SEA ICE OUTLOOK
2016 Report

Core Requirements for Pan-Arctic Contributions:
* REQUIRED

1. *Name of Contributor or name of Contributing Organization and associated contributors as you would like your contribution to be labeled in the report (e.g., Smith, or ARCUS (Wiggins et al.)).

Naval Research Laboratory (NRL), Marine Meteorology and Oceanography Divisions. Label as NRL_atm-ocn-ice

1b. (Optional but helpful for us): Primary contact if other than lead author; name and organization for all contributors; total number of people who may have contributed to your Outlook, even if not included on the author list.

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*Note, the NRL global coupled modeling group includes many more scientists. This author list only represents the main contributors to this report.

2. * Contributions submitted by a person or group not affiliated with a research organization, please self-identify here:
   _____ Yes, this contribution is from "Citizen Scientists."

3. * Do you want your contribution to be included in subsequent reports in the 2016 season?
   ____X___ Yes, use this contribution for all of the 2016 SIO reports (this contribution will be superseded if you submit a later one).
   _____ No, I/we plan to submit separate contributions for subsequent reports.
   _____ No, I only want to participate this time.

4. *"Executive summary" of your Outlook contribution: in a few sentences (using 300 words or less) describe how and why your contribution was formulated. To the extent possible, use non-technical language.

The projected Arctic minimum sea ice extent from the Navy's global coupled atmosphere-ocean-ice modeling system is 4.8 million km^2. This projection is the average of an 11 member ensemble. The range of the ensemble is 4.4 to 5.3 million km^2. Note that our ensemble range does not represent a full measure of uncertainty, and the system is currently in a development stage.

5. *Type of Outlook method:
   _X_dynamic model ___statistical ___heuristic ____mixed or other (specify)

6. *Dataset of initial Sea Ice Concentration (SIC) used (include name and date; e.g., "NASA Team, May 2016"):

Forecasts were initialized from the pre-operational US Navy Global Ocean Forecasting System (GOFS) 3.1 for the ocean and sea ice using the Navy Coupled Ocean Data Assimilation (NCODA) system. The ice model assimilated SSMIS and AMSR2 ice concentration products. Atmospheric initial conditions were from the operational NAVy Global Environmental Model (NAVGEM) using the Naval Research Laboratory Atmospheric Variational Data Assimilation System (NAVDAS-AR).

7. Dataset of initial Sea Ice Thickness (SIT) used (include name and date):

The ensemble forecasts were initialized using ice thickness from the GOFS 3.1 restart files on the appropriate start date. Ice thickness products are not assimilated by GOFS 3.1.

8. If you use a dynamical model, please specify:

a) Model name: Navy Global Coupled Earth System Model

b) Information about components, for example:

Component	Name	Initialization (e.g., describe Data Assimilation)
Atmosphere	NAVGEM	DA: NAVDAS-AR
Ocean	HYCOM	DA: NCODA
Ice	CICE	DA: NCODA assimilating SIC only

c) Number of ensemble members and how they are generated:

Eleven ensemble members were completed using a time-lagged approach. Model forecasts started on 2016-05-01 12Z, 2016-05-02 12Z, 2016-05-03 12Z, 2016-05-07 12Z, 2016-05-09 12Z, 2016-05-14 12Z, 2016-05-15 12Z, 2016-05-16 12Z, 2016-05-17 12Z, 2016-08-18 12Z, and 2016-05-20 12Z, and ran until the end of September 2016.

d) For models lacking an atmosphere or ocean component, please describe the forcing:

Model was a fully coupled atmosphere-ocean-sea ice system.

9. *Prediction of September pan-Arctic extent as monthly average in million square kilometers. (To be consistent with the validating sea ice extent index from NSIDC, if possible, please first compute the average sea ice concentration for the month and then compute the extent as the sum of cell areas > 15%.)

The September 2016 pan-Arctic sea ice extent forecast is 4.8 million km^2.

10. Prediction of the week that the minimum daily extent will occur (expressed in date format for the first day of week, taking Sunday as the start of the week (e.g., week of 4 September).

Week of September 4th

11. *Short explanation of Outlook method (using 300 words or less). In addition, we encourage you to submit a more detailed Outlook, including discussions of uncertainties/probabilities, including any relevant figures, imagery, and references.

We ran the Navy's Global Atmosphere-Ocean-Ice coupled system using initial conditions on 2016-05-01 12Z, 2016-05-02 12Z, 2016-05-03 12Z, 2016-05-07 12Z, 2016-05-09 12Z, 2016-05-14 12Z, 2016-05-15 12Z, 2016-05-16 12Z, 2016-05-17 12Z, 2016-08-18 12Z, and 2016-05-20 12Z. The atmospheric initial conditions are from NAVDAS-AR (Xu et al. 2005), which is part of the NAVGEM (Hogan et al. 2014) operational suite. The ocean/ice initial conditions are from the Navy's 3Dvar NCODA data assimilation system (Cummings 2005), which is a component of GOFS 3.1 using HYCOM and CICE (Metzger et al. 2014). SSMIS and AMSR2 ice concentrations are assimilated with NCODA. There was no bias correction performed on the results.

12. If available from your method for pan-Arctic extent prediction, please provide:

a) Uncertainty/probability estimate such as median, ranges, and/or standard deviations (specify what you are providing).

4.4 to 5.3 million km^2

b) Brief explanation/assessment of basis for the uncertainty estimate (1-2 sentences).

The uncertainty estimate is the range of the 11 member ensemble, and does not represent a full measure of uncertainty. Projections of September sea ice extent with this system have not been fully validated.

c) Brief description of any post processing you have done (1-2 sentences).

The only post-processing performed was the calculation of the mean September sea ice extent from sea ice concentrations.

For Sea Ice Probability (SIP): We computed SIP as requested: converted Sept mean SIC into SIE for each ensemble member. Then averaged the ensemble across the Sept mean SIE. Hence, SIP is the probability of sea ice cover in the ensemble and ranges from 0 to 100%.

For Ice-Free Day (IFD): We computed the first ice-free day when SIC falls below 15% for all points where there is at least 15% SIC on the day we initialized the model. If the point is ice free (SIC<15%) at initialization, IFD will be ordinal day 122 (May 1). If the point is always covered in ice (SIC>=15%), the IFD will be ordinal day 274 (Sept 30). We then computed the average and standard deviation of IFD across the ensemble.

d) Raw (and/or post processed) forecasts for this year and retrospective forecasts in an excel spreadsheet with one year on each row and ensemble member number on columns (specifying whether raw or post processed).

Member:	Raw September Mean Sea Ice Extent (million km^2)
2016-05-01 12Z	4.4

2016-05-02 12Z	4.9
2016-05-03 12Z	5.3
2016-05-07 12Z	4.4
2016-05-09 12Z	4.9
2016-05-14 12Z	4.8
2016-05-15 12Z	5.2
2016-05-16 12Z	4.7
2016-05-17 12Z	4.9
2016-08-18 12Z	4.6
2016-05-20 12Z	5.1

Submitting an Alaskan Regional Outlook (Optional, yet encouraged):

9. *Prediction of September Alaskan Regional extent as monthly average in million square kilometers. (To be consistent with the validating sea ice extent index from NSIDC, if possible, please first compute the average sea ice concentration for the month and then compute the extent as the sum of cell areas > 15%.)

The September 2016 Alaskan regional sea ice extent forecast is 0.87 million km^2.

10. Prediction of the week that the minimum daily extent will occur (expressed in date format for the first day of week, taking Sunday as the start of the week (e.g., week of 4 September).

Week of September 11^{th}.

11. *Short explanation of Outlook method (using 300 words or less). In addition, we encourage you to submit a more detailed Outlook, including discussions of uncertainties/probabilities, including any relevant figures, imagery, and references.

The methodology used for the Alaskan regional outlook was the same as the full Arctic prediction.

12. If available from your method for pan-Arctic extent prediction, please provide:

a) Uncertainty/probability estimate such as median, ranges, and/or standard deviations (specify what you are providing).

07.1 to 1.22 million km^2

b) Brief explanation/assessment of basis for the uncertainty estimate (1-2 sentences).

The uncertainty estimate is the range of the 11 member ensemble, and does not represent a full measure of uncertainty. Projections of September sea ice extent with this system have not been fully validated.

c) Brief description of any post processing you have done (1-2 sentences).

The only post-processing performed was the calculation of the mean September sea ice extent from sea ice concentrations.

d) Raw (and/or post processed) forecasts for this year and retrospective forecasts in an excel spreadsheet with one year on each row and ensemble member number on columns (specifying whether raw or post processed).

Member:	Raw September Mean Sea Ice Extent (million km^2)
2016-05-01 12Z	0.81
2016-05-02 12Z	0.89
2016-05-03 12Z	0.86
2016-05-07 12Z	0.73

2016-05-09 12Z	0.74
2016-05-14 12Z	0.75
2016-05-15 12Z	1.22
2016-05-16 12Z	0.99
2016-05-17 12Z	0.93
2016-08-18 12Z	0.71
2016-05-20 12Z	0.94

13) Tell us how you defined the region: either say NSIDC definition, or if you must use your own definition, describe it.

The NSIDC definition was used.

14) Tell us the maximum possible ice extent if every ocean cell in your region were ice covered. For example, if your model uses exactly the same grid as the satellite data, the area would be 4.00×10^6 km^2. The maximum possible extent is probably much larger than your actual Alaskan Regional Outlook. Be sure to exclude land and islands.

The maximum possible ice extent of every ocean cell in the region is 3.98 Mkm2. We simplified the mask to a 0/1 mask with 1s for the Bering, Chukchi and Beaufort regions, and applied it to the GOFS 3.1 grid via interpolation.

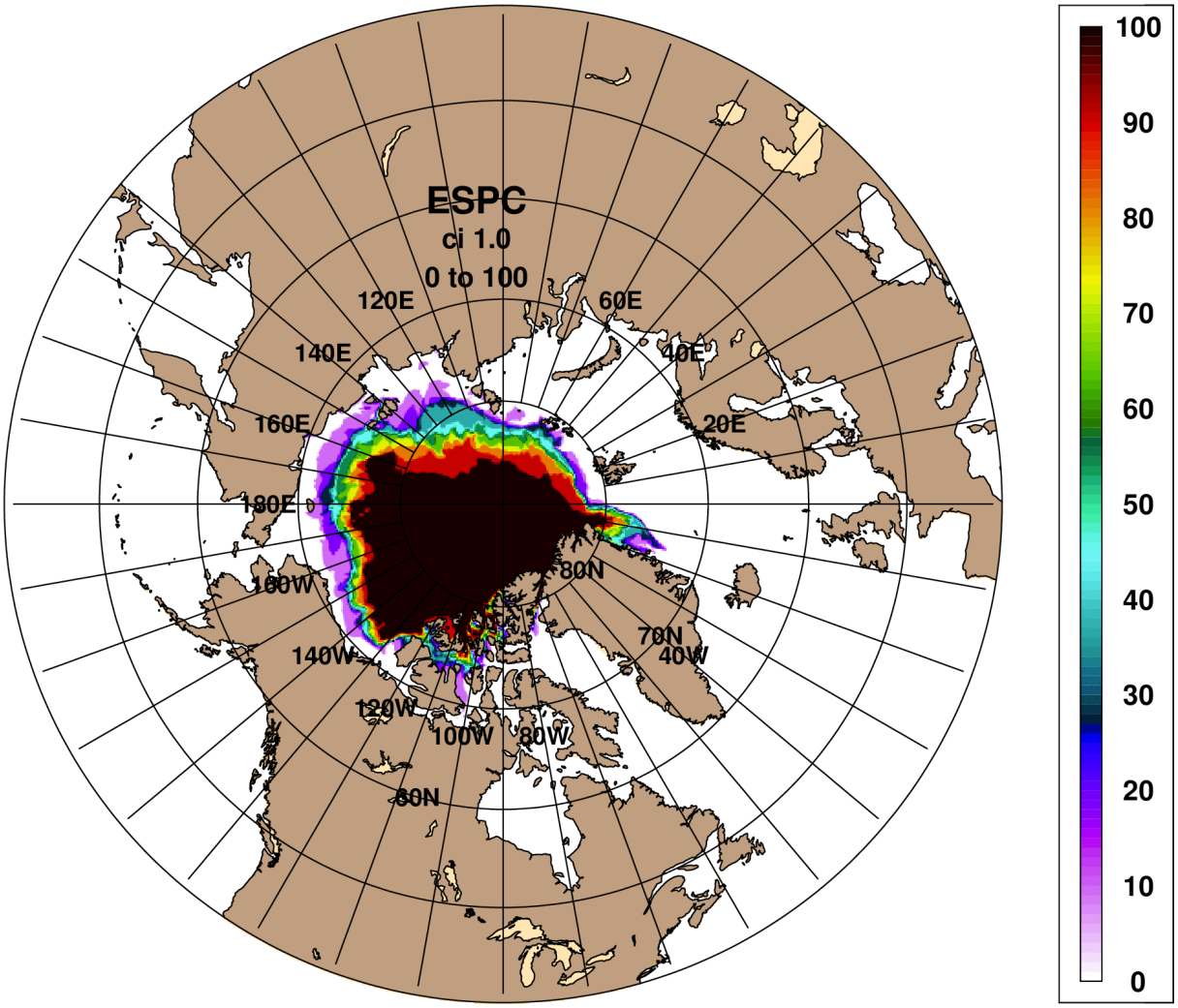

Figure 1: Sea Ice Probability (%) of the projected September 2016 mean ice extent from the Navy global atmosphere-ocean-ice coupled system.

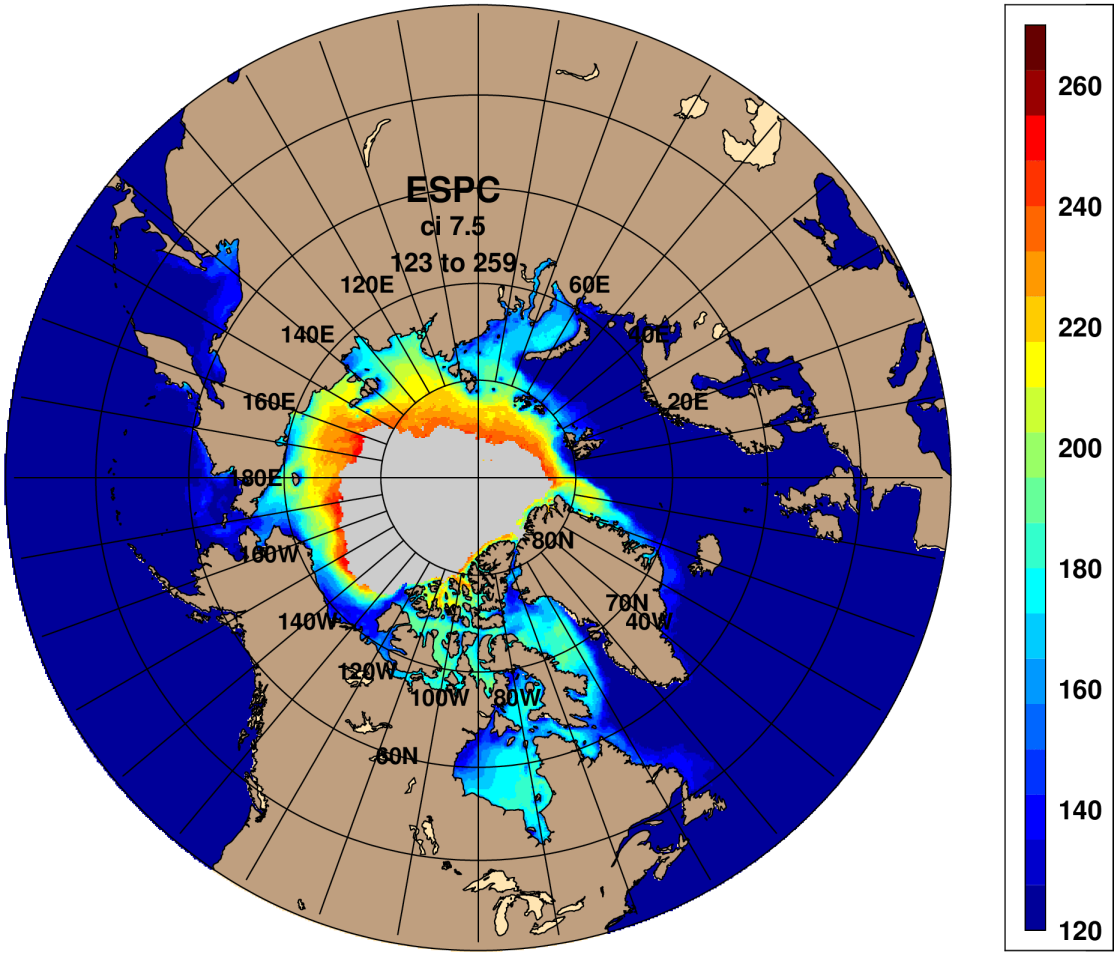

Figure 2: First ice-free ordinal date, with grey indicating a data void (i.e., no ice free days as the most likely outcome) from the Navy global atmosphere-ocean-ice coupled system 11 member ensemble.

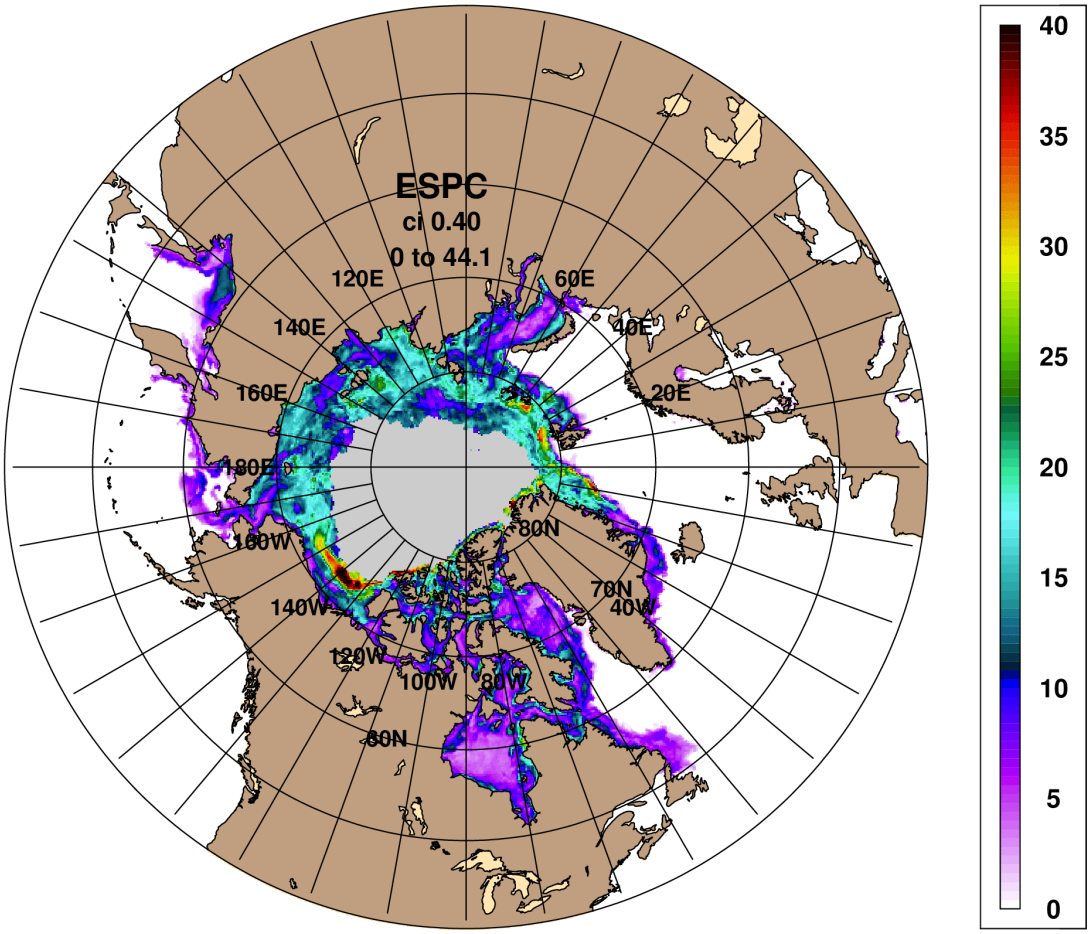

Figure 3: Standard deviation of first ice-free ordinal date, with grey indication a data void (i.e., no ice free days as the most likely outcome) from the Navy global atmosphere-ocean-ice coupled system 11 member ensemble.

References:

Cummings, J. A., 2005: Operational multivariate ocean data assimilation. *Quarterly Journal of the Royal Meteorological Society*, **131,** 3583-3604.

Hogan, T., and Coauthors, 2014: The Navy Global Environmental Model. *Oceanography*, **27,** 116-125.

Metzger, E. J., and Coauthors, 2014: US Navy Operational Global Ocean and Arctic Ice Prediction Systems. *Oceanography*, **27,** 32-43.

Xu, L., T. Rosmond, and R. Daley, 2005: Development of NAVDAS-AR: formulation and initial tests of the linear problem. *Tellus Ser. A-Dyn. Meteorol. Oceanol.*, **57,** 546-559.