Summer School

Modeling Techniques for Weather Forecast Applied to the Environment

Santiago de Compostela

15 -18 July 2001

Organized by:

Unidad de Observación y Predicción Meteorológica
Grupo de Física No Lineal
Facultad de Físicas
Universidad de Santiago de Compostela

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Program of the Summer School

Santiago de Compostela, 15-18 July 2001

15 th Sunday. Meteorological Models

09:15 Opening session
V. Pérez Muñuzuri. Faculty of Physics. University of Santiago de Compostela

09:30 Modeling Techniques for Weather Forecast Applied to the Environment
J. Casares. Consellería de Medio Ambiente. Xunta de Galicia

10:00 Numerical Modeling for Weather Forecast
B. Codina. Universitat de Barcelona

11:00 Mesoscale Model Nesting and Boundary Conditions
J. Dudhia, NCAR, Boulder, Colorado (USA)

12:00 *- Coffee break -*

12:30 The Hirlam-5 Project. Modelling at the Spanish Meteorological Institute (INM)
E. Rodríguez, INM

13:00 Numerical Weather Forecast in Galician Region (Spain) by Using Non-Hydrostatic Numerical Models (ARPS and MM5)
M. J. Souto. University of Santiago de Compostela

13:30 *- Lunch -*

16:00 Computer Laboratory for Numerical Simulation. Use of MM5 Numerical Model for Weather Forecast: First Approach.

16 th Monday. Data Assimilation Techniques and Applications

10:00 Meteorological Modeling for Fire Forecasting
C. Borrego. University of Aveiro, Portugal

11:00 Analysis and Assimilation for the ARPS Model at the Center for Analysis and Prediction of Storms
K. Brewster. CAPS. Oklahoma, USA

12:00 *- Coffee break -*

12:30 Data Assimilation with the 4D-var Method
I. Roulstone, Meteorological Office, UK

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16:00 Computer Laboratory for Numerical Simulation. Use of MM5 Numerical Model for Weather Forecast: Tests of Turbulence Parameterizations and Cloud Modeling.

17 th Tuesday. Meteorological Model Applications

09:30 Modeling the Climate at Global and Regional Scale
G. Míguez. Rutgers University (NJ), USA

10:00 Statistical and Machine Learning Techniques for Weather Forecasting
J.M. Gutiérrez, University of Cantabria

10:30 Assimilation of Time Delay GNSS Observations in NWP Models
L. Cucurull. Institut d'Estudis Espacials de Catalunya (IEEC)

11:00 Coupling of Oceanic and Meteorological Models
R. Neves. IST, Lisboa, Portugal

12:00 *- Coffee break -*

12:30 Coupling of Meteorological and Air Quality Models for Air Pollution Research
J.A. Souto, University of Santiago de Compostela

13:00 Factors Separation by Numerical Simulation: Boundary Model Physics and Dynamical factors
R. Romero, Universitat de les Illes Balears

13:30 *- Lunch -*

16:00 Computer Laboratory for Numerical Simulation. Use of MM5 Numerical Model for Weather Forecast: Discussion of Results

18 th Wednesday. Operational Forecasting

10:00 National Forecasting System of the Spanish Meteorological Service
M. Casares. Centro Meteorológico Territorial en Galicia. INM

11:00 Operational Weather Forecasting in the Catalan Meteorological Service
E. Vilaclara. Servei de Meteorología de Catalunya

12:00 *- Coffee break -*

12:30 Weather Forecasting in Galicia
J.J. Taboada. Observation and Weather Forecast Service, University of Santiago de Compostela

13:30 Closing session

14:00 *- Lunch -*

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Meteorological Modelling for Fire Forecasting

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Within the European Union, 91% of registered wildfires occurred in the Mediterranean Countries. For the period 1992-1997, the most affected country was Spain (153 859 ha burned), followed by Italy, Portugal, Greece and France. Fire prevention, control, and fighting constitute a major issue in these countries.

However, the climate and the state of the weather affect forest fires in different but inter-related ways. The climate determines the total quantity of vegetation cover available for combustion (since it controls the settling and the growth of forests) and the duration and the degree of severity of the forest fire season. On the other hand, weather conditions regulate the moisture content of the dead biomass, and consequently its inflammability potential. Therefore, ignition of forest fires is strongly related to weather conditions and their propagation is also affected by meteorological elements, such as wind velocity and direction.

Given the dependency between forest fires, climate and weather conditions, various entities responsible for the management and fighting of forest fires throughout the world have developed mathematical tools, which relate averages and extremes of meteorological factors with the occurrence of forest fires, the so-called fire weather indexes. Based on these indexes, calculated for a specific area, it is possible to plan preventive measures against forest fires, management actions of the forest areas, through the use of controlled fires, and the permanent alert situation when extreme values of climatic factors, which are part of the fire weather index, are verified. Beyond the use of the climatic averages and daily readings of the meteorological variables values, these indexes could also be used with atmospheric circulation models results, making possible to estimate the fire weather risk index, in a certain zone, with an higher temporal and spatial resolution.

The World Meteorological Organization recommends a hierarchy of services that can be provided by weather services institutions: (i) level 1: Fire weather warnings – minimum information on dry and/or windy conditions that may occurred during fire seasons; (ii) level 2: Fire danger forecasts – when an operational fire-danger-rating system exists the weather services may be responsible for its calculation or for the forecast of a particular weather elements used in the calculation of the fire weather index; and (iii) level 3: On-site forecast services – for a highly developed fire control organization with specialized fire weather forecasters in order to produce local forecasts during large wildfires and controlled burning activities.

Different indexes are applied on several countries around the world. It is possible to find cumulative indexes like Canadian system, Orieux index (France), Carrega index, Numerical index, Nesterov (Russian Federation), Spanish index (developed by ICONA), National Fire Danger Rating System (USA), Keetch- Byram, Mac-Arthur (Australia), and more simple ones, like Angstrom and Montalegre. These indexes use surface observations from several weather elements. The Haines Index, which is mostly applied in the western part of United States, uses the vertical structure of the atmosphere, through the analysis of the stability of the lower atmosphere and of the dryness in the upper levels. Comparative studies with different indexes for Europe, performed in the scope of the European Project MINERVE, indicate the Canadian System as the best one to apply to Mediterranean countries.

References:

William E. Reifsnyder and Bryan Albers (1994) Systems for evaluating and predicting the effects of weather and climate on wildland fires. Special Environmental report Nº 11, WMO – Nº 496. World Meteorological Organization.

R. Mata Reis and D. Rijks (1997). Scales for the assessment of forest fire danger (Resolution 9 (XI-RA VI) Item g (ii)). Regional Association VI Working Group on Agricultural Meteorology. World Meteorological Organisation.

http://climate.usfs.msu.edu/climatology/firewx

Chandler, C.; Cheney, Ph.; Thomas, Ph.; Trabaud, L. and Williams, D. (1991) Fire in Forest. Volume I and II. Krieger Publishing Company. Malabar, Florida.

Carrega, P. (1997). Instantaneous and automatic identification of weather types for a forest fire decision support system. The International Journal of Wildland Fire, Fairfiled, WA., Vol.7, nº3, p265-274.

Levine, J. (1991). Global Biomass Burning: atmospheric, climatic and biosphric implications. Cambridge, Massachusetts, London: The Massachussets Institute of Technology Press.

Tackle, E.; Bramer, D.; Heilman, W. and Thompson, M. (1994). A Synoptic Climatology for Forest Fires in the NE US and Future Implications from GCM Simulations. *International Journal of Wildland Fire* 4 (**4**), pp. 217-224.

Viegas, D.; Sol, B.; Bovio, G.; Nosenzo, A. and Ferreira, A. (1994): Comparative study of various methods of fire danger evaluation in Southern Europe. Proc. of the 2nd International Conference on Forest Fires Research. Coimbra, 21-24 November 1994, Portugal. Volume II. pp.571-590.

Miranda, A. I. (1998): Efeito dos incêndios florestais na qualidade do ar. Ph.D Thesis, University of Aveiro, Aveiro, Portugal.

Flanningan, M.; Wottom, M.; Carcaillet, C.; Richard, P.; Campbell, I. And Bergeron, Y. (1998) Fire weather: Past, Present and Future. Proc. from the 3rd International Conference on Forest Fires Research and the 14th Conference on Fire and Forest Meteorology. Luso, 16-20 November 1998, Portugal. Volume I, pp. 113-128.

Borrego, C.; Barros, N.; Miranda, A. I.; Carvalho, A. C. and Valinhas, M. J. (1998): Validation of two photochemical numerical systems under complex mesoscale circulations. *23rd Int. Tech. Meeting of NATO/CCMS on "Air Pollution Modelling and its Application"*, September 28-October 2, Varna, Bulgaria, pp. 411-418.

http://www.scd.ucar.edu/vg/FIRE/Fire98Early.html

Analysis and Assimilation for the ARPS Model at the Center for Analysis and Prediction of Storms (CAPS)

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CAPS was established to seek ways of better analysis and forecasting storm-scale weather (1-20 km grid scale) especially for the forecasting of severe weather, including heavy rains, thunderstorms, and conditions impacting aviation operations. A non-hydrostatic model, the Advanced Regional Prediction System (ARPS, Xue et al, 2000, Xue et al., 2001) was developed using modern coding standards. The primary analysis package in ARPS is ADAS (Brewster 1996), which is based on the Bratseth (1986) successive correction approach. This method iteratively approaches an optimal interpolation solution, and allows for the recognition of the different observation error characteristics of each data source. A telescoping-scales approach is used to combine data from observing systems with different resolutions. Special treatment is given to Doppler radar radial winds. A cloud analysis package is included which is an adaptation and update to the LAPS cloud algorithm (Albers et al., 1996). Continuous assimilation is achieved using the increments from ADAS in an incremental analysis updating system, similar to that described by Bloom (1996).

The ARPS is operational at CAPS using modest computing resources at 32 and 20 km resolution (http://www.caps.ou.edu/wx). ADAS is also run operationally at 10 km and 1 km for special projects. Research projects have been undertaken at CAPS using other resolutions, for example, a nest of 27-9-3 km. Other centers, such as a private forecasting company in Norman, a shuttle support center at NASA, the Korean Meteorological Agency, the Univ. of Utah and the Univ. of Santiago de Compostela are also using ADAS and/or ARPS operationally.

Using time-series of Doppler radial winds it is possible to retrieve the tangential component of the wind and then the pressure and temperature perturbations. Retrieved fields can be used in ARPS or they can be ingested in ADAS to be combined with other data.

At high resolutions there are special problems due to the intermittent nature of thunderstorms. For example, the location of the thunderstorm, or phase speed of a convective system can be mis-forecasted. To accurately correct such situations, a phase-correction technique has been developed and tested (Brewster 2001a). For a case tested, the forecast improvement was retained for about 3 hours despite complex storm interactions (Brewster, 2001b).

CAPS is developing a 3D-var system for comparison to the current analysis tools and as part of the Weather Research and Forecasting (WRF) model development effort. Separately, we are planning an upgrade to the cloud analysis scheme to include more observation types, to include the phase-correction, and to make it more compatible with the ARPS cloud physics routines.

References:

Albers, S.C., J.A. McGinley, D.A. Birkenhuer, and J.R. Smart, 1996: The local analysis and Prediction System (LAPS): Analysis of clouds, precipitation and temperature. *Wea. and Forecasting*, **11**, 273-287.

Bloom, S.C., L.L. Takacs, A.M. da Silva, and D. Ledvina, 1996: Data assimilation using incremental analysis updates. Mon. Wea. Rev., 124, 1256-1271.

Bratseth, A.M., 1986: Statistical interpolation by means of successive corrections. *Tellus*, **38A**, 439-447.

Brewster, K., 1996: Implementation of a Bratseth analysis scheme including Doppler radar. *Preprints*, *15th Conf. on Weather Analysis and Forecasting*, AMS, Boston, 92-95.

Brewster, K.A., 2001a: Phase-correcting data assimilation and application to storm-scale weather prediction, Part I: Method description and simulation testing. *Mon. Wea. Rev.*, **129**, submitted for publication.

Brewster, K.A., 2001b: Phase-correcting data assimilation and application to storm-scale weather prediction, Part II: Application to a severe storm outbreak. *Mon. Wea. Rev.*, **129**, submitted for publication.

Xue, M., K. K. Droegemeier, and V. Wong, 2000: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part I: Model dynamics and verification. *Meteor. Atmos. Physics*. **75**, 161-193.

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, and D.-H. Wang, 2001: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications. *Meteor. Atmos. Physics*. **76**, 143-165.

National Forecasting System of the Spanish Meteorological Service

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1. Exposure of the Organigrama for making forecast, at the Central site in Madrid, as well as at the meteorological center of Galicia.

2. Exposure of the various forecast products, and the aplications that have forecastings for convective phenomenous and for different weather situations.

3. Forecasting for the Marine.

4. Forecasting for the Aircraft.

5. Forecasting in general for the public Institutions, Councils, Tv, radios, fire preventions, and particular people.

6. Switching of the forecast at te meteorological center and at Madrid

Numerical Modeling for Weather Forecast

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Numerical weather prediction (NWP) is the basis of current weather forecasting. It consists in numerically solving the physical equations that describe the atmospheric behaviour. Although the problem was already formulated by Bjerknes at the beginning of the 20th century[1], and a naive attempt to solve it was made by Richardson in 1922[2], it was not until the sixties that computer power had grown enough so that NWP forecasts could become a reality restricted to a few of well established and funded official centers. Things have obviously changed since then and, three years ago, Mass and Kuo[3] published a paper in which they remarked with satisfaction the transition that had been going on in the United States in weather prediction as real-time NWP was spreading from those few centers to dozens of groups across that country. According to them, such transition was due to the confluence of three developments: (1) affordability of workstations capable of making 24-36 hour forecasts at moderate to high resolution in less than 6 hours; (2) availability of mesoscale models that run efficiently on these workstations; and (3), real-time accessibility over the Internet of grid analysis and forecasts from global scale models to provide initial and boundary conditions to run regional scale models. In spite of limitations derived from the strictly enforcing of WMO regulations on meteorological data dissemination, Europe has also experienced a similar trend over the past five years. Advantages and risks of this evolution –a consequence of technological rather than scientific developments– will be discussed during the lecture, and an overview on numerical weather modeling techniques and applications will be presented based on the author's experience with the mesoscale model MASS[4].

References:

Wiin-Nielsen, A., 1995: The birth of Numerical Weather Prediction. *Tellus*, **43AB**, 36-52.

Platzmann, George W., 1967: A retrospective view of Richardson's book on weather prediction. *Bulletin of the American Meteorological Society*, **48**, 514–550.

Mass, C.F., Kuo, Y.H., 1998: Regional real-time numerical weather prediction: current status and future potential. *Bulletin of the American Meteorological Society*, **79**, 253-263.

Codina, B., M. Aran, S. Young and A. Redaño, 1997: Prediction of a Mesoscale Convective System over Catalonia (Northeastern Spain) with a nested Numerical Model. *Meteorol. Atmos. Phys.*, **62**, 9-22.

Assimilation of Time Delay GNSS Observations in NWP Models

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The impact of the 4D-VAR assimilation of GPS-derived Zenith Total Delay (ZTD) into the MM5 Modeling System during a convective event is analyzed. We focus our analysis on the integrated water vapor and precipitation fields using data gathered from a permanent network of geodetic GPS receivers.

The network consists of five Trimble 400SSI GPS receivers which form baselines ranging in length from about 100 to 350 km with maximum altitude difference between GPS sites of about 2400 m. The geographical location of the GPS sites covers from around 0º to 4º and from 40º to 43º. The complex topography of the area suggests the use of the non-hydrostatic MM5 model to better resolve the orographic effects.

We have used the GPS precise orbits and clocks as well as consistent earth-rotation parameters provided by the International GPS Service (IGS) to estimate the ZTD stochastic process at the GPS sites.

The area under study is the NW Mediterranean region which is frequently affected by situations connected with heavy rainfalls. These events are mostly the results of mesoscale convective systems which are closely related to the surface conditions and the topography of the area. In addition, this meteorological phenomena mainly occurs in the autumn season and is characterized by heavy precipitation in very localized areas (less than 50 km) and during a short time (less than two hours).

The case study is carried out on 14 September 1999 during the evolution of a mesoscale convective system which produced a large amount of precipitation in the area under study (200 mm/24 hours). This work analyzes the 6-h period from 18 UTC to 24 UTC 14 September 1999.

We have selected the 4D-VAR strategy to investigate the impact of the retrieval problem in order to make use of the large amount of observational data in time. We made use of the MM5 Adjoint Model to assimilate the observations.

The results are compared with the observations at the GPS sites. Almost all the improvement achieved with the assimilation of the ZTD observations is found for the Zenith Wet Delay (ZWD) component which is directly related to the moisture content of the atmosphere. Since the precipitation forecast is sensitive to the humidity field, the results also yielded improvement of the short-range precipitation forecast around the location of the GPS sites.

This gives us confidence on the positive impact of the GPS estimates once they are correctly assimilated. This influence, in general, will depend on the model resolution and on the area under study. This study provides preliminary results on the use of GPS data to monitor NWP systems during the evolution of deep convective systems.

References:

Bevis, M., S. Businger, T. A. Herring, C. Rocken, R. A. Anthes, and R.H.Ware, 1992: GPS Meteorology: Remote sensing of atmospheric water vapor using the Global Positioning System. *J.Geophys. Res*., **97**, 15787-15801.

De Pondeca, M.S.F.V. and X. Zou, 2001: Moisture retrievals from simulated zenith delay "observations" and their impact on short-range precipitation forecasts. *Tellus*, **53 A**.

Emardson, T. R. and H. J. P. Derks, 1999: On the relation between the wet delay and the integrated precipitable water vapor in the European atmosphere. *Meteorol. Appl*., **6**, 1-12.

Grell, G.A., J. Duhia, and D.R. Stauffer, 1994: A description of the fifth-generation Penn State/NCAR mesoscale model (MM5). *NCAR Tech. Note*, NCAR/TN-398+STR, National Center for Atmospheric
Research, Boulder, CO, 138 pp.

Zou, F. Vandenberghe, M. Pondeca, and Y.-H. Kuo, 1997: Introduction to adjoint techniques and the MM5 Adjoint Modeling System. *NCAR Technical Note*, NCAR/TN-435-STR, 110 pp.

Mesoscale Model Nesting and Boundary Conditions

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In any mesoscale model simulation, whether for operational forecasts or scientific research, considerations of lateral boundaries and possibly nesting are required. Some basic choices have to made based upon domain area requirements, resolution requirements, forecast or simulation length, computing resources and data available.

Lateral boundary conditions for regional models typically have low time and space resolutions because they are usually derived from the output of either another model or an analysis system. Because the resolution of the boundary analysis is usually coarser than the regional model, and also it is only given every 6 or 12 hours, boundary conditions are interpolated both spatially and temporally to the regional grid. This leads to a degradation of the model's fine-scale results, particularly near inflow boundaries. It is therefore important to maximize the distance between the boundaries and areas of interest in the domain to allow the model to develop fine-scale structures, such as fronts or topographically forced features, within the domain. A quantitative guideline is to use an advective velocity and a forecast time to determine a minimum distance upstream to put the boundary. For example, for a 30 m/s advective velocity and a 24 hour forecast this distance is about 2500 km, and the total domain size may need to be 4000 km on a side.

Often local topographic features need to be resolved to accurately represent the meteorology in a region, or in flat regions high resolution may be needed to represent convective systems accurately. Given the above constraints on domain size and the resolution for local forecasts, nesting is often the most efficient way of meeting both needs. There are two classes of nesting, "one-way nesting" and "two-way nesting". For one-way nesting, first a coarse domain is run, then its output is used to interpolate initial and boundary conditions for a nest with a smaller grid size, and the nest is run. For two-way nesting the coarse and nested domains run together with the coarse domain providing boundary conditions at every time-step to the nest, while the nest feeds back information in its interior to the coarse mesh. This is therefore a two-way interaction between the nest and coarser domain, while in the one-way case no feedback from the nest to the coarse mesh is possible. One-way nesting is typically computationally cheaper, while two-way nesting may have some benefits in the coarse-mesh results, or in longer simulations. Both types of nesting can be extended to multiple levels, or have multiple nests within a coarser domain, and it is even possible to combine these techniques.

If a nest has one third of the grid size of the coarse mesh, it also needs one third of the timestep. In a typical set-up where the coarse domain and fine domain have a similar number of grid points, i.e. the fine mesh covers one ninth of the coarse mesh area with a 3:1 nest ratio, 75 per cent of the computational time is spent on the nest, and running with the nest is four times as expensive as running without it. With a second level of nest the ratio is 9:3:1 and 9/13 of the time is spent in the finest mesh.

MM5 allows three types of two-way nesting. (1) Interpolation: Here the nested information including atmospheric fields and topography are all interpolated from a parent domain. This type of nest can be started at any time after the parent mesh starts, and is best suited to regions of smooth topography or oceans. (2) Nested input: Here a nest input file is required, containing the full atmospheric and topographic information for the nest to start. This requires the nest to start at the same time as the parent mesh. (3) Nested terrain: Here a nest terrain file is needed, and the atmospheric fields and other time-dependent variables are interpolated. This method adjusts the topography when the nest starts, but the nest can start any time in the forecast, and higher resolution topography will be used. There will be a short adjustment period in the results after the nest starts, because of the inserted topography. Because the model has a terrain-following coordinate, changing the topography changes all the model levels slightly.

Statistical and Machine Learning Techniques for Weather Forecasting

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During the last two decades the skill of numerical Atmospheric Circulation Models (ACMs) used for short and medium-range weather prediction have increased substantially due to the advances both in assimilation procedures and physical parametrizations. Current ACMs integrated by different weather services to obtain daily predictions, simulate accurately the atmospheric synoptic dynamics on coarse-grained 40-100 Km resolution grids, covering a wide geographical area. However, at finer spatial resolution these models have much smaller skill, since the physical parametrization of sub-grid scale processes such as cloud formation, evaporation, orography, turbulence, etc., is a difficult task and, moreover, the parameters may not be tuned for a particular region of interest.

With the aim of gaining sub-grid detail in the prediction of regional areas of interest, several methods have been proposed in the literature; these techniques are referred to as *downscaling methods* (see Wilby and Wigley 1997 for a review). A standard numeric downscaling procedure consists of using the ACM gridded integrated fields as boundary conditions for a new higher resolution Limited Area Model (LAM), which includes parametrizations adapted for the region of interest (typically a few hundred kilometres). However, systematic errors from the ACM could also transmit to LAMs and, therefore, some filtering post processing technique is needed to eliminate such trends. When observations of local climate variables (e.g., precipitation, cloud, temperature) become available for a location of interest (a station), methods such as the Kalman filter provide an unbiased estimate forecast with certain desirable properties; in the case of Kalman filters, this is done by means of a linear optimum recursive filter which combines the model forecast and the observed local data, evolving dynamically both the predictions and their errors. The main limitation of these techniques is that they require a continuous feed of both predictions and observations up to the analysis time, and this information may be unavailable in some cases (much of the stations' records are not available online, or may include missing values).

Other downscaling strategies apply statistical techniques (*statistical downscaling*) and, more recently, machine learning techniques to model the relationship between gridded atmospheric patterns and local climates. Standard statistical techniques such as regression analysis (Enke and Spekat, 1997), canonical correlation analysis, Model Output Statistics (Glahn and Lowry, 1972), etc., allow characterizying the relationship between a database of atmospheric circulation patterns $\boldsymbol{x}$ and simultaneous historical records of local climate variables of interest y, by means of linear regression models, or correlations. In recent years, other machine learning techniques have been applied for automatically obtaining more general nonlinear models using modern nonparametric techniques such as feedforward neural networks (Gardner and Dorling, 1998; McGinnis, 1994), etc. The main shortcoming of these methods is that they assume stationarity of the atmosphere dynamics during the period of available data, and this is by no means guaranteed.

To overcome this limitation, other local methodologies have been also proposed. One of the most popular of these alternatives is the method of analogs, introduced originally by Lorenz in the framework of time series prediction (Lorenz, 1969). This method was originally proposed working with an embedding $\boldsymbol{v_t} = (y_{t-d}, \ldots, y_{t-1}, y_t)$ of the historical climate records $y_1, y_2, \ldots$ of a given variable. The method assumes that similar past observations may lead to similar future outcomes and, therefore, predictions are made based on the outcome of similar past cases. In this way, a prediction of y_{T+1} for an embedding $\boldsymbol{v_T}$ is obtained from that cases $\boldsymbol{v_t}$ closer to $\boldsymbol{v_T}$, according to some appropriate metric. This technique can be easily adapted to the downscaling problem by considering the gridded atmospheric pattern $\mathbf{x_t}$ as present case $\boldsymbol{v_t}$ and estimating a value for the local climate variable y_t based on similar past patters.

Several modifications of the analog method have been presented, each including an specific algorithm to obtain the analog ensemble from a database, i.e., those patters most similar to a given pattern of interest. Standard clustering techniques such as *k*-Nearest Neighbors or hierarchical clustering have revealed efficient for this problem, showing that the analog method performs as well as other complicated downscaling techniques (Toth, 1991).

References:

Enke, W. and A. Spekat (1997) "Downscaling climate model outputs into local and regional weather elements by classification and regression". *Climate Research*, 8, 195-207.

Gardner, M.W. and S.R. Dorling (1998) "Artificial Neural Networks (the Multilayer Perceptron) - A Review of Applicatios in the Atmospheric Sciences". *Journal of Applied Meteorology*, Vol 39, 147-159.

Glahn, H.R. and D.A. Lowry (1972) "The use of Model Output Statistics (MOS) in objective weather forecasting". *Journal of Applied Meteorology*, 11, 1203-1211.

Lorenz, E.N. (1969) "Atmospheric Predictability as Revealed by Naturally Occuring Analogues". *Journal of the Atmospheric sciences*, 26, 636-646.

McGinnis, D.L. (1994) "Predicting Snowfall from Synoptic Circulation: A Comparison of Linear Regression and Neural Networks". In: *Neural Nets: Applications in Geography*, B. Hewitson and R.G. Crane eds., *Kluwer Academic Publishers*, 79-99.

Toth, Z. (1991) "Estimation of atmospheric predictability by circulation analogs". *Montly Weather Review*, 119, 55-72.

Wilby, R.L. and T.M.L. Wigley (1997) Downscaling General Circulation Model Output. A Review of Methods and Limitations. *Progress in Physical Geography*, 21, 530-548.

Zorita, E. and H. von Storch (1999) "The analog method as a simple statistical downscaling technique: comparison with more complicated methods". *Journal of Climate*, 12, 2474-2489.

Modeling the Climate at Global and Regional Scale

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Simulation of the Earth's climate and future climate change scenarios requires integration of a general circulation model (GCM) for a prolonged period of time, usually several years or even centuries. The computer power required to perform such long simulations poses limitations on the formulation of GCMs for climate applications. Resolution is coarser (of the order of 250 km) than in a short term forecast model. Horizontal diffusion is higher and parameterizations of land surface interactions are less sophisticated.

In addition, on timescales exceeding a few weeks, the poleward transport of heat by the ocean circulation is comparable to that by the atmospheric circulation, and therefore ocean heat transport needs to be incorporated to produce reasonable climate simulations. Most of the current research effort is directed toward the development of coupled atmosphere-ocean models, which allow ocean transports to vary and feedback on the atmosphere.

Higher resolution is achieved by indirect means, such as statistical techniques or by the use of a regional climate model nested within the coarser resolution GCM, which is capable of resolving the regional variations in topography and land surface characteristics that are important to represent regional climate variations on scales needed for assessment of their economic and social impact.

My present work at the Center for Environmental Prediction at Rutgers University, involves the use of the RAMS model from Colorado State University, nested within the NASA/GISS (Goddard Institute for Space Studies) GCM, focusing on simulation of present climate and future climate change scenarios over the New York-New Jersey metropolitan area and surrounding region.

I will present the techniques that we are currently experimenting with for the downscaling of the GCM output from 5° x 4° to a few km. Presently we are considering one-way nesting, meaning that there is no feedback from RAMS to the GCM. RAMS is driven by the GCM at the boundaries, relaxing the regional model solution towards the GCM solution along a 4-5-point buffer zone adjacent to the border of the considered domain (Davis nudging). Another approach intended is the relaxing of only the long scales (equal of longer than those resolved by the GCM) toward those of the GCM, not only at the boundary but also in the interior of the domain. In this way we force the large scales to be like in the GCM, while allowing RAMS to develop the small scale structure.

References:

Giorgi, F., C. Shields Brodeur, and G. T. Bates, 1994: Regional climate change scenarios over the United States produced with a nested regional climate model. J. Climate, 7, 375-399.

Hansen, J. G. Russel, D. Rind, P. Stone, A. Lacis, S. Lebedeff, R. Ruedy and L. Travis, 1983: Efficient Three-dimensional global models for climate studies: models I and II. Mon. Wea. Rev., 111, 609-662.

Kidson, J. W. and C. S. Thompson, 1998: A comparison of Statistical and Model-Based Downscaling Techniques for Estimation Local Climate Variations. J. Climate, 11, 735-753.

Von Storch, H., H. Langenberg, and F. Feser, 2000: A spectral nudging technique for dynamical downscaling purposes. Mon. Wea. Rev., 128, 3664-3673.

The Hirlam-5 Project. Modelling at the Spanish Meteorological Institute (INM)

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The HIRLAM-5 Project is a model development co-operation between the meteorological institutes in Denmark, Finland, Iceland, Ireland, Netherlands, Norway, Spain and Sweden. There is a research co-operation with Météo-France. Furthermore, the Baltic states of Estonia, Latvia and Lithuania form a user group where research projects take place in co-operation with Finland or Sweden. HIRLAM-5 is a continuation of the previous HIRLAM Projects.

The main objective of the HIRLAM-5 project is to provide an operational production system for short-range forecasting which generates a comprehensive set of NWP products of higher quality than any available alternative. The system should be suitable for nowcasting with frequent update from observations, also non-conventional ones. The model should be used in the resolution range between 1-10 km during the time of the Project.

Main targets are: i) implement 3D- and 4D-VAR using high resolution (in space and time) non-conventional data; ii) set up a regular cycle of analysis and forecasts with the Reference system; iii) develop a mesoscale model; iv) increase accuracy, particularly for precipitation and strong winds; v) develop verification methods suitable for high resolution; vi) develop methods for estimating forecast skill.

HIRLAM has a hierarchical structure with Management Group (Project Leader, System Manager and Deputy Project Leaders for Modelling and Data Assimilation), Advisory Commitee (one representant for each member) and Council (Board of Directors General). There are some 70 scientist working more or less part time in the HIRLAM-5 Project. It corresponds to 22 full time positions.

HIRLAM has also a web site (http://www.knmi.nl/hirlam) with general information about the Project. Technical Reports are also available on-line. HIRLAM also publishes regularly (3 issues per year) a HIRLAM Newsletter with contributions on the ongoing work and a number of Workshop Proceedings on Specialized Topics.

The HIRLAM model is used at INM for all operational purposes at short range forecasting. Two implementations of the HIRLAM model (version 4.6.2) are operationally running. The coarser implementation has 0.5 degrees horizontal resolution in latitude and longitud, uses as boundaries the ECMWF predictions, and the integration area covers most of Europe and North Atlantic. The finer implementation has 0.2 degrees resolution, uses as boundaries the predictions from the 0.5 degrees model, and the integrations area covers the Iberian peninsula and surrounding seas. The model is routinely verified against observations (see http://www.inm.es/wwi/Boletin_ext/Opciones.html).

Factors Separation by Numerical Simulations: Boundary, Model Physics and Dynamical Factors

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The numerical modeling of atmospheric circulations is the most powerful tool available to scientists to develop a better physical understanding of the responsible mechanisms and its relation to the weather or the environment. In particular, many studies have used this potential to isolate the role played by different physical factors by means of sensitivity or *factor separation* techniques. One of such techniques (Stein and Alpert 1993) will be presented in the course. An unique feature of the technique is that the total effect by the considered factors is partitioned among the independent contributions of each factor and the synergistic contributions resulting from the interactions of different factors. This partitioning demands the completion of 2^n simulations in order to isolate the effects of *n* factors. The method is illustrated for a flash flood event in eastern Spain, simulated with the MM5 mesoscale model, in which the actions of the orography (a *boundary factor*) and condensational latent heat release (a *model physics factor*) are isolated (Romero et al. 2000).

Comparatively less attention, however, has been paid to the effects of internal features of the flow dynamics (jet streaks, troughs, fronts, etc.) probably because, unlike the boundary or model physics factors, modifying or switching off these elements in the simulations is not straightforward. The three-dimensional nature and mutual dependence of pressure, temperature and wind fields pose serious constraints on the ways these fields can be altered without compromising the delicate dynamical balances that govern both the model equations and actual data. A relatively clean approach to deal with the *dynamical factors* is based on the concept of potential vorticity (PV) and its invertibility principle (Hoskins et al. 1985). According to this principle, given some balanced flow constraints and proper boundary conditions for the meteorological fields (pressure, temperature and wind), the knowledge of the three-dimensional distribution of PV can be used to infer the balanced meteorological fields. Application of piecewise PV inversion is particularly useful, since once identified, any PV element of interest as well as its associated mass and wind fields can be isolated in a consistent way for the prognostic purposes. This methodology is illustrated for a cyclogenesis event over the Western Mediterranean, in which the piecewise PV inversion technique of Davis and Emanuel (1991) is applied to study the influence of two embedded upper-level PV anomalies on the MM5 model forecasts (Romero 2001).

References:

Davis, C. A. and Emanuel, K. A., 1991: Potential vorticity diagnostics of cyclogenesis. *Mon. Wea. Rev.*, **119**, 1929-1953.

Hoskins, B. J, McIntyre, M. E. and Robertson, A. W., 1985: On the use and significance of isentropic potential vorticity maps. *Quart. J. Roy. Meteor. Soc.*, **111**, 877-946.

Romero, R., Doswell, C. A. III and Ramis, C., 2000: Mesoscale numerical study of two cases of long-lived quasistationary convective systems over eastern Spain. *Mon. Wea. Rev.*,**128**, 3731-3751. *(Available on the speaker's web page).*

Romero, 2001: Sensitivity of a heavy rain producing Western Mediterranean cyclone to embedded potential vorticity anomalies. *Quart. J. Roy. Meteor. Soc.*, submitted. *(Available on the speaker's web page).*

Stein, U. and Alpert, P., 1993: Factor separation in numerical simulations. J. Atm. Sci., 50, 2107-2115.

Data Assimilation with the 4D-var Method

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In this talk I will review the research underpinning the 3-dimensional and 4-dimensional variational data assimilation (VAR) development programme at the Met Office and describe some of our recent progress - highlighting the scientific foundations of the work. Investigations of the causes of major forecast errors often traces them to error in the initial conditions: success in this research will reduce their frequency.

Most of the features we wish to represent and predict in numerical weather prediction (NWP) can be characterized as `balanced' - that means states that represent an equilibrium between the pressure gradient, Coriolis and buoyancy terms in the equations of motion. Balanced states are only a small subset of possible NWP model states; properly constraining the assimilation to be near balance is essential to make best use of incomplete observations. I will show how the principles of Hamiltonian mechanics can be used to derive balance constraints. Methods of imposing balance have been studied with the aim of making these definitions apply globally, in the presence of orography, and preserved under reconfiguration. Frictional effects are taken into account, and methods for deducing balanced vertical motion increments are under investigation. The latter are required in our attempts to improve the treatment of moisture, cloud and precipitation in VAR.

Coupling of Meteorological and Air Quality Models for Air Pollution Research

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Until the 80's, meteorological models were considered as a "necessity" to run atmospheric diffusion models (mainly, non-reactive models), in terms of "getting" single meteorological or simple grid data (either estimated or measured). But, with the increment of the performance computing, more and more sophisticated air quality models arise,

- Lagrangian dispersion models, with specific formulations of pollutants plume growth that applies more and more sophisticated atmospheric turbulence parameters.

- Eulerian air quality models, capable to run at high resolution and to solve complex chemical mechanisms. In this case, not only atmospheric flow, but also temperature, humidity, solar radiation and precipitation, are meteorological parameters required to solve the chemical reactions.

Coupling of these models are usually unidirectional, that is, the meteorological models calculate the input files for the air quality model. This typical approach was called "off-line" model, and it is based in the assumption that air pollutants have no influence in the atmospheric dynamic.

At the beginning of 90's a new generation of Eulerian air quality models appears, that are named "on-line" models, that is, meteorological and air quality models that solve "more or less" simultaneously. The main goal of this approach is to obtain accurate estimations of specific atmospheric parameters (turbulence, solar radiation, temperature) with high influence in some chemical reactions (i.e., O_3 production). However, because of its complexity (specially, in terms of numerical solution) and specificity, on-line models are only applied in some cases (i.e., Los Angeles Basin).

Currently, two different approaches of air quality models are usually considered in most of the research applications,

- Lagrangian particle dispersion models, for single source non-reactive air pollution studies.
- Eulerian "off-line" air quality models, for reactive air pollution studies.

In this speech, examples of both approaches will be presented, coupled to the same meteorological prediction model, Advanced Regional Prediction System (ARPS). Both examples are applied to the As Pontes power plant environment, in different scales.

References:

Carmichael, G.R., Peters, L.K., Saylor, R.D. (1991). The STEM-II regional scale acid deposition and photochemical oxidant model. I. An overview of model development and applications. Atmospheric Environment, **25A**, 10, 2077-2090.

Souto, J.A., Pérez-Muñuzuri, V., de Castro, M., Souto, M.J., Casares, J.J. (1998). Forecasting and diagnostic analysis of plume transport around a Power Plant. Journal of Applied Meteorology, **37**, 1068-1083, 1998.

Souto, M.J., Souto, J.A., Pérez-Muñuzuri, V., Casares, J.J., Bermúdez, J.L. (2001). A comparison of operational Lagrangian particle and adaptive puff models for plume dispersion forecasting. Atmospheric Environment, **35** (13), 2349-2360.

Numerical Weather Forecast in Galician Region (Spain) by Using Non-Hydrostatic Numerical Models (ARPS and MM5)

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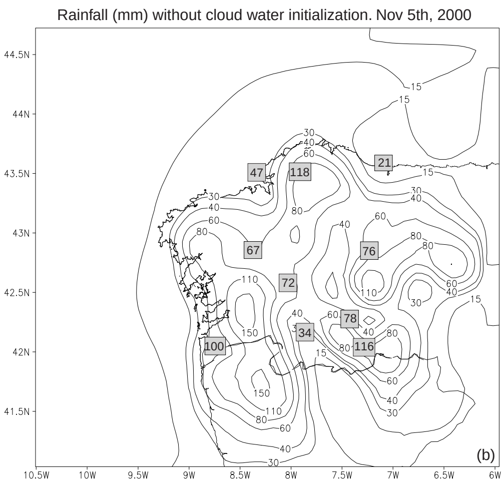
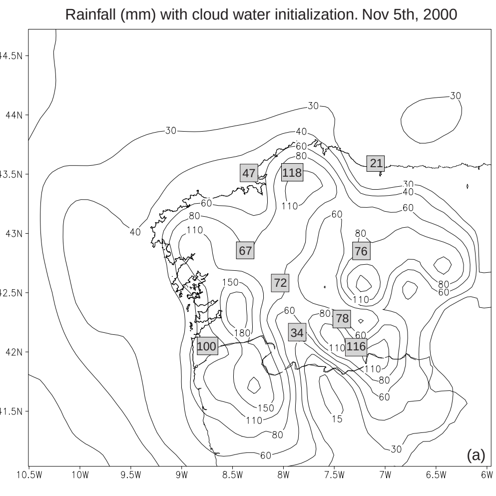
Two non-hydrostatic numerical models are applied to an operational numerical weather forecast in Galicia (Spain): the Advanced Regional Prediction System (ARPS), a general-purpose atmospheric model developed at the University of Oklahoma (USA) and the the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5). These models are run daily for 72-hour forecast at a 10-km horizontal resolution and the current forecast starts from 12-hour forecast of NCEP AVN model. Daily, these models run on CESGA (Supercomputing Center of Galicia) computers: ARPS model on a parallel-vector and MM5 on a shared memory processing server.

Galician region is located in a very complex terrain and land use domain, and the weather is highly influenced by the passage of cold fronts from the Atlantic Ocean and the interaction of these systems with local topography. This region has a high percentage (almost 50%) of rainy days per year. For these reasons, the estimation of precipitation processes in the models is very important, as the initialization of moisture and cloud fields. Particularly for ARPS model, procedures from the ADAS (ARPS Data Assimilation System) cloud analysis are being used to construct the cloud fields based on AVN data, and then applied to initialize the microphysical variables; for the operational runs, a three-category ice microphysics scheme is used. Comparisons of the ARPS predictions with local observations during November 2000 show that ARPS can predict quite well both the daily total precipitation and its spatial distribution. In figure below, the comparison between total rainfall over Galicia for 5, November, 2000 predicted by ARPS with (a) and without (b) cloud initialization and observations (numbers in boxes) is shown.





References:

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, 1995: ARPS Version 4.0 User´s Guide.

Xue, M., K. K. Droegemeier and V. Wong, 2001: The Advanced Regional Prediction System (ARPS)- A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part I: Model dynamics and verification. Meteor. Atmos. Phys., 75, 161-193

Dudhia, J., Gill, D., Guo, Y-R., Manning, K., 2001: PSU/NCAR Mesoscale Modeling System. Tutorial Class Notes and User’s Guide: MM5 Modeling System Version 3.

Kristjánsson, J. E., 1992: Initialization of cloud water in a numerical weather prediction model. *Meteor. Atmos. Phys.*, **50**, 21-30

Weather Forecasting in Galicia

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The aim of this paper is to explain how daily forecasts are made in Galicia. The first step is to examine the present state of the atmosphere. For this purpose we take into account the satellite images, both the visible and the IR ones. We also have other sources of information such as web cameras and meteorological data received from real time meteorological stations spread all over Galicia. After having an idea of the whole actual atmospheric situation, we try to look the synoptic situations which are forecasted by General Circulation Models, such as AVN, UKGC, etc. Consequently, we can see the location of high and low pressures and their evolution. Besides, we can guess the movement of hot and cold fronts and which of them affect our region.

After this first approach, it is necessary to translate the observed large-scale circulation into values of the same local meteorological variables, for example: temperature, precipitation… This is made by means of two non-hydrostatic Mesoscale Models: ARPS (Advances Regional Prediction System) and MM5 (Fifth Generation Mesoscale Model System). These models have been adapted to galician orography. The grid resolution is of 10 kilometers.

Nevertheless, weather forecasting is not just to write down the results of a better or worse model. The contributions of education and experience of forecasters are essential. The more climatological knowledge a forecaster has, better weather forecasts will be achieved.

Finally, a forecast verification: the process of determining the quality of forecasts, is done. There are a wide variety of forecast verification procedures. For example, for accuracy measures, contingency tables are used.

The weather maps made in this service are used by different media and also in a Internet web page daily updated.

References:

Weather Forecast Theory. Mariano Medina. INM Publication Services.

Weather maps. Javier Martín Vide. Oikos-tau Editorial.

Cloud Investigation by Satellite. Richard Scorer. Omega Editorial.

Statistical Methods in the Atmospheric Sciences. Daniel S. Wilks. Academic Press.

The contributions of Education and Experience to Forecast Skill. Paul J. Roebber, Lance F. Bosart. Weather and Forecasting. 21-40. March 1996

Operational Weather Forecasting in the Catalan Meteorological Service

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The *Servei de Meteorologia de Catalunya* (SMC) was born in 1996 and began issuing operational weather forecasts the spring of 1997. Products offered by SMC have been freely available and have increased largely since its foundation.

The SMC's operational weather forecast is based in two different numerical models:

- The Mesoscale Atmospheric Simulation System (MASS), a hydrostatic model that runs operationally twice a day (00 GMT and 12 GMT) as a result of an agreement between *Departament de Medi Ambient* (DMA), *Universitat de Barcelona* (UB) and *Fundació Catalana per la Recerca* (FCR). The model uses one coarse grid with 55 km resolution that covers West Europe, and one nested grid with 15 km resolution that covers the East of Iberian Peninsula. This model is run in the *Centre de Supercomputació de Catalunya* (CESCA) using an IBM SP2. AVN data is used as initial and boundary conditions. Three new resolutions are being considered to be run in the near future: 30 km resolution over the Iberian Peninsula, 8 km resolution over the East Iberian Peninsula and another with 2 km resolution over Catalunya.

- The *Global Modell* (GM) and *Lokal Modell* (LM) which are property of the DWD. The LM is a non-hydrostatic model with 7 km resolution that covers almost West Europe and works reasonably well at the Mediterranean area.

In addition to model and radiosounding data (Barcelona and Sort stations), remote sensing tools are used in operational weather prediction, such as satellite images (Meteosat and NOAA), lightning data and radar images. The SMC's lightning network detection system with 500 m resolution is being installed and the second radar of a network of four is going to be installed during 2001. Actual weather conditions are monitored using an automatic network of 140 stations and manual observations provided by amateur observers.

These observations are integrated in the workstation based *Sistema d'Ingestió, Integració i Visualització d'Informació Meteorològica* (SIIVIM) implemented by the *Universitat de Barcelona* (UB).

With all these elements a two hour meeting is held by SMC forecasters (6 people with university degrees of Physics or Geography) to discuss the weather forecast. Later different products are prepared: a general weather report available in the SMC Internet web page (updated three times a day at 07'30, 11'30 and 19'00), media weather forecasts for TV, radio stations and press (*El Periódico*, L*'AVUI*, *Ona Catalana*, TVC, etc), special support to power and building companies (FECSA, COPCISA, etc.) and specific citizens queries.

High Resolution Wind Diagnosis Using Mesoscale Model Output

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Wind forecasts are far from being accurate over complex terrain regions when they are obtained by direct interpolation of NWP model output at grid point resolutions for which models can still be run operationally (about 10 km). Air and maritime traffic, ground transportation safety, wildfire prevention and management are, among others, activities that are strongly affected by wind conditions. The need of wind forecasts at smaller scales in Catalonia led to a collaboration between the Catalan Weather Service and the University of Barcelona to develop a diagnosis- based forecast system inspired in the downscaling concept widely used in climate modeling[1] and wind power assessments[2]. Three-year 00 AVN output was dynamically downscaled in Catalonia using a three-step cascade of MASS model simulations[3] starting at 30 km grid point resolution down to 2 km through an intermediate 8 km mesh. The aim was to obtain a catalogue of high resolution wind patterns embedded in the 30 km run which could be easily run operationally. Working on real-time, once this run is completed, a simple automatic classification scheme looks for the closer simulation in the three-year catalogue to diagnose the wind features at smaller scales.

References:

Storch, H., Zorita E., Cubasch, U., 1993: Downscaling of global climate change estimates to regional scales: an application to Iberian rainfall in wintertime. *Journal of Climate*, **6**, No. 6, pp. 1161–1171.

Zack, J.W., Waight, K.T., Van Knowe G.E., Bousquet, M.D., 2000: A dynamical-statistical atmospheric modeling system designed to simulate wind-generated power production rates. *Proceedings of the AMS second symposium on environmental applications*.

Manobianco, J., Taylor, G.E., Zack, J.W., 1996: Workstation-based real-time mesoscale modeling designed for weather support to operations at the Kennedy Space Center and Cape Canaveral Air Station. *Bulletin of the American Meteorological Society,* **77**, No. 4, pp. 653–672.

Operational Numerical Weather Forecast in Galician Region (Spain) by Using a Non-Hydrostatic Numerical Model and its Validation

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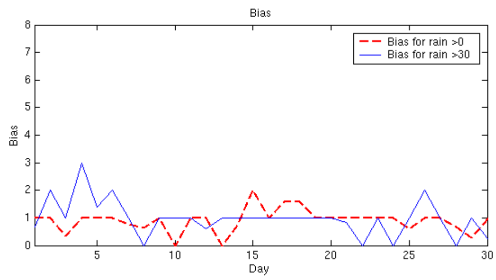
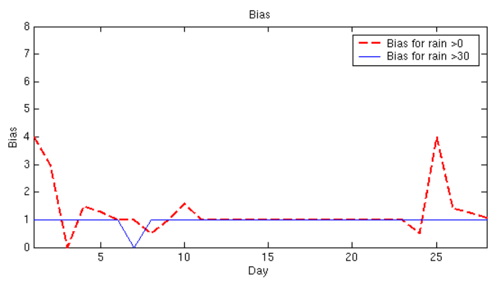
Since January 2000 the Advanced Regional Prediction System (ARPS) is being applied as an operational numerical weather forecast in Galicia (NW of Spain). Due to the high percentage of rainy days per year occurring in this region, the precipitation processes and the initialization of clouds and moisture in the model is very important. A cloud analysis procedure developed in the ADAS was used to initialize the cloud fields based on predicted relative humidity fields from the global AVN model. Comparisons of the ARPS predictions with local observations show that ARPS can predict quite well both the daily total precipitation and its spatial distribution. This last feature is very challenging at this region, as it is shown in the wide variance of the observed precipitation rates. ARPS can reproduce the influence of the complex terrain local features and the mesoscale circulations that combine to produce the complex spatial distribution of the rain in Galicia. In the figures below the precipitation forecast statistics are shown for November, 2000 (with heavy rain) and February, 2001 (less rainy). On the left the Bias (B=F/O) results are shown, where F is the number of stations in which the model predicts precipitation will reach or exceed a certain threshold, and O is the number of stations where the precipitation was observed to exceed the same threshold. On the right, the contingency tables for these months are shown.

a) November 2000



Observed		Predicted Yes	Predicted No
	Yes	70%	12%
	No	0%	18%

b) February 2001



Observed		Predicted Yes	Predicted No
	Yes	28%	2%
	No	3%	67%

References:
Albers, S. C., J. A. McGinley, D. A. Birkenheuer, and J. R. Smart, 1996: The local analysis and prediction system (LAPS): Analysis of clouds, precipitation and temperature. *Weather and Forecasting*, **11**, 273-287.

Gaudet, B. and Cotton W.R., 1998: Statistical characteristics of a real-time precipitation forecasting model. Weather and Forecasting, 13, 966-982.

Kristjánsson, J. E., 1992: Initialization of cloud water in a numerical weather prediction model. Meteor. Atmos. Phys., 50, 21-30.

Xue, M., K. K. Droegemeier and V. Wong, 2001: The Advanced Regional Prediction System (ARPS)- A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part I: Model dynamics and verification. Meteor. Atmos. Phys., 75, 161-193.

Xue, M., Droegemeier, K.K., Wong, V.C., Shapiro, A. and Brewster, K. (1995) ARPS Version 4.0 Users´s Guide.

Zhang, J, F. Carr and K. Brewster, 1998: Impact of initial cloud analysis on storm-scale precipitation forecasts. 16th Conf. Wea. Analysis and Forecast. Amer. Meteor. Soc., Phoenix, AZ.

Self-Organizing Maps for Local Weather Prediction

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Self-organizing maps (SOMs) is one of the most popular neural network techniques for visualizing and modeling high dimensional data. SOMs transform the input of arbitrary dimension into a one or two-dimensional quantized space subject to a topological (neighborhood preserving) constrain. This transformation is computed using an unsupervised learning iterative algorithm, so no domain knowledge is needed and no human intervention is required. As a result, the input space is clustered into representative features using a self-organizing process. Hence the underlying structure of the input space is kept, while the dimensionality of the space is reduced (see Kohonen, 1995 for an introduction to this field). In spite of their potentiality in meteorology, only a few applications of SOM in this field have been reported in the literature (see, for instance, Cavazos, 2000). In this work, we give some preliminary results of the application of SOM for short- and medium-term local weather forecasting. To this aim, we consider the ERA-15 reanalysis database (ECMWF Re-Analysis project http://www.ecmwf.int/research/era/index.html). It provides us with the daily Temperature (T), relative Humidity (H), Geopotential (Z) and U, V wind components at six pressure levels (300, 500, 700, 850, 925, and 1000 mb) at 1200 UTC, the period from 1979 to 1993.

We consider a grid covering the Iberian peninsula, and use different SOM configurations to obtain the most relevant features from the huge amount of ERA information (more than 500Mb). Thus, we obtain different atmospheric modes, each one related with a SOM cluster, formed by those dates in the database with a particular atmospheric configuration. These clusters are then used as analog ensembles for obtaining local weather forecasts following the method of analogs (see Zorita and von Storch, 1999; Toth, 1991 for an overview to this topic). We show that, in some circumstances, the SOM analog method outperforms standard analog methods for short- and medium-term forecasting and provides a clear interpretation of the results.

References:

Cano, R., Cofiño, A.S., Rodríguez, M.A. and J.M. Gutiérrez (2001). "Self-Organizing Maps for Statistical Downscaling in Weather Forecasting. A Case Study of the Iberian Peninsula". Submitted.

Cavazos, T. (2000) "Using Self-Organizing Maps to Investigate Extreme Climate Event: An Application to Wintertime Precipitation in the Balkans". *Journal of Climate*, 13, 1718-1732.

Kohonen, T. (1995) *Self-Organizing Maps.* Springer-Verlag, Berlin.

Lorenz, E.N. (1969) "Atmospheric Predictability as Revealed by Naturally Occuring Analogues". *Journal of the Atmospheric sciences*, 26, 636-646.

Toth, Z. (1991) "Estimation of atmospheric predictability by circulation analogs". *Montly Weather Review*, 119, 55-72.

Zorita, E. and H. von Storch (1999) "The analog method as a simple statistical downscaling technique: comparison with more complicated methods". *Journal of Climate*, 12, 2474-2489.

Line Source Dispersion for Vehicular Pollution Prediction near Rural Motorways

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Vehicular traffic has become a major source of air pollution in urban areas, and nowadays in rural areas, too. The aim of this study is to apply Scipuff, a Lagrangian dispersion model, to predict, in a prospective way, the pollutant concentration and dispersion near rural motorways, in a mesoescale level. The model will be applied to a section of 50 Km in "Eix Transversal", a road between Vic and Girona, in the province of Barcelona and Girona, Spain. It works in a 50 x 40 Km^2 domain, with a geographical interpolation of complex topography, obtaining a grid resolution of 2.5 Km. Lack of information is the major inconvenient to achieve the study in rural areas. Wind flows, essential to describe the resulting ambient air concentrations, are based only on the information of five meteorological stations. This obligates to make a meteorological flow interpolation in the rest of domain. To evaluate the quality of model's performance, model outputs will be compared with measurements using both quantitative data analysis techniques and statistical methods.

MeteoLab: A Matlab Toolbox for Statistical Analisys in Meteorology

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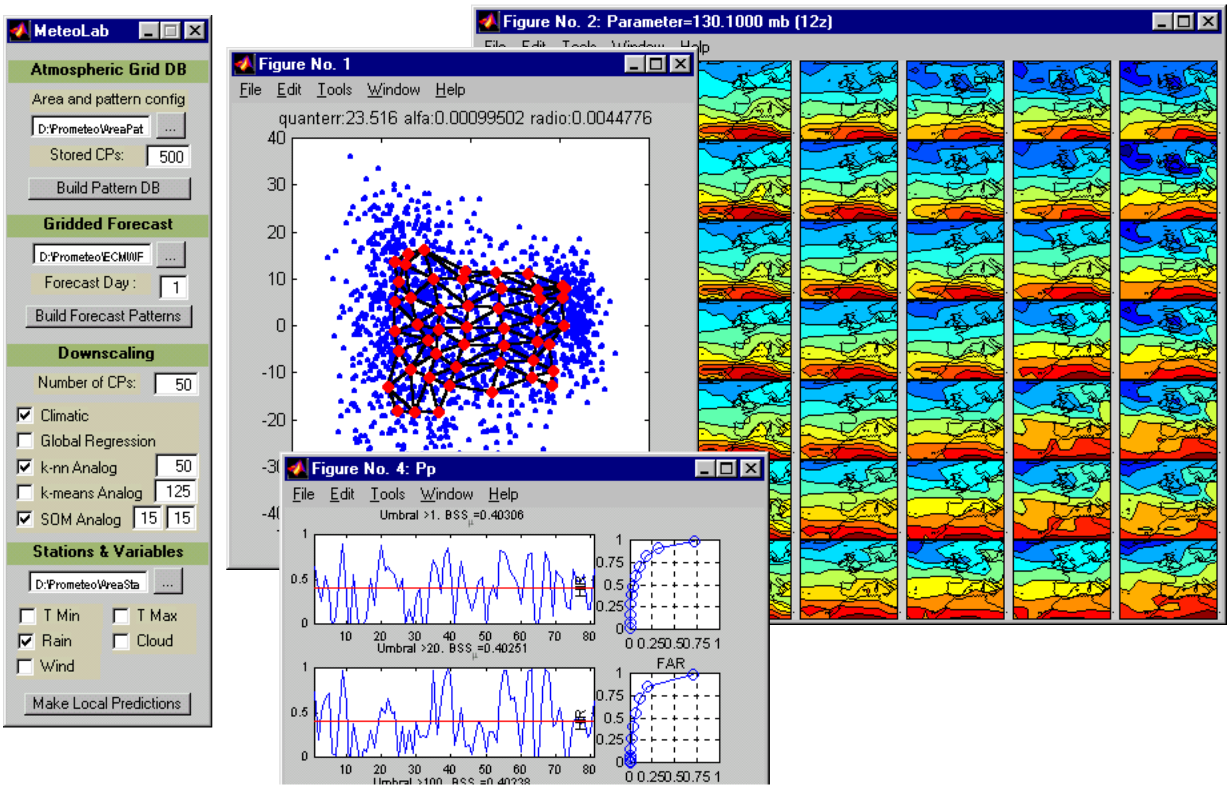
Meteolab is an integrated Matlab package for applying several statistical techniques to meteorological data (gridded forecasts and observations from local stations) and obtaining models with predictive capabilities. It also allows visualizing the obtained results using standard meteorological charts. Some of the methods included in the toolbox are:

- Importing and exporting grib-format or ASCII files.
- Principal Component Analysis of data (selecting a threshold value of explained variance).
- Clustering and classification of both predicted fields and/or observations using *k*-means.
- Linear regression analysis of selected meteorological variables and observations.
- Calculation and visualization of similar atmospheric fields within a database.
- Neural network training with desired input/output values from data.
- Self-organizyng maps for clustering and classification.

As an application of the toolbox we show how it can be used for obtaining local forecasts using different statistical approaches (global autoregressive models for observations, linear regression models for grided predictions and observations, and a method based on analoges).



Métodos Geoestadísticos Aplicados al Análisis de la Temperatura en la Comunidad Autónoma de Galicia

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Con objeto de cartografiar la distribución de la temperatura en Galicia durante el año 1999 se analizaron los datos correspondientes a diferentes estaciones meteorológicas distribuidas por toda la comunidad. A estos datos se les aplicó un análisis geoestadístico pormenorizado. El objeto de este estudio es obtener un mapeado eficiente de la temperatura a nivel regional. Los resultados arrojados por éste indican claramente la existencia de dependencia espacial pero ésta no responde a un único modelo sino a varios.
Los conjuntos de datos de temperatura mensuales y anuales empleados se obtuvieron a partir de 61 estaciones climatológicas situadas en Galicia. Además, se han utilizado datos exhaustivos de altitud del terreno derivados de un modelo de elevación digital y discretizados en celdas de 500x500 m.
La variabilidad espacial fue valorada mediante medias de semivariogramas escalados, utilizando la varianza como factor de escala. Los mejores ajustes de modelos y el número ideal de vecinos para realizar la estimación por krigeado fueron seleccionados empleando la aproximación por mínimos cuadrados y por validación cruzada.
Se ajustaron funciones esféricas y gaussianas a los semivariogramas experimentales, con un rango de dependencia espacial entre unos 16 y 60 kms, dependiendo del mes. En la *figura 1* se muestra un ejemplo del patrón de la dependencia espacial.

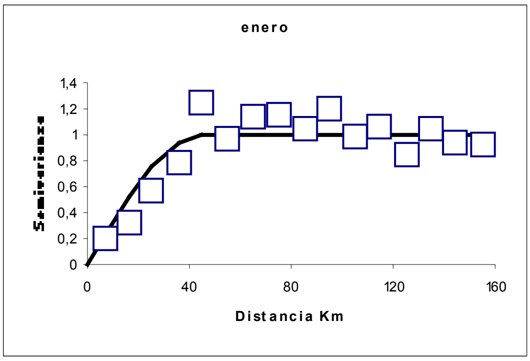

Figura 1. Ejemplo de datos experimentales mensuales (enero) y un modelo de semivariograma ajustado a ellos.

El análisis del semivariograma y los mapas de krigeado ilustran posibles procesos ambientales determinados por la distribución de la temperatura y permiten realizar inferencias sobre factores que controlan su variación espacial y temporal. Los mapas de krigeado proporcionan una evidencia adicional, que la topografía y la distancia a la costa son los factores principales que controlan el patrón de la distribución de la temperatura en la región estudiada.
En un segundo paso, los datos de temperatura se combinaron además con la información topográfica para mejorar la estimación a nivel regional. En este caso, los algoritmos geoestadísticos empleados fueron el cokrigeado ordinario y el cokrigeado colocalizado.
La exacitutd de la estimación de los diferentes métodos de interpolación geoestadística se evaluó empleando la validación cruzada. Generalmente, el cokrigeado y el cokrigeado colocalizado fueron más exactos y representaron mejor que el krigeado ordinario. La diferencia básica estuvo en el tamaño de las áreas en las cuales hay altos valores estimados de varianza, que fueron algo mayores para el mapa obtenido mediante krigeado ordinario. No obstante, los mapas obtenidos mediante diferentes procedimientos de interpolación geoestadística, básicamente presentan los mismos resultados, incluso si había un detalle ligeramente mayor en los mapas resultantes del cokrigeado y el cokrigeado colocalizado, debido a la contribución de la altitud como una variable secundaria. Así, la ganancia de los mapeados que incorporan a propósito las altitudes como información secundaria fue limitada, por lo que no se obtuvieron resultados muy diferentes por la aplicación de las diferentes aproximaciones geoestadísticas.

Referencias:

- Goovaerts, P. (1997): "Geostatistics for natural resources evaluation. Applied Geostatistics". Series. New York. 483 pp.

- Ministerio de Medio Ambiente y Energía: "Resumenes Climatológicos Mensuales de Galicia". Centro Meteorológico Territorial en Galicia. Sección de Climatología.

- Pebesma., E. J. (2000): "Gstat User's Manual". Departement of Physical Geography. Utrecht University. 100 pp.

Simulation of Episodic and Annual Acidic Deposition around As Pontes Power Plant

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The application of comprehensive air quality models, as the Sulfur Transport Eulerian Model 2 (STEM-II, Carmichael et al., 1991), to local and complex environments needs the validation of the model by comparison of field measurements to estimated acid deposition values, in order to obtain an estimation of confidence in model results, for the refinement of the model. In this case, the study was focused in As Pontes Power Plant environment, an utility located at the Northwest of Spain, an Atlantic region with sea influence (Souto et al., 2000) and complex topography, with very usual changeable weather conditions (Souto et al., 1998).

From 1990 to 1997, As Pontes Power Plant reduced its SO_2 emissions in more than 30 %, with a basis reduction of 30 % and episodic reduction up to 100 %, by mixing the local lignite (with S) with foreign coals from Wyoming, USA, and Indonesia (without S). Therefore, in order to estimate the effectiveness of this reduction in air quality and acid deposition, a systematic program of measurements was done, and the application of a comprehensive air quality model was proposed.

In this work, estimated wet acid and oxidants deposition of the most significant air pollutants in the As Pontes Power Plant environment (SO_2, SO_4^{2-}, NO_3^-, H_2O_2) are compared to measurements from several air pollution stations located 30 km around the power plant, during different 1997 episodes. In addition, a comparison of total acid deposition maps estimated from STEM-II results, and interpolated (by kriging) from acid deposition field measurements, are studied for 1990 and 1997.

From the comparison of 1997 episodic daily wet deposition, it was observed that STEM-II overestimates the SO_2 and SO_4^{2-} deposition, specially during short rain periods; the differences observed over daily rain periods are around 100 %. H_2O_2 deposition shows a coherent behavior with the measurements available.

For the comparison of estimated and interpolated total deposition maps, S deposition patterns seem to be very similar, with a significant change from 1990 to 1997, as both estimated and interpolated maps show a displacement of the maximum deposition from the SW to the NE of the power plant location. This can be explained by the episodic reduction of SO_2 emissions applied by the power plant, that affects mainly the dry deposition (Filla et al., 2000).

Although the episodic comparison of wet deposition estimated by STEM-II and observed values, shows differences of 100 % and more in some cases, the processing of episodic results in an annual basis show that the influence of these episodic differences is not so relevant as expected, at least for S deposition.

Acknowledgements
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References:

Carmichael, G.R., Peters, L.K., Saylor, R.D. (1991). The STEM-II regional scale acid deposition and photochemical oxidant model. I. An overview of model development and applications. Atmospheric Environment, 25 (10), 2077-2090.

Filla, M., Méndez, M.R., Souto, J.A., Casares, J.J., Lucas, T., Carmichael, G.R. (2000). A comparison of three different dry deposition velocities in STEM-II applied around As Pontes power plant. Air Pollution 2000 Conference, Cambridge, July 25-27 2000.

Souto, J.A., Pérez-Muñuzuri, V., de Castro, M., Souto, M.J., Casares, J.J. (1998). Forecasting and diagnostic analysis of plume transport around a Power Plant. Journal of Applied Meteorology, 37, 1068-1083, 1998.

Souto, J.A., Méndez, M.R., Balseiro, C.F., Casares, J.J. (2000). The influence of marine environment in acid deposition. Euroconference "Water & Life", May 25-27 2000.

Operational Forecasts with a Continuous Trained MOS System

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As computers are becoming more powerful, performance of mesoscale models is increasing, and realtime meteorological data is easily available on the Internet, the number of institutions and companies that run NWP models for their applications is growing very rapidly. However, although these models provide a better representation of the surface features than the larger models in which they are nested, the forecasts obtained by direct interpolations leave much to be desired. Therefore, a post-processing is still needed when accurate quantitative site-specific forecasts are required. The traditional statistical MOS approach has a major drawback: its requirement of long homogeneous data sets comes in contradiction to the constant updates and changes that these models undergo. On the other hand, the Perfect Prog approach is very poor, as it does nothing to correct the intrinsic model biases. Bearing all this in mind, we have overcome the lack of a long data set by relying on a shortest one but updating the coefficients of the predictor-predictand equations every day.
We have realized that training the system with a few weeks of data, the forecast errors decrease asymptotically reaching a level after which the addition of more data to compute the regression coefficients becomes worthless and time consuming. Using the mesoscale model MASS that we routinely run in our Department, and meteorological data from the Catalan regional network, some encouraging results of maximum and minimum temperature forecasts for several locations will be presented.

References:

Codina, B., M. Aran, S. Young and A. Redaño, 1997: Prediction of a Mesoscale Convective System over Catalonia (Northeastern Spain) with a nested Numerical Model. *Meteorol. Atmos. Phys*., **62,** 9-22.

Glahn, H. R., and D. A. Lowry, 1972: The use of Model Output Statistics (MOS) in objective weather forecasting. *J. Appl. Meteor.*, **11,** 1203-1211.

Wilks, D. S., 1995: *Statistical Methods in the Atmospheric Sciences*. Academic Press, San Diego, CA, 467 pp.

Humidity Initialization with Satellite and Radar Data: a Case Study

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An empirical technique to blend satellite and radar imagery into a conventional analysis has been implemented in a mesoscale NWP model in order to enhance the 3-dimensional humidity field. Temperatures retrieved from IR Meteosat images are used to locate and grossly characterize clouds. This information is further employed to dry or moisten individual atmospheric cells from a previous traditional analysis, based on standard surface and upper-air synoptic observations. Similarly, a procedure to improve the moisture analysis using radar reflectivity data has also been used. These methods have been implemented in a simulation covering part of Sweden and Findland using radar and satellite data provided by the Swedish Meteorological and Hydrological Institute and the Finnish Meteorological Institute. Forecasts have been compared against different control runs and analysis to evaluate the effects of the unconventional assimilation. As expected, preliminary results evidence that satellite data enhance the mid and high level moisture analysis, while radar data effects are mostly noticeable at the lowest level.

References:

Adler, R.F., and A.J. Negri, 1988: A satellite infrared technique to estimate tropical convective and stratiform rainfall. *J. Appl. Meteor.*, **27**, 30-51.

Codina, B., A. Sairouni, J. Vidal and A. Redaño, 1998: Using IR satellite data to improve the initialization of a mesoscale model. *Proceedings of SPIE*, **3495,** 145-150.

Hamill, T.M., R.P. d'Entremont and J.T. Bunting, 1992: A description of the Air Force real-time nephanalysis model. *Wea. Forecasting*, **7**, 288-306.

Young, S.H. and J.W. Zack, 1994: The use of non-standard data to improve the initialization of relative humidity in mesoscale models. *Proceedings of the Tenth Conference on Numerical Weather Prediction, Portland, Oregon, American Meteorological Society, Boston,* 326-327.

Zack, J.W., C.A. Mattocks and M.D. Bousquet, 1991: A statistical-dynamical mesoscale thunderstorm forecast system for the Kennedy Space Center. *Preprints to the Ninth Conference on Numerical Weather Prediction, Denver, Colorado. American Meteorological Society, Boston,* 447-450.

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