VALIDATION OF SIMULATED ATMOSPHERIC FIELDS FOR AIR QUALITY MODELING PURPOSES IN ITALY

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Since 2002, on behalf of the Italian Ministry of the Environment, ENEA has been leading a national Project, named MINNI (National Integrated Modelling system for International Negotiation, http://www.minni.org/), for the development of an Integrated Assessment Modelling system to support policy makers in the elaboration and assessment of air pollution policies at international, national and local level. MINNI consists of two main components: a multi pollutant Eulerian Atmospheric Modelling System (AMS), and the GAINS-Italy Integrated Assessment Model. The atmospheric transfer matrices provide the link between the AMS and GAINS-Italy. The AMS includes emissions, meteorology and pollutants dispersion/chemistry modules. In its first version, AMS was applied to estimate pollutants deposition and air concentration fields over Italy, with a spatial resolution of 20x20 km² and an hourly time step over the whole 1999 year. An improved version of AMS with a spatial resolution of 4x4 km² has been later implemented and applied on both year 1999 and 2005 (Vitali et al., 2008). A second phase of MINNI project is presently ongoing and foresees simulations for years 2003 and 2007. The meteorological data set is used to drive MINNI project air quality simulations, but it is also distributed to Regional Environmental Protection Agencies (ARPA) and other users to support downscaling activities and air quality simulations at local scale possibly employing different air quality model types and/or different emission data sets. The 2005 simulation was carried out using LAPS (Local Analysis and Prediction System; Hiemstra et al., 2006), in order to improve spatial resolution by means of a diagnostic tool and measured data assimilation. LAPS "is a mesoscale meteorological data assimilation tool that employs a suite of observations (meteorological networks, radar, satellite, soundings, and aircraft) to generate a realistic, spatially distributed, time-evolving, three-dimensional representation of atmospheric features and processes" (Hiemstra et al., 2006). LAPS has been initialized by the 20x20 km² spatial resolution fields calculated by the prognostic non-hydrostatic model RAMS (Regional Atmospheric Modeling System; Cotton et al., 2003), and by surface observations. For air quality simulation, LAPS meteorological fields are used to drive the Flexible Air quality Regional Model (FARM, Silibello et al., 2008; Gariazzo et al., 2007).

To verify the meteorological fields reliability and possibly define the limitations of the dataset, model results for year 2005 have been compared with independent observations at both national and local level. Friuli Venezia Giulia meteorological observations were chosen as an optimal independent data set because Friuli has a complex topographical structure and the regional meteorological network provides a comprehensive cover of the different environments and landscapes. The comparison between model results from RAMS and LAPS and measured values was carried out using model evaluation statistical indexes and direct comparison of observed and modeled data.

METEOROLOGICAL MODELLING

Background National Scale Meteorological Fields

The meteorological fields at national scale have been reconstructed by means of the prognostic non-hydrostatic model RAMS (Cotton et al., 2003). ECMWF analyses, available every 6 hours with an horizontal space resolution of 0.5 degrees, have been used as background fields. WMO surface observations, retrieved from ECMWF archives, were mostly available with time frequency of 1 and 3 hours over the whole Italy. Nudging technique has been employed by RAMS to assimilate data analyses during the whole model simulation.

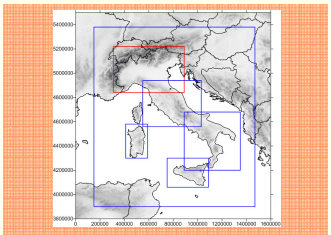


Fig. 1 MINNI National domain (20x20 km² resolution) and Regional sub-domains (4x4 km² resolution).

Regional high resolution meteorological analyses

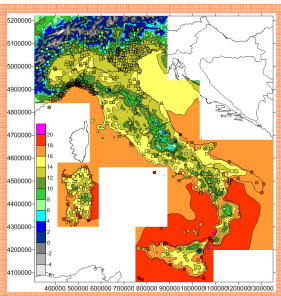
LAPS is an ensemble of modules that produce surface and three-dimensional analyses of wind, temperature, moisture and clouds merging a first guess meteorological field with observational data to generate a new atmospheric analysis. To realize an hourly representation of 2005 meteorological fields over the whole Italian peninsula, with a resolution of 4x4 km², the target domain has been subdivided into 5 sub-domains including respectively Sicily, Sardinia and Northern, Central and Southern Italy (Figure 1).

Although one of the main characteristics of LAPS is the possibility to include a wide range of measurements, for its application within the MINNI project only surface meteorological measurements were used. This choice was due to the extremely inhomogeneous time and space distribution of other available data types over Italy, while a diagnostic model needs a temporal homogeneous dataset, in order to preserve temporal continuity of meteorological fields.

METEOROLOGICAL EVALUATION

Comparison with Annual Indicators over all Regional Sub-Domains

Fig. 2 Annual mean temperature (°C): comparison between LAPS analysis field and observations from the ISPRA-SCIA database (coloured symbols).



As a first test of LAPS results, meteorological analysis fields were compared, over all the Regional sub-domains, with monthly and annual indicators calculated by Italian Superior Institute for Environmental Protection and Research (ISPRA, http://www.isprambiente.it) in the framework of SCIA database (http://www.scia.sinanet.apat.it).

Comparison was made for main meteorological variables. In Figures 2, 3 and 4 comparison is shown for annual mean temperature and wind speed and for prevailing wind direction.

A general good agreement between observed and model simulated data can be observed.

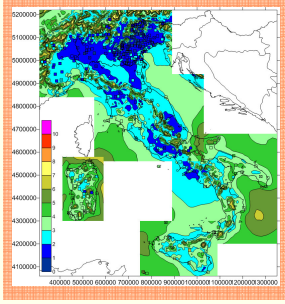


Fig. 3 Annual mean wind speed (m/s): comparison between LAPS analysis field and observations from the ISPRA-SCIA database (coloured symbols).

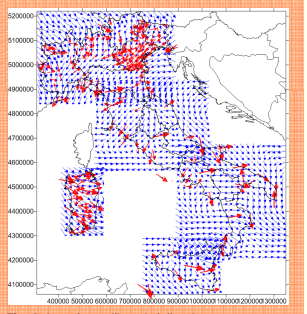


Fig. 4 Annual prevailing wind direction: comparison between LAPS analysis field (blue, one arrow every 6 grid points) and observations from the ISPRA-SCIA database (red).

Comparison with Meteorological Data over the Northern Italian sub-domain

In the frame of the Po-Valley Modelling Intercomparison Exercise (POMI, Thunis et al., 2009) a statistical comparison between simulated values and meteorological data, received from the Northern Italian Regions, was made. Statistic performances were obtained for different station types (Figure 5): plain (green), hilly (orange), valley (blue) and mountain (brown). Model provides a generally better description of meteorological fields in plain areas (Figures 6).

Fig. 5 Monitoring stations for meteorological validation in the frame of POMI exercise.

Poor performances over mountain areas were expected from a diagnostic modelling approach based on a limited resolution input measurements network insufficient to resolve topographic features, as it shown by similar results reported in literature (e.g. Hiemstra et al., 2006). The alpine valleys structure is anyway not resolved at the target model space resolution of 4x4 km².

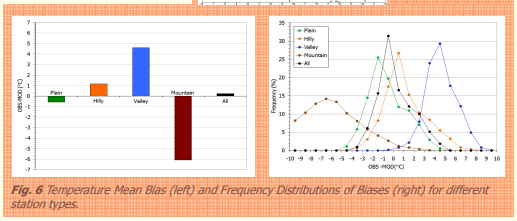


Fig. 6 Temperature Mean Bias (left) and Frequency Distributions of Biases (right) for different station types.

Comparison with Independent Observations over the Area of Friuli Venezia Giulia

Model results for year 2005 have been compared with independent observations over Friuli Venezia Giulia, an Italian region located at the North-Eastern boundaries of Italy. Friuli has a complex topographical structure and moreover, the regional meteorological network, managed by ARPA Friuli Venezia Giulia (http://www.arpa.fvg.it), provides a comprehensive cover of the different environments and landscapes (Figure 7).

The comparison of RAMS and LAPS results with observations shows that LAPS provides a generally better description of meteorological fields in the coastal and inland plain area, which is the main target for air quality assessment. An expected increase of the LAPS model performances is shown when the distance of control stations from the nearest assimilated one decreases (Figure 8). This behavior clearly represents the features of the adopted diagnostic approach providing best results when a sufficient number of good quality stations, representative of the surrounding territory, are assimilated. In spite of the difficulties of building a comprehensive and verified database of meteorological observations at national level, our results show the potential success of this approach in improving mesoscale meteorological model performances. The correction obtained by the meteorological analysis is exemplified by wind results described in Figure 9 for the stations of Udine and Grado. The overestimation of wind speed provided by RAMS, especially during the central part of the day, is removed by LAPS analysis producing a good reproduction of observations at the inland plain station of Udine and a moderate underestimation of measured data at the coastal lagoon station of Grado during the second half of the day. Even for the latter station LAPS anyway improves the reproduction of observed values (see e.g. station 3 in Figure 10). The removal of wind intensity overestimation potentially causing underestimation of near surface pollutant concentrations is a valuable results for air quality applications.

Figures 10 show respectively IOA and FB values for wind speed, temperature and humidity calculated for the 20 available stations located over the inland and coastal plain areas. In order to evaluate model performances with respect to diurnal cycle, four index values were calculated for each stations, corresponding to four different hours of the day (0, 6, 12, 18 l.s.t.). LAPS analysis correction is particularly effective for nocturnal humidity, that is generally underestimated by RAMS; diurnal overestimation, where present (see e.g. FB for stations 8 and 9 in Figure 10, lower right panel), is positively corrected too. The correction obtained for temperature is very effective for stations located at lower heights: LAPS IOA values are closer to 1 and FB closer to 0 than RAMS ones (Figure 10, middle panels).

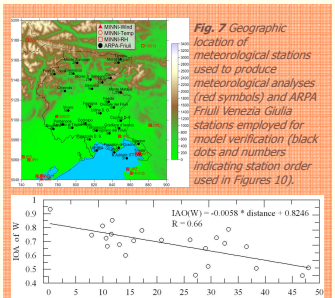


Fig. 7 Geographic location of meteorological stations used to produce meteorological analyses (red symbols) and ARPA Friuli Venezia Giulia stations employed for model verification (black dots and numbers indicating station order used in Figures 10).

Fig. 8 LAPS IOA values decrease with increasing distance of the control stations from the nearest assimilated station; only stations with terrain height lower than 300 m. a.s.l. were selected.

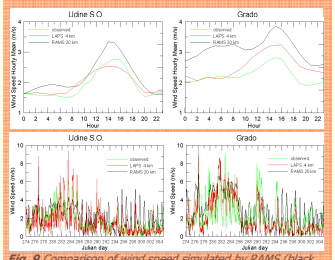


Fig. 9 Comparison of wind speed simulated by RAMS (black line) and LAPS (red line) with measurements (green line) at Udine (inland plain station, left panel) and Grado (coastal station, right panel) for hourly average values (top panel) and values measured during October 2005 (bottom panel).

In particular, the temperature diurnal cycle is better reproduced: in most cases data assimilation corrects nocturnal overestimation and reduces diurnal underestimation.

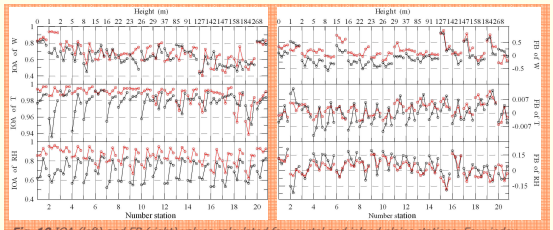


Fig. 10 IOA (left) and FB (right) values calculated for coastal and inland plains stations. Four index values are presented for each stations corresponding to four different hours of the day (0, 6, 12, 18 Local Solar Time). Black line refers to RAMS and red line to LAPS.

LAPS analysis correction effect is less evident in IOA values for wind speed and shows more variation among stations, even if a general reduction of FB absolute values is detectable. In general LAPS corrects RAMS wind speed overestimation leading to a slight underestimation at some locations.

CONCLUSIONS

The meteorological fields necessary to drive air quality simulations in the frame of MINNI project have been reconstructed by means of the diagnostic meteorological model LAPS, that has been used to downscale the background information provided by an annual simulation of the prognostic model RAMS. The comparison of RAMS and LAPS results with observations, for year 2005, shows that LAPS provides a **better description of meteorological fields in the coastal and inland plain areas**, which are the main target regions for air quality assessment. The **temperature diurnal cycle is better reproduced** by LAPS and, in particular, it corrects RAMS nocturnal overestimation. A **relevant improvement is obtained for humidity**, that is important for air quality applications because it influences PM and OH formation. The correction imposed by LAPS over RAMS **wind speed** is less clearly interpretable from statistical indicators, even if FB indicates the **correction of RAMS overestimation**, that is changed into a slight underestimation in LAPS results. This feature is quite relevant due to the influence of wind intensity on pollutants transport and dispersion. On the whole our results show the potential success of this approach in improving mesoscale meteorological model performances.

References

Cotton W.R., Pielke R. A., Walko R. L. , Liston G. E., Tremback C. J., Jiang H., Mc Anelly R. L., Harrington J. Y., Nicholls M. E., Carrio G. G., McFadden, J. P. (2003): RAMS 2001: Current status and future directions. Meteorology and Atmospheric Physics, 82, 5-29.

Gariazzo C., .Silibello C., Finardi S., Radice P., Piersanti A., Calori G., Cecinato A., Perrino C., Nussio F, Cagnoli M., Pelliccioni A., Gobbi G.P, Di Filippo P. (2007): A gas/aerosol air pollutants study over the urban area of Rome using a comprehensive chemical transport model. Atmospheric Environment, 41, 7286-7303.

Hiemstra C.A., Liston G.E., Pielke Sr. R.A., Birkenheuer D.L., Albers S.C. (2006): Comparing Local analysis and prediction system (LAPS) assimilations with independent observations. Weather and Forecasting 21, 1024-1040.

Silibello C., Calori G., Brusasca G., Giudici A., Angelino E., Fossati G., Peroni E., Buganza E. (2008): Modelling of PM10 concentrations over Milano urban area using two aerosol modules. Environmental Modelling & Software, 23, 333-343.

Thunis P., Triacchini G., White L. Maffeis G., Volta M. (2009) Air pollution and emission reductions over the Po-valley: Air quality modelling and integrated assessment. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009

Vitali L., Pace G., Zanini G., Bracco G., Miglior S., Finardi S. (2008): Application of the Local Analysis and Prediction System (LAPS) to carry out high resolution meteorological analysis at Italian national scale: implementation and first results for year 1999. ENEA RT/2008/18/ACS Report.

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