A GIS approach to ingest Meteosat Second Generation data into the Local Analysis and Prediction System

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Abstract

The Local Analysis and Prediction System (LAPS) is modified to ingest Meteosat Second Generation (MSG) data for cloud analysis. A first study is conducted to test the actual performance of the weather analysis software after new satellite bands are introduced. Results show that the system provides high quality cloud products such as cloud mask, cloud top height and cloudiness. A comparison with products from EUMETSAT’s Nowcasting SAF shows a general underestimation of the LAPS product although the results are not conclusive. The initialisation of the LAPS analysis with ECMWF and WRF fields does not show substantial differences in cloud products while having a certain impact on mean sea level pressure fields describing the Mediterranean cyclone of the examined case study. The study shows the potential of MSG data in refining the mesoscale analyses produced by LAPS. Moreover the software tools, based on open source codes for geolocation and geographical information systems, written for the transformation of MSG data into input files for LAPS have demonstrated a great flexibility and ease of use. The study open up an avenue for successive validation and refinement of the analyses together with their improved implementation for operational nowcasting and very short range forecasting applications.

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Weather forecasting
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1. Introduction

One of the most relevant challenges for numerical short-range limited-area weather prediction modeling is the correct definition of initial conditions at a suitable resolution. The initial conditions are normally based on large scale analyses, which correctly represent the synoptic features, but not the mesoscale forcings, due to their low spatial and temporal resolutions. Also, an optimal use of non-hydrostatic models, with their complex physical parameterization schemes and explicit description of hydrometeors and of convective processes, would require accurate analyses of cloud related parameters, such as, for example, atmospheric humidity, cloud fraction and optical thickness, liquid water and ice content, three-dimensional velocity field, etc. A merging of disparate data from diverse measuring instruments as radars, radiosondes, surface weather observations, satellites, … would then be desirable.

Several variational data assimilation techniques (3D-var, 4D-var, Kalman filtering,…) are available nowadays but they are implemented in centres where large computational resources are available and are generally used for global analysis.

A computationally less expensive, but also efficient approach, is used here. The Local Analysis and Prediction System (LAPS) (McGinley et al., 1992; Albers, 1995; Albers et al., 1996, Birkenheuer, 1999; Hiemstra et al., 2006) developed by the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) is a numerical diagnostic model specifically designed to generate 3D analysis over a limited domain. LAPS uses as first guess large-scale analyses or forecasts; then, the model combines and harmonises data from virtually every meteorological observation system (meteorological networks, radar, satellite, soundings, aircraft, …) to modify the background field using a two stage approach (McGinley et al., 2000).

The cloud analysis component of LAPS (Albers et al., 1996; Schultz and Albers, 2001) is designed to provide an accurate 3D representation of the water content in different phases (cloud liquid, rain, ice, snow, and graupel). A dynamic balance package (McGinley and Smart, 2001) uses the cloud
analyses (and their vertical motions) in conjunction with the initial analyses of the state variables to produce a final analysis. This balance package uses a 3D-Var approach to ensure the fields of mass and horizontal divergence are consistent with the cloud-derived vertical motions.

The LAPS analysis can be used to initialize mesoscale models and its accurate representation of clouds and precipitation allows for predicting precipitation without a spin-up period (hot start technique). It has been shown that the short-term prediction of convection and rainfall greatly benefits from the use of a mesoscale model initialized with the LAPS analysis, especially in the range 0-6 hours (Shaw et al., 2001).

The information provided by geostationary (GEO) satellites is very important for the LAPS analysis, in particular for the representation of the fields related to moisture. In fact, the satellite sensors receive radiation from the Earth and its atmosphere in several visible (VIS) and infrared (IR) spectral bands (captured by selected channels of the satellite instrument), from which several Earth and atmospheric parameters are retrieved such as cloud top temperature, water vapour absorption, …

GEO satellite data is used by different LAPS analysis modules, such as the cloud cover analysis and humidity analysis packages. Detailed description of the use of IR and VIS channels into LAPS can be found in Albers et al. (1996).

To date, the LAPS model is conceived to ingest remote sensing GEO satellite data from the Geostationary Operational Environmental Satellites (GOES), which cover the geographical domains of South America (GOES10), Pacific Ocean (GOES11), American continents (GOES12), while no attempt has been made to ingest data from Meteosat Second Generation (MSG) (Schmetz et al., 2002) satellites covering Europe and Africa, by taking into account the differences in the satellite data. The aim of this work is to implement a methodology for the ingestion of MSG data into LAPS.

The paper is organized as follows. Section 2 defines the tasks of the present work. Section 3 describes the MSG satellite data and the differences with the equivalent data derived from the
GOES instruments. Section 4 details the methodologies for the preprocessing of MSG data in order to obtain a data format suitable for LAPS satellite ingestion phase, based on a Geographic Information System (GIS) approach and open source components, and the modifications necessary to the LAPS code to allow for the ingestion of MSG data. Section 5 compares the LAPS cloud cover analysis with that produced with another analysis tool for MSG data in a case study of a tropical like cyclone over the Mediterranean Sea. Section 6 concludes the paper discussing the results and outlines the future developments to improve the methodology.

2. Description of the task

To carry on the ingestion of MSG data into LAPS several kinds of problems have to be faced with: the modelling of geographic data, the transformation of data into a format suitable for the LAPS ingestion routine, the identification of the correspondence between radiometric channels of the GOES instrument and those of the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board MSG, since LAPS reads appropriately only GOES data.

The geographic data model used in this work is a standardized spatial representation of fields measured over the Earth by the SEVIRI instrument. For our purposes, a raster data model (ISO, 2005) has been chosen since LAPS makes use of this kind of spatial representation. Note that the raster representation is an abstraction of the real world where spatial data are expressed as a matrix of cells or pixels where the shape of each cell must be square or rectangular with respect to a specific coordinate system. The original SEVIRI data are not raster modelled and thus several operations must be performed on them before they can be ingested into LAPS.

Hereafter the term “geographic data modelling” refers to the extraction of radiometric values from MSG data, their geographic projection and spatial resample into a spatial grid, which represents the LAPS simulation domain. These gridded datasets will be stored as 10 bit images (one numerical
matrix for each radiometric channel) in Network Common Data Form (NetCDF) files (Unidata, 2009), that is in the satellite data format used at FSL (Smart and Birkenheuer, 1995) and readable by LAPS ingest routines. Since the LAPS model ingests radiometric values from 5 channels of the GOES satellites, each one with specific characteristics in terms of the spectral band and physical variables that can be extracted from them, the present paper describes also the way the LAPS code should be modified so that the channels from MSG-SEVIRI corresponding to GOES channels can be correctly read by the model.

In general, satellite images are produced through a system composed by several instruments, software and hardware, on board the spacecraft and at the ground stations. Through these components, images are acquired and successively processed in order to accomplish various kinds of corrections for radiometric and geometric effects.

For our purposes, this system can be represented as a virtual instrument which reveals radiance signal incoming from the observed area and for distinct spectral channels. All of these analogic signals are spatially sampled in order to produce image pixels, and they are also amplified and transformed into digital numeric values named Digital Numbers (DN) or Digital Counts (DC). Each one of these instruments may be considered as a black box that we call “radiometric encoder”, which receives a radiance signal as input and produces a numeric output signal in the form of digital images.

Such images are completely characterized by their spatial features and by the algorithm relating DN to radiance values. Thus, to allow the ingestion of MSG into LAPS, it has to be taken into account that GOES and METEOSAT notably differ in terms of the “radiometric encoder”. Therefore the LAPS software should be modified in order to accomplish the right conversion from DN to physical variables like radiance, reflectance or brightness temperature.

3. Data sets
MSG data is described hereafter and a comparison is made between them and GOES data from the point of view of spectral bands in order to show which SEVIRI channels are good candidates to replace GOES data into the LAPS model.

The GOES imager is a five-channel instrument designed to measure radiation in the VIS and the IR portions of the electromagnetic spectrum. LAPS is designed to ingest GOES channel data (a VIS channel whose spectral band is centred at 0.6 μm, a middle-IR channel centred at 3.9 μm, a water vapour channel centred at 6.7 μm, and two thermal windows channels centred at 11.2 and 12.0 μm, respectively).

The imager equivalent to the GOES instrument over Europe and Africa is the SEVIRI on board the MSG-2 satellite (Meteosat9) positioned at 0° longitude and 0° latitude, in geostationary orbit, 35800 km above the Gulf of Guinea. The SEVIRI instrument is made up of 11 spectral channels that provide measurements with a resolution of 3 km × 3 km at the sub-satellite point every 15 minutes and a High Resolution Visible (HRV) channel whose measurements have a resolution of 1 km × 1 km.

The SEVIRI data is distributed to the user mainly through the EUMETCast service (EUMETSAT, 2006) or the EUMETSAT Unified Meteorological Archive and Retrieval Facility (UMARF) (EUMETSAT, 2001). The first is a dissemination system based on standard Digital Video Broadcast (DVB) technology (EUMETSAT, 2006) that uses commercial telecommunication geostationary satellites (HotBird at present) to distribute files and allows users to receive images and data in nearly real time, while the second is a retrieval service based on an on-line access to data catalogues. Both services provide SEVIRI images processed to Level 1.5 (EUMETSAT, 2007), obtained through the processing of satellite raw data (designated as Level 1.0 data). This processing level corresponds to image data corrected for radiometric and geometric effects, geolocated using a standard projection, finally calibrated.
To transform MSG data in a suitable data format for an application it is necessary to know the format in which the users receive the data via the dissemination service in order to choose the appropriate software tools to read and process the data.

This data consists of geographical arrays of $3712 \times 3712$ pixels and a sampling distance of $3 \text{ km} \times 3 \text{ km}$ at the sub-satellite point (except the HRV channel), i.e. the point on the Earth’s surface directly below the satellite. Each pixel contains 10 bit data that represents the radiance value, expressed in $10^{-3} \text{ Wm}^{-2}\text{sr}^{-1}[\text{cm}^{-1}]^{-1}$, codified in DC form.

The full Earth image (for channels 1-11) is composed by 8 segment files, each one consisting of 464 lines. This framework defines the so-called High Rate Image Transmission (HRIT) or Low Rate Image Transmission (LRIT) segment files (EUMETSAT, 2007). Each file is compressed by means of a wavelet algorithm.

An inspection of Table 1, which summarizes the spectral characteristics of Meteosat9 SEVIRI channels, reveals that channels 1,4,5,9 and 10 are the closest to the GOES imager channels in terms of spectral bands.

However, the procedure of substitution of GOES with MSG channels is not straightforward, since potentially corresponding channels may considerably differ in terms of spectral response, sensor calibrations, etc. (Doelling et al., 2004). For example, in terms of spectral response, the radiance measured in SEVIRI and related GOES channels may significantly differ due to: a) approximate correspondence among spectral bands, b) different instrument features, and c) calibration and correction algorithms. Thus a one-to-one substitution of the two imager products into LAPS may imply large errors in further LAPS processing. Nevertheless, since derived physical variables, as brightness temperature and albedo, are intrinsic features of the measured object (land, sea and atmosphere) under specific conditions, they are independent of the instrument. Thus satellite data substitution is meaningful if the right instructions to render the radiometric MSG values into such physical variables are provided to LAPS. The method used to solve this issue will be further explained in the following Sections.
3. The GIS approach

The purpose of the present section is to describe the methods and software tools used to obtain gridded radiometric values from the five selected SEVIRI channels and to transform them into an appropriate format for the LAPS satellite ingestion routine.

The grid containing the radiometric values should be consistent with that defined in the LAPS namelists, concerning geographic and geometric parameters relative to the simulation domain (as the geographic coordinate system, spatial resolution and geographic extent). As shown in Fig. 1, the procedure consists of different steps:

- Readout of the HRIT image segments containing SEVIRI data.
- Geographic re-projection of input data with respect to the LAPS user specified Coordinate Reference System (CRS) (OGP, 2008).
- Spatial re-sample of input data with respect to the LAPS user-specified spatial resolution.
- Extraction of geographic window to match the LAPS simulation domain.
- Production of input files in a format suitable to be ingested into LAPS.

To accomplish all of these operations, some open-source software tools are chosen. Among the available open-source projects, the tools that match the functional requirements and that ensure a good interoperability are selected:

- EUMETSAT WaveLet Transform Software (EUMETSAT, 2009c), the tool used to decompress SEVIRI HRIT data files;
- NetCDF (Unidata, 2009), a set of software library data formats that support creation, access, and sharing of array-oriented scientific data, required as LAPS ingests satellite data file only in this format;
Geospatial Data Abstraction Library (GDAL, 2009a), an Open Source library which allows to read and write many geographic data formats, encoding geographical information into files (GDAL acts as an interface for geospatial operations over the geographic data files for all supported data formats).

SEVIRI data are delivered in a specific CRS named “GEOS” (CGMS, 1999), i.e. the normalized geostationary projection that describes the view from a virtual satellite to an idealized Earth. The distance between the spacecraft and the centre of the Earth is 42164 km. The idealized Earth is a perfect ellipsoid with an equator radius of 6378 km and a polar radius of 6356 km.

Since the GDAL library (GDAL, 2009b) includes the GEOS projection and it can be compiled adding the MSG driver support with EUMETSAT’s Wavelet Transform software, GDAL is an excellent open source tool to carry out the procedure. As a consequence, SEVIRI HRIT/LRIT image segment file can be processed as normal raster files. Furthermore GDAL includes NetCDF among its output file formats.

In conclusion, given a specific MSG acquisition through the GDAL library and for each SEVIRI channels it is possible to extract a geographic window of data and process them in order to meet LAPS requirements on satellite input data format. The produced NetCDF files are not yet conformed to our needs because the LAPS satellite ingestion routine needs NetCDF files, which have a specific internal structure according to Satellite Broadcast Network (SBN) data model (NOAA, 1997). Unfortunately, SBN image data contains 8-bits per pixels and thus the adoption of this data model implies a data loss in terms of radiometric accuracy since SEVIRI data has 10-bits per pixel. To bypass this issue, the LAPS ingestion routine code has been “hacked” in order to allow to read modified SBN data model with 10-bits per pixel.

In reality LAPS is able to read satellite data models different from SBN, as gvar, fsl-conus and that of the AirForce Global Weather Center. Here, SBN has been chosen because it includes more general satellite data formats that are standard projections so that it is quite independent of the specific satellite platform.
As an example, Fig. 1 illustrates the GIS process that extracts SEVIRI data from the MSG acquisition and re-projects them into the LAPS simulation domain. Brighter pixels correspond to higher radiance values.

Figure 2a is a gray scale SEVIRI image while Fig. 2b shows the re-projected data over a simulation domain covering Southern Italy.

4. Assimilation procedure of LAPS data ingestion

As anticipated in section 1, LAPS is a complex numerical system conceived to perform gridded analyses by merging together numerous data sources. Figure 3 summarizes the logical data flow during the ingestion process. It is organized in four levels: data sources (top box) are formatted for ingestion routines into LAPS (second box); these routines produce intermediate files (third box) containing data in a format suitable for the LAPS analysis process (fourth box).

The satellite ingestion process named “lvd_sat_ingest” is now described, which produces satellite intermediate files with the “lvd” extension starting from MSG data that is in turn pre-processed as described in the previous section.

The LVD file is generated in NetCDF format. It contains 12 variables derived from the radiometric values of the 5 satellite channels described in the previous sections. Each variable is composed of a grid of values that covers the LAPS geographic domain.

Table 2 shows that two kinds of variables can be distinguished: those derived from the brightness temperature of the IR channels and those derived from the radiance of the single VIS channel used in this procedure.

The Lvd_sat_ingest process derives this information from the DCs of the gridded satellite data in several steps. First of all, it is necessary to convert DC into Radiance (L) and Brightness Temperature (BT). To accomplish this step, lvd_sat_ingest makes use of the so-called Satellite
Lookup Tables. These tables are automatically generated by the “genlvdlut.exe” LAPS module (on “localization script”) (NOAA, 2009) and contain the correspondence between DC and L or BT for each channel and for each satellite acquisition. Since GOES and MSG data are coded differently, tables suitable for SEVIRI channels have to be created in order to replace the GOES tables.

To determine the radiance for each channel, scaling parameters (cal_slope and cal_offset) have to be identified. The scaling parameters are contained into the header file named “prologue” of Level 1.5 SEVIRI images. Radiance values can be calculated by means of the following formula (EUMETSAT, 2008):

\[ L_{i,\text{ch}} = DC_{i,\text{ch}} \times \text{cal_slope}_{\text{ch}} + \text{cal_offset}_{\text{ch}} \]  

(1)

where \( DC_{i,\text{ch}} \) and \( L_{i,\text{ch}} \) are the digital count and radiance of pixel \( i \) and channel \( \text{ch} \), respectively.

For SEVIRI thermal channels (4-11), brightness temperature, expressed in \( 10^{-3}\text{Wm}^{-2}\text{sr}^{-1}\text{[cm}^{-1}]^{-1} \), can be calculated by simply inverting the Planck function at the channel wavelength, that is:

\[ T = \frac{c_1 V}{\ln \left[ 1 + c_2 \frac{V}{L_0} \right]} \]  

(2)

where \( \lambda_0 \) is the central wavelength of the channel expressed in \( \mu \text{m} \) and \( c_1 \) and \( c_2 \) channel varying constants listed in the EUMETSAT documents (EUMETSAT, 2007). Figure 4 summarizes the operational procedure in order to produce the LAPS MSG lookup table.

Finally, some orbital parameters relative to Meteosat9 have to be set into the LAPS routine, namely the distance between the spacecraft and the centre of the Earth (range_m), and the sub-satellite geographic coordinates (sublat_d, sublon_d).

After these modifications, the lvd_sat_ingest process can be normally launched to produce lvd intermediate files from MSG data. Figure 5 shows an example of lvd variables derived from
SEVIRI images (26 September 2006, 1200 UTC). Figure 5a shows the albedo,\(^1\) expressed as a fractional number from 0 to 1 and derived from the VIS channel (0.6 μm), while Fig. 5b shows averaged BT expressed in K and derived from the IR channel (11 μm) through mean filtering, which simply means replacing each pixel value in the BT image with the value obtained as average of the pixel itself with its neighbors.

5. Comparison with the MSG cloud cover products of the SAFNWC

To determine the reliability of the SEVIRI-MSG assimilation into LAPS it is important to ascertain if LAPS cloud outputs are consistent with the cloud analysis products generated with other tools. As a first step, some of the LAPS cloud variables are considered and compared with the equivalent meteorological products derived from the Satellite Application Facility in support to Nowcasting (SAFNWC). SAFNWC is a project started by EUMETSAT in February 1997 whose general objective is to ensure the optimal use of meteorological satellite data for nowcasting and very short range forecasting by means of the development and maintenance of appropriate software packages (http://nwcsaf.inm.es/).

Cloud cover and cloud top height variables are selected for comparison as they represent important parameters for nowcasting purposes (they may contribute to the analysis and early warning of thunderstorm development). Since the SAFNWC software package and LAPS ingest the same MSG data, the spatial comparison cannot be assumed as a validation process, rather as a pixel by pixel correspondence verification between these two tools and the consistency of the cloud cover.

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\(^1\) A rough method has been used to intercalibrate SEVIRI-MSG and GOES11 solar channels (0.6 μm), based on the assumption (not completely true) that the two detectors reveal the same spectral radiance values. For each pixel, the solar radiance of SEVIRI instrument has been transformed into digital numeric values (DN), using the same Visible-channel calibration coefficients as for GOES-11 imagers (http://www.oso.noaa.gov/goes/goes-calibration/goes-vis-ch-calibration.htm) and then albedo is calculated by mean of LAPS satellite ingestion routine.
A preliminary comparison is performed only for 3 time steps at 0900, 1200 and 1500 UTC on September 26, 2006. In the following subsections the characteristics of the region, the SAFNWC products, the methods employed to make the spatial comparison will be described. A discussion of the results will be followed by a meteorological analysis that checks the ability of the LAPS analysis in reproducing the correct meteorological features of the case study.

5.1. Geographic area characteristics

The geographic domain under consideration is approximately centred over Southern Italy. It spreads from 37.86 to 43.15 °N and from 14.03 to 20.96 °E, covers an area of 596 × 516 km² and is characterized by a complex topography alternate to lowland and sea. South-eastern Italy is the area affected by the tropical-like cyclone that will be analyzed hereafter (Moscatello et al., 2008a). This region is surrounded by the Ionian and Adriatic seas and thus the role of latent and sensible heat fluxes between the sea surface and the atmosphere can be very important in intensifying storms and cyclones, especially in late summer and early fall when the sea surface is still relatively warm.

5.2. SAFNWC meteorological products

Cloud cover LAPS analysis has been compared with the cloud cover produced by the SAFNWC software. In particular, the meteorological SAF product named Cloud Top Temperature and Height (CTTH) (EUMETSAT, 2009a) is considered. CTTH constitutes a class of MSG cloud products, computed through a processing sequence of Cloud Mask, Cloud Type and Cloud Top Height. This processing sequence makes use of several input data, which includes almost all MSG SEVIRI channel data and numerical weather prediction (NWP) parameters. NWP data used in this work are
provided by the European Centre for Medium-Range Weather Forecasts (ECMWF, http://www.ecmwf.int/) in GRIdded Binary (GRIB) format.

The SAFNWC software produces its output at SEVIRI IR full spatial resolution over any rectangular areas defined by the user inside the MSG full disk. Within the chosen geographic window, the SEVIRI IR spatial resolution ranges approximately from 4 to 5 Km.

Cloud Top Height data is produced as a 7 bit numerical matrix stored in Hierarchical Data Format (HDF) files. In order to extract the height (in m) of the cloud top, a linear conversion from count to height is needed through the following formula:

\[ \text{Cloud Height} = \text{gain} \times \text{Count}_{7\text{bits}} + \text{intercept} \]  

where gain and intercept are equal, respectively, to 200 m count\(^1\) and -2000 m (EUMETSAT, 2009b).

5.3. Methods

To provide a consistent comparison, SAFNWC products are first mapped onto the LAPS’s geographic projection, grid domain, and horizontal resolution. The projection chosen for the LAPS analysis is the Lambert Conformal Conic with a horizontal resolution of 4 km, which is close to the original resolution of SEVIRI IR data relative to our geographic window.

The comparison process between LAPS and SAFNWC cloud products occurs in two main steps. First, for each time step taken into account, LAPS and SAFNWC cloud masks are geographically overlapped to generate a spatial pattern that allows to identify the differences in cloud cover outputs. Figure 6 shows the areas where clouds are identified by one, both or neither of the two tools. To obtain a more quantitative comparison, these results are summarized in contingency tables as shown in Table 3. Two indices are used to quantify the differences between the two analyses, the
BIAS and PC (Proportion Correct or Hit rate) (Hyvärinen, 2007), which are calculated from the contingency table and expressed as

\[
\text{BIAS} = \frac{(A+B)}{(A+C)}
\]  

(4)

and

\[
\text{PC} = \frac{(A+D)}{(A+B+C+D)}
\]  

(5)

When BIAS = 1 there is an equal amount of cloudy pixels in both analysis (although it does not imply a perfect spatial overlap). When the BIAS smaller (larger) than 1, there are less (more) cloudy pixels in the LAPS outputs with respect to the SAFNWC outputs. The PC index is more informative on the mutual spatial location of cloudy pixels. When PC = 1 there is a total agreement between the analyses while, conversely, when PC = 0 there is a total disagreement.

Second, the differences between LAPS and SAFNWC cloud top heights are derived. As in the cloud mask comparison, cloud top height maps are overlapped and a height difference is generated pixel by pixel. Note that height differences are computed only on the pixels which come out cloudy in both analyses, as shown in Fig. 6.

Finally, the LAPS and SAFNWC cloud top heights are compared using a simple linear regression as a more rigorous consistency test. Scatterplots and coefficients of determination \( r^2 \) (Hiemstra et al., 2006) are also calculated to show how LAPS cloud top height are distributed with respect to SAFNWC data and to quantify how well the linear regression approximates the relationship between the two analysis.

Since there is not a straightforward way to establish appropriate thresholds that separate outliers from the correct pixels, sub-distributions of pixel by pixel absolute differences between the two cloud heights are computed. They include only the subsets (70%, 80% or 90%) of pixels that show the smallest discrepancies. Then linear regressions, scatter plots and \( r^2 \) are computed on such subsets. The use of three different pixel subsets, allows to better identify the degradation trend of
the statistical parameters (i.e., $r^2$) when a larger number of pixels are considered. Thus more complete information is provided about the matching between SAFNWC and LAPS cloud cover.

5.4. Results

In Table 4 the results of the cloud mask comparison are shown for the three analyzed time steps. BIAS and PC values are close to 1 demonstrating a generally good agreement between LAPS and SAFNWC for both amount and spatial location of cloudy pixels, as shown in Fig. 6. The third time step (1500 UTC) shows the worst result since LAPS reveals a larger amount of cloudy pixels localized in the lower right corner of the domain (Fig. 6c). A more thorough analysis reveals that LAPS produces a different response with respect to SAFNWC especially in the areas where clouds are thin and sparse (Fig. 7a). In fact, Fig. 7b shows that in the lower right corner LAPS detects a cloud cover less than 30%.

Note that cloud cover provided with the METeorological Aerodrome Reports (METAR), even though representing a rough set of information, is a very important first guess for the LAPS cloud detection in the lower troposphere (Albers et al., 1996). Absence of METAR cloud cover information prevents the LAPS analysis from accurately producing clouds below 5 km altitude. As an example, Fig. 8 shows the effect of removing METAR information from the LAPS analysis at 0900 UTC. By comparing Fig. 6a, that has been obtained by including just one METAR inland Calabria region, and Fig.8b it is possible to observe the absence of cloud cover over the south-western area in the LAPS analysis, while in the MSG image low and medium cloud tops are present.

Figure 9 and 10 show the cloud top height and their difference maps, respectively, expressed as absolute values (derived from the analysis with LAPS and SAFNWC) for the three time steps. From this preliminary analysis it is possible to see that in most of the domain the difference in cloud top
height is smaller than 1 km. Generally, such differences are smaller in the areas where there is a more uniform cloud cover.

Some differences can be attributed, at least partially, to a slight offset in the location of cloudy pixels. Although map reprojections have been accurately crafted, we suppose that SAFNWC and LAPS pixels refer to slightly different areas and this fact, combined with the fine spatial resolution (4 km), can lead to errors in some pixels, especially in the areas where the cloud cover or height is not uniform.

Figure 11 illustrates some statistical relationships between cloud top heights computed with SAFNWC and LAPS. Rows indicate the time step, while columns show the percentage of cloudy pixels taken into account as described in subsection 5.3.

The scatterplots make it easy to note that the data points are distributed mainly along the green regression line. A large number of dot clusters on the right side of the panels, especially for the percentile $q = 90\%$, and this means that LAPS generally underestimates the cloud top height with respect to SAFNWC. This underestimation of LAPS is probably due to the fact that LAPS is fit for GOES channels and not for MSG, that implies an imperfect calibration for the SEVIRI 11 μm channel spectral width. In fact, the BTs derived from this channel are fundamental for the definition of cloud top height. It may also be that LAPS is assigning too great an optical depth to these clouds (Albers et al., 1996).

The fact that the coefficients of determination range from 0.56 to 0.93 means that the linear model constitutes an acceptable approximation in describing the relationship between the two analyses. The high $r^2$ values for all the different percentile thresholds indicate that most of the pixels of the LAPS analysis generally fit well with SAFNWC analysis.

In conclusion, the case study shows that the ingestion of MSG-SEVIRI data into LAPS works quite well in reproducing the cloud horizontal structure, at least in the analyzed case study. More informed conclusions would require a long time series of analysis to develop a statistically meaningful evaluation.
d) Meteorological analysis

In order to verify the ability of the LAPS analysis in reproducing the characteristics of the cyclone that affected south-eastern Italy on 26 September 2006, mean sea level pressure (MSLP) and a vertical cross section of wind, temperature and humidity have also been examined.

Although the MSLP fields computed by LAPS surface processing is based on several input data (McGinley et al., 1991), our study revealed that background data represents the most important source of information.

Two types of background are used to initialize LAPS: the ECMWF data and the Weather Research and Forecasting (WRF) model (Skamarock et al., 1999) forecasts shown in Moscatello et al. (2008b). It is noted that the use of different background data has no significant influence on the cloud top height and cloud cover, whereas it determines a strong impact on the MSLP field. Figures 12 and 13 show the LAPS analysis MSLP for 3 time steps using WRF forecast and ECMWF data, respectively. The two background fields produce fairly different MSLP analyses. In particular, we see that the cyclone generated with the WRF model forecast as background fields reproduces the structure generated in Moscatello et al. (2008b).

Figure 14 shows the wind speed and the potential temperature in a vertical cross section at the latitude of the pressure minimum (that is located approximately in the middle of the figure), at 12 UTC, 26 September, when the cyclone has completely developed the characteristics typical of tropical cyclones. Similarly as in Moscatello et al. (2008b)'s Fig. 17, we see a minimum wind speed, of 6 m s⁻¹, in correspondence with the centre of the cyclone; also, a maximum of 26 m s⁻¹ is located about 30 km far from the centre, on the eastern side of the low. Above the centre, the existence of a warm core is apparent in the layer between 850 and 650 hPa. Thus, the vertical structure emerging from the LAPS analysis is consistent with that expected for a tropical-like cyclone.
Conclusion and future work

Software for the ingestion of MSG SEVIRI satellite data in the VIS and IR spectral bands into the Local Analysis and Prediction System (LAPS) is written and tested. Note that LAPS is originally designed for the input of GOES satellite data and its use outside the Conterminous United States (CONUS) area often has limitations. The present work represents a first step towards an operational use of LAPS over Europe using EUMETSAT’s GEO satellites.

The sensitivity of the LAPS scheme to the ingestion of VIS and IR data from Meteosat is examined by comparing its cloud analyses with those of EUMETSAT’s Nowcasting SAF. Results are very encouraging, though a general underestimation of cloud top height is found for LAPS with respect to SAFNWC. This suggests that adjustments are needed to transform the original GOES-based LAPS cloud scheme into the new MSG-based presented in the paper. This will be the first step to be done towards the improvement of the current version of the software.

The above mentioned comparison has also shown that the initialisation of the LAPS analysis with different background fields such as those of ECMWF and WRF has scarce influence on the derived cloud parameters while producing significantly different MSLP maps. Further studies are needed in this area to better understand these results, which depend, among the other factors, on the resolution of the input background fields.

Note that the present study is a first important step towards using physical analyses for mesoscale NWP models initialisation over Europe. Moreover, the LAPS scheme based on Meteosat is expected to be very instrumental for weather monitoring, particularly in case of complex and intense events. In this direction its use for meteorology, civil protection, hazard management and generally for nowcasting and very short range forecasting is to be considered in a short while.
Acknowledgments

The authors are grateful to Regione Puglia for support provided under the Progetto Strategico “Nowcasting avanzato con l’uso di tecnologie GRIS e GIS”. VL also wishes to acknowledge partial support from the Italian Space Agency (ASI) within the project “Prodotti di Osservazione Satellitare per Allerta Meteorologica” (PROSA) and from EUMETSAT within the Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF).

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Moscatello, A., M. M. Miglietta, R. Rotunno, 2008a, Observational analysis of a Mediterranean “hurricane” over south-eastern Italy, Weather, 63, 306-311


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<tr>
<td>0900</td>
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4) John McGinley,  
   NOAA, Colorado, USA,  
   John.A.Mcginley@noaa.gov

5) Markus Neteler  
   Fondazione Mach, Italy  
   neteler@cealp.it
Figure 1
Reading HRIT image segments → Geographic Reprojection → Spatial re-sampling → Geographic window extraction → Writing processed data in netcdf files
Figure 4
Reading Seviri Prologue file → Conversion of Digital Count values to Radiance values → Brightness Temperature computation for IR channels → Writing Lookup tables
Figure 11

The images show scatter plots for different times:

- **09:00**
  - \( r^2 = 0.92 \)
  - \( y = 132 + 0.96x \)
  - \( q = 70\% \)

- **12:00**
  - \( r^2 = 0.93 \)
  - \( y = 138 + 0.98x \)
  - \( q = 80\% \)

- **15:00**
  - \( r^2 = 0.91 \)
  - \( y = 600 + 0.89x \)
  - \( q = 90\% \)

All plots show a positive linear relationship between \( \text{LAPS HEIGHT} \) and \( \text{SAFNWC HEIGHT} \) with correlation coefficients ranging from 0.56 to 0.93.
Figure 13
Click here to download high resolution image
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