

# **Regression Analysis of Winter Sea Ice Drift in the Southern Beaufort Sea as a Result of Synoptic Atmospheric Forcing**

Matthew G. Asplin, David B. Fissel & Keath Borg  
**ASL Environmental Sciences Inc.**  
#1-6703 Rajpur Place, Victoria, BC

Matthew G. Asplin, PhD

**Now at:**

Department of Geography, University of Victoria  
W. Garfield Weston Awardee for Northern Research  
[asplin@gmail.com](mailto:asplin@gmail.com)

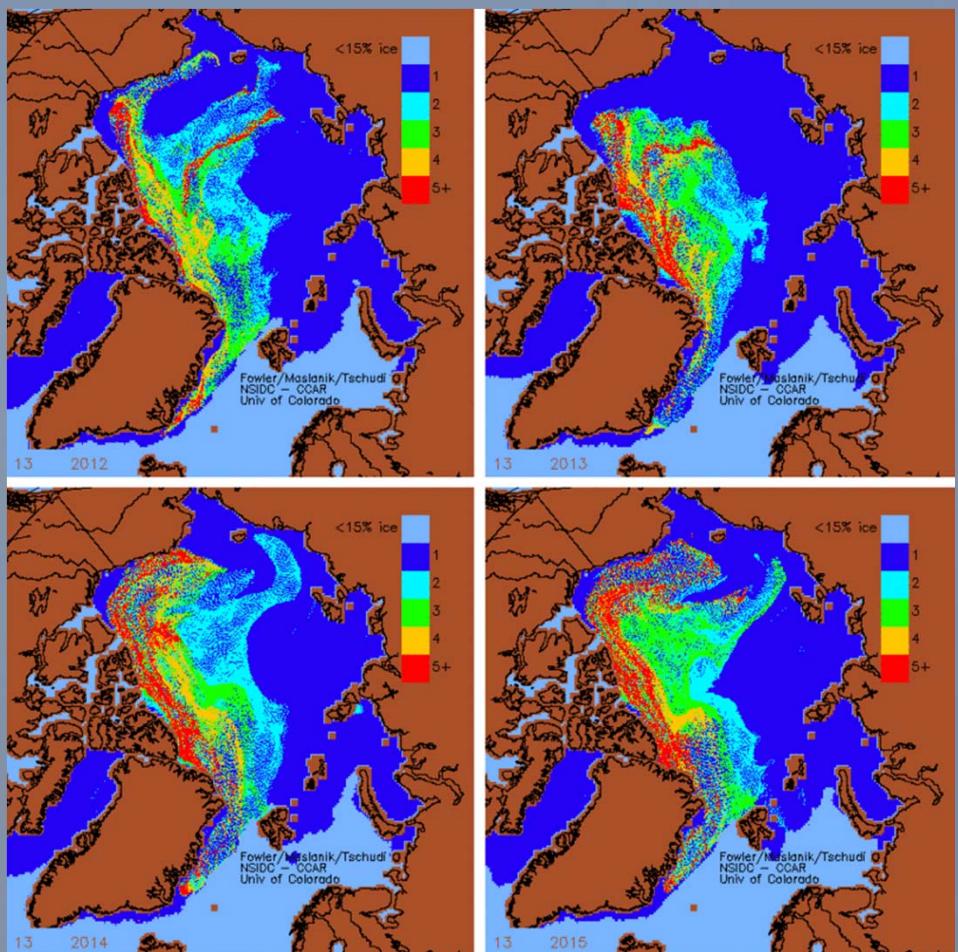
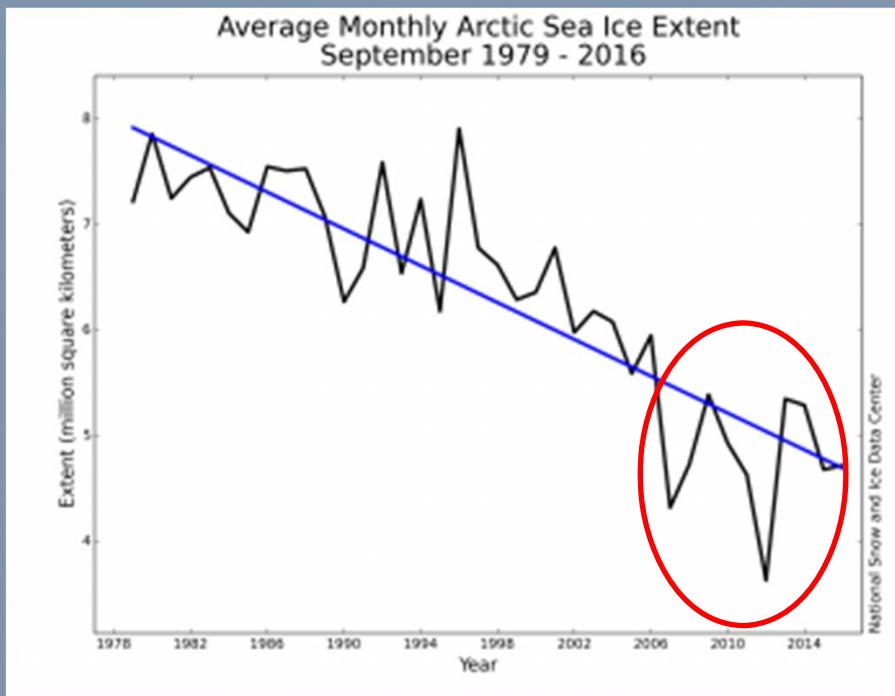


# Motivation

- To better understand sea ice motion during winter corresponding with the transition **from a multi-year to a first-year sea ice regime.**
- Scientific interest extends to important **dynamic sea ice processes** (i.e. rafting, ridging, sea ice lead formation).
- Implications for summer ice thicknesses and potential **ice hazards.**



# Declining Arctic Sea Ice



Left: summer min. ice extent (NSIDC 2016).

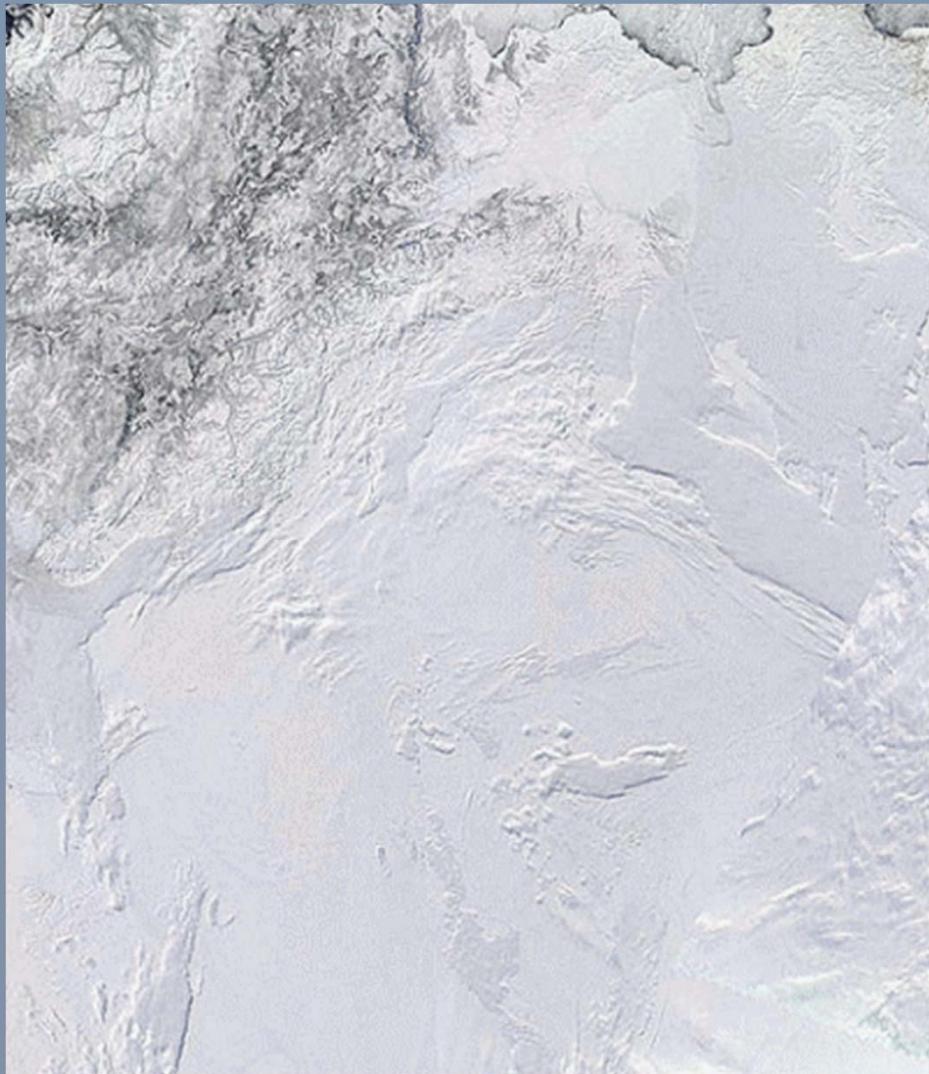
Right: NSDIC / Univ. of Colorado (2015).

September trend is  $-68\ 200 \pm 10\ 500 \text{ km}^2 \text{ yr}^{-1}$

Annual trend is  $-35\ 000 \pm 5\ 900 \text{ km}^2 \text{ yr}^{-1}$  (Parkinson, 2014)



# Winter Sea Ice Mobility



Source: NASA Earth Observatory, 2013

## Changes Observed

- Increased mobility of sea ice throughout annual cycle (Rampal et al., 2009)
- Reduced MY Ice volumes and extents (Maslanik ,2011; Parkinson, 2014)
- Increasing easterly wind forcing (Stegall and Zhang, 2012)

## Implications

- Increased FY ice coverage during winter
- FY ice prone to fracture & sea ice lead formation
- Winds drive sea ice dynamics (e.g. leads, pressure ridges) Spreen et al., 2011



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# Southern Beaufort Sea Wind Trends

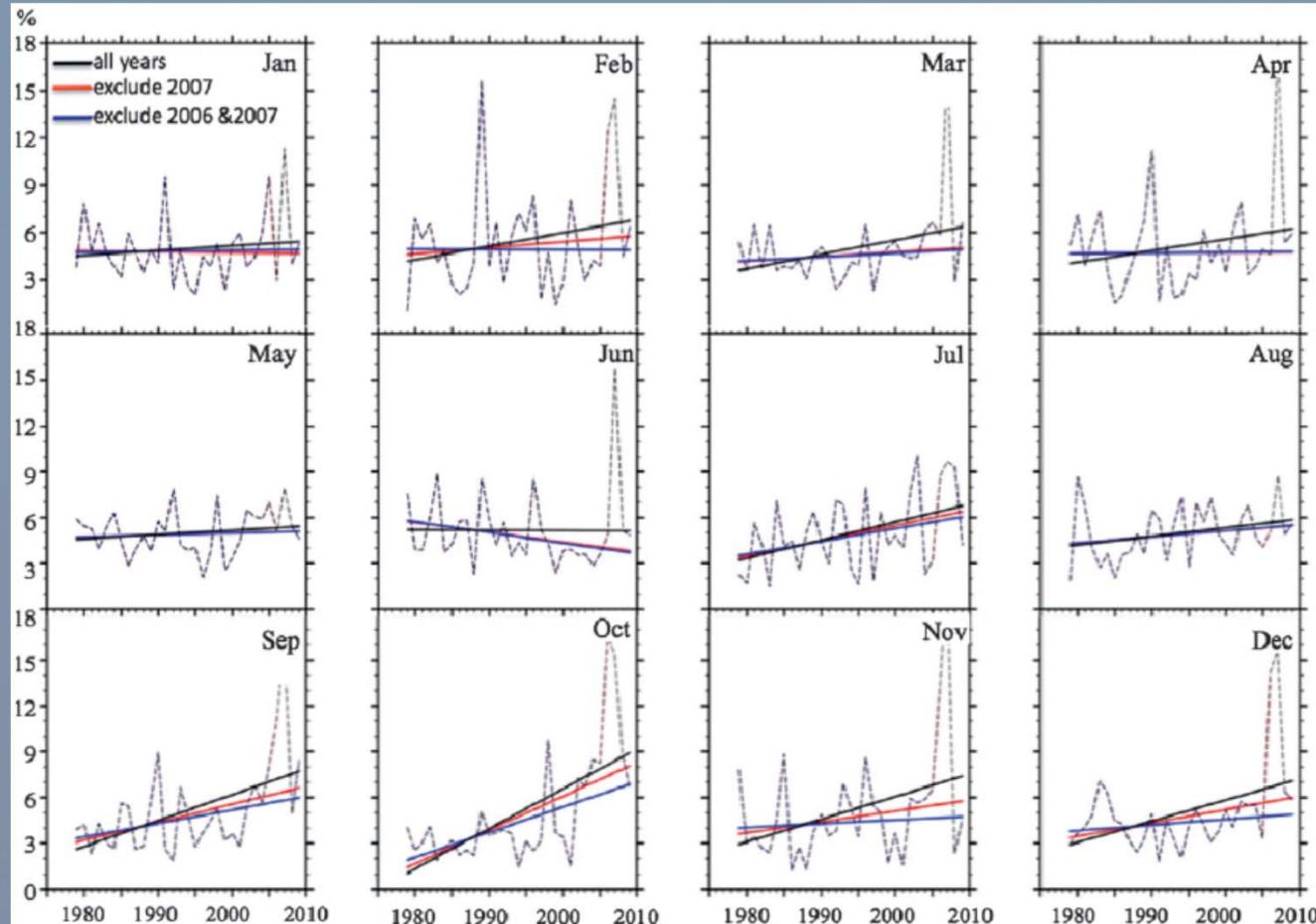
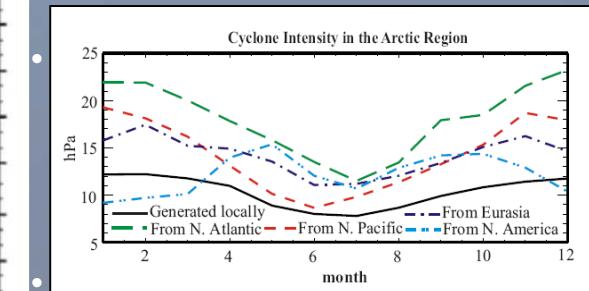


Figure 7A: Stegall and Zhang, 2012 - Monthly frequency of extreme wind events

- Easterly winds have become more frequent and intense during October – December (Moore, 2012, Moore & Pickart, 2012).

- Extreme wind events (>95<sup>th</sup> percentile) increased in frequency during all months (Stegall & Zhang, 2012).



- intense than summer (Zhang et al., 2004). Intensity increasing but not frequency (Simmonds & Keay, 2009).



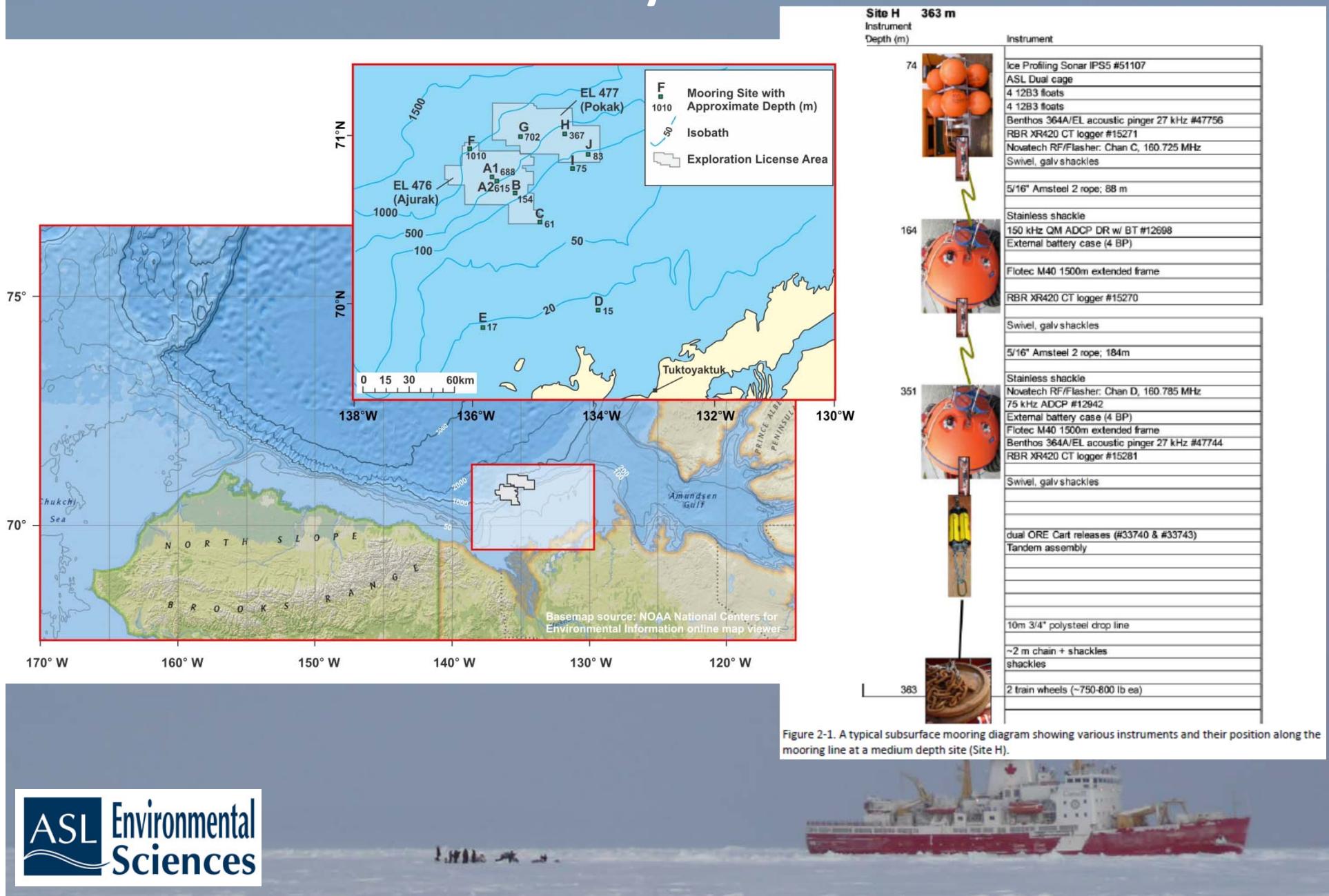
# Objectives

- 1) How does sea ice motion behave with respect to wind and ocean forcing? (magnitude and turning angle from regression analysis) Are these relationships statistically significant for winter 2009/2010 – 2010/2011?
- 2) How does the relationship between sea ice motion and wind forcing vary between different synoptic atmospheric circulation regimes (synoptic typing). For which synoptic type are these relationships statistically significant for winter 2009/2010 – 2010/2011?
- 3) How does ice motion response vary spatially along and across the continental shelf of the Canadian Beaufort Sea?
- 4) Are the observed relationships relevant for extreme wind forcing events? (case studies).



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# Study Area



# Regression Methods

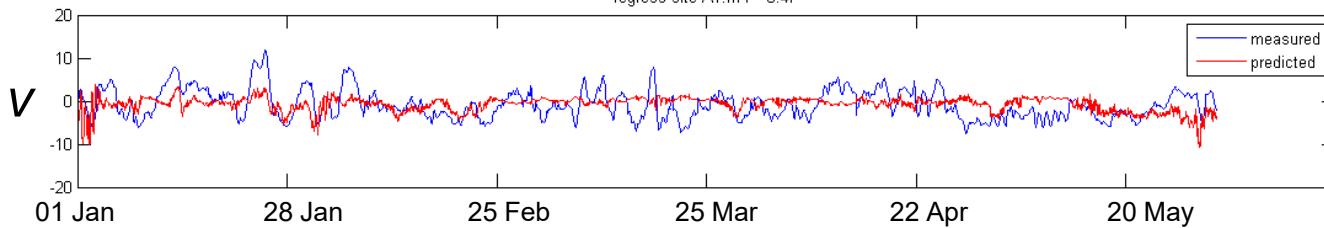
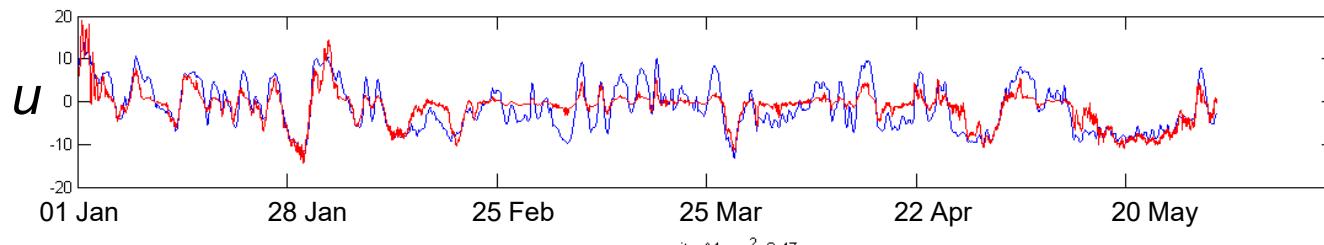
- High Resolution Meteorological Service of Canada (MSC) Beaufort Sea Wind Wave Reanalysis (Swail et al. 2007)
- Ice velocities and near-surface currents available at 20 min interval
- Seek events of strong, steady wind forcing constrained to 45° directional variability
- Regression methods follow Simizu et al., 2014

$$\begin{pmatrix} U \\ V \end{pmatrix} = F \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} + \begin{pmatrix} C_u \\ C_v \end{pmatrix}$$

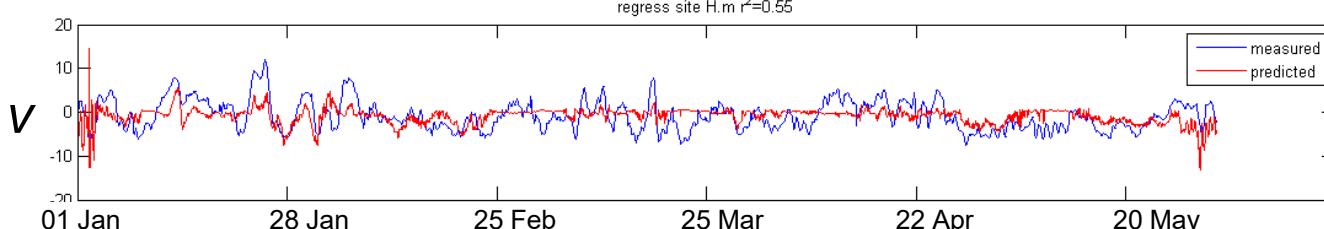
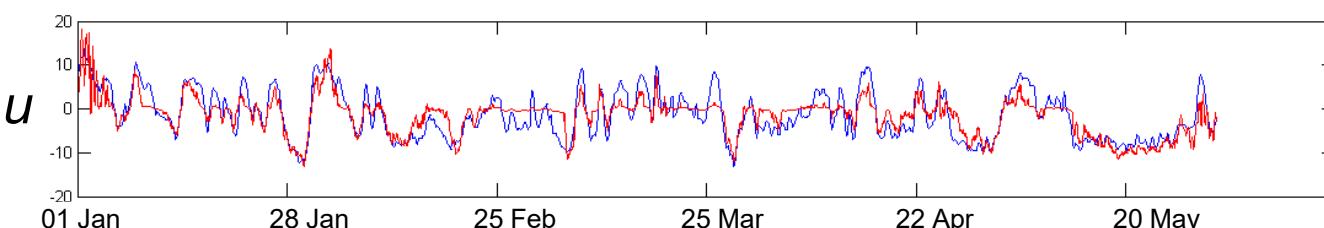


# Results

A1



H



# Ocean Current Forcing a Factor?

Without surface-ocean currents:

$$\begin{pmatrix} U \\ V \end{pmatrix} = F \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix}$$

**Site A1:  $R^2 = 0.47$**

**Site H:  $R^2 = 0.55$**

With surface-ocean currents

$$\begin{pmatrix} U \\ V \end{pmatrix} = F \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} + \begin{pmatrix} C_u \\ C_v \end{pmatrix}$$

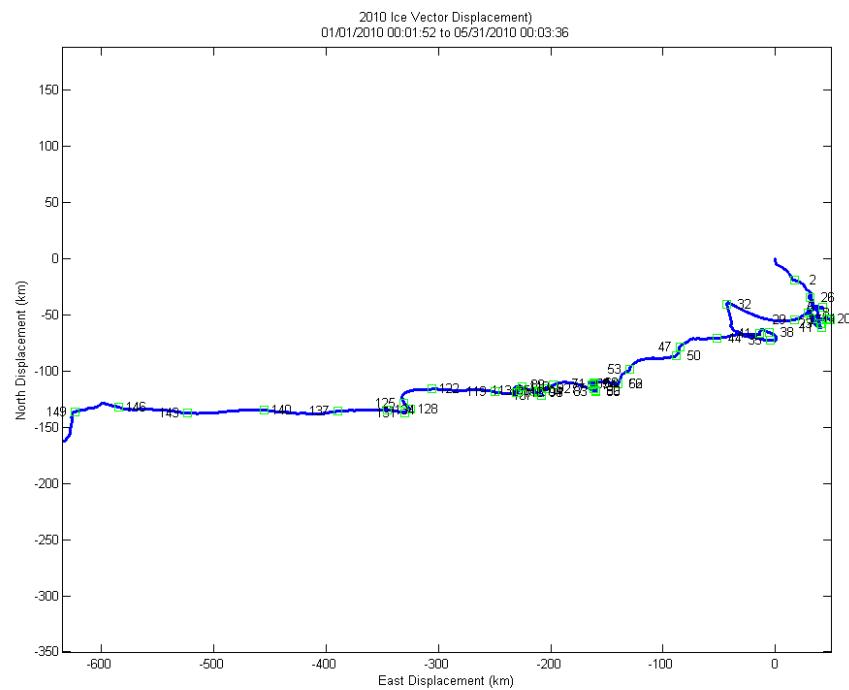
**Site A1:  $R^2 = 0.48$**

**Site H:  $R^2 = 0.58$**

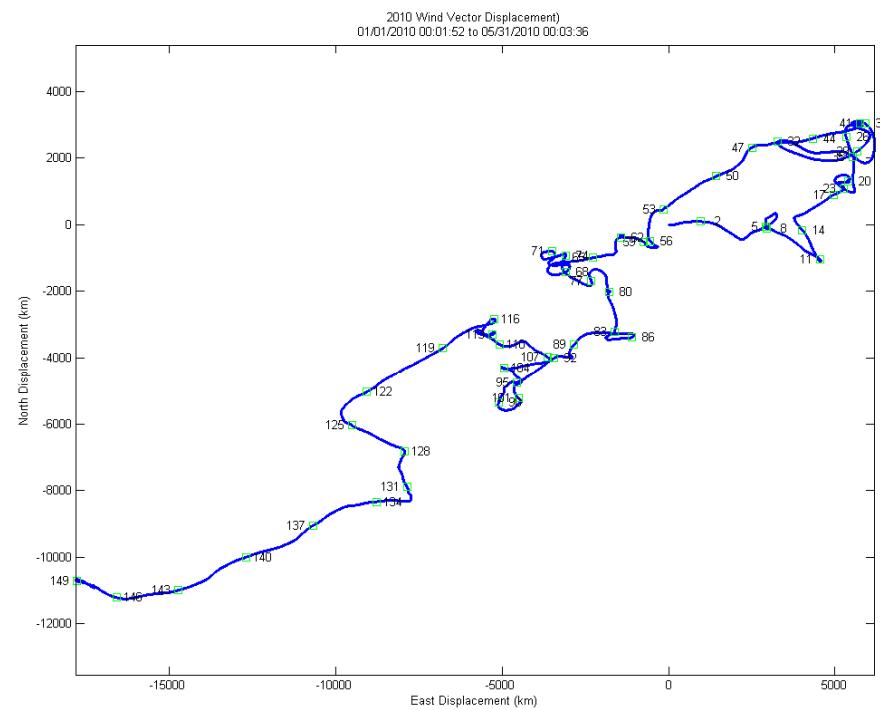


# Ice & Wind Vector Displacement

Ice:Jan – May 2010



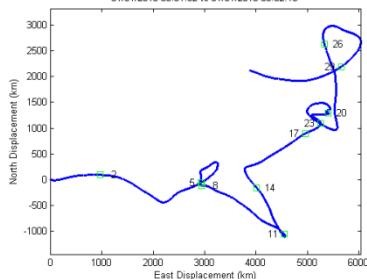
Wind:Jan – May 2010



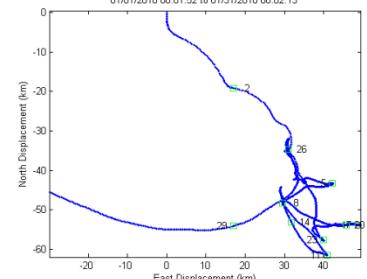
# Ice & Wind Vector Displacement

Wind: Jan

2010 Wind Vector Displacement  
01/01/2010 00:01:52 to 01/31/2010 00:02:13

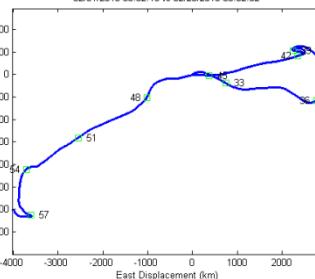


2010 Ice Vector Displacement  
01/01/2010 00:01:52 to 01/31/2010 00:02:13

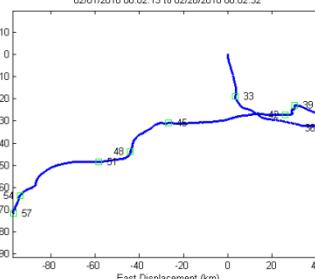


Feb

2010 Wind Vector Displacement  
02/01/2010 00:02:13 to 02/29/2010 00:02:32

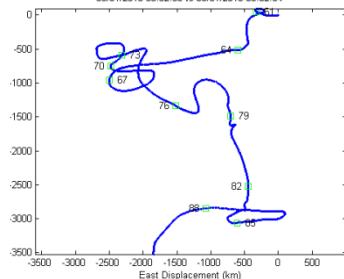


2010 Ice Vector Displacement  
02/01/2010 00:02:13 to 02/29/2010 00:02:32

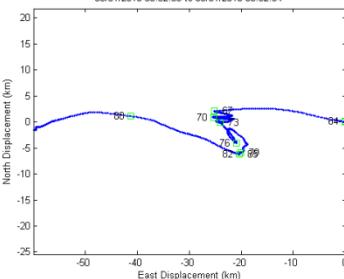


Mar

2010 Wind Vector Displacement  
03/01/2010 00:02:33 to 03/31/2010 00:02:54

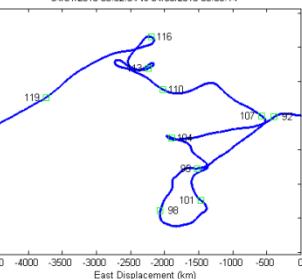


2010 Ice Vector Displacement  
03/01/2010 00:02:33 to 03/31/2010 00:02:54

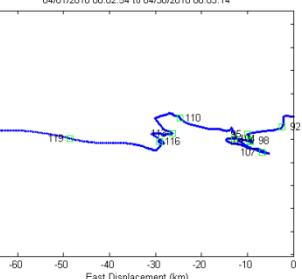


Apr

2010 Wind Vector Displacement  
04/01/2010 00:02:54 to 04/30/2010 00:03:14

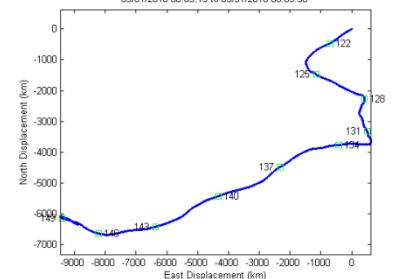


2010 Ice Vector Displacement  
04/01/2010 00:02:54 to 04/30/2010 00:03:14

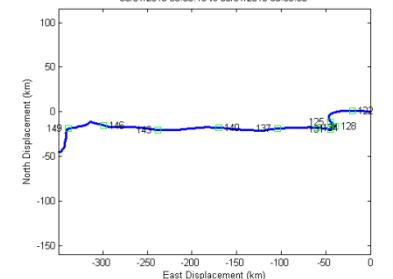


May

2010 Wind Vector Displacement  
05/01/2010 00:03:15 to 05/31/2010 00:03:36



2010 Ice Vector Displacement  
05/01/2010 00:03:15 to 05/31/2010 00:03:36

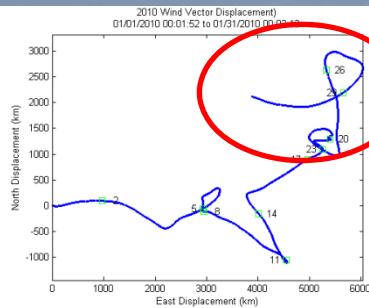


Ice



# Ice & Wind Vector Displacement

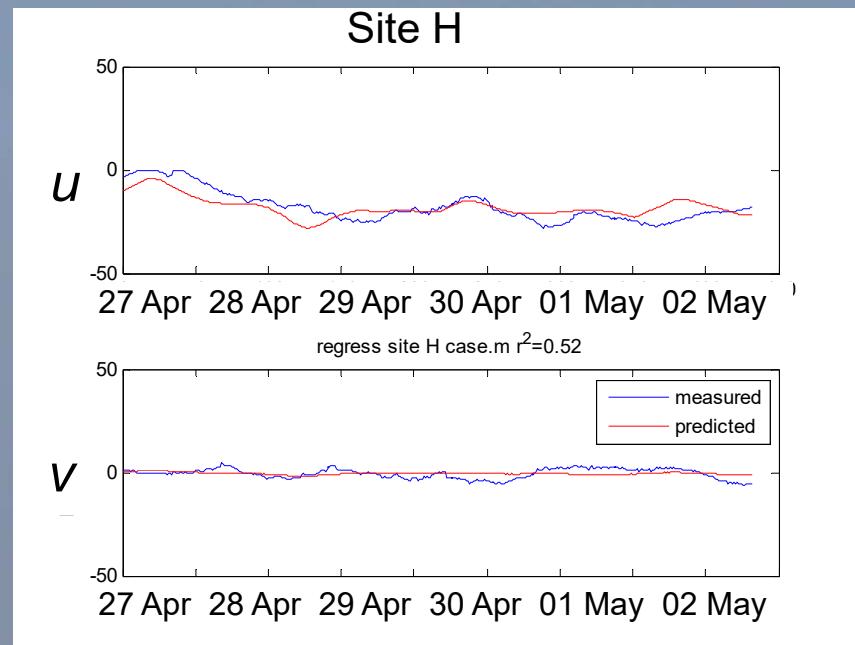
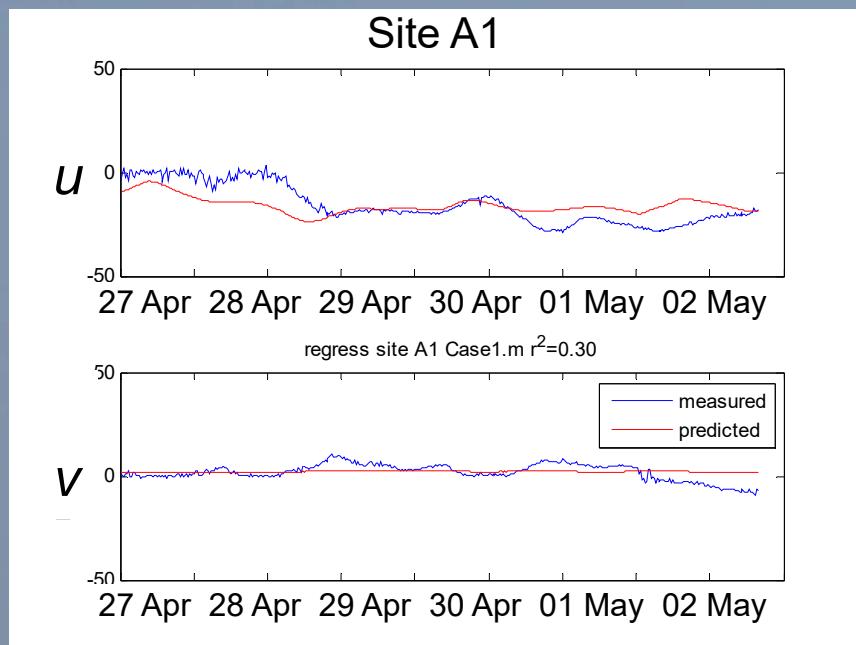
Wind: Jan



# Strong Wind Case Study 1

27 April – 02 May 2010

ST 9,11,3,3,2,3 (Strong Easterlies)



$$F = 1.28$$

$$\Theta = -30.9^\circ$$

$$R^2 = 0.30$$

$$F = 1.88$$

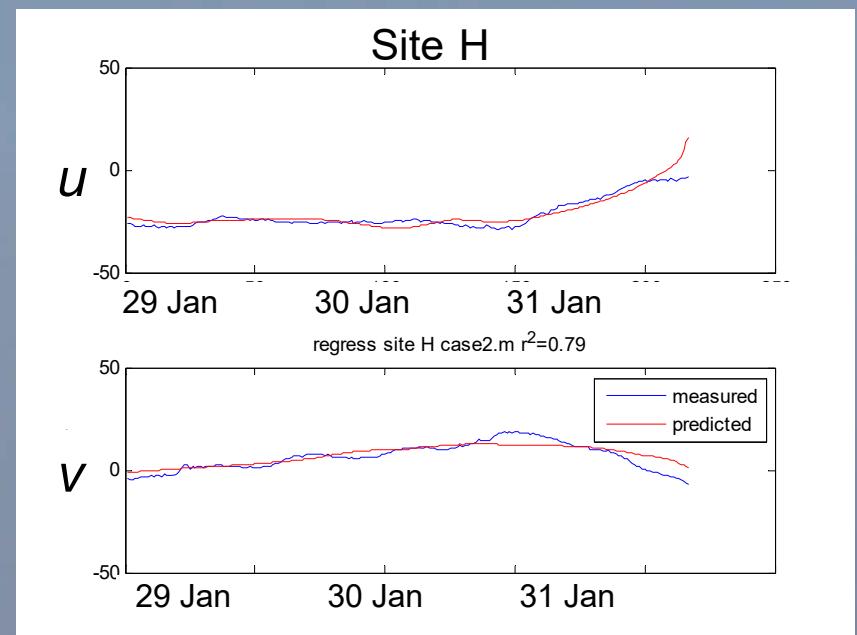
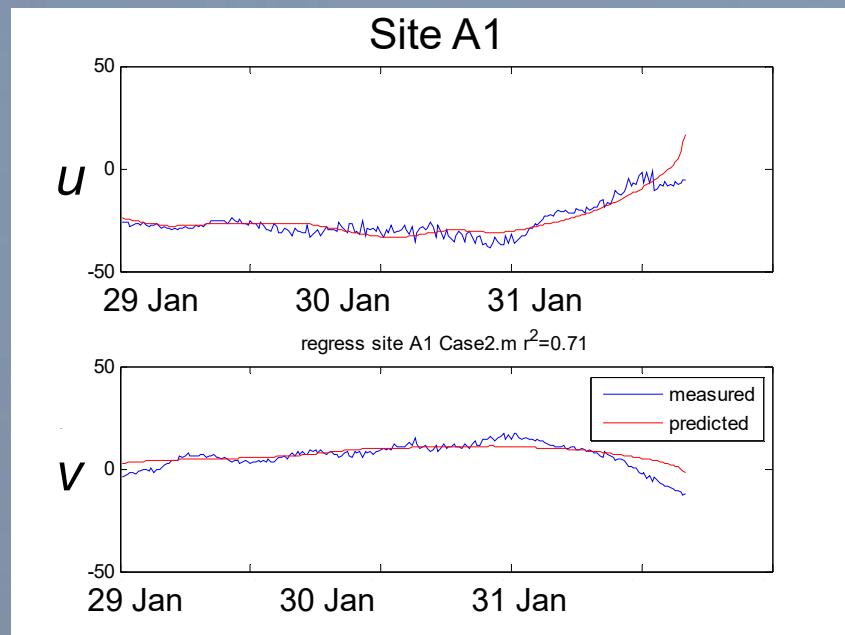
$$\Theta = -80.1^\circ$$

$$R^2 = 0.52$$



# Strong Wind Case Study 2

29 – 31 January 2010  
ST 8,8,10 (Strong Easterlies)



$$F = 1.79$$

$$\Theta = -95.5^\circ$$

$$R^2 = 0.71$$

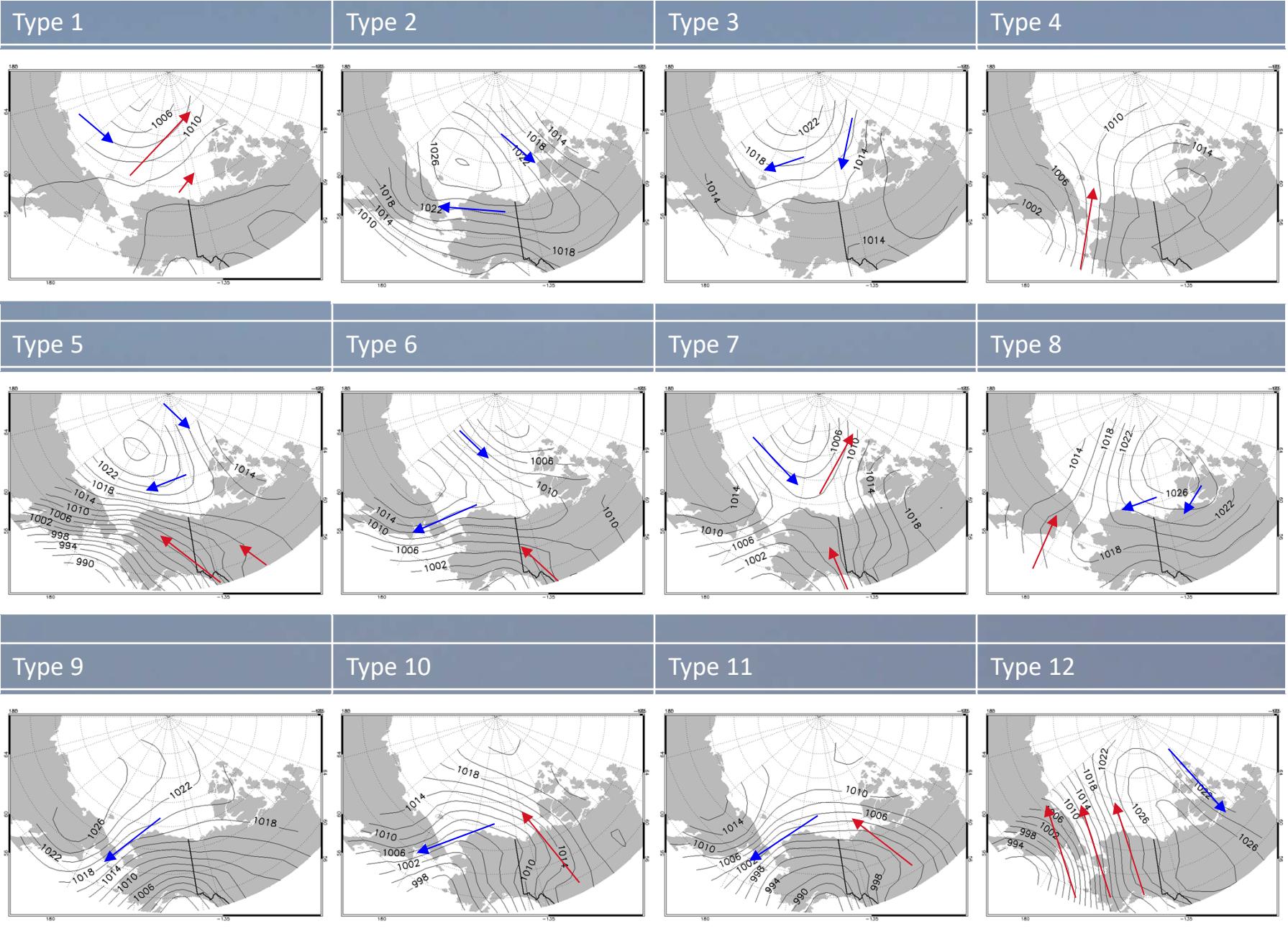
$$F = 1.94$$

$$\Theta = -22.8^\circ$$

$$R^2 = 0.79$$

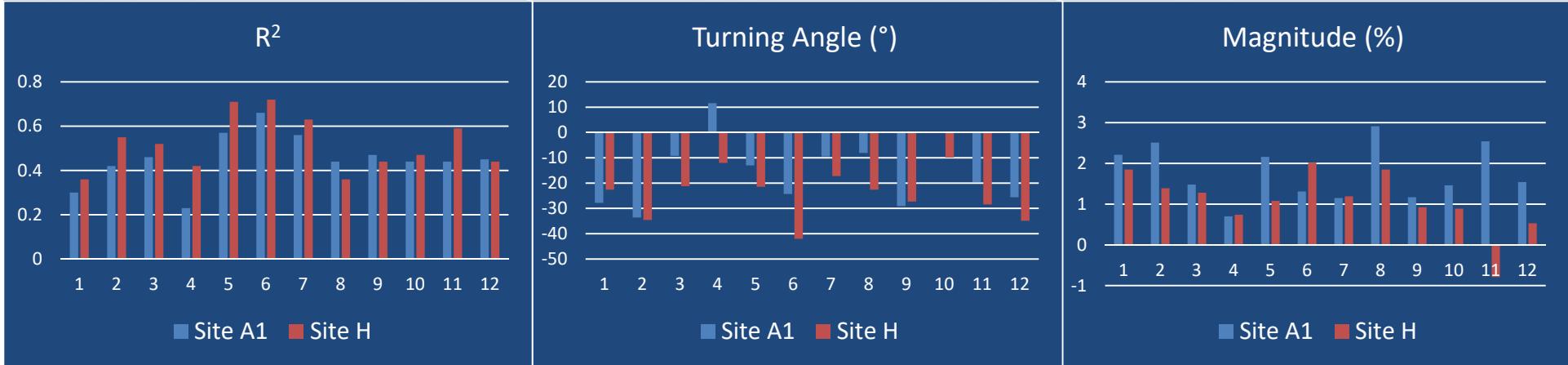


# Synoptic Climatology of the Southern Beaufort Sea Region: PCA Synoptic Types



Aspin et al., 2009; Aspin et al., 2015

# Regression by Synoptic Type



Type	1	2	3	4	5	6	7	8	9	10	11	12
N	792	2808	1944	720	936	864	1296	1224	1584	2016	2160	1008
STFreq	11	39	27	10	72	12	18	17	22	28	30	14
U Range (m/s)	-9.50	-10.37	-12.51	-7.34	-10.81	-8.47	-11.42	-12.42	-15.07	-17.19	-17.21	-11.82
+8.67	+13.43	+8.38	+9.50	14.55	+9.07	11.67	+2.90	+7.34	+9.26	+9.24	+9.90	
V Range (m/s)	-7.69	-11.10	-8.13	-6.78	-6.84	-5.14	-3.72	-9.09	-6.19	-8.30	-8.41	-6.82
+4.61	+12.39	12.37	9.46	2.77	+5.38	11.91	+4.23	+7.83	+9.71	7.91	-10.98	
F	2.21	2.51	1.48	0.70	2.16	1.31	1.15	2.91	1.17	1.46	2.54	1.54
Θ	-27.8	-33.6	-9.2	12.0	-13.0	-24.3	-9.5	-8.1	-29.1	0.0	-19.6	-25.6
R <sup>2</sup>	0.30	0.42	0.46	0.23	0.57	0.66	0.56	0.44	0.47	0.44	0.44	0.45
Type	1	2	3	4	5	6	7	8	9	10	11	12
N	720	1728	2088	576	936	360	720	1584	1296	1440	1152	432
STFreq	10	24	29	8	13	5	10	22	18	20	16	6
U Range (m/s)	-9.55	-10.30	-10.32	-6.05	-10.19	-10.02	-9.65	-12.41	-8.95	-13.29	-13.33	-6.07
+8.78	+13.31	+8.38	+9.52	+14.47	6.98	+5.93	+5.51	7.35	9.20	+8.33	+9.94	
V Range (m/s)	-5.10	-7.41	-11.59	-11.93	-6.53	-8.05	-6.14	-7.40	-7.42	-6.10	-7.52	-6.75
+4.72	+5.12	+2.92	+9.44	+2.78	4.75	11.91	+4.24	+7.87	+7.94	+7.95	+7.83	
F	1.85	1.39	1.28	0.74	1.08	2.02	1.19	1.85	0.92	0.89	-0.79	0.53
Θ	-22.6	-34.6	-21.2	-12.0	-21.5	-42.0	-17.2	-22.6	-27.3	-9.9	-28.4	-34.9
R <sup>2</sup>	0.36	0.55	0.52	0.42	0.71	0.72	0.63	0.36	0.44	0.47	0.59	0.44

A1

H

# Summary

- Magnitude of forcing ranged from 0.7 – 2.54% -- was greater for Site A1, but  $R^2$  was stronger for site H
- Response magnitude Including ocean current in regressions improved  $R^2$  negligibly for Site A1; by 0.03 for site H
- Case studies of extreme wind events show mixed results; Jan 29 – 31 2010 case study strong. Turning angles up to 92° to the right.
- Variability in results by synoptic type: Types 2, 5 – 7 & 11 showed the strongest  $R^2$ , turning angles between 0 – 42° to the right.



# Thank you!



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