Simulation of top-of-the-atmosphere visible reflectances
#UEF2024

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ECMWF NWP SAF

Simulated imagery from the ECMWF model - upgrades

48r1
Before 1st March 2024

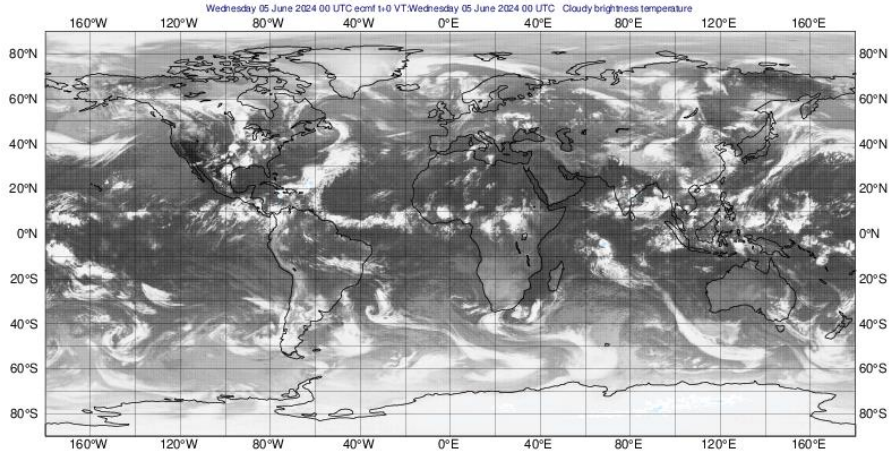
48r1
Since 1st March 2024

49r1
Q4 2024

Simulated top-of-atmosphere BTs
- Infrared imagery IR10.8 microns
- Water vapor imagery: WV 6.2 & WV 7.3
- RTTOV-13.0

ECMWF has launched new real-time imagery products to assist forecasters, who can now visualize medium-range predictions as would be seen from a visible sensor onboard a satellite.

Simulated infrared imagery (IR10.8)



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- Infrared imagery IR10.8 microns
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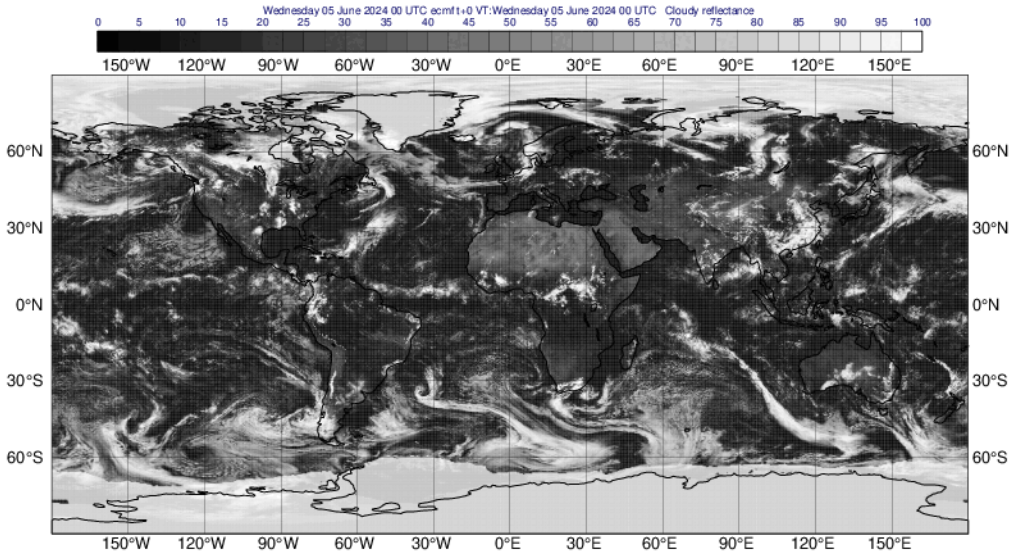
- RTTOV-13.0

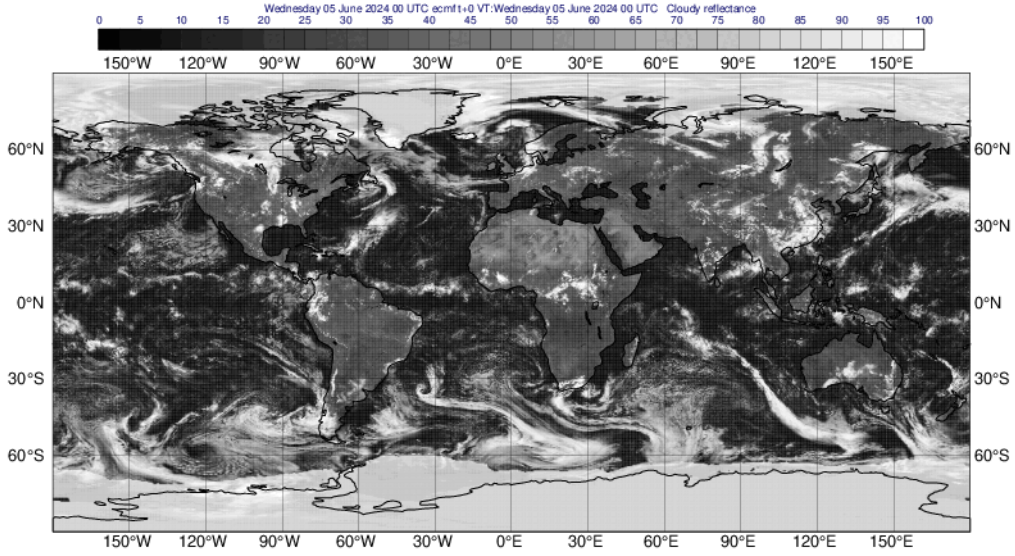
Simulated TOA reflectance
- Visible imagery 0.6 & 0.8 microns

RTTOV-13.0 / MFASIS-LUT

Simulated visible imagery 0.635 microns



Simulated visible imagery 0.810 microns

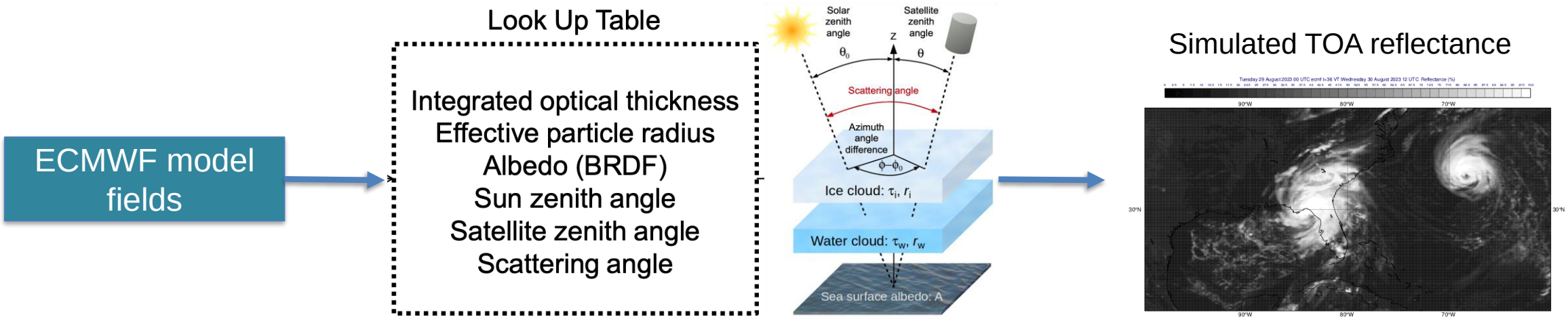


Simulated visible imagery: Approach

- Output from the high-resolution forecast models (e.g., atmospheric profile + surface parameters) is used as input to the RTTOV/MFASIS, which calculates simulated TOA visible reflectances over the spectral response of a particular satellite instrument channel.

- RTTOV-13.0 / MFASIS-LUT visible forward operator has been integrated within IFS cy48r1. MFASIS (Method for FAst Satellite Image Synthesis) is used for the fast simulation of satellite images in the visible spectral range in the presence of clouds.

Scheck, L. et al. (2016)



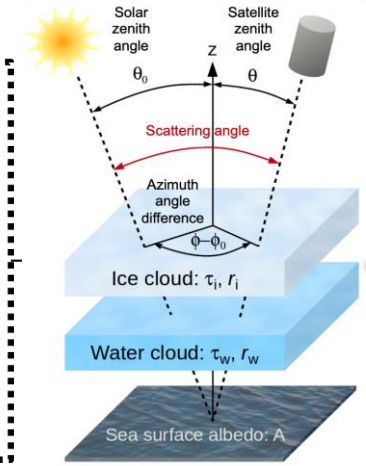
Simulated visible imagery: Approach

Scheck, L. et al. (2016)

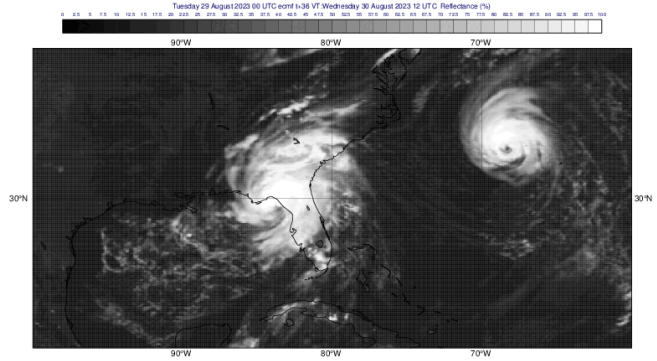
ECMWF model fields

Look Up Table

Integrated optical thickness
Effective particle radius
Albedo (BRDF)
Sun zenith angle
Satellite zenith angle
Scattering angle



Simulated TOA reflectance



- The reflectances are approximated by a function that depends on 8-parameters;
- Focus on non-absorbing or very weakly absorbing channels (wavelength range 0.47-0.86 microns), for which atmosphere has only little influence on the top of atmosphere reflectance so that the clouds can be approximated by two layers: one water cloud layer and an overlaying ice cloud layer.
- Cloud parameters are derived using the cloud water and cloud ice profiles from the input to RTTOV as well as the chosen settings in the options for cloud optical properties (cloud water OPAC, cloud ice Baum).

RTTOV surface reflectance

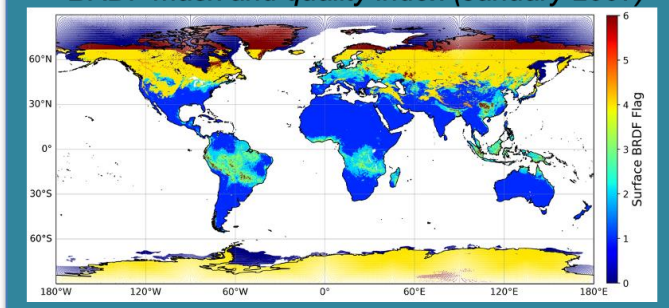
- π * BRDF (Bidirectional Reflectance Distribution Function) model for VIS

Sea
RTTOV's internal surface scheme

Elfouhaily et al., 1997

Atlas over snow-free land

BRDF mask and quality index (January 2007)



Vidot & Borbas, 2014

- Global atlas of mean monthly land BRDF values for 2007 at 0.1 degree; A mask is provided for each of the BRDF datum providing information on the surface type.
- IFS implementation accounts for the atlas for the month which corresponds to the current simulated imagery forecast time step.
- Satellite visible data used for defining the surface BRDF values, are not available over regions affected either by permanent polar night or by permanent cloud cover.

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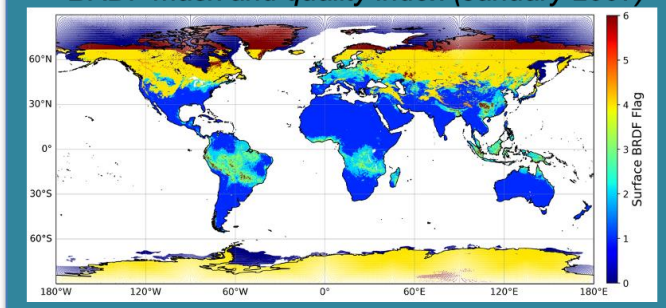


Vidot & Borbas, 2014

IFS Parametrization over snow-covered land

$$R_\lambda^{snow} = \max\left\{R_{max}^{snow} - \left[\max\left(\frac{T_{skin} - 268.15}{12}, 0\right)\right]^2, R_{min}^{snow}\right\}$$

where $R_{max}^{snow} = 0.85 - 0.45 f_{hveg}$ and $R_{min}^{snow} = 0.50 - 0.25 f_{hveg}$

$$R_\lambda = R_\lambda^{land} + (R_\lambda^{snow} - R_\lambda^{land}) \times f_{snow}$$

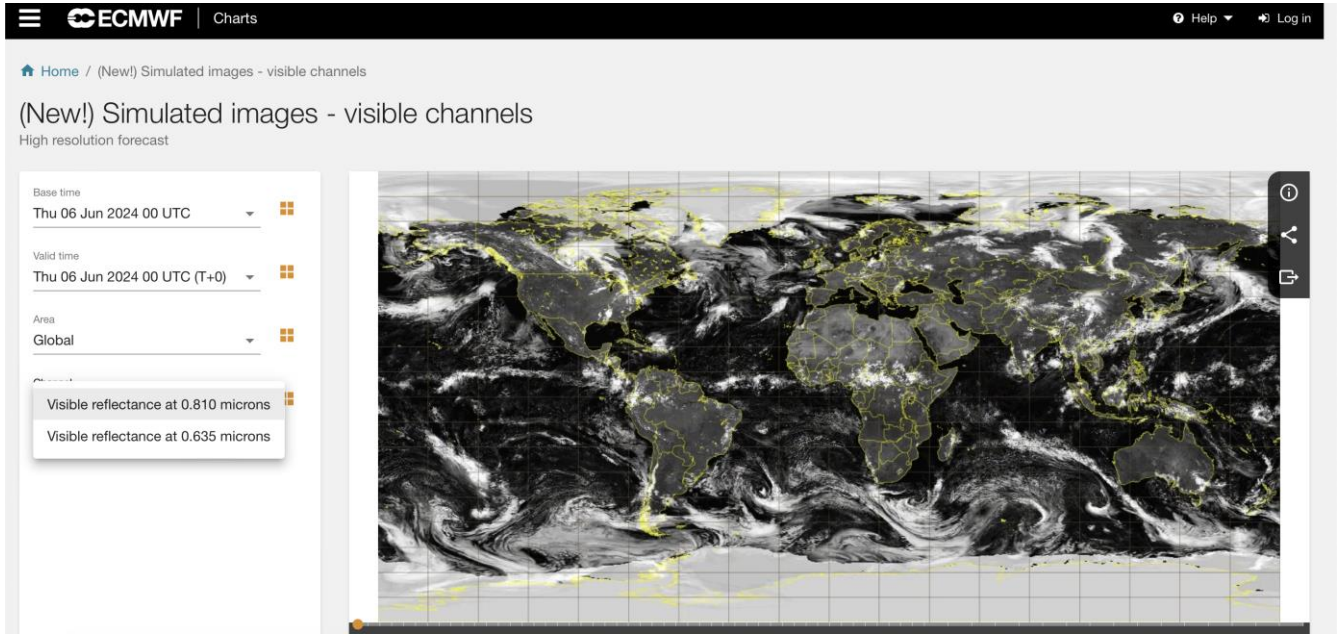
$$f_{snow} = \min(10000 \frac{h_{snow}}{\rho_{snow}}, 1)$$

Lopez et al. 2022, TM 892

- The reflectance over snow-covered land depends on the skin temperature and on the high-vegetation fractional cover;
- The overall reflectance of a given snow-affected land point includes:
  - the observed non-linear decrease of surface snow albedo with increasing temperature;
  - the observed reduction of snow-pack reflectance in regions with high vegetation;

Capturing clouds and surface conditions

A screenshot of the web charts product on Open Charts
https://charts.ecmwf.int



- TOA reflectances: percentage of reflected solar radiation by clouds and Earth surface
- Reflectances that would be seen at a visible wavelength are computed during the model run from every grid point of the forecast model.
- The image product assumes a nadir view for every model grid point, free from real satellite geometry distortions at high latitudes and allows a unique perspective, to see the entire globe in perpetual daylight at a range of forecast lead times.
- Sunglint is excluded - the assumption is that both sun and satellite are overhead everywhere on the planet.

Technical details, MARS, metadata

Visible simulated satellite images **GRIB encoding** from https://codes.ecmwf.int/grib/param-db

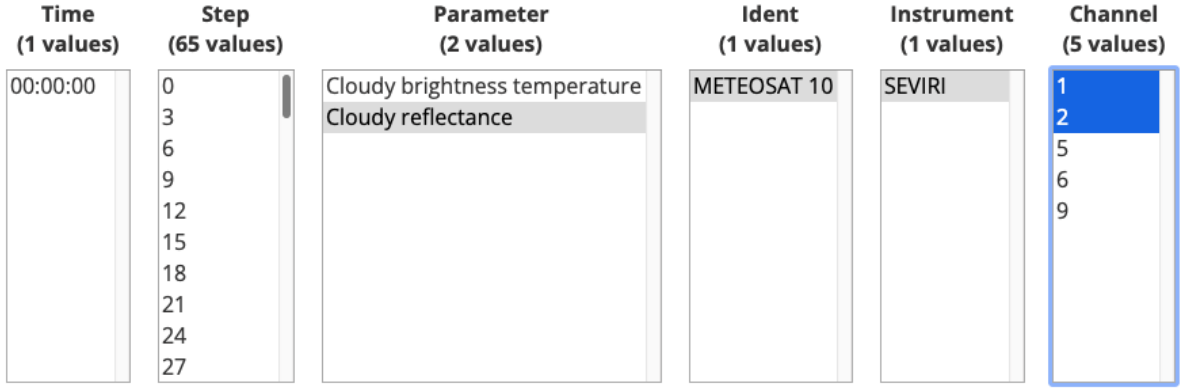
ParamID	shortName	longName	GRIB edition
260512	cdrfl	Cloudy reflectances	2

edition	centre	date	dataType	gridType	stepRange	shortName	packingType
2	ecmf	20240605	ssd	reduced_gg	0	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	3	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	6	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	9	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	12	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	15	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	144	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	150	cdrfl	grid_ccsds
2	ecmf	20240605	ssd	reduced_gg	240	cdrfl	grid_ccsds

dataType=ssd with the following post-processing steps out to 240 hours: 3 hourly forecast time step from T+0h to T+144h and 6 hourly forecast time step from T+150h to T+240h.

MARS catalogue

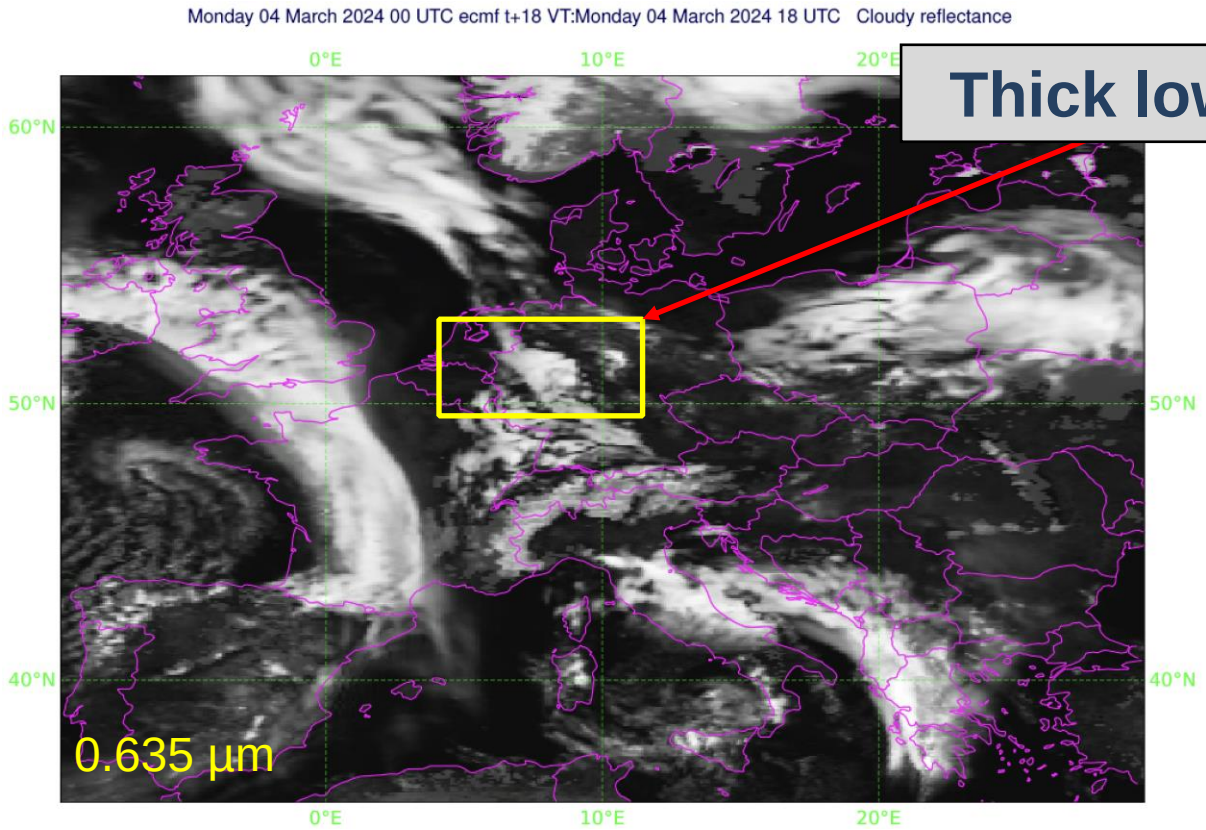
https://apps.ecmwf.int/mars-catalogue/?type=ssd&stream=oper&expver=1&class=od

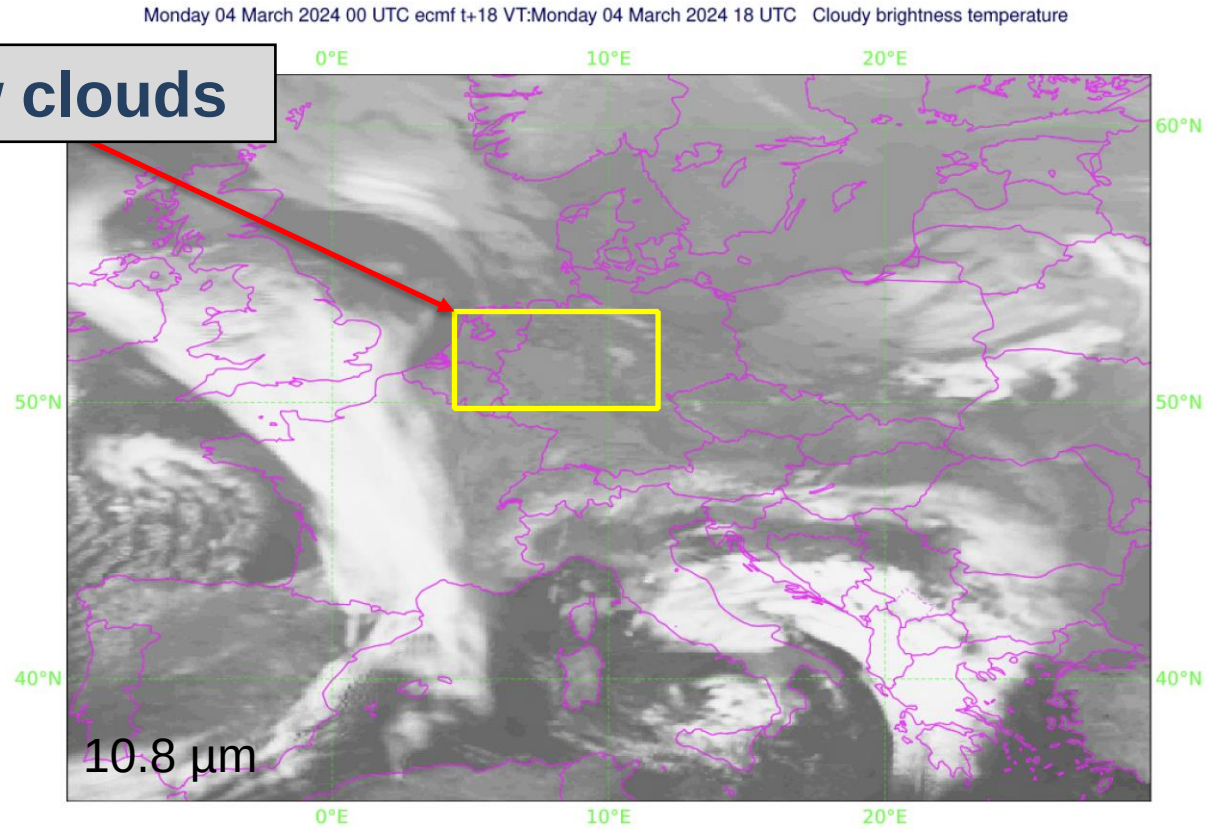


Characteristics of Meteosat-10/ SEVIRI channels

Channel No	Spectral band (microns)	Band central wavelength (microns)	ECMWF Simulated images in the MARS archive
1	VIS0.6	0.635	**Cloudy reflectances (cdrfl), since 28 February 2024 00 UTC**
2	VIS0.8	0.81	**Cloudy reflectances (cdrfl), since 28 February 2024 00 UTC**
5	WV6.2	6.25	Cloudy brightness temperature (clbt), since 8 March 2016, 00 UTC
6	WV7.3	7.35	Cloudy brightness temperature (clbt), since 8 March 2016, 00 UTC
9	IR10.8	10.8	Cloudy brightness temperature (clbt), since 8 March 2016, 00 UTC

Using simulating imagery – practical remarks

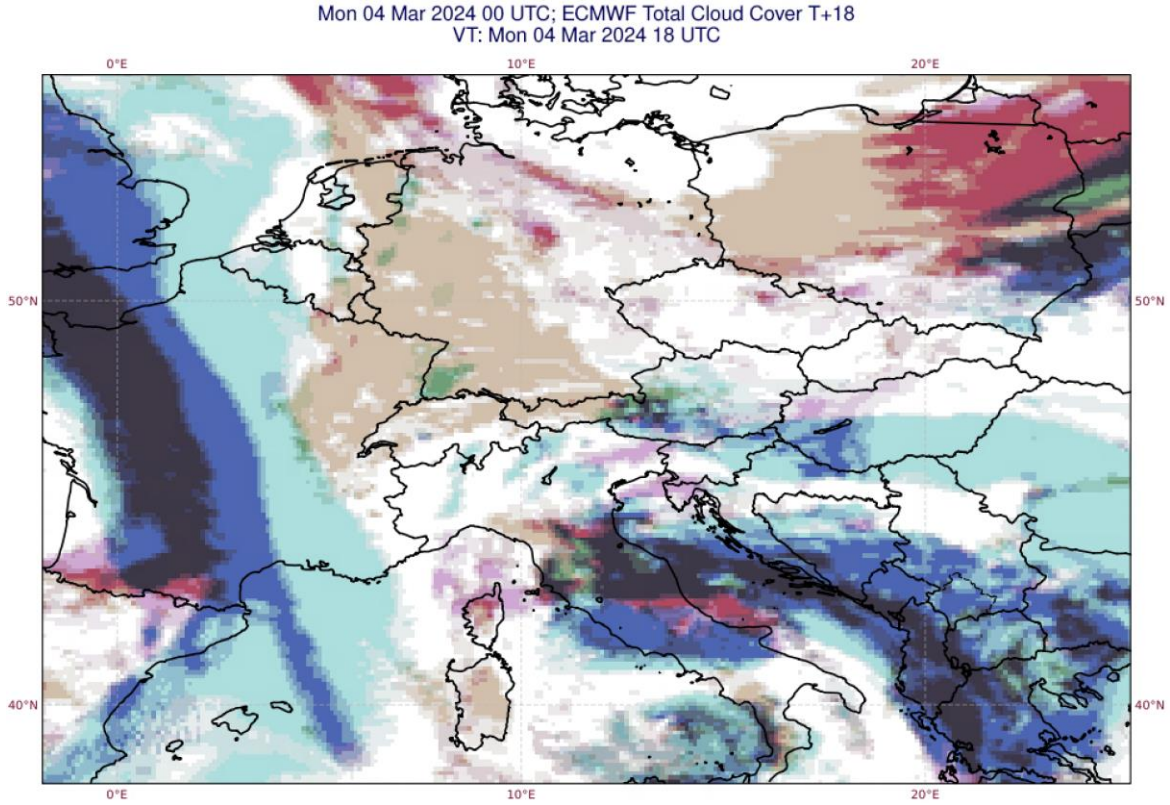


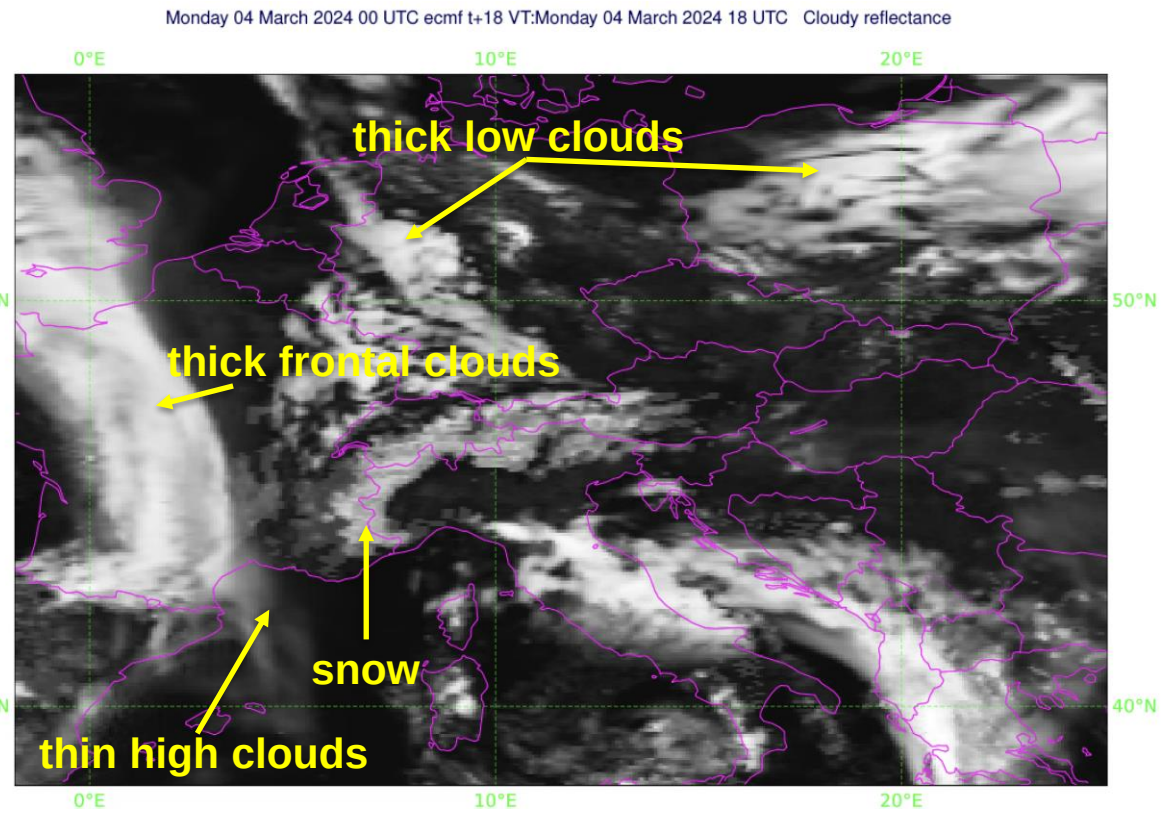


Thick low clouds

- Complement simulated IR imagery products
- Clouds have superior contrast properties at visible wavelengths (over cold surfaces) and in this new product, perpetual daylight illumination is used so forecasters can even see clouds at night.
- Provide greater details in cloud structure both day and night, e.g. low clouds in winter may be hardly noticed on IR but is likely to appear on visible imagery.

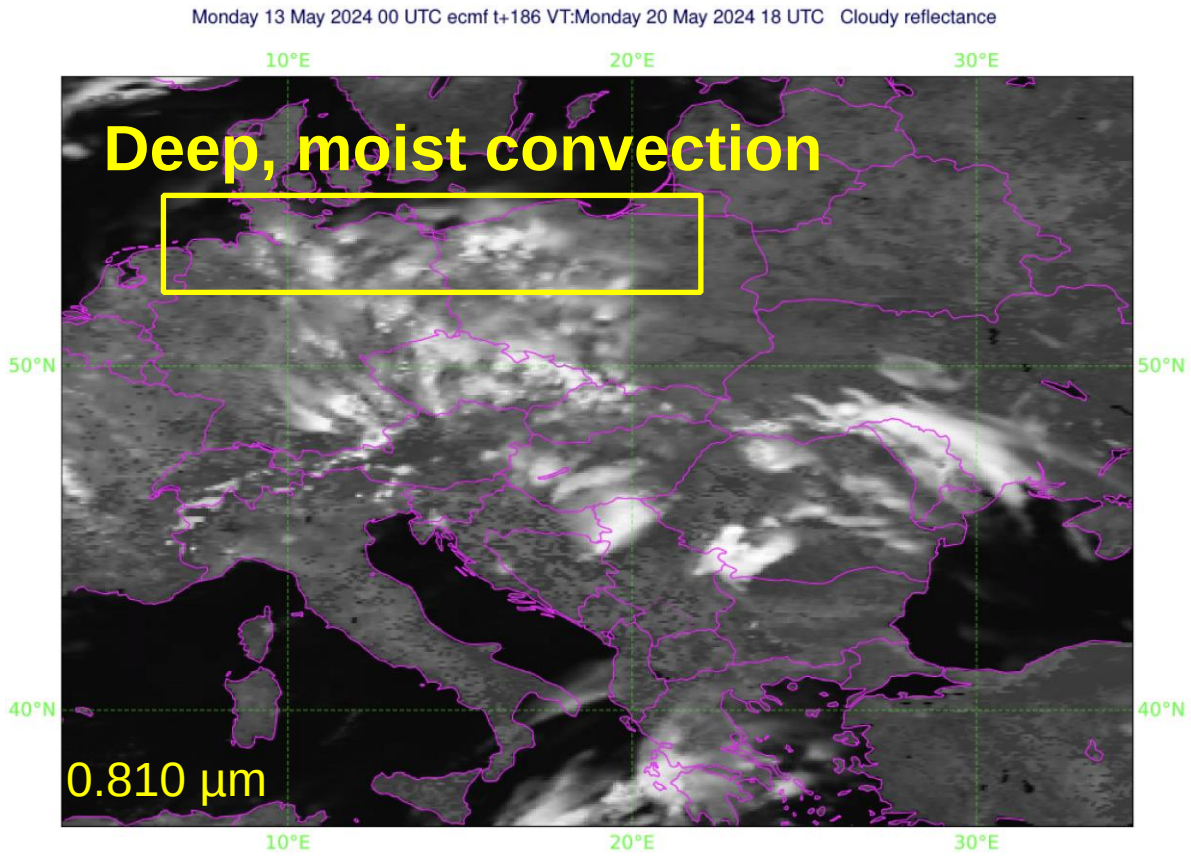
Using simulating imagery – main features

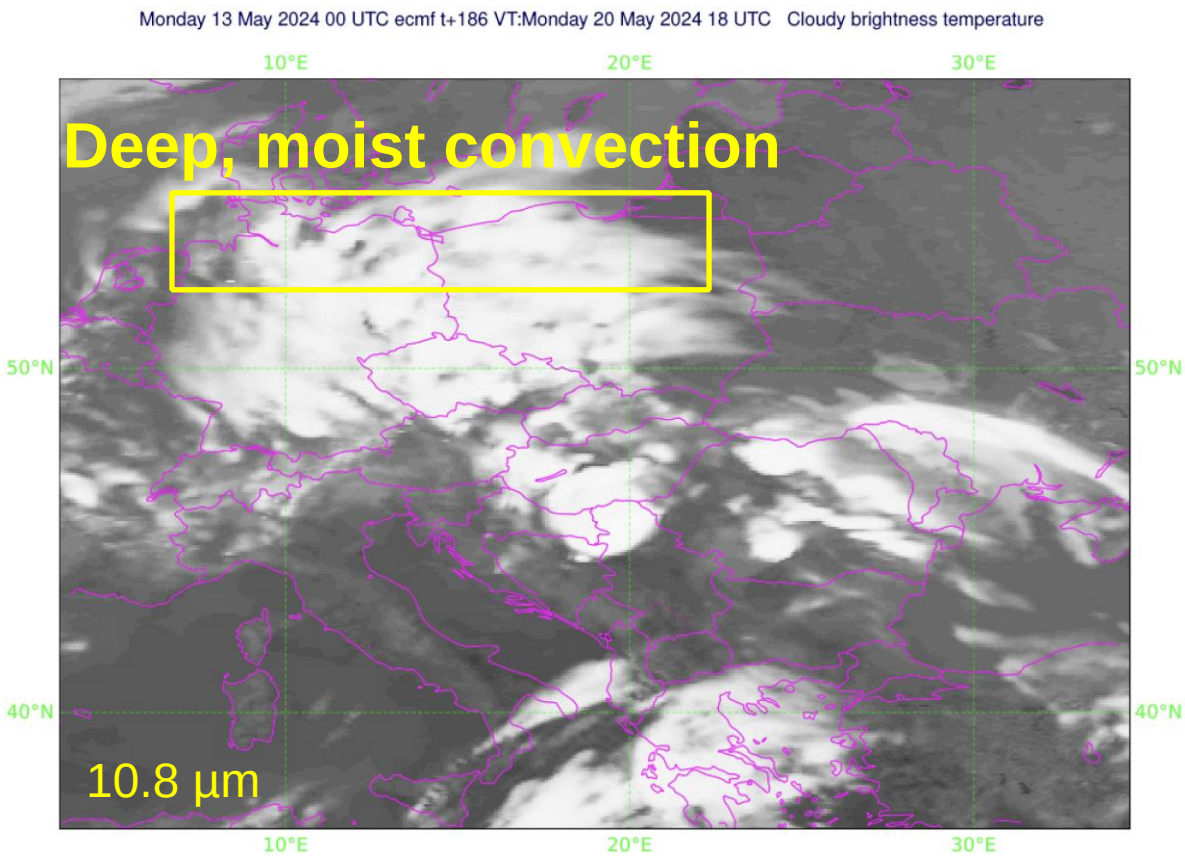




- Some surface features (e.g. large rivers), snow and ice.
- Higher cloud reflectance, thicker clouds with higher concentration of hydrometeors.
- Thin high clouds which are visible on infrared become much less pronounced in the visible channel.

Using simulating imagery – exposing model deficiencies





- These new products may highlight some possible deficiencies, issues and errors in the model – e.g. apparently too low cloud reflectance in this case of deep, moist convection.
- Too low cloud reflectance has been noticed in some cases of low clouds as well.

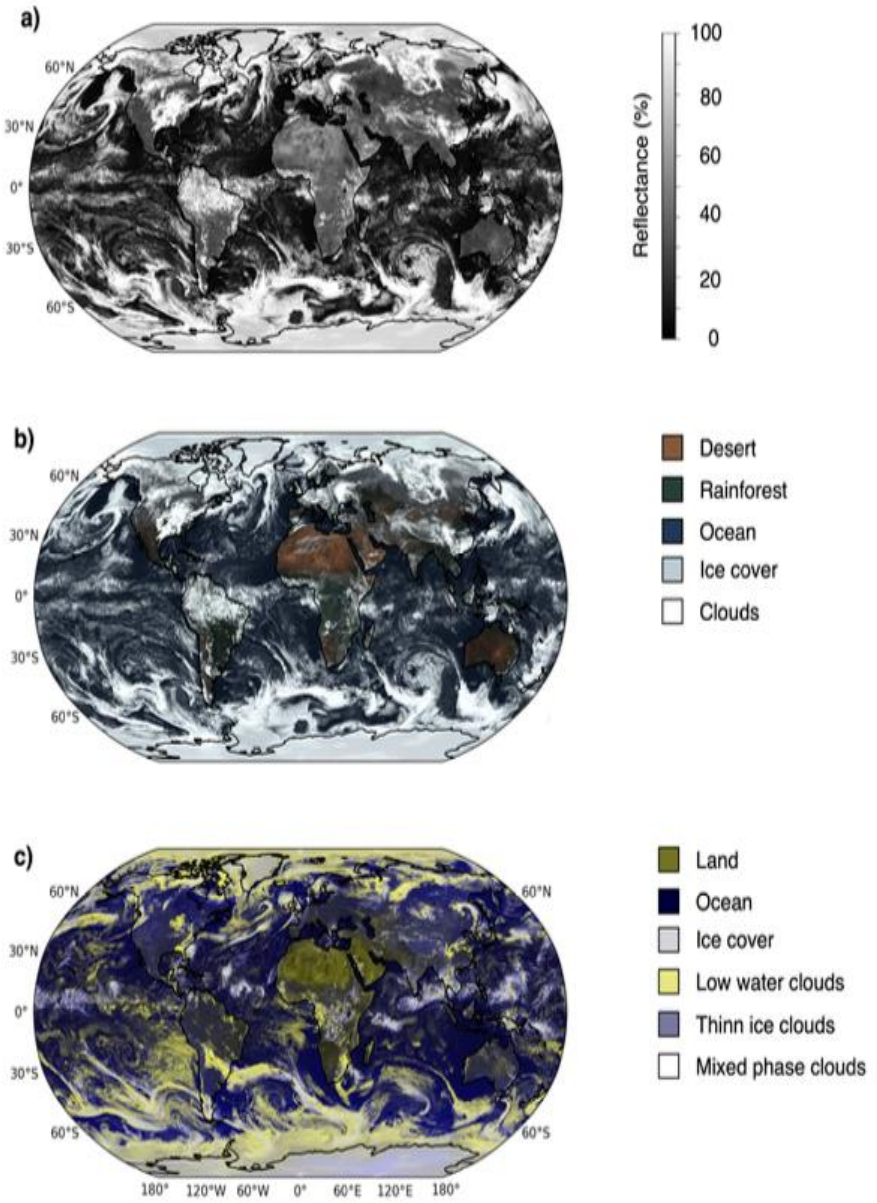
Simulated imagery – 49r1 enhancements

49r1
Q4 2024

Simulated TOA reflectance & BTs as representative for FCI/Meteosat-12 channels wavelengths

RTTOV-13.2 / MFASIS-NN

- "Red, Green, Blue" processing consolidates different channels of satellite imagery into single products with enhanced information.
  - True color RGB imagery (b)
  - Cloud RGB images (c)



MFASIS-NN is selected as solar scattering model instead of MFASIS LUT (improved treatment of mixed-phase clouds and capability to simulate NIR 1.6 microns channel).

a) Traditional single wavelength simulated images in the visible spectrum

b) True color RGB: In addition to the 0.64 µm channel, it also uses the 0.44 & 0.51 µm channels which are new on FCI.
The colours are close to those naturally observed. Different surface features can be identified: green/dry vegetated areas, deserts, oceans, snow/ice covered areas. Clouds and snow/ice have similar colours (bright white).

c) Cloud RGB: The yellow colour (as a combination of the 0.64and 0.865 µm bands) represents low-level clouds which strongly reflect solar light, while the level of the blue colour varies with the inverse of the normalized infrared brightness temperature in the 10.5 µm band.

Summary

- Near-real-time simulated imagery (tool for Member State forecasters / analysts) has been further developed to include VIS simulated images in addition to the existing IR images

  - Simulated imagery is an integral part of the operational IFS and available within the standard delivery times of all other ECMWF data and products.

  - The new product will play a crucial role in improving the visualisation of forecasts of high-impact extreme weather events through the complementarity of infrared and visible frequencies.

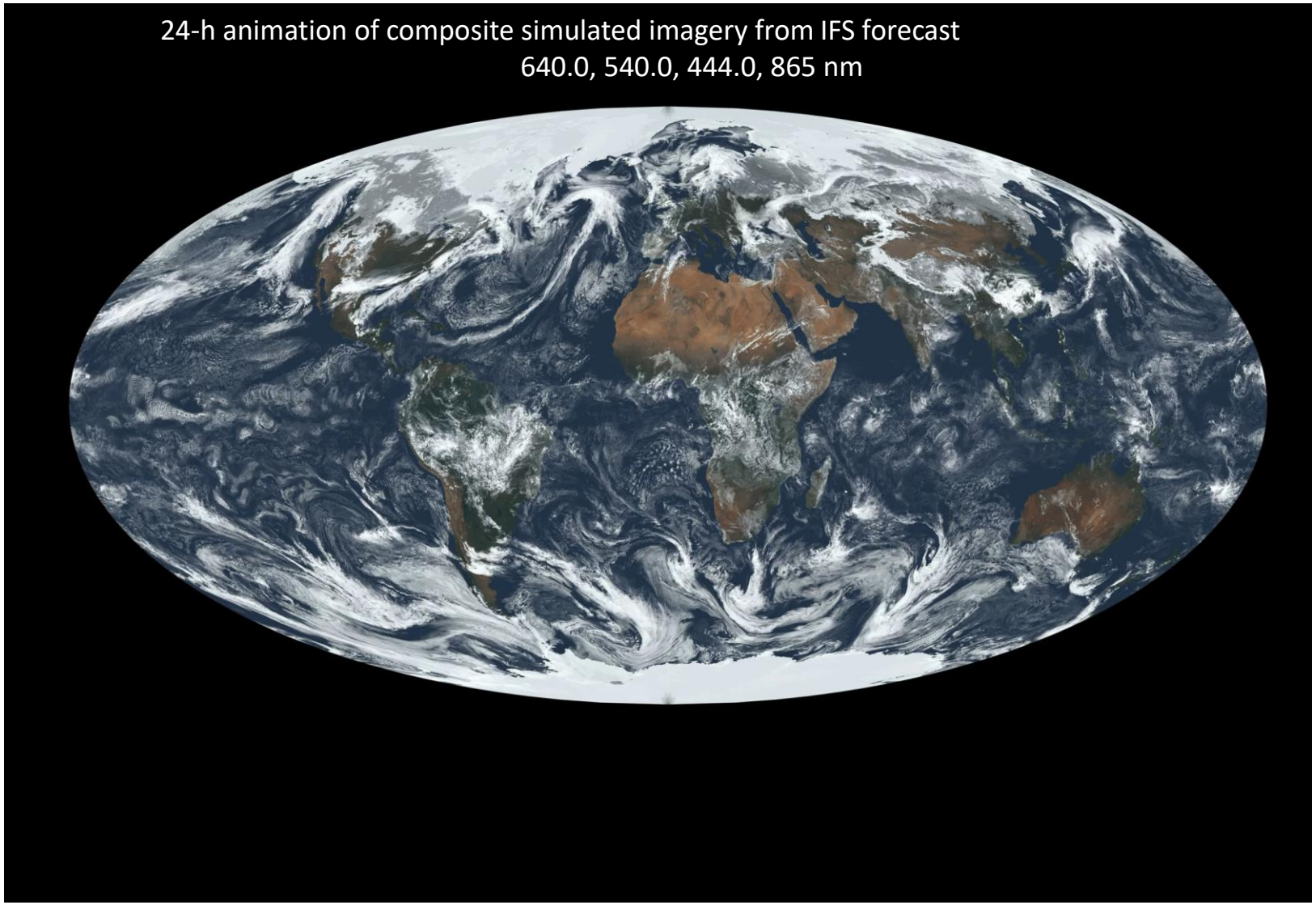
- We welcome feedback on these new developments at any time

- More enhancements in the upcoming IFS cy49r1, which include the neural network version of the MFASIS operator for visible radiances, which is an improved and faster operator to support simulated imagery activities.

  - Simulated visible and infrared images (as representative for FCI/Meteosat-12 channels wavelengths) will be generated, archived in MARS, made available in ECMWF web charts and in dissemination.

  - True/RGB colour images, in addition, could be constructed from the enhanced visible bands of FCI to display the Earth in colours similar with what we might see with our own eyes.

24-h animation of composite simulated imagery from IFS forecast
640.0, 540.0, 444.0, 865 nm



Thank you