Radiance PDFs for Climate Trending: IASI + AIRS vs Re-Analysis

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Overview

- AIRS up 10+ years, IASI 5+ years; Promise of 15+ years
- AIRS, IASI, (CrIS?)
  - Extremely stable: <0.01K/year
  - Good radiometric agreement. How well can we "connect" these instrument's radiometry?
  - Minimize radiometric sensitivity by using radiance PDFs
  - AIRS to CrIS SRFs conversion feasible. IASI to CrIS easy.
- CLARREO: Start date uncertain, so begin on longwave now with AIRS/IASI/CrIS!

This Talk

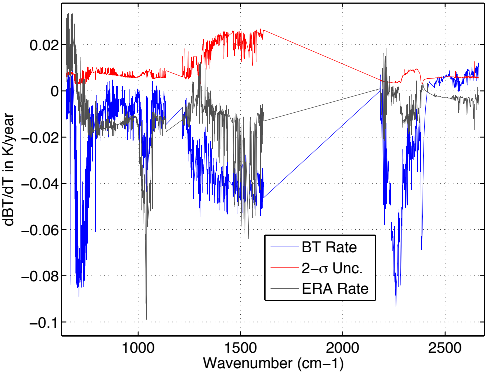
- Quick review (mostly stability)
- Radiometric intercomparisons and their uncertainty
- Conversion of AIRS to CrIS SRFs
- IASI vs AIRS 5-Year PDF rates (diurnal signals)
- AIRS 10-year PDF rates: minimize radiometric requirements for climate signals.

Issues Not Addressed in This Talk

Many practical issues not discussed here

1. Minor liens on AIRS, IASI radiometric calibration (vs time)
2. AIRS L1c approach (remove popping channels, add missing channels, frequency calibration adjustments)
3. Ignore full spectra! Concentrate mostly on one channel, 1231 cm^{-1}, to help understand PDF measurement sensitivity. 1231 cm^{-1} channel has least atmospheric absorption in longwave.
4. Geophysical understanding will generally require examination of full spectra.
5. Some comparison to re-analysis (ERA Interim). Hoping to improve mapping of re-analysis clouds to RTA profile with Xianglei Huang's help.

AIRS/IASI Stability: Use SST and CO_2 to Test



AIRS Clear Scene Subset

- From NASA/GSFC DAAC
- Nominally clear scenes
- Tropics only
- Linear growth rate: 9 years
- Trop. CO_2 growth evident
- Strat CO_2 growth cancelled by decreasing T

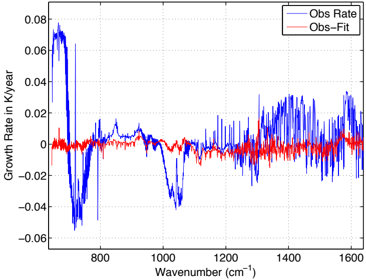
Clear Ocean Scene Linear Rates:

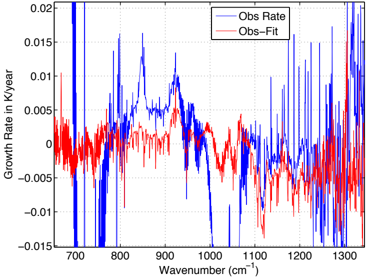
- AIRS vs SST products: 1231 cm^{-1}: 5.6 ± 8.1 mK/yr
- AIRS vs CO_2 in-situ trends: implies 6.9 mK/yr stability
- IASI vs SST, and CO_2, 5 years, implies stability < 0.01K/year

IASI Stability: Observed 5-year BT Rates

Compare to CO_2 in-situ, Tropical SST

Data are two point (ν) averages, removes Day1-Day2 processing diffs.





Optimal estimation fit for gas amounts, T(z), Q(z)
Heavily smoothed profiles, L1-type
Zoom on right shows feature at 1120 cm^{-1} not removed in fit

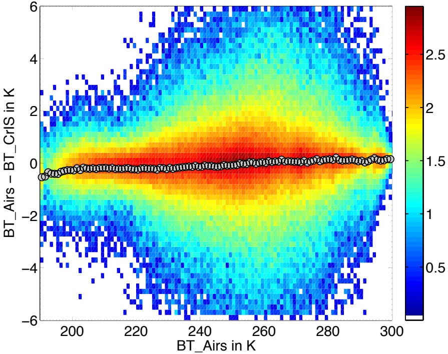
Tropospheric -0.06K/year due to CO_2 evident
Increase in O_3, Decrease in CFCs

MLO in-situ CO_2 rate: 1.99 ppm/year, Fitted rate: 1.99 ppm/year
ERA SST rate: -5×10^{-4} K/year, Fitted rate: 0.006K/year
Both of these results imply stability of 0.01K/year or better

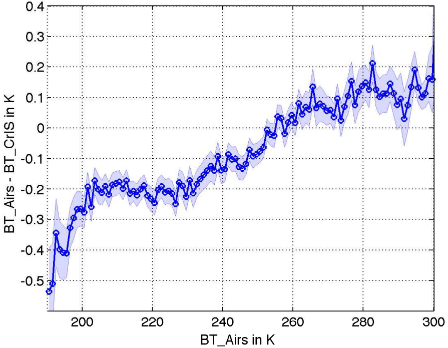
CrIS/AIRS SNO Example: 960 cm^{-1}; Long-Wave Band

For climate need to ensure limited scene-dependent biases between sensors, not just in the mean. PDF's *may* help by avoided troublesome scenes.

Sampling (log10 Scale)



Mean + 2σ

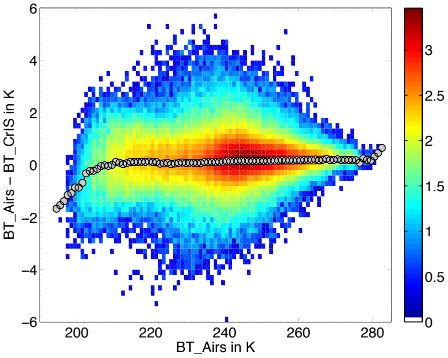


Note 2σ SNO uncertainty is $\sim$0.05K.

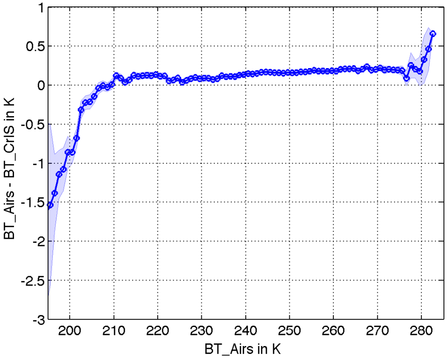
CrIS/AIRS SNO Example: 1586 cm^{-1}; Mid-Wave Band

Higher altitude H_2O channel.

Sampling (log10 Scale)



Mean + 2σ

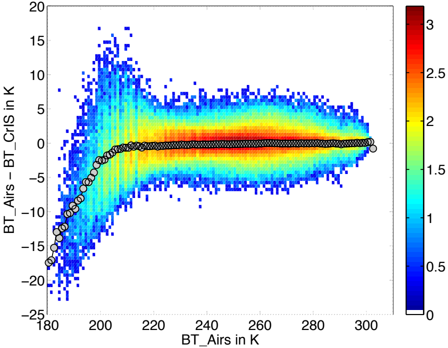


Mid-wave also has general trend of CrIS warmer relative to AIRS for colder scenes. Overall excellent agreement.

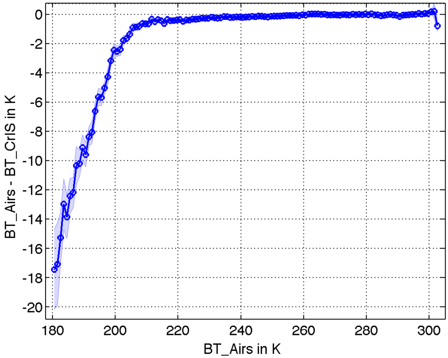
SNO Example: 2550 cm^{-1}; Short-Wave Band

Short-wave band window channel.

Sampling (log10 Scale)



Mean + 2σ



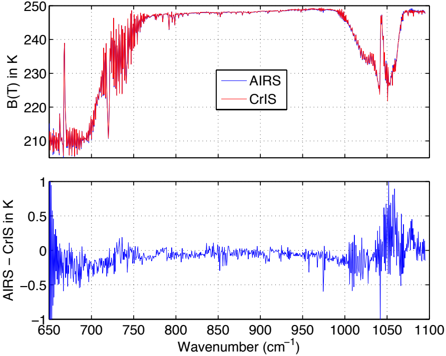
From 260K to 230K CrIS warms by about 0.2K relative to AIRS. Differences below 200K not unexpected. Probably can be improved, and will impact very few soundings. Work starting to understand.

Next Step: Convert AIRS SNO to CrIS SRFs

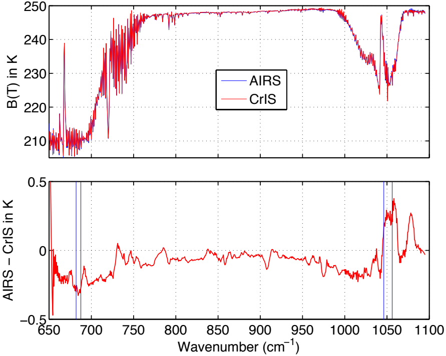
- For long-term climate radiance record, desire a common spectral response
- Cross-validation of sensors on a channel-by-channel basis may be helpful in understanding both sensors
- Howard Motteler (UMBC) has developed a very ingenious AIRS $\longrightarrow$ CrIS conversion based on AIRS deconvolution, followed by interpolation and convolution operations.
- Successful conversion of AIRS channel to CrIS requires removal of AIRS popping channels, and missing channels, this is the AIRS L1c product under development.
- George Aumann (JPL) kindly provided us with the prototype code for the AIRS L1c.

AIRS to CrIS SNO Conversion: Long-Wave

Raw Result



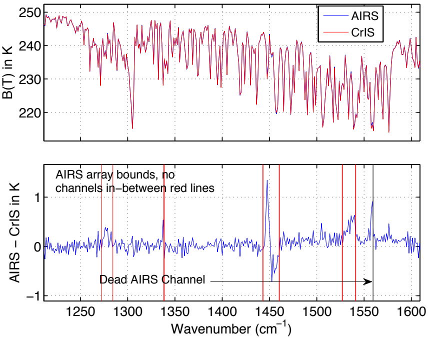
Slight Smoothing



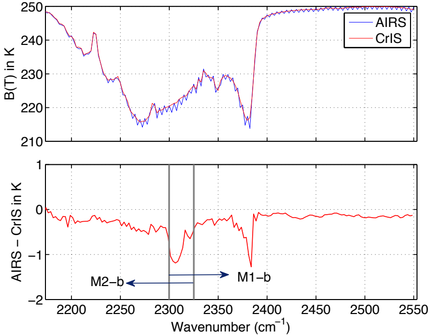
This conversion "adjusts" AIRS radiances by 10K+. Vertical blue lines on bottom, right denote locations where AIRS does not have channels, they are filled statistically in the L1c processing.

AIRS to CrIS SNO Conversion: Mid/Short-Wave

Mid-Wave



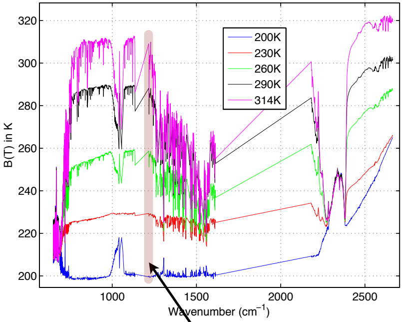
Short-Wave
Every other point averaged

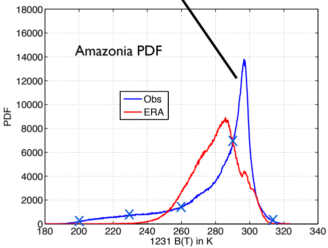


When averaged over all scenes, CrIS generally nearly identical to AIRS, or slightly warm. No statistics since the AIRS to CrIS conversion was run on averaged spectra only.

PDF Measurement Approach

Do not average all-sky radiances.





Retain more information: PDF rates, not Radiance Rates

- Averaging clear with cloudy scenes destroys information
- Bin (create PDFs) versus variable related to cloudiness
- I used 1231 cm^{-1} channel B(T): clearest window channel
- Data Set: 10 years of AIRS, only FOVs on each side of nadir
- Bins of B(T) 1231 cm^{-1}, from 190:1:320K
- Mean BT spectra in each bin are stable versus time
- All the information is in the PDFs in each bin

PDF Data Sets: AIRS, IASI, ERA-Interim

AIRS, IASI

- Near-nadir only (2/90 for AIRS, 4/60 for IASI)
- AIRS: 60 channels; IASI: 1 channel (1231 cm^{-1})
- Time series analysis used daily averages for regions of interest (TRANSCOM regions, latitude bins)

Simulated Radiances: ERA-Interim

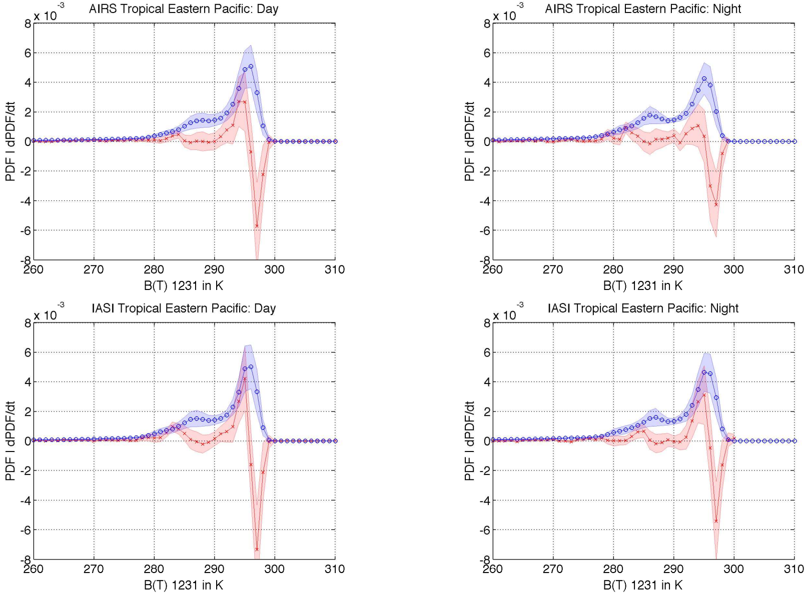
- Matched to closest grid/time point. Plan to switch to MERRA and interpolate in time, space.
- Radiances computed with SARTA-Cloudy, simple scattering scheme, random cloud overlap. The PDFs from SARTA-Cloudy in reasonable agreement with more sophisticated scattering and cloud overlap approaches.
- Simple algorithm to convert re-analysis vertical mass profiles to scattering layers

PDF Examined Here

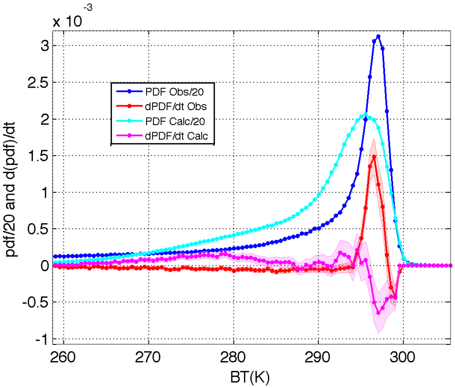
- Concentrate on PDFs for binning channel (1231 cm^{-1})
- This is nominally "worst case" channel with highest variability
- More opaque channels (CO_2, H_2O) will contain fewer cloud signals for hotter BT 1231 bins.
- Determine radiance rate spectra for each bin. Remove seasonal variability and convert radiance rates to geophysical rates using appropriate cloudy Jacobian.
- OR: compare to climate model rates, binned as well
- OR: use reanalysis for clear, and just bin cloud forcing
- OR: determine other conditional tests (cirrus, marine boundary layer clouds, etc.) and examine PDF rates rates, etc.

Diurnal Variability of PDF Rates (5-year rates)

PDFs divided by 25; Mean BT Rates (AIRS) -0.03K, -0.08K (IASI) 0.01K, 0.01K, all $2\sigma \sim 0.15$K



AIRS 10-Year PDF Rates: Tropical Western Pacific

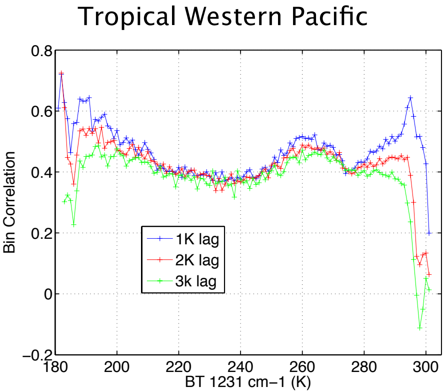


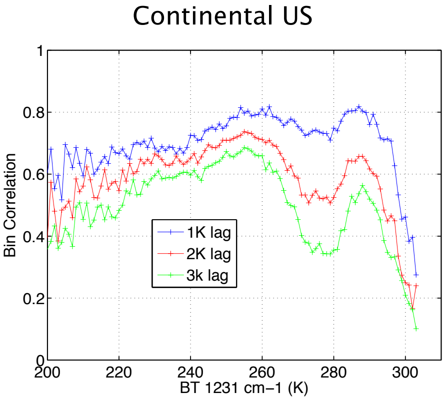
- X-axis in 1231 cm^{-1} observed BT value (binned)
- 10-Year PDF rate 2σ errors shaded
- 0.5K wide 1231 cm^{-1} bins
- Mean B(T) rate: 0.15K $\pm$ 0.05K
- Main conclusions: (a) high sensitivity, (b) cooler SST? (c) lower H_2O or fewer clouds?
- Agreement with ERA dPDF/dt calcs poor.

Concentrate on Obs: Blue/Red Curves

How correlated are the PDF rates? Curves are relatively smooth.

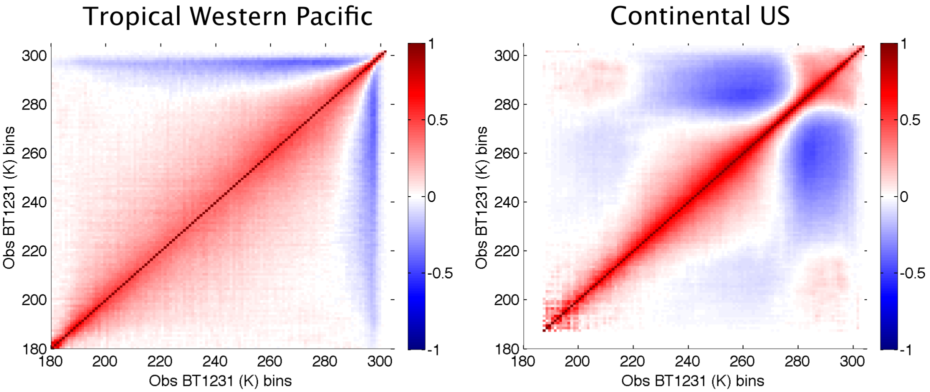
Correlation of 1231 cm-1 PDF Time Series



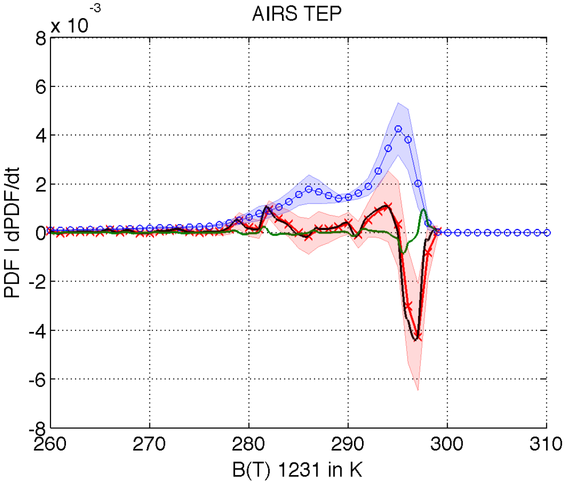


Implies PDF approach minimizes radiometric accuracy requirements. Highest accuracy needed near 300K (close to blackbody temperatures on instruments!) Rigorous analysis needed.

Correlation Matrix of 1231 cm-1 PDF Time Series



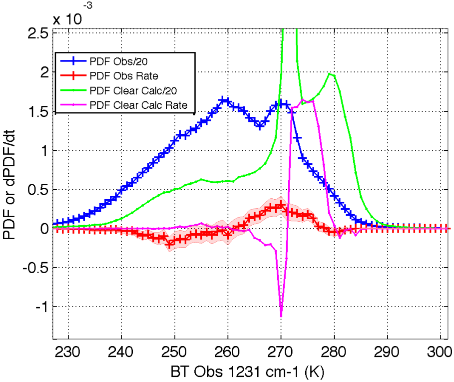
Effect of 0.2K BT Obs Error on AIRS TEP Rates

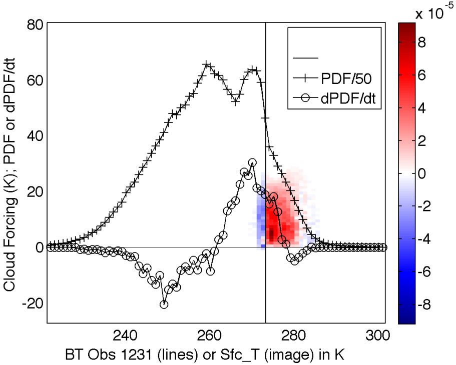


Black curve is rate with 0.2K radiometric shift

Green curve is difference in rate with 0.2K radiometric shift

Example: Arctic Region PDF Rates



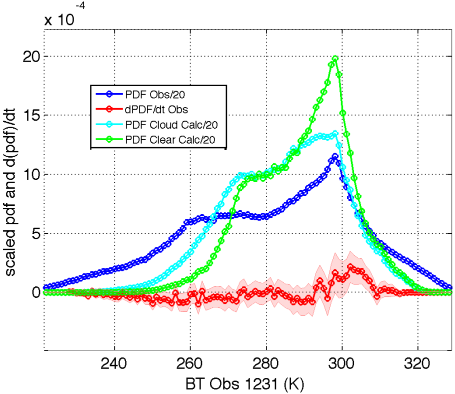


Mean 1231 BT rates: 0.088 ± 0.02K

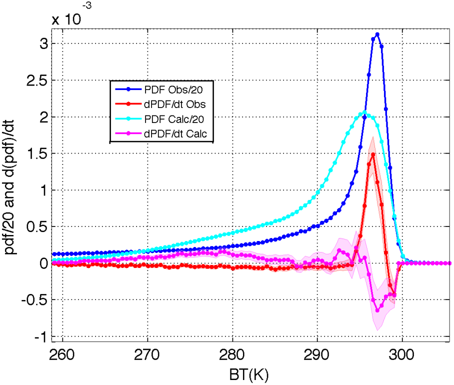
Cloud forcing = Obs radiance - Clear (computed) radiance.
Thus, dependent on ERA for good T(z), H_2O (z), and T_surface.

Example: US, TWP Region PDF Rates

US



Tropical Western Pacific



US Mean 1231 BT rate: 0.14 ± 0.07K

TWP Mean 1231 BT rate: 0.15 ± 0.05K

Conclusions

- Operational hyperspectral instruments are very stable
- With in-orbit overlap they can be compared to ~ 0.05K
- Diurnal: PDF rates (5-years) very similar between AIRS and IASI
- Use of PDFs provides more information than means, and lowers sensitivity to radiometric errors/offsets among instruments.
- However, real work needed to:
  1. Properly combine 3 instruments from 3 different organizations and produce scientifically useful climate data; (the experts are “aging” so need to move now), and
  2. Further develop the PDF approach to climate trending.