Towards Measurement of Earth's Far-Infrared Radiance Spectrum

Marty Mlynczak, Science Directorate, NASA Langley
Richard Cageao, Engineering Directorate, NASA Langley
David Kratz, Science Directorate, NASA Langley
David Johnson, Engineering Directorate, NASA Langley

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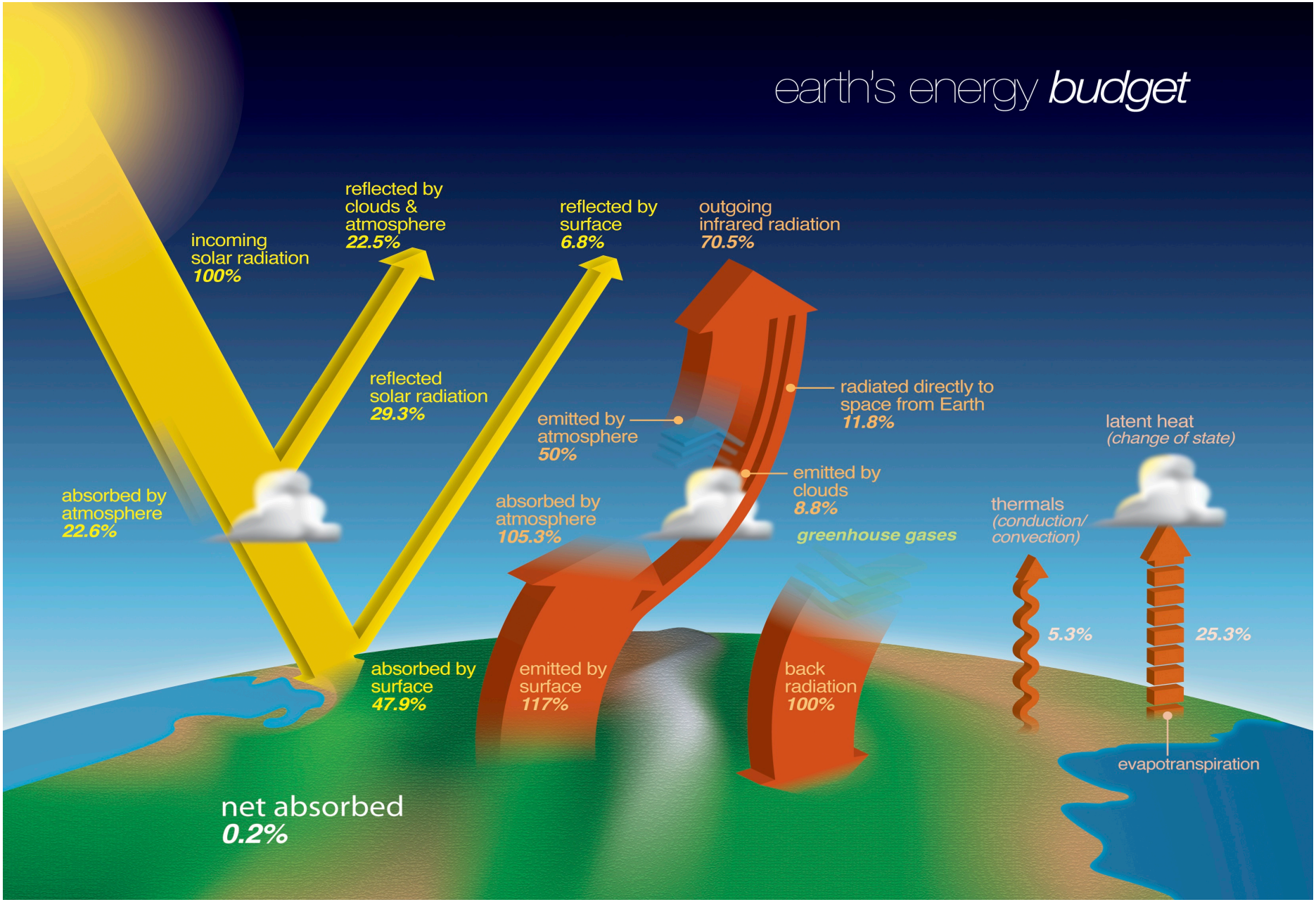
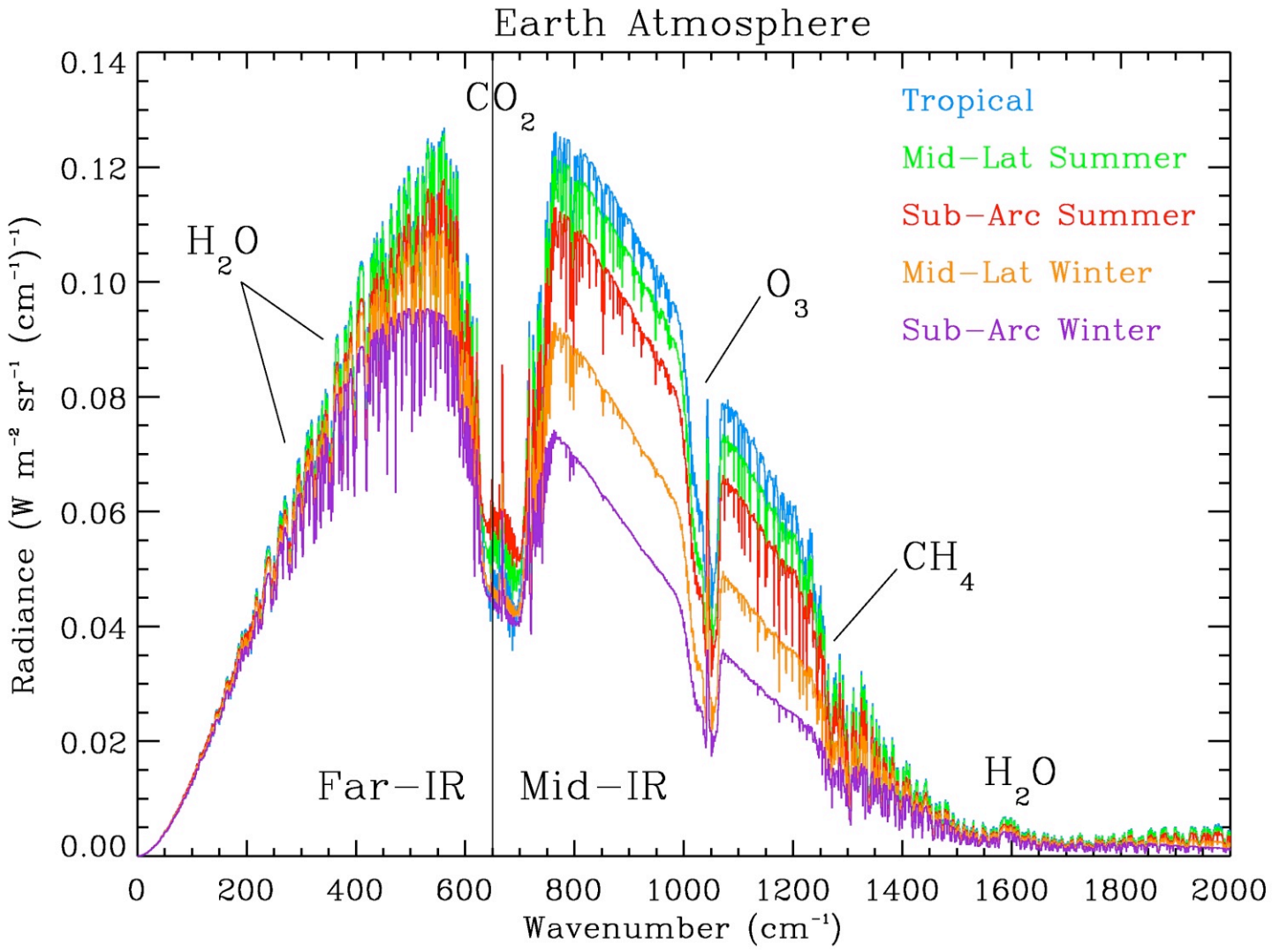
Outline

- **Review Earth's Top-of-Atmosphere Infrared Radiance Spectrum and the Importance of the Far-Infrared**
- **ESTO investments to achieve direct measurement of the far-infrared spectrum**
  - **FIRST**
  - **INFLAME**
  - **CORSAIR**
- **Recent progress in calibration, measurement, and simulation**
  - **FORGE and Table Mountain Field Experiments**
- **Prospects for the future**


earth's energy budget
incoming solar radiation 100%
reflected by clouds & atmosphere 22.5%
reflected by surface 6.8%
outgoing infrared radiation 70.5%
reflected solar radiation 29.3%
radiated directly to space from Earth 11.8%
emitted by atmosphere 50%
emitted by clouds 8.8%
greenhouse gases
absorbed by atmosphere 22.6%
absorbed by atmosphere 105.3%
latent heat (change of state)
thermals (conduction/ convection)
5.3%
25.3%
absorbed by surface 47.9%
emitted by surface 117%
back radiation 100%
evapotranspiration
net absorbed 0.2%

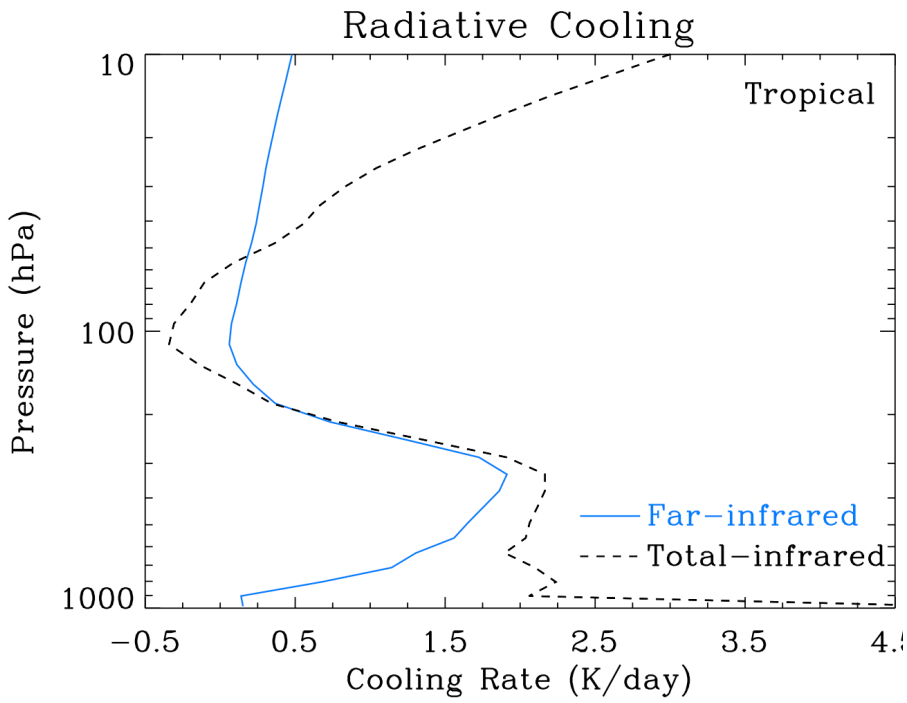
Clear Sky Top-of-Atmosphere Infrared Spectrum

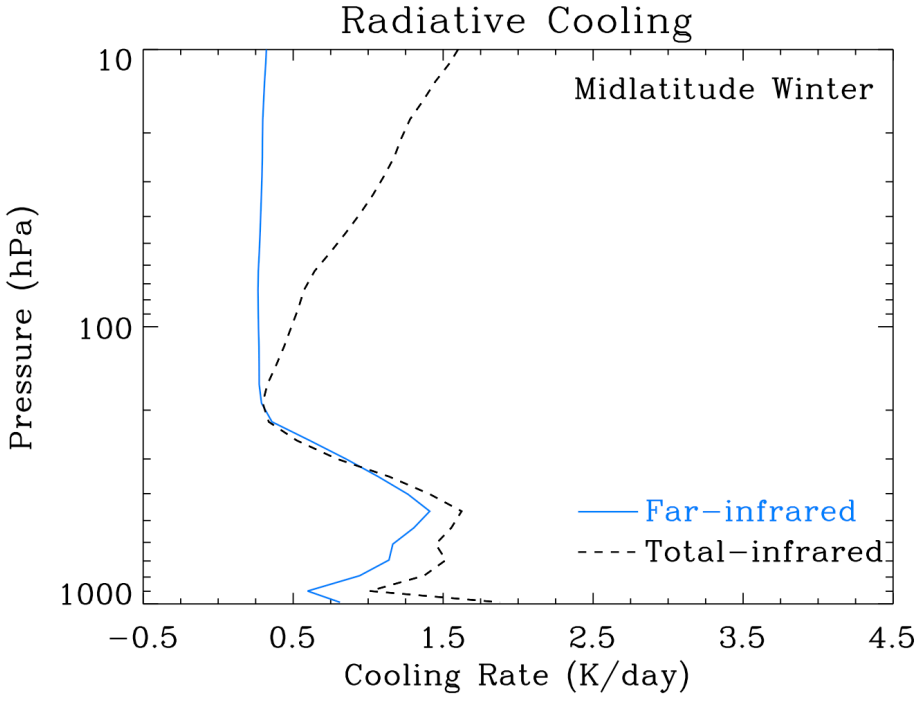


Compelling Science of the Far-IR

- Up to 50% of OLR (surface and atmosphere) occurs in far-IR
- Up to 75% of atmospheric OLR occurs in the far-IR
- Up to 50% of greenhouse effect is in far-IR
- Clear-sky cooling of free troposphere occurs in far-IR
- Upper tropospheric H_2O radiative feedback occurs in far-IR
- Cirrus and LW cloud radiative forcing has major component in far-IR
- Far-IR spectra are climate "benchmarks" and climate change "fingerprints"
- **Yet, far-IR spectra remain unobserved from space for 45 years!**

Infrared Radiative Cooling Rates

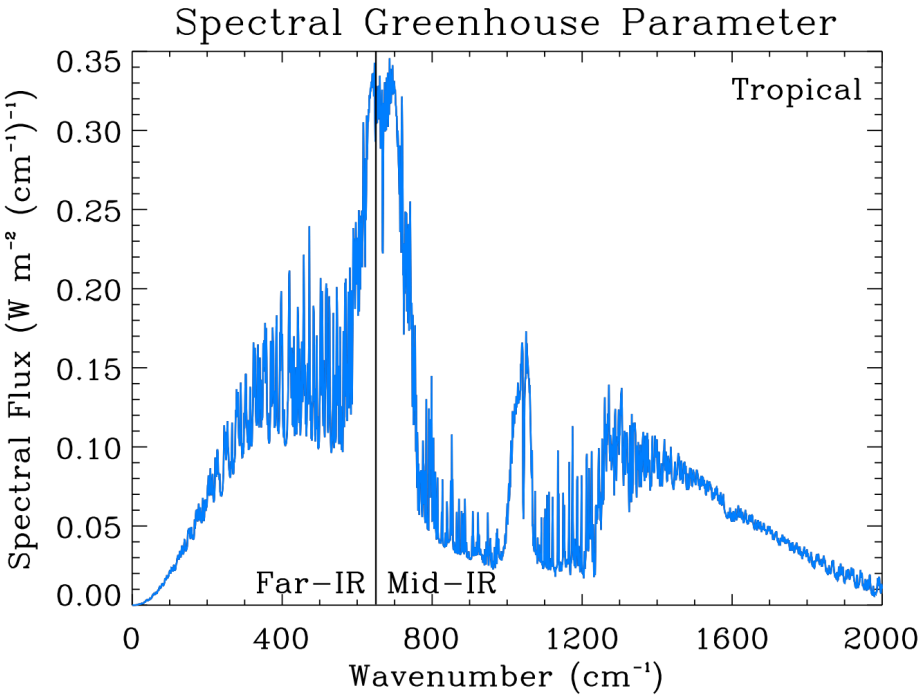


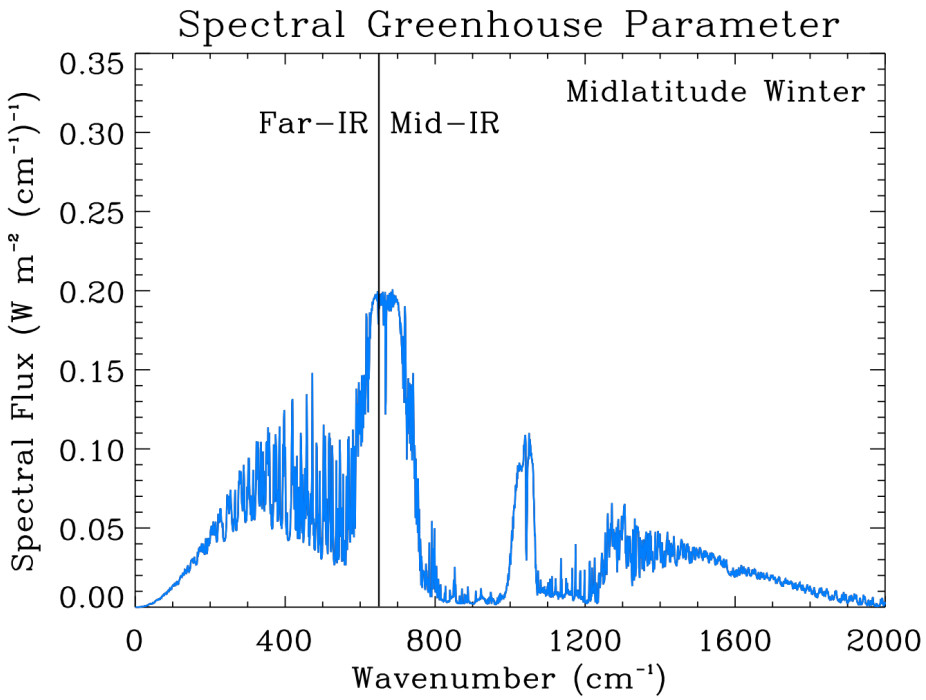


Radiative cooling above boundary layer is predominately in far-IR

Spectral Greenhouse Parameter

$$G_\nu = F_\nu(\text{surface}) - F_\nu(\text{TOA})$$





A large fraction of the natural greenhouse effect occurs in the Far-IR

Chronology of Far-IR Projects at Langley

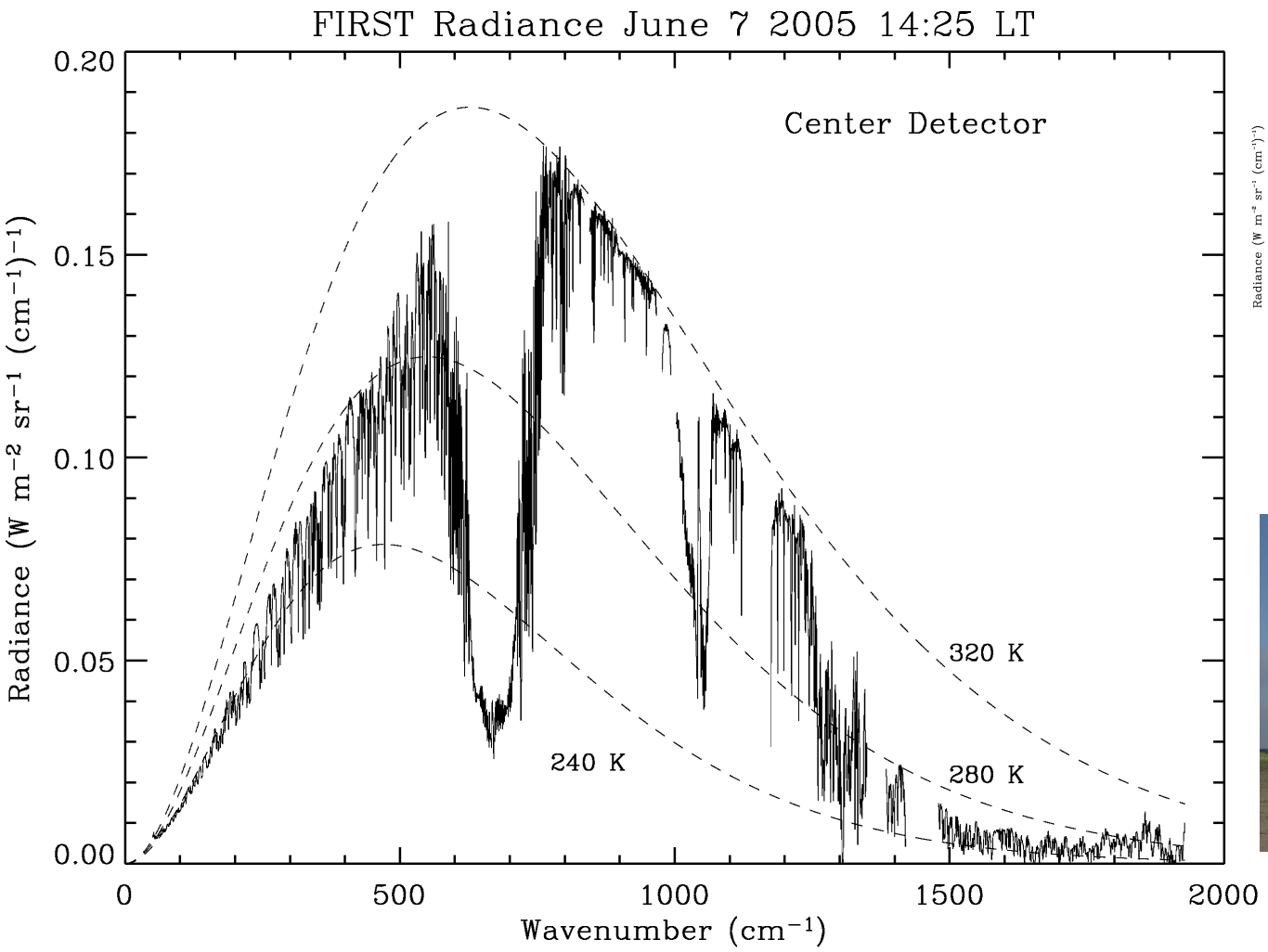
NASA ESTO has made substantial investments in far-IR measurement technology:

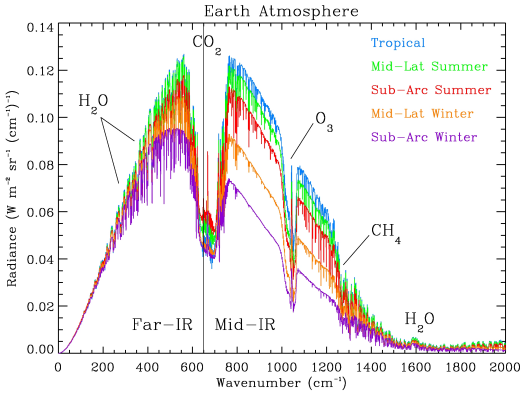
- FIRST Instrument
  - IIP 2001
- INFLAME Instruments
  - IIP 2004
- FIDTAP (Detector Technology)
  - ATI 2006
- FORGE (NASA component of RHUBC-II)
  - Radiation Sciences Program
- CORSAIR
  - IIP 2007
- FIREBIB (Detector Technology)
  - ACT 2008
- FIRST Recalibration & Deployment
  - ATI-QRS 2011

Far-IR Projects at Langley- FIRST Instrument

- FIRST Instrument
  - Far-Infrared Spectroscopy of the Troposphere
  - Michelson Fourier Transform Spectrometer
  - 6 to 100 μm or 1667 to 100 cm^{-1}
  - Operates from high altitude balloon OR from ground
  - Flew in 2005 and 2006 in Ft. Sumner, NM
  - Ground based campaign at Cerro Toco Chile in 2009
  - Calibrated to NIST standards in 2011/2012
  - Ground based campaign at Table Mountain, CA, in 2012

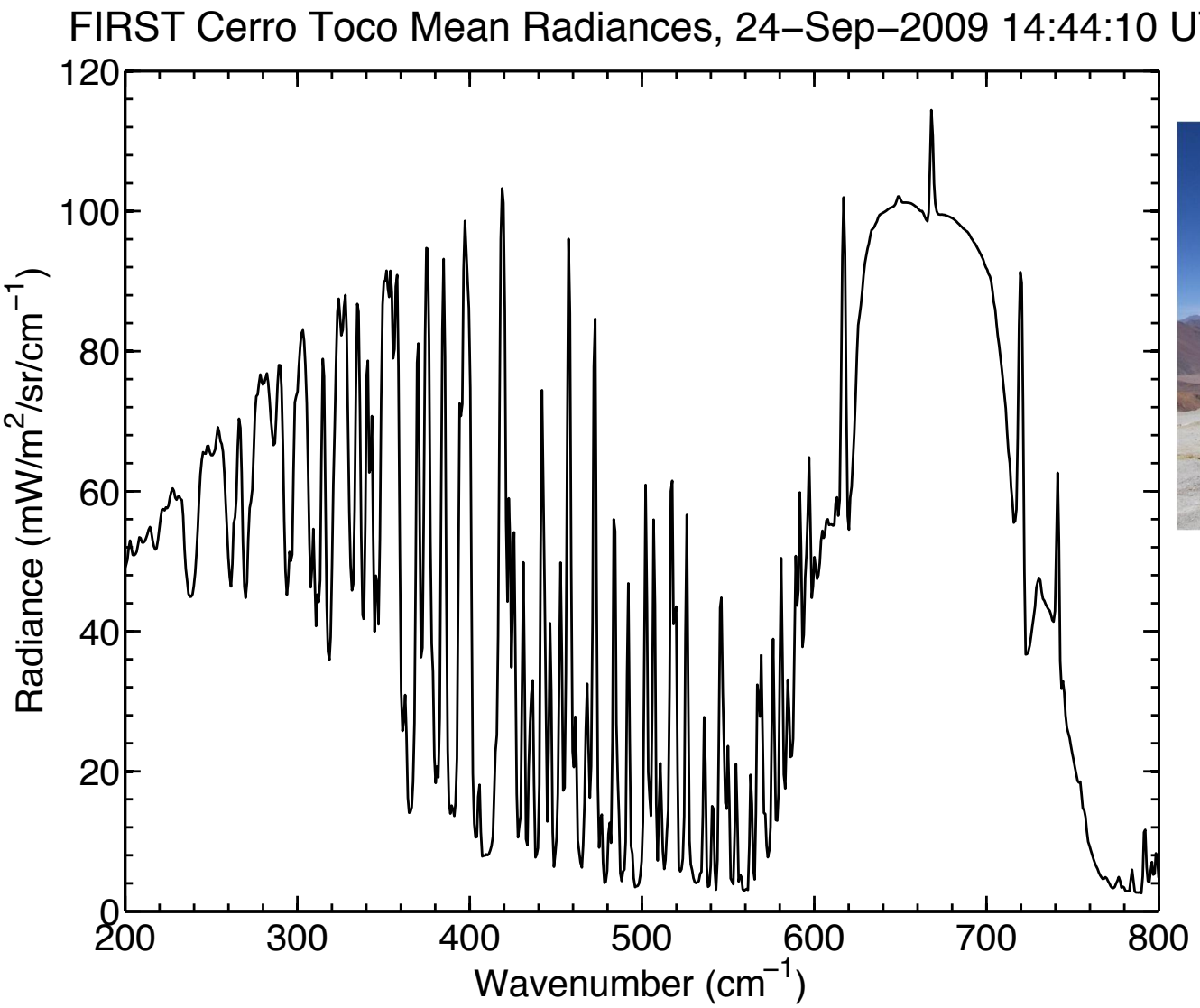
FIRST Thermal Infrared Spectrum - TOA

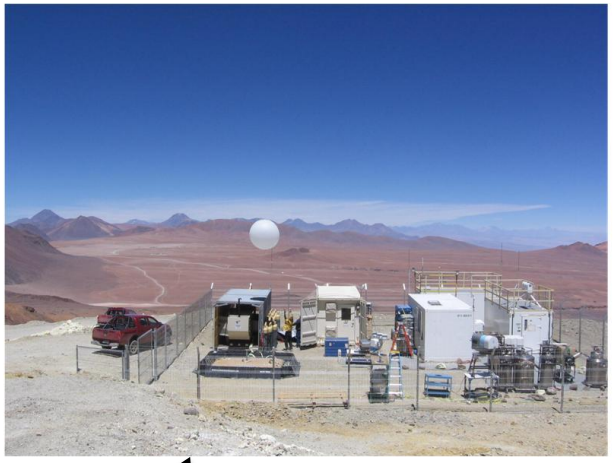




Mlynczak et al., GRL, 2006

FIRST Thermal Infrared Spectrum – Earth's Surface





Cerro Toco,
Atacama Desert, Chile

17,500 feet above sea level

Surface Pressure ~ ½ atm

FIRST Thermal Infrared Spectrum – Earth's Surface

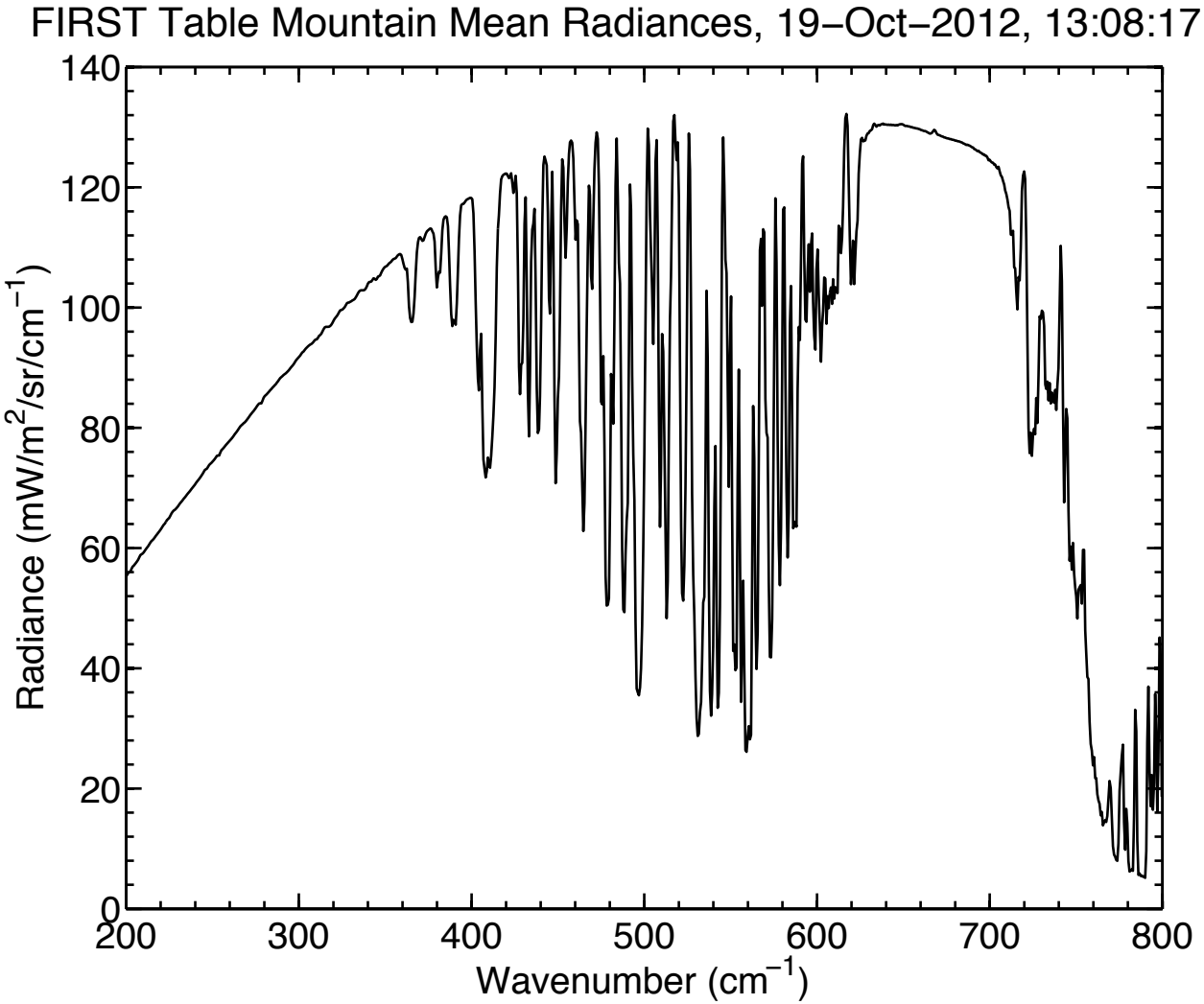


Table Mountain,
Mohave Desert, CA

7,500 feet above sea level

Surface Pressure ~ 3/4 atm

FIRST Thermal Infrared Spectrum – Earth's Surface

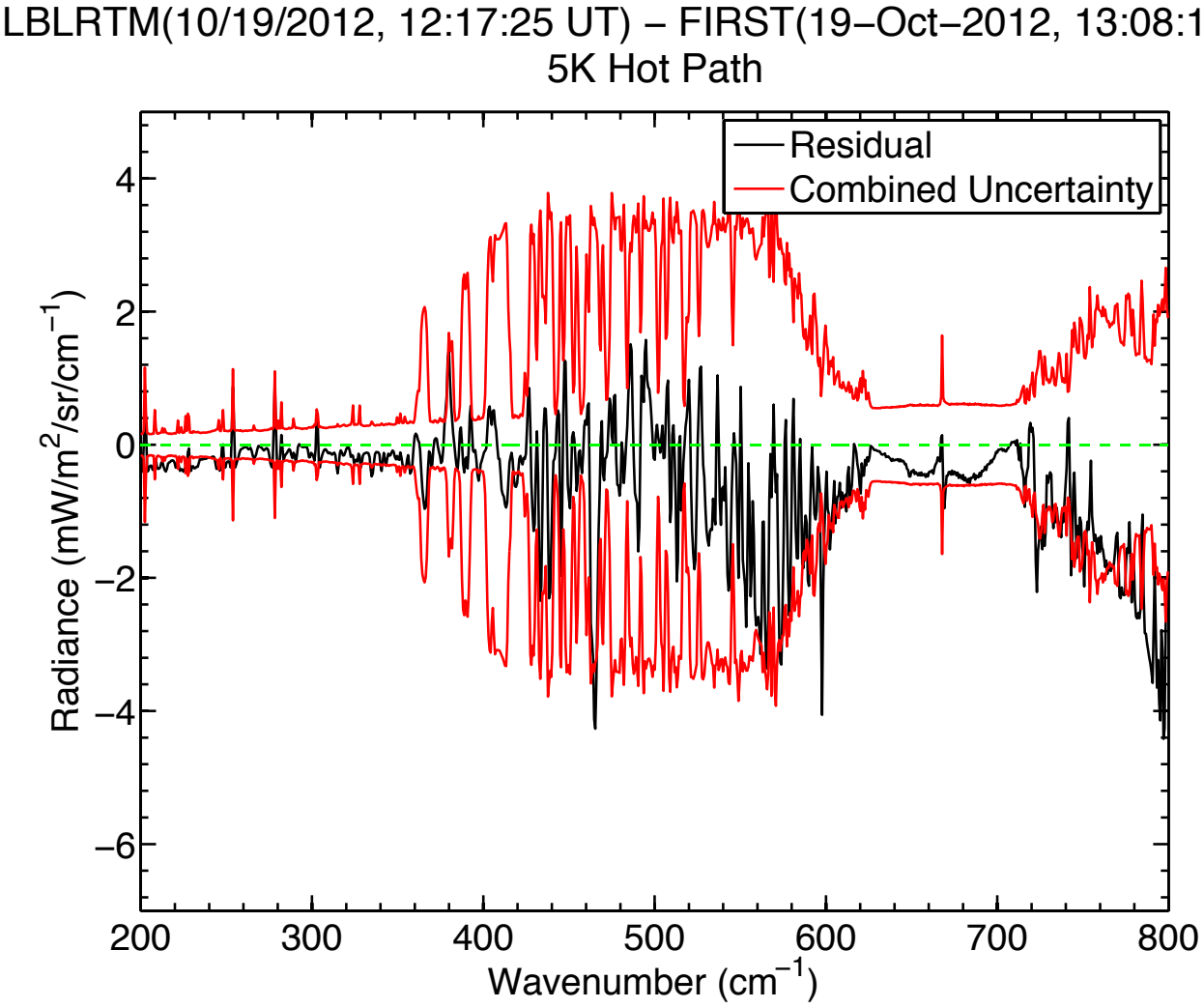


Table Mountain, CA

Comparing FIRST and model

Measurement Residual
- **Black Curve**

Uncertainty
- **Red Envelope**

FIRST and RT models agree to better than uncertainty in the far-IR!

ESTO Investments in Direct Far-IR Measurement

- **FIRST – ability to measure far-IR at the "top" and "bottom" of the atmosphere**

- **INFLAME – measuring the far-IR *within* the atmosphere**
  - **Designed and built at Langley**
  - **Successfully demonstrated technologies on Lear Jet flight**

INFLAME – Fundamental Aspects

Every atmospheric model has essentially 3 equations:

- **Momentum: (F = ma)**
- **Continuity: (Conservation of mass)**
- **Energy: (First Law of Thermodynamics)**

Energy equation requires knowledge of rate at which atmosphere heats and cools:

- **Radiation**
- **Latent process (water condensation/evaporation)**
- **Conduction**

INFLAME Goal: Measure the rates of heating & cooling of the atmosphere by visible and infrared radiation

In-Situ Net Flux within the Atmosphere of the Earth

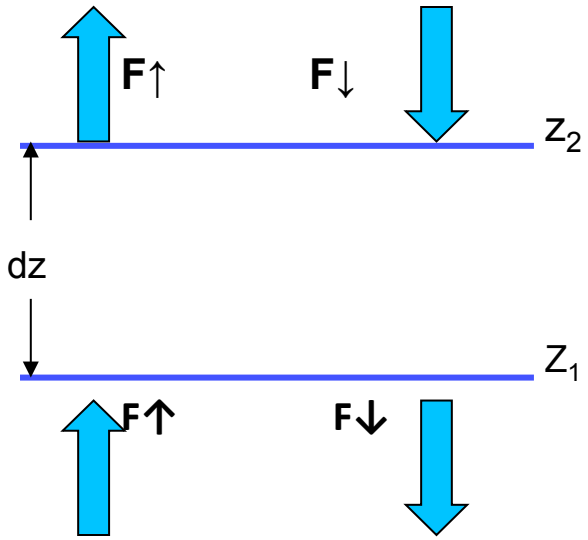
Atmospheric Heating and Cooling Rates

$$F\uparrow(z) = \int_0^1 I(z)\,\mu\,d\Omega$$

$$F\downarrow(z) = \int_{-1}^0 I(z)\,\mu\,d\Omega$$

$$F_{net}(z) = F\uparrow(z) - F\downarrow(z)$$

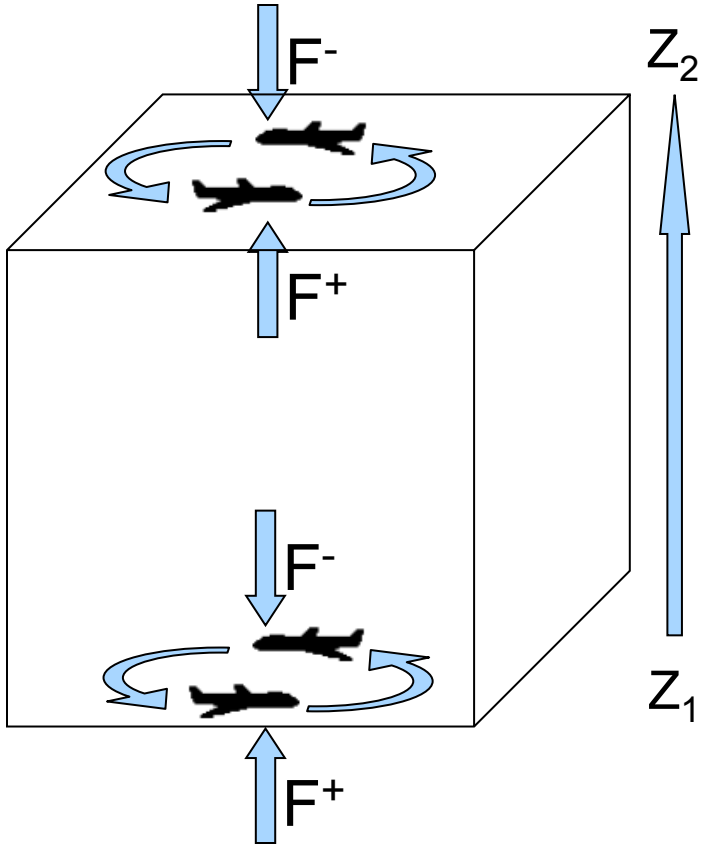
$$\frac{\partial T}{\partial t} = \frac{1}{\rho\, C_p}\,\frac{\partial F_{net}(z)}{\partial z}$$



Require an instrument to *directly* measure the net flux

Measuring Net Flux and Net Flux Divergence

- From an airborne platform:
  - Measure Net Flux at Z_1
  - Measure Net Flux at Z_2



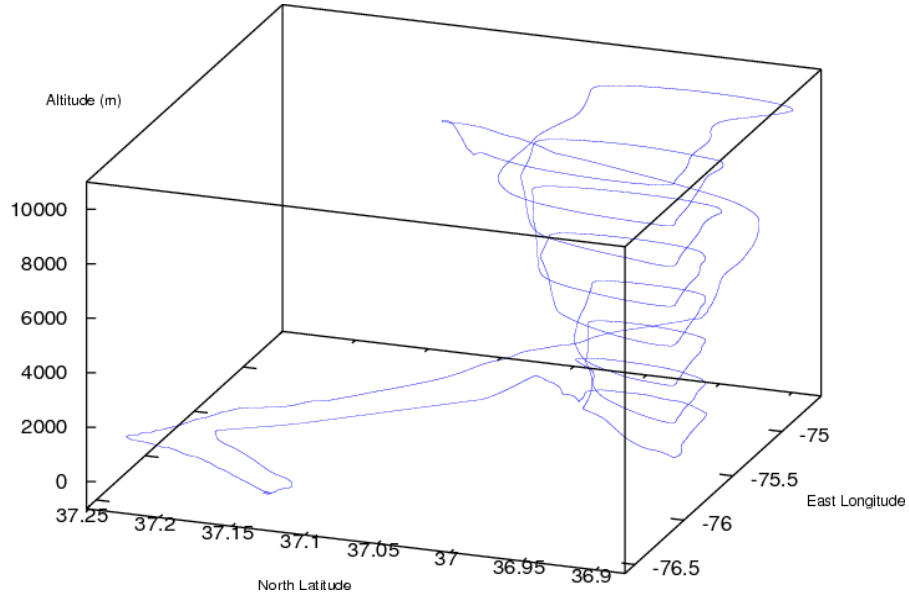
- Approximate Heating Rate by:

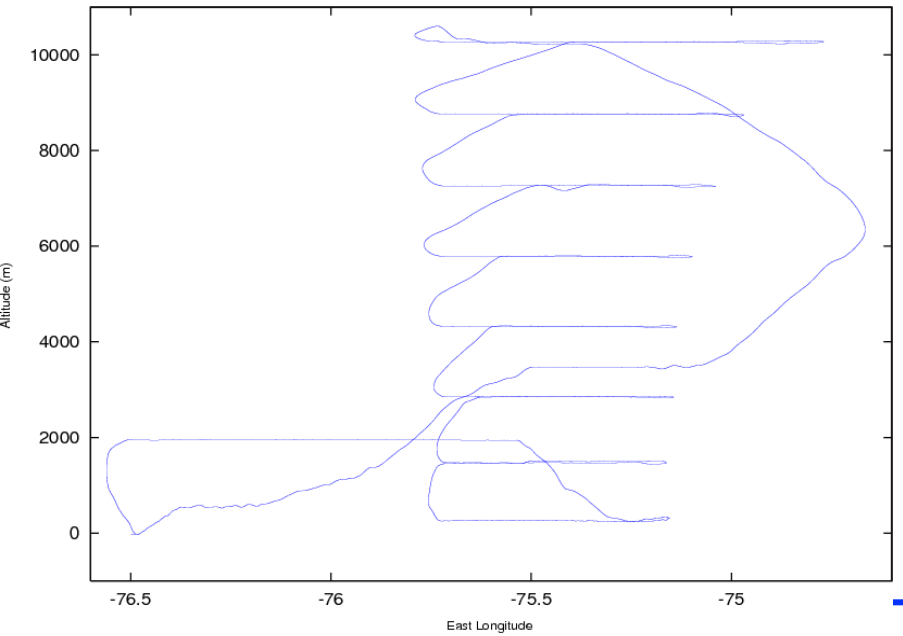
$$\frac{\partial T}{\partial t} = \frac{1}{\rho C_p} \frac{F_{net}(z_2) - F_{net}(z_1)}{(z_2 - z_1)}$$

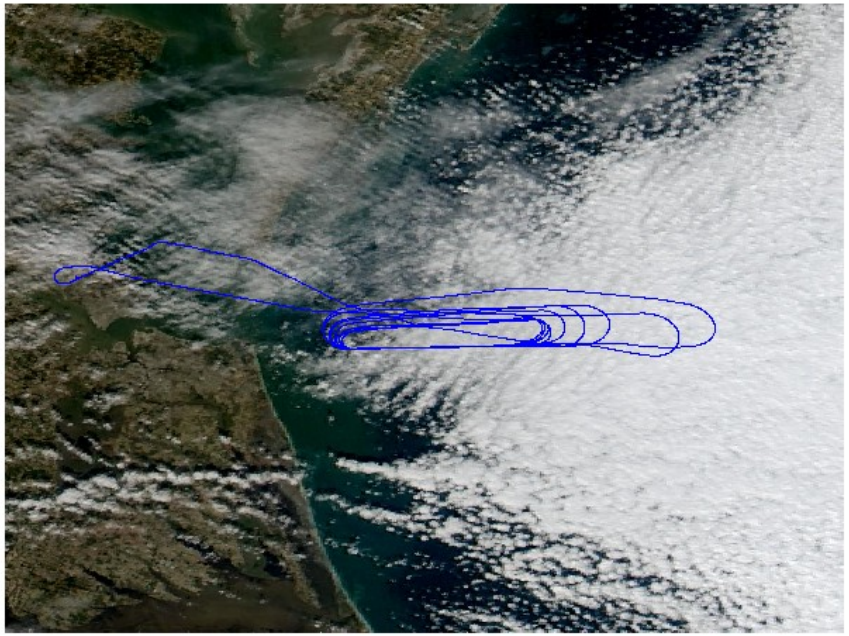
INFLAME instruments measure the net flux of infrared and visible radiation

INFLAME Instruments
Installation in Lear Jet Wing Pod

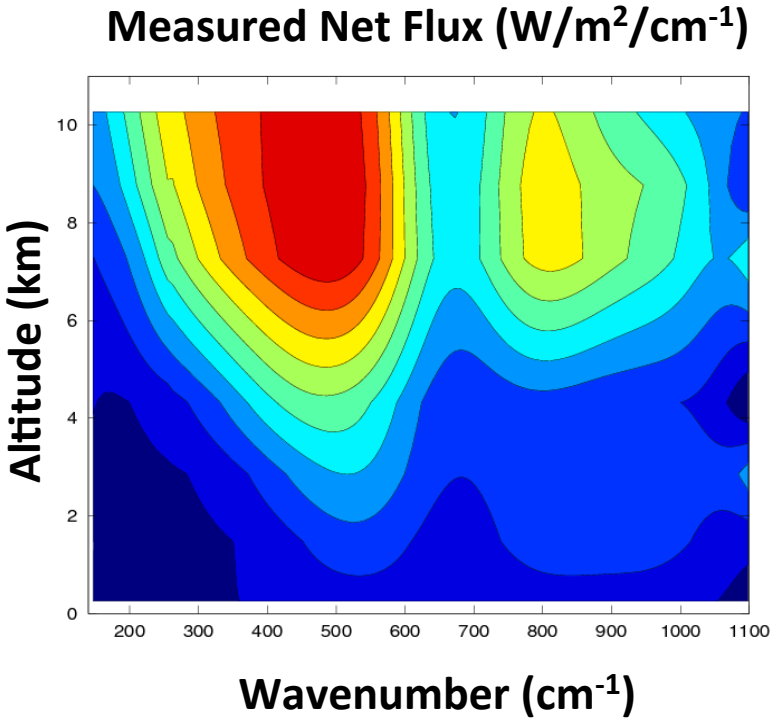
INFLAME Flight Profile January 2010

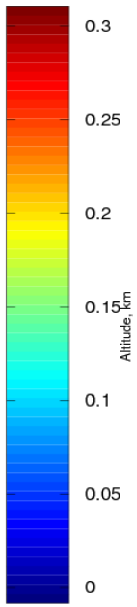


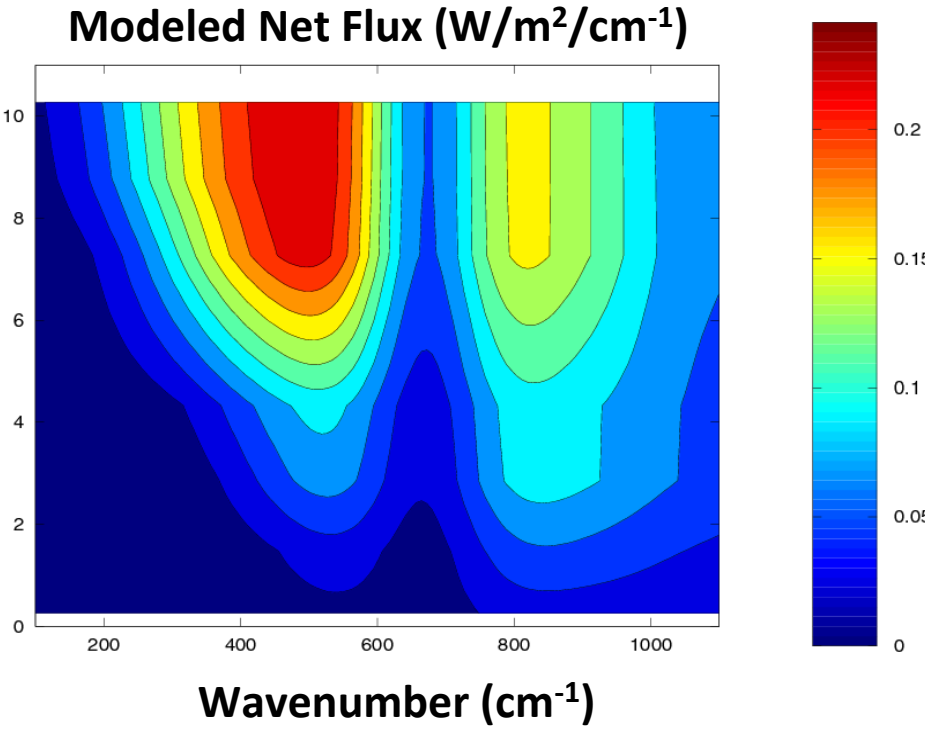




INFLAME Measured and Modeled Net Flux







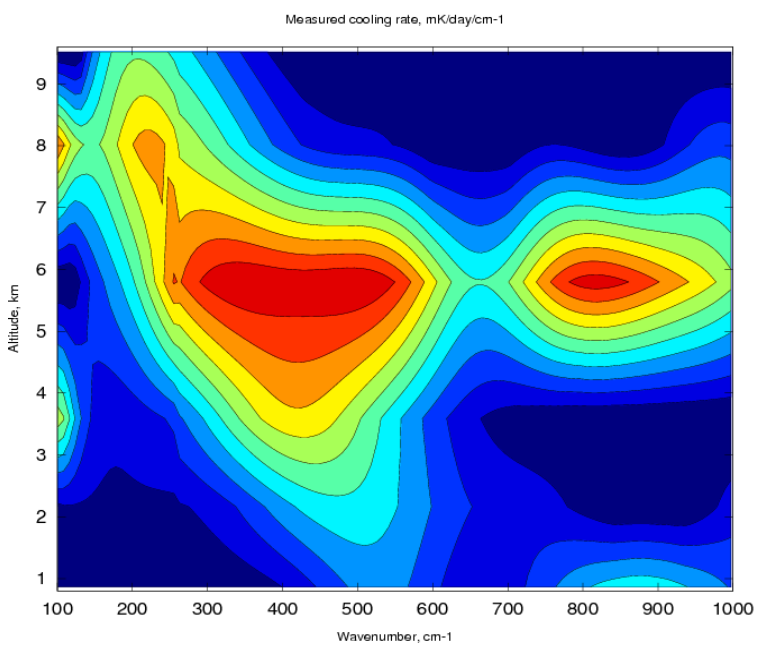
Measured LW Net Flux

1/5/2010

Calculated LW Net Flux

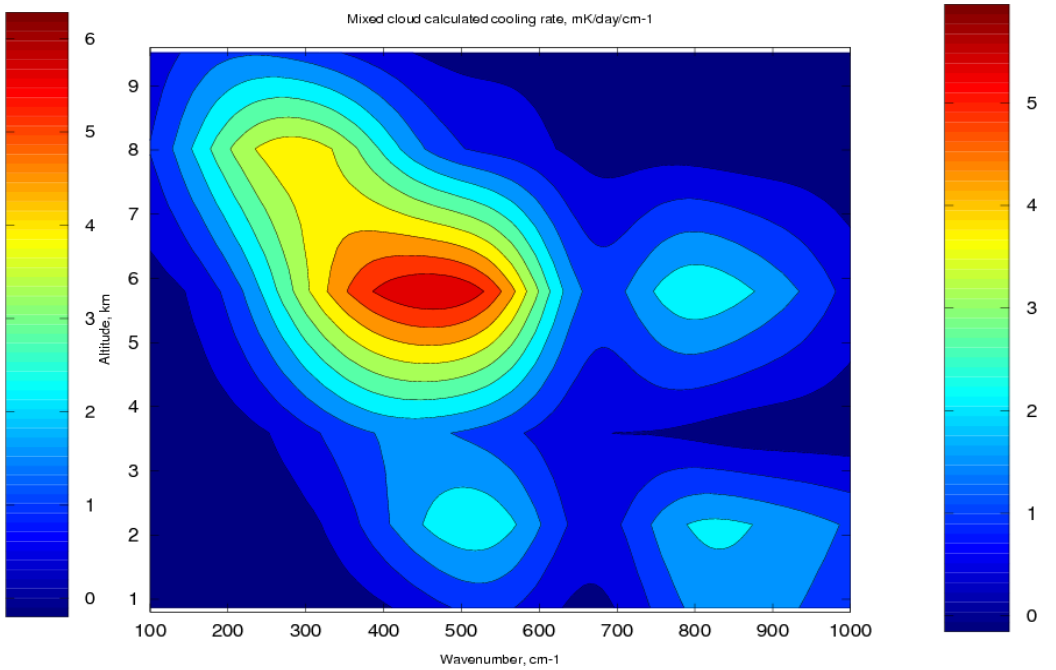
1/5/2010

INFLAME Measured and Derived LW Cooling Rates



Measured LW Cooling mK/Day/cm^{-1}

1/5/2010 flight.



Calculated LW Cooling mK/Day/cm^{-1}

1/5/2010 flight

Summary

- ESTO Investments over the past decade have enabled world-unique sensors to be developed for measuring climate change
  - At Langley, U. Wisconsin, and U. Colorado
- We are poised to open a completely new window on the climate system – the far-IR!
- Measurements of the complete IR spectrum – including the far-IR – enables us to understand processes (e.g., H_2O feedback) and to measure climate change
- The time is now to move forward with these measurement systems in a climate-focused mission such as CLARREO