where's the wind?

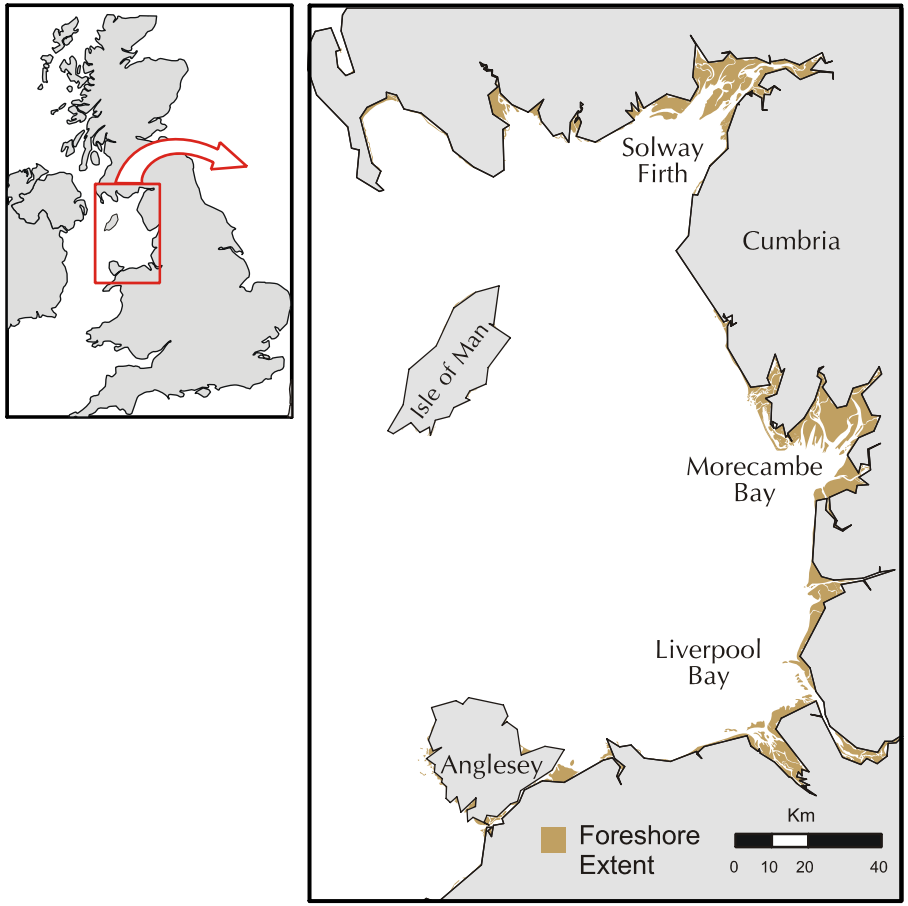
offshore wind resource assessment from synthetic aperture radar

Iain Cameron
Edinburgh Earth Observatory

Overview

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

Study area



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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

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Offshore wind industry

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- Offshore w
- Compared
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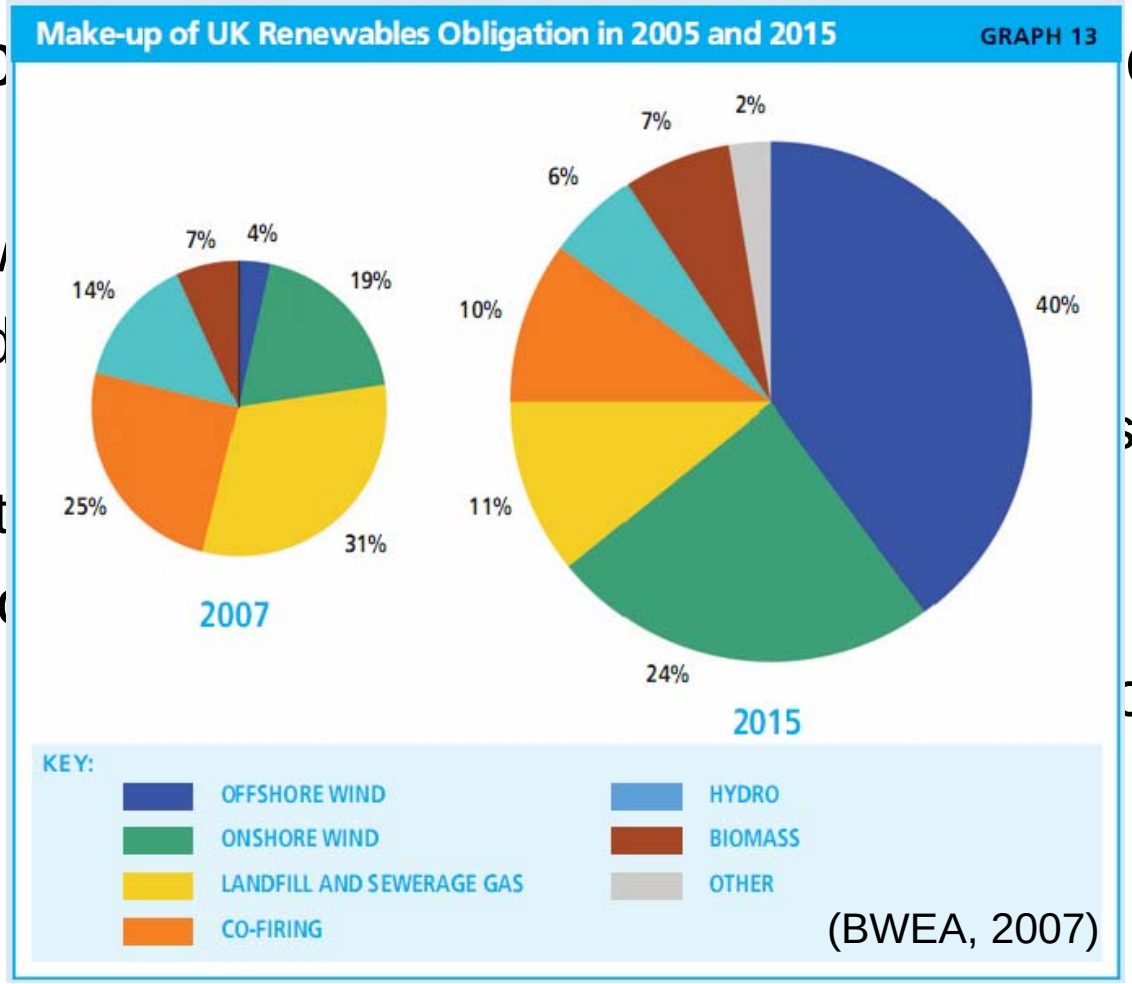

(BWEA, 2007)

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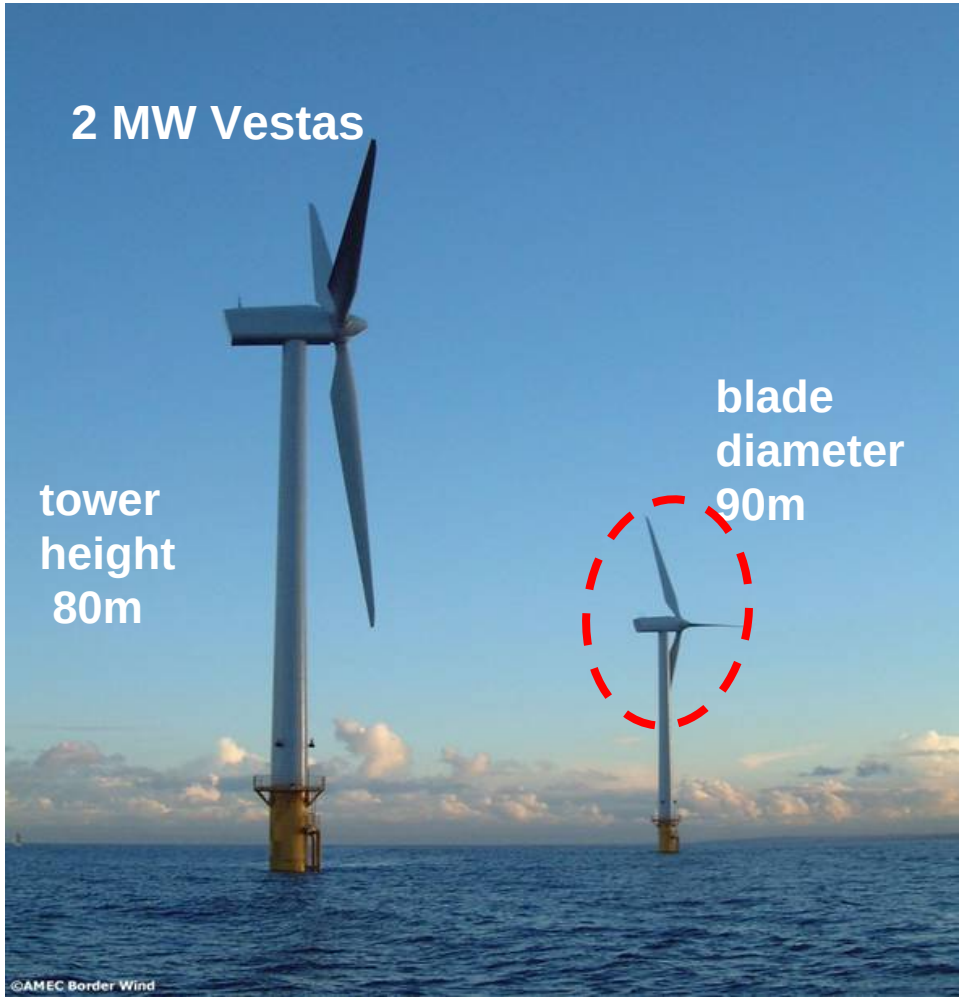
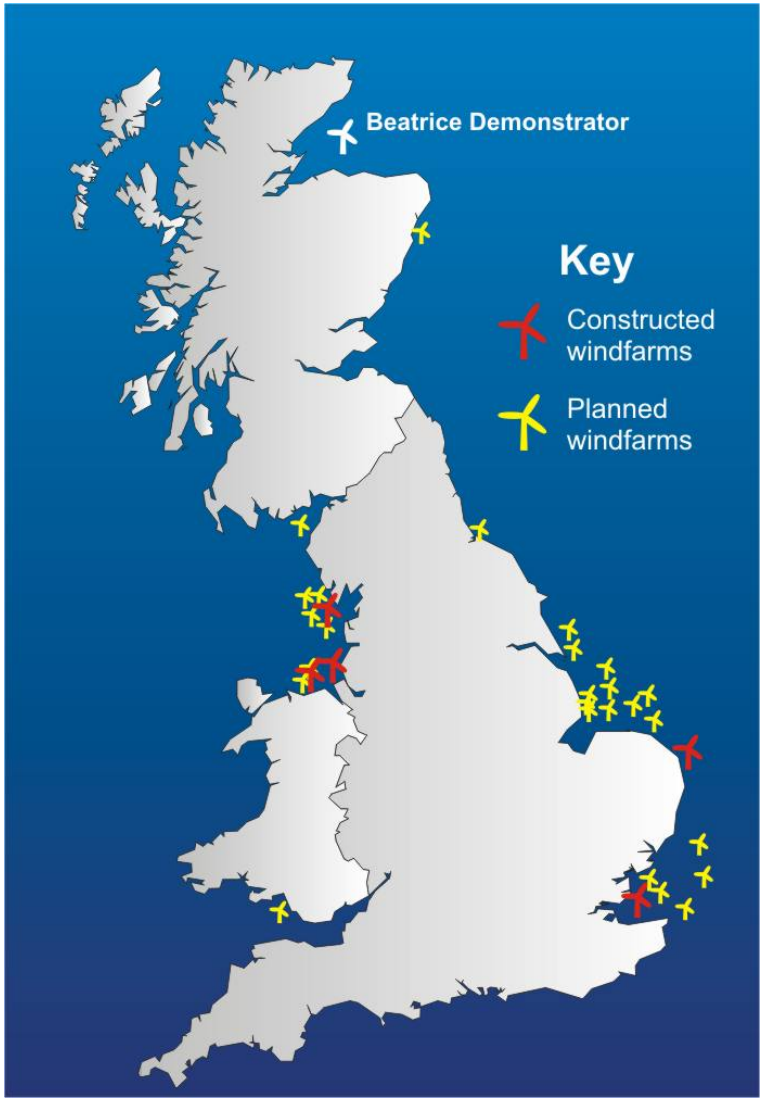
UK offshore wind farms





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UK offshore wind farms

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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

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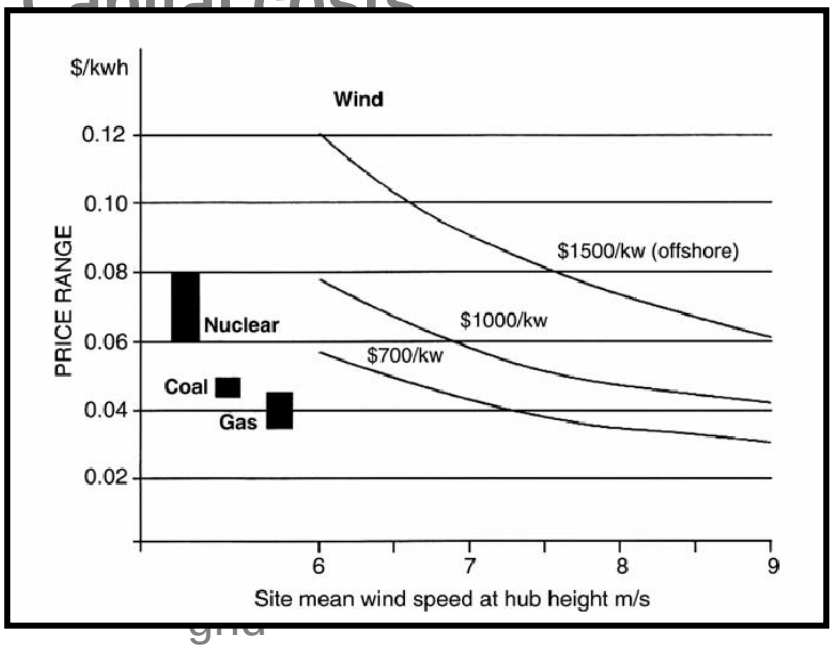
Wind power economics

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

Capital costs



(Sahin, 2003)

Availability

•i.e. turbine operating

Wind Resource

•Available energy strongly related to wind speed

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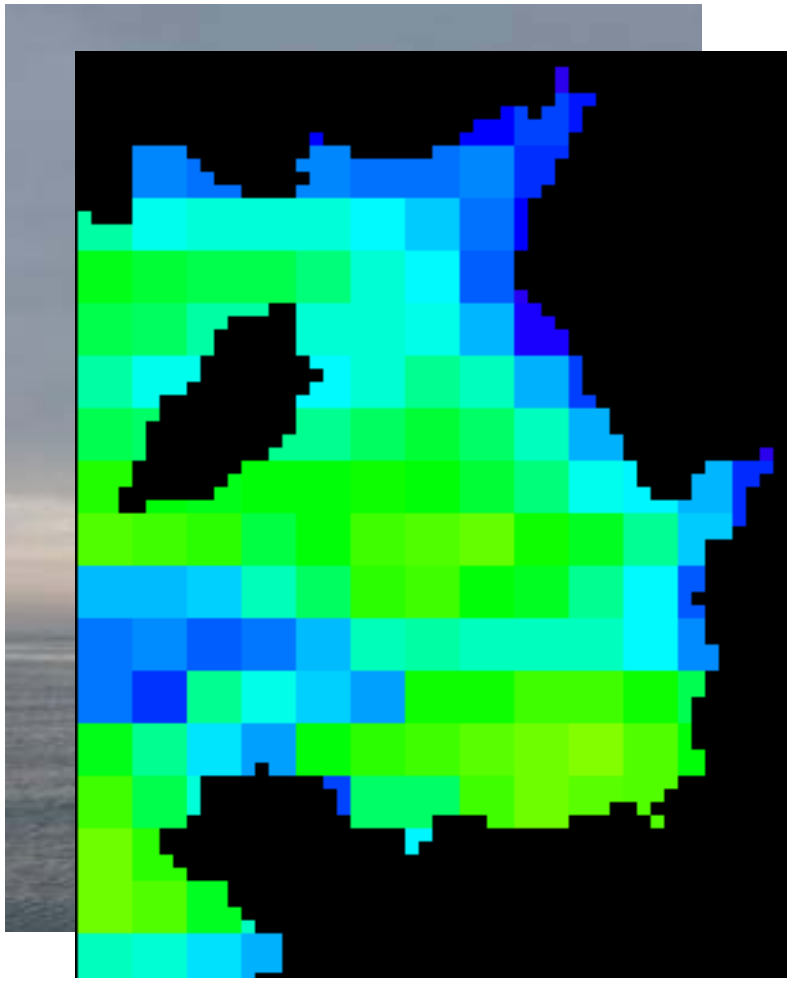
Wind resource assessment

- In-situ observations
  - Accurate observations
  - No spatial coverage

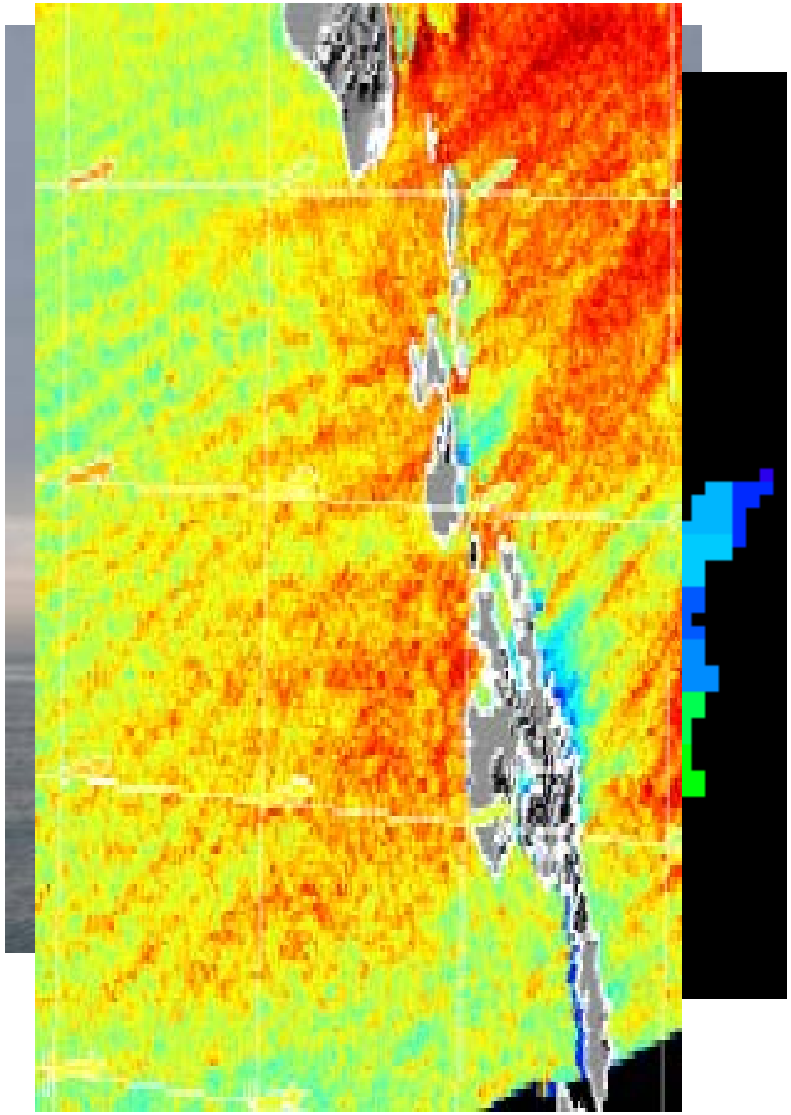
Wind resource assessment

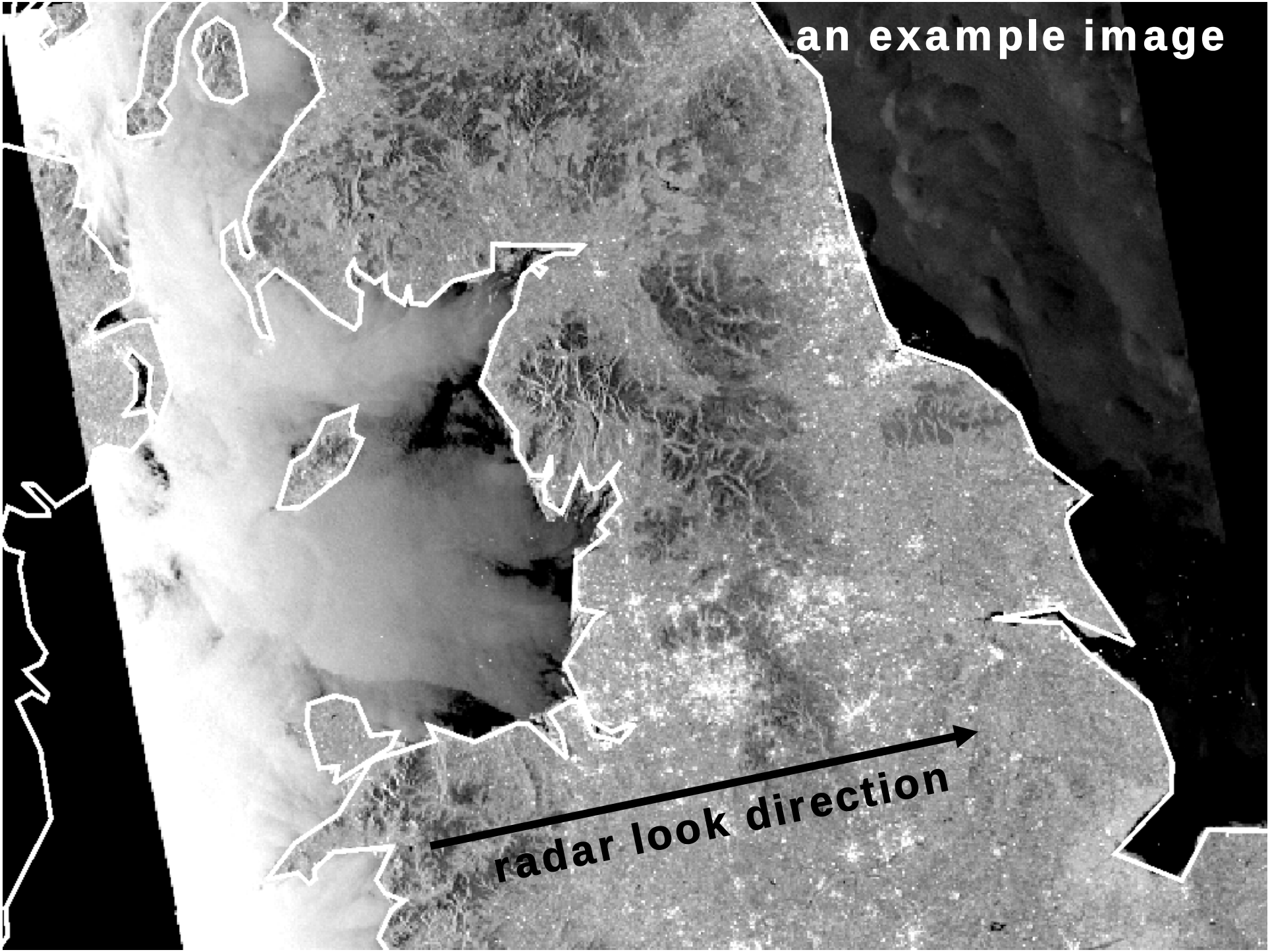
- In-situ observations
  - Accurate observations
  - No spatial coverage
- Numerical Weather Prediction (NWP)
  - Good temporal resolution
  - Moderate to low spatial resolution



Wind resource assessment

- In-situ observations
  - Accurate observations
  - No spatial coverage
- 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




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

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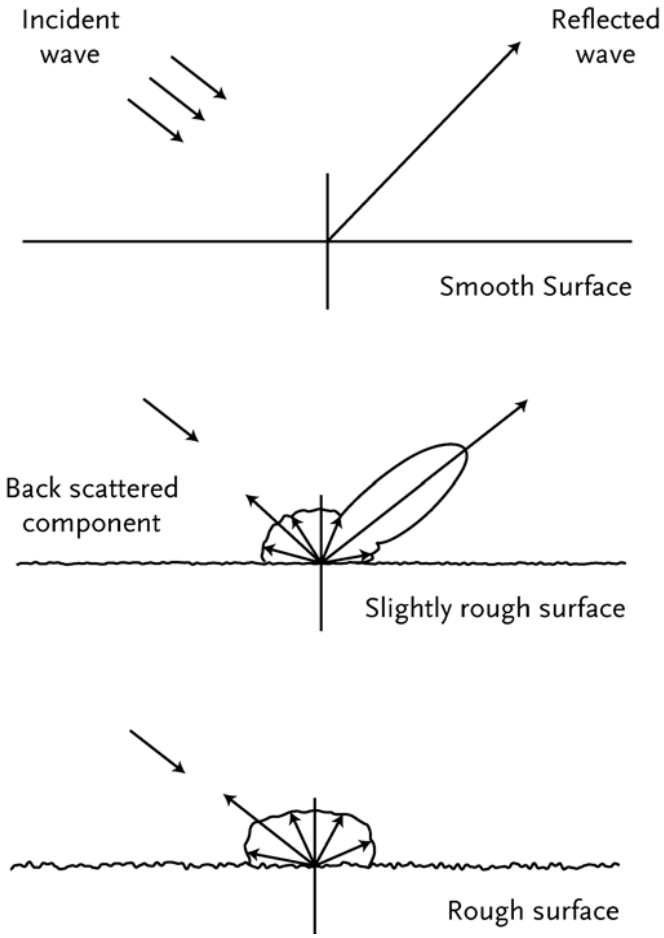
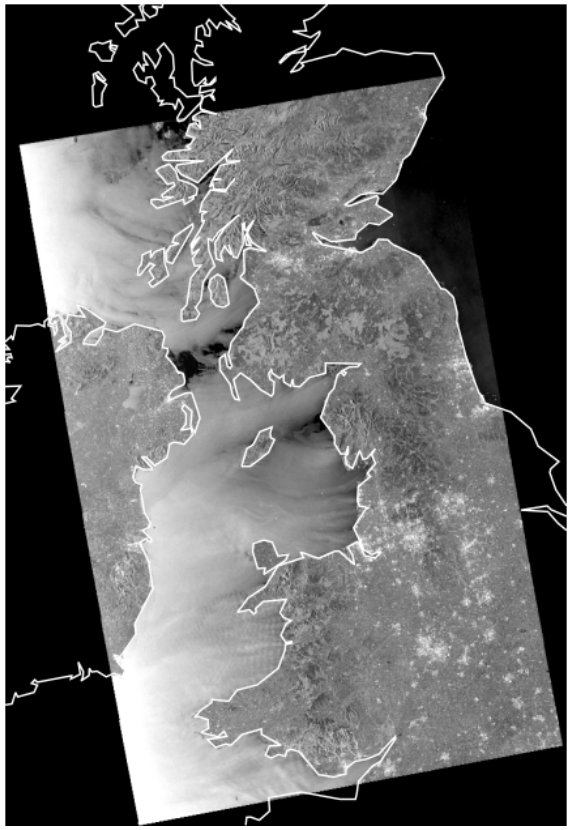
A. Developing the retrieval algorithm

Relating observations to wind

Wind → Surface roughness → Backscatter





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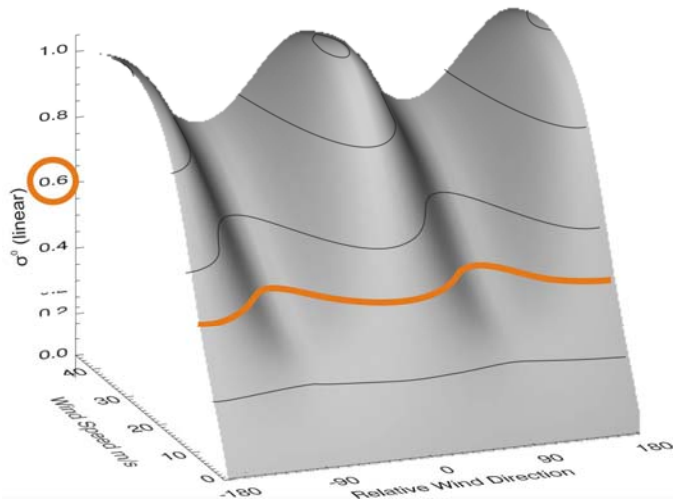
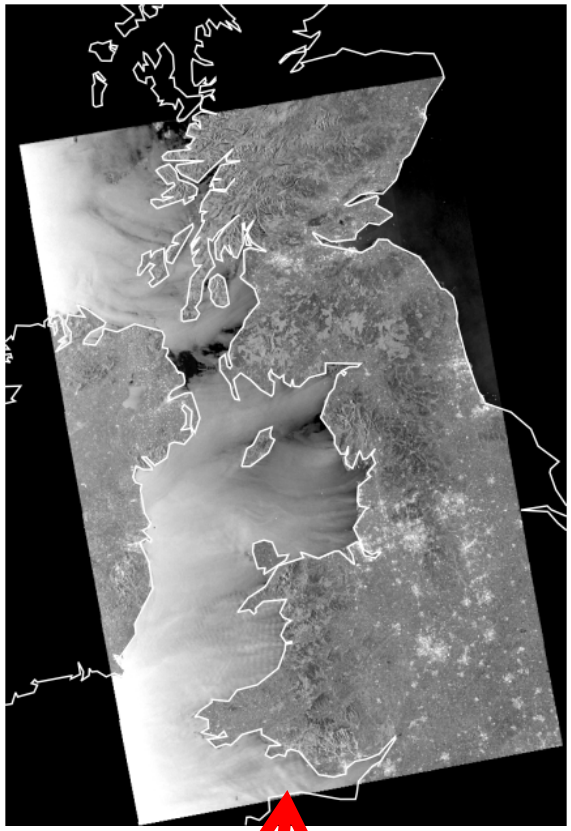
Relating observations to wind

Wind → Surface roughness → Backscatter



Backscatter Model



Wind direction
&
Wind speed

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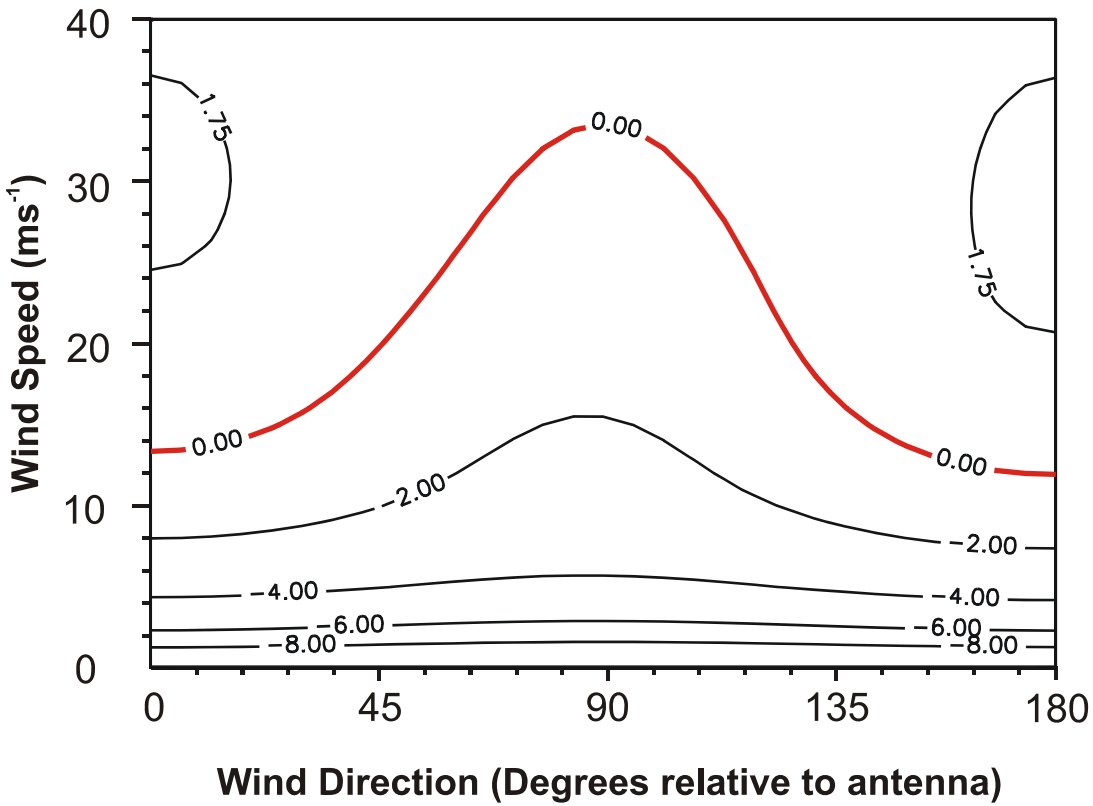
The retrieval problem



Underdetermined problem:

- –1 observation (radar backscatter)
- –2 unknowns (wind speed & direction)

= *infinite number of solutions*

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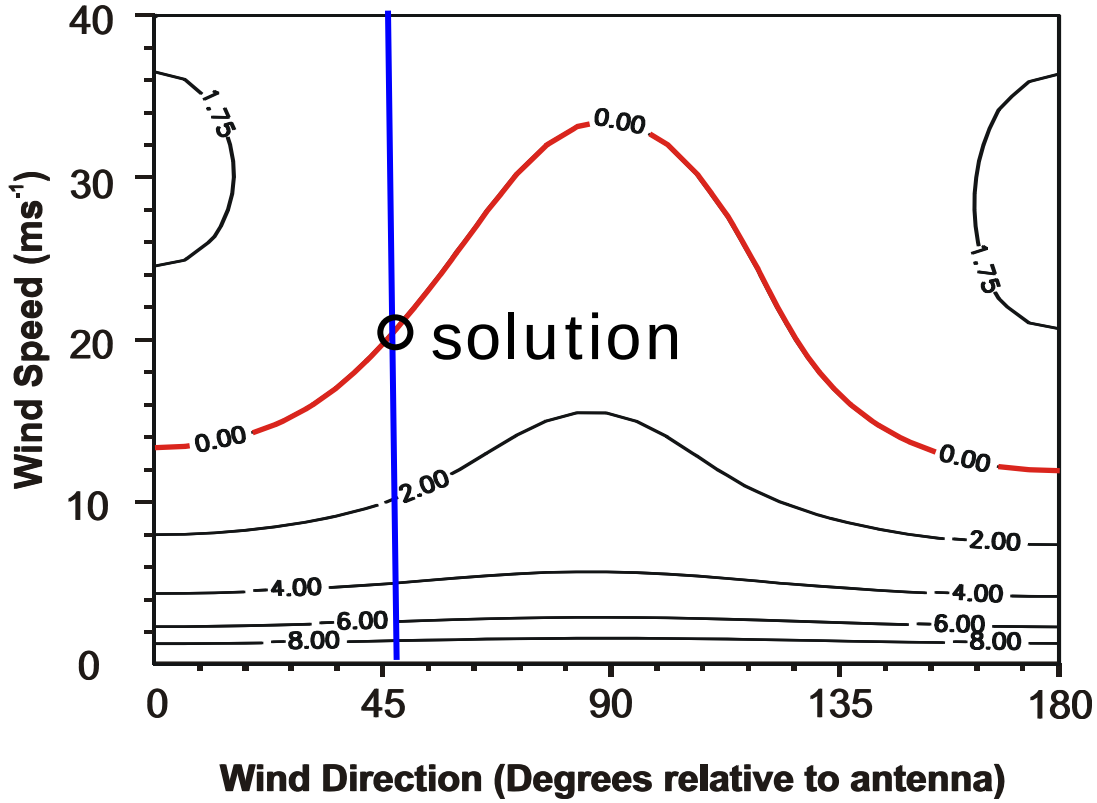
Classic retrieval method

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



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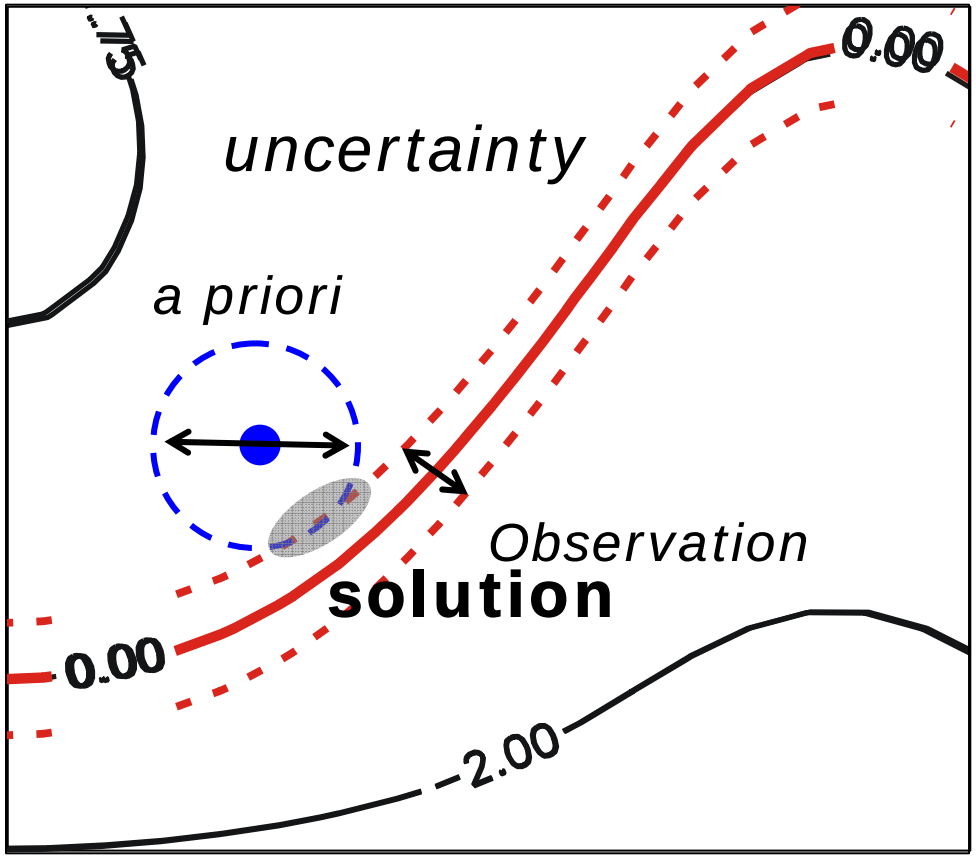
Bayesian retrieval method

Maximum Aposteriori Probability (MAP) algorithm

Iteratively estimates optimal wind vector given:

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



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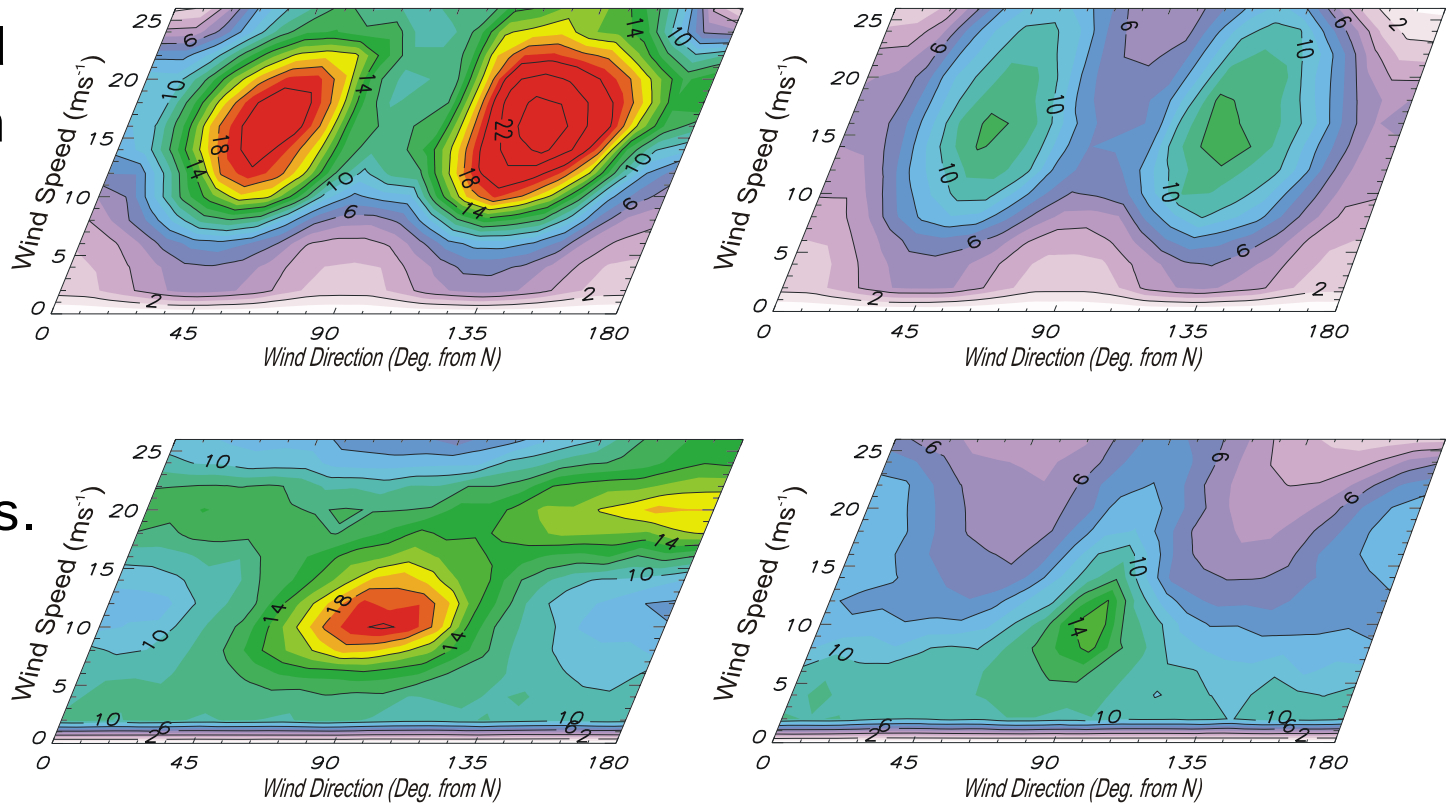
Sensitivity Analysis

DWSA **MAP**

20º wind direction error

10% obs. error

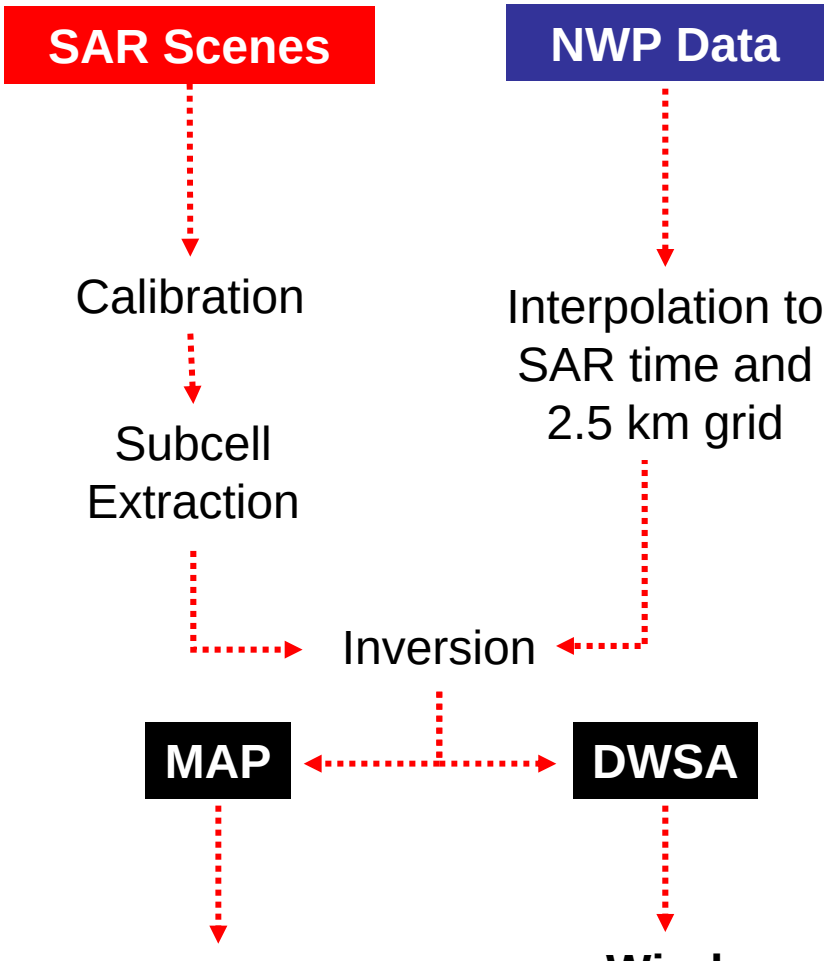


Plots show % error in wind speed

B.
Wind retrieval evaluation

Methodology

- Data:
  - SAR scenes- 63 Enivisat &ERS-2 scenes 2004-2006
  - UKMO Unified Mesoscale Model (UMM) surface wind
- 1.5 km^2 retrieval resolution



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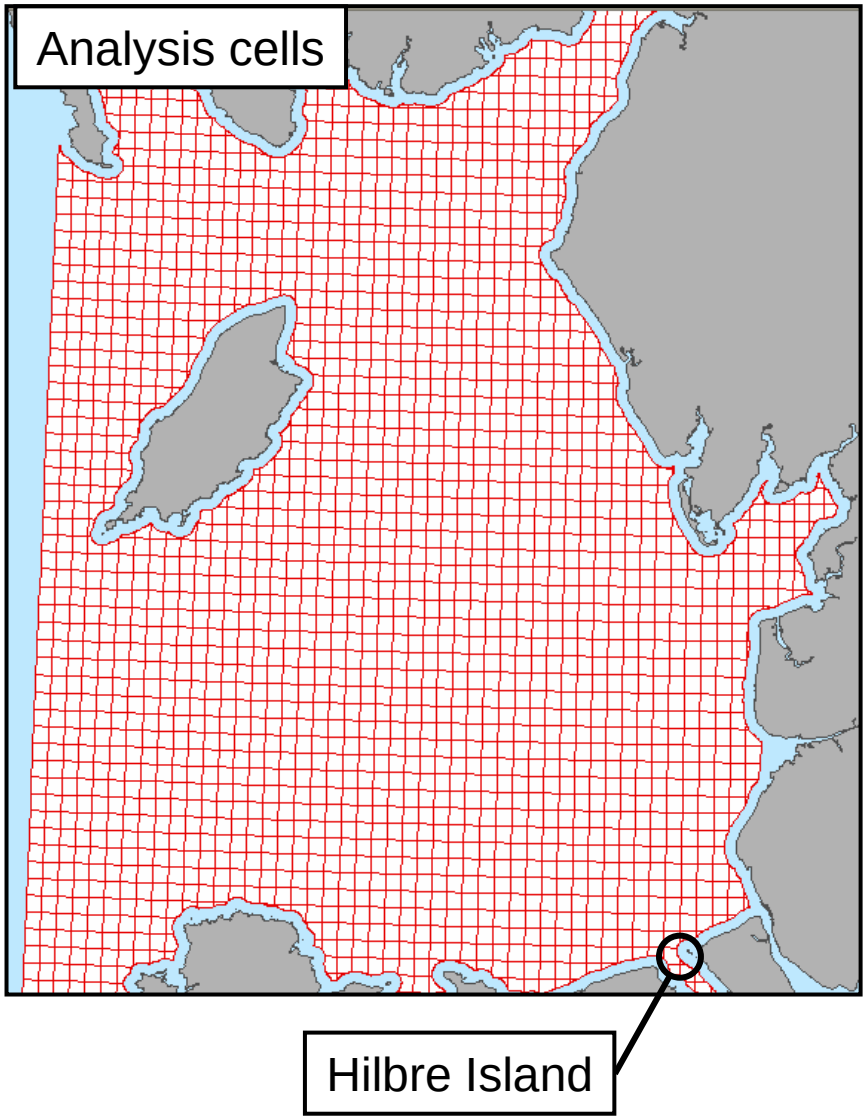
Methodology

- Data:
  - SAR scenes- 63 Enivisat &ERS-2 scenes 2004-2006
  - UKMO Unified Mesoscale Model (UMM) surface wind
- 1.5 km^2 retrieval resolution
- Validated against Hilbre Island insitu mast data



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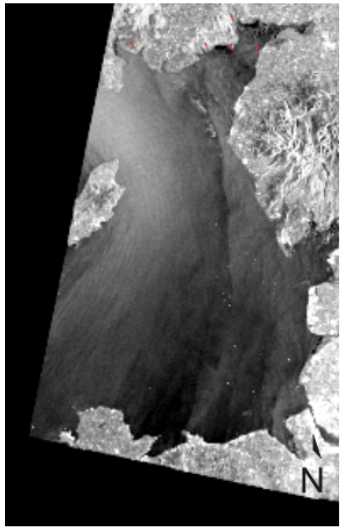
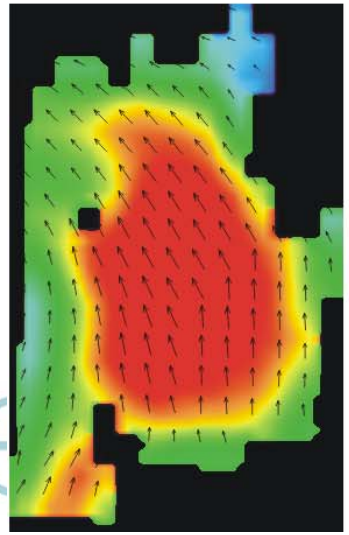
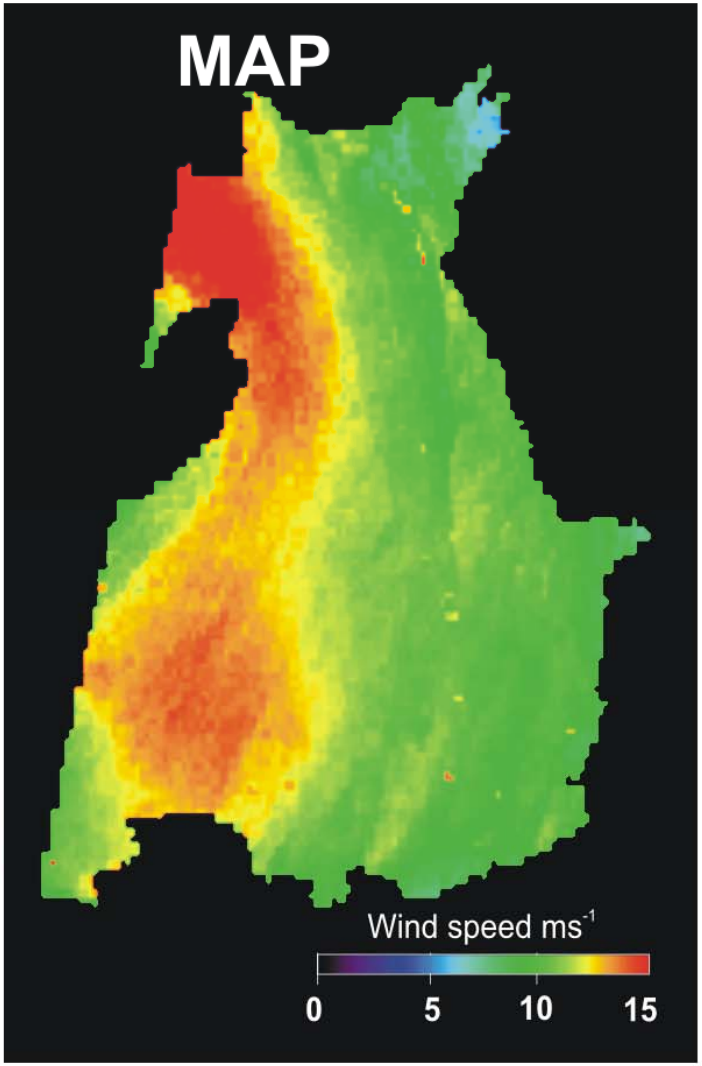
Example retrieval

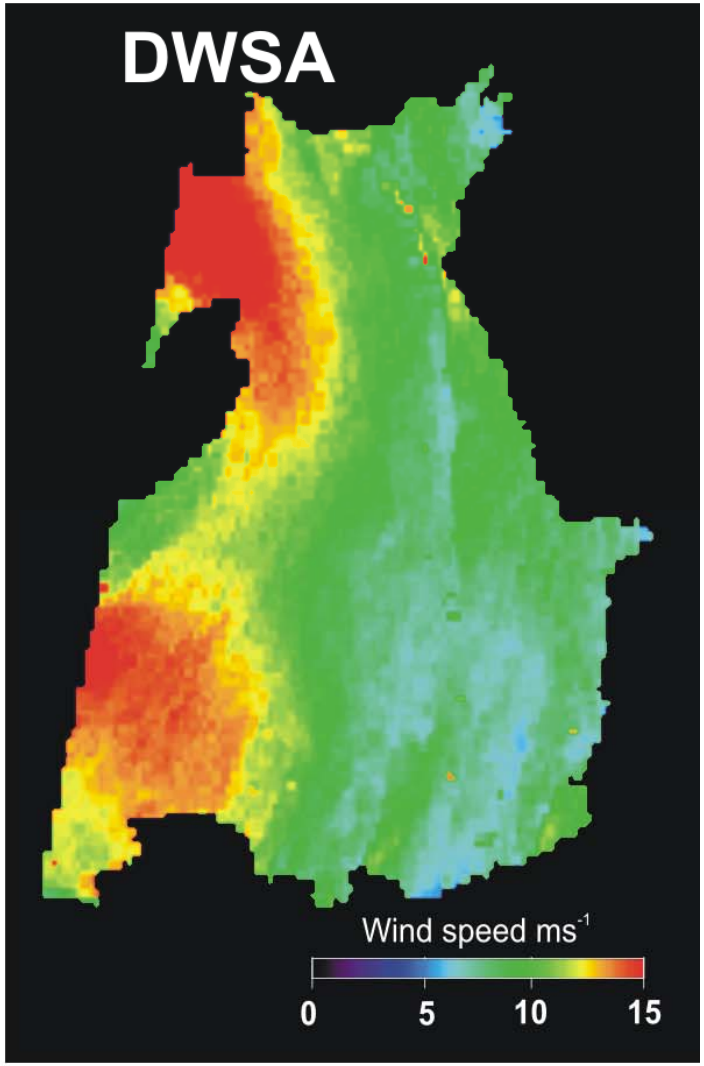
SAR



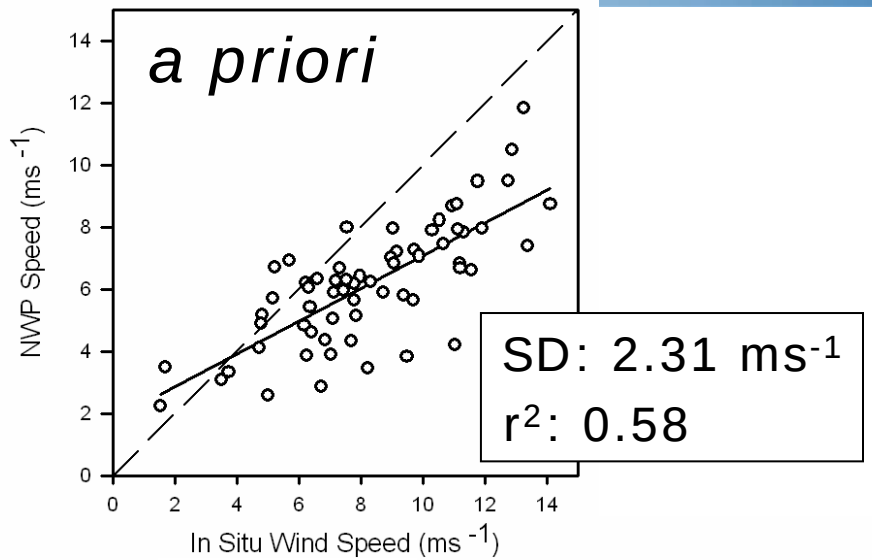
NWP

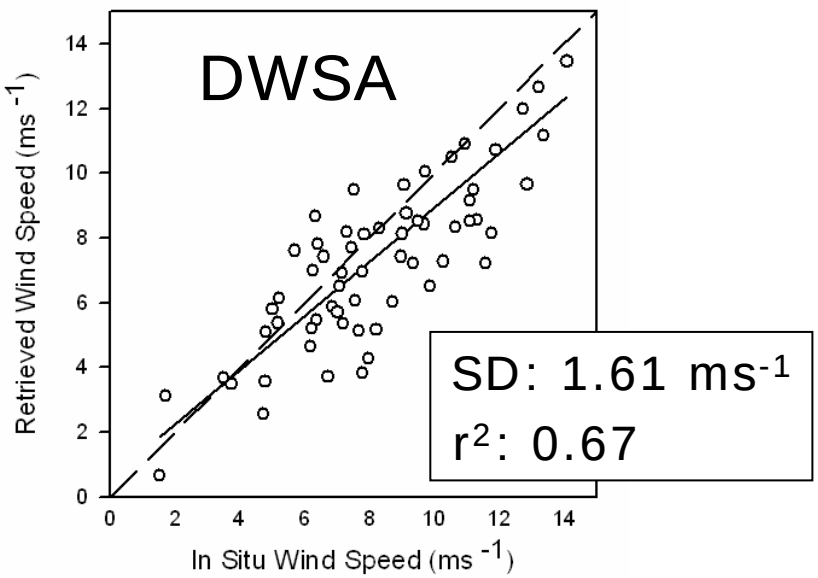


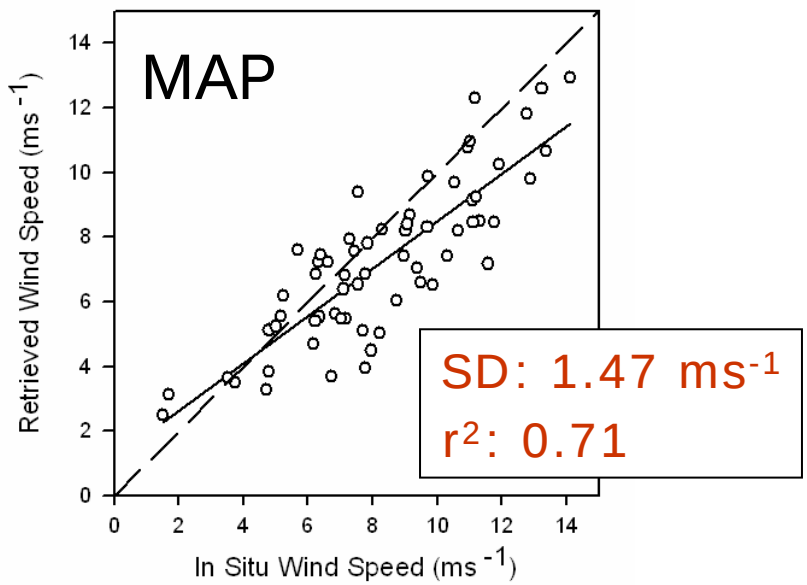




Validation


a priori
NWP Speed (ms -1)
In Situ Wind Speed (ms -1)
SD: 2.31 ms-1
r2: 0.58

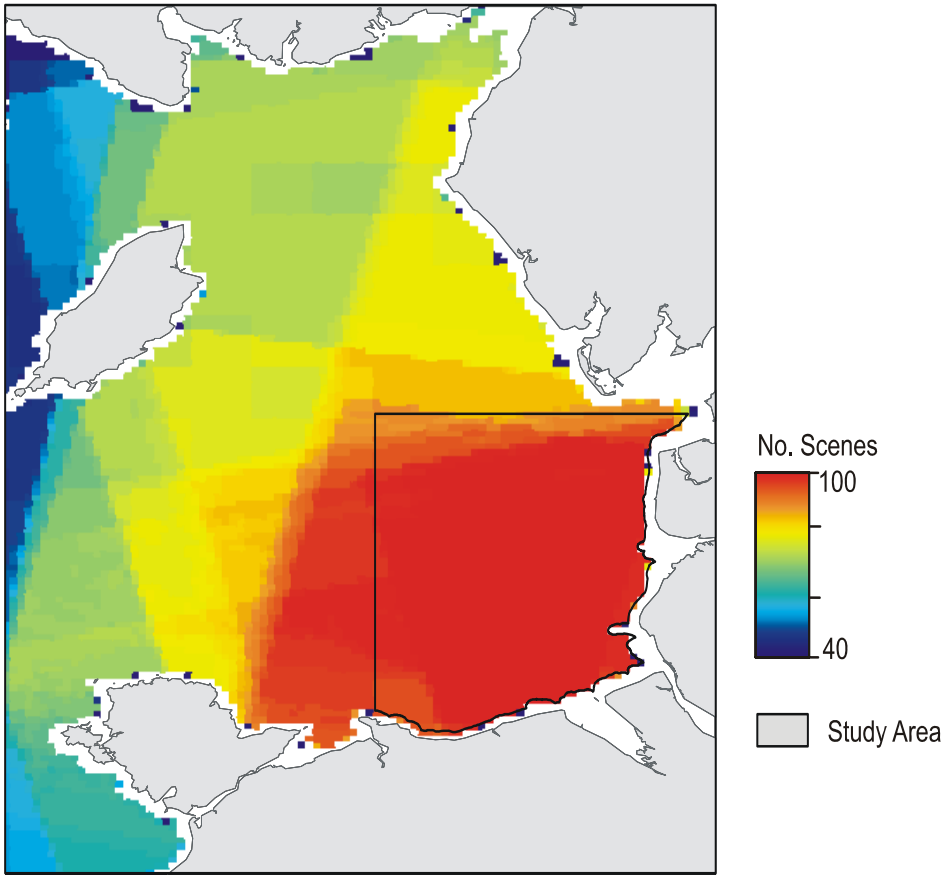

DWSA
Retrieved Wind Speed (ms -1)
In Situ Wind Speed (ms -1)
SD: 1.61 ms-1
r2: 0.67


MAP
Retrieved Wind Speed (ms -1)
In Situ Wind Speed (ms -1)
SD: 1.47 ms-1
r2: 0.71

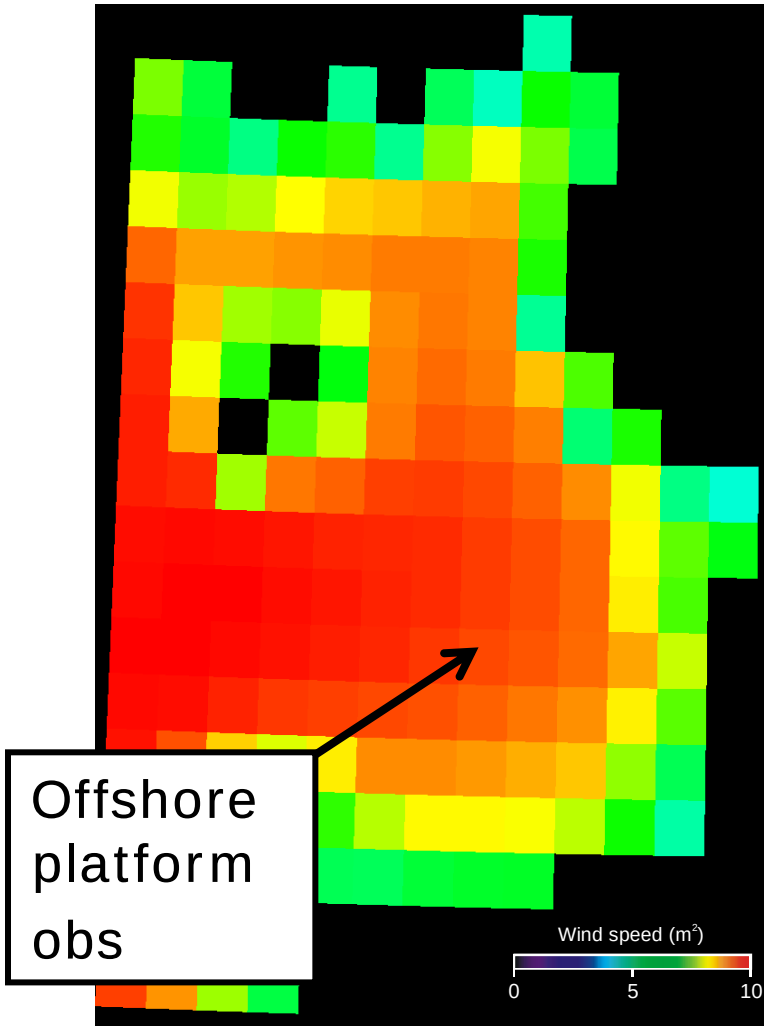
C.
SAR wind resource assessment

The data set

103 SAR scenes



UK Wind Atlas data



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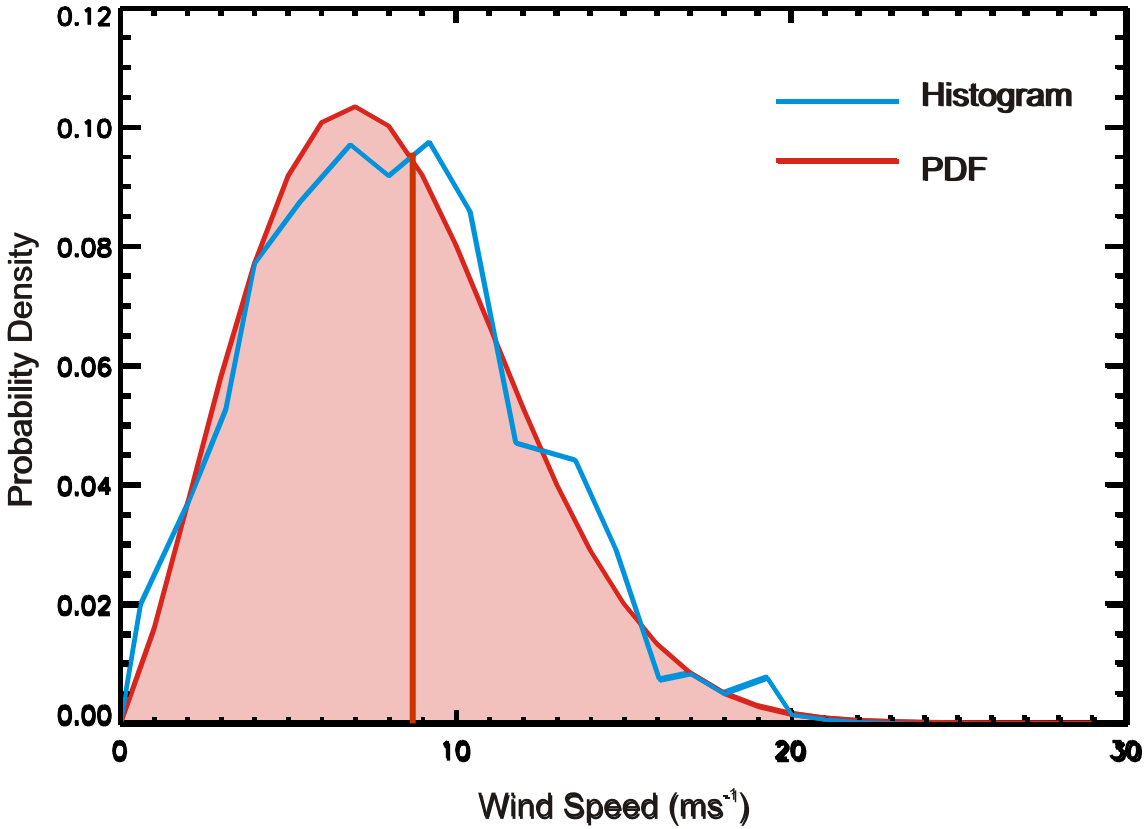
Key wind resource indicators

Wind speed scaled to turbine height (80m)



1. Mean Wind Speed

2. Wind Power Density

PDF

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

Area of rotor

Mean speed

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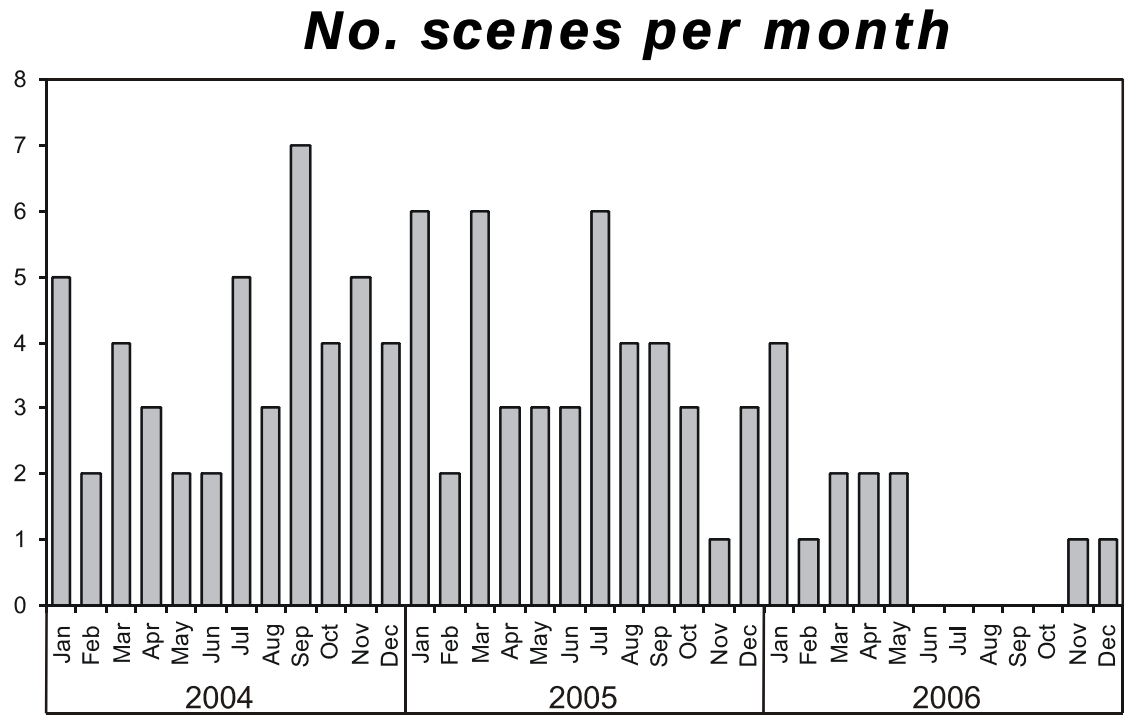
SAR sampling issues

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



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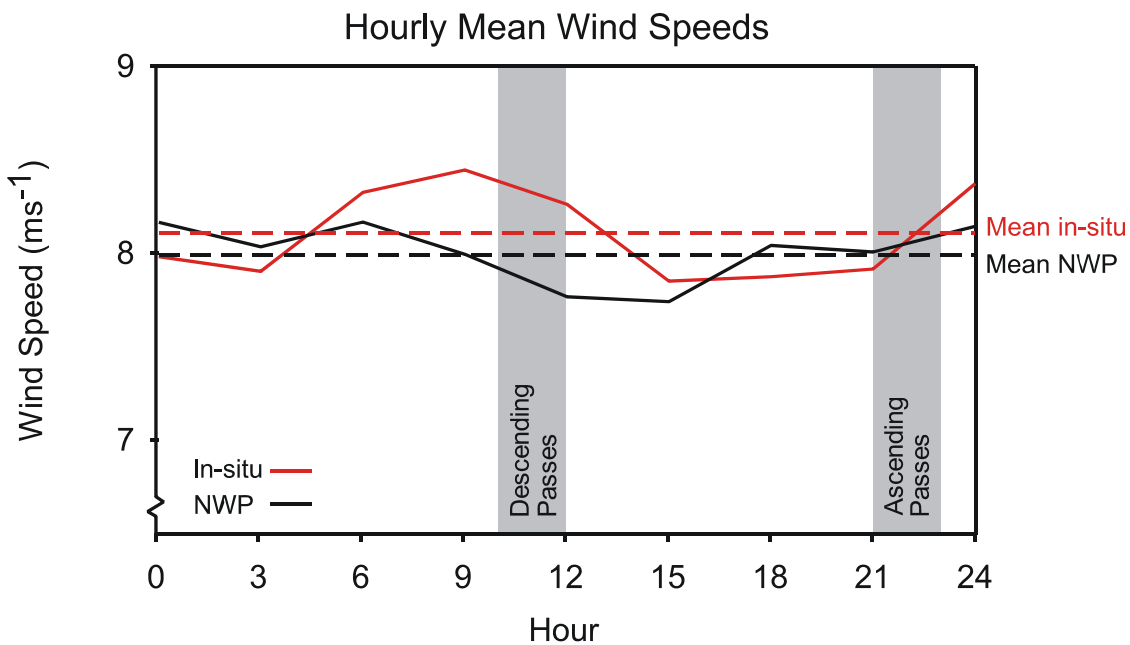
SAR sampling issues

1. Dataset density
   - Length of obs. period
   - No & distribution of obs.
2. Diurnal sampling
   - SAR pass at set times



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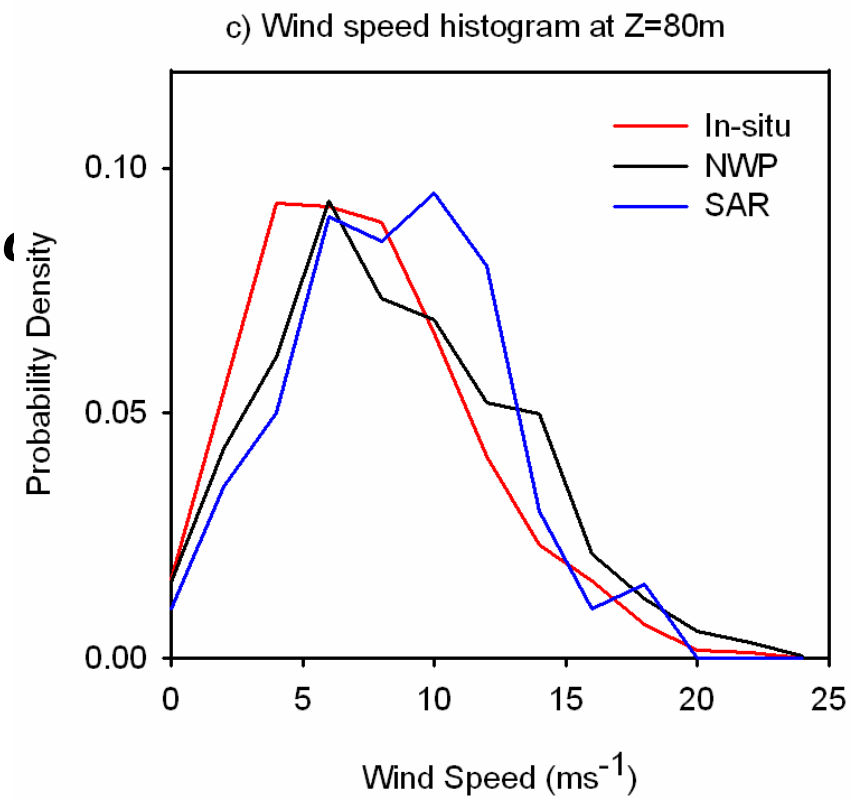
SAR sampling issues

1. Dataset density
   - Length of obs. period
   - No & distribution of obs.
2. Diurnal sampling
   - SAR pass at set times
3. Wind speed distribution truncation
   - Backscatter models unreliable below 2 ms^{-1}



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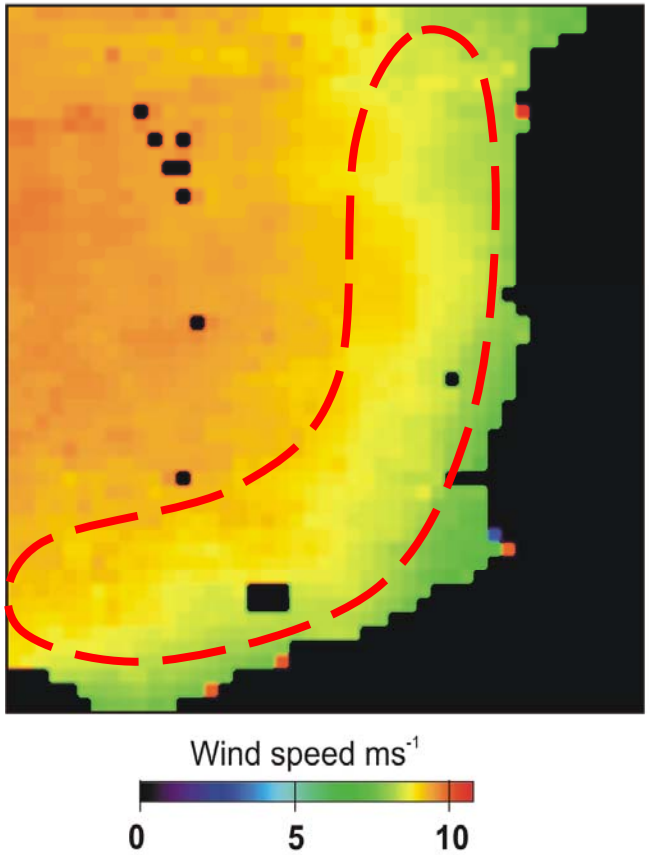
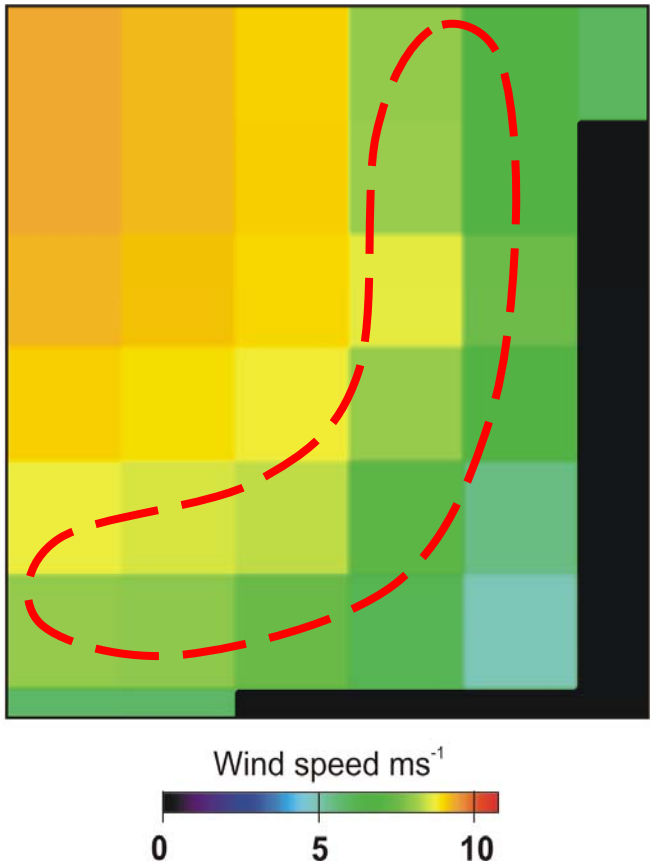
Mean wind speeds

SAR



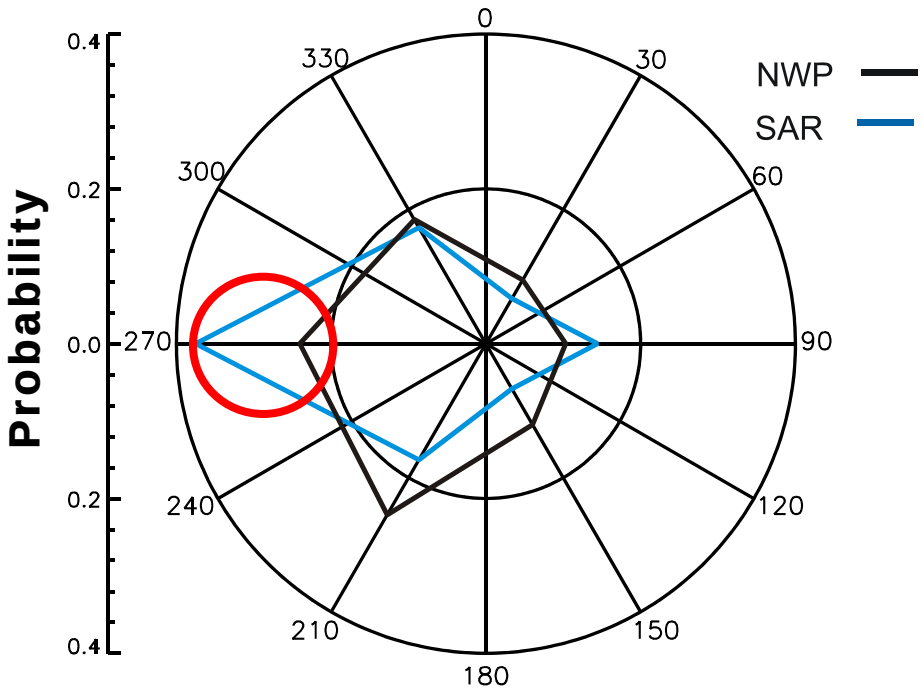
Wind Atlas



why are SAR wind speeds high here?

Mean wind speeds

Wind direction sampling



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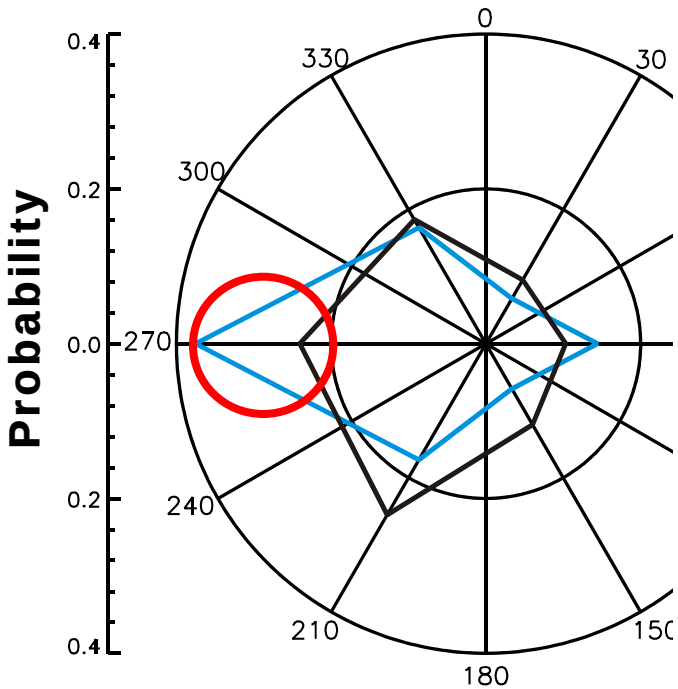
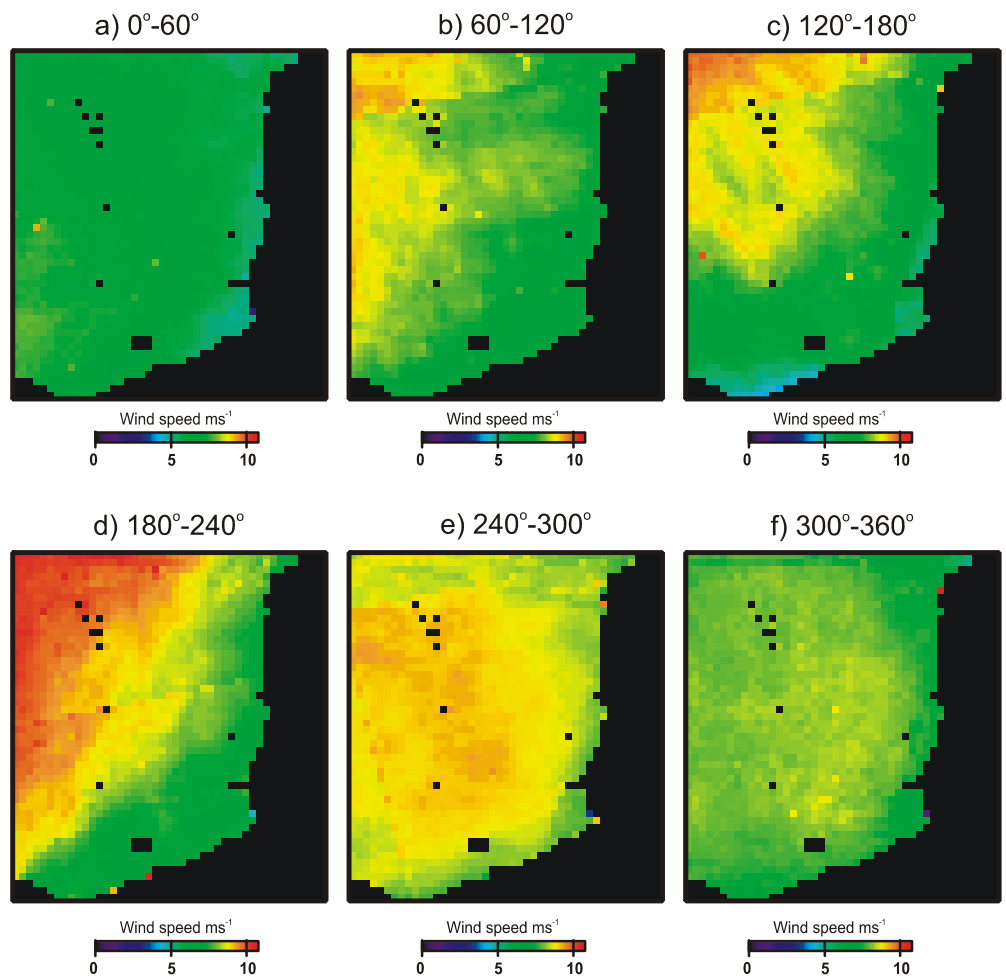
Mean wind speeds

Wind direction sampling



Mean speed per direction sector



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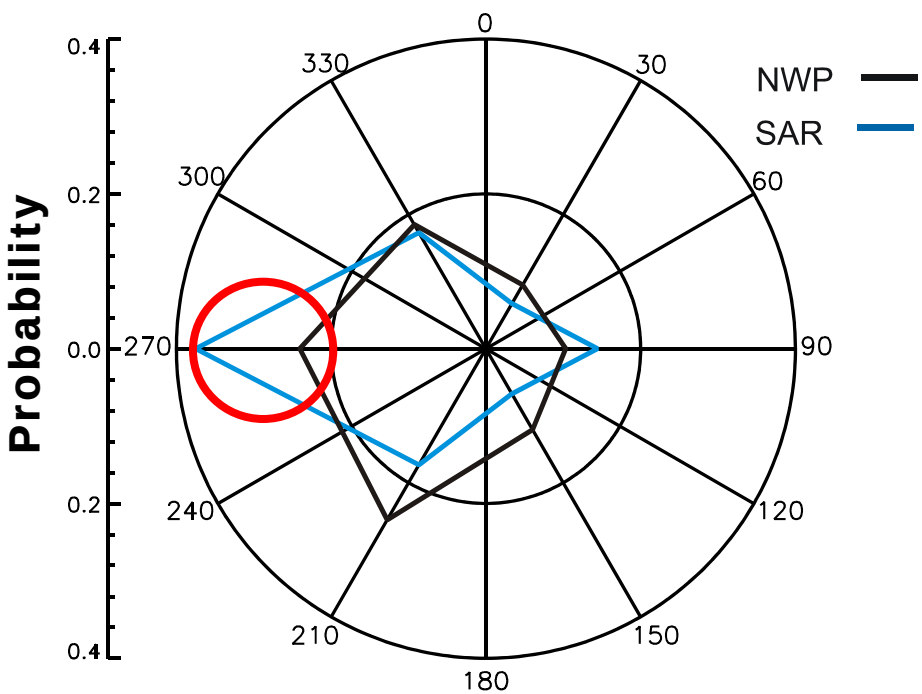
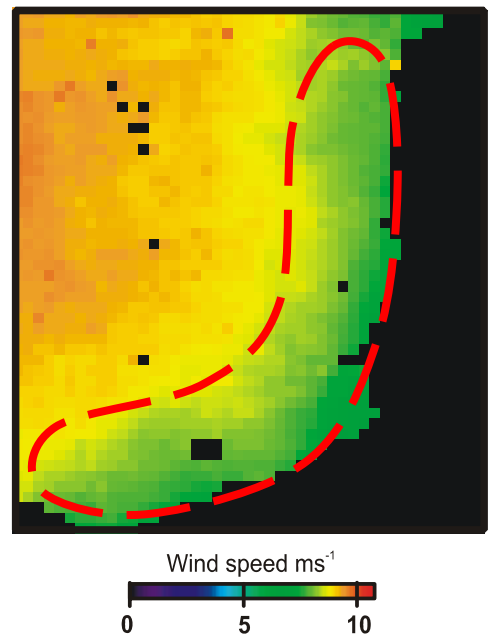
Mean wind speeds

Wind direction sampling



Weighted mean



$$\bar{v} = \frac{\bar{s}_1 w_1 + \bar{s}_2 w_2 + \ldots + \bar{s}_n w_n}{w_1 + w_2 + \ldots + w_n}$$

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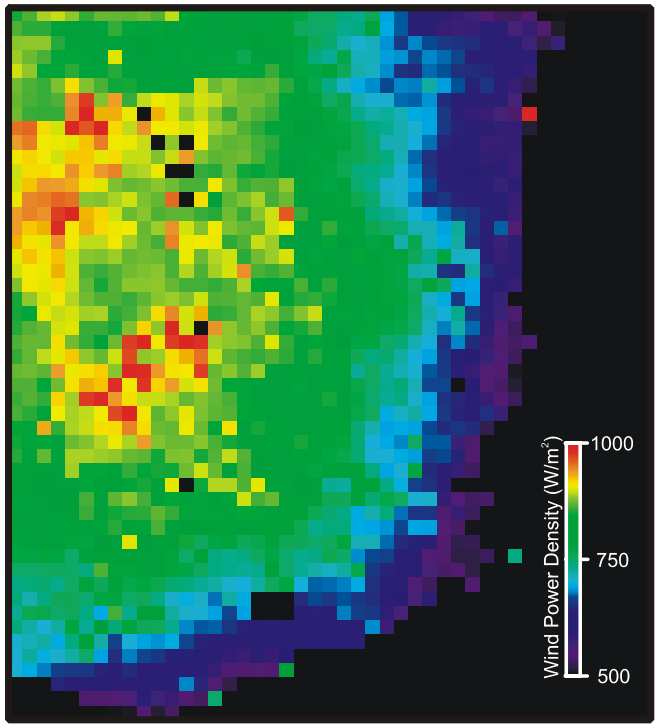
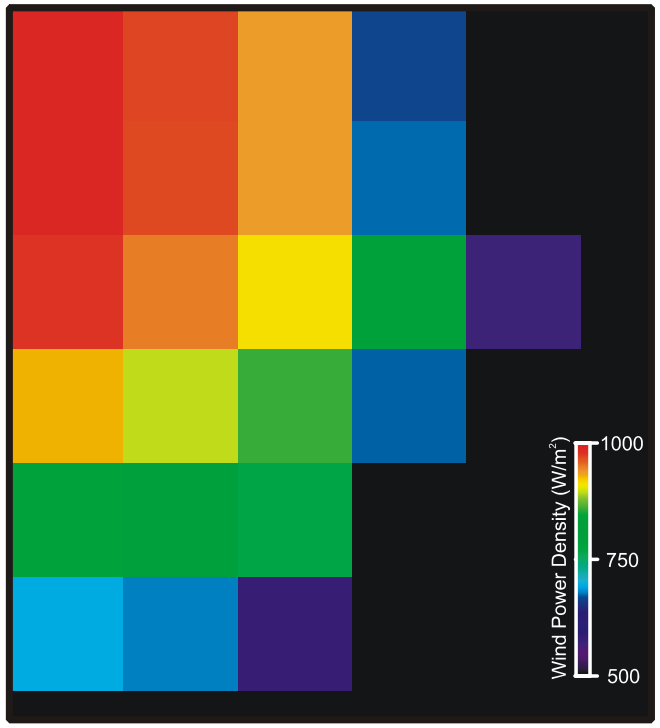
Wind power density

a) SAR

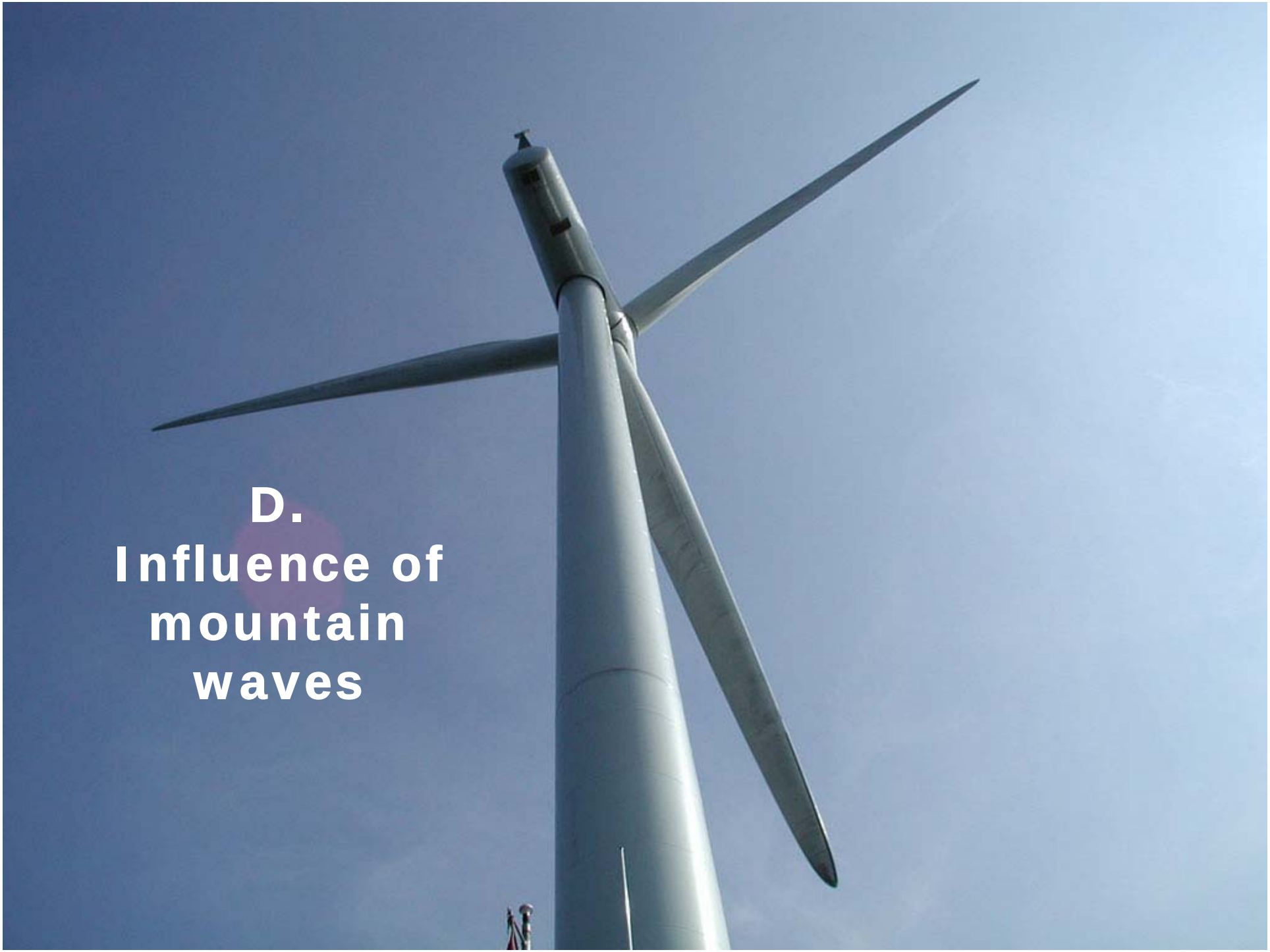


b) Wind Atlas



Poor result due to low number of scenes

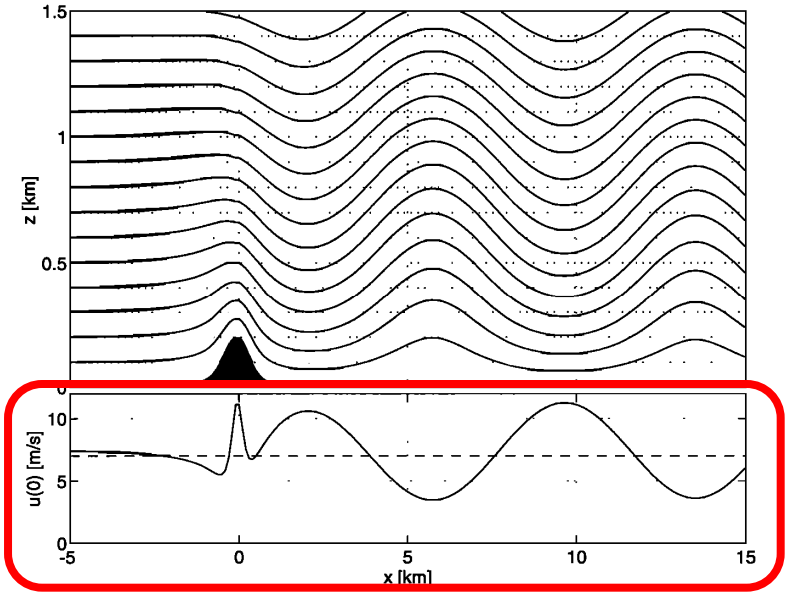
Over 170 needed to estimate the PDF accurately

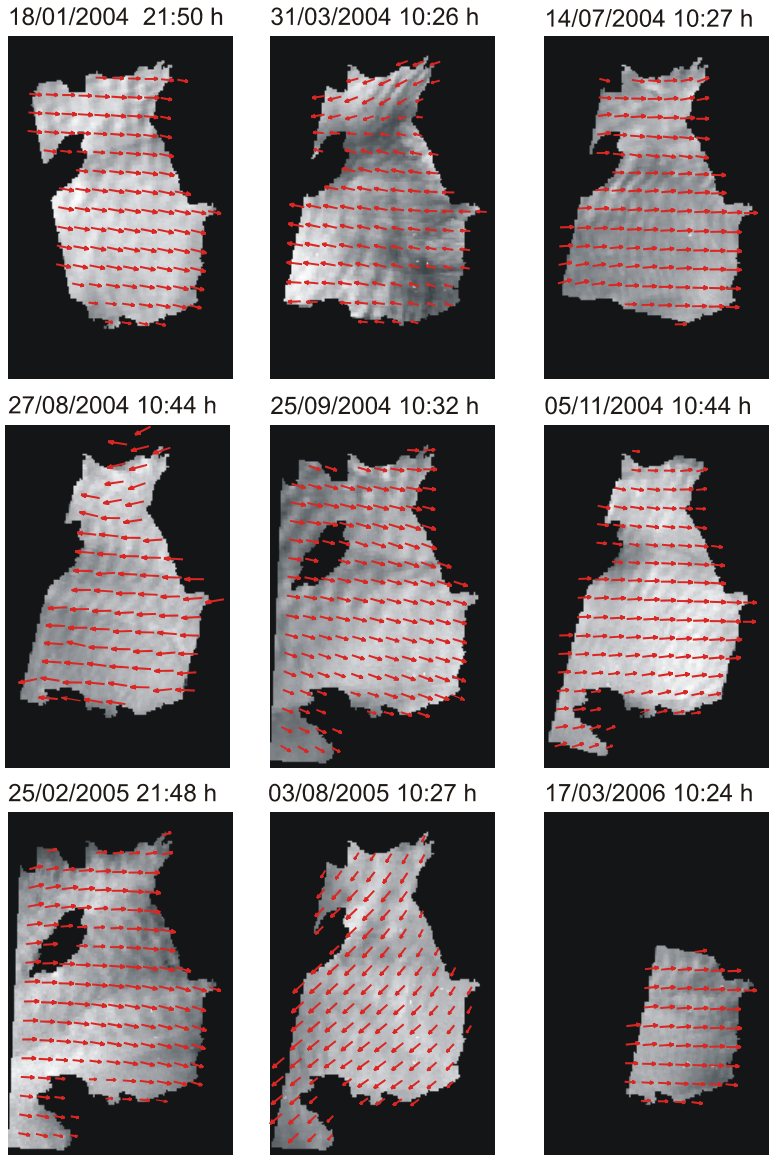


D. Influence of mountain waves

Mountain waves

- Generated by airflow over mountains
- Found in 1/3 of scenes
- Not currently resolved by UK NWP model
- Implications for wind resource?

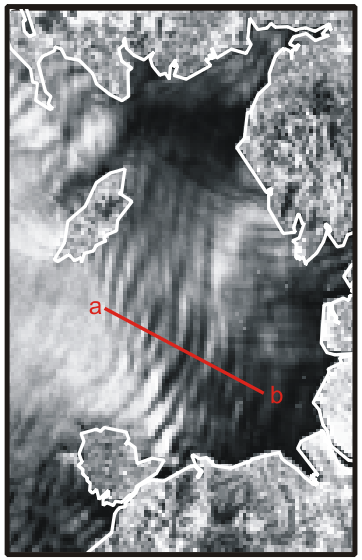




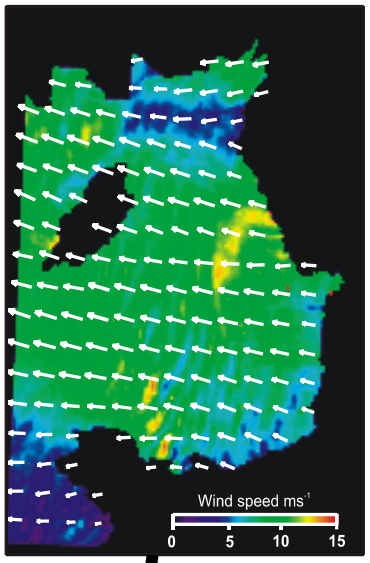
Event from October 2005

15/10/05

a) SAR Image

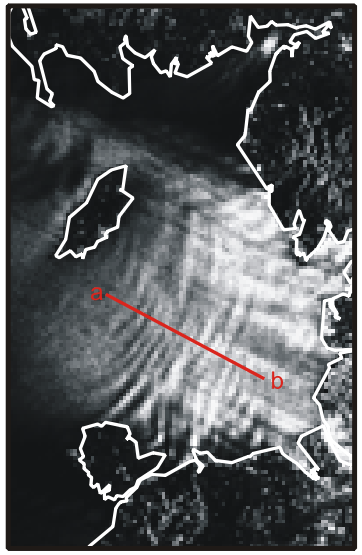


b) Wind Field

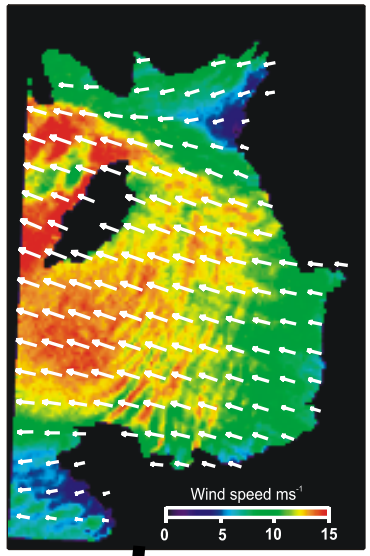


18/10/05

a) SAR Image

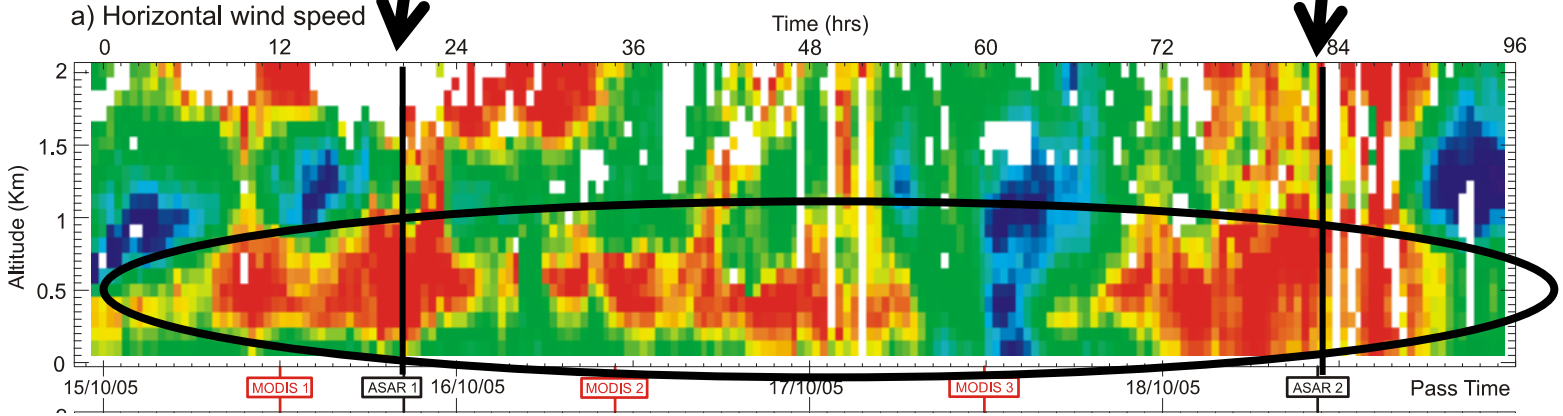


b) Wind Field



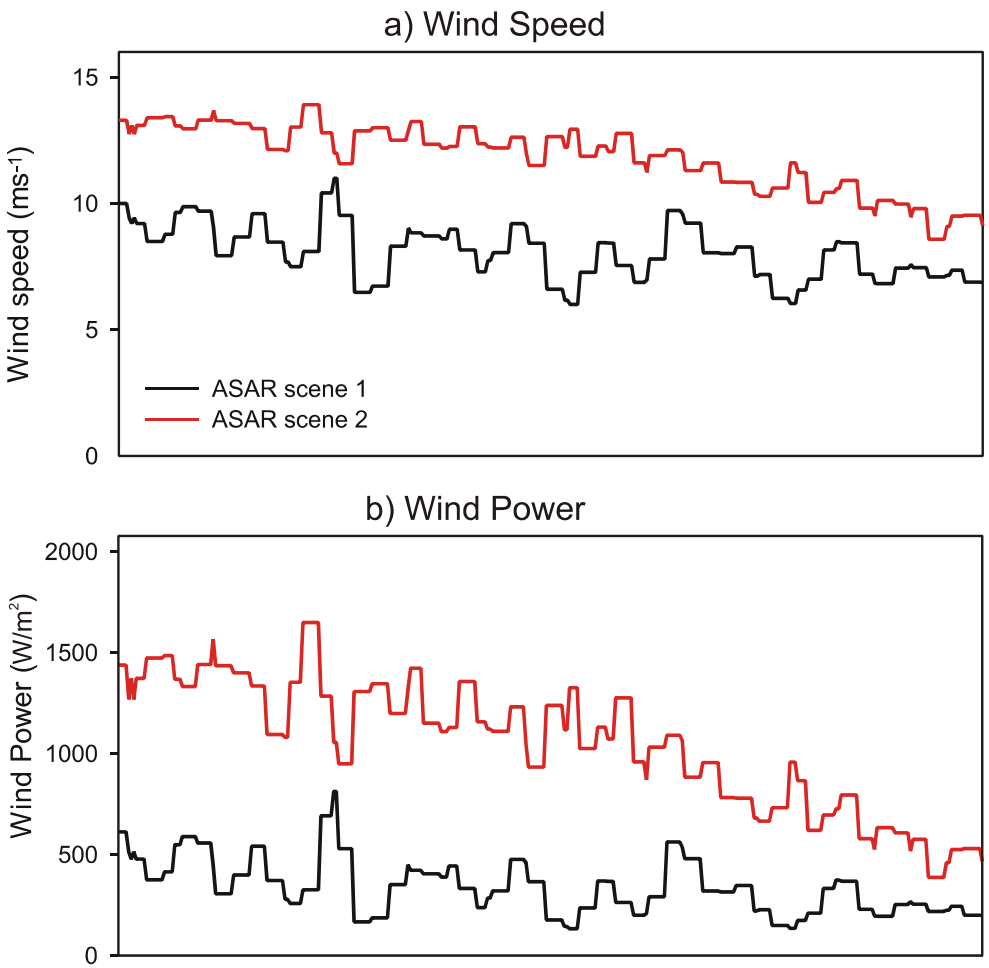
Radar wind profiler

a) Horizontal wind speed



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?



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Returning to criteria

Criteria for adoption of SAR

1. Accuracy

- Best case accurate to ~1ms^{-1}

2. Spatial Resolution

- Reliable estimates of backscatter possible at 1.5 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+

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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

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Questions?