Synthetic Aperture Radar for wind energy applications: potential and challenges at high wind speeds

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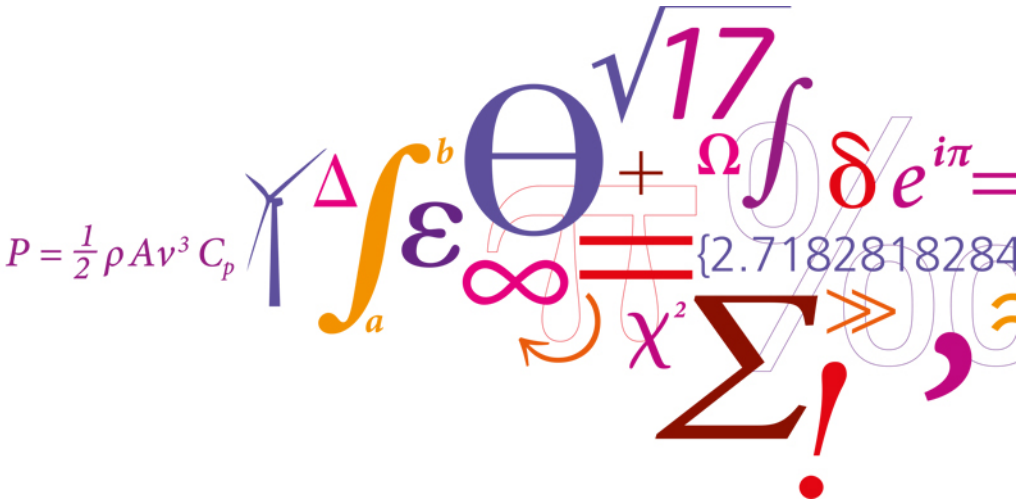

DTU Wind Energy
Department of Wind Energy

Offshore wind energy

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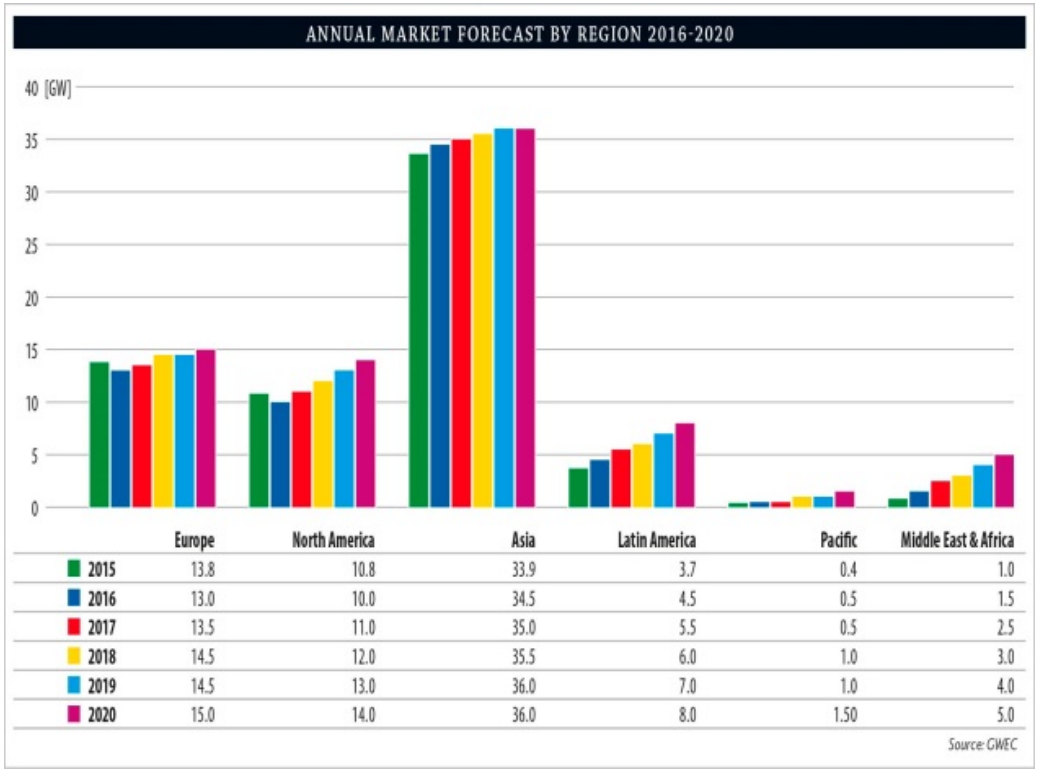
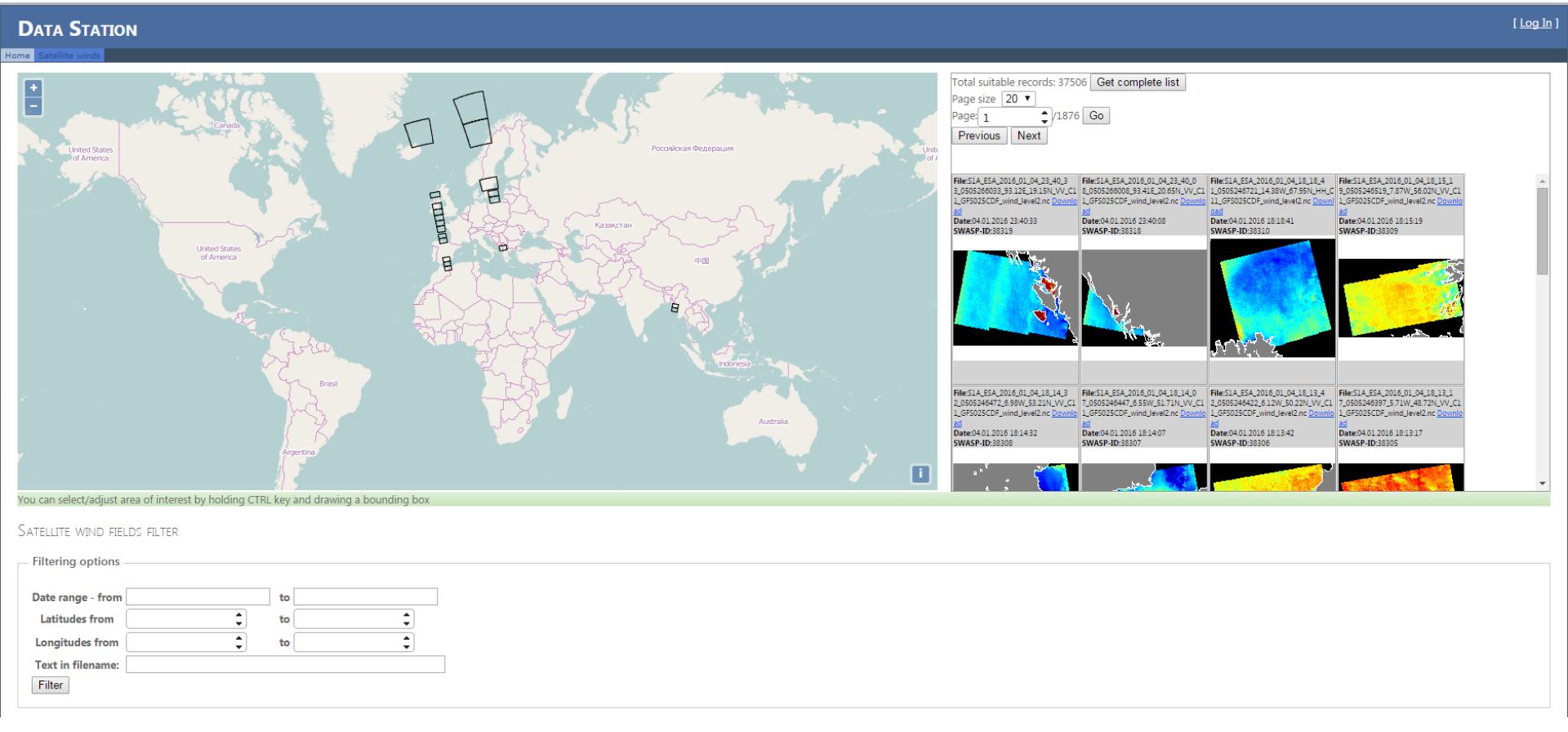


	Europe	North America	Asia	Latin America	Pacific	Middle East & Africa
2015	13.8	10.8	33.9	3.7	0.4	1.0
2016	13.0	10.0	34.5	4.5	0.5	1.5
2017	13.5	11.0	35.0	5.5	0.5	2.5
2018	14.5	12.0	35.5	6.0	1.0	3.0
2019	14.5	13.0	36.0	7.0	1.0	4.0
2020	15.0	14.0	36.0	8.0	1.50	5.0

Annual wind power installations 2016-2020. Source: GWEC.

SAR wind data archive at DTU

- 30,000+ ENVISAT ASAR scenes (2002-2011)
- 36,000+ Sentinel-1 A/B SAR scenes (2014->)



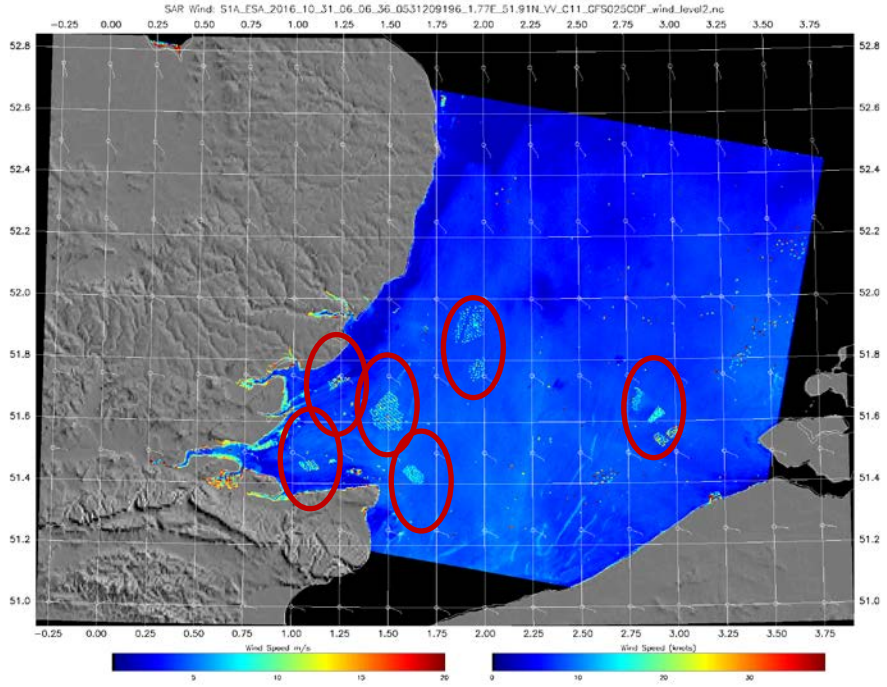
SAR Ocean Products System (SAROPS)

- Evolved from the APL/NOAA SAR Wind Retrieval System http://fermi.jhuapl.edu/
- SAR wind retrieval in near-real-time
- NOAA covers polar seas and US coastlines (operational)

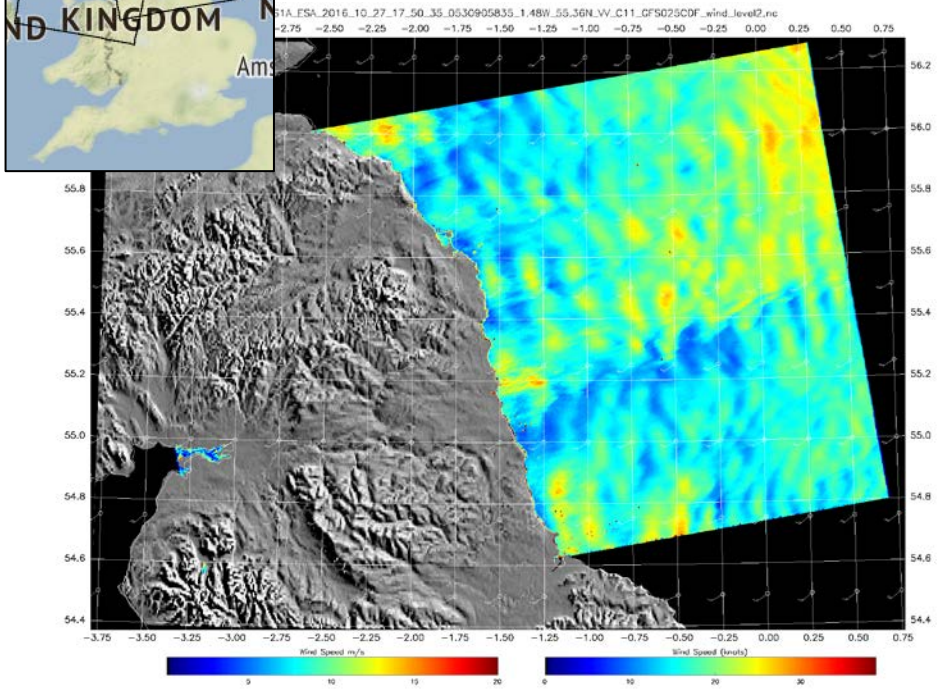
  Monaldo, F.M *et al*. (2015): A Weather Eye on Coastal Winds, *Eos*, 96, doi:10.1029/2015EO034581)

- DTU covers the European seas (routine)

Sentinel-1 A retrievals over the UK



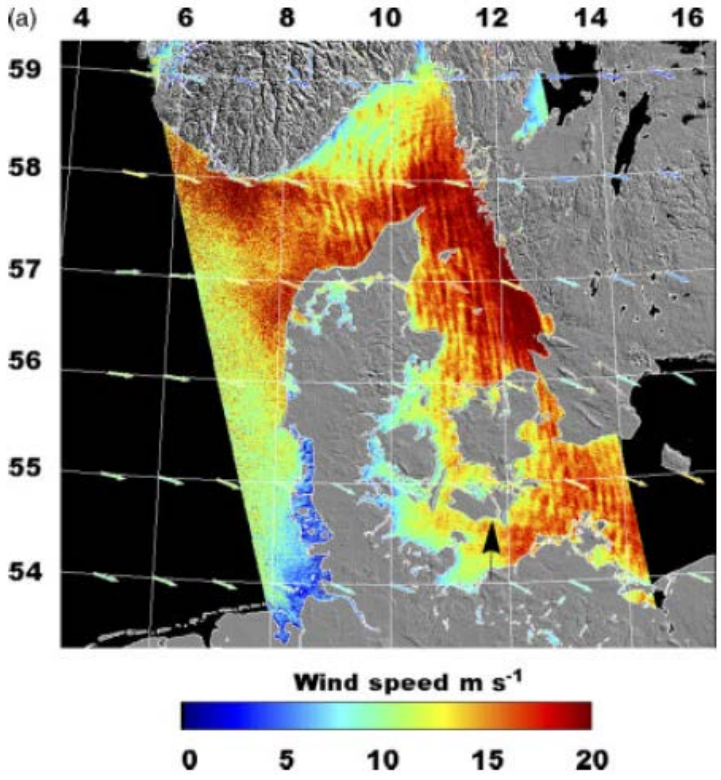
October 31, 2016 at 06:06 UTC



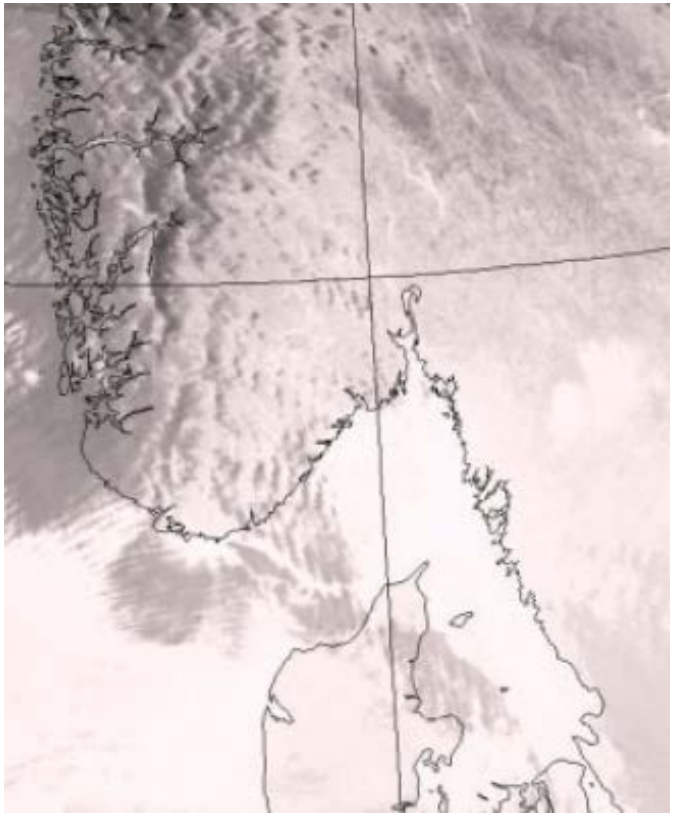
October 27, 2016 at 17:50 UTC

Mountain gravity waves

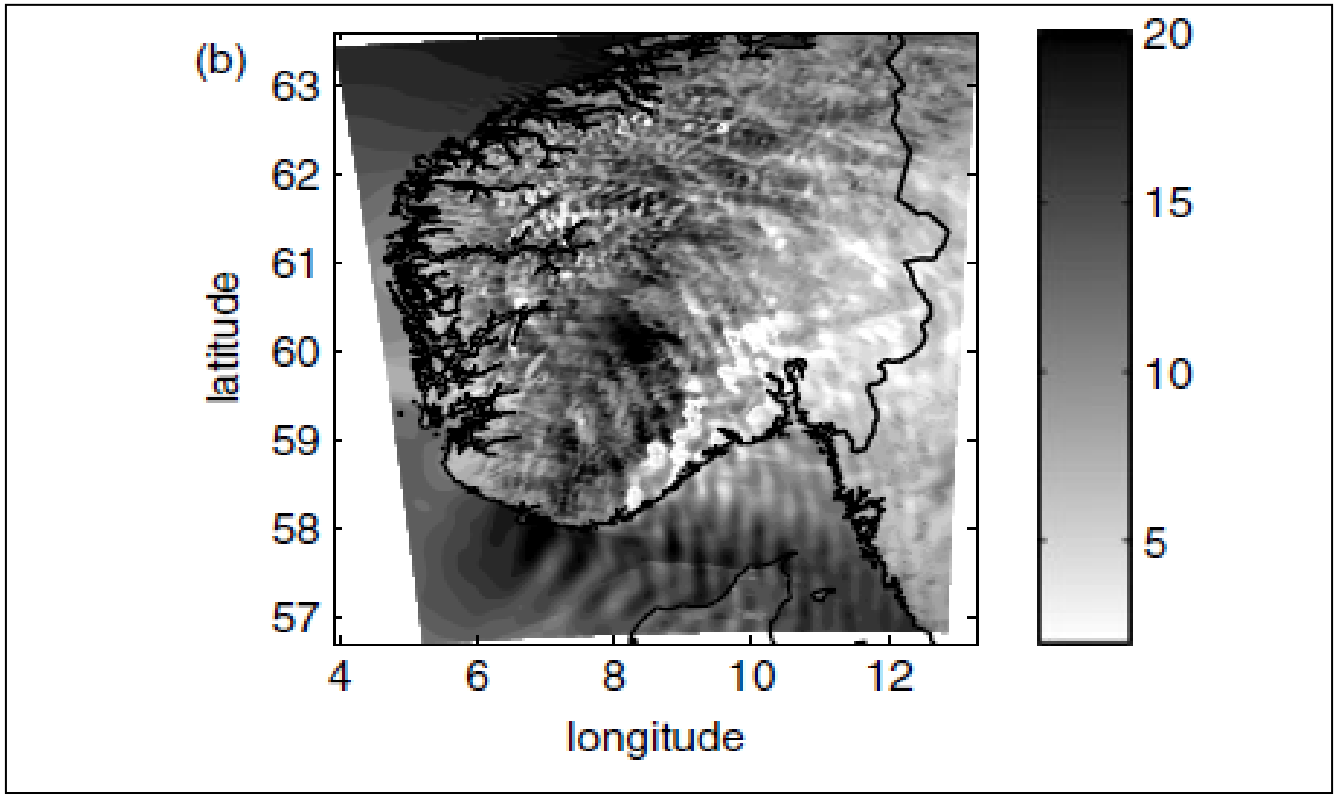
November 6, 2006



Envisat ASAR 10-m wind speed



Cloud image



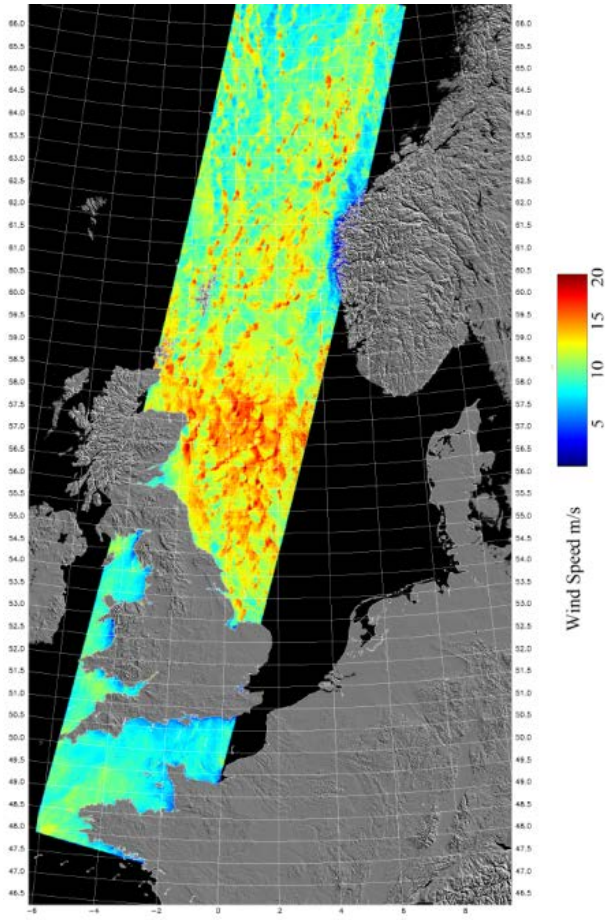
WRF wind speed

Larsén X., Larsen S. and Hahmann N. A. 2012: Origin of the waves in "A case study of mesoscale spectra of wind and temperature, observed and simulated": Lee waves of the Norwegian mountains, *Q. J. R. Meteorol. Soc.* **137** DOI:10.1002/qj.916, 138: 274-279.

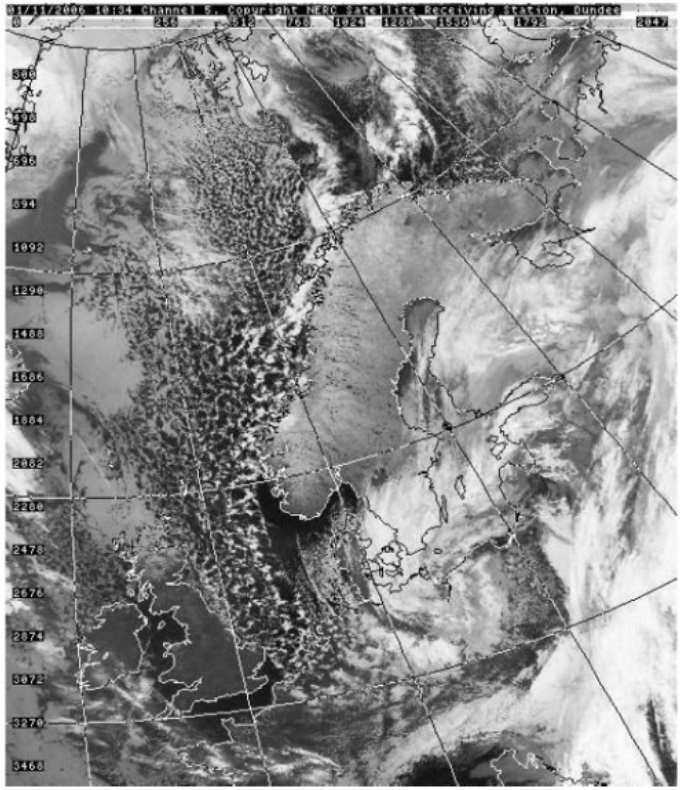
Larsén X., Larsen S. and Badger M. 2011: A case study of mesoscale spectra of wind and temperature, observed and simulated, *Quarterly Journal of Royal Meteorological Society*, Doi: 10.1002/qj.739, 137:264-274.

Larsén X., Vincent C. and Larsen S.E. 2013: Spectral structure of mesoscale winds over the water, *Q. J. R. Meteorol. Soc.*, DOI:10.1002/qj.2003, 139, 685-700.

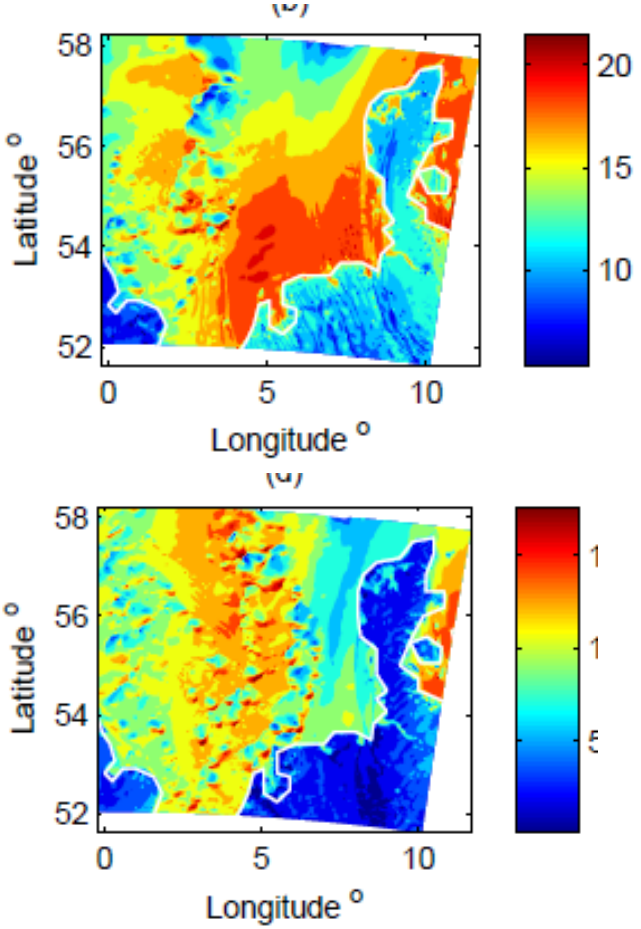
Open cells



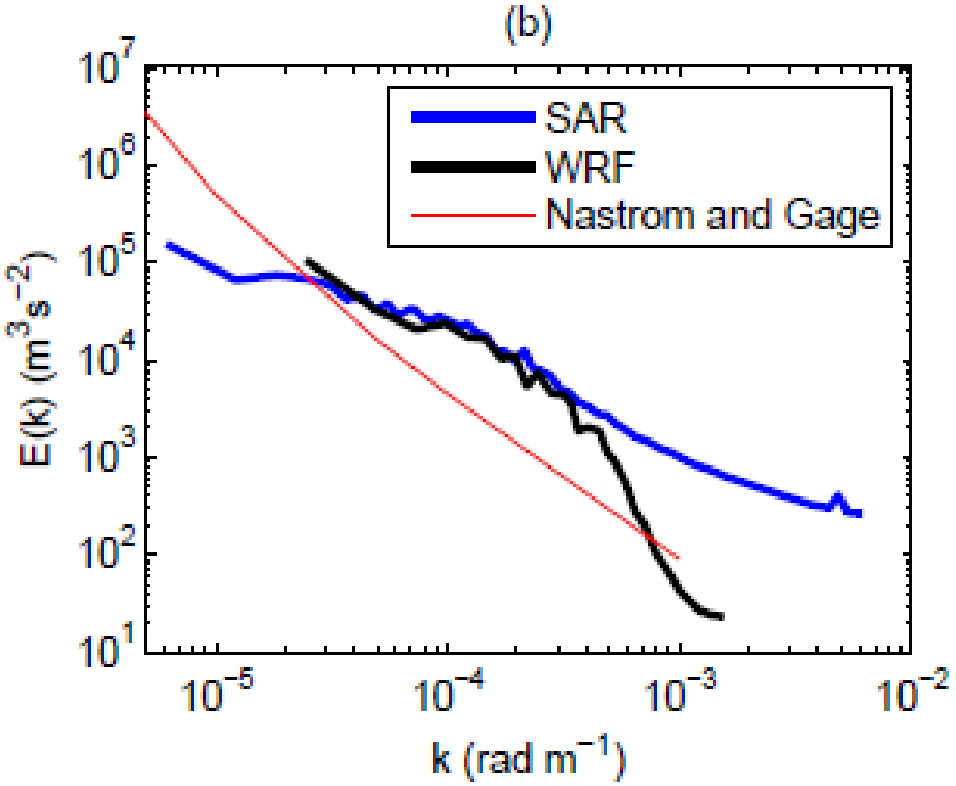
Envisat ASAR 10-m wind speed



Cloud image



WRF wind speed

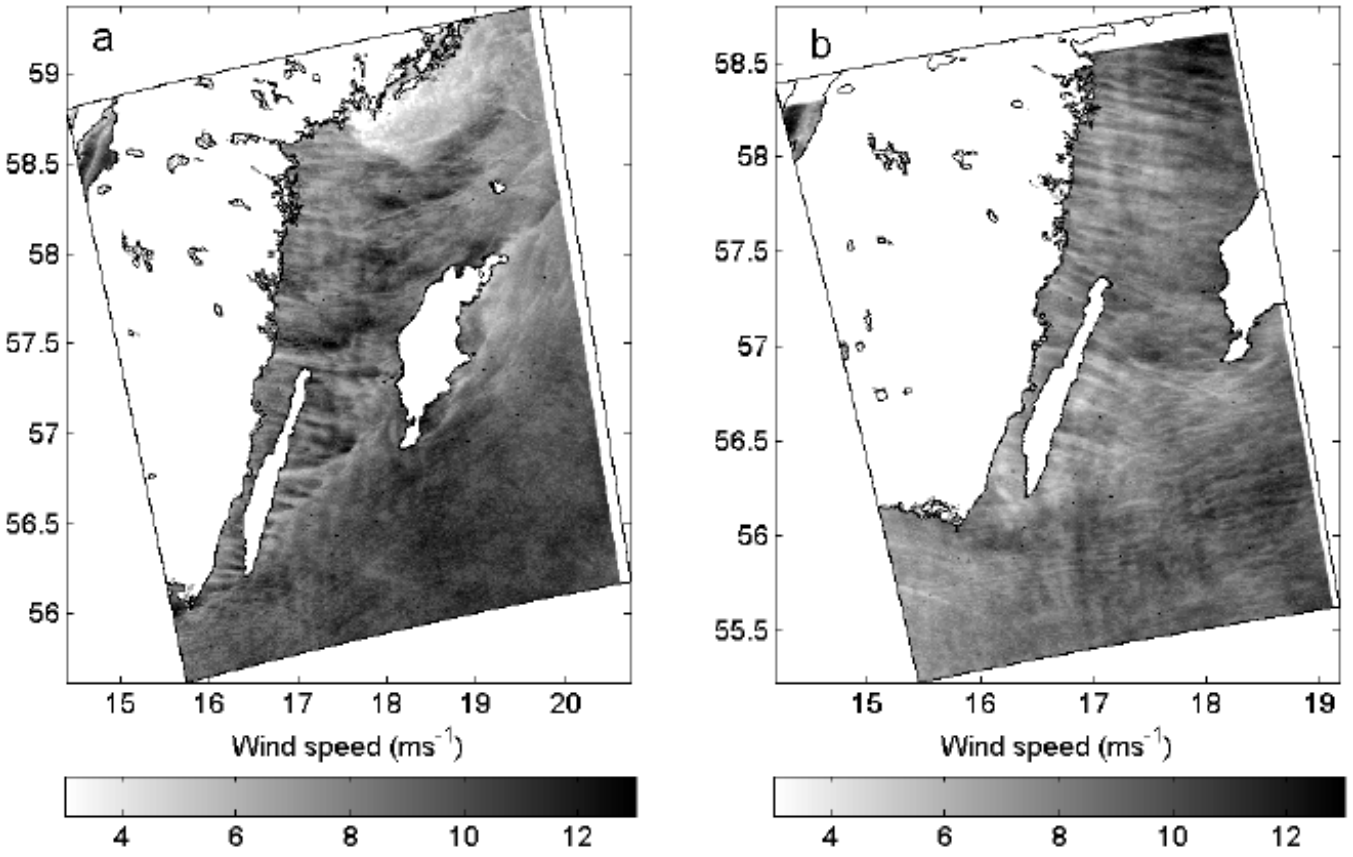


Larsén X., Du J., Bolaños R. and Larsen S. (2016) Storm Britta Revisted, Submitted to Natural Hazards.

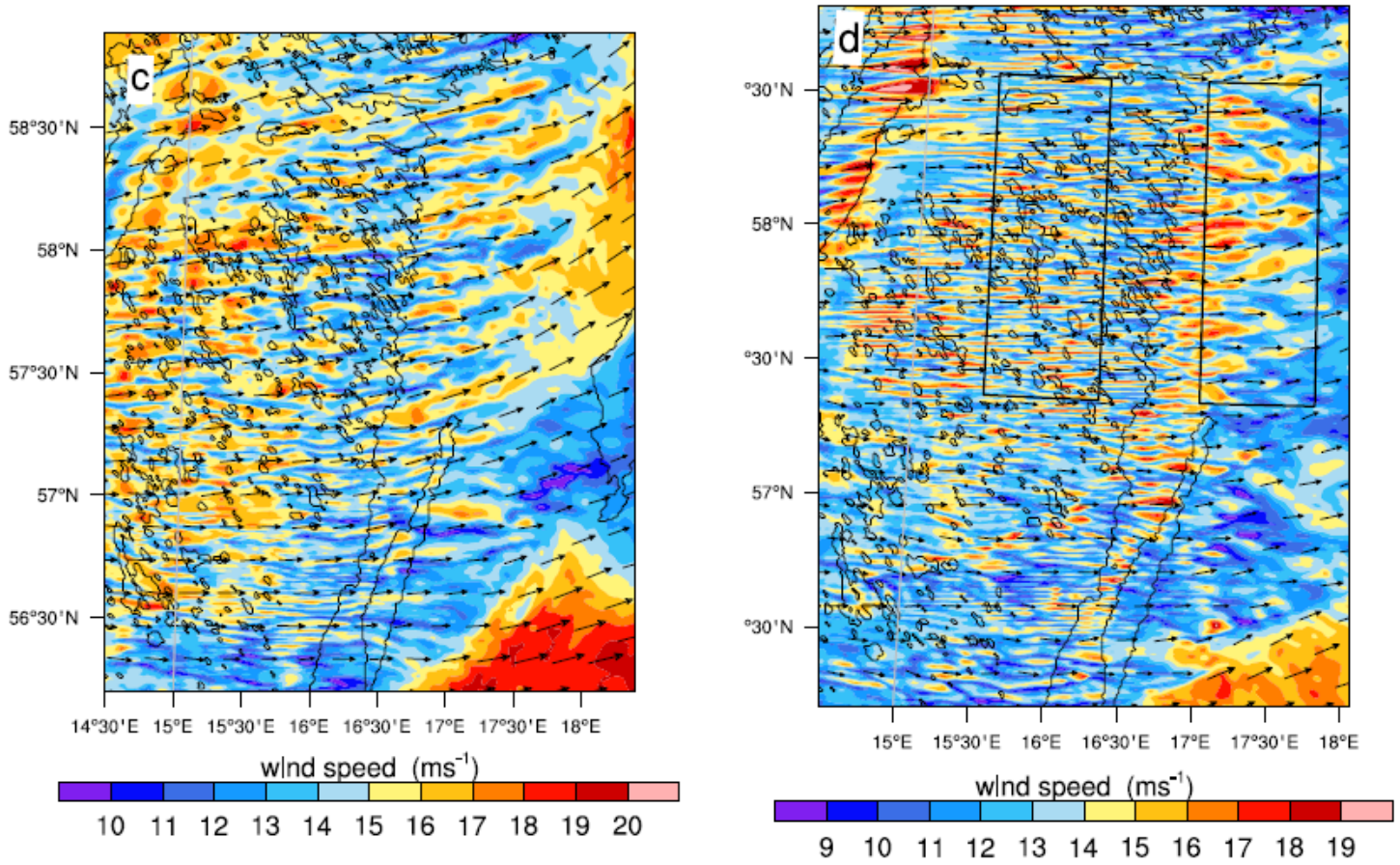
Larsén X., Vincent C. and Larsen S.E. 2013: Spectral structure of mesoscale winds over the water, *Q. J. R. Meteorol. Soc.*, DOI:10.1002/qj.2003, 139, 685-700.

Boundary layer rolls

May 17 and May 25, 2011



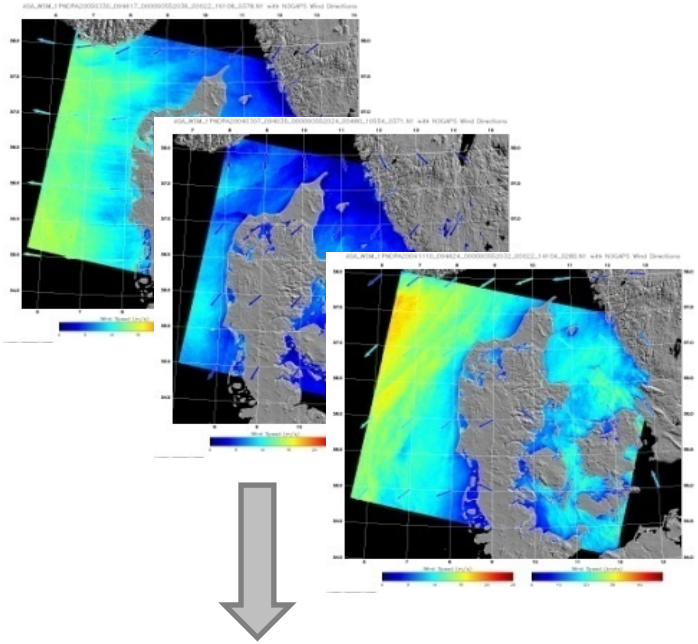
Envisat ASAR 10-m wind speed

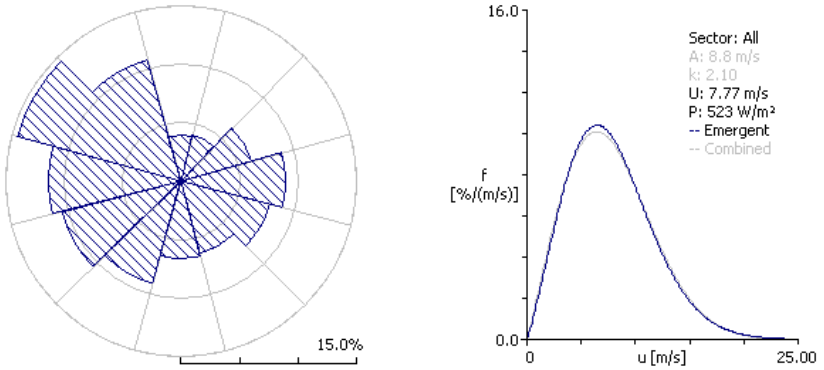


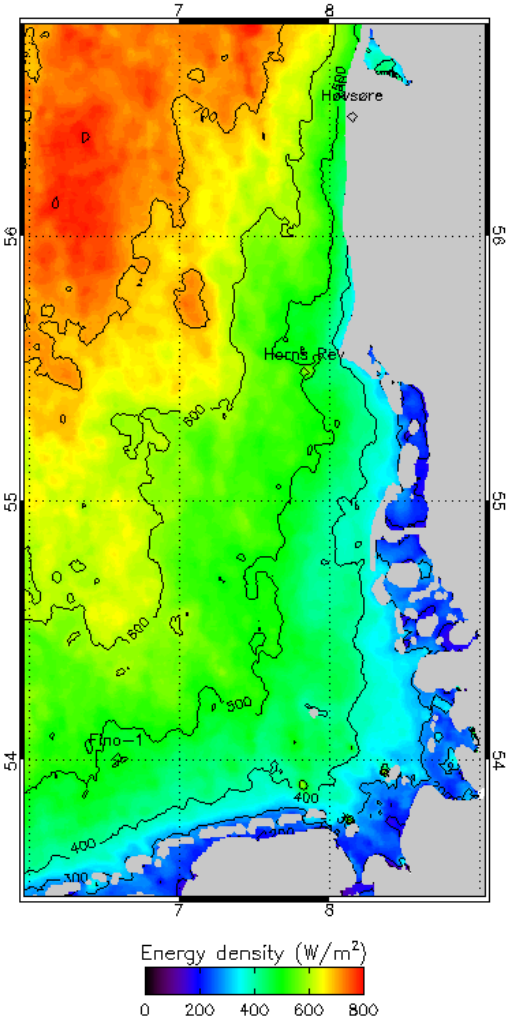
WRF wind speed

Svensson N., Bergström H., Sahlée E., Nilsson E., Badger M. and Rutgersson A. (2016), Offshore advection of boundary layer rolls, Submitted to BLM.

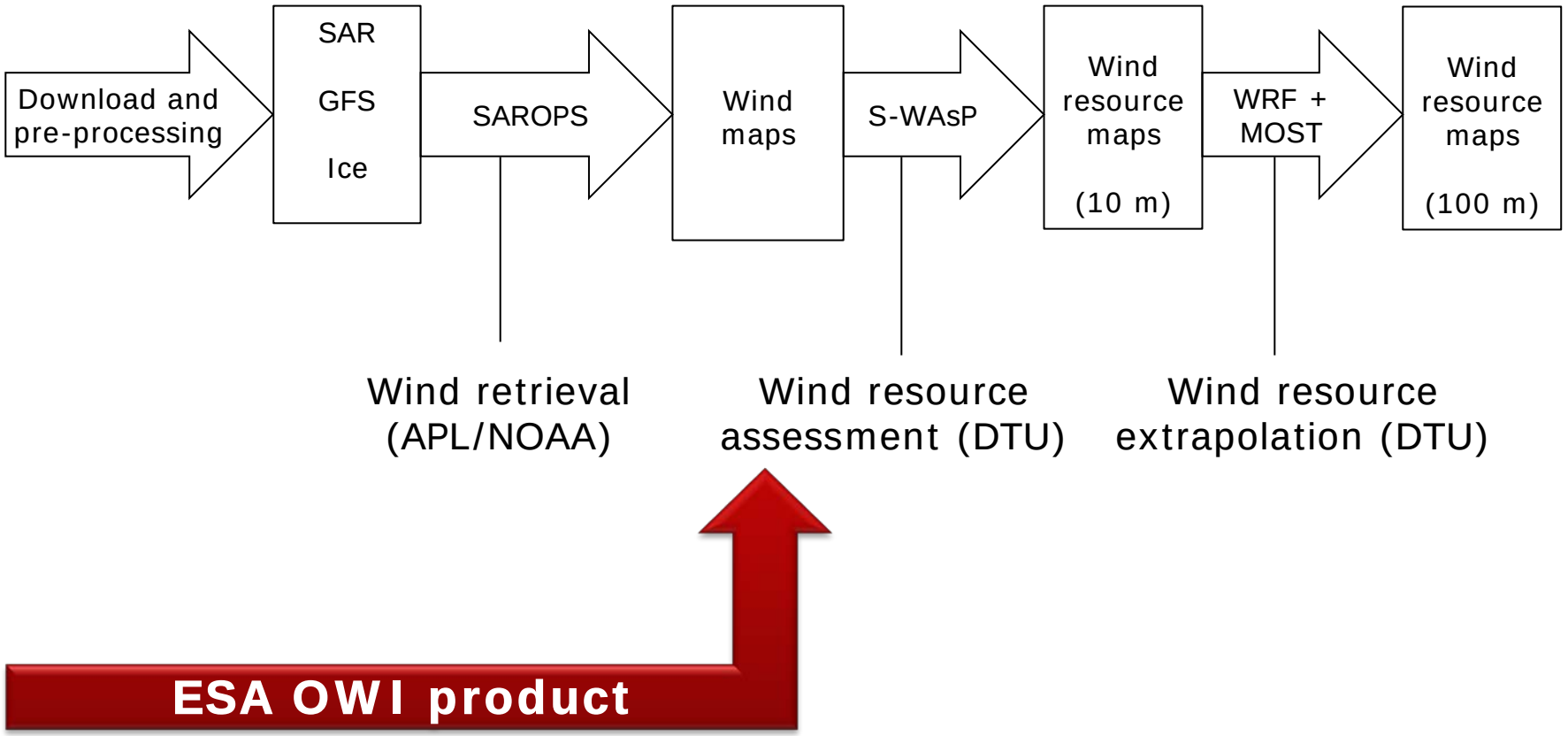
Wind resource mapping







Chain of processes



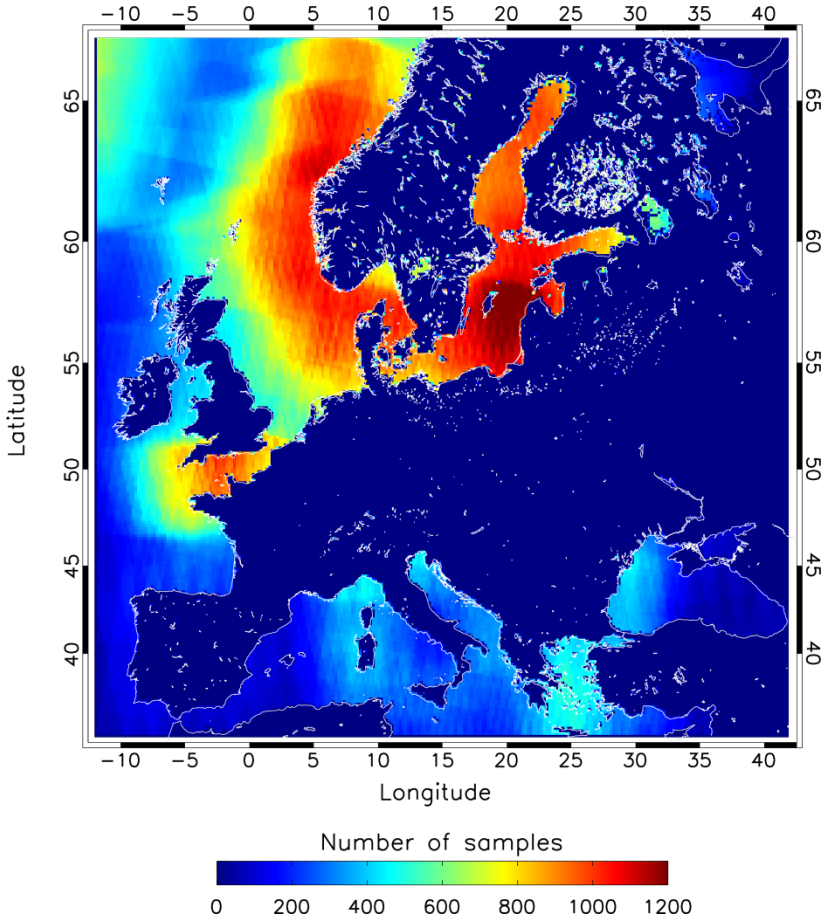
The New European Wind Atlas (NEWA)

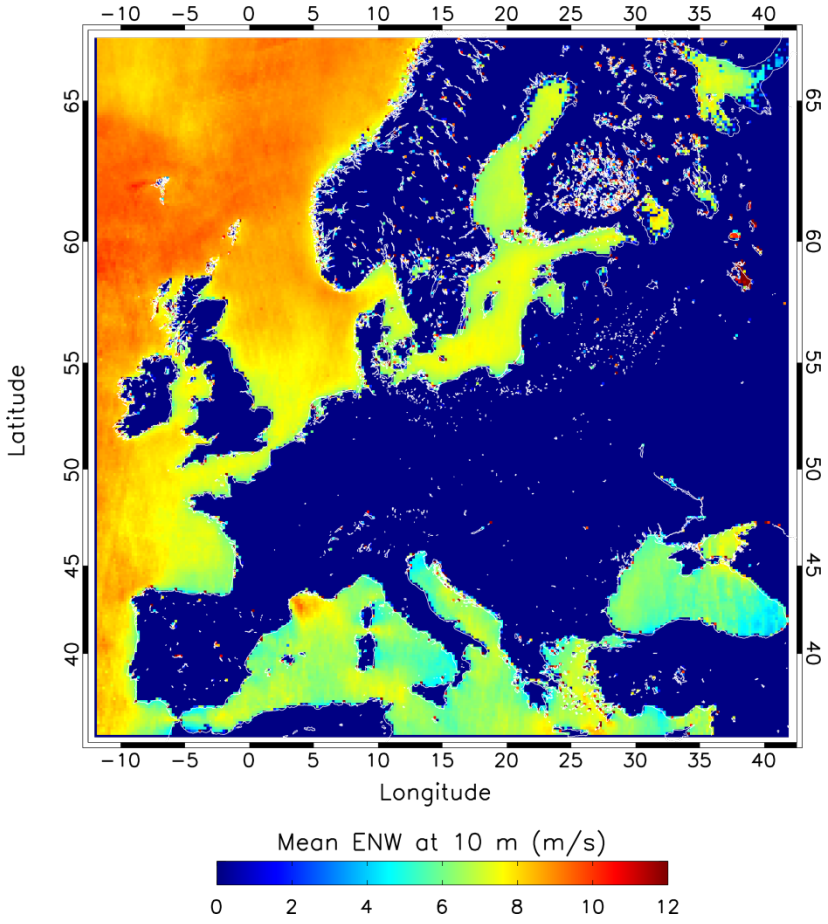
- Envisat ASAR and Sentinel-1 A/B
- Extrapolation to different heights up to 100 m
- Extensive measurement campaigns and modeling

Coverage of the satellite based atlas in NEWA

(image courtesy Google Earth)

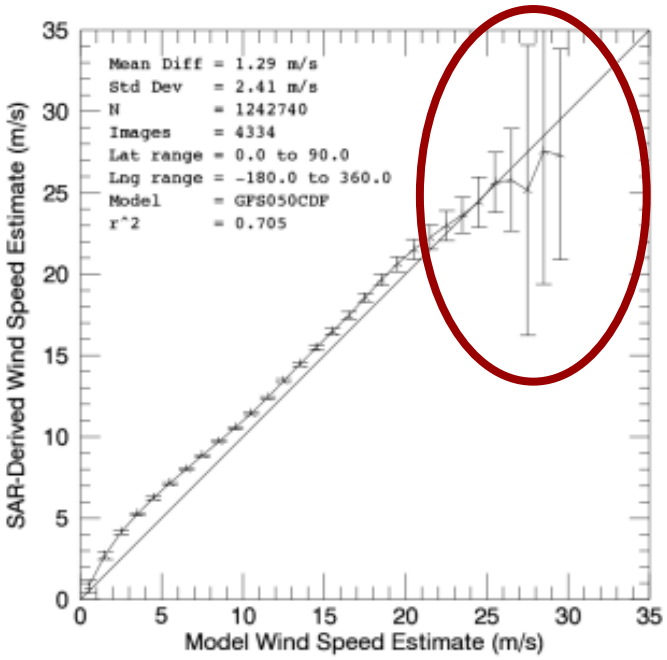
Preliminary 10-m atlas for Europe



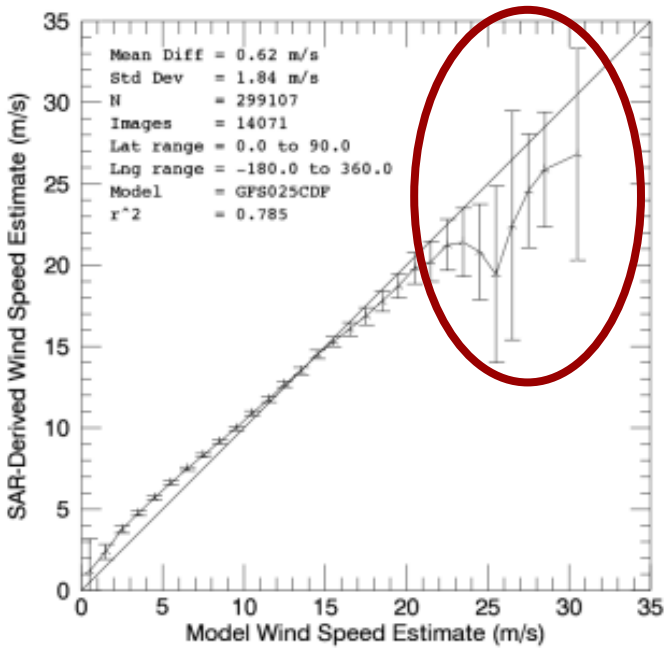


Envisat ASAR and Sentinel-1A/B combined

Wind speed comparisons



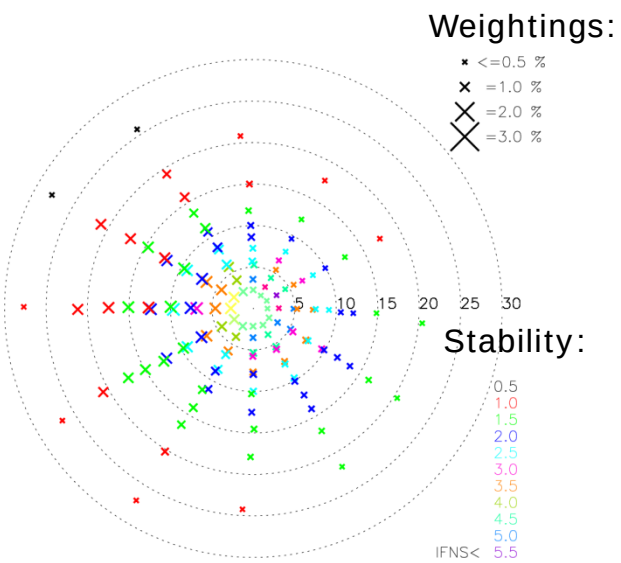
Envisat ASAR vs. GFS model



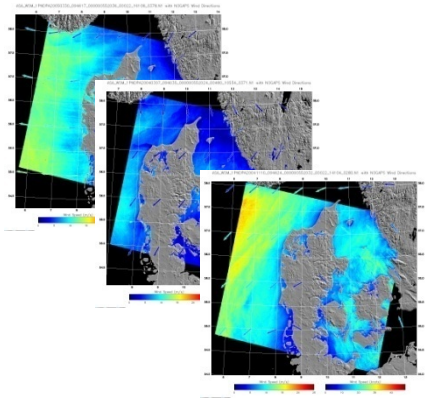
Sentinel-1A SAR vs. GFS model

See also: Monaldo, F.M *et al*. (2015): Preliminary evaluation of Sentinel-1A wind speed retrievals. IEEE JSTARS, doi: 10.1109/JSTARS.2015.2504324.

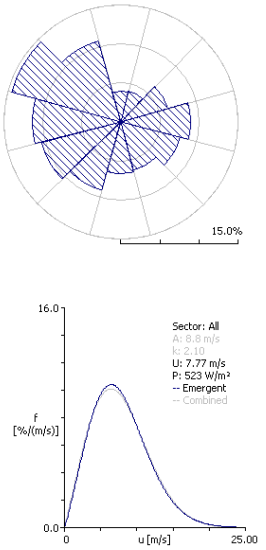
Wind class sampling



Wind class definition from NCEP/NCAR re-analysis data



Population of each wind class with a SAR wind field



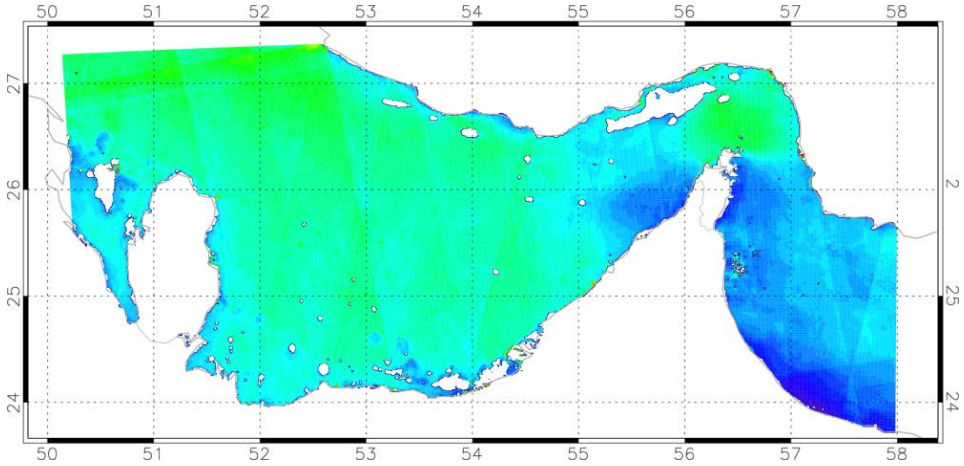
Weighting and Weibull fitting

Badger et al. (2010): J. Appl. Meteor. Climatol. 49, 2474-2491.

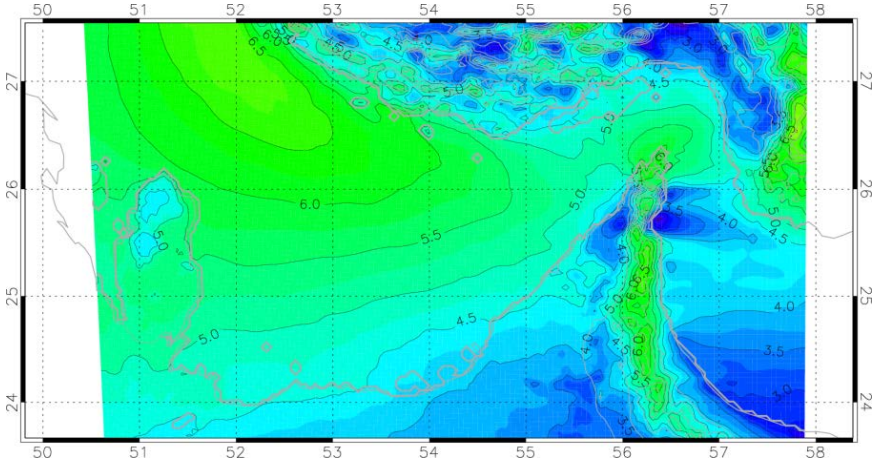
Advantages of wind class sampling

- Compensates for a limited number of SAR samples
- Long-term wind climatology may be obtained
- Results are directly comparable with mesoscale modeling results

Example from the UAE:



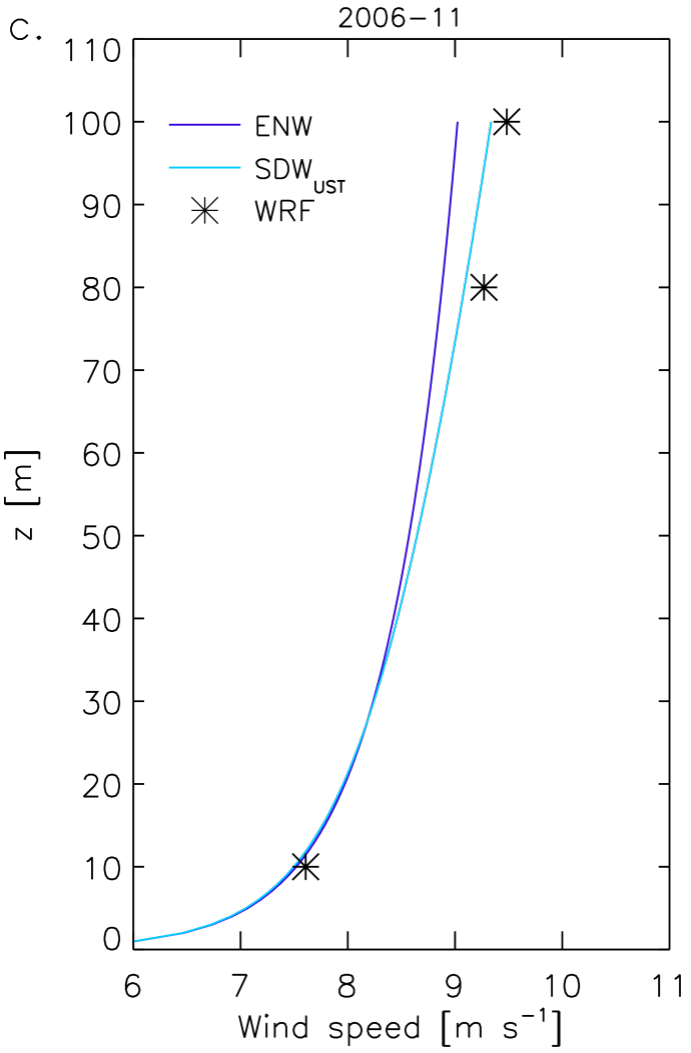
10-m mean wind speed from Envisat ASAR data (225 scenes)



10-m mean wind speed from KAMM mesoscale modeling

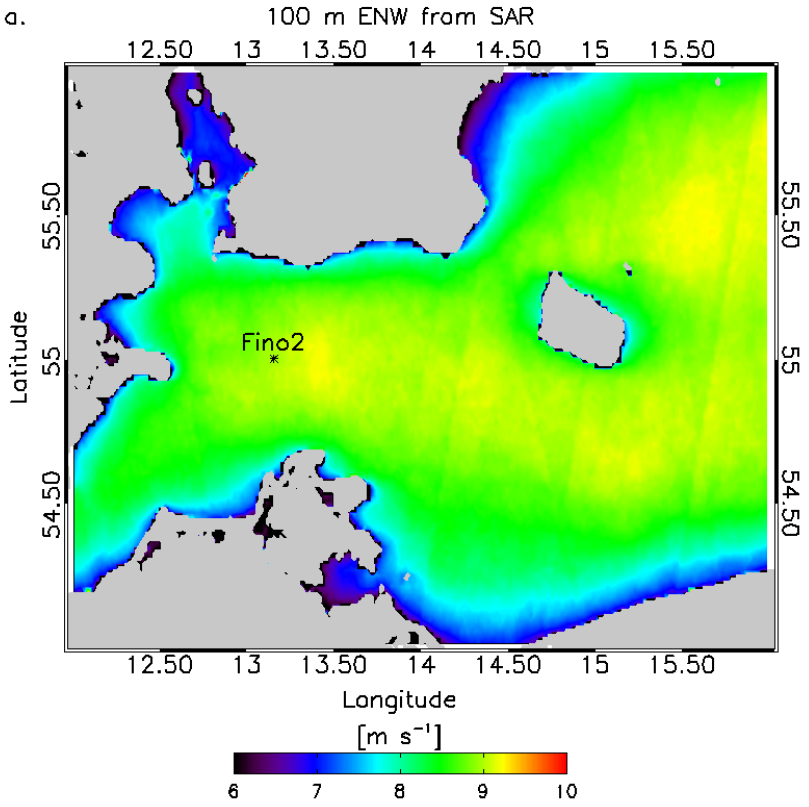
Long-term average wind profile

$$\left\langle \frac{\kappa\, u(z)}{u_*} \right\rangle = \ln\left(\frac{z}{z_0}\right) - \langle \psi_m \rangle$$

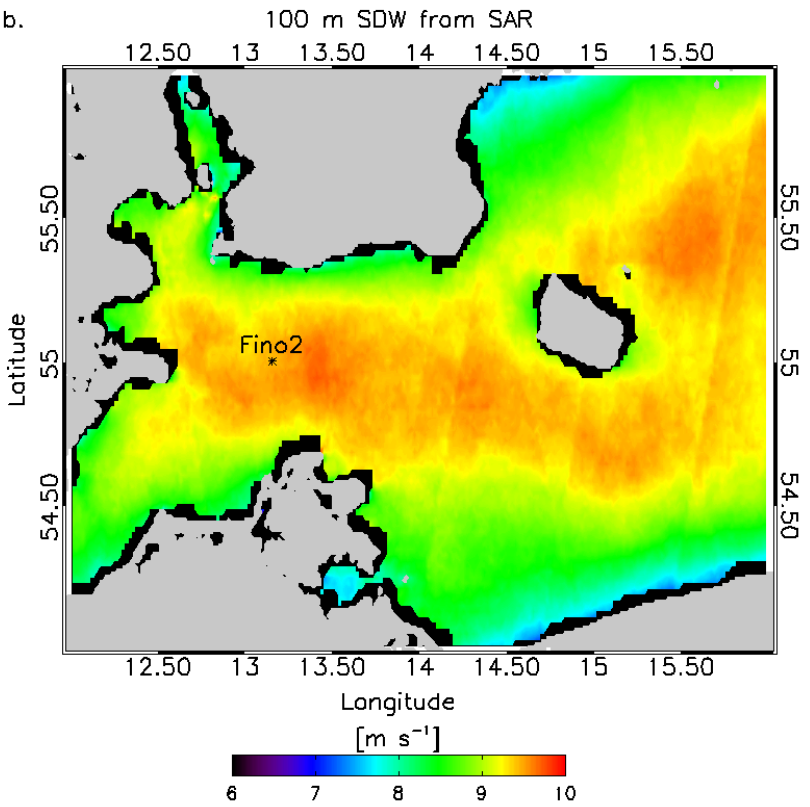


Fino-2 in the South Baltic Sea

Wind speed extrapolated to 100 m



Without stability correction



With stability correction

Badger, M. et al.(2016): Extrapolating satellite winds to turbine operating heights, *Journal of Applied Meteorology and Climatology,* 44, 975-991, doi: 10.1175/JAMC-D-15-0197.1.

Conclusions

- Future wind energy developments are global and high-wind issues must be considered

- SAR wind retrievals offshore are valuable for:
  1) Model validation
  2) Wind resource mapping
  3) Wind farm wake analyses

- Strenght of SAR winds: a high spatial resolution

- Limitations of SAR winds: Lack of high-wind samples and information above the 10-m level above m.s.l.

Acknowledgements

Satellite data:

The European Space Agency (ESA)

SAR wind retrieval systems:

JHU/APL and NOAA

Mast observations:

All mast data accessed through the NORSEWInD project. Horns Rev: DONG energy and Vattenfall, Fino-1 and Fino-2: Deutsches Windenergie Institut, Egmond an Zee: NoordZeewind, Greater Gabbard: SSE Renewables.

Funding:

EU-NORSEWInD, Icewind, New European Wind Atlas

Collaboration:

Frank Monaldo & Christopher Jackson, NOAA