FIRST Results from Cerro Toco, Chile

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Outline

• Review of FIRST project to date
  – Instrument specs
  – Timeline
  – Summary of results (mostly TMF)

• Field deployments
  – Table Mountain, CA
  – Cerro Toco, Chile

• Results from Cerro Toco
  – Comparing measurements, model calculations, and their uncertainties
FIRST Instrument

Instrument Characteristics

• 100 – 1000 cm⁻¹
• 0.643 cm⁻¹ resolution
• Calib. BB @ 46 C & 17 C
• 10 LHe bolometers
• Ge on polypropylene beamsplitter
• Plane mirror FTS
• 11 sec scan
Review of FIRST Project

- 2005 – FIRST built at SDL
- 2006 – Balloon flight at Ft Sumner
- 2009 – Cerro Toco Deployment for RHUBC-II campaign
- 2011 – Recalibration at SDL with LWIRCS
- 2012 – Deployment to Table Mountain
- 2013 – FIRST data corrected for nonlinearities
- 2014 – Receive final atmospheric dataset from Cerro Toco
Review of Table Mountain Campaign Results

• FIRST measurements at Table Mountain have been compared with LBLRTM calculations
• Conducted assessment of measurement and model uncertainties
  – FIRST and LBLRTM agree to within their combined uncertainties
  – The need to measure Far-IR shown as model uncertainty > measurement uncertainty
• Results from Table Mountain to be submitted to JQRST
• Moving forward with Cerro Toco analysis
Comparing the Campaigns

**Table Mountain, CA**
- Surface at 7500 ft
- Surface pressure approximately 775 hPa
- IPW approximately 3 mm
- Approximately 17.75 cm hot path
- Water vapor vertical profiles from radiosondes with flights of ~2 hrs

**Cerro Toco, Chile**
- Surface at 17,500 ft
- Surface pressure approximately 550 hPa
- Approximately 166 cm hot path
- A chimney on the FIRST trailer complicates correcting spectra for hot paths.
- **Water vapor vertical profiles every ~5 minutes from GVRP**
  - What exactly?
Comparing the Campaigns, cont.
Plot both on one figure

Radiosonde and GPS Daytime (6hrs to 18hrs) IPW for September 12 to October 25

Precipitable Water, 2009, Cerro Toco, Chile
FIRST Downwelling Radiance Spectrum

Comparison of FIRST Spectra

(Table Mountain) – (Cerro Toco)
FIRST Downwelling Temperature Spectrum

Comparison of FIRST Brightness Temperatures

Table Mountain, 10/19/12, 05:19 UT
Cerro Toco, 09/19/09, 09:19 UT

(Table Mountain) – (Cerro Toco)
Methods for Analysis of Cerro Toco

• Acquire spectra
  – Measurements from FIRST averaged in the 30 minute measurement block to reduce noise
  – Atmosphere vertical profiles placed on 71 atmospheric layers and processed through LBLRTM
    • An estimate for the hot path (hot air prior to the instrument) is included in the results subsequent to LBLRTM

• Compare modeled and measured spectra
  – Difference = LBLRTM – FIRST

• Calculate uncertainties in model radiance
  – Line strength uncertainties for water and CO2
    • From AER v3.2 line parameter database
  – Half width uncertainties for water and CO2
    • From AER v3.2 line parameter database
  – Water vapor and temperature measured profile uncertainty used at input to LBLRTM
  – Uncertainty in the water vapor continuum as calculated by the continuum model in LBLRTM
    • From correspondence with Eli Mlawer

• Include measurement uncertainty
  – Sky uncertainty
    • Standard deviation of the approximate 155 spectra recorded in 30 minutes
  – Uncertainty from laboratory calibration
    • From Applied Optics publication by Harri Latvikoski

• Calculated combined uncertainty
  – RSS of measurement uncertainty and model uncertainty
  – Compare measurement uncertainty and model uncertainty
Estimating the Hot Path Effect

Line-by-Line → Hot Path → $R_{out}$ → FIRST

- To estimate the effect of the hot path on entering radiation

$$LBL \times (1 - \varepsilon_p) + \varepsilon_p \times B(T_p)$$

- LBL = Intensity of radiation entering the hot path
- $\varepsilon_p$ = Emissivity of the hot path
- $(1 - \varepsilon_p)$ = Transmittance of the hot path
- $T_p$ = Estimated temperature of the hot path
- $B(T_p)$ = Intensity of radiation emitted in the hot path

Difference between model with a “hot path estimate” and measured ($R_{out} - \text{FIRST}$)
Results from 9/24/2009

Measured

Modeled – 13K (above atmospheric surface temperature) hot path estimate included
Uncertainties of Measured Spectra
RSS of Measurement Uncertainties

LBLRTM(09/24/09, 14:41:42 UT) – FIRST(09/24/09, 14:44:10 UT)

Radiance (mW/m²/sr/cm⁻¹)

Wavenumber (cm⁻¹)
Model Uncertainties from measured atmosphere
Model uncertainties from h2o line strength and half-width
Model Uncertainties from co2 line strength and half-width
Water vapor continuum uncertainty
RSS of Model Uncertainties

LBLRTM(09/24/09, 14:41:42 UT) – FIRST(09/24/09, 14:44:10 UT)

Residual
Model Uncertainty

Wavenumber (cm\(^{-1}\))

Radiance (mW/m\(^2\)/sr/cm\(^{-1}\))
RSS of Model and Measurement = Combined Uncertainty
Results from 9/13/2009

Measured

FIRST Cerro Toco Mean Radiances, 09/13/09, 11:53:11 UT

Modeled

Cerro Toco Calculated Radiances, 11:54:03 UT Sonde
LBLRTM - FIRST

LBLRTM(09/13/09, 11:54:03 UT) – FIRST(09/13/09, 11:53:11 UT)

Radiance (mW/m²/sr/cm⁻¹)

Wavenumber (cm⁻¹)
Uncertainties in Measured Spectrum
RSS of Measurement Uncertainties

LBLRTM(09/13/09, 11:54:03 UT) – FIRST(09/13/09, 11:53:11 UT)

Graph showing radiance vs. wavenumber with two lines: one for residual and another for measurement uncertainty.
Model Uncertainties from measured atmosphere
Model uncertainties from h2o line strength and half-width
Model Uncertainties from co2 line strength and half-width
Water vapor continuum uncertainty
RSS of Model Uncertainties
Combined Uncertainty

LBLRTM(09/13/09, 11:54:03 UT) – FIRST(09/13/09, 11:53:11 UT)

- Residual
- Combined Uncertainty

Radiance (mW/m²/sr/cm⁻¹)

Wavenumber (cm⁻¹)