Satellite Assimilation Activities for the NRL Atmospheric Variational Data Assimilation (NAVDAS) and NAVDAS-AR

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Introduction

The U.S. Navy's three-dimensional variational analysis system NAVDAS became operational at Fleet Numerical Meteorology and Oceanography Center (FNMOC) on October 1, 2003, paving the way for the direct assimilation of satellite radiances with the U.S. Navy's global[1] and mesoscale[2] numerical weather prediction models. AMSU-A radiance assimilation, which became operational at FNMOC on June 9, 2004, significantly improved the forecast skill: the two- to five-day forecast skill at 500 hPa increased by 3-10 hours in the Northern Hemisphere (Fig. 1a) and by 12-20 hrs in the Southern Hemisphere (Fig. 1b), compared to ATOVS retrieval control runs. Tropical cyclone track prediction skill also increased at all forecast ranges out to 5 days. Subsequent observation system experiments demonstrated that assimilation of ATOVS retrievals actually degrade NOGAPS tropical cyclone track forecasts, while assimilation of AMSU-A radiances improves the track forecasts (see Fig. 2).

The AMSU-A assimilation data selection, quality control and operational bias correction procedures are described in Baker et al. (2005). Although not apparent during the initial multiple-month assimilation tests prior to operational implementation, the AMSU-A bias correction procedure reinforces NOGAPS polar stratospheric biases, ultimately leading to occasional rejection of the Antarctic radiosondes by NAVDAS. The problem occurs because NOGAPS forecast errors are correlated with the bias predictors. The operational bias correction method uses seven predictors, as described in Campbell et al. (2004). They are the 1000-300 hPa tropospheric thickness and 200-50 hPa stratospheric thicknesses, modulated by the square of the sine and cosine of the latitude, skin temperature, NOGAPS total precipitable water and the derivative of the cloud liquid water equation (from Grody et al. 1999). The primary culprits leading to the feedback with the model bias were the skin temperature and the sine and cosine weighting of the thicknesses. The sine and cosine weighting gives too much weight to polar observations. The problems with the skin temperature are more subtle, as the stratospheric biases in the analyses are largely due to the assimilation of higher peaking AMSU-A channels (e.g. channels 8-11) that are not sensitive to the skin temperature. Instead, what

[1] Navy Operational Global Atmospheric Prediction System (NOGAPS)
[2] COAMPS® is a registered trademark of the Naval Research Laboratory

occurs is that errors in the model thicknesses (both tropospheric and stratospheric) are correlated with the model skin temperature – and this leads to the AMSU-A bias correction reinforcing the NOGAPS model bias.

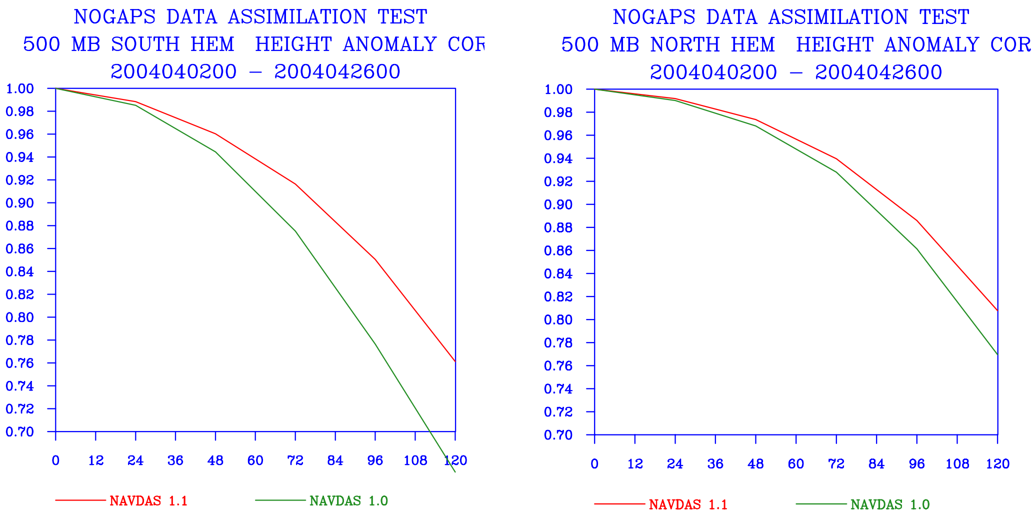

Fig. 1: Comparison of 500 hPa geopotential height anomaly correlations for the pre-operational tests with AMSU-A radiances (red line) and NESDIS ATOVS retrievals (green line). The assimilation period was from April 2, 2004 through April 26, 2005. The forecast improvement for the Southern Hemisphere is shown on the left, while the Northern Hemisphere results are on the right.

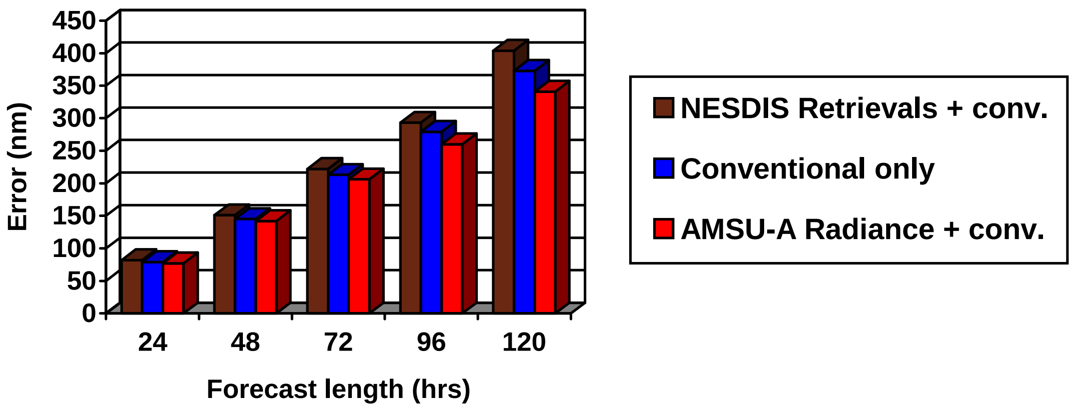

Fig. 2: Comparison of tropical cyclone track forecast skill for NOGAPS/NAVDAS for August 1, 2004 through September 30, 2004. The brown bars are for an assimilation run using conventional observations, plus NESDIS ATOVS retrievals, while the blue bars are for an assimilation run with conventional observations only (no satellite sounder data), and the red bars are for an assimilation run with conventional observations, plus AMSU-A radiances. The horizontal axis is the forecast length in hours, and the vertical axis is the track error (as verified against the post season best track) in nautical miles. The numbers of forecasts for each verification period are 289, 249, 212, 174 and 142.

Over the past year, we performed numerous tests to understand the source of this feedback, and to extensively test the most promising alternate bias correction scheme. Two methods, patterned after Harris and Kelly (2001) emerged as likely candidates. The observations are scan corrected first, using corrections derived for 18 separate latitude bands. A global air mass correction is computed using the 850-300 hPa and the 200-50 hPa thicknesses as predictors. The second method includes a predictor based on the computed cloud liquid water (following the operational scheme described above). The standard deviations of the bias-corrected innovations using the cloud liquid water based predictor are approximately 0.1K smaller for AMSU-A channel 4, suggesting that this predictor essentially corrects for small amounts of cloud liquid water below the QC threshold of 0.22 g/kg.

Both bias correction methods have proven to be stable over many months of assimilation, with no rejection of the polar radiosondes. Both substantially improve the fit of the analyses and forecasts, as compared against other observations, above 200 hPa or so, although there is little difference in tropospheric forecast skill, as measured by typical metrics such as the 500 hPa geopotential height anomaly correlation. The 100 hPa analyzed temperature difference between the operational analysis and the new analysis produced using the two-predictor method is shown in Fig. 3 for 00 UTC March 24, 2006. The differences (up to 10K) are most pronounced at the poles, and are minimal in the tropics.

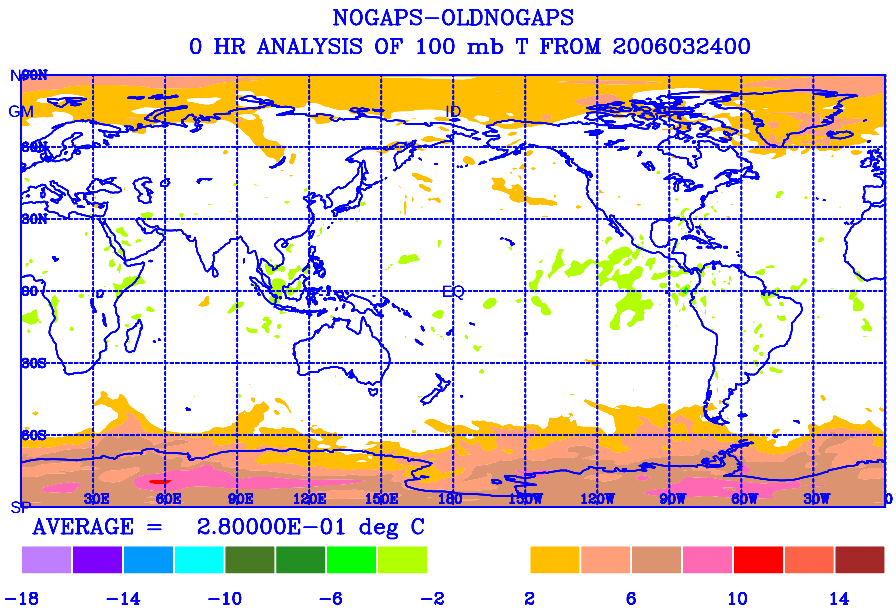

Fig. 3: 100 hPa temperature differences for two analyses valid March 24, 2006 at 00 UTC from assimilation runs using the two-predictor bias correction (NOGAPS) as compared to the operational bias correction (OLDNOGAPS).

The forecast skill in the Southern Hemisphere is slightly better for the method that includes the cloud liquid water predictor, although the differences are often not statistically significant. Because cloud liquid water is not computed over land, ice and snow, we have opted to implement the two predictor method for the sake of consistency between surface types. We have found that the new bias correction method is required to optimize the assimilation of new satellite observations, such as refractivity from GPS radio occultation measurements, AIRS radiances, and AURA microwave limb sounder (MLS) temperature retrievals. The new bias correction method will be implemented for AMSU-A later this year.

Improving AMSU-A data availability

Assimilation of AMSU-A from NOAA-18 became operational at FNMOC on September 19, 2005. The assimilation of the additional AMSU-A radiances observations improved the 5-day 500 hPa geopotential height anomaly correlations in the Southern Hemisphere by 3-5 hours, demonstrating the importance of a configuration of three high quality sounders for NWP.

In the operational environment, the real time data cutoff is at +3:00 after the analysis times of 00, 06, 12 and 18 UTC. It is not uncommon for one orbit of AMSU-A data to arrive just minutes after this data cutoff. FNMOC recently implemented a 5 minute delay in the real-time data cutoff. The start for the AMSU-A preprocessor is further delayed by an additional 120 seconds, as the satellite wind preprocessor is slower, and NAVDAS cannot begin until all observation types have been processed (data selection and QC). The combined delay for the AMSU-A preprocessor occasional allows an extra orbit of data to be assimilated by NAVDAS.

Refining AMSU-A assimilation techniques using the NAVDAS adjoint

An adjoint-based method (Langland and Baker 2004) monitors in real-time (00 UTC only) the impact of all atmospheric observations assimilated by NAVDAS on the short-range NWP forecast error. The technique uses adjoint versions of NAVDAS and NOGAPS and has been developed and tested at NRL-Monterey over the past several years. The observation impact statistics are used to evaluate observation quality, tune observation reject lists, and to provide guidance for modifying assimilation procedures. This technique has proven valuable for identify observing system issues relevant to the NAVDAS operational data assimilation. The measure of observation impact is defined as the difference in the forecast errors for two forecasts, the first starting from the analysis and the second starting from the background (6 hours prior). The difference in the forecast errors is due solely to the assimilation of observations at the analysis time. The forecast error is defined in terms of the vertically-integrated moist energy-weighted 24 (30) hour forecast error, from the surface to about 150 hPa. An example for AMSU-A radiances is shown in Fig. 4, and indicate that while AMSU-A channels 4-7 reduce the forecast error, channels 8 and 9 increase the forecast error. These results suggest a problem with the assimilation of AMSU-A channels 8 and 9, as these channels are generally of high quality, with low signal to noise ratios. We suspect that contributing factors are the operational bias correction, and insufficient model and analysis resolution in the upper troposphere and lower stratosphere. Recent observation impact results (not shown) generated from an assimilation run using the two-predictor AMSU-A bias correction appear to partially confirm these suspicions.

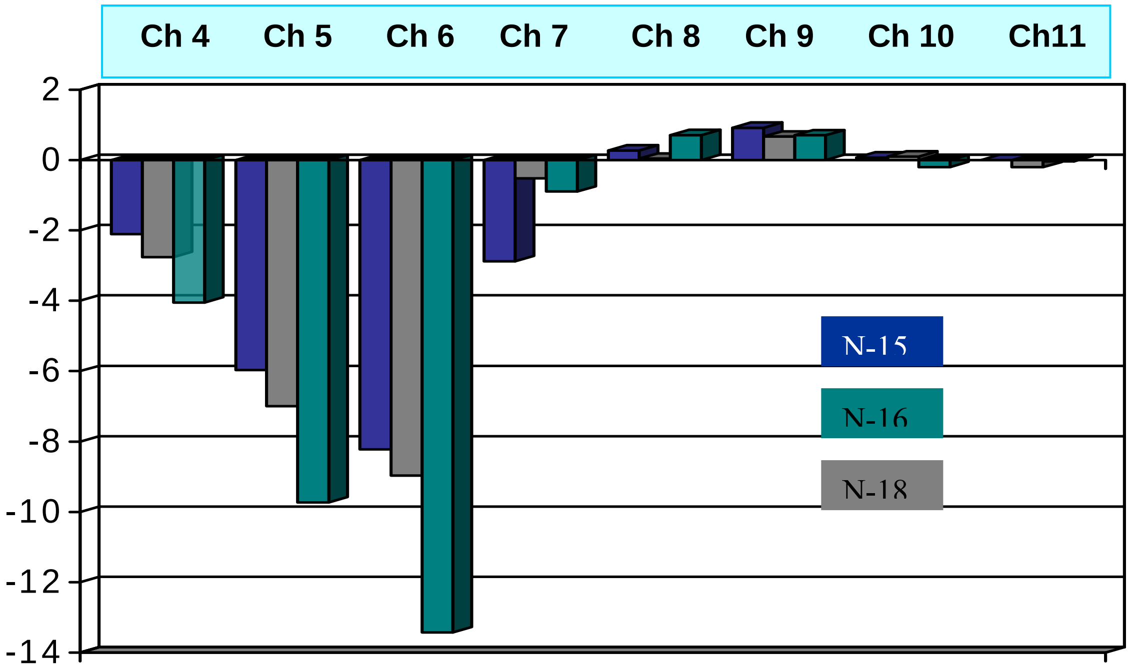

Fig. 4: Impact (J kg^{-1}) of AMSU-A observations on the 24h global forecast error in NOGAPS/NAVDAS, as a function of channel numbers (horizontal axis) and satellite (blue=NOAA-15; gray=NOAA-16; green=NOAA-18). Statistics were compiled for the period from January 1 to February 28, 2006, for 00 UTC. Negative values indicate forecast error reduction or beneficial impact.

Plans for future work

NAVDAS is an observation space 3DVAR algorithm, designed as a precursor for NAVDAS-AR, a four-dimensional weak-constraint variational data assimilation system. NAVDAS-AR (Accelerated Representer) is based on the representer technique first introduced by Bennett and McIntosh (1982). Xu and Daley (2000) designed a cycling version of the representer algorithm, and subsequent development (Xu et al. 2005; Rosmond and Xu 2006) has produced a flexible, computationally efficient algorithm for operational four-dimensional data assimilation. Current testing indicates that NOGAPS forecast skill using NAVDAS-AR has comparable forecast skill to the operational system. Operational implementation is planned for late 2008.

NAVDAS is also used for several other applications, including mesoscale data assimilation for COAMPS®, slated to become operational November 29, 2006. The two-dimensional univariate option for NAVDAS is being used to produce aerosol optical depth analyses for the Navy Aerosol Analysis and Prediction System (NAAPS), while the three-dimensional univariate option is being utilized for the global ozone analysis. NAVDAS and NAVDAS-AR will also provide the framework for the Navy's new ocean data assimilation systems. Finally, NAVDAS is used for the upper atmosphere assimilation and modeling research within the Remote Sensing and Space Sciences Divisions at the main NRL laboratory in Washington, D.C.

Finally, due to licensing issues, we are in the process of switching from RTTOV for the JCSDA Community Radiative Transfer Model (CRTM) for radiance assimilation for all sensors and all applications.

Acknowledgement

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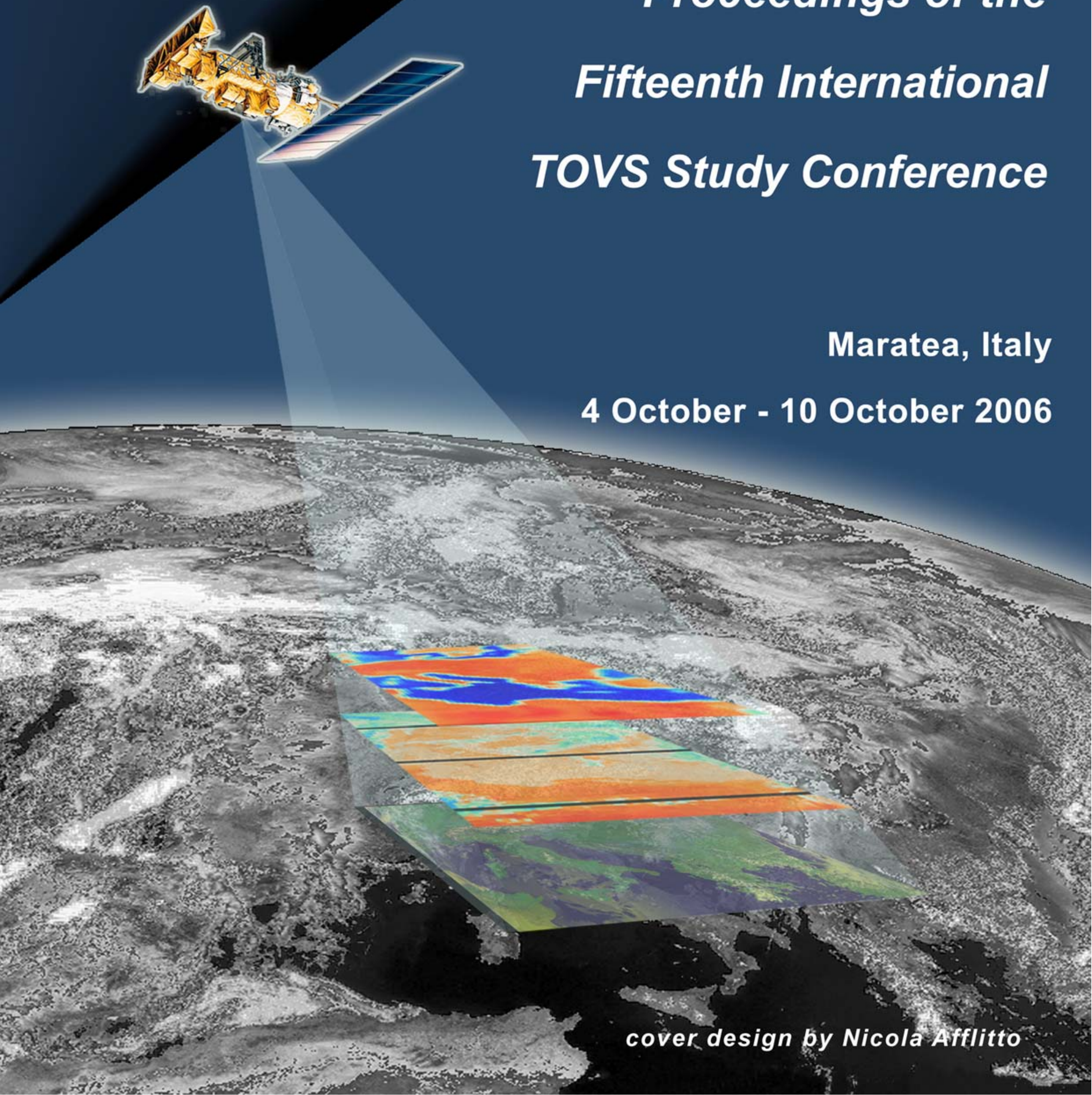

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