Trends in Upper Air Temperature in the Era of Aqua
Data sources

• GPS Radio Occultation: JPL genesis level 3
  - CHAMP (2001-2009), ~200 daily soundings
  - COSMIC (2007-2014), ~2500 daily soundings
  - Bayesian interpolation/spherical harmonic fitting: 14th degree for CHAMP, 20th degree for COSMIC (2007-2014)

• Infrared: AIRS level 3, version 6
  - Version 5 leaves too many gaps
  - Infrared only („AIRS“)
  - Combined infrared and microwave („AIRX“)
  - Neural net based on ECMWF analyses
  - Vertical resolution 5 hPa (~100 m)

• GPS Radio Occultation: JPL genesis level 3
Figure 8b has its ordinate range enlarged to ±4% (relative to 

10 year trend for each center is shown as well. Note that 

variability of annual average refractivity is approximately 

S zone, and (f) the 20–20 

and in the 20–30 km layer for (b) the 60–90 

suggesting significant value of GPS RO for global trend 

Deseasonalized fractional refractivity anomalies 

measured < (100, 200, 300) km apart. The median corresponds to the LHS of equation (6b), and the 

Globally (8–30 km layer, 90–60 

trend over all centers by less than ±0.04%/5 years. These 
trends from each of the four centers differ from the mean 

measurements < (100, 200, 300) km apart. The median corresponds to the LHS of equation (6b), and the 

(parentheses) to the RHS of equation (6b) and the 

Diameter of consistency between the CHAMP and SAC-C as a function of height for 

Four different retrieval centers 

centers are evaluated in section 5 and are used to 

Hereafter) to the times and locations of each 

profiles from NCEP reanalysis (on a 

interpolating 

period covering 10 July 2001 to 29 March 2003. We limit 

SAC-C temperature measurements in a statistical sense, 

of profiles used by the four centers in forming the MMCs. 

of 0.03–0.05% 

and ±0.06%/5 years, respectively (Table 3). The RMS for 

for the same zone are ±0.1%, ±0.04%, ±0.01%, ±0.05%, 

8–80 0.05/0.04 0.1/0.06 0.08/0.05 0.06/0.07 

8–30 0.05/0.04 0.1/0.05 0.07/0.04 0.05/0.06 

20–30 0.03/0.03 0.04/0.03 0.04/0.03 0.04/0.01 

12–20 0.04/0.04 0.06/0.04 0.06/0.05 0.05/0.01 

8–12 0.06/0.05 0.12/0.06 0.08/0.05 0.06/0.07 

8–30 0.03/0.03 0.04/0.03 0.04/0.03 0.04/0.01 

CHAMP and SAC-C and a significant deviation from the 

CHAMP and SAC-C occultation near the tropopause that 

is absent in the analyses. If this gradient is real, it would be 

observed gradient is likely to indicate a real temperature 

temperature is higher than 250 K.) (5) In the stratosphere, 

observed gradient in the atmosphere. 

predicted error effects on the trend analysis, we construct the 

MMC sampling error effects on the trend analysis. To reduce these sam-

noticeably impact our trend analysis. To reduce these sam-

graduated altitude of 6 km along with a mean value and 

drawn as maximum and minimum temperature gradients for each zone in the strato-

in the troposphere, some accounting for GPS 

RO retrieval error is still necessary (see below). 

resolution of 1 day along with one standard deviation (1-

Sigma) of trend uncertainty because of seasonal variations. 

We use a 90 km radius of analysis to determine the 

Sampling Errors: 

The following procedure is used. 

To quantify the difference between CHAMP and 

SAC-C profiles and those from the NCEP (before 2002) reanalysis.
indicating variability over latitude is also well below climate change levels. This, of course, does not imply that 14 years is necessarily sufficient to detect a true climate trend.

The standard error for all these curves are <0.01K. The third curve shows how AIRS-CrIS SNOs can be derived from subtracting (AIRS-IASI) SNOs from (CrIS-IASI) SNOs.

As the AIRS/CrIS/IASI record continues, any measurements of trends and anomalies will become increasingly sensitive to the quality of the instrument radiance record. In particular, the level of any instrument drift and/or inter-instrument calibration differences will become key inputs for error estimates of climate trends observed by these suites of hyperspectral IR satellites. At present, the NASA CrIS Level 2 team is developing retrieval approaches for CrIS with similar algorithms to AIRS, but using a CrIS-specific forward model (RTA) that is specific to the CrIS instrument line shape (ILS), (work done by the P.I. of this proposal).

These efforts cannot directly take into account radiometric calibration differences between these two sensors. In addition, the ILS differences for these sensors introduce slightly different atmospheric sensitivities that can affect the Level 2 products. Moreover, it is difficult to guarantee that the RTA errors are identical for two RTAs produced for instruments with different spectral resolutions, if the goal is climate-level trends when connecting these instruments.

We address the issue of ILS and radiometric differences between AIRS and CrIS (and IASI) in the research proposed here by converting the AIRS radiances to the CrIS ILS. This can be done very accurately on a scene-by-scene basis. After accounting for bad or missing AIRS channels, the conversion of AIRS to CrIS ILS retains about 1000 good equivalent CrIS channels, which is more than needed. The adjustment of the differences between AIRS and CrIS radiometry (on the order of 0.1-0.2K) can now be done for all channels, since they now have the same ILS.

This conversion of AIRS to CrIS is done within the context of our ROSES funded intercalibration effort for simultaneous nadir observations (SNO) studies, allowing us to directly determine inter-calibration differences between AIRS, CrIS, and IASI using the CrIS ILS for AIRS and IASI which will be used in the research proposed here. Figure 3 shows the results of one year’s worth of AIRS, CrIS, and IASI SNO differences, after AIRS and CrIS have been converted to the CrIS ILS using the procedures described here. The smoothness of these curves show how well we can convert AIRS to the CrIS ILS, and also shows that the mean long-wave and mid-wave radiometric differences between these instruments is in the 0.1-0.2K range.

The final major difference between what is proposed here and standard Level 2 retrievals is rather extreme data subsetting. These meteorological sensors sample nearly the full globe twice daily (day/night) producing a tremendous volume of data. Climate trends (even with nominal gridding) do not require this extreme sampling. Our initial experiments presented below used about a 1% equal-area weighted subset of the AIRS data. This can actually produce reasonable gridded maps at the 5x3 degree level over the 16-day orbit cycle. Climate trends are likely to have much larger footprints. We will initially concentrate on zonal trends, but will re-visit sampling for gridded trends later in the grant period.

Subsetting at this level provides an absolutely essential component for developing accurate, well-characterized trends with rigorous error bounds, which is the ability to reprocess over and over again. This also allows us to do Monte-Carlo studies of retrieval sensitivities and test many...
Background temperature: GPS RO (COSMIC)
CHAMP and COSMIC Overlap

Temperature bias [K]

Diagnostic uncertainty in trend [K/dec]

Trend during overlap [K/dec]

Diagnostic uncertainty in bias [K]

Diagnostic uncertainty in trend [K/dec]

Trend during overlap [K/dec]

Diagnostic uncertainty in bias [K]

Diagnostic uncertainty in trend [K/dec]

Trend during overlap [K/dec]

Diagnostic uncertainty in bias [K]
AIRS level 3 biases

Temperature bias [K]

Diagnostic uncertainty in bias [mK]

Trend during overlap [mK/dec]

Diagnostic uncertainty in trend [mK/dec]

AIRS upper Air Temperature Trends

Leroy: Upper Air Temperature Trends

10/19/2017
Upper Air Temperature Trends (2003-2014)
Leroy: Upper Air Temperature Trends

10/19/2017

Year

Temperature anomaly [K]

2004 2008 2012

200 hPa, 30N to 45N

200 hPa, 45S to 30S

200 hPa, 30N to 45N

200 hPa, 45S to 30S

Southern midlat tropopause, Summer, bias adjusted

Southern midlat tropopause, bias adjusted

Northern midlat tropopause, bias adjusted

Northern midlat tropopause, bias adjusted

Summer only

All seasons

More time-series (RO only)
CMIP5 (rcp45)
Conclusions

Great care is required in constructing level 3 products of GPS RO data: non-uniform sampling is a problem.

Bias drifts in AIRS level 3 products are ~ 0.5 mK/decade.

Spatial pattern amplitude of temperature trends in AIRS is suspect.

- Corruption by high cirrus?
- Trouble with calibration in extremely cold conditions?

Poleward migration of jet streams, even when no tropical warming. Possibility to test hypotheses for tropical width.

Poleward migration of jet streams, even when no tropical warming.

10/19/2017
Leroy: Upper Air Temperature Trends
Thank you.
Background

Motivation

• GPS Radio Occultation is now a 16-year uninterrupted record
  – Accurate by traceability to the international definition of the second
  – Sensitive to UTLS temperature unambiguously
  – Trends in temperature insensitive to retrieval system, satellite platform

• AIRS is now a 14-year uninterrupted record
  – Stable according to inter-calibration, target scene viewing
  – Sensitive to UTLS temperature but with cloud ambiguity
  – Sensitivity to retrieval system unknown
Theory for Width of Tropics

• Held and Hou 1980, steady, inviscid, closed circulation:

\[
\left( \frac{\nabla \cdot D}{\varphi H N} \right) \propto H \phi
\]

• Held 2000, taking eddies into consideration:

\[
\left( \frac{0 \theta \cdot \nabla \cdot D}{\eta \nabla \cdot H^B} \right) \sim H \phi
\]
Radio Occultation
Radio Occultation

Leroy: Upper Air Temperature Trends

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10/19/2017

GPS

β

LEO

α

θ

φ

Occulted GPS

Reference GPS

LEO

GPS
Spherical harmonic truncation bias

Bias: Genesis Climatology (gridded)

(overlap period)

14th degree truncation

Full truncation (overlap period)

Diagnostic uncertainty in bias [K]

 Diagnostic uncertainty in trend [K/dec]
Infrared Spectrum

Figure 1: Native spectra for all existing hyperspectral sounders. CrIS is now operating in high-resolution (HiRes) mode. The CrIS spectra have been hamming apodized.

Figure 2: Global averaged uncertainty in two AIRS channel B(T) linear-trends versus time (all trends start in Sept. 2002). These have been averaged over 40 equal-area latitude bins. The standard deviation over latitude for the 1231 cm\(^{-1}\) AIRS channel in 2016 was only 0.0013K/year, which suggests that the effects of inter-annual variability on the 14-year trends are well below the climate level.
GPS RO trend, bias-corrected