## PROGRESS TOWARD A COMBINED GPSRO & IR TEMPERATURE & RADIANCE DATASET

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### OUTLINE

- CLARREO climate benchmark concept
- Historical upper air observations (PAST)
- Recent operational satellite record (PRESENT)
- Future climate expectations (FUTURE)
- Conclusions

### **Proposed CLARREO Payload**



### **The CLARREO Benchmark Concept**

• CLARREO is to establish "benchmark" measurements having independent SI traceability paths ON-ORBIT from Radio Occultation, spectrally resolved InfraRed, and spectrally resolved <u>ShortWave</u> observations (Time standard, Temperature standard, Solar/Lunar standards)

• Independent measurements are considered essential for making irrefutable claims about atmospheric trends.

• One of the objectives of the UW SDT project was to use existing observations to create a prototype benchmark dataset as a proxy for the future CLARREO mission. Our emphasis was on the hyperspectal IR and GPS RO data collected over the past decade.

#### **Upper Air Observations: Radiosonde & Heritage Sounders**

WIREs Climate Change

Stratospheric temperature trends

#### Heritage Satellite Sounders

**FIGURE 2** | Vertical sampling of satellite and radiosonde observations of stratospheric temperature. *Left*: vertical weighting functions for satellite Microwave Sounding Unit (MSU) and Stratospheric Sounding Unit (SSU) stratospheric temperature observations as a function of pressure (left axis) and height (right axis). The dashed line at about 27 km (30 hPa) indicates the typical maximum height of historical global radiosondes data coverage (Figure 1). *Right*: schematic of atmospheric vertical structure and its latitudinal variation. (Modified from Climate Change Science Program Synthesis and Assessment Product 1.1<sup>4</sup>)



#### Seidel et al. WIREs Clim Change 2011 vol 2 pp592–616 DOI: 10.1002/wcc.125

- Controversy surrounds both the in-situ and remote observations due to inconsistent sensor calibrations
- Dashed line indicates upper limit of radiosonde data (30 mb).

### **Heritage Radiosonde Trends**

**Advanced Review** 

### Stratospheric temperature trends: our evolving understanding



Dian J. Seidel,<sup>1</sup>\* Nathan P. Gillett,<sup>2</sup> John R. Lanzante,<sup>3</sup> Keith P. Shine<sup>4</sup> and Peter W. Thorne<sup>5</sup>



• 50 year radiosonde Lower Strat. Temperature record: cooling 1958-1995 then stable since 1996.

### **Heritage Satellite Sounder Trends**

**Advanced Review** 

### Stratospheric temperature trends: our evolving understanding



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 30 year SSU lower strat. satellite record: seems to confirm radiosonde trend in Stratosphere but has major analysis uncertainties.

### **Recent GPS RO and Advanced IR Sounder Trends**

#### **COSMIC GPS RO**

#### **AIRS IR Sounder**



COSMIC-I: ~ 1,000 vertical Temperature profiles per day IR Sounder: ~ 324,000 vertical Temperature profiles per day

#### GPS RO Tropical Temperature Trends (Steiner et al. 2011)

Steiner, A. K., B. C. Lackner, F. Ladstädter, B. Scherllin-Pirscher, U. Foelsche, and G. Kirchengast (2011), **GPS radio occultation for climate monitoring and change detection**, Radio Sci., 46, RSoD24, doi:10.1029/2010RS004614.



- Predicted GCM stratospheric trends at about -0.5 K/decade
- Steiner et al. analysis is 10 times larger (-5 K/decade)
- Is this result credible? GPS/MET 1997 data seems inconsistent with Seidel et al.
- What trend do we see in IR radiance? What IR trend should we see?

# **Heritage IR Sounders**

### **1978 - current**

**Spectrally Resolved** Radiances can provide **High Absolute Accuracy** with trace-ability to SI standards.

2002-

1990/91

HIS,

S-HIS,

NAST-I

ITS



64 x 27 x 50 cm

1986-

1978-

HIRS

### **Spectral Coverage and Resolution Comparison**



from LBLRTM for US Standard Atmosphere

#### AIRS IR Brightness Temperature Trends (2003-2007)



• This old result for the five year period 2003-2007 shows a tropical BT trend of ZERO but with a large statistical uncertainty.

#### AIRS B.T. DECADAL TRENDS: 2003-2012

DeSlover et al., Detecting Climate Signatures with High Spectral Resolution Satellite Infrared Measurements, SPIE Europe, Dresden, Sept. 2013.



-60

-80

-150

-100

-50

0

Longitude

50

100

150

1000

0.02

dTB/dT

0.04

0.06

\_\_

03 04

05

07

06

08

Year

09

10

11

-0.4

-0.5

12

13

14

#### AIRS B.T. DECADAL TRENDS: 2003-2012

DeSlover et al., Detecting Climate Signatures with High Spectral Resolution Satellite Infrared Measurements, SPIE Europe, Dresden, Sept. 2013.



### **UW IR/GPSRO Matchup Dataset**

See Michele's paper for details on matchup methodology:

Feltz, M., et al., 2013: A Methodology for the Validation of Temperature Profiles from Hyperspectral Infrared Sounders Using GPS Radio Occultation: Experience with AIRS and COSMIC, JGR-Atmospheres, accepted.

### **AIRS and COSMIC L2 Matchup**



6% of the COSMIC profiles on this day are within 1 hour of a coincident AIRS observation. Matchups are possible with any operational satellite platform,

AQUA, METOP-A & -B, Suomi-NPP, and METOP-C, J1, ...

### **COSMIC Profile Geometry**



For L2 profile comparison the 3-D geometry of the RO profile is accounted for by finding the intersection of the COSMIC "ribbon" within the 3-D data cube of AIRS Tair retrievals.





### **GPS RO Profile intersection with IR retrieval fields**



### **GPS RO Profile intersection with IR retrieval levels**



- The black square is the closest IR profile to the COSMIC at 100 mb.
- The pink circle has radius of 150 km centered at the closest profile.
- The ray path IR soundings (red dots) account for horizontal gradients.





#### **GLOBAL**

#### AIRS - COSMIC (90S-90N)



- AIRS mean bias "error" shows vertical structure.
- "Natural Variability" estimates are very consistent.

#### AIRS - COSMIC (90S-90N)

#### **GLOBAL**



• Matchup dataset Inter-annual varibility of Temperature bias is small (< 0.1K)

#### **COSMIC/AIRS Matchup Dataset: July 2011**



#### COSMIC L2



COSMIC profiles for July 2011 at latitudes > 80 N and < 80 S. Note the smooth banded structure except for the discontinuity at the boundary between the troposphere and stratosphere.





Matching AIRS profiles for July 2011 at latitudes > 80 N and < 80 S. Note that all of the Antarctic July profiles have a systematic vertical oscillation which is an obvious artifact when compared to COSMIC.

#### AIRS L2 – COSMIC L2



The difference of each matched profiles is shown overlaid with the mean bias of both the Arctic (solid) and Antarctic (dashed). The vertical oscillation in the Antarcic AIR S profile is prominent.

#### **AIRS L1 Radiance Temperatures**



The corresponding nearest nadir AIRS L1 observed radiance temperature spectra appear to be perfectly normal. Use these spectra to obtain higher fidelity agreement with COSMIC profiles!

### **GPS/IR Matchup Dataset Example:** Antarctica





"Spectrally resolved" infrared specta have demonstrated much higher absolute accuracy than earlier filter radiometer IR sounders, e.g. HIRS.

AIRS brightness temperature accuracy is estimated to be about 0.2 K (1-sigma) or six times worse than CLARREO.

Use AIRS to evaluate the CLARREO benchmark concept and to begin the IR climate record.

#### **AIRS and COSMIC Time Series 2011: Antarctica**



One year of the GPSRO/IR matchup dataset are plotted for Antarctica. Note the coldest Antarctic strat temps are in July.

#### Unweighted L2 vs L2 L1 vs Unweighted L2



With the UW matchup dataset we can do a point by point comparison to quantify the interpretation of the GPS RO and IR radiances.

### **GPS/IR Matchup Dataset Example:** Antarctica



COSMIC profiles for Antarctica during Jan-Dec 2011 are matched with AIRS spectra. Each COSMIC dry temperature profile is weighted using calculated dBT/dT profile for a single AIRS channel (667.0 cm<sup>-1</sup>) selected to peak in the lower stratosphere.

The fit over all scene temperatures is within 2% (correlation of 0.98).

#### Weighted L2 vs L2

#### L1 vs weighted L2



AIRS vs GPS RO where the RO profile is weighted by the AIRS vertical sensitivity (weighting function). Shows good agreement.

#### **Probability Density Functions 2011: Antarctica**



Co-located IR BT and weighted COSMIC temperatures can be used in PDF analyses to confirm distribution shifts seen in the individual AIRS or COSMIC datasets or predicted by GCMs. What IR radiance trends should we expect in a changing climate?

What can we learn about future temperature trends and radiance trends from Dan Feldman's

**CLARREO IR OSSE ?** 

#### **IPCC AR4 A2 Scenario: Stratospheric Temperature Trend 2000 - 2100**

**Arctic (80N - 90N)** 

Trend: -0.053 K/yr = -0.53 K/decade

NaturalVar: 0.40 K

AR[1]: -0.18

Trend/NatVar: 7.5

TTD (ideal): 8.5 yr



NaturalVar: 1.4 K

AR[1]: -0.005

Trend/NatVar: 31.8

TTD (ideal): 22.2 yr





### Radiance trends from the CLARREO IR OSSE (2000-2099)



OSSE Radiance trend in tropical stratosphere is nearly zero (-0.006K/yr) which is 10 times smaller than the temperature trend!

#### Radiance trends from the CLARREO IR OSSE (July 2000-2099)



MODTRAN Brightness Temp @ 680 cm<sup>-1</sup> (K)

#### 20 hPa level Air Temperature July 2010



Note the warmest lower stratospheric temperatures in July are in the Arctic and the coldest in the Antarctic.

#### **CLARREO IR OSSE zonal temperature profiles (July 2000)**



- CCSM3 A2 scenario (see D. Feldman for details)
- The stratospheric temperature lapse rate is highest in the tropics.

#### **Carbon Dioxide Mixing Ratio: A2 Scenario**



- CO2 change in CCSM3 A2 scenario (see D. Feldman for details)
- CO2 more than doubles from less than 400 to more than 800 ppmv.

#### 100-year change in zonal temperature (July 2099 – July 2000)



• Result of CCSM3 A2 scenario model run with approx. doubling of CO2.

• Tropospheric warming and stratospheric cooling (+- 0.5K/decade)

#### Sensitivity of IR brightness temperature to CO2 change



The tropical profile has a larger stratospheric IR radiance change for a given CO<sub>2</sub> increase because the lapse rate is larger.

#### Carbon Tracker CO2 at 900 hPa



Note CO<sub>2</sub> sources (red) and sinks (blue) for July 2010

#### Carbon Tracker CO2 at 20 hPa



Note zonal banded structure in the stratosphere.

#### Zonally Average CO2 from Carbon Tracker (2010)



Vertical and latitude variations of CO<sub>2</sub> are large enough that they should be included in the calculation of TOA radiances and weighting functions.

#### CONCLUSIONS

- 1. Zonal analysis of UTLS temperature is already well underway in the GPS RO community. Results are preliminary but encouraging as the record will grow with time over the next decades.
- 2. Zonal analysis of TOA observed radiances is also underway in the Sounder community. Results are preliminary but also encouraging as that record will grow over the next decades.
- 3. The UW GPSRO/IR geo-located matchup subset allows for a quantitative assessment of the consistency between these two independent SI traceable datasets.
- 4. The CLARREO IR OSSE illustrates the need to distinguish between direct greenhouse gas radiance effects and TOA radiance changes due to atmospheric temperature by inclusion of CO<sub>2</sub> observations, e.g. CarbonTracker, in the interpretation of IR radiance trends.