INTERNATIONAL ENERGY AGENCY

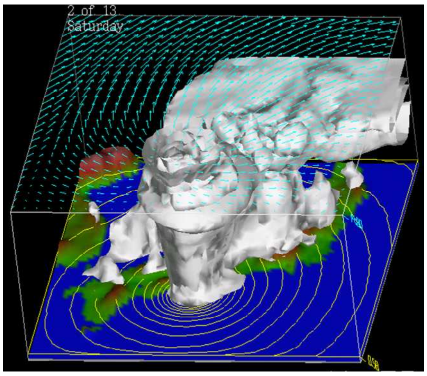
Implementing Agreement for Co-operation in the Research,
Development and Deployment of Wind Turbine Systems
Task 11

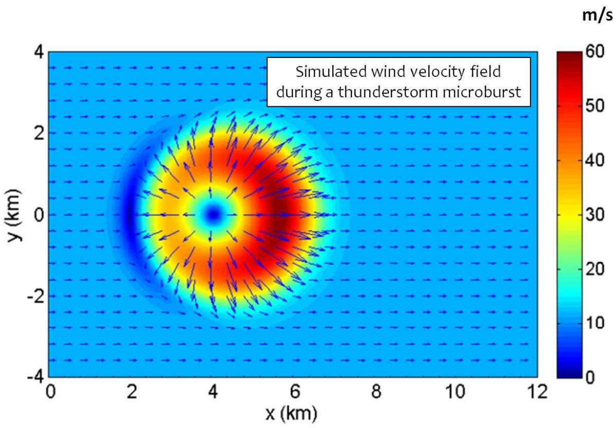
64th IEA Topical Expert Meeting

WIND CONDITIONS FOR WIND TURBINE DESIGN

December 14-15 2010,
National Institute of Advanced Industrial Science and Technology (AIST),
The University of Tokyo and The Japan Electrical Manufacturers' Association (JEMA)

Organized by: CENER





Scientific Co-ordination:

Félix Avia Aranda

CENER (Centro Nacional de Energías Renovables)

Urb. La Florida C/ Somera 7-9, 1ª

28023 - Madrid – Spain

Copies of this document can be obtained from:

CENER
Félix Avia Aranda
Urb. La Florida. C/ Somera 7-9, 1ª
C.P.: 28023 - Madrid – Spain
Phone: +34 91417 5042
E-mail: favia@cener.com

For more information about IEA Wind see www.ieawind.org

International Energy Agency

Implement Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems: IEA Wind

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes.

The IEA's Wind Implementing Agreement began in 1977, and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 24 contracting parties from 20 countries, the European Commission, and the European Wind Energy Association (EWEA) participate in IEA Wind. Australia, Austria, Canada, Denmark, the European Commission, EWEA, Finland, Germany, Greece, Ireland, Italy (two contracting parties), Japan, the Republic of Korea, Mexico, the Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the Agreement since 1978.

Two Subtasks

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry". A document dealing with Sodar measurements are presently under development.

The objective of the second subtask is to conduct topical expert meetings in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, Topical Expert Meetings are arranged four times a year.

Documentation

Since these activities were initiated in 1978, more than 60 volumes of proceedings have been published. In the series of Recommended Practices 11 documents were published and five of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task.

Operating Agent

CENER
Félix Avia Aranda
Urb. La Florida. C/ Somera 7-9, 1ª
C.P.: 28023 - Madrid – Spain
Phone: +34 91417 5042
E-mail:favia@cener.com

COUNTRIES PRESENTLY PARTICIPATING IN THE TASK 11	
COUNTRY	INSTITUTION
Canada	National Resources Canada
Denmark	Risø National Laboratory - DTU
European Commission	European Commission
Finland	Technical Research Centre of Finland - VTT Energy
Germany	Bundesministerium für Unwelt , Naturschutz und Reaktorsicherheit -BMU
Ireland	Sustainable Energy Ireland - SEI
Italy	Ricerca sul Sistema Energetico - RSE S.p.A.
Japan	National Institute of Advanced Industrial Science and Technology AIST
Republic of Korea	POHANG University of Science and Technology - POSTECH
Mexico	Instituto de Investigaciones Electricas - IEE
Netherlands	SenterNovem
Norway	The Norwegian Water Resources and Energy Directorate - NVE
Spain	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas CIEMAT
Sweden	Energimyndigheten
Switzerland	Swiss Federal Office of Energy - SFOE
United Kingdom	Uk Dept for Bussines, Enterprises & Regulatory Reform - BERR
United States	The U.S Department of Energy -DOE

Blank page

CONTENTS

Page

INTRODUCTORY NOTE

PRESENTATIONS

INTRODUCTORY NOTE

Prepared by Tetsuya Kogaki.

National Institute of Advanced Industrial Science and Technology (AIST)

a) Background

The world's total installed wind generation capacity reached 158.5 GW at the end of 2009, with over 38 GW coming online in 2009 alone, representing a 31.7% annual growth rate of the market. These figures show that there is huge and growing global demand for emissions-free wind power, which can be installed quickly, virtually anywhere in the world [1]. The rapid pace of wind power development worldwide has been supported by economic incentive programs such as Feed-in Tariffs and production tax credits along with supportive policies such as the renewable portfolio standard (RPS) program. However, from the technological standpoint, the continuing development and revision of international standards for wind turbine generation technologies brought about by the IEC 61400 series can also be seen as a major contributor to the rapid growth of wind energy worldwide. For example, wind turbines are classified according to extreme wind speeds and turbulence categories in IEC 61400-1 [2], a document that establishes safety requirements for wind power generation systems. This not only sets safe design requirements, but also allows manufacturers to inexpensively mass-produce and distribute standard wind turbines around the world.

Another aspect of the recent worldwide wind energy market is that the newcomers in wind energy development such as China and India have become a major driving force. Many countries in areas other than Europe and North America, such as Asia, Africa, the Middle East, Latin America and Oceania are now also promoting wind power generation projects. Over the last several decades, as can be seen from the records of global cyclone tracks (e.g., [3], [4]), tropical cyclones have disproportionately attacked East Asia, South East Asia, Oceania, South and Middle America. There are many complex terrains in southern Europe, such as Spain and Greece, the northern part of Italy, East Asia, Middle and South America such as Mexico. High levels of turbulence are anticipated in these areas. It is clear that the wind energy market is now expanding from former areas, where mild wind conditions are expected, to areas where there is a risk of much severer wind conditions.

The question now arises: can the current IEC 61400-1 standards for wind turbine design, which were compiled assuming moderate wind conditions, still apply to areas that have tropical cyclone attacks and/or high turbulence caused by complex terrain? Japan has a good deal of experience of problems related to typhoons and high turbulence levels. A statistical investigation of failures of wind turbine generator systems conducted in Japan has revealed the most significant causes of failure to be strong winds associated with typhoons and lightning. On the other hand, proving that high turbulence is the main cause of failure is more difficult than for other types of damage; however, in some cases, high turbulence caused by complex terrain has been clearly the main cause of wind turbine failure. When severe wind conditions are anticipated, Class S wind turbines are needed. However, in the current wind turbine market, there are almost no turbines designed according to Class S design requirements that can cope with the severe wind conditions characteristic of tropical cyclones and complex terrain. The severe wind conditions caused by tropical cyclones and complex terrain may have to be treated as standard wind conditions in the next edition of IEC 61400-1, to permit the expansion of the wind energy market while at the same time securing the safety and reliability of wind turbine generation systems at reasonable cost.

At the IEC TC88 meeting held in Boulder, USA, last March, revisions to IEC 61400-1 were proposed, and the resumption of MT01 activities was decided. The wind conditions characteristic of tropical cyclones, complex terrain and wakes are included in the agenda for revisions of IEC 61400-1. The specific drawing up of the requirements of wind conditions will be discussed at IEC TC88 MT01, which will begin soon; however, severe wind conditions have not been fully taken into account, since they are still at the R&D stage. Discussing and sharing information on unclear wind conditions at the Topical Expert Meeting of IEA Wind Task 11 is therefore of great importance, since it is expected to deliver safer and more reliable next-generation wind turbine design.

b) Topics to be addressed

The main objective is to hold a meeting to discuss and gather information on:

- Severe wind conditions caused by complex terrain, wake effects, and tropical cyclones such as typhoons and hurricanes
  - High turbulence, high angle of flow inclination, extreme wind speeds, extreme direction changes, etc.
- Impact of severe wind conditions on wind turbine design
  - Fatigue loads and ultimate loads
- Advanced simulation techniques of tropical cyclones, complex terrain and wake effects
- Statistical analysis of extreme wind conditions
- Advanced assessment techniques for site-specific wind conditions
- Definition of complex terrain and terrain complexity indicators
- Definition and marketability of new wind turbine classes, new turbulence categories and new wind models to cover severe wind conditions

c) Expected outcomes

One of the goals of the meeting will be to gather existing knowledge on the subject and come up with suggestions and recommendations on how to proceed with future developments. Based on the above, a document will be compiled, containing:

- Presentations by participants
- A compilation of the most recent information on the topic
- Main conclusions reached in the discussion session
- Definitions IEA Wind RD&D's future role in this issue

d) Agenda

Tuesday, December 14th

9:00 **Registration**. Collection of presentations and final Agenda

9:30 **Introduction by Host**
Dr. Kadoguchi, Deputy Director of ETRI, AIST

10:00 **Introduction by AIE Task 11 Operating Agent. Recognition of Participants**
Mr. Felix Avia, Operating Agent Task 11 IEAWind R&D

10:20 **Introduction of Attendees.**

10:30 **Presentation of Introductory Note**
Dr. Tetsuya Kogaki. (AIST)

1st Session Individual Presentations:

11:00 **Statistical analysis of wind turbine failures. Marketability of new wind turbine classes**
Hikaru Matsumiya, HIKARUWIND Lab. Ltd. JAPAN

11:30 **Turbulence characteristics in domestic sites in relation to IEC-61400 NTM model**
Sannosuke Tanigaki Wind Energy Corporation. JAPAN

- *12:00 Lunch*

2nd Session Individual Presentations:

13:30 **Experimental study of wake effects for complex terrain - Advanced simulation techniques of tropical cyclones, complex terrain and wake effects**
Junsuke Murata. Mie University. JAPAN

14:00 **Simulation of Thunderstorm downburst inflow fields and their influence on wind turbine loads**
Lance Manuel. University of Texas at Austin. USA

14:30 **Numerical simulation of typhoon winds with a mesoscale model**
Teruo Ohsawa. Kobe University. JAPAN

15:00 **Analysis of SODAR Measurements over Complex Terrain in JAPAN.**
Hiroshi Kubo, ITOCHU Techno-Solutions Corporation. JAPAN

16:00 **Adjourn**

18:30 - 20:00 Dinner (Splitting the bill. About 5,000 JPY)

Wednesday, December 15th

3rd Session Individual Presentations

09:30 Impact of severe wind conditions for wind turbine design
Hiroshi Imamura. WEIT. JAPAN

10:00 CFD simulations of wake effect in large wind farms
Stefan Ivanell . Gotland University. SWEDEN

10:30 Brief Introduction of China Extreme Wind Conditions Survey and research
Yu Zhang, China General Certification Center

11:00 Modelling turbulent typhoon time series
Michael Schmidt and Tanja Muecke. Univ. of Oldenburg. For Wind. GERMANY

11:30 Typhoon protection system for wind turbines
Niels Kjaer Launtsen and Morten Sloth. VESTAS. Denmark

●12:00 Lunch

13:30 Estimation of Extreme Wind Speed by using Monte Carlo Simulation of Tropical Cyclone
Atsushi Yamaguchi. University of Tokyo. JAPAN

14:00 Wind Turbine Loads in Simulated Stable and Neutral Boundary Later Flow Fields
Lance Manuel. University of Texas at Austin. USA

14:30 Discussion

15:15 Summary of Meeting

15:30 Short Technical Tour (the University of Tokyo)

17:00 End of the meeting

Thursday, December 16th

Optional Technical Tour

13:00 Meeting at the gate of the University of Tokyo "Todaiguchi" in front of the Komaba-Todaimae station of Keio Inokashira line

13:00 - 14:30 Bus from the Univ. of Tokyo to Mitsubishi Heavy Industries Yokohama Machinery Works

14:30 - 17:00 Visit at Mitsubishi Heavy Industries WT manufacturing facility and MWT-102-2.4 demonstration wind turbine

17:00 - 18:30 Bus to the Univ. of Tokyo

Blank page

PRESENTATIONS

IEA WIND Task 11 Topical Expert Meeting on Wind Conditions for Wind Turbine Design
December 14-15, 2010 (The University of Tokyo)

Introductory Note TEM #64 on "Wind Conditions for Wind Turbine Design"

Tetsuya KOGAKI

National Institute of
Advanced Industrial Science and Technology (AIST)

Background

Severe wind conditions caused by tropical cyclones and complex terrains are not fully reflected in the current IEC 61400-1 Ed.3.

- Tropical cyclones

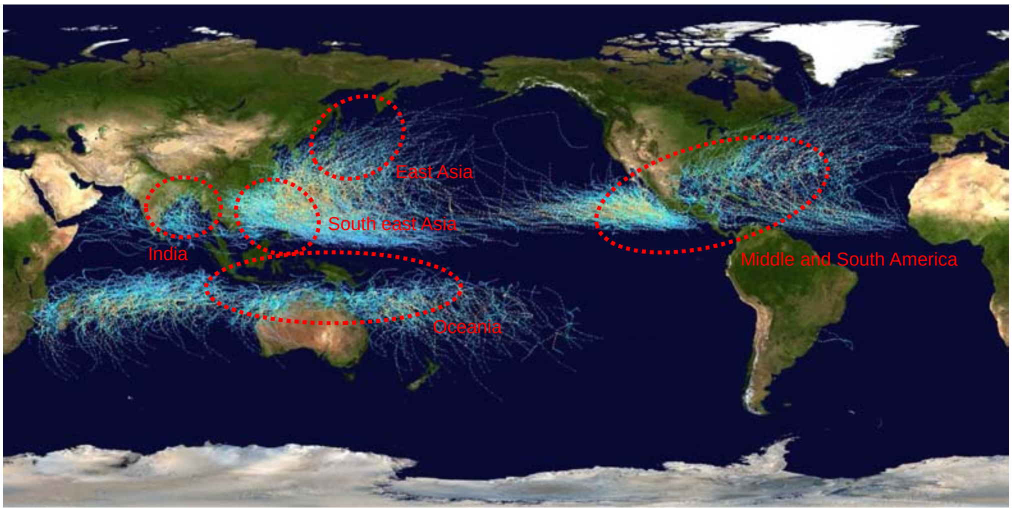
  tropical cyclones are not treated as the standard wind conditions in the current IEC document.

  "*The particular external conditions defined for classes I, II and III are neither intended to cover offshore conditions nor wind conditions experienced in tropical cyclones such as hurricanes, cyclones and typhoons. Such conditions may require wind turbine class S design.* " - IEC 61400-1 Ed.3 (2005), 6.2 Wind turbine classes, p.22.

- Complex terrain

  An increasing number of WTs are installed in the complex terrains including hills and mountains, where the turbulence intensity of the inflow could exceed the requirement for the turbulence category A.

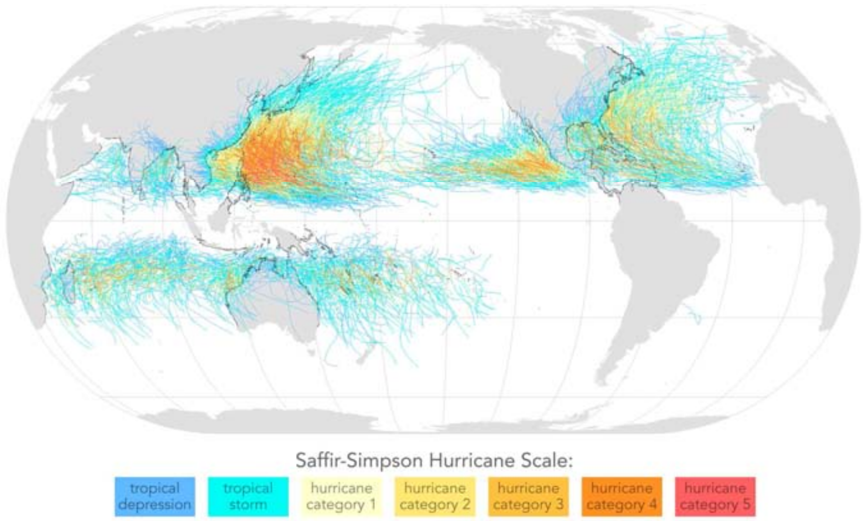
Worldwide Tropical Cyclones, 1985-2005



Source: Created using User:jdorje/Tracks by Nilfanion on 2006-08-05.
http://en.wikipedia.org/wiki/File:Global_tropical_cyclone_tracks-edit2.jpg
The Pacific Ocean west of the International Date Line sees more tropical cyclones than any other basin, while there is almost no activity in the Atlantic Ocean south of the Equator.

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 3

Tropical Cyclones, 1945 - 2006

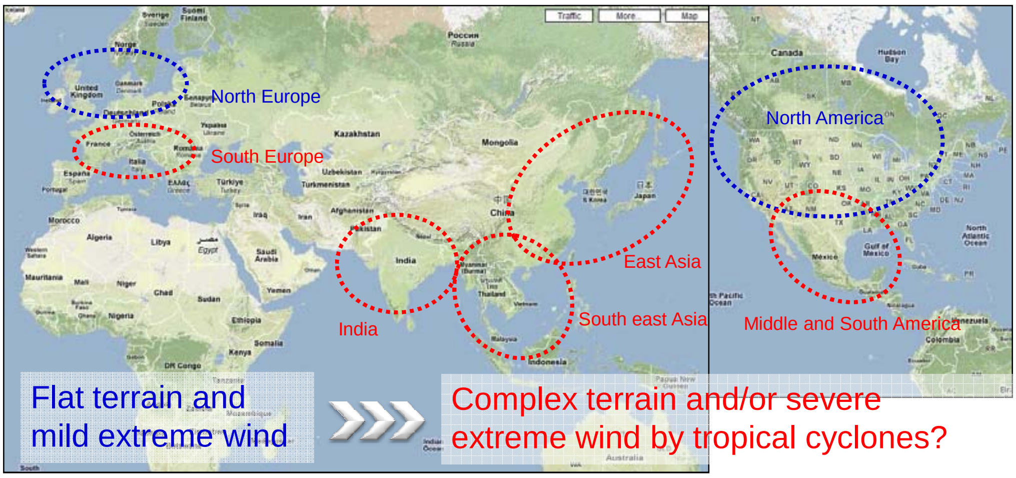


Author: Citynoise, Source: http://en.wikipedia.org/wiki/File:Tropical_cyclones_1945_2006_wikicolor.png.
Data from the Joint Typhoon Warning Center and the U.S. National Oceanographic and Atmospheric Administration.
Colors based on Template talk:Storm colour.

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 4

Trend of Wind Energy Market

AIST



Codes and standard of severe wind conditions caused by tropical cyclones and complex terrain for wind turbine design will be needed in order to expand the wind energy market, and in order to secure reliability and safety of wind turbine generation systems.

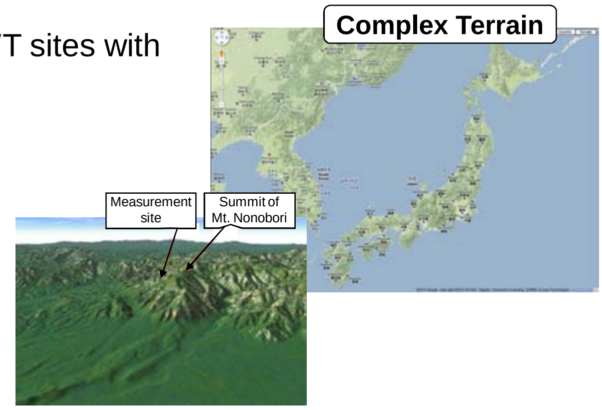
NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 5

Severe wind conditions by tropical cyclones and complex terrain

AIST

Japan is model case of WT sites with
- tropical cyclones,
- and complex terrain.

tropical cyclones

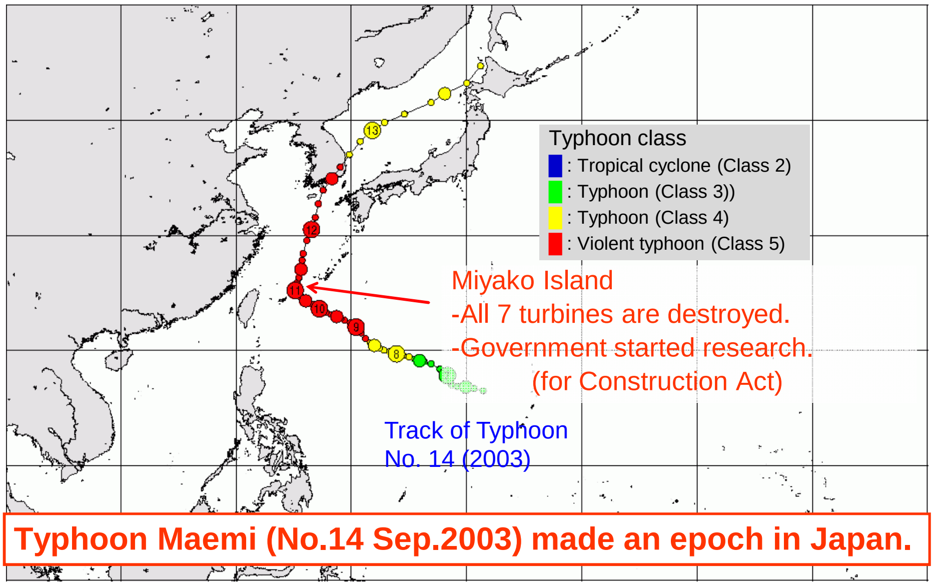


Japan has a lot of experience of troubles, and R&D results/data related to tropical cyclones and complex terrain.

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 6

Miyako Island Typhoon Disaster in 2003

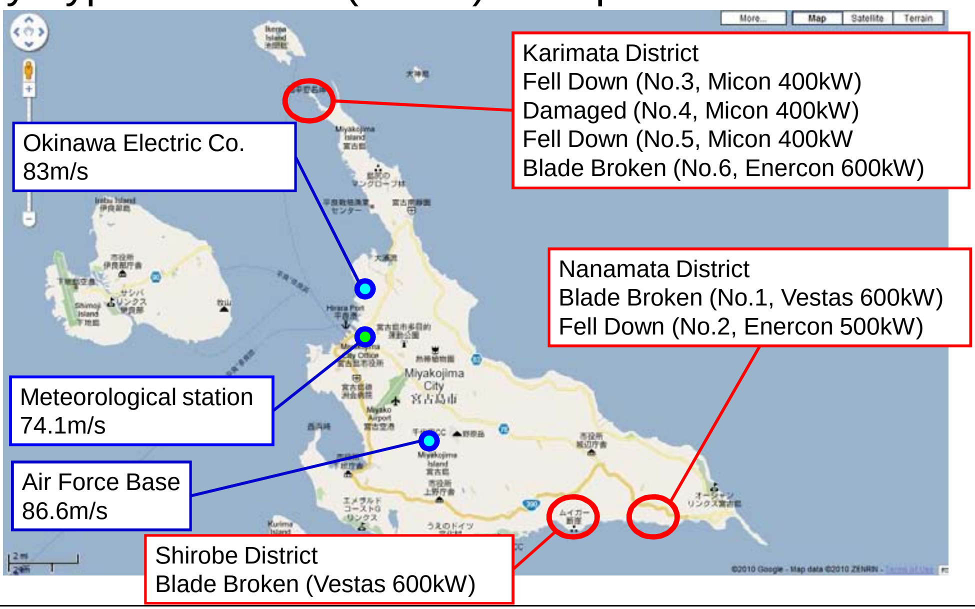
AIST



Courtesy of MHI NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 7

WT Failure in Miyako
by Typhoon Maemi(No.14) in Sept.2003

AIST



Courtesy of MHI NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 8

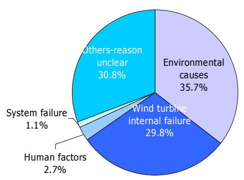
Statistical Investigation of Failures of WTGS

AIST

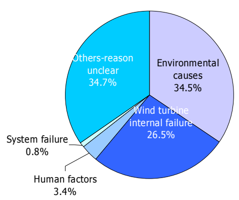
Most significant cause of failure/breakdown: **"Environmental causes"**

- **Strong wind (e.g. Typhoon)**
- **Lightning**
- **Turbulence**
  (Failures caused by the turbulence may be difficult to be concluded?)

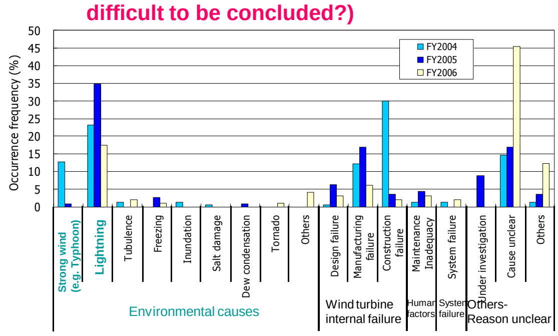
Actual Failure/Breakdown Causes



<FY2004 - FY2006>



<FY2004 - FY2007>



* from the Report of "Committee for Increase in Availability/Capacity Factor of Wind Turbine Generator System and Failure/Breakdown Investigation of Wind Turbine Generator System Subcommittee" by NEDO

Courtesy of NEDO   NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)   10

National R&D Project in Japan - #1

AIST

Project for Establishing Wind Power Guidelines for Japan (FY2005-2007)

Achievements and outcomes

- Simultaneous wind and load measurements
- Extreme wind speed map
- Database on extreme wind speed
- Guidelines for
  - Assessment of site specific conditions
  - Criteria for choice of machines “suitable for the site”
- etc.

Courtesy of NEDO   NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)   11

National R&D Project in Japan - #1

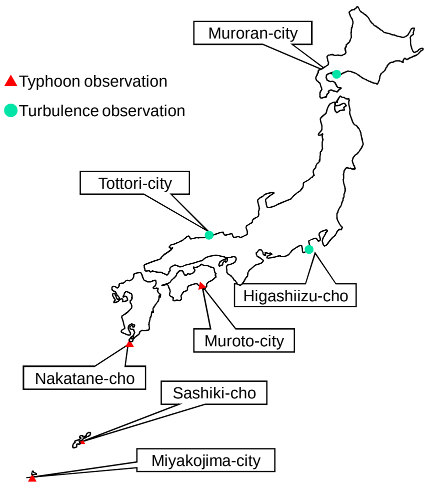
AIST

Project for Establishing Wind Power Guidelines for Japan (FY2005-2007)

- Simultaneous wind and load measurements

4 sites for Typhoon observation

3 sites for Turbulence observation



Courtesy of NEDO   NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)   12

National R&D Project in Japan - #1

AIST

Project for Establishing Wind Power Guidelines for Japan (FY2005-2007)

ITEM	Site A	Site B	Site C	Site D	Site E	Site F	Site G	IEC (IA)
Terrain complexity	Small	Large	Medium	Large	Small	Medium	Small	Standard
Height of evaluation	60m	30.5m	68m	37m	65m	35.3m	35m	Hub Height
Reference wind speed, V_{ref}	66m/s	79m/s	37-53m/s	73m/s	42m/s	51-72m/s	(83m/s)	50m/s
	▲	▲	◆	▲	●	▲	(▲)	
Annual average wind speed, V_{ave}	●	●	●	●	●	●	●	10m/s
Turbulence intensity, I_{ref}	0.18	0.18	0.18	0.21	0.22	0.23	0.22	0.16
	◆	◆	◆	◆	◆	▲	▲	
Flow inclination angle [deg]	6.6	7	10.4	16	0	2.1	1.4	8
	●	◆	●	●	●	●	●	
Wind share power law exponent, α	▲	●	●	◆	●	●	●	0.2

Evaluation: ● within IEC(IA), ◆ partially exceed IEC ▲ mostly exceed IEC

Courtesy of NEDO

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

13

National R&D Project in Japan - #1

AIST

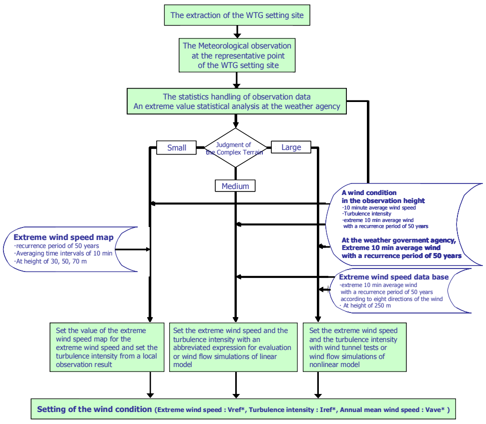
Project for Establishing Wind Power Guidelines for Japan (FY2005-2007)

Evaluation of site conditions

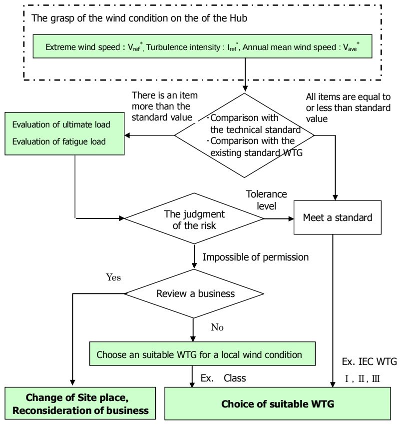
- Extreme wind speeds, V_{ref}
- Turbulence intensity, I_{ref}
- Annual average wind speed, V_{ave}

Criteria for choice of machines "suitable for the site"

- Choice of WTG
- Choice of site place
- Reconsideration of project



Flow for Choice of suitable WTG



Flow for evaluation of site condition

Courtesy of NEDO

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

14

National R&D Project in Japan - #2

AIST

Research and Development of Next-generation Wind Power Generation Technology/Research and development of basic and applied technologies (FY2008-2012)

Scopes and up-to-date outcomes

- Evaluation of representative severe turbulence characteristics.
- A draft revision of NTM (Normal Turbulence Model) .
- Evaluation of impact of the revised wind conditions.
- Evaluation of the ratio of V_{ref} to V_{ave} (V_{ref}/V_{ave}) and the ratio of the V_{e50} to V_{ref} (V_{e50}/V_{ref}).
- Evaluation procedures of extreme wind conditions by typhoon simulation techniques .

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 15

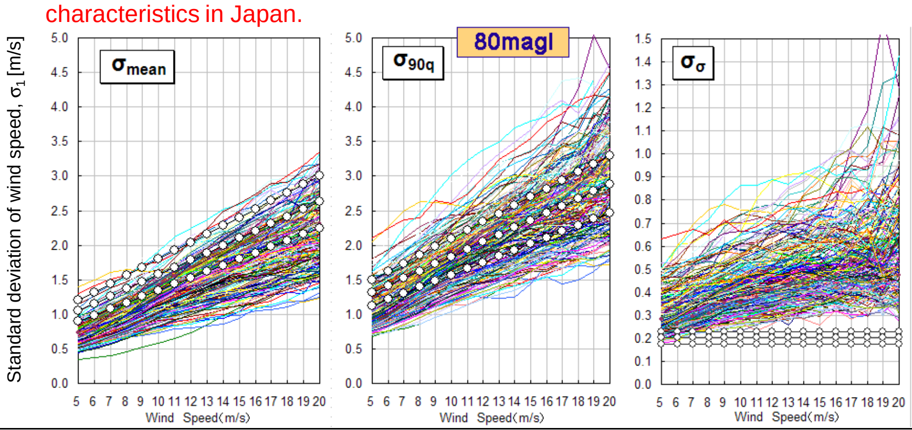
National R&D Project in Japan - #2

AIST

A mass of measured wind speed data were analyzed in detail.

- A mass of wind speed data measured at total of **418 sites** in Japan.
- Measured wind speed data of **259 sites** is adopted in this analysis (others were excluded because expected capacity factor were low, and those are not suitable for WTG project).

=> a mass of measurement sites is regarded as reflecting representative wind characteristics in Japan.

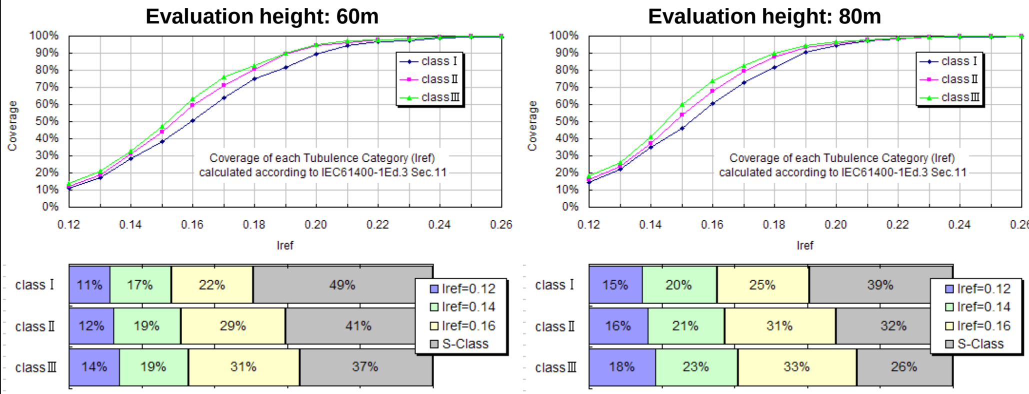


NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) 16

National R&D Project in Japan - #2

AIST

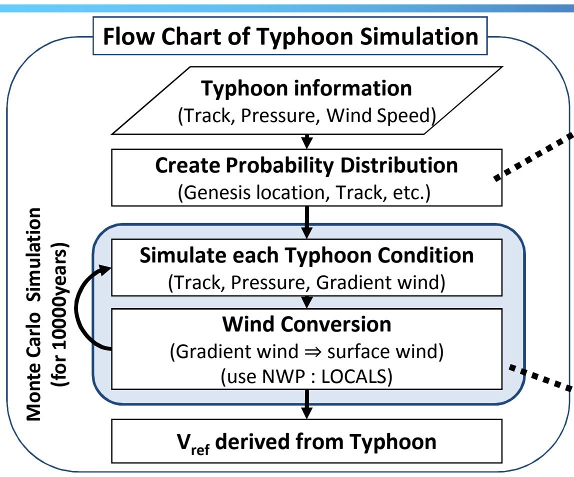
Research and Development of Next-generation Wind Power Generation Technology/Research and development of basic and applied technologies (FY2008-2012)

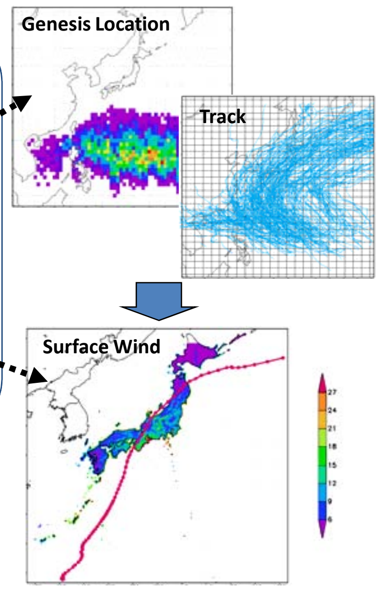


- **Turbulence intensity at 25 – 50% of measurement sites exceeds category A turbulence intensity in current IEC 61400-1 Ed.3.**

Estimation of V_{ref} by Typhoon Simulation

CTC





Input Data:
- **Previous Typhoon Information (over 50 years)**
  - **Track (latitude, Longitude),**
  - **Pressure of typhoon center, Maximum wind speed**
- **Elevation (mesh interval : 1km)**
- **Land Use (mesh interval : 1km)**

Courtesy of Itochu Techno-Solutions 18

Proposal at IEC TC88 (March, 2010, Boulder)

AIST

Action

We would like to propose the national committees to take actions as follows:

a) Review the proposed scope and submit comments;
b) Review the membership of the previous MT, confirm existing experts and/or appoint new experts for the maintenance team (MT 01);
c) Resume the activities of the MT01 including the discussion on the scope proposed in this DC.

Scope for Revision of IEC 61400-1

1) Definition of new wind turbine classes and new turbulence categories.
2) An additional wind model suitable for tropical cyclones regions, which include, the ratio of the reference wind speed to the annual average wind speed (V_{ref}/V_{ave}) and the ratio of the 3 second gust to the ten minute gust (V_{e50}/V_{ref}).
3) Annex for evaluation procedures of wind condition in the tropical cyclone regions and/or in complex terrains

=> Japan will contribute to revision of wind conditions regarding tropical cyclones and severe turbulence caused by complex terrain based on a lot of experience in this field.

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

19

IEA WIND TEM#64

AIST

- The resumption of MT01 activities was decided.
- The wind conditions of tropical cyclones, complex terrain and wakes are included in the agenda for revisions of IEC 61400-1.
- The specific drawing up of the requirements of wind conditions will be discussed at IEC TC88 MT01, which will begin soon;
- However, severe wind conditions have not been fully taken into account, since **they are still at the R&D stage**.
- Discussing and sharing information on unclear wind conditions at the Topical Expert Meeting of IEA Wind Task 11 is therefore of great importance, since it is expected to deliver safer and more reliable next-generation wind turbine design.

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

20

※) Dr. Matsumiya , IEA WIND Web site (www.ieawind.org)

Thank you
for your attention!

iea wind

The International Energy Agency
Implementing Agreement for Co-operation in the Research,
Development, and Deployment of Wind Energy Systems

NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

21

IEA WIND Topical Expert Meeting on "Wind conditions for wind turbine design" 2010.DEC Tokyo

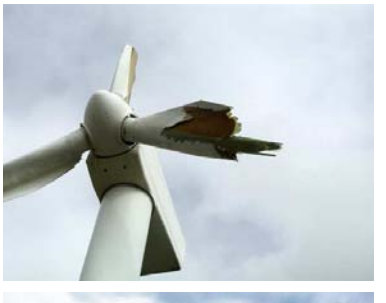
WIND TURBINE FAILURES IN COMPLEX TERRAIN

Hikaru Matsumiya[1], Sannosuke Tanigaki[2] and Tetsuya Kogaki[3]

1)HIKARUWIND.LAB, Ltd.,
2) 4)Wind Energy Ltd.,
3)National Institute of Advanced Industrial Science and Technology

INTRODUCTION

2003.Nov: Japan experienced very severe own wind conditions when Typhoon #14 attached Miyako Island to destroy all the wind turbines .



What's the problems?

Japan has severer wind, climate and topographical conditions than most of the "wind turbine developed" countries, in technically;

1.**Typhoon** wind conditions
2.**High turbulent** wind conditions
(due to complex terrain)
1.**High probability of lightning** attacks

The present report focuses on "high turbulence" to find out how it appears in the wind turbines failures.

National Investigation

In 2004: METI/NEDO set up Committee of Availability Improvement of Wind.

In 2007: Renamed as Investigation Committee of Failures/Accidents of Wind Plants

The committee reports have been published every year in Japanese.
Some results of 2009 Report was introduced in English at the RE2009 conference entitled as "**WIND TURBINE FAILURES IN COMPLEX TERRAIN"** (by H. Matsumiya, H. Kato, T. Naka, H. Imamura, S. Tanigaki and T. Kogaki)

Method of NEDO's Investigation

Since 2004, NEDO's Failure Investigation Project has send questionnaires to all wind power developers and the related organizations to inquire all severe wind turbine failures/accidents/troubles that longed more than 3 days under out of serves. (Definition)

In 2009,

- Number of objected turbines was 1,517 with 1,861 MW.
- This corresponds to 329 wind power plants operated by 183 developers.
- The respondents were 54 % of wind turbines in capacity.

Recent Tendency of Failures

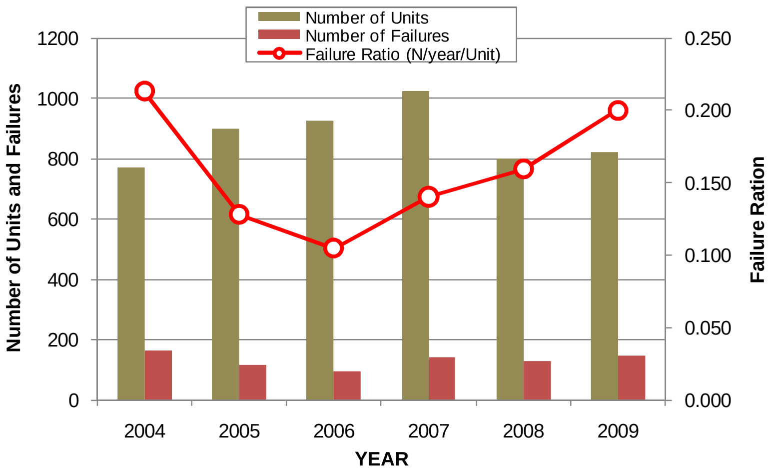
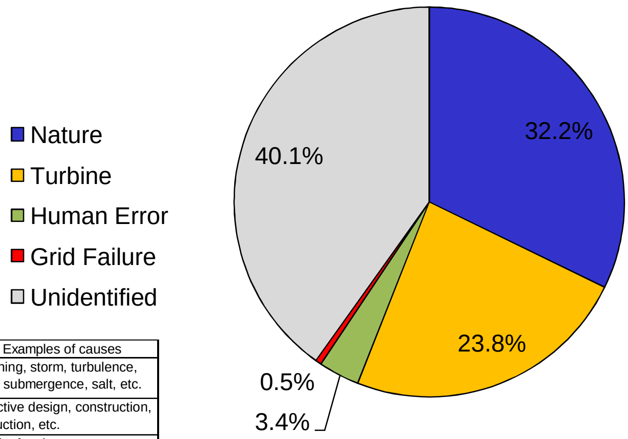


Fig.1 History of the ratio of failure (=number/year/unit) (period from 2004 to 2009).

The year 2004 was the extra ordinal year of typhoons, when 10 typhoons landed Japan while 4,3,4,0 and 1 in continued five years.

Causes of Failures



Classification	Examples of causes
1. Nature	Lightning, storm, turbulence, icing, submergence, salt, etc.
2. Turbine (Techanical)	Defective design, construction, production, etc.
3. Human Error	Deficit of maintenance, operation, etc.
4. Grid Failure	Failure in electrical grid
5. Unidentified	Including under-inspection

Fig.2 Ratio of causes of failures (Period of 2004-2009)

Natural Causes of Failures

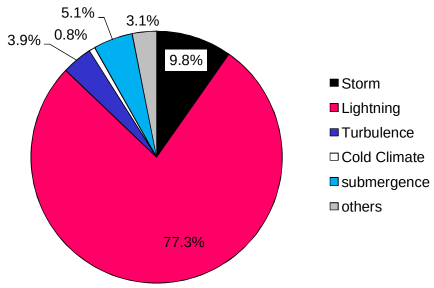


Fig. 3 Ratio of natural causes of failures (Period of 2004-2009)

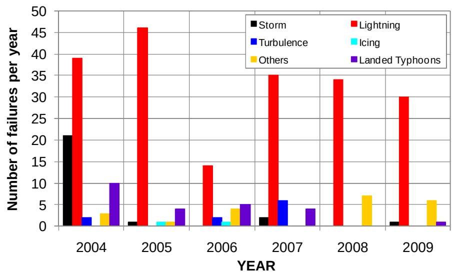


Fig. 4 Time history of failures caused by nature

NEDO 2009 REPORT:

➢ 32.2 % of the failures was caused by nature (if the unidentified causes are distributed in similarity with that of the identified, the ratio may around 50 %).

➢ The most rerious cause is **lightning attacks** which shares by **77 %** (Figure 3).

➢ **Storm** shares by **10 %**. **Turbulence** which is considered to be mostly induced by complex terrain shares **4 %** among natural causes.

Topographical Classes and Failures

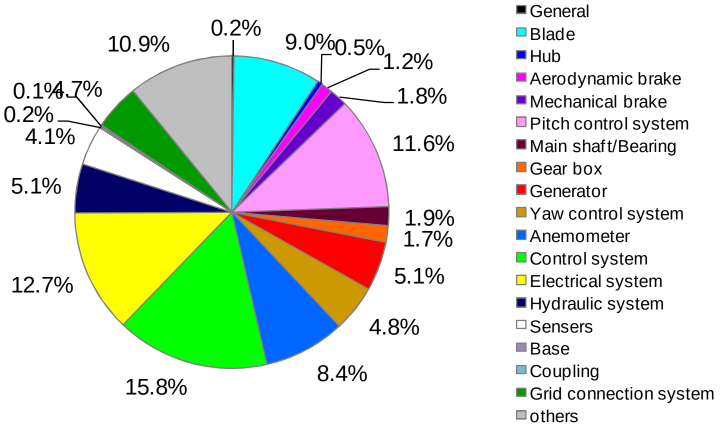
Table 1 Definition of Topographical Classes

Classification	Definition
Hills/Mountains	Complex terrain with an average slop greater than 10 %
Flat Inland Areas	Gnerally flat areas with a distance longer than 1 km from the closest coast linme
Coastal Areas	Areas with a distance closer than 1 km from the coast linme
Islands	Islands except big main islands (Honshu, Hokkaido, Shikoku,Kyushu and Okinawa)

Table 2 Numbers of Failues in different Topographical Classes

Classification	Number of Wind Farms	Ratio % (A)	Number of Failures (2009)	Ratio % (B)	Relative Ratio (B/A)
Hills/Mountains	402	49.0%	65	44.2%	90.3%
Flat Inland Areas	67	8.2%	8	5.4%	66.7%
Complex Coastal Areas/Islands	158	19.2%	19	12.9%	67.2%
Flat Coastal Areas/Islands	194	23.6%	55	37.4%	158.3%

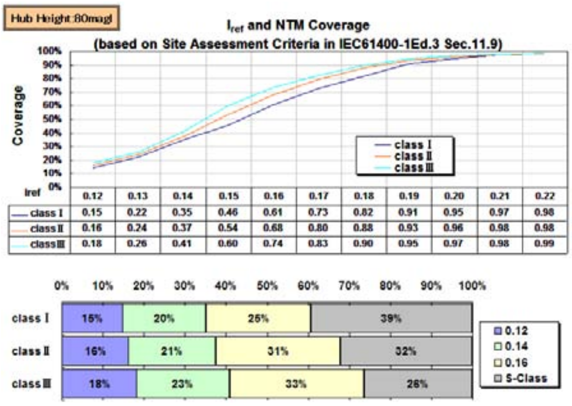
Failed Parts/Components (Fig.5)



Failed parts/components/systems are shown. Failures in **control system** are the most (15.8%), followed by those in **electrical system** (12.7%), with **pitch control system** (11.6%) and with **blade** (9.0%).

ISSUE OF COMPLEX TERRAIN

Figure 6 Coverage ratio of wind plant sites within IEC standard class



➢ **Field Test Program** had measured wind characteristics at 418 sites in the period from 1995 to 2008.
➢ A re-analysis revealed that out of all wind plant sites, from 1/4 to 1/2 of them might suffer from high turbulence intensity in IEC standard S-class.
➢ As shown in Figure 6, more than 26 to 39 % of the sites may out of IEC standard classes depending on turbine class.

Failures in different Topographical Classes

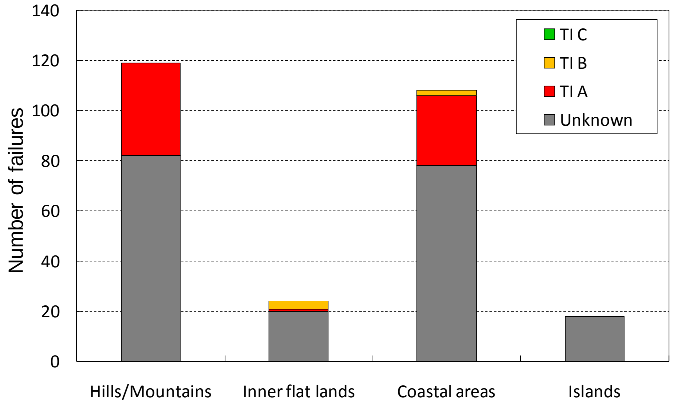


Fig.7 Number of failures at different type of topographies and sites' turbulence intensity categories

◆ Fig. 7 shows failure distribution among the topographies of sites. It became clearer that failures have occurred much more at hill/mountain sites and coastal areas than in inner flat lands and islands, which suggests high turbulence has possibly caused more failures.

Potential higher causes of Failures by High Turbulence

◆ An example of mechanical failure caused by turbulent flow. A turbine with a capacity below 300kW at hilly site was found severely damaged with its **blade bearing and pitch control mechanism** in April 2008 after 7 year of operation. Fig. 8 shows the damaged blade and Fig. 9 shows the turbulence intensity (TI) at the site.

Fig. 8 Damaged blade bearing

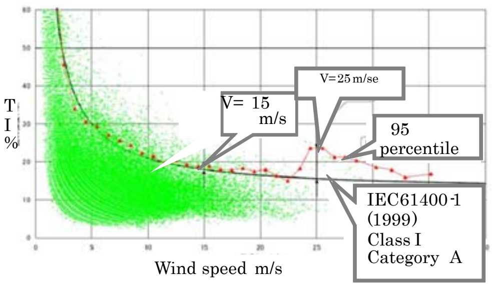


Fig 9 Turbulence intensity (TI)

CONCLUDING REMARKS

◆ Out of all failures/damages, those caused by nature was 32.2 %, while technical causes was 23.8 %. 40.1 % of the unidentified excluded, nature cause becomes 54.2 % and technical causes 40.0 %.

◆ Among natural failure causes, lightning is the highest (77.3 %), then storm (9.8 %) and turbulence (3.9 %). However, only around 20 % of the wind turbine failures have been technically identified.

◆ The database of Field Test Program has revealed that out of all wind plant sites, from 1/4 to 1/2 of them might suffer from high turbulence intensity in IEC standard S-class.

◆ It is desirable that an independent institute will continue this investigation with higher rights and duty of inquiry to identify technical causes of failures. All such efforts would help develop tougher wind turbines that fit to harder Japanese wind conditions, which is typical of severe wind conditions caused by complex terrain and tropical cyclones.

◆ This topic will be continued in various activities such as IEC standard, IEA expert meeting, National Research of Next Generation Wind Turbine Technology.

AKNOWLEDGEMENT

The present work was supported by NEDO's Investigation Program on Failures/Accidents of Wind Turbines and also a part of this study is funded by METI/NEDO in Research and Development Project of Next Generation Wind Turbine Generation Techno3ogy (R&D of Basic and applied Technology).

Turbulence Characteristics in Domestic Sites in Relation to IEC-61400 NTM model

[1]Sannosuke Tanigaki, [2]Tetsuya Kogaki, [3,4]Hikaru Matsumiya, [5]Hiroshi Imamura

[1]Wind Energy Corporation
[2]National Institute of Advanced Industrial Science and Technology(AIST)
[3]Invited Researcher, AIST [4]HIKARUWIND.LAB.Ltd.
[5]Wind Energy Institue of Tokyo.Inc.,

14,15 Dec. 2010

1

1. Objective
2. Wind Data
3. Distribution of Turbulence Characteristics
4. Coverage of NTM
5. Parameters of NTM equations
6. Suggestion on Amendment to 61400-1 Ed.3
7. Conclusion

14,15 Dec.2010

2

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

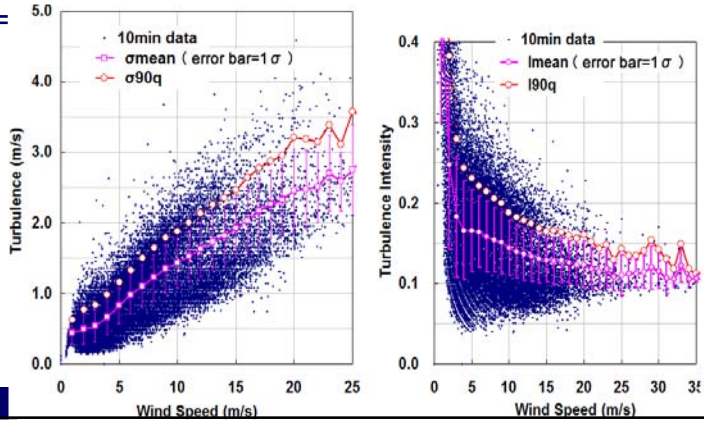
14,15 Dec.2010 3

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

1.Objective

- Turbulence of the wind is one of the major parameter for the design of wind turbines, closely related to its fatigue life.
- It is empiricaly known to increase linearly with wind speed.

σ : Wind Speed Standard Deviation TI : Turbulence Intensity(=



14,15 Dec.2010 4

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

1.Objective

- IEC61400-1Ed.3 gives Normal Turbulence Model (NTM) defined as linear function of wind speed :

σ_{90q} (V) = I_{ref} · (0.75V+ 5.6 [m/s]) : representative value

σ_{mean} (V) = I_{ref} · (0.75V+ 3.75 [m/s])

σ_{σ} (V) = I_{ref} · 1.44

where, I_{ref} is mean turbulence intensity of NTM at 15m/s.

I_{ref} =
0.16 (higher turbulene class ; category A)
0.14 (medium turbulene class ; category B)
0.12 (lower turbulene class ; category C)

14,15 Dec.2010 5

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

1.Objective

- The model should have been determined so that they can appropriately cover wind climate over the world.
  But,・ ・ ・ What is the reality?

- We have investigated applicability of the model to Japanese potential windfarm sites, with wind data accumulated in NEDO.

NEDO:
New Energy and Industrial Technology Development Organization

This study was funded by NEDO under "Research and Development of Next-generation Wind Power Generation Technology/Research and development of basic and applied technologies" project.

14,15 Dec.2010 6

1. Objective
2. Wind Data
3. Distribution of Turbulence Characteristics
4. Coverage of NTM
5. Parameters of NTM equations
6. Suggestion on Amendment to 61400-1 Ed.3
7. Conclusion

2.Wind Data -NEDO Field Test Program

- NEDO has so far accumulated vast amount of wind data widely covering over domestic potential windfarm candidates.

Wind Power Generation Field Test Program
(Detailed survey of wind conditions)

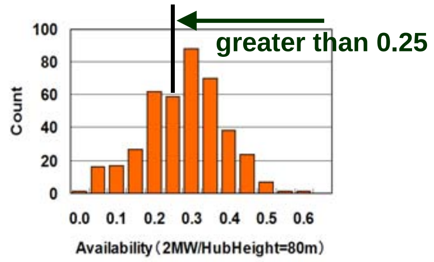
campaign period	**:**	**1995 to 2008**
number of measured sites	**:**	**586**
measuring period	**:**	**1 year each**
measuring height	**:**	**varies (20m to 50m)**

- Since measuring sites were selected through public advertisement from windy locations for future candidate for wind resource exploitment, statistical characteristics at these sites are considered represent general feature of Japanese wind farm sites.

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

2.Wind Data -Data Selection

- 259 windy sites were selected for analysis out from 586 sites of FT program, according to the criteria that:
  - measuring height ≧ 30m agl
  - capacity factor (theoretical) ≧ 25%
    - based on performance curve of 2MW model wind turbine (hub height 80m), and measured and extrapolated hub height wind speed

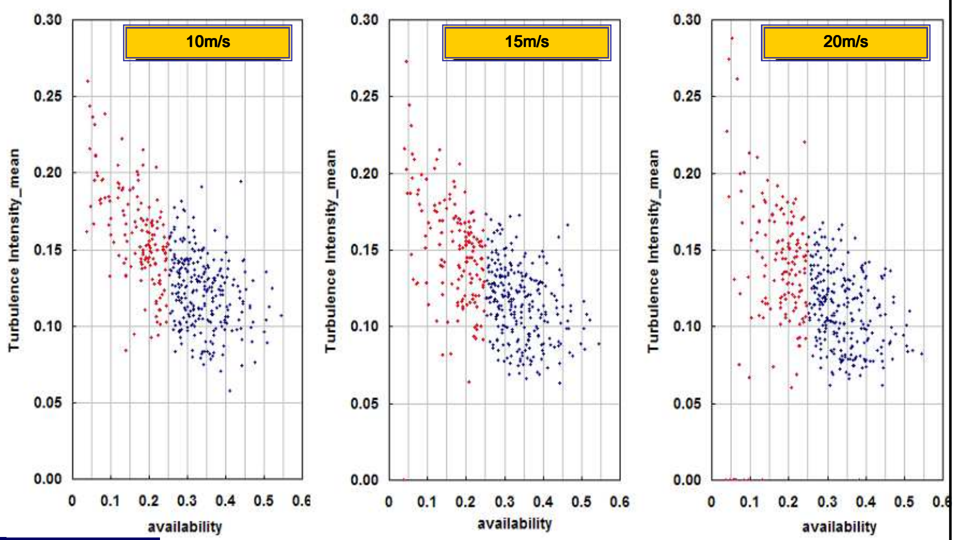


14,15 Dec.2010 9

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

2.Wind Data - Turbulence Intensity v.s. Availability

A gentle negative correlation in turbulence and availability.



14,15 Dec.2010 10

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

2.Wind Data - Measured data

- Wind data comprises 52,560 sets (1 year) of
  - 10min average wind speed
  - its standard deviation (turbulence)
  - 10min average wind direction

measured at 30mgl - 50magl varying depending on the site.

30magl (190sites)
40magl (31sites)
50magl (34sites)

Note:
Additionally to FT program sites ,4 sites (35magl 2sites, 45magl and 60m agl each 1 site) were included for the study.

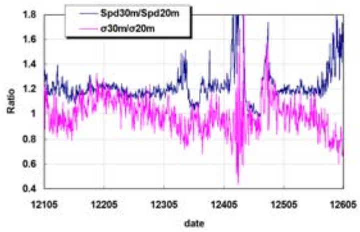
14,15 Dec.2010 11

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

2.Wind Data - Extrapolation to hub height

- For analysis, each measured 10min value was extrapolated to the one at hub height* assuming that:
  - Wind speed distiribution
    follows power law with exponent of 0.2.
  - Turbulence(wind speed standard deviation σ)
    stays constant with varying height.

*2 cases investigated : 60magl and 80magl



14,15 Dec.2010 12

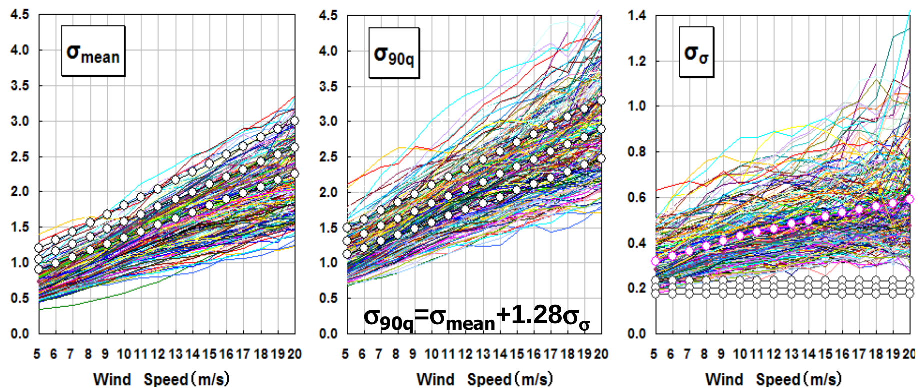
IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

14,15 Dec.2010 13

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

3. Distribution of Turbulence Characteristics

Distribution of Turbulence Standard Deviation σ_{xx} at 80magl



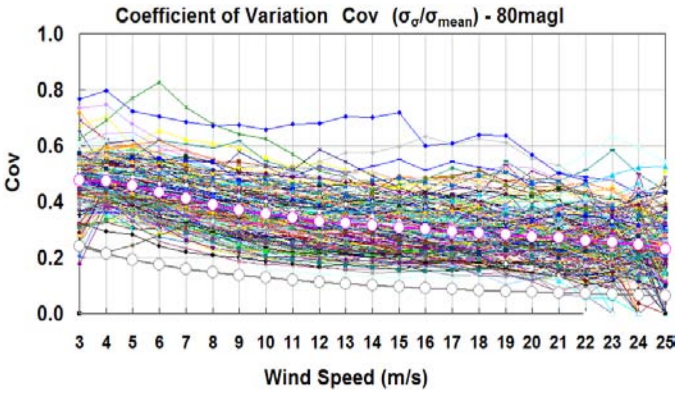
- For σ_{mean} , NTM fairly well covers most of the sites, however, for σ_{90q} , it is not the case!
- For σ_{σ} , NTM is far below observation!
  It explains why the above happened. Note that $\sigma_{90q}=\sigma_{mean}+1.28\sigma_{\sigma}$.

14,15 Dec.2010 14

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

3. Distribution of Turbulence Characteristics

Other expression of σ_σ ・・・・・



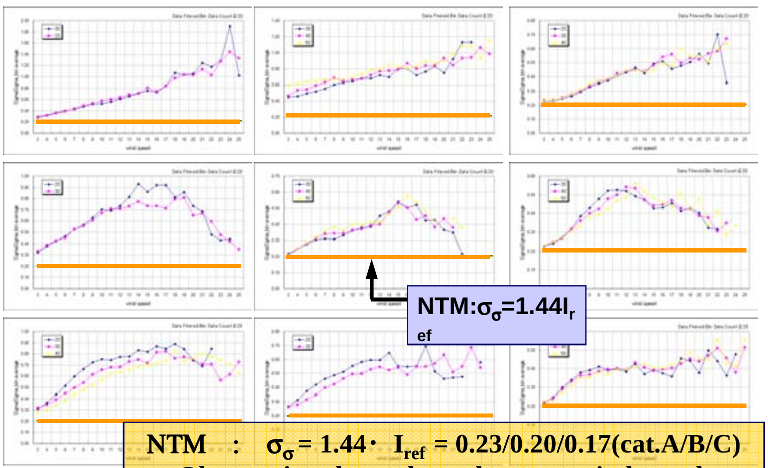
14,15 Dec.2010 15

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

3. Distribution of Turbulence Characteristics

Three distribution pattern of σ_σ ・・・

Note that uncertainty grows with increasing wind speed due to decreasing data count.

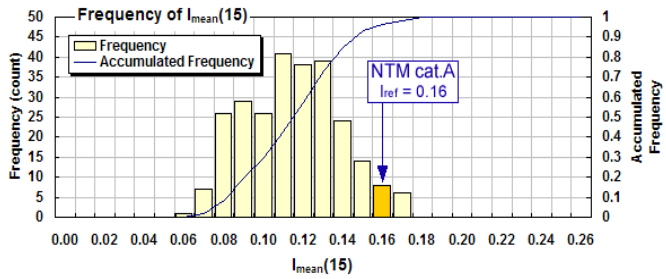


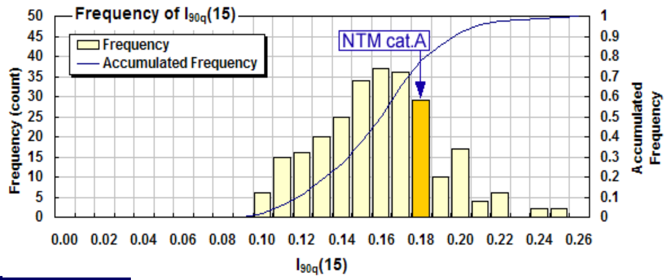
NTM : σ_σ = 1.44・ I_{ref} = 0.23/0.20/0.17(cat.A/B/C)
Observation shows dependency on wind speed.

14,15 Dec.2010 16

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

3. Distribution of Turbulence Characteristics





NTM

	$I_{mean}(15)$
cat.A	0.16
cat.B	0.14
cat.C	0.12

	$I_{90q}(15)$
cat.A	0.180
cat.B	0.157
cat.C	0.135

14,15 Dec.2010 17

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

1. Objective
2. Wind Data
3. Distribution of Turbulence Characteristics
4. Coverage of NTM
5. Parameters of NTM equations
6. Suggestion on Amendment to 61400-1 Ed.3
7. Conclusion

14,15 Dec.2010 18

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

4. Coverage of NTM

Wind turbines shall be assessed for suitability to the planned site.
Two assessment procedure are prepared by IEC61400-1 Ed.3.

Sec.11.9 Assessment by ref. to wind data	**Sec.11.10 Assessment by ref. to load/deflections**
Easy to assess, but tend to be too conservative.	Need complicated process, but leads to reasonable result.
compare: Which is severer?	compare: Which is severer?
wind conditions at the site / wind conditions assumed for design of the wind turbine	load and deflections calculated for site wind conditions / load and deflections calculated during design of the wind turbine

14,15 Dec.2010 19

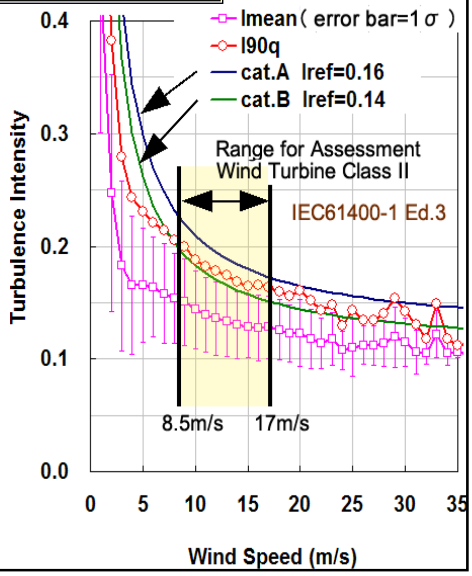
IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

4. Coverage of NTM

Sec.11.9 Assessment by Reference to Wind Data

- Items to be assessed :
  - Extreme Wind Speed
  - Wind Speed Distribution
  - Turbulence Distribution
- For turbulence, 90% quantile value shall be compared with NTM* at wind speed range of $0.2V_{ref}$ ~ $0.4V_{ref}$:
  - 10m/s ~ 20m/s (class I)
  - 8.5m/s ~ 17m/s (class II)
  - 7.5m/s ~ 15m/s (class III)

(*) $\sigma = I_{ref}\,(0.75V_{hub} + 5.6\ [m/s])$
$I = I_{ref}\,(0.75 + 5.6/V_{hub})$



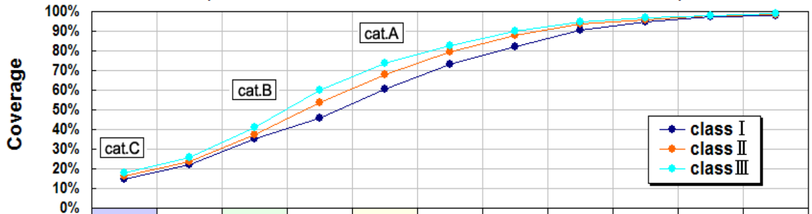
14,15 Dec.2010

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

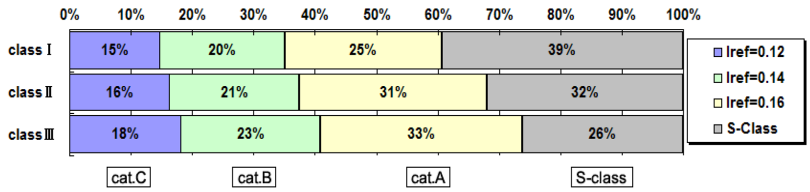
4. Coverage of NTM - by Sec11.9 Procedure

80 magl Hub Height

I_{ref} and NTM Coverage - 80magl
(based on Site Assessment Criteria in IEC61400-1Ed.3 Sec.11.9)



Iref→	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22
class Ⅰ	0.15	0.22	0.35	0.46	0.61	0.73	0.82	0.91	0.95	0.97	0.98
class Ⅱ	0.16	0.24	0.37	0.54	0.68	0.80	0.88	0.93	0.96	0.98	0.98
class Ⅲ	0.18	0.26	0.41	0.60	0.74	0.83	0.90	0.95	0.97	0.98	0.99



14,15 Dec.2010

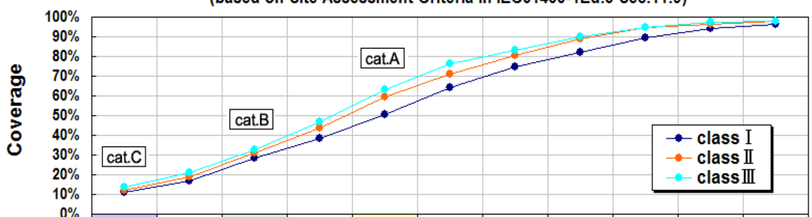
21

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

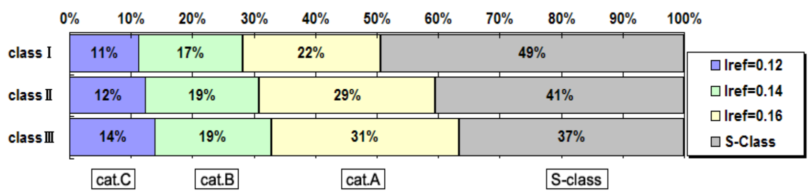
4. Coverage of NTM - by Sec11.9 Procedure

60 magl Hub Height

I_{ref} and NTM Coverage - 60magl
(based on Site Assessment Criteria in IEC61400-1Ed.3 Sec.11.9)



Iref→	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22
class Ⅰ	0.11	0.17	0.28	0.39	0.51	0.64	0.75	0.82	0.90	0.94	0.97
class Ⅱ	0.12	0.19	0.31	0.44	0.59	0.71	0.81	0.89	0.95	0.96	0.98
class Ⅲ	0.14	0.21	0.33	0.47	0.63	0.76	0.83	0.90	0.95	0.97	0.98



14,15 Dec.2010

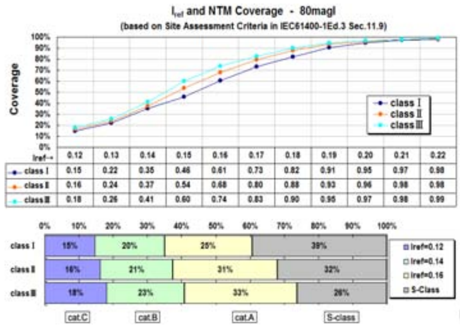
22

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

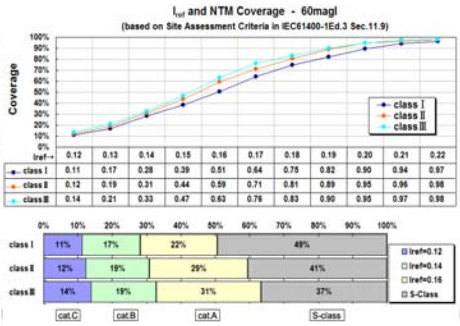
4. Coverage of NTM - by Sec11.9 Procedure

26%-39% (in case H_{hub}=80m)
37%-49% (in case H_{hub}=60m)

of the sites are outside standard turbulence categories,
i.e. standard turbines are judged unsuitable for these sites,
when assessed by sec.11.9 procedure.



Iref→	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22
class I	0.15	0.22	0.35	0.46	0.61	0.73	0.82	0.91	0.95	0.97	0.98
class II	0.16	0.24	0.37	0.54	0.68	0.80	0.88	0.93	0.96	0.98	0.98
class III	0.18	0.26	0.41	0.60	0.74	0.83	0.90	0.95	0.97	0.98	0.99



Iref→	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22
class I	0.11	0.17	0.28	0.39	0.51	0.64	0.75	0.82	0.90	0.94	0.97
class II	0.12	0.19	0.31	0.44	0.59	0.71	0.81	0.89	0.95	0.96	0.98
class III	0.14	0.21	0.33	0.47	0.63	0.76	0.83	0.90	0.95	0.97	0.98

14,15 Dec.2010 23

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

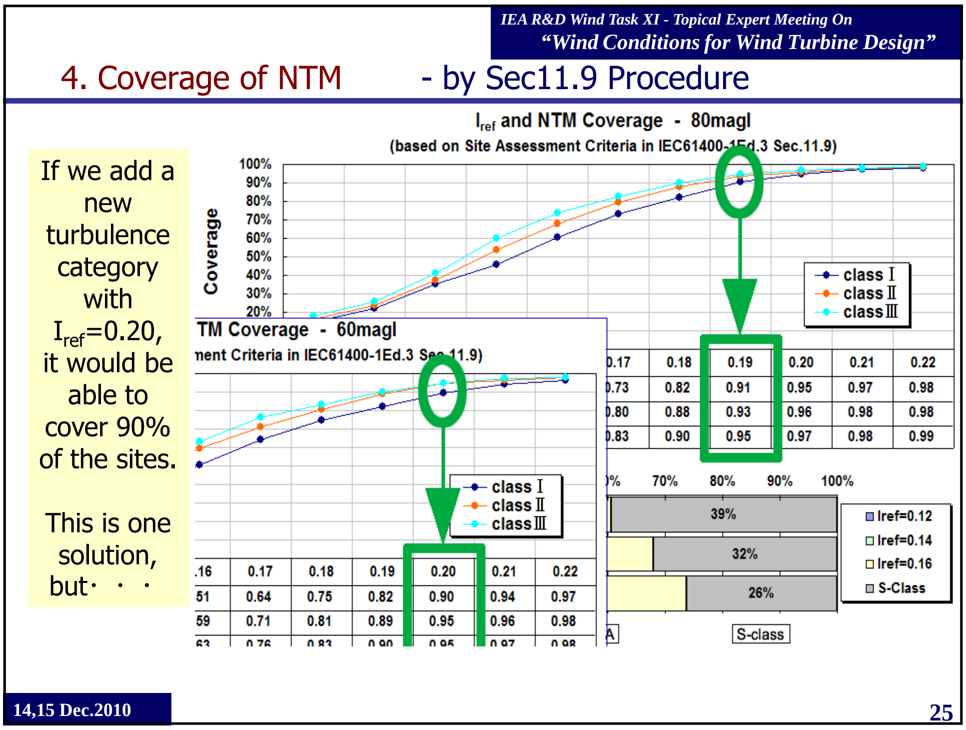
4. Coverage of NTM - by Sec11.9 Procedure

Then,
these sites require more sophisticated sec.11.10 procedure,
which can only be done by turbine manufacturer,
being a black-box procedure for other stake holders.

This is an onerous situation・・・・・.

Is there any measure to mitigate this situation ?

14,15 Dec.2010 24



IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

1. Objective
2. Wind Data
3. Distribution of Turbulence Characteristics
4. Coverage of NTM
5. Parameters of NTM equations
6. Suggestion on Amendment to 61400-1 Ed.3
7. Conclusion

14,15 Dec.2010

26

5. Parameters of NTM equations

NTM

- σ_{90q} (V) = σ_{mean}(V) + 1.2816 σ_{σ}(V) = I_{ref} (0.75V + 5.60 [m/s])
- σ_{mean}(V) = I_{ref} (0.75V + 3.75 [m/s])
- σ_{σ} (V) = I_{ref} x 1.44

can be expressed by general form as below:

$\sigma_{xx} = I_{ref}(a_{xx}V+b_{xx})$ & $\sigma_{xx} = A_{xx}V+B_{xx}$

a=0.75	&	b=5.60	for σ_{90q}
a=0.75	&	b=3.75	for σ_{mean}
a=0	&	b=1.44	for σ_{σ}

How are the value of these parameters distributed in the sites?

5. Parameters of NTM equations

① Constant [a_{xx}] in σ_{mean}

$\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$

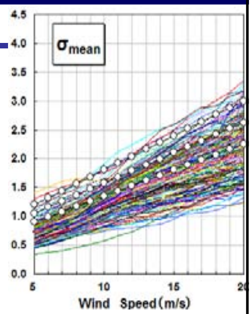
$\sigma_{xx} = A_{xx}V+B_{xx}$

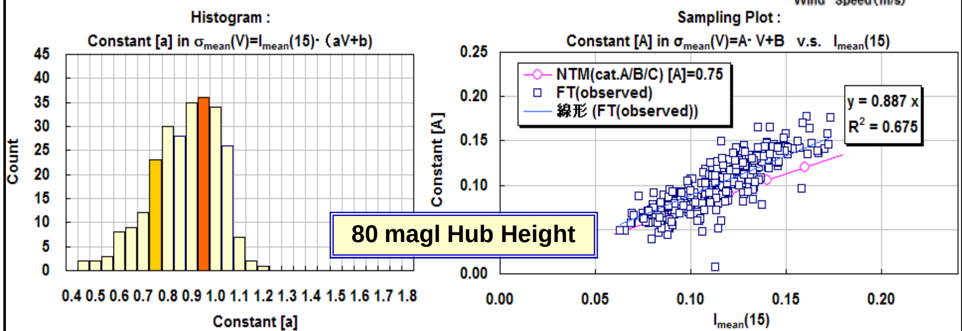
NTM value : 0.75

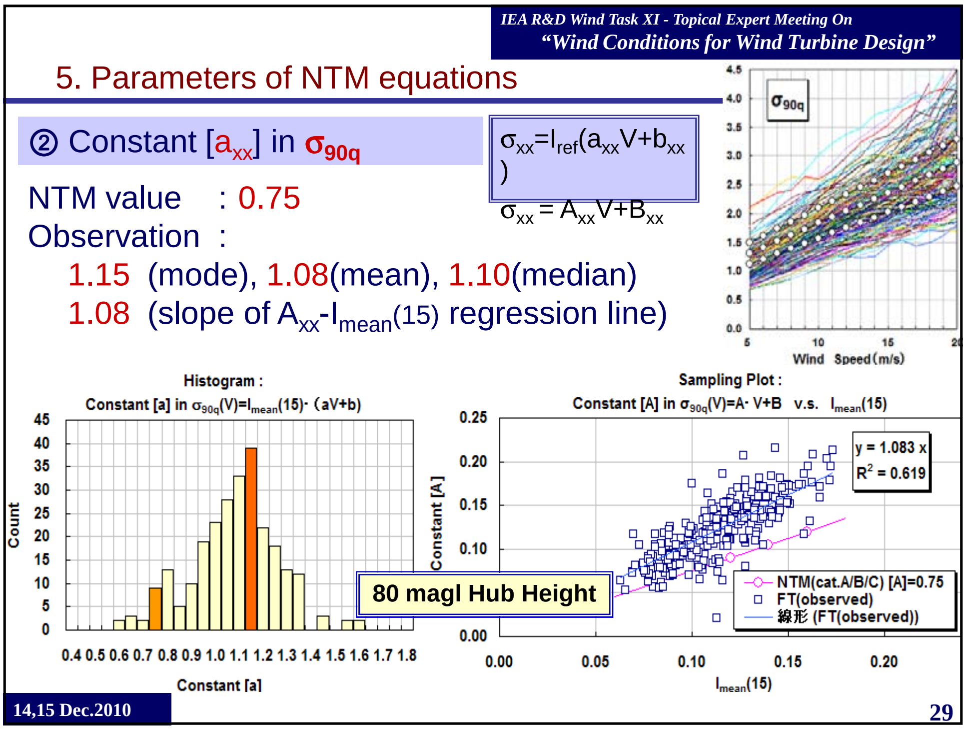
Observation :

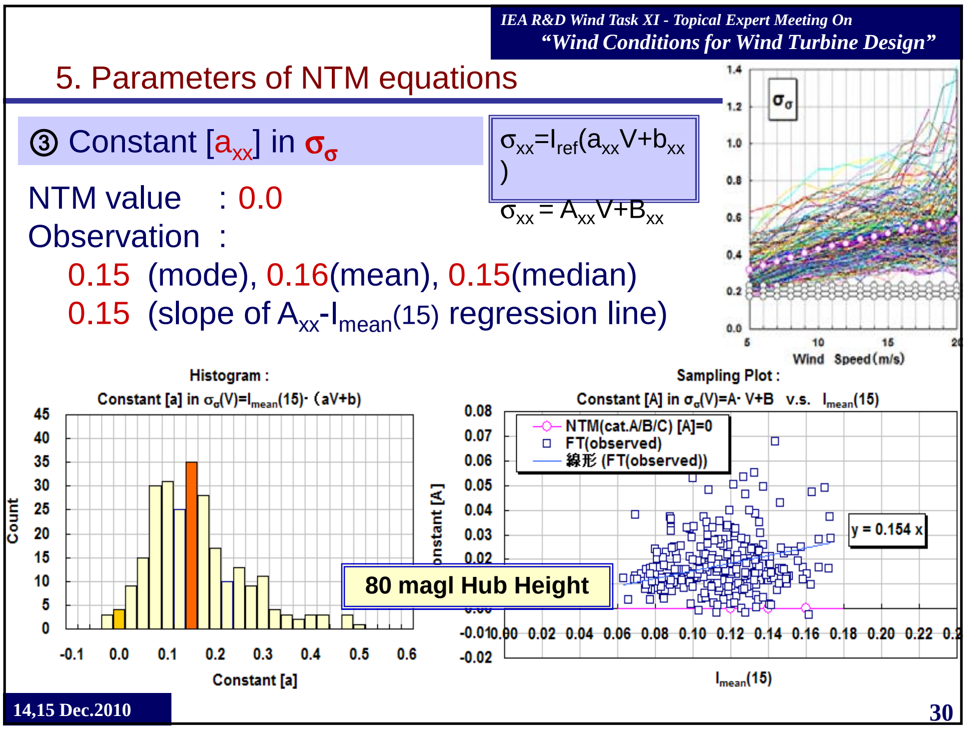
0.95 (mode), 0.87(mean), 0.89(median)

0.89 (slope of A_{xx}-I_{mean}(15) regression line)






IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"
5. Parameters of NTM equations
② Constant [a_{xx}] in σ_{90q}
$\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$
$\sigma_{xx} = A_{xx}V+B_{xx}$
NTM value : 0.75
Observation :
1.15 (mode), 1.08(mean), 1.10(median)
1.08 (slope of A_{xx}-I_{mean}(15) regression line)
σ_{90q}
Wind Speed (m/s)
Histogram :
Constant [a] in $\sigma_{90q}(V)=I_{mean}(15)\cdot(aV+b)$
Count
Constant [a]
Sampling Plot :
Constant [A] in $\sigma_{90q}(V)=A\cdot V+B$ v.s. $I_{mean}(15)$
Constant [A]
$I_{mean}(15)$
y = 1.083 x
R^2 = 0.619
NTM(cat.A/B/C) [A]=0.75
FT(observed)
線形 (FT(observed))
80 magl Hub Height
14,15 Dec.2010
29


IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"
5. Parameters of NTM equations
③ Constant [a_{xx}] in σ_σ
$\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$
$\sigma_{xx} = A_{xx}V+B_{xx}$
NTM value : 0.0
Observation :
0.15 (mode), 0.16(mean), 0.15(median)
0.15 (slope of A_{xx}-I_{mean}(15) regression line)
σ_σ
Wind Speed (m/s)
Histogram :
Constant [a] in $\sigma_\sigma(V)=I_{mean}(15)\cdot(aV+b)$
Count
Constant [a]
Sampling Plot :
Constant [A] in $\sigma_\sigma(V)=A\cdot V+B$ v.s. $I_{mean}(15)$
NTM(cat.A/B/C) [A]=0
FT(observed)
線形 (FT(observed))
y = 0.154 x
$I_{mean}(15)$
80 magl Hub Height
14,15 Dec.2010
30

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

5. Parameters of NTM equations: $\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$

Summing up・・・・・

Representative Values for [a] in $\sigma_{xx}= I_{ref}(aV+b)$

Representative Values	σ_{mean}		σ_{90q}		σ_{σ}	
	60magl	80magl	60magl	80magl	60magl	80magl
Mean	0.88	0.87	1.08	1.08	0.15	0.16
Medean	0.90	0.89	1.09	1.10	0.14	0.15
Mode	0.90	0.95	1.10	1.15	0.13	0.15
Increment	0.05		0.05		0.03	
Slope of Regression Line [A] vs $I_{mean}(15)$	0.89	0.89	1.09	1.08	0.15	0.15
NTM Setting	0.75		0.75		0.00	

Representative Values for [b] in $\sigma_{xx}= I_{ref}(aV+b)$

Representative Values	σ_{mean}		σ_{90q}		σ_{σ}	
	60magl	80magl	60magl	80magl	60magl	80magl
Mean	1.72	1.94	4.50	4.64	2.06	2.17
Medean	1.56	1.62	3.90	4.02	1.92	2.03
Mode	0.80	1.20	2.50	3.50	1.60	1.80
Increment	0.40		0.50		0.20	
Slope of Regression Line [A] vs $I_{mean}(15)$	1.54	1.63	4.04	4.25	1.95	2.03
NTM Setting	3.75		5.60		1.44	

14,15 Dec.2010 31

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

5. Parameters of NTM equations: $\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$

The following new NTM expression would better represent observation・・・・・

Present NTM

$\sigma_{mean} = I_{ref}(0.75V + 3.75 \text{ [m/s]})$

$\sigma_{90q} = I_{ref}(0.75V + 5.6 \text{ [m/s]})$

$\sigma_{\sigma} = I_{ref} \cdot 1.44 \text{ [m/s]}$

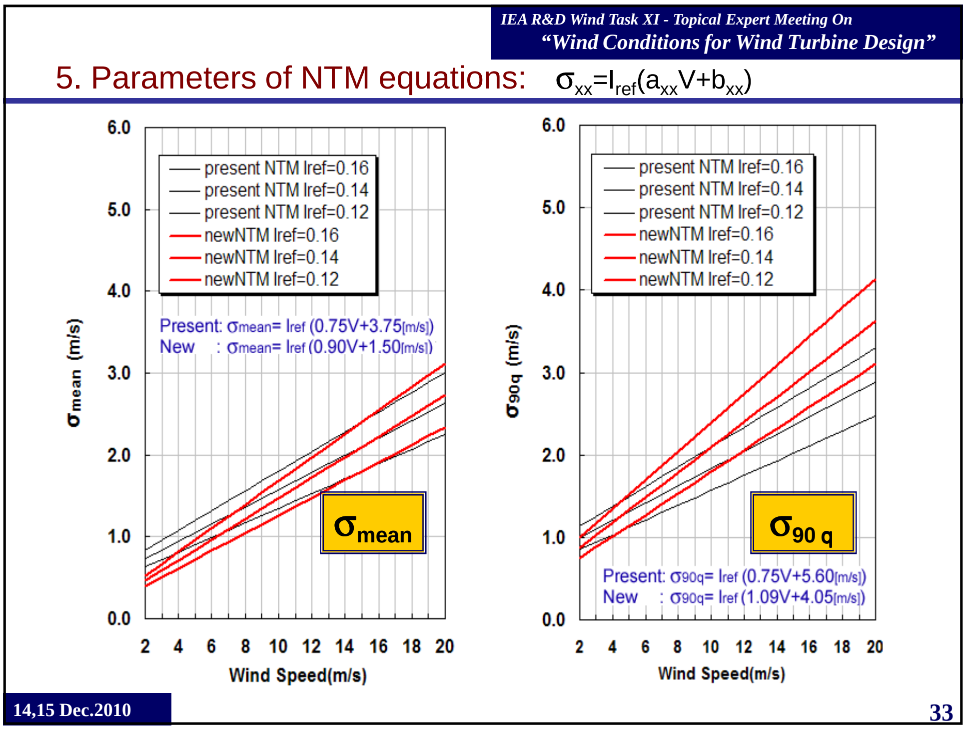
New NTM

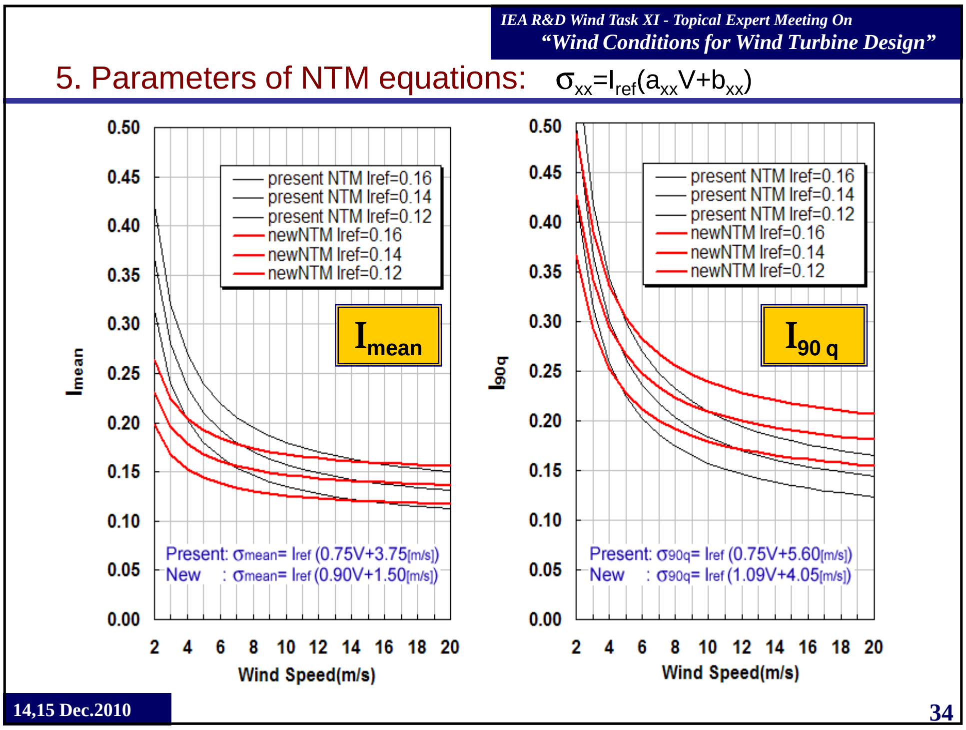
$\sigma_{mean} = I_{ref}(0.90V + 1.5 \text{ [m/s]})$

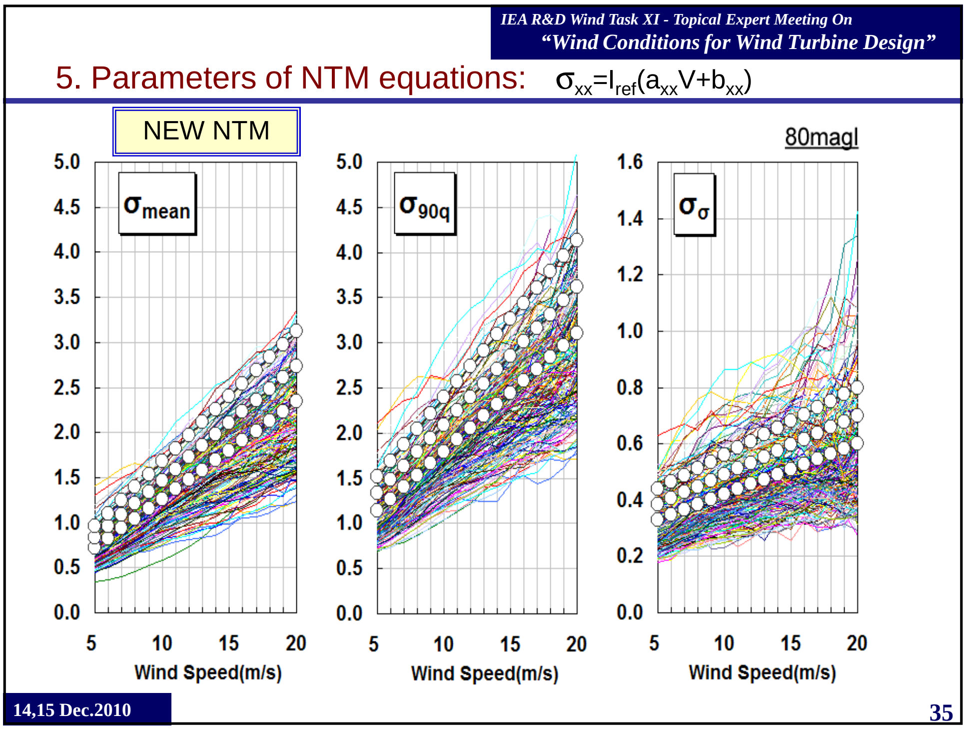
$\sigma_{90q} = I_{ref}(1.09V + 4.05 \text{ [m/s]})$

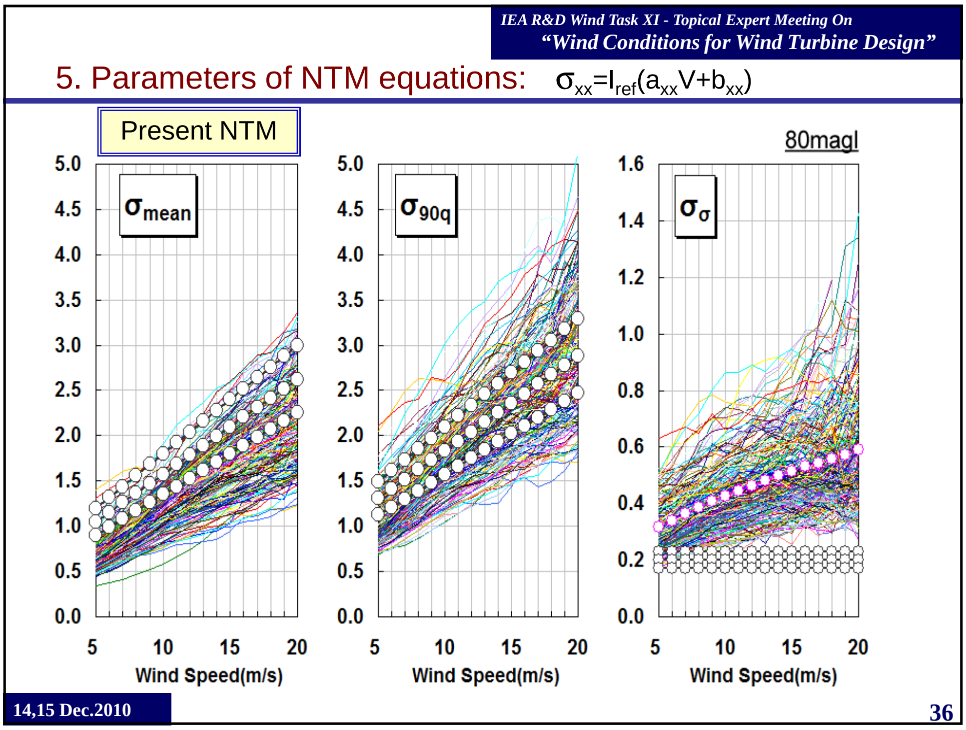
$\sigma_{\sigma} = I_{ref}(0.15V + 2.0 \text{ [m/s]})$

14,15 Dec.2010 32


IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"
5. Parameters of NTM equations: σxx=Iref(axxV+bxx)
present NTM Iref=0.16
present NTM Iref=0.14
present NTM Iref=0.12
newNTM Iref=0.16
newNTM Iref=0.14
newNTM Iref=0.12
Present: σmean= Iref (0.75V+3.75[m/s])
New : σmean= Iref (0.90V+1.50[m/s])
σmean
σmean (m/s)
Wind Speed(m/s)
Present: σ90q= Iref (0.75V+5.60[m/s])
New : σ90q= Iref (1.09V+4.05[m/s])
σ90 q
σ90q (m/s)
Wind Speed(m/s)
14,15 Dec.2010
33


IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"
5. Parameters of NTM equations: σxx=Iref(axxV+bxx)
present NTM Iref=0.16
present NTM Iref=0.14
present NTM Iref=0.12
newNTM Iref=0.16
newNTM Iref=0.14
newNTM Iref=0.12
Imean
Present: σmean= Iref (0.75V+3.75[m/s])
New : σmean= Iref (0.90V+1.50[m/s])
Wind Speed(m/s)
I90 q
I90q
Present: σ90q= Iref (0.75V+5.60[m/s])
New : σ90q= Iref (1.09V+4.05[m/s])
Wind Speed(m/s)
14,15 Dec.2010
34


IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"
5. Parameters of NTM equations: σxx=Iref(axxV+bxx)
NEW NTM
80magl
σmean
σ90q
σσ
Wind Speed(m/s)
Wind Speed(m/s)
Wind Speed(m/s)
14,15 Dec.2010
35


IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"
5. Parameters of NTM equations: σxx=Iref(axxV+bxx)
Present NTM
80magl
σmean
σ90q
σσ
Wind Speed(m/s)
Wind Speed(m/s)
Wind Speed(m/s)
14,15 Dec.2010
36

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

5. Parameters of NTM equations: $\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$

Coverage by the new NTM was calculated as before・・・・

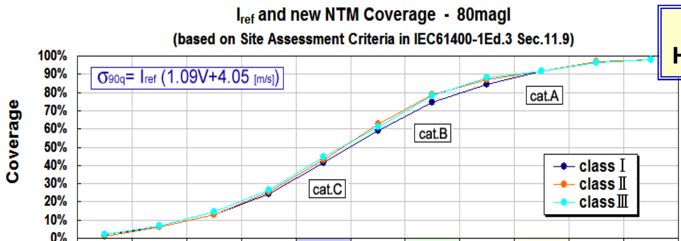
14,15 Dec.2010

37

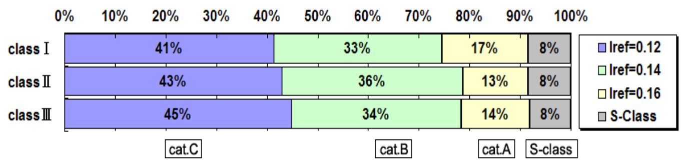
IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

5. Parameters of NTM equations: $\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$

80 magl Hub Height



Iref→	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
class Ⅰ	0.02	0.06	0.13	0.24	0.41	0.59	0.75	0.85	0.92	0.97	0.98
class Ⅱ	0.01	0.06	0.13	0.25	0.43	0.63	0.79	0.87	0.92	0.97	0.98
class Ⅲ	0.02	0.07	0.14	0.26	0.45	0.61	0.78	0.88	0.92	0.96	0.98



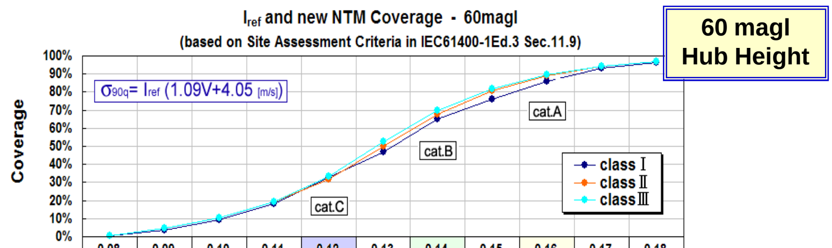
With existing categorization(Iref=0.12/0.14/0.16), new NTM covers more than 90% of the sites!

14,15 Dec.2010

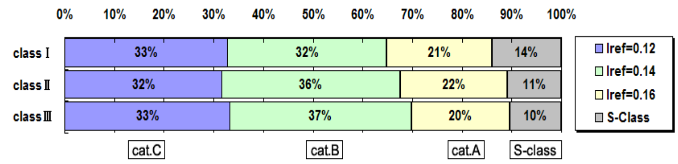
38

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

5. Parameters of NTM equations: $\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$



Iref→	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
class Ⅰ	0.00	0.04	0.09	0.18	0.33	0.47	0.65	0.76	0.86	0.93	0.96
class Ⅱ	0.00	0.05	0.10	0.19	0.32	0.50	0.68	0.81	0.89	0.94	0.97
class Ⅲ	0.00	0.05	0.10	0.19	0.33	0.53	0.70	0.82	0.90	0.94	0.97



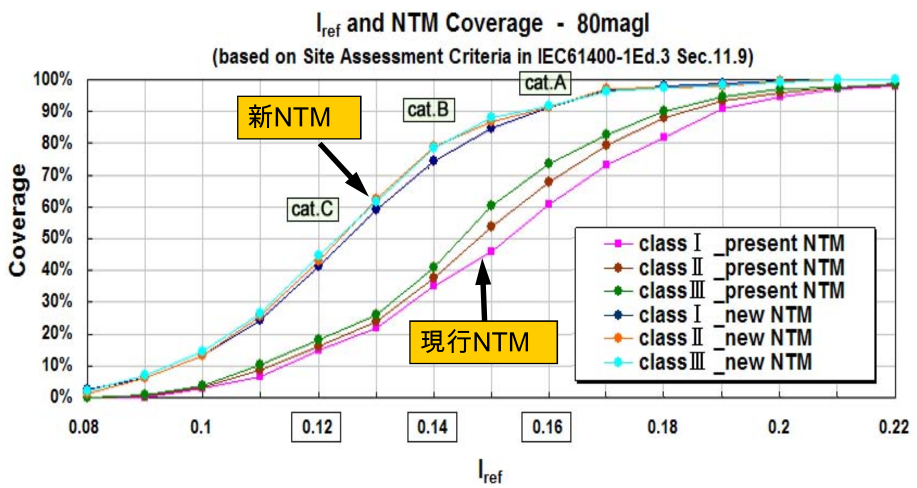
Similar result as 80magl Hub Height.

14,15 Dec.2010 39

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

5. Parameters of NTM equations: $\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$

Comparison: Present NTM and New NTM (80magl Hub Height)

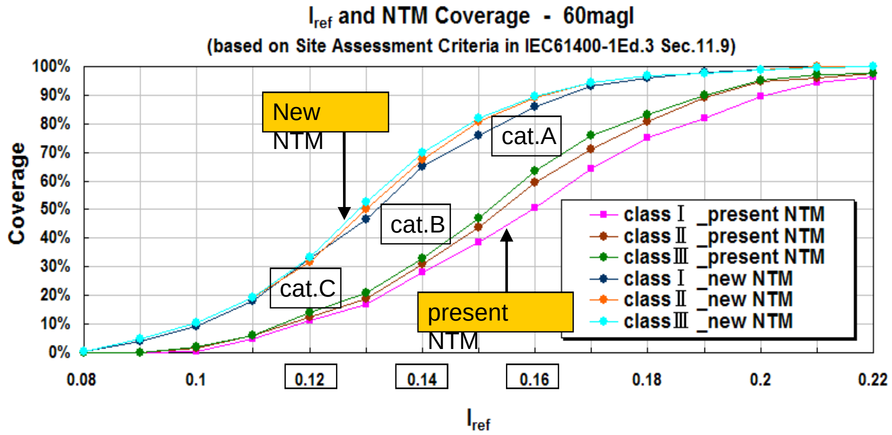


14,15 Dec.2010 40

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

5. Parameters of NTM equations: $\sigma_{xx}=I_{ref}(a_{xx}V+b_{xx})$

Comparison: Present NTM and New NTM (60magl Hub Height)



14,15 Dec.2010

41

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

1. Objective
2. Wind Data
3. Distribution of Turbulence Characteristics
4. Coverage of NTM
5. Parameters of NTM equations
6. Suggestion on the Amendment to 61400-1 Ed.3
7. Conclusion

14,15 Dec.2010

42

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

6. Suggestion on the Amendment to 61400-1 Ed.3

	Present	1	2	3	4
σ_σ	$=I_{ref}\cdot 1.44$	←	$I_{ref}\cdot 3.0$	$I_{ref}(0.15V+0.75)$	$I_{ref}(0.15V+2.0)$
σ_{mean}	$=I_{ref}(0.75V+3.75)$	←	←	←	$I_{ref}(0.9V+1.5)$
σ_{90q}	$=I_{ref}(0.75V+5.6)$	←	$I_{ref}(0.75V+7.0)$	$I_{ref}(0.94V+4.7)$	$I_{ref}(1.09V+4.05)$
I_{ref}	=0.12/0.14/0.16	Add 0.18 0.20	No Change (May add)	← ←	← ←

1 No change with NTM. New Turbulence categories added.

2,3 Change with σ_σ. (Same σ_σ value at 15m/s)
It involves change of σ_{90q} (Note: $\sigma_{90q} = \sigma_{mean} + 1.2816\ \sigma_\sigma$).
(Lower turbulence categories may be added.)

4 Change NTM according to results of previous section.
This suggestion is feasible only if our observation be verified represent worldwide wind climate.

14,15 Dec.2010 43

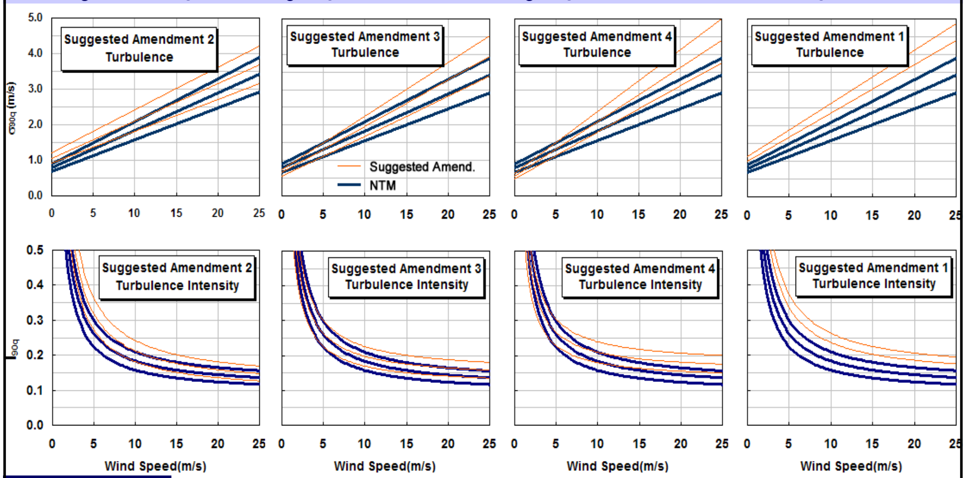
IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

6. Suggestion on the Amendment to 61400-1 Ed.3

Comparison of present NTM and suggested amendment

$\sigma_{mean}=I_{ref}(0.90V+1.5)$

$\sigma_\sigma=3.0\cdot I_{ref}$ $\sigma_\sigma=I_{ref}(0.15V+0.75)$ $\sigma_\sigma=I_{ref}(0.15V+2.0)$ new I_{ref}:0.18/0.20

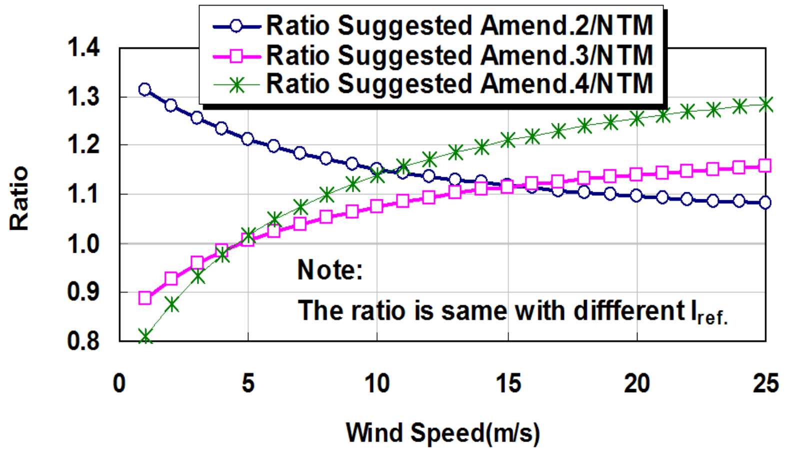


14,15 Dec.2010 44

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

6. Suggestion on the Amendment to 61400-1 Ed.3

Ratio of Turbulence Intensity(90% quantile) :
suggested amendment v.s. present NTM



14,15 Dec.2010

45

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

1. Objective
2. Wind Data
3. Distribution of Turbulence Characteristics
4. Coverage of NTM
5. Parameters of NTM equations
6. Suggestion on Amendment to 61400-1 Ed.3
7. Conclusion

14,15 Dec.2010

46

7. Conclusion

Wind data at 259 sites widely distributed in Japanese potential wind farm sites were analyzed in view of turbulence to assess suitability of turbulence model defined by IEC61400-1Ed.3

7. Conclusion

1.The following was observed:

(1) Linearity of σ-V relationship is excellent.

(2) For σ_{mean}, most of the sites are well covered by standard turbulence categories A, B and C.

(3) For σ_{90q}, considerable portion of the sites are not covered by standard turbulence categories.

(4) For σ_{σ}, there is big deviation between observation and NTM:

- Most of the sites lie far above NTM.
- Measurements in average show tendency of increase with wind speed, whereas NTM assumes it stay constant with wind speed.

(5) Slopes of observed σ-V regression lines were in average slightly greater than that of NTM.

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

6. Conclusion

2. Assessment according to Sec.11.9 procedure revealed that 26% to 49%, depending on wind turbine class and hub height, of the sites are not covered by IECstandard turbulence categories.

3. Suggestions were made on the amendment to IEC turbulence model and categorization to harmonize them with our observation.

14,15 Dec.2010

49

IEA R&D Wind Task XI - Topical Expert Meeting On
"Wind Conditions for Wind Turbine Design"

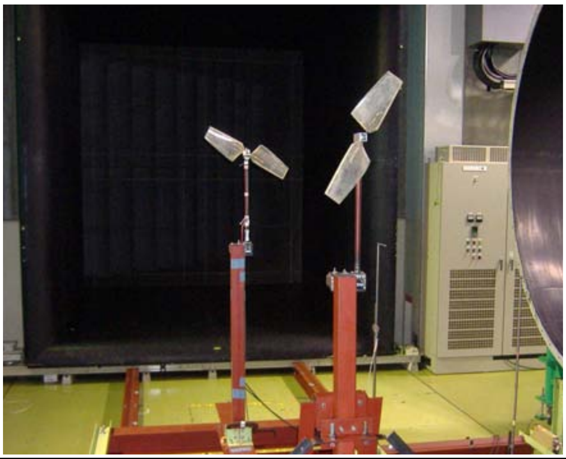
Thank you for your attention!

14,15 Dec.2010

50

IEA R&D Wind Task XI
Topical Expert Meeting on "Wind Conditions for Wind Turbine Design"
December 14-15, 2010, Tokyo, JAPAN

Experimental Study of Wake Effects for Complex Terrain



Mie University

Junsuke MURATA

Outline

1

- ■Background
- ■Objective
- ■Experimental Apparatus and Conditions
- ■Experimental Results
  - ・ Wind Speed Profile in Wake
  - ・ Turbulence Intensity Profile in Wake
  - ・ Wind Speed Fluctuation in Wake
- ■Conclusions
- ■Future Work

Background

2

■Wind Farm on Complex Terrain

○Restriction of Land Utilization

→Distance between wind turbines: as short as possible...

○Complex Terrain

・ High turbulence

・ Difference in height

→Distance can be shorter than flat terrain and offshore?

Aoyama Kogen Wind Farm (Japan)

Objective

3

■Objective of Work

○Establishment of Wake Model on Complex Terrain

・ Acquisition of basic data to estimate wake effects

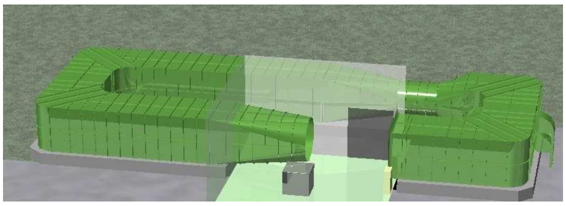
→Effects of Turbulence on wake

■Wind Tunnel Experiment

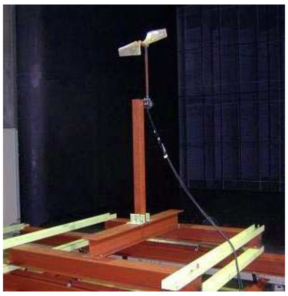
・ Wind tunnel, Test wind turbine, Turbulence grids and hot wire probe

・ Measurement of wind speed profile in wake

→Different turbulence intensities in main flow



Wind Tunnel



Test Wind Turbine

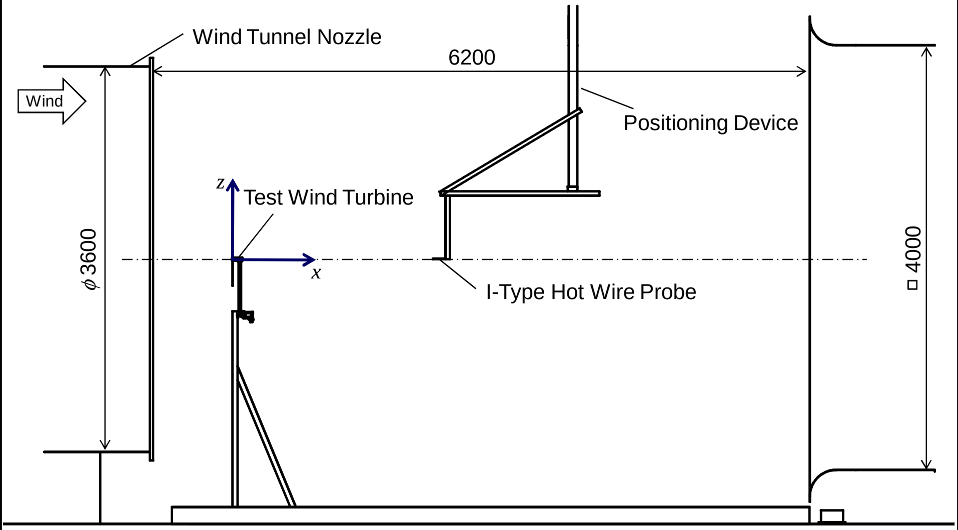
Experimental Apparatus

- ○Wind Tunnel
- ○Turbulence Grids
- ○Test Wind Turbine

Experimental Conditions

- ○Measurement Points
- ○Conditions

Experimental Apparatus 1/5



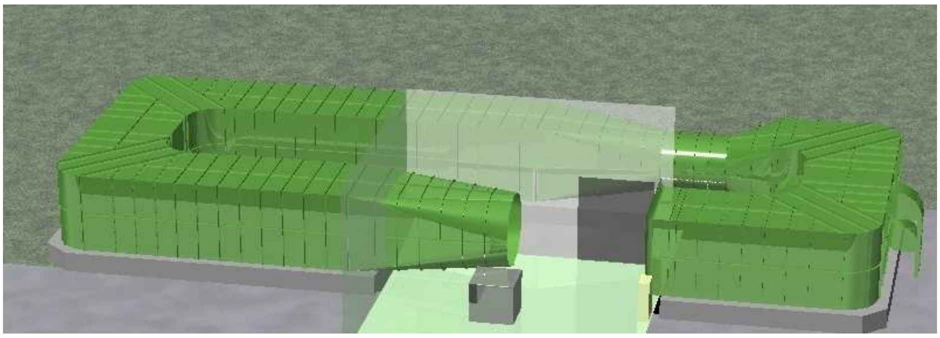
Experimental Setup

Experimental Apparatus 2/5

6

■Wind Tunnel

- Circulation type wind tunnel
- 3600mm diameter nozzle
- 6200mm length open test section
- 30m/s maximum wind speed



Circulation Type Wind Tunnel

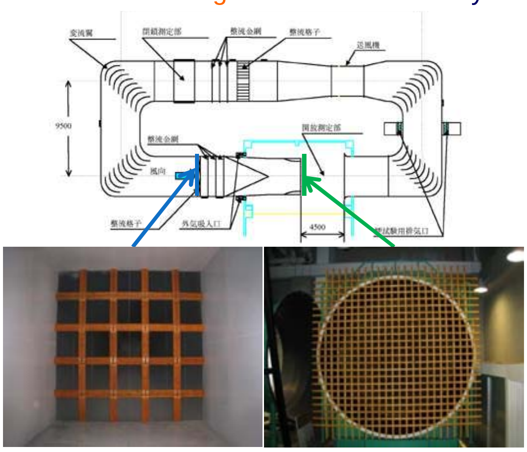
Experimental Apparatus 3/5

7

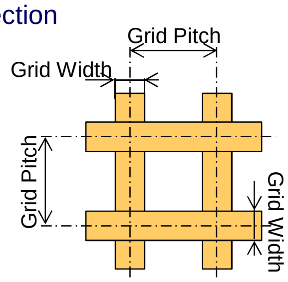
■Turbulence Grids

○Generation of Different Turbulence Intensities in Main Flow

- Fine grid: Attached on wind tunnel nozzle
- Coarse grid: Attached at honeycomb section



Coarse Grids **Fine Grids**



Parameters of Turbulence Grids

	Fine Grid	Coarse Grid
Grid Width	40mm	185mm
Grid Pitch	160mm	840mm
Blockage Ratio	0.438	0.391

Experimental Apparatus 4/5

8

■Turbulence Grids

- Low Turbulence: without turbulence grid
- Medium Turbulence: with coarse grid
- High Turbulence: with fine and coarse grids

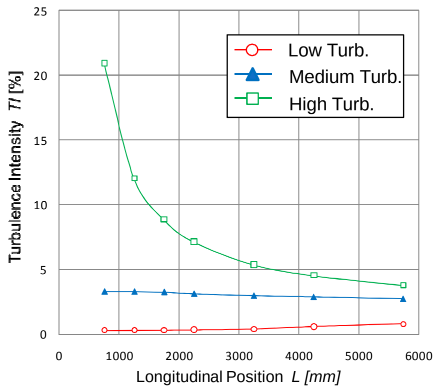
○Turbulence Intensity

$$TI = \frac{\sigma}{U_{\mathrm{main}}}$$

σ: Standard deviation of wind speed
U_{main}: Wind speed of main flow

→to figure out wind speed variance

- Low Turb.: about 0.5%
- Medium Turb.: about 3%
- High Turb.: 21% to 4%



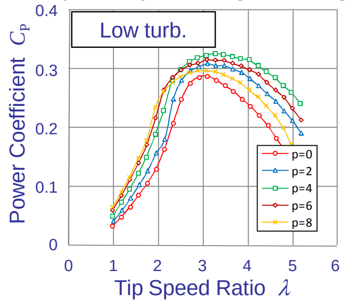
Turbulence Intensity in Main Flow

Experimental Apparatus 5/5

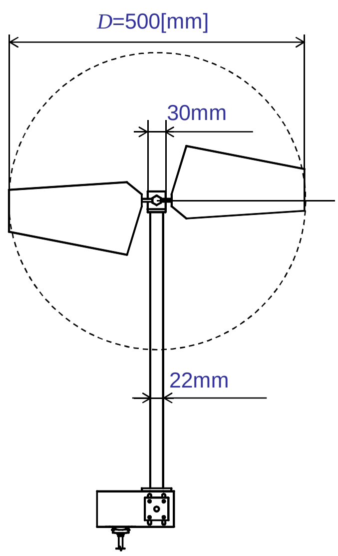
9

■Test Wind Turbine

- Two-bladed horizontal axis wind turbine
- Diameter: D=500 [mm]
- Long chord length blade
  →to keep Re & performance
- Maximum performance: C_P=0.33-0.34
  →Optimal tip speed ratio: 3.3-3.5
  →Optimal pitch angle: 4 degree



Performance of Test Wind Turbine

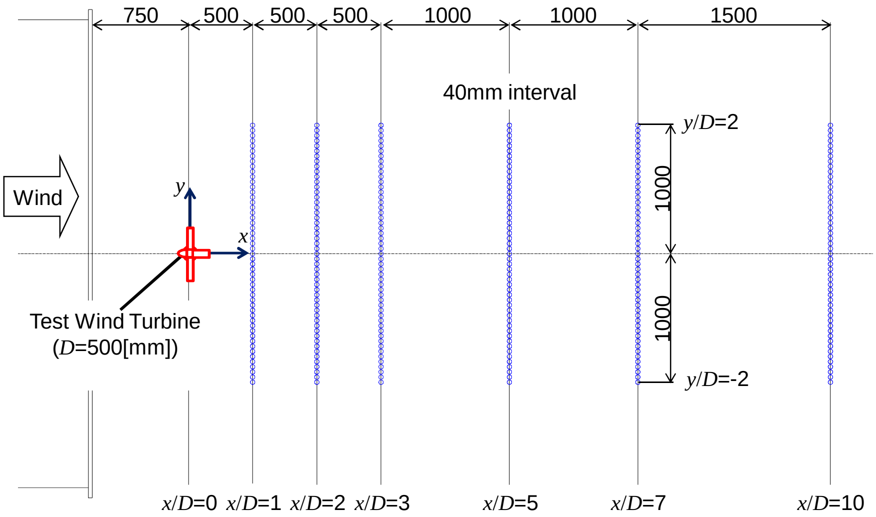


Test Wind Turbine

Experimental Conditions 1/2

10

■Measurement Points



Experimental Conditions 2/2

11

■Wind Speed Measurement

- I-type hot wire probe
- Sampling frequency: 1kHz
- Sampling time: 16.384sec (16384 data) at one measurement point

■Operation Conditions

- Wind speed: U_{main}=7 [m/s]
- Preset pitch angle: 4 degree
- Rotational speed: 950rpm (15.8Hz, λ=3.4)

→optimal operation

■Nondimensional Parameters

- Nondimensional wind speed:

$$U_N = \frac{U_{local}}{U'_{local}}$$

U_{local}: Local wind speed with test wind turbine
U'_{local}: Local wind speed without test wind turbine

- Turbulence intensity:

$$TI = \frac{\sigma}{U_{main}}$$

σ: Standard deviation of wind speed
U_{main}: Wind speed of main flow

12

Experimental Results

○Wind Speed Profile in Wake

○Turbulence Intensity Profile in Wake

○Wind Speed Fluctuation in Wake

Wind Speed Profile in Wake 1/2

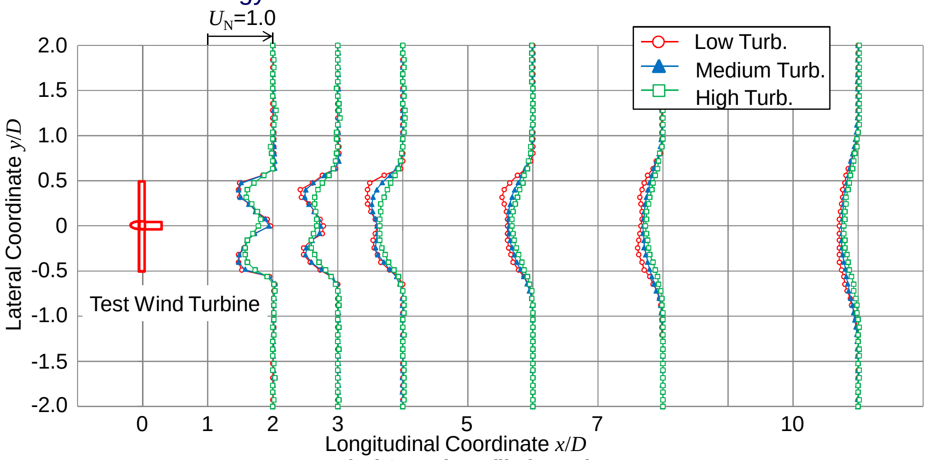
13

■Wind Speed Deficit

・ Deficit area: symmetric expansion with distance from wind turbine

・ Near wind turbine: small peak on y axis

→no energy extraction inside of blade root



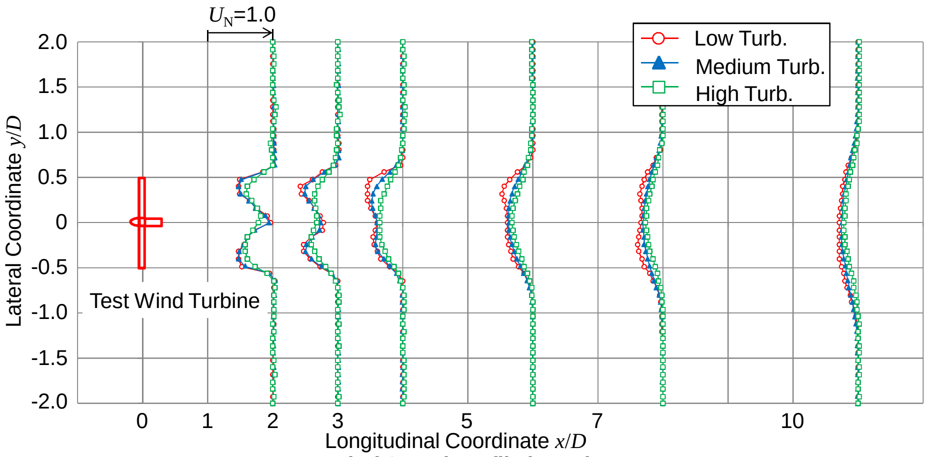
Wind Speed Profile in Wake

Wind Speed Profile in Wake 2/2

14

■Effects of Turbulence on Wake

- Slightly higher wind speed and flatter profile with higher turbulence
  →promoting entrainment of main flow and wake



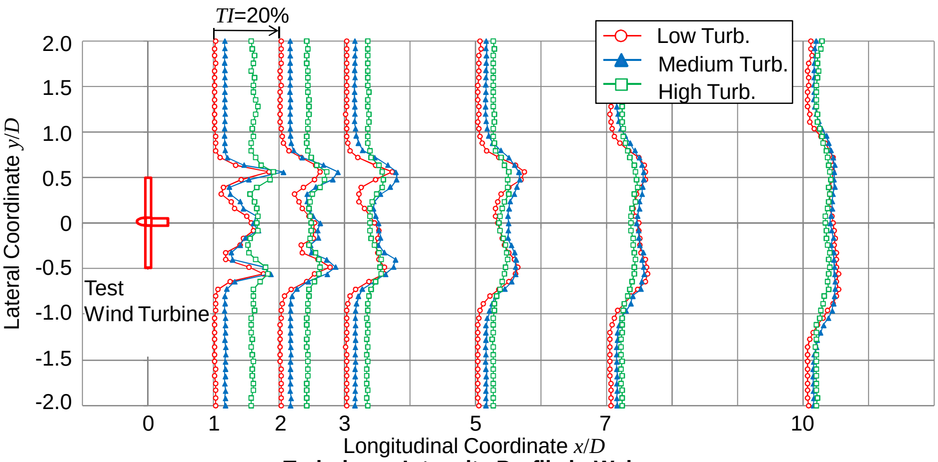
Wind Speed Profile in Wake

Turbulence Intensity Profile in Wake 1/2

15

■High Turbulence Region in Wake

- Peaks at $|y/D|$=0.56: tip vortex
- Flatter profile with distance from wind turbine



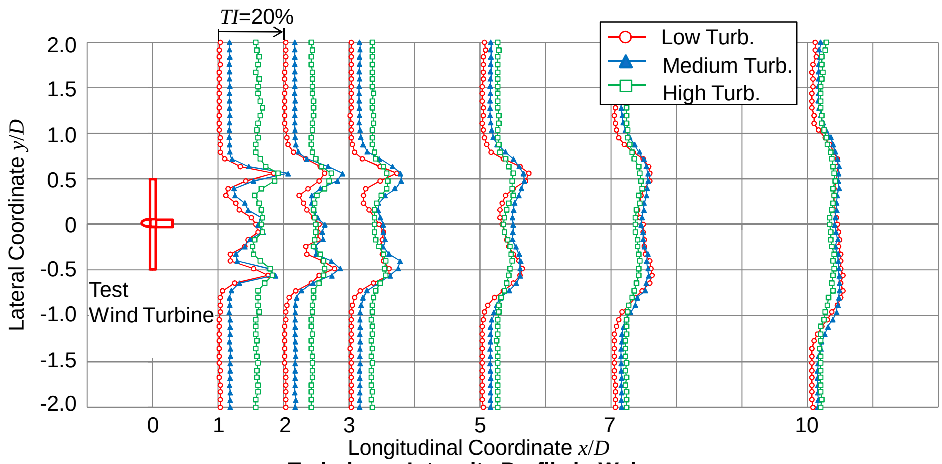
Turbulence Intensity Profile in Wake

Turbulence Intensity Profile in Wake 2/2

16

■Effects of Turbulence on Wake

- Peak value: about 20% almost same level
- Quicker flattening with higher turbulence intensity



Turbulence Intensity Profile in Wake

Wind Speed Fluctuation in Wake

17

■Bin averaged wind speed fluctuation

○Low and Middle turbulence

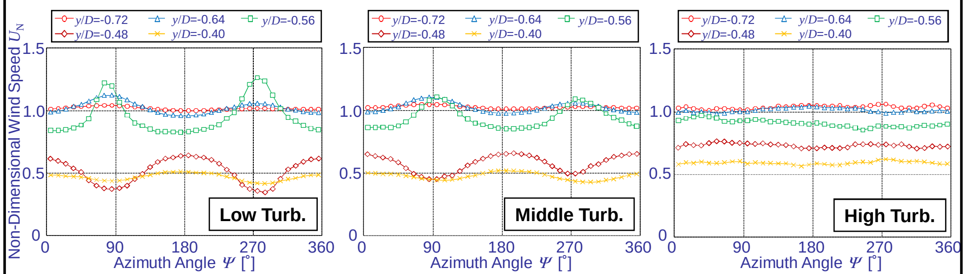
- Two cycle fluctuation
- Opposite peaks at inner part (|y/D|<0.5) and outer part (|y/D|>0.5)

→Approach and passage of tip vortices generated by two blades

○High turbulence

- No cyclic fluctuation

→Tip vortex structure is scattered by turbulence



Wind Speed Fluctuation in Wake at x/D=1.0

Wind Tunnel Experiment -Conclusions-

18

Using a hot wire probe, wind speed profiles were measured in wake generated by a wind turbine in various turbulence intensity conditions. The following were clarified by these measurements.

1.Turbulence of main flow influences wind speed profile in wind turbine wake. High turbulence intensities enable to entrainment of the main flow and the wake, and to recover quickly the velocity in the wake.

2.The maximum values of turbulence intensity in the wake are generated at near the blade tips and almost the same as in any turbulence condition.

3.The tip vortex structure is scattered by turbulence, and it isn't preserved with high turbulence.

Future Work 1/4

19

■Problems...

- ○Even "High Turbulence" condition
  - ・ Turbulence intensity < 10% in wake observation area
    → too low as complex terrain
- ○Effects of Other Parameters on Wake?
  - ・ Turbulence scale
  - ・ Anisotropy

■Future Work

- ○New Turbulence Grids are needed
  →Active Type Turbulence Grids
  - ・ Array of Small wings driven by servomotors

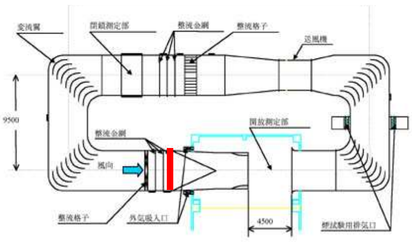
Future Work 2/4

20

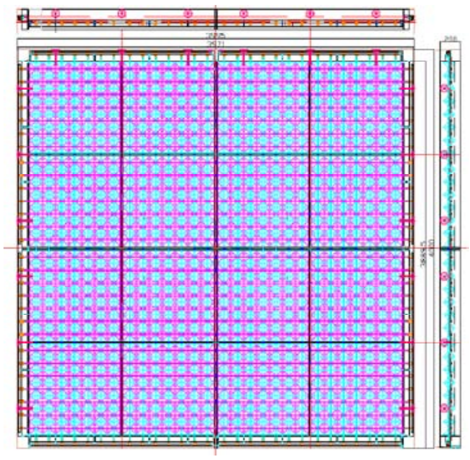
■Active Type Turbulence Grids

○For ϕ3600 large wind tunnel

- Shafts: 56
- Small wings: 1568
- Servomotor: 112



Attached Position



Active Type Turbulence Grids (Overall View)

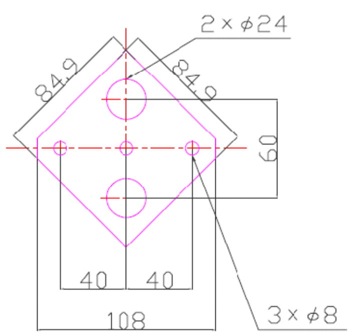
Future Work 3/4

21

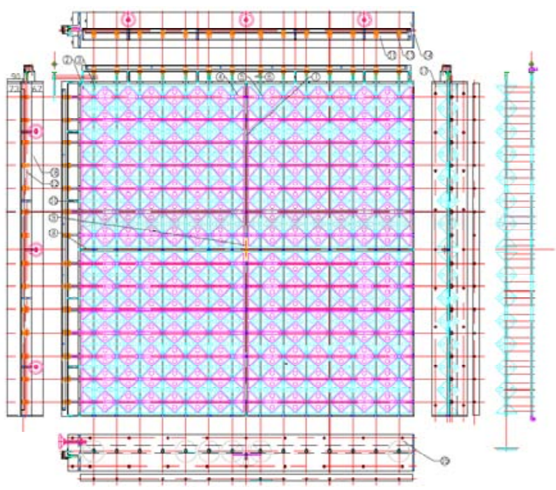
■Active Type Turbulence Grids

○For ϕ3600 large wind tunnel

- Shafts: 56
- Small wings: 1568
- Servomotor: 112



Small Wing



Active Type Turbulence Grids (Quarter Part)

Future Work 4/4

22

■Progress

○Finish assembling → Checking of operations

・ Rotating speed

・ Operation pattern

→Control turbulence intensity, turbulence scale and anisotropy?

Future Work 4/4

23

■Progress

○Finish assembling → Checking of operations

・ Rotating speed

・ Operation pattern

→Control turbulence intensity, turbulence scale and anisotropy?

Thank you for your kind attention!

Wind Turbine Loads during Simulated Thunderstorm Downbursts

Hieu Huy Nguyen (PhD student, University of Texas at Austin)
Lance Manuel (Professor, University of Texas at Austin)

IEA R&D Wind Task XI - Topical Expert Meeting
Wind Conditions for Wind Turbine Design
Tokyo, Japan – December 14-15, 2010

Motivation and Objectives

Motivation

Thunderstorms are common intense short-duration atmospheric (transient) events

The design standard (IEC 61400-1) for wind turbines does not explicitly address load cases associated with thunderstorm downburst-related velocity fields

Objectives

- to describe a deterministic-stochastic hybrid model for simulation of thunderstorm microburst-related wind velocity fields
- to compute loads on a utility-scale winds using the simulated thunderstorm downburst flow fields (with some control logic assumptions)

2/43

Nature of Thunderstorm Downbursts

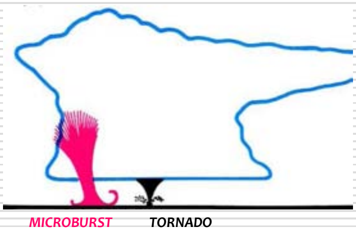
❖**Thunderstorms:** Produced at the base of convective clouds (often accompanied by lightning and thunder)

They can produce both tornadoes and downbursts

❖**A downburst:** A strong downdraft which includes an outburst of damaging winds at or near the ground (Fujita, 1985).

- MACROBURST: A large downburst with outburst winds extending in excess of 4 km (2.5 miles) in horizontal dimension. Max. *winds as high as 60 m/s*
- **MICROBURST**: Extends 4 km (2.5 miles) or less in horizontal dimension Max. ***winds as high as 75 m/s***

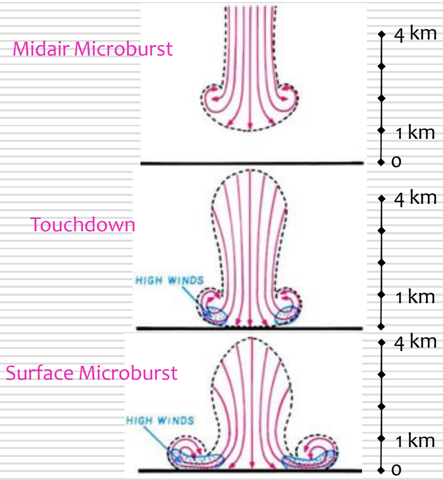
A cumulonimbus cloud with anvil top



(Fujita, 1985)

3/43

Nature of Thunderstorm Downbursts

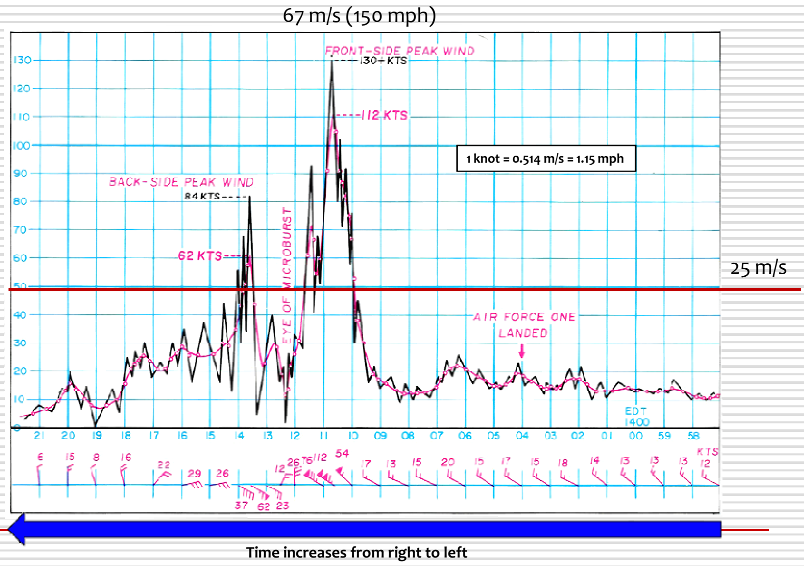


The three stages of a descending microburst (Fujita, 1985)

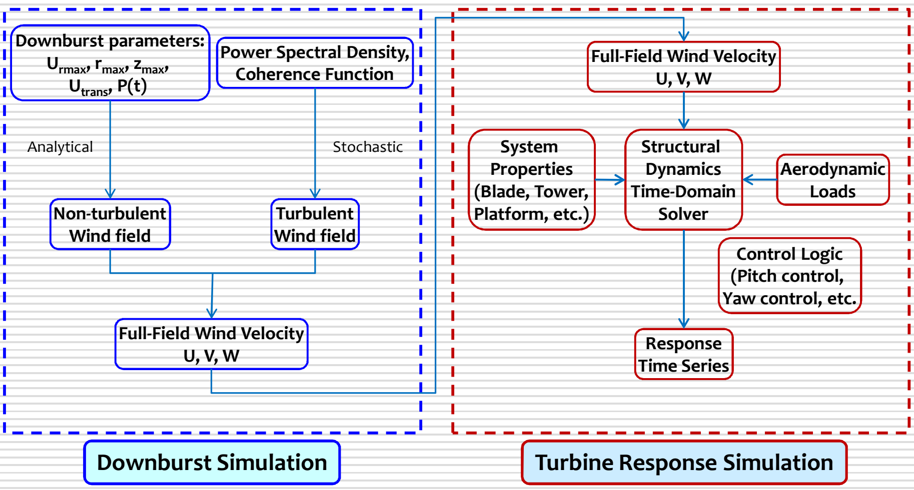
The curl phase soon after a microburst impacted the surface (Courtesy: NOAA Photo Lib.)

4/43

Andrews AFB Microburst on Aug. 1, 1983 at z = 5 m (Fujita, 1985)



Simulation of Downburst Wind Field & Turbine Loads



Downburst: Hybrid Model

❖ The wind velocity field can be described as the sum of two components:

$$U(x,y,z,t) = U_m(x,y,z,t) + u(x,y,z,t)$$

where

$U(x, y, z, t)$	=	total wind velocity field
$U_m(x, y, z, t)$	=	non-turbulent wind velocity field
$u(x, y, z, t)$	=	turbulent wind velocity field

❖ **A hybrid model**

1. The mean winds are caused by large-scale flow and thus may be considered to be deterministic
2. The fluctuations are induced by small-scale turbulence and thus are considered as modeled by a stochastic process.

7/43

Downburst: Non-turbulent

Several models to describe the non-turbulent wind field have been proposed and improved upon.

They include:

❖Oseguera and Bowles, 1988

❖ Vicroy, 1992

❖ Wood, 1998

❖ Holmes, 1999

❖ Chen and Letchford, 2003

❖ Chay et al., 2005

❖ Chen and Letchford, 2007

8/43

Downburst: Oseguera and Bowles, 1988

❖ Model represents an axisymmetric stagnation point flow and is based on velocity profiles from the Terminal Area Simulation System (TASS) study. It satisfies the mass continuity equation in cylindrical coordinates.

❖ The radial (U_r) and vertical (U_z) velocities:

$$U_r(r,z) = \frac{\lambda R^2}{2r}\left[1-e^{-(r/R)^2}\right]\left(e^{-z/z^*}-e^{-z/\varepsilon}\right)$$

$$U_z(r,z) = -\lambda e^{-(r/R)^2}\left[\varepsilon\left(e^{-z/z^*}-1\right)-(z^*)\left(e^{-z/z^*}-1\right)\right]$$

where

$U_r(r,z)$ = radial wind velocity component

$U_z(r,z)$ = vertical wind velocity component

r = radial coordinate from the center of the downburst

R = the characteristic radius of the downburst shaft

z^* = characteristic height out of the boundary layer

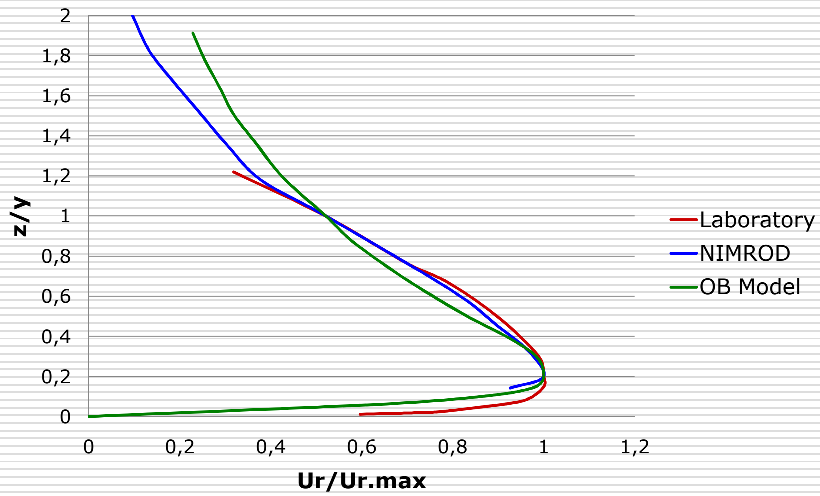
ε = characteristic height in the boundary layer

λ = intensity scaling factor

9/43

Downburst: Oseguera and Bowles ,1988

Comparison of Wind Vertical Profiles



NIMROD: Northern Illinois Meteorological Research On Downburst in 1978

10/43

Downburst: Vicroy, 1992

❖ A modification of the OB 1988 model.
Uses new shape functions to more accurately represent observed wind profiles.

$$U_r(r,z) = \frac{\lambda r}{2}\left[e^{c_1(z/z_m)} - e^{c_2(z/z_m)}\right] e^{\left[\frac{2-(r/r_m)^{2\alpha}}{2\alpha}\right]}$$

$$U_z(r,z) = -\lambda\left\{\frac{z_m}{c_1}\left[e^{c_1(z/z_m)}-1\right] - \frac{z_m}{c_2}\left[e^{c_2(z/z_m)}-1\right]\right\}\left[1-\frac{1}{2}\left(\frac{r}{r_m}\right)^{2\alpha}\right] e^{\left[\frac{2-(r/r_m)^{2\alpha}}{2\alpha}\right]}$$

where

$U_r(r,z)$ = radial wind velocity component

$U_z(r,z)$ = vertical wind velocity component

r_m = radius at which $U_{r.max}$ occurs

z_m = height at which $U_{r.max}$ occurs

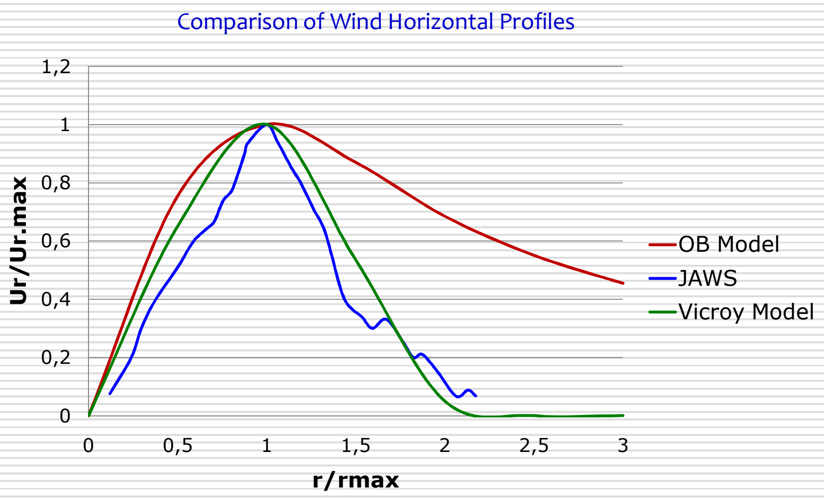
a, c_1, and c_2 are model constants;

$a = 2$, $c_1 = -0.15$, and $c_2 = -3.2175$.

λ is an intensity scaling factor

11/43

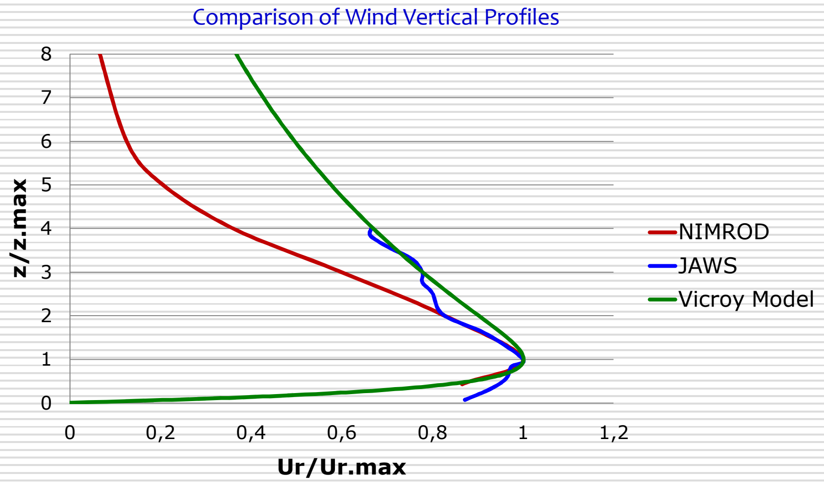
Downburst: Vicroy,1992



JAWS: The Joint Airport Weather Studies (JAWS) Project, 1980

12/43

Downburst: Vicroy,1992



NIMROD: Northern Illinois Meteorological Research On Downburst in 1978
JAWS: The Joint Airport Weather Studies (JAWS) Project, 1980

13/43

Downburst: Wood et al., 1998

❖ An empirical model describing the development of a velocity profile over a flat board (resulting from a static continuous impinging jet)

❖ The vertical wind profile is given by:

$$U(z) = U_{\max}\left(\frac{z}{z_{\max/2}}\right)^{1/6}\left[1-\mathrm{erf}\left(0.70\frac{z}{z_{\max/2}}\right)\right]$$

where

o $z_{max/2}$ = height at which $U(z_{max/2}) = 0.5U_{max}$

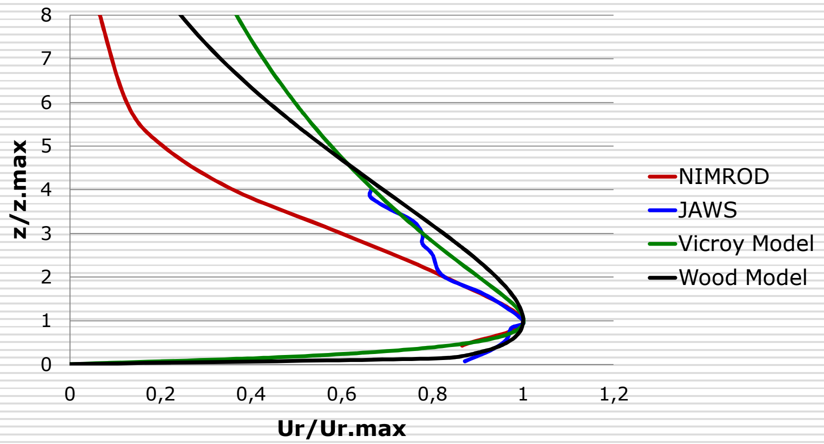
❖ Only valid once the wall jet stabilized beyond ~1.5 jet diameters.

❖ *Note:* there is no explicit radial dependence in this model

14/43

Downburst: Wood et al., 1998

Comparison of Wind Vertical Profiles



Given the range of z_{max} is 50-100 m AGL, the Vicroy model seems to estimate wind profiles over the height of a wind turbine (20-160 m) reasonably well.

15/43

Downburst: Other Models

- ❖ Other models and refinements to existing models were developed

  Holmes and Oliver (1999)
  Chen and Letchford (2003)
  Chay et al (2005)
  Chen and Letchford (2007).

- ❖ Not all are suited for wind turbine loads computations.

- ❖ We will describe the Chay et al (2005) model which we employed n this study.

16/43

Downburst: Chay et al., 2005

❖ Chay et al. modified earlier models by including the storm intensity Π(t), storm's translational velocity, U_{trans} and radial distance where the $U_{r.max}$ occurs as a function of time, $r_m(t)$.

$$\vec{U}_h(x,y,z,t) = \vec{U}_r(x,y,z,t) + \vec{U}_{trans}$$

$$U_r(x,y,z,t) = \Pi(t)\frac{U_{r.\max} r}{r_m(t)}\left[\frac{e^{c_1(z/z_m)} - e^{c_2(z/z_m)}}{e^{c_1} - e^{c_2}}\right] e^{\left[\frac{2-(r/r_m)^{2\alpha}}{2\alpha}\right]}$$

$$U_z(x,y,z,t) = -\Pi(t)\frac{U_{r.\max} z_m}{r_m(t)}\frac{c_2[e^{c_1(z/z_m)} - 1] - c_2[e^{c_2(z/z_m)} - 1]}{c_1 c_2[e^{c_1} - e^{c_2}]}\left[1 - \frac{1}{2}\left(\frac{r}{r_m(t)}\right)^{2\alpha}\right] e^{\left[\frac{2-(r/r_m(t))^{2\alpha}}{2\alpha}\right]}$$

where

$U_{r.max}$ = maximum radial velocity

U_{trans} = storm's translational velocity

z_m = elevation at which $U_{r.max}$ occurs;

$r_m(t)$ = time-dependent radial distance at which $U_{r.max}$ occurs;

Π(t) = storm intensity.

17/43

Why the Chay et al (2005) Model for Downbursts?

❖ It is based on the OBV models
(which were in good agreement with NIMROD and JAWS data)

❖ Incorporates improvements from other models:

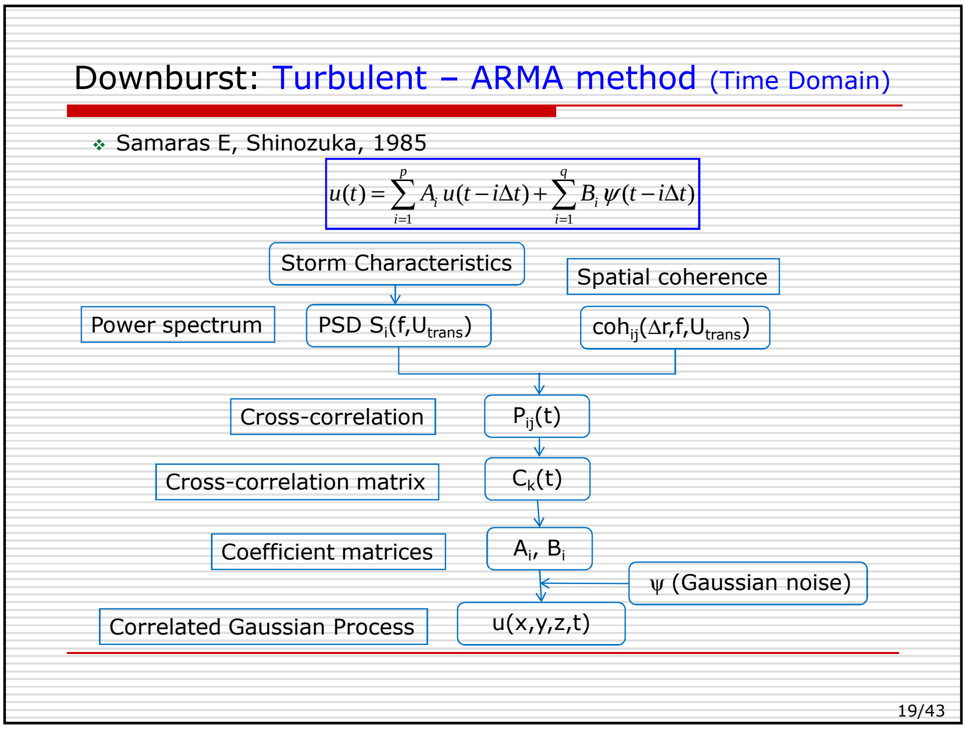
- From Holmes
  includes Storm translation speed
- From Chen and Letchford
  uses the hybrid model idea with a time-dependent intensity function.

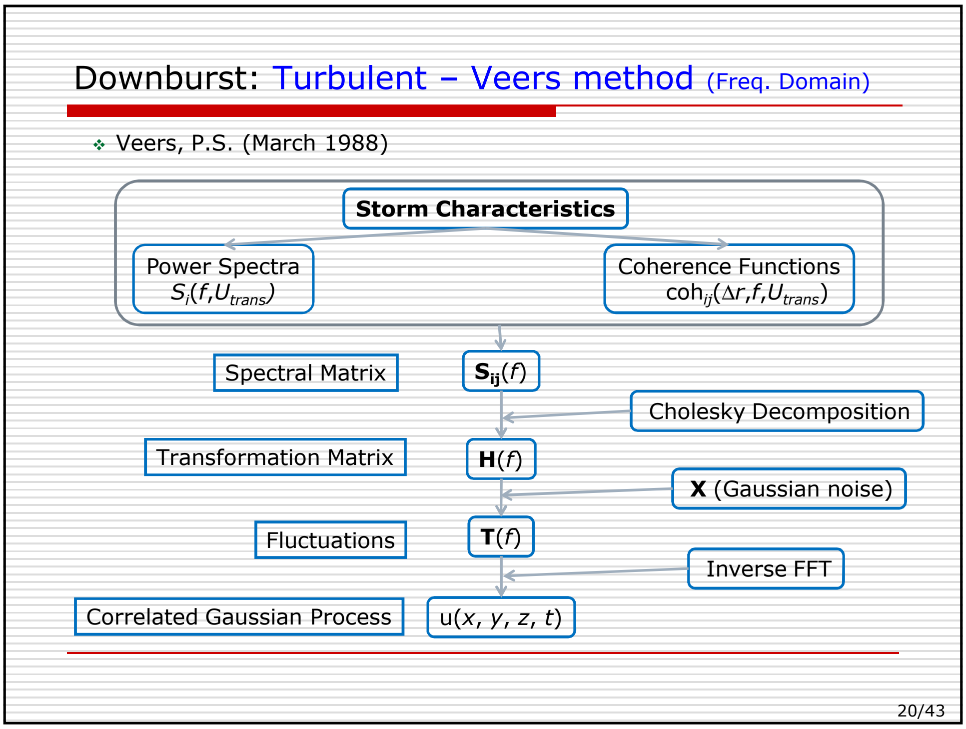
❖ Simple and comprehensive for wind turbine loads calculations (that involve time-domain structural and aerodynamic loads analyses)

❖ Model includes both radial (U_r) and vertical (U_z) wind components that are needed for wind turbine simulations.

❖ Reasonably accurate over expected heights of most utility-scale wind turbines.

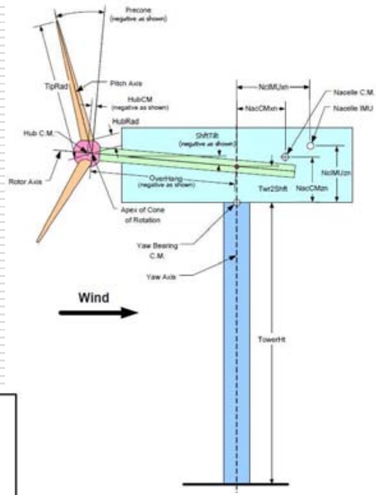
18/43


Downburst: Turbulent – ARMA method (Time Domain)
Samaras E, Shinozuka, 1985
$u(t) = \sum_{i=1}^{p} A_i u(t - i\Delta t) + \sum_{i=1}^{q} B_i \psi(t - i\Delta t)$
Storm Characteristics
Spatial coherence
Power spectrum
PSD $S_i(f,U_{trans})$
$coh_{ij}(\Delta r,f,U_{trans})$
Cross-correlation
$P_{ij}(t)$
Cross-correlation matrix
$C_k(t)$
Coefficient matrices
A_i, B_i
ψ (Gaussian noise)
Correlated Gaussian Process
u(x,y,z,t)
19/43

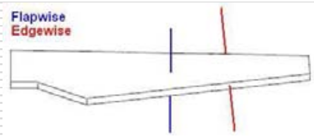

Downburst: Turbulent – Veers method (Freq. Domain)
Veers, P.S. (March 1988)
Storm Characteristics
Power Spectra
$S_i(f,U_{trans})$
Coherence Functions
$coh_{ij}(\Delta r,f,U_{trans})$
Spectral Matrix
$\mathbf{S_{ij}}(f)$
Cholesky Decomposition
Transformation Matrix
$\mathbf{H}(f)$
X (Gaussian noise)
Fluctuations
$\mathbf{T}(f)$
Inverse FFT
Correlated Gaussian Process
u(x, y, z, t)
20/43

Turbine Response Simulation – FAST (NREL)

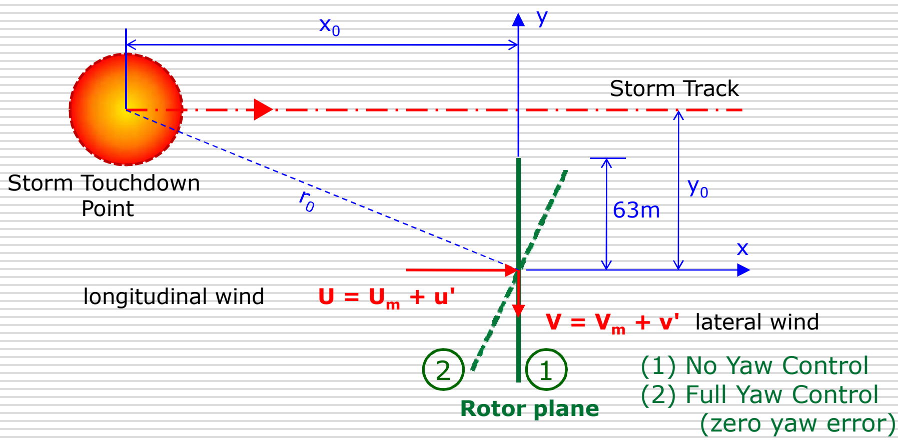
- ❖ Combined modal and multi-body dynamics formulation.
- ❖ Three-bladed turbines:
  - 9 rigid bodies (earth, support platform, nacelle,...)
  - 5 flexible bodies (tower, three blades, and drive shaft)
- ❖ 24 DOFs:
  - support platform motions (6), tower motions (4), nacelle yaw motion (1), variable rotor speed (1), etc.
- ❖Flexible Tower and Blades:
  - o Tower: Four mode shapes
  - o Blades: Two flapwise, one edgewise modes.



Layout of a conventional, upwind, three-bladed turbine (Jonkman, 2005)

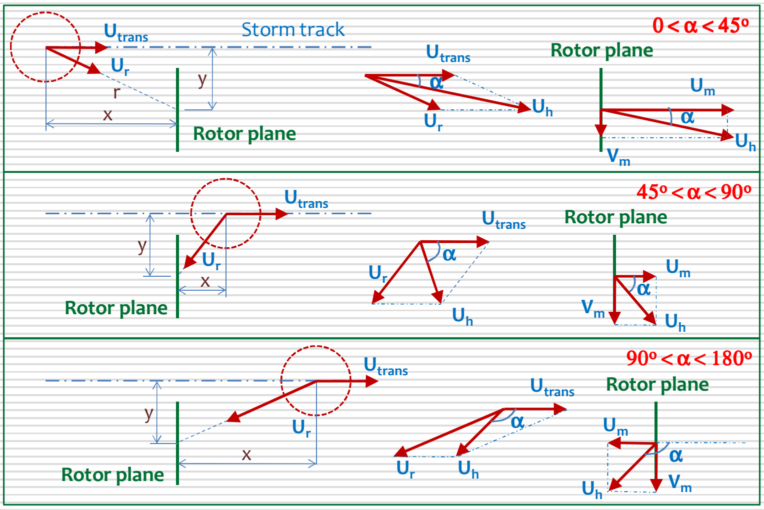


Problem Description



Plan View showing Thunderstorm Downburst and Wind Turbine

Changing Wind Direction in a Downburst



α = wind direction

23/43

Thunderstorm Downburst: An example

Storm Parameters:

1.Intensity build-up in 6 min; exponential decay after

$$\Pi(t) = \begin{cases} \frac{t}{6} & t \le 6 \\ e^{-\frac{t-6}{12}} & t > 6 \end{cases}$$

t is time in minutes

2.Maximum radial velocity, $U_{r.max}$ = 47 m/s

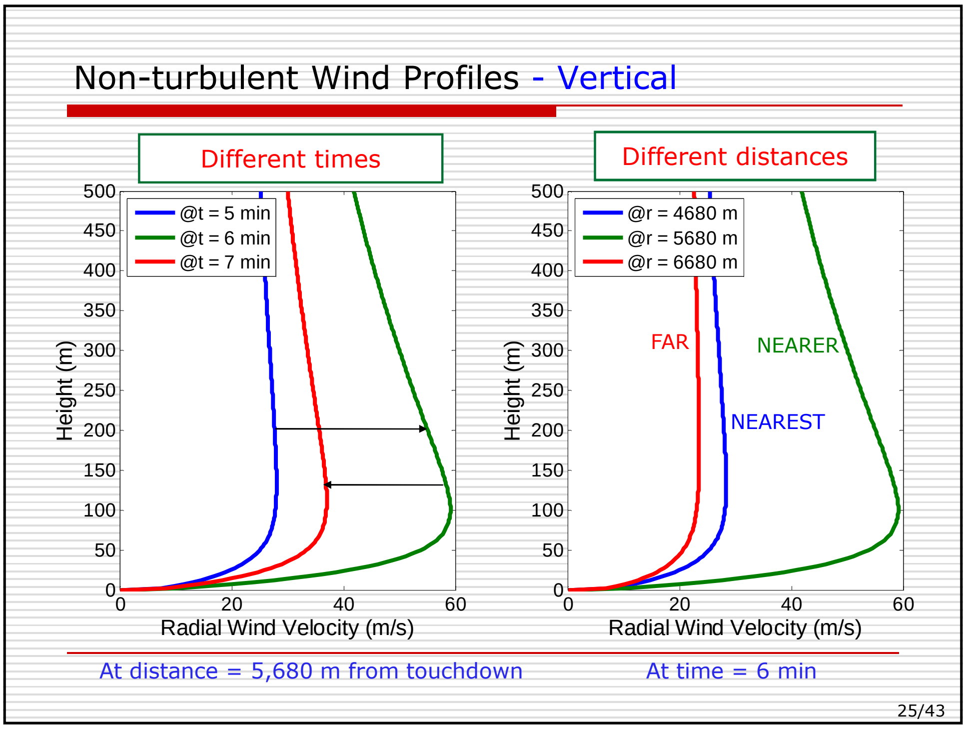
3.Storm translational (environmental) velocity at hub height, U_{trans} = 12 m/s

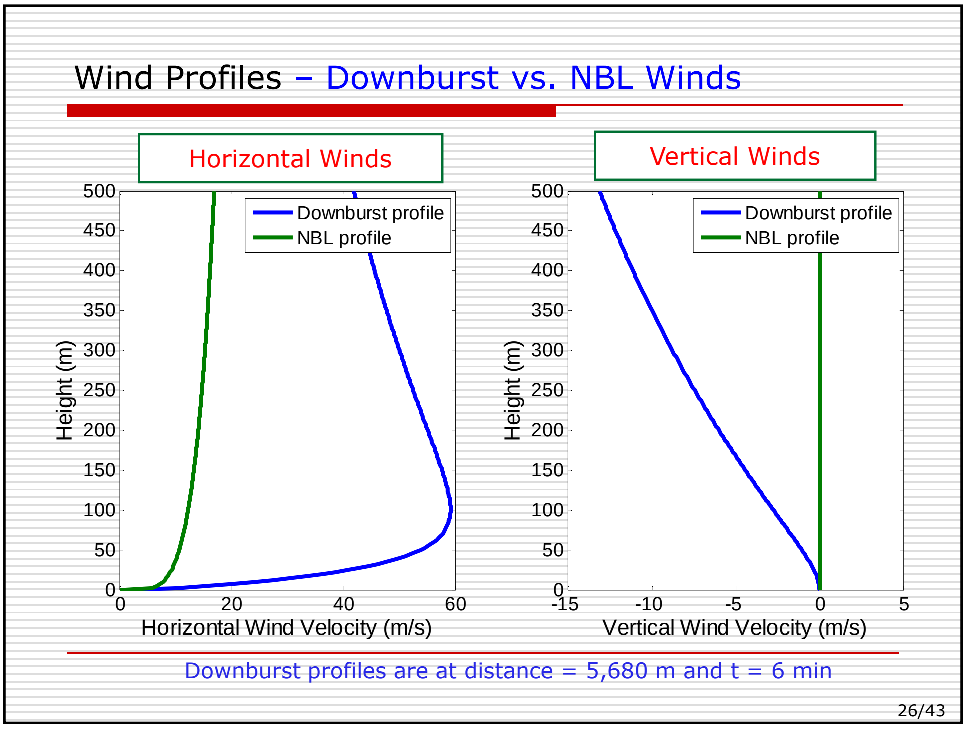
4.Radial distance at which $U_{r.max}$ occurs;

r_m = 1,000 (m) + 1 m/s × t (s)

5. Elevation at which $U_{r.max}$ occurs; z_m = 90 m

24/43


Non-turbulent Wind Profiles - Vertical
Different times
Different distances
@t = 5 min
@t = 6 min
@t = 7 min
@r = 4680 m
@r = 5680 m
@r = 6680 m
FAR
NEARER
NEAREST
Height (m)
Radial Wind Velocity (m/s)
At distance = 5,680 m from touchdown
At time = 6 min
25/43

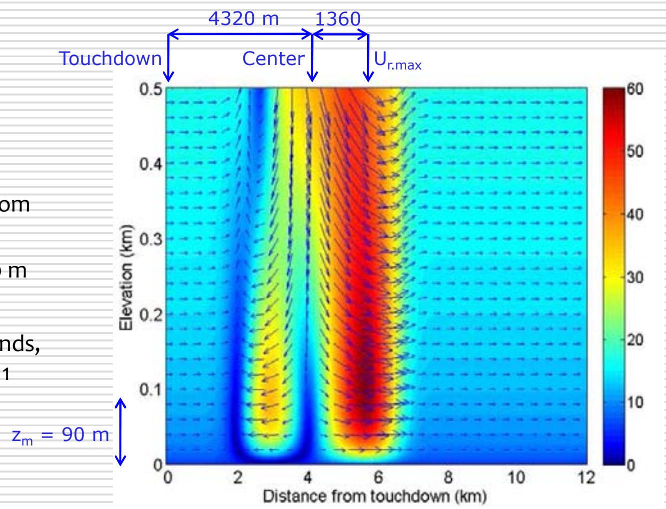

Wind Profiles – Downburst vs. NBL Winds
Horizontal Winds
Vertical Winds
Downburst profile
NBL profile
Height (m)
Horizontal Wind Velocity (m/s)
Vertical Wind Velocity (m/s)
Downburst profiles are at distance = 5,680 m and t = 6 min
26/43

Non-turbulent Wind Profiles Along Storm Track

Storm snapshot
at *t* = 360 sec

- Storm location from touch down:
  12 x 360 = 4320 m

- Radius to max winds,
  r_m = 1000 + 360 × 1
  = 1360 m



t = 360 sec (6 min)

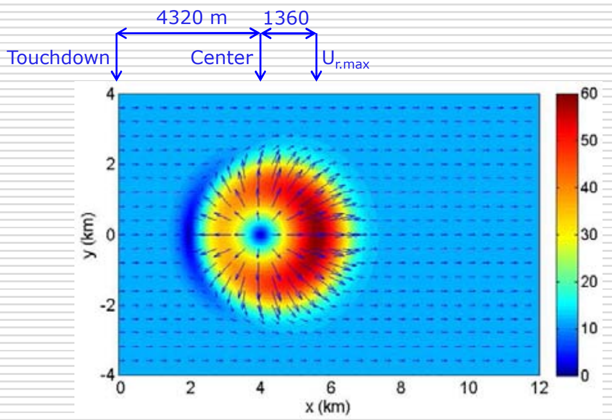
27/43

Non-turbulent Wind Profiles at *z* = 90 m

Storm snapshot
at *t* = 360 sec

- Storm location from touch down:
  12 x 360 = 4320 m

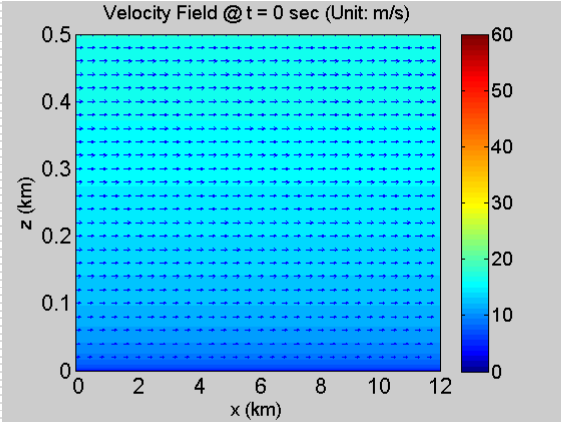
- Radius to max winds,
  r_m = 1000 + 360 × 1
  = 1360 m



t = 360 sec (6 min)

28/43

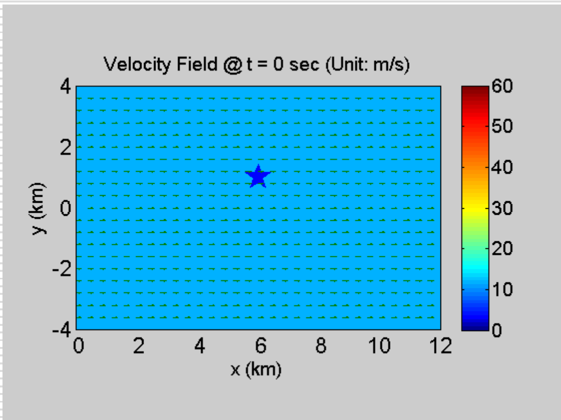
Non-turbulent Velocity Field Visualization



Evolution of the non-turbulent velocity field
in a vertical plane through the storm track

29/43

Non-turbulent Velocity Field Visualization



Evolution of the non-turbulent velocity field
in a horizontal plane @ height = 90 m

30/43

NREL 5-MW Baseline Wind Turbine Model

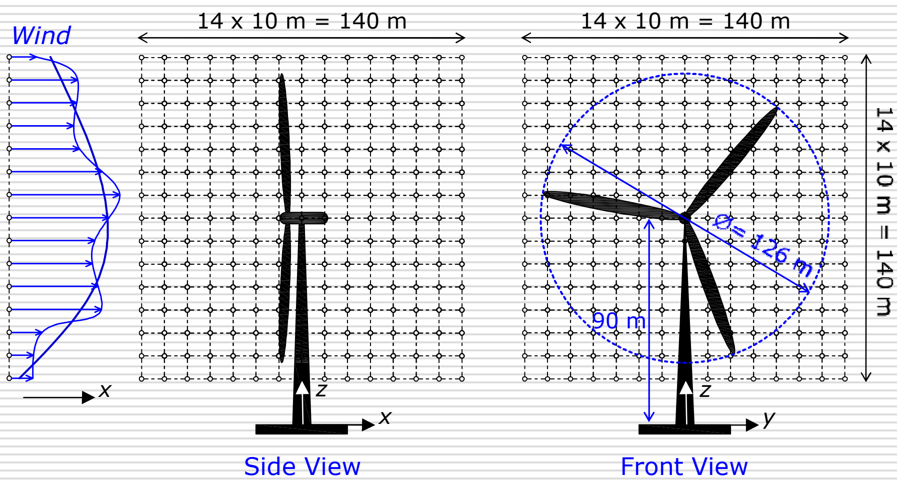
Properties/Dimensions	Values
Power Rating	5 MW
Rotor Orientation, Configuration	Upwind, 3 Blades
Control	Variable Speed, Collective Pitch
Drivetrain	High Speed, Multi-Stage Gearbox
Rotor Diameter	126 m
Hub height	90 m
Cut-In, Rated, Cut-Out Speeds	3 m/s, 11.4 m/s, 25 m/s
Cut-In and Rated Rotor Speeds	6.9 rpm, 12.1 rpm
Rated Tip Speed	80 m/s
Overhang, Shaft Tilt, Precone	5 m, 5°, 2.5°
Rotor Mass	110,000 kg
Nacelle Mass	240,000 kg
Tower Mass	347,460 kg

Specifications are based largely on the REpower 5M

REpower 5.0 MW Turbine.
(Photo: REpower Systems AG)

31/43

Turbine Response: Grid Discretization for Inflow



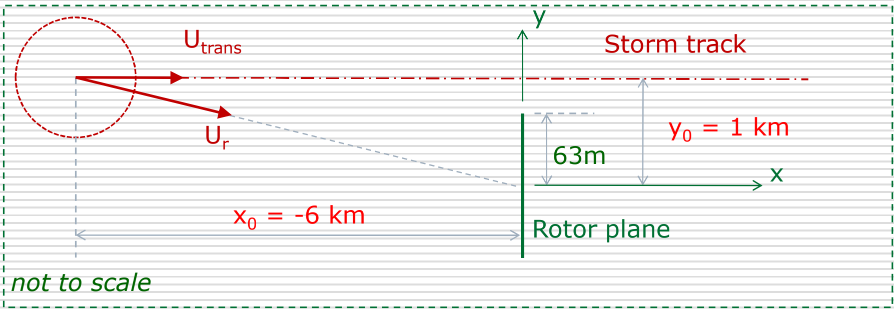
140 x 140 x 140 m grid (15^3 grid points)

32/43

Turbine Response Simulation: One scenario

Storm's Initial Locations w.r.t turbine system:

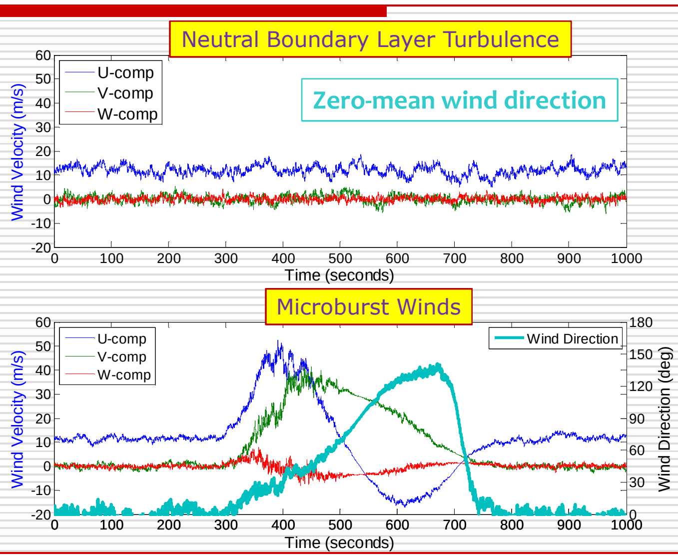
x_0 = -6km, y_0 = 1 km (as shown)



Assumption: No initial yaw error; and storm moves in the direction of the ambient *environmental* wind, U_{trans}.

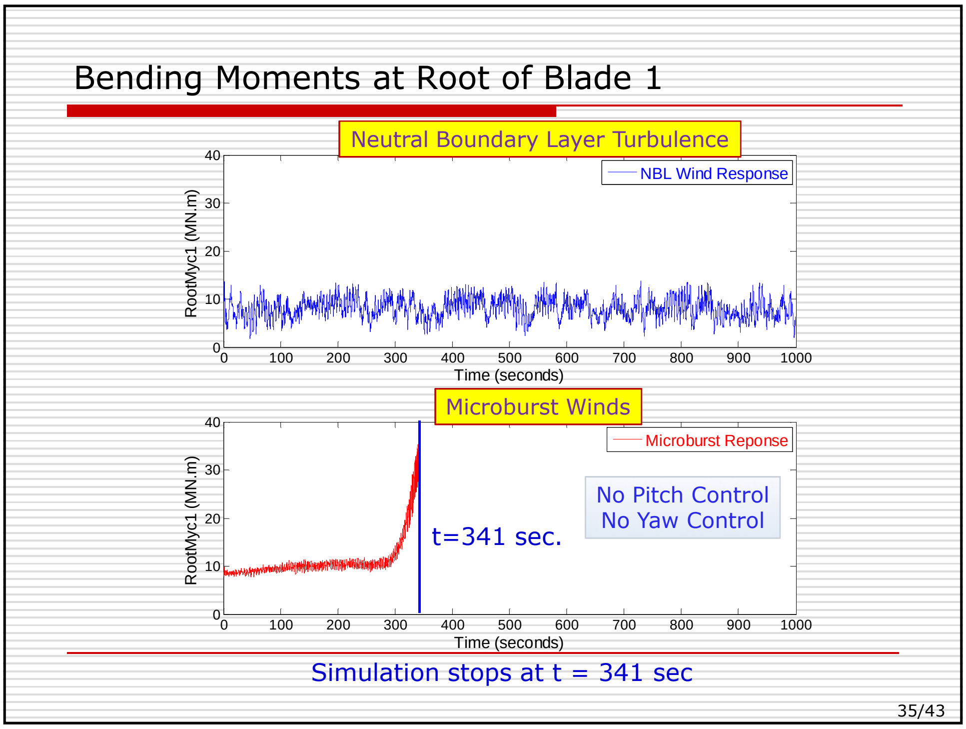
33/43

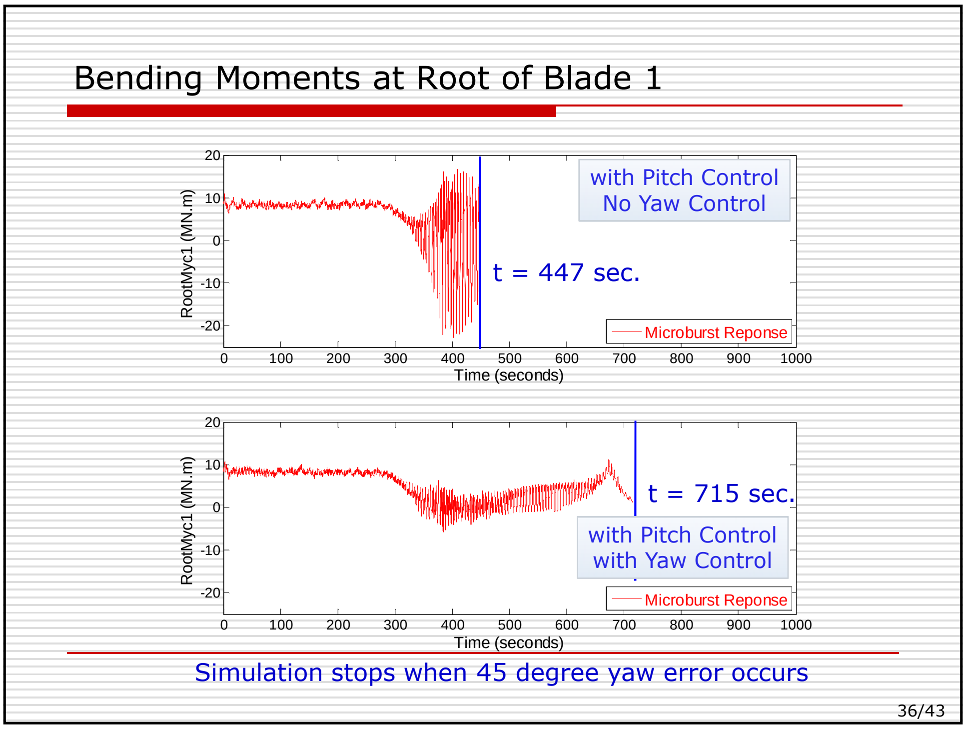
Wind Velocities, Direction at Hub (z = 90 m)



Thunderstorm downbursts are transients

34/43

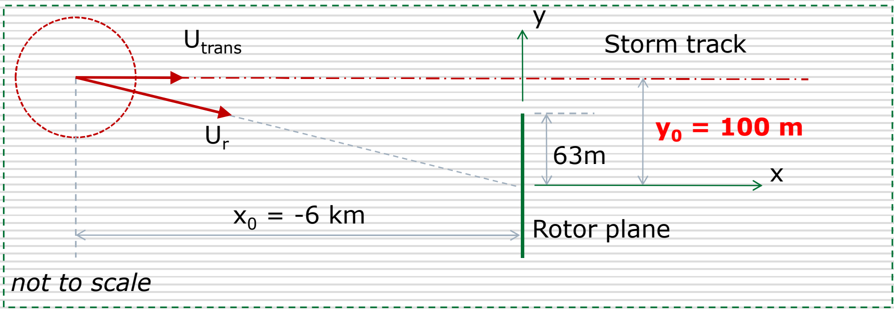

Bending Moments at Root of Blade 1
Neutral Boundary Layer Turbulence
NBL Wind Response
RootMyc1 (MN.m)
Time (seconds)
Microburst Winds
Microburst Reponse
No Pitch Control
No Yaw Control
t=341 sec.
Simulation stops at t = 341 sec
35/43


Bending Moments at Root of Blade 1
with Pitch Control
No Yaw Control
t = 447 sec.
Microburst Reponse
RootMyc1 (MN.m)
Time (seconds)
t = 715 sec.
with Pitch Control
with Yaw Control
Simulation stops when 45 degree yaw error occurs
36/43

Turbine Response Simulation: Another scenario

Storm's Initial Locations w.r.t turbine system:

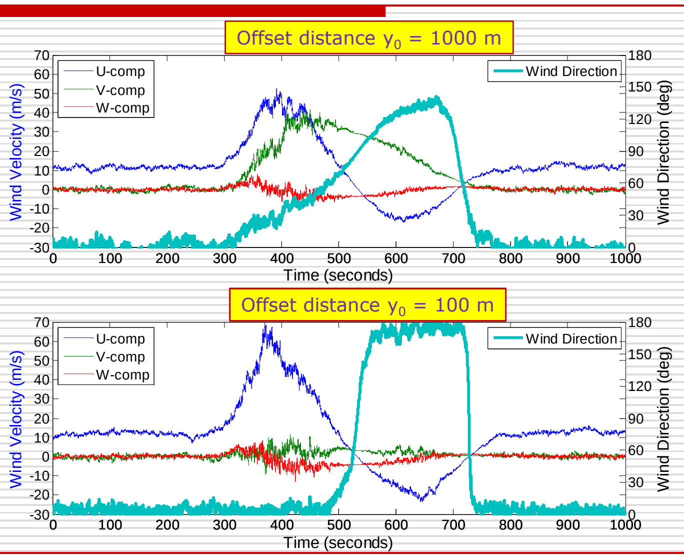
x_0 = -6km, **y_0 = 100 m** (as shown)



37/43

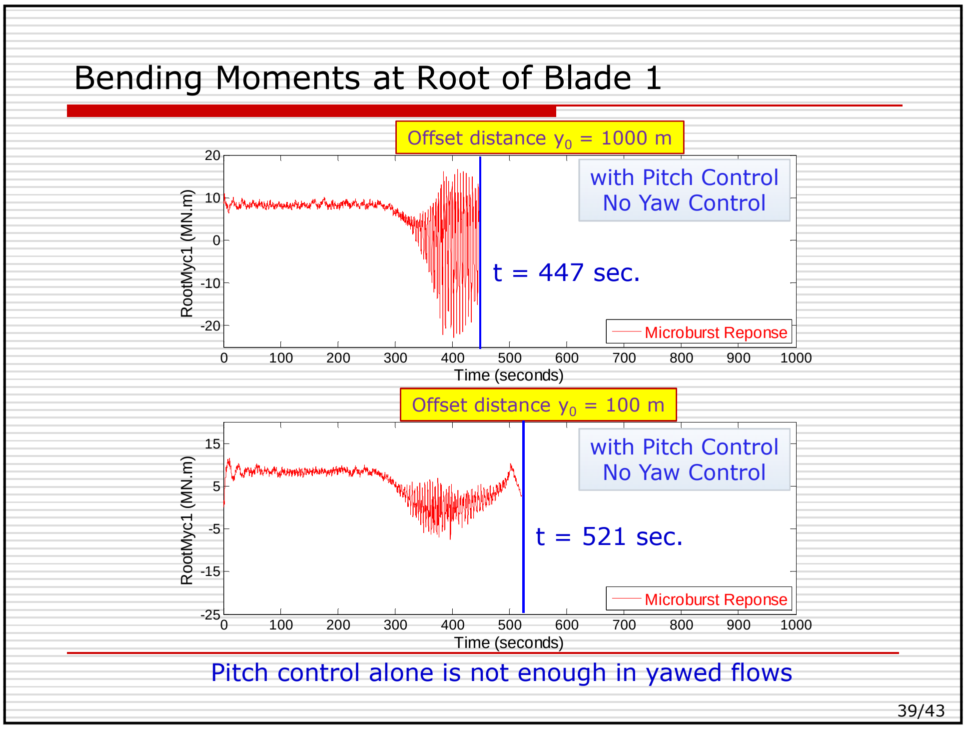
Wind Velocities, Direction at Hub (z = 90 m)

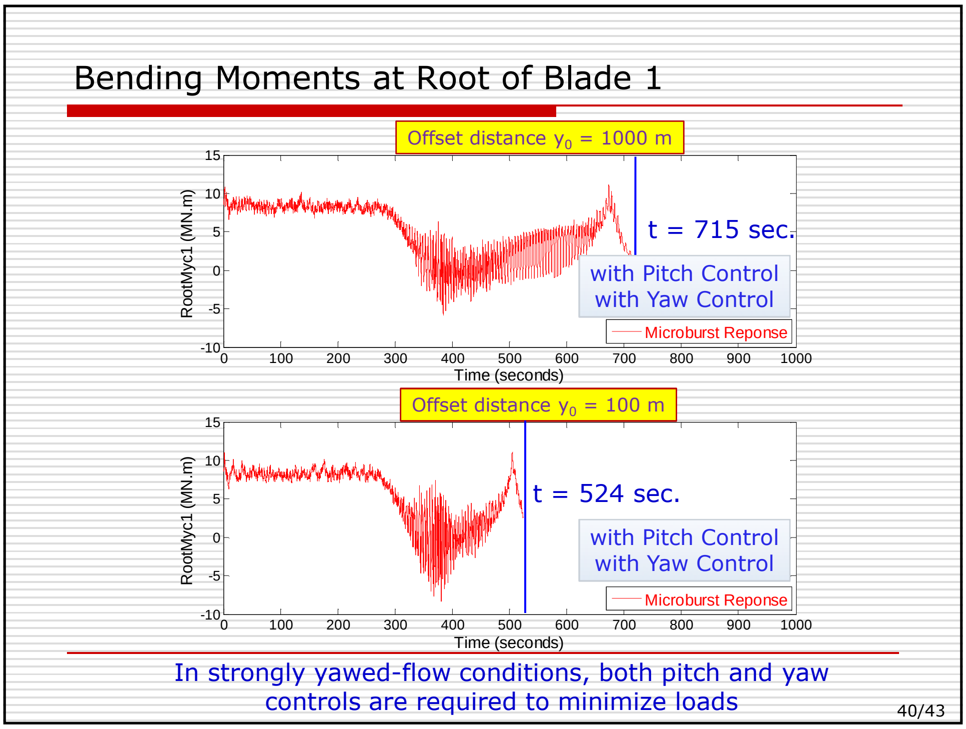
strongly yawed flow



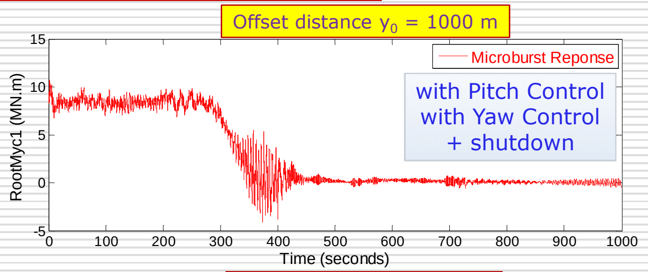
Large offset distance: large wind speeds and direction change occur at the same time → strongly yawed flow

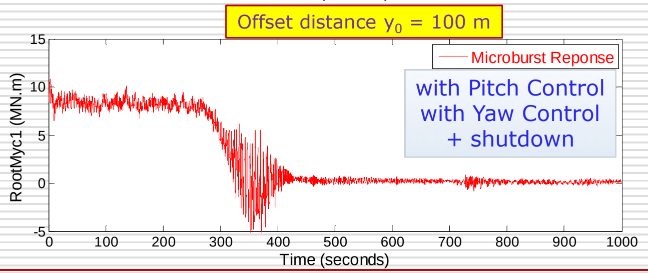
38/43


Bending Moments at Root of Blade 1
Offset distance y_0 = 1000 m
with Pitch Control
No Yaw Control
t = 447 sec.
Microburst Reponse
RootMyc1 (MN.m)
Time (seconds)
Offset distance y_0 = 100 m
with Pitch Control
No Yaw Control
t = 521 sec.
Microburst Reponse
RootMyc1 (MN.m)
Time (seconds)
Pitch control alone is not enough in yawed flows
39/43


Bending Moments at Root of Blade 1
Offset distance y_0 = 1000 m
t = 715 sec.
with Pitch Control
with Yaw Control
Microburst Reponse
RootMyc1 (MN.m)
Time (seconds)
Offset distance y_0 = 100 m
t = 524 sec.
with Pitch Control
with Yaw Control
Microburst Reponse
RootMyc1 (MN.m)
Time (seconds)
In strongly yawed-flow conditions, both pitch and yaw
controls are required to minimize loads
40/43

Bending Moments at Root of Blade 1





If winds above cut-out (25 m/s) for 10 revs (~50 sec), blades pitch to 90 deg.

41/43

Concluding Remarks

- Thunderstorm downbursts can cause very high wind speeds and large rapid direction changes
- A hybrid deterministic-stochastic model was employed to generate microburst flow fields; then loads on a 5MW turbine were computed for these flows
- The response of a wind turbine in such flow fields is strongly influenced by pitch and yaw control
- The storm's touchdown point relative to the wind turbine can lead to strongly yawed flows. In strongly yawed flow conditions (for large offsets from the storm path), effective yaw control is needed to limit turbine load ranges.
- Realistic shutdown sequences, blade pitch control logic, and yaw control logic are needed for accurate load estimation during downbursts

42/43

Acknowledgments

- Financial support from Sandia National Laboratories (Contract Nos. 743358 and 919589).
- Assistance with FAST and the turbine simulation model: Dr. Jason Jonkman of the National Renewable Energy Laboratory (NREL)

43/43

IEC Load Cases for Transient Events - EDC

Extreme Direction Change (EDC)

❖ The transient extreme direction change is given as follows:

$$\theta(t) = \begin{cases} 0^o & \text{for } t < 0 \\ 0.5\,\theta_e\left[1-\cos\left(\frac{\pi t}{6}\right)\right] & \text{for } 0 \le t \le 6 \text{ sec} \\ \theta_e & \text{for } t > 6 \text{ sec} \end{cases}$$

where θ_e is the extreme direction change magnitude

$$\theta_e = 4\arctan\left(\frac{\sigma_u}{U_{hub}\left(1+0.1\frac{D}{\Lambda}\right)}\right)$$

- σ_u = standard deviation of turbulence
- U_{hub} = hub-height wind velocity
- D = rotor diameter
- Λ = turbulence scale parameter (for hub height = 90 m, Λ = 42 m)

44/43

IEC Load Cases for Transient Events - ECD

Extreme Coherent Gust with Direction Change (ECD)

❖Magnitude of the extreme coherent gust: $U_{cg} = 15\ m/s$

❖Magnitude of the direction change: $\theta_{cg} = \dfrac{720\deg\ m/s}{U_{hub}}$

❖ Wind velocity:

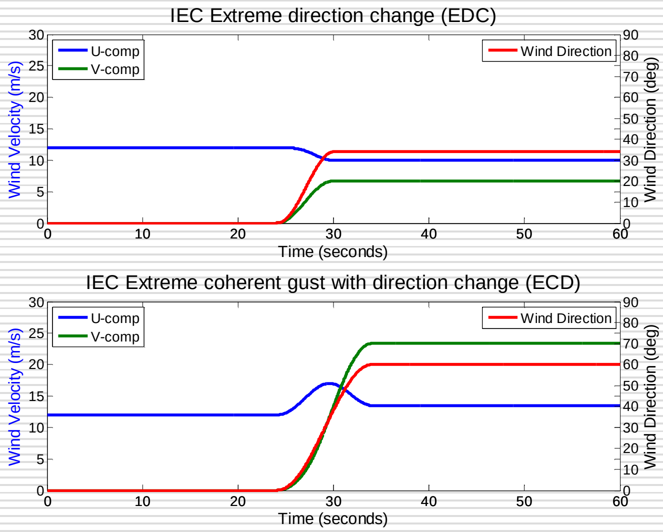
$$U(z,t) = \begin{cases} U(z) & \text{for } t < 0 \\ U(z) + 0.5\,U_{cg}\left[1 - \cos\left(\dfrac{\pi t}{10}\right)\right] & \text{for } 0 \le t \le 10 \text{ sec} \\ U(z) + U_{cg} & \text{for } t > 10 \text{ sec} \end{cases}$$

❖ Wind direction:

$$\theta(t) = \begin{cases} 0^o & \text{for } t < 0 \\ 0.5\,\theta_{cg}\left[1 - \cos\left(\dfrac{\pi t}{10}\right)\right] & \text{for } 0 \le t \le 10 \text{ sec} \\ \theta_{cg} & \text{for } t > 10 \text{ sec} \end{cases}$$

45/43

IEC Load Cases for Transient Events



Given: D = 126 m; Hub height = 90 m; U_{hub} = 12 m/s;

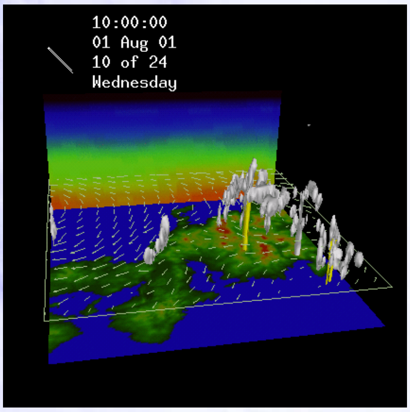
46/43

Numerical simulation of typhoon winds with a mesoscale model

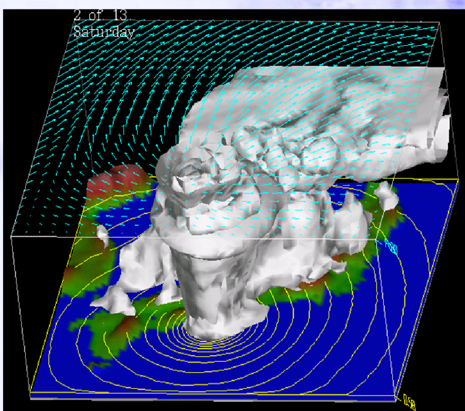
Teruo Ohsawa (Kobe University)
and
Taiichi Hayashi (Kyoto University)

Purpose

To investigate how well a meteorological mesoscale model can reproduce the wind fields of a tropical cyclone (Typhoon) .



Mesoscale Model MM5

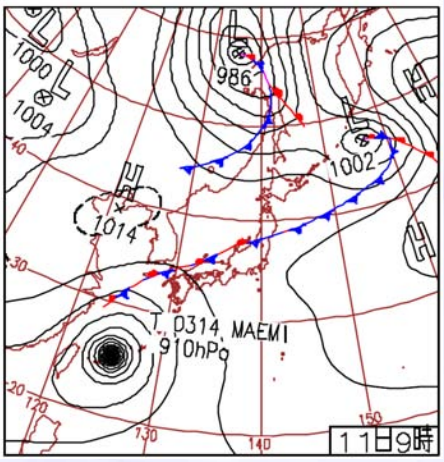


Ise-Bay Typhoon (1959) simulated with MM5

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

The typhoon investigated here is …

Typhoon T0314 (Maemi)



Surface analysis (09JST Sep 11, 2003)

Satellite IR Image (03JST Sep 11, 2003)

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Damages caused by Maemi

Of all 7 turbines on Miyako Island, 3 were collapsed and 4 were damaged to blades and nacelles (Maruyama et al., 2004)

from Maruyama et al. (2004)

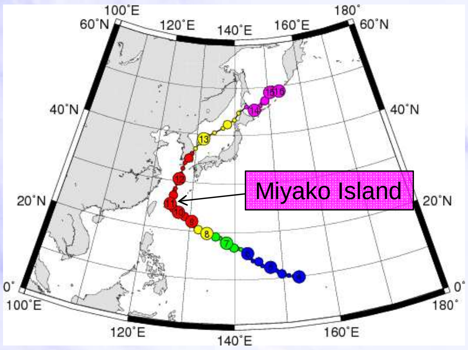
from JMA Miyako station (2003)

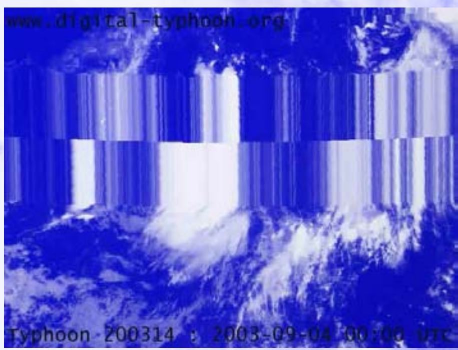
from Okuda et.al. (2003)

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Typhoon Maemi

Maemi occurred near the Mariana Islands on Sep 6, 2003 and moved northwest, hitting Miyako Island at its peak intensity.

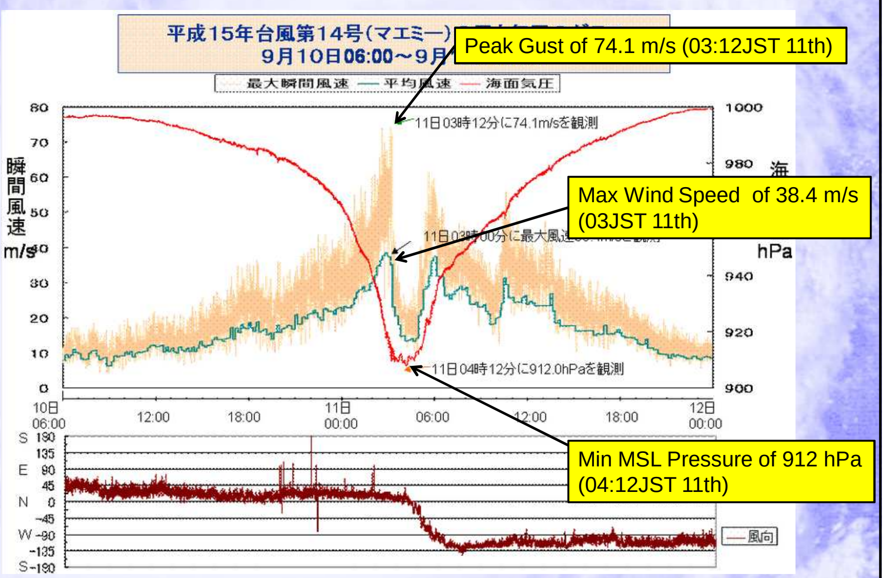




Cited from Digital Typhoon (http://agora.ex.nii.ac.jp/digital-typhoon/)

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Measurements at JMA Miyako Island station



IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

From here

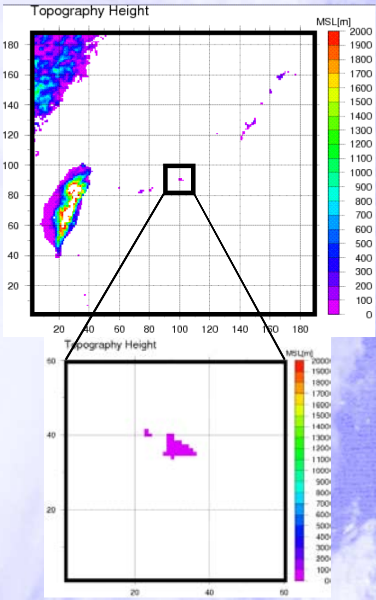
Numerical Simulation of Maemi
with mesoscale models MM5 and WRF

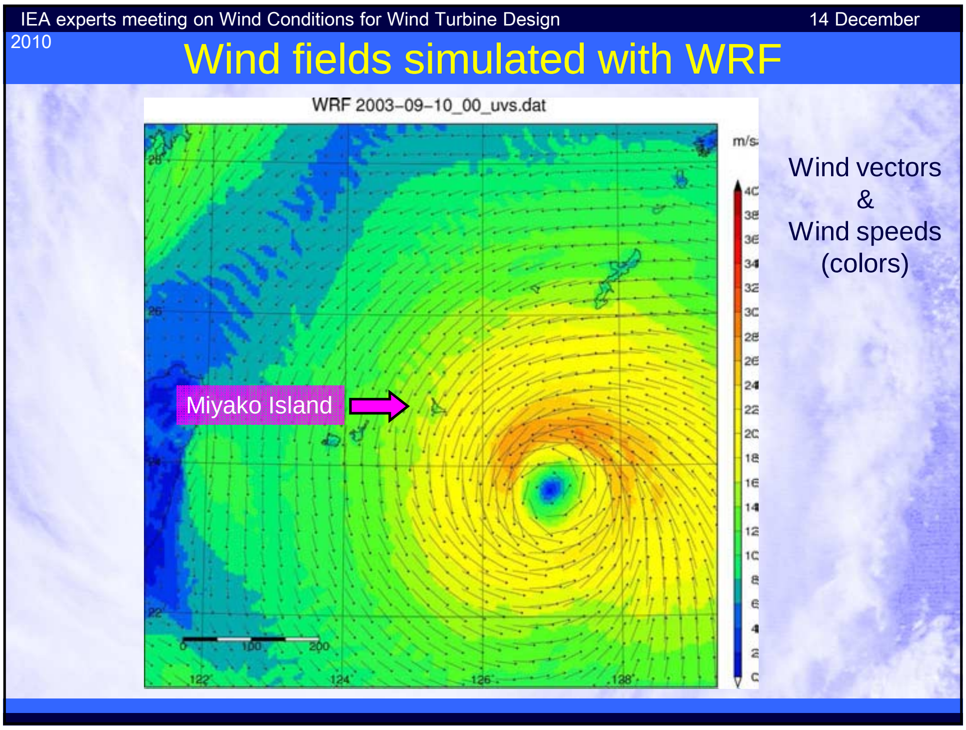
IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

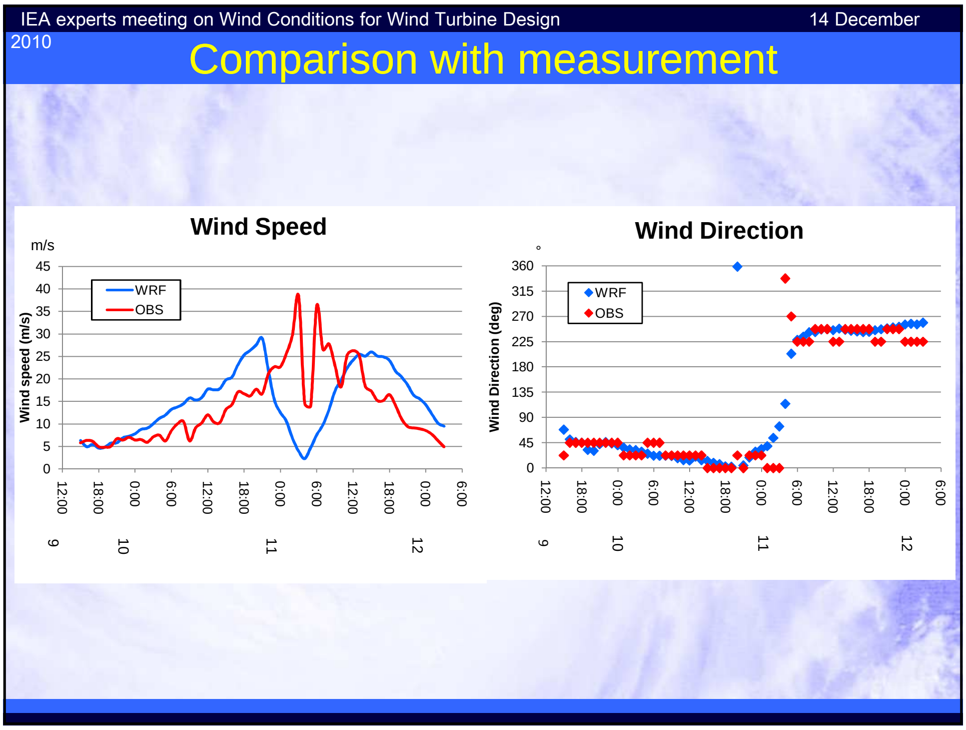
Model configuration

WRF v3.0

Period	Start: 15:00 JST Sep 9 2003 End: 03:00 JST Sep 12 2003
Input data	6-hourly 20x20km JMA RANAL Daily 0.05x0.05deg TOHOKU Univ. NGSST
Nesting	2-way nesting
Domain	Domain 1: 6 km (190x190 grids) Domain 2: 2 km (61x61 grids)
Vertical layer	35 levels (Surface to 50hPa)
Time step	Domain 1: 36 sec Domain 2: 12 sec
FDDA	On (Excluding PBL)
PBL Scheme	Mellor-Yamada-Janjic PBL scheme



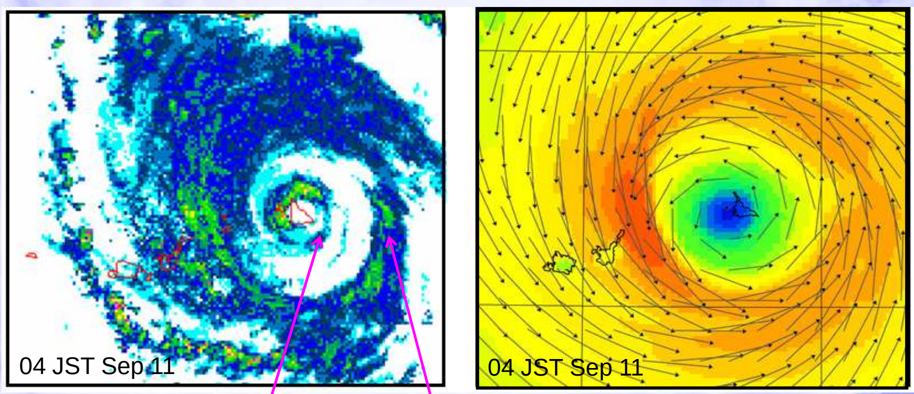

IEA experts meeting on Wind Conditions for Wind Turbine Design
14 December 2010
Wind fields simulated with WRF
WRF 2003-09-10_00_uvs.dat
m/s
Wind vectors
&
Wind speeds
(colors)
Miyako Island


IEA experts meeting on Wind Conditions for Wind Turbine Design
14 December 2010
Comparison with measurement
Wind Speed
m/s
Wind speed (m/s)
WRF
OBS
Wind Direction
Wind Direction (deg)
WRF
OBS

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Comparison with radar image

Radar WRF



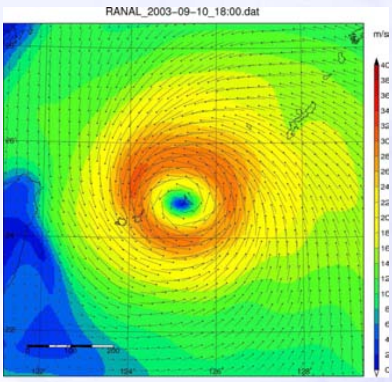
Small eye wall Large eye wall

The maximum wind speed in WRF corresponds to the large eye wall and the small eye wall is not reproduced.

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Reason for the unrealistic eye

Input data (RANAL) does not have enough resolution to express the center of Maemi.



In order to reproduce the detailed structure in the center of the Typhoon, the Typhoon bogussing scheme is used.

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

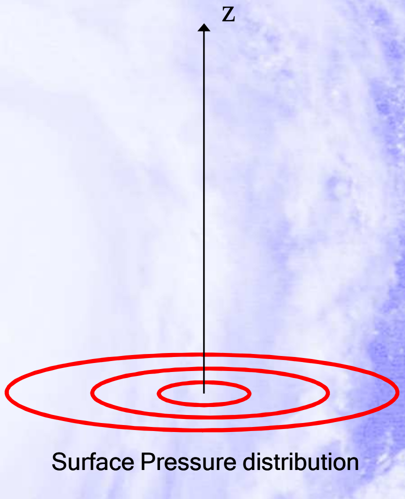
Typhoon bogussing scheme

JMA ANL bogus (Ohnogi, 1997 : Ueno , 2000)

1. Calc. of surface pressure
2. Calc. of geopotential height anomaly
3. Calc. of gradient wind
4. Addition of asymmetric components
5. Embedding typhoon bogus data

Fujita's Equation

$$p_s(r) = p_\infty - \frac{\Delta p}{\sqrt{1 + \left(\frac{r}{r_0}\right)^2}}$$



IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

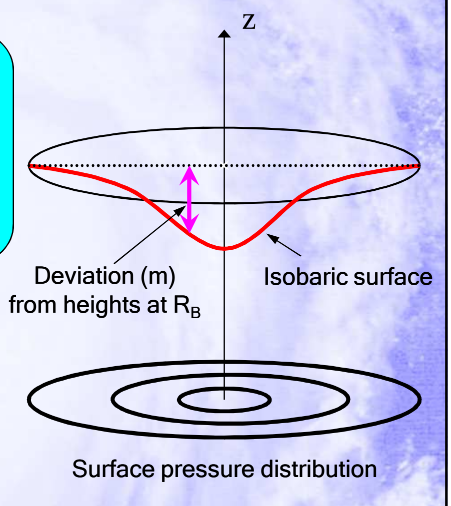
Typhoon bogussing scheme

JMA ANL bogus (Ohnogi, 1997 : Ueno , 2000)

1. Calc. of surface pressure
2. Calc. of geopotential height deviation
3. Calc. of gradient wind
4. Addition of asymmetric components
5. Embedding typhoon bogus data

According to Frank's analysis

$$D = \beta(\ln p - \ln p_s) \times \{[\ln p - \ln(P_{Ta0})]^2 + \varsigma\}^{-n} \times \exp\{\delta[\ln p - \ln(P_{Tax})]^2\} + \frac{R}{g}\int_{P_B}^{P_s} T_B d(\ln p)$$

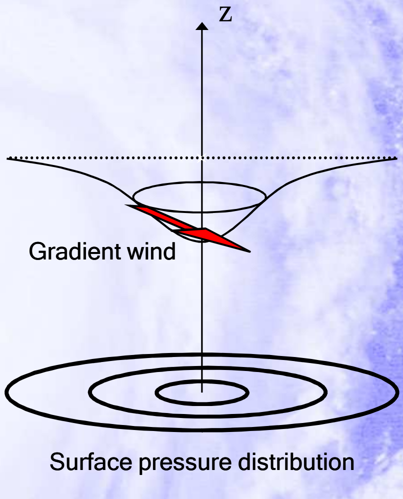


IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Typhoon bogussing scheme

JMA ANL bogus (Ohnogi, 1997 : Ueno , 2000)

1. Calc. of surface pressure
2. Calc. of geopotential height anomaly
3. **Calc. of gradient wind**
4. Addition of asymmetric components
5. Embedding typhoon bogus data



Gradient wind

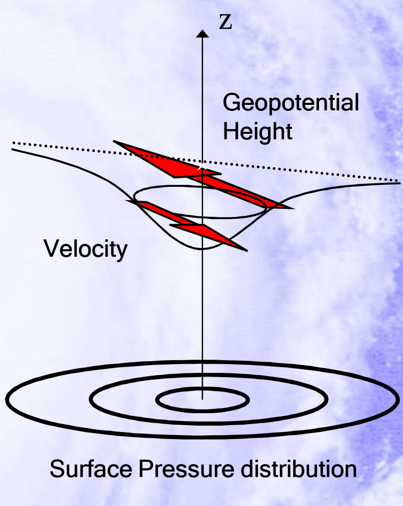
$$V_{gr} = \frac{1}{2}\left\{ -(f\,r) + \sqrt{(f\,r)^2 + 4\,r\,g\frac{dz}{dr}} \right\}$$

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Typhoon bogussing scheme

JMA ANL bogus (Ohnogi, 1997 : Ueno , 2000)

1. Calc. of surface pressure
2. Calc. of geopotential height anomaly
3. Calc. of gradient wind
4. **Addition of asymmetric components**
5. Embedding typhoon bogus data



Asymmetric components

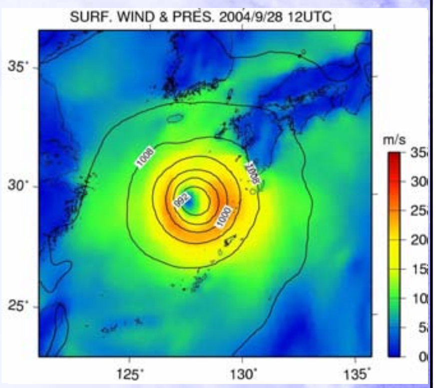
$$Z_b = Z_{bs} + \left(Z_g - Z_{gs}\right)$$
$$V_b = V_{bs} + \left(V_g - V_{gs}\right)$$

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Typhoon bogussing scheme

JMA ANL bogus (Ohnogi, 1997 : Ueno , 2000)

1. Calc. of surface pressure
2. Calc. of geopotential height anomaly
3. Calc. of gradient wind
4. Addition of asymmetric components
5. Embedding typhoon bogus data



JMA RANAL
(Sep 28, 2004 12:00UTC)

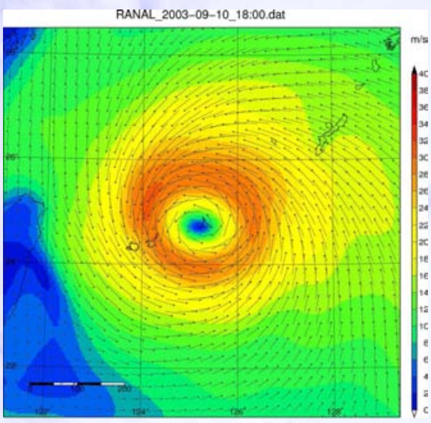
Cressman weighting function

$$W = \frac{R^2 - r^2}{R^2 + r^2} \qquad (R = Radius\ of\ typhoon)$$

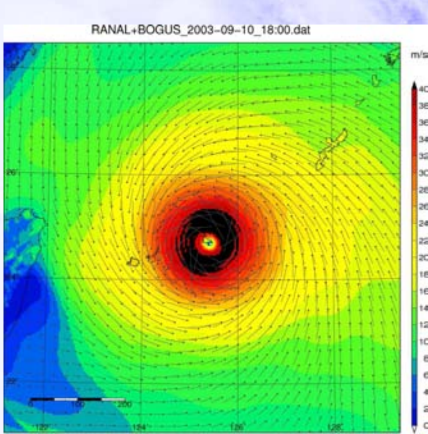
IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Before and after embedding the bogus

RANAL



RANAL + BOGUS

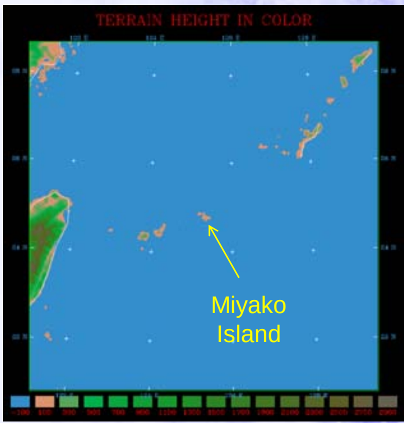


(Sep 11, 03UTC)

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

MM5 configuration

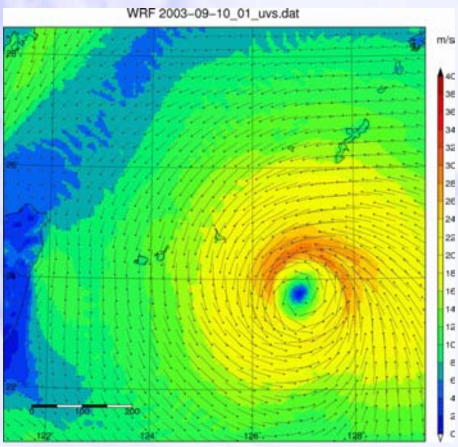
MM5 v3.7	
Period	Start: 00:00 UTC 11 Sep 2003 End: 12:00 UTC 10 Sep 2003
Input data	6-houlry 20x20km JMA RANAL Daily 0.05x0.05deg TOHOKU Univ. NGSST
Nesting	None
Domain	Domain 1: 3 km (301x301 grids)
Vertical layer	23 levels (Surface to 100 hPa)
Time step	Domain 1: 10 sec
FDDA	On and Off cases (Excluding PBL)
PBL Scheme	Eta (Mellor-Yamada) scheme



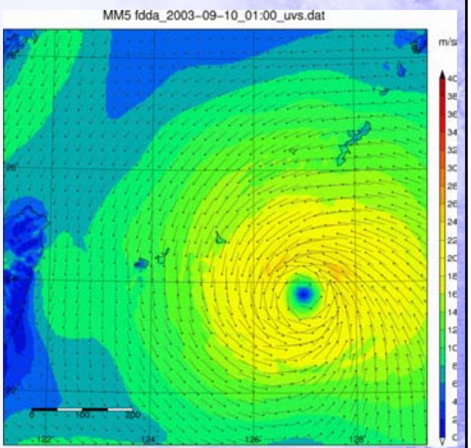
IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

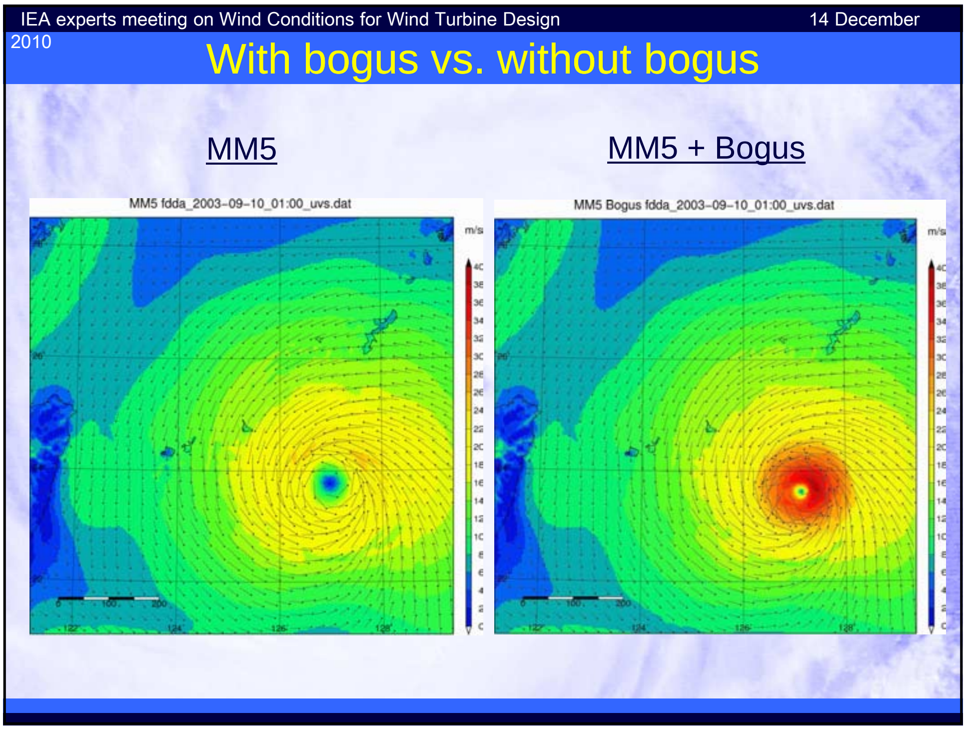
WRF vs MM5

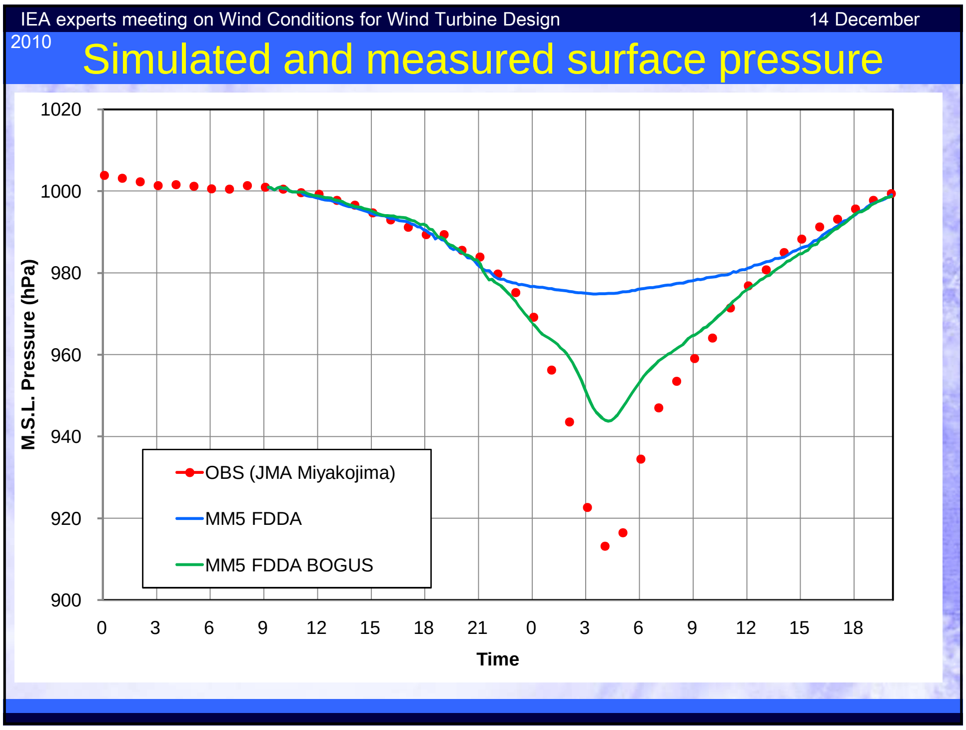
WRF 6km-grid



MM5 3km-grid

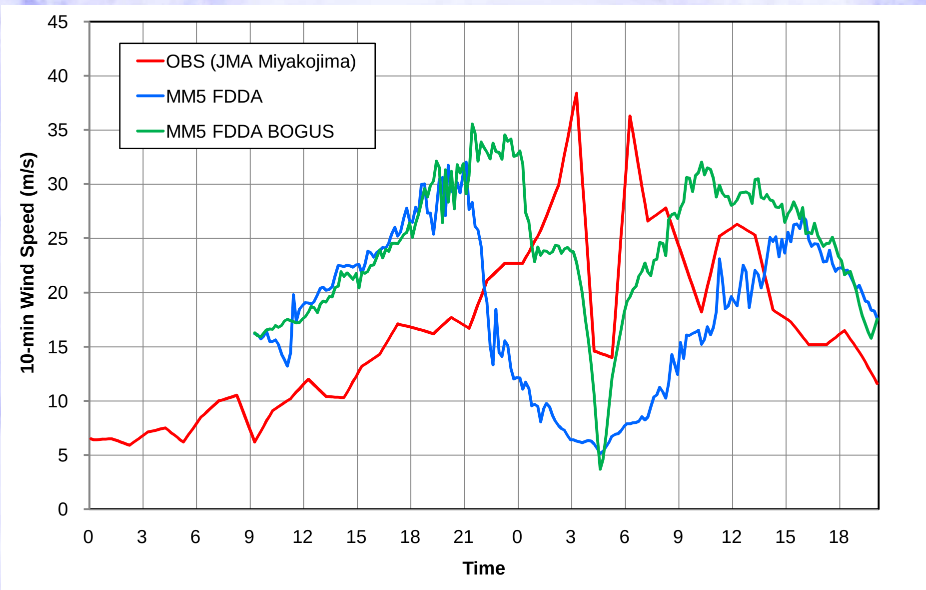



IEA experts meeting on Wind Conditions for Wind Turbine Design
14 December 2010
With bogus vs. without bogus
MM5
MM5 + Bogus
MM5 fdda_2003-09-10_01:00_uvs.dat
MM5 Bogus fdda_2003-09-10_01:00_uvs.dat
m/s


IEA experts meeting on Wind Conditions for Wind Turbine Design
14 December 2010
Simulated and measured surface pressure
M.S.L. Pressure (hPa)
1020
1000
980
960
940
920
900
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18
Time
OBS (JMA Miyakojima)
MM5 FDDA
MM5 FDDA BOGUS

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Simulated and measured wind speeds



IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Effect of FDDA

Four-dimensional data assimilation (FDDA)
Analysis nudging

$$\frac{\partial \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot W_\alpha \cdot \varepsilon_\alpha(\mathbf{x}) \cdot (\hat{\alpha}_0 - \alpha)$$

Physics equation — Analysis nudging term

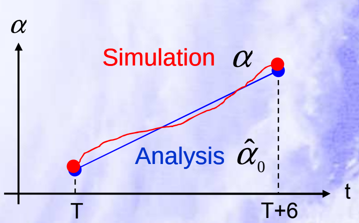
$\hat{\alpha}_0$: Interpolated large-scale analysis

G_α : Nudging factor

W_α : Weighting function

$$W_\alpha = w_{xy} w_\sigma w_t$$

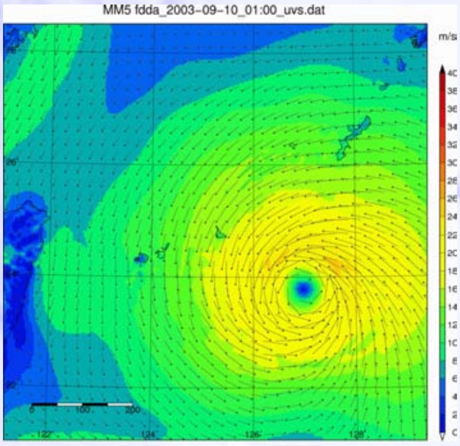
ε_α : Analysis quality factor (0 to 1)



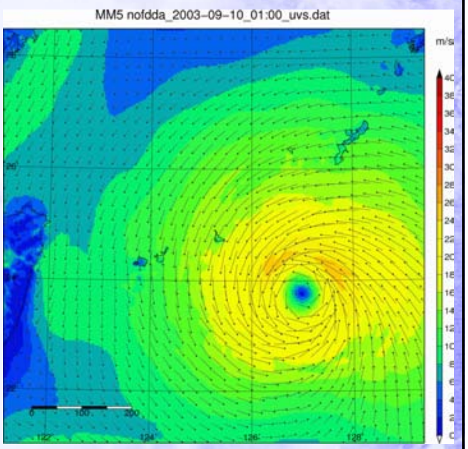
IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

FDDA vs. no FDDA

MM5 FDDA



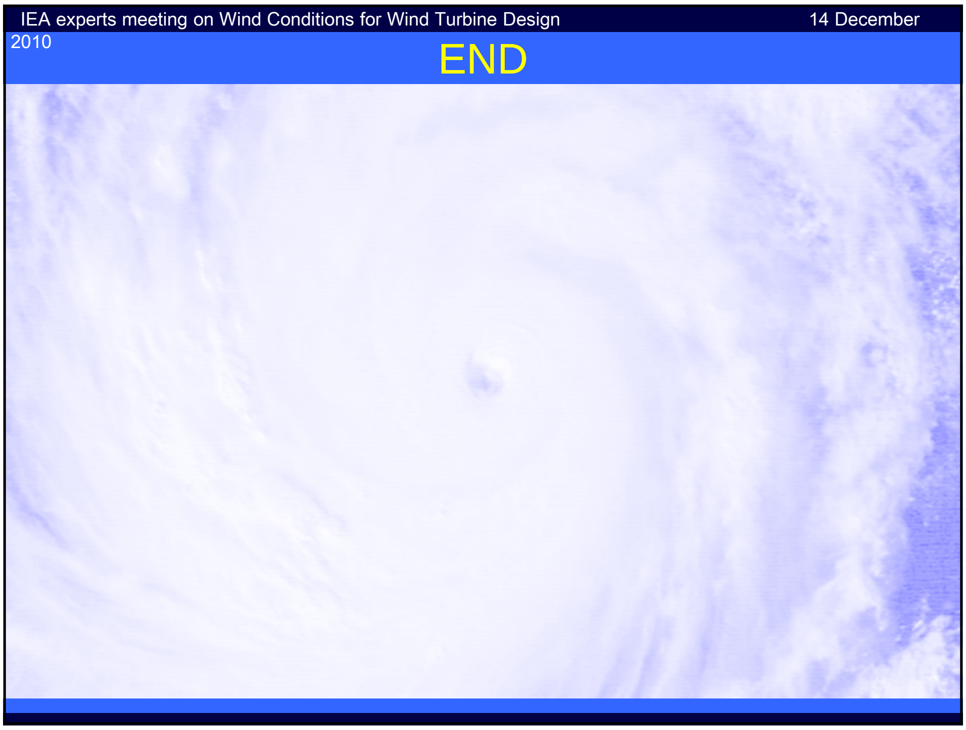
MM5 no FDDA

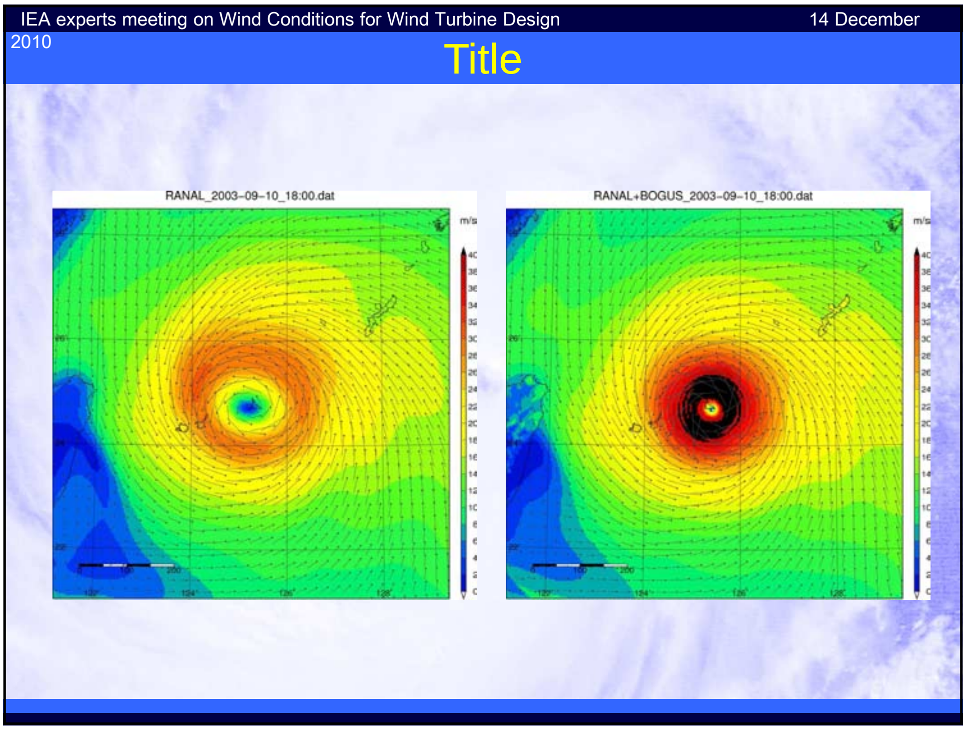


IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Summary

- In case of using JMA RANAL (20km-grid) for the Maemi simulation, a large eye is produced and the simulated winds are not in agreement with the measurement.
- By using the typhoon bogussing scheme, the radius of the eye becomes smaller and the simulated wind speed is in better agreement with the measurement.
- FDDA helps to keep the typhoon track correctly, but it tends to weaken the typhoon intensity.


IEA experts meeting on Wind Conditions for Wind Turbine Design
14 December 2010
END

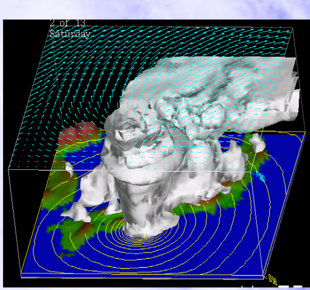

IEA experts meeting on Wind Conditions for Wind Turbine Design
14 December 2010
Title
RANAL_2003-09-10_18:00.dat
m/s
RANAL+BOGUS_2003-09-10_18:00.dat
m/s

IEA experts meeting on Wind Conditions for Wind Turbine Design 14 December 2010

Title

Mesoscale model

MM5 (5^{th} generation mesoscale model) by Penn. state univ. and NCAR



Typhoon simulation with MM5

Problems

1) Difficult to control typhoon track

→ Use of FDDA (Four Dimensional Data Assimilation)

2) Intensity of typhoon is often weak at the initial time

→ Introduction of Typhoon Bogus scheme

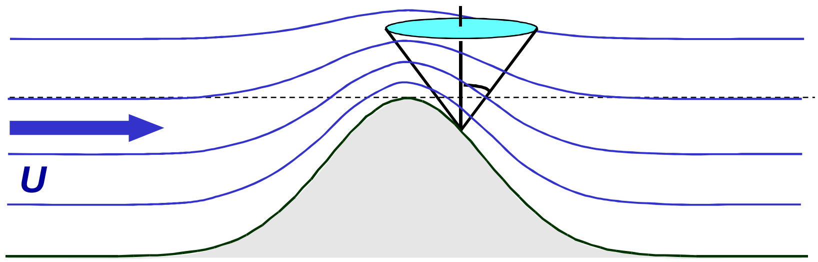
IEA Wind Task 11 TEM 2010, 14 Dec, 2010
University of Tokyo, TOKYO, JAPAN

Analysis of SODAR Measurements over Complex Terrain in JAPAN

Hiroshi KUBO
ITOCHU Techno-Solutions Corporation (CTC), JAPAN
http://www.engineering-eye.com/en/index.html
Hiroshi.kuboa@ctc-g.co.jp

Introduction

- Remote wind sensing devices tend to have errors when it measures the wind flow over complex terrain due to flow distortion.
- In order to evaluate the performance of SODAR over complex terrain in Japan, measurement campaign was done at Otsuki wind farm in the Island of Shikoku.
- We analyzed the SODAR data and collocated meteorological mast data.
- We considered the correction method for Sodar measurement over complex terrain by CFD.



2

Site Description

CTC

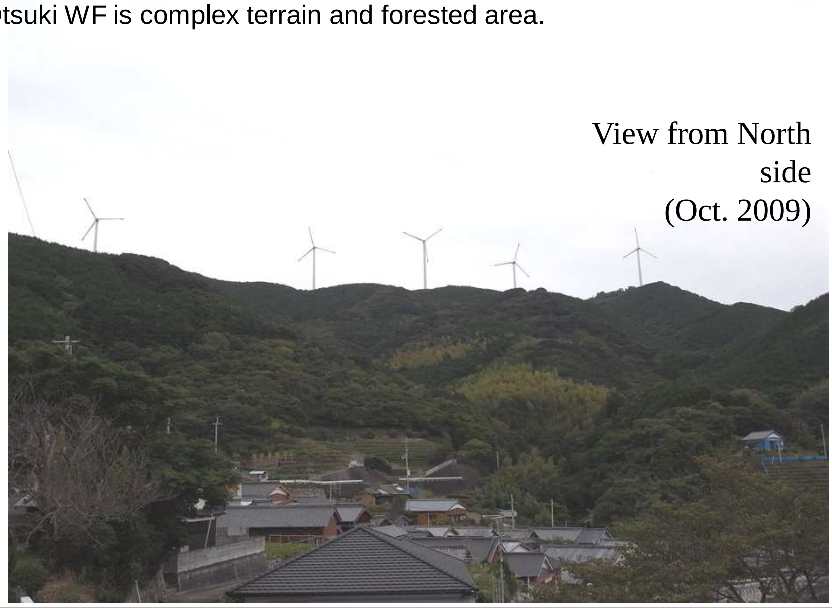
- The measurement site called Otsuki WF is located on the island of Shikoku
- The instruments were installed at a height of 280m asl along the mountain ridge.
- The prevailing wind directions are north-west (winter) and south-east (summer).

3

Site Description

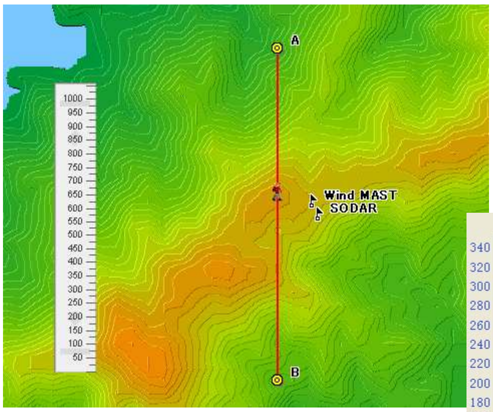
CTC

- Otsuki WF is complex terrain and forested area.



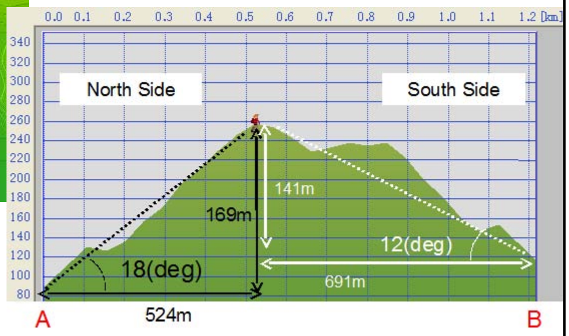
4

Site Description



Contour Map (10m interval)
By digital terrain data (50m grid)

- Otsuki WF has steep slope.
- Gradient Angle (A-B Cross section):
  - North side : 18(deg)
  - South side : 12(deg)

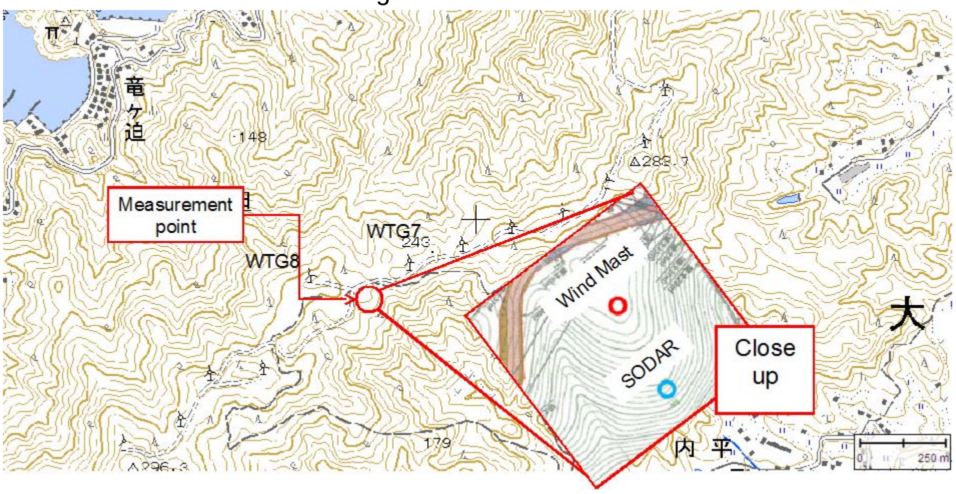


Vertical Cross Section

5

Site Description

- Wind flow is measured over complex terrain by SODAR.
- SODAR is located near the ridge line.
- Wind Mast which has 50m height is installed for SODAR validation.

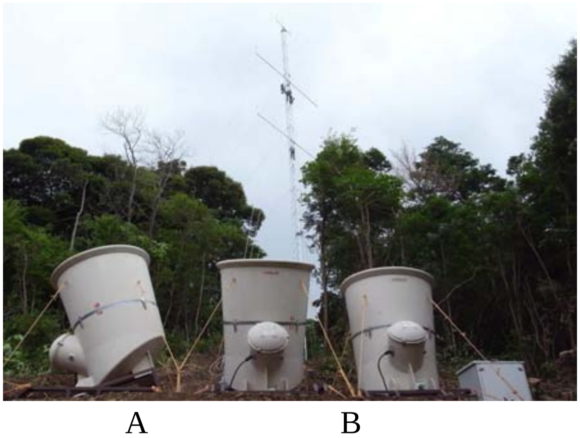


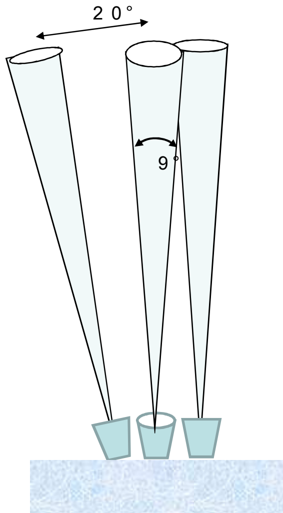
Terrain map around Otsuki WF

6

Measurement configuration

- Mono-static SODAR (SONIC Corporation,AR410N)
  - Measuring method : Monostatic doppler sodar
  - Transmission frequency : 2400Hz
  - Transmission pulse length : 30msec
  - Beam width : 9deg
  - Angle of inclination : 20deg

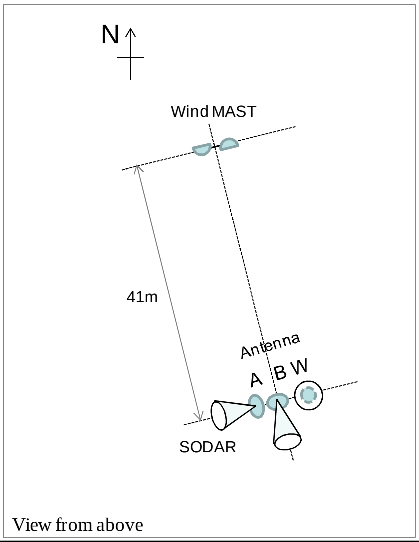


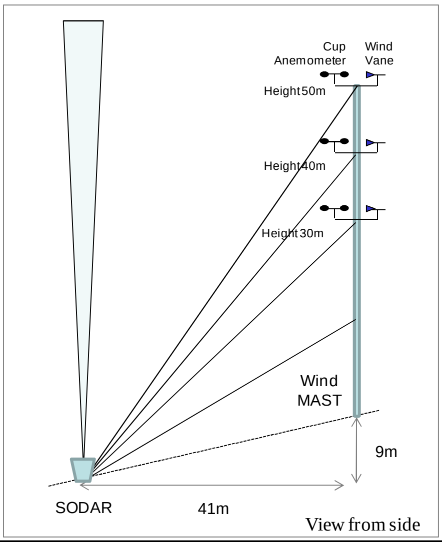


7

Measurement configuration

- Positional relationship between SODAR and Wind MAST
  - SODAR is 41m horizontal distance from Wind MAST.
  - There is 9m altitude difference between SODAR and Wind MAST



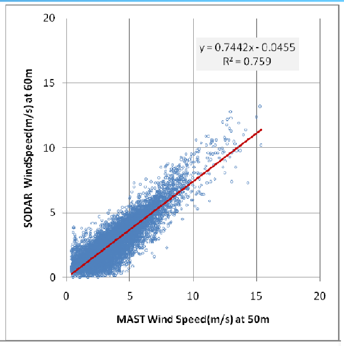


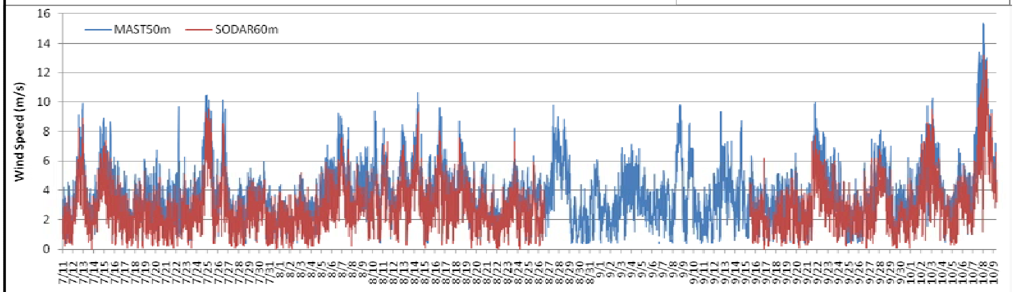
8

Comparison of the measured wind speed

CTC

- Comparison between cup anemometer and SODAR wind speed
  - The analyzed period started 11 July 2009 and ended 9 Oct 2009
  - SODAR measurement was analyzed for the data which acquisition rate for 10-min is over 80%.
  - Correlation coefficient between cup anemometer and SODAR was 0.871
  - Bias (SODAR – Cup Anemometer) was -1m/s
  - The 10min averaged wind speed of SODAR measurements was lower than that of cup anemometer



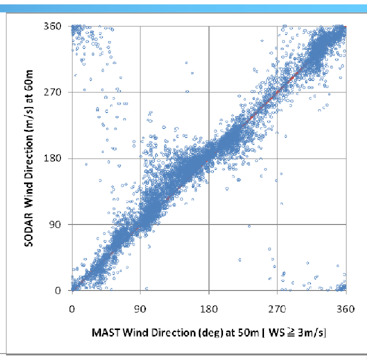


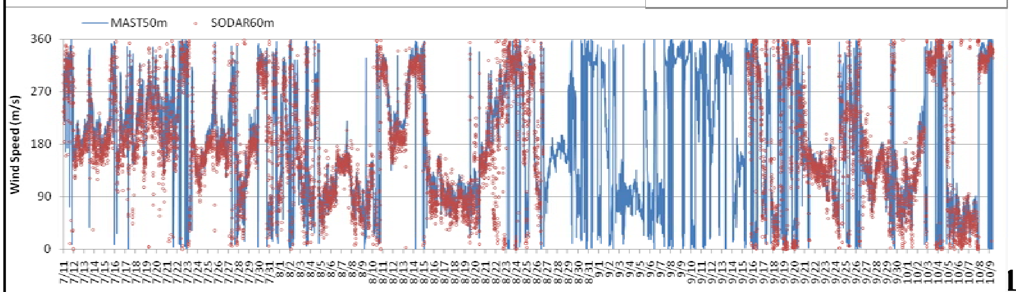
9

Comparison of the measured wind direction

CTC

- Comparison between wind vane and SODAR wind direction
  - Wind direction of SODAR is mostly coincided with that of wind vane
  - Low wind speed data is excepted. (WS>=3m/s)

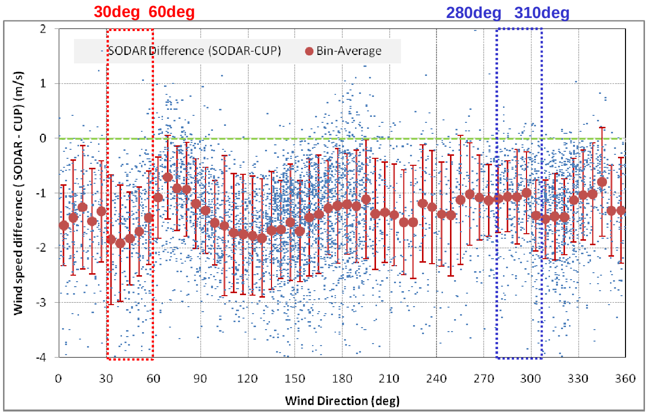




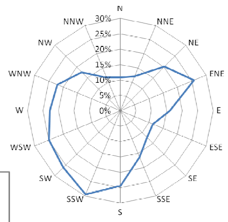
10

Comparison of the measured data

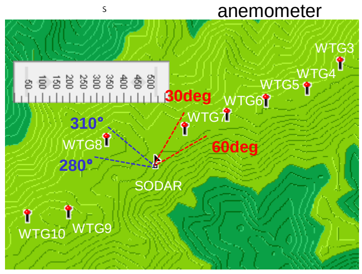
- Wind speed for wind direction
  - Wind speed difference (SODAR - Cup Anemometer) depends on wind direction.
  - Wind speed difference (SODAR - Cup Anemometer) in bin-average varies from -0.5m/s to -2.0m/s.



Wind speed difference for wind direction (WS>=3m/s)
Red circle: bin average for wind speed difference, Red line: standard deviation, Bin width: 6deg interval



Turbulence intensity (WS>=3) Measured by cup anemometer

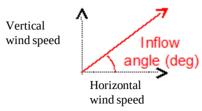


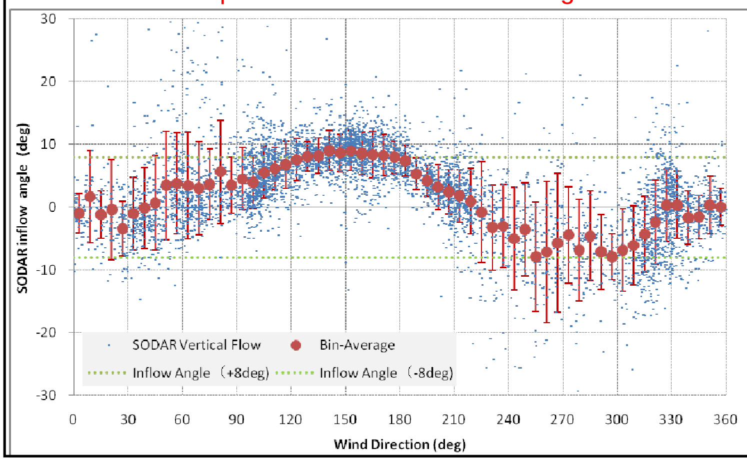
11

Analysis of the SODAR measurement

- Inflow angle for wind direction
  - In South East wind direction, inflow angle is the highest, 8(deg)
  - In the South East wind direction, inflow angle variability is the lowest.

⇒ This result points the flow distortion is high in this area.





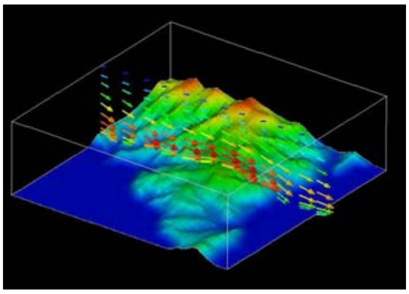
Topography map around measuring point

Inflow angle distribution for wind direction (WS>= 3m/s)

Red circle: bin average for wind speed difference, Red line: standard deviation, Bin width: 6deg interval

12

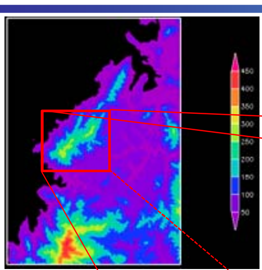
Speculation



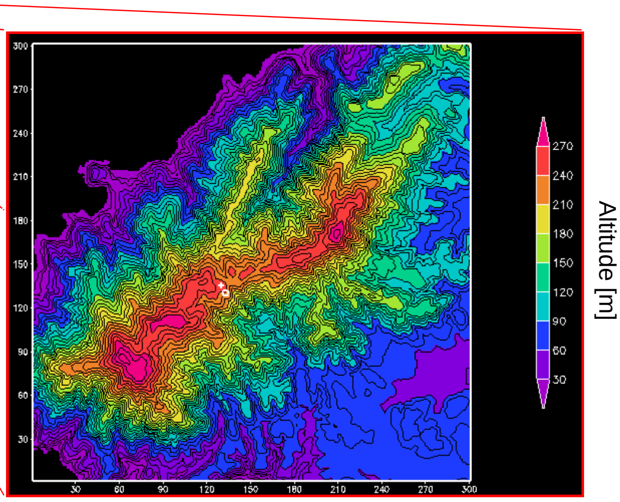
- We think such flow distortion over complex terrain causes the difference between SODAR and cup anemometer
  - Main assumption in the SODAR measurement is horizontally homogeneous.
    - But such assumption doesn't work over complex terrain due to flow distortion
  - Flow distortion for the spatial control volume of SODAR measurement can be estimated by CFD simulation.
  - In order to remove the effect of flow distortion, we have simulated the wind condition by CFD techniques around this area.

13

CFD simulation of flow over complex terrain



We have made the digital topography data in 10m mesh interval around the measurement point.



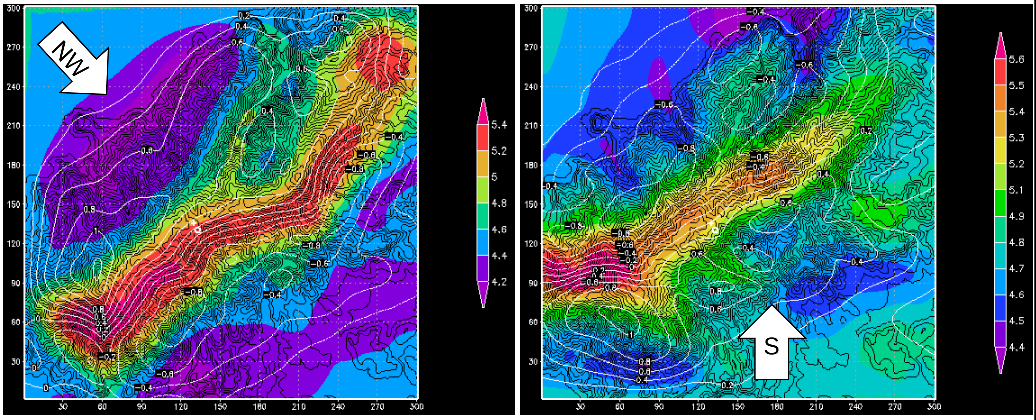
Digital Topography data around measuring point (10m mesh interval)

14

CFD simulation of flow over complex terrain

Results of CFD simulation (k-e model) in 10m-mesh

- Wind speed measured by wind mast is used as input wind speed of CFD simulation.
- Examples of respective wind direction are as follows (NW, S wind direction)



Example of the CFD result for respective wind direction sector (NW,S wind direction)
Color line: Wind speed[m/s], White line: Vertical wind speed [m/s], Black line: Altitude[m]

15

Correction of SODAR measurement by CFD

■Correction of inhomogeneous of vertical flow in SODAR measurement

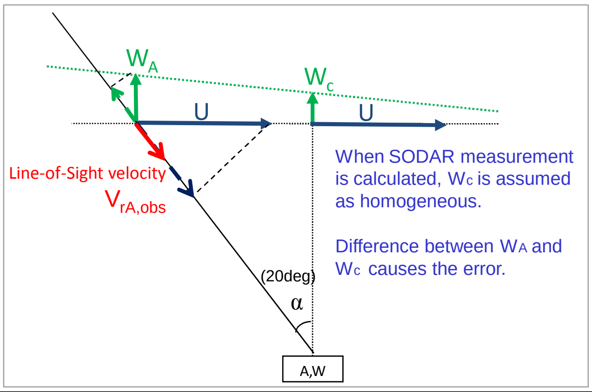
- Inhomogeneous of vertical flow causes the error for the SODAR measurement.
- In order to correct this effect , we applied CFD.

$$V_{rA,obs} = U\sin\alpha + W_A\cos\alpha$$

Application of CFD

$$U = \frac{1}{\sin\alpha}\left(V_{rA,obs} - W_A\cos\alpha\right) = \frac{1}{\sin\alpha}\left[V_{rA,obs} - \left(W_{c,obs}\cdot\frac{W_{A,CFD}}{W_{c,CFD}}\right)\cos\alpha\right]$$

V_{rA}= Line-of-sight velocity
W_c=Vertical flow component measured by SODAR W equipment.
W_A=Vertical flow component measured by SODAR A equipment.
α = Zenith angle for sonic wave of SODAR



In the case of zenith angle=20deg

Contribution to line-of-sight velocity of vertical flow is **2.8 times larger** than horizontal flow.

$$V_{rA,obs} = U\sin\alpha + W_A\cos\alpha$$

$$V_{rA,obs} = 0.34U + 0.94W_A \quad at \quad \alpha = 20\deg$$

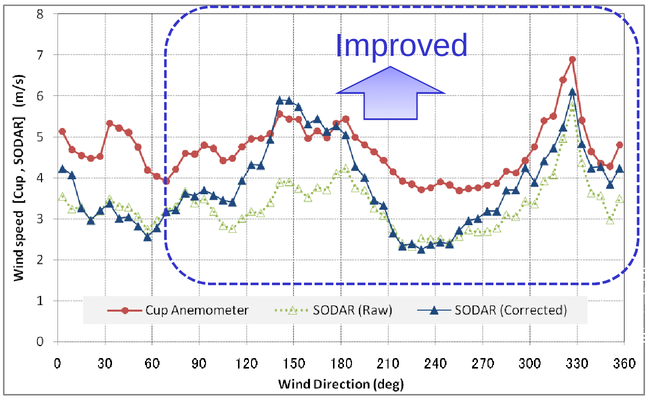
It is very important to understand the correct vertical flow condition.

16

Results for correction of SODAR data

We checked the improvement of wind speed difference for wind direction

- ➢Accuracy got better in some wind direction sectors.
- ➢But the results show that this correction method still has problems to resolve.



17

Summary and Future Plan

- ■ Wind flow was measured over complex terrain by SODAR.
- ■ The 10min averaged wind speed of SODAR measurements was systematically lower than that of cup anemometer
- ■ We have simulated the flow over complex terrain by CFD
  - ➢ We corrected the SODAR measurement by CFD simulation.
  - ➢ We confirmed the wind speed difference between SODAR and Cup anemometer got better in some wind direction sectors.
- ■ We will study the correction method for remote wind sensing measurement over complex terrain more precisely by using more advanced CFD techniques.

18

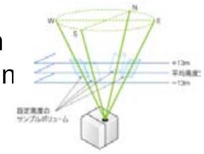
Future Plan

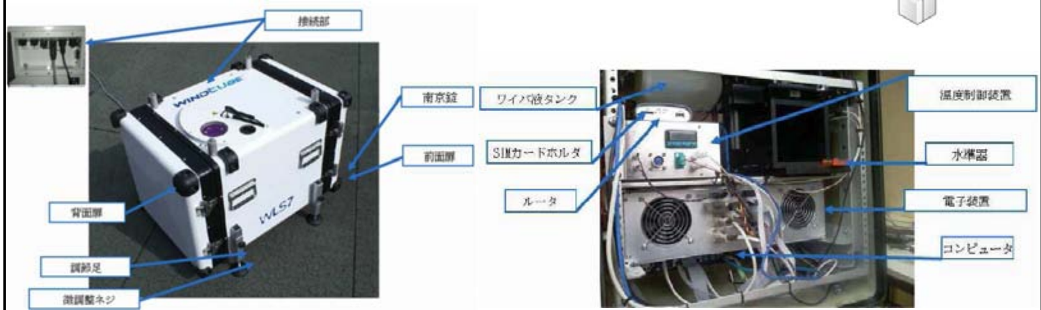
Installation of WindCube（Lidar,developed by Leosphere Co. ）

- We installed the WindCube at Hasaki in 6 Dec,2010.
- We plan to use the WindCube for investigation of accuracy and reliability on remote sensing technology.

Dec 2010 ：Test measurement at Hasaki, Ibaragi （flat terrain

Jan 2011 ~ ：Test measurement at Otuki, Kochi（complex terrain



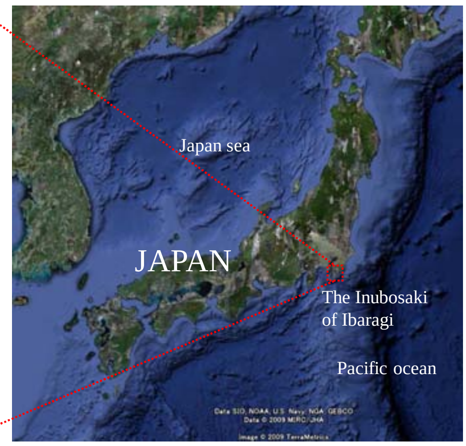


19

Future Plan

Site Description（Hasaki WF）

- The measurement site called Hasaki WF is located on the Inubosaki at Ibaragi
- The instruments were installed at a height of 5m along the seashore.
- We plan to compare the measurement result of flat terrain（Hasaki WF）with that of complex terrain(Otuki WF).

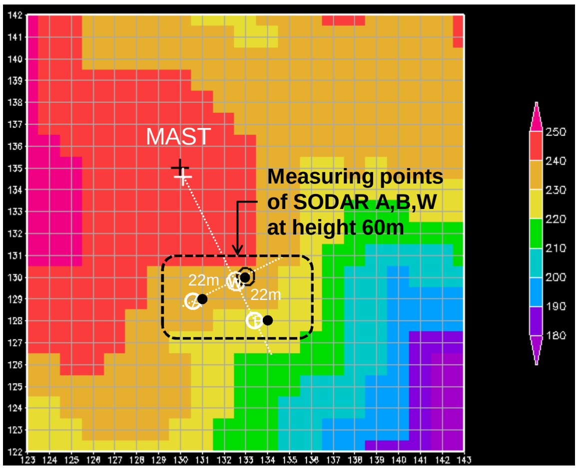


Thank you for your attention.

APPENDIX

CFD simulation of flow over complex terrain

Angle of inclination for SODAR	20 (deg)
Measuring height	60 (m)
Horizontal distance from SODAR installation	**21.8 (m)**

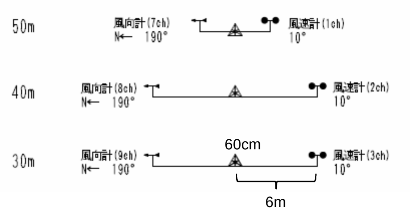


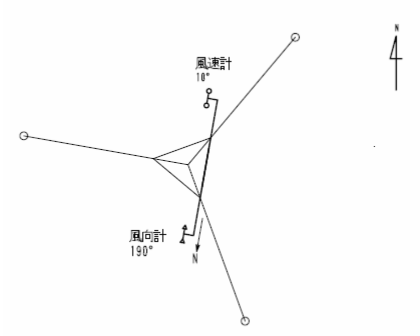
Color : Altitude(m)

Simulation area around measuring point (Simulated by 10m mesh topography data)

23

Met Mast Information





IEA R&D Wind Task XI - Topical Expert Meeting On

"Wind Conditions for Wind Turbine Design" 14 –15 Dec. 2010, The University of Tokyo, Japan

Impact of severe wind conditions for wind turbine design

- Impact of severe wind conditions on wind turbine design -

Hiroshi IMAMURA
Wind Energy Institute of Tokyo, Japan
imamura@windenergy.co.jp

IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo WEIT / AIST

Introduction 1/2

2 |17

NEDO project(2008-)

"Research and Development Project of Next Generation Wind Turbine Generation Technology (R&D of Basic and Applied Technology)"

Subjects

✓Technology toward highly safe and reliable wind turbine generation systems even in severer wind conditions such as typhoon and highly complex flow

✓Technology related to the very large wind turbine generation systems.

✓To solve these urgent subjects, the wind condition models for complex terrain and for Typhoons(Hurricanes) are developed in this project.

Wind condition model

✓Wind measurements in complex terrain by Met-mast and SODAR/LIDAR

✓Data analysis of NEDO FT-data and Guideline data

IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo WEIT / AIST

Introduction 2/2

3 |17

NEDO Guideline

- ✓ Japan published the Wind Power Guideline for Japan in 2008, as a result of the three years research project.
- ✓ Wind and load measurements in complex terrain and typhoon prone regions were carried out at seven sites.
- ✓ Wind and wind turbine load measurements by high frequency sampling have been performed.

Typhoon prone region

Complex terrain

IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo — WEIT / AIST

Purpose of the Work

4 |17

Development of a wind condition model in complex terrain

✓This work shows the results of analysis using NEDO guideline measurement data to develop the turbulence model in complex terrain.

✓Parameters of normal turbulence model (NTM) described in IEC 61400-1 are compared and evaluated using the guideline data.

Wind turbine class in IEC61400-1

Wind turbine class		I	II	III	S
Reference wind speed V_{ref} [m/s]		50	42.5	37.5	Values specified by designer
Turbulence category I_{ref}	A	0.16			
	B	0.14			
	C	0.12			

IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo — WEIT / AIST

Normal Turbulence Model (NTM)

5 |17

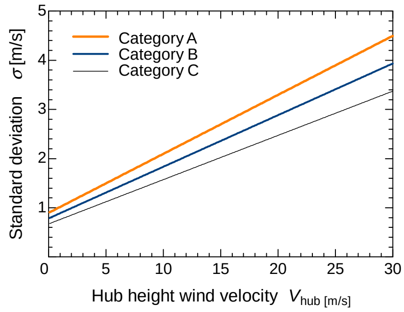
Turbulence Standard Deviation

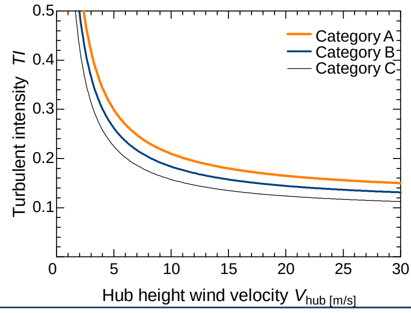
$$\sigma_{90q} = I_{ref}(0.75V + b), \quad b = 5.6\text{m/s}$$

$$TI_{90q} = \frac{\sigma_{90q}}{V} = \frac{I_{ref}(0.75V + b)}{V}$$

I_{ref} : Expected value of TSD at V=15m/s
TI : Turbulence intensity
V : 10min. averaged wind speed [m/s]
σ : Standard deviation of wind speed[m/s]
90q : 90%quantile

$\sigma_2 \geq 0.7\sigma_1$: Lateral comp.
$\sigma_3 \geq 0.5\sigma_1$: Upward comp.





IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo   WEIT / AIST

Revision of terrain complexity in 61400-1

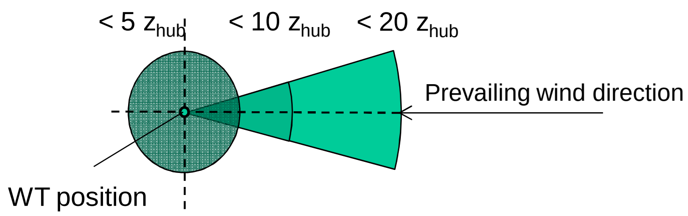
6 |17

Amendment to IEC 61400-1 Ed.3 (2009)

Introduction of a sector-wise amplitude for terrain complexity indicators

Table 4 – Terrain complexity indicators

Distance range from wind turbine	Sector amplitude	Max slope of fitted plane	Maximum terrain variation
< 5 z_{hub}	360°	< 10°	< 0,3 z_{hub}
< 10 z_{hub}	30°		< 0,6 z_{hub}
< 20 z_{hub}	30°		< 1,2 z_{hub}



✓ To evaluate the terrain complexity, sectorwise wind energy flux has to be considered.

IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo   WEIT / AIST

Turbulence structure correction parameter

- Turbulence structure correction parameter C_{CT}

$$C_{CT} = i_C \frac{\sqrt{1+(\hat{\sigma}_2/\hat{\sigma}_1)^2+(\hat{\sigma}_3/\hat{\sigma}_1)^2}}{1.375}$$

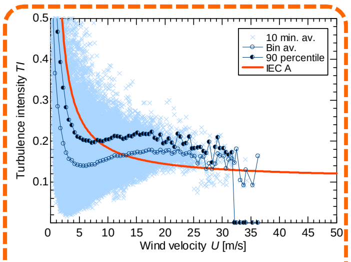
- Complexity index i_C
  - ✓ i_C is calculated depending on the terrain complexity in tab. 4(previous slide) and wind energy flux by sector-wise evaluation.
  - ✓ Sector-wise energy flux over 15% in complex topography → i_C =1
  - ✓ Otherwise i_C =0 – 1 by linear interpolation.
  - ✓ When the data of wind speed component can not be available, C_{CT} shall be set to 1.15 i_C

In NEDO guideline measurement campaign 3 components of the wind speed were stored by ultra sonic anemometer with high frequency sampling.

Characteristic of *TI* in a Complex Terrain(CT)

- 3 componets of turbulence intensity

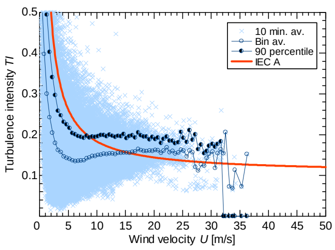
Measurement site



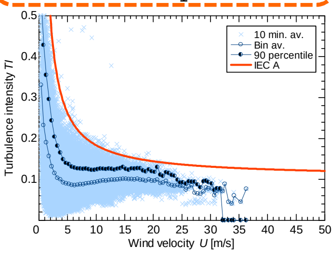
TI_1

Data excluded wake of WTG

	Iref	ratio
u	0.19	
v	(0.17)	0.89
w	(0.11)	0.58



TI_2

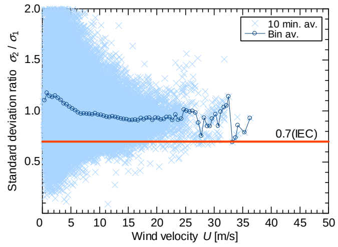


TI_3

TI in complex terrain is higher than IEC turbulence category

Turbulence structure correction parameter C_{CT} in CT

Evaluation of C_{CT} in sector-wise and wind bins

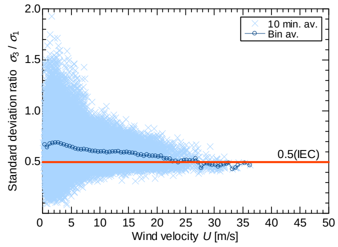


σ_2/σ_1

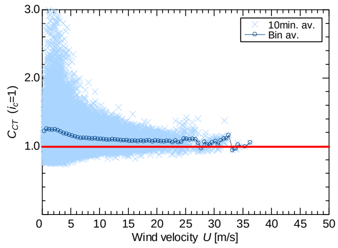
$\sigma_2 \geq 0.7\sigma_1$: Lateral comp.

$\sigma_3 \geq 0.5\sigma_1$: Upward comp.

$$C_{CT} = i_C \frac{\sqrt{1+(\hat{\sigma}_2/\hat{\sigma}_1)^2+(\hat{\sigma}_3/\hat{\sigma}_1)^2}}{1.375}$$



σ_3/σ_1

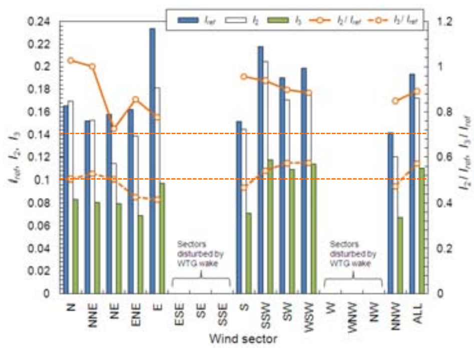


C_{CT} (i_c=1)

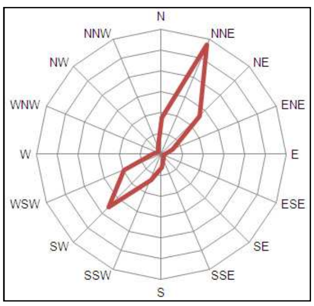
Lateral and upward comp. are higher than minimum values in IEC

Sector-wise Evaluation of turbulence

Evaluation of sector wise distribution of I_{ref}



Expected value at V_{hub} =15m/s

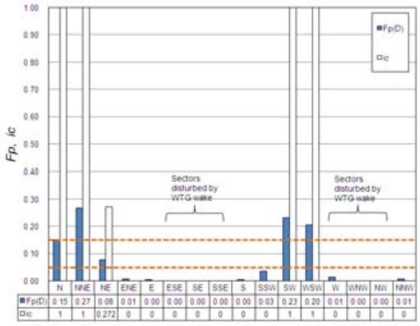


Sector wind energy flux

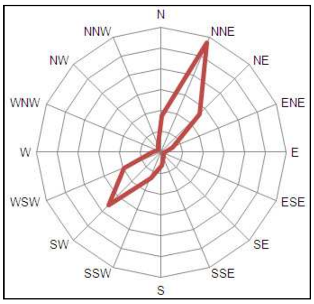
- ✓ I_{ref}, I_2 and I_3 are expected values of TI at 15m/s.
- ✓ Sectors affected by the wind turbine wake are excluded.
- ✓ I_{ref}, I_2 and I_3 are varied by the sector in this site.
- ✓ Relations of the turbulence standard deviation for σ_1, σ_2 and σ_3 may be depending on the terrain complexity.

Turbulence structure correction parameter C_{CT} in CT

Evaluation of sector wise distribution of I_{ref}



i_c in wind sector bins



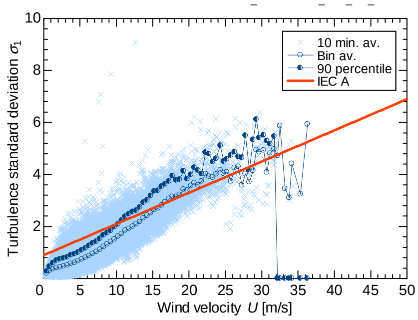
Sector wind energy flux

- ✓ Values of i_c for each wind sector bin are determined by means of IEC definition.
- ✓ Measured turbulence intensity is corrected by C_{CT}.

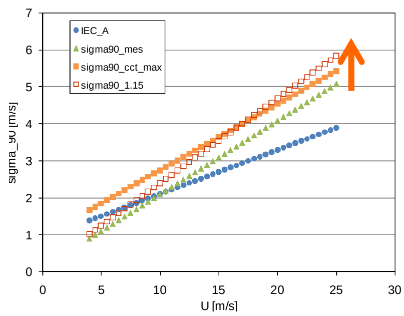
$$C_{CT} = i_C \frac{\sqrt{1+(\hat{\sigma}_2/\hat{\sigma}_1)^2+(\hat{\sigma}_3/\hat{\sigma}_1)^2}}{1.375}$$

Evaluation of 90 percentile of Turbulence STD

DLC 1.2 (*Vin* < *Vhub* < *Vout*, Fatigue)



Bin averaging for measurement data



Comparison of sigma90

- ✓ The distribution of the σ_1 is higher than the IEC category A.
- ✓ σ_1 is corrected by C_{CT} using measurement valueand C_{CT} =1.15i_c.
- ✓ The corrected values of σ_1 by using C_{CT} =1.15i_c. are higher than the measurement values.

⟶ The influences of corrected *TI* on fatigue load are evaluated.

Fatigue Load Index *LI*

13 |17

- Simple method for evaluation of fatigue load proposed by NEDO GL

Equivalent fatigue load :

$$L_{eq} = \sqrt[m]{\frac{\sum_i L_i^m h_i}{8766}}$$

L_i : load fluctuation

h_i : occurrence [h]

Fatigue load $\sim (\rho U \sigma)^{\gamma}$

Load Index :

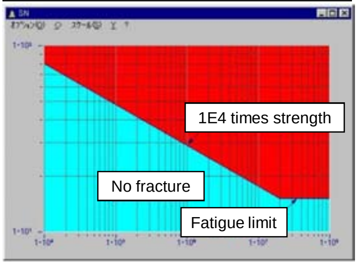
$$LI = \sqrt[m]{\frac{\sum_i (\rho U_i \sigma_{90,i})^{\gamma m} h_i}{8766}}$$

ρ : air density

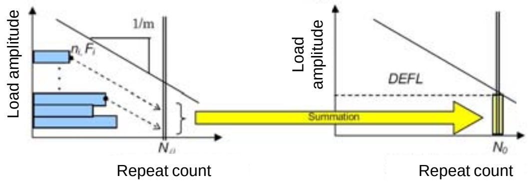
σ : turbulence std

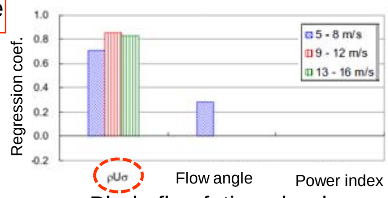
m : slope of S-N curve

m = 4(metal)、10 (composite)



S-N diagram





Blade flap fatigue load

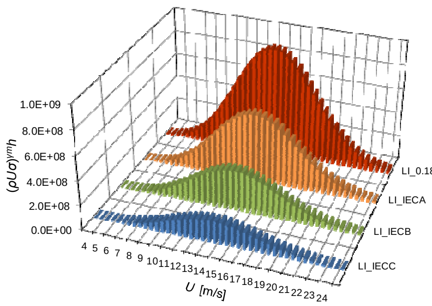
IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo WEIT / AIST

Comparison of *LI* for IEC Category

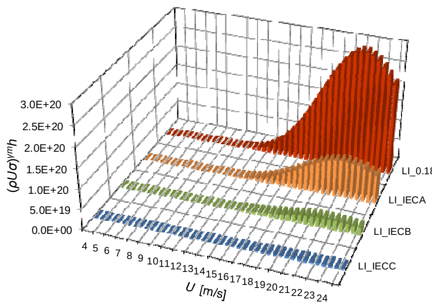
14 |17

- *LI* for DLC.1.2(*Vin* < *Vhub* < *Vout*)

Rayliegh distribution



Wind bin load fluctuations(*m* =4)



Wind bin load fluctuations(*m* =10)

Comparison of *LI*

m	C(0.12)	B(0.14)	A(0.16)	0.18
4	0.750	0.875	1	1.125
10	0.750	0.875	1	1.125

$$LI = \sqrt[m]{\frac{\sum_i (\rho U_i \sigma_{90,i})^{\gamma m} h_i}{8766}}$$

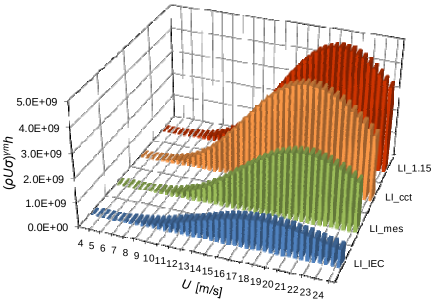
✓ Ratio of *LI* for each turbulence category is equivalent to the ratio of I_{ref} when the probability distribution of wind velocity and the average wind velocity are same.

IEA R&D Wind Task XI - Topical Expert Meeting @ Tokyo WEIT / AIST

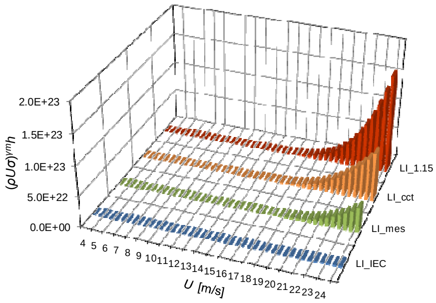
Comparison of *LI* in complex site

- *LI* for DLC.1.2(*Vin* < *Vhub* < *Vout*)

Weibull factor : k=1.62, C =7.32



Wind bin load fluctuations(m =4)



Wind bin load fluctuations(m =10)

Comparison of *LI*

m	IEC_A	Mes.	C_{CT}	$1.15i_c$
4	1	1.20	1.37	1.38
10	1	1.28	1.39	1.47

$$LI = \sqrt[m]{\frac{\sum_i \left(\rho U_i \sigma_{90,i}\right)^{\gamma m} h_i}{8766}}$$

✓ Comparison of wind fluctuation load $(\rho U\sigma)^{\gamma m}$ for different distribution of σ_1.
✓ *LI* evaluated by C_{CT} = 1.15i_c shows very conservative value than the others, although the effect of the turbine control is not included in the calculation of *LI*.

Conclusions

✓ Parameters of turbulence model described in IEC 61400-1 amendment were compared and evaluated using the NEDO guideline data in the complex site.

✓ The results showed that the correction of turbulence standard deviation by using C_{CT} =1.15i_c. may become very conservative for the fatigue load evaluation.

✓ Since the fatigue load index presented is a simple method to evaluate the IEC correction model of turbulence intensity, the effects of each component of the turbulence standard deviation to the fatigue load shall be evaluated by aero-elastic analysis such as Bladed or FAST.

✓ Japanese national committee for IEC TC88 will propose the new turbulence model in the coming MT01. The results in this study may contribute for the next edition of IEC 61400-1.

Thank you for your attention.

CFD simulations of wake effects in large wind farms.

Gotland University

Linné FLOWCentre

Ass. Prof. Stefan Ivanell, Gotland University.

In collaboration with:

Robert Mikkelsen, Jens N Sørensen, Kurt S Hansen, DTU,
Jan-Åke Dahlberg, Vattenfall, Dan Henningson, KTH

www.ivanell.se

Outline

Gotland University

Linné FLOWCentre

- Short about Gotland Univ. and the Wind Energy Dep.
- Status of the research in the area
  - Numerical Computations (2003-)
- Experience from existing farms
  - Horns Rev Wind Farm
  - Lillgrund Wind Farm
- New Nordic research consortium
  - Optimization and Control of Wind Farms

Outline

- Short about Gotland Univ. and the Wind Energy Dep.
- Status of the research in the area
  - Numerical Computations (2003-)
- Experience from existing farms
  - Horns Rev Wind Farm
  - Lillgrund Wind Farm
- New Nordic research consortium
  - Optimization and Control of Wind Farms

Gotland University

Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 3

Gotland University

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 4

Wind Energy Department

Gotland University

Linné FLOWCentre

Stefan Ivanell, Subject responsible Energy technology

Staff:

- 2 Professors
- 2 Ass. Professors
- 7 Lecturers
- 3 Phd students, 1 Project Coord., 1 Project Ass.

Education:

- Master level; 1Y Master, Wind Power Project Management.
- Bachelor level; 20 courses given in English and Swedish, on distance.

Research

- Coordination of a Nordic Consortium, Optimization of Large Wind Farms

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 5

Outline

Gotland University

Linné FLOWCentre

- Short about Gotland Univ. and the Wind Energy Dep.
- Status of the research in the area
  - Numerical Computations (2003-)
- Experience from existing farms
  - Horns Rev Wind Farm
  - Lillgrund Wind Farm
- New Nordic research consortium
  - Optimization and Control of Wind Farms

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 6

Background

- Simulation methods
- Stability analysis (wake length)
- Production variations in wind farms

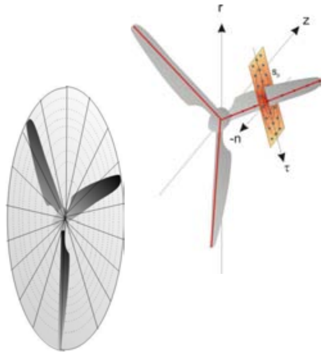
Gotland University

Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 7

Simulation Methods

- EllipSys3D
- Impossible to represent the flow structure locally around the blade and the wake at the same time
- ACD, ACL



Gotland University

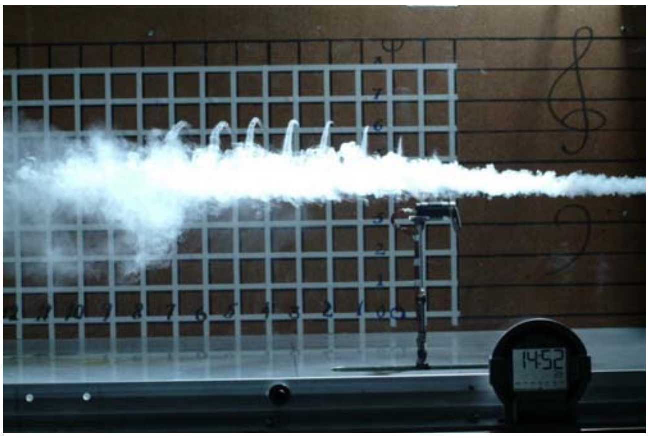
Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 8

Wake structure

Gotland University

Linné FLOWCentre



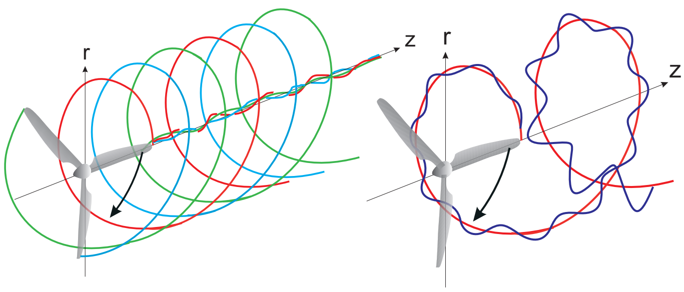
[Montgomerie, Dahlberg]

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 9

Stability of the tip vorticies

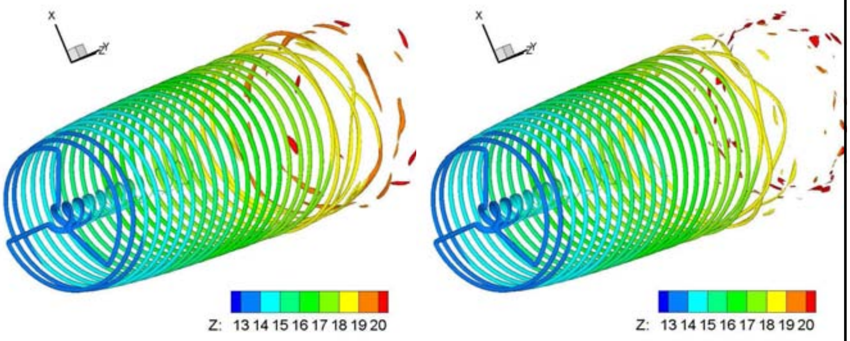
Gotland University

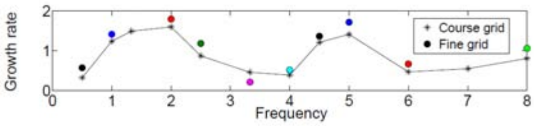
Linné FLOWCentre



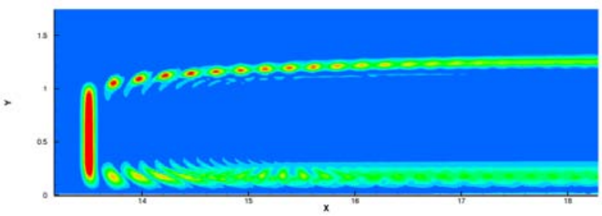
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 10

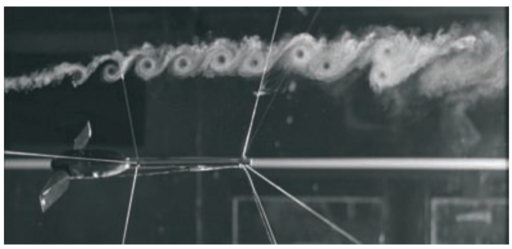
Instability mode: iso-contours of vorticity; 0.33Hz, 0.66Hz





Aggreement with experiment



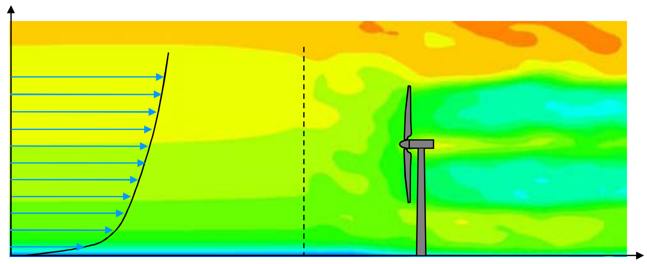


[Alfredsson, Dahlberg, 1979]

Pre-generated turbulent atmospheric boundary layer with ACD

Gotland University

Linné FLOWCentre

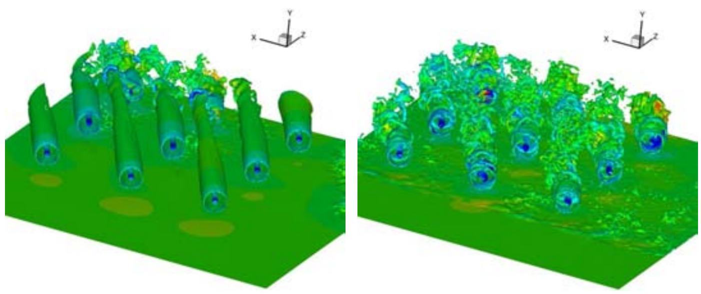


IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 13

Simulation of 9 turbines - with and without atmospheric turbulence

Gotland University

Linné FLOWCentre

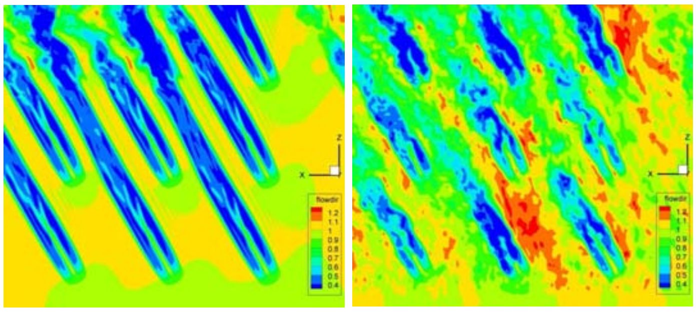


IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 14

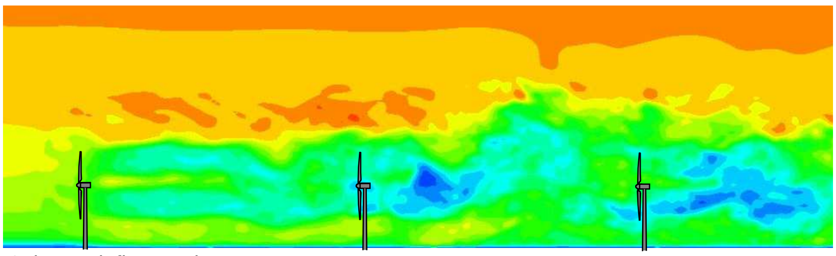
Simulation of 9 turbines - with and without atmospheric turbulence

Gotland University

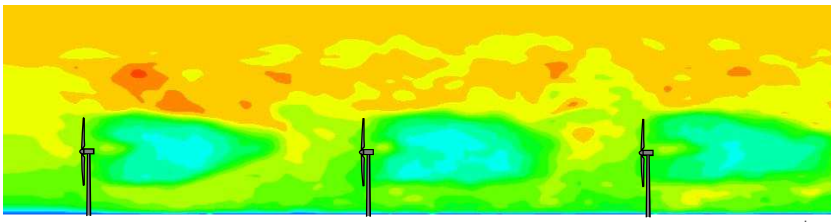
Linné FLOWCentre



Wake interaction



0 degree inflow angle

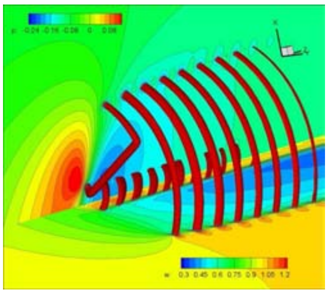


15 degree inflow angle

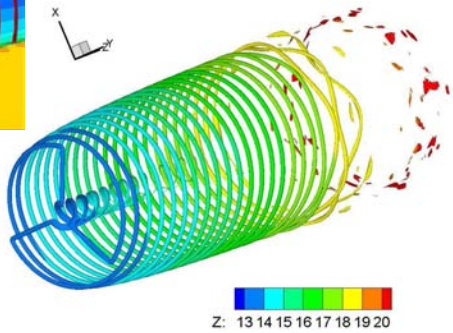
Background on wakes

Gotland University

Linné FLOWCentre



Analysis of numerically generated wake structures
Wind Energy
12:1, 2009, Pages: 63-80



Stability analysis of the tip vortices of a wind turbine
Wind Energy
Early view
DOI: 10.1002/we.391

Outline

Gotland University

Linné FLOWCentre

- Short about Gotland Univ. and the Wind Energy Dep.
- Status of the research in the area
  - Numerical Computations (2003-)
- Experience from existing farms
  - Horns Rev Wind Farm
  - Lillgrund Wind Farm
- New Nordic research consortium
  - Optimization and Control of Wind Farms

Outline

- Short about Gotland Univ. and the Wind Energy Dep.
- Status of the research in the area
  - Numerical Computations (2003-)
- Experience from existing farms
  - Horns Rev Wind Farm
  - Lillgrund Wind Farm
- New Nordic research consortium
  - Optimization and Control of Wind Farms

Gotland University

Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 19

Off shore – Horns Rev

80 turbines with total capacity of 160MW

Vestas V80-2.0MW turbines
Rotor diameter: 80m
Hub height: 70m

Wind Farm Site
Distance to coast: ~15 km
Wind farm area: 20 km^2

Gotland University

Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 20

Farm simulation – Horns Rev

Gotland University

Linné FLOWCentre

- Actuator discs (ACD)
- Periodic boundary conditions
- LES (Mixed sub-grid-scale model by Ta Phuoc)
- Introducing boundary layer
- Introducing atmospheric turbulence

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 21

Horns Rev Wind Farm

Gotland University

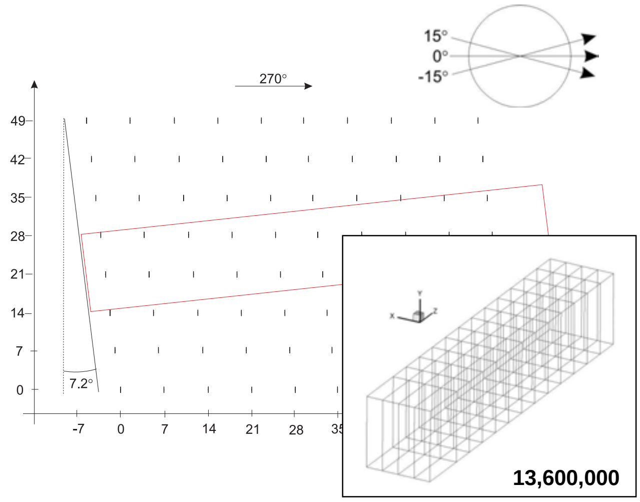
Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 22

Gotland University

Linné FLOWCentre

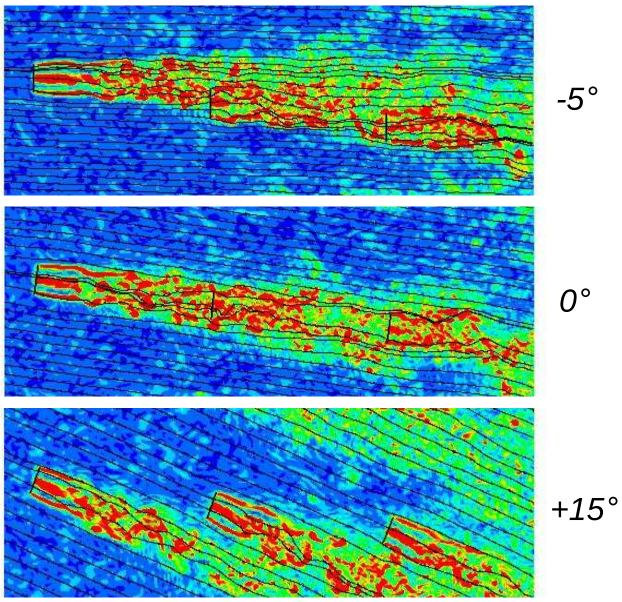
Simulation setup



IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 23

Gotland University

Linné FLOWCentre

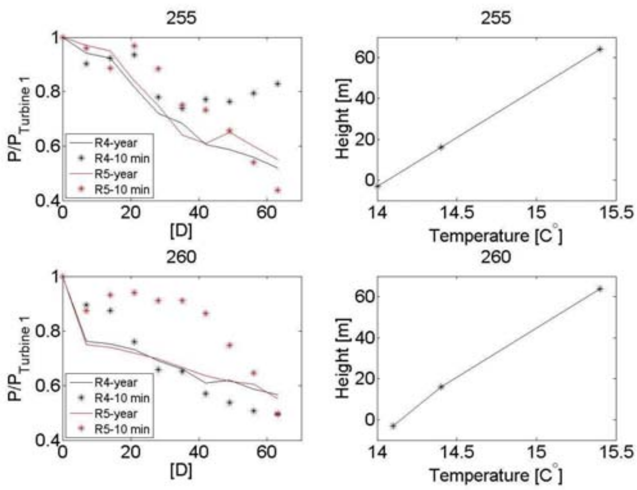


IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 24

Measurements

Gotland University

Linné FLOWCentre

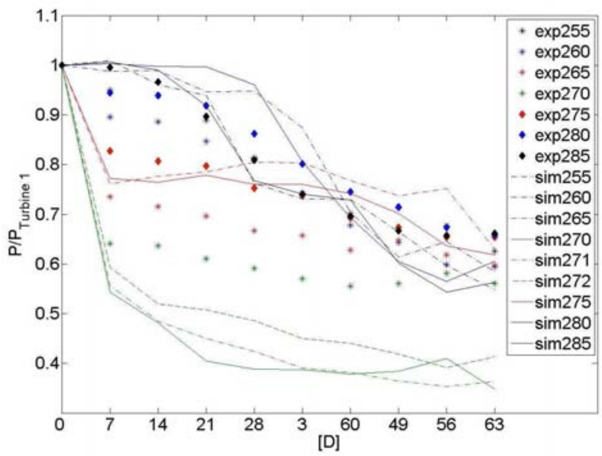


IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 25

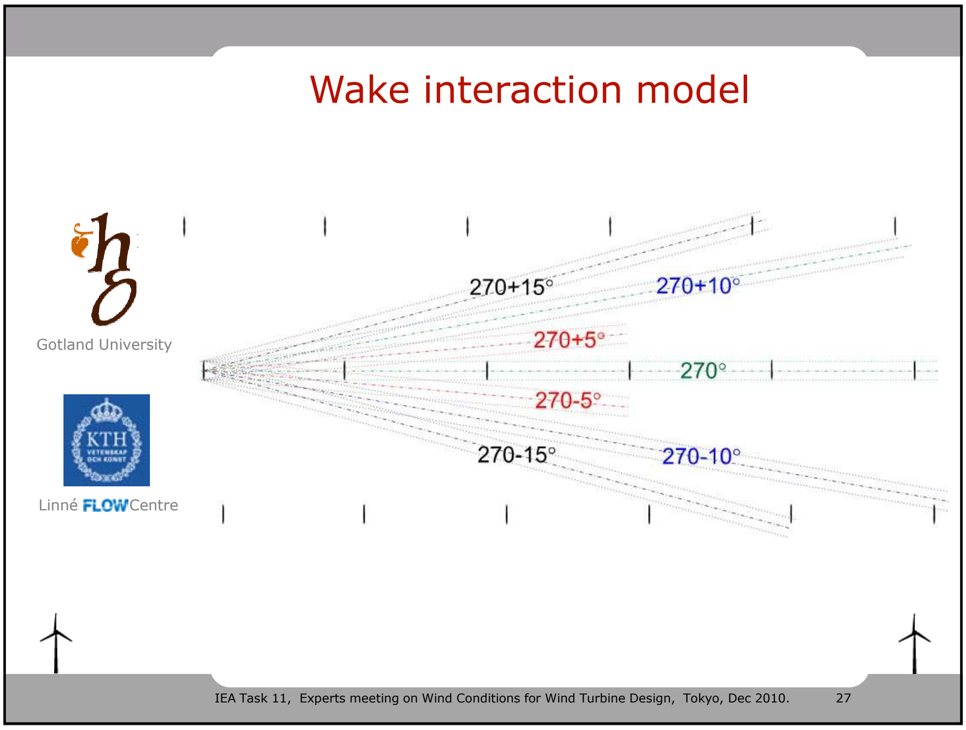
Results

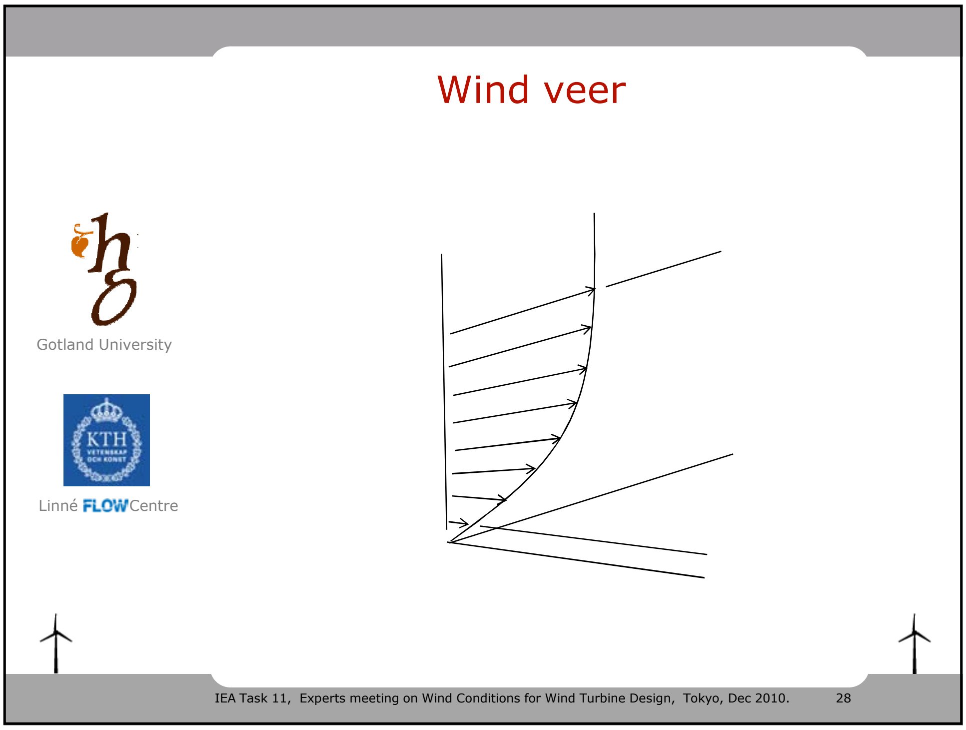
Gotland University

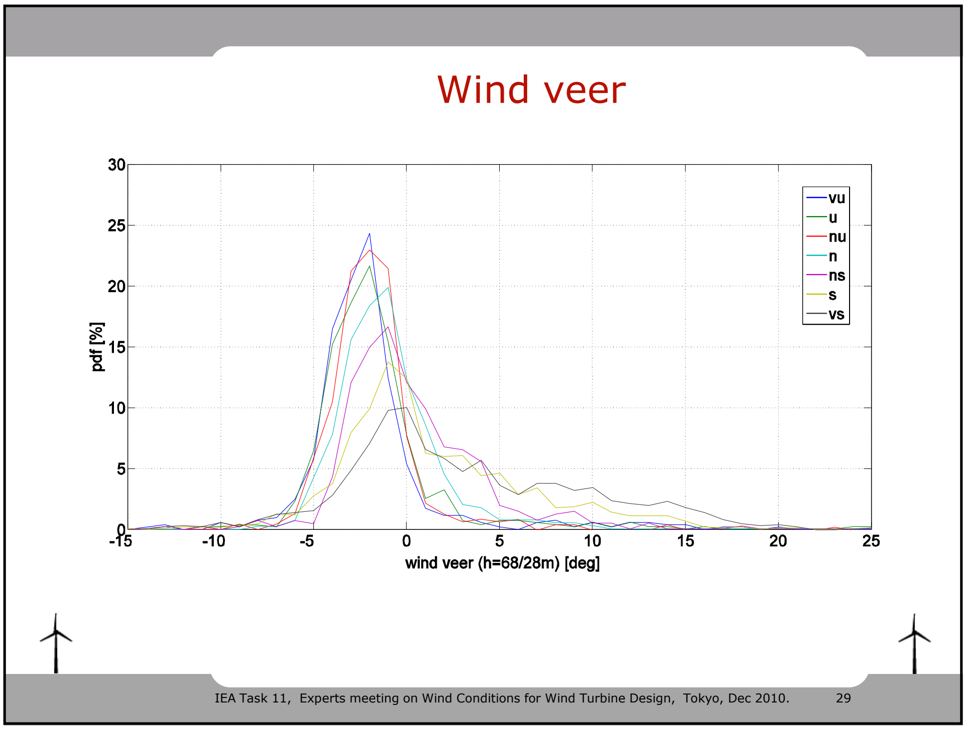
Linné FLOWCentre

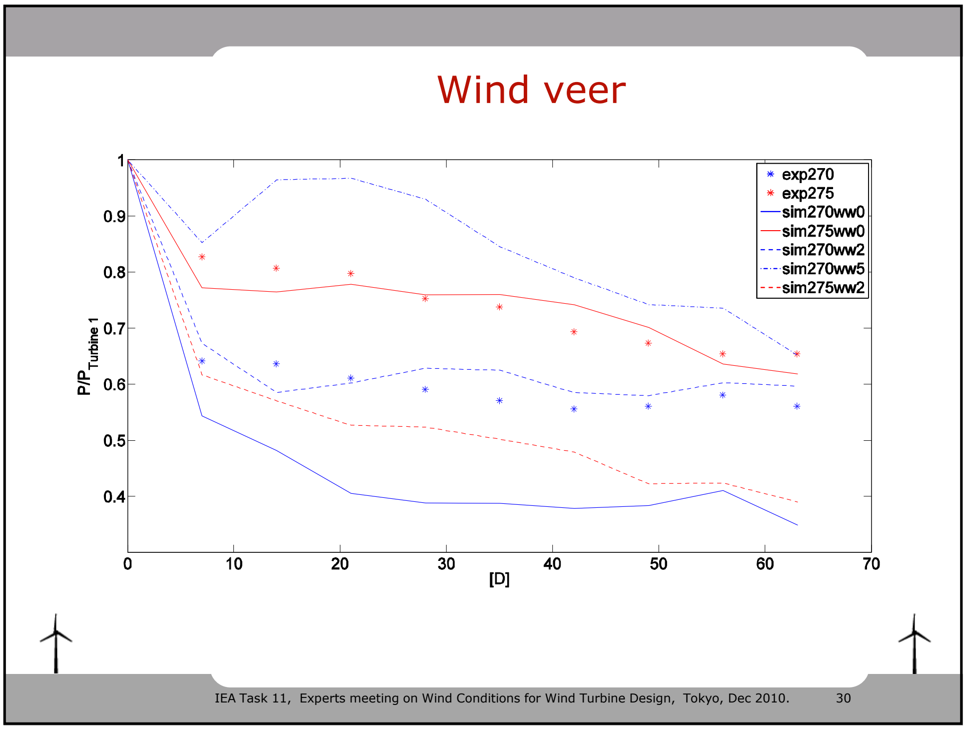


IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 26


Wake interaction model
Gotland University
KTH
Linné FLOWCentre
270+15°
270+10°
270+5°
270°
270-5°
270-15°
270-10°
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 27


Wind veer
Gotland University
KTH
Linné FLOWCentre
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 28


Wind veer
pdf [%]
wind veer (h=68/28m) [deg]
vu
u
nu
n
ns
s
vs
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 29


Wind veer
P/P Turbine 1
[D]
exp270
exp275
sim270ww0
sim275ww0
sim270ww2
sim270ww5
sim275ww2
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 30

Conclusions, Horns Rev

Gotland University

Linné FLOWCentre

- The study shows that the applied method captures the main production variation within the wind farm
- The result further demonstrates that the levels of production depend on wind veer to a great extent.
- Based on the number of uncertainties, the result predicts the production variation very well

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 31

Outline

Gotland University

Linné FLOWCentre

- Short about Gotland Univ. and the Wind Energy Dep.
- Status of the research in the area
  - Numerical Computations (2003-)
- Experience from existing farms
  - Horns Rev Wind Farm
  - Lillgrund Wind Farm
- New Nordic research consortium
  - Optimization and Control of Wind Farms

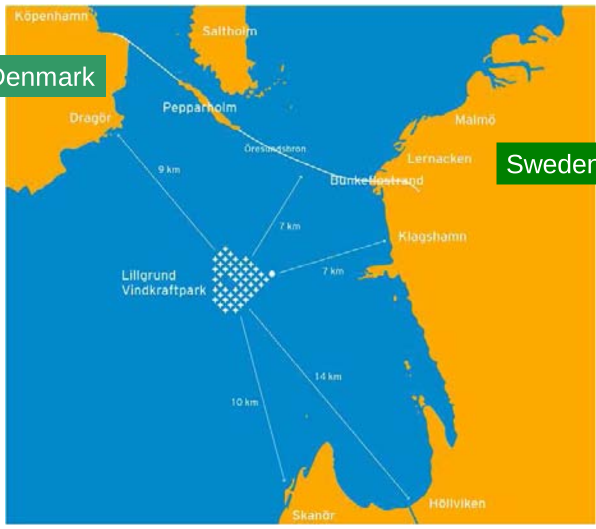
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 32

Lillgrund

Gotland University

Linné FLOWCentre

VATTENFALL



IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 33

Lillgrund

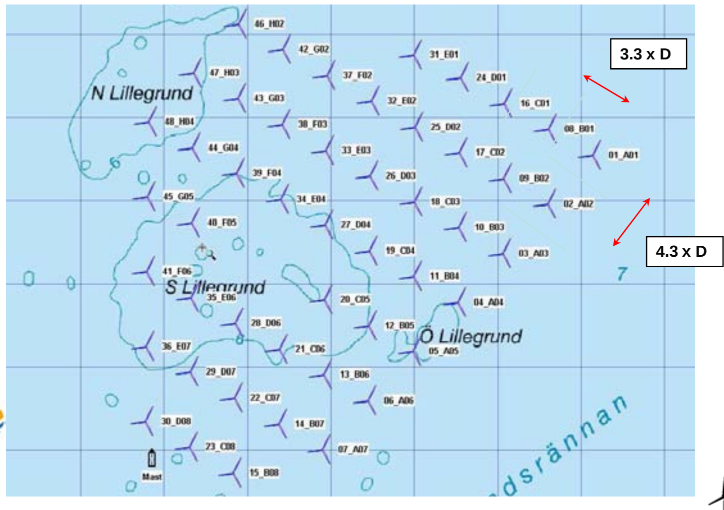
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 34

Lillgrund (48 SWT-2.3 MW)

Gotland University

Linné FLOWCentre

VATTENFALL



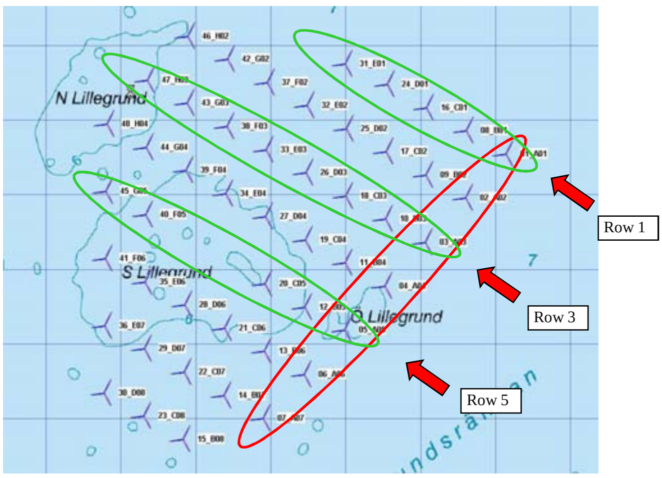
IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 35

Wake losses in row 1,3 and 5 (3.3xD)

Gotland University

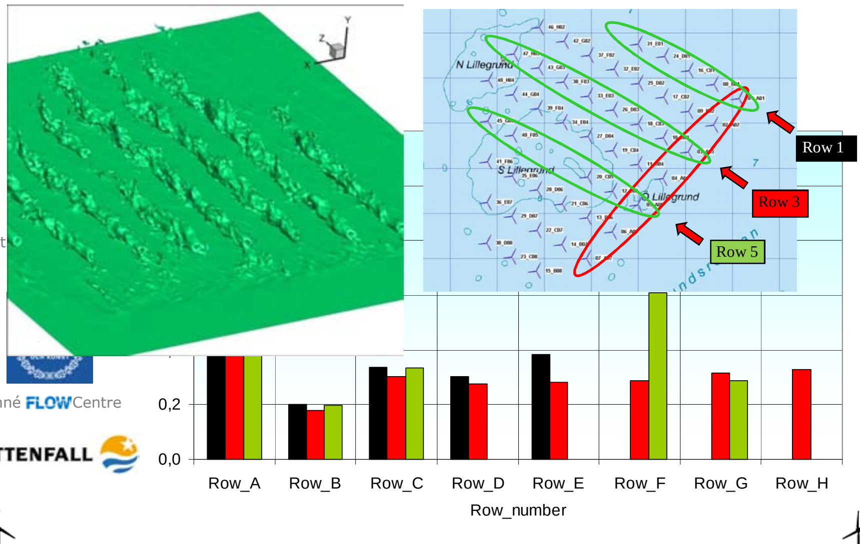
Linné FLOWCentre

VATTENFALL



IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 36

Wake losses (3.3xD)



Linné FLOWCentre

VATTENFALL

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 37

Outline

- Short about Gotland Univ. and the Wind Energy Dep.
- Status of the research in the area
  - Numerical Computations (2003-)
- Experience from existing farms
  - Horns Rev Wind Farm
  - Lillgrund Wind Farm
- New Nordic research consortium
  - Optimization and Control of Wind Farms

Gotland University

Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 38

Future work - Nordic Consortium

Optimization and control of wind turbine farms

Gotland University

Linné FLOWCentre

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 39

Gotland University

Linné FLOWCentre

Project 1: wake interaction and instabilities, KTH (Swedish Energy Agency)

Project 2: experimental validation, KTH (Swedish Energy Agency)

Project 3: optimization of wind farms, DTU (Danmark)

Project 4: Control and optimization of wind farms, HGO/KTH (VindForsk III)

Project 5: wake modeling, Kjeller Vindteknikk (Norge)

Project 6: Control of wind farms, Teknikgruppen/Scanwind (Vindforsk III)

+ (at least) 2 new PhD projects, positions will be announced soon.

IEA Task 11, Experts meeting on Wind Conditions for Wind Turbine Design, Tokyo, Dec 2010. 40


Thank you for your attention!
www.ivanell.se
stefan.ivanell@hgo.se

Brief introduction of China extreme wind condition survey and research

Zhang Yu
北京鉴衡认证中心
China General Certification Center

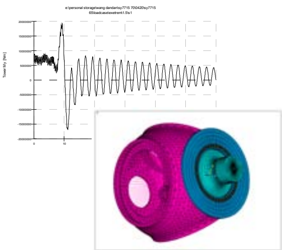
2010-12

Content

Introduction of CGC

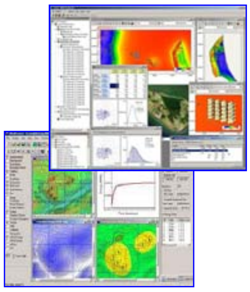
鉴衡认证
CHINA GENERAL CERTIFICATION

- PV, wind turbine and components certification
- On wind, we do



Certification (IEC Series)

Type testing (IEC Series)



Power prediction & Wind farm services

- Earliest and leading certification authority of wind in China
- Cooperating with CMA (China Meteorology Adm.) and Goldwind on China wind resources (condition) survey.

鉴衡认证
CHINA GENERAL CERTIFICATION

China coastline extreme wind condition survey (Typhoon)

©北京鉴衡认证中心

Damages of Typhoon

鉴衡认证
CHINA GENERAL CERTIFICATION

桑美Saomai, 2006

Chanchu, 2006

杜鹃Dujuan, 2003

Damages of Typhoon

鉴衡认证
CHINA GENERAL CERTIFICATION

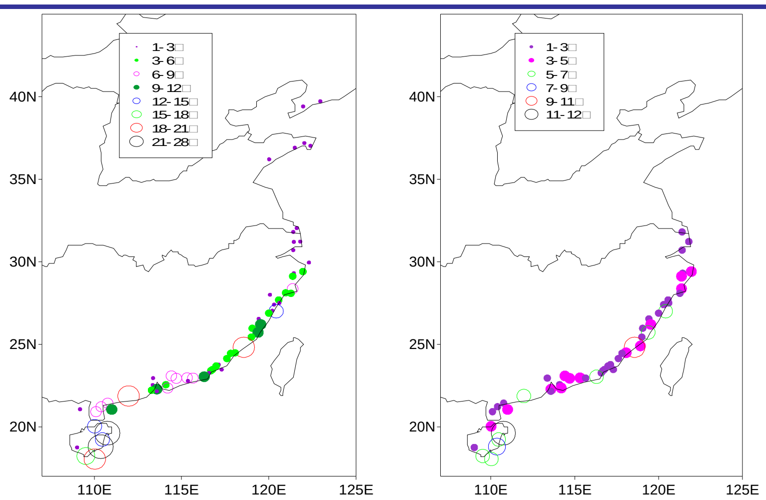
Rotor destroyed

Completely destroyed

2010, Megi, with 38m/s max 10min wind speed at center when landing, grid on

Frequency of attack

鉴衡认证 CHINA GENERAL CERTIFICATION

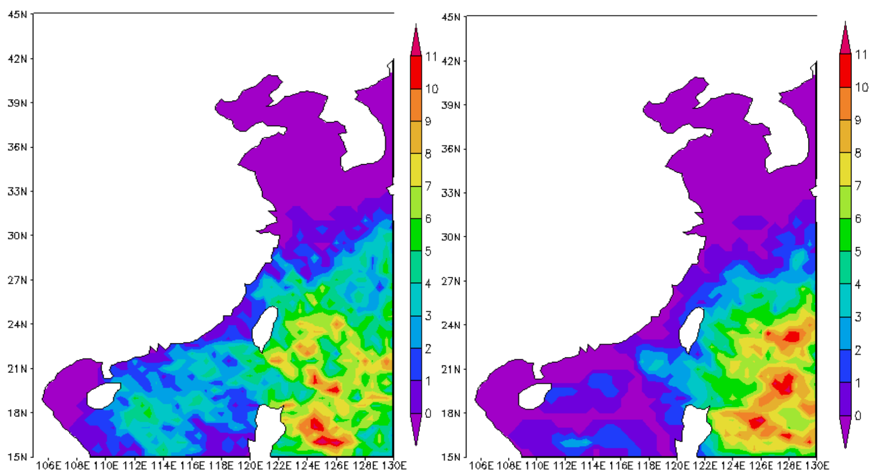


No. of tropical cyclones in recent 50y

No. of typhoons in recent 50y

Frequency of attack

鉴衡认证 CHINA GENERAL CERTIFICATION

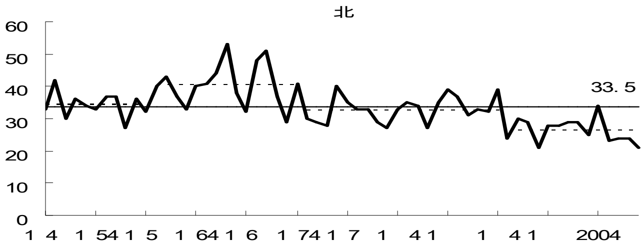


42.6 50 m/s times in 50y

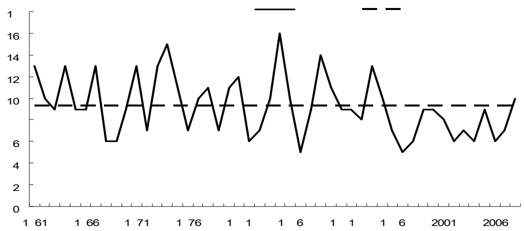
≥50m/s times in 50y

Frequency of attack

鉴衡认证
CHINA GENERAL CERTIFICATION



No. of tropical cyclones generated



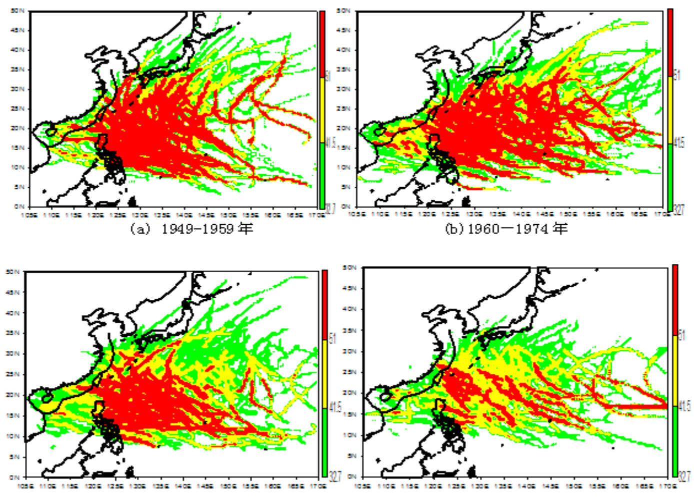
No. of tropical cyclones got into the mainland alarm zone

©北京鉴衡认证中心

From CMA

Frequency of attack

鉴衡认证
CHINA GENERAL CERTIFICATION



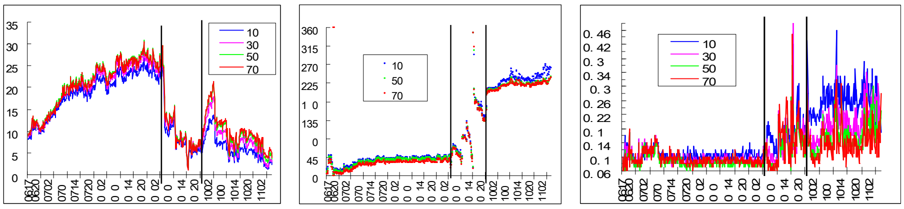
(a) 1949-1959 年 (b) 1960—1974 年

(a) 1975-1995 年 (b) 1996—2008 年

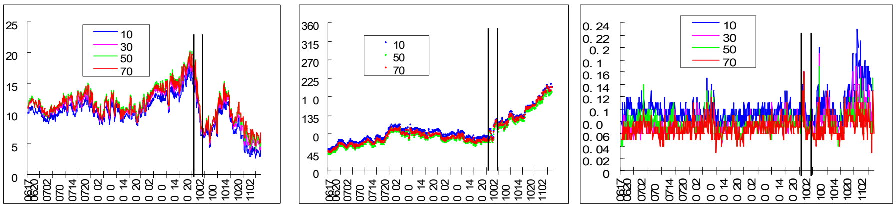
©北京鉴衡认证中心

Case studies

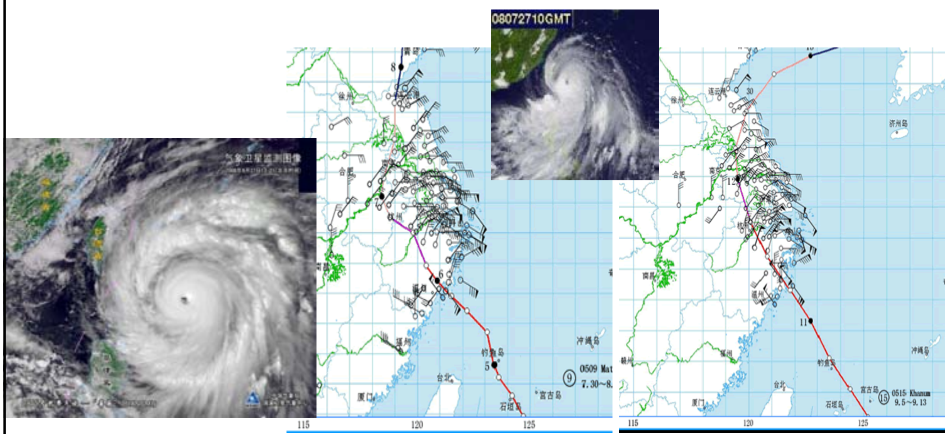
2009, Morakot



attacked by the eye



far from the eye



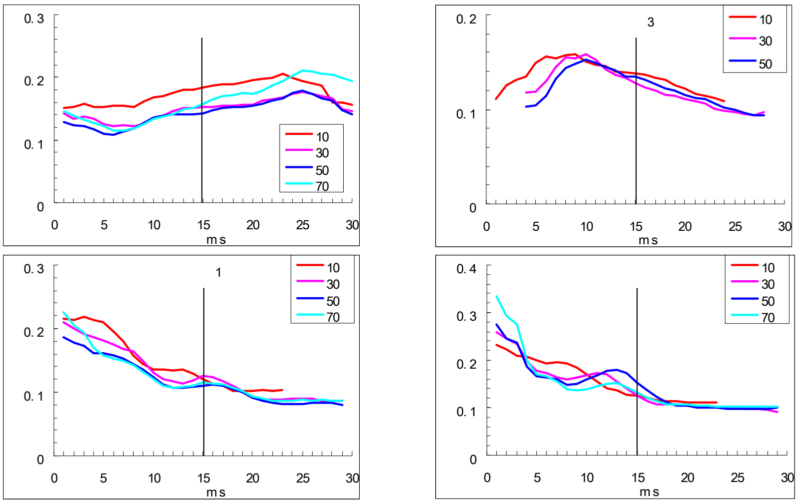
2005

2005

Case studies

2009, Morakot

鉴衡认证
CHINA GENERAL CERTIFICATION



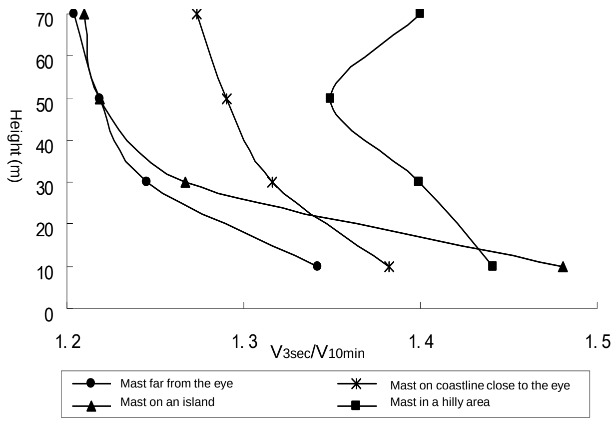
Influence of terrain (WS vs TI)

©北京鉴衡认证中心

Case studies

2009, Morakot

鉴衡认证
CHINA GENERAL CERTIFICATION



Influence of terrain (WS vs TI)

©北京鉴衡认证中心

For details above, please refer to: Zhang Xiuzhi, Impact of Typhoon on China Wind Industry, Jun 2010

Turbulence structure

鉴衡认证 CHINA GENERAL CERTIFICATION

Found in the survey of 3 typhoons (Vonfong in 2002, Dujuan in 2003 and Hagupit in 2002):

1. Significant downdraft in vertical near the eye
2. Turbulence integral scale expanded greatly in the principal and lateral direction, but not in vertical
3. Unusual turbulence power spectrum

Improved turbulence model for typhoon?

Refer to: Song Lili, Analysis on Boundary Layer Turbulent Features of Landfalling Typhoon, Acta Meteorologica Sinica, 2005, 63 (6);

鉴衡认证 CHINA GENERAL CERTIFICATION

Introduction of China wind resource and condition survey

©北京鉴衡认证中心

Introduction

鉴衡认证
CHINA GENERAL CERTIFICATION

Background:

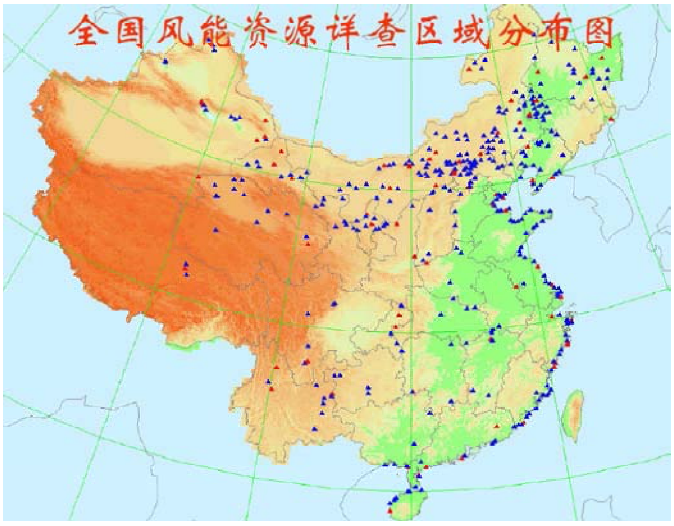
1. Supported by the Ministry of Finance of PRC
2. Involved CMA, CGC and Goldwind
3. Program began in 2007, construction completed in late 2009
4. Hundreds of million RMB budget

Masts:

1. Over 400 masts in total with 70m height
2. More than 70 masts with 100m height
3. 3 with 120m height
4. Supersonic anemometers equipped plus traditional ones
5. On land and along coastline

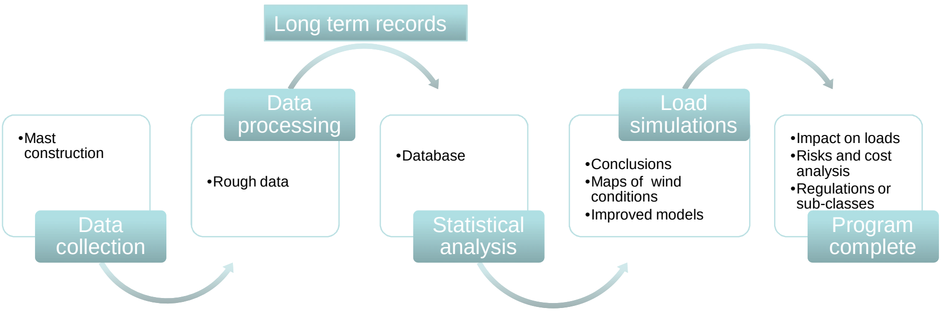
Map of the survey

鉴衡认证
CHINA GENERAL CERTIFICATION



Planned approaches

鉴衡认证
CHINA GENERAL CERTIFICATION



Further steps on wind condition survey

Summary

鉴衡认证
CHINA GENERAL CERTIFICATION

Typhoon:

1. Destructive due to more than wind speed, not typical extreme condition combined with terrains
2. Turbulence features may be special
3. Classification needed

More we concern:

1. Wake effect in extra large wind farms (wake model)
2. Inflow angle changes in typhoon……

Wind condition survey:

Hope to share more later

鉴衡认证
CHINA GENERAL CERTIFICATION

Thank you!

Zhang Yu
zhangyu@cgc.org.cn

Modeling Turbulent Typhoon Time Series

for "Typhoon-proved" Wind Turbines

Michael Schmidt, Tanja Mücke

CARL VON OSSIETZKY universität OLDENBURG

ForWind Center for Wind Energy Research

TEM 64, Tokyo, December 14/15th, 2010

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

Contents

Michael Schmidt, Tanja Mücke | Modeling Turbulent Typhoon Time Series

Acknowledgements to ...

- Ohsawa-sensei, Uni Kobe, Shirahama-data: Typhoons Orchid 1994 and Vicki 1998 (2 sets)
- Maeda-sensei, Uni of Kyushu, NeWMeK-data: Typhoons Bart 1999 and Usagi 2007 (8 sets)
- Prof. F. Masters, Uni of Florida, FCMP-data: Hurricanes Dennis, Rita and Wilma (all 2005, 5 sets)
- Hayashi-sensei, Uni Kyoto, Miyako-island data: Typhoon Maemie 2003 (6 “Sonic-”, 9 “Vane”-sets)

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

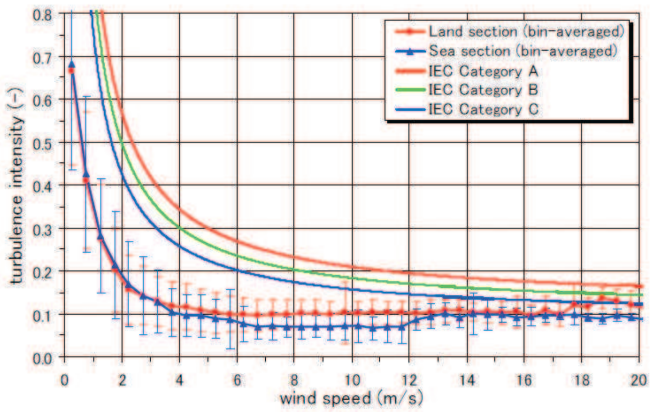
For modeling turbulent time series with a CTRW-Model (**C**ontinuous **T**ime **R**andom **W**alk) we have studied the typhoon data, to find general interdependecies between:

- Mean values (10min),
- Standard deviations, resp. Turbulence intensities,
- and Kurtosis (high order, 2-point statistics (increments of wind speed): a measure of number and heights of “jumps” in time series).

- Studied in Sonic anemometer data: vertical wind
- and wind directions.

Michael Schmidt, Tanja Mücke Modeling Turbulent Typhoon Time Series

TI in Shirahama-“non-typhoon-data” (Sonic), 2007

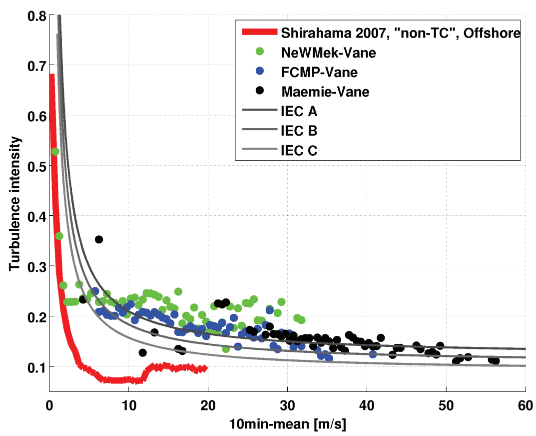


T. Ohsawa, S. Shimada. *Characteristics of Offshore Winds at Shirahama OO*, Proceedings of ISOPE, 2009

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

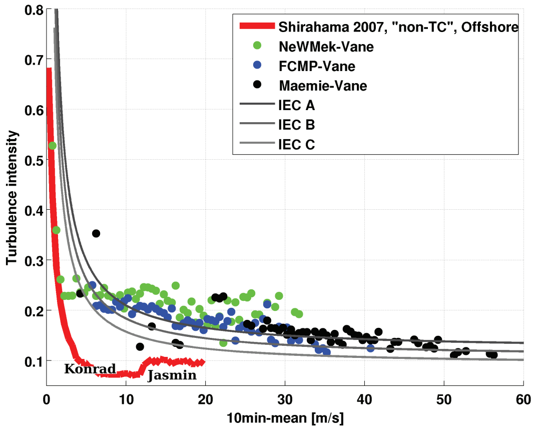
Turbulence intensity
Gust factors
Kurtosis and “Intermittence”

TI in Tropical Cyclones, “Vane”-data



Michael Schmidt, Tanja Mücke
Modeling Turbulent Typhoon Time Series

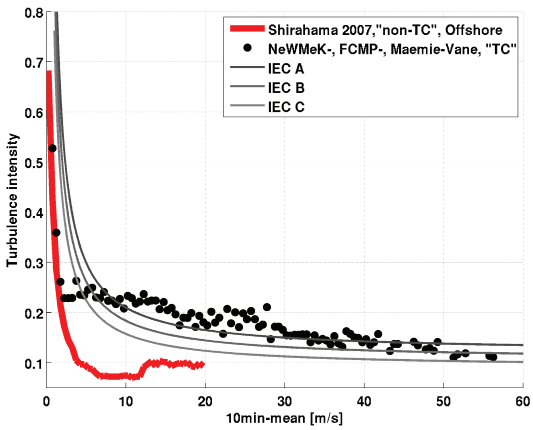
TI in Tropical Cyclones, “Vane”-data (and FINO-Sonic)



Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

Turbulence intensity
Gust factors
Kurtosis and “Intermittence”

TI in TCs, all “Vane”-data

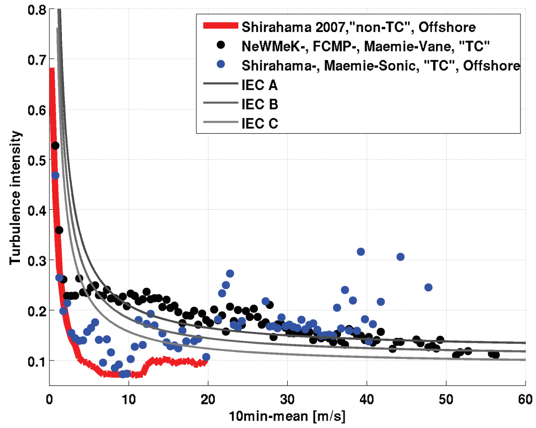


Michael Schmidt, Tanja Mücke
Modeling Turbulent Typhoon Time Series

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

Turbulence intensity
Gust factors
Kurtosis and "Intermittence"

TI in TCs, comparison of all "Vane-" and Sonic-data

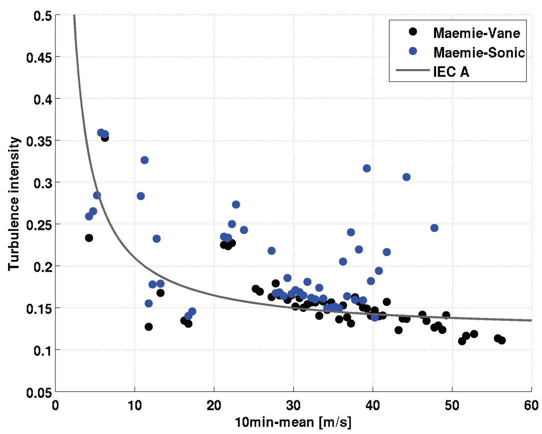


Michael Schmidt, Tanja Mücke | Modeling Turbulent Typhoon Time Series

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

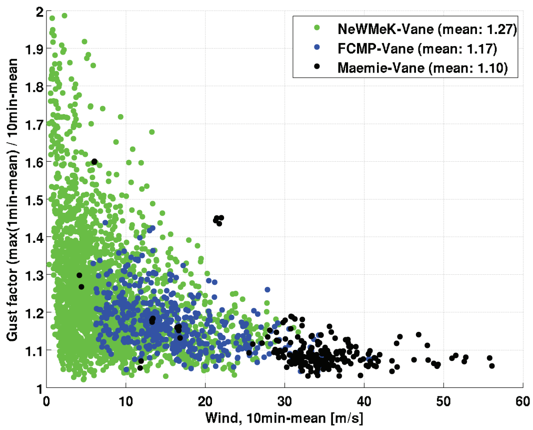
Turbulence intensity
Gust factors
Kurtosis and "Intermittence"

TI in Maemi, comparison of Sonic- and "Vane-"data

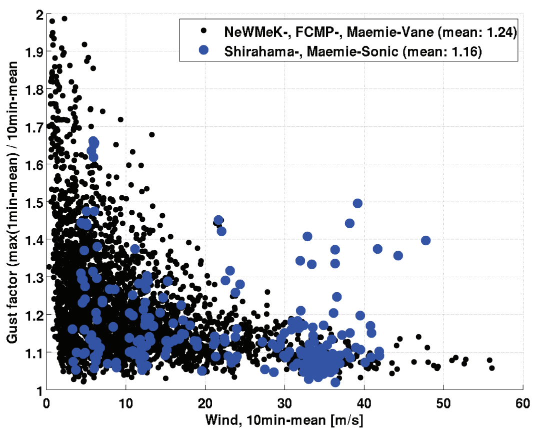


Michael Schmidt, Tanja Mücke | Modeling Turbulent Typhoon Time Series

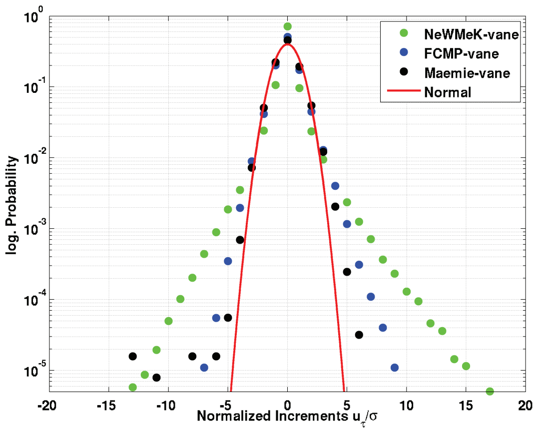
Gust factors in Vane-data



Gust factors in Sonic- and Vane-data

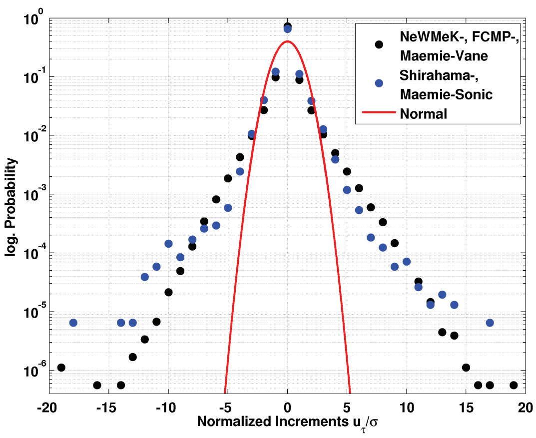


Intermittence of wind: does it mirror the topographie?



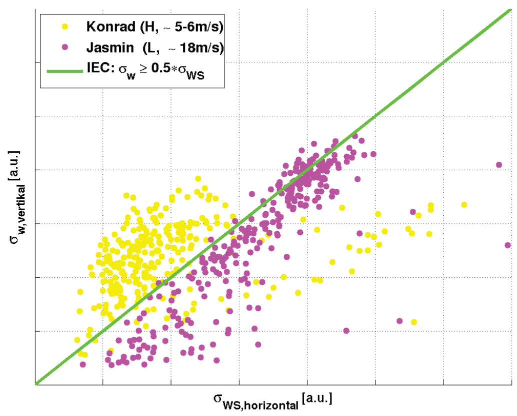
(Exzess-) Kurtosis $\neq 0$: PDF is non-gaussian or “intermittent”.

Intermittence in Sonic- and Vane-data

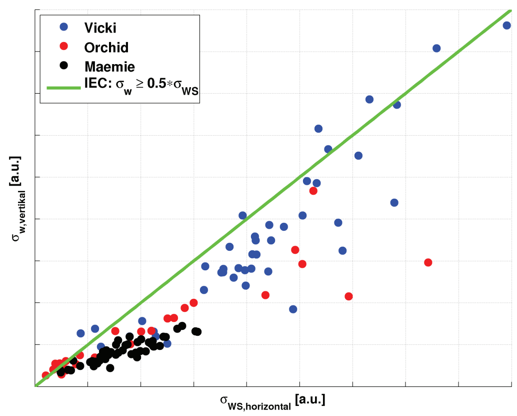


Vane-data from Onshore, but Sonic-data “Offshore”-sites.

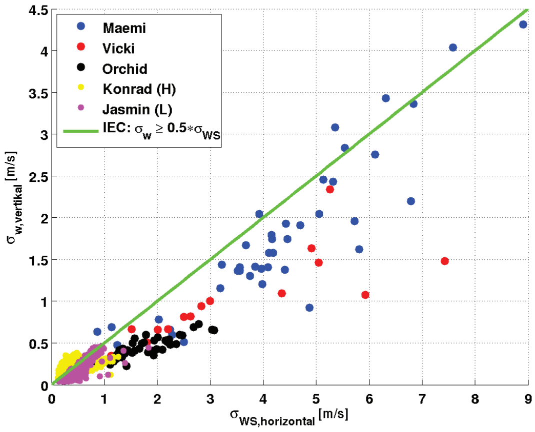
Vertical and horizontal σ's in mid-latitudes



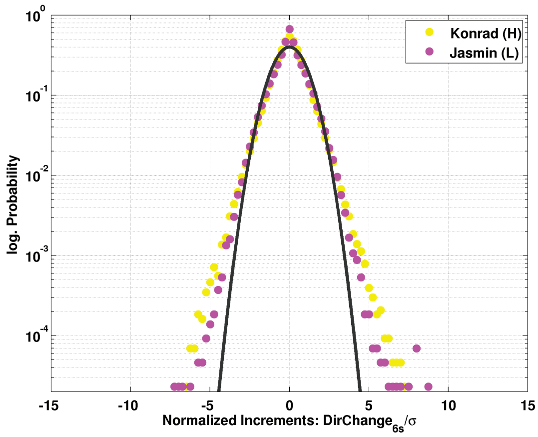
Vertical and horizontal σ's in typhoons



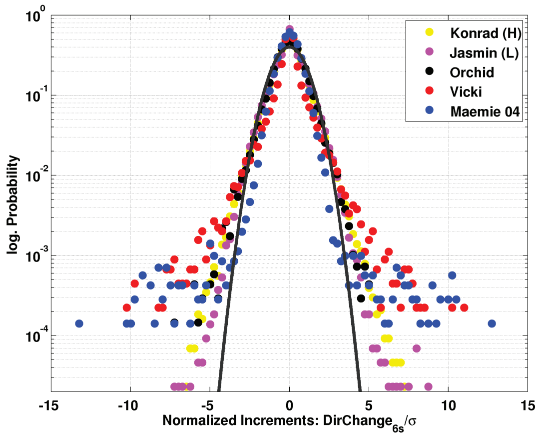
Comparison of vertical and horizontal σ's



Intermittent DC's in midlatitude wind (FINO-data)

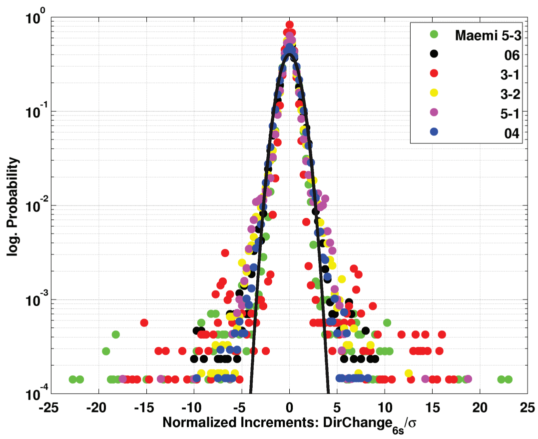


Intermittent DC's in midlatitude and typhoon winds



Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

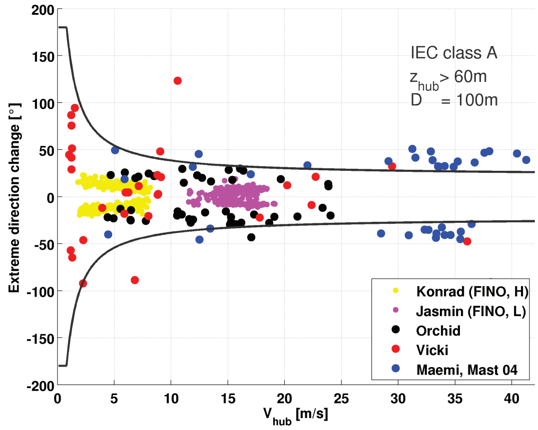
Intermittent DC's in Maemi



Michael Schmidt, Tanja Mücke
Modeling Turbulent Typhoon Time Series

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

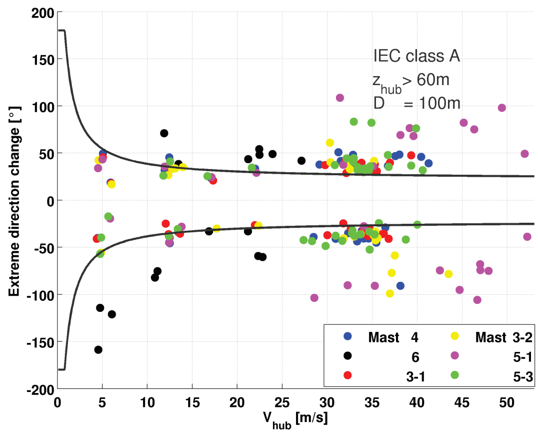
Extreme DC's (IEC) in midlatitudes and typhoons



Michael Schmidt, Tanja Mücke | Modeling Turbulent Typhoon Time Series

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

Extreme DC's (IEC) in Maemi



Michael Schmidt, Tanja Mücke | Modeling Turbulent Typhoon Time Series

Typhoon data and implications

- Sonic data are showing higher TI's, higher Gust factors, and higher kurtosis than "Vane"-data.
- Sonic data are resolving turbulence at high wind speeds more properly.
- "Vanes" may be too inert or 'lethargic' at high wind speeds.
- Kurtosis is not considered in IEC-regulations, should it?
- For designing WT in typhoon-affected areas there is a need for "Class S"-specification, e.g. for TI's and EDC's.

Data sets from Tropical Cyclones
Horizontal wind
Vertical wind: Standard deviations
Wind directions
Conclusions

New Standards

- "Typhoon-proved" Wind turbines has to be certified.
- IEC-regulations for "Class S"-Turbines are needed ...
  ... soon.

- We want to take part in this discussion ...
  ... and to accelerate its progress.

Michael Schmidt, Tanja Mücke Modeling Turbulent Typhoon Time Series

Thank you for attention.

www.forwind.de
tanja.muecke@uni-oldenburg.de
michael.schmidt@forwind.de

IEA, Task 11

Topical Expert Meeting on Wind Conditions for wind turbine design
Niels Kjær Lauritsen and Morten Sloth, Dec. 2010

[Date Month 20XX, Name, Department, etc.]

Content

- Load and Power modes
- Turbine damages seen when hit by a typhoon
- Yaw Power Backup
- Strengthen tower design

2 Name of presentation

Wind. It means the world to us.™

Wind Turbine Classes

IEC 61400-1 (Design Code)

- Design Climate Class: IEC Ia, IEC IIa, IEC IIIa

Reality

- Only a few sites really fit these climate classes

In order to utilize the turbine 100 % …

… a more flexible turbine is needed!!!

3 Name of presentation

Wind. It means the world to us.™

Load and Power Modes

Load Modes

- Reducing loads

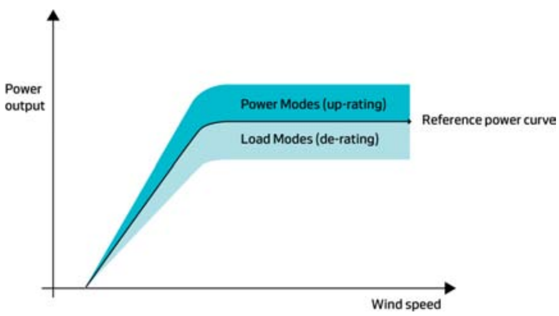
Power Modes

- Increasing Production (Site dependent)

1. release available with

new sales of:

- V90-1.8 MW 50/60Hz
- V90-2.0 MW 50Hz
- V90-3.0 MW 50/60Hz



4 Name of presentation

Wind. It means the world to us.™

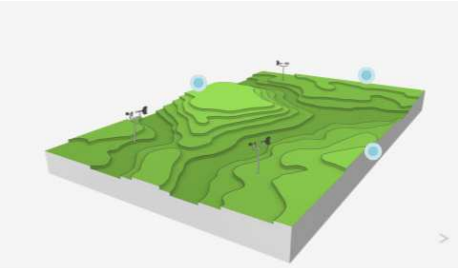
Topography

Due to the topography there can be:

- some rough climate sectors
- some smooth climate sectors

In order to utilize the turbine 100 % …

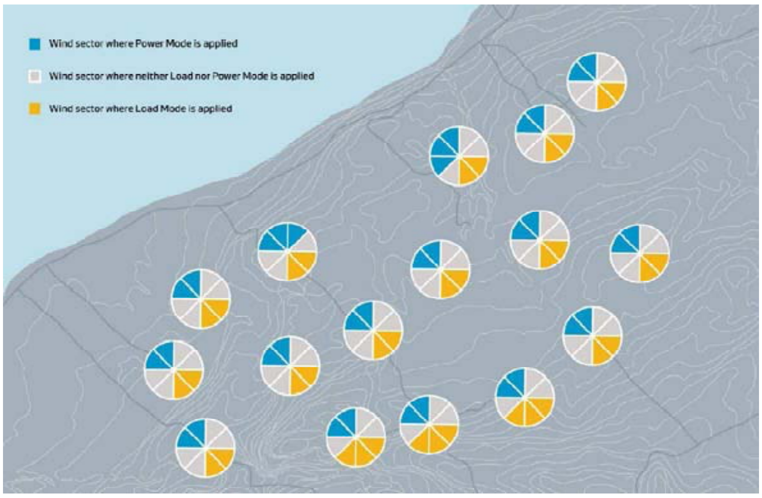
… a sector wise flexible turbine is needed!!!



5 Name of presentation

Wind. It means the world to us.™

Wind sectors



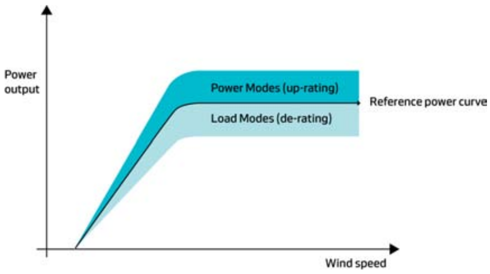
6 Name of presentation

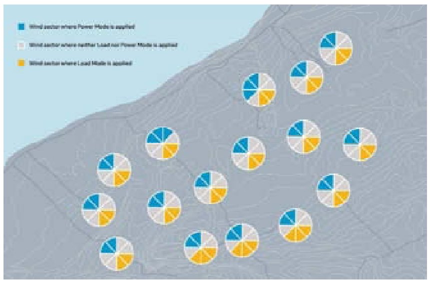
Wind. It means the world to us.™

Load and Power Modes…

…offers you the possibility of a sector wise flexible turbine.

The turbine will statically be configured with a mode in a sector.





7 Name of presentation

Wind. It means the world to us.™

Load and Power Modes – Work Flow

Input from costumer

8 Name of presentation

Wind. It means the world to us.™

Load and Power Modes – Work Flow

Input from costumer

Processing input

9 Name of presentation

Wind. It means the world to us.™

Load and Power Modes – Work Flow

Input from costumer

Processing input

Optimized production

- Contract is signed

10 Name of presentation

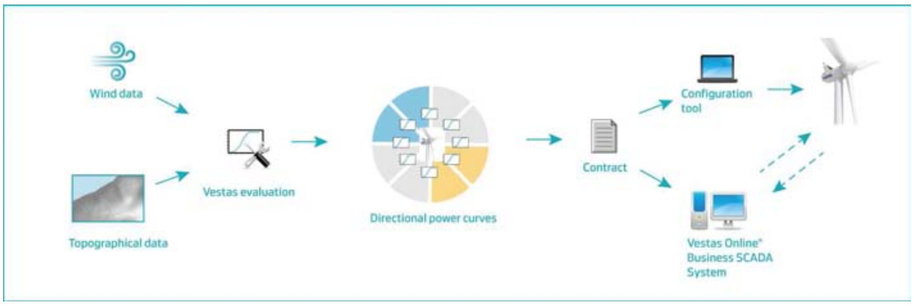
Wind. It means the world to us.™

Load and Power Modes – Work Flow

Automatic configuration of Load and Power Modes

SCADA

- Monitoring the configuration setup
- Presentation of online status
- Power curve calculation



11 Name of presentation

Wind. It means the world to us.™

Summary

Load and Power Modes provides a sector wise flexible turbine that make it possible to utilize 100% of the turbine on a given site.

Load and Power Modes is configured on the turbine during installation and checked constantly by SCADA.

For more information see general specification –

Load and Power modes (0005-8317)

12 Name of presentation

Wind. It means the world to us.™

Turbine failures seen when hit by typhoons

- Blades
- Yaw motors
- Yaw breakers
- Tower collapse

13 Name of presentation

Wind. It means the world to us.™

Yaw Power Backup System

Enables the turbine to yaw upwind during tropical cyclones even if the grid is lost.

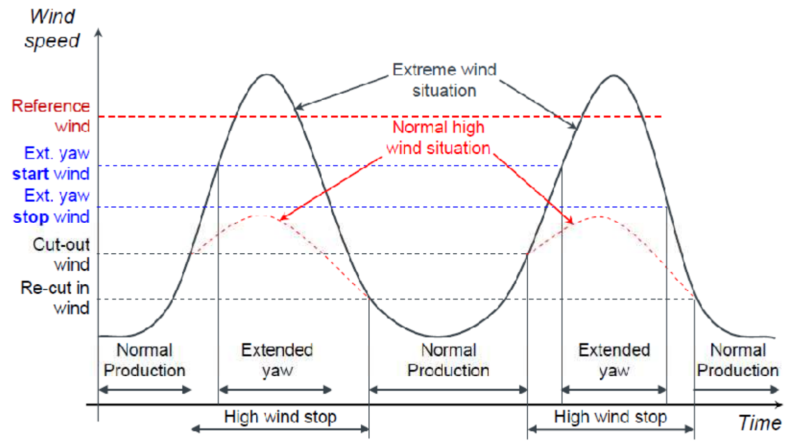
The YPB system consists of three main elements:

- A central placed power backup system that delivers power to the turbines when the grid is down.
- An extended yaw mode in the individual turbine which will allow the turbine to ignore certain warnings and alarm that normally would prevent yawing.
- An additional wind measurement system which is qualified for a higher wind speed than the standard wind sensor on the turbine. This will provide reliable wind data at high wind speeds.

14 Name of presentation

Wind. It means the world to us.™

Operational Strategy



15 Name of presentation **Wind.** It means the world to us.™

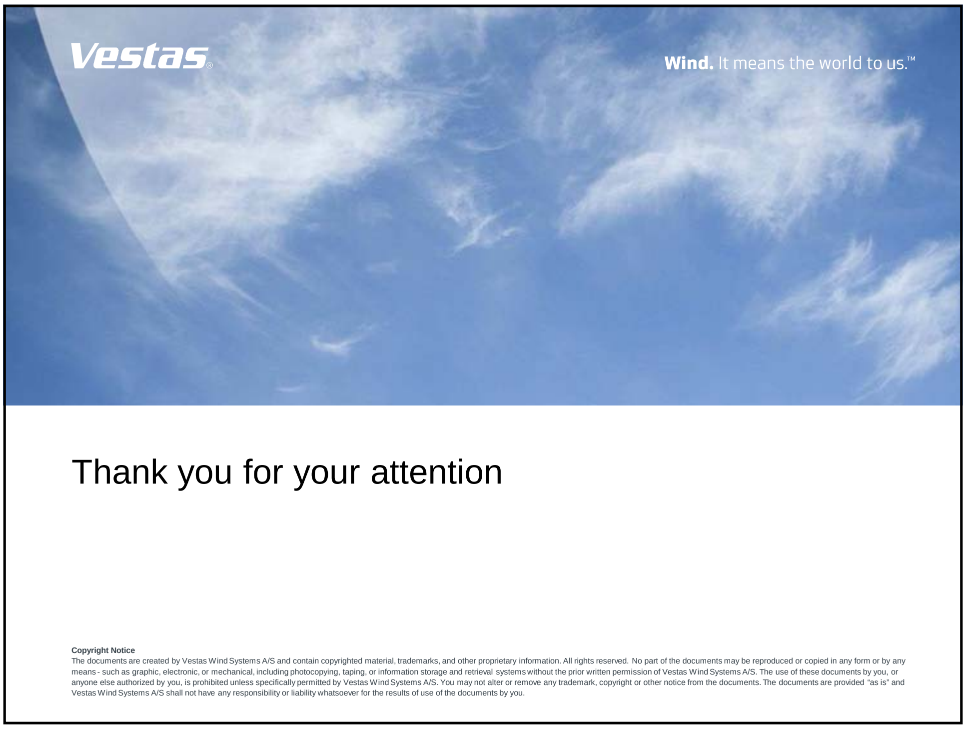
Typhoon Tower

Design Drivers:
- Japanese building code
- Survey of Japanese market
- Protection of the turbine during extreme wind events

Solution:

	V80 2.0MW HH78 IEC1a	V90 3.0MW HH75 IEC S
Wind zone:	IEC 1a: V_{ext} = 70 m/s V_{ref} = 50 m/s V_{ave} = 10 m/s	IECS: V_{ext} = 92 m/s V_{ref} = 50 m/s V_{ave} = 10 m/s
Number of sections:	3	4
Weight, tower:	Bottom: 54t Middle: 58t Top: 36,5t	Bottom: 58t Middle 1: 48t Middle 2: 41t Top: 26t

16 Name of presentation **Wind.** It means the world to us.™


Vestas
Wind. It means the world to us.™
Thank you for your attention
Copyright Notice
The documents are created by Vestas Wind Systems A/S and contain copyrighted material, trademarks, and other proprietary information. All rights reserved. No part of the documents may be reproduced or copied in any form or by any means - such as graphic, electronic, or mechanical, including photocopying, taping, or information storage and retrieval systems without the prior written permission of Vestas Wind Systems A/S. The use of these documents by you, or anyone else authorized by you, is prohibited unless specifically permitted by Vestas Wind Systems A/S. You may not alter or remove any trademark, copyright or other notice from the documents. The documents are provided "as is" and Vestas Wind Systems A/S shall not have any responsibility or liability whatsoever for the results of use of the documents by you.

Estimation of Extreme Wind Speed by using Monte Carlo Simulation of Tropical Cyclone

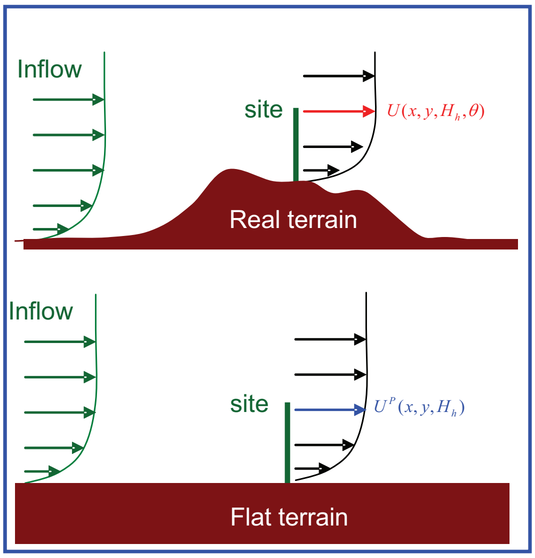
Atsushi YAMAGUCHI, The University of Tokyo

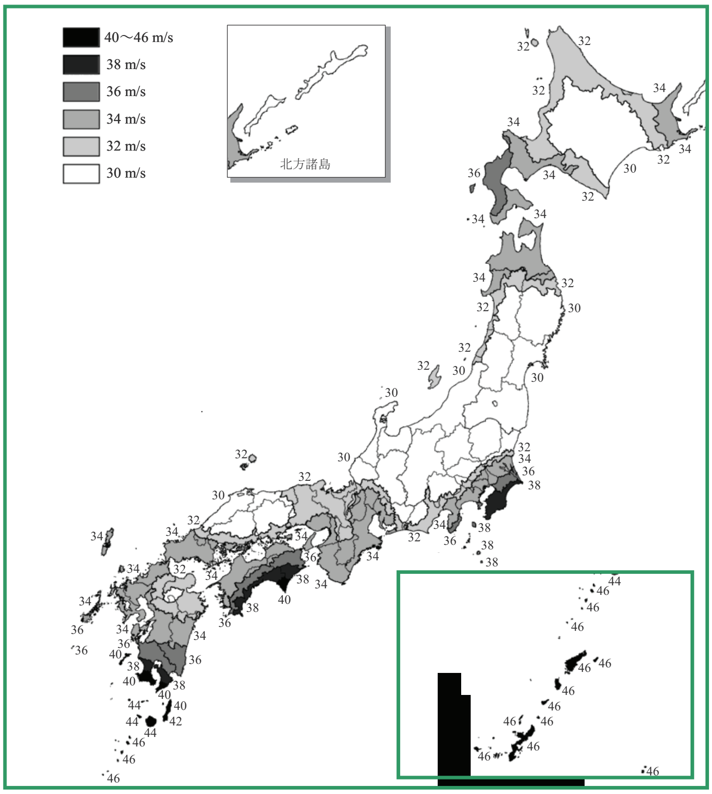
1

Design wind speed

2

$$U_h = E_{tV} E_{pV} V_0$$





IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Background 3

- Tropical and sub-tropical regions are called “mixed climate”, where the extreme wind speed is affected by both extratropical cyclone and tropical cyclone. (Gomes and Vickery 1978)
- Monte Carlo Simulation (MCS) of tropical cyclones are proposed and adopted in ASCE standard (2000) and AIJ recommendation (2004).
- In IEC61400-1 Annex E, a method based on Gumbel analysis and MCP (Measure, Correlate and Predict) method and Gumbel analysis is mentioned.

IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Estimation of extreme wind speed 4

V_n is the wind speed with the recurrence period of *N* years

↕

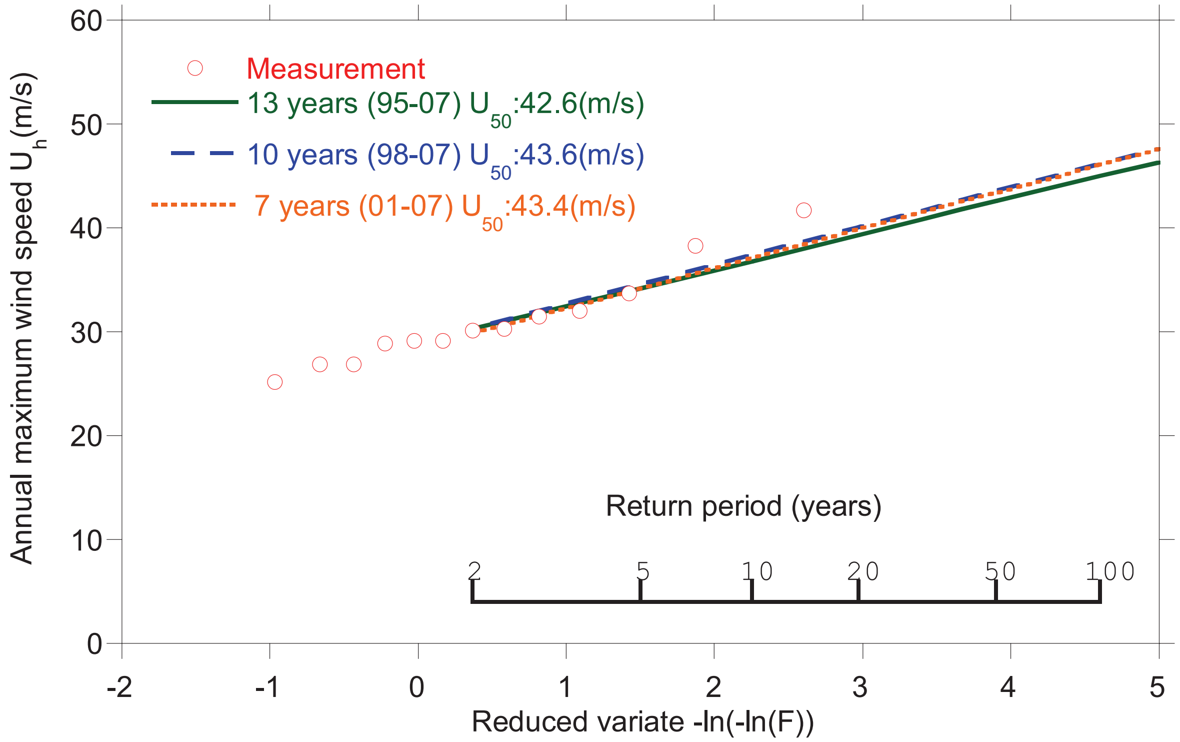
The probability that the annual maximum wind speed exceeds V_n is 1/*N.*

To estimate the probability distribution function *F* of annual mean wind speed *u*

IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Extreme wind speed by MCP

5



IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

MCS of tropical cyclone

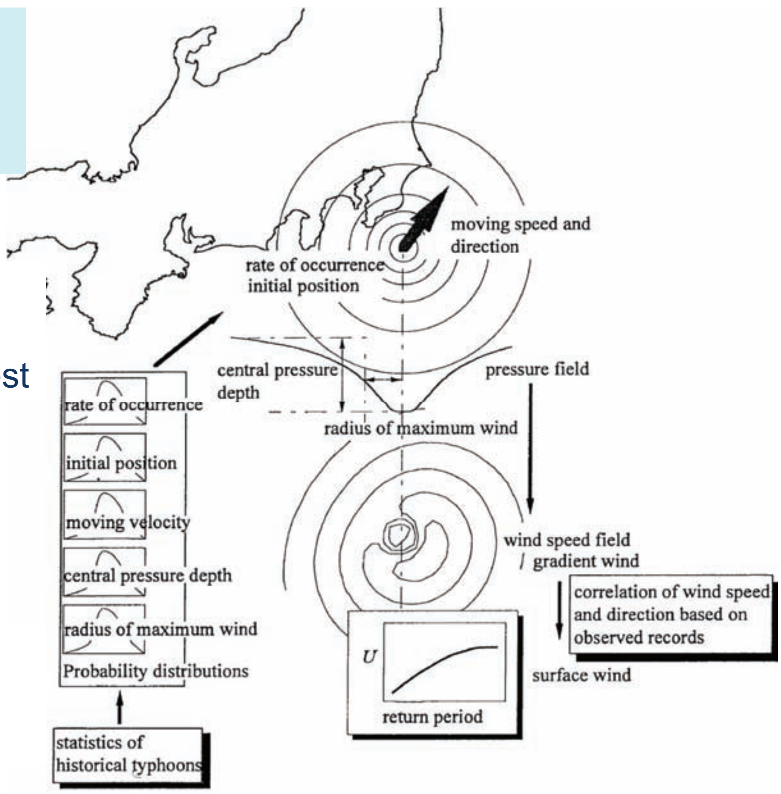
6

Model tropical cyclones with five parameters (Δp, R_m, C, θ, d_m)

PDFs of five parameters and annual occurrence rate is estimated for the site of interest

Generate virtual tropical cyclones for long term (10,000 years)

Annual maximum wind speed can be estimated for 10,000 years at the site of interest



IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

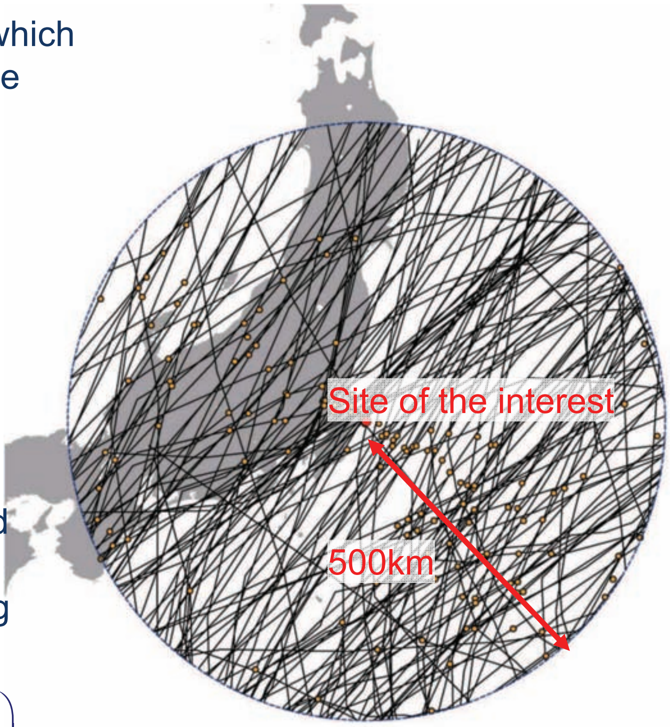
Parameters of tropical cyclones 7

Consider past tropical cyclones which passed within the simulation circle with the radius of 500km

The central pressure P_0, translation velocity C, approach direction θ, the minimum approach distance d_m and the annual occurrence rate λ are obtained from database.

The surrounding pressure P_∞ and the distance of maximum wind speed R_m are identified assuming Schloemer's model.

$$p(r) = p_C + (p_\infty - p_C)\exp\left(-\frac{R_m}{r}\right)$$



PDF of the parameters 8

Parameter	Probability density function	Model parameter
Central pressure difference Δp Radius of maximum wind R_m Translation velocity C	$a \times \frac{1}{\sqrt{2\pi}\sigma_{\ln x}} \exp\left[-\frac{1}{2}\left(\frac{\ln x - \mu_{\ln x}}{\sigma_{\ln x}}\right)^2\right] + (1-a) \times \frac{k}{c}\left(\frac{x}{c}\right)^{k-1} \exp\left[-\left(\frac{x}{c}\right)^k\right]$	μ: mean value σ: standard deviation k: weibull shape coefficient c: weibull scale coefficient a: mixing coefficient
Approach direction θ	$\frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{1}{2}\left(\frac{\theta - \mu}{\sigma}\right)^2\right]$	μ: mean value σ: standard deviation
Minimum approach distance d_m	$zd_{min}^2 - (z-2r)d_{min} - r$	z: model coefficient r: critical distance
Annual occurrence rate λ	$\frac{\lambda_m^\lambda \exp(-\lambda_m)}{\lambda!}$	λ_m: average annual occurrence rate

The correlations between the parameters 9

	Δp	R_m	C	θ	D_{min}
Δp	1.00	-0.20	0.08	0.00	0.37
R_m	-0.20	1.00	0.34	-0.01	-0.18
C	0.08	0.34	1.00	-0.23	-0.18
θ	0.00	-0.10	-0.23	1.00	-0.29
D_{min}	0.37	-0.18	-0.18	-0.29	1.00

Significant correlations can be seen between Δp and R_m, and between C and R_m.

IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Generation of tropical cyclones 10

The probability density functions of the parameters of tropical cyclones and the correlations among them must be satisfied simultaneously.

If all the parameters follow the normal distribution, classic orthogonal decomposition can be used.

$$\mathbf{x}^T = \{\ln(\Delta P),\ \ \ln(R_m),\ \ \ln(C),\ \ \theta,\ \ d_{\min}\}$$

Let $\mathbf{S}$ the variance-covariance matrix of $\mathbf{x}$.

Calculate eigenvalues λ_i and the eigenvectors ϕ_i of $\mathbf{S}$.

Generate vectors $\mathbf{z}$, the components of which satisfy normal distribution and no correlations between components.

calculate $\mathbf{x} = [\phi_i]^{-1}\mathbf{z}$ Then, the component of x satisfy normal distribution and the correlations

IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Modified orthogonal decomposition

11

- A little modification to classical orthogonal decomposition. (Ishihara et al., 2005)

$$\mathbf{x}^T = \{\ln(\Delta P),\ \ \ln(R_m),\ \ \ln(C),\ \ \theta,\ \ d_{\min}\}$$

Let $\mathbf{S}$ the variance-covariance matrix of $\mathbf{x}$.

Calculate eigenvalues λ_i and the eigenvectors ϕ_i of $\mathbf{S}$.

Generate vectors $\mathbf{z}$, the components of which satisfy mixed probability of normal and uniform distribution and no correlations between components.

calculate $\mathbf{x} = [\phi_i]^{-1}\mathbf{z}$

The component of $\mathbf{x}$ does satisfy the correlations but does not satisfy the distributions.

Modify the component of $\mathbf{x}$ so that they satisfy the distributions.

Correlations between parameters

12

Original

	Δp	R_m	C	θ	D_{min}
Δp	1.00	-0.20	0.08	0.00	0.37
R_m	-0.20	1.00	0.34	-0.10	-0.18
C	0.08	0.34	1.00	-0.23	-0.18
θ	0.00	-0.10	-0.23	1.00	-0.29
D_{min}	0.37	-0.18	-0.18	-0.29	1.00

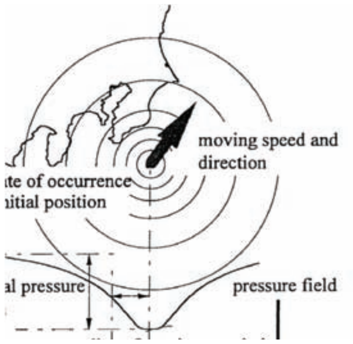
Simulated

	Δp	R_m	C	θ	D_{min}
Δp	1.00	-0.19	0.09	0.00	0.35
R_m	-0.19	1.00	0.31	-0.08	-0.18
C	0.09	0.31	1.00	-0.22	-0.17
θ	0.00	-0.08	-0.22	1.00	-0.30
D_{min}	0.35	-0.18	-0.17	-0.30	1.00

Pressure field and gradient wind field 13

Pressure field model (Shcloemer, 1954)

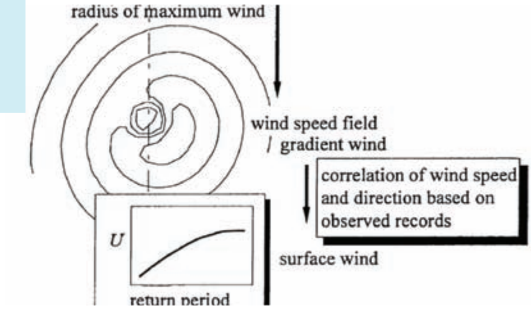
$$p(r) = p_C + \Delta p \exp\left(-\frac{R_m}{r}\right)$$



Gradient wind field

$$u_g(\vec{\mathbf{x}}) = \frac{-C\sin(\phi-\theta) - fr}{2} + \sqrt{\left(\frac{-C\sin(\phi-\theta) - fr}{2}\right)^2 + \frac{r}{\rho}\frac{\partial p(r)}{\partial r}}$$

$$\theta_g(\vec{\mathbf{x}}) = \pi - \phi$$



Wind speed and direction over flat terrain 14

Vertical profile of wind speed in the boundary layer of tropical cyclones (Ishihara et al., 1995).

$$u_{T,F}(H_h,t) = u_g\left(H_h/z_g\right)^{\alpha_u}, \quad u_g = \sqrt{v_{\theta g}^2 + v_{rg}^2}$$

$$\theta_{T,F}(H_h,t) = \theta_g + \theta_S\left(1.0 - 0.4\left(H_h/z_g\right)\right)^{1.1}, \ \theta_g = 0$$

$$\alpha_u = 0.27 + 0.09\log z_0 + 0.018\left(\log z_0\right)^2 + 0.0016\left(\log z_0\right)^3$$

$$z_g = 0.06\frac{v_{\theta g}}{f_\lambda}\left(\log R_{O\lambda}\right)^{-1.45}$$

$$\theta_S = \left(69 + 100\xi\right)\left(\log R_{O\lambda}\right)^{-1.13}$$

$$f_\lambda = \left(\frac{\partial v_{\theta g}}{\partial r} + \frac{v_{\theta g}}{r} + f\right)^{0.5}\left(2\frac{v_{\theta g}}{r} + f\right)^{0.5}$$

$$R_{O\lambda} = \frac{v_{\theta g}}{f_\lambda z_0}$$

$$\xi = \left(2\frac{v_{\theta g}}{r} + f\right)^{0.5} / \left(\frac{\partial v_{\theta g}}{\partial r} + \frac{v_{\theta g}}{r} + f\right)^{0.5}$$

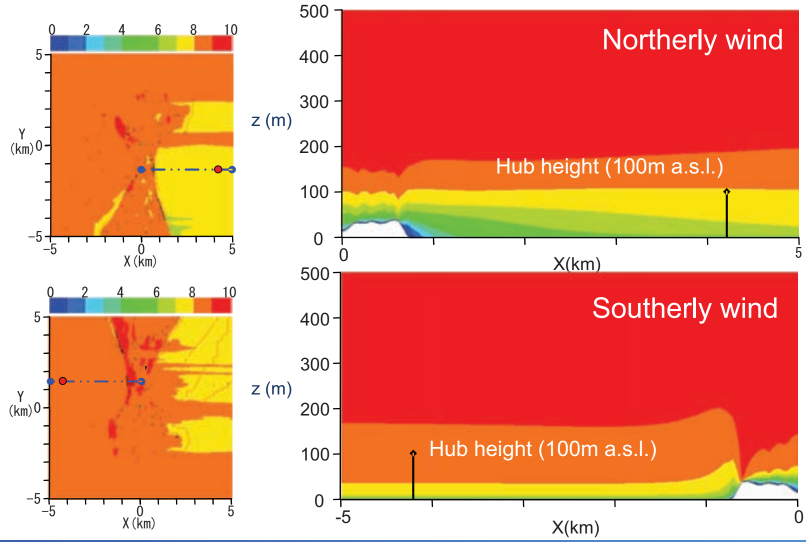
Local wind speed and direction

Wind at the site of interest is affected by local terrain

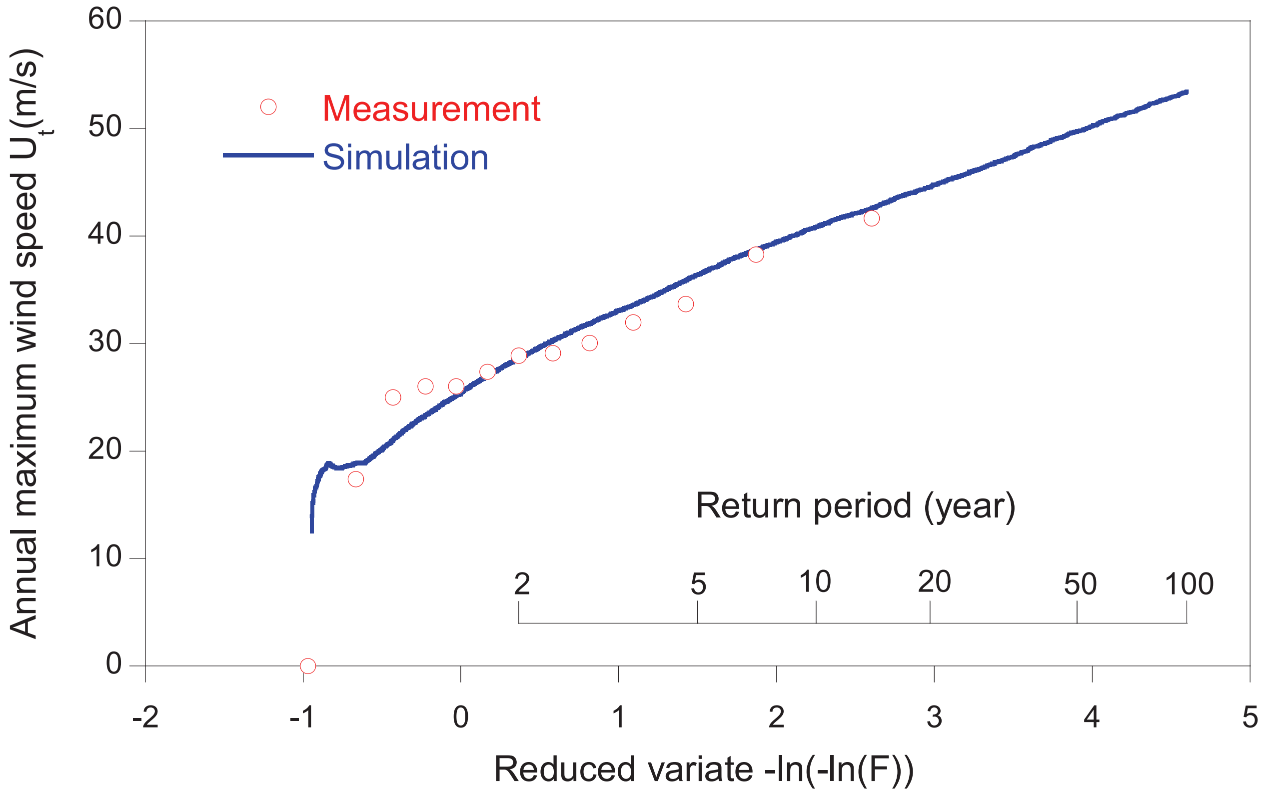
$$u_{T,R}\left(H_h,t\right)=C_{FR}\left(\theta_{T,F}\left(H_h,t\right)\right)\times u_{T,F}\left(H_h,t\right)$$

$$\theta_{T,R}\left(H_h,t\right)=D_{FR}(\theta_{T,F}(H_h,t))+\theta_{T,F}(H_h,t)$$

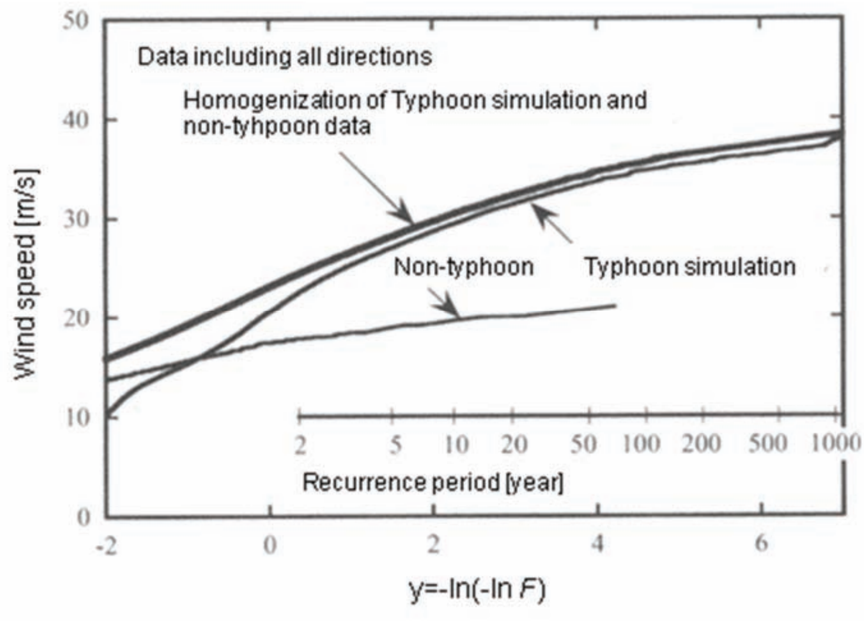
C_{FR} and D_{FR} can be calculated by CFD



Extreme wind speed (Tropical cyclone)



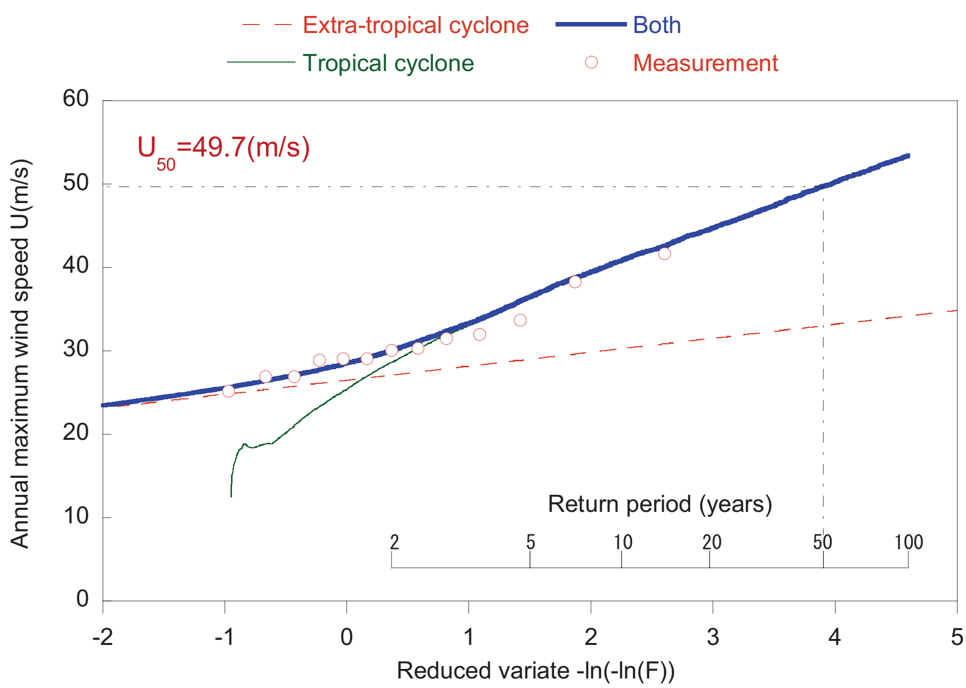
Extreme wind speed in mixed climate region 17



$$F^{\text{mixed}}(u) = 1 - \left[1 - F^{\text{extra-tropical}}(u)\right]\left[1 - F^{\text{tropical}}(u)\right]$$

IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

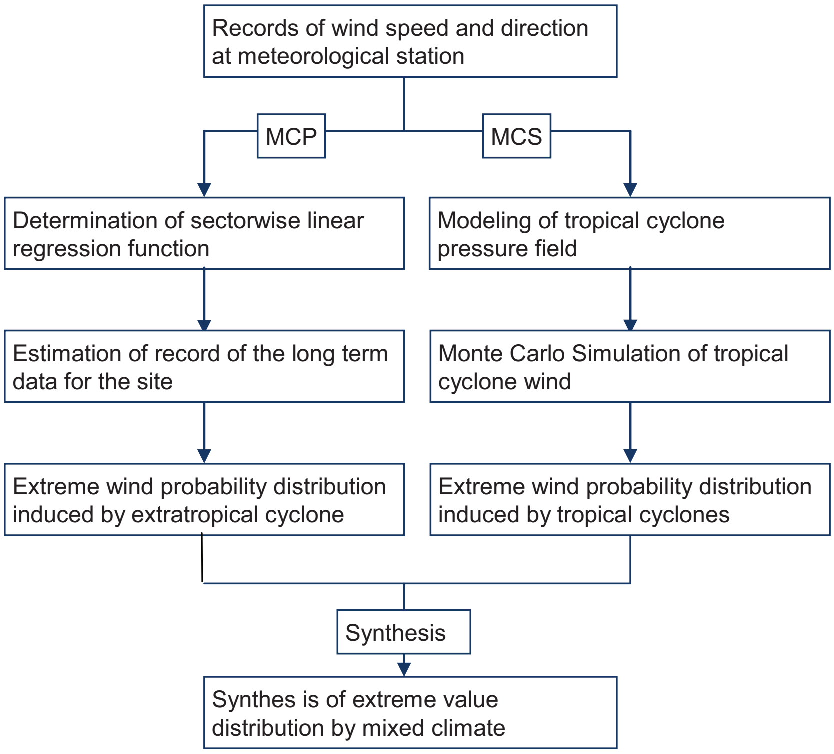
Example 18



IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Proposed method

19



IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Summary

20

- The method mentioned in IEC61400-1 (Gumbel analysis with MCP method) underestimates the extreme wind speed in mixed climate region.
- The MCS of tropical cyclones have been widely used in mixed climate regions and appropriately estimate the extreme wind speed.

IEA Wind Task 11, No.64, 14-15 December, 2010. Tokyo, Japan

Wind Turbine Loads in Simulated Stable and Neutral Boundary Layer Flow Fields

Jinkyoo Park (Master's student, University of Texas at Austin)
Sukanta Basu (Associate Professor, North Carolina State University)
Lance Manuel (Professor, University of Texas at Austin)

IEA R&D Wind Task XI - Topical Expert Meeting
Wind Conditions for Wind Turbine Design
Tokyo, Japan – December 14-15, 2010

Motivation & Objectives

Motivation

Flow fields associated with the Stable Boundary Layer (SBL) have some different characteristics than more conventional Neutral Boundary Layer (NBL) flow fields simulated in turbine loads computation

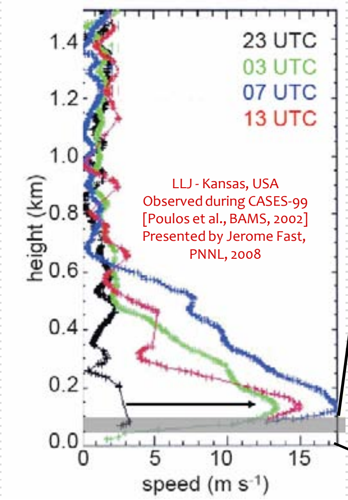
- sometimes, SBL fields are sometimes accompanied by Low-Level Jets (LLJs)
- SBL wind shear is different from NBL
- wind direction changes (wind turning) over the rotor plane in SBL fields

Objectives

- Generation of high-resolution four-dimensional inflow velocity fields for a range of atmospheric stability conditions that, to date, have not been systematically considered in wind turbine performance and design
- Comparison of simulated extreme loads and derived fatigue loads for a utility-scale turbine for the contrasting atmospheric flow fields

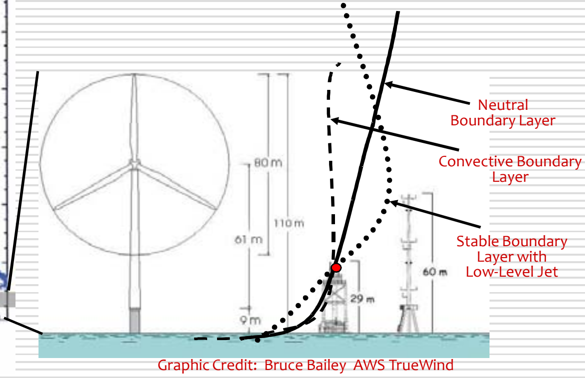
2/30

Why study the Stable Boundary Layer?



Low-level jets occur commonly at U.S. Great Plains sites as part of **stable atmospheric BL** flows

Loads in IEC 61400-1 only for Neutral BL



3/30

Outline

1. LES for the Stable Boundary Layer
2. Comparison of inflow characteristics
   SBL (LES-based), NBL (IEC/stochastic), and GPLLJ
3. Comparison of load statistics
   SBL (LES-based), NBL (IEC/stochastic), and GPLLJ
4. Influence of external parameters on inflow and turbine loads
   SBL (with LES) versus NBL (stochastic)
   SBL (with LES) versus GPLLJ (NREL code)

4/30

Inflow Simulation for Turbine Loads

Neutral (IEC Type)

- ❖ Wind profile
  logarithmic (or power law)
- ❖ Nominal wind speed shear
  α ~0.2
- ❖ Nominal wind directional shear
- ❖ Bottom-up boundary layer
- ❖Global scale intermittency absent

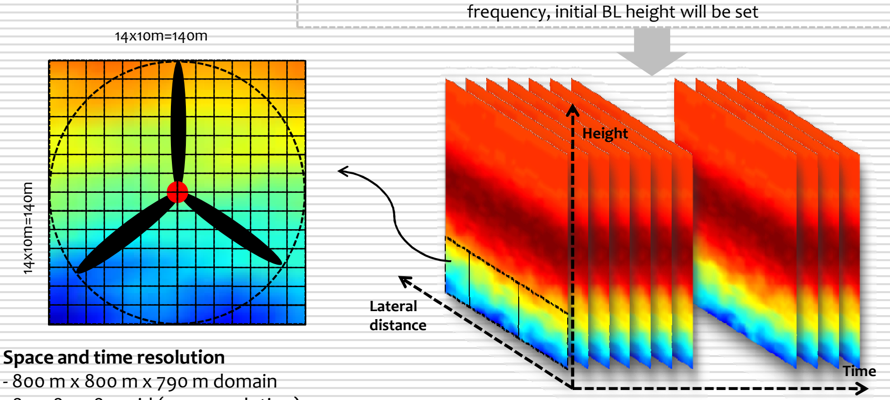
Stable (LLJ possibility)

- ❖ Wind profile
  jet- type
- ❖ Extreme wind speed shear
  shear exponent, α >>0.2
- ❖ Strong wind directional shear
- ❖ Bottom-up and upside-down
  boundary layers
- ❖ Global scale intermittency is often
  observed

5/30

LES – Computations with External Parameters

Geostrophic wind, cooling rate, roughness, inversion strength, Coriolis frequency, initial BL height will be set



Space and time resolution
- 800 m x 800 m x 790 m domain
- 80 x 80 x 80 grid (10 m resolution)
- Δt = 0.1 s → **output Δt'=0.4sec(2.5Hz)**
- duration = 12 hrs (i.e., 432,000 steps) → **output 108,000 steps**

6/30

LES – External Parameters

No.	Run Name	G (m/s)	CR (K/h)	z0 (m)	Hi (m)	N (K/m)	f (1/s)
1	G9C75Z3H200N3f10	9	0.75	0.03	200	3/1000	0.0001
2	G12C75Z3H200N3f10	12	0.75	0.03	200	3/1000	0.0001
3	G15C50Z3H200N3f10	15	0.5	0.03	200	3/1000	0.0001
4	G15C75Z1H200N3f10	15	0.75	0.01	200	3/1000	0.0001
5	G15C75Z3H200N10f10	15	0.75	0.03	200	10/1000	0.0001
6	G15C100Z3H200N3f10	15	1	0.03	200	3/1000	0.0001
7	G18C100Z3H200N3f10	18	1	0.03	200	3/1000	0.0001
8	G18C75Z3H200N3f10	18	0.75	0.03	200	3/1000	0.0001
9	G18C75Z3H200N10f10	18	0.75	0.03	200	10/1000	0.0001
10	G15C75Z3H200N3f10	15	0.75	0.03	200	3/1000	0.0001
11	G12C75Z1H200N3f10	12	0.75	0.01	200	3/1000	0.0001
12	G15C75Z3H200N3f08	15	0.75	0.03	200	3/1000	0.00008
13	G15C75Z3H200N3f12	15	0.75	0.03	200	3/1000	0.00012
14	G15C75Z10H200N3f10	15	0.75	0.1	200	3/1000	0.0001
15	G18C75Z1H200N3f10	18	0.75	0.01	200	3/1000	0.0001
16	G18C75Z10H200N3f10	18	0.75	0.1	200	3/1000	0.0001
17	G15C75Z1H200N3f12	15	0.75	0.01	200	3/1000	0.00012
18	G15C75Z3H200N10f08	15	0.75	0.03	200	10/1000	0.00008
19	G15C75Z3H200N10f12	15	0.75	0.03	200	10/1000	0.00012
20	G15C75Z10H200N3f12	15	0.75	0.1	200	3/1000	0.00012
21	G15C100Z10H200N3f08	15	0.1	0.01	200	3/1000	0.00008
22	G15C100Z10H200N3f12	15	1	0.01	200	3/1000	0.00012

⋮

G: Geostrophic wind

CR: Surface cooling rate

Z_o: Surface roughness

H_i: Initial height of BL

N: Inversion strength

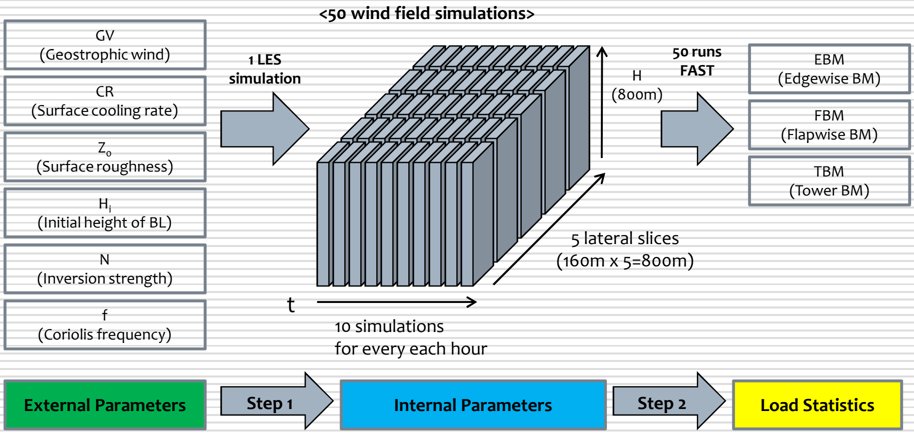
F: Coriolis frequency

Control Case

The effect of variation of external parameters on inflow characteristics and turbine loads is studied by changing external parameters and comparison with the control case

7/30

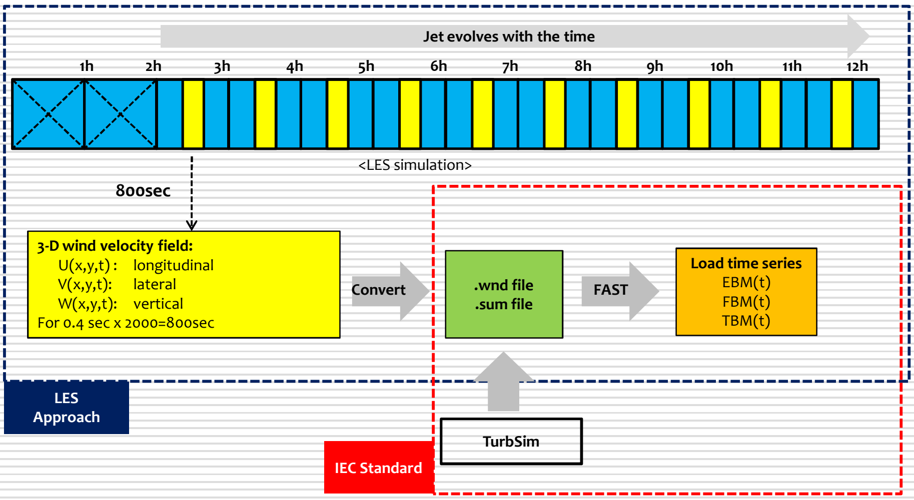
Effects of external parameters on wind fields and loads



Internal parameters evolve along with jet during the night;
thus, wind simulations every hour(excluding the first 2hours) will be analyzed for loads

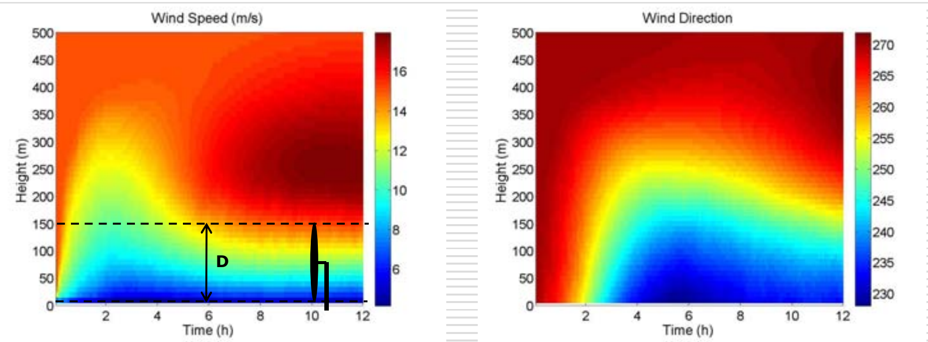
8/30

LES time series used for load calculation – What was done



9/30

LES Output



- Jet evolves with time changing its velocity and direction based on inertial oscillation in wind[1]:

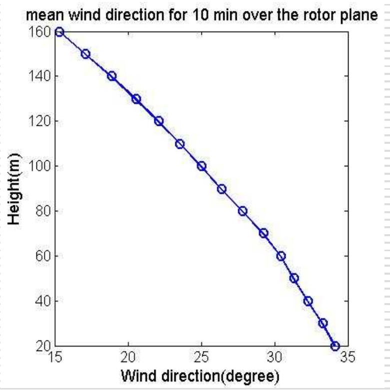
  $U = G + (V_0 - 0)\sin(ft) + (U_0 - G)\cos(ft),\ V = (V_0 - 0)\cos(ft) - (U_0 - G)\sin(ft)$

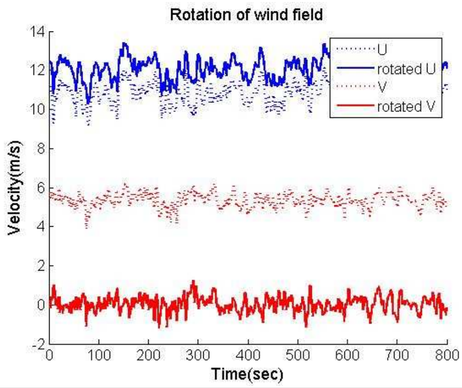
  (G: geostrophic wind speed, f: Coriolis frequency)
- Wind direction change → yaw error (need yaw control logic for loads computation)

[1]A Conceptual View on Inertial Oscillations and Nocturnal Low-Level Jets, van de Wiel, 2010

10/30

Rotation of wind field generated by LES





rotated wind component: $u' = u\cos\theta - v\sin\theta, \quad v' = u\cos\theta + v\sin\theta$

Find θ that makes lateral velocity at hub height equal zero.

Set $E[v'] = E[u]\cos\theta + E[v]\sin\theta = 0. \rightarrow \theta = -\tan^{-1}\left(\frac{E[v]}{E[u]}\right)$, ($\theta$: rotation angle)

11/30

Wind inflow comparison (LES-SBL vs IEC-NBL vs GPLLJ)

<Control Case>

Run Name	GV (m/s)	CR (K/h)	z0 (m)	Hi (m)	N (K/m)	f (1/s)
G15C75Z3H200N3f10	15	0.75	0.03	200	3/1000	0.0001

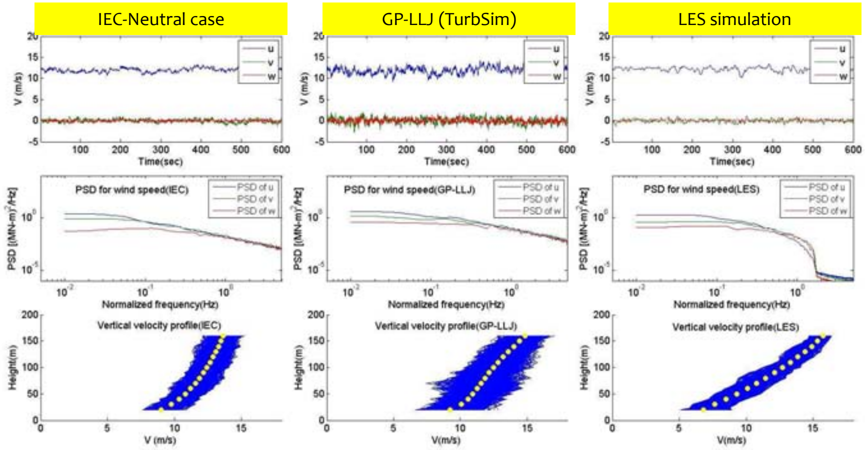
	IEC Neutral	GP-LLJ	LES
GV			$15m/s$
Jet height		$255m$	$255m$
Ri		0.14	0.14
V_h	$12.16m/s$	$12.16m/s$	$12.16m/s$
Z_0	0.03	0.03	0.03
TI	4.26%		4.26%
Vertical mean profile	Power law ($\alpha = 0.2$)	Jet profile	

*Final 10 minutes of wind simulation used for comparison

- From final 10 mins of LES wind field simulation, the resulting wind parameters (internal parameters) extracted were used to generate wind fields using TurbSim for the case of NBL (IEC) and for GPLLJ.
- Vertical wind profiles were set at default values in the TurbSim simulations (IEC: power law exponent = 0.2; GPLLJ: Jet profile).

12/30

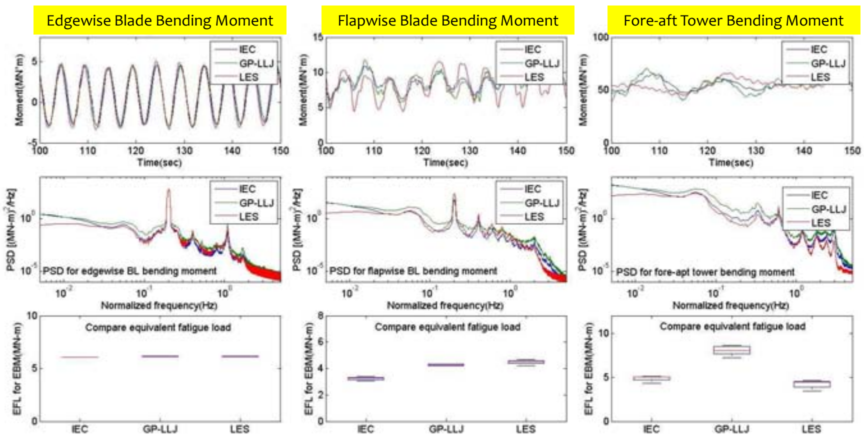
Wind inflow comparison (LES vs IEC vs GPLLJ)



• LES-generated wind fields show stronger shear than the other two cases
• Higher frequency turbulence energy is deficient in LES simulation due to time resolution (Δt=0.25 sec → Nyquist frequency = 1.25Hz).

13/30

Load comparison (LES vs IEC vs GPLLJ)



• Higher flapwise blade bending moment EFL with LES flows
→ higher shear causes greater fatigue damage in flapwise direction (mostly out of plane)
• GPLLJ flows have more turbulence energy at tower frequencies → higher tower EFL

14/30

Internal Parameters

- **V_h, hub-height 10-min mean longitudinal velocity:** An important parameter that influences output power as well as wind turbine loads
- **σ_U, hub-height standard deviation of longitudinal velocity:** A measure of turbulence which influences fatigue loads as well as extreme loads
- **α, wind shear power-law exponent:** A measure of the strength of the vertical shear. Higher wind shear might influence rotor loads
- **Ri, bulk Richardson number:** A measure that describes thermally produced turbulence relative to turbulence generated by vertical shear
- **H_{jet} , jet height :** Elevation above ground where the low-level jet occurs.

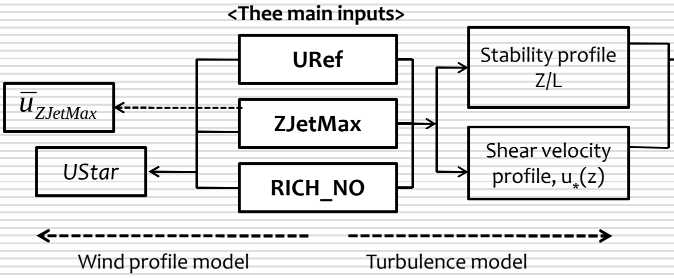
α	σ_U	V_h	Ri	H_{jet}

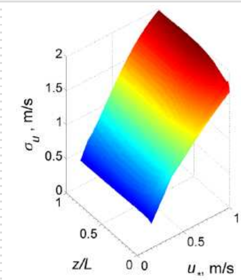
Used for NBL (IEC) Used for GPLLJ model

15/30

The GPLLJ Model (in TurbSim)

The Great Plains Low-Level Jet (GPLLJ) model is based on measurements from a 120-m tower and from an acoustic wind profiler collected during the Lamar Low-Level Jet Project in Southeastern Colorado.





The low-level jet wind speed profile is defined using Chebyshev polynomials:

$$\bar{u}(z) = \sum_{n=0}^{10} c_n \cdot T_n(z)$$

where z is elevation above ground, $\bar{u}$ is the mean speed, and $T_n(z)$ is the n^{th} order Chebyshev polynomial.

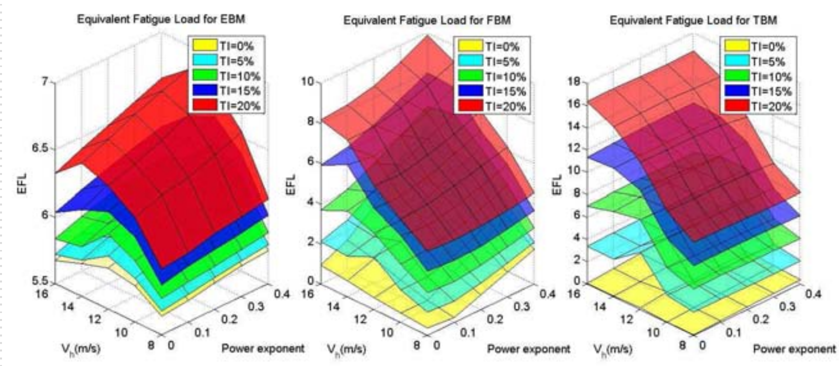
$$c_n = C_{1,n}\bar{u}_{ZJetMax} + C_{2,n}RICH\_NO + C_{3,n}UStar + C_{4,n}.$$

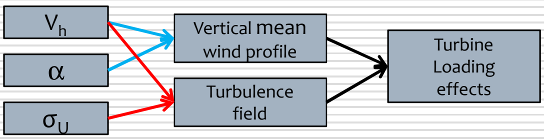
The coefficients, $C_{i,n}$ are determined by *ZJetMax*

Reference: TurbSim User Guide

16/30

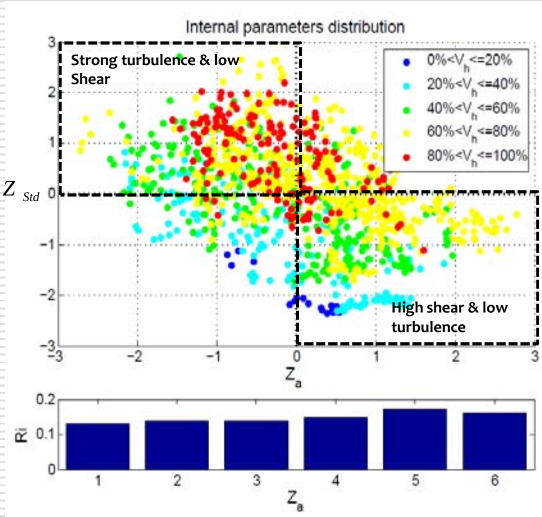
Influence of internal parameters on loads





- All three internal parameters, V_h, α and σ_U, have a direct influence on wind turbine loads.

LES-Based Internal Parameters

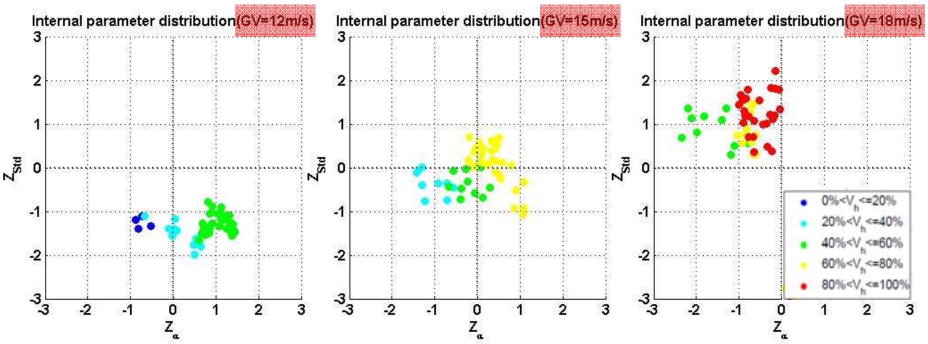


$$Z_{Std} = \frac{Std - m_{Std}}{\sigma_{Std}} = \frac{Std - 0.49}{0.16}$$

$$Z_a = \frac{a - m_a}{\sigma_a} = \frac{a - 0.37}{0.06}$$

1. LES-generated wind fields show much higher shear values (α up to 0.53 versus IEC neutral case which assumes α = 0.2)
2. Large proportion of LES-based internal parameters are with (i) strong turbulence and low shear; or (ii) high shear & low turbulence.
3. Large Richardson numbers are associated with high shear.

External parameters → Internal parameters

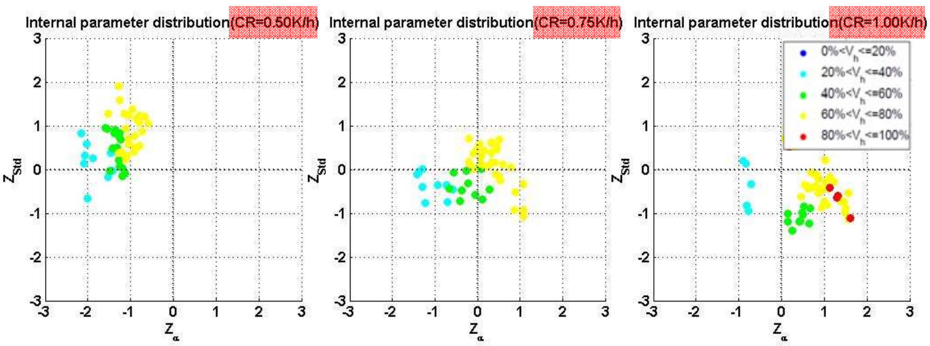


Run Name	G (m/s)	CR (K/h)	z0 (m)	Hi (m)	N (K/m)	f (1/s)
G12C75Z3H200N3f10	12	0.75	0.03	200	3/1000	0.0001
G15C75Z3H200N3f10	15	0.75	0.03	200	3/1000	0.0001
G18C75Z3H200N3f10	18	0.75	0.03	200	3/1000	0.0001

• As geostrophic wind speed increases, the level of turbulence increases while the vertical shear decreases due to competing influences of turbulence and shear

19/30

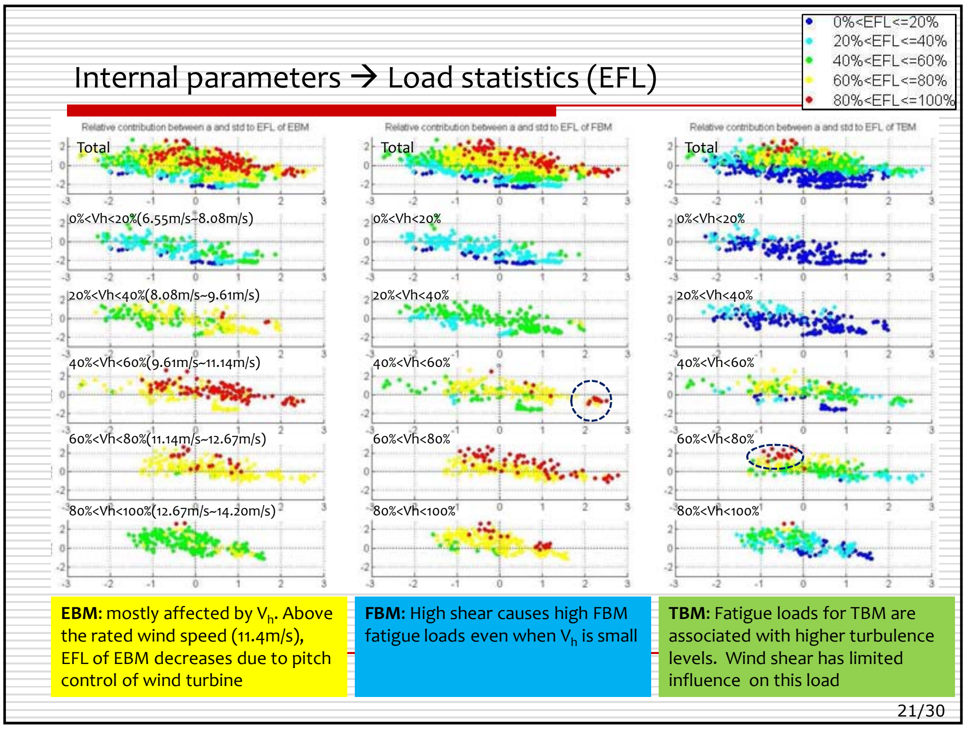
External parameters → Internal parameters



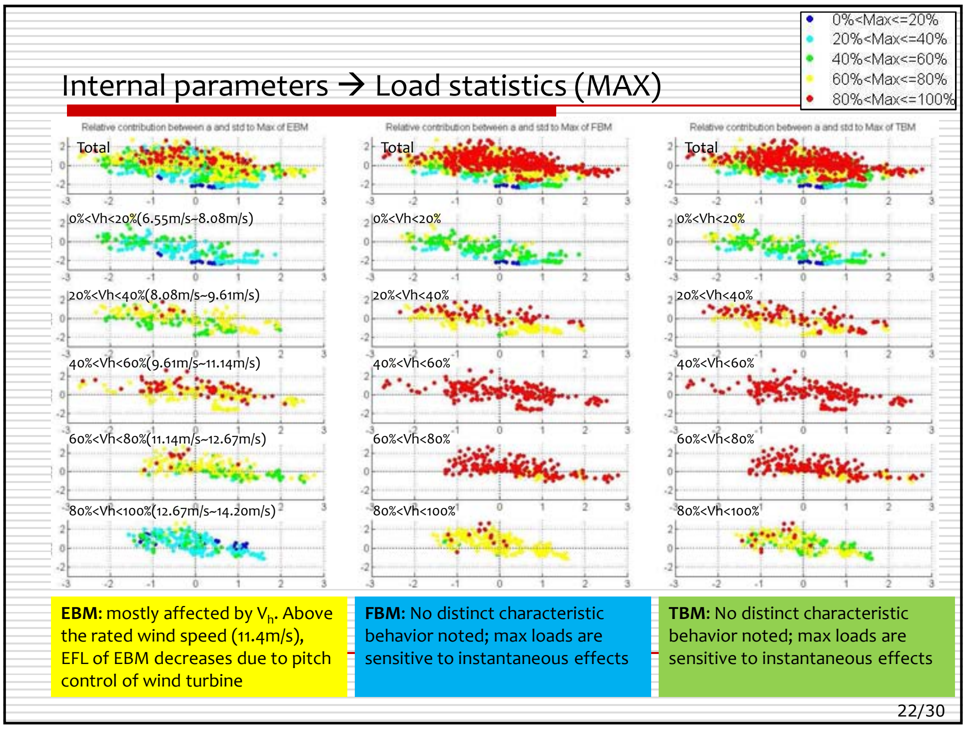
Run Name	G (m/s)	CR (K/h)	z0 (m)	Hi (m)	N (K/m)	f (1/s)
G15C50Z3H200N3f10	15	0.50	0.03	200	3/1000	0.0001
G15C75Z3H200N3f10	15	0.75	0.03	200	3/1000	0.0001
G15C100Z3H200N3f10	15	1.00	0.03	200	3/1000	0.0001

• As surface cooling rates increase, turbulence levels drop while vertical shear is enhanced due to the increased atmospheric stability

20/30

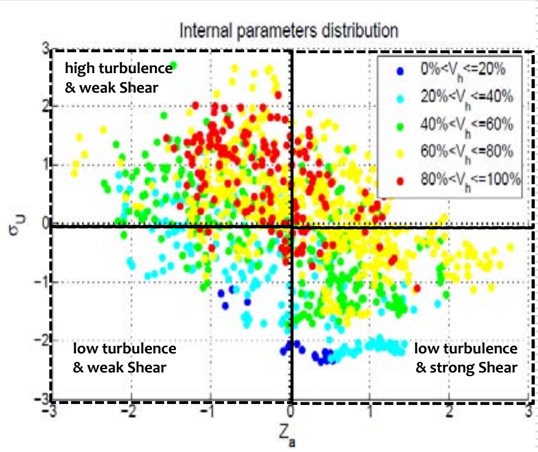


Internal parameters → Load statistics (EFL)
0%<EFL<=20%
20%<EFL<=40%
40%<EFL<=60%
60%<EFL<=80%
80%<EFL<=100%
Relative contribution between a and std to EFL of EBM
Relative contribution between a and std to EFL of FBM
Relative contribution between a and std to EFL of TBM
Total
0%<Vh<20%(6.55m/s~8.08m/s)
20%<Vh<40%(8.08m/s~9.61m/s)
40%<Vh<60%(9.61m/s~11.14m/s)
60%<Vh<80%(11.14m/s~12.67m/s)
80%<Vh<100%(12.67m/s~14.20m/s)
0%<Vh<20%
20%<Vh<40%
40%<Vh<60%
60%<Vh<80%
80%<Vh<100%
EBM: mostly affected by Vh. Above the rated wind speed (11.4m/s), EFL of EBM decreases due to pitch control of wind turbine
FBM: High shear causes high FBM fatigue loads even when Vh is small
TBM: Fatigue loads for TBM are associated with higher turbulence levels. Wind shear has limited influence on this load
21/30



Internal parameters → Load statistics (MAX)
0%<Max<=20%
20%<Max<=40%
40%<Max<=60%
60%<Max<=80%
80%<Max<=100%
Relative contribution between a and std to Max of EBM
Relative contribution between a and std to Max of FBM
Relative contribution between a and std to Max of TBM
Total
0%<Vh<20%(6.55m/s~8.08m/s)
20%<Vh<40%(8.08m/s~9.61m/s)
40%<Vh<60%(9.61m/s~11.14m/s)
60%<Vh<80%(11.14m/s~12.67m/s)
80%<Vh<100%(12.67m/s~14.20m/s)
0%<Vh<20%
20%<Vh<40%
40%<Vh<60%
60%<Vh<80%
80%<Vh<100%
EBM: mostly affected by Vh. Above the rated wind speed (11.4m/s), EFL of EBM decreases due to pitch control of wind turbine
FBM: No distinct characteristic behavior noted; max loads are sensitive to instantaneous effects
TBM: No distinct characteristic behavior noted; max loads are sensitive to instantaneous effects
22/30

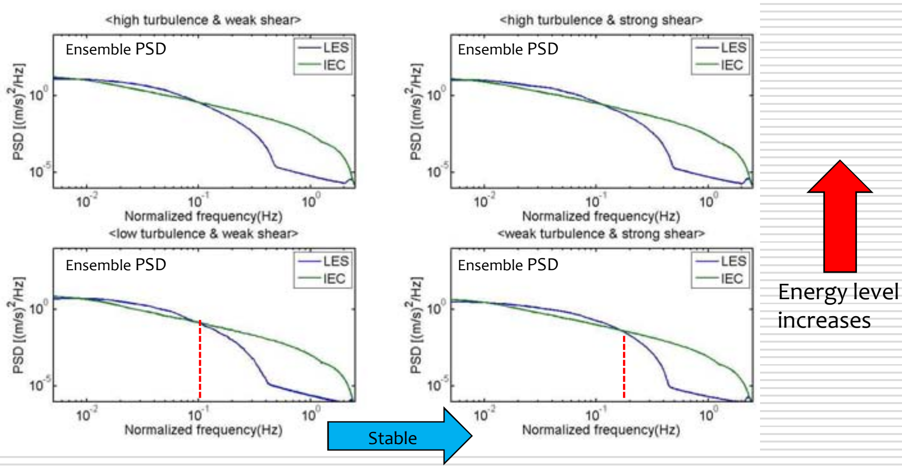
Comparison: LES vs IEC (Wind inflow)



- The 1100 combinations of internal parameters (V_h, α, σ_U) were extracted from 22 LES cases.
- These same combinations of internal parameters were used to generate wind fields using TurbSim IEC model (NBL).
- Wind inflow and load statistics were compared based on four different regimes to assess conditions that cause differences in loads

23/30

Comparison: LES vs IEC (Wind Inflow)

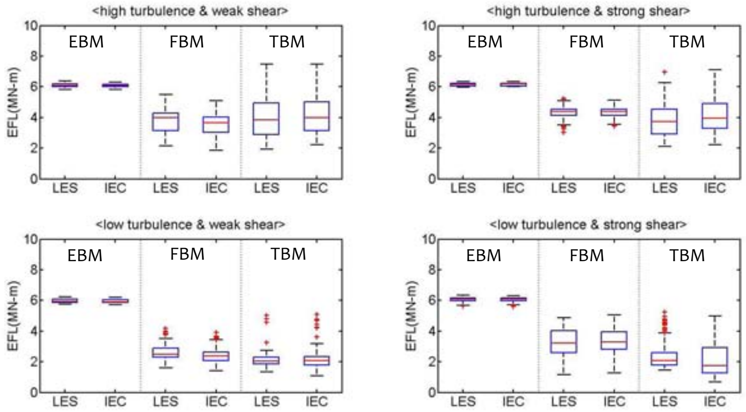


PSDs in IEC flows are not affected by stability

PSDs in LES flows show reduced high-frequency energy with increase in stability

24/30

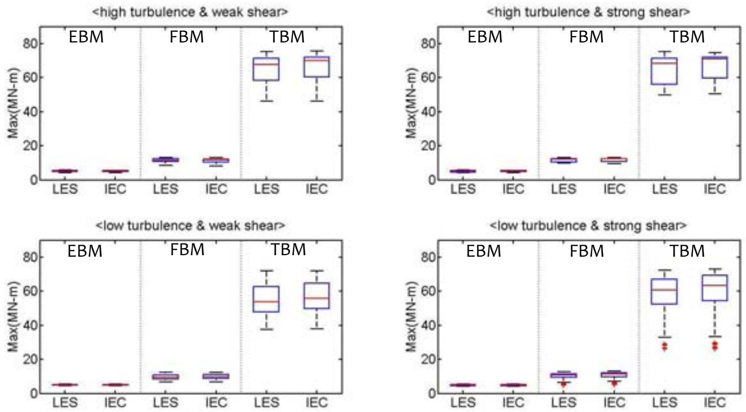
Comparison: LES vs IEC (Fatigue)



- Only small differences in EFLs between LES (SBL) and IEC (NBL) cases **if internal parameters are same**

25/30

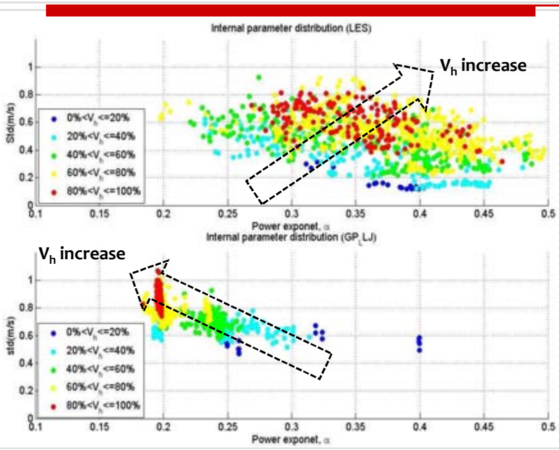
Comparison: LES vs IEC (Extremes)

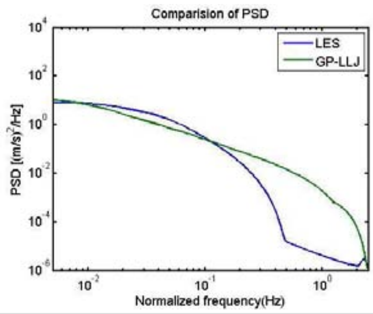


- Only small differences in load maxima between LES (SBL) and IEC (NBL) cases **if internal parameters are same**

26/30

Comparison: LES vs GPLLJ (Inflow)

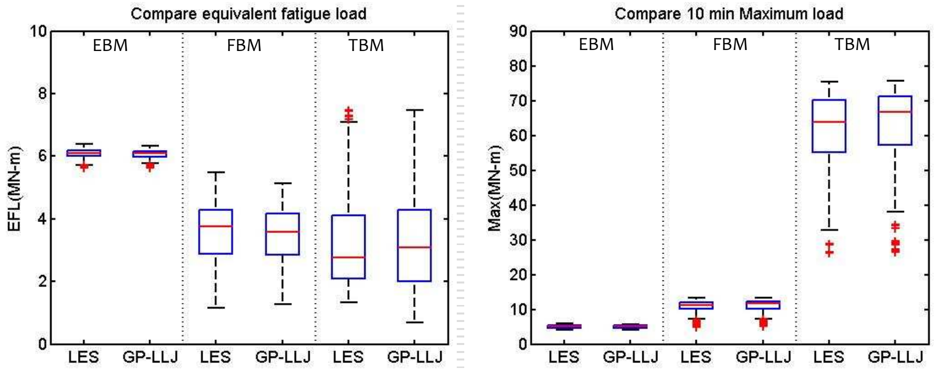




- Based on Ri, jet height, and V_h values extracted from LES, wind fields were generated using TurbSim's GPLLJ model and α, σ_U were computed
- The distribution of the GPLLJ internal parameters is very different compared to LES

27/30

Comparison: LES vs GPLLJ (Load Statistics)



- Only small differences noted in fatigue and extreme loads between LES and GPLLJ flows since to first order hub-height winds, V_h, are most important and these are same in LES as well as GPLLJ computations.

28/30

Concluding Remarks

- Large-Eddy Simulation (LES) was used to generate wind fields for the stable boundary layer (SBL) accompanied by strong wind shear.
- A parametric study of LES-based SBL flow fields for different "external" parameters including geostrophic wind, surface cooling rate, etc. was undertaken.
- Comparisons were made with flow fields from (i) stochastic simulation of the neutral boundary layer (NBL) where "internal" parameters such as wind shear, hub-height winds, and turbulence level were matched; and (ii) a data-based Great Plains Low-Level Jet (GPLLJ) procedure where hub-height winds, Richardson number, and jet height were matched.
- Fatigue and extreme loads on a 5MW wind turbine were compared for the SBL, NBL, and GPLLJ flow fields. Because of the selected matchings of the internal parameter sets, rotor and tower load levels were comparable.

29/30

Acknowledgments

- Sandia National Laboratories
  Contract Nos. 743358 and 919589 (PI: Manuel)
- National Science Foundation
  Grant Nos. CMS-0449128 (PI: Manuel), CBET-0967816 (PIs: Manuel, Basu)
- Texas Higher Education Coordinating Board
  Norman Hackerman Advanced Research Program
  Award No. 003658-0100-2007 (PIs: Manuel, Basu)

30/30

Summary of IEA RD&D Wind – 64th Topical Expert Meeting

Félix Avia, Lance Manuel

a) Participants

A total of 24 persons registered for this meeting. They represented the following countries: Germany, Japan, Sweden, and the USA. Experts from China were invited to participate in the meeting (actually China has already joined Task 11).

The participants represented a great variety of stakeholders related to the topic. Those were: research organizations, universities and consultants.

A total of 14 presentations were given:

1. **Presentation of Introductory Note**
   Dr. Tetsuya Kogaki. (AIST)

2. **Statistical analysis of wind turbine failures. Marketability of new wind turbine classes**
   Hikaru Matsumiya, HIKARUWIND Lab. Ltd. JAPAN

3. **Turbulence characteristics in domestic sites in relation to IEC-61400 NTM model**
   Sannosuke Tanigaki Wind Energy Corporation. JAPAN

4. **Experimental study of wake effects for complex terrain - Advanced simulation techniques of tropical cyclones, complex terrain and wake effects**
   Junsuke Murata. Mie University. JAPAN

5. **Simulation of Thunderstorm downburst inflow fields and their influence on wind turbine loads**
   Lance Manuel. University of Texas at Austin. USA

6. **Numerical simulation of typhoon winds with a mesoscale model**
   Teruo Ohsawa. Kobe University. JAPAN

7. **Analysis of SODAR Measurements over Complex Terrain in JAPAN.**
   Hiroshi Kubo, ITOCHU Techno-Solutions Corporation. JAPAN

8. **Impact of severe wind conditions for wind turbine design**
   Hiroshi Imamura. WEIT. JAPAN

9. **CFD simulations of wake effect in large wind farms**
   Stefan Ivanell. Gotland University. SWEDEN

10 Brief Introduction of China Extreme Wind Conditions Survey and research
Yu Zhang, China General Certification Center

11 Modelling turbulent typhoon time series
Michael Schmidt and Tanja Muecke. Univ. of Oldenburg. For Wind. GERMANY

12. Typhoon protection system for wind turbines
Niels Kjaer Launtsen and Morten Sloth. VESTAS. Denmark

13. Estimation of Extreme Wind Speed by using Monte Carlo Simulation of Tropical Cyclone
Atsushi Yamaguchi. University of Tokyo. JAPAN

14. Wind Turbine Loads in Simulated Stable and Neutral Boundary Later Flow Fields
Lance Manuel. University of Texas at Austin. USA

b) Discussion

Following the two days of presentations the floor was opened and a general discussion took place. A number of different topics were handled. In particular, the following topics were discussed:

- Definition of Extreme Conditions: Typhoons, Thunderstorms Downburst, etc.
- Data base of Extreme Conditions
- Wind Data Base for comparative analysis of IEC 61400-1 Normal Turbulence Model
- Increase cooperation between measurement and simulation work

Definition of Extreme Conditions: Typhoons, Thunderstorms Downburst, etc.

Codes and standards for severe wind conditions caused by tropical cyclones and complex terrain will be needed for wind turbine design in order to expand the wind energy market, and in order to secure reliability and safety of wind turbine generation systems.

A niche market already exists in very windy areas with extreme conditions: Very Complex Terrain areas, Typhoons areas, Thunderstorm Downburst areas, etc. For the development of this market, it is important to have WT Technology especially designed for such extreme conditions as we begin to gain a better understanding of these conditions. This is one of the targets of the NEDO research project: to develop Technology toward highly safe and reliable wind turbine generation systems, even in severe wind conditions such as typhoon and highly complex flow. To address these urgent subjects, wind condition models for complex terrain and for Typhoons (Hurricanes) will be developed in this NEDO project (H. Imamura).

The wind conditions associated with tropical cyclones, complex terrain and wakes are included in the agenda for revision of IEC 61400-1. However, to date, severe wind conditions have not been fully taken into account in design, since they are still at the R&D stage.

Discussing and sharing information on unclear wind conditions is therefore of great importance, since it is expected to deliver safer and more reliable next-generation wind turbine designs.

The definition of extreme storms was the first point discussed. The second issue discussed related to the definition of specific extreme condition classes in addition to those already included in the IEC standard.

There are already existing definitions of extreme transient events intended to describe characteristics such as are seen in thunderstorms, but more work is needed to verify whether the existing load cases in the standards adequately describe wind velocity fields associated with thunderstorm downbursts and other transient events.

This action should be carried out under the umbrella of the IEA Wind Implement Agreement in coordination with the IEC working groups.

The possibility to launch a new IEA Wind Task was discussed, but no decision was adopted during the meeting.

Data base of extreme storms

At the present time, there are large number of wind data being collected worldwide, including measurements in very complex terrain, typhoons areas and high turbulent intensity areas. However, to create an open Wind Data Base (WDB) is a very difficult task, due to confidentiality reasons that make it very difficult to have access to any existing data.

The National R&D Japanese project “Research and Development of Next-generation Wind Power Generation Technology/Research and development of basic and applied technologies (FY2008-2012)”, has wind speed data measured at a total of 418 sites in Japan

China has a new wind resource and condition survey program with more than 400 masts with 70 m height and 70 masts with 100 m height. Unfortunately, the data will not be public available, but the result of the analysis of the data will provide useful information.

One of the options suggested is to try to collect wind data from sites without information of the location of the site, to avoid confidentiality problems. Another option is to aggregate any data available and report it in summary form such as with joint and/or marginal probability histograms for key wind-related random variables. Such an approach would protect the identity of the sites used as well as allow the holder of the raw data to preserve their advantage of having collected the data.

Another option suggested was to try to find available wind data from public institutions (Meteorological Institutes, Airports, etc).

The possibility to launch a new IEA Wind Task to create an open WDB was discussed, but no decision was adopted during the meeting.

Specific Wind Data Base for comparative analysis of IEC 61400-1 Normal Turbulence Model

According to the information presented during the meeting, it is clear that the Normal Turbulence Model (NTM) included in IEC 61400-1 (defining three levels of turbulence intensity (TI), A=16%, B=14% and C=12%), underestimates TI values calculated for several places using measured data, mainly in complex terrain sites.

From the National R&D Japanese project "Research and Development of Next-generation Wind Power Generation Technology/Research and development of basic and applied technologies (FY2008-2012)", using measured wind speed data at **259 sites** in Japan, the turbulence intensity at 25 – 50% of the measurement sites exceeds category A turbulence intensity specified in the current edition of IEC 61400-1 Ed.3.

There is not sufficient information available on the process followed in the development of the NTM included in the IEC 61400-1 standard, but there was a general consensus among the participants that a review of the model is required.

The creation of a Wind Data Base (WDB) including wind data from different sites around the world would be very useful to perform needed analyses to try to verify the acceptability of the current NTM definition or to define new NTM coefficients, especially for complex terrain areas and/or specific class S sites.

The possibility to create a working group for comparative analysis of the NTM coefficients was discussed, but no decision was adopted during the meeting.

Increase cooperation between measurement and simulation work

Results were presented showing discrepancies between measured data and simulated data of typhoon winds. In order to improve the existing simulation models, more validation exercises are required.

One of the first constraints, as was already stated in previous paragraphs, is the lack of valuable measured data to perform these studies.

Another crucial point is the necessity to harmonise the measurements process of the wind conditions. Uncertainty in wind speed measurements contributes to the overall uncertainty. By adopting best practices in the design, selection, calibration, deployment and use of anemometry, uncertainty can be minimised.

There is no clear guidance on the best practice in the use of anemometry for measurement of extreme wind conditions. There are various types of anemometer on the market. Some are highly responsive and can be used for defining the detailed turbulence structure of the wind. The most commonly used type of instrument is undoubtedly the three-cup anemometer. Other types of instruments are available and can be more appropriate in specific applications.

The necessity for harmonization of the methodologies used to analyse measured wind data was also discussed. This action will allow performing more useful comparative studies of the results obtained, without the necessity of sharing the WDB used for the studies.

The possibility to organize comparative studies of analysis of extreme wind conditions between several institutions using similar data will help in the future to harmonise these methodologies and procedures.

c) Future actions under the umbrella of IEA Wind

During the discussions, several actions were identified as crucial ones to be carried out to improve existing knowledge in reference to the Wind Conditions for WT design.

These actions were discussed as was the possibility to launch a new Task under the umbrella of the IEA Wind Implement Agreement, and in coordination with IEC working groups. However, no decision was adopted during the meeting in this direction.

A general agreement among the participants was reached to arrange a new TEM in this specific subject in 2013 in order to exchange knowledge generated as the output of already existing research actions.

Participants List - WIND CONDITIONS FOR WIND TURBINE DESIGN

The University of Tokyo (Building 18, Komaba I Campus) . December 14th -15th, 2010

	Name	Last Name	Job Center	Country	E-mail
1	**Felix**	**Avia**	OA of IEA Wind Task 11 - CENER	SPAIN	favia@cener.com
2	**Michael**	**Schmidt**	ForWind, University of Oldenburg	GERMANY	michael.schmidt@forwind.de
3	**Tanja**	**Mücke**	ForWind, University of Oldenburg	GERMANY	tanja.muecke@uni-oldenburg.de
4	**Jinhua**	**Hu**	Goldwind Science	CHINA	hujinhua@golwind.de
5	**Yu**	**Zhang**	China General Certification Center	CHINA	chenlj@cgc.org.cn
6	**Leije**	**Chen**	China General Certification Center	CHINA	zhangyu@cgc.org.cn
7	**Stefan**	**Ivanell**	Gotland university	SWEDEN	stefan.ivanell@hgo.se
8	**Manuel**	**Lance**	University of Texas at Austin	USA	lmanuel@mail.utexas.edu
9	**Niels**	**Lauritsen**	Vestas Wind System A/S	DENMARK	nkl@vestas.com
10	**Morten**	**Sloth**	Vestas Wind System A/S	DENMARK	mosl@vestas.com
11	**Jonathan**	**Carboon**	Vestas Asia Pacific	DENMARK	jocab@vestas.com
12	**Junsuke**	**Murata**	Mie University	JAPAN	murata@mach.mie-u.ac.jp
13	**Hikaru**	**Matsumiya**	HIKARUWIND.LAB. Ltd	JAPAN	h-matsumiya@aist.go.jp
14	**Teruo**	**Ohsawa**	Kobe University	JAPAN	ohsawa@port.kobe-u.ac.jp
15	**Hiroshi**	**Kubo**	ITOCHU Techno-Solutions	JAPAN	hiroshi.kuboa@ctc-g.co.jp
16	**Sannosuke**	**Tanigaki**	Wind Energy Corporation	JAPAN	tngk@pop16.odn.ne.jp
17	**Atsushi**	**Yamaguchi**	The University of Tokyo	JAPAN	atshushi@bridge.t.u-tokyo.ac.jp
18	**Makoto**	**Lida**	The University of Tokyo	JAPAN	iida@cfdl.t.u-tokyo.ac.jp
19	**Chuichi**	**Arakawa**	The University of Tokyo	JAPAN	arakawa@cfdl.t.u-tokyo.ac.jp
20	**Hiroshi**	**Imamura**	Wind Energy Corporation	JAPAN	imamura@windenergy.co.jp
21	**Yoshishori**	**Ueda**	Wind Energy Corporation	JAPAN	y_ueda@mhi.co.jp
22	**Tetsuya**	**Kogaki**	AIST	JAPAN	kogaki.t@aist.go.jp
23	**Yasuyuki**	**Oguro**	JEMA	JAPAN	yasuyuki_oguro@jema-net.or.jp
24	**Kazuo**	**Shibata**	JEMA	JAPAN	kazuo_shibata@jema-net.or.jp
25	**Mina**	**Nakae**	JEMA	JAPAN	mina_nakae@jema-net.or.jp
26	**Katsushiko**	**Kadoguchi**	AIST	JAPAN	k.kadoguchi@aist.go.jp

The International Energy Agency Implementing Agreement for
Co-operation in the Research, Development, and Deployment of Wind Energy Systems