

## **AIRS observations of DomeC in Antarctica and comparison with Automated Weather Stations<sup>1</sup>**

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### **Abstract**

We compare the surface temperatures at Dome Concordia (DomeC) deduced from AIRS data and two Automatic Weather Stations at Concordia Station: AWS8989 , which has been in operation since December 1996, and AWS.it, for which data are available between January and November 2005. The AWS8989 readings are on average 3 K warmer than the AWS.it readings, with a warmer bias in the Antarctic summer than in the winter season. Although AIRS measures the skin brightness temperature, while the AWS reports the temperature of the air at 3 meter above the surface, the AIRS measurements agree well with the AWS.it readings for all data and separately for the summer and winter seasons, if data taken in the presence of strong surface inversions are filtered out. This can be done by deducing the vertical temperature gradient above the surface directly from the AIRS temperature sounding channels or indirectly by noting that extreme vertical gradients near the surface are unlikely if the wind speed is more than a few meters per second. Since the AIRS measurements are very well calibrated, the agreement with AWS.it is very encouraging. The warmer readings of AWS8989 are likely due to thermal contamination of the AWS8989 site by the increasing activity at Concordia Station. Data from an AWS.it quality station could be used for the evaluation of radiometric accuracy and stability of polar orbiting sounders at low temperatures. Unfortunately, data from AWS.it was available only for a limited time. The thermal contamination of the AWS8989 data makes long-term trends deduced from AWS8989 and possibly results about the rapid Antarctic warming deduced from other research stations on Antarctica suspect.

AIRS is the first hyperspectral infrared sounder designed in support of weather forecasting and climate research. It was launched in May 2002 on the EOS Aqua spacecraft into a 704 km altitude polar sun-synchronous orbit. The lifetime of AIRS, estimated before launch to be at least 5 years is, based on the latest evaluation, limited by the amount of attitude control gas on the EOS Aqua spacecraft, which is expected to last through 2015.

### **Introduction**

Our interest in looking at data from Antarctica was motivated by two considerations:  
1) A recent paper (Turner et al. 2006) claimed that, based on balloon launches from a

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number of research stations, the winter troposphere in the Antarctic has been warming at a rate of 0.6 K/decade, almost an order of magnitude faster than the 0.1 K/decade rise of the global mean temperature. It was expected that the temperature in the Antarctic would respond more rapidly to the global warming effects than the global average due to the very low winter temperatures, which reach below 200 K, but this large response was not expected. The first four years of AIRS data could be used to looking for enhanced warming trends in Antarctica.

2) The validation that a polar orbiting satellite infrared sounder produces climate quality data requires observations over a wide range of temperature conditions and long time spans. Polar orbiting satellites have many overpasses each day of Antarctica, and the combination of low temperatures and the availability of ground truth data can support this validation effort.

As a first step in this effort we report in this paper on observations limited to a 50 km circle centered on the Concordia research station, located at DomeC, a large plateau at 3250 meter above sea level at longitude E123.4, latitude -75.4 degrees, and a comparison of these data with two Automatic Weather Stations (AWS) at DomeC. One AWS, managed jointly by USA (Univ. of Wisconsin) and France (IPEV), is called "Dome C II", Argos ID is 8989. We refer to it as AWS8989. Data are available from <http://uwamrc.ssec.wisc.edu/> since December 1995 at 10 minute intervals. Apparently due to the concern that the expansion of the facilities at DomeC may be contaminating the readings from AWS8989, researchers funded by the Italian Space Agency installed an AWS a few km from AWS8989, at a location considered to be less sensitive to the potential thermal contamination. We refer to the data from this station as AWS.it. Measurements taken every hour between 27 January 2005 through 17 November 2005 are available from

<http://www.climantartide.it/accesso-ai-dati/dati-stazioni-utenti.php?lang=en>

In the following we compare the temperatures reported by the two AWS with AIRS measurements.

### **AIRS Overview**

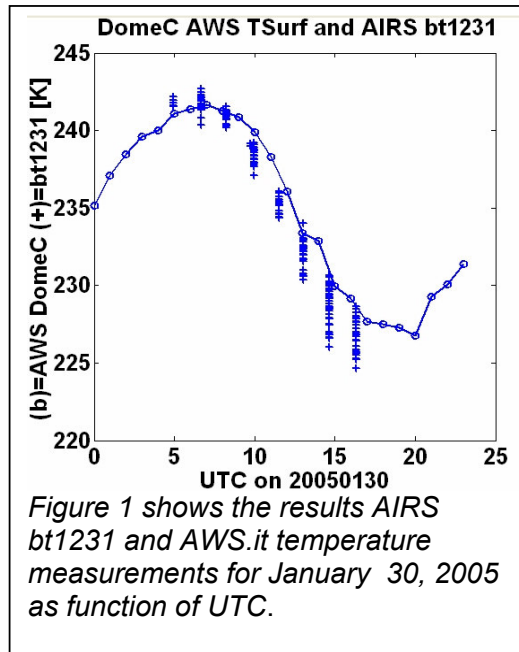
AIRS is a cross-track scanning grating array spectrometer, which covers the 650 – 2700 cm<sup>-1</sup> region of the infrared spectrum with 2378 independent spectral channels. The AIRS footprint diameter at nadir is 13.5 km. Details of the AIRS design are found in Aumann et al. 2003. AIRS was launched in May 2002 on the EOS Aqua spacecraft into a 704 km altitude polar sun-synchronous orbit with 14 orbits per day and 1:30 PM ascending node. The orbit is precisely maintained to eliminate confusion of climate trends with the diurnal temperature cycle.

AIRS was designed to meet the requirements of NOAA for weather forecasting and the requirements of NASA for climate, atmospheric composition and process research. The first goal of achieving global radiosonde equivalent sounding accuracy and forecast impact under clear and cloudy conditions has already been achieved (Chahine et al. 2006). Of particular interest from the climate viewpoint is that AIRS was designed from the start to generate climate quality data. The key to this was the minimization of the

moving parts count and active thermal control at the 10 mK level of the entire spectrometer. This literally freezes the calibration into the design at a temperature of 156 K. AIRS uses a fairly standard two point radiometric calibration, consisting of four cold space views and one view of a full aperture wedge cavity blackbody every 2.7 seconds. The absolute radiometric calibration is NIST traceable, and has been validated to within 200 mK for moderate temperatures (Tobin et al. 2006) and under Antarctic conditions (Walden et al. 2006). Comparison of MODIS Aqua, AIRS and HIRS/3 data for overpasses of Antarctica (Broberg et al. 2006) show a radiometric bias of less than 20 mK for temperature between 200 and 260 K. The radiometric stability has been validated using the 2616 cm<sup>-1</sup> window channel for temperatures in the 280-310 K range and under clear night conditions using the RTGSST (Thiébaux et al. 2003) at the better than 16 mK/year level (Aumann et al. 2006) using the first three years of AIRS data.

## Results

The +/-49 degree cross-track scan pattern of AIRS yields typically eight overpasses of DomeC each day. For these overpasses we have collected all spectra within 50 km radius of DomeC. Typically this results in 230 spectra per day. These measurements can be used by themselves, or they can be matched up with the temperatures reported



by the AWS. An AWS is typically mounted 3 meters above the surface, where it measures the temperature of the air, air pressure and wind velocity. Technically, the AIRS measurements are the brightness temperature of the surface. For the emissivity of ice/snow of 0.98 the brightness temperature is about 0.3 K lower than the physical skin temperature.

Figure 1 shows the results of AIRS and AWS.it for January 30, 2005 as function of UTC. The temperatures measured by the AIRS 1231 cm<sup>-1</sup> channel, bt1231, are shown as "+" points, the AWS.it measurements ("o") are connected in a line. The AIRS overpasses are spaced at about 1.5 hour intervals, while the AWS.it readings are produced every hour on the hour. The AIRS bt1231 tracks the diurnal cycle as the temperature drops from 242 K to 227 K, typical for an Antarctic summer day.

While the general agreement is good, AIRS bt1231 reads are increasingly colder at the lower temperatures. The reason for the discrepancy is due to the fact that AIRS measures the surface skin brightness temperature, while the AWS measures the temperature at a point 3 meters above the surface. One would expect that gradient between the surface and 3 meter above the surface is highly correlated with the vertical

gradient in the temperature in the lowest part of the atmosphere, particularly due to surface inversions, and that strong vertical gradients near the surface would be unlikely in the presence of significant wind near the surface. This is in fact what is observed.

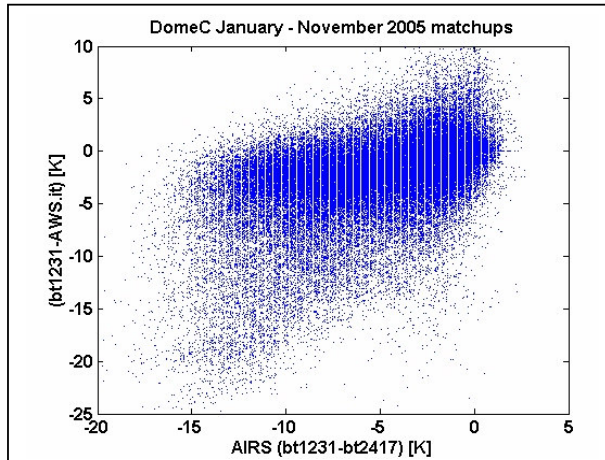


Figure 2. The difference between bt1231 and the AWS.it temperature shows a strong dependence on the surface temperature gradient.

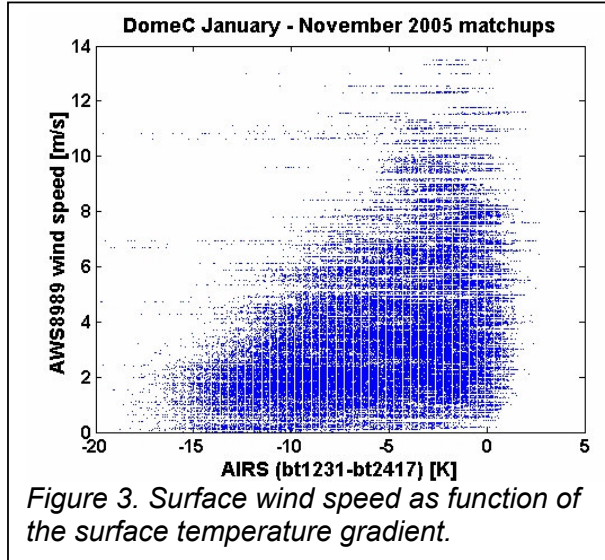


Figure 3. Surface wind speed as function of the surface temperature gradient.

Figure 2 shows the difference between bt1231 and AWS.it as function of the difference between the 1231 cm<sup>-1</sup> window channel and the 2417 cm<sup>-1</sup> CO<sub>2</sub> sounding channel, bt2417, for all 75661 matchups between AIRS and AWS.it from January through November 2005. Under polar conditions bt2417 represents the mean temperature in a several kilometer thick layer above the surface. Note that bt2417 is seldom colder, but is mostly warmer than the surface, sometimes by as much as 20 K. This is the opposite to temperature profiles under mid-latitude conditions, where the temperature decreases at 6 K/km with increasing altitude and bt2417 is typically 6 K colder than the surface. The existence of large surface inversions in the Antarctic is well known. If the warming in the first kilometer is less than a few K, the agreement between bt1231 and AWS.it is very good, but it degrades as the gradient gets larger. This gradient is absent in presence of significant surface wind speed. This is shown in Figure 3. In order to make a statistically meaningful comparison between the surface air temperature reported by AWS.it and bt1231, cases with a large surface gradient have to be eliminated. The prescription for filtering out cases

with large surface inversions is somewhat arbitrary. For AIRS data we simply eliminate all data with (bt1231-bt2417) in excess of some value, -3 K or -4 K. For infrared sounders where the 2417 cm<sup>-1</sup> channel is not available, such as HIRS/3, MODIS or CrIS, or where the 2417 channel is too noisy, as in IASI, one could eliminate all data where the surface wind speed reported by the AWS is less than some minimum value, 6 or 8 m/s.

Table 1. summarizes the results of such filtering. We use medians rather than means to suppress the effects of gross outliers.

	bt1231-AWS.it	pop. stdev	yield
all matchups	-1.91 K		75661
v>6 m/s	-0.39 K	2.1 K	11264
v>8 m/s	-0.31 K	2.0 K	4221
bt1231-bt2417>-4 K	-0.30	2.5	31694
bt1231-bt2417>-3 K	-0.17	2.4 K	24689

*Table 1.*

Either of the suggested filter schemes will drop the bias between the surface air temperature and the surface skin temperature to a fraction of one degree K, but with significant differences in the yield, the residual bias and the scatter in the data. The preferred method, bt1231-bt2417>-3 K has a bias of -0.17 K, with a yield of 32%.

The interpretation of the data from AWS8989 is more complicated. Figure 4 shows the temperatures reported by AWS8989 for all of the year 2005 as function of time in blue, with the temperature reported by AWS.it in red.

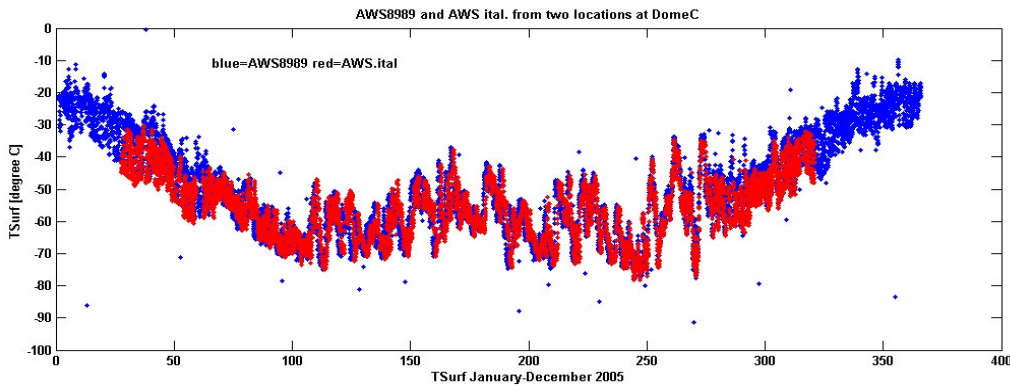


Figure 4. The temperatures reported by AWS8989 for all of the year 2005 as function of time (blue), appear to agree well with the temperature reported by AWS.it (red).

	bt1231-AWS898	pop. stdev	yield
all matchups	-3.55 K	3.27	75661
v>6 m/s	-2.40 K	2.4 K	11264
v>8 m/s	-2.1 K	2.1 K	4221
bt1231-bt2417>-4 K	-3.27	3.4 K	31694
bt1231-bt2417>-3 K	-3.26	3.5 K	24689

*Table 2.*

At first glance the agreement is very reasonable. A closer look shows the presence of a strong season dependent bias. AWS8989 reads consistently warmer in the winter than AWS.it. Table 2, which repeats the results of season independent filtering with the AWS8989 surface temperatures, shows that AWS8989 is biased warm by about 3 K relative to AWS.it.

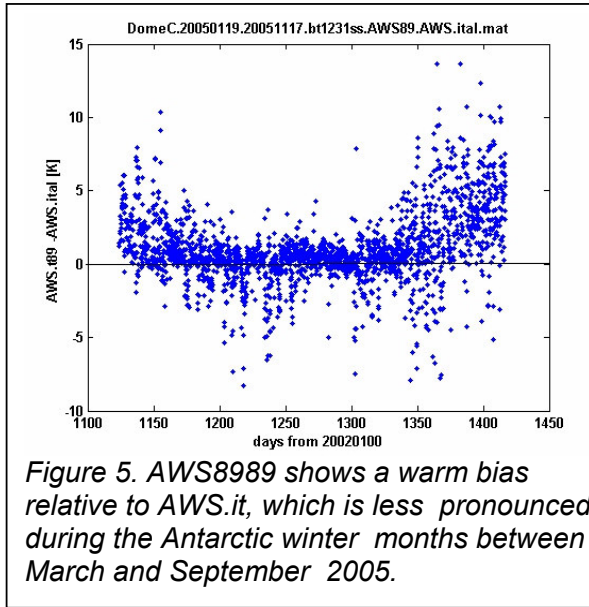


Figure 5 shows the difference between the temperatures reported by AWS8989 and AWS.it. There is a warm bias at all times, which is particularly pronounced during the Antarctic summer months, in Figure 5 before about day 1170 (March 2005) and after day 1350 (September 2005), counting from January 0, 2002.

Table 3 compares the results for the two AWS for data from summer and winter season for two possible vertical gradient filtered data, showing the median(AWS8989-bt1231) and median(AWS.it-bt1231). Only the AWS.it data show a consistently low bias relative to AIRS summer and winter using the (bt1231-bt2417) lapse rate filter.

**Discussion**

	bt1231-AWS8989	bt1231-AWS.it	AWS8989 -AWS.it
summer			+2.71 K
v>6 m/s	-2.85 K	-0.14 K	+2.26 K
bt1231-bt2417>-3 K	-4.16 K	-0.17 K	+3.72 K
winter			+0.36 K
v>6 m/s	-1.76 K	-0.99 K	+0.70 K
bt1231-bt2417>-3 K	-0.60 K	+0.06 K	+0.70 K

*Table 3.*

The AWS.it surface air temperatures agree very well with the AIRS bt1231 surface brightness temperature measurement, if a simple lapse rate filter is applied. The AWS8989 data are biased warm by about 3 K relative to AWS.it in the summer, but considerably less, 0.4 K,

during the winter season. Since AIRS agrees with AWS.it during both seasons within a fraction of one degree using the lapse rate filtered data for all matchups within a 50 km radius of Concordia Station, the difference between the two AWS is not one of calibration offset, but of the location relative to Concordia Station. The AWS.it data show consistently low bias relative to AIRS summer and winter. The AWS8989 set is biased warmer in the summer no matter which filter is used, but neither filter produces consistent results during the winter and summer seasons.

Our interest in looking at the AWS on DomeC was partly motivated by our interest in verifying the absolute calibration accuracy and stability of polar orbiting satellites, with AWS 8989 providing data as far back as 1997. The discovery of the warm and likely time dependent bias make AWS8989 less attractive. The very good agreement with AWS.it with surface inversion filtered data is very encouraging for the evaluation of the

radiometric accuracy and stability of current and future polar orbiting sounders at low temperatures. Unfortunately, data from AWS.it appears to have been available only for a limited time.

A cold bias due to cloud contamination is notorious for infrared sounder data. Careful inspection of the DomeC spectra show the drop in the brightness temperatures between 961 and 790  $\text{cm}^{-1}$  characteristic of snow/ice, but, at least statistically, no infrared evidence of the frequency independent spectra of "normal" clouds. The cold bias due to "normal" clouds under conditions of "normal" lapse rates of 6 K/km or more is due to the fact that infrared radiation from the surface is blocked by the clouds and re-radiated at a lower cloud top temperature. Optically thick clouds, if present at DomeC with the typical temperature inversion, would create a warm bias, which is not observed. This apparently minimal effects of clouds increase the appeal of DomeC for the calibration of Polar orbiting sounders.

Our interest regarding long-term trend evaluation relative to AWS8989 has to be re-evaluated given that AWS8989 appears to be contaminated by a season and likely long-term time dependent signal related to the increased activities at Concordia Station. Due to the extremely low temperatures, all AWS operated on Antarctica are very sensitive to thermal contamination, always in the direction of warmer temperatures. If similar thermal contamination is typical for a significant fraction of AWS on Antarctica, then some of the conclusions regarding the rapid warming of Antarctica may well be overstated.

## **Conclusions**

We compare the surface temperatures at DomeC deduced from AIRS data and two Automatic Weather Stations: AWS8989, which has been in operation since December 1996, and AWS.it, for which data are available between January and November 2005. The AWS8989 readings are on average 3 K warmer than the AWS.it readings, with a warmer bias in the Antarctic summer than in the winter season. Although AIRS measures the skin brightness temperature while the AWS reports the temperature of the air at 3 meters above the surface, the AIRS measurements agree well with the AWS.it readings for the summer and winter seasons, if data taken in the presence of strong surface inversions are filtered out. This can be done by deducing the vertical gradient above the surface directly from the AIRS temperature sounding channels or indirectly, albeit less efficiently, by noting that extreme vertical gradients near the surface can exist only if the wind speed is small. Since AIRS measurements are very well calibrated, the agreement with AWS.it is very encouraging. The warmer readings of AWS8989 are likely due to thermal contamination of the AWS8989 site by the increasing activity at Concordia Station. Data from an AWS.it quality station could be used for the evaluation of radiometric accuracy and stability of polar orbiting sounders at low temperatures. Likely thermal contamination limits the application of AWS8989 temperatures to quick-look validation and makes long-term trends suspect.

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## References

- Aumann, H.H. , M.T. Chahine, C. Gautier, M. Goldberg, E. Kalnay, L. McMillin, H. Revercomb, P.W. Rosenkranz , W. L. Smith , D. H. Staelin, L. Strow and J. Susskind, 2003, "AIRS/AMSU/HSB on the Aqua Mission: Design, Science Objectives, Data Products and Processing Systems", IEEE Trans. Geosci. Remote Sens., **41**, pp.253-264.
- Aumann, H. H.; Broberg, Steve; Elliott, Denis; Gaiser, Steve; Gregorich, Dave, 2006 "Three years of Atmospheric Infrared Sounder radiometric calibration validation using sea surface temperatures" J. Geophys. Res., Vol. 111, No. D16, D16S90 10.1029/2005JD006822 23 August 2006
- Broberg, S.E., H. H. Aumann, D.T. Gregorich and X. Xiong. 2006 « Evaluation of AIRS, MODIS, and HIRS 11 micron brightness temperature difference changes from 2002 through 2005" Proc. SPIE San Diego August 2006 6296-22.
- Chahine, M.T., T.S. Pagano, H. H. Aumann, R. Atlas, C. Barnet, J. Blaisdell, L. Chen, M. DivaKarla, E.J. Fetzer, M. Goldberg, C. Gautier, S. Granger, S. Hannon, F.W. Irion, R. Kakar, E. Kalnay, B.H. Lambrigtsen, S.Y.Lee, J. LeMarshall, W.W. McMillan, L.McMillin, E.T. Olsen, H. Revercomb, P. Rosenkranz, W.L. Smith, D. Staelin, L.L. Strow, J.Susskind, D.Tobin, W.Wolf and L. Zhou, 2006 «AIRS: Improving Weather Forecasting and Providing New Data on Greenhouse Gases », BAMS July 2006, **87**, 7, pp. 911-926.
- Thiébaux , Jean, Eric Rogers, Wanqiu Wang and Bert Katz (2003), "A New High-Resolution Blended Real-Time Global Sea Surface Temperature Analysis", BAMS, 84(5), 645-656.
- Tobin, David C.; Revercomb, Henry E.; Knuteson, Robert O.; Best, Fred A.; Smith, William L.; Ciganovich, Nick N.; Dedecker, Ralph G.; Dutcher, Steven; Ellington, Scott D.; Garcia, Raymond K.; Howell, H. Benjamin; LaPorte, Daniel D.; Mango, Stephen A.; Pagano, Thomas S.; Taylor, Joe K.; van Delst, Paul; Vinson, Kenneth H.; Werner, Mark W. ,2006 « Radiometric and spectral validation of Atmospheric Infrared Sounder observations with the aircraft-based Scanning High-Resolution Interferometer Sounder". J. Geophys.Res., Vol. 111, No. D9, D09S02 10.1029/2005JD006094
- J. Turner, T. A. Lachlan-Cope, S. Colwell, G. J. Marshall, W. M. Connolley, 2006 "Significant Warming of the Antarctic Winter Troposphere", SCIENCE 31 March 2006: Vol. 311. no. 5769, pp. 1914 – 1917 DOI: 10.1126
- Walden, V. P.; Roth, W. L.; Stone, R. S.; Halter, B., 2006 "Radiometric validation of the Atmospheric Infrared Sounder over the Antarctic Plateau" J. Geophys. Res., Vol. 111, No. D9, D09S03 10.1029/2005JD006357 12 May 2006

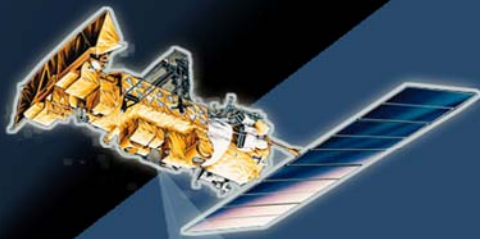


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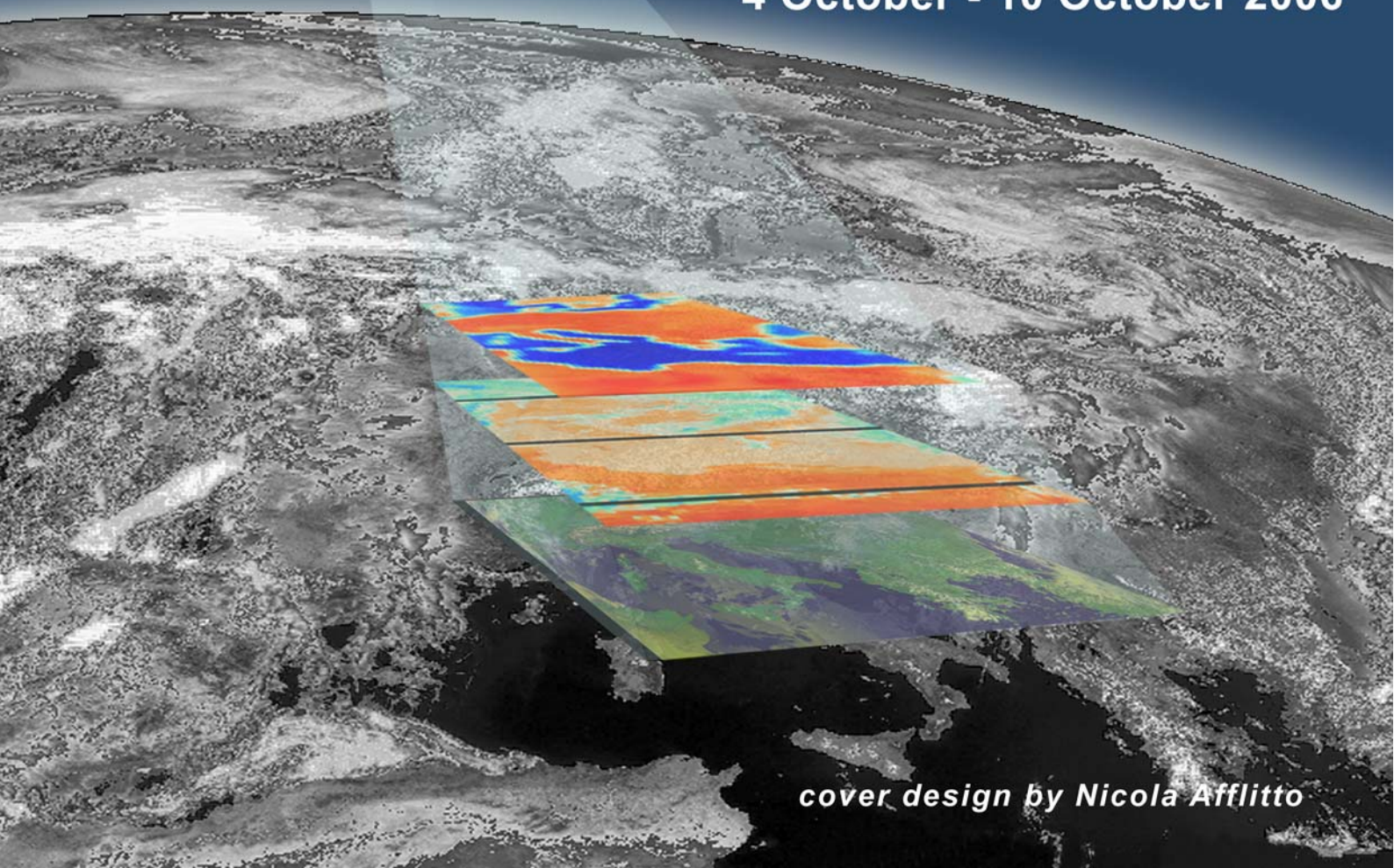
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