Global instability indices derived from EUMETSATs current and future hyperspectral Infrared sounding missions

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Summary

Convection can yield severe weather events (thunder, wind gust, tornadoes, hail, flash-flood…) which can have dramatic societal consequences. 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.

The measurements from EPS-IASI and the future EUMETSAT hyperspectral infrared sounder missions IASI-NG and MTG-IRS contain information about the thermodynamic state of the atmosphere, which are important to weather forecasting. In particular, 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. This unprecedented system offers a significant advance in operational observation and will be a great asset to regional short-range weather forecasting and nowcasting.

The hyperspectral infrared observations can be used to determine thermodynamic parameters and cloud information that can be used to supplement regional models for nowcasting, for the purpose of more accurately and quickly identifying areas of potential instability and associated weather phenomena like vertical motion, convection, precipitation, and severe storms.

A number of indices is planned to be generated centrally within the L2 processing facilities of IRS, IASI and IASI-NG. It aims at ensuring continuity with other GII products, e.g. MSG and consistency with the MTG-FCI follow-up products. It is completed with a few more indices collected in the literature and from initial interactions with forecasters.

We present here the results of the calculation of these indices based on real observations by IASI and on the full Earth's disk such as seen by MTG-IRS. The latter are the sub-products of the primary retrieved temperature and moisture profiles, based on realistic cloudy sky radiances simulation.

Overview

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.

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 vapour features across image sequences by synergetic imagery mission in the lower troposphere and ozone profiles retrievals in the upper troposphere, Atmospheric Motion Vectors (AMV) , 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.

MTG-IRS Thermodynamical products

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-vapour 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.

Instability indices and integrated quantities calculated by the IRS L2 processor to support the assessment of potential convective initiation at Day 1.

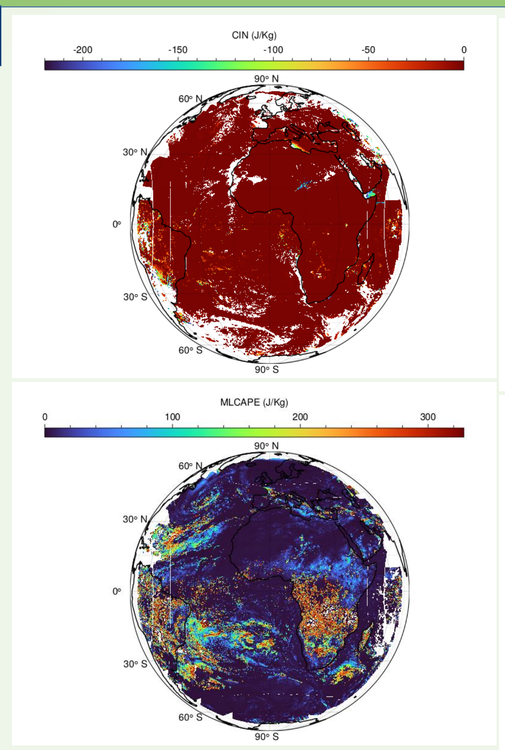
IRS synthetic dataset

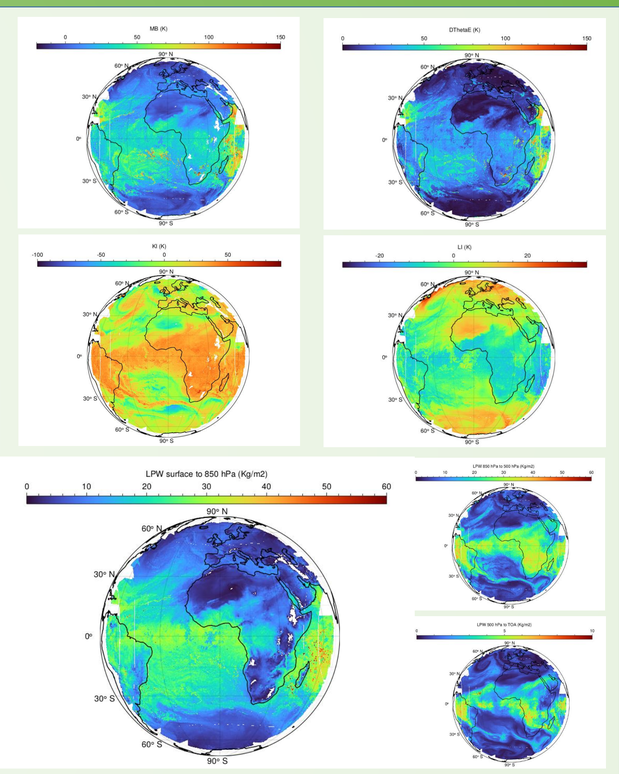
For verification purposes of the L2 processor prototype implementation, a set of reference L2 products has been produced from simulated IRS observations based on the state of the atmosphere on March 15, 2016 at 1200UTC. The dataset covers all the dwells of each of the four MTG-IRS local area scanning zones. The geophysical parameters, in particular the temperature and humidity profiles, are effectively retrieved along the line of sight and thus account for the parallax becoming important as the observation target departs from the sub-satellite point.

The L2 processing consists of a first retrieval of the surface and profile geophysical fields performed by a statistical method (piece-wise linear regression algorithm, PWLR) in both clear and cloudy situations. This step is followed, for the clear-sky pixels, by a second retrieval using optimal estimation method to refine the retrieved quantities from the first retrieval.

The post-processing step reconstructs the information at the vertical of the target point from the slanted retrievals (statistical and variational), which intercept it.

After the geometric correction, the instability indices, calculated after the methods described in the MTG-IRS Level 2 Algorithm Theoretical Baseline Document*[1], are derived in priority from the optimal estimation outputs. If the corresponding profiles are incomplete on the vertical grid, the full profile is reconstructed using PWLR profiles to fill the missing information. If too many levels are missing (e.g. more than half of them), then PWLR profiles are used. The quantities of the dataset are illustrated in the figures on the left. Nevertheless, the 0.25°x0.25° horizontal-resolution ECMWF analysis on this day may not yield any noticeable pre-convective conditions, which explains the low values of the CAPE.





*[1] MTG-IRS Level 2 Algorithm Theoretical Baseline Document https://www.eumetsat.int/media/45439

IASI-Level2

Python software provided to the hyperspectral competence area at EUMETSAT by the European Severe Storms Laboratory (ESSL) has been implemented and tested with IASI-L2 profiles (see example Case study, white box at the right) to generate many GII's, e.g. SB-, MU- and ML-(50hPa,100hPa) CAPE's, CIN's and lifted index (LI) next to precipitable water and moist adiabatic lapse rates. Those indices already covering most of the indices planned to be generated centrally within the future L2 product processing facilities (PPF) of MTG-IRS and IASI-NG.

To test the accuracy of the software provided by ESSL the results have been compared to the results of 2 different python packages that provide CAPE, CIN, LI and lapse rates, i.e. SHARPpy*[1] in version 1.4 and MetPy*[2] in version 0.12.2. It could been found that all 3 version compute different values sometimes deviating very strongly from each other. It has to be noted that the newest version of MetPy could not be used for this study and the version 0.12.2 we used threw lots of errors and precision warning during computation, resulting in large gaps. Furthermore, differences in computations between those S/W packages still need to be investigated to fully understand the differences in results. At this very early stage of this study this has not been looked into and the results we present here have to be considered preliminary. However, we tested the 3 versions on 4 different Cases during Summer 2018 over Europe with extreme weather events, like Heavy Rain Flood in Paris, Flash Flood in Frankfurt, Lightning and Hail Storm accompanied with a Flash Flood in the Dordogne, and a Hail Storm in Bordeaux. The results for the MU CAPEs are shown on the bottom left. While the scatterplot shows a direct pixel by pixel value comparison, the maps have been binned to focus more on weather situations than on smaller differences which are to be expected. The maps show that the main signals are captured by all 3 S/W for all 4 cases, however MetPy is missing or underestimates high CAPEs in some areas and cases. Best agreements between all S/W is found on the 4th of July 2018. Interesting; SHARPpy is the only one showing an area of high CAPE over the Atlantic on the 4th of July 2018. A feature that still needs to be validated. The overall results SHARPpy vs ESSL show very good correlation, while MetPy shows a poor correlation with ESSL and significant deviation in rel. difference for CAPEs below 500 J/kg and a clear underestimation of larger CAPEs. This preliminary results suggest that ESSL and SHARPpy are both well suited to be implemented in EUMETSAT PPF. However, ESSLs advantage over SHARPpy is computational speed, SHARPpy shows unique features over the Atlantic that still needs to be further investigated.

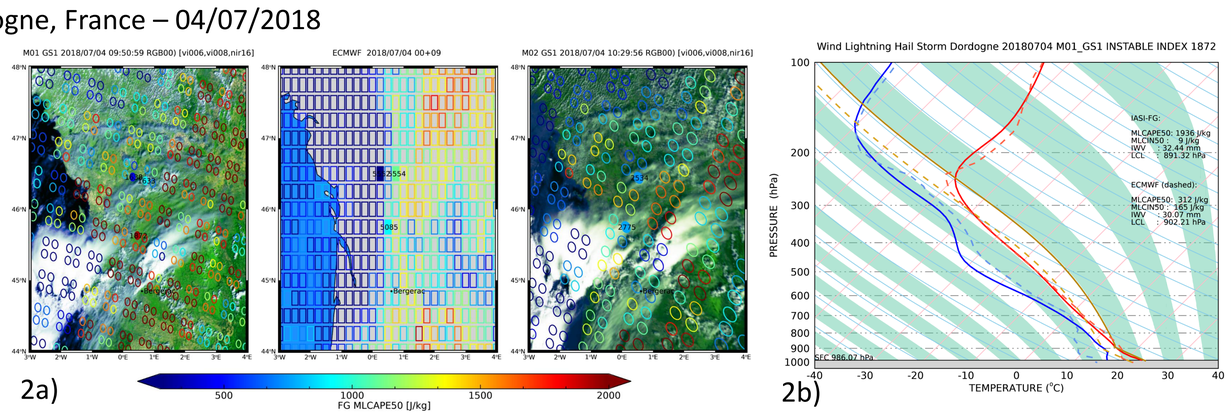
CASE study with IASI: Hail storm in Dordogne, France – 04/07/2018

1a) SEVIRI-RGB

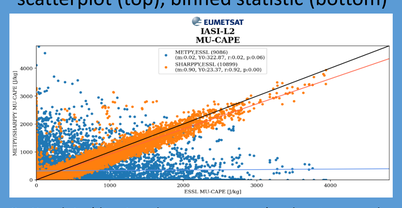
ECMWF forecasts 04/07/2018 at 09UTC

1b,c) Hail damages

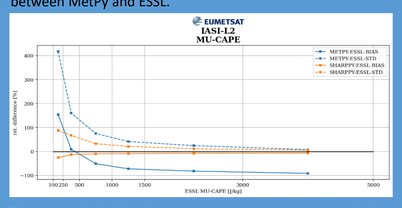
Wind, Lightning and Hail in the Dordorgne, France in July 2018. Prior to the main event at approx. 12 UTC (Fig:1a) the ECMWF Forecast from 9 UTC as well as IASI-A and IASI-B (Fig:2a) show a significant raise in Mixed Layer (50hPa) CAPE proving potential to forecast severe weather. Figure 2b) shows the the log-p, skew-T plot for the IASI-B pixel with the highest Cape in that area and the collocated ECMWF forecast. It shows that the forecast underestimates the CAPE, mainly due to too dry surface temperature and humidity. IASI and Forecast CAPEs have been calculated based on computation suggested by ESSL.



3) Metop-B, 4 cases combined scatterplot (top), binned statistic (bottom)



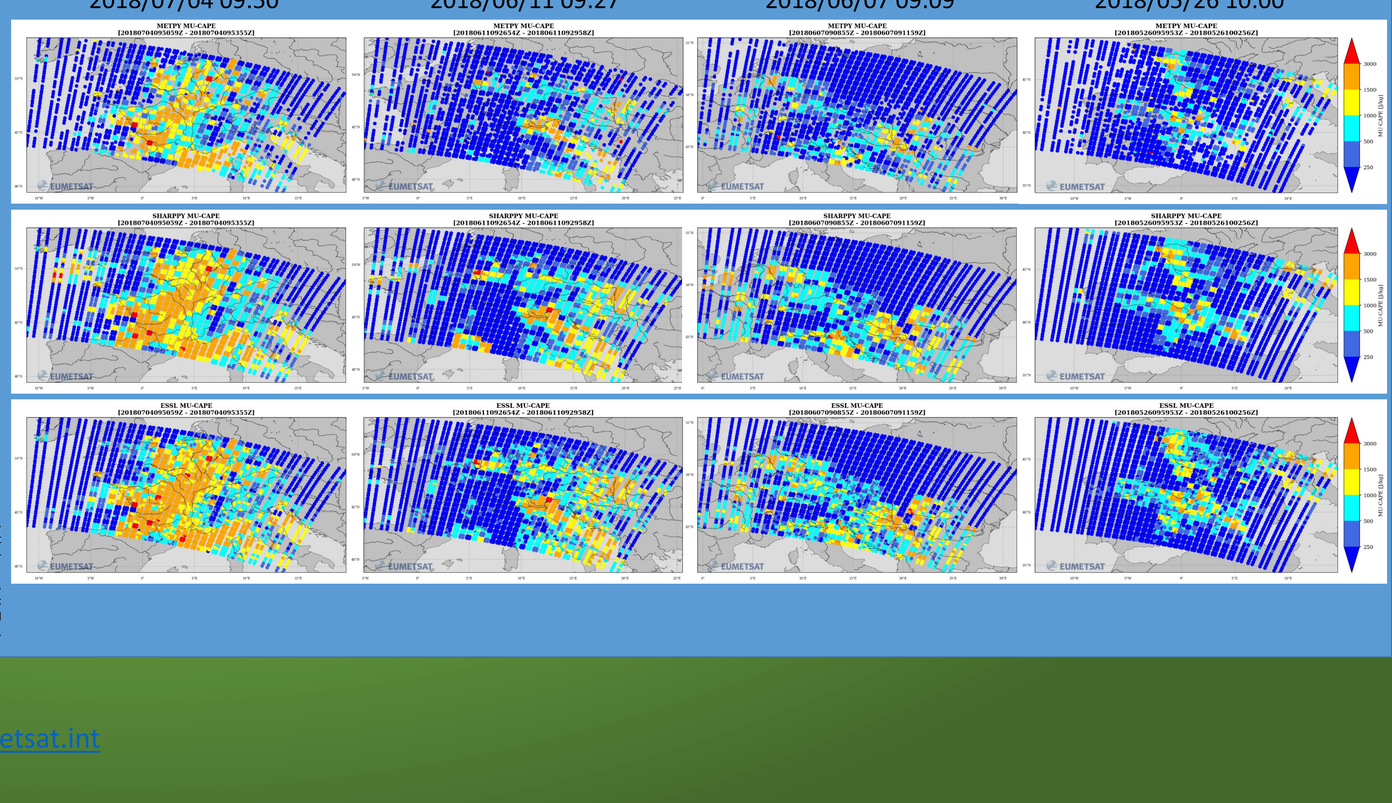
Scatterplot (direct value comparisons): showing good correlation for SHARPpy and ESSL and a poor correlation between MetPy and ESSL.



Binned statistic: MetPy shows elevated standard deviation for low CAPEs and underestimation (neg. bias) of larger CAPEs compared to ESSL.

4) MU CAPE - Metop-B; binned maps with discrete colorbar

2018/07/04 09:50 | 2018/06/11 09:27 | 2018/06/07 09:09 | 2018/05/26 10:00



*1) Blumberg, W. G., K. T. Halbert, T. A. Supinie, P. T. Marsh, R. L. Thompson, and J. A. Hart, 2017: "SHARPpy: An Open Source Sounding Analysis Toolkit for the Atmospheric Sciences." Bull. Amer. Meteor. Soc. doi:10.1175/BAMS-D-15-00309.1.

*2) May, R. M., Goebbert, K. H., Thielen, J. E., Leeman, J. R., Camron, M. D., Bruick, Z., Bruning, E. C., Manser, R. P., Arms, S. C., and Marsh, P. T., 2022: MetPy: A Meteorological Python Library for Data Analysis and Visualization. Bull. Amer. Meteor. Soc., 103, E2273-E2284, https://doi.org/10.1175/BAMS-D-21-0125.1.

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