Modeled Sensitivity of the Upper-Ocean Properties in the Nordic Seas to Wind Forcing

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Area of the Nordic Seas: $\approx 4.2 \times 10^6 \text{ km}^2$

$\approx 2.8$ areas of the Gulf of Mexico

$\approx 1.7$ area of the Mediterranean Sea

$\approx 11$ areas of the Baltic Sea
Cyclones in the Nordic Seas

Winter Cyclone Tracks

Sorteberg & Walsh, 2008

Average (1949-2002) Cyclone Activity

Sorteberg & Walsh, 2008

Meso-scale low pressure systems (e.g., Polar Lows):

Spatial scale: $O(100)$ km
Time scale: hours – day

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

Noer et al., QJRMS, 2011

Sorteberg & Walsh, 2008
Surface Winds, March 5, 2006

Cross-Calibrated Multi-Platform Ocean Surface Wind Components (CCMP)
- 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

NCEP Climate Forecast System Reanalysis (CFSR)
- Period covered: 1979 – March 2011; ~0.31° resolution, 1hr fields
- Assimilation: all available conventional and satellite observations
- Updated assimilation and forecast system (from NCEPR 2)
- Covers atmosphere, ocean, sea ice, and land
- Anticipated to supersede the older NCEPR products both in scope and quality

National Center for Environmental Prediction Reanalysis 2 (NCEPR)
- Period covered: 1891 – present;
- 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, monthly, daily averages

The primary source of forcing parameters in many Arctic Ocean model experiments
Exceedence Probability of $U > 17$ m/s during winter season, 2005-2007
Model Experiments with CFSR, NCEPR, and CCMP 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
  - Initialized from Sept. 2005
  - Run from Oct. 2005 – April 2006 with
    - CFSR winds
    - NCEPR winds
    - CCMP + CFSR (north of 78.375N) winds
Surface Winds and Total Surface Heat Flux, Jan. 13 2006
Surface Winds and SST Change
Jan. 13 2006

ARCco.08+CCMP

ARCco.08+NCEPR
Wind Impact on Fluxes through Fram Strait

Heat Flux (MW/m²) and Wind across Fram Strait, October 2005

CCMP, Oct. 10 2005 0:00 UTC

NCEPR, Oct. 10 2005 0:00 UTC

Days in October

Days in October
Water Mass Transformation in a Control Volume in the Barents Sea
Volume (km$^3$) of Water Masses, 10 January 2006
Net Volume Change of Water Masses Binned in T Groups

ARCco.08+CCMP

ARCco.08+NCEPR

Cold water produced on the Barents Shelf
Closing Remarks

(1) Winds in the CCMP, NCEPR, & CFSR are different:
   - Location, size, and timing of storms
   - On average, the NCEP winds have higher speeds compared to the CCMP & CFSR winds
   - In storms, the CCMP winds have higher peak values than both the NCEP & CFSR winds
   - CFSR winds have lower winds in the storms than the other wind products
   - Meso-scale cyclones are not resolved in the NCEPR data

(2) Oceanic response of the Nordic Seas to the winds is different:
   - In the storms, surface heat fluxes differ by ~2 times due to differences in the wind fields
   - Winds have obvious impact on Arctic – Nordic Seas exchange
   - Numerical experiments with different winds predict different processes of water mass formation in the region

(3) Are meso-scale cyclones represented in the CCMP (other scatterometer wind products)?
Mixed Layer Depth (m) in ARCCo.08

Defined as the average of the depths where:

\[ \frac{dp}{dz} > 0.001 \text{ kg/m}^4 \]

\[ (\rho(z) - \rho_0) > 0.01 \]

Estimated \( \Delta T \) in the mixed layer of 100 m depth over 6 hours of \( Q_{\text{tot}} = -1000 \text{ W/m}^2 \) is \(-0.05^\circ \text{ C}\).
Maximum Wind Speed
winter 2005-2007

CCMP

CFSR

NCEPR

Wind speed, m/s
Area-Integrated Heat Flux (TW), January 2006

Greenland Sea

Time integrated energy released to the atmosphere:
- ARCc+CCMP: -602 EJ
- ARCc+CFSR: -594 EJ
- ARCc+NCEPR: -655 EJ

Barents Sea

Time integrated energy released to the atmosphere:
- ARCc+CCMP: -652 EJ
- ARCc+CFSR: -637 EJ
- ARCc+NCEPR: -619 EJ
Change of the mean heat flux by 65TW results in the AOO regime change in the model

Dukhovskoy et al., 2004
Representation of Storms in the Wind Products

CCMP+CFSR
Oct. 5, 2005
Oct. 7, 2005
Oct. 17, 2005
Feb. 9, 2006

CFSR
Oct. 5, 2005
Oct. 7, 2005
Oct. 17, 2005
Feb. 9, 2006

NCEPR
Oct. 5, 2005
Oct. 7, 2005
Oct. 17, 2005
Feb. 9, 2006
Spatial Power Spectra of Winds along 70° N

Spatial spectra of NCEP(b) CCMP(r) CFSR(g) winds along 70°N

Synoptic-Scale Processes

Meso-Scale Processes

~600 km

~200 km

~100 km

95% C.I.

DoF = 16

Log_{10}(PSD), m^2/s^2

Log_{10}(cycle/km)
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 – days
- Very strong winds (>17 m/s)

“A classic Barents Sea polar low, February 9, 2011” (http://polarlows.wordpress.com/)

Noer et al., QJRMS, 2011

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

Polar Lows off the coast of Norway and Russia on January 7 2009 from NOAA AVHHR

Noer et al., QJRMS, 2011