J3.6 A SOIL MOISTURE INITIALIZATION METHOD, BASED ON ANTECEDENT PRECIPITATION APPROACH, FOR REGIONAL ATMOSPHERIC MODELING SYSTEM: A SENSITIVITY STUDY ON PRECIPITATION AND TEMPERATURE.

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1. INTRODUCTION

Numerical Weather Prediction (NWP) models have been used since late '70s as a major tool for supporting human activities. Since the very beginning the NWP models have represented one of the main issue to improving forecast skills. Most of such effort is attempted by large national and international centers that manage large data sets and different sources: satellites, weather station, radio-sounding, radar which are ingested into models through complex data assimilation methods.

At global scale, soil initialization plays a major role on medium to long term simulation while at regional scales such impacts are important at shorter time scales affecting forecast skills especially on surface variables as described in several papers Avissar (1998), Chen (1994), Golaz (2001), Meneguzzo (2002), Pielke (2001). Further more such sensitivities are larger on those NWP models which include a detailed descriptions of soil – vegetation – atmosphere interactions schemes. As a consequence a reasonable description of the initial state is therefore crucial to improve forecasts reliability.

For case studies the general approach is to establish a reasonable choice of the initial soil state based on available datasets, retrieved from satellite, weather stations or specific soil state bulletins. Another strategy is to derive the initial soil state from Global Circulation Models, but such fields are generally not due to real observed precipitation fields and with a coarse spatial resolution.

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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. RAMS version 5.05 is used for this study as part of a pilot data assimilation technique developed in collaboration with the Institute of Biometeorology of National Research Council (http://www.ibimet.cnr.it), Pasqui (2000), Meneguzzo (2003), Meneguzzo (2002), Pasqui (2002), Soderman (2003).

RAMS and its predecessors have been developed since the early '70s essentially as a research tool; nowadays it's 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 (http://www.atmos.colostate.edu) and at several research and operational centers worldwide. Only few peculiar features of RAMS are shortly described below, leaving the details to the direct reading of the reference papers.

2.2 Microphysics

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 see Pielke et al. (1992), Walko et al. (1995) and Meyers (1997).

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.

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 (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 has the third generation of LEAF. New features in this latest 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.

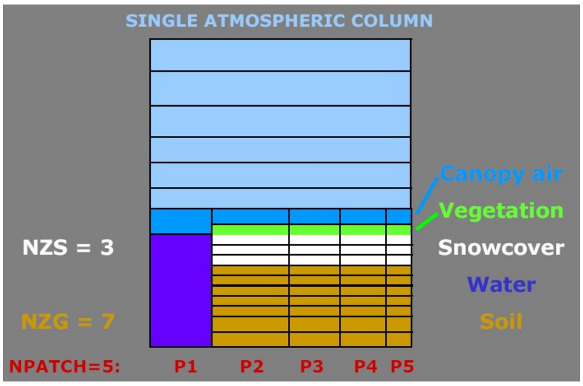

Fig. 2.1. LEAF vertical levels and patches scheme for a single RAMS column with eleven soil levels.

Such fluxes are first partitioned between water at ground and vegetation according to the vegetation fractional coverage. 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 RAPI Model

3.1 Introduction

The soil initialization state is very important on a wide range of behavior in weather forecast but availability of such information as first guess field is difficult. The new version of RAMS provides a method to produce initial soil state computed from simulated atmospheric and observed precipitation fields. In other words it is possible to run the LEAF model prescribing both the atmosphere state and rainfall, which, for example, could be the observed one. The atmosphere state is provided by a previous atmospheric RAMS simulation. It is clear that if an observed rainfall is used to force the water budget, the atmospheric forcing is not identical to the real one that produces the observed rainfall ingested. Differences in water exchange between soil – vegetation – air between the real one and the simulated could be important. But such soil first guess field posses some benefit like, a better realism on the evaluated water amount respect to what is just forecasted, better description of heterogeneity due to the acting hydrology model within LEAF, longer description of water cycle forcing respect to a simple initial estimation of soil state retrieved, for example, by a satellite.

3.2 RAPI – Scheme description

The soil initialization scheme is based on a special version RAMS called RAPI (RAMS Antecedent Precipitation Index). The RAPI model needs two different types of input:

1. *Precipitation Fields*: a distributed map of rainfall over the interest area and the selected time period (satellite estimate, radar, raingauges);

2. *RAMS Atmospheric Fields*, computed in a separate RAMS run on the same time period.

Using such information RAPI model computes energy balance, as the RAMS actually does, between atmosphere, prescribed from a previous RAMS run, and the provided rainfall fields. A complete strategy scheme is presented in fig 3.1. Using the observed rainfall has the advantage of computing a better and realistic water budget, at soil level, both for heterogeneity and reliability. Several benefits of using RAPI, both from a physical and an operational point of view, should be highlighted:

- The provided information on observed precipitation, using a simple preprocessing tool, is projected on a regular RAMS grid thus at the same resolution of the simulation. The observed precipitation should be provided on a regular Lat/Long area covering the interest area. The RAMS standard method for ingesting geographical information such as Sea Surface Temperature or Soil/Vegetation Dataset, is used providing a simple way for data input.
- The observed precipitation, once projected on the interest area, posses the same topography as model grids, so a basins budget could be more reasonable than soil moisture or temperature interpolation coming from a coarser grid simulation (e.g. a GCM field).
- This method could be simply nested , in time, in order to build up budget over long period. Subsequent simulation could be "*appended*" in the operational production cycle providing the continuity of the soil state information flow, describing in a proper way the long term behavior of soil.
- Due to the reduced number of equations solved in the model system, the RAPI run is computationally efficient.
- The method does not need only "*full real-time"* observed precipitation, because RAPI could be run, for example, at the end of a day in order to provide initial soil state for the following day simulation. So a simple RAPI use in an operational chain is possible.

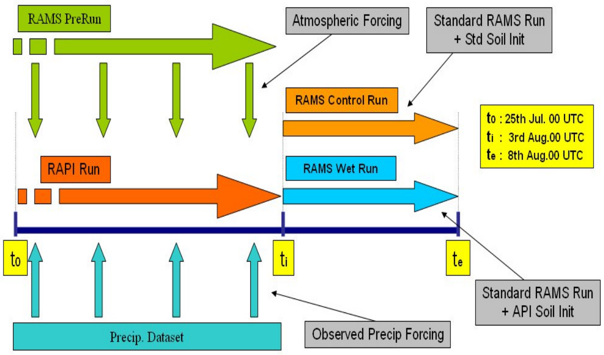

Fig. 3.1 Simulation time scheme proposed in this study, the RAPI model is forced by Precip. dataset and a RAMS atmospheric PreRun to produce a Soil.Init state used by the RAMS Wet Run. A simulation with a standard Soil.Init is used as the RAMS Control Run.

3.3 RAPI Step by step.

The RAMS simulation has performed on a 2002 summer period in order to stress the soil influence on low level atmospheric behavior and, in order to explain how the RAPI model works, a brief step by step description is presented here.

The RAMS simulation was performed using a 3 nested grids configuration at 32 – 8 – 2 km of horizontal resolution and 36 vertical levels with a resolution ranging from 50 m to 1100 m and 11 ground level down to -1.5 m with a stretched resolution. Initial and boundary conditions, every 6 hours, were from NCEP/NCAR reanalysis fields, Kalnay et al. (1996), while sea surface temperature, at 1° of resolution, were the weekly mean Reynolds reconstructed SST from NOAA. Initial soil condition was set as a standard operational run as follows:

- *Initial Soil Temperature*: it is set with an initial offset of the lower level atmospheric temperature, ranging between 1 and -1 °C (from top to bottom level) homogeneously distributed over the whole area. This is the standard soil RAMS initialization.
- *Initial Soil Moisture*: it is set to a typical medium - dry soil prescribed value, equal to 0.04. This is the fraction of total soil volume that is not occupied by solid soil particles (i.e., it is the fraction of total soil volume that is occupied by air plus water). Such value is the initial prognostic soil moisture, which is

in units of cubic meters of water per cubic meter of total volume, where that total volume is comprised of water plus air plus solid soil particles. Therefore such value is soil type dependent.

A run, called **PreparationRun** (**PR** hereafter) was started from 25th July 00 UTC to 3rd August 00 UTC, with the 3 grids configuration described above. The RAMS analysis file over such period represents the hourly "*atmospheric forcing*" for the RAPI model.
A hourly precipitation dataset, based on satellite estimation algorithm, Turk (2000) and Levizzani (2002), was collected over Europe and North Africa for the 25th July – 3rd August time period. Such data were stored on the RAMS standard Lat/Long format (same as SST, Vegetation Cover, Soil Textural Classes, etc.) as mentioned before and represent the "*observed precipitation*" dataset.
Once such files were available, the RAPI model could be run using these two input - datasets. The RAPI model, being able to run quickly, could run over the same period as RAMS, on a single processors in less than one hour, so about 30 times faster then the RAMS simulation over the same period on the DESMO Linux Cluster (see http://www.lamma.rete.toscana.it for details).
Once the RAPI simulation is completed, its output files can be directly ingested into RAMS for soil initialization. The soil state at 3rd August 2002, at 00 UTC, was selected as the initial time step for the **WET-Run** simulation (**WR** hereafter). A **CONTROL-Run** (**CR** hereafter) run were used to evaluate differences, initialized with a prescribed initial soil state (see fig 3.1 for the simulations scheme). The proposed sensitivity study can be summarized as follows: three simulation with same RAMS configuration, a **PR**, a **CR** and a **WR** where the only difference between **CR** and **WR** is the soil state at the initial time i.e. 3rd August at 00 UTC.
Because of the long period covered, the **PR** simulation is computationally expensive. Therefore such approach could, in principle, reduces the range of possible applications, but, due to the RAMS flexibility an alternative approach is available. For example, based on the same simulation framework, the **PR** could be executed with only the coarse grid and then finer grids could be added later using the "*history restart*" RAMS procedure.

4. CASE STUDY

4.1 Data and results

Model RAMS is used for regional high-resolution atmospheric simulation in the Mediterranean area. In Fig. 4.1 the three RAMS nested grids used in the study are presented along with their elevation values.

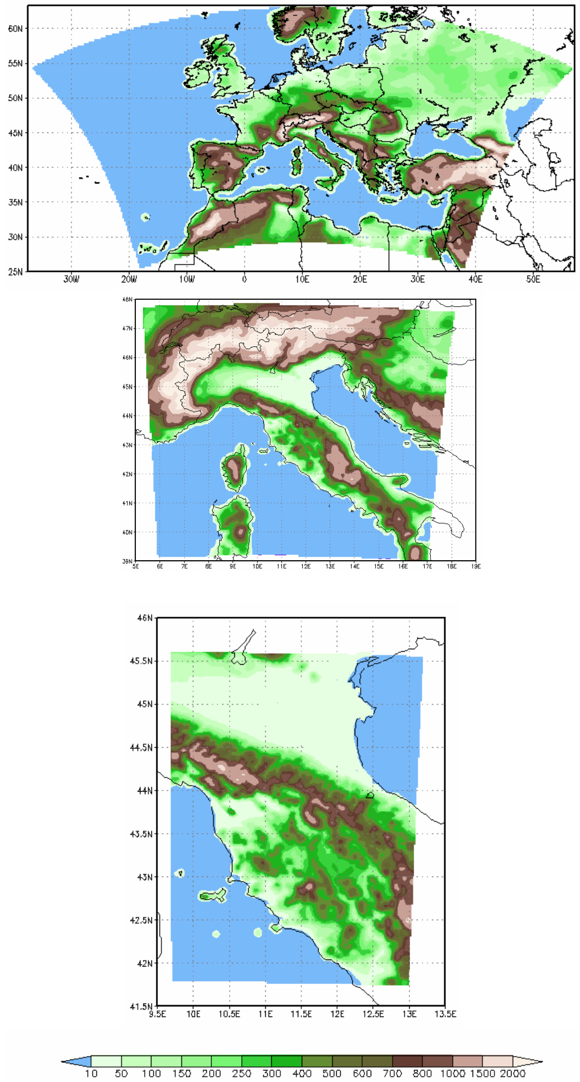

Fig. 4.1 Summary scheme of the three RAMS nested grids used, elevation is in meters.

Fig 4.2 shows the initial soil moisture for **WR** provided by the RAPI run, at the end of the **PR** to be compared with the standard **WR - CR** difference, shown in fig 4.3. In fig 4.4 the soil temperature differences **WR – CR** and in fig 4.5 the dew point differences on the finer grid are shown.

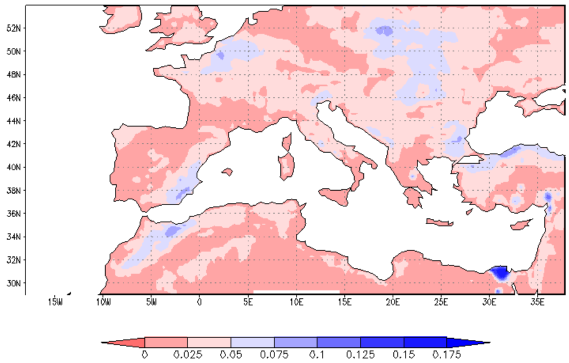

Fig 4.2 Initial soil moisture, on the coarser grid used as init soil moisture state in the WR expressed as cubic meters of water per cubic meter of total volume, where that total volume is comprised of water plus air plus solid soil particles at 3rd Aug 2002, 00 UTC.

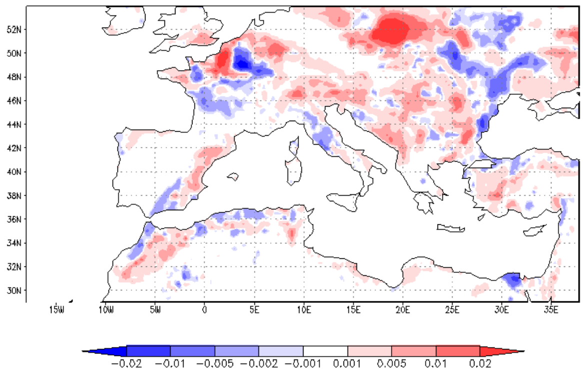

Fig 4.3 Initial soil moisture difference, expressed cubic meters of water per cubic meter of total volume, where that total volume is comprised of water plus air plus solid soil particles, on the coarser grid at 3rd Aug 2002, 00 UTC.

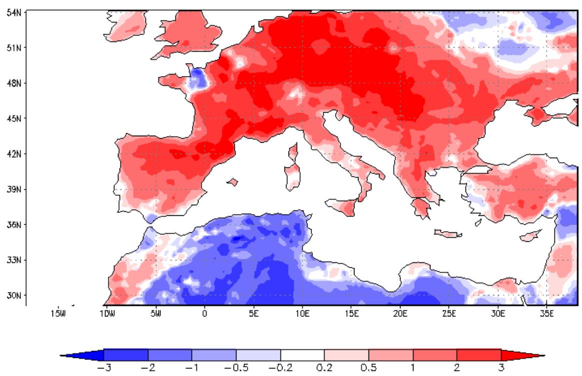

Fig 4.4 Initial soil temperature difference, WR – CR expressed in °C, on the coarser grid at 3rd Aug 2002, 00 UTC.

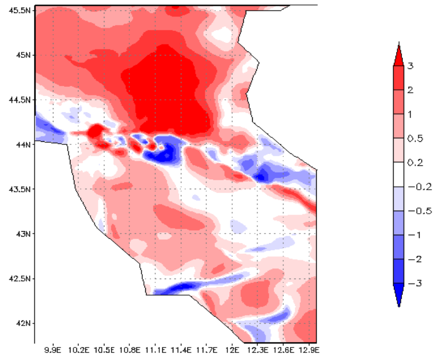

Fig 4.5 Initial dew point temperature difference, WR – CR expressed in °C, on the finer grid, 3rd Aug 2002, 00 UTC.

Observed rainfall amount Rudolf (1994), Rudolf (2003) from the Global Precipitation Climatic Centre (GPCC Homepage: http://gpcc.dwd.de) over the **PR** time period is shown in fig 4.6 while in the fig 4.7 the same on the **WR**/**CR** time period.

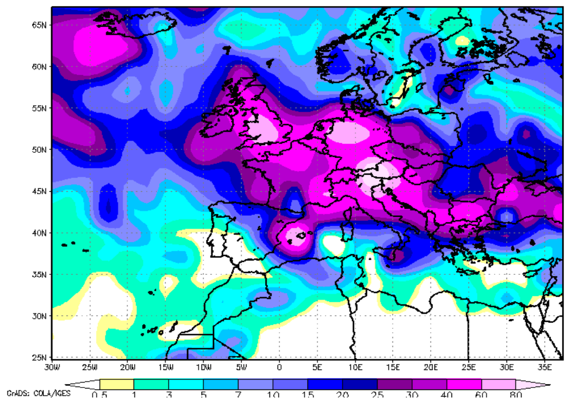

Fig 4.6 Observed rainfall, from the GPCP project, for the **PR** time period.

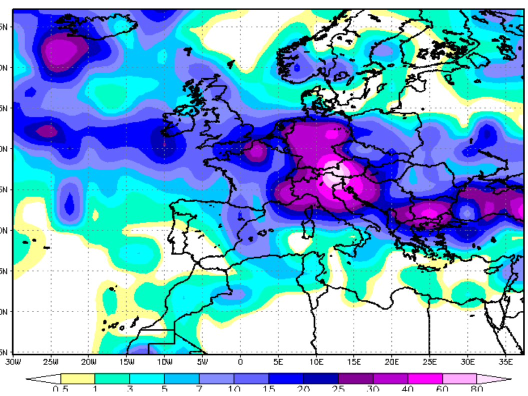

Fig 4.7 Observed rainfall, in mm, from the GPCP project, for the **WR/CR** time period.

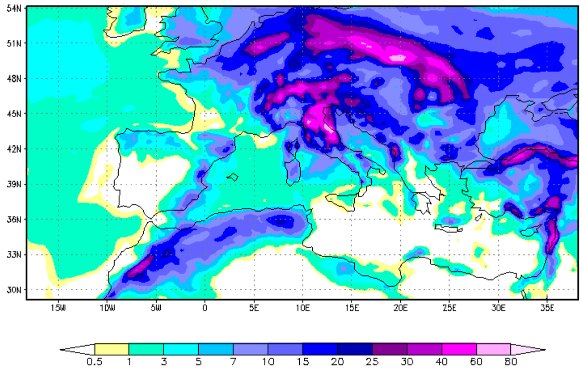

Fig 4.7 Accumulated RAMS rainfall amount, in mm, for the CR, for the 3rd – 8th August time period.

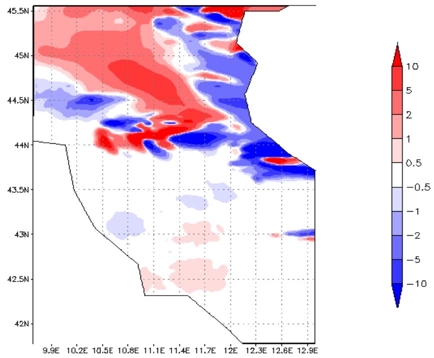

Fig 4.8 Accumulated RAMS rainfall amount difference, in mm, for the WR - CR, for the finer grid for the 3rd – 8th August time period.

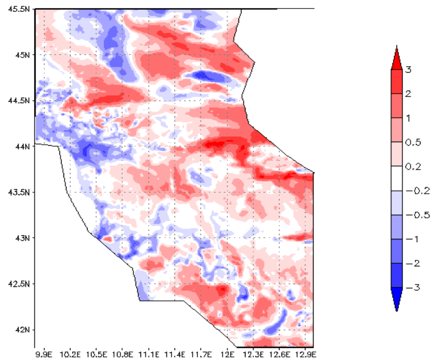

Fig 4.9 Final surface atmosphere temperature difference, expressed in °C, WR – CR, on the finer grid, 8th Aug 2002, 00 UTC.

At the end of the simulation period, after 120 hours of run, differences on precipitation and surface atmosphere temperature are shown in fig 4.8 and 4.9 from the finer RAMS model grid. Several dipoles structure were presented, showing that possible displacement of meteorological structure happened.

5. DISCUSSION AND CONCLUSIONS

In this work a new possible application of RAMS model is presented and explained using a summer 2002 case study. Only qualitative evidence of possible impacts are shown while, for quantitative estimates of benefits further study should be done. The simple usage of the RAPI model to build up reasonable the soil state as first guess field, encouraging a large range of application, from now–casting to regional climatic purposes. The RAPI model could be an important tool in order to estimate the soil wetness thresholds for hydrological application, especially for supporting the river basins monitoring systems.

6. ACKNOWLEDGMENTS

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