GEOSTATIONARY SATELLITE DATA ASSIMILATION FOR NOWCASTING PURPOSES

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ABSTRACT

The growth of the observational capabilities over the last decades allows for a detailed description of atmospheric structures, from large-scale phenomena down to cloud features. The prominent factor is the development of efficient remote sensing tools, satellite and ground based radar. The integrated use of the available data and numerical weather prediction (NWP) techniques to produce very short-range forecast operational products is a continuing challenge for the forecaster community. Furthermore, the increase of space-time resolution and the availability of Meteosat Second Generation (MSG) new channels will direct the use of geostationary satellites towards a deeper coupling between the analyses and NWP techniques for nowcasting purposes. The Local Analysis and Prediction System (LAPS) has been implemented to produce hourly high resolution 3D analysis to feed an intermittent assimilation cycle.

1. INTRODUCTION

The fine space and time resolution of local area models (LAM) does certainly require adequate analysis methods, especially for very short-range weather forecasting and nowcasting. Moreover, the operational use of non-hydrostatic models, with their very sophisticated physical parameterisations and explicit description of hydrometeor species, surfaces the need for accurate observations and analysis of the physical quantities, such as for example atmospheric humidity, cloud fraction, cloud optical thickness, liquid water content, ice content, etc… The inadequacy of traditional analysis methods based essentially on soundings and surface observations can in principle be overcome by coupling together remote sensing techniques and sophisticated analysis methods. Remote sensing in this respect can play a key role in accurately describing the structure of the atmosphere and, most of all, the presence of clouds, their genesis and evolution.

Physical initialisation has been attempted by several authors trying to ensure thermodynamic consistency between humidity, surface fluxes, rainfall distributions, diabatic heating and clouds (e.g. Krishnamurti, 1994). The

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increasing use of satellite data in data assimilation systems requires a reasonable simulation of clouds to make use of information not only in clear sky conditions, as is common practice today, but also in cloudy situations.

However, the representation of cloud-related processes in numerical weather prediction (NWP) models at all horizontal scales, except when the scale allows for explicit cloud resolving, still remains a formidable and challenging task. The analysis of humidity is likely to benefit from the physical analysis of related variables such as clouds and precipitation. At this stage information extracted from imaging radiometers becomes very important for NWP, and not only for nowcasting, in order to retrieve structures that were not necessarily present in the analysis background field.

In the following the Local Analysis and Prediction System (LAPS) (McGinley, 1989), developed at the NOAA Forecasting System Laboratory, is tested to verify the impact of remote sensing data onto the analysis chain. The resulting fields are used in an intermittent assimilation cycle for improving the forecast skill over a meso-β domain. The overall system is presented highlighting the impact of satellite data in the reconstruction of missing features and comparing the different scenarios that can be foreseen.

2. LAPS ANALYSIS SCHEME

LAPS was conceived and developed to support the operational activities of the Weather Forecasting Office (WFO) of the US National Weather Service. The ingestion of all data routinely available is one of the most relevant aspects of the system. The data set is composed by:

- Surface data - mesonet and baseline stations (SYNOP, METAR);
- Upper air soundings;
- Numerical model forecasts;
- Profilers - RASS, SODAR, Wind Profilers;
- Geostationary satellite data, cloud drift winds;
- Radar - 3D Reflectivity and Doppler wind fields, VAD, low-level reflectivity composite;
- Aircraft reports - ACARS and PIREPS.

Given the atmospheric physical constraints and WFO’s needs for fast and robust analyses, LAPS is based on simple successive correction method. It combines and harmonises the resulting dataset to obtain surface and 3D fields of meteorological parameters, that is temperature, pressure, humidity, wind, cloud, and other derived variables. Remote sensing, satellite above all, plays a key role in accurately describing the structure of the atmosphere with special emphasis on the presence of clouds, their genesis and evolution.

The ARPA-SMR implementation (Alberoni et al., 1998) is based on a 10 Km horizontal grid resolution over an area enclosing Northern Italy, approximately 1000×700 km^2, with 21 isobaric levels from 1100 to 100 hPa. The porting of LAPS over the European area required a considerable amount of work to adapt and modify the system. One of the main tasks was to adapt the system for the ingestion of METEOSAT data, since LAPS was conceived to use GOES data. GOES and METEOSAT notably differ in the number of available channels (5 for GOES and 3 for METEOSAT) and the resolution at sub-satellite point.

A description of LAPS analysis techniques can be found in Mc Ginley (1989) as regards the overall system. Details on the various sections are given by Albers (1995), Mc Ginley et al. (1991), Albers et al. (1996), and Birkenheuer (1991). To help the reader, we briefly recall the LAPS humidity and cloud analysis schemes, which are the field that are most affected from the satellite data.

3. LAPS CLOUD AND HUMIDITY ANALYSIS

The three-dimensional cloud cover analysis is done via the input of data from different sources that are combined with the model background. Surface observations, geostationary satellite infrared (IR) imagery, three-dimensional temperature analysis and three-dimensional radar reflectivity derived from full volumetric radar data are key input parameters. Other inputs are pilot reports from aircraft (if available), visible (VIS) satellite data whenever the solar elevation angle is > 15° and ground temperatures. The ingestion of radar data was disabled in the present exercise for an assessment of the impact of satellite data on the humidity analysis. Note that radar data, especially Doppler winds, play a key role that can by no means be disreagarded.

Surface observations of cloud cover are analysed to produce a preliminary three-dimensional cloud field. IR satellite data are first used in a selective deletion process that supplies more horizontal structure to the cloud field generated by surface observations. The IR brightness temperature measured by the satellite is compared with the expected brightness temperature calculated using the preliminary analysis, which will be eventually modified to ensure consistency.

A cloud-top height field is then generated from the satellite cloud-top temperature field (derived from Meteosat IR imagery) with the help of the LAPS three-dimensional temperature field. The cloud-top height field is then inserted into the preliminary cloud analysis allowing for a better definition of cloud heights and horizontal coverage. Conflicts between observations and satellite data are properly managed at this stage: surface observations dominate the analysis of low and warm clouds; satellite data take over for higher clouds so as to ensure consistency between derived analysis and measured IR brightness temperatures.

Finally, VIS satellite data are inserted. If the satellite-derived cloud cover is significantly lower, the cloud cover for each LAPS grid column is reduced accordingly.

The cloud analysis is then passed on to the humidity routines that convert cloud cover to specific humidity and combine it with background and observations to obtain the final three-dimensional analysis.

4. ASSIMILATION PROCEDURE

In order to produce accurate high resolution and frequently updated forecast, the LAPS system is coupled with the hydrostatic limited area model operationally used at ARPA-SMR, LAMBO. LAMBO is a grid-point primitive equations limited area model based on 1989/1993 versions of the ETA model running operationally at the National Centre for Environmental Prediction (NCEP) (Janijc, 1990; Mesinger et al., 1988).

In the operational suite of ARPA-SMR LAMBO runs every day, twice a day starting from the 0000 and 1200 UTC ECMWF analysis, at two different horizontal (40 and 20 km) and vertical resolutions (20 and 32 vertical levels). A new operational configuration is under testing upgrading the horizontal resolution up to 10 km and initialising the model run from a state obtained with an analyses nudging scheme developed at ARPA-SMR (Cacciamani et. al 2000).

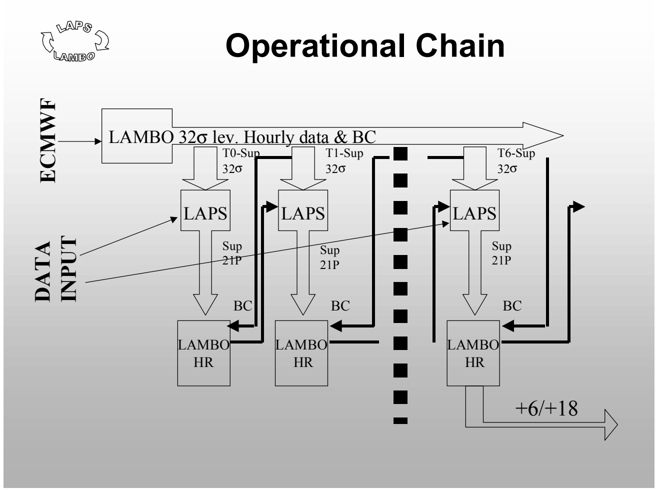

Figure 1 – Sketck of the assimilation procedure.

The assimilation procedure (see Fig. 1 for a pictorial reference of the assimilation chain) starts from the output fields of the model operational run. The forecasted fields are interpolated on the analysis grid. LAPS ingests the data available and produces the 3D field of temperature, specific humidity and the horizontal component of the wind.

A high resolution version of LAMBO is nested in the LAPS area; the model is run for one hour to produce the first guess fields for the next assimilation cycle. The boundary condition for the integration are taken from the operational run of LAMBO. Every 6 hours the model produce a +12 hours forecast, which are used for nowcasting purposes.

5. SATELLITE-BASED HUMIDITY ANALYSIS: CASE STUDIES

On 18 June 1997 two simultaneous supercells 50 Km apart swept the Po Valley W-NW to E-SE. An exceptional hailfall lasted for more than 3 hours over a strip 200 Km wide. There are no records of companion supercells over Northern Italy, a fact that attributes to the present observations a considerable meteorological interest. Readers can refer to Alberoni et al. (2000) for a more complete description of the event. The frontal displacement, which drove the evolution of this event, was correctly predicted by LAMBO. At 1200 UTC the satellite image shows a frontal branch ahead of the classical dry region well identifiable in the METEOSAT water vapour channel (Fig. 2a). The twin supercells are localised by the two high-humidity spots embedded in the front. A crucial aspect for the forecasting of this type of very severe weather is the correct identification of the mechanism that drives the convection. At the same time, the relative humidity background field at 400 hPa agrees reasonably well with the observed high troposphere humidity (Fig. 2b). The injection of sounding information maintains the same pattern over Northern Italy's Po valley (Fig. 2c) with a slight overall increase. The dry belt is reduced in its longitudinal extension while a drying in the upper troposphere is observed in the south-western part of the domain.

After the use of satellite information in the analysis process (Fig. 2d), small scale fluctuations appear where convective cores are located. In the middle of the Po valley high-humidity spots (relative humidity greater than 70 %) identify the position of the twin supercells system.

The relatively clear satellite scene, as it appears on the NOAA AVHRR channel 2 image at 1234 UTC (Fig. 3a), and the overall satisfactory forecasting skills of the phase and displacement of the frontal system explain the small impact of the ingestion of cloud data.

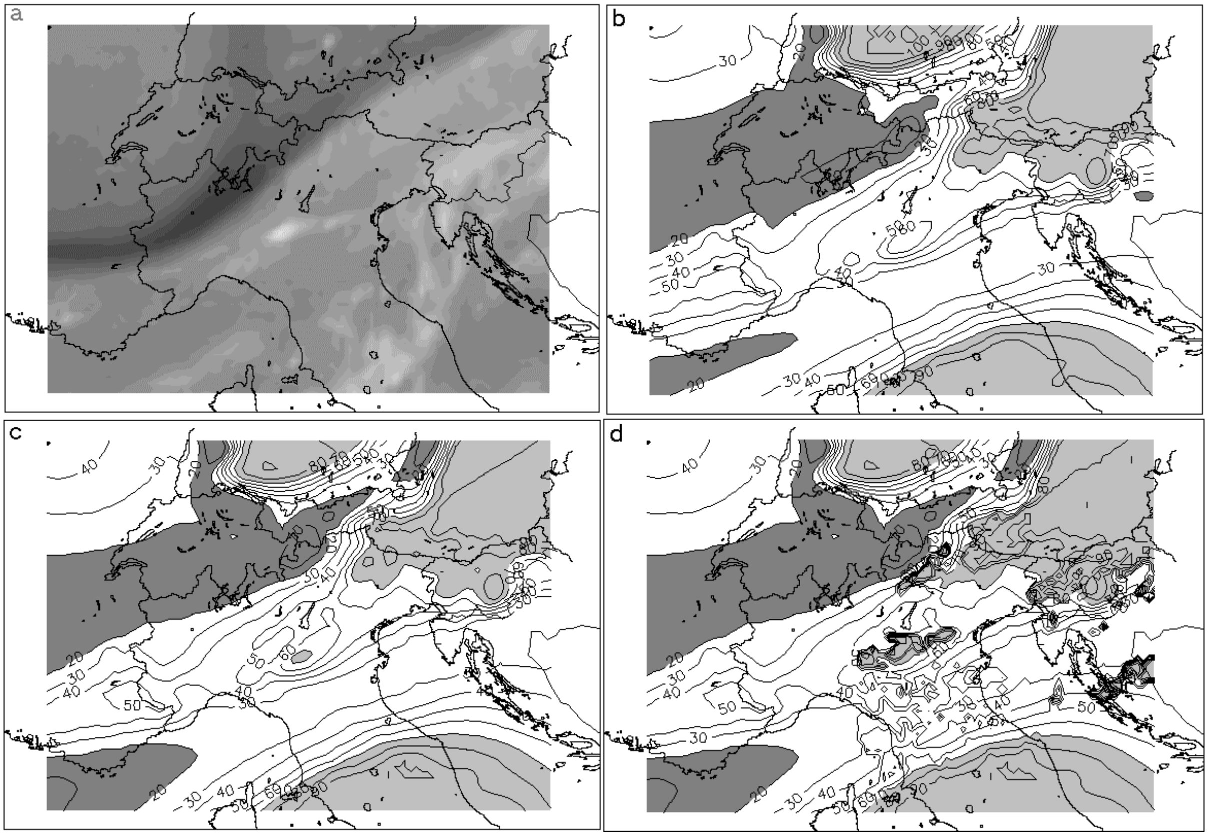

Figure 2 – 18 June 1997 1200 UTC. a) METEOSAT WV image remapped onto LAPS grid. Other plates refer to the 400 hPa relative humidity field (10% interval, dark grey encloses values lower than 20%, light grey those greater than 70%): b) background field (LAMBO); c) analysed field after the injection of raob data; d) analysed field after the injection of the cloud field.

The background total precipitable water field (Fig. 3b) reflects the high amount of water substance available ahead of the frontal system. The raob (Fig. 3c) data do not substantially modify the general pattern, while the use of METEOSAT IR data significantly increases the amount of total precipitable water in the vicinity of the twin system (Fig. 3d). The availability of such an amount of water sustains the strong convection observed during the event through the latent heat release.

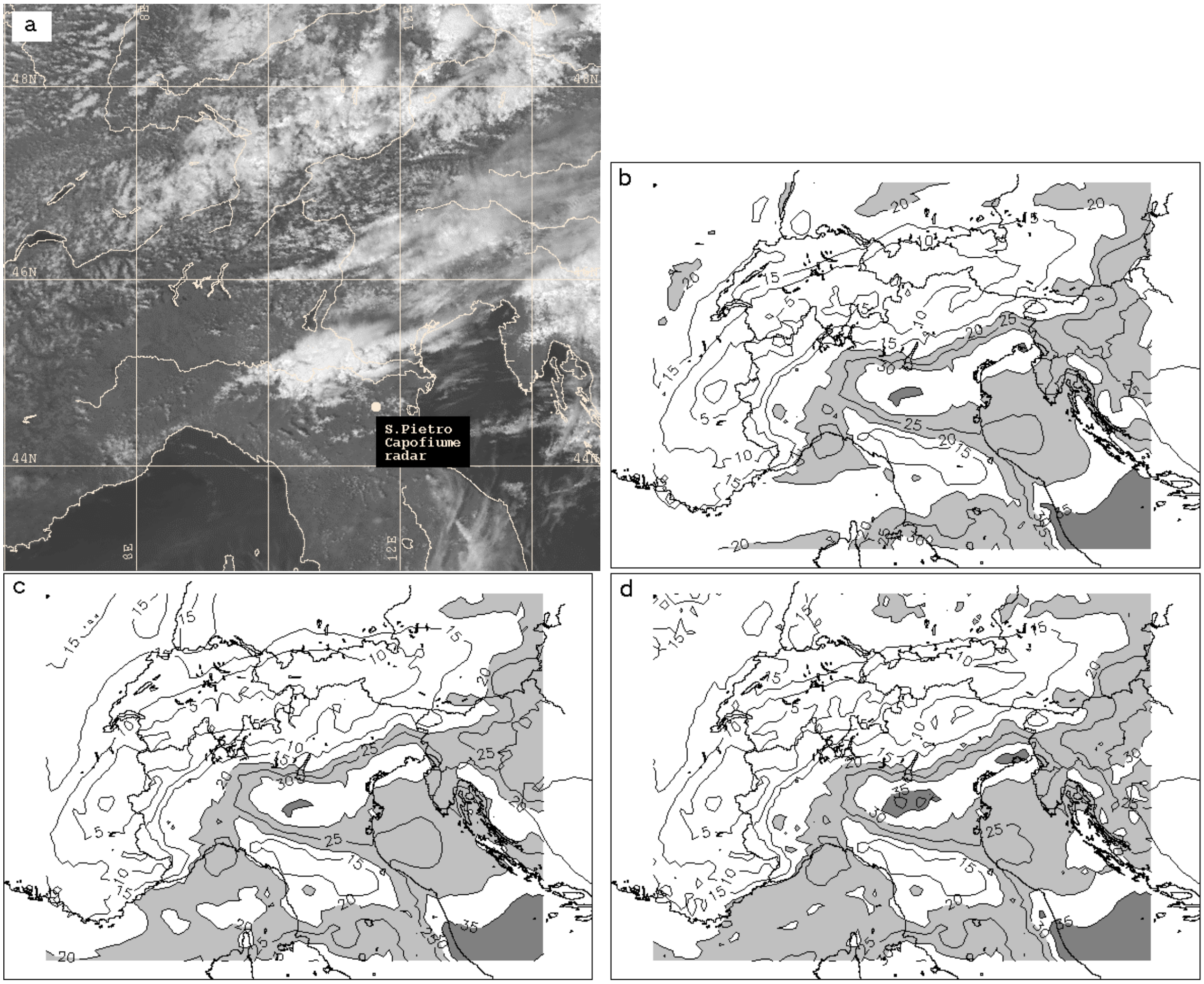

Figure 3 – 18 June 1997. a) 1234 UTC NOAA/AVHRR channel 2 image. Other plates show the total precipitable water field at 1200 UTC (5 mm interval, light grey refers to [20-30] mm interval, dark grey encloses values greater than 35 mm): b) background field (LAMBO); c) analysed field after the injection of raob data; d) analysed field after the injection of the cloud field.

The ingestion of METEOSAT IR and VIS data produce a more realistic description of the high-level cloudiness in the frontal region. Fig. 4 shows the 85% relative humidity isosurface that provides a rough description of height levels (the isosurface is shaded using temperature values). A layer of high clouds it present on the northern slope of the Alps and over the mountains in the analysis done with the satellite data (Fig. 4a). In the analysis carried out without the use of satellite data (Fig. 4b) the same isosurface is bounded at lower levels close to the surface. Furthermore note the crucial role of METEOSAT images in the reconstruction of the supercell system in the middle of the Po valley.

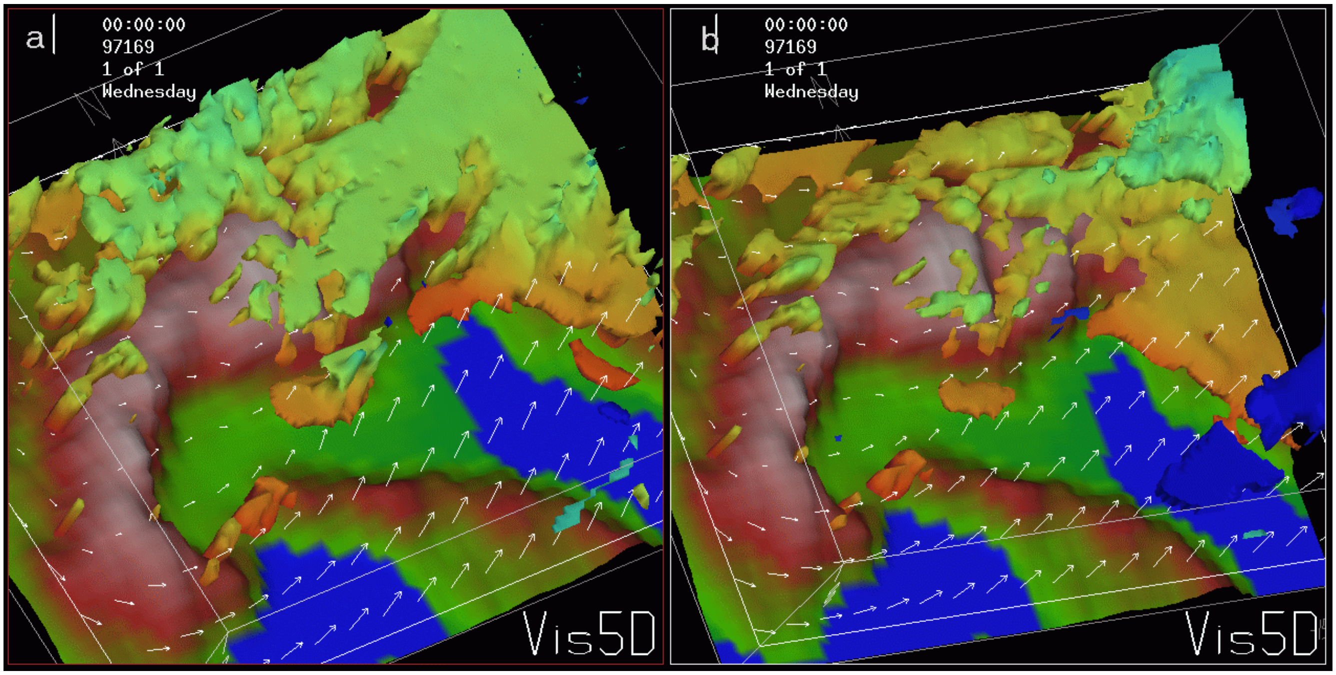

Figure 4 – 18 June 1997 1200 UTC. 85% relative humidity isosurface shaded with the corresponding temperature. a) LAPS analysis using METEOSAT IR and VIS data; b) LAPS analysis using only raob data. The 700 hPa horizontal wind vectors are also included.

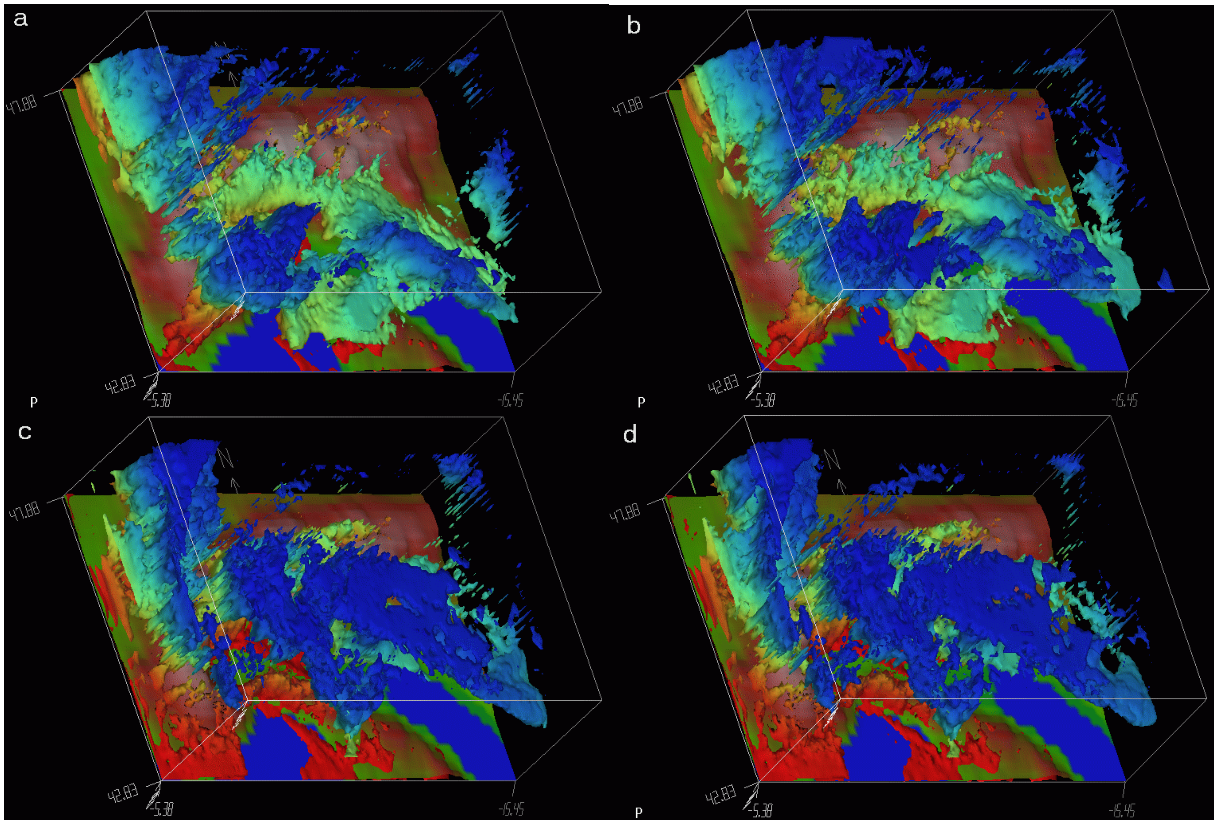

Figure 5 – 16 April 2000. 90% relative humidity isosurface shaded with pressure. a) one hour forecast of the LAPS-LAMBO system, started at 1900 UTC; b) same as a) but only LAMBO; c) same as a) but at +6 hours; d) same as c) but only LAMBO.

6. ASSIMILATION OF SATELLITE DATA: FIRST RESULTS

Results on the impact of the assimilation of satellite data on the intermittent assimilation cycle presented in section 3 are very preliminary. An assimilation run was recently conducted on 16 April 2000 1900 UTC. The LAPS-LAMBO system was run for a 6 hours forecast and compared with a forecast started from unmodified condition. At +1 hour forecast differences show up in the humidity fields, as becomes evident from the comparison of Fig. 5a (LAPS-LAMBO forecast) and 5b (control forecast). The high relative humidity north of the Alps is decreased, according with the set-up of a foehn episode. On the other side of the Alpine chain the southern flow impinges on the steep orography with a corresponding raise of humidity at upper levels. The use of satellite helps in increasing the localisation of the fields.

After 6 hours of integration the difference between LAPS-LAMBO (Fig. 5c) and the control run (Fig. 5d) are not so evident.

7. CONCLUSION

It is our opinion that the increase of space-time resolution and the availability of MSG new channels will direct the use of geostationary satellites towards a deeper coupling between the analyses and NWP techniques for nowcasting purposes.

The Local Analysis and Prediction System (LAPS) has been implemented and coupled with the LAMBO limited area model run operationally at ARPA-SMR. The use of satellite data gives a substantial contribute to refine the humidity analysis. This is particularly true when standard synoptic upper air observation are not present. Furthermore, the presence of sub-synoptic features, such as clouds, would not adequately show up in the analysis without the ingestion of timely and high resolution mesoscale data such is the case of satellite and radar information.

The humidity analysis is likely to benefit from increased attention to the analysis of related variables such as clouds and precipitation. At this stage information extracted from imaging radiometers becomes very important for NWP, and not only for nowcasting. Its role is prominent in retrieving structures that were not necessarily present in the analysis background field.

The resulting fields are used in a continuous assimilation cycle for the improvement of the forecast skill over a meso-β domain. The overall system has been presented highlighting the impact of satellite data in the reconstruction of missing features and comparing the different scenarios that can be foreseen. First and very preliminary results encourage further work to be done along this direction. In particular, more work is needed to extensively test the impact of such type of data in the analysed and forecasted fields.

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