J5.5 Atmospheric Regional Reanalysis simulations, based on RAMS model, as input for crop modelling

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1. INTRODUCTION

Numerical Weather Prediction (NWP) models have been used since late ‘70s as a major tool in meteorology also to improve forecast skills. Most of such effort is made by national and international centers that manage large data sets from different sources: satellites, weather station, radio-sounding, radar which are combined with models through complex data assimilation methods.

A crucial point is the initial data and boundary conditions used during the simulations both for atmosphere and for soil - vegetation. Atmospheric initialization plays a fundamental role at both the global and regional scale where initial and boundary conditions are important all over the simulation period in order to achieve good forecast. Proper initialization of soil conditions is important for medium to long term simulation in gobal scale simulations. At the regional scale proper initialization is crucial also at shorter time scales as it may affect forecast skills especially on surface variables (Avissar 1998, Chen 1994, Golaz 2001, Meneguzzo 2001, Pielke 2001). The sensitivity is generally larger for NWP models that include a detailed descriptions of soil – vegetation – atmosphere interactions schemes. As a consequence a realistic description of the initial state and boundary conditions are therefore crucial to improve forecasts reliability.

For operational forecasting purposes the general approach is to establish a reasonable choice of the initial atmosphere and soil conditions based on available datasets, retrieved from general circulation models, satellite, weather stations, etc. But the reliability of forecasted atmospheric and soil fields decreases with the simulation time. Accordingly, such kind of datasets cannot be used extensively for non – forecasting purposes. Recently a promising approach has been proposed: the so called Regional Reanalysis where the basic idea is to force regional models using “*only*” observed or reconstructed datasets. The most relevant experience on this is provided by the North American Regional Reanalysis Project (see http://wwwt.emc.ncep.noaa.gov/mmb/rreanl/ for a complete description and documentation) that covers the entire North American area. The advantages of using such approach have become evident while those datasets are used for research and specific application purposes. In this work we present our approach for building up a regional reanalysis dataset over the Mediterranean sea basin that can be finally used for agrometeorological and crop modeling purposes.

2. THE RAMS MODEL

2.1 Introduction

The Regional Atmospheric Modeling System, RAMS, has been used operationally at La.M.M.A. (http://www.lamma.rete.toscana.it), the regional meteorological service of Tuscany (Italy) since 1999. The latest RAMS version, 5.05, is used for this study as part of a Regional Reanalysis pilot phase developed in collaboration with the Institute of Biometeorology of National Research Council (http://www.ibimet.cnr.it) (Pasqui 2000, Meneguzzo 2004, Meneguzzo 2001, Pasqui 2002, Soderman 2003, Pasqui 2004a, Pasqui 2004b).

RAMS and its predecessors have been developed since the early ‘70s essentially as a research tool; nowadays the model is widely used both for research and operational forecast purposes in many meteorological centers around the world. Since early ‘90s a large number of improvements have been introduced from both the physical (new numerical schemes) and the computational point of view (the parallel computing design). A general description of the model can be found in Pielke et al. (1992), while a technical description can be found on the ATMET web site (http://www.atmet.com).

Today RAMS represents the state-of-the-art in the atmospheric numerical modeling and it is continuously improved on the basis of a multi-disciplinary work both at Colorado State University and at several other research laboratories worldwide. In synthesis, the physical package of the model describes a number of atmospheric effects: a two-way interactive nested grid structure, an atmospheric turbulent diffusion processes according with the Mellor-Yamada scheme, a cloud microphysics parameterization, modified Kain-Fritsch type cumulus parameterization, the Harrington radiative transfer parameterization short and long wave scheme and the Land Ecosystem Atmosphere Feedback scheme (LEAF-3) for soil – vegetation – atmosphere energy and moisture exchanges, described in Walko et al. (2000).

2.2 Microphysics

Among all the physical packages within RAMS a brief description of the microphysical scheme is provided here because it specifically deals with the

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proposed sensitivity analysis. The representation of cloud and precipitation microphysics in RAMS includes the treatment of each water species (cloud water, rain, pristine ice, snow, aggregates, graupel, hail) as a generalized Gamma distribution (Pielke et al. 1992).

The RAMS 5.05 uses a second–moment scheme for parameterization of cloud microphysics. It uses a generalized gamma size-spectrum and introduces ice–liquid mixed phase hydrometeor categories for ice crystals and a sophisticated heterogeneous nucleation parameterizations. The scheme predicts concentration and mass mixing ratios of eight forms of water categories: vapor, cloud water droplets, rain, pristine ice, snow, aggregates, graupel, and hail. Only the cloud droplets are assumed to be small enough to move with the air. All other categories fall down according to the environmental conditions and their specific dynamics. The only two categories which could nucleate from the vapor are cloud droplets and pristine ice. The remaining categories are built from existing hydrometeors and, once formed, may also grow by vapor deposition. Pristine ice, which is defined as relatively small crystals may continue its growth only by vapor deposition. The snow category is defined as consisting of relatively large ice crystals, which have grown by vapor deposition and riming. Aggregates are defined as ice particles that have formed by collision and coalescence of pristine ice, snow, and/or other aggregates. Aggregates, as snow, are allowed to retain their identity with moderate amounts of riming. Pristine ice, snow and aggregates are all low-density ice particles, having a relatively low mass and fall speed for their diameter. Graupel is an intermediate density hydrometeor assuming to be approximately spherical in shape. According to the assumptions, it is formed by moderate to heavy riming and/or partial melting of pristine ice, snow or aggregates. Graupel is allowed to carry up to only a low percentage of liquid. If the percentage becomes larger, by either melting or riming, a graupel particle is re-categorized as hail. Hail, in the model, is a high-density hydrometeor, which is assumed to be formed by freezing of raindrops or by riming or partial melting of graupel. Hail is allowed to carry any fraction of liquid water up to, but not including, 100%. In this case, a hail particle is re-categorized as water. Hydrometeors in each category are assumed to conform to a generalized gamma distribution, in which the shape of the distribution is determined by a special parameter n which may be any real number larger than or equal to 1. It controls the relative amount of smaller vs. larger hydrometeors in the distribution. When n=1, the Marshal – Palmer distribution is obtained, in which the number concentration decreases monotonically with diameter throughout the size spectrum. The larger the value of n, the more narrowly distributed the spectrum is and the distribution peaks at a larger diameter.

The scheme allows hail to contain liquid water and contains the description of the homogeneous and heterogeneous ice nucleation, and the ice size change by means of vapor deposition and sublimation.

A very efficient solution technique for the stochastic collection equation and a new technique for the prediction of sedimentation or precipitation of hydrometeors, which allows the definition of the fall velocity on the basis of the gamma size distribution, has been implemented by using a “look-up” table computed at the initial step. For a detailed description of the RAMS microphysical – precipitation scheme see also Walko et al. (1995) and Meyers (1997).

2.3 Soil – Veg – Atmos interaction representation: the LEAF scheme.

The surface heterogeneities connected to the vegetation cover and the land use are assimilated and described in great detail in RAMS by means of the LEAF (Land Ecosystem Atmosphere Feedback) model.

The LEAF model (for a complete description of version 2 see Walko et al., 2000) represents the vertical exchange of water and heat in several soil layers, including the effects of freezing and melting, the temporary water and snow cover, the vegetation and the canopy air. The surface domain meshes are further sub-divided into patches, each identified by a separate vegetation cover and land use, soil type, initial soil moisture and temperature (Fig. 2.1).

The balance equations for soil energy and moisture, surface water, vegetation and canopy air, and exchange with the free atmosphere, are solved separately for each patch. A hydrological model based on the Darcy law for the lateral down-slope water transport exchanges the moisture in the sub-surface saturated layers and the surface runoff.

The LEAF model assimilates standard land use datasets to define the prevailing land cover (for instance the USGS dataset) in each grid mesh and possibly the patches, then parameterizes the vegetation effects by means of biophysical quantities.

The RAMS model, version 5.05, used in this study makes use of the third generation of LEAF. New features of this version could be summarized as follows: a consolidated scheme for the BATS and LDAS land use classes used in LEAF-2, plus the SiB2 classes, into a set of 21 land use classes with biophysical parameters. The SiB2 algorithms were implemented for computing LAI, vegetation, albedo, roughness height, and vegetation fractional coverage from NDVI data. The 5th RAMS family now uses global FAO soil types dataset and an implemented standard input of observed snow cover for initial condition is now available.

The precipitation produced by both convective parameterization and bulk microphysical scheme, within the column grid, falls down on the vegetation coverage, producing a moisture fluxes and energy due to the different hydrometeors.

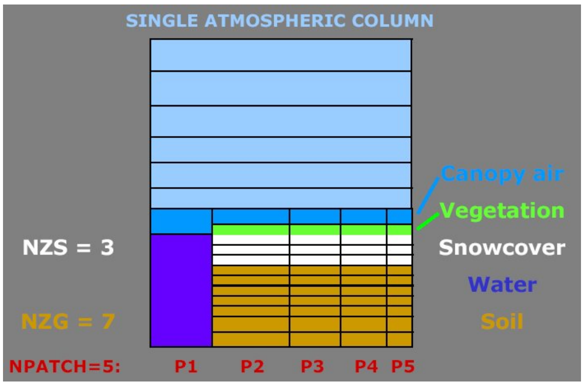

Fig. 2.1. LEAF vertical levels and patches scheme for a single RAMS column with eleven soil levels.

Such fluxes are first partitioned between water at ground and vegetation according to the vegetation fractional cover. Moisture on the vegetation surface is evaluated and when the combination of intercepted and dew formation exceeds the maximum amount that vegetation can hold it is brought to thermal equilibrium by heat transfer with vegetation and then collected in the surface water category.

3. The Regional Reanalysis Strategy

Since NCAR/NCEP Reanalysis Project released the atmospheric global dataset, a new and powerful possibility has become available to increase the knowledge of the atmosphere dynamic behavior (Kalnay 1996 and see the Project home page at http://wesley.wwb.noaa.gov/reanalysis.html). But an important space – time dynamical scale gap should be covered in order to catch regional atmospheric behavior. Parallel computing power at low costs is now a reality and, thus, dynamic downscaling using regional models is a new, real opportunity (Soderman 2003).

Due to the specific geomorphology of the Mediterranean Sea basin the low resolution Global Reanalysis datasets cannot resolve many characteristics of atmospheric regionalevents. The Alps and Appennini mountains are not well represented at such resolution. So it is important to define a "downscaling technique" for catching local atmospheric behavior. We propose a dynamic downscaling strategy using RAMS model nested into the NCAR/NCEP atmospheric fields along with a weekly high resolution sea surface temperature datasets for a long period simulation run as a pilot phase for further development.

This pilot phase started on September 2003 up to June 2004 made by a single long RAMS simulation without any model restarts.

Initial and boundary condition are those of the Reanalysis global fields updated every 6 hours while the SST fields were updated only every 8 days.

A "*two – way*" nesting technique is used for the RAMS grids at 32 km and 8 km of grid spacing as reported in fig 3.1 where the two domains are shown. Vertical discretisation is ensured by 36 levels with a stretched spacing ranging from 100 m (near the surface) to 1200 m in the free troposphere.

SST fields have been produced using a "*split window*" and a LOESS filter based on the 4 km resolution data from AVHRR (Advance Very High Resolution Radiometer) sensor on board NOAA satellites. This technique has been developed at La.M.M.A. in collaboration with the Free University of Berlin (for further details see http://159.213.57.71/sst/specifiche.html). An example of these SST fields is shown in fig 3.2.

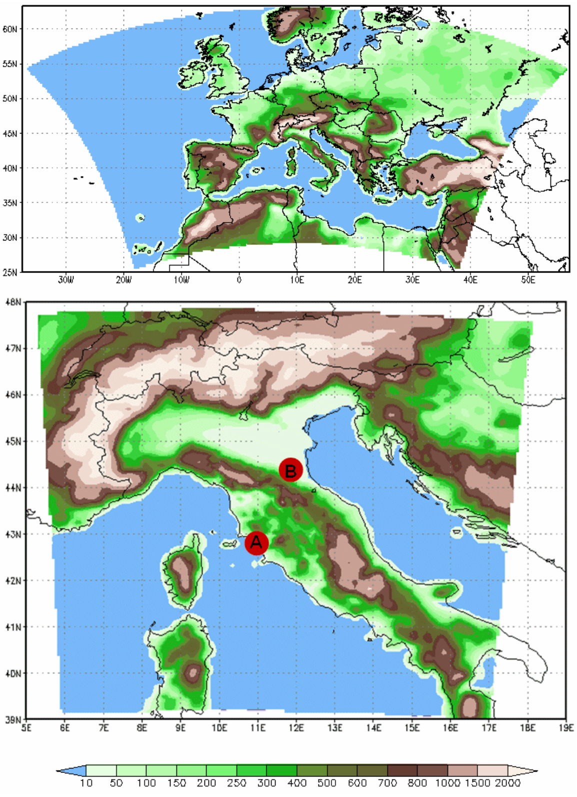

Fig. 3.1 Summary scheme of the three RAMS nested grids used, elevation is in meters. The agricultural test areas are shown in red

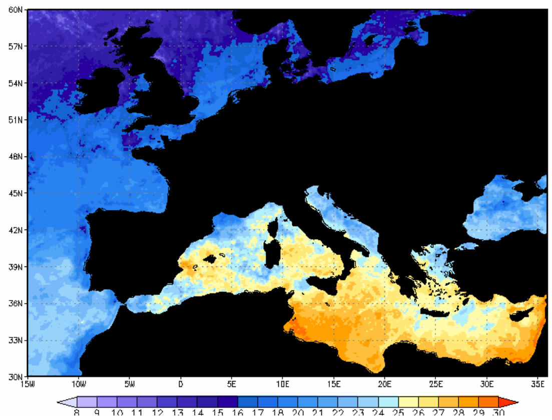

Fig. 3.2 An example of weekly mean Sea Surface Temperature field in Celsius produced for this study centered at Sep, 10th 2003.

Numerical stability issue has been ensured by typical RAMS configuration for what concerns a proper lateral nudging parameters set following previous seasonal simulations experience (Castro 2004, Gonzalo 2004, Baldi 2003a, Baldi 2003b).

4. CROP MODELLING AND CASE STUDY

Regional RAMS dataset was used as input for crop modeling in order to asses the applicability of diagnostic atmospheric datasets used in combination with crop models such as DELPHI.

The simulation model DELPHI originates from the AFRC-Wheat model that was originally developed in the UK (Porter, 1984). It is a deterministic “durum wheat” crop simulation model that uses a series of input to calculate phenological development, leaf area and biomass growth on a daily basis. Assimilation is calculated as a function of leaf area, daily mean irradiance, air temperature, water and nitrogen availability. Total evapotranspiration is calculated using Penman-Monteith equations and a soil water balance is calculated dynamically using precipitation and irrigation data. Soil properties and the main characteristics of the wheat variety (photoperiodic and vernalization responses) is also required. Allocation is described explicitly in DELPHI using a series of empirical allometric functions and modeling the mechanistic processes involved in assimilate partitioning among the different plant organs. Model output include daily and final estimates of the total above and below ground biomass of the crop as well as grain yield and the fraction of proteins in the grains. The weather parameters required in input are: maximum and minimum daily air temperature, total daily global radiation, vapor pressure deficit (VPD) calculated at 9am, mean daily wind speed, total daily rainfall and irrigation amounts. The model has been extensively calibrated and tuned for Italian conditions since 1998 and it is currently used operatively by one of the major “pasta” industries (Barilla Alimentare Spa) to make yield and quality predictions for durum wheat in Italy and elsewhere. Future model improvement include the calculation of the potential effects of pests and diseases which are not yet considered in the present version of the model.

A pilot study was made in order to evaluate the entire strategy of reconstructing coherent atmospheric fields with high reliability values. This period lasted since September 1st, 2003, up to June 1st, 2004. As mentioned before, during this period, the RAMS model has never been restarted, at all. Thus all the atmospheric forcing fields have been acting along the outer domain frame, which is 600 km thick. Even though an extensive evaluation of free troposphere fields is in progress and is not shown here, the first results showed a good agreement with the original Reanalysis datasets. A deeper understanding of spectral description of both datasets are needed over the Mediterranean region as highlighted by Castro (2004) in order to better understand the type of applications the Regional datasets are useful for. Two agricultural test areas were selected to compare simulated and observed data over the period January to April 2004. The results of the comparison of monthly mean surface air temperature and wind speed are shown in fig 4.1 and 4.2. The monthly mean RAMS dataset better approximated observations that the Reanalysis one. This is due both to the best RAMS spatial resolution (due enhanced grid spacing) and to the better physical description for atmospheric events made by the RAMS numerical schemes.

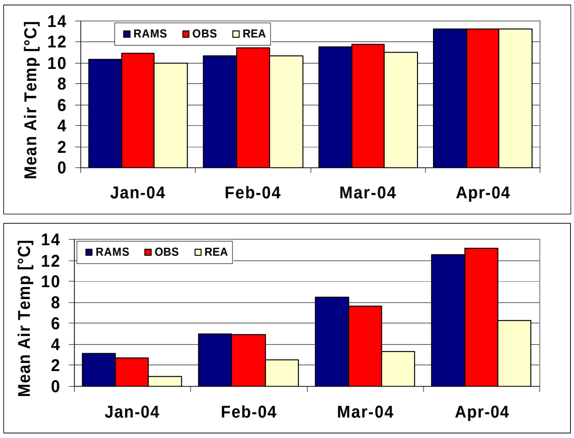

Fig. 4.1 RAMS (blue), OBS (red) and Reanalysis (yellow) monthly mean surface air temperature comparison for a selected period in the agricultural test areas: ***A*** (above) and ***B*** (below).

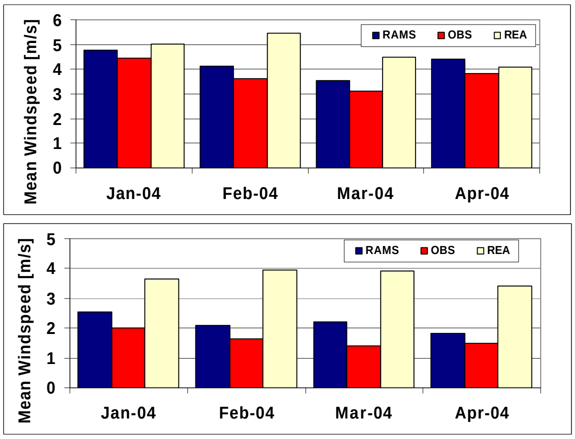

Fig. 4.2 RAMS (blue), OBS (red) and Reanalysis (yellow) monthly mean surface wind speed comparison for a selected period in the agricultural test areas: ***A*** (above) and ***B*** (below).

5. DISCUSSION AND CONCLUSIONS

In this work we have described a pilot phase study of a dynamic downscaling technique that uses the RAMS model nested into NCAR/NCEP Reanalysis dataset and high resolution weekly SST fields to build up coherent – high reliability atmospheric datasets for crop modeling and agricultural application.

The proposed strategy demonstrated a rather accurate matching between atmospheric dataset provided by the RAMS model and observations. These preliminary results seem promising thus encouraging not only further verification of RAMS atmospheric data trends, just for seasonal analysis studies, but also a further verification of application based on the Regional Reanalysis datasets.

6. ACKNOWLEDGMENTS

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