Design Conditions for the Hurricane Metocean Environment
January 15, 2015

Coordinator: Welcome and thank you for standing by. At this time all participants are in a listen-only mode. Today's conference is being recorded. If anyone has any objections, you may disconnect at this time. Now I'd like to go ahead and turn today's call over to Joel Klein. Sir, you may begin.

Joel Klein: Thank you, appreciate everybody being here today and trying to listen-in. we've got an exciting presentation and panel of experts and so I'm quite glad to be the moderator for this session so first I wanted to go through a few slides if we can. Maybe we can't.

Well, while we're bringing-up the slides, let me go ahead and utilize the time I have to talk about DOE and while we're interested in wind resource assessment and characterization for a long-term strategy, as you know wind is the fuel and there are a lot of complexities in resource assessment.

And also resource characterization that lead to risk for our users so who are the users? Anybody in the wind industry and the wind plant owner and operators and utilities and ISOs play a great deal for risk if it's high.

For example if an ISO is trying to count on wind power to generate power for an expected power load in a nearby urban area and the wind doesn't blow as forecast, do the lights go out because you were counting on a certain amount of wind in addition to the natural gas and coal or nuclear or other forms of fuel.

Consequently on the flip side if you had more wind than was forecast, do you have the ability to make money by putting that onto the grid so both over forecasting and under forecasting winds lead to dollar penalties to pay for

those situations, thus even that the fuel the wind is free, the risk costs significant amount of dollars on the daily operations.

It also costs dollars for siting and for proper equipment which is more of resource assessment, proper equipment being what turbines to use for what expected wind speed, where to locate the plant, how to situate the plant and align to the wind.

You can only do that by understanding the resource in the near term and what's expected over the lifetime of the wind power plant and DOE research has worked on these items to help lower the risk and thus the percentage interest rate for bank loans to lower the cost of investment as many as there is so why do we need to get better at all at wind characterization?

Why not just use the weather models that we have out there today? What's wrong with that? Well, weather models are set on temporal scales that are about an hourly time scale and that's if they're rapidly-refreshed models. Those are a special kind of model that look at time scales on that.

The energy market and the wind industry operates on about 10-minute time scales so there's a difference right there. Spatially weather models are designed for data that's on scales of 13 kilometers or greater and thus we can ignore a whole lot of changes in the horizontal plane of reference as well as we can ignore a great deal of changes in topography.

The wind industry needs items that are on a scale of 100 meters or less, thus these factors can no longer be assumed to be equal or similar to provide a quality forecast for the wind industry.

Now offshore part of the portfolio provides a complete new challenge because there are virtually no data observations to input into the forecast models at heights that are of use for wind turbines and wind power.

We also therefore have no reference points to learn how we can therefore correct errors in our forecasts or not and we're on the verge of in this country investing billions of dollars in that arena, making it a very high-risk arena. Now then further subdividing and looking down at the particular interests are high-risk event, extreme storms.

Those are ones that may not come along so often but will cause the huge dollar losses for our industry and nothing is more of an extreme event than a hurricane and today our Webinar tries to look head-on at this issue with a panel of three of my friends, colleagues and experts in this field.

I myself have been asked to moderate this session due to my background which I started out working nine years at the National Hurricane Center, moving from an entry-level position to what is equivalent to today's junior-level hurricane specialist in my last two hurricane seasons down there.

My graduate work was also in the field of tropical meteorology and oceanography and I'm very happy to be here and moderate today's session. You can see our list of panelists and I'll introduce them here in a short while.

I want you to pay particular instance to the bottom of Slide 2 here, the question-and-answer period and how to ask a question. Just click the Q&A at the top of the Live Meeting window, type-in your question and click ask to send the question. We'll look at those and we'll try and present as many as we can to our speakers.

Okay, so they have a lot of these wind exchange Webinars on the 3rd Wednesday of each month at 3:00 pm Eastern. Next one you can see there coming up.

And wind exchange contacts there is my information, (Bree) is standing right here next to me, helping me with this information. Ian Baring-Gould out of NREL and Suzanne Tegen at NREL as well and we'd like to thank all of you for being in attendance.

So without further ado I'd like to introduce our first speaker, Mark Powell who I met essentially from my first day in the Weather Service and then since have been over at DOE but he worked out at Key Biscayne, Florida for about 30 years there at the Hurricane Research Division.

He's since gone on to start his own company, HWind Scientific, a tropical cyclone impact services start-up located in Florida's capitol city of Tallahassee and so he is also working part-time at Florida State University's Center for Ocean, Atmospheric and Prediction Studies.

I can personally attest that he's published extensively in a variety of peer-review journals and does great work in those publications as well, taking a look at the destructive potential of hurricane risk and new metrics for hurricane destructive potential.

He serves as a meteorology team leader for Florida Public Hurricane Loss Model as well as being a distinguished American Meteorological Society Fellow and holding AMS certified consultant meteorologist designation. Mark would you please start us off here?

Mark Powell: Thank you very much Joel. I'd like to acknowledge - or Joel just acknowledged - where I'm currently working part-time for Florida State University and I wanted to spend a few seconds talking about this image here which is from Hurricane Isabel not too far off the site of one of one of our demonstration projects.

This is from an altitude of about 65 meters to this is about as low as you can get in a hurricane reconnaissance aircraft and safely take a photograph and it shows you some of the complexity of the sea surface in a hurricane and the sea surface or sea state is really key in determining the wind profile in a hurricane.

And so how that sea state changes with time depends on where you are in the storm and what types of waves and swells are moving through the area, sometimes with different directional properties, different wavelength properties and you can also see the white patches there so when a wave breaks a lot of air is ingested into the water column.

These form into bubbles and the bubbles have relatively long life cycles. It takes them a while to get up to the surface and while they're doing that they tend to elongate out into streaks and as the wind continues to increase and white-capping increases and wave breaking increases, you have more and more air being injected and it's more going in than is coming out.

So pretty quickly the entire sea surface goes white by the time you get to winds on the order of 100 knots and the surface roughness properties of the ocean really change as the behavior is manifested.

So going on to the second slide, this is just showing the affiliation here. This work is supported by an interagency agreement between the DOE and NOAA,

NOAA's hurricane research division at which I worked for up until about April and now I'm with Florida State which is a part of this cooperative institute between NOAA's AOML lab and a bunch of regional universities.

Next slide, what we're talking about here is looking at the design conditions and these are covered by a lot of different standards which mostly have origins in Europe but certainly hurricanes are capable of creating damage to very large structures that for example in the Gulf of Mexico from Hurricane Ike.

Next slide, when you go and look into some of these standards in depth and the standards are primarily developed for offshore structures used for oil and gas exploration and operations. It turns out that a lot of the information on the wind profile is based on data from a field study in the Norwegian Sea and this is very carefully done field study.

But the study did not include hurricane conditions and there may have been some because these are low-lying islands there may have been some differences between the kinds of information you get in a field study here and one that might be made out in the open ocean.

So that's moving on to the next slide, here's some examples where some of these standards are a little out of touch. For example in the IAC and DNV assessment of wind conditions, this statement that the roughness increases with wind speed and turbulence intensity should also increase with wind speed when a large body of work has indicated that this is really a function of roughness and sea state.

This also extends to the American Bureau of Shipping standard and the API guidelines where a power law profile is specified which is actually equivalent

to conditions over land rather than marine conditions so these standards need to reflect information that's relevant to hurricanes that affect the coastal U.S.

So how do we get information on - if we go to the next slide - how do we get this information? We need to sample the wind profile and we need to sample a lot of wind profiles and so we use this instruments called the GPS sonde which is depicted here as a little parachute.

It's a little cylinder just a couple of feet long, a few inches in diameter and these instruments have been dropped by the NOAA P3 research aircraft and the Air Force C-130 operational hurricane hunter aircraft since the late 1990s.

And the next slide shows a radar image of the eye wall of a couple of hurricanes which show the trajectories of these sondes when they're dropped and as the sonde drops it's falling at about 10 meters per second and when it gets into the boundary layer, it's subject to the inflow so it tends to turn more in towards the center of the storm.

So if hundreds of these profiles that we've looked at in the eye wall regions to get an idea of what the main profile is like and the next slide shows a series of profiles that we published in Nature with my co-authors Peter Vickery who's going to be talking next and Tim Reinhold from the Institute for Business and Home Safety.

And so when you compile 50 or 60 of these sondes in similar wind conditions, you can see a logarithmic wind profile and from that profile you can deduce the roughness and the sheer stress so the next slide depicts that profile. The open circles here represent a profile indicated from these open ocean conditions from GPS sonde.

So if you were starting with a reference wind speed of a little over 50 meters per second Category 3 conditions near to surface at 10 meters and you wanted to estimate the winds at the hub height of the turbine and here we're showing a turbine with 100-meter hub height, it's very dependent on what kind of wind profile you're going to use.

So if you use something based on the actual hurricane conditions in the open ocean, by the time you get up to 100 meters as shown in this open circle wind profile, the winds are around close to 60 meters per second but if you use the profiles that are in some of these standards, they have too much sheer in them so you get something more, you know, closer to about 70 meters per second.

And then the opposite problem if you're starting with a reference wind at the 100-meter height, let's say Category 3 conditions and then you want to work that back down to see what that represents at 10 meters and you use these profiles that have too much sheer in them, you're going to get a reference wind that's too low.

It'll be - it'll go - to Category 2 or 1 conditions so this is really important in how we establish the design conditions for these turbines so they can withstand hurricanes. Now there's a field component to this. If we go to the next slide, it's just showing a map, the general location of the demonstration project off Virginia Beach.

And the next slide shows a depiction of a field program between DOE and NOAA to try to collect additional wind profile measurements in the vicinity of any planned demonstration locations.

And this is considered what's called a piggyback type of a pattern which means that you're using somebody else's flight hours, somebody else is paying

for the flight and you're hoping that they're going to pass close enough to an area of interest where you can drop the GPS sonde.

Now if we go to the next slide, we actually had kind of a test run for this this past season. Hurricane Arthur passed about 90 nautical miles away from the planned demonstration side off of Virginia Beach and the next slide shows the locations of the GPS sonde, drop locations associated with Hurricane Arthur.

Unfortunately there's a gap there just off of Virginia Beach at least perpendicular to the track there and that happened to be associated with a flight that got cancelled and the flights before the storm made landfall in the Outer Banks were being paid for by NOAA's Centers for Environmental Prediction to try to get better information on forecasting the storm before landfall.

After landfall there's not as much concern because all the models were depicting the storm recurving, going out to sea so that second group of drops is actually research flights to investigate the transformation of the storm from being tropical to what's called extra-tropical.

So this is we had a little bad luck in the timing of the flights and cancellation of at least one flight to get additional data off of the demonstration location. I think what we're going to do as the next slide shows this is an example of the data coverage for three historical events near that location from Hurricane Dennis and Floyd in 1999 and Isabel 2003.

So we're going to start assembling a group of sonde data that are in similar water depths but maybe not in the same location and it's not essential to be in the exact location because really the wind profile's going to be dependent on the roughness which should be dependent on the water depth and the fetch.

So we're going to start putting together groups of sondes to look at this wind profile and see if what we're getting in the shallow-water condition is similar to what we're seeing in those open-water conditions and that completes my presentation. Thank you.

Joel Klein: Thank you, Mark, that's great and that's right where we should be and right on time. Let's move ahead to Peter's talk and then we'll come back to the questions at the end but Dr. Peter Vickery works as a Principal Engineer in ARA's Intrarisk Division.

He's a graduate of the University of Western Ontario and has over 30 years of experience as do all of the speakers and his experiences in particular are in wind engineering which includes leadership and development of the synthetic storm tracking technique used to assess hurricane risk, catastrophic loss modeling and ocean wind wave hazard modeling.

He's also very well-published as I can also attest to in there and he's a member of the American Society of Civil Engineers, a Fellow of Structural Engineering Institute, a member of the AMS, a registered professional engineer in the State of North Carolina which is probably the best state in the union according to me. Okay, go ahead, Peter.

Peter Vickery: All right, thank you Joel. Okay, I'm going to talk to you guys a little bit about, you know, modeling the hurricane hazard with respect to modeling the wind hazard, the wave hazard and I touched a bit on the storm surge and the tide modeling, combined them altogether.

So this slide here shows an example of some - this is the results - of a simulation where we have on there's some sites located off the coast of

Virginia here where we have obviously a significant wave height on the vertical axis here, mean wind speed on the vertical axis, you see here plotted versus returned period and this is from a simulation.

And each one of these dots represents the wind speed that's associated with a particular wave height so in this example here we've got a six-meter waves were associated with mean wind speeds of 10 meters of 60 meters per second.

So with the highest wind that's associated with, you know, a relatively moderate wave and the point we're trying to get across here is the correlation of I think the 500 or 1000-year return period wind speed and the 500 to 1000-year return period wave height is not very strong.

And in fact you are likely to get the 1000-year, 500-year wave associated with a much lower wind speed than the 500-year wind speed because things matter other than wind speed such as the fetch and the size of the storm so size is incredibly important of the hurricane is incredibly important for modeling waves.

So this next slide and it gives you a little talking into the model and how we go about developing these hazard curves so that in the hurricane hazard model there are kind of two main components.

One is the head and simulation and track modeling. That's really just modeling how the mode hurricanes move across the Atlantic Basin and the second component is the wind field, wave models and we've added storm surge and tide models now to the modeling process.

The wind hazard portion of this model has been extensively published in both meteorological journals and engineering journals. The model that I'm talking

about today is the first ever model developed that simulates the entire life cycle of hurricanes in the Atlantic Ocean.

And we've gone through extensive validation of the hurricane wind model which is key to driving waves and storm surge models and the model's been used in the intercoastal flood studies.

It's used in (unintelligible) loss estimation tool as well as well as developing the wind speeds given in the national standard for design of buildings in the U.S. This slide here presents a pictorial of how the simulation model works so as storms are initiated somewhere in the Atlantic or the Gulf of Mexico.

The example shown here is for a couple of storms initiating in the Eastern Atlantic and as the storms move along various five-degree squares of the Atlantic Ocean, the model samples where the storm is likely to head in the next six-hour period. At the same time is uses model for to estimate the intensity in terms of the central pressure.

We use a simple wind field model as the storm tracks across the ocean and we use that to invoke an ocean-mixing model to reduce the sea surface temperatures for intense storms as they move across because the maximum intensity of the storm is governed by the maximum potential intensity.

So you can never in the simulation you can never produce a storm that physically couldn't happen in nature so as the storms move across the ocean and make landfall and you see the central pressure of this storm here made landfall at 928 millibars and it weakens as it crosses the State of Florida.

And then strengthens - I guess there's some weakness - a little bit more moves up the coast and makes landfall in North Carolina. This storm down here sort

of followed an Ivan-like path except it made landfall in Louisiana rather than Florida so the simulation model realistically models, you know, how storms behave as they move in the Atlantic Basin.

So up in the Virginia area, just a couple of examples of how we sort of verify that the model is working. Twelve storms passing within 250 kilometers of a plus sign here. We keep track of the storm heading and it's plotted in a little thin red line there and the kind of the dots or actually plus signs represent the historical record of storm headings.

This historical record is based about the last 114 year and 900 - the Year 1900 - through to today and you can see that the model matches the overall storm direction in this part of the Atlantic Basin and we've developed these curves - validation curves - over the full Atlantic Basin to ensure ourselves that the model is doing the right thing in terms of its change in headings and (translation fees) crossing the Atlantic Ocean.

There's another example for return period where we and central pressures where we plotted the central pressure, the minimum central pressure while in the circle. This is the return period on the bottom axis so the return period plot goes out to 10,000 meters but if you look at the data, you really can only produce estimates out to about 50 years.

This extension of the curve out beyond the 50-year return period is, you know, was being used to drive the hurricane model for the rare and rarer events for which we don't have any historical data.

That was kind of a summary of the overall tracking model, a very, very brief summary. The next important step in the modeling process is a wind field

model. We use a simple numerical model, it's a 2D numerical slab model that takes into account the effects of friction on the behavior of the wind field.

It's most important for modeling the behavior of the hurricane as they move from the sea to the land but there's also important as the roughness changes throughout the storm over the ocean has an effect on the asymmetries in the modeled storm.

We go through and we first estimate the mean wind speed or gradient height so that's on the order of 500 to a couple of thousand meters above the surface depending on the individual hurricane.

And from that we use boundary layer models derived from drop sondes that Mark was speaking about in the previous presentation to estimate the surface level winds and then we apply gust factors.

And if the storm is moving over land, we model high-resolution terrain models to estimate the gust wind speeds, one-minute wind speeds and hourly mean wind speeds that vary with the surface roughness over which the hurricane is passing.

And as I mentioned earlier, the model's been extensively validated and I'll show you a couple of examples of the model validation story, get to some results. The wind field model uses something called the Holland B parameter and a radius to maximum winds.

This Holland B parameter it really in addition to kind of modifying the overall shape of the wind so this is the wind speed, the gradient height plotted versus sort of normalized radial distance from the center of the storm.

So as that wind speed's plotted here for all storms having exactly the same central pressure, exactly the same translation speeds and this is a radial profile and what we're showing here is that a B value of 0.75 you get a peak wind speed of only 40 meters per second.

As you extend out further and further from the center of the storm, it's a broader storm compared to this model hurricane with a B of 1.5. The model hurricane with a B of 1.5 has much, much higher winds towards the center but does not extend as far out - the high winds do not extend as far out - away from the center of the storm.

But these high winds moving well out away from the center of the storm, very important for modeling waves and typically the B value varies between .5 and 2.2. As you move further and further north the Holland B value tends to reduce so you tend to get the broader storms as we move further and further north.

Whereas in the Gulf of Mexico, it's more likely to experience storms with these higher winds but typically narrow so they're very intense storms so this is an example of some mean boundary layer plots similar to what Mark showed in the previous presentation.

And these solid lines represent the model that's used to estimate the surface level winds from the (Canadian) level winds and as Mark alluded to in his presentation we find a point at wind speeds of about 30 meters per second where the surface roughness of the ocean does not get any rougher and in fact tends to decrease as it gets higher and higher wind speeds.

So this type of modeling is included in this hurricane model but so it reflects the fact that hurricane roughnesses of the ocean do not tend to increase and

(apockly) models the reduced sheer and high winds that Mark spoke about earlier that is not captured in the standards used to design offshore structures.

And since I show a couple of examples of some wind field modeling, we have four storms making landfall in the U.S., three in the North Carolina area and one in the Gulf of Mexico. What we've plotted here and we're going to look at these plots on the top is the plotted peak gust wind speed.

This is time and the dots represent the observations and the solid line represents the model results and it's showing that for peak gust wind speeds, mean wind speeds, directions and pressures and the model works quite well so for modeling that. This is sort of a summary example where we compare the peak values from the model and the observations that match very, very well.

And finally an end-to-end validation where we've done the best we can in terms of using historical records and hindcasting storms and this solid line represents the model results for our wind hazard curve compared to an empirically-derived set of curves and they match quite well.

So finally just a check of the model for modeling winds and waves, this is for Hurricane Ophelia that grazed the North Carolina coast a few years back, 2005 and here we've got a plot of four days so the model is matching the winds, you know, two days well matching the winds well two days before landfall, matches the peak and we get pretty good matching of the significant wave heights as well.

So that's led to some confidence that the model is working well for producing winds and waves. I think I'd better skip over this but we do use a stratified sampling approach where we don't have to model hundreds of thousands of

storms but we've reduced our samples down to now a few about 1000 storms to perform our simulations.

This is an example results, example output from a simulated storm in the model where we have the model simulated wind speeds, the model simulated significant wave heights, the storm surge. The storm surge and the waves are coupled. We can also add the tide and we can keep track of the breaking waves and all of this information is retained for every storm that we simulate.

And finally at the end if one is looking at to see the design conditions for the wave conditions that are available that occur around the 100-year wind speed, we can actually produce a distribution of the waves that are likely to occur.

When the offshore structure is experiencing 100-year winds, you need to design for all of these different combinations of wave heights or you can dismiss the little ones and just concentrate on the big ones.

But there's always a range of design conditions and like I said, you rarely get the 100-year, the design wind and the design wave or the design storm surge at the same time.

So in summary there is a relatively low historical data out there to develop models with so you have to resort to synthetic storms. The synthetic hurricane simulations are now routinely in hurricane hazard modeling to solve this problem rather than use the hindcasts because it gives you many, many more different design scenarios and it allows for more robust design.

And you end-up with more reliable estimates with the long-return-period events and more reliable estimates of the joint wind-wave current and storm surge statistics and that's the end of my presentation.

Joel Klein: Thank you, Peter, appreciate that and we'll wait till the end to ask the questions again. Want to move on to George and give him some time here too. George has got over 34 years of experience. It's like a contest between these guys. If you don't have at least 30 years of experience, don't come to the party kind of thing.

And his experience is in researching marine renewable energy systems including offshore wind power, wave, tidal and ocean thermal energy conversion.

He's a Senior Research Associate at Virginia Tech and their Advance Research Institute and is a member of Dominion-led team for Virginia offshore wind technology advanced project which is currently received an award from DOE for a demonstration project just offshore of Virginia Beach so George, please share with us your information.

George: Thank you, Joel. Good afternoon, everyone. Thanks for going through this so we've heard a lot about the winds and really I'm going to focus on a very, very narrow slice of what's of concern to all the mid-Atlantic wind energy areas and that's what kind of wave is striking these turbine foundation substructures? How high is it? You know, Peter's done some excellent work.

And indeed the talk that I'm about to give and in his talk builds on some technology assessment project that was funded by the technology assessment program of the Bureau of Safety and Environmental - God, I'm just drawing a blank - the BSEE.

But anyway sorry about that but I will say that my project manager there Debbie O'Brien and then also John Cushing at BSEE and then (Dan

O'Connell) at (bohem). They've all been really very supportive of what proved a very complicated project and we'll be referencing that work.

You'll see citations to it as we go through the slides and I believe these slides certainly I can e-mail a PDF and I believe it will be made available from the organizers so it's really important for me to acknowledge that without this funding I would never have been able to work with Peter and also with Jeff Hansen and his crew at the field research facility in (duck).

So this is really I'm presenting results myself but this really builds on work done by many, many others so let me get right into the content so there are several design load cases and indeed coupled load modeling is an important piece of looking at both the aerodynamic load on the turbine rotor as well as the hydrodynamic loads from waves and currents.

And by far the most significant hydrodynamic load is the impulsive wave loading or the periodic and it can be impulsive if it's a breaking wave so I'm really going to drill right down into two design load cases or DLCs.

You know, a model like Peter's which produces a return period curve for significant wave height, that's just a parameter that describes the sea state. It doesn't really tell you about each individual wave and the turbine designers and the foundation designers, they actually run many, many simulations trying to simulate wave by wave what's happening so you need.

And there's certain sort of quasi-static load cases where you take the maximum wave and apply it along with a wind load and because in a given storm it would be too conservative to assume that you get the peak three-second gust at the same time as the maximum individual wave, the design load cases are divided into two types.

There's an extreme wind with a reduced wind and an extreme wave with a reduced wind and the multipliers are there so you take these parameters whether it's a mean wind speed, a 10-minute mean wind speed at hub height and you have to as Mark really pointed-out well in his presentation, these models are all surface models.

The synthetic hurricane model well, I mean, actually Peter produces the whole air column but a lot of times these models particularly with the validation is all referenced back to surface wind speeds.

And so the designer then has to choose a wind profile or a wind shear factor and extrapolate upward and again Mark's presentation showed how important that is to get that right, that sheer profile or you're going to way overestimate the sheer across the span of the rotor.

And likewise you've got to come up with what the maximum individual wave height is and so drilling down even farther, what I really want to focus on is this 1.86. That's in the standards now and is it the right multiplier? Is that what you multiply the significant wave height and what kind of wave is it?

Is it a non-breaking wave? Is it a very steep near-breaking wave? If it's a breaking wave is it a spilling break wave or is it a plunging breaker so all of those are really important questions that I don't think we have very good answers to yet, at least answers that I'm not comfortable with.

So going on so this is the bow tap is a demonstration project, one of three that is funded by the Department of Energy. We are in Budget Period 2, the 100% front-end engineering design or 100% FEE. There are a number of model

grids around us and Peter showed some of the wave information studies the U.S. Army Corps of Information wave information studies or WIS.

And I really want to focus just on two WIS grid points. There's one, 63197 which is close to the Chesapeake light tower as well as a Scripps wave-rider buoy that's with the coastal data information out of Scripps University and funded by the Army Corps of Engineers.

That's been out there for a long period of time so we've got some good validation measurements there and then the WIS grid point closest to the demonstration project site is 63196 so Peter went north-south.

He went along the three grid points that are just to the west of the commercial wind energy area. I'm going to actually look at what happens when you go from 97 to 96 to from inshore to offshore.

So this is again Peter did a - this is one thing that Peter - there's a reference to our work and you see Peter as well as our other collaborators here but really important about this synthetic modeling is exactly what Peter concluded with is that you can come up with a 100-year wind curve and then you have a large number even at the tail end of the probability distribution of different kinds of waves associated with that peak wind.

So depending on how the storms - the storm's history - and its size, you can have a variety of different waves even for just a given 100-year or 500-year or 1000-year return wind speed.

But one of the things that's pretty striking I think you'll all agree when you look at this graph is that it is no matter what the return period of the wind, the

waves just at this location with all the synthetic storms that Peter ran by it just don't get above six meters, the significant wave height.

So, you know, that's an unusual thing. Something's got to be influencing the wave field, okay, and so if we go farther offshore, wind doesn't change much but boy, all the associated waves can grow much bigger up to nine meters so if we go back and forth between these slides, again so there's the near-shore site. There's the offshore site so there's clearly something going on.

Like we now take again the same kind of process as Peter - he didn't show in one of his example storms - but some of the synthetic storms, the peak significant wave height does not always occur when you have the peak mean wind speed, the storm peak.

So if we go now down to the wave return period curve and I've actually put the values at 100 years and 1000 years, normally those values would be much farther apart if we were in deep water out in the open ocean so again you can see as we go across the shelf, this is the near-shore site near the light tower.

This is near the demonstration turbines. Obviously, you know, being farther offshore exposes us to much higher waves even though the overall wind hazard and associated winds with these waves don't really change a whole lot so this is really we learned this is the BSEE-funded project and now, you know, we really wanted to understand it more.

And we've been fortunate in moving forward in the Dominion that DMNE has funded some work to forecast - do some operational forecasting - for using different driving winds, not the synthetic hurricane model because that's a hindcasting approach by doing an operational forecast but they both use SWAN which stands for shallow water near shore.

It's a third-generation wave model and it's well-respected, well-understood. It's gone through many iterations and so again initially working with Jeff Hanson and Mike Forte at the field research facility in (duck) they have gotten funding from the Virginia Commonwealth Department of Mines, Minerals and Energy to develop and standup an operational grid forecasting grid around the commercial wind energy area and demonstration turbines off Virginia.

And to get some - to initially develop that model - they did their own hindcasting to see how well they hindcast. In this case we're going to show Hurricane Isabel.

Classic Cape Verde storm, major hurricane, Category 4 and 5 out in the open ocean. We were all very nervous of course and I'm sure some of you can certainly remember those events. I certainly remember being here and boarding-up. It made landfall blessedly as a Category 2 and not as a major hurricane.

It's an impressive satellite image and then you've seen these kind of hazard curves that Peter has. This shows the wind. It's Isabel is about a 30 - appears to be based on Peter's analysis - a 30-year event so it was certainly substantial but not what we designed to when the design codes have pushed out into the 50 and 100-year depending on the design load case.

But you can see that we've superimposed on this both Peter's model applied to the historical wind field as well as the measurement and you can see for Isabel the synthetic model did very well so that's why we have some confidence that Isabel, you know, probably falls in that sort of, you know, 30-year type return period as a wind event.

So now looking at the forecast or using the forecast model, this is the H wind swap that Mark his company continues to develop and maintain and improve on that product as a Legacy. There's Legacy maps. This is one of the Legacy maps available at the link you see in the lower left corner and focusing on two validation stations.

There's a wave-rider buoy off of the field research facility and there's also a three-meter discus buoy with strap-down accelerometer off the entrance to Delaware Bay. That's 4409 and you can see that the forecast winds track the observed winds, the measured winds.

The forecast model and the measured observations agree very well at these two stations and likewise the wave, the SWAN, those winds drove the wave and of course there was a lot of wave-driving even when the storm was far offshore. I'm sure many of you are familiar with the forerunner swell that come before a storm so it's a very complicated wave field.

And so anyway but the model did very well close to the storm, perhaps not so much farther afield but certainly to give us good confidence that SWAN seems the parameterizations of SWAN are capturing the wave physics at least well enough to pretty well reproduce the significant wave height, the sea state parameter.

So moving on, this is really this is something that Jeff Hanson and (Brian Blanton) did for me that was really helpful preparing for this seminar is I wanted to get on a common scale, what is knocking the waves down? We saw in the synthetic modeling something is knocking the waves down. What is it?

Is it bottom friction? Is it white-capping and streaking as Mark showed with his overflight of Isabel or is it surf-breaking which is really the influence of

the bottom and as you can see these are all at the same scale that's on the right side of the slide.

I believe this is in the meters-squared-per-second having to do with the various density of the sea surface and its rate of change but you can see that by far what really is making this - knocking the waves down - and dissipating the energy is surf-breaking.

And so again this is, you know, really calls into some question is, you know, there seem to be influences of the bottom in much deeper water than sort of classical coastal engineering and certainly the Annex C to the offshore wind standard.

Joel Klein: George, just a time check, this is Joel. We're going to have to finish-up here because we need to leave time for questions.

George: Okay, understood, so anyway so I'll just go quickly. You can go through these slides I guess and the follow-up but these basically are as a wave radar study and it shows that the (Raley) probability distribution is over conservative, at least for this winter storm that was measured.

And yet there's another I'll skip to all this, sorry I have to rush right through here at the end but in any case I do want to come to this slide. This is a photograph of a wave in very deep water, it's (feno) 1 relative to its 28 meters depth and the significant wave height is five meters.

You would normally not expect to see a depth limited breaking there but if you look at the time lapse, there certainly appears to be and you can download this and we don't have time to show the videos unfortunately. I would like to show - Joel do we have time to at least look at one video - or not?

Joel Klein: Well, it's 3:57.

George: All right so anyway, okay, no, I guess not so in any case (Richard Neal) who I saw was asking a question, he took some great videos at Frying Pan Shoals light tower and here's some links you can go to these.

You can see this amazingly long-lived spilling breaker that comes from the horizon and passes underneath the platform and then I actually want to correspond with (Richard) about this shot he took of the buoy and right at the very end before the video stops, it really looks like that might have been more of a plunging breaker than a spilling breaker.

So we really we have a lot to learn about the types of wave impacts that these offshore wind towers and I think sort of conventional theory is not necessarily going to serve us accurately.

Joel Klein: Thank you, George. We've got a question here for the group to please discuss the worst-case wind and wave and significant wave conditions for 100-year scenario for the Virginia side compared to the North Sea area that Mark Powell was talking about to begin with where the power curves were originated so for anyone of the panelists to answer or a combination.

Man: George do you want to take that one?

George: Well, I mean, you could do a whole seminar on that question. I mean it's, you know, overall the wind shear - Peter correct me if I'm wrong - but as Mark pointed out the wind shear is less.

I think the biggest difference between what's the North Sea environment where all the offshore wind experience is in terms of combined wind-wave loading is that the winds can very easily be misaligned with the waves.

You get the long-period waves that are being pushed by this storm, ahead of this storm. They travel as it's called a trapped fetch phenomenon. These storms tend to move at the group velocity, sometimes can move in their forward speed and so they create continue to plow a lot of energy into the waves.

And so much so that the long-period components run ahead of the hurricane and they actually arrive before the winds do and so the winds can actually initially while the turbines are still running those large swells can be arriving and the winds will be at 90-degree angles to the waves.

And then you get the local wind seek crossing those waves when the hurricane arrives so it's a much more complicated wave field than in the North Sea where you just have these large extra-tropical systems where the winds and waves are coaligned and that's probably the biggest difference.

Joel Klein: There's another difference too, that leads me to I believe we've got time for one last question here so we'll take this one but one of the things that those are opportunistic areas because we have (feno) towers in Europe. We have three (feno) towers over there but that's a cold shallow body of water and surely we have a continental shelf on the East Coast but it's a western boundary current.

And so it's a warm water boundary current which directly impacts the stability of the atmosphere and then will directly impact the winds that we're getting on structures that are out there.

You mentioned George a bit about the long period waves caused by the long fetch of wind (observer) and I would like if any of the three of you have opportunity to comment on the do you feel like the industry's taking into account the duration of the winds that could be experienced from a recurving tropical storm or hurricane going up the East Coast to our offshore leased areas.

Do you think they're properly taking that into account and also when the direction of the winds change abruptly such as in the eye of a hurricane, do you feel like the standards are taking that into account in today's wind industry?

Peter Vickery: This is Peter. I don't think the standards are properly taking that into account. I think the standards are based on hindcasting and then also the European winds. I think simulation models can take that into account but the standard currently does not in my interpretation of the standard.

Joel Klein: Mark or George do you have anything before we close-out here, do you want to add-in something?

Mark Powell: Well, in terms of the duration Joel I think these wind field models that are used for the, you know, evaluating the risks are actually pretty sophisticated now and because there's so much emphasis on validation against historical events, you know, like Peter showed some instances where he's reproducing the time theories of the winds at different locations.

If your model is able to do that, then you have a pretty good handle on being able to get representative duration conditions.

Joel Klein: George, you want to add anything or are you good?

George: No, I'm good, thanks.

Joel Klein: Okay, well it's about three minutes over time so unfortunately we're going to have to end this. I could chat with these guys all day and enjoy it so certainly I want to thank our three distinguished speakers and as always it's been a pleasure dealing with. I appreciate your effort.

Here you can see on the screen contact information for myself, (Bree) who sets-up these meetings and then two of our colleagues that work at NREL out in Boulder, Colorado that can be reached as well.

If you want to learn more about the whole wind exchange initiative, there's a Website there you can click on and I want to thank you very much for tuning-in today. We've had a good crowd online and I thoroughly enjoyed it. Thank you, everyone.

Man: Thank you.

Man: Thank you.

Coordinator: Thank you so much for participating in today's conference call. You may disconnect your lines at this time. Thank you and have a great day.