June 2022 Sea Ice Outlook Key Statements

Contributer	Type	Model Name	Arctic Extent	Median	Standard Deviation	Low Error Bound	High Error Bound	Antarctic Extent	Alaska Extent	Maximum Alaska Extent	Uncertainty Estimate Summary	Pan-Arctic Sea Ice Extent Anomaly	Executive Summary	Method Summary	Sea Icea Concentration Data	Sea Ice Thickness Data	Post-Processing Description
HEU Group (Zhao, et al.)	Statistical/ML	NA	4.5					18.4					The outlook is based on two statistical methods: climate trends regression prediction and previous bias correction. Based on the consensus that arctic sea ice is significantly decreasing, we calculate the trend of sea ice concentration in each grid in the Arctic region and then use this trend to predict the value of sea ice concentration in that grid this year. The satellite observation data of this year before the prediction are used to calculate the real change of this year, and further correct the change trend obtained by the regression of climate trend. This is the meaning of the previous bias correction. By combining the above two methods, a more reasonable distribution field of sea ice concentration is obtained, and then the sea ice extent is calculated.	When obtaining the regression prediction results of climate trend, we used the NSIDC-0051 sea ice concentration dataset of NSIDC NASATEAM algorithm, with a time range of 1989-2020 and a spatial resolution of 25km. Firstly, we calculated the linear regression coefficients of each grid during 1989-2020. The trend of climate change in the grid is analyzed, and the sea ice concentration of each grid in 2022 is calculated by using the linear regression coefficient. In the previous bias correction part, we also used the value of sea ice concentration from January to May 2022 of NSIDC-0081, calculated the curve of sea ice extent retrieved by satellite from January to May 2022, and compared it with the change of sea ice extent from January to May 2022 predicted by climate trend regression. The average difference between the two was obtained as a basis for previous bias corrections, climate trend predictions for September 2022 were then revised to obtain the final results.	NSIDC NASA Team, https://nsidc.org/data/nsidc-0051,https://nsidc.org/data/nsidc-0081,	NA	
Climate Prediction Center	Dynamic Model	CPC sea ice initialization system (CSIS)	4.9	4.85	0.24	4.51	5.35		0.97	3.97	The uncertainty estimate is calculated from the 20-member ensemble.		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.	The outlook is produced from the Climate Prediction Center Experimental sea ice forecast system (CFSm5). The forecast is initialized from the Climate Forecast System Reanalysis (CFSR) for the ocean, land, and atmosphere and from the CPC sea ice initialization system (CSIS) for sea ice. Twenty forecast members are produced. Model bias that is removed is calculated based on 2007-2020 retrospective forecasts and corresponding observations.	NASA Team Analysis from NSIDC	CPC sea ice initialization system (CSIS)	Twenty forecast members are produced. Model bias that is removed is calculated based on 2007-2021 retrospective forecasts.
Simmons, Charles	Statistical/ML	N/A	4.1		0.5						This is the error measured by the linear regression.	-0.01	This estimate is a linear regression of Moana Loa CO2 monthly CO2 concentrations, Northern Hemisphere snow area, and arctic ice area. The idea is to loosely model solar energy absorbed and retained.near the Arctic. (Similar estimates can be obtained using the Year instead of the Moana Loa CO2 concentration.) For May 2022, the estimate of a September sea ice extent of 4.1MK^2 is on trend. (The anomaly is -0.01MK^2. A simple linear regression of the September sea ice extent would produce the same prediction.) This regression is a minor variant of an approach used by Rob Dekker.	This is a simple linear regression of published May 2022 average values. snow_area is downloaded from https://climate.rutgers.edu/snowcover/table_area.php?ui_set=2 . The link is the northern hemisphere monthly link. (Due to limitations of my schedule, I'm using an estimated value of 16.66MK^2 for the May 2022 average snow area.) Moana loa co2 is downloaded from https://gml.noaa.gov/ccgg/trends/data.html Ice area is obtained from ftp://sidads.colorado.edu DATASETS/NOAA/G02135/north/monthly/data/	N/A	N/A	
ArCS II Kids	Heuristic	NA	3.52									-0.55	Mean ice extent in this September is expected to be 3.52 million square kilometers. This prediction was made by 22 elementary school children. First, they estimated the sea ice extent for each year from the sea ice distribution map for September 2002-2021. Next, based on the obtained graphs of the interannual changes in the ice extent, each person determined the prediction value for 2022. Finally, the ice extent of the prediction was calculated by averaging the determined values of the 22 individuals.	The predictions were made by 22 elementary school students divided into three groups. First, each group was given the ice distribution map for September since 2002. Then the ice extent was estimated by approximating the sea ice distribution as a triangle or trapezoid, or by counting the number of squares on a sheet with squares drawn on it. Obtained graphs of interannual variation of the ice extent were in good agreement with the actual variations. Based on the graphs, each person in each group predicted the sea ice extent for the year 2022. Predicted values varied widely between individuals: 16 out of 22 predicted a value smaller than 3.60 (million square kilometers), probably as a result of noting the downward trend and expecting that trend to persist this year. On the other hand, three predicted a value greater than 4.60. This is probably a result of the obscuring of the declining trend in recent years, especially in view of the increase in the last year.	10km grid data derived from AMSR-E and AMSR2, distributed by Arctic Data Archive System (https://ads.nipr.ac.jp)	NA	
Applicate Benchmark	Statistical/ML	None	4.57	4.57	0.62	3.33	5.82	18.28			Same as previous years: https://www.arcus.org/files/sio/32173/applicate_benchmark.pdf	0.5	Same as previous years: https://www.arcus.org/files/sio/32173/applicate_benchmark.pdf	Same as previous years: https://www.arcus.org/files/sio/32173/applicate_benchmark.pdf	NSIDC-0081	None	Same as previous years: https://www.arcus.org/files/sio/32173/applicate_benchmark.pdf
CPOM UCL (Gregory et al.)	Statistical/ML	N/A	4.5		0.37	4.13	4.87		0.33	4	Forecasts are Gaussian distributions. Forecast represents the mean, and uncertainties are given by the standard deviation	0.29	This statistical model computes a forecast of pan-Arctic September sea ice extent . Monthly averaged May sea ice concentration and sea-surface temperature fields between 1979 and 2022 were used to create a climate network (based on the approach of Gregory et al 2020). This was then utilised in a Bayesian Linear Regression in order to forecast September extent. The model predicts a pan-Arctic extent of 4.5 million square kilometres. Sea ice concentration data were taken from NSIDC (Cavalieri et al., 1996; Maslanik and Stroeve,1999) and sea-surface temperature data were taken from ERA5 (Hersbach et al., 2019)	Monthly averaged May sea ice concentration (SIC) and sea-surface temperature (SST) data between 1979 and 2022 were used to create a May SIC-SST climate(complex) network. Individual SIC grid cells were first clustered into regions of spatio-temporal homogeneity (and similarly for SST) by using a community detection algorithm (see Gregory et al, 2020). Links between each of these network regions (covariance) were then passed into a Bayesian Linear Regression to derive an estimate on the prior distribution of the regression parameters. Subsequently a posterior distribution of the regression parameters was then derived in order to generate the forecast of September sea ice extent.	N/A	N/A	
GFDL/NOAA (Bushuk et al.)	Dynamic Model	No SIT data is explicitly used in our initialization procedure.	4.56	4.58	0.21	4.01	4.94		0.53	3.94	These statistics are computed using our 30 member prediction ensemble.	0.35	Our June 1 prediction for the September-averaged Arctic sea-ice extent is 4.56 million square kilometers, with an uncertainty range of 4.01-4.94 million square kilometers. Our prediction is based on the GFDL-SPEAR_MED ensemble forecast system, which is a fully-coupled atmosphere-land-ocean-sea ice model initialized using a coupled data assimilation system. Our prediction is the bias-corrected ensemble mean, and the uncertainty range reflects the lowest and highest sea ice extents in the 30-member ensemble.	Our forecast is based on the GFDL Seamless system for Prediction and EArth system Research (SPEAR_MED) model (Delworth et al., 2020), which is a coupled atmosphere-land-ocean-sea ice model. The ocean model is initialized from an Ensemble Kalman Filter coupled data assimilation system (SPEAR ECDA; Lu et al., 2020), which assimilates observational surface and subsurface ocean data. The sea ice, land, and atmosphere components are initialized from a nudged ensemble run of the coupled SPEAR_MED model, which is nudged towards 3-D temperature, wind, and humidity data from CFSR and SST data from OISST. The SST values under sea ice are adjusted to the freezing point of sea water using OISST sea ice concentration data. The performance of this model in seasonal prediction of Arctic sea ice extent has been documented in Bushuk et al. (2022). For an evaluation of the model's September sea ice extent prediction skill from a June 1 initialization, see attached report.	OISST SIC data is used to correct assimilated SST values under sea ice.	No SIT data is explicitly used in our initialization procedure.	These forecasts are bias corrected based on a linear-regression adjustment using a suite of retrospective forecasts spanning 1992-2021.

University of Washington/APL	Dynamic Model	Initial SIT is from PIOMAS hindcast that also assimilates CrySat2 SIT data up to April 2020 (http://psc.apl.uw.edu/sea_ice_cdr/).	3.41		0.4							-0.81	Driven by the NCEP CFS forecast atmospheric forcing, PIOMAS is used to predict the total September 2022 Arctic sea ice extent as well as ice thickness field and ice edge location, starting on June 1. The predicted September ice extent is 3.41± 0.40 million square kilometers. The predicted ice thickness fields and ice edge locations for September 2022 are also available.	The PIOMAS forecasting system is based on a synthesis of PIOMAS, the NCEP CFS hindcast and forecast atmospheric forcing, satellite observations of ice concentration and sea surface temperature (SST), and CryoSat2 observations of sea ice thickness.	Initial SIC is from PIOMAS hindcast that also assimilates satellite SIC (NASA team) available from NSIDC (https://nsidc.org/data/nsidc-0081).	Initial SIT is from PIOMAS hindcast that also assimilates CrySat2 SIT data up to April 2020 (http://psc.apl.uw.edu/sea_ice_cdr/).	
NCEP-EMC (Wu et al.)	Dynamic Model	NCEP CFSv2 model guess (May 1-31, 2022)	4.34		0.37			18.37					The projected Arctic minimum sea ice extent from the NCEP CFSv2 model May initial conditions (ICs) using 124-member ensemble forecast (4 cycles each day May 1-31) is 4.34 million square kilometers with a standard deviation of 0.37 million square kilometers. The corresponding number for the Antarctic (maximum) is 18.37 million square kilometers with a standard deviation of 0.71 million square kilometers.	We used the NCEP CFSv2 model with 124-case of May 2022 initial conditions (4 cycles each day May 1-31) and model (bias-corrected for the Arctic).	NCEP Sea Ice Concentration Analysis for the CFSv2 (May 1-31, 2022)	NCEP CFSv2 model guess (May 1-31, 2022)	
IceTFT (Bin Mu et al.)	Mixed/Other	NA	4.85	0.15									IceTFT is a SIE forecasting AI system which predicts 12-month SIE up to 12 months ahead at Sea Ice Index from NSIDC NASA Team. IceTFT is based on a deep learning Temporal Fusion Transformer model which was proposed for multi-step forcasting directly instead of recursive approach., and has been trained and tested on SIE dataset from 1982-2021. IceTFT's monthly inputs include SIE, 11 climate variables(2m air temperature, 2m specific humidity, downward shortwave and longwave radiation flux, river and glacier runoff, precipitation, sea surface temperature, snow fall, clear sky downward solar flux, clear sky downward longwave flux and upward solar radiation flux) and time-step static metadata.	IceTFT's inputs include three types dataset, and each type of they is selected by separate variable selection network to filter unnecessary noises. The first input type is static metadata which are calculated by counting the days from start(1982-01-01). Gated Residual Network (GRN) in IceTFT generates different context vectors which are linked to the different location, and static covariate encorder condition temporal dynamics through these context vectors. The second input is SIE and three inputs are several physical variables which are used to provide atmospheric, oceanographic features for prediction. IceTFT use an LSTM encoder-decoder to enhance locality information of these time series. In addition, IceTFT uses a interpretable multi-head self-attentive mechanism to learn long-term features at different time steps. Note that IceTFT use SIE as input instead of SIC, and the output of IceTFT are 12-month SIE.	NSIDC NASA Team,Sea Ice Index, Version 3(https://doi.org/10.7265/N5K072F8)	NA	
ANSO IAP-LASG	Dynamic Model	None	3.78	3.82	0.29	3.14	4.34				The uncertainty was estimated by the ensemble member spread.		The prediction for the sea ice outlook June 2022 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 predictions 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 4-month lead dynamic model prediction from June 12th, 2022 the outlook predictions of Sea Ice Extent are 3.78 million square kilometers for pan-Arctic in September 2022.	FGOALS-f2 S2S V1.3 is a global coupled dynamic prediction system. The initialization of this prediction system is based on a nudging scheme, which assimilates wind components (U and V), Temperature (T) in atmosphere and potential temperature in ocean from 1 Jan 1980 to 1 June 2022, and 48 ensemble members are generated by a time-lag method. The predictions are available here for 12 months. This real-time S2S prediction system is fully operated on China's Tianhe-2 supercomputer.	None	None	The systematic biases have been corrected based on reforecast datasets
KOPRI (Chi et al.)	Statistical/ML	NA	5	4.97	0.19	4.68	5.22				We selected ten most accurate models in the training process and then use them for the uncertainty estimate.		KOPRI's prediction model uses the past 12-month data as inputs for the six-month predictions of Arctic sea ice concentration (SIC). The predicted September extent for 2022 is 5.00 million square kilometers using data from June 2021 to May 2022.	KOPRI's fully data-driven model was trained on historical NSIDC's daily SIC data from 1979 to 2021 using a combination of convolutional and recurrent neural networks. Since we observed a large visual discrepancy according to the neural network's loss functions, a new loss function was developed to improve both statistical accuracy and visual agreement. The 6-month prediction model is currently tuning up to improve predictability. Please find our recent published paper: Chi J, Bae J, Kwon Y-J. Two-Stream Convolutional Long- and Short-Term Memory Model Using Perceptual Loss for Sequence-to-Sequence Arctic Sea Ice Prediction. Remote Sensing. 2021; 13(17):3413. https://doi.org/10.3390/rs13173413	NSIDC NASA Team, https://nsidc.org/data/nsidc-0051, https://doi.org/10.5067/8GQ8LZQVL0VL, https://nsidc.org/data/nsidc-0081, https://doi.org/10.5067/YTTHO2FJQ97K	NA	Negative SIC predictions over ocean pixels were set to 0% and SIC predictions over 100% were set to 100%. We also used land and coastline masks from NSIDC's SIC data
Kondrashov (UCLA)	Statistical/ML	NA	4.9		0.16				0.55		his uncertainty corresponds to standard deviation of stochastic ensemble spread.	0.5	This model forecast is based on statistical/ML stochastic modeling techniques applied to the regional Arctic Sea Ice Extent (SIE) dataset.	Statistical/ML stochastic modeling techniques have been applied to the regional Arctic Sea Ice Extent (SIE) from Sea Ice Index Version 3 dataset. The daily SIE data were aggregated to provide weekly-sampled dataset over several Arctic sectors. The predictive model has been derived from SIE anomalies with annual cycle removed, and is initialized from latest SIE conditions by ensemble of stochastic noise realizations to provide probabilistic regional Arctic forecasts in September.	NA	NA	
FIO-ESM (Shu et al.)	Dynamic Model	PIOMAS, http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/data/model_grid	4.3										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 2022 is 4.30 (+/-0.39) million square kilometers. 4.30 and 0.39 million square kilometers is the average and one standard deviation of 10 ensemble members, respectively.	Our prediction is based on a climate model named FIO-ESM v1.0 (Qiao et al., 2013). Ocean and sea ice data are assimilated to initialize the model (Chen et al., 2016; Shu et al., 2021). Satellite observed daily sea surface temperature (from OISST), sea level anomaly (from CMEMS), sea ice concentration (from OSISAF), and PIOMAS sea ice thickness are assimilated to initialize the model.	OSISAF, OSI-430-b, https://osi-saf.eumetsat.int/products/osi-430-b-complementing-osi-450	PIOMAS, http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/data/model_grid	
METNO-SPARSE-ST	Statistical/ML	NA	4.639	4.639	0.36	4.279	5	17.773	0.497			0.015	AR model with NSIDC sea ice extent data. We used an updated adaptive length to construct the AR model.	AR model with NSIDC sea ice extent data	NA	NA	

Sun, Nico	Statistical/ML	NSIDC SIC * 2m	4.86			4.3	5.2	18.73	0.555	4	variation in Sea Ice Concetration	0.31	The forecast model is based on ice persistence. It uses incoming solar radiation and sea ice albedo derived from a predicted Sea Ice Concentration (SIC) value to calculate daily thickness losses for every NSIDC 25km grid cell. The initial thickness is calculated from AMSR2 sea ice volume and NSIDC SIC data. Instead of a long-term mean, the 2022 model predicts SIC change based on correlation to previous years. A special formula calculates a best new mean field. Years with a very high correlation get weighted more. For this month the mean field is made up of: "2007,2010,2010,2010,2013,2013,2013,2014,2014,2018" The mean forecast uses the SIC (1/4 weight) and mean SIC change per day (3/4 weight) to predict future SIC. The low forecast reduces the predicted SIC by 0.3Stdv for previously observed SIC for this day and a 10% increased bottom melt. The high forecast increases the predicted SIC by 0.10Stdv and a 10% decreased bottom melt. Since 2020 model includes a bias correction layer to reduce persistent errors of underprediction or overprediction based on past forecasts. This layer simulates ice drift or cold freezing air blowing from landmasses causing refreezing	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.	NSIDC NASA Team, https://nsidc.org/data/nsidc-0081, https://doi.org/10.5067/U8C09DWVX9LM	NSIDC SIC * 2m	none
LPHYS2268 - CDDF	Statistical/ML	NA	4.905785										https://alexiafavaro.wixsite.com/lphys2268	https://alexiafavaro.wixsite.com/lphys2268	NA	NA	
EMC/NCEP (UFS)	Dynamic Model	CPC sea ice initialization system (CSIS) (May 3 to May 9, 2022)	5.2		0.29			18.41					The projected Arctic minimum sea ice extent from the NCEP Unified Forecast System (UFS) model May initial conditions (ICs) using 7-member ensemble forecast (00Z May 3 to May 9 with C192) is 5.20 million square kilometers with a standard deviation of 0.29 million square kilometers. The corresponding number for the Antarctic (maximum) is 18.41 million square kilometers with a standard deviation of 0.31 million square kilometers.	We used the NCEP UFS model with 7-case of May 2022 initial conditions (May 3 to May 9 with C192) and bias-corrected for the Arctic.	NASA Team Analysis from NSIDC (May 3 to May 9, 2022)	CPC sea ice initialization system (CSIS) (May 3 to May 9, 2022)	
CPOM	Statistical/ML	NA	4.3		0.5						Mean forecast error based on forecasts for the years 1984 to 2021.	0.05	We predict the September ice extent 2022 to be 4.3 (3.8-4.8) million km2. This is just above the trend line. In spite of the large sea ice extent in May 2022, sea ice thickness and melt pond cover are quite normal with respect to the last decade.	This is a statistical prediction based on the correlation between the ice area covered by melt-ponds in May and ice extent in September. The melt pond area is derived from a simulation with the sea ice model CICE in which we incorporated a physically based melt-pond model1. See our publication in Nature Climate Change http://www.nature.com/nclimate/journal/v4/n5/full/nclimate2203.html for details2. References: 1. Flocco, D., Schröder, D., Feltham, D. L. & Hunke, E. C., 2012: Impact of melt ponds on Arctic sea ice simulations from 1990 to 2007. J. Geophys. Res. 117, C09032. 2. Schröder D., D. L. Feltham, D. Flocco, M. Tsamados, 2014: September Arctic sea-ice minimum predicted by spring melt-pond fraction. Nature Clim. Change 4, 353-357, DOI: 10.1038/NCLIMATE2203.	NA	NA	See references above
Met Office	Dynamic Model	Sea ice thickness (as all variables) is initialised using the operational FOAM ocean-sea ice analysis. Sea ice thickness is not assimilated in FOAM.	3.7		0.65	2.4	5	18			Uncertainty range is provided as +/- 2 two standard deviations of the (42 member) ensemble spread around the ensemble mean.		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 initialised over a 21-day period are used together to create a 42-member lagged ensemble or forecasts of September sea ice cover.	Ensemble coupled model seasonal forecast from the GloSea6 seasonal prediction system [based on, MacLachlan et al., 2015], using the Global Coupled 3 (GC3) version [Williams et al., 2018] of the HadGEM3 coupled model [Hewitt et al., 2011]. Forecast compiled together from forecasts initialized between 22 May and 11 June (2 per day) from an ocean and sea ice analysis (FOAM/NEMOVAR) [Blockley et al., 2014; Peterson et al., 2015] and an atmospheric analysis (MO-NWP/4DVar) [Rawlins et al., 2007] using observations from the previous day. Special Sensor Microwave Imager Sensor (SSMIS) ice concentration observations from EUMETSAF OSI-SAF [OSI-SAF] were assimilated in the ocean and sea ice analysis, along with satellite and in-situ SST, sub surface temperature and salinity profiles, and sea level anomalies from altimeter data. No assimilation of ice thickness was performed.	Sea ice concentration (as all variables) is initialised using the operational FOAM ocean-sea ice analysis. SSMIS sea ice concentration is assimilated using the EUMETSAT OSI-SAF (OSI-401b; See http://osisaf.met.no/docs/osisaf_cdop3_ss2_pum_ice-conc_v1p6.pdf)	Sea ice thickness (as all variables) is initialised using the operational FOAM ocean-sea ice analysis. Sea ice thickness is not assimilated in FOAM.	Bias correction in each hemisphere, calculated by evaluation of hindcasts over 1993-2016. Bias correction calculated from hindcast evaluation over 1993-2016. Arctic: +1.4 million sq. km; Antarctic: -0.1 million sq. km
NASA GMAO	Dynamic Model	Model-derived.	4.75	0.36	0.37	4.4	5.11		0.97	4.00193	The uncertainty is based on the spread of 10 ensemble members.		An experiment of the new GMAO seasonal forecasting system version 3 predicts a September average Arctic sea ice extent of 4.75 ± 0.37 million km2, or slighly less than last year's value of 4.92 million km2. The experiment is a test of the new version 3 ODAS and forecast ensemble sub-setting method in a near-real time setting. Comparison with NSIDC values suggest the system has more initial ice extent, which may be due to discrepancies between OSI SAF and the NSIDC near-real-time values.	The forecast uses a prototype the GEOS_S2S version 3 coupled system that was modified for this forecast. The model has an approximate grid spacing of ½° in the atmosphere and ¼° in the ocean. An offline version of the ocean data assimilation system (ODAS) was integrated through May 2022. The ODAS is driven by GMAO forward-processing atmospheric analysis. The ODAS assimilates available oceanographic observations and along-track ocean altimetry. The version 3 ensemble uses a staggered initialization of five atmosphere-perturbed ensemble members starting on every fifth day beginning 01-May. Five atmosphere-perturbed and ten ocean-perturbed ensemble members are started on the last day of the month. A total of 45 ensemble members were run through July, at which point the ensemble is sub-sampled based on an error growth assessment, with 10 ensemble members continuing the forecast integration through September.	OSTIA (https://doi.org/10.3390/rs12040720). The OSTIA sea ice concentration originates with OSI SAF (https://osi-saf.eumetsat.int/products/osi-401-b).	Model-derived.	Fields have been regridded to the NSIDC polar-stereographic grid. A template file from NSIDC contains the grid-box area.
UQAM (VARCTIC)	Statistical/ML	PIOMAS, http://psc.apl.uw.edu/wordpress/wp-content/uploads/schweiger/ice_volume/PIOMAS.thick.daily.1979.2022.Current.v2.1.dat.gz.	4.5056	4.5056		3.8966	5.0896				The lower bound constitutes the 5th percentile and the upper bound the 95th percentile of the credible region. Done via the posterior distribution obtained by standard Bayesian Methods for linear Vector Autoregressions.		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.	The VARCTIC, which is a Vector Autoregression (VAR) designed to capture and extrapolate Arctic feedback loops. VARs are dynamic simultaneous systems of equations, routinely estimated to predict and understand the interactions of multiple macroeconomic time series. Hence, the VARCTIC is a parsimonious compromise between full-blown climate models and purely statistical approaches that usually offer little explanation of the underlying mechanism. Precisely, we use an 8-variable Bayesian Vector Autoregression (VAR) with 12 lags and a constant which we refer to as the VARCTIC. We estimate the model over the period from January 1980 until February 2022. A detailed description can be found in the following paper: https://journals.ametsoc.org/view/journals/clim/34/13/JCLI-D-20-0324.1.xml	Fetterer, F., K. Knowles, W. N. Meier, M. Savoie, and A. K. Windnagel. 2017, updated daily. Sea Ice Index, Version 3. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: https://doi.org/10.7265/N5K072F8.	PIOMAS, http://psc.apl.uw.edu/wordpress/wp-content/uploads/schweiger/ice_volume/PIOMAS.thick.daily.1979.2022.Current.v2.1.dat.gz.	

UPenn-UQAM Group	Statistical/ML	NA	4.32	4.32	0.56	3.2	5.44				estimated stochastic model. The standard deviation computed from last 10 years prediction errors from a recursive pseudo-out-of-sample exercise.		The UPenn-UQAM 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.	We have supplied a forecast based on a statistical model with trend, a feed-forward loop, and stochastic shocks, estimated by direct projection. In the modeling process we explore different levels of aggregation of the underlying high-frequency (daily) concentration data and associated sea ice extent, and we tune the aggregation to optimize the predictive bias/variance tradeoff in forecasting September extent. It turns out that previous pseudo-out-of-sample forecast errors (residuals) are approximately Gaussian, which we exploit in making our out-of-sample forecast for this September. The predictive density is Gaussian, with the mean 4.32 million square kilometers and standard deviation 0.56 million square kilometers. (By symmetry, the mean and median coincide.) The approximate 95\% interval that we report is the mean plus or minus 2 standard deviations.	NA	NA	
NCAR/CU (Kay/Bailey/Holland)	Heuristic	NA	4.28	4.33	0.4	3.14	4.82				An informal pool of 27 climate scientists in early June 2022 estimates that the September 2022 ice extent will be 4.28 million sq. km. (stdev. 0.4, min. 3.14, max. 4.82). The uncertainty estimate is based on the scatter in entries in our informal pool.	0.14	An informal pool of 27 climate scientists in early June 2022 estimates that the September 2022 ice extent will be 4.28 million sq. km. (stdev. 0.4, min. 3.14, max. 4.82). 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 ; Data recently provided to Mitch Bushuk GFDL for a synthesis project). We think our informal pool provides a useful benchmark and interesting reality check for Sea Ice Prediction efforts based on more sophisticated physical models and statistical techniques.	An informal pool of 27 climate scientists in early June 2022 estimates that the September 2022 ice extent will be 4.28 million sq. km. (stdev. 0.4, min. 3.14, max. 4.82). Guesses were collected by sending an e-mail out to the scientists and tempting them with local bragging rights and with ice cream for those entering the top three closest guesses from those entering the top three farthest guesses. The actual value in a given year is taken from the October press release issued by the National Snow and Ice Data Center.	NA	NA	none
Lamont (Yuan and Li)	Statistical/ML	N/A	5.18	5.18	0.4	4.78	5.58	18.42	0.57		Arctic SIE uncertainty is 0.40, measured by RMSE using forecast of 2013-2020.		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. The September mean pan-Arctic SIE is predicted to be 5.18 million square kilometers (mskm) with an RMSE of 0.40 mskm, at the four-month lead. The RMSE is estimated based on our model forward forecasts from 2013-2020. The Alaskan regional SIE is predicted to be 0.57 mskm, lower than the observation in 2021. 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 18.42 mskm, with an RMSE of 0.57 mskm based on model cross-validation experiments.	The linear Markov model has been developed to predict sea ice concentrations in the pan Arctic region at the seasonal time scale. The model employs 6 variables: NASA Team sea ice concentration, sea surface temperature (ERSST), surface air temperature, GH300, vector winds at GH300 (NCEP/NCAR reanalysis) for the period of 1979 to 2012. It is built in multi-variate EOF space. The model utilizes first 11 mEOF modes and uses a Markov process to predict these principal components forward one month at a time. The pan Arctic sea ice extent forecast is calculated by summarizing all cell areas where predicted sea ice concentration exceeds 15%.	NSIDC NASA Team, https://nsidc.org/data/nsidc-0081, https://doi.org/10.5067/U8C09DWVX9LM.	N/A	First, a constant bias correction was applied to Arctic SIC prediction at each grid point. These biases were estimated based on the take-one-year-out cross-validated predictions for 1979-2012. Then a constant SIE bias also derived from the cross-validation experiments from 1979 to 2012 was corrected from the September SIE prediction. Finally, the model uses lower resolution sea ice concentration data (2-degree longitude x 0.5-degree latitude), introducing a 0.10 million square kilometers bias compared to 25kmx25km original satellite data. This resolution bias is corrected in the final Arctic SIE prediction.
Horvath, et al.	Statistical/ML	NA	5.07										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 ERA5	This statistical model computes the probability that sea ice will be present (concentration above 15%) for each grid cell in NSIDC's polar stereographic projection. Yearly data from 1980 through the present are used in a Bayesian logistic regression. Predictors include local surface air temperature, downwelling longwave radiation, and sea ice concentration, as well as the first principal component of geopotential height at 500mbars, and Pacific and Atlantic sea surface temperatures. Sea ice concentration data was obtained from NSIDC's Sea Ice Index V3 (Data Set ID:G02135), all other variables are from ERA5	NA	NA	
PolArctic	Statistical/ML	NA	4.71										This is PolArctic's fourth year submitting to the Sea Ice Outlook. Our September extent prediction is 4.71 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.	PolArctic's September SIO extent was generated using our Artificial Intelligence algorithm, and trained with historical NSIDC daily ice extent data. Our initial modeling efforts are to generate high quality seasonal forecasts of daily, spatial and temporal sea ice extents. To calculate our September extent outlook, daily results in September 2022 from our model are averaged.	NOAA/NSIDC, Sea Ice Index, Version 3. https://doi.org/10.7265/N5K072F8.	NA	
NSIDC (Meier)	Statistical/ML	NA	4.97		0.6			17.34			Standard deviation of the projections from using the 15 years between 2007 and 2021	0.78	This method applies daily ice loss rates to extrapolate from the start date (June 1) through the end of September. Projected September daily extents are averaged to calculate the projected September average extent. Individual years from 2005 to 2021 are used, as well as averages over 1981-2010 and 2007-2021. The 2007-2021 average daily rates are used to estimate the official submitted estimate. The predicted September average extent for 2022 is 4.97 (±0.66) million square kilometers. The minimum daily extent is predicted to be 4.84 (±0.66) million square kilometers and occurs on 16 September. The large range of estimates reflects the large variability in ice loss rates over the final 3+ months of the melt season. Based on the last 17 years (2005-2017), there is a 6% chance that 2022 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 2022 is 17.34 (±0.59) million square kilometers. The maximum daily extent is predicted to be 17.42 (±0.62) million square kilometers and occurs on 26 September.	This method applies daily ice loss rates to extrapolate from the start date (June 1) through the end of September. Projected September daily extents are averaged to calculate the projected September average extent. Individual years from 2005 to 2021 are used, as well as averages over 1981-2010 and 2007-2021. The 2007-2021 average daily rates are used to estimate the official submitted estimate. The method essentially provides the range of September extents that can be expected based on how the ice has declined in past years, though it is possible that record fast or slow daily loss rates may yield a value outside the projected range. It also can provide a probability of a new record by comparing how many years of loss rates yield a record relative to all years. It has the benefit that it can easily and frequently (daily if desired) be updated to provide updated estimates and probabilities and as the minimum approaches the "window" of possible outcomes narrows.	Maslanik, J. and J. Stroeve. 1999, updated daily. Near-Real-Time DMSP SSMIS Daily Polar Gridded Sea Ice Concentrations, Version 1. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/U8C09DWVX9LM.	NA	

Slater-Barrett (NSIDC)	Statistical/ML	None	4.83										This projection was made using the Slater Probabilistic Ice Extent model developed by Drew Slater (http://cires1.colorado.edu/~aslater/SEAICE/). The model computes the probability of sea ice concentration greater than 15% for Arctic Ocean grid cells in the EASE 25 km grid. These probabilities are aggregated over the model domain to arrive at daily ice extents. A September mean ice extent is calculated from daily forecasts issued on July 1. While the model has predictive skill at lead times up to 90 days, NSIDC runs the forecast model with a 50 day lead time. Forecasts issued on July 1 for September have lead times spanning 62 to 91 days. Therefore we consider the mean September ice extent forecast for the July sea ice outlook to have some skill.	This is a non-parametric statistical model of Arctic sea ice extent. The model computes the probability of whether ice concentration greater than 15% will exist at a particular location for a particular lead time into the future, given current ice concentration. The only input is sea ice concentration. Probabilities are computed using data from the past 10 years. These probabilities are adjusted using daily near-real-time concentrations to make a forecast. Pan-Arctic Ice extent is the sum of the product of grid-box area the probability of a grid-box containing ice on the forecast date. While not as sophisticated as a coupled ocean-ice-atmosphere models, this statistical method has the advantage that the forecasts for all points are completely independent in both space and time; that is, the forecast at any given point is not affected by its neighbors, nor its result from the prior day. Therefore, the model can adapt to changing conditions and is not inherently subject to drift. The model has performed well in comparison to others in the 2013/2014 SIPN Outlooks, in both extent value and spatial distribution. For 2012, a September mean forecast of below 4 million square kilometers was given. However, the model has also missed by as much as 0.6 million square kilometers in some years. Forecasting is difficult, but the model does have genuine skill at lead times as long as 90 days. Skill improves as lead time decreases, and September is the month with highest skill.	https://nsidc.org/data/nsidc-0081	None	
NSIDC Hivemind	Heuristic	NA	4.48		0.35						Standard deviation of all individual submissions		The value is an average of individual entries to the NSIDC Sea Ice Contest	All estimates from the entries are averaged to get the Arctic September extent estimate.	NA	NA	
ASIC, NIPR	Statistical/ML	NA	4.549									0.103	Monthly mean ice extent in September will be about 4.549 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), ice age, and mean ice divergence on April 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/2022-06-07-1/	We predicted the Arctic sea-ice cover from coming July 1 to September 20, using the data from satellite microwave sensors, AMSR-E (2002/03-2010/11) and AMSR2 (2012/13-2021/22). The analysis method is based on our research (Kimura et al., 2013). First, we expect the ice thickness distribution on April 30 from redistribution (divergence/convergence) of sea ice during December and April. Additionally, ice age distribution and mean ice divergence distribution which represents how much area of young ice is contained in the old ice on April 30 were estimated from the backward tracking of sea ice. Then, we calculated the summer ice concentration by multiple regression analysis based on the derived ice thickness, ice age, and mean ice divergence.	10km grid data distributed by Arctic Data archive System (https://ads.nipr.ac.jp)	NA	
RASM@NPS (Maslowski et al.)	Dynamic Model	See the above	4.91	4.877	0.33	4.392	5.689		0.546	3.927	The uncertainty of pan-Arctic September sea ice extent was estimated from the 31 ensemble members: see also Fig.4 in the supplementary material.	-0.357	The Arctic sea ice extent September 2022 minimum is predicted to roughly continue the September declining trend (of 0.528x10^6 km^2/decade) based on 2000-2021 output from the Regional Arctic System Model (RASM) hindcast simulation. The difference between the 31-member ensemble mean September sea ice extent prediction and the extrapolation 2000-2021 linear trend into 2022 is 0.357x10^6 km^2. Compared to the RASM September 2021 sea ice extent minimum (4.695x10^6 km^2) from the hindcast, the ensemble mean forecast for 2022 minimum is higher by 0.215x10^6 km^2, suggesting a 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 1.0 m and 1.5 m, with the thickest sea ice north of the Canadian Archipelago and Greenland within the range of 1.5 m-2.5 m, and almost no sea ice thicker than 3.0 m. The RASM September outlook has been commonly biased high in recent years (bias of 0.070x10^6 km^2 and standard deviation of 0.415x10^6 km^2) compared to the NSIDC observation (2000-2021), especially in the northern Barents/Kara and East Siberian seas.	We used RASM2_1_00, which is a recent version of the limited-area, fully coupled climate model consisting of the Weather Research and Forecasting (WRF), Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) and Sea Ice Model (CICE), Variable Infiltration Capacity (VIC) land hydrology and routing scheme (RVIC) model components (Maslowski et al. 2012; Roberts et al. or 2015; DuVivier et al. 2015; Hamman et al. 2016; Hamman et al. 2017; Cassano et al. 2017). The model is forced with CFSR/CFSv2 reanalysis output for RASM-WRF lateral boundary conditions and for nudging winds and temperature starting above 500 mb for September 1979-May 2022. Then, RASM is used for dynamic down-scaling of the global NOAA/NCEP CFSv2 7-month forecasts. Each of the 31 ensemble members ran forward for 7 months using outputs from CFSv2 forecasts. The CFSv2 forcing (https://www.ncei.noaa.gov/data/climate-forecast-system/access/operational-9-month-forecast/) streams used for the ensemble members were initialized every day (at 00:00) between May 1st and May 31st and used for RASM forcing at 00:00 on June 1st, 2022 and onward until the end of November 2022.	The initial sea ice conditions for the June Sea Ice Outlook were derived from the RASM 1979-2022 hindcast and are physically and internally consistent across all the model components. Neither data assimilation nor bias correction was used.	See the above	Daily mean sea ice with concentration <=15% and thickness <= 20 cm was excluded in the estimates of September sea ice extent.
NMEFC of China (Li and Li)	Statistical/ML	Sea Ice Index - Daily sea ice concentration(NSIDC NASA Team) and monthly sea ice extent from NSIDC.	4.54										We predict the September monthly average sea ice extent of Arctic by statistic method and based on daily sea ice concentration and monthly extent from National Snow and Ice Data Center. The predicted monthly average ice extent of September 2022 is 4.54 million square kilometers .	An optimal climate normal method is used to predict September average Arctic sea ice extent.	N/A	Sea Ice Index - Daily sea ice concentration(NSIDC NASA Team) and monthly sea ice extent from NSIDC.	
SYSU/SML-KNN	Statistical/ML	NA	5.04	5.04	0.31	4.73	5.35				We estimate our uncertainty with root-mean-square-error(RMSE) calculated from 2015-2020 hindcast.	0.8	A machine learning KNN model is used to predict the daily sea ice concentration (SIC) and the sea ice extent (SIE) of September 2022 in pan-Arctic. Daily averaged sea ice concentration ("NSIDC NASA Team, https://nsidc.org/data/nsidc-0081) fields between 1979 and 2021 were used to predict. The model predicts a pan-Arctic sea ice extent of 5.04(±0.31) million square kilometers and has a positive anomaly of 0.8.	Machine learning algorithm KNN (K-Nearest Neighbors) is used in this prediction. The principle is to find the K nearest neighbors of the input variables from the training data set and the prediction is the mean of the k-NN. In this SIC forecast, we considered the SIC as the training data. At the same time the library comprises simulated climate states selected in the same and adjacent date as the target states. We first compute the distance and pattern correlation for all states in the library. Then we sort the library in descending order based on the pattern correlation between fields to get the prediction od SIE. Then the SIC is obtained by point-by-point calculation and weighting according to the distance.	NA	NA	NA
SYSU/SML-MLM	Statistical/ML	NA	4.41	4.41	0.5	3.91	4.91		0.63		We estimate our uncertainty with root-mean-square-error(RMSE) calculated from 1979-2019 hindcast.	0.2	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 Artic 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.	The multivariate linear Markov model is a statistical model that combines principal component analysis and linear Markov model together, it can identify the large scale atmospheric and oceanic variability through principal component analysis and make linear Markov predictions based on its results (Yuan et al., 2016). To make predictions, first we extract time and space component from the data matrix, and we use linear Markov model to predict the target time component, which will be multiplied with space component to make a final prediction. Besides the parameters used in Yuan et al. (2016), e.g., sea ice concentration (SIC), sea surface temperature (SST), surface air temperature (SAT), here we further use monthly surface net radiation flux (NR) data from 1979 to 2019 to train our model. For this attempt, we use 2021 May monthly mean SIC data to initiate our model and make monthly SIC and SIE prediction.	NA	NA	No post-processing.
ARCUS Team (Wiggins et al.)	Heuristic	NA	4.75										The ARCUS Team submission is the median of all the values contributed by ARCUS team members.		NA	NA	