Far-Infrared Observations of the Radiative Greenhouse Effect

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Outline

• Review of Earth’s Energy Budget and Infrared Greenhouse Effect

• Development of the NASA FIRST Instrument

• Description of the FORGE campaign to Chile’s Atacama Desert

• FIRST results from the FORGE Campaign

• Relation to CLARREO mission
Earth’s Energy Budget
Earth’s Outgoing Longwave Radiation

Earth’s Atmosphere

- Tropical
- Mid-Lat Summer
- Sub-Arc Summer
- Mid-Lat Winter
- Sub-Arc Winter

Species:
- H₂O
- CO₂
- O₃
- CH₄

Radiance (W m⁻² sr⁻¹ (cm⁻¹)⁻¹)

Wavenumber (cm⁻¹)

Unobserved From Space

AIRS, IASI, CrIS
FIRST Instrument

FIRST - Far-Infrared Spectroscopy of the Troposphere

– Developed under NASA Instrument Incubator Program of ESTO
– 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
– Selected by NASA for FORGE Campaign in Chile in 2008
– FORGE Campaign August – October 2009
Earth’s Energy Budget

- Incoming solar radiation: 100%
- Reflected by clouds & atmosphere: 22.6%
- Reflected by surface: 6.8%
- Outgoing infrared radiation: 70.5%
- Radiated directly to space from Earth: 11.8%
- Greenhouse gases: 8.8%
- Evapotranspiration: 25.3%
- Latent heat (change of state): 5.3%

Net absorbed: 0.2%
The FORGE Project – Scientific Objective

• Use new observational capability provided by FIRST to directly observe and quantify entire infrared greenhouse effect

• Conduct “radiative closure” experiment
  – Measure infrared radiation emitted by the atmosphere – *at Earth’s surface looking up*
  – Simultaneously measure temperature and water vapor profiles to provide inputs for theory
  – Comparison provides fundamental test of knowledge of greenhouse effect

• Conduct experiment at high, dry location – Cerro Toco, Atacama Desert, Chile
  – Enables observations of fully-developed infrared spectrum at all significant wavelengths
  – Altitude: 17,600 feet above sea level. Mean pressure ~ 0.5 Atmosphere
  – *Precipitable Water Vapor < 1 millimeter*

• Part of larger “RHUBC-II” Campaign run by Dept. of Energy
  – Teams from U. Wisconsin, AER Inc., Italy, Germany, PNNL, Los Alamos NL, U. Denver, NASA Langley
  – Four separate FTS instruments covering 10 to 1800 cm⁻¹ (1000 µm to 5.5 µm)

*Safety of Team during deployment at altitude was paramount*
Earth’s Downwelling Infrared Radiation – at Surface

Tropical Atmosphere

Surface Radiance, IWP = 4.2 cm
Summit Radiance, IWP = 0.15 cm
Where is Cerro Toco?
The Chajnantor Plateau, Chile
Operations at 17,600 Feet
FIRST Radiance from Cerro Toco

Blue — FIRST Data

Red — LBL Calculation

PWV = 0.75 millimeter (“wet” day)
FIRST Radiance from Cerro Toco

Difference FIRST – LBL

Radiance (W m$^{-2}$ sr$^{-1}$ cm$^{-1}$)

Wavenumber (cm$^{-1}$)
FIRST Radiance from Cerro Toco

Difference FIRST – LBL

Radiance (W m$^{-2}$ sr$^{-1}$ cm$^{-1}$)

Wavenumber (cm$^{-1}$)
September 5 2009 – PWV = 0.75 mm

FIRST Radiance from Cerro Toco

Blue -- FIRST Data

Red -- LBL Calculation

Radiance (W m⁻² sr⁻¹ cm⁻¹)

Wavenumber (cm⁻¹)
September 19 2009 – PWV = 0.4 mm
September 19 2009 – PWV = 0.4 mm

FIRST Radiance from Cerro Toco – Sept. 19 2009

Blue -- FIRST Data

Red -- LBL Calculation
FIRST Radiance from Cerro Toco – Sept. 19 2009

Blue -- FIRST Data

Red -- LBL Calculation

Radiance (W m⁻² sr⁻¹ cm⁻¹)

Wavenumber (cm⁻¹)

600 620 640 660 680 700

0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14

NASA
Variation of Far-IR spectra over two hours

Increase of H$_2$O evident in measurements

Theory matches this observation
Composite Infrared Spectrum at Earth’s Surface

Downwelling Infrared Radiance at 17,600 Feet

Combined Spectra from all 4 Instruments at Cerro Toco
Onto the Future – The CLARREO Mission

- FIRST data pave way for us to understand science and instrument
- Pushes the envelope in calibration and climate system measurement
- Enables us to learn how to achieve the on-orbit accuracy goals of CLARREO
Summary

• FIRST instrument successfully developed and demonstrated

• Successfully and *safely* completed the FORGE campaign to Chile

• Nearly 400 datasets spanning 3 months are now available

• Preliminary data shows no major gaps in theory and observation of the far-infrared, in clear sky

• Agreement with other instruments (not shown) appears excellent

• Cirrus cloud days need to be examined still

• NASA ESTO Instrument Incubator Program a huge success

• Leading the way to CLARREO via science and instrument technology
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