National Aeronautics and
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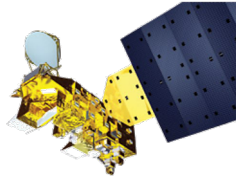
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Atmospheric Infrared Sounder



AIRS and CrIS comparisons with gridded radiances

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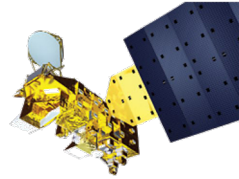
* Jet Propulsion Laboratory, California Institute of Technology

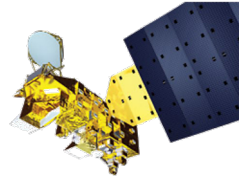
Introduction



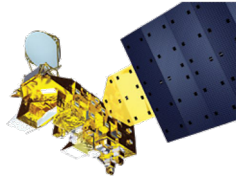
- We want to be able to study climate trends etc. across AIRS/CrIS epochs
  - Instrument artifacts make this difficult
  - We show results from a gridded radiance product that can help address this
    - StratRad: Stratified Radiances

- Monthly StratRad files are mostly mean radiances for grid cells of:
    - 18 10-degree latitude bins
    - 18 20-degree longitude bins
    - 10 9-FOV scan angle bins
    - 2 bins forAscending/Descending (~Day/night)
    - 2 bins for Land/sea
  - 18 * 18 * 10 * 2 * 2 = 12,960 spectra
    - 7000x data volume reduction
  - Dividing out the ~90,000,000 observed spectra per month gives ~7000 spectra averaged per bin, so instrument noise is reduced by sqrt(7000) ~= 80x
    - 0.3 K / sqrt(7000) => 0.004 K
  - But each bin represents observations from only ~30 orbital passes so “weather noise” from clouds is still an issue.
    - 20 K / sqrt(30) => 4 K

Outline

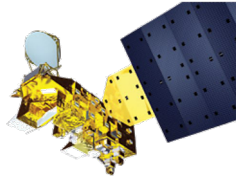


- AIRS & CrIS on their best behavior
  - Cloud optical parameters
- Instrument anomalies:
  - AIRS Module M-08 A/B
  - Right/Left Asymmetry
  - Shortwave



Cloud optical properties

Cloud optical properties



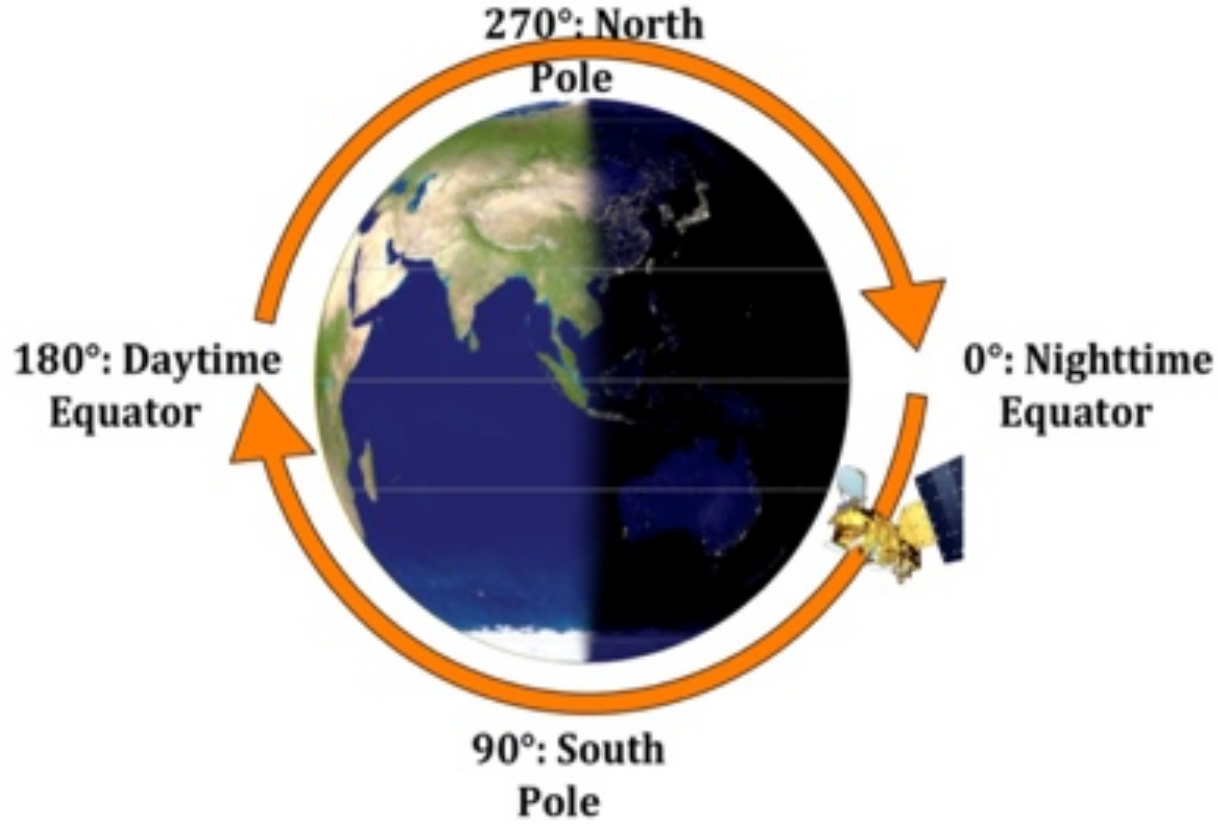
- Clouds are a sample domain where we can show that even though AIRS and CrIS differ, signals from AIRS-vs-AIRS and CrIS-vs-CrIS agree very well at showing regional, diurnal, seasonal, etc. changes.

- We will look at the full month of January 2018 for both AIRS and CrIS.

- The difference in BT across the 11-micron band indicates cloud thermodynamic phase (ice or liquid particles) and particle size.
  - AIRS channels at 830.5 and 961.1 cm^{-1} span this band.
  - For CrIS we use 830.625 and 961.25 cm^{-1}.

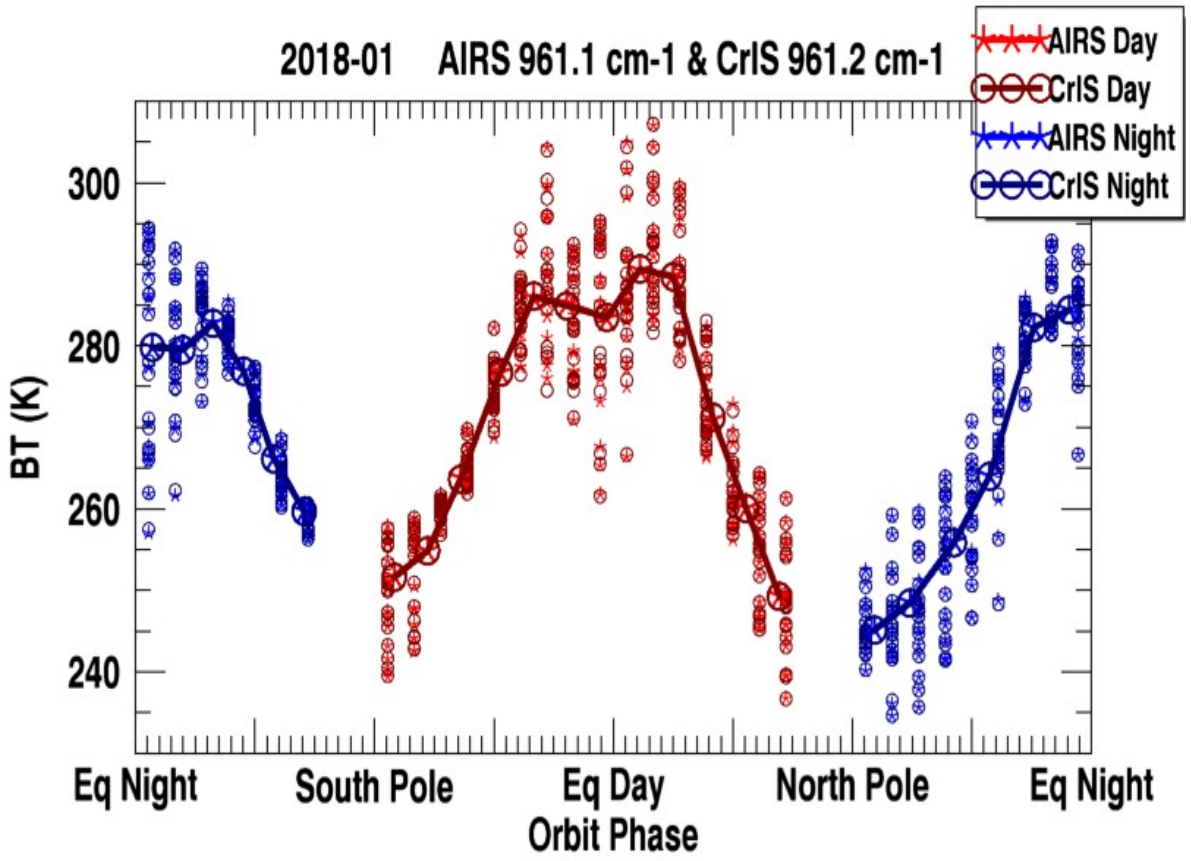
Polar orbital cycle

- AIRS and CrIS are on platforms with similar sun-synchronous polar orbits.
- This orbit gives a periodicity to certain classes of instrument artifacts.



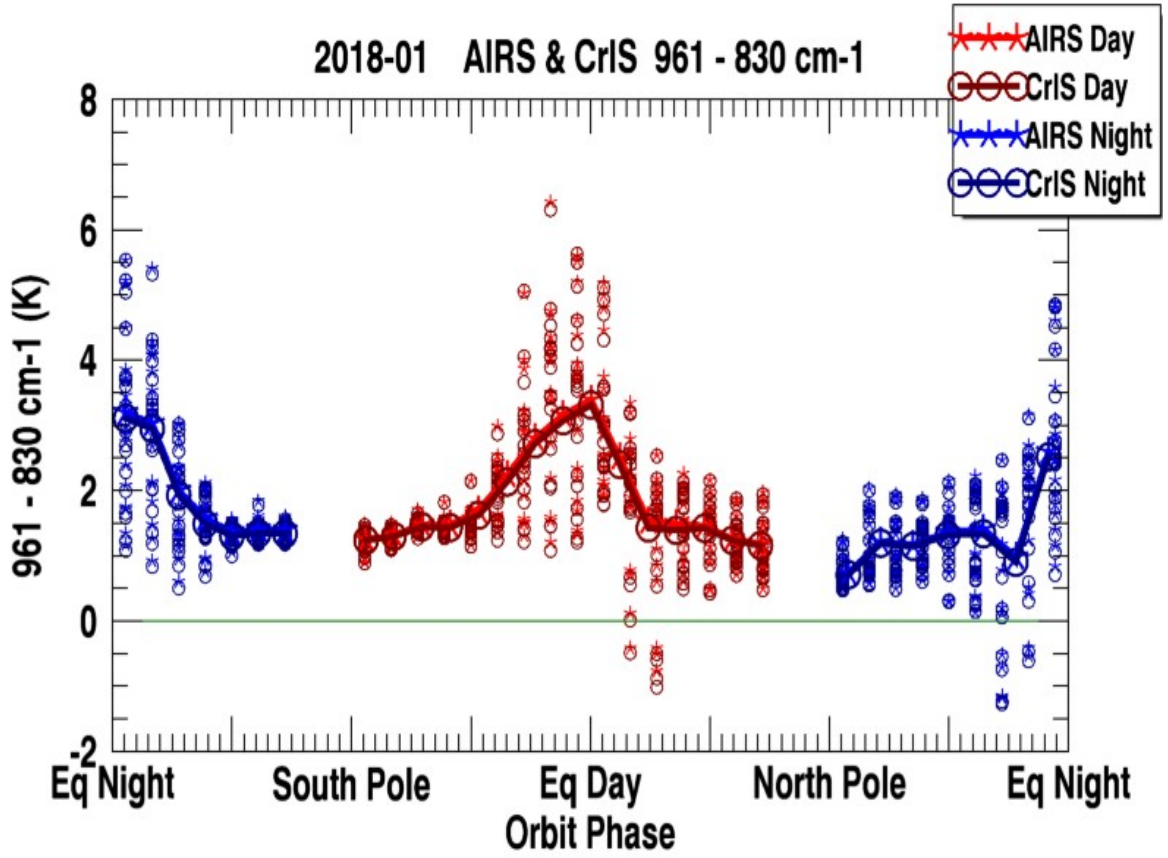
Cloud optical properties

- This shows the background BT structure for the 11-micron band for January 2018 as a function of orbital phase.
- It's hottest near the equator for day and night.
  - The cycle is not highly peaked because clouds at the equator "hide" the surface temperature.



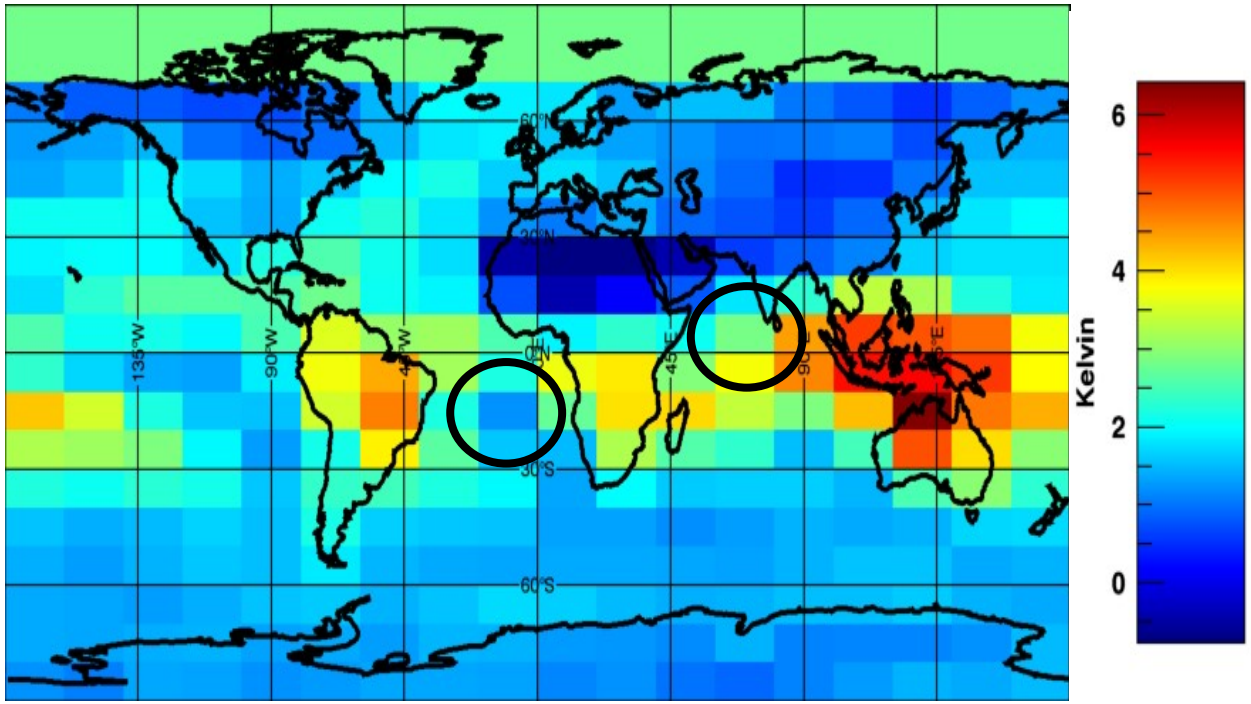
Cloud optical properties

- This shows the difference BT961-BT830 peaking pretty sharply near the equator where there are the most ice clouds.
- It also shows a great degree of variability.



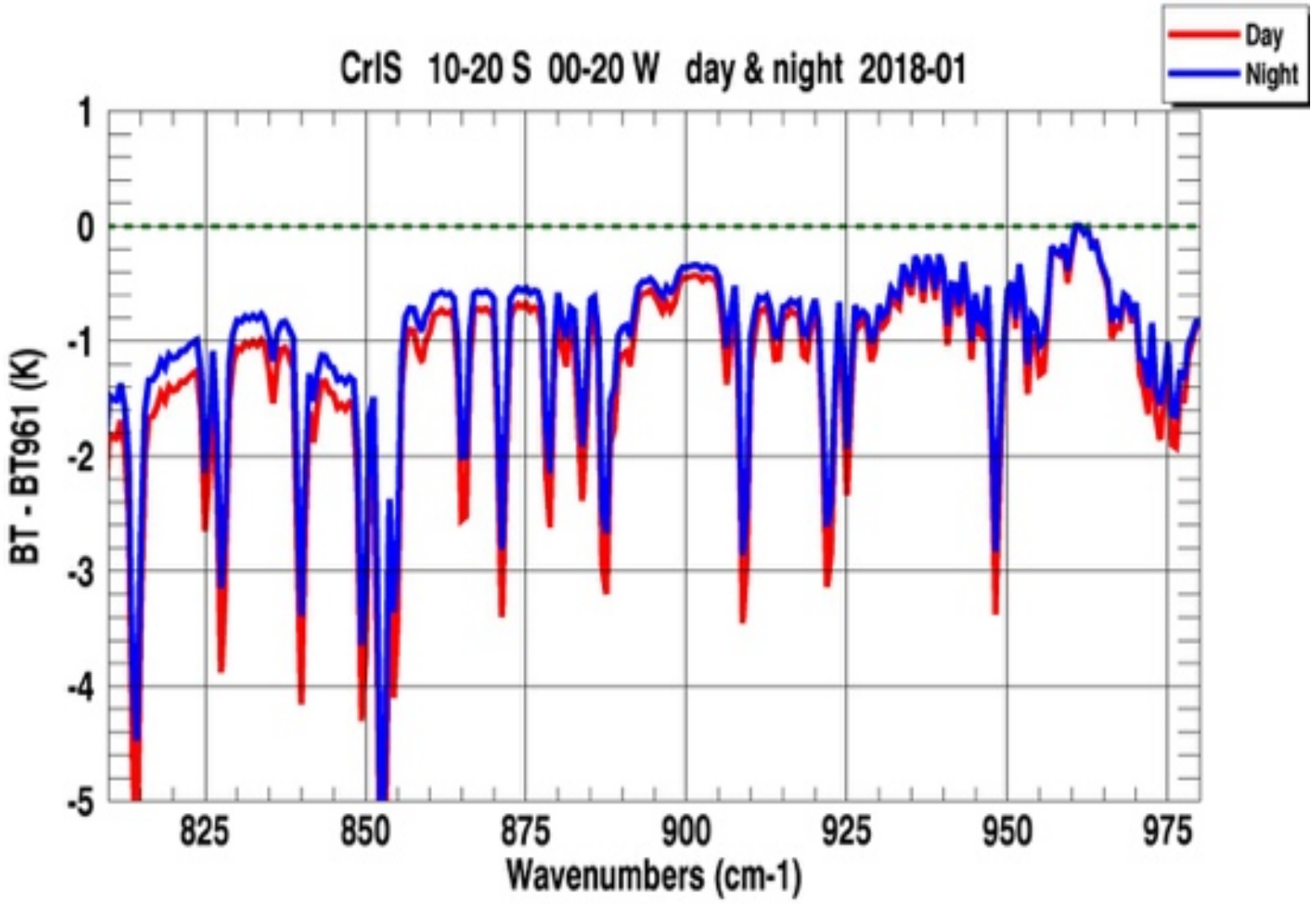
Cloud optical properties

- This map shows AIRS daytime BT961-BT830 for January 2018 daytime.
  - Black circles show locations of two tropical ocean areas with similar mean BT but very different BT961-BT830.

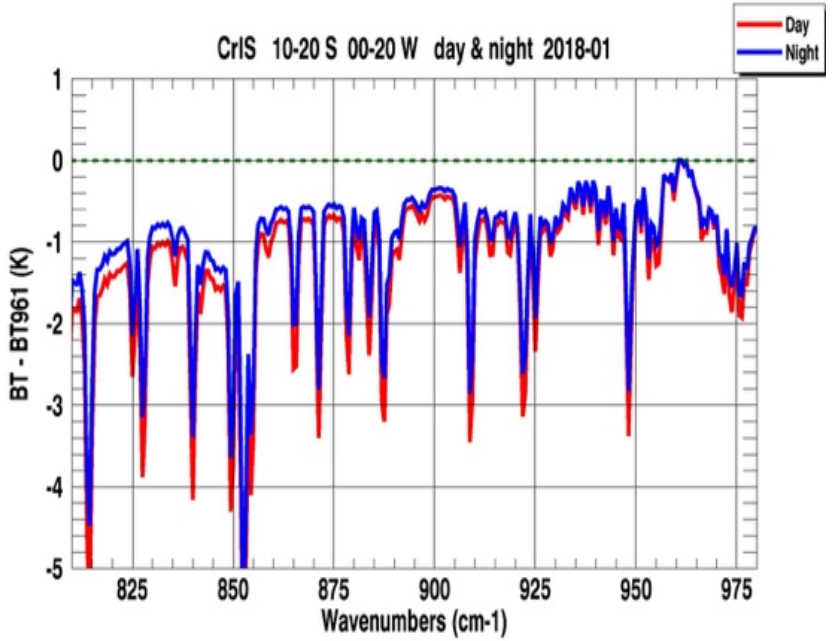


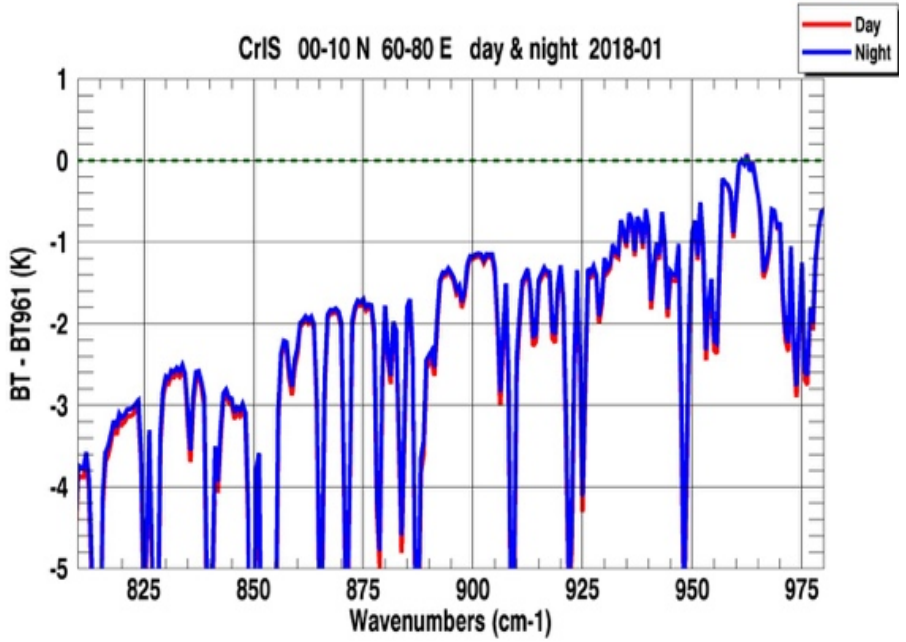
Clouds

- For these figures all spectra are differences from BT961 to make the shapes clearer.
  - Without this normalization, random biases from different sampling would dominate.
- CrIS data for 10-20 S 00-20 W
- There's a ~1 K slope over window channels in the range of 825-975 cm^{-1} – a shallow slope



Clouds from CrIS





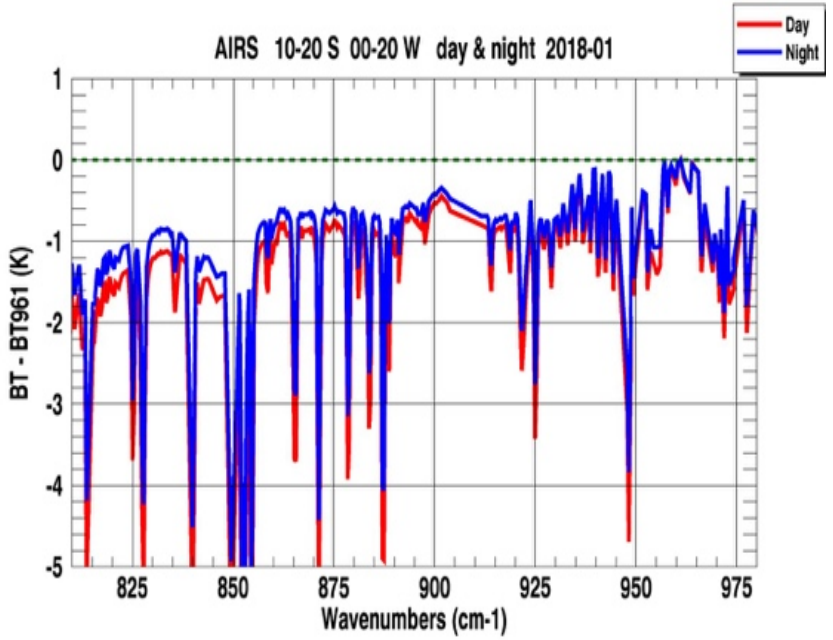
In the South Atlantic we see a relatively flat spectrum (dBT ~1 K) for both day and night

- Probably indicating mostly liquid clouds.

The Indian ocean case has a much steeper slope (dBT ~3 K)

- Indicating ice clouds.

Clouds from AIRS



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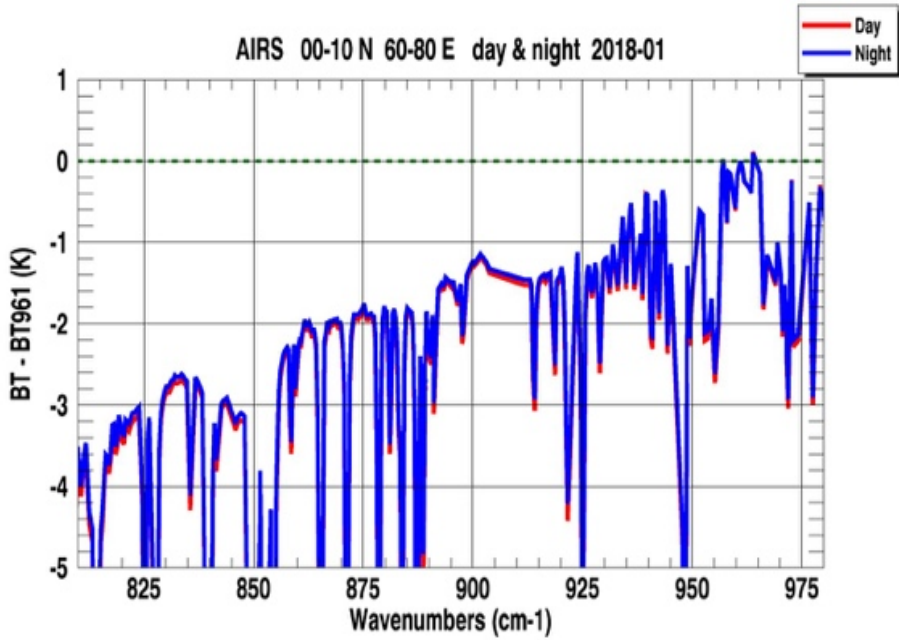
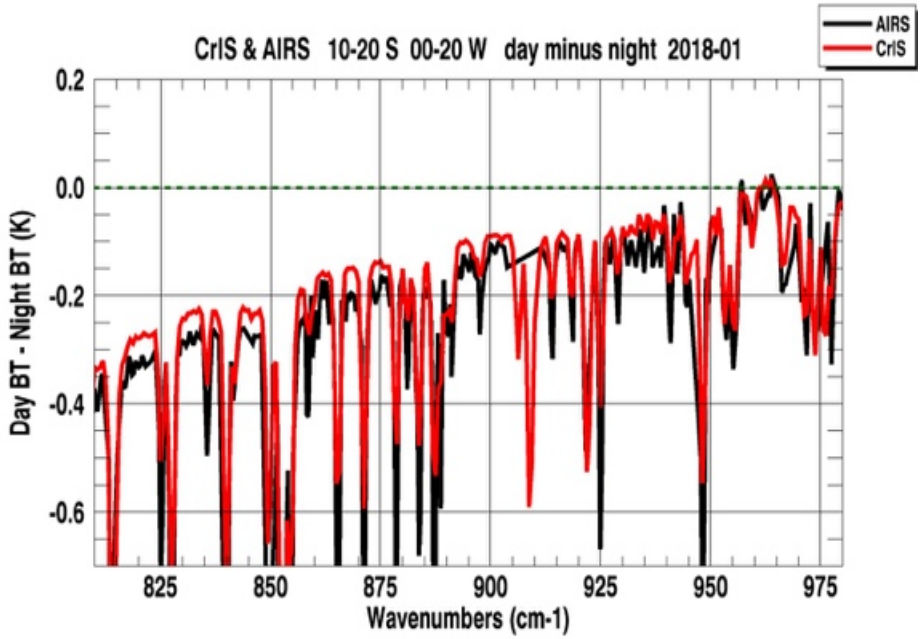


The Indian ocean case has a much steeper slope (dBT ~3 K)

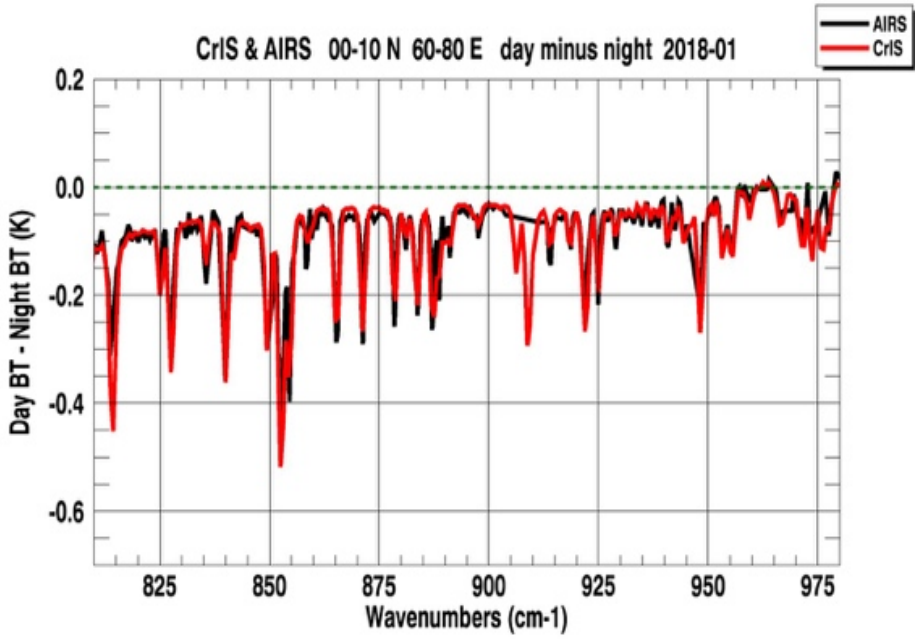
- Indicating ice clouds.

Day-minus-night clouds



In the South Atlantic we have a relatively flat spectrum (dBT ~1 K) for both day and night.

- But there's a relatively steep slope (dBT ~0.3K) in day-minus-night.
- Probably indicating a strong diurnal cycle in clouds here, with more ice clouds in day.



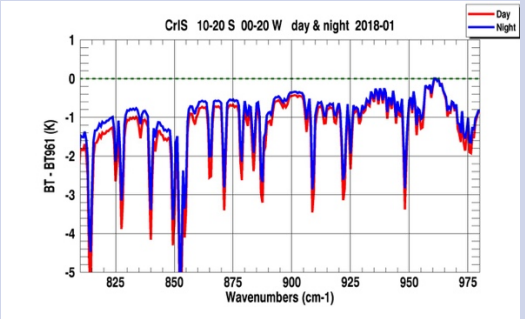
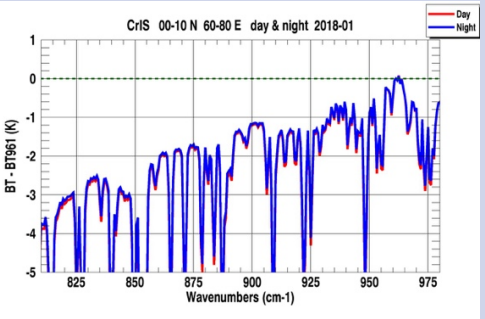
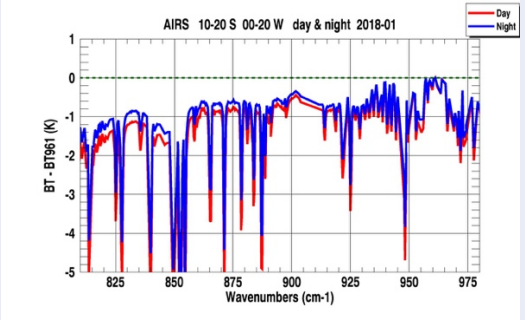
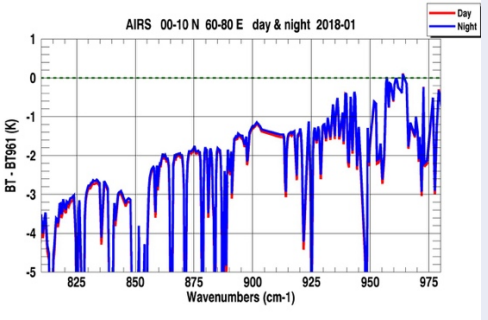
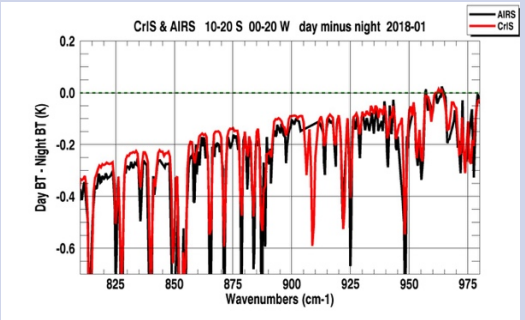
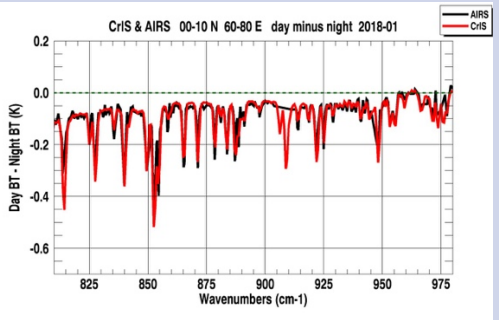
The Indian ocean case has a much steeper slope (dBT ~3 K)

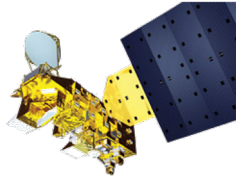
- But there's a shallow slope in day-minus-night (dBT ~0.1K).
- Indicating little difference in cluds between day & night.

Clouds

AIRS and CrIS produce very similar spectra.

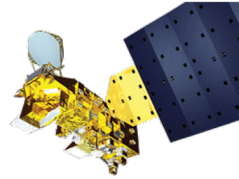
We would draw the same conclusions from the two instruments.

	10-20 S 00-20 W South Atlantic	00-10 N 60-80 E Indian Ocean
CrIS Day & Night		
AIRS Day & Night		
CrIS and AIRS Day-minus-Night		



AIRS Detector Module M-08 A/B

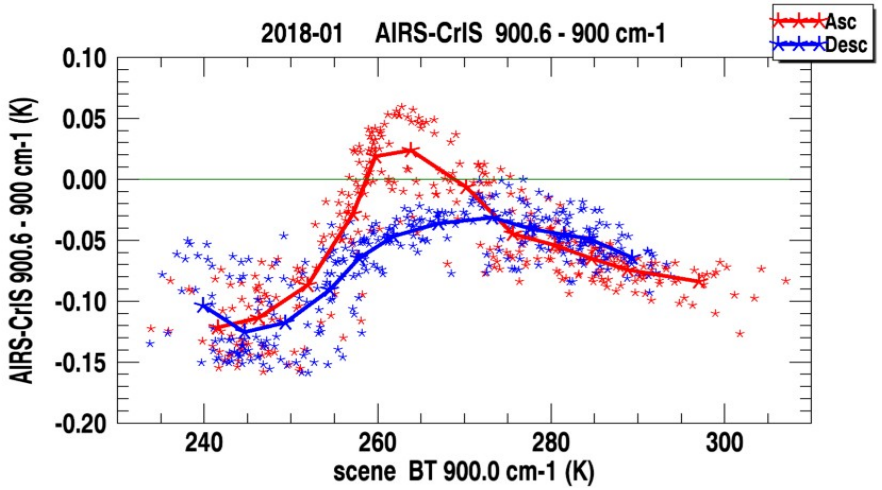
AIRS Module M-08 A/B

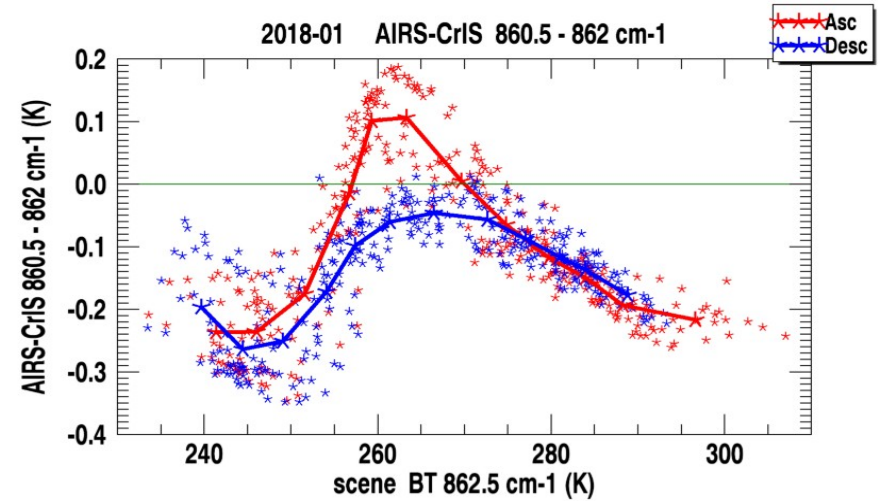


- AIRS has redundant A and B detectors for most channels.
  - Usually we use A+B for sqrt(2) noise reduction
  - Where A or B is bad the other is be used alone.
  - A and B are not equivalent.
  - The differences are clearest in AIRS Module M-08, spanning ~850-900 cm^{-1}.
    - M-08's spectral region is composed mostly of "window" channels, sensitive mostly to clouds and the Earth's surface, not atmospheric absorption by H_2O, CO_2, O_3 or other gases.
    - There is a contribution from the water vapor continuum in this region, which must be taken into account.
- For this comparison we use two pairs of window channels near each end of AIRS Module 8.
  - Because the two channels in each pair are both window channels and the difference in wavenumbers is minimal, they would be expected to give nearly identical results.
- The AIRS channels used near the 900 cm^{-1} end of M-08 are 900.3 cm^{-1} (B-only) and 900.7 cm^{-1} (A-only).
  - CrIS channels at 900.0 and 900.625 cm^{-1} are used as a reference.
- At the 860 cm^{-1} end of M-08 the effect is about twice as large.
  - AIRS channels at 860.8 cm^{-1} (A) and 862.4 cm^{-1} (B) are matched with CrIS channels at 860.625 and 862.5 cm^{-1}.

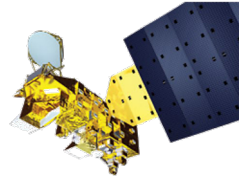
AIRS M-08 A/B: 2 channel pairs

- We see dBT (A-B) (Kelvin) for the 900 and 860 cm^{-1} pairs as a function of scene BT for January 2018.
- The patterns are the same
  - The 860 cm^{-1} pair has about double the magnitude: a range of about 0.4 K.
- We conclude that the same effect is seen throughout M-08.
- The remainder of the discussion here uses the 860 cm^{-1} channel pair because the greater magnitude gives a clearer signal.

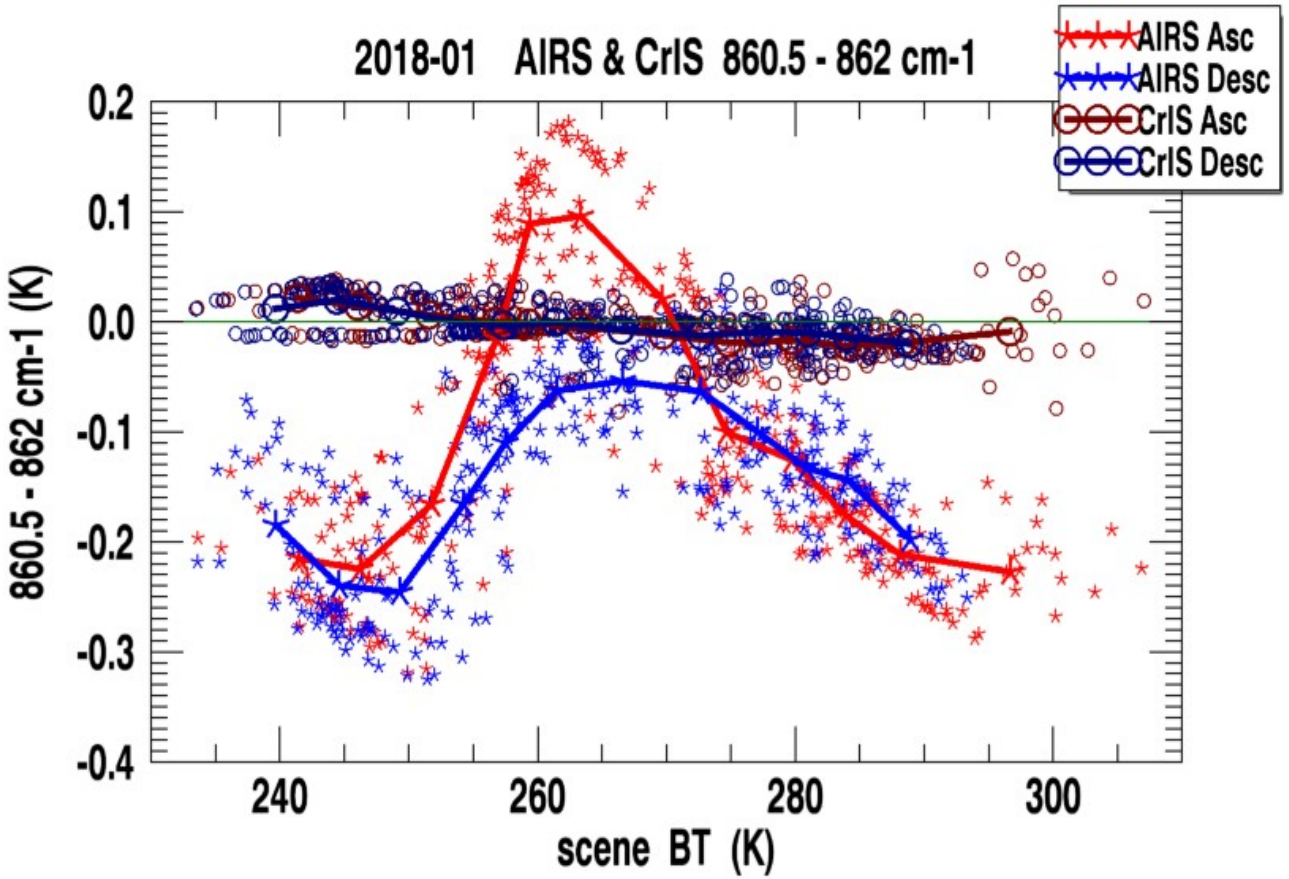




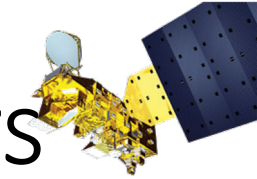
AIRS M-08 A/B: AIRS vs. CrIS



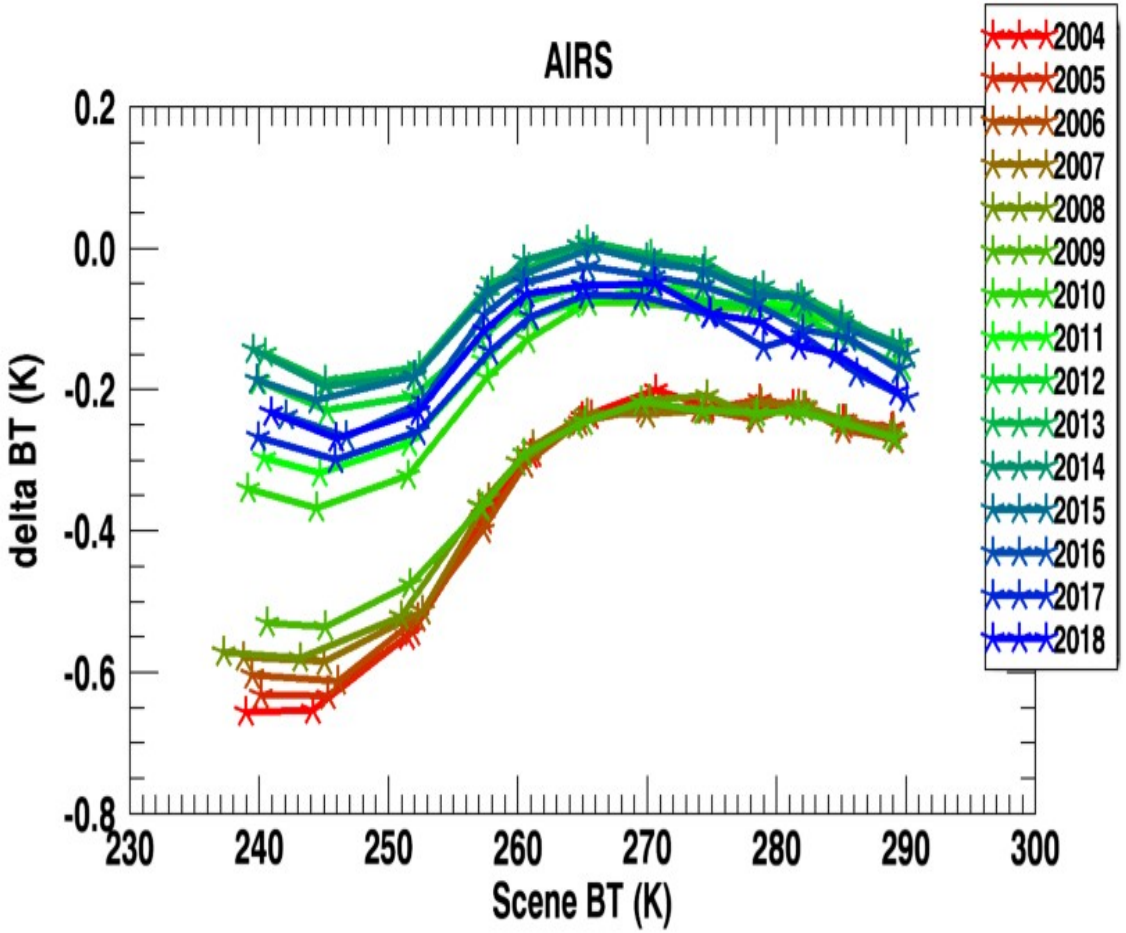
- CrIS data (circles and darker lines) with the AIRS data.
- The CrIS lines are nearly flat.
  - So there's no real diff between 860 & 862 cm^{-1}
- The AIRS differences must be some sort of AIRS instrument artifact.



AIRS M-08 A/B: January night: 15 years



- Night data for January of each year.
- There's a change during 2008.
  - The size of the difference decreased ~2x for the coldest scenes.
  - The decrease is much less for warm scenes.
- This could indicate that the problem is with the cold space views.
- Perhaps there is a small extra signal for Earth views.
  - The effect could get smaller as the scene signal gets larger for hot scenes.



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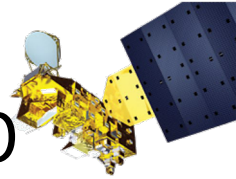
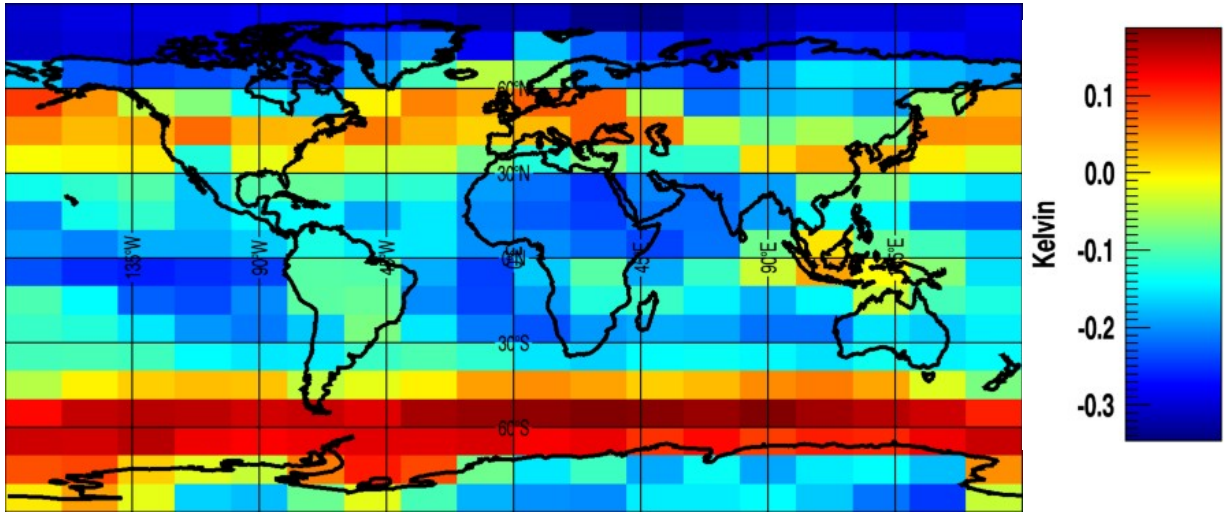
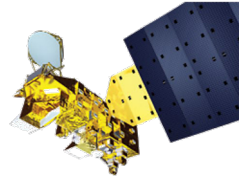
AIRS M-08 A/B: January 2018 day dBT map



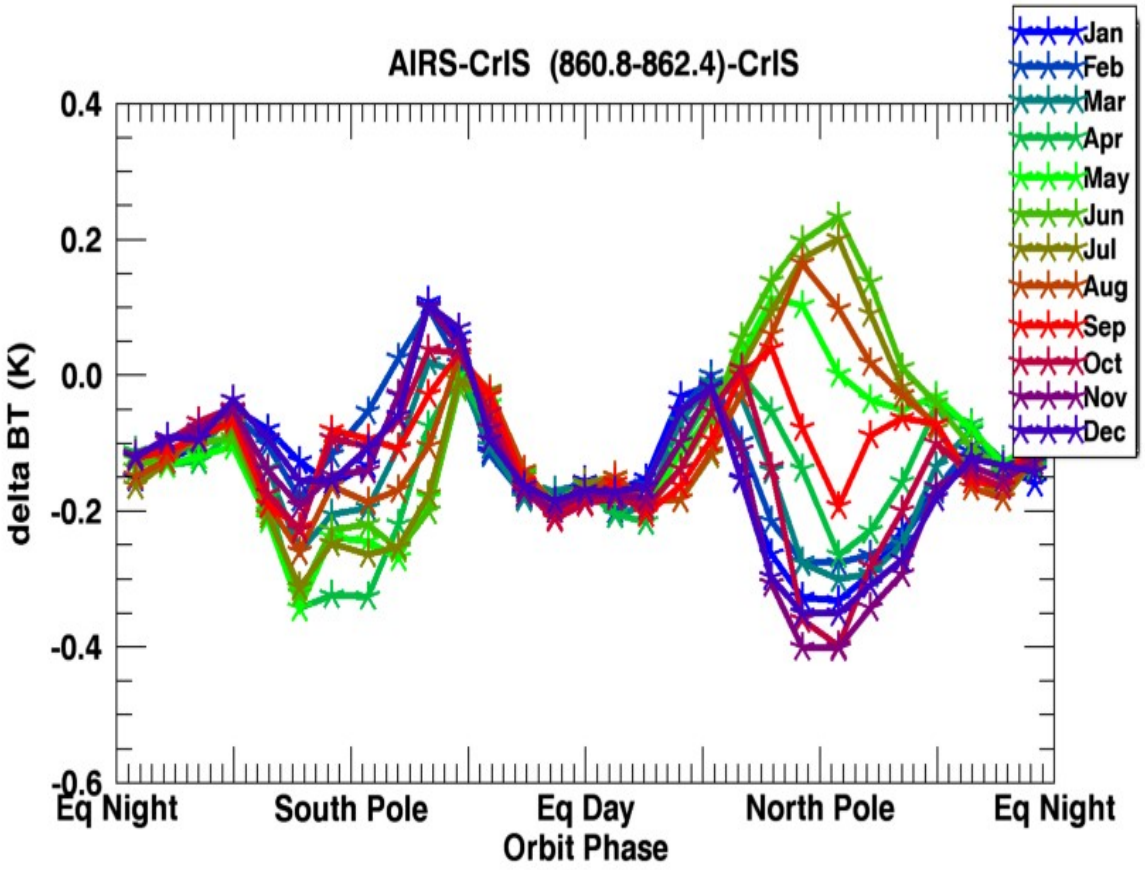
- A map of the double difference of AIRS-CrIS for 860-862 cm^{-1} channel BTs for January 2018 day.
- This is the difference of:
  - $(BT860_{AIRS} - BT862_{AIRS}) - (BT860_{CrIS} - BT862_{CrIS})$
  - Subtracting the CrIS difference removes the small geophysical variation, leaving only AIRS instrument artifacts.
- There's a strong zonal structure with a prominent feature near 55 S latitude.
  - This might be related to the climate conditions here
    - well illuminated ice & polar clouds
  - It could be an artifact related to the orbital position.
  - Perhaps stray light can enter AIRS because of how it is oriented at this point in its orbit.



AIRS M-08 A/B: Seasonal pattern vs phase

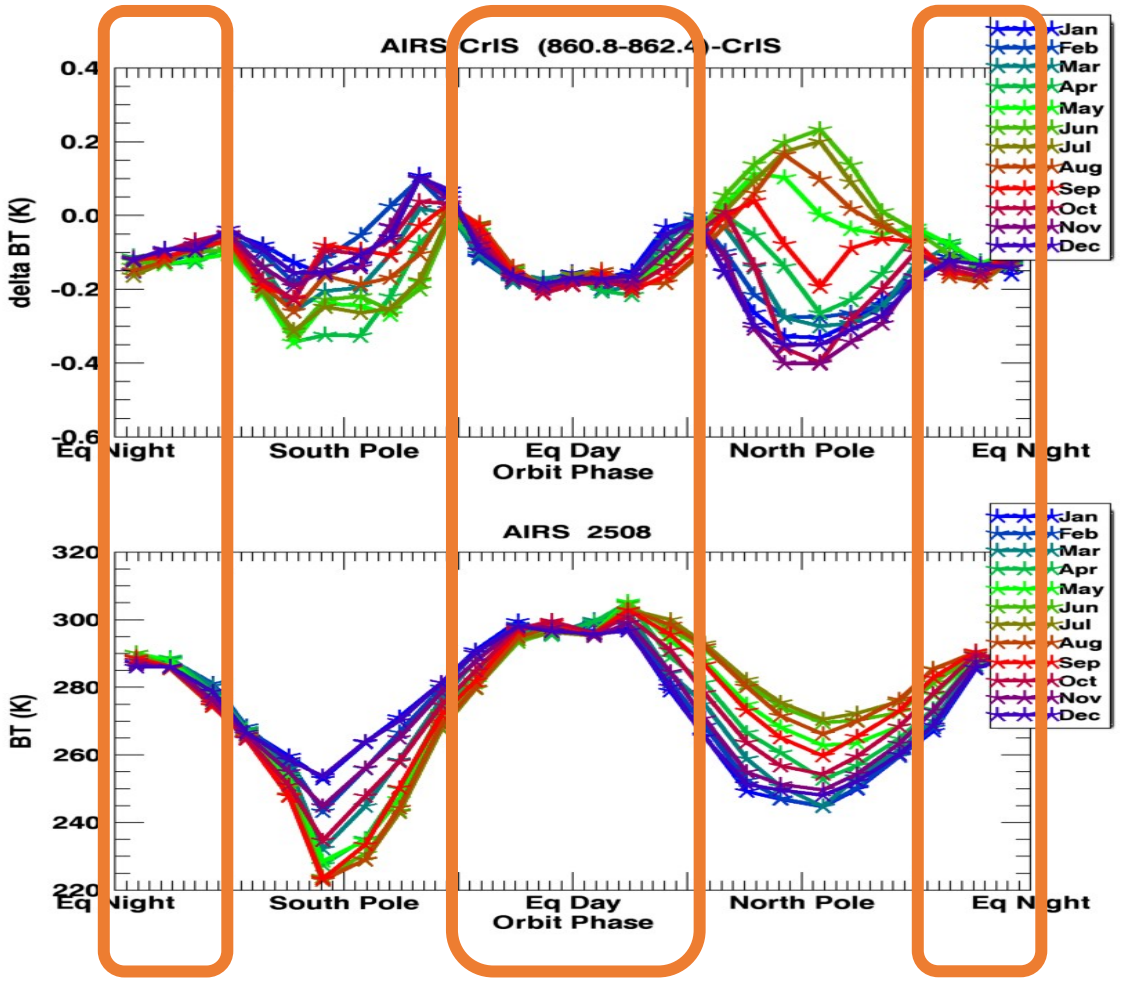


- Here we see the differences between the AIRS A-side and B-side channels compared to their CrIS references as a function of orbital phase for each month of 2017.
  - There's a different color for each month.
- Near the equator all months have almost the same pattern.
  - Day & night
- At high latitudes there's a large seasonal variation.
  - The variation is larger at the north pole
  - The two poles are out of phase



AIRS M-08 A/B: Seasonal pattern vs phase

- We can compare the equatorial zones to a window channel.
  - Showing 2508 cm^{-1}
- They compare well in the tropics
- It is more obvious with a sign flip



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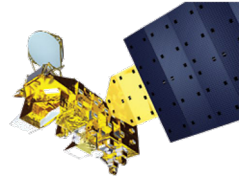

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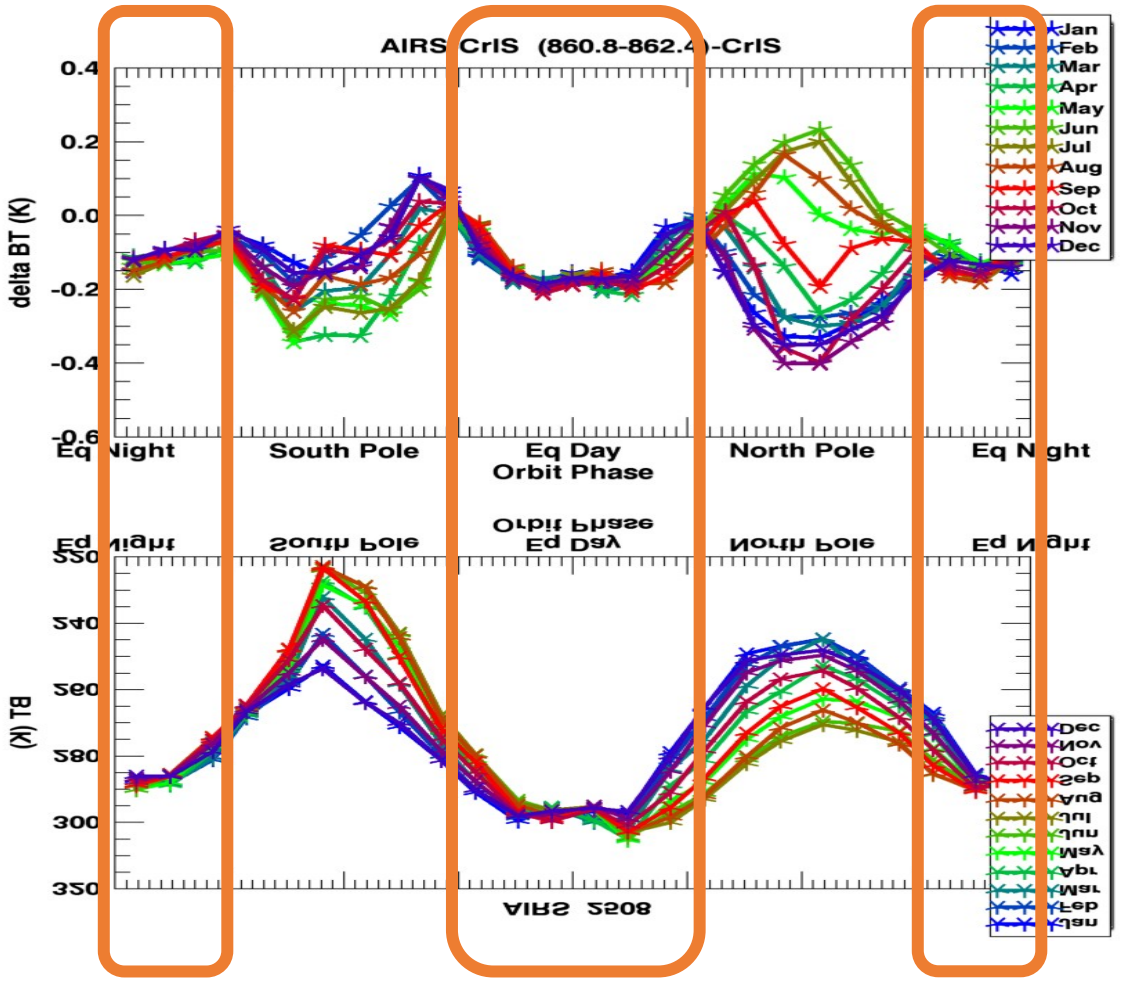
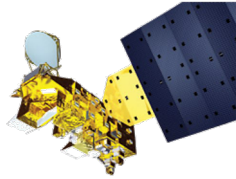
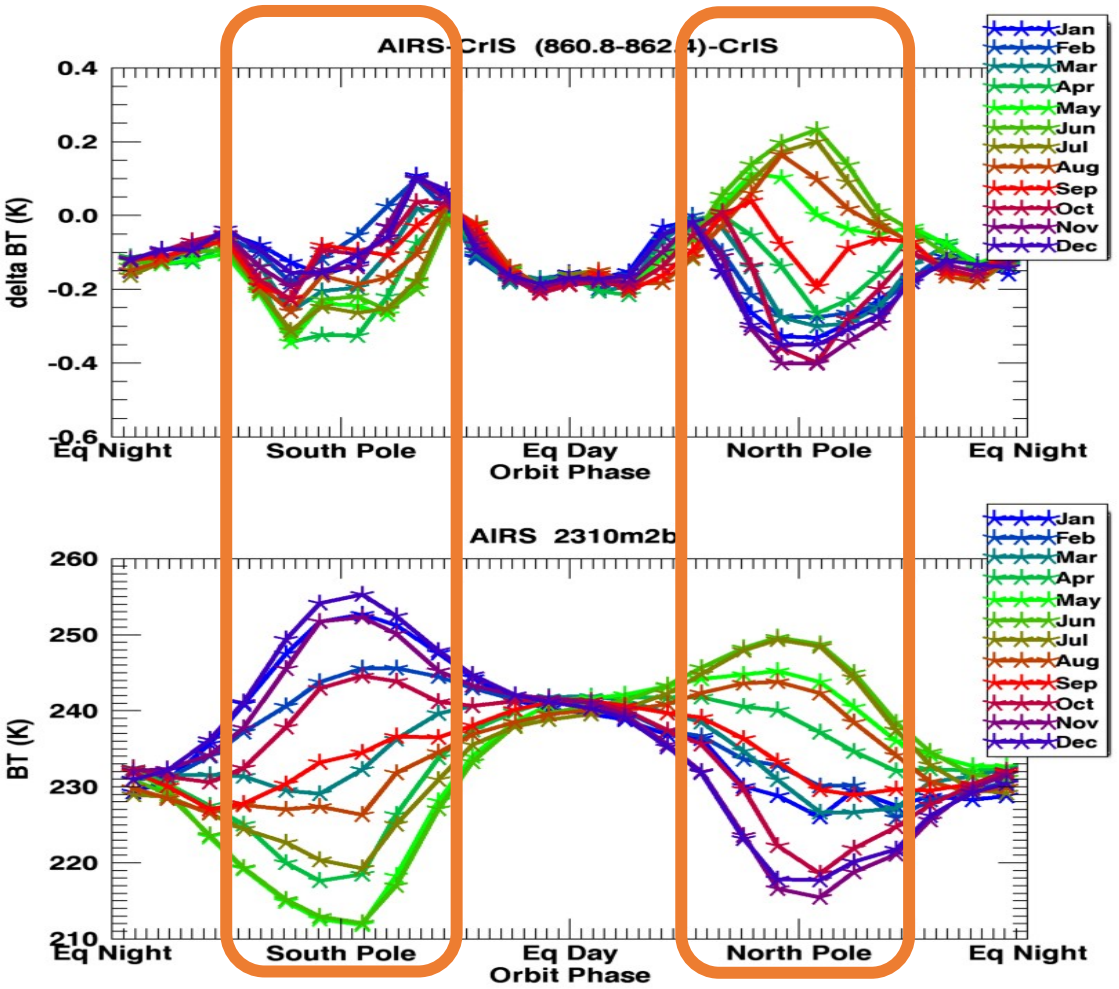
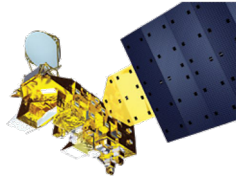


AIRS M-08 A/B: Seasonal pattern vs phase



- We can compare the polar zones to a stratospheric channel.
  - Showing 2310 cm^{-1}
  - Peak sensitivity is near 20 hPa
- They compare well around the north pole
  - Less well around the south pole
- Perhaps some weighted average over a broad band including window and stratospheric channels would duplicate the A/B difference pattern.
  - This could indicate a light leak affecting A and B detectors unequally.

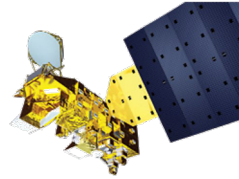




Right/Left Asymmetry

AIRS Calibration Coefficient Evaluation

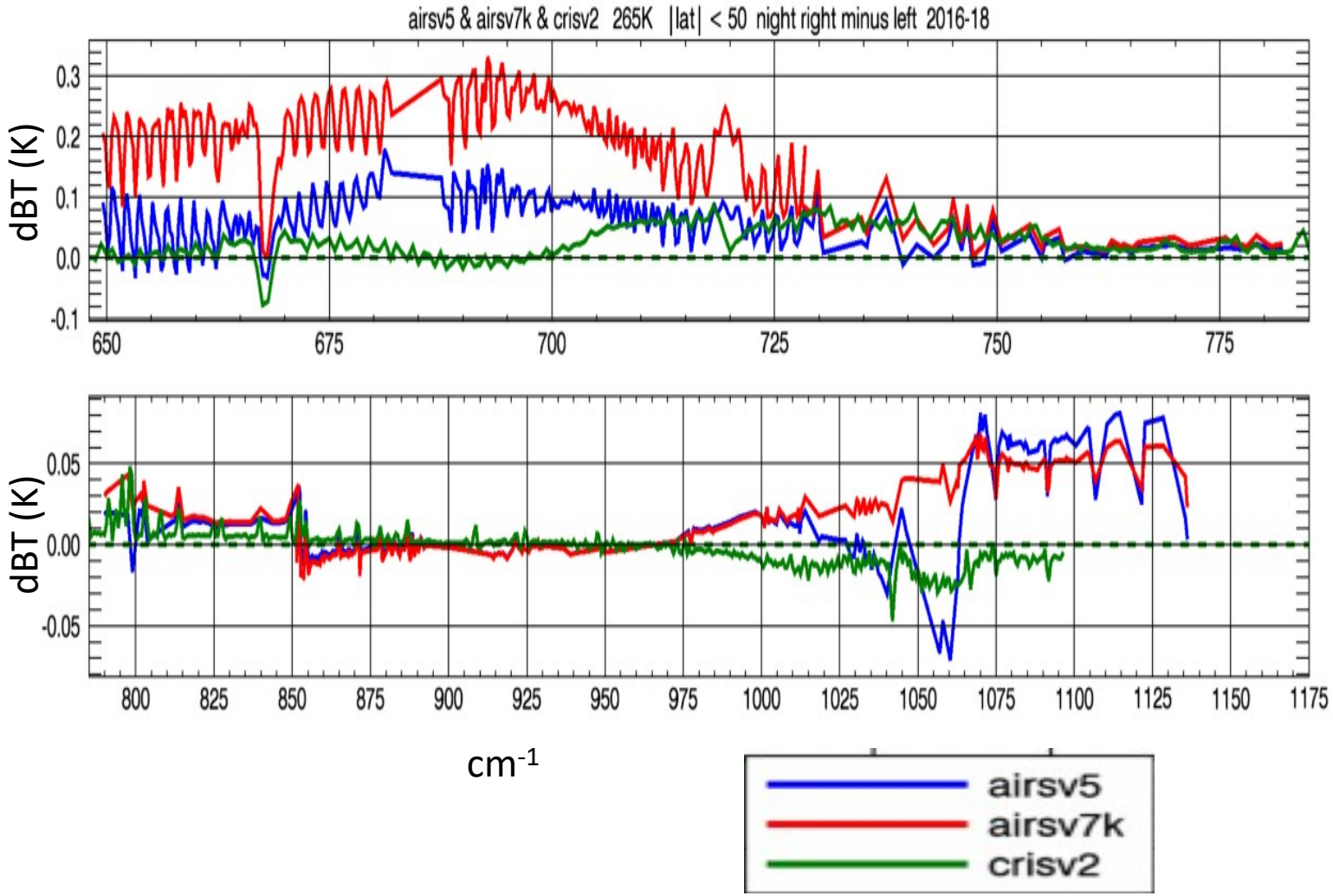
Right/Left Asymmetry



- AIRS and CrIS should both see similar signals when they look to the left and to the right.
  - There can be a small bias from diurnal cycles – both instruments “see” a later local time on the right compared to the left.
    - For tropical descending data this is roughly 2:00 AM vs 1:00 AM
    - The effect is small
- We use right-minus-left differences to look at AIRS vs CrIS
- We also look at the existing AIRS v5 calibration vs the proposed v7k

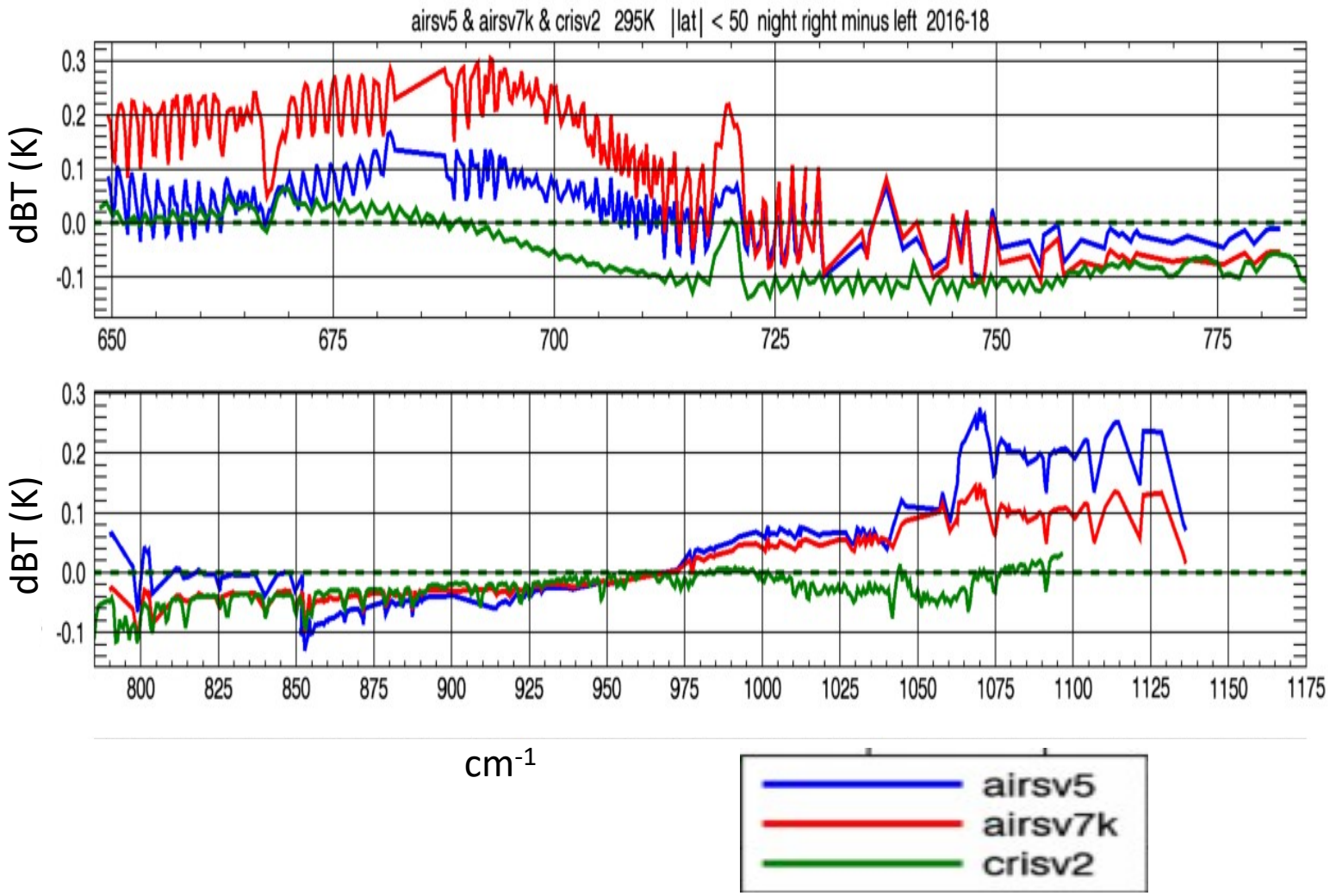
Right-minus-left longwave 265 K scenes

- Right-minus-left for cool scenes (BT961 = 265 K)
- CrIS generally is closer to zero
- Comparing AIRS versions:
  - Bias is larger for v7k ~700 cm^{-1}
  - Discontinuity at 850 cm^{-1} is about the same
  - V7k removes an odd feature near 1050 cm^{-1}



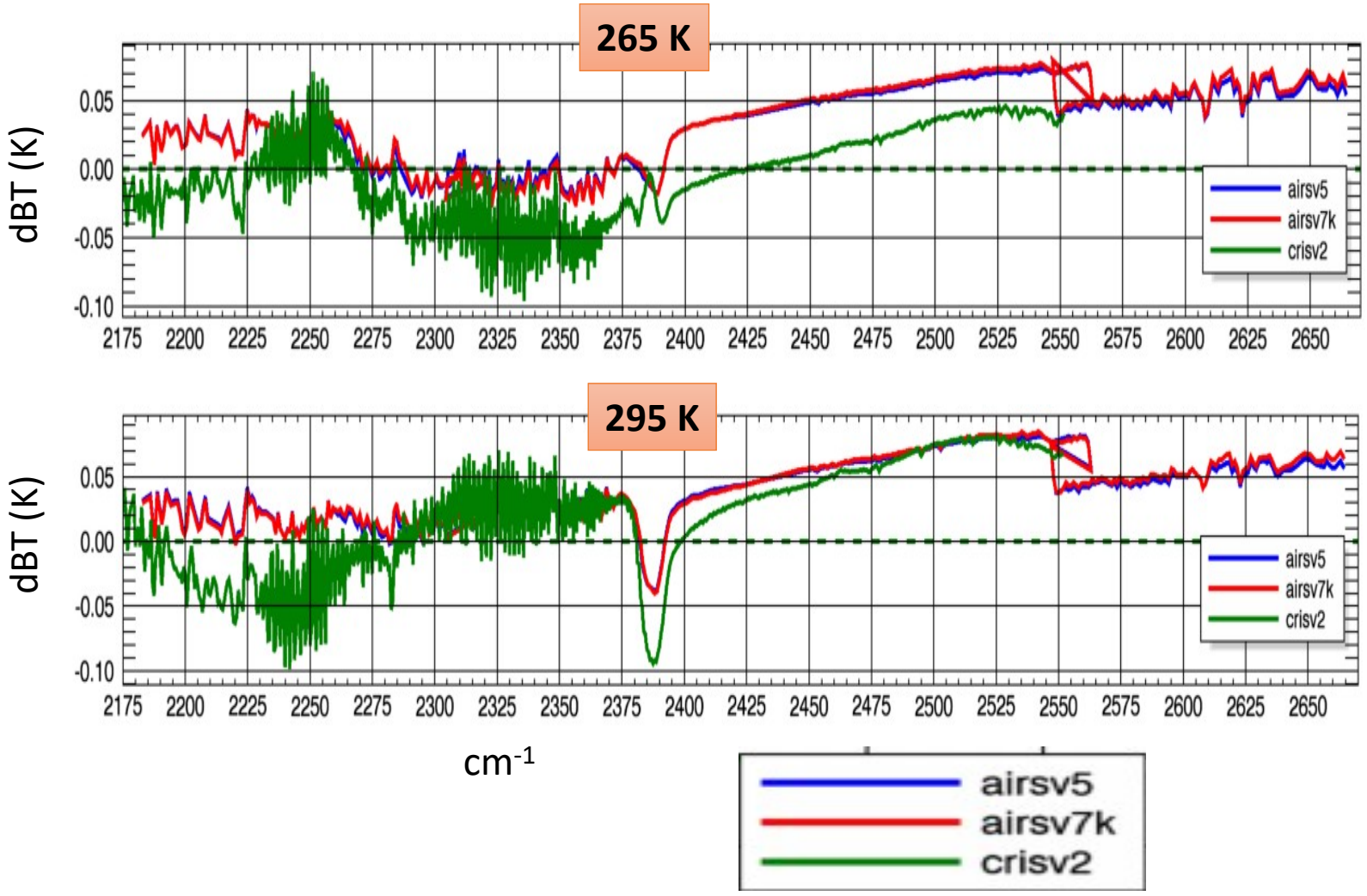
Right-minus-left longwave 295 K scenes

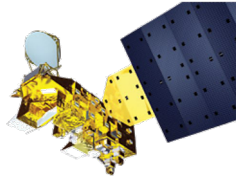
- Right-minus-left for warm scenes (BT961 = 295 K)
- CrIS generally is closer to zero
  - But not ~750 cm^{-1}
- Comparing AIRS versions:
  - Bias is larger for v7k ~700 cm^{-1}
  - Discontinuities at 850 & 910 cm^{-1} are improved by v7k
  - V7k decreases the bias around 1100 cm^{-1}



Right-minus-left shortwave

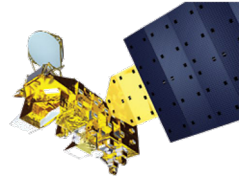
- CrIS has ringing and scene-dependent biases 2175-2400 cm^{-1}
  - Ringing is likely from Doppler
  - Biases could be from influence of BT in the warmer part of the band
- AIRS has a discontinuity around 2555 cm^{-1}
- Comparing AIRS versions:
  - There is no significant difference between v5 and v7k





Shortwave

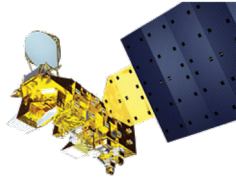
Shortwave



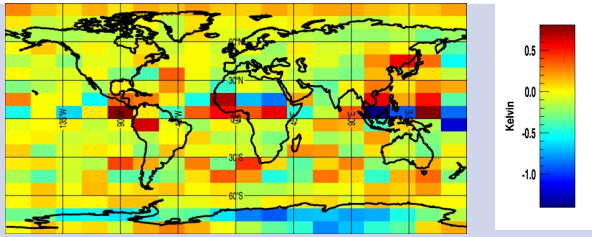
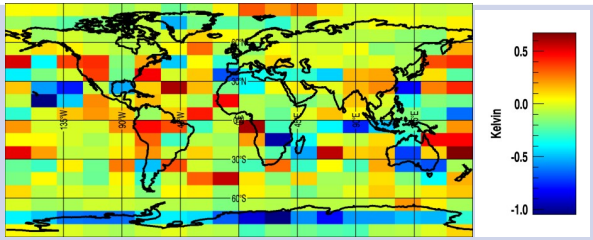
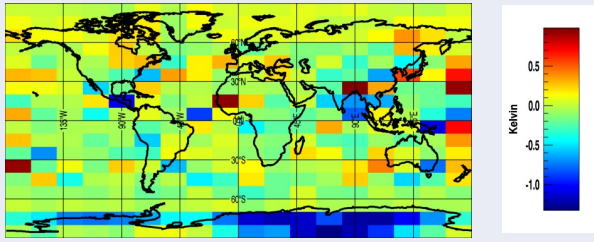
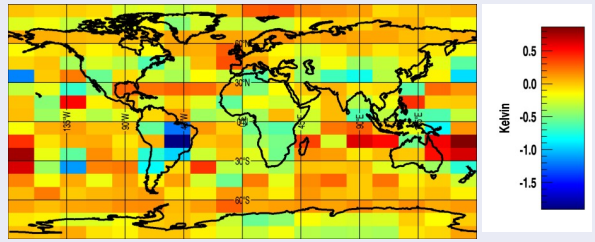
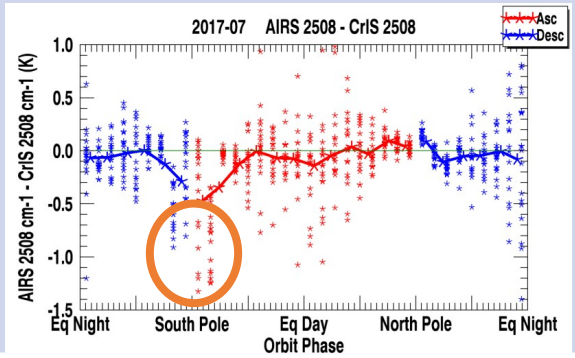
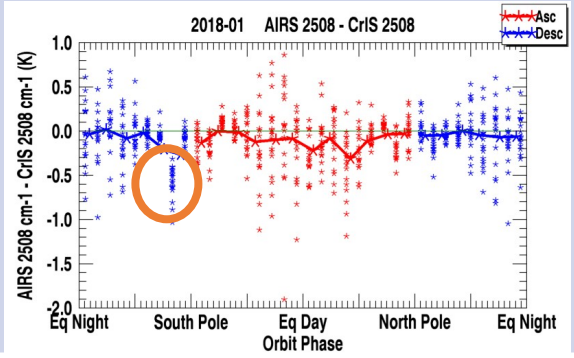
- Over the AIRS mission, the brightness temperature observed in the shortwave band has drifted relative to the other bands (up to 5 K at 2616 cm^{-1} at 200 K) for isolated very cold clouds embedded in warm regions.
- The current StratRad product does not isolate these scenes but can help our understanding of the shortwave band more generally.
- We compare the AIRS channel at 2508.1 cm^{-1} with the corresponding CrIS channel 2508.125 cm^{-1}.
  - To include seasonal effects, we look at data for July 2017 and January 2018

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
Atmospheric Infrared Sounder

Shortwave: AIRS-CrIS at 2508 cm^{-1}

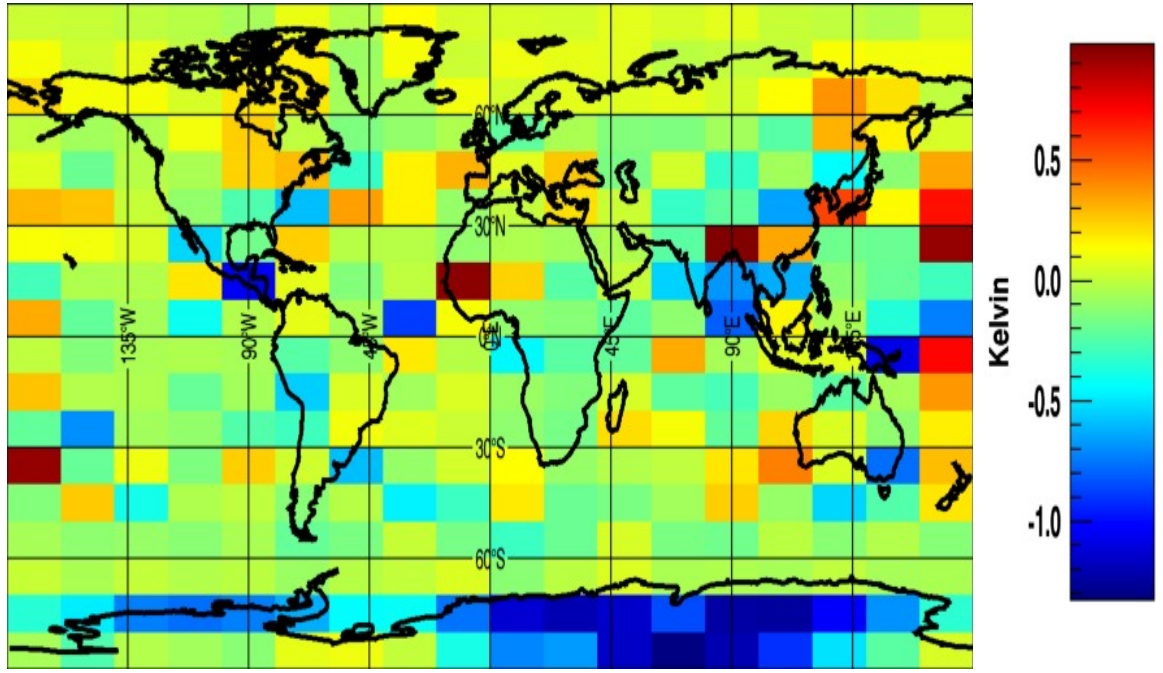


- Most variation looks random – just the result of sampling differences.
  - In some cases AIRS happened to see warmer spectra than CrIS in a given area over the course of this month.
  - In other cases CrIS was warmer.
- The last row shows the BT difference as a function of orbital phase.

	July 2017	January 2018
Desc Map		
Asc Map		
BT diff by orbital phase		

Shortwave: AIRS-CrIS at 2508 cm^{-1}

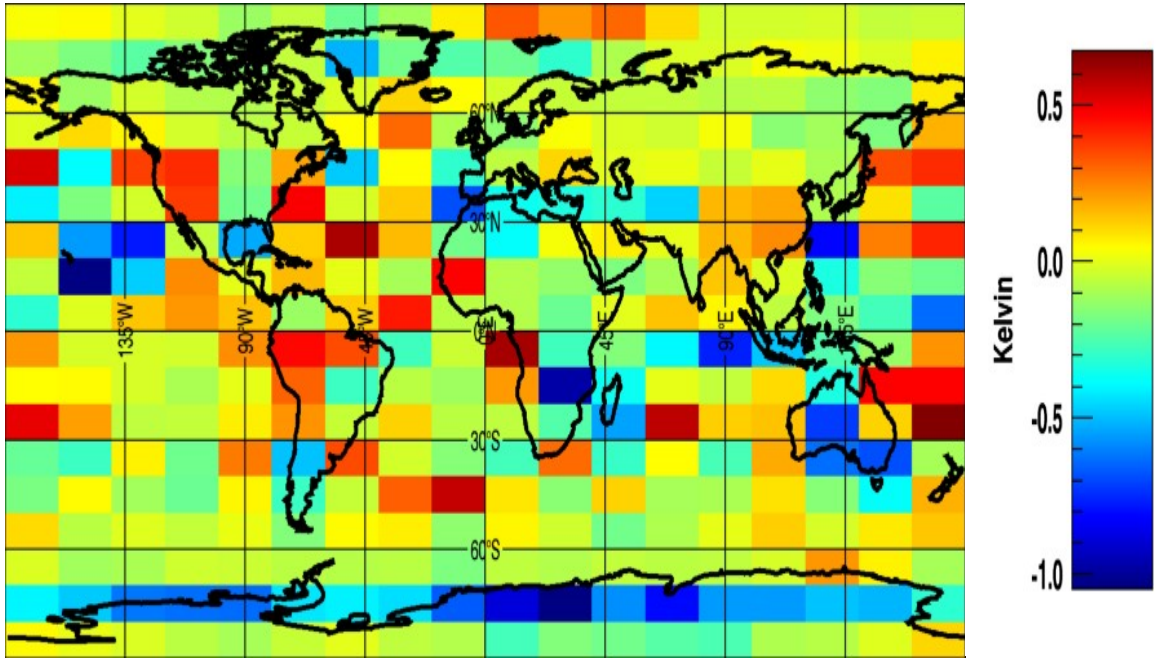
- The one clear coherent area of difference is ascending July in east Antarctica.
- This is a very cold area in austral winter, <~ 220 K
  - AIRS is ~1 K colder here.
- It could be a linearity problem with one instrument.
  - Perhaps CrIS can't respond to such cold scenes.
  - Perhaps AIRS overreacts somehow.



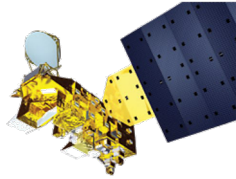
July 2017 ascending

Shortwave: AIRS-CrIS at 2508 cm^{-1}

- There's a stripe in the band from 70-80 south latitude.
  - AIRS is ~ 0.5 K colder than CrIS.
- The stripe corresponds to a particular point in the sunlit part of the orbits.
  - It could be a place where sunlight bounces off of the ice and into the space or earth view port of an instrument.

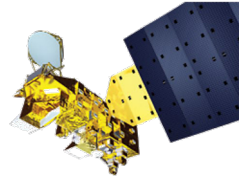


January 2018 descending



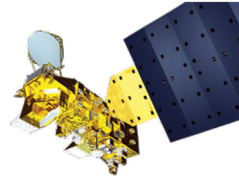
Conclusions

AIRS/CrIS artifacts documented here



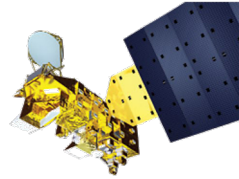
Artifact	Max magnitude	Wavenumber range (cm^{-1})	Temperature dependence	Orbital dependence	Seasonal dependence	Long-term change	Suspected cause
AIRS M-08 A/B diffs	0.6 K	850-910	Larger at cold BT	strong	Strong at poles	~0.4 K around 2008	Broadband upwelling light leak
Right/Left longwave	0.2 K	650-750	700-750 cm^{-1}	Unknown	Unknown	Unknown	Unknown
AIRS M-08 ends Right/left	0.1 K	850, 905	V7k eliminates at high BT	Unknown	Unknown	None	Polarization plus unknown
Right/Left ozone band	0.2 K	1000-1150	Parts larger at high & low BT	Unknown	Unknown	Increasing from launch	Polarization
Right/Left shortwave strat	0.05 K	2175-2375	Yes	Unknown	Unknown	Unknown	Doppler, signal spread
Shortwave cold Antarctic	1 K	2000-2600?	Only BT < 230 K	N/A	Only detected austral winter	No	Linearity
Shortwave latitude stripe	0.5 K	2000-2600?	Unknown	Very local	Strong	Unknown	Solar light leak

Conclusions

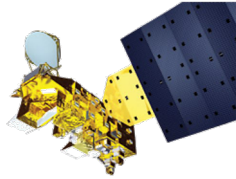


- We have illustrated some of the benefits of the StratRad approach.
- The investigations here contain important clues that might lead to full understanding and perhaps correction of instrument anomalies.
  - But just the material here is enough to help users know, for example, when and where to use AIRS M-08 channels with caution, and to avoid both AIRS and CrIS shortwave for November and December near 60 degrees South.
- We also show climate/weather signatures that show clearly in both AIRS and CrIS StratRad data.

Further Work



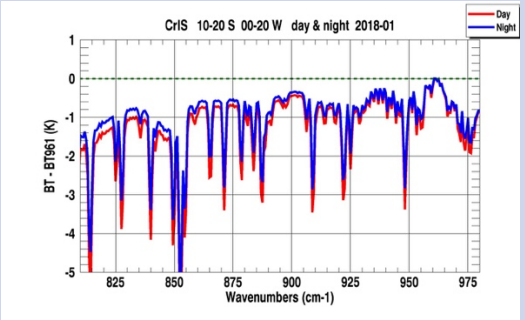
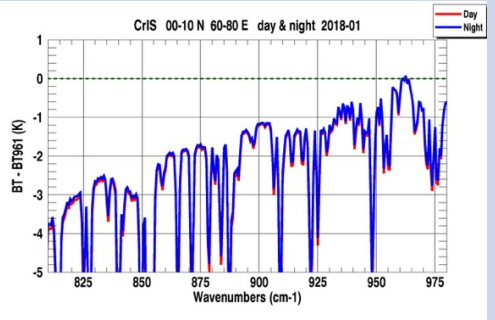
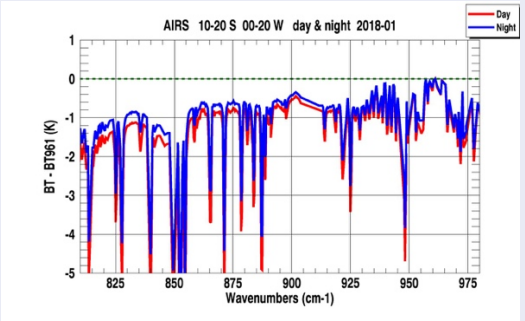
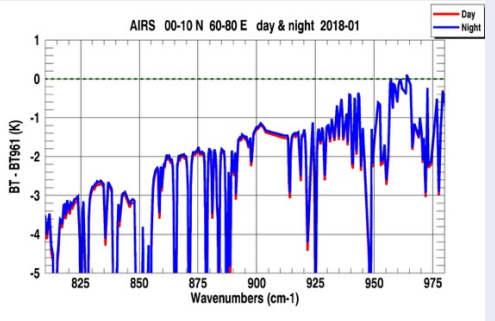
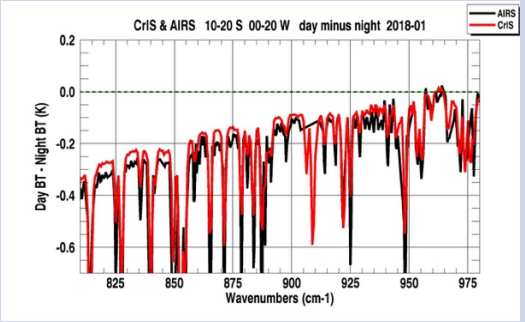
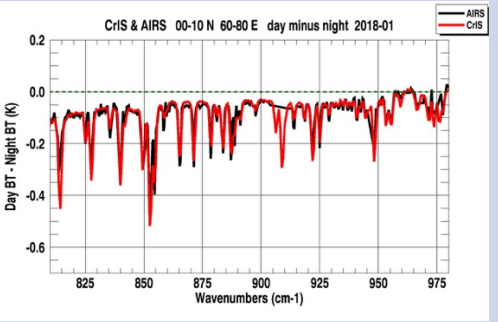
- This product will be evaluated for instrument monitoring.
- The StratRad product is being used to evaluate candidate calibration modifications for the upcoming AIRS version 7 release, including the proposed V7k.
  - By retroactively backing out the old V5 calibration and applying V7 to the averaged StratRad product we have the benefit of large amounts of V7 data without a large processing campaign.
- Variants of the StratRad product will be needed to characterize some artifacts fully, and also for climate work. Longitude is the least important of the current dimensions, so we plan to make products which replace longitude with binning on:
  - Scene homogeneity
  - Fine-grained scan angle
  - Cloud amount and thermodynamic phase; perhaps even cloud height, cloud overlap, and cloud microphysics
  - FOV number and sweep direction (CrIS only)
- Versions of the product should also be produced with AIRS Level-1C and eventually with AIRS resampled to CrIS SRFs.
- This approach can also be applied to:
  - IASI
  - Microwave sounders
  - AIRS's Visible/Near-Infrared channels
  - Perhaps imagers

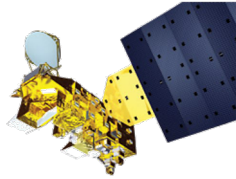


Backup material

Clouds

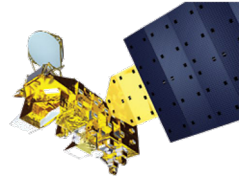
- For these figures all spectra are differences from BT961 to make the shapes clearer. Without this normalization, random biases from different sampling would dominate.
- AIRS and CrIS produce very similar spectra.
  - We would draw the same conclusions from the two instruments.
- In the South Atlantic we see a relatively flat spectrum (dBT ~1 K) for both day and night
  - probably indicating mostly liquid clouds.
- The Indian ocean case has a much steeper slope (dBT ~3 K)
  - indicating ice clouds.
- Interestingly, the South Atlantic case has a relatively large slope in the difference between day and night.
  - This probably shows a strong diurnal cycle in clouds here, with more ice clouds in day than night.

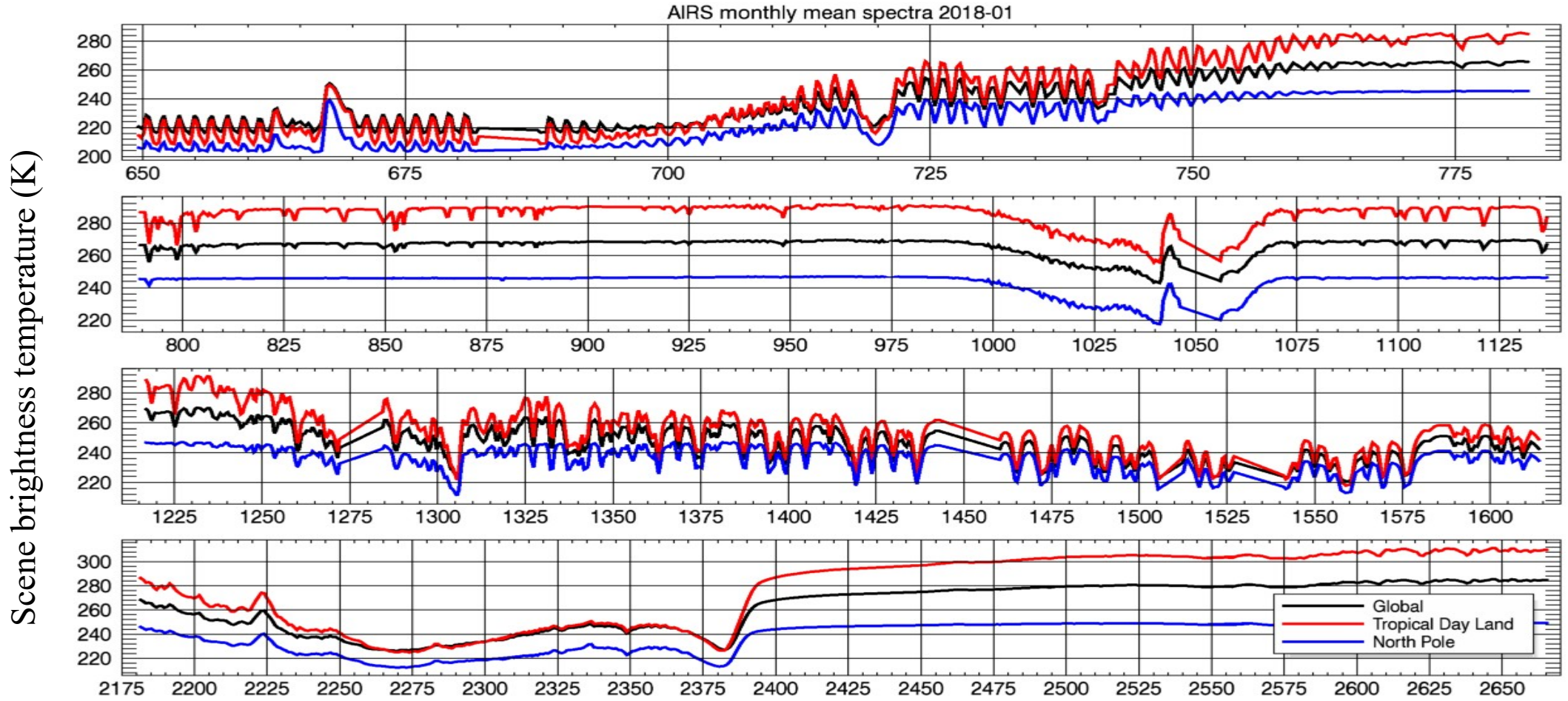
	10-20 S 00-20 W South Atlantic	00-10 N 60-80 E Indian Ocean
CrIS Day & Night		
AIRS Day & Night		
CrIS and AIRS Day-minus-Night		



Sample Visualizations

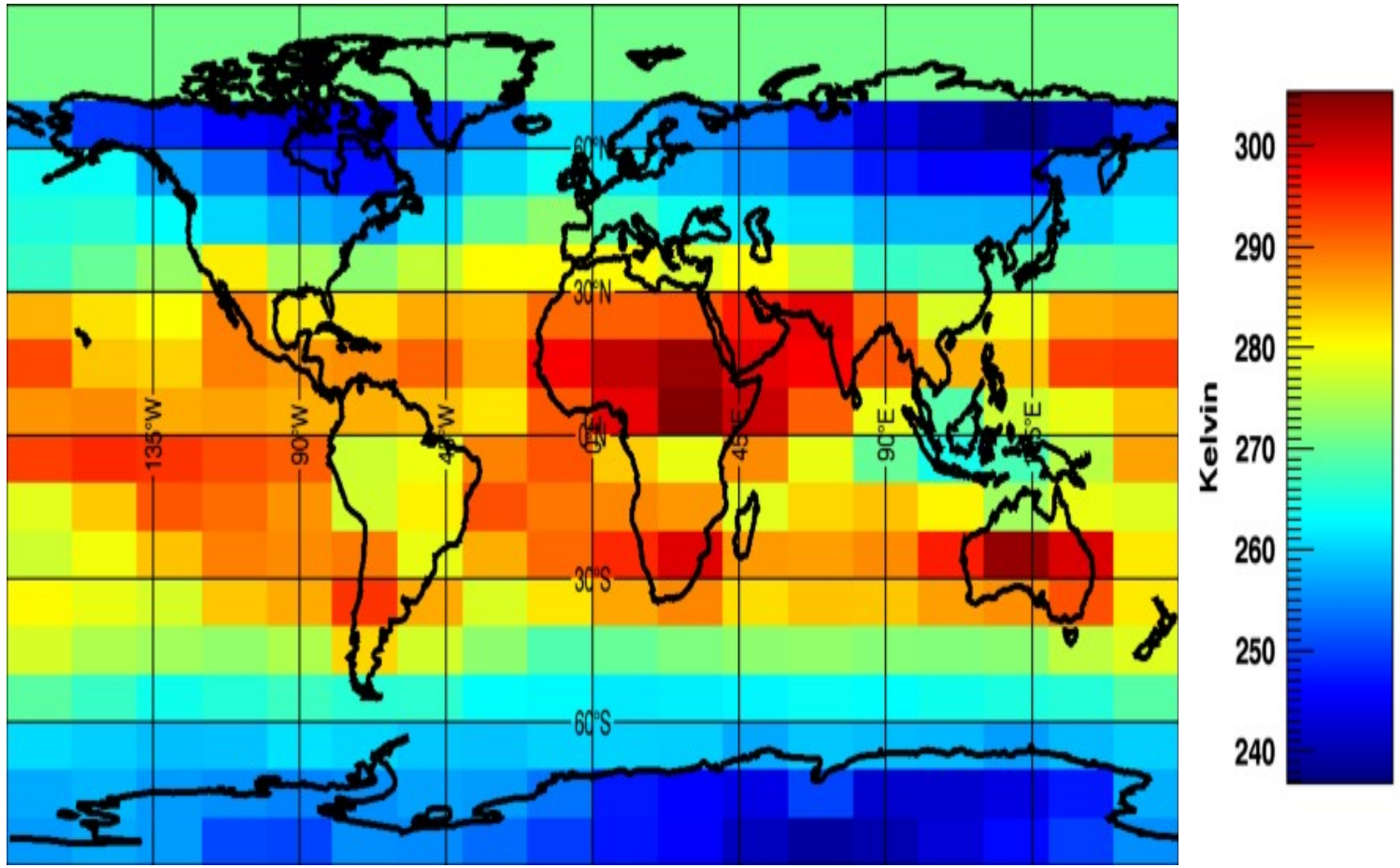
Sample monthly average spectra



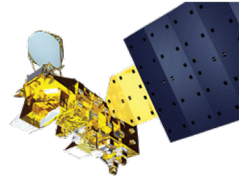


Sample visualization: global BT maps

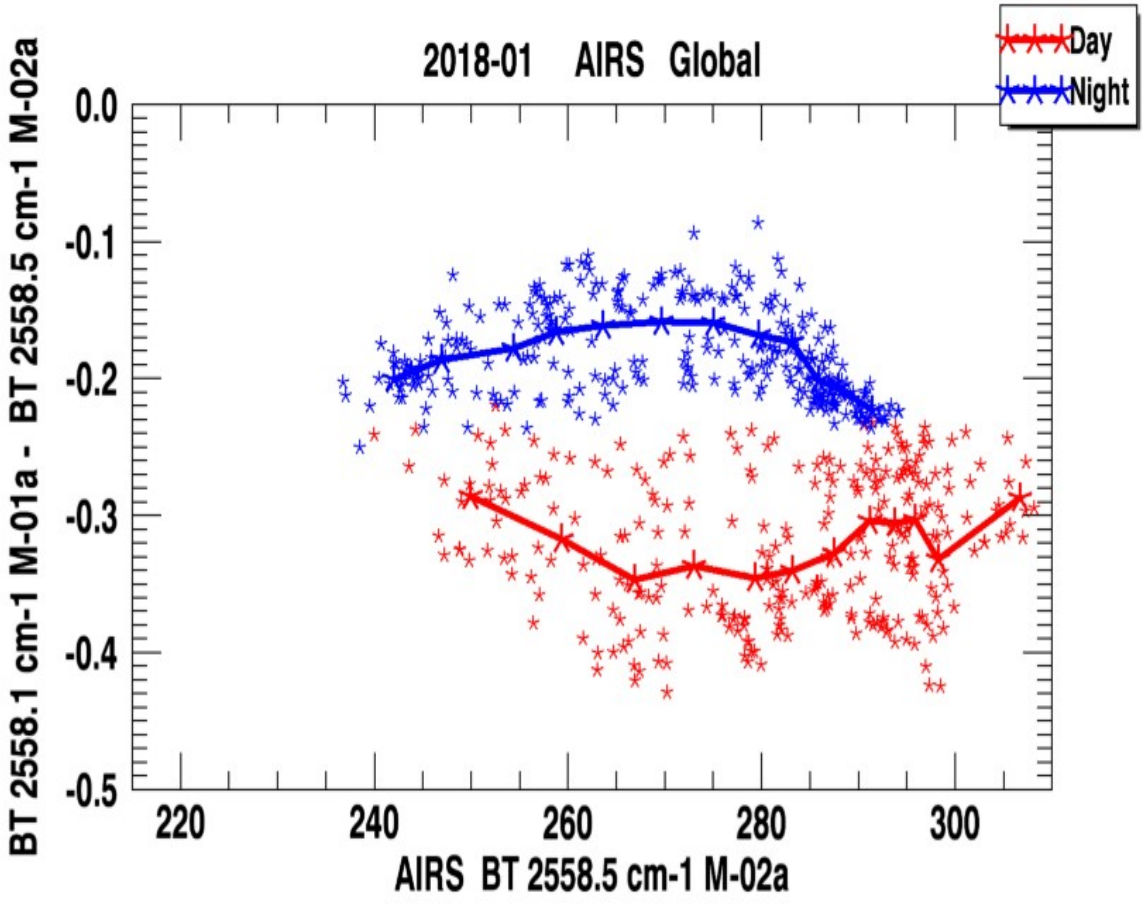
- *AIRS BT map daytime January 2018 1231 cm^{-1}*
- *There are hotter BTs in the tropics, especially deserts.*
- *Variability in window BT within the tropics is associated with amount and type of cloud cover more than with surface temperature.*
- *There is green filler in the northern-most two rows because there is no data in January with the sun above the horizon for 70-90 degrees north latitude.*



Sample visualization: BT diffs vs scene BT

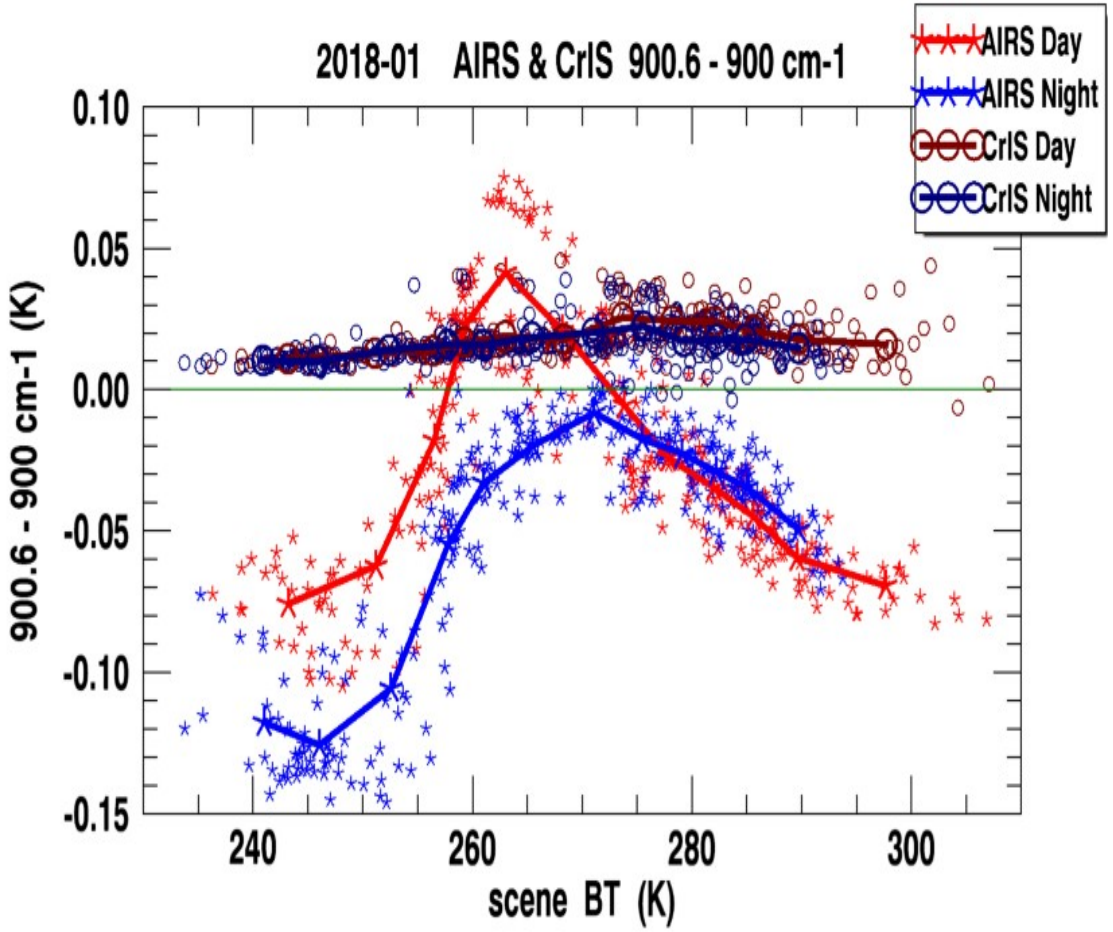


- Artifacts can vary strongly with scene BT, so this is the most important dependence to document.
- BT is not a dimension in the StratRad product, but we can easily find the BT for any subset for any channel.
- This figure shows data from the January 2018 monthly file for the AIRS instrument.
  - Data was averaged over the land/sea and angle dimensions.
  - The day/night dimension was used to separate the data into two sets.
  - Each lat/lon box was treated as an independent data point and the mean BT was calculated for each of the two selected channels.
  - The smaller stars in figure 3 represent this data directly as a scatter plot of the BT difference between the two channels (dBT) as a function of the BT on one of the channels
- In addition, to provide a visual summary, we sort the data by BT on the channel used as the X axis and divide it into quantiles.
  - For each quantile we calculate the mean of BT and dBT.
  - The larger, connected stars represent these means.
  - This summary is used to combine such sets into more complex visualizations



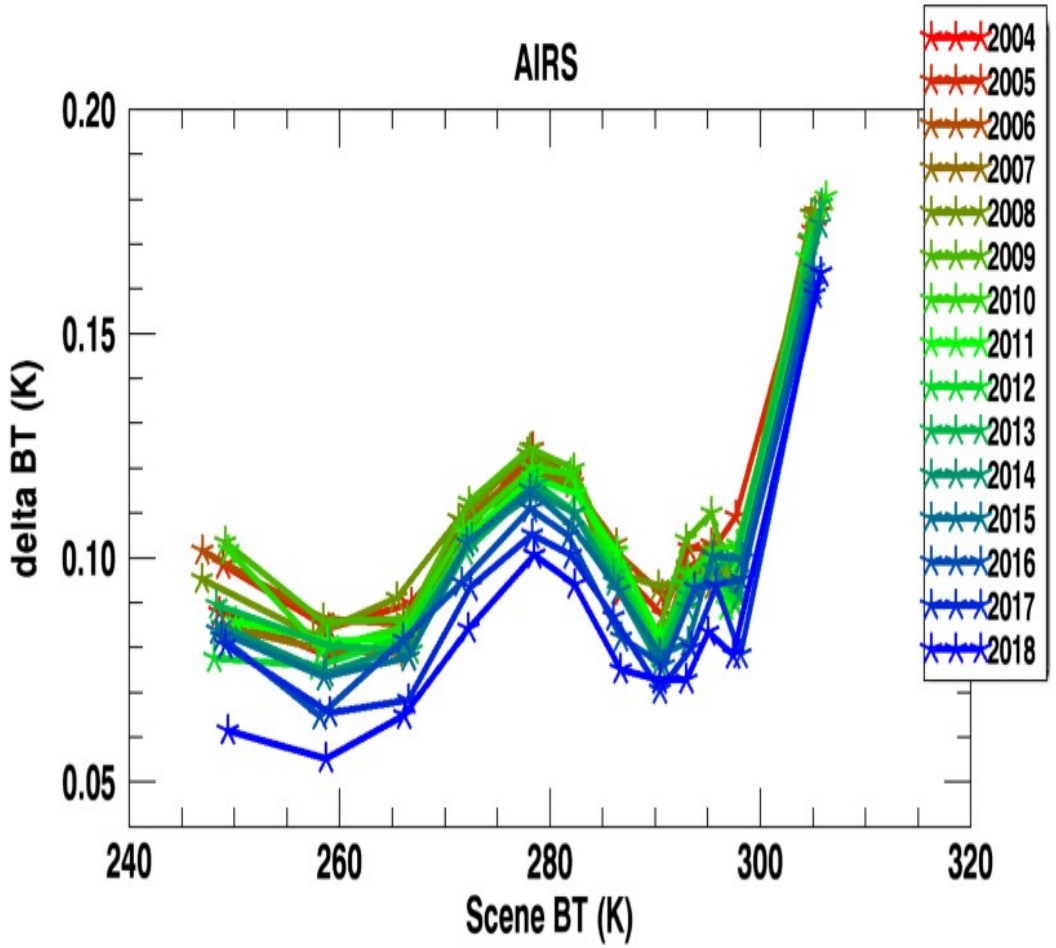
Inter-instrument comparisons

- For some AIRS channel pairs it is useful to compare to CrIS.
  - Emissivity effects, etc. will give the same diffs for CrIS and AIRS.
  - Instrument problems will give different patterns.
- The figure shows the BT difference for matched pairs of channels for AIRS and CrIS.
  - AIRS differences are bright red and blue with stars.
  - CrIS is in darker colors with circles.
  - AIRS looks suspicious.

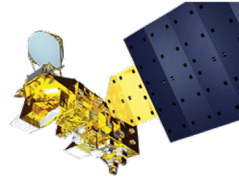


Trends

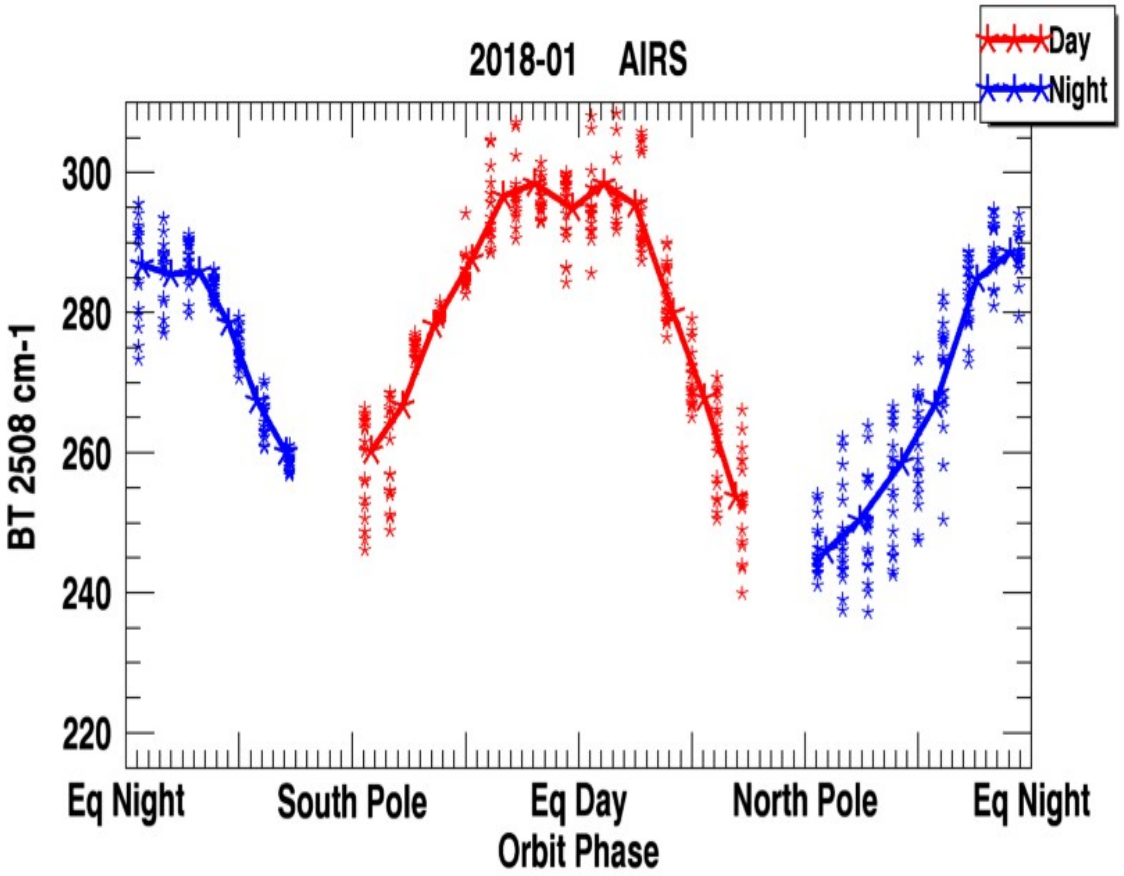
- We look for changes in the AIRS instrument over its 16 years of operations.
- Visualizing channel differences for different years shows how large these effects are and when they happened.
- Take the quantile data from different years and combine it.
  - Red-to-green-to-blue for different years.
  - Separate plots for day and night.
- The figure shows the scene BT vs. dBT for a pair of AIRS channels.
  - 2554 cm^{-1} channels on different detector modules
  - The difference is fairly constant over the years
  - But the difference is getting less positive in recent (bluest) years.
- Similar plots of the twelve months in a year show the seasonal cycle of these differences.



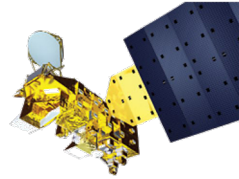
Sample visualization: scene BT vs orbit phase



- Scene BT at 2508 cm^{-1} vs. orbital phase for January 2018.
- Scenes are warmest near the equator and coldest at the poles
  - particularly whichever pole is in winter.
- Day is warmer than night
  - especially over land (esp. desert)
  - especially for shortwave channels, which see reflected solar light.

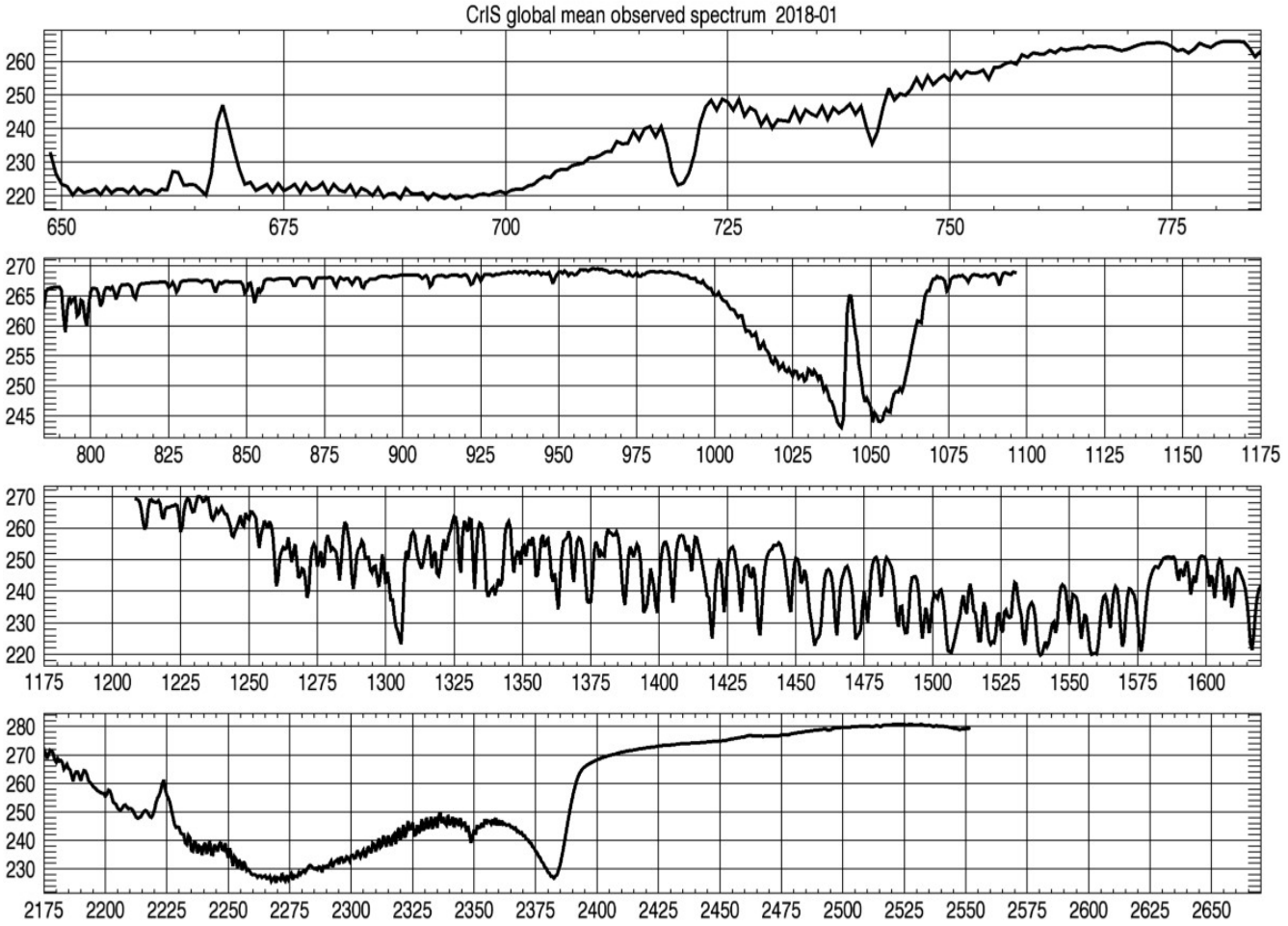


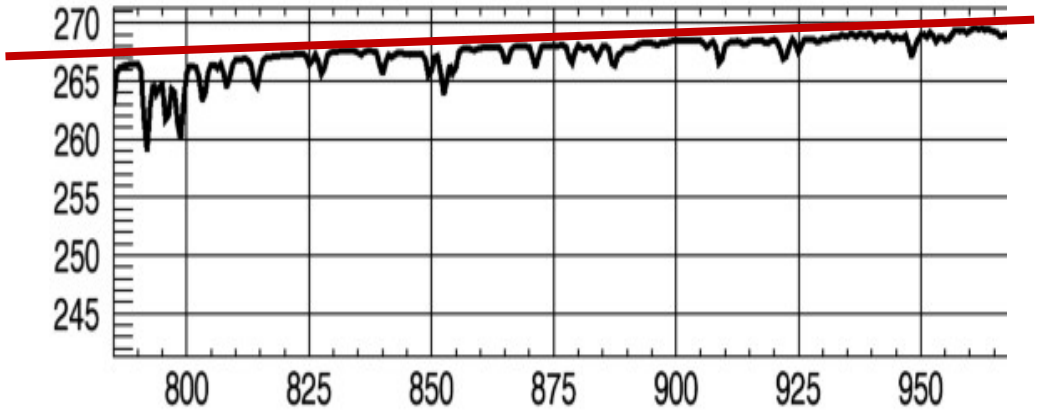
Sample Analyses



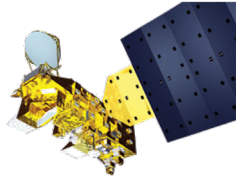
- We will use some of the capabilities of this product to investigate three areas:
  1. The differences in behavior between redundant A & B detectors for AIRS detector module M-08
  2. Shortwave behavior of AIRS and CrIS
  3. Global patterns of cloud properties

Global mean spectrum



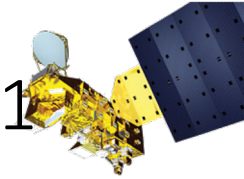


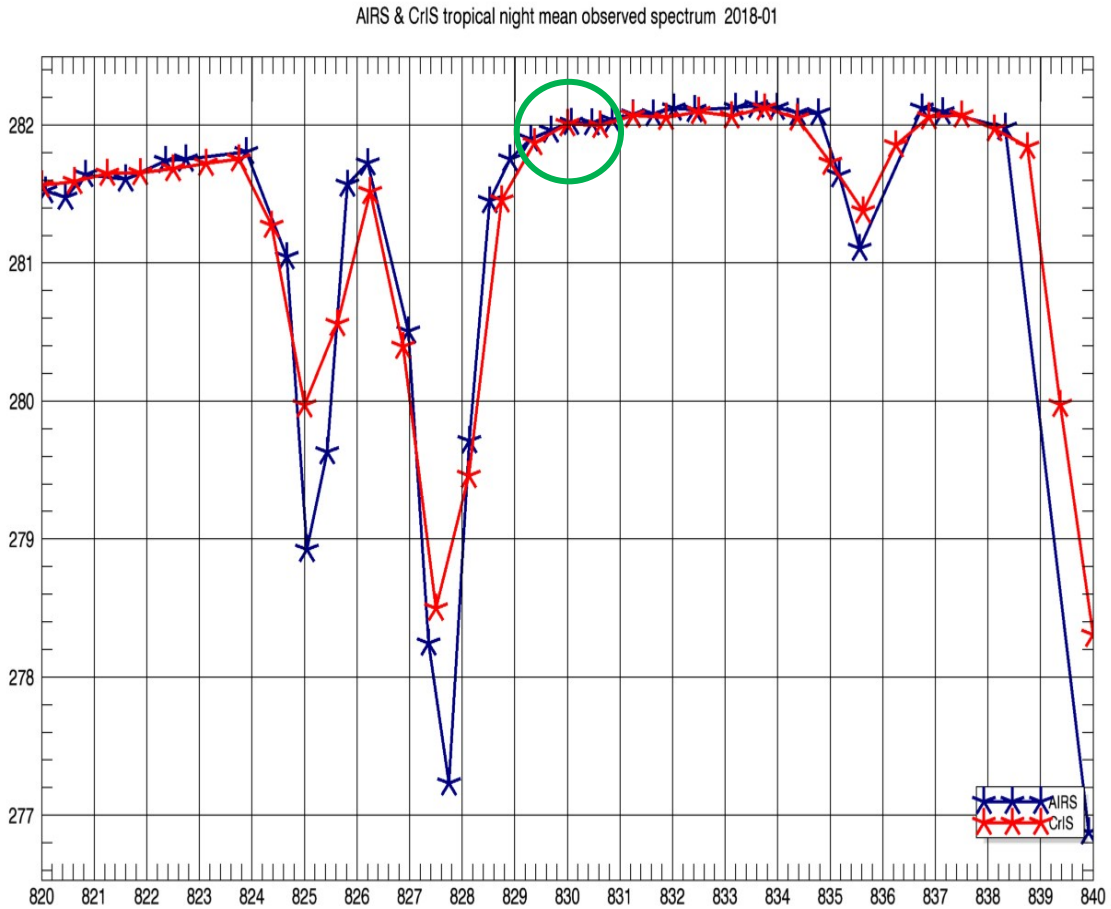
The slope in the most transparent regions around 11 um gives us information about clouds (details?)

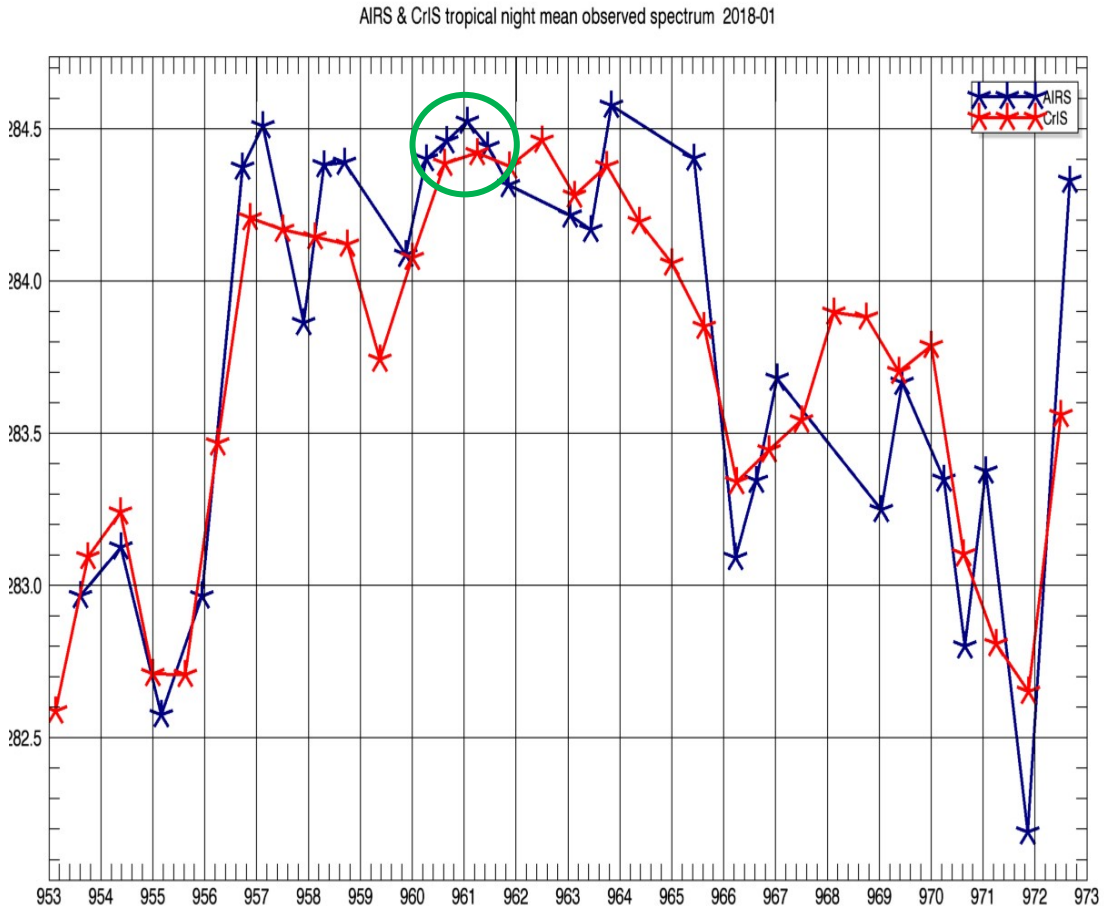


- Sample spectra with ice & water clouds, maybe also different ice particle sizes?

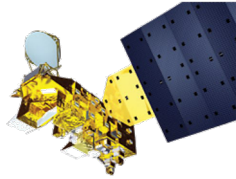
Key channels for slope: 830 & 961 cm^{-1}



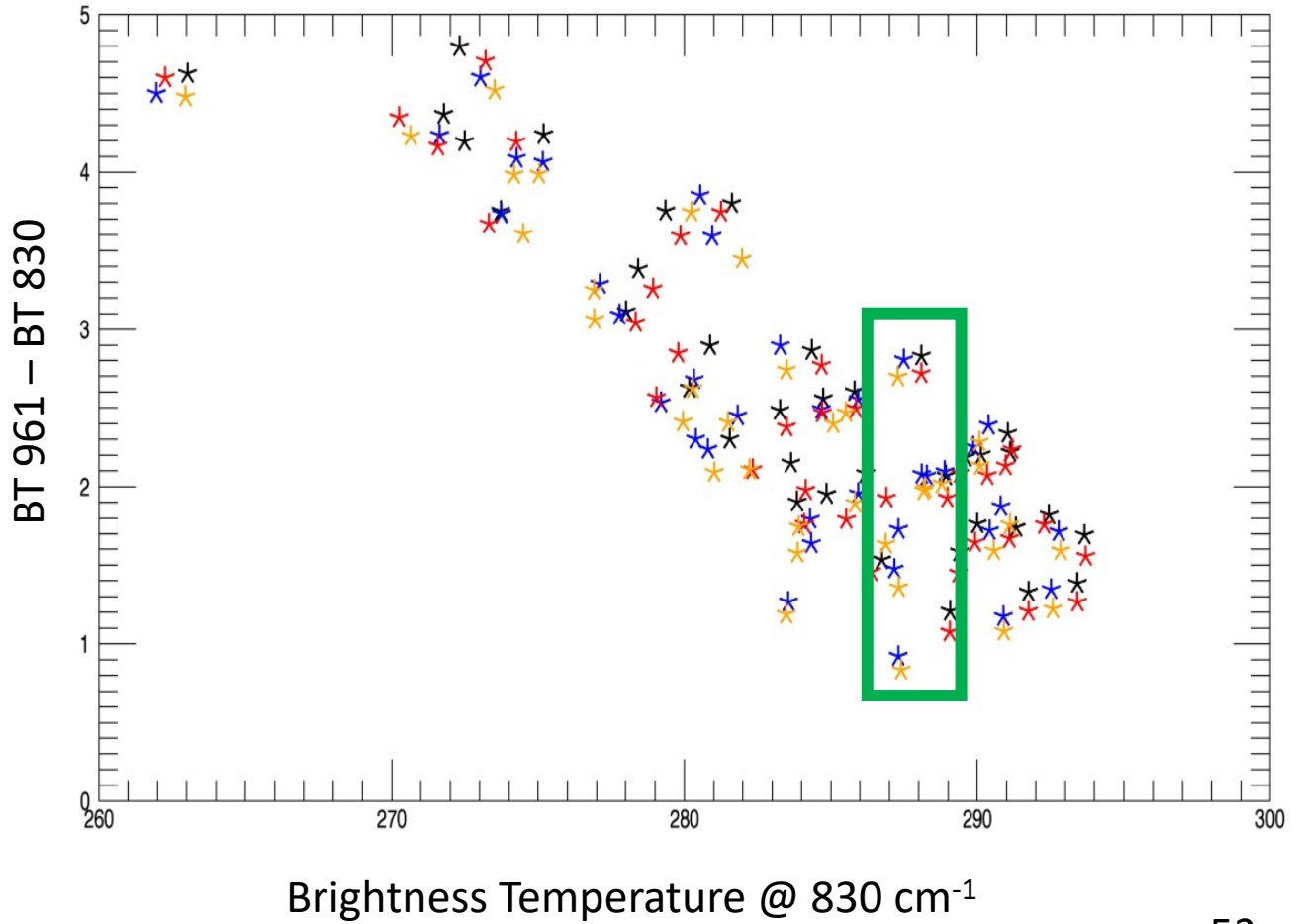




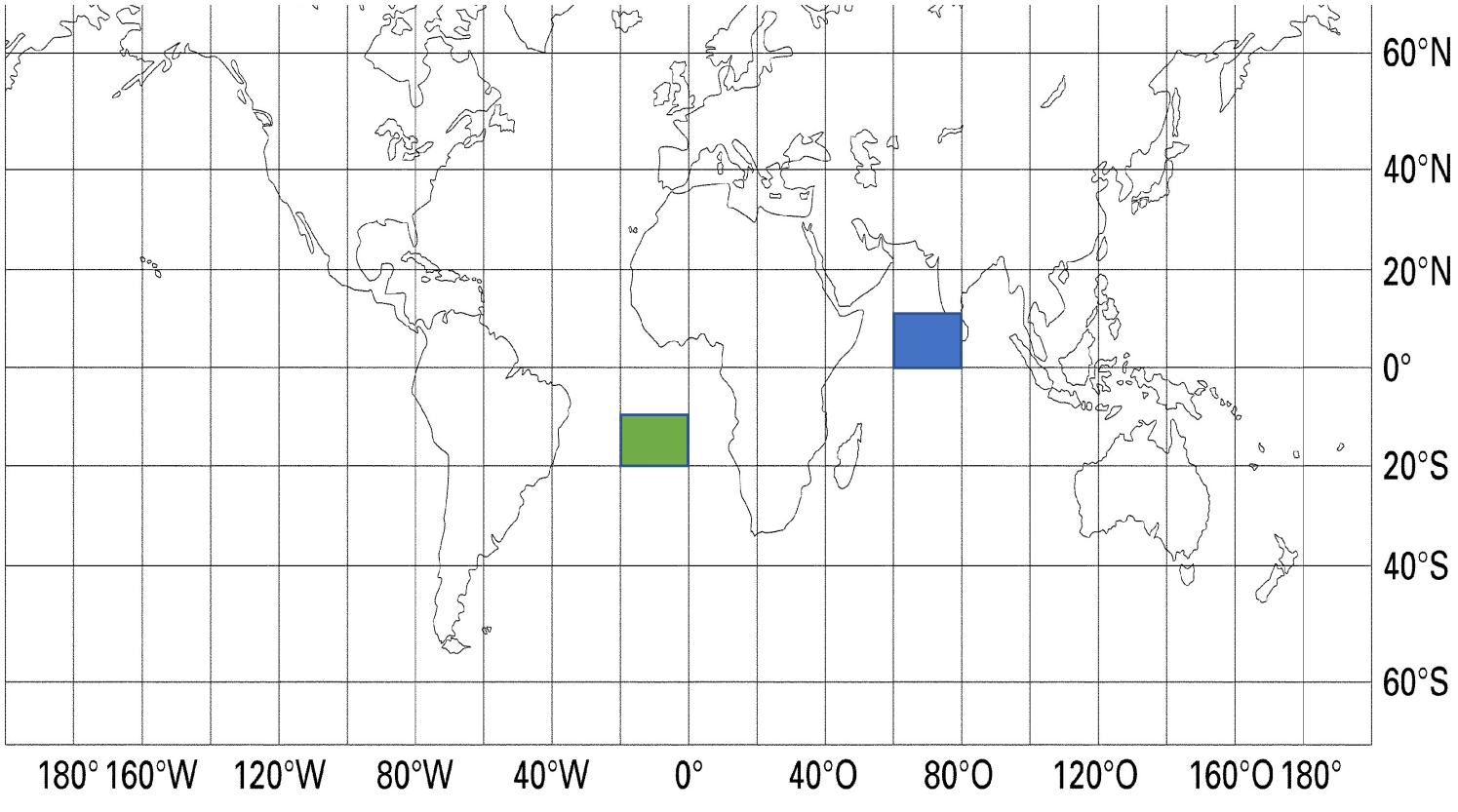
Ocean slope as a function of scene BT



- The slope is most closely associated with scene brightness temperature.
- Warmer scenes are clearer and flatter.
- But there is variation within BT.
- We investigate two cases near 288 K.



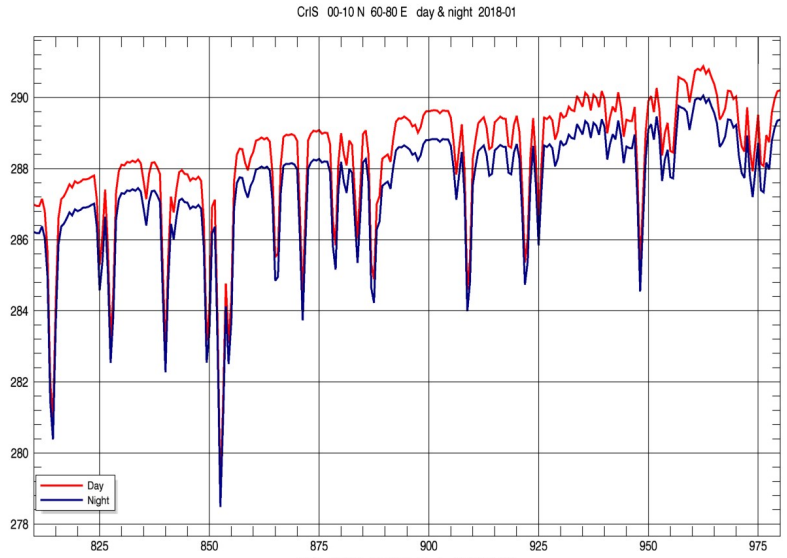
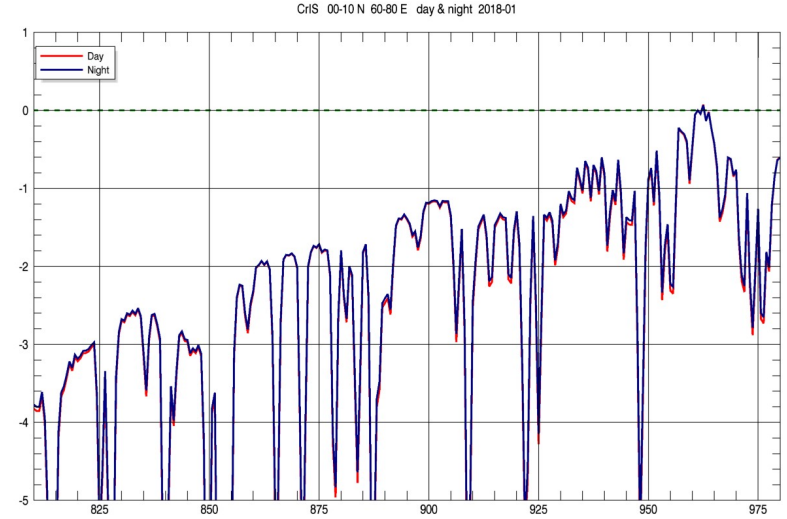
Locations of extreme slopes for 288-K tropical cases



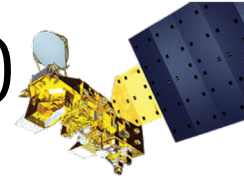
- South Atlantic 10-20S; 00-20W has a very shallow slope.
- Indian Ocean 00-10N; 60-80E has a steep slope

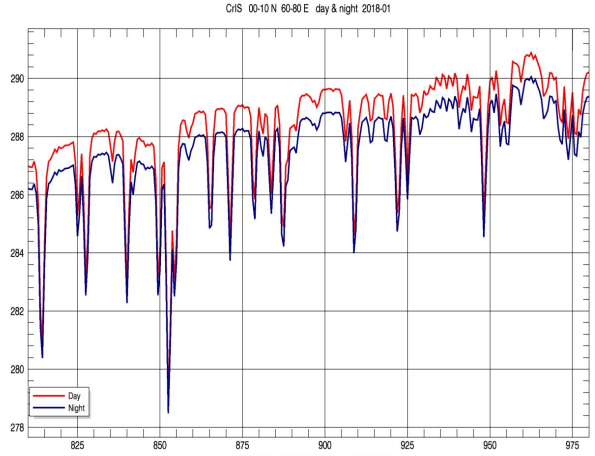
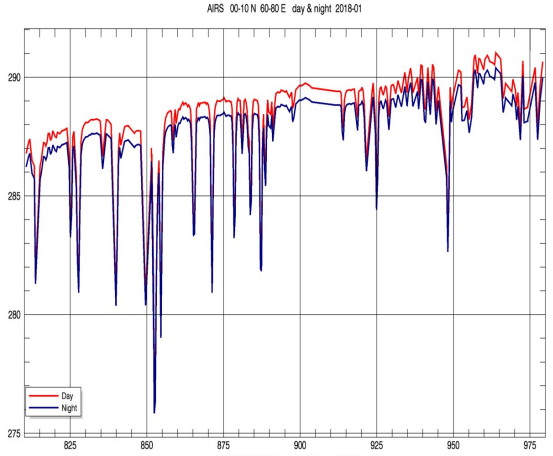
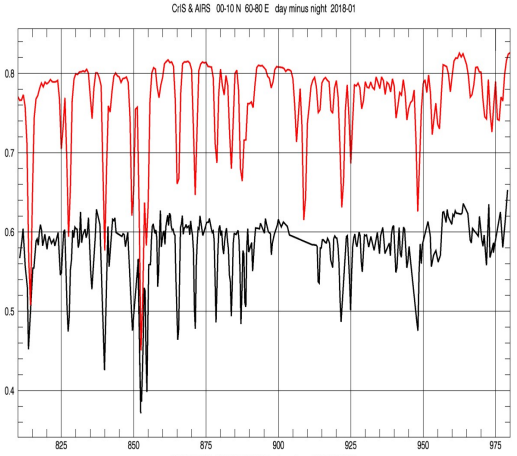
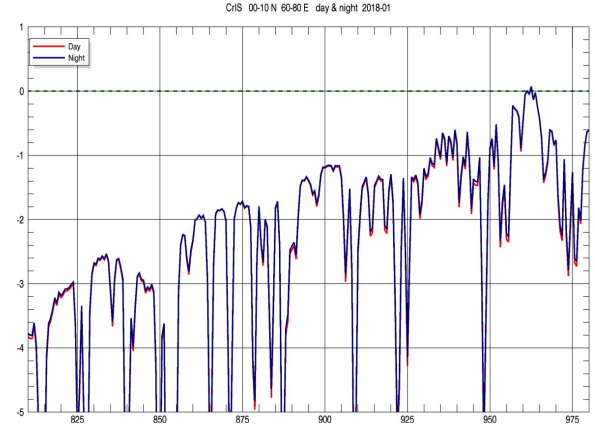
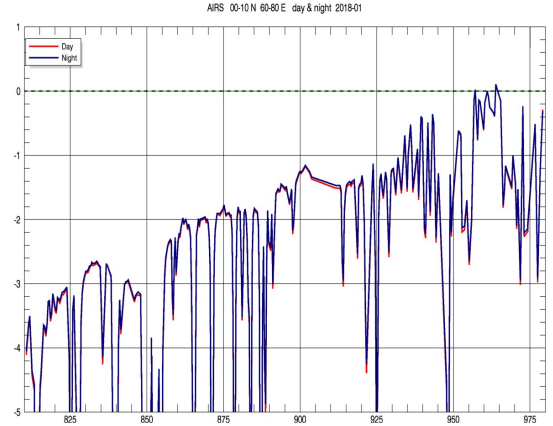
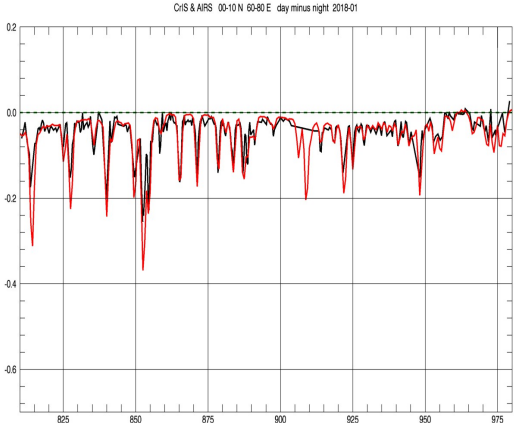
Debiasing spectra

- Even though each spectrum shown represents ~140,000 individual observations, they are not independent samples of weather systems, so significant biases are seen between instruments, day/night, etc.
- We subtract the brightness temperature at 961 cm^{-1} to compare the shapes of the spectra.

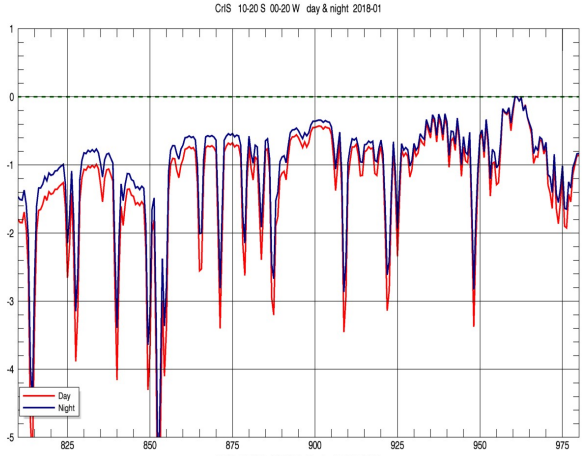
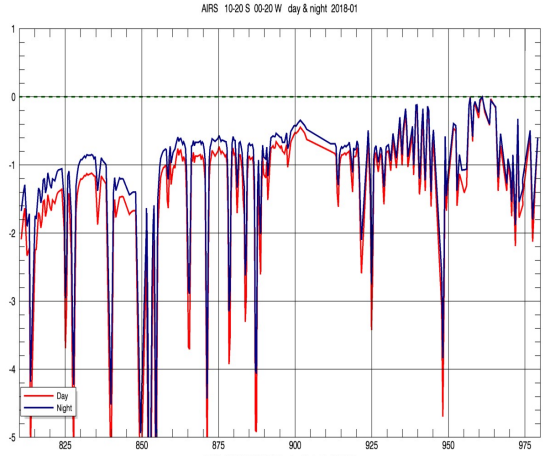
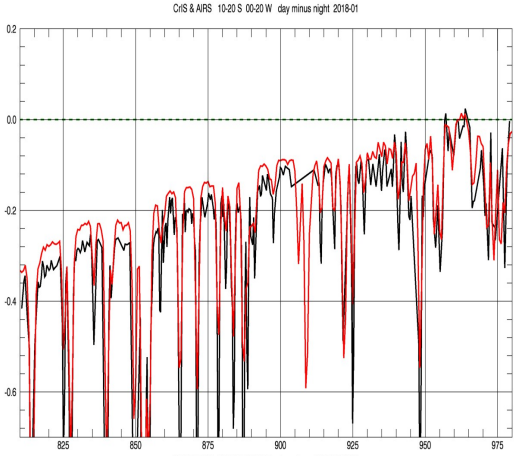
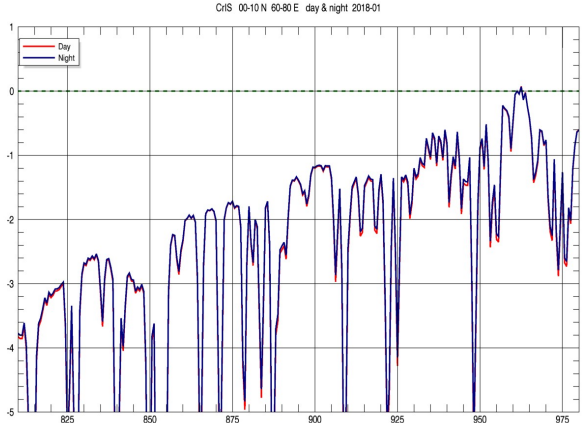
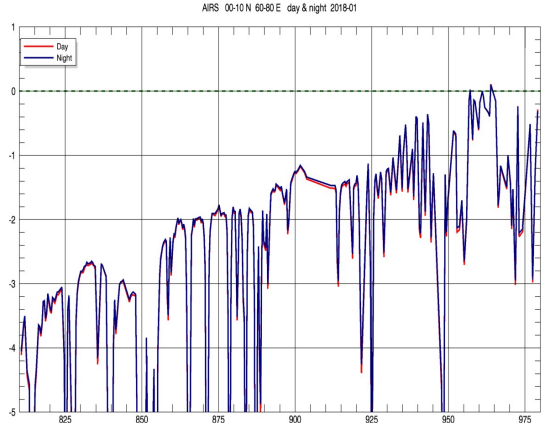
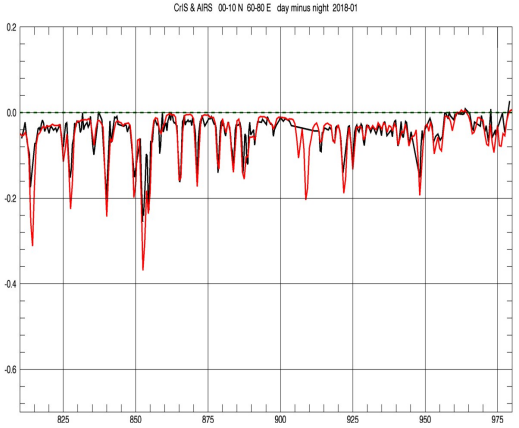
	CrIS Day & Night
00-10 N 60-80 E raw	
00-10 N 60-80 E Debiased at 961 cm^{-1}	

Debiasing spectra example: 00-10 N 60-80 E

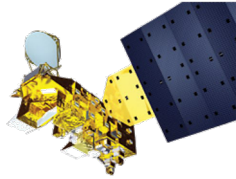


	CrIS Day & Night	AIRS Day & Night	CrIS & AIRS Day-minus-night
00-10 N 60-80 E raw			
00-10 N 60-80 E Debiased at 961 cm^{-1}			

Debiased spectra

	CrIS Day & Night	AIRS Day & Night	CrIS & AIRS Day-minus-night
10-20 S 00-20 W South Atlantic			
00-10 N 60-80 E Indian Ocean			

Observations



- AIRS and CrIS agree very well in the shapes of the spectra
- The South Atlantic case with a flatter slope has a greater slope in day-minus-night.
  - Brian Kahn to help say what this means.