The National Earth System Prediction Capability (National ESPC) Project

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National ESPC Overview

An interagency collaboration, initiated between Navy, Air Force and NOAA and expanded to DoE, NASA, and NSF in 2012, for coordination of research to operations of a National earth system analysis and prediction capability. The original project combined global weather models in an operational synoptic multi-model ensemble under NUOPC.

Seeks improved communication and synergy, for global prediction of weather, ocean, and sea ice conditions at weather to short-term climate variability timescales.

- Common prediction requirements and forecast model standards that enable agencies to improve leverage and collaboration.
- A national research agenda that will improve prediction across scales from days to decades.
- Cooperative focus projects to assess predictability of global scale high impact environmental conditions to inform S&T, R&D, and transition to operations.
- Towards an multi-model ensemble based air-sea-land coupled global prediction capability

The Navy Earth System Prediction Capability (Navy ESPC)

The Navy Earth System Prediction Capability (ESPC) program will provide a more **accurate, longer range, global** ocean and atmospheric forecast system for decision support to safety of flight, safety of navigation, sensor and weapon performance, and mission planning, mitigation and effectiveness decisions.

- Development of global coupled ensemble technologies will provide increased accuracy for **lead times of 1-30 days** as well as a **new capability** for accurate forecasts in the **Arctic** at all lead times and for **extended range outlooks** for probabilistic prediction globally.
- It will develop a Navy interface to NOAA products for seasonal to multi-annual lead times for operational and strategic planning through integrating atmosphere, ocean, ice, land and near-space forecast models into a seamless prediction system.
- This effort is the Navy contribution to a **National ESPC** for improved cross-Agency collaboration for Research to Operations, and the development of more efficient, accurate and scalable modeling systems for massively parallel new computational architectures to allow for improved real-time operational prediction across timescales.

Navy Arctic Roadmap

United States Navy Leadership Role and Missions in the Arctic Region

The Navy will continue to have a significant leadership role in the Arctic Region to enable the joint and interagency community to operate in this hard-to-reach, isolated, and harsh environment. Through its global reach capability and worldwide command and control, Navy leadership will support joint and interagency efforts, enhance information sharing, and develop enterprise solutions that can be employed across United States Government and allied partner agencies operating in the Region.

Additionally, Navy has Title 10 responsibilities to "maximize the safety and effectiveness of maritime vessels, aircraft, and forces of the armed forces" by means of marine data collection, numerical weather and ocean prediction, and forecasting of hazardous weather and ocean conditions.

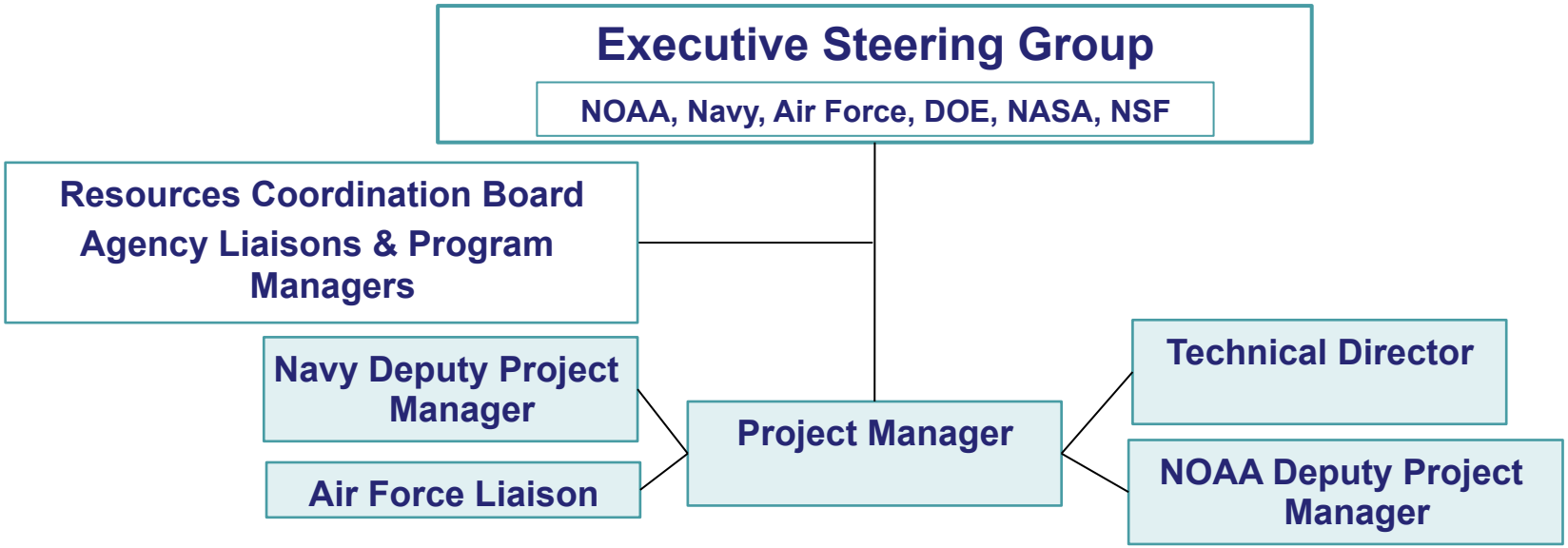
Navy Arctic Roadmap Implementation Plan

- Sustain development and participation in Earth System Prediction Capability (ESPC): Develop the capability for coupled ocean-atmosphere-land-cryosphere modeling in the Navy to support strategic decisions related to operations, platforms and facilities.
- Develop and execute a CONOPS for Arctic environmental Observer/ Forecaster (Sea Ice, Ocean and Atmospheric) support to Navy platforms operating in the Arctic that includes organizational structure and location.
- Support efforts to research, develop, resource and sustain an Arctic environmental observation and prediction system to support U.S. operations (Surface, Subsurface, HA/DR, SAR, and Air) in the Arctic as part of an interagency effort.

Need: Seamless Full Earth System

Partnerships:
NOPP
HFIP
NMME
USGCRP
USCLIVAR
NUOPC
Community Models

National ESPC Management Structure



Committees

Unified Ensemble Operations

Integrated Modeling Systems

- Common Global Model Metrics

Common Model Architecture

- Content Standards Committee
- Physics Interoperability

Focus Areas

Mid-Latitude Blocking

Seasonal Arctic Sea Ice

Seasonal Tropical Cyclone Track and Frequency

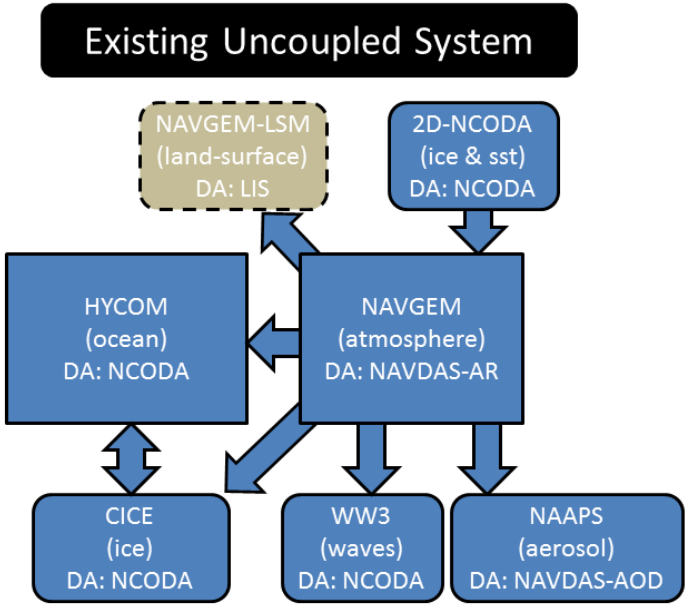
Coastal Harmful Algal Blooms/Hypoxia (HABS)

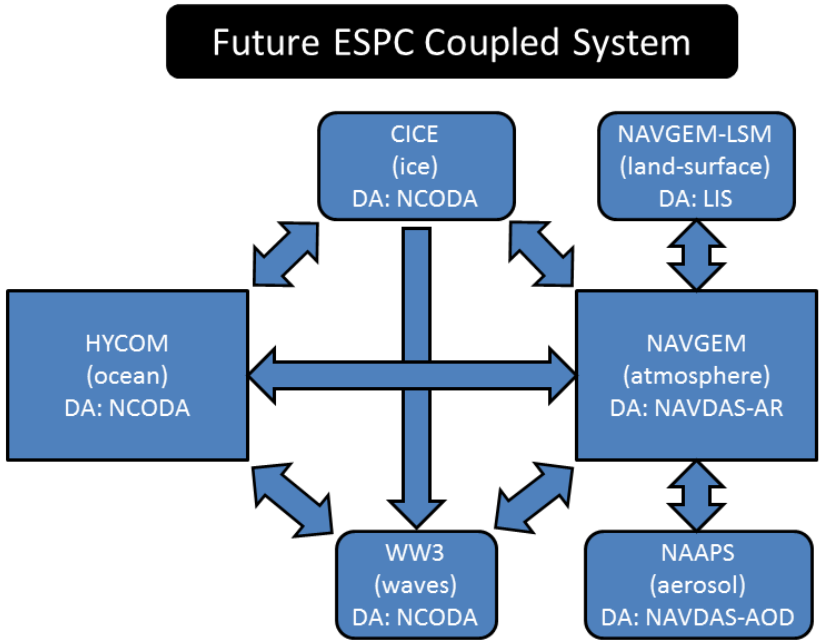
Atlantic Meridional Overturning Circulation (AMOC)

Navy ESPC Highlights - Infrastructure

Design infrastructure for operational implementation for coupled system

- Define implementation across operational systems, architecture requirements, cycling setup including DA





•"Operational Implementation Design" has details on data volumes, resources required, and operational job distributions

• Naval Research Laboratory Memorandum Report 7320--14-9498 http://www7320.nrlssc.navy.mil/pubs.php search under author Metzger, 2014.

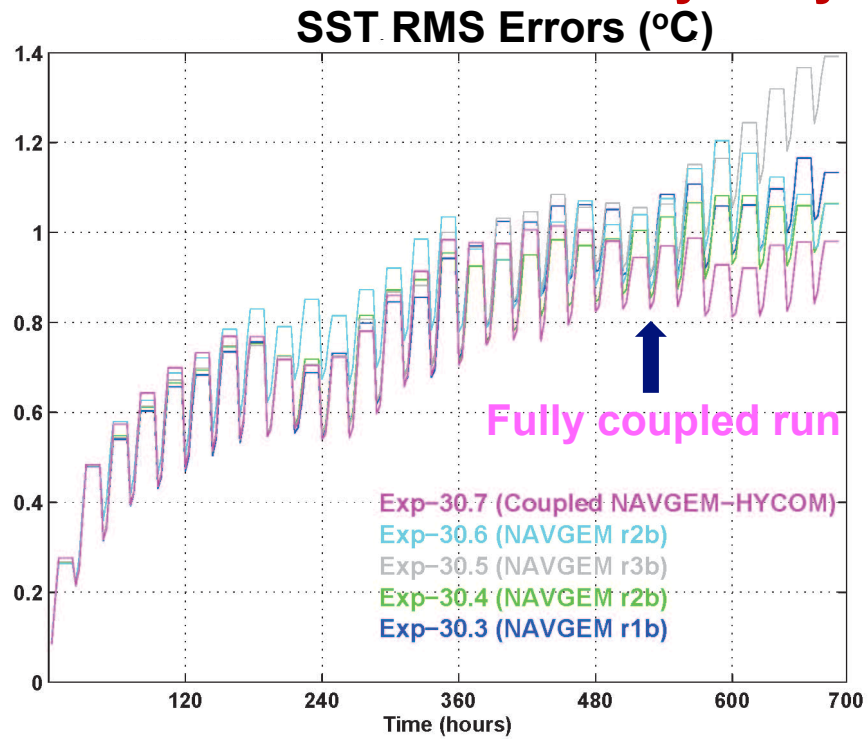
Navy ESPC
Operational Implementation Design

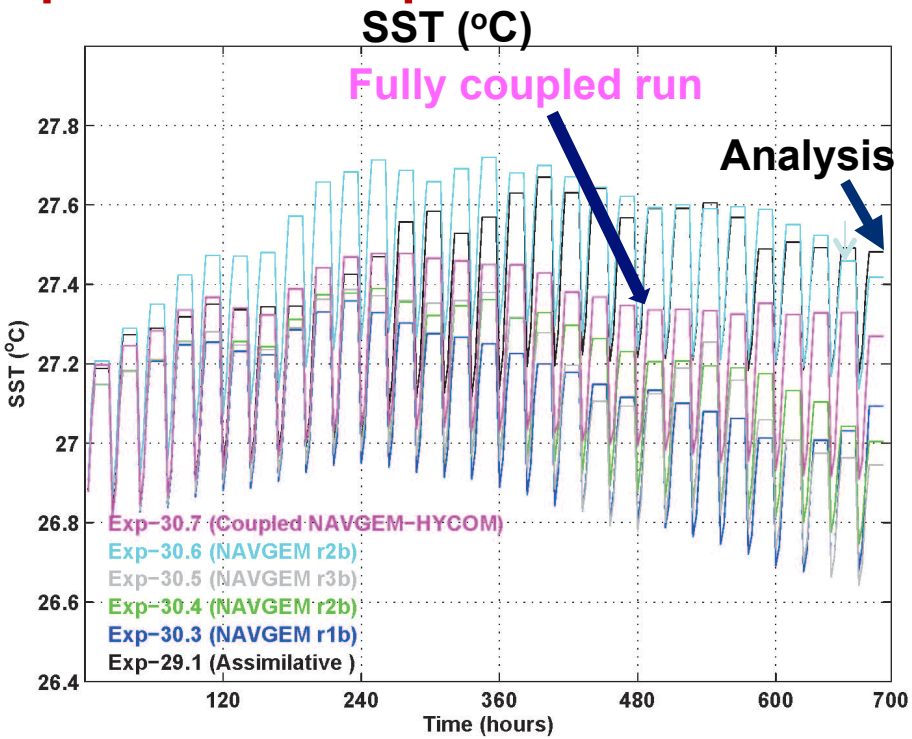
Projected horizontal and vertical resolutions of the individual ESPC system components at NCR-1 (IOC) in 2018.

Forecast	Time Scale, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE	Waves WW3	Land-Surface NAVGEM-LSM	Aerosol NAAPS
Deterministic short term	0-10 days, daily	20 km 80 levels (T639L80)	1/25° (4.5 km) 41 layers	1/25° (4.5 km)	1/8° (14 km)	3/16° (21 km)	3/16° (21 km)
Deterministic long term	0-30 days, weekly	20 km 80 levels (T639L80)	1/12° (9 km) 41 layers	1/12° (9 km)	1/4° (28 km)	3/16° (21 km)	3/16° (21 km)
Probabilistic long term	0-90 days, weekly	37 km 50 levels (T359L50)	1/12° (9 km) 41 layers	1/12° (9 km)	1/4° (28 km)	1/3° (37 km)	1/3° (37 km)

NAVGEM / HYCOM COUPLED PHYSICS
Progress – Coupled System Diagnostics

HYCOM Loosely/Fully Coupled Run Comparison





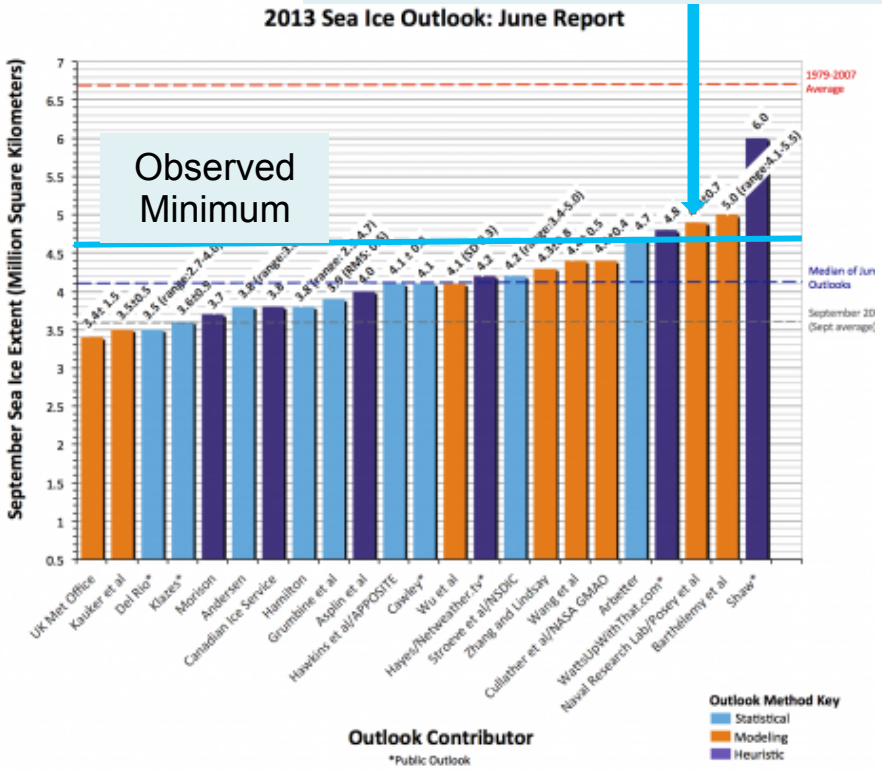
Plots show SST rms and bias errors for a NAVGEM/HYCOM coupled run and a sequence of loosely coupled runs for November 2011. The coupled run and the loosely coupled runs all use NAVGEM 1.1 and the new 41-layer HYCOM. The coupled run has a smaller bias and lowest forecast error than the loosely coupled runs. Coupling eliminates most of the cold bias found in the loosely coupled runs.

HYCOM-CICE Coupling

First US Navy long term seasonal forecasts of sea ice

- NRL participated in the Study of Environmental Arctic Change (SEARCH) Sea Ice Outlook 2013 estimating the Sept Arctic sea ice extent minimum.
- The Navy's Arctic Cap Nowcast/Forecast System (ACNFS) – HYCOM/CICE with prescribed atmosphere was used
- Integrated ACNFS through summer in ensemble mode using NOGAPS atmospheric forcing (2005-2012), eight independent runs each initialized from 01 May 2013 conditions
- Plan to augment this with coupled air/ ocean/ice configuration

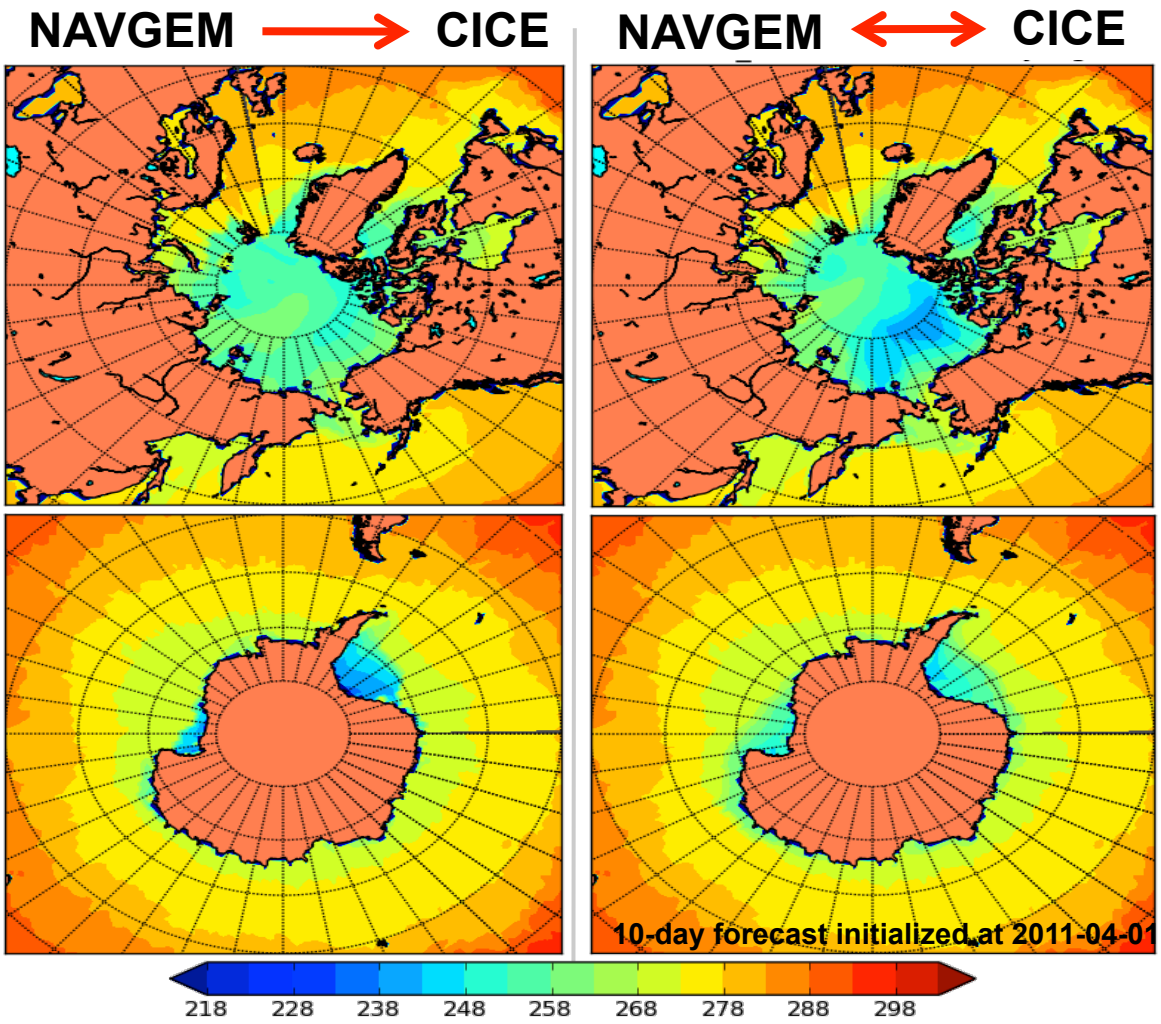
NRL Seasonal Prediction



Sept 2013 minimum extent
Observed– 4.81 Mkm^2
ACNFS estimate – 4.9 Mkm^2

Atmosphere & Sea-Ice Coupling

Sea Ice/Ground Temperature (K)



Allowing inter-model feedbacks as part of a two-way coupled system produces a **realistic forecast**, which permits use for further investigation into specific model biases and important coupling mechanisms.

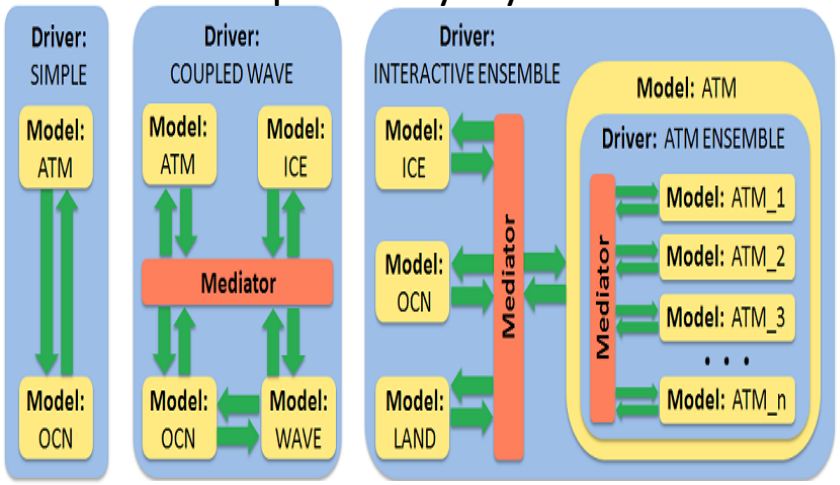
Earth System Prediction Suite (ESPS) Common Model Architecture

ESPS is a collection of Earth system component models and interfaces that are interoperable, documented, and available for community use. ESPS is intended to

- formalize code preparation for cross-agency use
- simplify "toolkit" code selection for the broader research community
- focus on coupled modeling systems
- leverage legacy investments from NASA, NOAA, NSF, DOE, and Navy
- bridge climate (CESM) and weather (ESMF) scales through software convergence
- establish "plug-and-play" implementation via the NUOPC interoperability layer.

ESPS codes:

- are NUOPC-compliant
- include model documentation
- have clear terms of use
- include compliance checking and tests for correct operation across the development community.

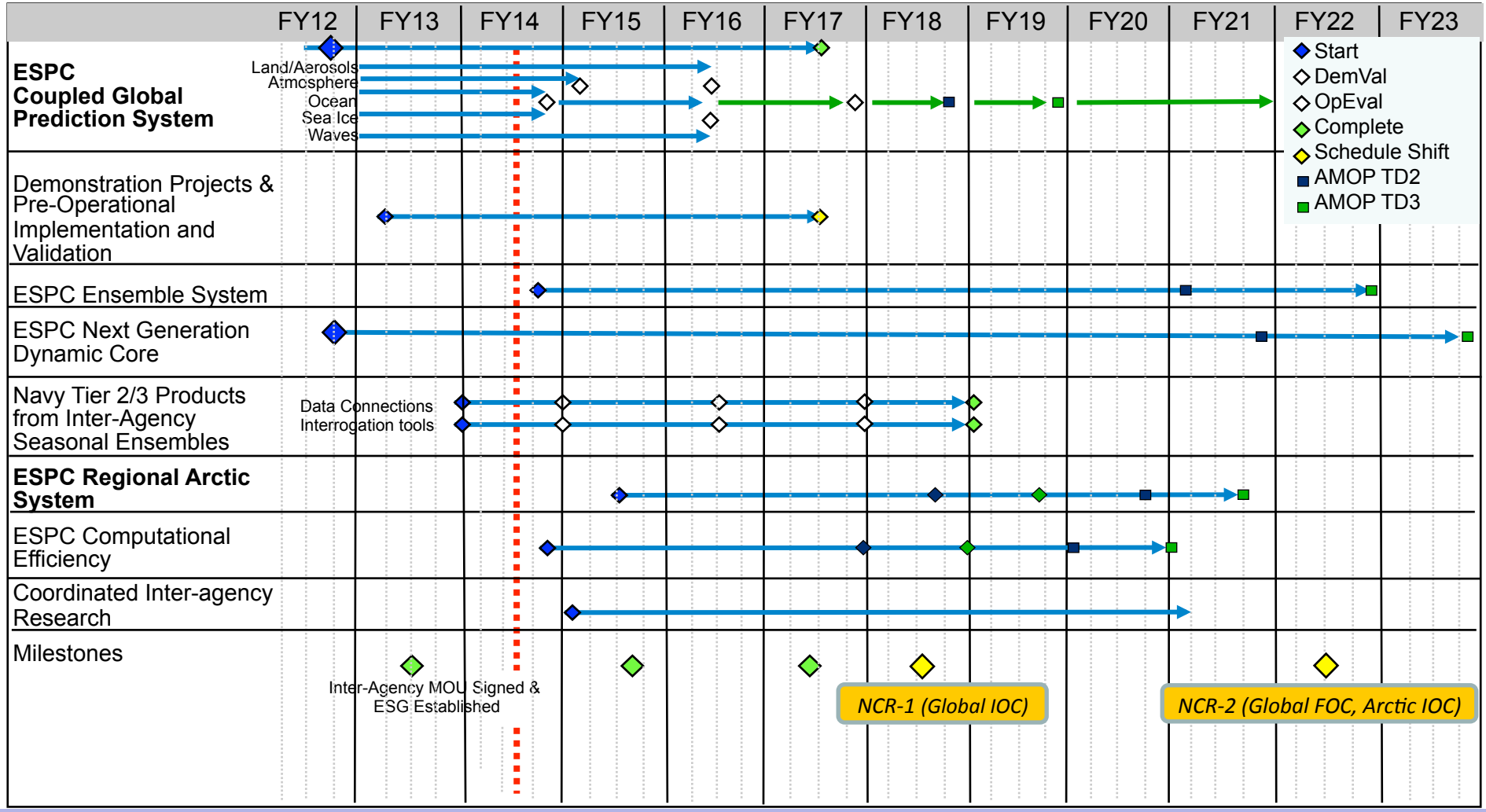


a.

http://www.earthsystemcog.org/

Deluca2013

Navy ESPC Global Coupled Prediction System Development



DRAFT
Interagency National ESPC Fielding Plan (2018)

National Global Prediction Needs

Boundary conditions for TC Track & Intensity, TC genesis, Hi Res Littoral air/ocean operations, EM/EO/NBC prediction Drought/Flood, Heat Wave/Freeze Prediction, Storm Surge/ Inundation/Erosion, Beach Warnings, Safety/Emergency/Public Health Operations, Ship & Aircraft Routing . . .

Strategic Planning, Environmental Stress Instability, Arctic Sea Lanes, Ship and Land Transportation Infrastructure Management, Agriculture/Fisheries Planning & Ecosystem Management, Water Resource Management, Energy Sector Planning . . .

Navy and DoD Capability

TC-COAMPS Others

NAVGEM/HYCOM/CICE/WW-3 NAVGEM Ensemble NUOPC/NAEFS Ensemble

DOD Applications of NOAA managed Seasonal Ensemble Prediction

Static Climatology/ Reanalysis based on past environment "Climatology Products"

HFIP Ensemble

NUOPC Ensemble

NOAA Capability

HWRF GFDL GFS

GFS, HYCOM, WW-3 GEFS Ensemble Multi-Model Ensemble

Climate Fcst System (CFSv2/3) National Multi-Model Ensemble (NMME)

CFS-R, HURDAT, etc.

Navy Arctic Guidance

National Security Presidential Directive 66 (2009)

- USN "Arctic Roadmap" (2009, 2014)
- N2N6E Arctic Capability Based Assessments (2010, 2011)
- Interagency Arctic Research Policy Committee (IARPC) Arctic Research Plan (2013)
- Department of Defense Arctic Strategy (2013)
- US National Strategy for the Arctic Region (2013) and Implementation Plan (2014)

Navy's Strategic Objectives for the Arctic Region

From 2014 USN Arctic Roadmap

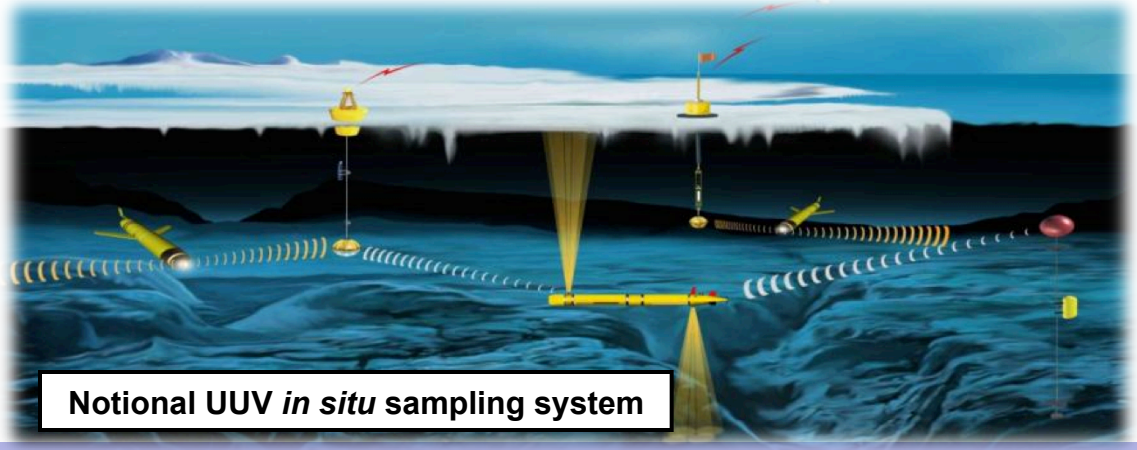
- Ensure U.S. Arctic sovereignty and provide homeland defense
- Provide ready naval forces to respond to crises and contingencies
- Preserve freedom of the seas
- Promote partnerships within the U.S. Government and international allies

ONR Arctic Research Program

MAJOR THRUSTS:

1. Generation of **new observing technologies and methods** (platforms, sensors, communications) that will enable persistent observational capabilities in the Arctic
2. **Improved basic physical understanding** of the Arctic environment and the important coupled processes that drive evolution and predictability in the Arctic region
3. Development of **fully-integrated Arctic System Models** incorporating the ocean, sea ice, waves and atmosphere for **improved prediction at longer lead times**, including the use of satellite SAR data for assimilation into integrated models

SAR Sea Ice Imagery



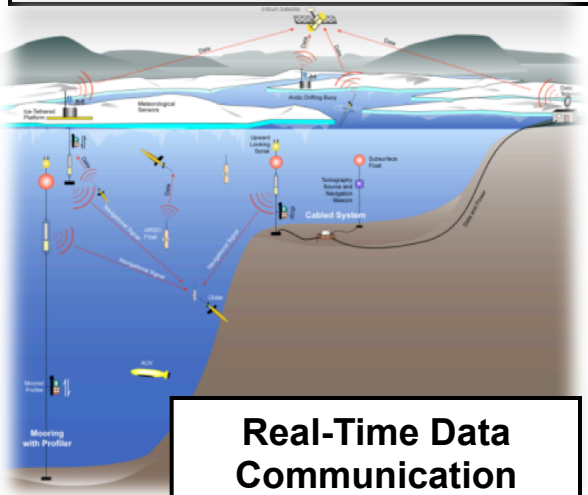
Notional UUV *in situ* sampling system

Advances in technology will be required to enable an interagency Arctic Observing Network that will support scientific exploration and be able to initialize predictive models of the environment

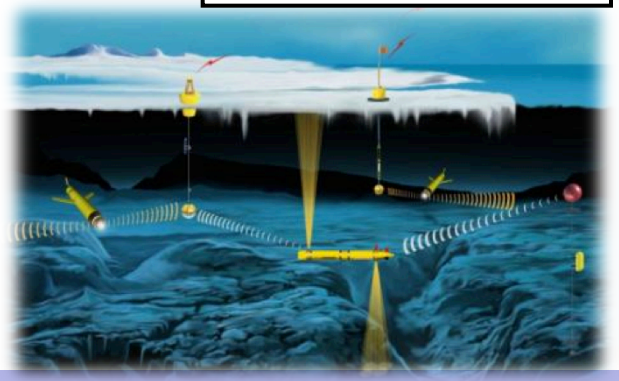
Thrust 1: Technology Development

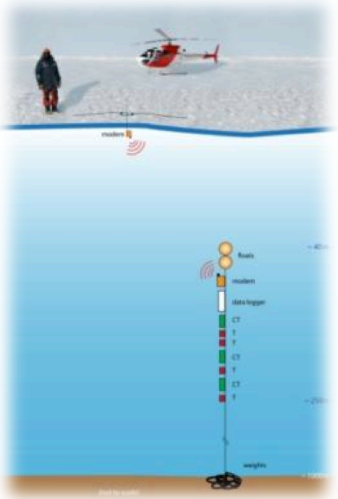
A sensing system must be developed to provide persistent observations that can further scientific understanding, provide long-term monitoring, and constrain the predictive models.

Autonomous platforms – Robust Sensors – Real-time Data Delivery – Key Environmental Variables

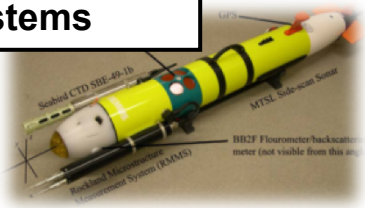


Real-Time Data Communication

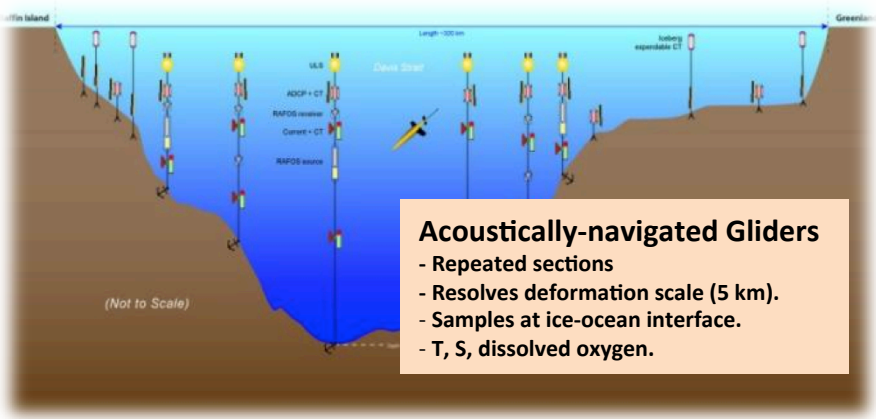




Novel Sensing Systems



Autonomous Platforms and Enabling Technologies

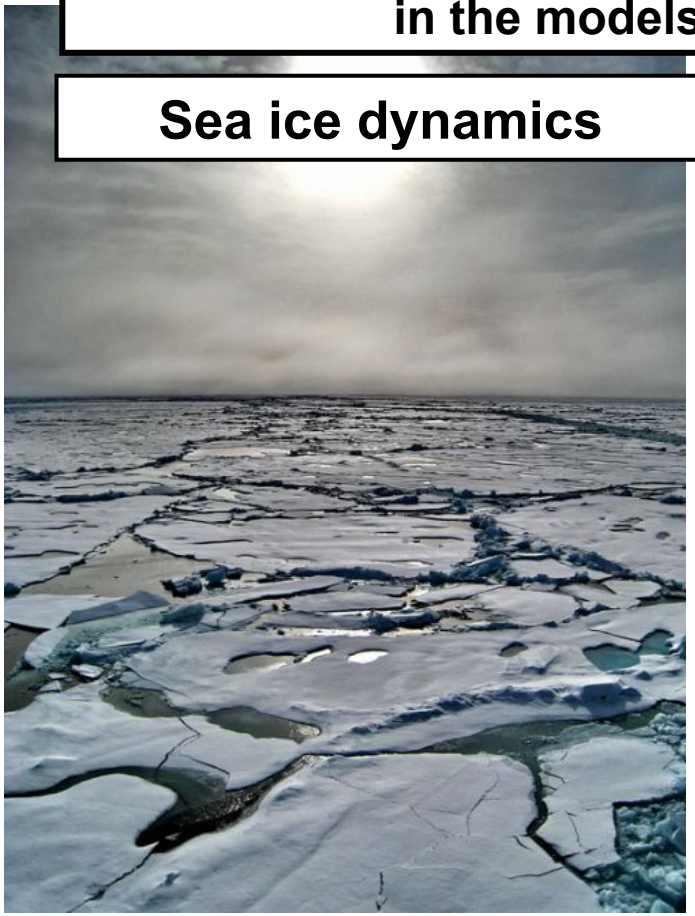


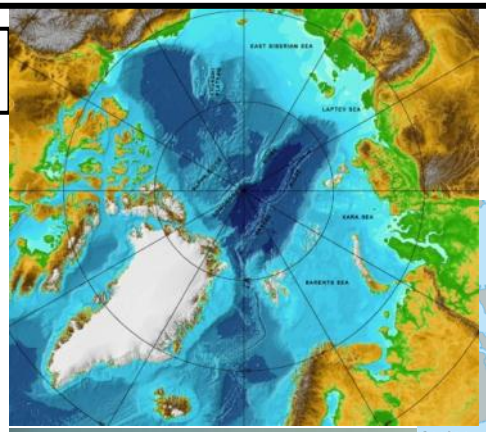
Acoustically-navigated Gliders
- Repeated sections
- Resolves deformation scale (5 km).
- Samples at ice-ocean interface.
- T, S, dissolved oxygen.

Thrust 2: Improved Physical Understanding

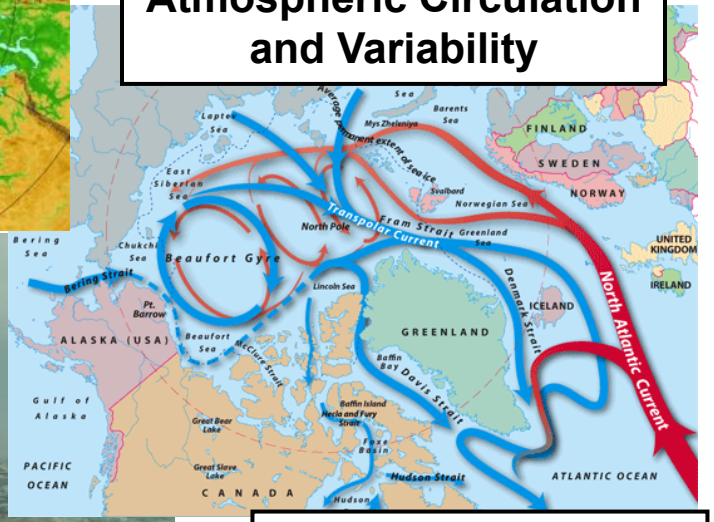
A better understanding of the integrated physics and dynamics in the "new" Arctic will enable more accurate representation of these processes in the models, leading to improved predictions

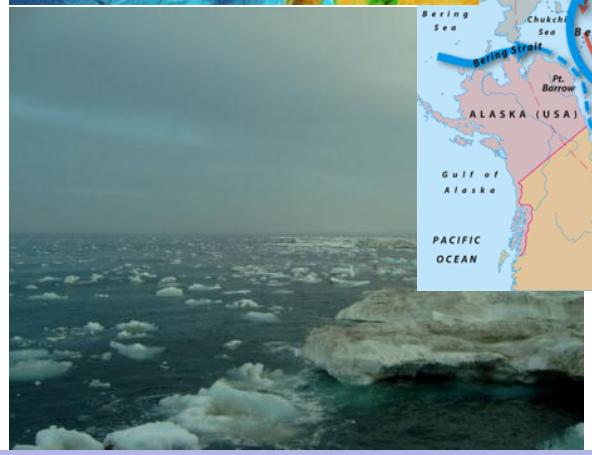
Sea ice dynamics





Changes in Oceanic and Atmospheric Circulation and Variability

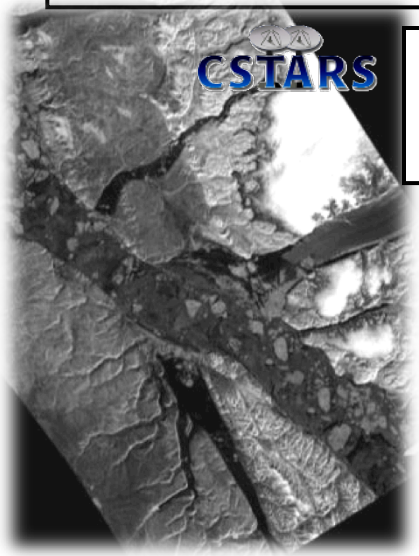




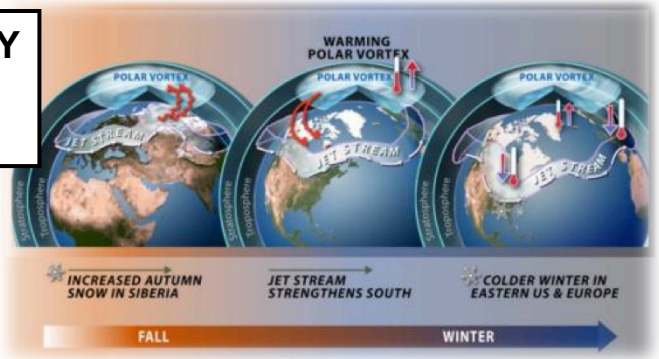
Changes in the Acoustic Structure of the Arctic Ocean

Thrust 3: Integrated Arctic Prediction

Fully-coupled ocean-wave-ice-atmosphere models with sufficient resolution to represent the relevant processes, and that assimilate in situ and remotely-sensed observations to create useful predictions of the operational Arctic environment at a wide range of lead times

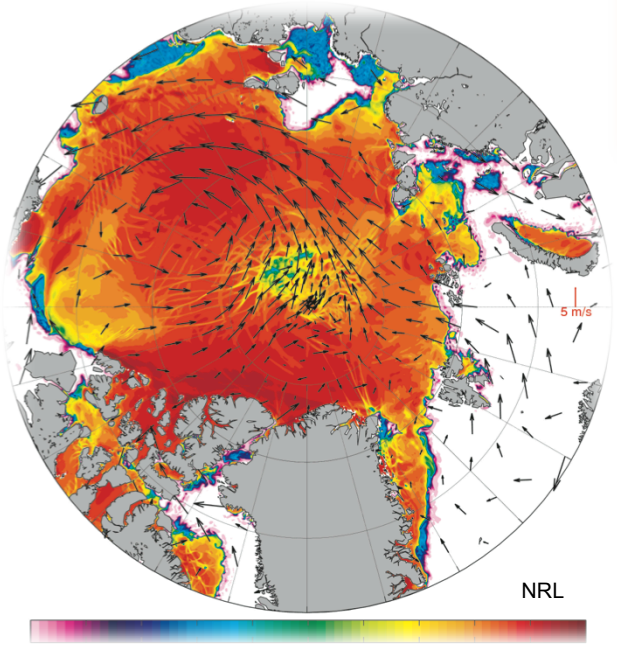


EARTH SYSTEM PREDICTION CAPABILITY
Integrated Arctic System Models
ocean – ice – wave – atmosphere

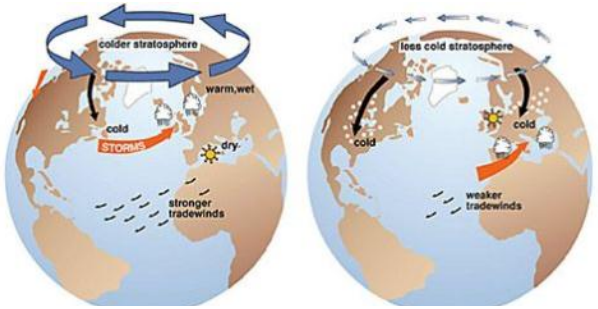


Advanced Data Assimilation

Ice thickness measured from below

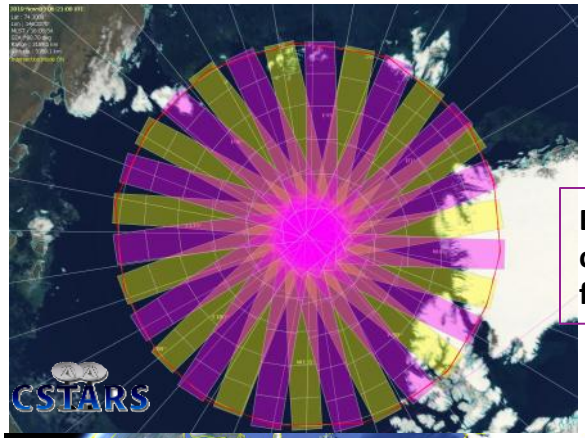


Coupling with Global Earth System Models

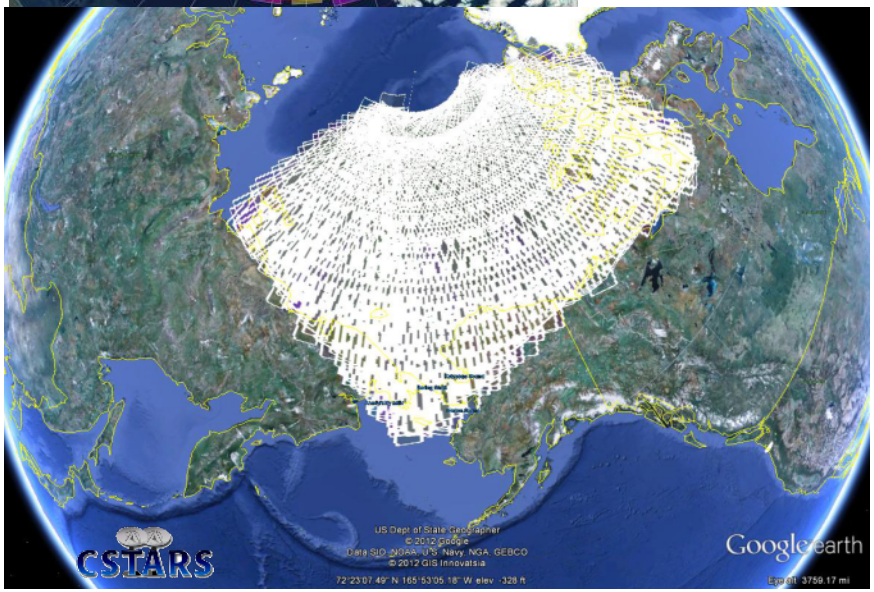


J. Wallace, University of Washington

Arctic Coverage Using Commercial SAR



Example of daily coverage available from COSMO-SkyMed



Merging of data from multiple commercial platforms can provide daily coverage of the Arctic at high spatial resolution.

Images will be analyzed for:

- Daily global Arctic mosaic map
- Daily/weekly rate of melting or freezing
- Iceberg and glacier monitoring
- Monitoring of Northwest Passage
- Glacial and ice movements (hourly, daily, weekly, monthly speed and direction)

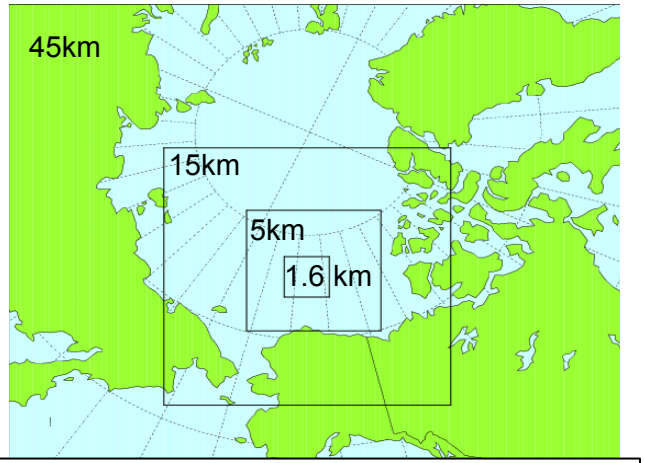
Algorithm development is ongoing for joint analysis of multiple platforms and sensor types.

Data collections focus on the Bering Strait and the Beaufort/Chukchi Sea areas in support of field efforts in 2014 and 2015.

Cooperative Model Development

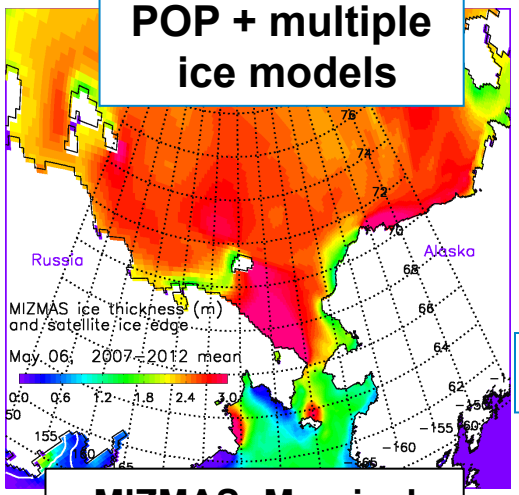
ONR is working the Arctic prediction problem on a variety of space and time scales, with NRL expertise and investment in model development with the academic performer community, including NPS, UW/APL and many others

NCOM-COAMPS-CICE-WW3



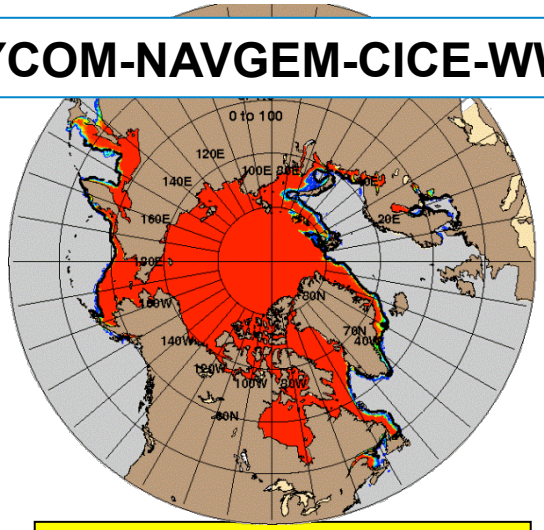
Future Regional Arctic System (RAS)
Flexible Coupled Relocatable Model Domain

POP + multiple ice models



MIZMAS: Marginal Ice Zone Modeling and Assimilation system (UW/APL)

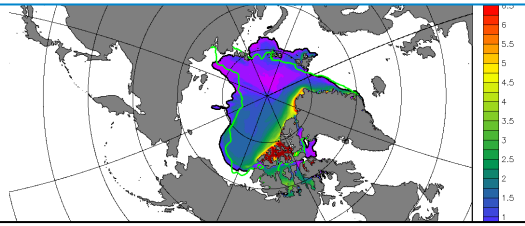
HYCOM-NAVGEM-CICE-WW3



Model grid resolution ~ 3.5 km

Black line is the independent ice edge location (NIC)

POP-Polar WRF-CICE

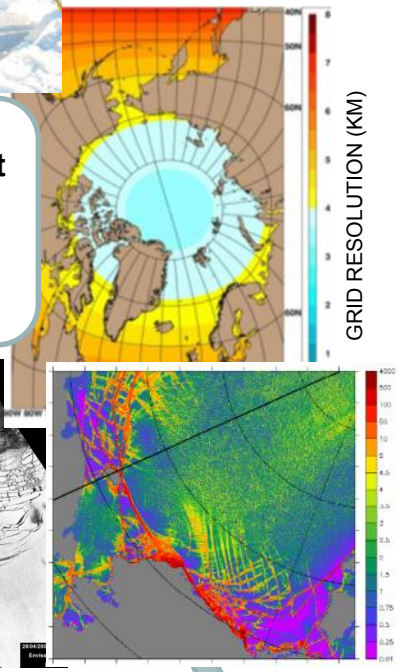


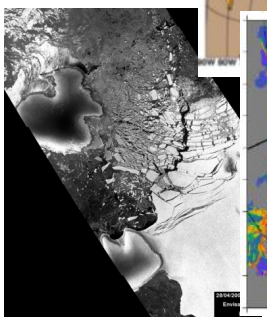
RASM: Regional Arctic System Model (NPS)

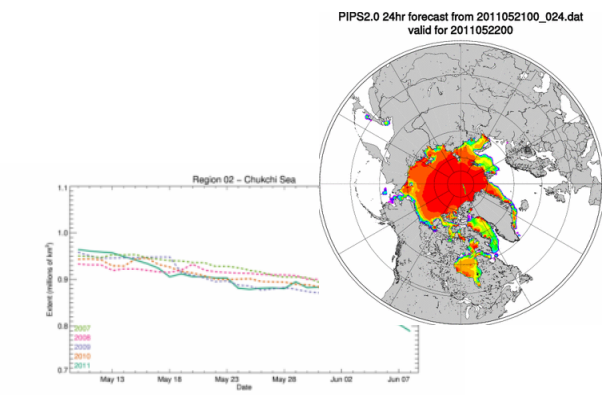
Development and Transition

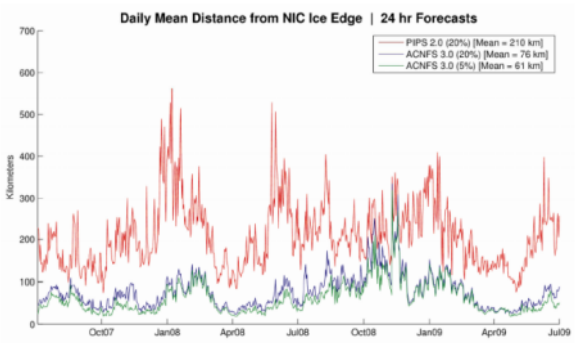
Fieldwork to better understand key physical processes

Improved physics built into data-assimilating integrated models









NAVAL METEOROLOGY AND OCEANOGRAPHY COMMAND

NATIONAL ICE CENTER
WASHINGTON D.C.

Arctic Prediction System Development

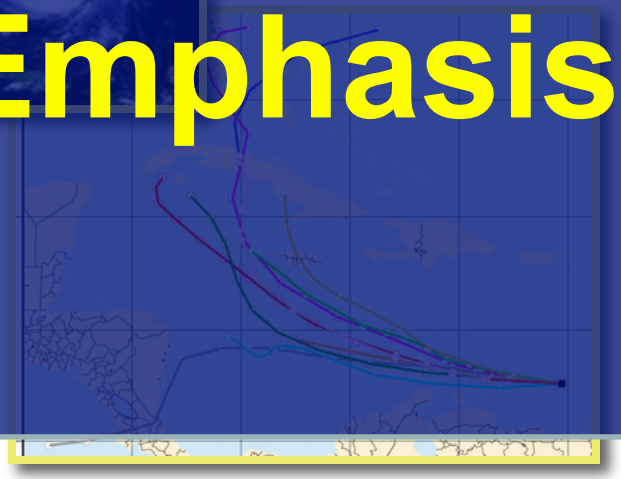
Validation and Verification

Transition to Operational Use

Backup

Challenges to Achieve a Weather-Ready Nation

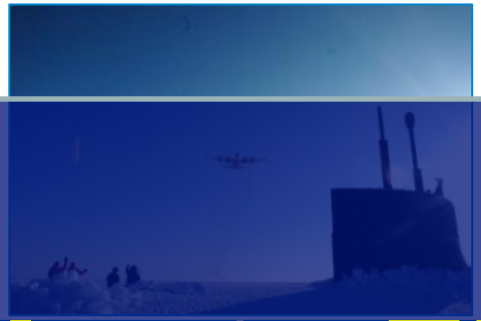
- Hail, Tornadoes, Tropical Storms & Hurricanes
- Winter Storms, Ice
- Extreme Heat and Cold
- Droughts and Floods
- Climate Adaptation
- Sea Level Rise
- Commerce and Navigation
- Aviation Transportation
- Food Security
- Air and Water Quality
- Ecosystem Health
- Private Sector and National Security



Home Field Emphasis

National Weather Enterprise
Public Safety and Economic Well-being of Nation
Public-Private Partnership

Defense Department Challenges – A Global Force for Good



Home Field Advantage ... at the Away Games

We provide worldwide forecasts to support DoD Operations – from the tropics to the poles, and from the depths of the ocean to the edges of space, across the coast to support stability operations, humanitarian assistance and disaster relief.

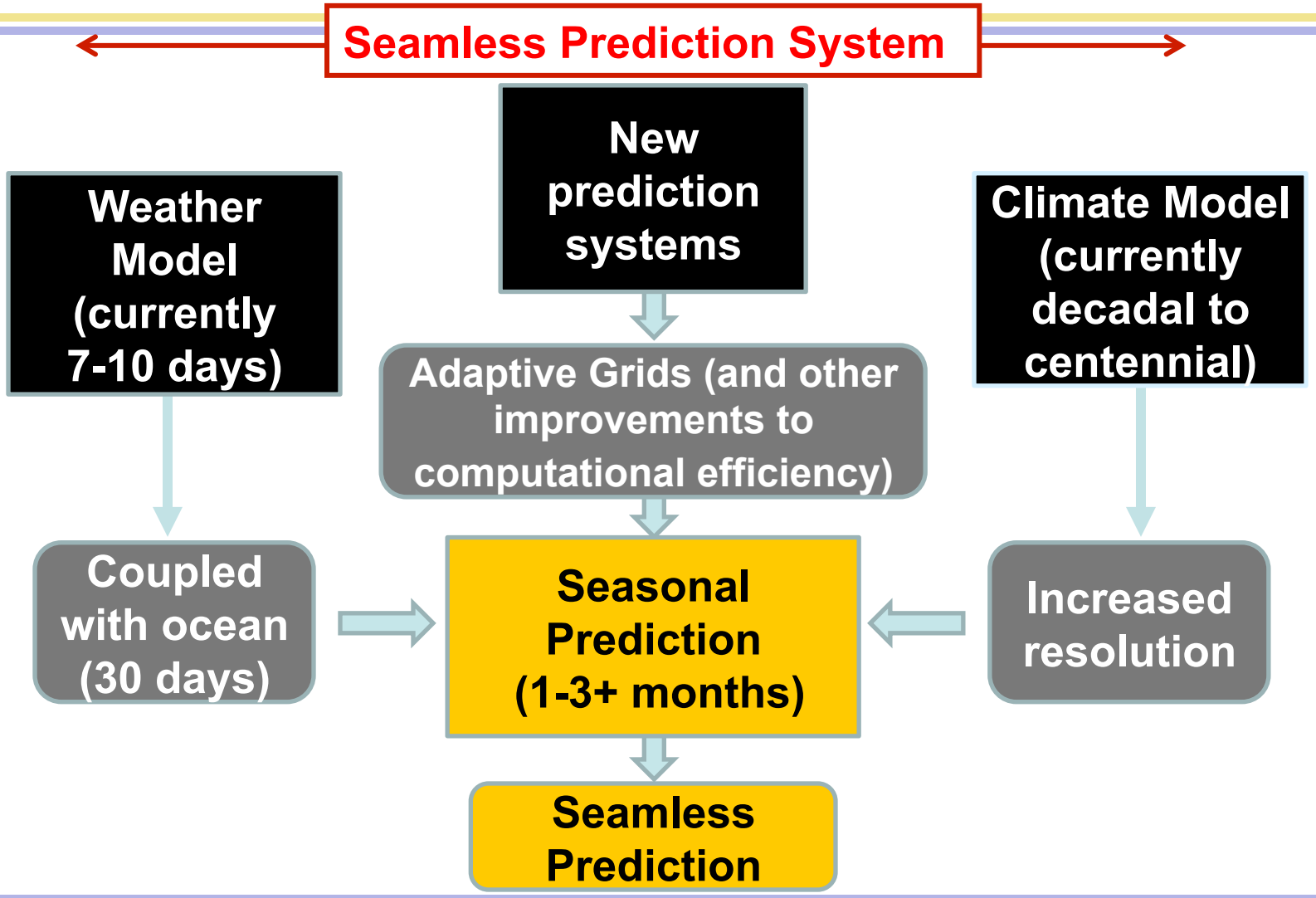
National ESPC Goals

Build the next generation operational national environmental prediction system:

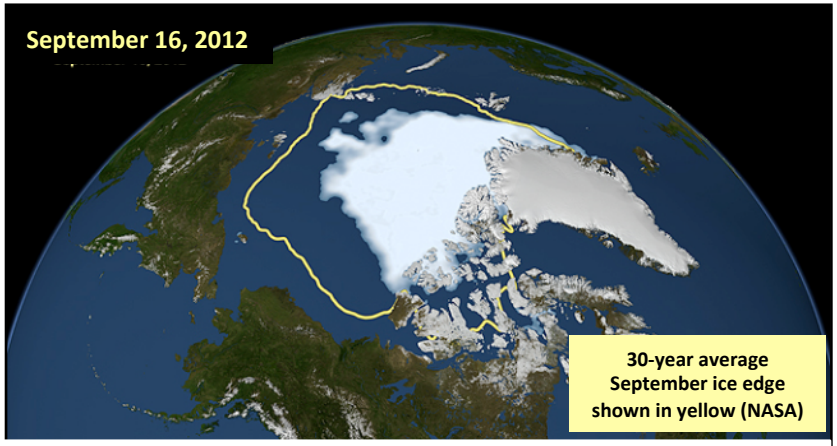
- Advance computational and environmental numerical prediction science and technology through coupled model development
- Identify and quantify uncertainty and risk though probabilistic prediction: multi-model ensembles
- Enhance our understanding of the complex interactions of the earth environmental system through process studies
- Improve operational predictive capability with better skill scores and longer lead times through technology transition
- Provide insight and guidance for informed decisions in an increasingly complex and changing global human enterprise

Implement an ESPC Suite across partner Operational Prediction Centers

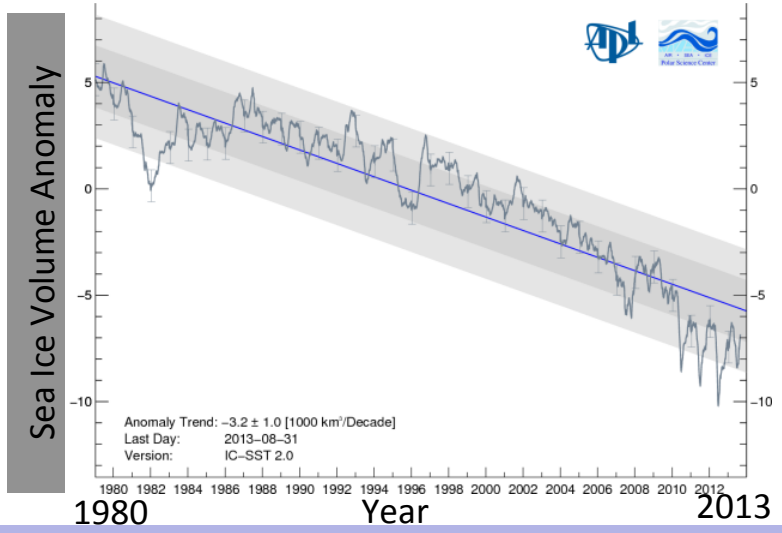
Strategy


Seamless Prediction System
New prediction systems
Weather Model (currently 7-10 days)
Climate Model (currently decadal to centennial)
Adaptive Grids (and other improvements to computational efficiency)
Coupled with ocean (30 days)
Seasonal Prediction (1-3+ months)
Increased resolution
Seamless Prediction

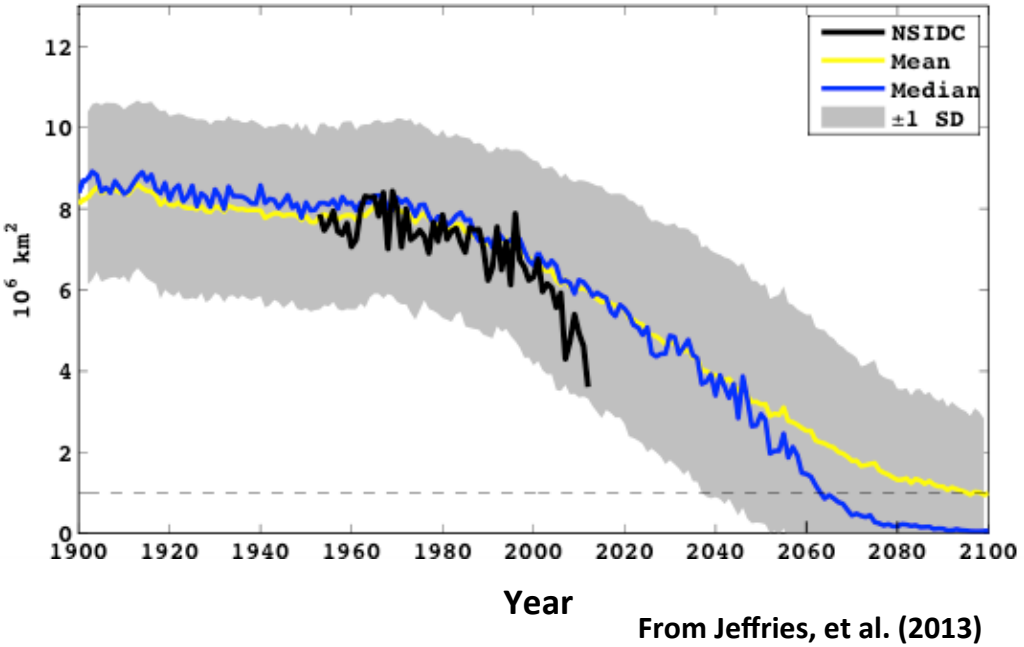
The Changing Arctic



Observed Changes in Arctic Sea Ice



Projected Changes in September Arctic Sea Ice Extent

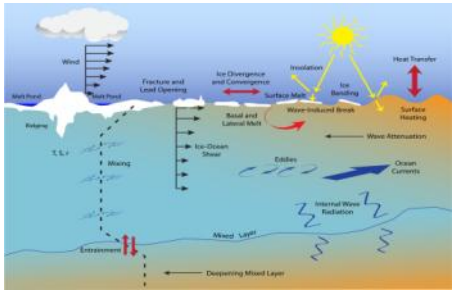


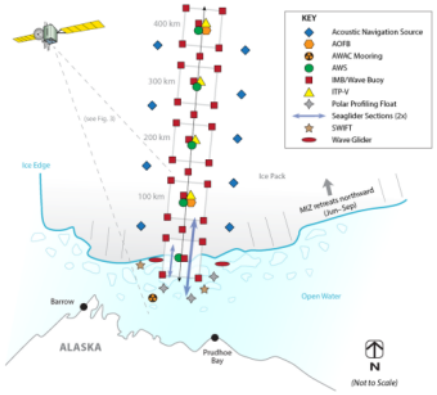
From Jeffries, et al. (2013)

FY14 Field Effort: Marginal Ice Zone DRI

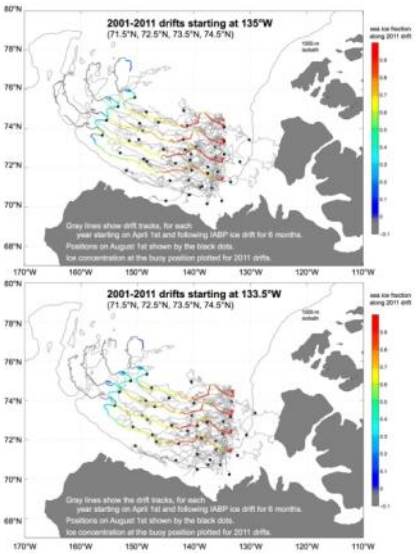
Marginal Ice Zone Initiative (FY12-FY16)

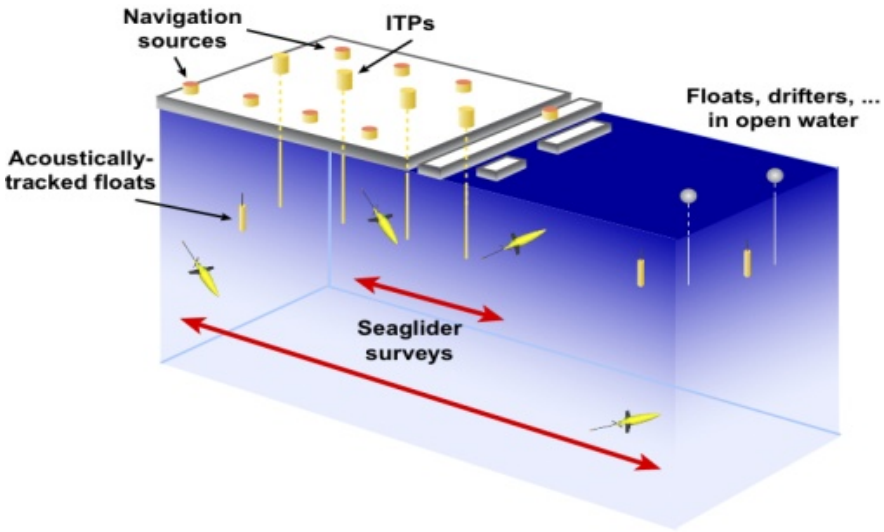
- A study of the emerging physics of the marginal ice zone during the summer melt-back period
- FY14: Major field experiment using buoys and UUVs with interagency and international cooperation





March 2014: Deploy sensor array along 135E, let sensors drift with ice
July 2014: Ship ops to deploy mobile sensing array in MIZ
September 2014: Recovery of observational assets





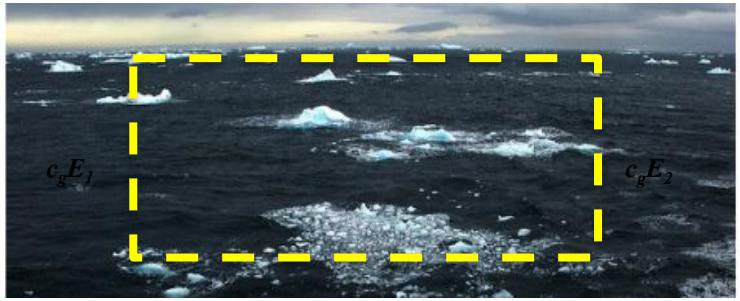
Better basic understanding of the dynamics of the Marginal Ice zone is needed to simulate and predict the ongoing decrease in summer ice coverage and volume in the Beaufort and Chukchi Seas

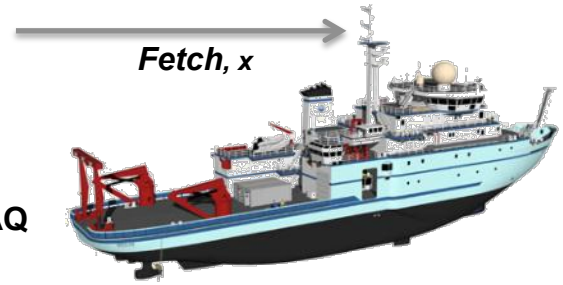
FY15 Field Effort: Arctic Waves and Sea State DRI

A study of ocean waves and swell in the Beaufort and Chukchi Seas, to better understand the impact of more Arctic open water on air-sea interaction and the remaining sea ice cover

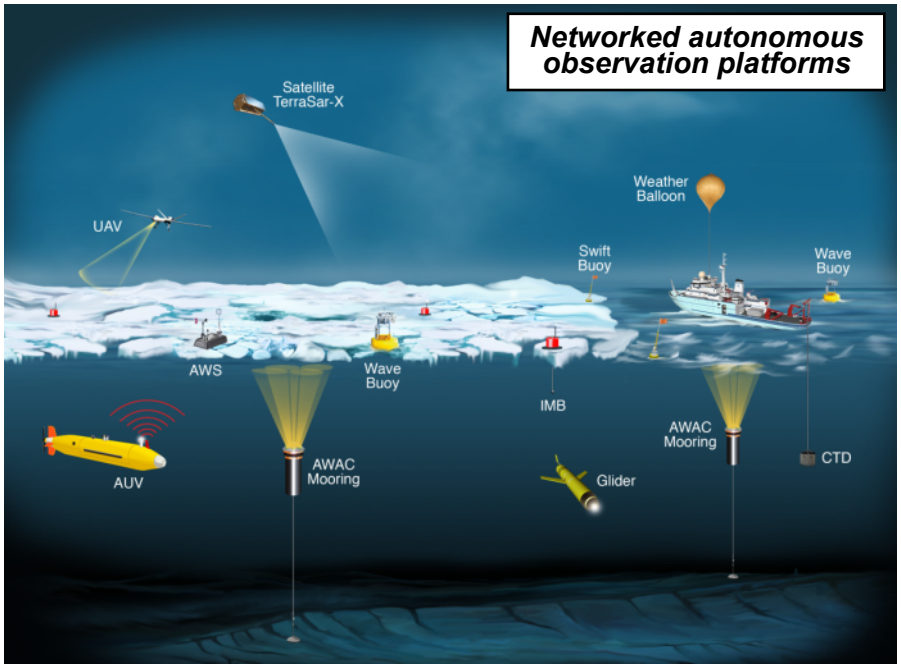
- **FY14: Pilot projects to test new platforms and observing techniques**
- **FY15: Major field effort in 2015 involving both autonomous sensors and sampling from the new UNOLS Arctic Research Vessel Sikuliaq**

$$d/dt\,(E) + d/dx\,(c_g E) = S_{wind} - S_{brk} + S_{nl} + S_{ice}$$





R/V SIKULIAQ



This knowledge will enable safer, more efficient naval operations in the Arctic through better Arctic domain awareness, improved sensing and communications, and assist in the development of coupled Arctic system models

Utilization of Academic Performer Data Collection Capabilities

UNIVERSITY OF MIAMI

CSTARS

Optical Sensors:

SPOT-4	France	(med hi-res - 10 m)
SPOT-5	France	(hi-res – 2.5 m)
SPOT-6	France	(hi-res – 1.5 m)
DEIMOS-1	Spain	(med hi-res - 22 m)
ENVISAT-MERIS†	ESA	(wide-res – 250 m)
ALOS/AVNIR-2†	Japan	(med hi-res - 10 m)
EROS-B	Israel	(very hi-res – 70 cm)
MODIS-TERRA/AQUA	US/NASA	(wide-res – 250 m)
FormoSat-2*	Taiwan	(hi-res – 2 m)

** virtual reception capability; † ceased operation, power failure, archive access*

Microwave Radar Sensors:

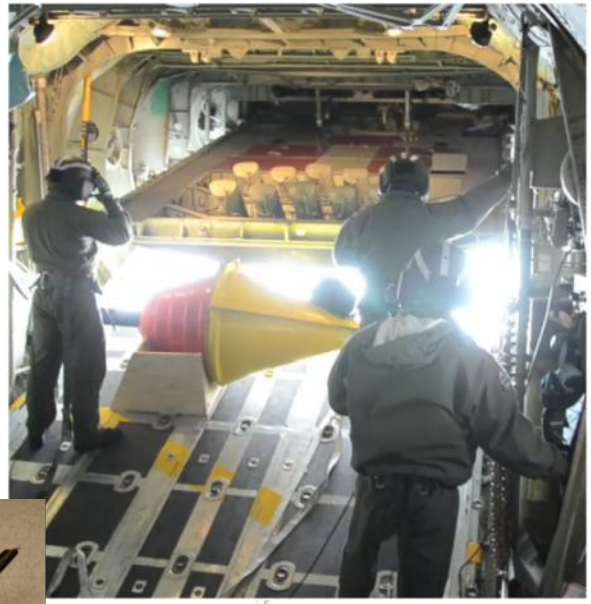
ENVISAT-ASAR†	ESA	(med-res – 25 m)
ERS-2$	ESA	(med-res – 25 m)
ALOS/PALSAR†	Japan	(med-res SAR – 10 m)
PAZ (TSX clone)	Spain	(very hi-res SAR – 1 m)
RadarSat-1	Canada	(med-res SAR – 10 m)
RadarSat-2	Canada	(very hi-res SAR – 1 m)
TerraSAR-X	Germany	(very hi-res SAR – 1 m)
Cosmo-SkyMed	Italy	(very hi-res SAR – 1 m)
Tandem-X	Germany	(very hi-res SAR – 1 m)

$operation to end early July – de-orbit, † ceased operation, power failure, archive access

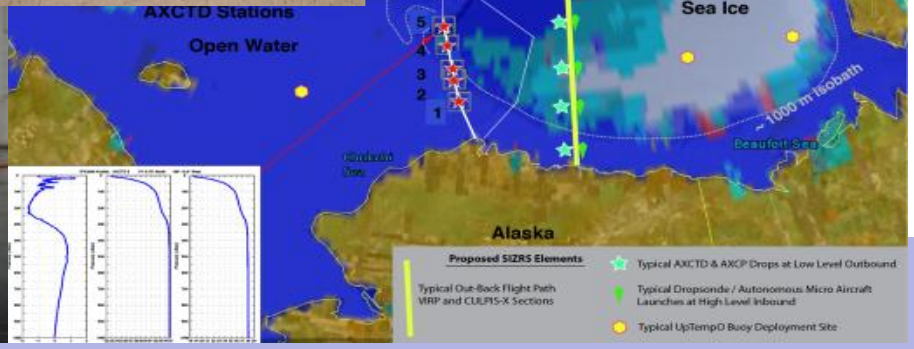
Seasonal Ice Zone Reconnaissance Surveys (SIZRS)

SIZRS Methods

- Conduct repeat (2-4 week intervals) atmospheric and oceanographic surveys of the seasonal ice zone using US-Coast Guard ADA flights (May-Sept. 2012-2014)
- Air deployed ocean sensors (AXCTD, AXCP), drifters
- Multispectral Imaging, LIDAR
- Atmospheric sensing (Dropsondes, drifting buoys)
- Regional modeling (Atmosphere-Ice-Ocean)
- Micro-Aircraft/Smartsonde development



USCG Kodiak C-130H



Example 322AG Core Program Investments

- **Operationally merged satellite visible/IR and passive microwave sea ice information for improved sea ice forecasts and ship routing (NASA/NRL Collaboration)**

- **Detecting, Tracking, and Predicting the Fine Scale Motion of Arctic Sea Ice Fragments from Multiple Satellite Sensors (CUNY w/ NUWC)**

- **Developing Remote Sensing Capabilities for Meter-scale Sea Ice Properties**

- **Enhancement of the International Arctic Buoy Program (UW)**

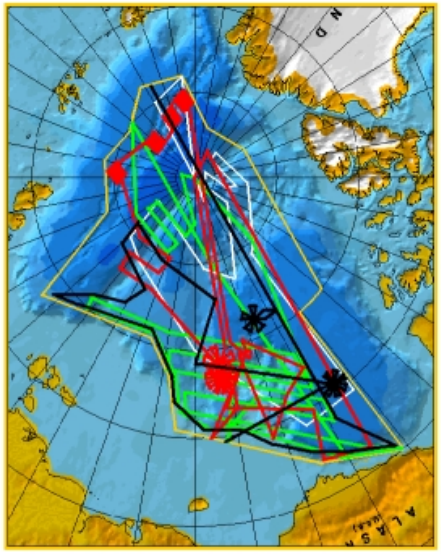
- **Multiscale Models of Melting Arctic Sea Ice (w/ Code 31)**

- **Sunlight, Sea Ice, and the Ice Albedo Feedback in a Changing Arctic Sea Ice Cover (UW & ERDC/CRREL)**

SCICEX

Coordinated effort between the research community and operational Navy to take scientific-quality observations in the Arctic from submarines

- **SCICEX Phase I: Dedicated Science Missions**
  - Vital role measuring Arctic bathymetry, ice, ocean
  - Dedicated science cruises ended in 1999
- **SCICEX Advisory Committees**
  - Science Advisory Committee (SAC)
  - Inter-Agency Committee (IAC)
    - ONR, NSF, USARC, ASL
- **SCICEX Phase II Science Plan Developed in 2010**
  - Currently running "Science Accomodation Missions"
  - "Menu" of preferred measurements to be taken in desired locations, time permitting
  - Next opportunity during the 2014 ICEX (March 2014)



Summary

ONR's Arctic and Global Prediction Program is investing in research to enable the Navy to prepare for and respond to future Arctic missions and concerns, in recognition of the emerging interest in the region.

Primary thrusts:

- **Observing tools, with an emphasis on autonomous platforms and sensors**
- **Basic understanding of the physical Arctic system, with a focus on the surface conditions and sea ice**
- **Development of the Arctic component of ESPC-class numerical prediction systems enabling improved forecasts**