Quantifying Lower Tropospheric Methane Using Total Column (NIR) and Tropospheric (TIR) measurements

Authors

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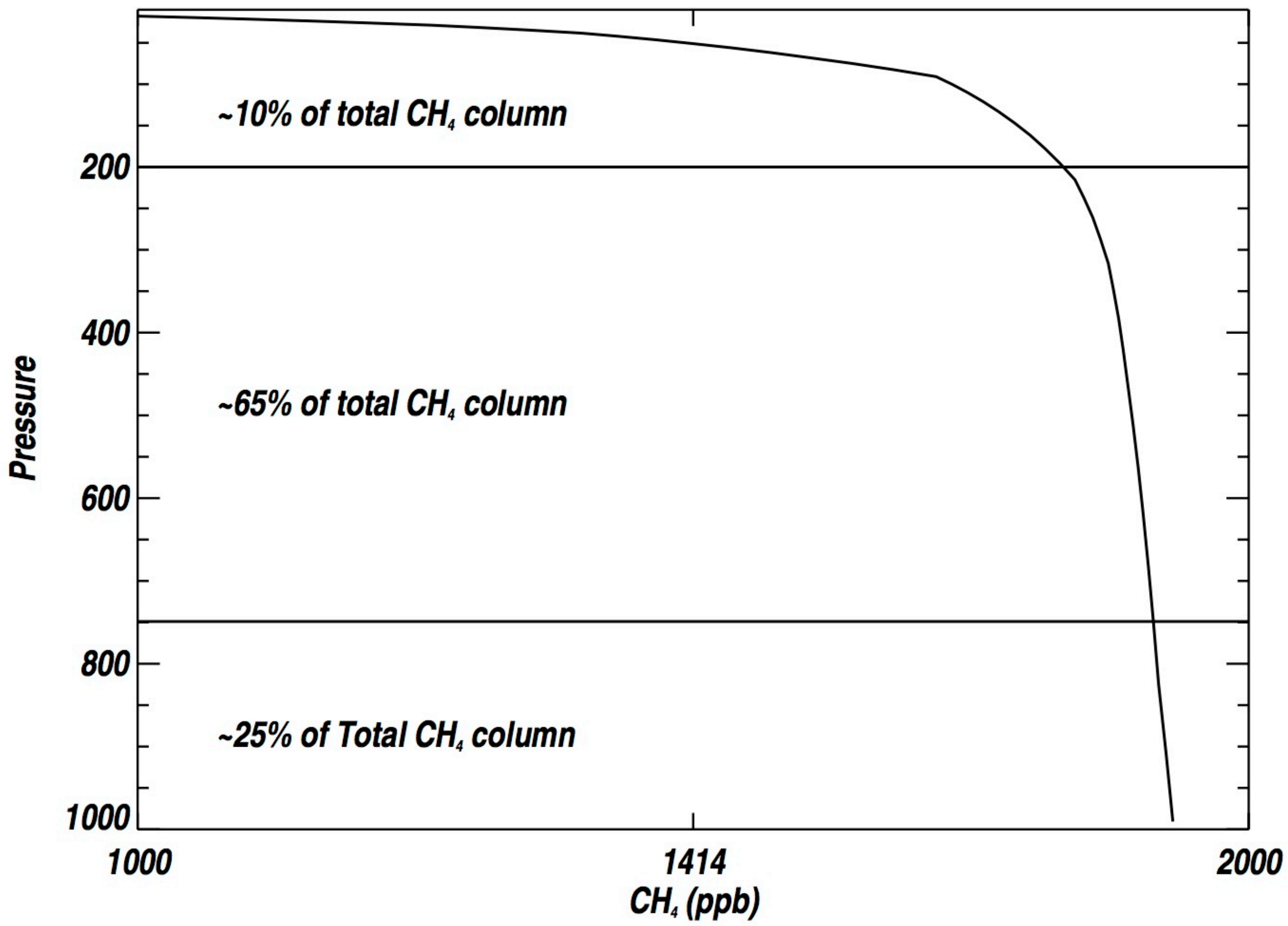
Methane profile at ~55 N in July 2006

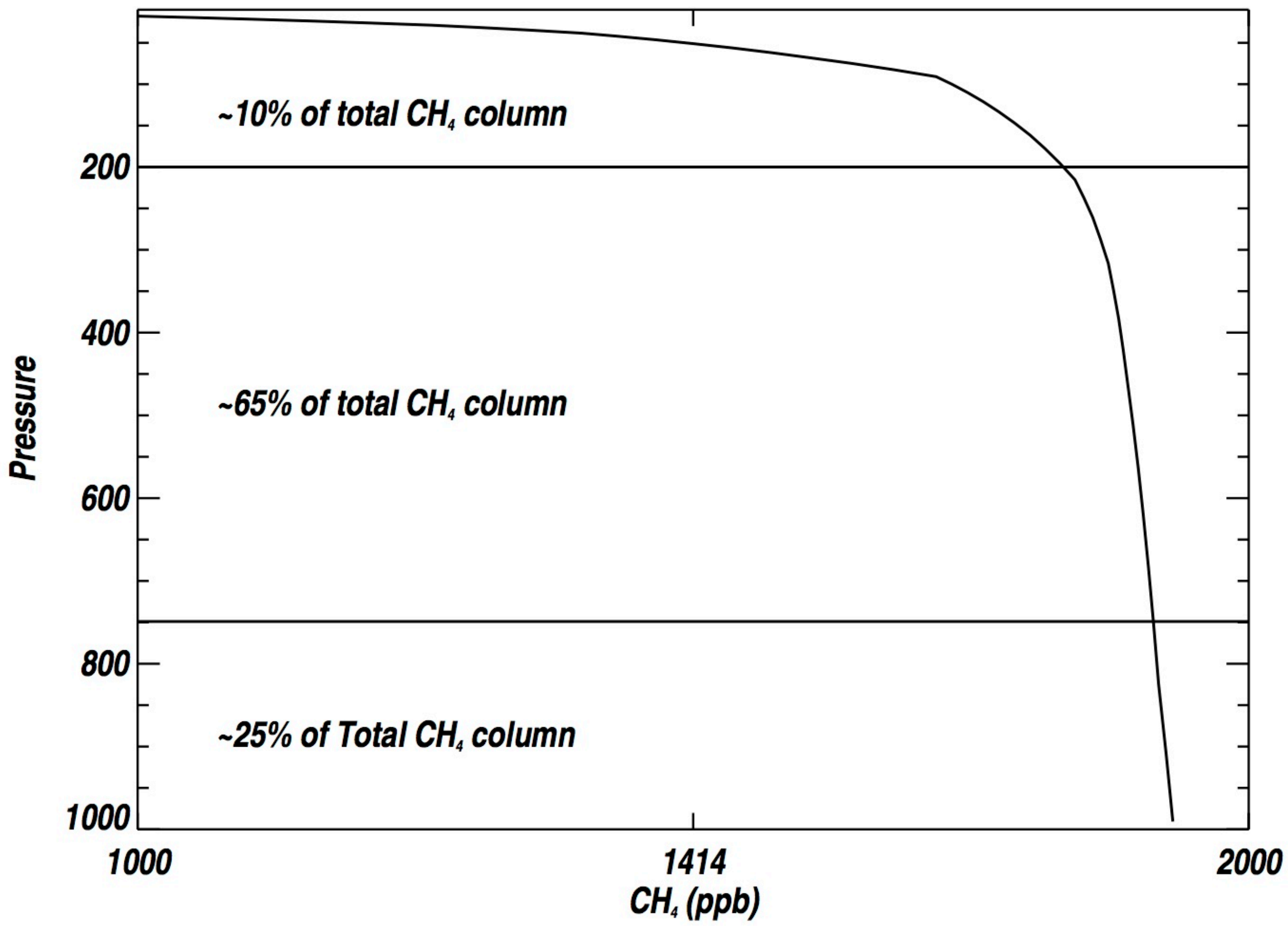


Primarily sensitive to sources really really far away from measurement

Primarily sensitive to sources ~1000's of km away

Primarily sensitive to sources ~100's of km away from measurement

Methane profile at ~55 N in July 2006

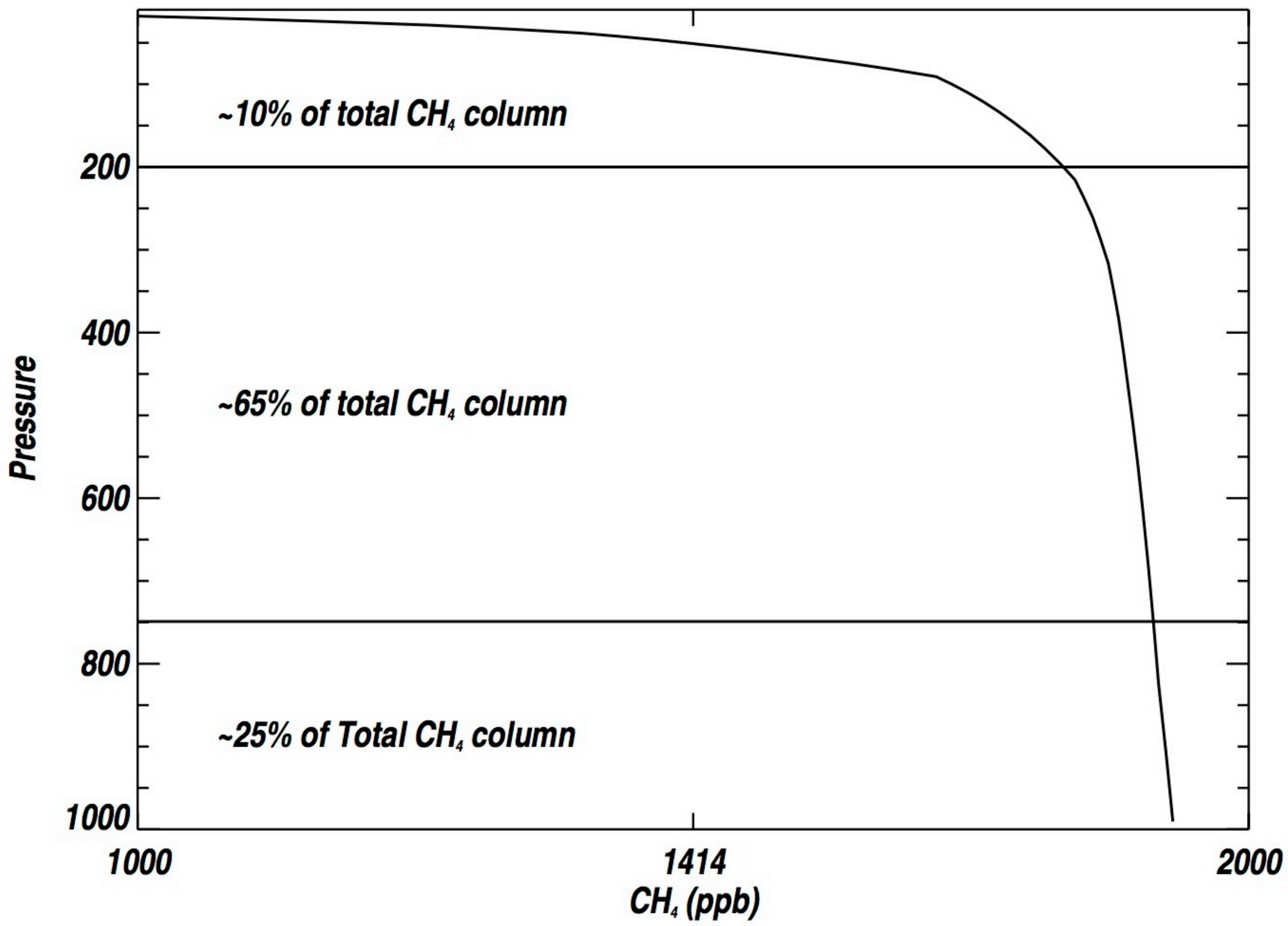


Chemistry, transport, and tropopause height

Transport and Chemistry

Boundary layer height, transport, and chemistry

Estimating Fluxes Using Surface Network

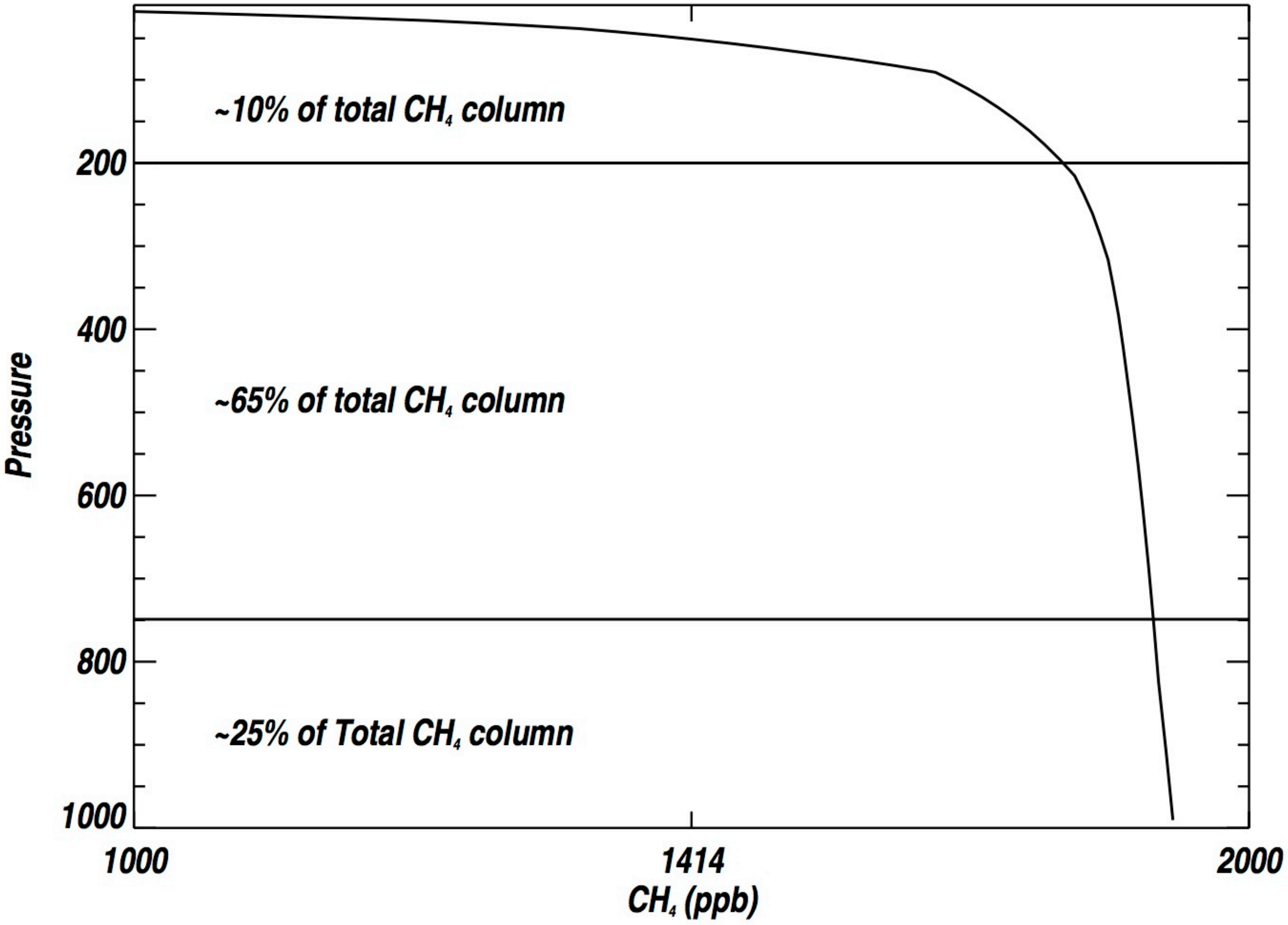


Transport and Chemistry

Boundary layer height,

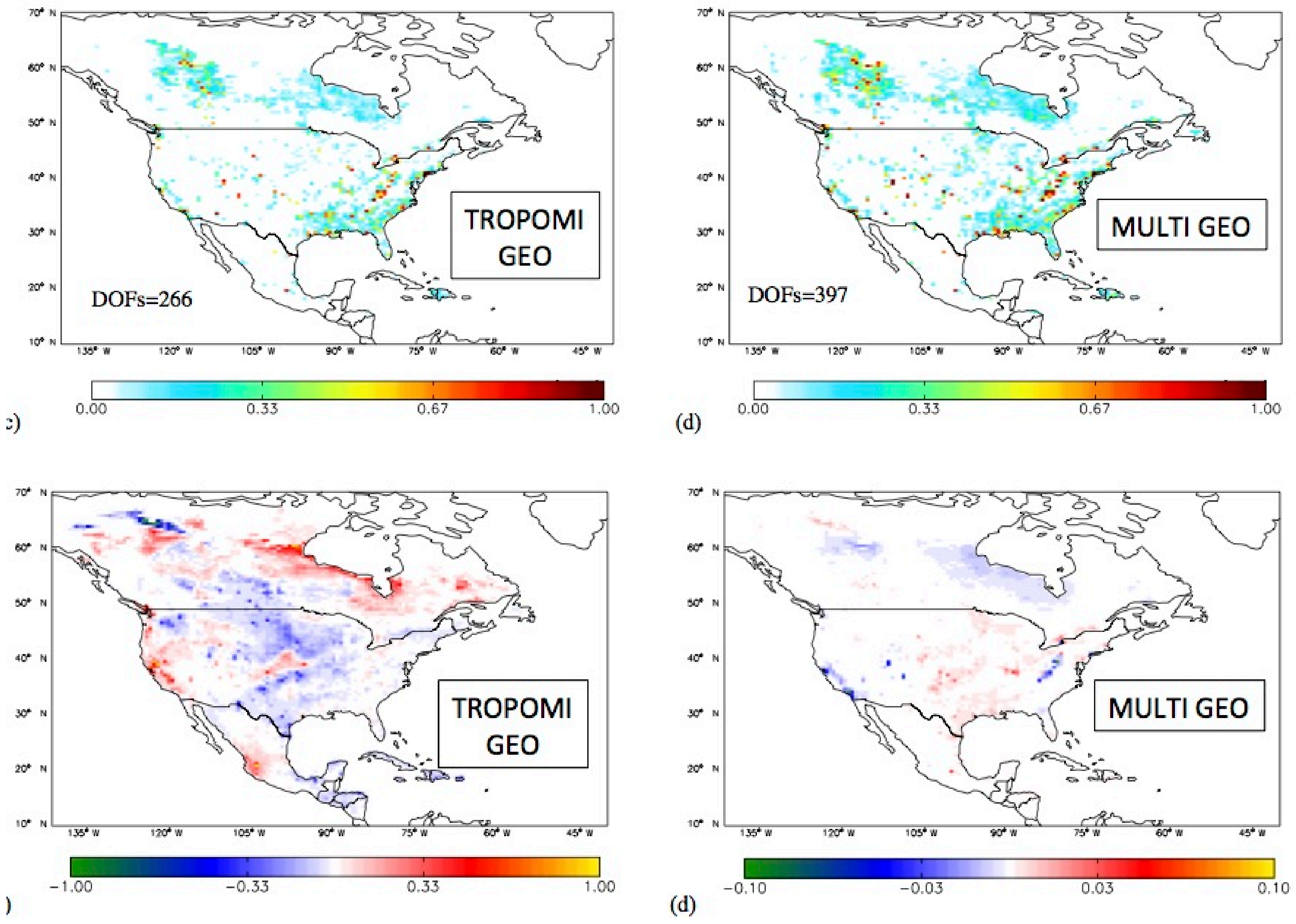
Transport, and chemistry

Estimating Fluxes Using Total Column Data



Need accurate model calculations of transport and chemistry over very long length scales (~1000's of km)

Estimating Fluxes Using Methane Total Column and Profiles from a GEO Orbit
Bousserez et al., ACP 2016

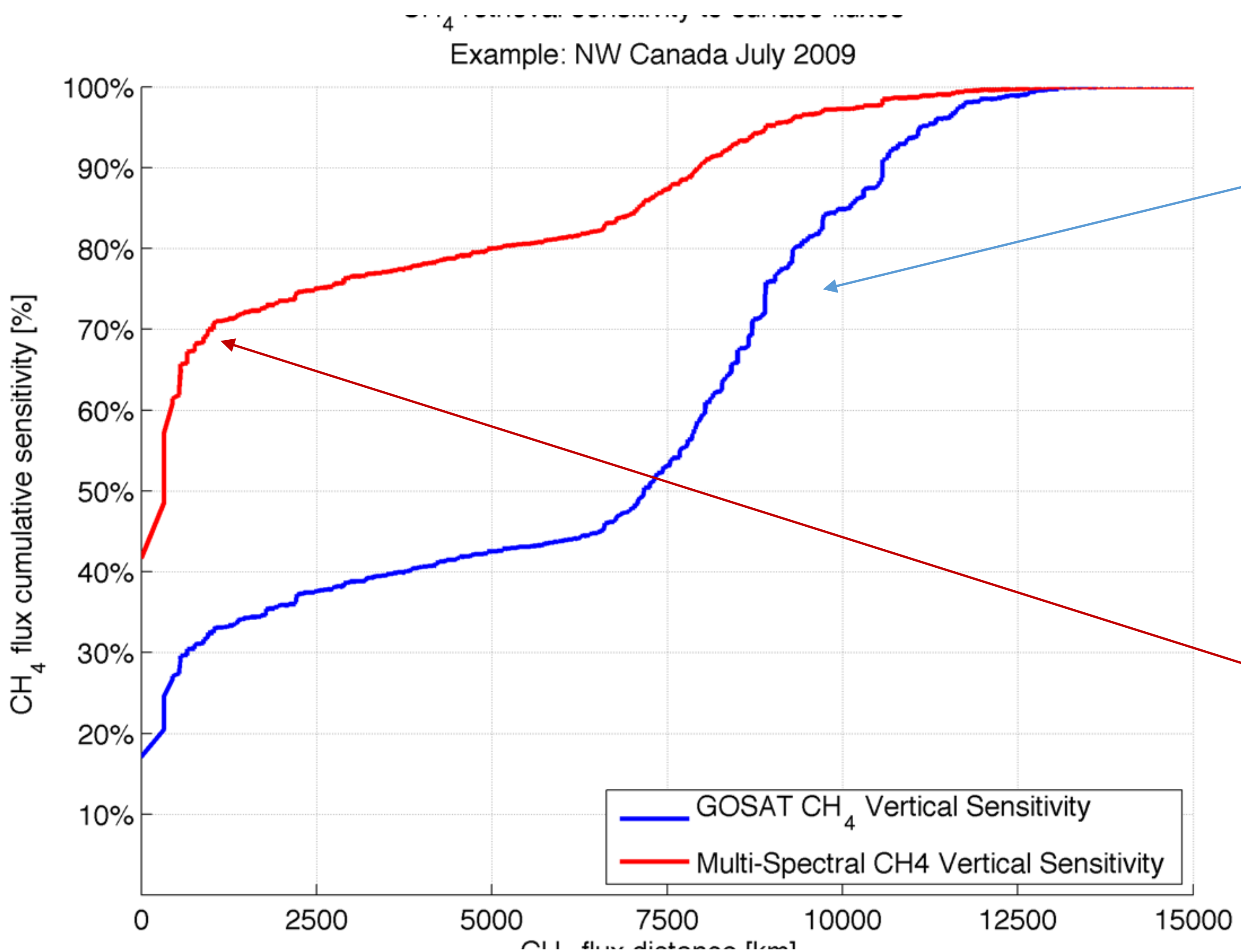


Use of Thermal IR and Near IR radiances allows for profiling of methane that can resolve the boundary layer.

Use of profiles (instead of columns) to quantify fluxes results in a:
~50% increase in sensitivity to surface fluxes

Substantial reduction in sensitivity to background errors (e.g. transport and chemistry)

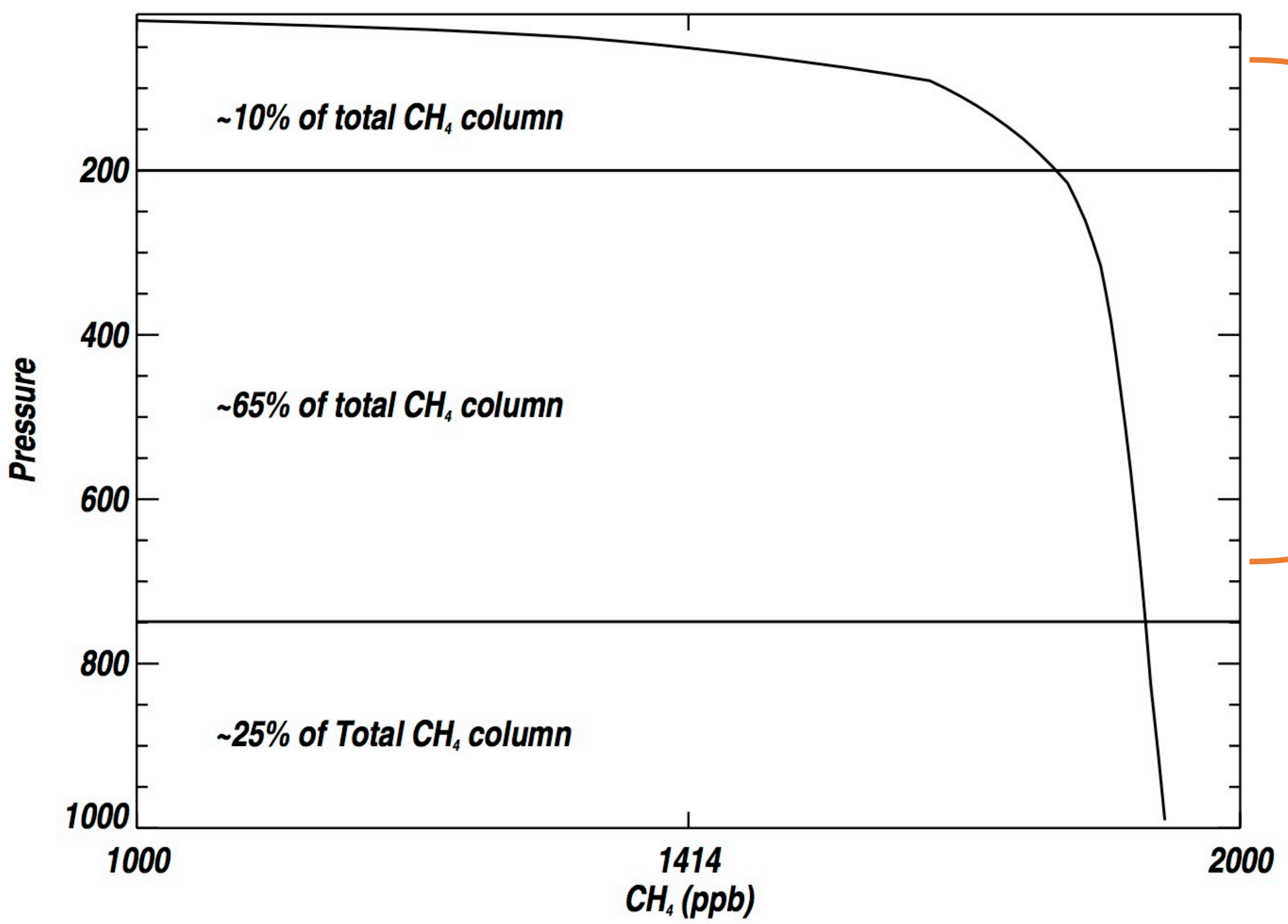
Sensitivity of Total Column and Lower-Tropospheric Methane (at high latitudes) to Methane Fluxes Using the Adjoint of the GEOS-Chem Model



Total Column Methane primarily sensitive to fluxes ~8000 km away

Lower-Tropospheric Methane primarily sensitive to fluxes ~1000 km away

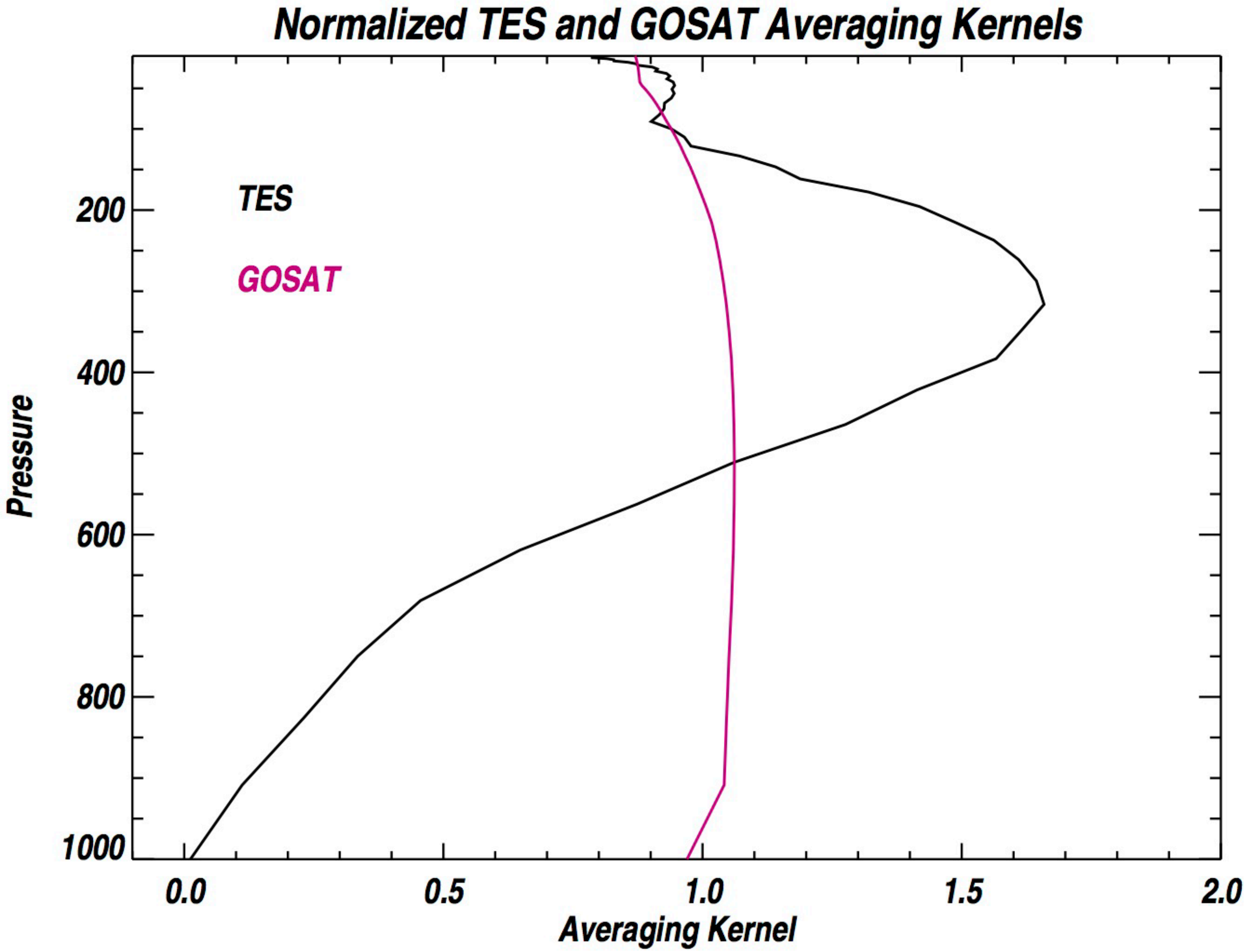
Estimating Fluxes Using Profile (or Lower Tropospheric Methane Measurements)



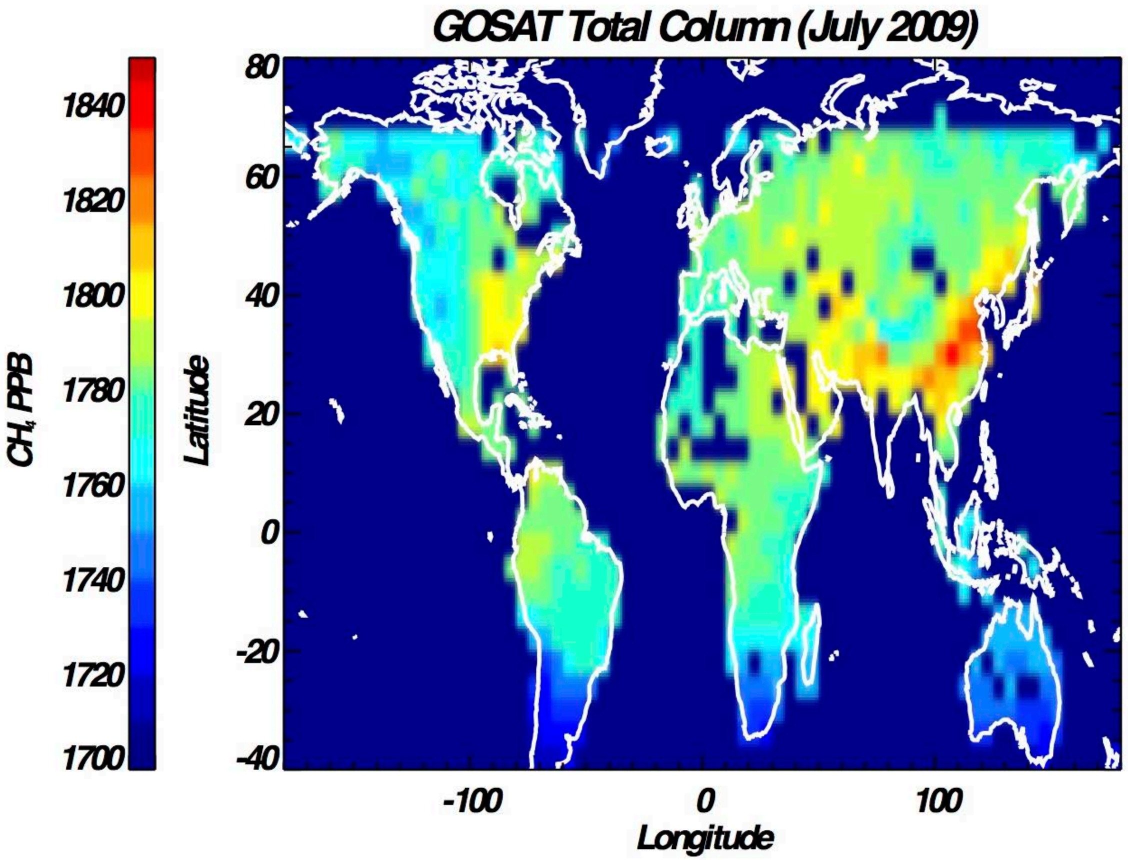
CH_4 from Thermal IR
(e.g. CRIS, TES, AIRS, IASI)

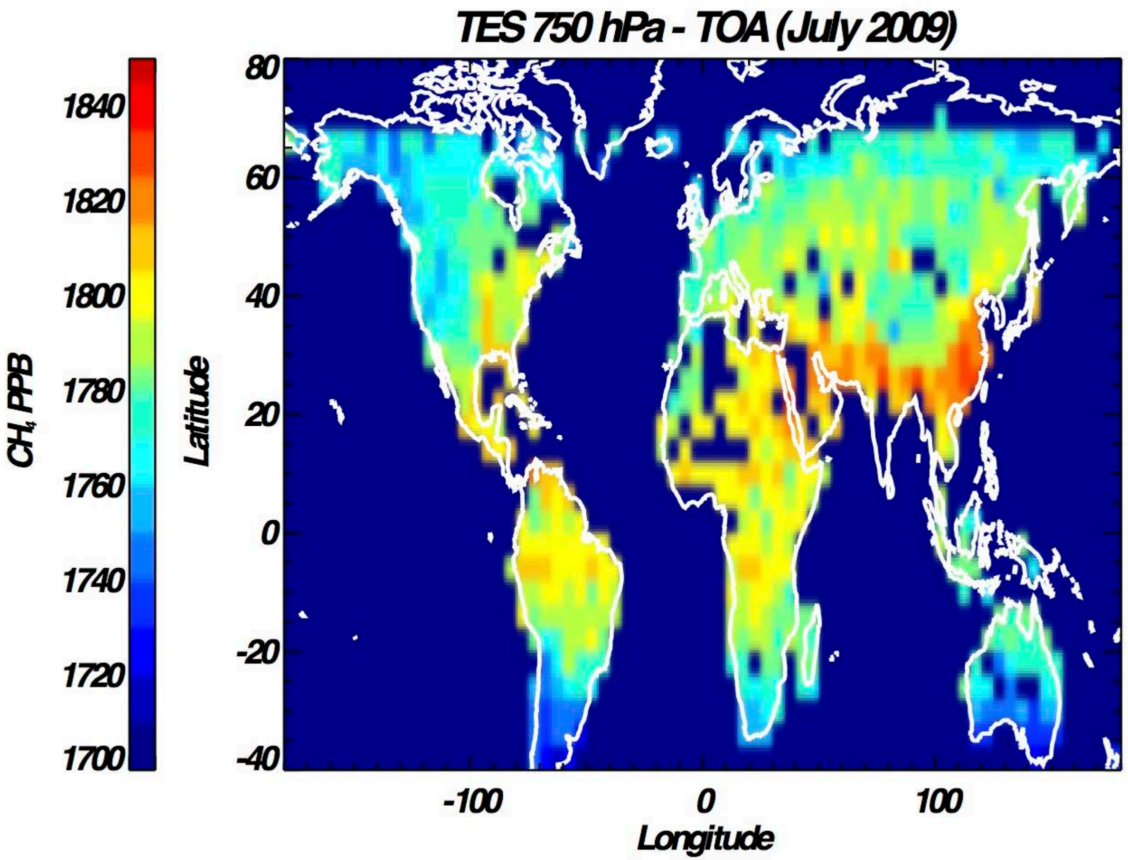
Total column CH_4 from Near IR
(e.g. TROPOMI, GOSAT, SCIAMACHY, GOME)

Example of Lower-Tropospheric Methane from GOSAT and TES: GOSAT and TES Total Column Averaging Kernels



Comparison of GOSAT Total Column and Aura TES FT/Strat Column (~850 hPa to TOA)





Precision ~15 ppb
Bias ~-17 to 2ppb
Parker et al., GRL 2011

Precision ~15 ppb
Bias ~26 ppb
Worden et al., AMT 2012; Alvarado et al., 2015

Both data sets use optimal estimation → a priori, vertical sensitivity (averaging kernels), and aposteriori uncertainties for noise and interferences are provide in the product files

Some Math: Derivation of Averaging Kernel and Uncertainties

$$\hat{\boldsymbol{C}} \quad = \boldsymbol{C}^{\boldsymbol{a}} + \boldsymbol{C}_{\boldsymbol{air}} \boldsymbol{h}^{\boldsymbol{T}} \mathrm{A}(\boldsymbol{x} - \boldsymbol{x}^{\boldsymbol{a}}) + \boldsymbol{C}_{\boldsymbol{air}} \sum\nolimits_{\mathrm{i}} \boldsymbol{h}^{\boldsymbol{T}} \boldsymbol{\delta}_{\boldsymbol{i}}$$

$$\hat{\boldsymbol{C}}_{\boldsymbol{L}} = \hat{\boldsymbol{C}}_{\boldsymbol{tot}} - \hat{\boldsymbol{C}}_{\boldsymbol{U}}$$

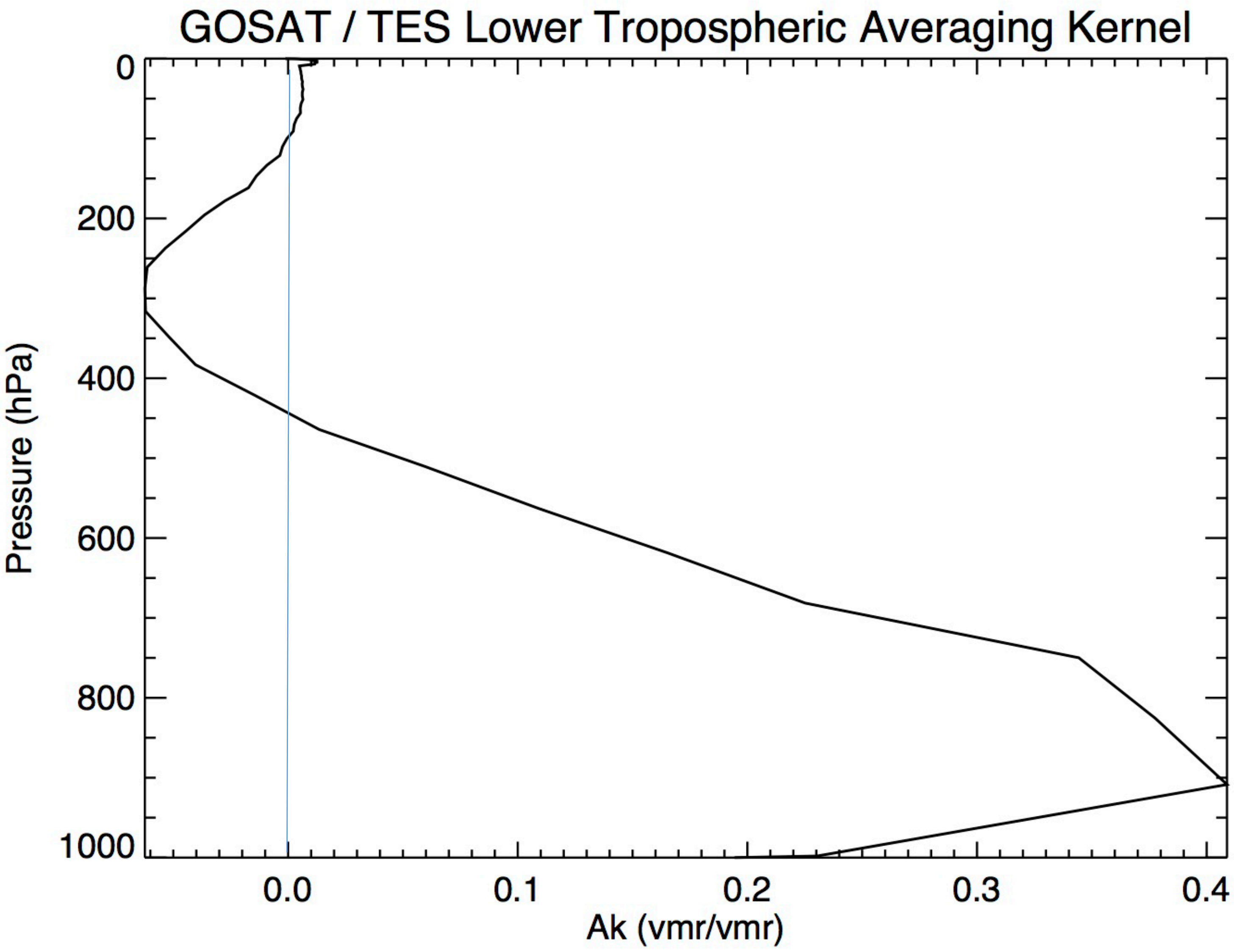
$$\hat{C}_L = C_L^a + C_{air}\, \boldsymbol{b}_{\boldsymbol{L}}(\boldsymbol{x}_{\boldsymbol{L}} - \boldsymbol{x}_{\boldsymbol{L}}^{\boldsymbol{a}}) + C_{air}\big(\, \boldsymbol{b}_{\boldsymbol{u}} \;- \boldsymbol{h}_{\boldsymbol{u}} \mathbf{A}_{\mathbf{UU}}^{\mathbf{TES}}\big)(\boldsymbol{x}_{\boldsymbol{u}} - \boldsymbol{x}_{\boldsymbol{u}}^{\boldsymbol{a}}) + C_{air} \sum\nolimits_{i} \boldsymbol{h} \boldsymbol{\delta}_{\boldsymbol{i}}$$

Divide above equation by the column of dry air in the lower troposphere and re-arrange and combine terms and we get:

$$\hat{X}_L = X_L^a + a^T(\boldsymbol{x} \quad - \boldsymbol{x}^{\boldsymbol{a}}\,) + C_{air}/C_L^{air} \sum\nolimits_{i} \boldsymbol{h} \boldsymbol{\delta}_{\boldsymbol{i}}$$

Now we have an equation that is similar to that described in Rodgers (2000).
Note amplification of uncertainties by about a factor of 4 due to $\boldsymbol{C}_{\boldsymbol{air}}/\boldsymbol{C}_{\boldsymbol{L}}^{\boldsymbol{air}}$ term

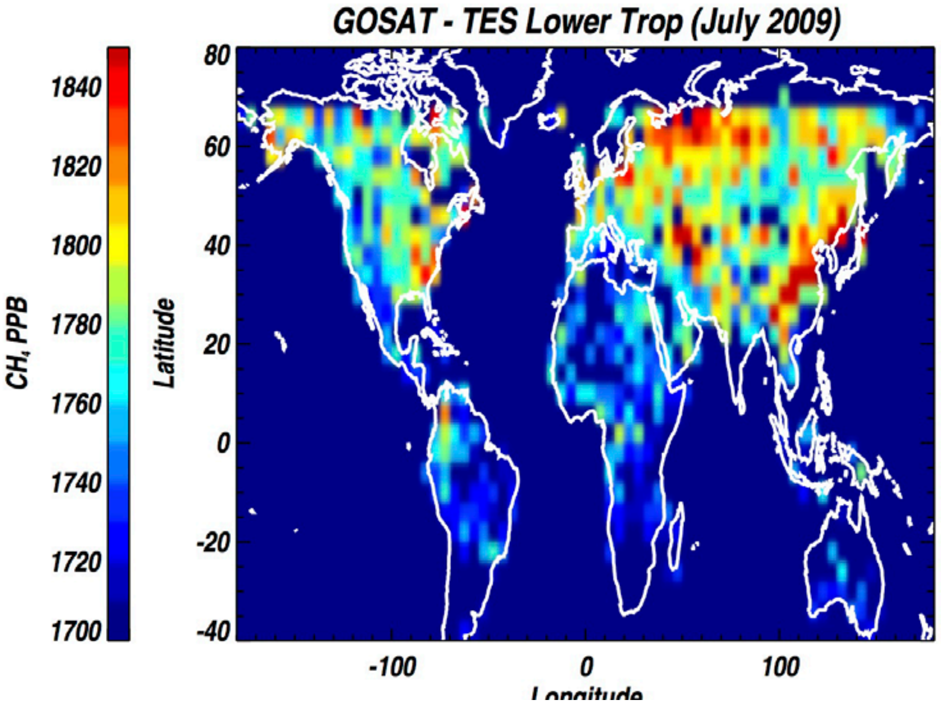
Worden et al., AMT 2015



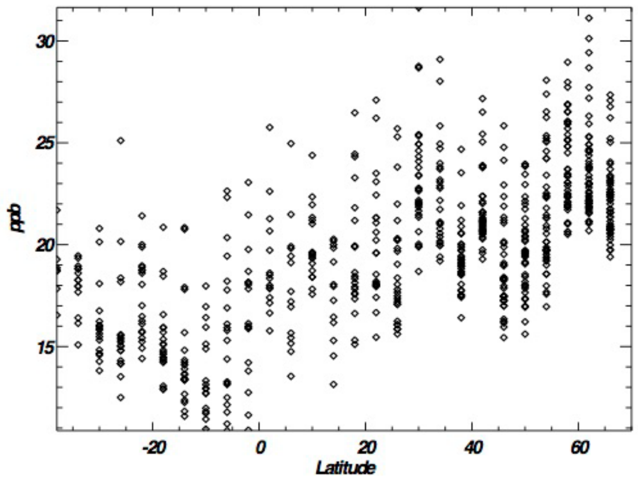
Reduced sensitivity of lower tropospheric estimate to stratosphere and upper tropospere → Reduced uncertainties due to transport and chemistry

Typical Averaging Lower Trop "column" averaging kernel peaks at 900 hPa → Greater sensitivity to nearby methane sources

Lower Tropospheric CH_4 Estimates are for a Monthly Average on a 4x5 degree bin

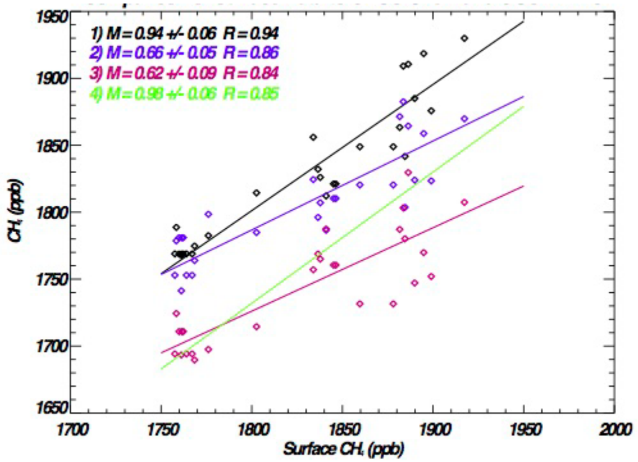


Precision



Precision depends on (1) noise, (2)sampling differences between GOSAT and TES, (3) cross-state error in TES free-tropospheric methane

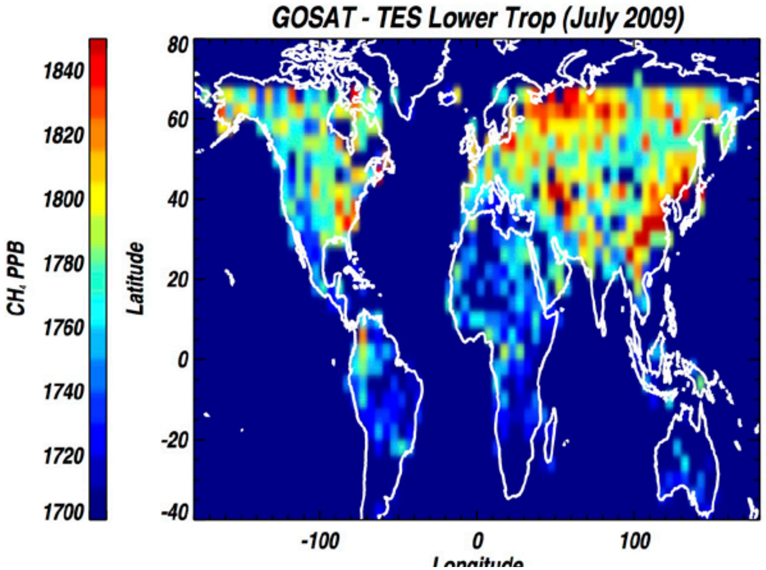
Comparison to Surface Network

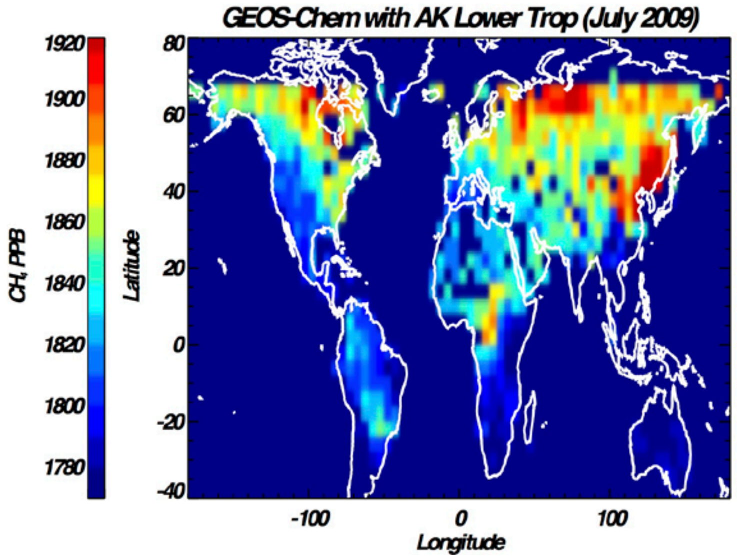


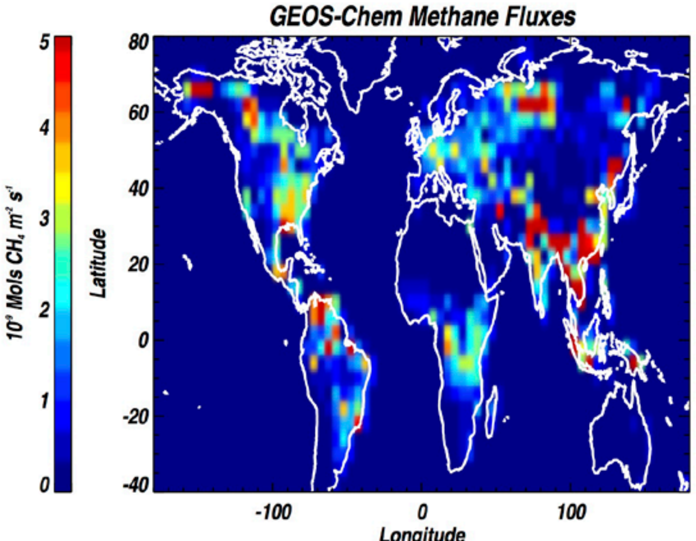
Comparison to surface data (via GEOS-Chem model) suggests that data are biased low by ~65 ppb)

Comparison between data and model (using averaging kernel and a priori constraints)reveal regional enhancements over methane sources

$$\hat{X}_L = X_L^a + a^T(\boldsymbol{x} \quad - \boldsymbol{x}^{\boldsymbol{a}})$$



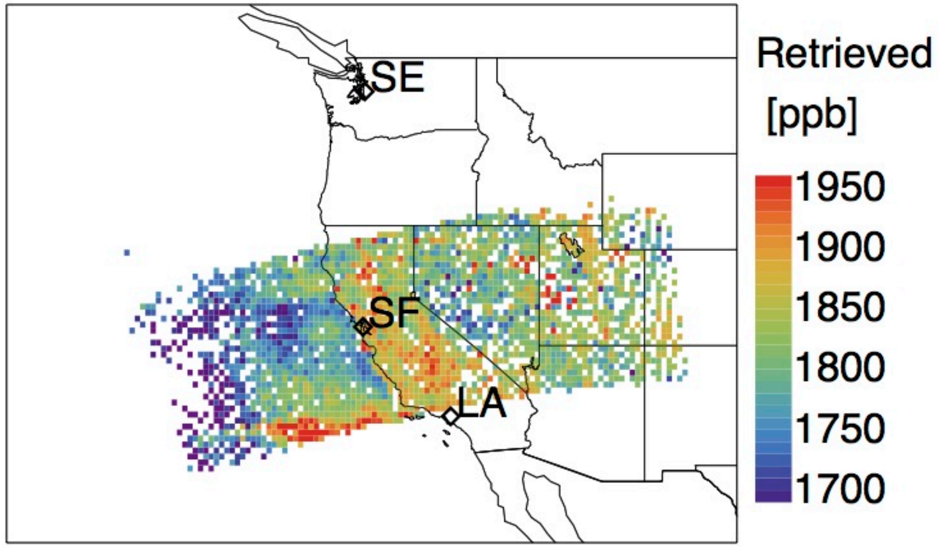




Lower Tropospheric Estimates from CRIS and TROPOMI

- **TROPOMI ~1000X soundings relative to GOSAT ~same precision and accuracy as GOSAT**
- **CRIS ~ 10000X soundings relative to TES ~same accuracy and better precistion than TES**
- **Precision of GOSAT/TES estimate ~30 ppb so precision of TROPOMI/CRIS estimate ~< 1 ppb**
- **Greatly increased precision and sampling allows us to better diagnose accuracy using surface network and aircraft data**

CRIS Methane Retrievals Based on Aura TES Optimal Estimation Composition Retrieval Algorithm



Summary

Lower tropospheric estimates based on CRIS/TROPOMI measurements can quantify boundary layer methane with ~1ppb precision or better at 100 km length scales

These data could potentially provide fluxes with greatly reduced uncertainty (~10x reduction) due to transport and chemistry error, one of the limiting errors for using satellite-derived estimates of methane fluxes to evaluate the processes controlling the global methane cycle.

Key to this effort is an optimal estimation based methane retrieval algorithm in order to quantify and characterize lower-tropospheric methane → subtraction approach depends on knowledge of vertical resolution, a priori constraints, and a posteriori uncertainties of both TIR and NIR based methane estimates.