A33A-0130 Implementation of Cloud Retrievals for Tropospheric Emission Spectrometer (TES) Atmospheric Retrievals

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1. ABSTRACT

Clouds substantially affect the observed infrared radiance and are ubiquitous in the atmosphere. Retrieval of temperature and trace gases must account for how clouds of all optical depths affect the observed radiation field. We have implemented an algorithm for the Tropospheric Emission Spectrometer (TES) to retrieve the altitude and effective optical depth of a frequency-dependent single-layer cloud. Simulations with a multiple scattering model show that this approach succeeds for targets containing a wide range of cloud optical depths and altitudes. TES retrievals with actual observed radiances have been successful with this approach. This cloud retrieval approach makes possible the retrieval and error characterization of atmospheric parameters like temperature, water, and ozone, in the presence of clouds.

2. MOTIVATION

(I) Clouds are ubiquitous and have a large effect on infrared radiance and retrievals

TES October global survey run #2147 statistics:

* 64% of targets our observation of BT at 11 um are more than 4K different from radiances predicted from GMAO clear sky initial guess

* 70% of targets with retrieved effective Cloud Optical Depth > 0.05

(II) To maximize use of TES measurements, we want to retrieve trace gases in the presence of clouds

3. ASSUMPTIONS / APPROACH

In order to to mitigate impact of clouds on trace gas retrievals we retrieve a cloud-like quantity with these characteristics:

ASSUMPTION	RATIONALE
Single layer clouds	Create tractable retrieval problem by reducing number of parameters
Clouds have Gaussian profile in altitude	Assumption makes Jacobians analytic
No scattering (scattering is absorbed in absorption)	Simple beginning to address thin and opaque clouds
Determine cloud OD initial guess from BT difference between observed and initial guess radiance	Clouds vary over orders of magnitude and Jacobians highly non-linear

APPROACH

Cloud layer effective optical depth:

$$\tau_\nu = \kappa_\nu e^{-\beta (z - z_c)^2} \Delta s$$

τ: optical depth in layer (freq. dependent)
κ: retrieved cloud extinction (freq. dependent)
β: scale factor
z: layer altitude
z_c: cloud altitude
Δs: layer thickness

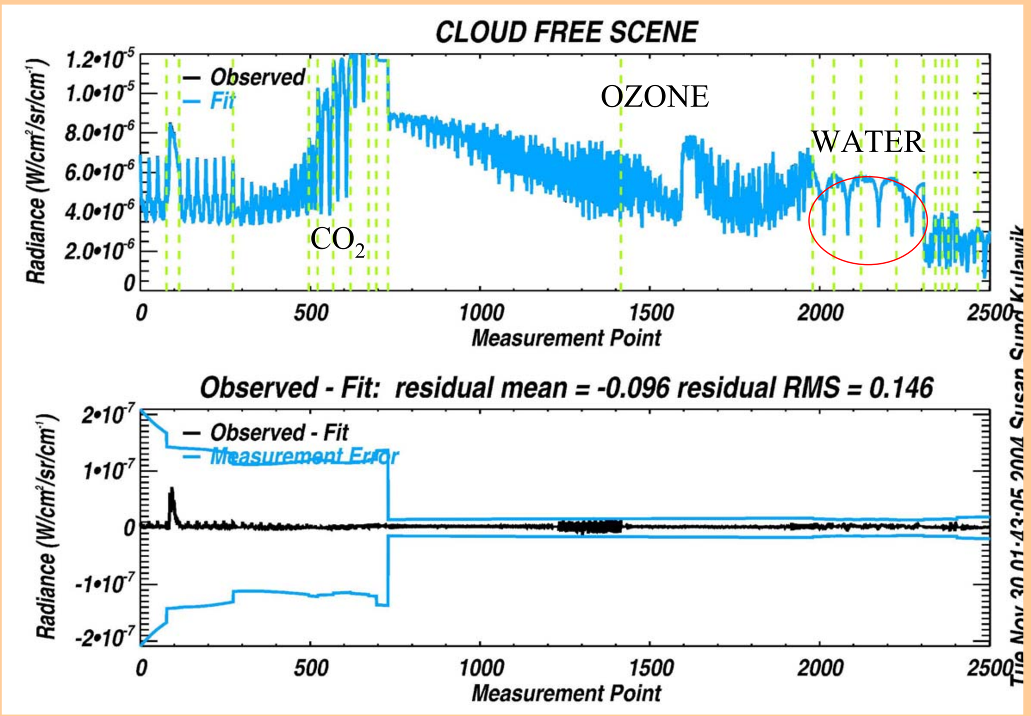
Jacobians, derived from above:

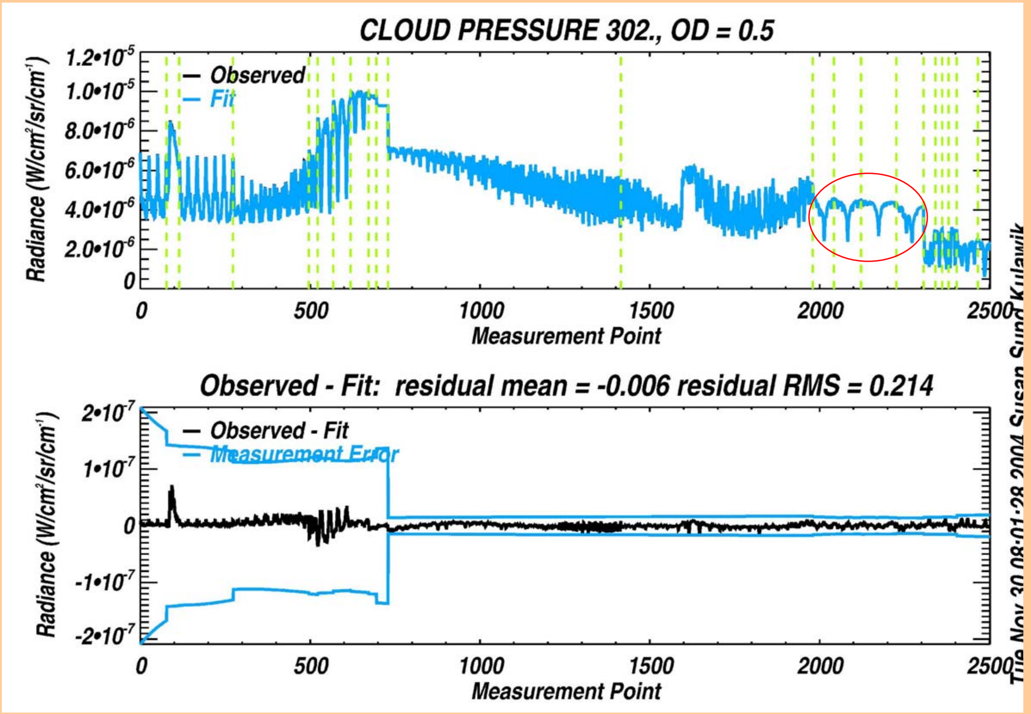
$$\frac{dL_{\nu_1}}{d\kappa_{\nu_2}} = \sum \alpha(\nu_1,\nu_2)\tau_{\nu_2} / \kappa_{\nu_2} \qquad \frac{dL_{\nu_1}}{dz_c} = \sum_{\nu_1} 2\alpha(\nu_1,\nu_2)\beta(z - z_c)\tau_{\nu_2}$$

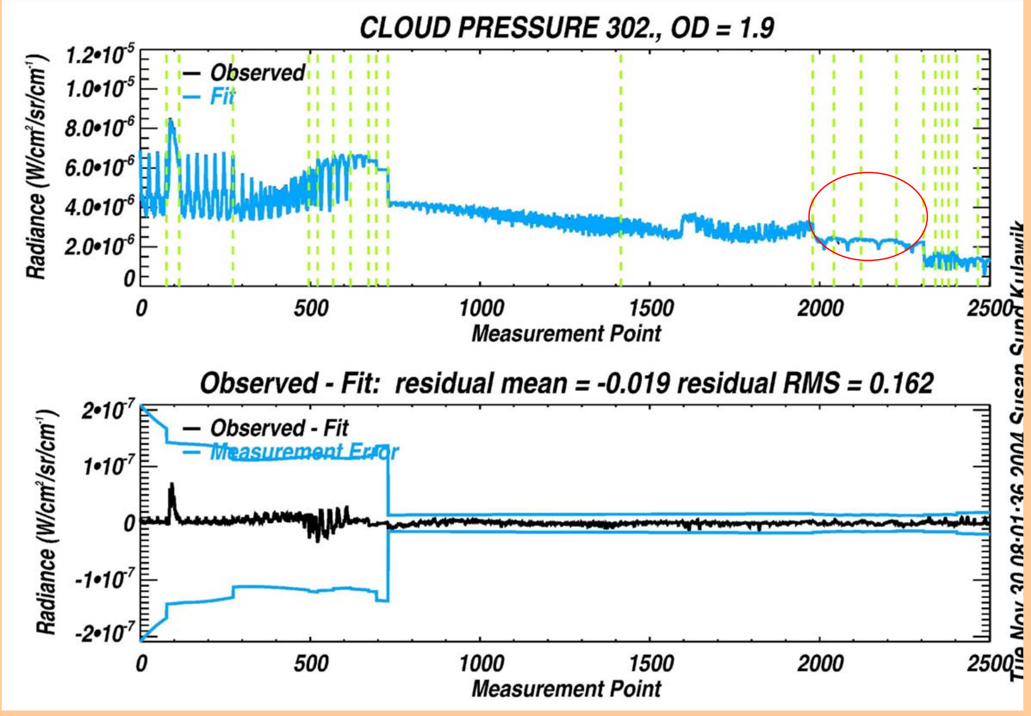
$\alpha(\nu_1,\nu_2)$: dependence of the interpolated value at ν_1 on the retrieval parameter at ν_2

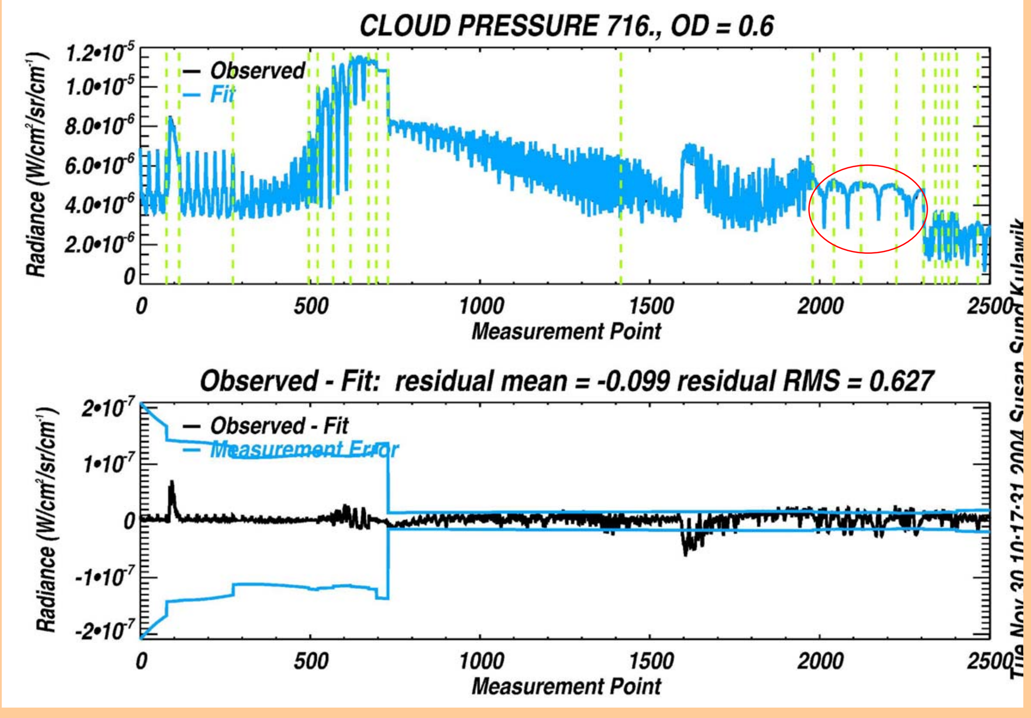
4. TESTING ASSUMPTIONS: FORWARD MODEL ERRORS

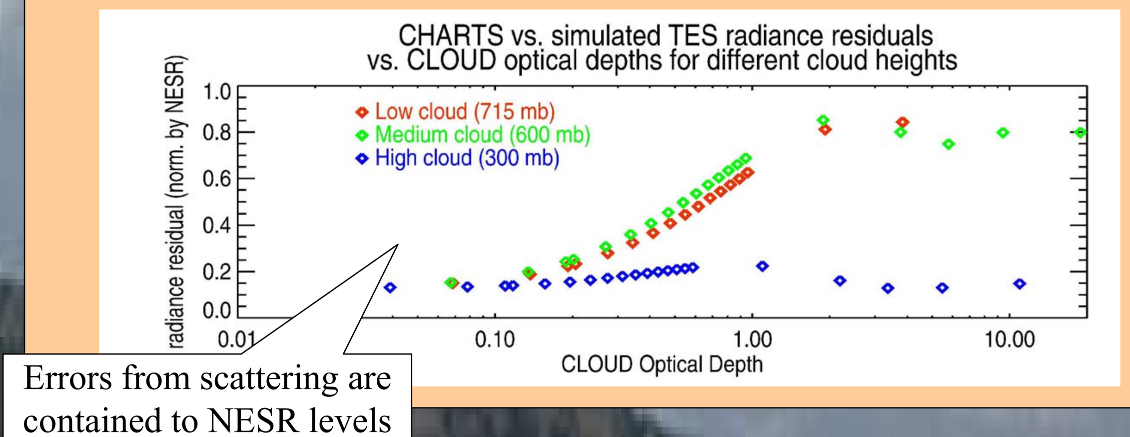
* Comparing model that includes scattering (CHARTS) vs. TES forward model w/ clouds (described in Panel 3)
* Plots show agreement for different cloud cases for the SAME atmosphere. Especially note water line changes
* **Lowest plot shows that clouds of all heights and optical depths can be adequately modeled by our approach**











5. CHARACTERIZING AND VALIDATING CLOUD EFFECTS ON TRACE GAS RETRIEVALS

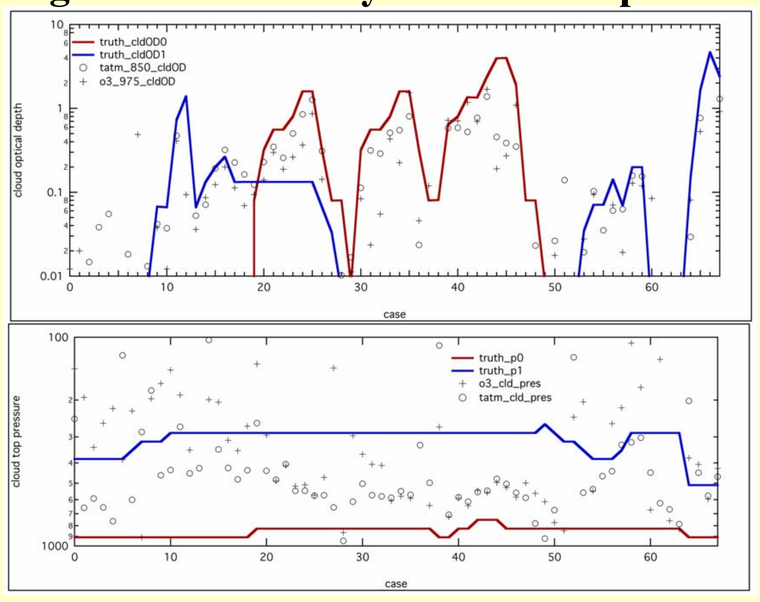
Purpose

(1) Determine if TES can retrieve temperature and trace gases in the presence of clouds
(2) Determine if TES reported errors are reliable in the presence of clouds

Test setup

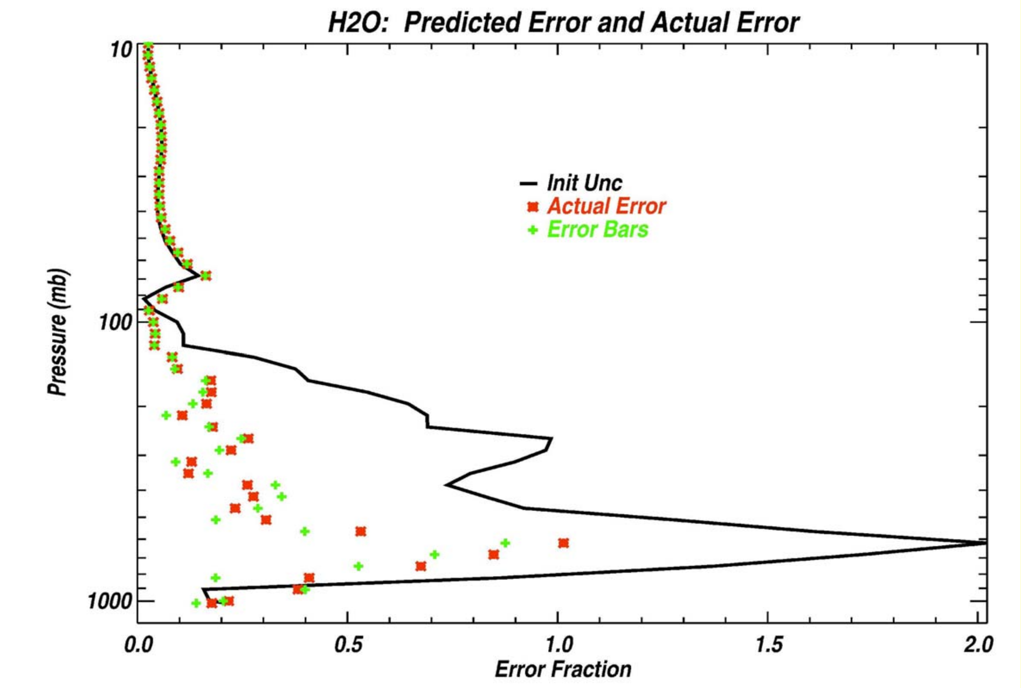
(1) 67 tropical test atmospheres
(2) has various thick and thin, high and low clouds AND double-layer clouds (see plot below)
(3) CHARTS used to run forward model (with scattering)
(4) TES retrieval used to retrieve atmospheric state

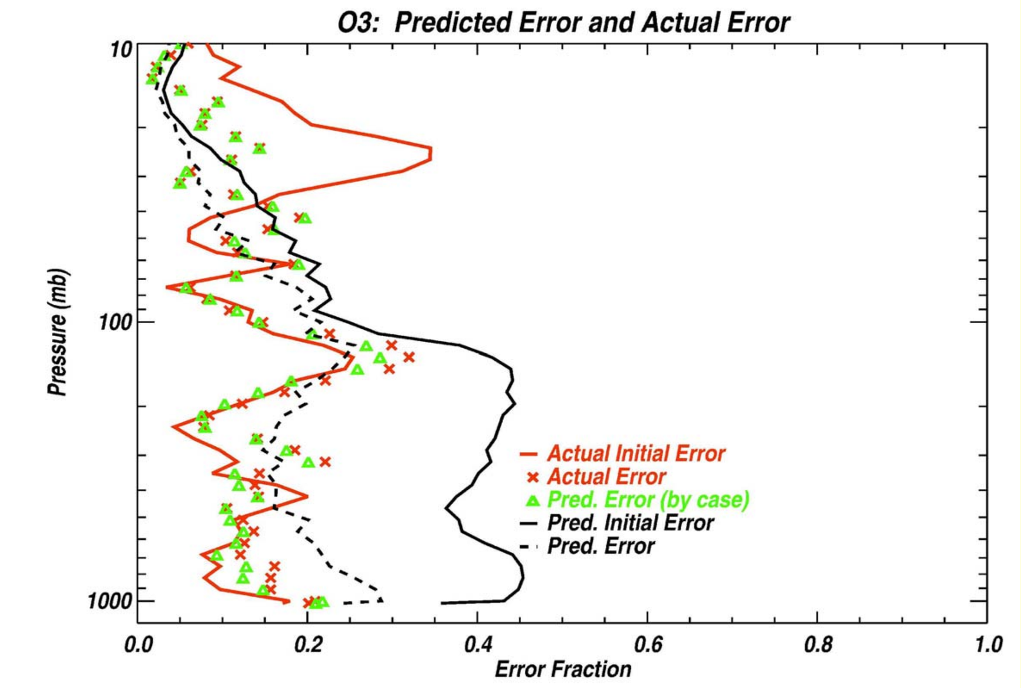
Single and double layer cloud composition



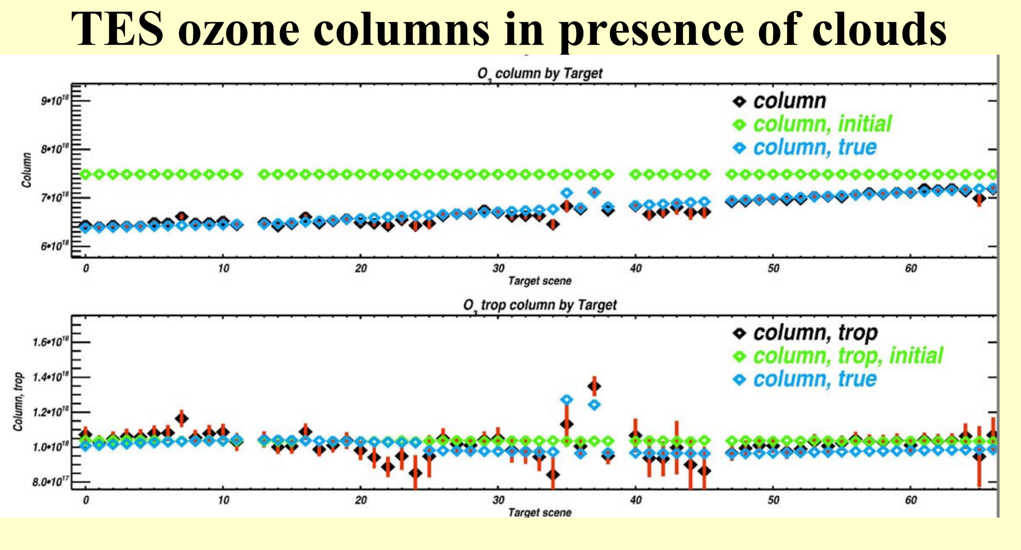
RESULTS

- **The TES expected errors (+, Δ) compare well to the ACTUAL errors (x)**
- **TES retrievals improve on the initial atmospheric state (—— = initial, x = retrieved error)**





TES ozone columns in presence of clouds



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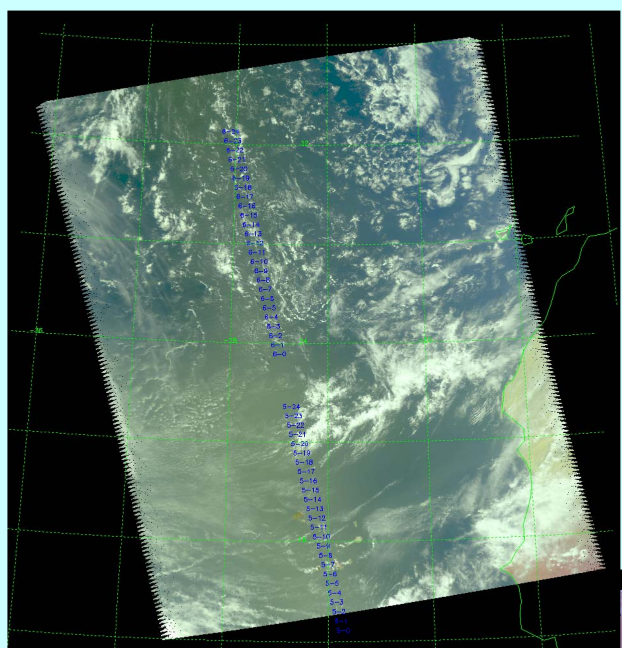
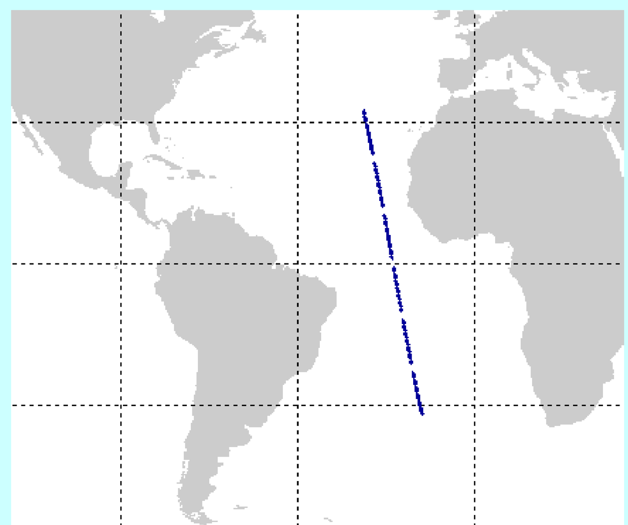
6. TES STEP AND STARE MODE

The TES Step and Stare takes a total of 150 scans along the TES orbit track each separated by about 0.4 degrees, covering about 4000 total miles.

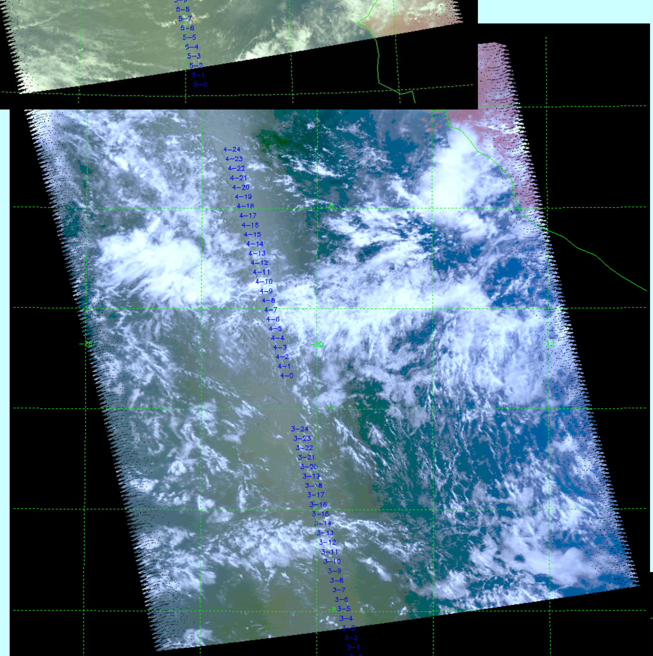
TES step & stare mode has several advantages over Global Survey mode: (1) it allows probing of smaller-scale variability, such as with clouds or biomass burning, and (2) it currently yields the best calibrated TES data

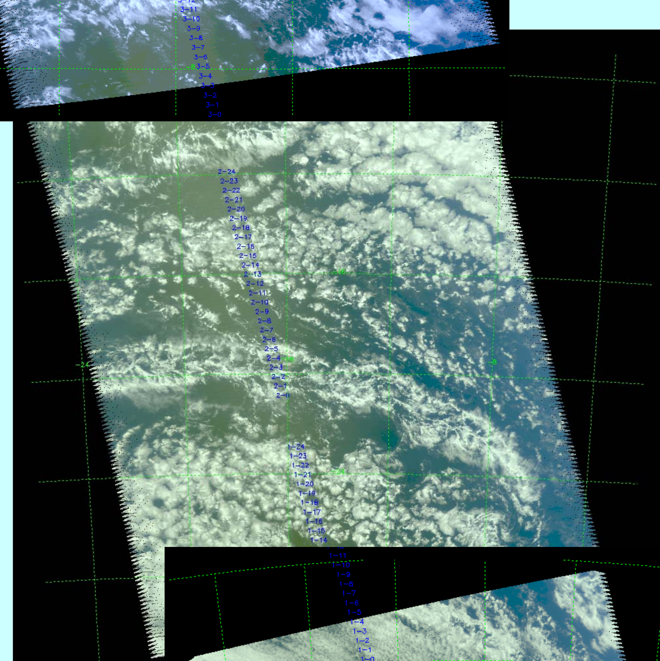
Below show the TES footprints for a Step & Stare dataset collected on 9/21/2004 crossing near Natal Island in the Atlantic Ocean:

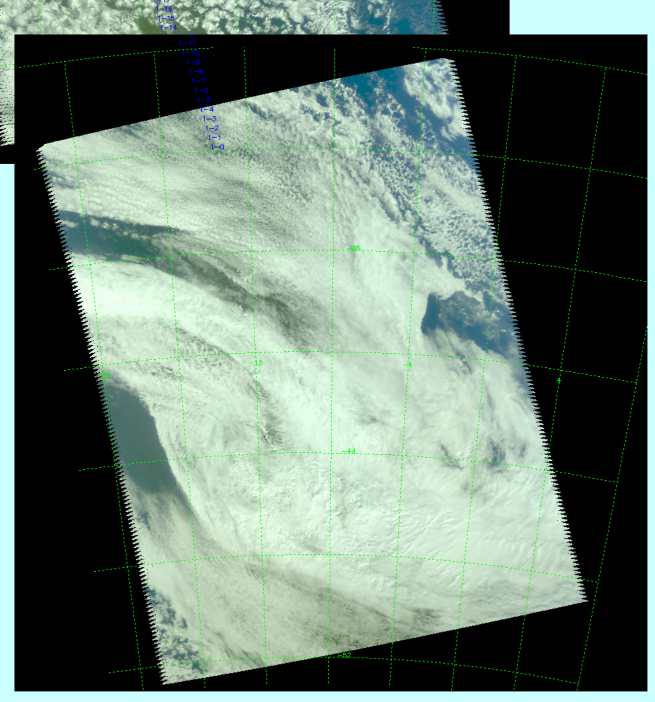




TES footprints on world map



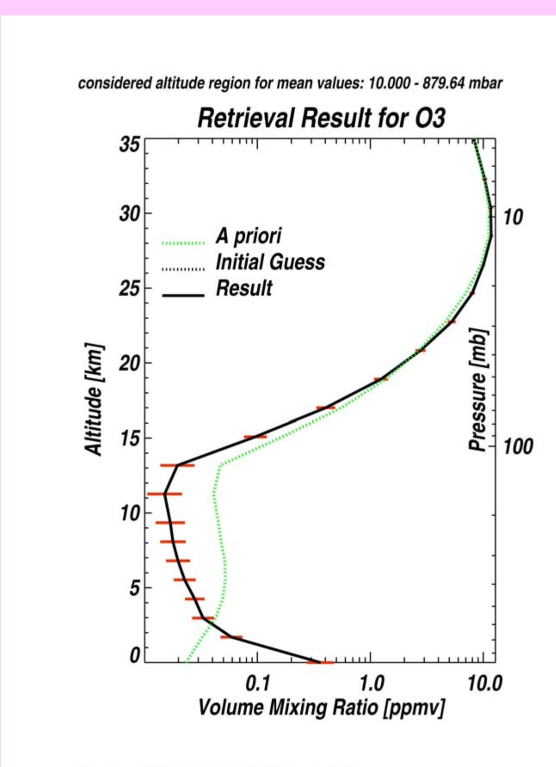




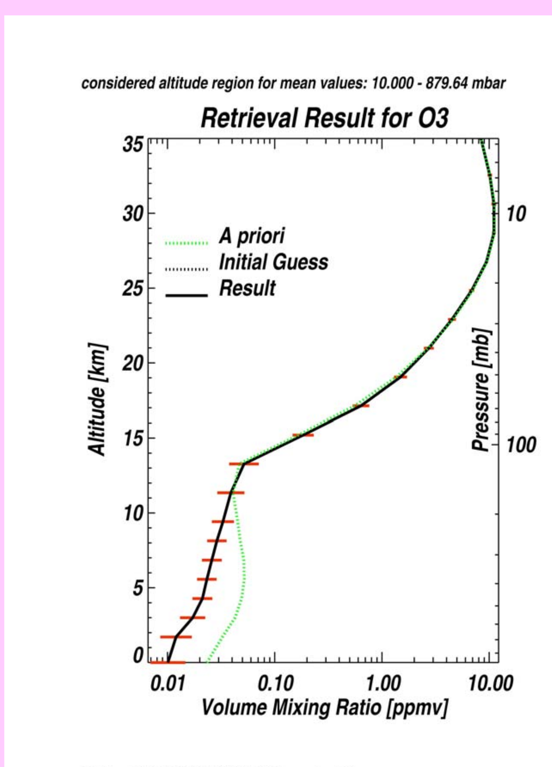
TES observation locations (blue) overlaid on AIRS visible data for Step & Stare

7. EXAMPLE RETRIEVAL WITH AND WITHOUT CLOUD

Without explicit cloud retrievals, TES retrievals alias the cloud's influence on the radiance into other retrieved parameters resulting in retrievals that are not trustworthy. Below shows an example ozone retrieval with and without retrieved clouds:



TES retrieval without cloud



TES retrieval with cloud (retrieved effective OD = 0.2)

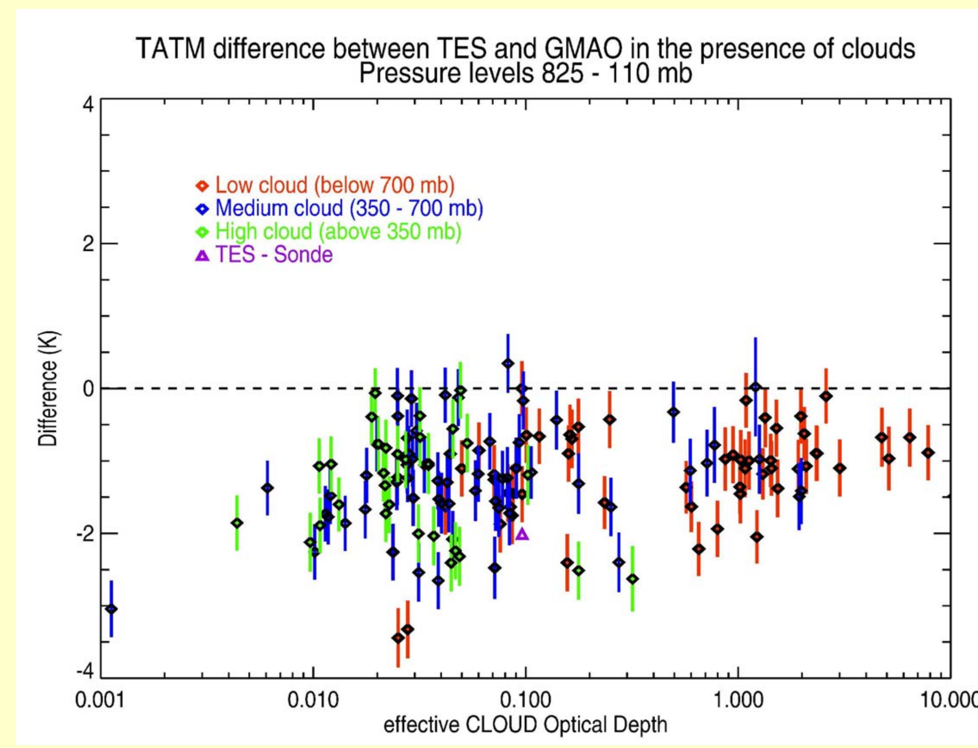
8. REAL DATA RETRIEVALS

Real data has no known "truth", however we can make comparisons to other data sources to detect (a) increased bias or (b) increased variability with increased cloud optical depths or cloud height. The quantities looked at were:

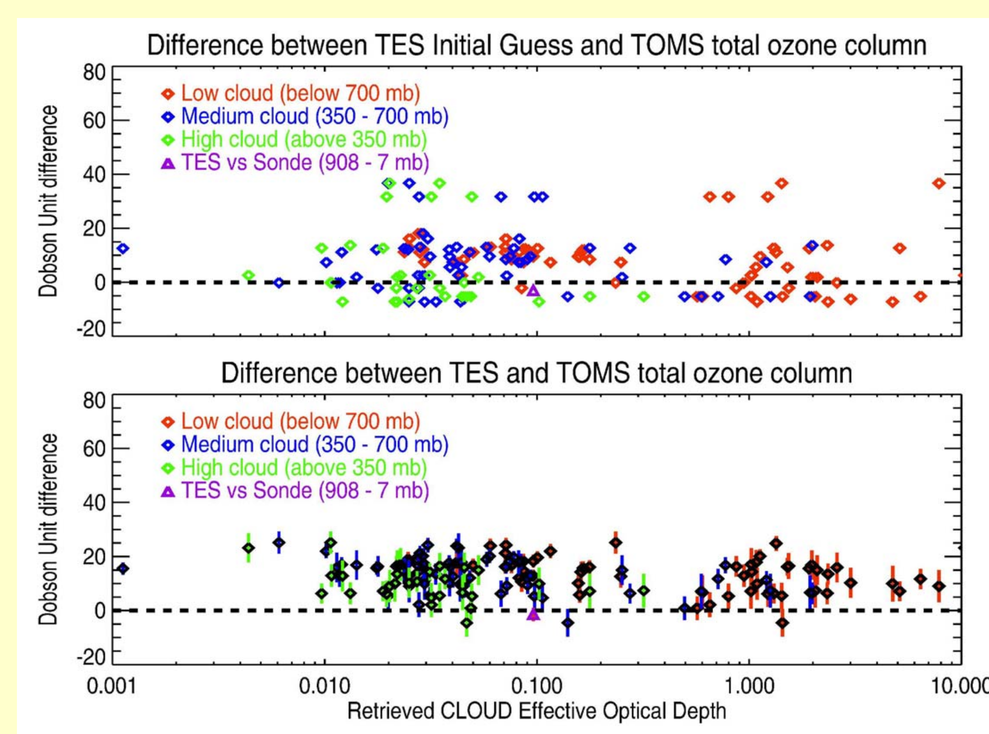
T_{ATM}: average value between 825-110 mb compared to GMAO and to single SONDE measurement
H_2O: Tropospheric column (surface to 100 mb) compared to GMAO and to single SONDE measurement
O_3: total column compared to TOMS and to SONDE data (SONDE data collected from 908-7 mb)

RESULTS

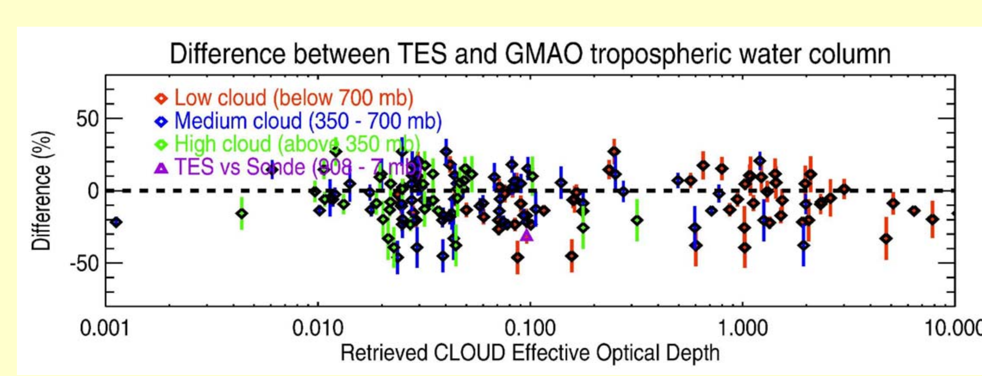
For this Step & Stare (shown in Panel 6) taken on 9/21/2004, there were 150 good retrievals out of 150 scans. The plots below show that TES retrieval skill for the above quantities is independent of retrieved cloud effective optical depth.



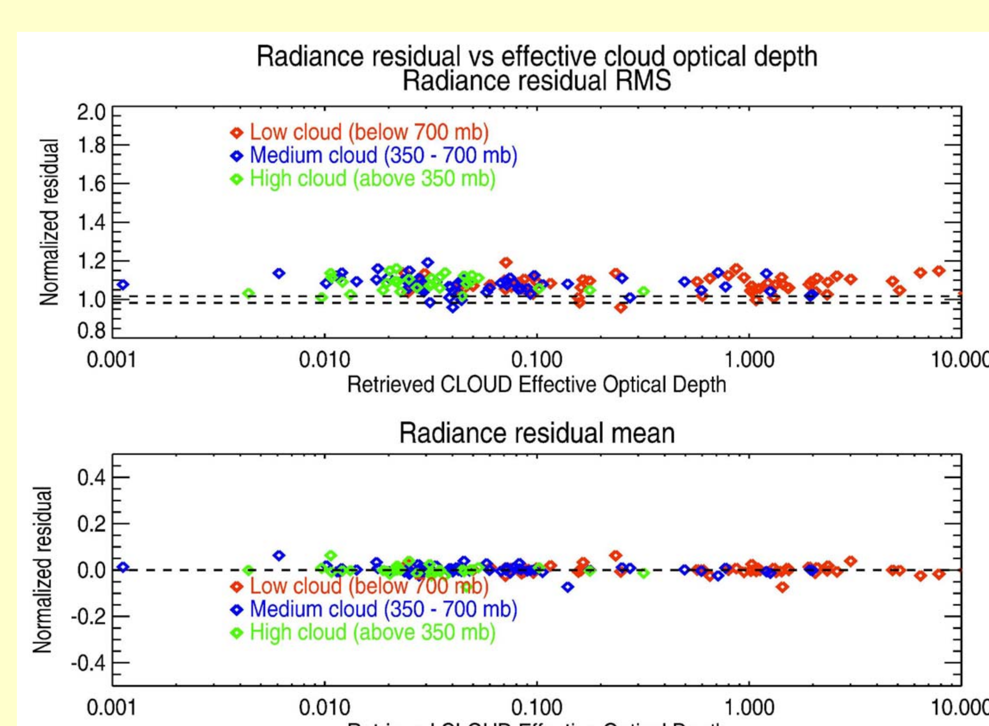
TES Tropospheric Temperature (vs. GMAO)
The plot at left shows that TES Tropospheric temperature retrieval skill is unaffected by clouds. The 1.2 K bias between TES and GMAO occurs at all cloud optical depths, and the variability of the difference shows no obvious dependence on the retrieved cloud effective optical depth or cloud height.



TES Total Ozone Column (vs. TOMS)
The plot at left shows that TES ozone retrieval skill is unaffected by clouds. The top plot shows the *initial guess* (from MOZART) difference from TOMS. The bottom plot shows the TES *retrieval* difference vs. TOMS. The 15 DU bias (out of 300 DU) between TES and TOMS occurs consistently at all cloud optical depths, and the variability of the difference shows no obvious dependence on the retrieved cloud effective optical depth or cloud height. The sonde comparison (Δ) shows excellent agreement between TES and the sonde.



TES Tropospheric Water Column (vs. GMAO)
The plot at left shows that TES Tropospheric water retrieval skill is unaffected by clouds. The the variability of the difference between GMAO and TES shows no obvious dependence on the retrieved cloud effective optical depth or cloud height. The sonde comparison (Δ) shows a 30% difference, which could be due to the 500 km distance between the sonde measurement and the closest TES measurement.



TES radiance residuals
TES radiance residuals do not show any trend with respect to cloud effective optical depth or cloud height. The radiance residual mean and residual rms show benign and consistent behavior for all cloud optical depths.

CONCLUSIONS

1) Single layer clouds without scattering are adequate to account for clouds' effects on trace gas retrievals (Panels 4 and 5)

2) TES error bars correctly account for errors due to clouds (Panel 5)

3) TES level 2 retrieval throughput approaches 100% for Step and Stare mode even in the presence of clouds (Panel 8)

4) TES retrieval skill for various averaged parameters is independent of cloud optical depth and height (Panel 8)

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