AIRCURRENTS

EUROPEAN WINDSTORMS: INCREASED REALISM IN SURFACE-LEVEL WINDS

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EDITOR'S NOTE: Editor's Note: AIR will shortly be releasing a major upgrade to its Extratropical Cyclone Model for Europe. In this article, Dr. Gerhard Zuba, Principal Scientist, discusses AIR's approach to modeling the structure and evolution of these storms, and AIR's new state-of-the-art approach to "downscaling" to incorporate local land effects at a very high spatial and temporal resolution.

By Dr. Gerhard Zuba

OVERVIEW

Winter storms, also called extratropical cyclones (ETCs), can traverse immense areas in a span of a few hours. While ETC wind speeds seldom rival those of major hurricanes, the large size of these storms and their relative frequency create the potential for widespread and recurrent insured losses.

Modeling extratropical cyclones depends first on accurately representing the meteorological characteristics and dynamic atmospheric flow associated with these complex systems, and then accounting for detailed land features that can have a significant influence on surface wind speeds at the local level. The 2010 update to the AIR Extratropical Cyclone Model for Europe leverages newly available high resolution land use/land cover data and an extensive database of historical wind speed observations to refine its surface wind field resolution to just 1 km by 1 km. With this enhancement, the model is able to capture at a high resolution such features as wind gusts, the change in wind speeds as they transition from a rural environment to an urban one, and the acceleration of winds up mountain ridges or on entering a narrowing channel. The result is drastically more realistic modeling of wind speeds—and losses—at the local level.

EXTRATROPICAL CYCLONES—AN INTRODUCTION

Ask a meteorologist what a tropical cyclone looks like, and she'll describe a calm, low pressure eye at the center, surrounded by a ring—or eyewall—of dense thunderstorm clouds and intense winds, beyond which are curved trails of rain bands that give the storm its spiral appearance. She may wax poetic about the simplicity of its horizontal symmetry, with winds decreasing predictably as you move outward from the center, and a gently sloped funnel-like vertical structure.

Ask her what an extratropical cyclone looks like, and the answer becomes more complex. Again, there's an area of low pressure, but also a high pressure ridge, low pressure trough, constantly interacting warm and cold fronts, and a strong upper-level jet stream. Within the storm, air flows both up and down, and surface winds can be enhanced by a number of substructures, including sting jets and gravity waves.

The satellite images in Figure 1 illustrate some of the differences in structure between tropical and extratropical cyclones. The asymmetry of ETCs and their complex temporal and spatial evolution make them considerably more difficult to model. Because their source of energy is not the warm ocean waters that spawn tropical cyclones, but rather the contrast in temperature between cold air masses from the poles and hot air masses from the equator, ETCs exist in a more dynamic set of atmospheric conditions. The bottom line is that, unlike the wind fields of tropical cyclones, those of extratropical cyclones cannot be realistically modeled using a handful of variables.

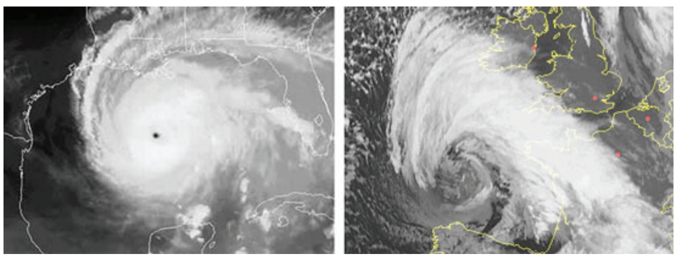

Figure 1. These satellite images show some of the structural differences between tropical cyclones (left) and extratropical cyclones (right). (Source: NASA and EUMETSAT)

CAPTURING STORMS IN 4-D WITH NUMERICAL WEATHER PREDICTION

Recognizing that statistical parameterization methods are insufficient for capturing the potential risk from extratropical cyclones, AIR introduced the industry's first winter storm model based on numerical weather prediction (NWP) in 2000. From what was first developed in the 1950's by the U.S. government as an operational weather forecasting system, numerical weather prediction technology is now used by all major meteorological agencies in the world and has found numerous other applications in academic and commercial fields.

Starting with a three-dimensional snapshot of environmental conditions—known collectively as "initial conditions"— NWP predicts how the atmosphere will change over time using mathematical equations that govern fluid flow and thermodynamics. To build the stochastic catalog of simulated ETCs for the AIR Extratropical Cyclone Model for Europe, AIR has obtained the initial conditions of more than 4,000 historical storms that occurred over Europe during the last 50 years. These initial conditions, which include sea surface temperatures, air temperature, wind speed, and water content and pressure, are obtained from an immense global dataset developed by the National Center from Atmospheric Research (NCAR) and the National Centers for Environmental Prediction (NCEP). The dataset is based on historical land surface, ship, upper and lower atmosphere weather balloon, aircraft, and satellite observations. The spatial resolution of the data is approximately 200 km, and its temporal resolution is 6 hours.

To refine and extend this data, AIR uses a higher-resolution regional NWP model developed by scientists at NCAR and Pennsylvania State University. Using the regional model, the coarser dataset is refined to a grid of more than 20 vertical layers that extend from the Earth's surface to the tropopause (about 14 km above the surface), at a horizontal resolution of 90 km (down from 200 km) and a temporal resolution of just one hour (down from six). By explicitly incorporating the effects of surface friction, land use variation, and the flux of surface heat, moisture, and momentum of the storm's energy, the model realistically moves the pressure and wind fields of simulated extratropical cyclones forward in time in response to topographical and atmospheric conditions.

While it is crucial that the model be able to capture the three-dimensional structure and temporal evolution of extratropical cyclones, it is only winds at the Earth's surface that cause property damage. As often observed during and in the aftermath of actual storms, extreme wind gusts can be highly localized. However, because of current limitations in computing power, the surface features in each grid cell need to be averaged before they are input into an NWP model. Thus to make it possible to analyze surface wind speeds at a given location, AIR researchers have developed an advanced downscaling procedure to model local land effects at a very high resolution.

DOWNSCALED NWP

While ETCs originate in the upper levels of the atmosphere, surface features on the land can have a profound effect on wind speed and wind flow, and accurate modeling of local wind intensity requires a process to enhance numerical weather prediction output to include these detailed features.

AIR's new downscaling methodology (schematically illustrated in Figure 2) takes a hybrid approach that includes both physical downscaling, which incorporates the physical properties of the surface that affect wind speed, as well as statistical downscaling, which acknowledges the statistical relationship between the modeled data and historical observations.

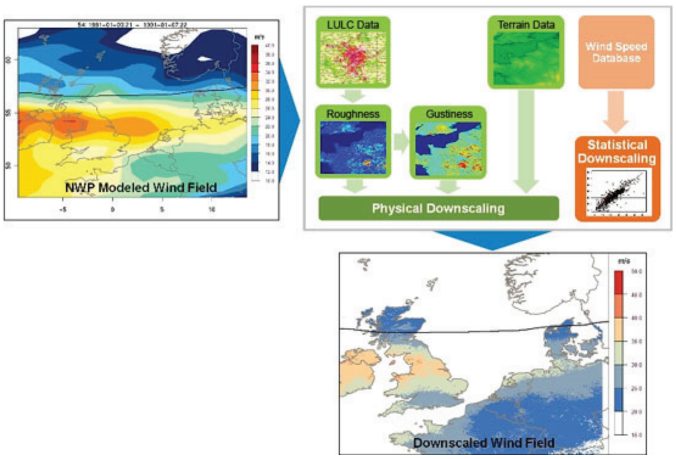

Figure 2. AIR's downscaling methodology includes physical downscaling, which uses land use/land cover and terrain data, and statistical downscaling, which takes into account historical wind speed observations.

PHYSICAL DOWNSCALING

For the purposes of downscaling, numerical weather prediction wind speeds at a height of about 150–180 meters above ground level (referred to as the boundary layer) are used. At this height, winds are not significantly influenced by specific surface features. Closer to the ground, wind flow can be affected by elevation, terrain, and obstacles like buildings and other built structures.

Physical downscaling translates boundary layer wind speeds to the surface (10 meters above ground level). To capture surface characteristics, AIR uses the USGS/EROS GTOPO30 database, which contains elevation data at a horizontal resolution of approximately 1 km by 1 km and a vertical resolution of 1 m. For land use/land cover (LULC), AIR uses the European Environment Agency's high resolution CORINE database to determine surface roughness factors.

As winds travel over terrain of varying surface roughness, the wind profile changes multiple times before arriving at any given location. To account for this, AIR computes an "effective" surface roughness by averaging the roughness over a few grid cells based on the direction of historical winds in past damaging storms. For most of the modeled countries, the dominant storm track is a westerly one during winter months. Figure 3 shows the averaged roughness across Europe.

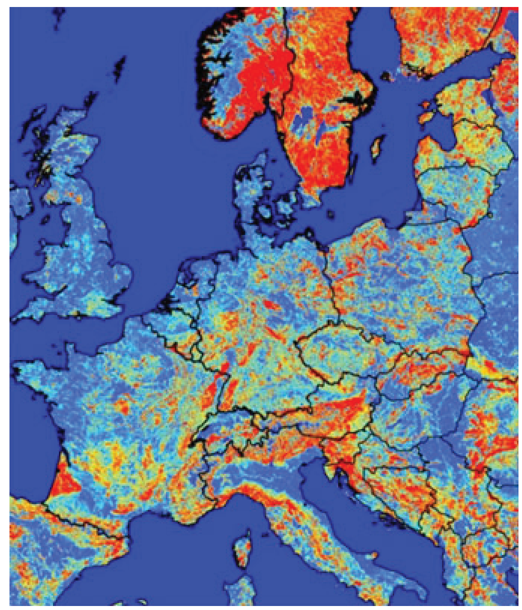

Figure 3. Averaged roughness across Europe

While surface roughness exerts a frictional drag on winds, it can also enhance gustiness. Wind gusts range from the very extreme that last only several seconds, to weaker ones that may last several minutes. Typically, very rough surfaces can increase gustiness, while smooth surfaces are associated with low levels of gustiness.

The temporal resolution of the NWP model output is approximately 10 minutes, which is inadequate to capture these high frequency gusts. Therefore, AIR researchers use well established formulas to convert model output to 3-second wind gusts. The process accounts for not only the gustiness of winds across different types of surfaces, but also from different directions across those surfaces.

STATISTICAL DOWNSCALING

While physical downscaling produces high resolution surface wind speeds, they are still derived from numerical weather prediction output at the boundary layer using surface parameters averaged over a relatively coarse resolution. This in effect removes the inherent variation in actual boundary layer wind speeds caused by high resolution terrain and land use/land cover changes. Accumulated over multiple grid cells, this can result in a regional mismatch (also called regional bias) of the NWP model. To correct this, AIR employs statistical downscaling to account for differences between NWP-modeled boundary layer winds and those observed in historical storms.

AIR has collected more than 30 years of wind speed data from monitoring stations in all 12 modeled countries. After removing the effects of surface features, these observed wind speeds are compared to NWP output, and a computational method is used to account for the statistical relationship and correct any regional bias.

CONCLUSION

The science behind modeling extratropical cyclone winds has seen significant advancements over the past decade. In 2000, AIR pioneered the use of numerical weather prediction in catastrophe modeling to more realistically capture the complex structure of these storms—an innovation that represented a vast improvement over previous parametric approaches. AIR's NWP methodology has been refined and enhanced over the years to capture the full four-dimensional structure of extratropical cyclone winds.

This year, with the spring 2010 release of the AIR Extratropical Cyclone Model for Europe, AIR introduces yet another set of enhancements to the application of numerical weather prediction, including the explicit modeling of storm clustering, as well as the innovative downscaling methodology discussed in this article. But no matter how cutting-edge the science, the true value of these enhancements can only be measured in terms of how realistically the model represents the hazard. To this end, AIR has validated modeled surface winds against a robust and detailed database of more than 30 years of recorded observations. AIR's downscaling approach—the first of its kind in the industry—sets yet another standard for modeling extratropical cyclone risk.

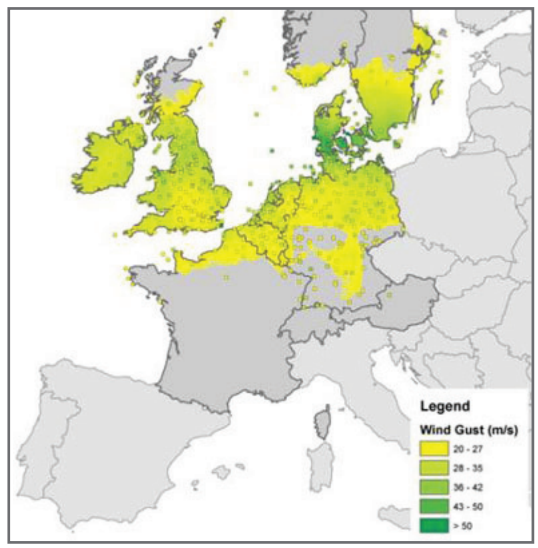

Figure 4. Modeled (represented by the continuous colors) vs. observed wind gusts for ETC Anatol (1999)

ABOUT AIR WORLDWIDE

AIR Worldwide (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 50 countries. More than 400 insurance, reinsurance, financial, corporate and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, site-specific seismic engineering analysis, and property replacement cost valuation. AIR is a member of the ISO family of companies and is headquartered in Boston with additional offices in North America, Europe and Asia. For more information, please visit www. air-worldwide.com.

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