An automated processing system for cloud-top height and amount from ATSR(2) stereo

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ABSTRACT: A pre-operational algorithm and associated IDL processing chain for fully automated retrieval of cloud-top height and amount from dual view ATSR(2) has been developed. This processing chain includes ingest of SADIST formatted data especially all orbital position and camera viewing angles, automated stereo matching and transformation into ground co-ordinates above the WGS84 ellipsoid. Five different stereo matchers are currently included for testing: M2 (mean of the normalised differences within a patch), M3 (median of the normalised differences within a patch), 2D Nested Maximum (a peak-valley correlation algorithm) P-Gotcha (a Pyramidal version of an in-house Adaptive Least Squares Correlation routine using sheet-growing) and CDWT (a Complex Discrete Wavelet Transform). An assessment of these different stereo matchers is presented which indicates that M2 satisfies the requirement for high throughput (<1 minute/ATSR scene) and pixel-level accuracy with an acceptable blunder-rate (c.1-5%). Examples will be shown of the application of this processing scheme to a wide variety of different ATSR(2) images. The scheme has been applied to the retrieval of cloud amount through the use of a ground Digital Elevation Model and initial results indicate better cloud masking than existing schemes based on radiometry. A companion paper (Muller, Dundas, Vogt, Clothiaux, 1999) describes the quality assessment procedure in more detail. This work is supported by the EU under the Fourth Framework Programme CLOUDMAP Project (Contract No. ENV4 CT97-0399) and by ESA under data grant AO3-422.

Introduction

One of the greatest current uncertainties in Global Climate Models is the role of clouds, particularly Cirrus and Marine StCu, in the Earth's radiation balance to determine whether clouds will enhance or decrease the effects of global warming. This study mainly focuses on natural Cirrus clouds and artificial Cirrus clouds (condensation trails of air planes) given the fact that these kind of clouds play a crucial role in a (local) increase of the so-called 'greenhouse' according to the current state of knowledge.

Existing cloud climatologies, such as ISCCP [*Rossow and Schiffer*, 1991] or the HIRS/TOVS CO^2 split window [*Wylie and Menzel*, 1991] do not provide the necessary accuracy either

- to test the effects of clouds, particularly broken clouds, on GCM forecasts or

- to assess the consequences of "global warming" on changing Ci & MrStCu cloud amounts

Previous HIRS/TOVS data suggest that upper-level cloud amounts have increased since 1982. It has been hypothesized that contrails may contribute towards this increase as shown below in Figure 1 for a time series from 1983-1996 [*Menzel et al.*, 1996].

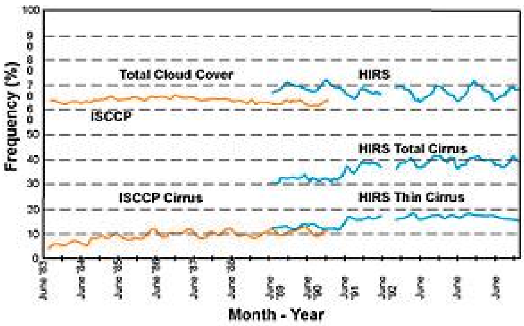

Figure 1. 13 years of cloud amount observations from ISCCP and HIRS/TOVS which indicates that upper-level cloud amounts are increasing. After [*Menzel et al.*, 1996].

Inspection of Figure 1, however, shows a sharp discontinuity between the ISCCP observations and the ones from HIRS/TOVS which is partly due to the different definitions of cloud amount (loc. cit.) and partly due to the different IfoV of the AVHRR/geostationary (for ISCCP) and HIRS/TOVS instruments.

(A)ATSR(2) (referred to hereafter as ATSR) will provide an unprecedented time series of 15 years of continuous cloud observations from the same instrument, albeit that it will be limited to the same local time and to observations at sparser time sampling than either ISCCP or HIRS/TOVS.

[*Hasler*, 1981; *Minzer et al.*, 1978] first presented results on the use of stereo photogrammetry to retrieve cloud-top heights albeit from sidewards overlaps on two geostationary satellites. ATSR owing to its unique conical scanning geometry [*Prata et al.*, 1990] can be employed to retrieve stereoscopic heights as first proposed by [*Lorenz*, 1985]. More recently, [*Prata and Turner*, 1997] showed the application of automated digital stereo photogrammetry to ATSR1 images. A fully automated processing chain has been developed by the authors for retrieving cloud-top heights from ATSR images from GBT SADIST2 formatted data using digital stereo photogrammetry. This includes an assessment of different stereo matching algorithms on ATSR. The processing chain is a macro within IDL with the stereo matcher being compiled from the original C code.

Processing Chain

The processing chain consists of an IDL routine called ATSR2_to_CTH. This routine takes as input arguments a SADIST2 file and a parameter file which includes the values for the appropriate stereo matcher and outputs a height file in WGS84 ellipsoid co-ordinates together with the appropriate matcher metric. The parameter file specifies which spectral bands are to be matched as well as the patch size (all the stereo matchers are area-based) and search radius to restrict the search in the forward view to the range of expected cloud-top heights.

Five different stereo matchers have been tested but only two, M2 [*Mandanayake and Muller*, 1995] and M3 [*Diner et al.*, 1996], have been implemented to date within the processing chain. Work continues on implementing the other three: 2D Nested Maximum (loc. cit.), P-Gotcha [*Day et al.*, 1992] and CDWT [*Magarey*, 1997].

M2 (multi-point matcher) is an area-based stereo matcher. It works by designating the imagery from one camera as the reference image and the other as the comparison image. A region, the patch size, is chosen in the reference image and a set of comparison patches within a search window is established in the comparison image. The matching metric is then computed by taking all the values in each patch and subtracting the mean values within the patch from each pixel to yield a normalised brightness. Then the absolute difference in the reference normalised patch minus the normalised values in the comparison patch averaged over the number of points being matched is tested against a threshold. The M2 metric is

$$SM2 = \frac{\dfrac{1/Npts\,|(R(xi,yj) - \langle R\rangle) - (C(xi,yj) - \langle C\rangle)|}{|(Rmax - Rmin]*[Cmax - Cmin])|}}{SIGMAm2}$$

(equation 1)

where

R(xi,yj) is the reference pixel values at (i,j)

C(xi,yj) is the corresponding value in the comparison image

Rmax, Rmin are the maximum and minimum values within the reference image respectively

Cmax, Cmin are the maximum and minimum values within the comparison patch respectively

Npts is the number of points begin matched

<R> is the average value within the reference patch

<C> is the average value within the comparison patch

i,j are the relative indices within the patches for summation and

$$SIGMAm2 = 1/Npts \frac{|[R((xi,yj) - \langle R\rangle]|}{|[Rmax - Rmin]|}$$

(equation 2)

The quantity SIGMAm2 is an estimate if the average uncertainty in the numerator of equation 1. For a reference patch the x and y values of disparity are those for which SM2 is smaller than or equal to threshold TM2. If SM2 > TM2 the disparity is discarded. If multiple matches from M2 satisfies the threshold criterion, the best match for a patch is defined as the one that minimises SM2. This is done by setting a secondary threshold AM2 where AM2=f.SM2min where f > 1. If the best match is the only one for which SM2 < AM2 it is classed as a successful match.

M3 is similar to M2 except medians rather than then means are used. SM3 ≤ TM3 are regarded as a successful match. TM3 and TM2 maybe different.

The reader is referred to the references quoted for details of the other matchers.

For ideal stereoscopic pairs, the two images should be taken at the same time. The time difference between the acquisition of the forward and the nadir is swaths 120 seconds. Equation 3 [*Prata and Turner*, 1997] is used for calculating the heights, where height, H is given by

$$H = YDIS/(\tan(ANGLEf) - \tan(ANGLEn))$$

(equation 3)

where

YDIS is the disparity
ANGLEf is the forward zenith angle
ANGLEn is the nadir zenith angle

It has been assumed that all the movement in the y direction is due to height. Also the increase in the size of the field of view from the forward view is not taken into consideration. The stereo matching schemes will fail if the areas to be matched are featureless or devoid of spatial contrasts. The zenith angles are calculated from information contained in the GBT header.

The entire operation from ingestion of raw image to the production of three-dimensional CTHs takes around 25 minutes on a Silicon Graphics workstation of relatively low specification. Code optimisation has been performed of the stereo matcher and it is the only compiled element as IDL is too slow at looping arrays. The remainder of the chain is written in IDL.

Comparison of stereo matchers

Tests performed on the five stereo matchers indicate that M2 produces the best results with regard to (1) speed traded against (2) accuracy; (3) reliability (i.e. blunder rate). P-Gotcha produces the highest accuracy but at the expense of the slowest speed. CDWT produces the worst results. Figure 2 shows a comparison of four of the matchers using the height-temperature relationship as a surrogate for a quality measure. Inspection of Figure 2 shows that M2, M3 and P-Gotcha had a reasonable relationship between CTH and brightness temperature for a scene containing thin high-level cirrus over lower level cloud. Although this relationship is not as "clean" as those shown by [*Watts and Baran*, 1997] it should be noted that no attempt has been made to pre-screen the CTHs using an optical depth threshold as performed by the aforementioned authors. In a separate paper presented here (Muller et al., 1999), a quantitative validation has been performed using ground-based radar+lidar measurements of CTH.

Figure 3 shows an early attempt to validate the performance of different stereo matchers using a comparison of non-cloud heights against a global terrain model. Clouds are first defined using the supplied RAL cloud mask [*Simpson et al.*, 1998]

For heights defined as "ground" by the RAL cloud mask difference statistics in elevations were performed. For Gotcha, the height differences had a mean of 0.09±1.38km wheras for M2 heights the mean was 0.22±1.81km. An alternative approach used the heights derived from M2 to define a cloud-mask when the heights were ≥1km above GTOPO30. When this new cloud mask was used, the mean difference for M2 reduced to 0.14±1.03km which is much closer to the theoretical value of ±0.75km originally proposed by [*Lorenz*, 1985]. These results also suggest that stereo-derived cloud masks may be much more reliable than equivalent radiometric ones. This hypothesis has been tested by [*Cawkwell et al.*, 1999] over the Greenland ice-sheet where significantly better results for cloud masks have been obtained than using conventional radiometric cloud masks.

Example application

A very wide range of ATSR2 images have been processed using the scheme described above. Owing to the lack of space, only one further example will be shown here. Figure 4 shows an area containing a large number of contrails over the Channel. Note that the matcher

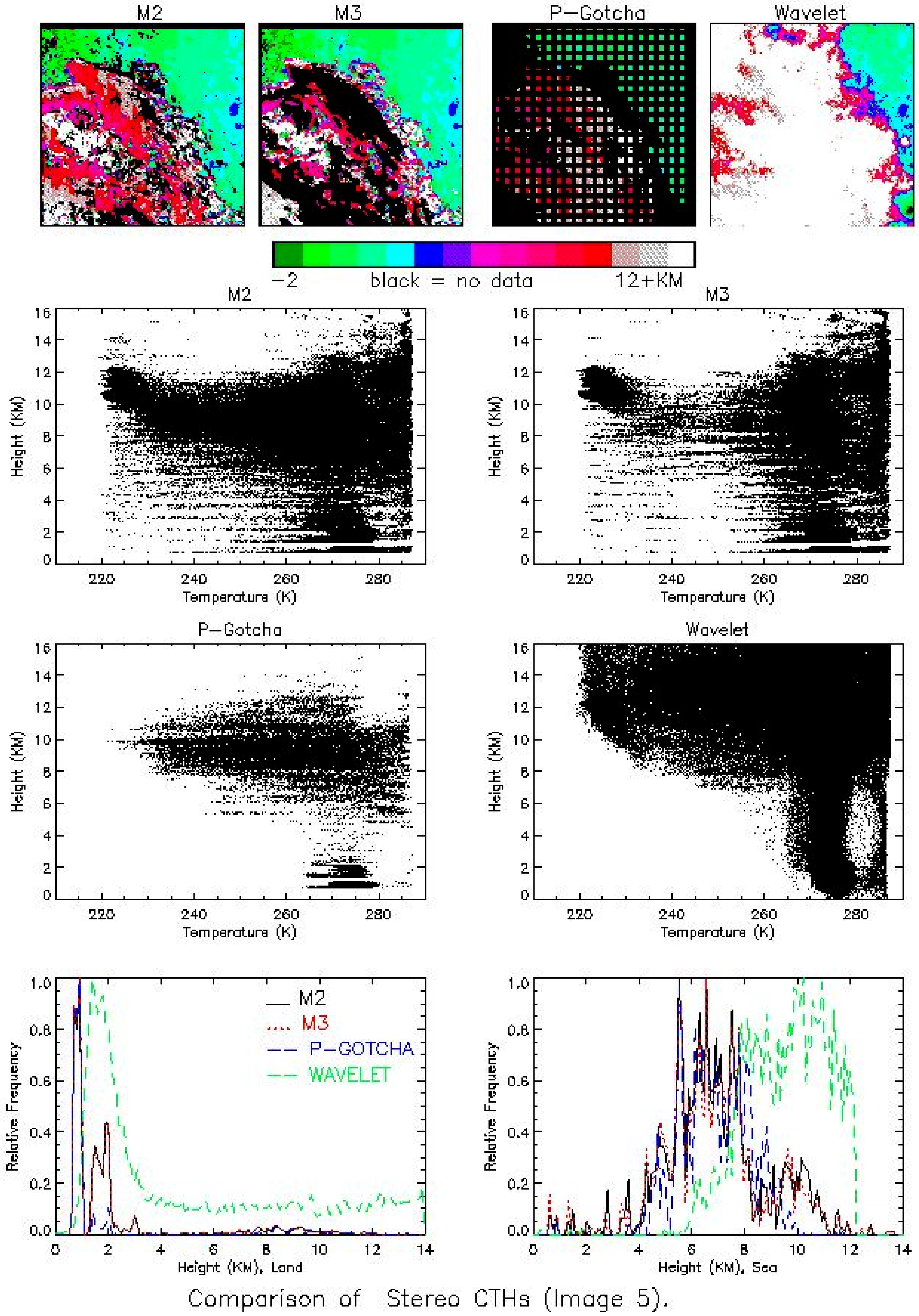

Figure 2. Comparison of stereo matcher output for four of the stereo matchers tested. Upper panel – CTH fields. Middle panel : Height vs 11µm brightness temperature. Lowest panel: CTHs over land and sea separately.

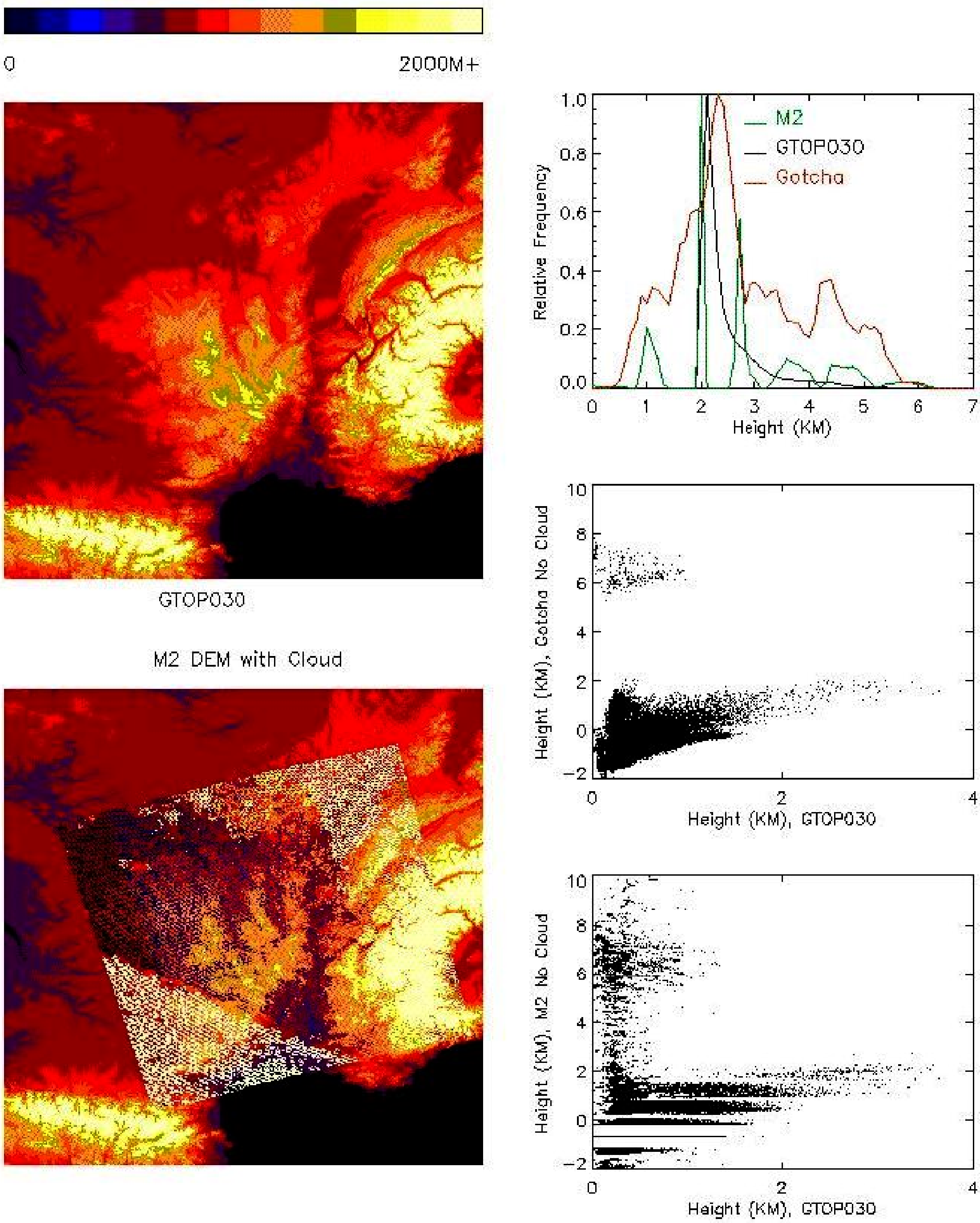

Figure 3. Comparison of stereo matcher output for two of the matchers tested. Upper left – ground DEM from GTOPO30. Lower left : Stereo matched heights blended into GTOPO30. Note white areas are RAL cloud mask . Upper right: Histogram of heights showing the pixel quantisation of M2. Middle right panel: Gotcha heights for areas masked out by RAL cloud mask. vs GTOPO30 DEM. Lower right panel: M2 heights for areas masked out by RAL cloud mask. vs GTOPO30 DEM.

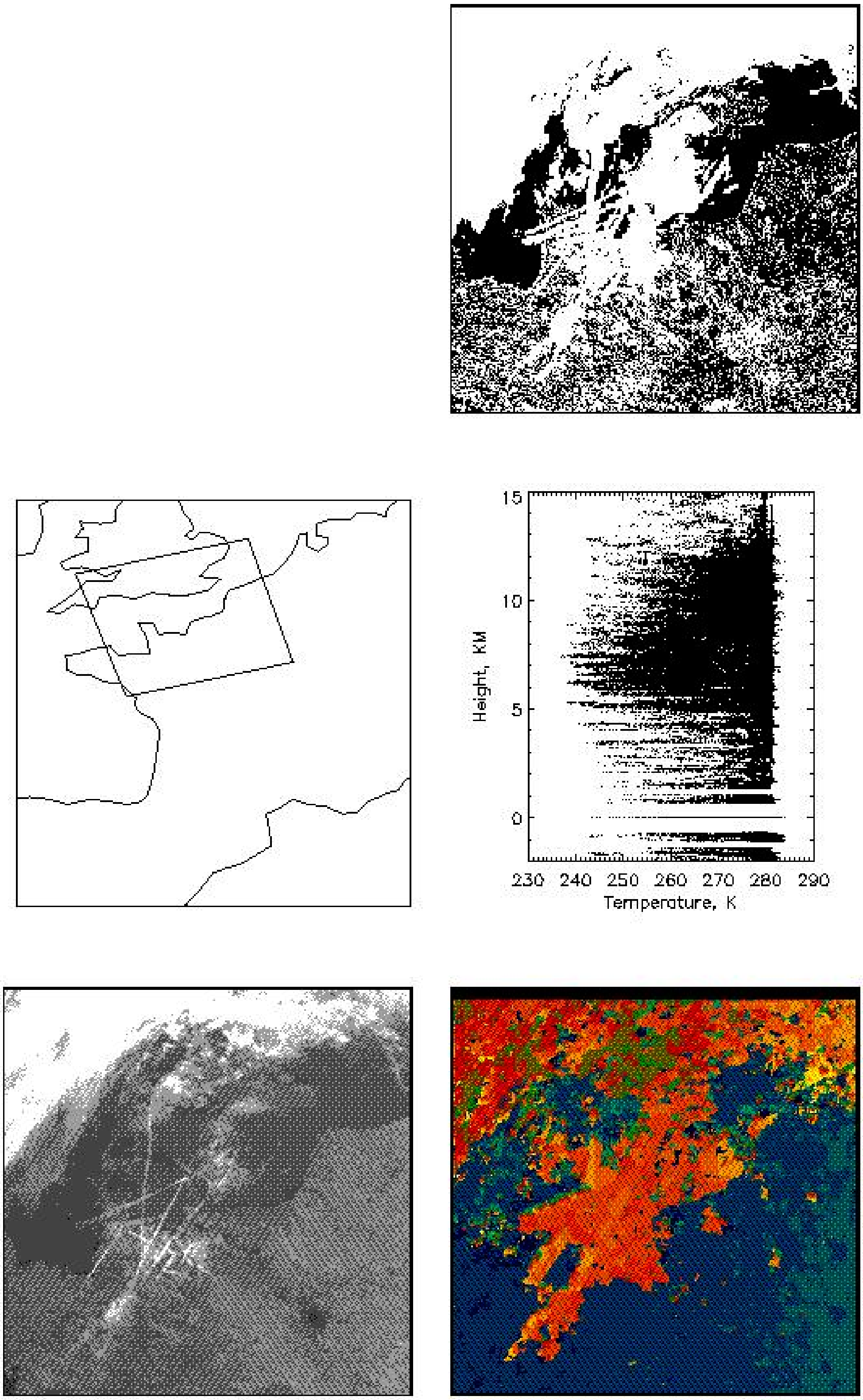

Figure 3. Results of M2 stereo matcher over the Channel. Upper right, Forward-Nadir 11µm temperature difference. Lower left: 11µm nadir image. Lower right: M2 CTH fields. Middle Right panel: Height vs temperature plot for all heights including the ground.

picks up the upper level cloud layer well as well as the semi-transparent haze layer at the altitude of the contrails. Automated detection of contrails relies on the 11-12µm temperature difference [*Lee*, 1989; *Meyer and Mannstein*, 1998] and can be significantly improved when altitude is added to the discrimination. These initial results suggest that stereo-matched heights can greatly assist with the detection of contrails. If information on ice crystal size can be added through, for instance the approach described by [*Baran et al.*, 1998] then ageing contrails may be able to be detected as their ice crystal size distribution is likely to be smaller than naturally occurring cirrus [*Sassen*, 1997].

Conclusions and Further work

The IDL processing system is being tested by other members of the EU-CLOUDMAP project including for future operational application in nowcasting and climate modelling by KNMI. A new version is currently also being developed for application to MISR data [*Diner et al.*, 1998]. It is planned that colleagues at the DLR Institüt für Physik der Atmosphäre will add the processing chain to their contrail statistics system to allow a better determination of CTHs over a five year time period. [*Meyer and Mannstein*, 1998]

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