SEA ICE IN THE NCEP FORECAST SYSTEM

Robert W. Grumbine and Xingren Wu
Environmental Modeling Center, NCEP/NWS/NOAA, College Park, MD 20740, USA

Keywords: sea ice, sea ice drift, global forecast system, climate forecast system, reanalysis

Contents

Summary

The treatment of sea ice in the National Centers for Environmental Predictions (NCEP) forecast system is described in this chapter. It summaries of how sea ice is handled in the mesoscale, real-time ocean, global and climate forecast system are given. Sea ice analysis and reanalysis, and sea ice drift model at NCEP are also described.

1. Sea Ice

Sea ice is frozen seawater. It forms when water temperatures reach their freezing point and it then floats on its own liquid phase. It covers approximately 7 percent of the world's oceans and accounts (in areal extent) for nearly two-thirds of the earth's ice cover (Washington and Parkinson 1986). The structure of sea ice in the Polar Regions is complex and includes many types, such as first-year ice, multiyear ice, frazil ice or grease ice.

Sea ice interacts strongly with both the atmosphere above and ocean underneath at high latitudes. The extent of sea ice is mainly influenced by, and has a significant effect on, the energy at the surface and ocean-atmosphere energy exchange. One of the most important factors influencing the structure of ice during the melting phase is the total radiation. Another important factor influencing ice melting is the air temperature. On the other hand, a sea ice cover significantly reduces the amount of solar radiation absorbed at the earth's surface due to the marked changes in the surface albedo. The presence of extensive area of sea ice suppresses heat gain by the ocean in summer and heat loss by the ocean in winter. Therefore, the changes in sea ice extent regionally and globally influence oceanic and atmospheric conditions, which in turn influence the distribution of sea ice (Zwally et al. 1983). The formation of sea ice by freezing, the deformation of sea ice by winds and ocean currents and the ablation of sea ice are all interactive physical processes. These involve turbulent (sensible and latent) heat transfer, wind stress, ocean heat flux, ocean currents, ice drift, solar radiation, cloud cover, and other factors.

Sea ice is an important, interactive component of the Earth's climate and weather system. It has been shown to play a significant role in global climate and weather and affects and reflects global changes of the atmosphere and oceans. The relationship between sea ice and climate/weather is complex. The importance of sea ice for global climate and weather has been well noted several decades ago (e.g. Walsh and Johnson 1979).

In view of the varied impacts of the atmosphere, ocean and sea ice on each other, a productive approach to understand these complex interactions is to use coupled numerical models, which include atmosphere, hydrosphere and cryosphere interactively. Coupled numerical models have been widely used for the study of climate and climate changes, and have been moved towards climate and weather prediction.

2. Sea Ice Observing

Sea ice models require a starting point, preferably observational. The best-observed quantity is total sea ice concentration (fraction of an area that has some sea ice coverage). Sea ice thickness is observed locally from ships and planes, and by upward-looking sonar on submarines or moorings. At large scale, satellites observe sea ice thickness by laser or radar altimetry. The sea ice velocity field is also an important quantity, but is not well-observed in near real time. The International Arctic Buoy Programme buoys are sparse and Arctic-only. Furthermore, satellite-derived ice velocities (e.g. Ardhuin and Ezraty 2012) lag real time. Fortunately, this variable, at least, is not crucial for forecasts, as ice equilibrates with its forcing within about 12 hours.

Sea ice concentration for National Centers for Environmental Predictions (NCEP) weather and ocean forecast models is derived from passive microwave observations (Special Sensor Microwave Imager, Special Sensor Microwave Imager Sounder, Advanced Microwave Scanning Radiometer) using the National Aeronautics and Space Administration Team-1 Algorithm (Cavalieri et al. 1992), Team-2 Algorithm (Markus and Cavalieri 2000), and NCEP regression against either. See Grumbine (1996) for the original operational implementation, and Grumbine (2014) for the history of operational systems since that time. The passive microwave observations provide daily, global coverage, at approximately 12 km resolution. This is not a limit for models such as the Global Forecast System (GFS), but is a factor for ice conditions in the mesoscale forecast system, with its 4 km grid spacing. For this reason, the mesoscale system (the North American Model (NAM)) uses the Interactive Multisensor Snow and Ice Mapping System (IMS) analysis (Chen et al. 2012).

Climate reanalysis projects, including that which was involved in the Climate Forecast System (CFS) version 2 (CFSv2) (Saha et al. 2014), require sea ice observations as well. Concentration fields have been constructed for the NCEP/NCAR Reanalysis (one degree and half degree (Kalnay et al. 1996)), the North American Regional Reanalysis (32 km, (Mesinger et al. 2006)), and the CFS reanalysis (CFSR, half degree, (Saha et al. 2010)). The sea ice analysis produces a global record of sea ice concentration for the CFSR for all points that may freeze anywhere in the globe. This is done daily on a grid of 0.5 degree latitude-longitude resolution throughout the period of the CFSR. When there are discontinuities in the production of the data set, newer data sets and newer methods are used.

The most recent ice for climate reanalysis is that from the CFSR (Saha et al. 2010). For 1979 to 1996, the sea ice concentrations for most of the globe are regridded from Cavalieri et al. (1996, updated 2007) (Goddard Space Flight Center Ice), except for (i) possibly ice-covered regions that lie outside that grid, (ii) large Canadian lakes, (iii) the Great Lakes, and (iv) sea surface temperature-based filtering of erroneous ice in the analysis. For the Great Lakes, the data used are Assel et al. (2002) from 1979 through the end of the data set in Spring, 2002, and passive microwave thereafter. Those grids are available 1-3 times per week throughout the period they are available. Concentrations were linearly interpolated between the observation dates, and those interpolated values are used here, averaged on to the target 0.5 degree grid from the native 2.55 km Mercator projection. For large lakes in Canada, the Canadian Ice Service (CIS, personal communication) analyses were used for all lakes which were analyzed from November 1995 through October 29, 2007 (initially 34, in November, 1995, increasing to 137 by October, 2007). From October 30, 2007 onwards, the concentrations are the operational NCEP passive microwave sea ice concentration analyses.

Due to the lack of observations of sea ice thickness covering the CFSR period, a sea ice merging scheme is used in the CFSR to add sea ice concentration into the system, instead of comprehensive sea ice data assimilation. The 6-hour model guess field and the analyzed sea ice concentration are used to produce a new initial condition. During the merging process, a quality control is applied to prevent the failure when there is a feedback between the ice analysis and the SST analysis. This is done on the sea ice model grid after the interpolation (regridding) is performed for SST and sea ice concentration. When the SST from the analysis is warmer than 275.3 K, or the sea ice concentration from the analysis is less than 15%, no sea ice is allowed to exist, so sea ice is removed from the CFSR initial condition. When the sea ice concentration from the analysis is greater than (or equal to) 15% and the SST is not warmer than 275.3 K, the CFSR initial sea ice concentration is reset to the analyzed value. If the model guess contains more sea ice, thin ice is removed first before thicker ice. In summer, the melt pond effect on ice albedo is considered (Mark Serreze and Hua-Lu Pan, personal communication at CFSR Advisory Board Meeting), which is done for the Arctic sea ice cover north of 70^{o}N only. When there are serious problems for sea ice concentration data from analysis, we only use model predictions. This happens for May 1-13, 2009.

-

-

-

TO ACCESS ALL THE **13 PAGES** OF THIS CHAPTER,
Visit: http://www.eolss.net/Eolss-sampleAllChapter.aspx

Bibliography

Girard-Ardhuin F., Ezraty R. (2012) . Enhanced Arctic sea ice drift estimation merging radiometer and scatterometer data. *IEEE Trans. Geosci. Remote Sensing*, vol. 50 (7), July 2012, pp 2639-2648. Doi: 10.1109/TGRS.2012.2184124. Open access version [Arctic ice drift estimation from satellite].

Assel R.A., David C., Norton D.C., Cronk K.C. (2002). A Great Lakes Ice Cover Digital Data Set for Winters 1973-2000, NOAA Technical Memorandum GLERL-121, 46 pp. [Ice cover on the Great Lakes].

Cavalieri D.J. (1992). Sea ice algorithm. NASA Sea Ice Validation Program for the Defense Meteorological Satellite Program Special Sensor Microwave Imager: Final Report, NASA Technical Memorandum, 25-32. [NASA Team-1 algorithm for sea ice concentration analysis].

Cavalieri D.J., Parkinson C.L., Gloersen P., Zwally H.J. (1996). Sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I passive microwave data, 1978-1996. Boulder, Colorado USA, National Snow and Ice Data Center. Digital Media. Updated 2007. [Sea ice analysis data from GSFC/NASA].

Chen, C., Lakhankar T., Romanov P., Helfrich S., Powell A., Khanbilvardi R. (2012) Validation of {NOAA}-Interactive Multisensor Snow and Ice Mapping System (IMS) by Comparison with Ground-Based Measurements over Continental United States, *Remote Sens.*, 4, 1134-1145. [IMS snow and ice analysis].

Drobot S.D., Maslanik J.A., Fowler C. (2006). A long-range forecast of Arctic summer sea-ice minimum extent. *Geophysical Research Letters*, **33**, L10501, doi:10.1029/2006GL026216. . [Seasonal sea ice prediction using statistical method].

Ek M.B., Mitchell K.E., Lin Y., Rogers E., Grunmann P., Koren V., Gayno G., Tarplay J.D. (2003). Implementation of the Noah land-use model advances in the NCEP operational mesoscale Eta model. *Journal of Geophysical Research,* **108**(D22), 8851, doi: 10.1029/2002JD003296. [NOAH land model].

Gemmill W., Katz B., Li X. (2007). Daily Real-Time, Global Sea Surface Temperature, A High-Resolution Analysis: RTG_SST_RH. NOAA/NWS/NCEP/MMAB Technical Notes 260, 39 pp. [Daily high-resolution SST analysis at NCEP].

Griffies S.M., Harrison M.J., Pacanowski R.C., Rosati A. (2004). A Technical Guide to MOM4. GFDL Ocean Group Technical Report No. 5, NOAA/Geophysical Fluid Dynamics Laboratory Available online at http://www.gfdl.noaa.gov/~fms. [GFDL MOM4 ocean model document].

Grumbine R.W. (1996). Automated Passive Microwave Sea Ice Concentration Analysis at NCEP. NOAA/NWS/NCEP/OMB Technical Note 120, 13 pp. [Sea ice analysis at NCEP, original version].

Grumbine R.W. (1998). Virtual floe Ice drift forecast model intercomparison, *Weather and Forecasting*, 13, 886-890. [Sea ice drift model at NCEP, updated from 1978 version].

Grumbine R.W. (2013). Long range sea ice drift model verification. MMAB Technical Note 315, 22 pp. [Sea ice drift model at NCEP, evaluation methods and skill to 16 days].

Grumbine R.W. (2014). History 1997-2012 of NCEP sea ice concentration analysis, MMAB Technical Note. [Sea ice analysis at NCEP, current (2014) version].

Hibler W.D.III (1979). A dynamic thermodynamic sea ice model, *Journal of Physical Oceanography*, **9**(4), 815-846. [Sea ice model, original implementation of modern ice dynamics].

Hunke E.C., Dukowicz J.K. (1997). An elastic-viscous-plastic model for sea ice dynamics. *Journal of Physical Oceanography*, **27**, 1849-1867. [EVP for sea ice dynamics, computationally efficient solution for modern ice dynamics].

Kalnay E., Kanamitsu M., Kistler R., Collins W., Deaven D., Gandin L., Iredell M., Saha S., White G., Woollen J., Zhu Y., Leetmaa A., Reynolds R., Chelliah M., Ebisuzaki W., Higgins W., Janowiak J., Mo K.C., Ropelewski C., Wang J., Jene R. Joseph D. (1996). The NCEP/NCAR 40 year reanalysis project. *Bulletin of the American meteorological society*, 77, 437-471. [NCEP/NCAR reanalysis].

Lindsay R.W., Zhang J., Schweiger A.J., Steele M.A. (2008). Seasonal predictions of ice extent in the Arctic Ocean. *Journal of Geophysical Research*, **113**, C02023, doi: 10.1029/2007JC004295. [Seasonal sea ice prediction using statistical method].

Markus T., Cavalieri D.J. (2000). An enhancement of the NASA Team sea ice algorithm. *IEEE Transactions on Geoscience and Remote Sensing*, **38**, 1387-1398. [NASA Team-2 algorithm for sea ice concentration analysis, original].

Maykut G. A., Untersteiner N. (1971). Some results from a time-dependent thermodynamic model of sea ice, *J. Geophys. Res*., **76,** 1550. [Mass and salinity conservation, detailed model of ice and salt accretion and rejection].

Mesinger R., DiMego G., Kalnay E., Mitchell K., Shafran P.C., Ebisuzaki W., Jovic D., Woollen J., Rogers E., Berbery E.H., Ek M.B., Fan Y., Grumbine R., Higgins W., Li H., Lin Y., Manikin G., Parrish D., Shi W. (2006): North American Regional Reanalysis, *Bulletin of the American Meteorological Society*, 87, 343-360. [North American Regional Reanalysis].

Nansen F. (1902). The Norwegian North Polar Expedition 1893-1896 Scientific results, Volume iii, number 9: Fridtjof Nansen, The Oceanography of the North Polar Basin, 1-427 with 33 plates. [Sea ice free drift with wind].

National Research Council, Committee on the Future of Arctic Sea Ice Research in Support of Seasonal-to-Decadal Predictions; Polar Research Board; Division on Earth and Life Studies (2012). Seasonal-to-Decadal Predictions of Arctic Sea Ice: Challengers and Strategies. Washington DC: The National Academies Press. [Challenge for Arctic sea ice prediction].

Okamoto K., Derber J.C., Yan B., Weng F., Wu X. (2004). Assimilation impacts of AMSU snow/ice emissivity model improvements. In Proceedings of *the13th Conference on Satellite Meteorology and Oceanography*, Norfolk, VA, USA, 20-23 September 2004, American Meteorological Society, P3.13, 2004. [AMSU snow/ice emissivity in NCEP GFS].

Saha S., Moorthi S., Pan H.-L., Wu X., Wang J., Nadiga S., Tripp P., Kistler R., Woollen J., Behringer D., Liu H., Stokes D., Grumbine R., Gayno G., Wang J., Hou Y.-T., Chuang H.-Y., Juang H.-M.H., Sela J., Iredell M., Treadon R., Kleist D., Van Delst P., Keyser D., Derber J., Ek M., Meng J., Wei H., Yang Y., Lord S., Van Den Dool H., Kumar A., Wang W., Long C., Chelliah M., Xue Y., Huang B., Schemm J.-K., Ebisuzaki W., Lin R., Xie P., Chen M., Zhou S., Higgins W., Zou C.-Z., Liu Q., Chen Y, Han Y., Cucurull L., Reynolds R.W., Rutledge G., Goldberg M. (2010). The NCEP climate forecast system reanalysis. *Bulletin of the American Meteorological Society*, ***91***, 1015-1057. [NCEP CFS reanalysis].

Saha S., Moorthi S., Wu X., Wang J., Nadiga S., Tripp P., Behringer D., Hou Y.-T., Chuang H.-Y., Iredell M., Ek M., Meng J., Yang Y., Pena Mendez M., Van Den Dool H., Zhang Q., Wang W., Chen M., Becker E. (2014). The NCEP Climate Forecast System Version 2. *J. Climate*, **27**, 2185–2208. doi: http://dx.doi.org/10.1175/JCLI-D-12-00823.1. [NCEP CFSv2].

Thorndike A. S., Rothrock D.A., Maykut G.A., Colony R. (1975). The thickness distribution of sea ice, *J. Geophys. Res.*, 80, 4501-4513. [Sea ice thickness distribution].

Walsh J.E., Johnson C.M. (1979). An analysis of Arctic sea ice fluctuations. *Journal of Physical Oceanography*, **9**, 580-591. [Arctic sea ice climatology and prediction].

Wang W., Chen M., Kumar A. (2013). Seasonal prediction of Arctic sea ice extent from a coupled dynamical forecast system, *Monthly Weather Review*, **141**, 1375-1394, doi: 10.1175/MWR-D-12-00057.1. [Sea ice prediction using CFSv2].

Washington W.M., Parkinson C.L. (1986). *An introduction to three-dimensional climate modeling*. 422pp, Oxford Uni. Press. [Climate modeling textbook].

Winton M. (2000). A reformulated three-layer sea ice model, *J. of Atmospheric and Oceanic Technology*, **17**, 525-531. [Sea ice model applied to GFS].

Wu X., Simmonds I., Budd W.F. (1997). Modeling of Antarctic sea ice in a general circulation model, *Journal of Climate*, **10**, 593-609. [Sea ice Modeling].

Wu X., Moorthi S., Okamoto K., Pan H.-L. (2005). Sea ice impacts on GFS forecasts at high latitudes. In Proceedings of the *85th AMS Annual Meeting, 8th Conference on Polar Meteorology and Oceanography,* San Diego, CA, USA, 9-13 January 2005, American Meteorological Society, 7.4, 2005. [Sea ice in NCEP GFS].

Zhang J., Steele M.A., Lindsay R.W., Schweiger A.J., Morison J. (2008). Ensemble 1-year predictions of Arctic sea ice for the spring and summer of 2008. *Geophysical Research Letters,* **35**, L08502, doi: 10.1029/2008GL033244. [Sea ice Prediction].

Zwally H.J., Comiso J.C., Parkinson C.L., Campbell W.J., Carsey F.D., Gloersen P. (1983). *Antarctic sea ice, 1973-1976: Satellite passive-microwave observations*. 206pp. NASA SP-459 Washington DC. [Analysis of sea ice from passive microwave satellite observation].

Biographical Sketch

Robert Grumbine was born in the US, earned a BS in Applied Mathematics with area of application in Astrophysics from Northwestern University (1985), MS (1987) and PhD (1989) from the University of Chicago, Department of the Geophysical Sciences. His thesis topic was deep ocean circulation driven by sea ice formation. He was then a UCAR Postdoctoral Fellow (1990-1991) studying paleo-ocean circulation. Since 1992 he has been working in the Marine Modeling and Analysis Branch of EMC, NWS/NOAA. Topics have included sea ice modeling, sea ice predictability, atmosphere-ice feedbacks, sea ice and sea surface temperature remote sensing, and evolutionary computing for optimizing model parameterization. He earned a NOAA Bronze medal for his work contributing to the implementation of the first ocean model in the National Weather Service.

Xingren Wu was born in China, received BS in Meteorology from Peking (Beijing) University, Beijing, China in 1986; and PhD in Earth Sciences from the University of Melbourne, Australia in 1993. From 1993 to 1995 he worked as a Postdoctoral Research Fellow on general circulation model development and sea ice modeling at Antarctic Cooperative Research Centre (AntCRC) and the University of Tasmania, Australia. He was then a Programming Scientist at CSIRO Atmospheric Research, Australia on Climate Impacts Study (1995-1996), followed by a term as a Research Scientist and Senior Research Scientist at Australian Antarctic Division and AntCRC on sea ice model development and climate change (1996 to 2003). He served as a Visiting Scientist in 2002 at National Ice Center, Washington DC, USA. From July 2003 to 2010 he worked at SAIC as Senior Research Meteorologist and Task Leader supporting the global forecast system (GFS) and Climate Forecast System (CFS) development at Environmental Modeling Center (EMC), NCEP/NOAA. Since July 2010 he has been at IMSG as Task Leader supporting GFS and CFS development at EMC, NCEP/NOAA. Dr. Wu received the NCEP Director Recognition Award in January 2011 based on his contribution to the CFSv2 development.