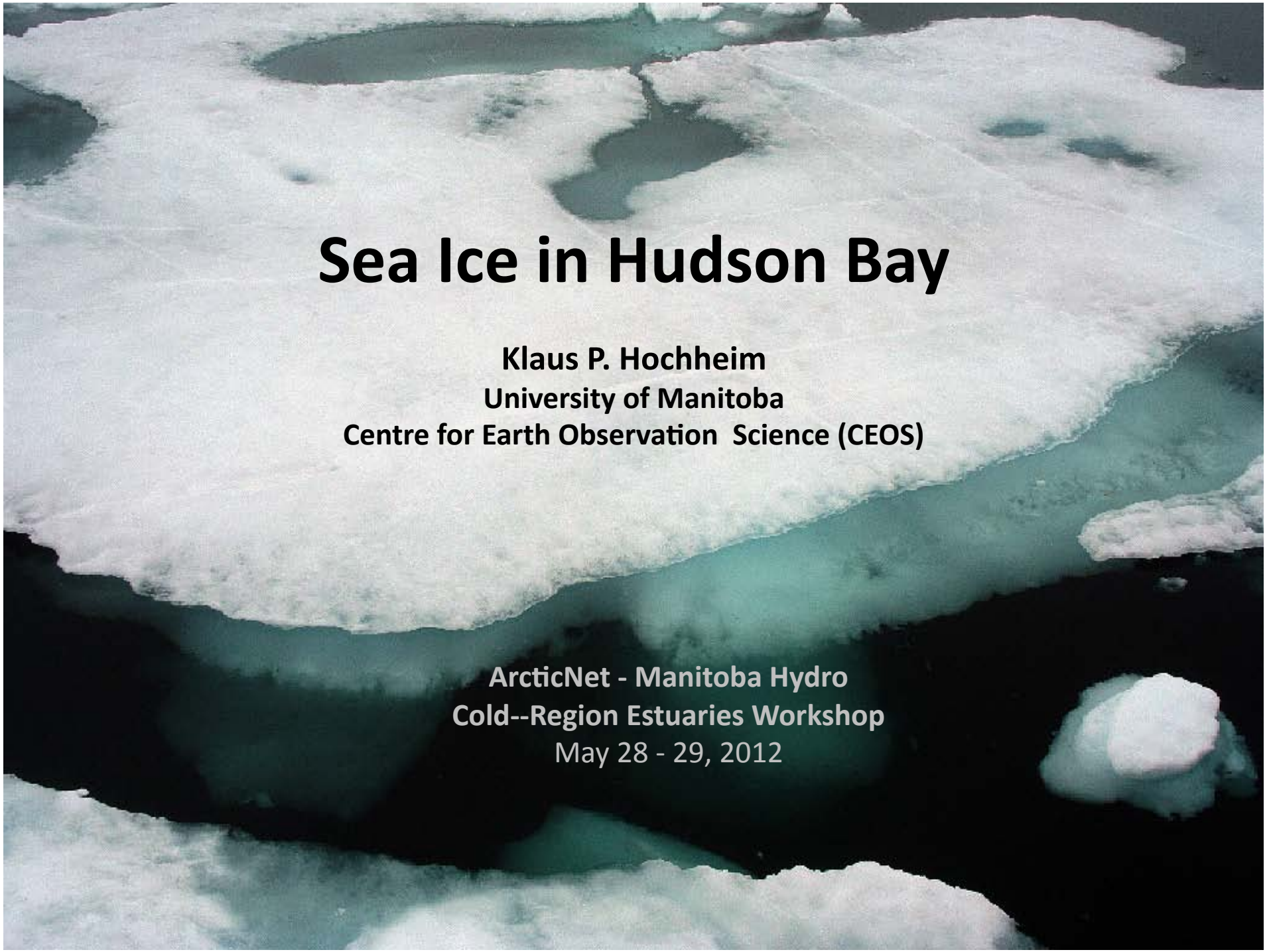

Sea Ice in Hudson Bay

Klaus P. Hochheim
University of Manitoba
Centre for Earth Observation Science (CEOS)

ArcticNet - Manitoba Hydro
Cold--Region Estuaries Workshop
May 28 - 29, 2012

Objectives

1) Examine the spatial distribution SAT trends surrounding HB region during the fall and spring period (1980-2005) and SAT trends dating back to 1950 to provide context to the observed changes in SIC and SIEs

2) Examine weekly trends in SICs and SIEs within HB

3) Examine the nature of weekly SIC anomalies in HB due to thermodynamic and dynamic forcing, specifically relative vorticity of ice within HB over 1980-2005 (spring)

4) Examine the relative contributions of SATs and relative vorticity to predicting SIEs in HB (spring)

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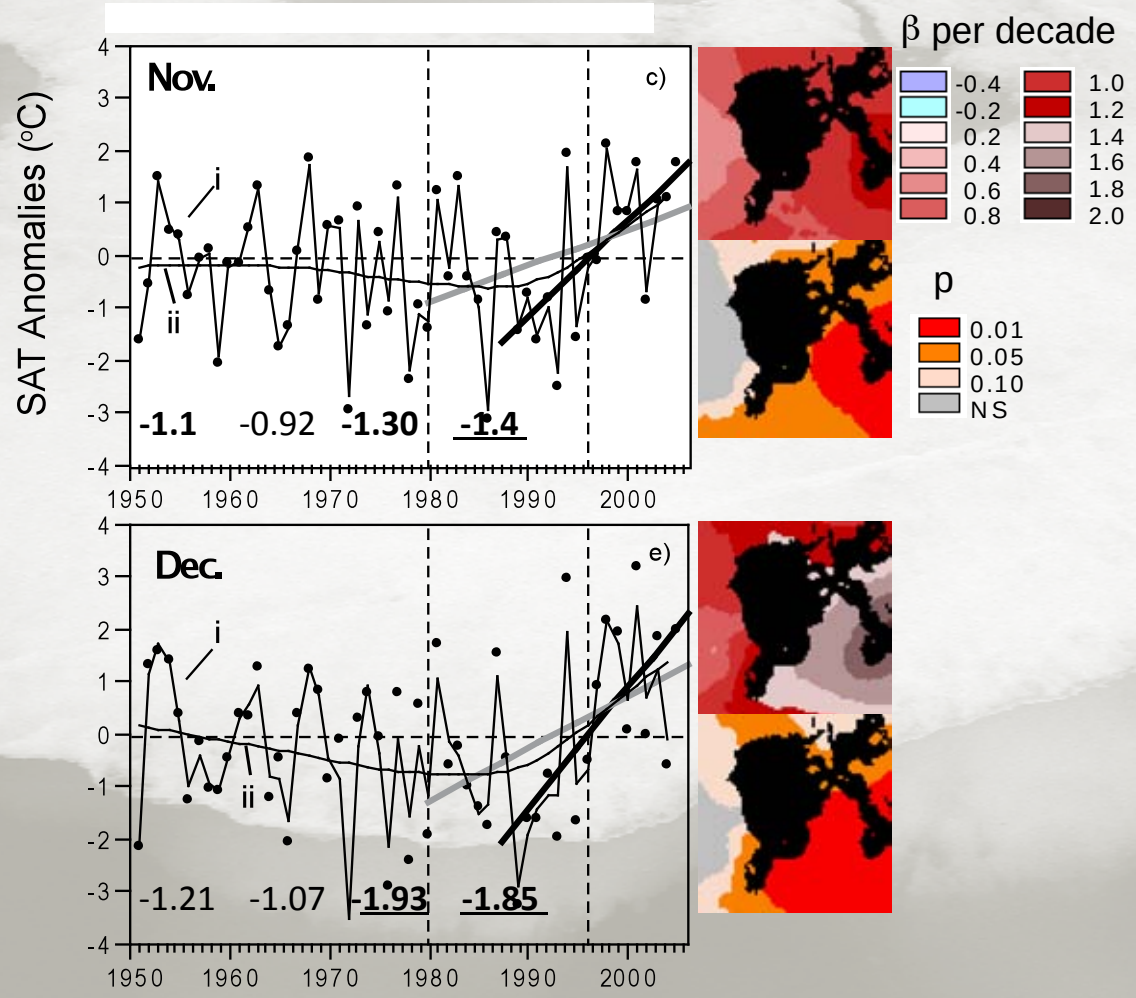
Fall
SATs anomalies



Years	β/d	Prob.
1950-1989	-0.12°C/d;	~~p=0.500~~
1950-2005	0.12°C/d;	~~p=0.285~~
1980-2005	0.71°C/d;	~~p=0.056~~
1989-2005	1.80°C/d;	p=0.005
1950-1989	-0.28°C/d;	~~p=0.177~~
1950-2005	0.13°C/d;	~~p=0.326~~
1980-2005	1.00°C/d;	p=0.025
1989-2005	2.30°C/d;	p=0.009

Gagnon and Gough [2006] -early 1960-1990 temperature trends in HB were predominantly negative and ice thickness trends positive during the fall and winter periods.

B=S_t; **B**=TK

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Atmospheric Forcing of Sea Ice in Hudson Bay during the Fall Period, 1980-2005
K.P. Hochheim and D.G. Barber, *Journal of Geophysical Research*, 2010.

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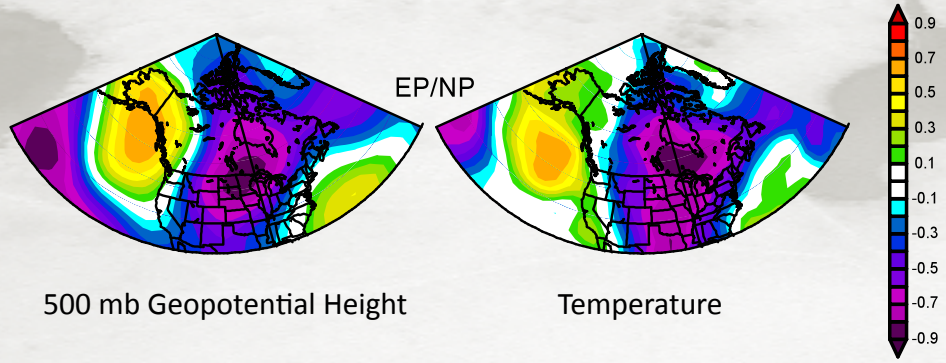
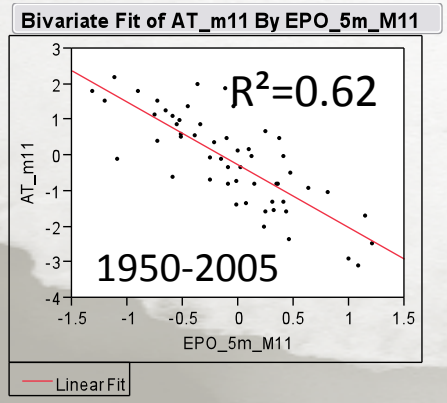
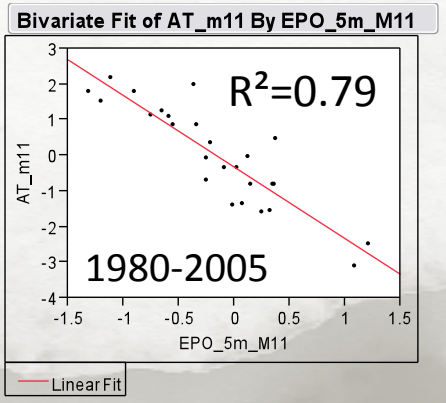
EP/NP (East Pacific/North Pacific): Fall Period

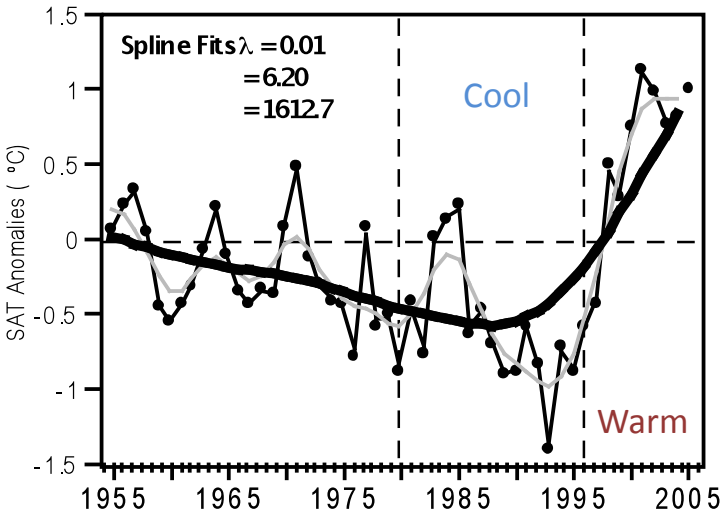


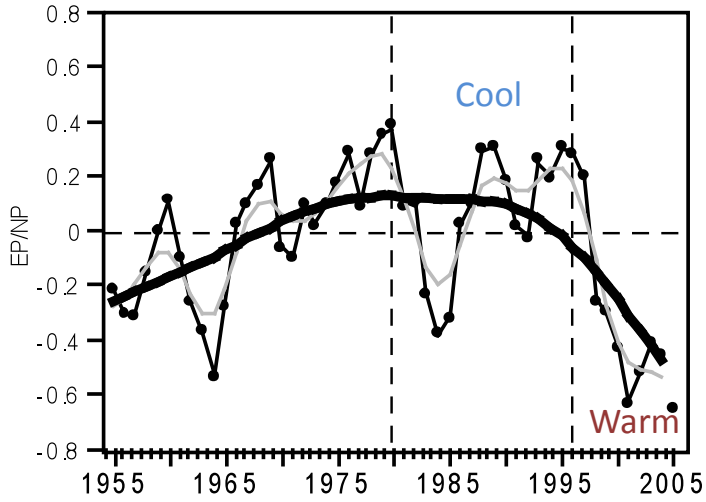
500 mb Geopotential Height Temperature

http://www.cdc.noaa.gov/Correlation/









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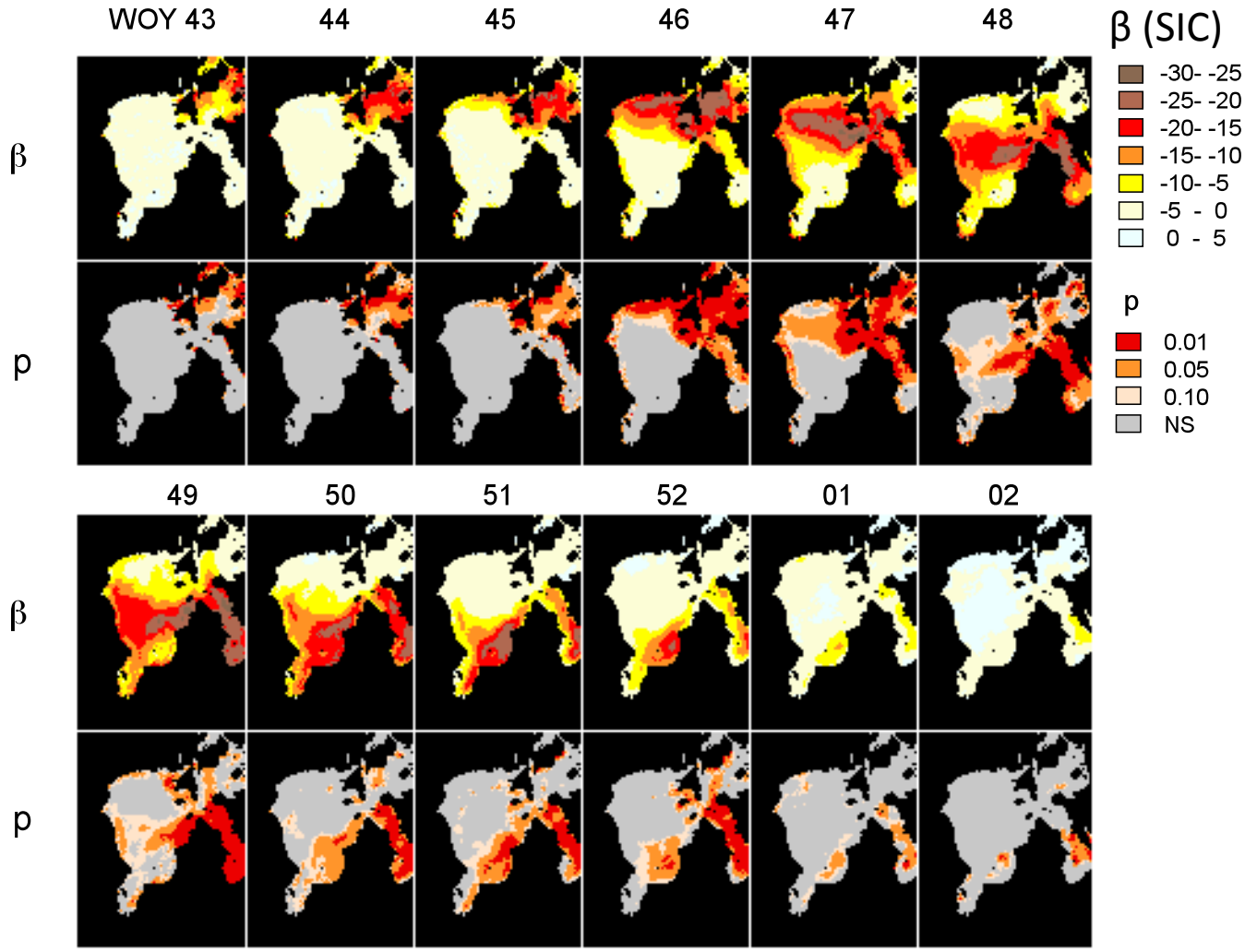
PMW data: fall SIC trends



	WOY 45	46	47	48	49	50	51	52	01	02
(β/10yrs) (90-99% prob.)	-12.7	-16.1	-16.8	-14.9	-14.3	-15.5	-12.1	-09.0	-05.7	-00.8
SD	4.3	4.8	4.7	4.6	5.7	4.3	6.7	5.3	2.4	2.2
% Area HB	9.4	34.0	52.0	50.3	57.4	36.8	41.5	33.4	14.8	10.0

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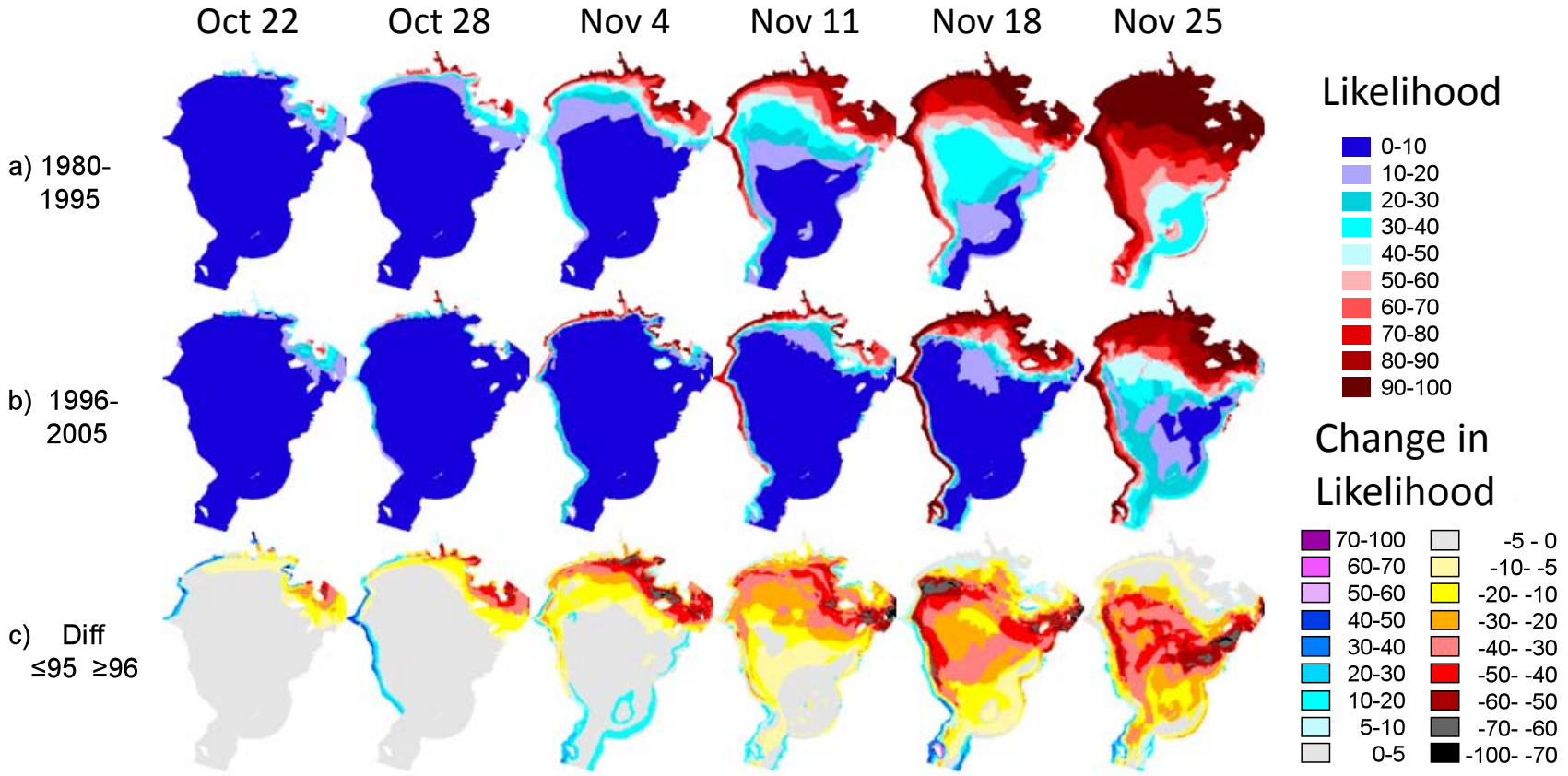
Likelihood of sea ice ≥80% concentration, 1980-1995 vs. 1996-2005



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Summary of mean differences in sea ice cover (Fall) (1980-95 vs. 1996-2005)

Data	Week	Year	SIE (% HB Area)	S.D. (%)	Area (km2)	p	
PMW	Nov 18	1980-95	14.74	16.66	1.19×10^5		
		1995-05	0.77	0.96	6.20×10^3		
		Diff (Δ)	-13.97		-1.12×10^5	0.015	> -112,000 km²
	Nov 25	1980-95	30.37	22.95	2.44×10^5		
		1995-05	7.32	7.14	5.89×10^4		
		Diff (Δ)	-23.05		-1.85×10^5	0.005	> -185,000 km²
	Dec 2	1980-95	51.91	23.75	4.17×10^5		
		1995-05	25.12	14.78	2.02×10^5		
		Diff (Δ)	-26.79		-2.15×10^5	0.004	> -215,000 km²
	Dec 9	1980-95	73.25	20.3	5.89×10^5		
		1995-05	43.28	22.69	3.48×10^5		
		Diff (Δ)	-29.98		-2.41×10^5	0.002	> -241,000 km²
	Dec 16	1980-95	87.77	15.43	7.06×10^5		
		1995-05	66.14	25.31	5.32×10^5		
		Diff (Δ).	-21.63		-1.74×10^5	0.012	> -174,000 km²
	Dec 24	1980-95	95.18	10.07	7.65×10^5		
		1995-05	79.93	19.1	6.43×10^5		
		Diff (Δ)	-15.25		-1.23×10^5	0.013	> -123,000 km²
	Dec 30	1980-95	99.29	2.25	7.98×10^5		
		1995-05	92.67	11.03	7.45×10^5		
		Diff (Δ)	-6.61		-5.32×10^4	0.027	> -53,200 km²

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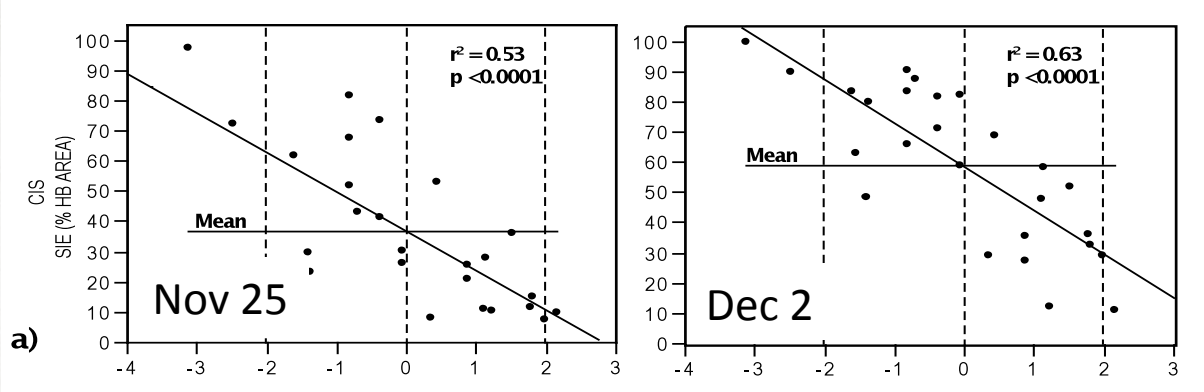
Changes in sea ice cover (km²) in Hudson Bay per 1°C change in temperature (3 month average)



November 25
(1980-2005)

+1˚C = -105,000 km² (less ice)

December 2
(1980-2005)

= -117,000 km²

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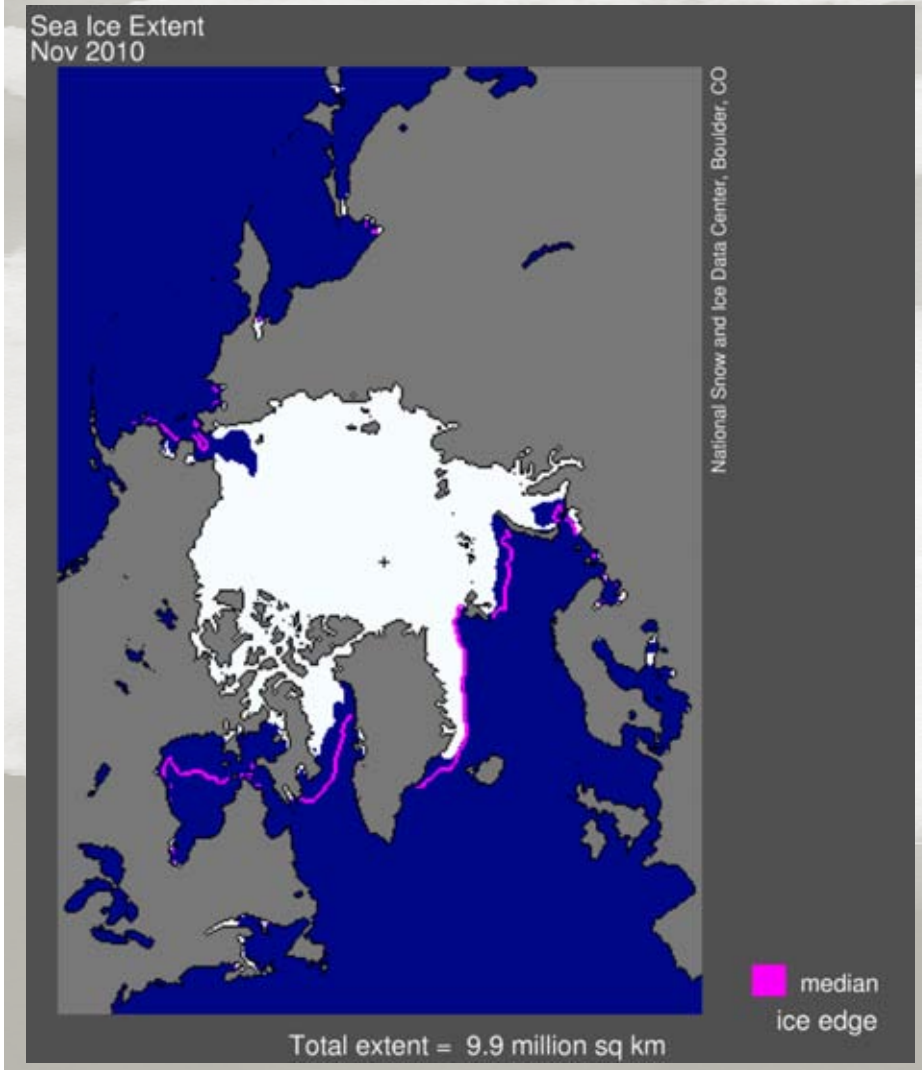
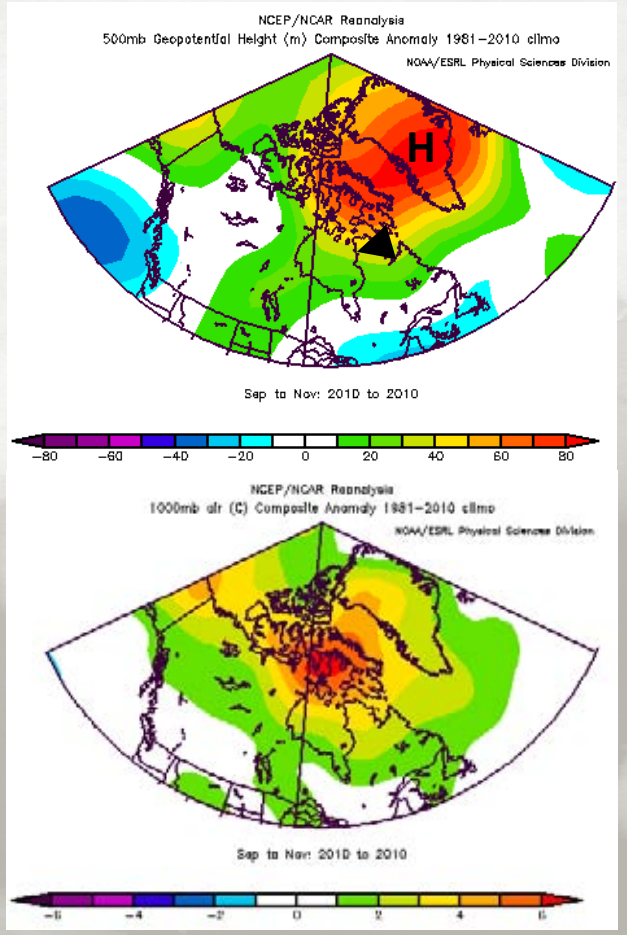


Nov. 2010

Arctic Ice Extent 12% below normal

Hudson Bay normally 50% covered only 17% covered by end of Nov. 2010.



Air Pressure

Air temperature 4-8˚C warmer

http://nsidc.org/arcticseaicenews/2010/120610.html

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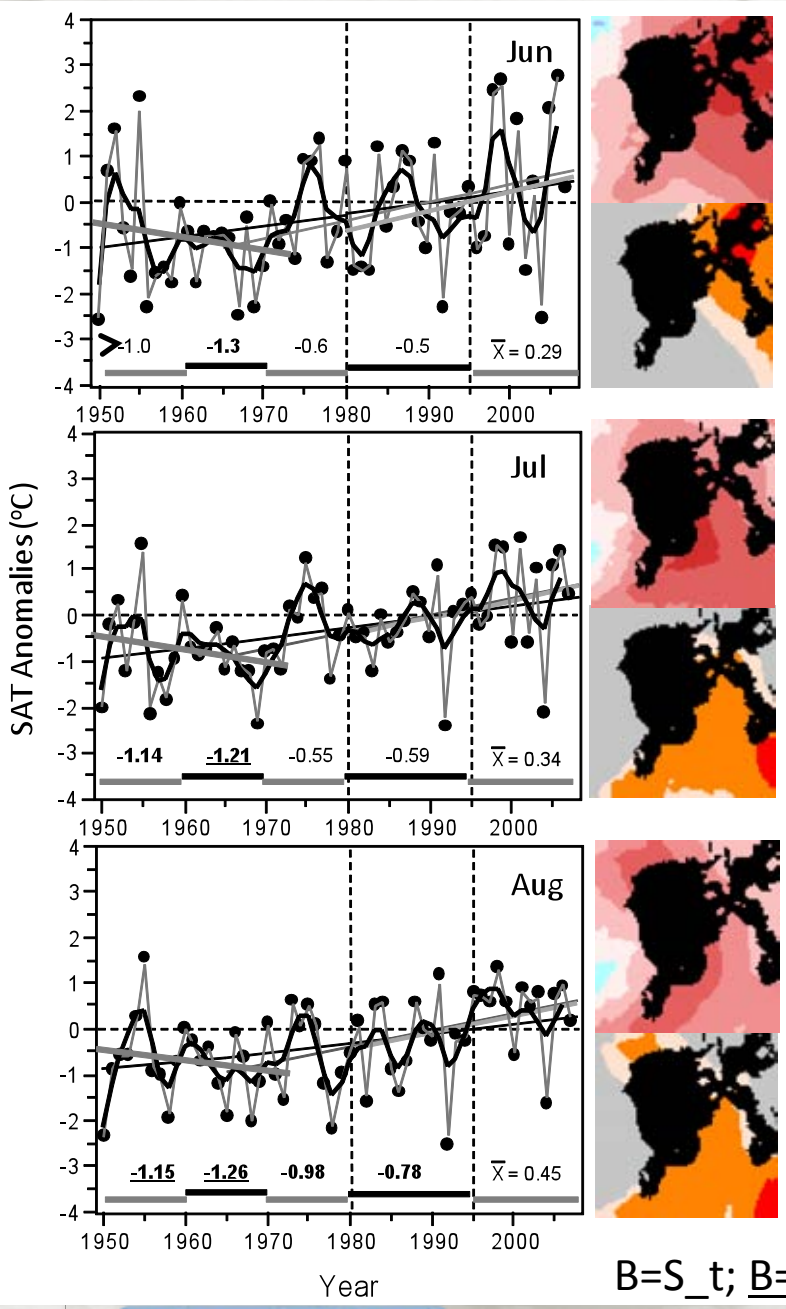
Spring SATs anomalies

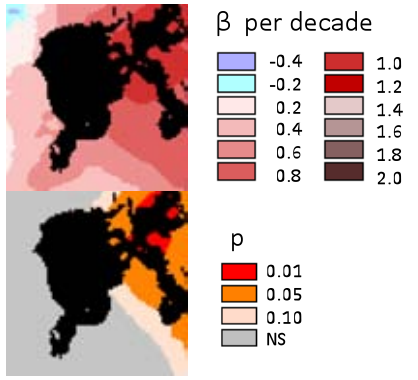
(AMJ)

(MJJ)

(JJA)

Δ in SAT relative to 1995-2005





B=S_t; TK

CANGRID data

(Climate Research Division of Environment Canada)

- Most significant SAT tends to the east and northwest (gridded SATa)
- Regional SAT anomalies surrounding HB are cyclical (5yr mean)
- SAT anomalies are trending upward (warming) (1960-2005) (0.26-0.30 °C/d (95-99% prob).
- JJA mean semi decadal SAT anomalies (from 1950-1995) statistically diff from those in the 1996-2005 period.

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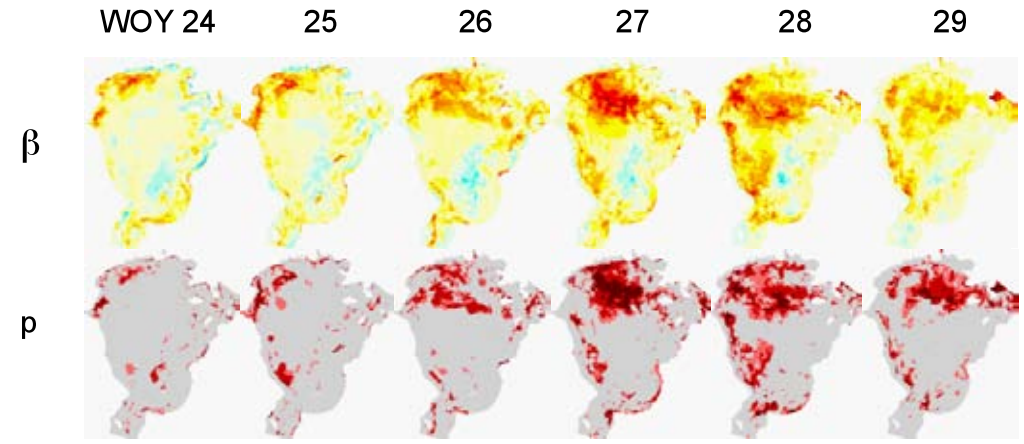
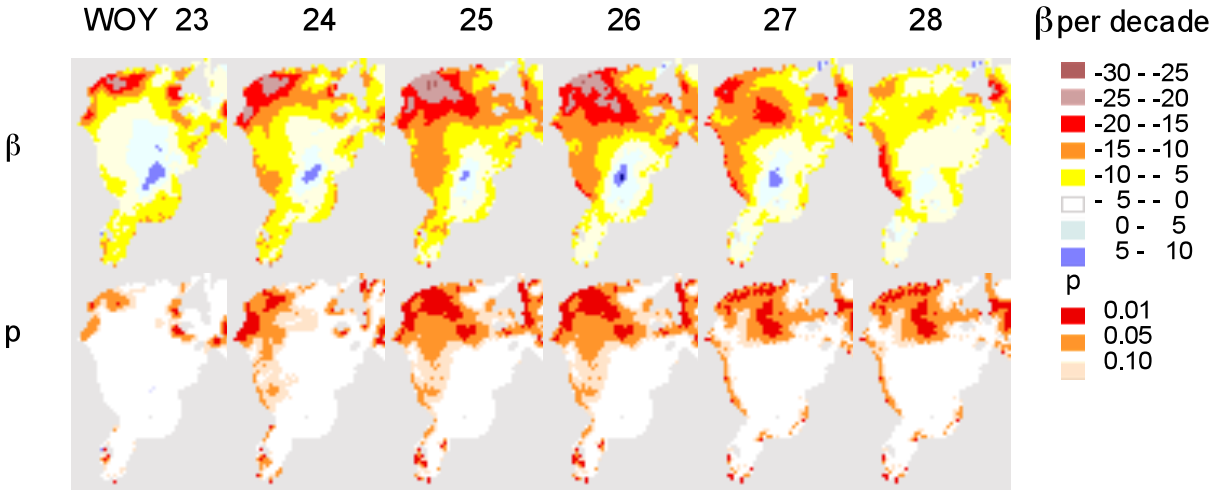
Trends in Sea Ice Concentration: Spring Period

CIS Data



PMW Data



Both positive and negative SIC anomalies present suggests presence of dynamic component

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Changes in SIE in HB, 1980-1995 vs. 1996-2005

Data	Week	Year	SIEA (% HB Area)	**Std Er	Area (km²)	p
CIS	24	1980-95	4.7	2.17		
SIC≥60%		1996-05	-5.3	2.54		
		Diff (Δ)	-10.0	3.35	-8.05×10^4	0.0064
	25	1980-95	6.1	2.69		
		1996-05	-7.7	3.14		
		Diff (Δ)	-13.8	4.13	-1.11×10^5	0.0028
	26	1980-95	9.5	3.46		
		1996-05	-11.5	4.01		
		Diff (Δ)	-21.0	5.32	-1.69×10^5	0.0006
	27	1980-95	11.0	4.26		
		1996-05	-11.5	4.97		
		Diff (Δ)	-22.6	6.55	-1.81×10^5	0.0021
	28	1980-95	10.1	4.15		
		1996-05	-10.1	4.85		
		Diff (Δ)	-20.1	6.38	-1.62×10^5	0.0043
	29	1980-95	7.8	3.76		
		1995-05	-7.6	4.39		
		Diff (Δ)	-15.5	5.78	-1.24×10^5	0.0132
	30	1980-95	3.9	2.61		
		1996-05	-1.9	3.04		
		Diff (Δ)	-5.7	4.01	-4.59×10^4	0.0650*

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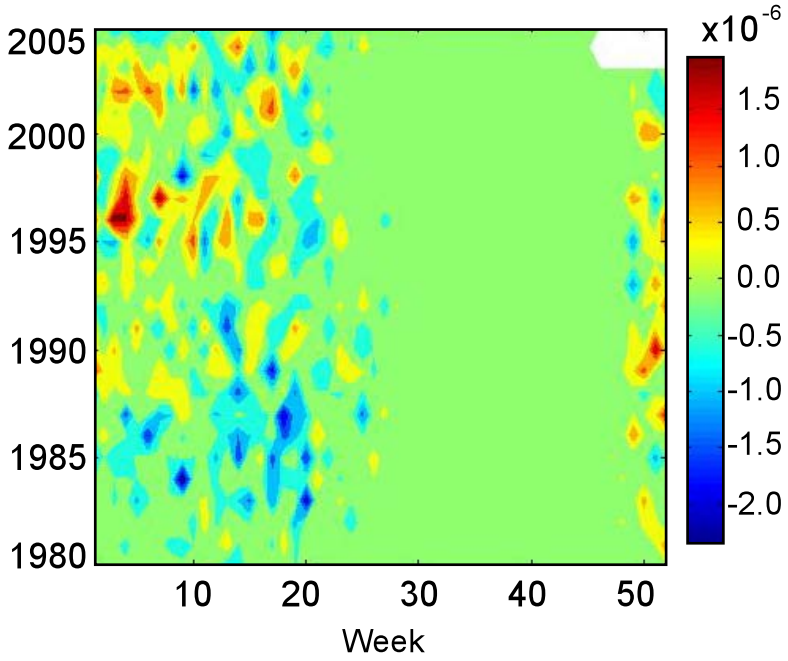
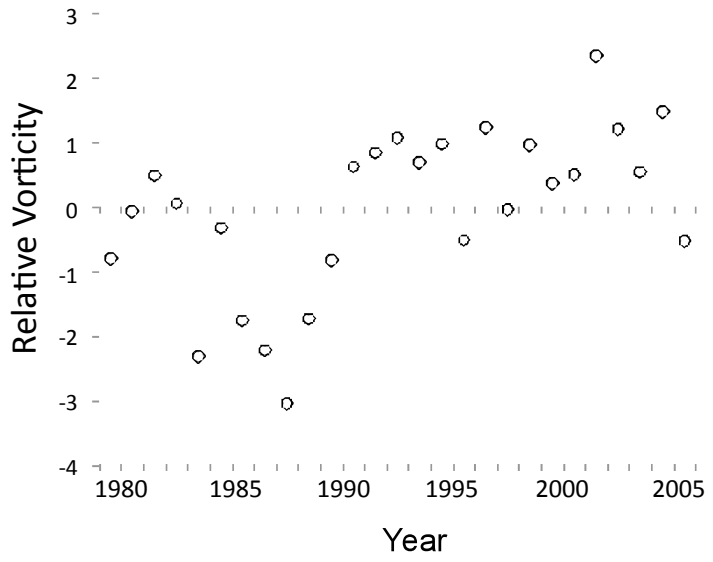
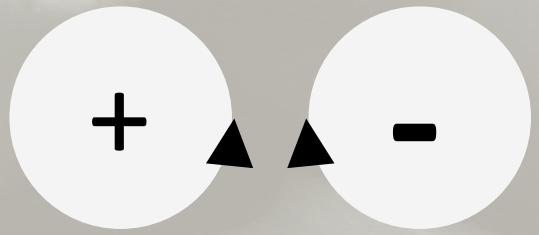
Dynamic Forcing: Relative Vorticity of Sea Ice





NSIDC : Computed from PMW data (http://nsidc.org/data/nsidc-0179.html)



Vorticity

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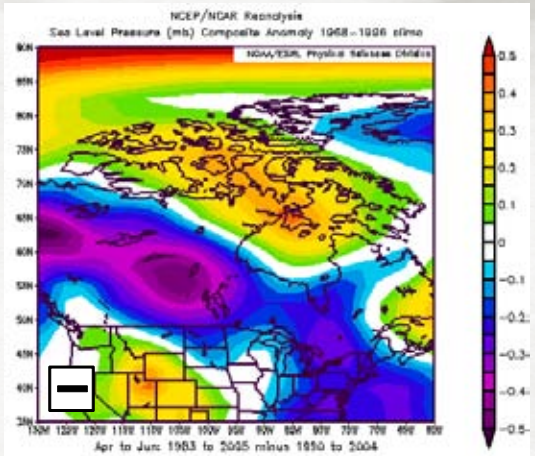
Dynamic Forcing of Sea Ice in HB: Relative Vorticity

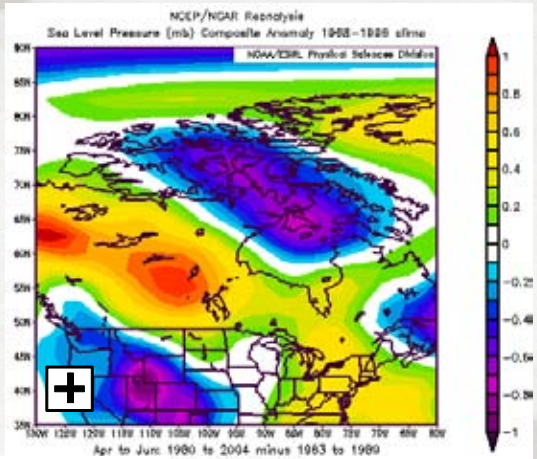
Surface Pressure Anomalies (AMJ)

Mean Wind Vectors (AMJ)

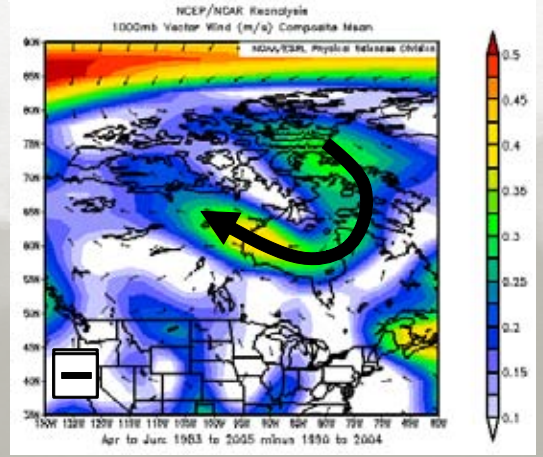
a)



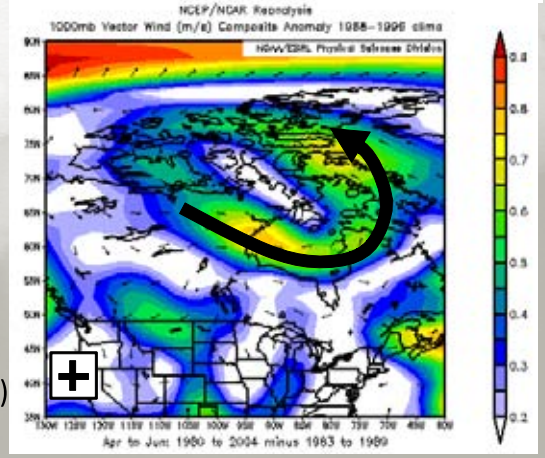
c)



b)



d)



http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl

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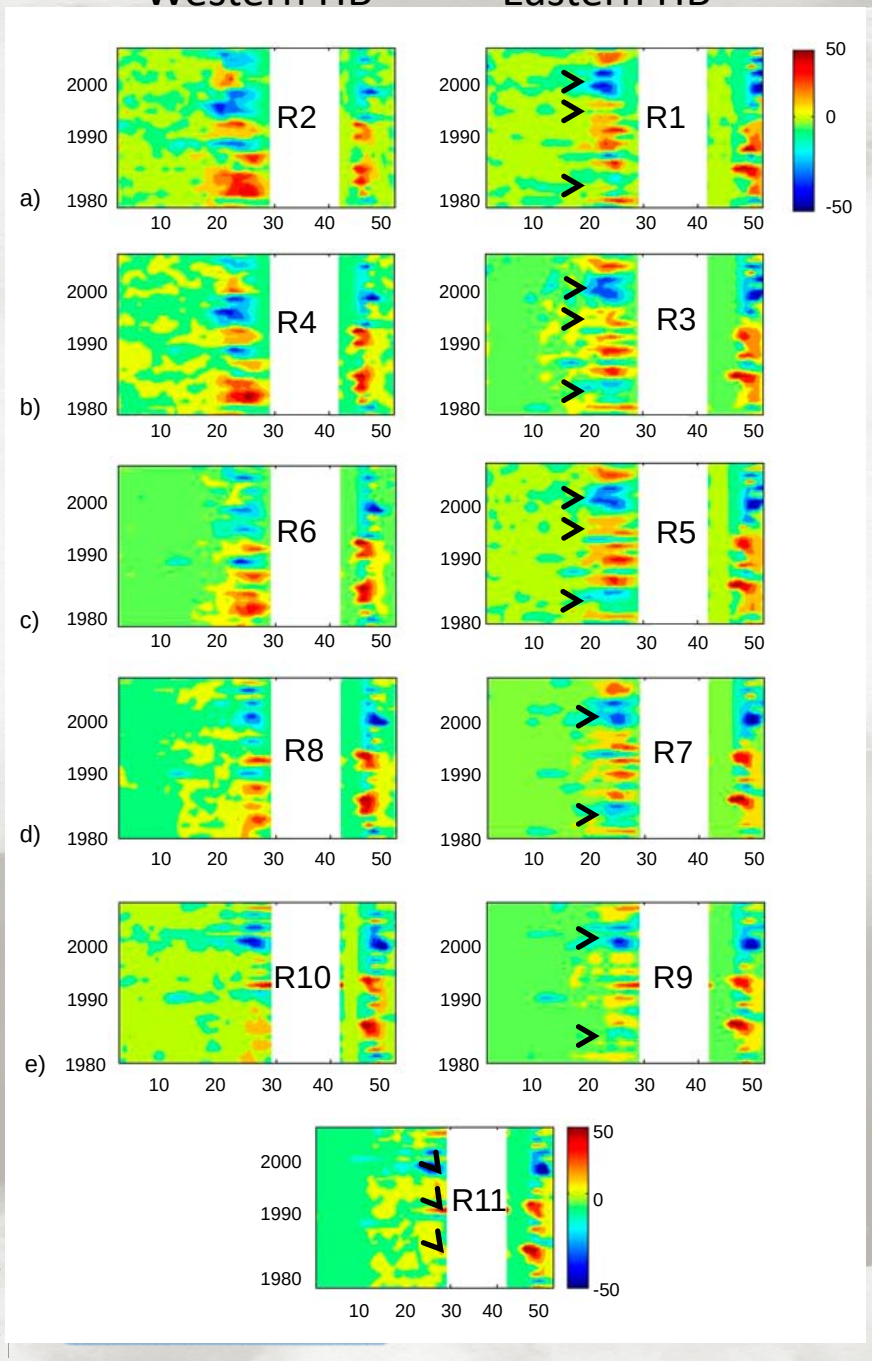
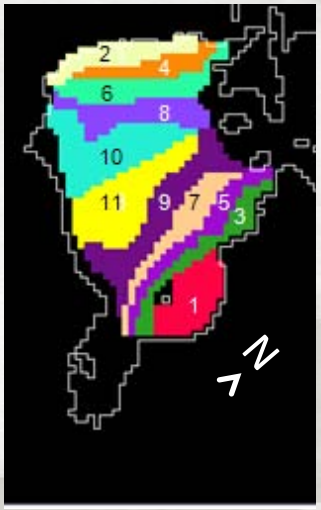
East-West Diopole Pattern of SICs

PMW SIC anomalies



Regions



Western Regions (2-6) (AMJ)
SIC anomalies correlated (R^2 = 0.65-0.74) to Spring SATs and Wind Dir; Spd.

Central Regions (8-11)
SIC anomalies correlated (R^2 = 0.44-0.66) to Spring SAT, Wind Dir.

Eastern Regions (1-7)
SIC anomalies correlated (R^2 = 0.70-0.73), Spring SAT, Wind Dir, Fall SATs

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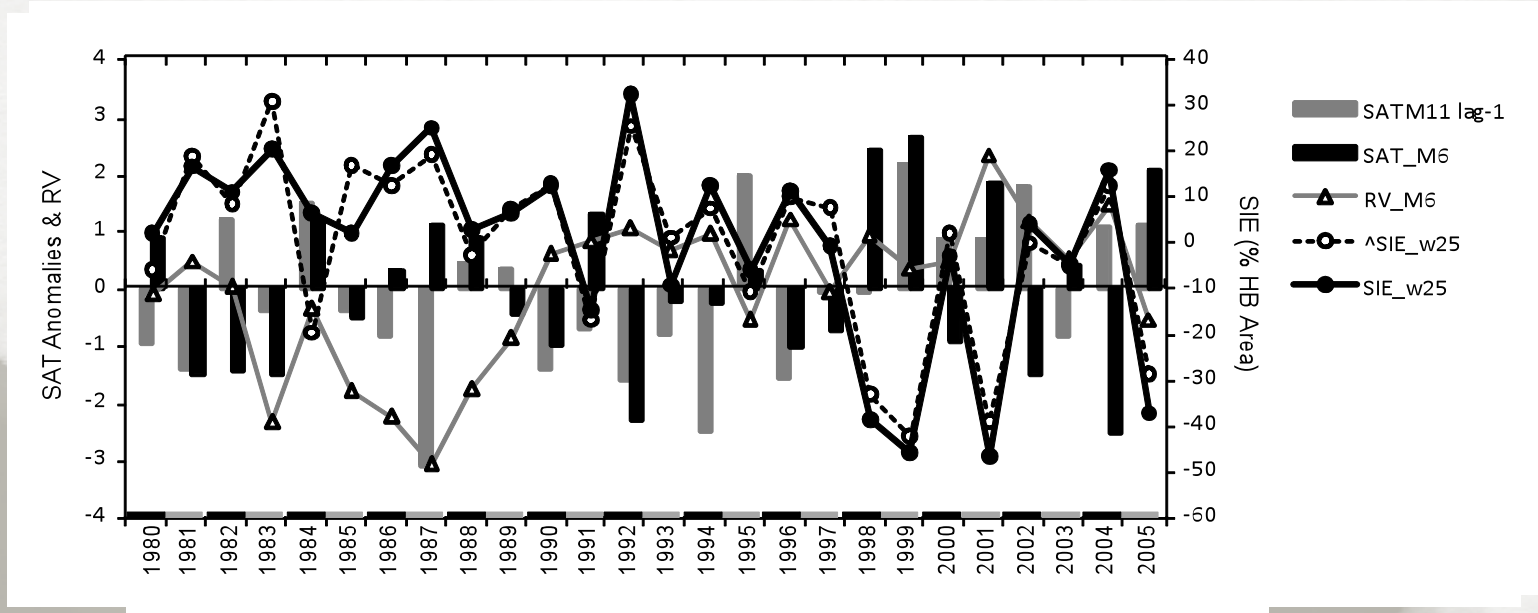
Sea Ice Extent (SIC≥ 60%): f (Spring/Fall SAT anomalies and RV)

			Variables		
Source	**WOY**	**R2**	**p (SAT M6)**	**p (SAT M11)**	**p (RV) M6**
PMW	25	***0.57***	<0.0001	-	-
SIC≥60		***0.77***	<0.0001	-	0.0004
		0.71	<0.0001	0.0029	-
		0.84	**<0.0001**	**0.0019**	**0.0003**

WOY 25 (3rd Week June)



- 1980 to mid 1990s cooler fall and spring SATs: = (+)SIEs
- 1983-1989 (-) RV: = (+) SIE (more sea ice).
- 1998-2005 warmer fall and spring SATs (with exceptions), combined with (+) RV: (-) SIEs (less ice).

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Conclusions

Fall Period

- The highest and most significant trends in SAT anomalies occur in the northern and eastern portions from 1980-2005, with overall trends in SAT anomalies increasing from October (0.6-0.8°C/decade) to December (1.1 to 1.6°C/decade).

- The statistically significant trends in SIC anomalies using the CIS data showed negative trends in SIC ranging from -23.3 to -26.9%/decade for weeks 43-48 resulting in significant reductions in sea ice extent

- The CIS data showed that for every 1°C increase in the mean regional air temperature around HB, the area of SIC ≥80% deceased by $1.05x10^5 km^2$ to $1.17x10^5 km^2$ for weeks 47-48 (late November). Similar results were shown for changes in SIEs using PMW data.

- Regional SAT anomalies around HB were shown to be closely related to atmospheric indices dating back to 1950.

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Conclusions…..

Spring Period

- **Both fall and spring SAT anomalies and RV** can play a significant role in determining local sea ice concentrations and Hudson Bay sea ice extents. Their relative contributions vary interannually on a Bay wide scale (e.g. SATs vs. RV)

- Spring SAT anomalies are trending upward (warming) (1960-2005) (0.26-0.30 °C/d (95-99% prob.

- Since 1990 the RV in HB has for the most part been positive contributing to lower SIE's.

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Several recent papers:

Hochheim, K. P., and D. G. Barber (2010), Atmospheric forcing of sea ice in Hudson Bay during the fall period, 1980–2005, J. Geophys. Res., 115, C05009, doi:10.1029/2009JC005334.

Hochheim, K.P., J.V. Lukovich, D.G. Barber (2011). Atmospheric forcing of sea ice in Hudson Bay during the spring period, 1980–2005. Journal of Marine Systems, Volume 88, Issue 3, Pages 476-487.

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