where’s the wind?

offshore wind resource assessment from synthetic aperture radar

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Overview

- Background
- Research objectives
  A. Developing the retrieval algorithm
  B. Wind retrieval evaluation
  C. SAR wind resource assessment
  D. Influence of mountain waves
- Conclusions
Offshore wind industry

• UK government aim to produce 10% UK energy by 2010 from renewable sources

• Offshore wind is a major growth area
• Compared to land:
  – Greater wind resource (25% higher 10km offshore)
  – Can install more and larger turbines
• 3 rounds of development planned
• Projected to represent 40% of renewable sector by 2015
Offshore wind industry

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(BWEA, 2007)
UK offshore wind farms

2 MW Vestas

tower height 80m

blade diameter 90m

Beatrice Demonstrator

Key

- Constructed windfarms
- Planned windfarms

©ANEC Border Wind
UK offshore wind farms

2 MW Vestas

tower height 80m
Wind power economics

**extraction cost** vs **energy produced**

**Capital costs**
- turbine design
- foundation type
- installation

**Transmission**
- connection to grid
- strengthening existing grid
  (Sahin, 2003)

**Availability**
- i.e. turbine operating

**Wind Resource**
- Available energy strongly related to wind speed

**Turbine efficiency**
- Larger turbines more efficient
Wind power economics

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Wind resource assessment

• In-situ observations
  – Accurate observations
  – No spatial coverage
Wind resource assessment

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- Numerical Weather Prediction (NWP)
  - Good temporal resolution
  - Moderate to low spatial resolution
Wind resource assessment

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- Numerical Weather Prediction (NWP)
  - Good temporal resolution
  - Moderate to low spatial resolution
- SAR (Synthetic Aperture Radar)
  - 15 years + of observations
  - High spatial resolution
  - Wind retrieval challenges
  - Relatively unproven method
Basics of SAR

an example image

radar look direction
Criteria for adoption of SAR

1. **Accuracy**
   - SAR must also be able to accurately estimate mean wind speed and wind power density

2. **Spatial Resolution**
   - Information should be at or below the scale of a wind farm

3. **Novel Relevant Information**
   - SAR should offer something new and useful

4. **Cost Effectiveness**
   - Crucial for commercial application
A. Developing the retrieval algorithm
Relating observations to wind

Wind → Surface roughness → Backscatter

- Incident wave
- Reflected wave
- Smooth Surface
- Slightly rough surface
- Rough surface
- Back scattered component
Relating observations to wind

Wind direction & Wind speed

Backscatter Model

Wind
Surface roughness
Backscatter
The retrieval problem

Underdetermined problem:
- 1 observation (radar backscatter)
- 2 unknowns (wind speed & direction)
= infinite number of solutions
Classic retrieval method

Directional Wind Speed Algorithm (DWSA)

Retrieves wind speed assuming observations and an *a priori* wind direction are true.

**Problems**
- Assumes variation in backscatter only due to wind speed changes.
- Doesn’t account for known retrieval errors.

![Graph showing wind speed vs. wind direction](image-url)
Bayesian retrieval method

Maximum Aposteriori Probability (MAP) algorithm

Iteratively estimates optimal wind vector given:

- **observation**
- **apriori wind speed/direction**
- **uncertainty on each**
Sensitivity Analysis

20° wind direction error

10% obs. error

Plots show % error in wind speed
B. Wind retrieval evaluation
Methodology

• Data:
  – UKMO Unified Mesoscale Model (UMM) surface wind
• 1.5 km² retrieval resolution
Methodology

- Data:
  - UKMO Unified Mesoscale Model (UMM) surface wind
- 1.5 km² retrieval resolution
- Validated against Hilbre Island insitu mast data
Example retrieval
Validation

**a priori**

- SD: 2.31 ms\(^{-1}\)
- \(r^2: 0.58\)

**DWSA**

- SD: 1.61 ms\(^{-1}\)
- \(r^2: 0.67\)

**MAP**

- SD: 1.47 ms\(^{-1}\)
- \(r^2: 0.71\)
C. SAR wind resource assessment
The data set

103 SAR scenes

UK Wind Atlas data

Offshore platform obs

Wind speed (m/s)

No. Scenes

Study Area
Key wind resource indicators

1. Mean Wind Speed
2. Wind Power Density

\[ \frac{P}{A} = \frac{1}{2} \rho \overline{v}^3 \bar{p}(v) \]

PDF

Area of rotor
Mean speed
SAR sampling issues

1. Dataset density
   - Length of obs. period
   - No & distribution of obs.

No. scenes per month

![Bar chart showing no. of scenes per month for 2004, 2005, and 2006.](chart.png)
SAR sampling issues

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   - Length of obs. period
   - No & distribution of obs.

2. Diurnal sampling
   - SAR pass at set times
SAR sampling issues

1. Dataset density
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2. Diurnal sampling
   - SAR pass at set times

3. Wind speed distribution truncation
   - Backscatter models unreliable below 2 ms\(^{-1}\)

![Wind speed histogram at Z=80m](image)
why are SAR wind speeds high here?
Mean wind speeds

Wind direction sampling

![Radar chart showing mean wind speeds with NWP and SAR lines, and probability range from 0 to 0.4.](chart.png)
Mean wind speeds

Wind direction sampling

Mean speed per direction sector

a) 0°-60°

b) 60°-120°

c) 120°-180°

d) 180°-240°

e) 240°-300°

f) 300°-360°
Mean wind speeds

Wind direction sampling

Weighted mean

\[
\overline{v} = \frac{\overline{s_1 w_1} + \overline{s_2 w_2} + \ldots + \overline{s_n w_n}}{w_1 + w_2 + \ldots + w_n}
\]
Wind power density

a) SAR

b) Wind Atlas

Poor result due to low number of scenes
Over 170 needed to estimate the PDF accurately
D. Influence of mountain waves
Mountain waves

• Generated by airflow over mountains
• Found in 1/3 of scenes
• Not currently resolved by UK NWP model
• Implications for wind resource?
Event from October 2005

15/10/05

a) SAR Image

b) Wind Field

18/10/05

a) SAR Image

b) Wind Field

Radar wind profiler

Wind speed (ms⁻¹)

Altitude (km)

Time (hrs)

Pass Time

15/10/05 16/10/05 17/10/05 18/10/05

MOA5 ASAR 2 MOA6 ASAR 3

0 12 24 36 48 60 72 84 96
Event from October 2005

- Potentially large variations in surface wind field
- May have implications for distributed generation
- SAR provides a snapshot
- BUT how do these events move & evolve at the sea surface?
Returning to criteria
Criteria for adoption of SAR

1. **Accuracy**
   - Best case accurate to \( \sim 1 \text{ms}^{-1} \)

2. **Spatial Resolution**
   - Reliable estimates of backscatter possible at 1.5 \( \text{km}^2 \) resolution (i.e. better than NWP models)

3. **Novel Relevant Information**
   - Hi. res. spatial wind field information
   - ability to identify mesoscale wind structures

4. **Cost Effectiveness**
   - Commercial cost per scene €400
   - Reliable wind power density may cost upwards of £70,000, offshore mast estimated at £250,000+
Conclusions

• Bayesian retrieval approach seems valid and relatively accurate
• Data set density is a critical parameter
  – 100 scenes adequate for mean wind speed
  – Sub-optimal for wind power density
• Synoptic wind field maps may be of great use

Outlook
• New commercial packages allow for quick and easy retrieval of SAR wind fields
• Current cost per scene (controlled by ESA) prohibitive
Questions?