Features of wind field over the sea surface in the coastal area based on SAR observations

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Wind Field Features in the Gulf of Finland derived from SAR

It is well-known that when wind is blowing from land to the water it's speed changes due to a number of effects. An Internal Boundary layer (IBL) develops over the new surface, growing in height with increasing distance downwind from the change of surface characteristics.

Wind above the IBL corresponds to the characteristics of the airflow above the land and, therefore, has a lower energy potential.
Wind Field Features in the Gulf of Finland derived from SAR

The IBL development can be originated on satellite images from increase of wind blowing from land to water due to decrease of surface roughness.
Wind Field Features in the Gulf of Finland derived from SAR

Atmospheric phenomena often leave fingerprints on the sea surface, which are detectable by synthetic aperture radar (SAR).

*Synoptic front*

*Atmospheric gravity waves*

*Wind fields reconstructed from SAR images with CMOD5.N*
Wind Field Features in the Gulf of Finland derived from SAR

Advantage of SAR data is their ability to resolve small-scale wind field features (with spatial resolution of 150 meters and larger) caused by wind transformation at the land-sea transition. Moreover, SAR images provide wind right up to the coast and in bays and straits.
Goals

- to investigate coastal area wind field features, associated with effect of wind acceleration in the developing IBL.

- to give a simplified empirical description of IBL evolution that can be used in the wind energy resource estimation.
Study Area: Gulf of Finland
Study Data: Envisat ASAR images

- operated from 2002 to 2012
- C-band (5.34 GHz)
- Wide Swath Mode spatial resolution ~ 150 m
- HH or VV polarization
Wind speed ($u$) is calculated through empirical geophysical model function relating the observed normalized radar cross section ($\sigma_o$) with incidence angle ($\theta$) and wind direction ($\Phi$).

\[ \sigma^\text{pol}_o = a(\theta, u)u^\gamma(\theta) \left[ 1 + b(\theta, u)\cos \Phi + c(\theta, u)\cos 2\Phi \right] \]

CMOD by definition gives equivalent neutral wind speed at 10 m height ($U_N$). It is further converted to wind stress:

\[ \tau_s = u_*^2 = \left( \frac{\kappa U_N}{\ln(10/z_0)} \right)^2 \]
Wind «shadows»

Raw SAR data with wind barbs from NCEP GFS

Wind field reconstructed from SAR images with CMOD5.N
Model Tool

“A model of wind transformation over water-land surfaces”
by V. Kudryavtsev, V. Makin, A. Klein Tank, J. Verkaik,

Solid line, - local observed wind; Dotted line, - wind over sea; Dash lines, - model simulations
Ancillary Data

1. Land roughness:
   *taken from Land Use Map GLC2000*

2. Sea Surface Temperature:
   *taken from satellite Global Odyssea Sea Surface Temperature, available at www.satin.rshu.ru;*

3. Air Temperature profiles:
   *taken from NCEP, http://rda.ucar.edu/datasets/ds083.2*
Results
Results

AB

CD

Graphs showing the relationship between friction stress ($\tau$, N/m$^2$) and fetch (km) for different wind speeds ($U_{1000}$).

- **AB**:
  - $U_{1000} = 13$ m/s
  - $U_{1000} = 22$ m/s

- **CD**:
  - $U_{1000} = 15$ m/s
  - $U_{1000} = 23$ m/s

- **AB**:
  - $U_{1000} = 18$ m/s
  - $U_{1000} = 26$ m/s

- **CD**:
  - $U_{1000} = 19$ m/s
  - $U_{1000} = 27$ m/s
Results
Surface wind stress reaches an equilibrium value at $X_f / G \approx 0.4$, which is the scale of the planetary boundary layer layer relaxation under the sea surface.

Mean value of geostrophic wind speed over the Gulf of Finland is 6-7 m/s, hence $X \approx 20$ km.
Summary

• IBL development is observed on SAR images as shading areas along the coastline and as wind “shadows” behind leeward side of the islands. Width of the "shadow" depends on the wind speed and atmospheric boundary layer stratification.

• In some cases areas of wind acceleration indicate local geographic features, such as multiply transformation of PBL, as it is observed over complex surface «land – Lake Chudskoe – land – Gulf of Finland».

• Measurements showed that in the area of wind acceleration the surface stress, normalized to the equilibrium value (far from the coast) is universal functions of the dimensionless fetch. Surface wind stress reaches an equilibrium value at $X_f/G \approx 0.4$, which is the scale of the planetary boundary layer relaxation under the sea surface.
Results

A quantitative measure of the wind energy available at any location is called the wind power density, which is defined for a unit area and per second as

\[ Power = \frac{1}{2} \rho U^3 \]

where \( \rho \) is air density and \( U_z \) is wind speed at certain height.

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The graph shows the wind speed and power density at 50 m as a function of fetch (km) with a distinction between land and water.