SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	A general-purpose data assimilation and forecasting system
Computer Project Account:	spitfede
Start Year - End Year :	2013 - 2014
Principal Investigator(s)	Stefano Federico
Affiliation/Address:	ISAC-CNR (Istituto di Scienze dell'Atmosfera e del Clima, - Consiglio Nazionale delle Ricerche)
Other Researchers (Name/Affiliation):	None

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The main task of this project was to improve and test a new data assimilation and forecasting system, named CRAMS (Calabria Regional Atmospheric Modelling System), which is developed at ISAC-CNR.

CRAMS is composed by two main components: an analysis package and a forecasting model. Both components are based on the RAMS (Regional Atmospheric Modelling System; Pielke, 2002. The references list is reported in the "Summary of results" Section.), which is used since 2005 in southern Italy to produce operational weather forecasting at the mesoscale (Federico, 2011). This project mainly focuses on the development of the 3D-Var data assimilation system, nevertheless, especially on the second year, the foacus was also on the set-up of a scheme to predict the electric activity in RAMS.

To better define the framework of thus special project, it should be mentioned that a version of the RAMS model is maintained at ISAC-CNR and is operational in southern Italy (Federico, 2011).

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

Few problems occurred at the start of the project. Most of them were caused because I was new to c2a and to the ECMWF computing environment, while I used ecgate mainly to retrieve data from MARS. Most of the initial problems pertained to the use of the xlf90 compiler and ar command on c2a. I was aided by the ECMWF staff to compile the RAMS model, which uses both C and Fortran routines. Moreover, RAMS uses HDF5 and some work was done to fix few problems with HDF5 routines because the version I used was not the same installed on c2a. However, also in this case, the support of the ECMWF staff was excellent.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The framework of the Special Project is really interesting and amazing. The staff support is excellent, the documentation is right and most of the tools that I use in my work are there (including IDL on ecgate). The only problem that I would like to mention is the duration of the jobs. The 24 h job limit may be not enough for specific, time consuming applications. In other terms, while it is well possible to develop modelling tools using, for example, coarse grid resolutions, it would be helpful to run jobs that last more than 24 h. In my experience jobs up to 72 h would be welcome.

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

During the first year of this special project the work focused on the development of the 3D-Var component of the analysis package for the RAMS (Regional Atmopsheric Modeling System, Pielke, 2002) model.

This model doesn't have a variational data assimilation system, while it has several tailored ad hoc methods like nudging and dynamical adaptation.

It is important to mention that a 4D-Var data assimilation system is already in use for RAMS (Zupanski et al., 2005; Polkinghorne et al., 2009). Nevertheless, this code is not available to the RAMS community, and the aim of this project was to realize a simple but effective variational system, suitable for applications and operational implementation in small meteorological centres.

The 3D-Var, indeed, requires less computational resources compared to 4D-Var (Rabier et al., 2000) or Ensemble Kalman filters (Anderson, 2001); it does not require the adjoint model and is simpler to implement. Of course there are drawbacks because of this "simplicity", the most important being the use of a constant forecast error covariance matrix.

The analysis system uses the incremental formulation of the cost-function (Courtier et al., 1994), ensuring that the analysis imbalance is kept at minimum as the first guess, to which the increments are added, is already balanced because it comes from the output of a numerical model. Moreover, a control variable transform is used to make the minimization of the cost-function practicable.

An important functionality of the 3D-Var is the possibility to use the same horizontal coordinate system as RAMS. RAMS uses a rotated polar stereographic projection, whose pole is near the centre of the domain to minimize the projection distortion (Pielke, 2002). In the vertical direction, RAMS uses the sigma-z terrain following coordinate (Pielke, 2002), while the analysis uses pressure.

The possibility to run the analysis on the same horizontal coordinate system as RAMS, eventually with coarsened horizontal resolution to speed-up the analysis, is an important feature because it simplifies the interpolation between the RAMS and analysis grids. The option to run the analysis on a regularly spaced longitude-latitude grid, as shown in Federico (2013) is still available to use the ISAN (ISentropic Analysis) package, which is the standard method to initialize RAMS (see the RAMS technical manual available at http://www.atmet.com/html/docs/rams/rams_techman.pdf).

Finally, the analysis package and RAMS model were completely integrated in a cycling mode.

The main result of the implementation of the 3D-Var system is synthetized in the work Federico (2013).

In the second year the attention was on the forecast and assimilation of lightning data. *Unfortunately, the assimilation procedure, while realized, is not yet fully tested and the following part of the report refers to the lightning scheme implemented in RAMS.*

The methodology implemented to simulate the lightning in the RAMS model is inspired from the works of Dahl et al. (2011a, 2011b). The method gives the flash density at the resolution of the RAMS grid-scale allowing for a detailed analysis of the evolution of simulated lightning activity. The methodology differs from Dahl et al. (2011a, 2011b) because it is designed to account for the differences of the meteorological models used and to focus on the charge separation processes occurring in the charging zone, and it also uses a different method to spatially distribute the simulated lightning associated to the convective cells.

More in detail, the method assumes a plane capacitor scheme and is based on the idea that the flash rate is not only determined by the charging rate, but also by the geometry-dependent discharge strength of each lightning flash. The flash rate is given by:

$$f = \gamma j \frac{A}{\Delta Q} \tag{1}$$

where f is the flash rate (s^{-1}), γ is the lightning efficiency (0.9), A is the area (m^2) of the plane plate capacitor, j ($Cm^{-2}s^{-1}$) is the charging current, and ΔQ (C) is the charge neutralized by the lightning.

For the application of this approach the geometrical properties of the capacitor need to be determined. These properties are formulated using the ice and graupel fields from the cloud resolving model and the idea underlying the parameterization is that the graupel contains the negative charge, while the ice has the positive charge. The charge is separated by the non-inductive graupel-ice mechanism (Saunders, 2008). In the formulation of the methodology, the ice field is given by the sum of pristine ice, snow and aggregates, while the graupel field is given by the sum of the graupel and hail hydrometeors.

The graupel region is identified by the region where the graupel concentration (g/m^3) is larger than 0.1 g/m^3 and the temperature is between 273 and 248 K. This limits the identification of the graupel cells into the charging zone. The ice region is identified by requiring its concentration larger than 0.1 g/m^3 and the temperature below 273 K.

In general, for an instantaneous output of the meteorological model, several ice and graupel cells are found. To identify them, the Hoshen and Kopelman (1976) labelling algorithm is used. This method, which was originally developed in the percolation theory, is an efficient way for labelling as a “cell” a continuous field satisfying some properties (for example graupel concentration larger than 0.1 g/m^3 and temperature between 273 and 248 K).
The methodology has been tested for six-case studies occurred in central Italy in fall 2011 and fall 2012. A detailed discussion of these cases, as well as of the methodology used to simulate lightning into the RAMS model, has been reported in Federico et al. (2014).
It is finally noted, that the comparison of simulated and observed lighting activity is an immediate and powerful tool to assess the model ability to reproduce the intensity and the evolution of the convection.
Another point that was considered in the second year of the special project was the verification of the RAMS model. This activity developed following two main directions: a) the verification of the surface parameters predicted by the model, and; b) the application of the RAMS forecast in the context of the wind power forecast.
For the first point, the performance of the RAMS model was evaluated for surface parameters: temperature, relative humidity wind speed and direction, and precipitation. With the exception of the precipitation, the verification has been performed by computing statistical scores for SYNOP stations over southern Italy, both land and mobile, distributed through the Global Telecommunication System (GTS) network. A dense non-GTS network over Calabria, southern Italy, is used for precipitation.
Results show that RMSE is about 2-3 K for temperature, 12-16 % for relative humidity, 2.0-2.8 m/s for wind speed and 55-75° for wind direction, the performance varying with the season and with the forecasting time. The error increases between the first and third forecast day. The verification of the rainfall forecast shows that the model underestimates the area of the precipitation, but the position of the forecast precipitation is well predicted. The performance of the RAMS forecast is detailed in Tiriolo et al. (2015a).
For the application of the RAMS forecast in the context of the wind power forecast, the RAMS model was used to explore the following two points: a) to show the performance of the power forecast for a wind farm located in the Apennines, in Central Italy, where the orography is complex; b) to show the impact of the horizontal resolution of the meteorological forecast for the specific site.
To explore the last point, the performance of two 48 h wind power forecasts using the winds predicted by the Regional Atmospheric Modeling System (RAMS) for the year 2011 were compared. The two forecasts differ only for the horizontal resolution of the RAMS model, which is 3 km (R3) and 12 km (R12), respectively. Both forecasts use the 12 UTC analysis/forecast cycle issued by the European Centre for Medium Weather Range Forecast (ECMWF) as initial and boundary conditions.
The R3 reduces the RMSE of the predicted wind power of the whole 2011 by 5% compared to R12, showing an impact of the meteorological model horizontal resolution in forecasting the wind power for the specific site.
The performance of the application of the RAMS forecast in the context of the wind power forecast is detailed in Tiriolo et al. (2015b).

References:

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Federico S., E. Avolio, M. Petracca, G. Panegrossi, P. Sanò, D. Casella, and S. Dietrich, 2014: Simulating lightning into the RAMS model: implementation and preliminary results. Nat. Hazards Earth Syst. Sci. Discuss., 2, 3351-3395, 2014 www.nat-hazards-earth-syst-sci discuss.net/2/3351/2014/ : doi:10.5194/nhessd-2-3351-2014

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Tiriolo, L., Torcasio, C., R., Montesanti, S., Federico, S.: Verification of a real time weather forecasting system in southern Italy, *Advances in Meteorology*, Volumes 2015, 14 pages, 2015a. http://dx.doi.org/10.1155/2015/758250.

Tiriolo, L., Torcasio, R. C., S. Montesanti, A. M. Sempreviva, C. R. Calidonna, C. Transerici, and S. Federico: Forecasting wind power production from a wind farm using the RAMS model. Atmosheric Science and Research, *in press, 2015b.*

List of publications/reports from the project with complete references

Four papers have been published within the framework of this project. They are listed below:

Federico, S.: Implementation of a 3D-Var system for atmospheric profiling data assimilation into the RAMS model: initial results, Atmos. Meas. Tech., 6, 3563-3576, doi:10.5194/amt-6-3563-2013, 2013.

Federico S., E. Avolio, M. Petracca, G. Panegrossi, P. Sanò, D. Casella, and S. Dietrich, 2014: Simulating lightning into the RAMS model: implementation and preliminary results. Nat. Hazards Earth Syst. Sci. Discuss., 2, 3351-3395, 2014 www.nat-hazards-earth-syst-sci-discuss.net/2/3351/2014/ : doi:10.5194/nhessd-2-3351-2014.

Tiriolo, L., Torcasio, C., R., Montesanti, S., Federico, S.: Verification of a real time weather forecasting system in southern Italy, *Advances in Meteorology*, Volumes 2015, 14 pages, 2015a. http://dx.doi.org/10.1155/2015/758250.

Tiriolo, L., Torcasio, R. C., S. Montesanti, A. M. Sempreviva, C. R. Calidonna, C. Transerici, and S. Federico: Forecasting wind power production from a wind farm using the RAMS model. Atmosheric Science and Research, *in press, 2015b.*

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

For 2015 I did not present any special project because I'm busy with the set-up of computing resources at home. However, the experience with the Special Project was really good and I'm planning for a second Special Project in 2016, with the development of the microphysical scheme of the RAMS model. Another important problem that I would like to consider is the assimilation of the lightning into the RAMS model.