MODELING OF EXTREME WIND EVENTS USING MM5: APPROACH AND VERIFICATION

Peter S. Dailey, Ph.D., and John L. Keller, Ph, D., CCM*

1. Introduction

The winds associated with winter storms over Europe can be particularly severe. The intensity of these storms and the destruction they bring make them particularly important to those insurers and re-insurers whose portfolios include impacted regions. Over just the last 15 years, the nine most damaging storms have resulted in over $28 billion (USD) of insured losses. Two storms that occurred in late December 1999 (Lothar and Martin) caused insured losses of nearly $7 billion. Concern for the potential economic cost from these storms to the European Community has provided justification for increasing research and field studies in hopes of improving the ability to forecast these extreme events (e.g., Joly, et. al, 1997; Goyette, et. al, 2000).

Insurers are not only interested in the intensity of such storms, but also the frequency with which they occur. Since robust and dependable observations extend back just over 50 years, it can be a challenge to estimate with what frequency damaging winds will occur for longer "return periods" of 100 or 500 years. The risk of enormous insured losses provides the motivation to characterize the regional extreme wind climate over Europe as realistically as possible.

The basic approach we have used to create a regional extreme wind climate for Europe involves the application of two techniques. First, using MM5, we extend and refine the 40-year NCAR/NCEP Reanalysis Project (ref. http://wesley.wwb.noaa.gov/reanalysis.html) data set to provide high-resolution information about storm structure and evolution. Second, we apply a stochastic ensembling technique to extend the 40-year wind climate allowing us to extract return periods of 10, 50, 100 years or more.

Once we understand the nature of extreme wind events, we can apply structural engineering models to assess the monetary damage associated with such events for a particular region or for all of Europe. This process can be applied to historical storms for verification purposes, and to future storms either in real-time or to forecast an upcoming winter season.

2. Model Implementation

We have selected MM5 as our NWP tool for modeling severe winter storms. The model is initialized and bounded by NCAR/NCEP Reanalysis data from 1958 to 1998 for each 36 h period that includes at least one winter season mid-latitude cyclone passing over Europe. The manually intensive process of creating this 40-year "storm catalog" reveals a total of 1037 such storms.

The MM5 model domain includes two grids (Fig. 1). The first, at 90-km resolution, allows for the storms to develop offshore prior to passing through the second grid, at 30-km resolution. Only data from the 30-km grid is used in the verification process and damage modeling. The positioning of the 30-km grid was selected to capture the majority of our client's exposures. There are 23 vertical levels stretched from the surface to the model top (~14 km). The lowest sigma-level lies near 50 m AGL. The model time step for the coarse grid is 4 minutes. Four-dimensional data assimilation (analysis nudging) is used to nudge the wind field to the reanalysis data. History data is saved each hour.

Using NWP, we can more accurately depict mid-latitude cyclones and the damaging winds associated with these storms. NWP represents a major advance over the conventional approach many catastrophe modelers have taken in the past and still use today. Traditionally, simple "engineering models" have attempted to model the wind footprints left by such storms using simple relationships between central pressure, storm track, and the wind field. Engineering models can still be a practical tool for symmetric storms (e.g., tropical cyclones), but fail on more spatially complex extratropical cyclones (Fig. 2).

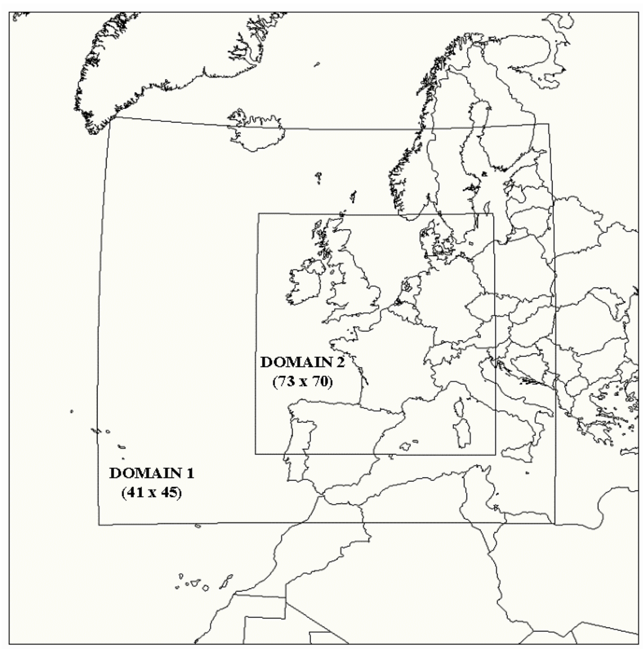

FIG. 1 - MM5 grid configuration used for wind modeling experiments. The coarse domain has a horizontal resolution of 90 km and the nested domain has a resolution of 30 km. The grid includes 23 vertical levels.

* Corresponding authors address: Peter S. Dailey, Manager, Atmospheric Sciences (pdailey@air-worldwide.com) and John L. Keller, Senior Scientist (jkeller@air-worldwide.com), AIR Worldwide Corporation., 101 Huntington Avenue, Boston, MA 02199-7603

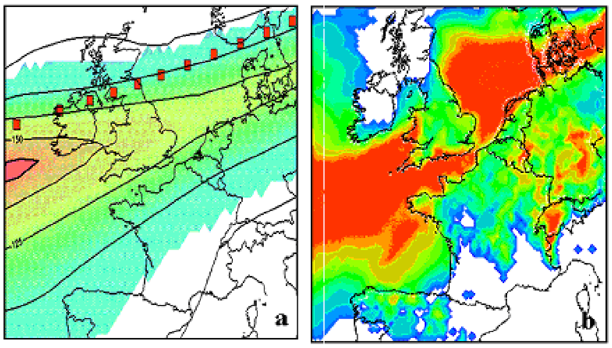

FIG. 2 - Maximum wind speed footprints for the 1990 windstorm Daria over the 36-hour period from January 25 12Z to 27 00Z using (a) conventional and (b) NWP modeling approaches. In panel (a), the wind intensity field is estimated using the storm track (red squares) and the storms central pressure over the lifetime of the storm. Contrast the simplicity of the footprint laid down by the parameterized model with the more complex footprint modeled using MM5.

3. Modeling Approach

Our goal in using NWP, more specifically the MM5 model, is to simulate European winter storms at a high enough resolution that the features important to the strongest surface winds can be accurately determined. While the 30 km resolution MM5, initialized and bounded with NCAR/NCEP Reanalysis Project data, reproduces the evolution of notorious historic European windstorms quite well, the boundary layer parameterization available in MM5's assimilation mode consistently underestimates the surface (10 m) wind over areas of strongest winds. Since the wind speed is a fundamental variable for estimating property damage, we have developed a specialized surface wind enhancement that provides more accurate surface wind speeds for these important regions.

For the physical basis of this surface wind "parameterization", we have investigated several possible mechanisms. It appears that the vertical momentum transport through the PBL by gravity waves is reflected near the surface as a strong pressure tendency. The resulting ageostrophic (isallobaric) wind response seems to explain most of the discrepancy with respect to the MM5's PBL surface wind.

Brasseur (2001) has reported that wind gusts associated with storms over Europe are characterized by the turbulent transport of momentum from the top of the boundary layer to the surface. Our review of Brasseur's work and extensive study of the most significant historical windstorms has revealed that gravity wave activity can serve as the transport mechanism for extreme winds, and as Brasseur concludes, the turbulent structure is of prime importance. The selection of 30 km as resolution of the nested domain is based on the horizontal scale required to resolve gravity waves and to provide sufficient insight to the evolution of these storms.

Figure 3 shows wind speed for three vertical cross-sections through the MM5-simulated storm Lothar, which occurred in late December 1999. Each of the panels is taken through Northern France, from the surface up to about 5-km. The first panel, showing the storm modeled at 90 km resolution, evolves a realistic field of "wind potential" aloft, but the planetary boundary layer (PBL) scheme at this resolution does not capture its transport through the PBL. The second panel, modeling the same storm at 30-km resolution, captures transport of momentum into the boundary layer. Finally, the panel showing the storm modeled at 10-km resolution captures more detail in the downward transport of momentum. We have determined the additional detail captured by the 10-km run does not justify the added computational expense. Thus, we have chosen to model European windstorms using 30-km horizontal resolution.

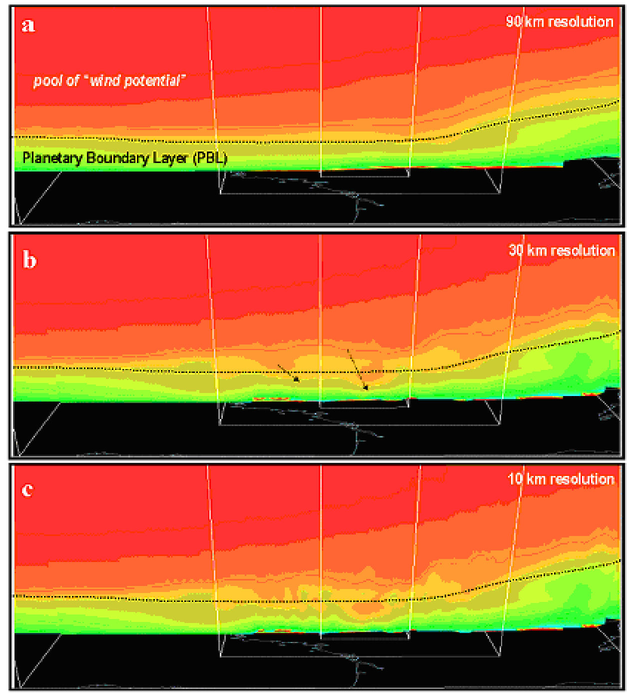

FIG. 3 - Vertical cross-sections of wind speed for Lothar simualtion at 09Z on December 26, 1999. Panels (a) - (c) model the storm at 90 km, 30 km, and 10 km resolution respectively.

4. Verification

We have verified our implementation and calibrated the technique of refining the surface wind field for six historical storms. Here, we provide one example.

To verify the applicability of our implementation of MM5 for modeling severe wind events, one must keep in mind the limitations and implicit error associated with both observations and model data. As we perform verification analysis on storms occurring over 10 years ago, the temporal and spatial coverage of the observations declines. Model grid points do not coincide with observation locations and are representative of an area-averaged field. Moreover, wind observations are typically a snapshot of winds occurring at the time of the observation and do not reflect the strongest wind that has occurred since the last observation. Finally, we have performed an intensive quality control of observational data to assure that it does not misrepresent the storm.

Figure 4 shows the modeled footprint for Lothar, one of the more damaging European storms on record in terms of insured loss. The modeled footprint matches well with observed winds. The path of strongest winds for this storm passed through northern France and southern Germany. The model shows a region of intense winds over the boundary of France and Switzerland, but these winds are more indicative of the presence of the Alps than the presence of Lothar itself.

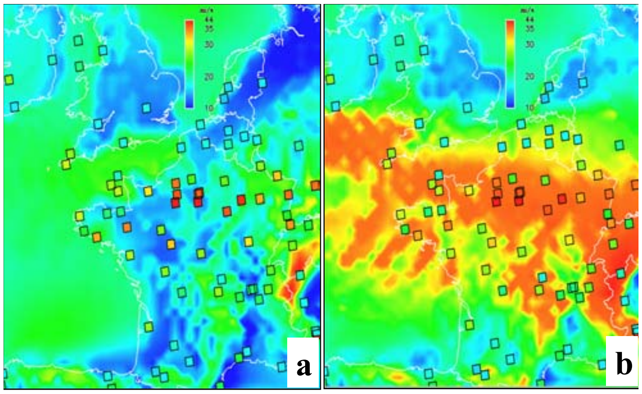

FIG. 4 - Event-maximum wind speed from MM5 PBL module (a) and that based on a parameterization that included the isallobaric wind calculated from MM5 surface pressure tendency (b) for Lothar 12Z 25 - 00Z 27 December 1999. Observed maxima are shown as colored boxes.

The "numb" response of the standard MM5 PBL scheme is clearly seen in the dramatically different maximum wind speed footprints. We have seen similar results for the other five cases. Figures 5 and 6 provide some evidence that much of this problem results from an underestimation of the ageostrophic flow that occurs during the most intense phase of the storm. Both are "snapshots" at 08Z 26 December 1999, about 20 hours into the MM5 simulation and at the time when Lothar was most severely affecting the Paris area. The former figure is the surface (10 m) wind speed as diagnosed by the MM5 PBL parameterization. In the latter figure we show the isallobaric wind flow calculated from MM5's 1-hour surface pressure tendency.

Figure 7 shows time series of modeled and observed (at three sites) wind speeds for near Paris. Note the differences in these observations despite their close proximity. There is a strong correlation, however, in the timing of the pulse of strongest winds for all locations, occurring roughly 20 hours into the simulation. The MM5 wind speed for Paris closely resembles the observations, especially around the time of the strongest pulse.

5. Extending the MM5 Wind Climate

Having verified that MM5 does a reasonable job simulating the surface winds associated with severe winter storms, we now consider the information most important to insurers. With what frequency will winds of a given magnitude impact their portfolio of European properties?

As a first step, we can take the 40 years worth of windstorms as simulated by MM5, and compute the average annual-maximum wind speed for the model grid. This gives an annual maximum return period wind speed map. We can do the same for 5, 10 and even 20 years, but the larger the return period, the less data used to compute the average. Thus, these longer return periods become less reliable using just the MM5-simulated wind climate. Moreover, with just 40 years worth of historical storms, we cannot directly determine the magnitude of the 100-year or 500-year return period wind field.

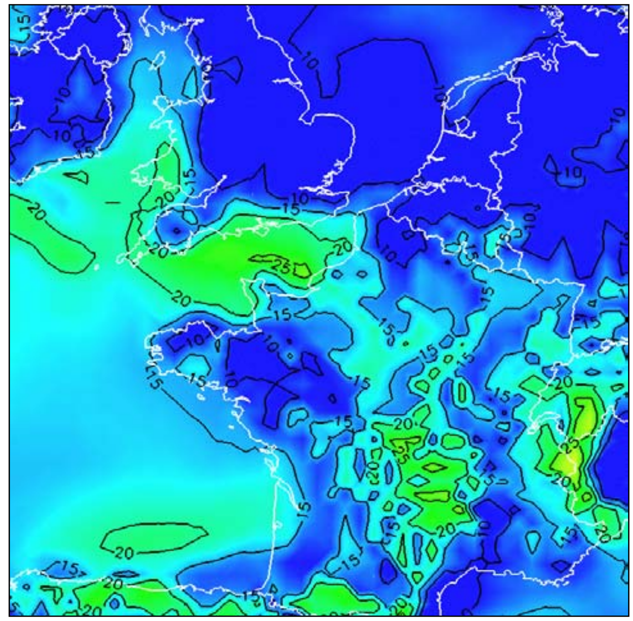

FIG. 5 - Surface wind speed from MM5 PBL module for 08Z 26 December 1999.

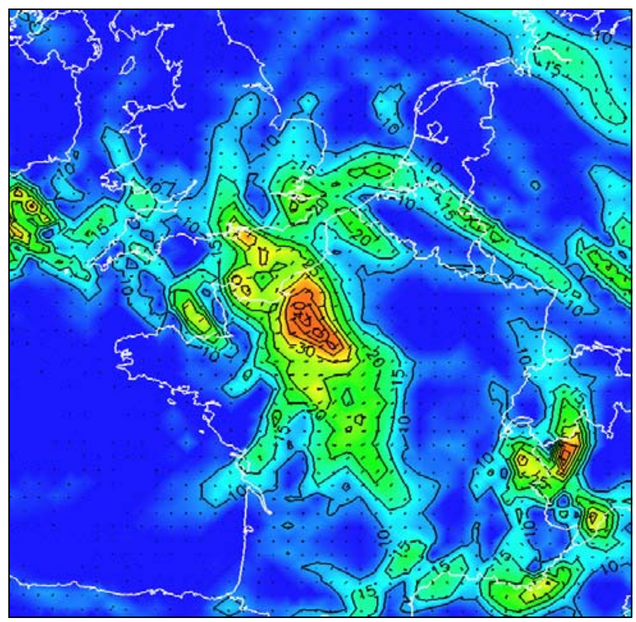

FIG. 6 - Isallobaric wind calculated from MM5 surface pressure tendency (b) for 08Z 26 December 1999.

We can increase the reliability and extend the return periods in two ways. First, we can perturb "seed storms" that comprise the 40-year MM5 wind climate to create an ensemble for each event. In effect, this perturbation technique results in an extension, or generalization, of the NCEP Global Reanalysis wind climate. A time series for each of an 11-member ensemble of MM5 simulations for Lothar is shown in Figure 7.

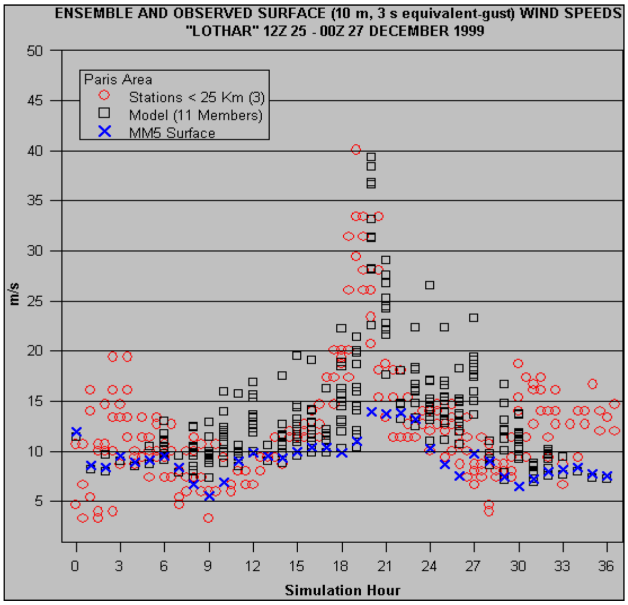

FIG. 7 - Time series of observed and modeled wind speed for Lothar for three locations near Paris, France. Observations (METARs) are available every half hour.

In addition to extending the number of members in the wind climate, we can extend the predicted maximum wind for periods longer than 40-years by applying a technique developed at Ris∅ Laboratory in Roskilde, Denmark (Abild 1994). This statistical technique, calibrated using long-term wind observations taken at Ris∅ and elsewhere in Denmark, allows us to compute any desired return period wind based on annual observed maximum winds. The uncertainty associated with the prediction is reduced as the number of observations increases. By treating MM5-simulated winds as observations, and increasing the number of observations using the perturbation process, we can reduce the uncertainty even for longer return periods.

Figure 8 shows the annual maximum wind speed (1-year return period) based on the MM5 40-year wind climate in panel (a). Note the detail in the map reflecting not only the incorporation of terrain effects included in the MM5 simulations, but also the 30-km resolution at which MM5 was run. Panel (b) shows the 100-year return period wind speeds using the Ris∅ technique. The same level of detail is present. Applying the stochastic technique has reduced the uncertainty (not shown) associated with this extended period for which observations are not available.

6. Summary and Future Work

We have shown that MM5 is capable of producing a realistic wind climate for European winter storms. Using the 40-year NCAR/NCEP Reanalysis data set, we have simulated hundreds of seed storms and produced estimated winds associated with such storms.

We have done extensive verification of winds observed during the most historically damaging storms. MM5 does an excellent job reproducing pressure tendency “pulses” responsible for the strongest surface winds. These features, which appear to be associated with gravity waves having wavelengths on the order of 10s of km, can be adequately simulated using 30-km resolution. Both the overall structure of the simulated footprint and time series for observing stations match well with MM5 predicted winds. One important future effort will be to accommodate complex terrain in our downscaling of MM5.

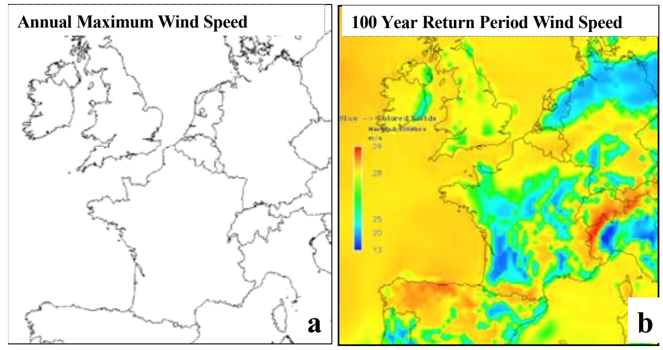

FIG. 8 - Return period wind speed maps. Panel (a) shows the average annual maximum wind speed using the 40-year MM5-simulated wind climate. Panel (b) shows the 100-year return period wind speeds using the Riso Laboratory technique for extending the annual maximum to longer periods.

Taking the MM5 results as “simulated observations”, we can produce an annual maximum wind speed map. This allows us to study the expected wind climatology over Europe. We can extend this wind climate to periods longer than that covered by the reanalysis data by applying the Ris∅ Laboratory technique to the annual maximum wind field. In the end, it is this information which is key to insurers and re-insurers assessing their portfolio risk to severe windstorms.

References

Abild, J., 1994: *Application of the Wind Atlas Method to Extremes of Wind Climatology*, Ris∅-R-722(EN), Ris∅ National Laboratory, Roskilde, Denmark, 173 pp.

Brasseur, O., 2001: Development and Application of a Physical Approach to Estimating Wind Gusts. *Monthly Weather Review*, **129**, 5–25.

Goyette, S., M. Beniston, D. Caya, R. Laprise, P. Jungo, 2000: Numerical investigation of an extreme storm with the Canadian Regional Climate Model: the case study of windstorm VIVIAN, Switzerland, February 27, 1990: *Climate Dynamics*, **18**, 145-168.

Joly, Alain, Dave Jorgensen, Melvyn A. Shapiro, Alan Thorpe, Pierre Bessemoulin, Keith A. Browning, Jean-Pierre Cammas, Jean-Pierre Chalon, Sidney A. Clough, Kerry A. Emanuel, Laurence Eymard, Robert Gall, Peter H. Hildebrand, Rolf H. Langland, Yvon Lemaître, Peter Lynch, James A. Moore, P. Ola G. Persson, Chris Snyder, Roger M. Wakimoto, 1997: The Fronts and Atlantic Storm-Track Experiment (FASTEX): Scientific Objectives and Experimental Design. *Bulletin of the American Meteorological Society*: **78**, 1917–1940.