Science, Service, Stewardship

Forecasting fish population response to climate change: a case study for the Bering Sea

Anne B. Hollowed, Z. Teresa A'mar,
N. Bond, W. Stockhausen, T. Wilderbuer
J. Overland

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Overview

Review Climate Forecasting Programs Worldwide

Framework for quantitative forecasts

Climate scenarios

Application to rock sole

Management strategies

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IPCC AR4

- Intergovernmental Panel on Climate Change (IPCC) concludes that "t*here is very high confidence that the global average net effect of human activities since 1750 has been one of warming"* (http://www.ipcc.ch/graphics/gr-ar4-wg1.htm)
- Changes in climate are expected to have lasting impacts on the properties of marine ecosystems, and the goods and services extracted from them.
- With a few exceptions, the IPCC AR4 assessment provides qualitative rather than quantitative predictions of impacts on marine resources (Fischlin *et al*. 2007).

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Reasons for Qualitative Predictions

1. Inadequate representation of the interactive coupling between ecosystems and the climate system.
2. Limitations of climate envelope models used to project responses of individual species to climate change.
3. Interactions between climate change and changes in human use and management of ecosystems are uncertain.

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Needs of international community for quantitative forecasts

Assess ecosystem effects of fishing under climate change – can we mitigate the impact?

Food security

Industry planning

Assessing management tradeoffs

Defining rebuilding and recovery for protected species

Important new science

Assess and improve forecasting skill

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ICES/PICES Coordinated International Effort

- Workshop 2 and 3 Gjion, Spain May 2008 (See Hollowed et al and A'mar et al. ICES J. Mar. Sci 2009)
- PICES 17 workshop, October, 2008 Dailan, China
- First joint ICES-PICES working group approved January 2009
- Coordination meeting prior to GLOBEC meeting Victoria B.C. June 2009
- Symposium April 25-29 2010 in Japan
- Publication 2011
- IPCC update 2013

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Schematic of Research Programs in the North Pacific

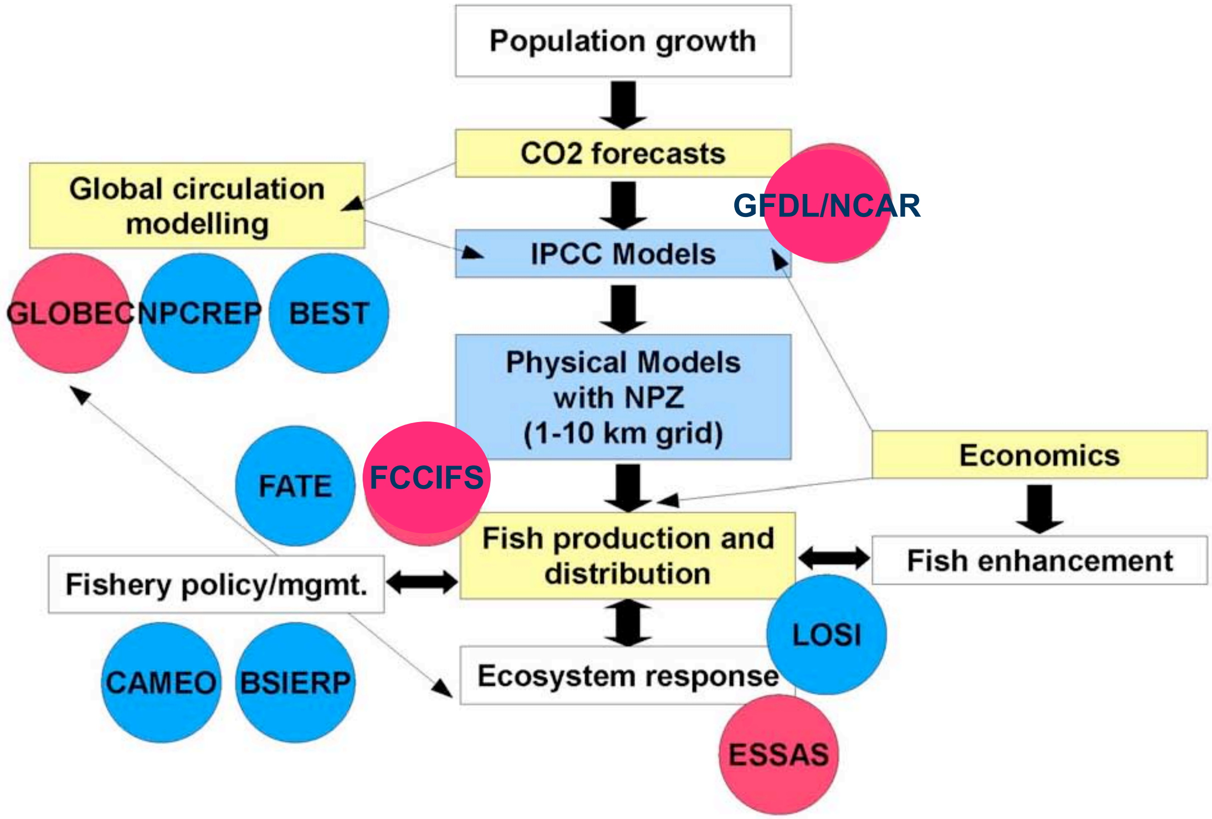

Fig. 1.1 Schematic showing linkages between U.S. national (dark blue) and international (red) research programs in the PICES region (see text for description of acronyms). National programs are expected to continue to fund research within the boxes.

Modelling approaches

- Statistical downscaling: IPCC scenarios downscaled to local regions and ecosystem indicators incorporated into stock projection models.
- Dynamical downscaling: IPCC scenarios downscaled to local regions and coupled to bio-physical models with higher trophic level feedbacks.
- Fully coupled bio-physical models that operate at time and space scales relevant to coastal domains.

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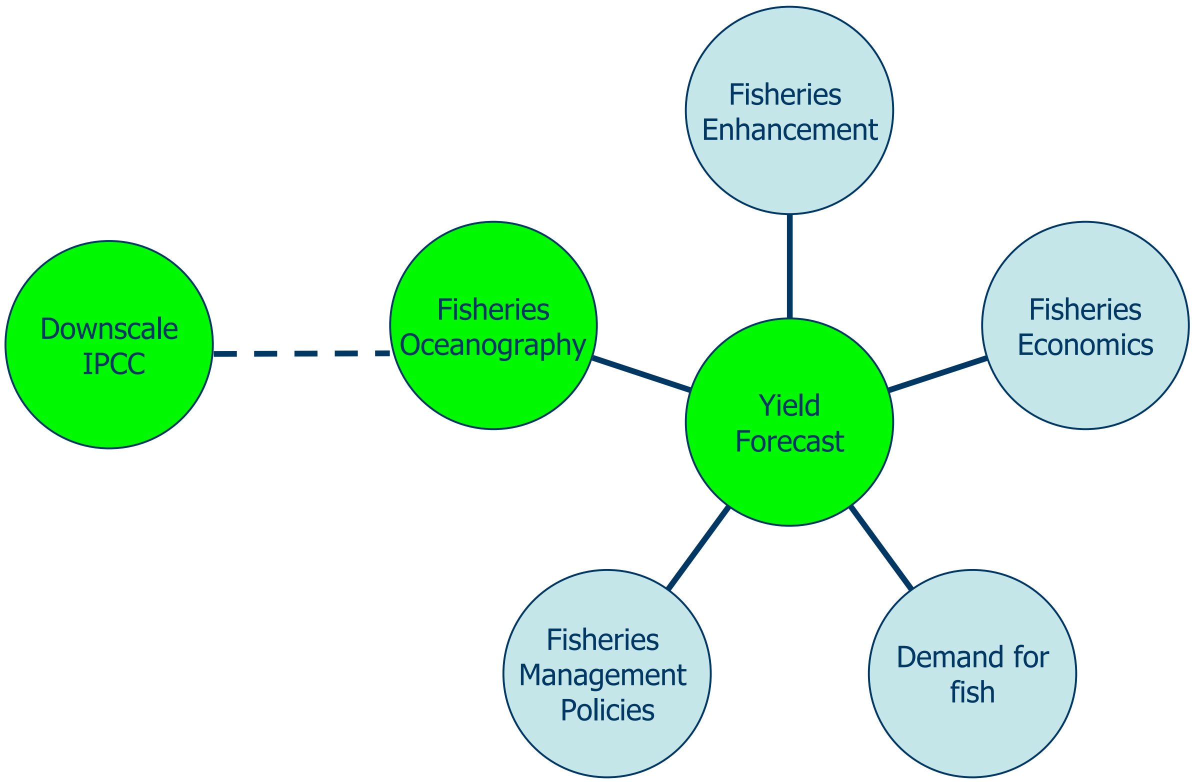
Elements of fisheries forecast model



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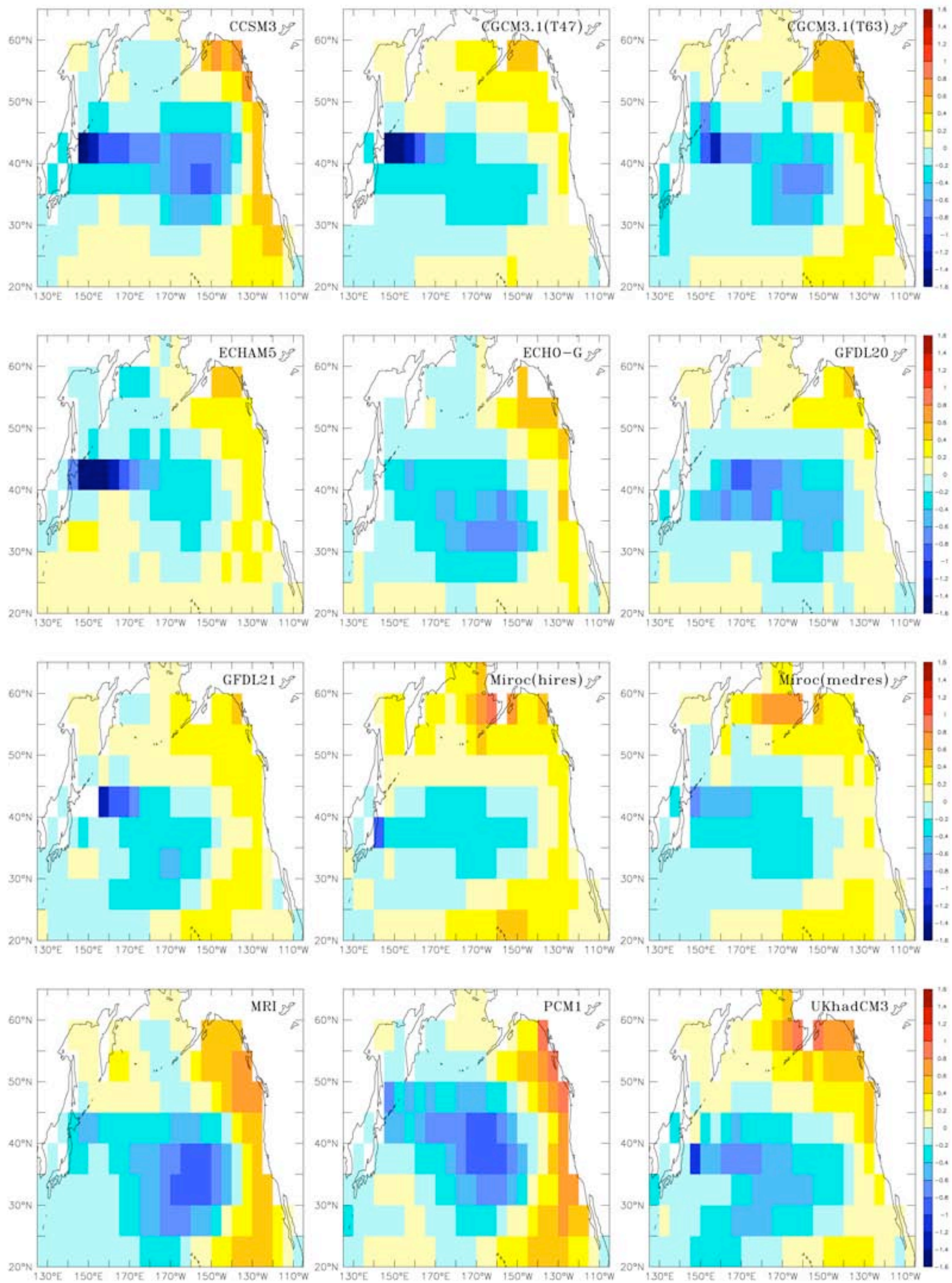
Framework for projecting impacts of climate change on fish and shellfish

- Identify mechanisms underlying production
- Evaluate climate model scenarios and select scenarios that appear to be valid for your region
- Assess oceanographic implications of scenarios and develop time series
- Incorporate time trend in oceanography in forecasting model for fish
- Evaluate harvest strategy under changing ecosystem

Models Contributed to IPCC AR4

	IPCC I.D.	Country	Atmosphere Resolution	Ocean Resolution	# of Control runs	# of 20c3m runs	# of A1B runs
1	BCCR-BCM2.0	Norway	T63L31	(0.5 - 1.5°) x 1.5°L35	2	1	1
2	CCSM3	USA	T85L26	(0.3 - 1.0°) x 1.0°L40		1	1
3	CGCM3.1(T47)	Canada	T47 L3 1	1.9° x 1.9°L29	2	5	5
4	CGCM3.1 (T 63)	Canada	T63L31	1.4 ° x 0.9 °L29	1	1	1
5	CNRM-CM3	France	T42L45	182x152L31	3	1*	1
6	CSIRO-Mk3.0	Australia	T63L18	1.875° x 0.925° L31	3	3	1
7	ECHAM5/ MPI -OM	Germany	T63L31	1.5°x1.5°L40			
8	FGOALS -g1 .0 (IAP)	China	T42L26	1°x1°xL30	9	3	3
9	GFDL-CM2.0	USA	2.5°x2. 0° L24	1°x1°L50	5	3	1
10	GFDL-CM2.1	USA	2.5°x2. 0° L24	1°x1°L50	5	5	1
11	GISS-AOM	USA	T42L20	1.4°x1.4°L43	2	2	2
12	GISS-EH	USA	5°x4°L20	2°x2° *cos(lat) L16	4	5	3
13	GIS S-ER	USA	5°x4°L13	5°x4°L33	1	9	5
14	INM-CM3.0	Russia	5°x5°L21	2°x2.5°L33	2	1	1
15	IPSL-CM4	France	3.75°x2.5° L19	2°x1 °L31	3	1	1
16	MIROC3.2(hires)	Japan	T106 L56	0.28°x0.188° L47	1	1	1
17	MIROC3.2(medres)	Japan	T42 L20	(0.5° - 1.4°)x 1.4° L44	3	3	3
18	ECHO-G (MIUB)	Germany/Korea	T30L19	T42L20	1	3	3
19	MRI-CGCM2.3.2	Japan	T42 L30	(0.5° -2. 5°) x 2° L23	3	5	5
20	PCM	USA	T42L18	(0.5 -0.7°) x 0.7° L32		1	
21	UKMO -HadCM3	UK	3.7°5x2.5° L15	1.25°x1.25° L20	2+1*	1	1
22	UKMO -HadGem1	UK	1.25°x1.875°L38	(0.33 -1.0°) x 1.0° L40	1+2*	2	1*
	Sum					55	40


CCSM3
CGCM3.1(T47)
CGCM3.1(T63)
ECHAM5
ECHO-G
GFDL20
GFDL21
Miroc(hires)
Miroc(medres)
MRI
PCM1
UKhadCM3
60°N
50°N
40°N
30°N
20°N
130°E 150°E 170°E 170°W 150°W 130°W 110°W

Ensemble Model Projections for North Pacific Marine Ecosystems

- Initial Selection - Pick models that replicate the observed character of the PDO in their 20th century hindcasts (12 of 22 pass test)
- Regional Perspective - Examine specific parameter(s) in region of interest; consider means, variances, seasonality, etc.
- Model projections - Use quasi-Bayesian method based on “distance” between hindcasts and observations; form weighted ensemble means
- Uncertainty/Confidence - Estimate based on a combination of inter-model and intra-model variances in projections

Integrated Ecosystem Research in the Bering Sea

Bering Ecosystem Study (BEST)

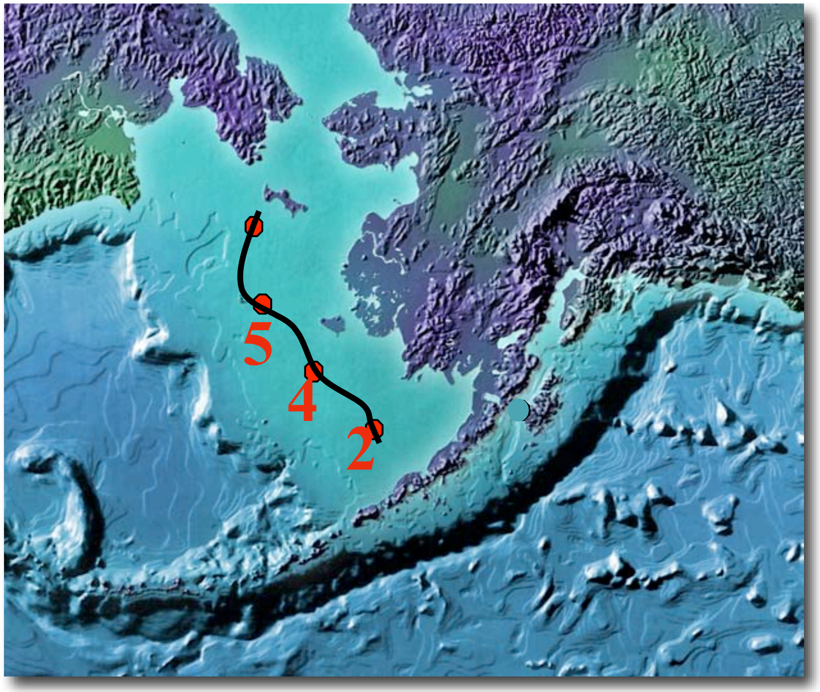
Bering Sea
Integrated Ecosystem Research Program (BSIERP)

Timeline and Study Area

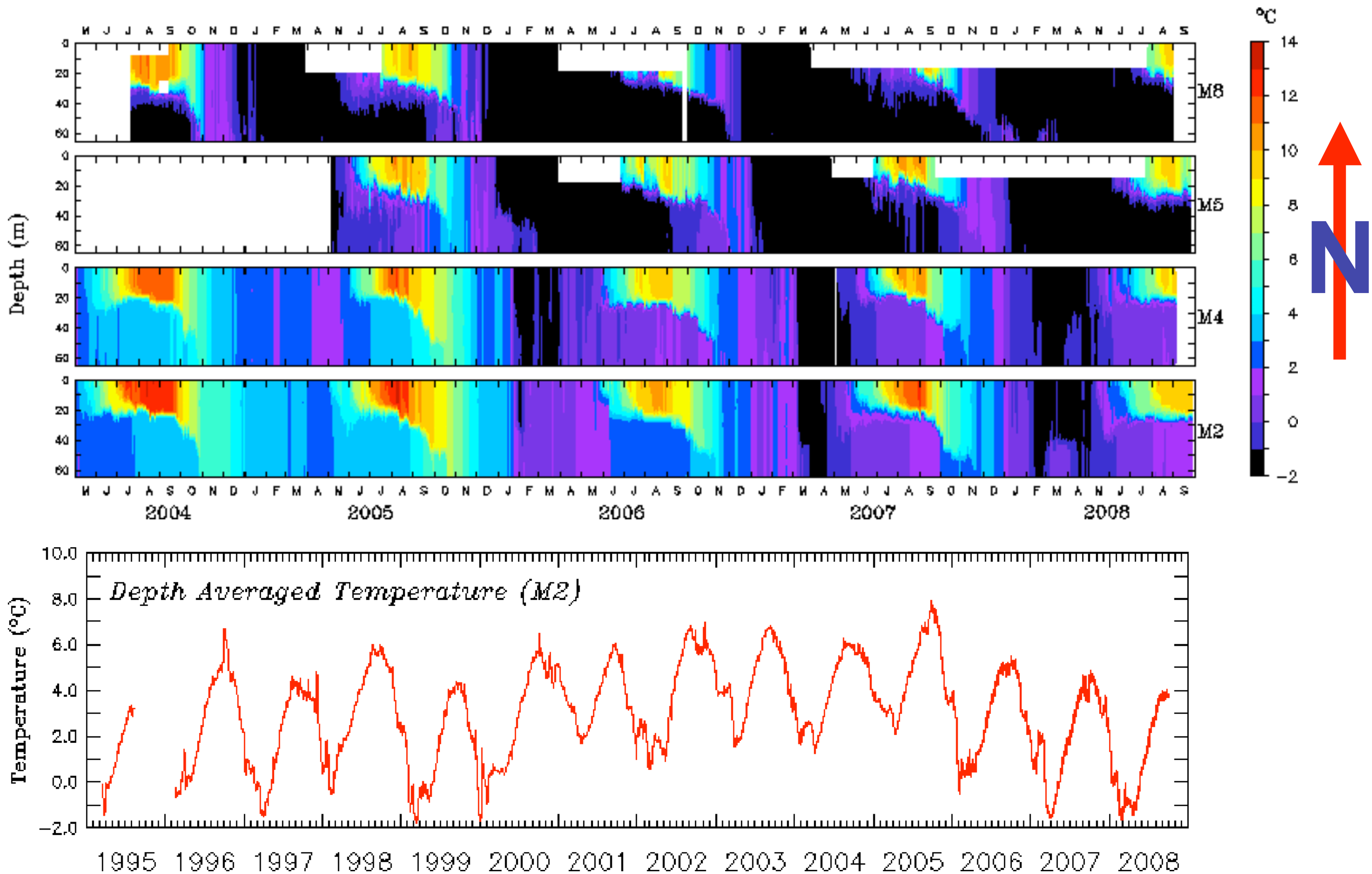
- Fieldwork 2007-2010

- Modeling 2008-2011

- Analysis and reporting 2011-2012

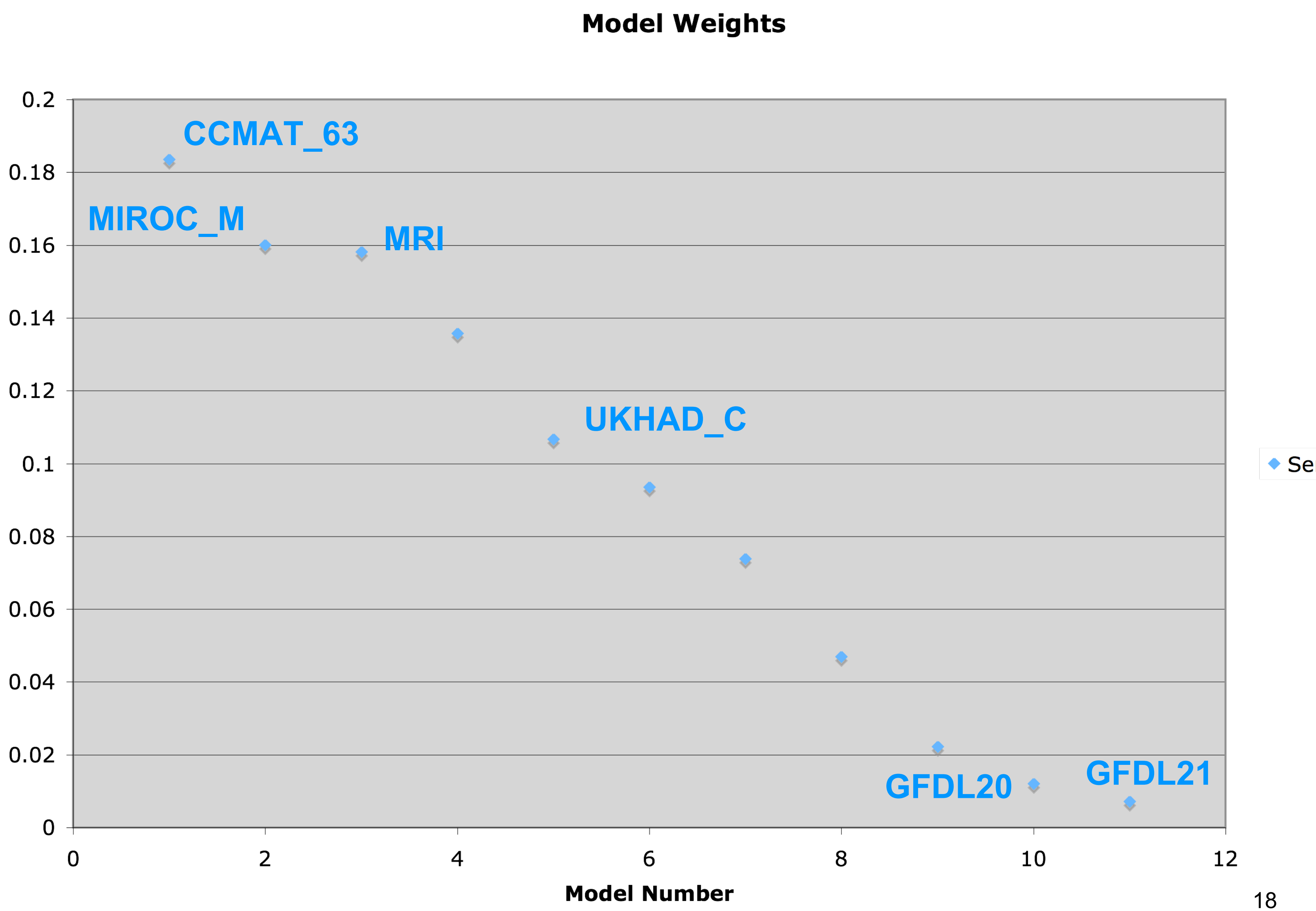


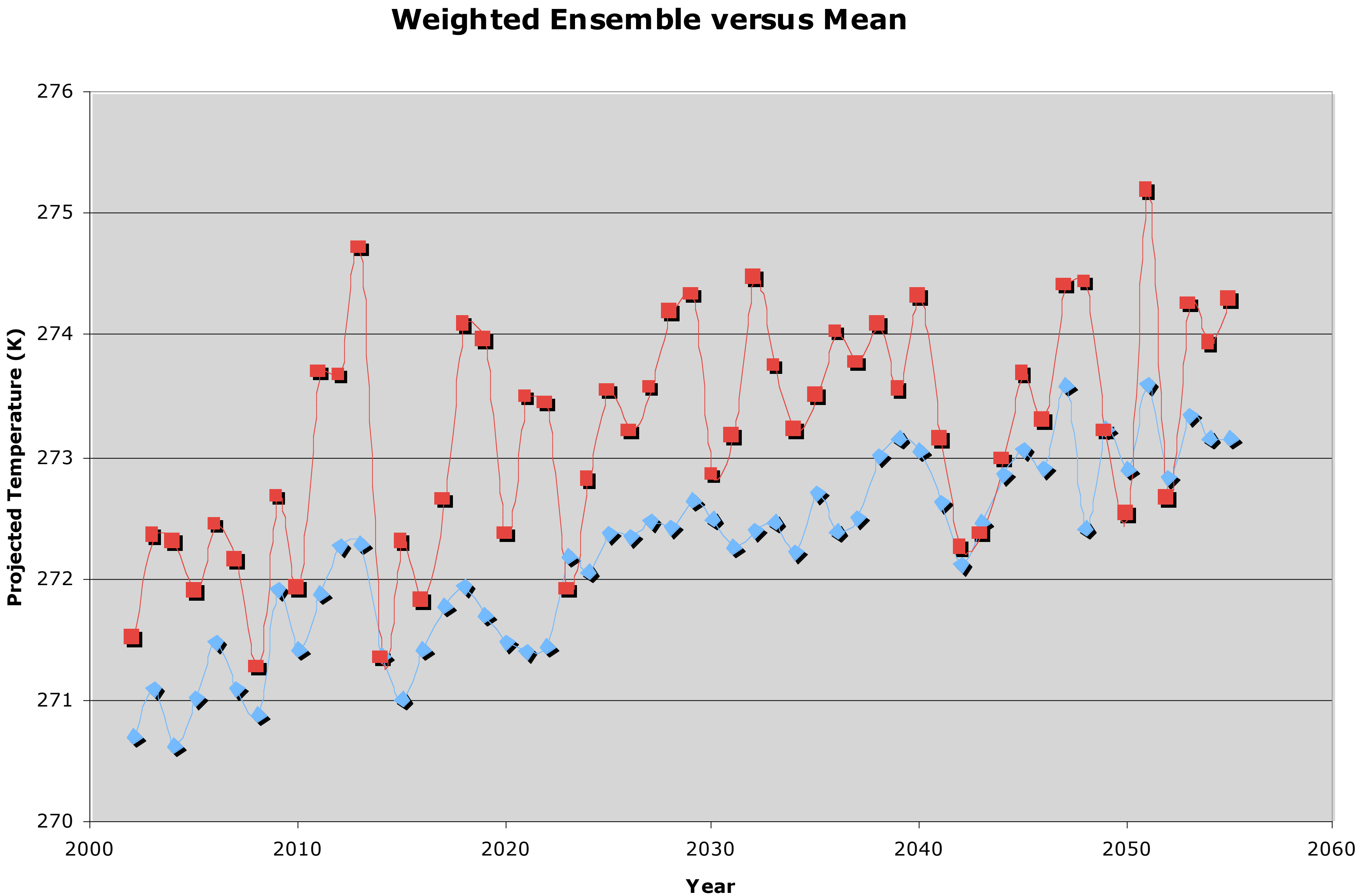
Bering Sea - Temperature



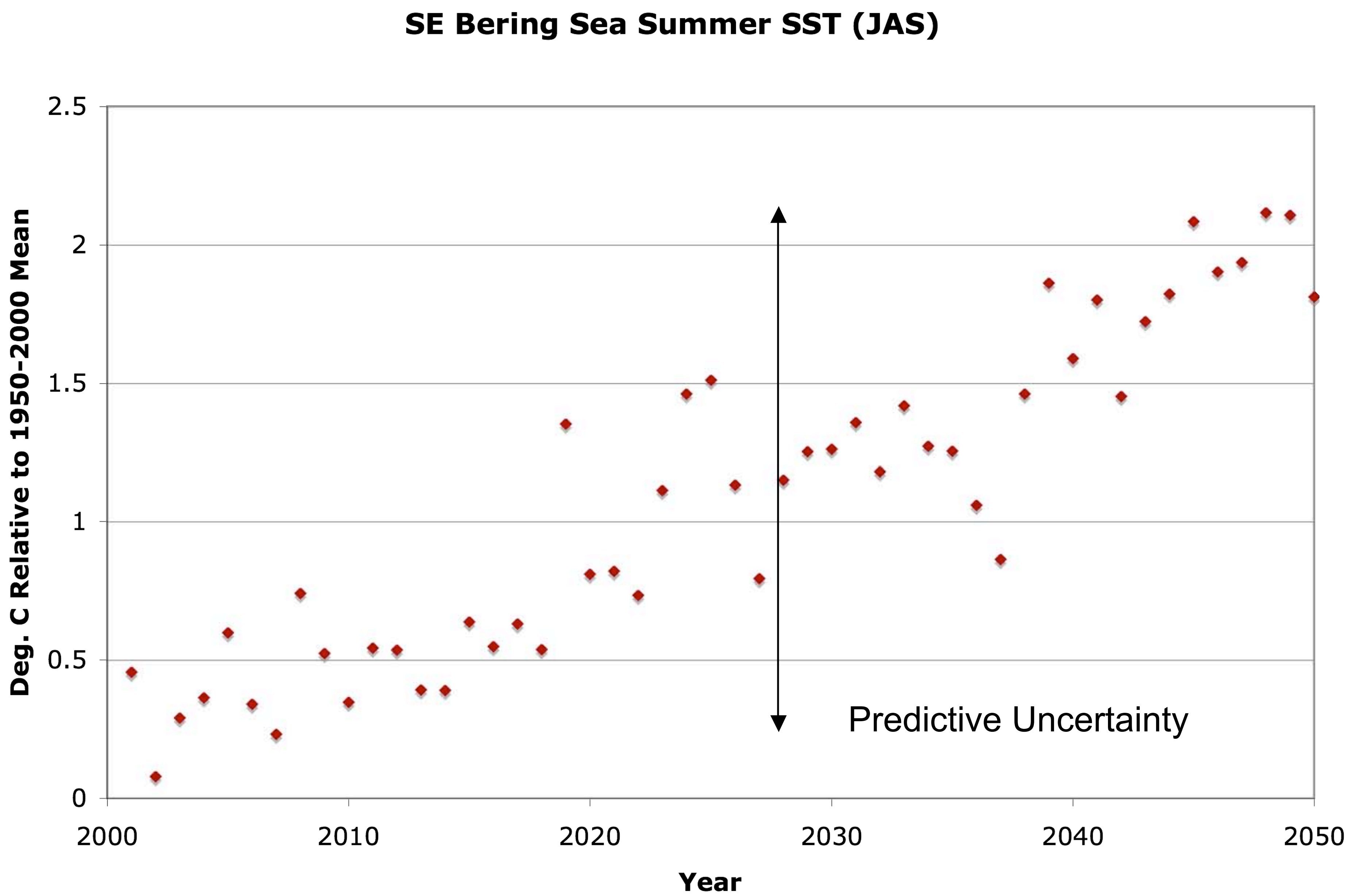
Biophysical moorings: Stabeno, Napp, Whitledge, Mordy

Model	Alaska temperature	Greenland temperature	60-90°N temperature	20-90°N temperature	Alaska sea level pressure	Greenland sea level pressure	60-90°N sea level pressure	20-90°N sea level pressure	Alaska precipitation	Greenland precipitation	60-90°N precipitation	20-90°N precipitation	Integrated Rank Index
MPI_ECHAM5	13	02	01	01	01	02	01	01	05	03	03	03	36
GFDL_CM2_1	06	01	03	05	05	04	04	02	02	01	01	02	39
MIROC3_2_MEDRES	02	03	04	03	10	01	03	05	07	04	06	08	56
UKMO_HADCM3	11	04	08	06	04	05	06	07	03	02	02	09	67
CCCMA_CGCM3_1	12	11	11	10	08	03	02	04	04	13	08	02	88
GFDL_CM2_0	06	09	09	14	04	08	08	04	01	09	10	06	88
MRI_CGM2_3_2A	11	14	13	07	02	10	11	06	06	06	05	04	95
NCAR_CCSM3_0	08	06	02	02	15	11	15	13	09	05	08	07	101
CNRM_CM3	01	07	05	05	07	12	12	11	12	08	12	13	105
NCAR_PCM1	14	10	13	14	06	06	05	12	08	10	05	10	113
CSIRO_MK3_0	06	12	14	12	11	07	09	09	11	12	11	05	119
INMC3_0	07	13	06	10	09	09	07	09	10	14	13	12	119
IPSL_CM4	11	08	07	12	14	14	11	15	13	07	09	11	139
GISS_MODEL_E_R	06	05	10	10	13	15	14	14	14	11	14	15	141
IAP_FGOALS1_0_G	15	15	15	15	12	13	13	10	15	15	15	14	167

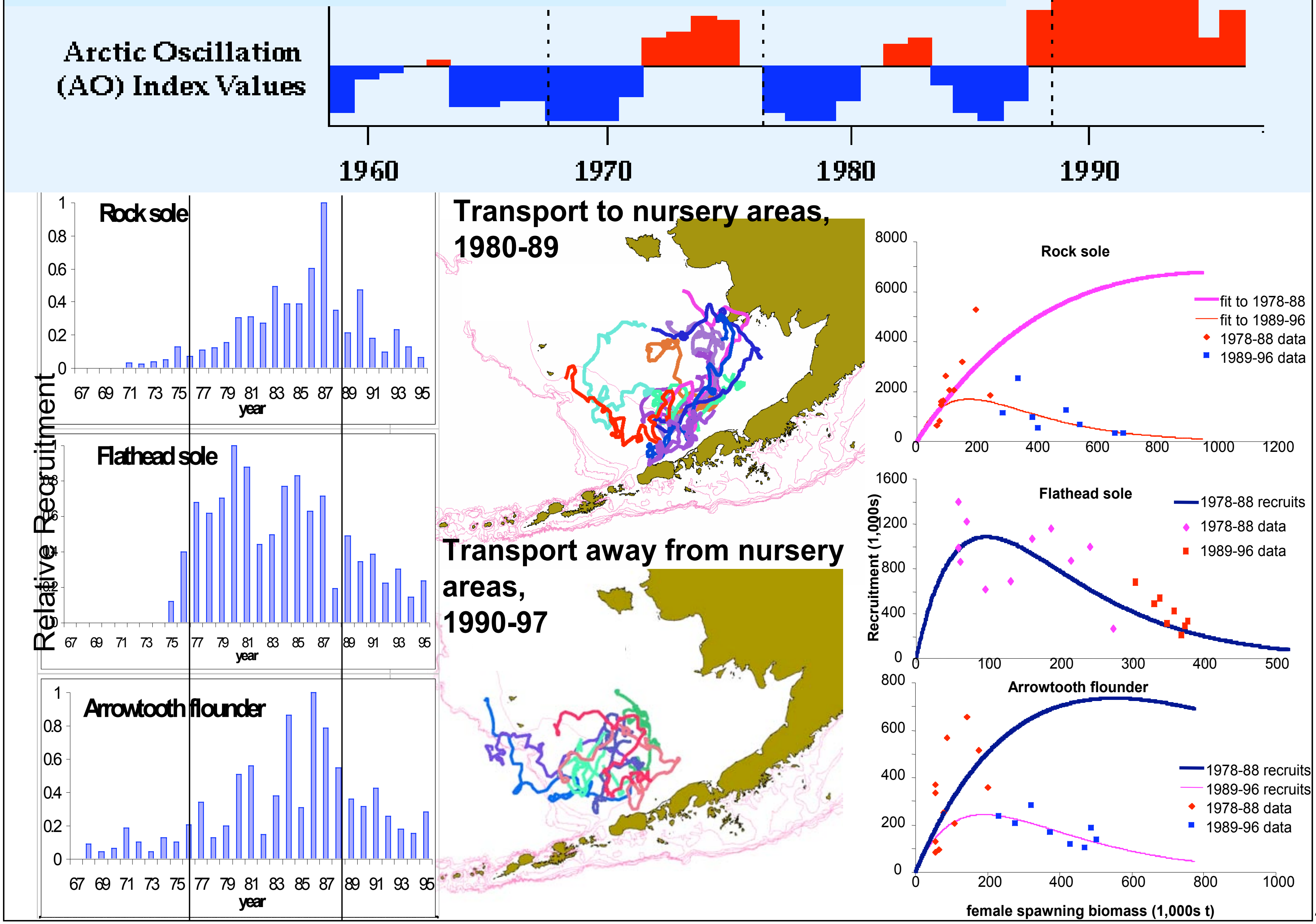

Model Weights
CCMAT_63
MIROC_M
MRI
UKHAD_C
GFDL20
GFDL21
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
Model Number
Ser



Weighted Ensemble versus Mean
Projected Temperature (K)
276
275
274
273
272
271
270
2000
2010
2020
2030
2040
2050
2060
Year


SE Bering Sea Summer SST (JAS)
Deg. C Relative to 1950-2000 Mean
2.5
2
1.5
1
0.5
0
2000
2010
2020
2030
2040
2050
Year
Predictive Uncertainty

Index of Advection in the E. Bering Sea and effects on winter-spawning flatfish recruitment



Wilderbuer et al. 2002. Prog. Oceanogr. 55:235-246

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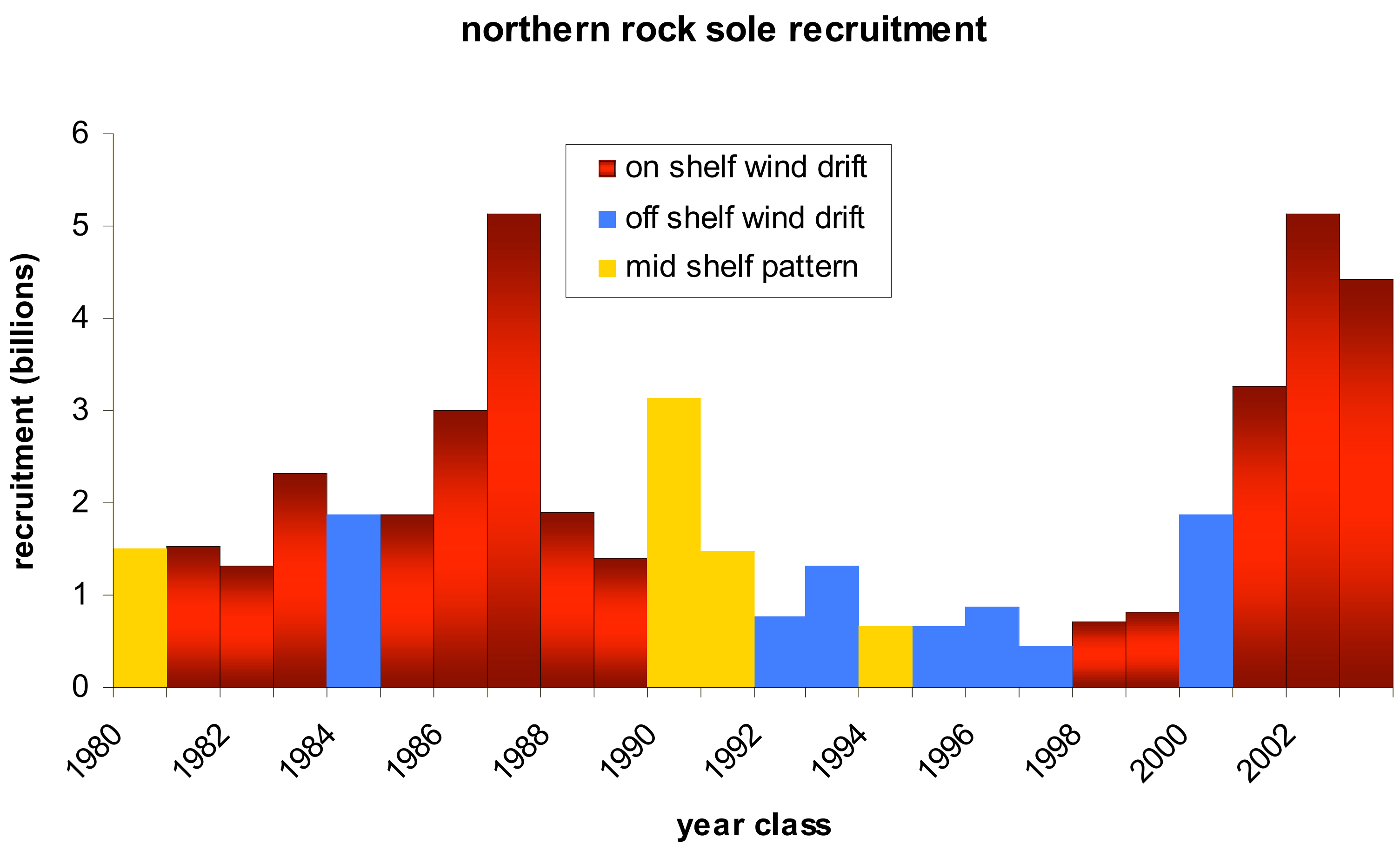
Forecast skill



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Incorporating Ecosystem Indicators into Stock – Recruitment Equations

$$R_{y+1} = \left(\overline{R}_1 e^{\left(\sum_{i=1}^{n} a_i I_{i,y}\right)} e^{(\varepsilon_y - \sigma_R^2/2)} \right); e_y \sim N(0, \sigma_R^2)$$

$$R_t = \left(\alpha * S_t * e^{-(\beta S + E1 + E2 \ldots)} \right)$$

Brooks and Powers ICES J. Mar. Sci (2008)

Generalized compensation in stock – recruit functions

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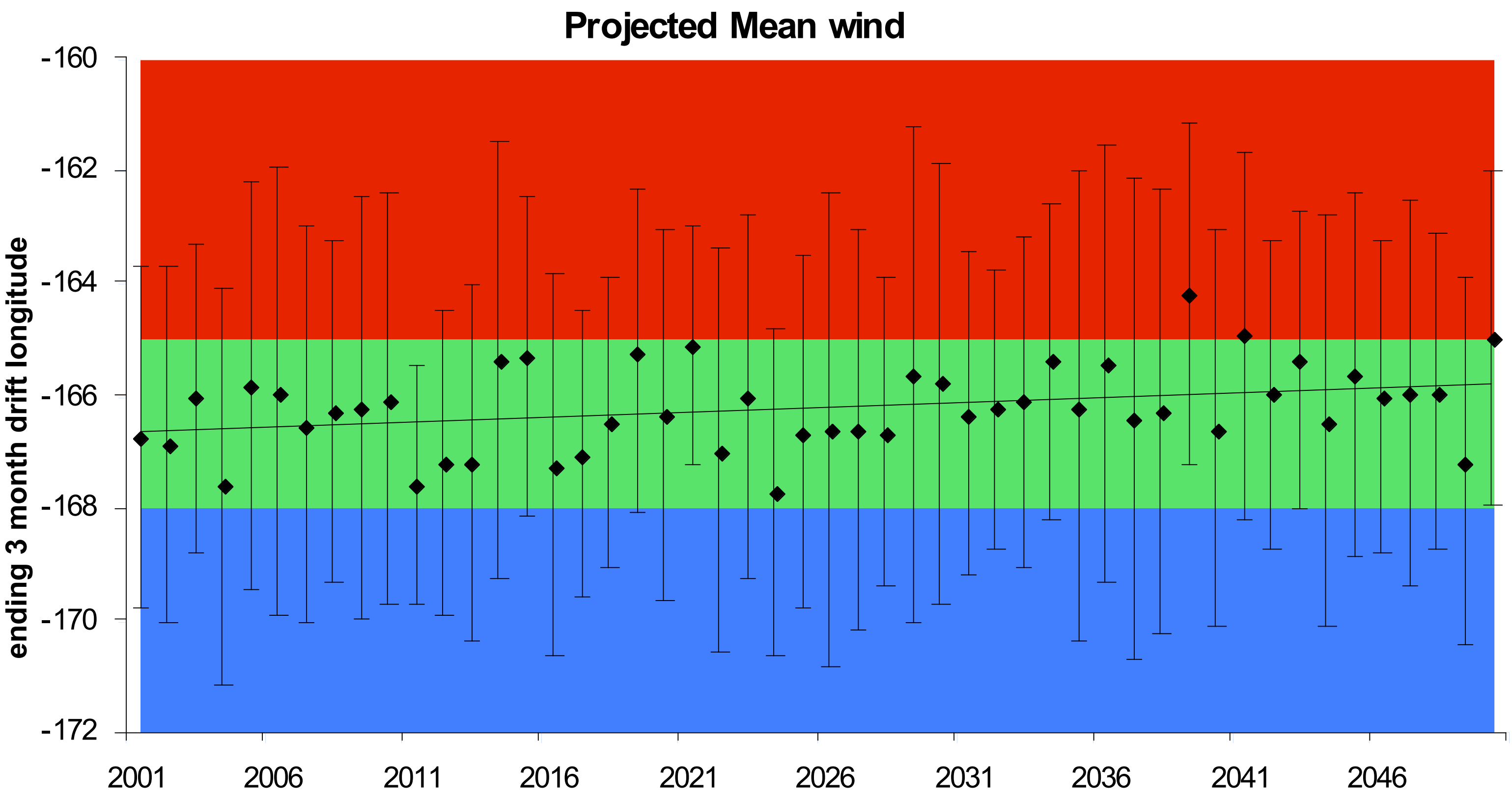
Rock sole recruitment forecast

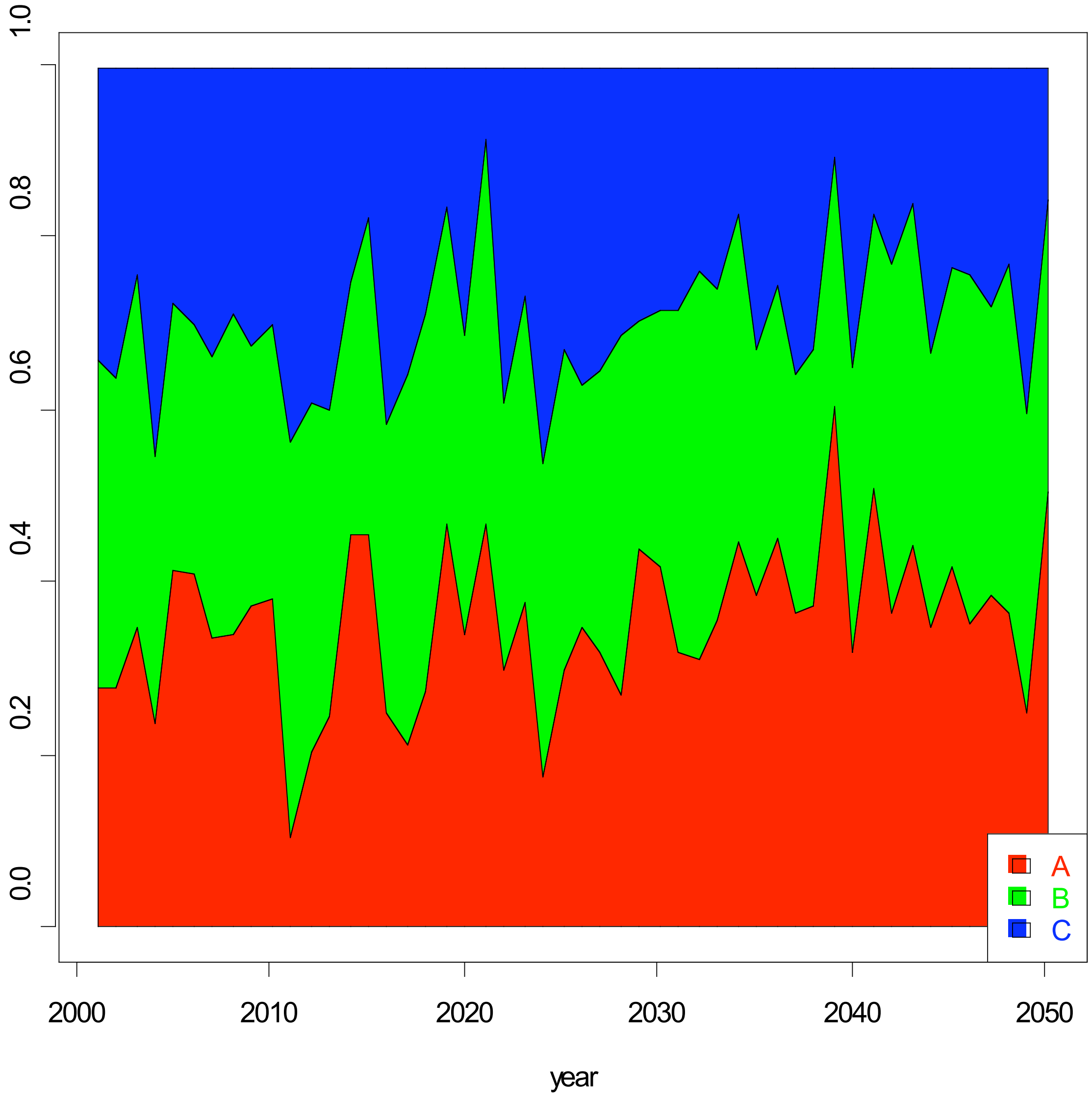
- Hierarchical bootstrap.
  - — Three climate conditions were characterized according to the range of the ending longitude *L* expected for larval drift under each condition: A) onshelf drift, B) midshelf drift, and C) offshelf drift.
  - — For each projected year, the corresponding predicted mean drift longitude and variance from the IPCC model results was used to draw a sample drift longitude from a normally-distributed population.
  - — The climate condition corresponding to the sample longitude was identified based on the limits for each springtime wind condition.
  - — A value for recruitment was randomly selected (with replacement) from the set of "observed" recruitments corresponding to the given climate condition.
  - — Repeat 20,000 times to generate bootstrap realizations for each projected year. For each year, the probability of occurrence for each climate condition was computed, as well as the mean and distribution of recruitment.

Predicted mean and standard deviation of the longitudinal endpoint of projected larval drift from springtime winds for 2001-2050

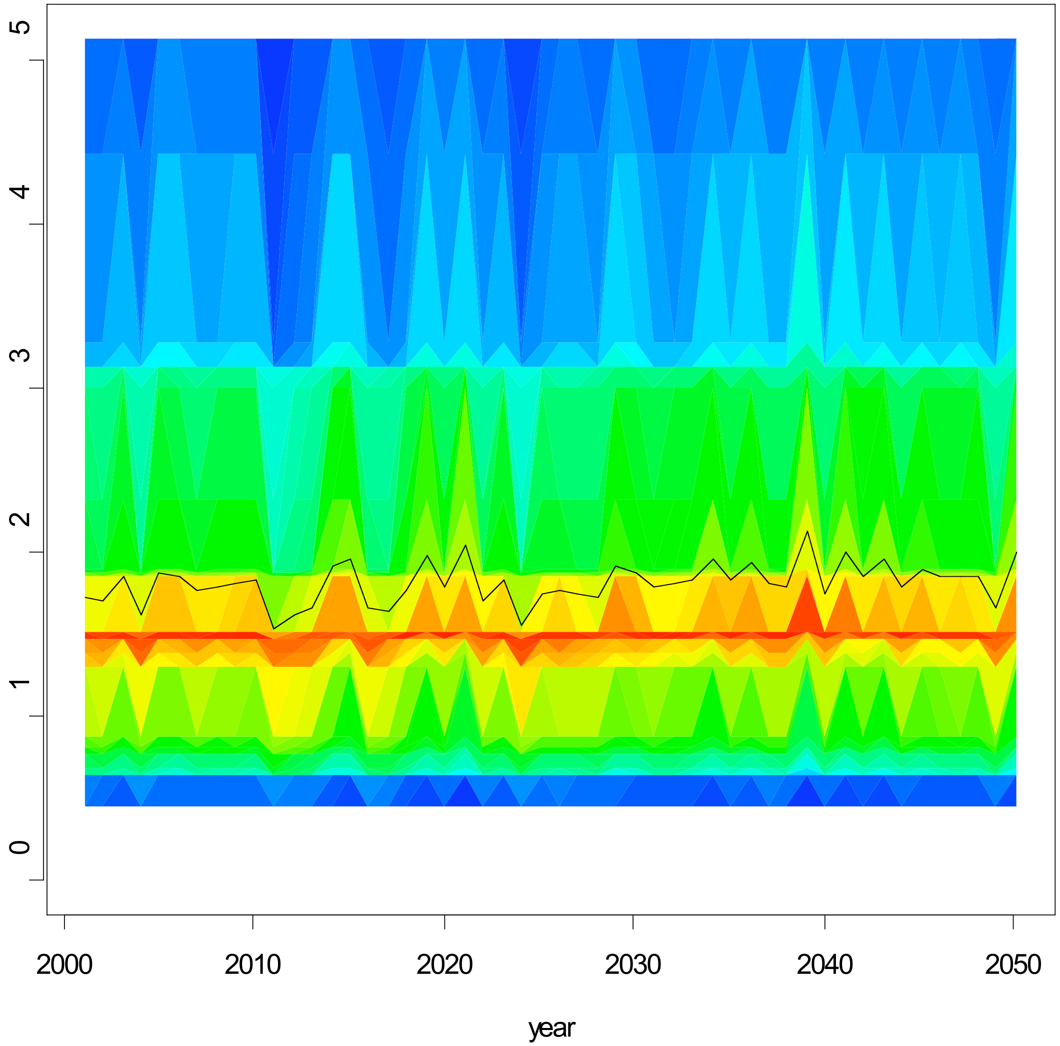


red region represents projected endpoints from onshore drift climate scenario, green region represents mid-shelf drift scenario, and blue region represents off-shelf drift scenario.

Cumulative probability of future springtime climate conditions (A, B, C) based on 20,000 bootstrapped samples/year (A= onshore winds, B = mid-shelf winds, C = off-shore winds).



Projected mean (black line) and quantiles (colored shading) for northern rock sole productivity (recruitment) by year. Quantiles are color-coded symmetrically from the median (bright red) to 0 or 100% (dark blue).



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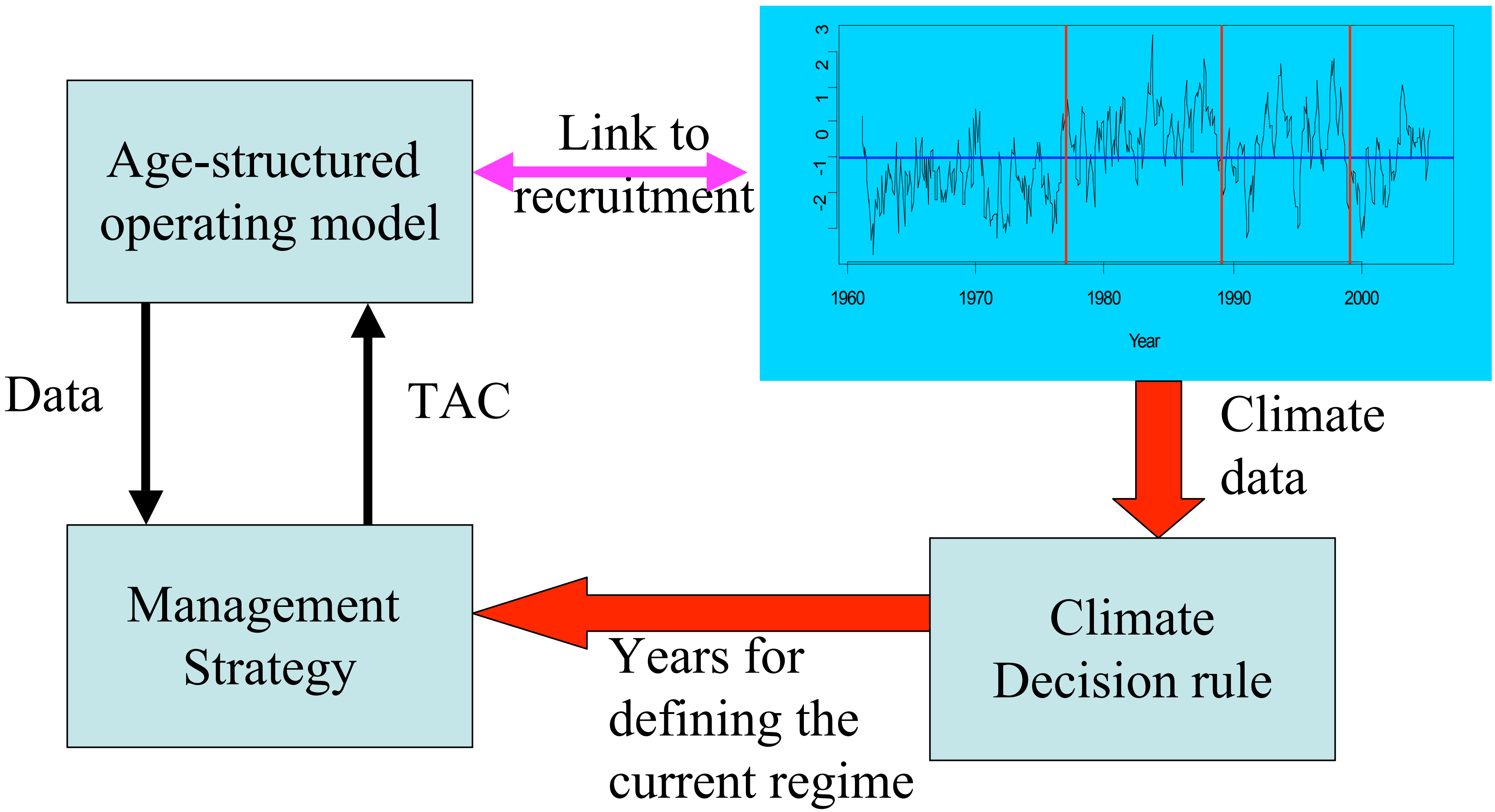
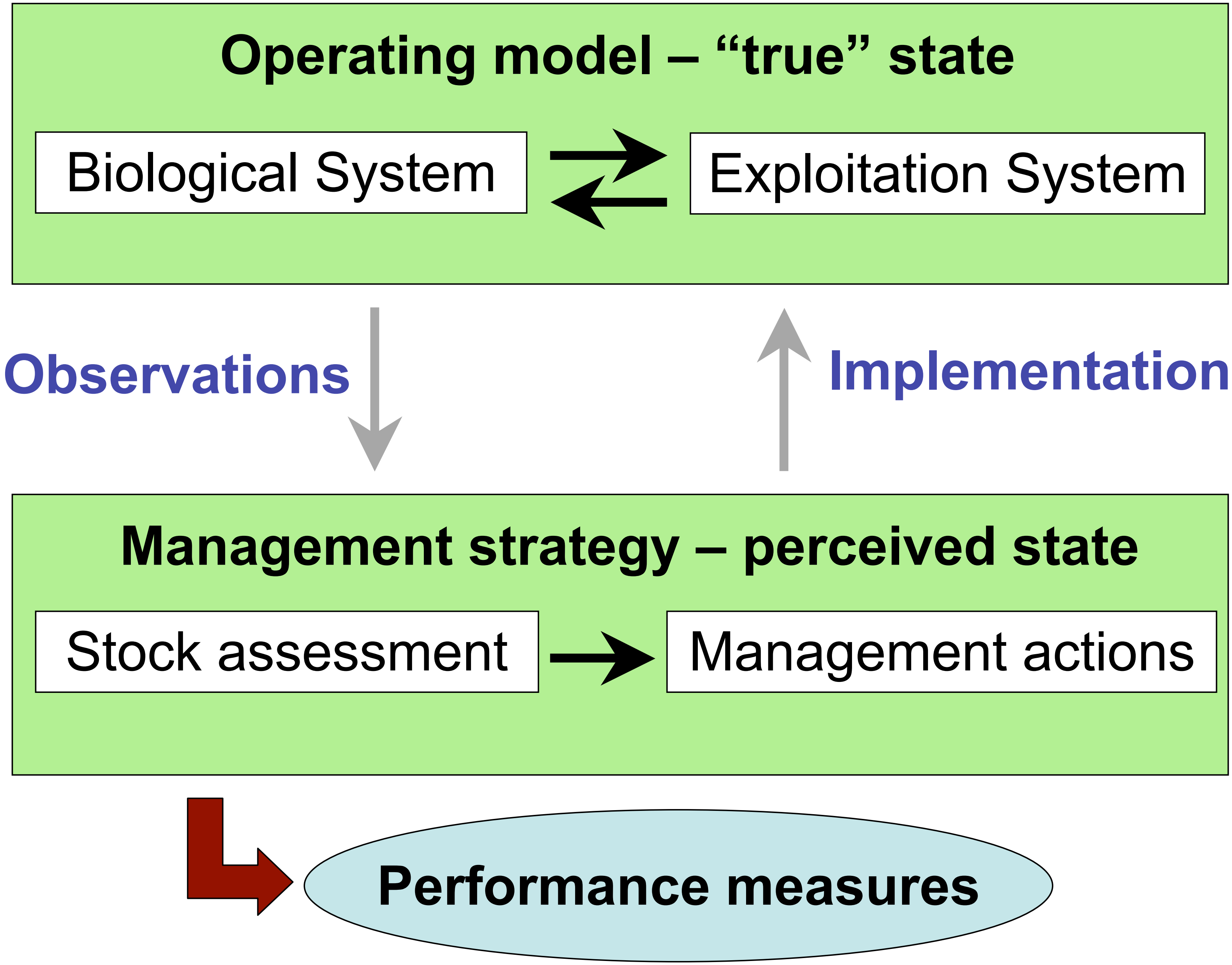
Flatfish Example Summary

- The simulations carried out for IPCC provide the opportunity to project Bering Sea winds for the next few decades.
- The magnitude of the projected change in the cross-shelf wind is comparable to the decadal variations observed in the 20th century.
- A ensemble climate forecast yields a modest increase in the cross-shelf wind from 2000 to 2050.
- These shifts in climate conditions are projected to be favorable to rock sole recruitment but uncertainty remains high.

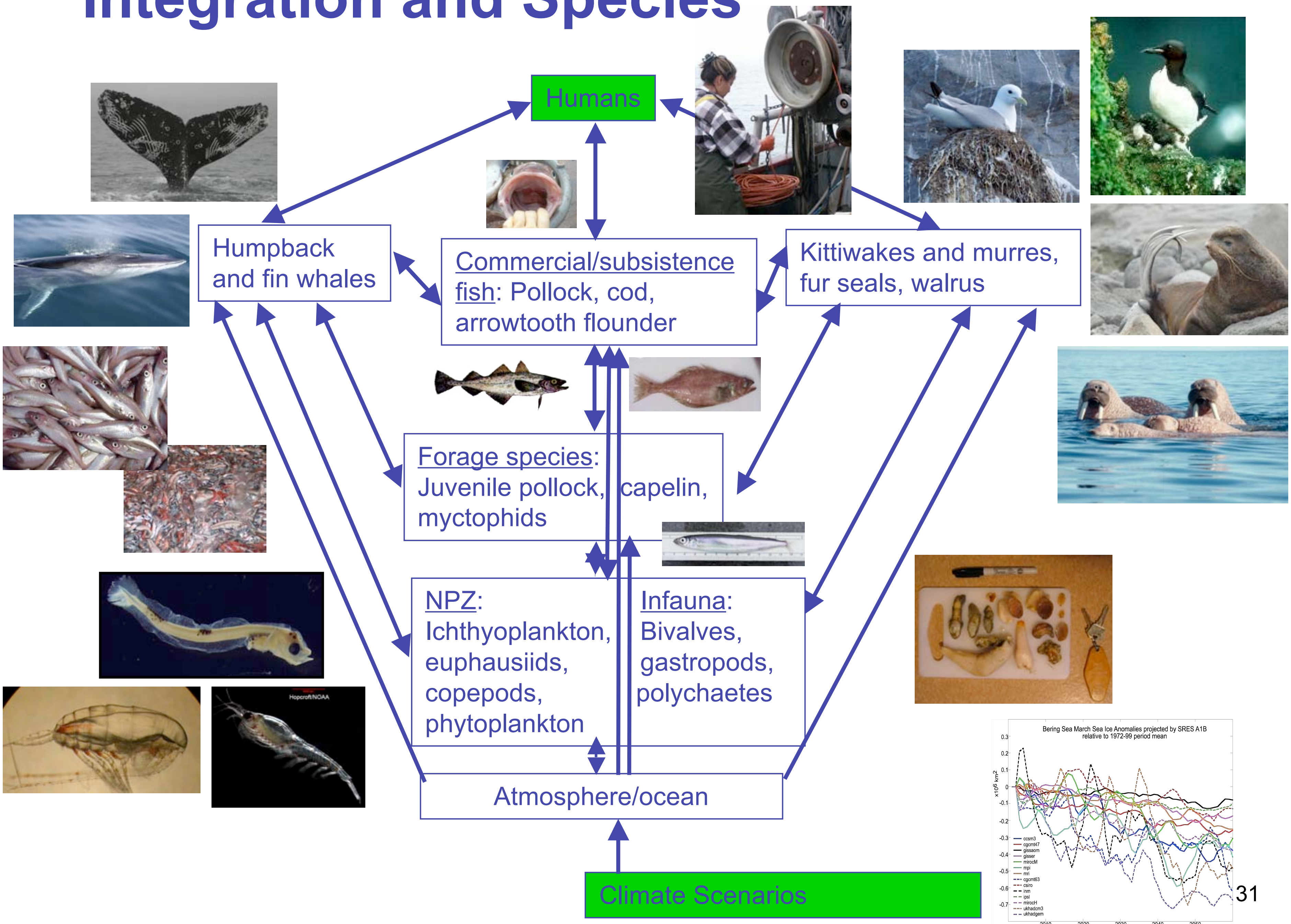
Management Strategy Evaluation: Climate Impacts on Productivity



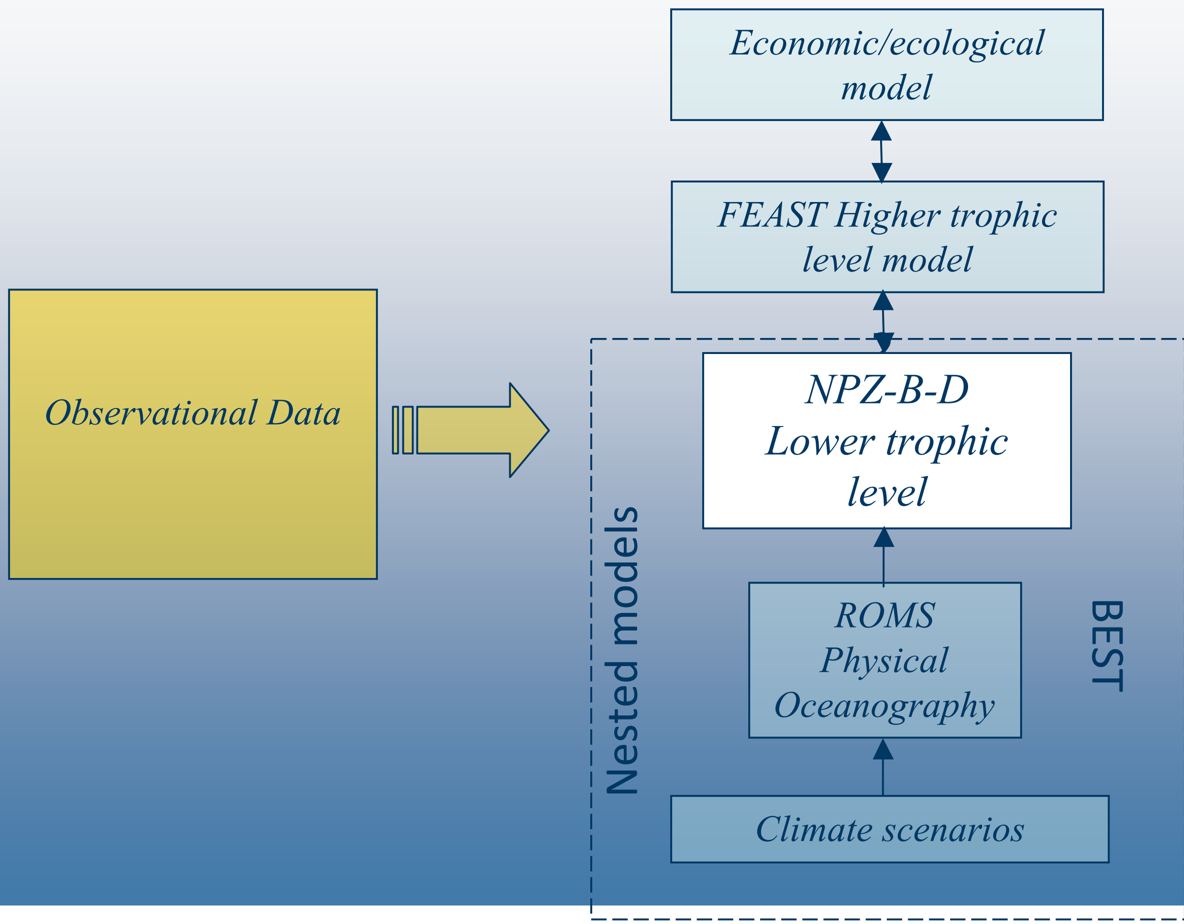


Operating model – “true” state
Biological System
Exploitation System
Observations
Implementation
Management strategy – perceived state
Stock assessment
Management actions
Performance measures

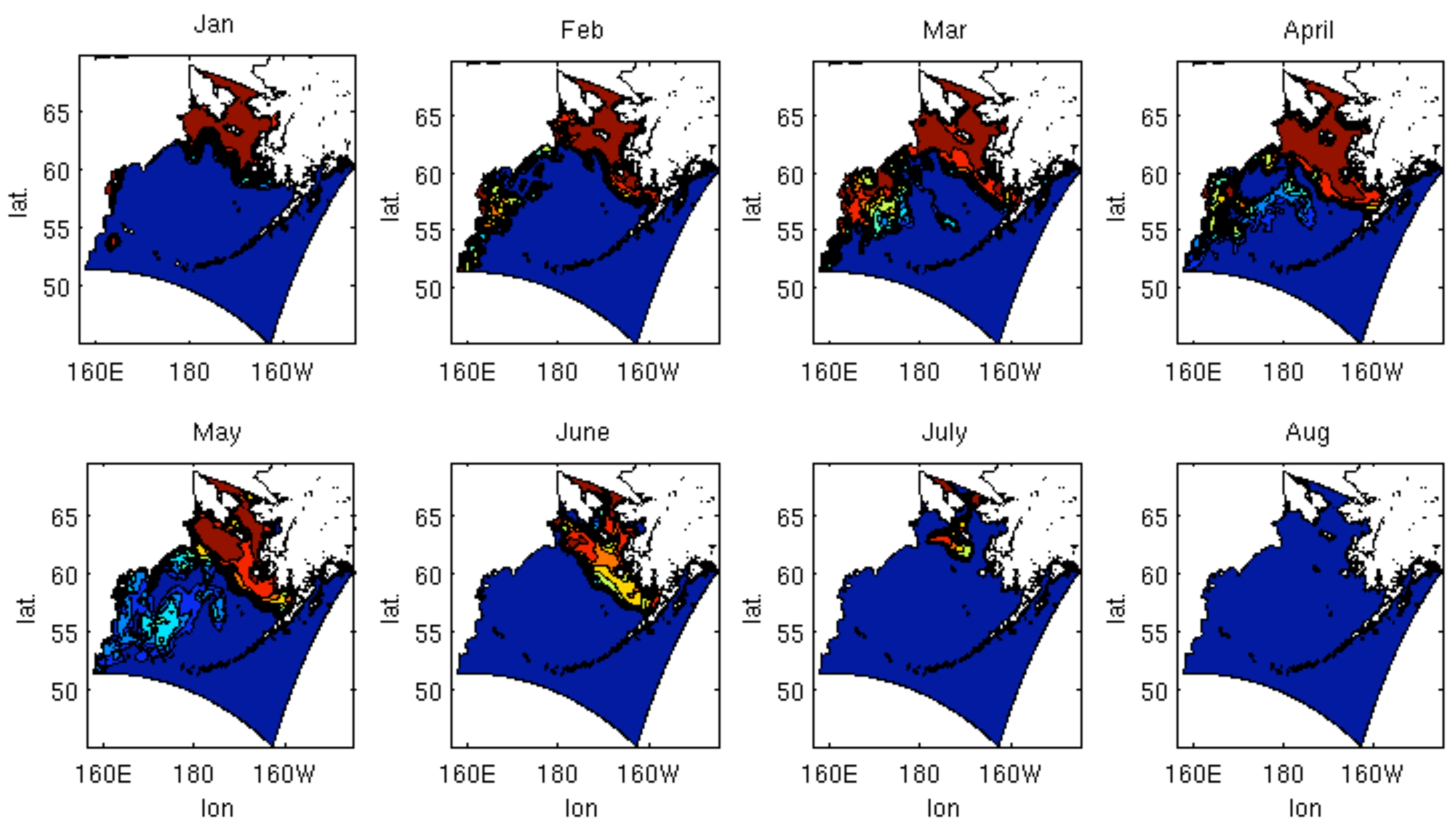
Integration and Species



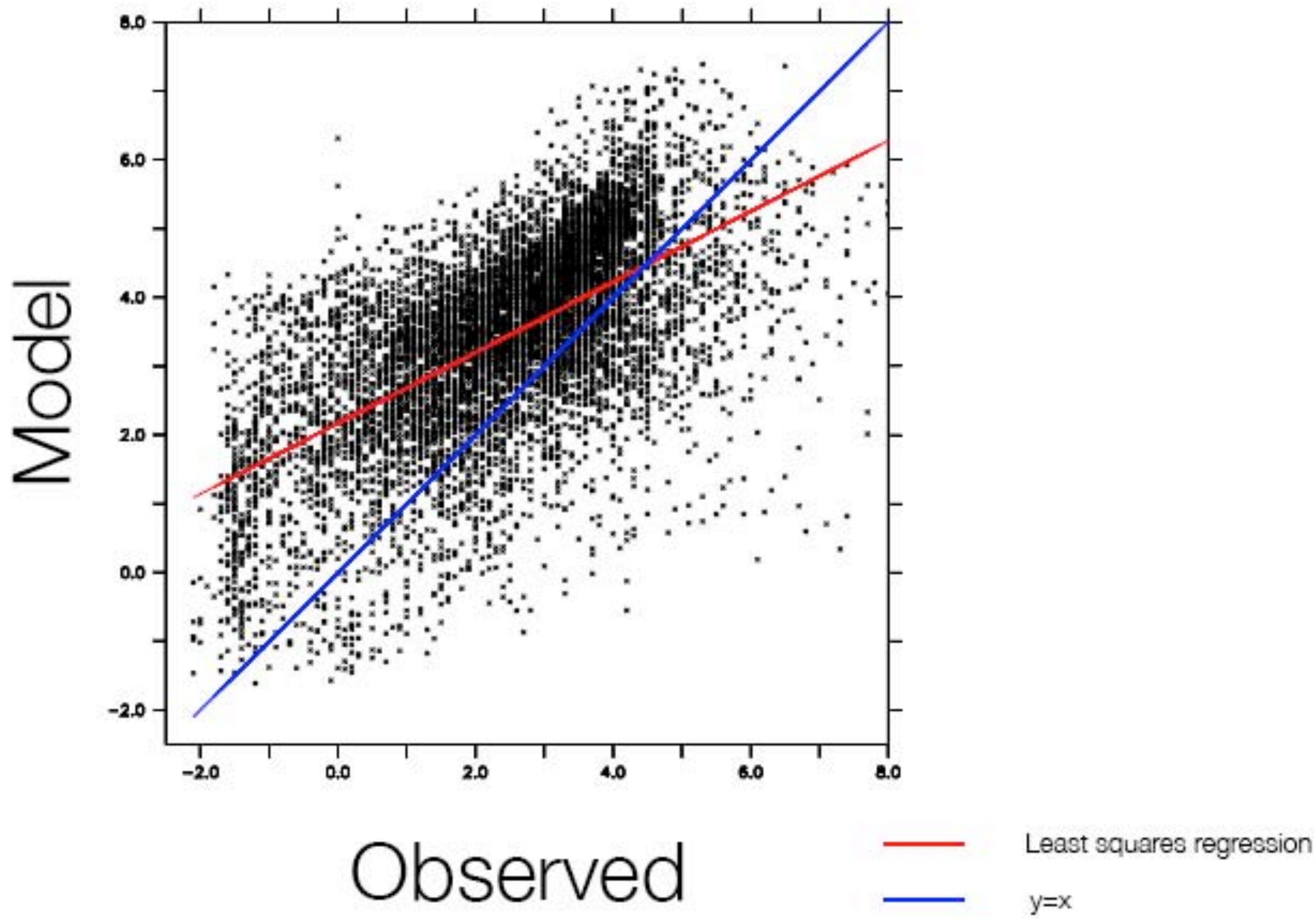
BSIERP **Integrated** modeling

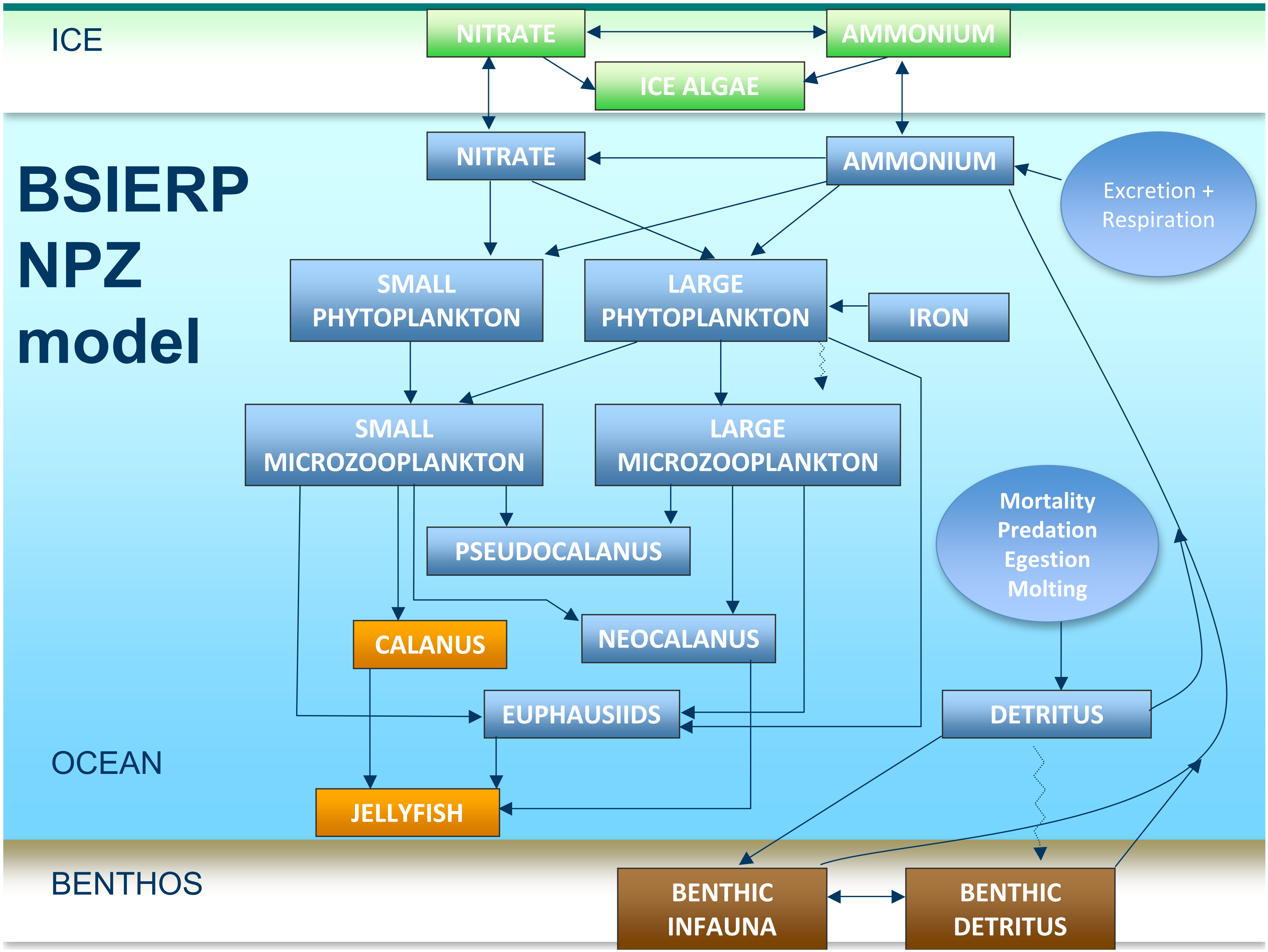


Modeled 1999 Ice Cover in the Bering Sea



Bottom temperatures





ICE
NITRATE
AMMONIUM
ICE ALGAE
BSIERP NPZ model
NITRATE
AMMONIUM
Excretion + Respiration
SMALL PHYTOPLANKTON
LARGE PHYTOPLANKTON
IRON
SMALL MICROZOOPLANKTON
LARGE MICROZOOPLANKTON
PSEUDOCALANUS
Mortality
Predation
Egestion
Molting
CALANUS
NEOCALANUS
EUPHAUSIIDS
DETRITUS
OCEAN
JELLYFISH
BENTHOS
BENTHIC INFAUNA
BENTHIC DETRITUS

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Summary

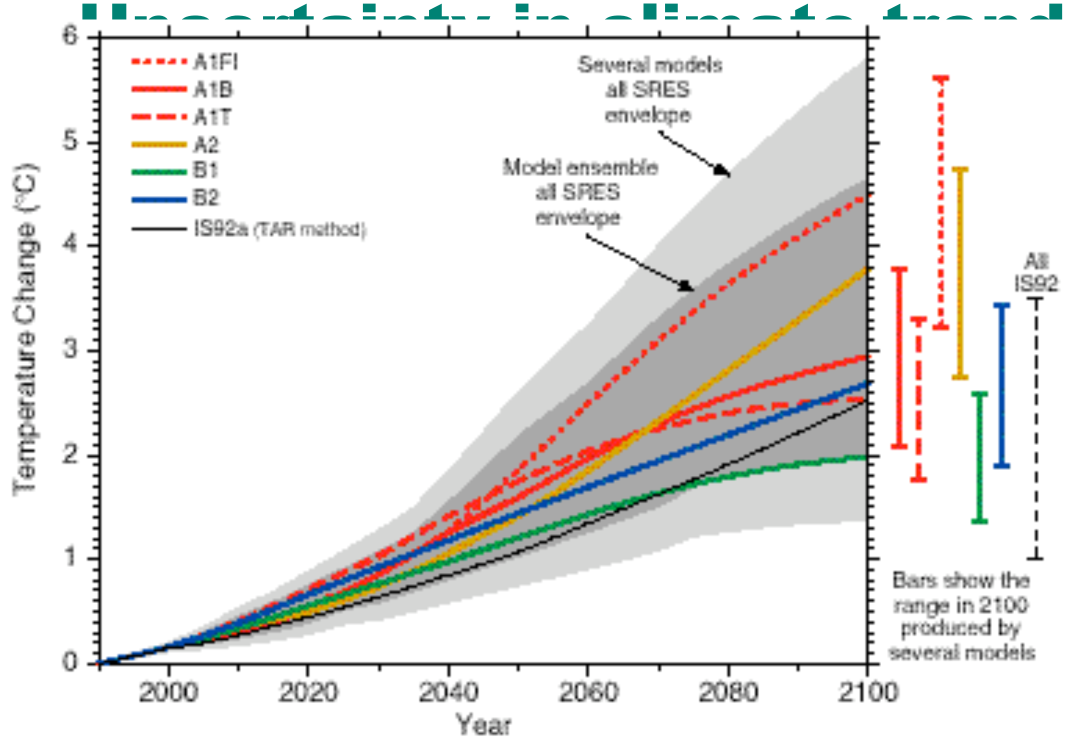
Short term 2009:

- Recruitment - mathematical representations of key processes incorporating ecosystem indicators.
- Incorporate expected demand and policy shifts.
- Observe and predict and assess skill.

Medium term 2012:

- Couple ocean circulation, prey production, fish production and predation with spatial and temporal feedbacks (BSIERP). Aydin and Bond et al.
- MSE A'mar (GOA pollock) Punt and Ianelli (BSAI pollock), rock sole (Wilderbuer), P. cod (A'mar and Thompson)

Uncertainty in climate trends



Two main sources of uncertain in future climate trends:
emissions future
climate sensitivity to a given change in emissions (geophysics)

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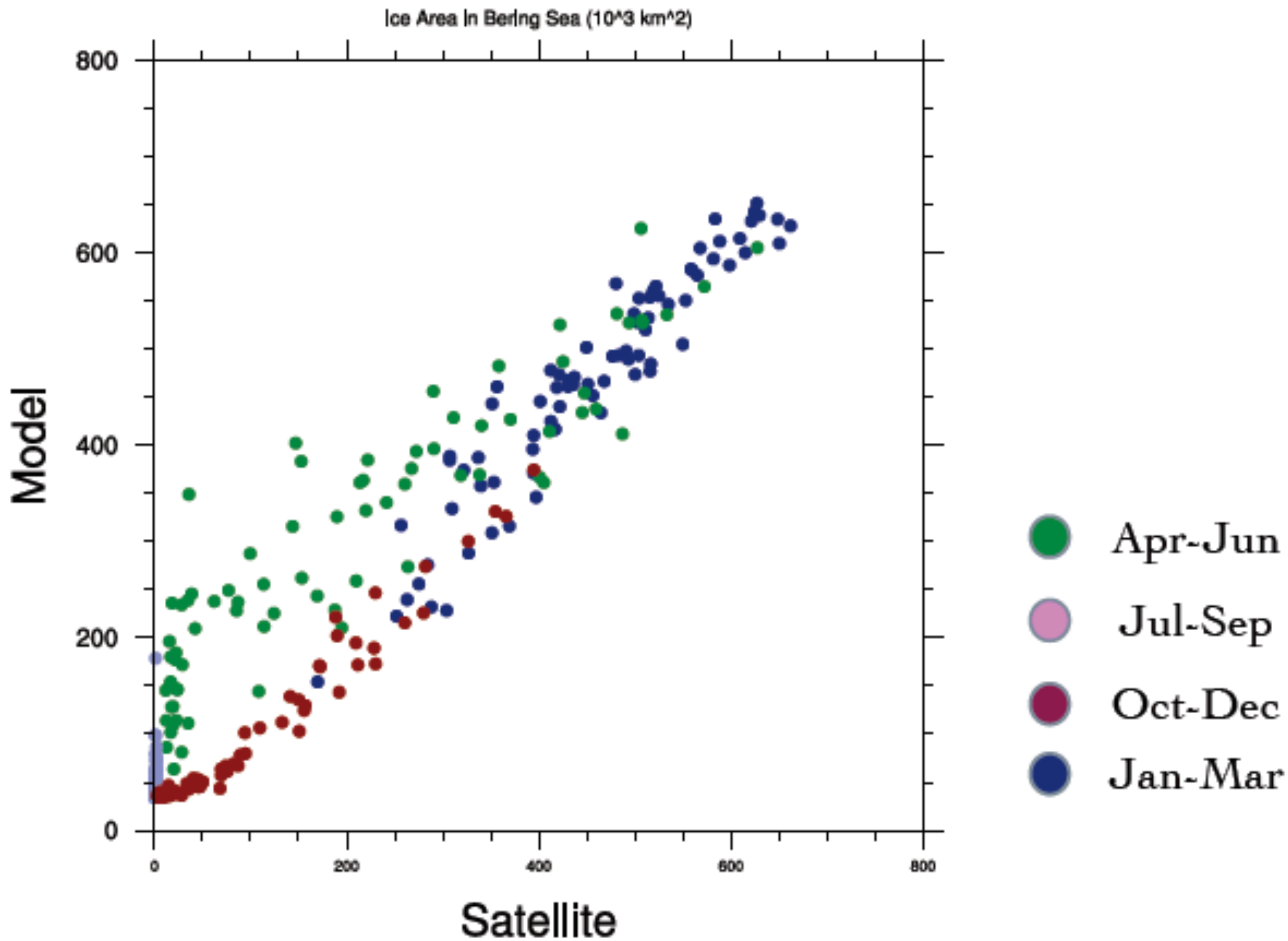
Seasonal sea ice extent



Empirical "Downscaling" Example: Summer Static Stability

- **Concept**
  - **Analysis of IPCC model projections in parallel with vertically-integrated model**
  - **Key parameter: Static stability - Sustained production**
- **Basis**
  - **Sea ice projections as proxy for summer bottom temps.**
  - **SLP patterns as proxy for wind mixing**
  - **Direct model forecasts for SST**
- **Result**
  - **Comparisons with ROMS/FEAST; uncertainty estimates**

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Zooplankton on the Bering Sea Shelf - Coyle et al. (2008)

Compared water properties and zooplankton abundance and community structure between a cold and warm year

	1999	2004	
Upper Temp	7.0	12.6	(deg. C)
Lower Temp	2.0	3.2	
Oithona	348	1633	(#/m3)
Pseudocalanus	404	1211	
Calanus	44	~0	
Thysanoessa	0.33	0.05	