Offshore wind resource assessment based on satellite wind field maps

Charlotte Bay Hasager
Ole Rathmann
Morten Nielsen
Rebecca Barthelmie
Sara Pryor
Ebba Dellwik
Risø National Laboratory, Denmark
Birgitte Furevik
Nansen Environmental and Remote Sensing Center, Norway

RISØ

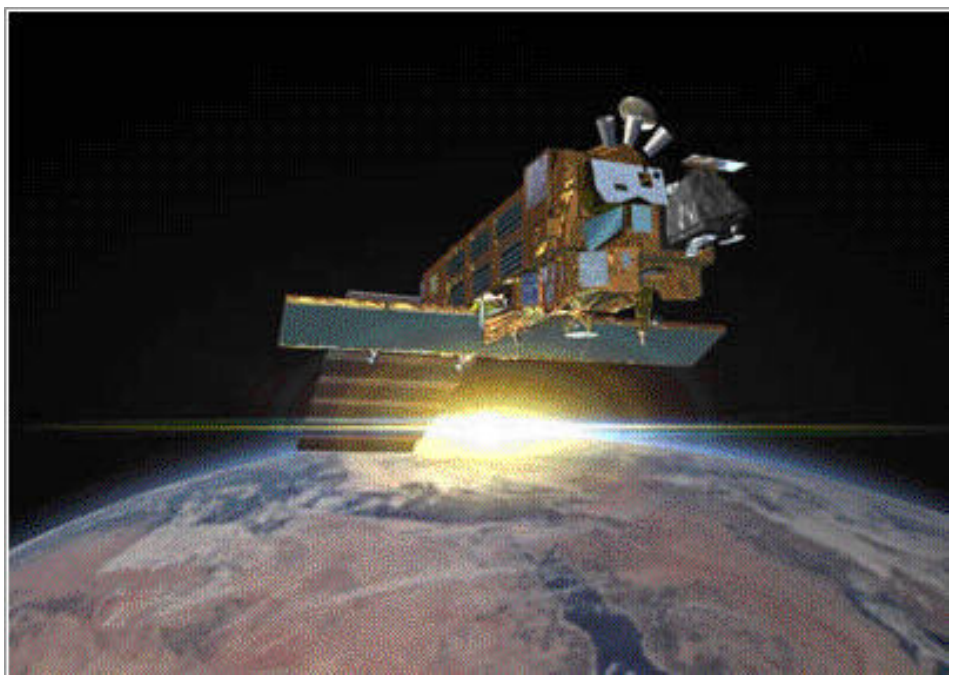
The objectives are

- to develop a tool for calculating
  wind resources from satellite wind maps

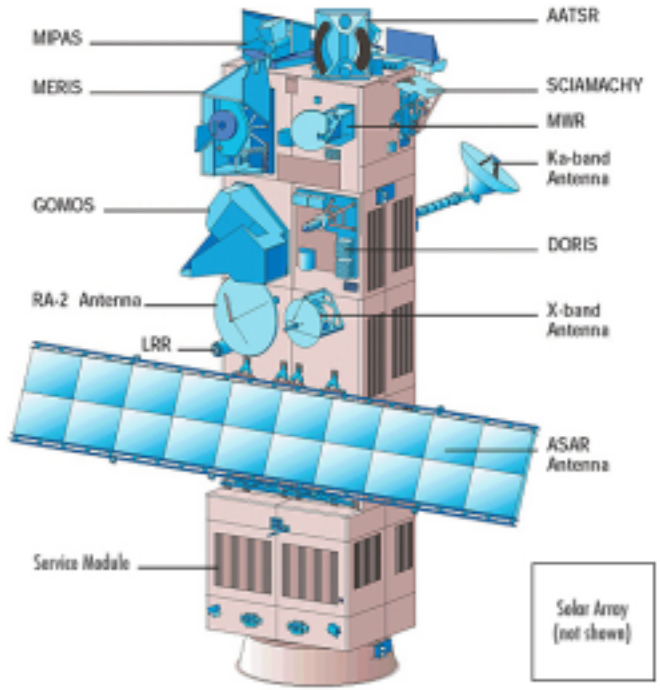
- to compare the results to meteorological data

The technical principle is based on
Synthetic Aperture Radar (SAR) instruments on-board satellites such as ERS-1, ERS-2, ENVISAT and Radarsat-1.

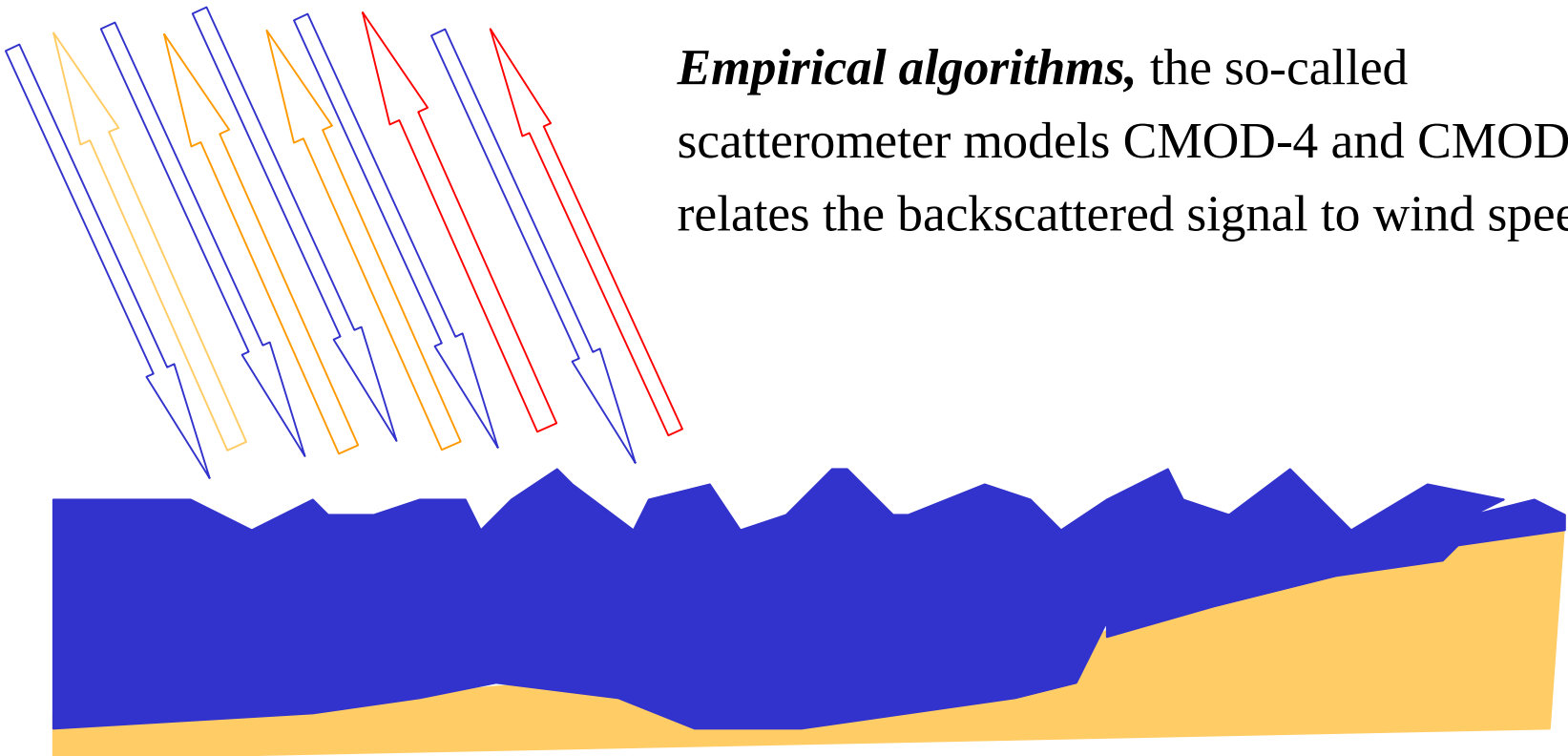
These map ocean winds with high spatial resolution, around 100-400 m grid cells. The observations are snap-shots in time, around 3 per month for any location on Earth since year 1992.



From http://envisat.esa.int/

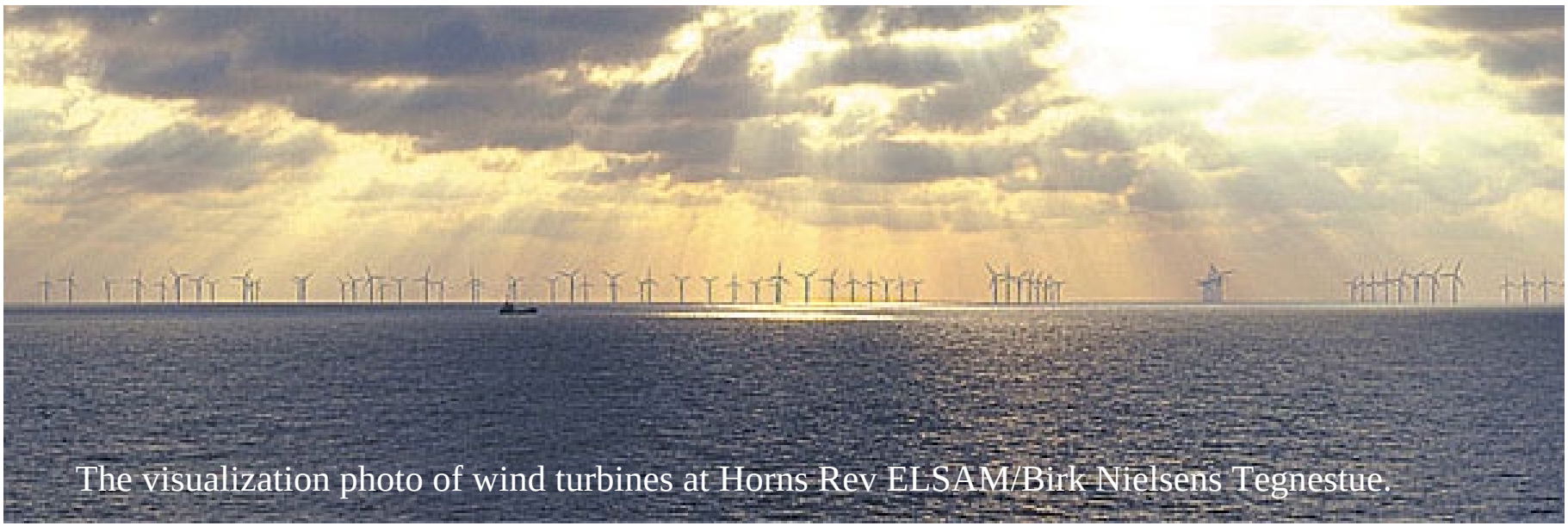


The physical principle is that capillary waves and short gravity waves at the sea surface created by the instantaneous wind field backscatters electromagnetic radiation in the C-band as emitted and received by the SAR instrument.



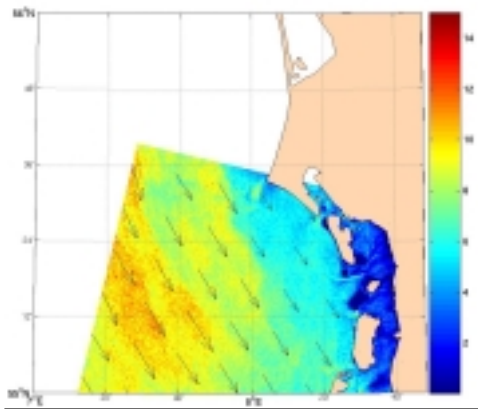
Empirical algorithms, the so-called scatterometer models CMOD-4 and CMOD-IFR relates the backscattered signal to wind speed.

The study site is Horns Rev in the North Sea, Denmark

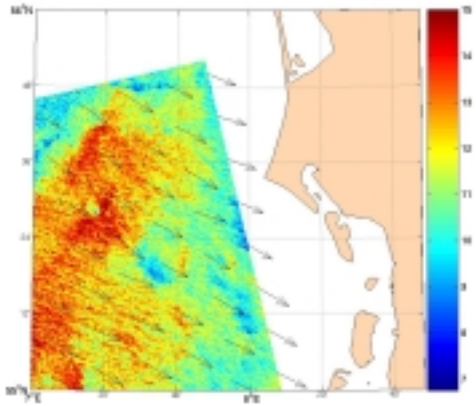


The visualization photo of wind turbines at Horns Rev ELSAM/Birk Nielsens Tegnestue.

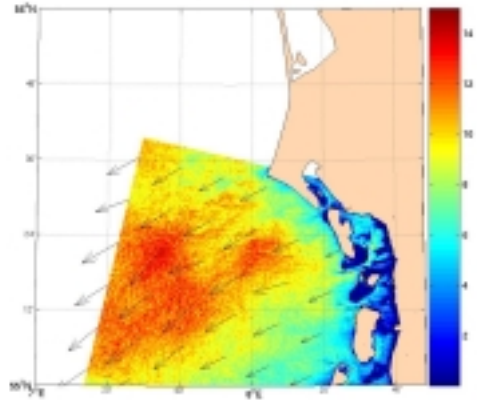
Examples of wind speed and wind direction maps



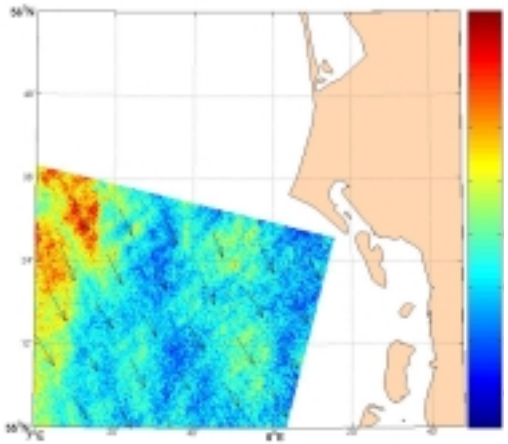
ERS-2 SAR 10 Aug. 1999



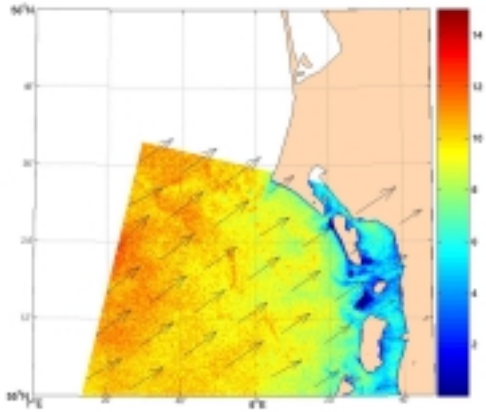
ERS-2 SAR 7 Oct. 1999



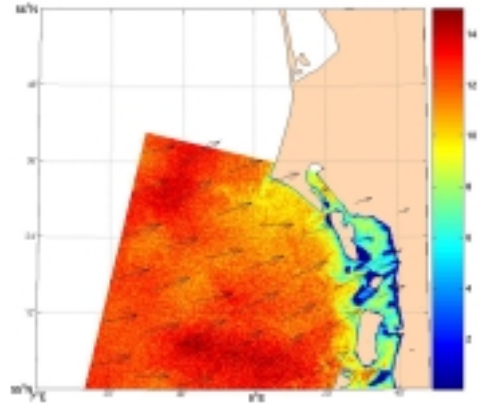
ERS-2 SAR 19 Oct. 1999



ERS-2 SAR 16 Jan. 2000



ERS-2 SAR 1 Feb. 2000



ERS-2 SAR 7 Mar. 2000

NERSC and RISØ has jointly developed a software in two parts for calculation of offshore wind resources based on satellite wind maps.

NERSC developed the part that calculates wind speed and wind direction from the SAR images.

RISØ developed the part that calculates wind resources from the wind maps. This part of the tool is called RWT, short for Risø WEMSAR Tool.

WEMSAR is acronym for an EU-project in years 2000-2003
'Wind Energy Mapping using SAR'

RWT is presented here

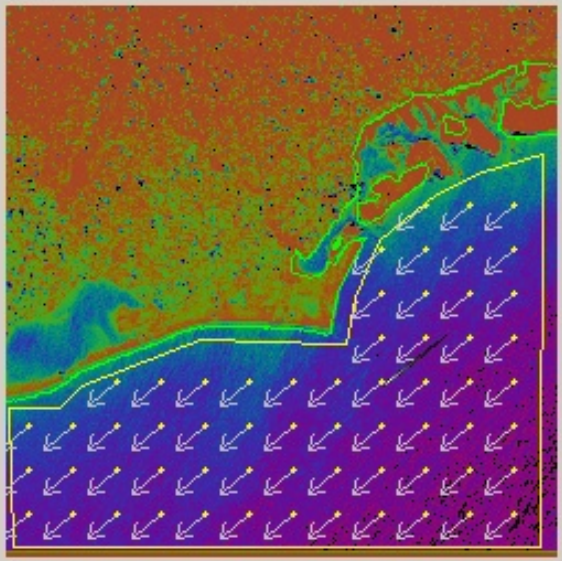
Risø WEMSAR Tool version 1.1

Satelite images | Wind statistics | Options

Selected scene

```
ERS-2 SAR
DATE:     20011023
TIME:     102646
ORBIT:    34030
FRAME:    2482
CORNER COORDINATES:
(row,col) :      lat,lon
(0,0)     :    55.9494 ,  9.2078
(253,0)   :    55.0685 ,  8.8102
(253,250) :            55.2756 ,  7.2846
(0,250)   :    56.1593 ,  7.6462
PIXEL SIZE: 400m x 400m
UTM 32
(row,col) : East      North
(0,0)     :  512978   6200604
(253,0)   :  487879   6102563
(253,250) :           391022   6126935
(0,250)   : 415913    6224772
```

Field



Selected site

Latitude: 55.5077

Longitude: 7.8750

Turbine hub height (m): 65

Show stream ☑

Show boundary ☑

Show footprint ☑

Show coast ☑

Displayed field
- ○ none
- ◉ wind speed
- ○ wind direction

Footprint contour (%): 5

List of satelite scenes

- ☑ 31024_2482_010327
- ☑ 31296_2482_010415
- ☑ 31360_1107_010419
- ☑ 31525_2482_010501
- ☑ 32026_2482_010605
- ☑ 32799_2482_010729
- ☑ 32820_1107_010730
- ☑ 33028_2482_010814
- ☑ 33092_1107_010818
- ☑ 33300_2482_010902
- ☑ 33364_1107_010906
- ☑ 33529_2482_010918
- ☑ 33822_1107_011008
- ☑ 34030_2482_011023

Select all | Select none

Boundary

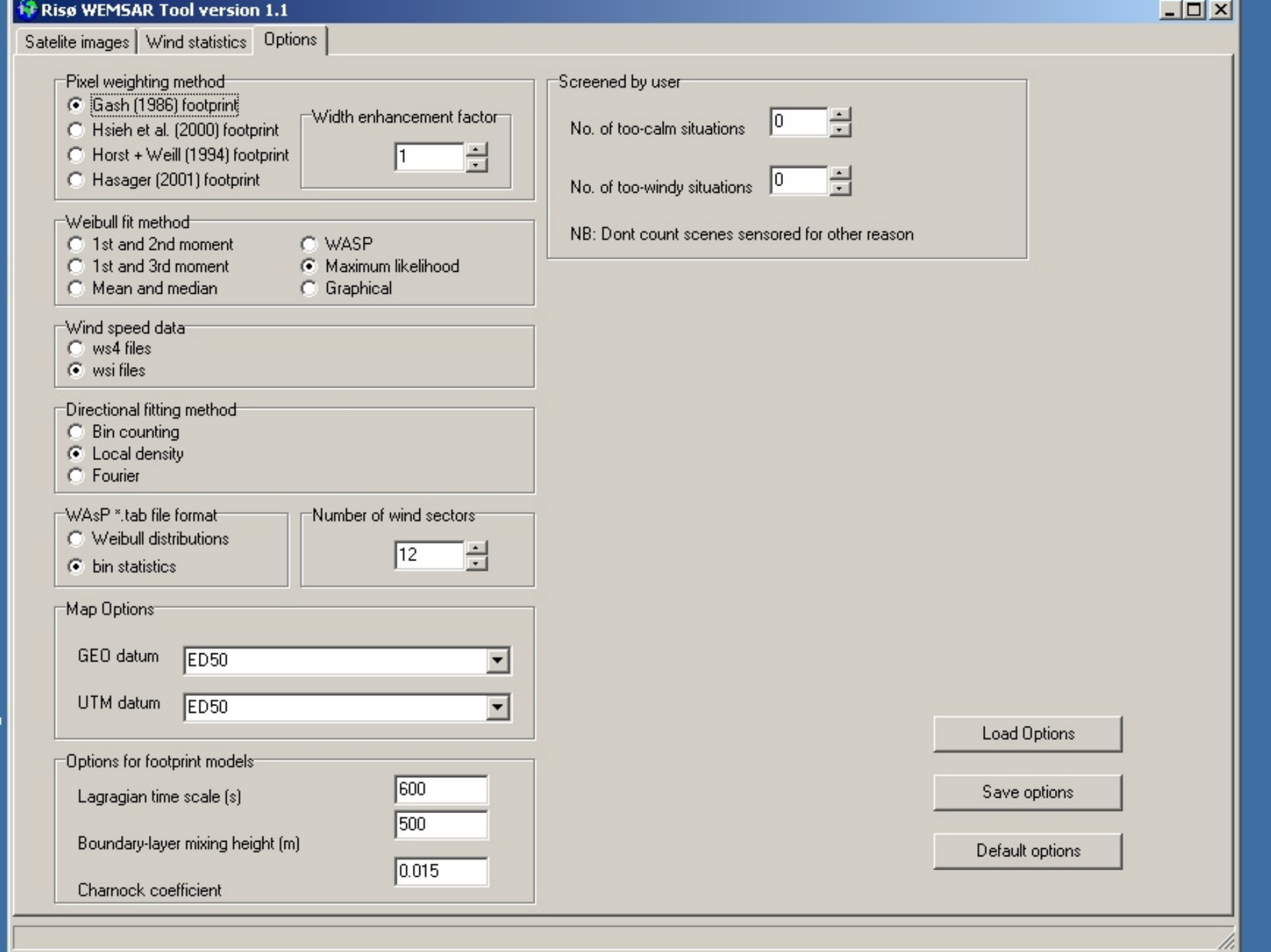
```
442992   6217618
440710   6208705
443601   6203863
446298   6180520
439569   6157462
438974   6155137
446730   6151557
455635   6144393
461209   6132288
462620   6123280
462948   6111656
394813   6129445
418821   6223224
```

Max Boundary | Save Boundary

List of scenes using all data within boundary

- ☐ 21340_1107_990520
- ☐ 21777_2482_990620
- ☐ 21798_1107_990621
- ☐ 22006_2486_990706
- ☐ 22070_1107_990710
- ☐ 22342_1107_990729
- ☐ 22507_2493_990810
- ☐ 22800_1107_990830
- ☐ 23072_1107_990918
- ☐ 23280_2493_991003
- ☐ 23344_1107_991007
- ☐ 23509_2493_991019
- ☐ 24010_2493_991123
- ☐ 24160_1107_991203
- ☐ 24346_1107_991216

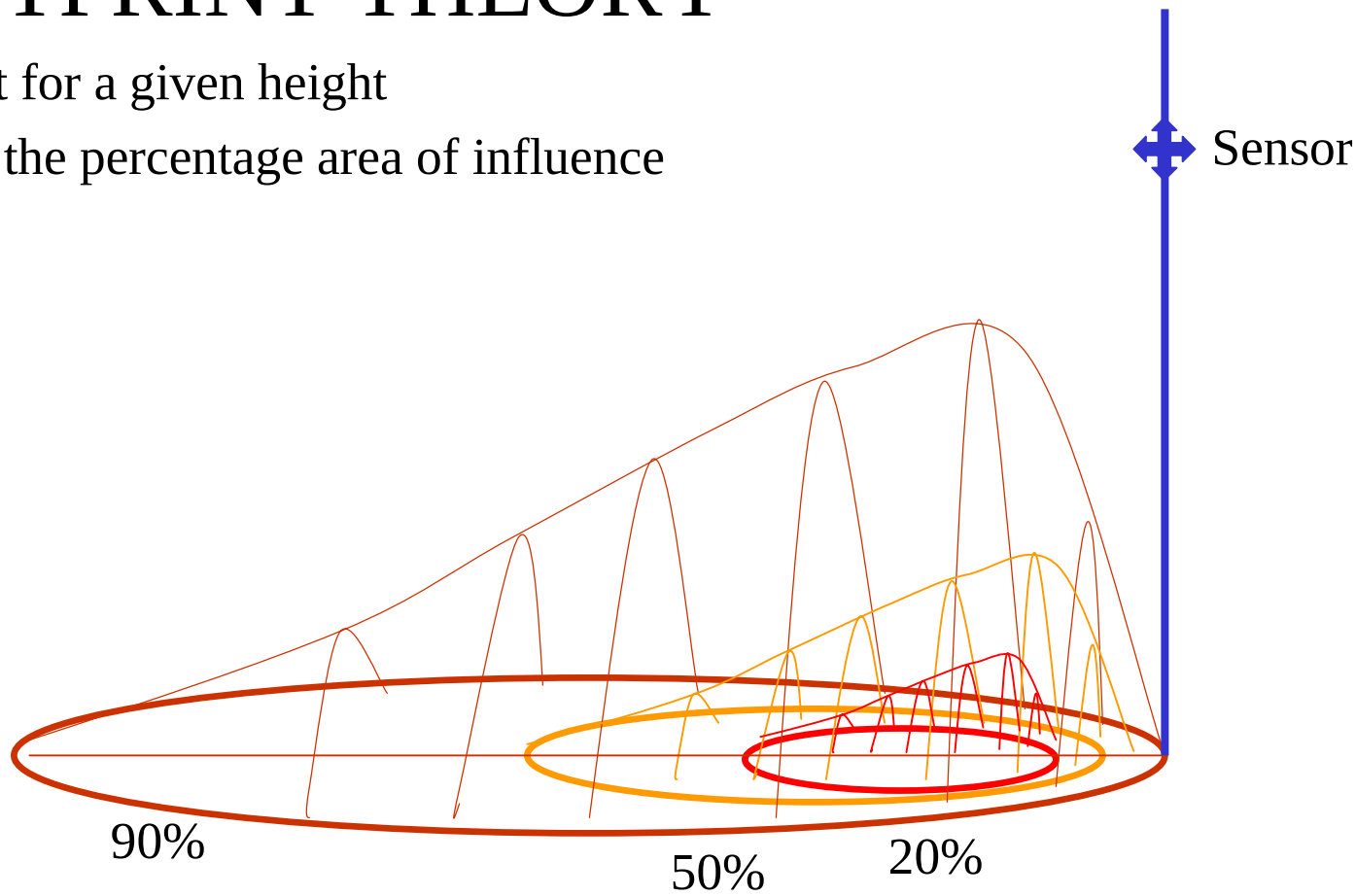
Speed = 12.77m/s Direction = 156.0 Deg @UTM 438.645E, 6134.234N


Risø WEMSAR Tool version 1.1
Satelite images
Wind statistics
Options
Pixel weighting method
Gash (1986) footprint
Hsieh et al. (2000) footprint
Horst + Weill (1994) footprint
Hasager (2001) footprint
Width enhancement factor
1
Weibull fit method
1st and 2nd moment
1st and 3rd moment
Mean and median
WASP
Maximum likelihood
Graphical
Wind speed data
ws4 files
wsi files
Directional fitting method
Bin counting
Local density
Fourier
WAsP *.tab file format
Weibull distributions
bin statistics
Number of wind sectors
12
Map Options
GEO datum
ED50
UTM datum
ED50
Options for footprint models
Lagragian time scale (s)
600
Boundary-layer mixing height (m)
500
Charnock coefficient
0.015
Screened by user
No. of too-calm situations
0
No. of too-windy situations
0
NB: Dont count scenes sensored for other reason
Load Options
Save options
Default options

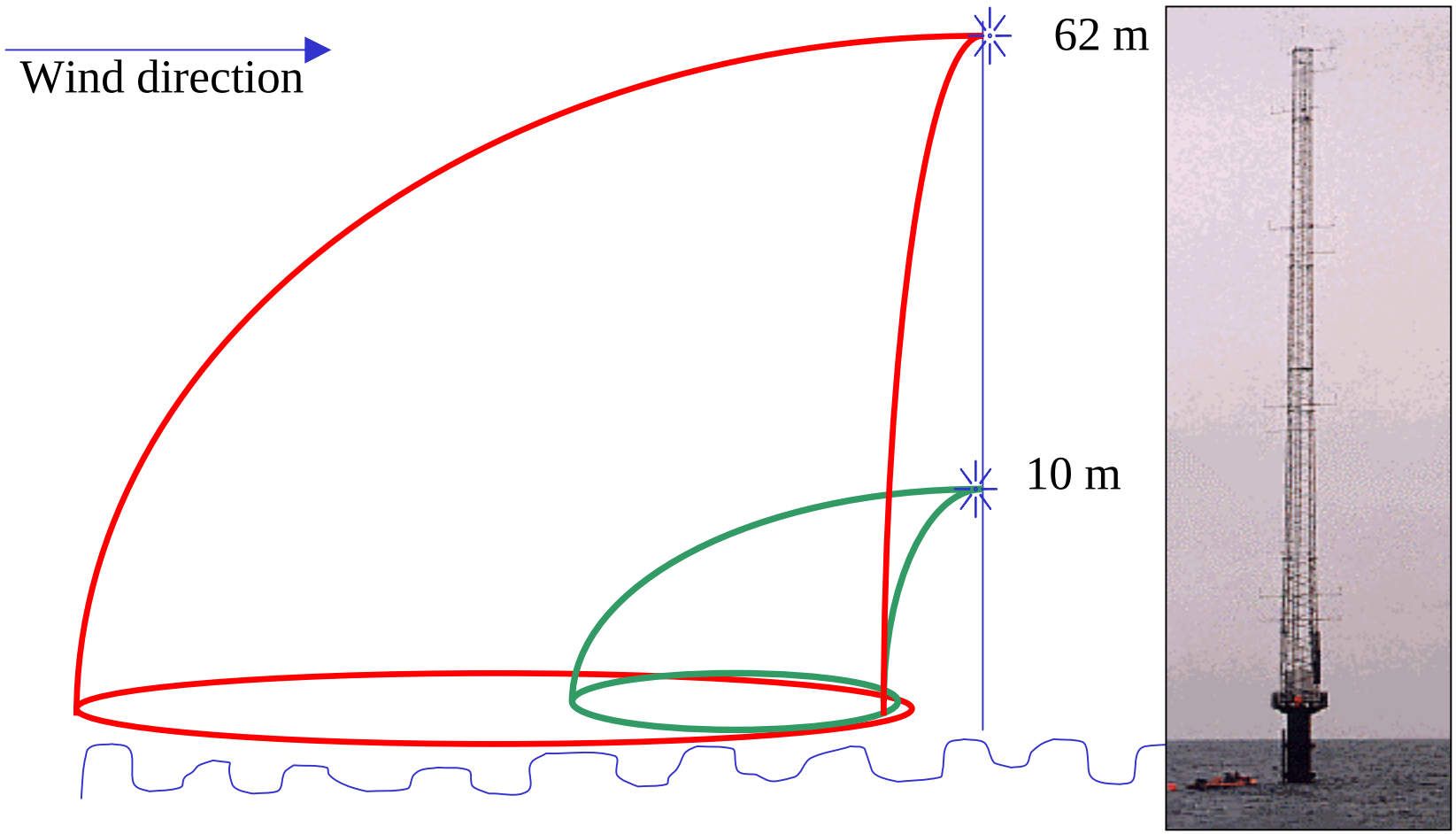
FOOTPRINT THEORY

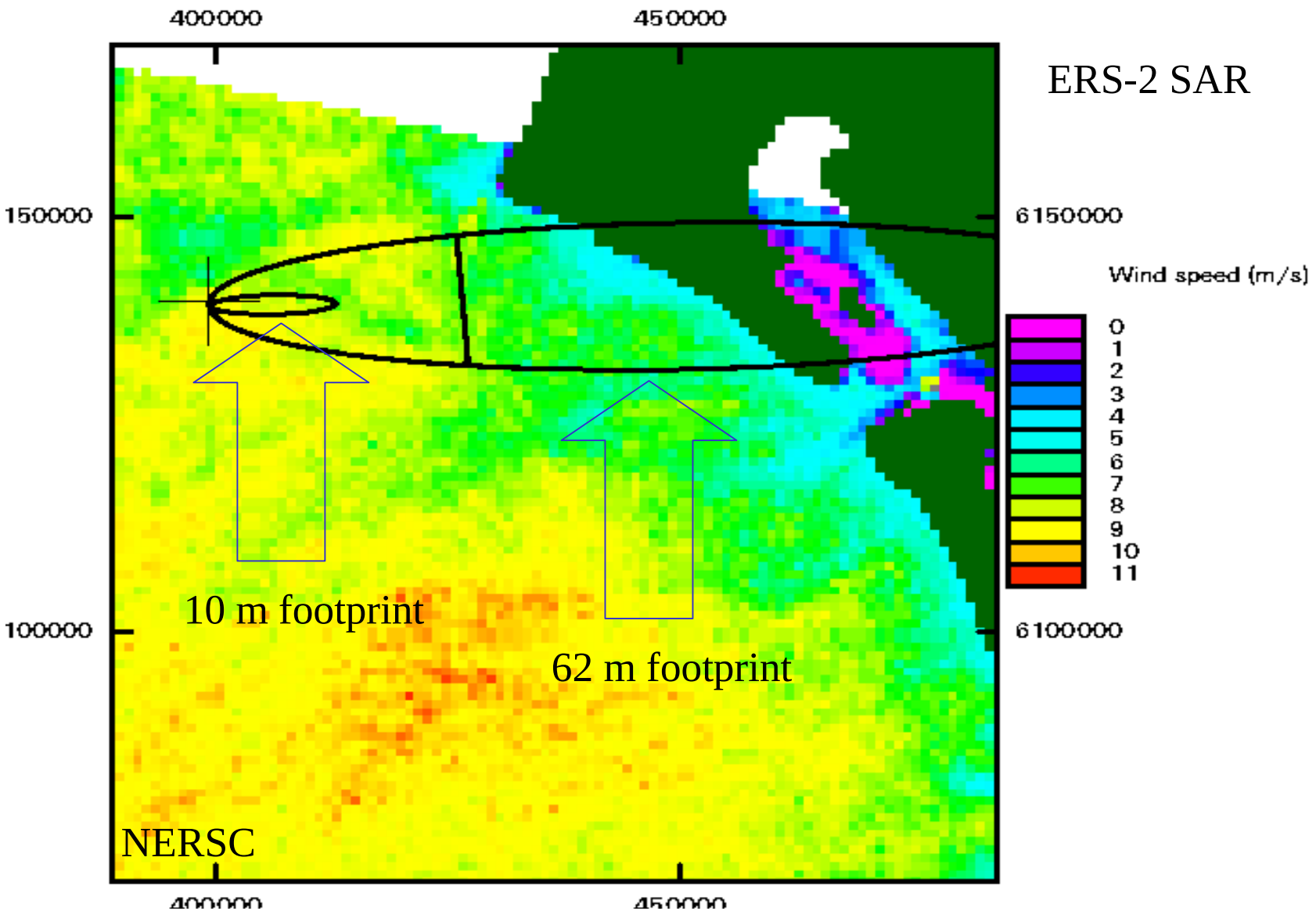
Footprint for a given height

showing the percentage area of influence



Upwind footprints for the Horns Rev mast





Wind field maps from SAR are valid for 10 m height

Risø WEMSAR Tool version 1.1

Satelite images | Wind statistics | Options

Scene	Speed	Direction	Heading
21340_1107_990520	3.33	123.7	347.7
21777_2482_990620	9.59	222.6	195.0
21798_1107_990621	9.57	315.1	346.6
22006_2486_990706	3.75	297.8	194.4
22070_1107_990710	2.05	72.8	347.1
22342_1107_990729	6.17	33.6	347.7
22507_2493_990810	9.87	328.9	194.5
22800_1107_990830	7.70	292.8	346.6
23072_1107_990918	4.34	95.8	347.1
23280_2493_991003	N/A	N/A	195.1
23344_1107_991007	10.13	275.4	347.7
23509_2493_991019	9.80	88.4	194.5
24010_2493_991123	0.97	232.1	194.5
24160_1107_991203	N/A	N/A	344.6
24346_1107_991216	11.63	244.8	347.7
24783_2493_000116	N/A	N/A	195.1

WASP observed wind data file (*.tab)

35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Save

Report

Directional fit:	Local density	
Wind speed data:	wsi files	
Number of wind sectors:	12	
Lagragian time scale (s)	600	
Boundary-layer mixing height (m)		500
Charnock coefficient	0.015	

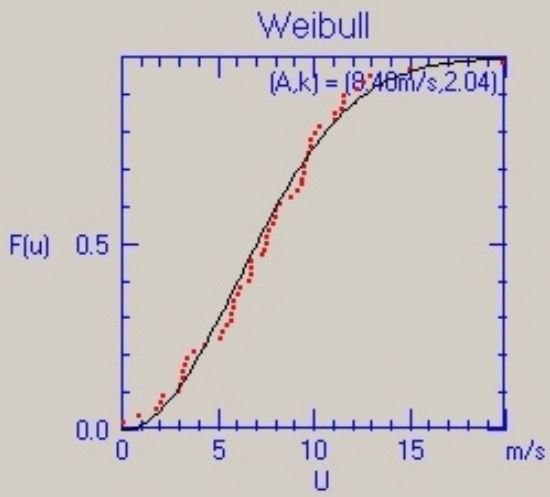
Save Report

Save Graphs

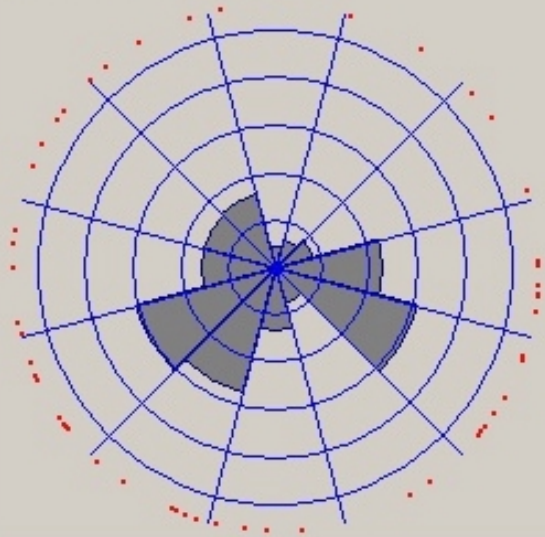
Total windspeed distribution

	Estimate	Uncertainty
Mean wind	7.44	0.72
Energy density	772.70	47.80
Skewness	0.61	13.12
Kurtosis	3.20	1.73
Weibull k	2.04	0.31
Weibull A	8.40	0.84

No. of samples 57



Directional distribution



WAsP - Untitled

File Member Library Tools Window Help

Workspace hierarchy

'Untitled' Workspace

'RWT' Observed wind climate

Library

Library folders

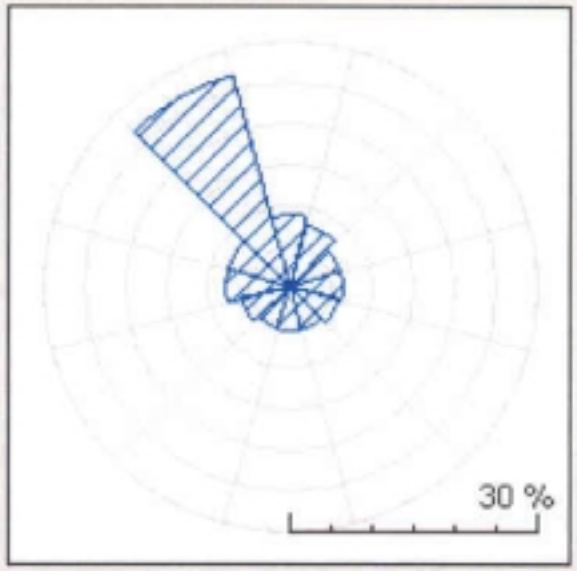
Sample files

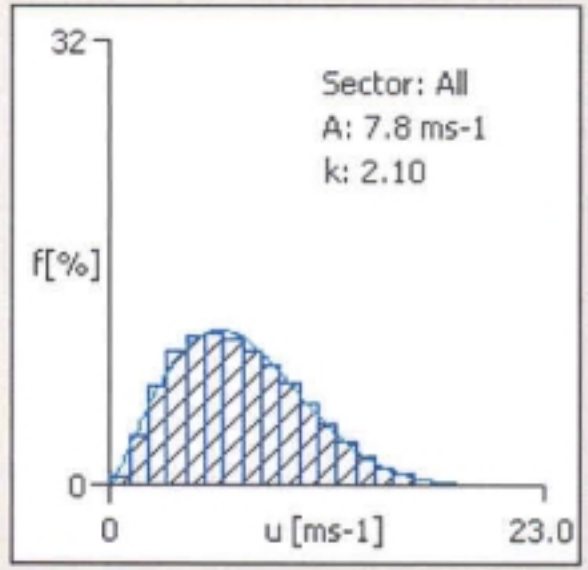
Turbine types

'RWT' Observed wind climate

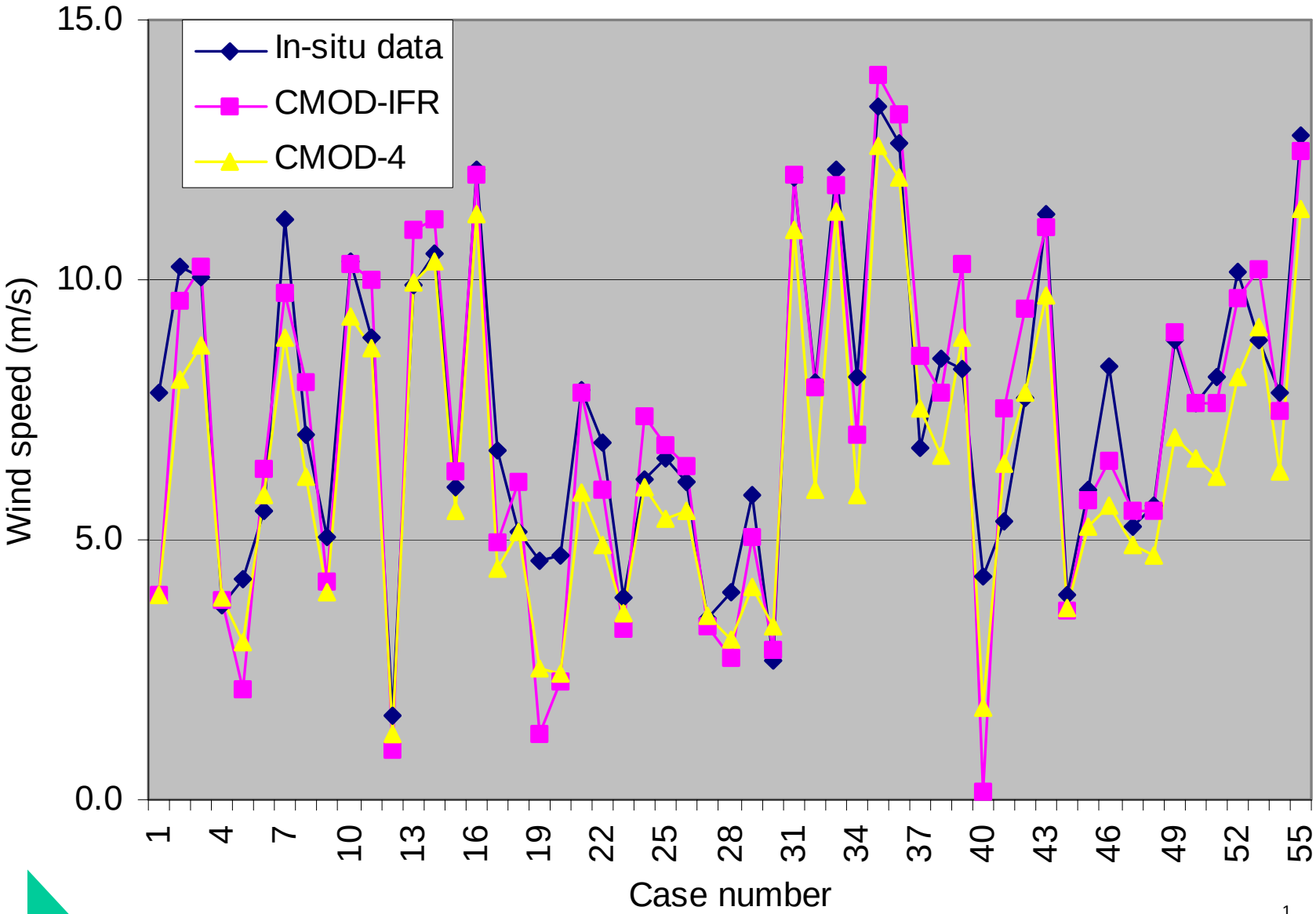
Remote-sensing wind statistics (Wemsar tool)

Data from 65 metres a.g.l. Latitude: 55.5077, Longitude: 7.875

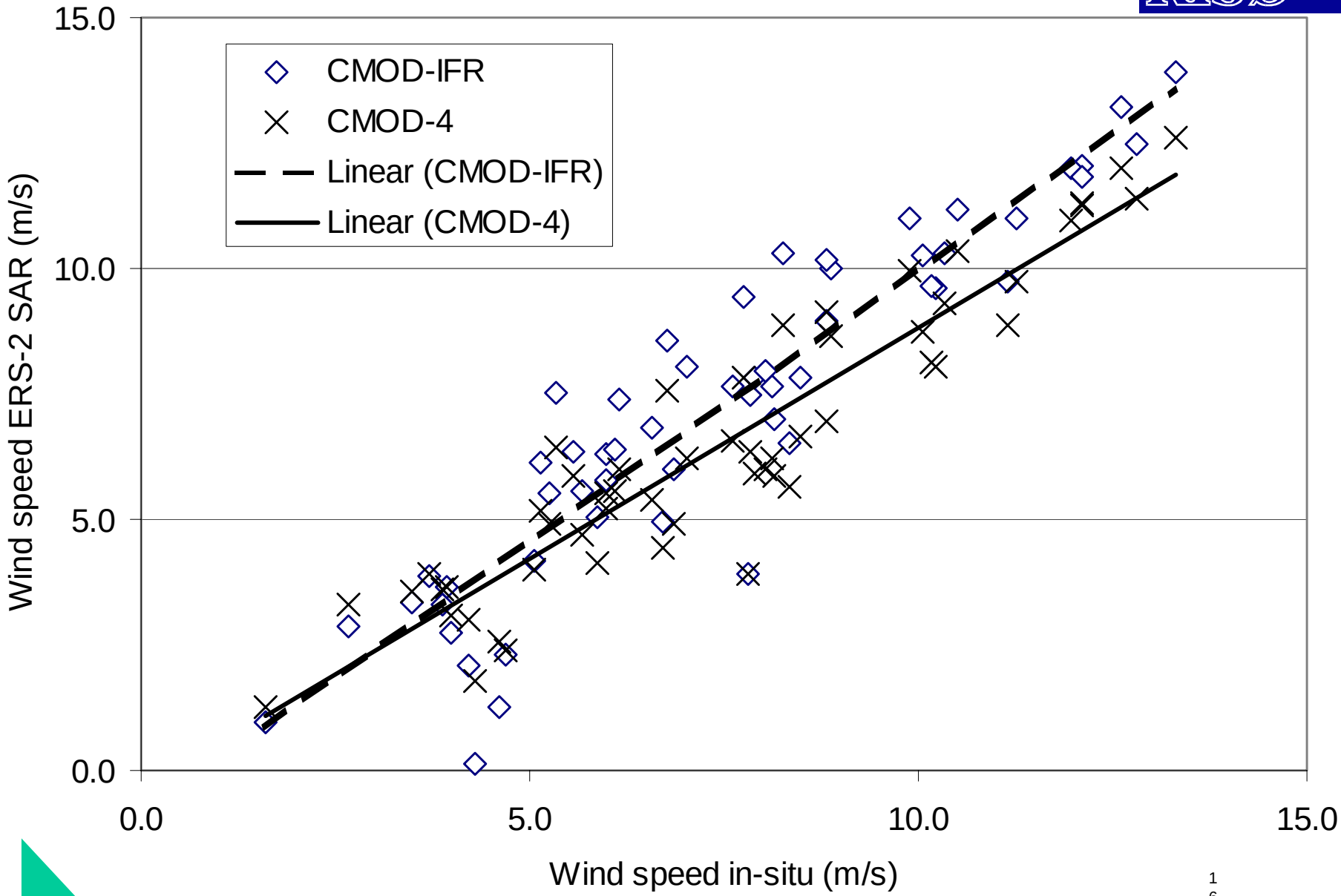




Comparison I: In-situ and satellite wind speed



Comparison II: In-situ and satellite wind speed with linear regression



Comparison III

Linear regression results between in-situ data and wind maps.
a is intercept and b is slope.

	a (m/s)	b (-)	Correlation coefficient R^2	Standard error (m/s)
CMOD-IFR	-0.85	1.09	0.87	1.20
CMOD-4	-0.38	0.92	0.89	0.94

Comparison IV: *Wind statistics based on 55 satellite image samples.*

		CMOD-IFR		CMOD-4		
		estimate	uncertainty	estimate	uncertainty	In-situ data*
Mean	m/s	7.16	0.65	6.47	0.53	7.36
Energy density	m3/s 3	639.9	32.31	427	15.23	
Skewness	-	0.51	12.39	0.36	11.64	
Kurtosis	-	3.04	1.49	2.86	1.19	
Weibull scale A	m/s	8.08	0.76	7.29	0.6	8.46
Weibull shape k	-	2.21	0.34	2.5	0.38	2.2
Covariance cov(A,k)	m/s	1.15		1.31		

* In-situ data are 10-min met-data May 99-Nov. 02 i.e.183.960 samples at Horns Rev calculated for the 10 m level based on

A. Sommer, 2003 OWEMES, p. 65-79

Conclusions

- A new software has been developed for calculation of offshore wind resources based on wind field maps from SAR satellite images
- WA^{S}P can be used directly for wind power calculation
- The wind resource results compare reasonably to in-situ data