Fourier Transform Spectrometer to Measure Carbon, Climate & Chemistry Couplings: Bridging ARM, Ecosystems and Satellite Scales for Long Term Monitoring & Process Studies

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ARM-CAPI-WG, 10/13/10

U.S. DEPARTMENT OF ENERGY | Office of Science

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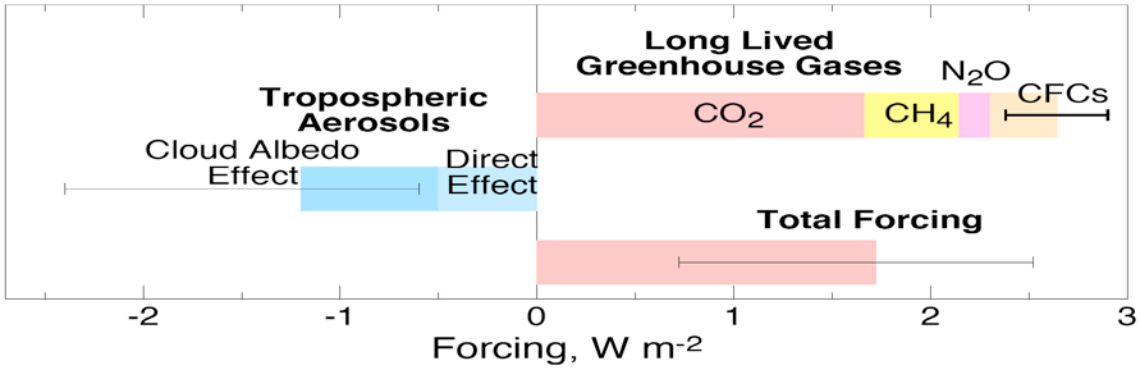
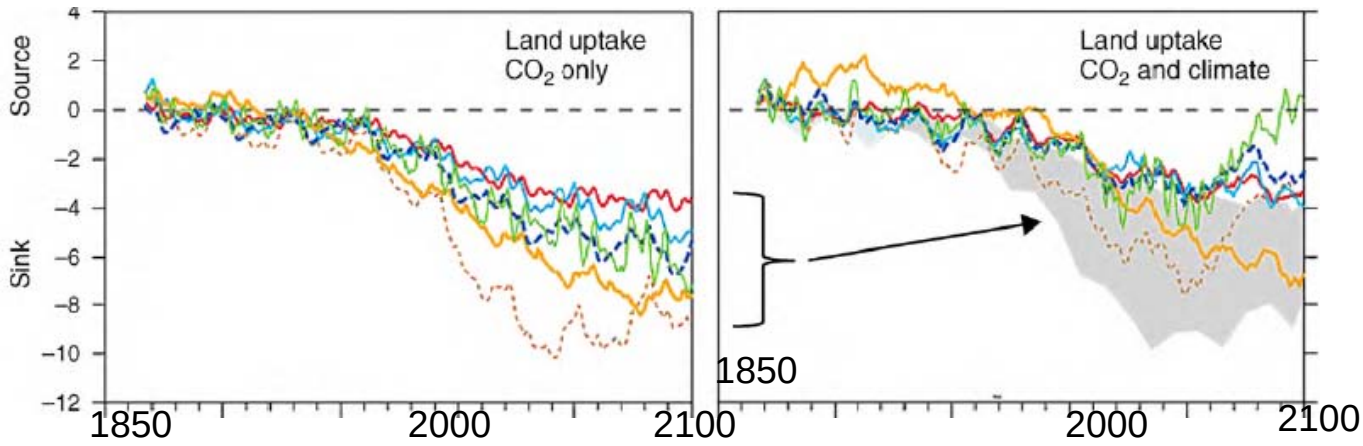
Strengthen OBER Leadership in integrated carbon-aerosol-cloud-radiation observations for more precise climate change predictions by bridging scales and coupling processes

- Largest "short term" uncertainty: Aerosols, Clouds, Radiation, Precipitation



Radiative Forcing
Cloud Feedbacks
(ARM-ASR-CAPT-ESM)

- Largest "long term" uncertainty: Terrestrial Carbon-Climate Feedback



2100 CO_2 uptake by land declines in models (TerCarbon-ESM)

IPCC-2007

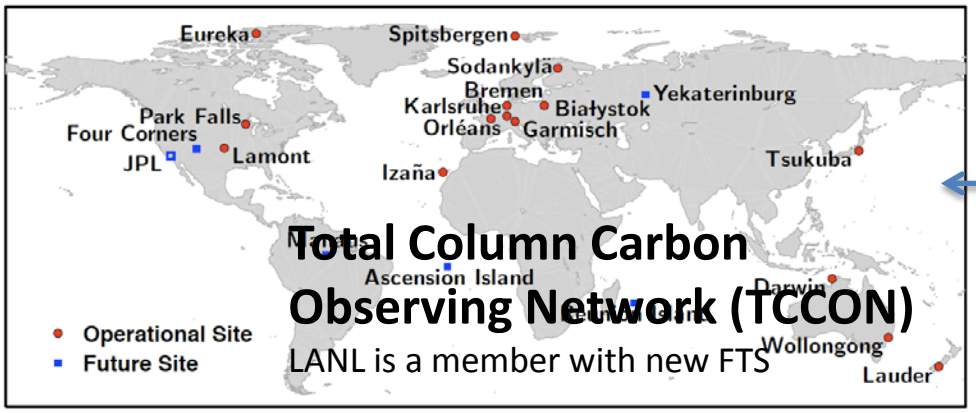
- OBER framework ideal to measure-link both on climate model scales

LANL-FTS facilitates integration of OBER's long term ground carbon cycle observations with new satellite data harnessing ARM's framework to refine models (e.g. CAPT)

BER-ARM sites

LANL operates TWP, Mobile, MAOS

CO_2 VALIDATION & SCALING FOR GLOBAL OBERVATIONS



Total Column Carbon Observing Network (TCCON)

LANL is a member with new FTS

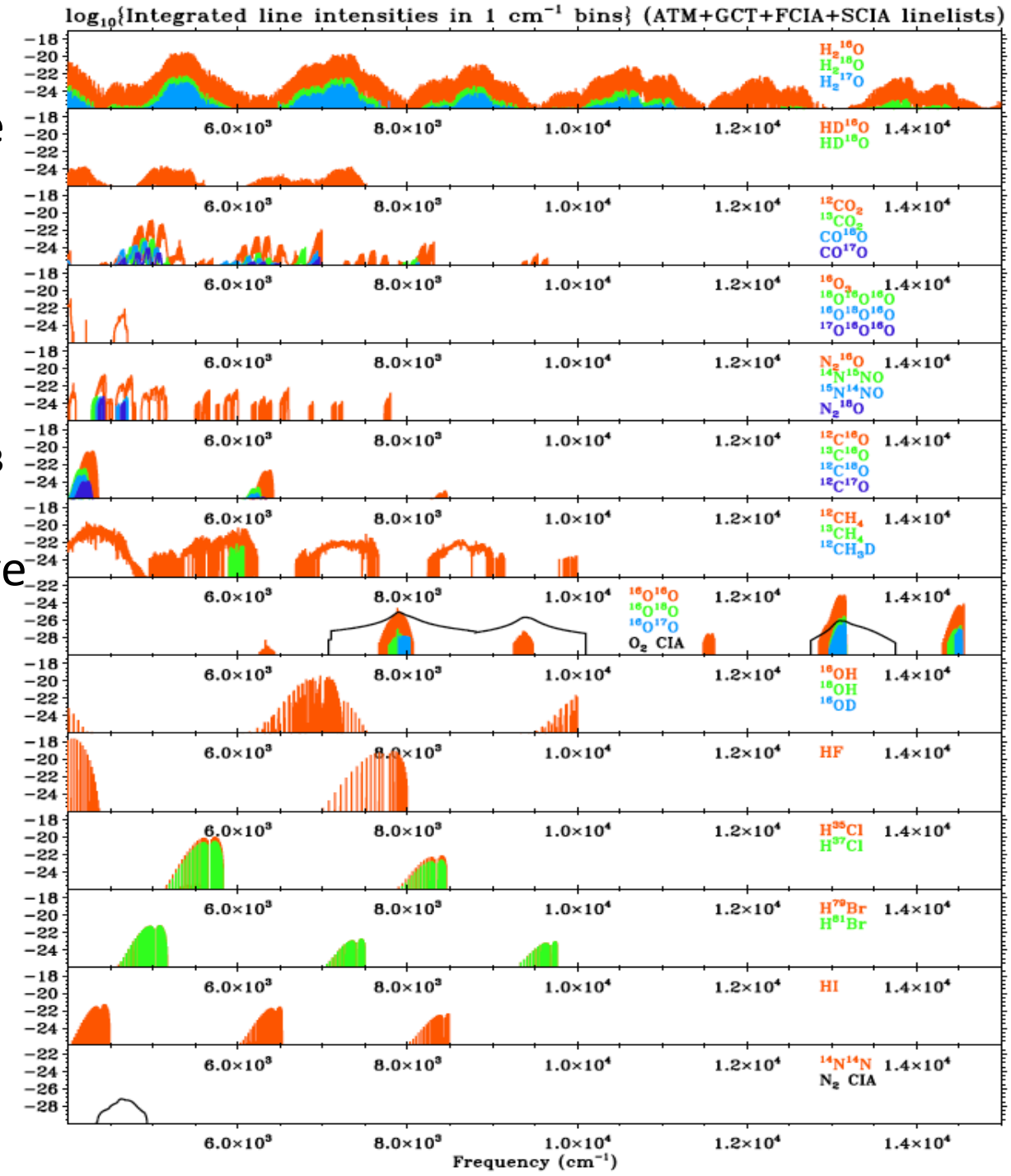
GOSAT and OCO-II

LANL is on Science Team

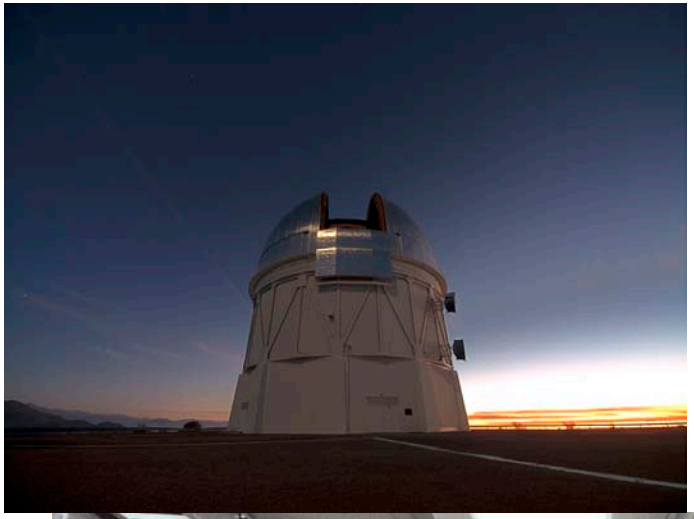
Total Column Carbon Observing Network (International self organized conglomerate)

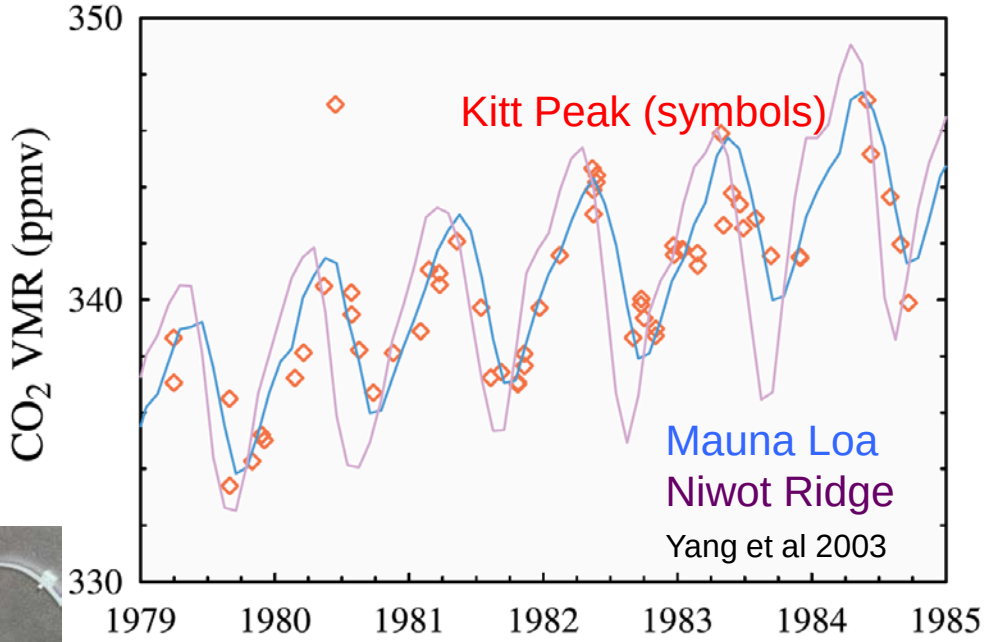
NASA-ARM-ESA-JAXA Synergies, GOSAT & OCO-2 (Feb 13) Validation
Direct solar high res spectra: H_2O/HOD, aerosol, LBL-RT validation

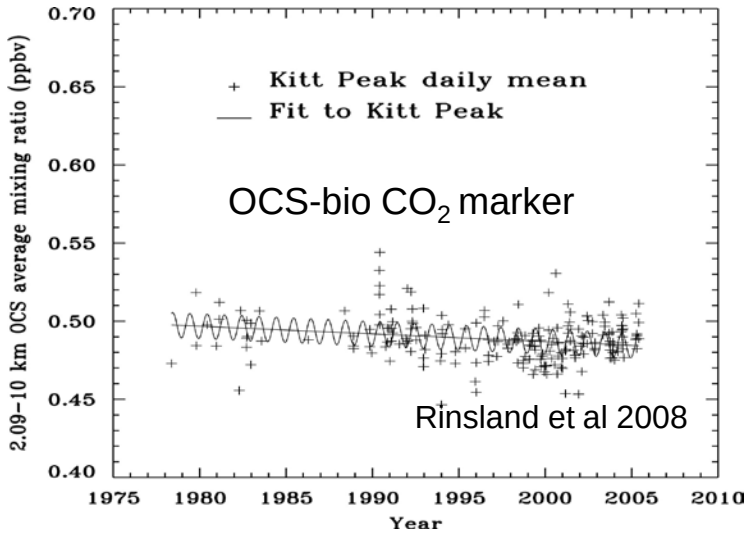
High resolution solar absorption spectra have fingerprints that can be used to retrieve column H_2O, CO_2, CO, CH_4, N_2O, O_2, their isotopomers, pollutants (NOx, SO_2, O_3 organics), aerosols and their precursors that drive climate change.



Astrophysics to Climate: Archived Kitt Peak Data Informs Large Scale Remote Atmospheric Observation Techniques







LANL-FTS: Automated Solar Observatory for Carbon, Climate, Chemistry (Radiation) Monitoring at Ecosystem Scales & High Frequency

- Sun Tracking Fourier Transform Spectrometer (FTS)
- UV-vis-NIR-MIR spectra high res.
- Column CO_2, H_2O, CH_4, N_2O, CO, NO_2, aerosols, HOD, $^{13}CO_2$
- Resolution 2 min., 10-100 km
- Transportable, Robotic, Rugged
- Meteorological Towers
- Aeronet-CIMEL (aerosols)
- In situ CO_2, CO, NOx, $^{13/14}CO_2$
- More versatile than JPL-FTSs at SGP and Darwin, Moveable
- Monitoring, Scaling, Validation

Scale Carbon-Climate-Chemistry Feedbacks and Attribute Emissions/Sinks Remotely

- How accurately can we infer large scale CO_2 fluxes?
- Can we use NOx, CO, $^{13}CO_2$ to attribute sources?
- Calibrate inversions for known emissions to evaluate more complex ecosystem carbon cycle models?
- FTS/Satellite data + WRF model + Emissions/Sinks
- Enable long-term large-scale monitoring of CO_2, H_2O, aerosols and trace gases in OBER (ARM) with rich climate data sets to enhance knowledge of carbon-climate-cloud-aerosol-water-radiation couplings at model grid scales.

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Outline

- Status of LANL-FTS (CO_2, $^{13}CO_2$, CO, NO_2, O_3)
  - Assembled and Tested Meets TCCON standard
  - First Light: Retrievals at Pagosa Springs, FIDO facility
- Four Corners Power Plant Closure Study
  - Site Preparation (power, gravel, fence) complete
  - Deployment Late August 2010
- Satellite-NO_2: Ozone Monitoring Instrument (OMI-NASA) trends at 4-Corners show abrupt changes
- WRF-Chem/Carbon for source attribution & sinks
- Attribution in situ (PTRMS), remote (FTS)

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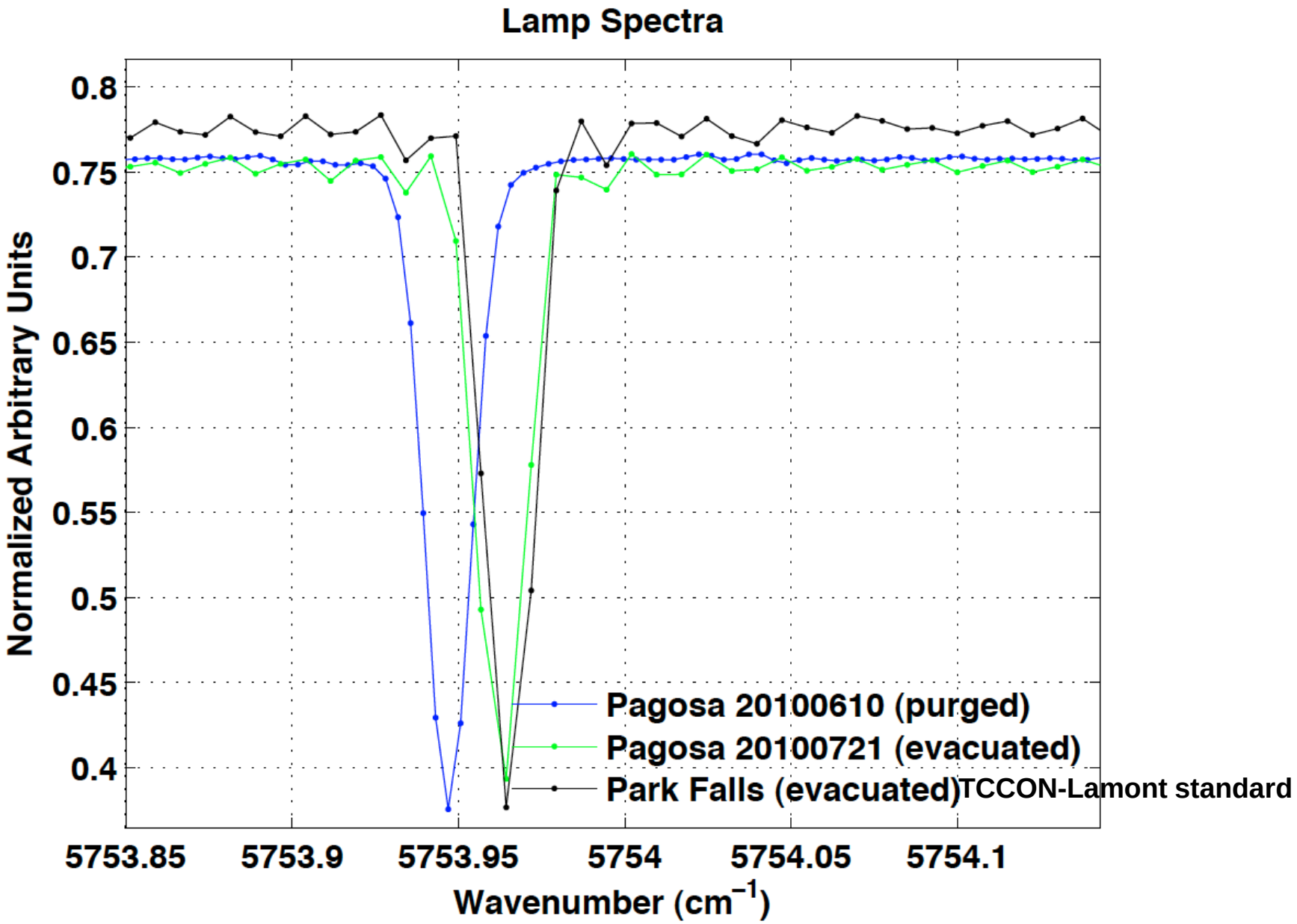
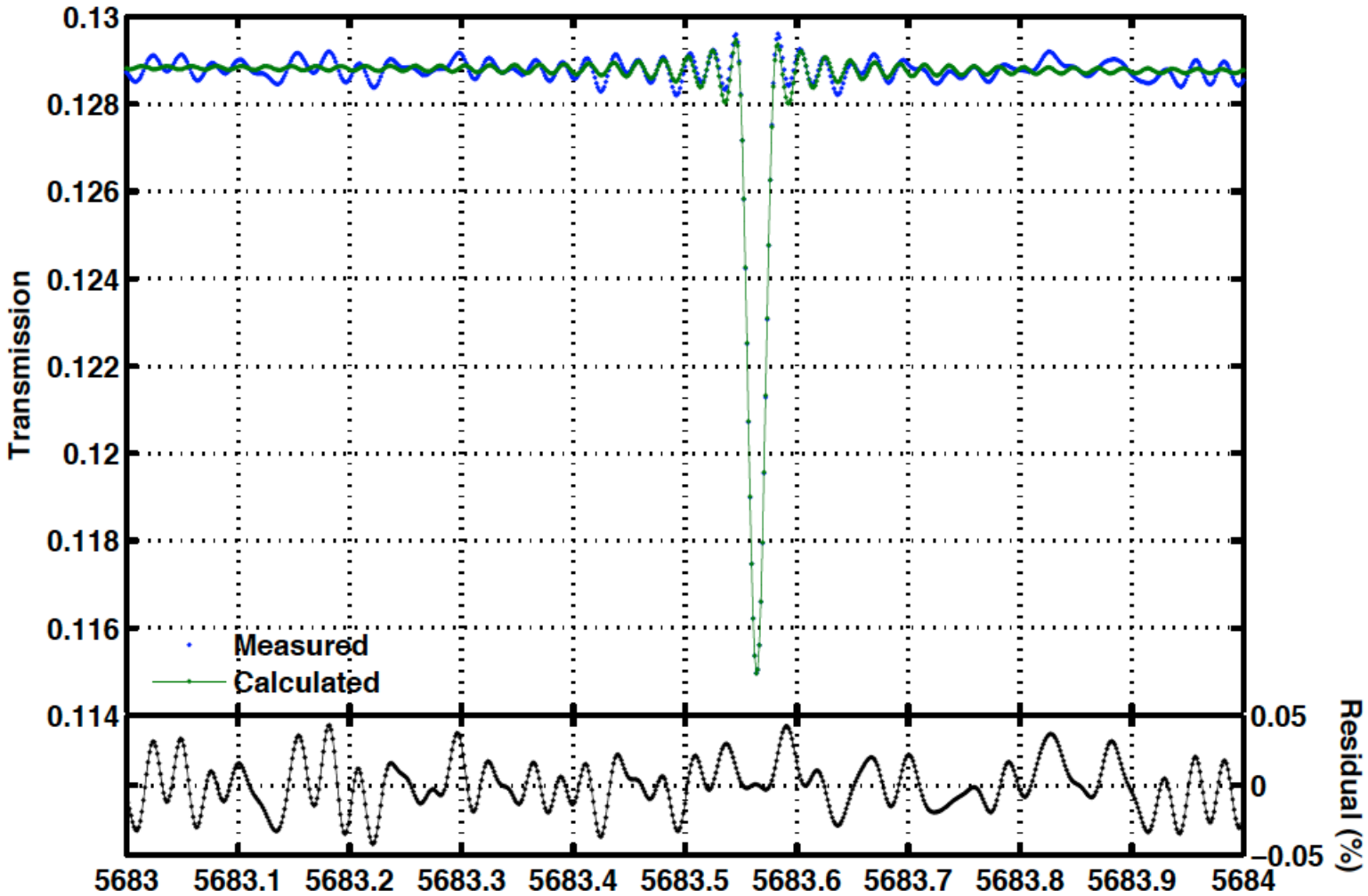
LANL Solar Tracking Fourier Transform Spectrometer (Vis-UV-NIR-MIR) for CO_2 and *signature scaling

AUTOMATED REMOTE SOLAR OBSERVATORY

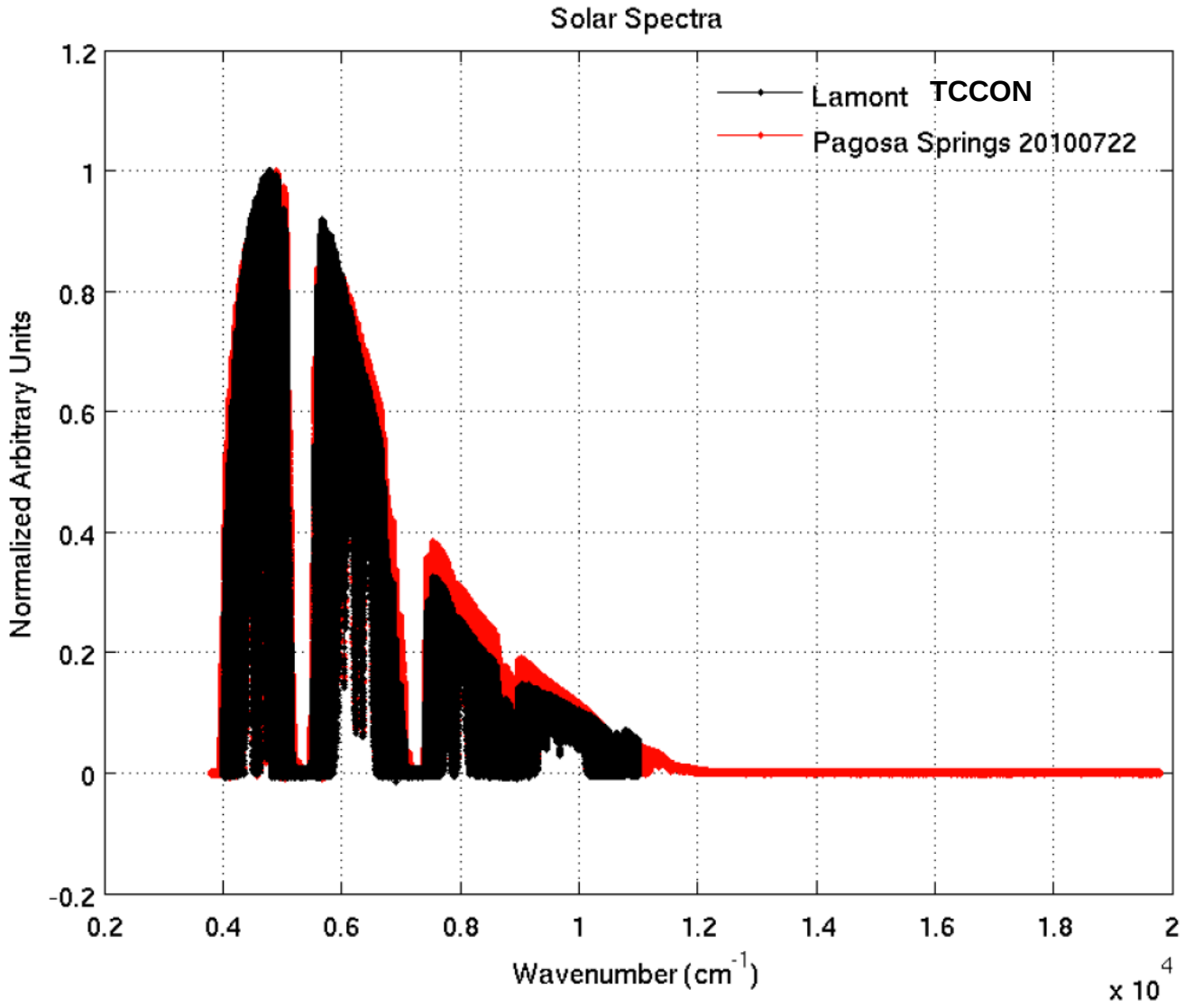
Wavelength Standard (TCCON): HCl line calibration



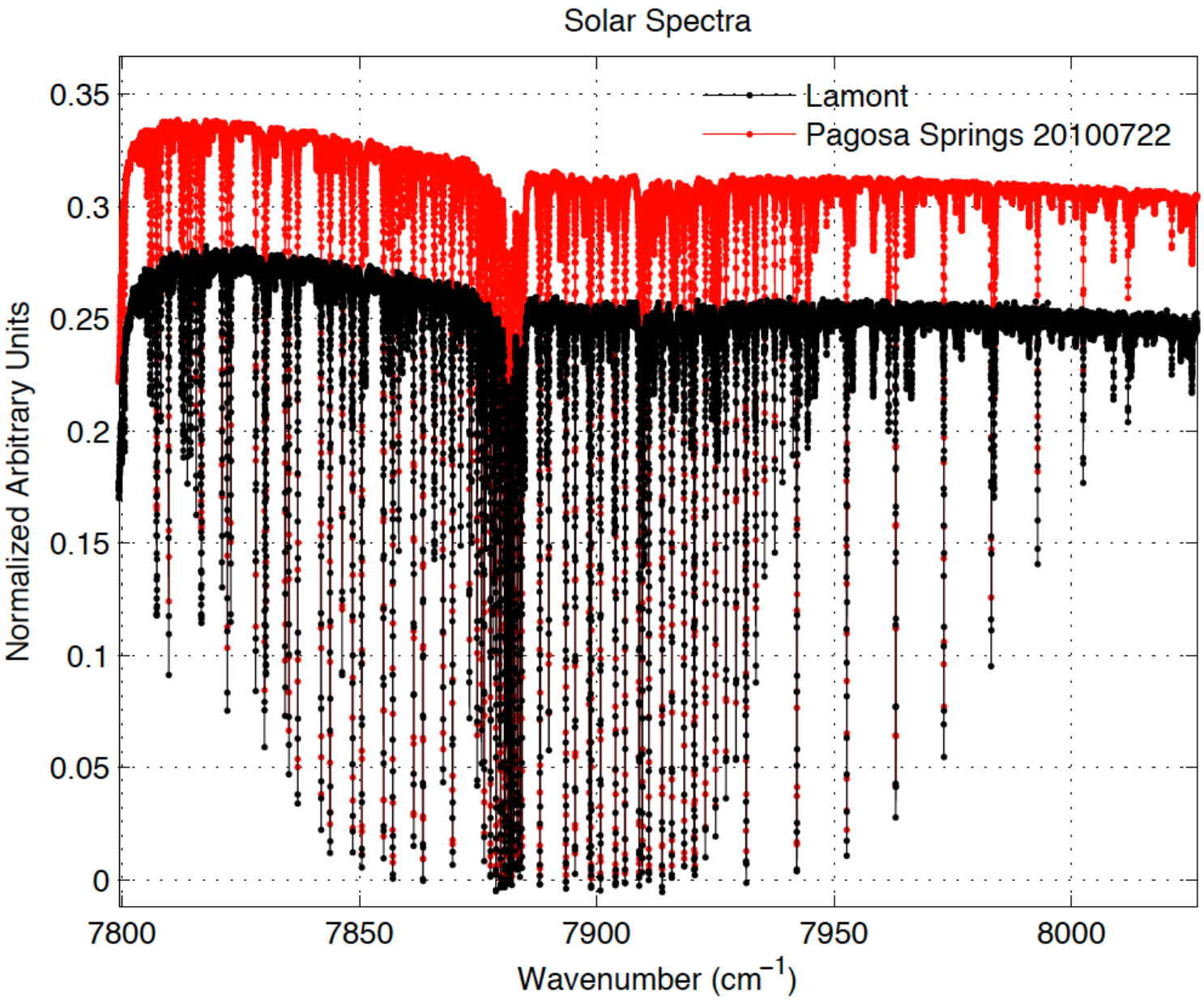
Resolves HCl lines (at 0.02 cm^{-1})



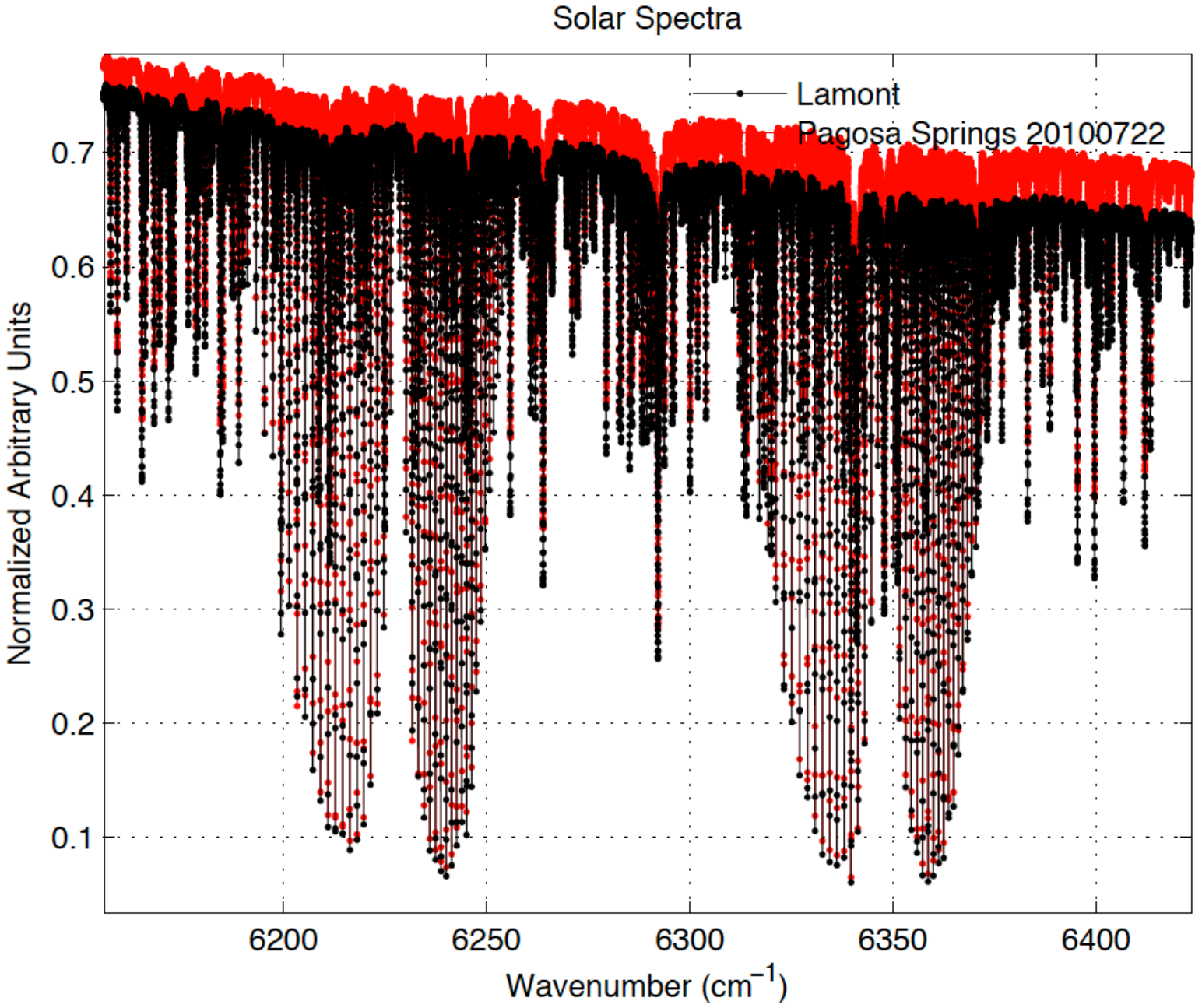
Solar Spectra (2 scans, 4 minutes)



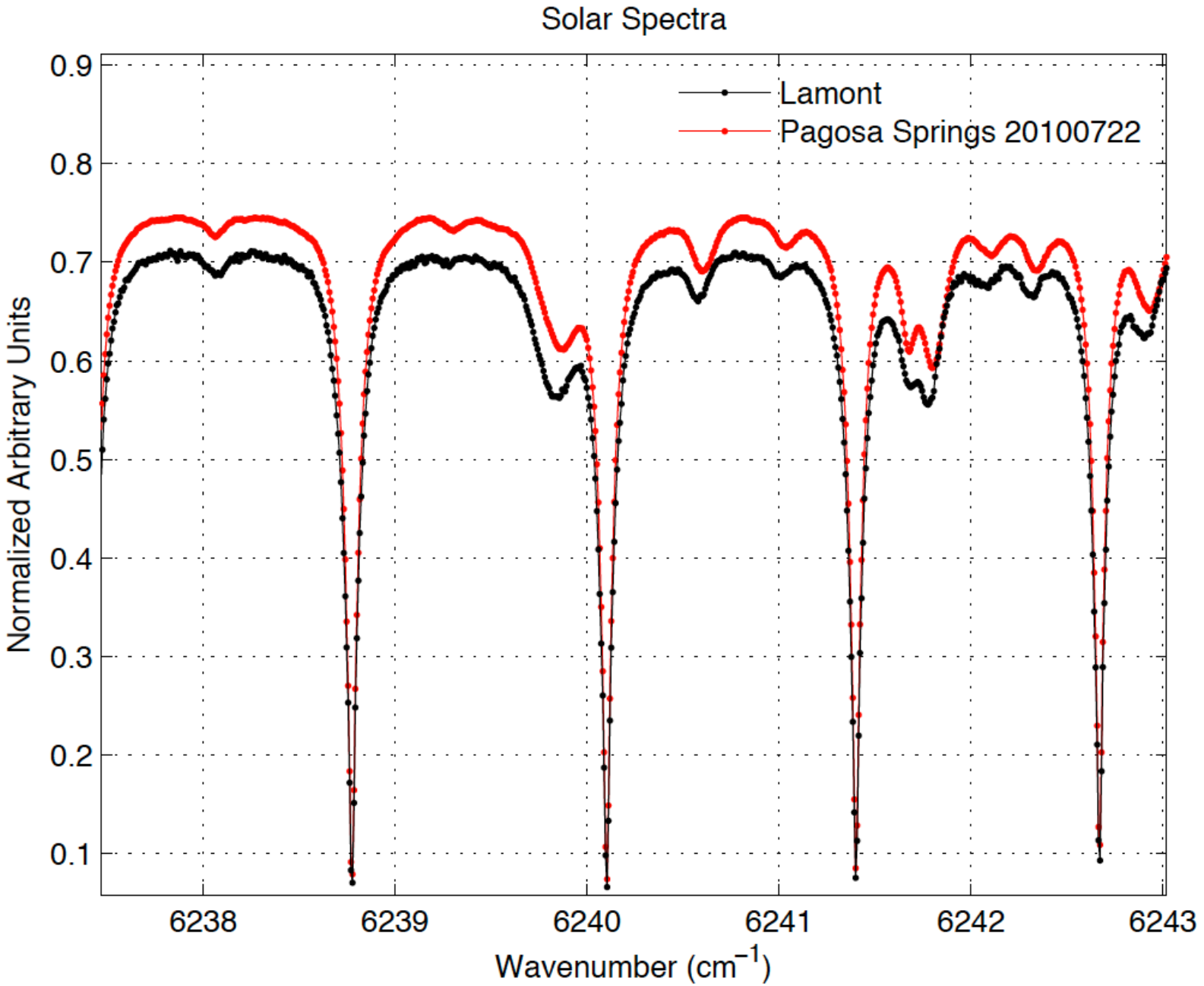
O_2 A-Band


Solar Spectra
Lamont
Pagosa Springs 20100722
Normalized Arbitrary Units
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
7800
7850
7900
7950
8000
Wavenumber (cm^{-1})

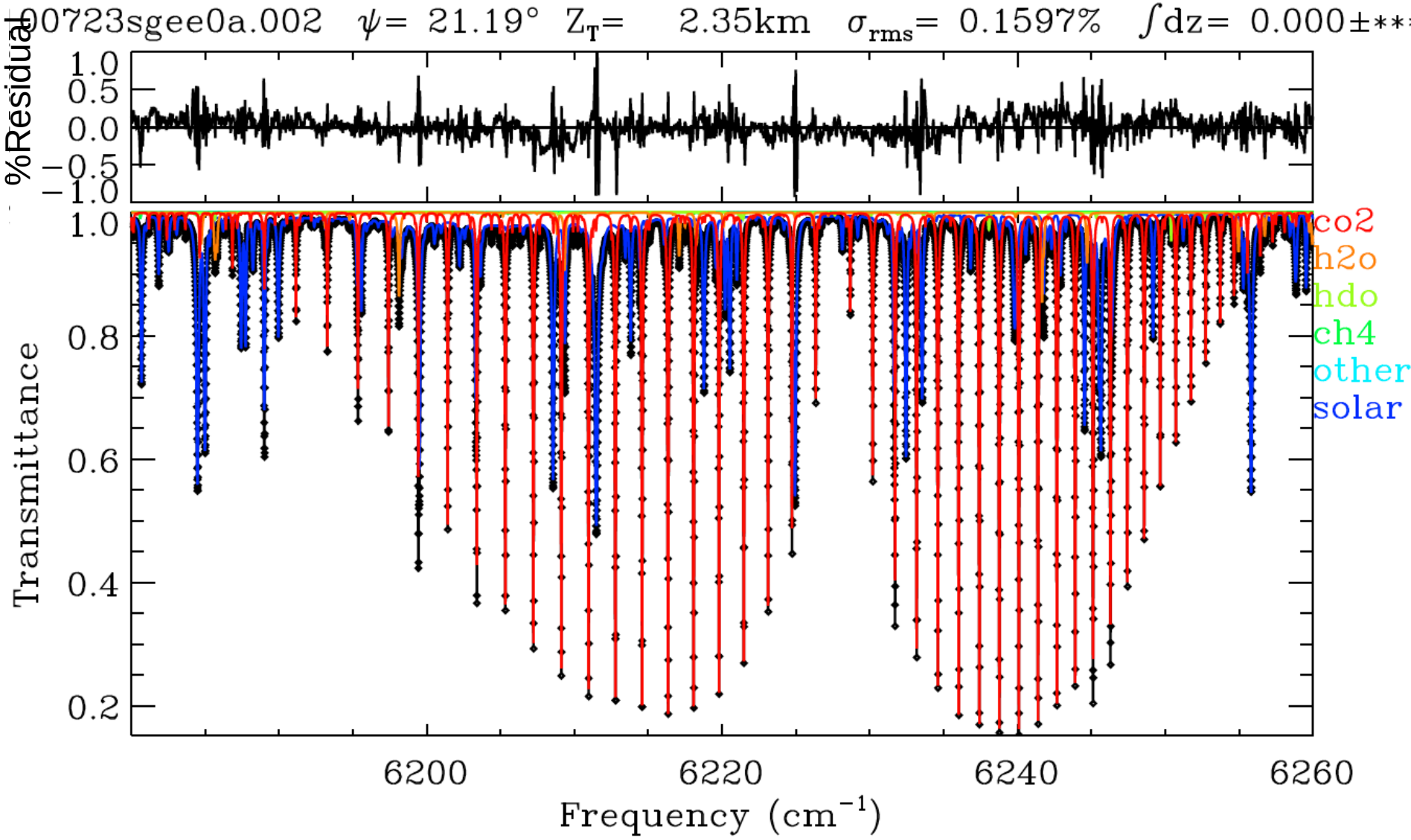
CO_2 Lines


Solar Spectra
Lamont
Pagosa Springs 20100722
Normalized Arbitrary Units
0.1
0.2
0.3
0.4
0.5
0.6
0.7
6200
6250
6300
6350
6400
Wavenumber (cm^{-1})

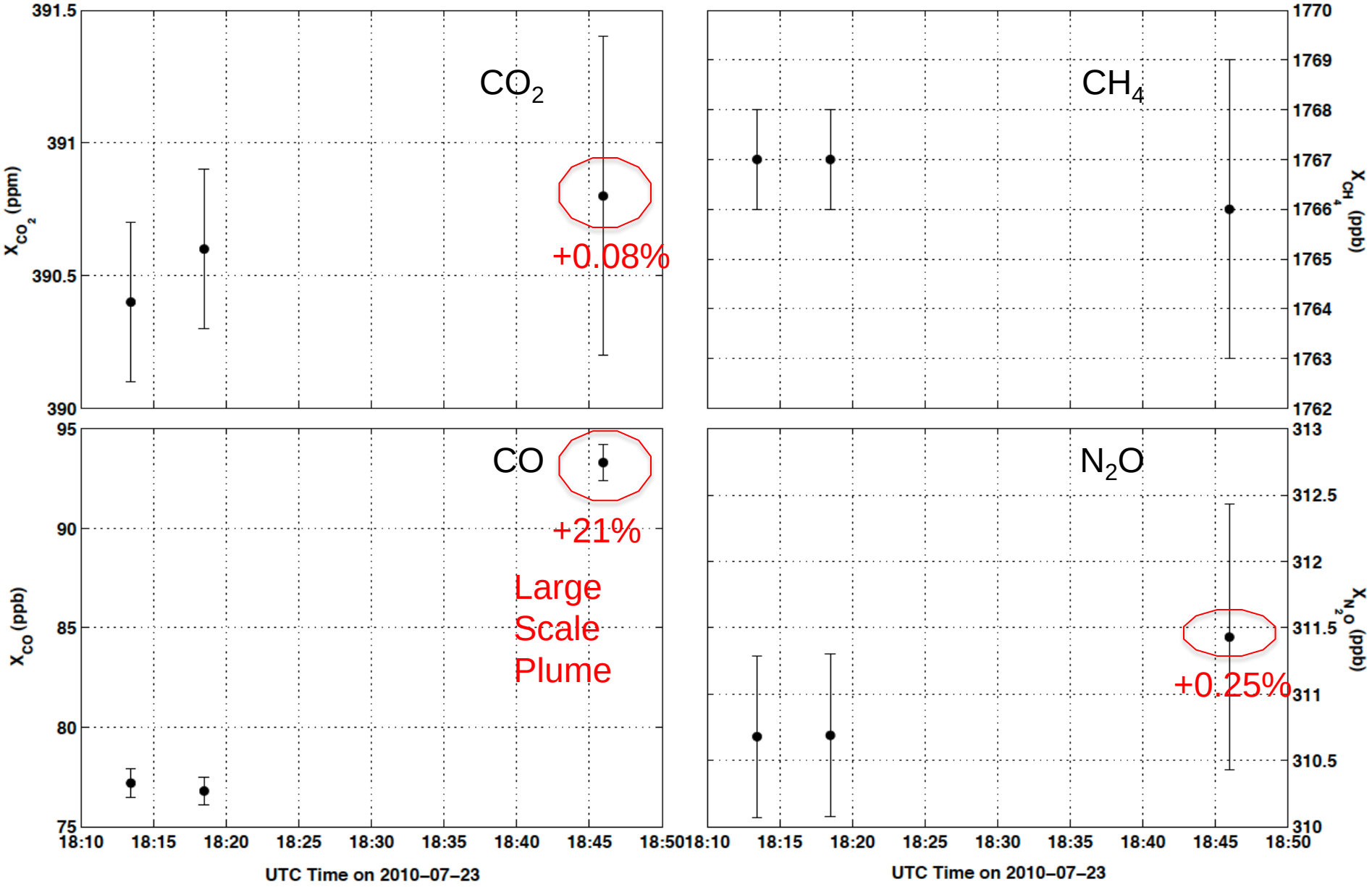
Individual CO_2 Lines



Solar Spectra Fit for CO_2 Retrieval



Column CO_2, CO, CH_4, N_2O at Pagosa Springs, 7/23/10



Progress in Pictures: LANL-FTS at ARM-Pagosa Springs

Progress in Pictures

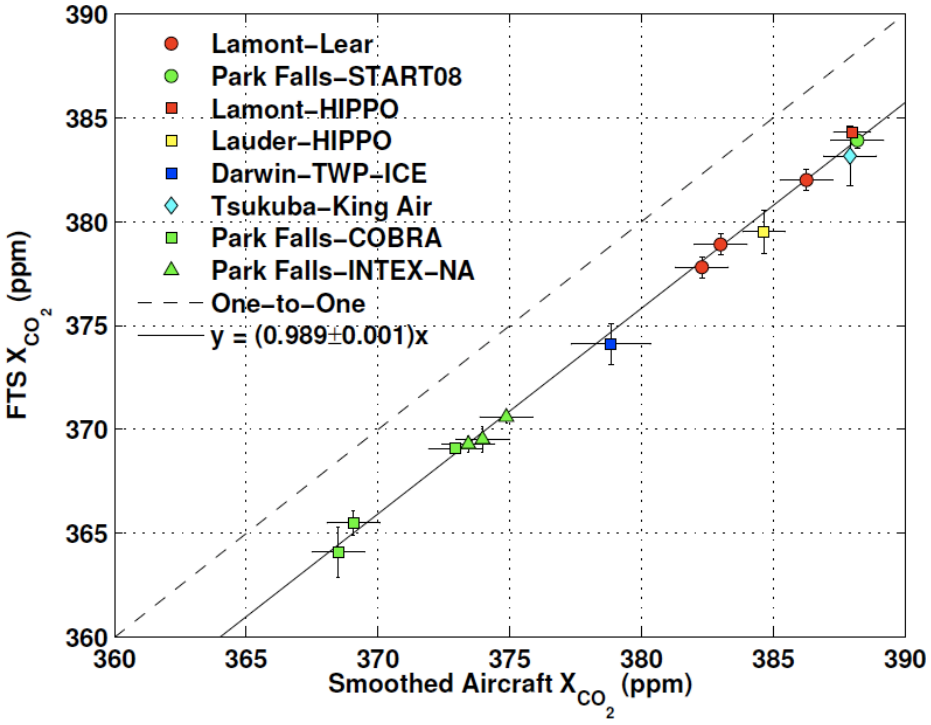
Location: San Juan Sub Station

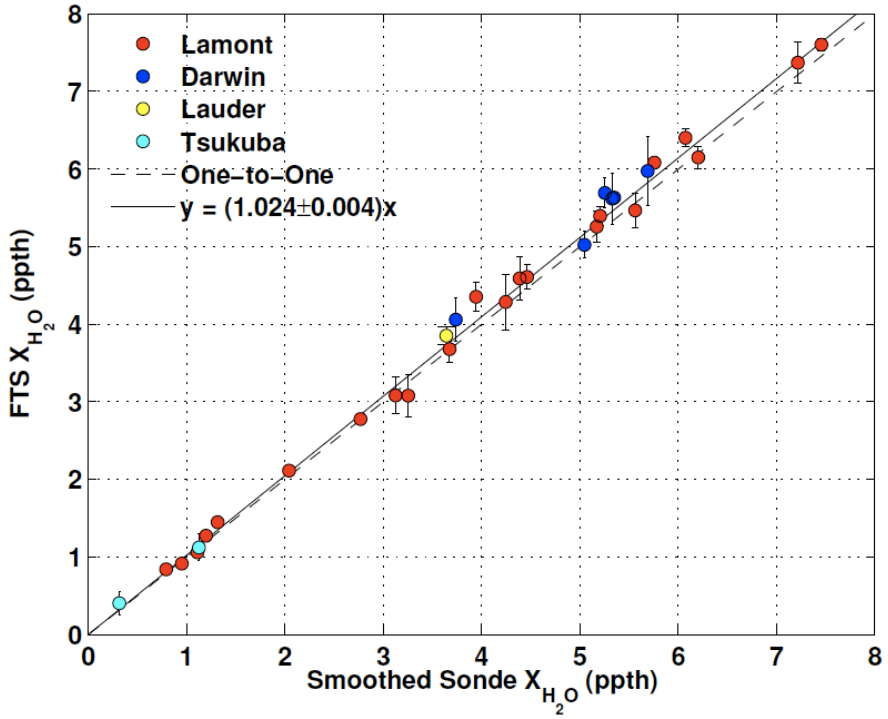
Site: Pre-prep

Site Ready Aug 2010: Gravel, Fence, Power

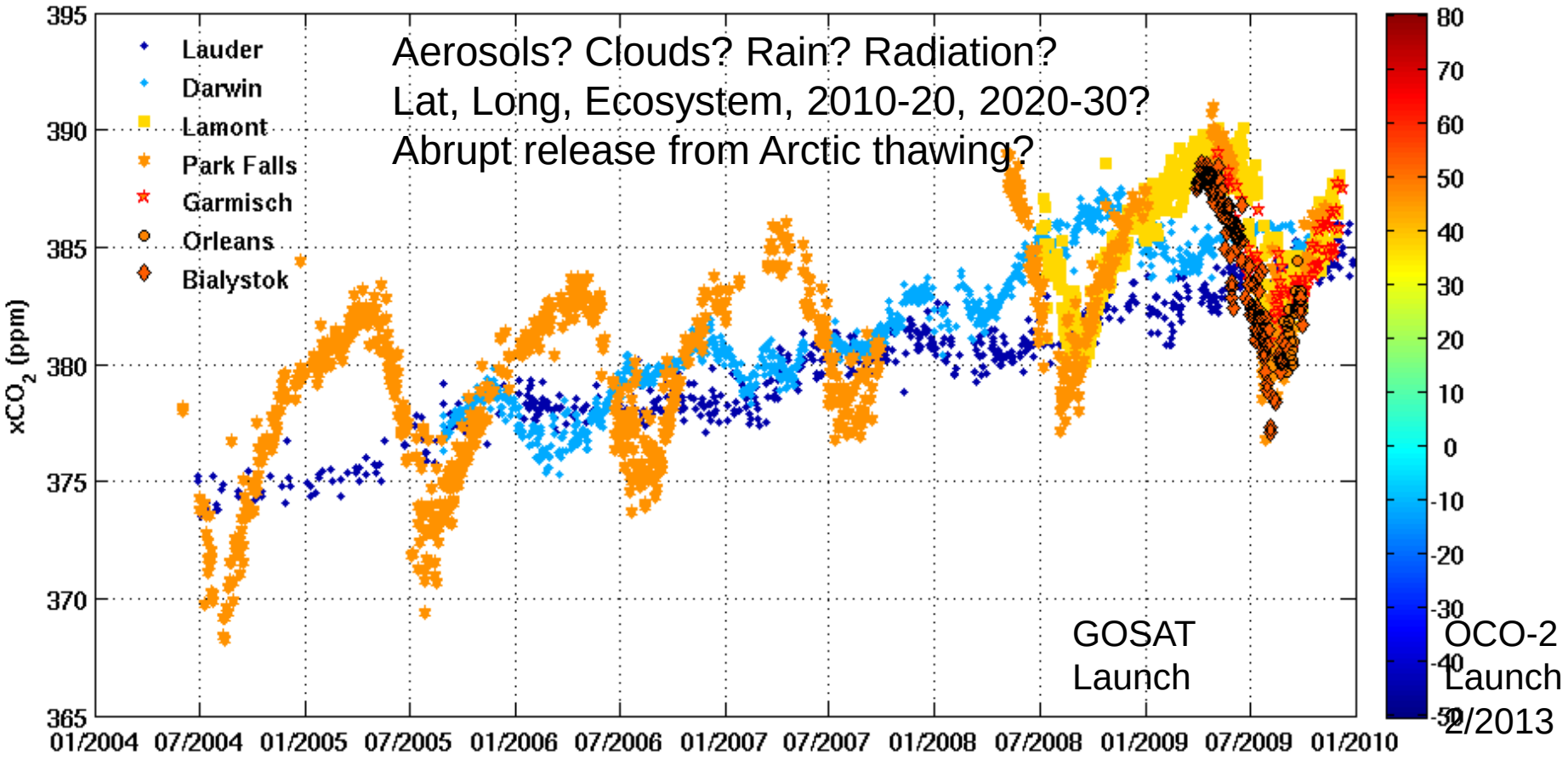
FTS Home: Move in late Aug

Calibration of Column CO_2 & H_2O with in situ profiles





Beyond CO_2 Time Series to Climate Feedback Process Measurements at ARM/AMF sites/campaigns



ARM CLIMATE RESEARCH FACILITY

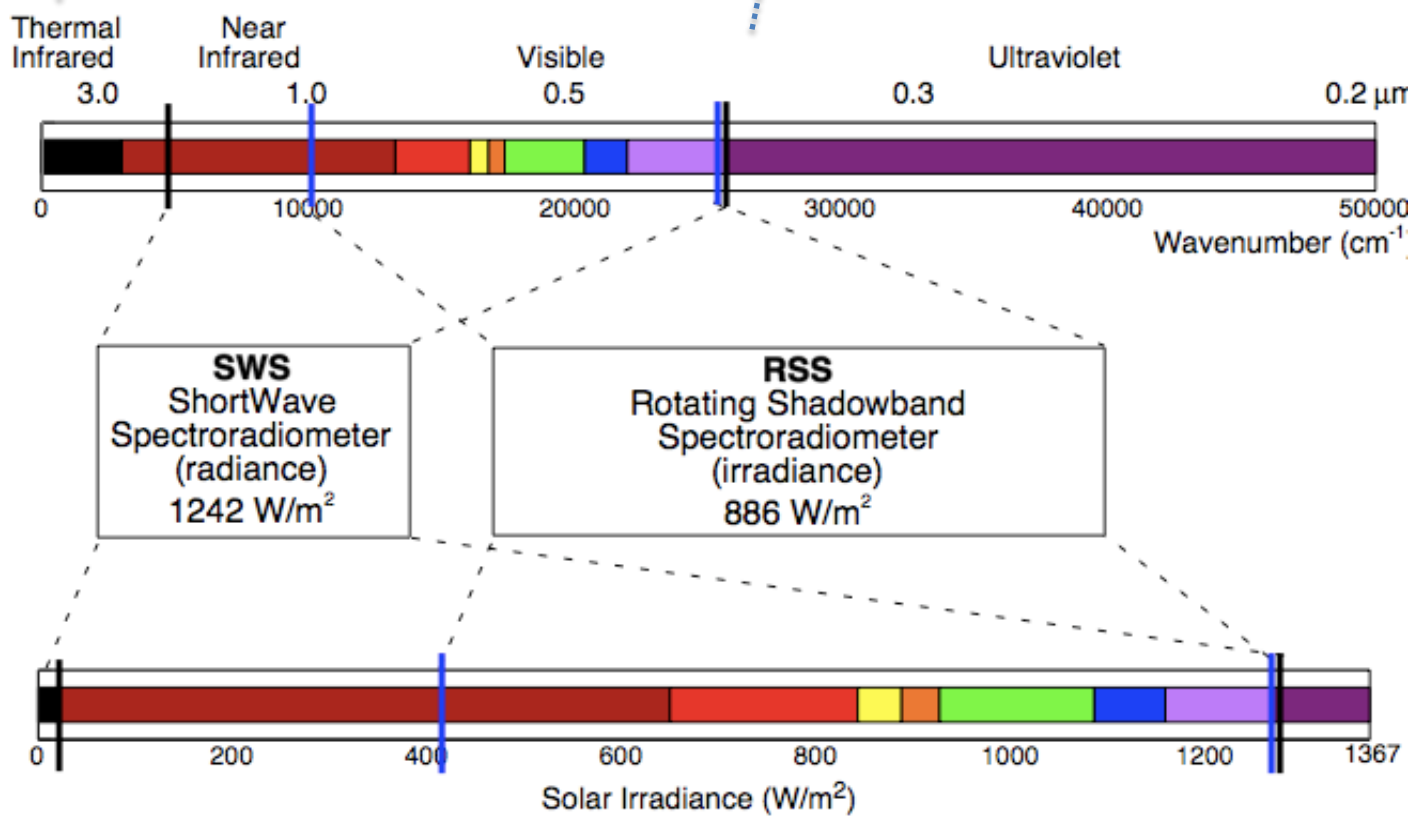
OCO

HIPPO HIAPER Pole-to-Pole Observations

Wunch, Wennberg et al

Advanced ARM High Resolution Continuous Lon Term Radiation Monitoring Capability

LANL-FTS (Aluminium), 0.02 cm^{-1} res. (2 minute), No absolute calibration, LBL-RT, Rad., CO_2, H_2O/HOD, Seasonality & Trends



Deriving H_2O Direct Beam Transmittance (T)

(Eli Mlawer, Joe Michalsky)

RSS Irradiance Measurement

Derive T(Gases,Rayl,Aerosol) using V_o

LBLRTM/CHARTS

Input MergedSonde

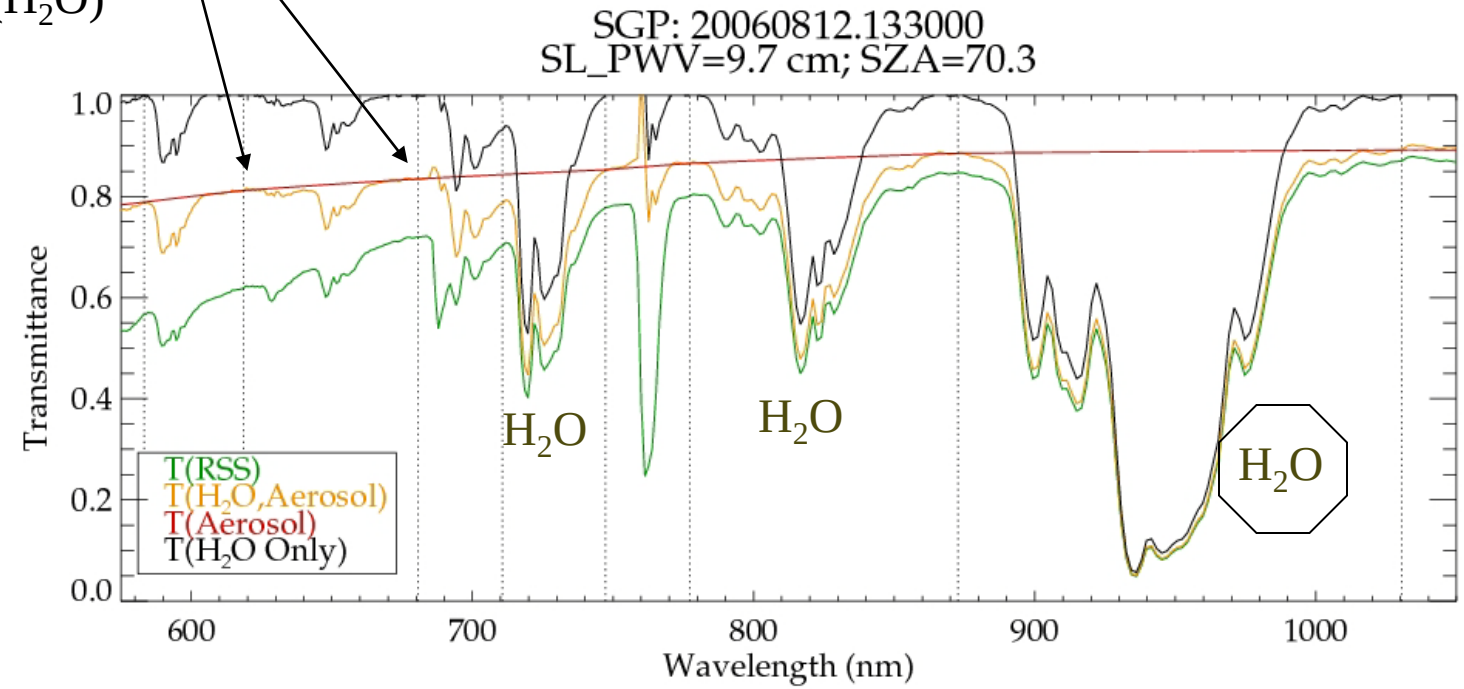
Compute T(Gases,Rayl)

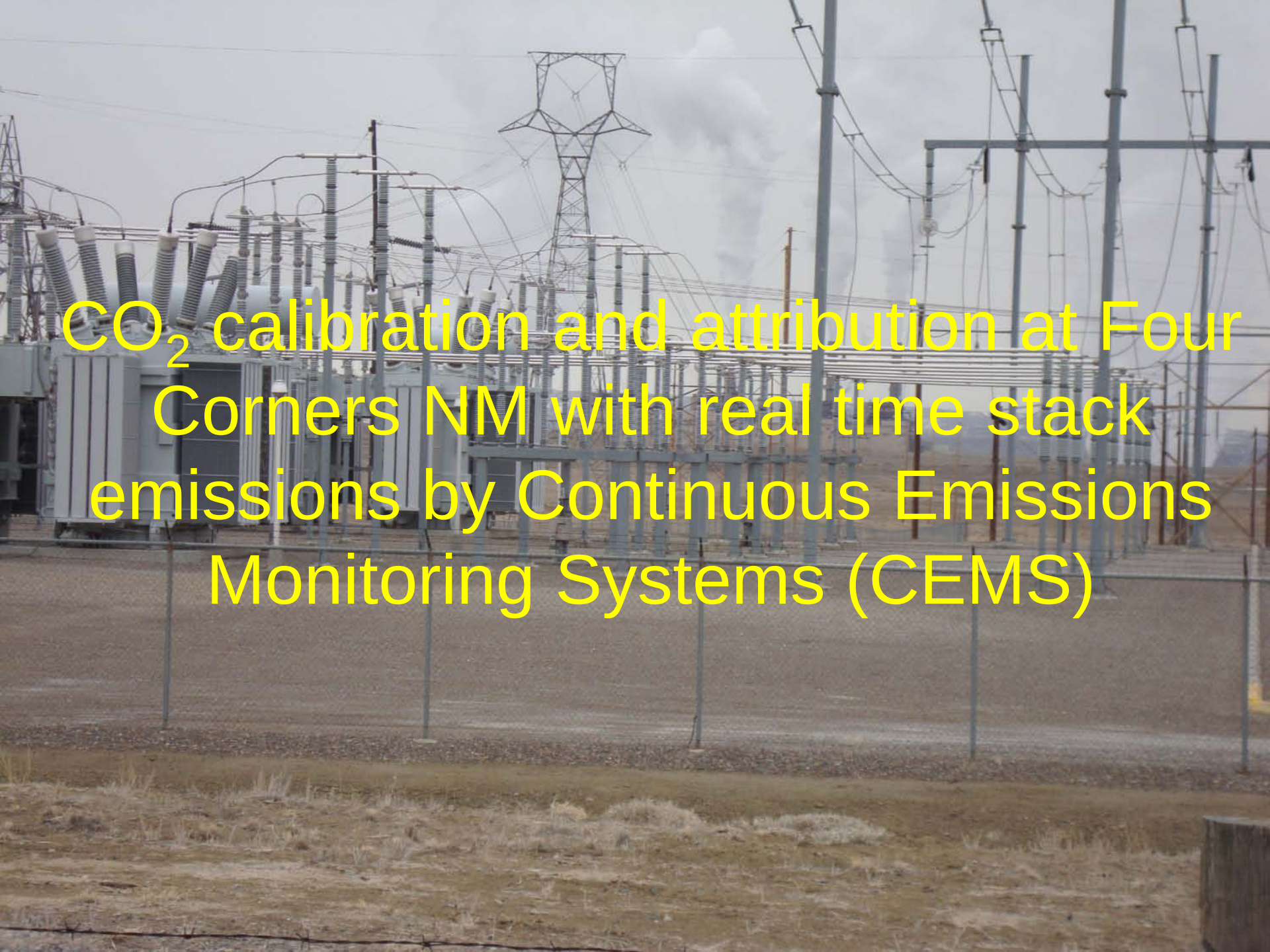
Compute T(Gases w/o H_2O,Rayl)

$T(H_2O)$

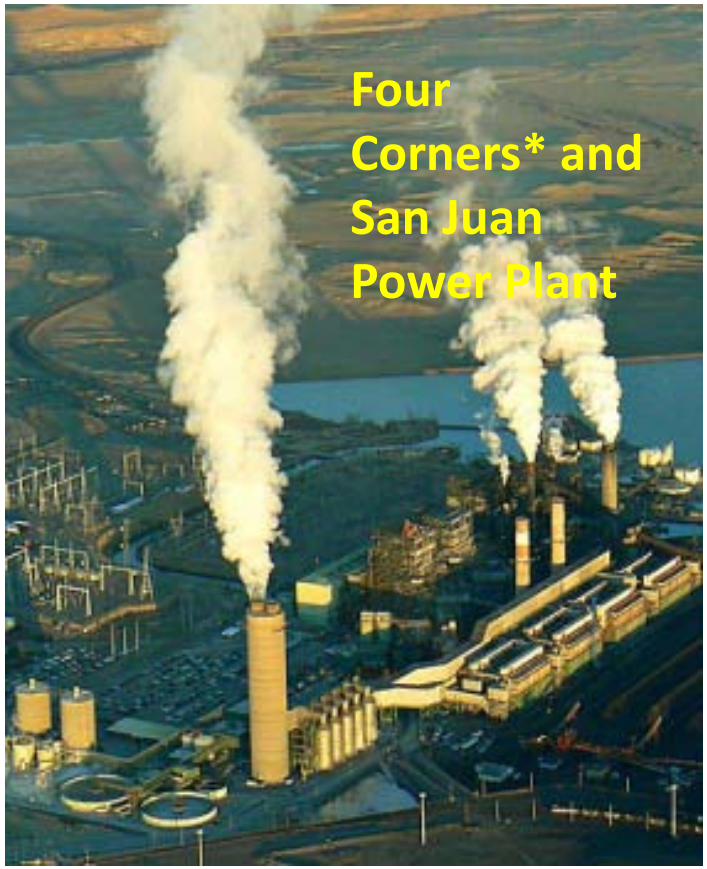
$T(Aerosol,H_2O)$

$T(H_2O)$




CO_2 calibration and attribution at Four Corners NM with real time stack emissions by Continuous Emissions Monitoring Systems (CEMS)

CO_2 Closure, Attribution & Scaling: 4-corners NM



We are combining column CO_2, NO_2 and CO observations using FTS, GOSAT, SCIAMACHY and MOPITT data to assess the ability of remote sensing to infer and attribute CO_2 emissions from a power plant.

FTS + EPA + Satellite

GIGANTIC POINT SOURCE

CO_2 (29 Mtons/year)

NO_x (79 Ktons/year)

IN STACK EMISSIONS (EPA-CEMS)

FTS, GOSAT, SCIAMACHY, MOPITT

WRF-Chem-VPRM Model

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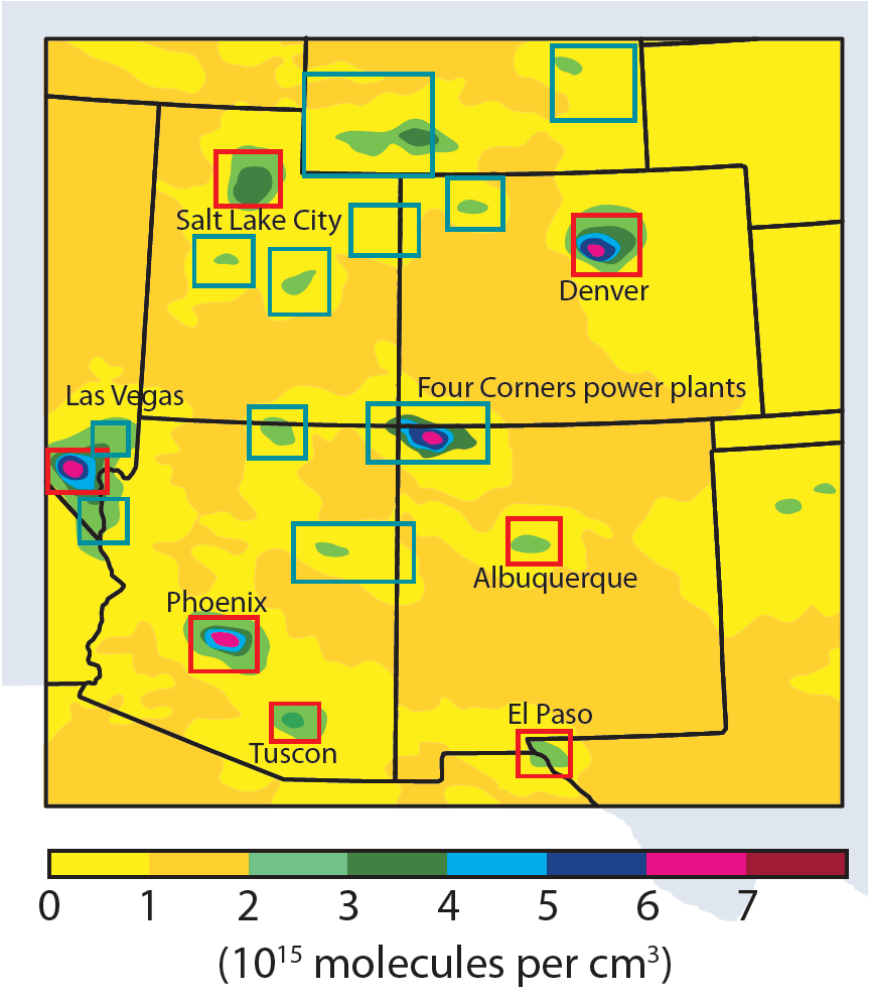
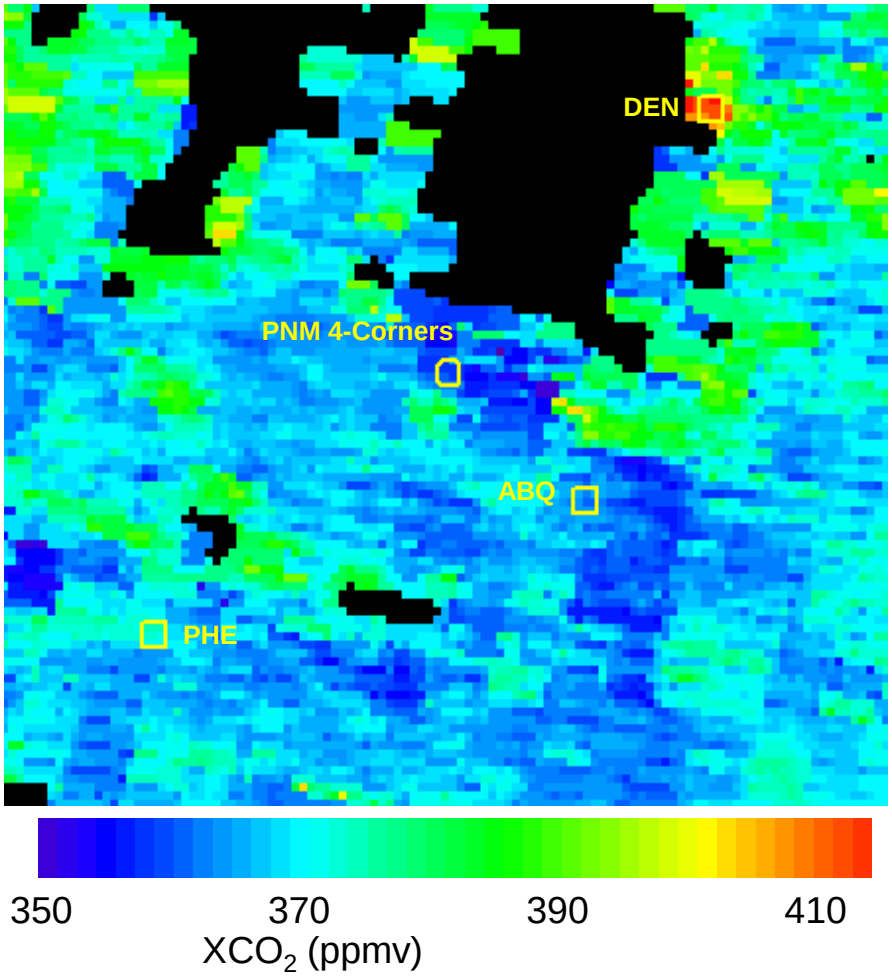
Current Satellites Resolve Large NO_2 Signal but not small CO_2 Signal at 4-corners



NO_2 SCIAMACHY (ESA)

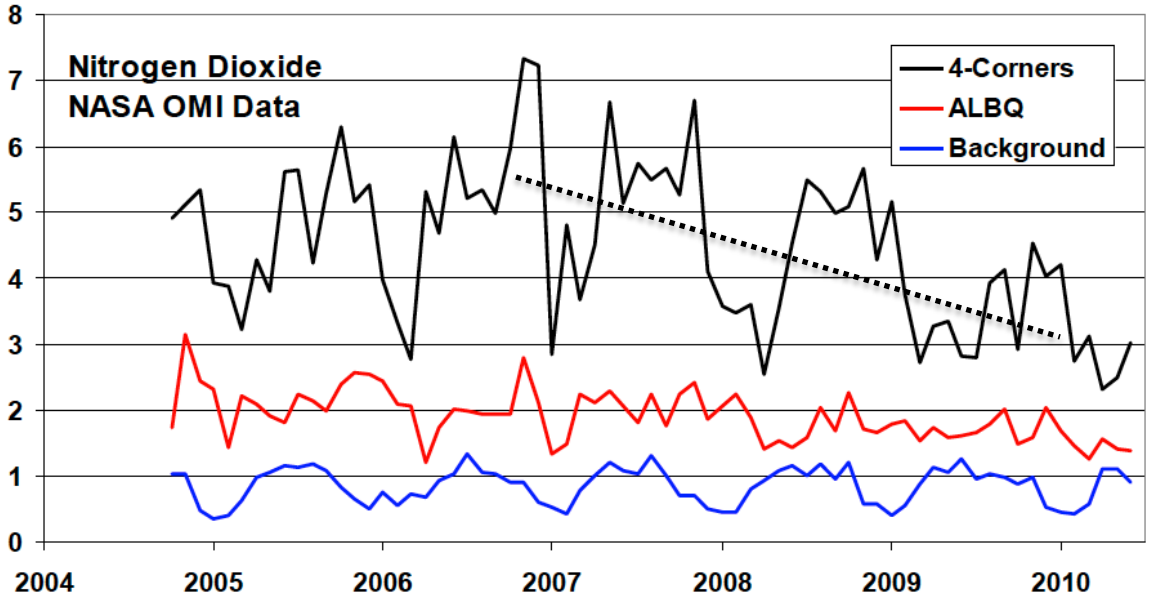


CO_2 SCIAMACHY (ESA)

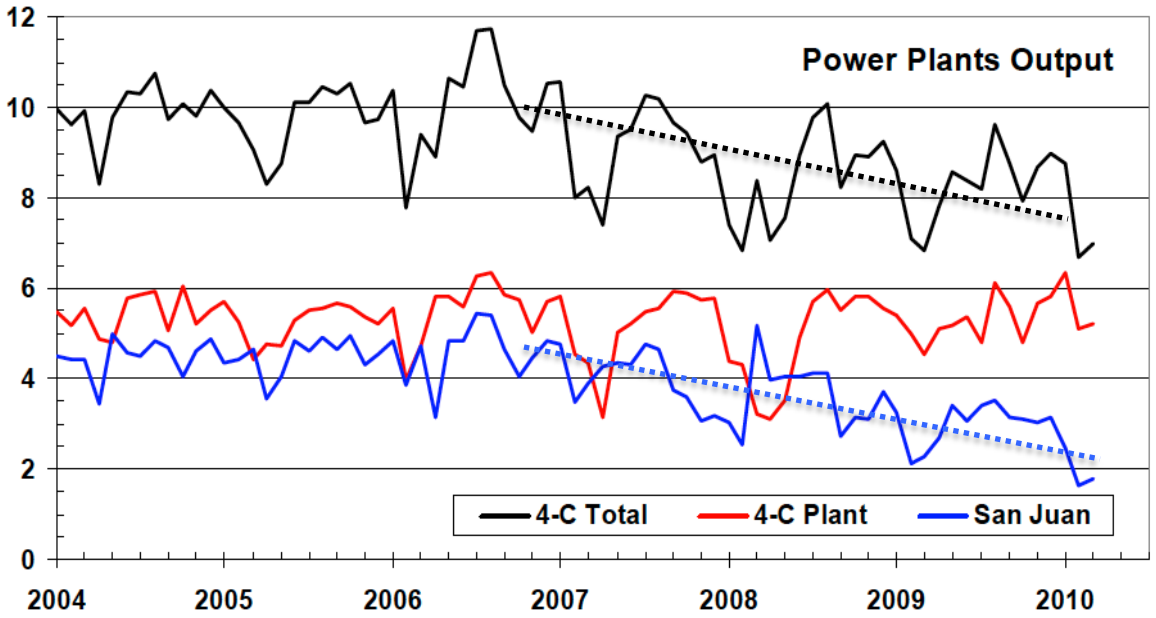
Satellite Verification of NO_2 decline from Boiler Environmental Upgrade

2006-2009 ($300M investment at San Juan Plant)

OMI
Top Down



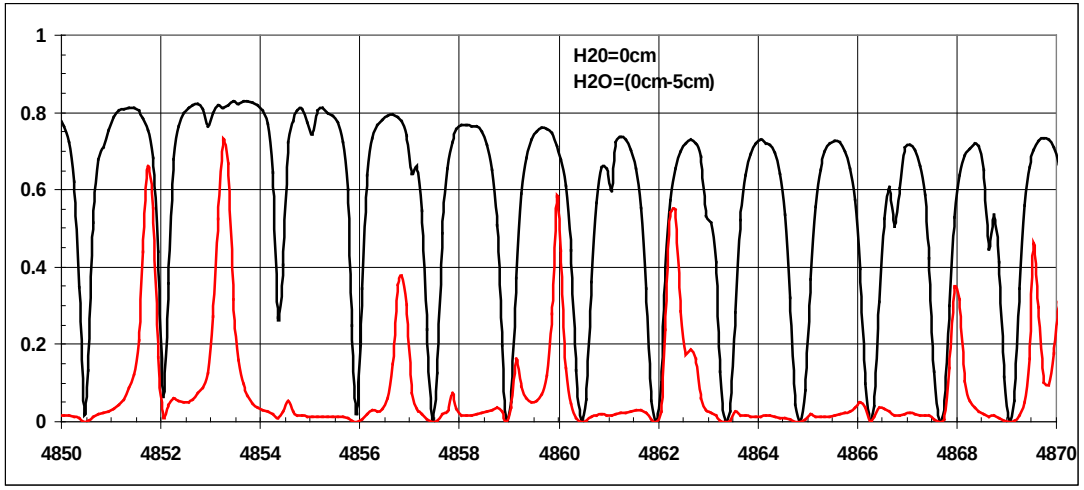
CEMS
Bottom Up

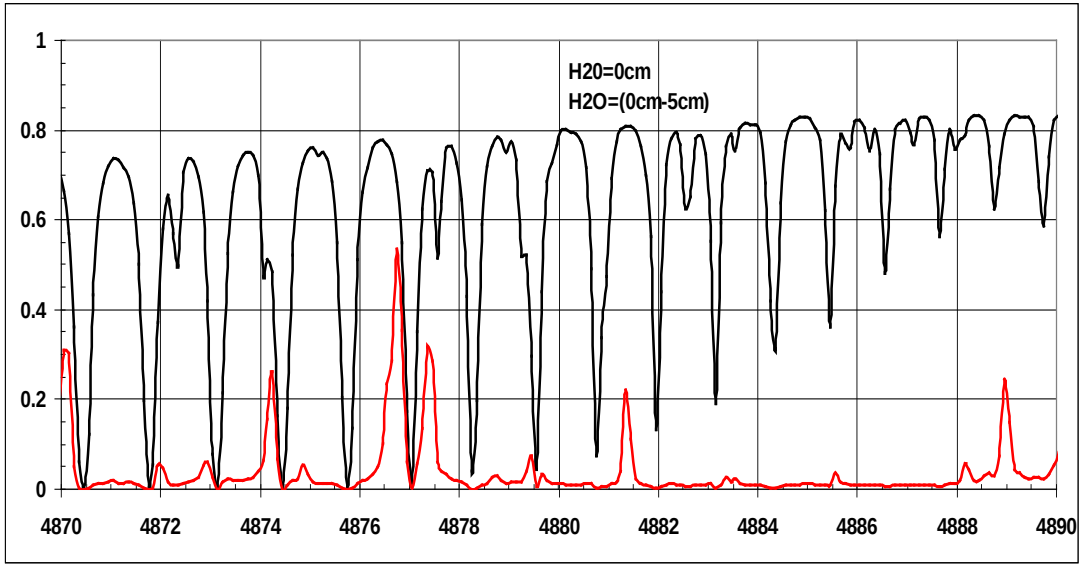


Analogue for detection of abrupt ecosystem carbon cycle shifts: Drought, Mortality, Arctic

Dubey, Chylek et al

Selection of spectral bands for CO_2 retrieval that are not contaminated by H_2O





Atmospheric transmission within CO_2 absorption band without any water vapor (black) and absorption of a humid atmosphere (red) within 4850 -4890 cm^{-1} (from 2.04-2.06 μm).

Spectral regions 4863-4967cm^{-1} and 4883-4887cm^{-1} provide the best chance for CO_2 retrieval without H_2O interference.

Acknowledgements

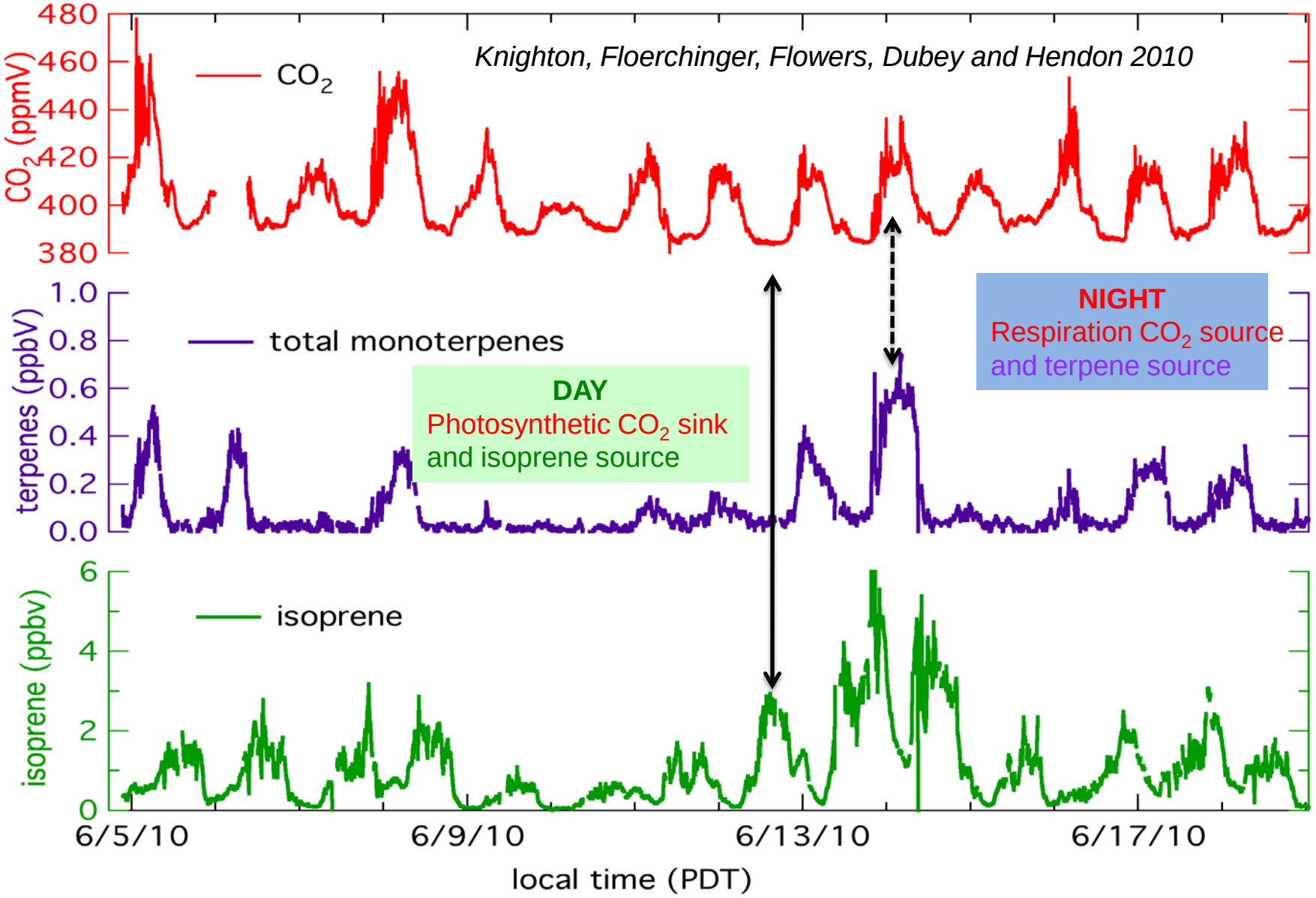
- OBER for funding/guidance, Ashley Williamson
- LANL ARM-FIDO Team, Kim Nitschke
- TCCON Network, Paul Wennberg & Debra Wunch
- Bruker Optics Engineers
- GOSAT, NASA, ESA-SCIAMACHY satellite data
- GEOS-Chem model, Daniel Jacob's group
- NMED/EPA/BLM for site access and collaboration
- LANL-Sandia-LLNL for nurturing climate observations

LANL-FTS ready to enrich OBER's carbon, climate and chemistry science synergistically

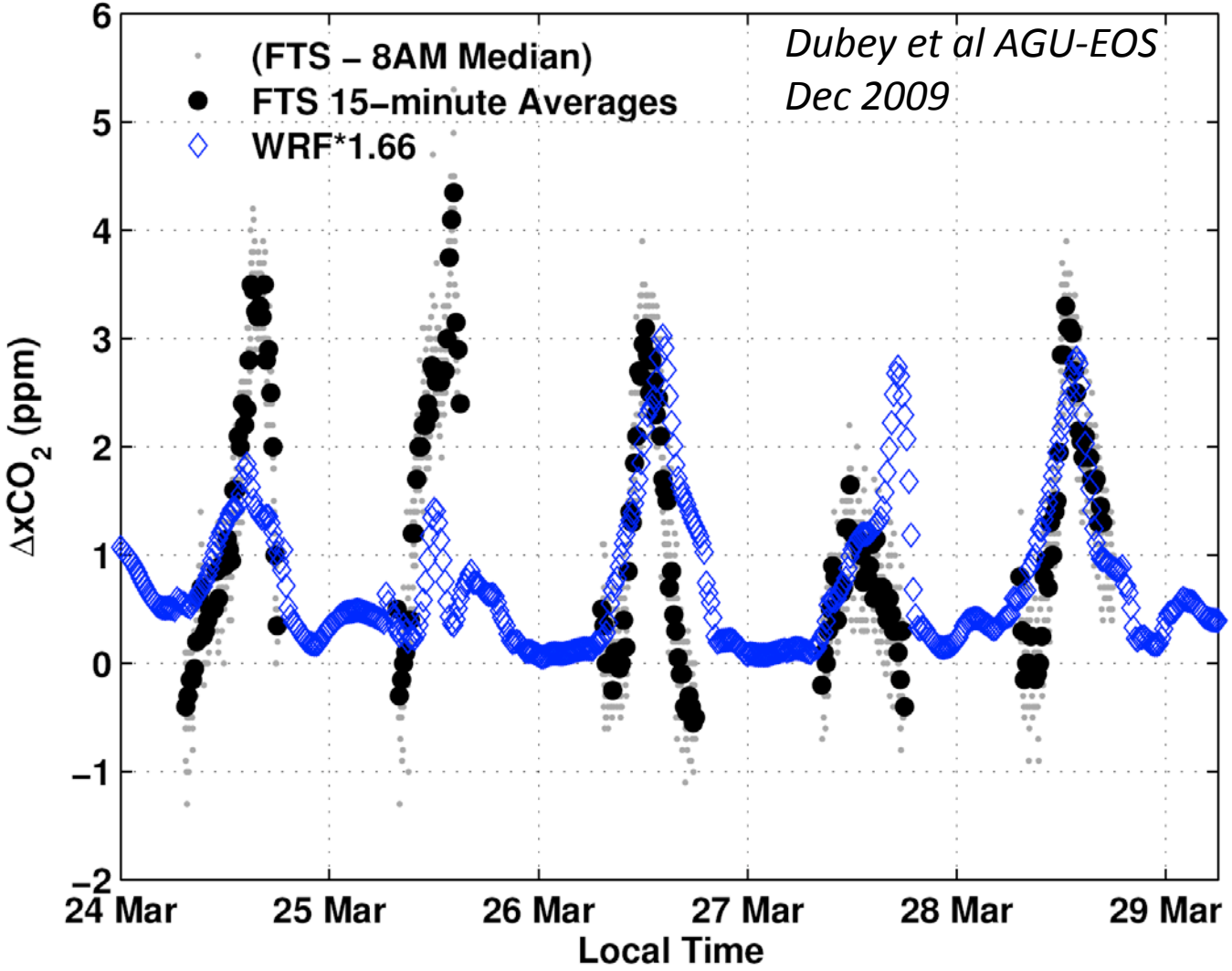
- Part of ARM proposal *The ARM Climate Research Facility in the Amazon Basin (with S. Martin, Harvard, 5/15/10),* fills gap in Amazon for OCO-2 validation
- NASA request for side by side cross calibration of OCO-2 instrument at JPL *(PI M. Gunson)*
- Operational synergy with LANL's AMF/TWP team for short/long term OBER deployments (*K. Nitschke*)
- Collaboration with Japan/UofAlaska for Arctic FTS to early detect potential abrupt CO_2/CH_4 release (*C. Wilson-RCI/NGEE)*

Exploit Natural Diurnal Variation for Attribution: CO_2 (Cavity Ringdown) and Biogenic Hydrocarbons (PTRMS) data at Forested site during CARES-2010.

LANL FTS's spectral range can enable this attribution on 10-100 km scale



Flux Verification in Los Angeles area: Vulcan Emissions + Weather Research Forecast Model Simulation compared to FTS data

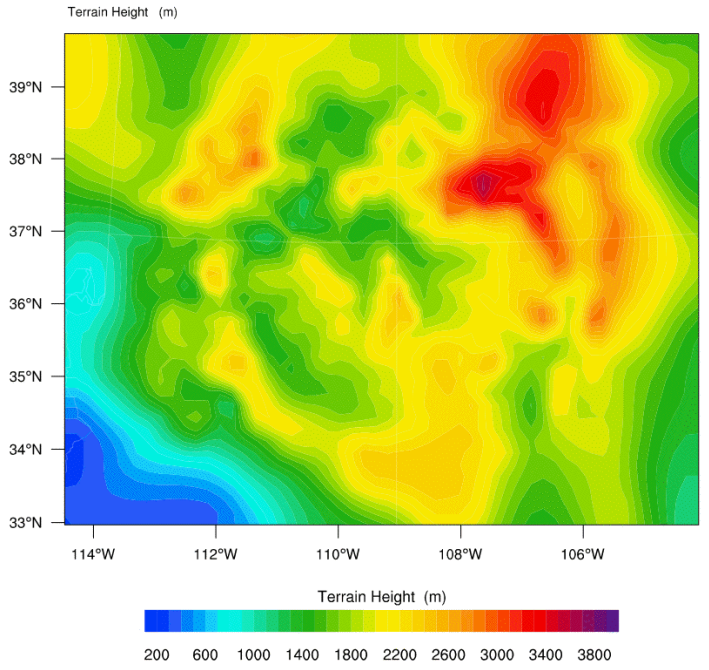


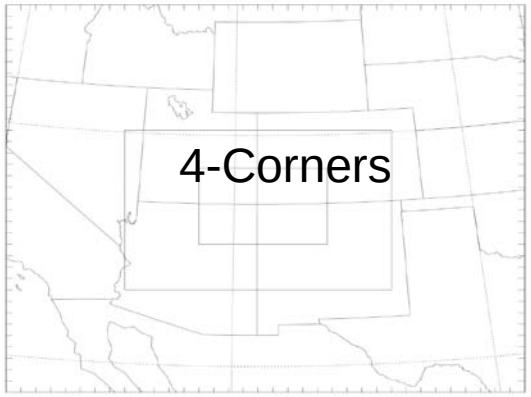
Vulcan emissions has to be scaled by 1.66 to agree with observation: LOW BY 66%!

Our confidence in land/ocean carbon cycle models much lower than emissions!

WRF simulations of the Four Corners Region

- Updating to WRF Ver 3.2
  - ➢ Older version is less supported
  - ➢ Improved WRF-Chem + VPRM
- WRF Version 3.2 requires newer compilers and NetCDF libraries that need to be compiled with the same compilers.
- Reinstalled NetCDF using with the newer compilers on Coyote.
- Installed WRF Ver. 3.2 on Coyote.
- Working on simulation of the Four Corners region.





Topography and Nested (56, 18, 6km) Grid Set up

LANL-FTS Progress

- Calibration: Meets/Exceeds TCCON standard
- Tracker cover working
- Sample solar spectra collected
- Retrieval codes applied to spectra for CO_2/O_2 (and CO, CH_4, N_2O) to data at Pagosa Springs
- Detected high CO plume with small CO_2 & N_2O increase
- System includes Aeronet-CIMEL and *in situ* CO_2, H_2O, CO, NOx, PTRMS, ^{14}C and isotopes etc
- Late October deployment