State of the Science, Understanding, Predictability, and Predictions First session, 8:50-10:10
Rapporteur: Dan Barrie

- **Mark Serreze**
  - Focus on Chukchi -- chokepoint for shipping; as Arctic opens up, there will be more traffic in this region; also oil/gas leases up there.
  - Runs north to the 150m isobath (shelf sea)
  - Generally fully covered by sea ice (small open water just north of the Bering Strait) on June 1 with full recession on average by September 1. Stays open until late October.
  - 2017 about a full month ahead of the average in terms of ice recession
  - Large amount of interannual variability
  - Looking at retreat date (<30% coverage) and advance date (>30% average)
  - Average retreat is July 17 and average advance October 28 -- in between is the open-water period, but huge range (+/-30 days by year)
  - Big trends in advance and retreat; larger advance trend, but larger interannual variability, also
  - Want to predict retreat and advance
    - Bering Strait deep inflow is thermodynamically very important
      - Driven by pressure difference that is a function between the salinity differences
      - How much of that heat and accompanying salinity transport prevents ice growth/encourages melt?
      - Inflow comes in at surface and then dives below the polar mixed layer
    - Albedo feedback and ocean heat also very important
      - Typical sea ice albedo feedback, on seasonal scale
      - Surface winds complicate the radiative feedback; winds can lead to a later retreat
  - Use microwave (concentration), reanalysis (NASA, ERA-I), ocean heat transport from A3 mooring (maintained by UW) at the Strait
  - Study approach: look at predictor level
  - For retreat
    - Moderate SW correlation (cloud radiative effect -- clouds warm surface in this case); -0.5 LW correlation (also because of cloud effect), heat inflow -0.81
    - Linear model with only Bering Straight Inflow has R^2 of 0.68

- - - Huge amount of heat from the inflow, which is used to melt ice or prevent it from forming
    - For advance
      - Small - SW, moderate + LW, 0.67 for inflow, small + for wind
      - Linear model with only Bearing inflow and retreat day gives good fit
    - How did the model do?
      - Well in 2007, but what about forecast fails? It's intraseasonal weather variability.
        - 2000 - retreat that was later than predicted because winds pulled out of the East and temperatures were below average
        - 2003 - more southerly wind and earlier retreat
        - 1991, 1992 also examples of forecast fails
    - Conclusions: Chukchi opening earlier, closing later; inflow is key to predictions; albedo feedback also useful; problem that the moorings need to be visited physically; summer weather predictability is low, also a challenge
    - **DISCUSSION**
      - Variations in inflow -- temperature/mass/interannual/multi-year?
        - *Variability is in both the temperature and the mass; inflow primarily determined by temperature, but winds can counter.*
        - *Data at monthly resolution, and see variability inter-monthly and interannually*
      - Have they used long model control runs to get fuller statistics
        - *Yes, want to move ahead and look at this from numerical predictive scheme; haven't gotten there yet*
      - Comment: correlations are simultaneous, so the model is not really a prediction model
        - Have they looked at co-linearity?
          - *Have run as a multiple-regression scheme, and a lot of co-linearity issues to deal with; only used heat inflow for looking at retreat and albedo mechanism+inflow to look at advance; hampered by short record of heat inflow*
      - Background state is changing; so how do they deal with that?
        - *They don't; run into this issue with sea ice in general, where the trends are very strong, e.g., sea ice thinning, which impacts especially retreat dynamics*
      - Weather timescale issue
        - *If there is some way to get a seasonal outlook of the weather conditions, it would be very helpful (anomalously cyclonic vs. anti-cyclonic conditions in the forecast region)*
- **Bruno Tremblay**
  - Lagrangian model fed with observed sea ice drift fed by satellites and buoys

- Looking at late-winter coastal divergence; if ice is blown away from coastline, new ice will grow, but this ice is thin and won't survive the following summer melt
- If you have divergence in february, the ice can re-grow by 1.5m; coastal divergence after february will lead to ice that is thin and will melt earlier -- this is a good predictor of the minimum sea ice extent in the Arctic ocean
- Draw a line and advect that in the lagrangian model
- Use coastal divergence as predictor
- Using observations to get at sea ice thickness from divergence
- Start from minimum sea ice extent and ask where the ice comes from
- Since 2005, you do not need to export ice out of the Arctic because the new ice is so thin
- Larger trend on peripheral sea export area as opposed to the export area
- Use a synthetic ice edge, and advecting backward in time
- Start in May, advect backward in time; take integral quantity and correlate with minimum sea ice extent
- Using Fram Strait ice export since it is the best predictor
- Positive AO -> more divergence -> more export; AO provides a first-order prediction for retreat in the late summer.
- Feedback responsible for a factor of 5 related to coastal divergence
- Pressure gradient just from Svalbard and other station provides good predictor, as well (can do this without satellite measurements)
- Coastal divergence and Fram Strait is well-correlated
    - Using a combination, the error is reduced to 330,000 square km
    - AO only -- 439,000 square km error
- Forecast for 2017 -- 3.7 million km^2
- Skill is present after 1993 when the sea ice is thin and responds more readily to changes in wind forcing
- **DISCUSSION**
    - How do they choose synthetic ice edge and is there a linear trend in the ice edge?
        - *They use the same one, and it is a first guess; could be better choices; give good correlation*
        - *Could use ice edge from previous year as persistence guess*
    - Arctic dipole has been dominant mode of forcing; how does that impact the forecast?
        - *Not a big fan of the second EOF, because EOF works on the stationary time series, but the second or third components are often just EOF representations of trends*
    - What are the main challenges for the models in capturing this mechanism?
        - *Running diagnostics on models, which do not have the same predictability as the observations; in the two models examined, there was a bias in the Arctic High, so the Beaufort Gyre is running parallel*

to the coast everywhere, so AO just speeds or slows the ice instead of impacting coastal divergence; sea ice thickness along the coastline is key as is proper location of the Arctic High

- **Cecelia Bitz**
  - Prediction is challenging because of such a large change in the mean state
  - Some indications that forecasting the Arctic better improves atmospheric forecast skill in lower latitudes (Jung et al. 2014) -- nudging Arctic variables
  - Sea ice has been forecast for only about a decade; motivated by large change in 2007; previous efforts were focused on nowcasting
  - Sea ice outlook began in 2008
    - 105 participants in 2016; submit forecasts in J, J, and A
    - Dynamic models -- ½ submitting full fields, and are being analyzed at regional scale
      - The dynamical models did best in 2016
    - Results are mixed, in general
  - Some unrealized model skill based on perfect model studies
  - Problem is that an observation used for making forecasts (sea ice extent) is only initially useful because there can be significant intraannual variability in the evolution of sea ice extent -- i.e., persistence is only modestly useful
  - Persistence of SST and thickness anomalies can enhance predictability of extent in certain seasons
  - Thickness anomalies are long-lived (up to years) and influence extent/concentration
  - Very high local lagged autocorrelations
    - Implication is that only 5-10 observations of thickness would give good representation of pan-arctic thickness because of the local point correlations and persistence
  - Known sources of predictability -- extent, thickness, SST, melt ponds…
    - Coupled interactions are very important
  - Assimilation of concentration significantly decreases the bias from at least 10% to more like 2%
  - Assimilation of concentration does not reduce thickness bias; need to assimilate thickness to make a dent on the thickness forecast
    - **Need thickness data**
  - Working on bias correction; temperature runs away quickly to incorrect model state; there are systematic problems with the forecasts
    - Have created a method to shift the sea ice edge as a bias correction
  - Forecast skill is often poor along coastlines, where stakeholders generally need good forecasts
  - **DISCUSSION**
    - In no-assimilation case, what atmospheric forcing is used?
      - *Using atmospheric reanalysis and a slab ocean*

- In result that shows no improvement in thickness when assimilating concentration, what covariance approach is being used?
    - *Using EnKF*
- David Bromwich/**Aaron Wilson**
    - A large amount of observations to take advantage of
    - Biases in many fields are very small and representative
    - Improved representation of near-surface wind speeds
    - Continuing major challenge is with the radiation; biases in SW are larger in ASR than in ERA-I
        - LW biases are large, although some improvements
    - Measuring local-scale wind featuers, like the tip jet off of Greenland and other orographically-forced wind circulations
    - Barrier flow critical
        - Increased resolution increases the wind speed, and ASR captures some features very well; enhanced gradient along sea ice edge; low wind speeds downwind of the fjords (topographic sheltering); onshore extension of high winds near Cape Farewell -- many of these features are not captured in ERA-I
    - ERA-I has high/low wind speed biases; big improvement in both factors in ASRv2, although ASR overestimates wind speeds in weak wind regimes (sheltering situations)
    - Doing some cloud work; focused on improvements to Polar WRF -- evaluating cloud sensitivity to the microphysics schemes, and working on parameter adjustments
        - See improvements in cloud liquid water path; decrease CCN
        - Some of the radiative characteristics are impacted; improved simulation
        - Decreasing CCN increases the liquid precipitation, which increases the liquid water path, and improves the SW radiation; small impact on lW radiation
        - Some work to be done looking at sensible heat fluxes
    - ASRv2 completed through 2012, now available at NCAR CISL
    - ASRv2 will be brought up to date in near future
    - Surface variables compare well with observations
    - Radiation in v2 improved over v1.
    - **DISCUSSION**
        - Plans to make real-time, to be used for forecasts?
            - *Would love to; matter of the right things coming together*
        - Plan to include 97/98 and extend the reanalysis backward in time
            - *They have been exploring this; would like to extend back to 1979 and bring up to date; there is a big push in the reanalysis community to drive resolutions down to 30km and beyond*
        - What are they doing with the lower boundary -- sea ice extent, or thickness, as well?
            - *Thickness, snow on sea ice are ingested; not clear whether thickness is variable and assimilated*

11.35 – 12.20: [each presentation 15 minutes including 5 minutes for discussions]
Scope: Arctic climate and variability, and mechanisms. Arctic sea-ice prediction skill. Arctic and midlatitude weather.
Rapporteur: Wilbert Weijer

11.35 Session
Bushuk (GFDL/NOAA): Regional Arctic sea ice prediction, mechanisms, forecast sills, future outlook. Predict sea ice extent on Seasonal time scales on 0-5 months. There is some skill, dependent on model. 12-24 months for perfect model predictions. Why the gap? How skillful are regional predictions of Arctic sea ice, how skillful could they be? Dynamics forecast mode: GFDL -FLOR (Forecast oriented Low Ocean resolution ~1 degree). Ensemble Kalman Filter coupled data Assimilation (ECDA). No assimilation of sea ice data. Hindcast set of experiments. (retrospective forecasts). Quantify with anomaly correlation coefficient (ACC). Skill of sea ice (September) with lead 2 (months), but less skill for detrended data. Now to regional: Highest skill for winter sea ice in North Atlantic sectors (Barents, Labrador, GIN Seas). North Pacific not so skillful. Also some skill summer sea ice extent, 1-4 months in advance.. Prediction skill barrier around May 1 initialization. How much better can we be doing? Perfect model predictability experiments (free-running model). 12 ensemble members, 6 start years, 6 start months, 3 year integration time. Winter sea ice volume is highly predictable quantity (even 3 years in advance). Huge gap between perfect model and operational skill. Does not carry over the summer sea ice (may barrier also here). So important to initialize forecast beyond May 1. Barents Sea January predictions. Winter skill coming from memory of ocean temperatures. Initialize with colder ocean: more sea ice.

Perlwitz (NOAA/CIRES-CU): Arctic amplification and mod-latitude weather. Models capture "observed" changes in Arctic near-surface warming since 1980. 50% or more of the signal in the Arctic is due to sea ice loss. What are the causes of Arctic tropospheric warming? 18 m thickness difference (1000-500hPa) during OND, outside natural variability, so must be forced. But only 20% from sea ice change. Most of the thickness change due to influences outside the Arctic (decadal ocean variability). Model errors potentially affect proper simulation of Arctic lower latitude connection. Sea ice thickness has strong impact on Arctic near surface temperature, but confined to lowermost troposphere. Stratospheric pathway of Arctic change-lower latitude linkages. Low SIC Barents-Kara Seas composited in AMIP simulations, large difference between forced response in models and observational composites. Models don't show warming of stratosphere. 11 low Artic had prevailing cold ENSO (La Nina), But also prevailing east phase of QBO. Influence of Arctic SIC change on tropospheric warming not detectable, external forcing may dominate. Forced signal of sea ice loss impact on strat polar vortex alone is judged to be small compared to other forced signals, small compared to internal variability. More work is needed to better understand the potential roe of model errors on simulating proposed Arctic lower latitude linkages.

Patterson (US CLIVAR): Results from Workshop on Arctic Change and possible influence in mid-latitude climate and weather. 70 agency funded projects (through 2014). Journal papers significant increase in recent decade. Several workshops within a year. New working group was proposed and approved. Largest working group. Now in third and final year. Objectives: etc… Inform funding agencies. Europeans through Horizons 2020. Workshop ()Feb 1-3, 2017, DC) 100 experts, international. Findings: Focus: seasonal and longer timescale and regional to global linkages. Address sources of inconsistency and uncertainties among studies. Not including extreme event attribution. Challenges: short observational records; determining role of Arctic vs lower latitudes, internal variability; discrepancies between AGCM and CGCM models; physical process lining Arctic and midlatitude not well understood; biases and

uncertainties exist in metrics for quantitatively detecting Arctic-midlatitude linkages. Arctic Rapid Change: many mechanism; Arctic mid-latitude linkages: potential pathways ordered according to confidence level. Recommended activities: expand observational datasets and analyses approaches of Arctic change and mid-latitude linkages. Establish modeling task force to plan coordinated modeling experiments and analysis. US Modeling centers invited to participate: Yannick Peings (ypeings@uci.edu). Twenty experiments comprise this MIP. PA_MIP. White paper by the working group; special collections.

Group A [Discussion Leaders: T. Ringler (DOE/LANL) and W. Maslowski (NPS).
Rapporteur: J. Fyke (DOE/LANL)] – Modeling the Arctic processes

Charge to the Group: What are top three priorities to be addressed over the next three years? And what would be the benefit of succeeding in each of these priorities.

Proposed self-organization: We frame the discussion from the perspectives of the seven modeling groups represented at this workshop. Navy, NOAA/GFDL, NOAA/NWS, DOE, NCAR, NASA-GISS, NASA-GMAO

Proposed Framing Questions:

What is the most pressing near-term bias that you expect to resolve (1 to 3 yr)?

-Arctic albedo, snowmelt timing, centennial scale of vegetation and associated diagnostics and physics

--often, error historically thrown into land model tunings

--now, these are becoming more important to understand

--(Bill Riley, LBNL): thermokarst lake simulation, albedo impacts of vegetation changes, permafrost thaw

-JF Francois (NCAR): representation of Arctic clouds & cloud droplets. In general, phase of precipitation reaching surface

-Gavin Schmidt: NASA: clouds! Radiation scheme, which may not be tuned to Arctic atmosphere

-Phil Rasch: clouds. Aerosols at high latitudes, and their impact on cloud characteristics

-Biggest cloud challenges:

---Phil R. (ACME): impact of clouds on radiative fluxes, water fluxes to high latitudes. Cloud phase important for both.

-Ruby Leung: useful to distinguish particular cloud issues. One issue may be resolution.

-Bin Zhoa: coupled biases, and the impact of ice-ocean coupling

--W. Maslowski: for various reasons, upper ocean structure (~150m) can be misrepresented, which impacts seasonal evolution of coupled ocean/ice/atm. System.

---mixed layer too deep

-----need eddy-resolving

-----need sufficient vertical resolution

-----virtual salinity fluxes may cause problems in Arctic regime (negative salinities)

--W. Maslowski: inconsistencies in models (e.g. fixed salinity melt temperature in sea ice) could impact coupled evolution

--JF Francois: in CESM, recent issue was too much Lab Sea sea ice. Vastly a resolution issue (lack of resolution of eddies)

-Wilbert Weijer: how is river runoff treated?

--all present models DO include a routing scheme to send water from land to ocean

--volume conserving: 1

--mass conserving: 1111

--Todd Ringler: rivers include more than mass fluxes (e.g. temperature). Tracking these may be important, but difficult

--distribution of water into ocean, also important (W. Weijer)

-Todd Ringer: processing salt through sea ice/ocean system:

--Adrian Turner:

----in CESM: sea ice assumed to be at constant salinity (so freeze/melt T fixed)

----in ACME: salinity now prognostic. But incompletely represented in coupled system, currently

----Gavin S.: in GISS Model, this problem is better resolved in due to reformulating ocean to accept sea ice salinity fluxes, within ocean boundary conditions

----In SIS1, salinity is constant, but SIS2 it may be prognostic

-Bill Riley: precipitation T important for land processes

---G. Schmidt: being worked on in GISS. But problem of tracking energy flux in precipitation is surprisingly complex.

-Ruby Leung: are aerosols important in Arctic?

---Phil R.: biases are large and a function of altitude

---amount reaching high latitudes strongly a function of scavenging on the path from mid-latitudes

---also function of high latitude flaring

-JF Francois: latitudinal distribution of precipitation, particularly across Greenland, hard to get correct. Partly due to local issues, partly due to broader circulation patterns

--Gavin S.: downscaling important for getting ice sheet surface mass balance

Top 3 challenges:

What is the largest technical challenge for improving the fidelity of Arctic simulations?

Provide context to the answer: time scale, spatial scale, model component(s), other ….

-technical challenges depend on which timeframe you're interested in. E.g. subseasonal prediction versus tipping point timeframes.

-land is be important on fast timescales. So, improving land processes could be important to improve, on near-terms

-need to better simulate Arctic, to better understand Arctic->mid-latitude connections

-short-term timeframes may have more success in funding due to current weather bill

-MOSAIC: new dataset constraining energy transfer through atm/sea ice/ocean system. Could be good for quantifying compensating errors

Biggest challenges, by modeling center, over next 3 years

Biggest challenges over next ~3 years

-RASM:

--improve coupling of momentum transfer from atm through sea ice into ocean

--radiative budget of Arctic ocean surface

-CESM:

--CMIP6 simulations

--clouds

-GFDL:

--completing CMIP6 models

--evaluating new coupled system

--dynamic veg

-ACME:

--clouds; ice nucleation in mixed-phased clouds

--land surface processes: thermal hydrology, runoff, subgrid topography in land model

--melt pond drainage in sea ice

-GISS model:

--cloud processes; mixed phase, aerosol cloud nucleation

--methane hydrates (as a subset of composition changes due to climate change)

-GMAO:

--initialization of ocean/sea ice over polar ocean (seasonal/sub-seasonal timeframes)

-EMC:

--metrics to measure fidelity of Arctic simulations (over very short timescales, 3-5 days)

Major themes found:

--room for improvement in all areas, and many processes are under-represented

--clouds in Arctic, for their effect on:

----surface radiative budget over land, sea ice, ocean

----the Arctic hydrological cycle

--good discussion around:

----improving representation of cycling of salinity/freshwater/carbon and other constituents through Arctic coupled system

----improving land models may uncover compensating biases, because of historical use of land to absorb broader errors

----upper Arctic ocean representation of stratification, and related impacts on surface fluxes and exchanges of mass/properties with lower latitude oceans

----Arctic to midlatitude understanding will improve from improved Arctic representation

----Scientific/operational interest across timescales, from a few days to climate projections

----other specific topics will be included in draft report

Group B [Discussion Leaders: M. Winton (NOAA/GFDL) and M. Cai (NSF).
Rapporteur: H. Archambault (NOAA/CPO)] – Arctic predictability

● What are the predictability sources in the atmosphere? In the ocean? Feedbacks between them (i.e., atmospheric flow regime influences ocean transport months later)

○ What about land-ocean issue -- river runoff from snowpack months earlier that influences the ocean?

○ Fresh water influence on vertical stability?

○ Thermal input?

■ Both are important

● A distinction between predictability of models vs. predictive skill

● Global vs. regional boundary conditions → need to have a global model

● Decadal prediction from ocean ICs

○ will keep looking at trends - different space/time averaging

○ How to best do decadal prediction?

○ Different initial states of ocean could give different optimal prediction times?

○ At two-ten year time frame, need to think about the problem as trend and initial-value problem
● Understanding past periods of Arctic warming -- better understand longer term predictability (ocean as a source of predictability)
● Sea ice model predictive skill at subseasonal to interannual scales
○ Has been no systematic evaluation of regional predictability across a number of models
■ Value of this: different models have strikingly different properties; can't identify opportunities for prediction unless have robustly assessed prediction
○ What is the upper limit of predictive skill, along with hindcast skill - where models are at, where are they doing well, where is there room for improvement by their own standards
○ Is the AO a source of predictability for sea ice? Can get a first order estimate of cyclonic vs. anticyclonic flow over a certain period
○ How do you overcome the predictability problem presented by the
○ weather?
○ What are the sources of predictability (low frequency modes) for different regions?
■ All contribute to basin wide prediction
● What is contribution of different modes to skill through
○ better initialization vs. reduced model bias?
○ Basin wide skill may only come from a couple of regions, a couple of predictability sources
■ Some predictability sources may be more useful than others for certain applications
○ What parts of the ocean have a long persistence timescale? Identify long memory
○ portions -- where you can get the biggest bang for your buck in terms of predictability?
○ Also may be useful just to be able to get periods of a week or two of strong winds

2) Additional skill to be gained by initialization of the model
● Sea ice thickness in summer
■ Data series are short, has questions associated with it
○ Cecilia's talk: ways to use proxies for thickness to assimilate into model to get at thickness assimilation in model

● Also ocean temperature in near ice region is potentially important for initialization
○ (under-explored so far)
○ Cryostat2, other new obs becoming available
○ More data, more moorings, more timely acquisition of data will be helpful
○ Seasonal weather outlooks (predicted atmospheric flow regime over a summer -- i.e.,
○ Coupled data assimilation becomes more and more important
○ System needs to be coupled - initializing all components
■ Not necessarily clear whether to do weakly vs. strongly coupled DA
■ Could also be regional differences
○ Best to start with coupled DA in tropics (outside of the Arctic)? If some of the prediction systems show big shocks, then it will be necessary to work on coupled DA
○ Starting with a very well balanced state is critical
■ Want to initialize sea ice thickness with Cryosat, others
○ No one is yet doing strongly coupled DA for thickness
■ Sea ice thickness anomalies in initial conditions persist for more than a year
● Also allows more influence from ice-albedo feedback
○ Need snow load to get ice thickness

○   May be enough right now to initial individual components and check that there are no shocks

○   An open question as to how to handle coupled DA between ocean-atmosphere vs. ocean-ice -- may be better to not do strongly coupled DA for ocean-ice

○   Thickness of the ice says something about importance of initializing it -- if it is a region where the ice is very thick, it is not a sensitive region

○   One thing to consider: What measurements/how many do we need? Cecilia's work suggests that relatively few in situ measurements may be needed because of strong spatial correlation

○   Also, how long do your obs time series need to be? At some point, sustained obs allow for initialization with anomalies

○   Opportunities from YOPP? Looking at obs network (radiosondes)

■   Data denial experiments for NWP suggest that satellite obs are always better→ not because of accuracy but because of volume

3) Model formulation

●   What aspects of the model lead to better predictive skill?

●   Bruno's prediction: dynamical mechanism for sea ice prediction

○   How well do models really capture the dynamics of sea ice?

○   This hasn't been looked at very much

●   Now can estimate ice strength -- can now constrain parameters -- see response to wind

○   Melt ponts: new in models (CICE5) -- most don't have melt ponds in thermodynamics of models

■   Melt ponds lead specifically to improved prediction of summer sea ice (some preliminary papers to suggest this)

○   Having the right wind in your model is absolutely essential -- > to first order, need right winds to have right potential predictability

○   Get Arctic weather regimes correct - coupled model improvement (hard to point to one specific thing to focus on)

●   Use of DA to look at model biases in sea ice