STORYING MULTIPOLAR CLIMES OF THE HIMALAYA, ANDES AND ARCTIC

Anthropocenic Climate and Shapeshifting Watery Lifeworlds

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A Transdisciplinary Pedagogy for Cryospheric Climes

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Introduction

How might we think about teaching climate change, especially with regard to the dramatic changes that are occurring in the cryosphere? I begin with two stories from the North Slope of Alaska, where I visited in 2014. The first tale I owe to the traditions of the Iñupiaq peoples of the region, as retold by Edna Ahgeak MacLean, Elder and linguist (Chance 2002, 13):

> One day an *avingaq* [mouse] decided to venture outside his hole and assess the rest of the world. When he stood up on his hind legs, lo and behold, to his surprise, he was able to reach the heavens. When he reached down, he felt the ground. When he reached in all directions, he was able to touch the limits of the world. He concluded that he was the largest person on the face of the earth.
>
> In reality, the poor mouse had surfaced from his hole in the ground into an old Iñupiaq boot sole turned upside down. The top of his heaven was the sole of the *atungak* and the outer limits of his world were the sides of the *atungak*.

My second story is a real-life-based fictionalized account I created for the classroom, based on my conversations with scientists and Iñupiaq community members as well as the work of scholars documenting Indigenous knowledge about sea ice (Eicken 2010; Gearheard et al. 2013).

> In the days when sea ice was still thick in the springtime, a Scientist went to Utqiagvik with a team of fellow scientists to study sea ice. He knew it well: its physics and chemistry, its seasonal cycles, but he wanted to expand

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> his understanding through field measurements. It was a perfect day, as the group walked from the shore over the ice. Clear sky, and nothing in the weather forecast to cause concern. Their footsteps crunched solidly, giving no inkling that beneath the surface layer of ice was frigid liquid water. It was the sea ice thickness, among other properties, that they intended to measure. The ice glittered where the low light of the sun caught the pressure ridges that were formed when the liquid water underneath pushed chunks of ice over each other. They walked to the edge where the sea ice met the liquid ocean, and proceeded to set up camp.
>
> As they were doing so, the Iñupiaq Elder who was their guide suddenly said, without preamble, that they had to get off the ice right now! They were skeptical, because the day was perfect, and there were no indications that anything might go wrong. But the urgency in his voice compelled them to obey, and they packed up. As they walked back toward the shore, there was a deafening crack behind them, and the region of sea ice on which they had set up camp broke off and floated into the Arctic Ocean.
>
> In those days, with no coastguard presence, being borne off into the harsh Arctic environment at the mercy of unpredictable currents was close to a death sentence. The Elder had saved their lives.
>
> The Scientist had thought there was only one way to know sea ice, and it was with this purpose that he had gone out to its far edge with his instruments. But the Elder knew sea ice in a completely different way. The ice had spoken to him, but not to the Scientist. The Scientist never forgot the experience.

The North Slope of Alaska has been home to the Iñupiat for thousands of years. Here, the tundra meets the frigid waters of the Arctic Ocean, and in winter, late fall, and early spring, the top surface of the ocean freezes and extends from the shore over liquid water, for a few miles. This is sea ice: not land, not sea, a liminal zone.

On a relatively warm April day (about −12°) I stood at the edge of sea ice near the town of Utqiagvik, looking at polar bear tracks that my kindly Iñupiaq hosts pointed out to me. The pressure ridges glittered in the sunlight, and the ice field stretched toward the horizon, the distant liquid water boundary lost to sight. Despite the snow goggles, I squinted in the dazzling light. The astronomical accident of the Earth's tilt, which deprives the Earth's northern extremity of the sun's light for nearly half the year, along with the tectonic movements that gave rise to this nearly enclosed ocean, create an environment where ice—and sea ice in particular—is both protagonist and storyteller (Figure 9.1).

My visit to Utqiagvik was the result of a failure and a fascination. The failure was in the classroom. As a theoretical physicist and educator concerned about the environment, I had started introducing basic climate science into my general physics courses. My hope was that in doing so I would be equipping students with the knowledge they needed to prepare for change, and perhaps to become

FIGURE 9.1 Shore of the Arctic Ocean near Utqiagvik, Alaska, with sea ice in the distance.

change-makers. These naïve expectations were quickly dashed when students' reactions revealed both a cognitive and emotional disengagement. Climate topics like the greenhouse effect, the carbon cycle, the absorption spectrum of carbon dioxide, and current and future impacts, were scattered through the semester, and key details were easily forgotten; meanwhile, emotional reactions ranged from grief, anger, and apathy, to paralyzing despair. "I'm just one person, what can I do," or "it doesn't affect me, so I'm not going to worry about it" were common refrains. The experience drove home to me the fact that *teaching just the science was not enough, and could even become counter-productive.* Clearly, I needed to become a student again. I decided to begin with the Arctic, which is "ground zero for climate change," with temperature rise now nearly four times the global average (Rantanen et al. 2022).

When I finally stood on that remote shore on a cloudy April day, the crisis of climate change that I had been studying and teaching for the last few years became viscerally real. Breathing the frigid air, with the sea ice glittering a few feet ahead of me, the "acute disjunction" which climate creates between our "affective, discursive and epistemological selves" (Bristow and Ford 2016, 6) seemed to dissolve in the undifferentiated whiteness of sea, land, and sky. The ice roads of Utqiagvik and the complete absence of vegetation on the snowy tundra indicated an entirely different way of being a human animal. During my short stay, I interviewed Iñupiaq town officials, a whaler, an Elder and educator, and a multitude of scientists, learning from them and from various scholarly works, and through them, from the ice. It became clear to me that reducing the climate crisis to a solely scientific-technological issue washed out "the thick textures of lived experience" (Bristow and Ford 2016, 6) that are necessary for a meaningful engagement with the crisis. This was the start of a journey in search of vehicles of meaning-making that could illuminate the transdisciplinarity of the climate crisis. One of the most powerful such vehicles is the story.

In the physics classroom, stories like the ones I have told above give rise to multiple questions. What does the mouse's story mean? How did the Iñupiaq elder know the ice was going to break off? Why were the scientists studying sea ice? Further, these stories are grounded in the local—the particularity of Iñupiaq history and culture, the specifics of changing social-environmental conditions along the northern Alaskan coast. We might consider these stories emerging from a particular cryospheric clime. Following the notion of a clime as the link between weather and place (Carey et al. 2014; Fleming 2014) the cryosphere might usefully be considered to be a mosaic of climes that share certain common features, but that are also distinct. Thus, the North Slope of Alaska is distinctly different, in social-environmental-historical terms, than, for example, the Yukon region to its southeast in Canada, or the Greenland ice sheet, or the highest peaks of the Himalayas—yet all are part of the cryosphere. These clime-specific stories, where the social and biophysical, the real and imaginary seem to be irrevocably intertwined, appear in stark contrast to the language of climate science: the graphs showing temperature change or carbon dioxide concentration or sea ice extent, or the journal papers estimating climate sensitivity or attempting to quantify the ice-albedo effect. In addition, physical scientists tend to seek the universal, and the local context only appears when universal laws are applied to a specific situation—whereas human cultural stories are firmly grounded in localness, in place.

The question arises: what use are stories? Why would anyone, much less a physicist, introduce them as part of a pedagogy of climate change? How might they inform a useful and inspired understanding—affective and cognitive—of climate science? And might the reverse be also possible—that one could discover stories in the detached, formal narratives of climate science? As a physicist, it is more than obvious to me that matter is active in the universe and has stories to tell, stories generally ignored in modernity's obsession with the exclusively human. As an educator, I also know that stories of the nonhuman seen through the lens of science can be made accessible, meaningful, and relevant to the nonscientist. But how—and why—should we bridge the divide between disciplines, between stories like those quoted above and the narratives of science, between human and nonhuman, local and planetary?

What I learned and continue to learn from my teachers, human and nonhuman, has led me to a fundamental reconceptualization of climate pedagogy, which foregrounds its transdisciplinary nature and makes issues of justice and ethics central. It proposes four dimensions of an effective pedagogy:

the scientific-technological, the transdisciplinary, the epistemological, and the psychosocial-action dimensions. Rather than reductively exploring each aspect, these dimensions are manifested relationally through stories and via three interdisciplinary meta-concepts (Singh 2021a). My primary impetus for developing such a pedagogy is this: when we are confronted with a phenomenon such as the climate crisis, which defies our current paradigms, we must go to it with a radical openness and humility, divesting ourselves (to the extent possible) of preconceived frameworks. In other words, we must acknowledge the phenomenon itself as teacher. In this chapter I begin with an invocation to sea ice in Alaska, focusing on its physical nature, seasonal cycles, and decline. I acknowledge the teachings of the sea ice and those of the climate problem as a whole. I then briefly summarize my pedagogical framework, including three key transdisciplinary meta-concepts. Thereafter I return to the Alaskan Arctic to illustrate these ideas, bringing out the connections between clime and climate, local and planetary, social and scientific, and human and nonhuman. I elaborate on the notion of cryospheric clime, and show how stories can help animate the concept.

Sea Ice: A Scientific Invocation

> It can be stiff and silent but also blasting and crushing with terrible noise, and it can advance and retreat as if a living being. Every year sea ice extends across 14–16 million km^2 in the Arctic (and 17–20 million km^2 in the Antarctic Southern Ocean) and then it shrinks and withers by the end of the summer to a fraction of its winter might. As it forms, persists, advances, and melts, it changes the ocean circulation, regulates global climate, and affects life in the polar regions.
>
> *(Krupnik et al. 2010, 2)*

In the late fall, the Arctic Ocean water starts to freeze. Tiny ice crystals, called frazil, begin to form. Depending on whether the sea is calm or rough, these crystals coalesce in different ways to build sea ice. This new ice, called first-year ice, may be anywhere from a few centimeters to a couple of meters thick. Sea ice is not as solid as it appears. During its formation, the concentrated salt water that is unable to freeze forms tiny pockets and passages, called brine channels, within the body of the sea ice. Sea ice, through its formation, reaches across scales, from the millimeter dimension of the frazil and the brine channels to the millions of square kilometers of the Arctic ice cap.

The shiny surface of the sea ice reflects the sun's energy back into space without much absorption; the cryosphere as a whole, rejects 30% of the sun's energy due to its shininess or albedo, thus limiting how much is absorbed by the Earth's system. In the summer, the sea ice begins to melt, and as it does, the brine channels expand and connect, forming a labyrinthine maze, releasing the concentrated salt water into the liquid ocean below. This highly dense salt water sinks toward the ocean floor, providing part of the impetus for the great system of ocean currents, the Global Conveyor Belt. As the summer progresses, some of the first-year ice, if thick enough, will survive the seasonal melt, helping to thicken the ice the next winter. This survivor ice, called multi-year ice, can be up to 20 m thick. Because it partly melts in the summer and allows the brine to run out, multi-year ice is a source of fresh water for Iñupiaq hunters and polar expeditions. Meanwhile, the brine channels provide space for ice algae to grow, which form the base of the sea ice ecosystem, a web of relationships that starts with the ice algae and continues all the way to polar bears, bowhead whales, and humans. For the Iñupiat on Alaska's North Slope, the sea ice provides much needed sustenance in the harsh winter months through the fresh meat of animals that spend time on it (seals and polar bears) and by making it possible to walk to where bowhead whales can be hunted. Thus the crucial importance of Arctic sea ice is simultaneously situated in the local (ecosystem well-being and Iñupiaq subsistence and culture) and the global (ocean currents and albedo). In fact, the paleohistory of the Earth's climate indicates the central role of Arctic sea ice in determining the onset and completion of the past million years of glacial and interglacial periods. Sea ice inhabits multiple temporal scales, from its winter/summer expansion and contraction to its paleohistoric past and its current rapid decline, exhibiting temporal multiplicities—"deep, accelerated, and troubled," like the tundra it borders (Andersen, this book).

From the shore near Utqiagvik, the sea ice appears stationary. But, as the Scientist and Elder story implies, ocean currents and winds are always moving it around. The Beaufort Sea just east of Utqiagvik happens to have a circular current that keeps sea ice in the area long enough to form multi-year ice. Eventually, the ice floats out of the Arctic Ocean via the Fram Strait on the East coast of Greenland, and melts in the warmer waters of the Atlantic Ocean.

Thus the extent of sea ice depends on new formation in winter versus the summer melt, and also on the amount of multi-year ice. When sea ice formation happens at the same speed as sea ice loss, the average amount of sea ice remains constant (a condition of dynamic balance), apart from seasonal fluctuations. But global heating is causing sea ice to melt at an alarming rate. Not only is there less ice formation and more summer melt, but multi-year ice has decreased significantly. The Beaufort gyre, which was once a sea ice nursery, is turning into a graveyard (NASA 2018). With summer melt occurring faster than winter formation, and with the disappearance of multi-year ice, it is not surprising that sea ice extent is dropping rapidly, into a state of imbalance. This has ramifications for the local ecosystems, human populations, and the entire planet—culminating in what Sverker Sörlin calls a cryohistorical moment, signifying human hegemony in the vanishing of a crucial element of the climate (Sörlin 2015, 327). Thus sea ice is going from balance to imbalance, and because it exists in intimate relation with the local and the global, it simultaneously affects and is affected by planetary-scale imbalances in carbon dioxide concentrations and energy (Loeb et al. 2021).

Sea ice belies the expectations of those who are not nurtured in its vicinity. Neither land nor ocean, it can be as stationary and solid as the tundra, or it can break or move in sudden and dangerous ways. In pictures, it looks as quiet as a snow-covered landscape in lower latitudes, but it is not silent—it creaks, groans, whines, and thunders.

The graph below is a compressed representation of the sea ice's story (Figure 9.2).

Teachings of the Sea Ice

What might we learn from the sea ice that is pedagogically useful for understanding clime and climate? Sea ice is a necessary aspect of coastal cryospheric climes of the Arctic and Antarctic, but its importance crosses boundaries of geography and time. To summarize, it tells us that the *local and global are intimately connected; it spans large scales of space and time*. In addition, it warrants a *transdisciplinary understanding*, since the meaning of sea ice, the implications of its decline, and how we might mitigate and adapt to its loss involve multiple disciplines, including the natural and social sciences, Indigenous culture, history and epistemology, and considerations of economics and justice. From my scientific invocation arise three additional "meta-concepts" that form the basis of my pedagogical framework. One is the idea of *balance or steady state,* and its opposite, *the state of change or imbalance.* As the dynamics of the sea ice change due to global heating, the speed

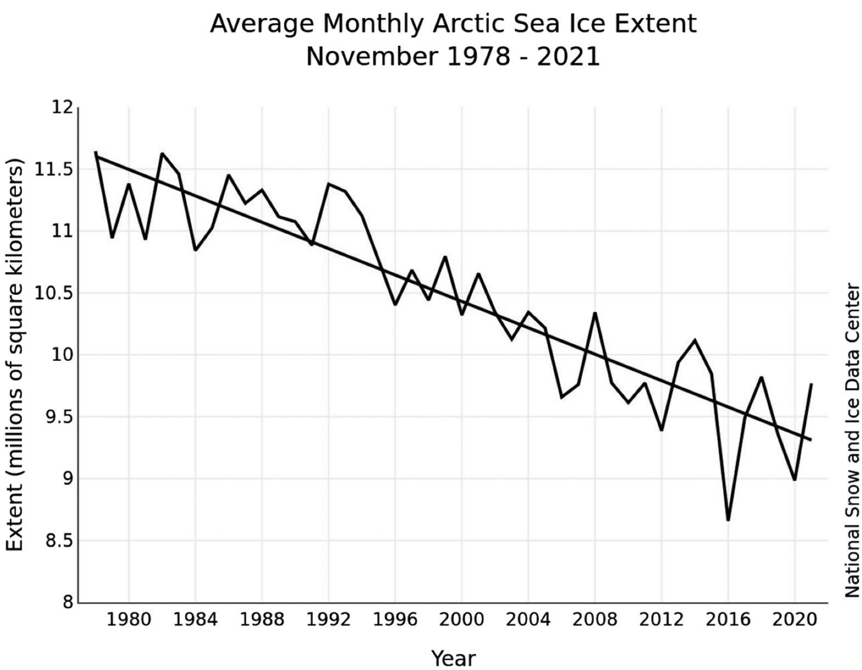

FIGURE 9.2 Monthly July ice extent for 1979–2021 shows a decline of 7.5% per decade.

Credit: National Snow and Ice Data Center.

of melt is gaining over the speed of formation. Scientists predict that Arctic summer sea ice will be completely gone by midcentury, and possibly even by 2035 (Guarino et al. 2020). This is unprecedented in human history, and represents a limit, boundary, or threshold with serious implications. Is it a threshold of no return? Such *critical limits, boundaries, and thresholds* crop up in multiple climatic phenomena. Sea ice also demonstrates a richness of relationships—between and within human and biophysical systems that extend from the local to the planetary. The nature of these relationships is *complex*, in a specific way that I will demonstrate with another story from the Arctic.

Larry Merculieff of the Alaskan Aleut Peoples tells the story (Landis and Fries-Gaither 2009) of a scientist who visited the Native Elders seeking information about moose populations in the region. Instead of answering him directly, the Elders asked him if he knew how many beaver dams were in the area. The scientist was puzzled—he was interested in moose, not beavers. The Elders pointed out that beaver dams affect the foraging areas of the moose. The scientist was looking at the moose in isolation from other species, but the Elders had a more holistic outlook, focused on *relationships*. Systems in which relationships are as important as the parts, so much so that the relationships can change the nature and function of the parts, are generally categorized as complex systems. Unlike simple systems, where causal relations are straightforward and often linear, the relationships in complex systems tend to be nonlinear and involve multiple kinds of causality. Ecosystems, social networks, the human endocrine system, and the global climate system are all examples of complex systems. Thus *complex entanglements* or interconnections abound in human-biophysical systems, including the climate. (Here I distinguish between quantum entanglement and complex entanglement, where the latter refers to connections and relationships at our scale that are a result of inherent relationality). Real-world systems with complex entanglements transcend dichotomies of human/nonhuman or social/ecological. What do beavers have to do with moose populations? How did the Elder know the ice was going to break? These questions are about relationships that recognize complexity in an embodied way. Survival and well-being in various environments require the ability to read the biophysical surroundings through direct bodily immersion, to know it as a participant, from within, through multiple and multispecies *relationships*.

Complex systems are not fully amenable to reductionism. The metaphor for a simple system is a clock: understand the springs and gears, and you've understood the clock. A spring is always a spring, and a gear always a gear. Contrast that with the "parts" of the global climate system, where the oceans, or the Amazon rainforest, can flip from net carbon absorbers to net carbon emitters. Additionally, the subsystems of complex systems are often themselves complex. Complexity in the climate system entails cascading and domino effects that may start out small and local, but that can quickly spread to other regions and even precipitate systemic changes in the whole.

Listening to the sea ice through the stories of the Iñupiat, it becomes clear also that the Iñupiat, despite a complicated relationship with the oil industry, have not contributed significantly to global climate change, and yet are subject to its worst impacts. The thinning ice is dangerous to walk on, making it hard to set up trails and camps for whaling, and increasing the risk of accidents; coastal erosion is worsened by both sea level rise and the lack of protective sea ice; whales are changing their routes in response to warming waters, and while polar bear populations are not yet endangered, they are declining in some areas because the seals are disappearing with the sea ice. Polar bears have been seen in Utqiagvik, apparently looking for food. No matter what the clime, neither the attribution nor the impacts of climate change are evenly distributed. Thus sea ice loss in particular, and climate change in general, are inherently problems of multispecies justice.

The teachings of the sea ice echo the lessons of the climate as a whole. The three meta-concepts of balance/ imbalance, limits, boundaries and thresholds, and complex entanglements can serve as boundary objects. Boundary objects (Star and Griesemer, 1989) are concepts flexible enough to have meaning across different social worlds, yet robust enough to retain their identity; they are useful even when there is a lack of consensus. Later in this chapter, I will show how these meta-concepts travel across the realms of the human/ biophysical, local/ global, scientific/social, and Indigenous/Scientific worlds through the help of another boundary object: the (appropriately chosen and contextualized) story.

An Effective Pedagogy of Climate Change

Like the sea ice, the larger phenomenon of climate change exists over enormous scales of space and time, through complex entanglements between and within human-biophysical systems. It is inherently transdisciplinary, transcending disciplinary boundaries; further, issues of justice and power are central to any serious consideration of climate change. Yet modern globalized industrial culture prioritizes short-term, spatially disconnected thinking, ignores complex interconnections and multiple kinds of causal relations in favor of simple, linear causality, separates disciplines into watertight compartments that rarely interact, and engenders a hierarchical social system that favors those with power and privilege. It is not surprising, then, that the mainstream education system reproduces rather than challenges the status quo. The lack of radical visions for climate education is one of five macro-level roadblocks that have been identified by scholars (Kwauk 2020). Climate change is rarely taught (or for that matter, acted upon) in a manner commensurate with its essential teachings. When it is taught, it is usually in a science class as a narrow scientific-technical subject, emphasizing a view of climate as "an objective reality to be manipulated through material intervention," and implying an "an unambiguous separation between Nature and culture" (Hulme 2008, 12). In a compartmentalized education system, an alternative option is to teach it in every class, through every discipline, by adopting an approach that may start in one disciplinary context, but reaches toward transdisciplinarity, paying attention to complex interconnections across space, time, and species, embracing localness as well as planetary-scale phenomena without privileging the latter, and foregrounding justice.

My only option currently has been to teach climate change in this manner in all my general physics undergraduate classes. This has also required changing classroom power dynamics, coming up with ways to avoid piecemeal learning, and taking inspiration from best practices, all of which are necessary to support an effective pedagogy of climate change. This I describe elsewhere (Singh 2021a) as one that foregrounds the transdisciplinary aspect of the climate problem, entangling the scientific with the social-cultural, so that students can develop a cognitive, affective, and integrated understanding that inspires them to engage in useful ways with the problem. The three transdisciplinary meta-concepts mentioned above provide the scaffolding for the essentials of climate science but also go beyond science to wider concerns. Here I focus on how these meta-concepts serve as boundary objects, and the role of stories in this context.

Across Space, Time, and Discipline: The Meta-Concepts

The sea-ice-mass imbalance currently underway in the Arctic is causally related to planetary-scale imbalances. Carbon dioxide concentration in the atmosphere is rising every year, a consequence of the imbalance in the carbon cycle: carbon dioxide is being put into the atmosphere faster than it is being removed. Through the greenhouse effect, this imbalance has an impact.

Thus we see that **balance and imbalance** manifest across scales, allowing us to connect the local to the planetary, and clime to climate. Depending on the degree and timescale of imbalance, the system at each scale may cross thresholds or limits that commit that system to change in one direction, changes that may not be reversible on human timescales, such as the changes in Arctic sea ice ecosystems, or the melting of the great ice sheets of Greenland and Antarctica. Interestingly, the causal flow in these nested phenomena is not necessarily only from the planetary to the local; as we know from the crucial role of Arctic sea ice, its continued melt means that more of the sun's energy is retained in the Earth system, exacerbating the greenhouse effect through vicious cycles, including, but not limited to the ice-albedo effect (Goosse et al. 2018). Arctic sea ice is considered a tipping element (Wunderling 2021) of the Earth's climate system. Tipping elements are Earth-system components susceptible to tipping points, that is, when they are subject to an external perturbation, they can switch to a qualitatively different state relatively quickly, and since tipping elements interact with each other, when one crosses a tipping point, this may instigate the others to do so as well; when the changes are all in the same direction, this tipping cascade may shift the entire Earth system to a new state, crossing multiple planetary boundaries.

Planetary or Earth-system boundaries are the planetary-scale manifestations of the second meta-concept of **limits, boundaries, and thresholds**; they are set by natural cycles and processes that define stable environmental conditions within which humans and the rest of the biosphere can thrive. Of the nine planetary boundaries proposed by Steffen and others (Steffen et al. 2015), humankind is in violation of five, including climate change and biodiversity loss, which represent, broadly speaking, a shift from conditions of relative balance to imbalance, toward a new and unknown balance. Tipping elements, therefore, connect regional phenomena like Arctic sea-ice loss to the planetary scale. The transition from balance to imbalance and the crossing of limits and boundaries at multiple scales is a result of **complex entanglements** between elements of Earth's biophysical system. At local scales, ecosystems may demonstrate relatively steady states, as well as shifts that are sometimes unidirectional, leading to the collapse of the old ecosystem and the establishment of a new one (for example, the classic case of kelp forests giving way to urchin barrens) because of such complex interconnections. Meanwhile, complex interconnections between tipping elements are only now being identified; for example, the possibility of Amazon rainforest dieback due to Arctic sea ice melt affecting ocean currents. This "domino causality" is one of many kinds of causal relations (apart from simple linear causality) that occur in complex systems (Grotzer 2012, 41).

Thus far I have attempted to demonstrate that the three meta-concepts travel across spatiotemporal scales, and are therefore useful for connecting the local and the global, clime and climate. But do these meta-concepts also travel across social worlds, an essential feature of a boundary object? And what is the role of story?

To explore this, let us return to the story of the Scientist and the Elder, and the question I posed earlier: how did the Elder know that the ice was going to break? The story allows us to explore more deeply the human components of the cryospheric clime of the Alaskan north shore, through the history and onto-epistemology of the Iñupiat. The Iñupiat have lived with the ice for millennia, knowing its seasons, moods, and voices through an immersive, embodied experience in which the body itself becomes a delicate environmental sensor. The sea ice has allowed the Iñupiat to live in one of the harshest environments on the planet by providing fresh food in the form of seals and bowhead whales. This is especially true in the winter, a half-year of semi-darkness, when the north shore is disconnected from the rest of the world by severe weather and killing temperatures, and the only available food is meat. Subsistence hunting is still necessary for survival, despite modernity and capitalism having transformed the lives of the Iñupiat. To hunt the whale, teams cut trails across the sea ice every fall and spring, carrying skin boats and supplies on snowmobiles. The ice allows the teams to get close to where the bowheads swim. The slightest change in conditions, learned through oral transmission of knowledge by Elders as well as immersive experience, warns and directs the hunter. The whale hunt is a sacred ritual, a key part of the identity of the Iñupiat. The animal is thanked for the sacrifice of its life, and the meat is never sold; it can only be shared. The belief is that the whale gives itself to the hunter. The entire community takes part in the hunt, the dragging of the carcass over the ice, and the butchering of the meat. Stored in outdoor ice cellars, the meat can feed multiple families over the long, dark winter.

The Iñupiat think of the sea ice as "home," a place that makes them homesick if they are away from it for too long. It is a place for travel, leading them to where the bowhead whales swim. It is where young people play sports, where the children learn to be Iñupiat. As Elder Nancy Neakok Leavitt says, sea ice is crucial for the very existence of the Iñupiat, allowing a cashless, subsistence way of life, providing their bodies with the kind of food needed to survive in the cold. Other Elders describe the sea ice as being "like a garden" (Gearheard et al. 2013, 63–69, 146). The vast repertoire of sounds that the ice makes, its variety of shapes and types are reflected in the complexity of the language, Iñupiaq. Such a detailed lexicon has survival value, but it also demonstrates how the sea ice has shaped a people, a culture, and a way of knowing.

This relationship with the ice and its creatures, nurtured over millennia, has resulted in a concept that is shared by many Indigenous cultures: "collaborative reciprocity" (Sakakibara 2016, 163), which speaks to the relationships between humans and nonhumans (including the physical landscape). It acknowledges that if an animal provides its body for one's survival, one must give back to the animal in some way. Far more than mere "give and take," this reciprocity is centered on the belief that "humans and animals physically and spiritually constitute each other, that the soul, thoughts, and behaviors of animals and people interpenetrate in a collaboration of life" (Sakakibara 2016, 163, 164). This is consistent with the notion that "we become with and through diverse others, ancestors and contemporaries, human and nonhuman" (Rose and Van Dooren 2017, 122). Perhaps it is in this sense that a whaler, in a video (PBS 2007) about the Iñupiaq whaling tradition, reportedly has the experience of "dying with the whale" when the whale is killed. The whale's gift demands an answering respect that is expressed through the centrality of whaling in Iñupiaq life and culture, from origin stories (the land itself being the body of a whale) to the annual festivities and ceremonies that are set by the whaling cycle.

Collaborative reciprocity implies the notion of **balance** in at least two senses: one, through the equality of human and nonhuman persons, and two, in mutual give and take beyond mere exchange. It acknowledges **limits, boundaries, and thresholds**, through the idea that you take only what you need, and also with regard to sharing, such as in the case of salmon-fishing timeshares between humans and grizzlies in parts of the Yukon (Clark and Slocombe 2009). When a whale is killed, every part of it is used. To waste any part is to disrespect its sacrifice. This notion of limits is consistent with the concept of societal boundaries (Brand et al. 2021) recently proposed by social-science scholars in response to the planetary boundary concept—self-limitations that societies may impose on themselves in order for humans and nonhumans to thrive. All this has material ecological consequences. Environmental history tells us that while some Indigenous cultures have inadvertently caused extinctions of species, their track record is far better than that of modern industrial civilization. Holism is a central aspect of many Indigenous cultures; the emphasis on relationships acknowledges **complex entanglements** between the human and the nonhuman. Thus the three meta-concepts that describe key features of the global climate problem are mirrored in crucial aspects of Indigenous epistemologies, even though their specific meanings are distinct (but recognizably similar) from those in the scientific context.

Stories and Climes

These stories demonstrate the importance of Indigenous paradigms. While we cannot regard Indigenous societies as "pure" cultures hermetically sealed in space and time from the rest of humankind (Smyer Yü 2021), Indigenous societies around the world are historically among the most successful human cultures. They have shaped and been shaped by their climes for millennia, without—for the most part—destroying their environment. Modern industrial civilization has the dubious distinction of threatening the survival of humankind and the biosphere in a mere 200 years or so. Collaborative reciprocity is a common feature of many Indigenous traditions, and it recognizes that the world is a priori complex. Science and modernity are still hampered by the reductionism and atomism of the Newtonian paradigm, which, despite its power, has a limited domain of validity.

In the Arctic, the vanishing of the sea ice also threatens the diminishing importance of Elders' knowledge in Iñupiaq communities. The accumulated knowledge of past generations includes an understanding of biophysical change, but under rapidly changing new conditions, these knowledge systems may not have time to change with the environmental changes. The loss of these knowledge systems, whether due to colonialism or modernity or rapidly changing environmental conditions, is an example of epistemicide (Santos 2014).

This point leads us back to the story of the mouse. This is at one level a teaching story about human hubris and foolishness. But we can also interpret it as a story about paradigms and epistemologies. Our preconceived notions about the world shape our reality. They limit our experiences and imaginations, resulting in what I call *paradigm blindness*. Elsewhere I discuss (Singh 2021b) how the Newtonian paradigm can be seen to undergird modern industrial civilization. We are constrained by this construction of reality, which habituates us to short-term, spatially disconnected, simple linear thinking, and limits our empathic reach and our relationships to a few humans like ourselves. Perhaps we are deluded into feeling larger than we are, rather like the poor mouse in the overturned shoe.

Indigenous cultures use stories to transmit values, traditions, and complex ecological information across generations. Scholars have pointed out the use of stories in strengthening community and building cultural resilience in the face of unprecedented social-environmental change, for example in the Iñupiaq community of Point Hope, Alaska (Sakakibara 2016) and among the Viliui Sakha people in northeastern Siberia (Crate 2008), where Indigenous people are creating new stories in response to these changes. Scholarly work on stories (Dillon and Craig 2022) points to their multiple functions: enabling multiple points of view, creating and consolidating collective identity, and providing a narrative model that enables explanation and understanding, including an anticipatory narrative model to deal with possible futures.

In the classroom as well, stories—whether mythical/ metaphoric, real-life, or fictional—can function in multiple ways. In the context of a pedagogy based on transformational learning theory (Mezirow and Taylor 2009), shared stories that are read, enacted, and interpreted together can help build a sense of community and enable an epistemic shift in the classroom and beyond. By breaking down walls between disciplines, and inviting the whole student to engage, they can facilitate both the cognitive and affective aspects of learning. In their transdisciplinarity, and by revealing the centrality of relationships, stories mirror the teachings of the climate itself. In this chapter, I have shown how three scientific meta-concepts can act as boundary objects across scales and social worlds. Carefully curated stories can also be boundary objects, enabling these meta-concepts to travel between worlds. Stories originating in the human dimension can take us, through these meta-concepts, to the scientific realm, and from the local to the global.

What about stories coming from the opposite direction, that is, from matter, the subject of scientific exploration, to the social worlds of humans? It has been suggested that climate scientists need to become better storytellers, because the language of science does not translate well to the public sphere. Instead, an approach that builds trust, contextualizes the content to the local community, uses the complexity and thick description inherent in a good story, and includes good listening as much as good storytelling has been recommended (Harris 2019). In the classroom as well, attention to student reception of a story is crucially important.

A fine example of a story crossing the boundary from the science side is the notion of storylining (Shepherd and Lloyd 2021), where the power of narrative is invoked to connect local-scale environmental change (for example, a single ecological event) to the bigger picture (statistics-based climate science), thus making causal sense of the local-global connection. A storyline is also a boundary object, because it can inhabit the local and global simultaneously, allowing the navigation of multiple social worlds, with implications for climate action, and law and policy. It can enable a transdisciplinary understanding of climate change (Shepherd and Truong, this book). As a means of storifying science in the classroom, it can also be pedagogically useful. If we allow nonhumans to be agents, then scientific phenomena can be rendered as stories. I have used approaches similar to storylining—storified renderings of causal relations in scientific phenomena, for instance, stories in which the sea ice speaks—in the classroom. I have also used embodied learning, such as the dramatized enactment of physical processes like the greenhouse effect, to help students transcend the subject-object separation in science toward a more "participant-observer" approach to learning.

This allows me to extend the concept of clime, thus: clime is an enactment or a performance in which the actors are human, nonhuman living beings, as well as elements of the local landscape, wind, and weather patterns. Through their multiple mutual relationships, cultural, ecological and geophysical distinctiveness is co-produced, such that a "sense of place" comes into being, what one might call an "ethos of place," to extend the notion of ethos as "what makes a group or kind distinct" (Van Dooren and Rose 2016, 80). Ecological classifications like bioregions (biomes) and ecoregions, generally don't take into account human settlements, cultures, or histories, whereas a clime—which may span ecoregions and fall within bioregions—entangles all of these. Cryospheric climes all share the physical characteristic of high albedo or shininess due to ice and snow, but are made distinct from each other by particularities of place, weather and climatic patterns, and ecosystems and species, including humans. The cryospheric clime of the north shore of Alaska, where the Iñupiat live, is defined by sea ice and tundra, the seasonal migration of the bowhead whale, and the history, customs, politics, and epistemology of the Iñupiat, which make it distinct from, for example, the cryospheric clime of Ladakh in the Himalayas. Because the three meta-concepts manifest in specific ways in particular climes, they help to particularize climes in the context of the climate crisis. Thus sea-ice-mass imbalance in the Alaskan Arctic impacts subsistence hunting and polar bear health (Whiteman, John P. 2018), while glacial melt in the Himalayas results in spring floods and summer drought that affect agricultural productivity. These meta-concepts are therefore useful in describing the current and future projected changes to "ethos of place."

In this chapter, I have described how the acknowledgment of climate as teacher allows for the emergence of a radically transdisciplinary pedagogy that – through varieties of selected stories, help make evident three meta-concepts that serve as boundary objects, traveling between climate and clime as well as between disciplines. Crucially, these stories center considerations of justice, including epistemic justice. The acknowledgment of nonhuman actors, including the elements of weather and climate, leads to an expansion of the concept of clime as an enactment with multiple human and nonhuman actors. Thus the cryospheric clime of the Alaskan North Slope is co-produced through the performances of sea ice, wind and ocean currents, polar bears and bowhead whales, and the history and culture of the Iñupiat, always entangled, always in mutuality.

References

Brand, Ulrich, Barbara Muraca, Éric Pineault, Marlyne Sahakian, Anke Schaffartzik, Andreas Novy, Christoph Streissler, et al. (2021) From planetary to societal boundaries: An argument for collectively defined self-limitation, *Sustainability: Science, Practice and Policy*, 17 (1): 264–291, DOI: 10.1080/15487733.2021.1940754

Bristow, Tom, and Thomas H. Ford. 2016. "Climates of History, Cultures of Climate." In *A Cultural History of Climate Change*, edited by Tom Bristow and Thomas H. Ford. Abingdon: Routledge.

Carey, Mark, Philip Garone, Adrian Howkins, Georgina Endfield, Lawrence Culver, and Sherry Johnson. 2014. "Forum: Climate Change and Environmental History." *Environmental History* 19 (2): 281–364. https://doi.org/10.1093/envhis/emu004.

Chance, Norman A. 2002. *The Iñupiat and Arctic Alaska: An Ethnography of Development*. Mason: Cengage Learning.

Clark, Douglas A., and D. Scott Slocombe. 2009. "Respect for Grizzly Bears: An Aboriginal Approach for Co-Existence and Resilience." *Ecology and Society* 42. Accessed January 2022. URL: http://www.ecologyandsociety.org/vol14/iss1/art42/.

Crate, Susan A. 2008. "Gone the Bull of Winter?: Grappling with the Cultural Implications of and Anthropology's Role(s) in Global Climate Change." *Current Anthropology* 49 (4): 569–595. https://doi.org/10.1086/529543.

Dillon, Sarah, and Claire Craig. 2022. *Storylistening: Narrative Evidence and Public Reasoning*. Abingdon: Routledge.

Eicken, Hajo. 2010. "Indigenous Knowledge and Sea Ice Science: What Can We Learn from Indigenous Ice Users?" In *SIKU: Knowing Our Ice: Documenting Inuit Sea Ice Knowledge and Use*, edited by Shari Fox Gearheard, Lene Kielsen Holm, Henry Huntington, and Andrew R. Mahoney, 357–376. Dordrecht: Springer Netherlands.

Fleming, James R. 2014. "Climate Physicians and Surgeons." *Environmental History* 19: 338–345.

Gearheard, Shari F., Lene K. Holm, Henry P. Huntington, Joe M. Leavitt, Andrew R. Mahoney, Margaret Opie, Toku Oshima, and Joelie Sanguya. 2013. *The Meaning of Ice: People and Sea Ice in Three Arctic Communities*. Hanover, New Hampshire: International Polar Institute Press.

Goosse, Hugues, Jennifer E. Kay, Kyle C. Armour, Alejandro Bodas-Salcedo, Helene Chepfer, David Docquier, Alexandra Jonko, et al. 2018. "Quantifying Climate Feedbacks in Polar Regions." *Nature Communications* 9. https://doi.org/10.1038/s41467-018-04173-0.

Grotzer, Tina. 2012. *Learning Causaility in a Complex World: Understandings of Consequence*. Lanham, MD: Rowman & Littlefield.

Guarino, Maria-Vittoria, Louise C. Sime, David Schröeder, Irene Malmierca-Vallet, Erica Rosenblum, Mark Ringer, Jeff Ridley, et al. 2020. "Sea-Ice-Free Arctic during the Last Interglacial Supports Fast Future Loss." *Nature Climate Change* 10: 928–932. Accessed January 10, 2022. https://doi.org/10.1038/s41558-020-0865-2.

Harris, Dylan M. 2019. "Telling Stories About Climate Change." *The Professional Geographer*. https://doi.org/10.1080/00330124.2019.1686996.

Hulme, Mike. 2008. "The Conquering of Climate: Discourses of Fear and Their Dissolution." *The Geographical Journal* 174: 5–16. https://doi.org/10.1111/j.1475-4959.2008.00266.x.

Krupnik, Igor, Claudio Aporta, and Gita J. Laidler. 2010. "SIKU: International Polar Year Project #166 (An Overview). In *SIKU: Knowing Sea Ice - Documenting Inuit Sea Ice Knowledge and Use*, edited by Igor Krupnik, Claudio Aporta, Shari Gearheard, Gita J. Laidler, and Lene Kielsen Holm, 2. Dordrecht: Springer.

Kwauk, Christina. 2020. *Roadmaps to Quality Education in a Time of Climate Change*. Brookings Institute. Accessed January 10, 2022. https://www.brookings.edu/wp-content/uploads/2020/02/Roadblocks-to-quality-education-in-a-time-of-climate-change-FINAL.pdf.

Landis, Carol, and Jessica Fries-Gaither. 2009. "Fruitful Collaboration: Western Science and Native Ways of Knowing." Beyond Penguins and Polar Bears website. Accessed August 8, 2022. https://beyondpenguins.ehe.osu.edu/issue/peoples-of-the-arctic/fruitful-collaboration-western-science-and-native-ways-of-knowing.

Loeb, Norman, Gregory C. Johnson, Tyler J. Thorsen, John M. Lyman, Fred G. Rose, and Seiji Kato. 2021. "Satellite and Ocean Data Reveal Marked Increase in Earth's Heating Rate." *Geophysical Research Letters* 48. https://doi.org/10.1029/2021GL093047.

Mezirow, Jack, and Edward W. Taylor, ed. 2009. *Tranformative Learning in Practice: Insights from Community, Workplace, and Higher Education*. Hoboken: Wiley.

NASA. 2018. Disappearing Arctic Sea Ice. March 15. Accessed September 15, 2021. https://www.youtube.com/watch?v=hlVXOC6a3ME.

PBS. 2007. "Iñupiaq Whale Hunt." PBS Learning Media Website. Accessed August 28. 2022. https://mass.pbslearningmedia.org/resource/echo07.sci.life.coast.eskimo/Iñupiaq-whale-hunt/.

Rantanen, Mika, Alexey Yu Karpechko, Antti Lipponen, Kalle Nordling, Otto Hyvärinen, Kimmo Ruosteenoja, Timo Vihma, and Ari Laaksonen. 2022. "The Arctic has warmed nearly four times faster than the globe since 1979." *Commun Earth Environ* 3 (1): 168. https://doi.org/10.1038/s43247-022-00498-3.

Rose, Deborah Bird, and Thom Van Dooren. 2017. "Encountering a More-Than-Human World: Ethos and the Arts of Witness." In *The Routledge Companion to the Environmental Humanities*, edited by U. Heise, J. Christensen and M. Niemann. London: Routledge. https://doi.org/10.4324/9781315766355.

Sakakibara, Chie. 2016. "People of the Whales: Climate Change and Cultural Resilience Among Iñupiat of Arctic Alaska." *Geographical Review*, 107: 159–184.

Santos, Boaventura de Sousa. 2014. *Epistemologies of the South: Justice Against Epistemicide.* Abingdon: Routledge.

Shepherd, Theodore G., and Elisabeth A. Lloyd. 2021. "Meaningful Climate Science." *Climatic Change* 169: 17. https://doi.org/10.1007/s10584-021-03246-2.

Singh, Vandana. 2021a. "Toward a Transdisciplinary, Justice Centered Pedagogy of Climate Change." In *Curriculum and Learning for Climate Action: Toward an SDG 4.7 Pathway for Systemic Change*, edited by Christina Kwauk and Radhika Iyengar, 169–187. UNESCO-IBE.

Singh, Vandana. 2021b. "Toward an Effective Pedagogy of Climate Change: Lessons from a Physics Classroom." Preprint. https://arxiv.org/abs/2008.00281.

Smyer Yü, Dan. 2021. "Symbiotic Indigeneity and Commoning in the Anthropogenic Himalayas." In *Environmental Humanities in the New Himalayas: Symbiotic Indigeneity, Commoning, Sustainability*, edited by Dan Smyer Yü and Erik de Maaker, 239–260. Abingdon: Routledge.

Sörlin, Sverker. 2015. "Cryo-History: Narratives of Ice and the Emerging Arctic Humanities." In *The New Arctic*, edited by Joan Nymand Larsen, Birgitta Evengård, and Øyvind Paasche, 327–339. New York: Springer.

Star, Susan Leigh, and James R. Griesemer. 1989. "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907–1939." *Social Studies of Science* 19 (3): 387–420. https://doi.org/10.1177/030631289019003001.

Steffen, Will, Katherine Richardson, Johan Rockström, Sarah E. Cornell, Ingo Fetzer, Elena M. Bennett, Reinette Biggs, et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347 (6223). https://doi.org/10.1126/science.1259855.

Van Dooren, Thom, and Deborah Bird Rose. 2016. "Lively Ethography: Storying Animist Worlds." *Environmental Humanities* 8 (1): 77–94.

Whiteman, John P. 2018. "Out of Balance in the Arctic." *Science* 359: 514, 515.

Wunderling, Nico, Jonathan F. Donges, Jürgen Kurths, and Ricarda Winkelmann. 2021. "Interacting Tipping Elements Increase Risk of Climate Domino Effects under Global Warming." *Earth System Dynamics* 12 (2): 601–619.