“MSG GLOBAL INSTABILITY INDICES FOR STORM NOWCASTING – VALIDATION STUDIES ON PRODUCT QUALITY AND ANALYSIS OF SENSIBILITY TO INPUT MODEL DATA”

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Introduction

A detailed storm prediction is still a very demanding activity for operational forecasting offices. Convection is often not properly predicted, where especially the exact location and intensity of the initial convection is important for further storm development. Using satellite data, an early detection of the unstable air and assessment of the potential of deep convection may help with the operational storm prediction. The usefulness of the EUMETSAT GII (Global Instability Indices product) for storm nowcasting has already been tested for the period of 2005 and beginning of 2006. Results were presented on EUMETSAT Conference in Helsinki in 2006.

In the frame of co-operation between EUMETSAT and IMWM, further works on validation of the GII indices during the entire 2006 storm season were done. The area of Poland used for this analysis suffers from many severe storms between April and September with highest storm activity in the May to August period. The satellite GII products for the storm season of 2006 were compared against convection development observed on satellite images and lightning detection as an indicator of storm occurrence. The results are statistically analysed.

The satellite retrieved GII requires data from NWP model for first guess atmospheric profiles. Therefore, it is interesting to investigate the possible influence of individual model data for final results of the GII product and possible propagation of model information through the GII processing scheme. For this purpose selected case studies were analysed with use of different NWP models results as input data, both ECMWF used for creation of operational product and other models used for local installations of GII retrieval software e.g. ALADIN.

Results of investigations and validation studies are presented together with the issue of the spatial resolution of the GII product.

![Fig.1. Annual mean of days with storms in Poland (“Atlas Klimatu Polski”, H. Lorenc, 2005)](image)

Global Instability Index

Convective systems, which may quickly reach high altitudes and can cause severe storms, are developing in a thermodynamically unstable atmosphere. A number of instability indices have been
defined to describe such situations, traditionally taken from temperature and humidity soundings by radiosondes. As radiosondes are only of very limited temporal and spatial resolution there is a demand for satellite-derived indices which can help in identifying storm potentials system. The EUMETSAT Global Instability Index product consists of a set of indices which describe the layer stability of the atmosphere. These indices are empirical in nature and might even be only relevant in certain geographic regions or under certain circumstances. The retrieval of these parameters from satellite data is only possible under cloud-free conditions.

The GII product comprises four classic instability indices:

- **Lifted Index (LI)**: 
  \[ LI = T_\text{obs} - T_\text{lifted from surface at 500 hPa} \]

- **K-index (KI)**: 
  \[ KI = (T_\text{obs}(850) - T_\text{obs}(500)) + TD_\text{obs}(850) - (T_\text{obs}(700) - TD_\text{obs}(700)) \]

- **KO index (KO)**: 
  \[ KO = 0.5 \Phi (\Theta_e(500) \Theta_e(700) - \Theta_e(850) - \Theta_e(1000)) \]

- **Maxim. Buoyancy (MB)**: 
  \[ MB = \Theta_e(\text{obs}(\text{maximum between surface and 850}) - \Theta_e(\text{obs}(\text{minimum between 700 and 300})) \]

where:
- \( T_\text{obs} \) is the observed temperature,
- \( TD_\text{obs} \) is the observed dew point temperature,
- \( \Theta_e \) is the observed equivalent potential temperature,
- all at the indicated pressure level (in hPa).

Fifth parameter in GII product is the total precipitable water content as an additional airmass parameter.

**Algorithm**

The physical retrieval tries to reconstruct a temperature and humidity profile from the satellite observed radiances or brightness temperatures of a given set of channels (IR 8.7, 10.8, 12.0, 13.4 μm and WV 6.2, 7.3 μm) and a first guess profile. A typical first guess field is a short-term forecast provided by NWP model. This background profile is often also referred to as “first guess”, as it is fed to the iteration scheme as an initial proposal for a solution. The method is an optimal estimation using an inversion technique, i.e. it tries to find an atmospheric profile which best reproduces the observations. Within the retrieval, the profile is modified until its simulated outgoing radiance field at the top of the atmosphere matches the satellite observations. The operational EUMETSAT implementation of the physical retrieval uses forecast fields provided by the European Centre for Medium Range Weather Forecasts (ECMWF) on a 1deg latitude/longitude grid. The core of the retrieval is the standard retrieval equation rearranged to:

\[
\chi_{n+1} = \chi_0 + S_x K_n^T \left( K_n S_x K_n^T + S_e \right)^{-1} \left[ (T_B - T_{B,n}) + K_n (\chi_n - \chi_0) \right]
\]

which only involves the inversion of the much smaller matrix.

with:
- \( x \): observation vector (temperature and humidity profile)
- \( n \): iteration step, \( n=0 \) denotes first guess or background profile
- \( T_B \): observed brightness temperature
- \( T_{B,n} \): simulated brightness temperature for profile of iteration step \( n \)
- \( S_x \): covariance matrix of first guess errors
- \( K_n \): weighting function matrix (Jacobians)
- \( S_e \): error covariance matrix of observed brightness temperatures and of the radiation model

![Fig. 2. Example of Lifted Index from global GII product](image)
RTTOV radiation model is used for the radiative transfer calculations. A typical feature of such an inversion scheme is its dependence on the first guess field and the fact that the retrieved profiles tend to retain the general characteristics of the first guess profile.

**Problem of NWP model data used as a first guess for retrieval of stability indices from satellite data**

Physical method of stability indices retrieval from MSG satellite data uses data from NWP model as a first guess. In MPEF GI processing scheme, ECMWF global model is used. Local installation of EUMETSAT software implemented in IMWM Poland uses ALADIN mesoscale model as a first guess. Two used models differ in spatial scale both horizontal and vertical.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>ECMWF</th>
<th>ALADIN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global model</td>
<td>Mesoscale model</td>
</tr>
<tr>
<td></td>
<td>Operational at ECMWF</td>
<td>Operational at IMWM Poland</td>
</tr>
<tr>
<td></td>
<td>/ run in Krakow branch</td>
<td></td>
</tr>
<tr>
<td>Domain</td>
<td>global</td>
<td>2270km x 2270km</td>
</tr>
<tr>
<td>Grid size</td>
<td>181 x 360</td>
<td>169 x 169</td>
</tr>
<tr>
<td>Levels</td>
<td>91</td>
<td>31</td>
</tr>
<tr>
<td>Resolution</td>
<td>1 degree lat/lon</td>
<td>13.5 km</td>
</tr>
<tr>
<td>Range</td>
<td>7 days</td>
<td>54 h</td>
</tr>
<tr>
<td>Runs</td>
<td>2 per day</td>
<td>2 per day</td>
</tr>
</tbody>
</table>

Table 1. Comparison of models used as a first guess by EUMETSAT MPEF and IMWM local installation of GI product generation.

Example presented below show comparison between operational GI product (Lifted Index) and the same product calculated on local installation with full SEVIRI resolution, using two NWP models. Generally, three presented products have good agreement. Satellite stability indices using mesoscale model with finer grid as first guess, present more details of local unstable conditions in mountainous region.

**Case study – stable situation (13 April 2007)**

Poland inside high pressure area. Dry and cold air over the whole Poland. Temperatures at Northern part of Poland – 10 deg C, slightly higher in South. Practically cloud free satellite image registered by NOAA/AVHRR (colour composition presented on Fig. 3.

![Fig. 3. Synoptic map and NOAA/AVHRR colour composition for 13 Apr. 2007.](image)

Case study presented below show comparison of retrieved K Index, Lifted Index and Total Precipitation Water, using:
- original EUMETSAT MPEF GI product with 15 x 15 SEVIRI pixel resolution (first guess ECMWF)
- locally implemented EUMETSAT retrieval software with full SEVIRI pixel resolution (first guess ECMWF)
- locally implemented EUMETSAT retrieval software with full SEVIRI pixel resolution (first guess ALADIN)

Fig. 3. Air stability indices retrieved from satellite data using different first guess and resolution.

Examples of profiles retrieval results in different atmospheric conditions present: first guess profiles from ALADIN NWP and final profiles after GII algorithm. In perfect stable situation both profiles are exactly the same - overlaid on diagram (Baltic Sea). Over land and in unstable conditions retrieved profile differs from first guess situation. Added value of satellite data is well seen.

Fig. 4. First guess and retrieved profiles of temperature and moisture in different conditions - added value of satellite data.
Generally retrieved air stability indices do not differ significantly when using ECMWF and ALADIN NWP models as a first guess. Local differences are mainly in mountainous areas, better depicted when ALADIN model is used as a first guess.

**Case study – Unstable situation 20 July 2007**

**Synoptic situation**
Record high temperatures in South-Eastern Poland in whole history of measurements. Temperature reached 36 deg. C. At the same time in North-Western Poland was only 20 deg. C. High difference of temperatures between two air masses resulted with rapid development of severe weather conditions.

Storm developing in South and South-Western part of Poland were gradually moving to East and North East direction covering practically half of country area. Hail storms produced 3 cm hail stones. In Czestochowa region, tornado causes large damages. Many buildings were destroyed, trees uprooted, electrical networks damaged. One person was killed by falling tree, 7 injured, 2 hit by lightnings.

![Fig. 6. Synoptic situation](image)

Operational GII product presented rapid development of unstable air in central and southern Poland close to the border between two mentioned air masses.

**Fig. 6. Evolution of GII Lifted Index at the morning time of 20 July 2007**
GII retrieval algorithm definitely corrects predicted by model air stability. Profiles of temperature and moisture are not changed in stable area (Baltic Sea). In unstable areas both moisture and temperature is corrected. In mountainous area orographic instability is well depicted. Moist unstable air from Czech Rep causing tornadic storm in Poland a few hour later moving towards NE is clearly seen.

**Results from statistics - 2006 storm season**

Two indices (K Index and Lifted Index) were compared with storm occurrence in period 8:00 - 21:00 UTC. Due to poor resolution of operational GII product, whole area of Poland taken to comparison. Contigency tables for KI and LI are presented below. The thresholds for stable/unstable conditions were taken as 20oC for KI and 0oC LI.

<table>
<thead>
<tr>
<th>Contingency table K Index  1.04 - 31.08.2006</th>
<th>Contingency table Lifted Index 1.04-31.05 and 7.07-31.08.2006</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No lightnings</strong></td>
<td><strong>Presence of lightnings</strong></td>
</tr>
<tr>
<td>KI &lt;20° (stable)</td>
<td>40 (correct negatives)</td>
</tr>
<tr>
<td>KI&gt;20° (unstable)</td>
<td>17 (false alarms)</td>
</tr>
</tbody>
</table>

Typical categorical statistics indices were computed:

<table>
<thead>
<tr>
<th>KI</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of Detection</td>
<td>POD=0.93</td>
</tr>
<tr>
<td>False Alarm Ratio</td>
<td>FAR=0.20</td>
</tr>
<tr>
<td>Probability of False Detection</td>
<td>POFD=0.30</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Presented results proved good score for both indices. KI gives more false alarms and area depicted as unstable is usually larger and much earlier indicated then from LI. Lifted Index has less false alarms and false detections but also number of misses is larger then from KI. Observed more precisely defined area of convection development. Accuracy is a bit better for KI.

Conclusions

- There is lack of perfect tool for determination of storm initiation area but stability indices are certain solution. Both unstable air presence and its dynamical changes may be used as storm predictors.
- The satellite observations contributed some additional information over the first guess, and these locations coincide well with the potentially unstable regions, which were not so well identified by the first guess.
- Full SEVIRI resolution of GII product is specially important in mid latitudes where cloudiness is part of the game. Number of clear pixels, where is possible to retrieve air stability indices, substantially grows with increased resolution.
- When generating GII with full SEVIRI resolution, use of NWP model with better spatial resolution increases quality of GII product.
- In unstable areas number of iterations during physical retrieval of profiles is larger then in stable places. Influence of satellite data is well seen. This is specially important for dynamic processes like deep convection.
- A few hour before severe weather conditions, GII gives proper warning. KI is more sensitive to early instability but shows much larger unstable areas then LI and gives more false alarms. LI gives reasonable information just before convection. More detailed area of possible convection. More missed prediction then KI.

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