2021 SIO August
Contributor Key Statements
Listed Alphabetically

ANSO IAP-LASG, 4.32, Dynamic Model. The prediction for the sea ice outlook July 2021 was carried out on China's Tianhe-2 supercomputer, with a dynamic model prediction system CAS FGOALS-f2 S2S V1.3. The dynamic model prediction system, named FGOALS-f2 (ice-ocean-atmosphere-land model), provides a real-time prediction in the subseasonal-to-seasonal (S2S) timescales. FGOALS-f2 S2S system has been established in 2017 by R&D team of FGOALS-f2 from both LASG Institute of Atmospheric Physics Chinese Academy of Sciences and PAEKL Chengdu University of Information Technology. The FGOALS-f2 S2S prediction results are used in three major national operational prediction centers in China. Basing on the 2-month lead dynamic model prediction from Aug 10th, 2021 the outlook predictions of Sea Ice Extent are 4.32 million square kilometers for pan-Arctic in September 2021.

APPLICATE Benchmark, 4.45, Statistical. Same as previous outlooks

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ARCUS Team (Wiggins et al.), 4.17, Heuristic. Our team submission is the median of all the values contributed for the September mean sea ice extent by 10 ARCUS team members.

ASIC NIPR, 4.371, Statistical. Monthly mean ice extent in September will be about 4.371 million square kilometers. Our prediction is based on a statistical way using data from satellite microwave sensor. We used the ice thickness (accumulated ice convergence) and ice age on June 30. Predicted ice concentration map from July 1 to September 20 is available in our website:
https://www.nipr.ac.jp/sea_ice/e/forecast/2021-08-12-1/

AWI Consortium (Kauker et al.), 3.92, Dynamic Model. For the present outlook the coupled sea ice-ocean model NAOSIM has been forced with atmospheric surface data from January 1948 to July 4th 2021 (combination of NCEP-CFSR and NCEP-CFSv2). All ensemble model experiments have been started from the same initial conditions on August 8th 2021. The model setup is identical to the SIO 2019 setup - a forecasting model (about 25km horizontal resolution) with optimized parameters (with the help of a generic algorithm (Sumata et al, 2019, https://doi.org/10.1175/MWR-D-18-0360.1)) is employed. We used atmospheric forcing data from each of the years 2011 to 2020 for the ensemble prediction and thus obtain 10 different realizations of potential sea ice evolution for the summer of 2021. The use of an ensemble allows to estimate probabilities of sea-ice extent predictions for September 2021. A variational assimilation system around NAOSIM is applied to initialize the model using the Alfred Wegener Institute's CryoSat-2 ice thickness product and a OSI SAF ice concentration product. In contrast to previous years no snow depth and sea surface temperature are assimilated due to the lack of these data streams. Observations from March and April were used. The assimilation system (Kauker et al, 2015, http://www.the-cryosphere-discuss.net/tc-2015-171) is unchanged with respect to previous years but no bias correction is applied any more to theCryoSat-2 ice thickness - this is not necessary anymore due to the optimization of the forecast model.

BDAL Group (Sahara et al.), 4.389, ML/Other. It is our goal to predict the 2021 September sea ice extent with a leading time of 2 months (at the end of July) using deep learning methods. The contributing factors are the monthly values of 10 atmospheric and ocean variables for the Pan-Arctic region. The monthly satellite retrieved sea ice data is taken from NSIDC GSFC NASA team, while atmospheric and oceanic variables data is taken from ERA5 global reanalysis product for 42 years, i.e, from January 1979 to July 2021. These atmospheric and ocean variables include surface pressure, 10-meter wind velocity, specific humidity, 2-meter air temperature, shortwave radiation, longwave radiation, rain rate, snowfall rate, sea surface temperature and sea ice extent.

Big Data REU Team 1 @ UMBC, 4.358, ML/Other.
We produced our Outlook as part of a project to predict both Arctic sea-ice concentration and extent using the latest deep learning techniques. The following predictors were used to obtain our Outlook: Surface pressure, Wind speed, Specific humidity, Surface temperature, Shortwave radiation, Longwave radiation, Rainfall rate, Snowfall rate, Sea surface temperature, and Sea ice concentration. Sea ice concentration data was obtained from the National Sea Ice Data Center, and data for all other variables was sourced from the ERA-5 re-analysis conducted by the European Center for Medium-range Weather Forecasts. All data was provided at a daily resolution from January 1979 to June 2021 with a value for each grid cell in the 448 by 304 pixel domain. For our deep learning models, the daily data was averaged to the monthly scale.

Chen, Thomas Y., 4.12, ML/Other. We utilized a random forest model, which is an aggregated ensemble of decision trees.

Climate Prediction Center, 4.41, Dynamic Model. The forecast is based on an initialized fully coupled system. Contributing factors include initial oceanic, sea ice and atmospheric conditions, with initial sea ice thickness being the dominant factor.

CPOM, 4.4, Statistical. We predict the September ice extent 2021 to be 4.4 (3.9-4.9) million km2. This is slightly above the trend line of September ice extent over last 43 years. In June 2021, melt pond fraction has been a bit below average with respect to last 15 years due to unusually low sea level pressure in the Arctic during June 2021.

CPOM UCL (Gregory et al), 4.53, Statistical. This statistical model computes a forecast of pan-Arctic September sea-ice extent. Monthly averaged July sea-ice concentration fields between 1979 and 2021 were used to create a climate network (based on the approach of Gregory et al 2020). This was then utilized in a Bayesian Linear Regression in order to forecast September extent. The model predicts a pan-Arctic extent of 4.53 million square kilometers. Sea ice concentration data were taken from NSIDC (Cavalieri et al., 1996; Maslanik and Stroeve,1999).

CSU-REU21, 4.23, Statistical. We consider the importance of the boreal winter mean large-scale atmospheric circulation (Icelandic Low, Arctic Oscillation) and the state of Arctic sea-ice concentration and thickness at the beginning of summer for predicting September sea-ice. In particular, our simple statistical model uses mean Arctic sea-ice thickness in the Beaufort Sea region as an important predictor for September sea-ice extent.

ECCC-CanSIPSv2, 4.77, Dynamic Model. Our outlook includes an estimate of pan-Arctic sea-ice extent (SIE) and anomaly extent, as
well as spatial forecast fields of sea ice probability (SIP), ice-free dates (IFDs), and ice-advance dates (IADs). The outlook was produced using the Canadian Seasonal to Interannual Prediction System (CanSIPv2; Lin et al., 2020: https://doi.org/10.1175/WAF-D-19-0259.1), which combines ensemble forecasts from two models, CanCM4i and GEM-NEMO, with a total of 20 ensemble members (10 from each model).

EMC/NCEP-UFS, 3.69, Dynamic Model. The projected Arctic minimum sea ice extent from the NCEP Unified Forecast System (UFS) model July initial conditions (ICs) using 62-member ensemble forecast (2 runs each day 00Z July 1-31 with C96 and C192) is 3.69 million square kilometers with a standard deviation of 0.34 million square kilometers. The corresponding number for the Antarctic (maximum) is 20.46 million square kilometers with a standard deviation of 0.84 million square kilometers.

FIO-ESM (Shu et al.), 4.5, Dynamic Model. Our prediction is based on FIO-ESM (the First Institute of Oceanography-Earth System Model) with data assimilation. The prediction of September pan-Arctic extent in 2021 is 4.50 (+/-0.27) million square kilometers. 4.50 and 0.27 million square kilometers is the average and one standard deviation of 10 ensemble members, respectively.

GP Regression (Cawley), 3.960695, Statistical. Prediction based on statistical extrapolation of previous September Arctic sea-ice extent observations.

IceNet1, 4.75, ML/Other. IceNet is a sea ice forecasting AI system which predicts monthly-averaged sea ice probability (SIP; probability of sea ice concentration > 15%) up to 6 months ahead at 25 km resolution on an EASE2 grid. IceNet is based on a deep learning U-Net architecture, and has been trained on climate simulations (CMIP6) covering 1850-2100 and observational data (OSI-SAF SIC and ERA5) from 1979-2011. IceNet's monthly-averaged inputs comprise SIC, 11 climate variables, statistical SIC forecasts, and metadata. IceNet is introduced in the following pre-print, with the study soon to be published in Nature Communications: https://doi.org/10.31223/X5430P. IceNet was also presented at the Oxford ML and Physics Seminar Series: https://youtu.be/JAKWhEU09Xo.

Kondrashov, Dmitri (UCLA), 4.56, ML/Other. This model forecast is based on statistical/ML stochastic modeling techniques applied to the regional Arctic Sea Ice Extent (SIE) dataset.

KOPRI (Chi et al.), 4.45, ML/Other. Korea Polar Research Institute (KOPRI) initiated a project to develop AI-based Arctic sea-ice prediction in 2020. The prediction model is currently in development using a combination of different types of neural networks. KOPRI's prediction model was trained using the past 12-month data for the future six-month of Arctic sea-ice concentration (SIC). The predicted September extent for 2021 is 4.45 million square kilometers using data from August 2020 to July 2021.

Lamont (Yuan and Li), 4.28, Statistical. A linear Markov model is used to predict monthly Arctic sea-ice concentration (SIC) at all grid points in the pan-Arctic region (Yuan et al., 2016). The model is capable of capturing the co-variability in the ocean-sea ice-atmosphere system. The September pan-Arctic sea ice extent (SIE) is calculated from predicted SIC. The model predicts negative SIC anomalies throughout the pan-Arctic region. These anomalies are relative to the 1979-2012 climatology. At the two-month lead, the September mean pan-Arctic SIE is predicted to be 4.28 million square kilometers (mskm) with an RMSE of 0.30 mskm. The RMSE is estimated based on our model forward forecasts from 2013-2020. The Alaskan regional SIE is predicted to be 0.69 mskm. A Similar statistical model was also developed to predict the SIE in the Antarctic (Chen and Yuan, 2004). The September mean pan Antarctic SIE is predicted to be 18.40 mskm, lower than September 2020 (18.77), with an RMSE of 0.66 mskm based on model cross-validation experiments.

McGill Team (Brunette et al.), 3.89, Statistical. Our research focuses on seasonal predictability of sea ice in the Arctic Ocean, using observations-based approaches. We are interested in the winter preconditioning effect on the pack ice before the summer melt. Specifically, we investigate how dynamic processes affect preconditioning, in other words, we ask how anomalies in the general circulation of sea ice will influence later conditions of the Arctic Ocean pack ice under a typical melt season. We investigate the skill of different sea ice predictors, including atmospheric forcing parameters that physically connect to wintertime sea ice dynamics.

The dovekSIE method builds on the correlation between winter Fram Strait sea-ice export and the following September sea-ice extent, via the mechanism of dynamical preconditioning (Williams et al., 2016; Brunette et al., 2019, Kim et al., 2021). A positive anomaly of the winter Fram Strait sea-ice export is associated with enhanced circulation of ice through the Transpolar Drift Stream and positive anomalies of coastal divergence of sea ice along the Eurasian coastlines. Increased coastal divergence late in the winter causes anomalies of younger and thinner ice in the peripheral seas, which is more vulnerable to melting in the summer.

The dovekSIE forecasts are generated using the sea level pressure difference between Greenland and Svalbard as a proxy for area of ice exported through Fram Strait. Sea ice tends to flow parallel to isobars and the pressure difference across Fram Strait correlates with sea ice export (r=0.44). Sea level pressure fields are available in near-real-time and therefore enable the continuous update of dovekSIE forecasts during winter via the web app.

We are supporting the activities of the Sea Ice Prediction Network with great enthusiasm. This is our fifth contribution to the Sea Ice Outlook.

Met Office (Blockley et al.), 4.3, Dynamic Model. A dynamic model forecast made using the Met Office’s seasonal forecasting system (GloSea). GloSea is a fully coupled Atmosphere-Ocean-sea Ice-Land (AOIL) model that produces a small 2-member ensemble of 210-day forecasts each day. Forecasts initialized over a 21-day period are used together to create a 42-member lagged ensemble or forecasts of September sea-ice cover.

METNO-SPARSE-ST (Wang et al.), 4.3, Statistical. AR model using NSIDC data

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Metservice (Yizhe Zhan), 4.38, Statistical. Our prediction is based on the strong correlation between detrended June top-of-atmosphere (TOA) reflected solar radiation (RSR) and September Sea Ice Extent (SIE) anomalies, as proposed by Zhan and Davies [2017]. This method is telling because the main contributor of TOA RSR anomaly in June is from the change of underlying surfaces and the sea ice state in early summer (June) largely determines the total absorbed shortwave solar radiation during the whole melt season.

Mihara Primary School (Iihoshi, et al.), 5.17, Heuristic. Monthly mean ice extent in September will be about 5.17 million square kilometers. We estimated the minimum ice area through discussion with students based on the ice map from 2004 to 2020.

NASA GMAO, 4.09, Dynamic Model. An experiment of the new GMAO seasonal forecasting system version 3 predicts a September average Arctic ice extent of 4.09 ± 0.33 million km2. The experiment is a test of the new MERRA2-Ocean ODAS and forecast ensemble sub-setting method in a near-real time setting. The forecast suggests a September-averaged ice cover that is similar in extent to the previous year.

NASA GSFC, 4.78, Statistical. NA

NCAR/CU-Boulder, 4.14, Heuristic. An informal pool of 35 climate scientists in early June 2021 estimates that the September 2021 ice extent will be 4.14 million sq. km. (stdev. 0.33, min. 3.14, max. 4.91). Since its inception in 2008, the NCAR/CU sea ice pool has easily rivaled much more sophisticated efforts based on statistical methods and physical models to predict the September monthly mean Arctic sea-ice extent (e.g. see appendix of Stroeve et al. 2014 in GRL doi:10.1002/2014GL059388; Witness the Arctic article by Hamilton et al. 2014 http://www.arcus.org/witness-the-arctic/2014/2/article/21066). We think our informal pool provides a useful benchmark and reality check for Sea Ice Prediction efforts based on more sophisticated physical models and statistical techniques.

NMEFC of China (Li and Li), 4.57, Statistical. We predict the September monthly average sea ice extent of Arctic by statistic method and based on monthly sea ice concentration and extent from National Snow and Ice Data Center. The predicted monthly average ice extent of September 2021 is 4.57 million square kilometers.

NSIDC Hivemind, 4.4, Heuristic. This method is based on individual NSIDC employees submitting their guess.

NSIDC (Horvath et al.), 4.91, Statistical. Yearly data from 1980 through the present are used in a Bayesian logistic regression to predict the probability that sea ice concentration will be above 15%. To estimate total sea ice extent, grid cells with a percentage above a certain threshold (chosen from a drop-one cross-validation test) are multiplied by the pixel area grid dataset provided by NSIDC's polar stereographic toolset and then summed. Sea ice concentration data was obtained from NSIDC's Sea Ice Index V3 (Data Set ID: G02135), all other variables are from NASA's MERRA2 dataset. https://doi.org/10.1029/2020EA001176

NSIDC (Meier), 4.5, Statistical. This method applies daily ice loss rates to extrapolate from the start date (August 1) through the end of September. Projected September daily extents are averaged to calculate the projected September average extent. Individual years from 2005 to 2020 are used, as well as averages over 1981-2010 and 2007-2020. The 2007-2020 average daily rates are used to estimate the official submitted estimate. The predicted September average extent for 2020 is 4.50 (±0.36) million square kilometers. The minimum daily extent is predicted to be 4.38 (±0.37) million square kilometers and occurs on 16 September. The standard deviation range has narrowed, reflecting the lower potential variability in ice loss rates over the final 1-2 months of the melt season. Based on the last 14 years, there is a 0% chance that 2021 will be lower than the current record low September extent of 3.57 million sq km in 2012.
Using the same method, the predicted Antarctic average extent for September 2021 is 18.96 (±0.29) million square kilometers. The maximum daily extent is predicted to be 19.07 (±0.33) million square kilometers and occurs on 30 September.

PolArctic, 4.06, ML/Other. This is PolArctic’s third year submitting to the Sea Ice Outlook. Our September extent prediction is 4.06 million square kilometers. Our efforts are to investigate the usefulness of Artificial Intelligence and Machine Learning (AI/ML) as a predictive tool for Arctic sea-ice extent. Hidden and non-linear relationships can be exposed through the use of AI/ML when high quality data is available. NSIDC’s daily record of sea ice extent creates the perfect test bed to leverage and assess the power of AI/ML.

RASM@NPS (Maslowski et al.), 4.503, Dynamic Model. The Arctic sea-ice extent (SIE) of daily September 2021 minimum is predicted on 9/19 (Fig. 1 in the supporting material; 4.40x10^6 km^2). It is expected to roughly continue the September declining trend (of –0.541x10^6 km^2/decade) based on 2000-2020 output from the Regional Arctic System Model (RASM) hindcast simulation (Fig. 2 in the supporting material). The difference between the 31-member ensemble mean September SIE prediction and the SIE extrapolated from the 2000-2020 linear trend into 2021 is +0.085x10^6 km^2. Compared to the RASM September 2020 SIE minimum (4.13x10^6 km^2) from the hindcast, the ensemble mean forecast for 2021 minimum is higher by 0.37x10^6 km^2, suggesting a temporary rebound similarly as it occurred following the 2007 and 2012 minima. According to the RASM ensemble mean predicted September sea-ice thickness distribution, the majority of surviving ice thickness ranges between 0.5 m and 1.5 m, with the thickest sea ice north of the Canadian Archipelago and western Greenland within the range of 1.5 m-2.5 m, and almost no sea ice thicker than 3.0 m (Fig. 3 in the supporting material). The RASM September SIE has been commonly biased high in recent years (mean bias of +0.085x10^6 km^2 and standard deviation of 0.419x10^6 km^2) compared to the NSIDC observation (2000-2020), especially in the northern Barents/Kara and East Siberian seas. Compared to the June- and July-initialized forecasts, the August predicted September SIE is slightly lower because of the decrease in the values of upper quartile accompanied with the smaller ensemble spread.

Simmons, Charles, 4.39, Statistical. The expected extent has increased by 0.39 million km2 since last month.

Sun, Nico, 4.95, Statistical. Each grid-cell is initialized with a thickness derived from the AMSR2 Sea Ice Volume model (https://cryospherecomputing.tk/SIT). For each day the model calculates average thickness loss per grid cell using the exact solar radiation energy and the predicted sea ice concentration as an albedo value.
Ice-loss(m) = Energy (solar in MJ)*(1-SIC) / icemeltenergy
SIC = sea ice concentration
icemeltenergy = Meltenergy per m3, (333.55
KJ/kg*1000(m3/dm)*0.92(density)/1000(MJ/KJ)
In 2020 the model was updated a bias correction layer to approximate sea ice drift.

SYSU/SML-KNN, 4.29, ML/Other. A machine learning KNN model is used to predict the daily sea ice concentration (SIC) and the sea ice extent (SIE) of September 2021 in pan-Arctic. Daily averaged sea ice concentration (“NSIDC NASA Team, https://nsidc.org/data/nsidc-0081)and sea surface temperature (“NOAA National Centers for Environmental Information”, ”https://www.ncdc.noaa.gov/oisst”) fields between 1978 and 2020 were used to predict. The model predicts a pan-Arctic sea-ice extent of 4.80(±0.31) million square kilometers and has a positive anomaly of 0.32.

SYSU/SML-MLM, 3.93, Statistical. A multivariate linear Markov model is used to predict monthly sea ice concentration (SIC), from which sea ice extent prediction of monthly September 2021 in Arctic is calculated to be 4.63±0.51 million square kilometers, and the Alaskan regional SIE is predicted to be 0.71±0.25 million square kilometers.

UCLouvain, 3.91, Dynamic Model. Our estimate is based on results from ensemble runs with the global ocean-sea ice coupled model NEMO3.6-LIM3. Each member is initialized from a reference run on May 1, 2021, then forced with the JRA-55 atmospheric reanalysis from one year between 2011 and 2020. Our final estimate is the ensemble median, and the given range corresponds to the lowest and highest extents in the ensemble.

UPenn Group 1, 4.74, Statistical. The UPenn group is composed of economists and statisticians interested in predictive modeling of many aspects of climate in its relation to economic activity. The Arctic -- and Arctic sea-ice in particular -- is of particular interest to us. As is well known, the Arctic is warming about twice as fast as the global average, and the Arctic amplification in surface air temperature is of course closely connected to the dramatic multi-decade reduction in Northern sea-ice. This loss of sea ice is one of the most conspicuous warning signs of \textit{current} climate change, and it also plays an integral role in the timing and intensity of \textit{future} global climate change. Not surprisingly then, we are keenly interested in predictive modeling of Arctic sea-ice, particularly summer ice.

UPenn (VARCTIC), 4.47, Statistical. When it comes to forecasting sea ice, there is tension between opting for statistical methods vs forecasts based on climate models. While the former are explicitly designed for the prediction task, they usually lack interpretative potential. That is, we may get a good forecast, but it is hard to know why. Institutions in charge of macroeconomic policy have been facing such dilemmas for years. One model, Vector Autoregressions, have been an increasingly popular tool to forecast economic aggregates as they are a compromise between theory-based methods and statistical ones. As a result, it is possible to obtain an explainable forecast which are the results of dynamic interactions between key Arctic variables. Hence, our forecast implicitly uses physical transmission mechanisms in the data, without specifying them explicitly.

UTokyo (Kimura et al.), 4.66, Statistical. Monthly mean ice extent in September will be about 4.66 million square kilometers. Our estimate is based on a statistical way using data from satellite microwave sensor. We used the accumulated sea ice convergence based on the 212 days backward tracking of the ice from June 30 to December 1.

University of Washington/APL, 4.32, Dynamic Model. Driven by the NCEP CFS forecast atmospheric forcing, PIOMAS is used to predict the total September 2021 Arctic-sea ice extent as well as ice thickness field and ice edge location, starting on

August 1. The predicted September ice extent is 4.32± 0.40 million square kilometers. The predicted ice thickness fields and ice edge locations for September 2021 are also attached.

Vandevoorde, Pirlet, and Audoor, 4.594692, Statistical. The probability of the sea ice extent being less than previous year is 36% according to our forecast.

Wu, Tallapragada, and Grumbine, 3.97, Dynamic Model. The projected Arctic minimum sea ice extent from the NCEP CFSv2 model July initial conditions (ICs) using 124-member ensemble forecast (4 cycles each day July 1-31) is 3.97 million square kilometers with a standard deviation of 0.14 million square kilometers. The corresponding number for the Antarctic (maximum) is 21.81 million square kilometers with a standard deviation of 0.61 million square kilometers.
