Non-linear estimation of carbon dioxide concentrations using the spectral information from the Atmospheric Infrared Sounder (AIRS)

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Talk Outline

- Statement of Objectives
  (CO_2 Retrieval but also T, WV, O_3, Clouds, Surface)
- Methodology
  (Processing Stages)
- Retrieval Equations
- Sensitivity Study
- CO_2 channel selection
- Vertical layering
- Residuals Analysis
- Dynamic Bias Tuning
- CO_2 weighting functions
- Unique method for handling first guess dependence.
- Case Study near Mauna Loa, Hawaii
- Conclusions

Objectives: Study properties of non-linear estimate of carbon dioxide spatial-temporal distribution

Approach & problem statement

- Geophysical parameters at cloud free pixels are retrieved with a non-linear radiative transfer formulation. The radiative transfer model for a cloud free atmosphere includes spectral reflection at the lower boundary. A modified UMBC SARTA code is used for atmospheric spectral transmittance calculations. The physical parameters included in the model are:
- (1) surface emissivity spectrum (13 spectral parameters),
- (2) surface temperature,
- (3) atmospheric temperature vertical profile (35 vertical parameters),
- (4) atmospheric moisture vertical profile (22 vertical parameters),
- (5) atmospheric ozone vertical profile (17 vertical parameters)
- (6) atmospheric CO_2 vertical profile (16 vertical parameters).
- In all 104 variables are estimated with each spatial pixel. A solution is derived from minimization of the spatial integral of a weighted absolute difference (measurement – model).

18 granules of AIRS measurements from Oct 2002 – Jan 2004 over Hawaii were processed and analyzed

Information flow chart

Non-linear spectral filtering using statistics of second spatial differential of AIRS radiative fields

Physical interpretation: *Cloud identification*

Initialization: ECMWF data for atmospheric parameters and surface temperature and pressure

Spatial smoothing at cloud free pixels

Physical interpretation: *Estimation of geophysical parameters of surface-atmosphere system at cloud free pixels*

Initialization: fixed CO2 vertical profile 365 ppmv at each level and ECMWF data for atmospheric parameters and surface temperature and pressure

Radiative transfer model tuning

feedback

Measurement model

$$\left.\begin{aligned}\tilde{\mathrm{J}}(\theta) &= \varepsilon(\theta)B[\mathrm{T_s}]\tau_s^{\uparrow}(\theta) + \int\limits_{\tau_s^{\uparrow}(\theta)}^{1} \mathrm{B}[\mathrm{T}(\mathrm{p})]\mathrm{d}\tau^{\uparrow}(\mathrm{p},\theta) \\ &\quad + (1-\varepsilon(\theta))\tau_s^{\uparrow}(\theta) \int\limits_{\tau_0^{\downarrow}(\vartheta^*)}^{1} \mathrm{B}[\mathrm{T}(\mathrm{p})]\mathrm{d}\tau^{\downarrow}(\mathrm{p},\vartheta^*) + \xi\end{aligned}\right\}$$

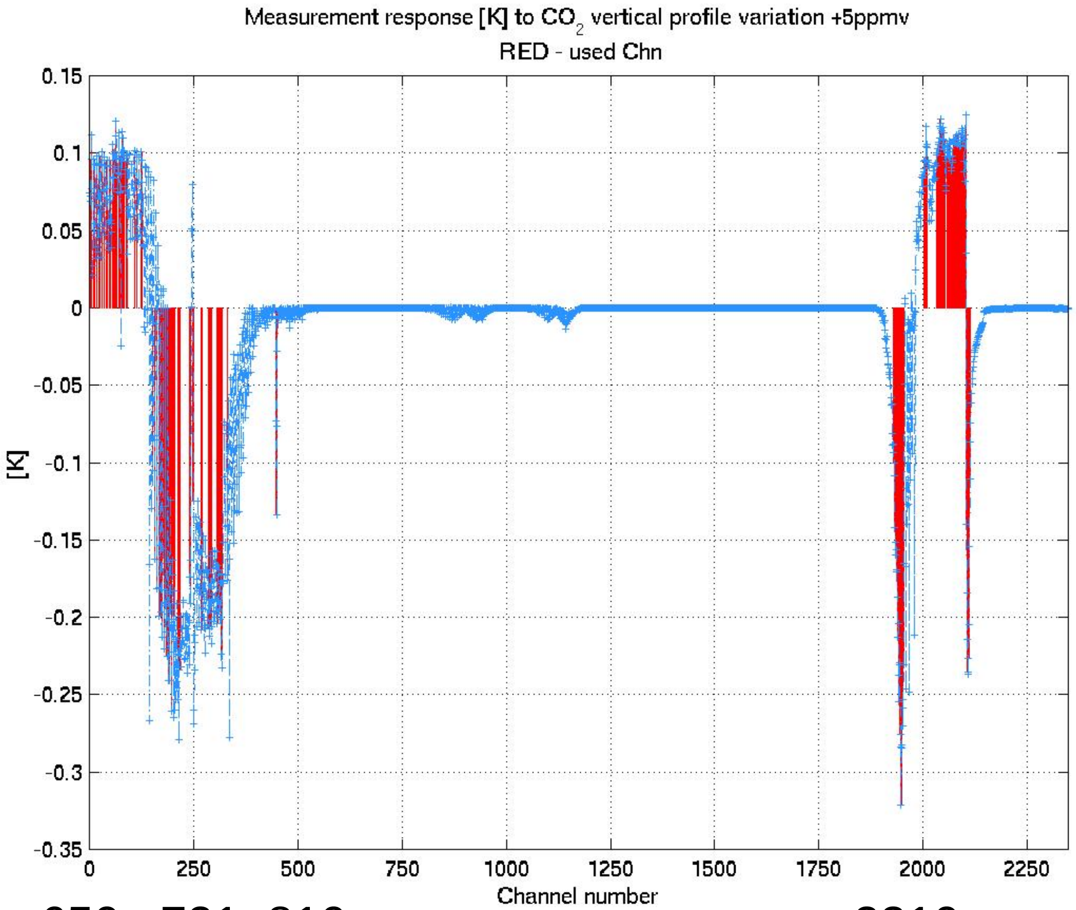
$$\hat{\mathrm{J}}(\theta) = F[\tilde{\mathrm{J}}(\theta)]$$

$$A[\varepsilon, \mathrm{T_s}, \mathrm{T}(\mathrm{p}), \tau(\gamma(\vartheta^*)), H_2O(p), O_3(p), CO_2(p)](t) = \hat{\mathrm{J}}(t,\theta)$$

$$\left(\varepsilon, \mathrm{T_s}, \mathrm{T}(\mathrm{p}), H_2O(p), O_3(p), CO_2(p)\right)(t) = A^{-1}[\hat{\gamma}(t-1,\theta), \hat{\mathrm{J}}(t,\theta)]$$

$$\hat{\gamma}(t) = \eta\hat{\gamma}(t-1) + (1-\eta)\arg\min_{\gamma} \overline{\left|\hat{\mathrm{J}}(t) - A[\gamma, A^{-1}[\hat{\gamma}(t-1), \hat{\mathrm{J}}(t)]]\right|}$$

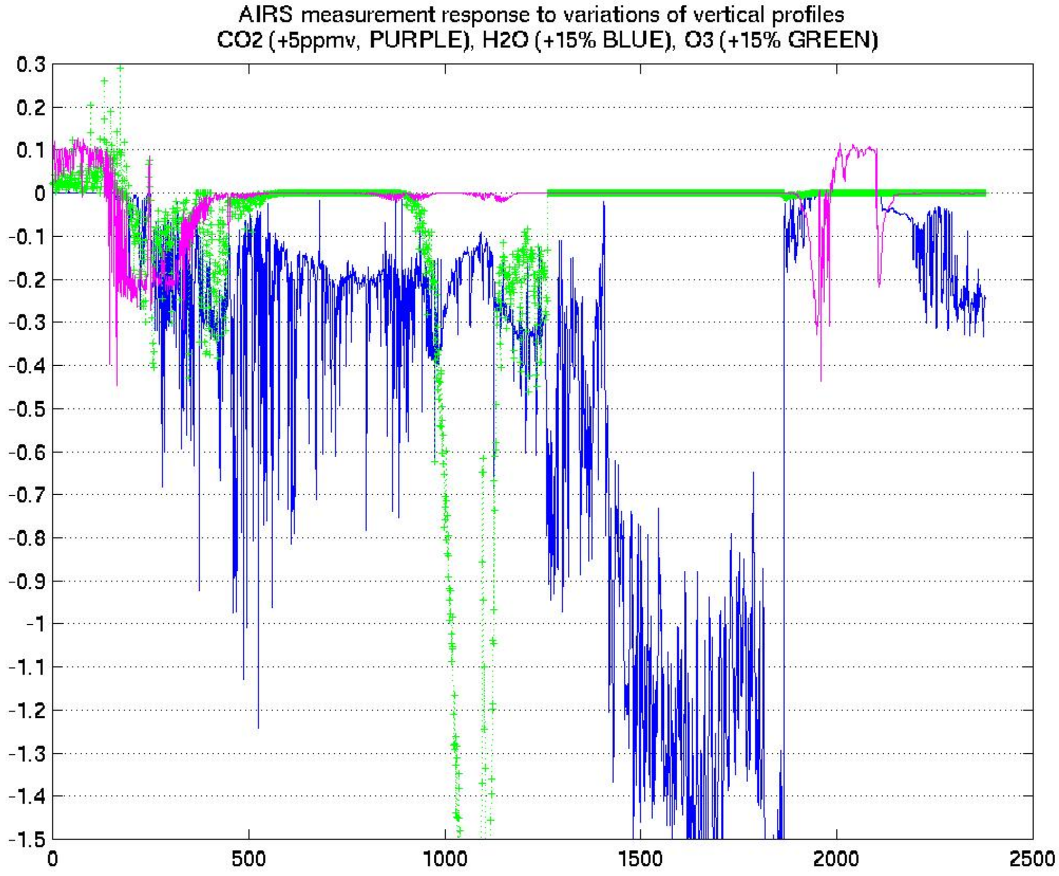
AIRS measurement response to changing the CO_2 vertical profile +5ppmv at each level from 365 to 370 ppmv



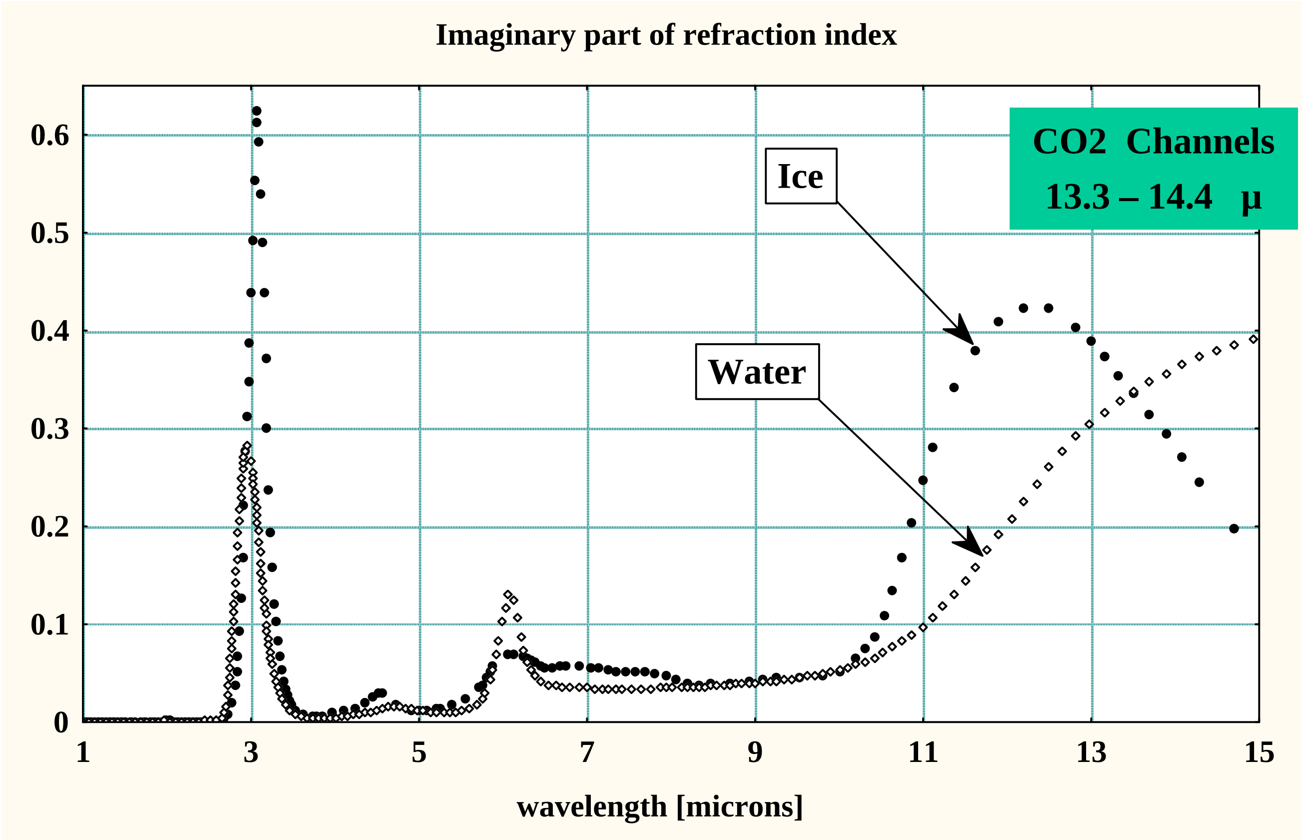
650 721 810 2310 cm-1

Location of spectral channels used for CO_2 estimation are shown in RED. The CO_2 signal is small ~.2K. There are ~150 spectral channels in SW+LW sensitive to 5ppmv CO_2 changes and not contaminated by signals from atmospheric moisture and ozone variations.

AIRS measurement response to changing the CO2 (+5 Purple), H2O (+15% Blue) and O3 (+15% Green) vertical profiles at each levels



Imaginary part of cloud particles refraction index

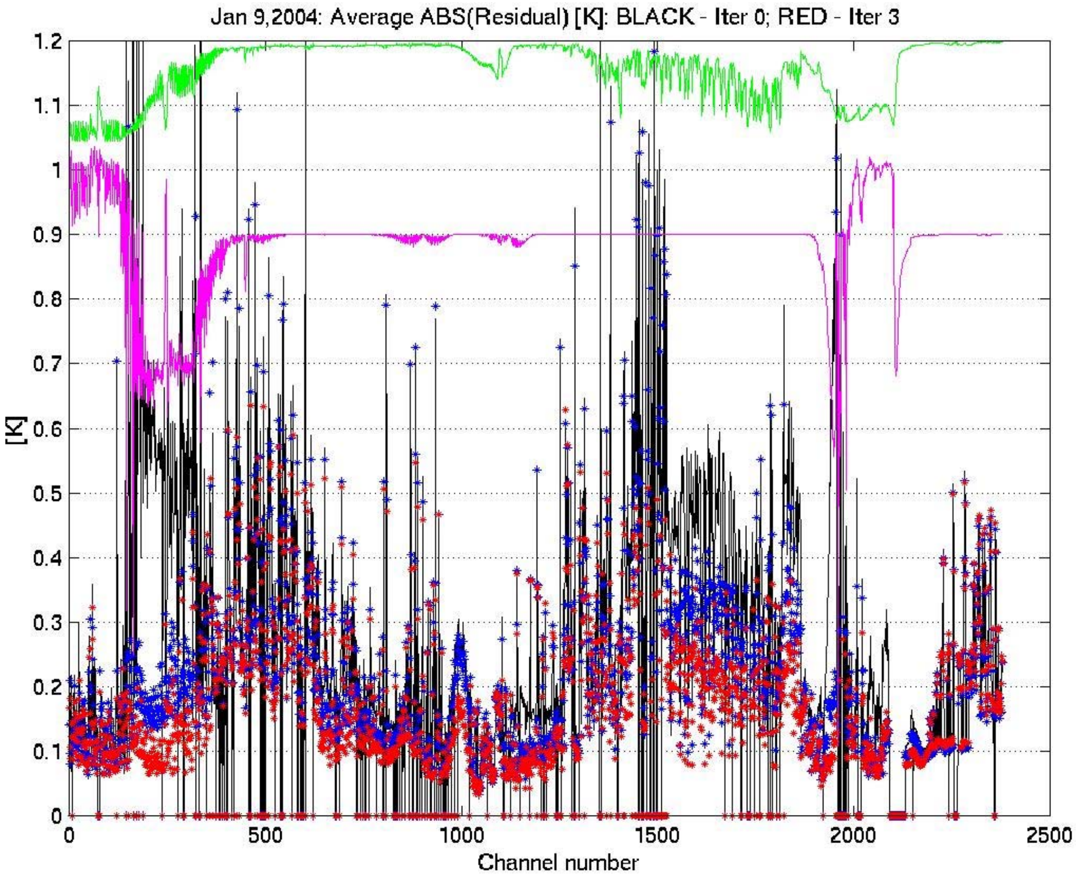


Spectral distribution of imaginary part of cloud particle refraction index indicates strong spectral absorption in the LW CO_2 channels

Selection spectral channels for CO2 retrievals

$$\nu(CO_2):\begin{cases}\left|\delta T_\nu[\delta Q(+5\ CO_2)]\right| > .098K\\ \left|\delta T_\nu[\delta Q(+15\%\ O_3)]\right| < .075K\\ \left|\delta T_\nu[\delta Q(+15\% H_2O)]\right| < .075K\end{cases}$$

Spectral distribution of average of the absolute (measurement – estimate) residual (in degrees K)



Black – 365 ppmv
Blue – 1st iter
Red – 3rd iter

Purple – response to 5 ppmv

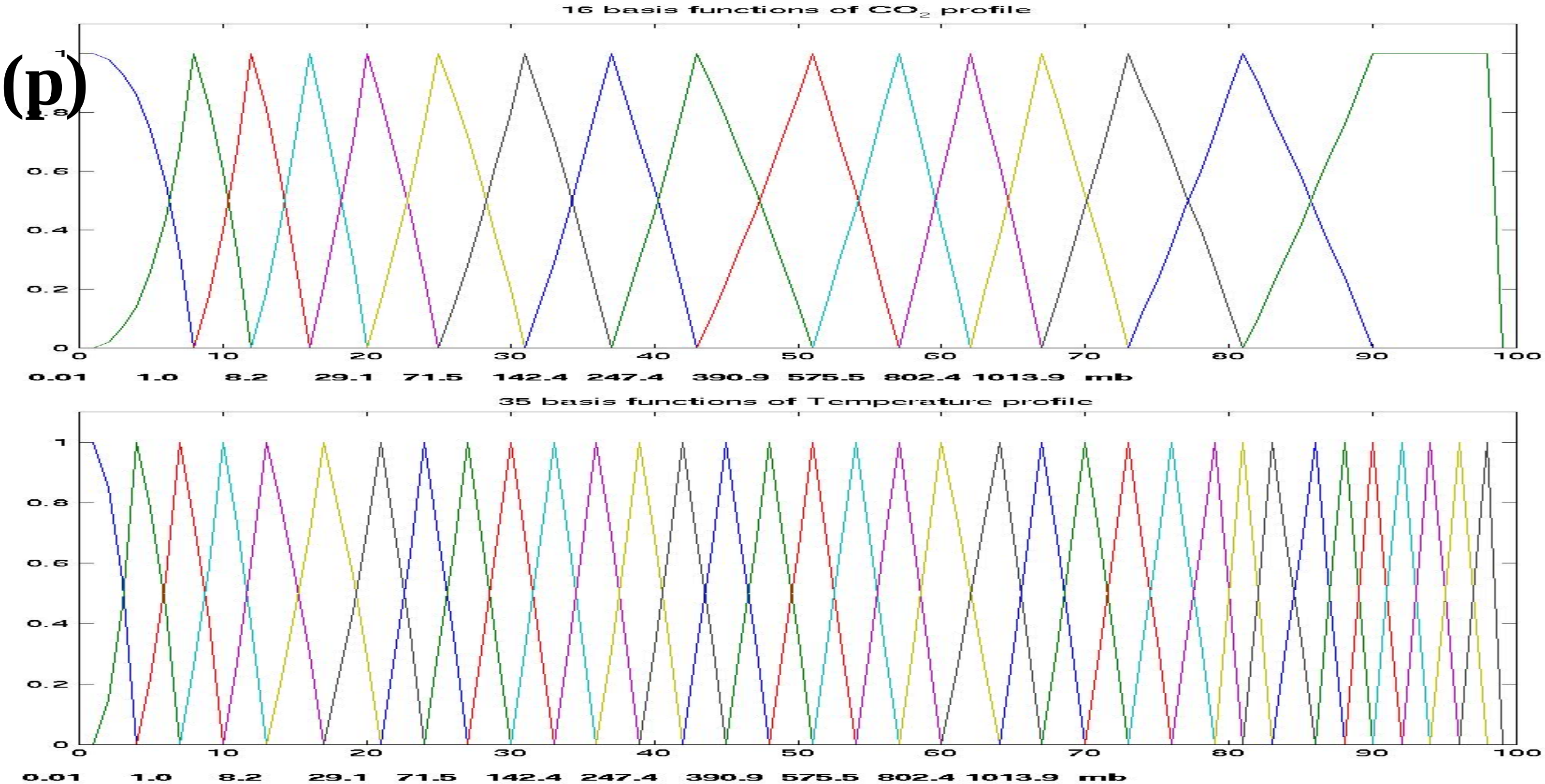
Green – normalized spectrum

Basis functions for parameterization CO2(p)[16] and T(p)[35] profiles

Variations of atmospheric temperature and CO2 profiles are represented by a linear expansion in the inverse problem solution Temperature parameterization has to be sufficient to estimate and remove the temperature signal from measurements

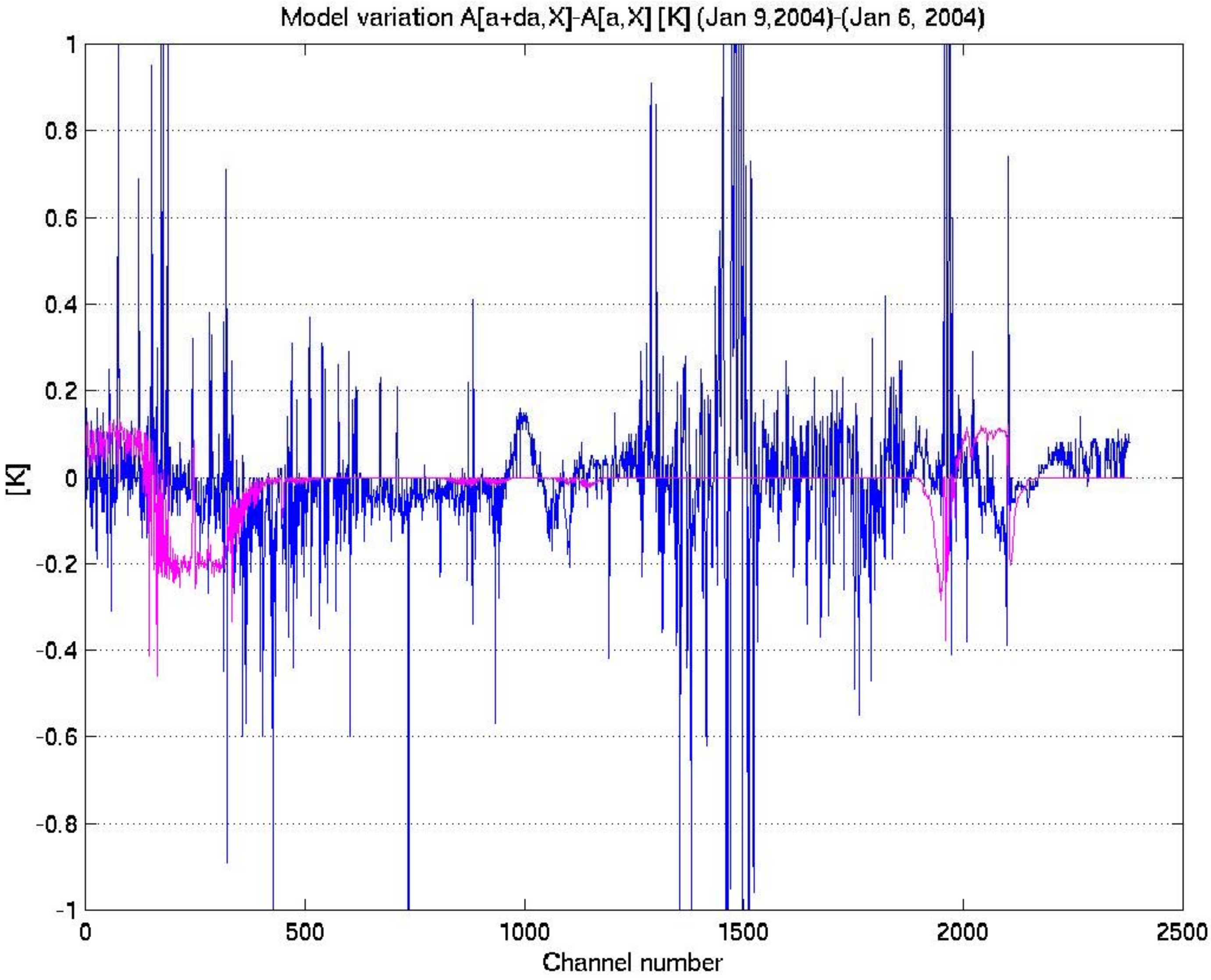
CO2(p)

T(p)



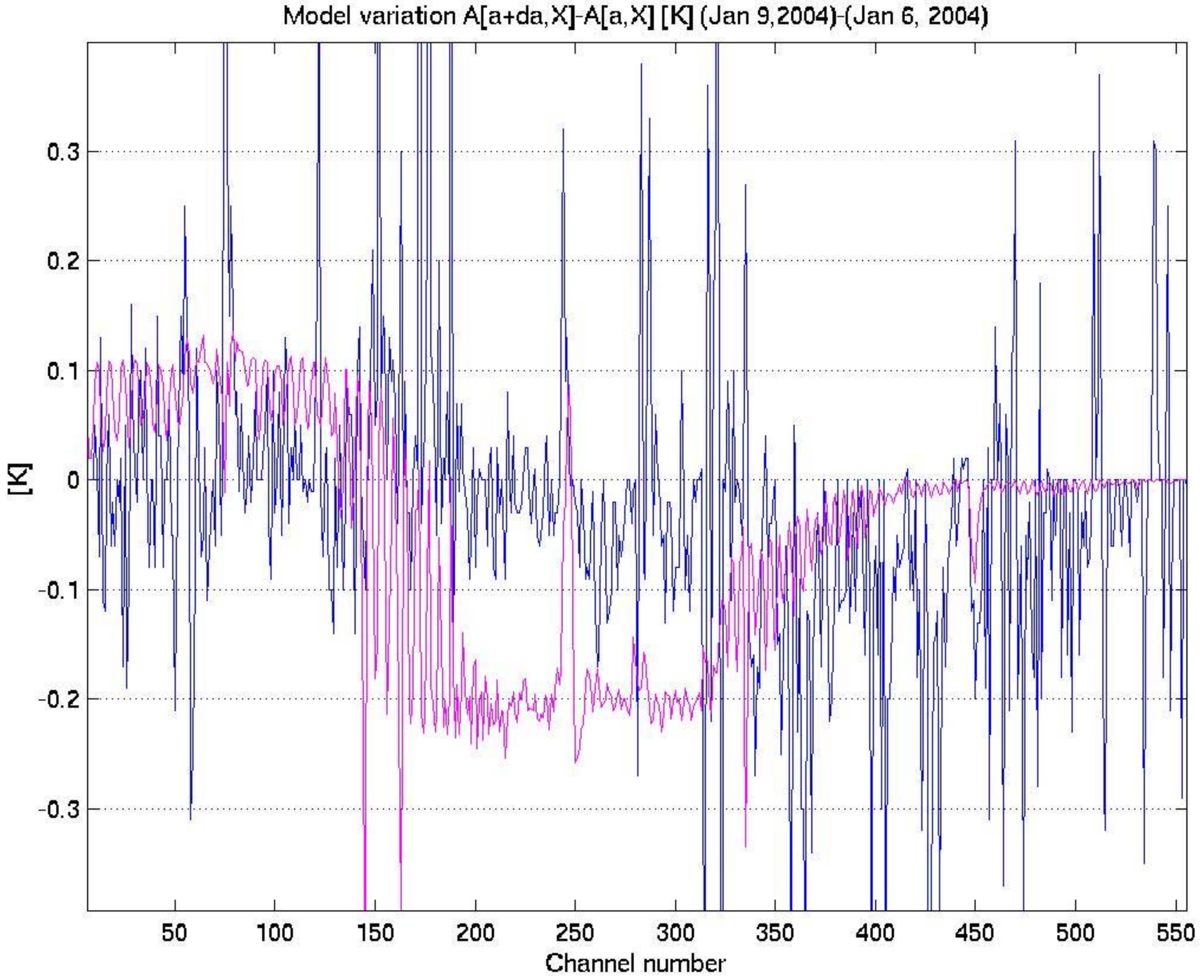
0.01 1 8 29 71 142 247 390 575 802 1013 hPa

Change in γ fit from 6 Jan to 9 Jan 04



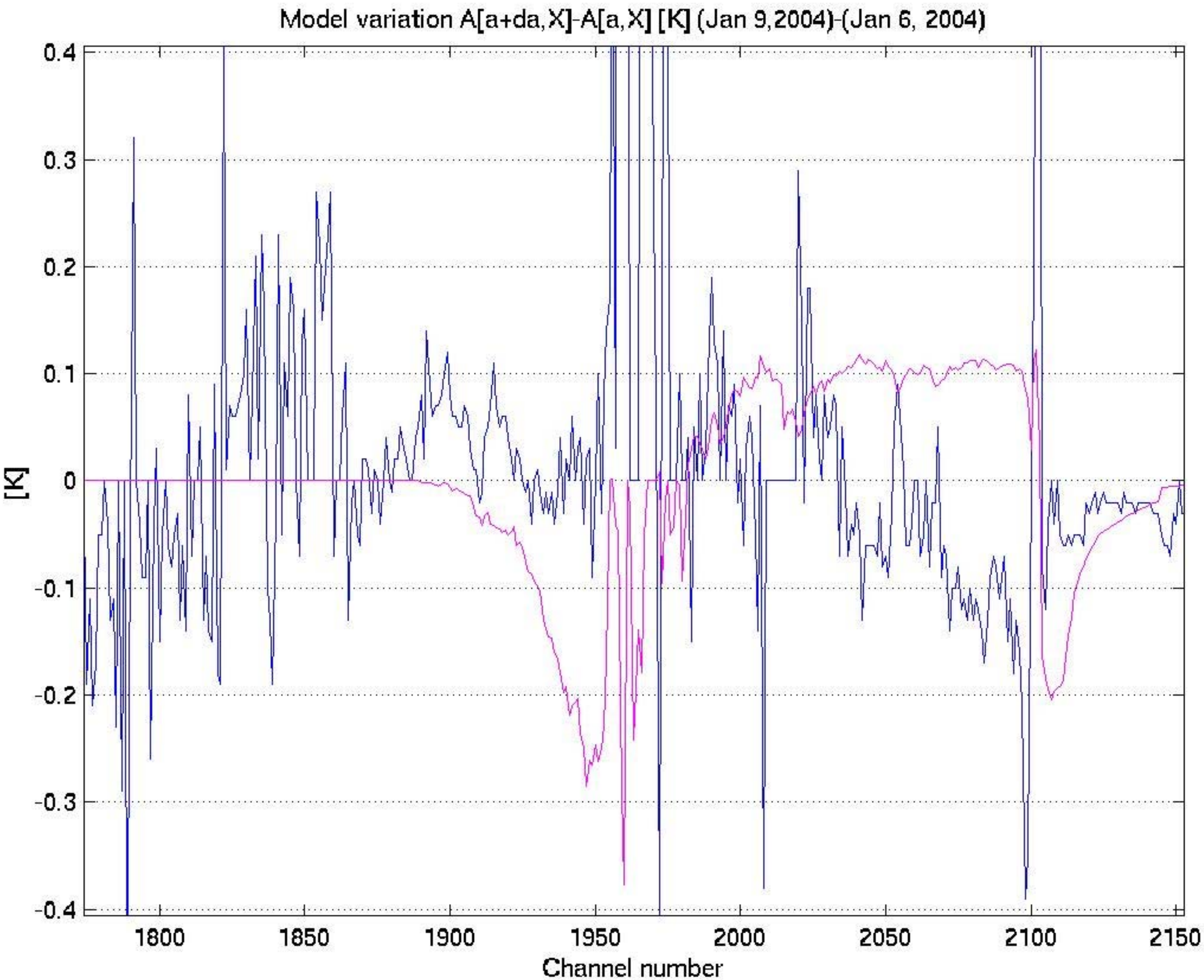
16 μm
- 4 μm

Change in fit from 6 Jan to 9 Jan 04



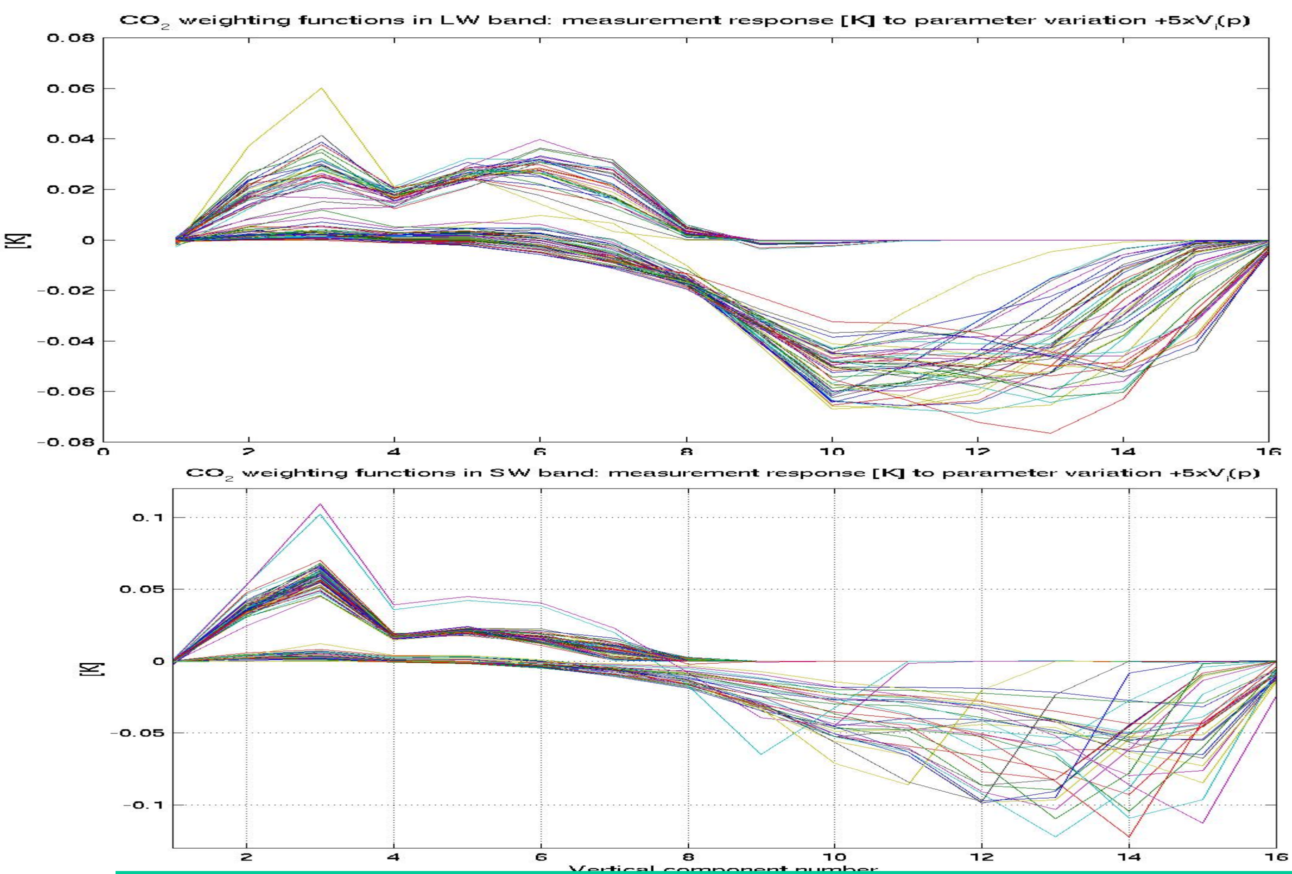
15 μm

Change in fit from 6 Jan to 9 Jan 04



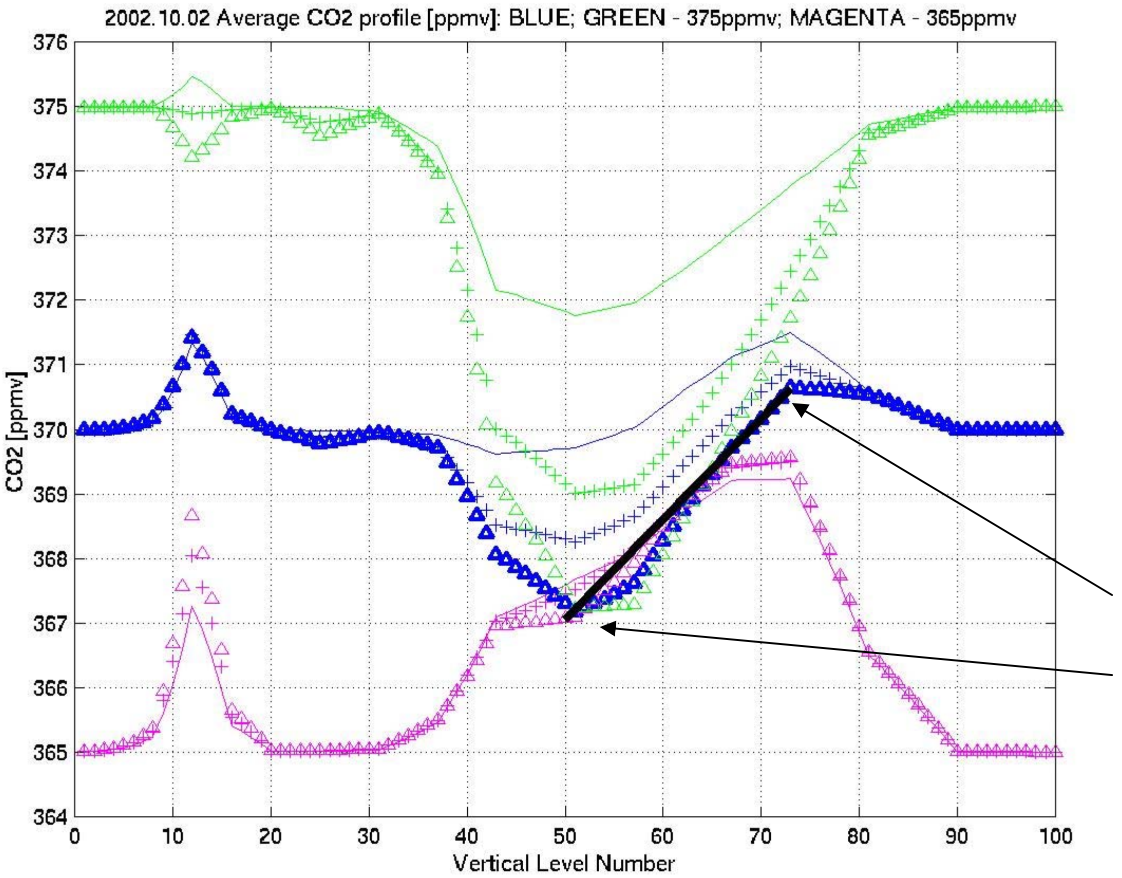
4.3 μm

CO2 weighting functions (converted with solution basis functions) within atmospheric layer 150 -600 hPa for soundings in LW and SW bands. Model also shows spectral effect of CO2 variations in stratosphere



0.01 .5 4.1 16 56 151 273 441 596 802-1013 hPa

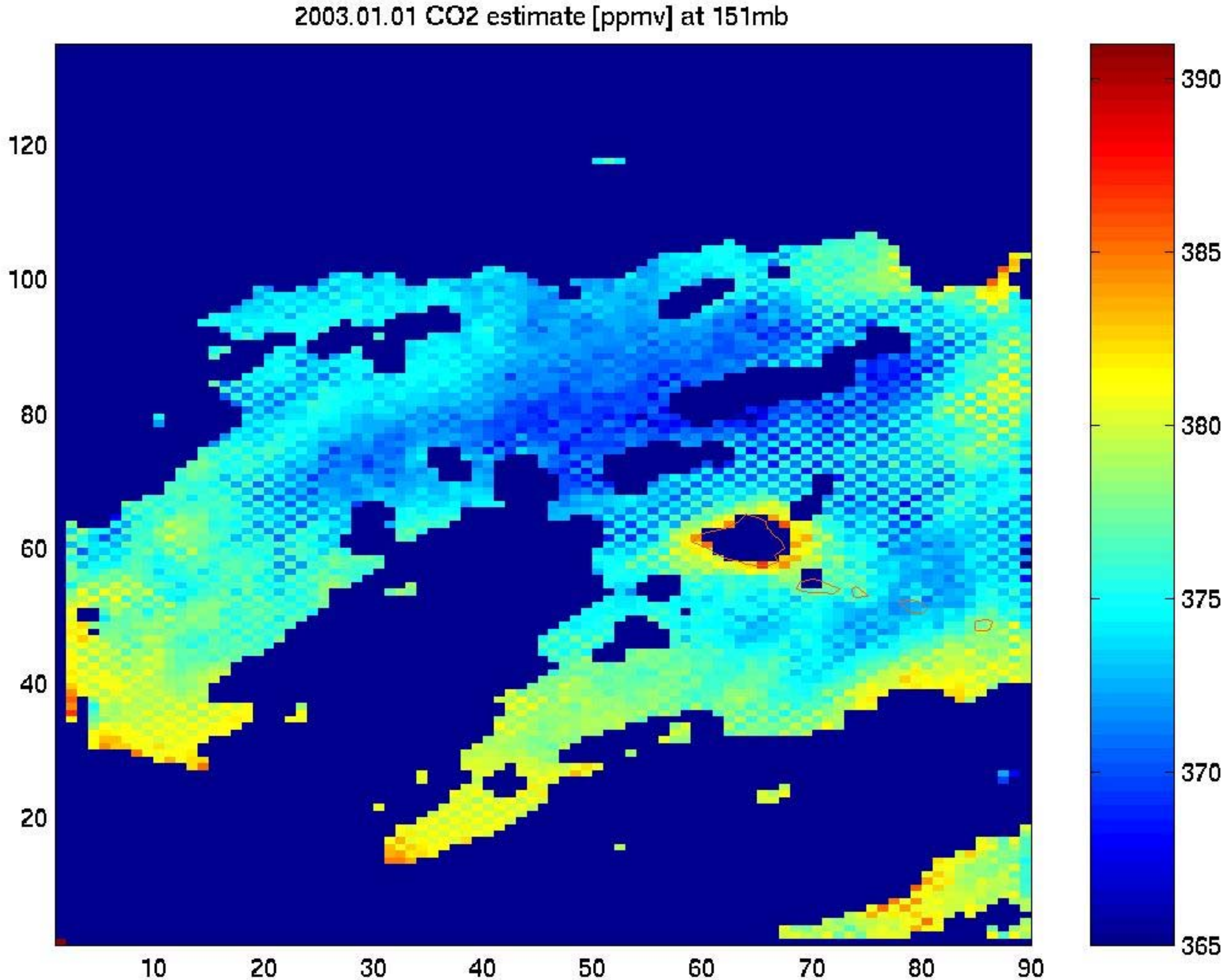
Estimating CO2 concentrations by minimizing residuals between AIRS measured radiances versus SARTA radiative calculations



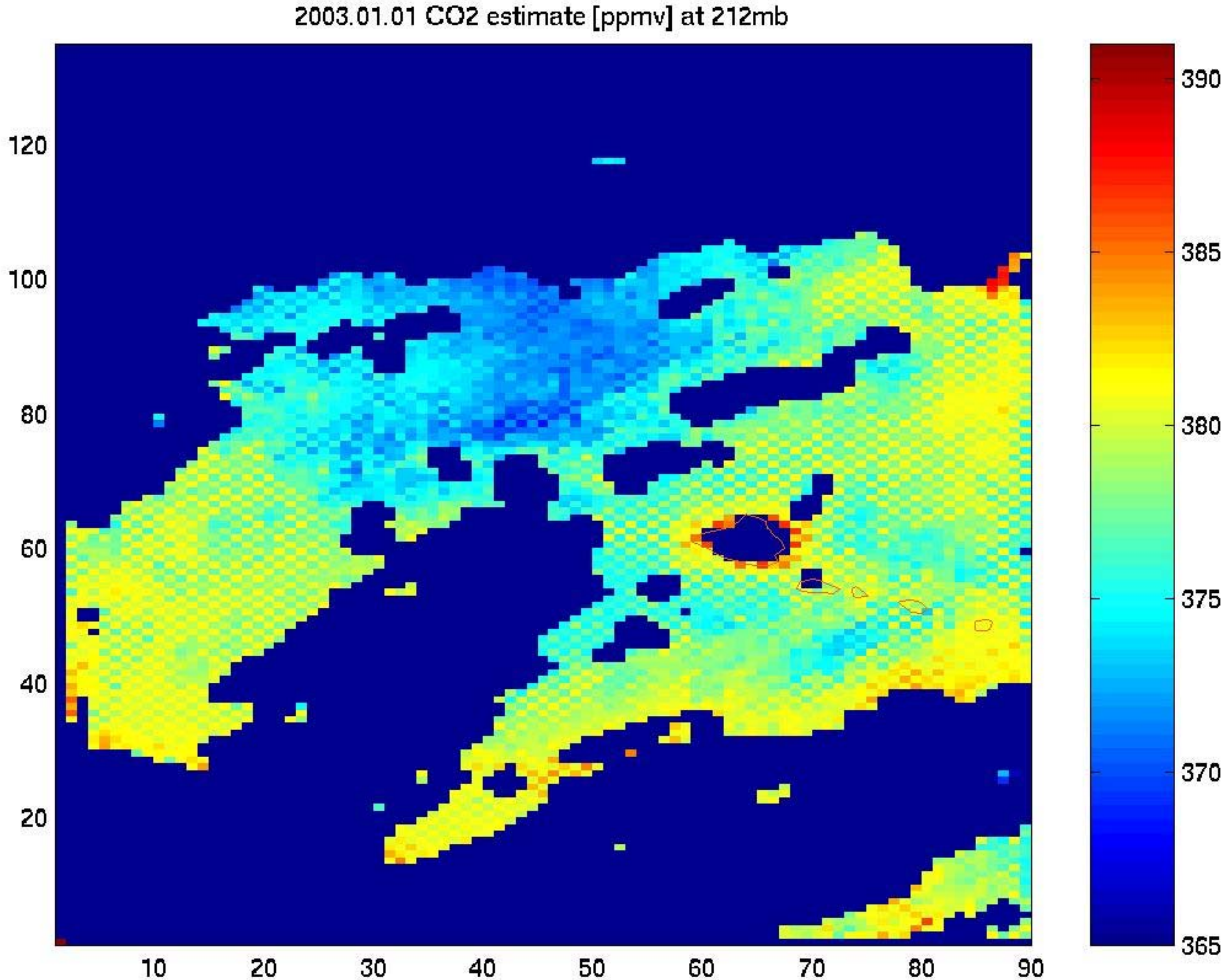
Initial first guess CO2 concentrations of 365 ppmv are alternated from 5 ppmv too high for one fov to 5 ppmv too low for the next (referred to as a checkerboard initialization).

Measurements provide adequate information from 150 to 350 hPa.

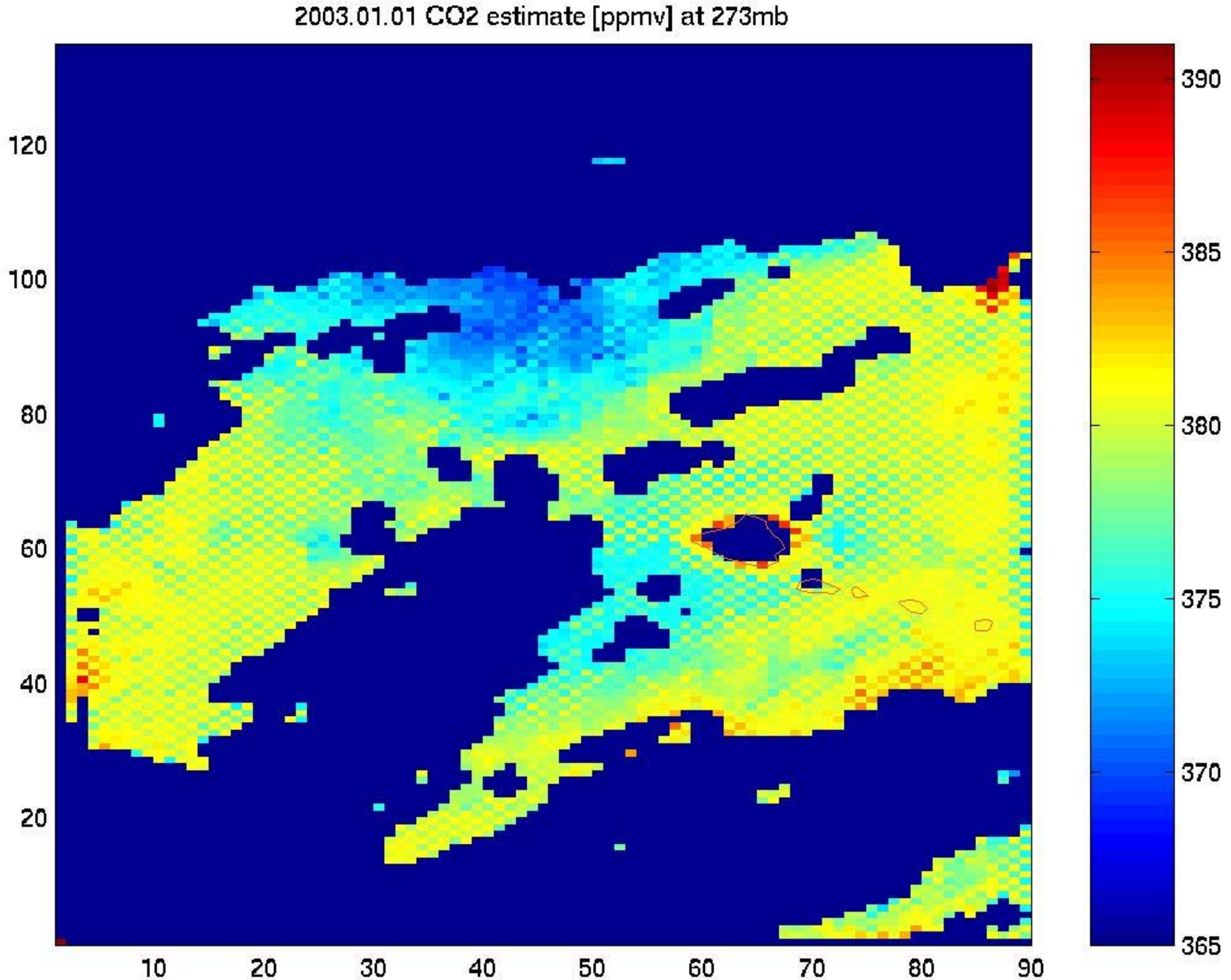
01 Jan 2003 CO2 @ 151 hPa



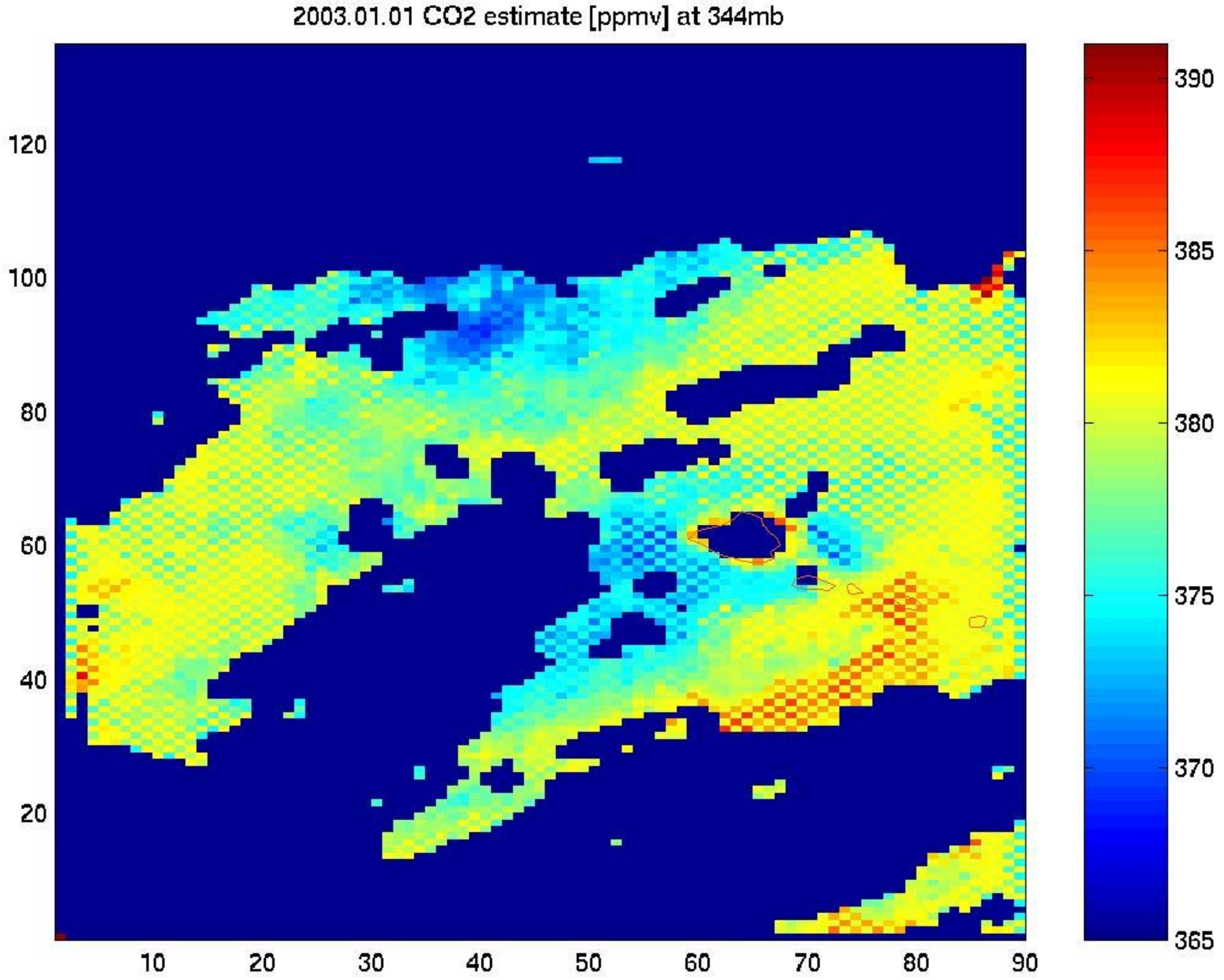
01 Jan 2003 CO2 @ 212 hPa



01 Jan 2003 CO2 @ 273 hPa

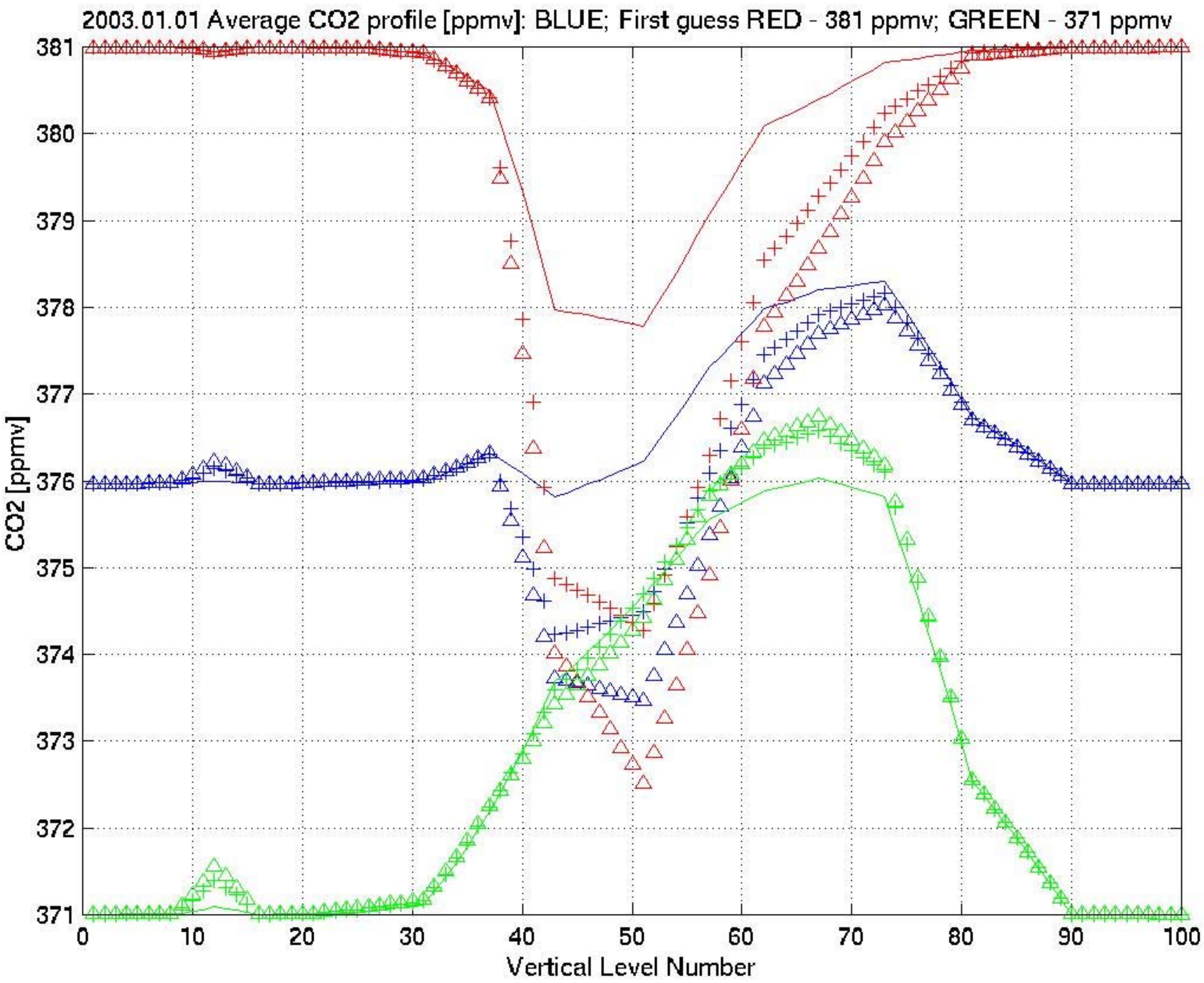


01 Jan 2003 CO2 @ 344 hPa

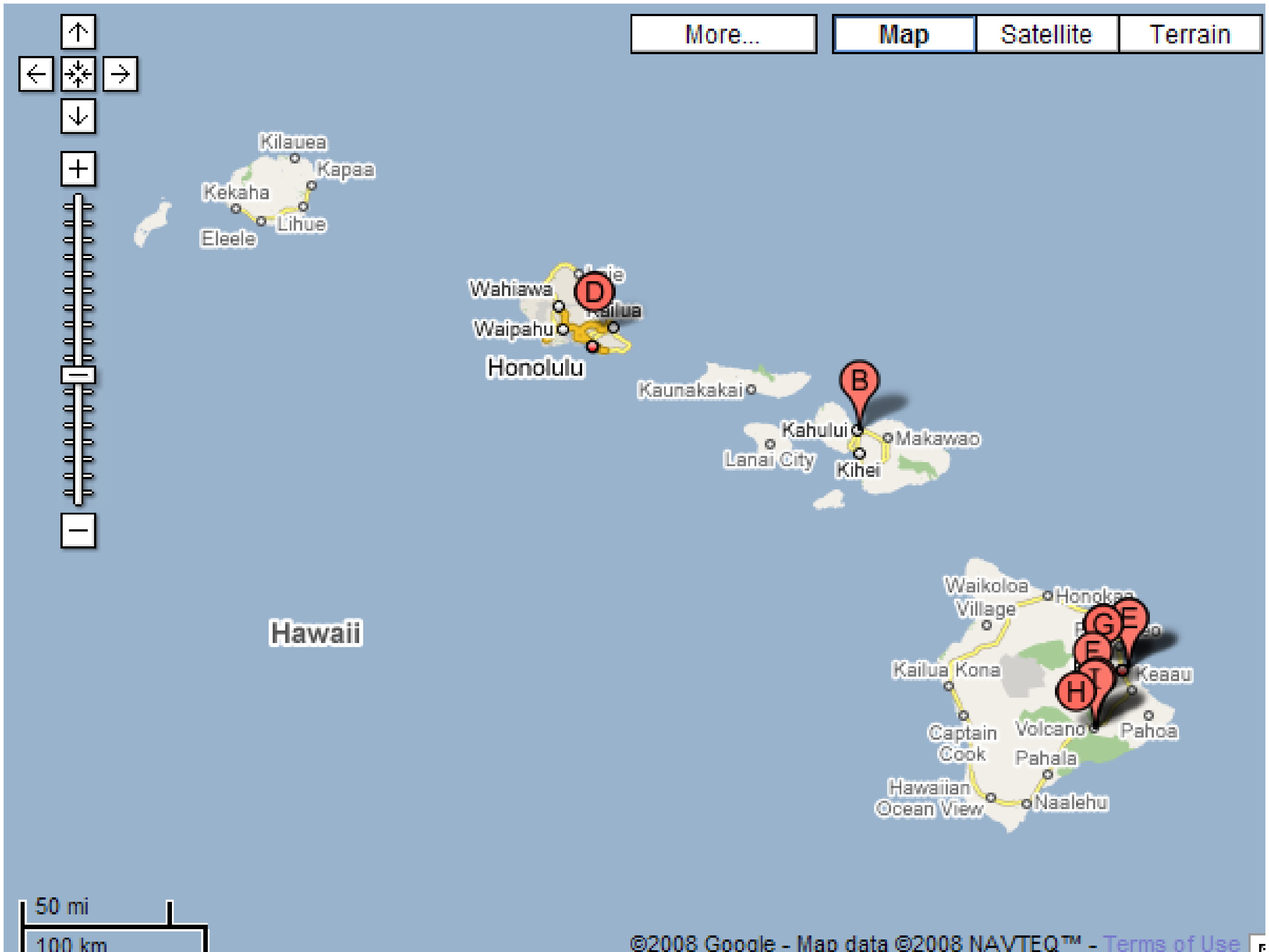


01 Jan 03

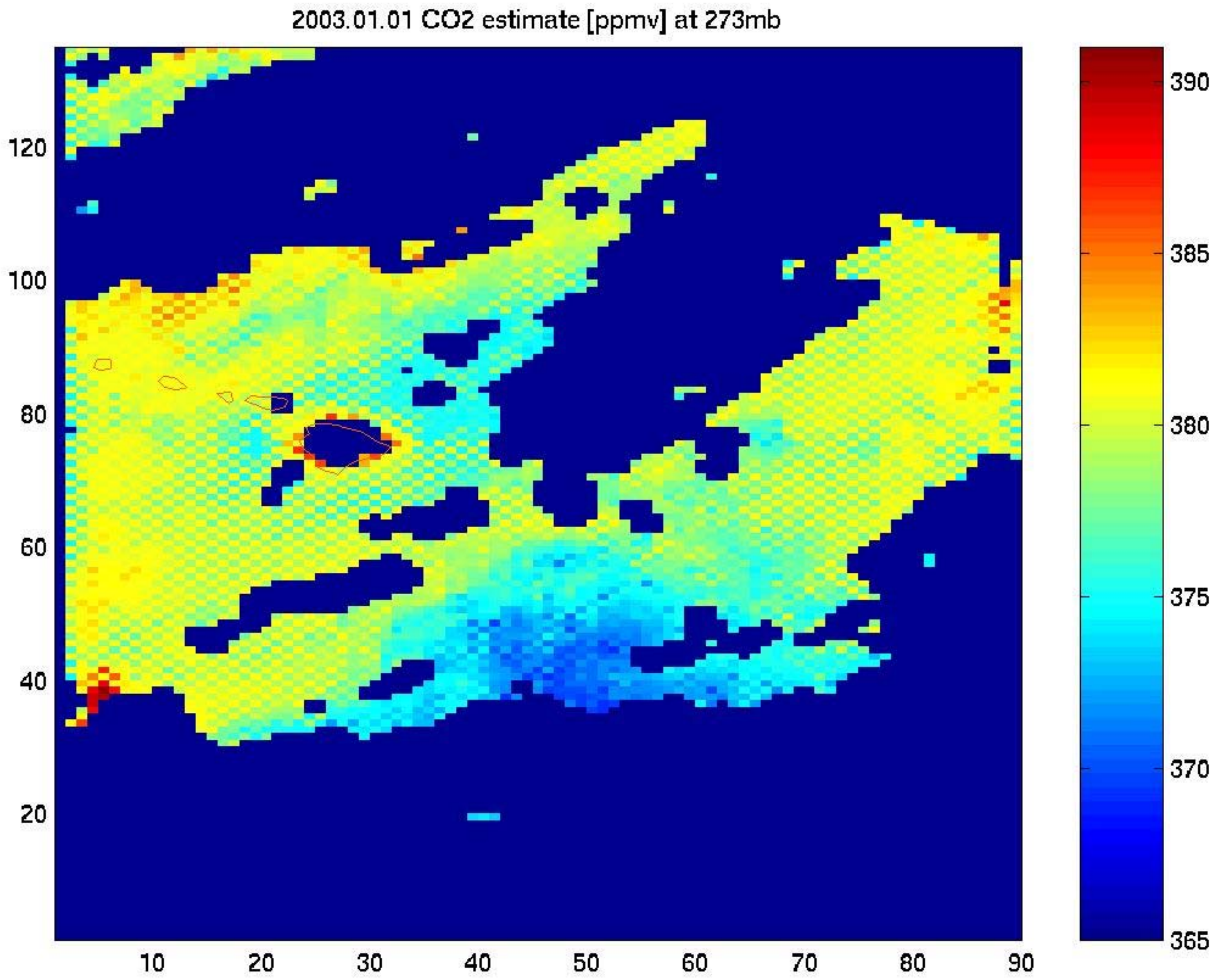
Mean CO2 Profile

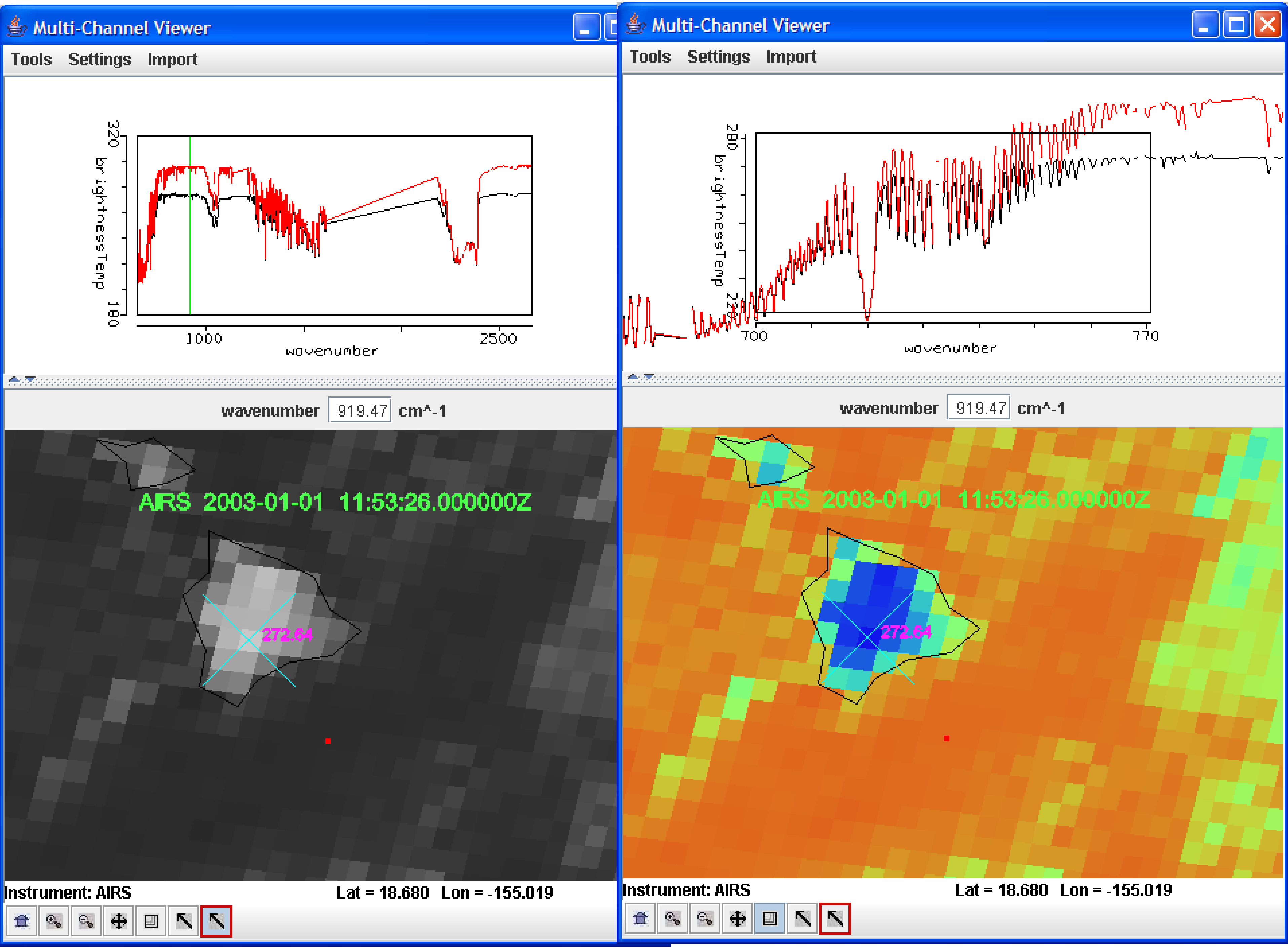


Active Volcanoes in Hawaii

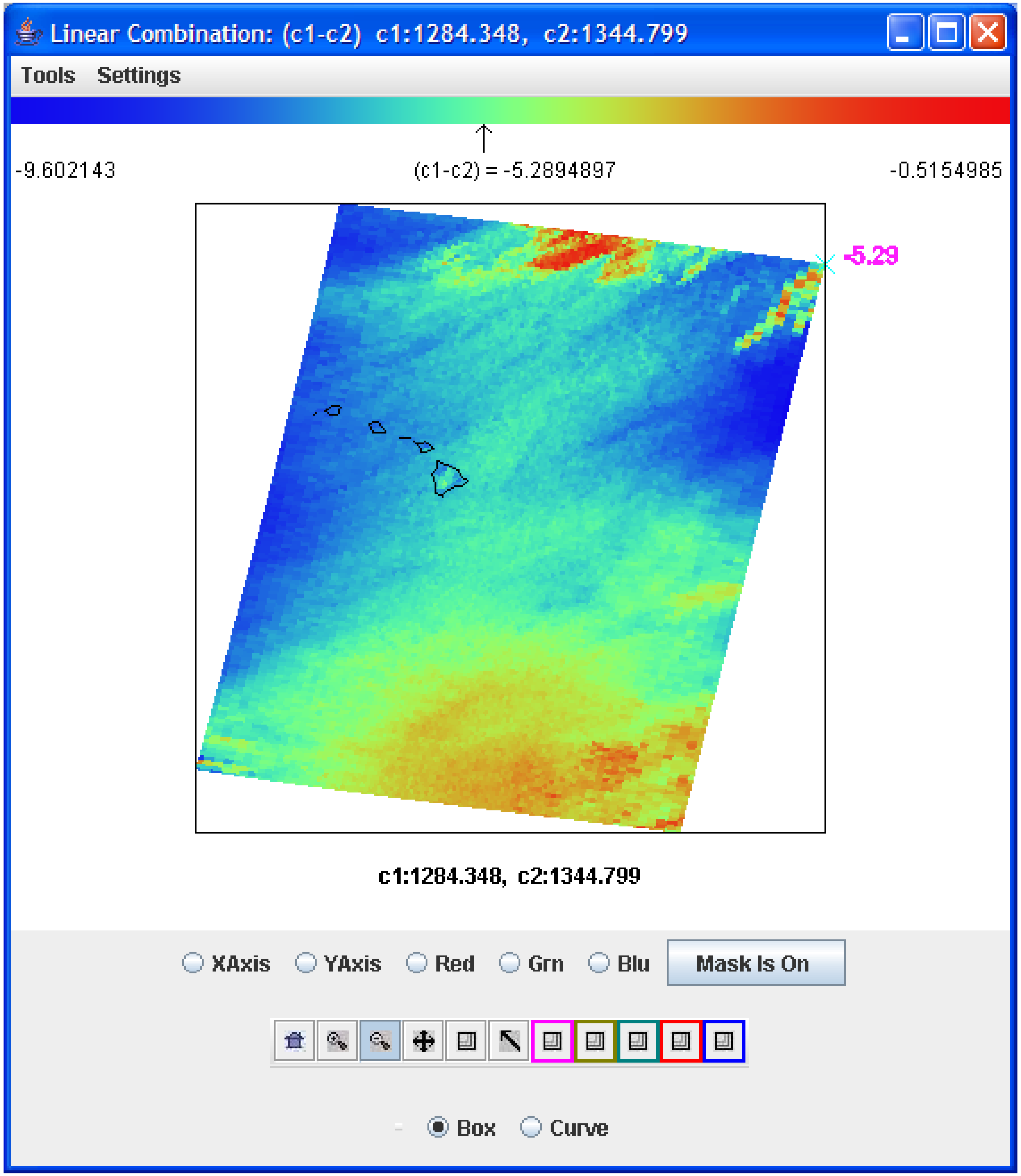


01 Jan 2003 CO2 @ 273 hPa

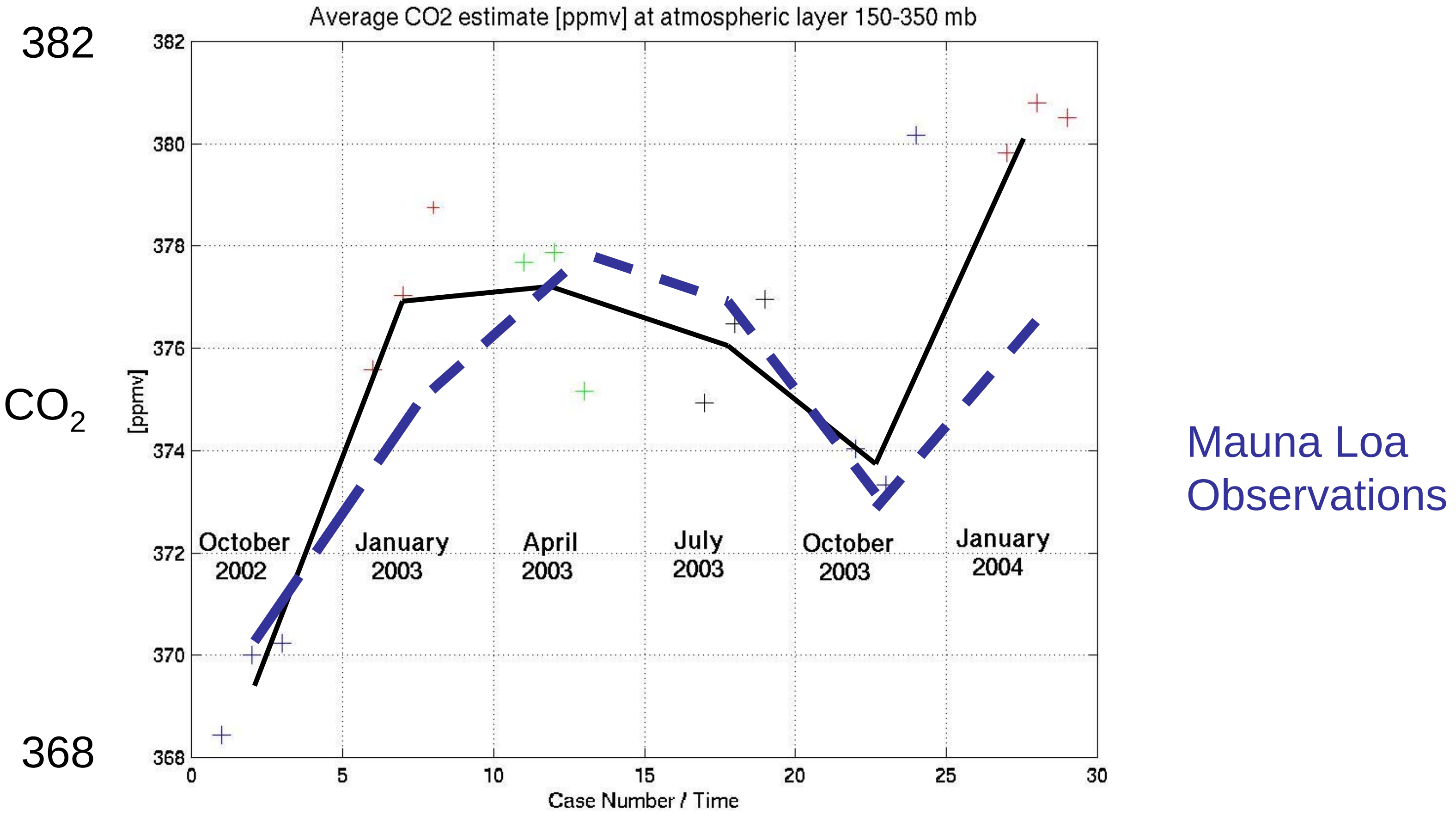



Multi-Channel Viewer
Tools Settings Import
320
180
brightnessTemp
1000
2500
wavenumber
wavenumber 919.47 cm^-1
AIRS 2003-01-01 11:53:26.000000Z
272.64
Instrument: AIRS
Lat = 18.680 Lon = -155.019
Multi-Channel Viewer
Tools Settings Import
280
brightnessTemp
700
770
wavenumber
wavenumber 919.47 cm^-1
AIRS 2003-01-01 11:53:26.000000Z
272.64
Instrument: AIRS
Lat = 18.680 Lon = -155.019

SO_2 signature is flat



Summary of Oct 02 – Jan 04 CO2 seasonal values



Conclusion

- Results of geophysical interpretation of AIRS hyperspectral measurements from 18 granules (18 days) (from Oct 2002 – Jan 2004) show that estimate of vertical CO_2 profile provide physically meaningful information at atmospheric layer 150-350 hPa
- Observed CO_2 fields demonstrate spatial consistency with noticeable horizontal and vertical variations
- Temporal (seasonal) variations of the estimated average CO_2 concentration at atmospheric layer 150-350 hPa demonstrate excellent correlation with temporal variations of direct CO_2 measurements over Hawaii