“Red sky at night, sailor’s delight. Red sky in morning, sailor’s warning”
—unknown

As long as humans have looked to the sky and observed the weather, they have wondered what will come next. If the sun is shining today, what does that mean for tomorrow? Does the late arrival of spring mean the summer harvest will fail? Does a prolonged stretch of heavy summer rain indicate a dry fall?

Without an understanding of how the atmospheric system works, the tools people had to predict the weather were limited to their own experiences. For example, warm and dry springs may lead to hot summers. Lingering snowpack in March may lead to cool Aprils. In each of these instances, the observer is using the past as a guide to predict the future. Specifically, the observer is using the a priori weather/climate at their location to predict future weather/climate at that same location. Extending this approach, an observer might also link conditions hundreds or thousands of kilometers away with present and future conditions at their location. As an example, many readers are aware that temperatures in Alaska are often inversely correlated with temperatures in the Lower 48 on medium to extended time scales.

This is the essence of analog forecasting. This type of forecast identifies patterns of weather and climate events over some time period and matches past instances with similar conditions, then uses those pattern matches to forecast future conditions. Not only is this type of forecasting conceptually familiar to the general public, it has received considerable academic interest for decades.

**CONTEMPORARY USE OF ANALOGS**

Perhaps the best-known use of analogs to generate forecasts is the use of the El Niño / Southern Oscillation (ENSO) index to highlight broad temperature and precipitation anomalies during periods when the tropical Pacific Ocean is warmer or cooler than normal. El Niño winters in Alaska are usually warmer than normal and La Niña winters are usually cooler than normal across the Great Land. Figure 1 shows a NOAA-generated map of wintertime climate impacts typically associated with La Niña. These associations are determined by looking at analog years where sea surface temperatures (SSTs) near the equator are above or below a certain threshold. Sometimes these forecasts are great, and other times they miss badly. Climatologists do have a deep understanding for the atmospheric response to warm tropical SSTs, and the use of analogs provides many months of lead time for estimating impacts to large geographical regions.

![Figure 1. El Niño / Southern Oscillation (ENSO) Source: https://www.weather.gov/media/jkl/SP-Midwest-LaNina-report-Final.pdf](https://www.weather.gov/media/jkl/SP-Midwest-LaNina-report-Final.pdf)
On a sub-seasonal time scale, several climate agencies use analogs to generate, or assist in generating, forecasts up to two weeks in advance. The Climate Prediction Center (CPC) uses analogs for their popular 6-10 and 8-14 day outlooks, and the Earth Systems Research Lab (ESRL) has an analog precipitation forecast that extends to the 14-day period. Many other agency and university initiatives also utilize analogs.

**FINDING ANALOGS**

The case for determining the presence or absence of an El Niño event is quite straightforward. Temperature anomalies in a very specific area of the tropical Pacific Ocean are plotted and if they are above normal by a certain amount for a specific length of time, an El Niño is declared. This is the simplest type of match—but it is not a pattern match. Since the El Niño region is very homogenous and relatively small, a simple arithmetic average is sufficient. For larger areas, patterns of anomalies matter more than arithmetic averages. You can end up in a situation with extreme positive and negative anomalies within a search domain that average out to near zero. A match looking for the near zero value will completely miss the pattern. Therefore, a pattern recognition algorithm is preferred to capture intra-domain variability. Figure 2 is an example of finding the best matches for sea level pressure (SLP) across the north Pacific Ocean. In this example, we looked for SLP matches in an area defined by the red box (25°N-60°N and 160°E-130°W). The leftmost image on the panel is the January-March 2017 SLP anomaly. The pressure was very high across the southern Bering Sea and transitions to slightly below normal to the south, southeast, and southwest. The middle panel shows the January-March 2014 SLP pattern. The area in the red box represented the closest average anomaly value to the left panel. The difference in the pattern though is plainly visible. There is nothing similar in the SLP patterns between 2017 and 2014. This demonstrates the problem with just using average values. The rightmost panel is the January-March 1996 SLP anomaly field. The pattern within the red box looks very similar to the pattern on the leftmost panel (2017). In this case, a root-mean-square (RMS) algorithm was used to look for pattern differences between the anomaly fields. The result is a much better depiction of an analog year based on the search domain.

**IARC/NOAA PROJECT**

In mid-2015, I began working on a NOAA-funded project to identify analogs for specific atmospheric drivers of sea ice variability. John Walsh at UAF-IARC is the Principal Investigator and Richard Thoman at NOAA/NWS is the Project Collaborator. From the grant description: “Given the importance of wind and temperatures for the evolution of sea ice anomalies, we propose to develop a monthly-to-seasonal analog forecasting system for sea level pressures and temperatures over the Arctic. This approach departs from the conventional statistical methodologies (e.g., screening regression) and dynamical model forecasts. Our rationale is that neither of the latter two approaches, widely used in seasonal sea ice outlooks, has shown the ability to capture large year-to-year changes of summer ice extent in recent years. The use of an analog approach to forecasts of atmospheric forcing therefore offers a novel and potentially useful approach to improved seasonal sea ice forecasts of pan-Arctic and regional sea ice extent.”

This project uses reanalysis data to represent various atmospheric parameters at a variety of height levels. Examples include: 2-meter temperatures, 850 hPa heights, sea surface temperatures...
(SSTs), 500 hPa temperatures, and many others. The project uses monthly Reanalysis (R1) data sets are available from 1948 through the present from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR). These data sets are usually updated only a few days after a month has concluded. The timeliness of the data is crucially important for forecast utilization. Other reanalysis data sets are posted weeks to months after the conclusion of a month. While useful for research purposes, this greatly reduces their utility for near real-time forecasts.

For the analogs project, we settled on the following variables: sea level pressure, sea surface temperatures, 2-meter temperatures, height by pressure level (1000 hPa to 10 hPa), and temperature by pressure level (1000 hPa to 10 hPa). Several composite indices are also used in the project for determining analog matches.

The project team developed a webpage that enables a user to define a search domain for analog selection, define the variable used in the search, identify a forecast area, and generate analog matches and forecasts. Figure 3 shows a screen capture of the webpage. Here are some of the user options:

- Selection of match domain and time period for finding analogs.
- Selection of forecast domain and time period for forecasting.
- Theme to forecast (may be different than theme to match).
- Weighting scheme for matches. An ordered list of matches is generated for each variable. The user can weight these any way they wish (e.g., 50% SLP and 50% 500 hPa heights).
- Selection from 16 different atmospheric levels for height and temperature variables.
- Trend or detrend the data.
- Auto-weighted selection based on multiple linear regression. Each of the variables is assigned a weight based on the proportional contribution (coefficient) to a regression equation.
- Use of predefined indices (e.g., PDO).
- Selection of user-generated indices from empirical orthogonal functions (EOFs).
- Manual selection of years.
- Choice of Pearson’s R or RMS match algorithm.
Figure 4 shows the output of an analogs analysis seeking matches for the north Pacific Ocean to generate a forecast for the Lower 48. The match criteria was 100% weighted on 850 hPa heights. The top left map in Figure 4 shows the actual 850 hPa height anomalies for the selection month (January 2017). The top five match years are displayed underneath (this image truncated to show only the top two matches). 1954 was the best match (analog), followed by 1996, 1973, 1994, and 1960. The program tracks each of those five analog years and computes the 850 hPa anomalies for the month of February. The anomalies are then superimposed on one another and a composite analog forecast is generated. As a composite forecast, the range of values is far less than the individual analog forecast years.

The sample forecast for the Lower 48 called for slightly higher 850 hPa heights in the southwestern portion of the Lower 48 with slightly lower than normal heights across the rest of the Lower 48. In the verification column, we see that the lower height pattern verified fairly well. As a verification test, we randomly selected 5 analogs in a loop 5,000 times and measured how often the analog forecast outperformed the randomly selected forecasts. In this example, the analogs forecast beat the no-skill forecast 71.5% of the time. At the bottom of the output page (not shown) the R-correlations are...
reported to the user. For this sample analysis, the R-values were:

- Multiple R (no sign) = 0.48
- SLP = +0.25
- 850 hPa Height = +0.26
- 2-Meter Temp = -0.24
- 850 hPa Temp = -0.25
- SST = -0.19
- Sea Ice Extent = +0.13

Knowing what the correlation values are allows the user to re-run the analysis if they find a variable in the match domain with a stronger relationship to the forecast variable/domain. In addition, inspection of the match years occasionally reveals a match which scores well but does not look as representative as other match years. In that case, the years can be manually selected based on a table of scores.

### CAUSE AND EFFECT

If we look at global correlation maps between a match variable during a certain month and a proposed forecast month, we see that some areas are positively correlated and others are negatively correlated. Figure 5 shows a sample output of correlations between all variables for the match and forecast time periods. The highlighted section shows the correlation map of 500 hPa heights in March with 2-meter temperatures across the Lower 48 in April. Orange colors show positive correlations and blue colors show negative correlations.

What does it all mean? We broadly see that there are positive correlations with the pattern of 500 hPa heights during March in middle latitudes, and 2-meter temperatures for the Lower 48 during the month of April.

If you look at a large enough area, there will always be areas of high and low correlations purely as a function of random chance. This is evident when we substitute a dummy variable for an atmospheric variable. For example, in parts of Alaska and Wyoming, 2-meter temperatures are weakly inversely correlated with the U.S. unemployment rate (not shown). However, the patterns are chaotic and not statistically significant. Clearly those patterns carry no practical meaning.

So how do we separate the wheat from the chaff? When is a correlation meaningful and when is it spurious? The answer is not always clear. With a large enough sample size, there are bound to be examples of correlations that exist, but that do not mean anything. The R1 Reanalysis data sets contain 10,226 grid points for each variable at each time step. A random sampling of this data set might generate 500+ points that exhibit some degree of significance! This is where knowledge of atmospheric processes and the climate system is imperative.

Just because there is a correlation between 600 hPa relative humidity over South America and surface temperatures in Greenland, for example, does not necessarily mean one is relevant to the other. Users are expected to apply basic knowledge of atmospheric processes and relationships to the analogs output.

### SEA ICE FORECASTS

The stated goal of the project is to identify analogs of known, or suspected, atmospheric variables that influence seasonal sea ice extent. Identifying those analog years and then tracking sea ice changes enables us to forecast sea ice for whichever month(s) we are targeting.

Right away we encounter a serious problem; namely, sea ice is dramatically decreasing. If the analog selection identifies match years in the early 1980s, the sea ice extent in those years was far larger than it is today. Using early 1980s values to estimate sea ice extent in the current year will yield wildly inaccurate results. The solution is to use departures from the trend line instead of raw values. The National Snow and Ice Data Center generates monthly linear trend lines from 1979 through the present, and reports the departure from that trend line in addition to the absolute sea ice extent. We employ the same technique for this project. Separate trend
lines are generated for the 1948–1978 sea ice extent and the 1979 to present sea ice extent (pre- and post-satellite era). The composite of departures from trend for the five analog years is then applied to the extrapolated trend line for the forecast year.

Unsurprisingly, if one month is well below or above normal for sea ice extent compared to the trend line, the next month is likely to show a similar departure. By the second month, the correlation is much weaker and by the third month, the relationship breaks down completely. Figure 6 is a scatter plot showing the June sea ice departure from trend line versus the following September sea ice departure from trend line. Note the almost complete lack of correlation.

**ANALOGS APPLICATIONS**

The stated goal of the project is to evaluate atmospheric conditions that drive sea ice variability on seasonal time scales. Last year, we submitted September sea ice forecasts to the Sea Ice Prediction Network in June, July, and August. Our forecasts outperformed many other dynamical and statistical forecasts—although we were not the best.

Beyond sea ice forecasting, the program is flexible enough to allow users to define any match domain they wish and likewise generate a forecast for any spatial domain they wish. The output graphics and diagnostics enable the user to assess the strength of the correlations and fine-tune the spatial domains and/or the variable choices. Here are a few possible applications:

- Fire managers make initial resource allocation decisions for the summer wildfire season in the preceding winter months. The analogs tool gives a first glance at possible conditions 4 to 6 months in advance.
- Tropical cyclone development is constrained by sea surface temperatures. The analogs tool can spot sea surface temperature patterns and identify match years with similar patterns. This may be used to fine-tune seasonal hurricane outlooks.
- The seasonal breakdown of the stratospheric polar vortex is important for temperature forecasts across North America. Identifying the 10-50 hPa height analogs may offer insight into the evolution of this feature.

The analogs tool was recently used as part of attribution study analysis of the warm 2015-16 winter in Alaska (Walsh et al., 2016). In that study, the forecast portion of the analogs program was not utilized and instead, the matches were the focus of the analysis. Those matches identified the atmospheric flow patterns similar to the winter of 2015-16 and a determination was made as to the proportion of warming that the atmospheric dynamics was responsible for.

**CONCLUSIONS**

Dynamic atmospheric modeling is an evolving, constantly improving science. As time progresses, the ability of models to pick up on patterns weeks and months in advance is steadily improving. That said, there are currently computational and theoretical limits as to how far into the future dynamic models can effectively model the atmospheric (not climatic) system. Analogs represent a bridge to the seasonal (2-12 month) forecast time scale.

A key point to remember is that analogs provide assistance and historical context when generating a seasonal forecast. Whenever an El Niño or La Niña seasonal forecast is a “bust,” critics come out of the woodwork to explain that the forecasters did not know what they were talking about; however, it bears repeating that analog forecasting is a tool in the toolbox for long-range planning—a tool with tremendous applicability.

Change is a part of life. In Alaska, we are used to annual changes from mosquito-filled summer days to crisp winter nights. We exchange the baseball hat for the wool one, top off our wood pile, and make sure our freezers are full. Our behaviors are learned actions that allow us to adapt to seasonal changes in our environment. But what happens when the change is unexpected? What are the adaptations people make in the face of a changing climate?

Historically, subsistence harvesters were affected by resource availability predominantly due to annual and seasonal environmental changes. Today’s subsistence harvesters not only respond to natural variation in resource availability and abundance but must also adapt to regulations, which place limitations on timing, location, and quantity of allowable harvest. University of Alaska PhD student Maggie Chan’s research focuses on how subsistence harvesters adapt to changes in fish availability, using the case study of Pacific halibut harvesters in Southeast Alaska.

Of the main user groups targeting halibut, there is the least available information on subsistence harvesters, who removed approximately 2% of all halibut fished in Alaska in 2014. Although subsistence harvesters remove a small percentage of halibut harvest by weight, there were over 9,000 registered subsistence harvesters in 2012, residing in hundreds of coastal communities throughout Alaska. In addition to biological changes to halibut populations, a regulation of the subsistence halibut sector began in Alaska in 2003 through the implementation of the Subsistence Halibut Registration Certificate (SHARC), which allows for subsistence harvest of halibut for members of federally recognized Alaska Native Tribes and rural residents of Alaska. With SHARC, subsistence halibut harvesters shifted from using sport guidelines to more liberal subsistence guidelines. In Southeast Alaska, the daily harvest limit for subsistence halibut changed from two fish, under sport guidelines, to 20 fish, under subsistence guidelines. Even though guidelines became more liberal, there has been a substantial decrease in participation rates and harvest amounts of subsistence halibut. In 2012, the number of registered SHARC holders and the total subsistence halibut harvest (net weight) were the lowest recorded since 2003. The downward trends are perplexing given the fact that the establishment of a subsistence halibut sector created more liberal guidelines for subsistence harvesters, including larger bag limits and additional gear choices. Chan’s project builds on existing ADF&G data to better understand how subsistence harvesters adapt to a landscape of environmental and regulatory changes.

Relying on interviews with subsistence harvesters, her project combined fishery metrics (e.g., fishing effort), spatial analysis, and interviews to fill gaps in our current understanding of subsistence harvest. Semi-structured interviews were conducted in 2015 and 2016 with subsistence users in the communities of Gustavus, Hoonah, and Sitka in Southeast Alaska. These communities were chosen because they have high participation in subsistence halibut harvest and reflect diverse demographics, e.g., population size and income. Participants were asked to describe their subsistence halibut fishing practices over their lifetime, including fishing effort, catch amounts of halibut and other species, fishing locations, and species preference. Additionally, participants were asked to identify primary fishing locations for halibut, salmon, lingcod, and rockfish. Each question on fishing behavior was followed by open-ended questions asking respondents to identify the reasons for changes in behavior (if any). Respondents marked his or her fishing locations on paper maps, which are currently being digitized (Figure 8) and analyzed.

In order to understand the effects of SHARC regulation on subsistence harvest patterns, a series of interview questions addressed the effects of SHARC, such as, “How did the 2003 subsistence halibut regulations affect the distance you travel on an average subsistence fishing trip?” Responses looking at SHARC regulation will be statistically evaluated and will
be compared with a previous ADF&G study from 2006 on effects of SHARC in Sitka. All interview questions are being transcribed and analyzed.

Analysis is not complete, but some preliminary findings have emerged. A majority of participants highlight the interconnectedness of subsistence harvesting from marine to terrestrial sources, including deer, shellfish, fish, and plant sources. It was common for participants to describe fish harvest amounts in comparison to the success of other resource harvest. For example, harvest amounts for halibut may depend on the success of hunting the previous year. However, management of resources is often by species, leading to a mismatch between the management and the harvesting behavior. Therefore, participants talked about the importance of regulatory flexibility, which has been a positive aspect of SHARC. The implementation of SHARC led to more liberal guidelines and bag limits for subsistence halibut, important features for flexibility. In fact, many participants commented that management of other resources should recognize the flexibility inherent in subsistence harvest, as SHARC does. While perceptions of SHARC were widely viewed as positive, there were differences in harvest and use patterns between communities and the type of SHARC. When Alaskan residents register for SHARC, they are required to self-identify as rural or tribal, based on their eligibility. In our preliminary findings, the harvest amounts for subsistence halibut was higher amongst tribal SHARC holders than rural SHARC holders. In addition, the percentage of halibut shared with other households was higher amongst tribal SHARC holders than rural SHARC holders. Some respondents noted that variations in harvest were related to differences in patterns of food sharing, and harvesting in groups.

In summary, findings highlight the importance of subsistence harvesting in rural communities in Alaska and that the management of such resources needs to recognize the unique features of subsistence harvesting, such as year-to-year flexibility in harvest amounts. Using an interdisciplinary approach, this project links behavioral changes (i.e., metrics of fishing behavior) with the reason driving those behaviors. Additionally, linkages between regulations and fishing behavior is a valuable step in moving towards ecosystem-based management, particularly because subsistence users rely on a portfolio of terrestrial and aquatic species.
CLIMATE REVIEW
NOVEMBER 2016–APRIL 2017

By Rick Thoman, National Weather Service, Alaska Region

NOVEMBER 2016
November produced a weather and climate mix across Alaska. The month started off with mild conditions, but much of the state saw significantly cooler weather later in the month. The two facets partially balanced out over much of the state. For Alaska as a whole, November 2016 ranked as the 41st warmest of the past 92 years—so very close to average. That was not the case, however, over the North Slope, where November was another very mild month. At Utqiagvik (Barrow), the monthly average temperature of 13.3°F was more than 12°F warmer than normal, and the fourth warmest November in the past 96 years. Juneau set or tied record high temperatures on four consecutive days early in the month.

Precipitation was generally near or above normal on the North Slope and along the Gulf coast and in Southeast Alaska, but well below normal over most of mainland Alaska. Statewide, this ranked as the 33rd driest November since 1925. Fairbanks finally established permanent winter snowpack on November 6th, three weeks later than normal and the latest since 1962. Anchorage Airport recorded only 1.3” of snow, the third lowest November in more than 60 years, and the ground around town was largely bare of snow at the end of the month.

Weather patterns became more active late in the month. A strong storm pounded the Aleutians and the western Alaska Peninsula on the 26th, with widespread reports of 60–85 mph winds. A fast-moving storm on the 29th brought strong winds to Southeast. Wind gusts up to 72 mph were recorded at Hydaburg, 64 mph on the roof of the Juneau Federal Building, and 58 mph on the roof of the Ketchikan Airport terminal and at Petersburg, causing local roof damage and closed roads due to downed trees.
DECEMBER 2016

December, like the previous month, brought a variety of weather and climate to Alaska. Parts of western Alaska were again very mild, while much of the eastern half of the state was cooler than normal, though not dramatically so. Both St. Paul and Barrow reported the third warmest December of record. Yet at Anchorage, December finished 3°F degrees cooler than normal, the first month since September 2015 to average below normal. Alaska-wide, temperatures this month ranked as the 38th warmest December since 1925.

As is usually the case, total precipitation for the month was regionally variable. Fairbanks had 32.9” of snow, more than twice normal and the highest in December since 1990. Anchorage finished up with 16.9” of snow, which is almost exactly normal. In contrast, much of the Gulf of Alaska coast saw another dry month. Seward received less than a third of the normal December precipitation, while both Kodiak and Yakutat had only about half of normal. Heavy snow fell over parts of central Southeast Alaska on December 6th and 7th. Pelican, on northern Chichagof Island, reported a whopping 31” accumulation. In the Juneau area, accumulations ranged from about 8” downtown to 13” in Mendenhall Valley.

A series of fast moving storms pounded the west coast of Alaska during the last days of the month. The first storm brought high winds and blizzard conditions to much of western Alaska on December 29th. Maximum wind gusts reached 65 mph in high winds and blizzard conditions to much of western Alaska during the last days of the month. The first storm brought very heavy snowfall over parts of central Southeast Alaska on December 6th and 7th. Pelican, on northern Chichagof Island, reported a whopping 31” accumulation. In the Juneau area, accumulations ranged from about 8” downtown to 13” in Mendenhall Valley.

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A series of fast moving storms pounded the west coast of Alaska during the last days of the month. The first storm brought high winds and blizzard conditions to much of western Alaska on December 29th. Maximum wind gusts reached 65 mph in Kotzebue and Nome, both of which caused brief power outages in those communities. Unlike some western Alaska storms that can go on for days, the blizzard conditions generally lasted less than 12 hours at any given place. The next storm hit hardest at Savoonga, on St. Lawrence Island, where winds on December 31st gusted to 80 mph and damaged roofs and walls of about 30 homes in the community, forcing several families to ring in the New Year sheltered in the community school.

January was an active weather month across Alaska, with changeable weather being the rule. For the state as a whole, both temperature and precipitation were very close to normal, though there was significant regional variation. This was another exceptionally mild winter month on the North Slope. Utqiagvik (Barrow) recorded an average temperature of -0.3°F, which tied with 2016 as the second warmest January in the past 95 years. In contrast, much of Southcentral Alaska was significantly colder than average, though not excessively so.

Much of mainland Alaska was significantly wetter than normal, but parts of coastal Alaska were unusually dry. Anchorage received 31.2” of snow, nearly three times normal and the second greatest January snowfall of record. During a storm on the 21st, the Anchorage Sports Dome collapsed under the weight of the snow (Figure 10). The same storm brought very heavy snow to Seward, with an estimated 30” in town and 32” at Moose Pass. The heavy snow prompted Seward City officials to close schools due to snow for the first time in recent memory. In sharp contrast, Juneau received less than 4” of snow for the month, only 13% of normal.

During mid-month, the coldest weather in several years gripped much of mainland Alaska. The cold weather was notable primarily because it had been five years since there was as widespread a cold snap, though there were no daily records set at any of the long-term climate stations. Fairbanks recorded a low temperature of -51°F on January 18th, the first time the temperature there had been in the negative 50s since January 2012. At Anchorage, the low at the Airport was -15°F on the 18th and 19th. Parts of east Anchorage and the Eagle River area saw temperatures drop to near -30°F. The lowest official temperature in the state was -59°F at Tanana on the 19th and 20th.

FEBRUARY 2017

February was a fairly typical winter month, with mild and cold spells and several notable storms. Overall, both average temperature and total precipitation were very close to normal, though of course there were local and regional differences. The North Slope in particular saw temperatures well above normal, though not at record levels. A few areas in western Alaska were significantly cooler than normal.

February is, climatologically, decidedly less snowy than earlier in the winter over most of the state, but this February brought significant snow to some areas. Fairbanks finished up with 23.3” of snow, more than twice normal and the sixth highest February total in nearly a century of snow observations. Kotzebue also received more than double normal snowfall, with 19.2” of snow. Valentine’s Day brought dynamic weather to a large part of the state as a strong and complex storm system brought very mild air northward over the state and produced very strong winds in the Panhandle. The storm brought freezing rain to the Anchorage area, and schools were closed in the Mat-Su Borough due to icy roads. There was a brief period of freezing rain as far north as Fairbanks. In Southeast, wind estimated as strong as 75 mph produced building damage and brought down power lines in Craig and Pelican. With the winds came exceptionally warm air: Juneau airport topped out at 53°F and at Annette 55°F, both record high temperatures for the date.

There was some cold weather too. Cold Bay, near the western end of the Alaska Peninsula, dropped to -6°F on the morning of the 20th. This was not only a daily record low but also the lowest February temperature there since 1947. A snowy weather pattern set-up over a swath of western and Interior Alaska during the
last week of the month. Many coastal communities saw blizzard conditions on the 22nd and 23rd. Unlike some western Alaska storms, there was a lot of snow with this storm. Both Nome and Kotzebue reported in excess of 10” of new snow. The snow spread eastward on the 24th and 25th, with heavy snow in parts of the Interior. Fairbanks received more than 10” of snow on the two days, while Denali National Park Headquarters received over 15” total.

**MARCH 2017**

Sustained cold and snow, at least by Alaska standards, have been in short supply in recent years. March, however, brought “old fashioned” weather back to much of the state, with considerably colder than normal conditions over most of the state. Overall, this month tied for 12th coldest March in the past 93 years. As often happens in March, much of mainland Alaska enjoyed many days of clear skies. At Fairbanks, 27 days during the month recorded a low temperature of -10°F or lower, and the low of -39°F on the 8th was the lowest temperature so late in the winter since 1964. The cold weather extended into Southeast, where the Sitka Airport reported the 4th coldest March since the mid-1940s. The North Slope was the regional exception to the cold weather: both Utqiagvik (Barrow) and Deadhorse recorded an average temperature about 5°F above normal.

The start of the 2017 Iditarod Sled Dog Race was moved from Willow to Fairbanks due to very low snow cover in parts of the Alaska Range (Figure 11). Temperatures were in the -20s the morning of March 6th as teams headed down the Chena River. However, the weather during the race was generally conducive to dog mushing, and there were no big storms to impact racers and their teams.

In Southeast Alaska, snow was the big story. At Annette, 30.2” of snow in March was the most in any calendar month since December 2001, and was more than the total snowfall in the previous three winters. At Juneau, 32” of snow was the most snow in March in a decade, with significant disruption to travel on 13th and 14th. The unusual snow cover near sea level
allowed for record low temperatures in some places. Most significantly, Ketchikan fell to +7°F on the 10th—the lowest temperature so late in the season. The Anchorage area enjoyed three weeks of dry sunny weather in March, but a late month snowstorm brought 6–12” of snow to the city on the 28th and 29th. There was enough snow, much of which fell overnight, to close schools for the day. At the Anchorage Airport, the 8.8” of snow was the fourth highest snowfall so late in the season.

**APRIL 2017**

April was a generally tranquil month over most of Alaska. Statewide, this was the eighth warmest April since 1925. Western Alaska was the farthest above normal area. Kotzebue recorded an average temperature of 24.3°F, 11°F above normal and the third warmest April of record. Both Nome and Bethel had a “top five” warmest April. The high temperature of 49°F at Kotzebue on April 30th is the warmest temperature of record there. In Southeast Alaska, numerous sites set records daily highs between the 12th and 14th. These included 64°F at Annette, 62°F at Sitka and 57°F at Haines. The state high for the month of 69°F at Annette on the 22nd was also a daily record.

April is often a dry month in Alaska, but this year was exceptionally so, with the statewide rank of second driest since 1925. Some places in the Interior and the North Slope had no measurable precipitation during the month. The only regions of the state with above normal precipitation during the month were Kodiak Island and a small area along southern Kenai Peninsula.

The last days of the month brought the first wildfire activity of season. The largest April fire was the human-started Zane Hills Fire, which burned just under 2000 acres of tundra near Selawik mid-month. A back-firing pick-up truck driving around the Mat-Su valley started four small fires in the Palmer and then Big Lake areas on April 20th. On the 24th, a small fire broke out on Douglas Island near Juneau, and on the 27th, the first smokejumper deployment of the season was required on a fire near Delta Junction.

**BREAK-UP**

River Watch is a decades-long partnership combining the science of the National Weather Service Alaska-Pacific River Forecast Center and the emergency management of The Department of Homeland Security and Emergency Management (DHS&EM) to provide real-time monitoring and timely alerts to keep Alaskan communities safe during breakup season. Figure 12 and Figure 13 are from this year’s River Watch efforts.

Break-up has also been specifically recorded for the Tanana River at Nenana. More than a century of consistently recorded dates and times of ice break-up on the Tanana River are a unique window into spring climate for the central Interior. Figure 14 plots the date of break-up each year, along with their trend (green line). Through the mid-twentieth century there was no trend, but since the mid 1960s break-up has tended to occur earlier in the spring: typical break-up is now a week earlier than it was before 1965.
Figure 13. River Watch team member Andy next to blocks of stranded ice in Aniak, May 4, 2017. Photo source: NWS.

Figure 14. Tanana River at Nenana Spring Ice Break-up Date, 1917-2017.

Data Source: NOAA/NWS Alaska-Pacific RFC
Sea ice in the Alaskan region was characterized by an early and rapid break-up in 2017, relative to historical standards. Figure 15 compares mid-May sea ice concentrations in 2017 and 2016. While some sea ice lingered in Norton Sound and Kotzebue Sound on May 17, the Bering Sea was generally ice-free by mid-May of 2017. A year earlier, sea ice had been more extensive in the area immediately south of Bering Strait and in the western Bering Sea. However, the most striking feature of the spring 2017 ice retreat was the large area of open water in the Chukchi Sea in mid-May. Aside from some shore-fast ice, open water could be found for about 100 miles offshore of the coast from Point Hope eastward almost to Utqiagvik (Barrow). This large amount of open water in the Chukchi Sea by mid-May appears to be unprecedented in the historical record. If freeze-up follows the pattern of recent years by not occurring until November, the southern Chukchi Sea may have six months of open water. While there may be some wind-driven intrusions of sea ice during this six-month period, the present situation provides a striking contrast to the 1980s and 1990s, when open water persisted for only one or two months in the southeastern Chukchi Sea.

Figure 16 provides a pan-Arctic view of the sea ice coverage in mid-June of 2017 and 2016. The large expanse of open water in the Chukchi Sea persisted into June; Figure 16 shows that the Chukchi’s ice cover was much less extensive in June of 2017 than in June of 2016. In comparison with the 1981-2010 mean extent (orange lines on the maps), the 2017 ice cover was also far north of its normal position in Hudson Bay and the Barents Sea. However, there was actually more ice in the Barents Sea in 2017 than in 2016.

For the spring of 2017, the total extent of sea ice on the pan-Arctic scale was the lowest on record since satellite records began in 1979. Figure 17 shows that the pan-Arctic ice extent of March–May 2017 was even well below that of 2012, the year with the lowest ice minimum on record. However, 2017’s ice extent has exceeded that of 2012 since early June, primarily because of the slower ice retreat in the North Atlantic/Barents sector in recent weeks. Nevertheless, 2017’s pan-Arctic extent remains in the lowest decile (10%) of historical ice extents for mid-June.

The ice cover of spring 2017 is not only unusually low in extent, but its thickness is also well below normal. Figure 18 shows the results of a model simulation by the University of Washington’s PIOMAS model. This model assimilates information on the coverage of sea ice and uses observed atmospheric conditions to compute the ice motion, deformation and thickness. The simulated thicknesses for April 2017 are generally in the range of 2 meters, except for larger thicknesses north of Greenland and the Canadian Archipelago. The simulated thicknesses are consistent with the observationally-derived estimates from NASA’s IceBridge program. Potentially more important for the evolution of the ice cover are the ice thickness anomalies (departures from normal), which are shown in the right panel of Figure 18. The ice is about one meter thinner than normal over much of the Arctic, with even larger anomalies north of Bering Strait.
Figure 16. Sea ice concentration on June 16 of 2017 (left) and 2016 (right). As shown by the color bars, concentrations range from zero (deepest blue) to 100% (brightest white). Image source: National Snow and Ice Data Center, University of Colorado, Boulder. ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/north/daily/images/

Figure 17. Pan-Arctic sea ice extent for the March-June period of 2017 (blue line) and 2012 (dashed black line) in relation to the 50th and 90th percentiles (light and dark shading) of past years of the satellite record. Image source: National Snow and Ice Data Center, University of Colorado, Boulder.
The implication is that the ice is more vulnerable than in the past to summer melt and a corresponding reduction in coverage during the coming months.

OUTLOOK FOR SUMMER 2017

The low thicknesses and the early retreat of the ice cover in 2017 are factors favoring an extreme minimum of sea ice by the end of the 2017 summer season. However, air temperatures and winds also affect the rate of ice loss during the summer. An analog forecast model developed by ACCAP’s Brian Brettschneider attempts to incorporate these drivers into a seasonal forecast of the September ice extent. The forecast is based on an analog procedure that identifies the past years with the atmospheric circulation and temperature most similar to the present year (2017) through May.

The forecast for September 2017 sea ice, calculated as a departure from the linear trend line, is a weighted mean of the September sea ice departures-from-trend-line of the five best analog years. The weighting factor is the number of times a particular analog year was selected when different predictor variables were used. Predictor variables include sea level pressure, upper air geopotential height, and air temperatures. NCEP/NCAR reanalysis is the primary data source. Predictor and predictand domains are pan-Arctic, although we also include indices of leading atmosphere-ocean modes of variability.

The predicted quantity is the departure from the linear trend of historical (1979-2016) pan-Arctic sea ice extent. For 2017, the weighted mean September ice extent of the best historical analog years is 4.48 million km$^2$, slightly below the trend line. This value is lower than the past four September values, but greater than the 2012 minimum.

Figure 18. Ice thicknesses (left) and departures from normal (right) in meters for April 2017 as simulated by PIOMAS model of the University of Washington. Image source: Jinlun Zhang, Applied Physics Laboratory, University of Washington.
WHAT CAN WE LEARN FROM AN ANCIENT, WARMER ALASKA BEAUFORT COAST?

By Louise Farquharson, PhD Candidate, Department of Geoscience, UAF

On the Beaufort Coast of Alaska, ancient beach deposits—now located 10 km inland and several meters above modern-day sea level—stretch for over a hundred miles from Utqiagvik (Barrow) east towards Deadhorse. These ancient beaches run parallel to the modern-day coast and are thought to have been deposited during the last interglacial period, between about 125,000 and 119,000 years ago. During this time, mean annual temperatures were 4-5°C warmer than today, and sea level stood 6-9 m higher in many parts of the world.

As climate change continues, we expect to see warmer temperatures, less sea ice, and higher sea levels. What can the geologic past tell us about the future of the Beaufort Sea Coast? In collaboration with scientists at UAF, the US Geological Survey, Utah State University, and the Alfred Wegener Institute in Germany, I decided to explore these deposits and find out.

INTO THE FIELD:
DIGGING, SCRAPING AND SAMPLING

To better understand how the Beaufort Sea Coast looked during the Last Interglacial period, I spent time getting muddy on the shores of large lake systems on the Arctic coastal plain. The lakes have eroded shorelines exposing sections of what had previously been identified as Last Interglacial beach deposits. We found wonderfully preserved tidal flat and beach deposits, which contained a plethora of fossil bones from walrus, seals, and whales. One of our most exciting finds was a walrus tooth. We also found hundreds of ancient shells which we hoped will reveal secrets about the Beaufort Sea Coast’s past.

In addition to reconstructing the environment of this time, we also wanted to confirm that the age of the beach deposits was indeed from the Last Interglacial period. For this, we employed optically stimulated luminescence dating, a technique which reveals the last time sand grains were exposed to direct sunlight before being buried. The sampling technique is challenging and involves opaque metal tubes which protect the sediment from direct sunlight. We carefully took a number of samples from the recently excavated deposits.

PUTTING THE PUZZLE PIECES TOGETHER

After two exciting field seasons of excavating, exploring and sampling, we began to pull together our evidence. What we
Figures 20–24. Fossils found in the ancient beach deposits (from top left clockwise): walrus tooth, articulated bivalve shell, mammoth tusk fragment, spruce driftwood, seal bone. Photo source: Louise Farquharson.
found was quite exciting! First, we identified sediments which suggested that at the time of their deposition, the coast was moving in a landward direction, a process called a "marine transgression". As the Beaufort Sea rose, it crept inland, turning what is now tundra and thermokarst lakes into tidal flats, lagoons, and eventually barrier islands and beaches. Additionally, we saw that in many ways the Beaufort was quite similar to the present day but contained many different invertebrate species from warmer waters further to the south.

The biggest surprise came when we began to interpret our optically stimulated luminescence ages. Instead of the marine transgression taking place during the peak of the last interglacial, 125,000–119,000 years ago, when we expected sea levels to be the highest, these deposits were much younger: between 110,000 and 70,000 years old, from a time when global sea level was tens of meters below present day. What could have made the sea level change in northern Alaska late?

Using the research team’s expertise as well as previously published scientific articles, we developed two main hypotheses to explain this unexpected finding: Hypothesis 1: Ice sheet Forebulge Collapse, and Hypothesis 2: The Grounded Ice Sheet.

HYPOTHESIS 1: FOREBULGE COLLAPSE

The first hypothesis centers around the process of isostatic adjustment, which takes place due to the weight of large ice sheets. During glacial periods, much of North America was covered by the Laurentide Ice Sheet, which extended all the way to the NW of Canada. The weight of this huge ice sheet would have caused the Earth’s crust to deform and depress below the ice sheet and bulge around the periphery, creating a forebulge (think muffin top). This bulge would have intersected with our study sites along the Beaufort Coast, causing it to be elevated above sea level during the Last Interglacial. As the ice sheet melted and decayed, the bulging around it would have subsided, causing sea level to rise locally around our site. If this hypothesis is correct, then the Beaufort Coastal Plain must currently be out of isostatic equilibrium…and sinking.

HYPOTHESIS 2: GROUNDED ICE SHEET

A second hypothesis also centers around the deformation of the Earth’s crust, but instead of uplift, it involves the crust being pushed down. One potential mechanism involves the presence of a grounded ice shelf along the Beaufort Coast that caused the area to be isostatically depressed. A big, heavy, grounded ice sheet, flowing east from Canada, could have depressed the Beaufort Sea coast below contemporary sea level, resulting in a marine transgression. An ice shelf at the time of our beach being formed has been suggested by a number of studies. This hypothesis requires the development of large ice sheets in the Arctic that are out of phase with glaciation in other regions.

Which hypothesis is correct? At present, the evidence leans most strongly in favor of Hypothesis 2, the grounded ice sheet, but we need to head back into the field and maybe offshore to confirm whether this is correct. Watch this space!