CHIRP: A Climate Hyperspectral Infrared Radiance Product Combining the AIRS and CrIS Satellite Sounding Records

GSICS Web Meeting

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A Climate Hyperspectral InfraRed Product (CHIRP)

Motivation

- Provide climate-quality homogeneous radiance time series spanning AIRS + CrIS, maybe IASI?
- User friendly by conversion to a single spectral instrument line shape (ILS)
- Will provide a high-stability 25+ year long record of climate forcings and responses
- Level 2 retrievals can use a common Forward Model (RTA) and channel selection for consistency
- Encourages conversion to radiance anomalies *before* geophysical retrievals, avoids many Level2 uncertainties.
- These sensors are far more stable than accurate, take advantage of that!

Details on CHIRP

1. Strow, L. L., Hepplewhite, C., Motteler, H., Buczkowski, S., & DeSouza-Machado, S. (2021). A Climate Hyperspectral Infrared Radiance Product (CHIRP) Combining the AIRS and CrIS Satellite Sounding Record. Remote Sensing, 13(3), 418. https://doi.org/10.3390/rs13030418
2. Motteler, H. E., & Strow, L. L. (2019). AIRS Deconvolution and the Translation of AIRS-to-CrIS Radiances With Applications for the IR Climate Record. IEEE Transactions on Geoscience and Remote Sensing, 57(3), 1793–1803. https://doi.org/10.1109/tgrs.2018.2869170

CHIRP Sensor Calibration Bias Adjustment

- CHIRP depends on sensor overlap (maybe via 3rd party satellites)
- CHIRP allows channel-by-channel intercomparisons
  - Done via SNOs
  - Done using large statistical samplings (for the same year)
- CHIRP presently uses SNPP-CrIS as the absolute radiance standard
- CHIRP presently under production at the NASA GSFC GESDIS
- CHIRP is being created for the full mission of each sensor *except* for SNPP-CrIS before final FSR mode configuration in Nov/Dec 2015.
- Expect data release in a month or so.

(Details on later slides)

Stability (AIRS parent CHIRP only)

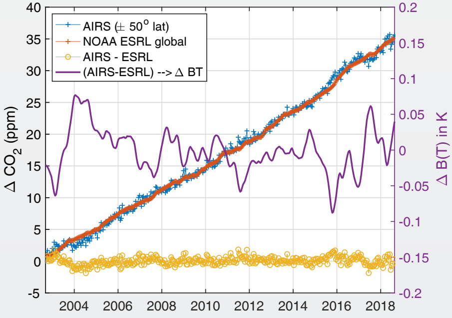
Strow, L. L., & DeSouza-Machado, S. (2020). Establishment of AIRS climate-level radiometric stability using radiance anomaly retrievals of minor gases and sea surface temperature. Atmospheric Measurement Techniques, 13(9), 4619–4644. https://doi.org/10.5194/amt-13-4619-2020

- Extensively examines AIRS stability (for well-behaved channels) for relatively warm, clear ocean scenes.
- Radiances time series converted to anomalies, from which geophysical OE retrievals of T(z), H_2O (z), O_3 (z), CO_2, CH_4, N_2O, and surface temperature were performed.
- CO_2 provides the best stability test, via inter-comparisons to NOAA ESRL global in-situ measurements.
  - AIRS stability for CO_2 channels: -0.023 ± 0.009 K/Decade
  - Is this an SI traceable measurement!
- Inter-comparison to sea surface climatologies (ERA (GHRSST), and OISST)
  - AIRS stability for window channels: ~0.028 ± 0.017 K/Decade
  - GHRSST and OISST trends differ by ~0.08K/Decade
- There are a number of AIRS channels that are not this stable
  - Shortwave: 16-year effective linear drift of 0.06K/Decade
  - A-only and B-only channels in the longwave exhibit smaller drifts
  - Colder scenes, especially in the shortwave, exhibit far higher unphysical trends (under investigation)

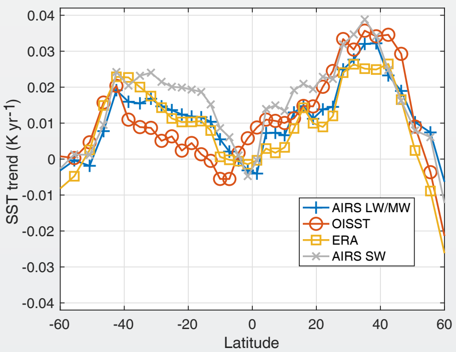
Similar approach will be applied to SNPP- and NOAA20-CrIS in the future.

AIRS Stability Examples

CO_2 Anomaly Retrieval



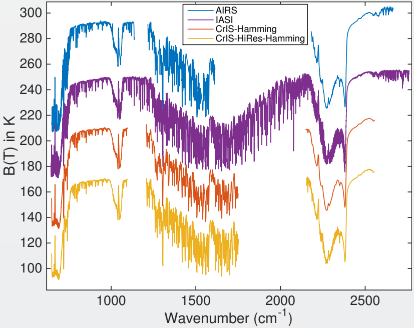
SST Linear Trend Inter-Comparisons



Similar results for N_2O but a clear discrete shift in AIRS radiometry seen in N_2O sensitive-channels. A single offset of this shift in the time-series brings N_2O channel trend stability into agreement with CO_2 trend stability. (Not implemented.)

Three Sensors Converted to Single Virtual Sensor

AIRS/CrIS/IASI Spectra



CHIRP

- FSR CrIS has 0.8/0.8/0.8 cm OPD
- NSR CrIS had 0.8/0.4/0.2 cm OPD
- CHIRP is 0.8/0.6/0.4 cm OPD

This makes CHIRP intermediate (for midwave and shortwave) between CrIS FSR and NSR.

CHIRP is Hamming apodized

- The hard part is AIRS to CHIRP
- Use of AIRS L1c (fill channels, popping removed, and frequencies shifted to a fixed grid) makes creation of CHIRP possible

CHIRP Algorithm

- Simple deconvolution to 0.1 cm^{-1} grid
- $S_a r = r_A$, $r_o = S_a^{-1} r_A$ using Moore-Penrose pseudoinverse
- $r_{A2C} = S_c \circledast r_o$
- Small additional terms using linear regression (mostly bias)
- Errors below assume AIRS ILS functions are perfect

AIRS2CrIS Mean Error (std. similar)

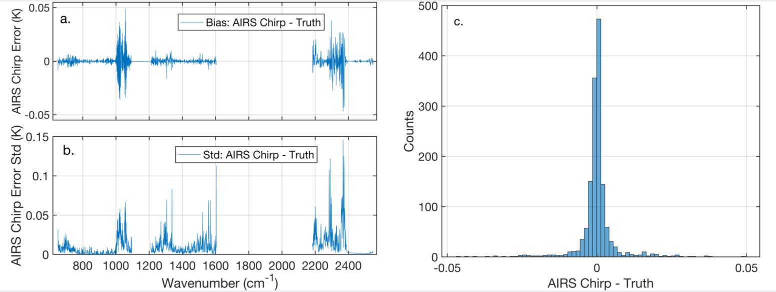
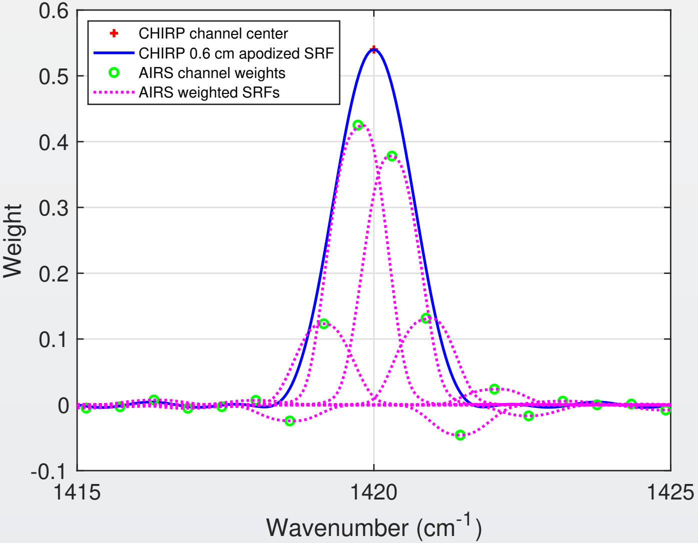


Illustration of AIRS Conversion to CHIRP



CHIRP Channel Details

- Very small amounts of AIRS L1c "fill" channels contribute to CHIRP channels
- AIRS L1c "fill" channels are quite accurate (validated using IASI->AIRS L1c SNOs, and using ECMWF double-difference clear ocean scenes).

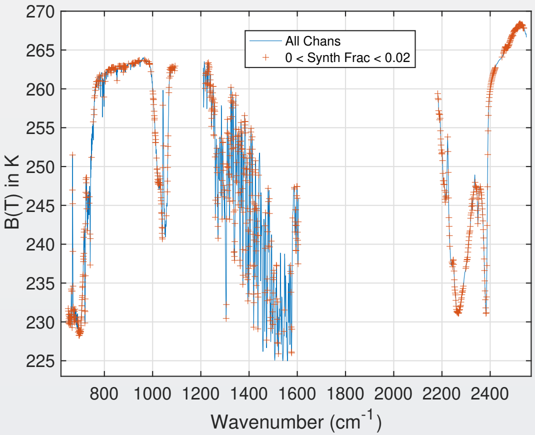
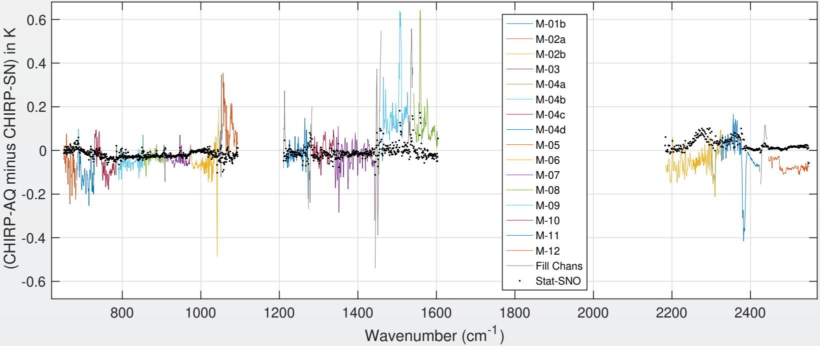


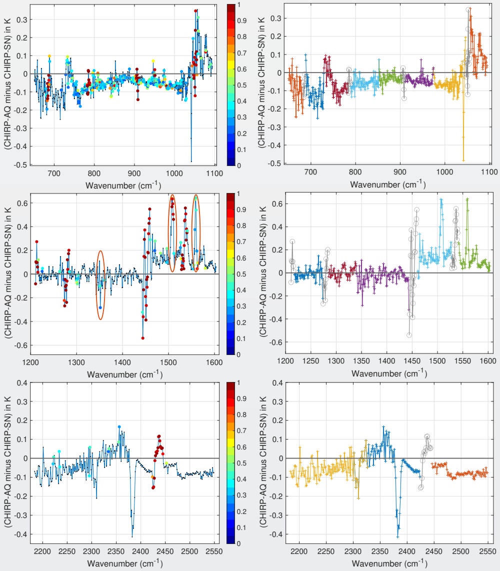
Figure illustrates a sample CHIRP spectrum highlighting channels that contain less than a 2% contribution from AIRS L1c channels that are synthetic.

CHIRP:AIRS minus CHIRP:SNPP Radiometric Offsets



- Different AIRS modules shown in different colors
- AIRS fill channels in gray
- KEY POINT: Black circles are the *differences*: (Statistical Biases) minus (SNO Biases).
- Statistical biases are equal-area weighted, SNO biases weighted to high latitudes, very similar
- This approach requires ~0.2K correction to statistical bias differences due to slightly different mean secant angle for AIRS vs SNPP (or NOAA20)

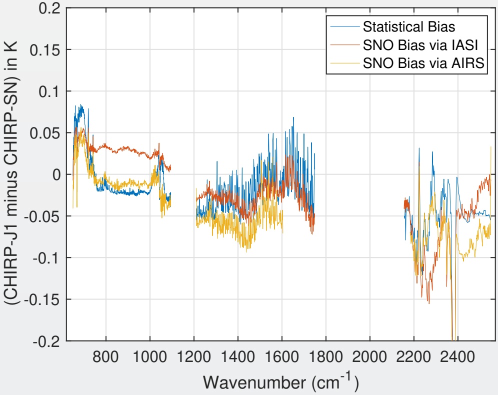
CHIRP:AIRS minus CHIRP:SNPP (larger offsets make sense)



Offsets for synthetic frac > 0.02

- Left: Color is amount of synthetic L1c
- Right: Colors: AIRS modules and synthetic channels (gray)
- High AIRS minus SNPP differences make sense, and are denoted in CHIRP Q/A so they can be avoided.

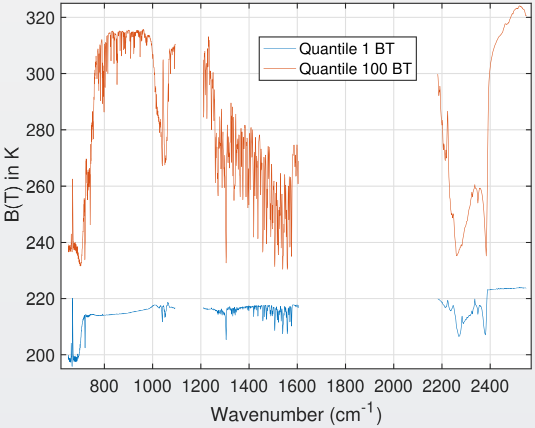
SNPP and NOAA20 Bias Offsets



- AIRS SNOs missing CHIRP channels right past 1615 cm^{-1}
- IASI based SNOs are "double-differences", (NOAA10 - IASI) - (SNPP - IASI)
- Statistical biases are equal-area based.
- CHIRP uses statistical bias estimates

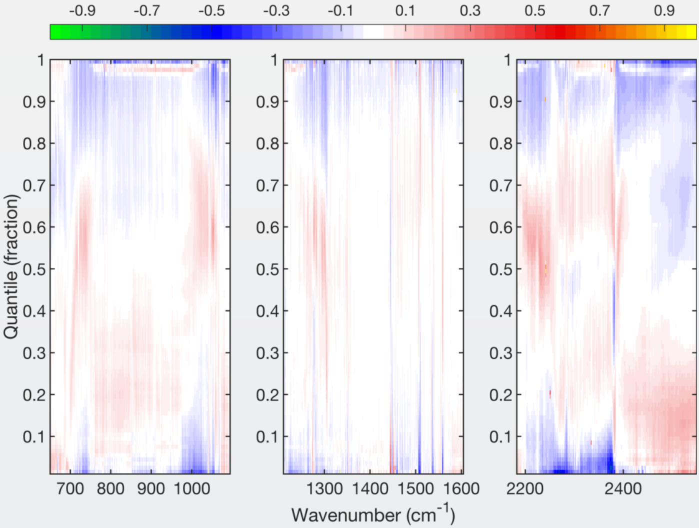
Scene Dependent Bias Differences (Quantile)

- Use 1% equal-area random dataset for AIRS, SNPP-CrIS (converted to CHIRP)
- Compute mean BT for observations for cumulative probabilities 0:0.01:1
- Examine the difference in quantile mean BT between AIRS and SNPP-CrIS



Mean BT spectra for the 1st quantile (coldest) and that 100th quantile (hottest)

Scene Dependent Bias Differences: Results



Bump in hot quantiles in window regions likely due to lower CrIS FOV size producing hotter scenes

Conclusions

- CHIRP will provide continuous (we hope) hyperspectral radiance record from 2002 through 2040 time frame
- We'd like to include IASI in this record, starting in 2007. (Conversion to CHIRP is trivial.)
- Radiometric stability of AIRS-CHIRP is quite good, but could be improved.
- Radiometric stability of SNPP- and NOAA2-CHIRP TBD.
- Radiometric offsets among sensors (at fixed points in time) are estimated to be accurate to ~0.03K
- Some liens
  - Very hot scenes (>315K): CrIS sees more hot scenes, smaller footprint?
  - Very cold scenes: still uncertaint
- Much final CHIRP validation remains
- Science:
  - Surface temperature trends
  - Water vapor trends, feedbacks
  - Temperature anomalies, etc.
  - Trace gases: long-term trends can use in-situ, other very minor gases might be better with raw data, not CHIRP

Application Slides: Surface T Trends (1)

What can you do with two hyperspectral channels?

- 1231 and 1228 cm^{-1} channels
- T_{surf} can be regressed from the the difference (BT1231 - BT1228)
  - This removes water and accounts for surface emissivity (which doesn't have to be perfect for trends)
- Subset for clear
- 18 year trends in K/Decade

Application Slides: Surface T Trends (2)