An overview of the MTG-IRS Level-2 Products

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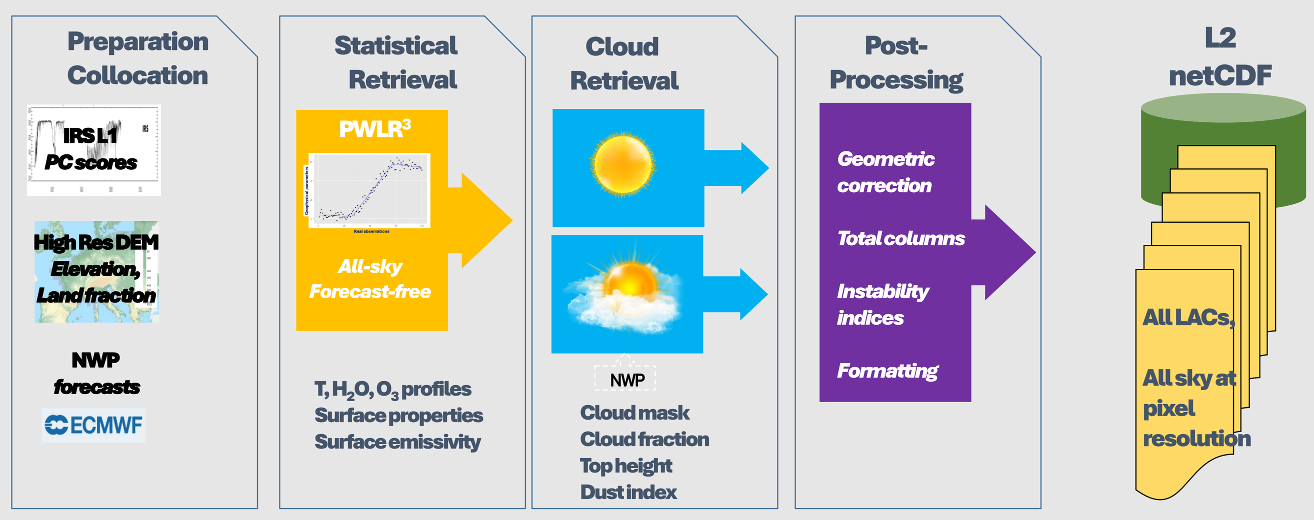
Summary

The Meteosat Third Generation (MTG) program is a cooperation between EUMETSAT and the European Space Agency (ESA). ESA develops and procures 4 satellites for the imaging applications (MTG-I) and 2 for the sounding applications (MTG-S), on behalf of EUMETSAT. Over the course of the next 20 years, the six satellites in the MTG satellite fleet will improve imaging and infrared sounding capabilities for meteorological and climate applications, benefiting both worldwide users and European national meteorological services. EUMETSAT develops and operates the ground segment used to control the satellites, acquires and processes the data, and delivers the products to users worldwide.

The hyperspectral Infrared Sounder IRS, deployed on MTG-S, is primarily designed to support numerical weather predictions at regional and global scales, including nowcasting. MTG-IRS will offer unparalleled data on atmospheric thermodynamic parameters with a high vertical resolution and horizontal sampling of 4 km at Nadir and temporal sampling of 30 minutes over Europe. It will provide 4-D hyper-spectral soundings of, inter alia, temperature, water vapor, ozone vertical profiles and trace gases to support atmospheric composition and air quality monitoring.

This unprecedented system offers a significant advance in operational observation and will be a great asset to regional short-range weather forecasting and nowcasting, for the purpose of more accurately and quickly identifying areas of potential instability and associated severe weather phenomena. Identifying areas with potential atmospheric instabilities is hence critical to issue accurate warnings, as early as possible, to prepare population, economic actors and civil protection. In this regard, The level 2 products will provide instability indices, aiming at ensuring continuity with other GII products, e.g., MSG and consistency with the MTG-FCI follow-up products. It is foreseen to supplement the products at a later stage with the Atmospheric Motion Vectors derived from the temperature, moisture and ozone vertical profiles.

L2 Processing chain



The MTG-IRS L2 retrieval algorithms build on a common hyperspectral infrared Level 2 approach, which has been operationally demonstrated for IASI and is also the basis for the IASI-NG L2 processing. The rationale is to operate consistent L2 products from the three EUMETSAT hyperspectral sounding missions where commonalities exist and hence optimize use of resources during development, operation and maintenance of their processing algorithms and software. Despite differences between the three sensors (IASI, IASI-NG, MTG-IRS), a major part of the processing can be accomplished with generic software libraries applicable to all HSIR missions. However, the IRS Level 2 processor includes specific algorithms and configurations tailored to IRS. These are required by the nature of the mission, like the correction for the geometry and due to its specific objectives, like the computation of convective parameters.

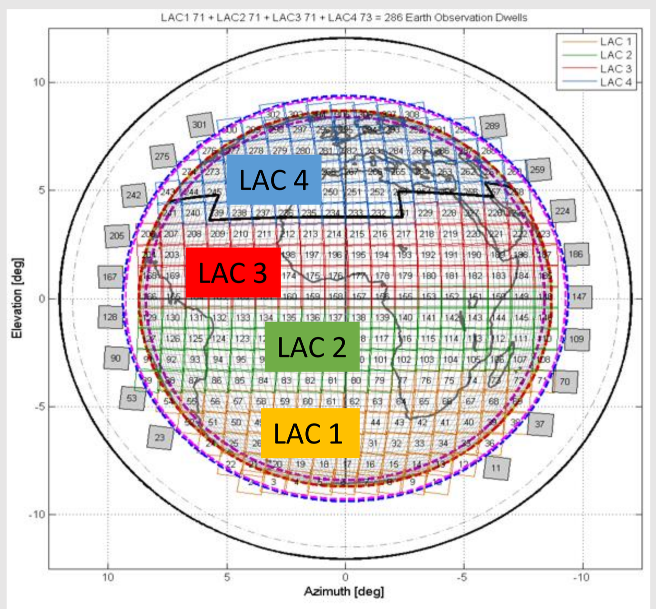


Figure 1: the Earth disk is divided in 4 regions of interest, namely Local Area Coverage (LAC). Each LAC is acquired in 15 minutes, with a revisit of LAC 4 covering Europe every 30 minutes.

Statistical Retrievals

• PWLR (Piece-Wise Linear Regression) is a statistical method relying on regression classes. These classes represent similar meteorological regimes or observation conditions. Within such classes, the validity of the linear relationship between the observations (the IRS L1 radiances in two bands, [679.5 – 1210] and [1600-2250] cm^{-1}, represented as principal components scores) and the retrieved variables is enhanced. The complete list of the retrieved geophysical parameters is summarized in **Table 2**.

- Fast all-sky statistical retrieval of temperature, water vapor, ozone slanted profiles, surface properties (emissivity, surface skin temperature and cloud signal. Note: CO_2 profiles are retrieved on slanted geometry but are not disseminated as part of the L2 end-product. They are used in the cloud characterization stage.
- The profiles are retrieved on the 137-hybrid sigma-pressure levels, then interpolated on the RTTOV 101-levels pressure grid. The information at the vertical of the target point is reconstructed from the slanted retrievals that intercept the vertical line (**Fig. 2**) in the post-processing stage.
- Surface emissivity is given on 10 spectral channels and can be reconstructed over the full spectral range through Principal Component transformation.
- Retrieval includes reliable quality indicators (error estimates) for each of the retrieved parameters.
- Total water vapor and ozone columns are by-products obtained by integration of the vertical profiles.

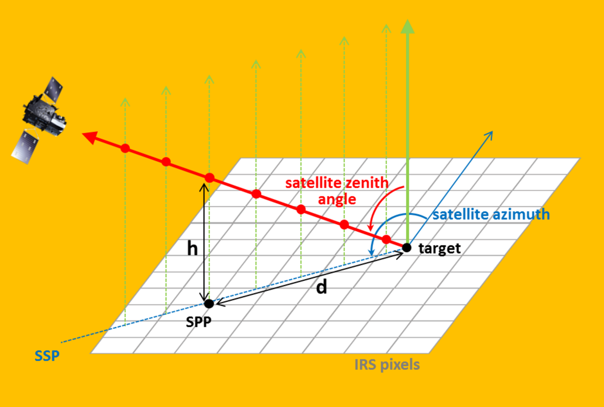
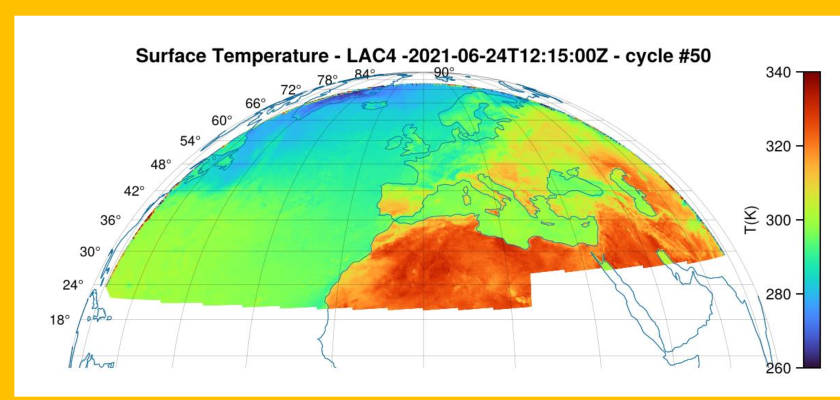


Figure 2: observed slanted and vertical profile provided to the end-users.

The synthetic 6-hour L2 IRS test dataset (TD-449) illustrating this presentation can be found on the EUMETSAT User Portal at https://user.eumetsat.int/resources/user-guides/mtg-test-data



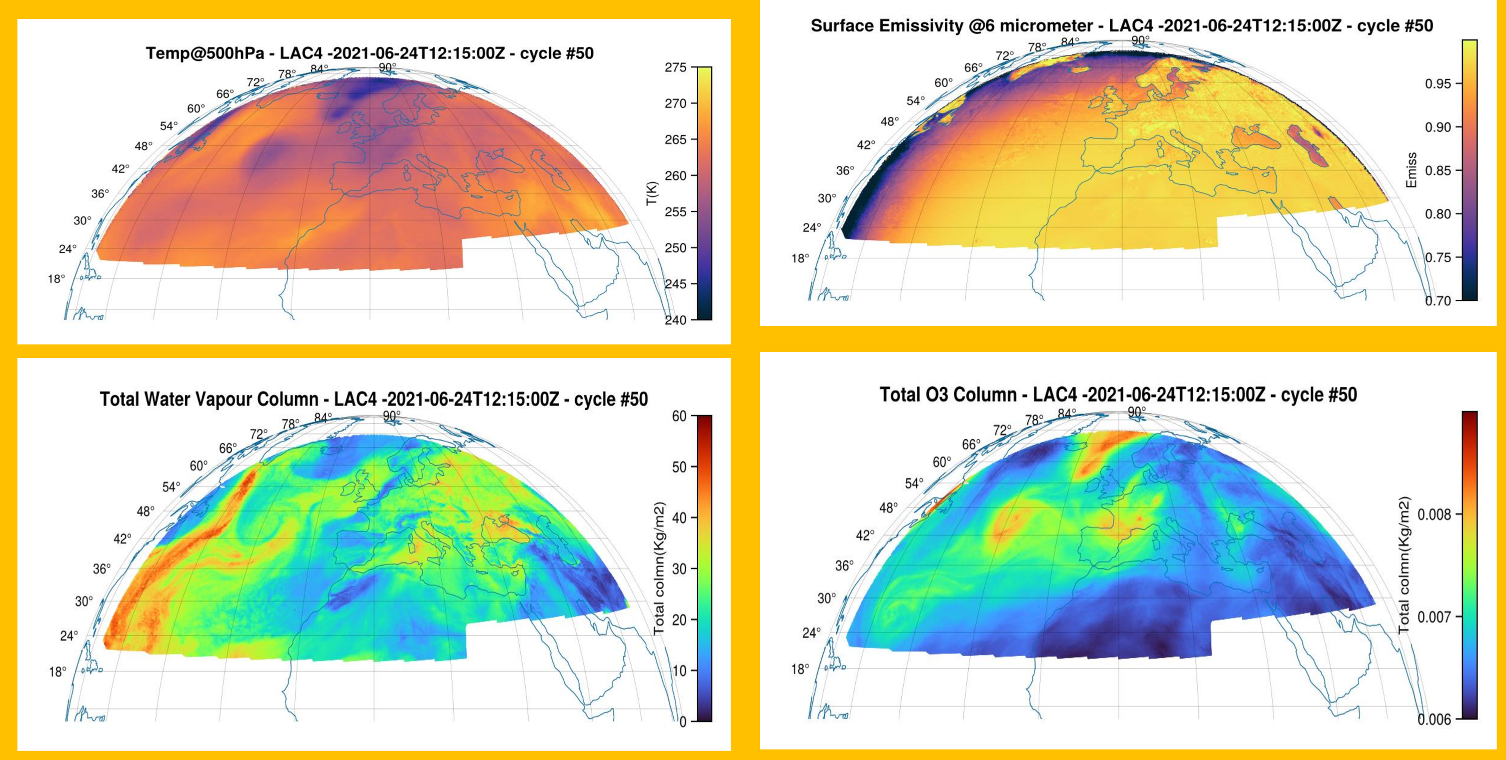
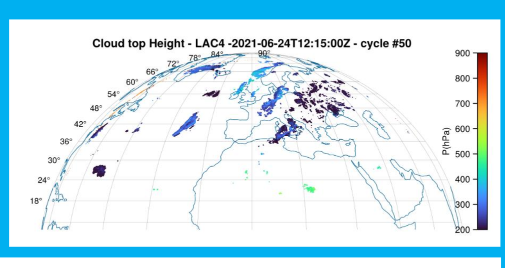


Figure 3: selection of statistical retrievals in LAC 4 on June 24, 2021 12:15UTC.

Cloud Scene Characterization

• The cloud detection is performed by the minimization of a cost function based on the differences between simulated radiances and IRS reconstructed radiances in the field of view. It allows to identify whether a pixel is clear/cloudy (moderately or strongly) or contaminated, and what is the most probable cloud top height and cloud fraction. The algorithm applies two cost functions independently; one assuming a single layer cloud and one assuming a 2-layer cloud. However, the 2-layers cloud model is still experimental.

- The retrieved Dust indicator is determined by calculating the weighed projection of the observed signal in the LWIR band onto typical aerosol signature.
- The cloud phase is determined by a simple brightness temperature difference tests on 3 channels between 8 and 12 micrometers. The difference is compared to a threshold that discriminates between ice, liquid water and mixed phase.
- 1D-var retrieval of effective cloud fraction and cloud top pressure of one-(operational on Day 1) and two-cloud layers using the simple cloud parametrisation of RTTOV as forward operator and analytic expressions for optimal effective cloud fractions for given cloud top pressures.



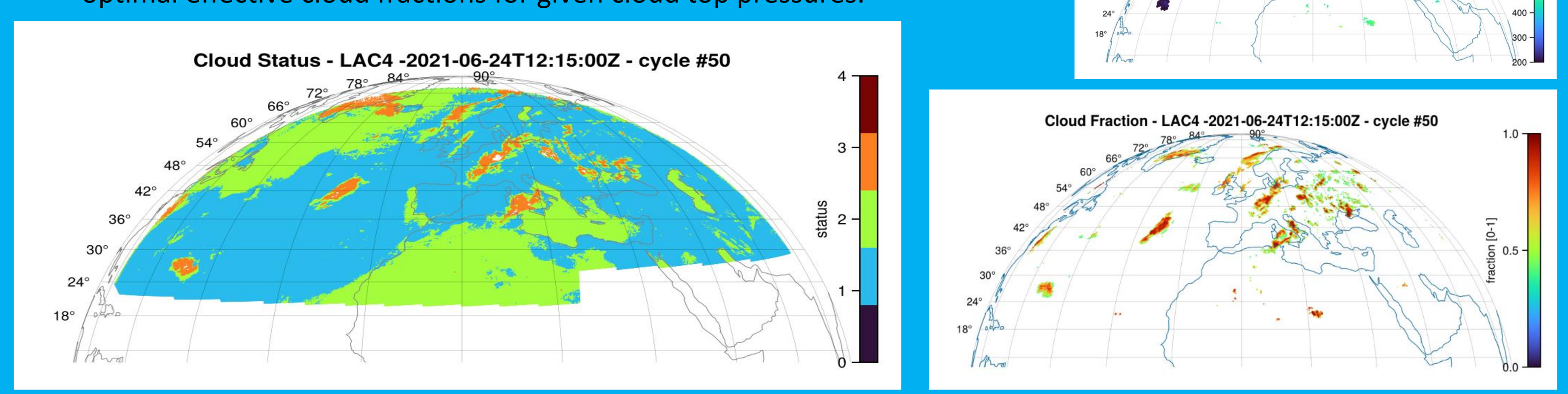


Figure 4: Cloud characterization (right: cloud top height, cloud fraction) in LAC 4 on June 24, 2021 12:15UTC. The Cloud Status (left) is the cloudiness classification: 1 = clear sky, 2 = cloud contamination, 3 = moderate cloud signal, 4 = strong cloud signal

MTG-IRS Thermodynamical products

The IRS mission is primarily designed to support numerical weather predictions at regional and global scales, including nowcasting. The instrument was hence specified with high spectral resolution (~0.6 cm^{-1}) in the infrared and high spatio-temporal sampling in order to provide frequent vertical atmospheric information to convective scale models consistent with their horizontal resolution. The high temporal frequency achieved from the geostationary orbit will in general increase the amount of information over dynamically important regions for Europe such as the North Atlantic and enhance the mid to short-range forecast capabilities.

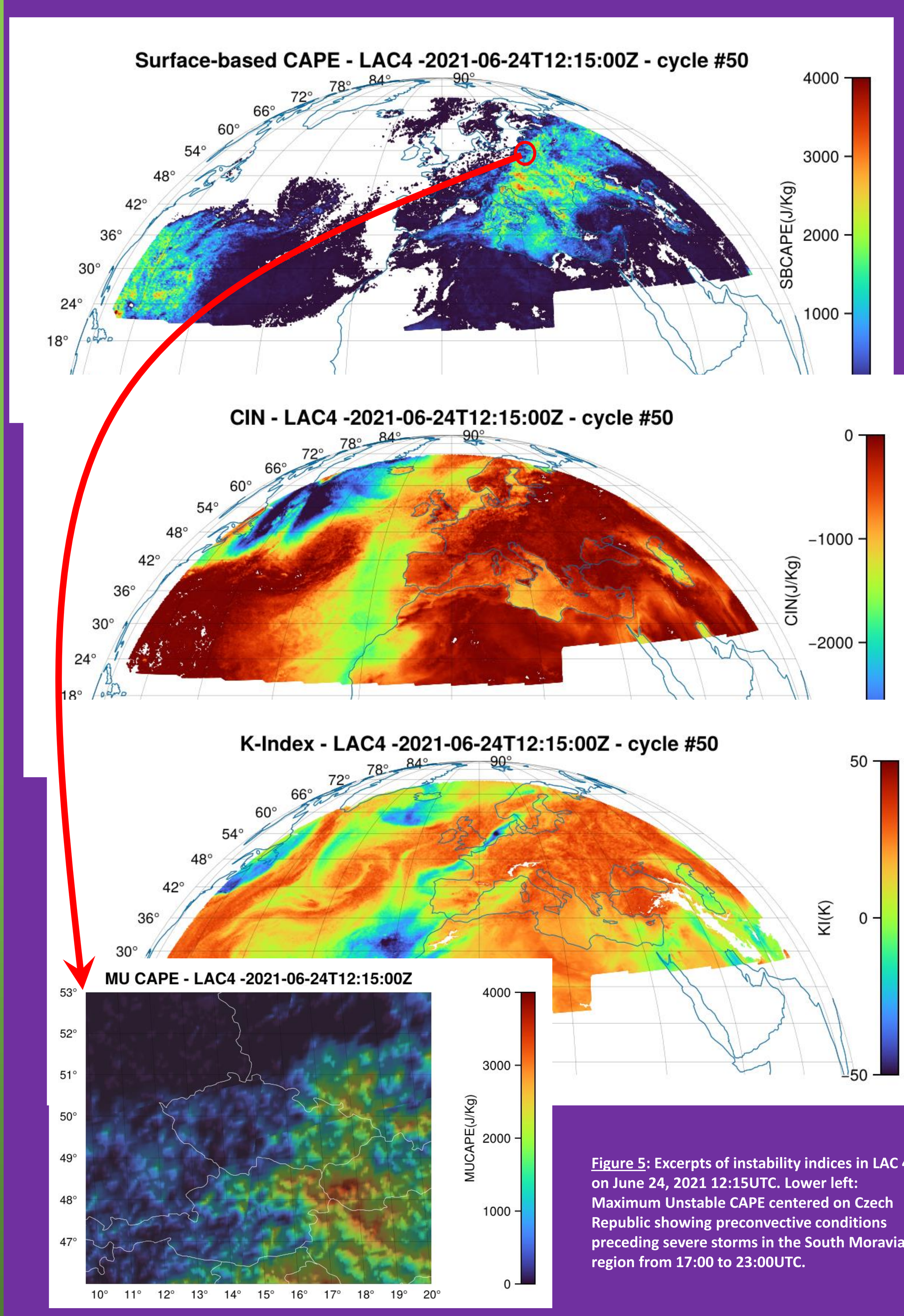
The thermodynamic parameters and cloud information retrieved from the IRS observations have direct applications for nowcasting in complement to regional models outputs, with the aim to improve reliability and lead-time in identifying and monitoring areas of interest, e.g., with rapidly developing atmospheric instability.

Index	Full name	Short description
LI	Lifted-index	Difference between the environment temperature at 500 hPa and the temperature of a surface-air parcel lifted adiabatically to that level.
K-index	K-index	Combined index assessing the potential for thunderstorm development concerning mid-level temperature lapse rate (between 500 and 850 hPa levels) and humidity (represented by dew-point temperature).
LPW	Layer Precipitable Water	Partial columnar amounts of water-vapor in layers. The boundaries are configurable and initially defined as [surface to 850 hPa] ; [850 to 500 hPa] ; [500 hPa to top of atmosphere]
Dθe	DTHETAE	Used to diagnose areas with vertically decreasing equivalent potential temperature, which are considered to be conditionally unstable.
MB	Maximum Buoyancy	Similar to DTHETAE, looking for vertically decreasing equivalent potential temperature in a larger vertical domain.
SBCAPE or CAPE	Surface-Based Convective Available Potential Energy	Amount of potential energy available for convection to an air parcel theoretically lifted to the level of free convection (LFC) and which would further ascent from its own buoyancy. It also relates to the maximum potential vertical speed within an updraft. Small or negative CAPE values are indicative of stable atmospheres.
MLCAPE	Mixed-Layer CAPE	Same concept as SBCAPE, but evaluated with the air parcel average located in the lowest 100-mb. It is commonly used to assess instability when the atmosphere is well mixed (e.g. in the afternoon)
MUCAPE	Maximum Unstable CAPE	Maximum of CAPE values computed for every level in the first 300 to 500 hPa (upper limit configurable). It helps assessing the possibility of elevated convections in case of low-level inversions (e.g. at night or behind a cold front).
CIN	Convective INhibition	Calculated at the same time as SBCAPE, in the case of stable atmospheric conditions.

Table 1: List of the instability indices in the IRS L2 Product.

As concerns geophysical parameter products intended to be disseminated in near real-time to the users, this is achieved through the provision in particular of temperature and moisture vertical profiles, and instability parameters. Derived from tracked cloud and clear-sky water vapor features across image sequences by synergetic imagery mission in the lower troposphere and ozone profiles retrievals in the upper troposphere, Atmospheric Motion Vectors, which can benefit convective-scale data assimilation and forecasts of potential severe weather, are foreseen to supplement the products at a later stage.

The list of instability indices and associated algorithms may further evolve as more experience is gained using LEO sounding products for nowcasting.



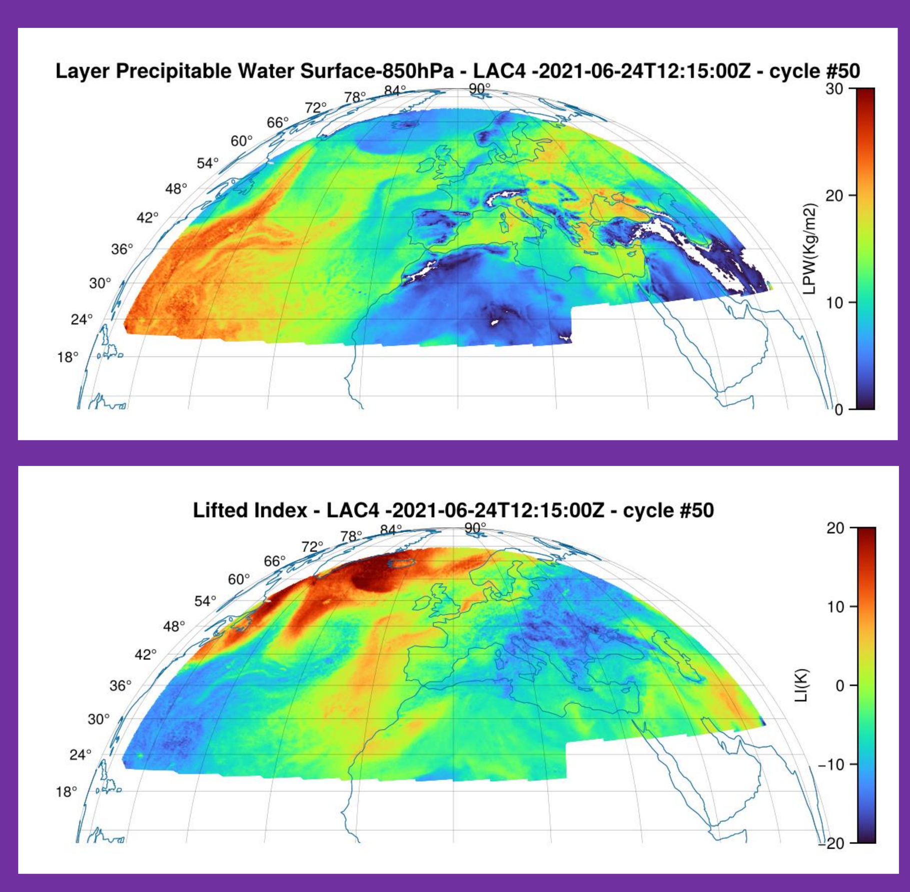


Figure 5: Excerpts of instability indices in LAC 4 on June 24, 2021 12:15UTC. Lower left: Maximum Unstable CAPE centered on Czech Republic showing preconvective conditions preceding severe storms in the South Moravia region from 17:00 to 23:00UTC.

State Vector Product content

The MTG-IRS L2 product contains the navigational and observational information, the atmospheric state vector, associated surface properties and quality indicators. Below are the elements of the so-called State Vector Product (SVP) intended to be disseminated and archived. The itemized list at Day-1 of MTG-IRS operations are stored as netCDF-4.

The product is generated for every LAC, each file corresponding to a dwell (160x160 pixels) within the LAC.

The geophysical variables values are encoded for storage volume optimization purposes. The estimated size for one LAC is 1120 MB (16 MB per dwell), using netCDF zlib compression (ratio=2). The actual size depends on the coverage selected and the number of successful pixel retrievals.

Parameter Description	Unit	Type	Dimensions
Contextual parameters			
Dwell central time (seconds since 01:01:2000 00:00:00)	second	double	1
Latitude	degree	float	160x160
Longitude	degree	float	160x160
Satellite zenith angle	degree	ushort	160x160
Satellite azimuth angle	degree	ushort	160x160
Sun zenith angle	degree	ushort	160x160
Sun azimuth angle	degree	ushort	160x160
Surface elevation	m	short	160x160
Land fraction	%	ushort	160x160

Parameter Description	Unit	Type	Dimensions
Instability indices			
Lifted index	K	short	160x160
K-index	K	short	160x160
Layer precipitable water	kg/m^2	short	3x160x160
Maximum buoyancy	K	short	160x160
Equivalent potential temperature difference	K	short	160x160
Convection inhibition index	J/kg	float	160x160
Surface-based CAPE	J/kg	float	160x160
Maximum unstable CAPE	J/kg	float	160x160
Mixed layer CAPE	J/kg	float	160x160

Parameter Description	Unit	Type	Dimensions
PWLR outputs			
Number of missing PWLR levels	-	ubyte	160x160
Surface pressure	hPa	ushort	160x160
Surface pressure error estimate	hPa	ushort	160x160
Surface skin temperature	K	ushort	160x160
Surface skin temperature error estimate	K	ushort	160x160
2m-temperature	K	ushort	160x160
2m-specific humidity	kg/kg	float	160x160
Obs -Calc	K	ushort	160x160
Surface emissivity	-	ushort	160x160x10
Surface emissivity error estimate	-	ushort	160x160x8
Temperature vertical profile	K	ushort	160x160x101
Temperature profile error estimate	K	ushort	160x160x40
Water-vapor mixing ratio vertical profile	kg/kg	float	160x160x101
Ozone mixing ratio vertical profile	kg/kg	ushort	160x160x101
Water-vapor profile error estimate (provided as dew point temperature)	K	ushort	160x160x30
Ozone profile error estimate	ln(kg/kg)	ushort	160x160x20
Total Water-vapor column	kg/m^2	ushort	160x160
Total Ozone column	kg/m^2	ushort	160x160

Parameter Description	Unit	Type	Dimensions
Cloud outputs			
Cloud latitude	degree	float	160x160x2
Cloud longitude	degree	float	160x160x2
Cloud Status	-	byte	160x160
Cloud Phase	-	byte	160x160
Cloud Layers	-	byte	160x160
Cloud Fraction	%	ushort	160x160x2
Cloud Top Pressure	hPa	ushort	160x160x2
Cloud Top Height	m	ushort	160x160x2
Dust Index	-	float	160x160

Table 2: Content and format of the State Vector Product on Day 1.