Analysis of the Relationship between a Change in Wind Field Curl Rate and Sea Surface Height within the Beaufort Gyre Region of the Arctic

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Beaufort Gyre

- Anticyclonic circulation system
- Between 130° - 180°W
- Contains the majority of the Arctic Ocean’s freshwater
- Circulation controlled by the Beaufort High
Ekman Mechanics

- Frictional drag of winds on ocean surface lead to **Ekman Transport**: Horizontal ocean water movement

- Coriolis effect: Surface ocean water deflected 45° to the right of the mean wind

- Spatial gradients in Ekman Transport lead to **Ekman Pumping**: Vertical ocean water movement
Doming in the Beaufort Gyre

Previous research by Giles et al. 2012:

- Accumulations of 8,000 ± 2,000 km$^3$ of freshwater in the Beaufort Gyre from 1996 to 2010.
- Wind-driven convergence controls freshwater variability within this region.

Project Goals

1. Quantitatively determine if there has been a significant anticyclonic wind curl regime over the time period of 1996 to 2010

2. Create a robust algorithm to obtain velocity measurements from drifting ice platforms’ location data and interpolate low-resolution sea ice drift velocity measurements to the individual platform drift tracks

3. Gain a better understanding of the relationships between the surface wind, ocean processes, and sea ice movement
Wind Curl ~ Data Sources

U and V wind components obtained from 1996 to 2010

- NCEP/NCAR Reanalysis
  - Daily Mean
  - 2.5° by 2.5° grid

- ECMWF Interim Reanalysis
  - Daily Mean
  - 2.5° by 2.5° grid

- Japanese 55-Year Reanalysis (JRA-55)
  - 4x Daily Observations
  - 0.75° by 0.75° grid
Wind Curl Methods

\[ \nabla \times \mathbf{u} |\mathbf{u}| = \left( \frac{\partial (v |\mathbf{u}|)}{\partial x} - \frac{\partial (u |\mathbf{u}|)}{\partial y} \right) \hat{z} \]

- *netCDF4* and *pygrib* modules used to read in data

- Trimmed data files:
  - Western Arctic: 70°- 82.5°N, 130°- 180°W
  - Entire Arctic: 70°- 90°N, 0°- 360°W

- Vorticity calculated with *Windspharm*, uses spherical harmonic wind vector analysis.
  - Validation completed with artificial datasets
Wind Curl Anomaly Plot

- Anomalies within the Western Arctic
- Total mean generated by averaging all months of wind curl data
- Annual anomalies computed by subtracting the total mean curl from the annual means of the monthly data.
- Error bars: Standard deviation scaled by square-root of $\chi^2$ per degree of freedom
- Slope error: Least-mean-square standard error
Average of All Reanalyses

Mean Wind Curl Anomalies: 1996-2010

\[-0.113 \pm 0.037 \left(10^{-6} \text{m} \cdot \text{s}^{-2} \cdot \text{yr}^{-1}\right)\]
Curl Trend & Uncertainty Plots

- Defined to the entire Arctic
- Curl trend defined by the difference field at each pixel:
  - Subtracted year i+1 from year i for all years of data, then averaged
- Standard error at each pixel from a least-mean-squares analysis over the 15 year period
- Both data fields projected onto a northern hemisphere polar stereographic conformal map projection
NCEP/ NCAR Reanalysis

NCEP Wind Curl Trend (1996 - 2010)

NCEP Wind Curl Trend Standard Error (1996 - 2010)
ECMWF Interim Reanalysis
Wind Curl Trend Conclusions

- Insignificant wind curl anomaly trend
- Error accounts for over 30% of the anomaly’s slope
- Further minimalized by the error bars
- Uncertainty in the trends average at about 60% of the calculated trend

Fresh water variability in Beaufort Gyre is not entirely controlled by the wind field . . . So what else controls it?
Moving onto the Arctic Ocean

- Seek to determine why climate models have underestimated the rate of sea ice melt

Models use low resolution sea ice data - could be missing movement between observational periods, thus decreasing calculated energy
Ice Velocity ~ Data Sources

- **High Resolution** SI04 SATICE drifting ice platform data
  - July 4\textsuperscript{th} to July 27\textsuperscript{th}, 2015
  - Observations taken every 15-minutes
  - Location as lat / lon with calculated errors
  - Single track - determined by ocean currents

- **Low Resolution** OSI-SAF 48 hour sea ice drift data
  - 62.5 km Polar Stereographic grid
  - Displacement as initial and final location in lat/lon
  - Field spans the entire Arctic Ocean
SI04 Drift Track: July 4\textsuperscript{th} to July 27\textsuperscript{th}

2,304 location observations were taken during this track
SI04 Velocity Profile and Associated Power Spectrum

**SI04 Buoy Speed Measurements**

Error: ± 0.0127 km·hr⁻¹

**Power Spectrum of SI04 Buoy Speed Measurements**
Just the tip of the iceberg . . .

- Interpolate low-resolution sea ice data to the track of the SI04 ice drifting platform
- Expand this study to longer time scales and more drifting platforms
  - Compare energy in high-resolution observations to that of the low-resolution observations
  - Determine how much energy the models are possibly missing
- Input changes into models

Example low-resolution ice drift plot to be interpolated. Note the Beaufort Gyre’s circulation!
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NCEP/NCAR Reanalysis

NCEP Wind Curl Anomalies (Daily Observations): 1996-2010

$-0.174 \pm 0.044 \ (10^{-11}\ m^2/s^2 \ yr^{-1})$
ECMWF Interim Reanalysis

ECMWF Wind Curl Anomalies: 1996-2010

-0.052 ± 0.032 (10^{-6} m \cdot s^{-2} \cdot yr^{-1})
JRA-55


$-0.112 \pm 0.043 \left(10^{-6} \text{m.s}^{-2} \cdot \text{yr}^{-1}\right)$