# Radiative Heating in Underexplored Bands Campaigns

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#### Spectral Cooling Rates Profiles in the Infrared for MLS



#### **Infrared Transmittance**



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#### Transparency of the Atmosphere in the Near-Infrared



#### Scientific Motivation for Radiative Heating in Underexplored Bands Campaign (RHUBC)

- Radiative heating/cooling in the mid-troposphere modulates the vertical motions of the atmosphere
  - This heating/cooling occurs primarily in water vapor absorption bands that are opaque at the surface - essentially unvalidated
- Approximately 40% of the OLR comes from the far-IR
  - Until recently, the observational tools were not available to evaluate the accuracy of the far-IR radiative transfer models
- Upper troposphere radiative processes are critical in understanding the radiative balance of the tropical tropopause layer and the transport of air into the stratosphere
- These processes need to be parameterized accurately in climate simulations (GCMs)

### The SHEBA Experience

• Collocated far-IR radiance measurements (AERI) and atmospheric profiling instruments deployed in the Arctic in 1997

• 4 cases from October used to adjust foreign water vapor continuum model (*Tobin et al.*, *JGR*, 1999)







#### Effect of Change



# Uncertainty in the WV Cntnm in Far-



### ARM's North Slope of Alaska Site

- North Slope of Alaska site one of ARM's permanent sites
  - (71°N, 157°E, 8 m MSL)
  - Established in 1998 in Barrow, operational ever since
- Good infrastructure



Many operational instruments AERI, radiosondes, 22.2 GHz radiometer, cloud lidar, cloud radar, etc. PWV typically 1-4 mm in winter Frequently clear-sky or ice-only cloud in Feb-Mar period





# Transmission in the Infrared



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### RHUBC - I



• ARM North Slope of Alaska Site, Barrow, AK (71°N, 157°E, 8 m MSL)

- February March 2007
- ~80 radiosondes launched
- 2 far-IR/IR interferometers
- 3 microwave radiometers for PWV observations
- Lidar for cirrus detection

Main objective: Conduct clear sky radiative closure studies in order to reduce uncertainties in  $H_2O$  spectroscopy

Line parameters (e.g. strengths, widths)  $H_2O$  continuum absorption model



#### **RHUBC-I** Scientific Approach

- Collect high-resolution, downwelling radiance measurements (AERI-ER: Atmospheric Emitted Radiance Interferometer - Extended Range) in low precipitable water vapor (PWV) conditions.
- 2. Collect collocated measurements of the atmospheric state (radiosondes, 183 GHz measurements) from which accurate water vapor fields can be obtained.
- 3. Using the atmospheric state measurements, calculate the downwelling surface radiance with a line-by-line radiative transfer model (LBLRTM).
- 4. Compare the measurements to the model calculations.

✓ Validate and refine the water vapor continuum and line parameters

✓ Incorporate improvements into GCM-appropriate radiative transfer models (e.g. RRTM)



### Small Diversion: Scaling Sonde H<sub>2</sub>O Profiles





# Analysis from SGP AERI:

Radiative closure improved after sonde H<sub>2</sub>O profile is scaled to agree with column amount retrieved from 23.8 GHz radiometer (MWR)

Turner et al. (2003) Cady-Pereira et al. (2008)

### Enhanced Sensitivity to Small PWV: Enter 183 GHz



Ground-based PWV retrievals primarily use observations around the 22.2 GHz  $H_2O$  line

• 22.2 GHz H<sub>2</sub>O line is weak

Sensitivity of T<sub>b</sub> is linear with PWV

Signal-to-noise is small when PWV < 10 mm

Sensitivity to PWV is 30x higher at 183 GHz than 22 GHz (when PWV < 2.5 mm)

Sensitivity of T<sub>b</sub> is nonlinear as PWV increases above 2.5 mm

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#### **183 GHz Intercomparison**

GVR



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**GSR** 

#### 183 GHz T<sub>b</sub> Residuals wrt Frequency



#### Cimini et al. (2008)

### Retrieval of 183 GHz Width: Results

Method: Use GVR measurementsWidth retrieval uses channels on either side of "pivot point"

- Crucial for information on width

 Result: GVR-based retrieval: 0.0992 cm<sup>-1</sup>/atm(± 2.5 %)

 CRB calculations (Gamache): 0.0997 cm<sup>-1</sup>/atm (± 3 %)

Included in MonoRTM v3.3 Payne et al. (2008)



### Far-IR Analysis: Results

- 17 cases used in study; H<sub>2</sub>O from sondes scaled by GVR +/- 7 PWV retrieval
- Adjustments made to water vapor continuum and selected line widths
- Delamere et al., JGR, 2010



### Foreign Continuum Evolution



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## **Impact on Net Flux Profiles**



Results in important difference in radiative heating rates.

#### Transmission in the Infrared



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### RHUBC-II, Cerro Toco, Chile



BOLIVIA

La Paz

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#### Atacama Large Millimeter / Submillimeter Array - Taiwan

#### **General Information**

ALMA Science

ALMA CSV

ALMA Engineering

**Image Gallery** 

People

Administration

Internal Document

#### ALMA IS THE WORLD'S LARGEST, MOST SENSITIVE RADIO TELESCOPE OPERATING AT MILLIMETER WAVELENGTHS:

The Atacama Large Millimeter/Submillimeter Array (ALMA) is the largest ground based, international astronomical observational facility ever built. It is currently under construction in the Chajnantor area in the Atacama desert in northern Chile. ALMA is designed to cover the wavelength range from 0.3mm to 9mm with an angular resolution of up to 0.004 arcsec. The baseline project consists of the 12-m array of up to 64 12-m telescopes, and the Atacama Compact Array (ACA) of 4 12-m telescopes and 12 7-m telescopes. ALMA will be studying a broad range of exciting science, such as weather patterns on solar system planets, the formation of planets and stars in our galaxy, the motions within active galactic unclei, and the formation of the earliest galaxies at  $z\sim10$ .

CONTACT

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Artist's conception of the ALMA antennas in a compact array. Image courtesy of NRAO/AUT and ESO. ALMA/Chajnantor Video Clip, Backgrounds & Photos (from ESO Press Release, 10 June 1999)

### View from Cerro Toco Location

#### Site location

### RHUBC-II Essential Facts

- August October 2009
- Cerro Toco (~5350 m), Atacama Science Preserve, Chile
- Scientific objectives
  - Conduct clear sky radiative closure studies in order to reduce uncertainties in WV spectroscopy
- Minimum PWV: ~0.2 mm
- 3 far-IR / IR interferometers
- 1 sub-millimeter radiometer for PWV
- 1 sub-millimeter FTS
- 1 near-IR FTS
- Lidar for cirrus detection

Overview paper: Turner and Mlawer, BAMS, July 2010

Additional support from: NASA; Italian Research Foundation; Smithsonian

### **RHUBC-II Guest Instruments**

#### Far-infrared Spectroscopy of the Troposphere (FIRST)

- PI Marty Mlynczak, NASA-LaRC
- Michelson interferometer
- 100 1600 cm<sup>-1</sup> (resolution ~0.64 cm<sup>-1</sup>)

#### **Radiation Explorer in the Far Infrared (REFIR)**

- Italian collaboration (RHUBC lead Luca Palchetti)
- Fourier Transform Spectrometer
- 100 1500 cm<sup>-1</sup> (resolution ~0.50 cm<sup>-1</sup>)

#### Absolute Solar Transmittance Interferometer (ASTI)

2000 - 10000 cm<sup>-1</sup> (resolution ~0.60 cm<sup>-1</sup>)

#### **Smithsonian Astrophysical Observatory FTS**

- PI Scott Paine
- 300 GHz 3.5 THz (3 GHz resolution)
- Operating in Chile at 5525 m from 2000 2008

#### **U. Cologne HATPRO**

• 7 channels from 22.2 - 31 GHz, 7 channels from 51-58 GHz









### ARM Instruments for RHUBC-II



GVRP



#### Radiometers

MFRSR

MPL





#### **AERI-ER**

#### Vaisala Ceilometer





#### Mawer et al., Far-IR Workshop



#### Met station



#### Spectral Observations 170 GHz (5.6 cm<sup>-1</sup>) to 3 $\mu$ m (3000 cm<sup>-1</sup>)

First ever measurement of the entire infrared spectrum from 3 to 1780 µm!



PRELIMINARY DATA

## **RHUBC-II** Water Vapor Profiles





Water vapor column amounts (PWV) measured by radiosondes during RHUBC-II. For reference, PWV for US Standard atmosphere is 14.3 mm.

### Miloshevich Adjustment to Sonde WV

- Daytime mean percentage biases in RH measurements by Vaisala sondes (RS92) relative to frost-point hygrometer measurements.
- However, the RHUBC-II conditions and sonde batches were different than in that study.



#### GVRP: channels centered at 1/0, 1/1, ..., 183, 183.3 GHz



#### Initial Adjustments to RHUBC-II Sondes

On average, the Miloshevich et al. adjustment leaves the near-surface water vapor unchanged and increases it higher up. The effect on PWV is a net increase of ~10%. The effect of the GVRP-based scaling is more variable.





Mlawer et al., Far-IR Workshop

## GVRP Retrieval - 919.1530





#### **Modified GVRP Instrument Function**



### Impact of WV Profiles on Sub-mm Closure



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### Issue with GVRP ?

For driest cases, brightness temperature for most transparent channels:

Calc ~9K GVRP ~7.5K

1E-5

170

1 Mawer et al., 1Fair-IR Workshop



180

178

Frequency (GHz)

182

184

#### GVRP-Model Residuals Depend on BT for All Channels





- Water vapor profile important for radiative closure analysis in sub-mm and far-IR
  - Determination of WV continuum, other spectroscopic parameters
- GVRP measurements can provide valuable information
  - Miloshevich et al. adjustments have questionable impact
  - Consistent positive residuals near line center for low PWV cases have been improved by utilizing more accurate instrument function
  - Consistent negative residuals in transparent channels for low PWV cases are not due to errors in radiative transfer model calculations
    - Reconsideration of calibration approach underway (Cadeddu and Turner)
  - Using current GVRP measurements, WV profile retrievals show significant decreases near surface and increases in mid-troposphere

#### Analysis Ongoing









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### **Error in Calibration Using Simplistic Analysis**

