Cover Note

Subject	**Advanced Satellite Image Products for Monitoring and Nowcasting of Severe Convective Storms**
Action proposed	Decision/Consideration/Information/Recommendation
Abstract	The document introduces a new type of image product called the blended "sandwich" product. The product combines two input images into one output image by a method of "layer blending", an advanced function available in some of the graphics editors. The blended images can be used in studies comparing the cloud top structure as observed in visible bands with cloud-top properties in the other bands – such as cloud-top brightness temperature, cloud-top microphysics, etc. The blended sandwich products become even more attractive when used operationally in satellite image loops, such as for nowcasting purposes. In the second part of the document we briefly address overshooting tops. Overshooting tops affect or generate all other features observed atop convective storms, so a solid understanding is essential for any storm-top related studies, as well as for their exploitation in various automatic algorithms. For their observation and detection, the 5-minute interval available in the current MSG RSS mode appears insufficient; thus we propose consideration of a shorter, 2.5-minute mode to be tested with MSG-1 (if feasible) once it becomes a backup satellite for MSG-2 and MSG-3. The ESSL Testbed activity provides an opportunity to test the operational benefits of the sandwich products, together with other satellite derived products, as well as the 2.5-minute rapid scan data (if feasible). This document has been provided by Dr. Martin Setvák, CHMI.
Views of other EUMETSAT bodies	-/-
Decision proposed	STG-SWG is invited to take note and discuss the proposals.
Majority required in Council	-/-
Cost implications	-/-
Reference documents	-/-
Annexes / Draft Resolution	-/-

Advanced Satellite Image Products for Monitoring and Nowcasting of Severe Convective Storms

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1. Introduction

In the early years of satellite meteorology, the black-and-white and colour enhancements were the only wider-spread methods of retrieving "hidden" information from the satellite imagery, such as cloud-top brightness temperature (BT) field in the IR bands (more on thin in section 2). These were later on followed by "RGB composite images", merging the information carried by several independent spectral bands into one single image; for these products this is achieved by loading the input bands or their mathematical combinations into the Red, Green and Blue channels of the output colour image, thus the "RGB product". Though the first atmosphere-related RGB image products appeared shortly after launch of the AVHRR, their boom came with the launch of instruments such as MODIS, and in operational meteorology with the first MSG satellite and its SEVIRI instrument. After being standardized by EUMETSAT and accepted by most of the European meteorological community, the SEVIRI-based RGB image products quickly became very popular among forecasters and researchers.

The latest contribution to these advanced image products are blended "sandwich" images, combining the information from one (typically) black-and-white image and one colour image (either colour-enhanced single-band image, or RGB product). The product combines the two input images into one final output image by a method of "layer blending", an advanced function available in some of the graphics editors (*for more info on layer blending see the Internet Resources*). Such blended images can be used in studies comparing the cloud-top structure as observed in visible bands with cloud-top properties in the other bands – cloud-top brightness temperature, cloud-top microphysics, etc. A typical example is the combination of a visible band with a colour-enhanced IR band; however, other combinations are also possible, as discussed in section 4. The blended sandwich products become even more attractive when used in satellite image loops.

This document describes in detail the principle of the sandwich product (in section 3), showing several examples, and several other possible applications (section 4); more examples from various instruments and MSG image loops will be shown at the meeting presentation. Among the applications, we address in more detail the observations of overshooting tops of convective storms (in section 5), discussing the impact of the scan repeat cycle period on detection of these features. In this context, we suggest for consideration a possibility of experimental 2.5-minute rapid scan mode (to be tested with one of the MSG back-up satellites, after launch of MSG-3). Finally, section 6 addresses the possibility of testing various advanced image products within the European Severe Storms Laboratory (ESSL, http://www.essl.org/) Testbed project.

2. Colour enhancement of the IR brightness temperature imagery

In November 2007, the Convection Working Group (CWG, http://www.convection-wg.org/) was established as an informal initiative of EUMETSAT, later joined by the ESSL. The scope of the group involves presentation and discussion of research results and forecasting techniques addressing various satellite-observed aspects of convection prior to and throughout its lifecycle (pre-convective environment, convection initiation, and mature convective storms), with an emphasis on improved detection and nowcasting of hazardous storms. The group brings together researchers from several continents, who meet at various regular meetings and workshops.

Among the problems the group faced at its beginnings was the large variability of the colour schemes used by various groups, institutions or weather services across Europe and the rest of the World when colour-enhancing the IR-window imagery. Therefore, it was agreed to unify on one common colour scheme, recommended by the group (and informally also by EUMETSAT on various occasions). This colour scheme, based on the standard IDL (Interactive Data Language) blue-red colour palette (used also in various other remote-sensing software packages or systems), assigns red to the lowest brightness temperatures (BT) and blue to the warm end of the BT interval used for the colour enhancement. An example of this colour enhancement is shown in the Figure 1a; additional comments addressing the enhancement can be found in the Annex I. This IR-BT colour enhancement is used in the sandwich product described in the next section.

3. The visible – colour enhanced IR-BT sandwich product

The origins of the sandwich product are closely related to studies of the tops of convective storms. When studying certain storm-top features in satellite imagery, it is essential to know their spatial arrangement in various spectral bands or advanced products based on these bands. The most typical example is the comparison of storm-top appearance in a visible band, available at high spatial resolution, with the IR-window brightness temperature (BT) field – e.g. when studying characteristics of the overshooting tops, various BT features (such as cold-U/V or cold ring phenomena), above-anvil plumes, etc. One possibility is comparing the images "side-by-side", or alternatively fast toggling of the images in various bands forward and backward (usable only on a computer, not in a printed form).

A more efficient and visually appealing option is blending ("sandwiching") the images together, using one of the blending functions available in some of the graphics editors, such as Adobe Photoshop, GIMP, or ImageMagick (*for web sites and more info on these see the Internet Resources*). The blended product ("sandwich") consists of two layers: the base layer, which is usually one of the visible or near-IR bands at the best pixel resolution possible, and the upper layer, containing a field such as the colour-enhanced IR-window image remapped to the same map projection and pixel resolution as the visible band.

The primary advantage of sandwich products is that they merge the features of the two input images into one single image, thus enabling one to observe the characteristics of both images simultaneously in one single product. In the case of the visible – IR-window sandwich combination (VIS/IR-BT), the visible band brings to the final image the cloud-top "morphology" (shadows and textures), while the colour-enhanced IR-window band adds the BT information. Such images often gain almost a 3D appearance, which is absent if the source input images are compared side-by-side. Finally, it is much easier to follow the evolution of convective storms (or any other weather phenomenon) in one single sandwich product, rather than in two windows, showing the input bands separately. This makes the sandwich products very attractive for operational applications.

When preparing the sandwich product images for case studies or publications, it is possible to further increase the quality of the final image by interactive tuning of the product by manually adjusting the options of the blending function. This applies namely when working with stand-alone data sets from imagers aboard polar orbiters, such as AVHRR, MODIS or VIIRS; one example of such interactively tuned sandwich products at high resolution is shown in Fig. 2, several other examples will be shown in the presentation. However, when processing a series of images from geostationary satellites, and especially for operational applications, the sandwich product has to be generated automatically. For these purposes it is possible to use e.g. the ImageMagick; details on this can be found in the Annex II.

4. Other possible combinations of sandwich products

Besides the VIS/IR-BT sandwich product described above, it is possible to combine the background VIS image with any other spectral band, or even better with one of the RGB products. Among other such combinations are the sandwich products of a visible band with one of the microphysical RGB products; examples of such sandwich products will be shown in the presentation. The use of these sandwich combinations is not restricted to storm monitoring, but supports nowcasting in general.

5. Overshooting tops and the impact of temporal sampling frequency

Overshooting tops (OT) of convective storms were among the main stimuli for development of the HRV/IR-BT sandwich product. As OTs affect or generate all the other features observed at tops of convective storms, across all the spectral bands, their solid understanding is essential for any storm-top related studies, as well as for their exploitation in various automatic algorithms. Overshooting tops can be frequently seen in HRV images (thanks to the shadows they cast) as well as in IR10.8 BT imagery (as the coldest pixels atop of convective storms). However, not all of the coldest pixels can be identified with a corresponding OT in HRV, and vice versa, so not all of the OTs from an HRV image match the coldest pixels (being occasionally warmer than their surroundings). Therefore, a tool was needed that can merge the information from both of these bands into one single image, which can then be used in animations. The sandwich product described above serves these purposes well. In parallel, methods for automatic detection of OTs are being developed (Bedka et al. 2010; Bedka 2011), namely for nowcasting and warning purposes. These methods are being verified through various means, and the sandwich VIS/IR-BT images can be used for this purpose as a subjective verification of the algorithm.

These activities addressing OTs show that a lifecycle of an OT can be shorter than 10 minutes. Some of the distinct OTs are present in one MSG Rapid Scan Service (RSS) image only, being absent in the previous and next frames. In contrary, some of the most significant OTs can persist much longer, for a period covered by several RSS scans. GOES 1-minute Super Rapid Scan Operation (SRSO) imagery, clearly shows the rapidly evolving nature of OTs; for examples of these see the CIMSS Satellite Blog website (http://cimss.ssec.wisc.edu/goes/blog/archives/category/severe-convection). As the minimum cloud-top BT is often used in various algorithms and nowcasting tools as a proxy for storm severity, and given the close link between the OTs and coldest pixels, a better understanding of OT behaviour, namely their typical lifecycle period and speed of their warming once they begin to descend, could significantly improve the applicability of OT and associated objective detection output for storm severity nowcasting and warnings.

For these purposes, **we propose for consideration an experimental, shorter rapid scan mode, optimally with 2.5-minute repeat cycle**. Such 2.5-minute rapid scan data could serve not only for the above mentioned studies of storm tops, but in general could be used for testing of various MTG and GOES-R algorithms. As we are aware that the present MSG RSS dat a is already used semi-operationally by many weather services, we propose to use for the experimental 2.5-minute rapid scan the Meteosat-8 satellite, after Meteosat-10 is put to service and Meteosat-9 takes over the RSS. We do not propose operational availability of such data; archive-access should suffice. Given the convective storm studies, an optimal period for such a data collection campaign would be spring – summer (May – August) 2013 or 2014 (according to all external factors which might impact the availability of Meteosat-8 for these purposes), covering as much of Europe as possible.

6. The ESSL Testbed

A growing range of satellite-based tools is steadily becoming available for weather forecasters to support forecasting and nowcasting, among which the “sandwich” products and overshooting top products discussed above. Such tools have typically been developed and tested in a research environment, but can strongly benefit from testing in a forecasting environment. Feedback from operational forecasters often helps developers to improve their product, such as was reported in a recent study on the Spring Program, an annual activity at the Hazardous Weather Testbed of NOAA, that brings forecasters and developers of tools physically together (Clark et al, 2012).

At the ESSL Testbed, the European Severe Storms Laboratory aims to create an optimal environment for testing of forecast-supporting tools in Europe. There, a quasi-operational forecasting setting is created with a focus on severe weather, in which developers present and explain their tools, forecasters give feedback, and the tools are put to the test. The first edition of the Testbed, to be carried out at the ESSL Training Centre in Wiener Neustadt, Austria, will take place from 4 June to 6 July 2012 and will be organized in collaboration with the Austrian Central Institute for Meteorology and Geodynamics (ZAMG). During this period, forecasters and developers prepare experimental forecasts and nowcasts, and jointly discover in which situations a tool performs best and how (small) modifications may improve its performance in other situations. As a corollary result, the Testbed has the effect of acquainting users from all over Europe with new satellite-based developments, since participants come from many of Europe's weather services, not to mention participation from overseas. Tools such as the "sandwich" products and the automatic detection of overshooting tops are likely to benefit from such testing. Later iterations of the ESSL Testbed in 2013 or 2014 would also greatly benefit from the use of the 2.5 min imagery where the benefits of this imagery in severe weather monitoring and warning can be demonstrated. In addition, the Testbed may provide an ideal "proving ground" for new tools to be developed within the MTG program.

7. Final comments and conclusions

In this document we presented a new category of image products: the sandwich class of advanced image products. The sandwich images can be used for both research and operational applications. Czech Hydrometeorological Institute (CHMI) has been using the IR-BT sandwich since July 2010 and a storm sandwich since February 2011 (for the RSS data), and the feedback of CHMI forecasters is very positive regarding their usefulness. Therefore, we recommend that these products should be further tested by other weather services or within the ESSL Testbed project. In the second part we propose for consideration the 2.5-minute rapid scan, to be tested (if feasible) with Meteosat-8 in 2013 or 2014. As the 2.5-minute scan mode is identical with that of MTG RRS, the datasets collected during this experiment might be used not only for research purposes, but also for development and validation of various algorithms being developed for MTG and GOES-R.

References:

Bedka, K. M., Brunner, J., Dworak, R., Feltz, W., Otkin, J., Greenwald, T., 2010: Objective Satellite–Based Detection of Overshooting Tops Using Infrared Window Channel Brightness Temperature Gradients. J. Appl. Meteor. Climatol., 49 181 – 202.

Bedka, K. M., 2011: Overshooting cloud top detections using MSG SEVIRI Infrared brightness temperatures and their relationship to severe weather over Europe. Atmos. Res., doi:10.1016/j.atmosres.2010.10.001.

Clark, Adam J., and Coauthors, 2012: An Overview of the 2010 Hazardous Weather Testbed Experimental Forecast Program Spring Experiment. Bull. Amer. Meteor. Soc., 93, 55–74. doi: http://dx.doi.org/10.1175/BAMS-D-11-00040.1

Internet resources:

Blend modes
http://en.wikipedia.org/wiki/Blend_modes

Photoshop Blend Modes Explained
http://photoblogstop.com/photoshop/photoshop-blend-modes-explained

Adobe Photoshop
http://www.adobe.com/photoshop.html

GIMP (GNU Image Manipulation Program)
www.gimp.org

ImageMagick
www.imagemagick.org/

IDL (Interactive Data Language)
http://www.exelisvis.com/ProductsServices/IDL.aspx

Convection Working Group – Case studies
http://www.convection-wg.org/case.php
CIMSS Satellite Blog – Severe convection
http://cimss.ssec.wisc.edu/goes/blog/archives/category/severe-convection

ANNEX I.

Additional comments on colour enhancement of the IR brightness temperature imagery

The main reason for the colour scheme as described in section 3 is the perception of the red colour by humans – our brain tends to assign the red colour to something which is dangerous or important. Since the potentially most dangerous parts of convective storms are those nearby the cold overshooting tops, it was decided to assign the red colour to the lowest temperatures, typically found at the summits of the overshooting tops. A suitable range for colour enhancement of the IR-window imagery over Central Europe appears to be the BT interval 200 – 240 K; for regions more to the north or weather situations with a lower tropopause, the scale needs to be shifted to higher BT values. In contrary, for regions closer to the Equator, the colour scheme needs to be shifted to lower temperatures, with the lowest temperatures around 185 K. An example of this colour enhancement is shown in Figure 1a. The other, less important reason for this colour scheme is its compliance with Wien's displacement law – red colours used for colder cloud tops, blue for the warmer ones.

ANNEX II.

Technical details and additional comments on the sandwich products

When setting up the sandwich product, there are several options to blend the two source image layers together. The most simple method is to use partial transparency applied to the upper layer, setting the layer opacity somewhere between 40% and 75%. However, much better results can be obtained by using a more advanced type of blending of the two layers together – for example in Adobe Photoshop the "Multiply" or "Linear Burn" functions, again in combination with the upper layer opacity. In principle, the upper layer colorizes the bottom layer, according to the script of the blending function. In most cases the bottom layer is a black-and-white image, however a coloured one can be used as well – e.g. a true colour image (this doesn't add much scientific information to the product, but can be used for aesthetics). For technical details of the blending functions see the links in the "Internet resources" above.

When processing a series of images from geostationary satellites, and especially for operational applications, the sandwich product has to be generated automatically. For these purposes it is possible to use e.g. ImageMagick; below is an example of the script (operationally used in CHMI) to create the sandwich product with this software:

```
# alpha blending  of the IR-BT layer
alpha=70
# sets the alpha blending of the IR-BT layer
convert ${ir_bt} -alpha On -channel Alpha -evaluate set ${alpha}%
${ir_bt_png}
# merging (blending) the two images together
composite ${hrv} ${ir_bt_png} -compose Multiply -quality 90 ${output}
```

For the VIS/IR-BT sandwich products, it is possible to improve the quality if areas warmer than 240 K are omitted and left fully transparent (see Figs. 1a and 1b). This way the IR-BT component of the sandwich image colorizes the coldest cloud tops only, leaving the rest of the image intact.

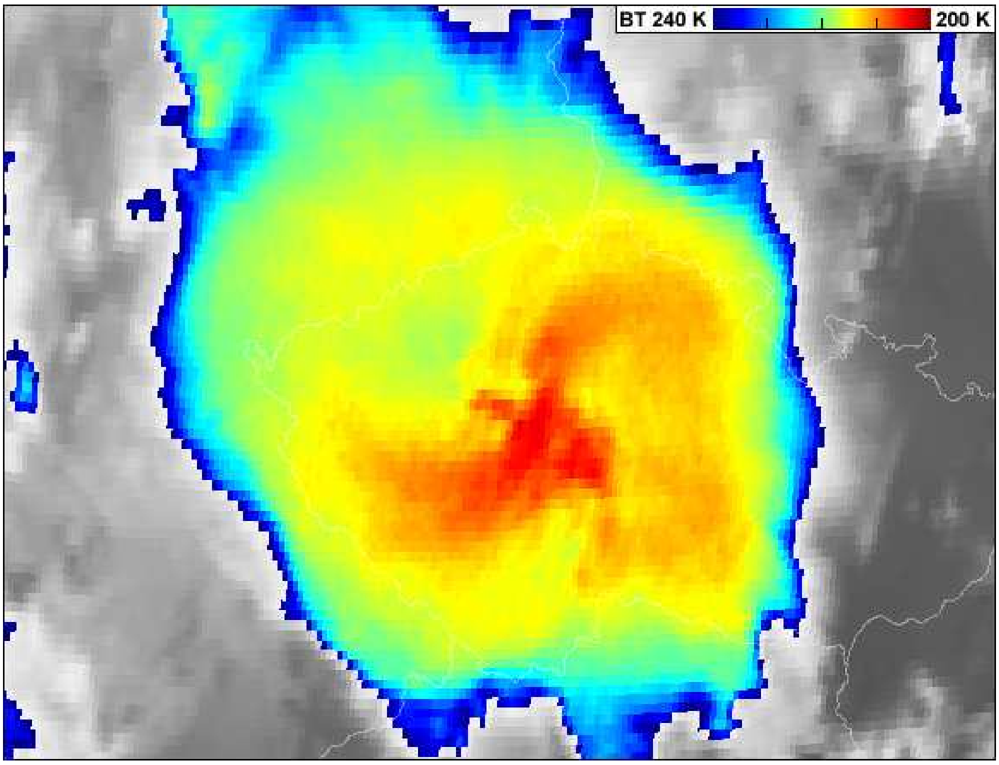

Figure 1a. 2011-07-13, 18:35 UTC, Meteosat-8. Example of colour-enhanced IR10.8 image, using the colour palette recommended by CWG. Areas warmer than 240K are shown in standard (linear) grey scale.

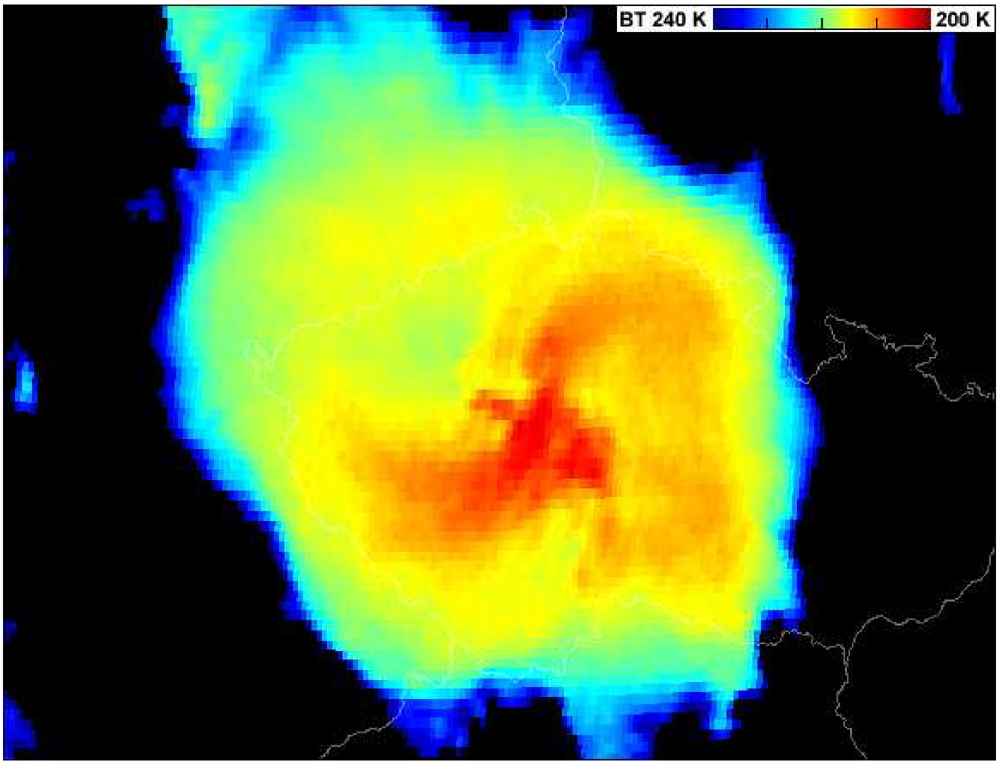

Figure 1b. The same as above, only the areas warmer than 240K are shown in black. This image, with the black being replaced by a transparent area, was used as the upper layer to create the sandwich product below (Fig. 1d).

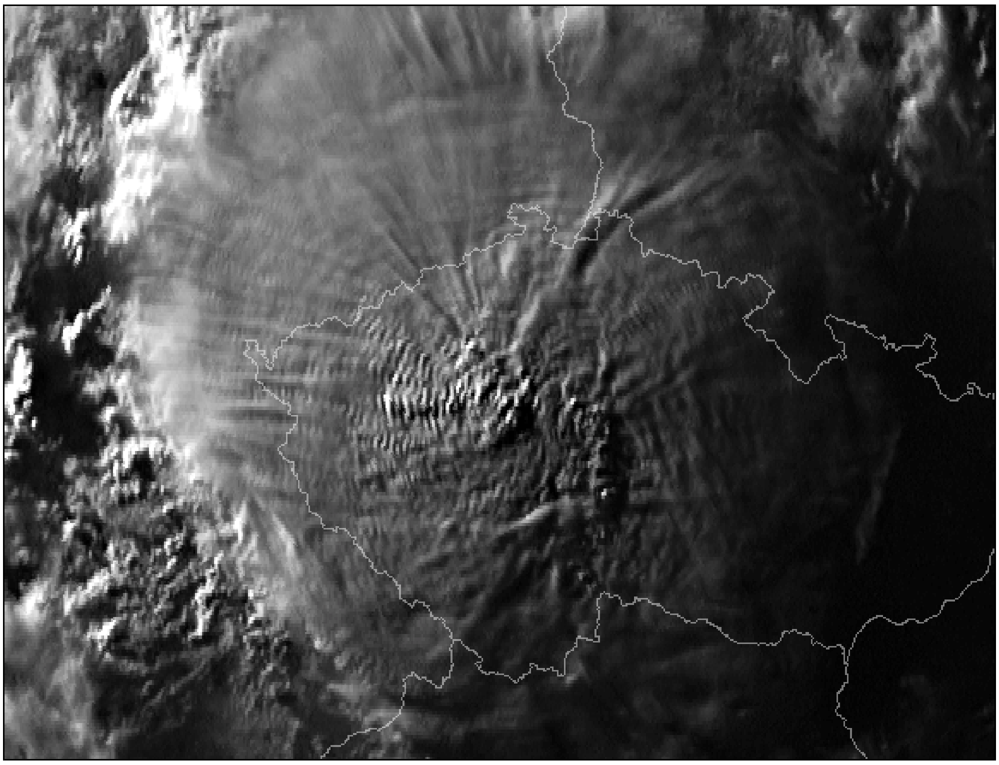

Figure 1c. The same storm as above in the HRV band. This image was used as the bottom layer to create the sandwich product shown below (Fig. 1d).

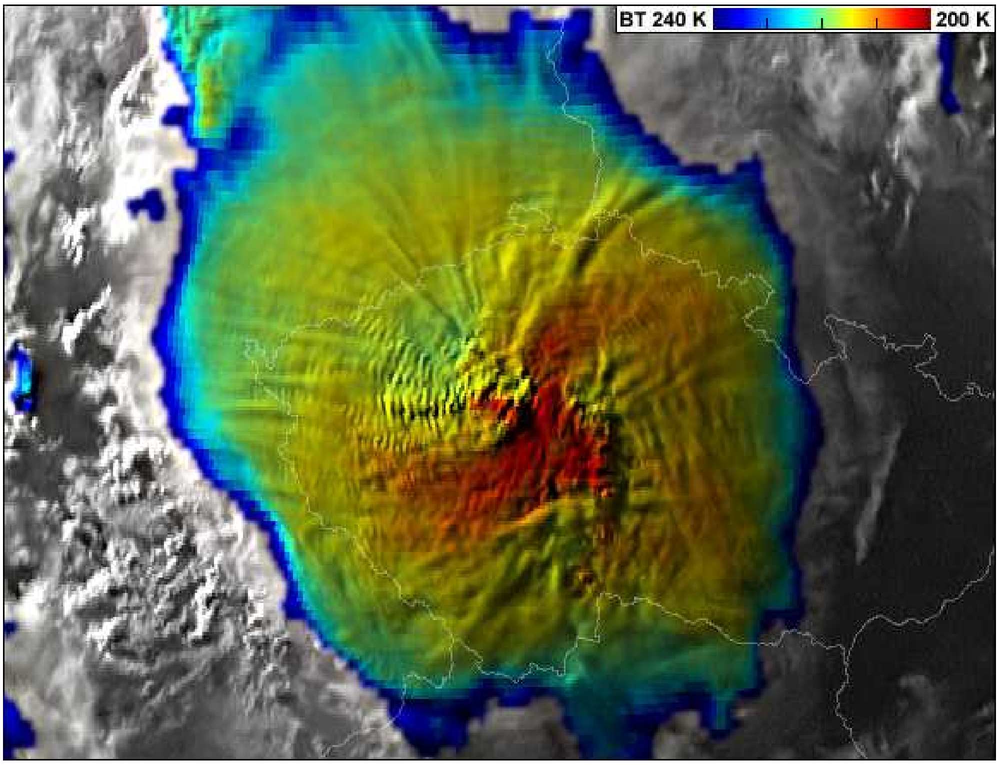

Figure 1d. Sandwich product (HRV/IR10.8 BT), based on the images 1b and 1c.

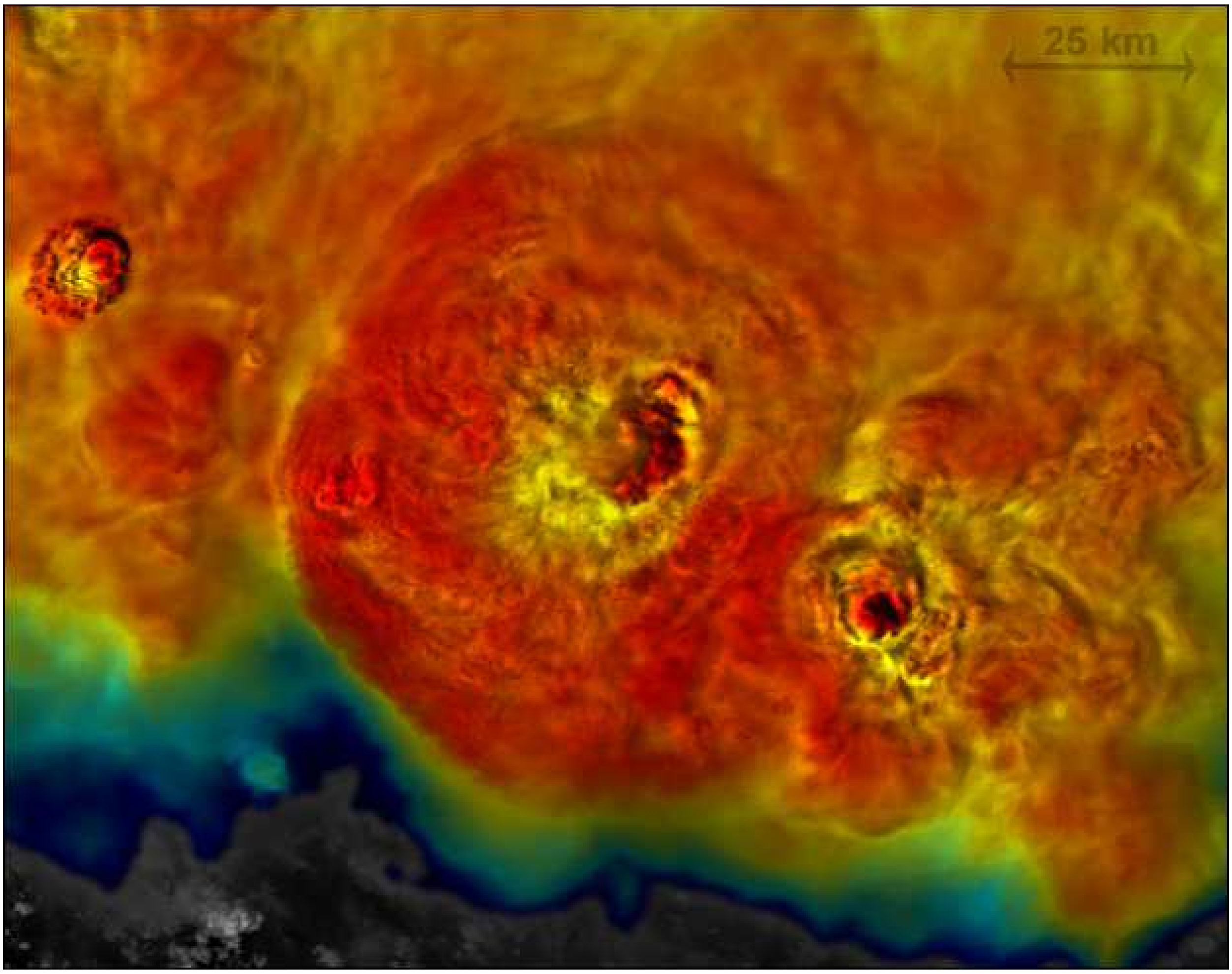

Figure 2. Example of a high-resolution VIS/IR-BT sandwich product, based on 250m MODIS band 1 (VIS) and 1 km band 31 (IR-window) data. The image shows a storm over west Brazil (2007-12-22, 18:37 UTC, MODIS/Aqua, centre of the storm about 9°S, 72°W) with distinct overshooting tops, cold-ring feature in IR-BT, gravity waves, and a faint plume spreading westward from centre of the OT inside the cold ring.