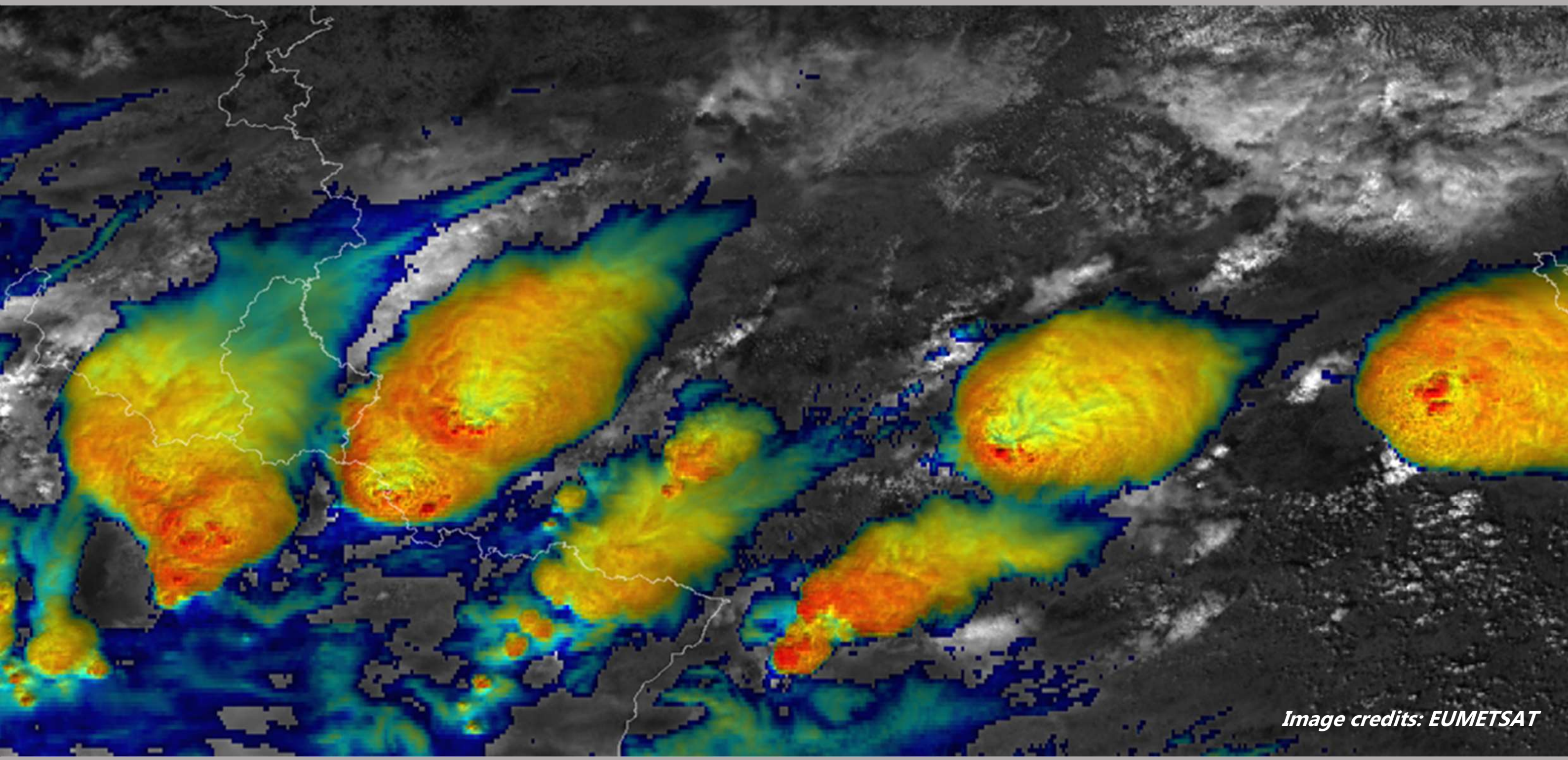
WHITE PAPER

Solar Irradiance Nowcasting with Satellite Data

Launch of Meteosat Third Generation: data value chain from space to solar plants



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Background

In this white paper, contributors Mathieu Turpin (Reuniwatt), Pilar Rípodas (AEMET) and Jochen Grandell (EUMETSAT) present the data journey of satellite data from space to solar plant, following the launch of the Meteosat Third Generation Imager-1 (MTG-I1) - the first of a new generation of satellites providing crucial insights for the early detection and prediction of fast-developing severe storms, weather forecasting and climate monitoring. This white paper highlights the accomplishments achieved through MTG characteristics, as well as the positive impact of the additional datasets and their improved quality and accuracy in solar irradiance forecasts in particular.

Abbreviations

CAMS	Copernicus Atmosphere Monitoring Service
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
GHI	Global Horizontal Irradiance
FCI	Flexible Combined Imager
LI	Lightning Imager
IRS	Infrared Sounder
SEVIRI	Spinning Enhanced Visible and Infrared Imager
UVN	Ultraviolet-Visible-Near-Infrared

Executive summary

Building on the decades-long legacy of Meteosat's first- and second-generation satellites, Meteosat Third Generation (MTG) will orbit the Earth at an altitude of 36,000 km with a stable view of Europe and Africa. The first Meteosat Third Generation satellite, the imager MTG-I1, was launched on Dec 13, 2022.

The success story of the MTG system launch, and the opportunities it offers outside the space sector are multifaceted: more and better observational data will provide the opportunity to enhance nowcasts, forecasts, and numerical weather prediction models.

Precise nowcasting is closely related with high quality satellite data nowcasting applications, like solar production forecasts. Solar irradiance forecasts allow power producers and grid operators to mitigate intermittency.

In this white paper, our contributors from EUMETSAT, AEMET and Reuniwatt highlight the satellite data journey and present the unique features and improvements achievable through the MTG satellite system: Jochen Grandell (EUMETSAT) highlights the new or improved functionalities of MTG-I1. How this data leads to better nowcasting and an improved quality of the calculated cloud properties is detailed by Pilar Rípodas (AEMET). Finally, Mathieu Turpin (Reuniwatt) explains how the satellite data and nowcasting algorithms find their way onto solar farms through satellite-to-irradiance forecasts, how and why the renewable energy industry can benefit from the improved satellite imagery and features of the MTG satellite system.

Expected improvements from the MTG-I mission include better spatial resolution and temporal resolution, and total lightning detection as a precursor of severe weather.

EUMETSAT's MTG mission objectives

EUMETSAT has provided the user community with more than three decades worth of satellite data, starting with the mandatory geostationary missions of the Meteosat First Generation, and since 2002 the Meteosat Second Generation (MSG) series satellites.

EUMETSAT has been developing the future geostationary program, the Meteosat Third Generation (MTG). The MTG system hosts a more advanced 16-channel VIS/IR Flexible Combined Imager (FCI) as well as a Lightning Imager (LI) on its geostationary imaging platform (MTG-I), whereas the sounding platform (MTG-S) will host the MTG InfraRed Sounder (IRS) and the Copernicus Sentinel-4 ultraviolet/near-infrared (UVN) sounding mission. The launch of the first MTG satellite (i.e. MTG-I1 hosting the FCI and LI) took place in December 2023, and an entry into full operations is expected in early 2024. The availability of the first MTG-S1 satellite for launch, hosting the two sounding instruments, is foreseen in late 2024.

The main missions achieved through Imaging and Sounding satellites MTG-I and MTG-S:

- **Primary mission**:
    - The primary mission of MTG, as a continuity and enhancement of Meteosat Second Generation (MSG) imagery, is to support Nowcasting and Short Range Forecasting of high impact (severe) weather. This is achieved through the improved capabilities of the Flexible Combined Imager over the heritage SEVIRI sensor on MSG. In addition, and as a very significant complement to the observation missions of MTG, this is achieved through the addition of a new lightning imaging capability and the atmospheric hyper-spectral soundings provided by the new Infrared Sounder.
- **Secondary mission**:
    - The secondary mission of MTG is to support the air quality monitoring over Europe, which is achieved through a synergy between the Sentinel-4 Ultraviolet-Visible-Near-Infrared (UVN) imaging spectrometer, the Infrared Sounder on-board the MTG-S, and the Imagery missions on MTG-I satellites, respectively.
    - The Sentinel-4 mission is part of the European Earth Observation Programme "Copernicus" which is run by the European Union together with the European Space Agency (ESA). The Sentinel-4 mission is conceived as the geostationary space component serving the specific needs of the Copernicus Atmosphere Monitoring Service (CAMS).

Conclusion

The launch of MTG-I1 took place on 13 December 2022, which is followed by a 1-year commissioning period, during which the satellite platform and the instruments go through an extensive in-orbit check-up to verify their performance, including also a first set of calibrations. Towards the end of commissioning, all products shall be validated against the requirements prior to commencing with the operational dissemination of products.

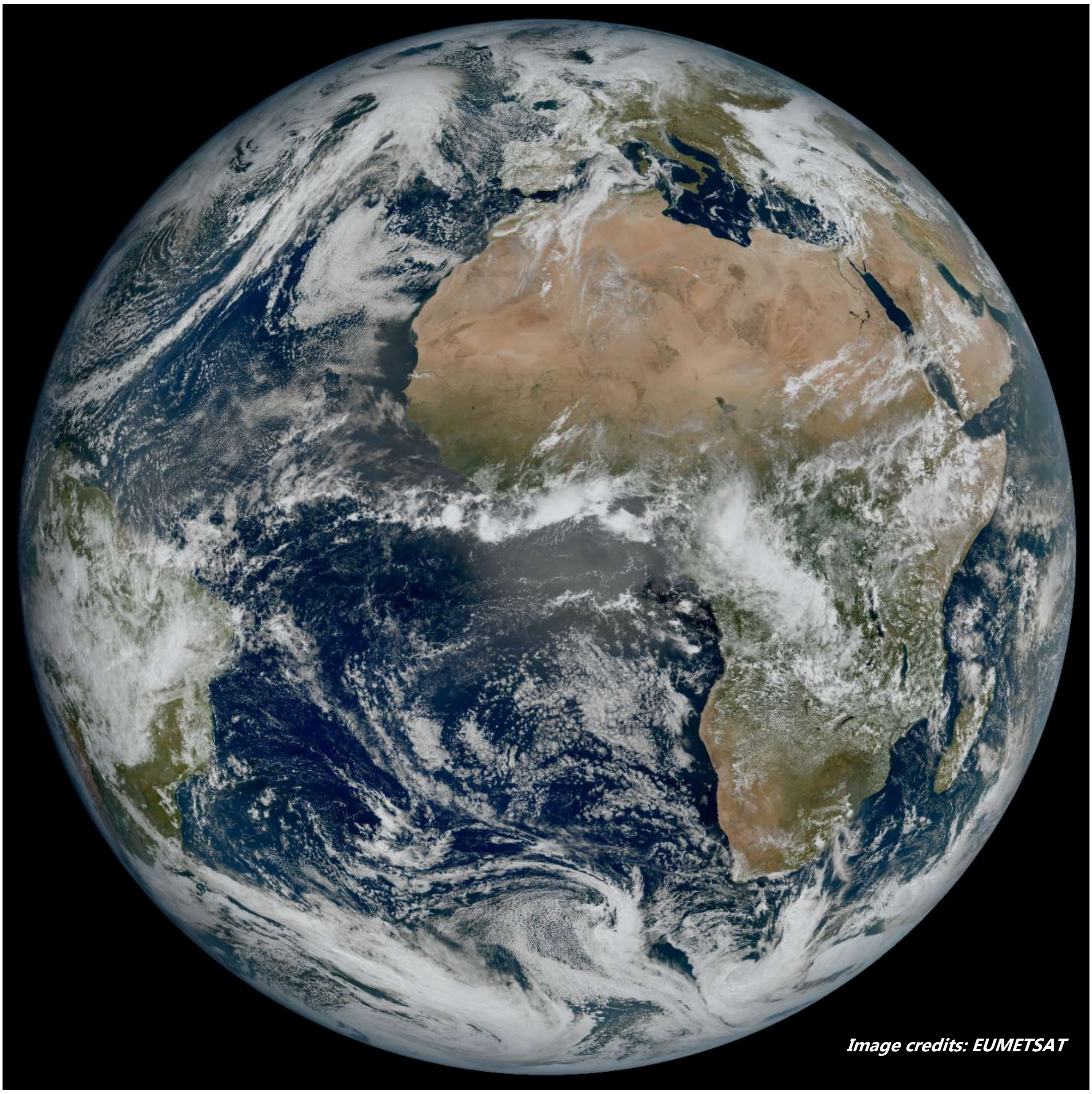


Figure 1: First image acquired by the MTG-I1 FCI instrument, and released to the public on May 4, 2023. It is a "True Colour RGB", using combination of four FCI channels allowing the generation of an image "as the human eye would see it". The image is from 18 March 2023. *Source: EUMETSAT and ESA, based on data provided by Thales Alenia Space.*

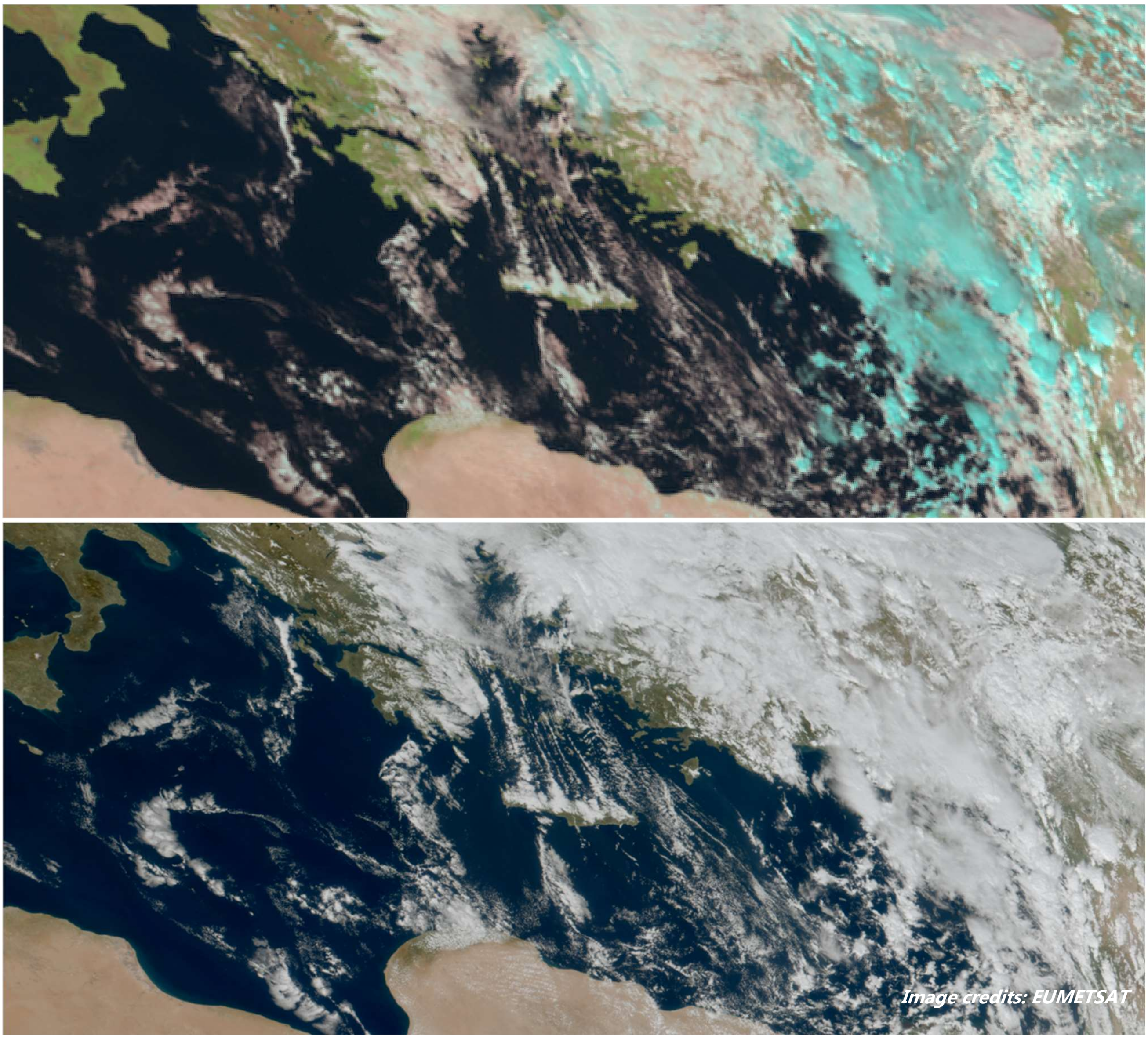


Figure 2: Comparison of MSG SEVIRI based "Natural colour" RGB and the corresponding MTG FCI "True colour RGB" imagery. The image is from March 18, 2023. *Source: EUMETSAT and ESA, based on data provided by Thales Alenia Space.*

Expected improvements from the MTG-I mission

The Flexible Combined Imager (FCI) provides state-of-the-art data over Europe and Africa for forecasting severe weather, and for near real-time monitoring of our changing atmosphere, land surfaces and oceans.

FCI, on the MTG-I satellite, will continue the very successful operation of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on Meteosat Second Generation (MSG). The user requirements have been formulated by regional and global numerical weather prediction (NWP) and nowcasting communities.

These requirements are reflected in the FCI design, which provide for several improvements in capability and performance:

- The scanning of the full Earth disc is achieved in 10 minutes, and of upper quarter of the disc (i.e., "Rapid scanning service" of Europe) in 2.5 minutes. For the heritage SEVIRI mission the full disk scanning took 15 minutes whereas the rapid scanning service was provided with new imagery every 5 minutes.
- The FCI measures in 16 channels (12 in SEVIRI) in the visible and infrared spectrum of which eight are placed in the solar spectral domain between 0.4µm to 2.2µm, delivering data at a 1km spatial sampling distance (resolution) at nadir (sub-satellite point the centre of the disc). The additional eight channels are in the thermal spectral domain between 3.8µm and 13.3µm, delivering data at 2km spatial sampling distance at nadir.
- Furthermore, the FCI samples two channels in the solar domain (0.6µm and 2.2µm) at higher spatial sampling distance of 0.5km and two channels in the thermal domain (3.8µm and 10.5µm) at higher spatial sampling distance of 1km at nadir.
- SEVIRI on MSG was observing the Earth in 12 spectral channels at 3 km resolution, with a single additional broadband VIS/NIR channel at 1 km.

The Lightning Imager (LI) on MTG will generate high-quality lightning products over especially over Europe, Africa and Atlantic Ocean. The LI has no geostationary heritage in space over Europe. Currently, and since a few years, both USA and China operate instruments capable of geostationary lightning observations.

The LI provides a capability of monitoring the total lightning activity, i.e. cloud-to-ground and cloud-to-cloud combined. This is different to ground-based systems whose focus is cloud-to-ground strikes, which is, however, only a small part of the lighting activity which is dominated by cloud-to-cloud lightning.

To highlight some of the improvements to weather forecasting and nowcasting:

- Accumulated lightning products over space and time bring imaging content into the lightning detection. Imaging optical pulses of lightning allows one to trace the extension and evolution of the electrical activity within clouds. This can be used to improve safety for outdoor activities.
- Improve flight safety over known critical areas (e.g. routes between South America and Europe)
- The availability of simultaneous and co-spatial LI data and state of the art cloud products from MTG FCI opens new opportunity for the development of "synergy products". For example, correlation between fire products and lightning products for the prediction of fire initiation.
- New key data for the Nowcasting of severe weather hazards.
- Complete coverage of Africa with the best overall available detection efficiency so far to provide African users with the most valuable LI products.

Conclusion

The improvements in spatial and temporal resolution of MTG-I FCI are very significant when compared to the heritage MSG SEVIRI mission, and will allow a much-enhanced observation of rapidly changing storm-scale features. The additional FCI channels are concentrated on the VIS and NIR bands, and will provide e.g. a much better characterisation of aerosols, allow true colour imagery and other improved RGBs, detection of thin cirrus, and various surface features such as the capability for much improved fire detection and observation with the improved fire channel at 3.8µm.

Lightning observations from a geostationary orbit is new to European and African users, but will provide a homogeneous and uniform complement to possibly existing areas of ground-based lightning. However, large areas are not well covered by any other type of observation. The added value of space-based lightning observations to short-term forecasting has been demonstrated by the use of comparable data e.g. by the National Weather Service in the USA, to assist forecasters in monitoring and predicting severe weather.

Lightning is also a new essential climate variable. EUMETSAT is already cooperating with WMO to produce data for climate studies/applications.

Nowcasting benefits from the new channels and the higher spatial and temporal resolution

Geostationary meteorological satellites provide information that is essential for nowcasting. The satellite data allow a better determination of the current state of the atmosphere that can then be extrapolated to obtain a nowcast for up to a few hours ahead.

The Satellite Application Facility on Support to Nowcasting and Very Short Range Forecasting (NWC SAF) is a consortium of the Meteorological Services of Spain (AEMET), France (Météo-France), Austria (GeoSphere), Romania (NMA) and Sweden (SMHI) led by AEMET and co-financed by EUMETSAT, whose objective is to optimize the use of the meteorological satellites for its application in nowcasting.

The NWC SAF is running for more than 25 years providing free software to registered users that can generate satellite derived products with nowcasting applications. Current software versions are NWC SAF GEO v2021.1.2 for geostationary satellites (EUMETSAT satellites, GOES-R, Himawari 8/9) and NWC SAF PPS v2021.3 for polar satellites.

The portfolio of current products include cloud products (cloud mask, cloud type, cloud top temperature and height, cloud microphysical properties), stability indices and water content in different layers, precipitation products (probability of precipitation and rainfall rate intensity), convection products (convection initiation and identification and tracking of convective cells), winds, identification of meteorological phenomena related to turbulence for aviation users, and extrapolation of satellite images and NWC SAF products a few hours ahead (see nwc-saf.eumetsat.int for more details).

In Figure 3 the NWC SAF cloud type product for the whole Earth is shown for 15 July 2019, 09:00Z. It has been generated by the NWC SAF team in Météo-France/Lannion with GOES-17, GOES-16, MSG, MSG/IODC and Himawari-8 data.

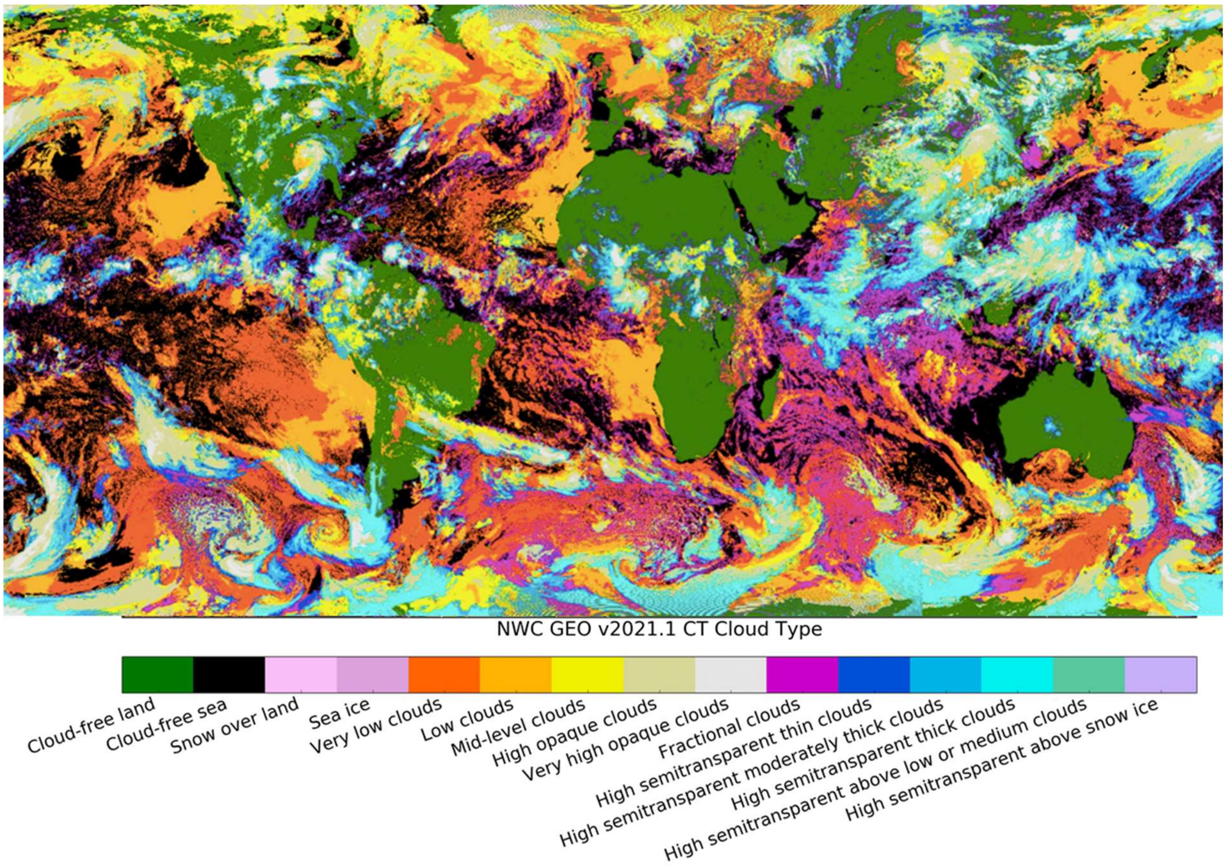


Figure 3: Cloud Type product for the complete Earth globe using GOES-17, GOES-16, MSG, MSG/IODC and Himawari-8 data

The satellite products can be of special interest in areas not covered by radars and/or when radars are not available for technical or other kind of problems. In Figure 4 you can see a comparison of the rainfall rate intensity provided by the CRRPh product (on the left) with the radar precipitation from the OPERA project (www.eumetnet.eu): Despite the difficulties to infer precipitation from IR and visible channels, the satellite product compares well with the radar data.

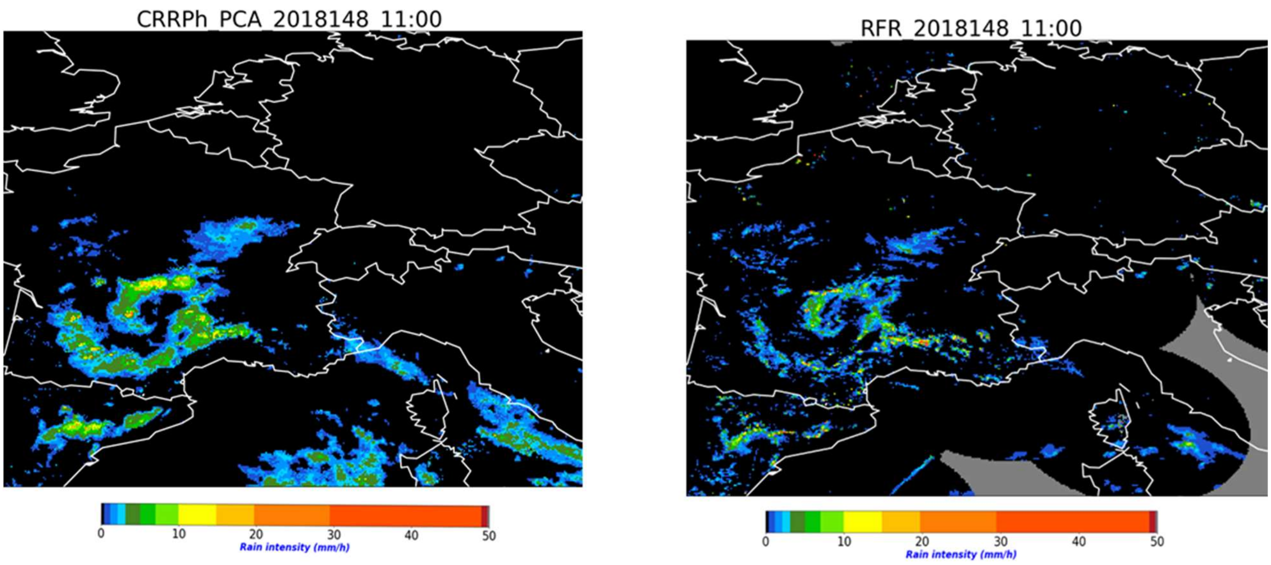


Figure 4: Left panel: rainfall rate intensity provided by the CRRPh product for the 28 May 2018 at 11:00 UTC. Right panel: precipitation intensity provided by the radar composition of the OPERA project for the same date and time. Figures provided by J.A. Lahuert (AEMET)

Many times, properties of meteorological systems affecting human goods and life vary in distances of few kilometers and evolve very rapidly. The new MTG satellite will ensure not only the continuity of the NWC SAF products, but allow for the improvement of current products as well as the development of new ones. The higher MTG spatial and temporal resolution with respect to MSG will provide more details of the meteorological systems and with higher frequency to nowcasters, who can then provide a better nowcast and warning services to the affected sectors and the general public.

All the NWC SAF products and their applications in other production chains will benefit from the MTG increased spatial and temporal resolution. In a first version of the NWC SAF software supporting MTG, the products (in particular the cloud products) will have the spatial resolution of the infrared channels. It's is planned to provide the cloud products at the resolution of visible channels (i.e. 1km at satellite nadir) in the following versions.

Furthermore, MTG imager (FCI) provides additional channels with respect to MSG imager (SEVIRI). The spectral characteristics of these new channels will contribute to improvements in the NWC SAF products. For example, the NWC SAF software uses the higher absorption of new channel 1.38 µm by water vapor with respect to other channels to improve the cirrus detection over land in day-time conditions. New channel 2.25 µm is used to improve the cloud phase detection. A future planned development for cloud multi-layer identification will make use of these new channels 1.38 µm and 2.25 µm.

All improvements in the NWC SAF products will be implemented consecutively, in the next, or the following NWC SAF software versions. For details, please reach out to NWC SAF. Lastly, the MTG system also includes new sensors of a type not available with MSG, providing additional valuable information for nowcasting:

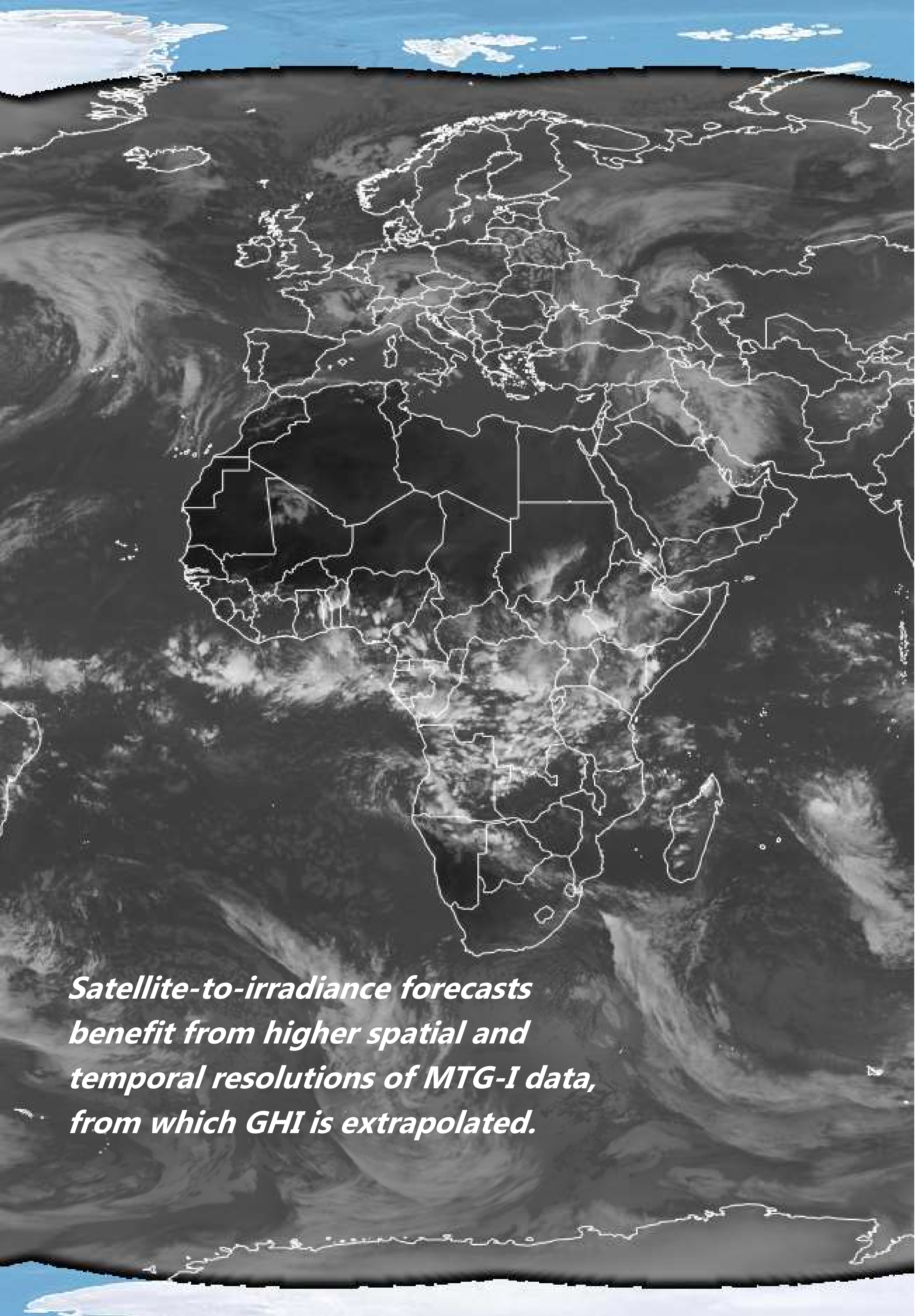
- The new Lightning Imager will provide data about lightning activity. The NWC SAF team plans new products with LI data: LiStack will provide the accumulation of the lightning activity in the time period and area defined by the user for monitoring applications, while LiJump will detect lightning jumps.
- The NWC SAF is developing a new software package with specific products from the IRS sensor, providing vertical atmospheric profiles. It will allow for a 4D representation of the atmosphere (including temperature and humidity), as well as stability indices. This product is without precedent for Europe and Africa.

Conclusion

The improvements in MTG satellites with respect to MSG in spatial and temporal resolution, new imager channels and new sensors increase notably the satellite nowcasting capabilities.

The current NWC SAF products will benefit from it, as will all the applications that use the NWC SAF products as their input.

In addition, new NWC SAF products are currently being developed specifically adapted to the data from the newly available sensors. On a long term, the NWC SAF aims to exploit the synergies of the main MTG sensors with nowcasting capabilities FCI, LI and IRS to improve the NWC SAF products.



Satellite-to-irradiance forecasts benefit from higher spatial and temporal resolutions of MTG-I data, from which GHI is extrapolated.

Reuniwatt

Nowcasting solar irradiance: An essential tool for grid stability

Solar energy depends on meteorological conditions, and their strong variations can have a direct impact on an electrical grid's stability. Photovoltaic power production relies on solar irradiance reaching solar panels and on the characteristics of the system which will transform the light into electrical current (tilt, cell yield, ...). Knowing that a cloud passing in front of the sun can instantly cause an 80% decrease of the local ground irradiance, it is clear that this also has an impact on the power production.

Thanks to advanced solar forecasting solutions, it is possible to better anticipate these fluctuations, improve market participation and make photovoltaic (PV) more flexible. Different forecasting technologies must be combined to provide forecasts on different time-scales, ranging from a few minutes to several days ahead:

- Day-ahead (Reuniwatt's **DayCast**™ solution) – from 6 hours ahead up to several days ahead
- Intra-day (Reuniwatt's **HourCast**™ solution) – from 10 to 15 minutes up to 6 hours ahead
- Intra-hour (Reuniwatt's **InstaCast**™ solution) – from 1 minute up to 30 minutes ahead.

A global optimisation ensures a smooth transition between short-term horizon forecasts and longer-term horizon forecasts leading to an increased forecast accuracy for lead times of 0 to 6 hours. The standard variable for solar energy forecasts is GHI (Global Horizontal Irradiance) forecasts.

Surface solar irradiance assessment based on satellite imagery

Reuniwatt's proprietary methodology **HourCast**™ anticipates the clouds' trajectory from satellite image analysis: cloud masses are identified in geostationary satellite images, and their movements are extrapolated. HourCast™ satellite-to-irradiance forecasts are hardware-free.

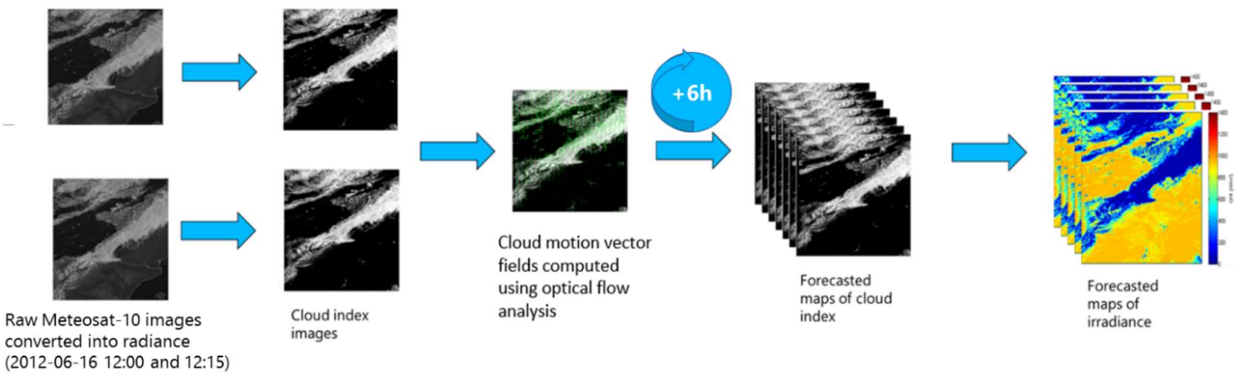


Figure 5: Overview of HourCast™ solar forecasting process based on cloud motion vectors derived from satellite images

The first step consists in the processing of satellite images by converting two consecutive images into cloud index maps, using Reuniwatt's proprietary SunSat™ algorithm[1]. Once the cloud index maps have been obtained, the movement of the clouds between these two images can be determined by analysing

[1] Cros et al. (2019). Real-time solar irradiance retrieval from satellite data: quality assessment of an operational tool using five satellites. 6th International Conference Energy & Meteorology, Copenhagen, Denmark

the optical flow, transformed into a vector field of the clouds' movements. This vector field is then applied to an image taken at T0 to extrapolate and forecast the various cloud index maps up to 6 hours ahead.

The desired forecast for a specific solar plant is extracted from the map with a spatial smoothing post-process[2]. Finally, the cloud index forecast is combined with a clear sky model in order to compute the effective Global Horizontal Irradiance (GHI) or alternative forecast variable, such as DNI (Direct Normal Irradiance), DHI (Diffuse Horizontal Irradiance), GTI (Global Tilted Irradiance), wind speed and direction at 10 m or turbine hub height, solar or wind power production (in kW), temperature at 2 m or turbine hub height.

The improved temporal resolution of MTG-I data will also allow us to update our forecasts at a higher frequency (every 10 minutes instead of 15 minutes) and feed our models with a larger amount of data over the same period, which leads to an overall increase in the resolution of the forecasts. Higher volumes of weather variables decrease forecast uncertainties, therefore higher temporal resolutions from MTG will result in improved performance. In addition, the better spatial resolution will allow our algorithms to better detect clouds and predict their movements.

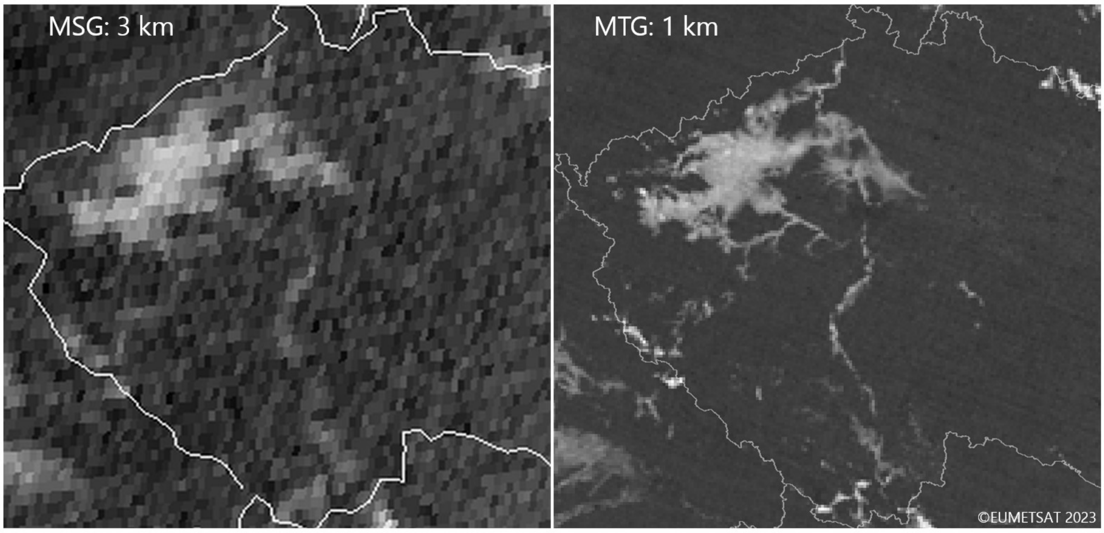


Figure 6: Example of fog detection, 16 Nov 2018, 01.37 UTC; simulated FCI imagery at 2km spatial resolution based on data from the VIIRS instrument on the NOAA Suomi-NPP satellite (right panel), and SEVIRI imagery at approximately 5km spatial resolution over Czech Republic (3km spatial resolution at sub-satellite point, left panel; Brightness Temperature differences (VIIRS I4 (3.7µm)–I5 (10.8 µm); SEVIRI 3.9µm–10.8µm)

Conclusion

The higher temporal and spatial resolutions of MTG-I/FCI satellite imagery will lead to improvements in the monitoring and forecasting solutions of solar plants. Taking advantage of the improved quality of EUMETSAT data and new NWCSAF products, solar forecasters will be able to feed their models with higher resolution input data, resulting in more frequent and more accurate cloud forecasts.

[2] D. Aicardi et al. (2022). A comparison of satellite cloud motion vectors techniques to forecast intra-day hourly solar global horizontal irradiation. Solar Energy.

FAQ

Q. What are the expected differences in terms of EumetCast infrastructure in order to retrieve MTG data?

A. EUMETSAT: I would refer to the EUMETSAT web page with further links to all relevant information regarding EUMETCast in the MTG era:

https://www.eumetsat.int/evolutions-eumetcast-services-mtg-era

Q. Who are your main users? How is the data provided to the user?

A. EUMETSAT: The main users are the national meteorological services of EUMETSAT member states, ECMWF, and in downstream the users of their services. In addition, African partners will receive data through existing frameworks. Internationally, data are provided to other EUMETSAT partners, such as NOAA. The main mechanism for data distribution is through EUMETCast Satellite and Terrestrial. For more information, please refer to this link:

https://www.eumetsat.int/evolutions-eumetcast-services-mtg-era

Q. Who are typical users of AEMET's nowcasting software products?

A. AEMET: The target users are the national meteorological services of the EUMETSAT member states. They use the NWC SAF products for their daily forecast/nowcast/warning issuing, and other applications, such as aviation meteorology. Other users are the national meteorological services of third countries. As the NWC SAF products can also be used as base for further developments, we also have users such as as universities, research institutions and companies of the EUMETSAT Member States and all around the world.

Q. What is the typical accuracy of satellite-to-irradiance forecasts?

A. Reuniwatt: The accuracy of forecasts strongly depends on several parameters: the local climate, the concerned time horizon, and the metric used. Therefore, a single answer does not work for any location worldwide. The accuracy depends on many variables. Nevertheless, some systems/methods can keep the accuracy level at different locations doing some onsite adjustments.

It is possible to compare intra-day forecasts with pyranometer data. Reuniwatt can provide extensive backtests (generation of historical forecasts using satellite archives for HourCast™) for very specific geographic coordinates, which can then be compared to onsite irradiance measurements.

However, it is very important to bear in mind that pyranometer data must be treated with caution. Ground measurements must generally go through a quality-check process, as they can be biased if the instruments are not well installed, calibrated and/or maintained over the years.

About EUMETSAT

EUMETSAT is an intergovernmental organisation based in Darmstadt, Germany, currently with 30 Member States. EUMETSAT operates the geostationary satellites Meteosat -10, and -11 over Europe and Africa, and Meteosat-9 over the Indian Ocean. In December 2023, EUMETSAT will launch the MTG satellite system. The data and products from EUMETSAT's satellites are vital to weather forecasting and make a significant contribution to the monitoring of the environment and climate change. The European Union has entrusted EUMETSAT with exploiting the four Sentinel missions of the Copernicus space component dedicated to the monitoring of atmosphere, ocean and climate on its behalf.

About AEMET

The State Meteorological Agency (AEMET, or Agencia Estatal de Meteorología) aims at the development, implementation and delivery of state's weather services and at supporting the performance of other public policies and private activities, contributing to the safety of persons and property, and to the welfare and sustainable development of Spanish society. The Agency has the status of meteorological authority of the state, as well as aeronautical meteorological authority. AEMET is the Leading Entity of the EUMETSAT Satellite Application Facility on support to Nowcasting and Very Short-Range Forecasting (NWC-SAF) Consortium.

About Reuniwatt

Reuniwatt is a major player of the solar radiation and cloud cover assessment and solar and wind power forecasting. Based on solid Research and Development works, the company offers reliable products and services intended for professionals of various fields, making the best out of two key facets of the meteorology: atmospheric physics and data sciences. A particular focus has been placed on solar energy forecasting, while developing cutting edge solutions to improve the short-term prediction of the solar resource. The company has won many grants, which makes Reuniwatt a European Champion with regard to innovation. and has also been selected among the national fast-growing companies to join the prestigious French Tech 120 programme.

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