

Report on the SCOPE-Nowcasting Pilot Projects

January 2017

The aim of the Sustained, Co-Ordinated Processing of Environmental Satellite Data for Nowcasting (SCOPE-Nowcasting) initiative is to provide consistent satellite products for nowcasting and severe weather risk reduction. A network of satellite operators, experts, and users is envisaged for the provision and dissemination of such products. The initiative is supported by WMO.

The concept for SCOPE-Nowcasting arose from discussions in 2010 in the WMO Expert Team on Satellite Utilization and Products (ET-SUP) following the benefits of the SCOPE for Climate Monitoring (SCOPE-CM) initiative noting that this SCOPE concept could be equally well applied in the area of nowcasting. The main prerequisites are:

- Mature underlying science
- Organized user community with established needs
- Opportunities and synergy with other initiatives
- Long-term stable status of the respective product
- Operational availability of the respective product
- Product consistency across platforms and smooth transition between individual satellite missions
- Product provision in standard formats
- Product delivery mechanism within the WMO Information System (WIS) framework

After discussions in ET-SUP-6 and ET-SUP-7, the concept was presented at the 3rd Asia Oceania Meteorological Satellite Users Conference in October 2012, and at the 41st Meeting of the Coordination Group for Meteorological Satellites in July 2013. The concept has gathered the support of satellite operators.

SCOPE-Nowcasting is aligned with a number of WMO initiatives, in particular the Severe Weather Forecasting Demonstration Project (SWFDP). SCOPE-Nowcasting products can complement and enhance the SWFDP final outputs, which are largely based on numerical prediction models. Linkages with other relevant initiatives and working groups will be sought, as appropriate.

The key objective of SCOPE-Nowcasting is the provision of satellite data and products. Users could be the NMHSs of small or developing countries with little expertise and/or missing reception and processing facilities, and users in more advanced nations where resources could be combined. Products are limited to satellite-based nowcasting products, that is, products that are useful in the forecasting range zero to six hours. Products fall into four broad categories:

- Basic (Atmospheric) Nowcasting Products: these are primarily products used qualitatively, such as visible and infrared imagery, image enhancements and colour composites
- Advanced (Atmospheric) Nowcasting Quantitative Products, requiring an underlying algorithm (e.g. precipitation, atmospheric motion vectors, stability indices)
- Ocean Products (e.g. sea surface winds obtained from scatterometer data)
- Atmospheric Composition Products (e.g. fire detection, smoke, sand/dust, aerosols, volcanic ash)

As a proof-of-concept, the SCOPE-Nowcasting initiative has started with four pilot projects, which were discussed in the SCOPE-Nowcasting-1 Ad-hoc Steering Group in November

2013 (see http://www.wmo.int/pages/prog/sat/documents/SCOPE-NWC-1_FinalReport.pdf).

These four pilot projects cover some of the above mentioned basic categories:

- Pilot Project 1: Basic Nowcasting, Provision of RGB imagery
- Pilot Project 2: Satellite derived volcanic ash information for aviation
- Pilot Project 3: Satellite derived precipitation information
- Pilot Project 4: Satellite derived sand and dust information

A detailed description of the background, status and achievements of each of the four pilot projects is given below.

Pilot Project 1: Basic Imagery

Recalling the four categories of products to be considered by SCOPE-Nowcasting, this pilot project falls into the first category of Basic Nowcasting Products. Enhanced satellite imagery should be made available as low-volume products for users with limited bandwidth. Specific focus here is WMO Region V where full resolution Himawari-8/9 data may not be available to all users because of reception station constraints, but where users may still well benefit from the spectral richness of the data. Another focus is on SWFDP regions (Severe Weather Forecast Demonstration Project) in WMO Regions II and V.

Multi-spectral satellite images are currently available for this region from Himawari-8 (operated by the Japan Meteorological Agency, JMA), to be complemented in the future by FY-4A (operated by the China Meteorological Administration, CMA) and by GEO-KOMPSAT-2 (operated by the Korea Meteorological Administration, KMA). Himawari-8 was successfully launched on 07 October 2014 and started its operational service on 07 July 2015. FY-4A was launched on 10 December 2016, the launch of GEO-KOMPSAT-2 is planned for mid 2017. Himawari-9 was launched on 2 November 2016.

Suitable channel composites are a well-established process to compress the information content of several spectral channels into a single image. Such channel composites are mainly meant for visual inspection, i.e. composite imagery can be produced and disseminated in simple graphics formats as e.g. JPEG.

Examples of channel composites are red-green-blue (RGB) composites, simple channel differences or the so-called sandwich product, which combines channels of different spatial resolution together with suitable colour enhancements.

An RGB composite in its simplest form combines three different spectral channels, where the information of the channels is put to the red, green, and blue beam, resp., of a 24-bit digital colour image. The information content of the underlying three images is fully preserved, while a given atmospheric or surface feature is enhanced and better visible than on each of the underlying greyscale pictures. More elaborate RGB schemes exist, where the individual colour input could e.g. be a channel difference image (thus containing the information of two channels), or where the individual input is scaled to certain brightness temperature or reflectivity ranges. Also, standard image enhancement techniques like contrast stretching, can be easily applied. This technique is of great help for operational users as e.g. forecasters.

A de-facto standard is originally based on the EUMETSAT MSG Interpretation Guide, and was further elaborated in two RGB Workshops (2007 in Boulder, USA and 2012 in Seeheim Germany), as summarized in http://www.wmo.int/pages/prog/sat/documents/RGB-1_Final-Report.pdf and http://www.wmo.int/pages/prog/sat/documents/RGB-WS-2012_FinalReport.pdf. Specific RGBs are defined to highlight e.g. fog/low stratus, dust, volcanic ash, snow cover, general air mass characteristics, and many other features. As there are theoretically many ways to combine channels in a colour scheme, standards are essential for harmonization, to facilitate training and communication between users. Figure 1 gives an example of an RGB composite.

The sandwich product combines individual channels (or channels differences or RGBs) of different spatial resolution. The prime application is the depiction of high cold cloud tops, preserving the temperature information from an IR window channel and the textural information from a high-resolution solar channel. Figure 2 shows an example.

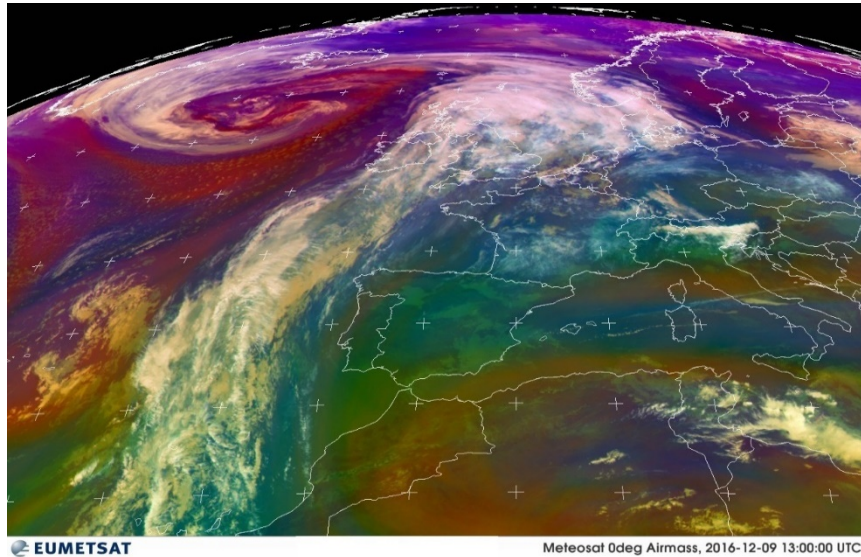


Figure 1: Airmass RGB, depicting warm moist air in green colour, cold air in blue and purple. Of high value is the depiction of jet streaks and areas of high potential vorticity in red. The RGB combines the information of an IR window channel (around 11 μm), the ozone channel (around 9.7 μm) and two water vapour channels (around 6.2 μm and 7.3 μm wavelength). Picture taken from the EUMETSAT website.

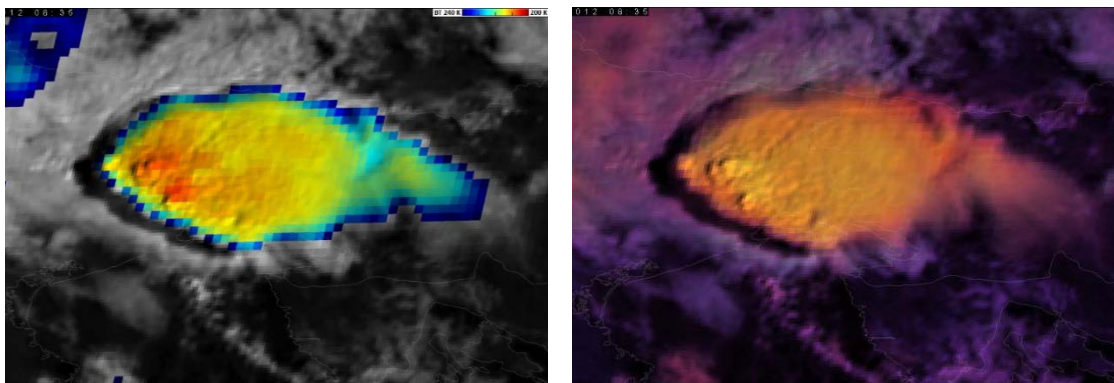


Figure 2: Sandwich product showing a convective storm. Left: IR/VIS sandwich, high-resolution (1 km) solar channel superimposed over colour-enhanced IR window image (3 km resolution), showing the coldest cloud tops in red with the corresponding textural information. Right: Storm RGB/VIS sandwich showing the same storm, but now the solar channel is overlaid with the convection RGB. Picture taken from the EUMETSAT website.

With the operational availability of Himawari-8 data, this pilot project has made good progress: Basic one-channel images of four individual Himawari channels, nine different RGBs, the IR/VIS sandwich product and two 2-channel composites are available on the JMA website at http://www.data.jma.go.jp/mscweb/data/himawari/sat_img.php?area=fd. Table 1 summarizes the availability, including a list of individual image sectors, and Figure 3 shows a screenshot of the website. The web interface offers the possibility of animations over 6 pre-defined intervals between 1 and 23 hours, and it offers a link to a very extensive RGB User Guide, where the individual RGB recipes and interpretation can be found.

Two SWFPDs fall into the footprint of Himawari-8 – the South-East Asia SWFDP and the South Pacific SWFDP (<http://www.wmo.int/pages/prog/www/swfdp/>). The JMA website offers image sectors that specifically cover the SWFD areas: the three different South-East Asia sectors (for the South-East Asia SWFDP) and one of the Pacific Islands sectors (sector no. 3 for the South Pacific SWFDP)

Individual Channels	<ul style="list-style-type: none"> • B03 (central wavelength 0.64 μm) • B07 (central wavelength 3.9 μm) • B08 (central wavelength 6.2 μm) • B13 (central wavelength 10.4 μm).
RGBs	<ul style="list-style-type: none"> • Day microphysics • Night microphysics • Dust • Airmass • Day Snow-Fog • Natural Colour • True Colour • True Colour Reproduction • Storm
Sandwich Product	<ul style="list-style-type: none"> • IR/VIS sandwich (B03 and colour enhanced B13)
Channel Combinations	<ul style="list-style-type: none"> • B03 and B13 (day and night) • B03 and B13 (specific enhancement for night)
Temporal Coverage	<ul style="list-style-type: none"> • Past 24 hours • Repeat cycle 10 minutes
Areal Coverage	<ul style="list-style-type: none"> • Full disk • Japan • Australia • Central Asia • New Zealand • Seven different Pacific island regions, region 3 covers the South Pacific SWFDP area • Three different South-East Asia regions, covering the South-East Asia SWFDP area • Total of nine different subareas in higher resolution
Animations	<ul style="list-style-type: none"> • Last 1 hour • Last 3 hours • Last 6 hours • Last 12 hours • Last 18 hours • Last 23 hours

Table 1: Overview of Himawari-8 real-time imagery availability on the JMA website

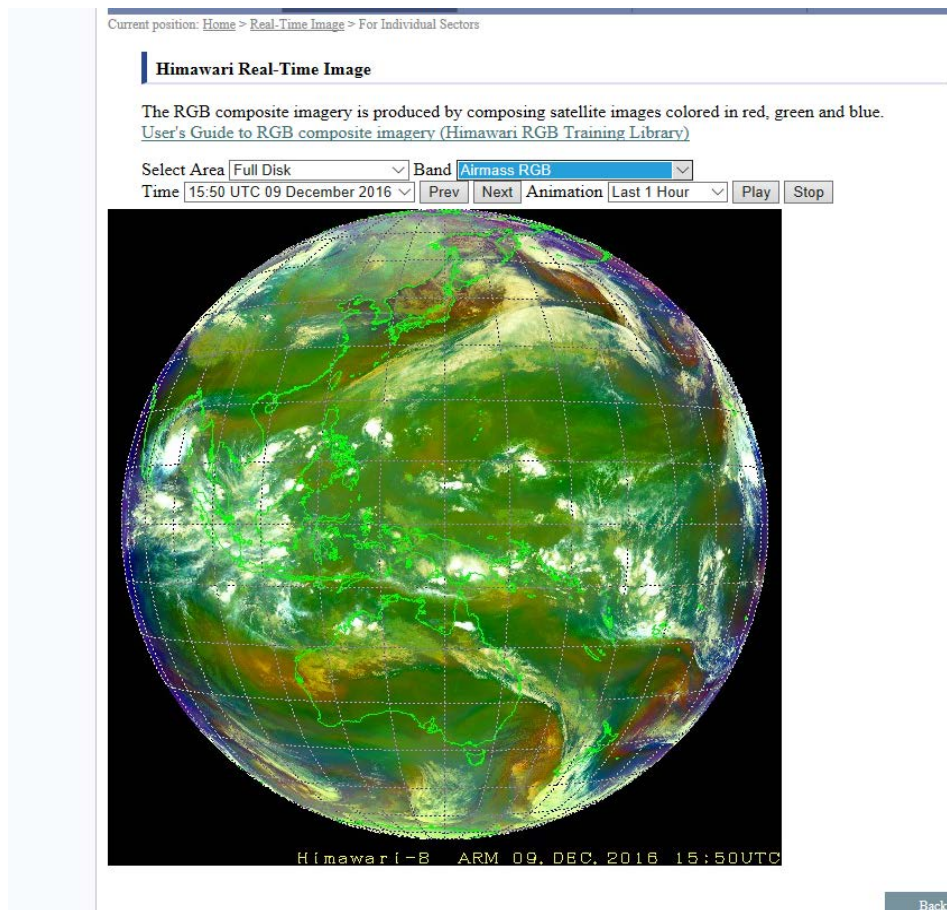


Figure 3: Screenshot of the JMA website, showing the Airmass RGB for the full disk http://www.data.jma.go.jp/mscweb/data/himawari/sat_img.php?area=fd.

It is expected that similar RGB products can be obtained from the future FY-4A and GEO-KOMPSAT-2 satellites. Some minor tuning may be necessary to account for slightly different channel response functions. Besides the satellite operators CMA, JMA, and KMA, the Australian Bureau of Meteorology (BoM) could serve as a one-point stop for the RGB products, i.e. individual users will not need to set up a suite of reception stations to just obtain basic imagery data. RGB products of all satellites could be web server hosted and maintained by BoM, i.e. the dissemination method would be the internet; an additional distribution method could be a DVB-S-based service such as CMACast. In addition, the SWFDP Regional Project websites could also be used for disseminating products.

Pilot Project 2: Advanced Products – Volcanic Ash for Aviation

Recalling the four categories of products to be considered by SCOPE-Nowcasting, this pilot project falls into the second category of advanced, quantitative products. Quantitative information on volcanic ash and SO₂ is of high importance to aviation, airlines, and the Volcanic Ash Advisory Centres (VAACs), which coordinate and disseminate information on atmospheric volcanic ash clouds that may be a threat to aviation. The VAAC based warnings are largely based on ground observations and numerical dispersion models, but ancillary satellite data can be useful, e.g. for the detection of volcanic eruptions in areas without ground observations, or for a better delineation of safe fly zones in the case of a more dispersed volcanic cloud.

Recent volcanic eruptions and their impact on air traffic have risen interest in satellite data and products concerning volcanic ash, and have also led to a number of scientific studies and developments on satellite derived volcanic ash products. A clear need for a globally consistent and operationally available satellite based volcanic ash product is expressed by aviation authorities, e.g. by the International Civil Aviation Organization (ICAO). The current situation, however, is that many products are available, each having certain strengths and weaknesses, which can often not even be quantified. Many of these products were never consistently validated and/or are only produced on an ad-hoc basis for a very limited number of volcanic eruptions. There is no international validation protocol for such products.

SCOPE-Nowcasting can thus play a role in endorsing a baseline volcanic ash product, which should ultimately be made available on an operational basis. To facilitate such operational readiness, an organized international effort is needed to quantify the accuracy of the available satellite products, aiming at establishing best practices for operational readiness. The first meeting of the SCOPE-Nowcasting-1 Ad-hoc Steering Group in 2013 therefore recommended that an algorithm intercomparison workshop should be held to address these benchmark issues. This would better describe the strengths and weaknesses of each retrieval algorithm, would demonstrate the product performance in different background conditions and thus help to improve the product error characterization.

This workshop was held on 29 June – 2 July 2015 in Madison, Wisconsin, USA (http://cimss.ssec.wisc.edu/meetings/vol_ash15/program.html). Workshop aims were to

- Quantify the differences between satellite-derived volcanic ash cloud properties from different techniques and sensors through pre-selected cases
- Establish a basic validation protocol for such products
- Document the strengths and weaknesses of different techniques as a function of satellite sensor
- Work towards a standardization of the units and associated quality flags
- Provide recommendations to users how to better utilize the products
- Create a road map for future scientific developments and intercomparison/validation activities

The workshop was organized such that algorithm providers could subscribe to the workshop to submit data for the intercomparison work and attend the Madison meeting. The produced datasets had to be submitted by early April 2015, in a prescribed format, in order to facilitate the actual intercomparison work which was performed prior to the workshop by an external contractor (Rutherford Appleton Laboratories, UK). A number of test cases were chosen, and each algorithm provider was expected to independently provide results for these cases, as appropriate.

The cases were chosen to coincide with independent ground and/or aircraft measurements that can serve as “truth”. The pre-selected cases also cover a wide range of ash cloud properties, background conditions, different geostationary sensors and VAAC regions:

- Sarychev Peak (Kamchatka, Russia, 15-17 June 2009)
- Eyjafjallajökull (Iceland, 16 April – 18 May 2010)
- Kirishimayama (Japan, 27 January 2011)
- Grimsvötn (Iceland, 21-23 May 2011)
- Puyehue-Cordón Caulle (Chile, 5-18 June 2011)
- Kelut (Java, Indonesia, 13-14 February 2014)

A total of 26 algorithm contributions were submitted to the workshop, covering different satellite sensors on polar-orbiting and geostationary platforms. The submissions involved products from instruments with a wide range of spatial resolution and spectral sensitivity, and a wide range of retrieval algorithms. Each product covered at least one of the following quantitative parameters: pixel position with identified ash, volcanic ash cloud height, total column mass loading, effective ash particle size, ash cloud optical depth (at 0.55 μm and/or 10 μm wavelength). Reference data were used from the CALIPSO CALIOP spaceborne lidar instrument, the UK FAAM aircraft, and ground-based lidar data.

The main conclusions of the workshop are:

- Passive satellite measurements can mainly detect the presence (or lack) of volcanic ash
- Automated ash detection methods do in general not approach the skill of a human analyst (using the same image data)
- Most detection algorithms have a lower detection limit of 0.01 to 0.1 g/m^2
- Uncertainty of satellite derived total mass loading is greater than a factor of 2, uncertainties in actual concentration will be even greater
- Complicated background scenes are common and further increase the uncertainty of all satellite products
- High spectral resolution measurements help to mitigate some of these issues, but are currently spatially and temporally limited (e.g. IASI onboard the Metop polar orbiter)

Due to resource limitations, not all datasets generated for the intercomparison workshop could be analyzed and validated, further work is needed to complete the analysis. The workshop is therefore seen as a first step of the SCOPE-Nowcasting pilot project towards an international intercomparison effort. The workshop concluded a number of recommendations to further advance the project, pending availability of resources:

- Extend the ash detection comparisons by including more human analysts
- Use DLR (German Aerospace Centre) aircraft data for additional comparison analyses
- Extend the use of independent ash optical depth and mass loading estimates
- Perform a more detailed analysis of the retrieval results, specifically for collocation with validation data and for certain scene attributes (land/water/underlying cloud)
- Assess impact of satellite viewing angle on the product accuracy
- Assess product differences between next generation geostationary imagers (e.g. Himawari-8, GOES-R) and heritage sensors
- Provide a database of volcanic ash optical properties
- Provide retrieval results for simulated data, e.g. to mitigate the spatial sampling problems
- Generate simulated satellite datasets, apply algorithms, and compare retrieval products to the observed and validated solution.

As an example, Figure 4 shows a particular ash detection result. A full presentation with many detailed comparison results is available on the workshop website.

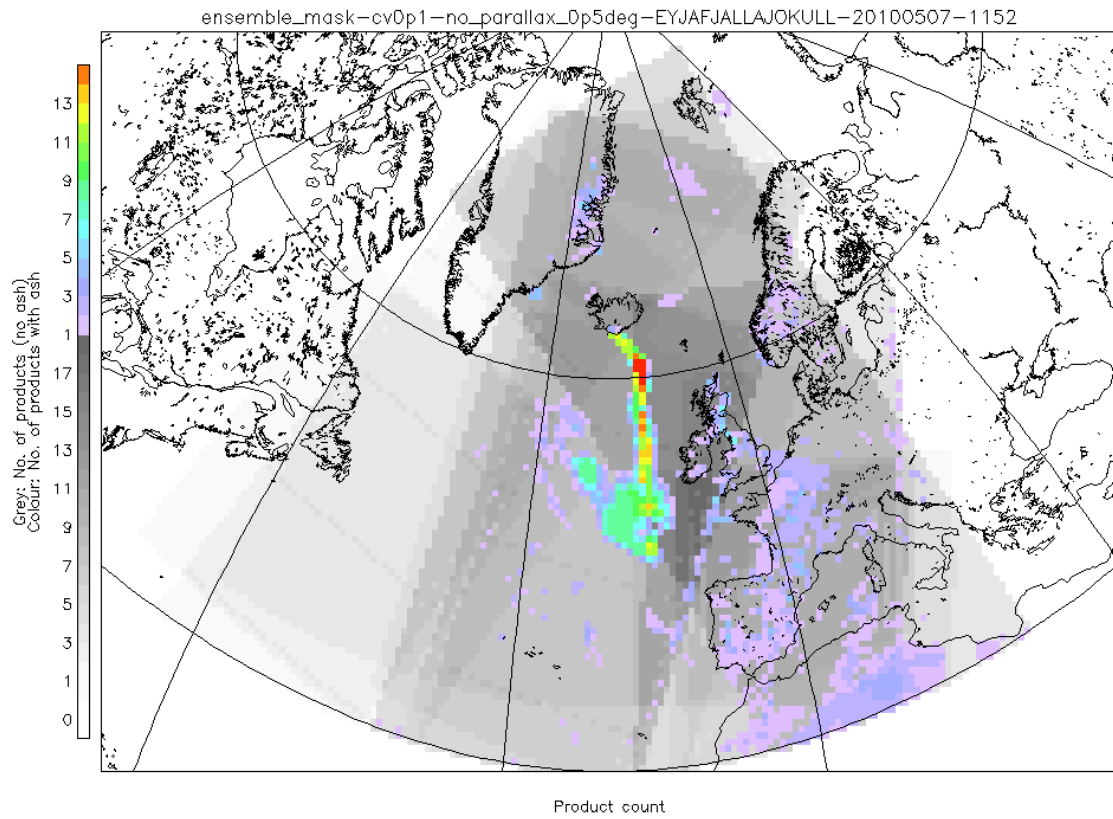


Figure 4: Ensemble ash mask for the 07 May 2010 Eyjafjallajökull case. Grey colours show the number of products that did not detect ash, the other colours show the number of products that have detected ash (according to legend on left of plot)

Pilot Project 3: Advanced Products – Precipitation

Again, this pilot project falls into the second category of advanced, quantitative products. There is a clear user requirement for a rapid and straightforward access to satellite based precipitation estimates, mainly to have guidance on severe precipitation events that may lead to flash floods. The required products should include the cumulated precipitation over the past 24, 48, and 72 hours as well as the current precipitation intensity and a 3-hour precipitation intensity nowcast, based on a Lagrangian extrapolation.

A number of satellite based precipitation products exist, derived from a range of instruments, as e.g. from space-borne precipitation radars, passive microwave or thermal infrared imagers. Precipitation estimates for nowcasting, however, have to rely on satellite data that are available in high spatial and temporal resolution. This implies that only geostationary imagers with their frequent repeat cycles can be the backbone of the application, i.e. the global precipitation estimates will have to rely on thermal IR data only.

The Brazil National Institute for Space Research INPE, specifically its Centre for weather and climate forecasts CPTEC, has set up a prototype website (<http://sigma.cptec.inpe.br/scope>) which displays precipitation estimates derived from the geostationary IR imagers. The underlying algorithm is the Hydroestimator, which is the current operational product for the US GOES satellite. This algorithm is applied globally for all latitudes between 60N and 60S. It is based on a fixed relationship between the IR (~11 μm wavelength) cloud top brightness temperature and rainfall, based on a statistical analysis using ground-based precipitation radar data. Empirical corrections are applied according to structural analysis of the nearby cloud fields. Some further corrections are applied to account for orographic effects and for very dry or moist environments, using Numerical Weather Prediction data.

A detailed algorithm description can be found in <http://www.ospo.noaa.gov/Products/atmosphere/ghe/algo.html>.

The up to 3-hour precipitation forecast is based on the Forecasting and Tracking of Active Cloud Clusters (ForTrACC) product, which was originally implemented at CPTEC/INPE for tracking Mesoscale Convective Systems. For this SCOPE-Nowcasting pilot project, the original algorithm was adapted to ingest the Hydroestimator data, and it produces 60, 120 and 180 minutes forecasts of 1-hour accumulated rainfall. A full description of this tracking algorithm can be found in <http://sigma.cptec.inpe.br/fortracc/?i=en>.

Figure 5 shows a screenshot of the web interface.

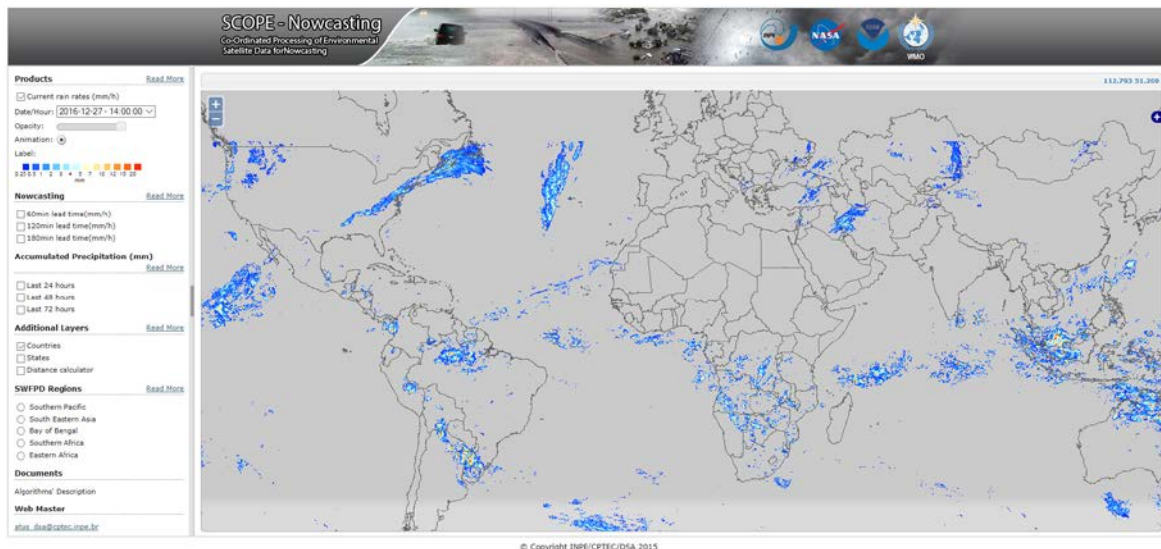


Figure 5: Screenshot of the INPE/CPTeCT SCOPE-Nowcasting website, showing the current precipitation intensity estimates

The map area of the site shows the precipitation intensity according to the colour legend on the left. Zooming and panning are possible. The navigation bar on the left (see Figure 6) offers several display options:

- Accumulated rainfall over the last 24, 48, or 72 hours
- Nowcasts for the next 60, 120, or 180 minutes
- Additional map layers (countries and states)
- An interactive distance calculator between two points on the map
- Pre-defined zoom into five SWFDP areas
- Link to the algorithm description

It will be necessary to expose this prototype to the user community, including WMO Members, to raise awareness and gauge interest, with the perspective of putting the product on a sustained footing.

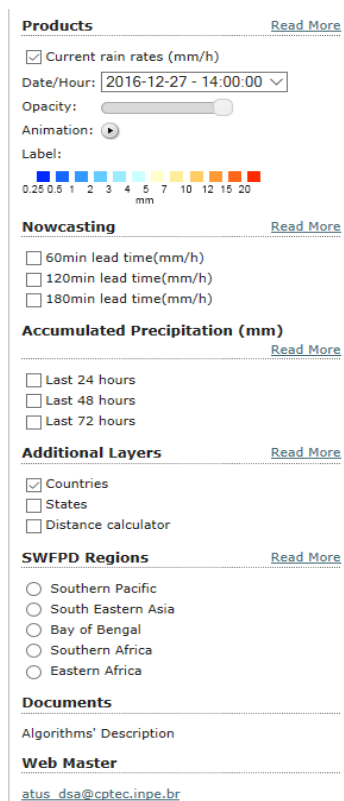


Figure 6: Close-up view of the navigation bar on the Pilot Project website

Pilot Project 4: Advanced Products – Sand and Dust Forecasting

As pilot projects 2 and 3, this project also falls into the category of advanced, quantitative products. Background to this specific pilot project is the importance of dust products in Eastern Asia, notably for China, Korea, and Japan, where Asian dust outbreaks occur frequently and can have a great impact on e.g. local weather, traffic, or health. Clear user requirements exist for dust products providing aerosol optical depth, effective particle radius, column density, and visibility. RGB imagery well picks up extensive dust outbreaks in a qualitative manner (Figure 7).

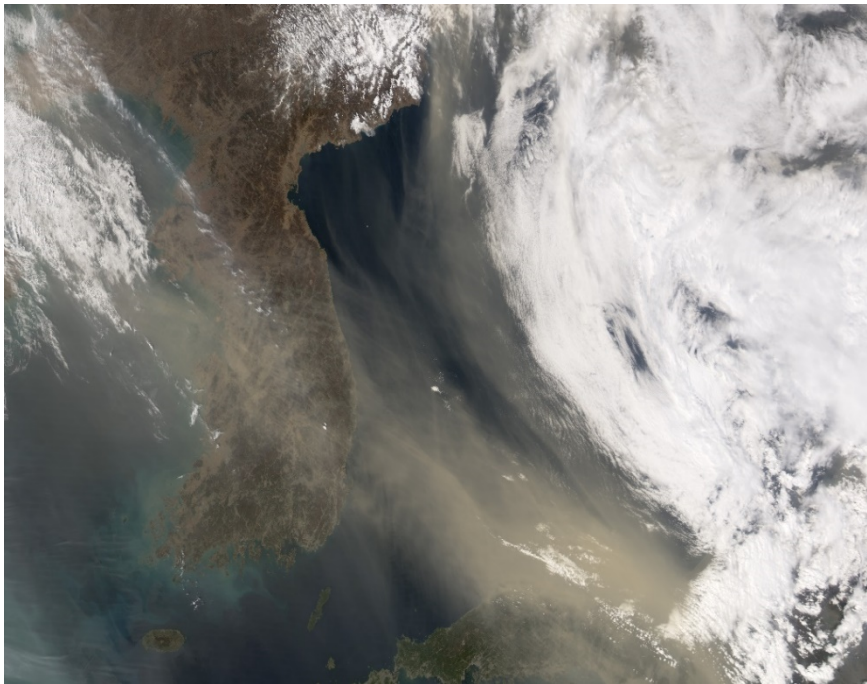


Figure 7: RGB image of a dust cloud over the Korean peninsula and the adjacent ocean (MODIS image, acquired on 08 April 2006, obtained from <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=16427>)

A number of quantitative satellite based dust products are available and may be further improved for the next generation geostationary satellites as Himawari-8, FY-4A, and GEO-KOMPSAT-2 Users, however, are faced with great inconsistencies, as illustrated by Figure 8.

These inconsistencies are especially found over land and are mainly due to the number of spectral channels used in the retrieval (e.g. a simple 11/12 μm split window technique vs. a more sophisticated approach using 8.7 μm data together with visible and near-infrared bands), due to assumptions on boundary conditions like surface emissivity, surface temperature, dust layer top temperature, and due to differences in the actual dust spectroscopy.

As for pilot project 2 (volcanic ash), there is a clear need of proper validation and further inter-comparisons. As ground-based observations of dust are of high importance, a first step of the project was to share in-situ dust observations (using sun photometers) between the agencies CMA, JMA, and KMA for further validation and to support case studies.

First results were presented at the 6th Asia-Oceania Meteorological Satellite Users' Conference (AOMSUC, November 2015 in Tokyo): Different retrieval techniques were used to derive aerosol optical depths from MTSAT (provided by JMA) and from MODIS (as a proxy for the future FY-4A AGRI instrument, provided by CMA), and the results were compared to AERONET ground station data, which provided a first insight into the retrieval performance, depending on actual aerosol load and background (land/sea).

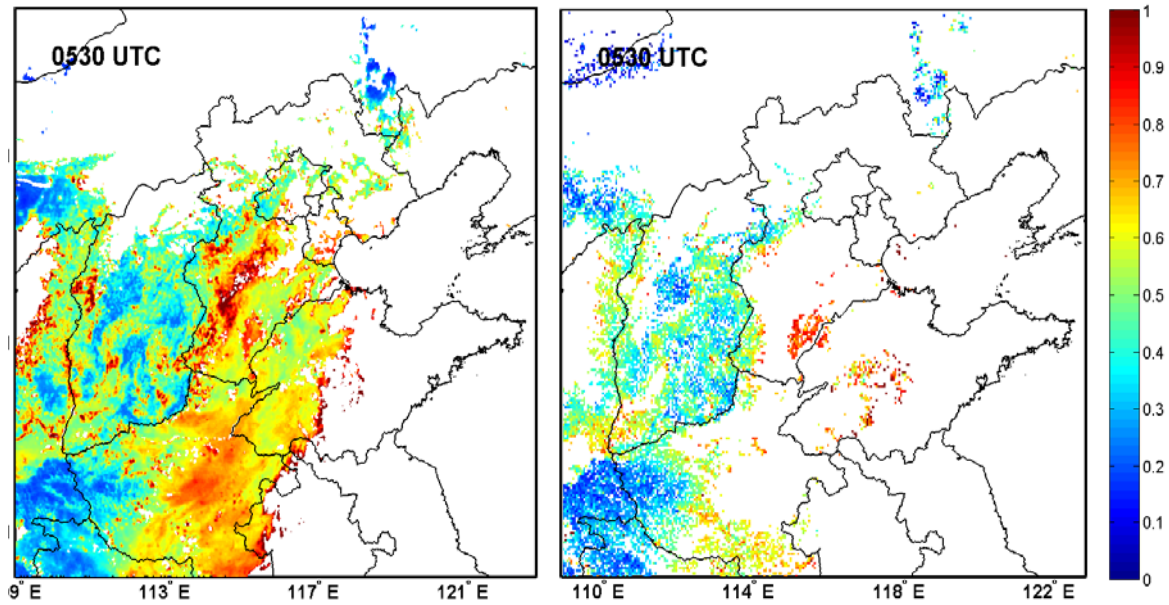


Figure 8: Aerosol optical depth using two different algorithms applied to Himawari-8.

It will be important to further validate the various satellite-based dust products, and to understand and quantify their differences. Links to the user community of such products should be further explored, such as the Asia node of the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS), hosted by CMA.