DEVELOPMENT OF A TOOL FOR OFFSHORE WIND RESOURCE ASSESSMENT FOR WIND INDUSTRY

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Wind resource assessment

1. Wind monitoring

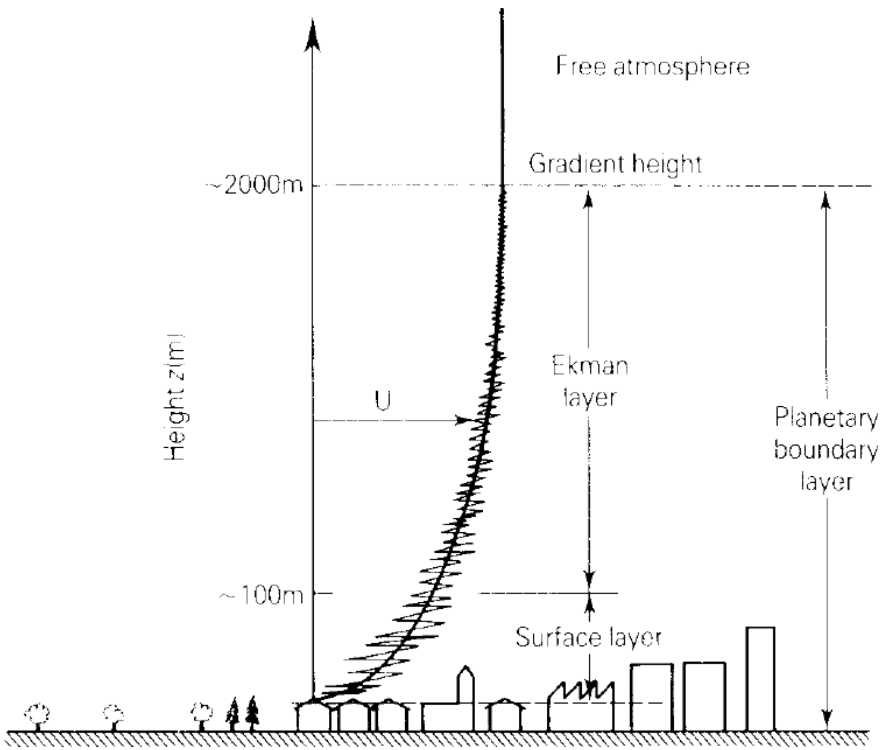
Date	Time	V80m	V40m	Dir80m	Dir40m
01/01/2007	00:00:00	9.22	8.55	221	225
01/01/2007	00:10:00	9.27	8.24	219	228
01/01/2007	00:20:00	8.6	7.59	217	229
01/01/2007	00:30:00	9.29	8.14	215	231
01/01/2007	00:40:00	9.65	8.69	219	226
01/01/2007	00:50:00	9.96	9.12	221	225
01/01/2007	01:00:00	8.72	7.88	221	226
01/01/2007	01:10:00	9.41	8.65	215	232
……	……	……	………	……..	………..
31/12/2007	23:10:00	1.76	1.33	89	37
31/12/2007	23:20:00	2.05	1.86	96	350
31/12/2007	23:30:00	2.17	1.57	101	346
31/12/2007	23:40:00	1.95	1.64	96	346
31/12/2007	23:50:00	1.9	1.59	96	346

Around 52,500 in-situ measurements at 2 to 5 different heights per year

Source: DNV GL

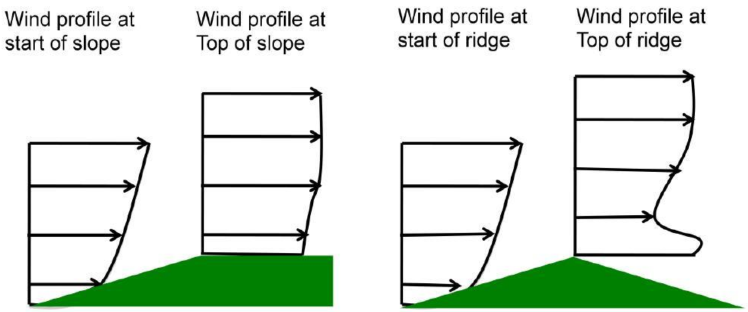
Wind resource assessment

2. Hub height resource estimation



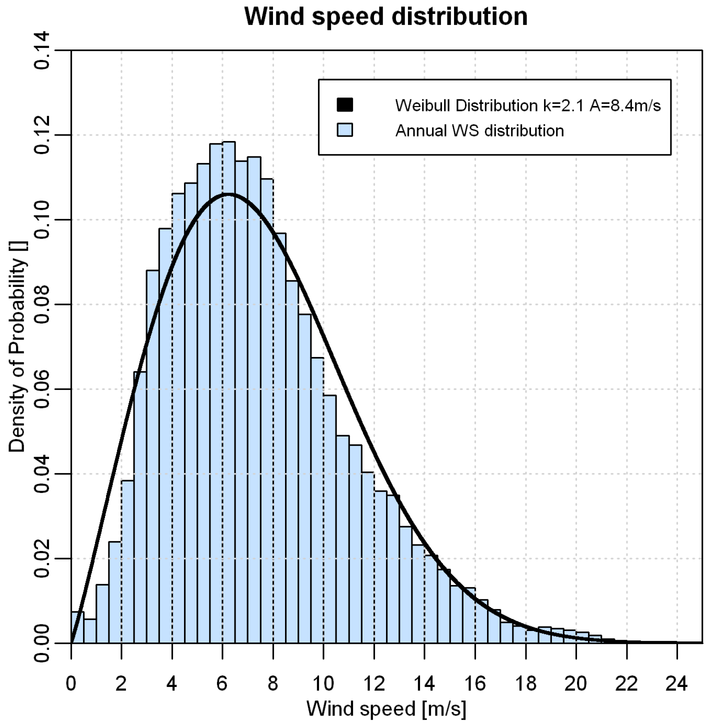
$$U(z) = U(z_r)\left[\frac{\ln(z/z_0)}{\ln(z_r/z_0)}\right]$$

Log law for neutral stability

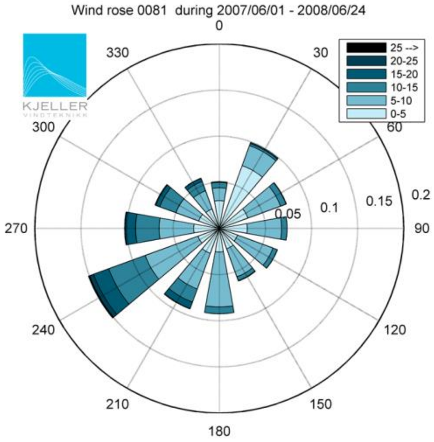


Wind resource assessment

3. Wind resource characterisation



$$P(U) = \left(\frac{k}{C}\right)\left(\frac{U}{C}\right)^{k-1} \exp\left[-\left(\frac{U}{C}\right)^{k}\right]$$



Source: Kjeller Vinderteknik

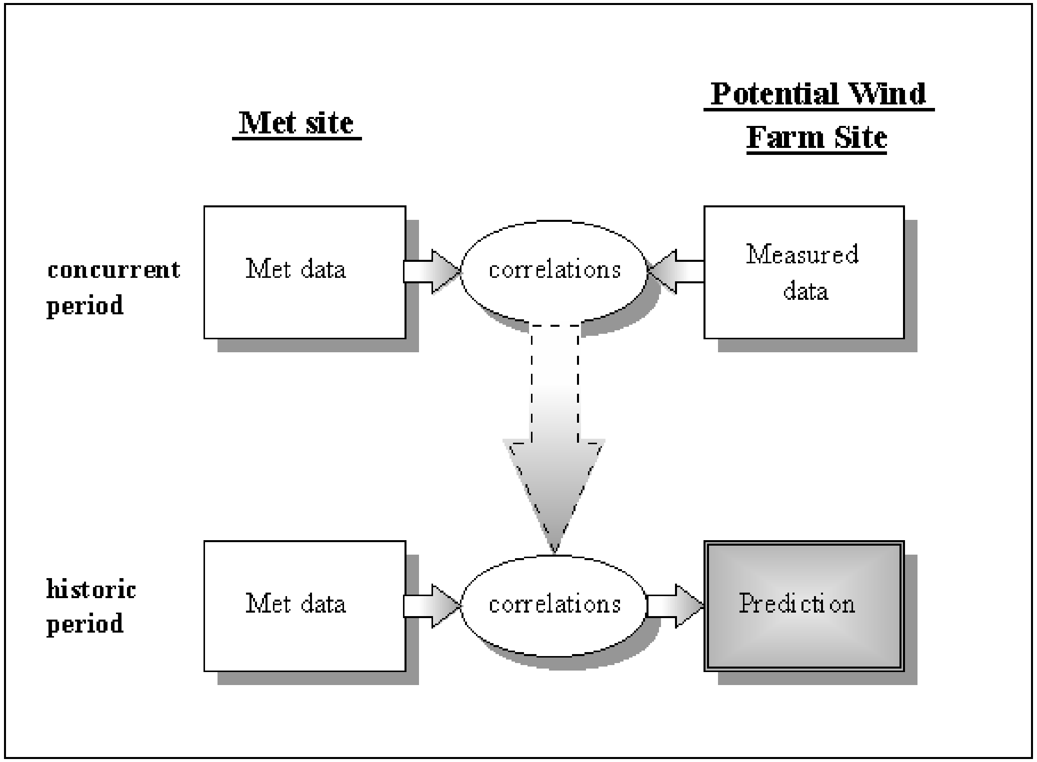
Don't forget temporal variation:

- Inter-annual
- Seasonal variation
- Diurnal variation
- Short-term (gust, turbulence)

Wind resource assessment

4. Climate adjustment process

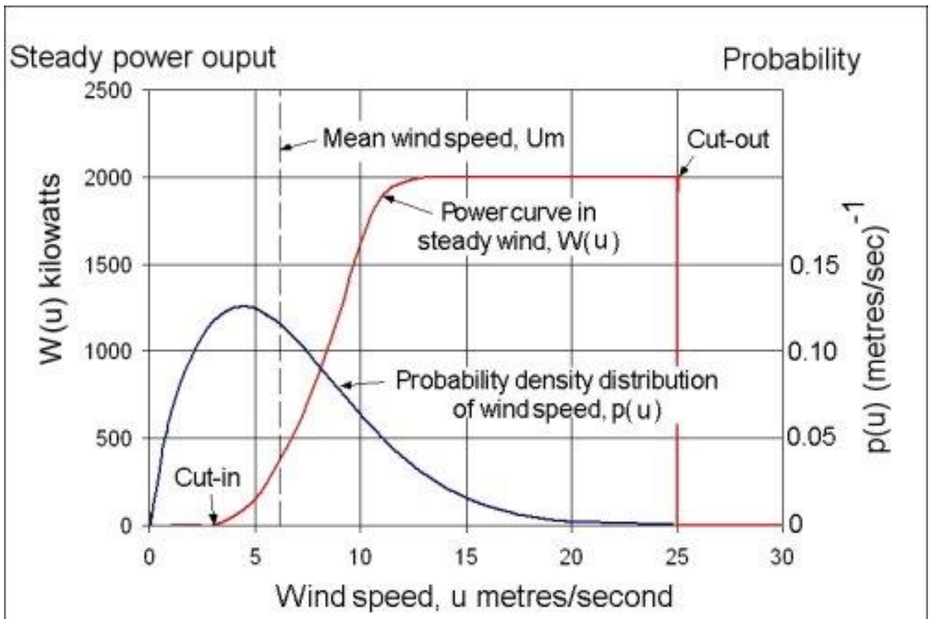
Assumption:
Wind resource is going to be similar to the past



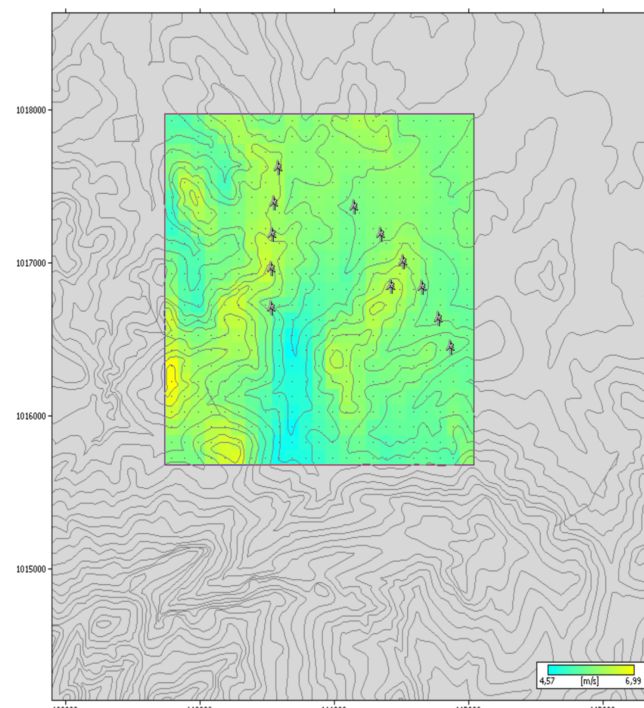
MCP process to reduce uncertainty

Wind resource assessment

6. Wind energy yield and micro-sitting



Steady wind power curve and wind speed probability density



Onshore micrositting by WAsP

Software design

1. Database
   - 1st block is to transform and insert data from datasets to database tables
   - Database composed by 1200 tables, one for each UTM square.
2. Addition of datasets from in-situ measurements
   - Optional
   - Offshore met masts or LIDAR's.
3. Filtering data
   - Rain rate, time zone, satellites to work with, etc.

I. Vertical wind extrapolation

Satellite hub height resource estimation

$$U(z) = \frac{U_*}{k}\left[ln(z/z_0) + \Psi_s(z/L_s)\right] \qquad z \gg z_0$$

Rewritten equation

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - \Psi_m\right]$$

Neutral winds at 10 m over the sea

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right)\right]$$

2 measurements at
different heights required

$$U(z) = U(z_r)\left[\frac{ln(z/z_0)}{ln(z_r/z_0)}\right]$$

I. Vertical wind extrapolation

1st methodology – Neutral stability

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right)\right]$$

+

$$z_0 = \alpha_c \frac{U_*^2}{g}$$

g = gravity

α_c = Charnock's parameter (0.0144)

Assumption

U(10) = satellite neutral wind speed

1. **Calculate U* and z_0 at 10 m**
2. **Calculate U when z is the hub height**

2 unknowns with 2 equations

Long or short terms

I. Vertical wind extrapolation

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2nd methodology – Stability correction

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right)\right]$$

+

$$z_0 = \alpha_c \frac{U_*^2}{g}$$

1. **Calculate U* and z_0 at 10 m**
2. **Calculate U when z is the hub height applying stability correction**

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - \Psi_m\right]$$

Ψm

- Friction velocity
- Air temperature
- Vertical heat flux

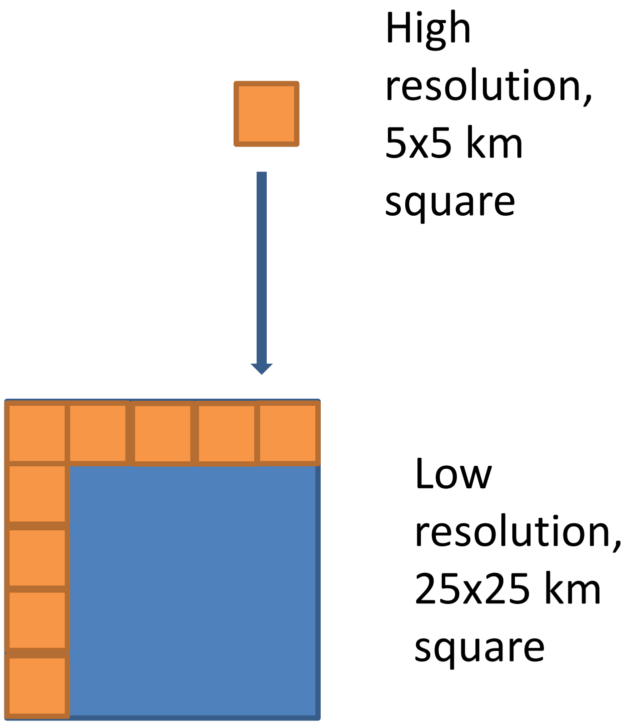
→ From Numerical Weather Prediction model

2 unknowns with 2 equations

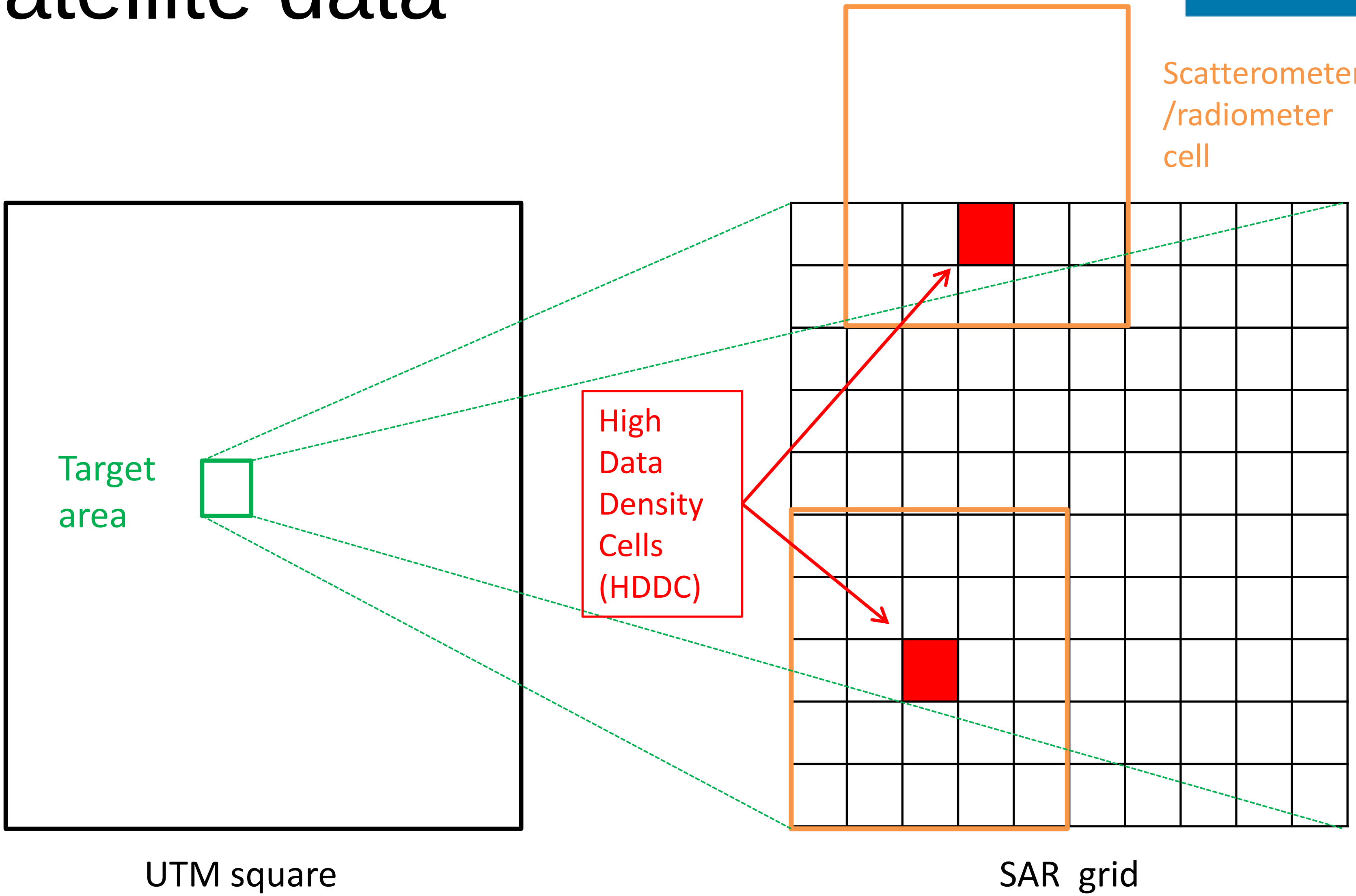
Long or short terms

II. Combining different satellite data

- Combine data at different resolutions:
  - 2*2 km (SAR data)
  - 12.5*12.5 km
  - 25*25 km (most common)
- Calculate the average for each point of the grid

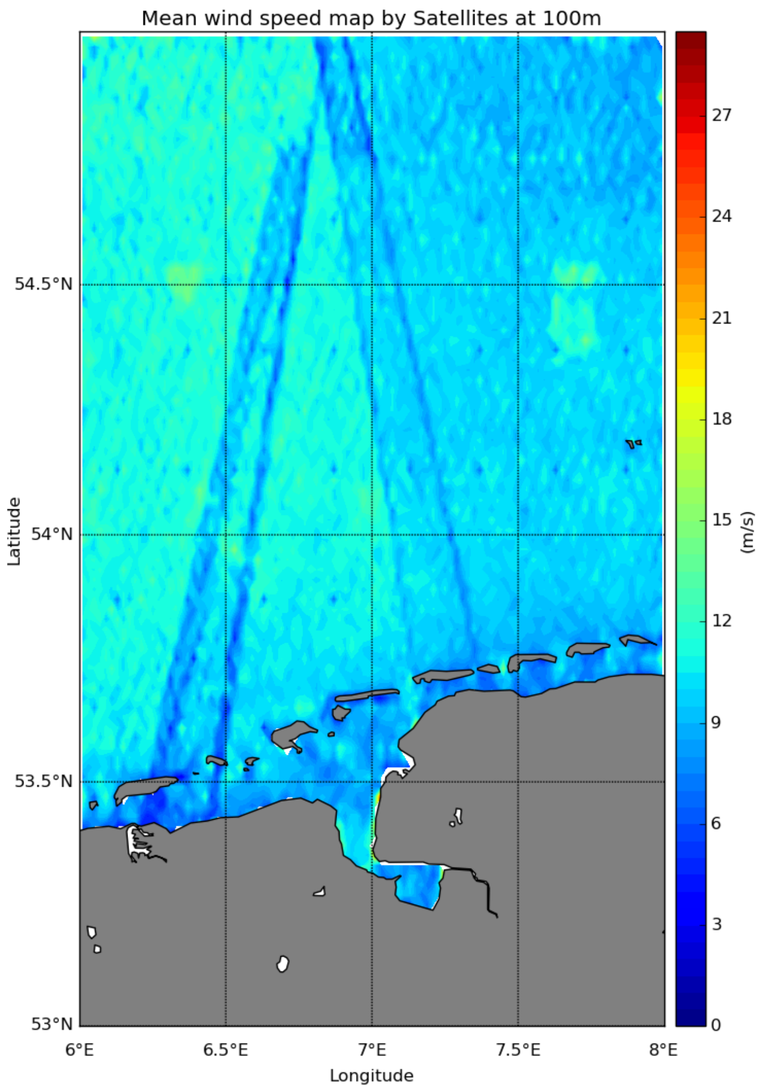


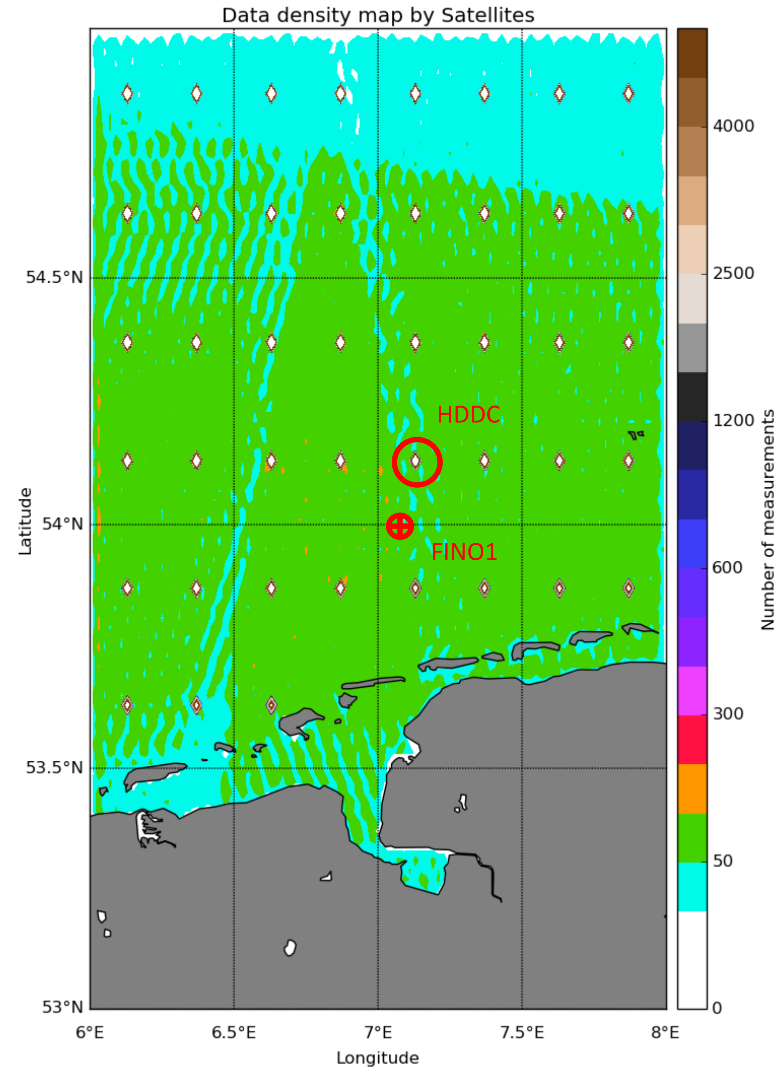
II. Combining different satellite data



Results

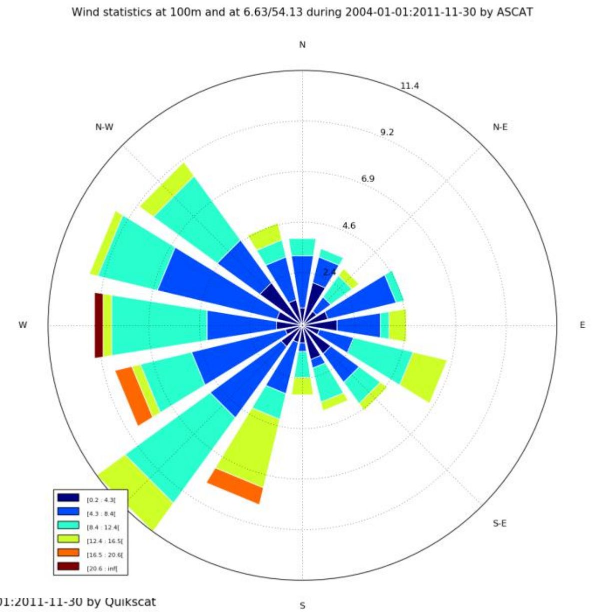
Wind map vs data density map

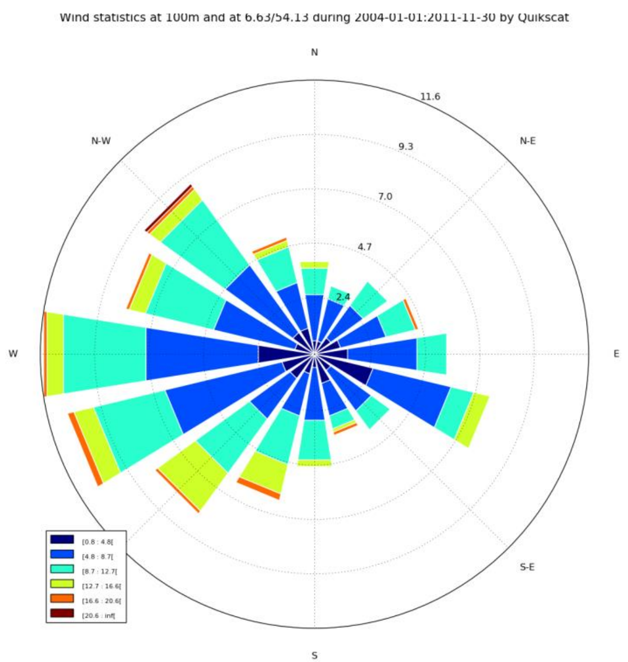


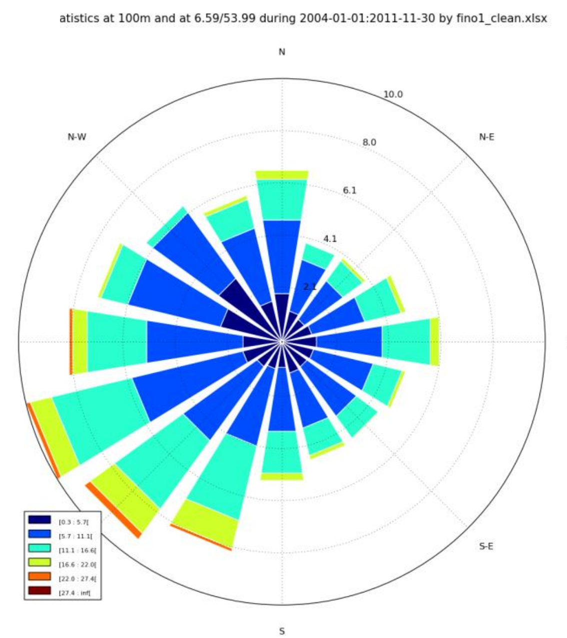


Results

Wind roses







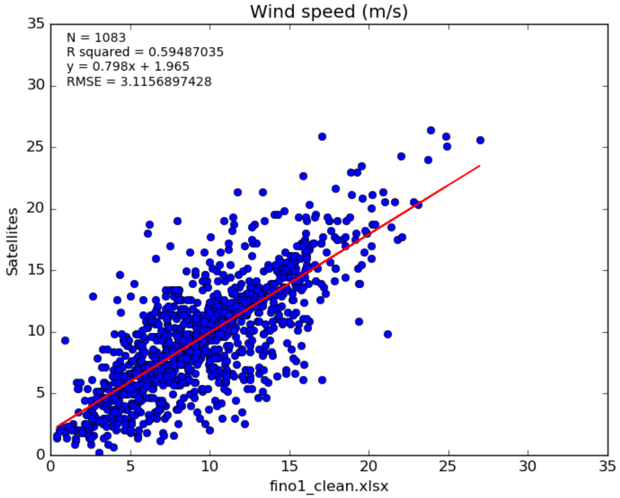
Results

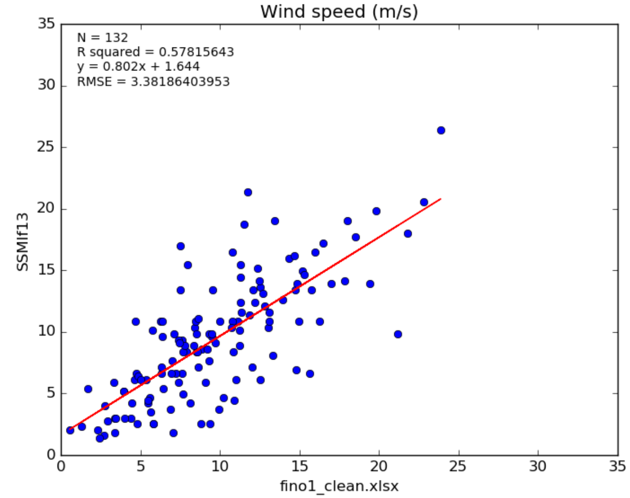
Table of parameters

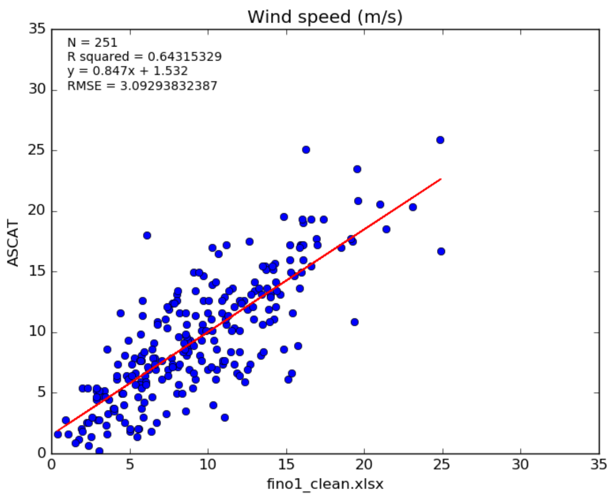
			$U_{10/30}$	U_{100}	K	C	σ	z_0	N
	OVERALL	FINO1	8.099	9.406	2.19	10.621	4.57	0.000391	>350000
OVERLAPPING	LONG TERM	Quikscat/FINO1	7.9/2.27%	9.499/-0.99%	2.885/-25.1%	10.645/-0.26%	3.577/17.9%	0.000113	708
		ASCAT/FINO1	7.85/5.15%	9.428/-0.23%	2.526/-18.2%	10.624/-0.03%	4.017/14.0%	0.000111	254
		SSMIf13/FINO1	7.68/3.76%	9.217/2.0%	2.463/-15.2%	10.391/2.16%	4.02/14.0%	0.000105	133
	SHORT TERM	Quikscat/FINO1	7.9/2.27%	9.544/-1.35%	2.278/-2.38%	10.774/-1.33%	4.471/0.84%	0.000156	708
		ASCAT/FINO1	7.85/5.14%	9.49/-2.26%	1.998/1.43%	10.7/-2.17%	5.016/-3.63%	0.00165	254
		SSMIf13/FINO1	7.68/3.8%	9.278/1.79%	1.95/7.1%	10.463/1.88%	5.015/-2.78%	0.000159	135

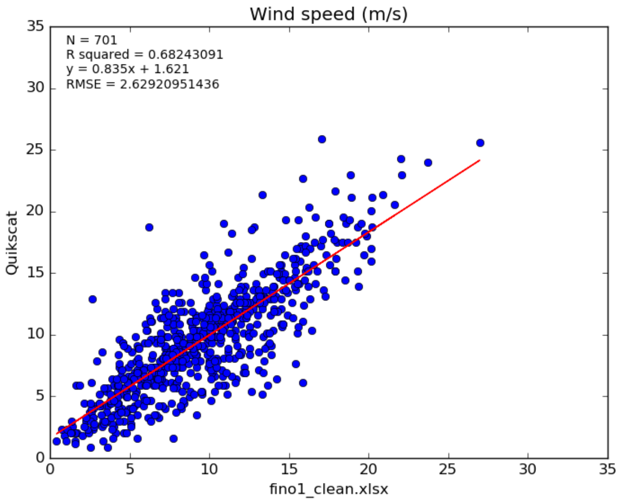
Results

Regression



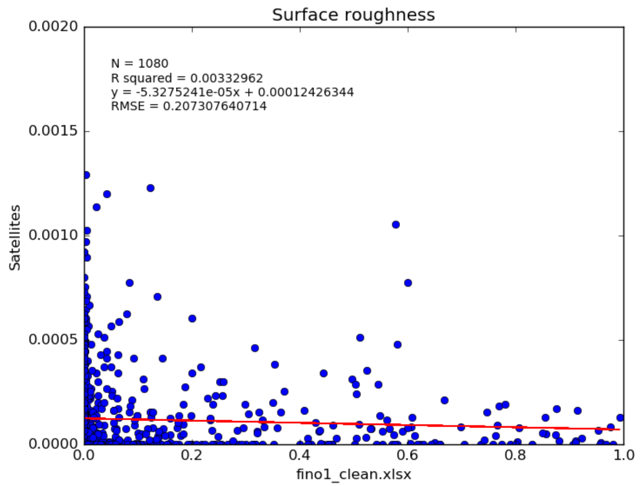


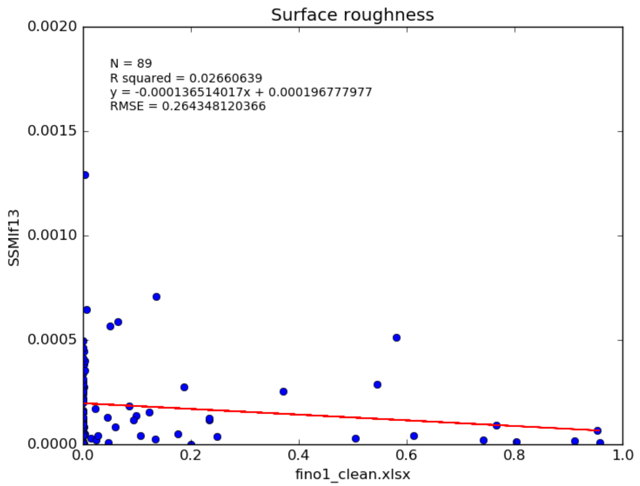


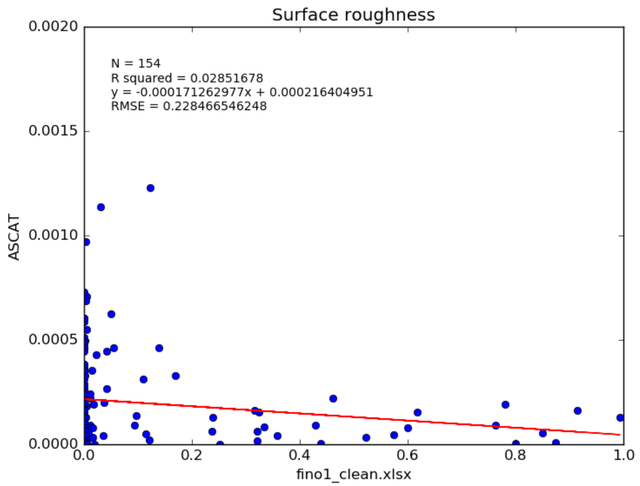


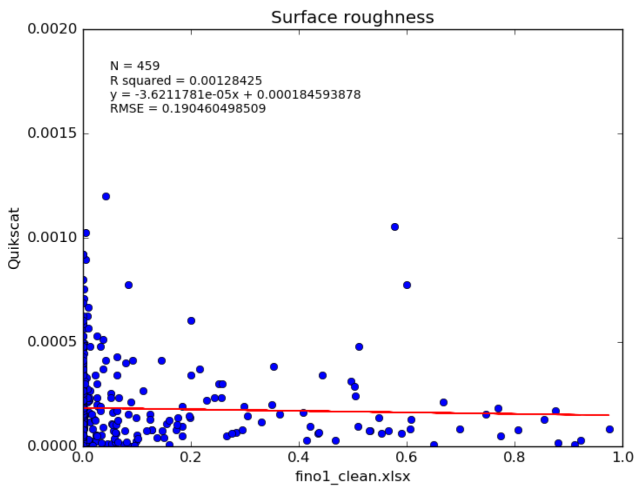
Results

Regression



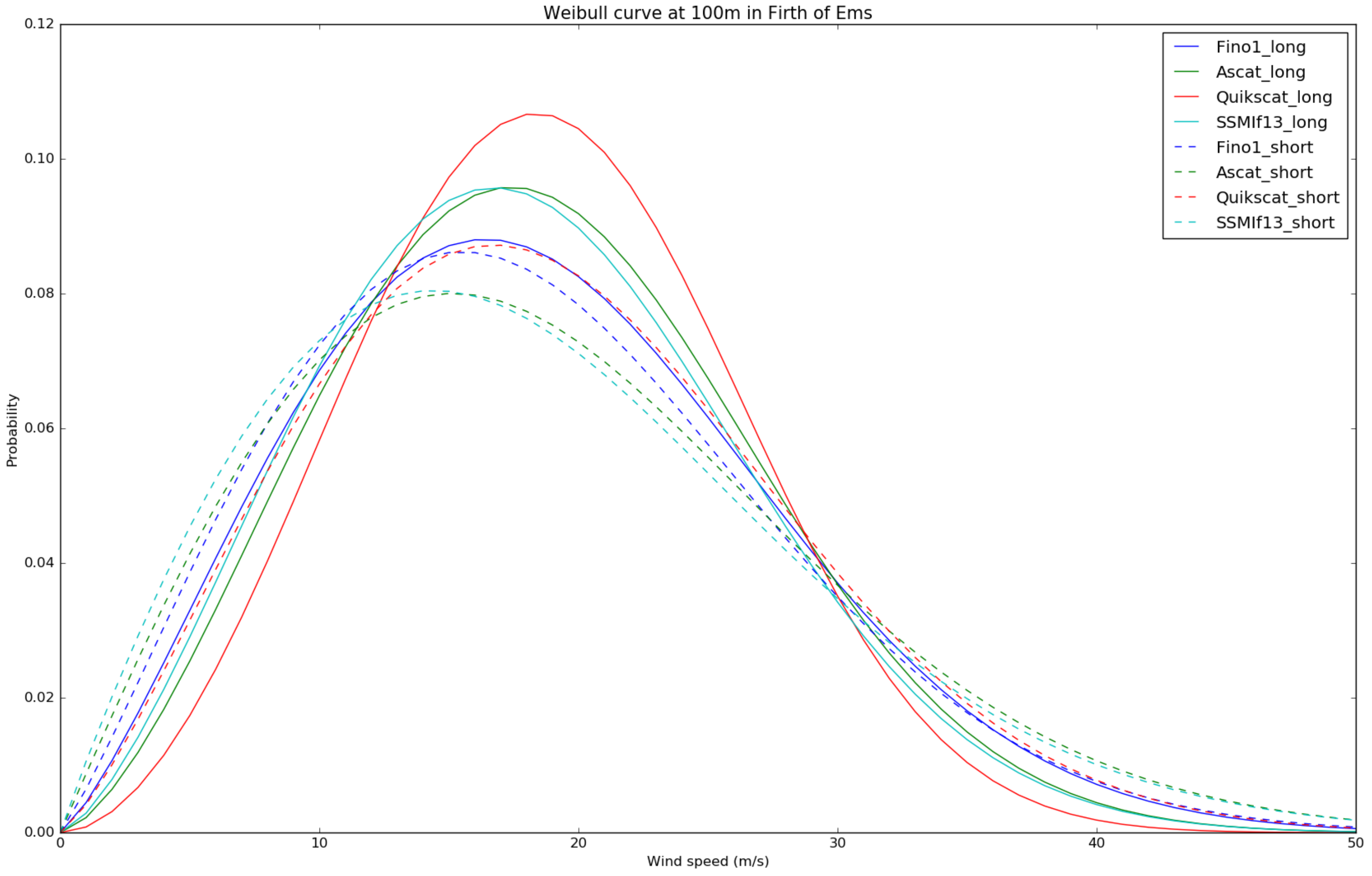






Results

Weibull curves



Summary

- Wind industry uses to handle over 300,000 measurements to parametize wind with accuracy; being mean wind speed at hub height and Weibull parameters the most important.

- In order to achieve similar accuracy with satellites, it is necessary to include as many devices as possible.

- Despite the distance in time and space, the met mast and different satellites achieved similar parameters after processing.

- While long-term extrapolation gives better mean wind speed values at hub height; short-term gives better Weibull parameters.

Wind map quality depends on data density which depends on the database.

Further development

- Addition of atmospheric stability correction for vertical extrapolation
- Calculate surface roughness according sea waves instead of as a function of neutral wind speed.
- Convert tool into a cloud-based software.
- Use satellite data as historical data in Measure-Correlation-Prediction method. Satellites as complement of in-situ measurements such as floating LIDAR's.
- Possible of inclusion of GNSS-Reflectometry.

Satellite wind measurements CAN BE a big cost reduction for offshore wind industry

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