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Corresponding author's e-mail address: setvak@chmi.cz

BLENDED "SANDWICH" IMAGE PRODUCTS IN NOWCASTING

Martin Setvák[1], Zdeněk Charvát[1], Michaela Valachová[2,1], Kristopher Bedka[3]

[1] Czech Hydrometeorological Institute, Satellite Dept., Na Šabatce 17, Praha, Czech Republic
[2] Charles Univ., Dept. of Meteor. and Environment Protection, V Holešovičkách 2, Praha, Czech Rep.
[3] Science Systems & Applications, Inc., NASA Langley Research Center, Hampton, Virginia, USA

Abstract

This paper focuses on a satellite image product called the *blended* (or *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 paper describes in detail the method of image blending, focusing namely at the most typical example - the combination of a visible band with a color enhanced IR-window brightness temperature field. Several examples of various sandwich products are shown, focusing on deep convective clouds and their details, such as overshooting tops, cold-U/V and cold-ring features, plumes and other.

INTRODUCTION

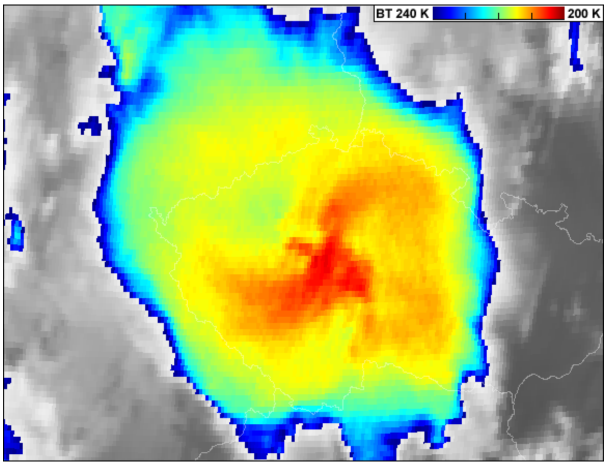
In the early years of satellite meteorology, the black-and-white and color enhancements were the only wider-spread methods of retrieving "hidden" information from the satellite imagery, such as cloud top brightness temperature (BT) field in the IR bands. These were later on followed by "RGB composite images" (e.g. Lensky and Rosenfeld, 2008), merging 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 color 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 the operational meteorology namely 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* (or *sandwich*) images, combining information from one (typically) black-and-white image and one color image (either color-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. 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 color-enhanced IR band; however, other combinations are also possible - e.g. using the "Storm-RGB" product for the upper layer. The blended sandwich products become even more attractive when used in satellite image loops. This paper describes in detail principle of the sandwich product, showing several examples and applications of these.

COLOR ENHANCEMENT OF THE IR BRIGHTNESS TEMPERATURE IMAGERY

In the past there was a large variability of the color schemes used by various groups or institutions when color-enhancing the IR-window imagery. Therefore, it was agreed by the Convection Working Group (CWG; http://essl.org/cwg) to unify on one common color scheme, recommended by the group (and informally also by EUMETSAT on various occasions). This color scheme is a "rainbow" color palette (used in IDL and various other remote-sensing software packages or systems), assigning red to the lowest brightness temperatures (BT) and blue to the warm end of the BT interval used for the color enhancement. The rainbow color palette is smooth, continuous one – in contrary to “block” or “step” color enhancements used by some other groups or institutions, which assign one specific color to a broader interval of BT. The main advantage of smooth color palette is that it shows more details of the cloud top. One of the reasons for selecting this particular color palette is that it follows the Wien’s displacement law – red colors being used for colder cloud tops, blue for the warmer parts of the cloud top.

Another, perhaps main reason for the color scheme as described above is the perception of the red color by humans – our brain tends to assign the red color to something 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 color to the lowest temperatures, typically found at the summits of the overshooting tops. A suitable range for color 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 (for an example of the impact of the tropopause height see Púčik et al, 2012). In contrary, for regions closer to the Equator, the color scheme needs to be shifted to lower temperatures, with the lowest BT around 185 K. An example of this color enhancement is shown in the Figure 1a. This type of the IR-BT color enhancement is used in the sandwich product described in the next section.



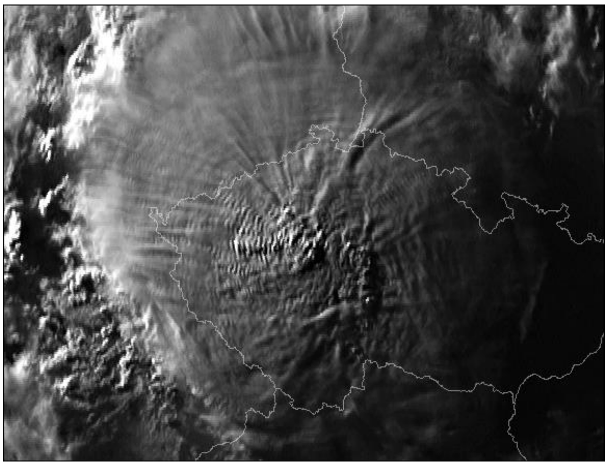


Figure 1a (left): **2011-07-13, 18:35 UTC, Meteosat-8, Czech Republic. Example of color-enhanced IR 10.8 image, using the color palette recommended by CWG. Areas warmer than 240 K are shown in standard (linear) grey scale. This image, with the areas shown here in grey scale being replaced by a transparent area, was used as the upper layer to create the sandwich product shown below (*Fig. 1c*).**

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

THE VISIBLE – COLOR 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 BTfield – 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 (GNU Image Manipulation Program) or ImageMagick. 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 color-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 color-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. 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. Finally, the main advantage of the sandwich product is in its animation possibilities, showing the evolution of studied phenomena in one single loop. This makes the sandwich products very attractive for operational applications. As the sandwich products are based on solar bands (visible or near IR), they can't be used at night.

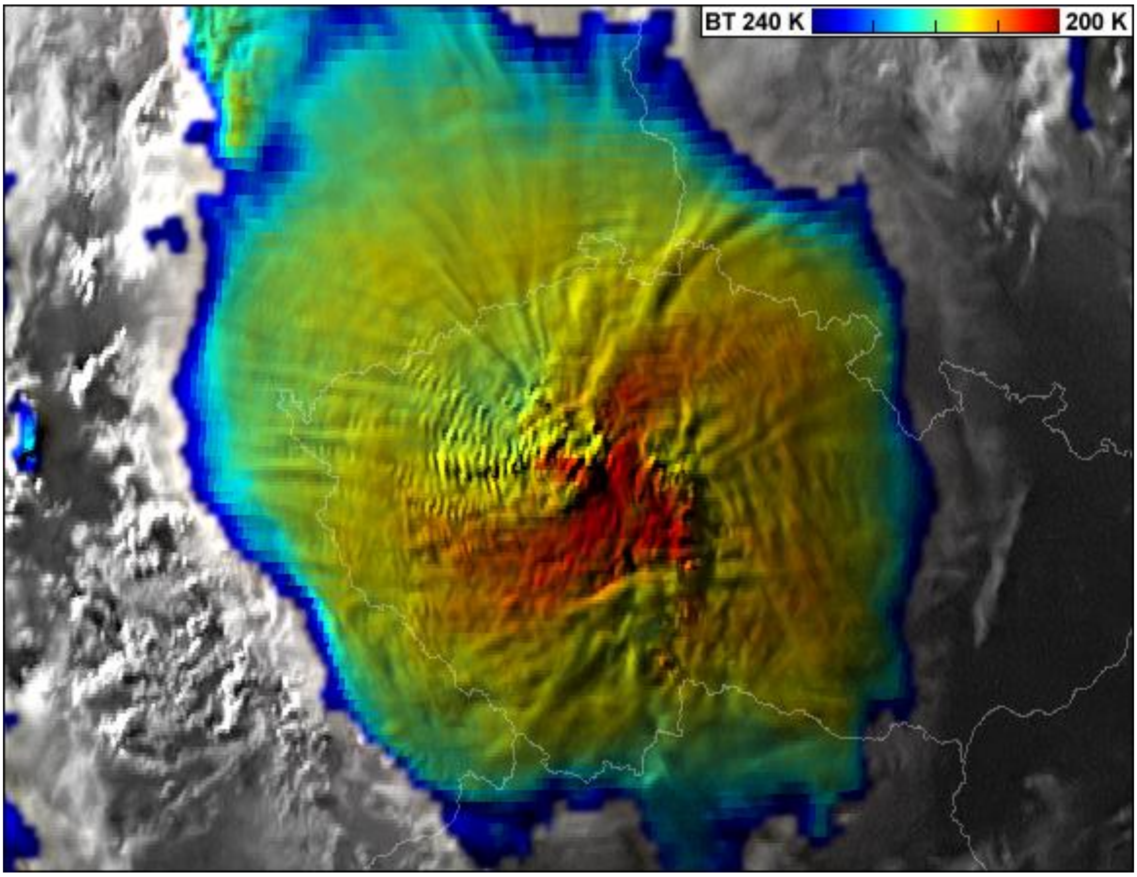


Figure 1c: **Sandwich product (Meteosat-8 SEVIRI HRV / IR10.8 BT), based on the images *1a* and *1b* above.**

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 colored one can be used as well – e.g. a true color image (this doesn't add much scientific information to the product, but can be used for aesthetics). Detailed information on the blending modes or blending functions can be found e.g. here: http://en.wikipedia.org/wiki/Blend_modes or here: http://photoblogstop.com/photoshop/photoshop-blend-modes-explained.

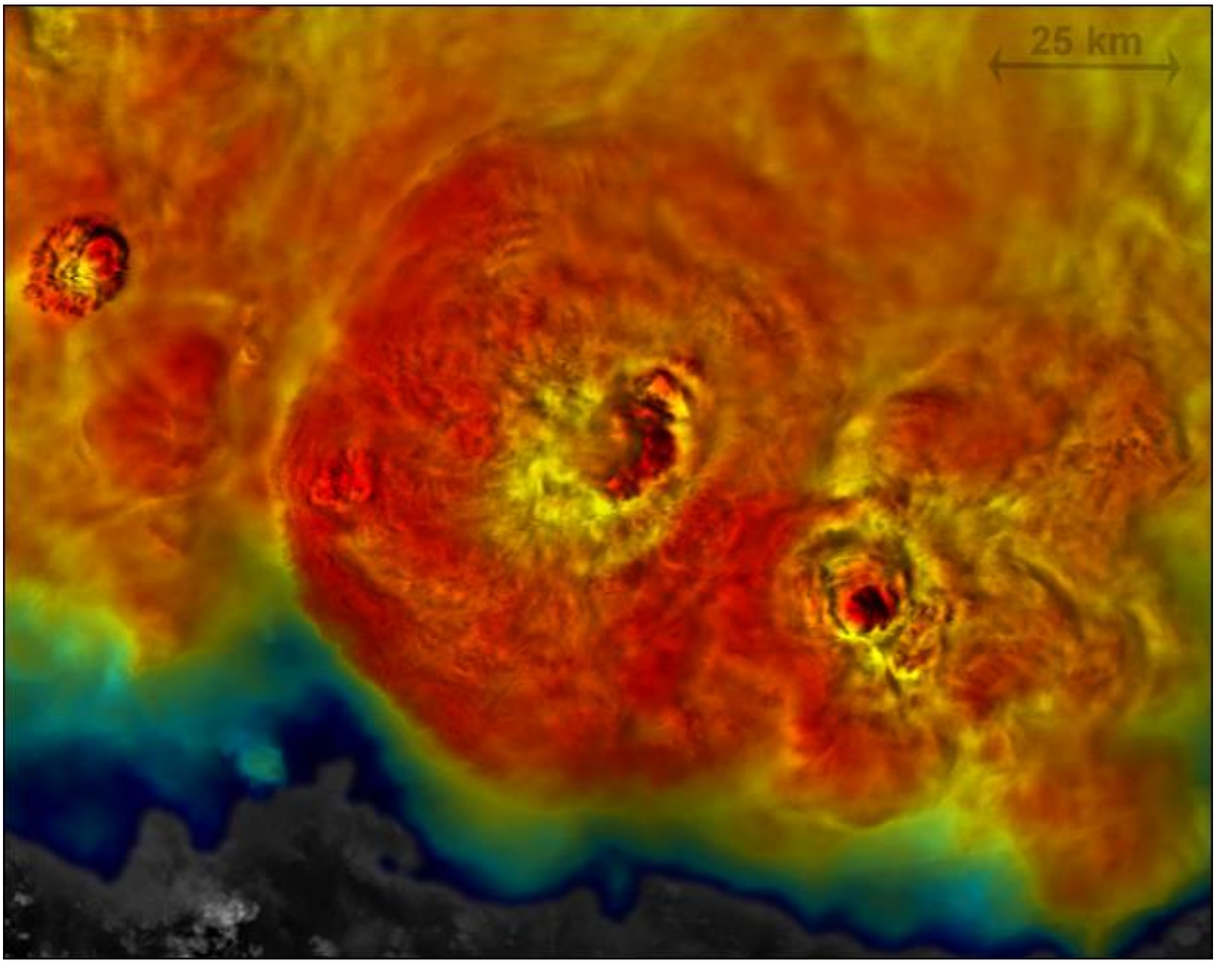


Figure 2: **Example of a high-resolution VIS/IR-BT sandwich product, based on the 250m MODIS band 1 (visible band), and 1 km band 31 (IR-window band) data. The image shows a storm over west Brazil (2007-12-22, 18:37 UTC, MODIS/Aqua) with distinct overshooting tops, a cold-ring feature in IR-BT, gravity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

When preparing the sandwich product images for case studies or publications, it is possible to significantly 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 the Fig. 2 below.

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. 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. This way the IR-BT component of the sandwich image colorizes the coldest cloud tops only, leaving the rest of the image intact.

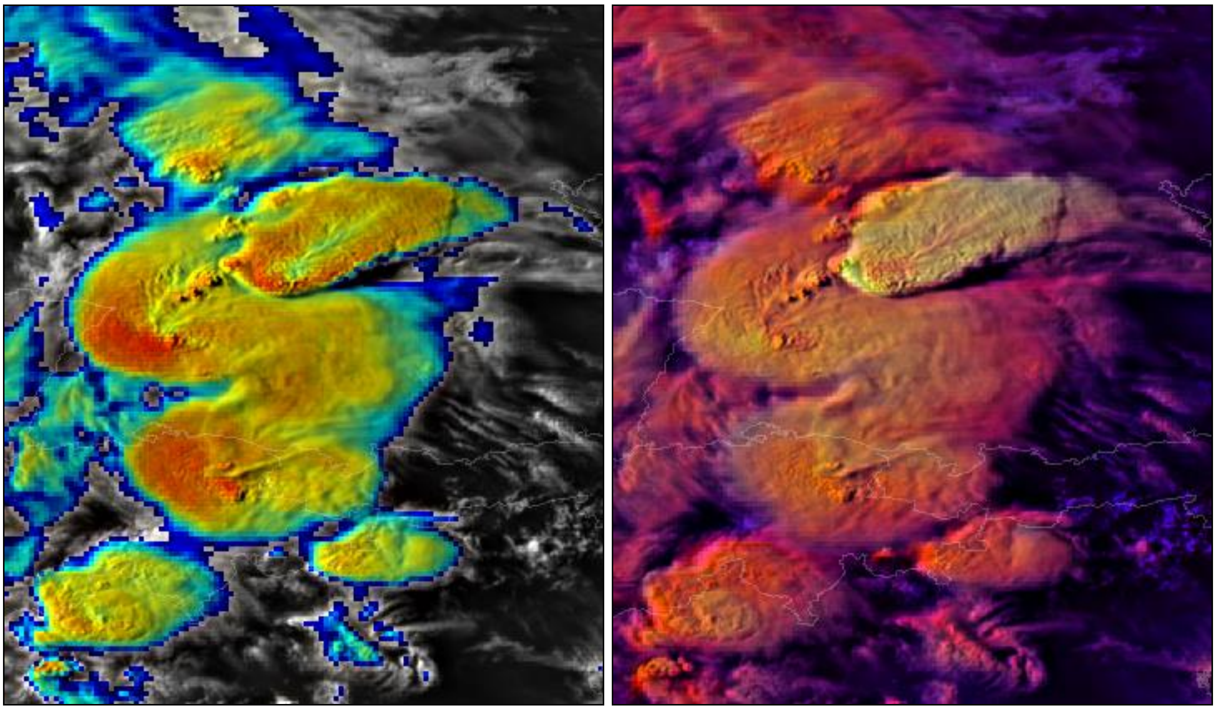


Figure 3**: 2011-07-12, 17:40 UTC. Examples of the Meteosat-8 (MSG-1) HRV / IR10.8-BT (left) and HRV / Storm RGB (right) sandwich products – convective storms above central and south Germany.**

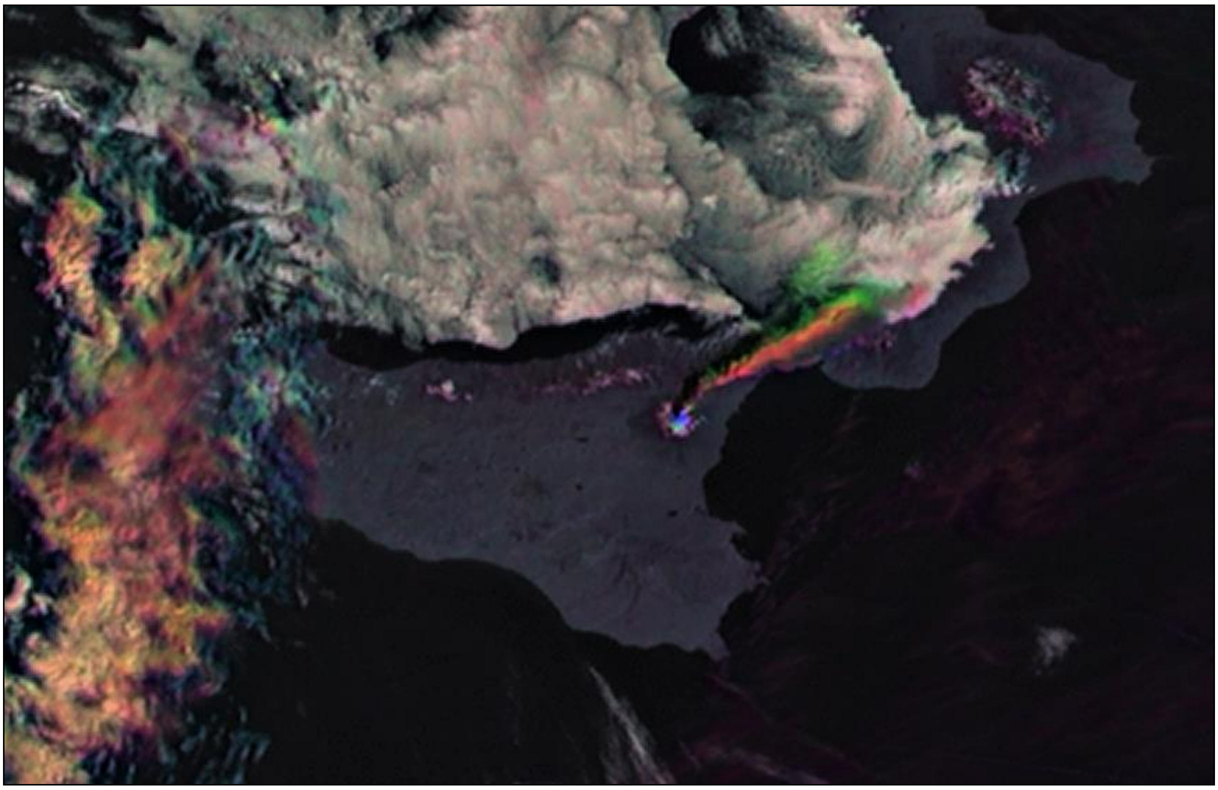


Figure 4: **2012-03-04, 09:10 UTC, Meteosat-8 (MSG-1). Example of the HRV / 24-Hour Microphysical RGB sandwich product, showing eruption of Etna.**

When setting-up the sandwich product(s), it is important to use (to maintain) the highest available resolution, not to lose the image details. When combining spectral bands at different resolution (pixel size), such as HRV with other SEVIRI bands, or MODIS band 1 at 250 m resolution with the other 500 m or 1 km MODIS bands, the lower-resolution images should always be remapped to match the higher-resolution image (band), not vice versa! When remapping (geo-referencing) bands at different resolution (pixel size), fine-tuning of their relative position may be needed, depending on the software/algorithms used for this. To fine-tune the relative position of the individual image layers, ground features (rivers, lakes, coastlines) should be used for this, not the clouds.

OTHER POSSIBLE COMBINATIONS OF THE SANDWICH PRODUCTS AND THEIR USE

The sandwich products, namely the most commonly used one - the HRV/IR10.8-BT, have been tested by several European national weather services for couple of years; usually the product gets a very positive feedback from the forecasters. It enables easier detection and monitoring of various storm-top features, such as overshooting tops, cold-U/V and cold-ring features, above-anvil ice plumes and other. It also helps avoiding misinterpretation of cloud-top "artifacts" (such as cloud gaps between individual storm cells), preventing confusion of these with some of the above-mentioned storm-top features. It also provides a more intuitive view of storm tops and their morphology.

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 standard RGB products. Among other such combinations are the sandwich products of a visible band with one of the microphysical RGB products, like the "Storm RGB" - see the Fig. 3, or the "24-hour Microphysical RGB" (Fig. 4). In the Czech Hydrometeorological Institute these two products are now used operationally. The use of these sandwich combinations is not restricted to storm monitoring only, but supports nowcasting in general. Also, besides the meteorological applications, the sandwich products appear to be very useful and attractive for studies of deep clouds and processes associated either with large fires (pyro-convection) or with significant volcanic eruptions; Fig. 4 shows an example of volcanic plumes above Etna as seen in the 24-hour Microphysical RGB sandwich product.

OVERSHOOTING TOPS IN SANDWICH PRODUCTS

As overshooting tops (OT) directly manifest strength of the updrafts which form them, their characteristics – namely their BT minima – are frequently used as one of the satellite-based indicators of possible storm severity. Typical OTs are manifested in IR imagery by very cold pixels and steep BT gradients around these, which are the basis of their automated detection methods (e.g. Bedka et al., 2010). In high-resolution visible imagery, the OTs can be revealed by their typical “bubble-like” structure and shadows they cast, however during day-time only. In “microphysical bands” (at 1.6, 2.2 and 3.5-4.0 μm) they may differ from their surroundings by their reflectivity, depending on the particle size and shape within them. Blending the individual images or products together into sandwich products offers the opportunity to study the properties of the OTs and their mutual relation with all the other storm-top features in one single image or loops of these.

Coldest pixels in IR bands are typically collocated with a summit of the OT in VIS images. However, OTs can be detected in IR only during their rapid ascent, not much is known about the speed of their warming during their descent or collapse. This might explain why we occasionally observe OTs in VIS, but not in IR - there are no distinct local minima in IR BT, as these OTs are already decaying and thus warming up. Namely for detection (by a human eye) of such warm OTs the sandwich product can be very useful. Fig.5 shows an example of such warmer OT (arrowed).

Other explanation for warmer OT temperatures can be in lower spatial resolution of the imager aboard some of the satellites (namely the geostationary ones). Pixel size of the instrument determines the size of the storm-top features we can distinguish. The better the resolution, the finer details can be resolved and the less averaging occurs. Given the fact that typical size of the OTs is of the order of several kilometres across, data from the instruments flown aboard polar orbiting satellites (with pixel size of the order of 1 km or better) enable more detailed studies of their various properties, including

BT. Thus, the spatial resolution of the used instrument also has a significant influence on the automatic OT detection techniques and their efficiency (Bedka, 2011).

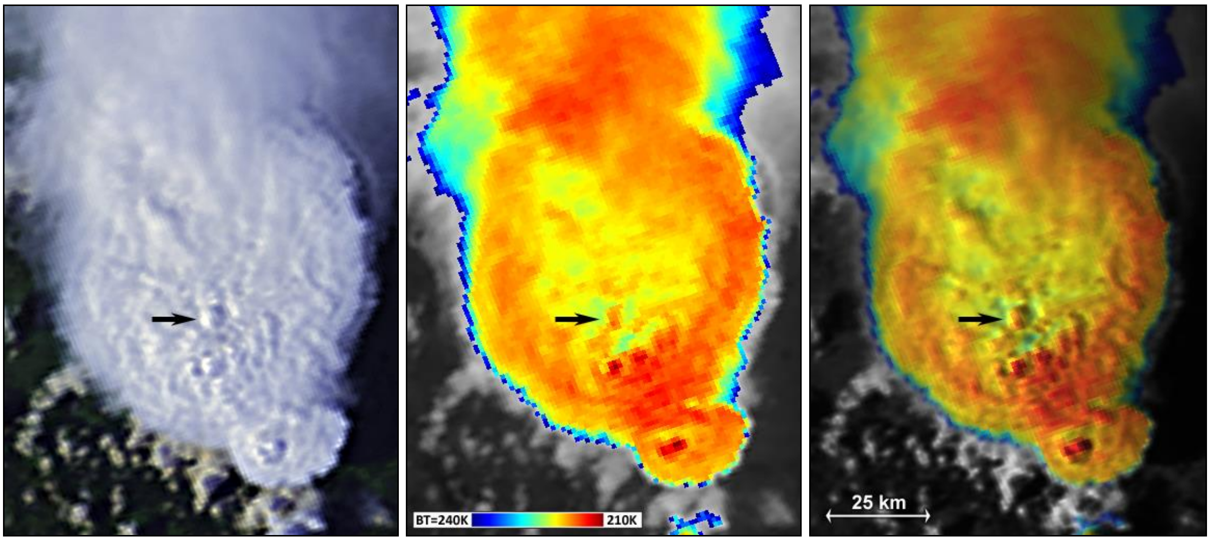


***Figure 5*: Example of warm OT (arrowed) in AVHRR imagery. While in solar bands (RGB composite of bands 1, 2 and 4, left image) the OT is well pronounced, in color-enhanced band 4 BT image (center, 210-240K) its temperature is relatively warm (216 K) as compared to the other OTs (210 K) further south, and comparable to the rest of the anvil top. Right image shows the sandwich product (of the band 2 and color-enhanced band 4 BT). 2012-07-05, 14:28 UTC, NOAA15, southwest Poland.**

The VIIRS High-resolution imaging channels aboard Suomi NPP satellite with its ~ 0.4 km resolution at nadir (~ 0.8 km at the swath sides) in all of its "I" image bands can provide detailed information about storm tops, unreachable ever before. The Fig. 6 shows fine details of a storm above central-east Germany. Coldest cloud top IR BT value reached 202 K (dark red). If the resolution of the instrument was ~ 1 km (similar to IR bands of AVHRR or MODIS), the lowest temperature would be several kelvins higher. Though the VIIRS-based sandwich product appears to be subjectively similar by its fidelity to that from MODIS (Fig. 2), it shows finer details due to better resolution in its IR image band (I5).

Another possible problem for OT detection is their high temporal variability. Since some of the cold OTs appear in one single MSG rapid scan (RSS) image only, or some of the tops appear warm from the very beginning (being detected in VIS bands only), certain ambiguity exists about their typical life time. The OT duration and warming speed issues may influence detection efficiency of OT BT-based detection methods (e.g. Dworak et al., 2012), and calls for better understanding of OT characteristics and their life cycle. Shorter RSS observations (either the planned MSG 2.5-minute RSS experiment, or GOES 1-minute data) can provide such information. Here the sandwich-based loops may help significantly namely for subjective OT detection and life cycle studies.

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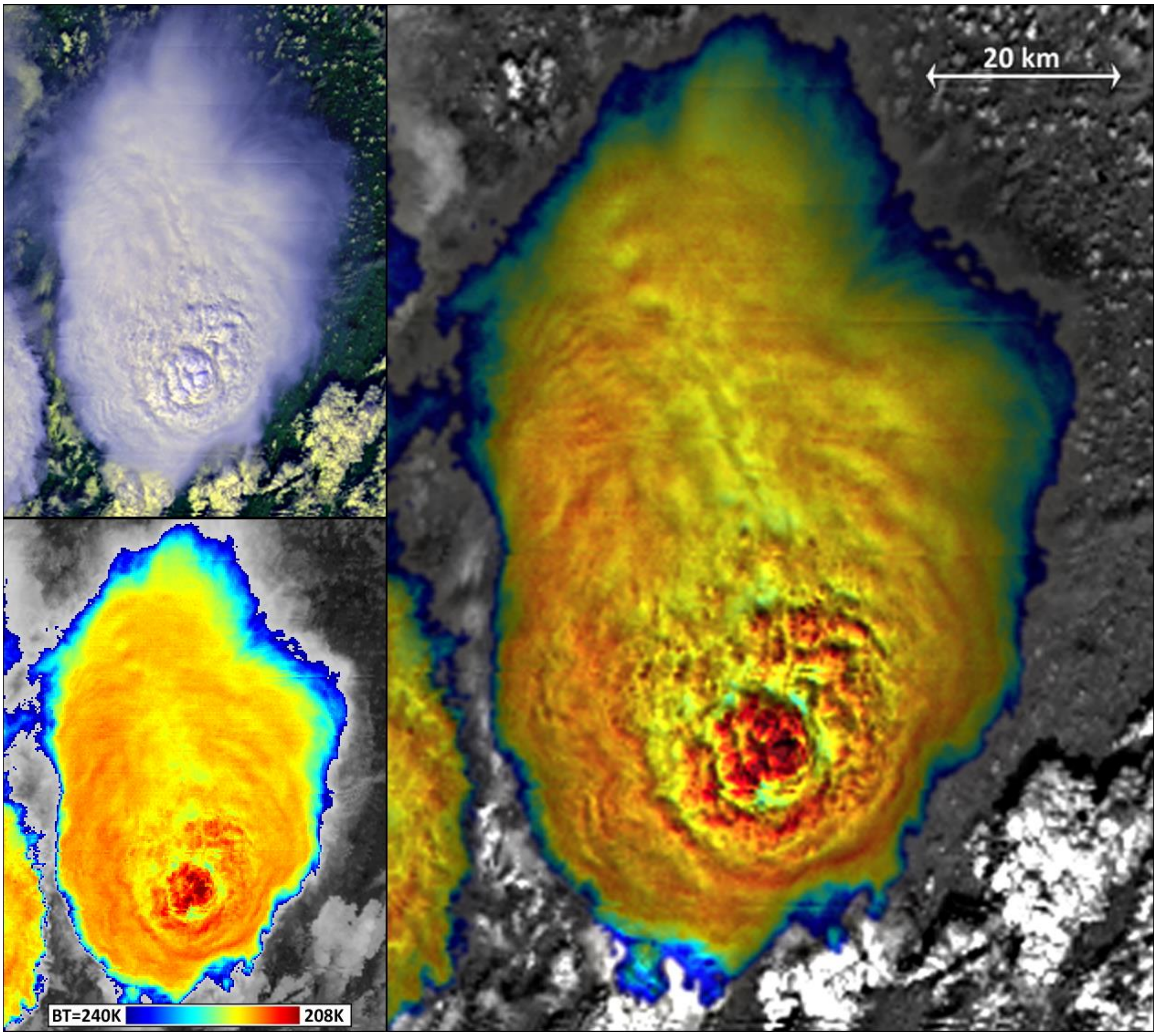

Figure 6: **2012-07-05, 12:07 UTC, Suomi NPP VIIRS, central-east Germany. Top left: RGB color composite of bands I1 (0.6 µm), I2 (0.9 µm) and I5 (11.5 µm). Bottom left: color-enhanced I5 (11.45 µm band) BT 208-240 K image. Right: sandwich product of I1 and color-enhanced I5 BT 208-240 K image.**

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