Climate Trending using Hyperspectral Infrared PDFs

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Overview

Hyperspectral IR Observing Systems

- NASA-AIRS up 10 years (but a calm 10 years)
- AIRS –> NOAA JPSS CrIS should provide 20+ years
- (AQUA + AIRS could last 15+ years)
- IASI up 5+ years, 2 follow-ons built, IASI-NG in planning
- All agree to 0.1-0.2K level on “Day 1”
- CLARREO cancelled. For now must rely on operational sensors for long-term IR radiance record.

Subjects Addressed/Avoided

- Only 10 years record, but several ENSO events
- Work to stitch together AIRS, IASI, CrIS not discussed here
- Quickly examine AIRS stability
- Concentrate on utility of AIRS PDFs and comparisons to ERA Interim Reanalysis

Overall Goals

Products

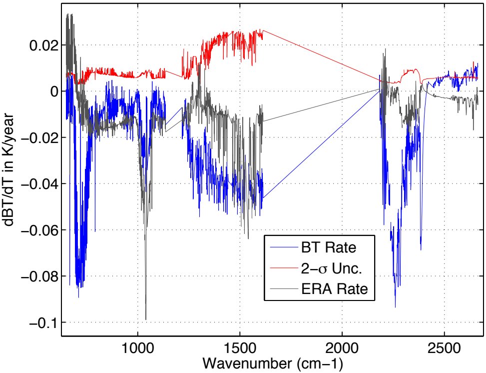
- Climate-level products with traceable accuracy
- Avoid inversions, convert to geophysical understanding as late as possible
- Limit data volume for ease of use
- Only use accurate, well understood external variables (SST)

Model Validation

- Re-analysis accuracy, esp. long-term trends, clouds
- RTA issues, and mapping of re-analysis fields to RTA grid
- Make case for integration of re-analysis to sensor times
- Close the gap between instrument and product providers and end-science users??

Need to show funding agencies what can be gained from rigorous development of long-term, multi-instrument hyperspectral radiance products. **Looking for feedback from science users.**

AIRS Stability (and comparison to ERA)



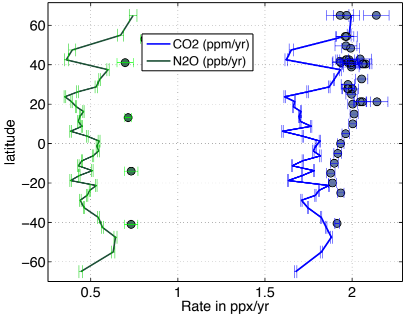
AIRS Clear Scene Subset

- 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

9-Year 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: 6.9 mK/yr (error?)
- AIRS vs N_2O in-situ trends: 10.1 mK/yr (error?)

OEM Retrievals from BT Clear Scene BT Rates



- OEM retrieval of geophysical variables
- OEM fit: CO_2, N_2O, CH_4, O_3, CFC column adjustments, H_2O profile, T profile
- Regularization: L1 derivative smoothing for H_2O, T profiles.
- A-priori zero for gas rates
- Circles are in-situ rates from NOAA CMDL

- AIRS radiometric drift estimates based on differences between the fitted CO_2 and N_2O rates and in-situ. Great potential for various systematic errors.
- AIRS radiometric stability is in the climate range: 0.01K/year or better.

Present use of IR Radiance Data (for Climate?)

(Addressing larger institutional efforts here)

Assimilation

- Clear only (or above clouds), avoid surface channels.
- Bias tuning (for RTA, instrument, and CO_2 for T-profile)
- Low data use, no cloud information, error characterization difficult
- But, multiple data sources and model constraints yield a tremendous re-analysis product

1-D Var Retrievals

- Cloud-clearing with non-gaussian errors hard to characterize
- Cloud property retrievals difficult to impossible under all conditions => sampling errors
- Level 3 data have complicated sampling characteristics/errors

AIRS PDFs

- Can we find ways to use radiances directly to:
  - Ensure full state sampling?
  - Enable rigourous error analysis by converting to geophysical units “as late and simply as possible”?
- Could do this with imagers. But:
  1. lot’s more data,
  2. more contamination (water, minor gases), and
  3. less stability/accuracy
- Compare to ERA-Interim reanalysis, helps connect to geophysics
- Using multiple channels others producing OLR with hyperspectral.

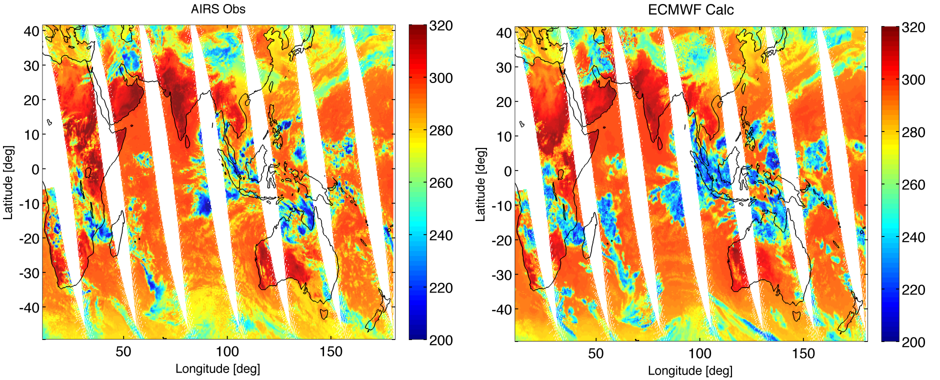
Detail of Data Set and RTA

Very simple approach for now.

- Full AIRS record, but only 2 FOVs on either side of nadir, ~2% of data. (needs improvement)
- Matched to closest ERA-Interim re-analysis grid point ==> relatively large time offsets
- Simulated radiances computed using UMBC SARTA RTA. Use very simple PCLSAM approach by Chou et. al. (J. Climate 1999) + Non-LTE + reflected solar.
- *Only two scattering layers: either 1 water, 1 cloud, or 2 water.*
- Developed simple algorithm to convert re-analysis vertical mass profiles to two layers, assuming random cloud overlap.
- Time series analysis used daily averages for region of interest.
- Almost totally concentrate on 1231 cm^{-1} AIRS channel. Least amount of H_2O in thermal region. Mostly a surface + cloud channel.
- Often show data in one geographic region using TRANSCOM definitions, ie Tropical Western Pacific

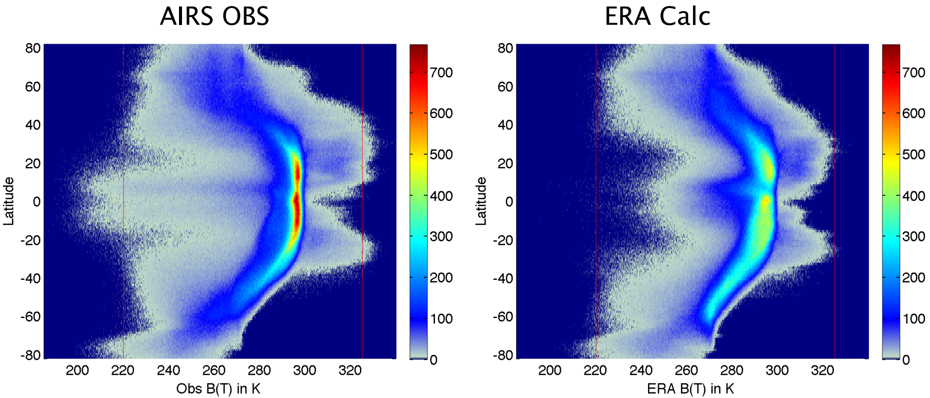
Snapshot Comparison: AIRS to ECMWF via SARTA RTA

Image of 1231 cm^{-1} channel B(T), March 10, 2011



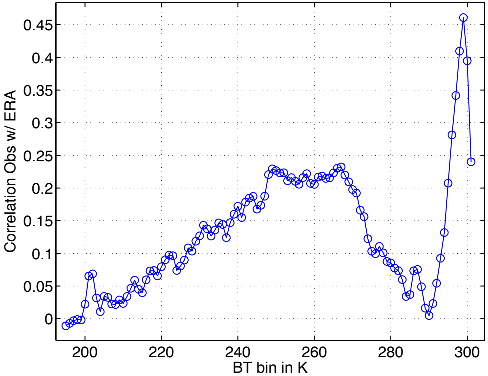
Note: ERA data is lower resolution than ECMWF with 6-hour versus 3-hour time steps.

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



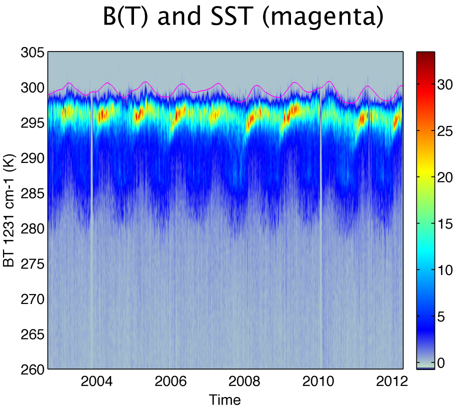
- ERA clouds spread out more (RTA mapping issue?)
- Lack of deep convection in ERA (well known)
- Some hotter observed scenes (time mistatch?)

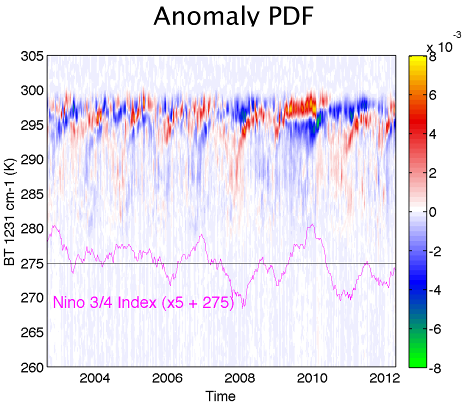
Correlation of Observed and Computed Radiances



- Data from western tropical pacific
- Reasonable correlation for clear
- Low correlstion for deep convective clouds, missing in ERA
- Correlation low for 280-290K, region of broken clouds

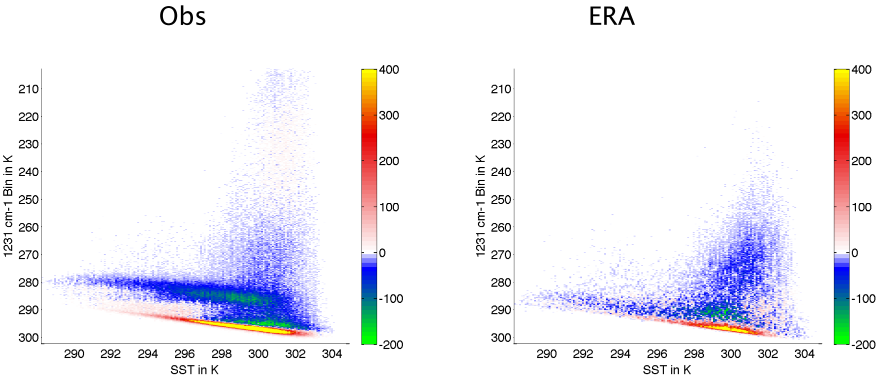
Western Tropical Pacific Time PDFs





Anomaly PDFs reflect ENSO very nicely. *BUT*, all low-BT structure is mostly due to changes in the surface tempearture, NOT changes in cloud forcing.

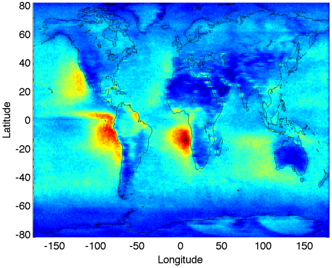
Western Tropical Pacific Time: Day-Night PDFs



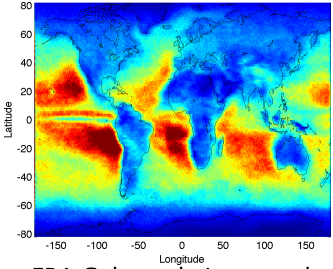
- Mixing all times, with large spatial extent
- Increase in low clouds at night not strong in ERA. Maybe conversion of ERA cloud to RTA grid missed these??
- Any interest in monitoring with high accuracy, relatively large fields of view?

Daytime Low Cloud Occurance (ERA? RTA mapping issue?)

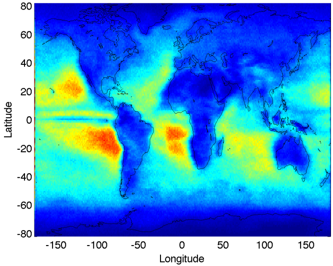
Obs



ERA

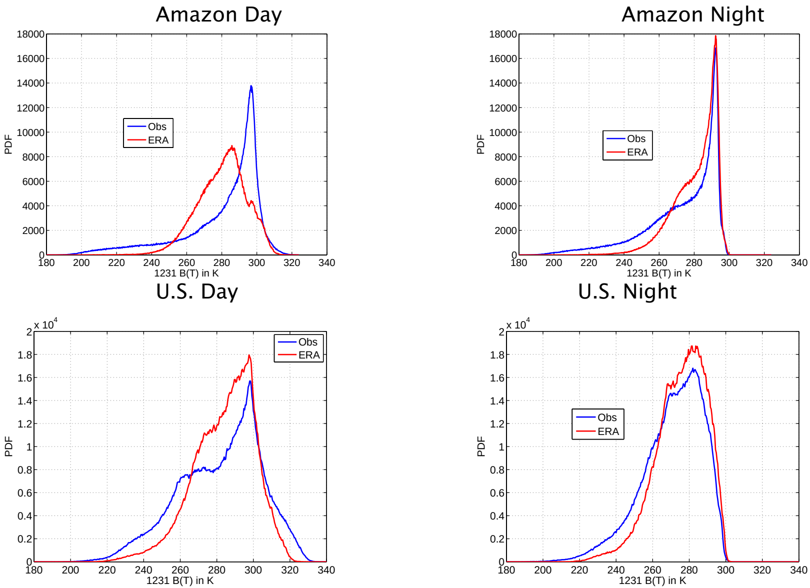


ERA Colorscale Increased



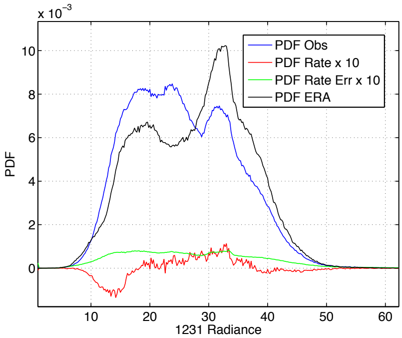
- Low cloud ≡ (2K < B_obs(T) - B_calc(T) < 9K).
- Almost no change if use [3K 8K]
- Using ERA for calc. BUT SST good to 0.2K, and ERA column water very good compared to thresholds.
- If use shortwave, do not need column water,results very similar

Amazonia and U.S. PDFs vs ERA)



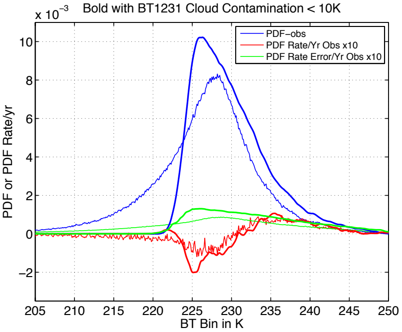
Two Examples: Arctic 1231 PDFs; Trop. Western Pacific 250 mbar Water

Arctic 1231 cm^{-1}



Obs BT Change: 0.06 ± 0.02 K/Year
ERA Change: 0.03 ± 0.03K/Year

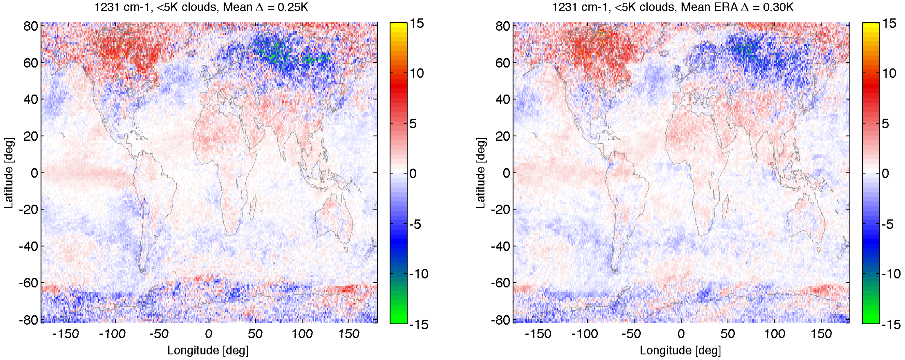
TWP



PDF rate of change negative near peak, implies more water vapor.
However, need to use temperature channels to ensure this is only a change in water.

1231 cm^{-1} Radiance Trends w/ Cloud Filter

2010-2008 ENSO warm-cold events.



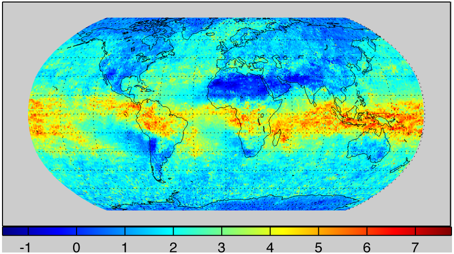
No potential sampling errors as with existing AIRS products

Big event: But, mean change in Obs is +0.15K

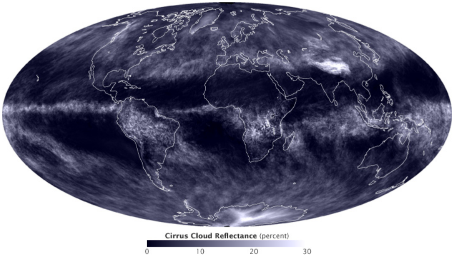
BUT, 10K max cloud filter based on ERA. Probably very insensitive to details ...

Small Particle Cirrus: March 2010

AIRS Cirrus



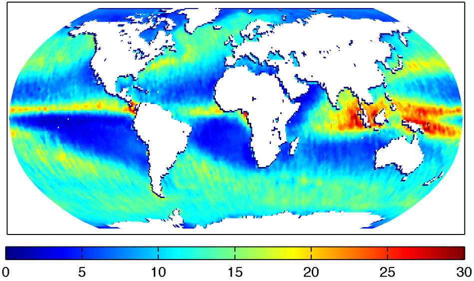
MODIS Cirrus



This is just B(T) 960 cm^{-1} minus B(T) 790 cm^{-1} that is large for small ice particles.

Just a reminder that one can also monitor some measure of thin cirrus (and compare to models).

Single Channel Cloud "Forcing"



- ERA clear sky fields *very good*, esp. SST (an input)
- 1231 cm^{-1} channel is mostly surface, clouds, with a little water
- Single channel forcing, R_clearcalc minus R_obs, is just clouds and should be very stable and very accurate.
- However, longwave cloud forcing appears to be exceedingly stable over time and with small SST changes, so not too interesting.

Conclusions

- Probably need a better RTA and better mapping of ERA clouds to RTA vertical grid before making definitive conclusions.
- Hope that this work could argue for getting NWP center(s) to produce a re-analysis at the sensor observing times for better model diagnostics.
- PDFs might be useful; rigorous analysis of their utility for climate trend detection has not been done.
- Hopefully this work could lead to better diagnostics of NWP, and climate model, cloud parameterizations.
- Difficult to say if raw hyperspectral radiance record can diagnose NWP temperature fields. They are really good at removing CO_2!
- A more sohisticated approach needed for H_2O than presented. Use of temperature channels for water will introduce uncertainties in CO_2.