# Weather Information Use in the Bering Sea: A Social Analysis of Risk, Uncertainty, and Marine Decision-making

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## 1. Highlights

Based on in-person interviews and fieldwork among fishermen and residents in Unalaska and Saint Paul Island, this report describes mariner experiences of weather impacts in the Bering Sea, analyzes the value of and context for weather information use, and portrays how mariners incorporate information into critical decisions regarding weather. The report relies upon rich data drawn from mariners' perspectives to emphasize the following arguments:

- Risk thresholds for decision-making in severe weather are not simply a matter of meteorological parameters, but also depends upon contextual factors, including economic and regulatory pressures, environmental change, mariners' orientation to risk, and the social organization of decisions among marine-related actors.
- Weather information is highly important to everyday operations and critical (safety, economic, and livelihood) decisions that mariners must make in the Bering Sea context. Mariners believe weather forecast availability, accessibility, communication, and accuracy have generally improved in recent years.
- The use of weather forecasts for decision-making is changing, particularly insofar as mariners engage a novel, pluralistic informational environment supported most significantly by the rise of internet-based private weather forecasts. Synthesizing information sources, mariners report, provides greater confidence in the capacity to anticipate weather systems, but it creates additional uncertainty regarding differences and changes among forecasts across information sources.
- The National Weather Service is well-regarded among mariners, especially by providing local expertise, embodied in knowledgeable human forecasters. Opportunities for improving weather services include (1) navigating informational pluralism by focusing attention on key decision mediators that can help reduce risk during extreme events, (2) communicating forecast uncertainty to improve decision-making past a 48-hour timeframe, and (3) building relationships to support the needs of tribal entities that serve local Bering Sea communities, particularly by providing information that spans the weather forecast timeframe to longer (climatic) timeframes relevant to livelihood in indigenous lands and marine environments.

## 2. Introduction and Background

Fisheries and marine transportation are critical to many facets of the society and economy of Alaskan communities. Weather conditions have a significant impact on mariners and marine-dependent coastal communities in Alaska, and therefore to Alaskan society altogether. The Bering Sea hosts among the most productive and economically significant fisheries in the United States and the world. It also holds extreme weather conditions, storm events, and a challenging climate in which to live and operate. Alaska waters experience an average of 11 hurricane force wind events a year. The harsh northern climate leads to distinct challenges when compared to those of mid-latitudes: Freezing spray is the number one cause of fatalities, while sea ice significantly impacts access to ports, fisheries activities, and nearshore subsistence hunting, transportation, and everyday cultural life. Poor communications infrastructure, paired with a changing communication and media landscape in the Bering Sea region can complicate messaging of significant events, especially to remote vessels and communities.

Moreover, the Bering Sea and coastal environments are changing in unprecedented ways. Global warming is significantly altering the climate dynamics of the region, particularly by shifting seasonal sea ice and weather patterns, changing atmospheric and ocean temperatures, altering regional marine ecosystems, advancing ocean acidification, and changing near-shore dynamics including sea level rise, coastal erosion, and storm impacts (Markon, et al. 2018; Marino 2012). Reduced seasonal sea ice extent has resulted in increased marine transportation and activity in open ocean areas (Stephenson et al., 2019; Patel and Fountain 2017), while making nearshore travel and use of shorefast ice challenging in others (Gearheard, et al. 2006; Druckenmiller et al. 2013). Climate change is projected to continue to alter coastal environments, ocean dynamics, and the character and geographic extent of the marine ecosystems upon which commercial and subsistence activities and peoples' livelihoods depend (Thoman, Richter-Menge, and Druckenmiller 2020; IPCC 2018; Vorosmarty, et al. 2018; Wang et al. 2018; Brinkman et al. 2016). To summarize, environmental change means that people not only experience "new" weather, but also that they experience weather in new ways because of the larger social and ecological context marked by rapid, interrelated changes.

Weather impacts in the Bering Sea region vary by geographic location, and they constitute weather risk depending on several major factors: the nature of marine activities/operations, the vulnerability of activities to seasonal and climate patterns, and the adaptability of activities under novel environmental conditions. Marine weather hazards, marine activities, and weather risk are therefore not unitary across the Bering Sea region. Those who reside near or operate in the Bering Sea utilize vessels that span from large container ships to large commercial fishing vessels and small skiffs used by subsistence fishermen, hunters and recreationalists. Others use seasonal sea ice for hunting, fishing, recreation, and winter transportation. The impacts of experienced and anticipated weather on decision-making therefore vary among mariners and those operating in the Bering Sea.

To meet the public needs of marine and coastal groups and communities, The National Weather Service (NWS) Alaska Region provides marine forecast services, as NWS has done for over half a century in support of operations in the Bering Sea region. With the goal of improving the accessibility of decision support services (henceforth DSS), empirical research is necessary to systematically document and evaluate the value of marine weather forecasts to those that operate in and depend upon the marine environment.

A major NWS priority area, DSS requires incorporating social science into a traditionally physical-science based domain of expertise (NWS 2013, 2018, 2019; Weaver et al. 2013; Hobday et al. 2016; Kettle, Trainor, and Loring 2017; Haavisto et al. 2020). Weather patterns and events vary in meteorological terms, but the context of decision-making regarding weather risk also depends upon social factors. Formal weather forecasts may vary across users in terms of how they are valued; how credible or useful users believe they are for specific times and places; their technical accessibility and the usability of product formats; and how easily forecasts may be incorporated into other information, forms of knowledge, and exogenous factors that shape decision-making. Although NWS Alaska Region has developed partnerships and outreach efforts, specifically tailored to communicate forecast information regarding extreme events and weather hazards, the decision context has yet to be studied from a social science perspective.

Sociologists recognize that practices of anticipation are a basic feature of pragmatic action across various social domains (Tavory and Eliasoph 2013; Mische 2009, 2014; Hall 2009, 2016; Baker, Ekstrom and Bedsworth 2018; Anderson 2010; Adam 1998). What this literature shows is that what people do, how they think, and how they make decisions are all regularly shaped by how they imagine, represent, or otherwise make futures "real" in the course of experience and social interaction. It stands to reason that if information shapes how people construct the future, then the process of using predictive information is essentially cultural—it relies upon rituals, taken-for-granted practices, tacit understandings of valid knowledge, and uses of and trust in technologies and information networks. Culture—whether the rationalized culture of a formal organization or the culture of tribal and fishing communities—shapes decision-making processes and courses of action. To understand the use and value of weather information, therefore, the analysis presented here hinges on a concept that can be labeled *anticipatory culture*. I define anticipatory culture as the practical and symbolic ways through which actors in a given social world answer the questions, "what's next?" and "now what?"

Providing an understanding of how people participate in anticipatory culture by engaging formal weather information can help to improve the relationship between the National Weather Service and communities who use or could further benefit from weather forecasts. Lessons on similar benefits abound in related areas of expertise that have employed social science, including, as examples, developments in community-based fisheries ecology and co-produced climate science. In Alaska, fisheries social science is relatively well developed and informs fisheries governance (Carothers et al. 2012; Carothers 2015; Raymond-Yakoubian and Daniel 2018; Himes-Cornell and Hoelting 2018). Likewise, numerous studies and active programs have addressed adaptation needs or facilitated social change regarding longer timescale climate and ecosystem changes, including in the Bering Sea region (Cochran et al. 2013; Huntington et al. 2013; Romero, Corral, and Pereira 2018; Robards et al. 2018). Systematic understanding of the social context for weather information use is less formally developed in the Alaskan context. Moreover, scholarship on fisheries social science and climate change adaptation in the Bering Sea region have yet to incorporate analysis of socio-cultural factors regarding the use and interpretation of formal weather forecasts. However, insofar as climate or ecosystem change is experienced, weather events frequently form the immediately relevant context for action, observation, and interpretation (Deemer et al. 2017; Weatherhead, Gearheard and Barry 2013). The timeframe of operational weather forecasts is thus significant to how a range of social actors anticipate the future across multiple timescales and how they incorporate predictive information into decision-making.

Weather decision-making and experiences of weather in the Bering Sea are characterized by risk. This study therefore investigates the current use of weather services in specific sectors of the marine community and their *risk thresholds*—defined as points in decision-making processes at which information regarding anticipated weather alters action based on a users' evaluation of the situation and assessment of risk. Results from such an investigation may then help NWS Alaska enhance DSS in a way that effectively adds value for local communities and marine stakeholders.

Given long-term uncertainty regarding climate, ecosystem, and economic change in the Bering Sea, tailored decision support may become more significant to Bering Sea operators and communities. The rapidity of perceived and experienced changes in weather patterns, storm impacts, and sea ice dynamics mean that reliance upon traditional knowledge and related norms around decision-making in the Arctic may increasingly upset capacity for operators and communities to adapt their practices and knowledge to new conditions (Slats et al. 2019; Krupnik et al. 2010; Gearheard et al. 2010; ELOKA 2019, 2020). As addressed in studies of indigenous communities, the problem of environmental change and indigenous livelihood is at once a matter of safety, subsistence, and the survival of cultural practices reproduced through engagement with the environment (Willette et al. 2015; Cornwall 2019; Maldonado, Colombi and Pandya 2014). Given that traditional and indigenous knowledge links weather to the holistic environment, moreover, research is required to ensure that innovative relationships between formal/scientific knowledge and traditional knowledge proceed on the basis of respect for cultural survival, tribal rights and data sovereignty (Lovett et al., 2019; Pulsifer et al. 2012). Indigenous groups and researchers have advanced innovate projects (see, e.g., Alaska Ocean Observing System 2020; Atlas of Community-Based Monitoring in a Changing Arctic 2020; Manrique, Sefarin and Pereira 2018). Tribal representatives, however, have recently documented cases of disrespect for traditional knowledge among government agencies, private industry, and research enterprises, and they consistently raise concerns that Arctic research is not sufficiently designed and carried out to respect indigenous culture and knowledge/data sovereignty (see Bahnke et al. 2020a, 2020b). To advance efforts to predict Arctic environments in a manner that is useful to communities, it is therefore important to understand the complete context in which decisions take place. Only then can weather services and related efforts effectively connect forms of knowledge and expertise across the diversity of places, situations, and cultures that characterize Alaska.

## 3. Research Questions

Drawing from existing literature and the context for NWS priorities regarding DSS, research pursuant to this report centered around answering the following research questions:

The initial research question is descriptive: *How do various groups operating in the Bering Sea anticipate future weather, and how do weather forecasts then inform marine decision-making?*

The second research question concerns the relationship between social factors and decision-making, which may impact how mariners use marine weather information: *How does the institutional and cultural context for decision-making impact how individuals and communities incorporate formal weather forecasts produced by NWS and other forms of weather information?*

The third research question is critical and exploratory: *What possibilities exist for improving weather forecasting and fostering impactful partnerships between NWS, local communities, and DSS partners? What information needs and gaps exist between present forecast products (including their format, accessibility, forecast delivery, and messaging) and the activities of mariners and communities regarding anticipated weather?*

## 4. Data & Methods

The choice to study specific communities in relative depth is guided by Crate's (2011) approach called "climate ethnography," which retools George Marcus' (1995) method of multi-site ethnography by recognizing the inter-scalar phenomena that manifest geographically expansive patterns but with local cultural particularities. An "ethnography of the Bering Sea" is hardly possible. However, study in geographically distinct sites provides for comparison as well as insights on the inter-connections that characterize Bering Sea climatic, weather, ecosystem, and social processes.

Second, study with Alaska Natives is inspired by work in Science & Technology Studies that aims to reconfigure the relationship between formal science/information and traditional ecological knowledge in applied settings. Rather than treat formal information on weather and climate as fundamentally separate from 'traditional' knowledge, I treat all knowledge as socially produced. Therefore, the applied setting of the National Weather Service forecast offices and regional headquarters can also be considered as an active fieldsite, in which predictive knowledge take shape through social processes and a particular cultural milieu (Fine 2007; Edwards 2010; Daipha 2015). The concept of anticipatory culture helps bring into focus the relationship between, on the one hand, what Anderson (2005) calls meteorologists' "cultures of prediction," and on the other hand, culture among weather information users including maritime communities and seafaring fisherman. The goal of this approach is to facilitate the incorporation of community perspectives, concerns, and diverse needs into the operational context of National Weather Service products, messaging, and policy.

I conducted fieldwork in Unalaska/Dutch Harbor in October 2019 and on Saint Paul Island from January through February 2020. Fieldwork in Nome has been postponed due to the COVID-19 pandemic and will be completed when feasible. The timing of fieldwork was designed to correspond to major, weather- and climate-impacted marine-based activities in each location, including commercial and subsistence fishing and marine mammal hunting seasons, the growth and retreat of sea ice, and the presence of major Bering Sea storm events. Fieldwork among commercial fishermen was supplemented with interviews at the Pacific Marine Expo event in December 2019 in Seattle, Washington. Data collection in each site consisted primarily of conducting semi-structured and in-depth interviews, observational research, participating in community meetings and events, and taking fieldnotes. In Unalaska, some fieldwork (including several interviews and a workshop) was co-facilitated with NWS forecasters. On Saint Paul Island, some research activities were graciously co-facilitated by the Aleut Community of Saint Paul Tribal Government. Consultation for fieldwork in Nome involves Kawerek, Inc., the regional Native non-profit associated with the Bering Straits Native Corporation, and existing NWS partners, especially those associated with the Sea Ice for Walrus Outlook (SIWO).


***Figure 4***: *Research sites: Unalaska (Aleutian Islands); Saint Paul (Pribilof Islands); Nome (Bering Strait); NWS Regional Headquarters in Anchorage*

This report is based on 39 primary informant interviews: 10 in Unalaska, 8 in Seattle, 18 in Saint Paul, and 3 in Anchorage. Interview participants have included subsistence and commercial fishermen, subsistence marine hunters, commercial fish processing plant operators, and residents, elders, and business or community leaders. Examples of community leaders include local and tribal officials, emergency managers, and harbormasters. I completed an additional 8 semi-structured interviews with NWS employees, including weather forecasters, meteorologists, technicians, sea ice analysts, union representatives, and regional administrators. Interviews with NWS employees were supplemented by routine shadowing of operational weather and sea ice forecasting shifts (in Anchorage, Alaska) and NWS outreach activities. Interviews lasted between 12 minutes and 2.5 hours, generally reflective of the different circumstances in which interviews were conducted, ranging from office spaces and community rooms to dockyards and on-board vessels during severe weather. Most interviews were audio-recorded, except in cases when consent to record was denied, or recording was not possible. In such cases, detailed interview notes formed the basis of data analysis. Photography, when appropriate and consented, supplemented other data.

All interview audio files and notes were transcribed by the author. Following transcription, I coded ethnographic fieldnotes, memos and interview transcripts, using “open coding” techniques facilitated by the qualitative data analysis program, Dedoose. Iterative open coding and memo writing were guided by the data collection and inductive analytic processes outlined by Emerson, Fretz, and Shaw (2011). Data collection, management, and analysis have been approved and governed by the University of Oklahoma Institutional Review Board (IRB), the appropriate governing body insofar as the research conducted was completed as part of a postdoctoral research position affiliated with the University of Oklahoma Cooperative Institute for Mesoscale Meteorological Studies (CIMMS).

Some notes regarding interview notation are in order. To protect the confidentiality of research participants, the report has removed individual-level identifiers and, when necessary, utilized pseudonyms instead of names. The only exceptions to the use of pseudonyms are in cases of mariners’ naming of active NWS employees. All interview excerpts are verbatim from interview transcripts, including tonal notation, except for the removal of some explicit language, individual identifiers, and repetitive phrases that inhibit an accurate representation of the speaker's language. To simplify some quotations, ellipses remove repetitive or irrelevant words. Italics strictly denote speaker's tonal emphases. Brackets indicate either the speaker's use of words in a non-quoted statement, or else added notation that provides a contextual reference or clarification of the speaker's intended meaning.

## 5. Results

In this section, I present results consecutively in five sections, organized as follows. First, I outline findings regarding weather impacts to marine activities and decisions in the Bering Sea context. Second, I present findings that demonstrate the role that social and economic context for marine operations play in shaping weather-impacted decision-making. This section also shows how users relate their vulnerability to weather hazards to the relative value, reward, or risk regarding their activities. Third, I draw upon mariner's experiences to consider the value of marine forecasts to safety and productivity. In this section I then outline the range of communication technologies and systems that mariners use to receive weather forecasts and support their activities. Fourth, I highlight mariner decision-making processes, which demonstrate how a changing technological and information landscape has led to novel practices of informational synthesis. Given multiple sources, no one information source shapes mariner decision-making, leading to a plurality of ways in which mariners anticipate future weather. In this section, I emphasize how mariners apply their own experience-based principles and methods for dealing with uncertainty regarding future weather. Fifth, and finally, I focus on the mariners' use and evaluation of specific NWS marine forecast products. I emphasize the special, if changing, role of NWS forecasters and products in the emergent context of informational synthesis. Specifically, the section addresses the role of persistent human interaction in mitigating risk, the special role of NWS in messaging weather events, and the value of official expertise for critical actors (whether formal DSS partners or not).

As a guide to the presentation of results, two conceptual diagrams depict marine decision-making processes and the function of weather information therein (see Figures 1 and 2, below). The conceptual model (Figure 2) is based on the analysis presented and discussed in the following sections. For comparison, I present a simple decision-making model (Figure 1) that does not account for the dynamic processes at play among the full range of factors that are incorporated in marine- and weather-related decisions. Figure 2 provides a refined conceptualization, which this report suggests may be incorporated into weather forecasting practices, delivery, and outreach.

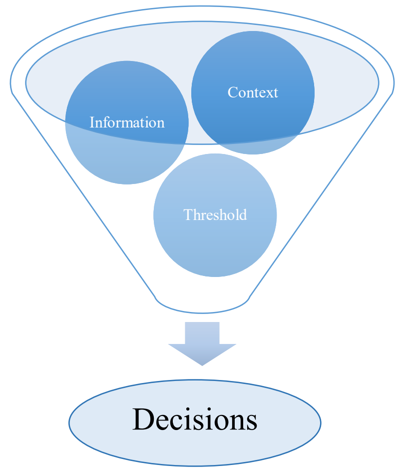


***Figure 1**: A Simple Heuristic of Weather-related Decision-making Processes*

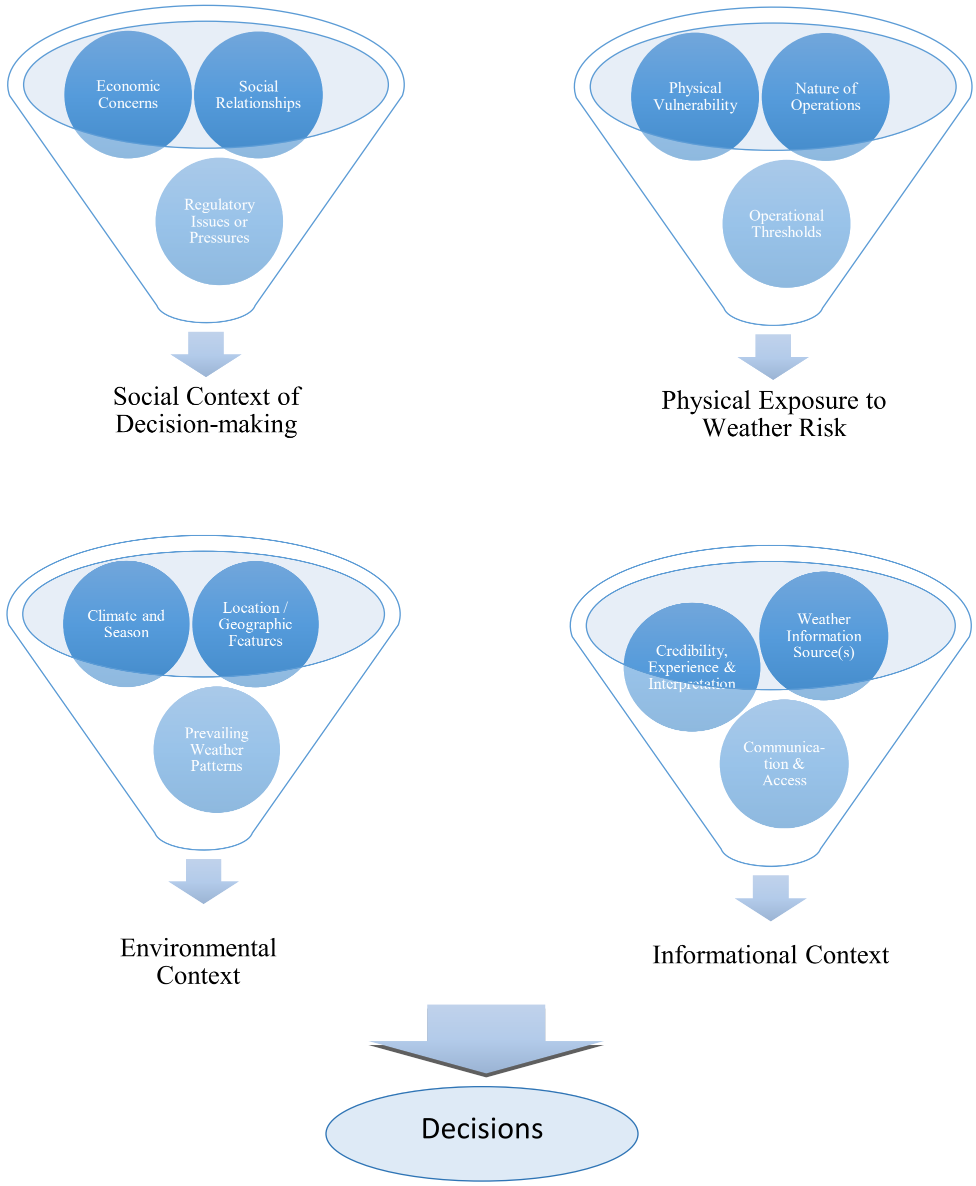


***Figure 2***: *A Conceptual Model of Social, Physical, Environmental and Informational Factors in Marine Weather Decision-making*

The analysis presented below in the remainder of the Results section helps to substantiate the significance of the factors depicted in this diagram. Following the Results section, the report concludes by connecting the research findings to recommendations, principally for NWS Alaska Region. The recommendations are preliminary, insofar as they are designed to inform ongoing collaborative efforts at NWS to relate forecast practices, social science, and community engagement. Such efforts can be supported by an empirical understanding of marine decision-makers that draws substantially from mariner accounts.

## 5.1. Weather Impacts on Bering Sea Operations

### *5.1.1. Severe Storms*

Severe storm systems are a major concern for mariners. When asked about the most significant weather impacts that concern marine operations, many cited major storms, associated with storm force winds and dangerously high seas—"low lows" (meaning strong, low pressure systems) as one mariner put it, continuing: "sometimes there is a storm that covers the whole state [all laugh], they call is a 'storm,' and down in Florida they call it a 'hurricane' [but] those are only a third the size [all laugh]." Another mariner expressed a common view among those that operate in the open ocean, namely the significance of knowing when and where major storms events would happen: "The key to us is when the *big ones* are coming. Because, we can endure, we will fish in 30 [knots]. But right, I see that one coming, that big mass [next week]. I hope it skirts south of here a little bit, but I don't know."

Many mariners internalize their experiences with severe storms in the form of cautionary tales that influence their risk thresholds. One boat captain in Unalaska recalled what he explained mariners had labeled "Black Sunday":

> Some [storms] really stick out. Black Sunday is what we called it in the Bering sea. I think it was in November. We were fishing Tanner crab and it was pretty much the perfect storm. It had been blowing steadily—a big system rolling from the Southwest—and we were all out fishing. The wind would come down, but we could still have these big rollers come in, and then it started to blow again, and that's when a big windstorm came in, and it was blowing steady 50, gusting 65 [knots]. And I remember, one wave that came up and just tossed the boat like this [gesticulating] and just tossed it completely sideways, just like it was a toy boat. Then I was just gunning it and trying to square off before the next one came around. And you know, there were 100 footers. It was just hellacious. I think we had 14 or 16 maydays that went out during that storm.

Cautionary tales, like that concerning "Black Sunday" above, provide reference points for mariners to both accept severe storm risk and work to mitigate it.

The more that mariners report understanding the dynamics of large low pressure systems, the more they report knowing how to interpret forecasted storm events, for example, regarding the timing of wind directional shifts or terrestrial influence that may impact decisions regarding marine transportation. Such weather changes, mariners report, can be especially difficult to understand in text-based forecasts, particularly when forecasts also change day-to-day. Mariners thus report being surprised by the strength and direction of storm impacts. As one described:

> Those systems move so fast and if you get on the top side of it, you know, or the front side, you get the southwesterly's, but on the backside you get the northeasterly's, so and sometimes, guys are fishing a huge area, and so that's why there's that difference [between observed weather and a zone-based text forecast].

Mariners seek to avoid severe storms; however, impact avoidance is often impractical. One Bering Sea crab boat captain in Unalaska characterized alternative scenarios for dealing with severe storms:

> So, if you have the opportunity to run and hide, you *do*…[but] it's not just whether it is feasible, it's if you have the *timeframe* to do it. It's also about the timing of your deliveries. So, if you know it's going to be ugly and cold, and you have this opportunity to deliver, then you try to get in there! [But] you've got to have something on board to deliver! You are not always going to be able to *play* that route. If you can afford to run 80 miles for a quick storm coming through to go hide, well, it's never

> *bad* to go hide, but 80 miles is a long time to go there and back. And if [the storm] is traveling through fast, it is just as easy to jog in one spot. It's not much fun. Nobody sleeps! But at least you're there for when it comes back down.

In the above example, this mariner implies that severe storm impacts, even when anticipated, may or may not lead to an alternative course of action. When accepting the risk of exposure to severe storms, however, mariners can be taken by surprise. Some storm systems develop stronger winds and seas than mariners anticipate. One boat captain in Unalaska described his difficulty in anticipating how storms channel through passes in the Aleutian Islands.

> Stronger winds out of bays and passes is one of the most under stated phrases ever in meteorology in Alaska. I mean we have been on the north side of Tenaga Volcano [Western Aleutians], and we got maybe a 998 or 1000 millibar low rolling through, maybe 25 or 30 knot winds. And it is blowing *100* coming off that volcano, and that's *sustained*! It will freaking rip over the tops of those things with these freaking whirling dervishes. It is all flying, ahhhwww! So, I call my dad up in Kodiak, and I go 'what the hell is going on out here? It is supposed to be 25 knots?!' And I am jogging 1/10 of a mile offshore, going *backwards*!

To deal with unanticipated severe storm circumstances, mariners rely upon seafaring knowledge and experience-based skills that mitigate risk during severe storms, a process that nevertheless caries risk. To "jog" in place is one strategy.

Mariners can also travel in a manner that can allow them to "beat" a storm, which may or may not be successful, as the following narrative of a uniquely severe storm captures:

> I mean it was just obvious that there were big sets. So, you spent the whole time trying to tack away from it. So, you would square off a bit and then a big breaker would come. You would try to get away, and then all of a sudden it would be just these hellacious seas…But I had a friend of mine out there: he thought he was going to hightail it to town…So he was running into town trying to beat it. And he didn't. And he was on a big boat, right in the wind. Equipment was smashed and this and that. And it filled up the aft part of the boat so much, that the water ran forward and hit the back of the wheelhouse and the deck and shorted out all their equipment in the galley and ran down into the engine room.

To navigate severe storms without "beating" them directly, mariners furthermore rely upon a working cartographic knowledge of a given area. A captain in Unalaska provides an example when he described his experience fishing along the Aleutian Islands during the fall season:

> You know, when we operate out of here [gestures at map to the Western Aleutians], there is nowhere to hide. Once you get out past Adak, past here, there are *very* few places to go. But these are all areas to fish. But you may have to travel a couple hundred miles [on open water]. That is a long stretch to be out in a small boat with nowhere you can duck for cover. So, we have to be really careful out there in the fall. The storms are coming too quick and it never calms down. And when the storm goes by, you still have a 15-foot swell rolling.

To evaluate the chances of encountering severe storms with reference to geographic areas, mariners rely upon meteorological knowledge specific to their experiences in such areas.

Although mariners reflect a wealth of knowledge regarding geography over the areas in which they operate, they vary widely on their degree of formal meteorological knowledge. In general, mariners report coming to settle upon unique practices of understanding the weather that they believe is most likely to impact them. One boat captain in Unalaska demonstrates how a relatively high level of formal understanding of storm tracks and weather information provides a given lens for understanding short- and long-term weather:

> The weather events that would concern us the most are typically, well, I call them "dead cyclones." They typically are generated in the South Pacific and roll out past the Philippines and Japan and are still pretty tightly packed when they hit up here. Last winter was a prime example of that: The storm track up there last winter, where they just shot *straight* across Adak right to Kamchatka. They did *not* deviate east. The Siberian high actually pulled them away further west. These are the things that we track, year after year, to know if the storm track is different. I mean, I look at the high-level winds to make my best estimation how the lows are going to manifest themselves as surface level winds, and the track they're going to take… The isobars start getting *really tight*…But typically, it is monthly. I mean, I am not just looking at today's weather and tomorrow's weather. I want to know also what the general trend is.

Although the above example suggests a relatively unusual formal understanding of weather patterns, most mariners similarly possess a method of relating the weather they have experienced in the past to their anticipations of short- and long-term future possibilities.

### *5.1.2. Wind Speed and Direction*

Mariners are particularly invested in interpreting storm directionality, insofar as they associate the directional source or character of storms with particular impacts. As one commercial fisherman in Unalaska explained, "you know, we usually get those northeasterlies and then we know it's going to get real cold. And with southwesterlies, those seem to be some of the strongest." In general, mariners report knowing the seasonality of weather patterns for the North Pacific/Gulf of Alaska and the Bering Sea, especially by connecting southwesterly storms with high swell and northerly winds with cold temperatures. A captain in Saint Paul demonstrates this basic sensitivity to storm directionality, in this case regarding freezing spray risk:

> I noticed a big temperature change when I crossed that 172 line…and I was going the right way [meaning, with the wind] so I wasn't really worried about [freezing spray]. But with the southerlies coming, that will probably go away really quick, but it's going to come back real soon. What, the southerlies will only be here for a couple days, and then is going to get *real* [expletive] cold.

For those engaged in nearshore activities in small vessels, for example, subsistence salmon fishermen in Unalaska, marine operations are even more sensitive to the timing and direction of severe storm events. As one tribal leader and former fisherman described:

> The weather patterns are unpredictable, especially from Cape Cheerful to Bishop Point. At times, we have to travel 50 miles down to Makushin Bay. And because of the impact to the salmon [pause]. That is the only robust salmon lake that we have, and when it gets impacted, we have to go farther down. And it is only a matter of time before someone loses their life. And that is the truth. It is inevitable. And not only that, just the *unpredictability*. I know Cape Cheerful and Cape Kervish(?) and that stretch of water down to Makushin is *not* safe unless you're going very fast.

In the above example, geographic knowledge rendered a given area dangerously "unpredictable" with respect to wind speed and direction. More generally, nearshore marine operations, like marine travel through nearshore bays and passes with strong terrestrial weather influence, are especially impacted by the directionality of severe wind events. As one longline halibut fisherman in Saint Paul Island described:

> Interviewer: What is the most important aspect of weather to your decisions?
>
> Fisherman: *Winds*! Wind dictates if you keep your gear out, or haul it. Wind is a problem if you didn't retrieve it earlier. Wind is also a major problem when you're going around points. With the right tides and wind direction…Well, you see these gray hairs? If you hit it wrong, it is like a car accident kind of

> feeling. These are small boats. With Southeast winds and tide changes, currents, and rips around the points, it gets *bad*!

Small boat fleets are especially sensitive to wind speed and direction, and such vessels have less of a range within which they can safely operate.

Because smaller vessels tend to operate closer to land, moreover, their operations are more affected by the dynamic interaction of land and sea. A halibut (long-lining) fisherman in Saint Paul provides a basic perspective on the impact of wind direction to his decision-making:

> [If] the weather is bad for the Northwest, we are going to the east side to fish. We will fish from Sea Lion Rock all the way to Northeast point on the east side. Or if it is blowing easterly, we are going to fish off Zapadni Bay right here, or over here at Reef Point, or go all the way around Southwest point up to North Point, if you've got an easterly wind and it is too rough to go around Reef Point up here.

Given the risk posed by tides, currents, and wind impact changes (depending on windward or leeward travel), those that operate small vessels near shore report a need to anticipate weather around various land features. More broadly, mariners suggest that wind speed and direction are both a sign of the character of a storm (e.g., a cold storm, or a high-seas storm) and are most difficult to anticipate when navigating nearshore environments.

### 5.1.3. Swell, Waves, Tides and Currents

Swell and wave heights significantly impact marine operations, including safety and productivity. Thus, anticipated swell and waves shape where and when mariners decide to travel or operate. Mariners reported widely different risk thresholds for waves, primarily based on vessel size, but also on other weather factors and on the degree to which waves make operating (as opposed to simply being kept safe) difficult. One fisherman, for example, described how risk thresholds regarding wind and waves were fundamentally linked:

> For [wind], it all depends on the swell, right? I was right next to the ice and it was gusting 70, but no swell. But in the open ocean, if it is 40/45 knots, up to 18-foot seas, I will ride at 20 [knots]. But if it is blowing 50/60 and is getting 20+, normally it is going to be 26 or 27 feet, *then* it is time for me to hide. I know that there are boats out there that ride it. Safety for me is number one concern. So, I am not going to be fishing, I am not going to be doing *anything*, that is risking the boat and the crew. But that is just my borderline, 18 to 20, and maybe 45 to 50 knots. It all depends on the size of your vessel. I know there are skippers that don't care that much about that, and they just ride it. But anyone in their right sense…[It is] too much.

If the combination of wind and seas is one marker of weather risk that impacts risk thresholds, the difference between average swell and experienced wave heights is another. Mariners generally recognize that average swell height can differ substantially from experienced wave heights. In some circumstances mariners report observed wave heights that result from a combination of swell and local factors, specifically tides and currents. These impacts may result in significantly higher, and more dangerous, wave conditions than anticipated. Although tidal and currents data was not a focus of this study, it is important to include these elements into analysis of decision-making around marine transportation during otherwise impactful weather events. One mariner addressed the combination of hazardous factors that arise in Unimak Pass, a high-traffic pass between the North Pacific and the Bering Sea:

> A lot of the ships, a lot of times going through Unimak pass, they have to tack, because they can't run on the line. Even those big boats [container ships] flex, right? Even these little boats flex. But a long one like that, a thousand-footer, there is a lot of torque and they have to, well, there are certain

> directions. And the swell period is a huge factor. You're familiar with tide rips, and with the wind against the water. I have seen some wicked vile stuff in the Aleutian Islands. And I mean, you cannot predict that. You just have to know where you are, and what direction the wind is blowing, and which way the currents are running. That is going to tell you how the waves are going to be. I don't know how many factors are in that.

The above discussion of operational risks in Unimak Pass demonstrate that mariners must deal not only with average wave and swell parameters, but with environmental circumstances that may change the character and impact of waves for a given vessels' operations. As a result, risk thresholds for wind and seas are not possible to quantify for a given area or for a given fleet, even for similar-sized vessels. Important factors include the size, load weight, and stability of the vessel, along with the experience and risk acceptance of a captain operating in a specific geographic area.

Nevertheless, all captains have *general* thresholds regarding wind and seas, which they draw upon in their decision-making. For example, one captain who operates in various North Pacific and Bering Sea fisheries, discussed how *safety* thresholds during storm events differ from thresholds for *operating* and fishing. Both, he explained, are important to consider:

> I mean, for seas, literally 35-foot seas, we can swim. It is not very comfortable, but the boats are built for it. You're not going to roll over. As far as operating…It depends on what we are doing. If we are *fishing*, 10 to 15 feet of swell is just about all we can operate in. After that, you get the boat rolling and it just rips all the fish off the hooks, right? So, it is *pointless* to operate in those conditions. Pot fishing, you can do 20–25-foot seas, depending on the direction.

Another mariner discussed some of the risk thresholds for operating in high winds and seas, while recognizing that risk depends on other factors, including for example, daylight for crew safety:

> There's a lot that goes into it. It depends on how hard the tides are running and stuff. But we get to around 50 to 60 [knots] up here before we have really been shut down. Generally, around 45 we start being cautious around what we do outside out of the light hours. But I think, low 40s, we pretty much aren't worrying as much.

Similarly, another mariner addressed how a concrete wind threshold for deciding to go out to sea may be distinct from a threshold to "run and hide" if already out on the water during a weather event:

> Interviewer: What are your thresholds for, 'okay, I am not going to go out'?
>
> Captain: 45 knots [firm]. Yes. If we are out there, we will stay out. You know, but, that is why we are in right now.

As the final example suggests, if mariners encounter unanticipated wind and seas that disrupt their plans and operations, then they may or may not decide to change their course of action. In other words, meteorological parameters do not shape decisions directly, even if they may elucidate the risk latent within operational decisions.

### *5.1.4. Physical Vulnerability to Hazards*

Vessel type, size, and gear loads influence how physically vulnerable mariners may be to weather hazards. One mariner expressed how operating different vessels and knowing how they handle weather takes "getting used to": "It is tough. [This] is a small boat, and I have fished on a bigger boat, where it is like, you can go fishing *anywhere, anytime*. But with this one, with weather...it is more difficult. It takes getting used to."

Most mariners base their accepted thresholds for weather risk on experiences with their vessels. Especially significant are past experiences they aim to avoid repeating in the future. In the following example, a fisherman in Saint Paul suggests that when he was younger he had adopted higher wind and wave thresholds, but then experiences of unanticipated severe weather changed how he tolerated risk given the size of his vessel:

> Interviewer: How often are you out in conditions that you do not expect?
>
> Mariner: [It] does not happen very often. And if it does start to happen, then…[pause] you know, knock on wood [knocks on table], I've been fishing so long, I do not push myself like I used to, when I was younger. I think I used to have 18 knots and 6-foot seas, I would say, the max I would go out in. Now it is less than that—4 feet. Even 4-foot seas are not nice, but that is about the max right now for me. I can handle that, but it is not going to be comfortable.
>
> Interviewer: With those thresholds, would you say that is common among the fleet, or would you say there are folks out there that may be have the thresholds you had when you were younger? How much variation is there?
>
> Mariner: There is some variation there, because well, like this guy Johnny. He's got this big Bristol Bay 32-footer. He will go fishing, and I will stay tied to the dock. Aaron has got a 46-footer, or something like that, so there is not going to be any issue for them. And most of us will probably all end up staying back.

As this discussion of comparative thresholds indicates, captains must know their vessels well in order to operate effectively. This level of knowledge extends to how the boat can handle certain elements of weather. A captain interviewed in Saint Paul provides the following understanding of how his ship accumulates less ice during freezing spray events, compared to other vessels:

> This boat, it has a really nice, curved bow, so it does not ice up as bad, I don't think. Whereas the real flat, straight up-and-down bows, like [a neighboring vessel] isn't too bad, but you see some of them are just a wall, and the icing on those can be a real [expletive].

Despite differences between vessels, some common themes for risk thresholds are notable. In particular, crab boat captains regularly cited around 45 knots as a wind threshold for safety. Thus, anticipations of these winds frequently entail making a critical decision regarding where or when to travel and operate.

When feasible, mariners may pre-emptively make decisions to mitigate their physical vulnerability to hazards, for example, by carrying less gear onboard. One mariner in Saint Paul described their situation during a major storm event:

> [Wind] thresholds depend if I'm packing a lot of gear around. You know, if it is cold, just like yesterday…It was cold, and I knew is going to be out of the North—so I dumped my gear down here, because I knew I couldn't make it up there before this windstorm. So, things like that.

As this example demonstrates, mariners routinely prepare for the weather conditions they anticipate. Preparations involve their knowledge of how their vessel, gear, and operations render them physically vulnerable to weather hazards. Although vessels may have absolute limits to operating in adverse conditions, mariners make decisions that may mitigate physical vulnerability so that potentially dangerous conditions are less impactful. Thus, for mariners, risk thresholds for weather-impacted decisions depend upon what steps may be taken, or skills employed, to reduce physical vulnerability.

### *5.1.5. Cold Temperature and Freezing Spray*

Mariners operating in the Bering Sea during the winter season are unanimously familiar with freezing spray, and many who participated in this study reported making critical decisions with respect to anticipated or observed icing conditions during cold storm events. Mariners recognize the phenomena as characteristic of Bering Sea winter. As one captain proclaimed, “Oh yeah! I try to avoid it as best as I can. But it’s like…all of a sudden you hit St. George and start going up, and the temperature seems like it drops dramatically up above there.” Although freezing spray is also common in the Gulf of Alaska and near the Aleutians, the risk especially haunts mariners who operate in the Northern Bering Sea during the winter season. One captain provided a comparison of sea ice, also a major concern, with the risk presented by freezing spray: “The sea ice doesn’t kill people, but I’ve been to many memorials for people who had died because of freezing spray.” The mariner offered the metaphor of being “like a Marine” after having attended funerals of other fisherman who had died during freezing spray events.

As a result of plausible risk of—or experiences with—tragic circumstances, mariners are acutely aware of freezing spray conditions. As one boat captain in Saint Paul described:

> Interviewer: When do you worry about freezing spray?
>
> Captain: I am, well, it is on my mind all the time. Don’t get me wrong, it’s a big concern for everybody. Or it *should* be a concern for everybody. It *better* be! [stern]. When I start getting too much, and I mean, you *know* when too much is too much, for the guys that have done this a while… That is on the top of my mind all day long.

Although mariners generally reflect this grave and cautious approach to freezing spray, how they evaluate risk is more complicated in practice. Mariners evaluate icing through direct and remote observations—including actual ice accumulation rate (as addressed in the prior example), wind speed and direction, wave height, air and water temperatures, and the influence of local features that may include sea ice or land topography.

Some mariners worry most about icing conditions when freezing spray is already impacting their vessel. Others make decisions to avoid freezing spray conditions altogether. Most, however, recognize icing as an issue with gradations of risk, ranging from a nuisance to operating to an immediately lethal threat. As one example, a captain of a trawling vessel operating northwest of the Pribilof Islands provided the following experience during a storm that included wind, sea, and temperature values within the NWS warning criteria for Heavy Freezing Spray: “Yeah, there was heavy freezing spray...It was probably pretty mild though, probably only 8 to 10 feet, 20-25 knots, so, definitely workable. It wasn’t making too much spray off the water.” This captain reported reducing speed to mitigate the risk of ice accumulation destabilizing the vessel. However, he evaluated the storm as involving conditions that could have proved dangerous, from his perspective, because they feature large, short-period waves:

> Captain: Yesterday, [freezing spray] was a high concern…A major concern is stability. Yesterday I was coming in, let’s say it was telling me ‘northwest 15 knots,’ but it was more like 25, right? So, and then, [forecasted] ‘7-foot seas’, but every now and then it was really 10. And [the waves], they were *close* together. You know, *six seconds*. So that is when we start getting the spray. And it is *cold*. So that is why I built up [ice accumulation], even though I was coming in very slow. I was averaging 4 1/2 to 5 knots. Just enough to build ice, you know? So, you can see there is a little bit [pointing to vessel railing]. If I had *pounded* into it [meaning, went faster], I was going to be icing up pretty bad.

Mariners emphasized different conditions that heighten or reduce possible freezing spray risk. Most understand the combination of wind, waves, and water and air temperatures to be important to consider. If the previous example addressed the significance of wave period and travel speed, the following example typifies how mariners emphasize ocean and air temperatures, which this captain in Saint Paul claimed results in qualitatively different types of ice that can accrete on vessels:

> I don't think I saw [water temperatures] go below 38. I was piling on the spray, but the water temperature was so warm that it never froze, just a little sludge…But when that water temperature gets down below 35, and *then* your freaking air temperature gets down there too [raises eyebrows, serious look]. Because, I mean, it was blowing 35 to 40 knots up there and it was cold, *but* the water temperature was still warm.

As the example demonstrates, mariners approach freezing spray risk by evaluating several relevant parameters, not unlike the algorithms utilized to formally forecast Freezing Spray (Overland 1990; Overland et al. 1986; Samuelsen 2018).

However, unlike formal forecasts, mariners note the significance of the quality of ice, especially when they deal with freezing spray in real-time. The quality of ice that may accrete onboard is a concern for those who do not otherwise consider heavy freezing spray an issue that alters their decision-making. In such cases, the exception is extreme events that generate ice "like concrete" at an alarming rate. The following discussion, although not typical, demonstrates how ice hardness presents unique impacts during extremely cold and windy events:

> Captain: If [air temperature] is 15°, we just knock it [ice] off when we have to…when it gets built up. We do not change where we are going or anything like that. But when it was 2° and blowing 45, it was *really* bad! You know, rails getting that big around [gesturing a growing shape with hands] in six hours *Bad*!...When it gets into single digits and it is blowing really hard, *that* is when it is a concern. And that just doesn't happen very often on the ocean. Unless you're really close to the ice pack, it is almost never. It is usually in the teens, at least, and then it is just a *different icing*, you know? Like this, this is [gesturing to ship], you know, you have got to pay attention to it, but this is nothing. Like, that stuff was like *concrete*. That is the other thing, it is just, you can't get it off without like a *jackhammer*. It is horrible.

The above example suggests that ice quality at lower temperatures may be more impactful than simply the quantitative accretion rate.

Although some mariners report continuing to operate in extreme conditions, for most pot- and trawl-based commercial fishing operations, the wind and temperature thresholds for freezing spray are not only adverse for vessel stability and safety. They also signal, for most, an inability to continue operating. Nets, pots, and equipment freeze up and become unusable. Dead loss of catch is a related concern:

> You have water and really cold air, so the pots are steaming when we lift them out of the water. By the time you take a pot full of opis [*opilio* crab] out, put it in the rack, and dump them on the table, they would *shatter*. And you are literally talking seconds. All you have is hockey pucks. And if you don't, they are so cold damaged they die as soon as you put them in the tank.

One mariner, as another example, reported that cold temperatures form a primary threshold of concern, because of the problem of working in such conditions and keeping crab from dying:

> Interviewer: What are some of your thresholds around wind, and related…?
>
> Captain: Just cold weather. Nobody likes working in cold weather. But we have to deal with it, it is part of the game. [A second mariner: Yep!]. [Laughs].

> Interviewer: A problem for the crew?
>
> Captain: For the crab! It's not good either [for the crew].

Cold weather that may involve freezing spray risk is, as this captain considered it, only somewhat avoidable. Therefore, despite cold conditions and an active Heavy Freezing Spray Warning, the captain indicated he was returning to the open ocean the following day:

> Interviewer: Are you going to wait out this weather, or leave [after offloading]?
>
> Captain: Not for a few hours. Probably tomorrow morning. We will let the ocean calm down a little bit. It is not nice out there right now! [Laughs].
>
> Interviewer: Do you worry about freezing spray in these conditions? Icing up, or…
>
> Captain: Oh yeah! I mean, it is part of the game. You have to face it, you know?

The "part of the game" sentiment contrasted with those who avoid situations that they believe are the riskiest, including severe storms, heavy freezing spray, and actively advancing sea ice. Another captain discussed how he accepts weather risk, because he does not believe alternatives are always feasible:

> Interviewer: How important is the duration of the storm? If it is a short window, you will just sort of ride it out, or…
>
> Captain: Yeah, well [pause], number one, you don't *have* that choice all that often. If we are up there, that is a day and a half run [from near Saint Matthew Island to Saint Paul Island]. You better have a pretty serious reason to go when it is like that. But, I would say I have seen that like twice in my life, maybe three times. Most of the time, we just go fishing, and we just knock [the ice] off. It is a heavy consideration with putting a stack on. But for everyday fishing, it is just not a concern [pause]. It is like a concern, but it is not something that is going to keep us from doing it.

Even as most considered somewhat extreme conditions to be "part of the game," others claimed operations are futile in adverse conditions that tax equipment and may require crew members "beating ice all day," an activity that crewmembers reportedly despise carrying out. One captain, excerpted below, demonstrates how he evaluates the risk of freezing spray as an issue of both safety and productivity:

> Captain: Off of St. Matthews, it [gets] really cold. And when it is like that, we either don't work and jog, and if we do work, we just stick to small deck loads and we travel until it starts icing up along the bottom of the wash. Because I don't really believe in the guys beating ice all day. Some of these guys [other crews], sometimes, will work *five times a day* beating ice. And we just *don't* do that.
>
> Interviewer: Is that because for the sake of your crew, or it is too risky?
>
> Captain: It is both. It is just counterproductive! You spend half the day beating ice.

Freezing spray is a major risk for Bering Sea mariners, and they take the risk seriously. Nonetheless, anticipations of freezing spray do not shape decisions in a uniform or straightforward manner. Such decisions depend on available alternatives, on an evaluation of costs and benefits associated with taking on versus avoiding risk, and the perceived hazards associated with simply dealing with the consequences, either by "beating ice", modifying speed or position, or, however attentively, "riding it out."

### *5.1.6. Sea Ice*

This section outlines how sea ice presence and absence impacts mariner activities, according to those interviewed as part of this study. Sea ice dynamics present different challenges for decision-making depending on geographic location and the uses or barriers to use presented by sea ice. Here, I emphasize how open-ocean marine activities confront sea ice during the winter season in the Bering Sea. I also discuss how those whom I interviewed, especially indigenous (Unangan) Bering Sea residents, evaluate decreased sea ice extent as a primary indicator of an uncertain environmental future.

Mariners, including Bering Sea crabbers operating similar vessels and participating in the same fisheries, expressed divergent orientations to sea ice. Some indicate that they simply stay away from the ice. This suggests that negative experiences or risk aversion influence decision-making. Others address sea ice as something that provides for good fishing grounds, because of ecosystem and hydrologic processes that occur near the ice edge. Others only see sea ice as something that means fishing grounds can or cannot be accessed, and thus a concern if it covers over or uncovers grounds they know to be generally productive. And still other mariners view sea ice primarily for its physical effects on weather, including colder air temperatures, freezing spray, and decreasing wave periods and heights because of less fetch nearer to the sea ice edge.

Sea ice coverage of the Bering Sea is highly variable year over year. Although annual sea ice extent in recent decades has greatly reduced, winters with significant ice growth still occur in a way that greatly affects marine operations (Stabeno and Bell 2019; Thoman et al. 2020; Wang et al. 2018).

Mariners register the effect of the ice pack on waves, wind, and temperature, meaning that they consider how the ice year impacts the weather patterns they may generally expect over the course of the season. The following mariner's statement about the combination of weather phenomena that made for cold winds and freezing spray in January 2020 is exemplary:

> I think 2012 was the last time I saw single digits [air temperature], that sort of nasty wind, and [sea] ice. You have to have all three. You have to have super cold, heavy winds, and ice within striking distance. That is what creates that super cold, I guess. It just doesn't seem like it ever gets that cold unless the ice is in play. But you have to be just far enough away from it that you still get a swell. Because if you are 5 miles away from it, it is not as bad.

The following interview excerpt provides a detailed example of a mariner who anticipated how ice growth could impact their operations:

> Captain: I've seen that [i.e., forecasted ice growth], that it was quite a bit of always above St. Matthews, and here in five days it was going to be *on* St. Matthews. So well, we have fish about 80 miles southwest of St. Matthews. So… It will get critical if the ice keeps coming that way. Then the guys will be like, "*whoa*!" It will change my mind. I won't want to go up there! If it is going to come down all the way there, we will just stay down here. The nice thing about down here is we can just shuffle it out to the edge [i.e., separating the shallow northern Bering Sea waters from deeper water south of the Pribilof Islands]. Usually, the ice down here doesn't get all the way to the edge, unless we have a severe situation. And it can. We have been pushed all the way down to St. George. So, the ice, it can push us off the edge. I think in 2004 we got shut down. And '06 or '07. But everyone got pushed down, and everybody just quit. And then when the ice was gone, we came back in April.

As this case demonstrates, sea ice primarily serves to block access to given areas or complicate how mariners may operate near sea ice. As already indicated, some treat sea ice quite differently.

Mariners that accept the risk of operating within the flow ice and near the pack ice at times utilize the sea ice as a break from heavy wind and swell that, in cold circumstances, could include dangerous freezing spray conditions. The following is an example of such a situation, faced and narrated by a crab boat captain who reported being near the sea ice frequently throughout the winter 2020 season:

> Captain: We are way up, just straight west of the south end of St. Matthew's [Island]. And it [sea ice] has gotten close—probably 10 miles a couple of times. I mean flows, not the main ice pack. And you know, for two days I actually went and sat in the ice and just avoided spray, because it was blowing northeast at 45. It was horrible! So bad. [January] seventh and eighth, I think. Horrible—some of the worst I have seen.
>
> Interviewer: Did you decide in advance to go in [to the ice] and get out of the freezing spray?
>
> Captain: When it started getting that cold, we had gotten done the one evening full of pots, and it was obvious that it was getting bad. And so, I just started jogging that way, and I just said 'just keep going, it is going to get calm!' And we got into the flow. I mean, this boat is built for dealing with ice. We have got an ice belt. We have got 1-inch thick steel around the waterline. So, we do not mind going and ice flows. So yeah, we drove in, and we just drifted in the big ice flows to not get banged around and not make much more ice ['ice,' meaning freezing spray accumulation]. It [sea ice] is handy for that, but it sucks for everything else! [laughs].

In the example above, ice was utilized for relative safety. This decision was clearly dependent upon the mariners' high risk tolerance (compared to mariners who avoid sea ice altogether) and the individual's understanding of the vessel's capabilities when faced with alternatives, namely freezing spray or flow ice.

For those who live year-round in Bering Sea communities, the sea functions not only as a source of risk but also a source of livelihood and a sense of environmental security (Dickie 2019; Thoman et al. 2020). Local indigenous residents in Unalaska and Saint Paul treat sea ice in a remarkably different way compared to commercial mariners. The anticipatory culture among primarily Unangan people makes sea ice meaningful to life and livelihood with less reference to the physical limitations that ice presents and more reference to the function of ice in the Bering Sea ecology. An ecological perspective on sea ice relates to those common among indigenous residents in the more northerly Arctic. Yet, because the ice edge is intermittent and historically irregular in the Bering Sea, local perspectives on its role in ecological processes is distinct from a physical perspective that seeks to reconcile Western science and sea ice-dependent cultural practices (for example, regarding on-ice transportation and hunting on shorefast ice) in the Bering Strait, Chukchi, and Beaufort Sea regions (Deemer et al. 2017; Druckenmiller et al. 2013). Although those in the Pribilof Islands rarely directly utilize sea ice for hunting, fishing, and transportation, sea ice registers as inherently valuable to Unangan people, for whom the southern Bering Sea is indigenous territory. The most remarkable changes that signify, for Bering Sea residents, large-scale environmental transformation are the reduction or total loss of the ice season, along with warming ocean temperatures and major recent marine habitat changes.

An example of one tribal leader in Saint Paul expresses the general sentiment. Ralph retired from fishing but maintains a leadership role in the subsistence seal hunts sponsored by the Aleut Community of Saint Paul Tribal Government ("it's a real honor," he described). He attributed various changes in the region, which he had observed over his lifetime, to sea ice loss: "We *need* the ice to come down." As he outlined, "the ice is what feeds the ocean": it "protects the fish" (from over-zealous fishermen, he indicated, smiling) and "refreshes the ocean," allowing the existing food web from plankton to marine birds, mammals, and humans to thrive—a principle supported (if complicated) by studies in marine ecology (Brown and Arrigo 2013). Ralph therefore spoke of the 2012 ice season with a sense of longing, as if his sense of security relied upon what he called "cycles" of ice that had yet to transpire. With winds shifting from the north and temperatures dropping during the time of our meeting, Ralph was hopeful that, although it had been years since the sea ice reached the Pribilofs, the ice would return this year. Around the same time, an elder put this hope in context: "Now people here feel the cold and treated like it's a good thing. Before, the cold was a bad thing. Now it's *good* sign. You feel those north winds blowing for several days. It's cold, and you know it's bringing the ice down. And what is it that [a local fisherman] tells us? Something like, 'I know it's tough. Cold's *tough*—but it's good for the Bering Sea.'"

For commercial mariners and local residents, sea ice significantly impacts how they act with respect to future weather and environmental conditions. Taken together, weather impacts are of primary significance to marine-based livelihood and operations. If this section outlined how weather impacts operations, the following section addresses the major factors that structure weather-related decision-making in the Bering Sea.

## 5.2. Contextual Factors and Thresholds Regarding Mariner Decision-making

As already indicated in cases of mariners' varied approaches to weather risk, marine decision-making depends upon various contextual factors. In other words, experienced or anticipated weather alone does not determine action. What contextual factors matter the most to Bering Sea mariners? This section raises five factors. I outline findings on the role of economic factors, regulatory factors, issues associated with environmental change, individual-level orientations to risk, and the social/organizational context. These factors, when taken together, shape the decision-making situation into which formal weather information is incorporated. After presenting findings about contextual factors, therefore, it will then be possible to represent the ways in which weather information is incorporated into marine decision-making.

### *5.2.1. Economic Factors*

For those involved in commercial fisheries, economic factors structure how weather figures in decision-making and risk. Most important is how fishing seasons, understood primarily in regulatory but also ecological terms, relate to seasonal weather patterns. In open and quota-based fisheries, the pressure to be out on the water fishing as much as possible varies depending upon the abundance that characterizes the fishery and the success rate of a given vessel, crew, or fleet.

Although rationalization (addressed in the following section) has changed the competitive nature of winter *opilio* crabbing and, as in some other fisheries, replaced "Derby-style" fishing with an established quota system, there is still a basic economic logic to risky decision-making. One crab boat captain in Saint Paul described the economic logic that influences his decisions about where and when to fish, and why he accepts more risk than other fisherman:

> Captain: It has been horrible weather, and the issue has been the weather and the conditions, more so than the crabbing, up there. It is not been epic. But it is good enough.
>
> Interviewer: Do you feel like with the weather component of that, that other folks might just stay away?

> Captain: Stay away?…*Oh yeah*! No, I think 80% of the boats would never go up there in these conditions. Because, you know, unless you can take a significant amount of gear, with icing conditions, with all that, it is just *not* a smart place to be! Because you can get overwhelmed too quickly. You know, with the building ice, and with the ice flows coming on top of you and you can't get your gear out.
>
> Interviewer: is that mostly a function of the boat, is a function of your decisions?
>
> Captain: it is the boat, it is the captain, and it is the gear—a combination of all three. Because you have to have gear, to have the confidence to fish in it, you have got to have the gear that will stay put, and then just having the experience of dealing with it. I have had some, *oh*, some *close calls*!...And there's always a little risk. Like I said, the fishing *has* to be good enough to warrant the risk. If you're getting 100 average, you're just going to go down with everybody else and just deal with it. But when you're getting a 300 average, and everybody else is struggling, [quietly] it might be worth staying! And in the past, it has been a 500 average or a 600 average, you know? And is it worth the risk at that point? Yeah! It comes down to making that decision, 'is this worth the effort that I'm putting into it, and the stress that it is putting on me in the boat and the crew?' Because it is not easy.

As this captain demonstrates, weather risk relates to economic decision-making. Although "risk" and "reward" are not so easily defined, clearly pressures remain for mariners to pursue economically advantageous situations, in the face of—or, in this case, even because of—weather risk.

Since economic success is tied to their rate of success, fishermen may face situations in which weather risk and economic risk overlap, for example if a fisherman has not filled their quota near the end of a fishing season. A boat captain in Saint Paul, who has participated in the local halibut fishery since the 1980s, emphasized that "panic mode" sets in when he may have yet to fill his halibut quota when more severe weather arrives with the fall season:

> [In] August, for us, it starts, it starts to get windy out. And that's when things shift, you know, the weather is starting to break. So you really start to push after a while. And you don't *want* to push, but you *have* to, based on the amount of quota that is left to catch. And you kind of get in a little panic mode, so to speak, because you want to make more money—you want to catch more halibut. That is what it is all about. But you are really starting to come up against the wall here, with the weather breaking. Because I've been able to go, like in August, I have fished only five times in the month of August before, because it was so windy out. The weather was *so* bad! And so, that sticks in your mind. You know? And come September, the weather here is not very [pause] *forgiving*, let me say it that way.

Despite the variety of tools, techniques, and experiences that make fishing activities successful, dependable, and profitable, fishermen in general recognize the unpredictable nature of their successes. Fishing "stories" that mariners regularly narrate are often marked by surprise, that is, marked by either problematic risk or unanticipated success. Within many of these stories threads a narrative of economic pressure—to be out on the water, to fish more, and to do so efficiently and safely. Thus, the "panic mode," as addressed in the previous example, signifies the intersection of weather, climatic, and economic factors at play in mariners' decision-making.

### *5.2.2. The Regulatory Environment for Marine Operations*

Fisheries regulation and policy strongly influences how mariners make decisions or take risks regarding anticipated weather. The clearest case of such an influence is that of Crab Rationalization, a policy adopted by the North Pacific Fisheries Management Council in 2005 and which allocates total allowable catch of given crab species to captains and processors at an established percentage (called a quota) of the estimated total allowable catch (see NPFMC 2017). As a formal government official and fisherman in Unalaska described, the rationalization of fisheries was part of a larger regulatory and political process of replacing the "wild West days" (which he associated with the 1970s and early 1980s) with a more administrative, accountable, and sustainable approach to fisheries management and the local economy.

How does regulatory change impact the relationship, established above, between weather- and economic risk-taking? To answer this question, it is helpful to analyze mariners' evaluations of the pre-Rationalization period. One long-time fisherman and former fish processing fleet manager in Unalaska recalls the history of crabbing and weather risk in the Bering Sea:

> Mariner: I lost a number of boats to sinking. I have lost two boatloads of crewmembers off the Pribilofs, you know, it could have been a combination of icing conditions and full pot loads onboard. That was one reason I was in support of the rationalization of that fishery—so they would each have their own quotas. And they wouldn't *have* to go fish. [Previously] It was 'race for fish' and that was all that was.
>
> Interviewer: Do you think with rationalization and other factors, the risk has substantially decreased?
>
> Mariner: *Oh yes*! [pause] But, then we had that disaster with the Destination.[1] And why was he rushing to be out there, when he didn't need to be out there, with the bad weather? He could've stayed in town. But he used to do codfish before he was doing crab. And I guess he was worried about all the good areas, where he fished, being taken or something like that. That was really tragic! But we used to have two or three *a year*.

The view, as portrayed in the excerpt above, that regulatory change has decreased exposure to weather risk appears common among mariners who had experience operating before and after fishery rationalization policies. As another example, a recreational vessel operator and former Alaska Department of Fish & Game observer (who worked aboard Bering Sea vessels to monitor crab and fisherman compliance with regulations), provided a comparative perspective on the effect of rationalization on how mariners "care about the weather":

> It was *different*. So, they cared about the weather. And I remember, they cared about it. And they were concerned about it. And I do remember going and hiding at times. Because they just knew it. But then, well, now they can work *around* the weather. They want to get on the grounds, but they don't have to in the same way. They have their piece of the pie and they can go and get it at any time. So, it will be interesting to see with the [weather] system coming up, how many boats will go out, [when] the season opens on the 15th? Because now they don't *have* to go out. But will they? You still want to get your pots in the area that you want to get your pots. Time is still money. But, they don't *have* to.

Discussions with mariners over several days before and after the opening the fishery referenced above (the Red King Crab fishery) indicated that mariners made various decisions regarding when and how to begin crabbing as the season commenced in October 2019. Some risked severe weather, while others waited for calmer conditions. In any event, the rationalization of fisheries clearly tends to reduce pressure to operate and fish amid weather risk.

Another mariner who reported being a captain for 34 years presented a similar comparison to those provided above:

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[1] The National Transportation Safety Board comprehensive report determined that "the probable cause of the capsizing and sinking of the fishing vessel Destination was the captain's decision to proceed during heavy freezing spray conditions without ensuring the vessel had a margin of stability to withstand an accumulation of ice or without taking sufficient mitigating action to avoid or limit the effects of icing." (see https://www.ntsb.gov/investigations/AccidentReports/Reports/MAB1814.pdf).

> I know all the problems you can run into. I have [seen] all of it, you know, 50 to 60 knots. We get some serious stuff. But with the crab fishery the way it is, this day and age you don't need to, because the crabs are just there, so when it gets *savage*, we will just go hide. We don't have that train of thought anymore, where you have to [be out].

Given a set quota for the season, mariners generally expressed feeling less open to operating in risky weather. A typical reflection came from a long-time mariner, whose ideas about risk and safety vacillated when he considered the present situation compared to the pre-Rationalization past:

> Interviewer: My understanding has been that the crabbing has been a little hit and miss [this season]. Does that impact your decisions around weather and freezing spray?
>
> Captain: No. No. If [the weather] was better, I would still be here [in the harbor]. Because I got what I got to catch, and... If it were the Derby days I *might* be out there…*Maybe* [pensive], well, no, I probably wouldn't be with this kind of weather. No. Even during the Derby days. It's just not *worth* it!

This mariner suggests that severe weather risk, even in "the Derby days," would cause him to remain in port and out of the open ocean. Nonetheless, the comparison demonstrates that he held a higher risk tolerance when embedded in a competitive economic situation that more directly rewarded risky behavior.

The case of Crab Rationalization shows the sensitivity of weather-related risky decisions to economic and regulatory pressures. Changes in the political economy of the Bering Sea have a clear impact on how mariners make decisions about weather, and how likely they are to either embrace risk or avoid severe weather conditions. Another source of change that impacts mariners' decision-making regards environmental change, which may combine with other pressures and sources of uncertainty to heighten weather risk.

### *5.2.3. Environmental Change and Novel Geographies of Operation*

The reported impacts of climate and environmental change on both weather patterns and marine operations varied among those interviewed as part of this study. Although not a focus of the present report, mariners often had the depth of experience in the Bering Sea to pointedly speak about climate change. Most noteworthy is how personal experiences of environmental change in the Bering Sea over the long-term relates to a pervasive sense of future uncertainty, at once socio-economic and environmental. The following excerpt is drawn from an interview, conducted by myself and an NWS meteorologist, with a native leader and long-time mariner in Unalaska. His long-term perspective connects "unpredictability" in everyday weather to a macro-level uncertainty about the trajectory of the climate:

> Tribal Leader: That's the weather…[but] what I am concerned about is, okay, what is *in store*? Looking at just the weather patterns, just from me being raised here: from the seasons being so predictable in the 60s, and in the 70s, you saw more of a turbulent pattern. In the 80s, it seemed to warm up quite a bit. [But] spring was *spring*, summer was *summer*. Fall was *fall*, and winter was *winter*. And just repeat. It was so predictable to where you could feel it in your *blueprint*. And that is *gone*. And now we see more of a flat line, just as boring, constant 45 to 55° [air temperature], and it is getting *warmer*, it really is.
>
> Zeke: When you say flat line, you mean seasonally, or how would you, based on your experience, describe that?

> Tribal Leader: just boring, just ranging from 34° to 45°, that's it, that is our winter. We used to have 10 feet of snow, down now to no snow. But you know I think the shifting, whatever is happening, it is at a summation point.
>
> Meteorologist: so, from your perspective, when have you seen the greatest change in the climate? Like what time period was the biggest difference?
>
> Tribal Leader: I think, looking at what was predictable, I think I would say 2008 to 2010, that [was when] I was not able to tell. And it is an *inner feeling*, it *really* is. You know, looking at last winter, normally you're able to tell, being born and raised here, what the heck is what, and what is going to happen. You know, you can look *forward* to it.

As with others that are concerned about the broad implications of climate change, this individual went on to raise doubt about the economic future:

> Tribal Leader: And you know, here's what worries me with whatever is happening with this change: it's our economy. It is important that we diversify. I like to say, 'we are Pollock junkies,' and we *are*. We are reliant on that fish. Even though the Pollock biomass has grown 5000%, there is going to be a tipping point to some ecosystem, whether it is the phytoplankton or, *what*? How can you predict that? Everything seems so unpredictable… I mean, it goes against everything in somebody's blueprint, whether it is what you looked to in your traditional ecological knowledge, or just beginning downright confused about the whole climate thing. In the end, it does not leave you with a good, secure feeling…I am hoping it gets colder. I am hoping that something changes.

As this individual explained, ecological and economic change overlap with seasonal-scale weather to generate a pervasive "unpredictability." This unpredictability relates the dramatic changes of the past to bear on future uncertainty, a phenomenon documented among other Alaskan communities (Moerlein and Carothers 2012). In particular, for indigenous people in Unalaska and Saint Paul, uncertainty regarding the future is mirrored by a general sense of lost knowledge that some indicate would be necessary to adapt to changing economic and environmental conditions.[2]

One fisherman and Unangan elder in Saint Paul provides the following reflection on "lost" knowledge about the Bering Sea:

> Unangan people had their ways [of knowing weather]. Tanya's husband is from Atka. And [looking to Tanya] like you told me, individuals studied clouds. And they used their skin boats, and they got their cloud readings. See, I've always called the Aleutians the 8,000 year school, because that is how long the Unangan people lived, island hopping in the Aleutians. The reading of the clouds, that is part of that, which was lost.

Upon reflecting on the meaning of lost knowledge, this individual proceeded to compare ancestral knowledge with the contemporary situation: "We are almost like *babies* now. It is a shame because we used to island hop all the way to Kodiak." As he explained, "Veniaminov, who wrote two centuries ago, told stories about how Unangan people made 14- or 16-hour voyages. *Of course* they had learned how to read the water."

The persistence of Unangan maritime culture, language, and economic survival thus faces the compounded challenge of a colonial legacy, environmental change, and a challenge of maintaining local/traditional knowledge, given a pervasive sense of an uncertain future. Akin to uncertainty around the meaning of sea ice, seasonal change, and prevailing feelings about indigenous livelihoods—bookended by colonialism on the one hand, and climate change impacts

[2] On the theme of "loss" more generally in the sociology of environmental change, see Elliot (2018).

to seasonality on the other—suggest that anticipations of the future are generally deeply frustrated.

Although mariners in general face prospects of ecosystem shifts, commercial mariners operating in rationalized fisheries generally acknowledged the cyclical, if not boom and bust, nature of Bering Sea commercial fisheries. Nonetheless, several mariners report operating in new locations, because of changing ecological and climate conditions. Existing research regarding hunting, fishing, food processing, and marine transportation, demonstrate that climate- and seasonal-level changes are dramatically influencing *when* and *where* people are operating in the Bering Sea, Western Alaska, and the Arctic (Markon et al. 2018; Thoman et al. 2020; Loring, Gerlach and Penn 2016; Johnson 2016; Struzik 2016). Climate projections indicate that novel weather patterns, seasonal sea ice coverage, and ecosystem changes make operational changes inevitable (Labe, Peings and Magnusdottir 2018, Labe, Magnusdottir, and Stern 2018; Brown and Arrigo 2013). Seasonal change is therefore a central component of how people come to operate in novel environmental conditions. Such conditions carry weather risk insofar as individuals and communities may lack relevant knowledge and experience. As addressed in this study, accumulated experiences, memories, short-hand principles, and traditions form common ways of thinking and making decisions. In new places or circumstances, the capacity for people to integrate these resources into their anticipations of the future may fail to provide a basis for risk evaluation in their decision-making.

### *5.2.4. Experience and Individual Orientation to Risk*

Interviews among veteran and novice mariners suggest that orientations to risk are shaped by experiences with specific weather events and patterns, which in turn inform how forecasts are interpreted as portending more or less risky conditions. Interaction with freezing spray risk provides a case of risk orientation conditioned by experience with northerly Bering Sea storms:

> Interviewer: If there was a freezing spray warning out, do you feel you would automatically heed it?
>
> Captain: I don't know, I look at it like, if it is coming at you, coming from the northwest of the Northeast or the North, from either Alaska or Russia, it will be typically *colder*. So, if it is blowing that way, like it is right now, I usually look to NOAA weather to see if they have a say, and kind of go from there. Also, on Windy, if you do the detailed forecast, you can see the [surface air] temperatures. So, I do that a lot too, so you can just tell. You get a 27-degree temperature with 25 to 35 knot winds, you're probably going to start freezing.

In this case, interestingly, an active Heavy Freezing Spray advisory did not result in a decision to alter plans: "Yeah, I mean, I am not sure about today or tonight, but it could be rough getting out." Thus, experience relates to how mariners imagine weather to present manageable or unmanageable risk.

A pattern of experience-based (rather than forecast, Warning-based) risk evaluation held for other mariners interviewed:

> But that is generally how we do it [with freezing spray conditions]: from about 10 until midnight, and from there till about six in the morning, it is just bitter cold. And those hours we just don't even work. We just shut down. But, like, we are going to go back out in this. We do not want to leave around the ice a hundred thousand grand of gear. I want to move my gear.

Although weather information helped this mariner to anticipate possibly poor operating conditions, the risk of losing gear near the ice proved more significant than having to deal with freezing spray conditions. Still other, experienced mariners, made decisions under similar circumstances to minimize risk:

> Interviewer: Can you tell me some of your concerns around this storm?
>
> Captain: No concerns! [sarcasm] That's the idea—Stay here, until this freezing spray crap is over. Basically, until Saturday. Are you calling me a sissy or something? [laughs].

This individual believed that no mariner had a reason to risk operating in this storm, although other captains (confirmed by Automatic Identification System, or AIS, observations) indicated that at least some fishing vessels continued to operate during the storm event in question: "Nobody is in a hurry to go out and heavy freezing spray, I mean it is blowing, or gusting, over 40, and with this temperature nobody really wants to be out there. You know, really, there is no reason to."

Despite espousing a "safety first" approach weather risk, most mariners willingly offered accounts of past mistakes featuring such risk. For example, several captains showed me pictures they had taken of freezing spray accumulated at sea in the past months or years. One fishing boat captain in Saint Paul provided the following reflection regarding a risky situation in the Southern Bering Sea:

> Mariner: Boats sink. You know, the *Scandies Rose*, stuff like that.[3] They can capsize. So, they [crab boat captains] have to be careful with that. Same with me...We were packed with ice! [showing images on phone from January 2020, near Unalaska] It was *this* thick!
>
> Interviewer: at least 6 inches or so, on the bow?
>
> Mariner: *More*! These are my nets [pointing]. That is the thing, I do not have pots, but the nets are what provides structure. Now, [firmly] *this* is too much. I was filled with fuel and freshwater, and then you have 6 inches of ice! You know, that is why I decided to go to town. When you start feeling the boat a little lazy role, it is not very good. That is why, when it comes to the weather, I'm always on top of it. Because of what I do. And because I know the limitations of the boat I am on.

Mistakes are typically rationalized as poor decisions made under multiple pressures and complex weather factors. Past experiences and memories help structure risk and decision-making. The variation in past experiences may therefore explain why individual mariners report different thresholds for weather parameters; such thresholds are founded in experience, not simply an objective measure of risk.

As the following example indicates, mariners' risk-taking stems from neither a direct response to a formal warning nor an objectively meteorological approach to weather. Rather, how mariners deal with the risk depends upon the nature of their operations:

> Interviewer: How do you make the decision, regarding whether to go or not?
>
> Captain: well, I look at the stability report and what they recommend, that is, what the Coast Guard recommends for icing conditions. And I just go with my own feeling after that. You know, because…
>
> Interviewer: How do weather forecasts enter into your own feeling, then?
>
> Captain: well, I take a look at them, and just decide, if it is worth going up there, [depending on] how cold it is, and what [operations] you have to do. I mean, I can't haul big loads of gear obviously when it is heavy freezing spray. You just can't get a whole lot of gear moved. You have to stop and de-ice

[3] The *Scandies Rose* was a ship that capsized, killing all but two mariners onboard, on December 31, 2019. For mariner perspectives on the incident and its relationship to weather risk, see Krakow and Wieber (2020).

> every so often, too, even when we are just moving little loads of gear around. I just gather all the information you can and take a look at it, you know? [With an active NWS warning] it just depends on which way I am running to get to the gear…*and* what it will be like when I get there, because I can take heavy freezing spray on my stern, but, you know, knowing that once I *get* there the weather pattern is going to change, and you could see it all in the forecast.

As this captain's narrative suggests, risk awareness is generally a function of operational principles (including, in this case, not "hauling big loads of gear"), formal information, and a given, desirable course of action.

### *5.2.5. Social Organization of Decisions: Captains, Fleets, and other Key Actors*

Weather decision-making is a social process. Decision-makers are embedded in groups of people, integrated into a network of people characterized by formal roles and social interests, and dependent upon social actors who provide or disseminate weather and related kinds of information. How these actors are organized and how they communicate with one another is an important component of marine decision-making.

Boat captains are important weather decision-makers in the marine community. They take responsibility for their crews, even as they may also face exogenous pressures (e.g., from fish processors) and with input from others (e.g., in a given fleet, or from weather service providers). A captain in Saint Paul demonstrates a common way captains and crews relate to one another with respect to weather decision-making:

> You look at the forecast for the week, and then you look at it for the day, and then you are constantly checking it, because once it starts to go, for me, because I am the skipper on my boat, and I got these guys that depend upon me… They are not thinking what I am thinking. They are there working for me. And I have had them say, 'you know, it is not so bad out here,' and I have come back and said '*no*, we have got to go now!' And it was *really* bad when we came around Southwest point. And then my guys said, 'I will never argue with you about the weather again' [Firm/solemn tone]—whenever it is you say you want to go, okay, let's go. No more arguing for me.' You know? Because, I saw it, I saw the clouds and the weather, so you are thinking about what the forecast is saying. And we *knew* it was Southeast, and I know that Southeast is not going to be good if it picks up any more than it is right now. I know we are going to be in deep shit coming around Southwest point. That is all riptide area. Very, very scary.
>
> And the guys on the boat, they are not feeling the fear and everything that you are, because you are in charge of it all. It is a whole another world when you are a deckhand versus being the skipper. Totally. Because it all falls on you. You know? And we have everything on my boat. I have an eight-man life raft, survival suits for all my guys, flares [listing tone], you know we have all the safety equipment to pass the Coast Guard inspection. We have it all. But even still, it all falls and you, and so you have got to kind of read it right.

If captains are primary decision-makers on the water, other actors are also important to messaging and responding to weather events.

Geographically expansive severe weather can significantly impact mariners and shore-based processors on a fishery- or fleet-wide basis. While on Saint Paul Island, during storm events, it was not uncommon to see dozens of boats anchored near one another in the bays on the leeward side of the Island. On the one hand, therefore, fleets at given seasons and during weather events often act in unison. On the other hand, captains often characterize their decision-making around weather risk by comparing themselves to one another. One commercial fisherman in

Saint Paul described his orientation to weather risk that demonstrates this comparative dimension of decision-making:

> For all of us that work in Alaska, we have got to be on top of the weather. There are boats that do not care much about it: 'oh yeah, we ride it out!' You know, last week we had a big storm too. I was down by St. George [Island]. So, boats were there hiding. North winds blowing 50 to 60. It was so freaking cold that I made ice... *Behind* the island! So, imagine being out there in that!

If, on the one hand, a "fleet mentality" organizes how mariners receive, discuss, and distribute weather information and make their decisions, a weather-impacted fleet can present problems. Most commercial fishing captains report that weather strongly impacts when they decide to offload their catch (also called "making deliveries" to a given shore-based processor that may be designated based on a commercial and regulatory arrangement). The perspective of a processor fleet manager speaking with a crabbing captain shows how weather can create a situation in which vessels break their arranged delivery schedules, either because of weather impacts they have encountered or else because they wish to "run and deliver" to reduce the risk of remaining at sea:

> Fleet Manager: There is always communications, so we have really good relationship with the fleet, and an understanding that if there is a big storm coming in, and it's quite obvious that everyone is going to be slow down…
>
> Captain: See, [explaining] There's a lot of people that love to run in at the same time then, so it is going to get ugly.
>
> Fleet Manager: So, there is a rotation that has to be, and that is the order of how vessels are going to be offloaded…but if everyone comes in at the same time, well [sighs].

## 5.3. Getting the Forecast: Communication Technology and Messaging

This section first describes the overall value of weather forecasts to mariners and marine-based activity in the Bering Sea, followed by a survey of how mariners receive weather forecasts. The central focus is on technological change and its impact on weather decision-making. After outlining the means of receiving weather information, the report can then focus on a central aspect of weather information use and decision-making in the Bering Sea context: the *pluralism* and *synthesis* that characterize weather information in its contexts of use.

### *5.3.1. General Value of Forecasts*

Weather impacts and weather information shape everyday operations for marine-dependent operations. The salience of weather forecasts to individuals and industries is difficult to overstate. A fishing fleet manager provides a common perspective among mariners:

> Interviewer: In your role as fleet manager, when does weather really impacts your operations?
>
> Fleet Manager: *Every day* in Dutch Harbor! [All laugh]. I mean no matter what, if it's crab season or Pollock season or cod season or halibut season…Weather is *always* a factor! Which is why I always monitor it, in the morning, midday, evening. You know, because we know how fast it can change.

Similar statements abound among mariners, who intimately acknowledge how unforgiving Bering Sea weather could be in unanticipated extreme weather. A fisherman in Saint Paul described how the local fleet tend to "congregate" in certain areas based on what weather forecasts indicate, stating sternly: "The first thing you do when you're going to go out, is you check the weather that is the number one thing. And that makes the decision on what you're going to do. Always, every day. Because, like I said, we are a small boat fleet. And you have to check the weather. You *have* to."

Weather "talk" has long been a common feature of social life in modern society (Golinski 2003, 2007). Yet discussion of weather conditions—frequently moderated by weather forecasts—are particularly central to daily life, social interaction, and consideration among those with whom I spent time on Saint Paul and Unalaska. The mariners on Saint Paul with whom I spent significant time on a regular basis, routinely gathered weather information. If internet access were available, individuals would check phone-based apps. If within cell phone reception, individuals would call the automated National Weather Service phone number to check local conditions and forecasts. For reasons of safety, decision-making, and livelihood, weather forecasts structure everyday life. Some treat weather predictability with skepticism; conversation about weather regularly featured the uncertainty or changes to weather forecasts (when updated). Nevertheless, the act of checking the weather was a central aspect of daily routines.

### *5.3.2. The Role of Technological Change in Weather Information Use*

If weather forecasts are important to the everyday and critical decision-making among mariners, how does access to forecasts figure into decision-making practices? Technological change has always influenced not only the production of forecast information, but the way people get and interpret weather information and thereby incorporate it into their lives and decisions (Henson 2010, Sherman-Morris 2005, Bostrom, et al. 2015). Technological change in Alaskan marine and coastal communities is no exception. However, because of the remoteness that characterizes the Bering Sea/Western Alaska Region, technological change is unique in this context. Most significant to this study is the recent rise of internet connectivity and associated forms of (mostly private, app-based) weather information.

When one mariner and fleet manager was asked to reflect on the change that has been most significant to making a living in the Bering Sea, he swiftly replied, "*technology*," specifically communication technology. He believed that "getting information in and out from the fleet" has improved safety, and that the shift to a situation in which "you can see your own weather picture" has changed the basic relationship between mariners and weather. Mariners generally confirmed this perspective, in which communication and information technology have changed operations with respect to anticipated weather. For example, one senior captain discussed what he termed the "revolutionary change" in how mariners have come to interact with weather information: "we used to have to be like weatherman," he stated, speculating that either "we are just getting dumber" about understanding weather, or else mariners have so much information that they do not have to worry about being weather experts like they had to be in the past.

### *5.3.3. Radio, Telephone, and Weather Fax*

In previous decades, radio broadcasts and weather fax charts, both disseminated by NWS, formed the primary, if not exclusive, sources of marine weather information for mariners on the open ocean. Many mariners still rely upon these sources, either solely or in combination with internet-based sources. Some changes in communication devices maintain the same source and format of information. For example, a radio broadcast of an NWS marine zone forecast resembles that of a phone call that can retrieve an automated NWS audio forecast. In areas with cell phone reception, but minimal internet, some mariners have transitioned from relying upon

VHF broadcasts to relying upon a phone: “Nowadays, we have phones, and everybody checks the phone, when earlier on we used to always call the Weather Service with the VHF radio. But VHF is the backup now, you could say, for what is happening out there.”

Usage of some devices for receiving forecasts, including the weather fax, are clearly in decline. Although some mariners report still relying upon the weather fax charts, which are also available online, forecasts depicted through weather fax charts present a case in which the communication medium shapes the message. In other words, the weather fax apparently holds a burden of interpretive skill, which newer mariners may never have learned to carry. One more senior mariner described his past experience with weather fax-based forecasts:

> We used to have the weather fax machines, and I thought those were the best things ever! Because I got good at *reading* those things. And I could tell the wind direction, and the way to hide, and some of everything, you know? And then you would get a little picture the ice edge every once in a while, through their, which was helpful…But we just cease to use the [more] old school stuff—look at your barometer and things like that, and the weather fax machine. I used to really rely on those pretty heavily.

The future of radio-, telephone-, and fax-based communication is unclear. Yet interviews with those that use only these communication sources shed some light on the pace of change that they see among their fellow mariners. Nate, a boat captain in Saint Paul, described how he relies exclusively on radio to retrieve weather forecasts. He did so primarily because of the high costs associated with onboard internet access: “I just don't want the bill. It is expensive! You are talking up to 30 or $40,000 a year, possibly.” When asked if he felt that radio broadcasted forecasts were accurate and sufficient for informing his decisions, he responded, “Yup. The only thing out there that is more accurate is Windy.ty. That’s it.” He went on to address that in the future, he may turn to using web-based products when they are more affordable. Like others, Nate viewed this imagined technological trajectory as following the general trend of how mariners are coming to access weather information.

### *5.3.4. Direct Communication*

Mariners regularly communicate directly with one another. Information, especially about the weather, circulates widely among fishing fleets and coastal communities. A fisherman in Saint Paul characterized a common occurrence, in which mariners weigh their own decisions against their fellow mariners, whom he jokingly characterizes as “sheep” to signify the collective nature of marine decision-making:

> So, we will sit around the dock and bullshit. And we are like *sheep*, you know [both laugh], and like we *all* go. [voice louder, animated, story-telling tone] Or you go out there, and then you find out, ‘Ahhh, it is too shitty to fish!’ and then, maybe we will come back, and maybe somebody else will say ‘No, we are *going*! We are going to go.’ It comes down to that.

Other mariners report calling one another before making a critical decision, at times providing new information that shapes the decision. As a basic example, I asked one captain in Saint Paul how they deal with discrepancies between the weather forecasts they use (in this case, NWS forecasts and Windy). Fellow fisherman formed the common denominator: “well, it’s just—Call up your buddy and see what he’s got going on—‘hey what is going on over there?’” As opposed to acting with a “herd” mentality, as described above, mariners often simply compare their own thinking with that of people they consider to be trustworthy peers.

As another example, one boat captain told me that he and a fellow fisherman had recently communicated about a freezing spray warning, in combination with readout from a satellite device-derived text forecast. One of them did not realize how cold the air temperatures would be: "I called my buddies, and they are like, '*oh*, I had no fucking clue!' I was like, '*yeah*...[scolding tone, firm] *Be ready*!...But if you are not following all of them or something, you will not know it is going to be 5 degrees out in the middle there [i.e., a marine zone]." Direct communication generally helps mariners measure their interpretation of weather information against others' interpretations, at times changing how they anticipate risk or choose to behave.

Direct communication is important, given the array of raw data sources that mariners may regularly access. Mariners generally believe that public and private sources of marine weather information have the same data, a similar structure, and are only different because of the means providers use to disseminate and display information. The only major exception is the common understanding that only NWS produces formal warnings and sea ice information. As a result of how mariners perceive weather forecasting—chiefly as a highly automated process—most do not recognize the role human forecasters may play in producing a forecast. As a result, many do not know about options for communicating directly with weather service providers.

Although many mariners do not directly contact NWS weather forecasters, many recall previous periods that featured direct communication with NWS personnel. Despite technological change in weather forecasting and digital communication, recollections of the past are surprisingly positive. One mariner, among many, spoke in generally favorable terms about the simplicity of information in past decades, even as he acknowledged the problem with the paucity of available data and information:

> Windy C [ a private weather app] seems like…Well, I don't know. I am still getting a feel for it, to tell you the truth…I used to *religiously* dial in twice a day and listen to Peggy [Dyson], and that was *it* for weather. We just used to listen to Peggy out of Kodiak in the old days, you know? And she would get the tugboats, so you would get real-time reports from all the tugboats that would call in, and that was pretty good, you know? And then Cold Bay weather was pretty good. I kind of liked it, actually.

Although most mariners agreed that weather forecast accuracy has improved, the person-to-person interaction characteristic of prior periods had helped to establish forecasters' credibility, knowledge, and expertise. Interestingly, mariners recalled trust being important even in past circumstances when those individuals who broadcasted weather information were not themselves weather forecasters, a point that suggests human interaction can support credible expertise even when it is disconnected from forecast production.

As another example, a mariner in Unalaska, after receiving contact information for the Anchorage Weather Forecast Office, immediately recalled how a friend and fellow fisherman "would always call the Weather Service in Kodiak. Jacob was his name. They were on a first name basis [laughs], it was just like, 'Jacob,' you know?" A different fisherman in Unalaska recalled his experiences of interacting directly with NWS personnel over the radio, who at times provided critical forecast insight:

> Like talking to one of the forecasters with the National Weather Service Kodiak, and I forget that guy's name in Cold Bay—on the sideband weather? I don't know if he is on anymore. But you could ask them, like, 'Hey, I am getting ready to cross the Gulf, can you give me, like, should we take the normal plan, go all the way up and around to Cape Spencer, or can we shoot straight across?' And there have been times where they would recommend, 'Hey, stay south, you are going to get a better

> trip.' You know? I mean, it is eight days open ocean, but [pause] So…I really don't see that coming from NOAA and the National Weather Service [anymore].

What the above examples suggest is that credibility is important to supporting decisions, but that people can secure credibility and foster relationships of trust over time in a qualitatively different manner than can textual or graphical information output. The objective accuracy of data is thus only one component of how users attribute expertise to forecast producers, a finding that aligns with other studies of the attributional and relational nature of expertise (Collins and Evans 2002; Grundmann 2017).

The value of direct communication is significant for mariners who report having spoken with sea ice forecasters with the Alaska Sea Ice Program (ASIP). Sea ice dynamics are a weather element that is not forecasted by other, private weather services. Moreover, mariners generally do not report having experience-based methods or principles for anticipating sea ice growth or movement in the absence of formal weather information. Therefore, ASIP provides a critical service that is well-established among mariners as the primary source of short-term sea ice information for the Bering Sea.

Direct communication is especially important when dealing with uncertainty under stressful conditions. Mariners speak to one another on docks and over the radio in order to weight decisions and to gain perspective on their own decision-making. A similar process unfolds when mariners speak with forecasters, except forecasters are seen as embodying weather expertise and hold greater credibility than forecast products alone. Yet, as with communication between mariners, direct communication with forecasters does not always reduce exogenous uncertainty and weather risk. As one example, a boat captain in Saint Paul narrated how he decided to leave gear near sea ice based on a phone conversation with an ASIP forecaster, in combination with other forecasts:

> Captain: At the time I was pretty close to St. Matthew [Island] at that time. And that is right when I decided to take off and go to town. I went to Dutch Harbor, and then the weather [expletive] changed, and the ice was coming down, and I was like 'oh no, oh God! With all the shit that I have [meaning weather information]? [Breathes heavy] And I compared it all, and *everything* was the same: it was a *five-day* window of southerlies, and I looked good! And I was like, 'I'm going, I am out of here, I'm going to go deliver, and then I'm going to come back out and have an empty boat load, and I'll be able to grab what I need to, and hopefully move on before the ice gets to me.' Well, as soon as I got to town [Dutch Harbor[, the weather forecast changed and went back to northerlies, and I am just like, 'Oh my God!'
>
> Interviewer: Did you lose gear?
>
> Captain: No, not for me, but, I mean, going from one extreme to the total other in the flip of a switch? And it's like, 'you have got to be shitting me! How can you be so far fucking off, and not know that that is coming?' At least, that is the way that I felt about it. I mean, I did *my* job, but at least...[sigh] I don't know, I mean, I thought I did my job, and checked the research about what the guys put out.

Situations like those narrated above suggest limits to direct communication, insofar as a single conversation may not appropriately capture outstanding contingencies as they unfold over time. Moreover, such situations suggest that changes in the forecast, however accurate according to weather forecasters, may not reach mariners who have already committed to a course of action. Direct communication can perhaps best assist mariners by qualifying the uncertain and contingent nature of any information that may be provided.

Limitations notwithstanding, it is important to consider that the mariner addressed above trusted ASIP forecasters and their forecasts. Trust is therefore not necessarily correlated to factual accuracy. As the mariner quoted above later stated, "I have talked to her quite a few times," and he stated that he would continue to do so in uncertain situations. Thus, direct communication can overcome experiences with unanticipated weather and forecast changes, whereas experiences that lack direct communication may simply lessen the overall confidence mariners place in forecasts, damaging the longer-term credibility of weather services and its import to critical decisions.

### *5.3.5. Satellite Communications*

Many mariners carry satellite devices for communication purposes. Those that used such devices typically reported that they purchased and began to use them within the past several years, beginning around 2015. Satellite devices, such as the Garmin inReach device, allow users to text or call contacts synced to a cell phone, as well as to retrieve text forecast products. As of 2020, forecast retrieval was supported by the weather service companies OCENS/WeatherNet and Dark Sky/Apple. Access to satellite networks, for example the Iridium network, is available for a monthly subscription, and forecasts are available for an additional cost. Mariners reported that such devices provide important supplemental resources that can allow them to access weather information without the internet and with more convenience than, for example, VHF radio transmissions.

Although some rely upon satellite devices as a primary means of getting weather forecasts, most who carry such devices use it in combination with other sources. One crab boat captain in Saint Paul shows how satellite devices can function as a "back up" source of information: "So, I have this [inReach device] as a backup. Don't get me wrong, I have been using that thing [points to handheld device]," as he described, to compare the forecast it displays with the forecast provided by the web-based app, Windy. The captain went on to conclude, "I've got like three or four different ways I can go about doing it. Then I just compare them." When comparing, he showed how he looks for patterns across the sources: "As long as it is somewhat close, especially when it is like this out, then it's pretty [good]…And like when this shit comes down, that's when you want the right forecast."

### *5.3.6. Internet Access at Sea*

According to those who addressed the topic of internet availability, most reported having gained internet connectivity since 2015. One captain, Norton, stated that 2017 marked when he and other mariners began utilizing internet onboard. With that capability, as he described, many captains began to rely heavily upon Windy: "Pretty much everyone has got one [i.e., internet access], except for maybe ten of us [in the fleet]…We all have the weather on our radios too. But most are going Windy. There are a couple of other programs out there too." In Norton's narrative, he equated internet connectivity with the use of Windy, confirming a pattern by which mariners get internet access in order to receive web-based weather information (primarily through graphical apps, like Windy). When speaking with one mariner who had yet to get internet access, I addressed the possibility of point-and-click weather forecast functions, which are available via the NWS website. Although receptive to this function, of which he was not otherwise aware, he nevertheless simply equated his anticipation of getting internet access with the intention to use "the Windy program."

Another mariner, a captain named Kevin, discussed how receiving the forecast has changed over time. His discussion is relatively typical for those who have been operating in the Bering Sea for a similar amount of time (Kevin stated he had been a captain since 2008, but worked in the region for longer):

> It has progressed over the years. I mean we used to listen to it [i.e., the weather] on the sideband like everybody else. And then it got into just looking up the forecast on the Internet, once we got that. And now that it is a little better Internet, we got the [Windy] app…I pretty much rely on it now.

Kevin stated that he gained internet access onboard in 2018, around the time he believed others were likewise doing so.

The rise of internet connectivity and its association with internet-based, private weather applications is a clear pattern, based upon interviews with mariners. What remains to be seen is how weather information based on internet-based technology relates to the plethora of types and uses of weather information. The following section therefore presents analysis of how mariners synthesize information technologies and sources, including web-based applications, NWS forecast products, direct communication, and personal observation/experience.

## 5.4. Pluralism and Synthesis in a Changing Informational Environment

To begin to understand how mariners synthesize information types and sources, let us first outline in greater detail how mariners use and interpret internet-based weather apps. This investigation is important insofar as these sources are increasingly popular as mariners' primary source of information. Any goal regarding the improvement of weather forecast delivery, or public understanding of weather forecasts and events, must therefore begin with an empirical understanding of the tools upon which mariners are increasingly reliant.

### *5.4.1. Mariner Perspectives on 'Windy' and App-based Forecasts*

Given multiple sources of information, presented in different modalities, mariners generally reported appreciating the option to interact with visual and text data simultaneously. Many mariners therefore utilize the Windy.com website or its associated internet-based app that users conveniently have on their phones and/or integrated into their visual displays in their vessel's wheelhouse. Based on having accompanied mariners in the wheelhouse as they were interacting with weather forecasts, it is clear that the combination of visual and text information matches their needs for information when making decisions. Mariners often must consider operations by geography, especially marine routes of travel, and by time, for example, travel times, times spend at fishing grounds, and delivery schedules. In other words, mariners must visualize their operations and weather across time and space. Many find this operational reality well represented by a graphical format that allows the user to toggle by time periods and zoom in and out geographically.

A boat captain in Unalaska provides a common perspective on the value of Windy's graphical display:

> I think the best feature about Windy is that you can go day by day and *see*. And that is what it has done for laymen like myself. Because, if you have a good internet connection you can just press play and watch the weather systems move, and [see] how they are reacting to spot changes. So that is something that [Windy] has done.

When reading a forecast using Windy or related applications, mariners closely view the "meteogram" that accompanies the graphical display and includes quantitative figures for specific, customizable meteorological parameters. The meteogram tool allows mariners to quickly align their interpretation of graphics with quantitative forecasted values, which they can then compare to their individual thresholds. One mariner, looking closely at a forecast for wave heights and wave period, demonstrates the process of using graphical apps and meteogram data:

> Like I said, I have not updated. But it is going to be easterly, and that is going to be Northeast. See the difference? The difference is because this wind is close to the ice. That is why this swell is smaller [showing small swell on computer graphic map]. But if I go down…see, it increases. Even though it is the same intensity. 31... 31... But this area is close the ice, that is why it's smaller, see? Farther away from the ice it is bigger. And that it is the same [pointing]. And then, the water travels more, and the swell turns.

The mariner used the combination of visual and textual data to inform his evaluation of when and where wind and wave characteristics would impact his operations. He claimed that a text forecast would have insufficiently informed this evaluation.

Another mariner demonstrated how he uses Windy to make his own estimation of cold storm impacts, specifically freezing spray:

> Captain: I use just Windy C. I just look at that, and look at the highest gusts, mostly. And these gusts [gesturing to the Windy dashboard] are just too much for me. And with those temperatures, not much gets off the boat. The spray that hits your boat stays on your boat.
>
> Interviewer: That is primarily to evaluate freezing spray, or just to know the gusts?
>
> Captain: Well, the combination of the temperature and the wind. I mean, if it was warm I would probably be out there in 40 knots.
>
> Other Mariner: Wind means waves. And waves mean spray. And spray—cold spray—means icing.

This example shows the value mariners receive through the capability of aligning a given parameter, in this case wind gusts, with their operational needs. More specifically, because many mariners have internalized the conditions conducive to freezing spray, they often rely upon their own techniques for interpreting forecasted wind, temperature, and wave values with respect to operational and safety risk. When mariners already rely upon Windy for routine forecasts, they also use its functions to evaluate the chances of encountering extreme conditions, including freezing spray.

Graphical app-based information, mariners report, is furthermore useful because of the capacity to visualize localized weather patterns, which may be absent from other information formats. One example is strong terrestrial influence on winds and seas along the Aleutian Islands. One boat captain, who reported fishing all along the island chain, provided a comparison:

> I have had times where it is freaking screaming, and we are fishing three or 4 miles off the beach right here and it is flat calm. I mean, these are really big volcanoes right here [points at a map]. These guys over here have 25-foot seas and getting blasted, but over here it is glassy calm. You can see that the ocean is angry by the little wavelets—it is like this pent up monster. But from whatever local condition, the wind is getting funneled right over the top of us. And a lot of times, Windy will *show* that. It will show "variable 10" [knots] or "variable 15" for 3 miles out, and then the thing gets real again. But you would not see that if it were just a big "L". You wouldn't see the localized thing anywhere and you would think, "Oh, I can't go fishing there." So, we utilize [Windy] especially along the Aleutian Islands.

This individual demonstrates how visualizing larger patterns and local environmental circumstances nuances mariners' understanding of weather. In the situation described, it informed his decision to safely operate, despite a generally stormy weather pattern. Other mariners corroborated the perspective, through which visualized local weather assisted decision-making regarding possibly dangerous conditions near land. As one mariner described, "what you see by looking at Windy is just how much the land affects the wind!"

Mariners' descriptions of information use in nearshore circumstances reflects a broader point of view, namely, that graphical apps are more precise. The following discussion, in which a fisherman describes how he shifted from using NWS zone-based forecasts to Windy, demonstrates ideas about forecast precision that are common among Bering Sea mariners who use graphical forecast apps:

> I have been using Windy more often, and Ralph, my copilot, he checks the National Weather Service too, but often I just don't have it on my computer. [Windy] *has* been a game changer. It is the visual representation and being able to scroll through it linearly, versus looking at a weather fax every six hours, and having to…Yeah, and you know a lot of people can't even *read* that. I mean, they just don't get how the [weather] systems work …Windy is updated, what, every four hours they put out another? And the files are itty bitty, and we can download them just for the area that we are operating in. And so, that has been the biggest advance for us. I haven't looked at your 3- to 5-day Outlook. 24 hours, pretty much spot on. But you guys are forecasting a *200-mile* chunk!

This interview excerpt shows how mariners link together several issues that inform how they evaluate information sources, in this case Windy and NWS zone forecasts: the "visual representation" of predicted weather, concern for the frequency of forecast updates, and the capability of downloading data tailored to the specific geographic areas of operational interest. In the preceding example, the mariner went on to discuss how using Windy to understand smaller-scale weather features informed his decisions. He concluded with the following assessment: "If we just went by the area forecast we would have never left the dock." Thus, mariners link their capacity to view precise areas and features to their ability to make informed decisions.

Because they value graphical forecasts that allow them to see local weather patterns, many mariners adopted Windy or similar apps as soon as they gained internet access onboard their vessels. Many are satisfied. As one relatively junior mariner praised, "It is absurdly accurate...We use it pretty religiously." Exclusive use of internet-based apps exhibits a generational pattern, with newer or younger mariners being more comfortable relying upon Windy forecasts alone. However, not all mariners agree that app-based, private weather information provides more usable information. Some prefer the simplicity of NWS products that they are familiar with, and which allow them to gain a synoptic view of the general patterns. For example, one fishing boat captain in Unalaska compared himself to other mariners, stating:

> Captain: I do not use Windy. I know a lot of guys are using that…It is convenient, and it is cute, you know, but I can make up my own analysis pretty much by just what the [NWS] charts are saying…Before I had internet [onboard], I would just go to the library, and download fax charts and check it out. Now, it is just strictly on the Internet. I just got online and get the charts. And I feel pretty comfortable with the forecast.

As this captain's perspective shows, experience and learning over time inform the usefulness of a given product. Given one's experience with information, some mariners prefer one information source over another because of perceived forecast accuracy and usability.

Those who transitioned from primarily using NWS products to using a private app, however, generally believe that the forecast data (and by extension, accuracy) remains the same—only the format and user interface is different. For example, when discussing forecast uncertainty, one fisherman in Unalaska outlined how he combines Windy and NWS forecasts, but in the end he concluded:

> Mariner: It is all based on your [NWS] data, right?
>
> Interviewer: Well, I was going to say, when you are looking at Windy, are you familiar what models you are looking at there [pointing to "ECMWF" model selector]?
>
> Mariner: Well, it is all generated by the National Weather Service!

A fisherman in Saint Paul similarly stated that he primarily utilizes the app, Windfinder, "but then I kind of look at what is going on with the *actual* forecast—the NOAA marine weather."

Beliefs regarding underlying weather data suggests a general pattern in mariner consideration of weather information: most understand formal forecast information to have a common source. Belief in a common source, mostly believed to be NWS, is likely the result of how opaque weather forecasting has become for users, primarily thanks to many aspects of weather services having become automated. The most significant and striking feature of the resulting informational environment is how mariners end up synthesizing information sources.

### 5.4.2. The Practice of Synthesizing Information to Make Critical Decisions

In practice, mariners typically rely upon their ability to synthesize and compare multiple information sources. As already indicated, most mariners believe forecasts, including those produced by private and public weather services, have greatly improved. The following example is drawn from an interview that included two mariners and two NWS meteorologists:

> Captain: You can see from the buoy weather, and Windy, and NOAA, and you can compare the three—and they are getting *so* much better over time—not just the broadband [*sic*. sideband?]. You tell me it's coming down at noon, and I kind of believe you now! [Laugh]. I am just saying that it's getting so much better. And it's not *us*! [laughs].

This mariner evaluated improved forecasting with reference to his experience of various information sources that he reportedly used.

When measured by routine frequency of use, the most common order of information sources that mariners use begins with the Windy app, followed by NWS products, and finally word-of-mouth or direct communication. The following narrative, provided by a mariner in Saint Paul, demonstrates the basic pattern:

> I use Windy. [That is] just about it. I check the NOAA weather every once in a while, especially if I need something other than, like, the wind. Because they show the ice more and also freezing spray, that kind of thing. I check that usually once a day, or something. But, Windy is *really* nice. You can kind of just see what is going to happen, especially [with] wind direction."

Another mariner, a fishing captain in Saint Paul, follows the somewhat typical approach taken by open-ocean Bering Sea mariners:

> We have Internet and, let's see, it is probably up right now. I use this one. [Pulls up the NWS Marine Zone text forecasts]. I am old school, so the text. The zone forecast. That is what I use. As backup. I use that to back up this: [Pulls up Windy]. Windy TY. It's pretty accurate. It's pretty nice. It is pretty

darn accurate. We get some pretty good information. But I usually back it up. If I'm doing something critical, I will back it up [with] the NOAA zone forecast—Just to make sure.

The use of NWS as a "backup" source shows how informational synthesis is especially important to a decision to do "something critical," which the mariner further described as situations that involve vulnerability to weather hazards over a relatively long distance or extended timeframe.

Although synthesizing NWS- and private weather services may be the most typical method of using information to anticipate future weather, practical and local knowledge also plays an important role. A small boat operator in Unalaska discussed how she considers wind direction and duration over a several-day timescale, using forecasts alongside "mariners' folklore":

> What I really look at in the forecasts is where the winds are going to be coming from *later*. So, when I'm out there for eight or 12 hours, or a day or two later, what am I going to have to be dealing with? Because I know where the nasty winds come from and how fast the seas build. The great thing about the Bering Sea is that the seas, they built fast, but they come down fast. But if you're on the Pacific side though, they take a while to build, but to take a really long time to come down. That is the Mariner's folklore.
>
> There is a few [sources] I will kind of look at to see, is everybody kind of coming into agreement. But then I will kind of decide, and if it looks like there's something going on, I use the [NWS] point forecast to decide, 'okay, which direction to go? Am I going to go east around towards Beaver Inlet? Or am I going to go West?' Because it depends on wind direction—you can have these southerly winds that keep coming up through Akutan, and it just kind of hauls up through there. But if you go West, you know, nothing. Or vice versa.

"Folklore" or mariners' experienced-based principles, therefore, interact with the processes through which mariners evaluate other information sources.

Mariners at times trust their own conclusions based on synthesizing information sources, even when faced with an NWS Warning. For example, one fishing captain in Saint Paul stated that "NOAA sends the weather report, which I can check twice a day, if I want to. And they tell you [the warning]." Yet this individual stated that they do not always receive the warning, but rather evaluate risk by other means. As he stated:

> For the most part, I don't know. Like, this [gesturing to graphic display on console] does not tell me if it is going to be 'heavy freezing spray' or not. But by seeing what the water is doing to the boat…Let's say I have a little glaze...and [mimicking checking the weather on console] 'oh shit, yeah, it is going to be cold!', and then…Or sometimes, you have the windchill, and we can go up to -18 or -20, and [speaking firmly], you *know* it is going to freeze!

In this case, the mariner described their concern as being guided by a synthesis of personal observation and their interpretations of weather patterns displayed on a graphic-based weather app. When pressed about their ability to anticipate freezing spray, then, this individual relied upon an ingrained principle regarding storm directionality:

> Interviewer: So, do you feel like you have a pretty good way of anticipating when you're going to hit freezing spray?
>
> Mariner: No, but as soon as I know it is going to come from the north, it is just freezing. I think any wind coming from the north is going to be cold. Southerly, it is more warmer. It is more shitty. Easterly is cold, but not freezing. Westerly is not cold, but it brings big, big seas…But yeah, after doing that for many years, you kind of have an idea. Like I said, I can see what's coming.

Rather than expressing absolute confidence, this captain instead indicated that he trusted his own interpretation of multiple information sources, filtered by experience-based principles. This interpretive process helps to explain the seemingly contradictory position that he, on the one hand, cannot anticipate freezing spray conditions, but on the other hand, "can see what's coming." Like other mariners, this captain relies upon the process of synthesizing information. Indeed, he trusts the outcome of that process over any single forecast product, including an official warning.

### *5.4.3. Dealing with Uncertainty*

Mariners recognize that their anticipations of future weather are contingent, and they must consider the uncertainty of weather forecasts along with the limitations of their own understanding and control. Although many respondents in this study provided some critical assessments of weather forecasts, by and large mariners are humble about the capacity to predict future situations. Moreover, an apparent culture of responsibility, accompanied by a hierarchical chain-of-command in decision-making, means that most captains take it upon themselves to make decisions despite uncertainty and risk. This is evident in mariner's narratives of tragic or near-tragic circumstances. Such narratives, structured by themes of remorse and danger, typically feature both unanticipated weather *and* reproachable decisions.

In practice, mariners deal with uncertainty by weighing alternative scenarios, informed by their operational demands and the information they view as most reliable. For example, one mariner in Saint Paul discussed how he interprets a wide range of projected wind values by relying on his trust and experience with NWS text forecasts and warning products:

> Interviewer: With extreme weather, are the thresholds with your vessel different than the warnings?
>
> Captain: Nah, I like the way… The Weather Service have been doing it this way for so long. And so, you can read between it. Like, '15 to 35 [knots],' uhhhh, *gosh*, I wonder what they mean by that? [laughs] Well, they could mean 15, or 35, or both! You know, but I think it works. And I think the service is good, the weather [forecast] is really great.

In this example, the captain went on to outline his preparations for dealing with a freezing spray scenario, which he prepared for based on how he interpreted a recently issued NWS Heavy Freezing Spray warning:

> Interviewer: Is [the warning] something you will heed, and do something different?
>
> Mariner: *Yes*! We will make sure we are tight. And we will be ready to run for cover.

Clearly, mariners deal with uncertainty by relying upon the expertise embedded in formal forecast products. However, considerations of uncertain risk among mariners may rest more on tradition and experience, rather than a rationality centered on event probabilities or a deliberate calculation of risks and benefits. As an initial relevant point, most mariners I interviewed place little faith in forecasts past two to three days, even if they often considered longer-term forecasted weather. Yet the timeline of such "faith" varies considerably. One mariner discussed his perspective on uncertainty over a longer time horizon:

> The weather is supposed to turn around southerly here [at] some point. Yeah, I don't know much about what is happening after that. I don't put much faith into forecasts, you know out two weeks. Five or six days, I have pretty good confidence [pause]…generally speaking. You know, I'm not looking at an almanac and trying to decide where to go fish [laughs].

Rather than following strict rules regarding forecast timeframes, most mariners gauge forecast uncertainty by evaluating how forecasts change.

One fishing boat captain in Saint Paul demonstrates an experience-based adaptation to uncertainty, namely, the practice of evaluating how forecasts change as they are updated:

> Captain: It can change, but if I don't see any changes and it remains the same for two or three days, and let's say, today is, what? Friday? So that low is for Monday, and it has not changed since yesterday.
>
> Interviewer: So, you'll look at it tomorrow—the update?
>
> Captain: Yes. So, it is a 50/50 chance it is going to be the same, or it is going to increase, you know? So that is my window. Like three days, four days. You know, if I don't see radical changes, then I can plan ahead. And I have been using this [Time Zero weather service[4]] for three years now. And we can get the weather from NOAA, at least every six hours... It changes every six hours. Or it remains the same. For example, we were seeing this low coming, and it was *huge*, bringing pretty big seas, and, you know, the day before, that day was going to be, let's say, 40 miles away from me to the East. Overnight, it took a turn, and I was going to be right in the freaking *middle*. And I was going to get 40-foot seas, so I needed to run! It was like, '[expletive] that, I'm out of here!" You know? I can't…On this little guy [vessel], I cannot just ride over 30-foot seas. It is too much.

Mariners who follow how forecasts change, as this example shows, respond to the updated information. However, mariners generally interpret major changes in forecast updates to signal uncertainty in the weather pattern. An updated near-term forecast, even if remarkably different, is generally considered to be trustworthy. Yet changes in longer-term forecasts—even if they are based on improved forecast confidence from a meteorological standpoint—generally cause decreased forecast confidence among mariners. In other words, the dynamic level of confidence at play among forecasters is not necessarily transferred to forecast users.

For context, most routine weather services issue deterministic forecast products, meaning they do not explicitly address uncertainty or probabilities of event occurrence. Instead, they collapse alternative possibilities and uncertainties into a given set of forecasted values. Uncertainty is neither represented nor qualified, except within the NWS forecasters' Area Forecast Discussion (provided regularly by each Weather Forecast Office) and auxiliary communications related to Warning products or specialized DSS. Given deterministic representations of an uncertain future, how do mariners respond? First, many mariners distrust long-range information, viewing it as inherently less reliable. Second, as addressed, mariners work to interpret changes in forecasts as they are updated. The following example demonstrates how one mariner internalizes the issue of forecast uncertainty into how he interprets forecasts:

> When I see weird freaking scribbles and all this kind of stuff on the three-day outlook, I place almost *zero* reliability on that, because it changes so fast. And I look at the [NWS] forecasts, which come out every six hours, right? And when you guys are changing it dramatically every six hours, I know I can just throw it out the window for any time after 24 hours. And that's just the nature of the beast. I mean, this is a violent place… I mean you can barely see the anchors on the boat [laughs]! I mean, I understand the dilemma. There are so many things. Obviously, I am not a meteorologist, I know they are looking at a lot of bigger data sets than I am. And it is amazing doing what [forecasters] do.

By monitoring changes in the forecast, this mariner has learned to distrust changes in forecast products, which to him indicate both an unpredictable system and a sign that forecasters have less confidence in the forecasts that they are issuing. Important, this mariners' perspective suggests a possible disconnect between forecasters' and users' interpretations of forecast

[4] On Time Zero's basic and subscription-based proprietary forecast products, see https://mytimezero.com/high-resolution-weather-forecasts (retrieved June 2, 2020).

changes. In particular, major forecast changes may represent improvements and higher confidence among forecasters but may represent lower confidence to forecast users. From mariners' standpoints, it is not easy to determine what a change in the forecast means insofar as the reasoning for the changes and its relationship to uncertainty is opaque to them.

Those who primarily use text- or other deterministic weather information without diligently evaluating forecast uncertainty report being regularly upset by unanticipated forecast changes. The following excerpt, from an interview with a Bering Sea crab boat captain, provides an example of frustration with forecast changes retrieved by an inReach satellite device (the captain's primary information source):

> Captain: I like it. It does really screw us up with, just, how much it changes. For instance, I get a lot of, like, we hear it is going to be blowing 'east 45' or something like that, so we will set our gear east-west. Well, then, 12 hours later we check the weather, and it says north-south, and you're like 'what the [expletive]?' And then 12 hours later it's is a whole different direction. And I know this is how it goes, but...
>
> Interviewer: So, with the inReach, you are just getting the text?
>
> Captain: Yes. I just use a cell phone. So, we call the inReach number, and then it's there [inaudible]. Every once in a while, they are all terrible and get in the wrong order, but most of the time they are all pretty good.

This example shows that mariners may fail to access or recognize significant changes in the forecast when they are reissued or updated. In this case, wind direction affected how this crabber decided to set pots and operate. Such unanticipated changes appear more common among those that make critical decisions based on text forecasts. This may be because people can register changes in the forecast differently when they are updated automatically (as in Windy) and displayed graphically, which may allow mariners to grasp the larger features of the weather systems they expect to encounter.

### 5.4.4. Principles of Experience-Based 'Bias' Correction

To act in the context of uncertainty, mariners frequently report their own methods of anticipating future weather by adjusting forecasts to align with their experiences, local knowledge, or evaluations of the various information sources that they regularly synthesize. The following example shows that the process of comparing information sources incorporates practices of 'bias correction' of individual sources. Such practices depend on a mariner's past experiences and the weather dynamic they are seeking to identify, in this case, the timing of a storm passing. After identifying three information sources—Windy, Windfinder, and NWS—Ron, a halibut fisherman in Saint Paul, described:

> I look at all of them, then compare. The trends are often close for all of them, but the timing can be different. I find Windy poor in the *timing* of wind, especially when it is going to come down after a storm. And that is important, because you're looking for when the storm will come down [to decide] when you can get out on the water.

Another mariner in Saint Paul demonstrates the common process, in this case regarding how he calibrated wind and wave values projected by a web-based graphical forecast. The calibration process led him to evaluate that fishing in the conditions he anticipated would not be possible:

> Captain: So, right now it says 5 knots. [Speaking as he interprets the graph] And it is kind of variable 10. [Pause]. And I like this [graphical display] a lot better. I know that I have not updated. But it is

going to be pretty nice, you know? And then you're going to have some southeast [winds], and it's going to be like, well, this is the low that I'm talking about [pointing to weather system displayed on a screen]. So, if I put my cursor over it, it is saying 32 knots. Uhh, it is going to be more like 45, you know?

Interviewer: That is interesting that you kind of calibrate that way…

Captain: Well, because I know that I can go with this, and then I go with the wind meter. And uhh [brief chuckle], when I see this, '35 knots,' it is a no fishing day for me, because I am a small boat, right? And then it says 13-foot seas, but it is going to be more like 17, 18. I'm not saying it is going to be steady. But you will see 18 footers. And they are going to be nine seconds apart. So, it is going, it is not going to be [expletive], but it will be uncomfortable [firm tone]. This is seven seconds apart [reading values displayed on-screen], that is fucking shitty.

A kind of bias correction in this case allowed the mariner to make a critical decision by related his experiences on the water and with forecasts to the combination of several forecasted weather elements.

As another example, a captain in Unalaska detailed how he tended to adjust NWS forecasts with respect to tides:

In my experience, it is 'big tides, big weather.' It is not 100% sure, but if I am looking at your three-day prediction, okay? And I'm coming into king tides, especially solstice tides either in December or in late June or July. Then I am going to add 10 to 15 knots to your forecast, and that is what it is going to be. If you are calling Southeast at 25, I call Southeast 35 to 40. Just based on the violence of the tides coming up. Conversely, if we are coming into neap tides, like now, near the equinox. It could be *minus* 10 of what you are forecasting. It is not boilerplate, but it is pretty dog gone close.

Although the mariner quoted above related his correction to forecasts with reference to tides, interviews generally suggest that the most common practice of adjusting forecasts involves wind speed values. One mariner exemplifies the process of adding wind values to an app-based weather forecast for open waters in the Bering Sea: "I am going to add…it varies, but, between 10 and 15 [knots]. When I see my report, it is just not accurate, [but] at least I have an idea, about 75% of the time, which is good."

A fisherman in Saint Paul demonstrated a similar practice, in this case adjusting wind and seas forecasted by a private weather app, which the mariner stated was his sole source of weather forecasts:

Mariner: This one, I can see the direction of the swell, the intensity, you know, all kinds of stuff that I can see here. And when I see it, it is more accurate. Umm [rethinking statement]. One thing though, like, it says, '30 knots,' and I know I have to add up 10 knots.

Interviewer: So that is what you use, and then you kind of modify that…

Mariner: Yes, and then I go with the 'quick meter'[?] and that is pretty accurate. Simply with the swell, it is telling me seven here. It is most likely 11. You know, I have always got to put in that margin of error. It is not accurate sometimes.

Another fisherman in Saint Paul provides a case of using local knowledge gained from experience and conversations with an NWS employee to add wind values, in this example, to NWS nearshore forecasts for the Pribilof Islands:

Because of my years fishing, and the experience, I guess, and with working with guys out there…There was another guy, he was in the Coast Guard and then he worked for the Weather Service. And so, he used to tell us, 'if we tell you it is blowing 10 miles an hour, let's say, here, or if it is blowing 15 here [pointing to map]. Add 5 miles an hour more to it if you are out on the water.' You know, it was those kinds of

> things, which you are able to *learn* from the guy in the Weather Service here, personally, to work on figuring out what is going on out of the water.

Mariners, as these examples show, adjust forecasts while they interpret them. To do so, they rely upon shorthand principles rooted in advice and their own experiences with weather. Experiences with under-forecasted winds and seas leave special impressions upon mariners. Having dealt with unanticipated risks, experiences tend to inspire 'bias correction' in order to establish caution and contingency as a part of marine decision-making.

## 5.5. Use and Evaluation of National Weather Service Products

### *5.5.1. Experiences with Improved Forecasts*

Those that regularly utilize NWS forecasts agree that weather forecasts have improved. As already addressed, many mariners synthesize weather information sources. Therefore, praise for improved forecasts is often given to the entire weather forecasting enterprise. However, NWS products are also singled out for their improvements over time. The sentiment expressed by two mariners in Unalaska captures the general value of improved forecasts:

> Mariner 1: Between the two of us we have logged a lot of miles on the Aleutian Islands. When we tell you we bank on [NWS]…you do not hear us bitching about anything, right? I cannot imagine how crazy weather predicting in this environment is.
>
> Mariner 2: Let me give you guys this much for certain, you are tons better! I mean, *way* way way better. I don't know if it is just experience, or equipment. Because I just remember...Well, our joke was 'variable 15', no 'variable *50*.'

In other words, past experiences led these mariners to believe that forecasted winds, although given a range of 'variable 15' knots, could in fact be 50 knots. As these individuals continued to discuss, the reliability of NWS forecasts had improved their ability to operate safely with less stress regarding the range of weather conditions they must anticipate.

Similar evaluations abound. Another mariner suggested that the timeframe of forecasted weather is the most significant improvement: "Your guys' weather reports are so much better! I mean, you can almost give it to us to the hours, or close [Laughs]. So, that has improved a great deal, compared to just saying it's going to blow 45 *today*. So obviously you guys have seen the growth in your own industry big time on that." Such improvements in forecast precision and accuracy immediately help mariner decision-making. The mariner quoted above, for example, continued by stating that forecasts refine time-sensitive decisions: "This really helps [us] out, like, [characterizing a decision] 'well, I may just go ahead and stop at midnight, because it's going to get real bad for a few hours, and then I'll just get up early.' You know? Because the weather will be better. It is not always right, but it is getting there."

The above examples demonstrate the direct value of improved forecasts. They show, moreover, that forecast accuracy is significant when it results in a refined product, for example, a text product that delineates an hourly timescale instead of a daily timescale. Thus, improved forecast skill (in meteorological terms) positively facilitates decision-making when it is represented directly in the forecast products that mariners use.

### 5.5.2. *Marine Zone Text Products*

Mariners generally tend to associate "NOAA weather" and "National Weather Service" forecasts with weather fax charts and, more commonly, with marine zone text forecasts. Those with internet access in their homes, on their devices, or on their ships, often have specific marine zone forecast pages bookmarked in an internet browser. Others only get NWS text products via radio- or telephone-based automated readouts.

Although mariners frequently reported appreciating NWS text forecast products, a common evaluation concerns the size of open water marine forecast zones. The following statement, given in a frustrated tone, captures the common difficulty in interpreting marine zone forecasts with reference to marine operations:

> Literally, I mean, you know how big [the zone] is. You get the whole section with this weather, and it can be really nice over here and terrible down here, and how are you going to average *that*? 179 is pretty small, but 410, 412, 413, they are so [expletive] big! I don't even know how you could really break them down. But if they were broken down into, maybe four sections? Or even the north and south of it? That would be helpful.

This individual discussed how marine zones are such common reference points that doing away with them would not be helpful. Instead, he recommended "breaking them down" into quadrants.

Very few interview respondents use, or have learned about, marine point forecasts. Among open ocean mariners that had heard of the product, none stated they use point forecasts as a primary source of forecast information. This is likely a result of the endemic use of zone forecasts and infrequent use of the full NWS website. Still, when modeled with mariners two had internet access, the product appeared useful to them.

One small boat mariner reported that point forecasts had allowed her to understand nearshore waters with greater accuracy, which she discussed as vital to her decisions to go out on the water:

> I am on a 22-footer. You go around the corner, and it is a totally different world. So, it is important to know what [the weather] is going to be doing west of here. Even though it is a few miles as the crow flies, it is a big difference. I like to be able to do the point forecast, because there is like… rounding Cape Cheerful, you have to know what the seas are doing, what the winds are doing, and what the tides are doing. For a small boat, you kind of have to pay attention to those things. Because it could be beautiful here, and then you go around it is just, *pshhh*, naughtier than hell, like, *eww*!

This respondent went on to describe that the point forecast as her primary weather information source. Other respondents that report using the point-and-click function cite difficulties navigating NOAA webpages, especially when on the water. Although marine zone forecasts provide a common reference point for mariners, their future centrality to marine weather decision-making is unclear, given the rise of graphical app-based forecasts that provide different representations. Although text-based forecasts function as an important, if sometimes secondary, information sources, it remains unclear how forecast improvements to text-based products may result in enhanced decision-making among mariners.

### 5.5.3. *Warnings, Watches and Advisories*

Most mariners are familiar with National Weather Service marine warnings, either from prior experiences with radio broadcasts or from ongoing use of text-based forecasts and warnings integrated into general media- and web-based weather services. Regarding marine weather in the

Bering Sea, mariners also demonstrate in interviews a common language that involves National Weather Service categories—including for example, “storm” versus “gale” warnings, or “freezing spray” versus “heavy freezing spray” warnings. However, mariners interpret the meaning of formal warnings differently. For instance, mariners I spoke with rarely change operations or plans based on a “Freezing Spray” (as opposed to a “Heavy Freezing Spray”) warning.

The following example demonstrates how a captain evaluates their recent operations, conducted in a zone for which Heavy Freezing Spray had been forecasted: “Like, we’ve been doing this a *long* time. If it says, ‘Freezing Spray Warning,’ like, it just doesn’t, it doesn’t matter. If it says, ‘Heavy Freezing Spray,’ then we consider it.” When asked to clarify, this mariner stated:

> It is not cold enough to really… to build ice. Maybe a little bit. Upon together examining the boat’s bow, which is covered in a layer of ice, the captain stated: “If it is like this, there is no way. You ain’t getting this under ‘Freezing Spray.’ You might get a little sheen built up on the deck, or 1/4 inch on the rail. At that level, maybe a little ice, but it will also just get knocked right back off, the next [time] you get a big splash, because it is not cold enough to really freeze solid.

Another mariner suggests that experiences with what he viewed as over-forecasted freezing spray meant that he does not necessarily heed warnings unless he also considers other information and experience-based thresholds.

Interviews suggest that mariners may therefore open themselves to risky situations when they cannot properly anticipate freezing spray:

> Interviewer: With [freezing spray], do you feel like those were risks you know are were getting into?
>
> Captain: Well…if I had to say it, [pause] More often than not, when you say, ‘Freezing Spray,’ we are not going to get any. You know, ‘Heavy Freezing Spray,’ that means we will get a little.

Warning categories, as interviews generally demonstrated, thus carry a high degree of interpretive flexibility. Still others discussed an appreciation for the current NWS differentiation between warning categories. Again, with reference to freezing spray, one mariner reported that how the warning category matched his decision thresholds: “It is pretty close, usually. Like for Heavy Freezing Spray, if it is only blowing 10 or 15 knots, that is just ‘Freezing Spray.’ Usually, you guys just call that Freezing Spray, not Heavy Freezing Spray. I am not sure exactly when it becomes that.”

Regarding freezing spray risk, mariners generally agreed that warning categories must be interpreted in the context of operations—the duration of extreme conditions, the direction of intended travel, and the nature of operations (e.g., carrying gear and pots, or not). One captain reflected on how he makes decisions around moving gear while potentially dealing with freezing spray conditions. He used examples drawn from his own decision-making to reflect on how crab captains generally may or may not heed warnings:

> Captain: So, if I am way up by St. Matthew, up here, and I have to move 100 pots 30 or 40 miles north, and it is going to blow northeast or north 45 knots—and those are all bitter winds—and I’m thinking, ‘we are going to pile this shit [ice] on even just moving 40 miles’... I can put 26 tons of ice on, and so you go, ‘okay, am I only going to take 80 pots instead of 100?’ And that is something that I have never seen in the forecast for freezing spray. ‘Heavy Freezing Spray,’ I mean, there are a number of *degrees* of heavy freezing spray. I mean, if you have ice fog on the water and it is 10° out,

> then…Or anytime you get near land, the temperature drops. You know, that is where you get the bitter colds.
>
> Interviewer: So, you experience lot of variability within that heavy freezing spray category?
>
> Captain: yeah, so you could say 'North of 58° latitude or whatever, extreme icing conditions,' or something like that…Because a lot of guys, they see that [warning] and that is all they know: 'Well, oh, it says icing conditions, I can take it.' I mean, we just had an incident of a boat that rolled over a couple years ago, and I've *known* those guys, you know, I knew Sam for a long time. And here is a condition where there is *no way* he should have been out there—with a load of gear, and that area, with the currents! It is easy to be an armchair quarterback, but those were extreme conditions and all other boats that were in there were eventually kicking pots off. It was too much, you know?

The above discussion of freezing spray suggests that formal warnings are hardly interpreted as a direct indicator of conditions mariners should expect. Regarding freezing spray, the warning categories are given various meaning and significance. Mariners vary in how they consider "warning" thresholds to signify risk conditions, according to the other information sources they consult and the operations they are planning. These considerations, however, are upheld by a common understanding that Freezing Spray warnings do not often match an environmental threshold to successfully and safely operating. In turn, this makes for situations of risk, not only because of recklessness or lack of experience with marine operations, but because warnings are flexibly interpreted among mariners.

### *5.5.4. Alaska Sea Ice Program*

As already indicated, mariners who operate in the Bering Sea during the winter strongly rely upon ASIP products and expertise. Indeed, in interviews, no mariner cited any other sea ice information source that they utilized. From an operational standpoint, therefore, any developments in sea ice forecasting should be linked to ASIP products already in use.[5] Along with improvements in weather forecasting that mariners addressed, those who had been operating in the Bering Sea for decades evaluated recent developments in sea ice information as being substantially more accurate and usable.

A boat captain in Saint Paul, Earl, provided some perspective on how sea ice information has changed over time. Earl had only recently restarted crabbing in the Bering Sea, having taken a 15-year hiatus, during which he fished off the Oregon coast. His comparative perspective is therefore instructive. First, in prior periods, mariners had to rely more substantially on their own observations of sea ice. Earl discussed having intentionally travelling into the ice to evaluate its movement and to determine whether crabbing near the ice edge was too risky or not. As he put it: "Sometimes I used to fish all day and then I would run up at night and pull up into the ice and just drift with it, to kind of get an idea that way." When asked if he recalled having travelled into the ice regularly, Earl responded that when "we used to fish the sea ice" the "ice is kind of a respite—you can sleep, and you are not bouncing around. And then you just drift with it… I've gotten stuck in a couple of times." The practice carried risk and was generally inferior to utilizing sea ice forecasts, insofar as it could waste time and lead to further problems. For example, Earl narrating a situation, "one time, back in the 80s," in which "a couple of flows came in together on me, then froze solid, [and] I drifted all the way into Russia waters." Earl

[5] The only possible exception was discussion of what one mariner insisted on being the most useful—"quality satellite imagery"—which he may have regularly obtained from non-ASIP sources, in addition to the charts provided by ASIP (which incorporate satellite data).

suggested that sea ice information was not as available in the past, compared to 2020. He therefore reported being pleased with recent developments in sea ice forecast products available through ASIP, which could replace riskier practices.

Although ASIP is the primary sea ice information source, some mariners reported that they still synthesize ASIP charts with their own observations regarding sea ice movement.

> Mariner: If we are working near the ice, we will run up and see where it is, and see if it matches what I see on the picture [meaning, ASIP charts]. And when we find it, we sit in it and see how fast it is moving. It is easy to move with the current. And we will see what kind of speed it is moving. And we will see and gauge how much time we have left where we are at, and then decide whether to stick around or move.
>
> Interviewer: Do you ever call the National Weather Service Ice Desk?
>
> Mariner: Yes. I have. I have in the past. When they were in Cold Bay, I think they were in Cold Bay. There was a guy in Cold Bay that used to do the weather. And I used to talk to him now and again. You know. But it's different. We just have so much information at our fingertips now. It's different.

The preceding narrative suggests several important features regarding NWS ASIP. First, the ASIP charts are basically universal. For this mariner, the chart is simply called "the picture." Second, mariners trust their own experiences and observations, and appreciate the ability to measure these against formal information sources. This value is reflected in the mariner's description of traveling into the ice to "move with it." The value of comparison may form part of the larger practice of synthesizing information when making critical decisions, which in this case could result, in the case of crabbing near the ice edge, losing expensive gear. Third, this mariners' discussion of information "at our fingertips" is disconcerting, insofar as ASIP staff (in Anchorage, not Cold Bay) are available to assist mariners, and such assistance may clarify mariners' understanding of sea ice dynamics. In this example, that may include an explanation of sea ice forecasting for ice growth, which is more dependent on wind than currents, as this mariner suggested. Finally, use of "the picture" may entail that mariners circulate ice charts, but may not consider Sea Ice Outlooks. Interestingly, very few mariners reported using seasonal-level or long-range forecast information, whether for sea ice or seasonal climate.

Mariners utilize ASIP products in combination with non-NWS weather information sources, suggesting possible ways in innovate how NWS products are developed in the future. Product integration is one possible avenue. For example, under-utilized or new NWS products may be linked to ASIP products, given that the latter are already in use. In a different direction, ASIP data may be made more available for import into other graphical forecasts.

Innovation in this direction could build upon the clear value already derived from ASIP by taking into account the common practices of informational synthesis. The following discussion, with a captain in Saint Paul, shows a somewhat typical, if enthusiastic, discussion of the value of sea ice information for those who operate near sea ice in the Bering Sea:

> I always look at it! I mean, I look at the five-day forecast and the picture basically every day it comes out—if there is any concern at all. And then I have talked to both people, Mike and Mary-Beth, at the Ice Desk and they have both been very helpful. I kind of use the combination of the two. They give me an idea. And, you know, I've been doing it long enough that I look at my Windy app and see exactly where I'm at. And, you know, it is not rocket science, most of it. I can get a pretty good idea of what is going to happen. They have a little bit more insight into it. But that Windy app is really the *bottom way* [with emphasis, likely meaning 'most important']. That and the Ice Desk are probably the two things that I use the most.

The excerpt demonstrates several common themes. First, direct communication helps shape how mariners consider other information that regularly use. Second, improvements to forecasts can most directly add value to marine decision-making when they account for the technologies and information sources that mariners synthesize and rely upon. The following section addresses some recommendations for the National Weather Service Alaska Region, which may enhance the value and effectiveness of its products, given the analysis and findings presented above. The following recommendations are necessarily abbreviated and preliminary. They require collaboration and consultation among NWS staff to refine and, finally, make actionable.

# 6. Discussion and Recommendations

## 6.1. Adapting to the Informational Environment

The informational environment, addressed above, has transformed how people gather, evaluate, and use weather information. This presents a situation for NWS that may involve competition with other information sources as well as adaptation to user practices of information synthesis. NOAA/NWS may maintain data infrastructure, run weather models, and issue warnings that are incorporated into the entire weather forecast enterprise, yet NWS no longer holds a monopoly on weather prediction. Although a general issue for NWS and public weather services, some special opportunities and challenges may be addressed with respect to maritime and coastal Alaska.

The first recommendation is to ensure that NWS maintains the forecasts and services upon which communities and users substantially rely. For example, eliminating VHF radio broadcasts would not impact every Alaskan mariner, but would greatly impact those who rely upon it. Even for those mariners who utilize private weather services, moreover, NWS often provides a critical source of comparative information.

Second, NWS Alaska Region should consider how to either strategically make some forecast products available to other weather services or else invest in educational activities regarding its services. This is especially important in the event of new forecast capabilities or tools. If forecast tools are developed such that their value is only realized by using NWS products, the reality of informational synthesis should be acknowledged. NWS should especially account for the rise of private graphical app-based forecasts when developing marine forecast products. Product developers can adapt either by generating web- or app-based platforms that can provide better, user-friendly forecasts, or—perhaps equally ambitious—develop partnerships with private companies whose products are already in use (for example, Windy). As one example, sea ice information or zone- or polygon-based warnings may be incorporated into private graphical forecasts. At present, for instance, Windy.com incorporates NWS text Warnings, but uses their own color- and labeling scheme to represent "severe" weather warnings on their graphical output. This report cannot evaluate the feasibility of integrating NWS products and private, graphical forecasts, but it does indicate that it may be a strategic direction, unless NWS plans to develop its own app-based platform.

Even without formal integration, general modeling improvements clearly result in increased accuracy among both private and public weather forecasts. Yet experimental forecasts, tailored products and messages, and products that involve significant forecaster input may also provide unique value to mariners and coastal communities. Because NWS is not the sole source of forecast information, however, the development of NWS tools must take the informational environment into account by budgeting and planning for outreach activities to their intended users. For example, this study finds that few people utilize weather.gov (the NWS main webpage), except for some use of area- or zone-based text forecasts. Yet web-based products, for example the Area Forecast Discussion "Marine" section, the NWS point forecast function, experimental forecast products, and graphics may be especially useful to the marine community. Such usefulness would require significant outreach, advertisement, or training workshops with strategic partners.

Third, NWS could support existing or new partnerships that engage in the "co-production" of weather services, in which knowledge is produced *with* communities, rather than delivered *to* "customers." Because such an approach is resource- and time-intensive, it should be implemented for selective community needs for which NWS expertise is particularly relevant. The co-production of the Sea Ice for Walrus Outlook (SIWO) and the Alaska-Pacific River Forecast Center's River Watch Program are but two examples that directly integrate forecasters and user-participants (see also AAOK 2019). These programs are useful because participants provide observations, while also directly benefiting from the information they help to produce. Likewise, they build relationships and expand the social capital that people require to connect their local communities to relevant expertise and services (Adger 2003; Lo and Fan 2020; Robards, et al. 2018). These existing programs generally illustrate that new NWS services must engage their publics to create value for them, especially if services require community input and observations.

The fourth recommendation concerns direct communication, outreach, and community presence. The examples of outreach and co-production in the case of forecast innovations speaks to an issue raised through this study, namely the continued importance of direct communication to how mariners and marine communities anticipate the future and make decisions. Mariners and coastal communities in Western Alaska benefit from direct communication and active relationships between NWS and user communities. Tribal leaders interviewed in Saint Paul and Anchorage, for example, believed strongly that the Weather Service Office (WSO) should be preserved on the Island. This report does not evaluate the complexity of WSO siting, funding, and maintenance, in the case of Saint Paul, involving the Automated Surface Observing System and the relationship between NWS, the Federal Aviation Authority, and local agencies. For local mariners and residents in Saint Paul, the value of the WSO was perhaps more social and symbolic than meteorological *per se*. The presence on the Island of a meteorologically-trained NWS staff member, who is very integrated into the life of the community, provided a source of support and information for a community that is geographically remote, strongly dependent upon NWS forecasts, and otherwise in cooperative, if tense, relationship with NOAA. Given the history and contentious presence of NOAA Fisheries on the Pribilof Islands, NWS in fact may serve a role in helping to establish productive, conciliatory collaborations between NOAA (as a whole) and communities.

This report therefore recommends that NWS consider the social value provided by WSO personnel alongside their function in the data infrastructure (for example, in launching balloons for upper air measurements). Reduced human labor in the latter should not discount the former functions. Indeed, it may be productive and strategic to enhance training for WSO personnel, who may perform local outreach to community partners. At present, WSO personnel hold no such roles formally, although they (like others in the Service) have long connected with the communities they serve.

The outreach principle extends to the WFO and Regional levels. Forecast innovation continues to focus on scientific and computational advances and technological improvements. These gains realize value for people not in their production, but rather in their use. The context of use, as presented in this study, entails layers of interpretation, information synthesis, and shifting social, economic, and environmental realities that NWS must keep in its purview to fulfill its mission. As one example, the analysis above suggest that the seasonality of commercial and subsistence fishing activities may depend upon mariners' economic and regulatory pressures, which intersect with anticipated seasonal weather patterns or pattern changes. Forecasting innovation may add value when improvements are delivered in a way that most directly corresponds to these activities. Because such pressures may not be static over time, supporting decisions may require sustained correspondence and active relationships to be effective.

One need only take a cursory look at the role of community-level relationships in having established the original validity of government weather prediction in the early-twentieth century United States to recognize that the trust, credibility, and effective use of government weather services are hardly inevitable (see Pietruska 2011). Rather, they take active work, outreach, and collaborative relationships. The increasing use of app-based forecasts among mariners notwithstanding, because many rural areas of the United States are under-served by private weather services, the function of government services remain all the more relevant.

## 6.2. Building Partners for DSS

Formal DSS requires expert collaboration modulated by technical skills and tailored information. The DSS mission is undoubtedly enhanced through relationship-building. In rural Alaskan communities, which are primarily Native Alaskan villages who disproportionately face weather and climate impacts, such relationship-building is particularly important to support. DSS with federal agency core partners and emergency managers may be established through bureaucratic and formal channels, for example the Incident Meteorology program and its relationship to federal- and state- fire management agencies. Such channels are not likely solely sufficient to form impactful relationships between NWS (at the Regional and WFO levels) and remote communities. Nevertheless, below I discuss several possibilities for formal DSS, which I suggest may be extended beyond the case areas to other communities and partnerships across Alaska.

### *6.2.1. Messaging Weather Events and Patterns: Linking Key Actors in Marine Decision-making*

NWS can develop DSS with harbormasters, fleet managers, and leaders in organizations that otherwise form critical nodes in the network of mariners and marine decision-making. Harbormasters make decisions regarding port operations. Often embedded within municipal or otherwise public entities, harbormasters make various critical decisions regarding weather and harbor operations. Weather information use among harbor operators is mixed, however, suggesting opportunities for decision support. Based upon interviews with harbor operators and fleet managers in Saint Paul and Unalaska, respondents indicate the value of longer lead times regarding extreme weather that may, for example, substantially alter port traffic and harbor operations or else may require harbormasters to close facilities.

The harbormaster of Saint Paul, for example, indicated that he decided to "close the port down about ten or eleven times last year," during the [crab season]. He stated that he makes the decision to close the port based on observed weather and the telephone recorded NWS zone forecast (marine zone 179). He described that he then notifies the local Public Safety department of the decision and announces the closure "on channel 16 to all the mariners." Direct communication with NWS forecasters may have assisted in this decision-making process, given that the harbormaster operated under relatively explicit thresholds for swell direction and height when making decisions to close the port. Harbor closures can significantly affect mariner and processing industry operations, thus providing a clear circumstance in which DSS may be of high impact and value.

Fleet managers, employed by fish processing companies, are those that oversea the relationship between mariners and processing operations. They work to schedule boats' deliveries and therefore coordinate frequently with individual boat captains and the fleet as a whole. Thus, those that manage commercial fishing fleets are a central node in marine decision-making. A fleet manager in Saint Paul indicated that to ensure efficient processing operations, he tries to plan ships' deliveries 72 hours in advance. In return, he stated, mariners "bank on that timeline." Fish processing plants are central to commercial fishing. Unlike harbor operators or emergency managers, however, commercial fleet managers they represent private firms. Nevertheless, they are primary stakeholders in marine operations, and have considerable influence over how information spreads among a fleet. Mariners regularly communicate with the plants to which they deliver, and weather is a primary factor determining when and how boats travel, come to port, offload their catch, and return to sea.

However, fleet managers vary in their weather knowledge. Some managers appear to trust their own evaluations. As one stated: "So even when I see Southwest in Adak, I know that were getting at the aftermath of that, even if I don't see that written into the forecast". As this fleet manager described, southwest winds and seas indicated for him the most severe storms that would impact the fishing fleet. Managers and processing plant staff also likely vary regarding how much of a role they play in disseminating weather information. One example of a proactive role is that of a major plant in Unalaska, the fleet manager of which regularly communicates weather information. After speaking with those who deliver to this plant, it is clear that this is an important information source for some mariners, as the following excerpt shows:

> Captain: I get an ice picture from my cannery down in Dutch Harbor.
>
> Zeke: Is that Arnie, then?
>
> Captain: Arnie, yeah. He sends me an ice picture every day. Great guy, especially with all that he has going on…If he is sending it to me, why do I have to [access it]? I'm not going to bother getting on there.

Although critical actors in the fishing industry and harbor operations may or may not utilize NWS products and take an active role in messaging weather events, they are generally not directly connected to NWS personnel. Fleet managers, I suggest, are one private entity that may benefit from greater direct communication with forecasters in a DSS capacity. Fleet managers have a direct interest in knowing and planning for how mariners respond to weather patterns and extreme events. Routine interaction, coordination, and weather-impacted decision-making are already well-established between mariners and fleet- and plant managers. Because these managers are central to the network of commercial fisherman, they may also be a more reliable point of contact for weather forecasters, compared to interacting with mariners directly (for example, to secure or promote ship-based weather observations).

Furthermore, the centrality of processing operations may mean messaging extreme events or conducting outreach that instruct mariners on the use of NWS products and services could most reasonably be directed to processing plant personnel, many of whom have a breadth of experience as mariners. Such messaging and outreach, when necessary, may also be more equitable and eliminate the logistical problems associated with communicating with those who are operating at sea.

In addition to identifying key players that can help to message weather events, partnerships could be established that help to tailor forecast information by more deeply acknowledging seasonal livelihoods and marine activities that characterize the Bering Sea and coastal communities. For example, the *opilio* crab fleet clearly has a working knowledge of the Alaska Sea Ice Program. However, most activities in the Bering Sea are likewise seasonal, and the nature of decision-making and risk during specific seasons could benefit from new partnerships, including with industry groups, local/tribal governments, and state and federal fisheries agencies. One mariner, whom I interviewed, suggests a basic pattern among fishermen, who fish different seasons in different geographic areas throughout the year: "It's Pretty much just the *opi* for now. But then, I tender salmon. I use one of these boats and ride all summer long and drive around picking up salmon. I do that and Bristol Bay, Area M, sometimes."

A subsistence hunter and commercial fisherman in Saint Paul likewise emphasizes the importance of weather to the community, especially during the summer fishing months:

> We look at the weather, we look at it *every day*. *Every day*. No matter what. No matter who you are in the community, everybody always looks at the weather, and everybody talks about the weather. And so, for me, halibut fishing, our season starts in June, normally in June, and goes sometimes in the September. And we check the weather every day.

Coastal communities reliant upon specific subsistence resource "seasons" match the more itinerant or rotating pattern among commercial fishermen. In all cases, the seasonality of activity corresponds to certain weather patterns and different exposures to risk or productivity gains related to weather. The extent to which seasonal activities, in addition simply to seasonal weather, is internalized among forecasters' work and NWS practices is variable. It is a thus a direction of growth, particularly given a relatively high level of staff turnover among forecasters. If developed, however, such a direction could strongly augment mariners' use of non-NWS services, which are not predicated upon a capacity or interest to know local Alaskan communities.

### *6.2.2. Tribal Entities in Alaska Native Cultural Context*

Coordination between NWS and tribal entities is a federal policy priority and a priority for NWS Alaska Region. Findings from fieldwork among Unangan people in the Bering Sea are not representative of the tribal, cultural, and geographic diversity that characterizes the varied situations of Native Alaskan cultures, villages, and governmental/tribal organizations. However, several themes emerged related to issues of weather risk, long-term uncertainty, and economic precariousness that may be considered across Native Alaskan community contexts in the Bering Sea/Western Alaska region and beyond.

Residents who situate themselves with reference to a long-term history, and who imagine themselves as participating in a long-term future, necessarily link everyday life, including experiences of weather, to these larger timescales. The focus of this study was not on improving long-term predictive capacity (a meteorological problem). Yet it does find that capacity to link short-term to long-term forecasting may help those for whom anticipating the future across those timeframes is most relevant. To understand why anticipation across timescales, and the role of NWS in shaping that process, is so significant, it is necessary to understand the cultural context, in this case of Unangan people in the Pribilof Islands. I will then suggest that NWS can incorporate aspects of this context into future partnerships, outreach, and product development and delivery among Native Alaskan communities.

Indigenous livelihood is tied to *place*, and thus to the use values that come from the social relationship to the local environment. The exchange values, which stem from the commodification of commercial fish species, for example, are important to regional and village economies. Yet, for most Unangan people with whom I spent time, concern over subsistence resources (and the policies and rights which could protect access to them) related to concern over sustainable commercial development. Thus, the NWS central mission to protect life and property, to be appropriately matched to indigenous livelihood and concerns over future weather, can adapt to indigenous understandings of life, property, and the future. In the case of the Pribilof Islands, these concepts are necessarily related to colonial history and the relationship between people and the Bering Sea ecosystem.

The colonial legacy on the Aleutian and Pribilof Islands looms large for natives of the Bering Sea region. Prior to Russian invasion, tribes had consistently occupied the Aleutian island chain for eight to ten thousand years (McCartney and Veltre 1999). Given that the culture was marine-based, with especially advanced boating, navigation, and hunting technologies, Unangan elders, including those that have been deeply involved in commercial development, considered—if not lamented—lost knowledge and ways of living within the marine environment. Unalaska Island had been a major indigenous Unangax̂ center, and by the end of the eighteenth century was an important hub for Russian (and later American) colonial activity for all of Alaska (Veniaminov 1840). An estimated 80% of the total indigenous population of the Aleutian Island chain was decimated by colonial violence and disease in the Russian Period, from first contact in 1741 until the United States purchased the territory in 1867 (Torrey 1983). Along with indigenous population loss, native culture and language was disrupted, and many marine mammal species, especially sea otters, were hunted to near extinction along the chain.

The Pribilof Islands (labelled by Russian founders as "Saint George" and "Saint Paul" Islands) over 200 miles north of Unalaska, held no stable settlement until Russian *promishleniki*, or fur hunters, arrived in the late 1780s. They soon drove Aleut slaves from Unalaska and nearby islands to serve as seal hunters and processors. When first opened to Russian colonial sealing, Saint Paul Island held from four to six million Northern fur seals, which migrate to the island's rookeries from Spring to Fall. The population was on the brink of collapse just several decades after commercial sealing began. Upon the sale of Alaska to the United States in 1867, the American Commercial Company ran the sealing operation as a monopoly for the US Treasury, thus taking control of Unangan labor and livelihood on the Island, where Unangax̂ were formally "wards of the state" (Elliot 1906). Competition for furs grew, and the population of the fur seals declined rapidly, while Unangax̂ gained little rights in the following decades under United States rule (Kohlhoff 1995; Torrey 1983; Reedy and Lowe 2017).

Unangan culture on Saint Paul Island, therefore, has always been strongly but complexly tied to the fur seal, which for centuries has represented the means to life and subsistence on Saint Paul Island but also the yoke of colonialism. Moreover, since the prohibition of the commercial seal harvest in 1983, the fur seal population initially rebounded but is now in steady decline because of the changing Bering Sea ecosystem. Contemporary Unangax̂ nevertheless still attribute prime cultural significance to the seasonal cycle of migration, arrival, mating, pupping, the subsistence harvest, and the departure of the seals. As one prominent cultural leader of the Pribilof Islands had put it, "if the fur seal is gone, our culture is also gone." For many residents, likewise, the colonial history and present precariousness of the fur seals (Sidon and Zador 2019) reflect the socio-ecological uncertainty of the Island's cultural future (for comparison, in the case of Unalaska, see Sepez et al. 2007). Declining human population on the Island, changing economic prospects, difficulty advancing native language literacy, climate, and ecosystem shifts—these changes register for some local people as of a whole, rather than as separate issues.

As already addressed, some native mariners lament the colonial experience as having erased cultural adaptations to the local marine environment. Yet native mariners, who acknowledge uncertain livelihoods and marine environments for the future, also draw strength from the resilience that characterizes the indigenous history in the Bering Sea. Two halibut fishermen in Saint Paul once discussed how they would fair if the halibut fishery, which they had transitioned into once the commercial seal industry closed in the early 1980s, were to fail. As one concluded, "I don't know what St. Paul will be like without [the halibut fishery]. I mean, we are Aleuts, and Aleuts *survive*, but if we don't know what's next, and today that means if halibut fishing goes away…that makes me uncomfortable." The uncertainty of the present expresses, for many, the temporal dissonance experienced by those who live in the light of a deep local heritage and an unstable vision of how to secure, as the First Alaskans Institute (2017) proclaims, indigenous "progress for the *next* 10,000 years."

To compare, some individuals whom I interviewed operate in the Bering Sea with relatively minimal attention to longer-term future trends and place little significance on the historical and environmental context for their marine activities. Many do not report interacting with local native people. To be sure, many fishermen discussed that they participated in the industry since childhood and describe being part of multi-generational businesses. Even so, in general, large-scale commercial fishermen operating in the Bering Sea are less concerned about climate change and its possible impacts on marine resources. Mariners are keenly aware of environmental change, especially because the results of fisheries stock assessments structure the allocation of fishing quotas from season to season. They also live by the annual cycle of fishing seasons and the weather patterns that structure their everyday decisions. Nevertheless, many view their operations as sustainable, insofar as the shorter time frame of the immediate future is the preeminent concern. Common to other regulated extractive-productive industries, some fishermen expressed that federal and state regulations on the industry over-manage their activities out of uninformed concern for environmental problems, including climate change.

How can NWS, which is grounded in Western science and a rational-bureaucratic organization, engage Native Alaskan issues? One area of strategic partnership could be to further connect short- and long-term forecasts and projections. Another could be to engage tribal leaders in the co-production of knowledge regarding weather and climate. Some such projects are already underway in Alaska and in the circumpolar North, but few directly involve NWS. Such engagement could help NWS to secure partners that can provide useful observational data while also advancing tribal goals of cultural revitalization, safety, and economic (subsistence and commercial) security.

## 7. Conclusion

The possibility of NWS Alaska Region building upon existing or new partnerships with Alaska Native tribal entities brings into relief the larger issue addressed in this report. Namely, how can NWS continue to successfully engage communities of users by integrating their concerns, activities, and perspectives into the production and dissemination of weather forecasts and related weather/climate information? To conclude, it is worth reflecting on prior situations for the Signal Service and Weather Bureau (the administrative precursors to the National Weather Service). Over the past two centuries, weather prediction and forecasting have had to adapt to novel social, environmental, and scientific/technical circumstances. In the process, public weather services have at times been overtly challenged by alternative bases of weather knowledge, including charismatic 'weather prophets,' publics frustrated by poor information, and private firms that would make weather services into a market. The play of these forces has entailed gains and losses, challenges, and opportunities, regarding the support of a public informed about and prepared for future weather (Baker 2019, Pietruska 2017). In the past, to deal with these issues, innovations in public weather service have always entailed technical/scientific developments as well as concerted efforts to connect the Service to communities. At a time when technological change is altering forecasting and forecast users, and when the *anticipatory culture* of the Bering Sea is beset by environmental, economic, and sociocultural change, it is necessary to consider how knowledge producers can best relate to the communities they serve. It is the goal of this report, and the research effort which it represents, to continue to enliven how NWS Alaska Region incorporates social science and the needs, perspectives, and voices of the diverse communities it serves.

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