Uncertainty in Ocean Surface Winds over the Nordic Seas

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# Surface Winds

<table>
<thead>
<tr>
<th>National Center for Environmental Prediction Reanalysis II (NCEPR) [Kanamitsu et al., 2002]</th>
<th>NCEP Climate Forecast System Reanalysis (CFSR) [Saha et al., 2010]</th>
<th>Arctic System Reanalysis, interim version (ASR) [Bromwich et al., 2010]</th>
<th>Cross-Calibrated Multi-Platform Ocean Surface Wind Components (CCMP) [Atlas et al., 2011]</th>
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</thead>
<tbody>
<tr>
<td>• Period covered: 1979 – 2013; • Assimilated observations: surface pressure, SST and sea ice distribution, scatterometer winds (since 2002) • Products include 3- and 6-hourly data on ~1.9 x 1.9° global grid</td>
<td>• Period covered: 1979 – 2013; ~38 km resolution, 1hr fields • Assimilation: all available conventional and satellite observations • Updated assimilation and forecast system • Covers atmosphere, ocean, sea ice, and land</td>
<td>• Period covered: 2000-2012; • Blend of modeling and observations; • Produced using Polar WRF and the WRF-VAR assimilation system; • 3hr data, 30 km</td>
<td>• Period covered: July 1, 1987 – 2011; 0.25° resolution, 6hr fields • The data set includes cross-calibrated satellite winds derived from SSM/I, SSMIS, AMSR-E, TRMM TMI, QuikSCAT, SeaWinds, WindSat and buoy observations. • Satellite data are assimilated into the ECMWF Operational Analysis fields.</td>
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Wind climatology is compared to the climatology derived from the QuikScat Winds (RSS gridded product)
January Winds, 2004-2008

QuikSCAT

NCEP

CFSR

ASR

CCMP

Every 4th vector plotted

Every 5th vector plotted

Every 4th vector plotted

Every 6th vector plotted

0 5 10 15 20 m/s
Mean Directional Offset relative to the QuikSCAT

NCEP

CFSR

ASR

CCMP
Spatial Eigenvectors of the 1st EOF and Principal Components of the Area-Mean Vorticity

• Circulation around a closed cell:

\[ C = \oint \mathbf{v} \cdot d\mathbf{l} \]

• Area-mean vorticity:

\[ \zeta = \frac{C}{A} \]

(Bourassa and Ford, JAOT, 2010)

• Diameter of the closed cells is 200 km
Ekman Pumping (m/day) Estimated from the Wind Data
January, 2004-2008

\[ w_{Ek} = \frac{1}{\rho_0} \left[ \frac{\partial}{\partial x} \left( \frac{\tau^y}{f} \right) - \frac{\partial}{\partial y} \left( \frac{\tau^y}{f} \right) \right] \]
**Model Experiments with Different Winds**

**0.08° HYCOM/CICE Modeling System of the Arctic Ocean**

- **ARCc0.08**: Coupled HYbrid Coordinate Ocean Model and Los Alamos Sea Ice Model (CICE 4.0)
- 32 vertical ocean levels
- Atlantic and Pacific Boundaries at ~39°N
  - Closed (no-ice) in CICE
  - Nested into 1/12° Global HYCOM
- Run from Oct. 2005 – April 2006 with
  - CFSR winds
  - NCEPR winds
  - CCMP + CFSR (north of 78.4N) winds
  - ASR + CFSR (south of ~42N) winds
Ekman Pumping in the Simulation

January $T^\circ C$ and $\sigma_0$ (kg/m$^3$) Contours from HYCOM – CICE Forced with the CCMP Winds

Lifted isopycnals due to the cyclonic Greenland Gyre driven by cyclonic winds during winter
During Winter 2005/2006 averaged over the Central Greenland Sea from HYCOM – CICE forced with different winds.

Low-pass filtered time series of the wind curl over the Central Greenland Sea.
East Greenland Current’s structure:

- Thermohaline driven throughflow (a small seasonal cycle) (~ 8 Sv at 75N, Woodgate et al., 1999)

- A western-intensified southward flow of a wind-driven gyre (a large seasonal cycle) (~ 19 Sv at 75N, Woodgate et al., 1999)

[Aagaard, 1970; Stevens, 1991; Woodgate et al., JGR, 1999]

- A western-intensified southward flow is a western-boundary current that balances the northward Sverdrup flow driven by the curl of the wind stress:

\[ V = \frac{1}{\rho_0 \beta_0} \hat{k} \cdot \nabla \times \tau \]
Low-Pass Filtered Transport of the East Greenland Current from the Model Experiments with Different Wind Forcing
Maxima/minima in the wind-driven Sverdrup transport correspond to the maxima/minima in the southward volume flux of the EGC with ~1 month delay.

From the time-scale analysis [Anderson and Killworth, 1979; Anderson et al., 1979; Jonsson, 1991], wind-induced changes on seasonal timescales must be propagated by barotropic Rossby waves in the Nordic Seas.

Linear barotropic Rossby wave speeds suggest a timescale of $O(1 \text{ mo})$ for a Sverdrup balance to set up after a wind is applied to the Greenland Sea basin [Jonsson, 1991].
Summary

• Climatology of ocean surface winds over the Nordic Seas from the NCEPR-II, CFSR, CCMP and ASR is validated by comparing against QuikScat RSS:
  • Monthly mean winds
  • 25th and 75th percentile winds
  • Cross-correlation of the wind speed anomalies
  • Directional offset
  • Area-mean wind vorticity

• Qualitatively, there is a good agreement in climatology across the wind data. NCEPR winds have noticeable biases compared to the other wind products.

• Sensitivity of the large-scale ocean response to discrepancies in the wind fields is assessed using Arctic Ocean HYCOM-CICE forced with different wind data:
  • Upwelling (“doming”) of the isopycnals in the Greenland Gyre in winter
  • Wind-driven transport of the ocean currents (EGC, volume fluxes in the Fram and Denmark Straits)

• Disagreement in the ocean processes among the model experiments stems from differences in the wind stress curl derived from the wind data
Synopsis from the IOVWST 2013:
Cyclones in the Nordic Seas

- **Large-scale low-pressure systems:**
  - Spatial scale: $O(10^3)$ km
  - Time scale: days-week

- **Meso-scale low pressure systems (e.g., Polar Lows):**
  - Spatial scale: $O(100)$ km
  - Time scale: hours – day

**Representation of a large-scale cyclone in the wind products 20 December, 2004**

**Spatial Wind Spectra**

[Graph showing spatial wind spectra with legends for QuikSCAT, NCEPR, CFSR, ASR, CCMP]
Correlation Coefficients between Wind Speed Anomalies from the Wind Products and QuikScat

UTC Time of Observation

Ascending Pass

UTC Time of Observation

Descending Pass

NCEP vs QSCAT

ASR vs QSCAT

CCMP vs QSCAT
July Winds, 2004-2008

QuikSCAT

Every 4th vector plotted

NCEP

Every 5th vector plotted

CSFR

Every 6th vector plotted

ASR

Every 4th vector plotted

CCMP

Every 6th vector plotted

0  5  10  15  20 m/s
Circular-Circular Correlation with QuikSCAT

\[ \rho_c(\Phi, \Theta) = \frac{E[\sin(\Phi - \overline{\Phi}) \sin(\Theta - \overline{\Theta})]}{\sqrt{\text{Var}[\sin(\Phi - \overline{\Phi})] \text{Var}[\sin(\Theta - \overline{\Theta})]}} \]

- \( \rho = \pm 1 \) iff \( \Phi = \pm \Theta + \theta_0 \)
- \( \rho = 0 \) if \( \Phi \) and \( \Theta \) are independent (the converse may not be true)  
  \([\text{Jammalamadaka & Sarma, 1988}]

All winds show a strong relation with QuikSCAT:
\( \Phi \approx \pm \Theta + \theta_0 \)
January 75th Percentile Winds, 2004-2008
Correlation Coefficients between Wind Speed Anomalies

NCEP vs QSCAT
CFSR vs QSCAT
ASR vs QSCAT
CCMP vs QSCAT

UTC Time of Observation
Ascending Pass
0h 4h 8h 12h 16h 20h

CCMP
October 4, 2004, 6:00 UTC

QuikSCAT
October 4, 2004, Ascending Pass