Remote Sensing of Spatial Distributions of Greenhouse Gases in the Los Angles Basin

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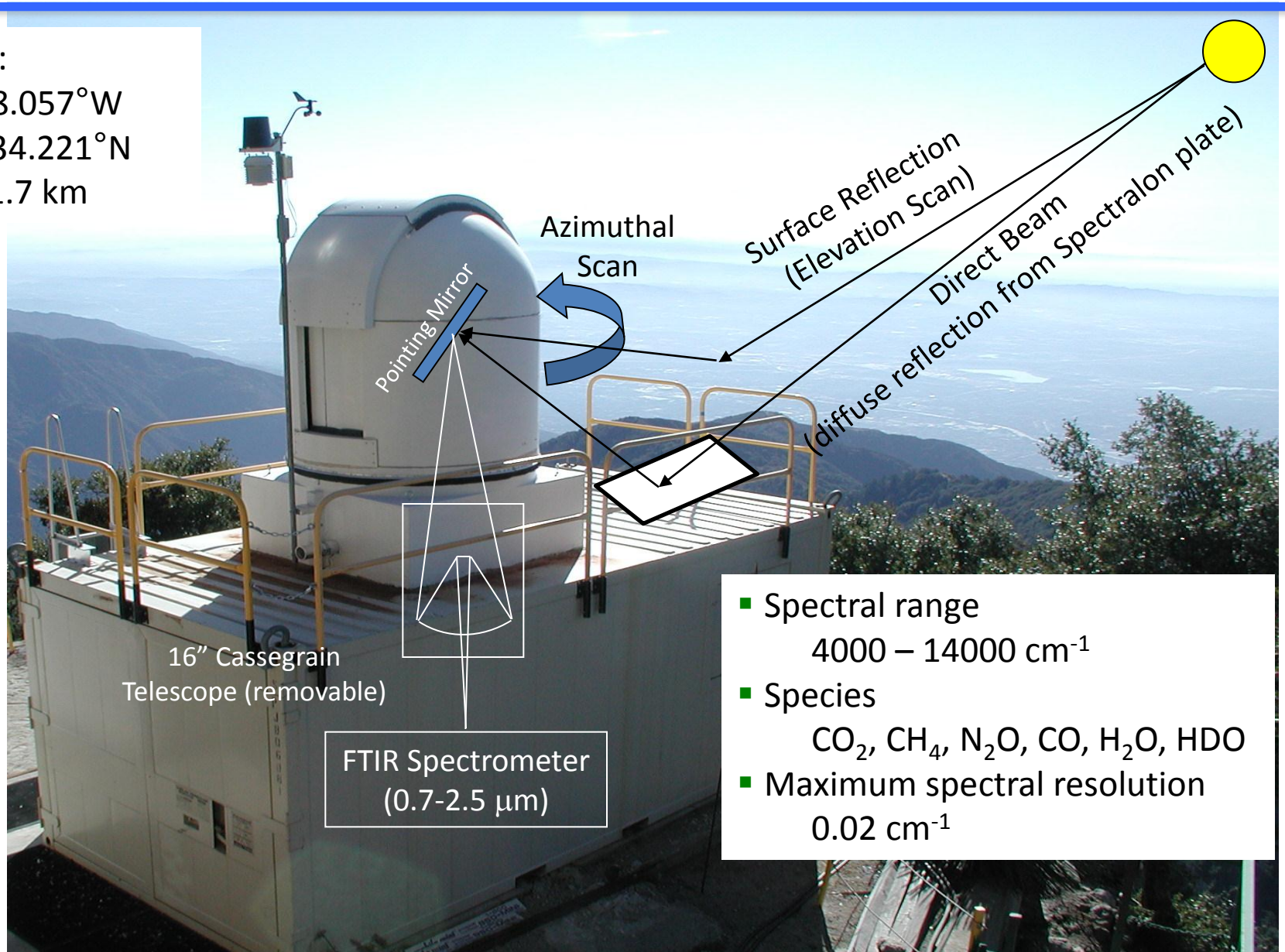
Introduction

- The Los Angeles air basin is a significant anthropogenic source of greenhouse gases and pollutants including CO_2, CH_4, N_2O, and CO, contributing significantly to regional and global climate change.
- Recent legislation in California, the California Global Warming Solutions Act (AB32), established a statewide cap for greenhouse gas emissions for 2020 based on 1990 emissions.
- Verifying the effectiveness of regional greenhouse gas emissions controls requires high-precision, regional-scale measurement methods combined with models that capture the principal anthropogenic and biogenic sources and sinks.
- We present a novel approach for monitoring the spatial distributions of greenhouse gases in the Los Angeles basin using high resolution remote sensing spectroscopy.
- We participated in the CalNex 2010 campaign to provide greenhouse gas distributions for comparison between top-down and bottom-up emission estimates.

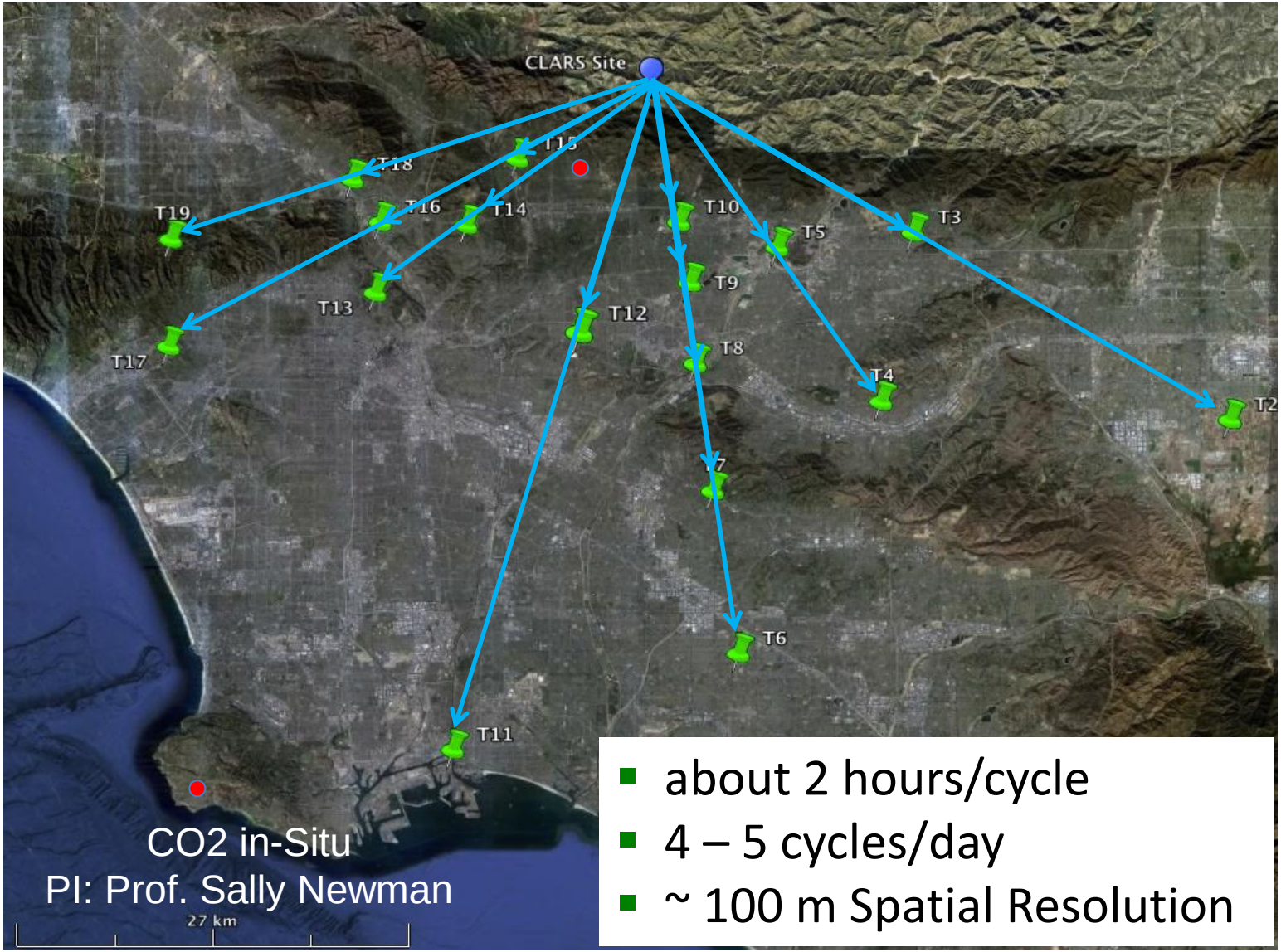
California Laboratory for Atmospheric Remote Sensing (CLARS) at Mt. Wilson

Long:
118.057°W
Lat: 34.221°N
Alt: 1.7 km



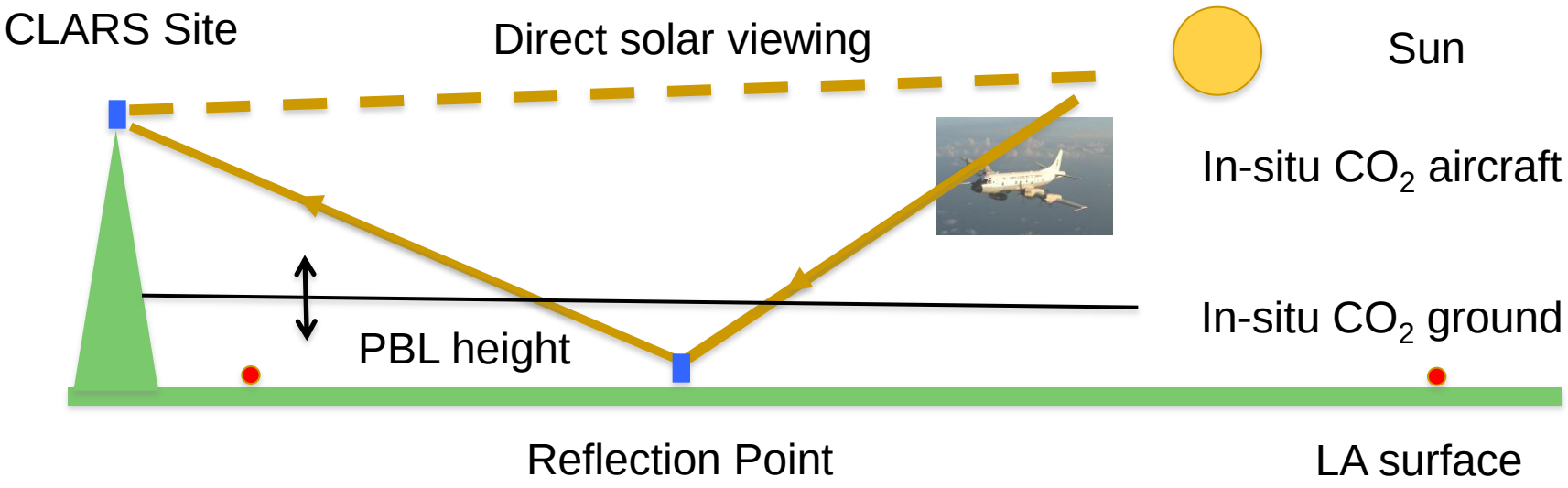
- Spectral range
  4000 – 14000 cm^{-1}
- Species
  CO_2, CH_4, N_2O, CO, H_2O, HDO
- Maximum spectral resolution
  0.02 cm^{-1}

Reflection Points Selected for CLARS-FTS



- about 2 hours/cycle
- 4 – 5 cycles/day
- ~ 100 m Spatial Resolution

Viewing Geometry of CLARS FTS



- CLARS FTS measures slant column densities (in molecules/cm^2) of greenhouse gases along light path
- The light path transverses through the boundary layer twice
- Distant reflection points have a much longer path though the boundary layer than the nearby points
- Simultaneous measurements of O2 column abundance and surface pressure contains the light path at each reflection point

Measurements Using CLARS FTS

- Measurements made on 31 days during CalNex (in **blue**)
- No measurements available when cloudy because CLARS FTS needs solar light as light source
- Measurements for long term record are continuing

May 2010

Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	**14**	**15**
16	17	18	19	**20**	**21**	**22**
23	**24**	**25**	**26**	27	**28**	**29**
30	**31**					

June 2010

Su	Mo	Tu	We	Th	Fr	Sa
		1	**2**	**3**	4	**5**
6	**7**	**8**	**9**	10	**11**	**12**
13	**14**	**15**	**16**	**17**	**18**	**19**
20	21	22	23	24	25	26
27	28	29	30			

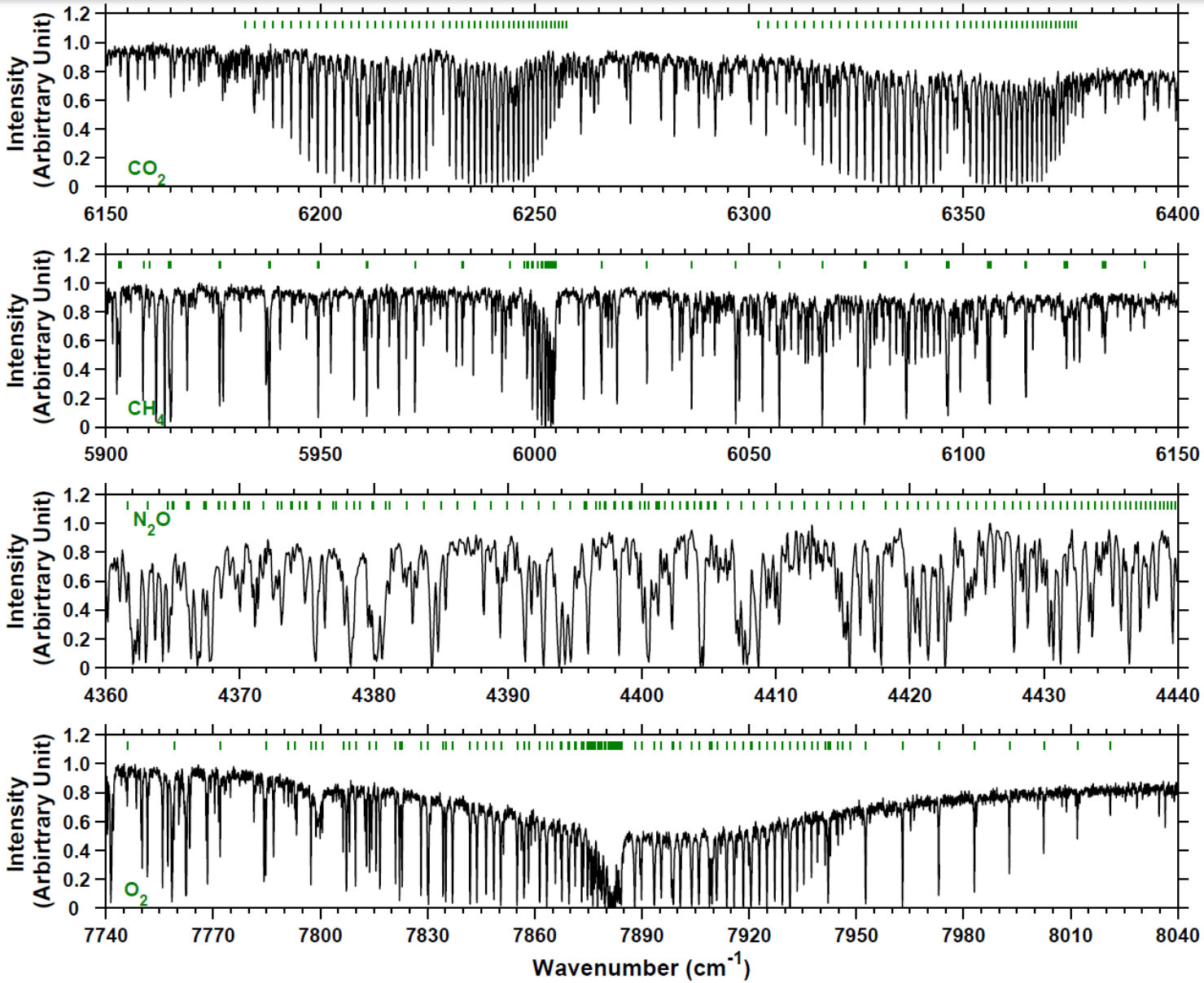
Sample CLARS FTS GHG Spectra
Reflectance from Land Surface

CO_2
1.6 μm

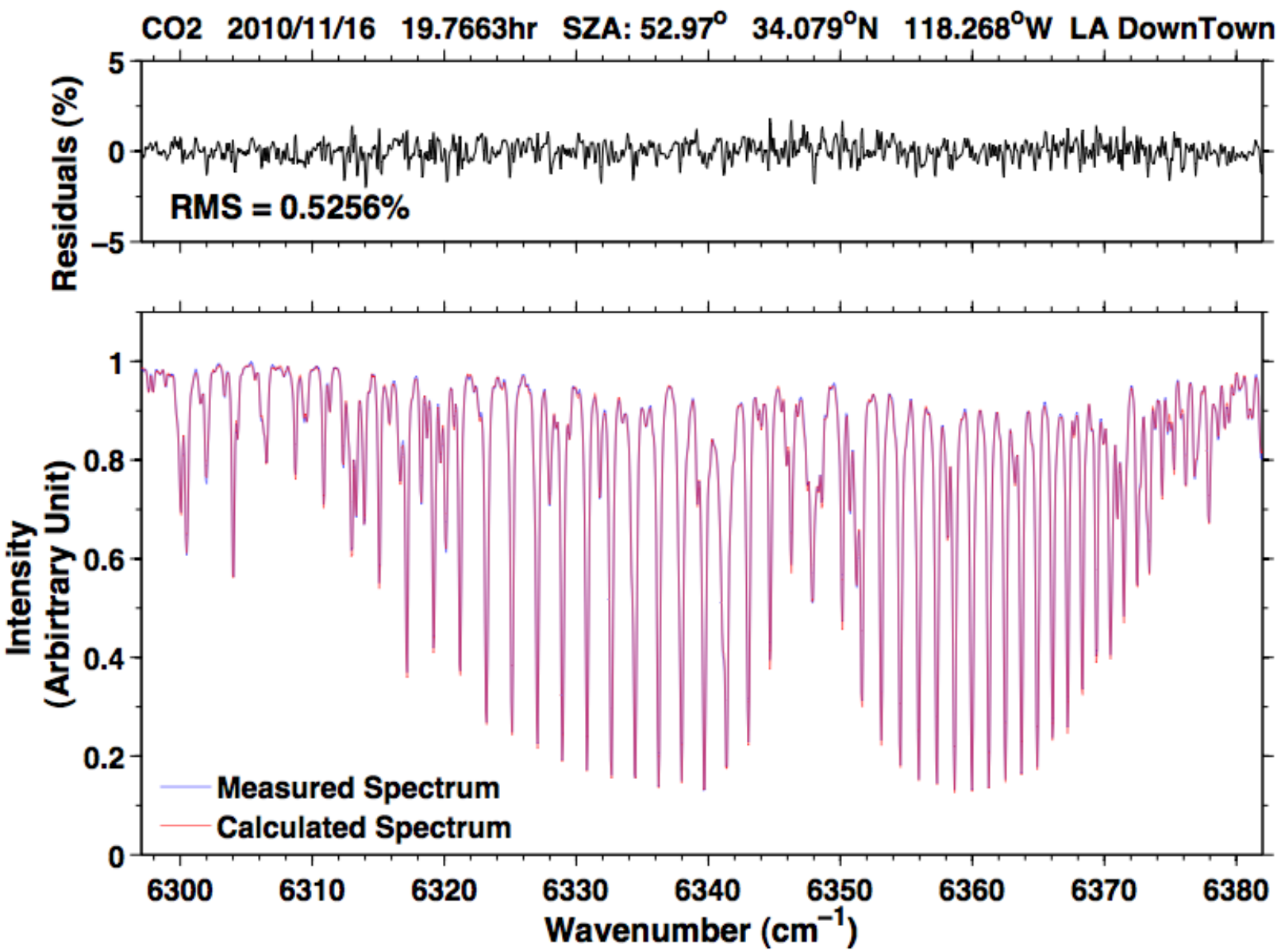
CH_4
1.7 μm

N_2O
2.3 μm

O_2
1.3 μm



Spectral Fitting to Determine CO_2 Slant Column Density

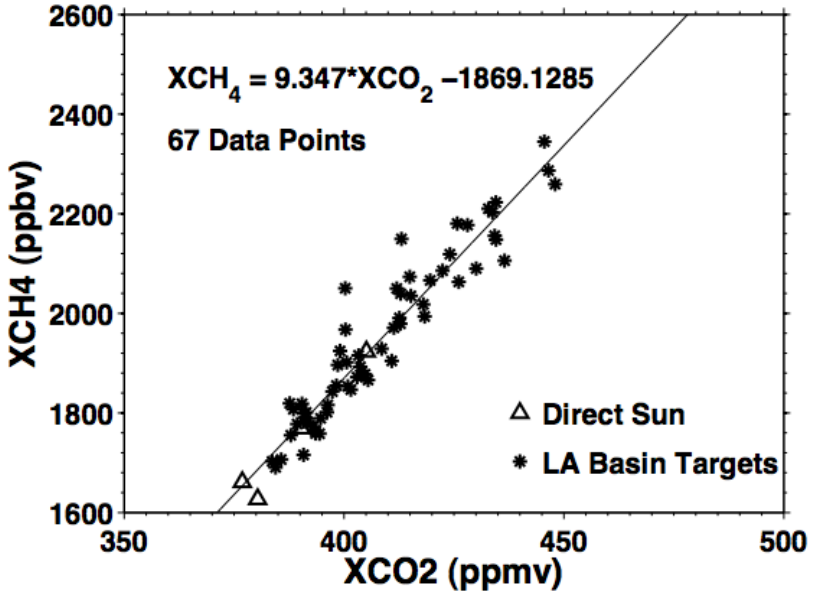


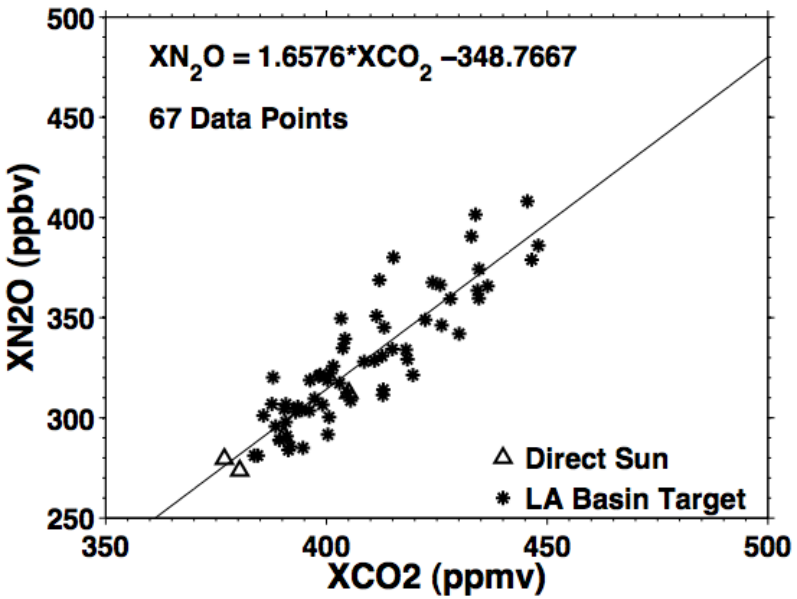
Measurement Precisions

Species	Slant Column-averaged Volume Mixing Ratio (Typical Range)	Retrieval Precision (Random Error)
XCO_2	380-500 ppmv	± (0.5-1) %
XCH_4	1800-2200 ppbv	± (0.5-1) %
XCO	20-200 ppbv	± (2-4) %
XN_2O	250-350 ppbv	± (2-4) %

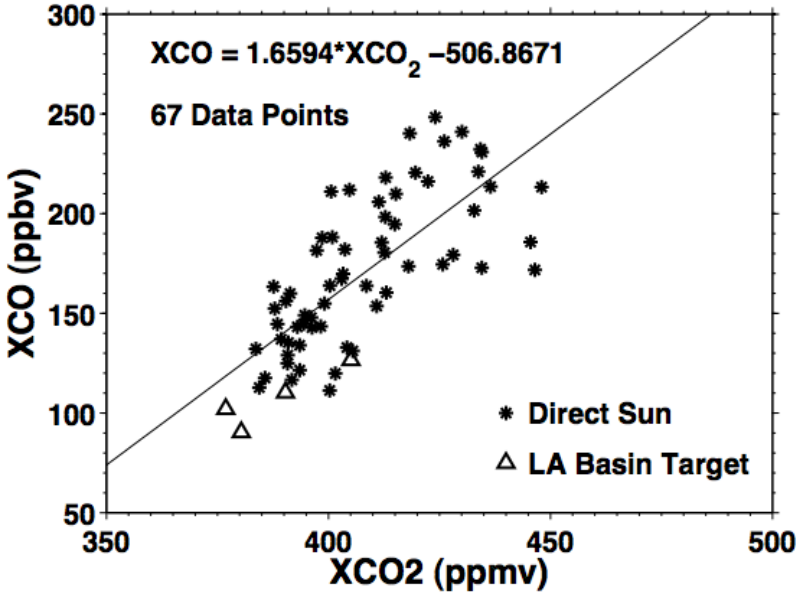
- XGAS = 0.2095x[Slant Column Density of GHG] /[Slant Column Density of O_2]
- Random error includes only the precision of the fitted spectra.
- Systematic error sources:
  - errors in spectroscopic parameters
  - higher-order uncertainties in optical path due to aerosols (O_2 measurement corrects first-order scattering effects)

XCO_2:XGAS Correlation on May 29th, 2010

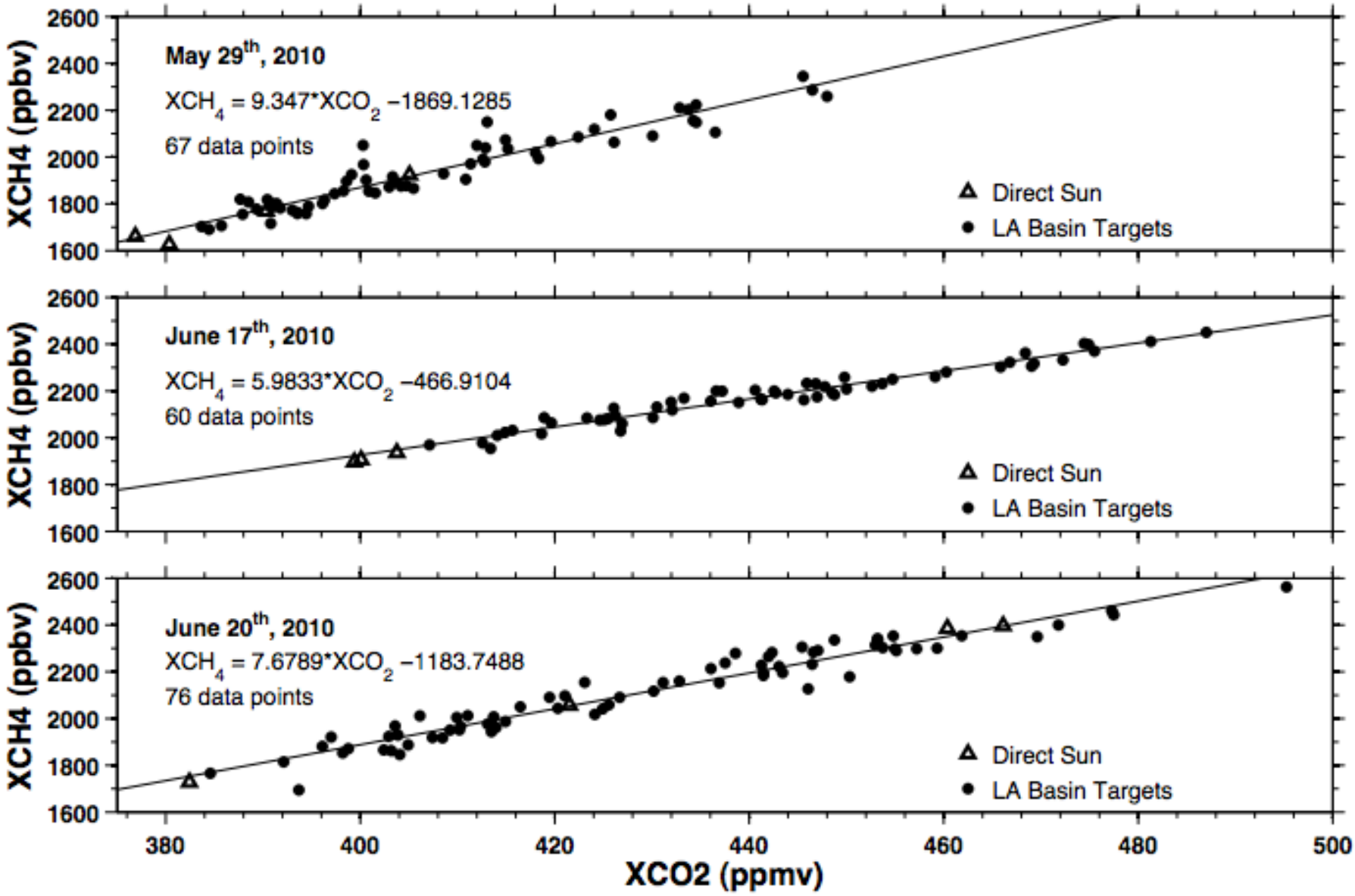




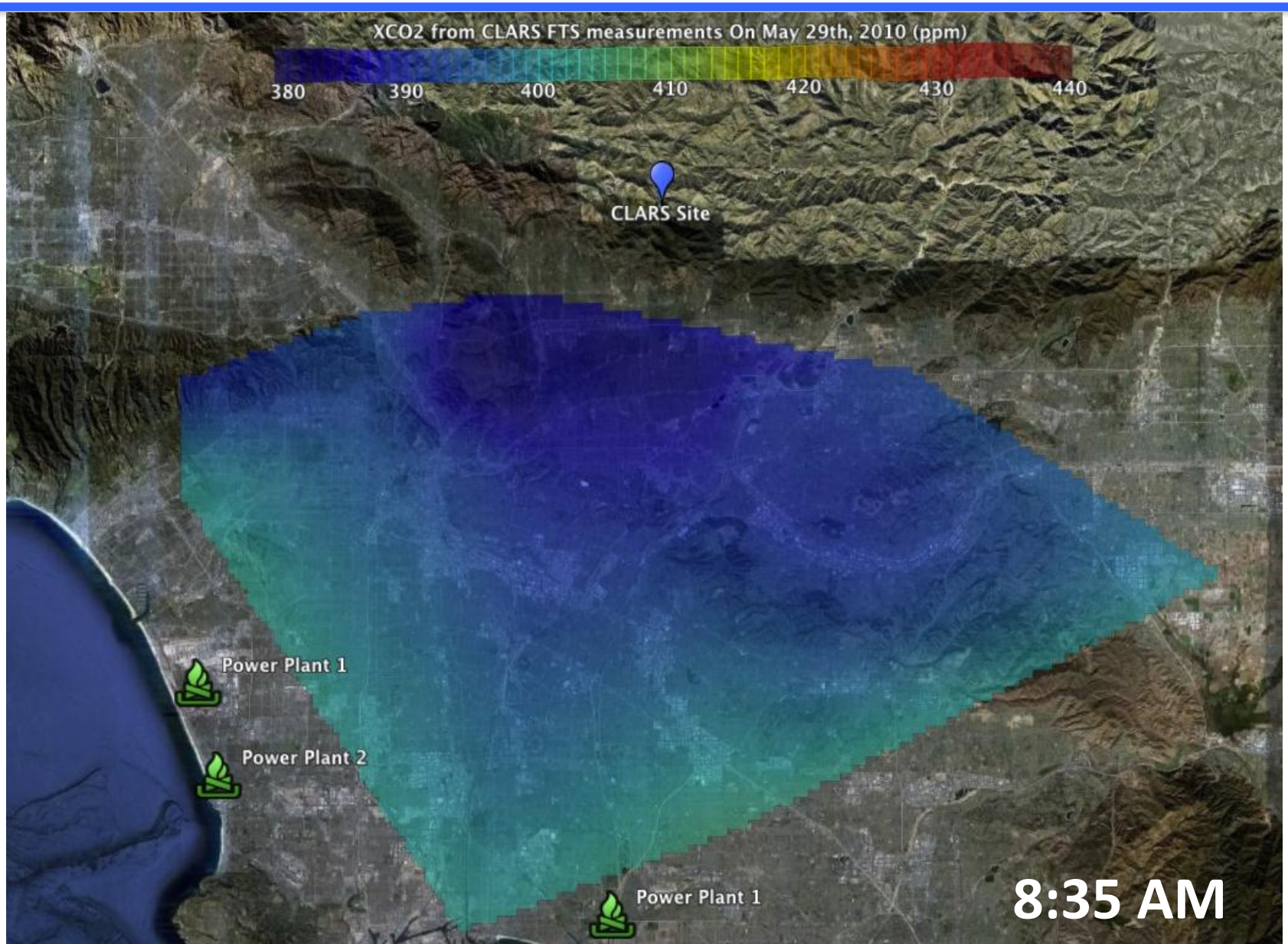
- XGAS = 0.2095x[GHG] /[O2]
- Ideal weather condition
- Near full day coverage
- XGAS for all targets on the pointing list are included



CH_4:CO_2 Correlation on May 29th, June 17th, June 20th, 2010



XCO_2 Distribution over LA Air Basin on May 29th, 2010



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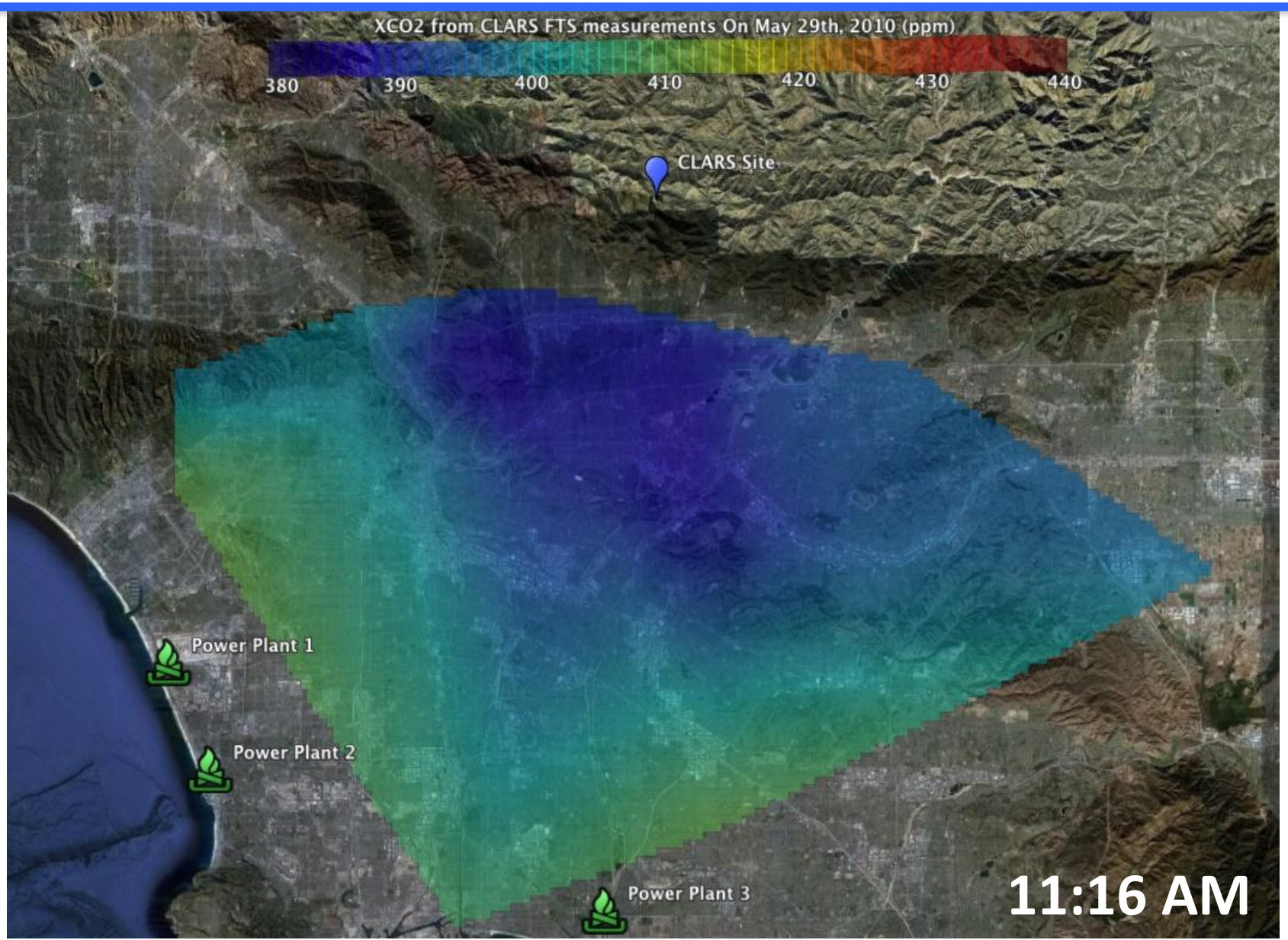

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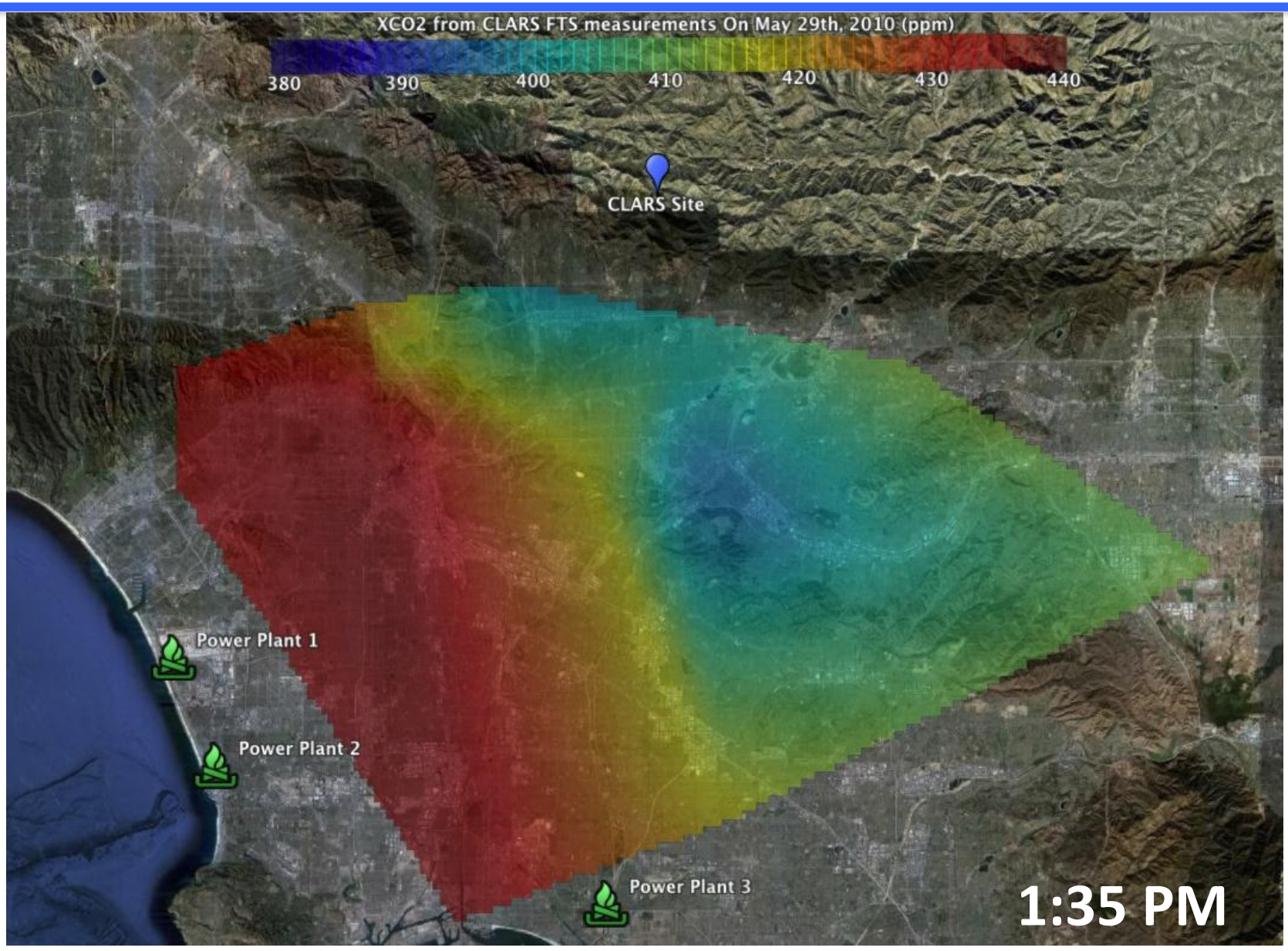
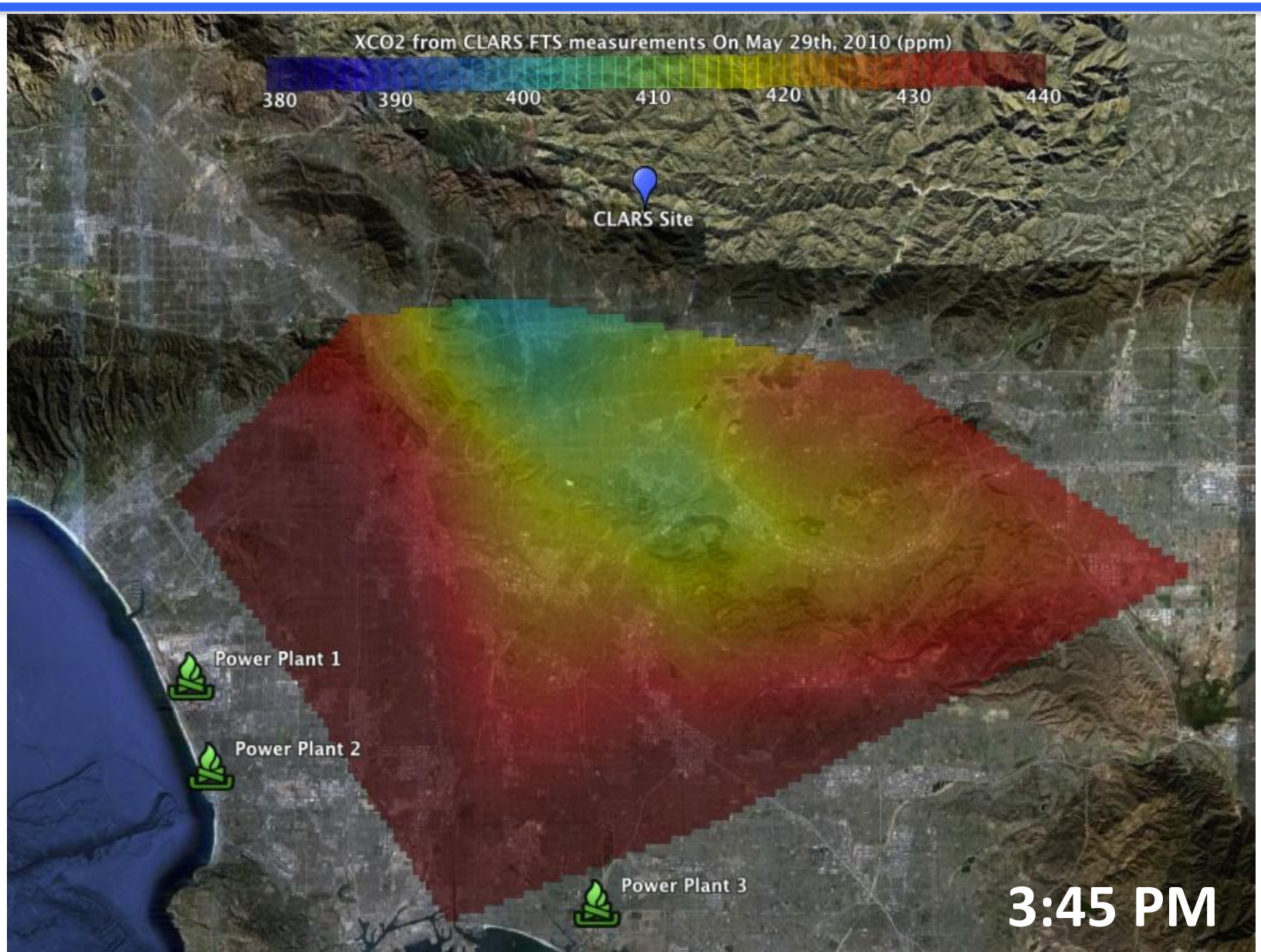
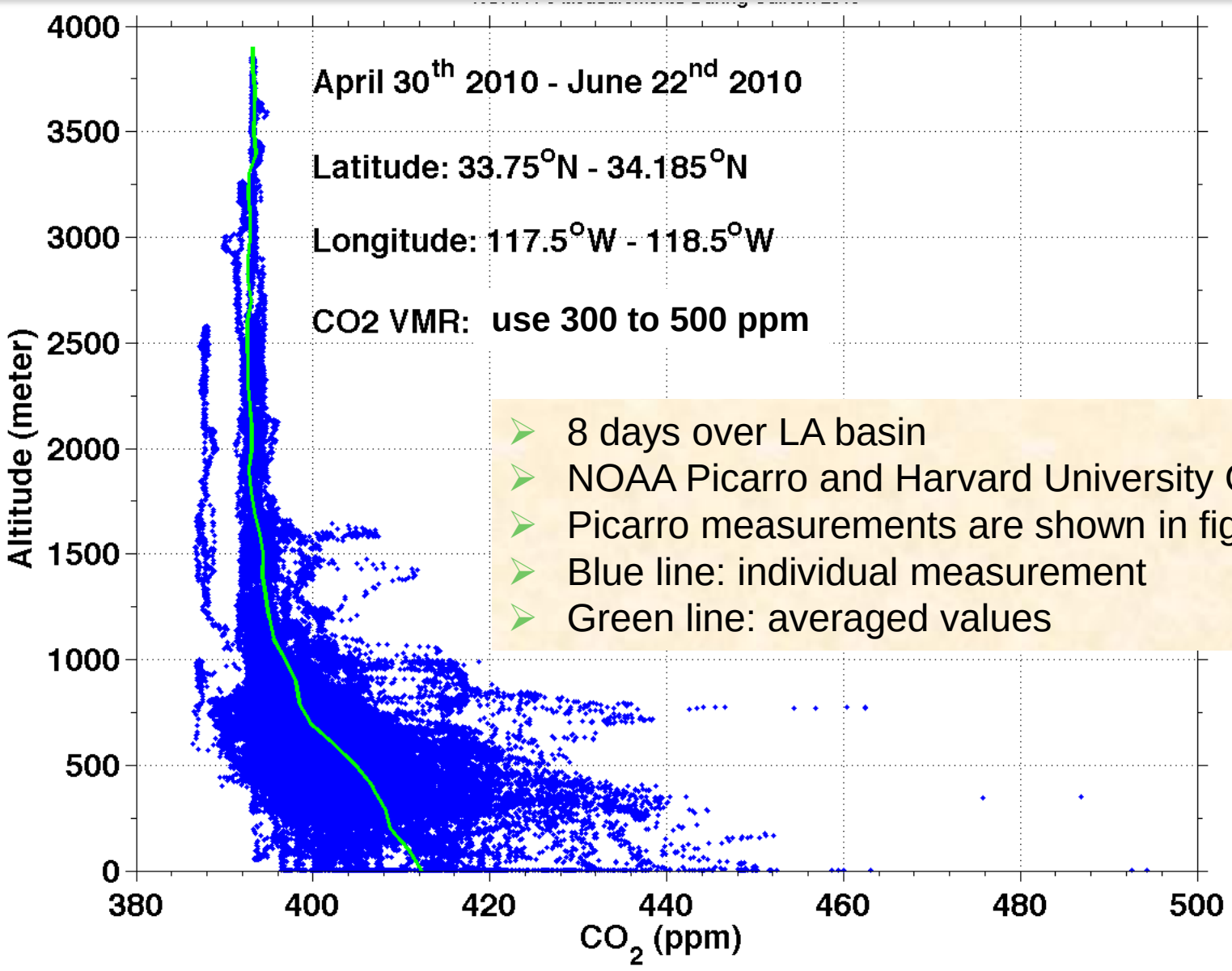


XCO_2 Distribution over LA Air Basin on May 29th, 2010

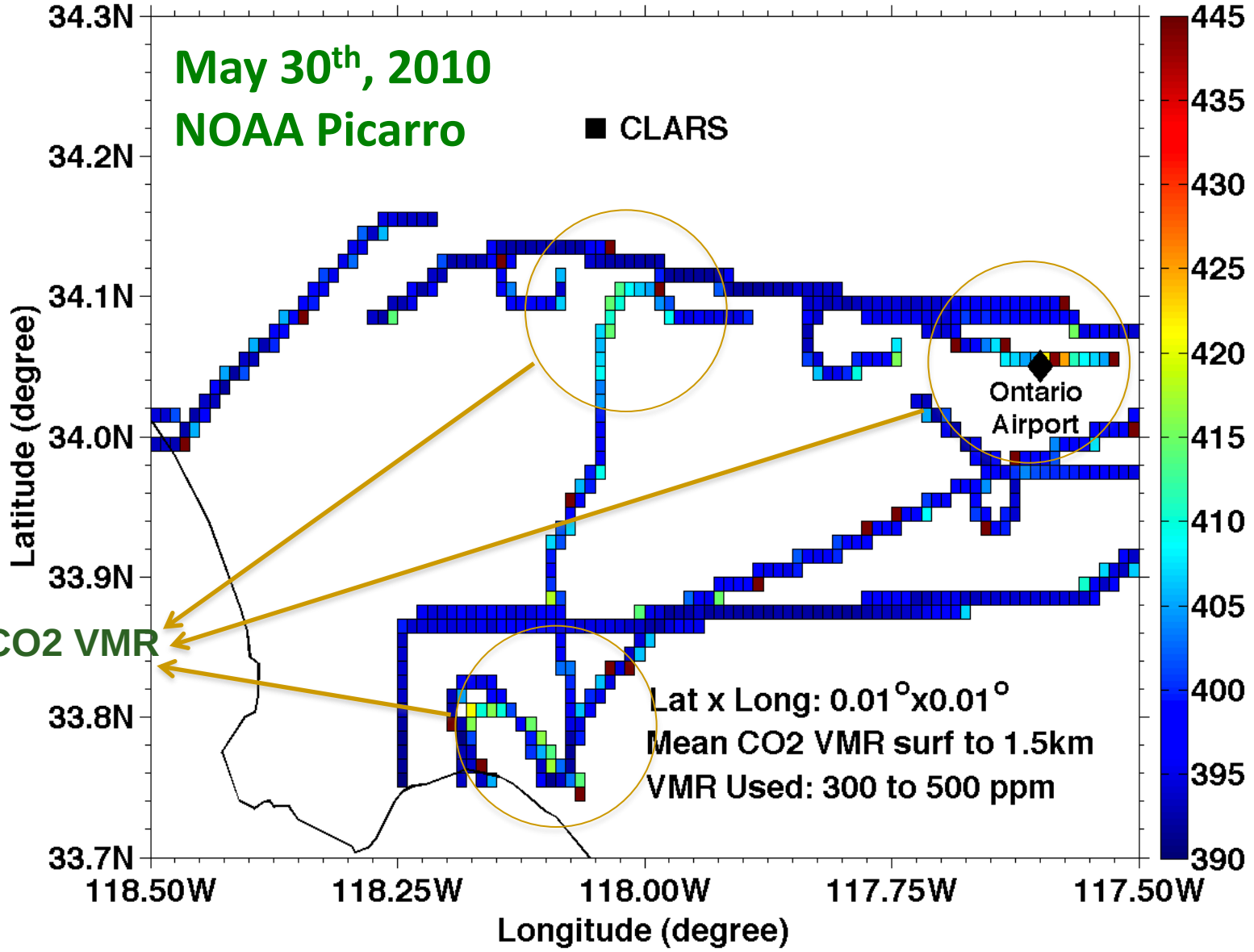


CO_2 Measurements From NOAA WP3 Flight During CalNex 2010



- 8 days over LA basin
- NOAA Picarro and Harvard University QCLS
- Picarro measurements are shown in figure
- Blue line: individual measurement
- Green line: averaged values

CO_2 Measured by Picarro on NOAA P3 Plane During CalNex 2010



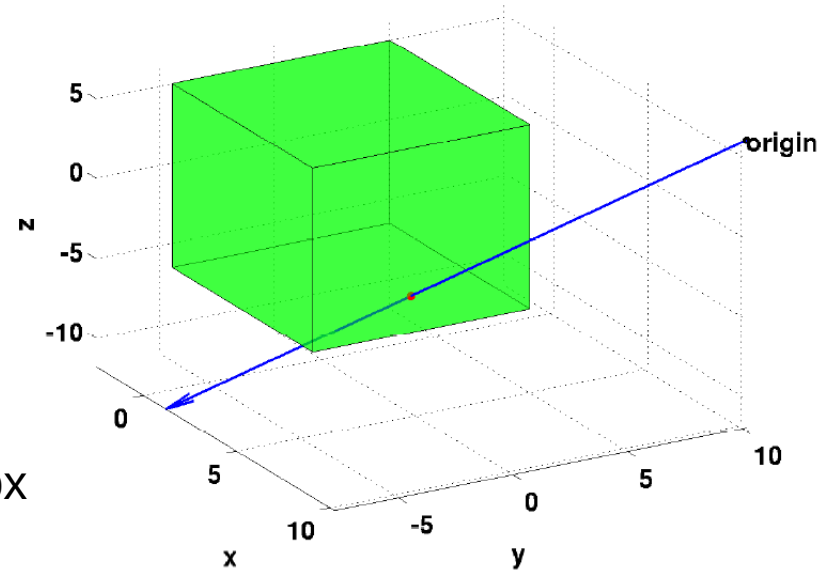
Validation Method

- **Challenges when compare in situ measurements to CLARS FTS measurements directly**
  - Spatial differences (vertical and horizontal directions)
  - Temporal differences
- **Possible solution**
  1. Use in situ measurements to validate simulations of WRF-VPRM and WRF-CHEM models
     - The status and results of modeling work will be present by Dr. ChangHyoun Park et al. (Poster #20) on Wednesday afternoon
  2. Use simulations of WRF-VPRM and WRF-CHEM models to validate CLARS FTS
     - Integrate slant column density within those model grid boxes along CLARS FTS viewing direction
     - Compare to the CLARS FTS measurements

Integration Slant Column Density in Each Grid Box of Model - Ongoing

- **Ray tracing program**
  - Based on Smits' algorithm

    Journal of Graphics Tools, 3(2):1–14, 1998
  - Input
    - Coordinates of origin [lat, long, alt]
    - Incident angle of sun light to grid box
    - Coordinates of grid box boundary
  - Output
    - light travel distance inside grid box
    - coordinates of outlet point



- **Compute the slant column density within each grid box**
  - GHG SC (molecules/cm^2) = GHG(molecules/cm^3) x light path (cm)

Summary and Future Work for CLARS FTS

- During CalNex campaign (May 14th to June 20th, 2010), CLARS FTS made measurements on 31 days (out of 38 days).
- Measurements are continuing after CalNex campaign for long term record.
- XCO_2, XCH_4, XCO, XN_2O are are computed using measured column densities. The XGAS show correlations that will be used to determine the emission rates of GHG.
- Validation/improvement of retrieval method using correlative data (ground-based and aircraft) are ongoing.
- The WRF-VPRM and WRF-CHEM models for Los Angeles are being developed by the group of Qinbin Li at UCLA. The model will directly assimilate GHG and CO slant columns to derive top-down emissions (poster P20 by Dr. ChangHyoun Park et al. on Wednesday afternoon)

Acknowledgements

- Drs. Geoffrey C. Toon and Jean-Francois Blavier at JPL
- NOAA
- California Air Resources Board
- NASA
- UCLA JIFRESSE
- Your Attention

Los Angeles Air Basin December 31st, 2009

Estimation of Measurement Uncertainty

Optimal Estimation Formulism [Rodgers 2000]

$$\mathbf{S} = (\mathbf{K}^T \mathbf{Se}^{-1} \mathbf{K} + \mathbf{Sa}^{-1})^{-1}$$

Where

S is a n by n covariance matrix

K is a n by m Jacobian matrix

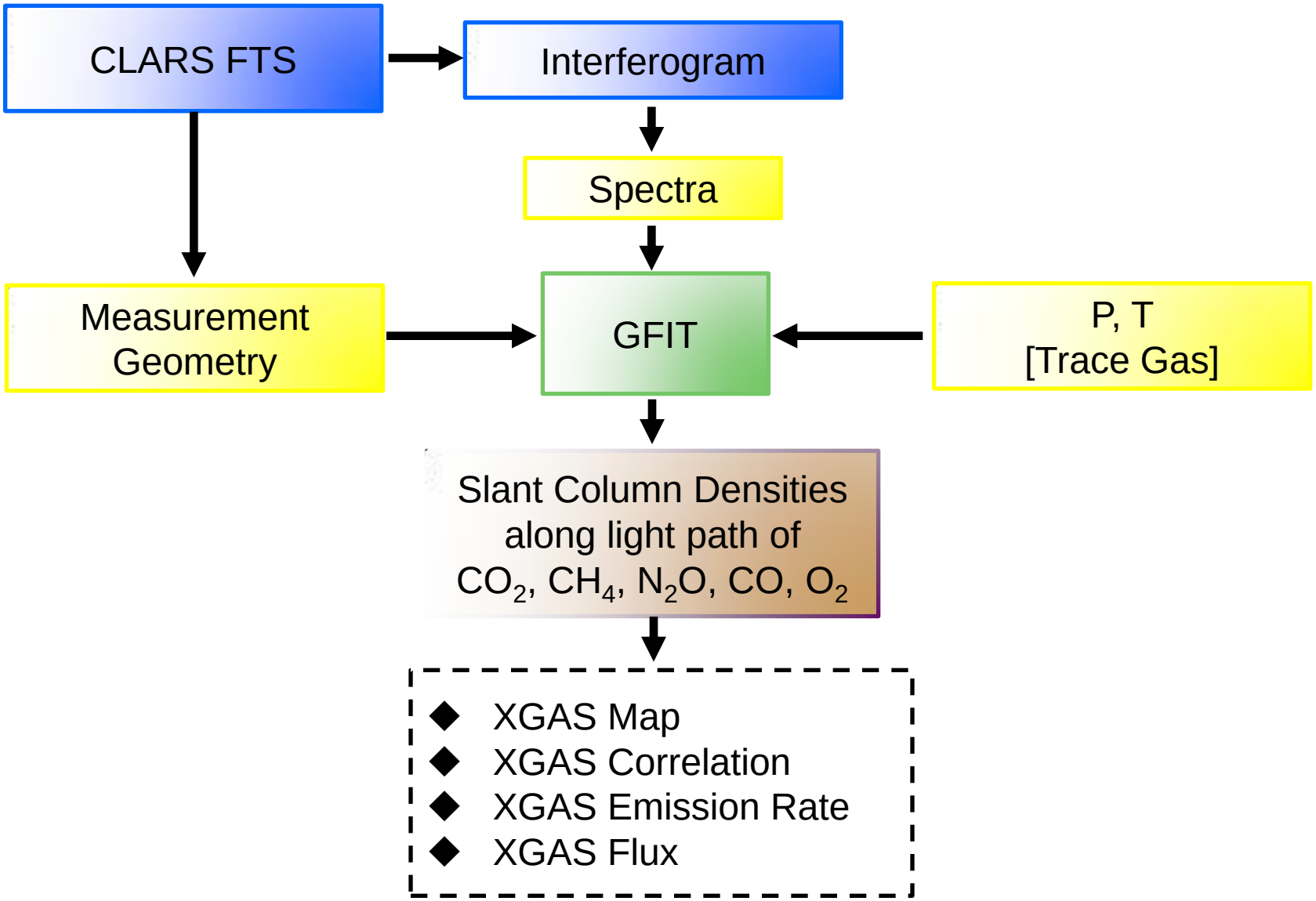
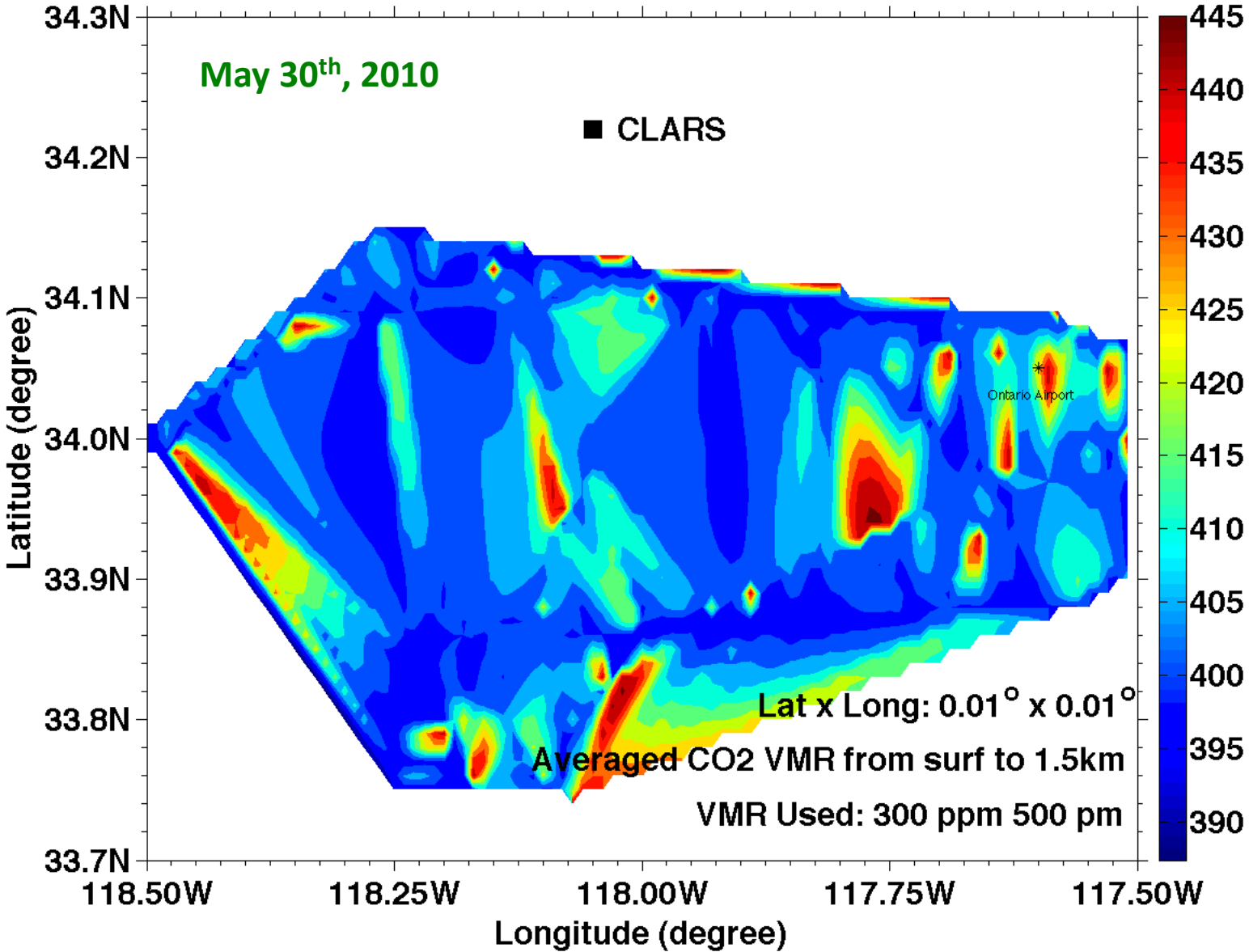
Se is a m by m covariance matrix of measurement noise

Sa is a n by n covariance matrix of a priori uncertainty

n is the number of parameters contributing to measurement uncertainty

m is the number of spectral data points

CLARS FTS Data Processing Program V1.0



CO_2 Measurements From NOAA WP3 Flight on May 30th, 2010