Hyperspectral Radiance PDFs for Climate Trending

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Overview

- AIRS up 10+ years, IASI 5+ years; Promise of 15+ years
- AIRS, IASI, (CrIS?) extremely stable: <0.01K/year
- Hyperspectral IR rich source of climate information
- CLARREO: NASA long-term IR hyperspectral climate mission "delayed" for many years

AIRS, IASI, CrIS: What kind of Climate Data Record?

- Must have full sampling (unlike retrievals/assimilation)
- Retain full accuracy: Use radiances "as long as possible"
- Now: Compare to NWP re-analysis (best full climate record?)
- Later: Compare to climate models.
- AIRS: climate change signals in 5 years with 15 years total?

Note: OLR can be very accurately computed from AIRS, IASI, with much better understanding of the source changes in OLR.

This Talk: Examine AIRS/IASI PDFs vs Re-Analysis

Radiance PDFs: Probability Distribution Functions

- Examine 1231/2616 cm^{-1} PDFs (window, sensitive to clouds, most non-Gaussian PDF)
- Compare obs PDFs to ERA-Interim simulated PDFs
- Use SARTA-cloudy. Mapping re-analysis to RTA is non-trivial.
- How do AIRS, IASI 5-year linear PDF rates (dPDF/dt) compare?
- Results suggest that using PDFs for climate trending reduces radiometric accuracy requirements.

Converting to geophysical units “as late as possible” improves error traceability.

Issues Not Addressed in This Talk

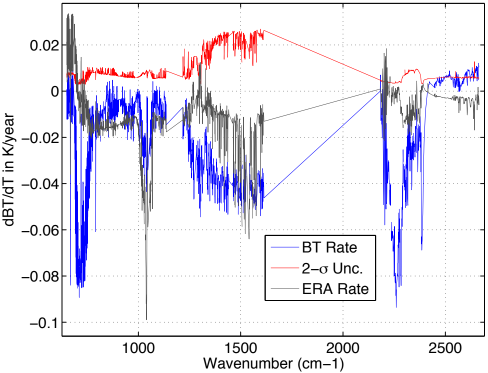
Many practical issues not discussed here

1. Minor liens on AIRS, IASI radiometric calibration (vs time)
2. Intercalibration of AIRS and IASI (SNOs). Already near 0.1-0.2K.
3. Spectral response "normalization". See L. Strow et.al. poster on AIRS to CrIS/IASI conversion. IASI $\longrightarrow$ CrIS trivial.
4. AIRS L1c approach (remove popping channels, add missing channels)
5. For now, full spectrum (all channels) rates only examined for "clear" scenes, not for binned "cloudy" scenes.
6. Conversion of radiance rates to geophysical units (only for minor gases, SST).
7. No process studies, etc. Just trending.

Other Methods for Climate from IR Hyperspectral

- 1D-Var retrievals
  - Significant a-priori information needed
  - Some minor gases ignored.
  - Cloud-clearing errors difficult to characterize
  - Global CO_2 variability ignored (at least for AIRS)
- NWP Data Assimilation
  - Traceability of errors difficult, but they are small
  - AIRS/IASI undergo adaptive bias corrections (for CO_2, etc.)
  - Cloud, surface information not assimilated.
  - Minor gases ignored except O_3 (ECMWF)

AIRS/IASI Stability: Use SST and CO_2 to Test



AIRS Clear Scene Subset

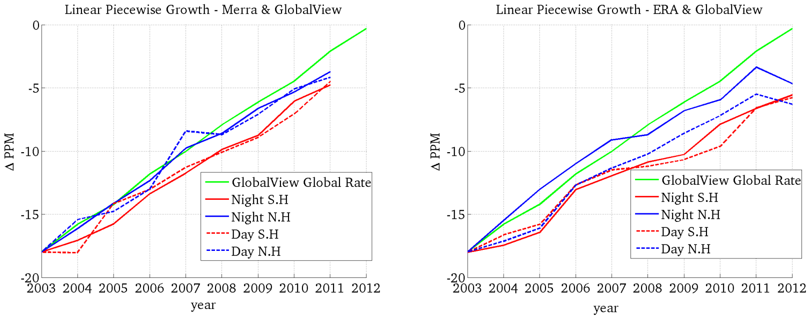
- From NASA/GSFC DAAC
- Nominally clear scenes
- Tropics only
- Linear growth rate: 9 years
- Trop. CO_2 growth evident
- Strat CO_2 growth cancelled by decreasing T

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

AIRS Stability: Comparison to Reanalysis

Compare to NASA/GMAO Merra, ECMWF ERA



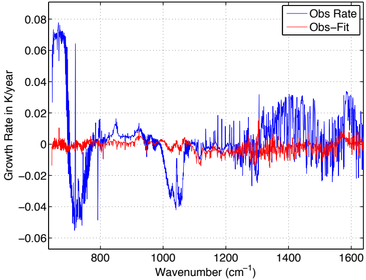
Reanalysis used for temperature
CO_2 retrieved using 791 cm^{-1} line
CO_2 rate dependent on re-analysis "stability" and AIRS stability
Data derived using 1-day per month

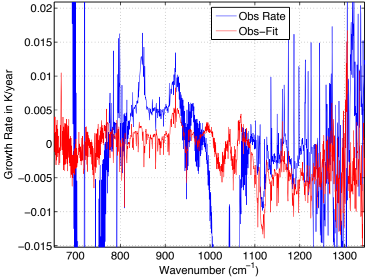
Merra compared to in-situ implies AIRS/Merra stability < 0.01K/year

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

PDF Data Sets: AIRS, IASI, ERA-Interim

AIRS, IASI

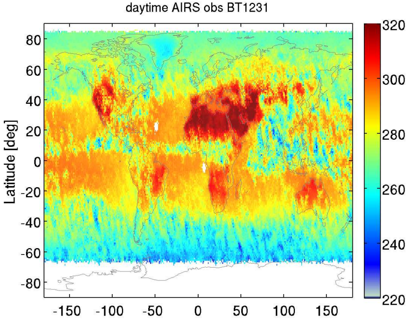
- Near-nadir only (2/90 for AIRS, 4/60 for IASI)
- AIRS: 60 channels; IASI: 1 channel (1231 cm^{-1})
- Time series analysis used daily averages for regions of interest (TRANSCOM regions, latitude bins)

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

ERA-Interim vs Obs: AIRS

1231 cm^{-1} channel B(T) for One Month

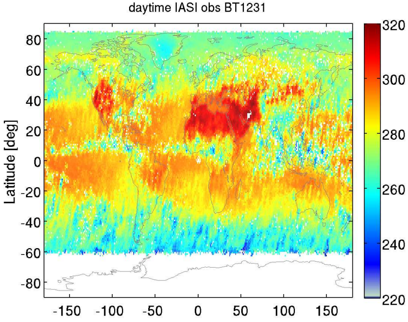


Poor longitudinal sampling causes vertical striping.

Deep convective clouds missing: Partially model grid resolution issue, but very similar results with much higher spatial resolution forecast output.

ERA-Interim vs Obs: IASI

1231 cm^{-1} channel B(T) for One Month



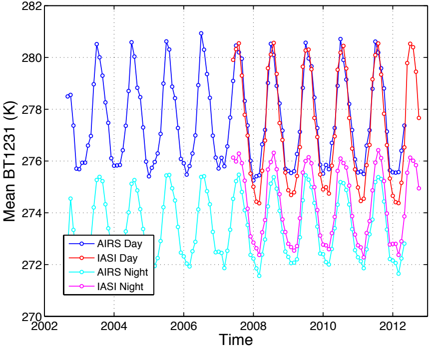
Note IASI 9:30 am surface temperatures cooler than AIRS 1:30 pm.

Deep convective clouds also missing at 9:30 am. Have not yet checked results with much higher spatial resolution forecast output.

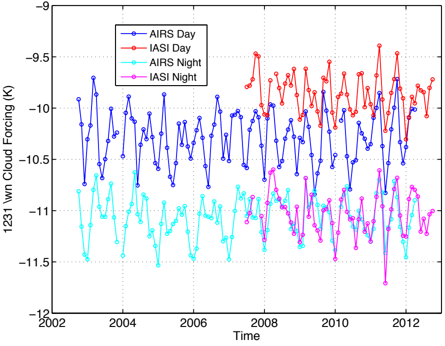
Global Time Series of 1231 cm^{-1} Channel

BT Means: no use of PDFs

MEAN

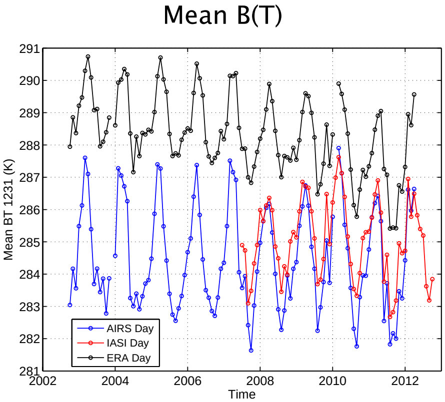


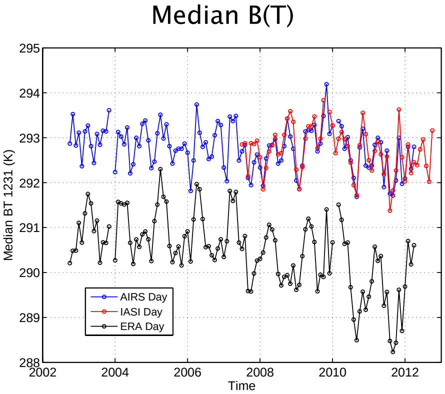
CLOUD FORCING



Regional Time Series of 1231 cm^{-1}

North Tropical Ocean: BT Mean vs Median, Confusion



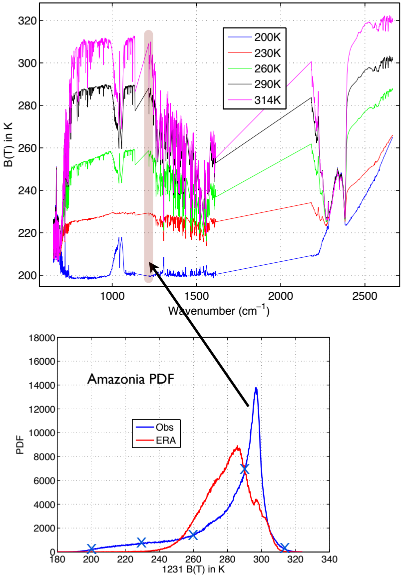


Negative slope of ERA is very large (not seen in most regions). Not seen in AIRS, IASI. Hard to determine source using mean or median.

Non-Gaussian statistics makes analysis difficult: Use PDFs and spectra that are associated with each PDF (TBD!).

PDF Measurement Approach

Do not average all-sky radiances.

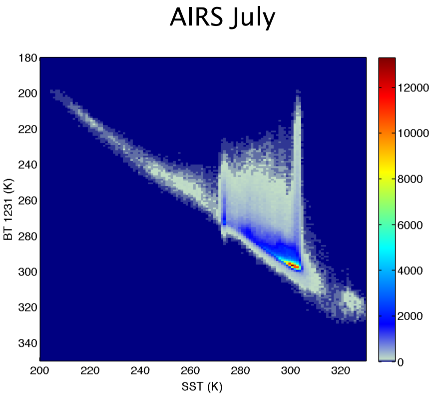


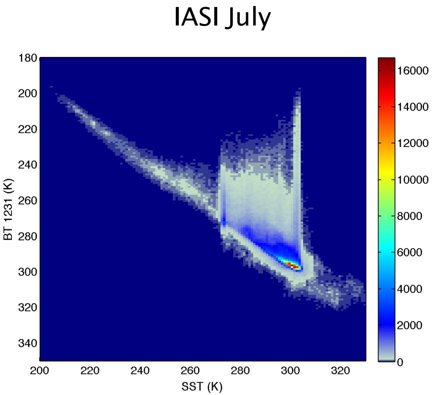
Retain more information: PDF rates, not Radiance Rates

- 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

Global Ocean 1231 cm^{-1} PDFs vs SST

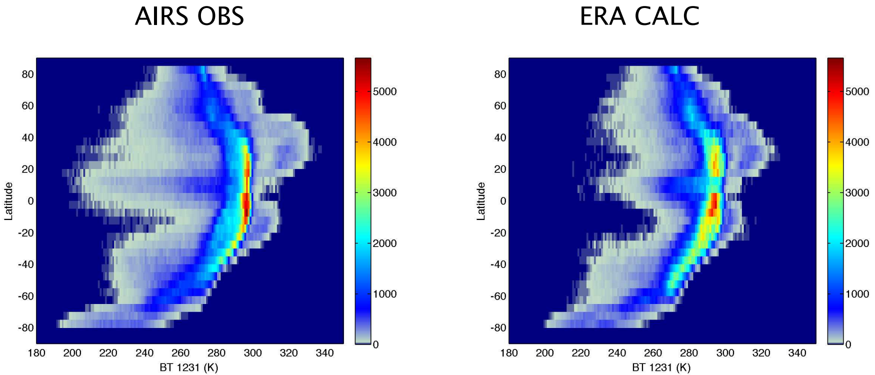
SST Uncertainties/Stability Climate Quality





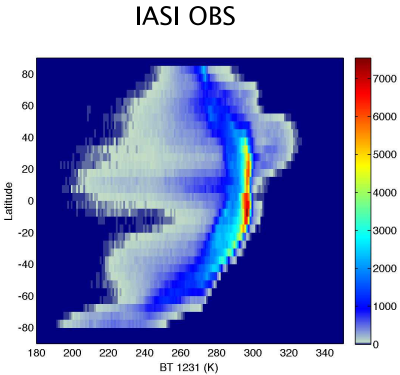
Illustrates general distribution of global 1231 cm^{-1} PDFs.
AIRS, IASI Similar; AIRS sees more hot scenes due to orbit time.

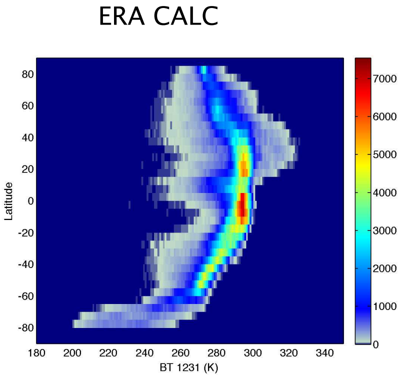
Overview of AIRS vs ERA 1231 cm^{-1} PDFs for July



- Reasonable correlation for clear
- Low correlation for deep convective clouds, missing in ERA
- Correlation low for 280-290K, region of broken clouds

Overview of IASI vs ERA 1231 cm^{-1} PDFs for July

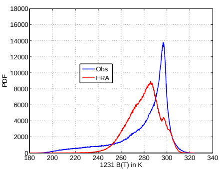




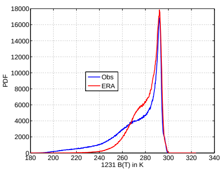
- Reasonable correlation for clear
- Low correlation for deep convective clouds, missing in ERA
- Correlation low for 280-290K, region of broken clouds

Regional PDFs: Amazon, U.S.,Tropical Pacific (AIRS)

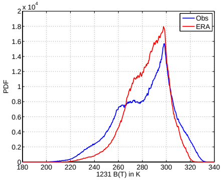
Amazon Day



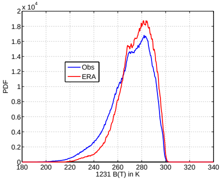
Amazon Night



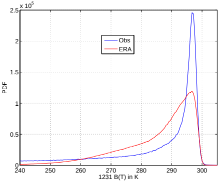
U.S. Day



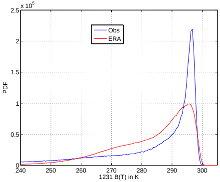
U.S. Night



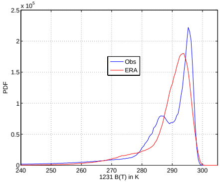
TWest Pacific Day



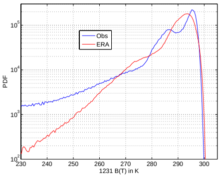
TWest Pacific Night



TEast Pacific Night

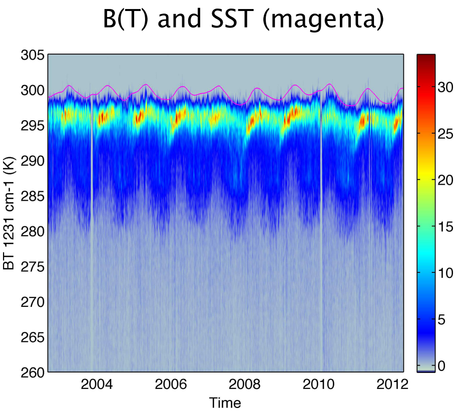


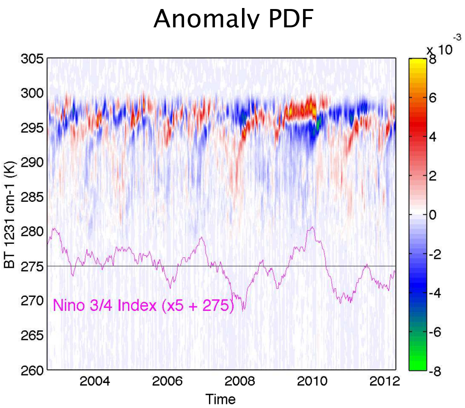
TEast Pacific Night



ERA missing deep convective clouds (not just grid cell size)
ERA Tropical PDFs wider due to grid cell size issues.
ERA missing marine boundary layer signature in TEast Pacific (secondary hump at 285K). Partly due to grid cell size.

Example: PDFs Versus Time: Tropical WPacific



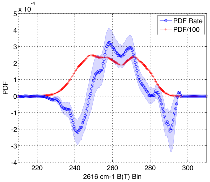


Illustrates variability in various 1231 cm^{-1} PDF bins.
Low cloud responses very clear.
Anomaly PDFs reflect ENSO very nicely.

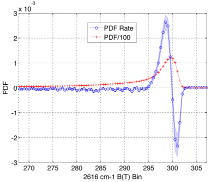
AIRS 10-Year PDF Rates

Using 2616 cm^{-1} channel: *No* H_2O interference

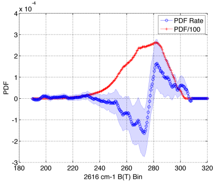
Arctic



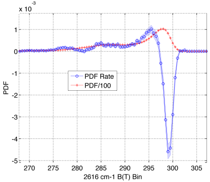
TWest Pacific



U.S.

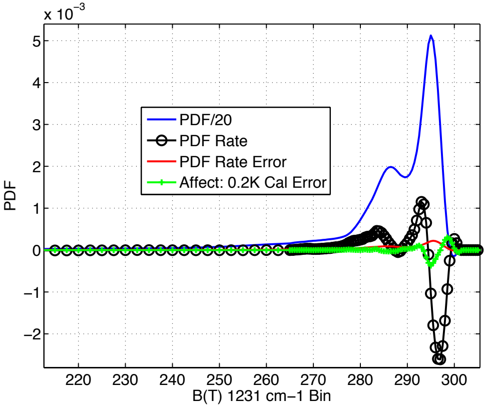


TEast Pacific



- Red: PDF/100, Blue: PDF Rate (/year)
- Rates are smooth with 2616 cm^{-1} B(T) $\Longrightarrow$ reduced accuracy requirements
- 10-year PDF rates generally larger than 2-σ errors, esp. in tropical oceans.
- Nominal sensitivity: TWest Pacific positive "hump" $\equiv$0.02K/year
- ERA rates agree fairly well, except for Tropical Pacific (not shown).
- Arctic data highly aliased to lowest Arctic latitudes
- Full spectra, plus nominal independent knowledge of T_{surf} will allow scientific insight. Can do similar curves binned by cloud forcing using independent SST.

TEast Pacific PDFs: Max Sensitivity to BT Calibration



TEP worst case for “sharp” dPDF/dt curve

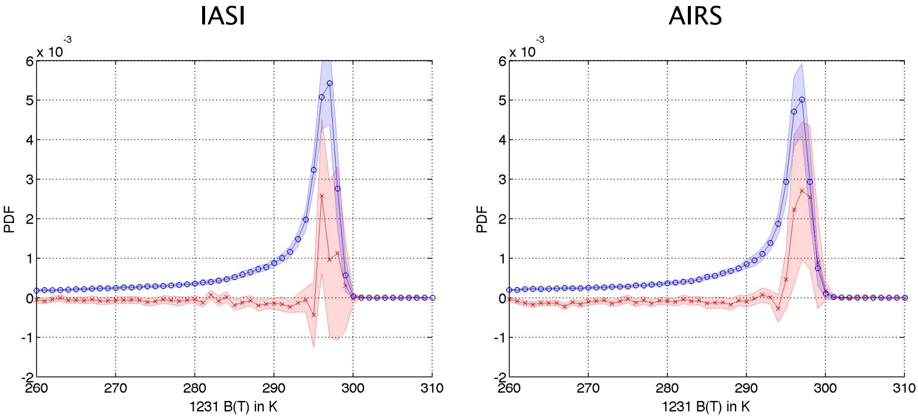
Plot shows, in green, PDF rate error for a 0.2K B(T) offset error

PDF rates relatively insensitive to calibration error (x-axis offset)!

AIRS+CrIS/+IASI good enough for CLARREO IR objectives??

Diurnal Observations: IASI vs AIRS PDF Rates

Tropical Western Pacific, 5-year rates



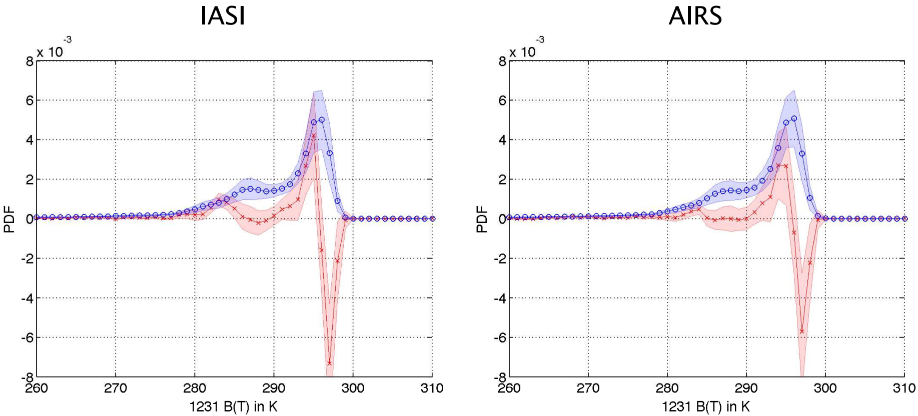
PDF : Errorbars are seasonal variability.

PDF linear rate : errorbars are 2-σ uncertainties.

Rates fairly similar.

Diurnal Observations: IASI vs AIRS PDF Rates

Tropical Eastern Pacific, 5-year rates



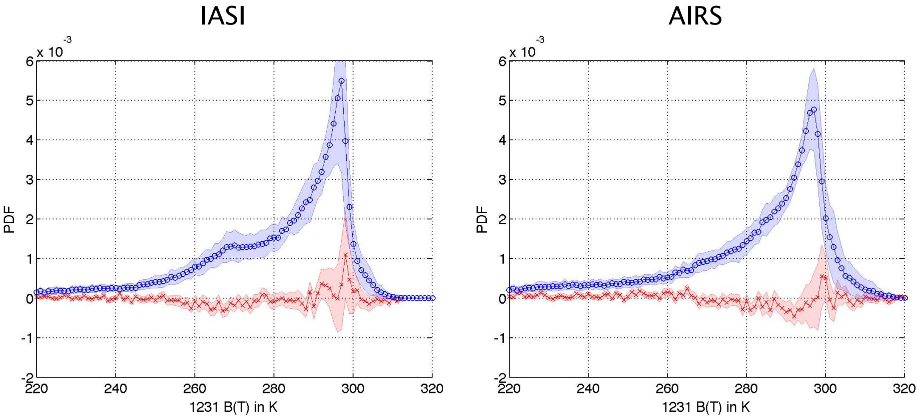
PDF : Errorbars are seasonal variability.

PDF linear rate : errorbars are 2-σ uncertainties.

Rates very similar.

Diurnal Observations: IASI vs AIRS PDF Rates

Amazon, 5-year rates



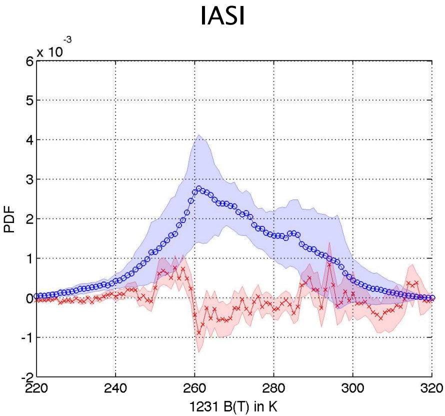
PDF : Errorbars are seasonal variability.

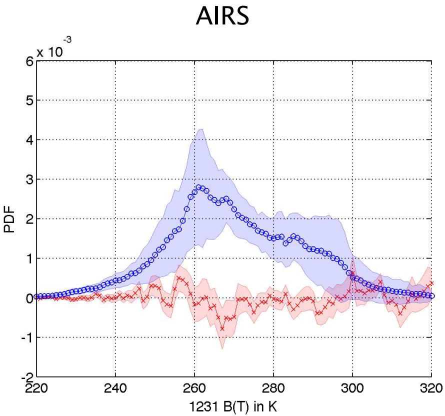
PDF linear rate : errorbars are 2-σ uncertainties.

Rates very similar.

Diurnal Observations: IASI vs AIRS PDF Rates

Continental Europe, 5-year rates





PDF : Errorbars are seasonal variability.

PDF linear rate : errorbars are 2-σ uncertainties.

Rates very similar. Sharper transition near 260K for IASI?

IASI, AIRS have very similar rates. Suggests good sensitivity to diurnal changes in climate.

Conclusions

- AIRS and IASI have sufficient stability for climate trending (IR CLARREO).
- Radiance/B(T) PDF rates for climate trending use full sampling, and allow traceable error bounds (relative to retrievals).
- PDFs may provide a powerful approach for reducing radiometric accuracy requirements for infrared climate trending.
- Comparisons of hyperspectral PDFs with simulated PDFs from re-analysis products may provide useful diagnostics of re-analyses. Cloud fraction/grid size issues require attention.
- We plan to move to GSFC GMAO Merra re-analysis (3-hour steps) plus interpolation (time, space).
- Careful radiometric/spectral matching of AIRS, IASI, CrIS needed, that work is underway.
- Start to compare re-analysis PDF rates with observations.