Report on NGGPS Sea Ice Modeling Workshop

Feb 3-4, 2016 – Boulder, CO

Contributors to this report: Ligia Bernardet* (NOAA OAR ESRL and CU CIRES), Marika Holland* (NCAR), Janet Intrieri* (NOAA OAR ESRL), Richard Allard (NRL), Cecilia Bitz (UW), Robert Grumbine (NOAA NWS), Annarita Mariotti (NOAA OAR CPO), Eugene Petrescu (NOAA NWS ARH), Avichal Mehra (NOAA NWS), David McCarren (CNMOC National ESPC), Jessie Carman (NOAA OAR), and Louisa Nance* (NCAR)

*Also affiliated with the Developmental Testbed Center's Global Model Test Bed

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Executive Summary

- A sea ice modeling workshop was convened on February 3-4, 2016 in Boulder, CO with the primary goal of reaching a recommendation to NOAA's NGGPS program on the choice of a sea ice model for inclusion in the NCEP UGCS.
- Several sea ice modeling efforts, along with various earth-system modeling systems, were reviewed by workshop participants. It was noted that the majority of advanced sea ice models have similar physical parameterizations, and that the differences among advanced models is smaller than the uncertainty due to external forcing.
- Given that the use of a community-contributed and supported model in UGCS was raised as a priority for model selection, participants recommended the tentative adoption of the CICE model, pending follow-up testing and addressing concerns raised regarding model governance and differences in staggering between the grids used in the UGCS ocean models and CICE.
- The framework for follow-up testing was discussed and important points regarding resolution, domain, coupling, verification metrics, and observations were raised. The importance of the ocean model for ice model performance was also discussed, and will need to be a factor in the test design. These issues will be considered by a tiger team

formed to design and conduct the tests. Test results may also be used to prioritize future model development efforts.
- A variety of synergistic efforts in the scientific community were identified and recommendations for future model development were put forth.

Workshop Goals

The overarching purpose of this workshop was to inform NOAA on the inclusion and selection of a community-contributed sea ice model into the future NCEP UGCS, a prediction system being developed by the NOAA OST NGGPS program. Another workshop goal was to identify potential research and development opportunities and gaps. The UGCS will be a single, fully-coupled Earth modeling system with application to forecasts from days to seasons, spanning spatial scales from 1 to 25 km. While the sea ice model to be selected for inclusion in UGCS needs to have good performance for all forecast applications over these time and space scales, this workshop focused on the short- and medium-term sea ice forecast needs.

This workshop, which was hosted by the DTC's GMTB, brought together experts from the community to discuss the state of sea ice and coupled modeling systems, forecasting, and predictability to inform the selection of the UGCS sea ice model. Discussions also centered around enhancing collaborations and highlighting areas of needed research and development. Information about the workshop, as well as all presentations, can be found on the workshop website.

The first operational deployment of the UGCS, scheduled for April 2019, is expected to be a short-term atmosphere-only numerical weather prediction application. While a timeline for the initial operational capability of a coupled UGCS forecast application is yet to be determined, EMC leadership expressed the need to reach a decision on the selection of a sea ice model by September 2016. This timeline, created to allow NOAA/NWS/NCEP/EMC and GMTB to start advanced testing of the model in a coupled configuration, was one of the driving factors of the recommendation.

The simplified UGCS timeline is listed below.

- FY15. Test and evaluation of multiple atmospheric dynamic cores.
- FY16. Selection of single atmospheric dynamic core.
- FY17. Integration of UGCS model components (atmosphere, ocean, sea ice etc.) within the NEMS framework.

Workshop Sponsors, Organizing Committee, and Structure

This workshop was sponsored by:

- NOAA NWS
- NOAA OAR - CPO MAPP Program
- ONR

The organizing committee represented a broad group of stakeholders in sea ice modeling and was composed of Marika Holland (NCAR), Janet Intrieri (NOAA OAR ESRL), Richard Allard (NRL), Cecilia Bitz (UW), Robert Grumbine (NOAA NWS), Annarita Mariotti (NOAA OAR CPO), and Eugene Petrescu (NOAA NWS ARH).

The NGGPS sea ice workshop was scheduled immediately following, and in the same venue as, the ONR Sea State Sea Ice Forecasting workshop, which was aimed at assessing the performance of prototype sea ice and wave modeling initiatives led by NOAA ESRL and NRL in support of the ONR Sea State DRI field campaign. The Sea State deployment included wave-ice studies, atmospheric flux measurements, and sensor deployments from the research vessel Sikuliaq from September 30 through November 15, 2015 in the marginal ice zone. Similar efforts led by NRL in support of the Healy Arctic missions conducted in July – October, 2015 were also discussed.

By scheduling the two workshops in sequence, the NGGPS sea ice workshop benefitted from a larger community presence and from the lessons learned about short-term, high-resolution, sea ice forecasts in configurations both coupled and uncoupled with the atmosphere. The agendas for both workshops are provided in Appendix 1.

Perspectives on Community Modeling

A number of perspectives on community modeling were presented including information from Ligia Bernardet (NOAA ESRL GSD and CU CIRES), Marika Holland (NCAR) from the Community Earth System Modeling Project, and Adrian Turner (LANL). It was noted that a community modeling approach has significant benefits through capitalizing on the expertise of numerous scientists in the development and use of an individual model. In general, it was felt that for an effort to be a true "community model" more was required than just a freely available code base. For example, this could include community involvement in the model development strategy, the availability of documentation and training, and institutional support to enable community involvement in model development, testing, and use. Several ongoing efforts were highlighted that have incorporated elements of community modeling practices in these and other ways. These efforts have successfully built active and engaged communities that enhance the modeling system quality and capabilities.

Sea Ice Models and Prediction Systems Presented

Robert Grumbine (NWS NCEP) presented an overview of the NCEP Drift model and the KISS model. He discussed accumulated drift over of a period of N (1-16) days and summarized publications dating back to Nansen (1902) on how drift calculations were based on geostrophic wind speed and direction. A high-level summary of KISS was presented. KISS incorporates a superstructure consistent with ESMF, NEMS and NUOPC. Additional topics discussed included the testing of skill measures, bias corrections and potential freeze/melt rates.

Pam Posey (NRL-SSC) presented an overview of the U.S. Navy's operational Arctic Cap Nowcast/Forecast System (ACNFS) which is comprised of the LANL CICE4 coupled via the ESMF/NUOPC layer to HYCOM. The model domain extends from 40N to the Pole with a horizontal resolution of 3.5 km near the Pole. Ocean observations and ice concentration are assimilated into the system through the NCODA system. The ACNFS assimilates AMSR2 and SSMI/S ice concentration utilizing an ice mask from the NIC. The system produces a nowcast and 7-day forecast each day. Model output is pushed to the NIC and NWS Anchorage Forecast Office. The ACNFS will be replaced in the coming months by the GOFS 3.1, which is similar to ACNFS but covers both hemispheres. A description of the Navy's validation metrics for ice and ocean was presented. The metrics include ice edge location, ice thickness and ice drift versus observation. The Navy's ESPC, under development, includes a global atmospheric model (NAVGEM) coupled to CICE5.1; HYCOM (1.75-km resolution at the North Pole) with tides and WAVEWATCH III. A deterministic system will run for 16 days and an ensemble system with a minimum of 28 members will run weekly for 30 days. Model resources and timings on HPC platforms were presented.

Adrian Turner (LANL) presented an overview of LANL's sea ice modeling activities. CICE5.1 is structured on a quadrilateral "B" grid where the u- and v- component of velocity are located at the vertices while ice concentration and mass are at the center of the grid cell. The model is coded in FORTRAN 90 and is parallelized via a grid decomposition with MPI or OpenMP. Model input/output is in NetCDF. The model dynamics include an elastic-viscous plastic and elastic-anisotropic-plastic sea ice rheology and an incremental remapping advection scheme. The vertical thermodynamics include the Semtner 'zero' layer model, Bitz & Lipscomb thermodynamics and "mushy ice physics". Three melt pond representations in the model include the simple CESM formulation, topographic formulation where melt water runs to the thinnest category and level ice ponds. The ice thickness distribution typically employs 5 thickness categories. CICE includes a mechanical redistribution in which the convergence of sea ice causes the ridging thickness to be moved from thin to thick ice categories. CICE has two radiation scheme options: 1) CCSM3 in which the albedo depends on the temperature and thickness of the ice, and 2) Delta-Eddington which is a multiple scattering radiative transfer model; albedos are determined from inherent optical properties of sea ice. CICE is well documented and includes many additional options and features. Recent developments were discussed including the MPAS sea-ice model which uses Voronoi tessellation grid with variable resolution and should be released within the next 18-24 months. No new versions of CICE are planned past version 5.1 with the exception of bug fixes etc. The LANL "column package" was discussed. It is not publicly released, but is currently available through a collaborative agreement that includes certain conditions.

Axel Schweiger (UW Polar Science Center) presented an overview of PIOMAS. The system is composed of the POP ocean model which is on a generalized curvilinear grid. The sea ice model has a multi-category (12) ice thickness and enthalpy distribution with a multi-category snow depth distribution. The sea ice dynamics model uses a teardrop-plastic rheology. It is one-way nested to a global ice-ocean model (GIOMAS) for open boundary conditions. Tidal forcing includes up to 8 constituents. A new floe-size distribution has been added and a melt pond parameterization is in development. PIOMAS assimilates satellite sea ice concentration and sea surface temperature. The atmospheric forcing to drive the modeling system is the NCEP/NCAR Reanalysis (default), but they have also used ECMWF, ERA Interim, MERRA, CFSv2, etc. Forecasts are made on a seasonal and 9-day range. The mean ice thickness is calibrated with in situ ice draft/thickness data from the period 1975-2009. Ice motion is calibrated with IABP buoy data from 1979-2010. Additional tuning parameters include albedo and the surface air drag/roughness. PIOMAS is a regular contributor to SIPN and the ice thickness/volume is widely used for model comparison and initialization of GCM model experiments. There is no user level documentation, but numerous PIOMAS-related publications are in peer-reviewed journals.

Mitch Bushuk (Princeton University and GFDL) presented an overview of sea ice prediction in the GFDL model framework. A summary table of the current GFDL seasonal forecasting models included CM2.1, FLOR, FLOR-FA and Hi-FLOR. The atmospheric component for all 4 models is AM2 (ranging from AM2.1 (2°, 24L) to AM2.6 (1/4°, 32 L). The MOM4 ocean model (1°, 50L), SIS1 sea ice model (1°; 5 categories), LM2/3 land model are all components of the seasonal forecasting systems. All four seasonal models are initialized using ECDAv3.1. SIS1 is the current seasonal forecast model. SIS2 model physics improvements were presented. The common aspects from SIS1 used in SIS2 include an EVP rheology, ice thickness distribution with multiple ice thickness categories and fast atmospheric coupling timestep. New SIS2 features include a C-grid differencing to be consistent with the ocean model; this allows for a better representation of ice transport through channels and forward compatibility with the MOM6 ocean model; revised thermodynamic algorithms (CICE4-like); Delta-Eddington radiative scheme; ice age tracer; and a Git version control/GitHub, which allows for shared development. Future (planned) SIS2 model physics improvements include: melt ponds, mushy physics, ridging parameterization, embedded sea ice dynamics into MOM6 and a unified, physically-based approach to ice-ocean interactions. SIS2 is moving towards CICE5-like model physics, but in a framework consistent with a GFDL coupled modeling approach. GFDL seasonal sea ice forecasting was discussed in which 10-12 ensemble members are included in forecasts from 1982-present. Examples of arctic sea ice extent forecast skill were presented along with a study showing the importance of initial conditions in examining regional forecast skill.

Xingren Wu (IMSG) presented an overview of the CFSv2 Sea Ice modeling program. The GFDL Simulator is based on the EVP ice dynamics model of Hunke and Dukowicz (1997) and uses the Winton (2000) 3-layer thermodynamic model with an ice thickness distribution. The model has a 2-layer sea ice and 1-layer snow configuration and 5 categories of sea ice. The sea ice and ocean models are on a tripolar grid to avoid a singularity at the North Pole. A schematic showing the sea ice component in the CFSv2 assimilation and forecast system was presented. In CFSR/CFSv2, sea ice concentration is assimilated by nudging the concentration towards the observed value. A CFSR reanalysis of the atmosphere, ocean, and sea ice has been performed for the period of 1979-2010. The CFSv2 operational products are available to the public. Graphical depictions of the CFSR sea ice bias and standard deviations for September for the period of 1982-2009 were presented. Comparisons of ice thickness and ice volume versus ICESat, PIOMAS and CFSR were also shown. Future development includes NEMS coupling between the atmosphere, land, ocean, waves, and aerosols as part of NGGPS. Data assimilation plans include assimilating ice concentration and thickness using a Local Ensemble Transform Kalman Filter. Plans for CFSv3 include consideration of more than one sea ice model including CICE, SIS2 and KISS.

Frederick Dupont (Environment Canada) presented an overview of the operational Canadian Regional Ice-Ocean Prediction System (RIOPS). The system is composed of CICE4 coupled to NEMO 3.1 with horizontal resolutions ranging from 2-8 km. A graph depicting ice velocities bias relative to the IABP was presented for the period 2003 – 2008. They found that the ice velocity can be improved by changing the ocean model physics; the 1.5 turbulence scheme (H05f) yielded better results than the 2.5 k-eps. Ice thickness from RIOPS versus ICESat for the Fall 2007 was shown. A grounded landfast ice represented by a basal stress parameterization is included in RIOPS. The system runs with a continuous tide cycle. A spectral nudging technique is used to nudge toward the global ocean analysis at a coarser (1/4°) resolution. Ice concentration from the 3D-VAR regional analysis is used to spread the ice concentration increment among 10 categories. RIOPS is evaluated using RadarSat analyzed ice concentration, IMS land/sea mask, IABP buoys for ice velocity and Class-4 (GODAE) metrics for ocean characteristics. Examples of error metrics were presented for ice concentration and ice velocity for the period of October 2014 – July 2015. Future plans include ocean data assimilation to begin testing in summer 2016, upgrade to CICE5, extensions of the model grid to the Pacific and the interactions with surface waves (ocean and ice). Environment Canada will be supporting the YOPP with their global/regional modeling systems.

Predictability Issues at Various Scales

Robert Grumbine (EMC) and Cecilia Bitz (UW) made presentations on the many aspects of sea ice that are desirable to predict and on the physical processes that need to be represented in the models to realize predictability. These aspects include ice presence (usually with a concentration above 15%), thickness, snow depth, first ice-free date, and freeze-up date. Although many current operational systems can and do predict all of these quantities, at this time only the predictability of the first two (presence and thickness) have been extensively explored.

Sea ice has predictability for two principal reasons. First, sea ice is a relatively slowly varying material, so knowledge of the current conditions offers information about the future. Second, sea ice is strongly influenced by the ocean, which is another slowly varying component. While climate forcing is causing sea ice changes, for the time scales discussed it is precisely the predictability of the climate transients (local/regional ice distributions) that are of interest.

Sea ice is a relatively slowly varying material due to its latent heat storage and insulating properties. Sea ice thickness anomalies at a given geographical point have a decorrelation time of about a year. However, by following the mean drift, the decorrelation time increases by about 50% or more. Because of the heat storage and insulating properties, the timescale of variability increases with thickness.

Due to its control of the melting rate in spring, the thickness of sea ice in winter strongly influences the predictability of sea ice area in the following summer. Indeed, there is a high correlation between ice thickness in winter and spring with sea ice presence the following summer (Holland et al. 2011). Due to the high uncertainty in forecasts of thickness of sea ice, predictability of sea ice area is lowest in the spring.

In a thinner sea ice regime, the sea ice thickness strongly influences subsequent seasons' thaw and freeze-up. A positive sea ice area anomaly in the fall growth season is associated with early date of freeze-up, creating a local positive thickness anomaly that slows the ice retreat during the next spring, and results in a local positive sea ice area anomaly. This mechanism can repeat from one year to another (Guemas et al. 2014).

Sea surface temperature persistence can also drive season-to-season predictability. A negative sea ice area anomaly in spring (less cover) is associated with a warmer sea surface temperature anomaly due to atmosphere fluxes. The warmer sea surface temperature can lead to a negative sea ice area anomaly the following fall, during freeze-up (Guemas et al. 2014).

Recommendation for Choosing a Sea-ice Model for UGCS

The modeling systems discussed during the workshop were briefed by representatives from GFDL, NOAA ESRL, NRL, LANL, Environment Canada, UW-APL and NWS NCEP. Many of the sea ice models have advanced physics, and the physics packages used in the various models are comparable, placing the various models in a similar state of readiness regarding representation of sea ice physical process. The exception is KISS, which is a simplified statistical model. In addition, several of these systems are regular contributors to SIPN. Many systems use CICE4 or CICE5, while GFDL is implementing CICE5 physics into SIS2 since their MOM6 ocean model is on a C grid, while CICE uses a B grid.

Given that the sensitivity to different sea ice models is likely smaller than the uncertainty in forcing (e.g., by the atmosphere or ocean), and the short timeline in which decisions need to be made, the agreed upon recommendation to the NGGPS program is to avoid investing resources in a model intercomparison exercise, and instead focus the effort in testing and evolving a single "advanced" sea ice model. Since the existence of a community of model users and developers was put forth as a criterion of great importance in the model selection process, workshop participants endorsed the selection of CICE for inclusion in UGCS, pending testing of its performance in coupled mode for short-term NWP, and addressing the issues listed below.

CICE is a mature model, which is being used for short-term sea ice prediction in several efforts throughout the community, such as by NRL (Hebert et al. 2015), in the Canadian RIOPS, in ESRL-RASM, and in the US Navy's ACNFS. CICE is also extensively used by the climate community as part of CESM and several of its physical parameterizations have been incorporated in SIS. Finally, CICE is already being tested as a NEMS component (fully coupled with GSM and MOM5) for inclusion in CFS v3. Due to its large community of users, several tools for plotting and conducting diagnostics are available through peer-to-peer distribution mechanisms.

Two concerns regarding the use of CICE need to be addressed before it can be adopted as part of UGCS.

- CICE uses an Arakawa B-staggered grid. A large fraction of the physics represented by CICE (with the exception of rheology, momentum and horizontal transport) is available as a column model, which can be used in an arbitrary horizontal grid of a host model. For example, GFDL's SIS is comprised of CICE and MOM both in a C grid; HYCOM also uses a C grid. When implementing CICE as part of UGCS, it is important to mitigate undesirable numerical issues that can possibly result due to differences in grid staggering between component models.

- CICE is primarily developed by DOE LANL, with internal governance. It was discussed how a more open governance system would be desirable to meet NOAA's mission needs if CICE was to be adopted by UGCS. The possibility of forming a consortium for CICE governance and support, including DOE, Navy, NOAA, NSF and primary contributors to CICE, was discussed as a possible framework to consider to ensure that the mission needs of the operational prediction agencies using CICE may be incorporated into development priorities.

The following action items were identified as next steps after the workshop:

- Post this workshop report (Responsibility: GMTB; by March 31, 2016)
- Form tiger team to plan sea ice model test (Responsibility: GMTB, with team participation from other institutions; by March 31, 2016)
- Execute test and evaluate results. Present test results to the community for feedback (Responsibility: GMTB, with collaboration from EMC; by September 30, 2016)
- Investigate possible CICE consortium (Responsibility: GMTB will foster inter-institution conversations about sea ice code management; by December 31, 2016)

Numerical issues due to B-versus C-grid staggering differences between the coupled sea ice and ocean models will be investigated by EMC and collaborators as a by-product of applications being designed and implemented in NEMS:

  - UGCS Regional: HYCOM-KISS (now)
  - UGCS Seasonal: MOM5-CICE (now)
  - UGCS Seasonal: HYCOM-CICE (now)
  - UGCS Seasonal: MOM6-CICE/KISS (future)

The timeline for these comparisons will be determined by the progress made on these NEMS-based applications.

Considerations for the Sea Ice Model Test Design

During the BOGs, workshop participants discussed several topics regarding the design for the sea ice model tests. These are non-binding recommendations that will be taken into consideration by the tiger team when designing the tests.

- **Initialization**. The initialization of the sea ice model is a critical aspect of the forecast system skill and needs to be carefully considered.
- **Coupling**. Testing should be conducted both in standalone and coupled (with atmosphere and ocean) models. The choice of ocean and atmospheric models needs to be carefully considered as it will be influential in determining the outcome of the test.
- **Ensembles**. Ensemble runs should be considered for testing in 2016 or beyond.
- **Time scales.** Relevant time scales for assessment are 5 days, 0-16 days and 0-30 days. Seasonal timescales should also be considered as part of these tests.
- **Datasets for evaluation**. Both field experiment data and routine, well-validated data from satellite, buoys, etc. should be employed. Specific suggested datasets are listed in the BOG2 report.

- **Assessment goals.** Models should be assessed with an eye toward the improvement of operational forecast products.
- **Metrics and baseline**. The evaluation could benefit from the use of traditional and non-traditional metrics, possibly including a score card (a list of metrics can be found in the BOG2 report). A framework for the test could be improvement over a relevant baseline (such as persistence or uncoupled model). Case studies could be employed.
- **Domain**. Testing should be done on a global domain, and careful consideration should be given to choice of horizontal resolution for maximum relevance to UGCS NWP operations.
- **CICE configuration**. Evaluation could include the different parameterizations and configurations of CICE.
- **Computational resources.** Testing should inform needs for computational resources, and not vice versa. In other words, the model configuration for testing should not be constrained by today's HPC resources.

Synergistic Activities, Opportunities for Collaboration and Future Directions for Research and Development

Overall, the workshop revealed a broad suite of sea ice research, modeling and prediction activities ongoing or planned nationally and internationally, that provide context for the envisioned NOAA sea ice forecasting initiative as part of the unified EMC coupled model. In addition to those already discussed in previous sections of this report, other relevant activities presented at the workshop included the following:

- The Sea Ice Prediction Network (SIPN), which aims to improve sea-ice forecasts, advance sea-ice outlooks and improve sea-ice models. The activity currently provides an intercomparison of May-July outlooks for September sea-ice conditions (e.g., September minimum sea ice extent, first ice free day, etc.) based on a variety of tools including dynamical models.
- The NOAA OAR CPO, which includes three programs relevant to sea-ice forecasting, involving NOAA and the external community: the ARP, serving as the focal point for NOAA Arctic observations; the CVP program, with various research projects on understanding Arctic sea-ice mechanisms and predictability; the MAPP program including research and development in support of the EMC unified system, the NMME initiative, including seasonal sea ice hindcasts/forecasts from several models, and a planned sub-seasonal to seasonal prediction multi-model experiment including sea ice forecasts (SubX).
- NOAA OAR research on sea ice forecasting at several of its laboratories, which include GLERL research and development on coupled ice-ocean forecasting.
- The National ESPC, an effort to coordinate research to operations across the various agency programs. Research foci include predictability of sea ice extent and seasonal ice free dates on weekly to seasonal timescales. Several targeted projects in this area,

augment on-going agency programs efforts. Other relevant US coordination initiatives include USGCRP interagency research activities and the IARPC.
- The Navy ONR broad suite of observational, process study, data assimilation, modeling and prediction activities, in support of its mission goals.
- The UK Met. Office community modeling efforts, including sea ice forecasting.
- The WWRP hours-to-seasonal Polar Prediction Project and the WCRP seasonal-to-decadal Polar Climate Predictability Initiative, supporting the emerging WMO GIPPS. A YOPP is planned for 2017-2019, which provide new data and model experiments.

The above mentioned activities are synergistic to the selection and further improvement of the sea-ice model as part of the EMC unified system and provide opportunities for community collaboration. Observational data and model data from other prediction systems provide benchmarks for validation and terms of comparison to guide the model selection. Over the next few years, new observations, research on processes and predictability, and development of models and prediction systems will continue to advance community sea-ice forecasting capabilities. Discussions at the workshop acknowledged the importance of having EMC sea-ice modeling activities be well connected with synergistic community activities to inform model selection outcomes and also guide future system evolution. Some topics singled out as priorities for modeling system development were (not prioritized):

- Higher resolution
- Rheology
- Isostasy
- Coupled issues
- Ice type (pancake, grease, etc.)
- Snow on sea ice
- Marginal ice zone and ice edge processes in general
- Sea ice model applications to NWP
- Modular software infrastructure that allows extending the UGCS sea ice model to accommodate future developments in dynamics, thermodynamics, etc.
- Need for better observations of ice thickness to evaluate the performance of the models and the nature of thickness changes

In the short term, it was recommended that results from the test runs performed by the core group be publicly presented for feedback (e.g., at webinars or workshops), as a means to enable community input. In the longer term, fostering future community collaboration on research and development will be key to ensuring an evolving state-of-art sea ice modeling system for EMC.

Appendix 1. Agenda

DAY 1 / Tuesday, February 2, 2016

Sea State Modeling/Forecasting Workshop

0830 - 0840 **Workshop Motivation**

- Workshop motivation, goals, anticipated outcomes - *Scott Harper (ONR)*

0840 - 0910 **Sea State Cruise Overview**

Cruise overview, ocean & sea ice obs for model validation, any initial results, analysis plans - *Jim Thomson (UW)*

Forecast usage, atmospheric obs for model validation, any initial results, analysis plans - *Ola Persson (NOAA ESRL)*

0910 - 1010 **Sea State Modeling & Forecasting**

Each speaker to describe the forecast model, system components, coupling, initialization fields, boundary conditions, data assimilation; bias corrections; validation strategy & examples; process study foci & analysis plans; hindcasts; limits of predictability; testing & model adjustments planned for next freeze-up season

- WW3 Wave Forecasts - *Erick Rogers (NRL)*
- COAMPS - *Dave Hebert (NRL)*
- RASM-ESRL - *Amy Solomon (NOAA ESRL)*

1025 - 1055 **Perspectives on Assessing Skill & Metrics**

- *Bob Grumbine (NWS NCEP)*
- *Andrew Slater (NSIDC)*
- *Matt Newman (NOAA ESRL)*

1100 - 1200 **Break-Outs** - Part 1

Four rotating groups to successively build-out input for each topic listed below. Each group rotates every 30 mins (2 BOG rotations before lunch & 2 after lunch). Assigned moderator & rapporteur stay with each topic to capture consistent notes.

BOG1: Observations for Validating/Evaluating/Improving Model Performance

Lead – Jim Thomson; Note-taker - Janet Intrieri

BOG 2: Understanding Key Processes

Lead - Amy Solomon; Note-taker – Pam Posey

BOG 3: Intercomparisons/Metrics

BOG 4: Model Improvement Plans

Lead – Annarita Mariotti ; Note-taker – Mimi Hughes

1200 - 1245 Working Lunch Discussion

1245 - 1345 **Break-Outs** - Part 2

1345 - 1405 Break to gather thoughts for report-outs

1405 - 1535 **Break-Out Reports**

- Report-outs from the 4 BOG Leads
- Develop comprehensive list of input from all groups on model intercomparison strategies & skill metrics; identified process studies; analysis priorities; improvement & testing runs, new development; etc.

1545 -1645 **Outline Next Steps for Forecast Comparisons, Process Understanding, & Model Improvement Plans**

- Prioritize tasks from compiled BOG list
- Outline next action steps, POC's, timeline, deliverables, etc.
- Discuss next field season opportunities & possible Arctic testbed exercise
- Discuss missing pieces, gaps, coordination & activities that need funding
- Assign presenter for next day's summary presentation to NGGPS
- Determine workshop community output piece & ongoing communication plan

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DAY 2 / Wednesday, February 3, 2016

0830 - 0900 **Workshop Welcome** Janet Intrieri (NOAA ESRL)
NGGPS deliverables, timeline, & workshop goals - *Hendrik Tolman (NWS NCEP)*
Sea State Workshop Recap - *Rick Allard (NRL)*

0900 - 1000 **Perspectives on Community Sea Ice Model Needs & Criteria** Rick Allard (NRL)

- Perspectives on facilitating a "community" model
  - *Ligia Bernardet (NOAA ESRL)*
  - *Marika Holland (NCAR)*
  - *Adrian Turner (LANL)*
- An overview of sea ice coupled processes that give rise to predictability at various forecasting timescales and their representation within models
  - *Wx-scale: Bob Grumbine (NWS NCEP)*
  - *Seasonal-scale: Cecilia Bitz (UW)*
- An overview of envisioned prediction products out of the NGGPS in view of their application -e.g., extent? thickness? lead time? uncertainty quantification? resolution etc.
  - *Gene Petrescu, Becki Heim (NWS Alaska Region)*
- Perspectives on verification/criteria for NGGPS sea ice model selection
  - *Bob Grumbine (NWS NCEP)*

1020 - 1230 **Candidate Model Round-Up** Cecilia Bitz (UW)
Current Wx-Scale to Seasonal Scale Sea-ice prediction systems

- Prediction intercomparison example - *Cecilia Bitz (UW)*
- Current status of sea ice coupling in NEMS/NGGPS *Dave Bailey (NCAR)*
- Presentations of candidate models

[Presentations should include overview info, initializations, processes, readiness/maturity, feasibility of community model configuration and NEMS compatibility, code management philosophy, processes represented, initialization, boundary conditions, outputs, applicability limits, future envisioned development path/support, computational costs, code/documentation availability, skill metrics/criteria/experiments/data used for evaluation for each model; behavior as part of coupled models, etc.]

- *NWS Drift & KISS Models- Bob Grumbine (NWS NCEP)*
- *U.S. Navy ACNFS/GOFS 3.1 - Pam Posey (NRL)*
- *LANL CICE - Adrian Turner (LANL)*
- *UW PIOMAS - Axel Schweiger (UW)*
- *GFDL-SIS2 - Mitch Bushuk (NOAA GFDL)*
- *NWS CFSv2 SIS - Xingren Wu (NWS NCEP)*
- *Canadian Model - Fred DuPont (EC)*
- Discussion of common model threads, capabilities, products, feasibility, etc. based on the presentations

1230 - 1330 Working Lunch Discussion

1330 - 1530 **Model Selection Criteria/Skill/Testing - Break-Outs** Janet Intrieri (NOAA ESRL)
BOG 1 Room 1214: *Develop criteria for the sea ice model selection that consider the unified model applications and community modeling support*
Lead: Bob Grumbine; Note-taker: Becki Heim
BOG 2 Room 2503: *Determine skill metrics for testing candidate models*
Lead: Avichal Mehra, NOAA/NWS/EMC; Note-taker: Mitch Bushuk
BOG 3 Room 2603: *Provide input on model testing methodology & goals, mechanism for reviewing results, and delivery of recommendation*
Lead: Rick Allard, NRL; Note-taker: Frederick DuPont
BOG 4 Room 2607: *Model development path/community engagement*
Lead: Marika Holland; Note-taker:Adrian Turner

1600 - 1645 **Break-Out Group Reports & Plenary Discussion** Annarita Mariotti (NOAA CPO)
- Report-outs from the 4 BOG leads
- Develop comprehensive list of input from all groups; summarize

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DAY 3 / Thursday, February 4, 2016

0830 - 0945 **Other Key Considerations** Marika Holland (NCAR)
- SIPN Update - *Cecilia Bitz (UW)*
- Current status of sea ice coupling in NEMS/NGGPS - Dave Bailey (NCAR)
- CPO Sea Ice Projects - *Annarita Mariotti (NOAA CPO)*
- ESPC Sea Ice Projects - *Jessie Carman (NOAA ESPC)*

- ONR Update - *Scott Harper (NRL)*
- GLERL Sea Ice Forecasting Projects – *Jia Wang (NOAA GLERL)*
- UKMet Office Community Modeling Efforts – *Ed Blockley (UKMet)*
- Polar Prediction Project - *Chris Fairall (NOAA ESRL)*
- UKMet Office Community Modeling Efforts – *Ed Blockley (UKMet)*

1010 - 1200 Outline Next Steps - Ligia Bernardet (NOAA ESRL)

- Summarize NGGPS deliverables, timeline, etc.
- Discuss coordination opportunities and needs
- Develop specific comparisons/testing projects and participants
- Capture gaps and desired evolution pathway over next few years to meet needs
- Discuss/finalize workshop recommendations/output

1200 **Workshop Adjourn**

Appendix 2. List of Participants

First Name	Last Name	Affiliation
Richard	Allard	Naval Research Laboratory
David	Bailey	NCAR
Neil	Barton	Naval Research Laboratory
Ligia	Bernardet	NOAA ESRL GSD
Cecilia	Bitz	U Washington
Rainer	Bleck	NOAA ESRL
Mitch	Bushuk	Princeton University
Jessie	Carman	NOAA/OAR
Philip	Chu	NOAA/GLERL
Christopher	Cox	CIRES/NOAA-ESRL
Richard	Cullather	NASA GMAO
Florence	Fetterer	NSIDC, CIRES
Andrey	Grachev	NOAA ESRL / University of Colorado CIRES
Robert	Grumbine	NOAA/NWS/NCEP
Scott	Harper	Office of Naval Research
David	Hebert	Naval Research Laboratory
Becki	Heim	NWS Alaska Sea Ice Program
Sean	Helfrich	NOAA/NIC
Marika	Holland	NCAR
Mimi	Hughes	NOAA ESRL and CIRES
Janet	Intrieri	NOAA ESRL
Yi	Jin	Naval Research Laboratory
Philip	Jones	Los Alamos National Laboratory
Nicole	Kurkowski	NWS
Paul	Kushner	University of Toronto
Annarita	Mariotti	NOAA Climate Program Office
Wieslaw	Maslowski	Naval Postgraduate School
Jeremy	Mathis	NOAA
Dave	McCarren	CNMOC/National ESPC
Avichal	Mehra	NWS/NCEP/EMC
Louisa	Nance	NCAR
Matt	Newman	University of Colorado/CIRES and NOAA/ESRL/PSD
Caryn	Panowicz	US National Ice Center
Ola	Persson	CIRES/NOAA/ESRL
Paul	Pestieau	Canadian Ice Service
Gene	Petrescu	NWS ARH ESSD
Pamela	Posey	Naval Research Laboratory
Erick	Rogers	Naval Research Laboratory

Ignatius	Rigor	Polar Science Center, Applied Physics Laboratory, University of Washington
Andrew	Roberts	Naval Postgraduate School
Axel	Schweiger	University of Washington/APL/PSC
Anna	Shlyaeva	NOAA/University of Colorado
Andrew	Slater	NSIDC, University of Colorado
Amy	Solomon	NOAA/University of Colorado
Ivanka	Stajner	NOAA/National Weather Service
Adrian	Turner	Los Alamos National Laboratory
Alan	Wallcraft	Naval Research Laboratory
Jia	Wang	NOAA Great Lakes Environmental Research Laboratory
Shouping	Wang	Naval Research Laboratory
Xingren	Wu	EMC/NCEP/NOAA
Yongfei	Zhang	University of Washington

Appendix 3. List of Acronyms

ACNFS - Arctic Cap Nowcast/Forecast System
AK - Alaska
AM - Atmospheric Model
AMSR2 - Advanced Microwave Scanning Radiometer 2
APL - Applied Physics Lab
APL - Applied Physics Laboratory
ARH - Alaska Region Headquarters
ARP - Arctic Research Program
BOG - Break Out Group
CCSM - Community Climate System Model
CESM - Community Earth System Model
CFS - Climate Forecast System
CFSR - Climate Forecast System Reanalysis
CICE - The Los Alamos Sea Ice Model
CIRES - Cooperative Institute for Research in the Environmental Sciences
CM - Climate Model
CNMOC – Commander, Naval Meteorology and Oceanography Command
CU - University of Colorado
CPO - Climate Program Office
CVP - Climate Variability and Predictability
DOE - Department of Energy
DRI - Departmental Research Initiative
DTC - Developmental Testbed Center
ECDA - Ensemble Coupled Data Assimilation
ECMWF - European Centre for Medium-Range Weather Prediction
EMC - Environmental Modeling Center

ERA - ECMWF ReAnalysis
ESMF - Earth System Modeling Framework
ESPC – Earth System Prediction Capability
ESSD -Environmental and Scientific Services Division
ESRL - Earth System Research Laboratory
EVP - Elastic Viscous Plastic
FLOR - Forecast-Oriented Low Ocean Resolution
FLOR-FA - FLOR - Flux Adjustment
FY - Fiscal Year
GCM - General Circulation Model
GFDL - Geophysical Fluid Dynamics Laboratory
GIOMAS - Global Ice-Ocean Modeling and Assimilation System
GIPPS - Global Integrated Polar Prediction System
GLERL - Great Lakes Environmental Research Laboratory
GMAO – Global Modeling and Assimilation Office
GMTB – Global Model Test Bed
GODAE - Global Ocean Data Assimilation Experiment
GOFS - Global Ocean Forecast System
GSD - Global Systems Division
GSM – Global Spectral Model
Hi-FLOR - High-Resolution FLOR
HPC - High-Performance Computing
HYCOM - Hybrid Coordinate Ocean Model
IABP - International Arctic Buoy Program
IARPC - Interagency Arctic Research Policy Committee
ICESat - Ice, Cloud, and Land Elevation Satellite
IMS - Interactive Multisensor Snow and Ice Mapping System
IMSG - IM Systems Group
KISS -- Keeping Ice'S Simplicity
LANL – Los Alamos National Laboratory
LM - Land Model
MAPP - Modeling, Analysis, Predictions and Projections
MERRA - Modern-Era Retrospective Analysis for Research and Applications
MPAS - Model for Prediction Across Scales
MOM – Modular Ocean Model
MPI - Message Passing Interface
NASA - National Aeronautics and Space Administration
NAVGEM - NAVy Global Environmental Model
NCAR - National Center for Atmospheric Research
NCEP – National Centers for Environmental Prediction
NCODA - Navy Coupled Ocean Data Assimilation
NEMO - Nucleus for European Modeling of the Ocean
NEMS – NOAA Environmental Modeling System
NIC - National Ice Center

NGGPS – Next Generation Global Prediction System
NMME - North-American Multi-Model Ensemble
NOAA – National Oceanic and Atmospheric Administration
NRL - Naval Research Laboratory
NSIDC – National Snow and Ice Data Center
NUOPC - National Unified Operational Prediction Capability
NWP - Numerical Weather Prediction
NWS - National Weather Service
OAR - Oceanic and Atmospheric Research
ONR - Office of Naval Research
OST - Office of Science and Technology
PIOMAS - Panarctic Ice Ocean Modeling and Assimilation System
POC - Point of Contact
POP - Parallel Ocean Program
PSC – Polar Science Center
QA - Question and Answer
RASM - Regional Arctic System Model
RIOPS - Regional Ice-Ocean Prediction System
SIPN - Sea Ice Prediction Network
SIS - Sea Ice Simulator
SSC - Stennis Space Center
SSMIS - Special Sensor Microwave Imager/Sounder
UGCS - Unified Global Coupled System
UKMet - United Kingdom Meteorological Office
UW - University of Washington
WCRP - World Climate Research Programme
WWRP - World Weather Research Programme
YOPP - Year of Polar Prediction

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