Atmospheric Parameter Climatologies from AIRS: Monitoring Short-, and Longer-Term Climate Variabilities and "Trends"

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ABSTRACT

The AIRS instrument is currently the best space-based tool to *simultaneously* monitor the vertical distribution of key climatically important atmospheric parameters as well as surface properties[1,2], and has provided high quality data for more than 5 years. AIRS analysis results produced at the GODDARD/DAAC, based on Versions 4 & 5[3] of the AIRS retrieval algorithm, are currently available for public use. Here, first we present an assessment of interrelationships of anomalies (proxies of climate variability based on 5 full years, since Sept. 2002) of various climate parameters at different spatial scales. We also present AIRS-retrievals-based global, regional and 1x1 degree grid-scale "trend"-analyses of important atmospheric parameters for this 5-year period. Note that here "trend" simply means the linear fit to the anomaly (relative the mean seasonal cycle) time series of various parameters at the above-mentioned spatial scales, and we present these to illustrate the usefulness of *continuing* AIRS-based climate observations. Preliminary validation efforts, in terms of intercomparisons of interannual variabilities with other available satellite data analysis results, will also be addressed. For example, we show that the outgoing longwave radiation (OLR) interannual spatial variabilities from the available state-of-the-art CERES *measurements* and from the AIRS *computations* are in remarkably good agreement. Version 6 of the AIRS retrieval scheme (currently under development) promises to further improve bias agreements for the absolute values by implementing a more accurate radiative transfer model for the OLR computations and by improving surface emissivity retrievals.

Keywords: infrared, remote sensing, satellite sounders, cloud parameters, sea surface temperature, surface skin temperature, upper tropospheric humidity, outgoing longwave radiation, satellite-based climatic trends

1. INTRODUCTION

Operational meteorological satellites capable of atmospheric sounding have been in polar orbits for nearly three decades. However, comprehensive satellite-based atmospheric parameter climatologies are sill in their infancy. In principle, satellite sounders can provide an ideal platform to retrieve important atmospheric variables simultaneously and even on longer time scales. Their (main) ability to retrieve *vertical profiles* of atmospheric temperature and humidity may be regarded as having a twice-a-day *global* coverage of radiosondes. This is very useful since radiosondes provide only a spatially uneven coverage over about one-third of globe. Due to this limited coverage, for example, a good understanding of water vapor (*the* most important greenhouse gas)-related climate feedbacks is not well established, as the still lingering Lindzen[3] hypothesis indicates. Reliable, long-term satellite sounder measurements would help make general circulation models [GCMs] a much more reliable tool of weather and climate change prediction in (at least) two ways: they could provide input for the necessary parameterizations on one hand, and test/validate the model results on the other.

The AIRS/AMSU sounding retrieval methodology allows for the retrieval of key atmospheric/surface parameters under partially cloudy conditions. This allows for up to 80-90% global coverage, far greater than the conventional satellite sounder retrieval methods, which are limited to clear-sky conditions. The AIRS/MSU Version 4.0/5.0 retrieval methodology is essentially a physically-based system, it is independent of GCM except for surface pressure, and it uses "cloud-cleared" radiances to produce solutions.

The AIRS/AMSU sounding retrieval methodology allows for the retrieval of key atmospheric/surface parameters under partially cloudy conditions. The following bullets highlight an overview of the AIRS/MSU Version 4.0/5.0 retrieval methodology in some detail:

• Physically-based system;
• Independent of GCM except for surface pressure;
• Uses cloud cleared radiances to produce solution;
• Basic steps:
1) Microwave product parameters – solution agrees with AMSU-A radiances;
2) Initial cloud clearing using microwave product;
3) AIRS regression guess parameters based on cloud cleared radiances;
4) Update cloud clearing using AIRS regression guess parameters;
5) Sequentially determine surface parameters, temperature, moisture, ozone, CO, and CH_4 profiles;

•Apply quality control:
a) Select retrieved state - coupled AIRS/AMSU or AMSU only retrieval parameters;
b) Determine cloud parameters consistent with retrieved state and observed radiances. One set per Field-of-View of effective cloud fraction (A_{eff}) for up to two cloud layers, as well as cloud top pressure (C_{tp}) for up to two cloud layers;
c) Compute all-sky OLR and clear-sky OLR from all parameters via radiative transfer. Note that in Version 4.0 the all-sky OLR *gridded* product calculation had an error, so in the followings we use only the clear-sky OLR product.

2. METHODOLOGY

In order to assess the reasonableness and compatibility of DAAC AIRS Version 4.0 and 5.0 products, we have obtained 1° x 1° gridded monthly mean average (Level 3) data, covering the first 5 full years of operation, *i. e.,* from Sept. 2002 till August 2007. These data are available through the WEB-site of the DAAC at NASA/GSFC (http://disc.gsfc.nasa.gov/data/datapool/AIRS/index.html). Note that Version 4.0 is referred there as "V003" products, whilst Version 5.0 is referred to as "V005".

Our main aim here is to assess eventual utility of AIRS data for climate research, and this requires compatibility with variability of other long term data sets. A preliminary inter-comparison of interannual/intraseasonal variability was presented in last year's volume of this conference[6]. Here we focus on the consistency of the 5 year long series of "climatic anomalies", relative to the mean seasonal "climates" obtained from the averaging of the first five years of each respective "AIRS month". All DAAC version 4.0 and 5.0 monthly mean fields have been spatially interpolated to include missing data grid points, whilst elevated terrain is excluded at the appropriate pressure levels. After the AIRS 5-year 1° x 1° monthly mean "climatologies" were generated, we've computed the monthly mean *anomalies* as area weighted (when "areas" were larger than the 1° x 1° grid) differences from the area weighted monthly climatologies. Considering the relatively short length of the AIRS dataset, regional anomalies/trends, which tend to be always larger than global anomalies/trends, are expected to be less affected by possible instrumental drifts, for example. Thus, besides creating the time series of global, tropical and regional anomalies, we've computed linear trends fitted to the anomaly time series of each grid-point also.

Next, interrelationships among the various anomaly products are addressed and evaluated for consistency with principles of atmospheric physics. Of course, we have to keep in mind that findings for a 4.5 year period may not be significant to draw authorative climate inferences.

3. RESULTS

Before presenting our "AIRS climate anomaly/trend" assessments, on Fig. 1 we illustrate the AIRS "climatology" of surface skin temperature for the four representative months of the seasons:

4 Full Years Based "Climatological" AIRS Surface Skin Temperature Means

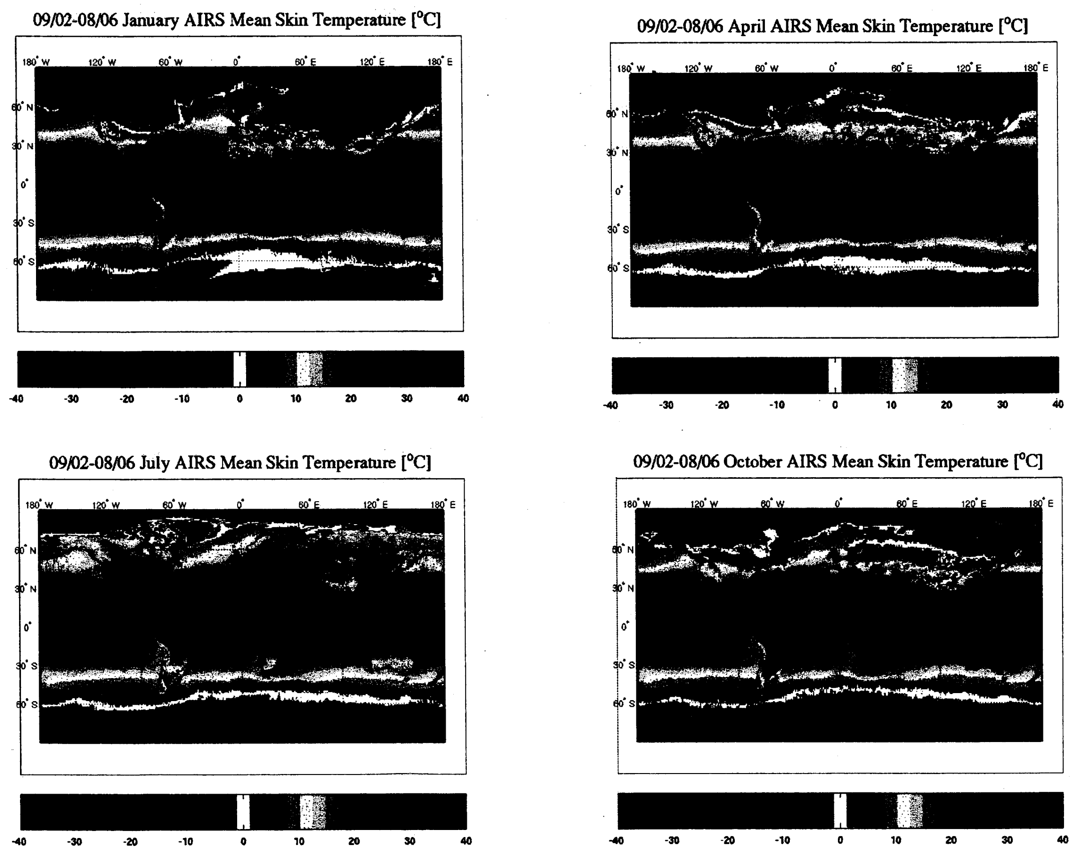


Figure 1

The effect of the yearly march of the solar insolation is obvious.

On Fig. 2 we show four 8-day average maps of the surface skin temperature anomalies, selected from the last 4 months of the Version 4.0 data. Surface skin temperature is a close proxy of sea surface temperature (SST) over oceans and its anomalies were computed relative to the (so far) 4-yr long AIRS surface skin temperature monthly mean "climatology". It is apparent that the El Niño conditions are turning towards La Niña, by the time shown on the last panel. Indeed, operational SST analyses indicate that a La Niña cycle has started in February, 2007. Fig. 3 compares the NOAA *vs.* the AIRS anomaly for the beginning of March 2007 for the same map-projection. The NOAA operational SST anomaly figures were taken from the http://www.osdpd.noaa.gov/PSB/EPS/SST/climo.html WEB-site. NOAA/NESDIS has been producing SSTs from satellite data since 1972. Monitoring of SST from earth-orbiting infrared radiometers has had a wide impact on oceanographic science. Beginning in mid-1996, a new satellite-only climatology (for 1984-1993) became available and made it possible to generate more accurate SST anomaly products from the operational 50-km daily SST field. The NOAA/NESDIS operational SSTs are provided twice a week in near real-time and use both day and night retrievals. Since the satellite-only SST monthly mean climatology is derived only from nighttime SST observations to eliminate the diurnal variation caused by diurnal solar heating at the sea surface (primarily at the "skin" interface, 10-20 μm), only nighttime SST analyses are used to ensure consistency between the satellite SST observations and the climatology. The original satellite-only SST monthly mean climatology data is at 36 km resolution and was derived from the Multi-Channel SSTs (MCSSTs, see McCain *et. al*[7], for example) reprocessed by the Rosenstiel School of Marine and Atmospheric Science (RSMAS) of the University of Miami.

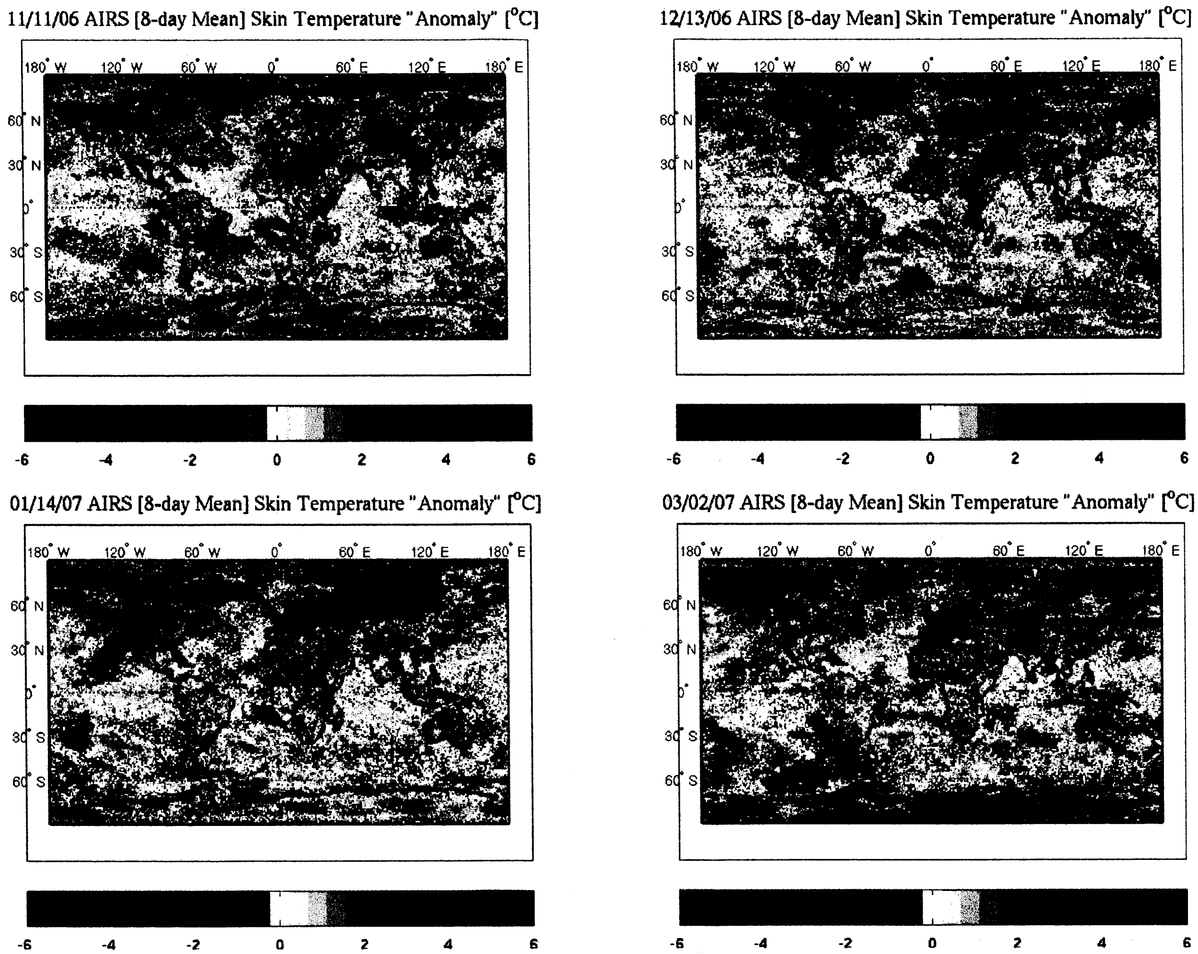


Figure 2

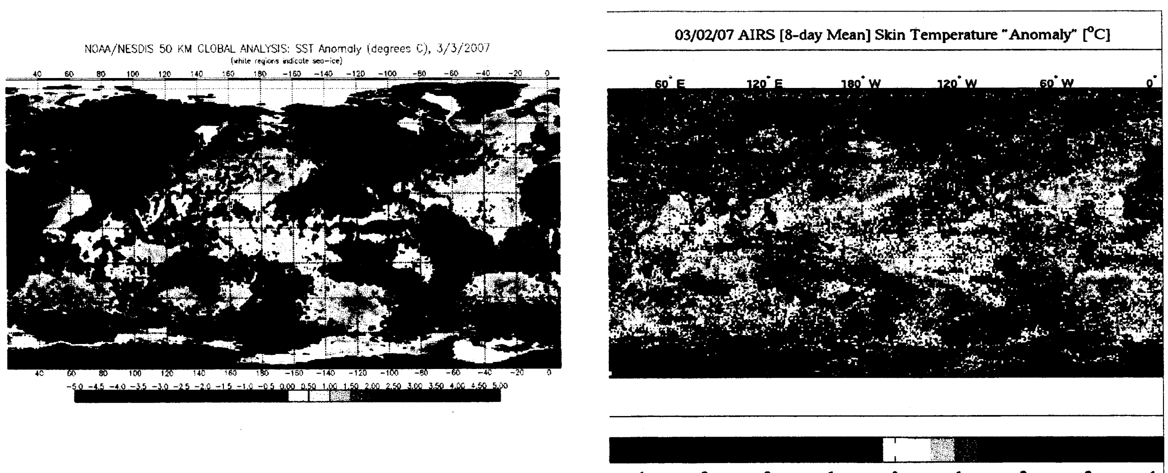


Figure 3

This climatology is based on nighttime observations from 1984-1993, with SST observations from the years 1991 and 1992 omitted due to aerosol contamination from the eruption of Mt. Pinatubo. In-situ SSTs from drifting and moored buoys are used to remove any biases, and statistics are compiled with time. The monthly

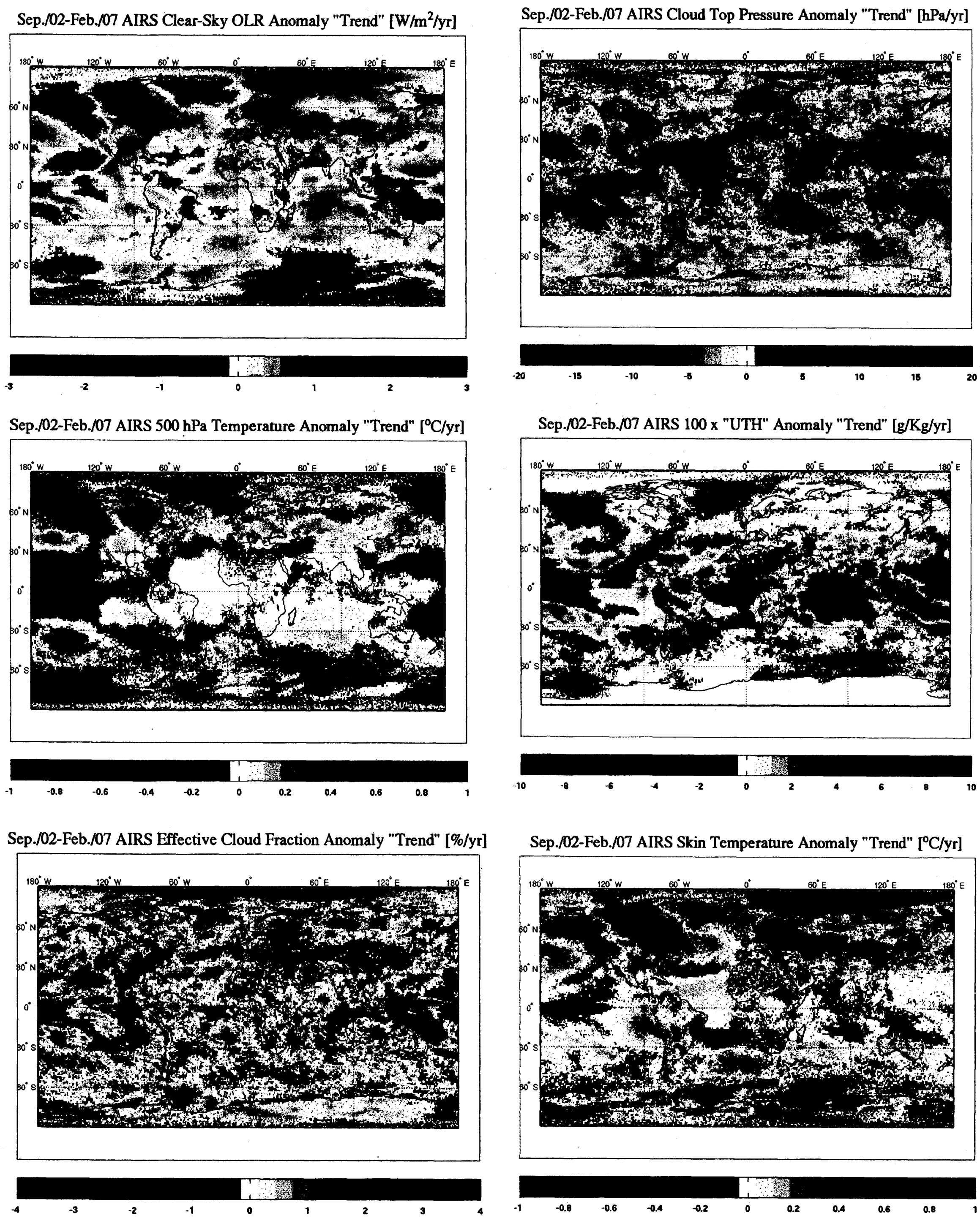


Figure 4

mean climatology data is then interpolated to 50 km resolution to match the operational SST field. To obtain the SST climatology for a specific date, just like we are doing for the AIRS climatology, linear interpolation is applied on the two SST monthly mean climatology files that are closest to that date. Despite based on different type of satellite instruments, twice weekly *vs.* 8-day averages and different climatological 'baselines', the

The El Niño/La Niña conditions discussed related to Figs. 2 and 3 prompted us to focus next on the equatorial region: namely the temporal variability of crucial climate parameters at *each 1°* longitude averaged latitudinally over the +/-5° and the +/-10° latitudes. As a function time, these values then constitute the hovmoller diagrams presented in the following figures. First, we've tried to use the monthly temporal resolution level 3 data, but, for example, we could not see (Fig. 6a) the onset of the La Niña on the ~90-180W region in February 2007, as indicated by the NOAA SST analyses. Fortunately, 8-day averages are also standard AIRS level 3 products, so we made use of them for the purpose of creating the equatorial hovmoller diagrams. Fig. 6b clearly

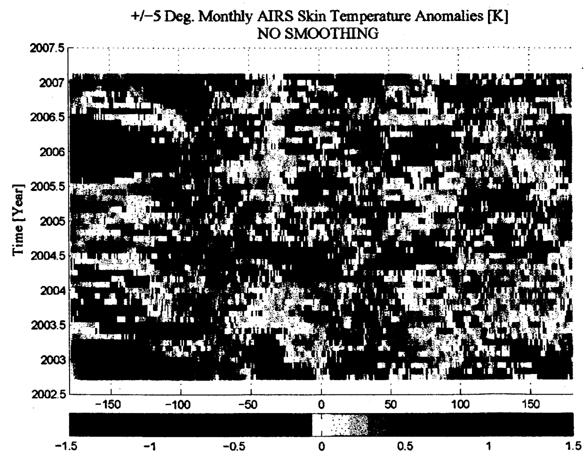


Figure 6a

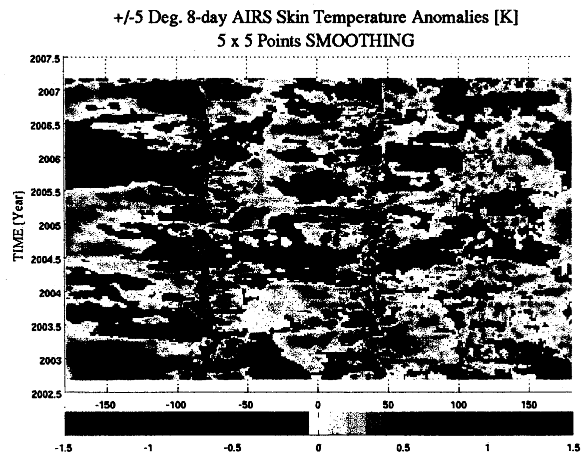


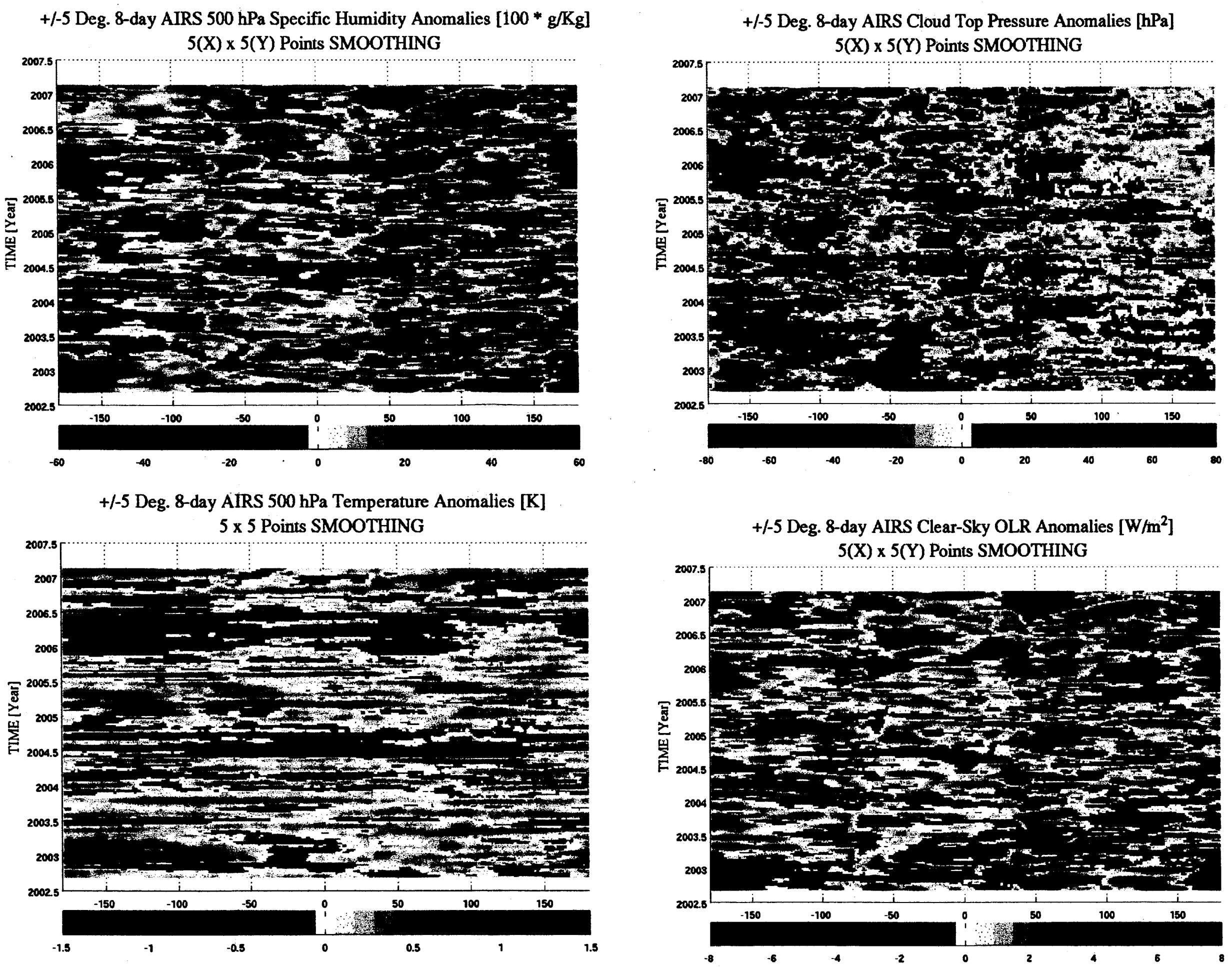
Figure 6b

shows the appearance (upper left corner) of cold SST anomalies in February of this year. Figure 7 consist of an ensemble of additional 5 panels of 8-day temporal and +/-5° latitudinal average based hovmoller plots. Physical relationships among several variables are visible in these plots, in particular between UTH (here, specific humidity above 500 hPa) and clear sky OLR, UTH and effective cloud fraction (A_{eff}), A_{eff} and clear sky OLR, as well as skin temperature and cloud top pressure (C_{tp}). These relationships are underlined by the high cross-correlation values shown in bold typeface in Table I, *i. e.,* real physical connections are likely. Though not shown, the +/-10° latitudinal average based hovmoller plots show very similar (slightly subdued) patterns and (slightly smaller) cross-correlations.

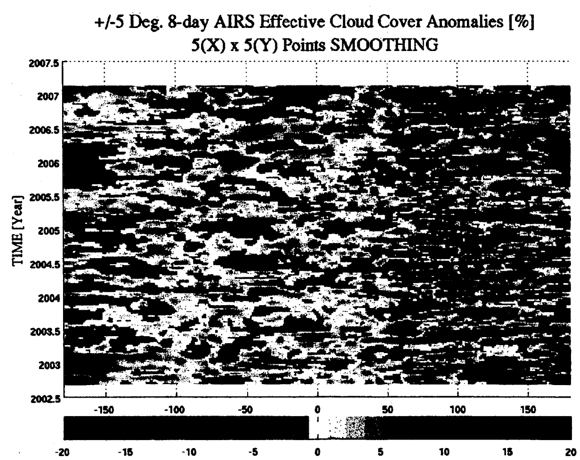
Table I: Correlations between anomalies of climatic variables for the trendmaps (regular typeface) and for the +/- 5° latitude belt Hovmoller maps (bold typeface).

	T_{skin}	Clear-Sky OLR	"UTH"	A_{eff}	C_{tp}
T_{skin}		0.78	0.12	0.10	0.04
Clear-Sky OLR	**-0.04**		-0.23	-0.11	0.05
"UTH"	**0.21**	**-0.88**		0.28	-0.21
A_{eff}	**0.09**	**-0.76**	**0.76**		0.15
C_{tp}	**-0.47**	**0.21**	**-0.24**	**-0.11**	

Next, we've turned our attention to large-scale anomaly timeseries: global, tropical and regional. For "regions", based on the hovmoller analyses and the ongoing El Niño/La Niña conditions, we've selected "Region#1" as the +/-5°, 120-180W region, and the 50% larger +/-5°, 90-180W region as "Region#2". Fig 8a shows the timeseries of the global mean AIRS monthly anomalies. We can see that clouds are definitely extend higher in



the atmosphere, and surface sky OLR both increase in much of any "trend" is region depicted on Fig .8b, pronounced increase in correlations among these presented in Table II, interesting story: Notice the correlation between the temperature and UTH. This been rather high and water vapor climate predicted by GCMs and In fact, the only places we positive correlation are



temperature and clear-this 4.5 yr period. Not apparent in the tropical except the still cloud top height. Cross-anomaly timeseries, however, tell an week *negative* global mean surface number should have *positive*, in case the feedback operated as conventional wisdom. do have a strong "Region#1" and

Figure 7

"Region#2", *i.e.,* the warmest equatorial areas (see Table III). Apparently, leaving the deep tropics, the assumed to be all powerful water vapor feedback fades, actually to oblivion in a global sense. This, in turn, leads to less amplified greenhouse warming in the global sense, a kind of in line with Lindzen's old suggestion[5]. In the deep tropics, by the way, all the cross-correlations among the climate variables considered in this study are quite high, as Fig. 8c also attests, showing five of the "Region#1" anomaly timeseries.

Table II: Correlations between anomaly timeseries of climatic variables for the Globe (regular typeface) and for the Tropics (bold typeface).

	T_{skin}	Clear-Sky OLR	"UTH"	A_{eff}	C_{tp}
T_{skin}		0.80	-0.08	-0.36	-0.55
Clear-Sky OLR	**0.42**		-0.32	-0.28	-0.61
"UTH"	**0.14**	**-0.53**		0.25	0.44
A_{eff}	**-0.30**	**-0.33**	**0.47**		0.55
C_{tp}	**0.18**	**-0.18**	**0.32**	**0.36**	

Table III: Correlations between anomaly timeseries of climatic variables for Region#1 (regular typeface) and for Region#2 (bold typeface).

	T_{skin}	Clear-Sky OLR	"UTH"	A_{eff}	C_{tp}
T_{skin}		-0.53	0.66	0.70	-0.70
Clear-Sky OLR	**-0.53**		-0.93	-0.84	0.64
"UTH"	**0.69**	**-0.92**		0.87	-0.61
A_{eff}	**-0.71**	**-0.78**	**0.85**		-0.57
C_{tp}	**-0.66**	**0.50**	**-0.52**	**-0.40**	

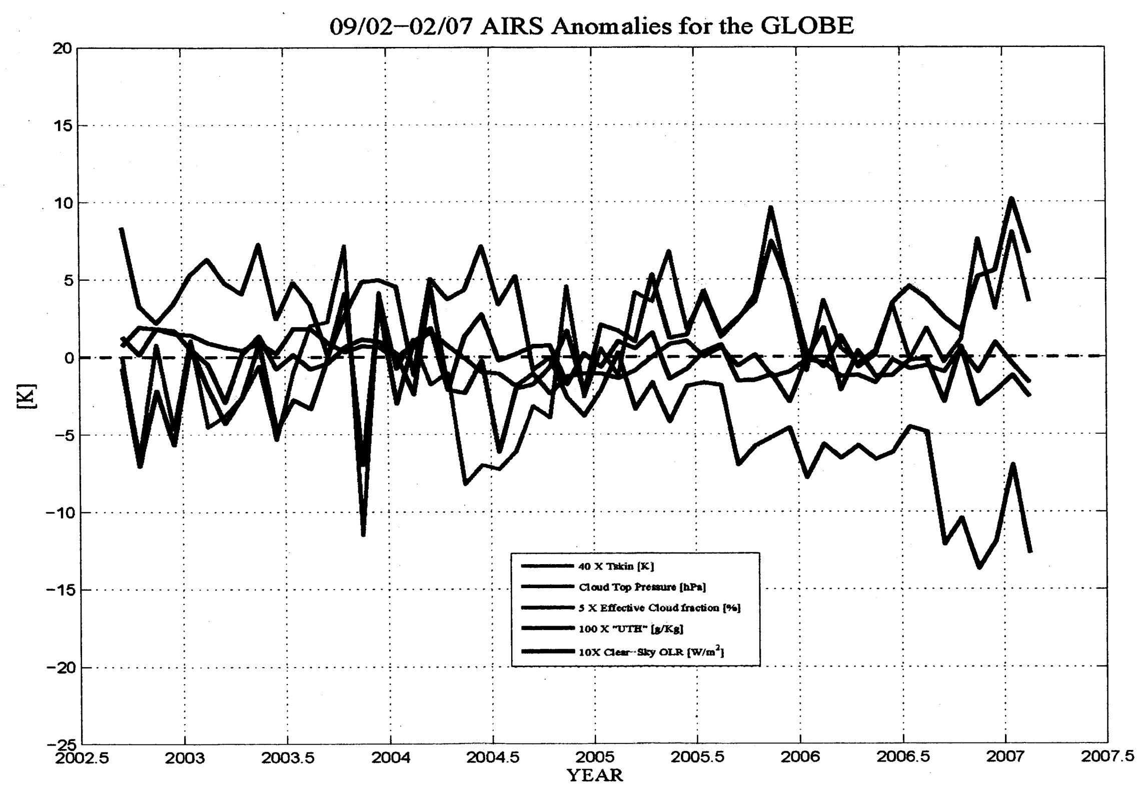


Figure 8a

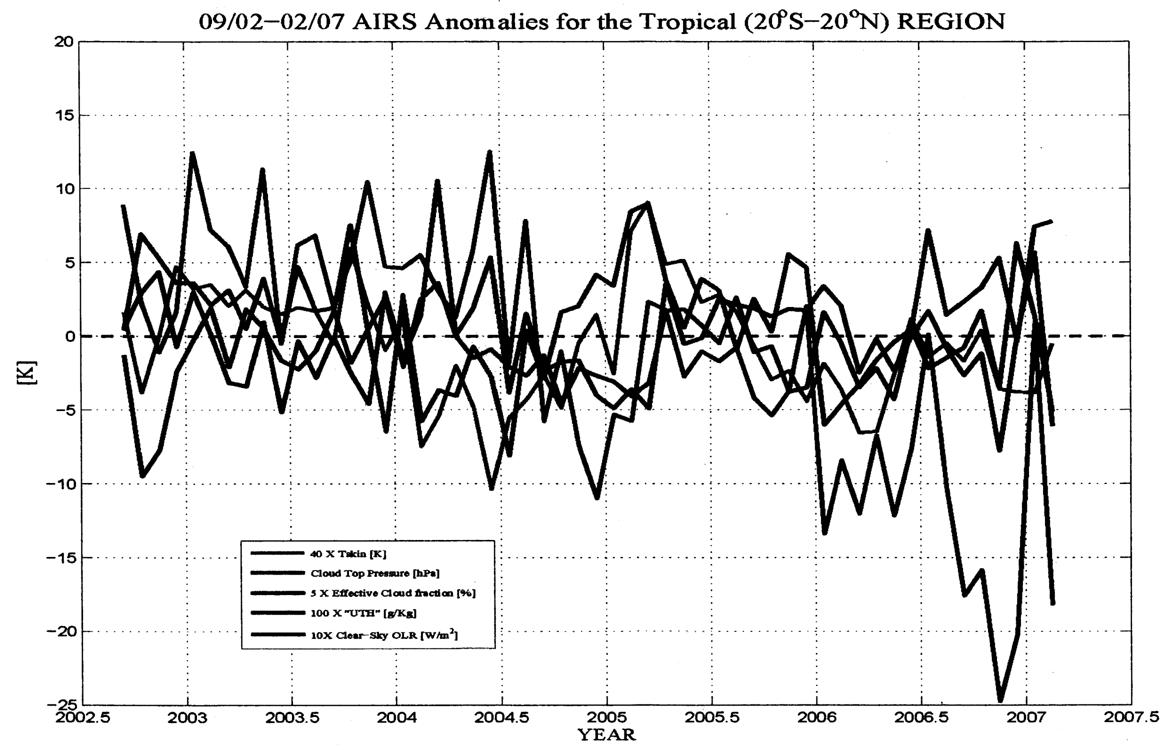


Figure 8b

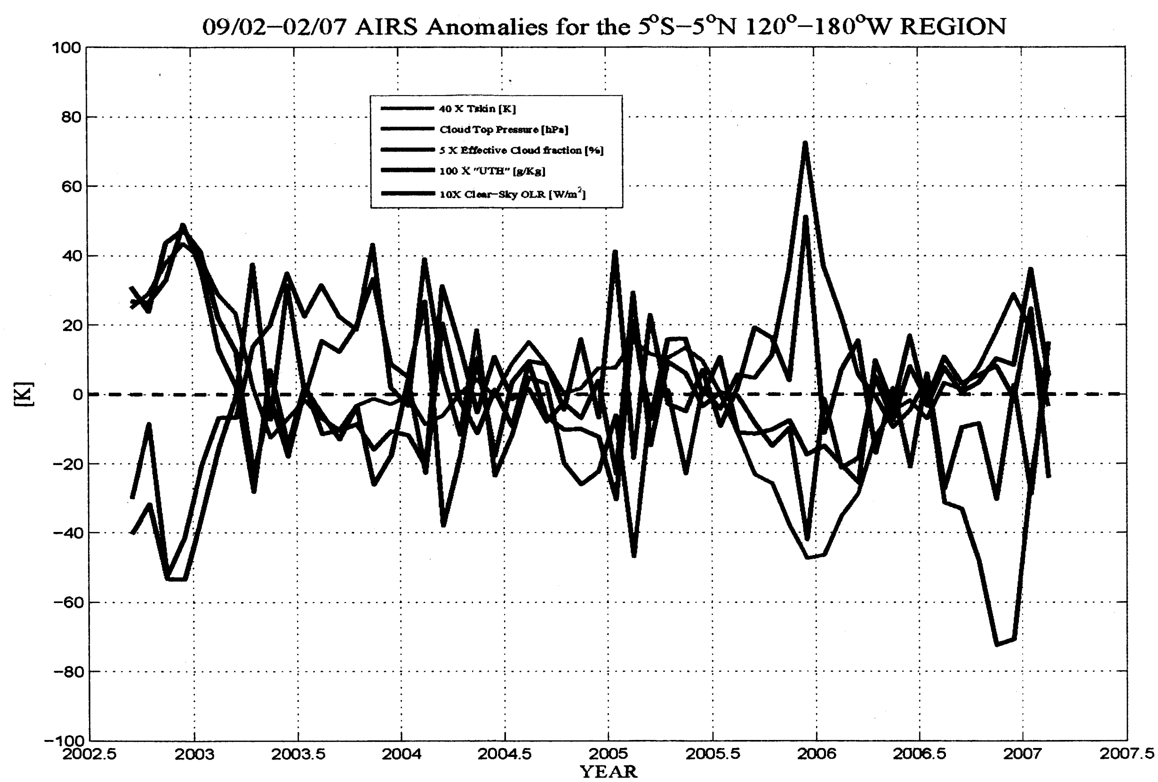


Figure 8c

4. SUMMARY

The AIRS Version 4.0 monthly mean and 8-day average products as well as their temporal and spatial anomalies show reasonable consistency with each other and with other satellite products. Spatial and temporal interdependencies and correlations are also well represented by the (so far 4.5 yrs-long) AIRS Version 4.0 monthly and 8-day gridded retrievals. Version 5.0 (see Joel SUSSKIND's paper elsewhere in this issue), which DAAC will start processing before the middle of 2007, offers even better AIRS retrieval results for long-term assessments. Version 5.0 (and the future Version 6.0) will be even more useful for climate purposes because the spatial coverage of the Version 5.0 level 2 products (from which the level 3 products introduced here were created) is better. It is also independent of the microwave retrievals to a large extent and has additional products like all-sky OLR and Coarse Climate Indicators.

Nevertheless, even this preliminary evaluation Version 4.0 retrievals provides several "climatic" insights. For example:

- The change of the global mean temperature profile over the first 4 years of AIRS operation is fully consistent with GCM predictions for greenhouse warming as well as with independent measurements: surface and lower tropospheric warming and mid- and upper-tropospheric as well as stratospheric cooling. Meanwhile, in the Tropics, surface and upper tropospheric warming as well as mid-tropospheric and stratospheric cooling are observed, as expected. However, the magnitudes appear to be too large.

- On the other hand, the water vapor feedback, computed by models to enhance the greenhouse gas increase-induced greenhouse warming by about 60%, may not be operating as predicted. In fact, these admittedly short-term AIRS data analyses show that on the *global* scale, surface skin temperature and UTH exhibit a (week) *negative* correlation instead of the expected strong positive correlation. Of course, even if this finding remains to be robust, it would just mean that the greenhouse warming will be closer to the lower limit of the predicted range than to the upper one, *i. e.,* we still have to worry about it.

- Of course, these considerations are still preliminary, so we are planning to extend the scope of these initial assessments, including comparative validation studies using other, independent atmospheric parameter measurements.

- Obviously, to assess such climatic questions more reliably, the effects of potential instrumental drifts have to be severely limited, for example. We also need to compile the longest possible satellite sounder-based climatology, so we are also working on its *backward* extension, by integrating it with the *other* sounder-based climate dataset, namely the TOVS Pathfinder "Path-A" retrievals, available from 1979 through 2004. We hope that the AIRS-based dataset will complement/continue these satellite-sounder-based climatologies well into the future.

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