OPTIMALLY COMBINING OZONE FROM TROPOSPHERIC EMISSION SPECTROMETER (TES) AND OZONE MONITORING INSTRUMENT (OMI) DATA

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TES website: http://tes.jpl.nasa.gov

1. ABSTRACT

We show results from joint TES-OMI retrievals for May-August, 2006. We combine TES and OMI data by linear updates from the spectral residuals. Combined retrievals from the UV and IR spectral ranges have previously been shown to result in increased tropospheric sensitivity and resolution, and of particular interest, increased sensitivity to the planetary boundary layer. Results are compared to the OMI and TES results, and to near by sondes.

INTRODUCTION

- **Worden et al., 2007 (above right) shows that combined UV/IR retrievals will result in increased sensitivity especially at the planetary boundary layer**
- **We now combine OMI & TES data using optimal averaging and linear updates**
- **The end goal is a non-linear joint retrieval of TES & OMI ozone**

METHOD

TES and OMI profile retrievals use non-linear optimal estimation. It can be shown under the appropriate assumptions that the non-linear estimates can be linearly related to the true state. Consider two state vectors, $\hat{\mathbf{x}}_1$ and $\hat{\mathbf{x}}_2$, which represent TES and OMI retrievals, respectively:

$$\hat{\mathbf{x}}_1 = \mathbf{x}_a + \mathbf{A}_1(\mathbf{x}_{true} - \mathbf{x}_a) + \mathbf{G}_1\mathbf{n}_1 \quad (1)$$
$$\hat{\mathbf{x}}_2 = \mathbf{x}_a + \mathbf{A}_2(\mathbf{x}_{true} - \mathbf{x}_a) + \mathbf{G}_2\mathbf{n}_2 \quad (2)$$

where:

$\hat{\mathbf{x}}$ is the estimated value,
$\mathbf{x}_a$ is the a priori state,
$\mathbf{x}_{true}$ is the true state,
$\mathbf{n}$ is the spectral noise vector,
$\mathbf{A}$ is the averaging kernel, defined $\mathbf{A} = \mathbf{S}(\mathbf{K}^T\mathbf{K})$,
$\mathbf{G}$ is the gain matrix, defined $\mathbf{G} = \mathbf{SK}$,
$\mathbf{S}$ is defined $\mathbf{S} = (\mathbf{K}^T\mathbf{K} + \mathbf{\Lambda})^{-1}$,
$\mathbf{\Lambda}$ is the constraint matrix,
$\mathbf{K}$ is the noise normalized Jacobian $\mathbf{K} = \partial(\mathbf{radiance})/\partial\mathbf{x}\,\mathbf{S}_e^{-1/2}$, and
$\mathbf{S}_e$ is the measurement error covariance.

If these results are combined using simple averaging and have identical averaging kernels, then the averaged result is:

$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{A}_1(\mathbf{x}_{true} - \mathbf{x}_a) + (\mathbf{G}_1\mathbf{n}_1 + \mathbf{G}_2\mathbf{n}_2)/2 \quad (3)$$

In this case, the precision improves by $1/\sqrt{2}$, however because the averaging kernel in equation (3) has not improved over equation (1) or (2), the sensitivity to the true state, degrees of freedom, and vertical resolution will not improve. Another, better, way to "average" the retrievals is to perform a joint retrieval on the two targets:

$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{A}(\mathbf{x}_{true} - \mathbf{x}_a) + \mathbf{Gn} \quad (4)$$

If the reasonable assumption is used that measurement errors are uncorrelated between the two targets, then $\mathbf{A} = \mathbf{S}(\mathbf{K}_1^T\mathbf{K}_1 + \mathbf{K}_2^T\mathbf{K}_2)$, $\mathbf{S} = (\mathbf{K}_1^T\mathbf{K}_1 + \mathbf{K}_2^T\mathbf{K}_2 + \mathbf{\Lambda})^{-1}$, and $\mathbf{G} = \mathbf{S}(\mathbf{K}_1 + \mathbf{K}_2)$.

Equations (1) and (2) can be used to substitute in for $\mathbf{K}_1^T\mathbf{K}_1\mathbf{x}_{true}$ and $\mathbf{K}_2^T\mathbf{K}_2\mathbf{x}_{true}$, respectively. Some of the terms cancel, and the joint retrieval can be written:

$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{SS}_1^{-1}(\hat{\mathbf{x}}_1 - \mathbf{x}_a) + \mathbf{SS}_2^{-1}(\hat{\mathbf{x}}_2 - \mathbf{x}_a) \quad (5)$$

Similarly, a linear update can be done from the combined residuals. For this, the "initial guess" must be consistent between the two results. If $\mathbf{x}_{init}$ is set to the average of the two results; then the fitted radiances can be modified to correspond to $\mathbf{x}_{init}$ and stacked to

$\mathbf{L}_{fit} = [\mathbf{L}_{fit1} + \mathbf{K}_1(\mathbf{x}_{init} - \hat{\mathbf{x}}_1), \mathbf{L}_{fit2} + \mathbf{K}_2(\mathbf{x}_{init} - \hat{\mathbf{x}}_2)]$. With these initial conditions, the updated state is:

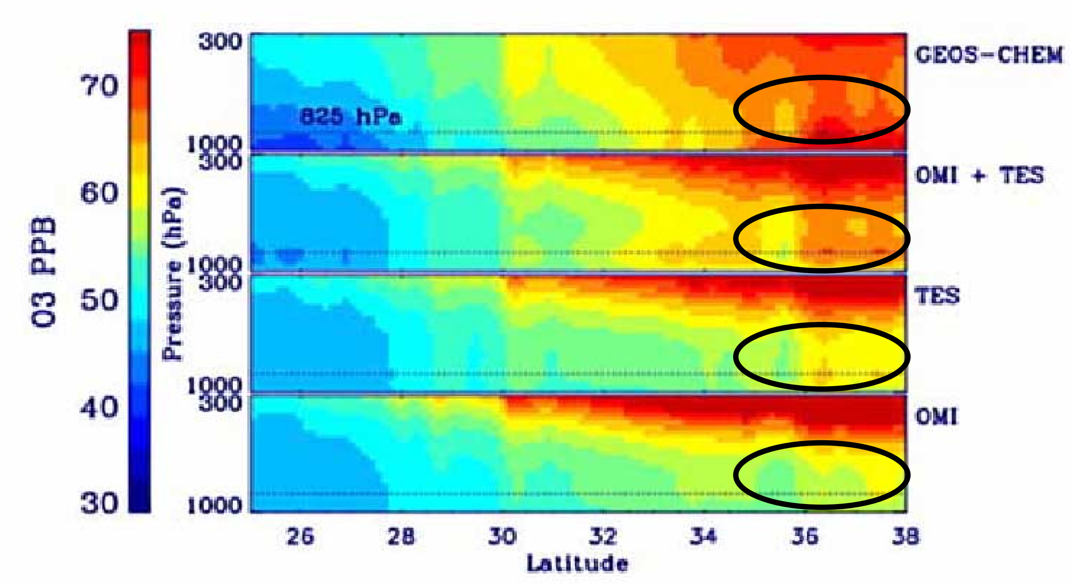
$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{G}(\mathbf{L}_{obs} - \mathbf{L}_{fit}) + \mathbf{A}(\mathbf{x}_{init} - \mathbf{x}_a) \quad (6)$$

In theory, either Eq. (5) or Eq. (6) will work; in practice Eq. (6) can be more stable.

Improved tropospheric ozone profile retrievals using OMI and TES radiances

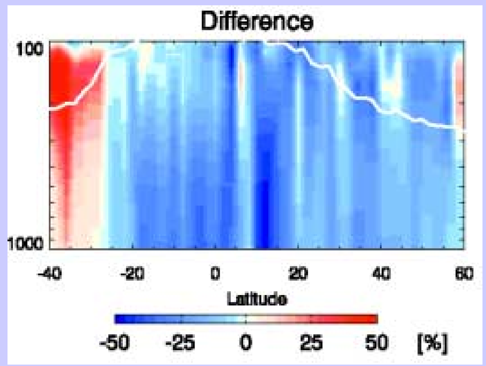
John Worden,[1] Xiong Liu,[2] Kevin Bowman,[1] Kelly Chance,[2] Reinhard Beer,[1] Annmarie Eldering,[1] Michael Gunson,[1] and Helen Worden[1]

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L01809, doi:10.1029/2006GL027806, 2007



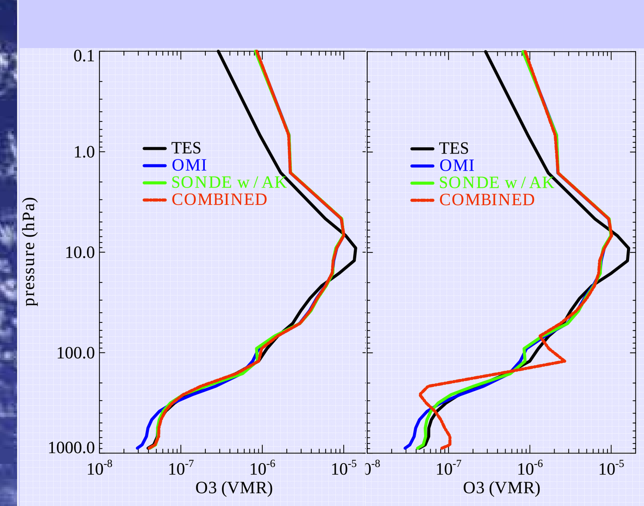
Worden et al. (2007) showed that simulated joint retrievals from TES and OMI results in enhanced boundary-layer sensitivity

Combining "real" data must account for biases and other systematic errors, such as calibration, spectroscopic, aerosol and cloud errors or inconsistencies



OMI profile retrieval - TES shows a bias, with TES high relative to OMI

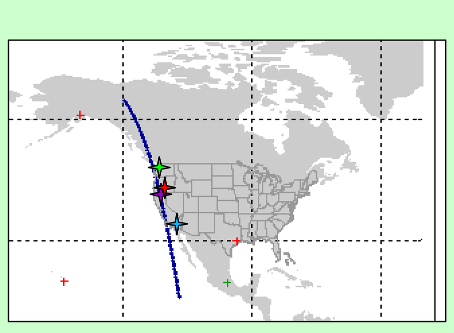
SIMULATED RESULTS OF COMBINED RETRIEVALS



LEFT Simulated results show improvement in the combined retrieval (red) compared to the sonde.

RIGHT When a 10% bias is introduced between TES and OMI "true", the combined result tends to jackknife

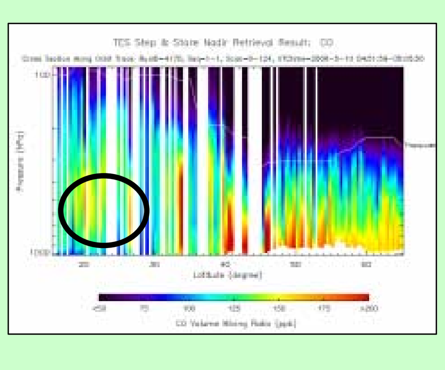
DATA – OMI, TES AND CORROBORATIVE



May 3, 2006 Aura nadir ground track passes near the Trinidad Head sonde station (41N, 124.1W). Other available corroborative data (not currently utilized):

- Los Angeles (34N, 118W)
- Mt. Bachelor Oregon station (44N, 121.7W)
- Cheeka Peak observatory (48.3N, 124.6W)

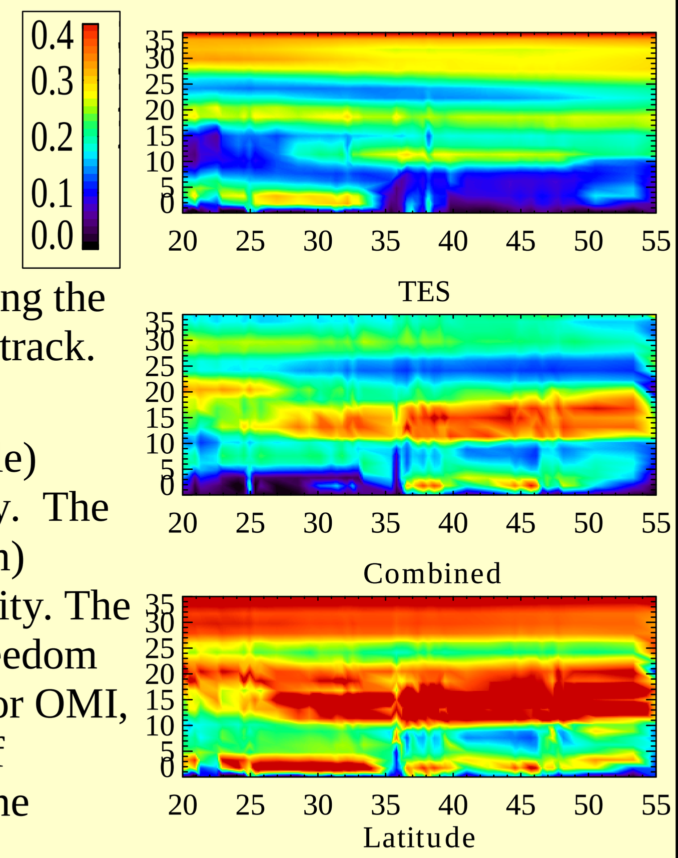
MODIS images show cloud-free land scenes from California through Canada for this day



TES CO shows elevated CO in the mid trop at 20-30N, and also 40-55N.

OMI and TES ozone characterization

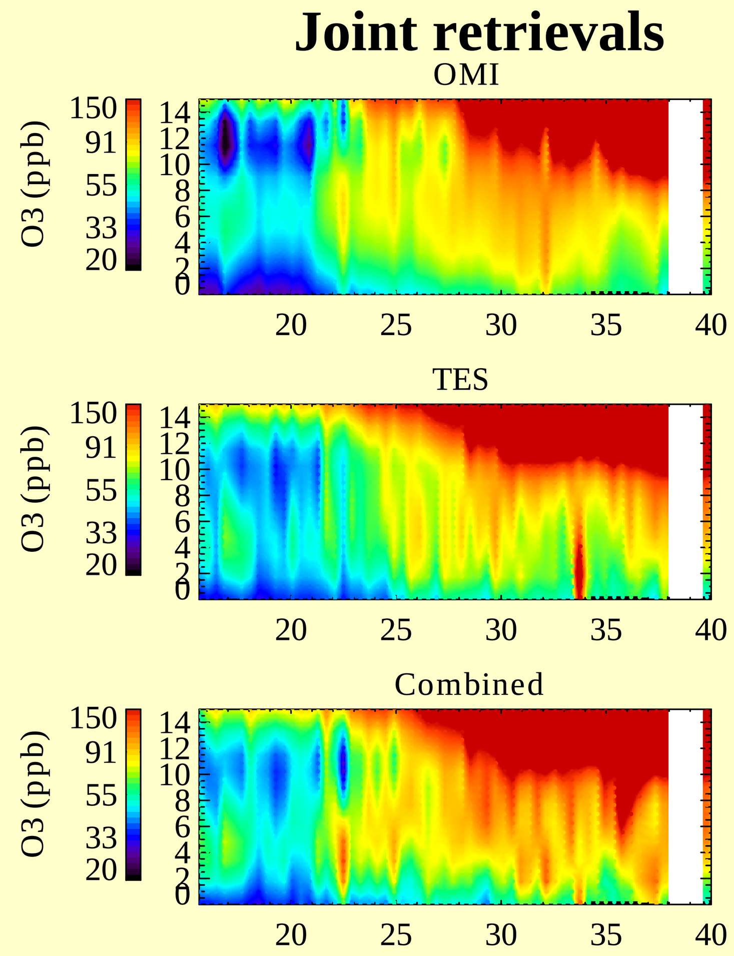
SENSITIVITY



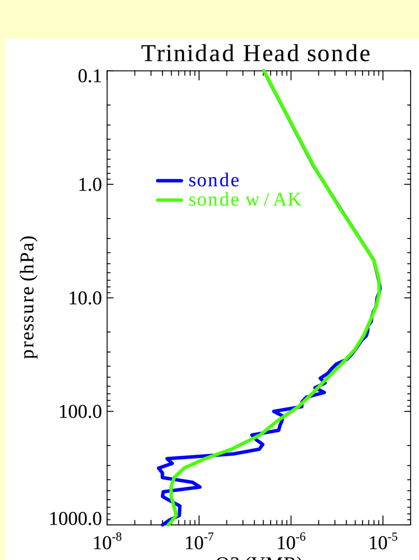
Curtain plots of the diagonal of the averaging kernel show sensitivity along the May 3, 2006 Aura ground track.

OMI (top) and TES (middle) display different sensitivity. The combined retrieval (bottom) shows the greatest sensitivity. The tropospheric degrees of freedom increases from about 2.0 for OMI, 2.7 for TES to 3.7 total. Of particular interest is near the planetary boundary layer.

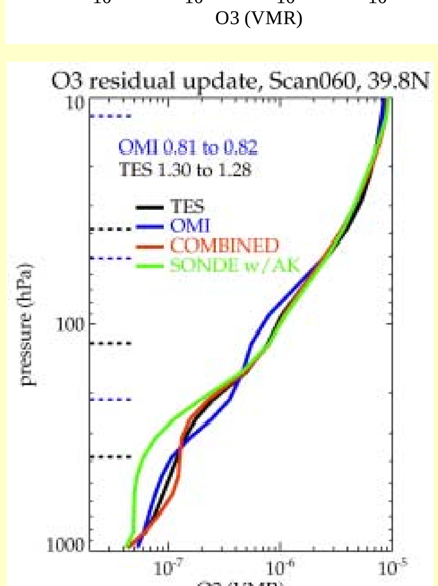
Joint retrievals



OMI and TES results are shown for May 3, 2006. The combined results from the residuals using Equation 6 with retrieved bias between TES and OMI.



Trinidad Head sonde provides a check of results in conjunction with surface ozone sites. The application of the joint averaging kernel "smooths" the sonde to what TES+OMI would see (Worden et al., 2007)



The combined retrieval, using Equation 6 with additional terms added to account for OMI/TES biases. Results do not compare well to the sonde in the lower and mid tropsphere; as shown in Worden et al. (2007), the spatial-temporal distance between sondes and satellite measurements sometimes results in poor matchups indicating more coincidences needed.

CHARACTERIZATION CONCLUSIONS

- Optimally combined OMI & TES ozone results in increased sensitivity and resolution including at the boundary layer
- In the troposphere, combined retrievals have 3.7 degrees of freedom, a significant increase over 2.0 and 2.7 for OMI and TES, respectively
- Biases between OMI and TES retrievals need to be carefully characterized and corrected before optimally combining