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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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REGULATORY POLICIES AND PRACTICES SUBCOMMITTEE

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THURSDAY

AUGUST 18, 2011

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B3, 11545 Rockville Pike, at 1:00 p.m., William Shack, Chairman, presiding.

SUBCOMMITTEE MEMBERS PRESENT:

WILLIAM J. SHACK, Chairman

DENNIS C. BLEY

CHARLES H. BROWN, JR.

JOHN W. STETKAR

NRC STAFF PRESENT:

GIRIJA SHUKLA, Designated Federal Official

SELIM SANCAKTAR

BRAD HARVEY

MILTON BALLENTINE

ALSO PRESENT:

EMIL SIMIU

PETER VICKERY

I-N-D-E-X

P-R-O-C-E-E-D-I-N-G-S

1:00 p.m.

CHAIR SHACK: The meeting will now come to order. This is a meeting of the Advisory Committee on Reactor Safeguard Subcommittee of Reactor Policies and Practices. I am Bill Shack, Chairman of the Subcommittee.

Subcommittee members in attendance are John Stetkar, Charles Brown and Dennis Bley. Mr. Girija Shukla of NRC Staff is the designated Federal Official for this meeting.

The Subcommittee will hear presentations from the NRC Staff regarding the new Staff Guidance for use in selecting the design basis hurricane wind speed and hurricane generated missiles that a new nuclear power plant should be designed to withstand, as discussed in the draft Reg Guide 1.221, Design Basis Hurricane and Hurricane Missiles for Nuclear Power Plants.

We have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting. The meeting will be open to public attendance.

The Subcommittee will gather information, analyze relevant issues and facts and formulate

proposed positions and actions, as appropriate, for deliberation by the full committee.

The rules for participation in today's meeting have been announced as part of the notice of this meeting published in the Federal Register on July 25th, 2011. A transcript of the meeting is being kept and will be made available as stated in the Federal Register notice.

Therefore, we request that participants in this meeting use the microphones located throughout the meeting room when addressing the Subcommittee. The participants should first identify themself and speak with sufficient clarity and volume so they may be readily heard.

Please silence your cell phones if you have them. We will now proceed with the meeting. And I call upon Selim Sancaktar of the NRC staff to make introductory remarks.

MR. SANCAKTAR: Thank you. My name is Selim Sancaktar. I work for the NRC in Office of Research. We are here to provide a presentation on impending Regulatory Guide 1.221, on Design Basis Hurricane and Hurricane Missiles for Nuclear Power Plants.

I will quickly pass it on to one our major

presenters, Brad Harvey, from the Office of New Reactors. Besides myself there are three presenters here and they are, in my opinion, are very good representatives of their respective fields and I hope that you will receive useful and satisfactory information from each of them.

So with this I will pass to Brad. And I think we'll shift your way.

MR. HARVEY: Good afternoon. My name is Brad Harvey. And I am a Senior Physical Scientist in the Division of Site Environmental Reviews within the Office of New Reactors. I was responsible for initiating a user's need that resulted in development in Reg Guide 1.221.

This slide outlines my presentation. I plan to review the regulatory basis for Reg Guide 1.221 and describe the history of NRC's Extreme Wind Regulatory Guidance. Including explaining the Design Basis Wind Law Criteria and presenting the basis of the Design Basis Tornado Wind Speeds.

The intent of this presentation is two-fold. One, to describe the basis for defining the Design Basis Tornado Wind Speeds and the Design Basis Hurricane Wind Speeds as corresponding to an exceedance frequency of 10^{-7} per year.

And two, to explain why the design basis tornado maximum wind speeds have decreased over time to the point that it was no longer clear that the revised design basis tornado wind speeds would bound corresponding hurricane wind speeds in all areas of the United States.

One of the regulatory criteria that establishes the requirements for the design basis tornado and hurricane can be found in Appendix A to 10 CFR, Part 50. General design criteria for nuclear power plants.

In particular GDC 2 says, structures systems and components important to safety shall be designed to withstand the effects of natural phenomenon such as tornados, hurricanes while at loss of capacity to perform the safety functions.

The design basis for SSCs shall reflect appropriate consideration of the most severe of the natural phenomenon that have been historically reported for the site and surrounding area. With sufficient margin for the limited accuracy, quantity and period of time in which the historic data have been accumulated.

Another regulatory criteria now establishes the requirement for design basis tornado

and hurricane can be found in Subpart B, which is the evaluation factors for stationary power reactor site applications, to Part 100 citing criteria.

In particular, 10 CRF 100.20(c)(2) says meteorological characteristics of the site that are necessary for safety analysis or that may have an impact upon plant design, such as maximum probably wind speed and precipitation, must be identified and characterized.

10 CRF 100.21(d) further states that the physical characteristics of the site, including meteorology, must be evaluated and site parameters established such that potential threats from such physical characteristics will pose no undue risks to the type of facility proposed to be located at the site.

The U.S. NRC Regulatory Guide suggests two design points for wind loads, as shown in this table. For example, Reg Guide 1.142, which describes acceptable methods for the design of safely-related concrete structures, states that the procedures and requirements described in American Concrete Institute Standard, ACI 349-97 are generally acceptable to the staff.

As a result the guides in ACI 349-97, as

well as guides presented in several SRP sections, such as 2.3.1 and 3.8.4, form the basis for this table. The first design point is commonly called the operating basis window which represents a severe environmental load that could infrequently be encountered during the life of the plant.

ACI 349-97 and SRP 2.3.1 define the operating basis wind as wind velocities and forces associated with 100-year recurrence interval or an exceedance frequency of 10^{-7} per year. SRP 3.3.1 describes the procedures that should be used to transform the operating basis wind load into and equivalent pressure.

The second design point is commonly called the design basis tornado, which represents and extreme environmental load that is credible but highly improbable. Reg Guide 1.76 defines the design basis tornado as corresponding to an exceedance frequency of 10^{-7} per year calculated as a best estimate.

SRP 3.3.2 describes procedures that should be used to transform and design basis tornado parameters into effective loads. As shown in the last column in this table the operating basis window, in a design basis tornado load, are used with different load factors and load combinations. In ACI 349-97 to

evaluate the capacity of concrete structures to withstand wind pressures.

For example the operating wind basis W has a load factor of 1.7, here, which in part accounts for the probability that wind speeds higher than the operating basis wind load might occur during a plant's life. No such factor appears for design basis tornado load, down here.

Note that Reg on 1.221 is intended to represent hurricane loads that represent an extreme environmental load that is credible but highly improbable. Similar to that of a design basis tornado with an exceedance of 10^{-7} per year.

MEMBER STETKAR: Brad, I don't want to dwell on this too much. But the notion of credible but highly improbable, can you explain the notion of credibility to events that you claim you understand with a frequency of once in ten million years?

MR. HARVEY: I think that for the purposes of my factor. If you look at ACI 349-97 --

MEMBER STETKAR: No. I'm asking you. Can you explain the notion of the, not ACI, not the Reg Guide, can you explain your understanding as an NRC/NRO manager.

Of what can be credible when you're trying

to say we understand that at a exceedance frequency of once in ten million years. Given the age of the Earth and the age of recorded history on the Earth and the range of variability in extreme meteorological events?

Is there any notion of credibility to those known loads?

MR. HARVEY: Credible may not be the right word here. Highly improbable is probably the word.

MEMBER STETKAR: Well, I'd highly grant you that highly improbable is 10 to the ninth, I'd also grant you that once in 10,000 years is highly improbable. Maybe even once in 1,000 years is highly improbable to a lot of people.

MR. HARVEY: But when it comes to tornados though, it is possible that some place in the United States we have seen tornados that have the wind speeds that we're discussing.

MEMBER STETKAR: Absolutely, that's correct. There's strong variability, I'm not --

MR. HARVEY: So in that point --

MEMBER STETKAR: But we have seen those.

MR. HARVEY: But that's why they're credible.

MEMBER STETKAR: Right. Exactly, I'm not arguing about the credibility of the things that we've

seen or are slightly larger than things that we've seen.

MR. SIMIU: Could I?

MEMBER STETKAR: Sure.

MR. SIMIU: It is true that we don't have many data sets of size ten million or larger.

MEMBER STETKAR: Show me the one, I'd really like to see it.

MR. SIMIU: Well, I was joking. But we do have estimation methods that have a certain credibility and have been tested for many recurrence intervals that are --

MEMBER STETKAR: So we've looked at several ten million year snapshots of the Earth's history and have that information.

MR. SIMIU: No, we looked at various snapshots where we had, for example, 30 years of data and could make credible extrapolations to 1,000 to 10,000 years, which can be verified.

Even though we don't have, at a particular location, a 10,000 year site. We do have many locations and if we pool those data we can make some inferences to a larger mean recurrence interval that are credible.

That establishes, to some extent, the

credibility of the methodologies that I used to make inferences for larger mean recurrence intervals than those that have been experienced in a lifetime or two lifetimes.

So credibility pertains to the estimation methods that is applied to a large number of data sets. That is one way to address your very legitimate question.

MEMBER STETKAR: Well also I note that in your examples you said we can use information perhaps compiled over decades to maybe a couple hundred years to have some confidence in extrapolating out to, I think you used 1,000 years or 10,000 years.

That's one degree of extrapolation and some amount of uncertainty. Extrapolating yet another factor of 1,000 beyond that to ten million years is a daunting challenge.

MR. SIMIU: It is. And it is a challenge that needs to be addressed.

(Simultaneous speaking)

MEMBER STETKAR: The question is why does it need to be addressed? Why does this arbitrary 10^7 that we are expending a lot of effort on, what's the basis for that number? Why is it not 10^{-4} or something that we can --

MR. HARVEY: My presentation goes into that a little bit. It's basically it's part of a second paper that we provided to the commission which it responds, we affirm, 10^{-7}.

MEMBER STETKAR: Well, sure. Seven's only like five more than two. So it's not a big abyss.

MR. HARVEY: The way I look at it, it's a highly improbable event. So you're right, it's very hard with any sort of perceived accuracy whatsoever to calculate that.

MEMBER STETKAR: That's the key.

MR. HARVEY: But my point --

MEMBER STETKAR: Are we making regulatory decisions based on a perceived degree of confidence or credibility in numbers that perhaps have very little, if any, basis for that perceived degree of confidence or credibility?

In other words should we be making regulatory decisions based on numbers that we have a higher degree of confidence in, perhaps one in 1,000 or one in 10,000 years if you'll allow me that, that might have higher wind speeds and perhaps somebody would have to deal with that.

MR. SIMIU: Well we already have --

MEMBER STETKAR: I'm sorry lower wind

speeds. Lower wind speeds.

MR. SIMIU: We already have done that for the building we're in, for example. We don't want it to collapse every ten years. We have 1,000 to 10,000 even 100,000 years. When you consider, which is another way of saying that we have a probability of failure that is perceived as sufficiently low.

And we would like nuclear power plants to be safer even than this building that we don't want to collapse, because we're in it. But the consequences will be so great that we take additional work.

CHAIR SHACK: John, this is really, the newest metrics for new reactors kind of stuff.

MEMBER STETKAR: No, I understand that. But it's also something that's being published in the year 2012 that may not be updated for another 30 or 40 years given the recurrence interval of updating regulations.

CHAIR SHACK: I think it will take a policy, a second --

MR. HARVEY: The second paper that we presented the Commission with alternatives reducing the frequency and they didn't buy into it. Hence, I'm following, it's a policy decision the Commissioners made in 2004 and I feel compelled to live to it.

SRP 3.3.2, which is entitled Tornado Loads, is concerned with the design of structures that must withstand the effects of design basis tornado. SRP 3.3.2 states that tornado effects can be divided into three groups. One, tornado effects caused by the direct action of airflow on structures.

Two, atmospheric pressure changes effects caused by differential pressure between the interior and exterior of a structure during the passes of a tornado.

And three, tornado generated missiles. Tornado effects considered in design should include combinations of tornado wind effects, atmospheric pressure change effects and tornado generated missile impact effects.

This slide shows acceptable methods for combining these effects and establishing the total tornado load on a structure, as specified in SRP 3.3.2.

MEMBER BROWN: Can you go back?

MR. HARVEY: Sure.

MEMBER BROWN: You have two equations?

MR. HARVEY: Yes.

MEMBER BROWN: I'm not a statistician or number cruncher like this. But I've Wt and Wp and

then I've got the same thing as a bunch of other factors. You're giving them two conditions that they have to consider? They can either do one or the other? They can either consider pressure and not exclude the wind load and the missile impact?

MR. HARVEY: My understanding is they would evaluate both of these and take the more conservative of the two as the design basis.

MEMBER BROWN: So it's a combinational issue? I mean that's what, if you use one effect et all, but if that's more conservative than the other one where you put a factor in front of it. And then the other ones don't have to overwhelm that other half in order to become more conservative, is that?

MR. HARVEY: I think that's correct.

MEMBER BROWN: So the wind effects and the missile effects have less impact than the atmospheric pressure change? It's the pressure changes that do most of the destruction in a tornado? The pulses?

MR. VICKERY: It depends on the building.

MR. HARVEY: And they don't occur at that same time.

MEMBER BROWN: Well I know missiles and the other things don't necessarily occur at the same time.

MR. VICKERY: Neither does the pressure change and the wind. If a building is very, very leaky then the pressure change doesn't really play a role at all. If the building is sealed then the pressure --

MR. HARVEY: Yes, I understand that point. All right, go ahead. I'm just trying to wrap myself around two different equations applying for this, and how do you pick. I mean do you choose leaky buildings or non-leaky buildings?

MR. HARVEY: Well I think it depends on the building. Some buildings are like this, they're intended to leak a bit. So you'll see that one of the design basis tornado criteria is the pressure rate.

Or the rate of increase and decrease of pressure. And so you can show that the building can adjust to that, almost instantaneously, so you can make the pressure term go away.

MR. BALLENTINE: Excuse me. My name is Milton Ballentine, and I work for the Structural Engineering Branch and we have gone thoroughly over SRP 3.3.2, and just to support what Brad said. We consider both the differential pressure and the combination of the wind speed plus the missiles and we have the most conservative case to take into

consideration. So we look at both.

MEMBER BROWN: But you might have circumstances where the other two are zero and all you have to do is consider atmospheric pressure?

CHAIR SHACK: You just pick the one that's controlling. I mean you have a structure that sort of deals with both, but you design to the controlling one.

MR. BALLENTINE: Exactly.

MEMBER BROWN: I just kind of had a hard time seeing the differential pressure changes being based on observing what you see in some of these great videos of tornados ripping through stuff and the missile impact, which is really cramming, you know, really destroys stuff when it hits this.

It being less of an effect than the atmospheric pressure, but I'll, since I'm not an expert on this I'll --

(Off microphone discussion)

MEMBER BROWN: No, there have been videos of the houses blowing apart from the pressure changes as well. Go ahead, I'm just trying to learn something here.

MR. HARVEY: The staff's definition of an extreme environmental wind load has been evolving

during the last several decades. Until Reg Guide 1.221, the staff's definition of extreme environmental wind load has been based on the definition of a design basis tornado. Because tornado loads are assumed to be the bounding wind for all meteorological phenomenon.

The design basis tornado was first defined in the original version of Reg Guide 1.76 in April of 1974. The definition of design basis tornado was revised in March 1988 with the issuance of a staff internal position based on additional historic tornado data that was available at that time.

The staff revised this definition of design basis tornado again in April of 1993 by stating in SECY 93-87 that the design basis tornado should have mean recurrence 10^{-7} per year instead of 10^{-7} for probability of occurrence at the upper 90 percent confidence interval level.

In October 2004, SECY 04-200 confirmed that the design basis tornado should have a mean recurrence interval 10^{-7} per year and committed to updating Reg Guide 1.76 to reflect more recent tornado wind speed data that were available. The draft revision of Reg Guide 1.76, DG-1143, was distributed for public comment in February of 2006.

And the final Revision 1 to Reg Guide 1.76 was issued approximately a year later in March 2007. With the issuance of Draft Reg Guide 1.221, or DG-1247 in August 2010, the staff if proposing for the first time to expand its definition of the extreme environmental wind load to include hurricanes.

Because variable data were available when the original version of Reg Guide 1.76 was written in 1974, generalized conservative estimates were utilized in the development of the original design basis tornado.

Since then the National Severe Storms Forecast Center, which is now known as the Storm Prediction Center, has developed a tornado database which provides information on the intensity and damage area of tornados which have occurred in the United States since 1950.

The staff has revised its design basis tornado over time using the information compiled in this database, along with more sophisticated data analysis techniques. As a result the maximum wind speeds associated with the design basis tornado have decreased from 360 miles per hour in 1974 to 230 miles per hour in 2007.

We will explore the reasons for this trend

in the following slides. Okay my understanding is you prefer to skip over.

CHAIR SHACK: Yes, I think that we can come back to this if we have time today.

MR. HARVEY: That's just how the tornado model works. What I do want to point out, and briefly describe is the Fajita Tornado Scale, or F-Scale. Direct measurements of wind speeds in a tornado are rare because tornados only exist for short periods of time at random places. And they have a tendency to destroy local measurement equipment.

The F-Scale was induced in 1971 as a method for rating tornado intensity based on observing the damage inflicted on human built structures and vegetation. The F-Scale for a tornado is determined after performing a ground and/or aerial survey of the damage caused by a tornado.

Qualitative descriptions of the observed damage are then used to classify the tornado. The staff's first guidance on design basis tornados are provided in the original version of Reg Guide 1.76 which was issued in April 1974.

Design basis tornado specified in Reg Guide 1.76 were based on assumptions and mathematical models and in 1974 document WASH-1300, Technical Basis

for Interim Regional Tornado Criteria.

WASH-1300 selected its maximum design basis tornado wind speeds on the premise that the probability of occurrence of a tornado that exceeds a design basis tornado should be on the order of 10^{-7} per year per nuclear power plant.

The staff calculated the expected frequency of different tornado wind speeds for the three different regions in the continental United States using 13 years of regional tornado frequency data, 1955 to 1967.

And two years of tornado intensity data, 1971 through 1972, based on the newly defined Fajita Tornado Scale, or F-Scale. This slide shows the resulting Reg Guide 1.76 design basis tornado for three regions within the contiguous United States.

Reg Guide 1.76 concluded that a maximum speed of 360 miles per hour should be consistent with a 10^{-7} per year probability of occurrence for much of the United States east of the Rocky Mountains.

Model wind speeds of 300 miles per hour and 240 miles an hour were appropriate for regions west of the Rocky Mountains, which are Regions 2 and 3.

The Regulatory Guide specified the nuclear

plant should be designed to withstand the design basis tornado for each region or comprehensive analysis be provided to justify the selection of a less conservative design basis tornado.

In March 1988 the staff issued an interim position on the design basis tornado based on the analysis presented in NUREG/CR-4461, which is the Tornado Climatology of the Contiguous United States, which was dated in May 1986.

NUREG/CR-4461 recalculated tornado wind speed frequencies using a significantly improved tornado database containing 30 years of data, 1954 through 1983.

The resulting wind speed estimates were lower than the wind speed estimates presented in WASH-1300, Regulatory Guide 1.76, for most of the United States.

To account for uncertainties in the database and analysis, the staff included in its interim position that the 10^{-7} per year probability of current wind speed at the upper level of the middle 90 percent confident level of NUREG/CR-4461 should be used as the wind speed for the design basis tornado.

On this basis the staff interim position recommended a maximum wind speed of 330 miles per hour

for Region 1. Again, this shows the resulting staff interim design basis tornado for four regions within the contiguous United States.

SECY 93-087 was prepared by the staff in April 1993 to present the Commission with recommended positions pertaining to evolutionary and passive light-water reactor designed certification policy issues.

The staff recommended in SECY 93-087 that a 10^{-7} per year mean probability of occurrence, instead of the more conservative upper 90 percent confidence level presented in the staff interim position, should be used as a basis for the certified standardized tornado wind speed.

Based on the analysis in presented in NUREG-4461 the wind speeds associated with a tornado having a mean recurrence interval 10^{-7} per year were estimated to be about 300 miles per hour east of the Rocky Mountains and 200 miles per hour west of the Rocky Mountains.

Therefore, the staff recommended that a maximum tornado wind speed of 300 miles per hour be used in a design basis tornado employed in the design of the evolutionary and passive advanced light water reactors. SECY 93-087 also stated that the staff

expected that this criterion would not preclude citing the advanced light water reactor plant designs on most sites in the United States.

Furthermore, if a tornado has, at a selected site, exceeded the approved certified standardized design envelope the COL Applicant would have the option of performing a site-specific analysis to demonstrate the design is acceptable for the site.

December 2003 the staff sought Commission approval, via SECY 03-227, to issue Review Standard RS-002 for processing applications for early site permits. The guidance in RS-002 called for the use of the following for selecting site specific tornado parameters.

One, Regulatory Guide 1.76, which specify a maximum wind speed of 360 miles an hour for much of the United States east of the Rocky Mountains.

Two, a staff interim position which specified a maximum wind speed of 330 miles and hour for much of the United States east of the Rocky Mountains.

Or three, a site-specific analysis to justify a different wind speed. In the process of --

CHAIR SHACK: You didn't really expect anybody to pick 1.76 did you?

MR. HARVEY: Probably not, no. But that's what the guidance said. In the process of approving RS-002 the Commission expressed concerns regarding an apparent inconsistency between the maximum tornado wind speeds assumed for the certified standard reactor designs, which is 300 miles an hour. As discussed at SECY 93-087.

And the guidance related to tornado wind speeds in RS-002 that would be applied to sites that might host these new reactor designs. In order to address this inconsistency the Commission directed the staff to, one, update its regulatory guidance including Reg Guide 1.76 to reflect more recent tornado wind speed data that are available.

And two, develop options in applying a risk informed approach to the selection of a design basis tornado. In response to this directive, the staff again updated NUREG/CR-4461 and issued SECY 04-200 in October 2004.

Providing the Commission with three options for applying a risk informed approach to the selection of design basis tornado.

These options were. Option one, maintain the current SECY-93-087 definition of design basis tornado as a tornado having a mean frequency of 10^{-7}

per year. This option was based, in part on preliminary results from advice in NUREG/CR-4461 that indicated that the updated maximum wind speeds for tornados having a mean frequency of 10^{-7} per year would be on the order of 300 miles an hour.

Option two, develop a risk informed alternative approach that would permit the use of a less conservative design basis tornado of higher frequency, that is lower maximum wind speed by a higher probability that a maximum could be exceeded.

This approach would permit a design basis tornado of higher mean frequency than 10^{-7} per year if a risk analysis satisfactorily demonstrates that the risk form tornado strikes with frequencies between the selected design basis frequency, at 10^{-7} per year, was sufficiently small.

The third options was to relax the definition of design basis tornado to initiating frequency of less than 10^{-7} per year, i.e. closer to 10^{-6} per year, in order to be consistent with the definition of well advanced, adjusted and recent risk informed regulatory guidance.

In the response to SECY 04-200, the Commission approved Option 1 because the inconsistencies in NRC regulatory guidance documents

concerning the design basis tornado parameters were expected to be resolved with the update NUREG/CR-4461.

This meant that the definition of the design basis tornado as having a tornado having a mean frequency of 10^{-7} per year was being maintained.

Revision one to NUREG/CR-4461 was completed in April 2005, and its results were used to generate a Draft Revision 1 to Reg Guide 1.76, DG-1143, in January 2006. The tornado database used in revised CR-4461 included information recorded from January 1950 through August 2003.

The methods used in revising the analysis were similar to those using analysis of previous tornado climatology and that results in the initial publication NUREG/CR-4461 in 1986, except for, one, a term was added to account for the finite dimensions of structures whereas the original NUREG/CR-4461 assumed the power plant was a point structure.

And two, the valuation of wind speeds along and across the tornado footprint were accounted for, whereas the original NUREG/CR-4461 did not account for the variation of the intensities along the tornado path.

The results of this study, which are shown in the next slide, indicated that maximum wind speed

of 300 miles an hour is appropriate for tornados for the central portion of the United States.

A maximum wind speed of 260 miles per hour is appropriate for the western portion of the Great Plains and for the east coast. And a maximum wind speed of 200 mile and hour is appropriate for the western United States.

With the publishing of DG-1143, the staff decided the new design basis missile spectrum from SRP 3.5.1.4 into DG-1143. The selected design basis missile spectrum for nuclear power plants included, one, a massive high-kinetic energy missile that deforms on impact.

Two, a rigid missile that tests penetration resistance. And three, a small rigid missile of sufficient size that pass through any openings or protected barriers.

The staff determined that a six inch schedule 40 steel pipe and an automobile are acceptable as a penetrating and massive missiles, respectively, for use in a design of nuclear power plants as common objects near the plant's site.

In order to test the configuration openings in the protected barriers, the missile spectrum also included a one inch solid steel sphere

as a small, rigid missile. The table on this slide shows the resulting missile speeds.

These missiles were derived by solving the equations in motion for a missile imbedded in a tornado wind speed. Resulting are the missile maximum horizontal speeds were approximately 45 to 40 percent of the maximum tornado speeds for each region.

The maximum speed calculated for the pipe and spear missiles were somewhat less. Especially for the lower wind speeds in tornado Regions 2 and 3. The missile vertical velocities were assumed to be two-thirds of the missile horizontal velocities.

As discussed previously, the F-Scale has been used to rate tornado intensity based on the amount of damage created by the tornado. The original F-Scale was introduced in 1971.

Little information was available that time on damage caused by wind, so the original F-Scale represented little more than educated guesses at wind speed ranges for specific tiers of damage.

The Enhanced Fajita Scale, or EF-Scale was subsequently formulated as a result of research which suggested that the wind speeds required to inflict damage by intense tornados on the F-Scale were greatly overestimated. A process of expert elicitation among

structural engineers and meteorologists resulted in the EF-Scale.

The new EF-Scale was publicly unveiled by the National Weather Service on the same day that DG-1143 was issued for public comment, which was February 2nd in 2006. It began operational use on February 1st, 2007. As for the F-Scale, the EF-Scale is a damage scale and only a proxy for actual wind speeds.

The major difference between the two scales is the adjusted wind speeds. For example, the old F-Scale listed F4 tornados as having a three-second gust wind speeds between 210 and 261 miles per hour.

The new EF-Scale found that the three-second gust wind speeds between 166 and 200 miles an hour were sufficient to cause the damage previously ascribed to the F4 range of wind speeds.

MEMBER STETKAR: So now we understand that lower wind speeds cause the same damage that we thought was caused by higher wind speeds in the past?

MR. HARVEY: That's correct.

MEMBER STETKAR: Thanks.

MR. HARVEY: Go ahead.

MEMBER BLEY: Yes, because I wasn't around to follow that stuff as it was done. Both scales were

based on expert judgement --

MR. HARVEY: On the damage.

MEMBER BLEY: On the damage.

MR. HARVEY: The SR was probably a little bit less expert.

MEMBER BLEY: What kind of thing did we learn that meant the second experts be, we hope, better than the first? Did we have much actual instrumentation in any of these? Do we have any real measurements that help support it? Was it calculations, wind tunnel --

MR. HARVEY: I think it was calculation on wind tunnel tests.

MR. SIMIU: Yes, it's also that Fajita was a meteorologist and had very limited structural engineering experience. In time structural engineers tried to back calculate the loads that would cause certain degrees of damage.

And they concluded that Enhanced Fajita Scale was more appropriate than the strictly subjective and, I wouldn't say uneducated, but subjective estimates by a meteorologist of what the structural resistance of certain buildings would be under loading.

MEMBER BLEY: I'm just curious, because

like I say, I didn't follow it. Is there a large body of calculations, a large broad expertise in this area that led to this. Is it a consulting firm or two that did the calculations and put this all together?

MR. SIMIU: I think that, yes Larry was involved.

MR. VICKERY: Yes, sort of. Larry Twisdale was involved but he got fed up and left.

(Simultaneous speaking)

MR. SIMIU: It was the Texas Tech.

MR. VICKERY: In my opinion it was too low, but that's just my opinion.

MR. SIMIU: Texas Tech.

MEMBER BROWN: You mean you think the wind speeds are too low?

MR. VICKERY: Yes, but it's just my personal opinions.

MEMBER BLEY: So you think it's the reverse of what --

MR. VICKERY: No.

MEMBER BLEY: You think it should go even further than it's gone?

MR. VICKERY: No. I think if they went from 117, well, that's a bad example. Going from 209 to 165, it's probably higher than 165, that's all.

But it sure isn't 209.

MEMBER BLEY: Okay.

MEMBER BROWN: So you think they adjusted too much?

MR. VICKERY: I think, my personal opinion, based on our calculations for the hurricanes is it's a little bit too low, but it's judgement.

MR. SIMIU: You're not a structure engineer yourself.

MR. VICKERY: Yes, that's an advantage in some cases. I do make calculations.

MEMBER STETKAR: You know in the last decade or so there's been a lot more measurements of tornados. I mean it's become kind of a fad to go out and try to measure things. And one can argue about how reliable some of those measurements are.

But tornados are not particularly rare events around the country. And there are people who fanatically follow those things and try to measure wind speeds and --

MR. VICKERY: But not at ten meters.

MEMBER STETKAR: Not at tem meters, no.

MR. VICKERY: And that's the problem.

MEMBER STETKAR: That is true, that is a problem. But at least at ground level I think we have

better data than we had 30/40 years ago.

MR. VICKERY: Yes --

MEMBER BLEY: I want to go a little further in understanding how this develops. We've got the EF numbers now that I assume correspond to the same kind of, I mean on your earlier slide you showed us the F-Scale and showed photographs, so I guess a person could say, gee, well we had about that much damage so that's an F3.

Do we have, you know, are we using the same set of six photographs for --

MEMBER BROWN: No.

MEMBER BLEY: What are we using these days and who we thought -- like most, I assume most tornado don't hit anything so you can't use, most of them you use the ones that hit stuff that --

MR. HARVEY: There's like a set of 28 different criteria you that you look at. You look at the structure itself, whether or not it's a residential house or a commercial grade building.

MEMBER BLEY: So there's descriptive criteria of what would have happened --

MR. HARVEY: Yes, much more so than just pictures. And it's a quantum leap forward from the F-Scale to the EF-Scale.

MEMBER BLEY: There's an agency that actually goes out and tracks these or is it --

MR. HARVEY: The National Weather Service actually every --

MR. VICKERY: The folks in Oklahoma make the final discernment, determination.

MR. HARVEY: Yes, they do. The experts will go out there and they look at the damage and they characterize the intensity the length and the width of the tornado.

MEMBER BLEY: Then they do that based on the EF-Scale now and these criteria?

MR. HARVEY: Correct.

MR. VICKERY: Yes.

MR. SIMIU: And they take into account the type of code on which a structure was designed. And I will add it's a very imperfect system still. It's the best one could do so far.

MR. VICKERY: Yes, it's certainly better than what they had before and they had a lot of opinion.

MEMBER BLEY: I just needed some basic background. Go ahead.

MR. HARVEY: Okay. Because the design basis wind and draft Revision 1 to Reg Guide to 1.76,

or DG-1143, were developed using the F-Scales. And the National Weather Service began implementing the EF-Scale in February 2007 its second revision to NUREG/CR-4461 was developed which recalculated design basis tornado wind speeds using wind speed estimates based on the EF-Scale.

Those tornado characteristics that were directly related to wind speed, such as the probability of exceeding given wind speed at a point, should a point be struck by a tornado, were factored by switching to the EF-Scale and therefore significantly impacted Revised NUREG/CR-4461 analysis.

The revised design basis tornado wind speeds predicted by Revision 2 to NUREG/CR-4461 became the basis for the final Revision 1 to Reg Guide 1.76.

Design basis tornado wind speed estimates based on the EF-Scale are considerably lower than those based on the F-Scale. For example the highest design basis tornado winds speeds using the EF-Scales predicted in Revision 1 to NUREG/CR-4461 was 300 miles an hour.

Whereas the highest design basis tornado wind speed using the EF-Scale, as predicted in Revision 2 to NUREG/CR-4461 is 230 miles an hour.

CHAIR SHACK: Your slide should be

Revision 2, right?

MR. HARVEY: It's Revision 1 to Reg Guide 1.76. Revision 2 to NUREG/CR-4461.

CHAIR SHACK: Oh.

MR. HARVEY: Which is a point of confusion all the time. The tornado missile speeds were also recalculated for each tornado region based on each region's new design basis tornado wind speed.

Note that a smaller and lighter automobile missile is used for Region 3 as compared to Regions 1 and 2 because the heavier automobile used in calculation for Regions 1 and 2 would have a lower kinetic energy than in Region 3.

The result of an automobile missile maximum horizontal speeds are approximately 35 to 40 percent of the maximum tornado speeds for each region.

The maximum speed calculated for the automobile missile is also used for the pipe missile, because the pipe can be a surrogate for a rigid component of a larger missile, such as building debris that may become airborne in the tornado wind field.

The resulting sphere missile maximum horizontal speeds are approximately eight percent of the maximum tornado speeds for each region. The pipe and sphere missiles are assumed to impact at all

heights, whereas the automobile missiles are assumed impact only up to 30 feet above the highest ground elevation within 0.5 miles of plant structures.

The missile vertical velocities are assumed to be two-thirds of the missile horizontal velocities.

Since design basis tornado wind speeds were decreased as a result of the implementation of the EF-Scale it was no longer clear that the revised tornado design basis wind speeds at an exceedance frequency of 10^{-7} per year would bound hurricane wind speeds in all areas of the United States at the same exceedance frequency.

This prompted an investigation, NUREG/CR-7005, into extreme wind gusts during hurricanes at an exceedance frequency of 10^{-7} per year. The NRC also commissioned a second report, NUREG/CR-7004, to calculate velocities associated with several types of missiles consumed for different hurricane wind speeds.

The two new reports form the basis for the new Reg Guide 1.221. These two consultant reports, along with resulting Reg Guide 1.221 will be discussed in the presentations that follow.

Any questions on tornados at this point?

CHAIR SHACK: Good introduction.

MR. HARVEY: Thank you. I'm going to turn it back, to Selim, let's do musical chairs again.

MR. SANCAKTAR: This is Selim Sancaktar from Office of Nuclear Regulatory Research. I have a few slides just to set the stage for the next two presenters, who will have some substantive and useful technical information.

NRO came to research the user need to provide a supplementary Reg Guide to the existing Reg Guide 1.76. The supplementary Reg Guide would investigate the hurricane as opposed to tornados. This information on this slide pretty much, I think, is what he talked about. So with your permission I'll just skip it unless you have questions.

I think this Slide Number 10 pretty much speaks for itself. When you look at it it shows that in time the estimated wind speeds came down for design basis purposes. So they came down from a range of say 300 miles per hour to 230. So this immediately begs the question whether the tornado is still the limiting phenomenon for the purpose of design basis.

Not only for the wind speed but also for the missile speed. Because sometimes even with slightly lesser wind speeds you can still get more missile speed in hurricanes as opposed to tornado. So

it's a little bit tricky.

So NRO requested us to investigate it and --

MEMBER BROWN: Is that solely because of sustained speed as opposed to gusts that you would get in tornados?

MR. SANCAKTAR: No, it's --

MEMBER BROWN: I asked that because I've sat through two hurricanes in the last four years at my Miami Beach place and it was sustained, I mean, it just didn't --

MR. SIMIU: I think I have a simple explanation. A tornado comes and goes, it produces an impact on the missile. And then missile picks up some speed, the tornado goes and leave the missile alone.

MEMBER BROWN: Normal acceleration in other words?

MR. SIMIU: Yes. In a hurricane you have a wide wind field and it keeps adding momentum to the --

MEMBER BROWN: Yes, that's what I meant by sustained.

MR. SIMIU: Yes.

MEMBER BROWN: If it were a sustained effect, you're continuously accelerating as opposed to

settling. Which takes it and throws it like a baseball or something.

MR. SIMIU: Yes, you are exactly on the mark.

MEMBER BROWN: Okay. I just wanted to make sure I understood the metric. Thank you.

MEMBER STETKAR: So when I came into this there was already a White Paper being prepared, internal to RES, trying to assess who could do this job. What is technically, is this job doable.

Technically what we felt technically qualified people for the wind aspect of it, wind speed, were really few. We located like two and luckily both of them did. And we feel --

CHAIR SHACK: They got the deal with the NRC contracting? What a deal.

MR. SANCAKTAR: And it's my personal opinion that we were lucky enough to get people who are at this cutting edge of this field for wind estimations, which is, as you alluded before, is rather subject full of uncertainties and this and that. So it's not a solid easy to do thing.

And for missile part we got Emil from NIST and he actually wrote a book on the subject of that so I don't have to say anything else. And based on their

work we developed two NUREG/CRs, one is on the hurricane wind speeds and the other one is on the missile speeds.

The second one is really independent of the first one. It gives results that what we can use the speeds of the first one to figure out. We created a draft Reg Guide and submitted the draft Reg Guide with the two NUREG/CRs for public comments.

We received some comments and we addressed them. The new Reg Guide follows the same format and same kind of set up as its complimentary Reg Guide 1.76.991.

And we have provided the draft Reg Guide, the Reg Guide, the NUREG/CRs and the responses to all the public comments to other cognizant NRC offices, not only NRO but also NRR, to obtain their concurrences and we have done that.

So in the next part of the presentation we have the two main authors of the two NUREGs who will present each one. And we will start with Peter Vickery of ARA. And at any point between now and the next 30 minutes or so, at your convenience, we can take a break. We can take it now or maybe --

CHAIR SHACK: No, let's go along a little bit.

MR. SANCAKTAR: Yes, okay. You just chose the time as you wish to 2:45.

CHAIR SHACK: I don't know that we'll make it to 2:45, but we'll make it a little longer. Before Peter starts, since we haven't seen him before, can you just give us a little background.

MR. VICKERY: Okay. My name is Peter Vickery, I work at Applied Research Associates and I've been there for 20 odd years. I guess the main qualifications our firm had was the model that we, the hurricane simulation model we've developed over the last, since the early 90s I guess that's fully progressed.

It's formed the basis of the American Society of Engineers Standard Number 7, which is the design standard for wind loads in the United States. The hurricane model is used for that standard. It's also used in FEMA's Hazus Model, the same simulation, at least part of that model has been used in FEMA studies.

Looking at coastal flood risk in North Carolina and the Chesapeake and we also have some proprietary models, they're offshoots of that model. So it's fairly well accepted, I think it's a very well accepted modeled. And it's viewed as a state of the

art simulation model at the moment for hurricane risk anyhow.

MEMBER BROWN: So they include storm surges, water surges, as well or just wind, inland wind effects or visual audits wind effects?

MR. VICKERY: Well the model can be used to drive a storm surge model. So that's a separate model to do that. We have done so. Both probabilistically and with determinate simulation.

MEMBER STETKAR: Peter, I'm not a civil engineer. So ASCE, what sort of recurrence intervals do they typically use for industrial structures or hospitals or schools or something like that?

MR. VICKERY: All right, it just changed. Prior to the current edition, the 2010 Edition, the nominal design was a 50-year or 100-year with the appropriate load trackers on it, 100-year for the hospitals.

And to the wind load factor with 1.6. And then they've taken new tacks now and the wind load factor is being set equal to one. And they're designing that the hospitals for the 1,700-year wind.

MEMBER STETKAR: 1,700-year?

MR. VICKERY: Yes.

MR. SIMIU: I would like to add something

since you're not a civil engineer. It is not possible to rely strictly on the new recurrence interval on the load. You have to associate when that load, the limit state that that load will induce.

And indeed, the 1,700 or 700 year loads inherent in the design basis wind does not collapse the structure. It does something less than that.

MEMBER BLEY: Okay, thanks.

MR. VICKERY: It's an elastic based design so it's supposed to yield.

MEMBER STETKAR: I'm lucky I can build a stick thing, so thanks. It helps.

MEMBER BROWN: To the uneducated like myself in the civil engineering role, it sounds like you went from a 1.7 design factor that you applied --

MR. VICKERY: 1.6.

MEMBER BROWN: Or 1.6, excuse me. To one and then changed the time frame. That almost sounds like you reduced the standard is --

MR. VICKERY: Actually if the hurricane simulation model hadn't changed you would have got exactly the same answers designing a building with the old standard as with the new standard with the appropriate load factor.

So in the interior of the country where

the wind hasn't changed, you'll theoretically get exactly the same answers.

MEMBER BROWN: So the longer period?

MR. VICKERY: The 50 years with a 1.6 is identically equal, in the interior of the country, with the 700 years with the 1.0 factor.

MEMBER BROWN: Okay from an analysis and structural design perspective?

MR. VICKERY: Exactly the same.

MR. HARVEY: Same pressure.

MR. VICKERY: Same pressures. That was the intent when we made this change, basically the 50 and 100-year to the 1,700-year. So that was the way those values were set, be that right or wrong. And then perhaps in the next edition something a little more rationale will be applied to that.

MEMBER BROWN: Okay.

MR. VICKERY: Okay. So I'm going to give some background on the simulation methodology that was used to come up with the design, the 10^{-7} wind speeds in that hurricane prone region of the states, and the reason we use simulations for modeling hurricanes is because there is not a sufficient historical record of wind speeds that fit a distribution and move on.

So we have to use a simulation approach.

Simulation approaches have been around, for hurricanes, since the late 60s and have slowly improved as the years have gone by.

Now in our model I'm going to talk about what's called a Holland and B and Radius to maximum wind model. Holland B describes kind of the general shape of the storm.

So a B with a hurricane, like Andrew, produces relatively strong winds. It had gust winds speeds in the line of say 160/170 mile an hour neighborhood. Hurricane Katrina, which had roughly the same central pressure at landfall, only produced peak winds, gust winds of 120 to 130 miles an hour. And that is because the B describes the tightness of the pressure grading.

On RMW models it's the size of the storm, which is important for this, and the missile part. And it goes through a lot of work on what we've done to validate the pieces of the model. And then we've made some changes to the ASC based model to address the 10^{-7} study. And I talk a little bit about our wind field model, which is, of course, important.

And then go into details that the model changes and finally give the maps.

MEMBER BLEY: Somewhere in this discussion

it would help me a lot if you'd reflect the details of what you're telling us at a simpler level. So when you build the simulation model, under some set of hypothesis, you're modeling what the storms can do?

MR. VICKERY: Yes.

MEMBER BLEY: In a real crude expert judgement elicitation model you're trying to integrate everything at a high level and say how likely things would be down here.

You're assigning somewhere a probability distributions to the likelihoods of either the parameters of the model or, if it's got multiple models within it, which model controls and that sort of thing.

So if you could give us a hit of where the uncertainty is hiding here and where you're addressing it it would help me a lot.

MR. VICKERY: Okay. I guess I'll go over this slide in some detail then. Because this is kind of an overview slide of how the simulation methodology is done.

MEMBER BROWN: Just be careful. Don't get too far away from the microphone.

(Simultaneous speaking)

MR. VICKERY: But basically the overall

methodology is we start simulating storms out in the open ocean. And what we've done is on initiation points we view the historical record from the National Hurricane Center directly.

And we sample, in this particular instance, we sample, we did 10 million years of storms. And it's all based on the 100-year record. So what we have --

MEMBER STETKAR: From that 100 year record, how many storms are you actually talking about? About 200 or 300?

MR. VICKERY: That make landfall? Yes in that neighborhood. Overall the number of storms usually develop them all it's averaging about five or six a year.

MEMBER BLEY: And also it would strike me until the last 20 to 50 years it was probably pretty vague about where the storm actually started.

MR. VICKERY: That's why we didn't want to change it. We used the exact started points because there are biases built in there. And we didn't want to start messing around with trying to bias-correct it and push the storms back.

The study points had to be consistent with the way we model the tracks. And we were not willing

to mess around with trying to bias-correct the --

MEMBER BLEY: And that's a historical record of where people assume they started?

MR. VICKERY: Yes. Because as you go back further and further in time the starting points shift to the west. Well that's not really true. It's just that the observations, they didn't pick them up until they were further west. So we didn't want to back that off.

Because if we started shifting those back to the east a little further there's probably other storms that initiated in the east that didn't even get into the shipping lanes. We didn't want to mess with it.

MEMBER BLEY: Let me just suggest something and tell me how you'd deal with it. The historical record of where the starting points were, since they didn't pick them up as early. The storms when they were picked up were much more well formed, had higher winds, than probably where we pick them up today.

Do you account for that variability in the starting form of the hurricane in using these historical starting points?

MR. VICKERY: Starting conditions are

based on historical record. And that's correlated with latitude.

MEMBER BLEY: And it would tell you what was known about the storm at that point? Okay.

MR. VICKERY: Because of lot of it wasn't that much known though.

MEMBER BLEY: That's what I figured. I mean, ships report them and it was kind of random if they would --

MR. VICKERY: And the pressure data going back, it's kind of sketchy. I mean there's really complete records from probably the 70s of pressure data. And I'm going to go back to --

MEMBER BLEY: And out of all those storms then, from the 70s up to now, you're probably talking --

MR. VICKERY: Hundred-ish.

MEMBER BLEY: Hundreds. Well that's okay.

MR. VICKERY: And as you get closer to the United States the historical record gets better. So the landfall, the information we have on landfalls, goes back to 1900s pretty good. Not perfect but we treat it as perfect.

MEMBER BLEY: And we had some form of measurements on those?

MR. VICKERY: Yes and we concentrate on the pressure measurements at landfall, not so much the wind speeds. Because there's lot of subjectivity that goes into these winds. And if people don't account for anemometer heights terrain and what have you. Now the pressures aren't affected so much by that.

MEMBER BLEY: Okay. Thanks. That helps me.

CHAIR SHACK: One of the papers I tracked back to from your references is James and Mason where they take a slightly different approach. They argue that you might introduce bias by using only the historical data. So they sample around to get different initiation points.

And I just, I assume you've looked at that --

MR. VICKERY: We're initiating that for an Australian model.

CHAIR SHACK: Yes, now they did it partly because they didn't have as big a database as you did.

MR. VICKERY: Right.

CHAIR SHACK: But aren't you kind of limited? I mean you also pick your starting intensities from the historical database which would sort of restrict you in some sense that you've only

got a 100 year sample of that.

You know, but they try to, at least had a distribution that gives them a chance of getting these intensities that are greater than the observed.

MR. VICKERY: Well, what I should have brought, a long time ago we did an example. We picked a storm, I think it was Andrew actually. And we let it go and the mean, well it kind of ballpark-ished what Andrew did historically, but the spread is enormous. So they forget where they've been after about three or four time --

MEMBER BLEY: That would have been really interesting to me.

CHAIR SHACK: You said they forget, you mean the model forgets? So your mean works out fairly decently, but the general extent, the boundaries are expanded?

(Simultaneous speaking)

MEMBER BLEY: I would think of it differently, Charlie, and then correct me if I'm way off base here. The storm actually, I mean, that's given the information about the storm. It could go many different places. On average --

MR. VICKERY: Yes.

MEMBER BLEY: -- models doing, so the

storm itself might go in many different ways.

MEMBER BROWN: Yes, I've got that point I think.

MR. VICKERY: Yes we did some detail studies on another version of the model for the American Petroleum Institute actually, verifying the model in a forecast, which it wasn't designed to do. It's not tarot. And so coming back to that, the modeling approach and where we initiate the storms.

In this 10^{-7} study really what we're doing 10,000 one hundred year simulations. So it's a number of different realizations of that 100-year record. What could have happened given our limited knowledge of the distributions associated with the pressures and the track and all that stuff.

So it's just different realizations that could have produced some very, very strong storms given what we know now about the history. So it's not really a ten million year hurricane. It's what we know now it's the one that has a chance of about one in ten million of occurring. So don't think it was --

MEMBER BLEY: That's what I was hoping you guys would have said early on. I was getting really disturbed, that sounds rational.

MR. VICKERY: Well, it's a long story. It

confuses a lot of people.

MEMBER BLEY: Yes obviously. Yes, we don't need, it's not about --

MR. VICKERY: So the way the model works is we initiate these storms and the model, these are two examples from the simulation methodology where you can see the pressures here. And what we've done is in each five degree grid square we have statistics of given where the hurricane is now and a couple of steps back, depending on the grid square.

It predicts what the change in the translation speed will be and the change in the heading and what the intensity of the storm will be. And the intensity is modeled with a relative intensity concept. Not pressure concept. It gets converted back to a pressure later in on the simulation process.

So over the entire Atlantic Basin we have these grid squares, a set of statistics describing what that storm is going to do next, given which grid square it is and where it has been. And it slowly tracks across --

CHAIR SHACK: And that's all interpolated from historical data?

MR. VICKERY: Fit to historical data.

CHAIR SHACK: So fist principle stuff is

not, is there first principle stuff --

MR. VICKERY: First principle part of this is in the intensity model. Because that is based on the maximum potential intensity of a hurricane, which is based on the sea surface temperature.

MEMBER BROWN: Okay, so that's where you factor that stuff in?

MR. VICKERY: Yes. Okay. So we track the storm along and what you're seeing here, you probably can't read the numbers, it's the central pressure and this particular storm starts out at 997 millibars. And it slowly intensifies, makes a curve and goes to Tampa.

And once the simulated storms, as we move them across the ocean, once they get within 500 kilometers of a site that we're interested in, we turn on the wind field model and start computing the wind speeds.

And we don't turn the wind field model on until the last minute, so to speak, because it just takes a lot of computational time. And then we track the wind speeds.

And in this particular study we just score the maximum wind speed that occurred at a site. Maximum peak gust wind speed that occurred at a site.

And so we have at the end of the day, a huge synthetic record of peak gust wind speed at a number of sites, produced from a suite of storms that, to the best of our knowledge, match the statistics of today.

And this is just a flow chart of what I just said. So I'm going to get straight to the results of the simulation model in terms of the validation portion. And what I've got plotted here is, we've got all the various coastal regions, so I'm going to pick this. Then I'll do Texas.

So this is all storms that make landfall on the Texas coast. On the horizontal axis is the return period in years. It goes from one to 1,000. And you see how the historical record cuts out around 100 years. These are the land-falling central pressures.

The dots, those open squares, are the historic data, rank ordered and then using a simple occurrence rate, Poisson Occurrence Model, inverted into return period values. Texas, Louisiana, Mississippi and Alabama and so on.

Now the light grey lines come from, again, this re-sampling of, in this case it was 100,000 year simulation, the re-sampling of that simulation to come up with upper bounds and lower bounds of what the

model had produced in that set of time.

In that period. And the historic data fit into that air range, which we termed that I think it's the 90 percent confidence range.

So based on our set of simulations the model matches within a 90 percent confidence the observations have taken place for all land-falling storms along Mississippi and Alabama and so on.

And then we've got it all wrapped up together for the Gulf Coast. And then finally, at the bottom, the U.S. Coast. So we've, the best we can, verified the model is getting the regional variation in the central pressures at landfall. And the total along the entire U.S. coastline.

And then we've broken up a little bit finally --

MEMBER BROWN: Can you help me on one thing? Are the lower pressures --

MR. VICKERY: Are bad.

MEMBER BROWN: Are bad. Okay, that's what I thought I remembered.

MR. SIMIU: It's like a cup that you stir.

MEMBER BROWN: I understand, that's what I thought I was remembering. I just wanted to make sure I was in the right ballpark looking at the change

in the curves.

MR. PASCAL: And then we broke it up into some smaller coastal segments instead of entire states. So Texas we broke up into four different bits and we looked at that too.

I mean you can look at it in detail, but we've looked at it in finer regions and in broader regions and it passes the statistical test for equivalence in the central pressure.

And you can see how the model moves on beyond the period of record and starts to, this is somewhere around Florida Regions 14 and 15, it starts to flatten out as you get further on in time. I mean, in probability.

So that describes the overall entire model. Of the track, that's only the track portion of the model. So it's the tracking, intensity and occurrence rate. Because we go back here, these are implied measures of occurrence in that return period. So it's both the probability distribution and the rate of occurrence are buried in this plot here.

MEMBER BLEY: Intuitively it sounds right that it would tend to flatten out. But is there some theoretical minimum pressure you can develop in a storm?

MR. VICKERY: Yes, we pulled that from Kerry Emanuel's work on the maximum potential intensity. And we reset the limit in the model from what we were for ASC to a lower value. I can't remember what the value is, but it's pretty low. And the model actually never hit that value when we ran the simulations.

MEMBER BLEY: Okay.

MR. VICKERY: Which is good. Then next thing is this Holland B parameter. And I just go to --

CHAIR SHACK: But suppose that we're global warming fans. Could we heat up the ocean and then see what happens then? Would that, you know, that's one way to simulate what the effect of global warming would be if it occurred?

MR. VICKERY: That's one way, it wouldn't be right.

CHAIR SHACK: It wouldn't be right.

MEMBER BROWN: Sorry to burst your bubble.

CHAIR SHACK: I'm just trying to anticipate questions that could come up at a full committee meeting.

MR. VICKERY: Right, well when the ocean heats up other there are studies looking at wind shear

effect as well. And as the ocean is getting warmer apparently the wind shear is increasing at well. So wind shear inhibits the formation of hurricanes and warmer sea surface temperatures allow for more intense hurricanes.

MEMBER BLEY: So you get you fewer bigger hurricanes is that what it is?

MR. VICKERY: The overall viewing right now, and there's a lot of uncertainty on it, is that in the future in a warmer climate. Maybe that's the future, maybe it's not. There will be fewer category 1, 2 and 3s. But more Category 4s and 5s. Now we have recently looked at the land-falling rate of Categories 4s and 5s.

Looking at taking the AMO, the Atlantic Multidecadal Oscillation, and separated it out into warm years and cool years. And we're in a warm cycle right now. That appears to be a result of a natural variation, perhaps a long-term trend.

But it shows that on average the number of Category 4s and 5s in the warm cycles is double what it is, depending on where you are, up to double along the Atlantic Coast than what it is on the long-term. But the P Value associated with that is like 0.6/0.7.

MEMBER BROWN: What's that mean?

MR. VICKERY: It means the chances are --

MEMBER BROWN: It won't hit?

MR. VICKERY: Chances are the difference is just statistical chatter and not a real difference.

MEMBER BROWN: Oh, okay.

MR. VICKERY: And we've found that time and time again. You know, we're getting these ratios that appear in the literature. But statistically you can't say with any confidence that the data is showing that. This is just for landfalls. It's not for --

CHAIR SHACK: This is landfalls associated with the cycles, the warm cycles and the cool cycles. Whether it really makes a difference, you're saying, is statistically uncertain.

MR. VICKERY: Landfalls, right. We did not look at storms in the ocean because we weren't really interested in that. We were looking at landfalls only. This is for another reason.

But that's what our conclusions are now. And something we're going to put into one of our models with a lot of warnings on it. So that's what we've found.

Okay, so that gives you the track and the intensity. So this next thing is the Holland A parameter. Now I want to go down to this portion of

the slide here.

And what I've got going across the axis from the bottom, from left to right, is the distance from the center of the storm divided by the radius to maximum winds.

So that's just where the maximum winds are. And on the vertical axis is the gradient wind speed. This is all for the same central pressure and the same radius to maximum wind and the same translation speed of the storm.

And we changed the speed parameter from 0.75, which is down here, that produces a maximum wind speed of 40 meters per second. And then we increase the B to 1.5, that's kind of a biggish B, and it goes up to about 55 meters per second.

So this B has a bigger factor on what the magnitudes of what the wind speeds are. It's not a perfect representation of the pressure/wind relationship, but it's better than ignoring it which is commonly done, I guess until our paper in 2000.

And we have a simple model for that, for B, that basically says B will get smaller as storms become larger and B will get smaller as storms move to the north. There's some other parameters in there. We put this into this nice little non-dimensional

parameter.

But the bottom line is the further south you are, the bigger the B. The further north you are the smaller the B. And the bigger the storm on average, the smaller the B.

The big storms have, all things being equal, lower wind speed than the same storm that's smaller. Because the smaller storm is going to be associated with a bigger B. On average.

CHAIR SHACK: The Figure 2-7 in the NUREG seems to have a different database for the B parameter than you're showing here.

MR. VICKERY: Figure 2-7?

CHAIR SHACK: Yes, it's Figure 2-7. It's referring back to the 2009 paper.

MR. SIMIU: On Page 14.

MR. VICKERY: Which NUREG?

CHAIR SHACK: The winds data.

MR. VICKERY: Oh, okay. Yes. That's taken from a 2009 paper. And it's got more information on it. What it showed was what the current model is, which is this model here. And then you see another line in the NUREG that's over here.

CHAIR SHACK: Yes, that's what bothered me about the --

MR. VICKERY: Okay. That's the old model. So we were showing in that particular paper why the wind speeds in the new model are lower than the --

CHAIR SHACK: Oh, so that's just the model. I thought it was data that was showing the distinct trend that you guys keep missing.

MR. VICKERY: No. Okay, maybe the text needs to be adjusted to reflect that.

CHAIR SHACK: Well you need to put this figure in.

MR. VICKERY: That's fine we can do that. I mean I'm glad somebody's taking notes.

CHAIR SHACK: I mean this figure looks like what I'd expect to see in a regression fit.

MEMBER STETKAR: Well the other one would be perfect.

CHAIR SHACK: Yes, I could say that looks like some of my data.

MR. VICKERY: Yes, the point was that the new model and the old model are different and the newer model produces lower wind speeds than the older model. So the 2000 is the older model and the new model is 2008. This work is based on the 2008 model.

And the next slide talks about the radius to maximum wind. Without getting into a lot of

details here, all it's really saying is as the central pressure deficit increases, or the central pressure decreases, storms on average get smaller.

So what's happening here is, on average, as the intensity goes up the storms are going to get smaller -- I'm sorry as the central pressure goes down the storms are going to get smaller. And because the storms get smaller the B on average is going to be higher. So all your winds basically come from small storms with Bs.

And they're going to affect relatively small areas. If you look from a wind point of view that's bad, from a storm surge point of view that's good. The little storms don't produce much storm surge. So the 10^{-7} wind --

MEMBER BROWN: Not even locally?

MR. VICKERY: No, not even locally. 10^{-7} wind is not going to be associated with a 10^{-7} storm surge. Okay, so this is just a summary of the event model. The Hazus model was validated with landfall data for 2007, we haven't updated since but two storms since then are not going to make any difference.

It was calibrated to match the historical period from 1900 to 2007 and we have statistical models for the size of the B and the size of the storm

that are based on less of a record. They're based on 30 years actually, or less.

MEMBER STETKAR: We're going to have to take a break soon, or at least I will. But let me just ask you about --

CHAIR SHACK: This slide is a good place to break I think.

MEMBER STETKAR: It probably is, that's why I wanted to get this one question in though. If you drop back to your, it doesn't make any difference. you said that you validated the model, the landfall model, with some data.

And indeed I went back through NOAA records, I've got 110 years worth of NOAA records on landfall data as a function of intensity.

And for the entire U.S. Atlantic and Gulf Coast your total landfall frequency seems to be pretty comparable to the total data. However, when I start to focus on individual areas, and I happened to take the Texas coast because it was just the first chunk that I ran into.

The frequencies that you're predicting compared to the historical frequency of landfall starts to diverge. And I found that, I found it in Texas where I was seeing, not much higher but --

MR. VICKERY: In our stuff?

MEMBER STETKAR: No, your frequency was low compared to the historical landfall frequency.

MR. VICKERY: I don't believe that.

MEMBER STETKAR: Okay, I've got the data. And I noticed it also up in New England and Long Island. Now I didn't try to fight my way through Florida and the Carolina's because it's, you know, it's not my job to do that.

(Simultaneous speaking)

CHAIR SHACK: You've got to be careful with the definition of what the hurricane is. Our is a hurricane tromping the coasts in Texas.

MEMBER STETKAR: That's what I've done.

MR. VICKERY: Okay.

MEMBER STETKAR: You know, as best as the NOAA record, they show peripheral wind effects, but they, at least in my understanding of the data I have, are crossing the Atlantic.

MR. VICKERY: Well this is the NOAA data from HURDAT. It's from the official, if you want to look it up --

CHAIR SHACK: Well in reading your 2000 paper it seems to indicate roughly the same thing. You're under predicting the number of storms in Texas,

in particular.

MR. VICKERY: Yes, but we're not now.

CHAIR SHACK: When I went through the table and I did the Texas one I get, what did I get, 0.25 per year and it's point 0.36 on the 100-year record.

MR. VICKERY: I'd like to see that record you've got.

CHAIR SHACK: It's from Newman.

MR. VICKERY: That's old.

CHAIR SHACK: Well it's up to 1998, yes.

MR. VICKERY: No, I'd like to see that, because I don't believe it.

MEMBER STETKAR: My record happens to come from, if you want to write down the web, and it's 1900 through 2009, it's www.nhc.noaa.gov/ms-excel, E-X-C-E-L, select hurricane strikes.20100204.xls. It took a little bit of doing to find that.

MR. VICKERY: What we use --

MEMBER STETKAR: It's in the record now.

MR. VICKERY: We use something called TPC Number 5.

MEMBER STETKAR: I don't know what that is.

MR. VICKERY: It is the official landfall

document. That has the land-falling characteristics of all storms that make landfall in the United States, with the exact latitude and longitude, name of the storm if it's named. Central pressure if it's known, no and the central pressure is known for all of them. And the wind speed if it's known.

And also our plots here only include storms that have central pressures less that 990. So if there's some very weak storms they wouldn't show up in the plots.

MEMBER STETKAR: In your plots.

MR. VICKERY: In our plots, yes.

MEMBER STETKAR: Yes, I mean this NOAA database covers everything, you know, the Saffir-Simpson Scale.

MR. VICKERY: But when you said, what are you comparing it to with the model?

MEMBER STETKAR: Just landfall frequency. Now if you've got a restriction on central pressure less than X then you're predicted interval frequency is going to be lower obviously than this.

MR. VICKERY: No. Yes, but where exactly did you pull the model results?

MEMBER STETKAR: The model results?

MR. VICKERY: Yes.

MEMBER STETKAR: From the table, the Table 2.1 Hurricane Landfall Frequency by Saffir-Simpson. That Saffir-Simpson Scale.

MR. VICKERY: Where? I want to make sure we're on the same page here.

MEMBER STETKAR: It's on Page 28. It's not in your presentation material here.

MR. VICKERY: No, it's in the report.

CHAIR SHACK: It's in the NUREG.

MR. VICKERY: Page 28, oh the model results. I see.

CHAIR SHACK: That's what we used for the, at least I --

MEMBER STETKAR: I use this also.

MR. VICKERY: Which one did you use? The pressure?

MEMBER STETKAR: No, the second, well wind speed.

CHAIR SHACK: It seems to agree better with historic record if I do wind speed. I'm assuming --

MR. VICKERY: Oh yes it should. Okay. Our pressures agree with the --

CHAIR SHACK: With the NOAA data?

MR. VICKERY: Yes, but you've got to

exclude Category 1s, to make this fair you really ought to exclude Category 1s. Now the reason is our model mathematically predicts the one-minute wind speed. It's a mathematical representation, one-minute wind speed.

Now, and this is a big discussion we had with the National Hurricane Center, not just us, but engineers in general. Their definition of a hurricane is the maximum one-minute wind speed at the time of landfall that could occur.

MEMBER BLEY: What's that mean?

CHAIR SHACK: That could have occurred?

MR. VICKERY: It's never measured. You never have a measurement to prove that their wind speed is right or wrong. And they can't, and they say well, it could have occurred. Can't argue with that. But the analysis that most engineers do don't support their wind speeds.

And there are a lot of Category 1s out there that aren't 1s, they're probably tropical storms. And so in that respect there would be some differences. And that's why we use pressures.

MEMBER BLEY: And that may be part of it.

MR. VICKERY: Because there's no argument about what the pressure was. And at the lower

threshold to be a hurricane, to be a Cat 1, you have to have that 74 mile an hour.

Well, the model will probably underestimate the Category 1s. Because it will produce, you know, lower wind speed. So we won't count it. We will not count it.

CHAIR SHACK: That was what was funny when I looked at that table with the pressure is that, you know, you seem to be, there's less Category 1s than there are Category 3s for example, in Texas. Because there's five times as many Category 3. And then somehow that didn't seem right. But maybe that's true.

MR. VICKERY: It's because we're underestimate.

MEMBER STETKAR: They're going to underestimate the one's too. Texas looks kind of funny though when you get in the two to three range.

MR. VICKERY: We're going to underestimate what NAC says is the number of one's. And still even with their re-analysis, we disagree with some of their re-analysis what the wind speeds are. But again, that's why we concentrate on these distributions or what the pressures look like at landfall.

Because those are the things you can't

argue with.

MEMBER STETKAR: But you only have reliable pressure measurement for the last 30/40 years is that --

MR. VICKERY: Landfall is better.

MEMBER STETKAR: Landfall is better?

MR. VICKERY: And this would have been a nice little study too that's come up recently. If you went back and you look at the changes in the historical record as Chris Landsey does these re-analyses, how the wind speeds are changing. I'm fairly confident that they pressures are not changing nearly as much as the wind speeds are changing.

They seem to be more reliable, more stable. For a better word. We've always stuck with the pressures because of that. And that's how all engineers who have been doing these simulations worked with the pressures, they don't work with the wind speeds. Because they're all estimated. The final values are estimates.

MEMBER BROWN: Are those pressures at the center of the storm, at the eye?

MR. VICKERY: Yes, they're the minimum.

MEMBER BROWN: But how many measurements, normally, do you get in order to do that. I mean it

just wasn't some of, what is it, the guys that fly through, you get a gradient of pressures as you fly through. And you'll average them?

MR. VICKERY: No you apply the profile.

MEMBER BROWN: Okay so you use a profile. Okay, and I would think that the profiles from earlier years are not as good as the profiles over the last 40 years.

MR. VICKERY: Correct.

MEMBER BROWN: Okay.

MR. VICKERY: Unless there happened to be a measurement right at that time of landfall.

MEMBER BROWN: Yes, well I was just trying to get a handle on your comment about using pressures. And you go back 60, 70, 80 years and you say, yes you've got some pressures. But I would suspect that the profiles aren't as good at landfall in the pressures as they are --

MR. VICKERY: They're not. But it's a more stabilized --

MEMBER BROWN: I wasn't arguing with that. I'm just trying to get a characterization.

CHAIR SHACK: Do you want more bad data or fewer good data?

MR. VICKERY: I wouldn't argue that there

could be, in fact be low biased. Yes, in the historic. But some of the old ones, the 1935 storm, somehow they got that one about right and they got it at very, very low pressure at 892 millirems. Still yet to be beaten in the U.S., Atlanta.

CHAIR SHACK: Well let me suggest we take a break here until five of.

MR. VICKERY: And I'm going to start to get into my real time.

CHAIR SHACK: Okay, we've got 15 minutes.

(Whereupon, the meeting in the above-mentioned matter went off the record at 2:35 p.m. and went back on the record at 2:55 p.m.)

CHAIR SHACK: Okay, gentlemen, let's get back to it.

MR. VICKERY: Okay. So the next thing I wanted to talk about is the wind field model. That given we've got the B and RMW in our track now, that has to be converted into a wind speed. And it's done by handing all that information off to the wind field model.

Now I don't want to get into the details of this ugly equation, but a very simple wind field model for a hurricane can be described by this, the

BDT term and this pressure grade interim along here. So all that's saying as you get this type pressure gradient the wind speed is faster and faster and faster.

And that's basically, that type of equation is used quite commonly in model hurricanes, it's simple. Now our model is a two-dimensional numerical model and the main reason we're using that is because we add the effects of this frictional term here.

And this frictional term changes the characteristics of the overall wind field. And that's the main term, so that's the main difference between this simple numerical model and the very simple gradient-balance model. A gradient-balance model, which is this term and this term.

And I think I deleted the slide to what that pertains to. I've got some stuff about talking about the drag coefficient over the ocean here. I think for the sake of time I'm going to skip those because it's not that germane to wind speeds on land.

Okay not coming back to this gradient, I don't have it explained here. This gradient-balance model is the derivative and the Coriolis, which I forgot about, matching the pressure-gradient.

Now, as I said, that's a commonly used model for estimating what the winds at the top of band well, actually maybe 1,000 meters above the earth, are like in a hurricane.

Now with this numerical model is divided the wind speed results from the numerical model at roughly this gradient height by the simple gradient-balance model and drawn these contours here.

And so values greater than one indicate, this is a storm moving towards the top here, and this is basic radius, normal edge radius heading out horizontally and directly from the center of the storm here.

And this 1.2 in the top-left quadrant, this means that the numerical model, or the slab model, is predicting higher winds 20 percent higher than you would get using the simple-gradient balance models. And these results are similar to what you'd get in full 3-D models, not exactly the same but it's better than just using the gradient-balance model.

The Boundary Layer model we use, it's derived from aircraft data where they drops on to the ocean and they track the variation of wind speed with height. We fit a modified log model to that.

Where we've got wind speed at height Z is

equal to Z_0 over k to the friction velocity time the logarithm of the height divided by the surface roughness, Z_0, just tells you how rough the ocean or the land is.

Small numbers mean a smooth surface. And we've modified it by this a to the z over h to the n power, which causes this boundary layer model to suck back as we get further up away from the ground. That's basically the modification we've used.

And this simple model matches the observations over the ocean very well. There are no observations on land so we have to use this particular model and then we use standard Boundary Layer Theory to transition the hurricane boundary layer from the sea to the land.

That's all well and good but at the end of the day to find out how good your model is you've got to compare to real wind speed data. So it's great to have a fancy model, but it doesn't help you much if it doesn't work, if it doesn't reproduce observations.

So at ARA we've produced estimates of wind speeds for most significant U.S. land-fallen hurricanes since 2004 for the Federal Government. In terms of FEMA, and we've validated our wind field models to comparisons to observations and our wind

field models was also even used by NIST in their Katrina/Rita wind speed publication.

The way we do these validations is, for an example here, this is a wind --

MEMBER STETKAR: Peter, you said since 2004, that's like a dozen hurricanes?

MR. VICKERY: That's what we've been doing for FEMA. We've validated going back to 1979.

MEMBER STETKAR: Okay.

MR. VICKERY: And done some other further back more recently. But we've been funded by FEMA to do this and they've published the results since 2004.

MEMBER STETKAR: Okay. Thanks.

MR. VICKERY: And one of the key things of doing these validations of the wind speeds is you have to know the terrain. All of the validations we do is in something called standard open terrain conditions. And basically an unobstructed wind slowdown down a grass way is unobstructed terrain. And that's what the model produces. It produces estimates of wind speed in flat, open terrain conditions.

And this is an example here of the anemometer at Miami International Airport. And you can see for wind speeds coming from the east, north is to the top of the page, it's pretty much flat open

terrain. But for other directions it's not flat open terrain.

And we have to correct these measurements for these terrain effects. It's not a perfect correction but it's better than not doing it at all. I'll talk about that in a little bit.

This is another example for Hurricane Katrina, where we have the anemometer is placed at the center of this bulls eye here. And so if the wind's coming from the south it's going to be good open terrain. And the wind's coming from other directions it's going to be affected by the upstream terrain.

And long story short, by estimating the turbulence intensity you can back out comparisons, back out adjustment factors. So in this example, for winds coming from 30 degrees through 70 degrees, so that's winds coming this direction through to about here, we've had to increase the wind speeds by an average of about 15 to 20 percent.

So what that's saying is the measurements are underestimating the true winds by 15 to 20 percent.

MEMBER BROWN: Your reference was at the top when you made your 30 degrees?

MR. VICKERY: Yes, so 30 degrees, well,

it's from here, that direction through to that direction.

MEMBER BROWN: Okay, I just missed your first pointer movements. Thank you.

MR. VICKERY: Okay. And this is an example here of model comparisons. And I'll skip straight to this slide here, no I'll do this one. There's a peak gust wind speed on this axis and time plied on the horizontal axis. The solid line is the model. The dots are from the observations, not corrected for terrain.

I'm going straight down to the bottom slide here, these are the dots adjusted for terrain.

MEMBER BLEY: And what's that wiggle out at the right here?

MR. VICKERY: This wiggle?

MEMBER BLEY: Yes.

MR. VICKERY: Going to the eye.

MEMBER BLEY: Oh, okay.

MR. VICKERY: And as luck would have it, or not have it, the anemometer recording system failed. I think they ran out of fuel actually. But it shows the importance of doing these adjustments for the wind speed measurements.

A part of the peak gust wind speed should

just, in a perfect simulation, the observed should touch it about once every hour or so. Because it's supposed to be a measure of the envelope of the peaks.

It should not go through the middle. A perfect simulation the mean wind speed would go through the middle here, which it doesn't, so it means our corrections aren't perfect. And there's just some more examples here showing some typical corrections.

This is showing an anemometer in Texas for Hurricane Rita. You can see for winds coming out of the north there's going to be corrections and the correction factors in the neighborhood of 1.15.

MEMBER BLEY: And when you developed these correction factors, are they based on local measurements, local experts?

MR. VICKERY: Based on the turbulence intensity, which is the gustiness in the measured winds. You can back out what the effective surface roughness had to be to produce that.

MEMBER BLEY: Oh, to produce that.

MR. VICKERY: And then you do the corrections.

MEMBER BLEY: So they actually are based on wind measurement?

MR. VICKERY: Yes based on measurements.

MEMBER BLEY: And then for instance those?

MR. VICKERY: And here's just and example of the Rita comparisons. Peak gust wind speeds before correction and after correction. And again the model's not perfect.

And this area in the model and it's inability to be perfect every time it comes into our uncertainty estimates down the road, which actually drive some of the 10^{-7} winds.

So it's a validation step, it's very, very important in addressing the inability of the model to estimate these wind speeds perfectly. And this is just a summary for Hurricane Ivan. These are all at locations with data points. And then we've got comparisons here, an X, Y scatter plot.

MEMBER BROWN: Is the variation, this is an education question again. You talked about the imperfectness of the model. Is it because the computational end of it? You have to make certain assumptions to fit within the computational ability of the computers you've got? Or is it because of some other unknown physical factors?

MR. VICKERY: A combination.

MEMBER BROWN: Some things that are unknown, you just don't know the other factors that

you supposed to --

MR. VICKERY: I'm going to touch on a few of those in a few more slides. About where some of these errors are coming from, or we think they're coming from. But overall, I mean, there's not that much bias. It's able to map out this regional winds reasonably well.

Now just another example from Hurricane Ike. I'll just skip over these. This is a plot showing, if you look at one of the journal articles we reference you can dig it out of there, but it's storm by storm comparisons of model and observations. Starting with Hurricane Wilma in the top left in 2005. Going down to Hurricane Frederick in 1979.

And then we munched them all together here. And these are all of the comparisons we have done at the time this slide was prepared, which was back in 2007 time frame I think. And there's a couple of things you should pay attention to here.

We've got comparisons on land, are the open squares, and we've lumped them all together. Now you see the maximum wind speed we have is 60 meters a second, so about 130 mile an hour peak gusts. That's the maximum we have.

And there have been bigger wind speeds

recorded in hurricanes, but that was not the maximum in the storm. So this is only comparisons of the maximum model wind speed compared to the maximum observed wind speed. So for example --

MEMBER STETKAR: Run that by us, or by me again. I didn't quite appreciate that subtlety.

MR. VICKERY: I wish I had my Hurricane Charlie one. Let's pretend that these four measurements weren't here. Okay so I would never know what the maximum observed wind speed was in that storm. So it wouldn't be included in that scatter plot.

MEMBER STETKAR: Right.

MR. VICKERY: So that's all I'm saying. So I would have had, let's say I had this point as my very last point here.

MEMBER STETKAR: But I thought you said something else, that there had been higher wind speeds measured in storms.

MR. VICKERY: But not at the peak. So let's say this one had died at 140 miles an hour and kept on going. So we've got that 140 mile an hour measurement, which is bigger than what was on the scatter plot, but it didn't measure the peak.

The actual wind speeds were higher, so I

can't include it in a model validation comparison. Comparing the maximum values the model produced, right.

MEMBER BLEY: Because he's trying to compare the maximum.

MR. VICKERY: Trying to compare the maximum --

MEMBER BLEY: He doesn't have that measurement but --

MR. VICKERY: We don't have the measurement.

MEMBER STETKAR: Yes, okay.

MR. VICKERY: And the biggest one recorded was for Andrew before, about 15 minutes before it failed. Maybe it was the biggest one, probably it wasn't.

But these errors come about from a combination of us not being about to model anomalous features in the wind like down verse barrier in the wind field, but our model with standard value A theory, they come about from the inability of a single B and a single RMW to model what can be quite a complex structure of a pressure field.

It comes about from, in some cases, you can actually have storms with a maximum wind speed to

occur on the left hand side of the storm, because of some other meteorological phenomena going on in the storm.

You can have cases where you can have, a pressure gradient can vary, you can have high pressure on one side of the storm and a lower pressure on the opposite side of the storm. That's going to produce an asymmetry that we can't model.

So there's a number of these different features that come in to the inability to do appropriate wind model representation. And we've tried to take care of, tried to treat that best we can, by putting in a random modeling, a random error term.

Based on the data we have, we use a coefficient variation of ten percent, we get a sample from that when we do our simulation. Talk to --

MEMBER BLEY: You use that same one wherever you do this analysis?

MR. VICKERY: Yes, we have to have something in there to take into account the fact that the model is not perfect. And taking measurement and validations, these validation studies are the tool we used for assessing what that uncertainty is in the wind field anomalies.

CHAIR SHACK: Yes, now when you say errors here, these are really errors in the wind field model.

MR. VICKERY: Well, that's, see some of them is probably errors in the measurement too which, but they get lumped into the --

CHAIR SHACK: Into the, right.

MR. VICKERY: -- into the wind model summaries.

CHAIR SHACK: I mean, it doesn't involve the tracking and --

MR. VICKERY: No.

CHAIR SHACK: -- any of that.

MR. VICKERY: That's treated as perfect. But this is an example here, so all the pieces are put together now, we have the wind field model and we run it through the simulation.

So this is an example here, what we've done for the United States, is we've gone back and we've either estimated, using the same wind field model, unfortunately, the mass of wind speed produced by the hurricane anywhere in the United States.

Or we've used, we've also got different folks' estimates of what the measured wind speeds were in these hurricanes. So the dot, the plus signs here are estimates based on the historical track in the

wind field model, and the various colored symbols are other peoples' estimates.

And the solid line here is the model estimate. So what it's saying, and I apologize for mixing units in between meters per second and miles an hour, I collected these from various papers.

But what this is saying here is this is a hurricane simulation model, it's producing a maximum, 100-year return period peak gust wind speed anywhere in the United States, a mean estimate, is just a tad under 80 meters per second, so about 170 miles an hour.

So this gives you a kind of an overall sense of how the model is comparing, at least country wide or coast, yes, along the coast --

CHAIR SHACK: How do you assign a return period to these experimental points?

MR. VICKERY: These odd points here?

CHAIR SHACK: Yes well, or any of them?

MR. VICKERY: The historical method is easy, you just rack them and stack them. You've got the probability, and you know the occurrence rate, boom you're done.

CHAIR SHACK: Okay, so I just, through a rank order.

MR. VICKERY: Yes, and you've got the occurrence rate so you can trim that to return period very easily. The next thing we do is a little trickier, is if you used order statistics for these other measurements from, say Powell or Goldman or what have you, you get a different order. So we've matched their estimates with the order statistics we got from the simulations.

So the order might in fact be wrong. And then we've done this state by state. So there was a question coming up about Texas. So our 100-year wind speed anywhere in the state of Texas, we've got examples here, the solid line is no wind field modeling uncertainty, and the dashed line is with wind field modeling uncertainty.

So our 100-year wind speed in the state of Texas is about 70 meters per second, that's about 150 miles an hour. But at a single point in Texas, it's a hell of a lot less. It's probably around 110, 120, depending on where you are.

MEMBER STETKAR: It's 120.

MR. VICKERY: Does that help answer your question?

CHAIR SHACK: No. But continue, it's getting there.

MEMBER BLEY: And these curves now, are the, these are the maximum, so you don't show distribution on that.

MR. VICKERY: Right. These are the maximum wind speeds --

MEMBER BLEY: Not of all years, right.

MR. VICKERY: -- historical record and the simulation, with and without the wind-field modeling uncertainty. And this is just to give people a sense that the model is not out to lunch.

And when you put all the pieces together, you know, the RMW model, the B model and the track model and all that, it's producing reasonable answers.

MEMBER BLEY: So, over the years, you've had this basic model for quite a few years now, right? Which gets updated, but have there been key occurrences, storms that have led you to see discrepancies that led you to change the model?

MR. VICKERY: No.

MEMBER BLEY: Okay, so they're just marginal improvements along the way and, are they shifts or they have to do with the uncertainty.

MR. VICKERY: We had a shift from, we made a shift in 2006 when we updated the hurricane, this physical model for this Holland B parameter. Remember

earlier --

MEMBER BLEY: Okay, that's fine.

MR. VICKERY: You saw that other plot, that was a change in the Bs, and that made a big difference. Other than that I think that's the only real huge change we made. So and then the next bit of sort of change we've made for the 10^{-7} study.

Okay, so our main model changes. The ASE base model had a minimum radius to maximum winds of eight kilometers, we've reduced that to now four kilometers, so it's a pretty tiny storm we allow for.

Our initial set of, we use a reduced set of wind speed tracks for our calculations, so we use a basically a stratified sampling approach, where we started out with 23.2 million hurricane tracks making landfall in the U.S. and we've pared that down to 3.5 million, still a lot.

And now we've introduced a duration-dependent gust factor which lowers the effects of the gust factor for fast-moving small storms. That's only because you don't have much time to generate a peak gust wind speed, it is normally 1.5 times the mean.

MEMBER BLEY: Tell us a little more about your second bullet.

MR. VICKERY: Yes, I'm going to.

MEMBER BLEY: Okay.

CHAIR SHACK: That was one of my calculations, I took the 23 million and divided by 10 million to get 2.3 --

MR. VICKERY: It's about 8 to 1.

CHAIR SHACK: -- and, but then when I went back to the table, I don't get 2.3, I get 1.5.

MR. VICKERY: What table?

CHAIR SHACK: The landfalls, you know, once it strikes, the landfalls in the U.S.

MR. VICKERY: Well this has nothing to do with that.

CHAIR SHACK: I thought the 23 million was the number of storms that made landfall, in the total record, so I divided --

MR. VICKERY: Oh, sorry, that produced a peak gust wind speed greater than some threshold.

CHAIR SHACK: Oh okay, so they're not apples and oranges.

MEMBER STETKAR: But the 23 million should be, I'm sorry.

MR. VICKERY: 23 million is 2.3 per year.

(Simultaneous speaking)

MR. VICKERY: -- there was a peak gust wind speed greater than 50 miles an hour and it got

counted.

CHAIR SHACK: So it's --

MEMBER STETKAR: It is larger, yes. I was presuming you were going to say it had to produce a peak gust wind speed greater than, you know, 130 miles an hour.

MR. VICKERY: No, wind speeds are 50 mile an hour thresholds for --

(Simultaneous speaking)

CHAIR SHACK: I thought we were only counting hurricanes here, we are counting --

MR. VICKERY: At the end of the day, we did.

CHAIR SHACK: Okay.

MR. VICKERY: The model produces all ranges of tropical cyclones. The counting, the validation stuff on landfall using NHC data, yes hurricanes, but all the other stuff is there too.

So this is the distribution of the number of storms that we had by maximum wind speed bin. So for example, for a 200-mile-an-hour bin, we produced about 10,000 storms and again --

MEMBER STETKAR: And this is from your 23 million --

MR. VICKERY: This is from the ten million

year simulation or the 23 million mile storm.

MEMBER STETKAR: This is through 23 million population. I didn't count them up. So if I look at this plot --

MR. VICKERY: This is anywhere in the United States.

MEMBER STETKAR: I understand. If I look at this plot and I counted up numbers of events down in the tails, because when we're projecting very low frequency extreme numbers, extreme storms, the behavior of that tail in this sample, and I'll call it a sample, is very, very important.

At the upper end of that tail you have, kind of a couple of storms, about two or so, in bins that are in the 300-mile-an-hour peak gust wind speed range.

MR. VICKERY: Right.

MEMBER STETKAR: How would the behavior of that tail, and if I back up sort of a quarter of the way into that distribution change, instead of using what you're calling a nominal 10^{-7} year simulation, instead of having 23 million samples, I had 230 million samples for 2,300 million samples.

In other words how would the, if you ran, instead of 23 million samples, you ran this out over

what you're calling more years, how would the behavior of that tail change?

MR. VICKERY: It would be a guess, but remember we've also put this wind field modeling error term --

MEMBER STETKAR: No, no everything is a guess because it's a model, I mean --

MR. VICKERY: No, it would be a guess to what the model change would make.

MEMBER STETKAR: Have you looked at it, I thought you used to run this model for like a 10^{-6} year sample, 100,000 smaller, or 100,000 --

MR. VICKERY: Yes, I used to run it for 100,000.

MEMBER STETKAR: How does the shape of that tail change when you do that, when you compare the --

MR. VICKERY: I've got some comparisons in here of that, I think.

MEMBER STETKAR: On this type of plot, comparison plot?

MR. VICKERY: No.

MEMBER STETKAR: Okay. But it would be interesting to see how that would change as you go from, if you got it for 100,000 versus ten million.

MR. VICKERY: If I remember right we didn't change the 100-year winds, or for the 1000-year winds at all. In fact there's a plot coming up that shows some of these comparisons I believe.

MEMBER STETKAR: Okay maybe I can understand what it means.

MR. VICKERY: But we also sampled on top of this, the random error term, it smooths this distribution out in the tails too. It makes a big difference. I don't have a plot of that, but the random error term smooths out the distribution of the tail.

MR. VICKERY: Coming back, we use this weighting function where, though we had 1.2 million storms of 60 miles an hour with gusts somewhere, it doesn't make, I don't think, it doesn't really matter. And then, so we only simulate one percent of those low-end storms, and every time that one makes a landfall it gets a weight of one over the number of percent we simulated.

We retained every storm that produced a peak gust wind speed on land greater than 170 miles an hour, so there's no weighting applied to those storms whatsoever. But now this is how we made our reduced set. So we went from 23 million to three and half

million.

And that's just, this is the total storm weight, this is just the inverse of the previous plot, and log space, so most of them are, a good chunk of them are one.

And here are some examples here, goes out to, I think what we did is we did a couple of sites where we ran the wind field model for the entire time, and it took for bloody ever, both the full set and the weighted set, and it really didn't make any difference.

So we are confident, based on this plot, that the reduced set was enough, and coming back to your tail question --

MEMBER STETKAR: Well, Peter --

MR. VICKERY: What you see is a tail problem here.

MEMBER STETKAR: Yes, before you leave this slide, though, these are the actual results from the model that feeds the NUREG, is that correct?

MR. VICKERY: Yes.

MEMBER STETKAR: Okay. This --

MR. VICKERY: Or the random error term is put on.

MEMBER STETKAR: Right, I understand.

Yes, this is another set.

MR. VICKERY: Right.

MEMBER STETKAR: That has the error term put on.

MR. VICKERY: Yes.

MEMBER STETKAR: Okay.

MR. VICKERY: And okay, the next step. So these are the basic winds. The next step --

MEMBER STETKAR: Let's back up to that, before we get into it. Because one of the fundamental problems that I have, other than a shift in scale, is if I'm looking at the Miami plot, the upper left hand corner one that I can see a little bit better on my piece of paper here.

Your logarithmic scale is, for people who can't read it, is not a decade logarithmic scale, the center point is a frequency of once in 10,000 years --

MR. VICKERY: Right.

MEMBER STETKAR: The right-hand vertical line is a frequency of once in ten million years. So that's a factor of 1,000 reduction in frequency. If I look at it for Miami, that's an increase in peak gust wind speed, if you'll allow me to round off, from 200 to about 235 miles an hour.

MR. VICKERY: Fifteen percent or so.

MEMBER STETKAR: Yes. What fundamental physics is driving the fact that I can predict, with some confidence, a factor of reduction in frequency of 1,000, once in 10,000 years to once in ten million years, with an increase in peak gust wind speed of only about 15 percent, 200 to 235 miles an hour?

If I plot that, and I did, if you could plot it on a linear scale, you know, it would look like a vertical line. If you plot it on a logarithmic scale it's still a very, very steep drop-off. There must be something in terms of fundamental physics that drives that notion.

MR. VICKERY: That it only increases by 15 percent?

MEMBER STETKAR: Over an estimate of, you call it recurrence period, I call it frequency, over an estimated reduction in the frequency by a factor of 1,000, not a factor of ten.

MR. VICKERY: Because you have to have all these exactly right conditions to get this potential intensity to be one. It's not sampling those right conditions until maybe once in a while.

MEMBER STETKAR: That's, the phrase that you just said, it's not sampling those except for once in a while --

MR. VICKERY: Based on our current period of record, because it's using the tropopause temperature data is a 50-year record. Sea surface temperature is a 100-year record, but it just re-samples current years, and it has to hit the right combination of low tropopause temperature and high sea surface temperature, and to produce the very, very high, or very, very low central pressure demonstrated.

MEMBER STETKAR: The question I have then is, how sensitive is the shape of that distribution out in that tail, to your sampling algorithms and the number of samples you're taking and, you know, you're limited by your data set.

MR. VICKERY: Yes. It's a good question that I don't know the answer to it.

MEMBER BLEY: Have you done any stratified sampling, something like that?

(Simultaneous speaking)

MEMBER STETKAR: Well this is stratified sampling.

MR. VICKERY: It already is a stratified sampling.

MEMBER STETKAR: Have you looked at conversions of your sampling results? You know if it's a Monte Carlo sampling, I'm assuming --

MR. VICKERY: Yes, we have in the past. I didn't readdress it this time.

MEMBER STETKAR: I mean, that's really, really important if you're trying to predict, if you're results are very, very sensitive to a random hit of one sample --

MR. VICKERY: Yes, I don't think they are, but --

MEMBER STETKAR: You don't think they are?

MR. VICKERY: No, but, again we --

CHAIR SHACK: Well I worry more about the fact that the initial conditions are limited. You know, you can, as long as the initial conditions span only a certain range, you can hit them as many times as you want.

MEMBER STETKAR: That's the other part of the problem and, you know, so I'd be more inclined to assume that, that in fact sets my true limits. He could sample until hell froze over --

CHAIR SHACK: Well, that's true. I mean if you had perfect sampling, you're still limited by the range of your --

MR. VICKERY: Again is --

CHAIR SHACK: But, you know is this range of variables, you know, could they shift? Well they

could presumably shift that we had some anatomy changes, but --

MR. VICKERY: If you get any climatic changes they could shift. Yes, it's undivided data, that's really all I can say to there.

MEMBER BLEY: Is there a way, when you do this kind of modeling, to unravel exactly what's contributing to these events out on the table? What congruence of conditions have led to these --

MR. VICKERY: Yes, what we found in the path is actually the very low tropopause temperatures that drive it. It's the low tropopause and the high sea surface temperature at the same time.

At the end of the day, let me move on a little bit further on here, these results are driven by the, actually the wind field, probably, uncertainty drives them, so we weren't particularly concerned about it.

MR. SIMIU: Yes but for example, Peter, you have no radius of maximum wind speeds less than four kilometers. So you ran around a trillion simulations and still you won't have, you have a censoring based on judgement and experience, so it limits the tail, I believe.

MR. VICKERY: I would probably go, well I

might go the other way actually but, because you've also reduced your strike area too. But, yes, we have cut it off at four kilometers, which is pretty damn small.

But not very much I can say to expand, we've done some sanity checks at the end, comparing it to Emanuel's stuff, to see if it's in the ballpark.

MEMBER STETKAR: It is just that I'm, you know, I'm stepping back, you know, Lord knows I don't know anything about this simulation stuff, or the model. Everything I read gives me a lot of confidence that you really, really understand the behavior of a cyclonic wind field pretty well.

I step back to regulatory decisions that are being based on the assertion that we have confidence that a change of 15 percent in peak gust wind speed results in a reduction of a factor of 1,000 in frequency, because people are making decisions on the same level.

This is a 10^{-7} and I need to design to 220 miles per hour peak gust wind speed, if I follow it along the Texas coastline. Well if that's off, you know, it's an artificiality of the 10^{-7}.

A 200 and whatever I said was, 200 miles per hour, is a factor 1,000 times more likely. And if

the tail of that distribution is off a little bit on this very, very sharp logarithmic scale, for a 10^{-7} frequency, maybe I have to design to either a much higher wind speed or, you know, I'm making a wrong regulatory type decision. You follow what I'm saying?

MR. VICKERY: Yes, because we did not do a formal uncertainty study.

MEMBER STETKAR: Yes. You don't know the shape of that if I were to fit an uncertainty distribution on those curves. You don't know the shape of those uncertainties, how they're --

MR. VICKERY: Well it's going to be, it will be limited at the top by the maximum --

MEMBER STETKAR: That's what I was going to ask you. What is, theoretically, you said there are some notions of theoretical maximum, you know, I don't even know the phraseology, the minimum pressure. Is there a maximum, you know, associated with that, in up or down on peak gust wind speed, I mean, as a practical matter?

MR. VICKERY: That's a good question, I don't know --

MEMBER STETKAR: Yes, you're projecting those two hits out in the tail of the previous

distribution were up in the sort of 300 mile an hour a range, but only a couple of hits which, is there a theoretical upper bound that says, well we just can't, for something that's called a hurricane, we just can't get something that's higher than 320, 330 miles an hour?

MR. VICKERY: Not that I know of but, you mean --

MEMBER STETKAR: That would give us a sense of what that's --

MR. VICKERY: Yes, I understand --

(Simultaneous speaking)

MR. VICKERY: -- what's going on, I mean the frictional, I guess the best way to do that is to run a full numerical model. To look at the potential upper limits, to try and get a handle on that.

Otherwise, it's hand waving. I need to kind of quit hand-waving, say, that's the really, the only way to get a handle on that. And still, you're going to be limited by the ability of that model.

You're going to need a very, very fine grid. So I have to kind of bail on that one. Because I hit, I mean I can't answer it any better than that.

MEMBER STETKAR: Okay, thanks.

MR. VICKERY: It certainly adds to the

uncertainty.

MEMBER STETKAR: Thanks.

MR. VICKERY: I'm going to try to speed up now. Next thing is the, I'm going to go over this very quickly. An enhanced gust factor, well I'm going to skip the math but, the gust factor approach we use is based on a, it's a theoretical estimate of what the mean gust wind speed will be in a turbulent manner blowing at the surface based on a one-hour stationary record.

And in open terrain that gust factor is about 1.52, it varies some with wind speed. Give them an hour, and the turbulence associated with standard open terrain, which is typically in the order of 10, 12, 15 percent, I don't remember the exact number.

But as your period, your hour reduces, you don't have enough time to hit that maximum, so the probability of getting 1.5 times the gust wind speed goes down. And as that period gets shorter and shorter, that effective gust factor goes down, down, down.

But we have, we together the little model that takes into account, it accumulates the gust factor as the storm goes through. So a very, very short storm, very tight, fast-moving storms so you

don't have a lot of time, you'll have an effective gust factor that's lower than 1.5.

And we looked at the effect of that in here for South Florida with our full storm set, and with this non-stationary gust factor, it reduced the wind speeds by a little bit.

And the same deal in New York, but again, you also, again in New York, remember we've got this kink at the high end. So this is an example of not running enough simulations.

Next one is we have a translation speed adjustment, I won't get in too much details on this, but the model, we believe when this is going to get very, very fast-moving storms is not behaving correctly, so we've reduced the effective translation speed that's -- the storm took, translates it, in this case 30 meters per second, but the translation speed we feed into the wind field model is actually 20 meters per second.

And that's, we've done that because, when you're looking at the 1938 hurricane, with very high translation speed, the results just looked, weren't quite right. And since we've made that change, it's validated well for Hurricane Juan in Halifax which was a fast-moving storm well North.

This is a tough, you have these gust factors kind of being all over the place, plotted versus mean wind speed, this is from Hurricane Wilma. It's very hard to see here, but the mean gust factor is 1.5-ish, and this is just showing the observations are bouncing all over the place.

MEMBER STETKAR: This is the 15-minute, you used the term mean, is it a 15-minute mean?

MR. VICKERY: These days it's a 15-minute mean.

MEMBER STETKAR: Yes that's, okay. I think some of them were ten minutes, but that's okay.

MR. VICKERY: And here's another example of wind field modeling uncertainties with this Holland B parameter. You can see in this, whatever hurricane it is, Hurricane Allen with a pretty decent central pressure deficit of 106 millibars, so about 907, yes about 907 millibars central pressure.

The thin line is the observations from aircraft, and the solid line is the model, so it's not matching perfectly. And the same deal with the wind speeds, it's underestimating the peaks here, but that's another contributor to the error term.

And again, this all lumps into this plot we've developed before so, errors are coming around

from not getting the gust factors right, or the distribution of the gust factors, because of anomalous winds, B, its B representation, not being able to do a perfect representation of the hurricane.

So we've all fed it into a catch-all error term for the wind model. And this is what that wind modeling error term does, is without the wind field modeling is for the South Florida here, it's tailing off at ten to the minus seven, around 230 miles per hour, and with this uncertainty bumps up to 260 miles an hour.

And you'll see in New York it smooths out the tail shape a little bit, because you're adding extra randomness to the process.

MEMBER BLEY: You change the direction of curvature too. Yes, it's really significant.

MEMBER STETKAR: Remember this is a log plot.

MR. VICKERY: This is an example of an anomalous wind speed, a few anomalous wind speeds popping up and changing the shape of the curve.

And by adding this additional uncertainty term, you screwed up the tail. It's something that the insurance companies do all the time to estimate their tail probabilities for high losses. Sampled

again from some simulations that were done before.

Okay, so that's the model. These are all the grid points we used.

MEMBER STETKAR: What, the 25 mile grid, or is it fixed grid?

MR. VICKERY: It's a fixed grid, I don't remember. It's tighter at the coast, very tight at the coast.

MEMBER STETKAR: Yes.

MR. VICKERY: I don't remember what our spacing is inland. Okay, this is, first off we wanted to compare, this is the NRC model results for the 100-year and then the 1,000-year wind speeds and think the next one compares it to ASCE 7.

So at the 100-year, look at the 140 mile an hour here in the NRC model, and at the ASCE model. It shifts a little bit so the NRC model is a little bit weaker than the ASCE 7, which is consistent with the gust factor change. And, you know, that's it. If the gust factor change that would do that, make that change.

MR. HARVEY: Which version of the ASCE model are you using?

MR. VICKERY: It's the 2009, it is the most current version.

MR. HARVEY: Okay.

MR. VICKERY: It's the 100 year wind speed. And finally for the 10^{-7} view kind of results here for Texas was the 220 mile an hour winds. Up at the tip of the Mississippi Delta they're up around 260 miles an hour. Down in the Miami area, the 290 mile and hour in the Keys.

North Carolina coast, this is where the Brunswick nuclear plant is, it's around 220 miles an hour. And then you're getting up to the northeast, it's not surprisingly the lot, the biggest around 190 miles an hour, in the Nantucket area, and not much in Maine.

And this is a map just showing where the hurricane basis designed winds exceed a tornado, it's not that big an area but mostly Florida and little bits of North Carolina and Texas.

MEMBER STETKAR: And along the Gulf Coast.

MR. VICKERY: And along the Western Gulf coast of course.

MEMBER BLEY: Very narrowly.

MR. VICKERY: Very narrow, yes.

MEMBER BLEY: Well, it's got to be right along the coast line.

MR. VICKERY: So our overall summary, and

I'll be right on time. Okay, the original model was developed and validated using data since 2007, and when that model was developed we had the new statistical models for the B and radius to maximum wind.

It was extensively validated, the wind field model portion was on shore and off shore. This wind field model, the approach used here, was also used in ASCE 7 but played a much smaller role because you're only in the 100,000 year kind of range there.

The model's been very thoroughly peer viewed, and it was used to develop the ASCE 7 designed wind speeds.

Now this time around for the NRC, we've updated the model, we started with the ACSE 7 wind speed model, we reduced the radius to minimum radius maximum wind to four kilometers.

We have a reduced storm set to enable all the model run sets that we've done. We have a mean gust factor now that takes into account storm duration. I didn't review this before I came here.

Okay, the $10^{-6}/10^{-7}$ winds are strongly impacted by the wind field model uncertainty term which I already talked about. And then we did kind of a back of the envelope validation study, not really

validation but kind of a sanity study.

And we took that 290 mile an hour wind on land and we assumed it hadn't been fully transitioned into full over land wind speeds gusts. So the gust factor was back in the range of 1.7/1.8, this 290 mile an hour corresponds to roughly one minute sustained wind speed over water in the range of 190 to 220 mile an hour, there's a swath in there too.

And then we compared that to the, so that's 85 to 98 meters per second. That's a humming wind, nevertheless. And then the Massachusetts Institute of Technology on their website, this is Kerry Emanuel's group, they published their maximum potential intensity match and we looked at August, September and October.

And in the south Florida area the ten percent exceeds probability mpi, is greater than 90 meters per second. So this suggests that our results are in the right range and comparable to a those of another study that uses, it's a different approach but they also, they just estimate what the maximum potential intensity is.

It's not out to lunch, assuming the maximum potential intensity theory is any good, so we've taken that as gospel. So that's kind of the

summary of where the model came from what we did, and the resulting results. The final results. Any more questions?

CHAIR SHACK: No, I noticed you did that frequency study to estimate one possible shift in the temperatures. The other discussion is you could do the temperature changes in the ocean just to look for potential effects. But, I mean, these are all kind of guesswork things.

MR. VICKERY: Yes, John has this doubtful look in his eyes.

MEMBER STETKAR: Well, but, I mean, you know, I appreciate the presentation I just don't understand why, I'd like to more carefully understand why the types of projections that I've done, admittedly, you know, with hours worth of effort.

MR. VICKERY: Are so much higher?

MEMBER STETKAR: Are so much higher. I believe it's because they're more, they're not quite estimates, they're more area estimates.

MR. VICKERY: Yes, and I tried to do that, you know, as I said, I took first the Texas coast and looked at, that's obviously wrong. So then I narrowed down to one county and that's also a bigger area but it's starting to get into typical footprints of

reasonably severe hurricanes.

You know, if I look at a 20/30 kilometer, you know, radius of strong winds for example.

MEMBER STETKAR: Well what was the number you had, the 100-year number that you had based on what you had given.

MR. VICKERY: For a Texas or the single county?

MEMBER STETKAR: Texas.

MR. VICKERY: Now I have to, hold on let me pull up the Texas model.

MEMBER STETKAR: That's a comparison we can do.

MEMBER STETKAR: The 100-year for Texas?

MR. VICKERY: Yes.

MEMBER STETKAR: Peak gust?

MR. VICKERY: Yes.

MEMBER STETKAR: Hold on let me get a curve that I can look at. Well I've got a range, the problem is I have a range.

MR. VICKERY: That's fine.

MEMBER STETKAR: And I don't get --

CHAIR SHACK: The differences are big enough you don't need to worry about --

MEMBER STETKAR: The differences are big

enough I don't need to worry about it because my about 50 or 60 year range is somewhere in the 170 to 230 or 240, I'm sorry about 170 to about 200 mile an hour peak gust, three second peak gust wind speed. And your 100-year of 10^{-2} is on the order of a 120.

MR. VICKERY: Right and for the state we get any --

MEMBER STETKAR: That's state.

MR. VICKERY: Okay, well on the coast we're getting 157/158, that's still lower than what you're getting.

MEMBER STETKAR: I'm trying to understand, you know, why what I'm doing is just insane.

MR. VICKERY: Yes, there's some kind of error there, either in the way the wind speeds are estimated.

MEMBER STETKAR: Well as I said, mine is, what I did was I just took the simple NOAA data estimating Saffir-Simpson category, which is approximate and the ranges of wind speeds.

MR. VICKERY: Because your 200 miles an hour is more than we get, and the data would suggest, for the entire United States.

MEMBER STETKAR: Well, but that 200 miles an hour is just a 30 percent increase on the upper

bound of a CAT, what would be a CAT 4 hurricane. That's all that is.

MR. VICKERY: Okay.

MEMBER STETKAR: It's not a statistical sampled thing because I have no idea what the actual distribution of wind speeds within, you know, that family set is.

MR. VICKERY: Right.

MEMBER BLEY: So you took like a CAT 3 and just distributed it over --

MEMBER STETKAR: I didn't distribute it, all I have is the lines drawn, this is the upper bound this is the lower bound, I have no idea what the distribution looks like between --

MEMBER BLEY: When you calculate, I'll say at a point. But you look at a point and you look at everything your models generated through that point and come up with an estimate. So we don't have estimate of how broad that represents, it's just the maximum of everything generated at a particular place?

MR. VICKERY: Well we could, everything at that one particular point, now if we'd saved everything, which we didn't do, we could have produced an estimate of what the maximum wind speed was anywhere, in any size region you want.

MEMBER BLEY: You could pick that county.

MR. VICKERY: Because we have the event by event maximum wind speeds. We had them, we don't have them any more I don't believe.

MEMBER STETKAR: What is, and as I say we're running short on time so we should stop this.

MR. VICKERY: We should move on.

MEMBER STETKAR: The curious thing for me is that I only have a snapshot of historical data over 110 years that I've converted into some sort of simple minded exceedance curves.

At the point at which my data end, the slope of those exceedance curves looks like the slope of your exceedance curve. In other words, except for the fact they're shifted in wind speed substantially and as that shift in wind speed as you translate out through this logarithm and plot makes a huge difference.

MR. VICKERY: Yes, it does.

MEMBER STETKAR: You know down to the 10^{-5}, 10^{-6}, 10^{-7} frequency range.

MR. VICKERY: Right.

MEMBER STETKAR: Because the shapes seem to be about the same.

MR. VICKERY: Well the shape should be

about the same.

MEMBER STETKAR: It seems that the exceedance, you know, notion is working, you know, it seems to be comparable. It's just, I don't understand the dramatic shift which has, you know, a hugely magnified effect way down at those low frequencies.

MR. VICKERY: Right, and we'd have to look at it together in a lot more detail to sort out the differences.

MEMBER STETKAR: Yes, and that's what Bill --

CHAIR SHACK: I think it's time to move on. Now we're going to take these winds and fling things with them.

(Off microphone discussion)

MR. SIMIU: So I will go to the slide which says the reports documents and approach to and results of the calculation of hurricane borne missile speeds for the design of nuclear power plants.

The missile spectrum, we use missile spectrum based on discussions with the staff, the NRC staff. Some of the missiles are the same as the missiles that are used for tornado.

For the design basis tornado missiles but in addition the staff requested that we look at two

additional missiles. And it is the last item here, states that it is a safety concern that wind-borne siding missiles may compromise the structural integrity of the nuclear island Seismic Category 1 structures.

This addition was required because of the characteristics of those missiles differ significantly from those of the four missiles tabulated in the Regulatory Guide 176, Revision 1.

So the theory that underlies our calculations is simple. It's Newton's second law. And the force of that acts on the missile is proportional to the square of the relative velocity of the missile.

Of wind field with respect to the missile, which is why we see some differences. There the hurricane minus v_{mh} and v_{mv}. And A, the parameter, A here, is proportional to an estimate of the average draft coefficient. An estimate of the exposed area and the mass, and the rule being the specific weight, the specific mass of air.

So these are the two equations that govern the horizontal and the vertical velocity of the missile. The following assumptions were made and some of them differ from the assumptions that are made in

the case of tornados.

First, hurricane updraft speeds are negligible, this is not the case for tornados. Missiles starts motion with zero initial velocity from an elevation H. I do not know what that elevation H is, in RG 1.76 it was assumed that H, by convention, that H was 40 meters.

So we took this initial condition, the initial elevation, is of measure or is commensurate with the time that the missile is exposed to the wind flow. If the missile is near the ground the gravity force brings it very quickly at the ground and then there is no more aerodynamic force.

So we took all, we performed calculations for all those initial heights. Wind speeds, assumption Number 3, vary with heights above ground in accordance with the power law. One power law for open terrain, I think the exponent view was 1.1 divided by seven. And for suburban terrain where the exponent of the power law was, if I recall well, one divided by four.

And the fourth assumption, a simplified assumption, the missile drag coefficient is independent on average of missile position or relative missile speed with respect to the wind flow.

There have been some attempts, maybe 30 years ago, to follow the missile and it's rotate and it's rotation stumbling throughout the trajectory, many of the assumptions that accompanied this procedure looked arbitrary and difficult to support.

So the results didn't differ much from when the Assumption 4 is used. So following the procedure that we used in Regulatory Guide 1.76, I think it was, we used Assumption 4, it's the same assumption that was used for missiles.

This shows the missiles spectrum schedule 45 a large automobile for Regions 1 and 2. A smaller automobile were used for tornado Region 3, and a solid one inch diameter solid steel sphere.

We started these additional missiles, for which we assume that the drag coefficient was 1.2, steel board batten siding coated with PVC, this was not my choice.

(Off microphone discussion)

MR. SIMIU: A slab and a plank. That was Jerry's suggestion, it was, if you will, scientific curiosity, I believe that. But also the realization that these things can happen. So he wanted us to know what would be the consequence of it.

For all open and suburban terrain cases

the equations of motion have to be solved numerically but we wanted to check our numerical solver.

And we found that if we assumed that the wind speed is uniform with height, doesn't vary with height, it was possible, by a variety of tricks that I learned in my sophomore year, to find a solution of the deferential equation, enclosed form.

And then we tested the numerical solver for this and we were very relieved to find that the results were the same. So we inferred from that that the results for the open and suburban terrain cases where the winds profile and the power law structure would be correct also.

Okay this slide, which is difficult to read, is reproduced from the report and provides wind speeds corresponding to various missile speeds are not corresponding to various wind speeds at ten meters above ground in open terrain. These are the speeds that you get from Peter's calculations. So this is the standard wind speed and the corresponding missile speeds tabulated for various types of missiles.

CHAIR SHACK: For the Boundary Layer Variation you have in the velocity, is that similar to the Boundary Layer Variation that Peter showed or that you --

MR. SIMIU: Yes, no actually Peter shows a modified logarithmic law which deviates from the logarithmic law considerably at very high elevations. Our elevations never exceeds 40 meters because we don't have updrafts.

So we just used, we didn't use a logarithmic law, which we could have used the American Society of Civil Engineers standards. ASCE 7 uses the power law, because it's been around for 50 years and codes change slowly.

In fact, because there's a discrepancy between ASCE profile, and the profile that's meteorological, researchers use, which are algorithmic and the logarithmic that was introduced in the standards through the back door somehow.

But this wouldn't make much difference. So we calculated terminal horizontal wind speeds and we calculated terminal total wind speed. That is the result of the vertical and of the horizontal.

And then we created those graphs that cover all possible missiles via this Parameter A. And again we do it for various wind speeds and we get the results here.

And I have here a few examples of wind speeds. For 125 meters per second, three second

hurricane wind speed, at ten meters above ground in open terrain.

The calculated maximum horizontal wind speeds over open terrain were H=40, are approximately and then we list them here. We also list in color the corresponding speeds when the three second hurricane wind speed is 103 meters per second.

And then we list in parentheses the corresponding values for initial heights, 20 and ten meters per second. So here the speeds we calculated which are higher than their counterparts, for tornados for the reason that Mr. Brown pointed out earlier.

So this is a summary of the tornado wind speeds which show that the wind speeds are indeed smaller in tornados than in hurricanes. And because I wanted to keep my presentation short, I am now at a point where I can state the conclusions, for the seven types of missiles of interest tables are provided and the report is very thick.

Because I provided tables for all possible conditions as well as requested, legitimately by the Nuclear Regulatory Commission.

So of the seven types of missiles of interest, tables are provided which list missile speeds and the time the missile reaches the ground

level for hurricane wind speeds at ten meters above ground in open terrain, ranging from 40 meters per second to 150 meters per second.

In increments of five meters per second and for flow over open terrain and over suburban terrain, both horizontal missile speeds and total missile speeds. The resultance of horizontal and vertical speeds, are listed.

Plots showing those missiles as function of perimeters characterizing the missile properties are also provided. Similar tables and plots list maximum as opposed to terminal missile wind speeds.

The terminal wind speeds is not necessarily the highest wind speed because as the speeds in the boundary layer decrease, they decelerate the velocity of the missile and that's why we picked the maximum velocity speed during its trajectory. And this is my admittedly prosaic presentation, every thing is exact except for the parameter A.

CHAIR SHACK: Yes. What's your source for the parameter A for the drag coefficients? The sphere I can --

MR. SIMIU: Yes, you have in front of you a historical monument, I am historical monument, in the sense that I was present at the creation, I did

the calculations that went into the 1974 document. A long time ago, I was a young man then.

And so we consulted the staff, we looked at, there used to be a compendium of drag coefficients by a German scientist that came to the United States after World War II by the name of Hoerner, it was a classic, and now you look it up, you look the CDs on internet.

CHAIR SHACK: Okay, I'll do a Google search for it.

MR. SIMIU: Yes so, see 1.2 is a reasonable drag coefficient, except to use that smaller drag coefficient for the sphere. I think that was 0.4. I think I have it written even in that presentation.

So, as I said, it's prosaic, it's approximate, I didn't make any decision, and will not make any decision. I was not mandated to make any decision on what the missile will come down from.

A 40 meters, 30 meters, 20 meters, it probably depends on the sites, on the surroundings, on the judgement of the staff for any particular power plant, so we only provided the basic information. And the bulk of the work was done by my coworker, who is a Professor of Math at the University of Maryland,

name is Potra.

And I also, in addition to acknowledging Florian, my coworker, I wanted to say that in my very long career, I never worked with a sponsor that was as meticulous and helpful in checking everything I did, and finding errors, thank you.

(Laughter)

MR. SIMIU: Here and there.

MEMBER STETKAR: Really small errors.

MR. SIMIU: Tolerable.

MEMBER STETKAR: Tolerable errors.

MR. SIMIU: After being corrected they were tolerable.

CHAIR SHACK: As you say, it's a very useful piece of work.

MR. SIMIU: Thank you.

CHAIR SHACK: For people, to do these things.

MR. SIMIU: I think it's clean. I mean, it's clean and transparent. In fact, we also supplied the software to NRC, we put it on our site when the report would be released so that anyone who knows that particular -- I don't remember what kind of software it is, but they can do their own calculation.

CHAIR SHACK: Well I like the little

tricks to do the closed form solutions. It goes back a long way.

MR. SIMIU: It's when, a long way and I have to brag, I did that. I didn't allow the mathematician to do it, he just checked it. I was rather proud of myself because I did that stuff in the year of the Lord 1952.

CHAIR SHACK: Any additional questions? If we were going to come forward to the full Committee, how should we do that. Yes, right.

MEMBER STETKAR: That's an excellent -- I'm going to take this one, then. It's an excellent question, though. We cannot bring it to the full Committee.

CHAIR SHACK: Yes, you know that's a good question. I mean, I think it's, you know, it's basically a done deal, so the work is coming out. This was more for our information, it was really not a --

MEMBER STETKAR: I mean I haven't become, I'm convinced that I'm wrong, but I'm not convinced that they're right. And I don't know, but on the other hand if I step way back from it --

CHAIR SHACK: Well you're certainly not going to figure that out at a full Committee meeting

--

MEMBER STETKAR: Absolutely not --

(Laughter)

MEMBER STETKAR: Where is it clear, you know, before I die I'm going to figure it out. But the, if I step way back from the whole purpose of this, identifying areas in the United States where the risks, I'm sorry, the limiting condition might be a hurricane, is certainly a useful exercise.

You know, and this exercise has done that, and qualitatively it certainly makes sense. I mean, there's nothing counterintuitive about the locations that have been identified along the coastlines in Florida, where hurricanes ought to be more limiting than tornados, that makes a lot of sense.

The design basis wind speeds that people are using in those regions are like any other design basis event, you have to design to something. So people are going to design to whatever those design basis wind speeds are. I have no problem with that either.

As in any kind of design, you design to the double-ended guillotine shear with a presumed simultaneous loss of offsite power with a single failure. That's a design basis, it's an arbitrary

design basis.

The only question is then, putting confidence in the fact that we believe that those design basis conditions will occur once in ten million years.

CHAIR SHACK: Well let's just say that they're sufficiently conservative.

MEMBER STETKAR: They're reasonable for a design basis, but presuming that the frequency of those conditions would be once in ten million years, may be questionable. Maybe once in 10,000 years or once in --

MR. SIMIU: If you take --

MEMBER STETKAR: -- 100,000 years, but not once in ten million years. That's a risk argument, it's not --

MEMBER BLEY: What we'd normally want to see is for a given wind speed, the uncertainty in that wind speed, what we have here is a maximum wind speed, and not a real clear statement of --

MEMBER STETKAR: How the uncertainty is in each part of the process.

MEMBER BLEY: Is there a chance it could be higher, that sort of --

MEMBER STETKAR: Well, yes, I mean it's

characterized as the best estimate maximum, whatever that means.

MR. SIMIU: My sponsor for the 1974 documents, when I expressed my own dismay on, upon hearing this ten million years criterion, told me, it's qualitative and it's there for legal purpose, it doesn't have real physical significance. That's what --

MEMBER STETKAR: Historically I believe that's the case. However we've learned an awful lot in the last 30, you mentioned '74 or whenever, in the last 30 or 40 years about the dangers of over-characterizing our confidence in very small numbers.

MR. SIMIU: Yes.

MEMBER STETKAR: And for a whole variety of --

MR. SIMIU: 1.999999.

MEMBER STETKAR: Well, and especially for natural phenomenon, I mean people have characterized for example, you know, we design to the 1000-year flood and then try to rationalize why we had two 1000-year floods in the last decade, that type of activity.

That some of those recurrence intervals or frequencies that were perhaps thrown about 30 to 40 years ago as being very rare events, we're learning,

are still rare events, but not nearly as very rare as whatever people presumed they would be in the past.

That's, as I said, that's my, my sense of this exercise is, on a qualitative basis to define a set of more limiting conditions along coastal areas for the designers.

I think it makes a lot of sense. It's just saying that we have confidence that those conditions will occur once in ten million years, as compared to the fact that maybe the true mean frequency might be once in 10,000 years, which is a huge difference. It's still a very rare event.

MR. SIMIU: The ten million is a figure of speech, so to speak.

MEMBER STETKAR: Well, but the problem is, it is used in a regulatory process and it's used by other people in terms of a level of confidence about design margins.

MR. SIMIU: Have you heard of an approach, a reliability approach, called information-gap approach?

MEMBER BLEY: No, Dennis tends to read much more than I do --

MR. SIMIU: If you wish, there is a new blog, I have nothing to do with it, but if you give me

your cards, I'll send you, I just received it two days ago. It's been around for a long time. It's been used in, for military applications, probability of missilling by the Iron Dome protective device.

So maybe that would be useful to look at. I don't guarantee that it will be useful --

MEMBER BLEY: It would be worth looking at, sure.

MEMBER STETKAR: It would be worth looking at, certainly.

MR. SIMIU: If you would write your emails on a piece of --

MEMBER STETKAR: I have a paper.

MEMBER BLEY: When we're done, we'll give it to you.

MEMBER STETKAR: We'll get it to --

(Simultaneous speaking)

MEMBER BLEY: Yes, it's worth looking at. I mean, there are lots of techniques. I'm kind of like, though, I mean this, I might have a greater feel, I have a pretty comfortable feeling that this is conservative and it, you know, seeing some details under the results might make me understand it better, you know --

MR. VICKERY: What kind of details?

MEMBER BLEY: Well, the spread, how broad the spread is underneath your maxima. You know what the results of the simulation look like in terms of, I'm not saying that right --

MR. SIMIU: I'd like to add one little point. I don't know how valid it is, but it may be worth considering. If you simulate, if you have 100 years worth of data, and you try to fit a probability distribution to those data, I mean seems time for a new distribution.

What we found, with absolute regularity, is that those probability distributions have limited tail lengths, they stop somewhere --

MEMBER BLEY: Have limited what?

MR. SIMIU: Tail lengths.

MEMBER BLEY: Yes.

MR. SIMIU: The tail is not infinite. It stops somewhere. I tried reading Kerry Emanuel's papers to find out where they stop, and I wasn't able to. From his thermodynamic considerations, I couldn't get to put my finger on a wind speed.

There can be no wind speed greater than 190 miles per hour.

MR. VICKERY: No, there is nothing there.

MR. SIMIU: It is not in there. But it's

interesting that the extreme value theory, for what it's worth, seems to tell you that the tail is not infinite, and that what's --

MEMBER STETKAR: That helps an awful lot when you're doing simple, you know, extrapolations, it at least gives you some anchor point --

(Simultaneous speaking)

MEMBER STETKAR: -- zero were very, very small.

MR. SIMIU: A fundamental question that one may ask is, how valid is extreme value theory, it is based on some assumption itself. But I thought it was an interesting indication. It stops somewhere. From my 100 years of data, I get maximum tail, and I know that it's wrong.

It may be very different, but it still tells me for all locations, 53 locations along the Gulf Coast and Atlantic Coast, it tells me it never goes infinite.

MR. VICKERY: Yes, but it is very subjective as to exactly where that tail is, and it can change the results significantly.

MEMBER STETKAR: That's true. The subjectivity, I mean in terms of, engineers worry about subjectivity in terms of precision. I come back

to the difference between precision and accuracy.

MR. VICKERY: Yes, you can be precisely wrong.

MEMBER STETKAR: You can be precisely wrong, but you might be in the right ballpark.

MR. VICKERY: Right.

MEMBER STETKAR: And perhaps being in the right ballpark with some subjective estimates is more useful, is more valuable than just saying, well we can't do it precisely.

MR. VICKERY: Yes, it's kind of what the simulation approach is at the end of the day, right?

CHAIR SHACK: Well I suppose we could go back and look at this maximum potential intensity approach, which is a physical basis for a limit, if --

MR. VICKERY: Yes you could, but you also need to consider the whole thing together. Look at the, you know, you've got uncertainty in the missile population, all of, what missiles you're going to choose, their starting heights and all that stuff.

You can't just take the hazard and isolate it, you have to look at the whole thing together. Because you don't exactly know yet which one is driving --

MEMBER BLEY: Yes.

MR. VICKERY: -- the uncertainty at the end of the day.

MEMBER BLEY: That's certainly true enough.

MR. VICKERY: The missile spectrum is incredibly simplified. Now is that more important than being off by ten miles an hour? Or not? I mean that's, you need to look at the whole picture, on the perforation equations, the whole bit.

You can't get focused on one part of the problem, to find out where your dollars are best spent.

CHAIR SHACK: My concern is that we have some additional questions, but these additional questions that are better pursued at a full Committee meeting.

MEMBER BLEY: Certainly not.

CHAIR SHACK: I think, you know the better question is --

MEMBER STETKAR: Well, John did sort of like a, you know that 100,000, if you've got that binning for the 100,000 so you can compare it to the 10^{-7} bins.

CHAIR SHACK: At current use of the population --

MEMBER STETKAR: The population --

CHAIR SHACK: -- of events.

MEMBER STETKAR: -- of wind speeds. Your destination would be 23 million over your five mile per hour bins.

MR. VICKERY: Yes.

MEMBER STETKAR: Peak gust winds for your --

CHAIR SHACK: Is there an equivalent for your 100,000 miles? Or your 100,000 simulation? Just so we could see what the difference looked like?

MR. VICKERY: I've never plotted it out for that one.

MEMBER STETKAR: That comparison, as I said by itself doesn't answer, you know, my wrongheadedness about plotting the data, but it does answer a bit about potential sensitivity of tails of the simulation sampling processes.

MR. VICKERY: We don't have 100,000 years on the same grid.

MEMBER STETKAR: Okay.

MR. VICKERY: That's the tricky part.

MEMBER STETKAR: The previous grid was a much larger grid?

MR. VICKERY: No, we have different grids

floating around. We have, we just did a half a million one on a zip code grid, but that doesn't help.

CHAIR SHACK: Well of course you did that other one for, what was it, eight kilometer, you changed the minimum --

MR. VICKERY: Yes, but that's --

CHAIR SHACK: The RMW which would affect this, right?

MR. VICKERY: Only at the tails.

(Simultaneous speaking)

MEMBER STETKAR: God, I would hope it would not affect the flat part of that distribution.

MR. VICKERY: Yes, I wish we could even, well we had some disk crashes so we lost some of the data from the 10^{-7} study. We have a lot of it, but not all of it, if we had to quickly come up with that.

For the one stage we did have a full set of a small -- oh we have the, we may still have the full sets at some individual locations. We could extrapolate, I mean, pare down to 100,000, take the first 100,000.

MR. SIMIU: How long would it take you to run the data?

MEMBER STETKAR: You'd have to think about that.

MR. VICKERY: Well the problem is you've got to rerun all those damn tracks, that's what takes all the time.

CHAIR SHACK: Yes, suppose you just take the 10^{-7} data set and start plotting the first X, second X, and see how it changes?

MR. VICKERY: I'll --

MEMBER STETKAR: That would, I mean that would give you a feel for how that tail shapes --

CHAIR SHACK: Floats around.

MEMBER STETKAR: -- floats around.

MR. VICKERY: Right. I guess the only thing I can do is look to see if we have that available. I'll make a note to see if I can dig that out.

MEMBER STETKAR: I guess the bigger concern is, you know, is it worth bringing before the full Committee?

MEMBER BLEY: I'm not sure that we need the full Committee.

CHAIR SHACK: No, I mean if we had a problem I'd bring it to the full Committee, but I'm not sure that our problems rise to the level that they need to be addressed at the full Committee.

MEMBER STETKAR: That's --

(Simultaneous speaking)

MEMBER STETKAR: In terms of the Subcommittee, you know I'm obviously with, having the tails, then my problem is simply characterizing that design basis, wind speed as a 10^{-7} per year wind speed. I have absolutely no -- assigning a frequency to it.

MR. SIMIU: You know would save the situation, if instead of saying that it is the 10^{-7} 1000ths wind speed, you could say it's an estimate of the 10^{-7} wind speeds.

MEMBER STETKAR: No, I feel much more comfortable saying, well we've done a lot of analytical work, there's a lot of uncertainties and we're going to use, as a design basis wind speed, this wind speed without assigning a frequency to it, to avoid this notion that we're designing for a once-in a-ten million-year event, or once-in-100,000-year event, or once-in-10,000-year event.

CHAIR SHACK: Gorinsky pointed out to me that we're missing what could be an important part, which are the public comments. We ought to hear what other people have had to say about it.

MR. VICKERY: The ones that we got, we did get public comments. They mostly whined that the wind

speeds are too high.

MEMBER BROWN: I read the public comments, and that's fundamentally the crux of it, and they thought they were, the numbers were --

CHAIR SHACK: Too high?

MEMBER BROWN: Too high, yes. That was from the --

(Simultaneous speaking)

MEMBER BROWN: -- but the response was, even though I'm not an educated, you know, numerical, throw in the hand waving and the statistics, they seem to be reasonable responses to the guidance. And become, they stuck with their numbers.

MR. VICKERY: Yes, we put a fair bit, or at least on the ARA's, we put a fair bit of effort into the responses.

MR. SHUKLA: Selim, you want to go through these?

MR. SANCAKTAR: I don't have anything really, fundamentally new to add. If you want I can go through my few slides but, as you wish.

CHAIR SHACK: So you felt there was really nothing from the public comments that really affected the outcome?

MR. SANCAKTAR: Right. In fact, my

personal opinion was, they only deserve a paragraph each, but I think we did a lot more than that.

MEMBER BROWN: Well you didn't have any public, any --

MR. SANCAKTAR: We got four, we got two public comments, really. One for --

MEMBER BROWN: Two of them were editorial, the other two were complaining about, not complaining, they articulated that the speeds were too high.

MR. SANCAKTAR: One was from a group called Case, and they were really talking about something totally different.

MR. VICKERY: Yes, they were out in left field.

MR. SANCAKTAR: They were talking about, out there about Turkey Point sites and, we couldn't tell exactly how it related to this.

MEMBER STETKAR: I sort of read theirs, but I couldn't understand whether their assertion was that your predicted wind speeds for Turkey Point were too high?

MR. SANCAKTAR: I couldn't understand what the question was, that what --

(Simultaneous speaking)

MEMBER STETKAR: Yes, I got through that

and I got really confused and I didn't, honestly go back and re-read it again after I got better educated on the analysis.

MR. SANCAKTAR: But we were very polite and responsive.

MEMBER STETKAR: But you didn't have any comments from any stakeholders --

MR. SANCAKTAR: Except Bechtel who, there were two questions, Case and Bechtel. There were other questions that were really internal, and they were addressed.

So the Bechtel question was really posed in a lot of detail. But in reality all it said was there are a lot of uncertainties, yes, and then it kind of said, well these are kind of conservative, which, and then Peter wrote a pretty detailed response for that. Other than that there was nothing else.

CHAIR SHACK: Any comments from the gallery?

MEMBER BLEY: As comments go, I would like to really thank you for a presentation that helped me a lot, very professional and honest responses to us officially, and very interesting.

MR. SANCAKTAR: I think this draws a line in the sand. The question is, what other lines can be

drawn and what's the conflict level, in general? But I think what Peter did was scientifically very honest, and he explained it well, I think.

And it is really pretty much at a state-of-the-art level. There is no hocus-pocus in it. He didn't try to make, cop out certain things or, you know, introduce artificial ways to create things.

And so we are drawing a line. If people are not satisfied with it, there's always a cop out, you multiply something with a safety factor of 1.2, 1.5, 2, et cetera.

But speaking from a scientific point of view, I think this is a pretty good work and probably, in time, it will become more and more sophisticated. Around ten years from now I'm sure there will be a lot more added to it in various ways.

(Off the record comment)

MR. SIMIU: Also it's unfortunate that --

MEMBER STETKAR: My only concern is that in ten years we don't have the perfect storm, and suddenly find out that there's some fundamental errors in the assumptions, or we didn't handle the uncertainties correctly or things like that.

MEMBER BLEY: There is nothing we do that doesn't have that possible.

MEMBER STETKAR: That's absolutely true -- well, except for people going back and saying what we should have learned from the data we had available.

MEMBER BLEY: But it seems they've done a pretty good job of learning from that, near as I can tell.

CHAIR SHACK: Yes, I mean, I think the biggest assumptions you have is that, you know, the process is going to remain stationary, it's not going to change in time. You know, we've got the historical database, I think we've worked that, as far as I can tell, as rigorously as we can.

You know, there's that assumption in there that, that's still going to be valid in the future, but I don't know that there's a whole lot you can do about that at the moment.

MEMBER BROWN: One observation is that the numbers, previously you were using the tornado standards, and the numbers now are bigger than the tornado standards in some circumstances so it's become more --

CHAIR SHACK: Conservative.

MEMBER BROWN: -- conservative relative to how the new plants should apply those.

MEMBER BLEY: Except the reason this

happened is because we changed the scaling on the tornados, and that makes all the tornado events look lower than they looked before.

MEMBER BLEY: I understand that but I --

MEMBER BROWN: So actually we're relaxing it a bit.

MEMBER BLEY: Well, but you're boosting it back up --

MEMBER BROWN: No.

MEMBER BLEY: -- the tornados were relaxed, and now you've boosted it back up.

MEMBER BROWN: -- down here, and we're catching at this point, instead of down here.

MEMBER BLEY: All right, I understand we're going --

(Simultaneous speaking)

MEMBER BROWN: One other observation from an uneducated, since I don't have all the statistical stuff that you guys do is that, you take this information, you come up with impacts and energies and then those have other factors applied to them by the designers.

MEMBER BLEY: Oh, yes.

MEMBER BROWN: So that the margin of error it's like, when you look at standards for bridges, you

know, all of a sudden you start looking at them, gee they've multiplied everything by two by the time they finish the struts and the other things that they've got to do to make sure the bridges hold up.

So I was comfortable with it, and I don't have the expertise that anybody else does, it just sounded like, technically it sounded like a reasonable story.

And it was definitely not a relaxation, relaxation, relaxation of anything, because the numbers were fairly large, for a reason, based on, you know, best data we have.

CHAIR SHACK: Yes, as I said, I think it's a --

MEMBER BROWN: And if John would have told me before when I'd been accused of wanting being too deterministic, how can you not, risk-informed approach well, gee Barney, you didn't protect for meteorites hitting the plant.

MR. SANCAKTAR: No, no -

MEMBER BROWN: I'm just, don't beat me up right now. Just wait until later.

(Laughter)

MEMBER STETKAR: The frequency of a 10^{-7} 220 mile an hour three-second peak gust wind speed you

need is smaller than the frequency of a one-meter meteorite hitting a 1-acre spot and being distributed around the United States. It's --

(Simultaneous speaking)

(Laughter)

MEMBER BROWN: I would be overwhelmed rapidly here, with my qualitative subjective thought processes.

CHAIR SHACK: Well if there are no further questions or comments, I think we'll adjourn.

MEMBER STETKAR: And I don't think we need to bring this to the full committee --

CHAIR SHACK: Close the record.

(Whereupon, the meeting in the above-entitled matter was concluded at 4:38 p.m.)

Regulatory Guide 1.221 "Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants"

August 18, 2011

A Presentation to Advisory Committee on Reactor Safeguards Regulatory Policies & Practices Subcommittee

Presentation Outline

- Regulatory Basis. History of Extreme Wind Regulatory Guidance

  Brad Harvey, NRO
- Regulatory Guide 1.221

  Selim Sancaktar, RES
- NUREG/CR-7005 Hurricane Wind Speeds

  Peter Vickery, ARA
- NUREG/CR-7004 Hurricane Missiles

  Emil Simiu, NIST
- Public Comments on Regulatory Guide

  Selim Sancaktar, RES

Regulatory Basis and the History of Extreme Wind Regulatory Guidance

Brad Harvey
NRC Office of New Reactors

Presentation Outline

- Regulatory Basis
- History of Extreme Wind Regulatory Guidance
  - Design Basis Wind Load Criteria
  - History of Design Basis Tornado Wind Speeds
    - RG 1.76 (WASH-1300)
    - Staff Interim Position (NUREG/CR-4461)
    - SECY 93-087 (NUREG/CR-4461)
    - SECY 04-0200
    - DG-1143 (NUREG/CR-4461, Rev. 1)
    - RG 1.76 (NUREG/CR-4461, Rev. 2)
  - Why a New Regulatory Guide on Hurricanes

Regulatory Basis

- Appendix A to 10 CFR Part 50
  - GDC 2: *Design bases for protection against natural phenomena*
    - SSCs important to safety shall be designed to withstand the effects of natural phenomena such as … tornadoes, hurricanes … without loss of capability to perform their safety functions.
    - The design bases for these SSCs shall reflect appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated …

Regulatory Basis

- Subpart B to 10 CFR Part 100
  - 10 CFR 100.20(c)(2)
    - Meteorological characteristics of the site that are necessary for safety analysis or that may have an impact upon plant design (such as maximum probable wind speed and precipitation) must be identified and characterized.

Design Basis Wind Load Criteria

Type of Load	Site Parameter/ Characteristic	Exceedance Frequency	ACI 349-97 Load Combinations and Factors
A severe environmental load that could infrequently be encountered during the plant life	Operating Basis Wind	10^{-2} per year	$U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7W + 1.7R_o$
An extreme environmental load that is credible but highly improbable	Design Basis Tornado	10^{-7} per year	$U = D + F + L + H + To + R_o + W_t$

Combined Tornado Load Effects

$$W_t = W_p$$

$$W_t = W_w + 0.5W_p + W_m$$

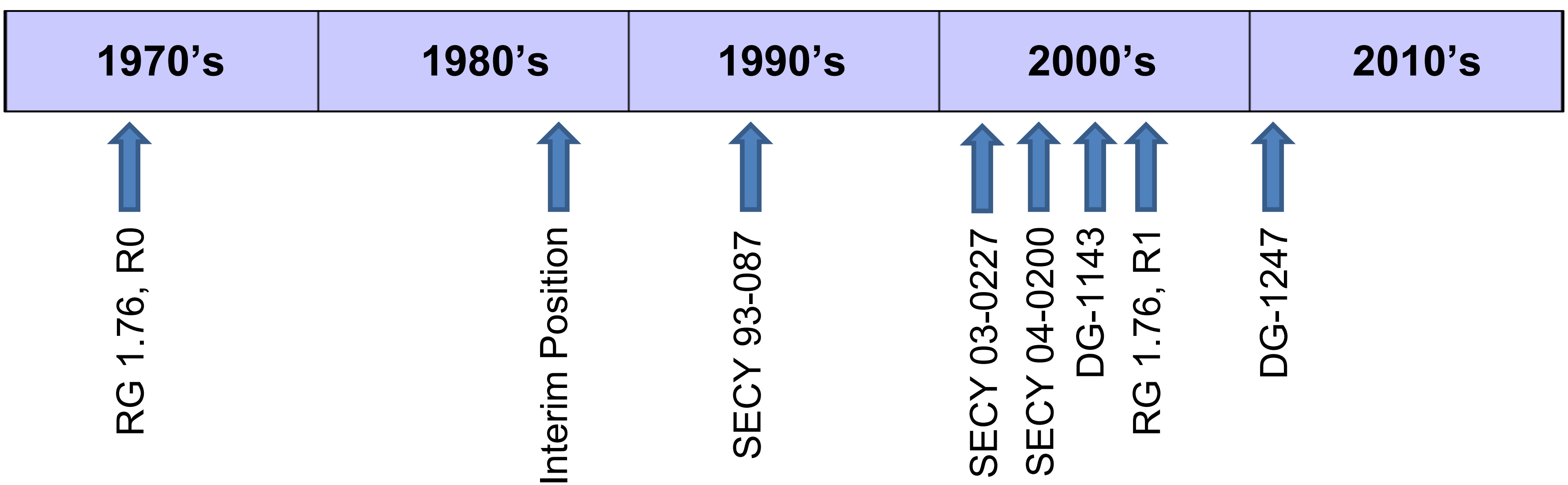
W_t = total tornado load

W_w = load from tornado wind effect

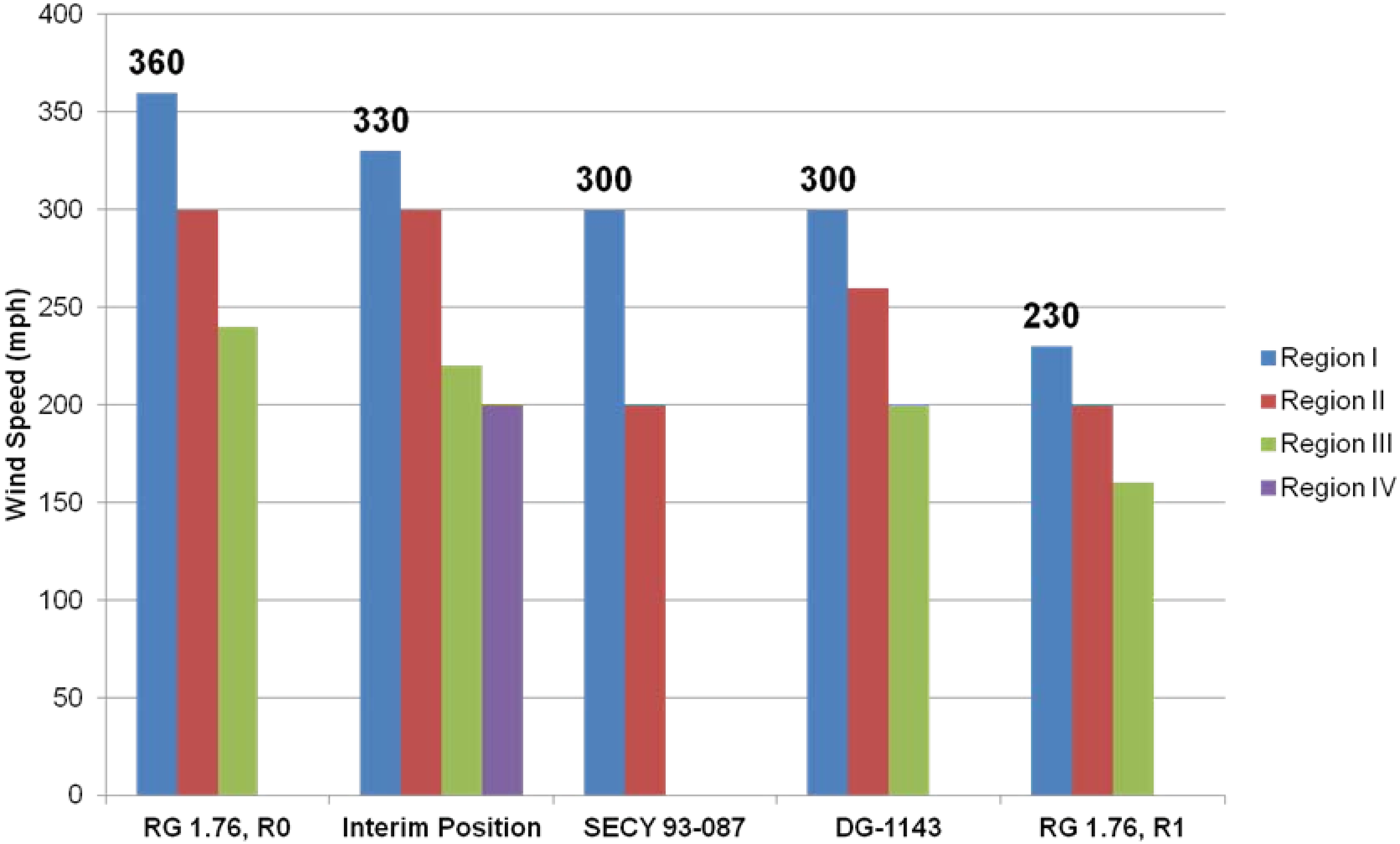
W_p = load from tornado atmospheric pressure change effect

W_m = load from tornado missile impact effect

History of Extreme Wind Regulatory Guidance



History of Design Basis Tornado Wind Speeds



Tornado Model

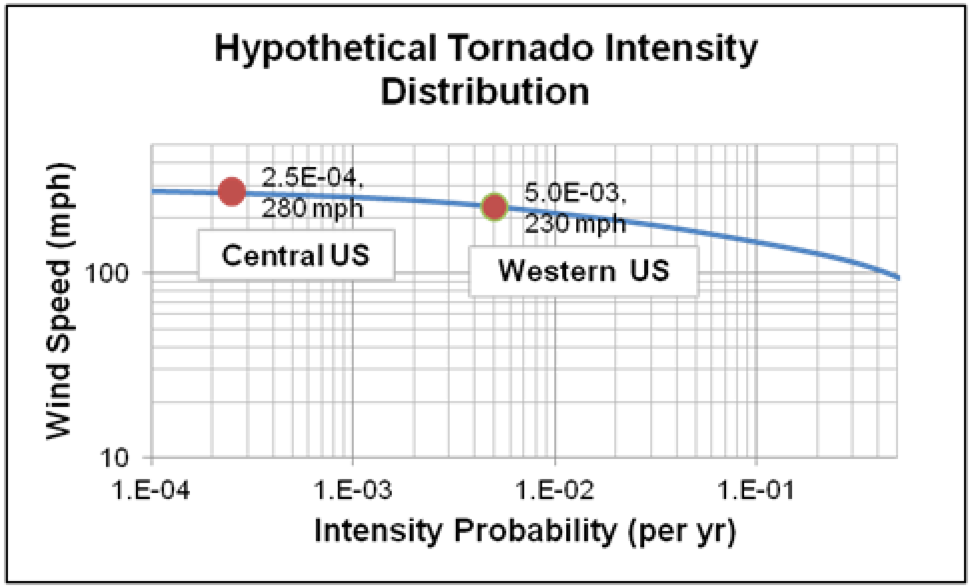
$$P(u \geq u_o) = P \times P(u \geq u_o \,|s) = 10^{-7}\,/yr$$

$$P = A_t/(N\,A_r); \quad P(u \geq u_o \,|s) = A_{u \geq u_o}/A_t$$

$P(u \geq u_o)$	is the probability of the wind speed, u, exceeding some value u_o
P	is the probability (per year) that a tornado will strike a particular location
$P(u \geq u_o \,\|s)$	is the conditional probability that the wind speed u will exceed u_o, assuming that a tornado strike, s, occurs
A_t	is the total area impacted by tornadoes in the region of interest, A_r
N	is the number of years of tornado records
$A_{u \geq u_o}$	is the total area impacted by wind speeds greater than u_o

Tornado Model

$$P(u \geq u_o) = P \times P(u \geq u_o | s) = 10^{-7} /yr$$



Location	Strike Probability P	Conditional Probability $P(u \geq u_0 / s)$	Wind Speed u_0
Central US	4.0×10^{-4} per yr	2.5×10^{-4} per yr	280 mph
Western US	0.2×10^{-4} per yr	50×10^{-4} per yr	230 mph

Pressure Drop and Rate of Pressure Drop

- The pressure drop Δp within the tornado is a function of the tornado maximum rotational speed V_{rm}

$$\Delta p = \rho V_{rm}$$

- The rate of the pressure drop dp/dt is a function of the pressure drop Δp, the radius of the tornado R_m, and the tornado's translational speed V_t

$$(dp/dt) = \left({V_T}/{R_m} \right) \Delta p$$

  - The radius of the tornado (where the maximum rotational speed occurs) is assumed to be 150 ft
  - The translational speed is assumed to be 1/5th of the tornado's maximum speed

F-Scale for Tornado Damage

F Number	Wind Speed (mph) Fastest ¼ Mile	Potential Damage
0	40-72	
1	73-112	
2	113-157	
3	158-207	
4	208-260	
5	261-318	

(a) Wind speed estimates based on observed damage

RG 1.76, Revision 0
(April 1974)

- *Design Basis Tornado for Nuclear Power Plants*
  - WASH-1300, *Technical Basis for Interim Regional Tornado Criteria (May 1974)*
    - Probability of occurrence of a tornado that exceeds the DBT should be 10^{-7} per year
    - 13 yrs of regional tornado frequency data
    - 2 yrs of tornado intensity data
      - Fujita tornado scale (F-Scale)
  - Maximum wind speed: 360 mph

RG 1.76, Revision 0

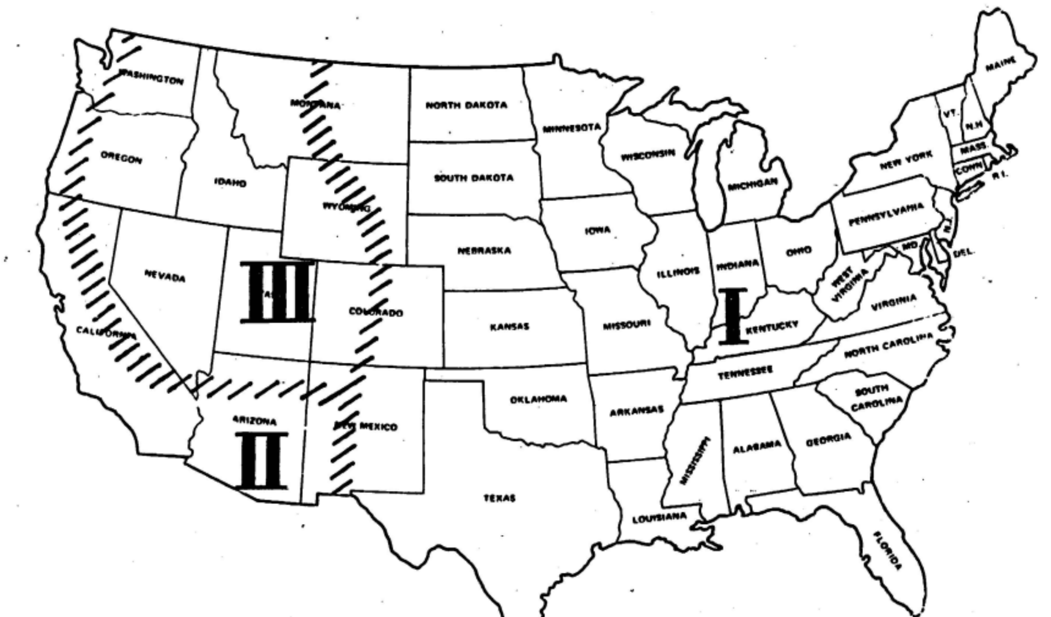


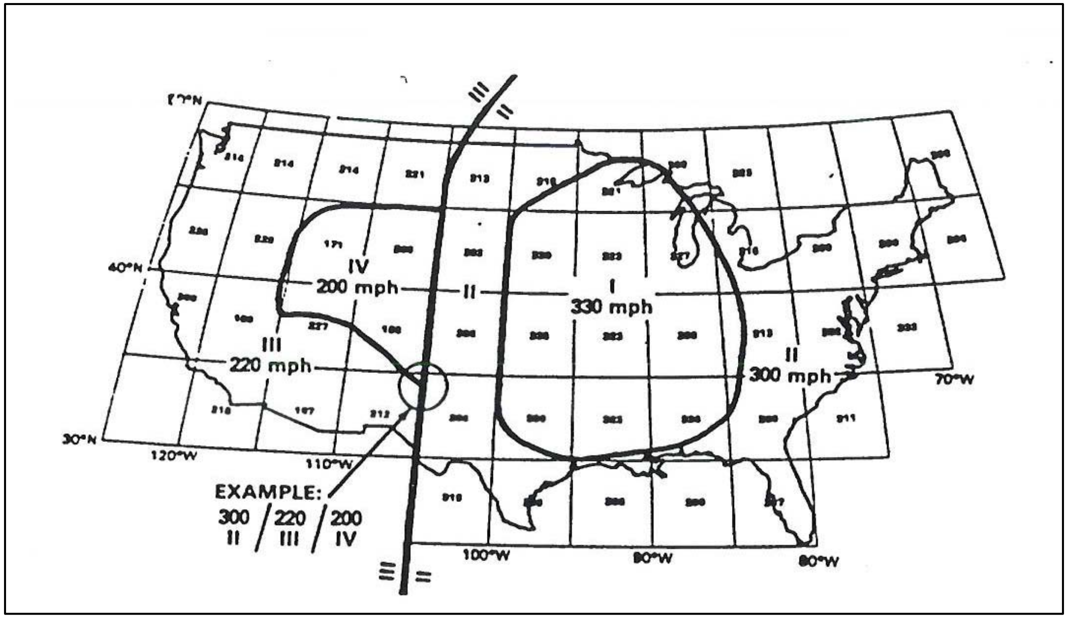
Figure 1. TORNADO INTENSITY REGIONS

Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	360	3.0	2.0
II	300	2.25	1.2
III	240	1.5	0.6

Staff Interim Position
(March 1988)

- LS Rubenstein (NRC) letter to EE Kinter (ALWP Utility Steering Committee*), ALWR Design Basis Tornado*
  - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States* (May 1986)
    - 10^{-7} per year probability of occurrence at the upper 90% confidence level
    - 30 yrs of tornado frequency and intensity data
      - Fujita tornado scale (F-Scale)
  - Maximum wind speed: 330 mph

Staff Interim Position



Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	330	2.4	1.7
II	300	2.0	1.2
III	220	1.0	0.5
IV	200	0.9	0.3

SECY 93-087

(April 1993)

- *Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced LWR Designs*
  - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States* (May 1986)
    - Wind speed values associated with tornado having a mean recurrence interval of 10^{-7} per year
  - Maximum wind speed: 300 mph

SECY 03-0227

(December 2003)

- *Processing Applications for Early Site Permits*
  - RS-002 guidance for selecting site-specific tornado parameters
    - RG 1.76 (360 mph east of the Rocky Mts)
    - Staff interim position (330 mph east of the Rocky Mts)
    - Site-specific analysis
  - RS-002 siting guidance conflicted with SECY 93-087 certified standard reactor design guidance
    - 300 mph
  - Commission Directive
    1. Update guidance (e.g., RG 1.76) to reflect more recent tornado wind speed data
    2. Develop options in applying a risk-informed approach for selecting the design basis tornado

SECY 04-0200
(October 2004)

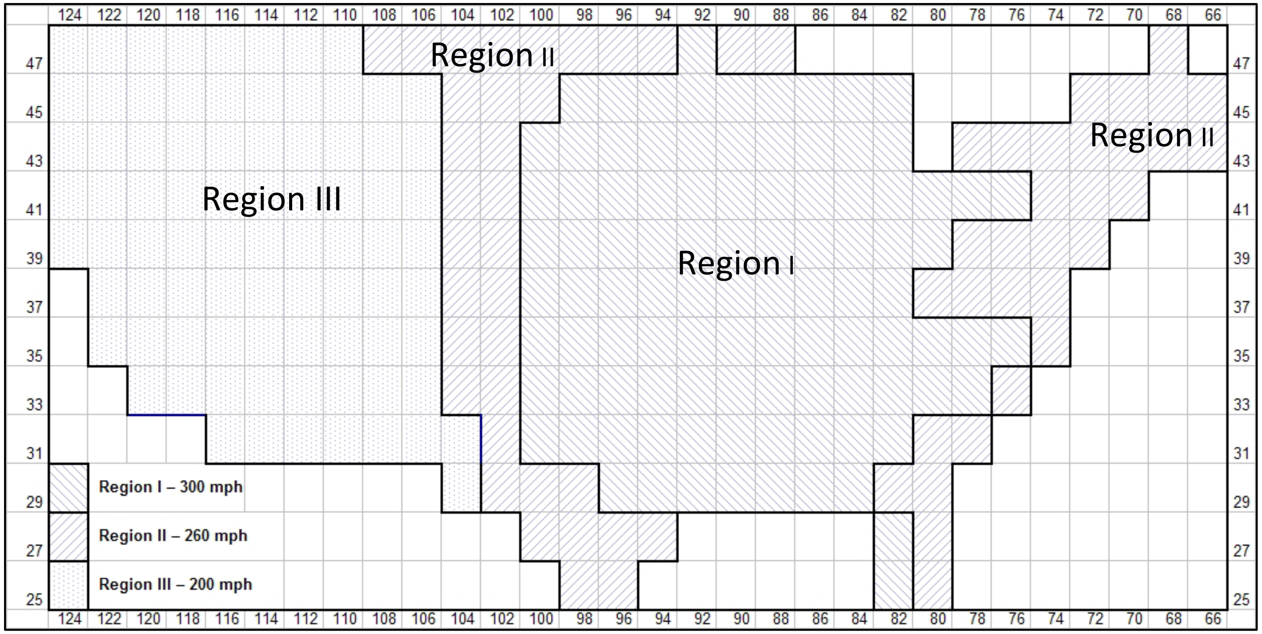
- *A Risk-Informed Approach to Defining the Design Basis Tornado for New Reactor Licensing*
  - Staff Suggested 3 Options
    1. Maintain SECY 93-087 definition a design basis tornado having a <u>mean frequency</u> of 10^{-7} per year
    2. Develop a risk-informed approach that would permit using a less conservative design basis tornado
    3. Relax the definition of the design basis tornado (e.g., initiating frequency ≈10^{-6} per year)
  - Commission Directive
    - Approved Option 1
    - Proceed with updating NUREG/CR-4461

DG-1143 (draft R1 to RG 1.76)

(January 2006)

- *Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants*
  - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States,* Rev. 1 (Apr 2005)
    - Wind speed values associated with tornado having a mean recurrence interval of 10^{-7} per year
    - 53 yrs of tornado frequency and intensity data
      - Fujita tornado scale (F-Scale)
    - Finite dimensions of structures ⇨
    - Variation of wind speeds within the tornado path ⇨
  - Maximum wind speed: 300 mph

DG-1143 (draft R1 to RG 1.76)



Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	300	2.0	1.2
II	260	1.5	0.8
III	200	0.9	0.4

DG-1143 (draft R1 to RG 1.76)

Design Basis Missile Spectrum

Missile Type		Pipe	Auto	Sphere
Dimensions		6.6 in dia x 15 ft long	16.4 ft x 6.6 ft x 4.3 ft	1 inch dia
Mass		287 lb	4000 lb	0.147 lb
Horizontal Velocity	Region I	105 mph	116 mph	92 mph
	Region II	85 mph	101 mph	47 mph
	Region III	18 mph	76 mph	16 mph

Vertical velocity is equal to 67% of the horizontal velocity

F-Scale vs. EF-Scale for Tornado Damage

FUJITA SCALE (F-Scale)			ENHANCED FUJITA SCALE (EF-Scale)	
F Number	Fastest ¼ Mile[a] (mph)	3 Sec Gust[a] (mph)	EF Number	3 Sec Gust[a] (mph)
0	40-72	45-78	0	65-85
1	73-112	79-117	1	86-110
2	113-157	118-161	2	111-135
3	158-207	162-209	3	136-165
4	208-260	210-261	4	166-200
5	261-318	262-317	5	Over 200

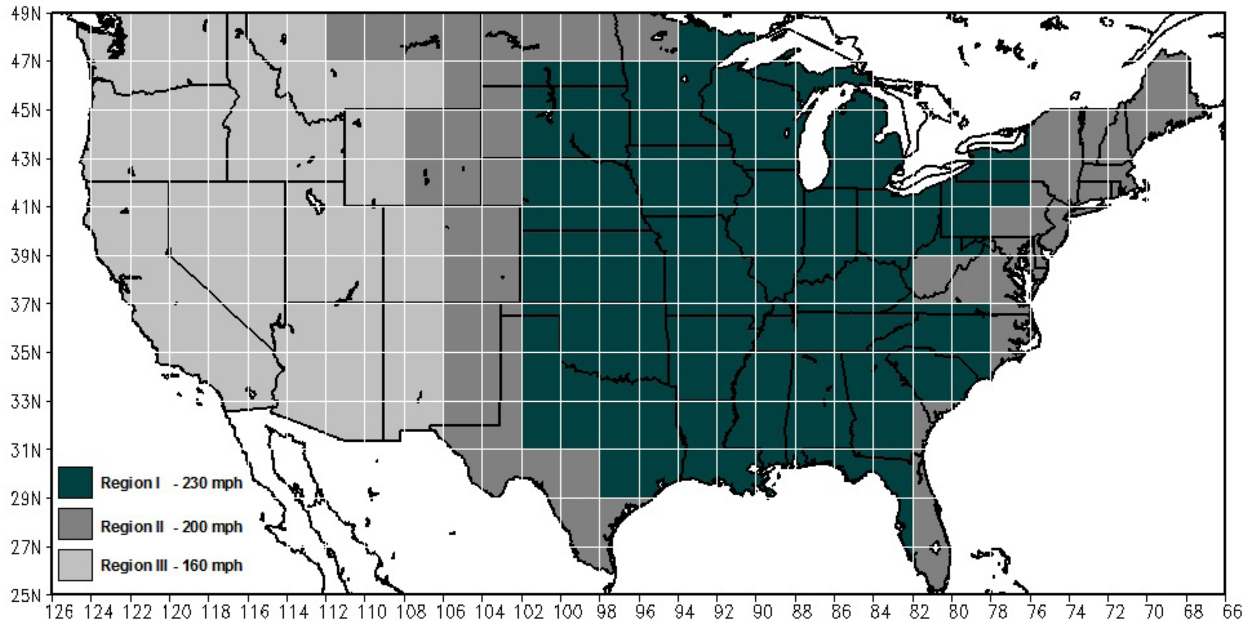
[a] Wind speed estimates based on observed damage

Revision 1 to RG 1.76

(March 2007)

- *Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants*
  - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States,* Rev. 2 (Feb 2007)
    - Wind speed values associated with tornado having a mean recurrence interval of 10^{-7} per year
    - 53 yrs of tornado frequency and intensity data
      - Enhanced F-scale
    - Finite dimensions of structures
    - Variation of wind speeds within the tornado path
  - Maximum wind speed: 230 mph

Revision 1 to RG 1.76



Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	230	1.2	0.5
II	200	0.9	0.4
III	160	0.6	0.2

Revision 1 to RG 1.76

Design Basis Missile Spectrum

Missile Type		Pipe	Auto	Sphere
Dimensions		6.6 in dia x 15 ft long	Region I & II 16.4 ft x 6.6 ft x 4.3 ft Region III 14.9 ft x 5.6 ft x 4.9 ft	1 inch dia
Mass		287 lb	Region I & II 4000 lb Region III 2595 lb	0.147 lb
Horizontal Velocity	Region I	92 mph	92 mph	18 mph
	Region II	76 mph	76 mph	16 mph
	Region III	54 mph	54 mph	13 mph

Vertical velocity is equal to 67% of the horizontal velocity
Height of auto is limited to 30 ft above the highest ground elevation within 0.5 mi

Why a New RG on Hurricanes?

- Public Comment on DG-1143:
  - The use of the EF scale would tend to place a greater emphasis on hurricane wind loads. At a very low probability of exceedance rate of 10^{-7} per year, hurricane wind speeds in the Atlantic and Gulf regions would approach or exceed tornado wind speeds.

Discussion/Committee Questions

Regulatory Guide 1.221

Dr. Selim Sancaktar

NRC Office of Nuclear Regulatory Research

NRO User Need

- Regulatory Guide (RG) 1.221 is prepared in response to the NRO User Need Request (NRO-2007-003) for Design-Basis Hurricane Wind Speeds for new NPPs

- This RG is intended to supplement the existing Regulatory Guide 1.76 revision 1.

Background for the Hurricane RG User Need

- Recent work on tornadoes has led to the acceptance by the National Weather Service (NWS) of the Enhanced Fujita (EF) scale. Both the Enhanced Fujita scale and the original Fujita (F) scale assign wind speed ranges to degrees of damage caused by the tornado.
- The wind speed ranges assigned to a given degree of damage are lower for the Enhanced Fujita scale than for the original Fujita scale, since it was found that lower wind speeds could cause a given amount of structural damage than was thought when the Fujita scale was originally constructed. As a consequence, the NPP design-basis tornado wind speed, defined as the wind speed with a 1E-7 per year exceedance frequency, has been lowered.
- Based on the EF-Scale, the maximum design-basis tornado wind speed for any location in the United States is 230 mph.
- Based on the original F-Scale, the maximum design-basis tornado wind speed is 300 mph.
- The design basis tornado wind speeds given in Regulatory Guide 1.76, rev. 1 are based on the EF-Scale.

Background for the Hurricane RG User Need

- As a result of lowering the maximum design-basis tornado wind speed from 300 mph to 230 mph, the 1E-7 per year design-basis tornado wind speed may no longer bound the 1E-7 per year design-basis hurricane wind speed for plants situated along the Gulf, Atlantic, and Pacific coasts of the United States.

- Therefore, regulatory guidance may be needed to define 1E-7 per year design-basis hurricane wind speeds for new plants located along the Gulf, Atlantic, and Pacific coasts.

Project Scope Leading to RG 1.221

- RES commissioned two NUREG/CRs to recognized experts as technical support for the REG guide 1.221. The resulting reports are:

- NUREG/CR-7005: Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants

- NUREG/CR-7004: Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants

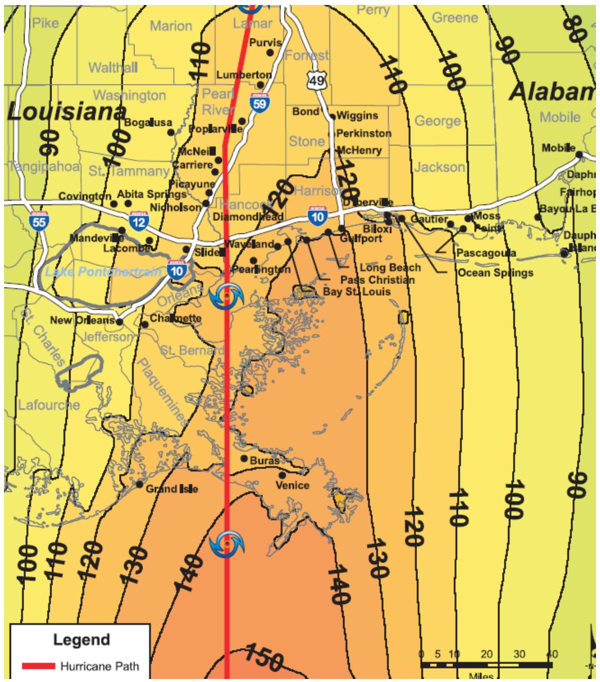
Project Scope Leading to RG 1.221

- A draft RG (DG-1247) was created and submitted for public comments, together with the NUREG/CRs.
- After the public comments are received, the three documents were finalized.
- RG1.221 is intended to complement RG 1.76 and has the same general structure as RG 1.76. The reg guide is intended for use by NRO for new plant applications.
- Draft RG, RG, the NUREG/CRs and the responses to public comments were provided to other cognizant NRC offices and their concurrences were obtained.

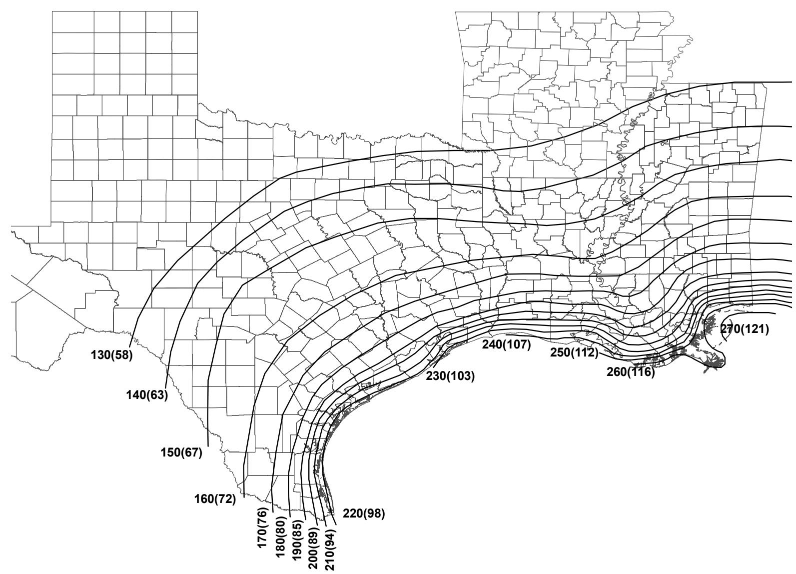
Supporting NUREG/CRs

- NUREG/CRs 7005 and 7004 are referred to as acceptable technical approaches that can be used by new reactor applicants.
- In the next part of the presentation, the two NUREG/CRs will be briefly discussed by their authors.

Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants



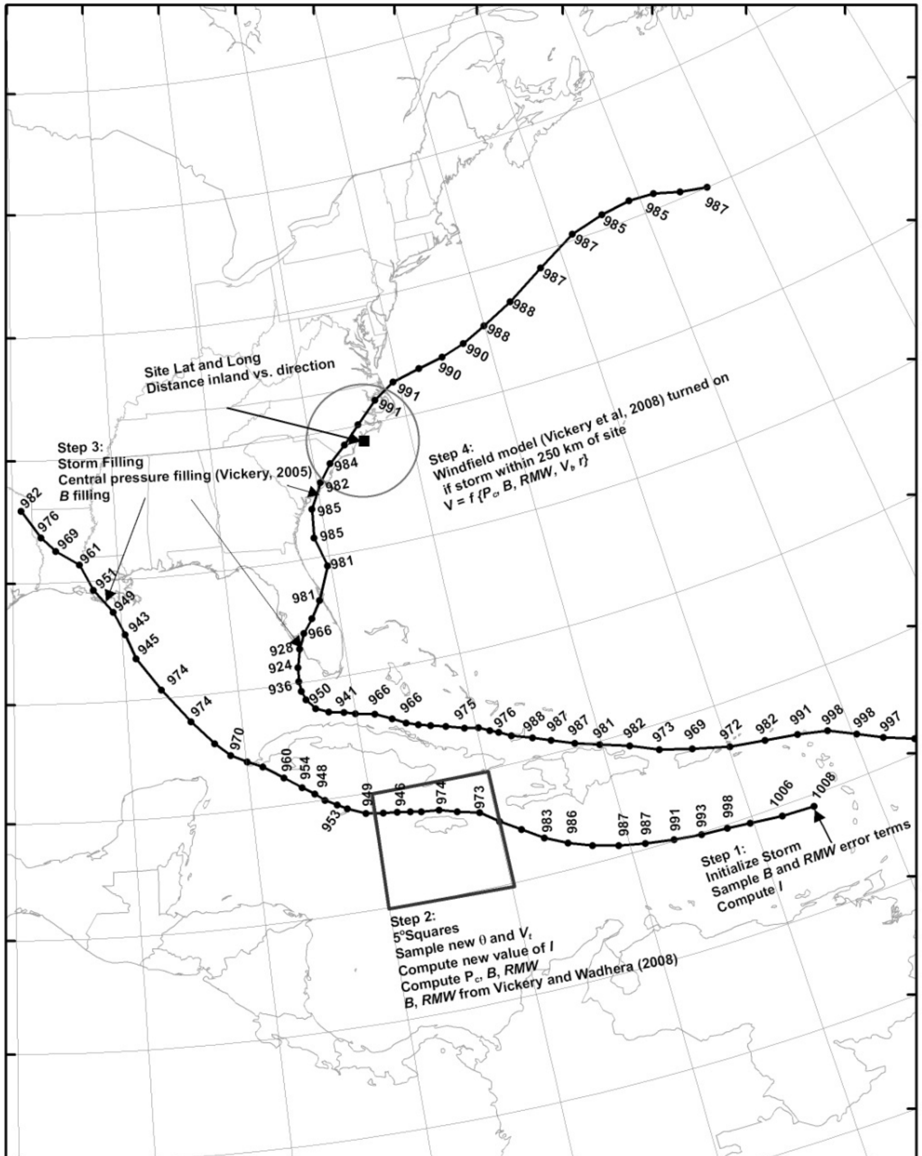
Peter J Vickery
Applied Research Associates, Inc
8537 Six Forks Rd, Suite 600
Raleigh, NC 27615



Overview

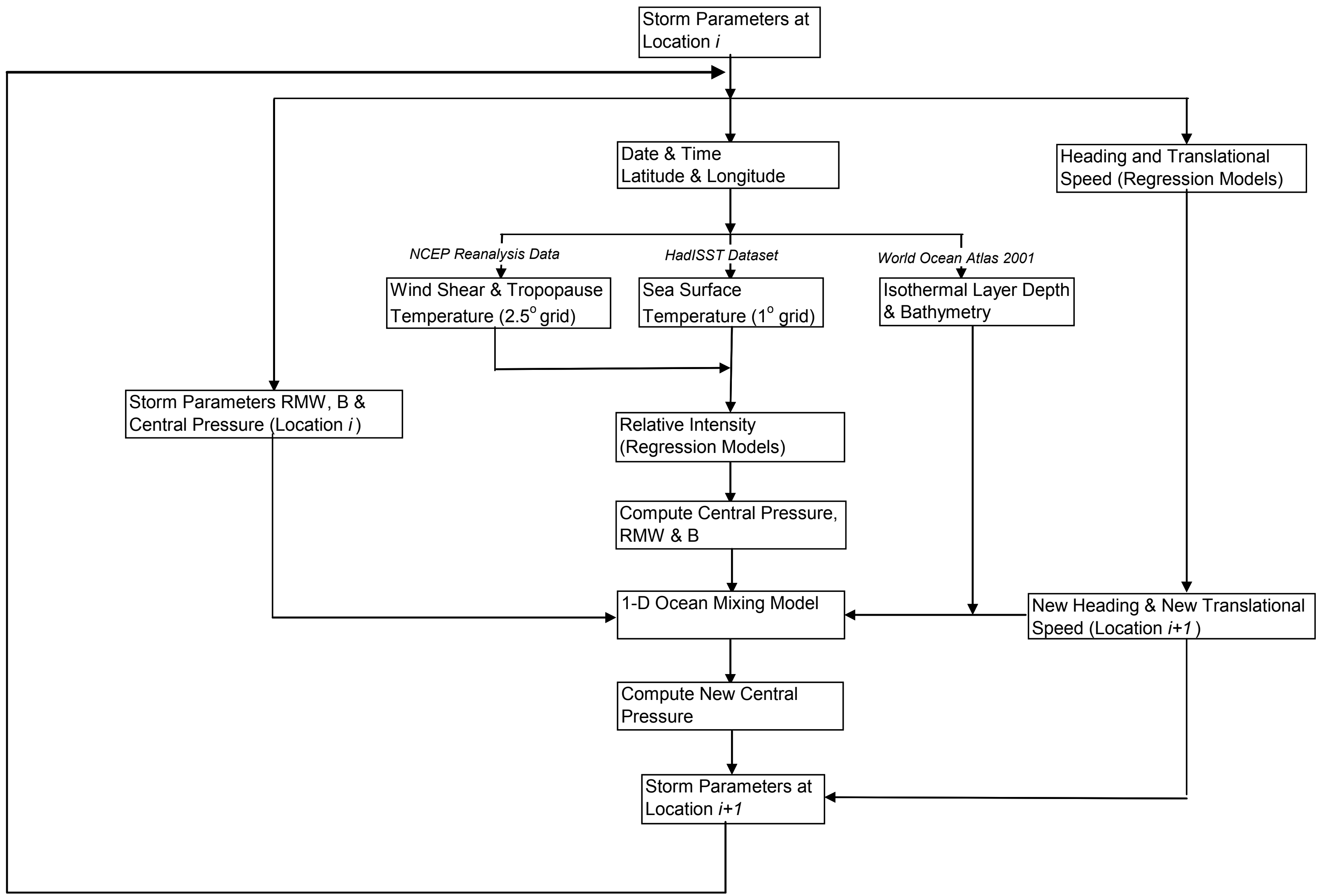
- Simulation Methodology Overview
  - B and RMW models
  - Hazard model validation
  - Model changes for 10^{-7} study
  - Wind Field Model
    - Sea surface drag coefficient
    - Hurricane boundary layer model
    - Validation examples
- 10^{-7} Study Simulation Methodology
  - Model changes
  - Wind Speed Maps
  - Summary

Simulation Approach and Flow Chart

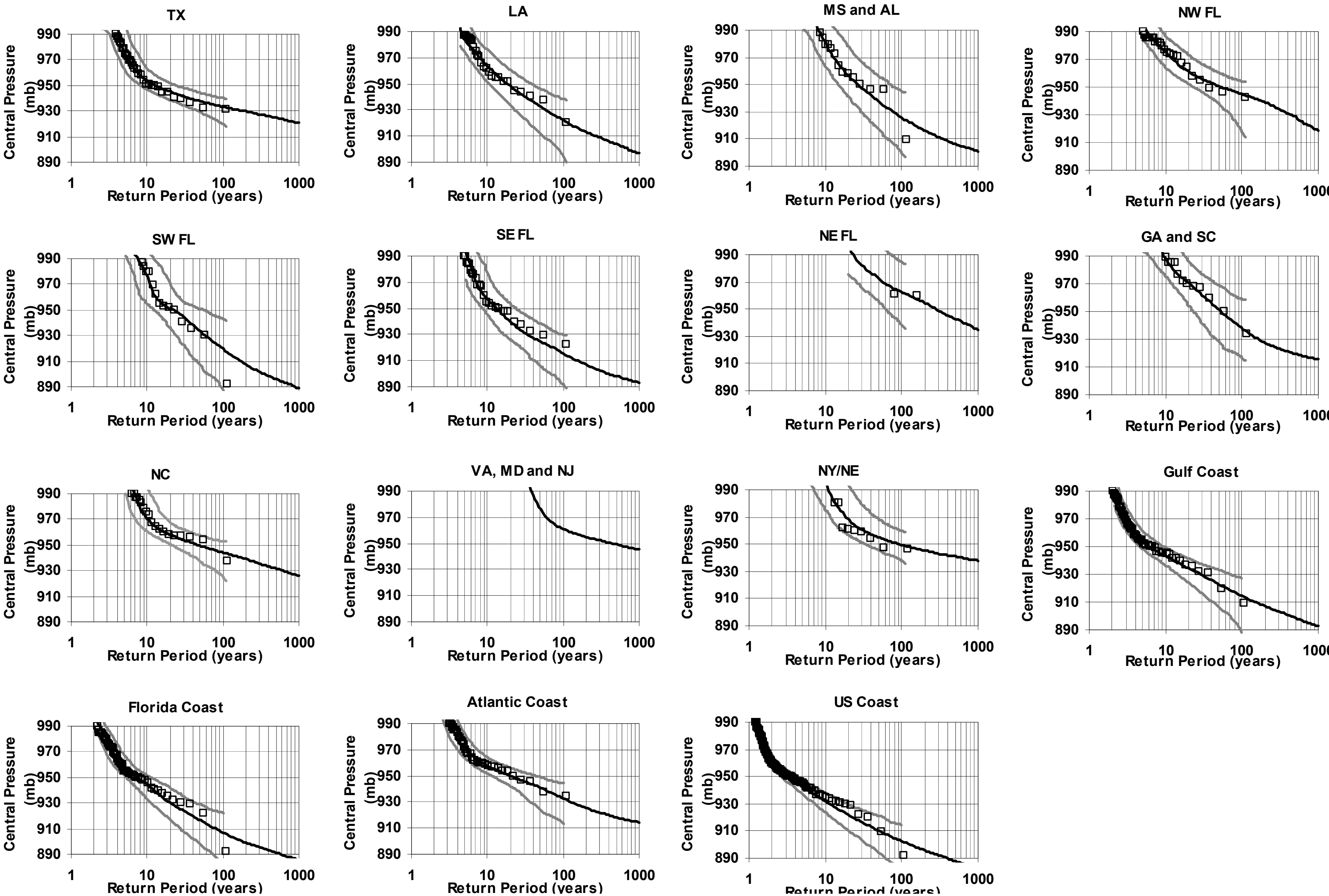


Track model uses historical data through 2007

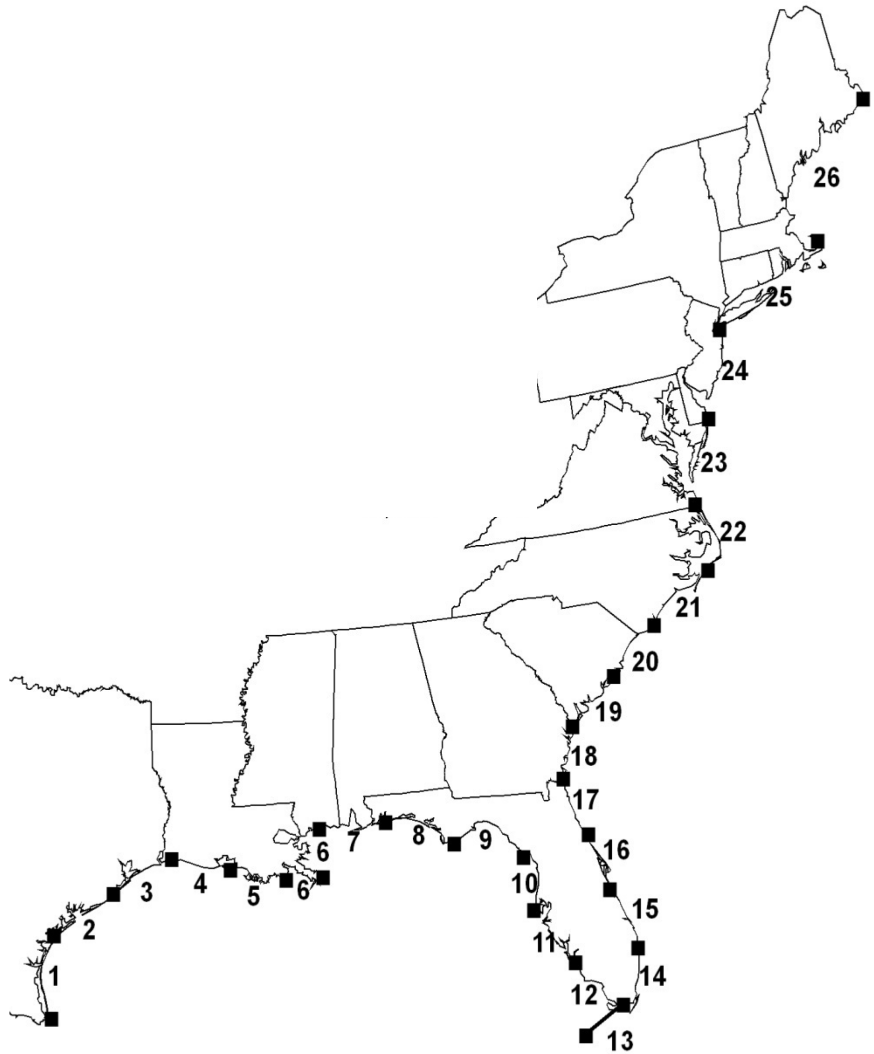
Simulation Approach and Flow Chart



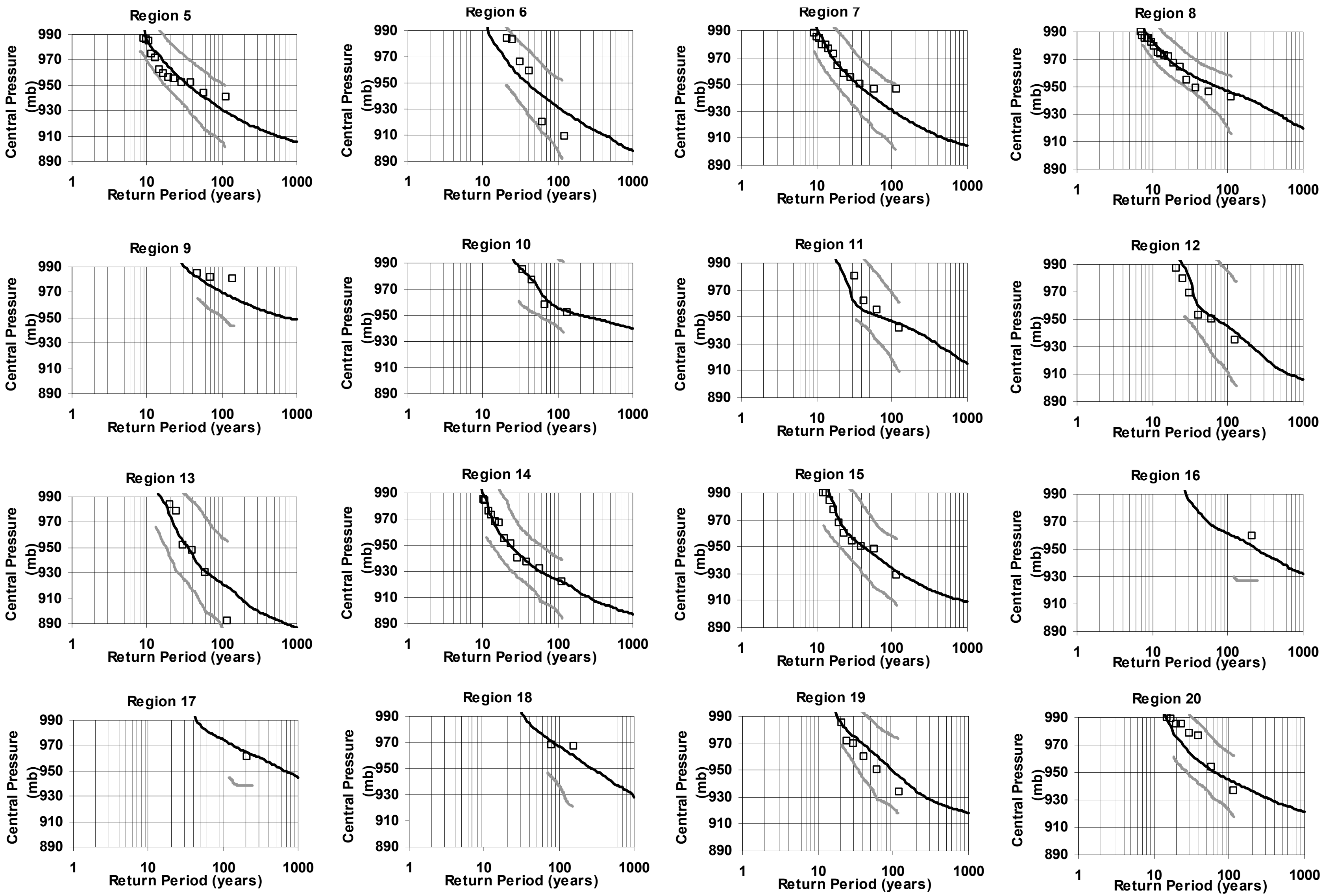
Landfall Pressures



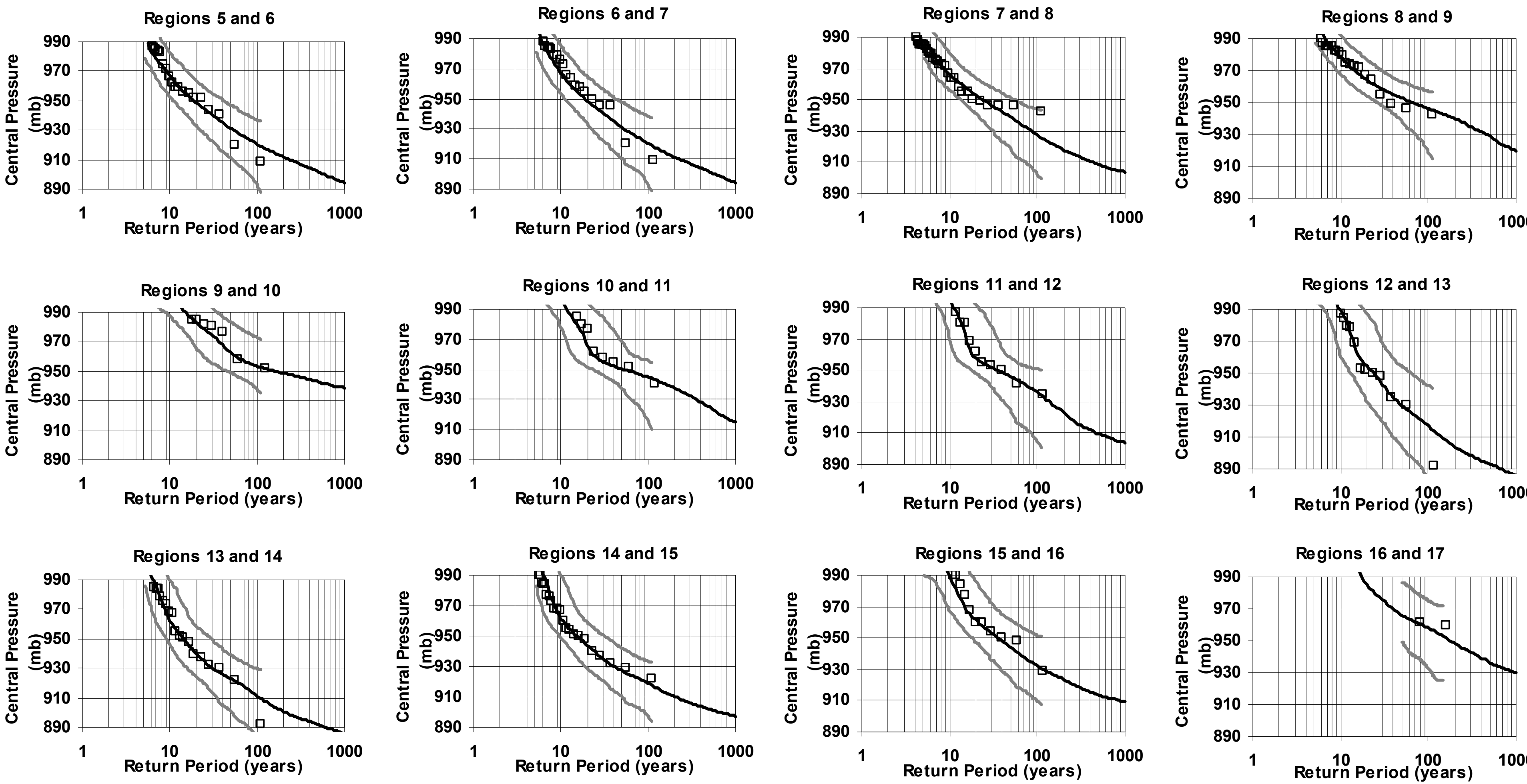
Coastal Segments



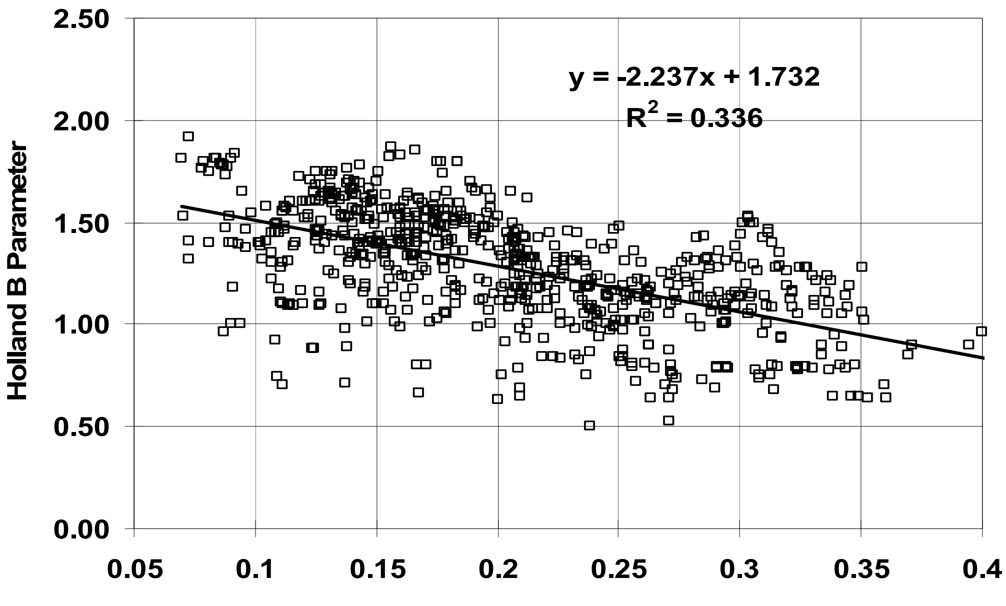
Landfall Pressures

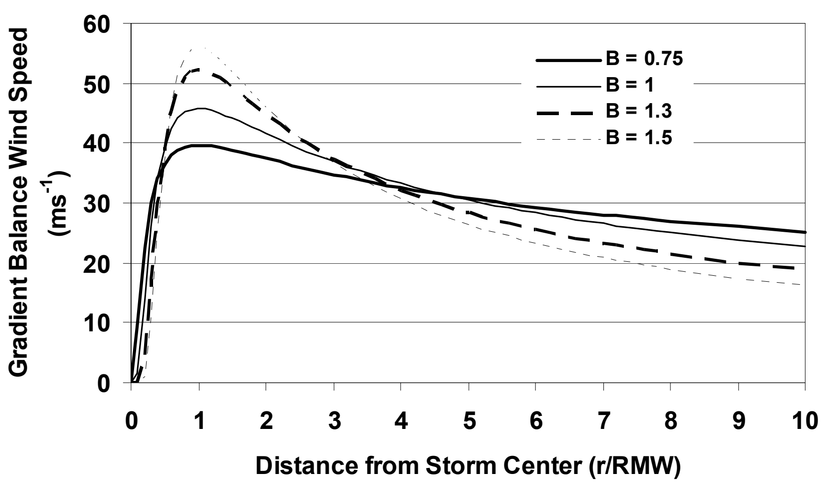


Landfall Pressures



Holland B Parameter





- B estimates derived from upper level flight data and H*Wind snapshots of hurricane wind fields.
- B modeled as a function of A where

$$A = \frac{RMW \cdot f_c}{\sqrt{2R_d T_s \cdot \ln\left(1 + \frac{\Delta p}{p_c \cdot e}\right)}}$$

R_d is the gas constant for dry air, p_c is the central pressure, T_s is the sea surface temperature (˚C), Δp is central pressure difference, RMW is radius to

maximum winds

Vickery and Wadhera (2008), "Statistical Models of Holland Pressure Profile Parameter and Radius to Maximum Winds of Hurricanes from Flight Level Pressure and H*Wind data", *Journal of Applied Meteorology and Climatology*, ***47,***

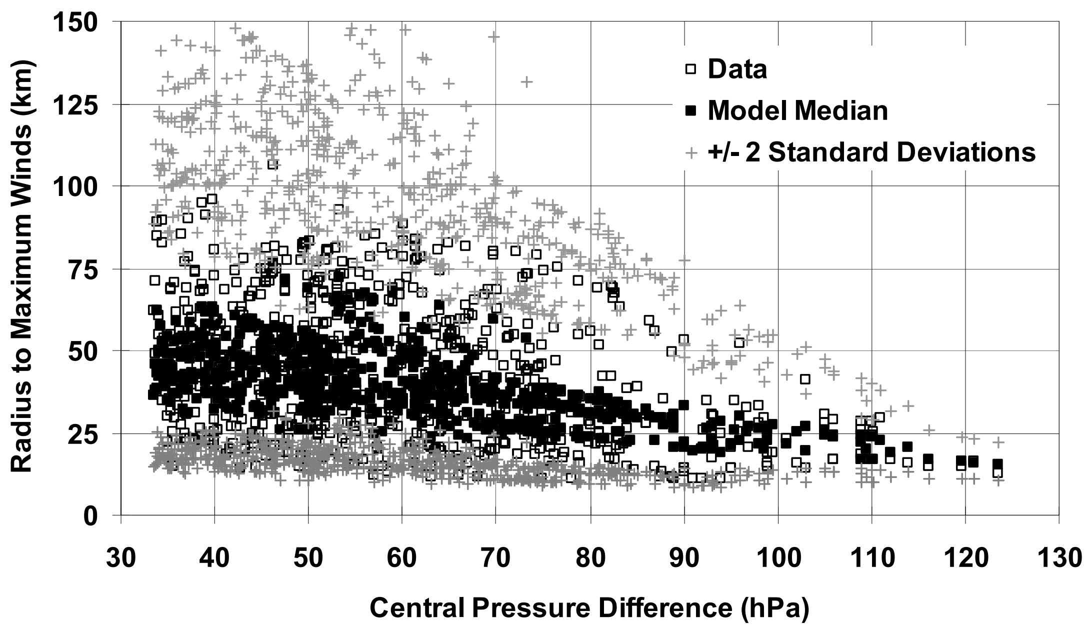
RMW Models

- Atlantic Region

$$\ln(RMW) = 3.015 - 6.291\times 10^{-5}\,\Delta p^2 + 0.0337\Psi + \varepsilon \quad r^2{=}0.297, \sigma_{\ln RMW}{=}0.441$$

Δp is central pressure difference, Ψ is the latitude and ε is the random error term. The error, $\sigma_{\ln RMW}$, is modeled in the form:

$\sigma_{\ln RMW} = 0.448$	$\Delta p \le 87$ hPa
$\sigma_{\ln RMW} = 1.137 - 0.00792\Delta p$	87 hPa $\le \Delta p \le$ 120 hPa
$\sigma_{\ln RMW} = 0.186$	$\Delta p >$120 hPa



ARA Event Model Summary

- Hazard model developed/validated using data through 2007
- Simple ocean mixing model to limit intensity
- Calibrated to match historical record for the period 1900-2007
- Statistical models for *B* and *RMW*

Wind Field Model
Equations of Motion for Model Hurricane

$$\frac{d\vec{V}_s}{dt} + f\left|\vec{k} \times \vec{V}_s\right| = -\frac{1}{\rho}\nabla p + \nabla \cdot (K_H \nabla \vec{V}_s) - \frac{C_D}{h}\left|\vec{V}_s + \vec{V}_c\right|(\vec{V}_s + \vec{V}_c)$$

u

$$\frac{\partial p}{\partial r} = \frac{\Delta p B}{r}\left(\frac{R_{\max}}{r}\right)^B \exp\left(-\left(\frac{R_{\max}}{r}\right)^B\right)$$

Drag Coefficient over the Ocean

Powell, 1980

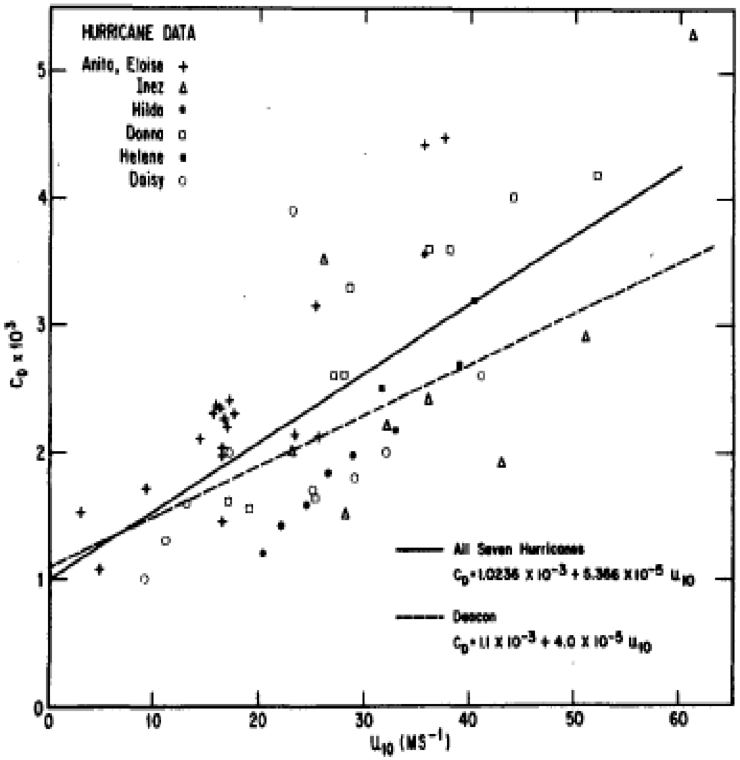
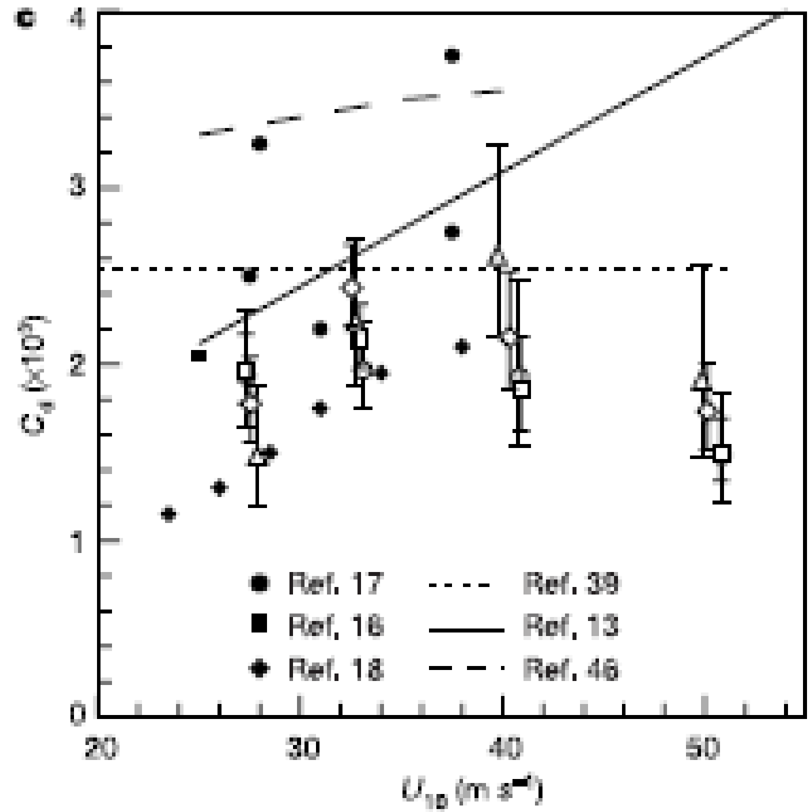


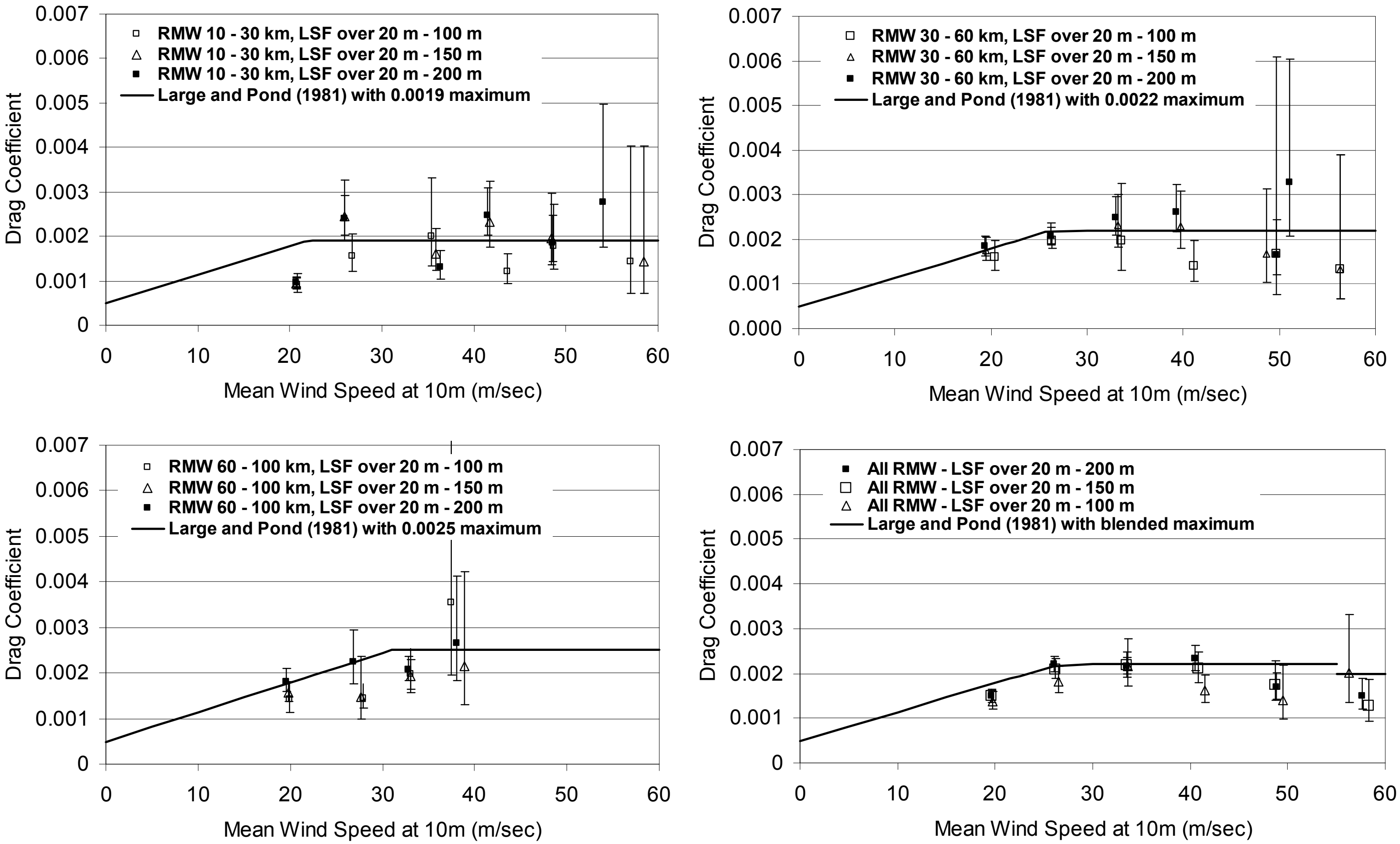
FIG. 5. Ten meter level neutral drag coefficient from several studies plotted versus wind speed.

Powell, et al, 2003

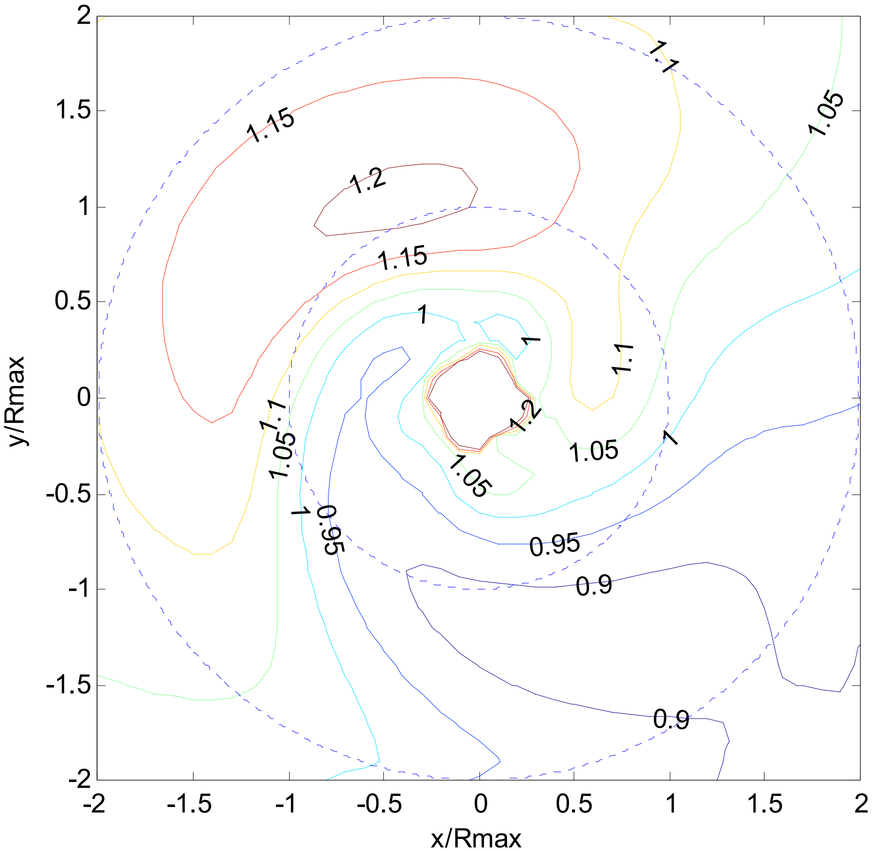


C_d (open terrain) = 0.00471

Sea Surface Drag Coefficient Model



Hurricane Jet Strength



Storm is moving towards top of page

- Jet Strength = Wind Speed at top of BL divided by gradient balance wind

$$\frac{d\vec{V}_s}{dt} + f\left|\vec{k} \times \vec{V}_s\right| = -\frac{1}{\rho}\nabla p$$

- Magnitude of jet strength similar to results from full 3D models

Hurricane Boundary Layer Model

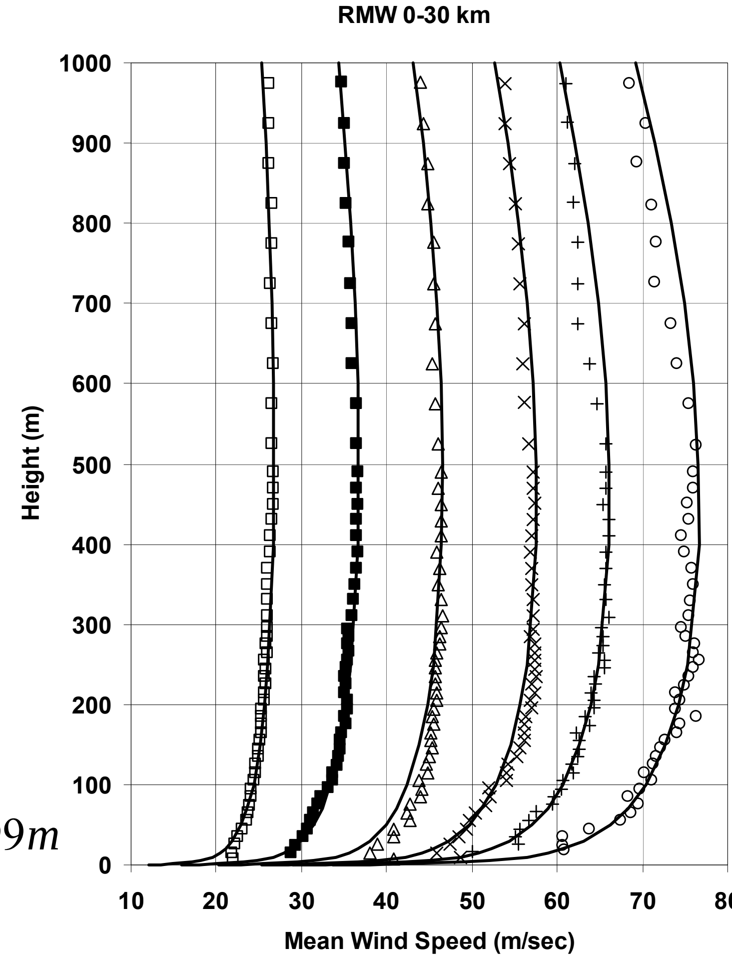
- Boundary Layer Model developed using Dropwindsonde data.

- Includes the radial variation of BL height
- Marine Boundary Layer Model given by:

$$U(z) = \frac{u_*}{k}\left[\ln\left(\frac{z}{z_o}\right) - a\left(\frac{z}{H^*}\right)^n\right]$$

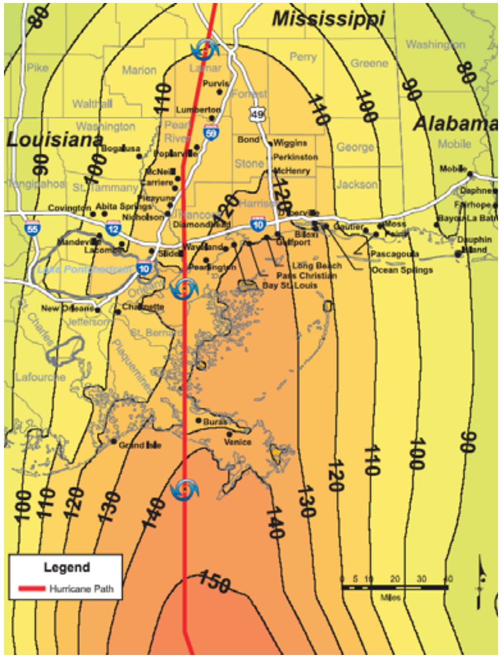
- Boundary layer Height given by:

$$H^* = 343.7 + 0.260 / I \qquad r^2 = 0.75, \quad \sigma_e = 99m$$

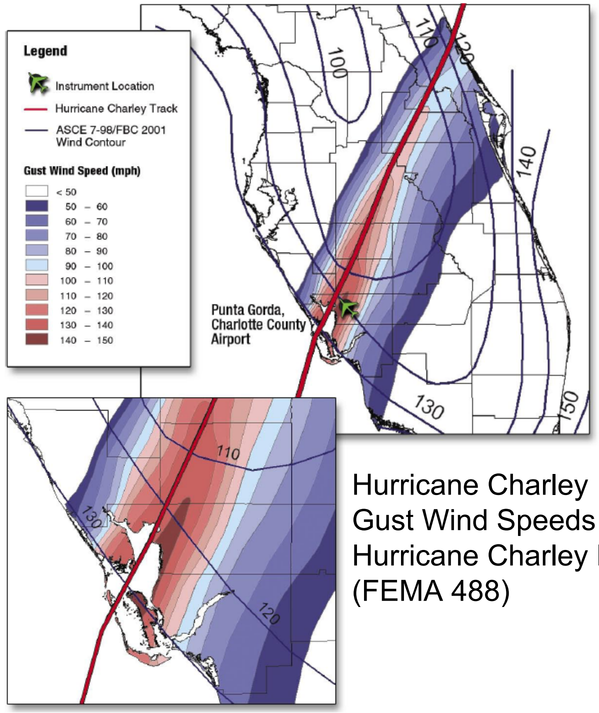


Vickery et al (2009), “A Hurricane Boundary Layer and Wind Field Model for Use in Engineering Applications”, *Journal of Applied Meteorology and Climatology, 2009,* ***48****, 381-405*

Example Wind Speed Validation Studies



Hurricane Katrina
Gust Wind Speeds
Hurricane Katrina MAT
(FEMA 549)

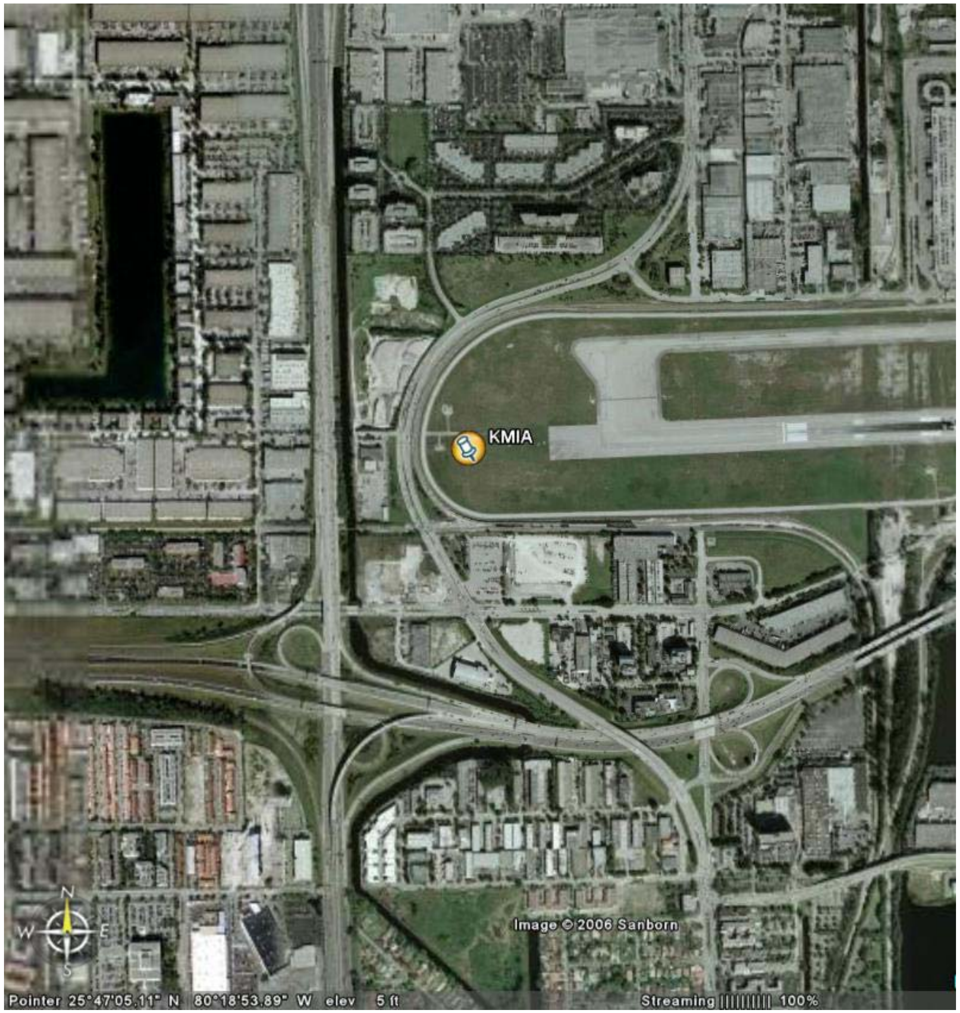


Hurricane Charley
Gust Wind Speeds
Hurricane Charley MAT
(FEMA 488)

Hurricane Ivan
One Minute Wind Speeds
Hurricane Ivan MAT
(FEMA 489)

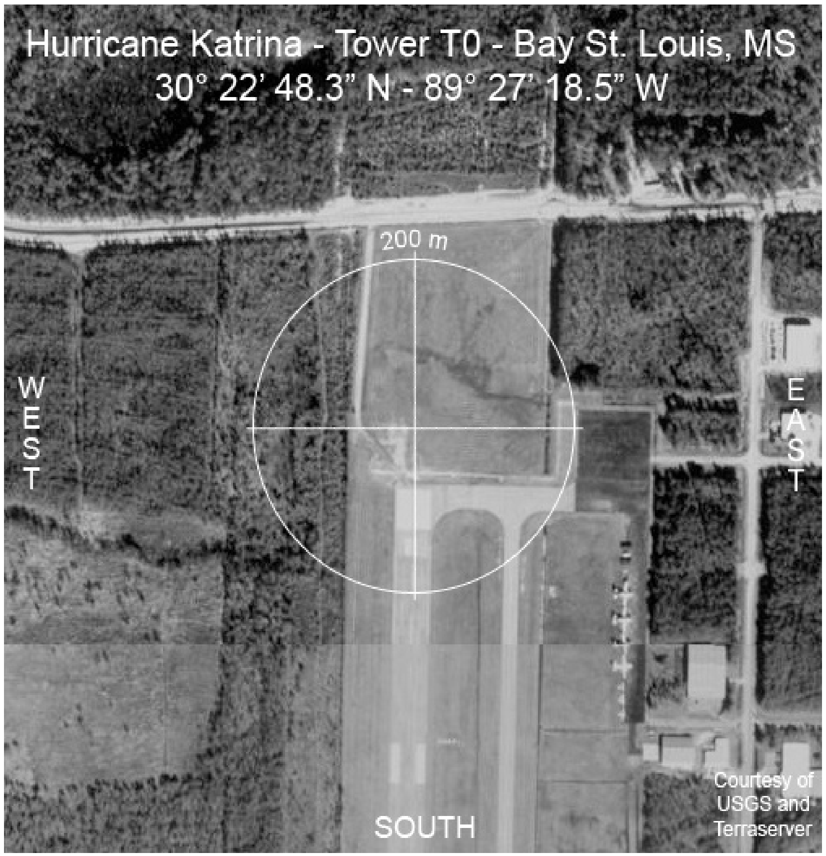
- Have produced estimates of wind speeds for most significant US land falling hurricanes since 2004 for FEMA.
- Estimates from a validated wind field modeling approach
- Katrina and Rita wind speed estimates also published by NIST

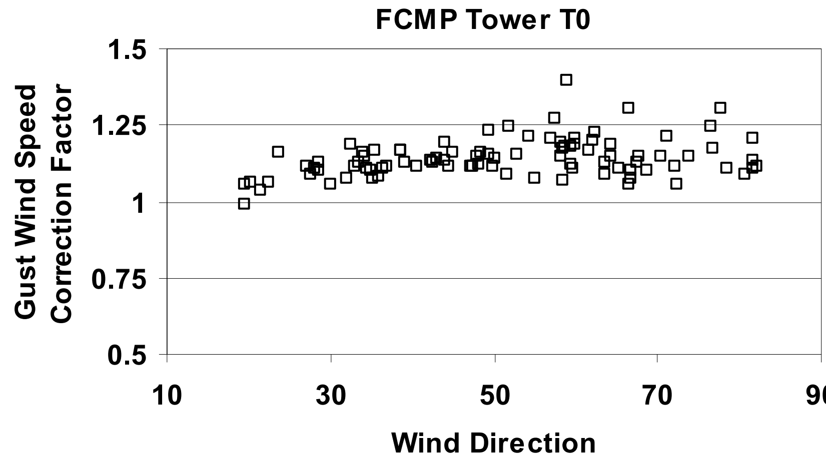
ASOS Anemometers Terrain Corrections

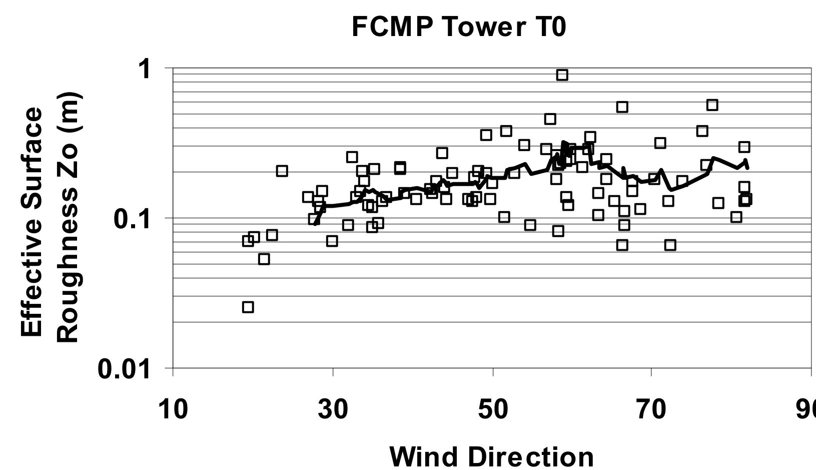


- Open terrain winds for winds from east only
- All other directions wind speed are affected by upstream terrain
- ASOS measurements will generally understate true open terrain wind speeds, unless wind is approaching over a long open fetch.
- Generated direction wind speed correction factors by direction using ESDU

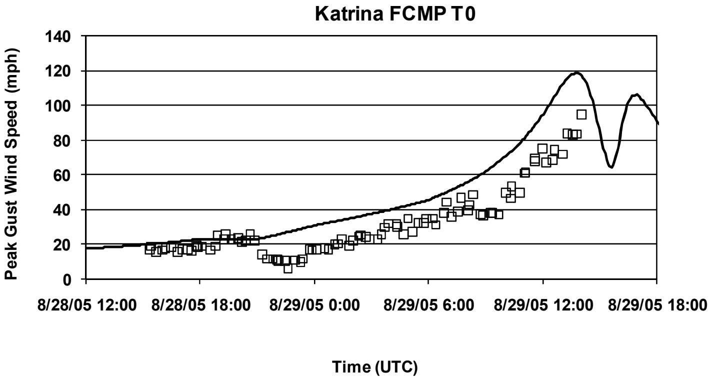
Katrina FCMP T0 – Turbulence Intensity Method

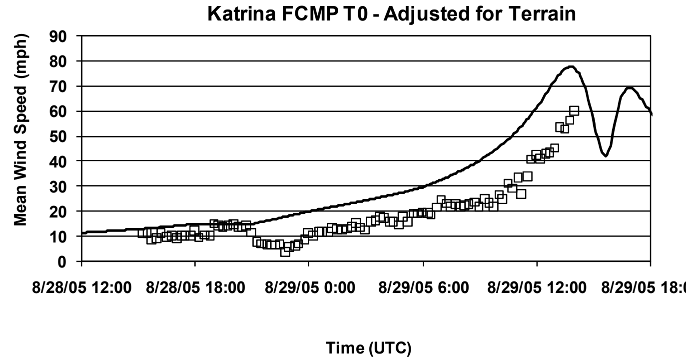


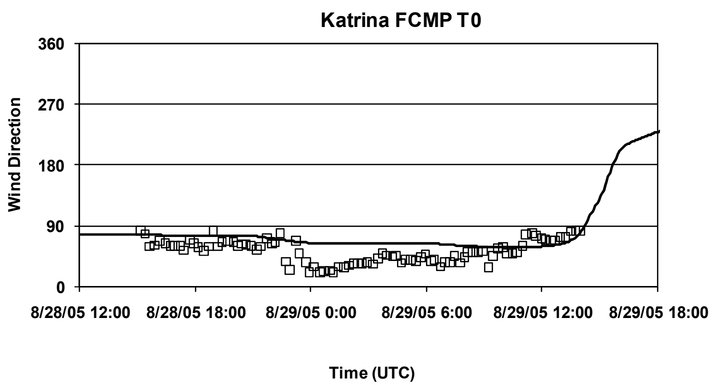


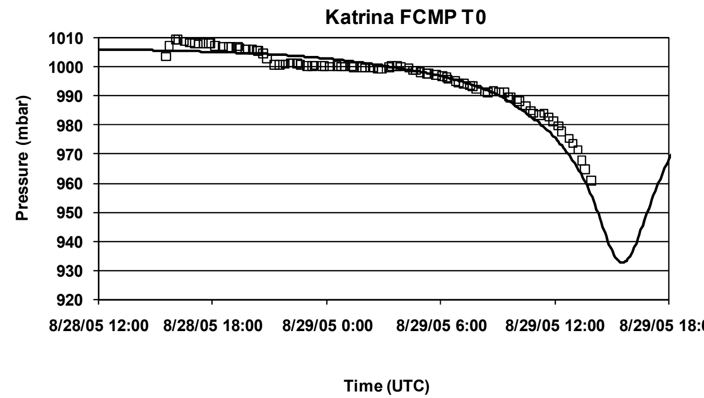


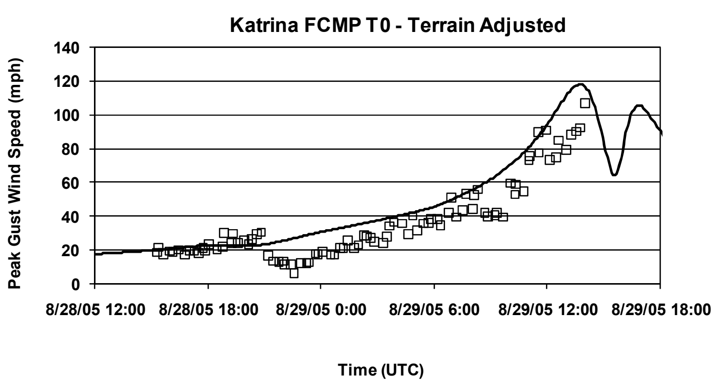
T0 Wind Speed Comparisons

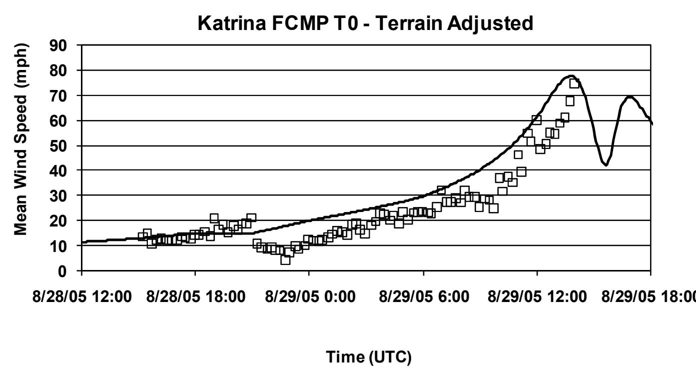




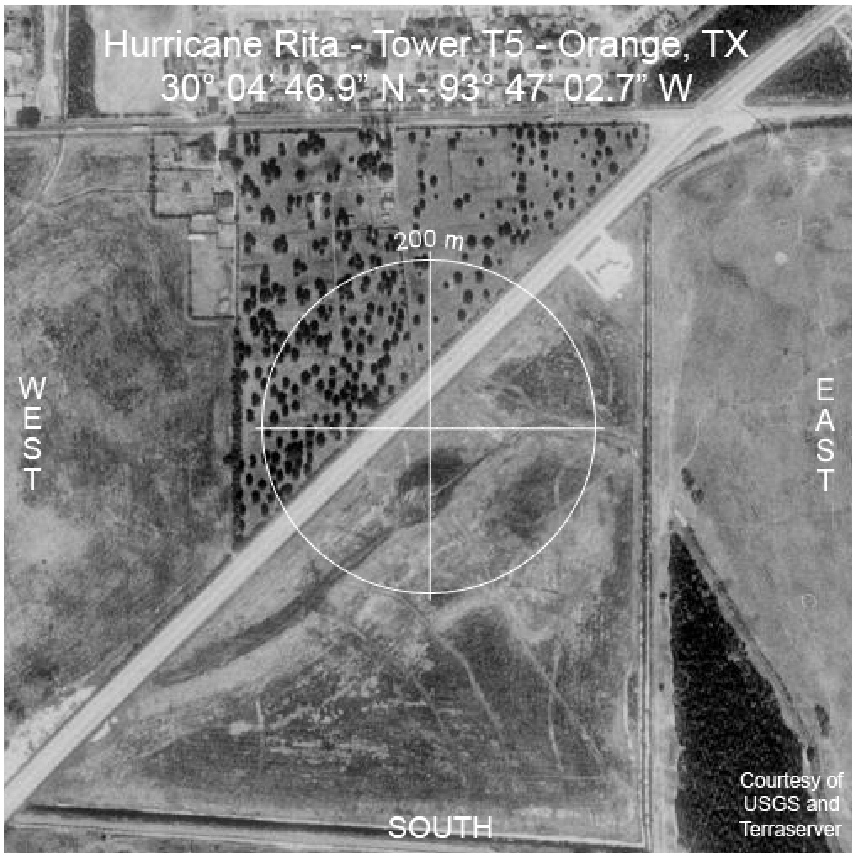


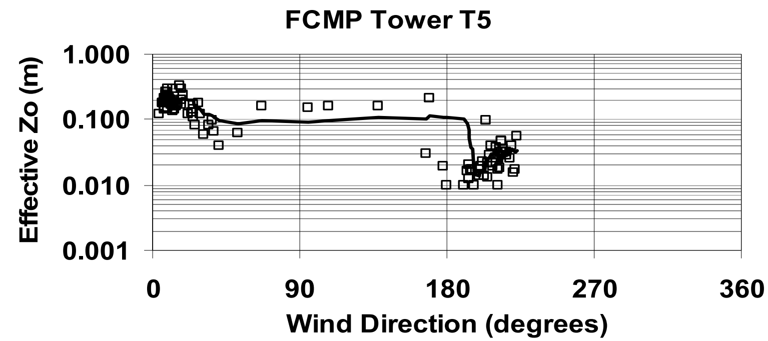


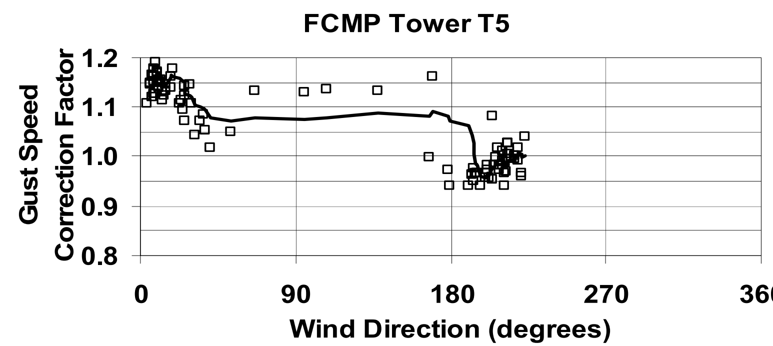




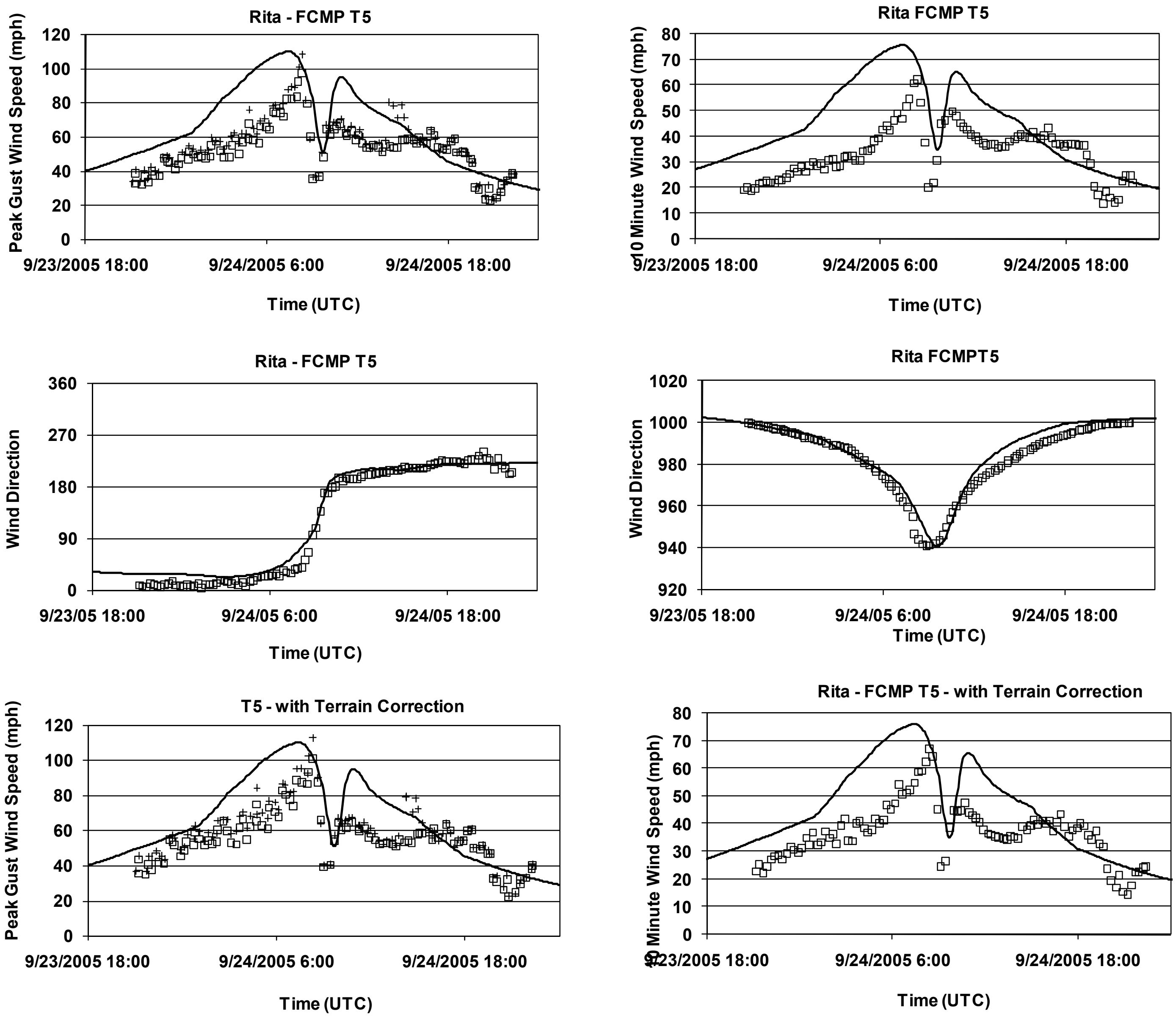
Rita FCMP T5 – Turbulence Intensity Method



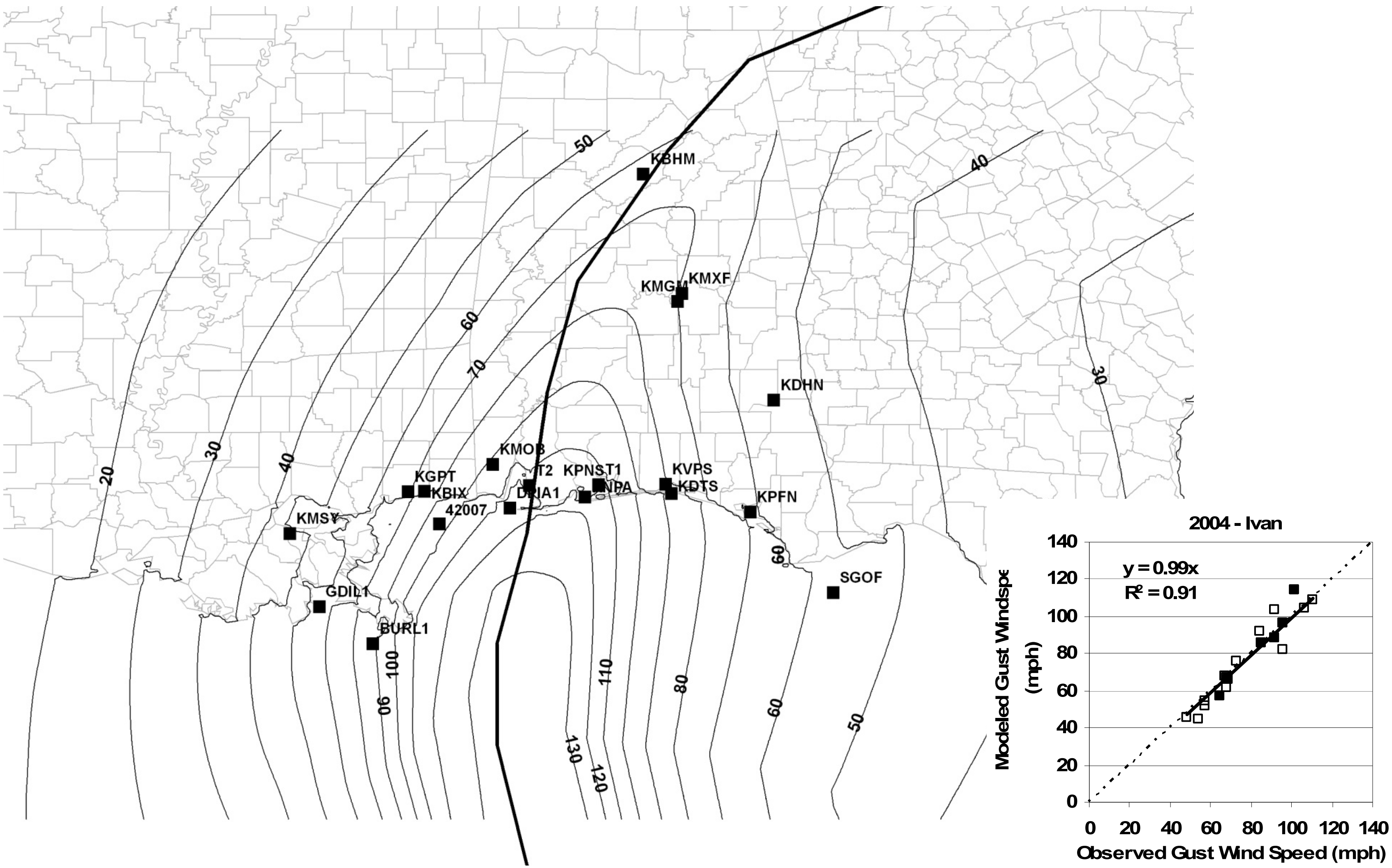




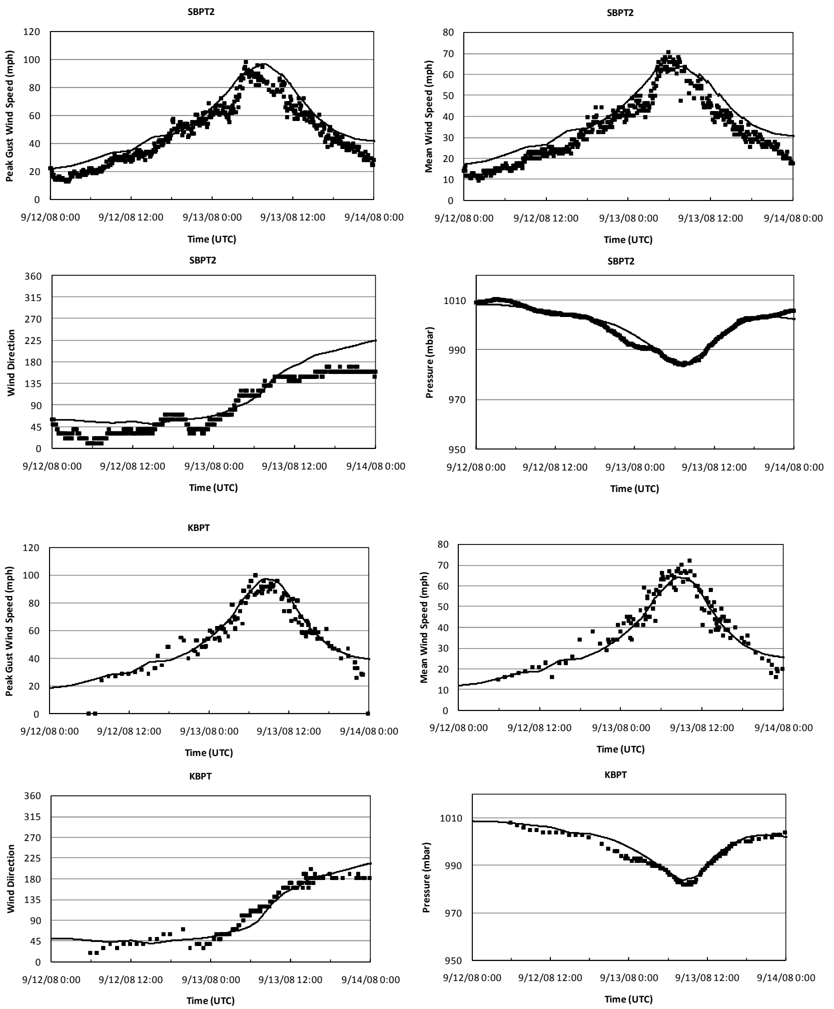
T5 Wind Speed Comparisons



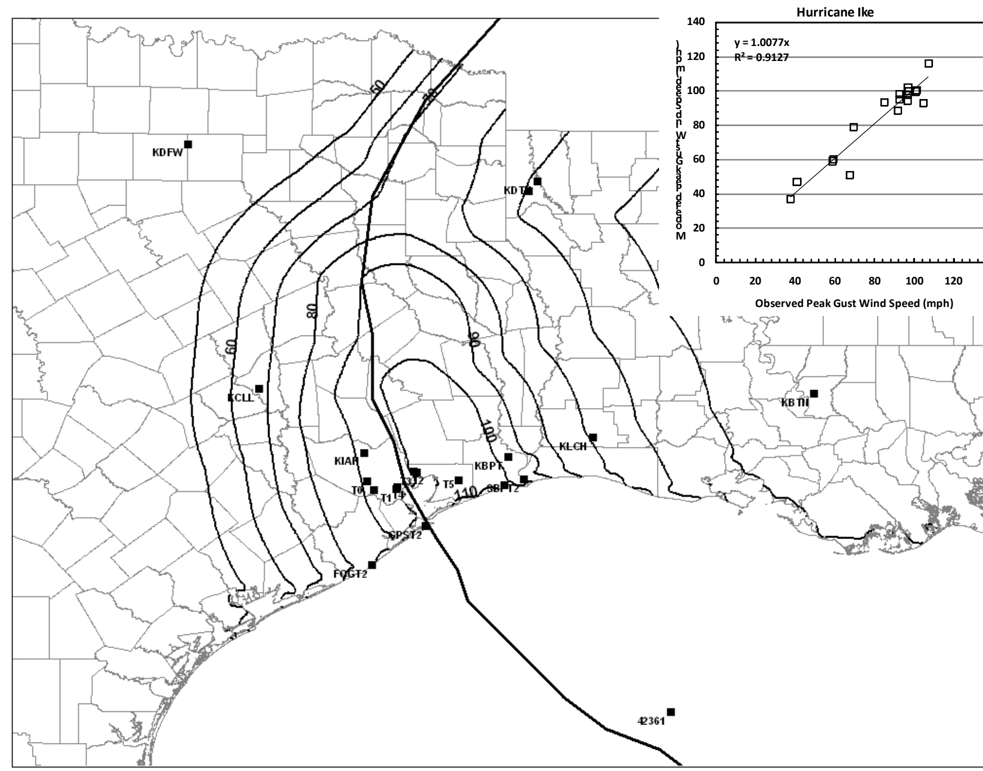
Hurricane Ivan Validation



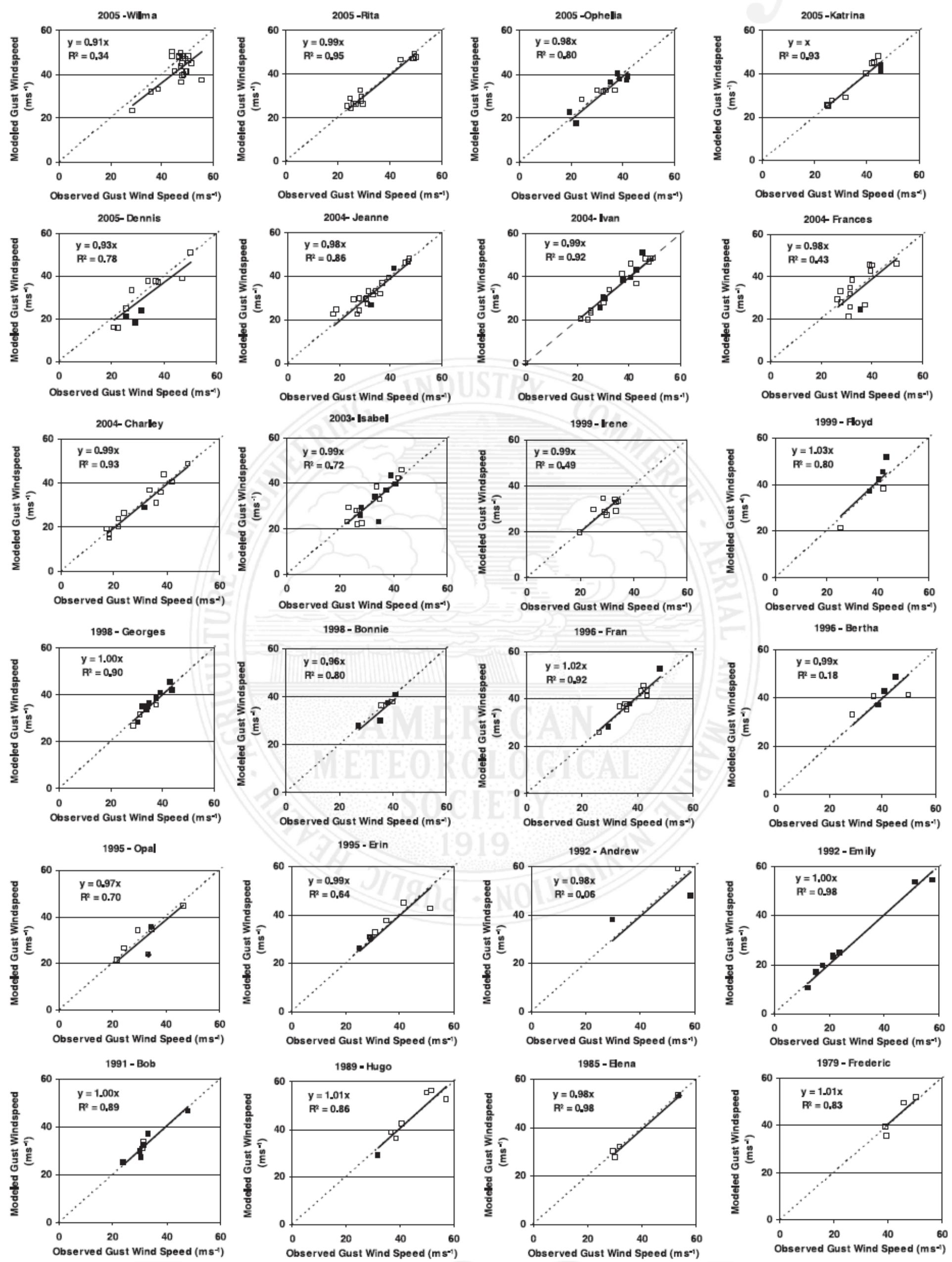
Hurricane Ike



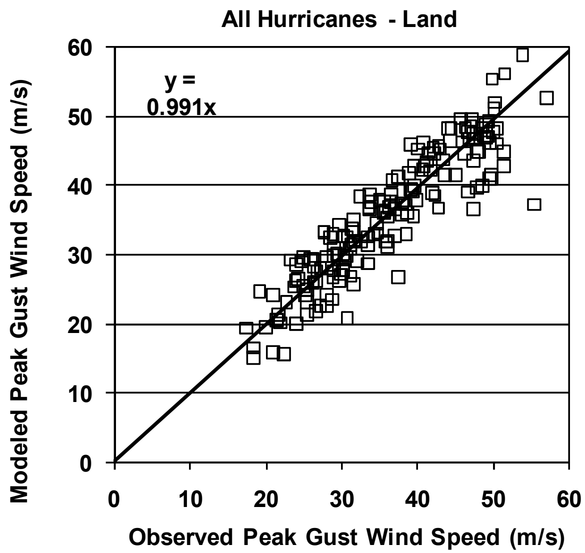
Estimated maximum peak gust wind speed on land ~ 110 mph near the coast to the right of the landfall location.

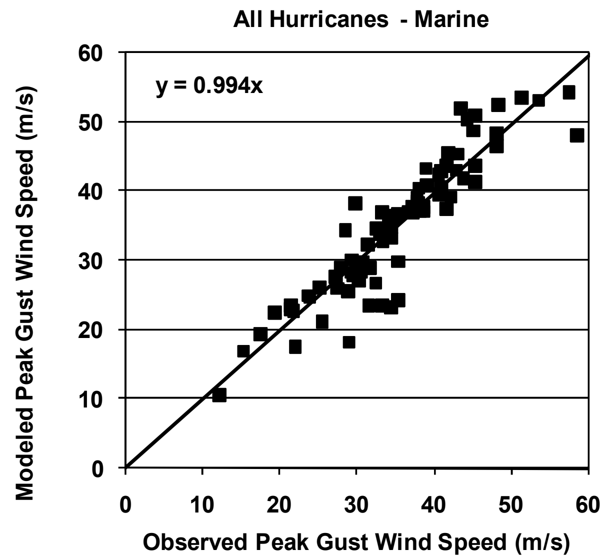


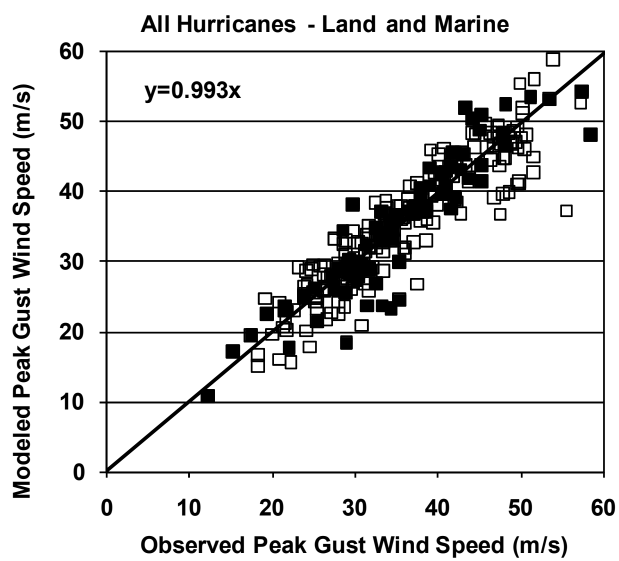
Storm-by-Storm Comparison Summaries



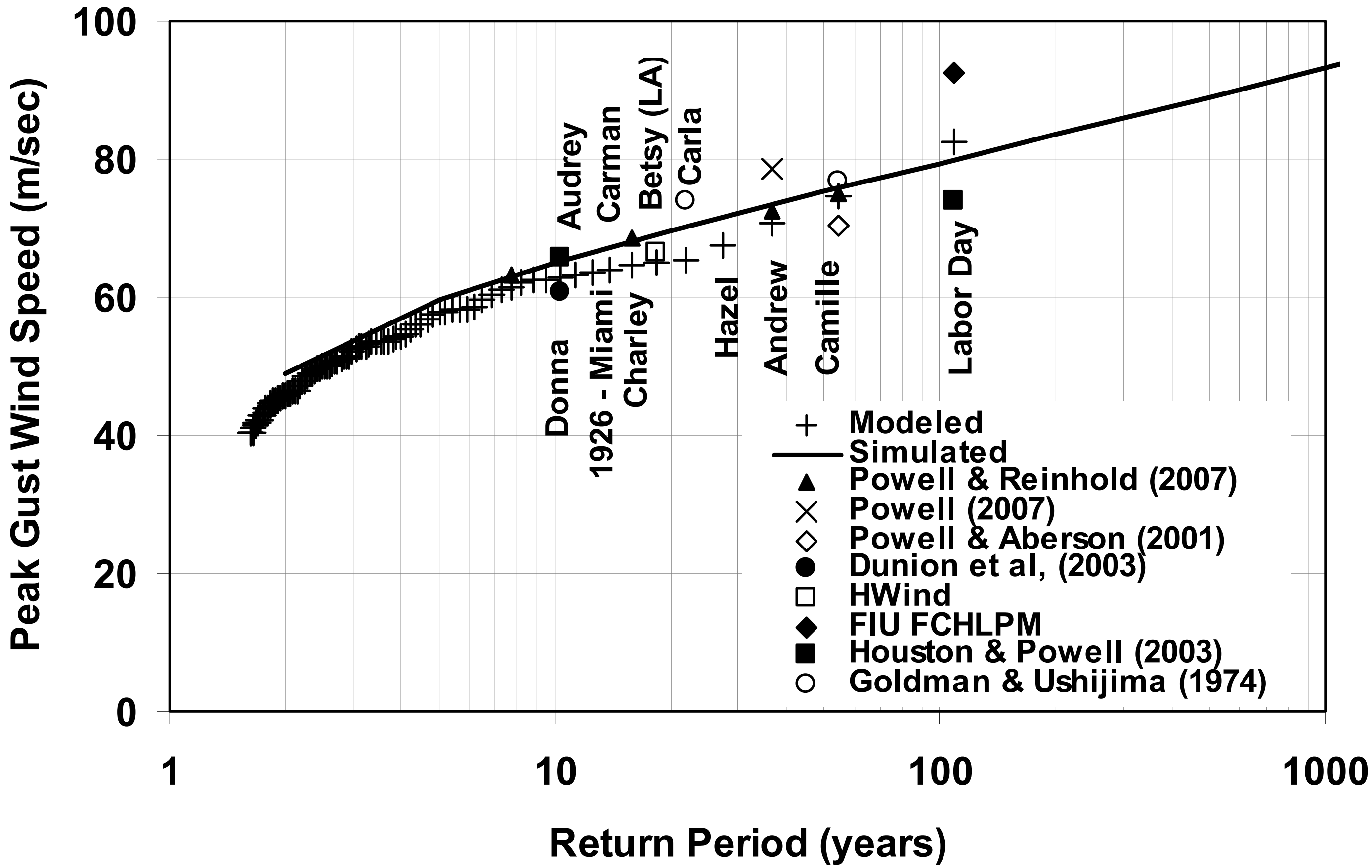
Assessment of Model Errors



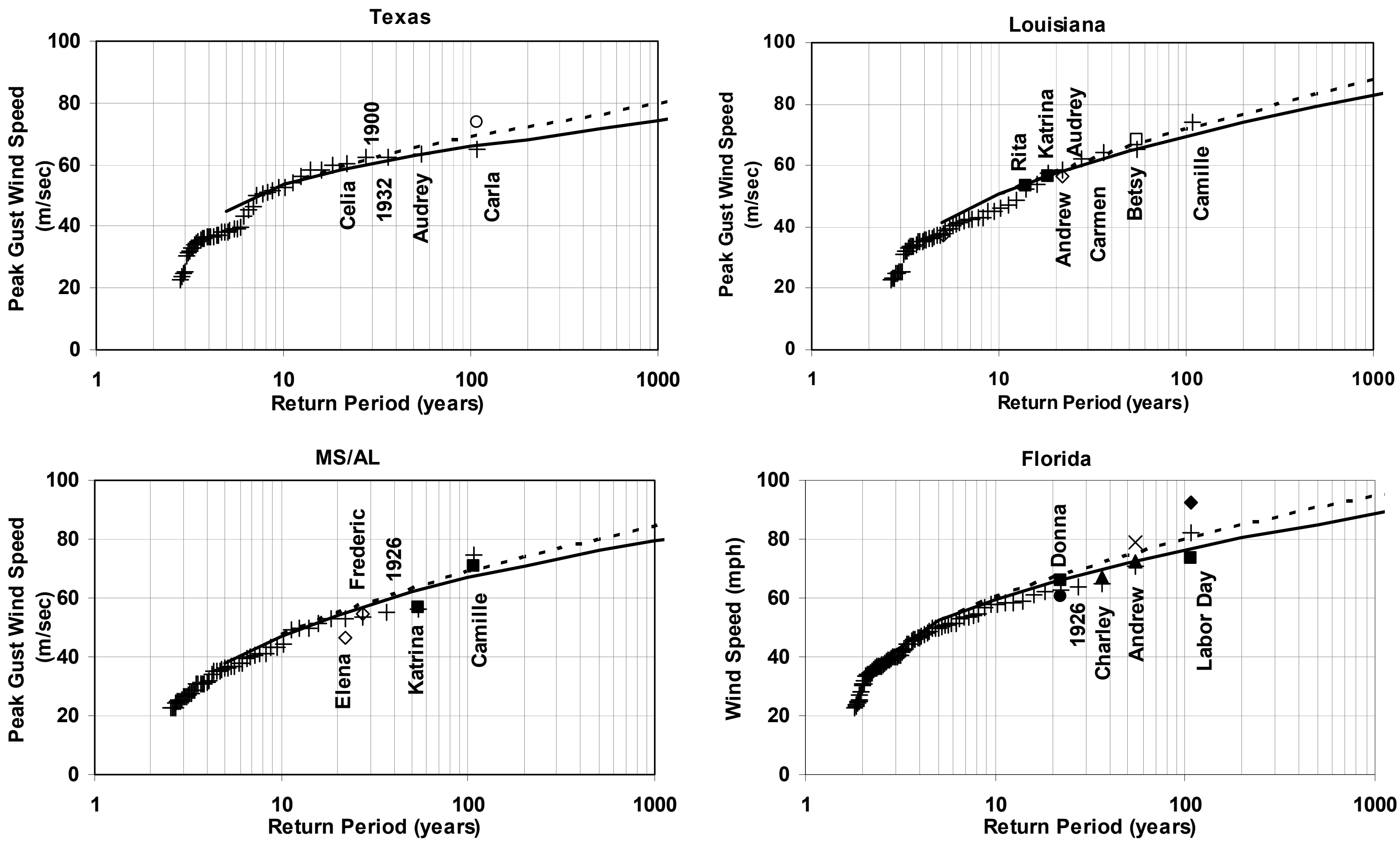




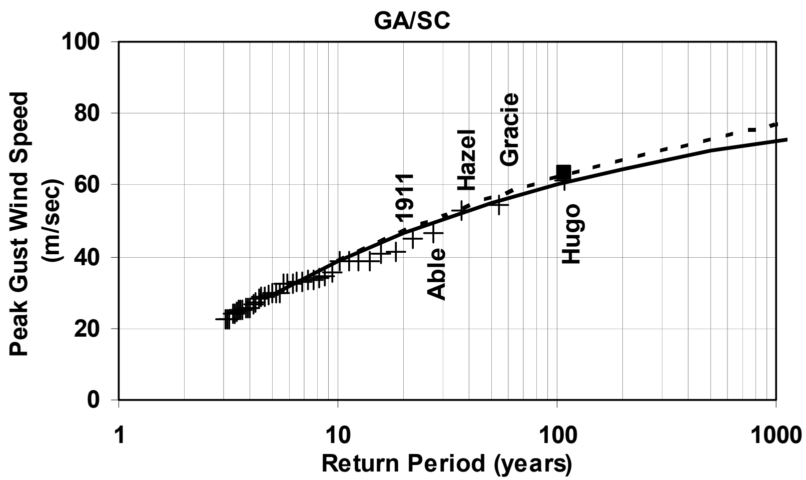
Simulated vs. Historical Maximum Wind Speeds

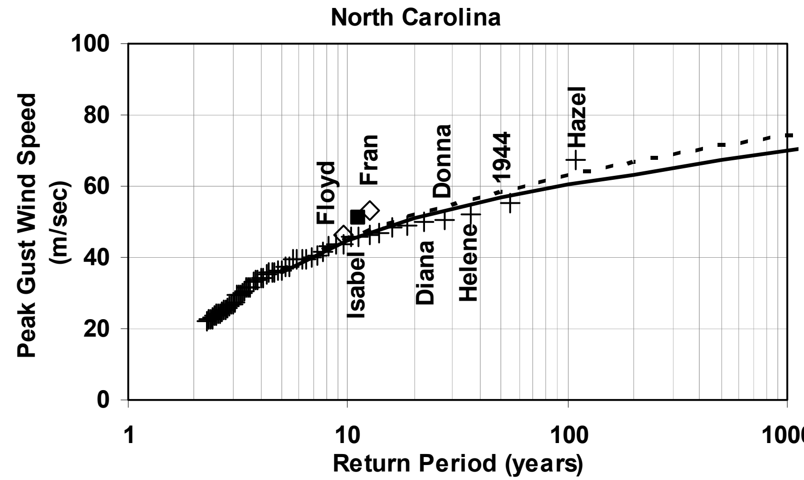


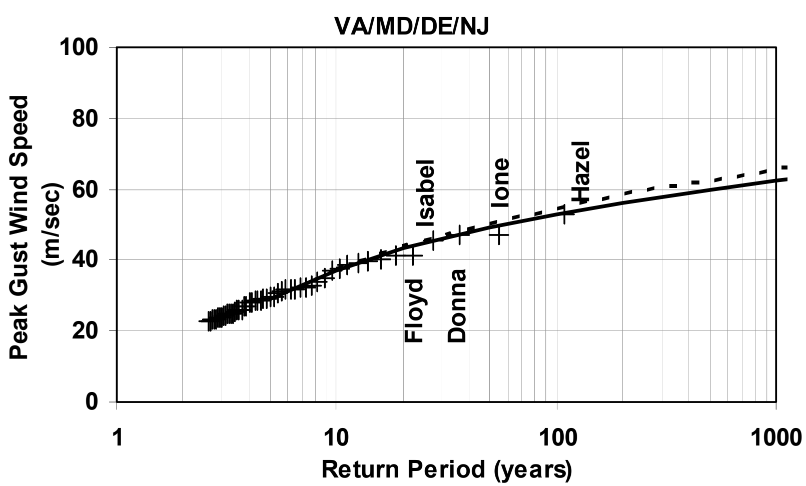
Simulated vs. Historical Maximum Wind Speeds

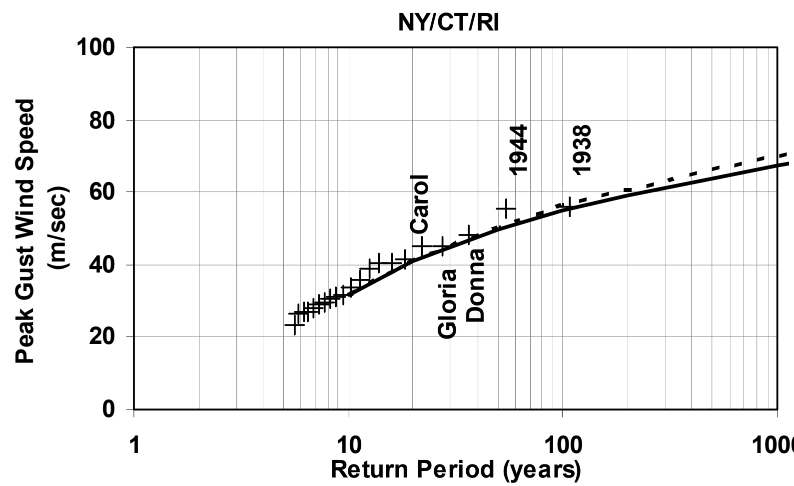


Simulated vs. Historical Maximum Wind Speeds





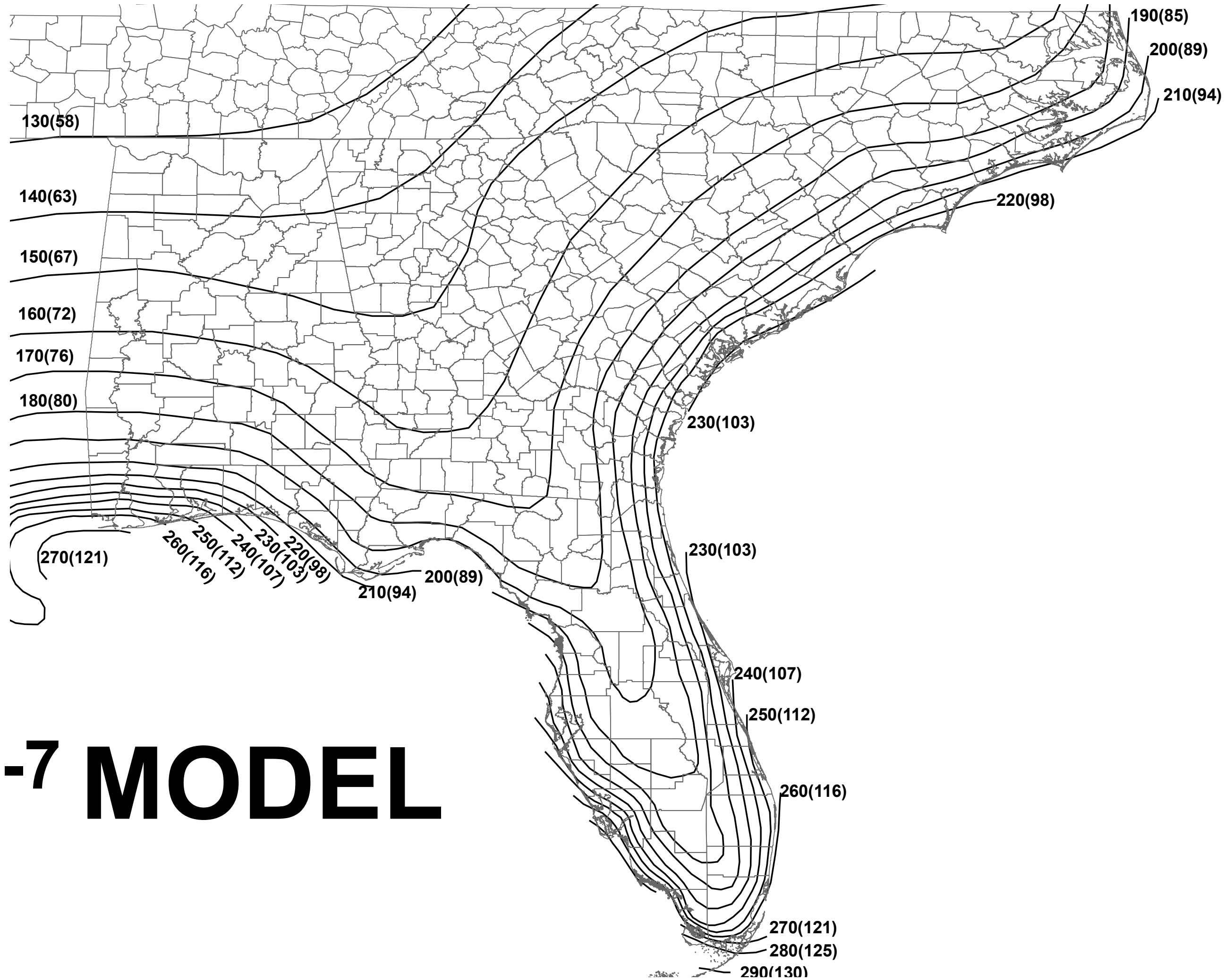




Original Model Summary

- 2-D Numerical solution of a translating hurricane (slab representation)
- Model change to incorporate smaller minimum values of RMW
- Wind speed variation with height based on dropsonde data
- Extensively validated over both land and water

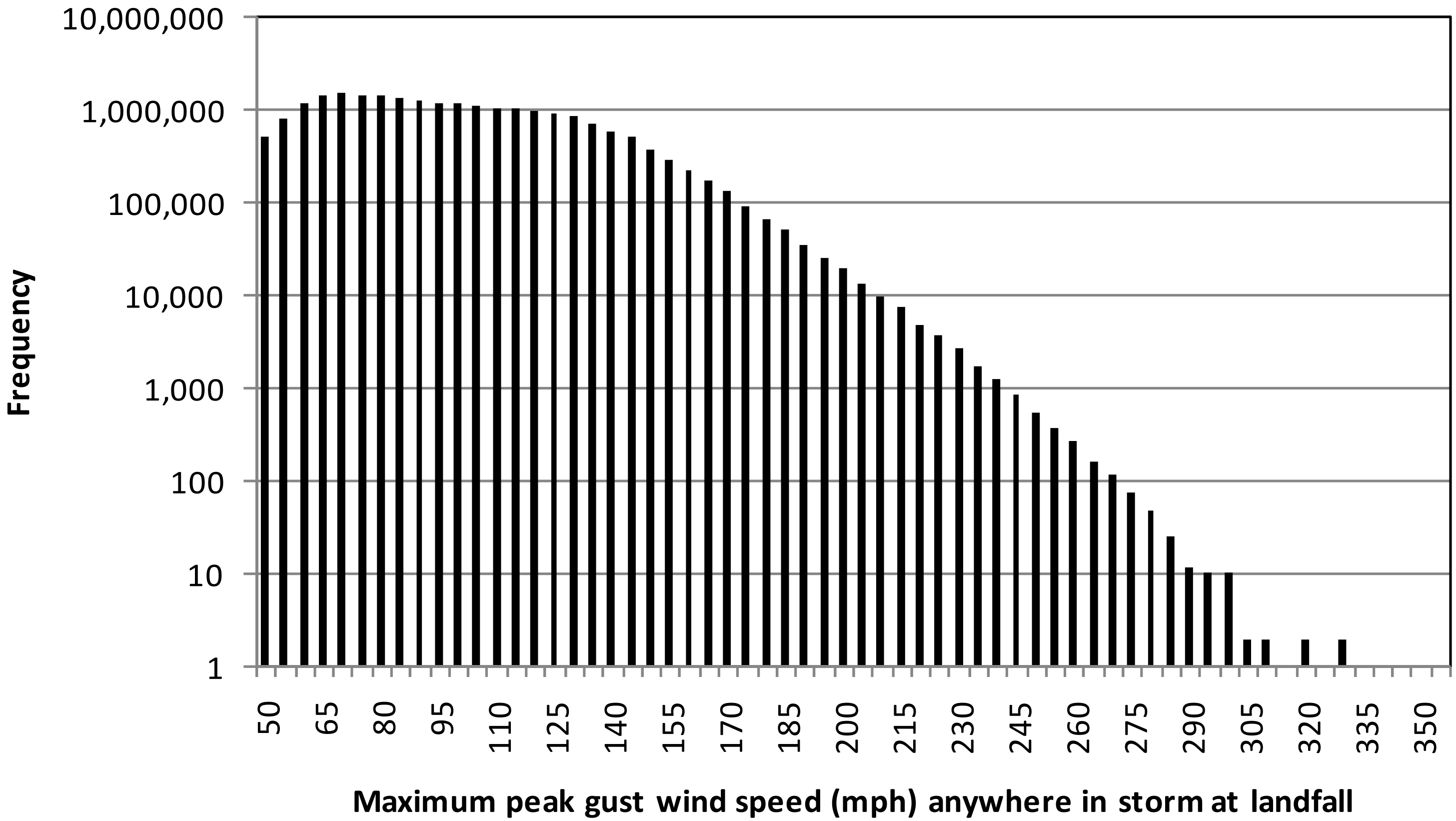
NRC 10^{-7} MODEL



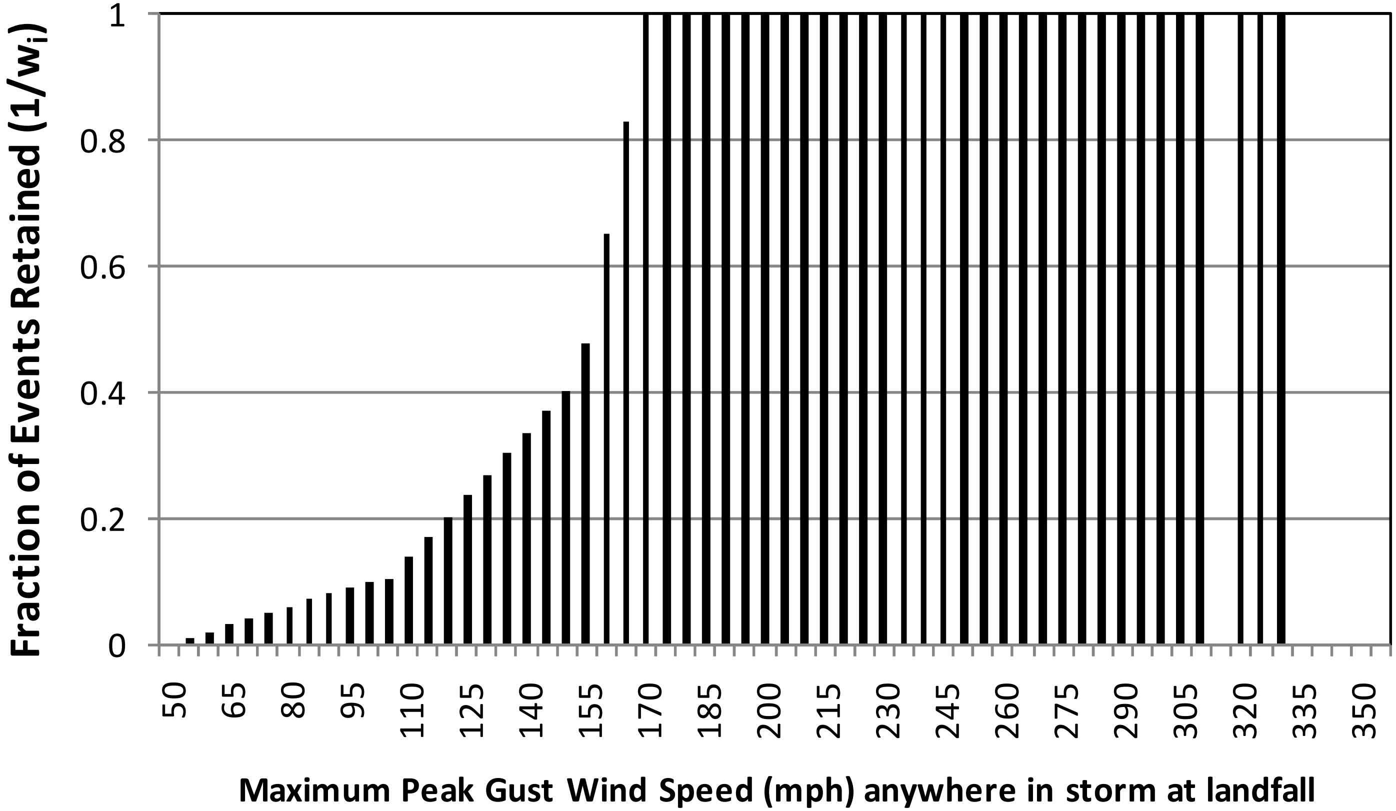
Model Changes

- Smaller minimum RMW (4 km vs. 8 km in original model)
- Reduced storm set for wind speed calculations (23.2 million in full set vs. 3.5 million in reduced set)
- Duration dependent gust factor (lower gust factors for tight, fast storms)

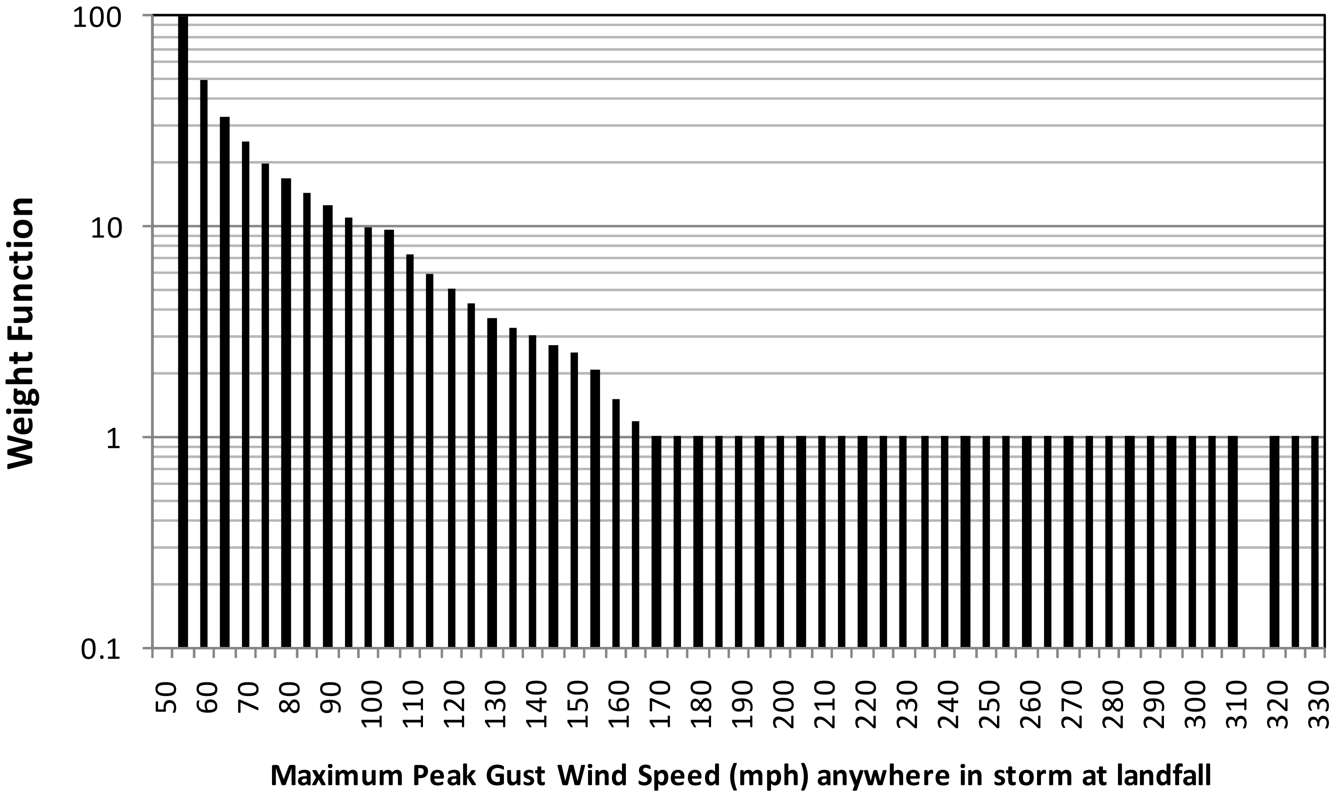
Peak Gust Wind Speed (10m, Marine) at Landfall from 10^7 Year Simulation



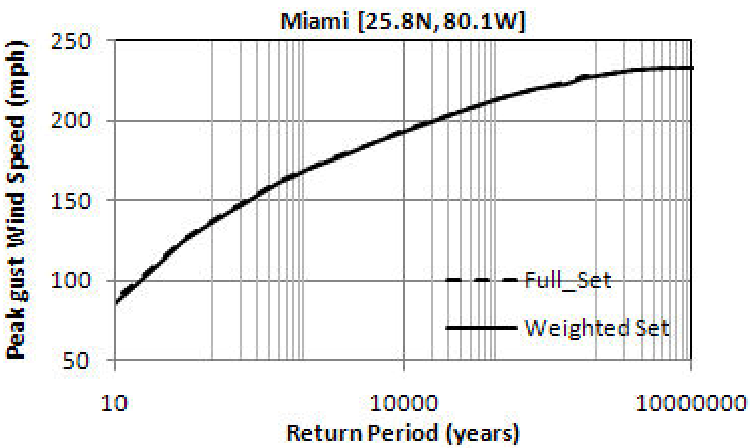
Fraction of Storms Retained vs. Peak Gust Wind Speed (10m, Marine)

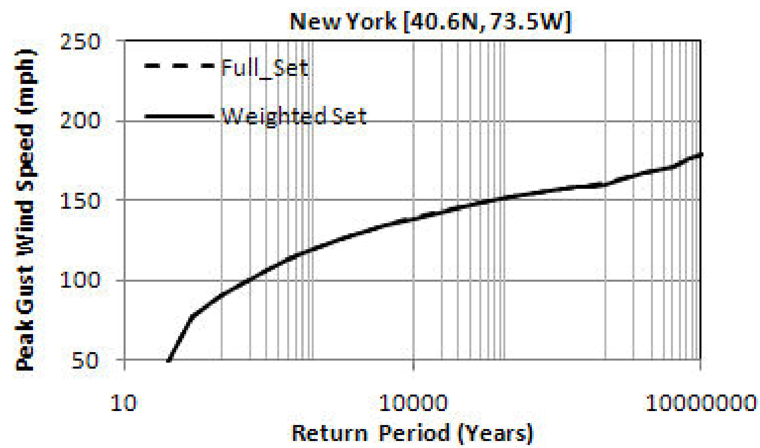


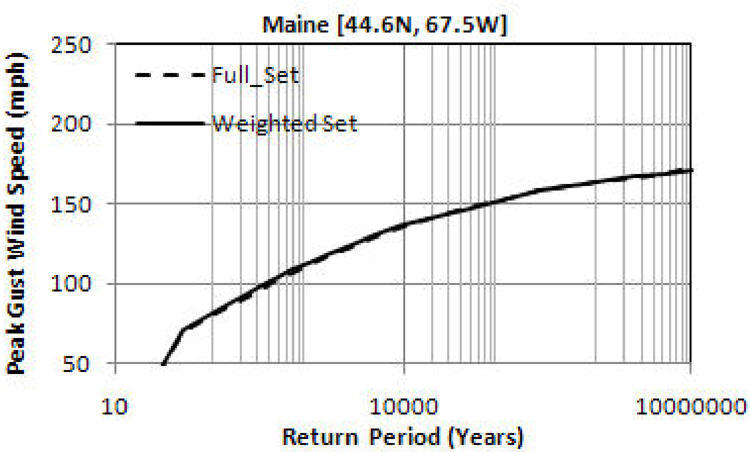
Storm Weight vs. Peak Gust Wind Speed (10m, Marine)



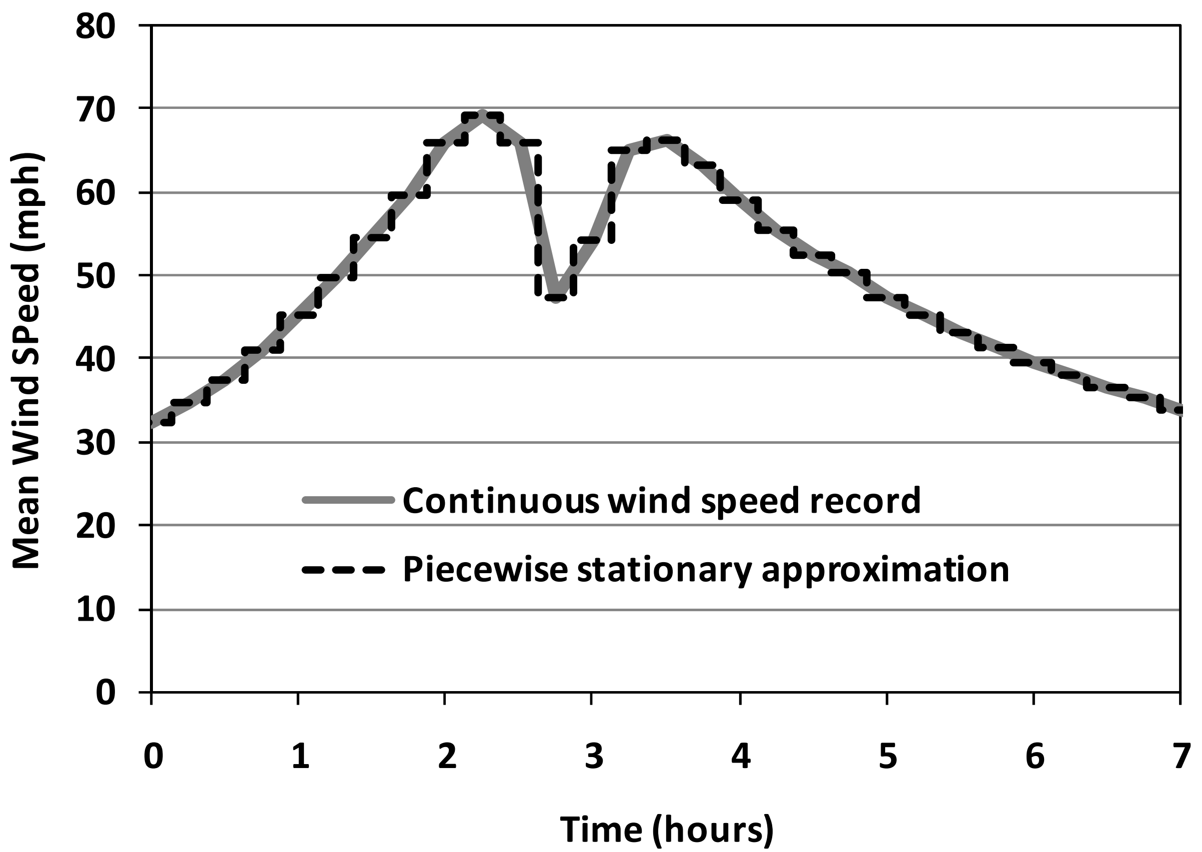
Effect of Reduced Storm Set on Predicted Wind Speeds







Enhanced Gust Factor Consider Storm Duration



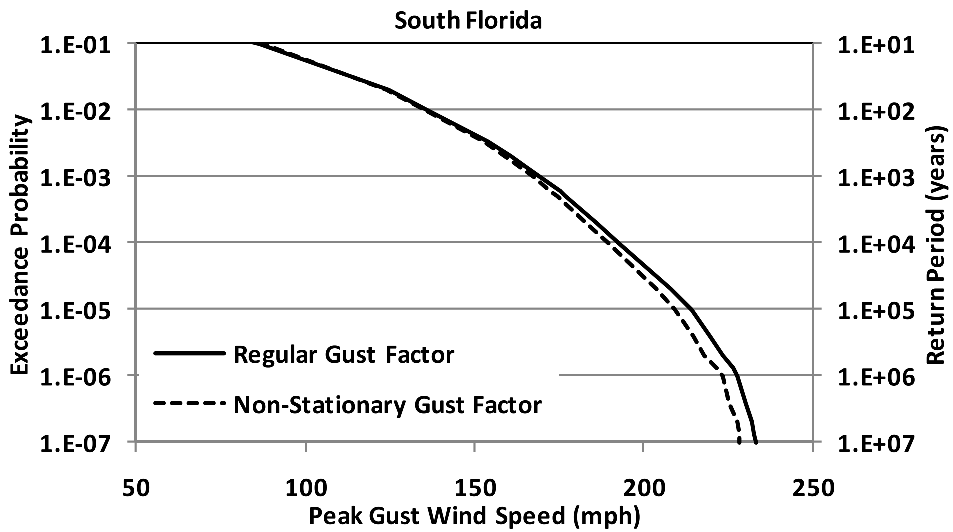
Enhanced Gust Factor Considers Storm Duration

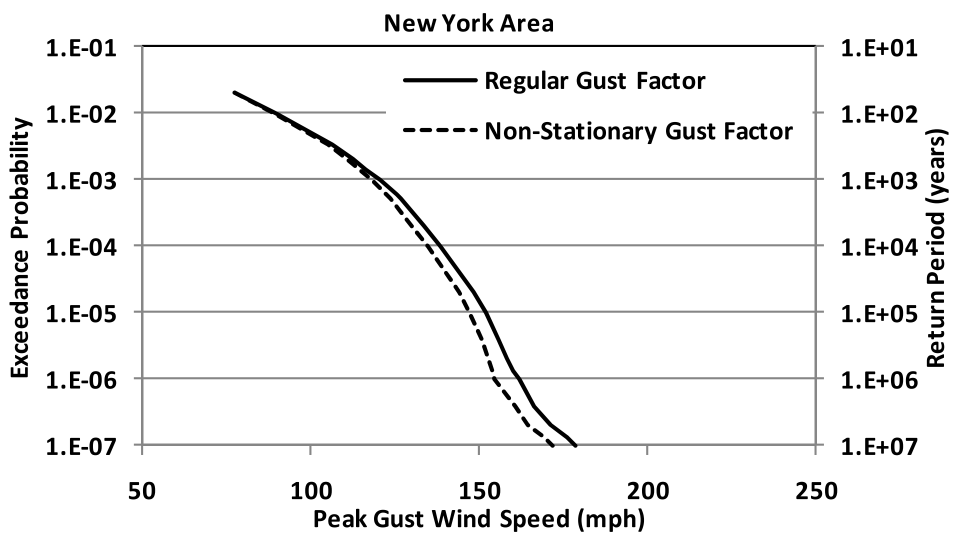
- Following Davenport (1964), a non-dimensional variable η is defined as: $\eta = \dfrac{u - \bar{u}}{\sigma(u)}$
- the cumulative density function for the largest maxima within a segment is:

$$P_{\max_i}(\eta) = \exp\left[-vT\exp\left(-\frac{\eta^2}{2}\right)\right]$$

- $P_{max}(u)$ within a segment is $P_{\max_i}(u) = \exp\left[-vT\exp\left(-\frac{1}{2}\left(\frac{u-\bar{u}}{\sigma(u)}\right)^2\right)\right]$
- For multiple segments $P_{\max}(u) = \prod_{i=1}^{N} P_{\max_i}(u)$
- Mean peak-gust wind speed $\hat{u}$ is $\hat{u} = \int_0^{\infty} u p_{\max(u)du}$; $\hat{u} = u + g\sigma(u)$
- The peak factor g is $g = \sqrt{2\ln vT} + \dfrac{0.577}{\sqrt{2\ln vT}} + \ldots$
- Crossing rate v is computed using the ESDU (1982) models for atmpspheric turbulence

Enhanced Gust Factor Considers Storm Duration





Translation speed adjustment

- To reduce the overestimation of the translation speed effect on rapidly moving hurricanes, we implemented a reduced translation speed so that the effective translation speed c_{eff} passed into the wind field model is defined by:

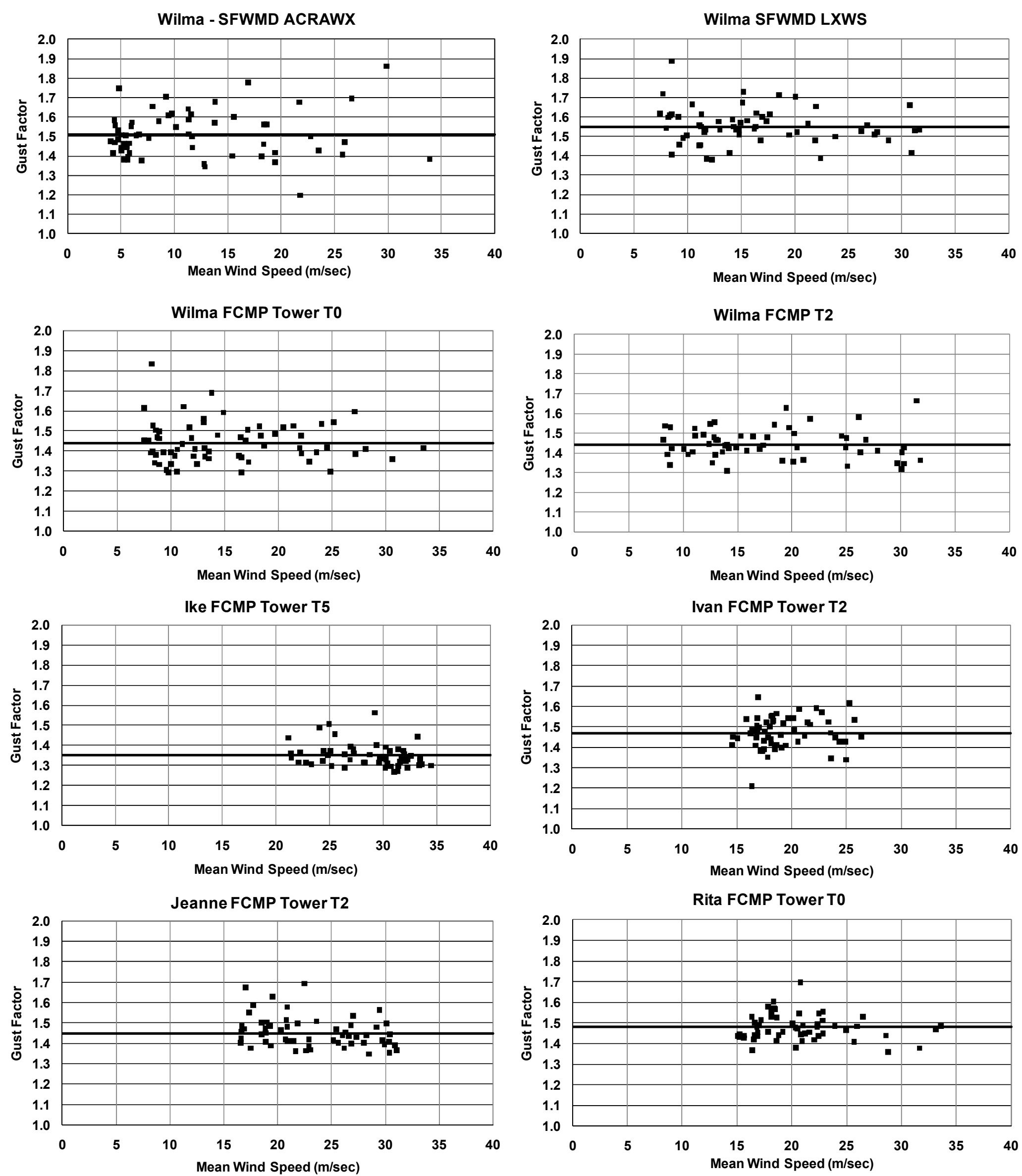
$$c_{\mathrm{eff}} = c, \qquad c < 15 \text{ m/s}$$

$$c_{\mathrm{eff}} = 15 + \frac{c - 15}{3}, \qquad 15 < c < 30 \text{ m/s}$$

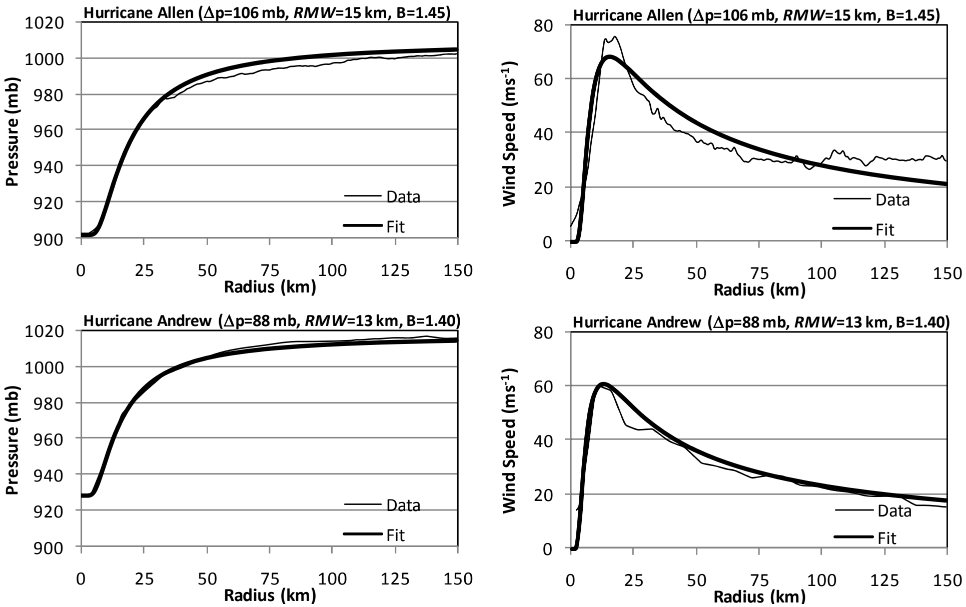
$$c_{\mathrm{eff}} = 20, \qquad c > 30 \text{ m/s}$$

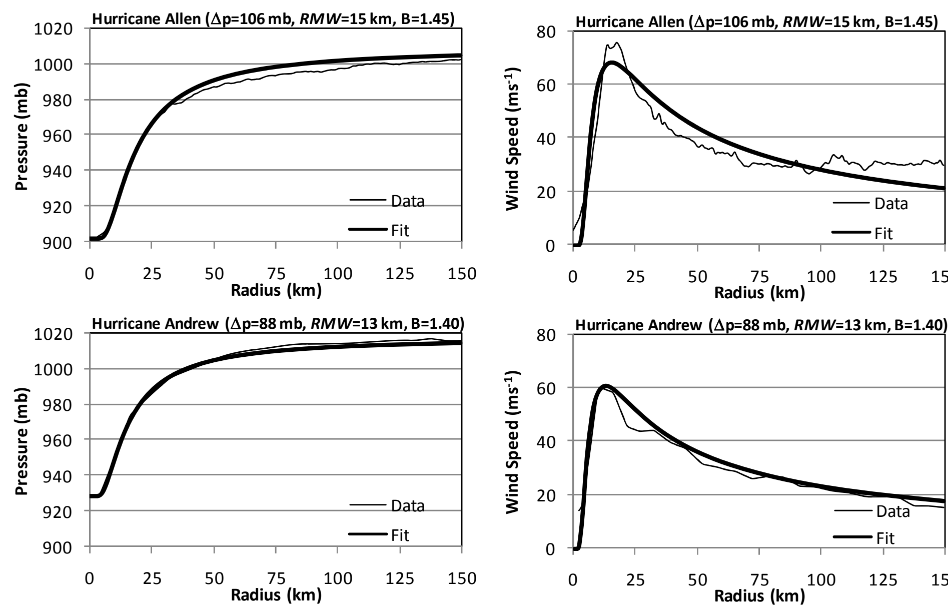
- where c is the original translation speed
- This modified translation speed improved comparisons between model and observed winds for the 1938 hurricane and has since been used in Hurricane Juan validations (Halifax, MS)

Windfield Modeling Uncertainties: Example Gust Factor Errors

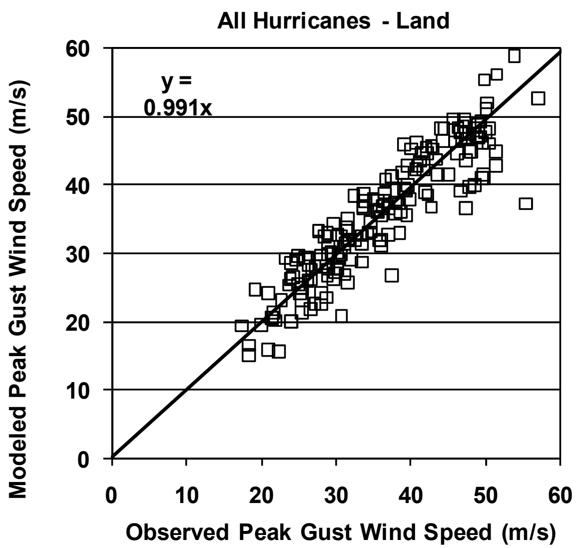


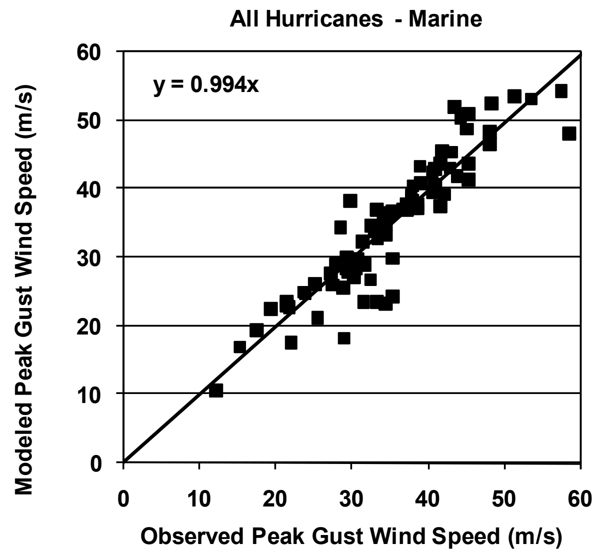
Windfield Modeling Uncertainties: Example Wind Model Limitations

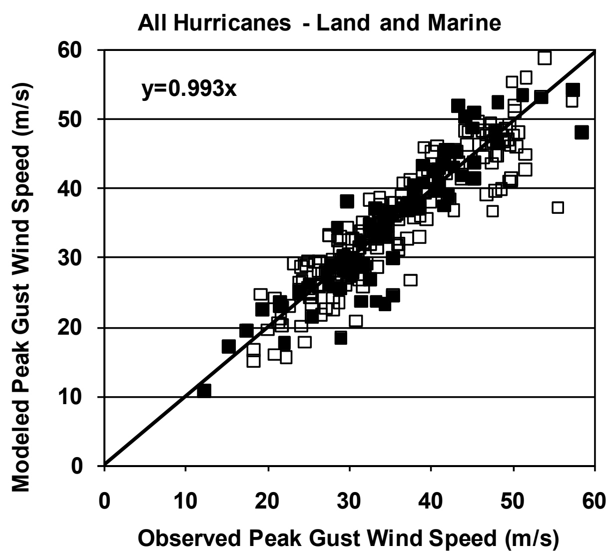




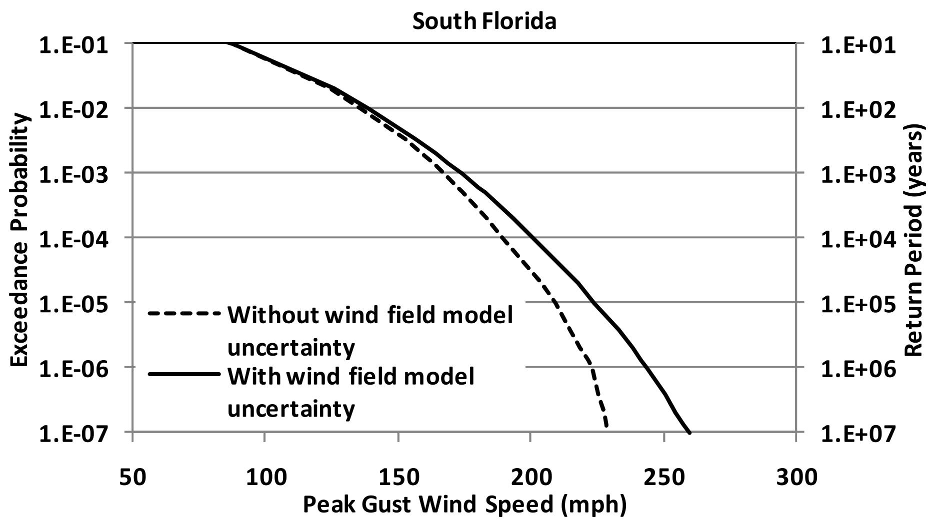
Windfield Model Uncertainty

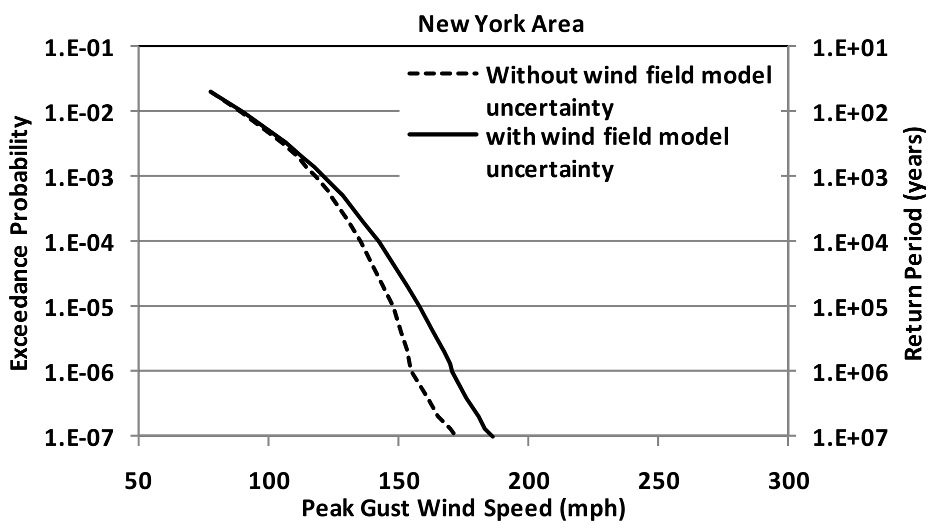




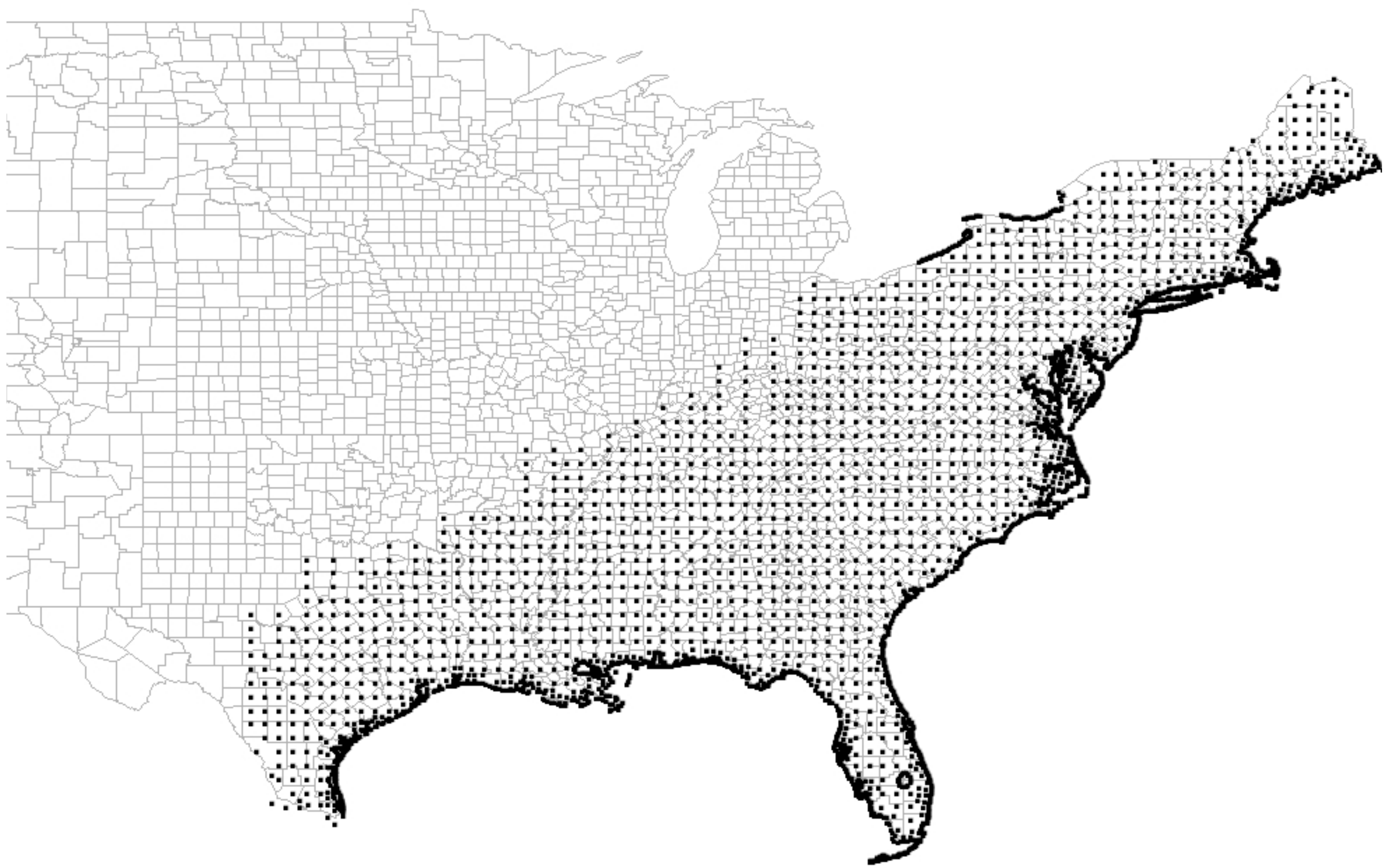


Windfield Modeling Uncertainties: Example Impacts on Wind Speeds



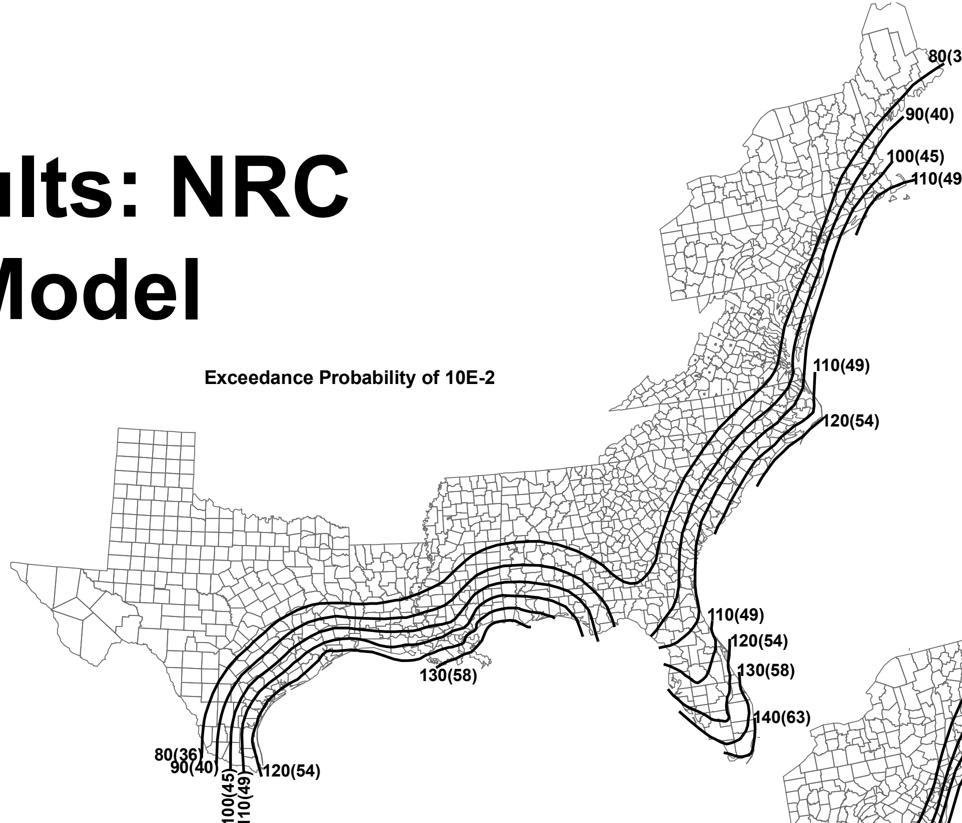


Locations of 3575 Points for Wind Speed Computations

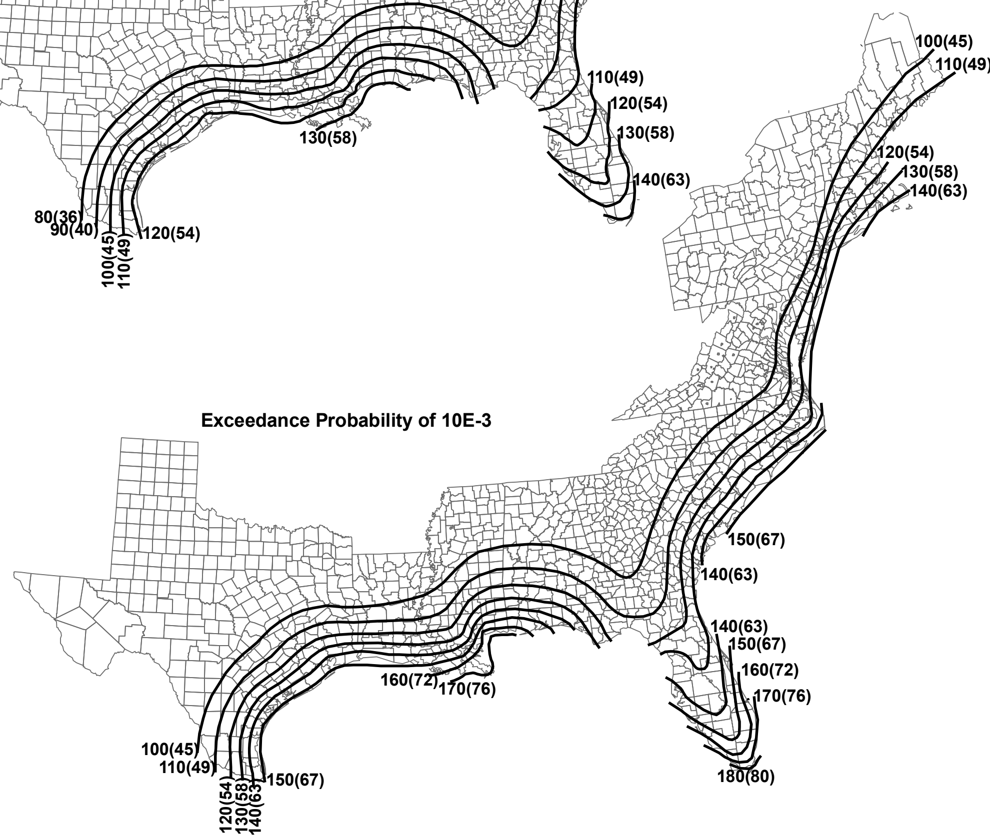


Results: NRC Model

Exceedance Probability of 10E-2

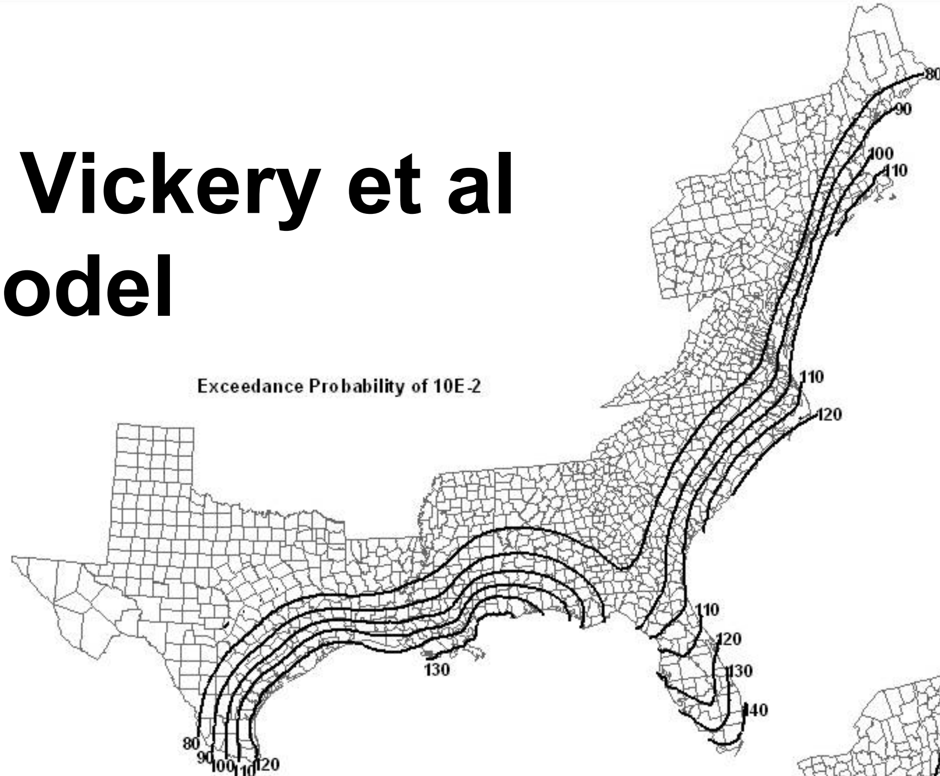


Exceedance Probability of 10E-3

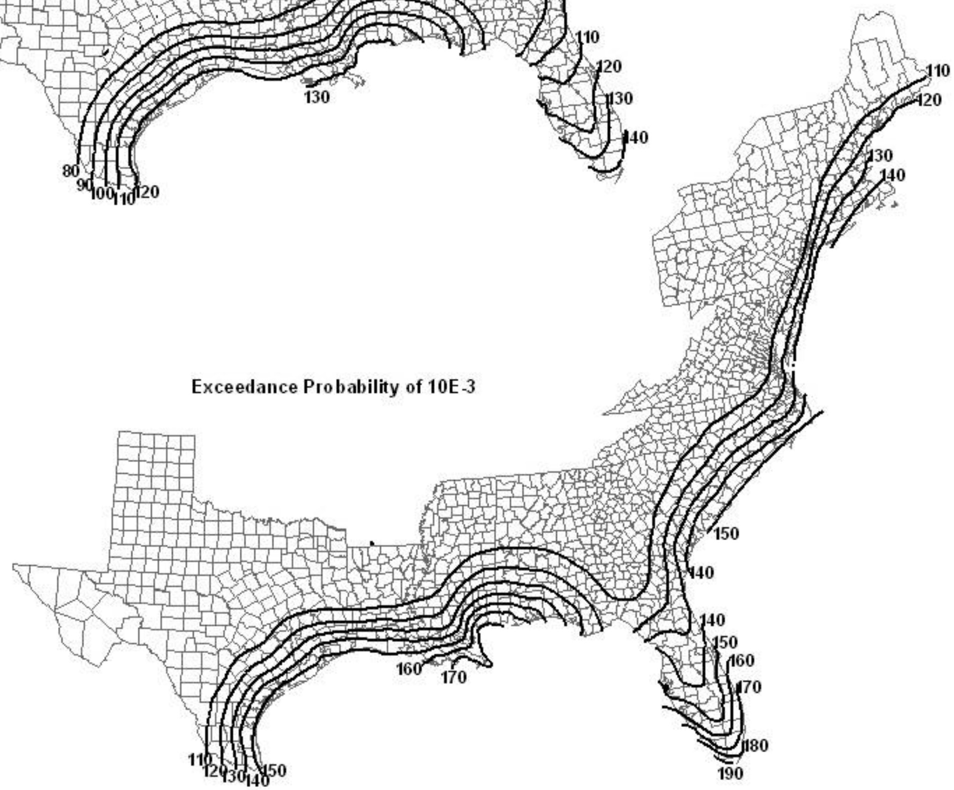


Results: Vickery et al (2009) Model

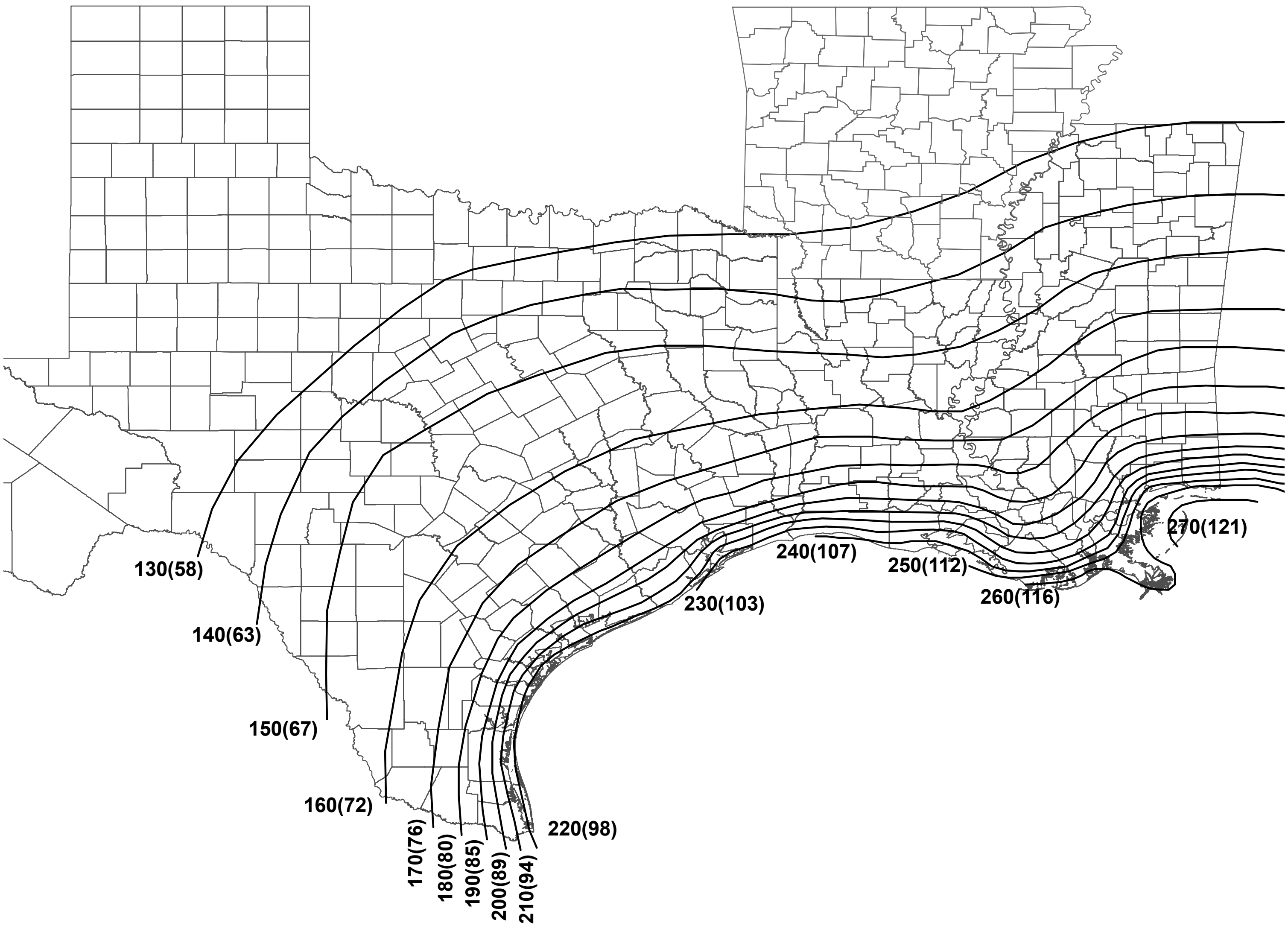
Exceedance Probability of 10E-2



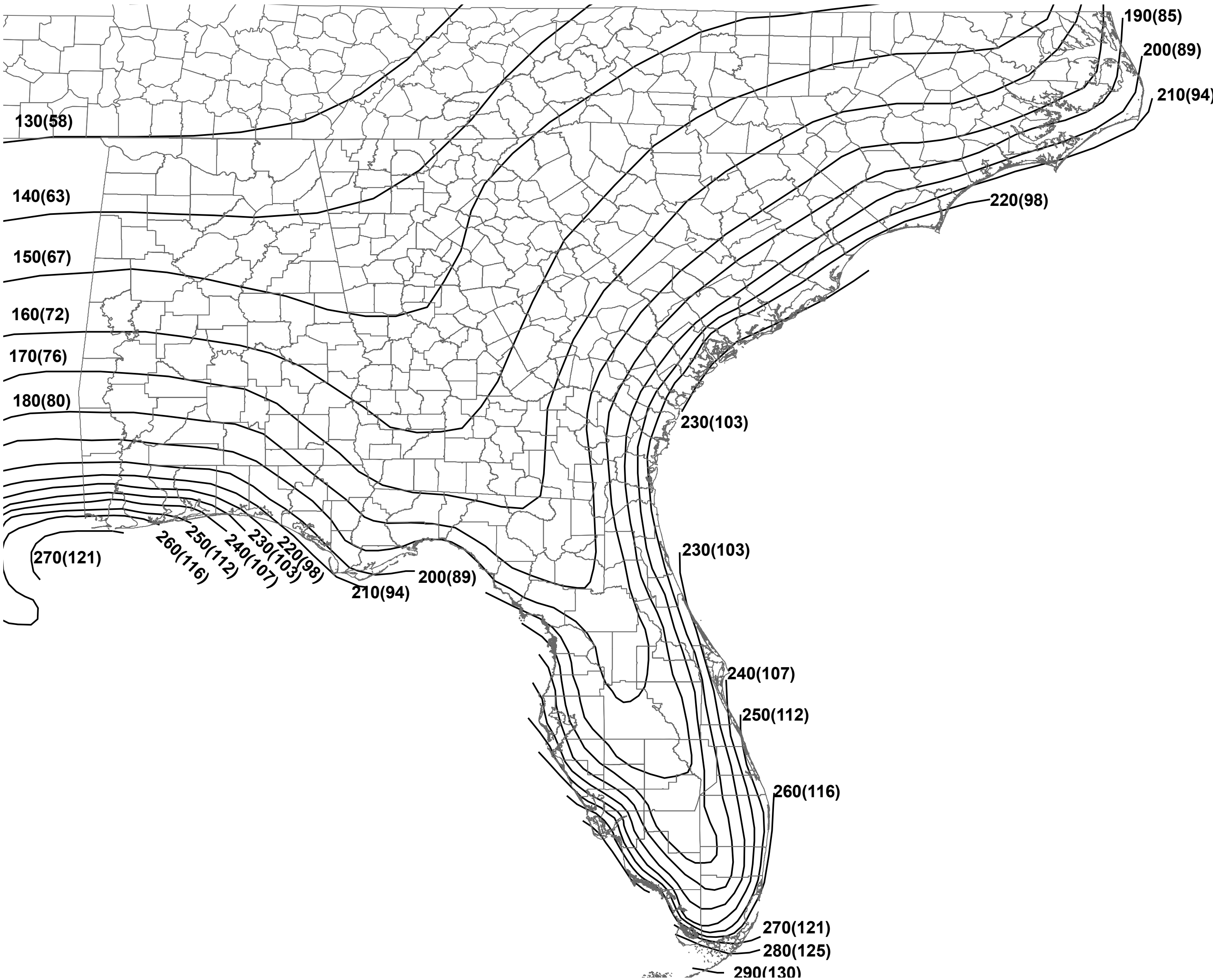
Exceedance Probability of 10E-3



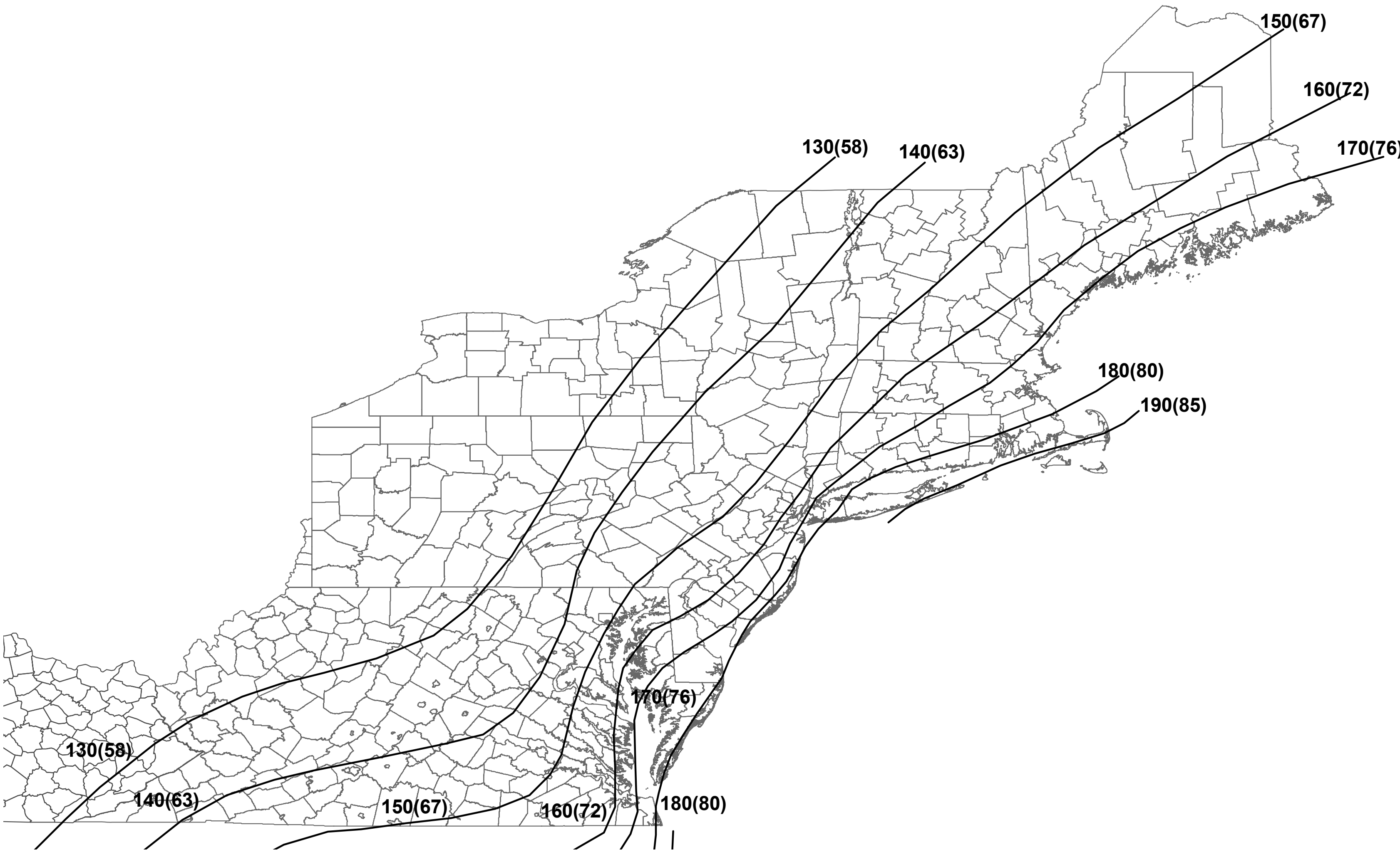
Annual Exceedance Probability: 10^{-7}



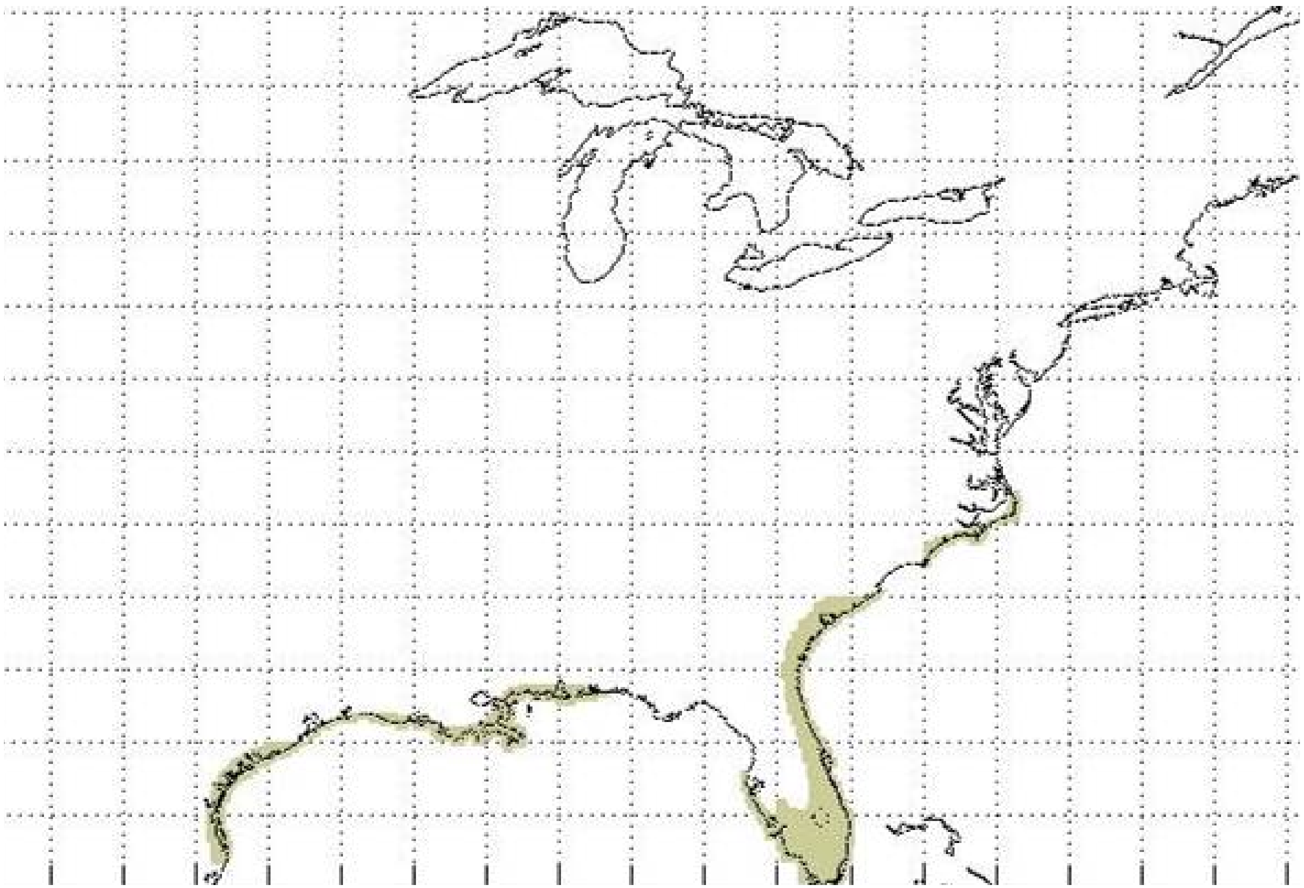
Annual Exceedance Probability: 10^{-7}



Annual Exceedance Probability: 10^{-7}



Locations Where Design-Basis Hurricane Wind Speeds Exceed those for Tornadoes (annual exceedance probability of 10^{-7})



Summary

- Original Model
  - Hazard model developed/validated using data through 2007
  - Simple ocean mixing model limits intensity
  - New statistical models for *B* and *RMW*
  - Wind model extensively validated through comparisons of modeled and observed winds both onshore and offshore
  - Windfield model errors included in wind speed estimates
  - Peer reviewed, used to develop ASCE 7-10 design wind speeds
- NRC Model Changes and Enhancements
  - Based on model used to develop ASCE 7-10 wind speeds
  - Minimum RMW reduced to 4 km for 8 km
  - Reduced storm set/weighted sample to enable model runs
  - Mean gust factor model takes into account storm duration

Summary

- NRC Model Changes and Enhancements
  - 10^{-6} and 10^{-7} winds strongly impacted by the windfield modeling uncertainty term (gust factor variation, wind field and parameter modeling deficiencies)
  - Maximum 10^{-7} gust wind speed of ~290 mph on land (~ 1 km inland in the FL keys). Assuming a gust factor in the range of 1.7 to 1.8 this 290 mph value corresponds to a one minute sustained wind speed over water in the range of 190 to 220 mph (85 – 98 m/sec). MIT 10% exceedance probability MPI for August, September and October in the South Florida area is >90 m/sec. This comparison suggests results are reasonable.

Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants (NUREG/CR-7004)

Emil Simiu
Engineering Laboratory, NIST

Florian A. Potra
Information Technology Laboratory, NIST

NIST

Objective and Scope

- The report documents an approach to and results of the calculation of hurricane-borne missile speeds for the design of nuclear power plants.
- The missile spectrum, the assumptions on which the calculations are based, and the range of wind speeds being considered, were based on discussions between the authors and NRC staff.
- Four types of missiles were considered in Regulatory Guide 1.76 (RG 1.76), Revision 1, entitled "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants”.
- In order to provide an adequate coverage, three more types of missiles (one plate-like missile and two plank-like missiles) were included in the missile spectrum. Such missiles arise from dislodged metallic siding attached to Non-Seismic Category buildings during a tornado event.
- It is a safety concern that those wind-borne siding missiles may compromise the structural integrity of the neighboring nuclear island Seismic Category I structures. This addition was required because the characteristics of those missiles differ significantly from those of the four types tabulated in RG 1.76, Rev. 1.

Equations of horizontal and vertical motion of missile in flow with constant velocity v_h

- Horizontal and vertical projections of Newton's second law applied to the missile embedded in the wind flow:
- $dv_{mh}/dt = (v_h - v_{mh})\{a[(v_h - v_{mh})^2 + v^2_{mv}]^{1/2}\}$
- $dv_{mv}/dt = g - av_{mv}[(v_h - v_{mh})^2 + v^2_{mv}]^{1/2}$

where $a = ½\rho C_D A/m$

Basic Assumptions

1. Hurricane updraft speeds are negligible.

2. Missile starts motion with zero initial velocity from elevation *h.* Following Rev. 1, RG 1.76, *h* = 40 m; however, calculations for *h* = 30 m, 20 m, and 10 m were also performed.

3. Wind speeds vary with height above ground in accordance with power law for (a) open terrain and (b) suburban terrain.

4. Missile drag coefficient is independent, on average, of missile position or relative missile speed with respect to wind flow.

Missile Spectrum

- *Missile spectrum contains all missiles considered in RG 1.76:*
- a=½ x 1.2 kg m^{-3} x 0.0043 m^2/kg =0.0026 m^{-1} (*Sch. 40 pipe*)
- a=½ x 1.2 kg m^{-3} x 0.0070 m^2/kg =0.0042 m^{-1} (*5 m x 2 m x 1.3 m automobile*; tornado regions I, II)
- a=½ x 1.2 kg m^{-3} x 0.0095 m^2/kg =0.0057 m^{-1} (*4.5 m x 1.7 m x 1.5 m automobile*; tornado region III)
- a=½ x 1.2 kg m^{-3} x 0.0034 m^2/kg =0.0021 m^{-1} (*Solid steel sphere*, C_D=0.41)

Additional missiles studied

($C_D = 1.2$)

- *Steel board batten siding coated w/ PVC*

  (3.05 m x 0.305 m, m = 3.8 kg; a = 0.176 m^{-1})

- *Slab*

  (3.05 m x 1.53 m, m = 38 kg; a = 0.085 m^{-1})

- *Plank*

  (A = 1 m^2, m = 9.06 kg; a = 0.079 m^{-1})

Numerical Solutions

- For all open and suburban terrain cases, equations of motion were solved numerically.

  To check the accuracy of the numerical solver, the equation of motion was solved for a case where a solution in closed form could be obtained (wind speeds invariant with height). Excellent agreement was found between numerical and analytical solutions (Appendix A).

Table 1 - Terminal horizontal missile speeds - 40 m, open terrain

	Missile Characteristic, a (m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
v_{10}	*Steel sph.*	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	9.9	11.7	16.6	20.1	37.9	37.5	34.8
45	12.1	14.2	19.9	24.0	42.5	42.1	38.9
50	14.4	17.0	23.4	28.0	47.1	46.6	42.9
55	17.0	19.8	27.1	32.1	51.7	51.1	46.9
60	19.6	22.9	30.9	36.4	56.2	55.5	50.8
65	22.4	26.0	34.9	40.8	60.7	59.9	54.7
70	25.4	29.3	39.0	45.3	65.1	64.2	58.5
75	28.4	32.8	43.1	49.8	69.4	68.5	62.3
80	31.6	36.3	47.4	54.4	73.8	72.7	66.0
85	34.9	39.9	51.8	59.1	78.0	76.9	69.7
90	38.3	43.7	56.2	63.9	82.3	81.0	73.3
95	41.8	47.5	60.7	68.7	86.5	85.1	76.9
100	45.3	51.4	65.2	73.6	90.6	89.2	80.4
105	49.0	55.4	69.9	78.5	94.7	93.2	83.9
110	52.7	59.4	74.5	83.4	98.8	97.1	87.3
115	56.5	63.6	79.2	88.4	102.8	101.0	90.8
120	60.4	67.7	84.0	93.4	106.7	104.9	94.2
125	64.3	72.0	88.8	98.4	110.7	108.8	97.5
130	68.3	76.3	93.6	103.5	114.6	112.6	100.8
135	72.3	80.6	98.5	108.6	118.5	116.3	104.1
140	76.4	85.0	103.4	113.7	122.3	120.1	107.4
145	80.6	89.5	108.3	118.8	126.1	123.8	110.6
150	84.8	94.0	113.2	123.9	129.9	127.5	113.9

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

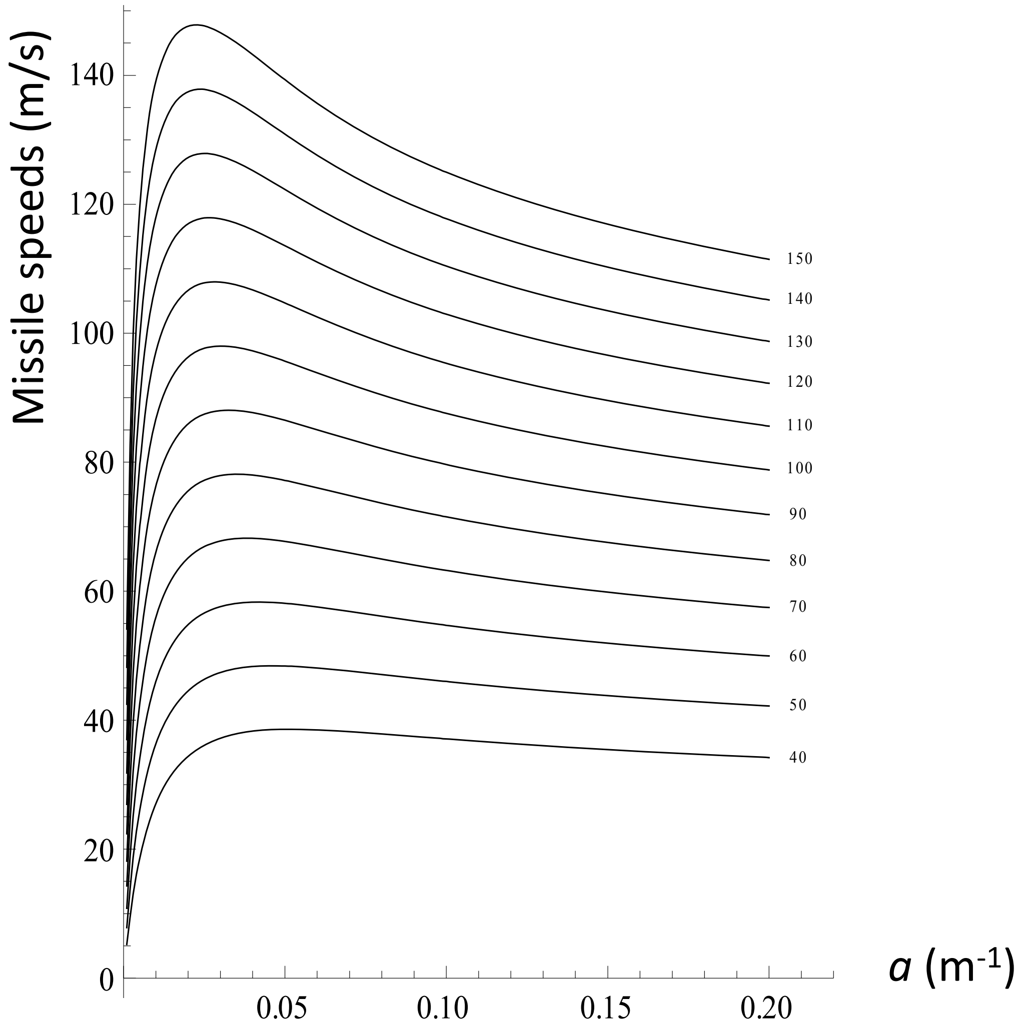
Table 2 - Terminal total missile speeds - 40 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	27.7 (69)	28.1 (65)	29.5 (56)	31.0 (49)	39.3 (16)	38.8 (15)	35.4 (11)
45	28.4 (65)	29.1 (61)	31.4 (51)	33.5 (44)	43.8 (14)	43.2 (13)	39.4 (9)
50	29.4 (61)	30.4 (56)	33.6 (46)	36.4 (40)	48.2 (12)	47.6 (12)	43.4 (8)
55	30.6 (56)	31.9 (52)	36.2 (41)	39.6 (36)	52.7 (11)	51.9 (10)	47.3 (7)
60	32.0 (52)	33.8 (47)	39.0 (38)	43.1 (32)	57.1 (10)	56.3 (9)	51.2 (7)
65	33.8 (48)	35.9 (44)	42.2 (34)	46.8 (29)	61.4 (9)	60.6 (9)	55.0 (6)
70	35.7 (45)	38.3 (40)	45.5 (31)	50.7 (27)	65.8 (8)	64.8 (8)	58.8 (5)
75	37.9 (41)	40.9 (37)	49.1 (29)	54.8 (25)	70.1 (8)	69.0 (7)	62.5 (5)
80	40.2 (38)	43.7 (34)	52.9 (26)	59.0 (23)	74.3 (7)	73.2 (7)	66.2 (5)
85	42.8 (35)	46.8 (31)	56.8 (24)	63.3 (21)	78.5 (7)	77.3 (6)	69.9 (4)
90	45.5 (33)	49.9 (29)	60.8 (22)	67.8 (19)	82.7 (6)	81.4 (6)	73.5 (4)
95	48.5 (30)	53.3 (27)	64.9 (21)	72.3 (18)	86.9 (6)	85.5 (5)	77.0 (4)
100	51.5 (28)	56.7 (25)	69.2 (19)	76.9 (17)	91.0 (5)	89.5 (5)	80.5 (3)
105	54.7 (26)	60.3 (23)	73.5 (18)	81.6 (16)	95.0 (5)	93.5 (5)	84.0 (3)
110	58.0 (25)	64.1 (22)	78.0 (17)	86.4 (15)	99.1 (5)	97.4 (4)	87.5 (3)
115	61.5 (23)	67.9 (21)	82.5 (16)	91.2 (14)	103.1 (4)	101.3 (4)	90.9 (3)
120	65.0 (22)	71.8 (19)	87.0 (15)	96.0 (13)	107.0 (4)	105.2 (4)	94.2 (3)
125	68.7 (21)	75.8 (18)	91.7 (14)	100.9 (13)	110.9 (4)	109.0 (4)	97.6 (2)
130	72.4 (19)	79.9 (17)	96.3 (14)	105.8 (12)	114.8 (4)	112.8 (3)	100.9 (2)
135	76.2 (18)	84.0 (16)	101.1 (13)	110.8 (12)	118.7 (3)	116.5 (3)	104.2 (2)
140	80.1 (17)	88.2 (15)	105.8 (12)	115.8 (11)	122.5 (3)	120.3 (3)	107.5 (2)
145	84.0 (16)	92.5 (15)	110.6 (12)	120.8 (11)	126.3 (3)	124.0 (3)	110.7 (2)
150	88.1 (16)	96.8 (14)	115.5 (11)	125.9 (10)	130.0 (3)	127.6 (3)	113.9 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Figure 1 - Terminal horizontal missile speeds - 40 m, open terrain



Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40,50,…,150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Example Missile Speeds

- *For 125 m/s [103 m/s], 3-s hurricane wind speeds at 10 m above ground in open terrain*, calculated maximum horizontal missile speeds over open terrain for *h* = 40 m (20 m; 10 m) are approximately

- Solid steel sphere:
- 64 m/s [47 m/s] (46 m/s [33 m/s]; 32 m/s [22 m/s])

- Schedule 40 pipe:
- 72 m/s [53 m/s] (53 m/s [38 m/s]; 37 m/s [26 m/s])

- 5 m automobile, tornado Regions I and II):
- 89 m/s [67 m/s] (69 m/s [51 m/s]; 51 m/s [37 m/s])

- 4.5 m automobile, tornado Region III):
- 98 m/s [76 m/s] (79 m/s [59 m/s]; 60 m/s [45 m/s])

Design-basis tornado-borne missile horizontal speeds in RG 1.76

Region I -- *design-basis maximum tornado wind speed 103 m/s (230 mph)*

- 8 m/s (solid steel sphere),
- 41 m/s (Schedule 40 pipe),
- 41 m/s (5 m automobile).

Region II -- *design basis maximum tornado wind speed 89 m/s (200 mph)*

- 7 m/s (solid steel sphere)
- 34 m/s (Schedule 40 pipe)
- 34 m/s (5 m automobile).

Region III -- *design-basis maximum tornado wind speed 72 m/s (160 mph)*

- 6 m/s (solid steel sphere)
- 24 m/s (Schedule 40 pipe)
- 24 m/s (4.5 m automobile, Region III).

Conclusions

- For the seven types of missile of interest, tables are provided which list missile speeds at the time the missile reaches the ground level, for hurricane wind speeds at 10 m above ground in open terrain ranging from 40 m/s to 150 m/s in increments of 5 m/s, and for flow over (a) open terrain and (b) suburban terrain.
- Both horizontal missile speeds and total missile speeds (resultants of horizontal and vertical speeds) are listed.
- Plots showing those missile speeds as function of a parameter characterizing the missile properties are also provided. Similar tables and plots list maximum (as opposed to terminal) missile speeds.

Regulatory Guide 1.221 Public Comments

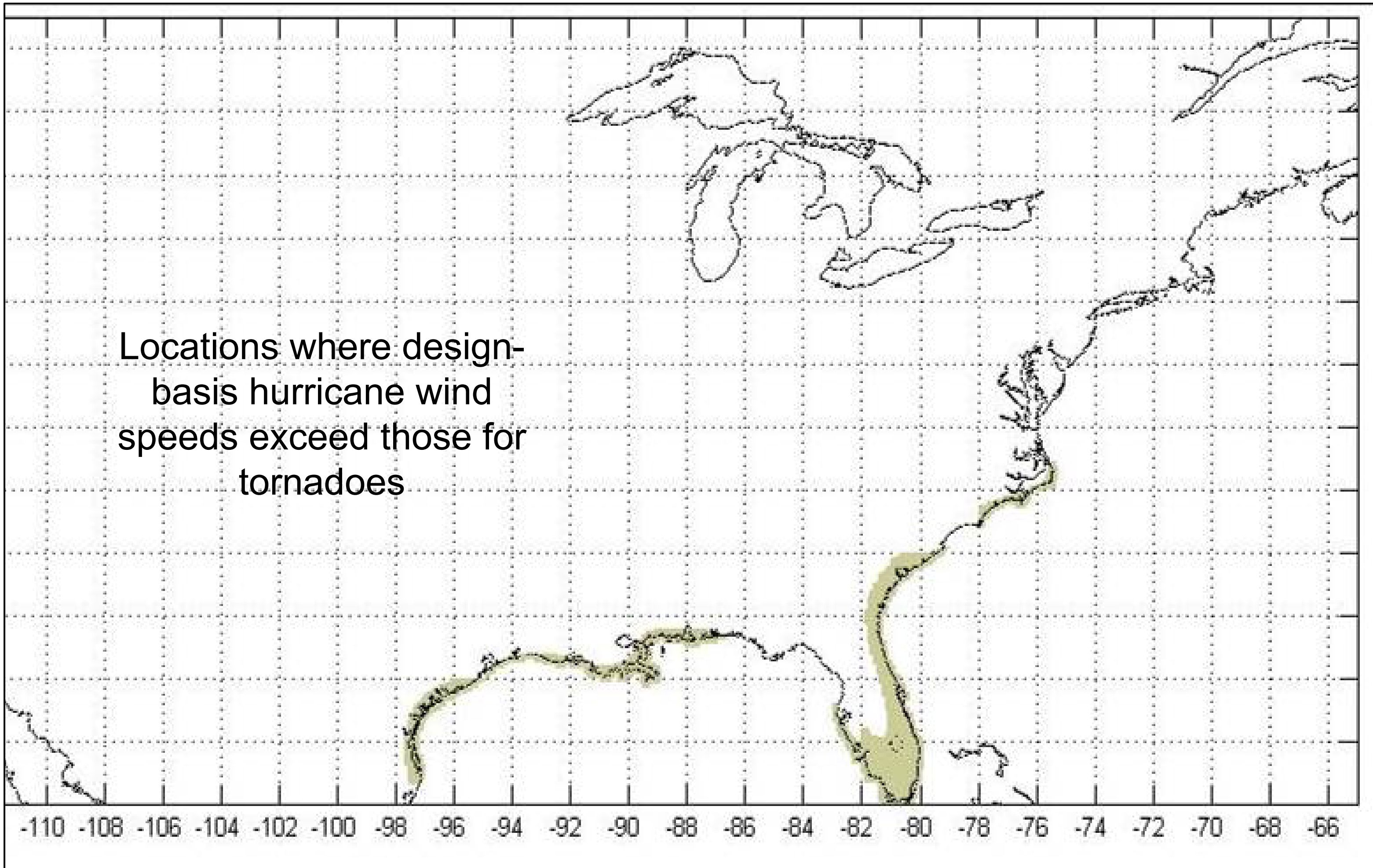
Dr. Selim Sancaktar

NRC Office of Nuclear Regulatory Research

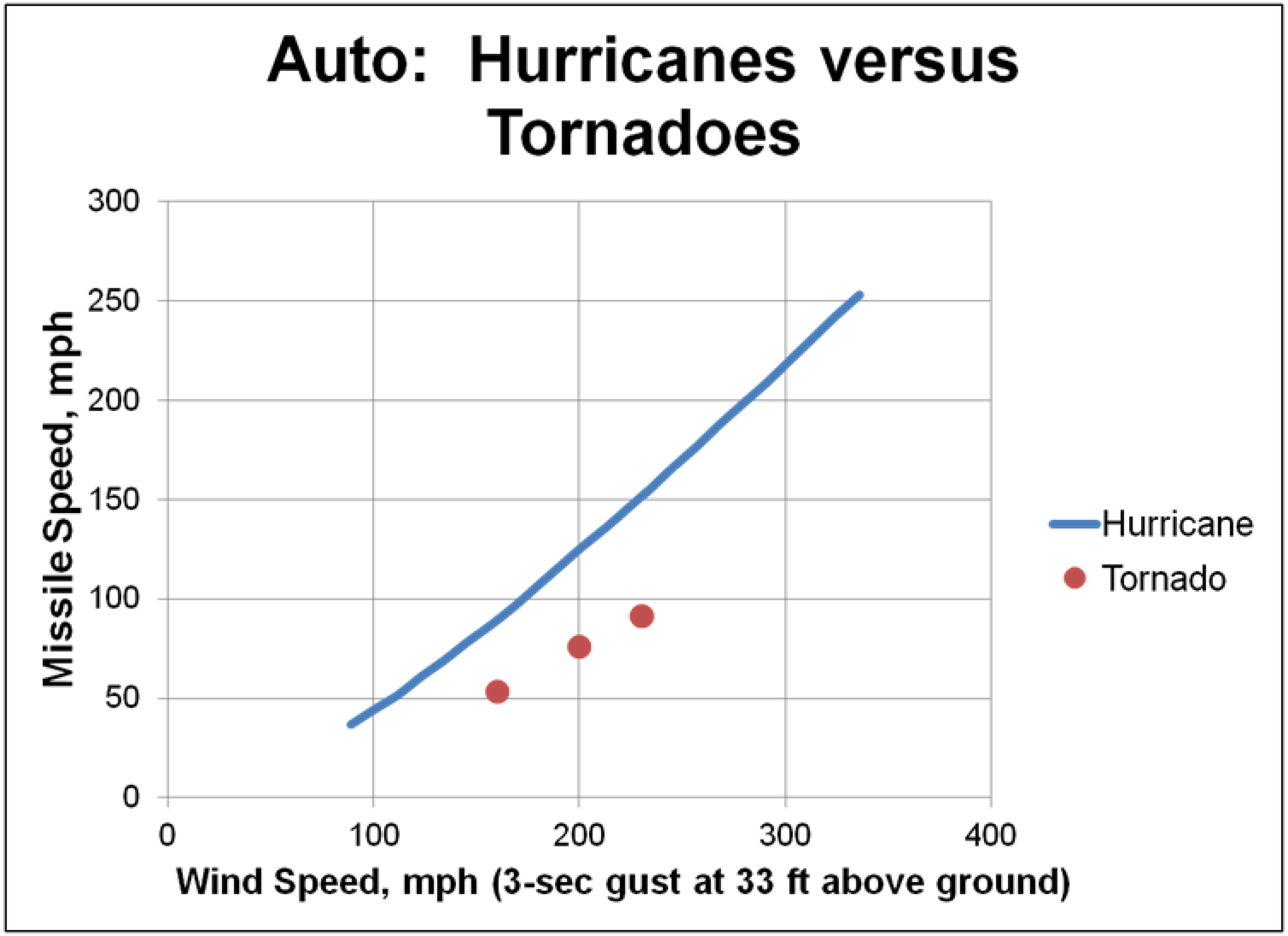
Public Comments and Conclusion

- Three comments were received after the public comment period was closed.
- The comments were addressed; none of the comments impacted the essence of the RG and the NUREG/CRs.
- Four documents are created and are ready to be declared as final (RG, two NUREG/CRs and responses to the public comments).

Design-Basis Hurricane Wind Speeds



Maximum Horizontal Missile Speeds



Maximum Horizontal Missile Speeds

- The same missile has a higher maximum velocity in a hurricane wind field than in a tornado wind field with the same maximum (3-sec gust) wind speed
  - Tornado missiles are subject to the strongest winds only at the beginning of their flights
  - Hurricane missiles are subjected to the highest wind speeds throughout their trajectory

Conclusions

- Design-basis hurricane wind speeds are higher than those for tornadoes along the coastline south of the border between North Carolina and Virginia
  – Maximum: 290 mph in the Florida keys
- Airborne missiles fly faster in a hurricane wind field as compared to a tornado wind field of the same strength

Backup Slides

Tornado Model

$$P\ (u \geq u_o) = P_p\ (u \geq u_o) + P_l\ (u \geq u_o)$$

Point Structure Term

$$P_p\ (u \geq u_o) = P_p \times P_p\ (u \geq u_o\ |s)$$

$$P_p = A_t\ /\ (N\ A_r)$$

$$P_p\ (u \geq u_o\ |s) = A_{u \geq u_o}\ /\ A_t$$

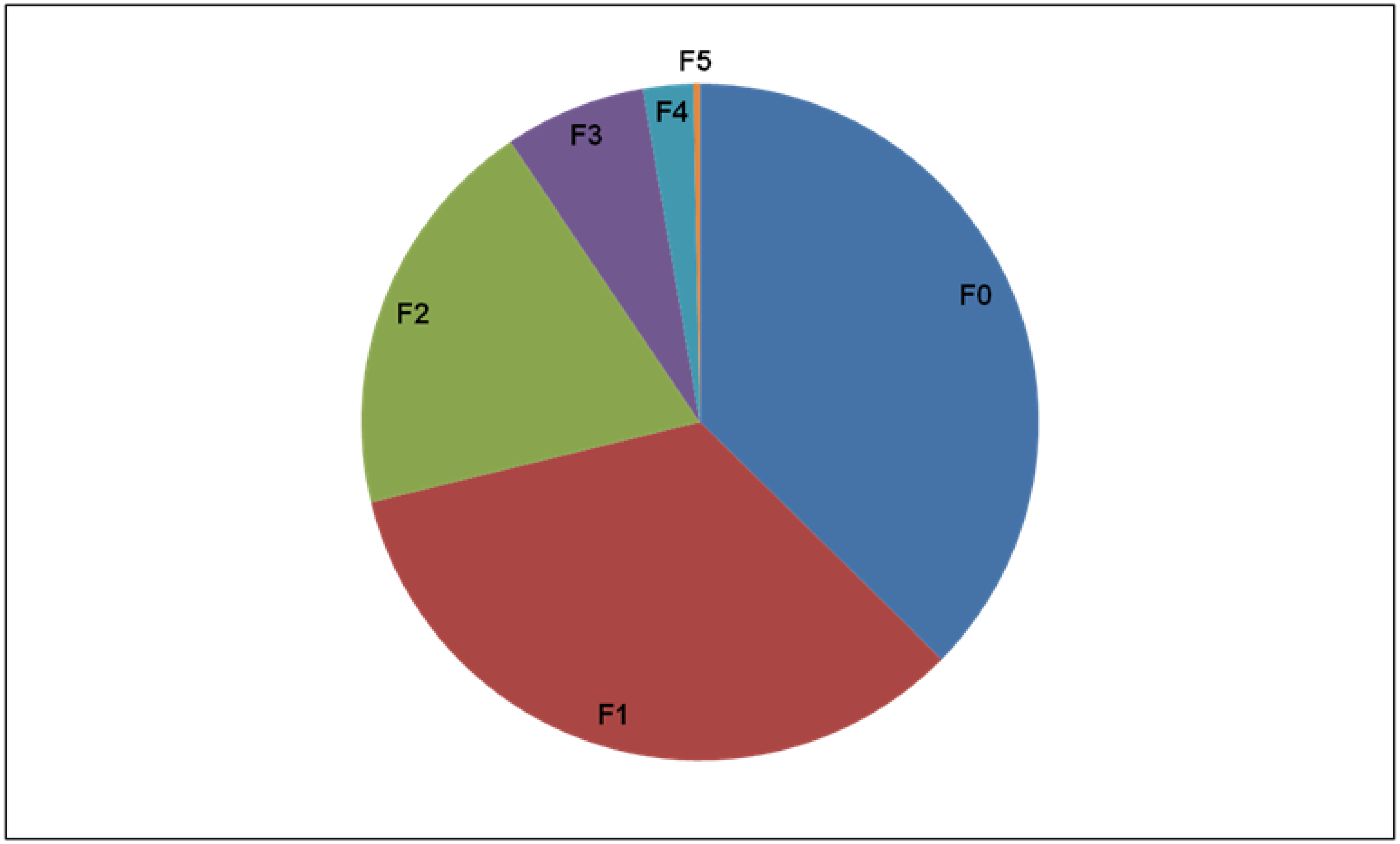
Large Structure Term

$$P_l\ (u \geq u_o) = P_l \times P_l\ (u \geq u_o\ |s)$$

$$P_p = A_t\ /\ (N\ A_r) = (w_s\ L_t)\ /\ (N\ A_r)$$

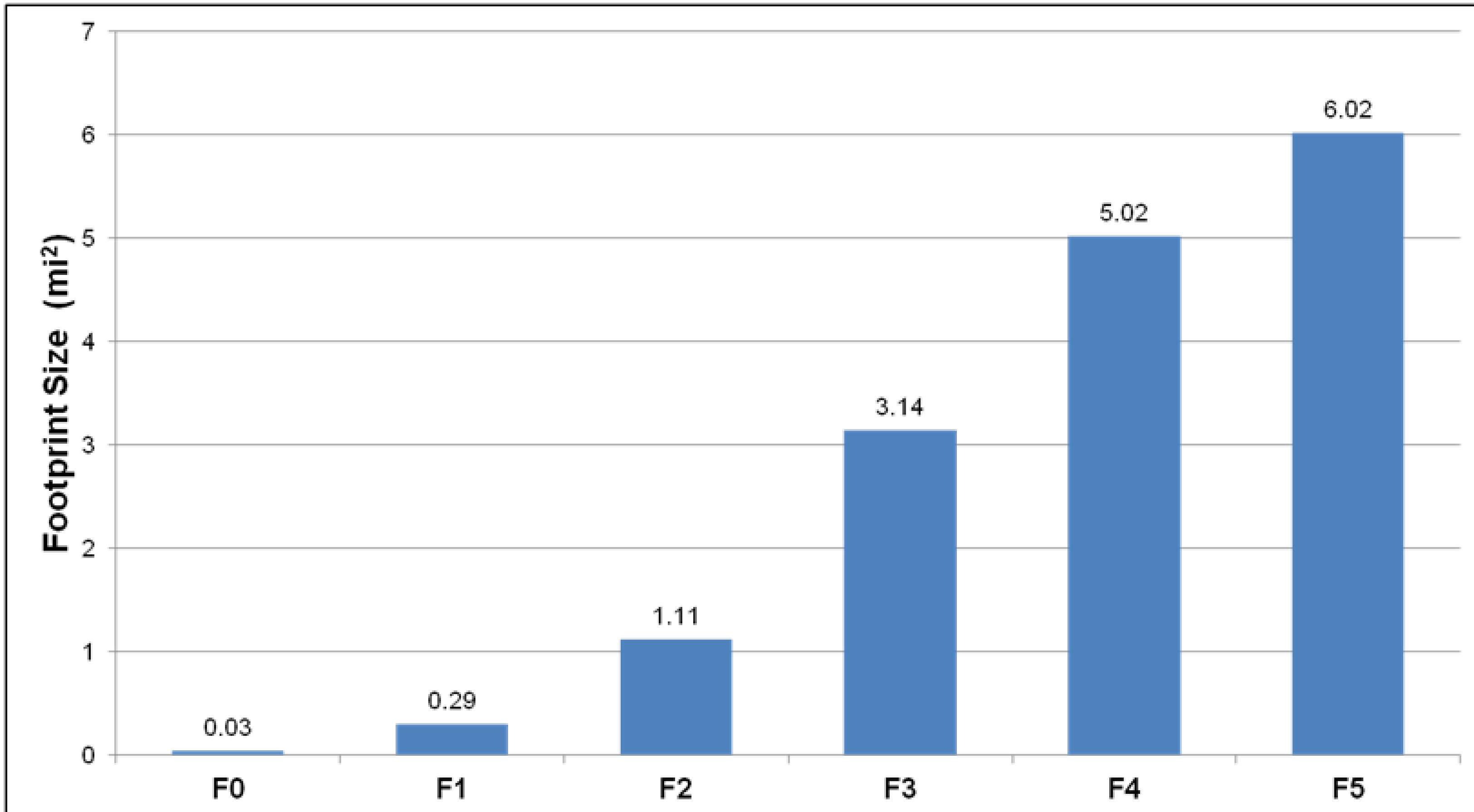
$$P_l\ (u \geq u_o\ |s) = L_{u \geq u_o}\ /\ L_t$$

Frequency of Reported Tornado Intensities
Jan 1950 - Aug 2003

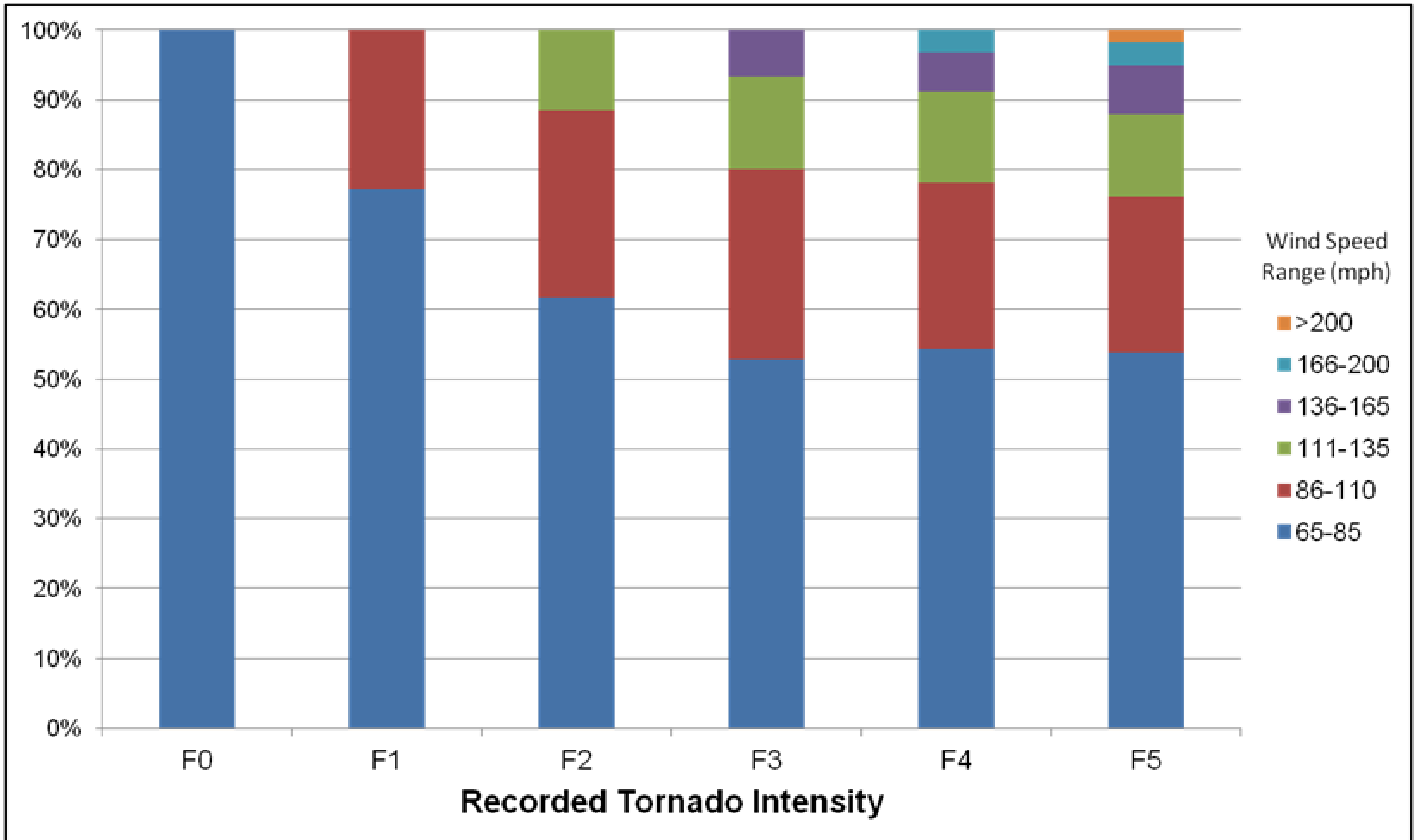


Size of US Tornadoes as a Function of Reported Intensity

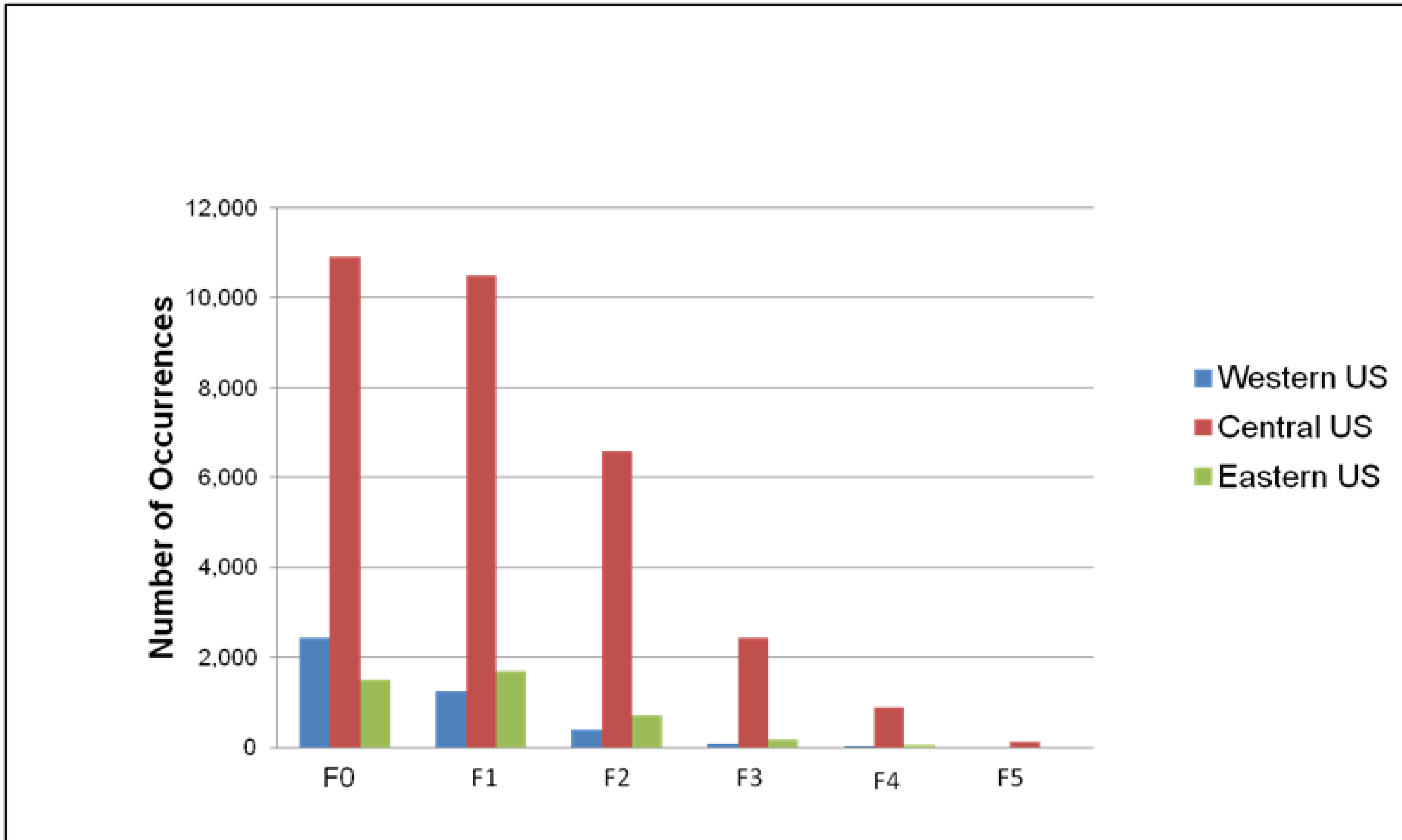
Jan 1950 - Aug 2003



Variation of Wind Speed within the Impact Area

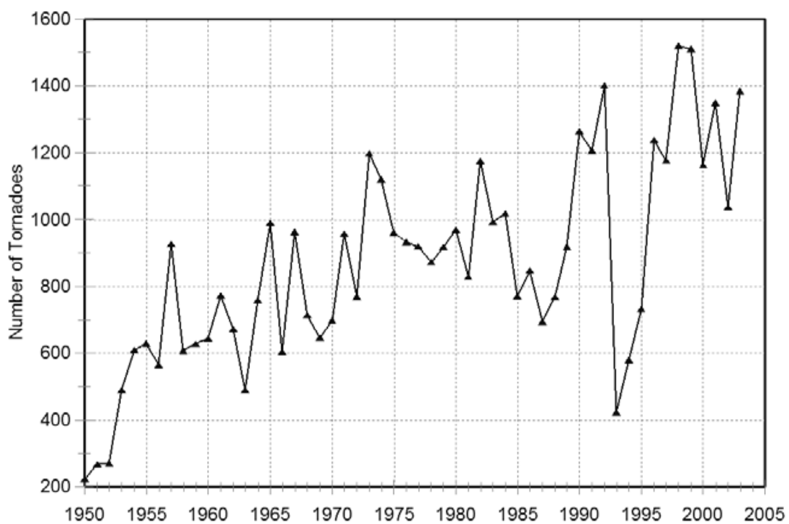


Regional Tornado Statistics
Jan 1950 - Aug 2003

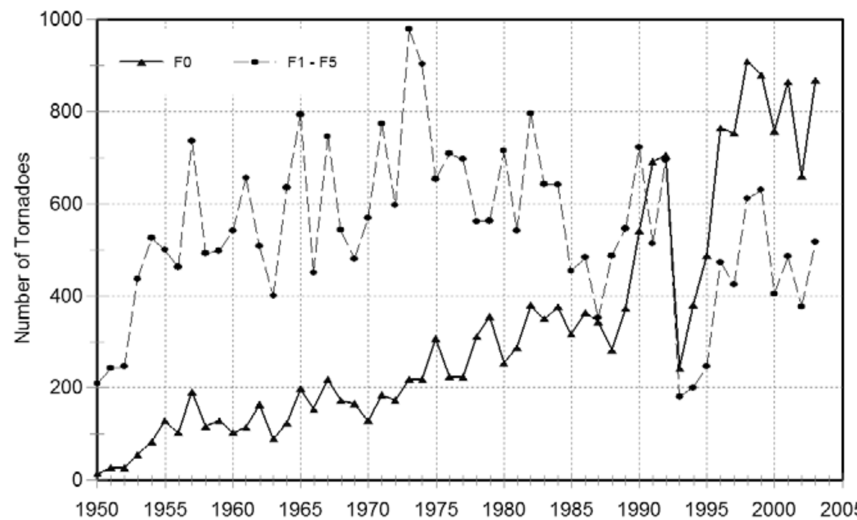


Tornado Frequency Trends

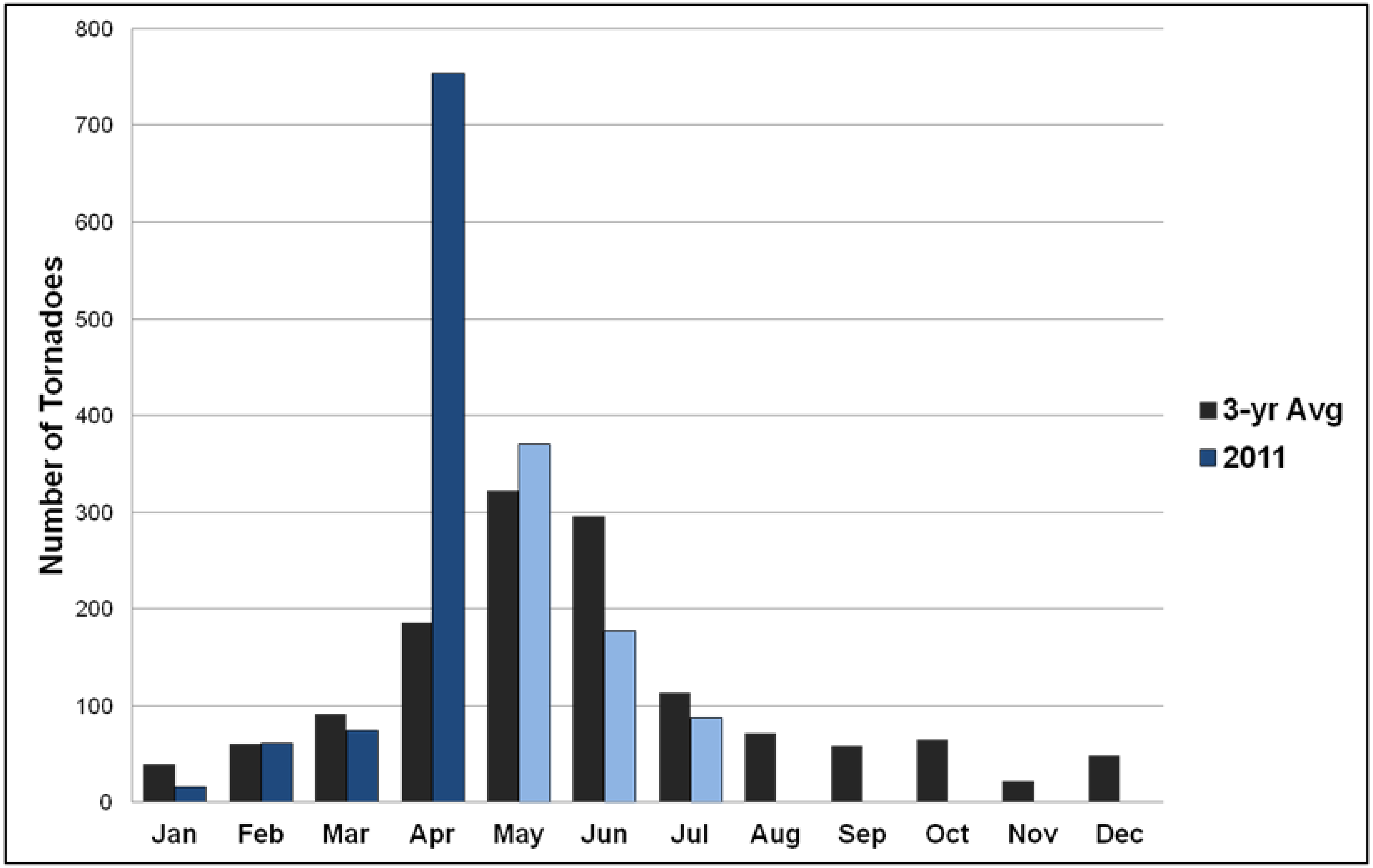
Annual Number of Reported Tornadoes
(Jan 1950 - Aug 2003)



Number of F0 and F1-F5 Tornadoes
(Jan 1950 - Aug 2003)

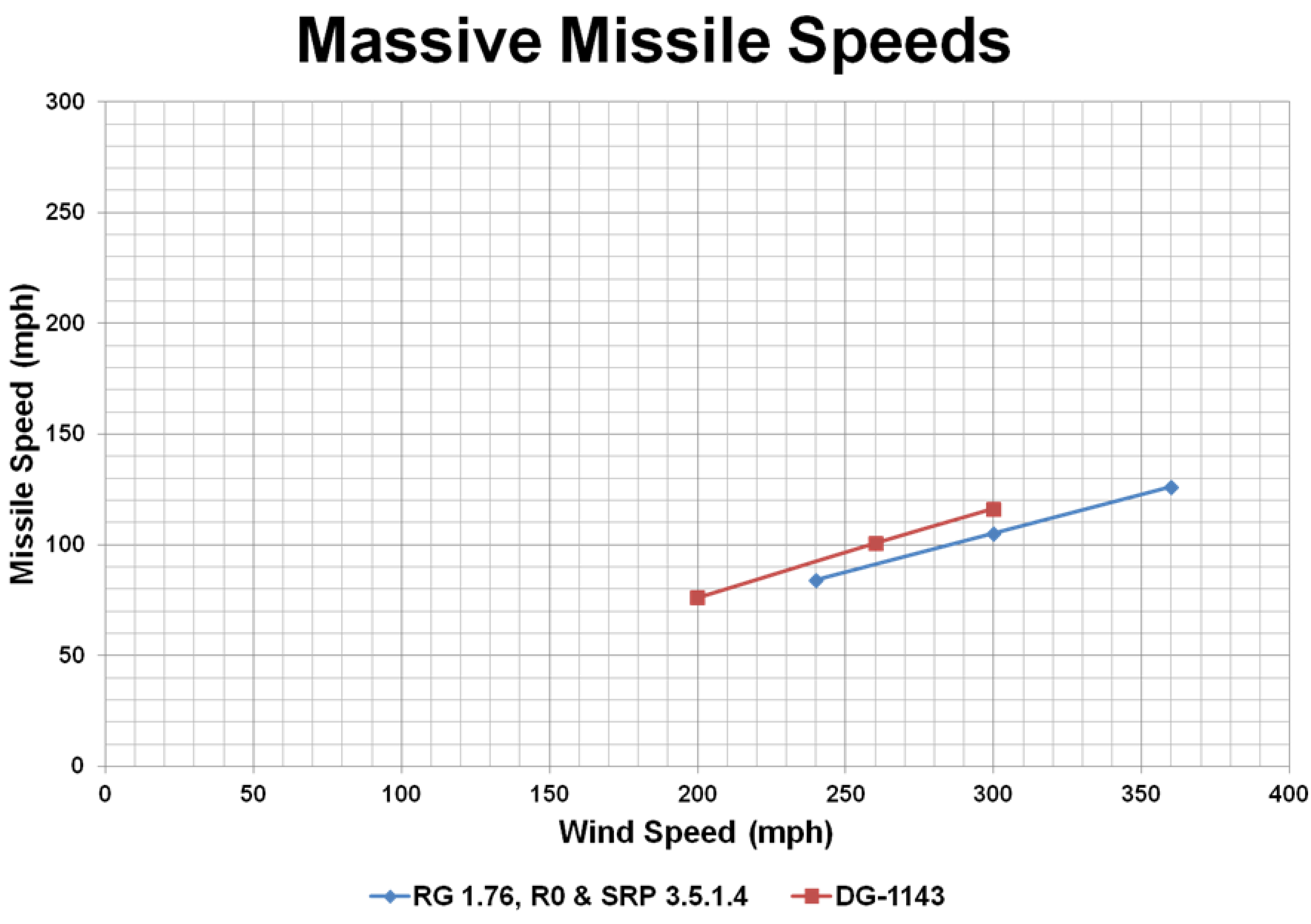


2011 Tornado Statistics



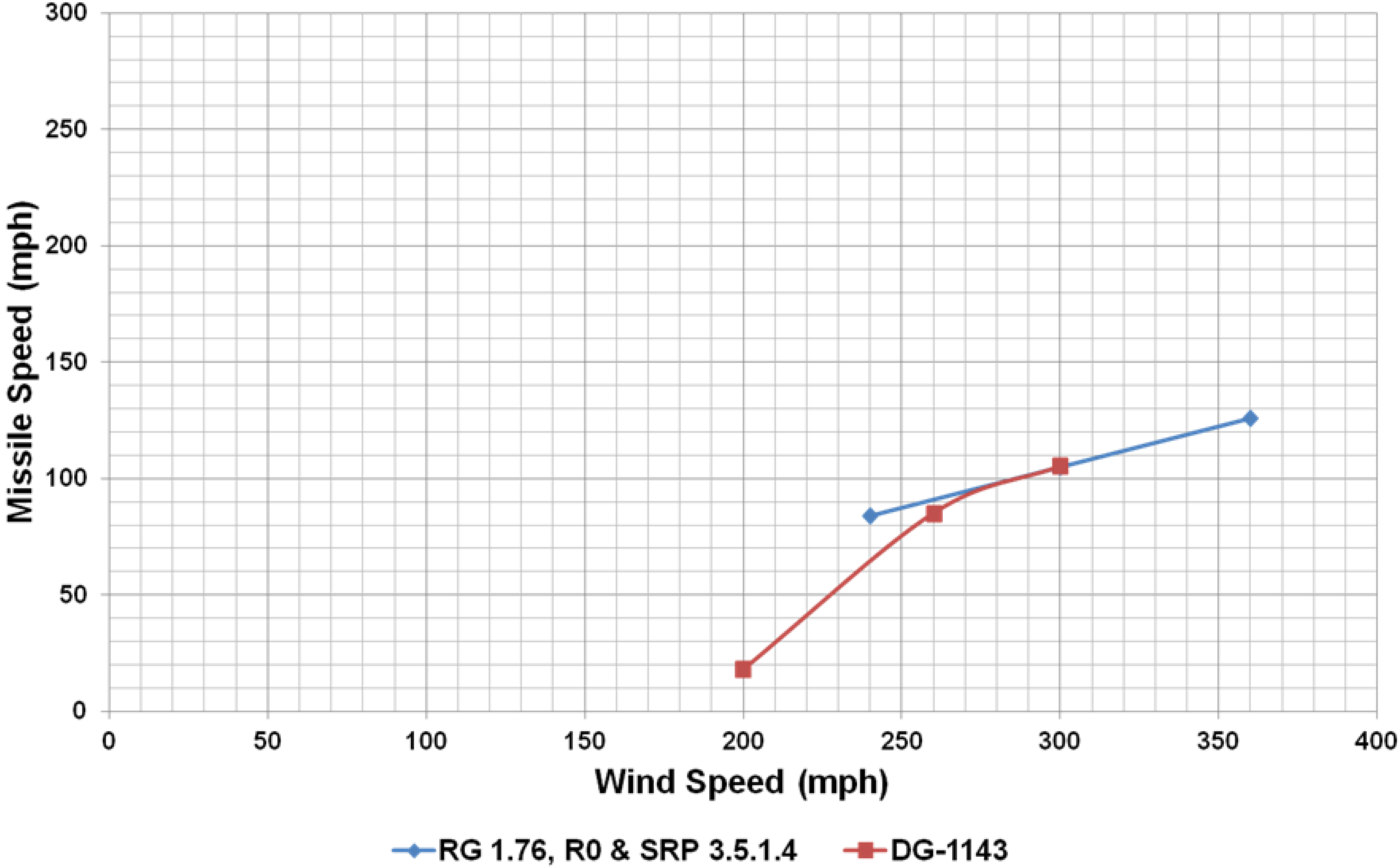
Recommended Tornado Design Wind Speeds

	124	122	120	118	116	114	112	110	108	106	104	102	100	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66
47	0	144	130	158	142	91	103	159	168	164	198	180	199	186	186	183	213	195	169										191	
45	117	138	127	148	137	107	124	132	150	154	177	194	200	204	205	212	217	213	212	208	183	210						95	166	179
43	84	119	113	71	148	114	147	148	151	162	186	197	201	211	216	221	223	222	220	215	212	215		184	203	176	179	169	172	170
41	133	0	100	0	0	123	146	137	132	158	177	198	207	219	225	225	228	230	223	226	225	220	221	222	204	197	201	200		
39	152	151	130	148	83	146	125	142	123	120	177	191	210	223	229	230	225	227	227	226	225	215	202	203	200	202	172			
37		162	142	81	0	108	130	117	125	151	161	192	215	225	232	229	220	219	224	223	218	205	189	194	201	194				
35		159	134	140	0	138	142	124	112	136	163	194	217	229	235	228	226	227	226	229	219	200	208	206	193	195				
33			76	160	153	140	141	148	72	144	164	198	212	221	226	227	227	226	228	228	219	213	207	214	188					
31					135	140	142	148	145	151	161	187	200	207	214	222	221	223	224	219	215	210	195	193						
29		Region 1 -- 230 mph									123	182	183	200	208	211	211	204	211	205	203	198	199							
27		Region 2 -- 200 mph											203	186	196	173						212	198							
25		Region 3 --160 mph												181	192							227	191							

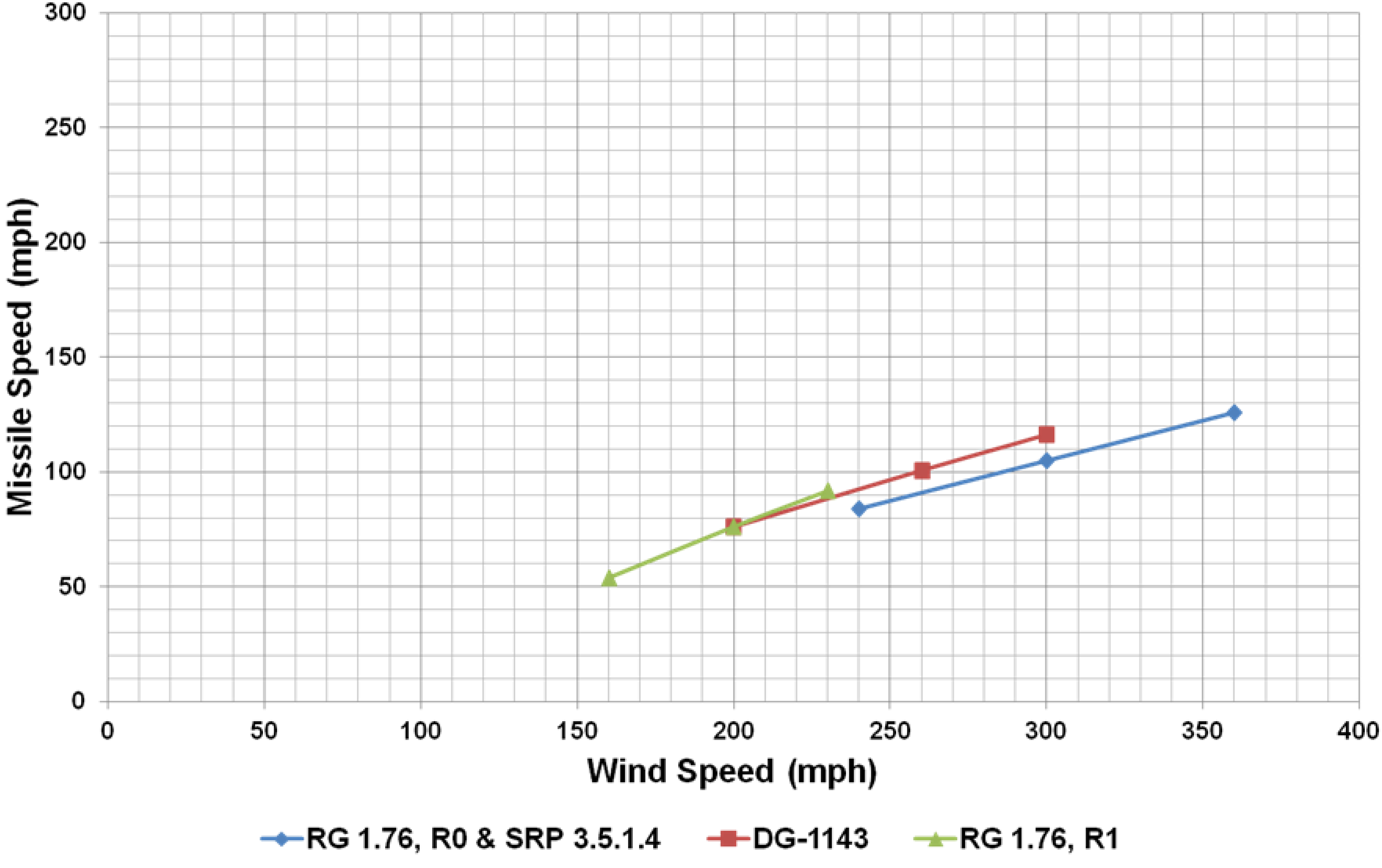


Massive Missile Speeds
Missile Speed (mph)
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
Wind Speed (mph)
RG 1.76, R0 & SRP 3.5.1.4
DG-1143

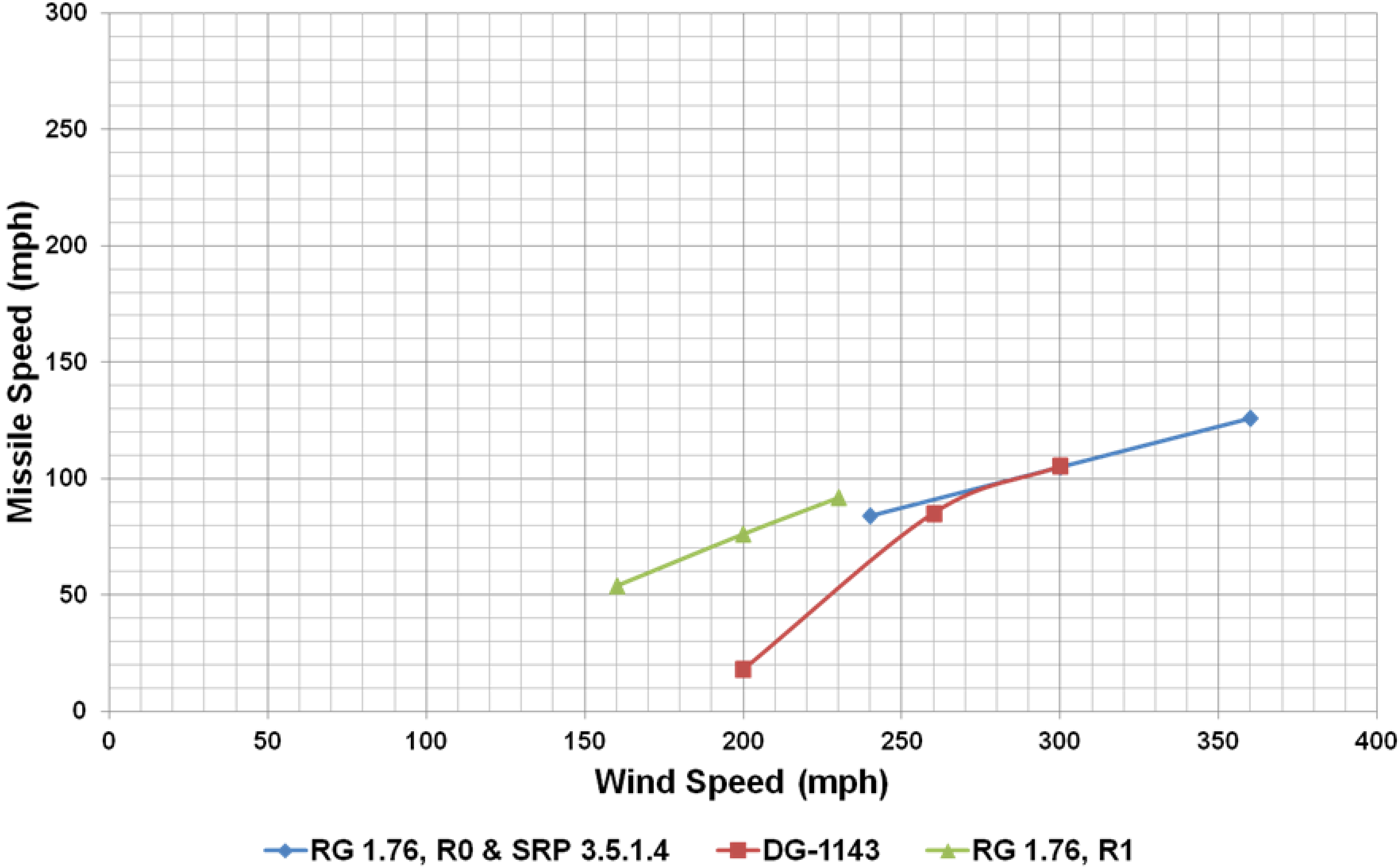
Rigid Missile Speeds



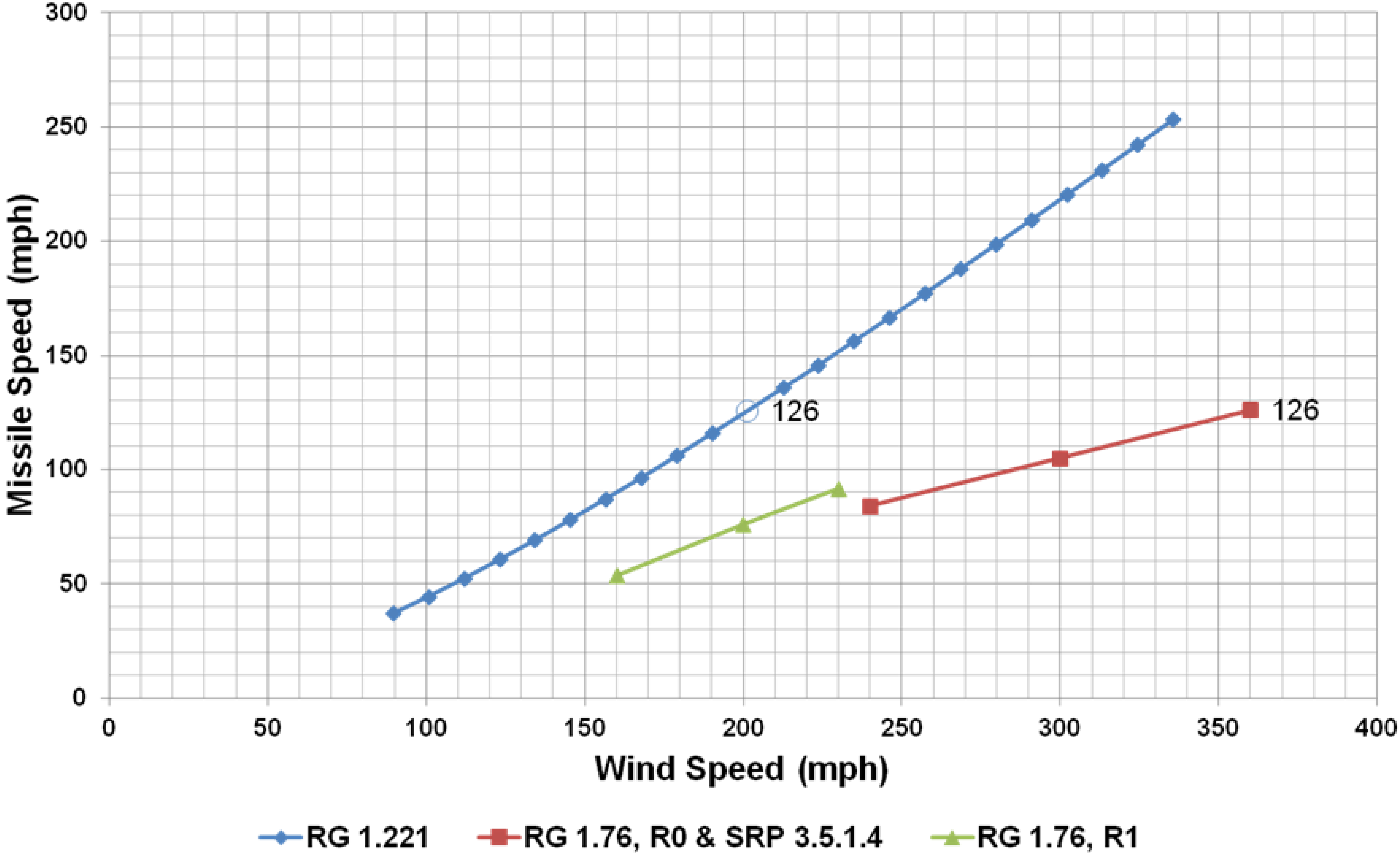
Massive Missile Speeds

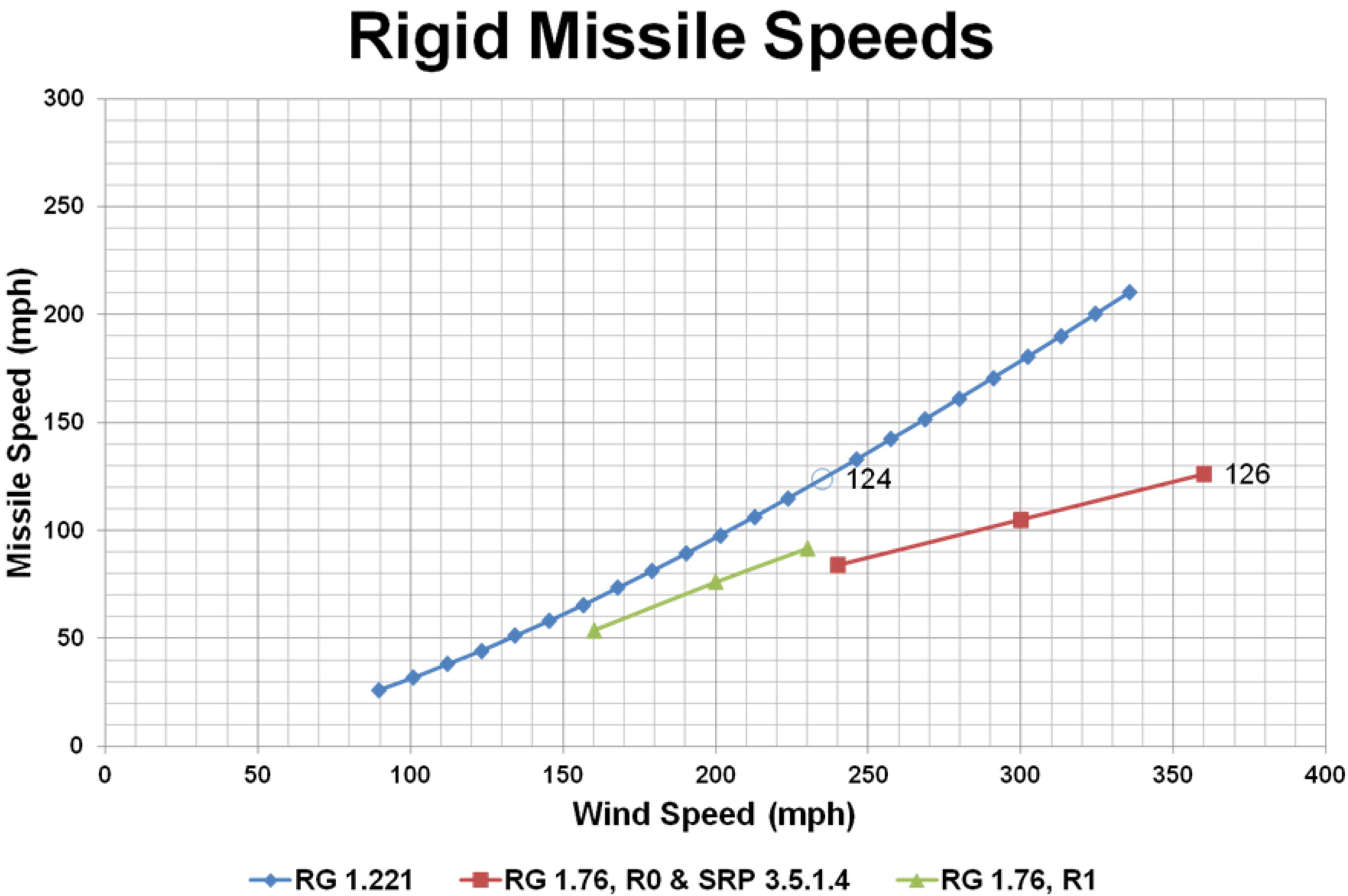


Rigid Missile Speeds



Massive Missile Speeds





Rigid Missile Speeds
300
250
200
150
100
50
0
Missile Speed (mph)
0
50
100
150
200
250
300
350
400
Wind Speed (mph)
124
126
RG 1.221
RG 1.76, R0 & SRP 3.5.1.4
RG 1.76, R1