Can satellite sampling of offshore wind represent wind speed distributions?

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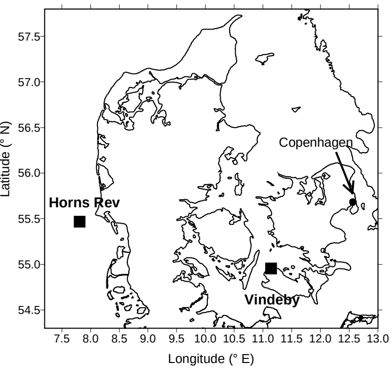


Sites

1) Vindeby offshore wind farm - 48 m offshore mast 2 km from the coast. Half-hourly mean data from Nov. 1993 - Aug. 2001 (database of 112,746 records)
2) Horns Rev 16 km west of the coast of Denmark. One years data from 62 m meteorological mast (Jun 1999 - May 2000).

Introduction

Given the difficulties of measuring offshore wind resources, satellite observations are an attractive proposition potentially giving spatial variability and wind speed and direction. The accuracy of remotely sensed parameters is not considered here. Instead we focus on sampling biases relative to in situ observations. We use in situ data from two offshore sites resampled to mimic remotely sensed data to examine these errors and to provide uncertainty limits for derived moments of the wind speed distribution.

SAR sampling criteria vs. in situ data

Remotely sensed wind speeds differ from in situ observations because of:
1) Differing averaging periods: Synthetic Aperture Radar (SAR) responds to capillary waves that are almost instantaneously coupled to atmospheric flow while meteorological observations are averaged over 10, 30 or 60 minutes
2) Data set density: Limited number of satellite passes/images processed
3) Temporal biases: Introduced as the satellite orbits the globe
4) Truncation of the actual wind speed distribution: SAR operational range ~ 2 – 24 m s^{-1}

Method

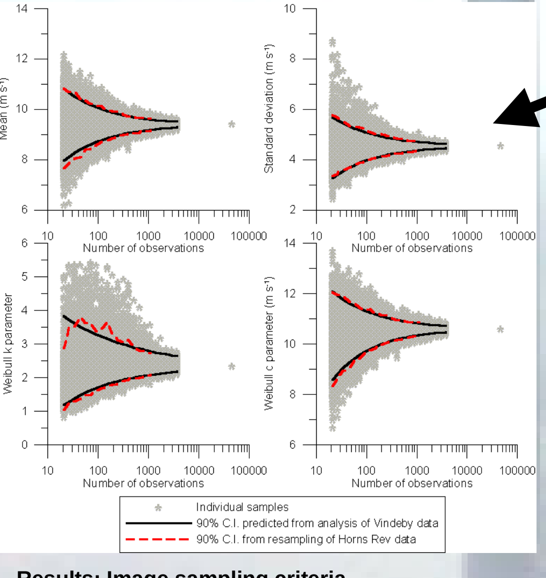
The data sets were randomly and multiply resampled for a range of numbers of observations (n) from n = 21 to n ~ one tenth of the database according to SAR criteria 1-4 (above). We compare statistical properties of the distribution parameters derived from data sets which meet each of the criteria (and the cumulative criteria) with those derived from the entire database. As expected the mean wind speed is the most robust characteristic of the data set, and both the random error associated with each resampled group and the systematic error (or bias) in estimation of the mean is low even for small n. The random error and bias are considerably larger for the standard deviation and the higher moments. The bias is indicated by the asymmetric confidence intervals shown on the Figure below.

Results: Wind energy

In terms of wind resource estimation the largest effect, neglecting the sparse data series, is the bias introduced by truncation of the data set to replicate the operational range of the SAR algorithms. E calculated using k and c for 2 < U < 24 m s^{-1} is over 10 % higher than that calculated using the entire data series, as is E computed for the data set conditionally sampled for all of the SAR data stratification parameters.

Probability distribution parameters for 30 min data from 48 m height at Vindeby SMW

	Criteria	Weibull parameters: Shape (k)	Weibull parameters: Scale (c) (m s^{-1})	Energy density (E) (W m^{-2})
1	Entire dataset	2.26	9.02	522
2	Entire dataset: one minute data	2.32	8.52	431
3	11:00-12:00 and 22:00-23:00 DST.	2.35	9.09	519
4	03:00 - 04:00 DST	2.14	8.81	509
5	U: 2- 24 m s^{-1}.	2.16	9.25	585
6	Cumulative criteria 3 & 4	2.26	9.33	577



Results: Uncertainty bounds

90 % confidence intervals (C.I.) were derived for the distribution moments and Weibull distribution parameters based on sparse resampling of the Vindeby data set with and without SAR criteria. The Horns Rev wind speed data set (measurement height = 62 m) was then resampled for varying n and the 90 % confidence interval from the data compared to that predicted by the fits derived from the Vindeby data. The results indicate generally good agreement. The least well predicted parameter is the Weibull k due to its relationship with data variance. Nevertheless, based on this analysis it may be inferred that the uncertainty bounds derived from the Vindeby data have general applicability to other relatively high wind speed regimes.

The number of randomly distributed observations required to obtain an estimate of the distribution parameters within ±10 % of the actual time series value for a confidence level of 90 % based on 30 min. average wind speeds measured at 48 m at Vindeby SMW computed with statistics derived from the initial database of > 100,000 observations.

Mean	Standard deviation	Skewness	Kurtosis	Weibull k	Weibull c	Energy density
56	150	9712	>10,000	1744	71	1744

Results: Image sampling criteria

The Vindeby data were also used to assess how many SAR images are required for prediction of the wind distribution parameters. Assuming an uncertainty of ± 10 % at a confidence level of 90 % is acceptable for the end user, of the order of 60-70 **randomly selected** images are required to characterise the mean wind speed and Weibull c parameter, while of the order of 150 images are required to obtain a variance estimate, and nearly 2000 are needed to obtain a robust estimate of energy density (or Weibull k). These estimates are conservative since they assume perfect accuracy of the wind speed retrievals and that the remotely sensed data do not exhibit range or temporal biases such as those that characterise the current applications of SAR.

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