Impact of meteorological radar and satellite data onto mesoscale analyses.

P.P. ALBERONI[a,b], V. LEVIZZANI[b], P. MEZZASALMA[a], S. COSTA[a] & R. RIZZI[c,b]

[a] *A.R.P.A.-Servizio Meteorologico Regionale, Viale Silvani 6, 40122 Bologna, Italy - e-mail:* p.alberoni@smr.arpa.emr.it
[b] *Institute of Atmospheric and Oceanic Sciences (ISAO-CNR), Bologna, Italy*
[c] *ADGB, Dept.of Physics, viale Berti Pichat 6/2, I-40127 Bologna, Italy*

ABSTRACT

The increase of weather information collected by remote sensing instruments in the last decades has noticeably impacted the analysis procedures. Data are now collected with a much greater time and space resolution and fully describe mesoscale features from meso-cyclones down to the cloud scale. The NOAA Forecasting System Laboratory (FSL) has developed the Local Analysis and Prediction System (LAPS), an integrated system to ingest and analyse meteorological data from different observational sources. LAPS combines and harmonises the input data for the derivation of surface and 3D fields of temperature, geopotential or pressure, humidity, wind and cloud cover. The calculation of other derived variables, e.g. instability index and total precipitation amount, is also included. Its implementation at ARPA-SMR is devoted to hourly analyses as a base of a nowcasting system under development and has been run for a pre-operational test during the last few months. The impact of the injection of meteorological remote sensing information will be discussed on a case-study basis.

1. INTRODUCTION

Local area models' (LAM) time and space fine resolution does certainly require more adequate analysis methods, especially for very short-range weather forecasting and nowcasting. Moreover, their very sophisticated physical parameterisations clearly show the inadequacy of traditional analysis methods based essentially on soundings and surface observations. 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 increasing use of satellite data in data assimilation systems necessitates a reasonable simulation of clouds to make use of information not only in mainly clear sky, as is common practice today, but also in the presence of clouds.

However, the representation of cloud related processes in numerical weather prediction (NWP) models at all horizontal scales, except when the scale allows to resolve clouds explicitly, still remains a formidable and challenging task. The analysis of humidity 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.

In the following the Local Analysis and Prediction System (LAPS), developed at the NOOA Forecasting System Laboratory, is tested to verify the impact of remote sensing data onto the analysis chain.

2. LAPS OVERVIEW

LAPS was conceived and developed to support the operational activities of the Weather Forecasting Office (WFO) of the U.S. 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 – GOES or METEOSAT, 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 but effective analysis techniques. The main product is the synthesis of input data to derive surface and 3D fields of temperature, geopotential or pressure, humidity, wind and cloud fields. The calculation of derived variables, for examples instability index or total precipitation, is also done. The prediction section couples the analysed fields with a local area model for frequently-updates very short-range forecasts.

The first step of the LAPS implementation is called localisation. It consists of the development of an ingestion shell to reformat local data sources into LAPS input files. After this phase the analysis codes are run and outputs stored in NetCDF format.

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 satellite data. GOES and METEOSAT notably differ in the numbers 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 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 wind, humidity and cloud analysis schemes.

2.1. LAPS cloud and humidity analysis

The three-dimensional cloud cover analysis needs 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. Only for this part of the work, the ingestion of radar data was disabled in order to assess satellite impact on the humidity analysis.

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; for higher clouds, the satellite data take over so as to ensure consistency between derived analysis and measured infrared 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.

2.2. LAPS wind analysis

The LAPS wind analysis scheme (Albers, 1995) merges the LAM background field with Doppler radar (previously averaged and remapped on LAPS grid), sounding and surface wind (spread vertically in the boundary layer). The wind algorithm is a three-pass procedure. First a Barnes scheme is applied to all data, except radar radial wind, to evaluate the wind components. Then the wind vector is projected on the radar co-ordinate system to extract a radial analysed component; if the gap between the observed radar radial component and the analysis is below a fixed threshold the wind components are reconstructed from Doppler radial wind and tangential analysed wind. Finally, two more Barnes cycle are applied to take into account the newly added information.

3. DOPPLER RADAR WIND ANALYSIS: AN EXAMPLE

On 18 June 1997 two simultaneous supercells 50 Km apart swept the Po Valley W-NW to E-SE. An exceptional hailfall last for more than 3 hours over a 200 Km-wide strip. This event was characterised by an intense south-westerly flow with strong vertical shear, making it an ideal test bed to explore the use of Doppler radar wind measurements in meso-scale analysis procedures. The SMR's Doppler radar is located in the eastern Po Valley 30 km north of Bologna, with a Doppler range of 110 km.

In Fig. 1 the background and analysed 500 hPa wind field are displayed, while in Fig. 2 the radar-based wind analysis is plotted together with the sounding-based analysis. The background shows a smoother wind field, with an underestimated cyclonic and anti-cyclonic circulation in the left part of the LAPS area and more zonal, slightly weaker winds over the rest of the domain.

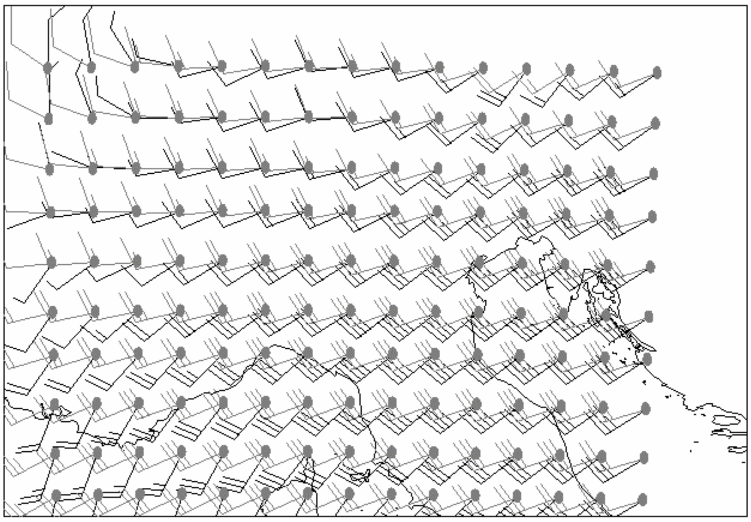

Figure 1: 18 June 1997 1200 UTC 500 hPa. Background (gray) and LAPS wind field (black).

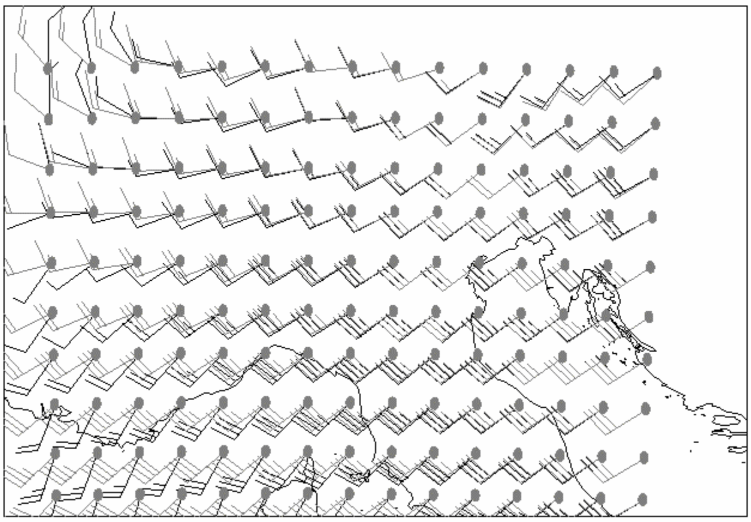

Figure 2: 18 June 1997 1200 UTC 500 hPa. Radar based analysis (gray) and sounding based wind field (black).

The radar-based wind analysis well depicts the medium tropospheric flow, intensity and direction, over the central-eastern area, while the western section is too far from the radar so that poor results are obtained. Note that the radar covers only a small portion of the entire domain. The good agreement observed in the analysed fields is encouraging in the use of such data.

4. SATELLITE BASED HUMIDITY ANALYSIS: CASE STUDIES

Two storm events will be discussed: a thunderstorm outbreak, which produced severe weather in the Po Valley on a late afternoon in summer 1999; winter conditions characterise the second event occurred on February 1999 and associated with intense snow falls.

4.1. The 22 Jul 1999 storms

A cold front approached the Po Valley from NW: damaging winds, widespread hail and a few tornadoes were reported. LAM forecasts completely missed the strong convection that formed in the plains of Northern Italy, resulting in an impressive lack of humidity in the background field that LAPS analysis will be able to correct. The METEOSAT IR image at 1800 UTC spots strong convection in the middle of the Valley advected by an intense westerly flow towards Austria and Slovenia (Fig. 3).

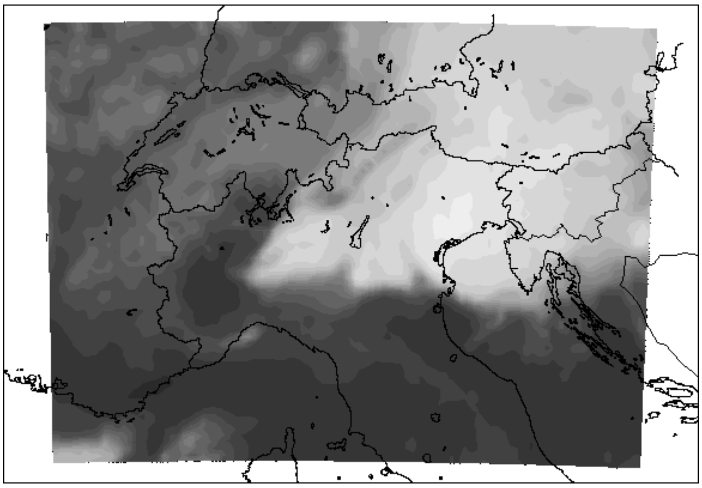

Figure 3: 22 July 1999 1800 UTC. METEOSAT IR equalised image.

The simultaneous 800 hPa background moisture field (Fig. 4) shows the cold front over the Adriatic Sea, followed by dry air intrusion around the Alps (see the field over Austria and the presence of the Mistral from Provence in the west). The dry tongue over the central Valley is most likely due to a katabatic wind from the alpine slopes.

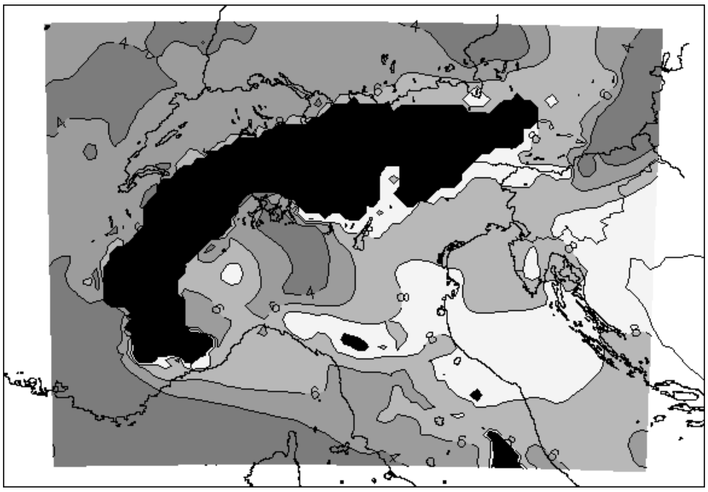

Figure 4: 22 July 1999 1800 UTC, 800 hPa. Background specific humidity (g/kg). The black area represents the topography.

The injection of surface cloud observations has substantially modified the lower tropospheric structure in the eastern sector, filling the dry pocket over Austria. This effect is not so evident over northern Italy. Surface observations detected low clouds with cloud base around 700 m AGL. However, the presence of dry air aloft, coming from the model background, lead to a rather shallow cloud layer. Finally, the LAPS humidity scheme detected moister air also over Northern Italy (Fig. 5), highlighting the presence of convective cloud clusters.

Figure 5: As Fig. 4 but for LAPS humidity analysis with satellite data

In the medium troposphere (500 hPa), air is nearly saturated (Fig. 6) by LAPS in areas where the model background (Fig. 7), wrongly locating the frontal system, missed also the development of convection.

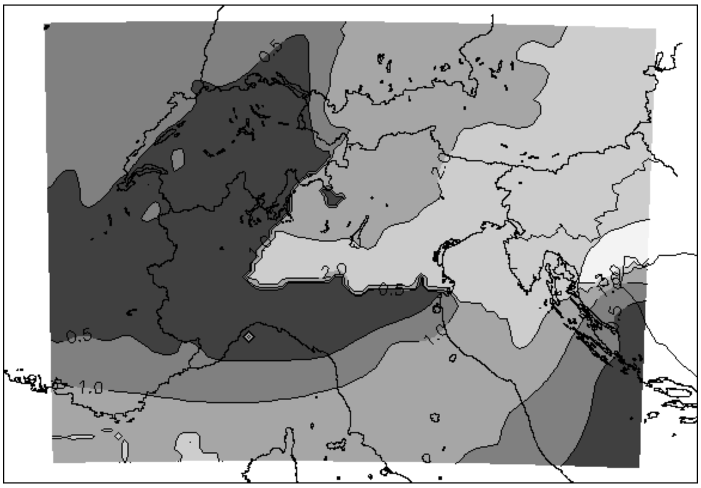

Figure 6: 22 July 1999 1800 UTC, 500 hPa. LAPS humidity analysis with satellite data

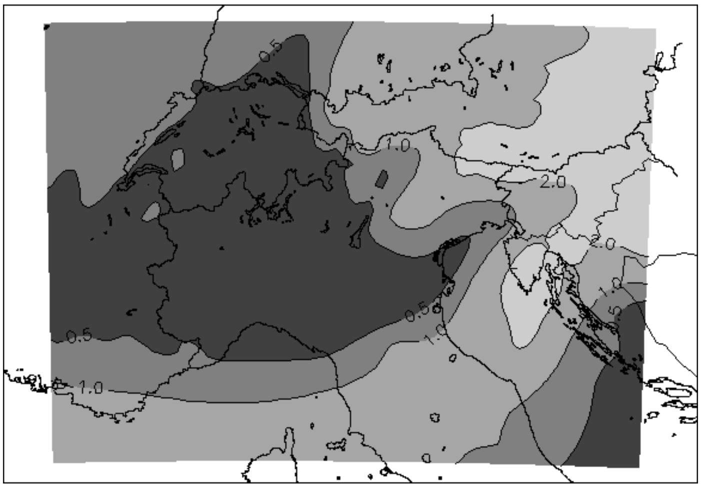

Figure 7: As Fig. 6 but for background field

4.2. The 10 Feb 1999 snowfalls

A strong cyclonic system passed over the LAPS area on 9-10 February 1999. The occluded front lingered over the eastern sector of the Po Valley for several hours on 10 February, producing widespread snowfalls. The relatively small number of available surface observations leads to significant changes in the background fields in areas far from the observation sites. In this case satellite data tend to retain the background as the true field. At 1100 UTC background data (Fig. 8) show pockets of dry air in the lower atmosphere near the eastern slopes of the western Alps and in the French coastal regions. In the Po Valley of northern Italy the humidity field looks quite smooth.

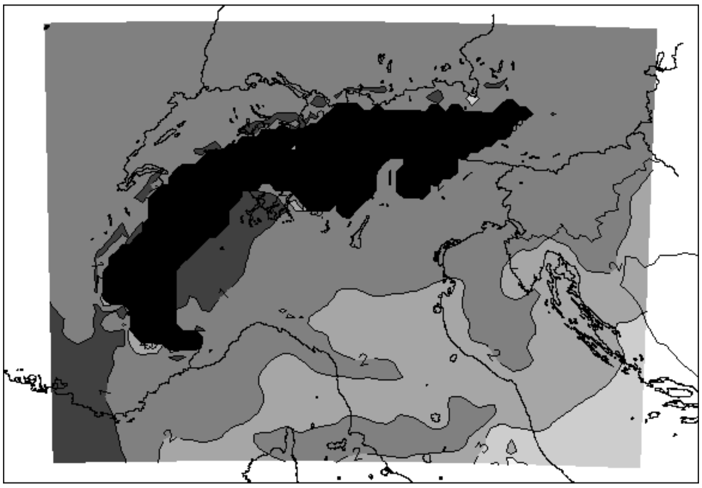

Figure 8: 10 February 1999 1100 UTC 800 hPa. Background specific humidity (g/kg). The black area represents the topography.

After the insertion of surface observation data (Fig. 9), the Adriatic region is moister as well as a large region between France and Corsica.

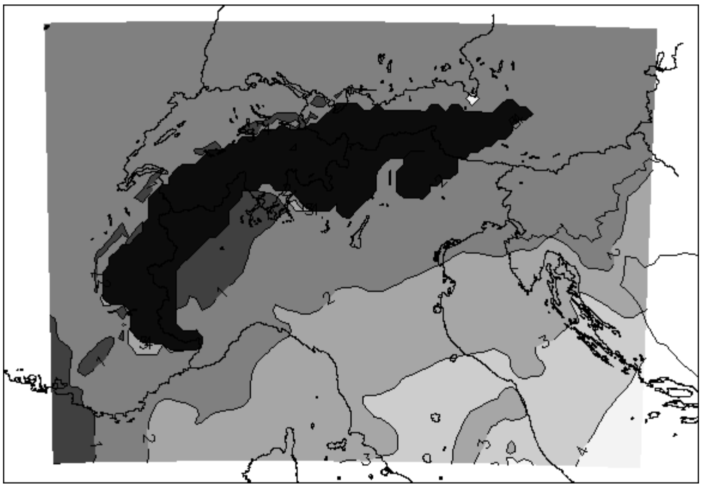

Figure 9: As Fig. 8 but after the insertion of surface observation.

The injection of satellite data into cloud analysis (Fig. 10) does not substantially modify the humidity values in the Adriatic region, where a deep cloud cover is present. Along French coast, on the contrary, values are more similar to the background pattern. At 1100 UTC only the Italian surface observations are available at SMR, so that no further information should be added in the grid points outside the Italian peninsula. The moister air appearing between France and Corsica after the injection of surface data seems to be the result of extrapolation within the Barnes analysis scheme. Only where clouds are actually detected by the satellite (Fig. 11) the final analysis retains higher amounts of specific humidity.

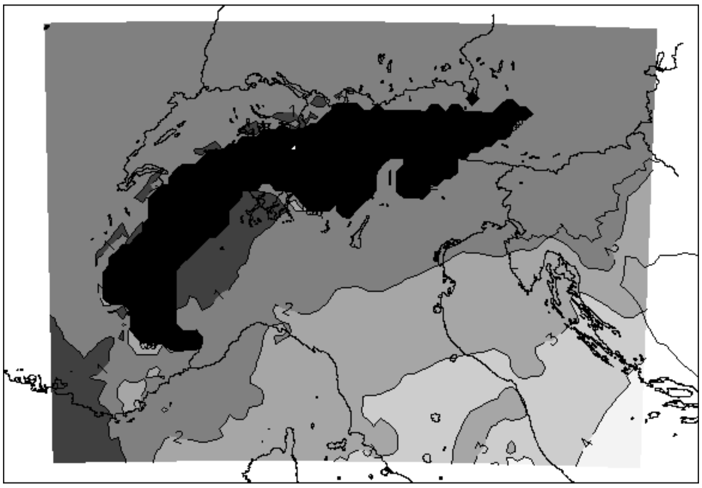

Figure 10: As Fig. 8 but for LAPS humidity analysis with satellite data.

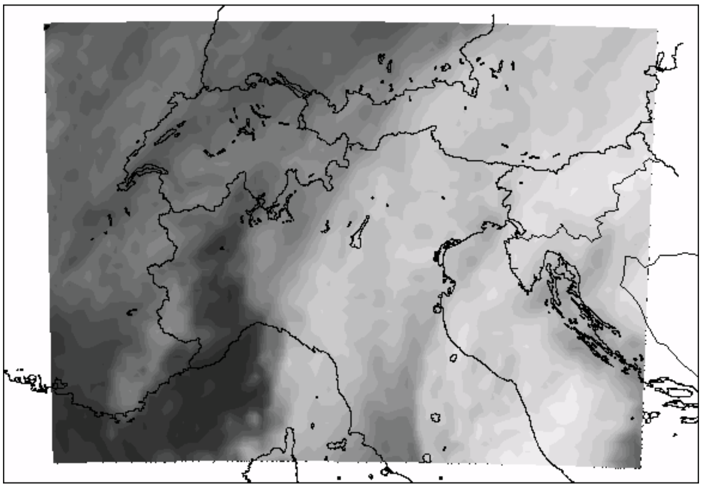

Figure 11: 10 February 1999 1100 UTC. Meteosat IR normalized image.

In the medium troposphere (not shown) the model background gives correctly saturated air, so that the satellite data improve the analysis by exactly positioning the cloud cover.

5. CONCLUSIONS

The use of remote sensing information, routinely available at many weather services, allows to closely monitor the evolution of mesoscale weather features. Furthermore, the development of techniques like LAPS, that combine together meteorological data of different sources, supplies a useful tool to meteorologists for better understanding and forecasting weather features. The major aspect of LAPS is an enhanced exploitation of available data, both conventional and non-conventional (radar, satellite etc.).

Remote sensing measurements have a crucial importance when conventional data are not available, as in case of uninhabited areas, seas, and data network failures.

The impact of the injection of meteorological radar and satellite data on the LAPS wind and humidity analysis has been explored trough the study of three representative events.

First, it has been shown how the use of radar radial wind is able to correct the preliminary wind field analysis, even at distance greater than the Doppler range. The comparison with an analysis derived from sounding information achieves a good confidence level both in direction and strength.

The second event taken into account regards a not correctly forecasted convective development over Northern Italy. The massive injection of moisture in the troposphere as a consequence of strong convection was unpredicted and consequentially missed in the background field. The satellite, on the contrary, has detected the presence of convective clouds, allowing a consistent moistening of the troposphere performed by the analysis package.

Finally, a non-synoptic time analysis has been proposed. A complete lack of surface observations in a large area of the LAPS domain has leaded to overestimate cloud cover and humidity, where the background field has correctly located drier air. The absence of clouds in the satellite field has readjusted the analysis, retaining those areas where clouds were really present.

Note that the data contribute both in correcting the background fields when they lack physical structure and content and also, on the opposite, in retaining their structure when the additional information are misleading or incomplete. In this sense the analysis is more complete and safe. Remote sensing data have, hence, improved our capability in analysing some fundamental meteorological variables that serve as input into numerical models. In the next future LAPS analyses will be the initial conditions of the local model implemented at SMR, allowing to provide frequently up-to-date short-term forecasts.

ACKNOWLEDGEMENTS

Part of the authors acknowledge the support of the European Union through contract ENV4-CT98-0733 CLOUDS. The authors are grateful for support from Agenzia Spaziale Italiana, Project "Studio del Ciclo Idrologico da Piattaforme Satellitari: Nubi e Precipitazioni" and from CNR Gruppo Nazionale per la

Difesa dalle Catastrofi Idrogeologiche, Project "Osservazioni di precursori di eventi estremi e gestione del rischio – Sensori remoti e precipitazioni estreme". NOAA-Forecasting System Laboratory (FSL) is acknowledged for making available the LAPS software.

REFERENCES

Alberoni, P.P., S. Costa, A. Selvini, J. McGinley, & V. Levizzani: Implementation and test of a mesoscale data assimilation system for Northern Italy. *MAP Newsletter*, 1998, **9**, 70-71.

Albers, S.C.: The LAPS wind analysis. *Weather and Forecasting*, 1995, **10**, 342-352.

Albers, S., J.A. Mc Ginley, D. Birkenheuer, & J.R. Smart: The Local Analysis and Prediction System (LAPS) Analysis of clouds, precipitation, and temperature. *Weather and Forecasting*, 1996, **11**, 273-287.

Birkenheuer, D.: An algorithm for operational water vapor analysis integration GOES and dual-channel radiometer data on the local scale. *J.Appl.Meteor.*, 1991, **30**, 834-843.

Krishnamurti, T.N., G.D. Rohaly, & H. Bedi: On the improvement of precipitation forecast skill from physical initialization. *Tellus*, 1994, **46a**, 598-614.

Mc Ginley, J.A.: The Local Analysis and Prediction System. *Prepr. 12th Conf. Weather Analysis and Forecasting*, Monterey, CA, Amer.Meteor.Soc., 1989, 15-20.

Mc Ginley, J.A., S. Albers, & P. Stamus: Validation of the composite convective index as defined by real-time local analysis system. *Weather and Forecasting*, 1991, **6**, 337-356.