Sensitivity of Ocean Processes in the Nordic Seas to Surface Winds from the 1/12° Arctic Ocean HYCOM-CICE

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Arctic Ocean Circulation

- Atlantic water + intermediate layer, 200-1700 m
- Pacific water, 50-200 m
- Surface water circulation
- River inflow

Figures are estimated in- or outflows in Sverdrups (million m$^3$ per second)

Arctic Monitoring and Assessment Programme

Nordic Seas

- Arctic Ocean
  - Bering Strait
  - Chukchi Sea
  - East Siberian Sea
  - Laptev Sea
  - Kara Sea
  - Greenland Sea
  - Iceland Sea
  - Norwegian Sea
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
  - PL: Very strong winds (>17 m/s)

"Yet owing to their small scale, polar lows are poorly represented in the observational and global reanalysis data <...>". Zahn & von Storch, Nature (467), 2010

From October 1993 to September 1995, more than 2500 cyclones are missing from ECMWF ERA-40 reanalysis data over the northeast Atlantic. Condron et al., JGR(113), 2008

Only 25% of the total number of mesocyclones observed in satellite data are represented in the reanalysis data (ERA-40). Condron et al., JGR(113), 2008
<table>
<thead>
<tr>
<th>Dataset</th>
<th>Details</th>
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<tbody>
<tr>
<td>National Center for Environmental Prediction Reanalysis II (NCEP/DOE)</td>
<td>Period covered: 1979 – 2009; 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. NCEP/NCAR Reanalys.1 is the primary source of forcing parameters for the AOMIP experiments.</td>
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<tr>
<td>NCEP Climate Forecast System Reanalysis (CFSR)</td>
<td>Period covered: 1979 – March 2011; ~38 km resolution, 1hr fields; Assimilation: all available conventional and satellite observations; Updated assimilation and forecast system; Covers atmosphere, ocean, sea ice, and land; Anticipated to supersede the older NCEPR products both in scope and quality.</td>
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<tr>
<td>Arctic System Reanalysis (ASR)</td>
<td>Period covered: 2000-2010; Blend of modeling and observations; Produced using Polar WRF and the WRF-VAR assimilation system; 3hr data, 30 km (10 km); The final product will be at 15 km resolution.</td>
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<tr>
<td>Cross-Calibrated Multi-Platform Ocean Surface Wind Components (CCMP)</td>
<td>Period covered: July 1, 1987 – 2011; 0.25° resolution, 6hr fields; The data set combines data derived from several scatterometer satellites; Satellite data are assimilated into the ECMWF Operational Analysis fields.</td>
</tr>
</tbody>
</table>
Spatial Wind Spectra

A fit to aircraft observations of KE spectra follows a $k^{-(5/3)}$ power law in the mesoscale

$(Nastrom$ et al., $J$, Atm. Sci., 42, 1985)
Surface Winds
January 13
2006
6:00 UTC

Ocean Surface Winds from QuickScat,
01/13/2006, 6:00

- 29-31 m/s
- 23-25 m/s
- 30-35 m/s
- >30 m/s

Remote Sensing Systems
www.remss.com
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 \( \sim 39^\circ \) 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 \( \sim 42^\circ \)N) winds
CCMP

Volume Transport, Fram Str. (Sv)

Northward

Volume Transport, BSO(Sv)

CFSR

Volume Transport, Fram Str. (Sv)

Southward

Volume Transport, BSO(Sv)

ASR

Volume Transport, Fram Str. (Sv)

Southward

Volume Transport, BSO(Sv)

EPI

Volume Transport, Fram Str. (Sv)

Southward

Volume Transport, BSO(Sv)
Mean Surface Flux (W/m²)
Surface Winds
Jan. 13 2006, 0:00 UTC

Net Surface Flux (W/M²) from HYCOM Forced by Different Winds

ARCco.08+CCMP  ARCco.08+NCEPR  ARCco.08+CFSR  ARCco.08+ASR
Water Mass Transformation in the Barents Sea

January Mean Sea Surface Temperature

HYCOM+CCMP
Volume (km³) of Water Masses, 1 January 2006

HYCOM+CCMP

Atlantic Water

Norwegian Coastal Current

Bottom Water
Production and Export of Water Masses during Jan. – Feb. 2006 (km$^3 \times 10^3$)

Dense Water $S > 34$, $T < 0^\circ C$
Summary

(1) Winds in the CCMP, NCEPR, ASR, & CFSR are different:
   - Location, size, and timing of storms
   - On average, the NCEP winds have higher speeds compared to the CFSR, ASR, CCMP
   - In storms, CCMP peak winds are higher than NCEPR, ASR & CFSR winds
   - CFSR & ASR winds have lowest winds in the storms
   - Meso-scale cyclones are not represented in the NCEPR, CFSR, CCMP wind fields

(2) Oceanic response to the wind forcing is different:
   - Different upper ocean circulation
   - Winds have distinct impact on Arctic – Nordic Seas exchange (Fram Strait and BSO)
   - In the storms, surface heat fluxes differ by ~1.5 times among the models
   - Discrepancies in the wind forcing impact process of the water mass formation in the Nordic Seas in the model
   - Export rate of the dense water produced in the Barents Sea varies among the models by as much as 2 times

(3) Good agreement between simulations driven by CCMP and CFSR winds

(4) Contribution from meso-scale cyclones needs to be estimated
Exceedance Probability (U>17 m/s), winter 2005-2007
Net Change of Volumetric Content of Water Masses (km$^3$) during Jan. – Feb. 2006
Effect of Wind on Volume Transport through Fram Strait

Volume Transport through Fram Strait (upper 15 m)

CCMP Winds

NCEPR Winds

Transport

Normal Wind

m/s

CCMP, Feb. 12 2006 0:00 UTC

NCEPR, Feb. 12 2006 0:00 UTC
Cyclones in the Nordic Seas

Winter Cyclone Tracks

Large-Scale Low Pressure Systems
Spatial scale: O(1000) km
Time scale: Days – week

Average (1949-2002) Cyclone Activity

Sorteberg & Walsh, 2008
Maximum Wind Speed, winter 2005-2007
Nordic Seas Region

ASR Data Assimilation Result: Polar Low
10 m Wind and Satellite Image

06 h DEC 20, 2007  D. Bromwich

Volume flux through the boundaries of the control volume