Using Collocated AVHRR Imager Measurements to Constrain Cloud Cleared Radiances from IASI

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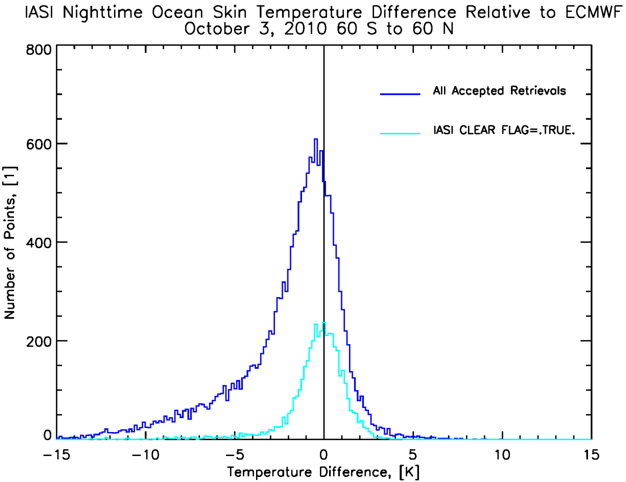
IASI Only Cloud-Clearing



$$\mathrm{MEAN}(\Delta T_{\mathrm{RET-ECMWF}}) = -1.901\mathrm{K}$$
$$\mathrm{STD.DEV}(\Delta T_{\mathrm{RET-ECMWF}}) = 3.027\mathrm{K}$$
$$\mathrm{CORREL}(T_{\mathrm{RET}}, T_{\mathrm{ECMWF}}) = 0.9368$$

$$\%\mathrm{CASES\ ACCEPTED} = 60.07\%$$
$$\%\mathrm{CASES} \geq |3\mathrm{K}|\ \mathrm{ABOUT\ MEAN} = 22.78\%$$

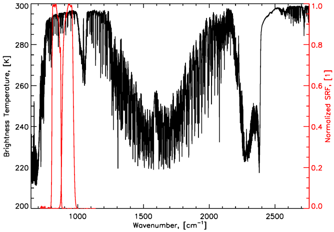
Background and Motivation

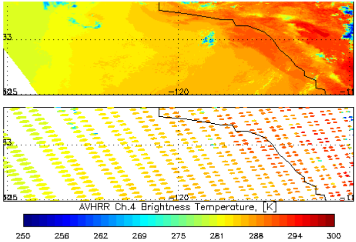
- Smith, et al. (2004) and Li, et al. (2005) showed that collocated AIRS IR sounder and Aqua MODIS imager measurements enable direct calculation of high quality cloud-cleared radiances without the use of a forward model to estimate clear sky radiances.
  - Their methods rely on the high spatial resolution MODIS measurements and cloud-mask to estimate clear-sky measurements in MODIS IR spectral bands spatially collocated and averaged onto the AIRS footprints.
  - The use of IR spectral bands covering the spectral domains sampled by the AIRS instrument enables direct comparison of the clear-sky MODIS measurements to AIRS and therefore does not require a priori assumptions about the geophysical state (i.e., surface properties, trace gas concentrations and/or water vapor abundances) to enable calculation of clear-sky radiances.
  - Noise amplification was not considered; however, the reported accuracies of the cloud-cleared radiances for successfully cleared cloudy scenes (30% of all cloudy scenes) were $0.5K$ or better.

In what follows we apply the single formation cloud-clearing equations in the η formulation (enables multiple cloud-formations) to solve for cloud-cleared radiances from IASI and AVHRR.

Sample IASI Spectrum and AVHRR Spectral Response Functions

Top: CLAVR-X AVHRR Ch.4 BTs (courtesy A. Heidinger)
Bottom: AVHRR collocated onto IASI footprints (courtesy H. Sun)





Spectral convolution of IASI to AVHRR resolution

Spatial convolution of AVHRR to IASI footprints

We want to exploit the high spatial resolution of the multispectral AVHRR data to improve and/or enhance IASI retrievals in two ways:

1. QA cloud-cleared radiances using spectrally convolved IASI and spatially convolved subpixel clear AVHRR to compare apples to apples.
2. Utilize subpixel ($\approx 1km$ AVHRR versus $\approx 12km$ IASI) /multispectral (visible/NIR) information about clouds from AVHRR to improve/validate cloud-clearing, improve our 'clear-estimate', and/or develop syngeristic products thereby enhancing other retrievals.

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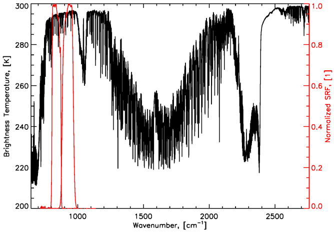
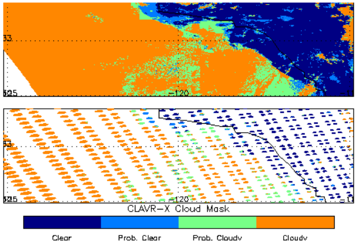


Spectral convolution of IASI to AVHRR resolution

Top: CLAVR-X Cloud Mask (courtesy A. Heidinger)
Bottom: AVHRR collocated onto IASI footprints (courtesy H. Sun)



Spatial convolution of AVHRR to IASI footprints

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Methodology to Test Collocations and Instrument Synergy

- Use a single days worth of data Oct. 3, 2010 (performed analysis on various days in 2010 and found similar results).
- Collocate AVHRR measurements for channels 4 (928.15cm^{-1}) and 5 (833.25cm^{-1}) to IASI fields-of-view (FOVs) in 2×2 array forming the IASI field-of-regard (FOR).
- Use CLAVR-X cloud-mask to aggregate AVHRR clear (and/or all-sky) pixels onto IASI FOVs using the IASI spatial response or integrated point spread function $IPSF$

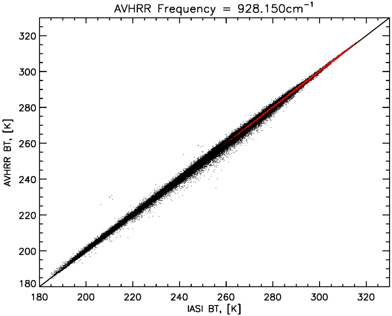
$$R^{clr}_{A_i} = \sum_{l=1}^{n^{clr}_{AVHRR}} IPSF_l R^{clr,l}_{A_i} \quad (1)$$

- Use the AVHRR SRF (NOAA KLM User's Guide) to spectrally convolve the IASI radiance to AVHRR spectral resolution.

$$R_{A_i} = \sum_{\nu} SRF_{i,\nu} R_\nu \quad (2)$$

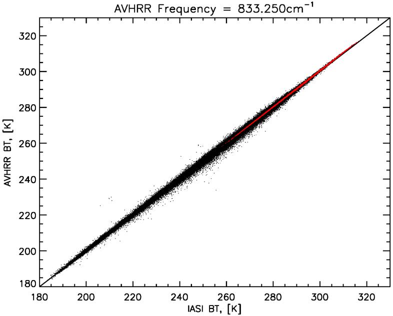
All Collocations of AVHRR BTs and IASI BTs for 10/03/2010

Black: All Cases, Red: Clear Cases



Stats for all cases

$$\mathrm{MEAN}(\Delta\mathrm{BT}_{\mathrm{A-I}}) = -0.163K$$
$$\mathrm{STD.DEV}(\Delta\mathrm{BT}_{\mathrm{A-I}}) = 0.422K$$
$$\mathrm{CORREL}(\mathrm{BT}_{\mathrm{A}}, \mathrm{BT}_{\mathrm{I}}) = 0.9998$$

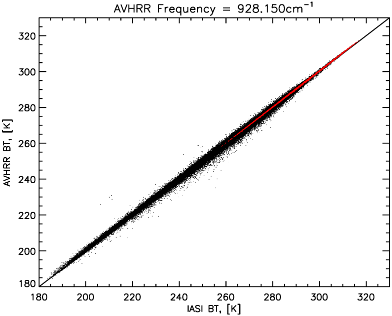


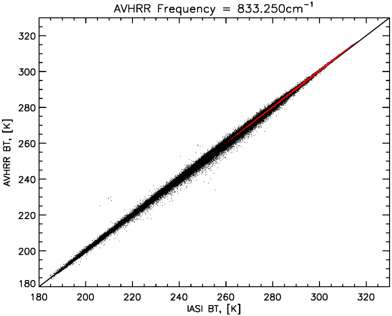
Stats for all cases

$$\mathrm{MEAN}(\Delta\mathrm{BT}_{\mathrm{A-I}}) = -0.203K$$
$$\mathrm{STD.DEV}(\Delta\mathrm{BT}_{\mathrm{A-I}}) = 0.417K$$
$$\mathrm{CORREL}(\mathrm{BT}_{\mathrm{A}}, \mathrm{BT}_{\mathrm{I}}) = 0.9998$$

All Collocations of AVHRR BTs and IASI BTs for 10/03/2010

Black: All Cases, Red: Clear Cases





Stats for clear cases

$$\mathrm{MEAN}(\Delta \mathrm{BT}_{\mathrm{A-I}}) = -0.321K$$
$$\mathrm{STD.DEV}(\Delta \mathrm{BT}_{\mathrm{A-I}}) = 0.109K$$
$$\mathrm{CORREL}(\mathrm{BT}_{\mathrm{A}}, \mathrm{BT}_{\mathrm{I}}) = 0.9999$$

Stats for clear cases

$$\mathrm{MEAN}(\Delta \mathrm{BT}_{\mathrm{A-I}}) = -0.425K$$
$$\mathrm{STD.DEV}(\Delta \mathrm{BT}_{\mathrm{A-I}}) = 0.117K$$
$$\mathrm{CORREL}(\mathrm{BT}_{\mathrm{A}}, \mathrm{BT}_{\mathrm{I}}) = 0.9999$$

Discussion

- We have found excellent agreement between all-sky and clear sky spectrally convolved IASI measurement and spatially convolved AVHRR measurements.
- There is a small channel dependent bias between AVHRR-IASI with IASI generally being warmer than AVHRR.
- Standard deviation between the two instruments is $< 0.5K$ for non-uniform scenes and $\approx 0.1K$ for uniform clear scenes!
- Differences between AVHRR and IASI are dependent on the scene brightness temperature (saw this comparing the bias of clear to all-sky data).
  - L. Wang and C. Cao, 2008 found a similar result using a different collocation methodology and data from 2007.
  - Slopes are generally small ($\approx 1K$ at the cold end compared to $-0.3K$ at the warm end).
- Differences between instruments also has a small $< 0.1K$ scan angle dependence that needs investigated - also reported by L. Wang and C. Cao.

In what follows we've performed a bias correction to the AVHRR measurements R_{A_i} similar to what is done for AMSU and IASI or AMSU and AIRS :

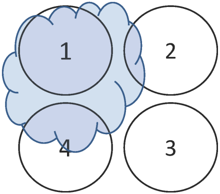
$$R'_{A_i} = a_0 + b_0 R_{A_i}$$

We've not attempted to force any scan angle dependent differences to zero.

So we have highly accurate collocations . . .

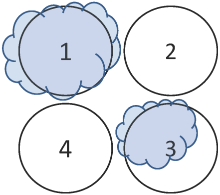
How do use these to produce cloud-cleared radiances R_ν^{cc}?

Case I: Clear (AVHRR CLAVR-X Cloud-Mask) FOVs - Hole Hunting



FOV 3 clear by AVHRR CLAVR-X Cloud Mask

$$R_\nu^{cc} = R_\nu^{FOV_3}$$



FOV 2 and FOV 4 clear by AVHRR CLAVR-X Cloud Mask

$$R_\nu^{cc} = \frac{1}{2}(R_\nu^{FOV_2} + R_\nu^{FOV_4})$$

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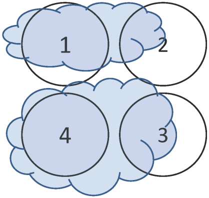
and so on . . .

Case II: Partially Cloudy (AVHRR CLAVR-X Cloud-Mask) FOVs



Sort FOVs to minimize amplification of noise and calculate the cloud-cleared radiance R_ν^{cc} using FOVs j and k

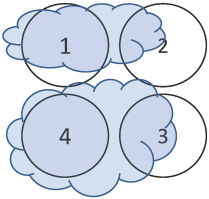
$$R_\nu^{cc}(j,k) = R_\nu^{FOV_j} + \eta(j,k)\left(R_\nu^{FOV_j} - R_\nu^{FOV_k}\right)$$

with $\eta(j,k)$

$$\eta(j,k) = \frac{\sum_{i=1}^{2}\left[R_{A_i}^{clr} - R_{A_i}^{FOV_j}\right]\left[R_{A_i}^{FOV_j} - R_{A_i}^{FOV_k}\right]}{\sum_{i=1}^{2}\left[R_{A_i}^{FOV_j} - R_{A_i}^{FOV_k}\right]^2}$$

Note that we chose to perform single η experiments at this time. Future work will extend results to multiple-η's and cloud-formations.

Case II: Partially Cloudy (AVHRR CLAVR-X Cloud-Mask) FOVs



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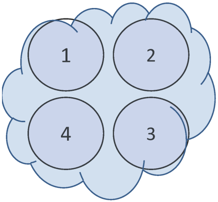
with $\eta(j,k)$

$$\eta(j,k) = \frac{\sum_{i=1}^{2}\left[R_{A_i}^{clr} - R_{A_i}^{FOV_j}\right]\left[R_{A_i}^{FOV_j} - R_{A_i}^{FOV_k}\right]}{\sum_{i=1}^{2}\left[R_{A_i}^{FOV_j} - R_{A_i}^{FOV_k}\right]^2}$$

We then select FOVs (j', k') such that $R_\nu^{cc}(j', k')$ has the minimum amplification factor and agrees best with the clear estimate $R_{A_i}^{clr}$.

Case III: Overcast (AVHRR CLAVR-X Cloud-Mask) FOVs



We could

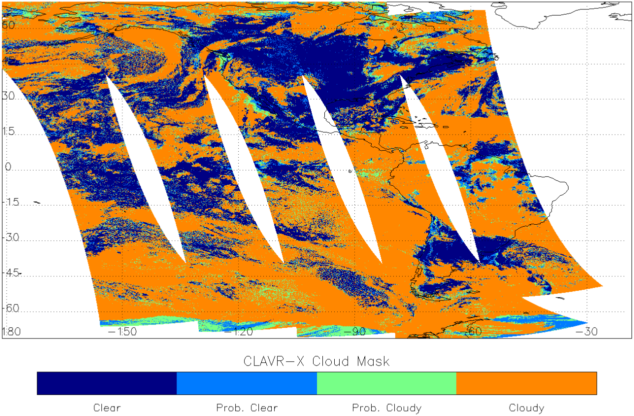
1. use AMSU/MHS to estimate clear
2. perform retrievals above the clouds
3. model the clouds
4. ...

but at this point, we punt !

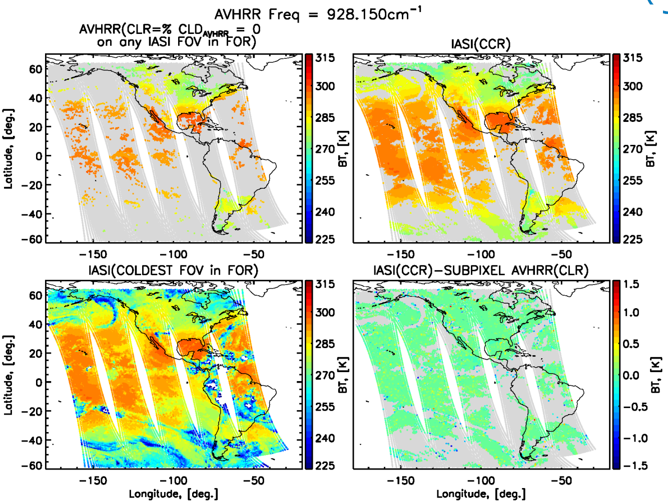
Yesterday, Joao showed interesting results from AIRS in stratocumulus regions we'll probably rethink how we handle overcast low cloud situations.

CLAVR-X Cloud Mask (Courtesy of A. Heidinger) For Several Partial MetOP-A Orbits

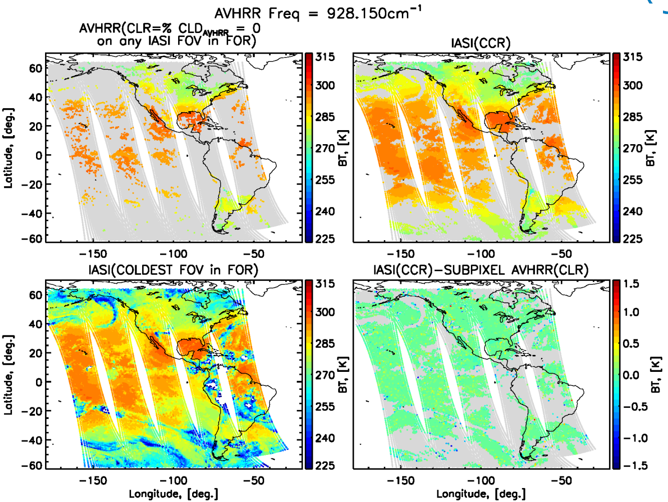
Used For This Analysis - Viewangle Restricted to IASI Viewangles



$\approx 10\%$ of the single FOV IASI footprints are clear.
$\approx 2.5\%$ of the 2×2 IASI FORs are clear.
$\approx 39\%$ of the 2×2 IASI FORs are completely overcast.

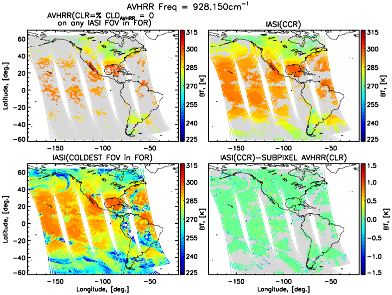


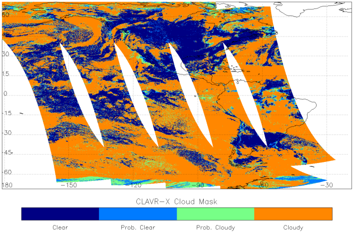
Clockwise From Top Left: Clear IASI Single FOVs, Successful IASI Cloud-Cleared Radiances (CCR) Using AVHRR, IASI CCR-Subpixel AVHRR Clear, Coldest IASI FOV in 2×2 FOR.



These panels show the relative yield of a clear only algorithm vs. the AVHRR cloud-clearing algorithm and also an estimate of the cloud contrast across the IASI FOR provided by the ΔBT expected relative to the coldest FOV in the IASI FOR.

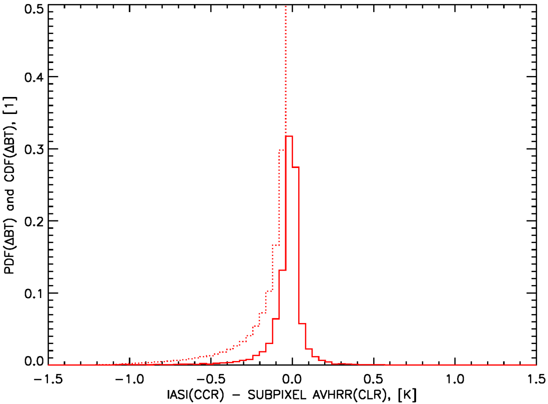
Comparison of the IASI+AVHRR Cloud-Clearing to the AVHRR Cloud Mask





Areas with unsuccessful retrievals (in gray) in the left figures generally indicate regions with spatially uniform clouds (in orange) as shown in the right hand figure.

Verification the CCR Algorithm Works: AVHRR Freq = 928cm^{-1}



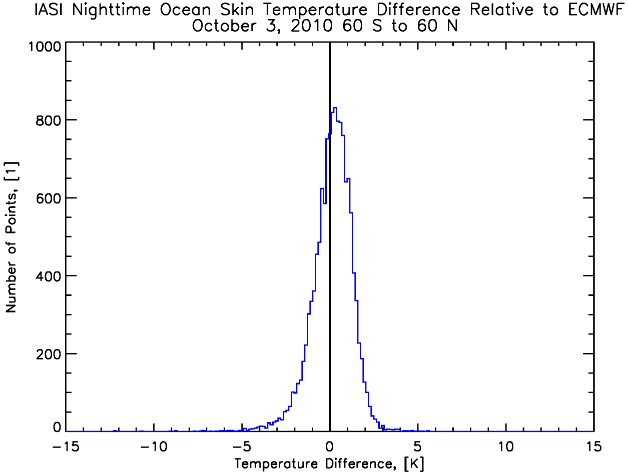
$$\mathrm{MEAN}(\Delta\mathrm{BT}_{\mathrm{I(CCR)-A(CLR)}}) = -0.032K$$
$$\mathrm{STD.DEV}(\Delta\mathrm{BT}_{\mathrm{I(CCR)-A(CLR)}}) = 0.125K$$

Next Steps

So the algorithm can "fit" AVHRR clear BTs ... are these any good?

- We need to verify that the AVHRR clear radiances are an accurate representation of the surface leaving radiances as viewed by IASI.
- We do this by running the AVHRR+IASI cloud-cleared radiances through our operational IASI retrieval algorithm to produce a retrieved geophysical state.
  - No further cloud-clearing is performed - we tell the algorithm that the radiances are clear.
  - Noise amplification/reduction of the resultant radiances is not properly treated in this experiment - we use IASI nominal $\mathrm{NE\Delta N}$. We expect that proper handling of noise should improve results over what is shown.
- We then compare these retrieved geophysical state products, namely ocean surface skin temperature to ECMWF model ocean surface temperature to gauge the skill of our cloud-clearing algorithm for the orbits shown in previous slides.

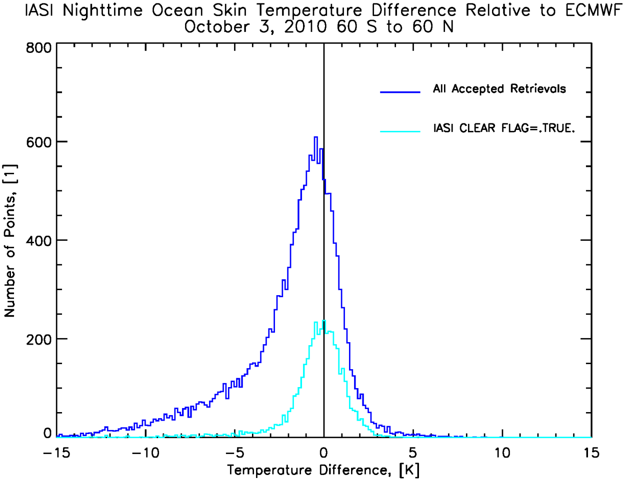
AVHRR + IASI Cloud-Clearing



$$\mathrm{MEAN}(\Delta T_{RET-ECMWF}) = 0.109K$$
$$\mathrm{STD.DEV}(\Delta T_{RET-ECMWF}) = 1.160K$$
$$\mathrm{CORREL}(T_{RET}, T_{ECMWF}) = 0.9851$$

$$\%\mathrm{CASES\ ACCEPTED} = 46.95\%$$
$$\%\mathrm{CASES} \geq |3K|\ \mathrm{ABOUT\ MEAN} = 1.952\%$$

IASI Only Cloud-Clearing



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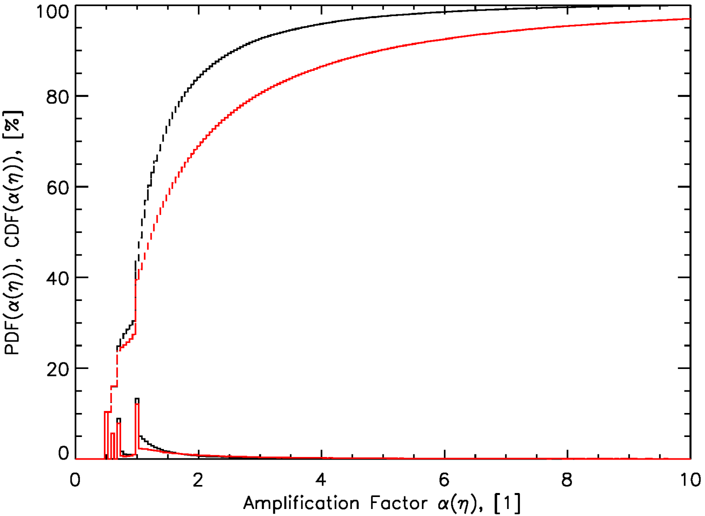
Discussion and Future Work

- We've utilize collocated AVHRR and IASI measurements to constrain cloud-clearing η's and clear column radiances from IASI.
- Cloud cleared IASI BTs and clear-sky AVHRR BTs for surface sensitive channels agree in an RMS sense to better than $\approx 0.13K$ for a variety of atmospheric conditions (land, ocean, clear, cloudy, etc.).
- Surface temperature retrievals from the IASI + AVHRR system agree with ECMWF skin temperatures to within $0.1K$ with a standard deviation of $\approx 1K$.
  - The retrievals are successful on $\approx 47\%$ of IASI FORs with no difference in yield from the top of the atmosphere to the surface.
  - The outlier rate of the IASI + AVHRR algorithm's SST retrievals is also small $< 2\%$.

Discussion and Future Work

- Current results were run at AMSU spatial resolution; however, characterization of sub-pixel clouds within IASI single fields-of-view enable retrievals to be run at increased spatial resolution (we're not tied to an AMSU footprint).
  - At best we can run retrievals at single FOV IASI resolution (clear cases).
  - If we constrain our retrievals to the 2×2 FOR of IASI, we could also run at $1/2\times$IASI FOR spatial resolution ≈ 25km
  - Extending our results to multiple cloud-formations (solve for more than 1 η) would require adding at least 1 more FOV so at a minimum retrieval spatial resolution would be close to an AMSU footprint.
- We can envision many synergistic products (e.g., cloud products, surface products, etc.) from the collocated retrieval system
- We plan on extending the results using MODIS and AIRS data from NASA's Aqua satellite as well as with VIIRS and CrIS.

Noise Amplification Factor



black : best fit to clear estimate and lowest amplification factor

red : best fit to clear estimate only