ASSIMILATION OF CLOUDY AMSU-A MICROWAVE RADIANCES IN 4D-VAR[1]

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Abstract

The assimilation of cloud-affected satellite microwave radiances within Numerical Weather Prediction systems will allow a significant increase in the observational information used to constrain forecast models. In particular, the 23GHz and 31GHz microwave window channels of the AMSU-A instrument contain much information on cloud liquid water which is currently not fully exploited.

Work at the Met Office has studied the effect of allowing the gradient of the observations with respect to cloud liquid water to influence the analysis through innovations in cloudy radiances, using the RTTOV radiative transfer model and an incremental cloud liquid water operator in the variational data assimilation. In this way, AMSU-A radiances at 23GHz and 31GHz are now being assimilated in all cloudy situations (except in heavy precipitation, detected using the scattering index method) at the Met Office in pre-operational tests. This will provide the basis for future assimilation of high resolution cloud and precipitation affected AMSR radiances. The assimilation of these AMSU-A data gives a notable improvement in fit to observations which is preserved into the six-hour forecast. In addition, there is a strong positive impact verifying against analysis on southern hemisphere and tropical large scale fields.

1. Introduction

Currently, AMSU-A channels peaking in the lower troposphere are not assimilated in the Met Office 4D-Var if there are significant amounts of liquid water present in the field of view. This screening of cloud-affected data leads to large gaps in data coverage. The microwave window channels on AMSU-A contain information on cloud liquid water which is currently not exploited in the assimilation system. Channel 1 of AMSU-A (23GHz) has sensitivity to both water vapour and liquid water emission and absorption effects. Channel 2 (31GHz) is sensitive to liquid water only. Section 2 shows how cloud information in the model background can be exploited by use of these channels in a radiative transfer system.

Recently, a new incrementing operator which diagnoses increments for cloud liquid water and vapour has been developed at the Met Office, designed to be used with a total moisture control variable in 4D-Var. This revised operator allows the assimilation of cloud-affected observations, such as AMSU-A Channels 1 and 2; a fuller description of the operator is given in Section 3.

[1] This work has also been submitted to the proceedings of the 3rd Meeting of the International Precipitation Working Group, held at Melbourne, Australia, 23-27 October 2006.

In order to assimilate cloud-affected radiances, cloud water must first be analysed in the Met Office Observation Processing System (OPS) 1d-Var. This pre-processing is not optimal as it does not yet employ an incremental scheme, and the effects of this are mentioned briefly in Section 4.

Initial assimilation studies have been undertaken, assimilating NOAA-16 AMSU-A window channels in the context of the 4D-Var cloud incrementing operator to assess the impact on the forecast and analysis. The assimilation experiment set-up and results are outlined in Section 5.

2. AMSU-A Microwave Window Channels

As mentioned in Section 1, the AMSU-A window channels have a sensitivity to absorption and emission by cloud liquid water that is not currently utilised. Figure 1 illustrates the extent to which there is information on liquid water contained in the model background which can be exploited by use of these data. Modelling the radiative effects of liquid water brings simulations of top-of-atmosphere brightness temperatures (calculated using RTTOV (Saunders *et al.*, 1999)) much closer to observations at these frequencies.

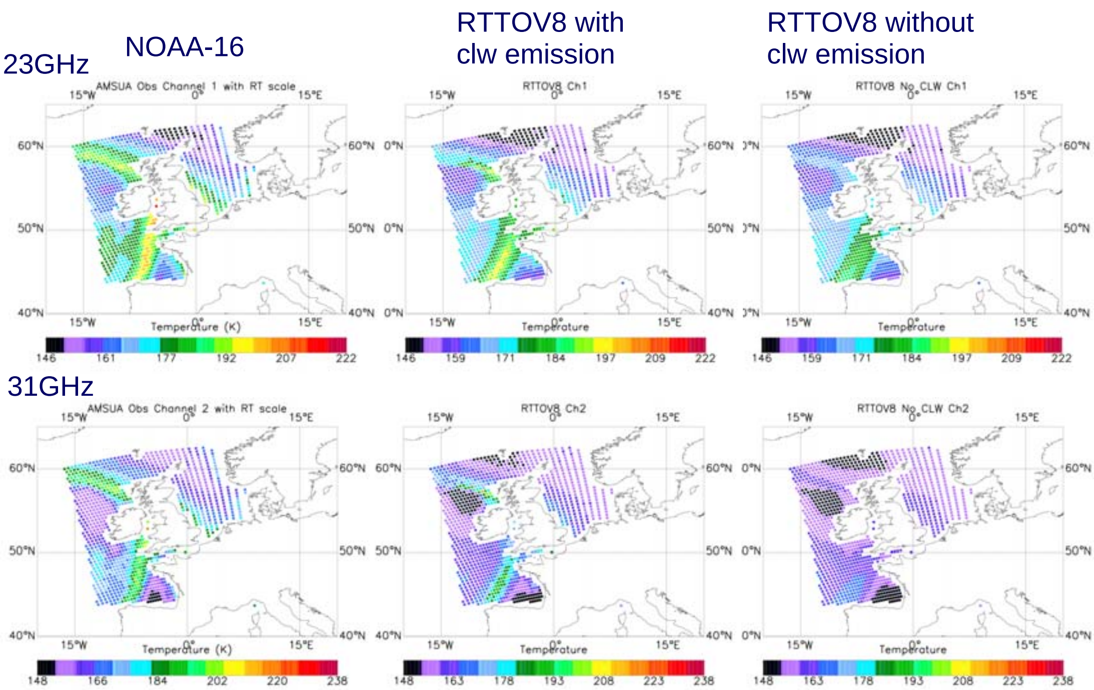
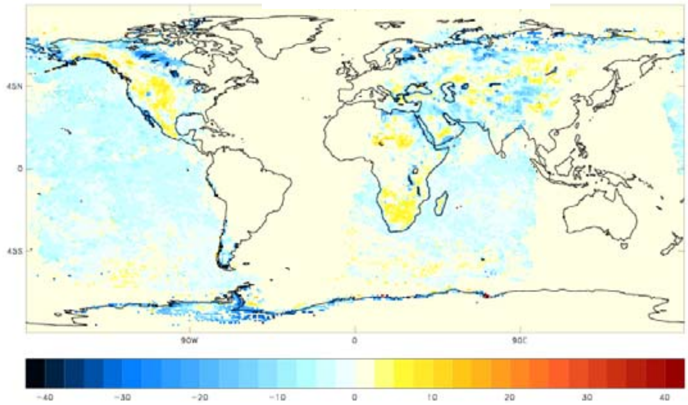


Figure 1: Top-of-atmosphere brightness temperatures for 23GHz (top row) and 31GHz (bottom row): NOAA-16 observations (left column), model simulations including the radiative effects of liquid water (centre column), and model simulations ignoring the radiative effects of liquid water (right column).

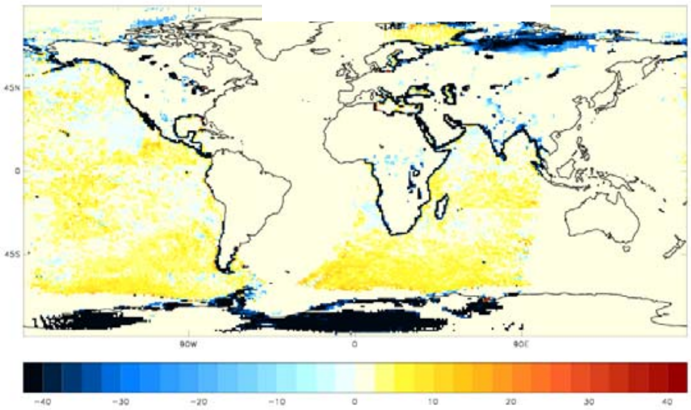
Figure 2 shows global maps of the innovation bias for NOAA-16 AMSU-A Channel 2 calculated over four weeks using the radiative transfer model RTTOV and Met Office global model background fields with the operational assimilation setup (i.e. AMSU-A Channels 1 and 2 not assimilated).

Cloud Free



Mean O-B (K)

Cloudy



Mean O-B (K)

Figure 2: Global brightness temperature innovation bias maps (observation minus background) for AMSU-A Channel 2, based on four weeks' data, in cloud-free conditions (top) and cloudy conditions (bottom). Blue indicates a negative bias: observed brightness temperature is colder than the model. Yellow indicates a positive bias: observed brightness temperature is warmer than the model

AMSU-A Channel 2 has a negative innovation bias (i.e., the observed brightness temperature is colder than the model) in clear conditions and a positive innovation bias (i.e., the observed brightness temperature is warmer than the model) in cloudy conditions. At the wavelengths of the AMSU-A window channels, brightness temperature generally increases linearly with the amount of liquid water in the profile. Therefore, these biases may be due to data selection (i.e., the model has cloud in some clear areas and no cloud in some cloudy areas) but they may also be due to a systematic under-estimation of liquid water in clouds by the model. In this case, it is expected that the assimilation of the AMSU-A window channels would add moisture to the system.

3. Cloud Incrementing Operator

Previously, the Met Office variational analysis scheme produced water vapour analyses using a single moisture control variable (relative humidity). In order to enable observational information on cloud to be assimilated, a new incrementing operator for cloud and moisture has been developed, designed to be used with a total moisture control variable (Sharpe, 2005). The incrementing operator partitions total moisture increments into vapour and cloud components for use by observation operators; currently only changes to water vapour and cloud liquid water (not yet cloud ice water) are considered.

If the background state is $\mathbf{C_x}$, then the analysis, $\mathbf{C_x}^+$ is:

$$\mathbf{C_x}^+ = \mathbf{C_x} + \mathbf{K}\mathbf{C_w}'$$

The model state $\mathbf{C_x}$ includes humidity, liquid cloud, ice cloud and cloud fraction. $\mathbf{C_w}$' is the analysis increment and includes temperature increment **T**', pressure increment **P**' and total water increment $\mathbf{q_T}$'. As mentioned above, currently $\mathbf{q_T}$ includes water vapour and liquid cloud.

K is an incremental variable transform operator between control variable space and model parameter space. In this instance, **K** requires linear physics and applies a physically based constraint on the adjustment of cloud, water vapour and temperature.

4. 1D-Var Pre-Processor

Prior to being assimilated in 4D-Var, observations are passed through a 1D-Var pre-processor, which is currently formulated using full field total water (Deblonde and English, 2003) as opposed to utilising the incrementing operator. This approach leads to approximately 8% of observations (including sounding channel observations which are currently assimilated) being rejected in 1D-Var. Because data is thinned and satellite passes overlap within a six-hour window, data volume in 4D-Var is not reduced but is biased away from cloudy areas to clear regions. This biased data selection is known to give negative impact (English *et al*, 2002).

5. AMSU-A Assimilation Experiments

A four-week assimilation trial was run using a low cost version of the Met Office operational system: namely using 3D-Var and reduced NWP resolution. The trial consisted of switching on NOAA-16 AMSU-A channels 1 and 2 in the pre-processing and assimilating the radiances directly in 3D-Var. The new data were assimilated in the extra-tropics, over sea, in all conditions except for heavy precipitation as defined using the Bennartz scattering index (Bennartz *et al*, 2002). The information contained within these data were exploited by processing cloud liquid water as an active variable and utilising the incrementing cloud liquid water operator described earlier. Bias correction coefficients for the window channels were calculated via a 10-day run where the data was processed but not assimilated. Clear air data only was used to generate the bias corrections, effectively ignoring the potentially large bias from the cloudy data. The options for bias correction generation when assimilating these data operationally are discussed in Section 6.

5.1. Fit to Analysis

Verification of large-scale fields such as mean sea-level pressure, temperature, 500hPa geopotential height and jet level winds against analysis can be seen in Figure 3, which shows the impact at six different forecast periods. The chart is divided into three sections: northern hemisphere on the left, tropics in the centre and southern hemisphere on the right. The chart indicates the difference between trial RMS error and control RMS error for each field at each time; a positive difference indicates that the trial RMS error is larger than the control RMS error, and so the AMSU-A cloudy assimilation results in a negative impact compared to control; a negative difference in RMS indicates a positive impact.

It can be seen that there is a strong positive impact on southern hemisphere and tropical large-scale fields. Most fields and forecast ranges show an improvement in the southern hemisphere, apart from humidity at 850hPa, which is degraded in all regions compared to the control against analysis. There is very strong improvement in tropical temperature fields at 500hPa and 250hPa, although tropical fields at 50hPa demonstrate a negative impact. The impact is more mixed in the northern hemisphere.

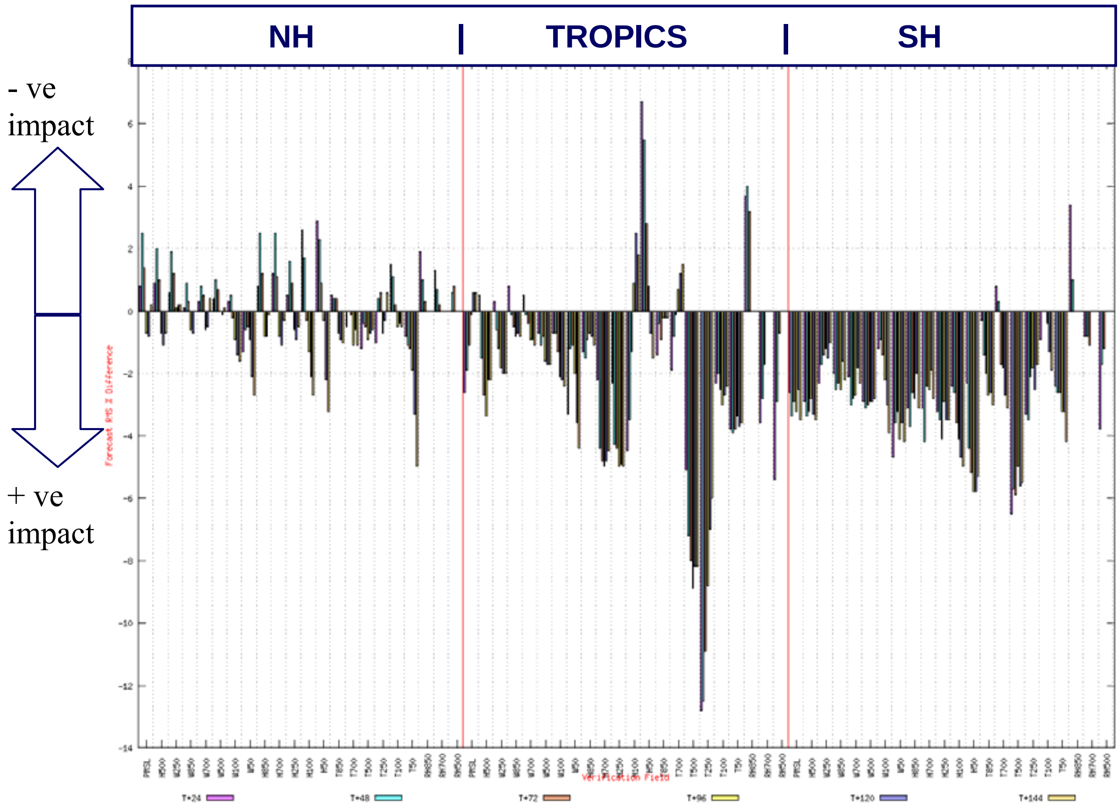


Figure 3: Verification of large scale fields against analysis for six forecast ranges. The chart shows trial-control forecast RMS difference: a negative difference indicates positive impact from the AMSU-A cloudy assimilation.

5.2. Fit to Observations

Assimilating the cloud-affected microwave window channels led to an improvement in fit to observations, which is preserved into the six-hour forecast. This can be seen in Figure 4, which shows the difference between the top-of-atmosphere brightness temperatures, simulated from the first six hour forecast fields produced by the assimilation, and the corresponding observations. There are several areas (two examples are indicated) where the difference between simulations and observations is larger in magnitude for the control run (top image) than the AMSU-A assimilation run (bottom image), indicating that assimilating these data has brought the model cloud fields closer to reality.

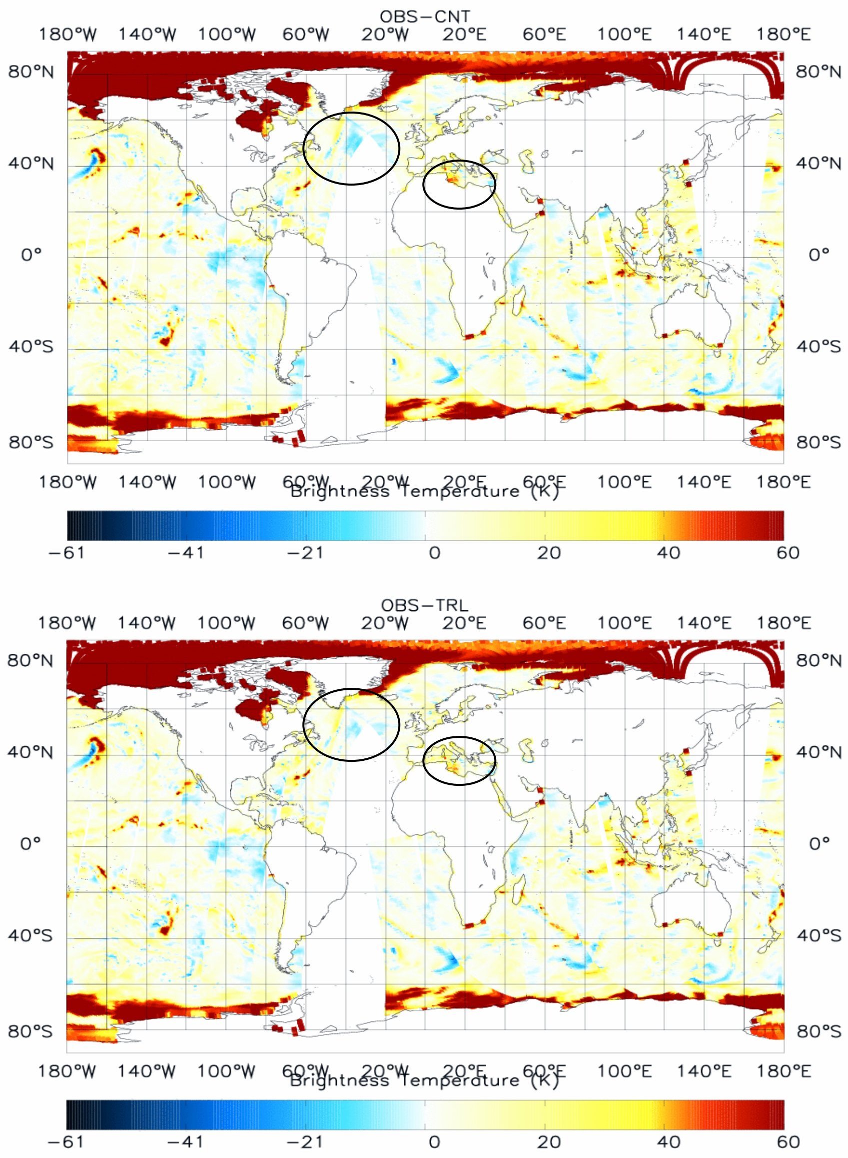


Figure 4: Observed brightness temperatures minus simulated brightness temperatures (simulated from T+6 model fields) at 31GHz for control run (top) and AMSU-A assimilation run (bottom).

6. Conclusions and Further Work

Direct assimilation of AMSU-A cloudy radiances at 23GHz and 31GHz utilising a cloud liquid water incrementing operator in the variational assimilation leads to improved cloud fields and some benefit to large scale fields in the tropics and southern hemisphere.

Since this study was undertaken, some of the issues relating to the biased data selection have been resolved in the pre-processing. Eventually it is planned to implement an incremental 1d-var with the same incrementing cloud operator to provide an optimal pre-processing system.

Generation of bias corrections for cloudy data remains an issue which must be resolved before operational use. The three main options are to not bias correct the data, to bias correct only clear air data (as in this study) or to bias correct all data (which may lead to some degradation in clear air assimilation). These options are currently being tested, and operational assimilation of cloudy AMSU-A radiances is planned for early 2007, followed by investigation into assimilation of cloud and precipitation affected AMSR radiances.

7. References

Bennartz, R; A. Thoss, A. Dybbroe, and D.B. Michelson, 2002... Precipitation analysis using the Advanced Microwave Sounding Unit in support of nowcasting applications. *Meteorological Applications*, Volume **9**, pp.177-189.

Deblonde, G. and S.J. English, 2003. One-dimensional variational retrievals from SSMIS-simulated observations, *Journal of Applied Meteorology*. **42**, No. 10, pp. 1406-1420.

English, S.J., Hilton, F., Jones, D.C., Smith, A.J. and Whyte, K.W, 2002. ATOVS and SSM/I assimilation at the Met Office. *Proceedings of the XIIth International TOVS Study Conference*, *Lorne, Australia*, 28 February – 5 March 2002, pp72-78..

Saunders, R., Matricardi, M., Brunel, P.,1999. An improved fast radiative transfer model for assimilation of satellite radiance observations. *Quarterly Journal of the Royal Meteorological Society,* **125,** No.556 1407-1425.

Sharpe, M. C., 2005. Adding cloud to the Met Office variational analysis system, *Proceedings of the Fourth WMO International Symposium on Assimilation of Observations in Meteorology and Oceanography*, *Prague, Czech Republic,* 18-22 April 2005.

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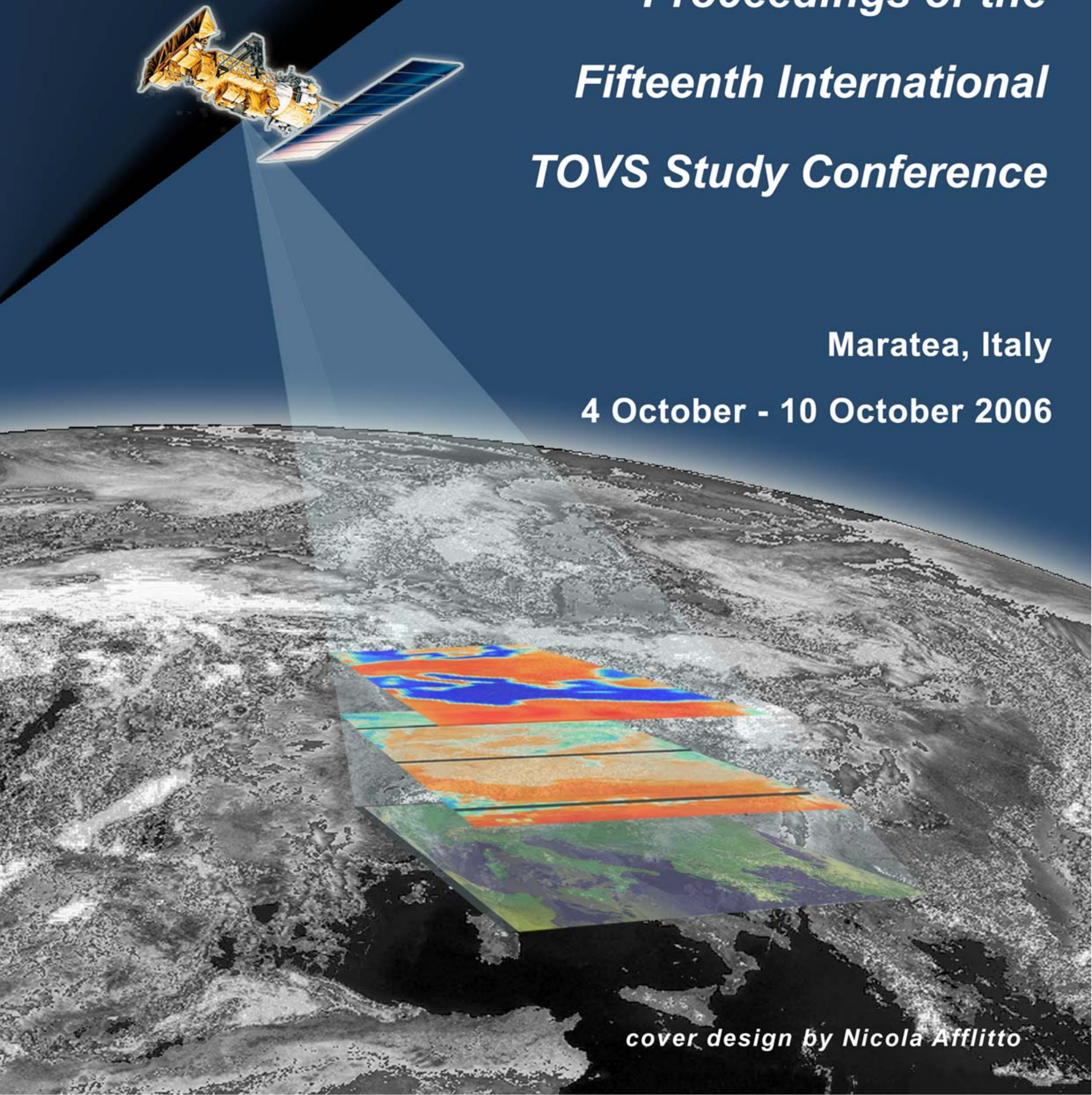

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