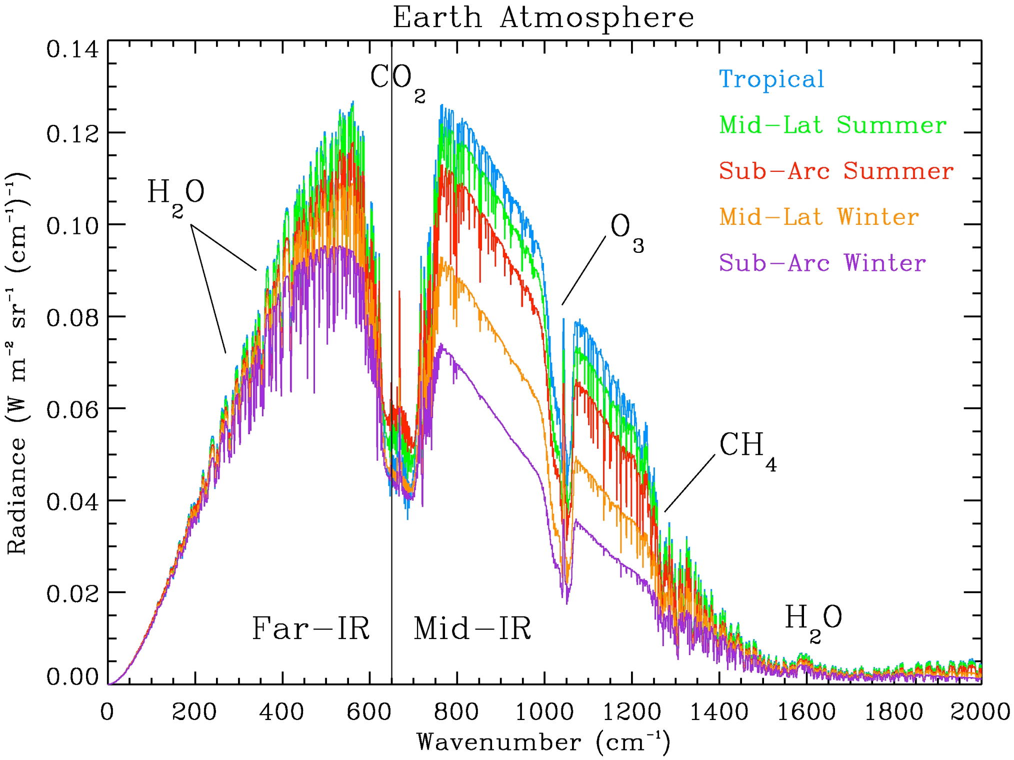
Measurement of Decadal Scale Climate Change from Space



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Outline

- Acknowledgements

- Difference between “weather” and “climate” measurements

- An approach to measuring climate trends using IR radiances

- Technology development for *accurate* IR radiance measurement
  - The FIRST instrument and science results

- Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission status
  - ***CLARREO is not cancelled!***

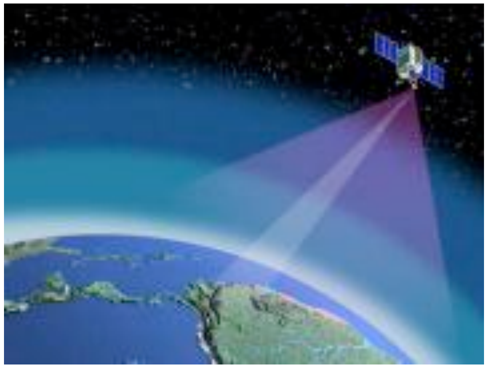
- Summary

Acknowledgements

- CLARREO Science Definition and Integrated Product Teams
  - University of Wisconsin
  - Harvard University
  - NASA Goddard
  - NIST, Gaithersburg Maryland
- NASA Earth Science Technology Office
- NASA Science Mission Directorate

Weather and Climate: Different Observing System Requirements

- **Weather**



- Need to observe much of Earth on synoptic time scales
- Random noise a dominant source of error
- Individual radiance measurements used to derive data products
- Data used for initial value problem – generating a weather forecast

- **Climate**

- Sampling sufficient for seasonal means & avoiding time/space biases
- Systematic error dominates ability to do trend detection
- Zonal & global means, seasonal to annual timescale, 1000's of radiances
- Data used in assessing boundary value problem – climate change

Weather and Climate have different observation requirements

Generating a Benchmark for Climate Change Detection

- Measuring climate change requires measurement of a ***benchmark***

- Climate benchmark characteristics:
  - Very high accuracy for decadal trend detection
  - Unbiased spatial and temporal sampling
  - Information content sufficient for trend detection and attribution

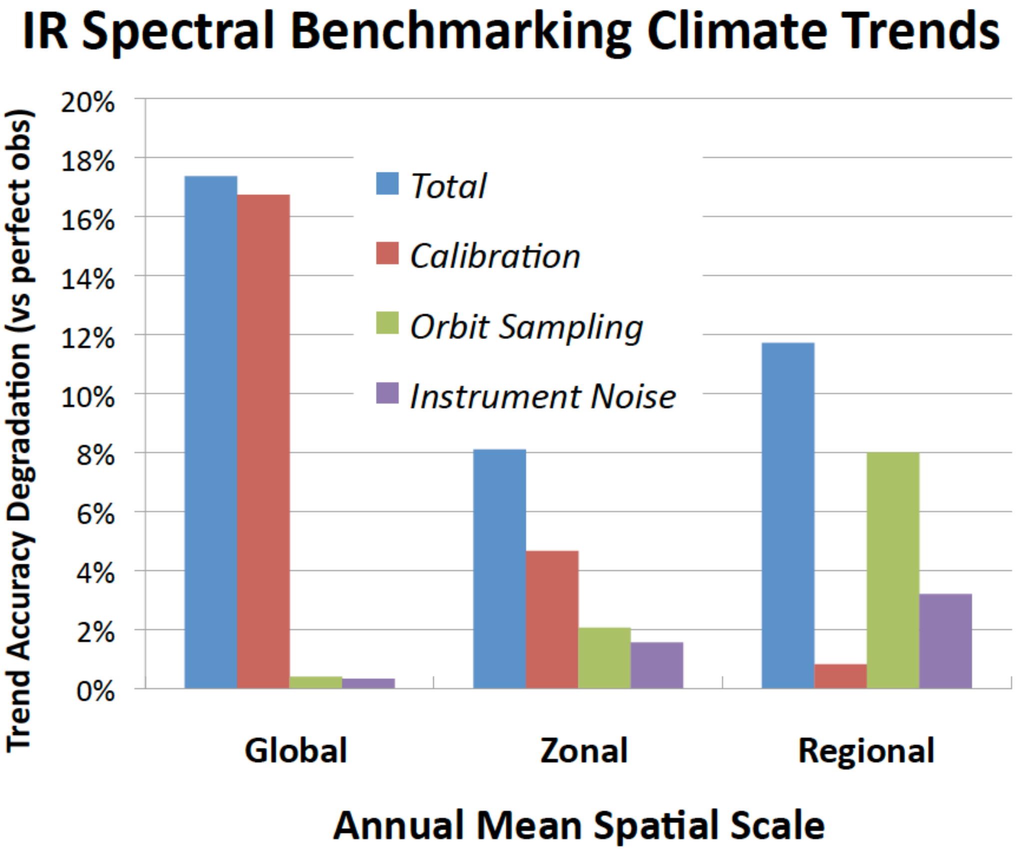
- The accuracy of benchmark observations is required *only at large time and space scales such as zonal annual, not at instantaneous field of view.*

- *Therefore the uncertainty in the benchmark is determined over many 1000s of observations: never 1, or even a few*

- Benchmarking requirements are very different than a typical NASA Earth Science process mission interested in retrievals at instantaneous fields of view at high space/time resolution

Climate Benchmarks establish basis for observing climate change

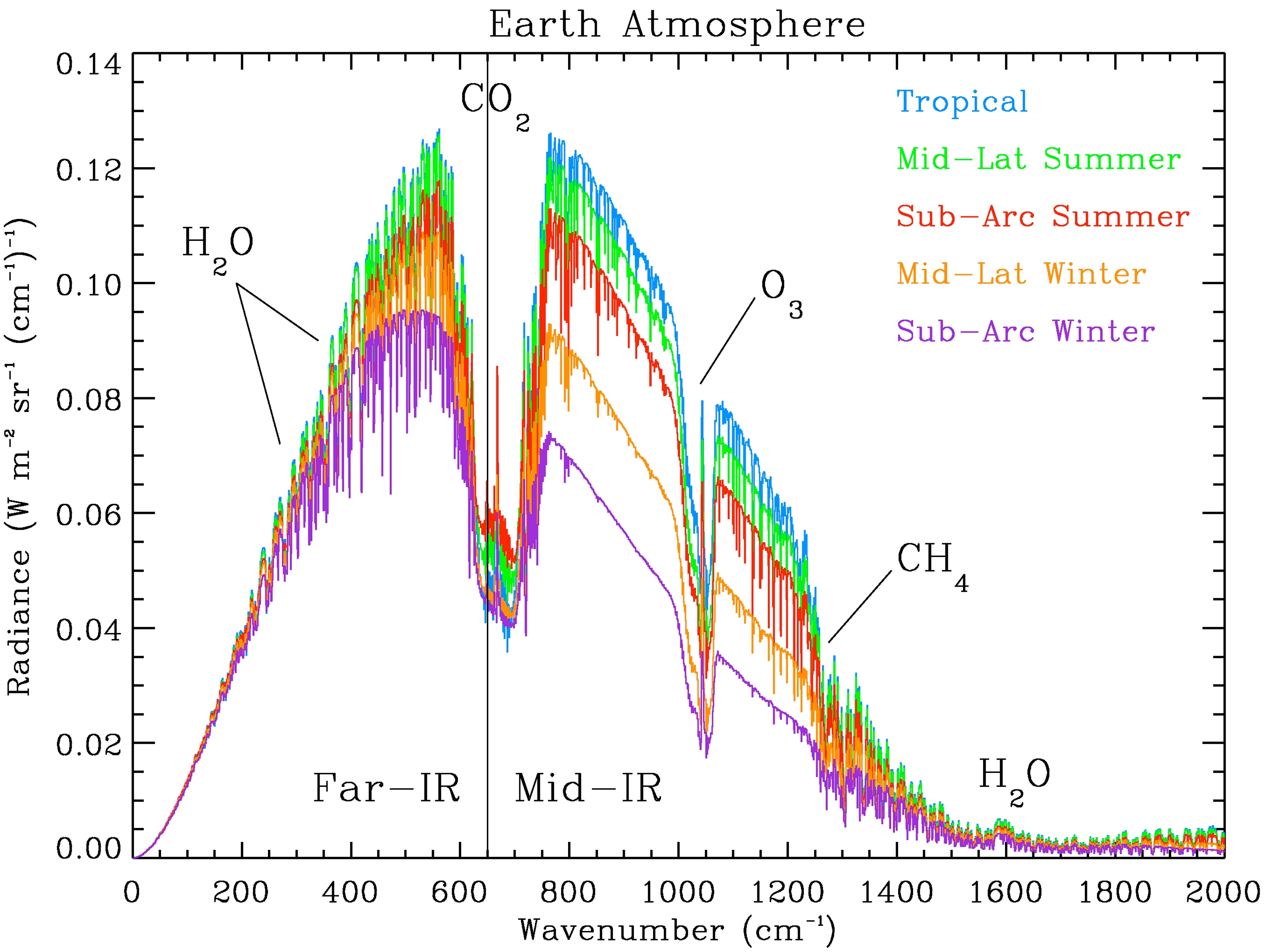
Trend Accuracy: Error Sources, Scales



- Calibration uncertainty dominates largest climate scales
- Orbit sampling dominates smallest climate scales
- Instrument noise less important at all scales, even for IR
- All results for 1 90 degree orbit

Calibration dominates largest climate scales, orbital sampling the smallest

Infrared Spectral Radiance as a Climate Benchmark



Infrared spectra are rich in information content on atmospheric T and composition

An approach to measuring climate change using IR radiances

- From space, observe time series of *accurate* infrared radiances
  - Zonal to global spatial scales
  - Annual to decadal time scales
  - Essentially the entire infrared spectrum

- Time differences in zonal and global radiance spectra are related to changes in atmosphere (T, H_2O, clouds…)

- If difference is linear in changes in temperature, H_2O, CO_2, etc., derive changes via linear regression:

- That is,

$$\Delta R_\nu = \sum_i \frac{\partial R_\nu}{\partial x_i} \Delta x_i$$

Observed change

Radiance derivative

Change in T, H_2O, etc.

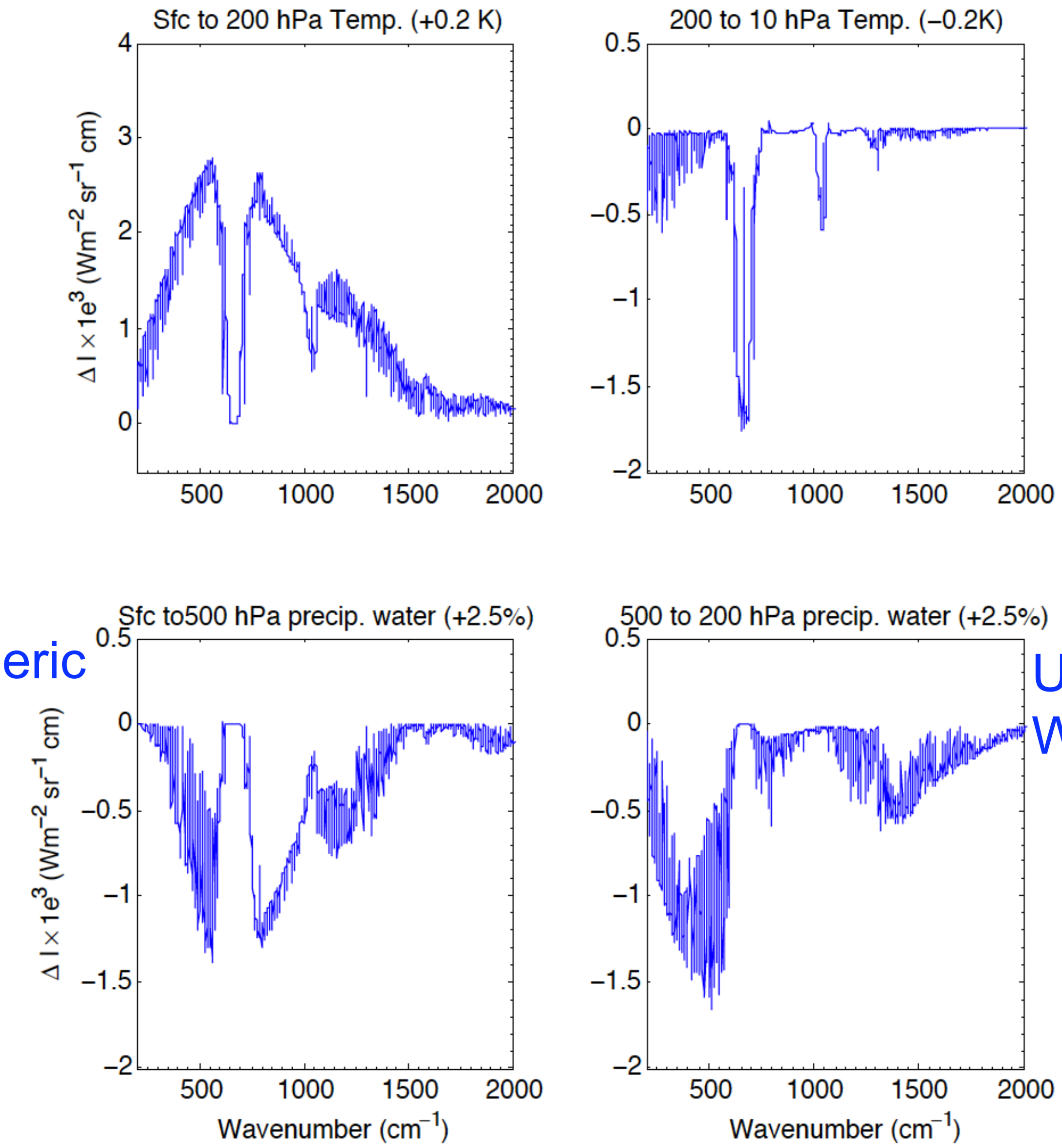
Radiance derivatives dR_ν/dx_i

Tropospheric Temperature

Stratospheric Temperature

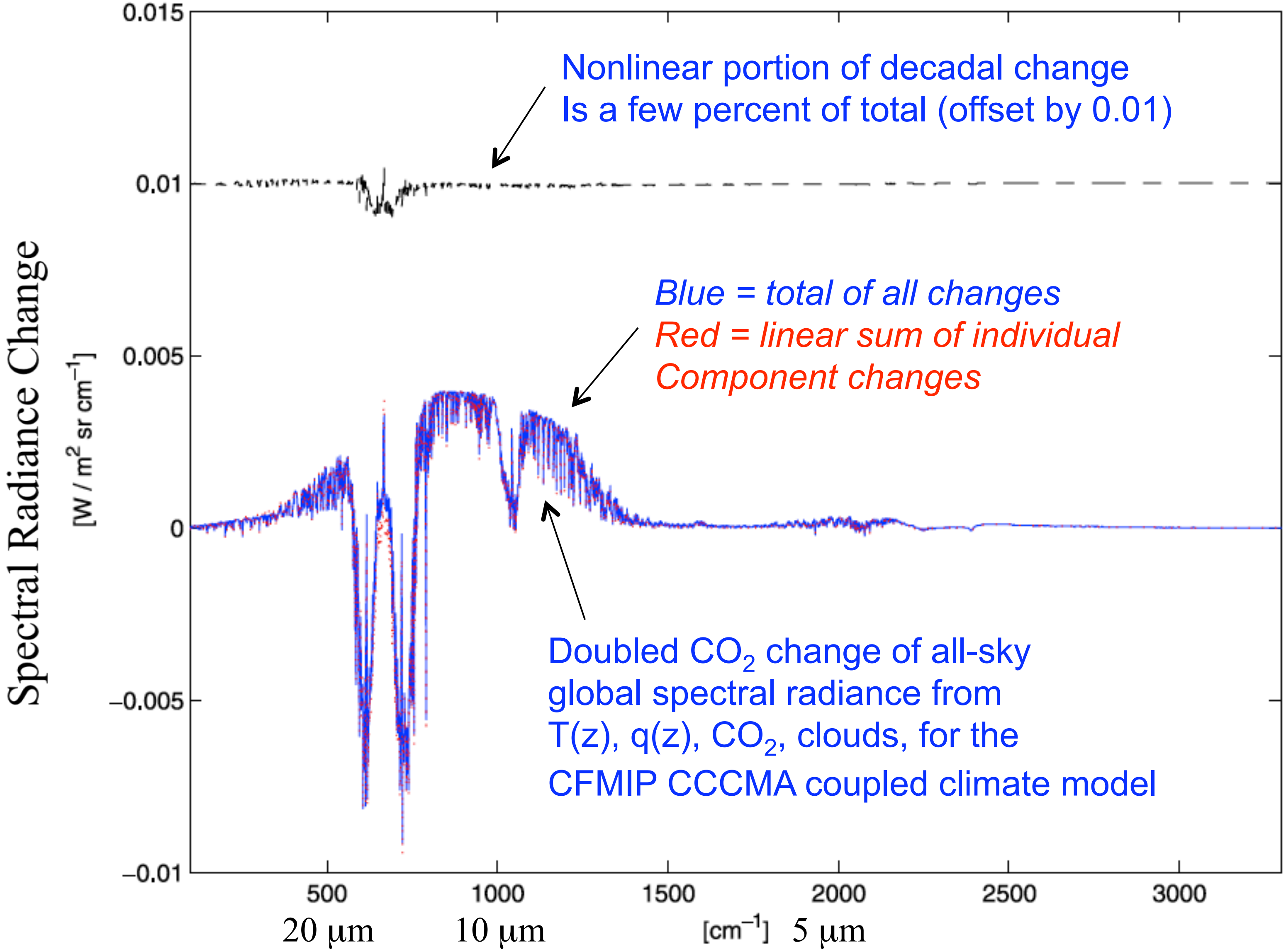
Lower Tropospheric Water Vapor

Upper Troposphere Water Vapor



Spectral shape and magnitude are different for specific changes

Spectral Decadal Change is Linear!



Nonlinear portion of decadal change
Is a few percent of total (offset by 0.01)

Blue = total of all changes
Red = linear sum of individual
Component changes

Doubled CO_2 change of all-sky
global spectral radiance from
T(z), q(z), CO_2, clouds, for the
CFMIP CCCMA coupled climate model

After
Huang et al.
2010

Instantaneous changes are nonlinear: decadal change is highly linear

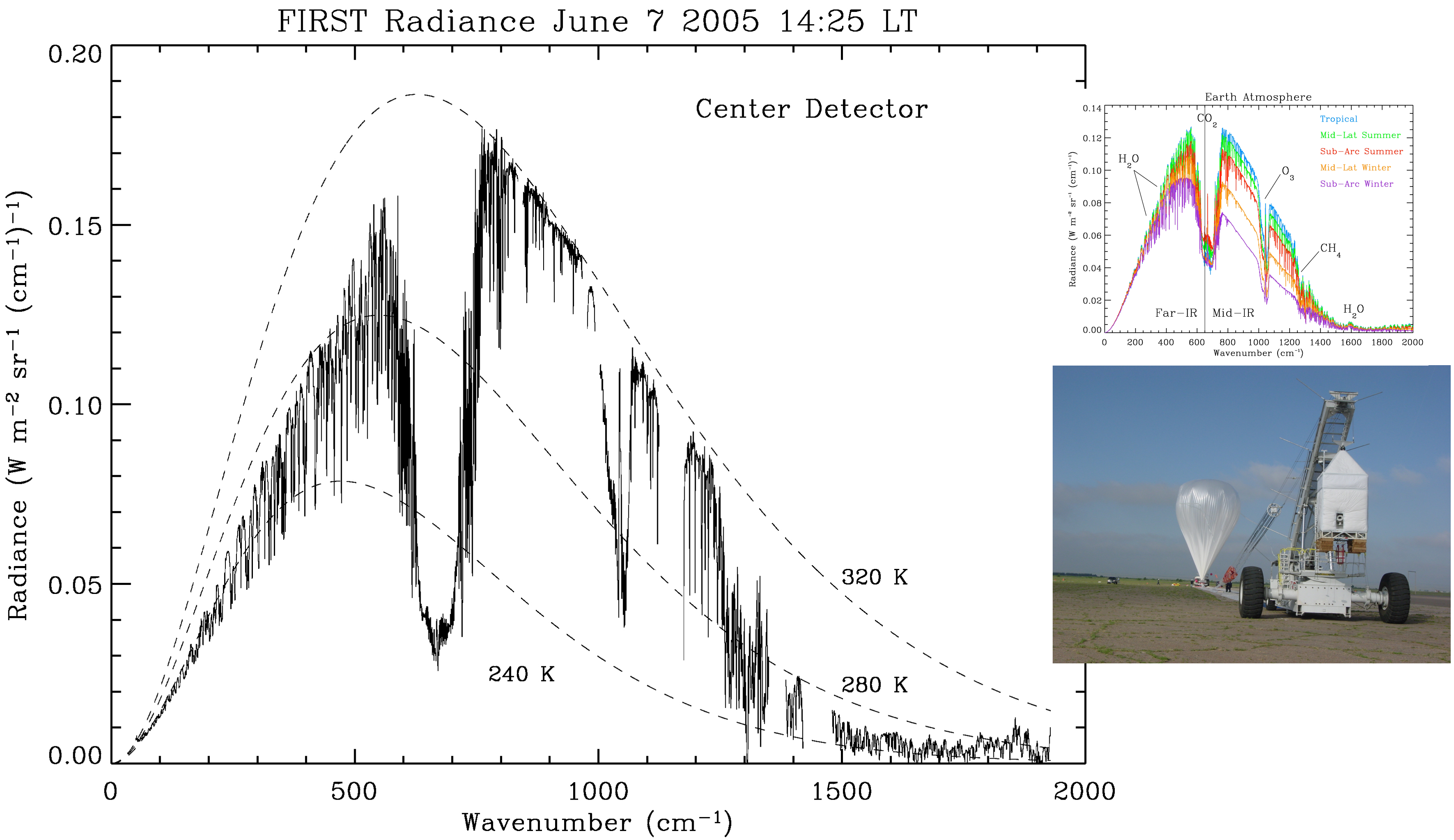
Achieving Accurate Space-Based IR Radiance Measurement

- Accurate, space-based measurements of IR spectra provide ability to observe and diagnose decadal scale change
- NASA’s Earth Science Technology Office (ESTO) has made substantial investment in infrared spectral sensing technology over the last decade
- Numerous projects at Langley and U. Wisconsin/Harvard totalling over $20 M investment
- Examine one of these, Langley’s Far-Infrared Spectroscopy of the Troposphere (FIRST) instrument

FIRST - Far-Infrared Spectroscopy of the Troposphere

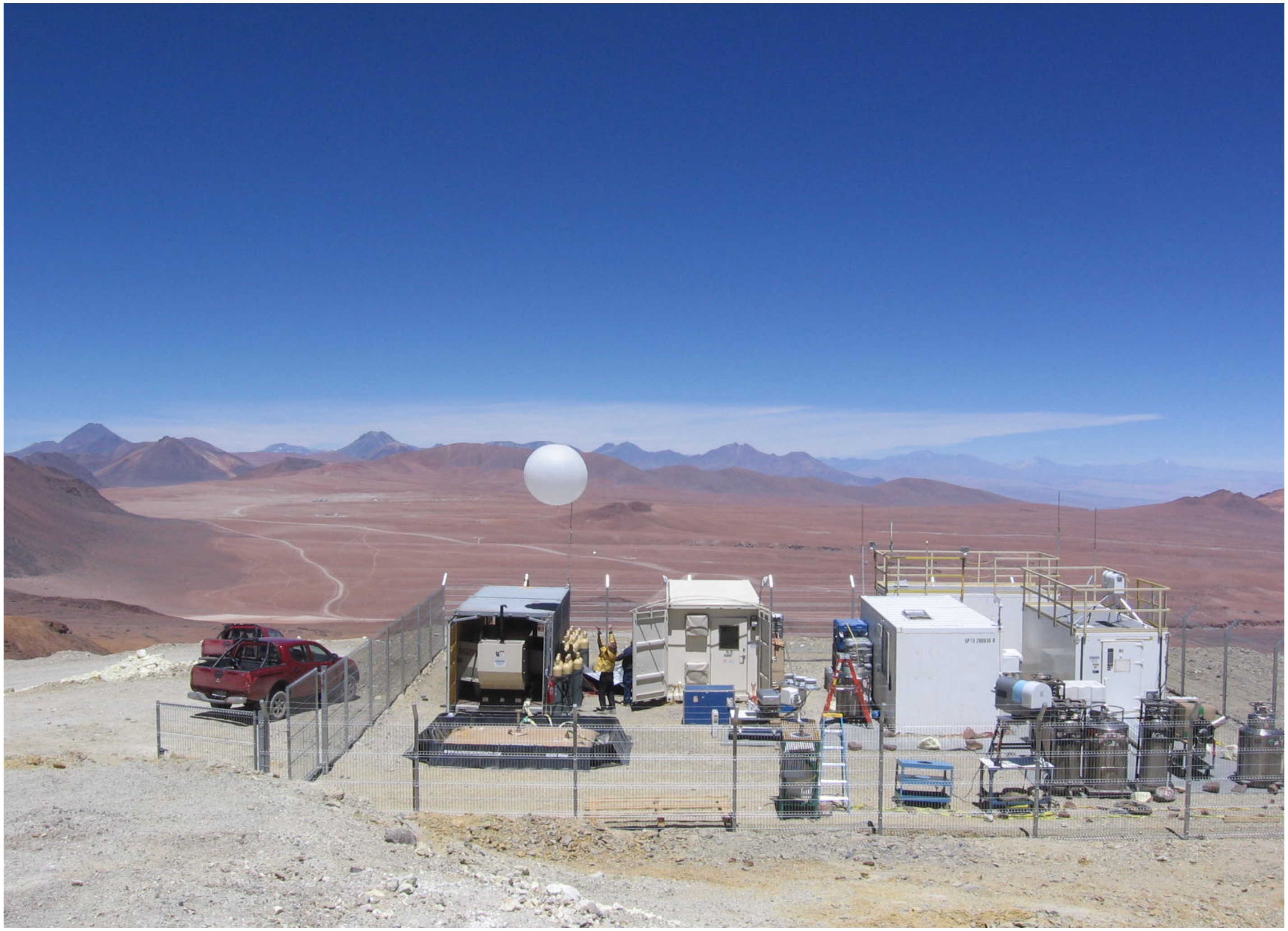
- Michelson Interferometer
  - *6 to 100 μm on a single focal plane*
  - *0.625 cm^{-1} unapodized (0.8 cm OPD)*
  - *Germanium on polypropylene beamsplitter*
  - *Bolometer detectors @ 4 K*
- Demonstrated on a high-altitude balloon flight June 7 2005
- Second balloon flight September 18 2006
- Ground-based capability demonstrated March 2007
- FORGE Ground Campaign Atacama Desert Chile

FIRST Thermal Infrared Spectrum - TOA

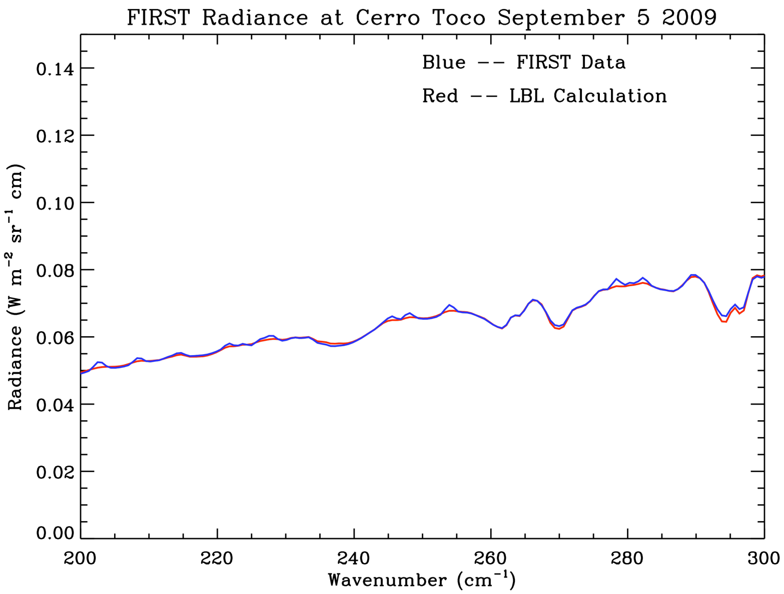


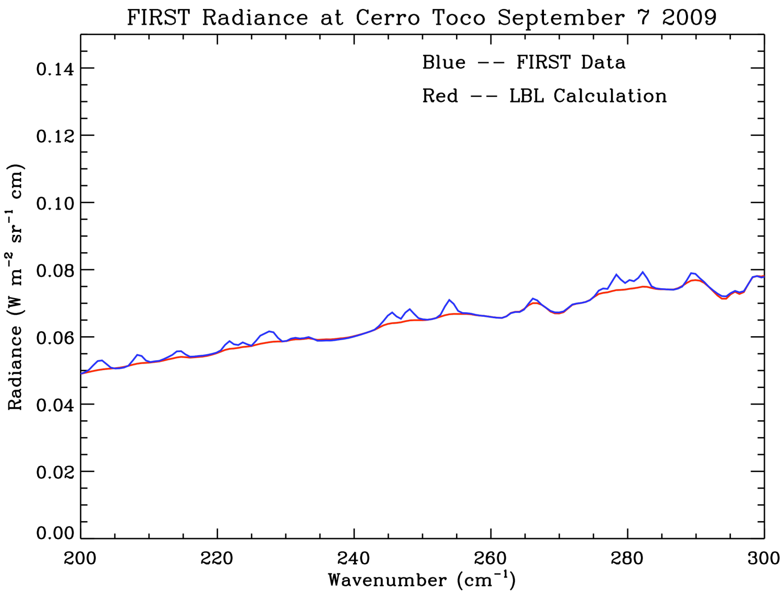
Mlynczak et al., GRL, 2006

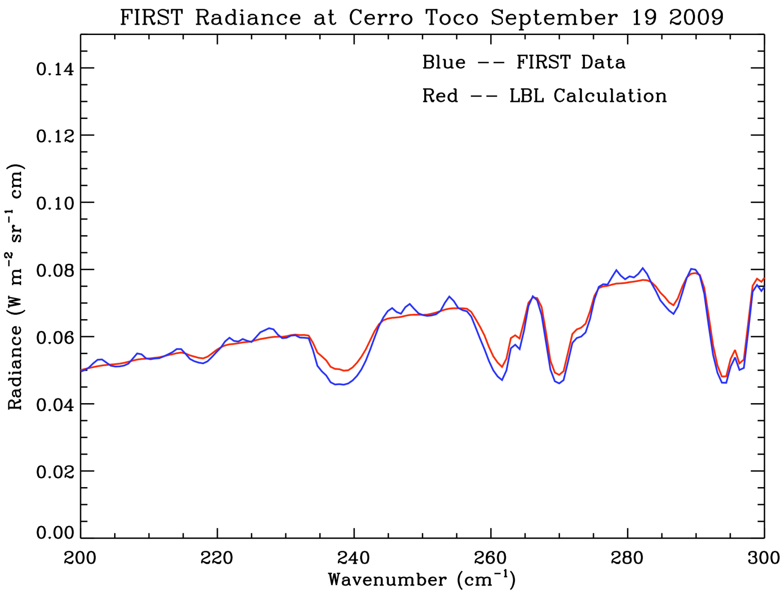
FIRST Operations at 17,600 Feet
Cerro Toco, Atacama Desert, Chile

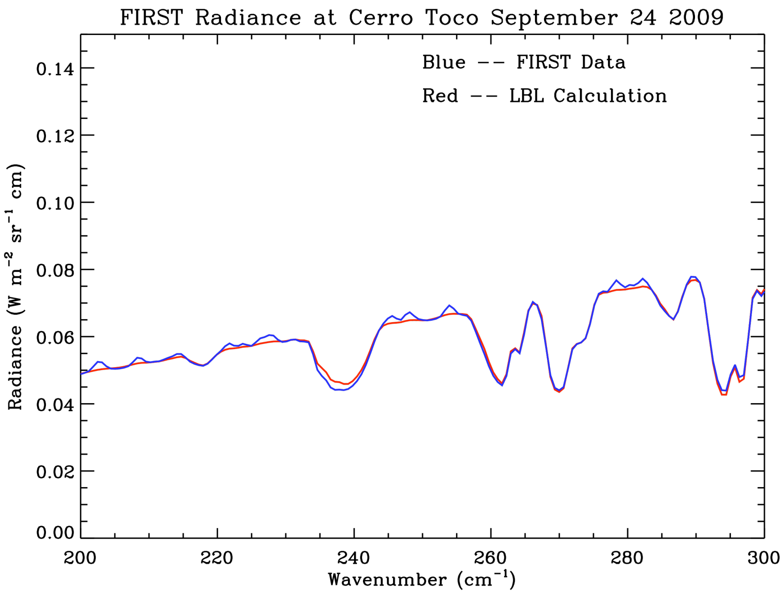


FIRST Data 200 – 300 cm^{-1}; September 5, 7, 19, 24

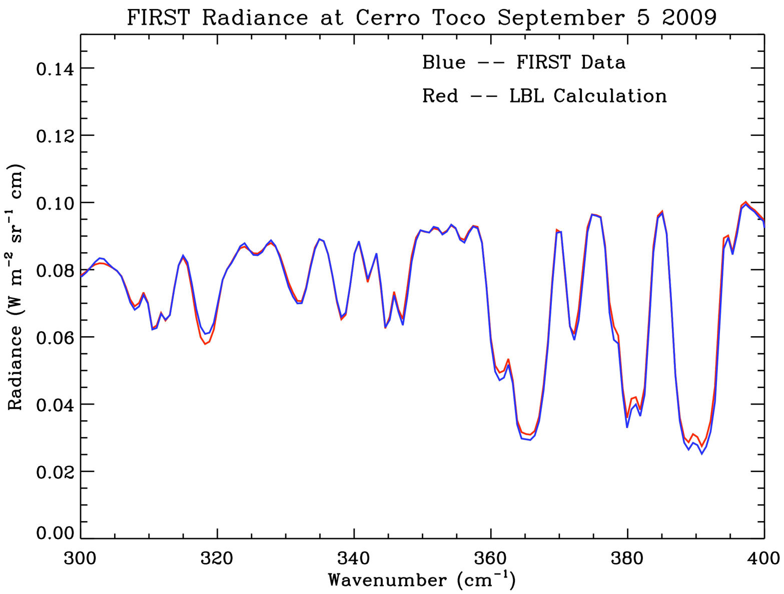

FIRST Radiance at Cerro Toco September 5 2009


FIRST Radiance at Cerro Toco September 7 2009


FIRST Radiance at Cerro Toco September 19 2009


FIRST Radiance at Cerro Toco September 24 2009

FIRST Data 300 – 400 cm^{-1}; September 5, 7, 19, 24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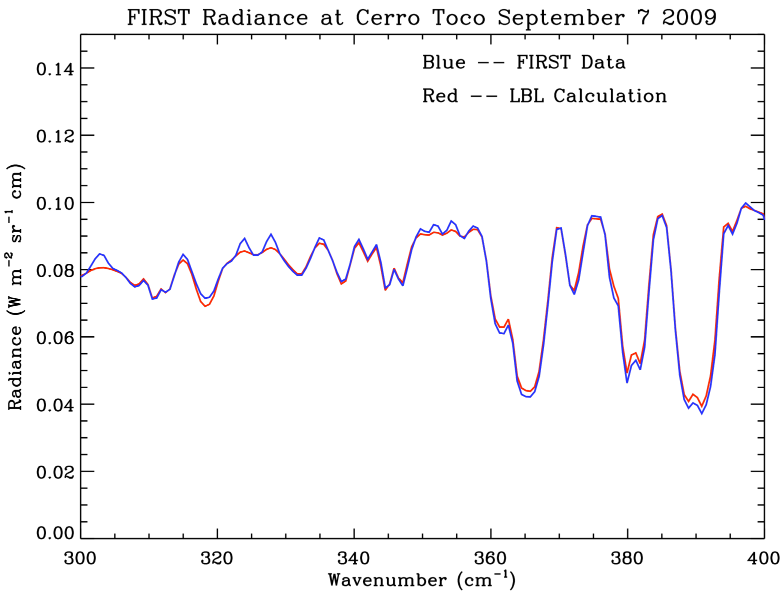
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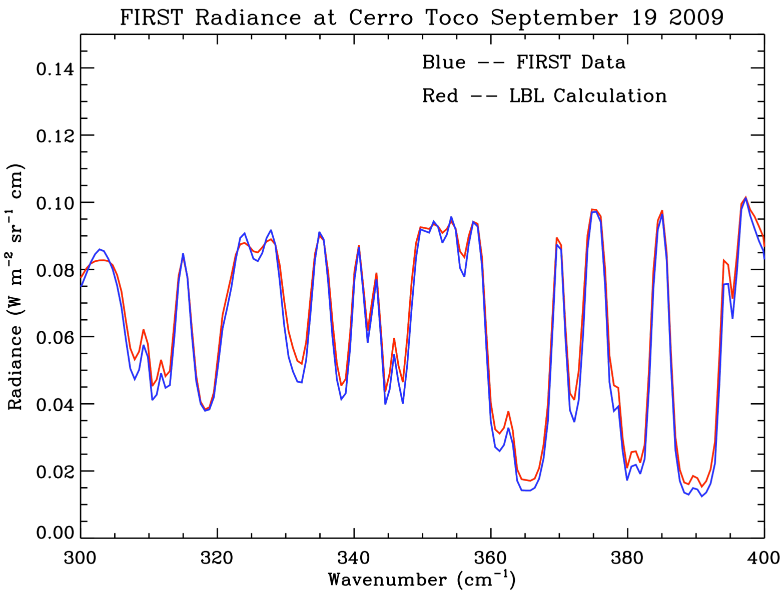
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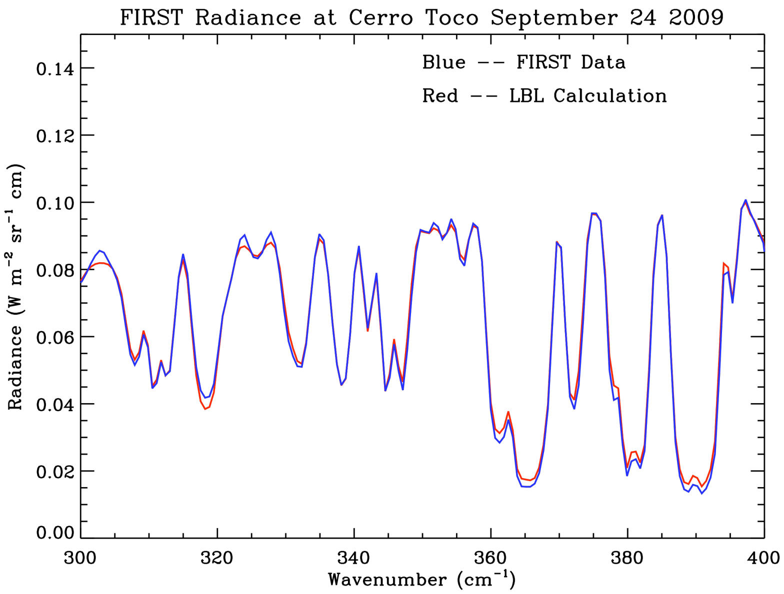
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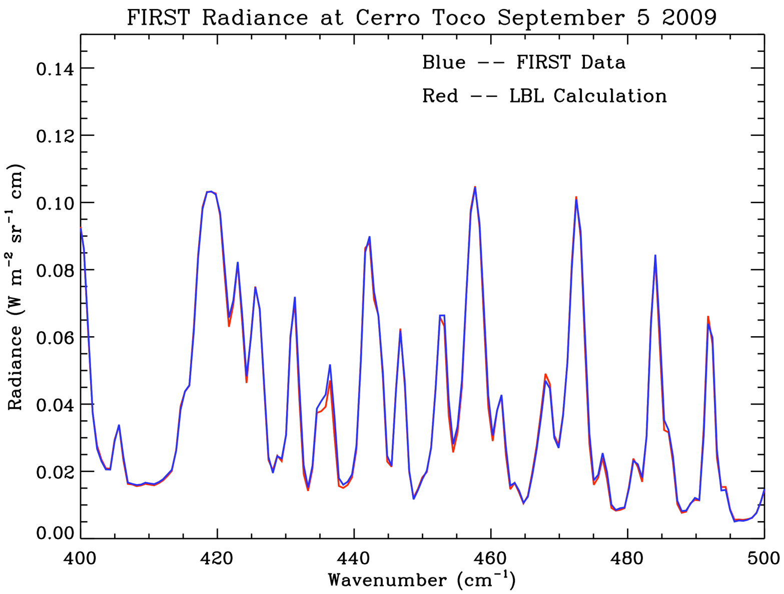
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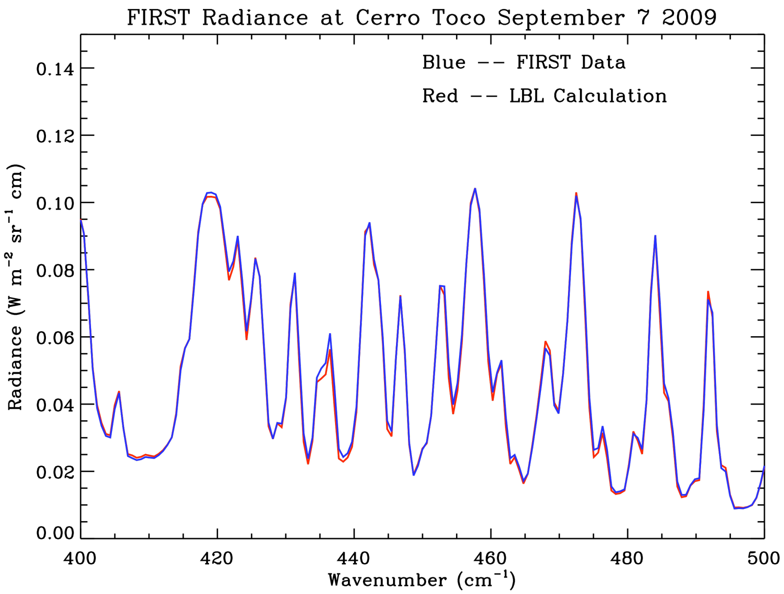
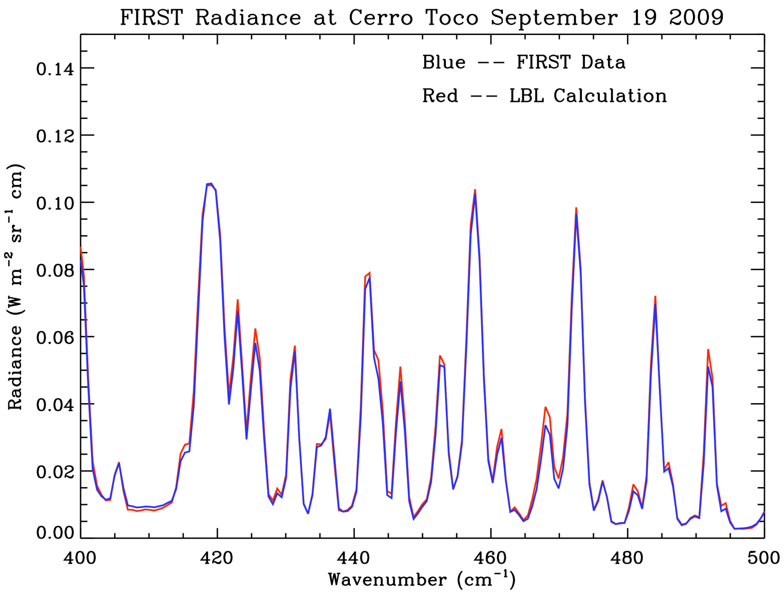
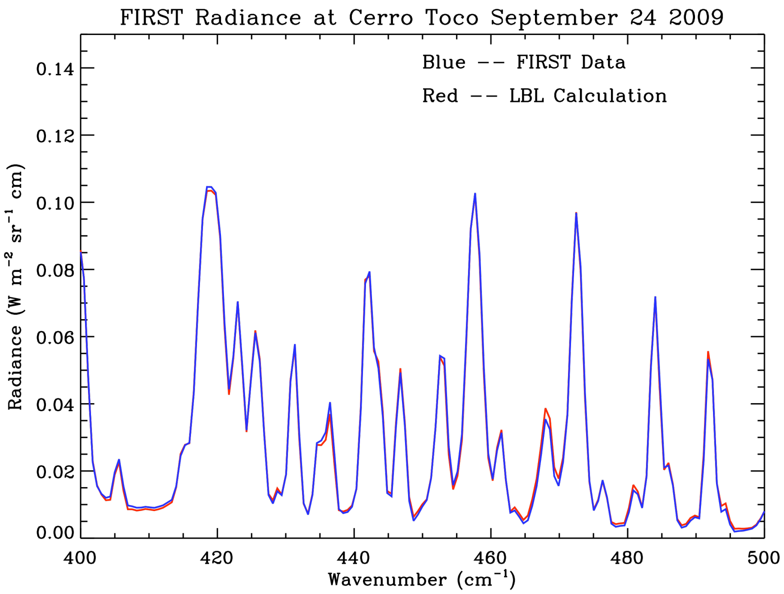

FIRST Radiance at Cerro Toco September 7 2009

FIRST Data 400 – 500 cm^{-1}; September 5, 7, 19, 24


FIRST Radiance at Cerro Toco September 19 2009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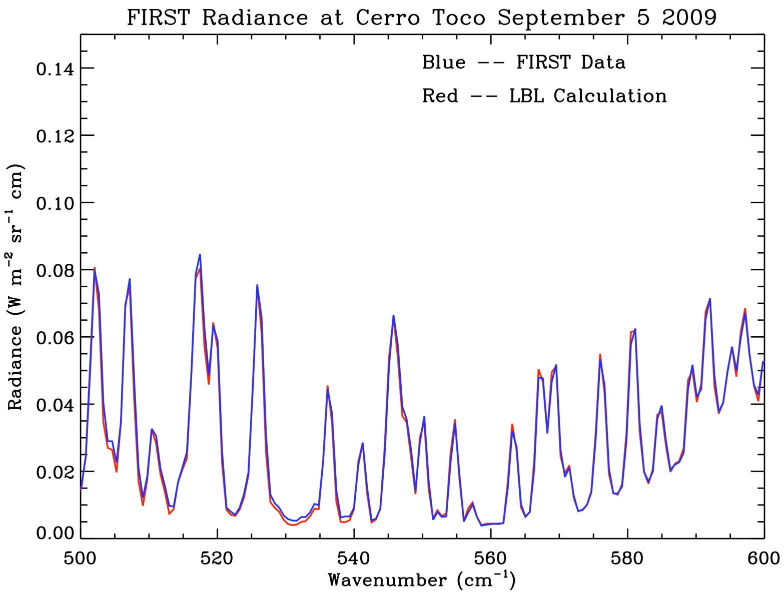
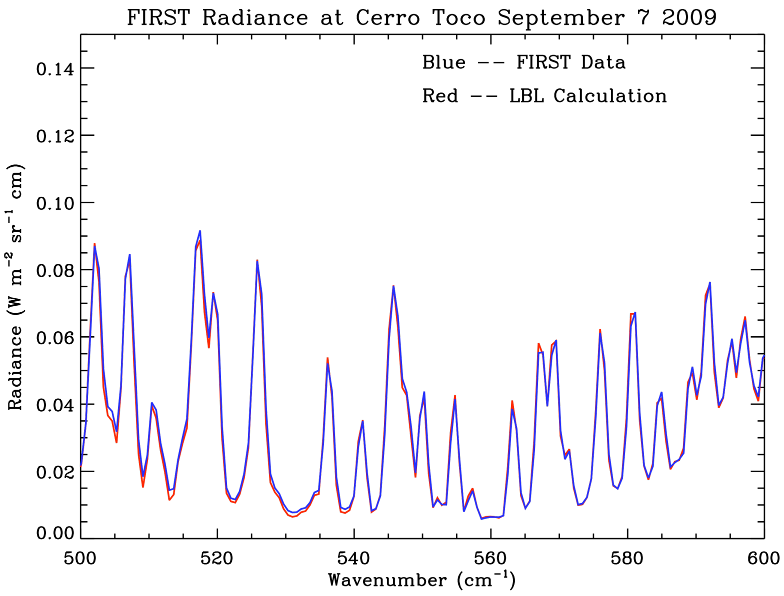
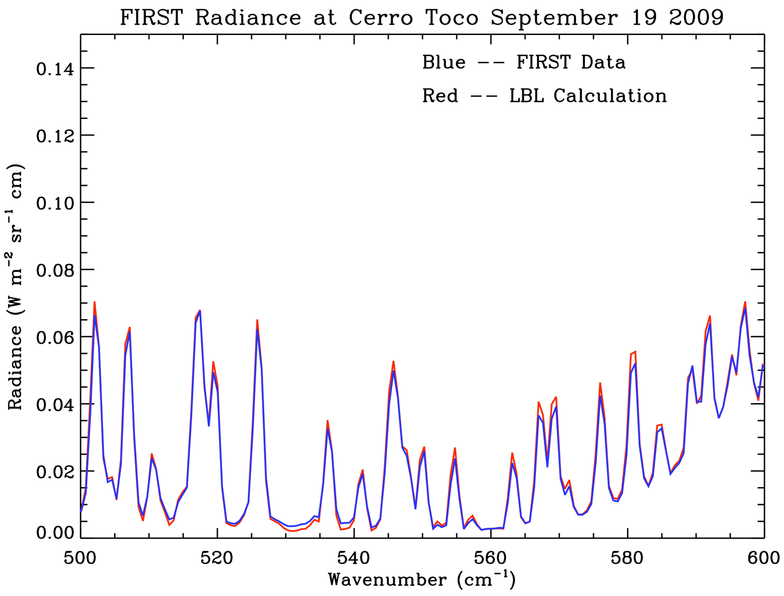
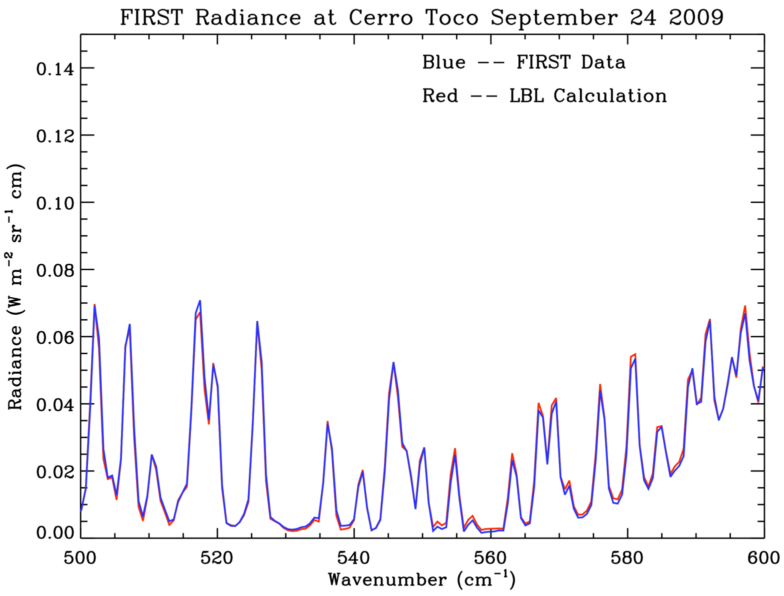
FIRST Data 500 – 600 cm^{-1}; September 5, 7, 19, 24


FIRST Radiance at Cerro Toco September 5 2009


FIRST Radiance at Cerro Toco September 7 2009


FIRST Radiance at Cerro Toco September 19 2009


FIRST Radiance at Cerro Toco September 24 2009

Summary (1 of 2)

- Time series of accurate infrared spectra yield quantitative measures of decadal atmospheric change

- Experiment design must consider:
  - Instrument calibration – 0.1 K (3-σ) in brightness temp
  - Instrument noise – evaluate to be sure truly random
  - Spatial sampling, i.e., satellite orbit, measurement frequency
  - Temporal sampling – full diurnal cycle

- NASA investment over last decade has enabled development of spectrometers and related technologies to establish infrared climate benchmarks from space

- "CLARREO" Mission designed to do this……

Summary - CLARREO Mission Status

- Mission Concept Review successfully completed November 2010, ready in Jan 2011 to proceed to phase A

- NASA Langley mission lead. Team members include:
  - LaRC, GSFC, JPL, NIST
  - UC-Berkeley/DOE, Harvard, U. Wisconsin, C.U.-LASP, Utah State-SDL, Univ. Miami, Univ. Maryland, Univ. Michigan;
  - International collaboration with UK and Italy

- NASA budget reductions in Feb 2011: CLARREO remains indefinitely in pre-phase A studies, with no current planned launch date

- Science studies continue with Science Definition Team

- Mission risk reduction activities continue including completion of infrared and reflected solar Calibration Demonstration Systems and NIST standards improvements

CLARREO continues in pre-formulation and is looking for opportunities