W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N
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WMO/EUMETSAT WORKSHOP ON RGB SATELLITE PRODUCTS

17-19 SEPTEMBER 2012

SEEHEIM, GERMANY

Regulation 42

Recommendations of working groups shall have no status within the Organization until they have been approved by the responsible constituent body. In the case of joint working groups the recommendations must be concurred with by the presidents of the constituent bodies concerned before being submitted to the designated constituent body.

Regulation 43

In the case of a recommendation made by a working group between sessions of the responsible constituent body, either in a session of a working group or by correspondence, the president of the body may, as an exceptional measure, approve the recommendation of behalf of the constituent body when the matter is, in his opinion, urgent and does not appear to imply new obligations for Members. He may then submit this recommendation for adoption by the Executive Council or to the President of the Organization for action in accordance with Regulation 9(5).

EXECUTIVE SUMMARY

The WMO/EUMETSAT Workshop on RGB Satellite Products[1] was held 17-19 September 2012 in the Lufthansa Training and Conference Centre in Seeheim, Germany, with 29 participants from all WMO Regions. The event was organized in liaison with, and support to, the WMO-CGMS Virtual Laboratory on Education and Training in Satellite Meteorology (VLab) and the WMO Severe Weather Forecasting Demonstration Project (SWFDP). The workshop involved lectures, discussions and practical exercises by experts and practitioners in the use of RGB satellite products, mostly for nowcasting and short-range forecasting. The meeting also allowed for revisiting recommendations on global standards for RGB composite satellite imagery developed in 2007.

Primary objectives of the workshop were to take stock of standards and best practices in the generation and use of RGB composite imagery in support of operational forecasting applications, and training. Sessions were dedicated to

- Provide an overview on RGB product generation and application
- Discuss integration of RGB products and derived quantitative products
- Operational applications of RGB products
- Scientific applications of RGB products
- Present RGBs from different imagers and sounding instruments
- Practical work on displaying and analyzing RGBs

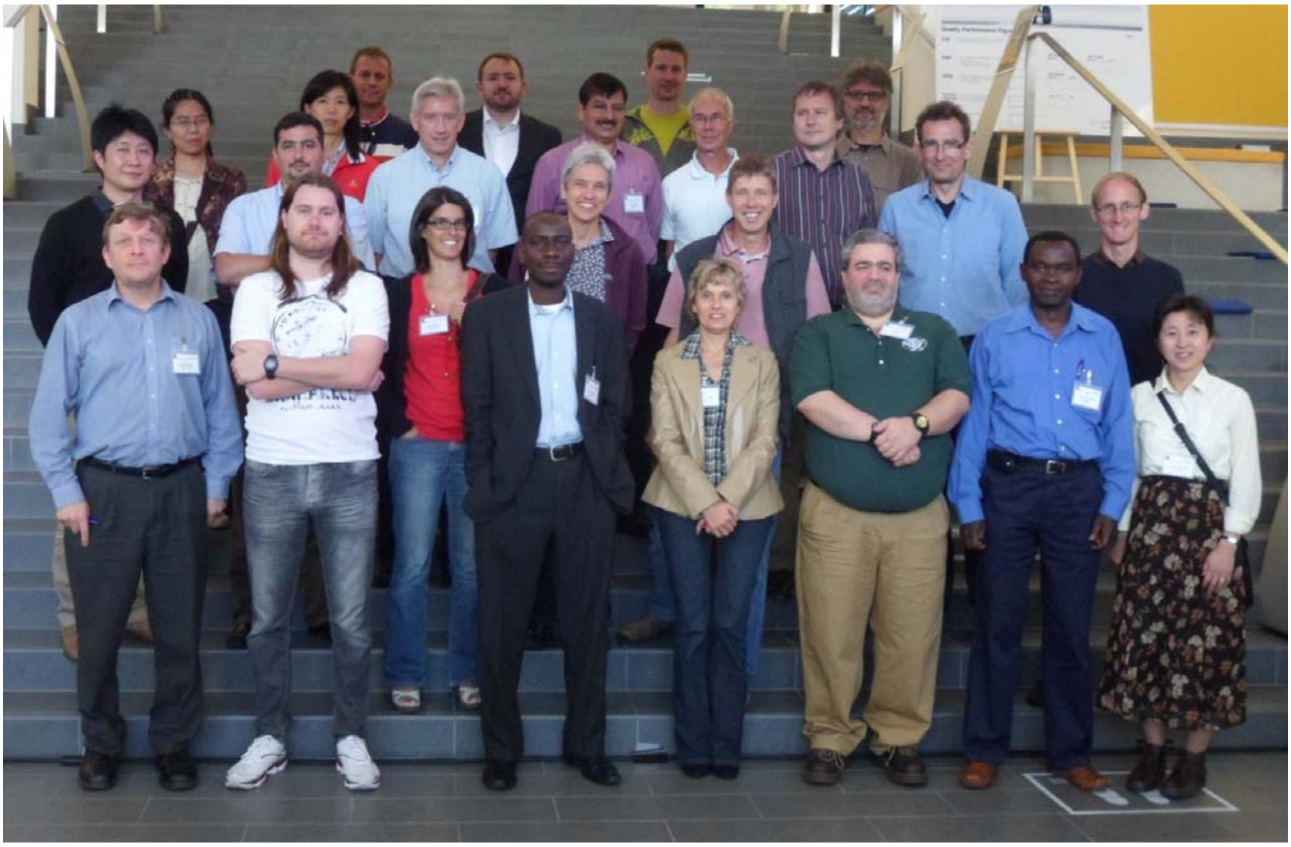
Participants agreed on 18 recommendations that should be followed to further enhance the utility of RGB satellite products for research, operational applications, and training in satellite meteorology. The workshop:

1. Confirmed the validity and usefulness of standard RGBs satellite products ("RGBs" hereafter), as recommended in 2007[2] (see also Annex III);
2. Reiterated channel rules for RGBs (use of reflectance in VIS, BT in IR);
3. Recommended the combined use of RGB and quantitative products (satellite-derived or other, GIS) as a general rule; e.g., animated RGB sequences provide meteorological context for derived quantitative products in operational forecasting;
4. Recognized advances in deriving quantitative products, in particular in consistency over time, although challenges remain (e.g., in twilight conditions);
5. Considered RGBs based only on IR channels to be most robust for operational weather monitoring purposes, while recognizing the value of blended products;
6. Encouraged the development of consistent and sensible terminology for RGBs, e.g., common definitions of terms 'natural colour', 'pseudo', 'synthetic' (with Action on workshop sub-group led by Andrew Molthan to develop such terminology);
7. Stressed the requirement for continued implementation of relevant imaging channels on future GEO/LEO meteorological missions, recognizing the importance of Airmass and 24-h Microphysics RGBs;
8. Identified the need for increased focus on validation and spatio-temporal homogeneity of quantitative products (e.g., surface "natural colour" RGB vs Fractional Vegetation Cover);
9. Recommended the standardized use of split window IR channel differences (11.0-12.0 µm)

[1] RGB (Red-Green-Blue) satellite products (or composites) refer to satellite imagery with the information content of multiple spectral channels mapped against an RGB colour scheme, for optimized visualization while at the same time preserving pattern and texture of atmospheric (e.g., cloud) and surface features, as well as continuity over time.

[2] WMO (2007): RGB Composite Satellite Imagery Workshop, Final Report. Boulder, CO, USA, 5-6 June 2007, http://www.wmo.int/pages/prog/sat/documents/RGB-1_Final-Report.pdf

10. Required the resolution of digitized radiometric satellite signals to be at least 10 bit (in IR equivalent to about 0.2 K for 280 K scene brightness temperature), especially important for calculating differences;
11. Referred to the EUMETSAT Convection WG's recommendation regarding ambiguity of the so-called convective storms RGB product, and recommended the consistent use of terminology when interpreting this product with respect to ice particle size;
12. Confirmed that RGB colour interpretation should be improved through clear association with features, for example by colour palettes, mouse roll-over pop-ups, and icons;
13. Stressed that training on RGB interpretation was important and recommended that such training include sources of misinterpretation, such as: limb cooling effect, diurnal variation, emissivity/reflectivity dependency, merits and limits (ash concentration…), sun eclipse effects, colour simulators for specific features (e.g. fog);
14. Recommended that forecaster bench display system retain full RGB resolution (in geometric and colour space);
15. Recommended that the RGB community continue to discuss emerging RGBs which use a wide range of spectral domains and variables (e.g., passive and active MW, space weather variables, ocean colour radiances, sea-surface temperature, significant wave height, sounder radiances);
16. Recommended that a literature review be undertaken on the state-of-the-art of operational RGB applications;
17. Encouraged satellite providers to make available high-resolution satellite imagery data in real time, for evaluation, validation and training purposes, fully consistent with their mandate and data policy.



From left to right:

Front Row: Bodo Zeschke, Thiago Souza Biscaro, Carla Barroso, Hama Hamidou, Estelle de Coning, Brian Motta, Ignatius Gitonga, Ayako Takeuchi

Second Row: Sungwook Hong, Tahar Saouri, Michael Fromm, Renate Brummer, Jochen Kerkmann, Roland Winkler, Stephan Bojinski

Third Row: Ning Niu, Jian Liu, Virendra Singh, HansPeter Roesli, Andreas Wirth

Fourth Row: Kevin Fuell, Andrew Molthan, Sauli Joro, Tom Rink

Not in picture: Phil Watts, Volker Gärtner, Marianne König, Vesa Nietosvaara, Mark Higgins

0. INTRODUCTION

The three-day workshop, jointly organized by WMO and EUMETSAT, opened at 09.00 on Monday 17 September 2012 in the Lufthansa Training and Conference Centre, Seeheim, Germany, hosted by Jochen Kerkmann (EUMETSAT). The meeting was co-chaired by HansPeter Roesli and Stephan Bojinski and had 29 participants from all six WMO Regions (see list of participants in Annex I and the agenda in Annex II). The event was organized in liaison with, and support to, the WMO-CGMS Virtual Laboratory on Education and Training in Satellite Meteorology (VLab) and the WMO Severe Weather Forecasting Demonstration Project (SWFDP).

As mentioned in the workshop invitation and the opening remarks by the co-chairs, primary objectives of the workshop were to take stock of standards and best practices in the generation and use of RGB satellite products[3] (also referred to as “RGBs” hereafter) for research, operational applications such as operational weather forecasting, and training in satellite meteorology. The workshop aimed to review and, as appropriate, confirm recommendations made at a predecessor workshop in 2007[4] for RGB schemes focusing on cloud microphysics, air mass/potential vorticity, and surface properties (see Annex III for details). The 2012 workshop involved a larger number of experts, practitioners and users, provided a platform for the exchange of knowledge, experience, and methods, and contributed to community-building.

A total of six sessions were dedicated to

- Provide an overview on RGB product generation and application
- Discuss integration of RGB products and derived quantitative products
- Operational applications of RGB products
- Scientific applications of RGB products
- Present RGBs from different imagers and sounding instruments
- Practical work on displaying and analyzing RGBs

Given the introduction of a new generation of geostationary imagers over the coming five years (through Himawari-8/9, GOES-R, GEO-KOMPSAT, and MTG), adequate and timely preparation of users to the new capabilities is necessary to ensure maximum benefit, and to mitigate risks associated with the transition to the new imagers. The WMO Commission for Basic Systems issued a guideline[5] to this effect, for consideration by both satellite operators and user institutions. Among others, the guideline recommends the instigation of user preparation projects five years in advance of the anticipated launch date. It was noted that the workshop provided a timely contribution to optimize the exploitation of upcoming imagers in terms of RGB products.

In preparation to the workshop, all presentations and background documents were made available to participants on a EUMETSAT ftp server and a dedicated meeting website hosted by WMO. References to documents and online resources are given in Annex IV. Individual presentations are available from the presenters or from the organizers upon request.

1. SESSION 1: OVERVIEW RGB PRODUCTS (RGB TUTORIAL)

Jochen Kerkmann provided an overview with the motivation for using RGB satellite products for a range of applications, the basics of their generation, and examples based on the Meteosat Second Generation SEVIRI imager. In short, RGB satellite products based on multiple

[3] RGB (Red-Green-Blue) satellite products (or composites) refer to satellite imagery with the information content of multiple spectral channels mapped against an RGB colour scheme, for optimized visualization while at the same time preserving pattern and texture of atmospheric (e.g., cloud) and surface features, as well as continuity over time.

[4] WMO (2007): RGB Composite Satellite Imagery Workshop, Final Report. Boulder, CO, USA, 5-6 June 2007, http://www.wmo.int/pages/prog/sat/documents/RGB-1_Final-Report.pdf

[5] WMO (2012): CBS Guideline for Ensuring User Readiness for New Generation Satellites (CBS-15/Doc.4.2(1)), http://www.wmo.int/pages/prog/sat/documents/SAT-GEN_CBS-15-GuidelineUserReadiness.pdf

channels can convey more information in a single image than single-channel grayscale imagery while at the same time preserving pattern and texture of atmospheric and surface features. He recalled the guidelines established in 2007 for the creation of RGBs, demonstrated the use of standard RGBs for operational forecasting, and introduced other RGBs. He highlighted the importance of using standard RGB schemes to better guide users by avoiding ambiguity and mis-interpretation of composites. There are theoretically many ways to combine the different channels in a colour scheme, therefore adherence to standards and best practices is essential ("RGB" is just one, orthogonal colour space). Besides the potential for confusion, another disadvantage of RGB image composite is their inability to be used by colour-blinded users.

The RGB schemes recommended as best-practice five years ago (cf. Annex III), largely based on the MSG Interpretation Guide, could since be confirmed as they were successfully adopted by the European user community. These best practices should therefore be further promulgated.

Some general rules for creating "good" RGB products (in terms of contrast enhancement, interpretability) were presented. The workshop recognized different degrees of complexity in interpreting RGBs, depending on physical properties of interest, channel sensitivity, channel combination, and channel-derived signal (radiances; brightness temperatures). An application and user-dependent trade-off between information content and interpretability needs to be achieved. Adding information to RGBs, such as feature delineation facilitates interpretation and should be encouraged (upon mouse roll-over, or hard-coded in imagery; analyses from numerical weather prediction models and other quantitative products, e.g., contour lines of wind fields, aerosol optical depth).

The workshop also recognized a need for harmonizing terminology related to RGB satellite products:

Andrew Molthan leads an Action, assisted by Kevin Fuell, Brian Motta and Renate Brummer, to develop standard basic terminology definitions for "True colour", "Natural colour", "Pseudo-natural colour", and "Synthetic", for acceptance by the RGB community.

The use of RGB products in operational forecasting was then demonstrated, covering two complementary RGB composite schemes (cf. Annex III):

- Microphysics RGB (clouds/dust; with day/night capability)
- Airmass/Potential Vorticity RGB (with day/night capability)

and five application-specific RGBs composite schemes for:

- Day microphysics (for inferring cloud phase and delineating ship trails)
- Night microphysics
- Day convective storms
- Day Snow-Fog
- Natural colours

The need to make users of RGB satellite products aware of artefacts in the imagery (e.g., due to stray light, limb effects) was emphasized. Others stressed the value of standard products as compared to tuned products to analyze specific phenomena.

Renate Brummer provided an introduction to the use of RGB satellite products on the basis of the NPP VIIRS instrument, which features 16 moderate resolution bands and five fine-resolution bands in VIS, NIR-SWIR, MWIR, LWIR, and one day-night band. She provided good examples for applying "true colour" and "natural colour" RGBs for detecting fires and mapping surface features (e.g., iron mine, floodings), and for distinguishing liquid/ice clouds and snow/ice on the ground.

It was noted that the missing green channel on GOES-R ABI is being replaced by a simulated green channel. Himawari-8 ABI does feature a green channel.

2. SESSION 2: INTEGRATION OF RGB PRODUCTS AND DERIVED QUANTITATIVE PRODUCTS

In this session, based on keynote talks by **Marianne König** and **Jochen Kerkmann**, participants discussed the relative strengths and weaknesses of RGB satellite products and quantitative products (i.e., derived using a physics-based algorithm) and the benefits of using both in conjunction, leaning mostly on MSG product development.

The following observations were made:

RGB imagery:
- Allows for a quick way to explore satellite data
- Provides rapid visualizations and animations
- Depends on the quality and digital resolution of the original channel signal (10-bit from satellite, 8-bit for imagery)
- Can be regionally/geographically adjusted
- Have an element of subjectivity
- Cannot be averaged over time
- Provide more spatio-temporally consistency (e.g., more fidelity at feature edges)

Quantitative products:
- Need to work everywhere, anytime
- Require ancillary data (e.g., emissivity, coastlines)
- Can be validated
- Can be assimilated in models
- Can be averaged over time
- Are more objective than RGBs
- Are less spatio-temporally consistent than RGBs
- Are more difficult to animate

Participants discussed these differences using ash cloud products as an example. Volcanic ash is well observable with MSG imagery in the absence of clouds, providing a solid estimate of spatial and temporal distribution. However, a strong signal in the RGB composite does not necessarily mean the presence of more ash; furthermore ash clouds with very low or very high ash mass loadings are not easily identifiable. It was noted that the combined use of NWP output results and volcanic ash RGB product provides more value.

The usefulness of RGBs in conjunction with quantitative products for detecting convection and overshooting cloud tops in particular was also discussed.

Phil Watts presented results of cloud phase studies using instruments in the A-train, such as on Cloudsat and Calipso, used to infer on the vertical distribution of cloud top ice, winds. He showed comparisons of these results with RGB cloud microphysics products and NWP output.

Bodo Zeschke reported on comparison of RGB products and derived quantitative products using the example of the Airmass RGB (as per Annex III) compared with isentropic potential vorticity, water vapour-derived and model-derived upper air winds over Australia. He investigated the signatures of the various products and raised questions on the added value of the Airmass RGB in lower latitude regions. He also looked into the differences in Airmass RGBs derived from MODIS and SEVIRI.

Carla Barroso / Nuno Moreira (remote participation) provided an overview of advantages and disadvantages of RGB satellite product and quantitative (“objective”) products. They presented “recipes” and underlying physical basics for the “natural colour”, “cloud/storm”, “dust” and “forest fires” RGBs, and compared them with matching quantitative products (Fractional Vegetation Cover, Leaf Area Index, FAPAR; cloud phase, cloud type; dust flags; fire radiative power, respectively).

It was noted that poor quality of channel calibration and consistency in areas of sensor overlap (e.g., overlapping field of views of geostationary imagers) can negatively impact the consistency of quantitative products as well as RGB products. Activities in the Global Space-based Inter-Calibration System (GSICS) and the Committee for Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) aim at improving sensor-to-sensor intercalibration and quantitative validation of satellite sensors.

Participants enquired whether there was a recommended hierarchy in the use of different RGBs to interpret phenomena. It was noted that for teaching purposes, the physical basics of the input channel signals need to be understood. Also, participants noted that the best value of using RGB products came from their use in combination with other products, such as from models, radar and other ground-based systems, thereby benefiting from the strengths and mitigating the weaknesses of each technique (e.g., in dusk/dawn conditions).

In his presentation, **Hama Hamidou** reported on the operational use of RGB satellite products in tropical West Africa. He emphasized the value of satellite-derived products in the absence of radar and good synoptic in-situ coverage, as is the case in parts of West Africa. Lack of appropriate training of forecasters posed a challenge when select from the large number of products available on EUMETCast the ones most useful for any particular case.

He noted the usefulness of the MSG-derived Dust RGB satellite product and the challenges associated with detecting convective systems by day and at night in his area of interest using the standard RGB composites provided on EUMETCast. Such systems sometimes caused severe flooding events and required the combined use of the nighttime Microphysics RGB and the Airmass RGB (cf. Annex III).

Virendra Singh provided an overview of current and planned satellite imager capabilities by IMD, along with reception and processing ground segments in India, and product suites generated from current Indian and non-Indian missions (such as MODIS). Generation of standard RGB satellite product, such as the Airmass RGB, is planned, following the examples provided in Annex III.

He articulated IMD’s interest in adopting the recommended standard RGB schemes for their service applications. Interest in participation in the WMO-CGMS Virtual Laboratory for Education and Training in Satellite Meteorology was also expressed, along with the need for technical support in applying RGB algorithms and installation/use of the McIDAS-V visualization software.

In a remote presentation, **Tim Schmit** showed ways to combine qualitative RGB imagery and quantitative products to maximize their value (and to remove the “tyranny of versus”), using examples derived from imagers and sounders. He showed examples for overlaying contour lines of total precipitable water, cloud top temperature, rain rate, aerosol optical thickness with RGB composites. The planned product suite (baseline, future) of the GOES-R Advanced Baseline Imager (ABI) was also introduced. The 5-minute scan repeat cycle (and 1-minute rapid scan) of the GOES-R ABI will allow enhanced monitoring of a range of events (winds, dust, fires, storms), as compared to the current 15-30 minute temporal sampling of the GOES imagers.

After the session, participants followed the kind invitation by EUMETSAT to attend the Metop-B launch event at EUMETSAT HQ in Darmstadt.

3. SESSION 3: OPERATIONAL APPLICATIONS OF RGB PRODUCTS

Brian Motta showed RGB satellite product examples based on AVHRR, MODIS, GOES, NPP VIIRS and elaborated on benefits and challenges associated with using RGBs in operational forecasting (such as in US Weather Forecasting Offices). The GOES-R Proving Ground program had proven beneficial in preparing the uptake of ABI-derived RGBs by forecasters. RGBs should also be considered useful for public weather services, i.e. for broadcasting purposes.

He discussed the necessity for guidance in the generation of RGBs that were understandable and useable by operational forecasters. The recommended standard RGBs developed at the 2007 workshop served as a useful basis in this regard, but may need revisiting and expanding.

Some examples for RGBs for space weather-related applications (delineating sun cold and hot spots and its corona) based on the SUVI instrument were also shown.

Carla Barroso elaborated on the use of RGBs by the Meteorological Institute of Portugal (IM) for nowcasting purposes: tracking convective systems, fire detection, dust storm tracking (mostly with North African provenance), and detecting coastal fog. Comparisons of standard RGB products (nighttime Microphysics RGB, Airmass RGB) with quantitative products provided by the EUMETSAT Nowcasting SAF were shown, for cases of severe convection.

Estelle de Coning presented the use of RGBs in the South African Weather Service (SAWS). She showed the use of the SUMO display software for visualizing RGB imagery and overlays of radar and lightning data. Rain gauge observations were used to correct biases in the SEVIRI-based HydroEstimator which is used in a flash flood forecasting system in South Africa. A survey among forecasters showed preferences in using standard RGB satellite products. Case studies were shown for the use of RGBs in analyzing: severe weather events associated with heavy rainfall and high wind speeds; a volcanic ash event related to eruptions in the Puyehue-Cordón Caulle volcanic complex (PCCVC) in the Chilean Andes; a tropical cyclone. She concluded with stressing the usefulness of RGBs for operational nowcasting, noting the value of regionally-tuned products provided by the WMO Regional Specialized Meteorological Centre (RSMC) hosted by SAWS Pretoria.

Thiago Biscaro showed examples for the use of multi-channel imagery in the operational environment of INPE, for thunderstorm tracking and evolution, and lightning forecasts. He noted the value of satellite imagery for operational forecasting and nowcasting given the relatively poor radar coverage of Brazil.

Bodo Zeschke presented an overview of the use of RGB satellite products by the Australian Bureau of Meteorology (BoM), based on MTSAT, FY-2, NOAA-18, MODIS, and showed comparisons of MODIS with MSG-based products. The freeware HYDRA multispectral data analysis toolkit enables these comparisons and has been used by the WMO-CGMS VLab Centre of Excellence maintained by BoM. Preparations are underway for using RGBs from the upcoming geostationary imager on Himawari-8/9. Further advice is sought on the optimum use of RGBs by operational forecasters.

Kevin Fuell and Andrew Molthan introduced the work of the NASA Short-term Prediction, Research and Training (SPoRT) program, aimed at transitioning NASA data and research capabilities into operational forecasting in the 2-day forecasting range. The best-practice RGB schemes (cf. Annex III) are used for this purpose. Examples were shown for applying MODIS-derived RGB imagery in monitoring dust events, fire events, cloud microphysics, and the 2010 oil spill in the Gulf of Mexico. RGBs from VIIRS, MSG and the GOES sounder are also considered. They identified challenges in the generation and use of RGBs, namely accounting for artefacts (e.g., limb effects), illumination geometry effects (e.g., sun angle), and differences in spectral responses between channels on different instruments. It was stressed that RGB satellite products should be compatible with the US AWIPS-II forecaster display system to ensure uptake.

Tahar Saouri provided an overview of the Satellite Remote Sensing Centre maintained by DMN Morocco. He presented the motivation of DMN for generating and using RGB satellite products and described the use of a defined colour palette associated with standard RGBs to provide intuitive guidance to interpret the phenomena shown by the RGBs. Since such colour palettes are displayed concurrently with the RGB on forecasters' desks, they by implication adapt to the specific colour rendering of the display system.

Ignatius Gitonga presented a short overview of the use of RGB satellite products by the Kenya Meteorological Department for the purpose of nowcasting, short-range and seasonal forecasting.

Roland Winkler from AustroControl introduced the use of the visualization tools Cinesat and VisualWeather for superimposing difference images and RGBs optimized for tracking convective phenomena. He described the interest by the aviation industry for detecting ice clouds and especially super-cooled water droplets to provide icing warnings. Such products were so far available from satellites only on an experimental basis.

Andreas Wirth explained the use of RGB satellite products by the Austrian Meteorological and Geophysical Service (ZAMG). Using the newly-introduced VisualWeather visualization system, the Service uses recommended RGB products (Airmass, 24h Microphysics, Convective storms) as well as unconventional channel combinations for particular applications. He introduced the products made available through ePort on the EUMETrain webpage (cf. References in Annex IV).

Participants stressed that high-resolution RGB animations should be made available online in near-real time for training purposes.

In a second presentation, **Bodo Zeschke** demonstrated operational application of the Severe Storm RGB in Australia using MODIS imagery by showing several examples of severe storms signatures in the RGB and discussing a possible way of classifying storms based on cloud top features. He also compared the RGB products with MODIS high-resolution visible imagery and radar sequences, indicating overall good consistency. Animated imagery sequences were necessary to properly monitor the evolution of convective systems.

Vesa Nietosvaara showed the example of using the 24-h Microphysical RGB to detect fog over snow-covered areas, which is a particularly difficult given the similarity in spectral signature in the VIS and IR. He further elaborated on the training programmes undertaken by EUMETSAT, aimed at facilitating the acceptance of new products and techniques by operational users.

4. SESSION 4: SCIENTIFIC APPLICATIONS OF RGB PRODUCTS

HansPeter Roesli and Jochen Kerkmann showed examples for scientific applications of RGB products related to dust clouds, ash/SO2 clouds, water/ice clods, low-level moisture, tuned and special RGBs, and long-term RGB loops. The signature of high and low-lying dust clouds and its dependence on cloud optical thickness were demonstrated. The comparison of Dust RGB imagery and dust profiles from Cloudsat/Calipso complemented the interpretation of the RGB regarding dust layering and thickness. The power of RGB satellite products in detecting volcanic ash was contrasted with the complexity of detecting ash in the presence of clouds, and discerning cloud microphysics in the presence of ash.

Based on a composite of Meteosat-9, GOES-11, MTSAT-1R imagery and using the split window difference, they showed a loop of the Southern Hemisphere circumpolar flow using volcanic ash as a tracer. Long-term (covering weeks or months) RGB loops are also useful for land monitoring (e.g., monitoring water influx into the Okavango delta; Lake Chad water level fluctuations; biomass burning) and sea ice monitoring.

Mike Fromm discussed the utility of RGBs for investigating fire-induced thunderstorm clouds, also referred to as pyrocumulonimbus (pyroCb). Referring to the 2010 fires in the Russian Federation, he showed analyses of pyroconvection in areas where smoke had been injected into the stratosphere through in-cloud updrafts. He raised the question on the effect of fire-induced smoke on stratospheric chemistry and regional climate conditions, given the long lifetime and long-ranging transport of particles in the stratosphere.

5. SESSION 5: RGBS FROM DIFFERENT IMAGERS (AND SOUNDERS)

HansPeter Roesli briefed the workshop on microwave-derived RGBs using the Oceansat - 2 OSCAT's Ku-band and the MetOp-A ASCAT C-band showing partial melting of the Greenland ice sheet in summer 2012.

Mike Fromm showed examples of RGB techniques for investigating the microphysics of convective and baroclinic cyclone ice clouds heavily polluted with absorbing aerosols. These include pyrocumulonimbus (pyroCb) clouds. For this purpose, he used a "True colour" and day microphysical RGBs, and comparisons with CloudSat CPR reflectivity profiles.

Andreas Wirth elaborated on the use of RGBs based on the polar-orbiting MetOp and NOAA-19 AVHRRs for detecting night fog in small valleys in the Austrian Alps.

Ayako Takeuchi reported on the use of RGB products at JMA, mainly for characterizing overshooting tops of clouds and based on MTSAT. Single-channel images are routinely used for operational weather forecasting, and in volcanic ash monitoring. RGB composites based on VIS/IR channels are mainly provided to aviation users with a focus on (5-minute) rapid scan mode, and for visualization purposes. She gave a preview on using the advanced imager on Himawari-8/9 (due for launch in 2014/16) with its 16 channels, noting that the final product suite was yet to be decided.

Sungwook Hong provided an overview of KMA's status and plans regarding the use of COMS imager data. He explained the staggered acquisition of imagery in the COMS field of view, with a 15-minute repeat cycle over the Korean peninsula, hourly repeat cycle over a larger area, and 3 hours for the full disk. RGBs were used and compared with radar retrievals when tracking the 2012 typhoon Bolaven. Imager channels on GEO-KOMPSAT-2A,B are not yet fully decided. KMA also has plans for a polar-orbiting meteorological satellite.

6. PRACTICAL SESSION: RGBs WITH McIDAS-V

In this final session, workshop participants installed a version of the graphical visualization and analysis tool McIDAS-V on their laptops and followed a demonstration of its capability led by **Tom Rink and HansPeter Roesli**. McIDAS-V can be used for editing, animating (e.g., creating loops), displaying, enhancing, overlaying and analyzing satellite imagery, and is fit for training as well as for operational purposes (depending on data latency). It is freely available, open source software based on Java and Jython. Adapters (readers) exist for a range of data formats, including NetCDF, HDF, GRIB, BUFR, GIS formats, OpenDAP, ADDE. Many online learning resources exist, and the package is available at http://www.ssec.wisc.edu/mcidas .

7. FINAL SESSION: ACTIONS AND RECOMMENDATIONS

Participants agreed on 18 recommendations (and one resulting action) that should be followed to further enhance the utility of RGB satellite products for research, operational applications, and training in satellite meteorology. The workshop:

1. Confirmed the validity and usefulness of standard RGBs satellite products ("RGBs" hereafter), as recommended in 2007[6] (see also Annex III);
2. Reiterated channel rules for RGBs (use of reflectance in VIS, BT in IR);
3. Recommended the combined use of RGB and quantitative products (satellite-derived or other, GIS) as a general rule; e.g., animated RGB sequences provide meteorological context for derived quantitative products in operational forecasting;
4. Recognized advances in deriving quantitative products, in particular in consistency over time, although challenges remain (e.g., in twilight conditions);
5. Considered RGBs based only on IR channels to be most robust for operational weather monitoring purposes, while recognizing the value of blended products;
6. Encouraged the development of consistent and sensible terminology for RGBs, e.g., common definitions of terms 'natural colour', 'pseudo', 'synthetic' with Action on workshop sub-group to develop such terminology

   Action: Andrew Molthan (NASA/SPoRT), assisted by Kevin Fuell, Brian Motta and Renate Brummer, to develop standard basic terminology for RGBs for the terms 'true colour', 'natural colour', 'pseudo-colour', and 'synthetic'
7. Stressed the requirement for continued implementation of relevant imaging channels on future GEO/LEO meteorological missions, recognizing the importance of Airmass and 24-h Microphysics RGBs;
8. Identified the need for increased focus on validation and spatio-temporal homogeneity of quantitative products (e.g., surface "natural colour" RGB vs Fractional Vegetation Cover);
9. Recommended the standardized use of split window IR channel differences (11.0-12.0 μm)
10. Required the resolution of digitized radiometric satellite signals to be at least 10 bit (in IR equivalent to about 0.2 K for 280 K scene brightness temperature), especially important for calculating differences;
11. Referred to the EUMETSAT Convection WG's recommendation regarding ambiguity of the so-called convective storms RGB product, and recommended the consistent use of terminology when interpreting this product with respect to ice particle size;
12. Confirmed that RGB colour interpretation should be improved through clear association with features, for example by colour palettes, mouse roll-over pop-ups, and icons;
13. Stressed that training on RGB interpretation was important and recommended that such training include sources of misinterpretation, such as: limb cooling effect, diurnal variation, emissivity/reflectivity dependency, merits and limits (ash concentration…), sun eclipse effects, colour simulators for specific features (e.g. fog);
14. Recommended that forecaster bench display system retain full RGB resolution (in geometric and colour space);
15. Recommended that the RGB community continue to discuss emerging RGBs which use a wide range of spectral domains and variables (e.g., passive and active MW, space weather variables, ocean colour radiances, sea-surface temperature, significant wave height, sounder radiances);

[6] WMO (2007): RGB Composite Satellite Imagery Workshop, Final Report. Boulder, CO, USA, 5-6 June 2007, http://www.wmo.int/pages/prog/sat/documents/RGB-1_Final-Report.pdf

16. Recommended that a literature review be undertaken on the state-of-the-art of operational RGB applications;
17. Encouraged satellite providers to make available high-resolution satellite imagery data in real time, for evaluation, validation and training purposes, fully consistent with their mandate and data policy.

LIST OF PARTICIPANTS

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WMO/EUMETSAT Workshop on RGB Satellite Products: Standards, Applications and Opportunities

Seeheim, Germany, 17-19 September 2012
Lufthansa Training and Conference Centre
Draft Agenda (v4)

Online: http://www.wmo.int/pages/prog/sat/meetings/RGB-WS-2012.php

Monday, 17 September 2012 (8.30-17.00 h)

8.30 – 9.00 h	Registration
9.00 – 9.30 h	Welcome and Opening of the Workshop Chairmen: HansPeter Roesli (EUMETSAT) and Stephan Bojinski (WMO)
9.30 – 10.00 h	Coffee / Tea

Session 1: Overview RGB Products (RGB Tutorial)

10.00 – 11.30 h	Keynote: Jochen Kerkmann
11.30 – 12.00 h	Discussion
12.00 – 13.30 h	Lunch

Session 2: Integration of RGB Products and Derived Quantitative Products

13.30 – 14.30 h	Keynote: Marianne Koenig & Jochen Kerkmann
14.30 – 15.00 h	Coffee / Tea
15.00 – 15.45 h	Keynote: Tim Schmit (online)
15.45 – 17.00 h	Contributions from Carla Barroso / Nuno Moreira (IM), Hama Hamidou (EAMAC), Phil Watts (EUM)
17.30 h	Icebreaker (EUMETSAT HQ, Metop-B launch)

Tuesday, 18 September 2012 (9.00-17.00 h)

Session 3: Operational Applications of RGB Products

Keynote: Brian Motta, Carla Barroso and Nuno Moreira, Estelle de Coning

Contributions from: Andreas Wirth (ZAMG), Vesa Nietosvaara (EUM), Kevin Fuell (UAH), Andrew Molthan (NASA/SPoRT), Roland Winkler (Austro Control), Hama Hamidou (EAMAC), Thiago Biscaro (CPTEC), T. Saouri (NMMD)

Session 4: Scientific Applications of RGB Products

Keynote: HansPeter Roesli and Jochen Kerkmann, Mike Fromm

Contributions from: Phil Watts (EUMETSAT), Renate Brummer (CIRA)

Wednesday, 19 September 2012 (9.00-17.00 h)

Session 5: RGBs from different Imagers (and sounders) (VIIRS, MODIS, AVHRR, SEVIRI, MTSAT, FY-3, etc.)

Keynote: HansPeter Roesli, Mike Fromm

Contributions from: Andreas Wirth (ZAMG), Ayako Takeuchi (JMA), Renate Brummer (CIRA)

Session 6: Practical Session: RGBs with McIDAS-V

Introduction by Tom Rink and HansPeter Roesli

Final Session: Actions and Recommendations

Adjourn

STANDARD RGB SCHEMES

The 2007 RGB Composite Satellite Imagery Workshop[7] recommended several RGB composite imagery schemes, as guidance and best practice. For each table, a derived meteorological / physical parameter is suggested for each of the Red, Blue and Green components, and a suggested scheme to derive these parameters from imager data at different spectral bands is given, using the channel identification definitions given in Table 1 below:

It was agreed to group the RGB products into two 'families', one focussing on atmospheric attributes and the other focussing on surface attributes.

A1) Focus on atmospheric attributes – cloud microphysics (and surface hot spots)

RED	**(LWIR_split_window – LWIR) difference** Cloud optical thickness: thin → thick* Boundary layer moisture: moist → dry	**(LWIR_split_window – LWIR) difference** Cloud optical thickness: thin → thick Cloud water content: low → high	**VIS_long** Cloud optical thickness: thin → thick
GREEN	**(LWIR – MWIR) difference** Cloud phase: water → ice Cloud optical thickness: thin → thick Surface type: rock → sand	**(LWIR – SWIR) difference** Cloud particle size: large → small Cloud phase: ice → water	**NIR / reflected part of SWIR)** Cloud phase: ice → water Hot spots: no → yes
BLUE	**LWIR** Temp. of radiating surface: cold → warm	**LWIR** Temp. of radiating surface: cold → warm	**LWIR** Temp. of radiating surface: cold → warm
Focus of RGB product	**** low cloud, dust, ash-SO_2 (valid 24 hours)**	**hot spots, low cloud/fog (valid night time only)**	**convective intensity (valid day time only)**

* Arrows indicate: from no to full colour (here: thin–black / thick-red)
** Different phenomena (low cloud, dust, ash, SO_2) require different tuning of enhancements (e.g. temperature difference range, gamma contrast enhancement)

The above three RGB schemes assign the same physical meaning to the colour beams. According to the diurnal coverage the red and green beam are assigned to the best proxy available, i.e. equivalent blackbody temperature from IR signals for the 24-hour (including dusk-dawn

[7] WMO (2007): *RGB Composite Satellite Imagery Workshop*, Final Report. Boulder, CO, USA, 5-6 June 2007, http://www.wmo.int/pages/prog/sat/documents/RGB-1_Final-Report.pdf

periods) and night time coverage, solar reflectance for daytime coverage. Goal of these RGBs is to monitor cloud type and structure (including convective intensity in daylight) and the evolution of lifted dust and ash/SO_2 plumes. The first scheme excels in 24-hour coverage including dusk-dawn with only minor colour variations in identifying dust and ash/SO_2 when fine-tuned accordingly. Key to the scheme is the MWIR channel

A2) Focus on atmospheric attributes – air mass, potential vorticity and cloud systems

		Cloudy scene	**Clear scene**
RED	(WV_upper_trop – WV_mid_trop) difference	Cloud top temperature warm → cold*	Height of moisture layer mid-level → high-level
GREEN	(OZONE-LWIR) difference	Cloud top temperature, ozone content above cloud warm → cold, rich → poor	Ozone content rich/polar → poor/subtropical
BLUE	WV_upper_trop inverted	Cloud top temperature, upper tropospheric humidity warm → cold, dry → moist	Upper tropospheric humidity dry → moist
Focus of RGB product		**Cloud top height (colour of low cloud indicating air mass type)**	**Air mass type Potential vorticty anomaly**

* Arrows indicate: from no to full colour (here: warm–black / cold-red)

This RGB scheme highlights the major cloud systems together with polar/subtropical air mass and areas of potential vorticity anomaly. It is an excellent tool for monitoring the synoptic situation. Key to the scheme is the OZONE channel.

B) Focus on surface attributes

RED	**VIS_long**	**NIR**	**VIS_long VIS**	**VIS_long**	**(LWIR-SWIR) difference**	**NIR**
GREEN	**VIS_medium**	**VIS_medium**	**VIS_short SWIR or NIR**	**VIS_medium**	**VIS_long**	**VIS_long**
BLUE	**VIS_short**	**VIS_short**	**SWIR or (SWIR-LWIR) difference LWIR**	**VIS_short**	**VIS_short**	**VIS_short**
Focus of RGB product	**Vegetation**	**Water-Land wetness**	**Snow/ice cover and cloud properties**	**Smoke**	**Fire Hot Spots**	**Pre- and post-fire conditions**

Table 1: Definitions for channel identification used in abovementioned RGB schemes

Channel identification	MSG SEVIRI	GOES Imager (current generation)	MTSAT Imager	GOES Advanced Baseline Imager (next generation)
VIS_broad_band	0.4 – 1.2 µm			
VIS_short				0.45 – 0.49 µm
VIS_medium	0.56 – 0.71 µm	0.52 – 0.72 µm	0.55 – 0.8 µm	0.59 – 0.69 µm
VIS_long	0.74 – 0.88 µm			0.846 – 0.885 µm
NIR				1.371 – 1.386 µm
NIR	1.50 – 1.78 µm			1.58 – 1.64 µm
NIR				2.225 – 2.275 µm
SWIR	3.48 – 4.36 µm	3.78 – 4.03 µm	3.5 – 4.0 µm	3.80 – 4.00 µm
WV_upper_trop	5.35 – 7.15 µm	6.47 – 7.02 µm	6.5 – 7.0 µm	5.77 – 6.60 µm
WV_mid_trop				6.75 – 7.15 µm
WV_mid_trop	6.85 – 7.85 µm			7.24 – 7.44 µm
MWIR	8.30 – 9.10 µm			8.3 – 8.7 µm
OZONE	9.38 – 9.94 µm			9.42 – 9.8 µm
LWIR				10.1 – 10.6 µm
LWIR	9.80 – 11.80 µm	10.2 – 11.2 µm	10.3 – 11.3 µm	10.8 – 11.6 µm
LWIR_split_window	11.0 – 13.0 µm	11.5 – 12.5 µm	11.5 – 12.5 µm	11.8 – 12.8 µm
LWIR	12.4 – 14.4 µm	(1) 12.9 – 13.8 µm		13.0 – 13.6 µm

(1) available from GOES-12 onwards

REFERENCES

Background Documents

WMO (2007): RGB Composite Satellite Imagery: Recommendations for global standards (Report of 2007 Workshop)

Roesli et al. (2006): Harmonising SEVIRI RGB Composites for Operational Forecasting.

Lensky & Rosenfeld (2008): Clouds-Aerosols-Precipitation Satellite Analysis Tool (CAPSAT). Atmos.Chem.Phys., 8, 6739–6753

Millington et al. (2012): Simulated volcanic ash imagery: A method to compare NAME ash concentration forecasts with SEVIRI imagery for the Eyjafjallajökull eruption in 2010. J. Geophys. Res., 117, D00U17, doi:10.1029/2011JD016770

Online Resources

MSG Interpretation Guide

RGB Real Time Images (from MSG)

SEVIRI RGB image loops (for volcanic ash detection, NILU)

RGB Products Explained (COMET)

EUMeTrain training resources on RGB and other products

Operational Use of RGB Products (EUMeTrain)

EUMeTrain Platform for Online Research and Training (ePort) with 6-hourly RGB products

NexSat web page (US Navy, NRL)

McIDAS-V web page (SSEC, University of Wisconsin)

RAMSDIS imagery products of GOES-E/W and Tropical (CIRA)

(last accessed: 14 Dec 2012)