Monitoring Conditions Offshore with Satellites

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DTU – Technical University of Denmark

KAIST Workshop, February 2013

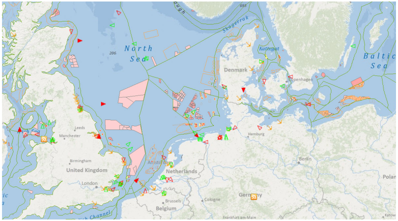
Outline

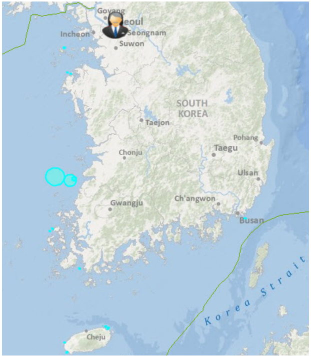
Motivation

- Offshore renewable energy activities
- Need to understand and monitor conditions offshore
- Wind: resource assessment, forecasts
- Waves: loads on structures, wave energy
- Sea Surface Temperature (SST): forecasts, wind profiles

Wind Measurements

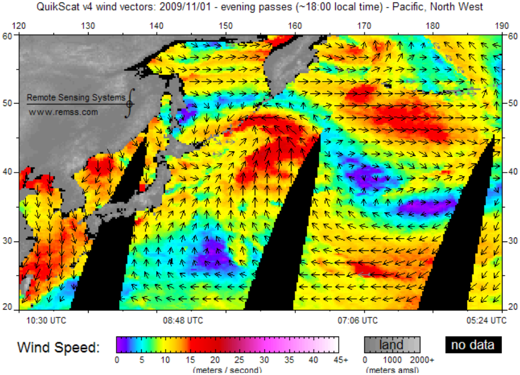
- Offshore masts expensive
- Foundation/maintenance costs increase (depth, distance from land)
- Alternatives:
  - Lidars
  - Satellites
  - Meso/micro scale models





QuikSCAT

- Scatterometer: backscatter from small scale ripples
- Operating frequency: 13.2 GHz
- SeaWinds on QuikSCAT: speed & direction
- **E**quivalent **N**eutral **W**ind 10 m
- 2–20 m s^{-1} –> RMSE 2 m s^{-1}



Advanced Scatterometer (ASCAT)

- On MET-OP (A & B)
- Operational since 2007
- Radar frequency 5.2 GHZ: less sensitive to rain
- Resolution: 25 km, 12.5 km

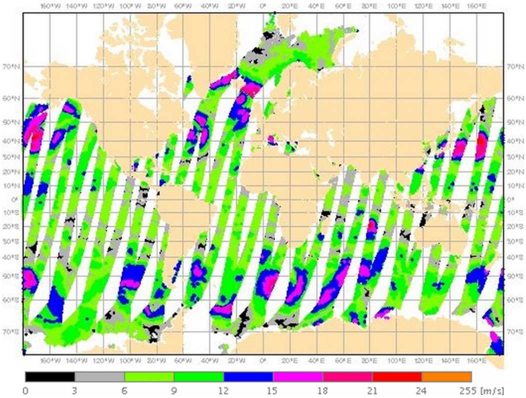


Figure: ASCAT instrument on METOP: example of descending (morning) pass from KNMI (http://www.knmi.nl/scatterometer/ascat_osi_25_prod/ascat_app.cgi).

OCEANSAT-2 Scatterometer (OSCAT)

- Operational since 2009
- Operating frequency 13.5 GHZ
- KNMI releases 50 km resolution products
- 10 m Equivalent Neutral Wind
- Wind speed range 0–50 m s^{-1}

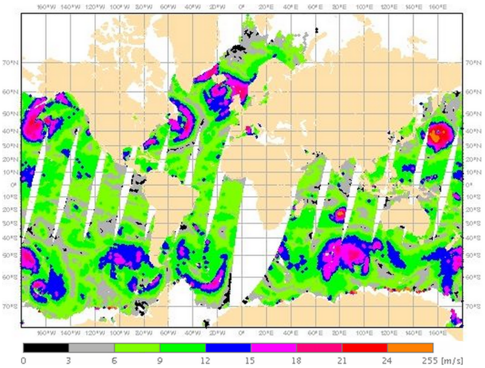


Figure: Morning (descending) OSCAT passes on the 14/02/2013 from KNMI (`http://www.knmi.nl/scatterometer/oscat_50_prod/oscat_app.cgi`).

Synthetic Aperture Radar

- **A**dvanced **S**ynthetic **A**perture **R**adar on ENVISAT: speed
- Operation 2002–2012, infrequent revisiting time
- Very high spatial resolution ($\sim$150 m on WSM)
- Processing & wind retrieval at DTU Wind Energy
- Johns Hopkins ANSWRS system & NOGAPS model wind directions

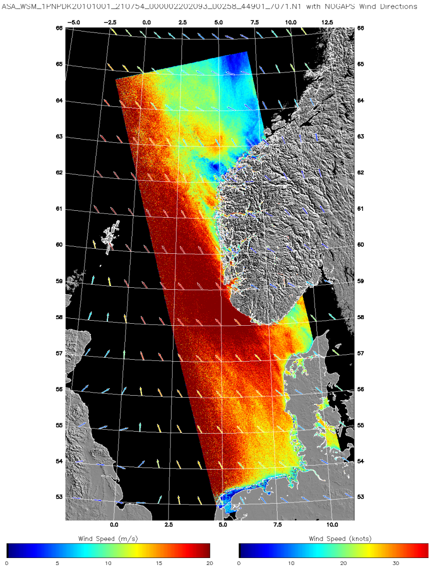
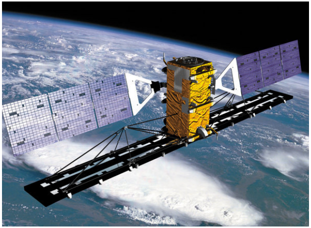


Figure: Wind field retrieved from ENVISAT ASAR, 01/10/2010

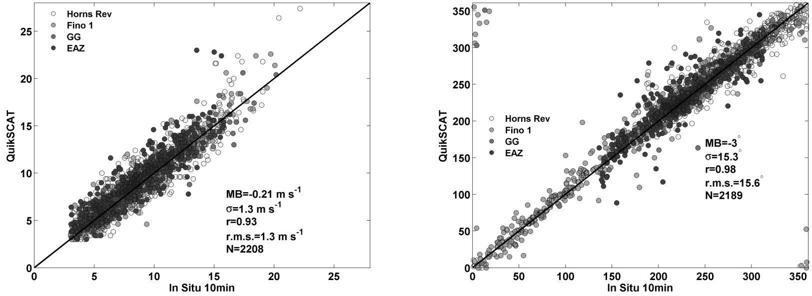
Synthetic Aperture Radar



- RadarSat-2: 2007–now
- Sentinel-1 to be launched in 2013

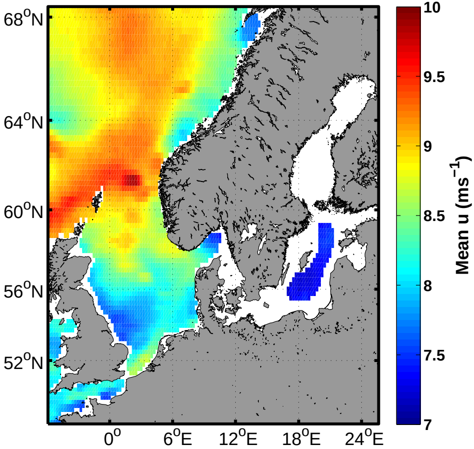
†Images are courtesy of ESA.

QuikSCAT vs North Sea Masts



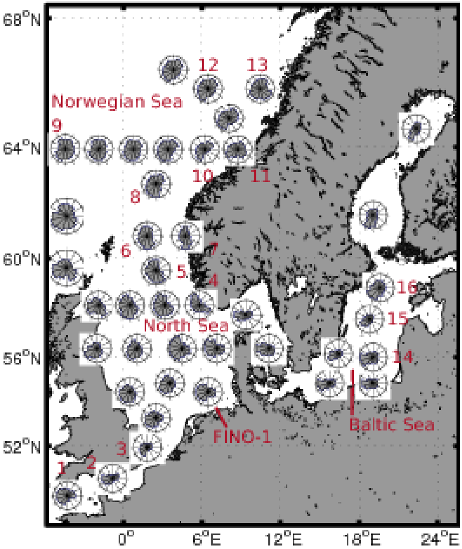
†Karagali et al. 2012, Wind Characteristics from the QuikSCAT satellite, *Wind Energy*, early view

10-year Mean Wind Speed



† Karagali et al. 2013, Temporal & spatial variability of 10 m winds, *Renewable Energy*, 57, 200-210.

Wind Direction Distributions



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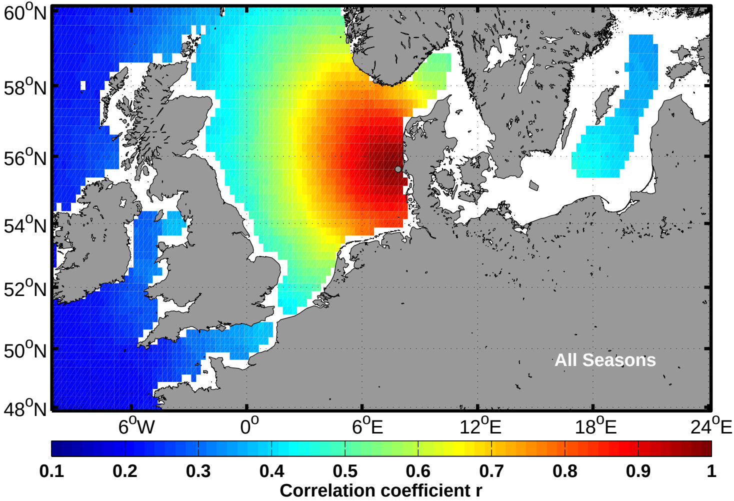
† Karagali et al. 2013, Temporal & spatial variability of 10 m winds, *Renewable Energy*, 57, 200-210.

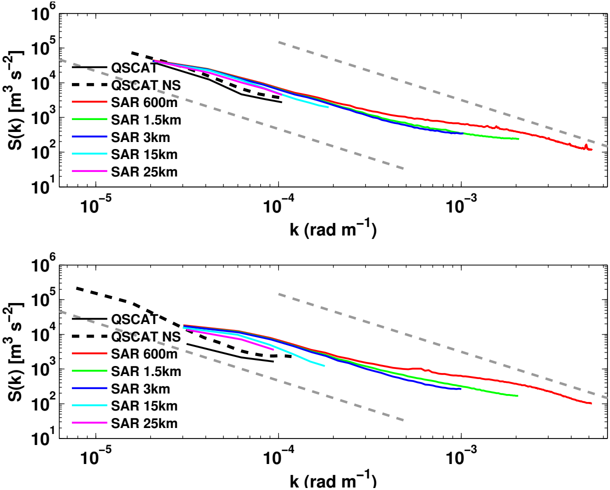
Spatial Correlation of Wind Speed



r>.9: 68 grid cells $32*10^3$ km^2 (4% North Sea area)

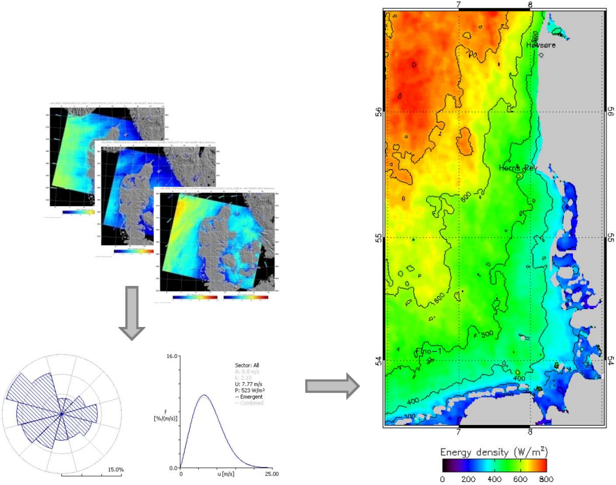
† Karagali 2012, *DTU-Wind Energy PhD Thesis 03*

Spectral Properties of SAR, QuikSCAT



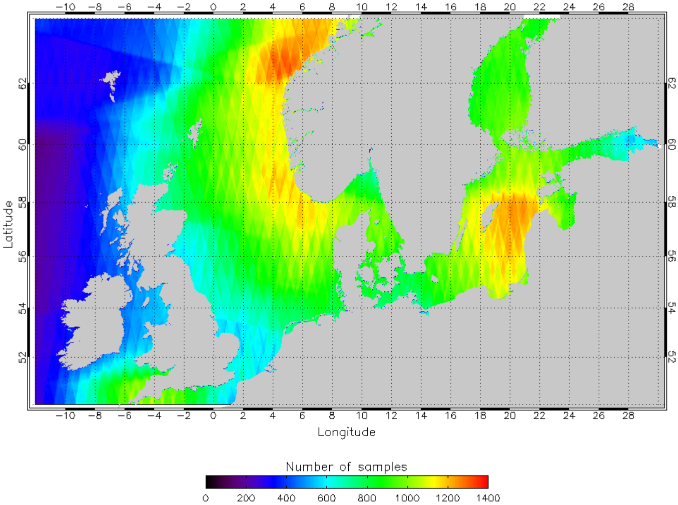
† Karagali 2012, Spectral properties of QuikSCAT & SAR 10 m ocean winds, *DTU-Wind Energy PhD Thesis 03*

Wind Class Sampling



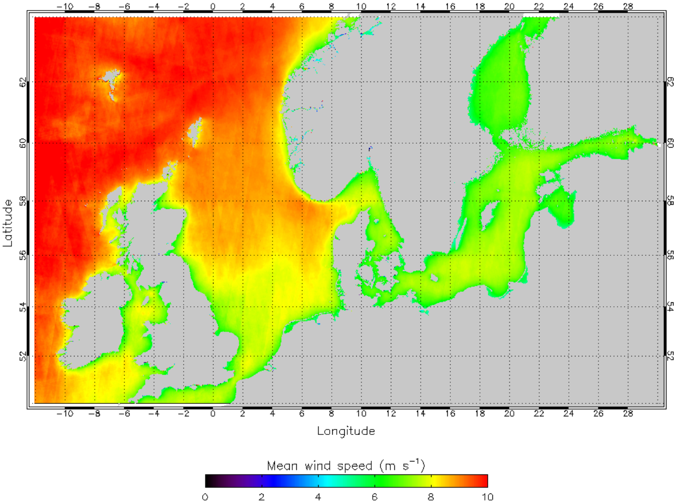
†Badger et al. 2010, Wind class sampling of satellite SAR imagery for offshore wind resource mapping, *J. Applied Meteorology & Climatology*, 49, 2474-2491

NORSEWInD ASAR Wind atlas



SAR scenes used for the wind resource assessment atlas. Courtesy: DTU Wind Energy & CLS.

NORSEWInD ASAR Wind atlas



Mean wind speed from the resource assessment atlas. Courtesy: DTU Wind Energy & CLS.

Altimeters

- Radar vertically transmitting short pulses towards ocean surface
- Receives reflected signal
- Time between signals = distance satellite–Earth
- Shape of return signal = significant wave height
- Multiple missions: TOPEX/POSEIDON, JASON-1/2, ENVISAT RA-2, CRYOSAT
- Long revisiting times: 10–35 days
- Available climatologies: ESA's GlobWave

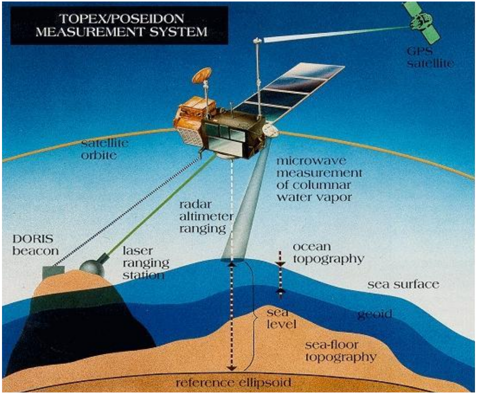


Figure: The TOPEX/POSEIDON principle of function. Image taken from AVISO (`http://www.aviso.oceanobs.com/es/kiosco/newsletter/newsletter01/focus-on.html`)

Significant Wave Height

$$H_s = 4\sqrt{\overline{\eta^2}}$$

- η: wave height
- Average crest-to-trough height of $\frac{1}{3}$ largest waves

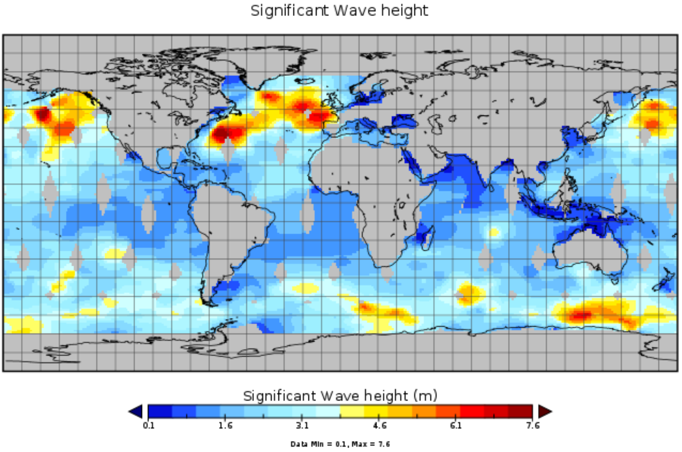
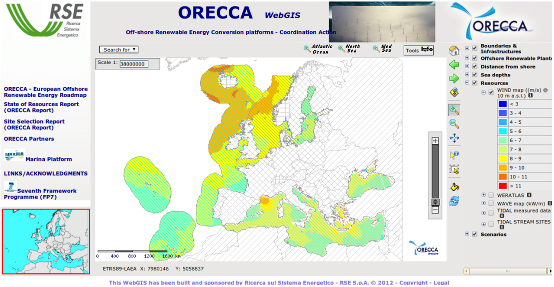


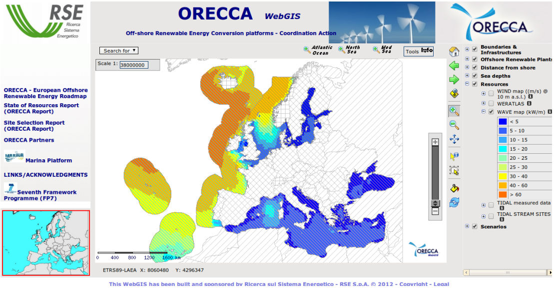
Figure: Latest NRT Significant Wave Height merged product, from Aviso (http://www.aviso.oceanobs.com/en/data/products/wind-waves-products/mswhmwind.html)

EU–ORECCA

Roadmap for research activities on offshore renewable energy conversion platforms for

- Wind
- Waves
- Other





EU–MARINA

- Multi-purpose platforms for marine renewable energy
- Integrated wind and wave/current energy
- Site assessment for deployment of deep offshore renewable energy platforms

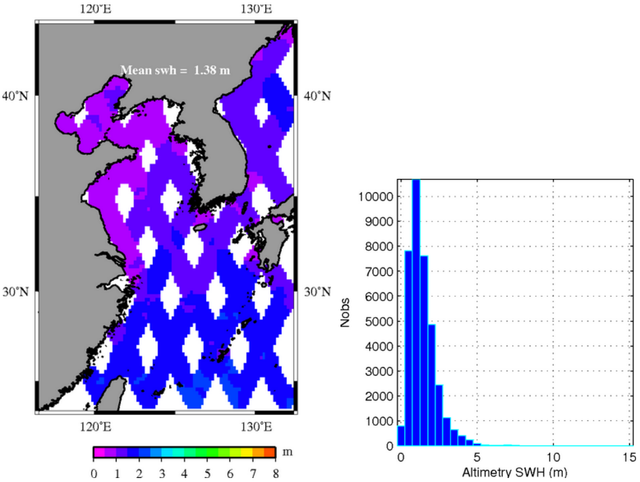
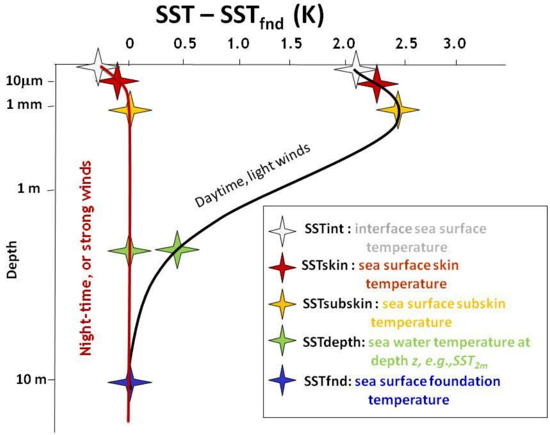


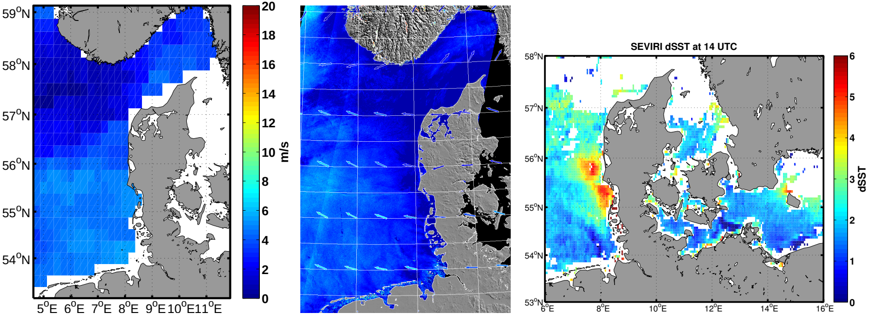
Figure: Average SWH and Observations histogram, Jason-2, DMI, COI (*http* : //*ocean*.*dmi*.*dk*/*validations*/*waves*/*satellite*/2008_07 − 12.*ys_new*/*index*.*php*)

Definitions of SST



Vertical distribution of SST. From Minett & Kaiser-Weis (2012)

Satellite Winds & SST

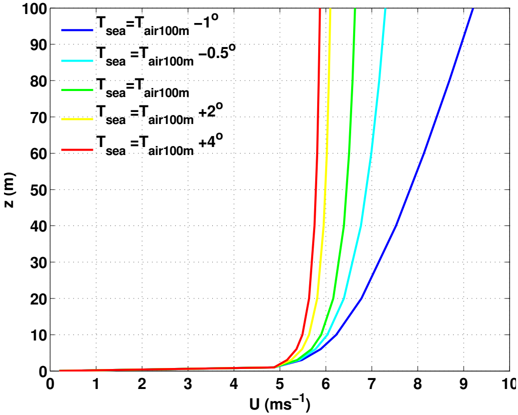


QuikSCAT, SAR and SEVIRI SST warming on the 04/07/2006

Wind Profiles

$$u = \frac{u_*}{\kappa}\left[\ln\left(\frac{z}{z_0}\right) - \Psi_M\right]$$

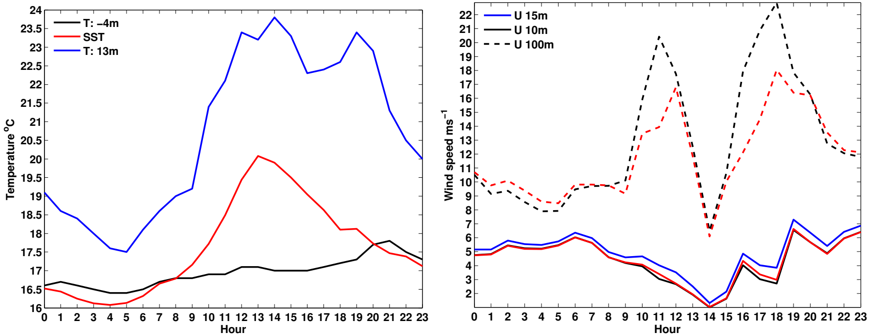
- u: wind speed at height z
- u_*: friction velocity
- κ: von Kármán constant ($\sim$0.4)
- z_0: surface roughness
- Ψ_M: stability & height dependent



Compared to neutral case

- \- 1°: 39% increase of u_{100m} (167% for wind power density)
- $+$ 2°: 8% decrease of u_{100m} (22% for wind power density)

Using SST and Bulk Water Temperature



Measured air & sea temperatures at Horns Rev on the 04/07/2006 (left). Measured wind speed at 15 m (blue), extrapolated wind speeds at 10 m (solid) and 100 m (dashed), using the T 13 m for the air temperature & either the T -4 m (black) or the SST (red) for the sea temperature (right).

SST from Space

Infra-red sensors

- Infra-red radiation from “skin”
- No measurement through clouds
- High resolution
- SEVIRI (Geostationary)
- ATSR, AVHRR, MODIS (Polar)

Microwave sensors

- Radiation from “sub-skin”
- Measurement through clouds
- Low resolution – away from land
- TMI and AMSR
- Polar orbiters

Diurnal Warming Thresholds

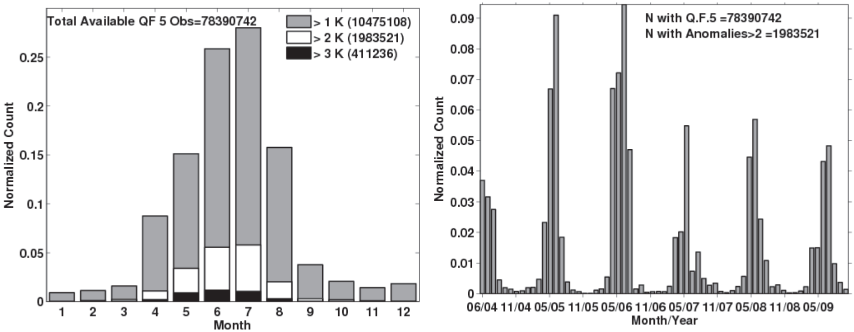


Figure: Left: Annual distribution of anomalies exceeding the threshold of 1, 2 and 3 K from June 2004 to October 2009. Right: Temporal distribution of anomalies exceeding 2 K.

†Karagali et al. 2012, SST diurnal variability in the North Sea and the Baltic Sea, *Rem. Sens. Environ.*, 121, 159-170

Spatial Extend of Diurnal Warming

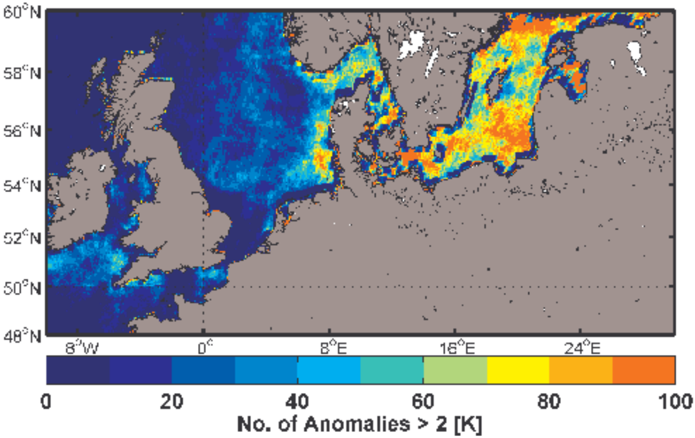
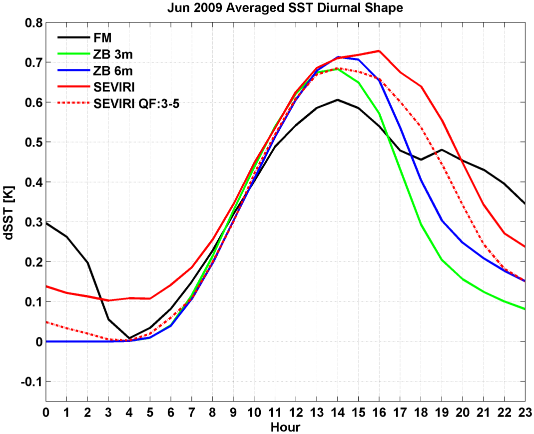


Figure: Spatial distribution of warming cases exceeding greater than 2 K (SEVIRI)

†Karagali et al. 2012, SST diurnal variability in the North Sea and the Baltic Sea, *Rem. Sens. Environ.*, 121, 159-170

Modelling the diurnal cycle



SEVIRI (red), the Filipiak et al. (2011) model (black), the Zeng & Beljaars (2005) $d_1 = 3m$ (green) and $d_2 = 6m$ (blue).

†Karagali & Høyer 2013, Observations and modeling of the diurnal SST cycle in the North and Baltic Seas, *J. Geophys. Res.-Oceans*, DOI: 10.1002/jgrc.20320

Conclusions

- Satellite winds applicable for initial resource assessment
- QuikSCAT: long temporal & spatial coverage –> mean wind characteristics
- Roadmap for installation of masts, run high res. models
- SAR: very high resolution, close to land
- Identification of local, small-scale features
- Altimeters can be used for climatological wave resource assessment
- Validation of wave models vs radar altimeter data
- Diurnal SST variability important for certain areas/seasons
- Potentially important for atmospheric modelling

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Perspectives

- More scatterometers in operation –> longer data sets
- Satellite winds lifted to hub heights
- Resolving of diurnal warming in NWP models
- Using SST when extrapolating measurements
- Evaluate impact of SST daily variability on atmospheric models

Thank you

Questions?