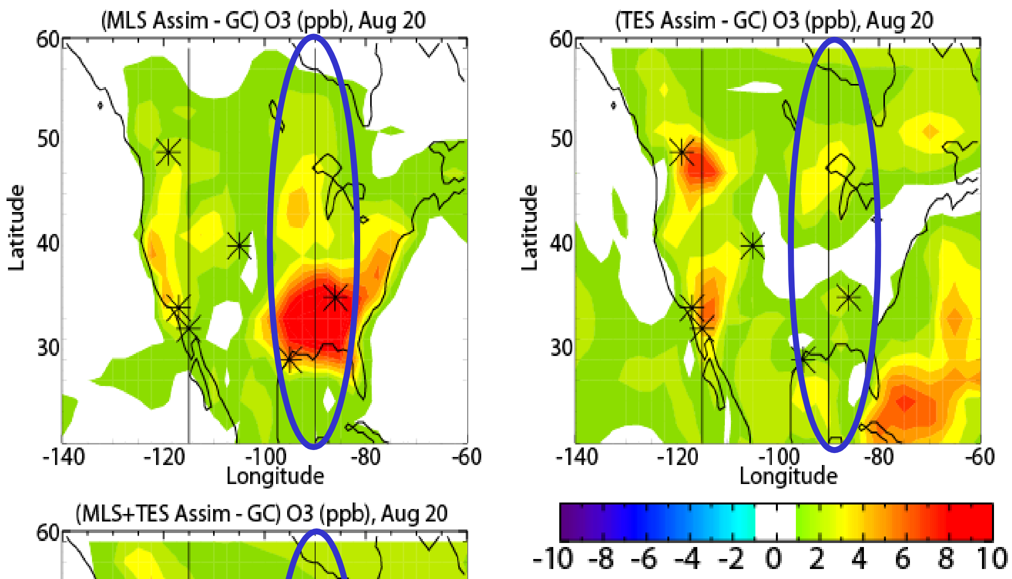


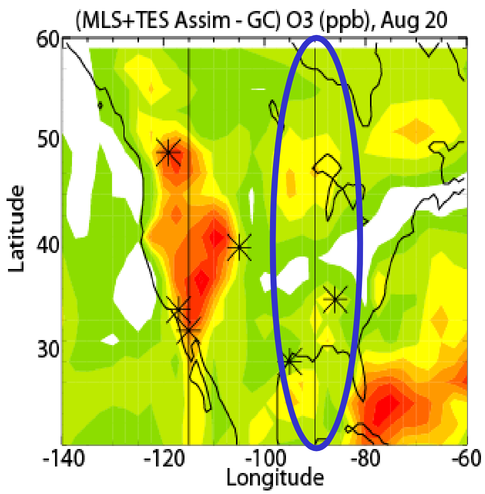
Impact of Assimilation
Western U.S.
Aug 20, 2006



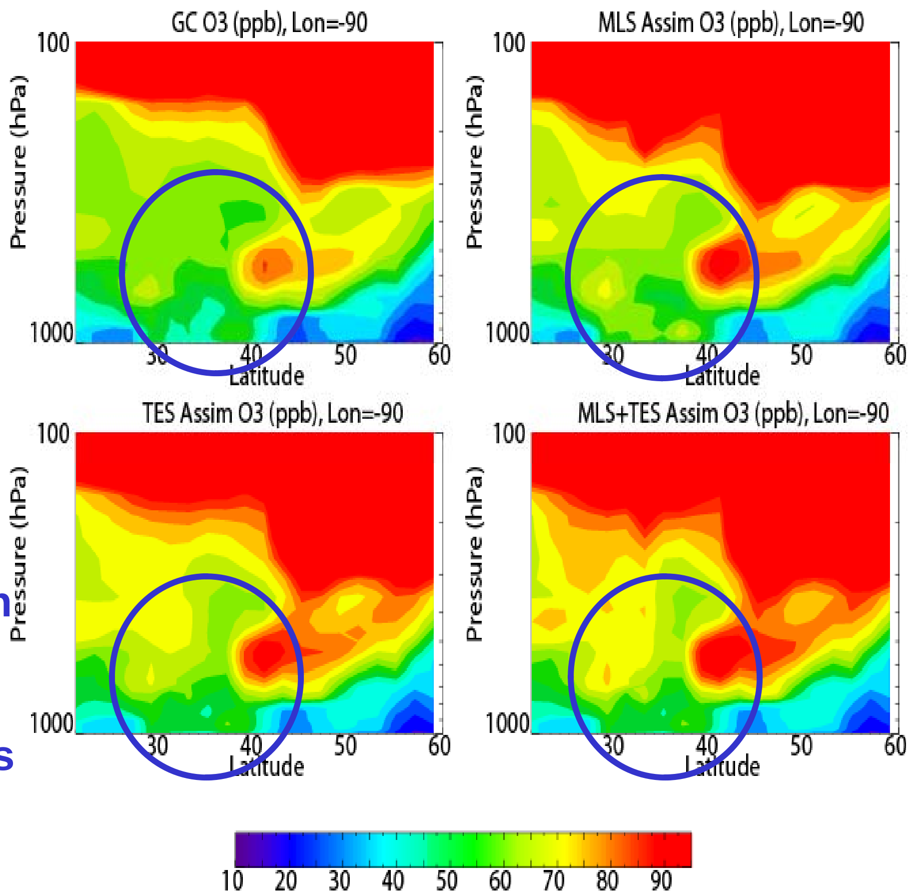


Impact of Assimilation South-Eastern U.S. Aug 20, 2006

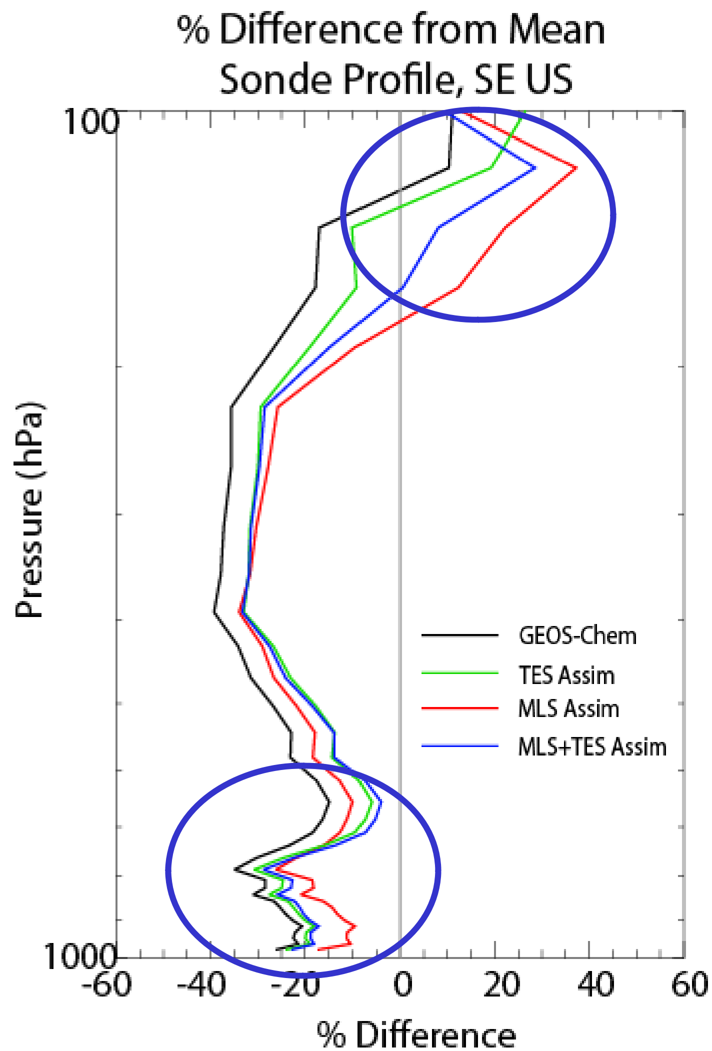


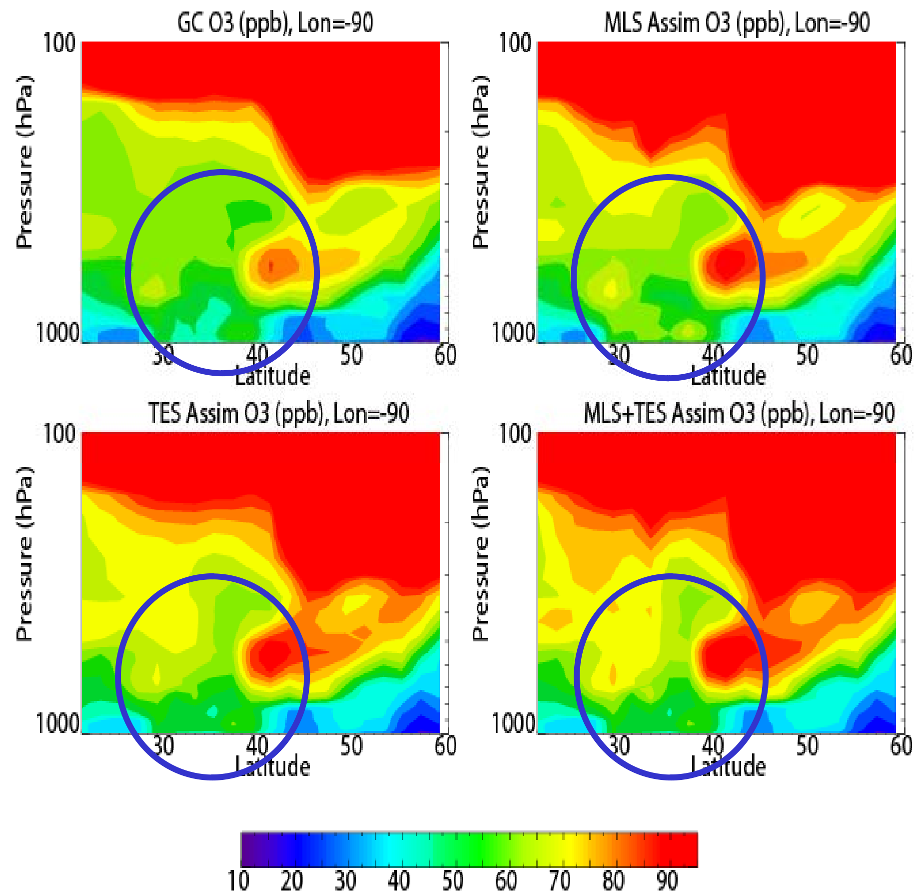


MLS and TES assimilation both enhance UT and MT O_3 significantly. In the MLS assimilation the O_3 is also enhanced in the BL, while in TES the increase is largely confined to the MT.

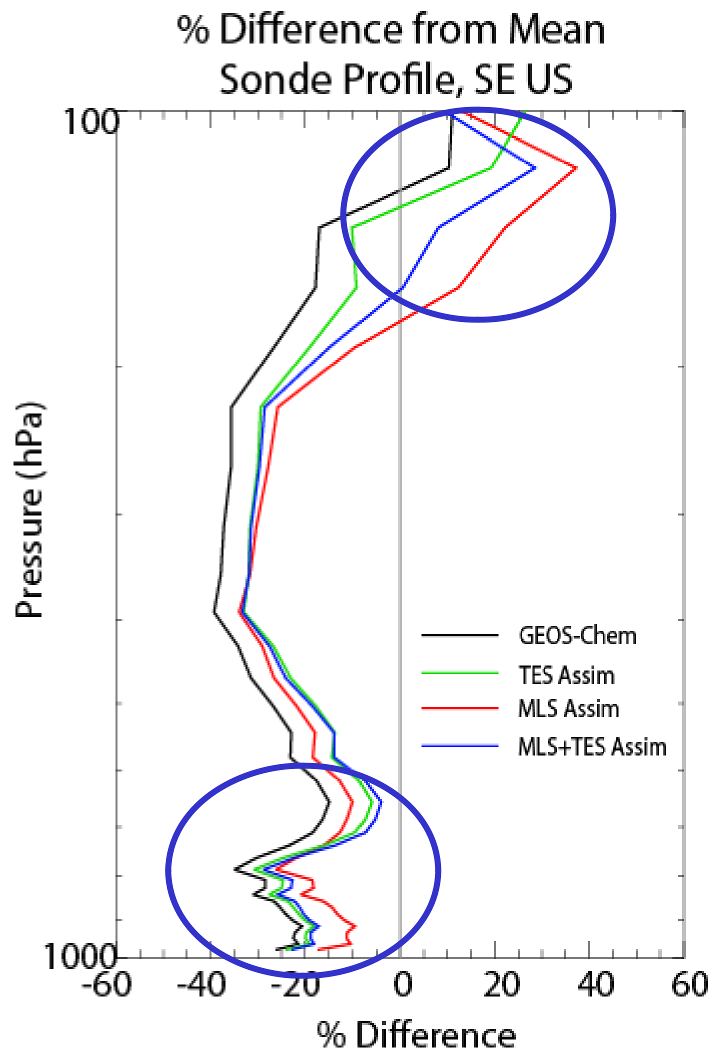


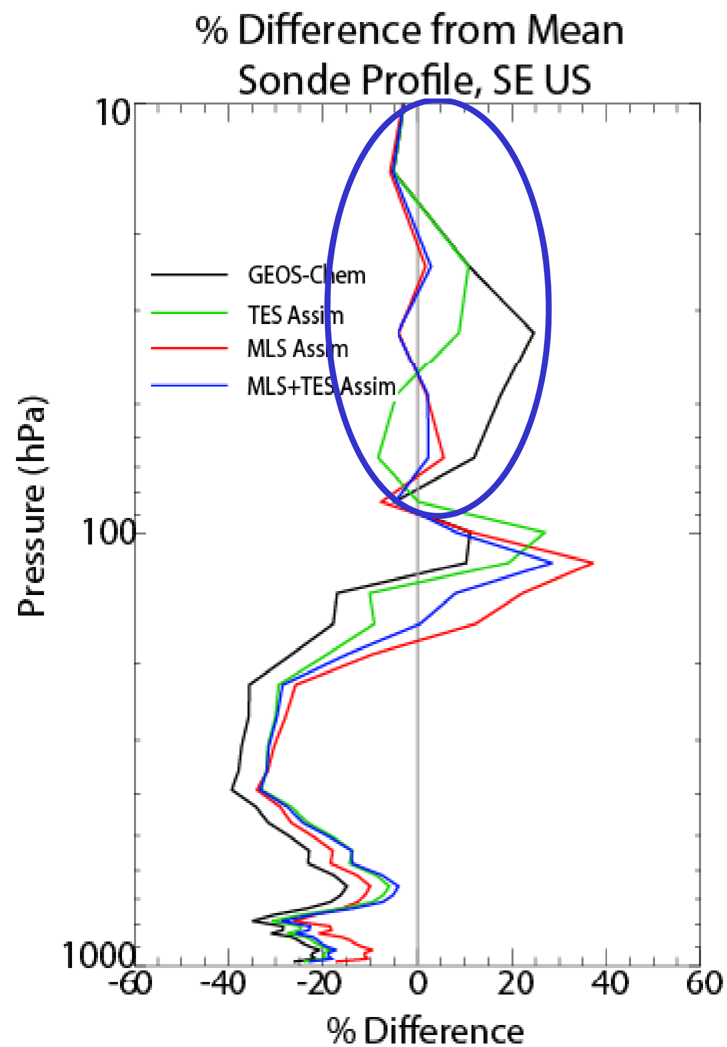
Impact of Assimilation South-Eastern U.S. Aug 20, 2006



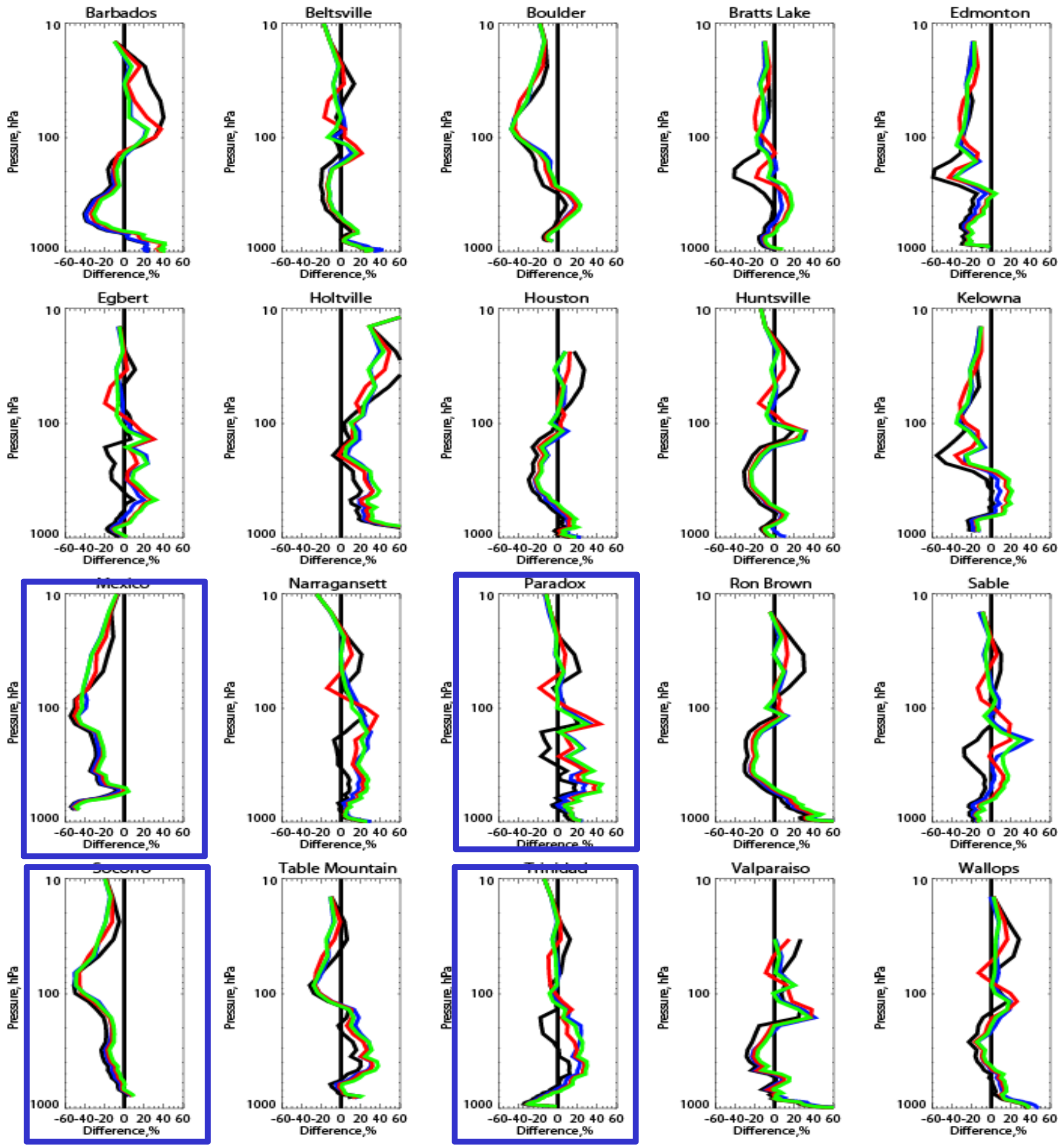


Impact of Assimilation South-Eastern U.S. Aug 20, 2006





Comparison to IONS Sondes
Aug, 2006



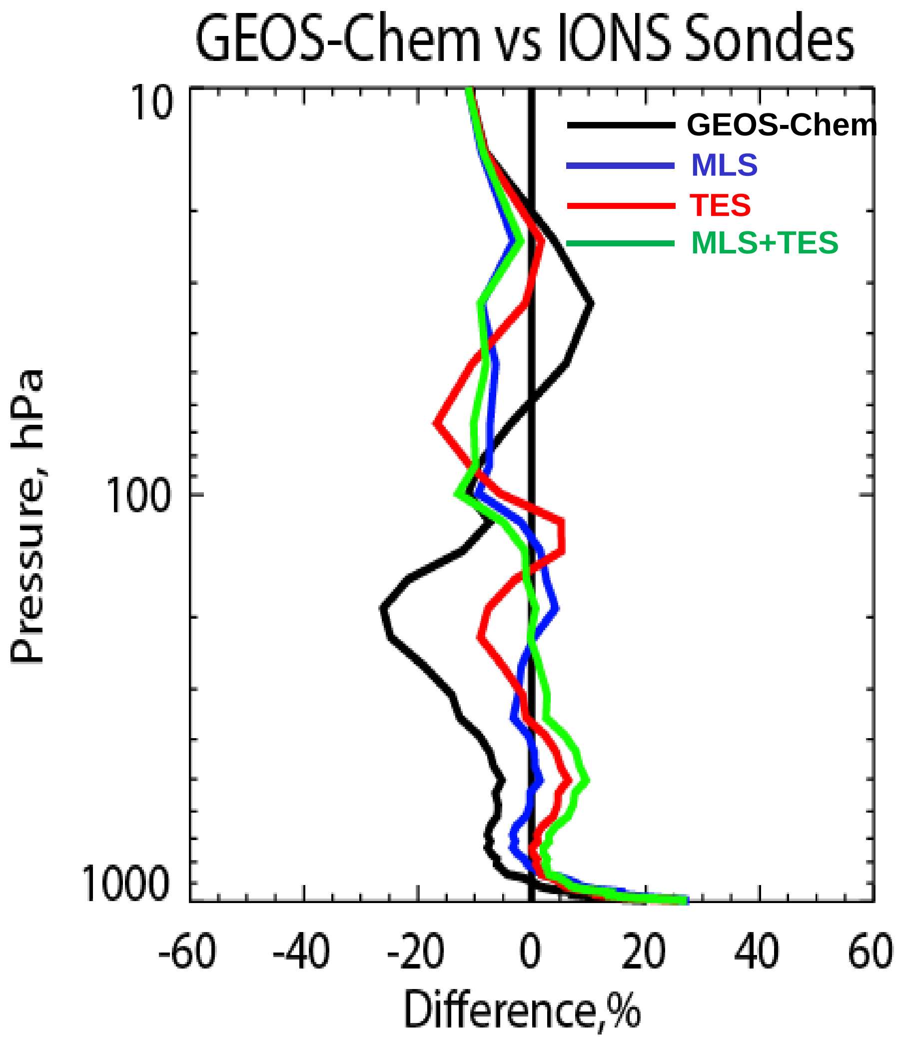
- Comparison to mean sonde profile for IONS sonde locations, Aug 2006

GEOS-Chem
MLS Assimilation
TES Assimilation
MLS+TES Assimilation

- Below 100 hPa, the assimilation acts to increase O_3, which generally improves the performance but in some locations creates a bias or exacerbates existing GEOS-Chem biases

- Above 100 hPa, the assimilation acts to decrease O_3. This also generally improves the performance relative to sondes, but in some locations it results in a low bias

Comparison to IONS Sondes
Aug, 2006



- Overall, the assimilation reduces the model bias with respect to N American sondes to within 5-10% below 100 hPa.
- MLS assimilation alone provides the best correction in the troposphere, indicating the importance of UTLS O_3 for the entire column
- In the stratosphere, the assimilation decreases O_3 and slightly degrades the model perfomance over N America. This is not what we expect from the MLS measurements, and it is unclear whether it is an issue of mixing of air from the subtropics, where GEOS-Chem greatly overestimates O_3, or whether a longer assimilation is needed.

Conclusions and Next Steps

- Joint assimilation of MLS and TES reduces the mean model bias with respect to N American O_3 sondes over the entire troposphere from ~10-25% to with 5-10%
- However, there are large regional differences and in some areas assimilation exacerbates model biases
- The assimilation is ~10% negatively biased with respect to N American sondes above 100 hPa, and the roles of measurement error, mixing from other regions, and assimilation length need to be disentangled
- We need to understand what the assimilation is telling us about model vertical mixing, especially in the case of MLS alone
- The next step is to examine the impact of assimilation on STE and better constrain its role in the tropospheric O_3 budget
- 4-D Var assimilation with the GEOS-Chem adjoint will allow analysis of sensitivity to emissions and processes