Naval Research Laboratory
Arctic Initiatives

CAPT Paul Stewart
NRL, Washington DC

The Navy and Marine Corps Corporate Laboratory

NRL: The DoN's Corporate Laboratory

Lines of Business

- **Sensors, Electronics and Electronic Warfare**
- **Materials/Processes**
- **Battlespace Environments**
- **Undersea Warfare**
- **Information Systems Technology**
- **Space Platforms**

- **Technology Transfer**

NRL Rich Arctic Research History

Benthos studies 1950


1958

Starts as a WW II effort In 1944

By 1947, civilian science Is supported

By 1980, Navy is gone, & so are most Civilians

Originated as Arctic Research Lab (ARL) in 1947
Re-named Naval Arctic Research Lab (NARL) in 1967, Navy departed 1980

Ice Island Station T-3 1971

1967 Resupply


1963 Storm – Preview of Global Warming?

The Navy and Marine Corps Corporate Laboratory

NARL frequent visitors during the Cold War

Arctic Navy Relevance

- Possibility of "ice free" Arctic heightens interest about Arctic transit
  - In 2008 and 2009, both NW Passage and Northern Sea Route opened
- Navy Arctic Roadmap (Nov '09)
- Improved Arctic predictability required for near-term operations and long term asset acquisition
- Operational challenges:
  - Protection of future sea-lanes
  - Mobility
    - Surface combatants are not ice-strengthened
    - Submarine transit risks
    - Limited surveys
  - Use of UAV's limited by communications and icing
  - Use of AUV's to monitor ocean under ice
- Sovereignty issues

ONR/NRL Arctic Initiatives

- Naval Arctic Environmental Research
  - **Improved Physical Understanding**
  - **Integrated Arctic Modeling and Prediction**
  - **Developing New Technology for collecting data in the Arctic**

New ONR Arctic Research Program

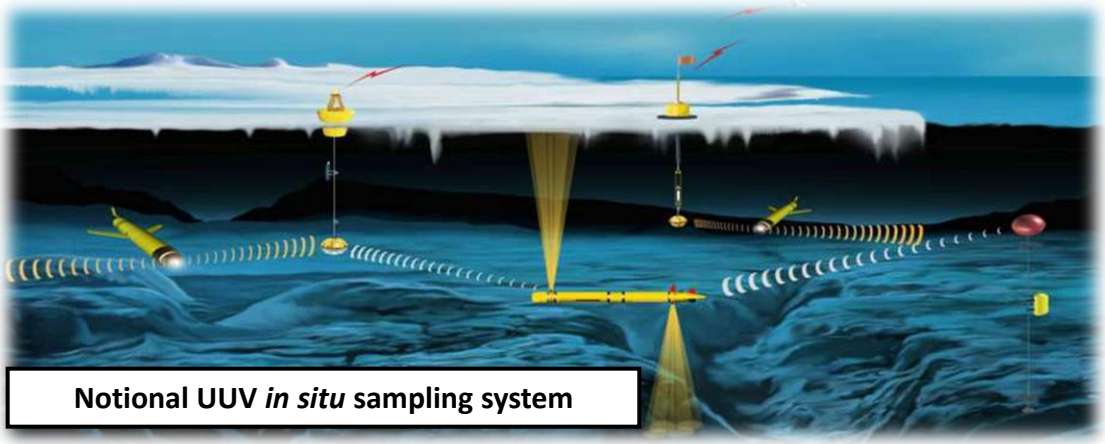
Starting in FY12

In response to priorities identified in coordination with Task Force Climate Change, a new research program focused on the Arctic has been created at ONR through a realignment of FY12 funds

PROGRAM GOALS:

- **Improved basic physical understanding** of the Arctic environment and important coupled processes operating in the Arctic region
- **Development of a new, dynamic, fully-integrated Arctic System Model** incorporating the ocean, sea ice, waves and atmosphere to enable improved predictions of the high-latitude operational environment at longer lead times, including the use of **satellite SAR data** for assimilation into integrated models
- Generation of **new technologies** (platforms, sensors, communications) that will be required for **persistent observation and operation** in the harsh Arctic environment

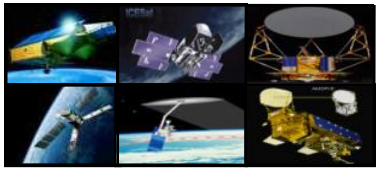
SAR Sea Ice Imagery

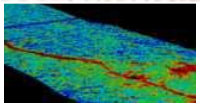


Notional UUV *in situ* sampling system

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

NRL: An Integrated Multi-Discipline Program



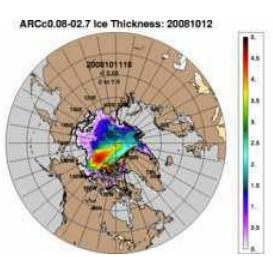


Code 7220
Satellite Algorithms

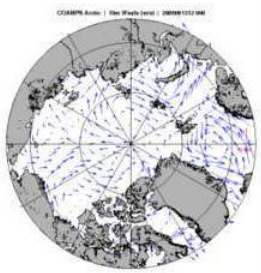
Code 7420
Airborne Campaign

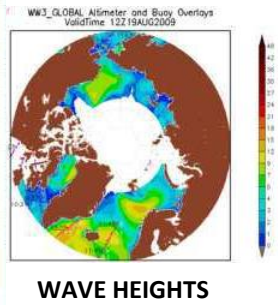
NRL, CRREL
In-situ

Code 7320/7500/7600
Arctic Modeling

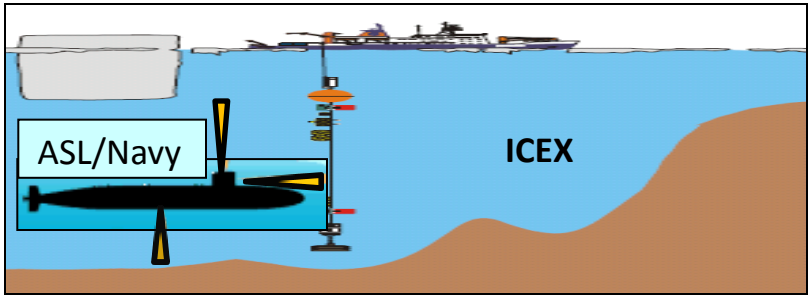


ICE THICKNESS


SURFACE WINDS



WAVE HEIGHTS



Strategy

Remote Sensing Synergism

–Collect in-situ data (ice/snow thickness)
–Develop airborne algorithm from in-situ data
–Utilize airborne data to derive satellite algorithm

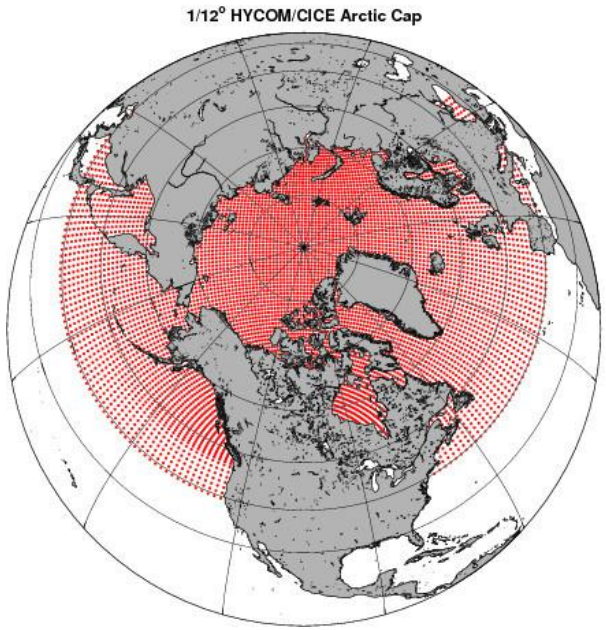
Ice-Ocean Modeling Scheme

–Validate model ice thickness against new satellite/airborne data
–Simulate snow forcing on ice distribution

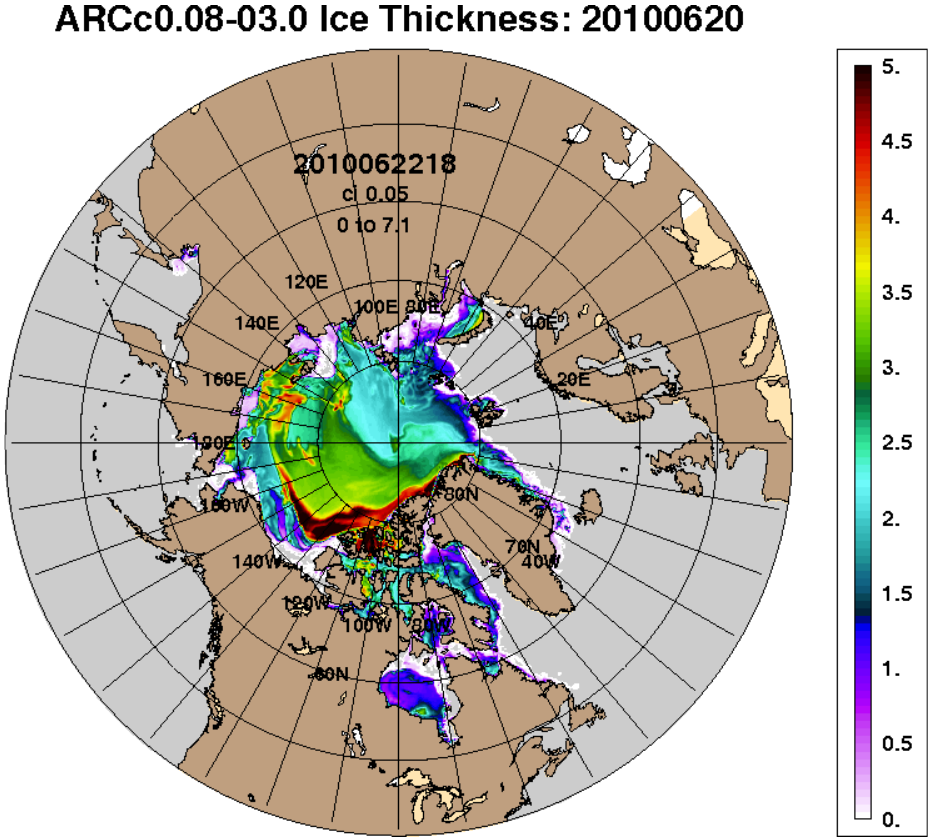
Leverage existing Arctic programs

NRL Recent Transition of the Arctic Cap Nowcast/Forecast System (ACNFS)

- **ACNFS consists of :**
  - **Los Alamos Community Ice CodE (CICE) model**
  - **HYCOM Ocean Model**
  - **NCODA data assimilation (SSMI Ice concentration, Temp, Salinity, Sea Surface Height**
  - **Ocean model nested in Global HYCOM**
  - **It is the ice and ocean component of the Navy's Earth System Model**

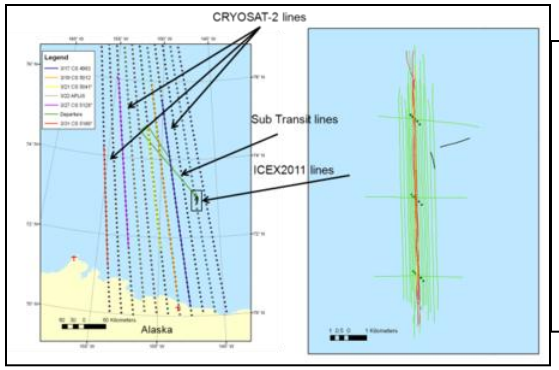


Arctic Cap model domain: every 20th grid point plotted. Resolution ~3.5 km near pole.



Arctic Cap Model ice thickness June 15, 2010 – June 13, 2011. Scale in meters

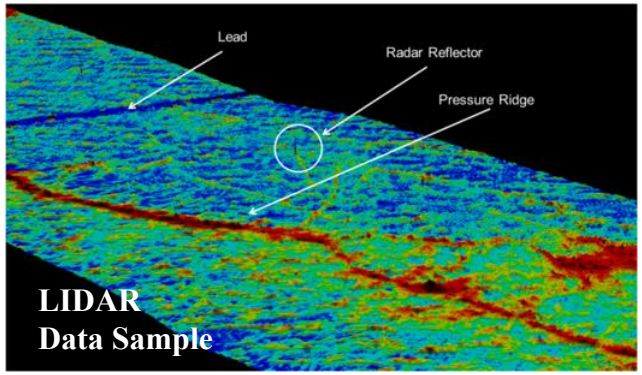
NRL In-Situ-Airborne-Satellite Data Acquisition Initiative in the Arctic



NRL Flight Lines Overlaid on Submarine transit lanes and Cryosat transects

ONR Funded "Prequel" Program: Code 7420 FY11 program for in-situ-airborne-satellite data acquisition in Arctic leveraging:

- **US Navy's ICE Exercise (ICEX) 2011,**
- **Commissioning phase of the European Space Agency's (ESA) CryoSat2 satellite, and**
- **NASA Operation IceBridge and ESA's CRYOsat Validation Experiment (CRYOVEX).**



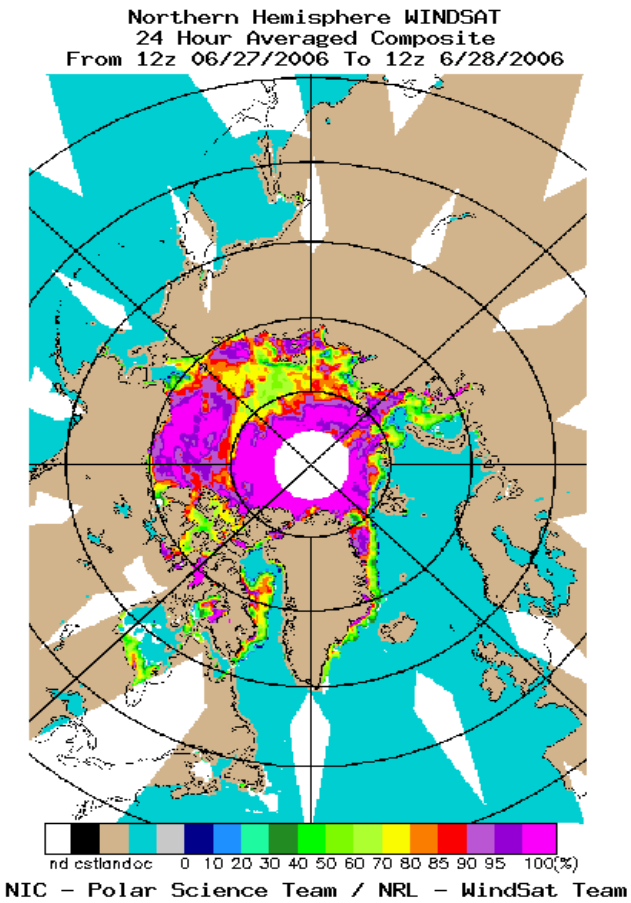
LIDAR Data Sample

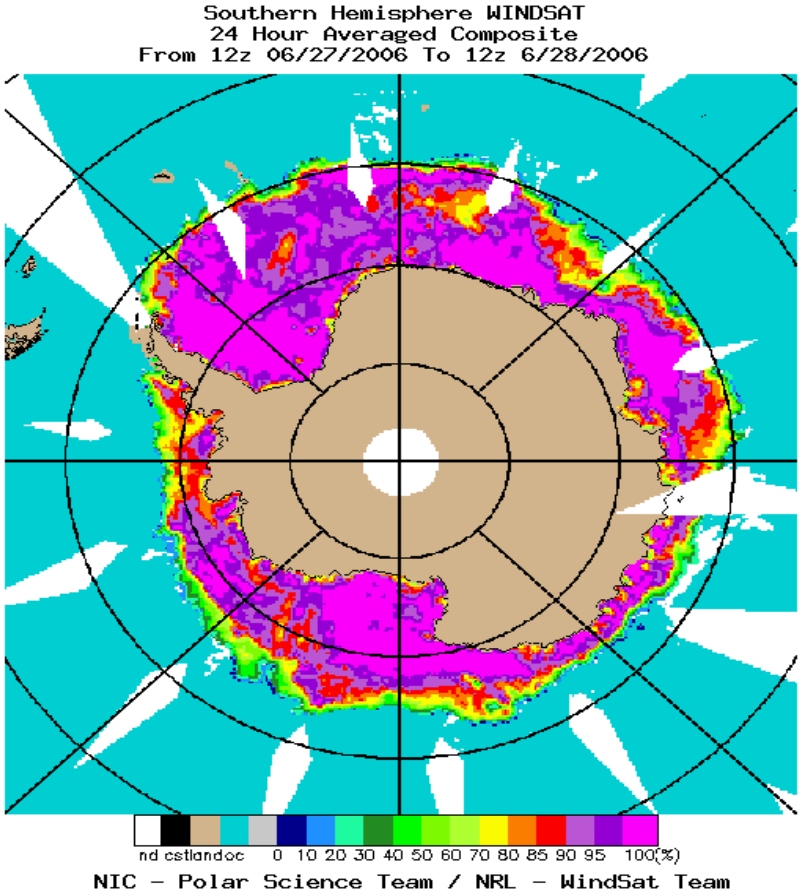
CRREL Insitu Data Collection

NRL Airborne Field Collection

Airborne measurements, validated by *in-situ* measurements, will provide regional ice thickness and snow-depth-on-ice; These data will aid development of satellite retrieval

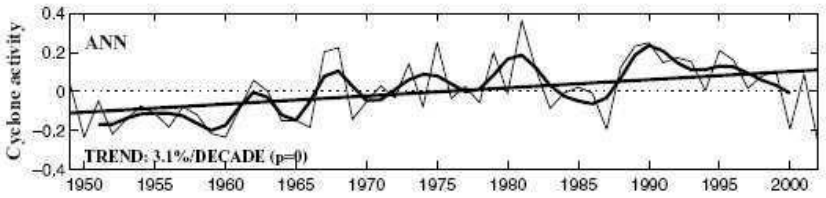
WindSat Sea Ice Products





- Sea Ice Concentration (based on heritage algorithm)
- Product Provided Twice Daily to the National Ice Center
- Developing new algorithms to study multi-year ice structure

Effects of Waves on Arctic Ice



Time series trend (1949-2002) of annual total Arctic cyclone activity (given as accumulated positive vorticity anomalies).

- Indications of increased incidence and intensity of storms affecting Arctic; producing more energetic ocean waves.
- Decreased ice coverage, more open water, larger fetch for wave generation within the Arctic; larger surface waves present.
- Ocean waves can fatigue and fracture sea ice and encourage melting.

Objective: Create methodology to quantify change in Arctic wave climate and resultant mechanical forces acting on ice.

Predicting the Changing Arctic Environment
Coupled Model Development

Objective

- Improved understanding of the physical processes in the Arctic
- Developed new model physical parameterizations influencing the Arctic weather for Navy's atmospheric prediction systems

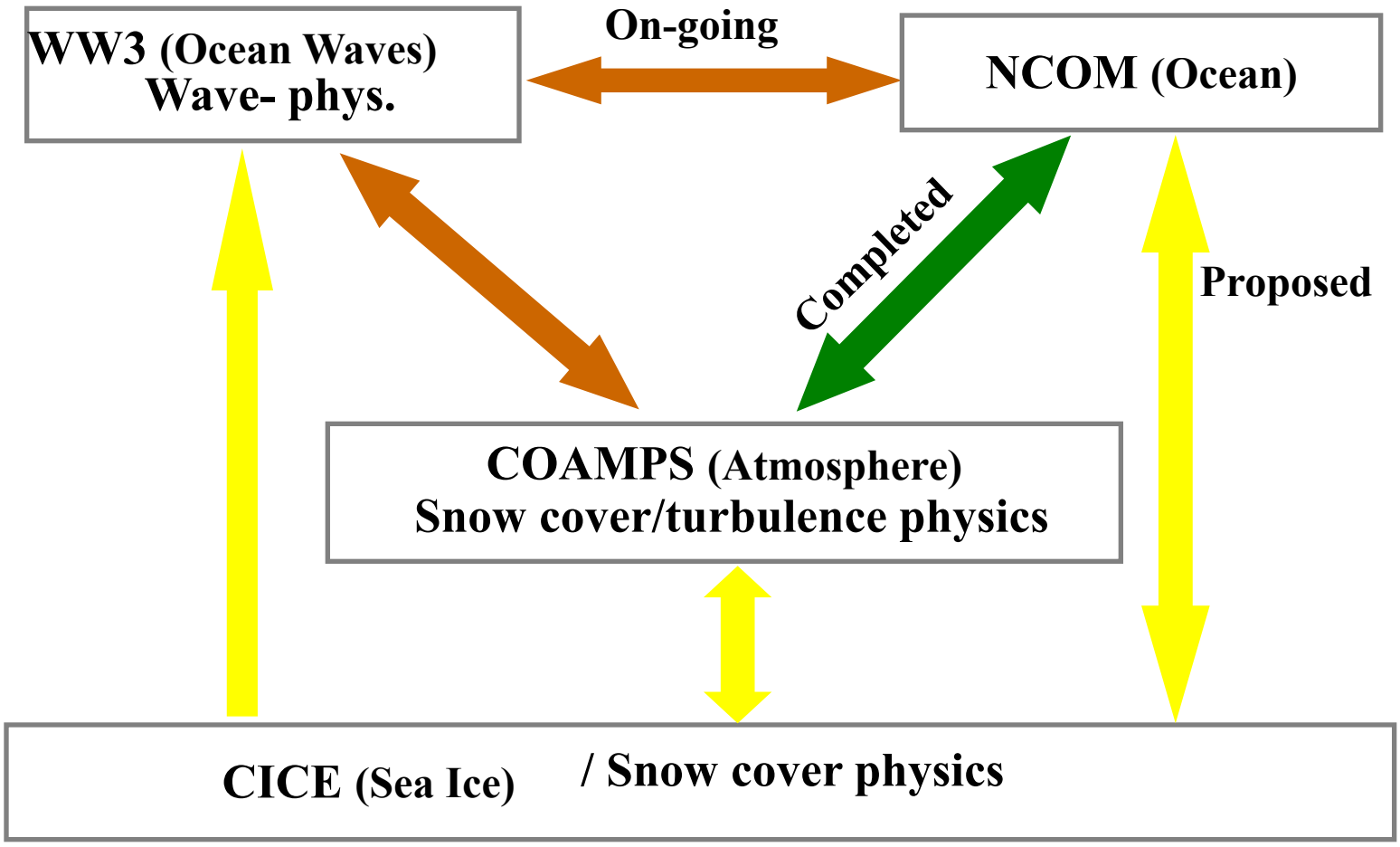
Approach

- Used NOGAPS simulations to explore the sensitivities of upgraded physical parameterizations operating in the Arctic
- Developed improved parameterizations for the Arctic stratus cloud and turbulent mixing using cloud resolving model, COAMPS©
- Performed data assimilation and high-resolution simulations using Navy's advanced global data assimilation/forecast system, NOGAPS

Payoff

- Improved the forecast of the Arctic atmosphere
- New physical parameterizations for atmospheric prediction systems and more accurate fluxes for Navy's ocean/ice/wave models

Coupled COAMPS-Arctic (Proposal)

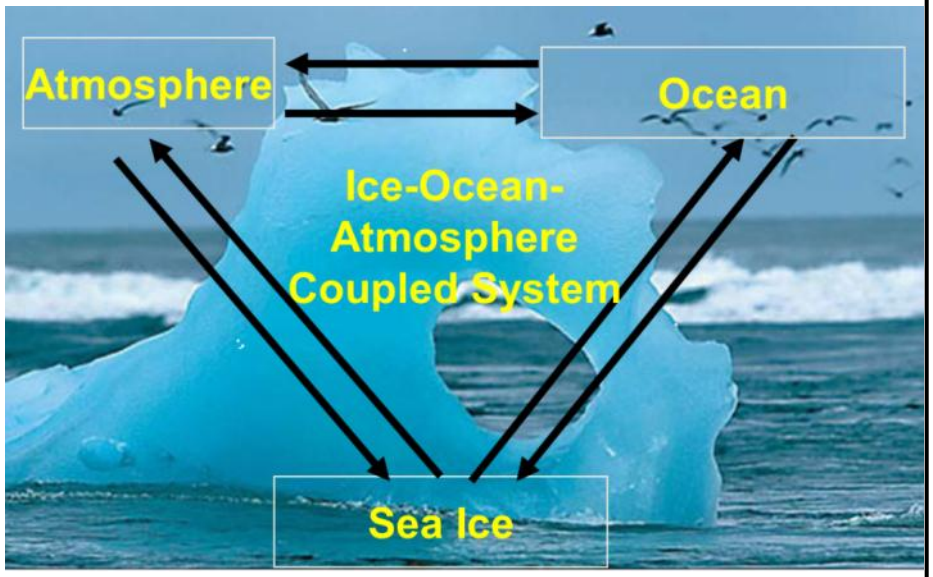


- **Focus one: Modeling physics (Wave, Snow cover/Turbulence)**
- **Focus two: Coupling integration (COAMPS-NCOM-CICE-WW3)**

A Coupled High-Resolution Arctic Modeling System
(Proposal)

Objective: **Develop and demonstrate the Navy's first high-resolution fully coupled relocatable arctic ice-ocean-atmosphere (IOA) prediction system with an advanced representation of energy exchange at the IOA interface.**

Payoff: **New arctic prediction capabilities enabling fully coupled weather forecasts and intra-seasonal assessment in Navy's strategic and tactically significant areas.**



Approach: **Build a six way coupler to link three IOA components; advance the representation of energy exchange at the IOA interface; develop an accurate and efficient relocatable capability for the coupled system; and evaluate the IOA system using available observations by performing both short-term (1-5 days) and intra-seasonal (10-90 days) simulations.**

Battlespace Environments

Joint 7300-7500 New Start Proposal for 2013-2015
Rick Allard and Shouping Wang

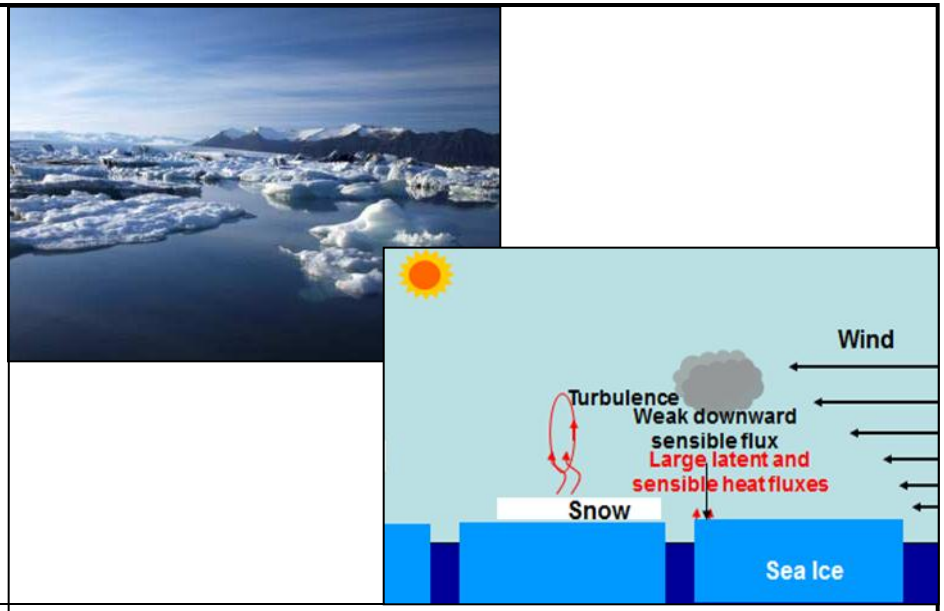
New Start funding profile ($K)

FY13$	FY14$	FY15$	FY16$
600	600	600	0

High-Resolution Coupled Modeling of Arctic Atmosphere-Sea Ice Interaction in the Marginal Ice Zone (Proposal)

Objective: Investigate the complex interactions between atmospheric radiation, surface exchanges of heat, momentum, and moisture, and sea ice in the Marginal Ice Zone.

Payoff: New capability for high-resolution uncoupled and coupled forecasting in the Marginal Ice Zone. Inclusion of additional physical parameterizations such as ice, snow, and Arctic clouds to better represent the key interactions among the Arctic processes.



Approach: Develop and evaluate an air-sea-ice prediction capability for the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) by integrating its atmosphere-ocean component with a sea-ice model, and by implementing advanced physical representations of critical processes involving the air-ice interface in the MIZ. Initially, a one-way coupled capability for the ice component will be used.

COAMPS® is a registered trademark of the Naval Research Laboratory

Submitted in pursuant of ONR Departmental Research Initiative: Emerging Dynamics of the Marginal Ice Zone

Dr. James D. Doyle **Code 7533**
831-656-4716 **james.doyle@nrlmry.navy.mil**

Proposed Funding Profile ($K)

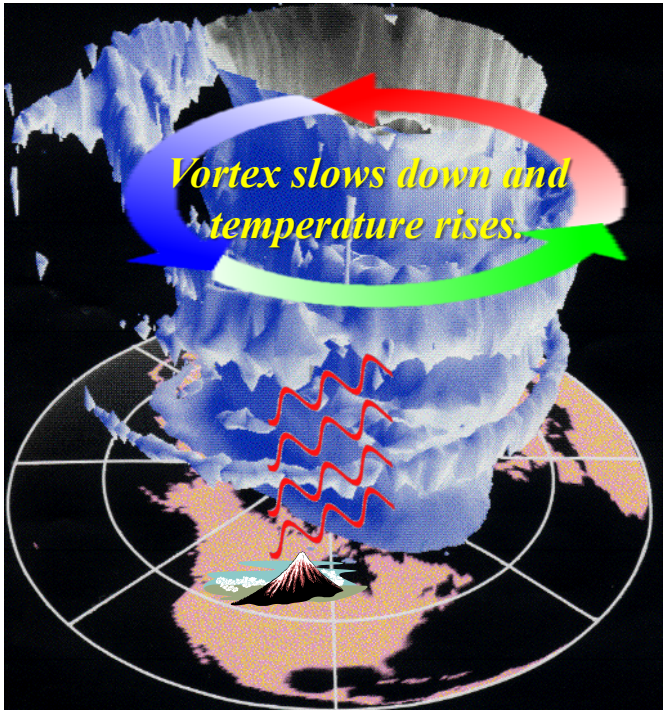
FY12	FY13	FY14
$150K	$150K	$150K

The Navy and Marine Corps Corporate Laboratory

Sudden Stratospheric Warming & Arctic Oscillation
(proposal)

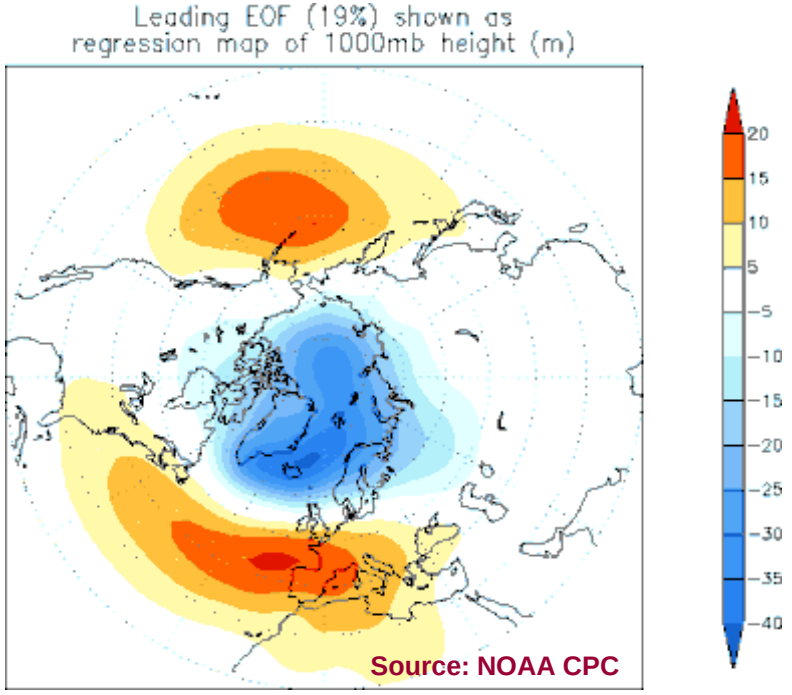
Sudden Stratospheric Warming (SSW)

- An event where the polar vortex of westerly winds in winter hemisphere abruptly slows down or even reverses direction, accompanied by a sudden rise of stratospheric temperature
- Caused by the breaking of vertically-propagating planetary and gravity waves originating from the troposphere

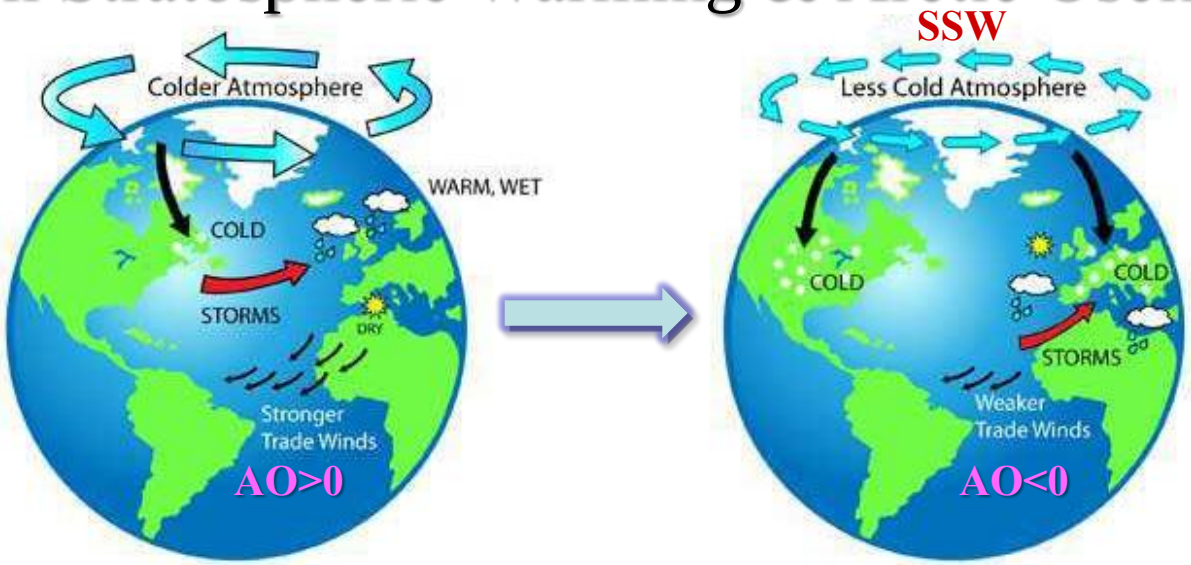


Arctic Oscillation (AO)

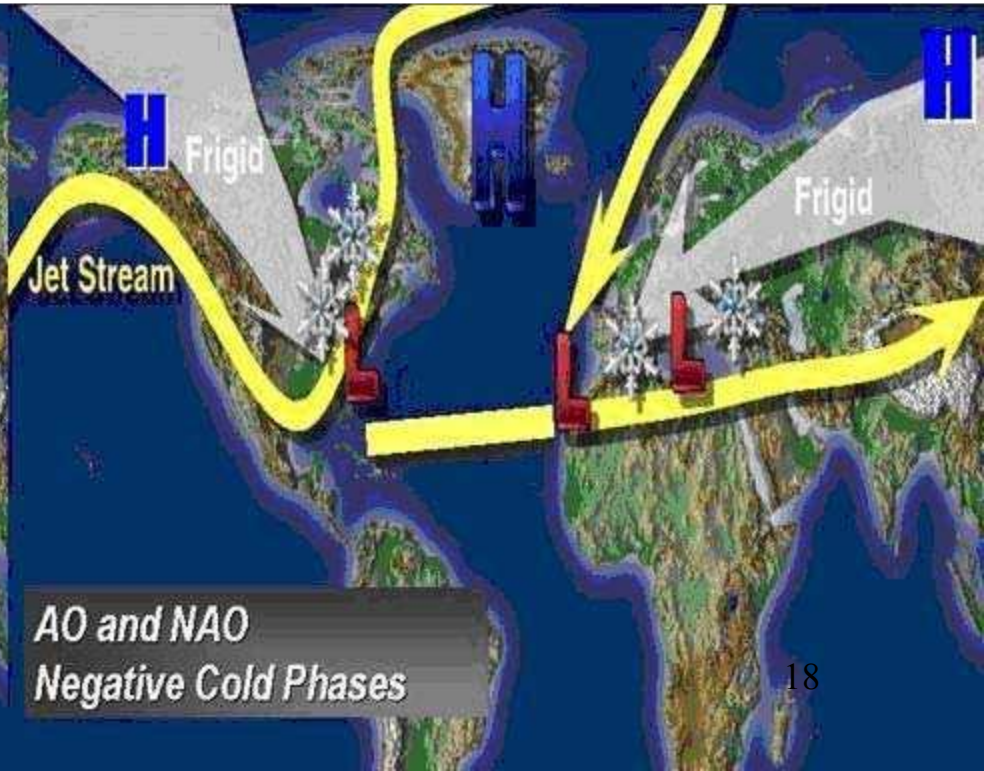
- A large scale seesaw in atmospheric mass between the subtropical high and the polar low
- A projection of the daily 1000-hPa geopotential height anomalies poleward of 20°N onto the leading mode (EOF) of the long-term geopotential height data



Sudden Stratospheric Warming & Arctic Oscillation



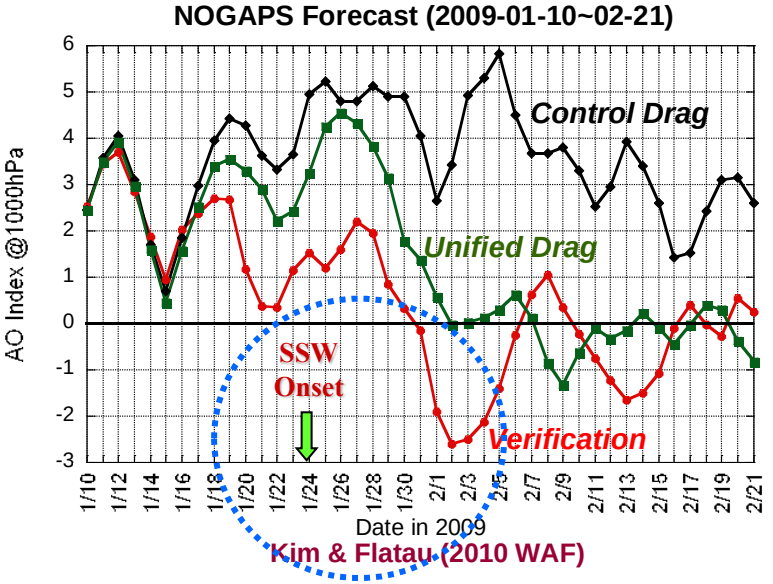
The Arctic stratospheric vortex weakens, allowing cold polar air, which is normally confined by the polar vortex, to leak southward and flow into the mid-latitudes.



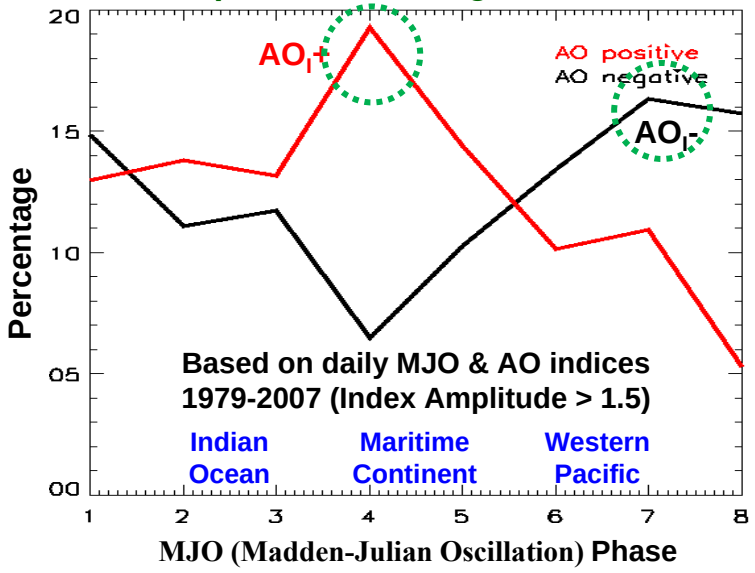
Sudden Stratospheric Warming & Arctic Oscillation

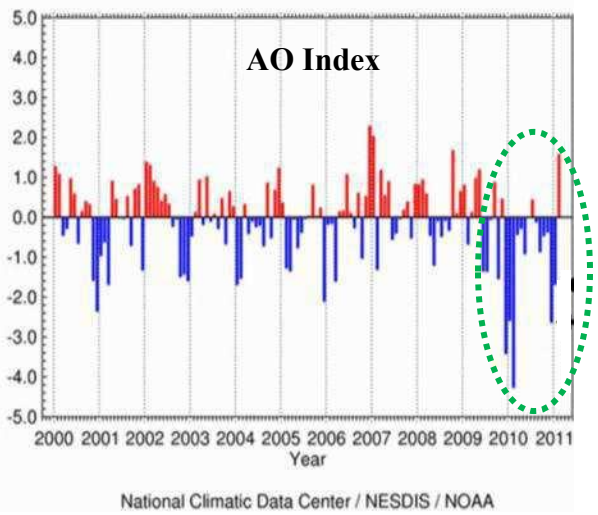
The Earth's environment is going through significant change at an accelerated pace.

- Strongly negative AO indices are found in association with strong SSW events, concurrently with severe cold weather and rain/snowfall in the mid-latitudes.
- The impact of SSW can reach the surface (& change AO sign) in a few days (Kim & Flatau 2010), much faster than what was previously reported and believed.
- AO is linked to tropics (Flatau & Kim 2010).
- AO Index values have been strongly negative in winter over the last few years, with unprecedented frequency and strength.



Percentage of the MJO phase for positive and negative AO

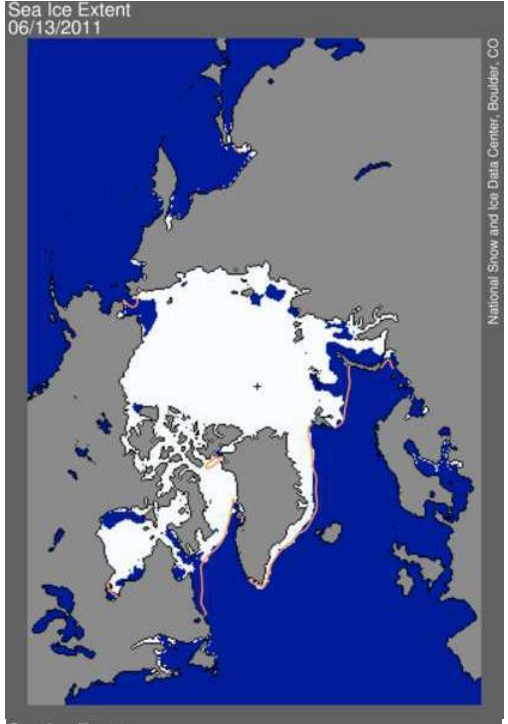


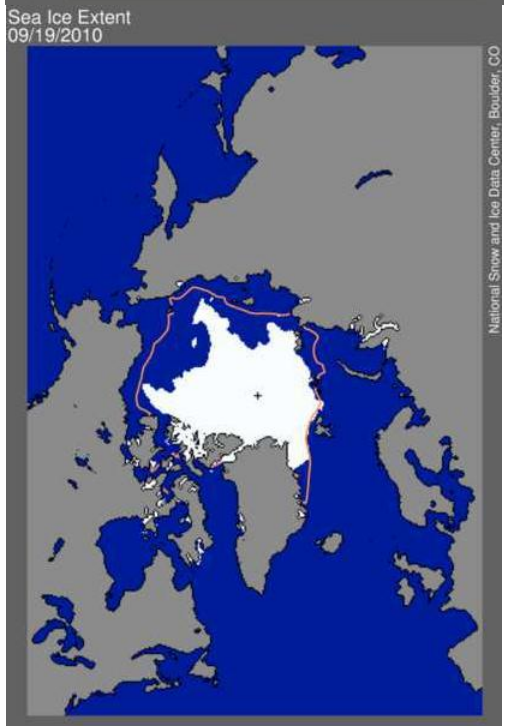


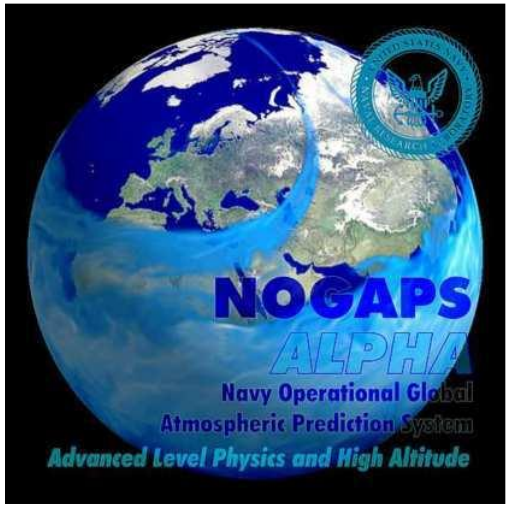
Flatau & Kim (2010 JGR submitted)

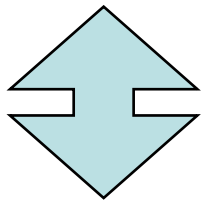
Improving Climate Predictions in the Arctic

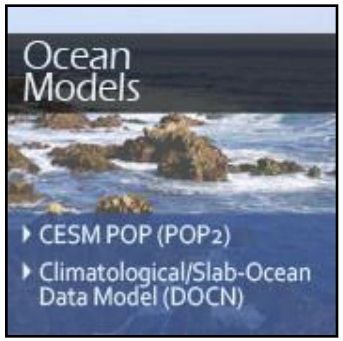
(Proposal)

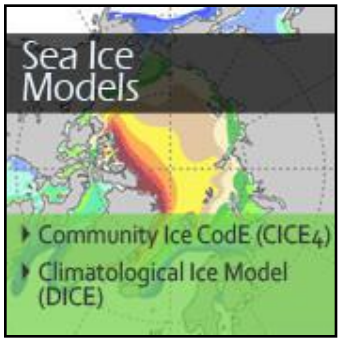












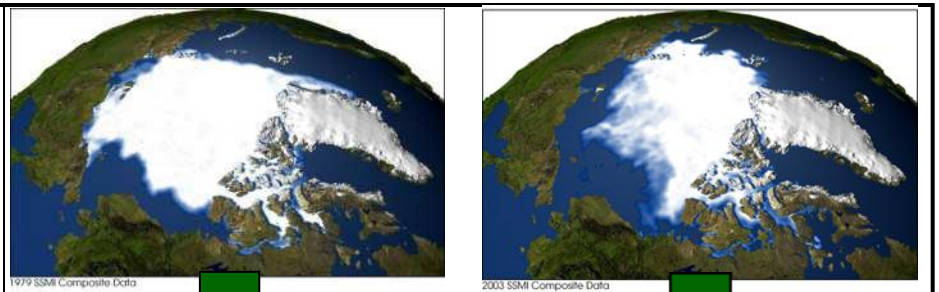
When and where will the Arctic sea ice will open up? For how long?

POC: Dr. Fabrizio Sassi
Code 7646
Tel: 202-767-3827

Impact of Accurate Ice/Ocean Conditions on Large-scale Atmospheric Forecasts (Proposal)

Objective: Investigate impact of changing Arctic Sea conditions (sea surface temperature and sea ice) on high-resolution global forecasts of atmospheric circulations on monthly to seasonal time scales.

Payoff: Improved knowledge of the physics of retreating summer ice edge and marginal ice zone through improved understanding of how lower boundary conditions influence accuracy of extended-range atmospheric forecasts.



Approach: Conduct high-resolution Navy Global Environmental Model (NAVGEM) monthly-to-seasonal hind-casts using prescribed lower boundary conditions of varying skill (e.g., static conditions, climatology, and analyzed "true-state" conditions). Compare results to establish how important accurate SST and sea ice conditions are for skillful forecasts of prevailing arctic atmospheric conditions.

Submitted in support of ONR Departmental Research Initiative: Emerging Dynamics of the Marginal Ice Zone

Dr. Carolyn A. Reynolds Code 7532
831-656-4728 carolyn.reynolds@nrlmry.navy.mil

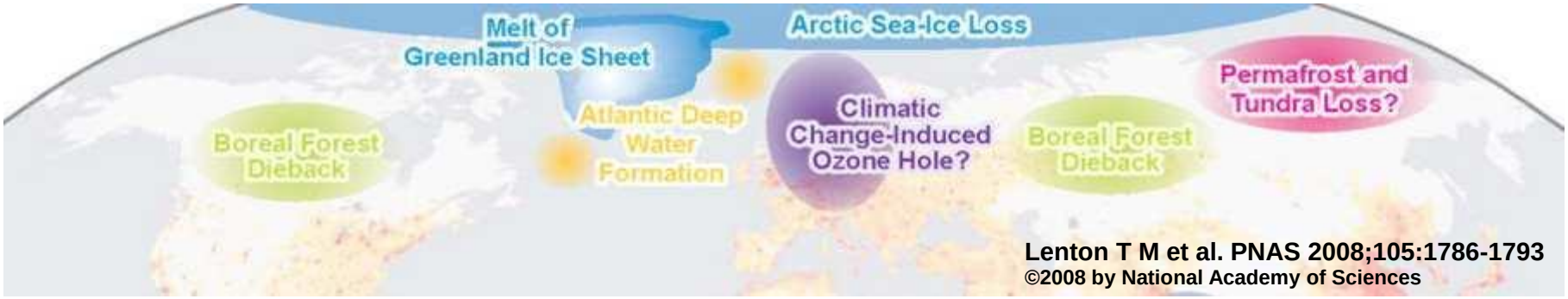
Proposed Funding Profile ($K)

FY12$	FY13$	FY14$
125	150	150

New Rules of Predictability (Proposal)

Objective: To reveal how weather predictability in potential new climate states (for focus regions including the Arctic) will differ from that of present day, and to identify the prediction system adaptations necessary for the Navy to retain and improve weather forecast skill in these states.

Motivation: The Arctic climate of the future may visit unprecedented parts of the earth-system parameter space:



Lenton T M et al. PNAS 2008;105:1786-1793

1. The Arctic air will be much warmer and wetter;
2. There will be new boundary forcings (e.g. complete loss of Arctic summer sea-ice or widespread disappearance of tundra, among other possibilities);
3. The polar Rossby waveguides will be restructured;

These changes are likely to push the Arctic system past one or more bifurcations, which are points in parameter space where the response of a chaotic system to perturbations changes abruptly.

Identifying the Important Tipping Points

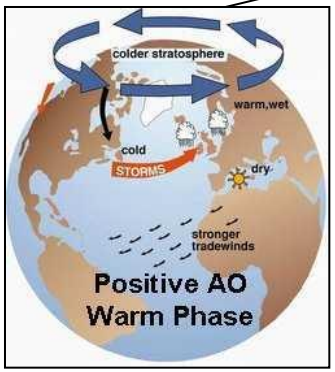
New Rules of Predictability (Proposal)

- Bifurcations can drastically change the predictability of Arctic weather.

- It is possible that Arctic weather events will become both more intense and less predictable, a two-edged problem for Arctic naval operations.

- Part I of the proposed project will quantify how the Arctic predictability changes are manifest in metrics including: error energy cascade and scale interaction, error dimension, structure, propagation, linear regime length, error amplification rate, and teleconnections.

Ex. In a more nonlinear and unstable moist environment, forecast errors in important Arctic phenomena such as polar lows (left) may amplify much more rapidly.



Ex. Familiar slow modes of polar variability ("teleconnections") such as the Arctic Oscillation (AO) (left), may be fundamentally altered, or entirely new modes may emerge.

- Part II of the proposed project will identify adaptations to Navy prediction systems that will retain and improve forecast skill in the new Arctic environment (An example: Formulation of new nonlinear techniques to cope with reductions in linear regime length).

TOTAL OCEAN MONITORING ENTERPRISE (TOME)
Arctic Monitoring System

Operational Problem:

Lack of a persistent pervasive maritime sensors in the arctic.

Inability to fuse and disseminate data to local law USCG, local law enforcement, and native responders at the unclassified level.

Lack of a Common Operational Picture (COP) including oceanographic, weather, and maritime data required for a coordinated response to an event in the arctic

Capabilities Solution:

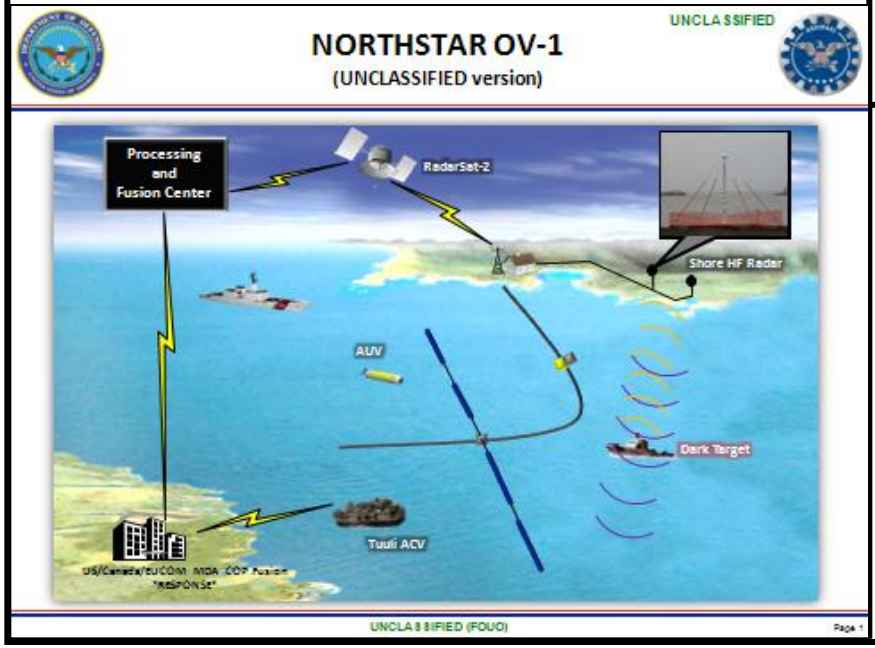
Integrate multi-sensor shore based sensor system with Open Mongoose System (OMS) fusion engine to provide comprehensive solution:

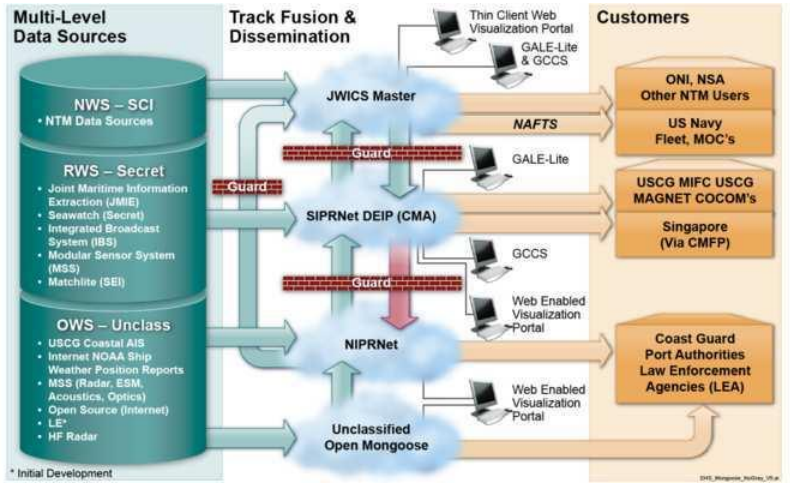
Mobile sensor system: ELINT, Acoustic, MWIR Imaging, AIS

HF Surface Wave Radar: wave and surface current measurement, over the horizon vessel detection

Open Mongoose System: Unclassified version of the Mongoose fusion engine used in S2A. Fuse vessel tracks from unclassified data and disseminate to users at that level.

Integrate existing environmental data in the COP





Arctic Open-Ice ASW Issues (Proposal)

As a result of reduced multiyear ice, the Arctic is rapidly acquiring the types of maritime activities in the summer months that normally occur elsewhere in the world's ice-free oceans

However, "ice-free" conditions in the Arctic means < 15%, sufficient to significantly impact active sonar ASW operations

Upward-refracting sound propagation paths will lead to long-range interaction with the sea-ice. While most sea ice is 1-10 m thick, ~15,000 to 30,000 icebergs are produced annually by the glaciers of Greenland and can last several years; only 1-3% make it to the North Atlantic.

Icebergs in particular are large, variable and very strong discrete Scatterers

- **> Faceted nature and highlight structure will generate numerous false targets**
- **> Their variability will lead to large acoustic uncertainty**
- **> They could be exploited to hide and haven submarines**

NRL S&T OBJECTIVES

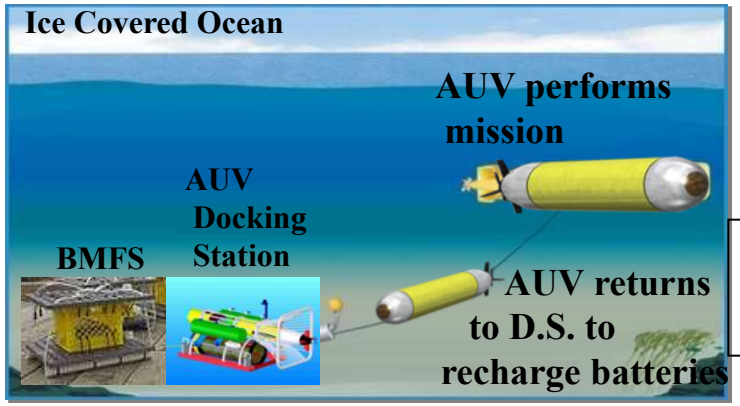
Develop physics-based acoustic models characterizing mid-frequency undersea reverberation and clutter in Arctic open-ice fields based on scatterer physics, oceanography, and sonar parameters

NAVY PAYOFFS

High-fidelity models for sonar performance characterization and synthetic trainers; improved classifiers for active sonars; environmental optimization of sonar settings

BMFC (Benthic Microbial Fuel Cell)

An array of BMFCs being prepared for deployment. Each BMFC consists of a weighted anode laid flat onto the sediment surface and a brush cathode suspended in overlying water.

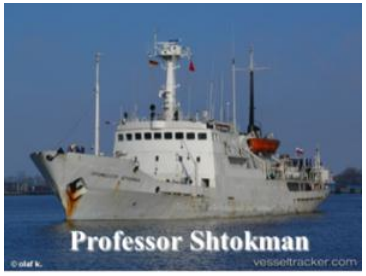


- Persistently generates battery-level power in marine environments
- Consumes marine sediment organic matter (fuel) and seawater oxygen (oxidant) as naturally found and naturally replenished
- Long term power for sensors based on sediment energy to bacteria
- Will reduce cost and logistics burden of maintaining remote sensors
- TRL 5/6, multiple research prototypes have been field tested
- Power limited by mass transport of fuel. Regions near methane hydrates have high fuel mass transport. BMFCs should generate high power at such sites for higher power applications such as UUV recharging. Testing at a cold seep (another type of high fuel mass transport site) supports this hypothesis .

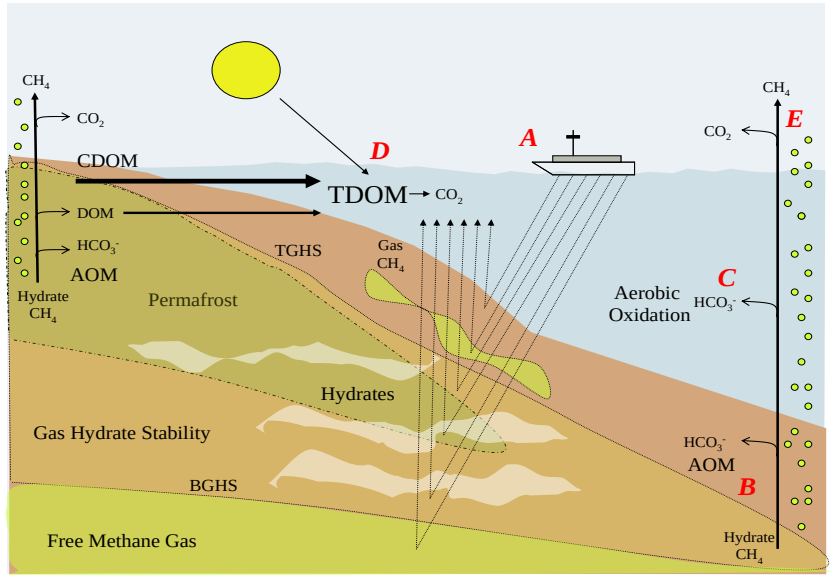
Tentative CONOP – Place BMFS and AUV docking station near Methane Hydrate to enable continuous trickle charge of docking station for rapid recharge of AUV

Climate Change and Energy Exploration in the Arctic

- Seismic and geochemical data to predict deep sediment hydrates
- Estimate spatial variation in the vertical methane fluxes
- Shallow sediment methane contribution to sediment and water column carbon cycling.
- Sediment methane flux to the water column and into the atmosphere.
- Microbial communities in sediments and the water column.
- Model development that tracks the fate of methane in the sediment and the water column, for both the dissolved and free gas phase.

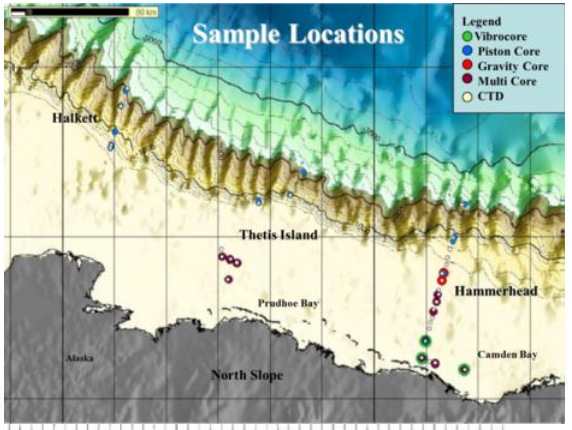


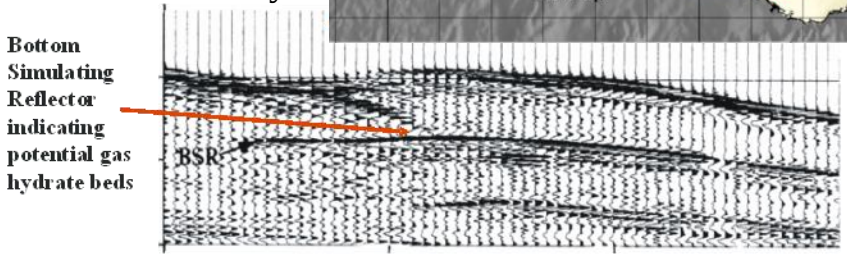
PI: Richard B. Coffin, NRL,
CO-PIs: Jens Greinert, NIOZ Netherlands; Warren Wood, NRL Stennis; Kelly Rose, NETL-DOE



Data includes: A) seismic profiles, B) sediment geochemistry; C) water column methane cycling; D) tundra carbon transport; and E) gas flux to the atmosphere.

Offshore from the current tundra methane hydrate exploration lead by BP Amoco. Transects from nearshore to the slope to evaluate permafrost and deep sediment hydrate distribution and stability.





Methane Relative to Climate Change

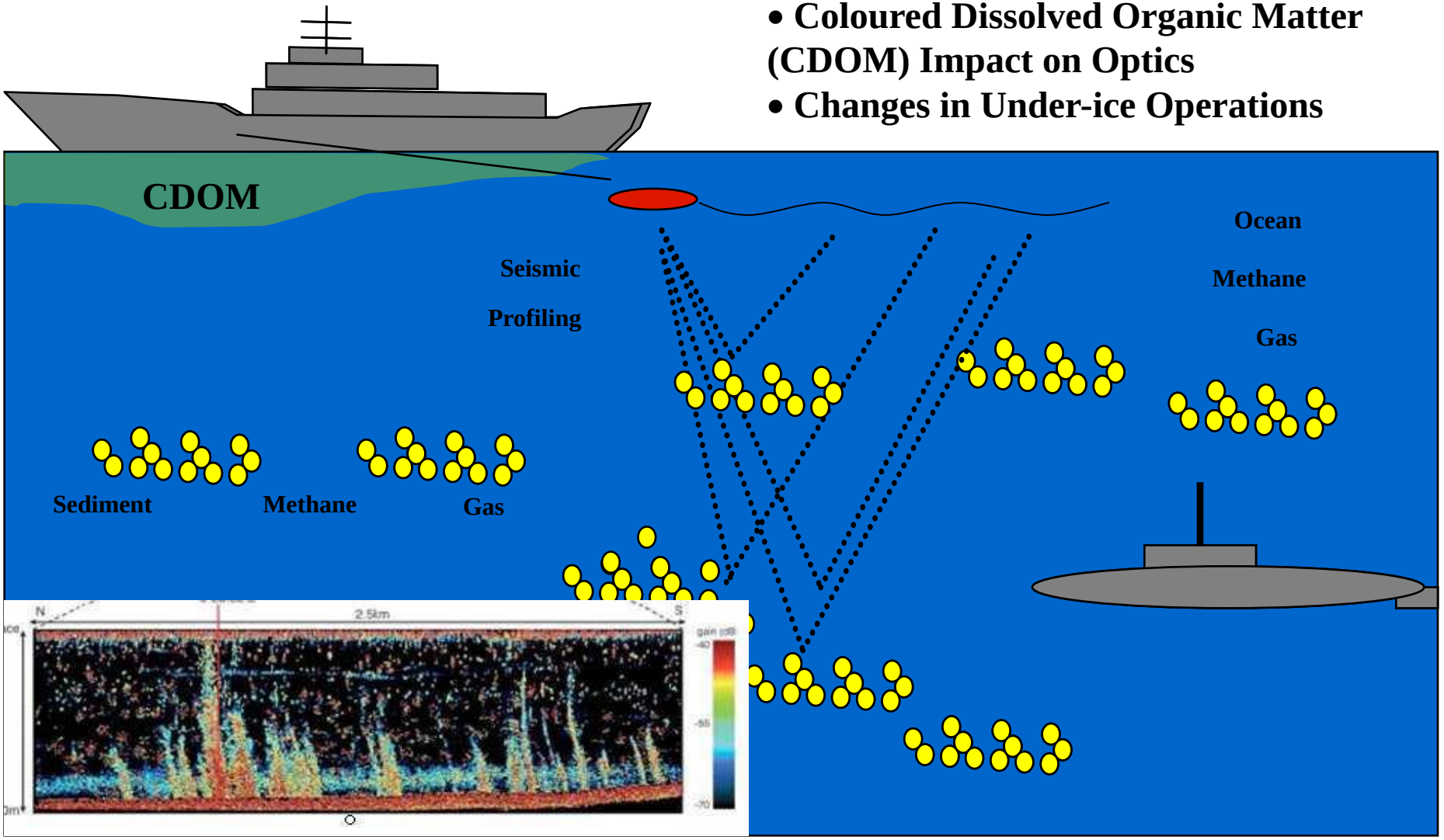
News media's interpretation:

"Massive Methane Melt off Siberia"

"Get ready for the methane apocalypse"

Methane Release Impacts on Navy Issues

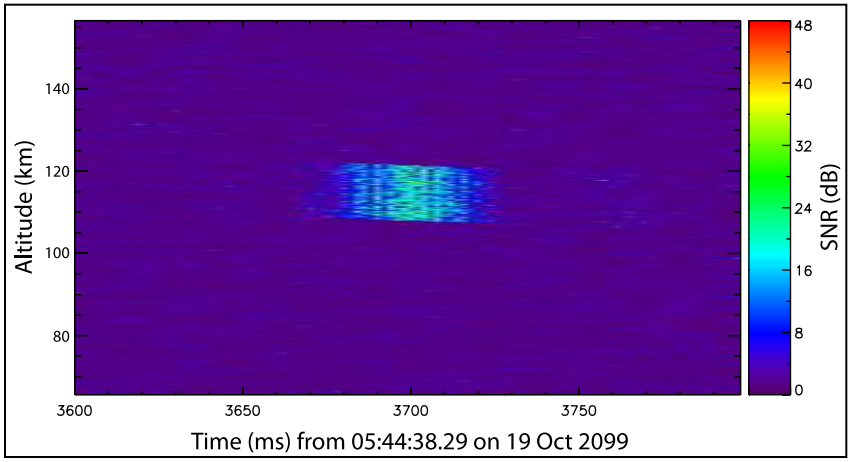
- **Changes to Acoustic Propagation**
- **Coloured Dissolved Organic Matter (CDOM) Impact on Optics**
- **Changes in Under-ice Operations**



Meteor RADAR Studies at Resolute Bay, Canada

Meteors deposit several tons of metallic ions into the atmosphere every day

These ions are believed to be catalyst sites for "Sporadic-E," a buildup of excess ionization in the atmosphere around 100 km in altitude



Sporadic-E is an atmospheric phenomenon that greatly reduces the performance of OTH RADARs

Arctic Communication Issues

Operational Problem:

In 2006, Monaco conducted 100 Year Anniversary of King Albert I's Arctic expedition of 1906.

Limited communication in the Arctic region.

Objectives:

Provided satellite communication service to the Monaco North Pole Expedition from April 10 - April 19, 2006.

Exploit unique opportunity to get first-hand experience using Iridium communication equipment in the harsh arctic environment.

Verify performance achieved with multi-channel Iridium modems to provide faster transfer of large images and files.

Since multi-channel Iridium modem was not ready in time for the expedition, NRL developed process to use multiple single channel modems to provide faster transfer of large images and files.

Capabilities Solution:

ONR/NRL owned Iridium satellite equipment was used to provide unclassified communication service.

Iridium phones and pagers were used for communication between the base station, dog sled teams and the Monaco Palace for daily public reports / interviews.

Multiple Iridium data modems were used to get weather/ice information from Moscow and to send video and images back to Monaco Palace for daily posting to the Internet.

Pagers allowed the team to leave the phones off conserving battery life. The base station could send text message to the pager when needed via the EMSS website.

Iridium antennas after a snow afternoon.

Iridium phone and modems at base station

NRL Iridium antenna pole at the base station

Issues:

- Unable to identify any other viable SATCOM communication services that cover the polar regions. Current system has an expected lifetime into the mid 2010s.
- Russians purchased Iridium phones two weeks prior to the expedition suggesting they do not have a viable option other than HF.
- It is unlikely that another private venture such as Iridium can currently make the business case for a LEO satellite system with polar coverage. Systems such as Globalstar with their inclined orbits and fewer satellites are more cost effective.

NRL Potential Collaboration and Licensing Activity

- **NRL's TTO has been contacted by both multi-national and several small companies interested in technologies related to:**
  - Acoustic sensing
  - Ice sensing, imaging and measurement
  - Visualization and mapping ice in water columns
  - Synthetic aperture radar
  - LIDAR
- **Interested companies include:**
  - TerraSond
  - Fugro

Collaboration with private businesses can lead to development of COTS capabilities needed in the future by Naval Forces

Scientific Development Squadron ONE (VXS-1)

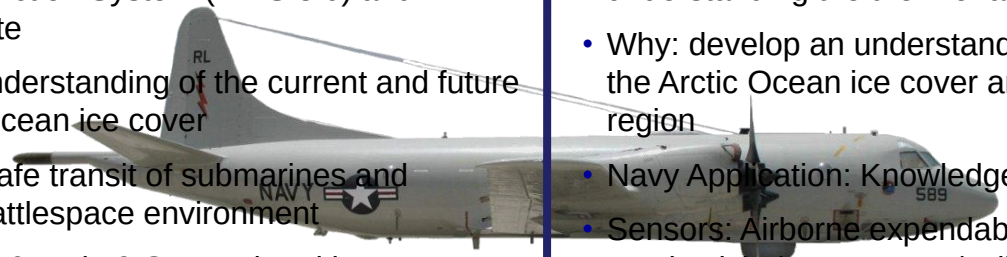
- **Provides airborne research capability**
- **Sensor and system test bed, airborne surrogate**
- **Worldwide deployable**
- **2 Theater Capable Research Configured NP-3D**
  - NRL / USGS / NGA
  - Joint IED TF
  - ONR
  - NSF / NOAA
- **1 AEW NP-3D**
  - MDA
  - NAVSEA
- **2 RC-12**
  - NRL / SOCOM
  - NRL / Remote Sensing
- **1 MZ-3A Airship**
  - JIEDDO
- **4 Scan Eagle UAS's**
  - NSCWDD
  - NEO
- **12 Officers, 76 Enlisted, 4 Civilians**

Airborne Laboratories

Arctic Airborne Geophysical Research Capabilities

Sea-Ice Thickness

- Capability – Measurement of extended profiles of sea-ice thickness, age and surface characteristics (age, snow-cover, contaminants)
- Modeling Component : validation and calibration of the Navy Polar Ice Prediction System (PIPS 3.0) and CRYOSAT II Satellite
- Why: develop an understanding of the current and future state of the Arctic Ocean ice cover
- Navy Application: Safe transit of submarines and knowledge of the battlespace environment
- Sensors : airborne 10 and 18 GHz radar altimeters, scanning lidar altimeter, thermal imager, hyperspectral imager, Multi-Band Synthetic Aperture Radar



Synoptic Arctic Water-Column Grid

- Capability – Acquisition of synoptic, large-scale grid of water-column data over the Arctic Ocean Basins
- Modeling Component – data needed to test various models of ocean circulation in a vastly undersampled region that is key to understanding the thermohaline circulation of the major basins
- Why: develop an understanding of the current and future state of the Arctic Ocean ice cover and the heat-transport budget of the region
- Navy Application: Knowledge of the battlespace environment
- Sensors: Airborne expendable bathy-thermograph and conductivity/temperature/salinity buoys to be dropped in leads in the ice from a long-range aircraft

** Note – capability can be combined with sea-ice measurements*

Remote Sensing and Definition of the Ice-Covered Continental Shelf Break

- Capability: Rapidly localizing the continental shelf-break by means of airborne remote sensing measurements in ice-covered regions that are difficult to survey by conventional shipboard methods
- Modeling component – forward and inverse crustal gravity and magnetic models
- Why: Direct application to sovereignty determinations under the Law of the Sea for underwater territories in the ice-covered Arctic
- Navy Application: Naval operations in the region
- Sensors – Airborne gravimeter, magnetometer, radar altimeter, precise aircraft trajectory determination via long-baseline, kinematic Global Positioning System

Naval Research Laboratory

Questions?

The Navy and Marine Corps Corporate Laboratory