Methane from the Tropospheric Emission Spectrometer (TES)

Vivienne Payne[1], John Worden[1], Susan Kulawik[1], Christian Frankenberg[1], Kevin Bowman[1], Kevin Wecht[2]

1. Jet Propulsion Laboratory/California institute of Technology
2. Harvard University

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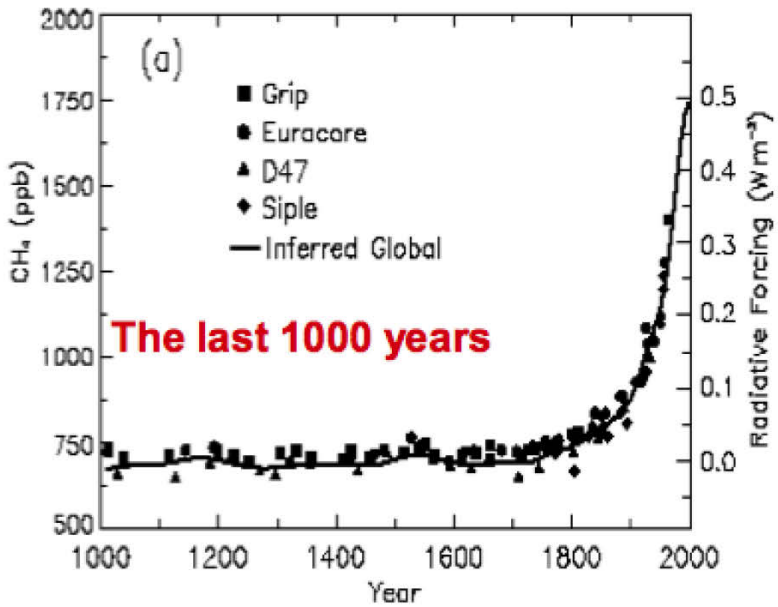
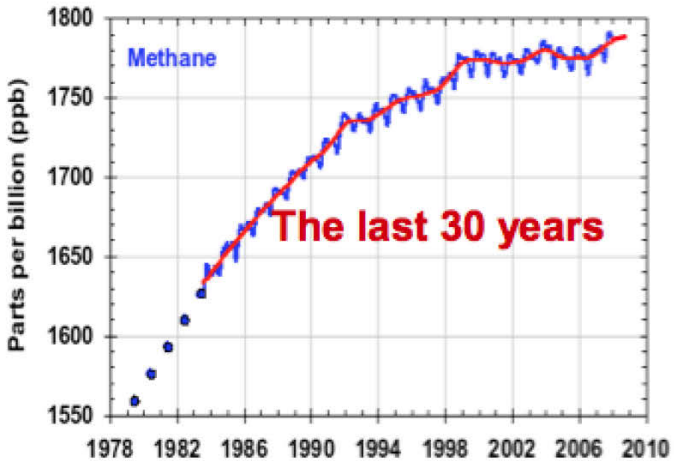
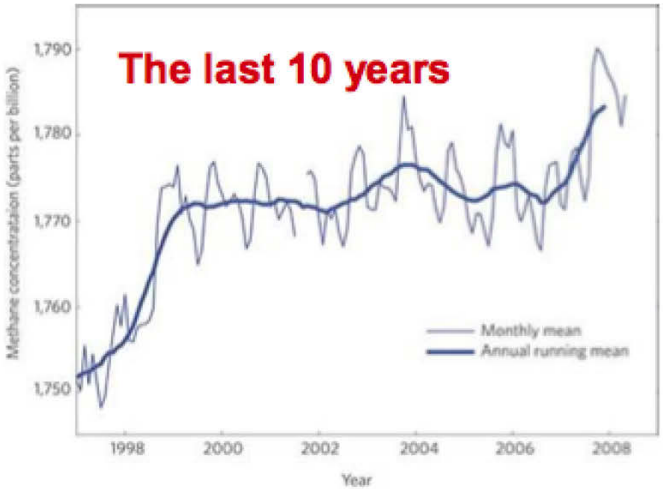
Why measure CH_4?

Better understanding of sources needed to support emission control strategies







Leveling off in past decade.
Uptick since 2007 not understood

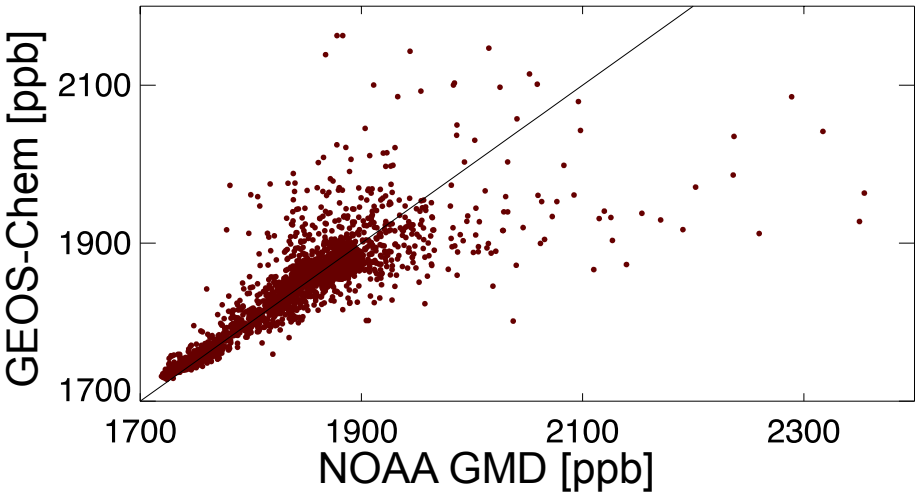
Taken from D. Jacob's presentation at the Air Quality and Climate Conference, Kona, Hawaii, 2011

CH_4 emissions

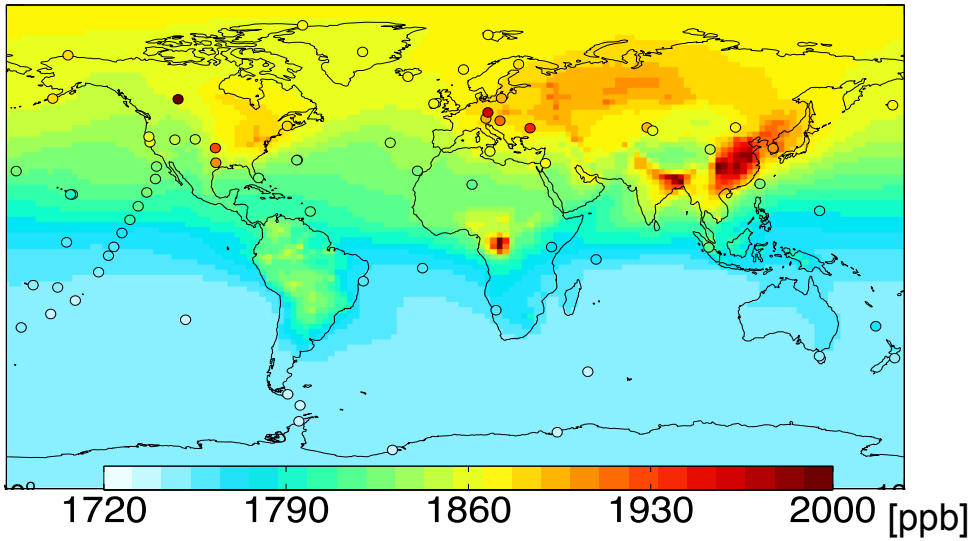
- **Anthropogenic**
  - Energy (coal and industry, gas)
  - Agriculture (rice paddies)
  - “Enteric fermentation” (e.g. cows)
  - Waste (landfills, sewage)
- **Fires**
  - Tropical biomass burning
  - Boreal fires
- **Natural**
  - Potential large changes in emissions due to climate change
  - **Wetlands**
    - Largest *natural* source of CH_4
    - Tropical wetlands contribute most
    - High latitude wetlands also important
  - Other sources?
    - Ebullition (bubbling) from high latitude lakes
    - Release from ocean floor?

Global distribution of CH_4: Surface

- **2008 annual average**
- GEOS-Chem surface map shows expected locations of strong source regions
- Global model provides a good simulation of surface data
  - ***in the annual average,***
  - for locations ***where surface data exist***
- Missing northern Hemisphere sources?



GEOS-Chem and GMD surface methane

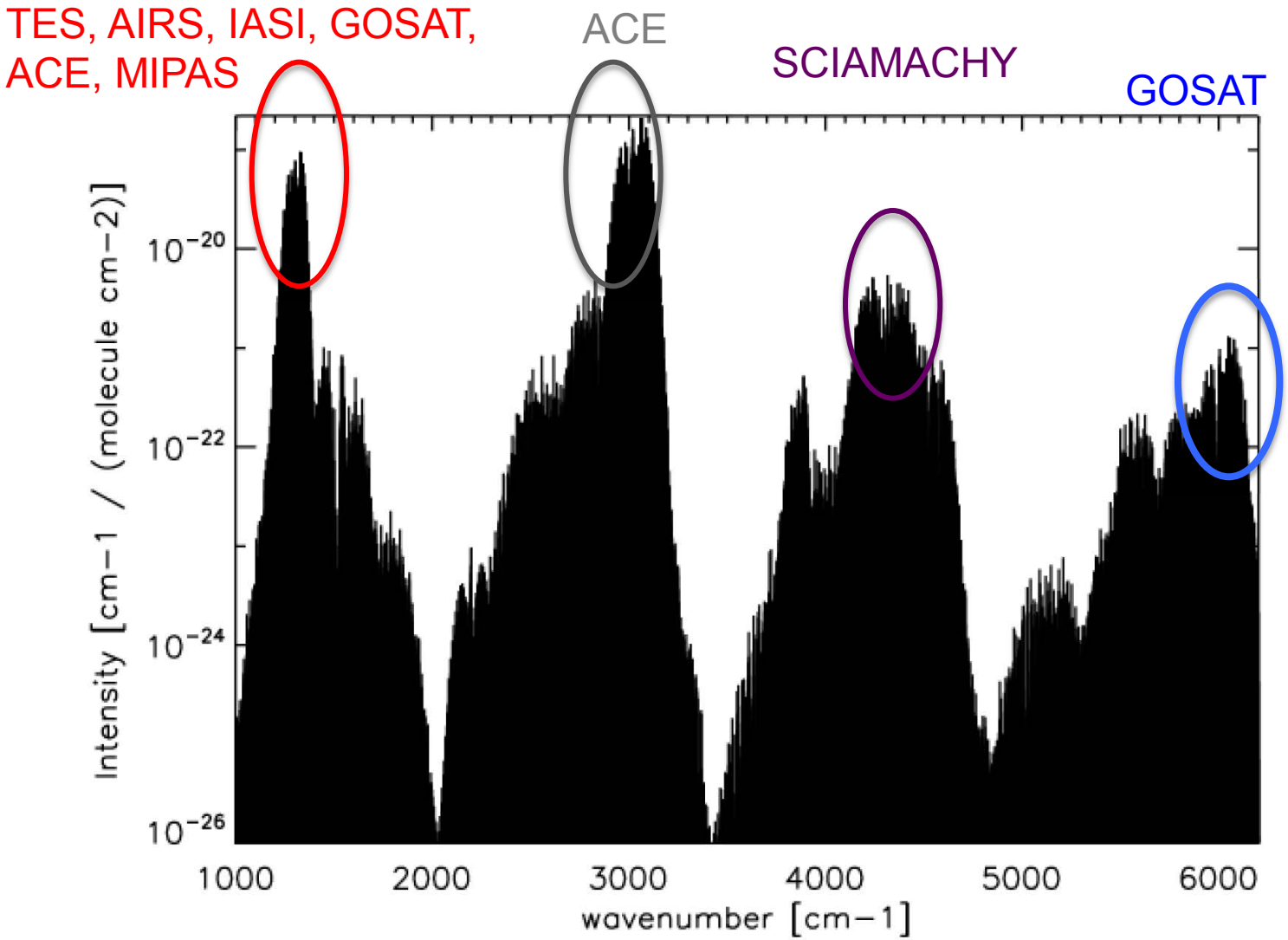


Figures from K. Wecht, Harvard

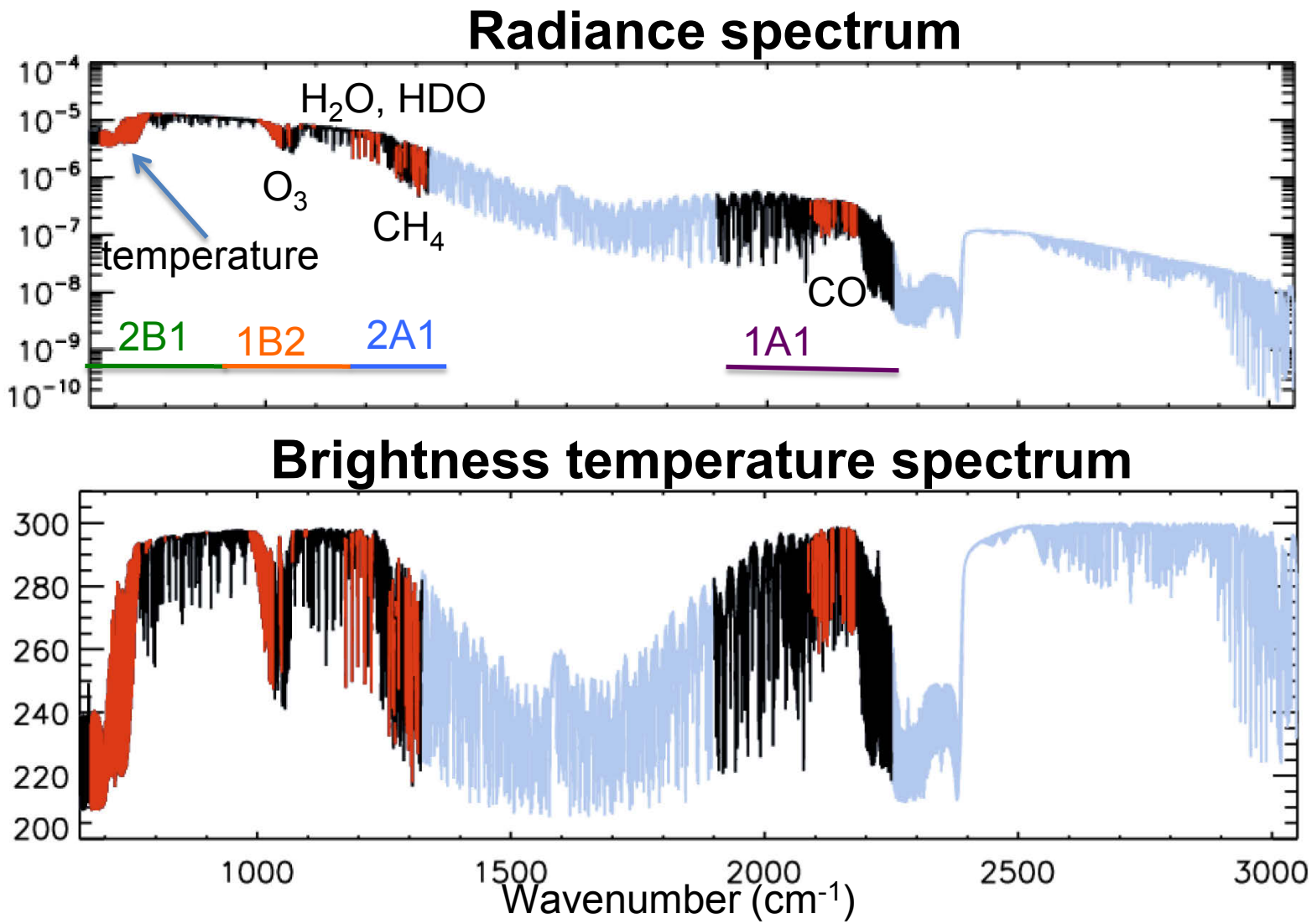
Tropospheric CH_4 measurements

- **Limb** (ACE, MIPAS)
  - Measurements down to 5-6 km
- **Thermal infrared, nadir** (**TES**, AIRS, IASI, GOSAT)
  - Good high latitude coverage
  - Limited near-surface sensitivity
- **Shortwave infrared, nadir** (SCIAMACHY, GOSAT)
  - Sensitivity over entire column

Spectral features of CH_4

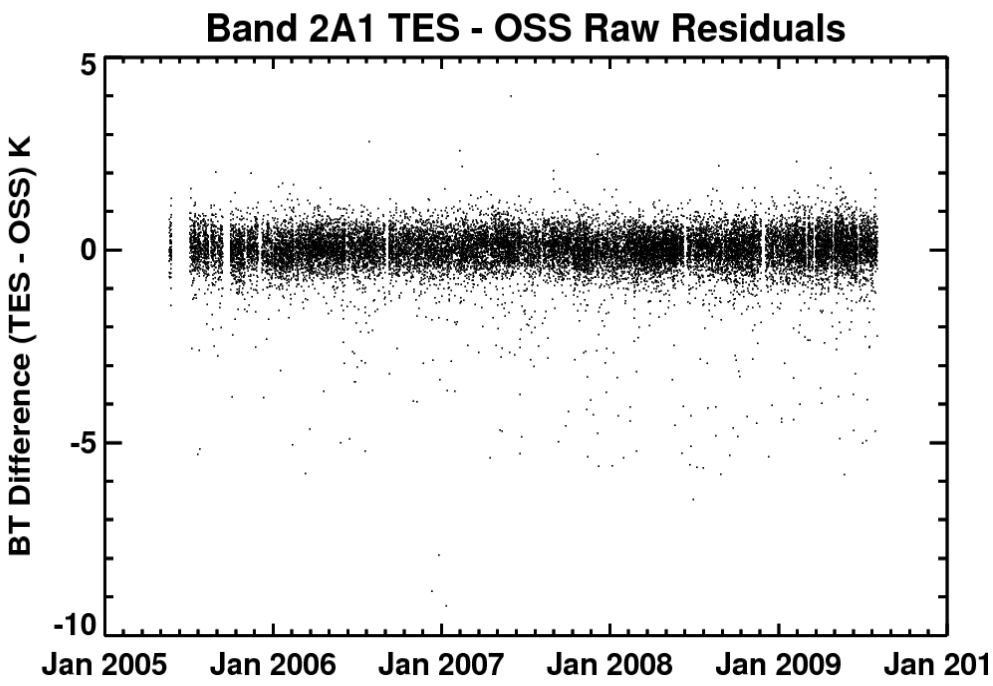


Aura TES: spectral coverage



Stability of TES radiances

- Connor et al. [2011] AMT
- Compare TES **measured** and **calculated** radiances
  - "window regions"
  - Clear-sky
  - Ocean
  - Tropical regions
  - RTGSST product
    - Well constrained by buoy observations



Trend analysis shows no discernable trend from 2005 to 2009

Satellite measurements in the thermal IR

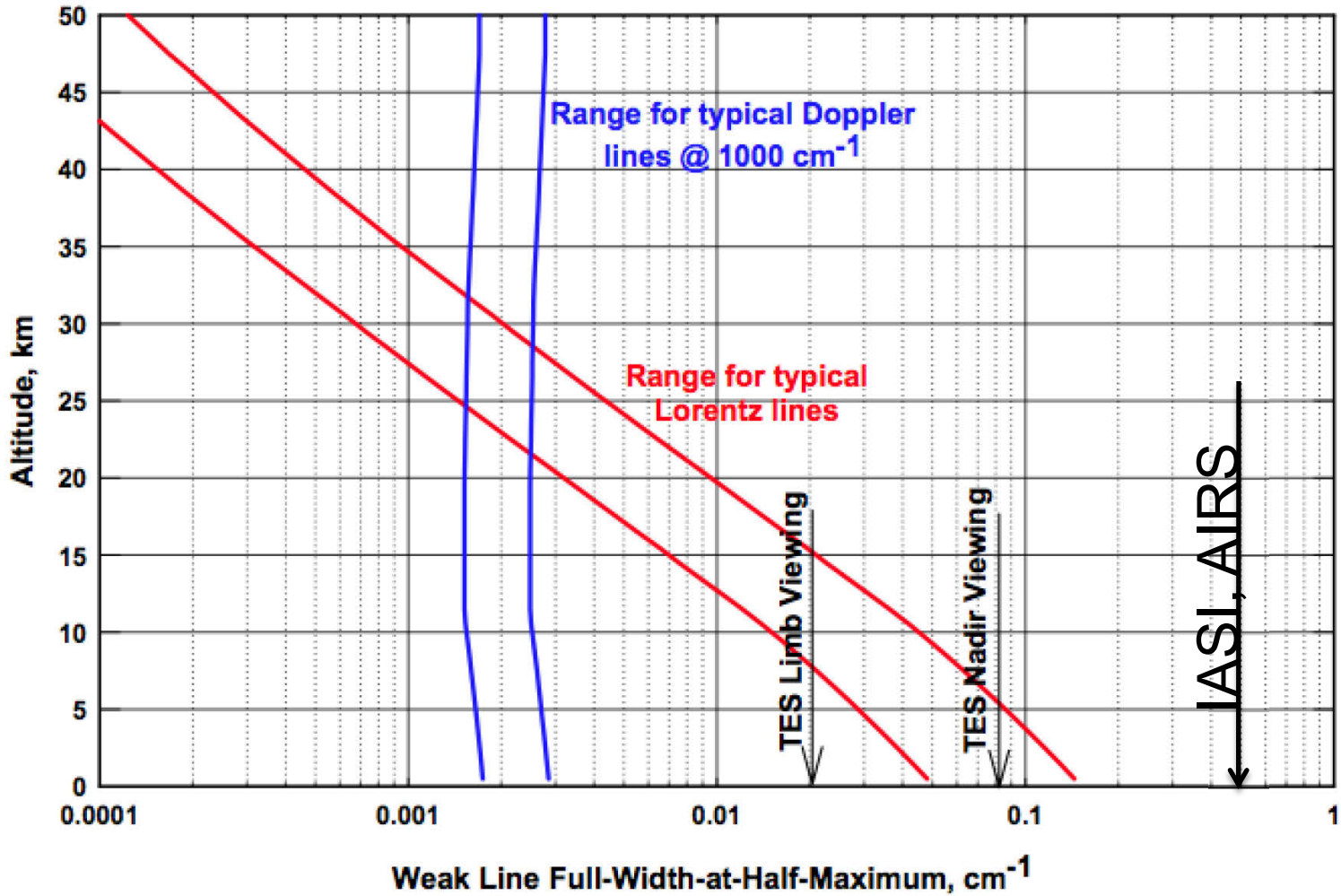
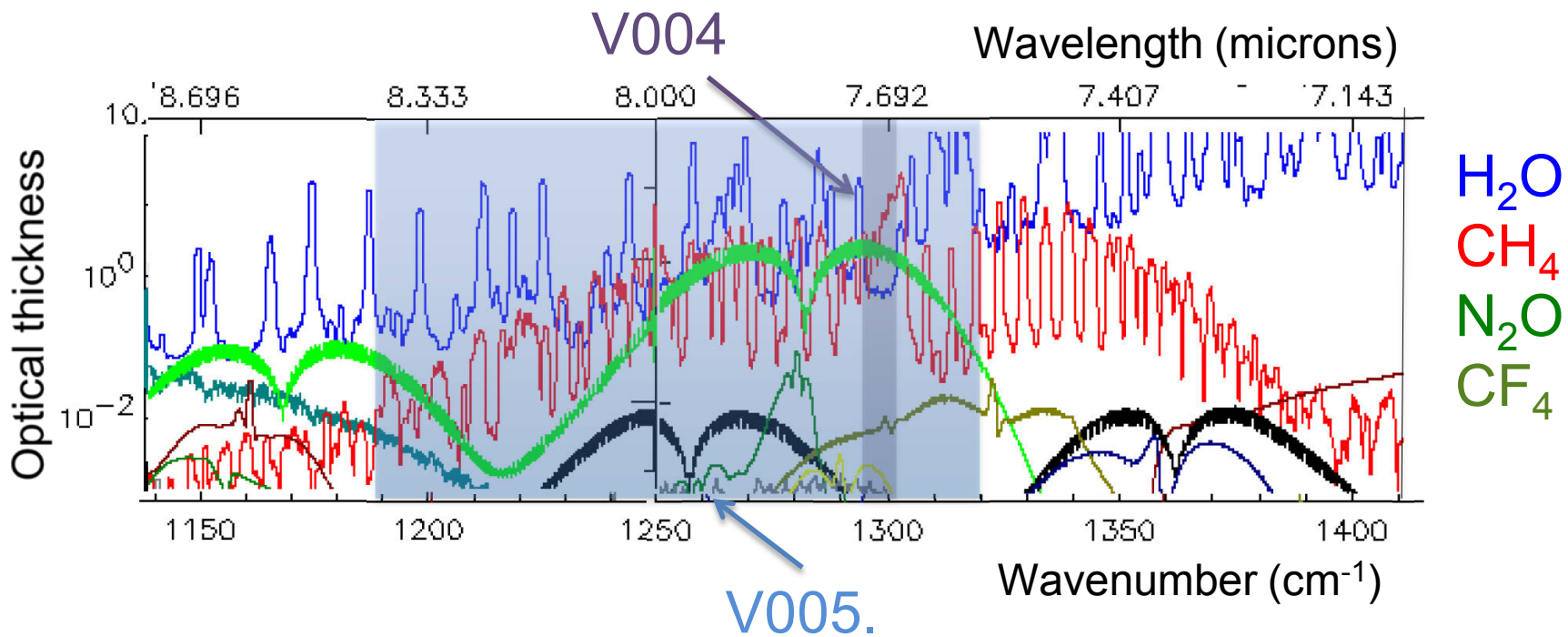


Figure: Reinhard Beer

TES CH_4 retrieval versions

https://www.atm.ox.ac.uk/group/mipas/atlas.html

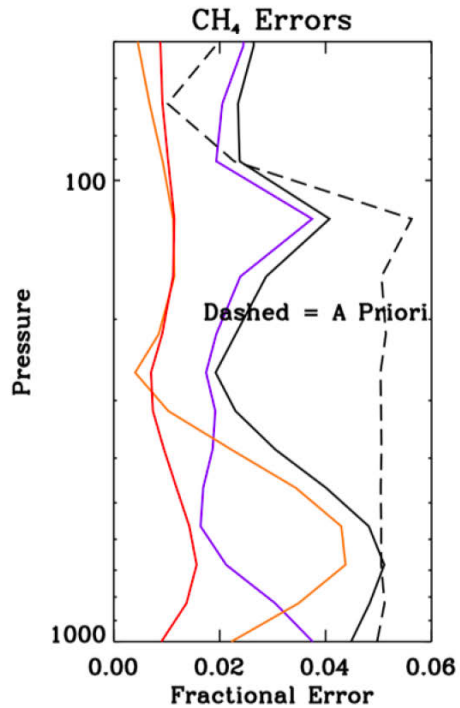


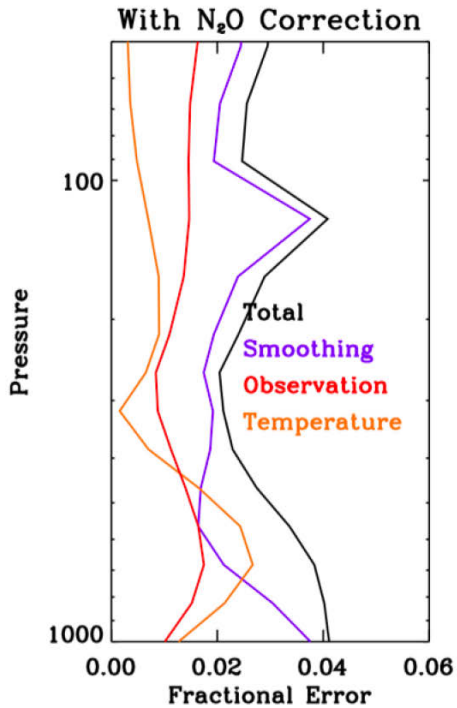
Primary interferents: H_2O, HDO, N_2O

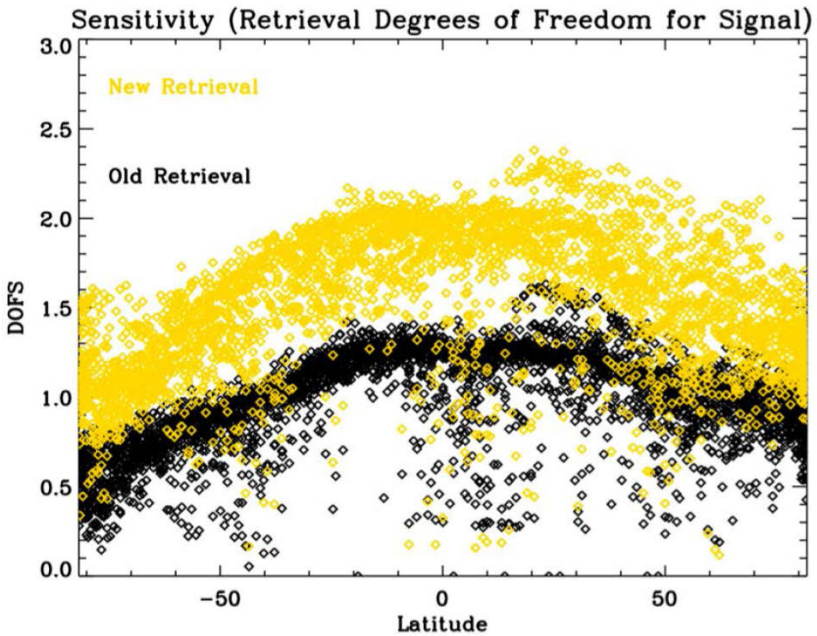
For V005, retrieve these jointly with CH_4

V005 CH_4

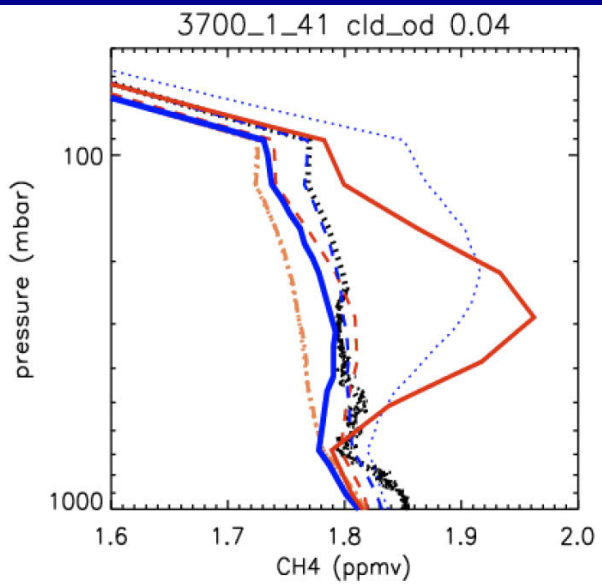
- V005 algorithm described in **Worden et al. [2012], AMT**
  - Sensitivity between 800 and 100 hPa
  - Random error: ~1.5 % for free tropospheric average



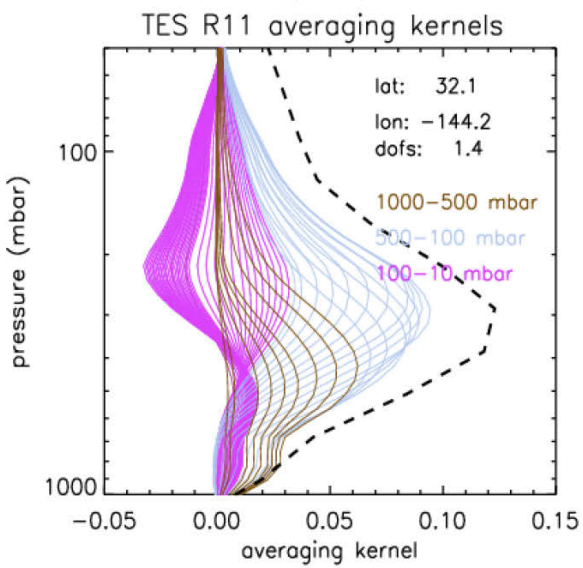


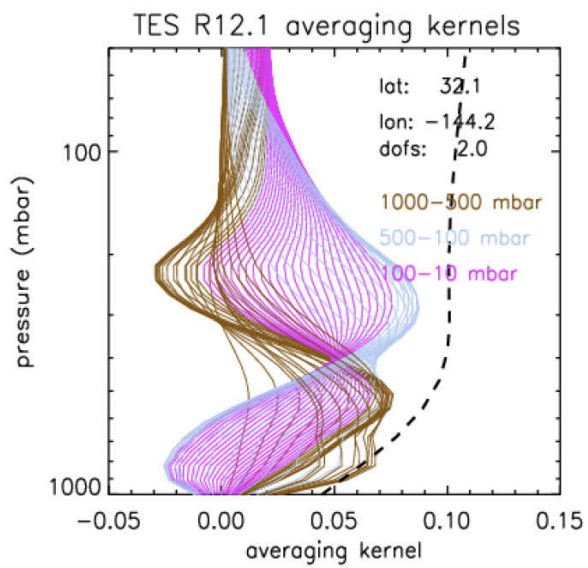


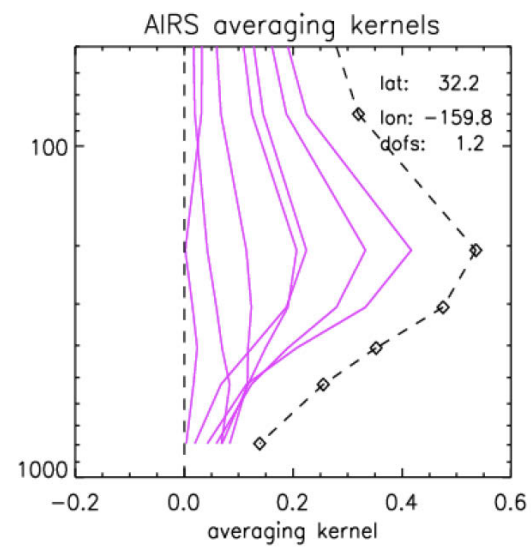
INTEX-B: "cherry-picked" example



DACOM aircraft profile
TES a priori
TES V004
DACOM with R11 AK & a priori
TES V005 (before N_2O correction)
TES V005 (after N_2O correction)
DACOM with V005 AK & a priori



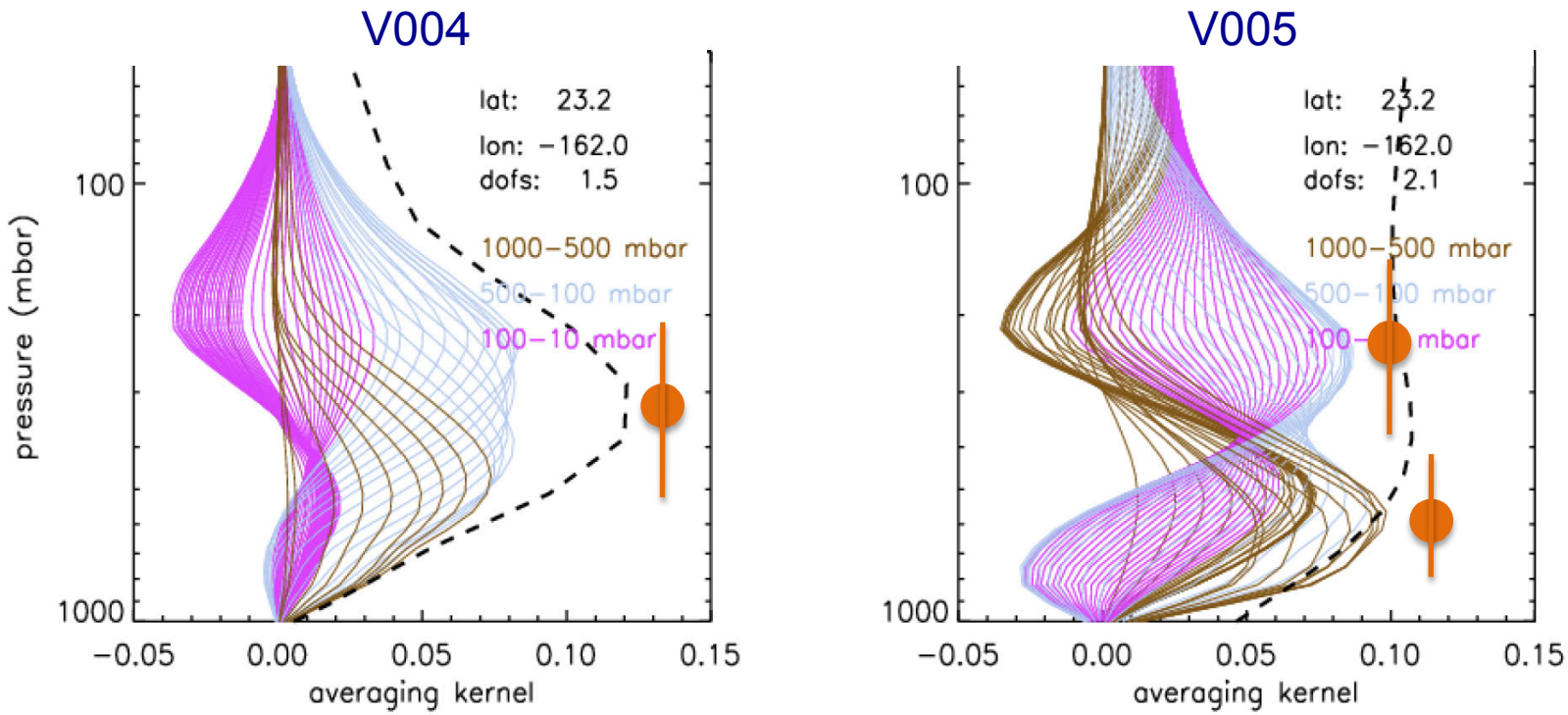




Dashed line in AK plots is the sum of the rows of the AK * 0.1

V004 vs V005 averaging kernels

Dashed line in AK plots is the sum of the rows of the AK * 0.1

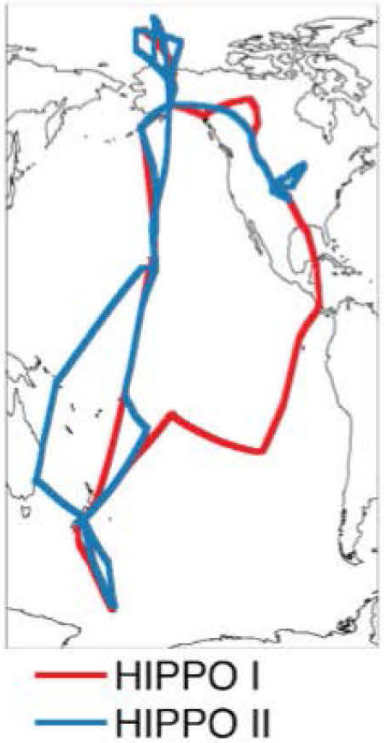


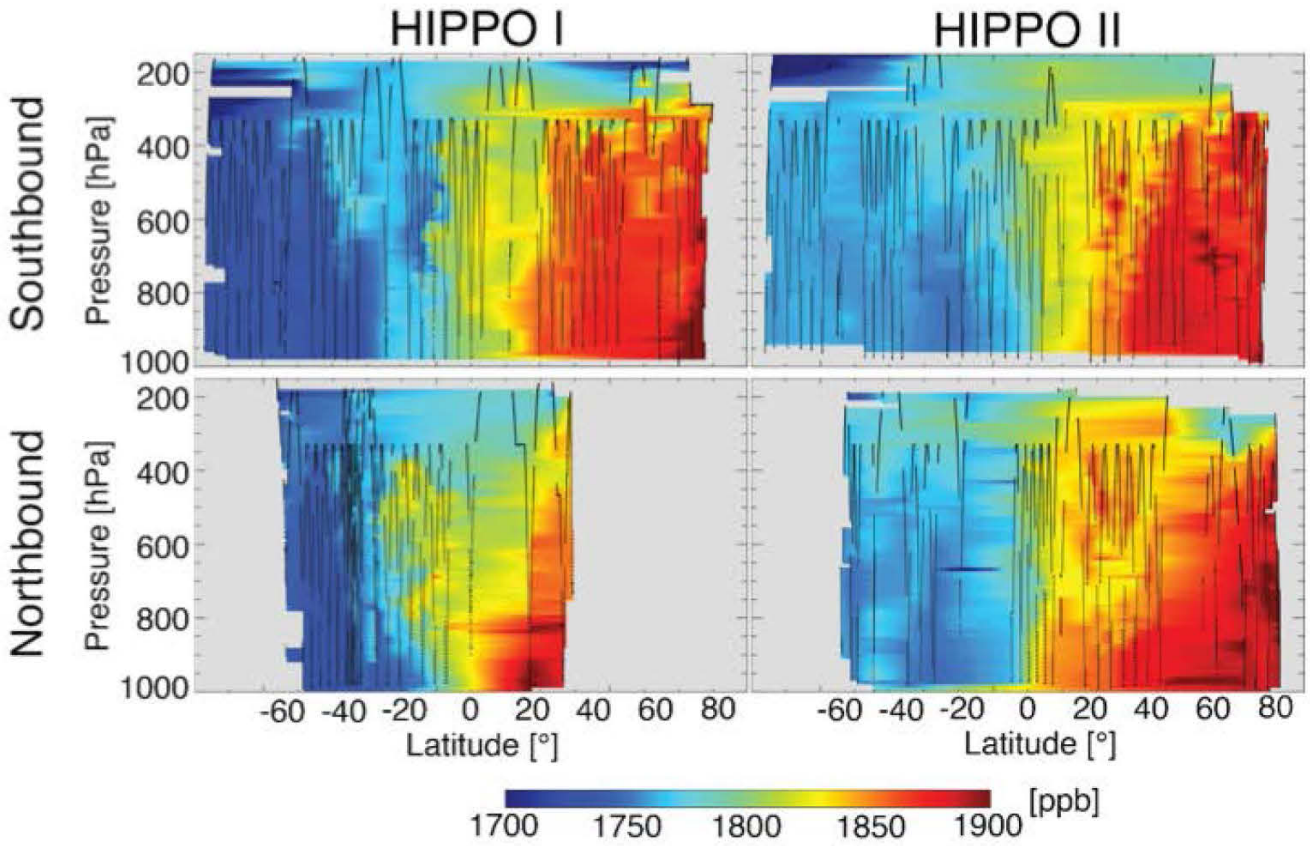
V005 provides improved sensitivity to the lower troposphere

Results presented in terms of "Representative Tropospheric Volume Mixing Ratio" **(RTVMR)** (Payne et al. [2009] JGR)

Validation against HIPPO

HIPPO: HIAPER Pole to Pole Observation program

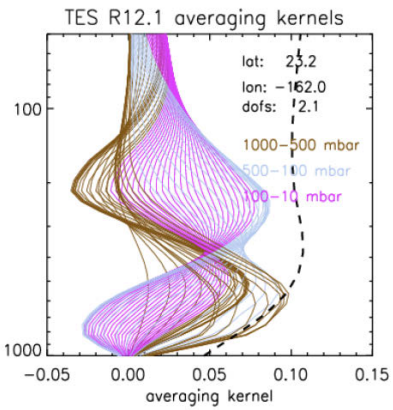


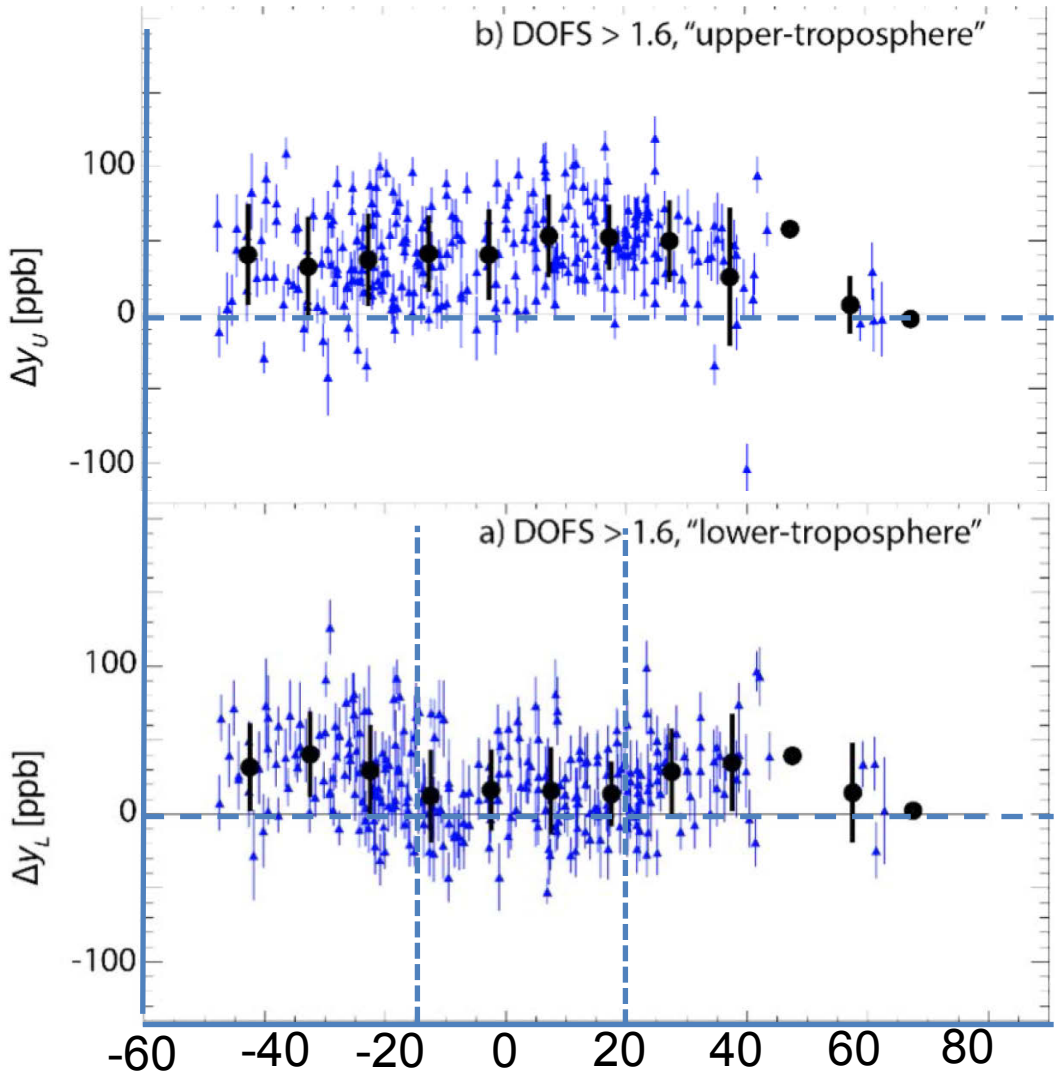


Figures from Wecht et al. [2012], ACP

Validation against HIPPO

Wecht et al. [2012]





Bias: 2.4 %
s.d.: 1.7 %

Bias: 0.9-1.6 %
s.d.: 1.6-1.7 %

Consistent with random error estimate

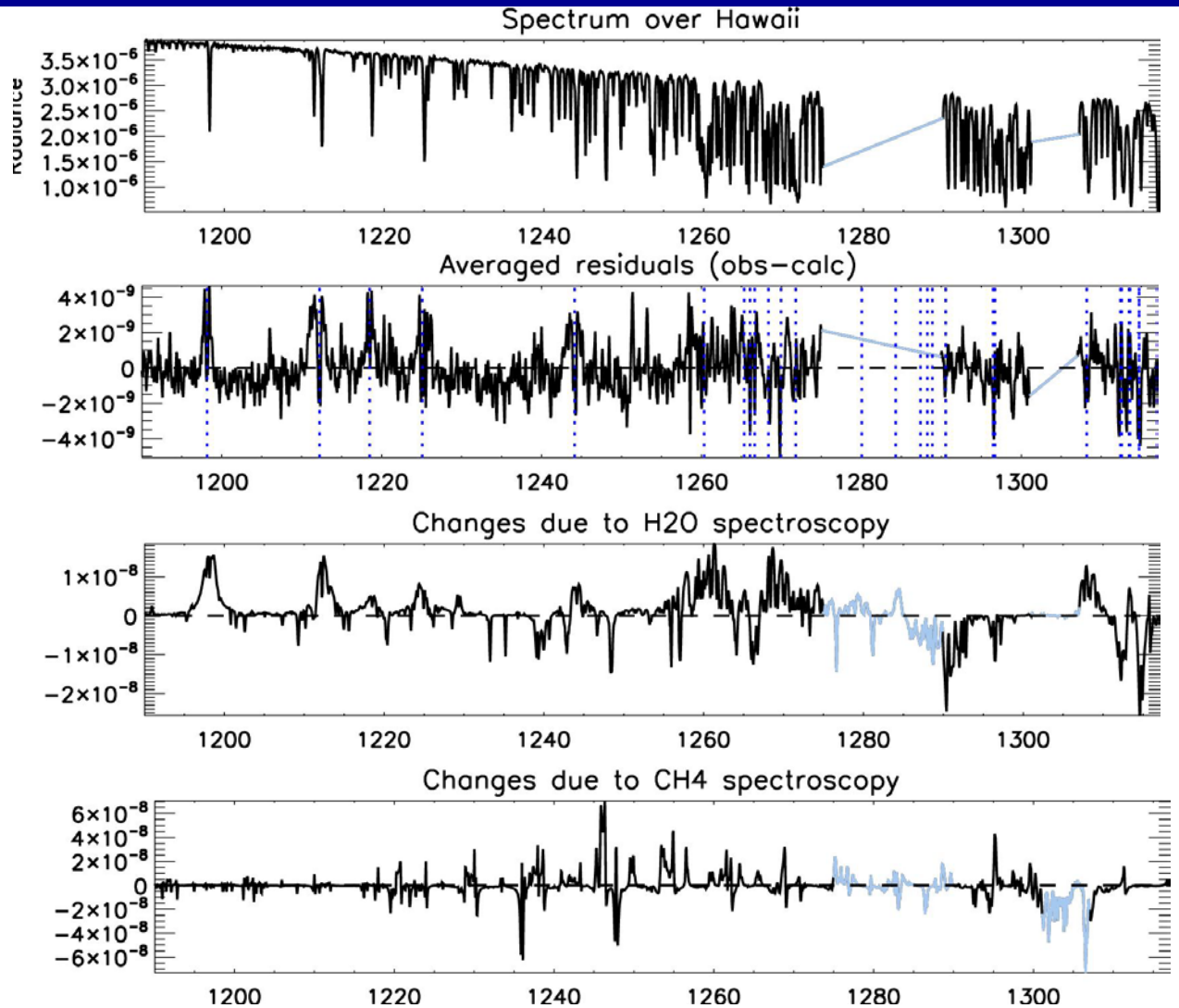
Sources of systematic errors

- **Forward model**
  - **Temperature**
  - Trace gas interferents (H_2O, HDO, N_2O)
  - **Clouds**
  - **Spectroscopy**
    - Line parameters, lineshape, continuum
- **Instrument calibration**

Forward model: Spectroscopy

- **Line parameter database**
  - **maintained by Atmospheric and Environmental Research (AER)**
    - **http://rtweb.aer.com**
    - largely based on HITRAN 2004
    - CO_2: P, Q and R branch line mixing from Niro et al. (2005)
- **Possible updates:**
  - Validated against independent radiometric measurements
  - Under consideration for inclusion in TES database
    - **CO_2** line positions and intensities from MIPAS database
    - **CO_2** widths and line mixing from Lamouroux et al. (2010)
    - **H_2O** widths, tdep, pressure shifts from HITRAN 08
    - **H_2O** line positions, intensities from Coudert et al. (2008)
    - **CH_4** line parameters from HITRAN 2008
    - **CH_4** line mixing from J-M. Hartmann
      - » Tran et al., (2006) updated for H08 line parameters
      - » **See Karen Cady-Pereira's poster**

Impact of spectroscopy changes



Vertical blue lines show positions of strong H_2O lines

A number of residual features are associated with strong H_2O lines.

CH_4 line parameter updates and line mixing also introduce significant changes.

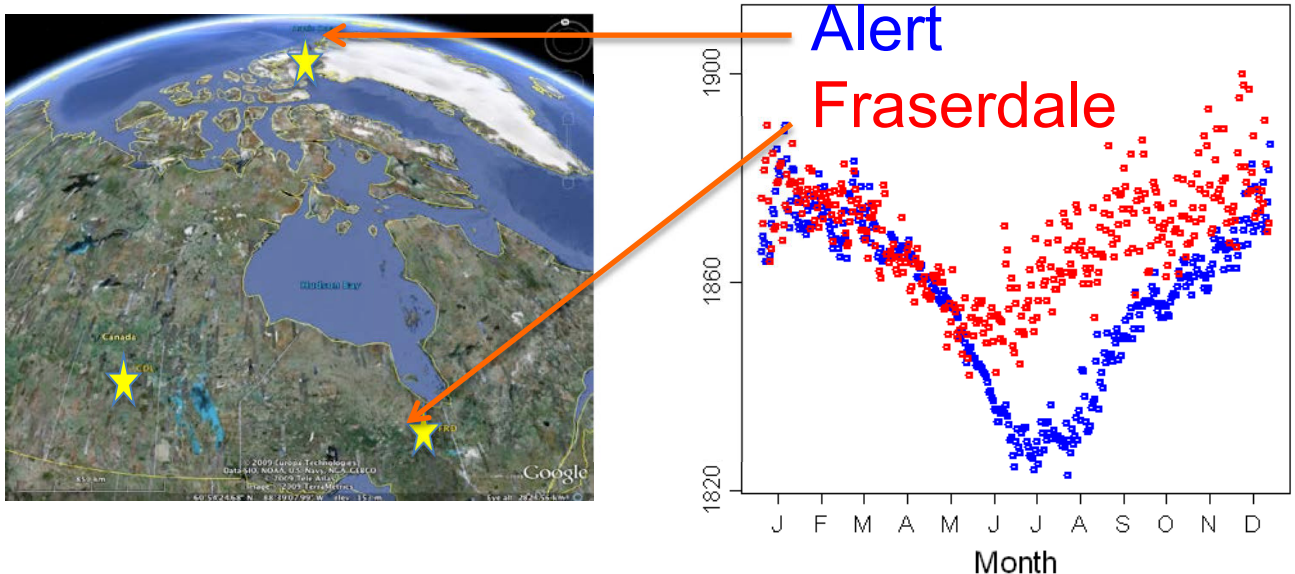
Next step: Evaluate impact of spectroscopy updates on retrievals

Results

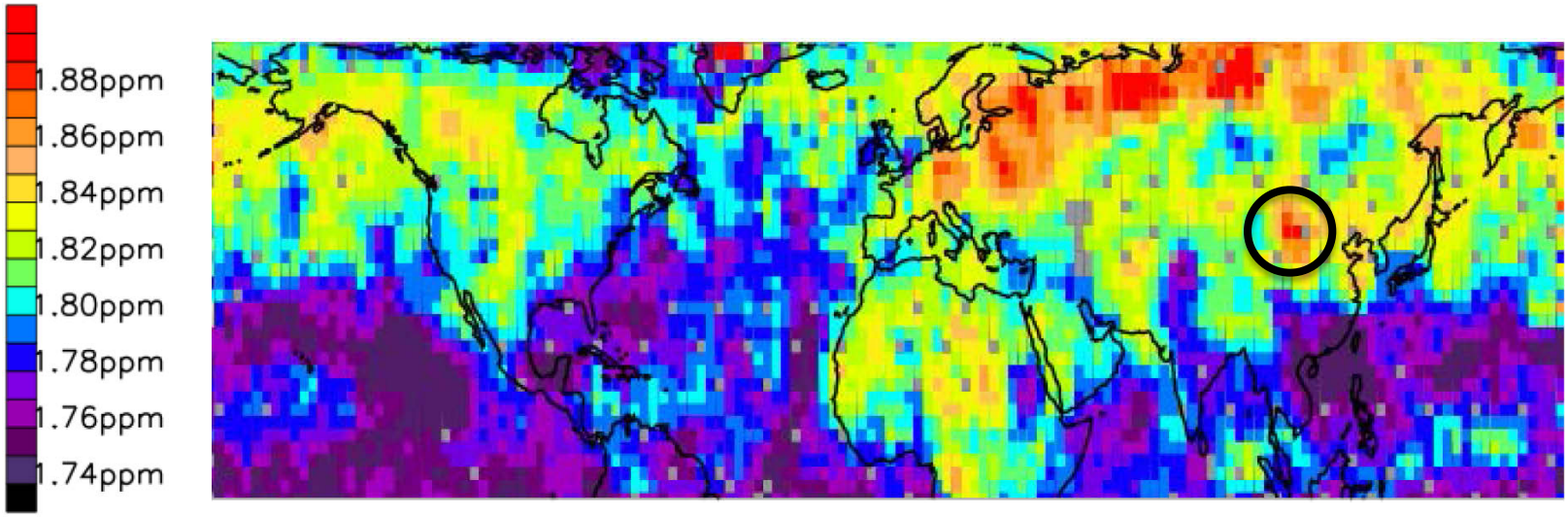
- Factors influencing TES CH_4 fields:
  - **Transport**
    - Advection
    - Mixing
    - Convection
  - **Emissions**
  - **Variations in retrieval sensitivity**
  - **Chemistry**

Sources, sinks and seasonal cycles

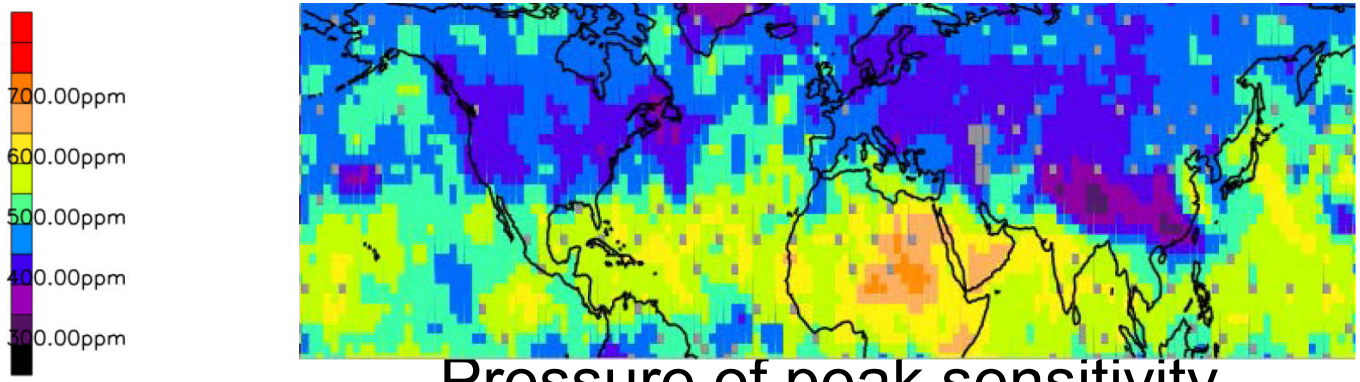
- Background levels determined by OH chemistry
- **Various sources: different seasonal variation, spatial distribution**
- **Example**: Influence of **wetland emissions** at surface
  - Environment Canada surface monitoring sites
    - Alert: Background site. Cycle reflects **OH chemistry**.
    - Fraserdale: Strongly influenced by wetland emissions.



TES V5 NH monthly means: Jan '06



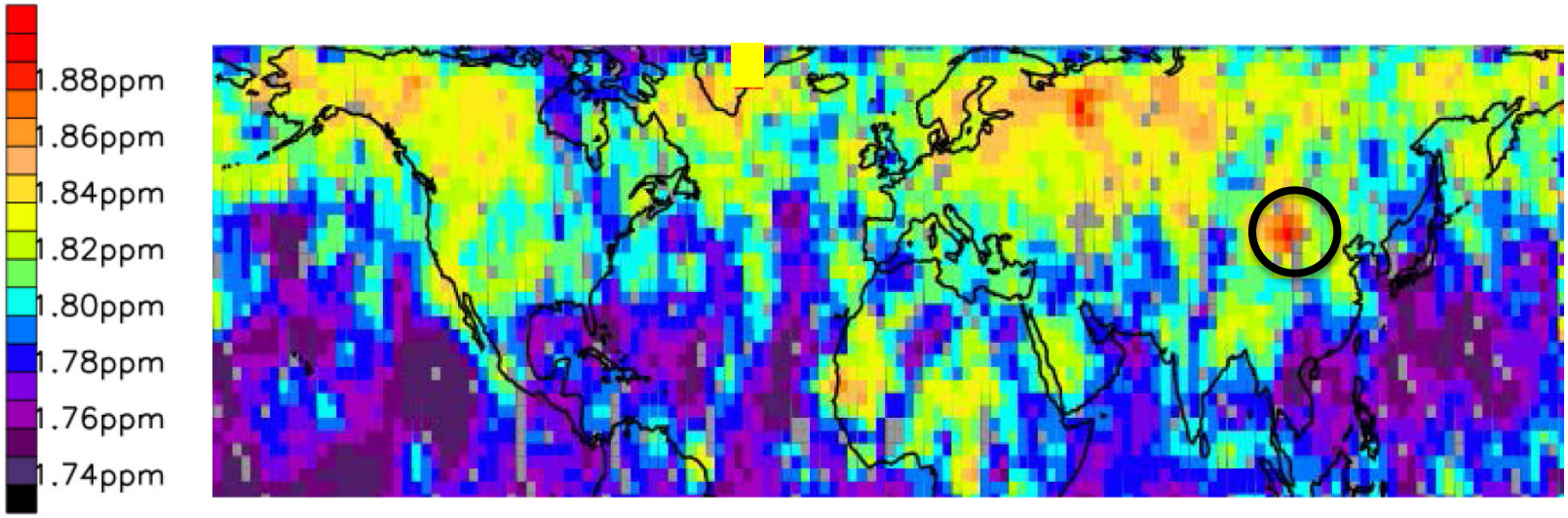
RTVMR



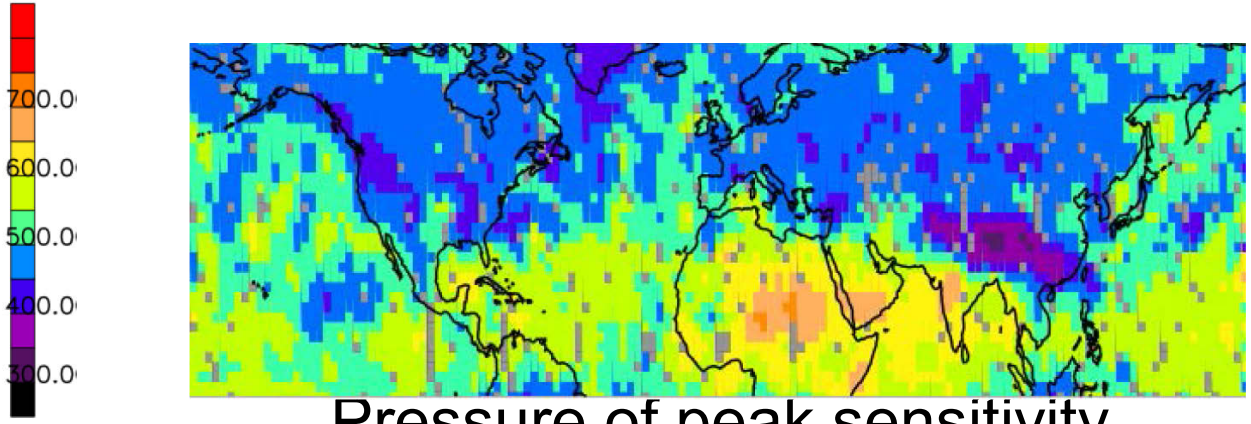
Pressure of peak sensitivity

Average pressure depends on cloud-screening thresholds

TES V5 NH monthly means: Feb '06

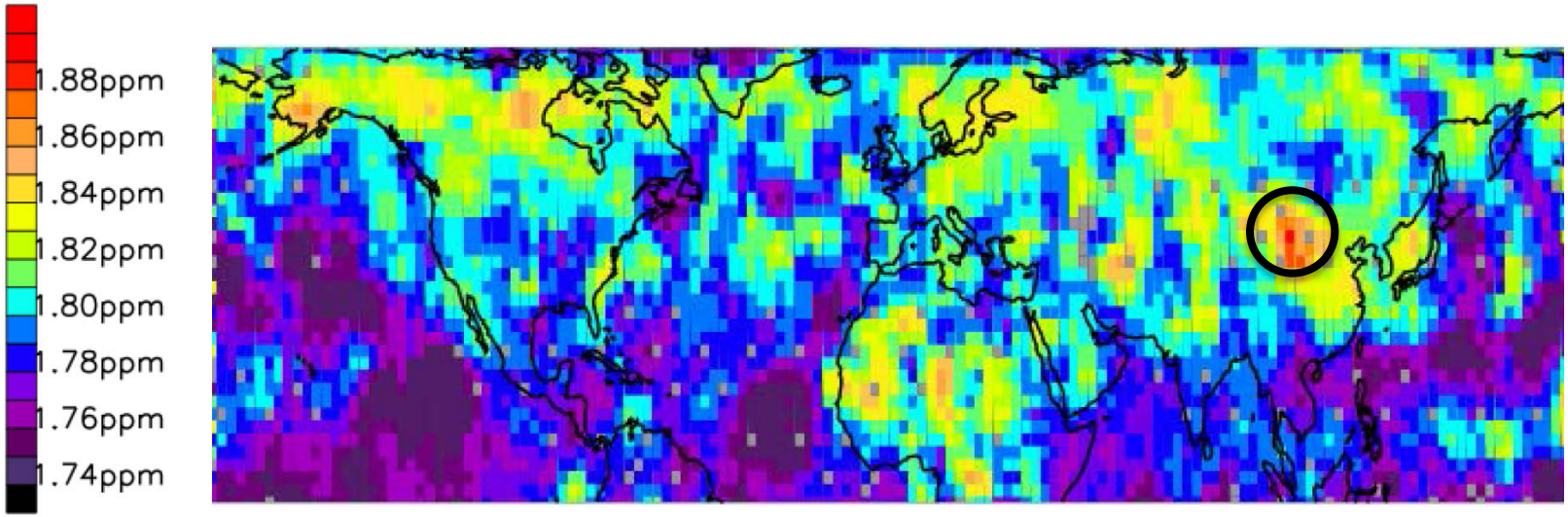


RTVMR

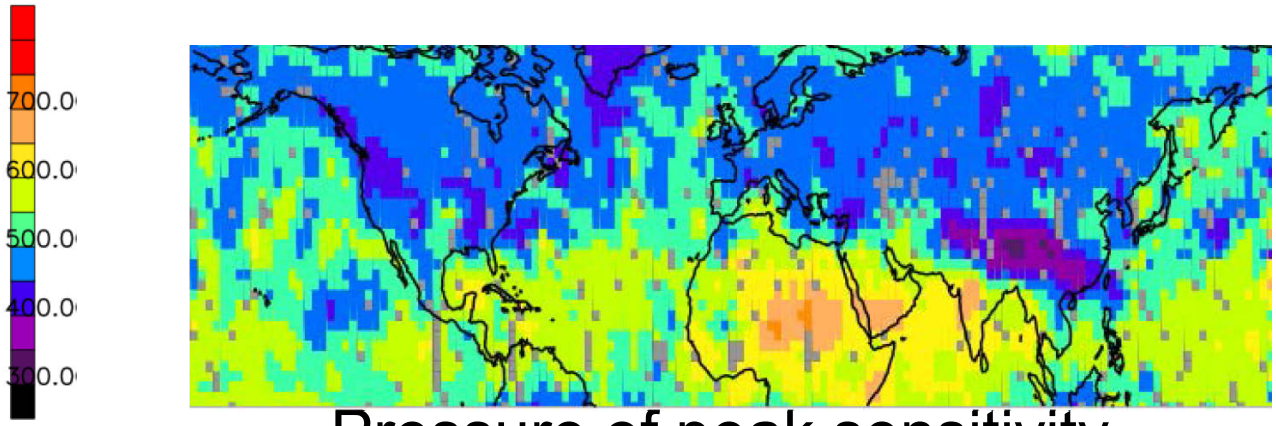


Pressure of peak sensitivity

TES V5 NH monthly means: Mar '06

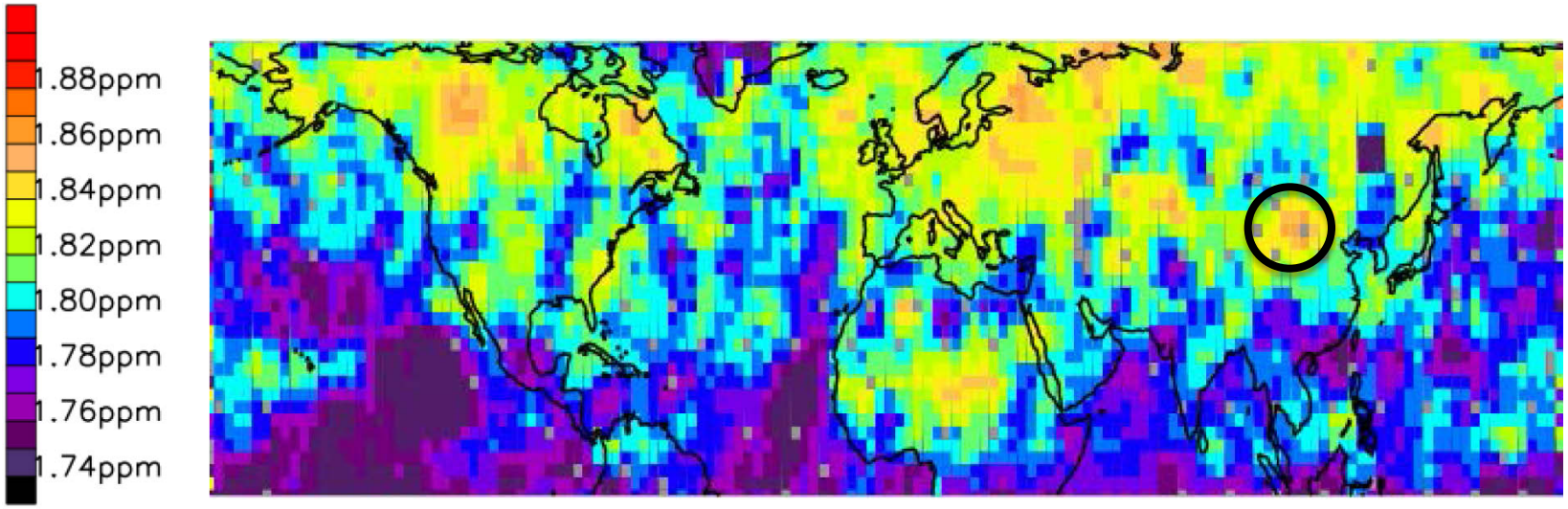


RTVMR

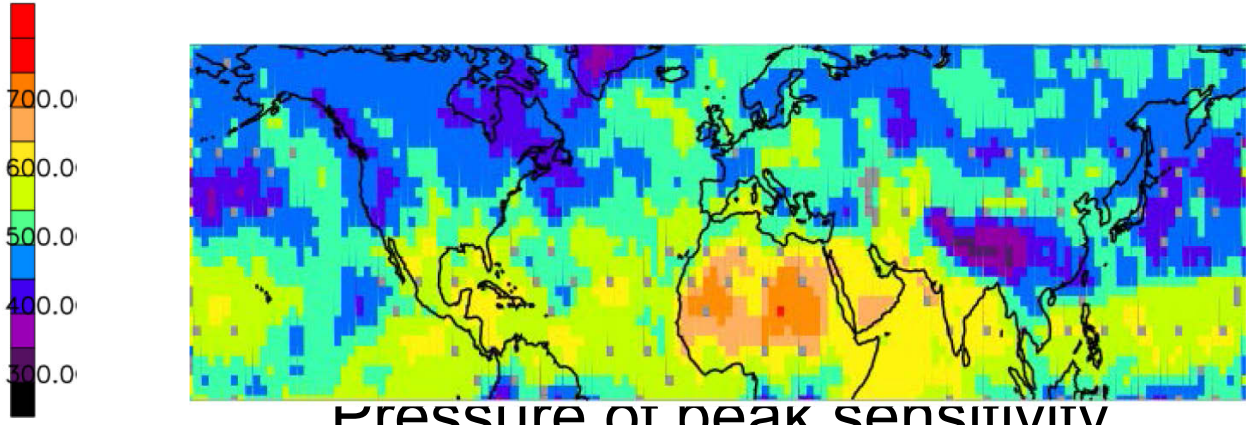


Pressure of peak sensitivity

TES V5 NH monthly means: Apr '06

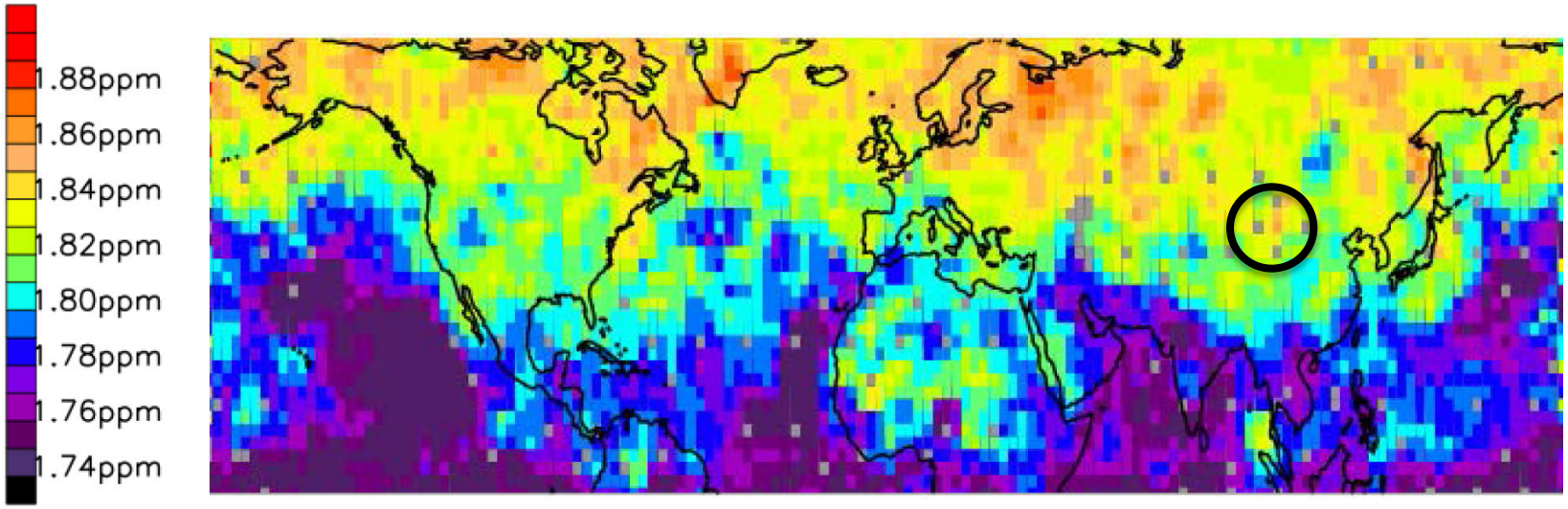


RTVMR

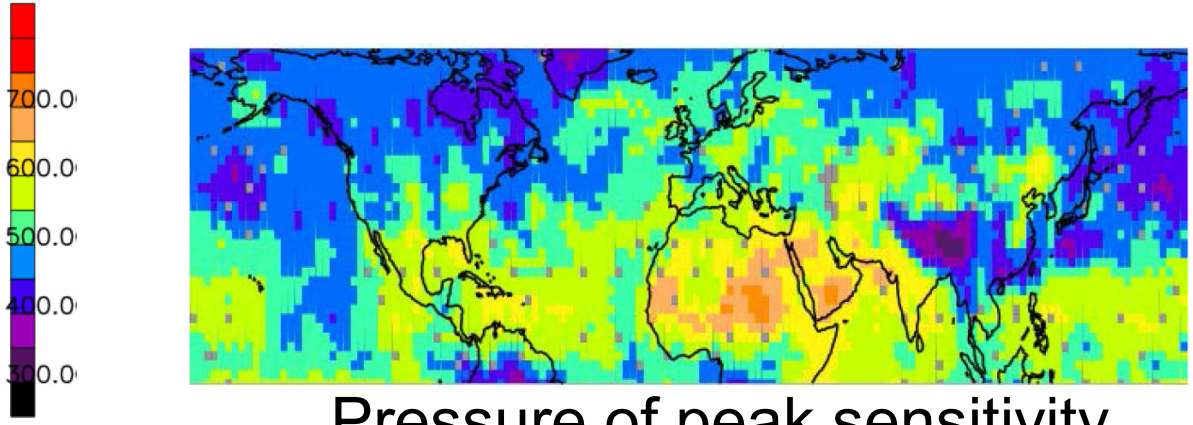


Pressure of peak sensitivity

TES V5 NH monthly means: May '06

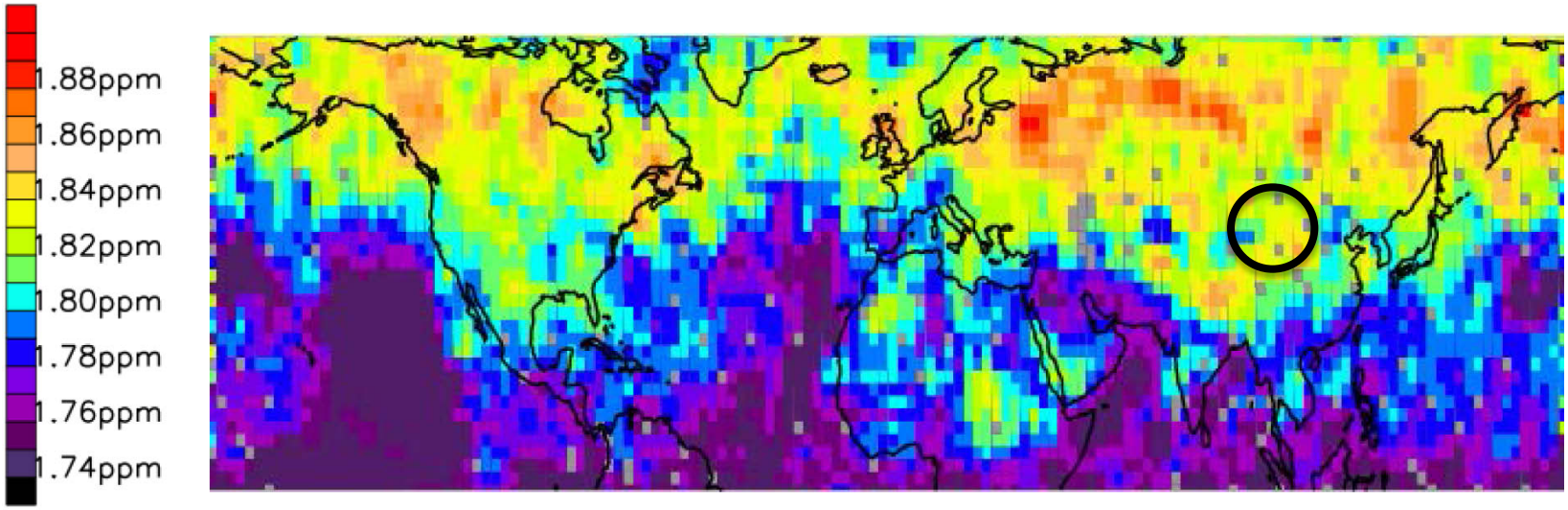


RTVMR

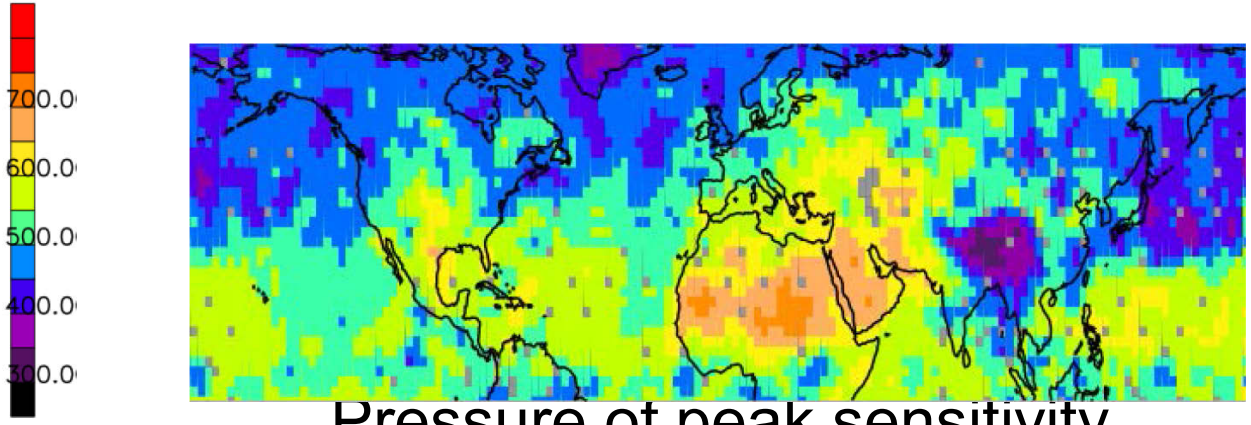


Pressure of peak sensitivity

TES V5 NH monthly means: June '06

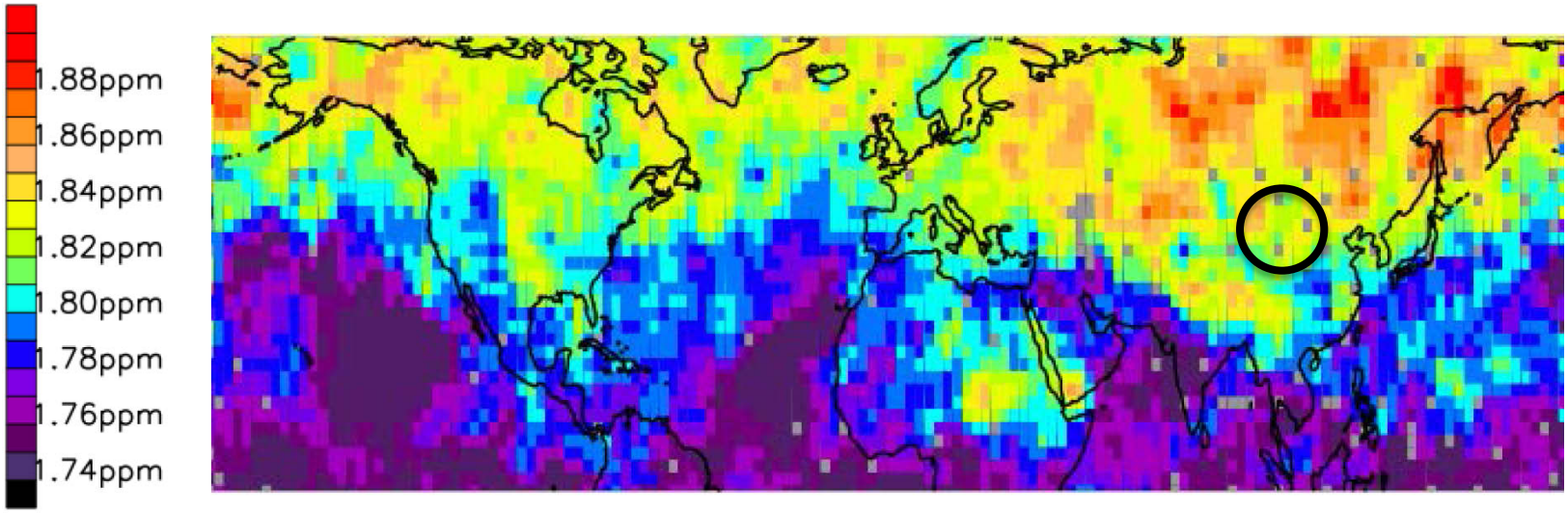


RTVMR

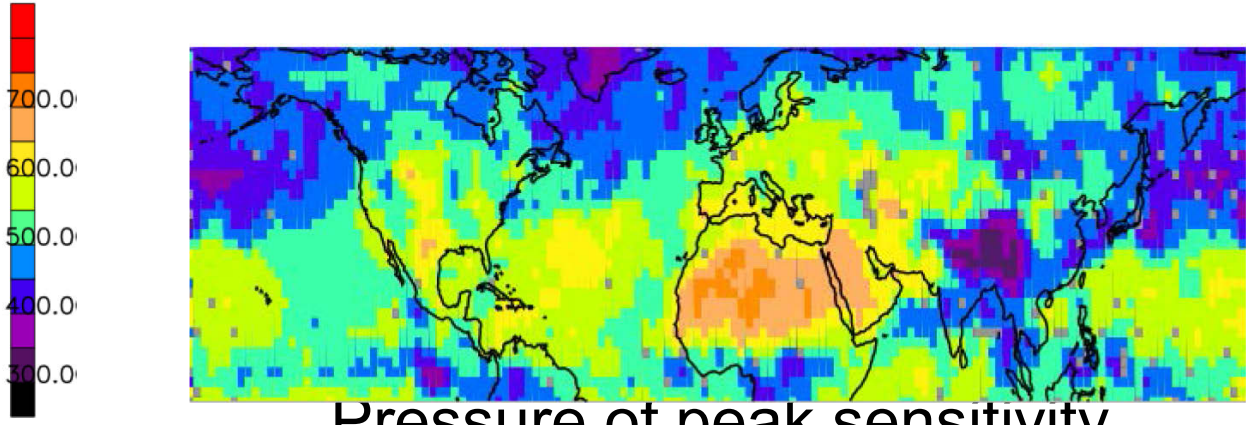


Pressure of peak sensitivity

TES V5 NH monthly means: July '06

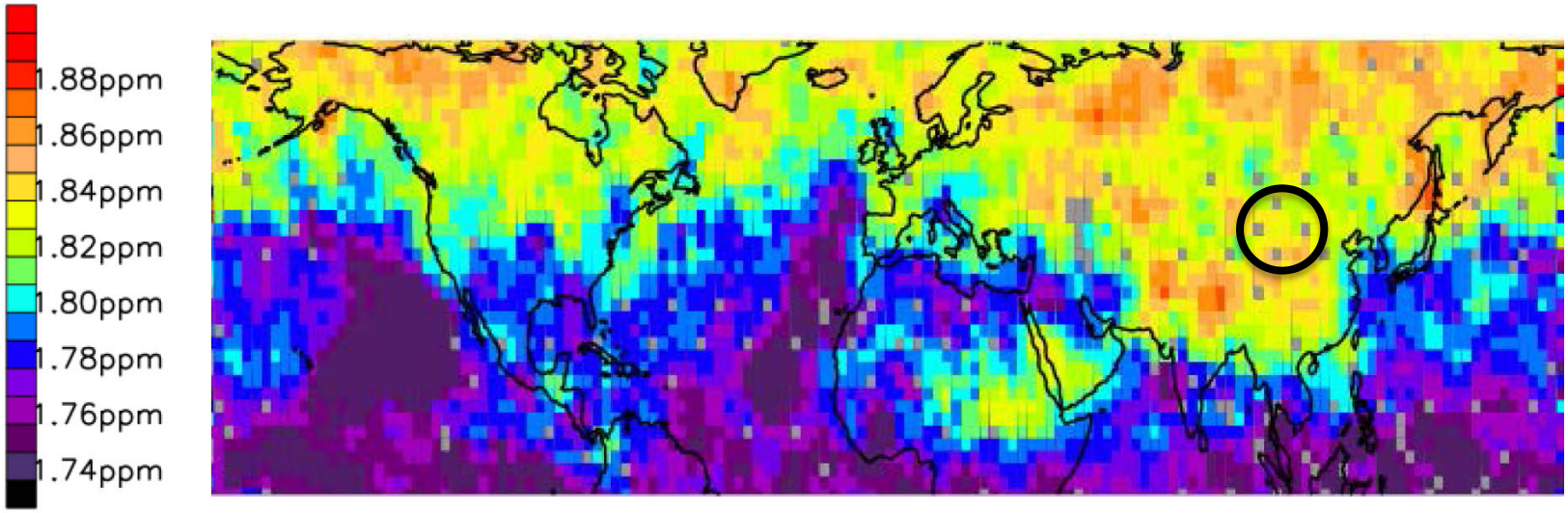


RTVMR

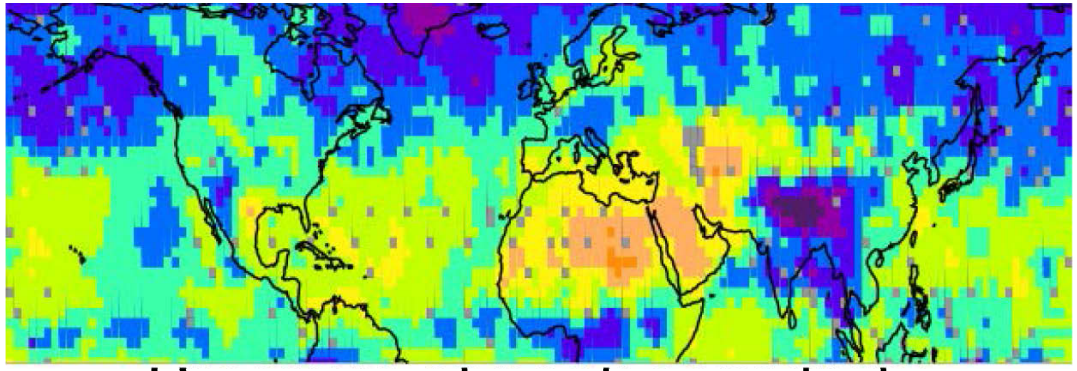


Pressure of peak sensitivity

TES V5 NH monthly means: Aug '06

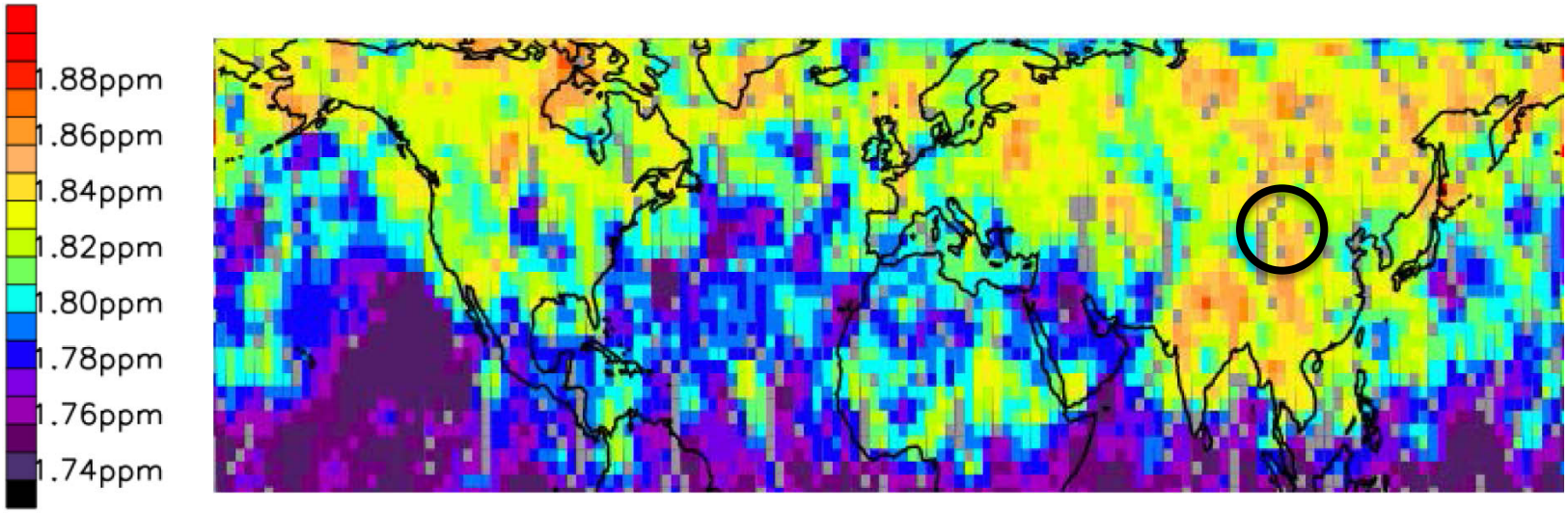


RTVMR

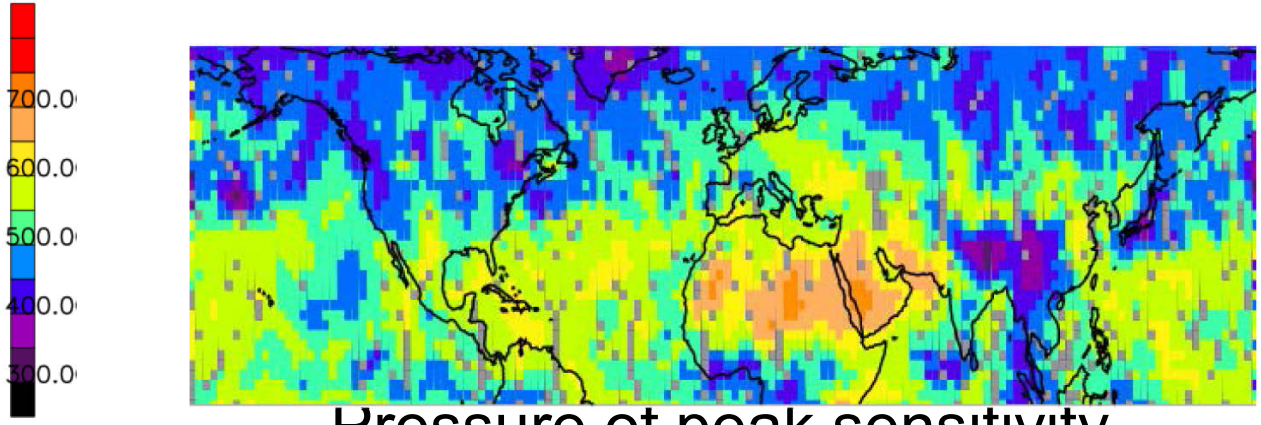


Pressure of peak sensitivity

TES V5 NH monthly means: Sept '06

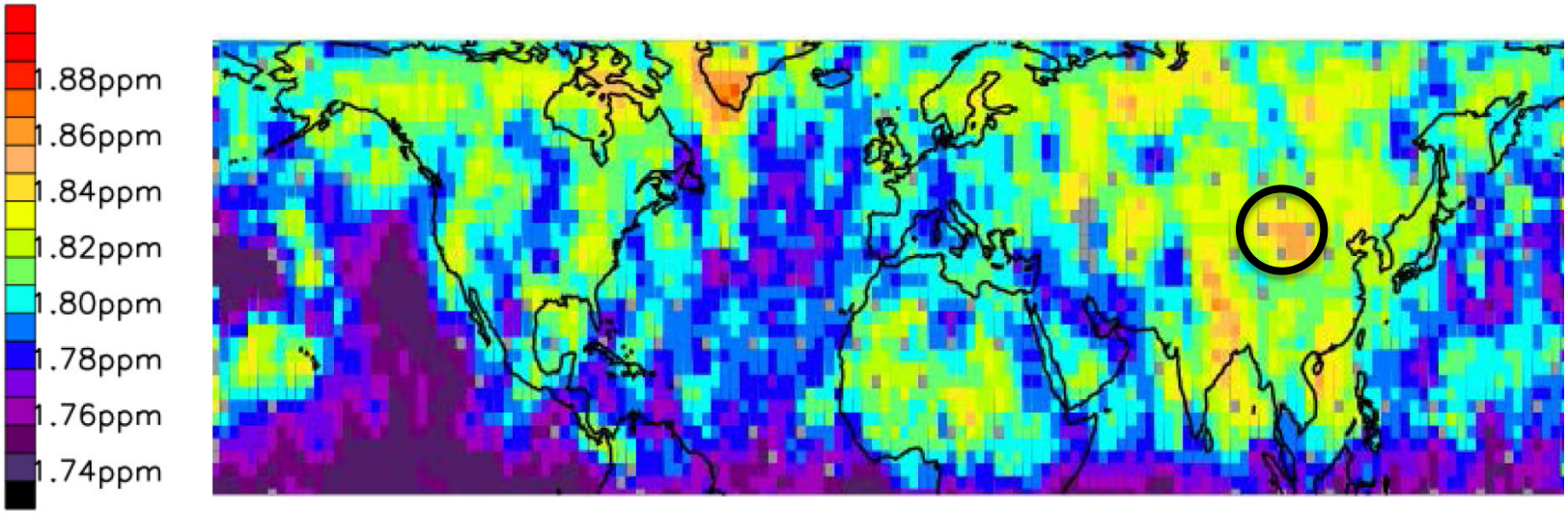


RTVMR

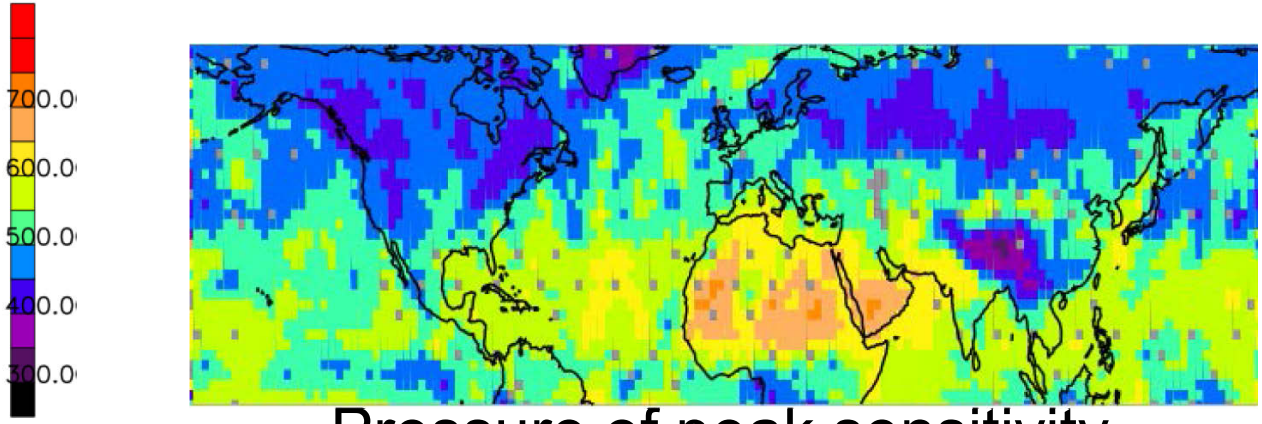


Pressure of peak sensitivity

TES V5 NH monthly means: Oct '06

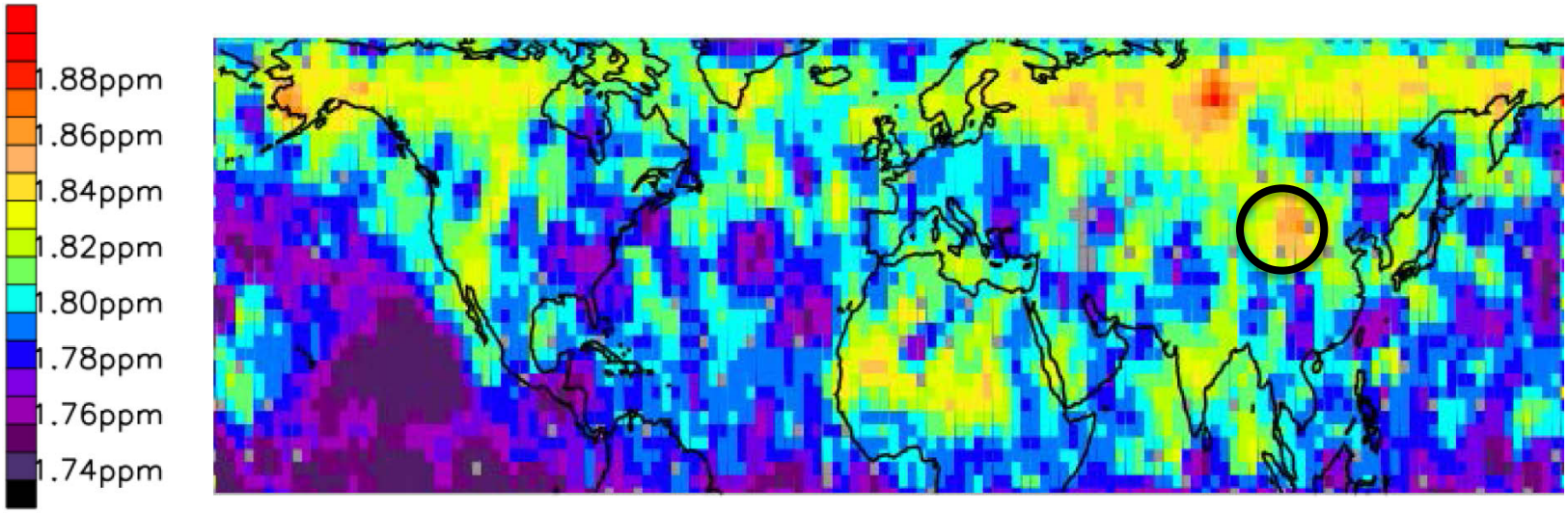


RTVMR

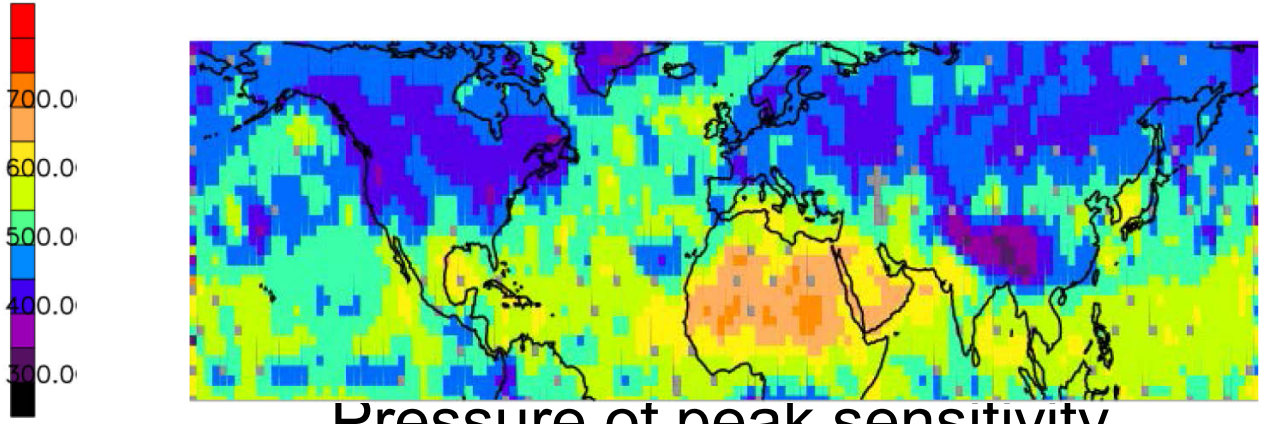


Pressure of peak sensitivity

TES V5 NH monthly means: Nov '06

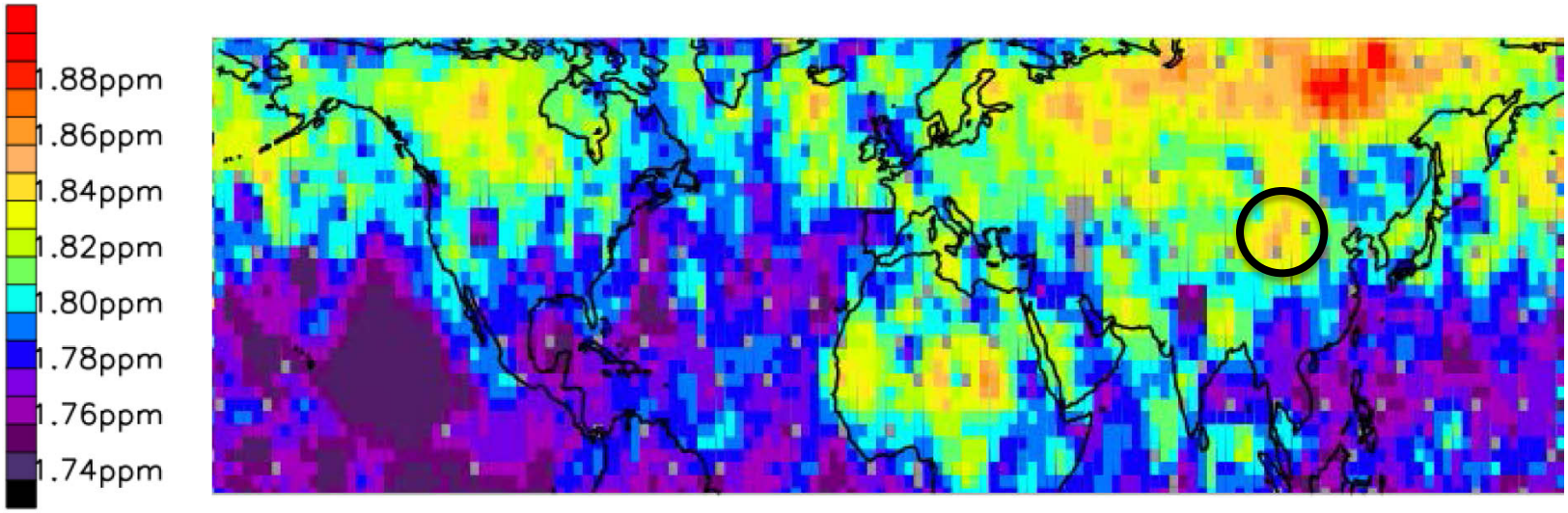


RTVMR

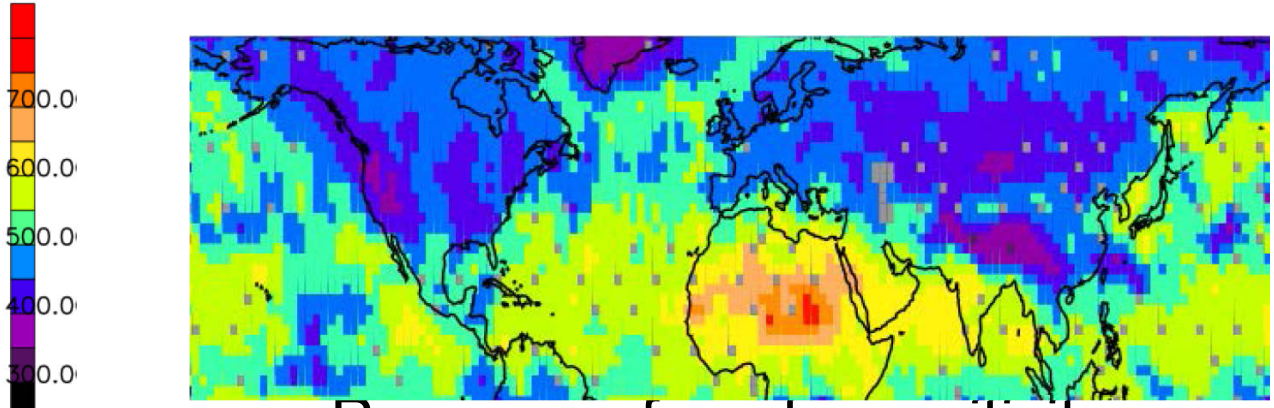


Pressure of peak sensitivity

TES V5 NH monthly means: Dec '06



RTVMR

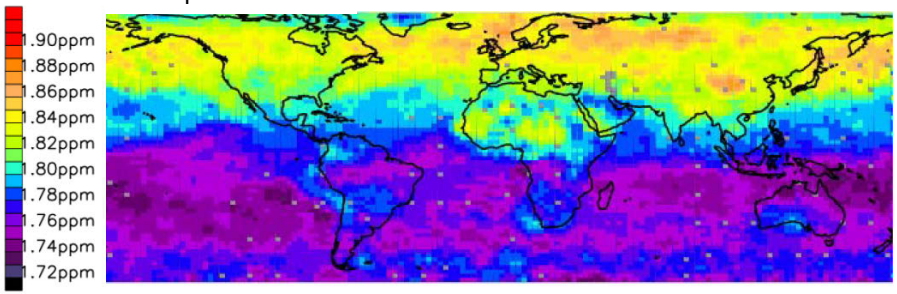


Pressure of peak sensitivity

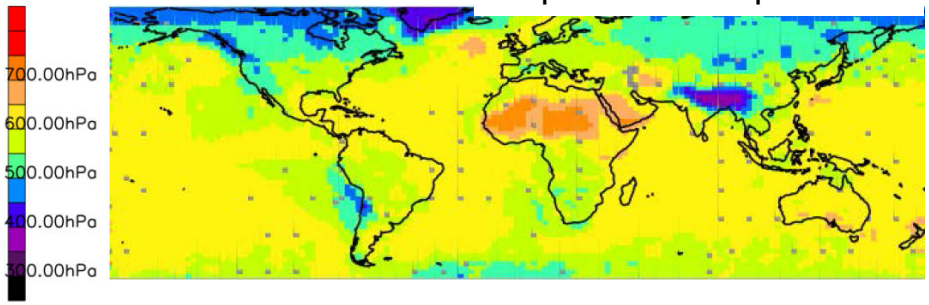
Changes in time

2006 annual mean

CH_4 RTVMR

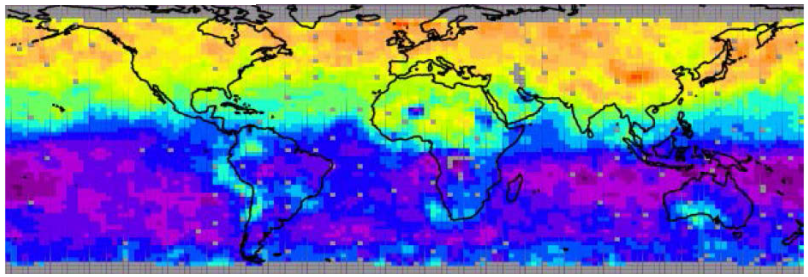


Representative pressure

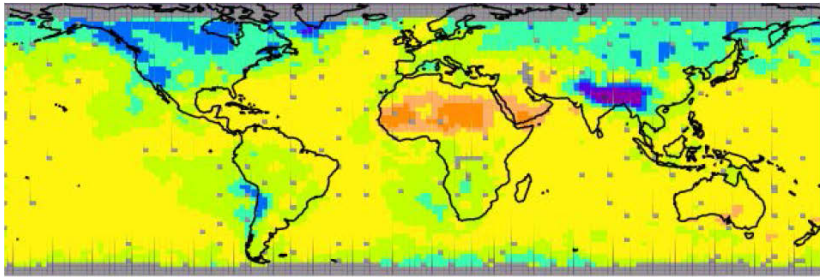


2009 annual mean

CH_4 RTVMR

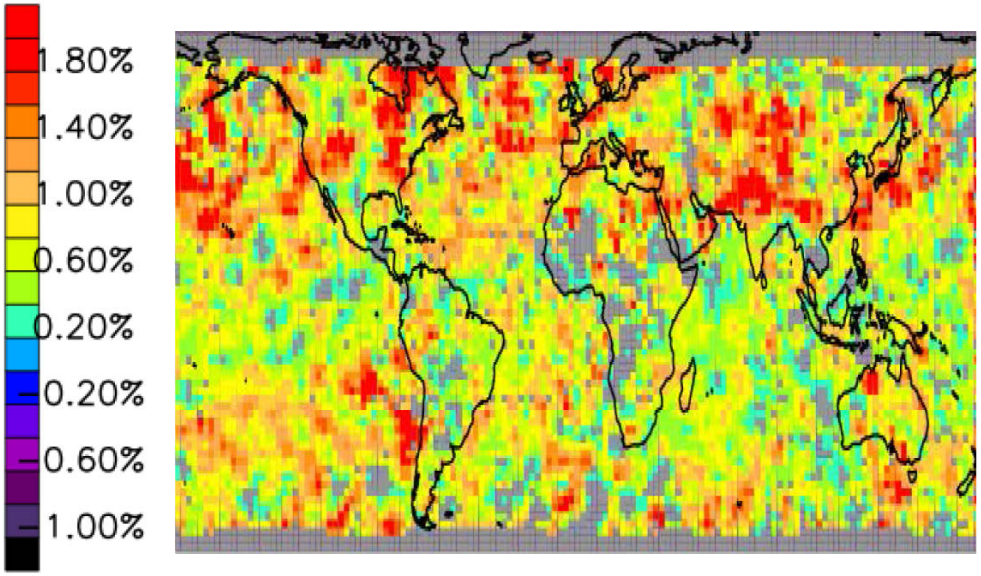


Representative pressure

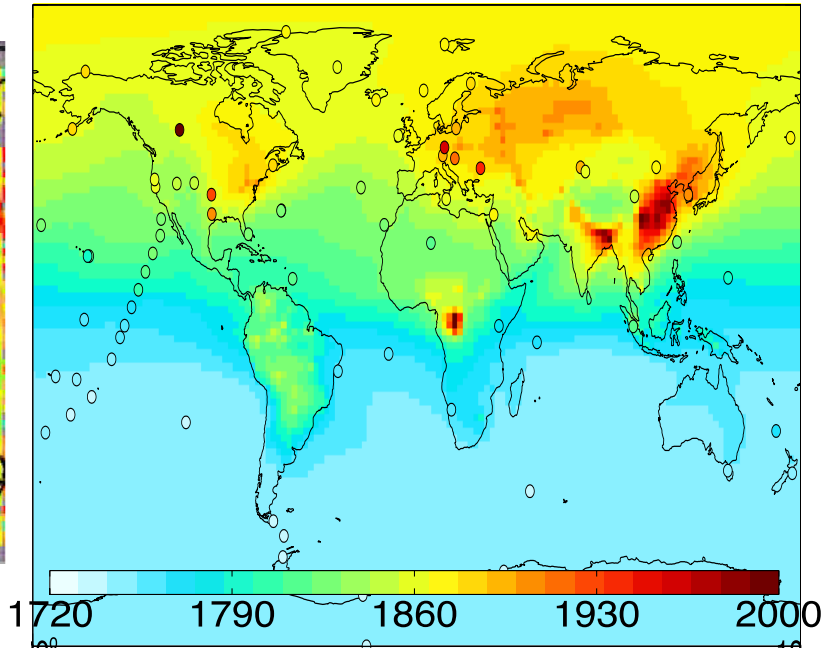


2009-2006 difference

TES 2009-2006 difference



GEOS-Chem 2008 surface CH_4



- Increases of 0.5 to 2 %
- Represents differences in the free troposphere
  - Don't expect to see correlation with surface sources
  - Stronger influence from northern hemisphere???

Summary/conclusions

- TES V5 CH_4 captures **latitudinal gradients**, **regional variability** and **interannual variation** in the free troposphere
- V5 joint retrievals offer improved sensitivity to lower troposphere
- **Time series extends from 2004 to present**
  - V5 reprocessing in progress
- **Upper tropospheric bias**
  - Mitigated by N_2O correction
  - Appears largely spatially uniform, so can be corrected
- How to relate free-tropospheric values to surface emissions?
  - **Combination of TIR data with data from SWIR and models**

Backup slides