

Frontiers: Modeling  
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## 1. Types of Models

There are several types of models in the physical Earth system sciences which are used in studying extreme events. Physical models, such as wind tunnels, are applied to investigate, for instance, the extreme wind pressure forces which could occur on a roof, or on building siding and windows. Model aircraft are inserted into wind tunnels to assess their ability to withstand extreme turbulence. Engineers use this information to design actual buildings and aircraft, with additional strength added for insurance. Statistical models are applied to assess extremes where past episodes are used to create the statistics. Numerical models have been developed where physical constraints (such as the first "law" of thermodynamics) are included, along with parameterizations of other aspects of the system being modeled. Numerical weather prediction models provide an example of this type of tool. Models can also be cataloged into their use for i) diagnostic studies; ii) process investigations; and iii) prediction. Diagnostic models, with respect to extreme events, use observed data, perhaps constrained by physical constraints, to extrapolate and interpolate to locations where data was not observed. This type of model, for example, is used after a hurricane makes landfall and wind damage assessments are completed. The wind field of the hurricane is evaluated using this approach. Process models are designed to understand how extreme events occur, such as the maximum intensity of a hurricane given a defined sea surface temperature. Predictive models attempt to forecast the occurrence of extreme events such as the track of a hurricane or an early fall freeze.

## 2. Model limitations

Models are limited in their realism by the extent to which they are constructed from basic physical concepts and from parameterizations. Physical concepts are those aspects of a model which are derived from fundamental physical concepts, which are assumed invariant in space and time. The acceleration of gravity, the advection of a quantity by the wind and the pressure gradient force, for example, are fundamental concepts in atmospheric models. Parameterizations, in contrast, are always derived with observational data where arbitrary constants and functions are used to fit the parameterization to the data. Even though the parameterization often has the appearance of being based on fundamental concepts, these arbitrary constants and coefficients always appear. The representation of clouds and precipitation, radiative fluxes, and turbulence in atmospheric models represent processes that are always parameterized in numerical weather prediction and climate models. Process models will necessarily be limited in their ability to represent extreme events, if the parameterizations are based on observational data that did not occur associated with these extreme events. Similarly, model prediction of extreme events is limited as a result of the incompleteness of the parameterizations. With statistical models, they are even more constrained since the entire model is constructed based on what has occurred. It is not appropriate to

extrapolate any such statistical model outside of the range of parameters from which it was constructed. Even given this constraint, however, it is often very difficult for process models to perform better in prediction, than the statistical models, as soon by Landsea and Knaff (2000) in their comparison of statistical and dynamic forecasts of La Niñas and El Niños. The resolution of a model also limits the spatial and temporal scale to which it can be applied. At least 4 grid increments are needed in each spatial direction, for example, before a feature can be resolved with significant accuracy in atmospheric and ocean models. For features that are smaller than 4 grid intervals, all computational techniques that represent their movement in these models suffer from serious errors. Interpolation to scales smaller than this resolution can only provide the illusion of higher resolution.

### 3. Value of models

Despite these limitations, models are able to provide some information regarding extreme events. In atmospheric sciences, numerical models are using maximum estimated realistic large scale inputs of water vapor and wind convergence to simulate the maximum potential precipitation that can potentially occur in a given region. This information is critical for water resource managers, in order not to over design yet provide the needed protection from floods. This use of models is thus a combination of a process model with an expert system (the meteorologist who provides the large scale "extreme weather condition"). Process models also provide considerable value as sensitivity simulations. By perturbing one component of the model, an assessment can be made to determine if a significant change in one or more model extreme events occurs. This is the approach used by the climate change community where the radiative effect of anthropogenically doubled greenhouse gases on the global climate is assessed, but other man-caused changes in the climate system are ignored. The term "scenario" has been used to describe these sensitivity experiments, but a scenario is more correctly a realization from an ensemble of model simulations, where all important direct effects and feedbacks within the system being studied are included.

### 4. Conclusions

Diagnostic models are useful in assessing the spatial and temporal structure on an extreme event, after it has occurred (using observed damage and other data). Process models provide a procedure to explore the sensitivity of an extreme event to perturbations in the model forcing and representation of the processes in the model. It needs to be recognized, however, that process models are always incomplete estimates of how the real world system works. Banks (1993) refers to such modeling as "exploratory modeling." Statistical predictive models can provide actual accurate forecasts for extreme events when the event falls within the envelope of data from which the model was constructed. Numerical models can estimate extreme events which have never occurred in a specific region providing the initial data that is inserted into the model (the "initialization") is unique, and the parameterizations in the model are unimportant in the occurrence of the extreme event or the parameterization fortunately works outside its development range. Numerical weather prediction models, for example, have been so

successful for many (but not all!) extreme events since the models are so constrained by the initial observed data, and the parameterizations work since the extreme event has occurred elsewhere before, and the parameterization has been tuned to represent such an occurrence. In the context of extremes in future climates, the feedback within the Earth system are so nonlinear, and the direct affects of humans incompletely understood, that even process models are inadequate. For this reason, it is proposed that a vulnerability perspective be adopted to provide protection (or adaptation) from the range of all plausible extreme events, rather than seeking to predict the future extremes. Process models, as contrasted with their use as predictive models, are the more useful tool for extreme event assessments, as they may, in principle, be able to provide brackets as to what is possible in the real world, and what is not.

#### References/Bibliography

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