Seasonal Prediction Algorithms: Statistical Methods in Seasonal Sea Ice Forecasting

3 Categories:

complexity ↓

1) **Persistence (anomaly persistence / using past ice to forecast future ice)**
2) **Empirical models (relating antecedent climate to ice)**
3) **Down-scaling / MOS (inferring more detailed information from regional/global model output)**

Present an overview using examples from SEARCH SIO and CIS activities

Search SIO / NAIS … what is being forecast

SEARCH SIO

Pan-Arctic: September Sea Ice Extent … One number!

↓

Regional: Open to any regional sea ice parameters (BSI, Barrow break-up, ice area around Svalbard, ice area in the peripheral seas, open/close shipping routes)

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NAIS Sea Ice Outlook for Arctic Waters

Table 3: Western Arctic - Break-up Outlook Dates

	2008	Median	Outlook for 2009
Mackenzie Bay - Clearing	22 Jun	19 Jun	14-16 Jun
Kugmallit Bay - Clearing	24 Jun	26 Jun	21-23 Jun
Tuktoyaktuk Peninsula - Fracture[1]			
Mackenzie Bay to Cape Bat - Open water route			
Coastal waterway Mackenz Bay to Prudhoe Bay - Open drift or less			
Coastal waterway Prudhoe to Point Barrow - Open drift or less - Close pack (refreeze)			
Cape Lisburne to Point Bar - Open drift or less - Open water route			
Wainwright - Open drift or less			
Coastal waterway Prudhoe to Barter Island - Open drift or less			
Open water route to Taloyoak			
Amundsen Gulf - Fracture[1] - Clearing			
Coronation Gulf - Fracture[1] - Clearing			
Queen Maud Gulf - Fracture			
Larsen Sound - Fracture[1]			
Peel Sound - Fracture[1]			

Table 2: Eastern Arctic - Break-up Outlook Dates

	2008	Median	Outlook for 2009
Route across Northern Baffin Bay - Open drift or less - Bergy water route	23 Jun 16 Jul	17 Jul 27 Jul	03-05 Jul 10-12 Jul
Baffin Bay - Clearing	29 Aug	08 Sep	26-28 Aug
Davis Strait - Clearing			
Home Bay - Open drift or less			
Cape Dyer - Open drift or less			
Open water route to Hall Beach			
Foxe Basin - Clearing			
Pond Inlet - Fracture[1] - Clearing			
Admiralty Inlet northern half - Fracture[1] - Bergy water			
Lancaster Sound - Fracture[1]			
Barrow Strait to Resolute - Fracture/eastern[1] - Fracture/western[1]			
Wellington Channel - Fracture[1]			
McDougall Sound - Fracture[1]			
Kane Basin - Fracture[1]			
Jones Sound - Fracture[1]			
Norwegian Bay - Fracture/southern[1] - Fracture/northern[1]			
Eureka Sound - Fracture[1] - Bergy water			
Pacer Goose route to Thule -Open drift or less -Bergy water route			

orth American Ice Service

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Table 1: Hudson Bay and Approaches - Break-up Outlook Dates

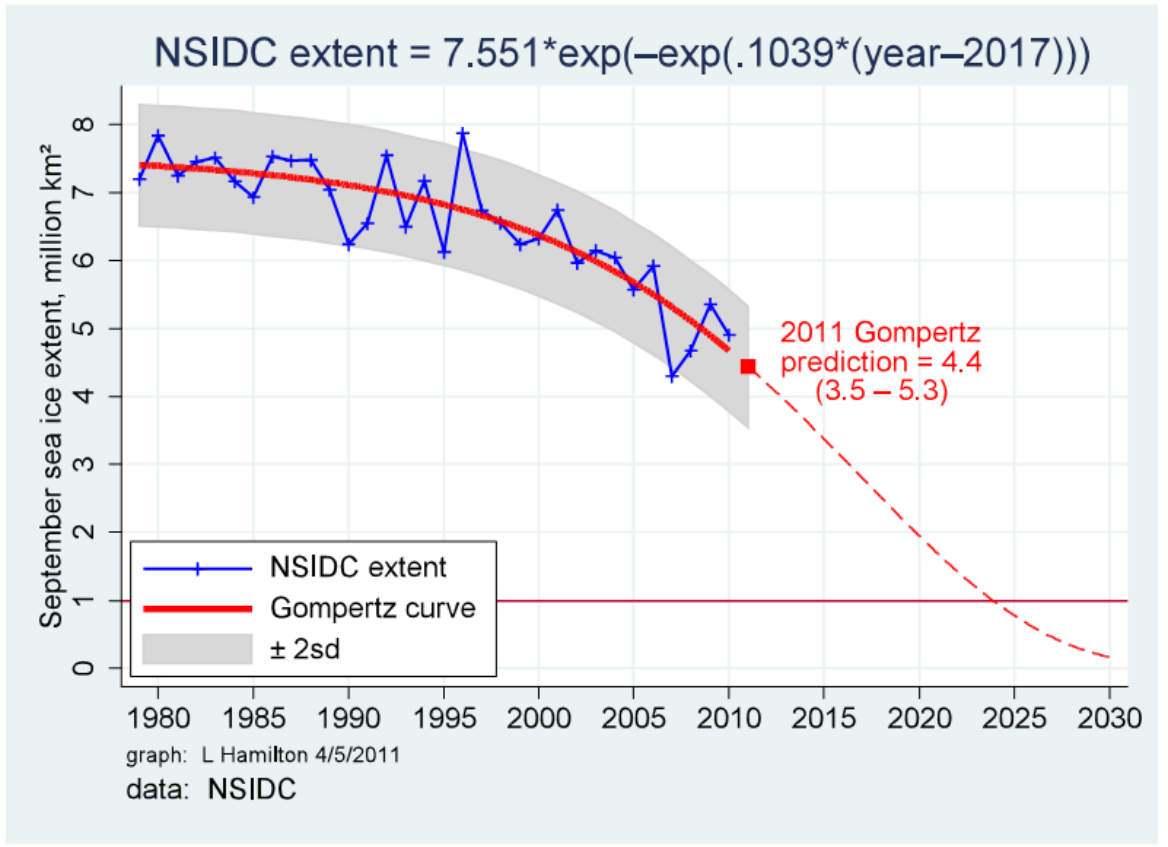
	2008	Median	Outlook for 2009
Labrador Coast to Cape Chidley - Clearing	28 Junl	26 Jul	01-03 Aug
Frobisher Bay - Open drift or less - Clearing	26 Jul 04 Aug	19 Jul 06 Aug	14-16 Jul 10-12 Aug
Ungava Bay - Clearing	17 Jul	03 Aug	07-09 Aug
Bergy water route through Hudson Strait (eastern entrance to south of Nottingham Island)	26 Jul	27 Jul	25-27 Jul
Hudson Strait - Clearing	01 Aug	07 Aug	10-12 Aug
Bergy/open water route to Churchill (eastern entrance of Hudson Strait to Churchill)	26 Jul	28 Jul	25-27 Jul
Open water route through northern Hudson Bay (south of Nottingham Island to Churchill)	11 Jul	19 Jul	20-22 Jul
Hudson Bay - Clearing	26 Aug	16 Aug	01-03 Aug
James Bay - Clearing	22 Jul	29 Jul	29-31 Jul

PERSISTENCE

Year-to-year persistence

*** fit functions to the historical extent time-series**

*** SIO: linear and non-linear fit**

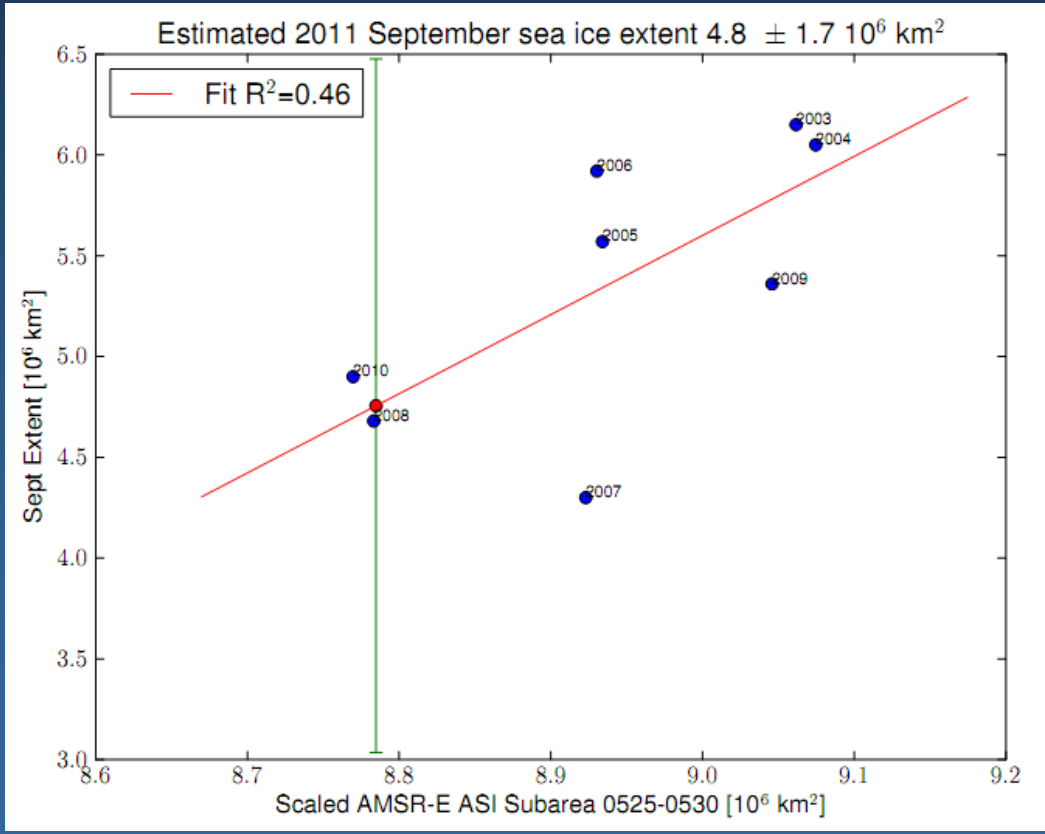


Contributor: Hamilton

PERSISTENCE

Month-to-month persistence

* relate past ice (monthly ice area, ice age, ice type, ice decay rates etc.) to September ice extent
* variants of regression

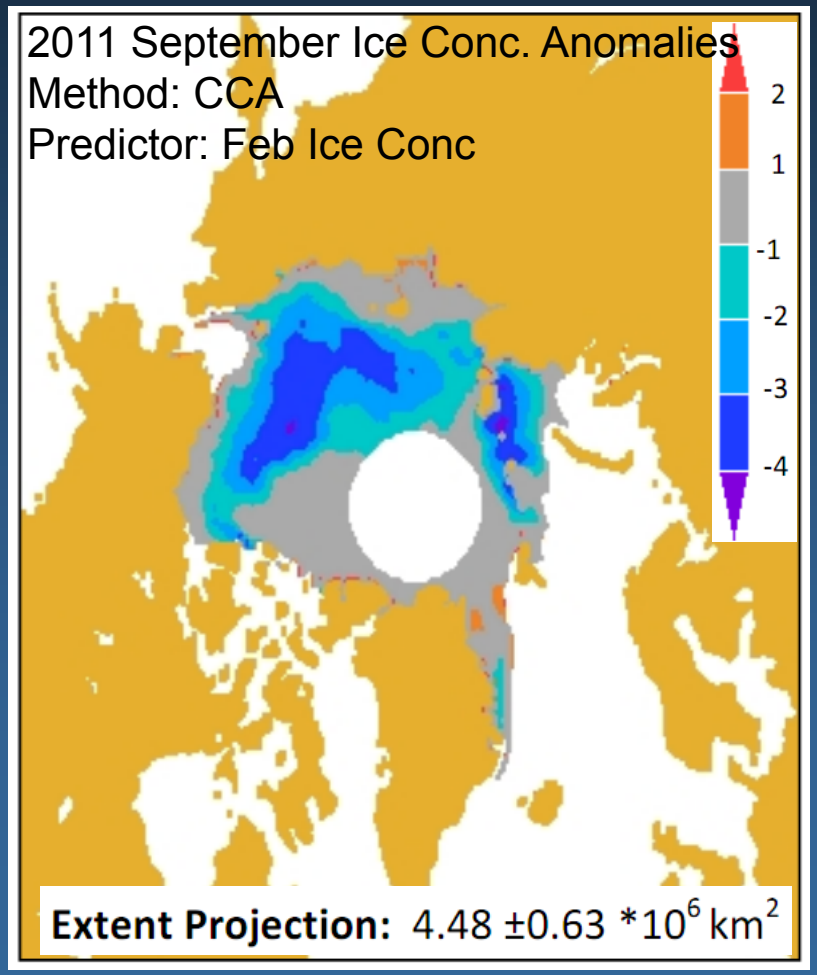


Contributor: Beitsch

PERSISTENCE

Month-to-month persistence

*** more complex regression techniques to predict location of anomalies**



Contributor: Tivy

PERSISTENCE

Regional month-to-month persistence
*** forecast regional ice area**

Regional ice area lagged correlations: ALL ICE DETRENDED

	Pan-Arctic	Beaufort/Chukchi	East Siberian	Laptev	Greenland	CAA	rents/Kara
Sep	6%	1%	22%	4%	1%	5%	2%
Oct	11%	1%	21%	3%	11%	7%	2%
Nov	12%	1%	4%	3%	3%	5%	8%
Dec	12%	14%	0%	2%	1%	8%	15%
Jan	15%	3%	1%	3%	5%	1%	29%
Feb	22%	9%	0%	9%	13%	4%	26%
Mar	12%	17%	2%	1%	3%	1%	27%
Apr	11%	38%	11%	11%	0%	8%	9%
May	19%	9%	20%	21%	1%	22%	11%
Jun	55%	39%	34%	51%	12%	44%	40%
Jul	63%	48%	58%	60%	36%	43%	62%
Aug	76%	64%	82%	72%	73%	82%	78%
Sep	100%	100%	100%	100%	100%	100%	100%

Beaufort-Chukchi Sea: **1.32 ± 0.26 *10^6 km^2**, based on May MYI

East Siberian Sea: **0.43 ± 0.16 *10^6 km^2**, based on September All Ice

Laptev Sea: **0.24 ± 0.12*10^6 km^2** , based on May All Ice

Kara-Barents Sea: **1.49 ± 0.11 *10^6 km^2**, based on April MYI

Greenland Sea: **0.26 ± 0.07*10^6 km^2**, based on February All Ice

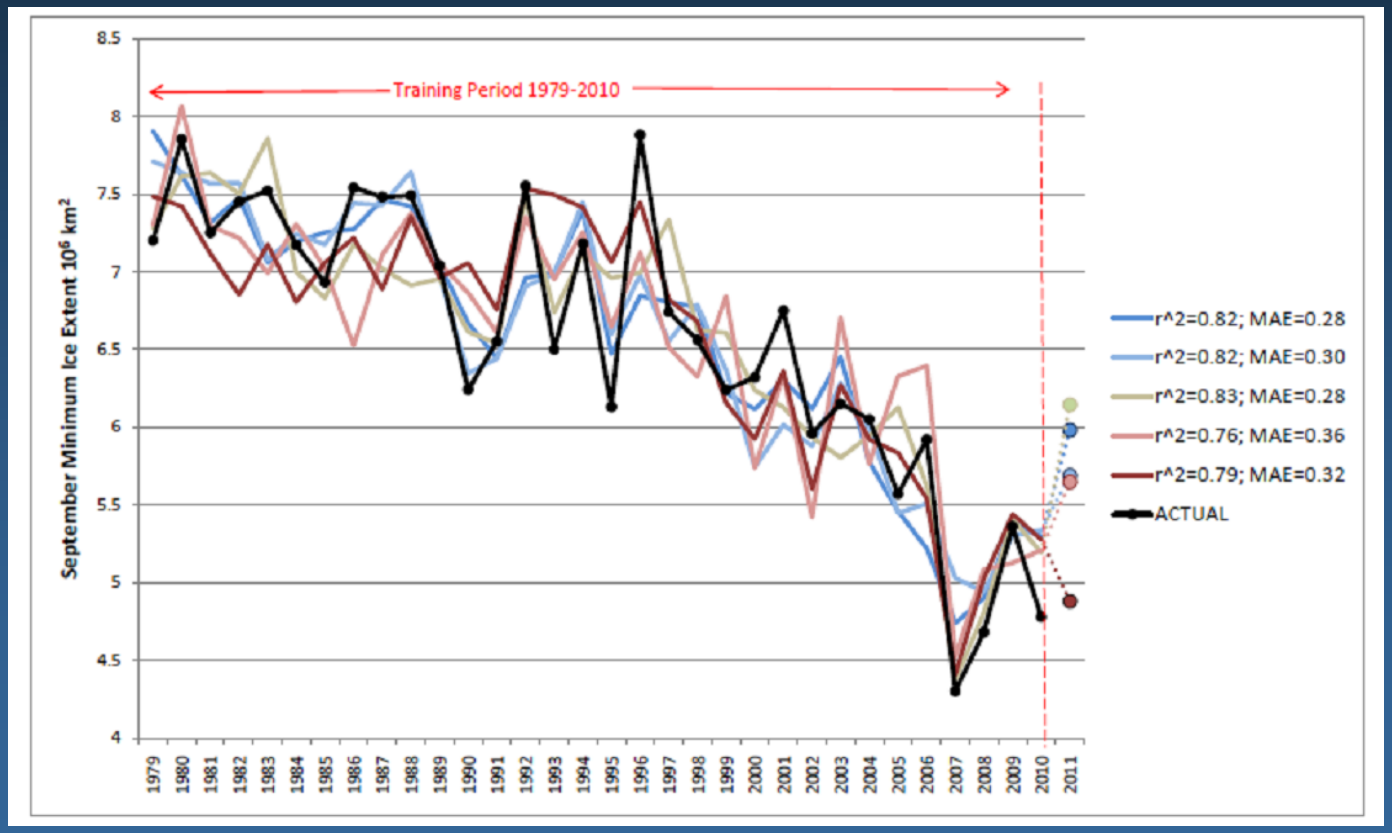
Contributor: Tivy

EMPIRICAL MODELS

Relate present/past climate to future sea ice
*** regression based methods**

Method:
Multiple Linear Regression

Predictor pool:
Teleconnection Indices, NCEP data (SST, SAT, SLP, z500), sea ice



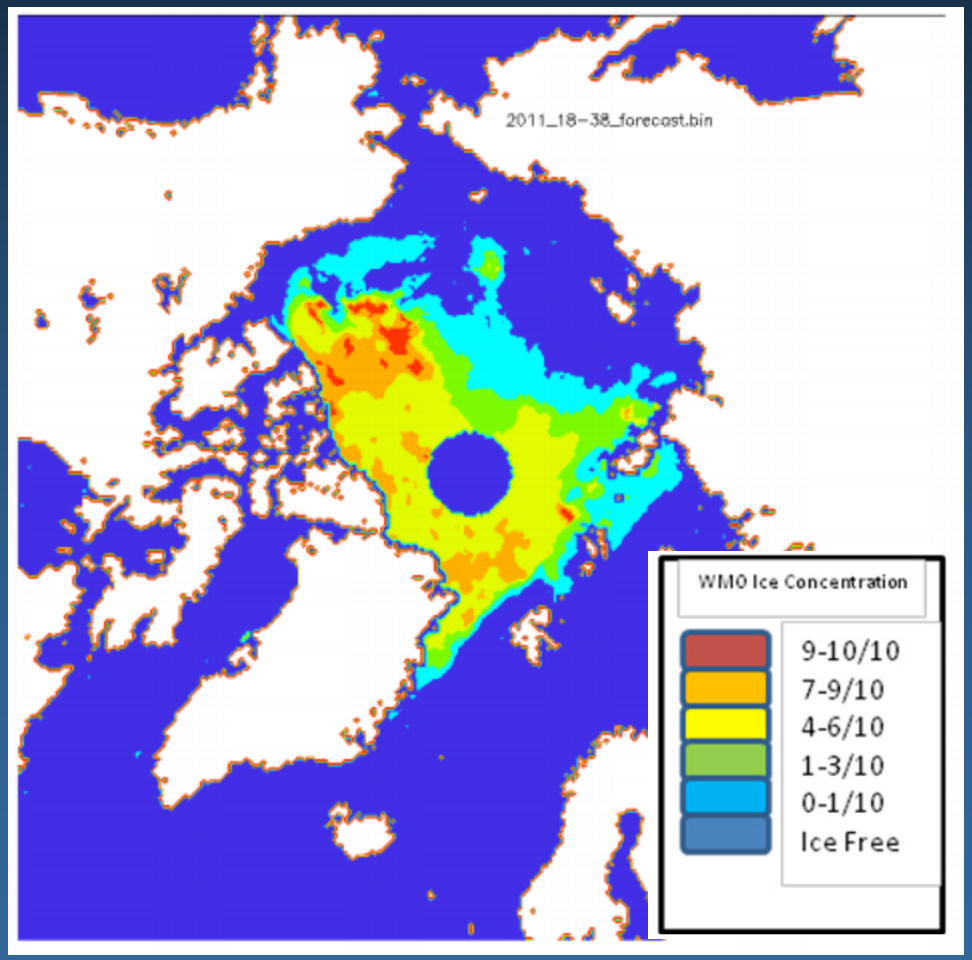
Contributor: Tivy

EMPIRICAL MODELS

Relate present/past climate to future sea ice
*** regression based methods**

Method:
Multiple Linear Regression at each grid point

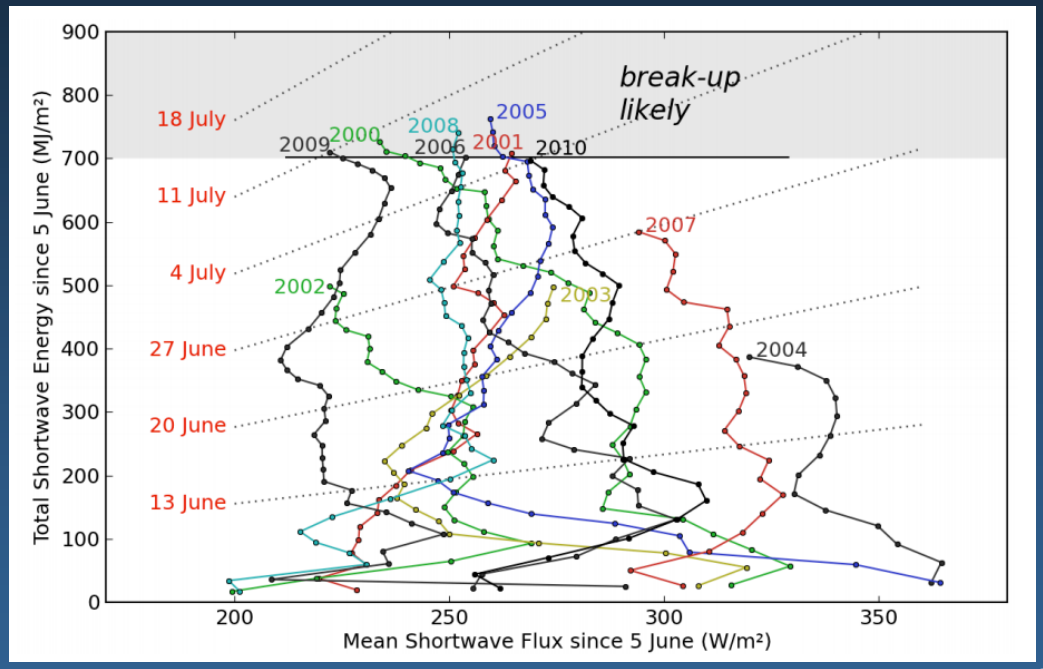
Predictor pool:
sea ice, SLP, 2m air temp.



Contributor: Arbetter

EMPIRICAL MODELS

Relate present/past climate to future sea ice
*** regional scale**



Barrow break-up
** based on short-wave flux from WRF

Contributor: Petrich

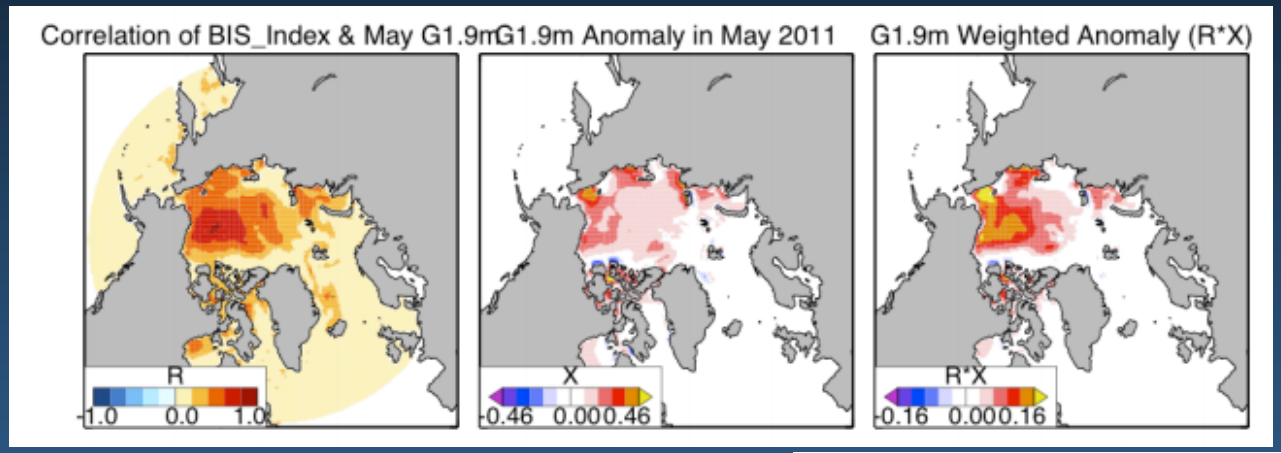
Ice around Svalbard (72 to 85N and 0 to 40E)

$$Ice_{September} = 224642 + (-22995.0 * AO_{March}) + (0.11207 * Ice_{February}) + (11992.54 * SST_{April})$$

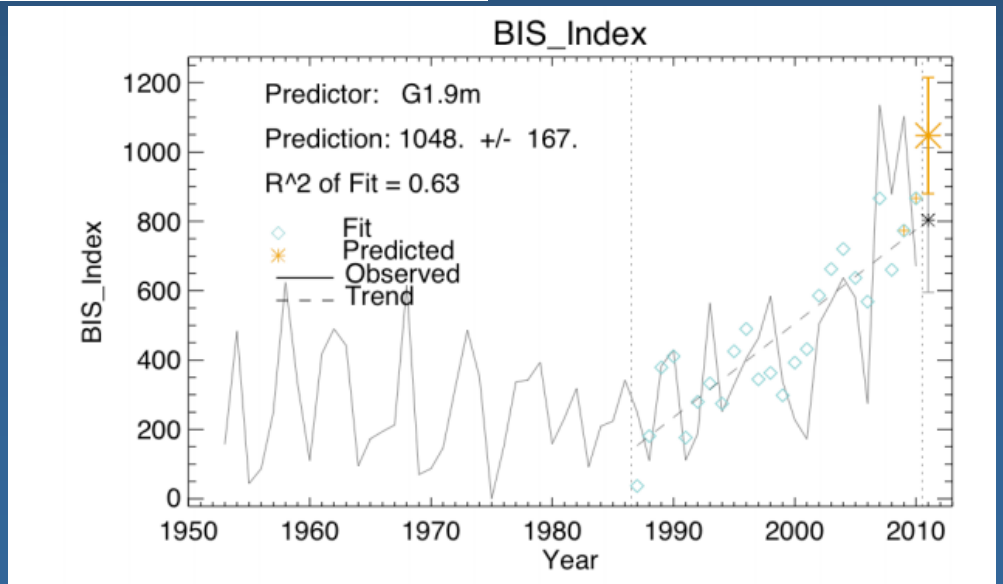
Contributor: Gerland

“DOWN-SCALING” MODEL OUTPUT

Predicting the Beaufort Severity Index (BSI) using output from the PIOMAS model (thickness, conc., extent)



Correlation of BSI with PIOMAS output

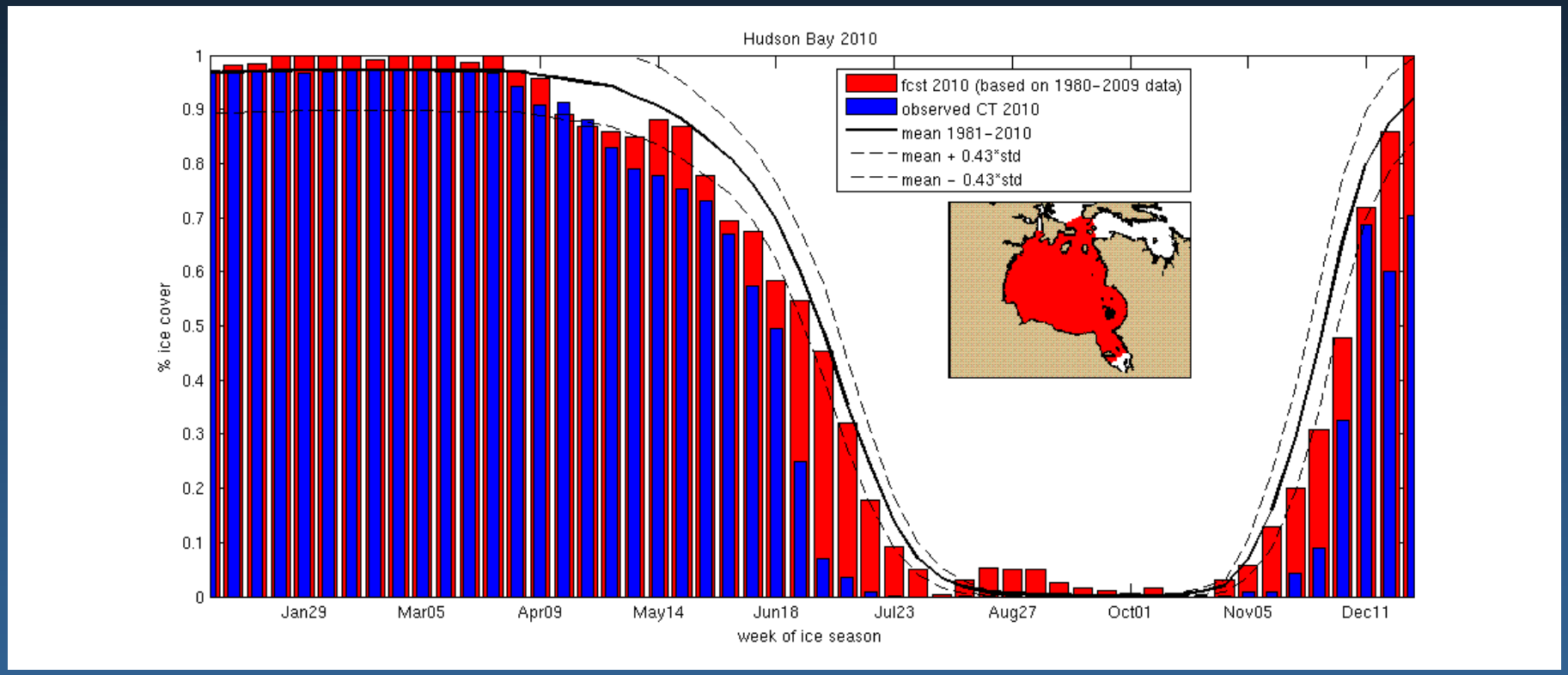


Contributor: Lindsay

To support the NAIS outlook, seasonal forecasting models are required to :

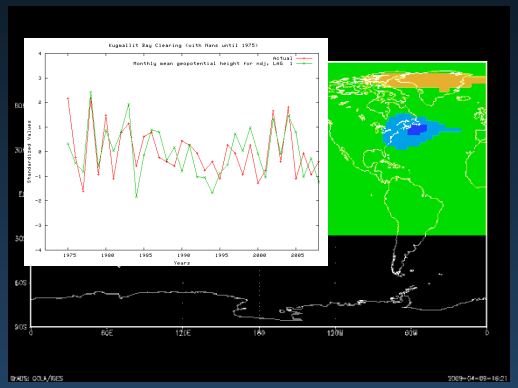
a) **Predict the dates of actual sea ice events**
b) **Predict the general pattern of break-up / freeze-up**
c) **Predict general evolution of the ice season**

CIS: Autoregressive Model



CIS: Automated Multiple Linear Regression

Gridded climate data are included in the predictor pool after being reduced to a single time-series.



1. Narrow the predictor pool (initial pool ~ 1000 predictors)

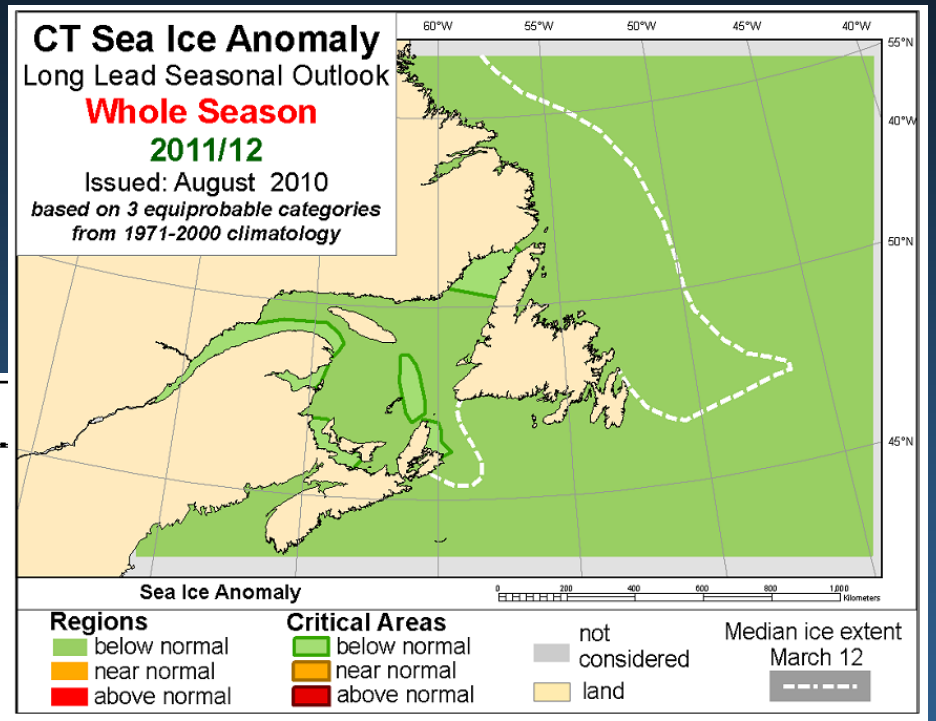
2. Generate the final model equation by step-wise regression

3. Test that the model is statistically robust
   a) check regression assumptions
   b) Monte Carlo to test for artificial skill ($r^2 > 0.6$)
   c) Leave-one-out cross-validation to test for over-fitting

4. Compare the skill of the model to benchmark models (climatology, analog, persistence)

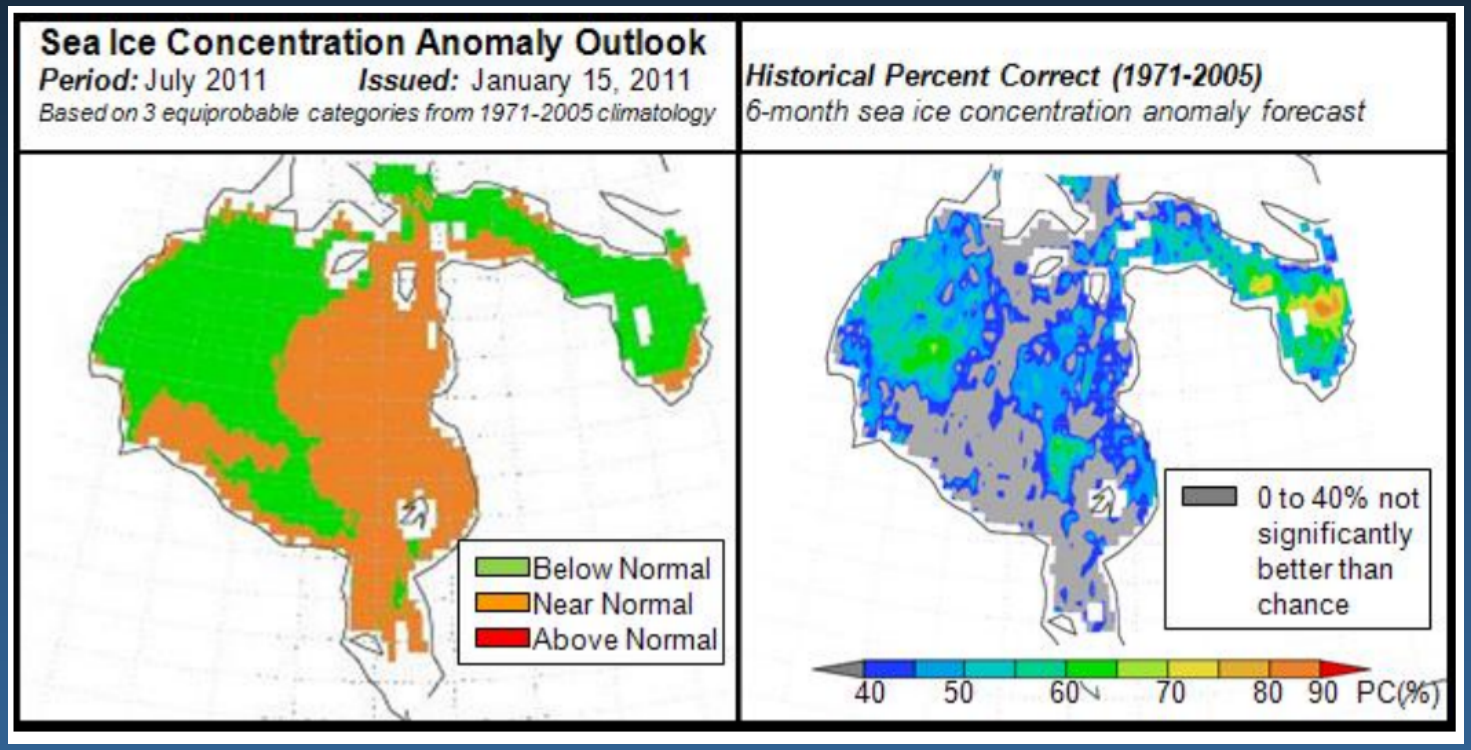
5. Confirm that predictors make physical sense

CIS: Automated Multiple Linear Regression



Forecast Parameter	Persistence Forecast Skill	Analog Forecast Skill	Model Sig.	Model Skill	
Barrow Strait to Resolute – Fracture / Western	-0.27 (15%)	0.13 (42%)			
Cape Dyer -Open drift or less	-0.18 (21%)	0.25 (50%)			
James Bay – Clearing	-0.14 (24%)	-0.09 (27%)			
Frobisher Bay – Open drift or less	-0.11 (26%)	0.36 (57%)			
Hudson Bay – Clearing	-0.11 (26%)	0.15 (43%)			
Tuktoyaktuk Peninsula – Fracture	-0.05 (32%)	0.00 (33%)			
Kugmallit Bay – Clearing	-0.02 (32%)	0.10 (40%)			
Route across Northern Baffin Bay – Bergy water route	0.03 (35%)	0.00 (33%)			
Jones Sound – Fracture	0.03 (35%)	0.51 (67%)			
Coronation Gulf – Fracture	0.03 (35%)	0.45 (63%)			
Route across Northern Baffin Bay – Open drift or less	0.07 (38%)	0.06 (37%)			
Pond Inlet – Fracture	0.07 (38%)	0.15 (43%)	95	0.36 (57%)	14%
Admiralty Inlet Northern Half – Fracture	0.07 (38%)	0.15 (43%)			
Hudson Strait – Clearing	0.07 (38%)	0.25 (50%)	95	0.36 (66%)	16%
Churchill – Open water route	0.07 (38%)	0.21 (47%)	95	0.58 (72%)	25%
MacKenzie Delta – Clearing	0.07 (38%)	0.25 (50%)	95	0.36 (57%)	7%
Wellington Channel – Fracture	0.16 (44%)	0.00 (33%)	95	0.45 (63%)	30%
Labrador Coast to Cape Chidley – Clearing	0.25 (44%)	0.22 (48%)	95	0.54 (69%)	21%
Ungava Bay – Clearing	0.34 (56%)	0.25 (50%)	95	0.49 (66%)	16%
Coronation Gulf – Clearing	0.34 (56%)	0.10 (40%)			

CIS: Canonical Correlation Analysis (CCA)



PREDICTORS: FALL (OND) SAT, z500 and <u>North Atlantic SST*</u>

LONG-LEAD FORECAST TOOL DISCUSSION AND ANALYSIS (REVISED 05/11)

FORECAST TOOLS: (TEMPERATURE & PRECIPITATION)

CFS - **AN ENSEMBLE MEAN FORECAST FROM A FULLY-COUPLED - ONE-TIER OCEAN-ATMOSPHERE DYNAMICAL**

CCA **- CANONICAL CORRELATION ANALYSIS** LINEARLY PREDICTS THE EVOLUTION OF PATTERNS OF TEMPERATURE AND PRECIPITATION **BASED UPON PATTERNS OF GLOBAL SST - 700MB HEIGHT - AND U.S. SURFACE TEMPERATURE AND PRECIPITATION** FROM THE PAST YEAR

ECCA - THE **ENSEMBLE IS CREATED BY MAKING FORECASTS USING VARIOUS PREDICTOR VARIABLES** TO MAKE FORECASTS, THEN AVERAGING THE FORECASTS WITH EQUAL WEIGHTS.

ENSO COMPOSITES

OCN - THE **OPTIMAL CLIMATE NORMALS** METHOD PREDICTS T AND P ON THE BASIS OF **YEAR-TO-YEAR PERSISTENCE** OF THE OBSERVED AVERAGE ANOMALIES FOR A GIVEN SEASON

CAS - CONSTRUCTED ANALOG ON SOIL MOISTURE IS BASED ON EMPIRICAL ORTHOGONAL FUNCTIONS (EOF) FROM DATA OVER THE LOWER 48 STATES BEGINNING IN 1932. THIS TOOL CONSTRUCTS A SOIL MOISTURE ANALOG FROM A WEIGHTED MEAN OF PAST YEARS. THE WEIGHTS ARE DETERMINED FROM THE SIMILARITY OF SOIL MOISTURE CONDITIONS IN PRIOR YEARS TO A COMBINATION OF RECENTLY SOIL MOISTURE OBSERVATIONS AND A MEDIUM RANGE FORECAST OF SOIL MOISTURE OUT TO 14 DAYS BASED ON MRF TEMPERATURE AND PRECIPITATION FORECASTS

SMLR - SCREENING MULTIPLE LINEAR REGRESSION TOOL IS USED TO EXTRACT INFORMATION FROM A VARIETY OF SOURCES TO PRODUCE A FORECAST FOR SEASONAL AND MONTHLY TEMPERATURE AND PRECIPITATION.

CONSOLIDATION (CON) - AN OBJECTIVE, SKILL WEIGHTED COMBINATION OF THE OCN, CCA, SMLR, ECCA, AND CFS FORECASTS IS USED AS A FIRST GUESS IN PREPARING THE FORECAST MAPS. THIS TECHNIQUE MAKES OPTIMUM USE OF THE KNOWN SKILL OF OUR FORECAST TOOLS.

Summary

- Statistical methods being used are variants of regression (AR, MLR, CCA, etc…)
- Role in the near term: forecast local scale to hemispheric scale parameters and compliment physical model forecasts
- Role in the long-term: likely move towards down-scaling model output
- Open Question: How are we going to assimilate forecasts from the suite of statistical tools and physical models