CGMS XXX USA-WP-23
Agenda Item: II.2
Discussed in WG-2

Intercalibration of Geostationary and Polar-Orbiting Infrared Window and Water Vapor Radiances

Summary and Purpose of Document

An overview of the procedures and results for intercalibrating the geostationary infrared window and water vapor radiances using one polar-orbiting sensor as a reference. This is the USA response to Action 29.26

Action Requested: None

INTERCALIBRATION OF GEOSTATIONARY AND POLAR-ORBITING INFRARED WINDOW AND WATER VAPOR RADIANCES

Mathew M. Gunshor [1], Timothy J. Schmit [2], and W. Paul Menzel [3]

[1] Cooperative Institute for Meteorological Satellite Studies
[2] NOAA/NESDIS/ORA/ASPT
[3] NOAA/NESDIS/ORA

Madison, Wisconsin, 53706 USA

1. INTRODUCTION

The ability to compare the measured radiances from different instruments has become increasingly important, as satellites traditionally used for weather monitoring have proven to be useful for a variety of applications, such as input in global climate models. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) has been intercalibrating five geostationary satellites (GOES-8, -10, METEOSAT-5, -7, GMS-5) with a single polar-orbiting satellite (NOAA-14 HIRS and AVHRR) on a routine, automated basis using temporally and spatially co-located measurements. The focus of this effort has been in comparing the 11-µm infrared window (IRW) and the 6.7-µm water vapor (WV) channels (AVHRR does not have a 6.7-µm channel). This year the analysis focuses on seasonal and long-term trends. In addition to the routine processing of NOAA-14 intercalibration data, NOAA-15 HIRS and AVHRR data have been collected for the IRW and WV bands for approximately 12 months. GOES-12 was launched July 23, 2001 and during the checkout period data were collected for comparison with NOAA-14, -15, and GOES-10 at the mid-point between the two satellites. AIRS, a potentially powerful new tool in the intercalibration effort, has arrived with the launch of Aqua on May 4, 2002 and preliminary comparisons with GOES-10 demonstrate the viability of comparing a broadband instrument with a high spectral resolution instrument such as AIRS.

2. APPROACH

The intercalibration approach used was described in prior CGMS proceedings. It is repeated here for completeness. Collocation in space and time (within thirty minutes) is required. Data is selected within 10 degrees from nadir for each instrument in order to minimize viewing angle differences. Measured means of brightness temperatures of similar spectral channels from the two sensors are compared. Data collection in IRW channel is restricted to mostly clear scenes with mean radiances greater than 80 $mW/m^2/ster/cm^{-1}$, and no additional effort is made to screen out clouds from the study area. In the WV channel there is no clear scene restriction applied. Data from each satellite are averaged to an effective 100 km resolution to mitigate the effects of different field of view (fov) sizes and sampling densities; HIRS under-samples with a 17.4 km nadir fov, AVHRR GAC achieves 4 km resolution by under-sampling within the fov, MODIS is sampled at 1 km, GOES imager over-samples 4 km in the east west by 1.7 and METEOSAT and GMS have a nadir 5 km fov. Mean radiances are computed within the collocation area. Clear sky forward calculations (using a global model for estimation of the atmospheric state) are performed to account for differences in the spectral response functions (Figures 1 and 2). The observed radiance difference minus the forward-calculated clear sky radiance difference is then attributed to calibration differences.

Thus,

$$\Delta R_{cal} = \Delta R_{mean} - \Delta R_{clear}$$

For comparing a geostationary satellite to HIRS,

$$\Delta R_{cal} = [R^{GEO}_{mean} - R^{GEO}_{clear}] - [R^{HIRS}_{mean} - R^{HIRS}_{clear}]$$

Where *GEO* indicates geostationary, *HIRS* indicates the HIRS instrument, *mean* indicates the mean measured radiance, and *clear* indicates the forward calculated clear-sky radiances. Conversion to temperatures for a comparison of a geo to HIRS is accomplished by,

$$\Delta T_{HIRS} = [B^{-1}{}^{GEO}_{mean} - B^{-1}{}^{GEO}_{clear}] - [B^{-1}{}^{HIRS}_{mean} - B^{-1}{}^{HIRS}_{clear}]$$

Where B^{-1} indicates converting radiance to brightness temperature using the inverse Planck Function. An identical method is used for calculating the temperature difference between a geostationary satellite and AVHRR (ΔT_{AVHRR}). This approach is identical for HIRS and AVHRR comparison to all geos using NOAA-14 and -15.

For comparing AIRS to GOES-10, the high spectral resolution AIRS data is convolved with the GOES spectral response function and then compared to GOES. This works well in areas of the infrared spectrum where AIRS coverage includes all of the GOES spectral bandwidth. However, in the water vapor region AIRS does not cover some of the GOES bandwidth and methods for improving the comparison are currently under study.

During the GOES-12 checkout period (September 23, 2001 through October 27, 2001) data were collected for comparing the GOES-12 imager to NOAA-14 and NOAA-15. In addition, GOES-10 and GOES-12 imager data were compared at the mid-point between the two satellites (112.5 West). The GOES-12 water vapor channel covers a wider spectral range and has higher resolution than those on previous GOES. Figure 3 shows an example of imagery from the new water vapor channel on GOES-12.

3. RESULTS

Intercalibration results for the five operational geostationary satellites compared with NOAA-14 and -15 are shown in Tables 1 and 2. The mean is the average of all cases for the indicated satellite and a negative sign indicates the measurements, after correction for spectral response differences, from the polar-orbiting instrument (HIRS or AVHRR) are warmer than those from the geostationary instrument. In general, all five geostationary instruments are measuring colder mean corrected temperatures than HIRS and AVHRR in the IRW channel; they measure warmer corrected temperatures on average than HIRS in the WV channel. The standard deviation is the deviation about the mean. In the IRW channel the standard deviations for ΔT_{AVHRR} are lower than they are for ΔT_{HIRS}; the standard deviations for the WV channel comparisons are larger than those in the IRW channel for ΔT_{HIRS} for NOAA-15, but this is not always true for those comparisons for NOAA-14.

Figure 4 shows the results for comparing GOES-12 to GOES-10. This figure also shows the importance of correcting for spectral response differences, even when comparing instruments from the same series. AIRS compared very favorably to GOES-10 as well. After correcting for convolution errors AIRS was less than 0.1K colder than GOES-10 for 3.9-μm (band 2), 1.0K colder at 6.7-μm (band 3), 0.2K colder at 11.0-μm (band 4), and 0.3K colder at 12.0-μm (band 5). The estimated convolution error is only large for band 3, where it is approximately 2.6K, compared with less than 0.1K in all other bands.

Table 1. January 2000 through July 2002 IRW (top) and WV (bottom) comparison of geostationary satellites and NOAA-14 HIRS and AVHRR.

N-14 Delta (geo – leo)		GOES-8 IRW	GOES-10 IRW	MET-5 IRW	MET-7 IRW	GMS-5 IRW
Number of Comparisons	ΔT_{HIRS}	42	353	352	424	137
	ΔT_{AVHRR}	42	353	352	424	137
Mean	ΔT_{HIRS}	-0.6 K	-0.6 K	-0.8 K	-1.1 K	-0.9 K
	ΔT_{AVHRR}	-0.3 K	-0.1 K	-0.4 K	-0.7 K	-0.6 K
Standard Deviation	ΔT_{HIRS}	0.8 K	1.2 K	1.1 K	1.1 K	1.0 K
	ΔT_{AVHRR}	0.3 K	0.3 K	0.6 K	0.7 K	0.6 K

N-14 Delta (geo – leo)		GOES-8 WV	GOES-10 WV	MET-5 WV	MET-7 WV	GMS-5 WV
Number of Comparisons	ΔT_{HIRS}	237	488	458	327	252
Mean	ΔT_{HIRS}	1.5 K	2.2 K	3.9 K	3.9 K	1.2 K
Standard Deviation	ΔT_{HIRS}	0.7 K	0.8 K	1.3 K	0.8 K	1.0 K

Table 2. September 2001 through August 2002 IRW (top) and WV (bottom) comparison of geostationary satellites and NOAA-15 HIRS and AVHRR.

N-15 Delta (geo – leo)		GOES-8 IRW	GOES-10 IRW	MET-5 IRW	MET-7 IRW	GMS-5 IRW
Number of Comparisons	ΔT_{HIRS}	39	168	175	198	40
	ΔT_{AVHRR}	39	168	175	198	40
Mean	ΔT_{HIRS}	-0.1 K	-0.1 K	-0.5 K	-1.2 K	-0.6 K
	ΔT_{AVHRR}	0.1 K	-0.2 K	-0.6 K	-1.0 K	-0.7 K
Standard Deviation	ΔT_{HIRS}	0.9 K	1.4 K	1.8 K	1.1 K	1.3 K
	ΔT_{AVHRR}	0.4 K	0.4 K	1.4 K	0.7 K	0.4 K

N-15 Delta (geo – leo)		GOES-8 WV	GOES-10 WV	MET-5 WV	MET-7 WV	GMS-5 WV
Number of Comparisons	ΔT_{HIRS}	119	219	200	0	78
Mean	ΔT_{HIRS}	0.6 K	1.8 K	3.2 K	na	-0.1 K
Standard Deviation	ΔT_{HIRS}	1.1 K	1.5 K	1.8 K	na	1.7 K

4. SEARCHING FOR SEASONAL TRENDS

The data were divided into four seasons as a first approximation. Winter covers December 22 through March 20; spring covers March 21 through June 21; summer covers June 22 through September 21; fall covers September 22 through December 21. Mean temperature differences for each season do not reveal an obvious seasonal dependence. As an example, seasonal means of temperature differences for NOAA-14 AVHRR are shown in Figure 5. While there are differences for any given leo from one season to the next in Figure 5, there are no consistent trends from one geo to the next. In addition, the variations from season to season are relatively small, in all cases smaller than the standard deviation over the entire time period. Cursory examination of time series plots also does not reveal any obvious seasonal dependence of temperature differences. Figure 6 shows a time series plot of GOES-10/NOAA-14 AVHRR temperature differences (ΔT_{AVHRR}) for the IRW as an example. There are almost no points for the last 2 months of 2001 because NOAA-14 AVHRR had a scan motor problem and data was unusable for most of that period. There are several analysis techniques shown in Figure 6. The dotted line is the mean temperature difference (ΔT_{AVHRR}) for the entire time period. The dashed line is a cumulative mean, the mean of all values in the time series from the beginning. The solid, bold line is an interpolated running average. Data are interpolated to a temporal resolution of one calculation per day and then averaged with a 21 day running filter. Any point on the solid line is the average of the 10 interpolated values before and after, including said point. This illustrates a smoother curve where possible seasonal dependencies may be seen as opposed to the scattered nature of the actual calculations. While there does not appear to be a seasonal dependence in this plot, there may be other patterns that are not as easily explained. For instance, a comparison of the GOES-10 / NOAA-14 (ΔT_{HIRS}) plots in the IRW and WV channels reveals some similarity in the interpolated running average where peaks and valleys appear in the time series (not shown). This may indicate that there are some patterns present, but perhaps not easily distinguishable from the noise, and not associated with a seasonal trend in the traditional sense.

5. CONCLUSIONS

Using a polar orbiter as a reference, the five geostationary satellites compare favorably in the infrared window channel, within nearly 1K with few exceptions. In the largest data set, the geos are within 0.5K (HIRS) and 0.6K (AVHRR) for NOAA-14. Comparisons in the WV band show more variability; using only HIRS they compare to within 2.7K using NOAA-14 and 3.3K using NOAA-15. GOES-8, -10 and GMS-5 form one group that compare favorably to each other in the WV and METEOSAT-5 and –7 form another. METEOSAT-7 is used to calibrate METEOSAT-5, so a favorable comparison is not unexpected and reflects upon a successful use of vicarious calibration methods. However, the differences in the WV comparisons between GOES / GMS and METEOSAT are difficult to explain. A partial explanation may be attributed to the broader water vapor bandwidth of METEOSAT (see Figure 2) and the difficulty in calculating atmospheric water vapor transmittance. Other causes may be a higher degree of uncertainty in the calibration of the WV channel for some instruments and the greater inhomogeneity of the atmospheric water vapor structure.

It is not possible, from this study, to determine which satellite is the most accurate or has the best calibration. It is only possible to compare them to each other. It may be possible to use AIRS as a “truth” measurement and get a better idea of the absolute calibration of geostationary instruments.

6. FUTURE WORK

As data becomes more readily available from AIRS comparisons will be done with all geos. New instruments such as NOAA-16, NOAA-17, and MSG will also be included in future analyses.

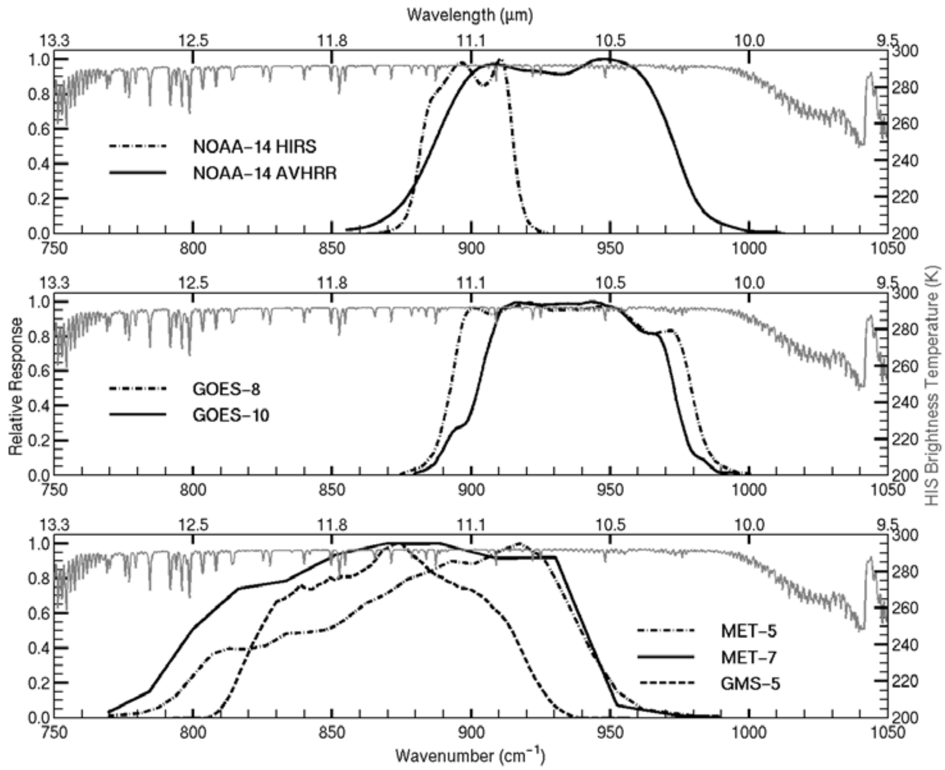

Figure 1. Infrared Window Channel spectral response functions with a high spectral resolution earth emitted spectrum from a High-resolution Interferometer Sounder.

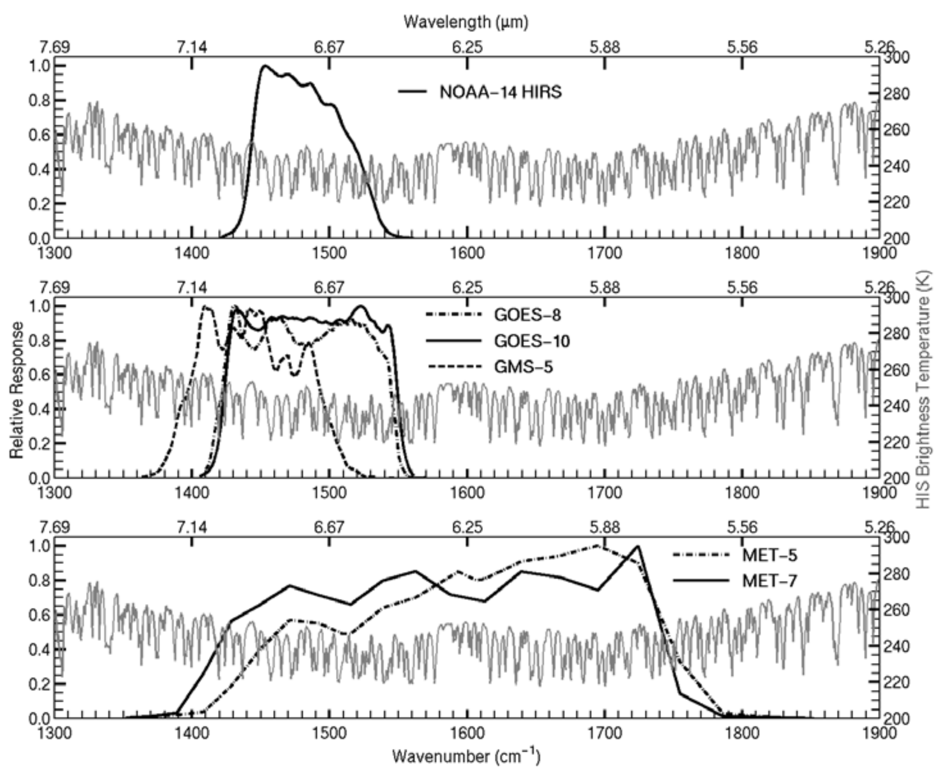

Figure 2. Water Vapor Channel spectral response functions with a high spectral resolution earth emitted spectrum from a High-resolution Interferometer Sounder.

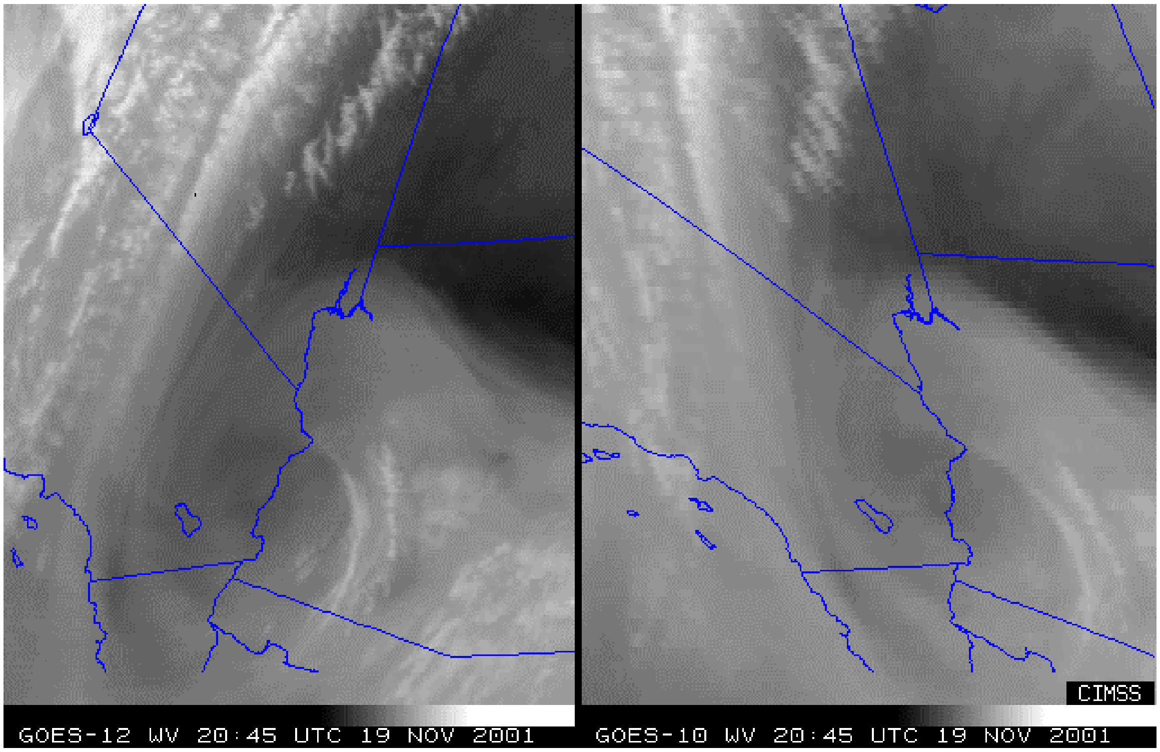

Figure 3. The new water vapor channel on GOES-12 (shown here over the western United States) is higher resolution than its predecessors.

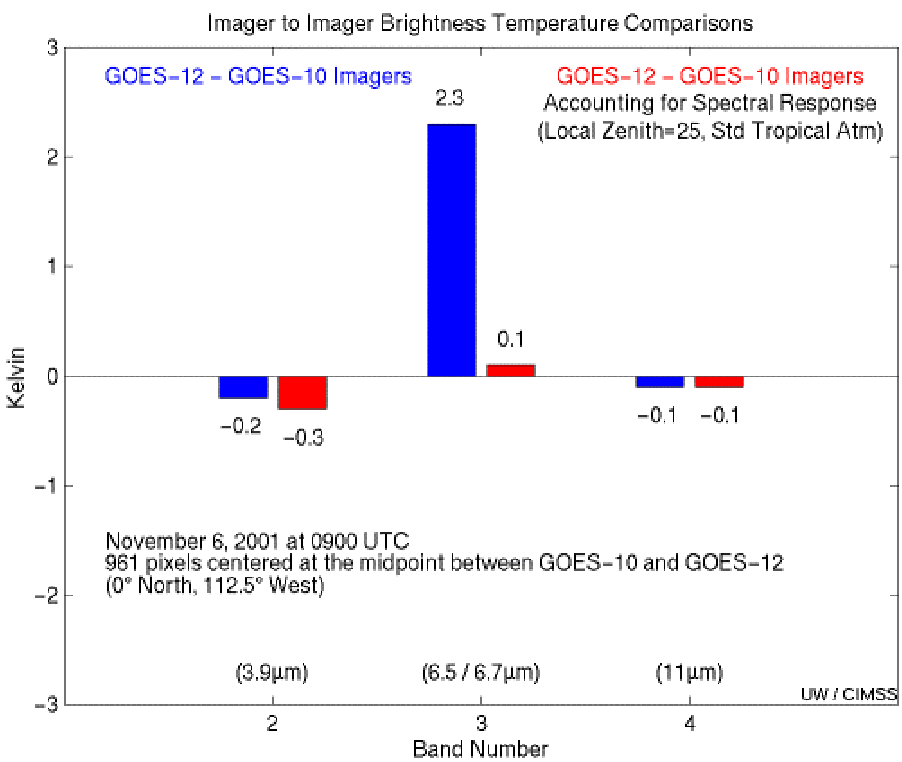

Figure 4. November 5, 2001 at 18:05 UTC; GOES-12 compared to GOES-10. The first bar is an uncorrected comparison and the second bar accounts for spectral response differences.

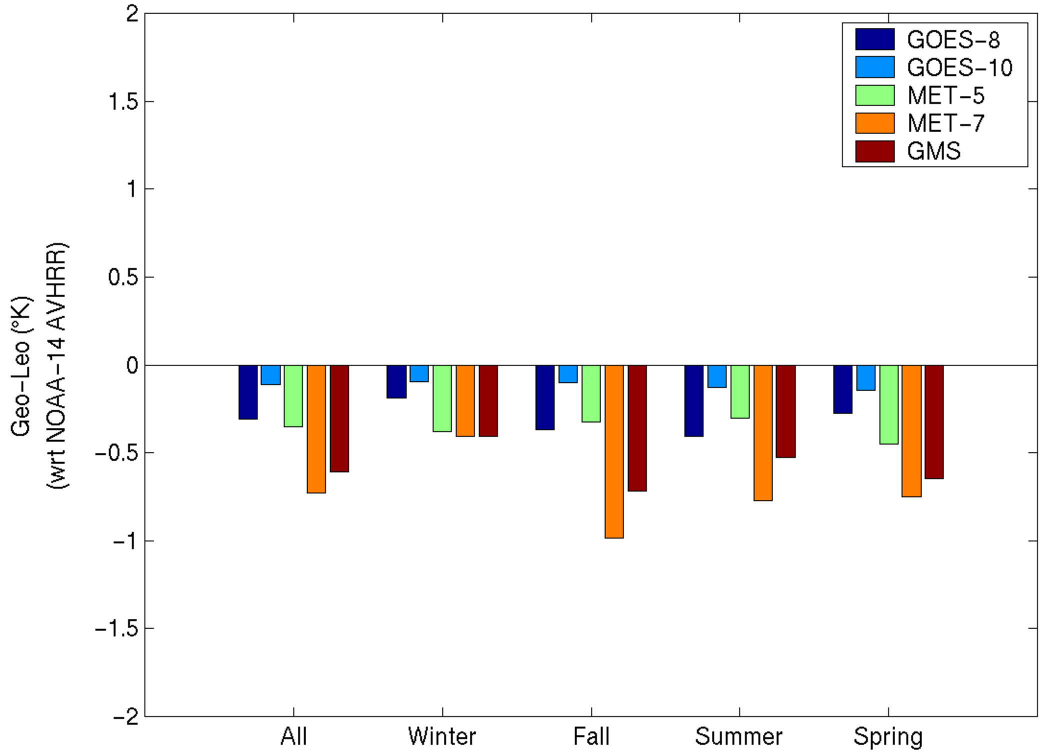

Figure 5. Seasonal mean temperature differences for NOAA-14 AVHRR (ΔT_A) in the IRW from January 2000 through July 2002.

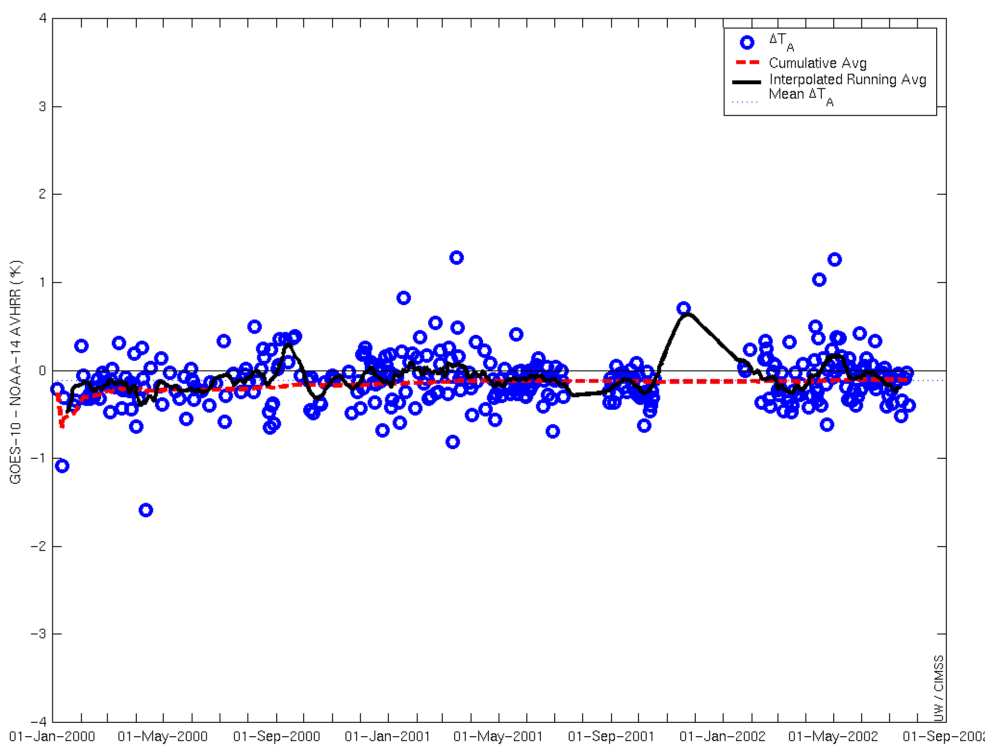

Figure 6. Temperature difference time series for GOES-10 and NOAA-14 AVHRR (ΔT_A) in the IRW from January 2000 through July 2002.