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ARTICLE

Mainstreaming the Full ENSO: Linking Present Weather and Future Climate

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Abstract In this article we propose that all countries that are striving to become a Weather-Ready Nation (WRN) would benefit greatly from including El Niño-Southern Oscillation (ENSO)-related research findings into their decision-making processes, not only when an El Niño or a La Niña forecast has been issued quasi-periodically. For an aspiring WRN, to benefit from ENSO information, such as disruptive or beneficial changes that could be foreseeably expected to occur in seasonal flow and in sub-seasonal hydrometeorological anomalies, requires its continuous mainstreaming about the status of the ENSO process into a WRN's decision-making activities. The ENSO process provides a bridge between sub-seasonal weather anomalies and a sub-decadal climate phenomenon as well as a bridge between coping with weather extremes today and preparing for climate change-related hydrometeorological hazards in the future. ENSO extremes every few years provide a chance to evaluate a nation's strategic and tactical responses to hydrometeorological hazard forecasts and disasters. Each successive ENSO extreme and its Neutral phase tests previously designed best practices. Involvement of today's youth and young professionals on climate, water, and weather issues has been increasing and will do so in coming decades. Shifting awareness and attention to ENSO and away from ENSO extremes is crucial. The heightened urgency for understanding the full ENSO "cycle" especially by youth and young professionals today is because they will soon be in professional positions that enable them to advise decision makers about climate policy issues. Their understanding of the ENSO cycle is critically needed, as global warming is expected to continue to increase for the rest of the twenty-first century.

Keywords ENSO · WRN · Hydromet · Climate change · Young professionals

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1 Introduction

This article acknowledges a new urgency to understand the influences that the full El Niño-Southern Oscillation (ENSO) cycle—not just its well-known extremes (El Niño and La Niña)—has on the characteristics and behavior of the "normal" flow of the seasons and on a country's seasonal climate. As many countries strive to become Weather-Ready Nations (WRNs), their efforts could benefit from the continuous monitoring of the flow of information from physical and social science research about the ENSO phenomenon (for example, mainstreaming ENSO). By becoming El Nino ready nations (ENRNs) as well, their societies would be provided with the earliest "heads up" about seasonal climate anomalies (and disruptions) for which they might have to prepare.

The involvement as well as the influence of today's youth and young professionals on climate, water, and weather issues has been steadily increasing and will continue to do so for the coming decades. A United Nations (n.d.) statement on "youth in action" reported that:

> Young people's unprecedented mobilization around the world shows the massive power they possess to hold decision-makers accountable. Their message is clear: the older generation has failed, and it is the

> young who will pay in full—with their very futures. Young people are not only victims of climate change. They are also valuable contributors to climate action. They are agents of change, entrepreneurs and innovators. Whether through education, science or technology, young people are scaling up their efforts and using their skills to accelerate climate action.

The heightened urgency for understanding the full ENSO "cycle" especially by youth and young professionals today is because they will soon be in professional positions that enable them to advise decision makers about climate policy issues. Their understanding of the full ENSO cycle is needed now more than ever, as global warming of atmosphere and oceans is expected to continue to increase for the rest of the twenty-first century (NASA 2022). They, along with today's policymakers, must be made aware of an emerging scientific debate that has been brewing about what the global climate regime might be like by the end of the century: will global climate be more like that witnessed during El Niño episodes or that witnessed during La Niña events? The scientific research jury on this issue is still out, speculation notwithstanding. Regardless, the next generation of leaders and advisers must be aware of the implications of either possible climate future.

Because ENSO's extremes recur irregularly (within a 2-to-7-year time frame) (NWS 1998), each event's consequences should trigger a review of societal plans every few years or so for hydrometeorological disaster risk reduction (DRR) and for disaster response and recovery. In this regard, ENRN should be understood as a forward-looking notion in the sense that it provides a glimpse (a snapshot in time) and a time-stamped indicator of a society's readiness capability to respond to or cope with foreseeable (though not yet assured) global warming's impacts on a full ENSO cycle (its El Niño, La Niña, and Neutral phases), its effects on seasonality, and the disruption of seasonal climate. Societies live by the flow of the seasons that, over time, successive generations have come to consider as normal. As changes in a country's seasonality become noticeable, they are sure to elevate concerns about food insecurity, water resource availability, energy needs and wants, new disease-borne vector outbreaks, and infestation of invasive agricultural pests. As an example, for climate change and food insecurity in the United States "the effects on seasons of a changing climate are already being seen across the country and vary region to region: temperatures have risen across seasons, growing seasons have become longer, precipitation patterns have changed, and extreme precipitation events have increased in frequency and severity. Because of the sensitivity of agriculture to weather and climate conditions, these impacts can have substantial direct and indirect effects [on] production and profitability" (USDA 2013); for a seasonality and health example, see Ramirez and Lee (2022). The time to act on what was once thought an unimaginable future is now.

2 Introduction to ENSO

Atmospheric scientists have written that the natural flow of the seasons is a major contributor to variability in the global climate regime. The full ENSO cycle is another major contributor to climate variability. As McPhaden et al. (2006, p. 1742) noted: "Except for the regular progression of the seasons, ENSO is the most predictable climate fluctuation on the planet." Other scientists have observed that ENSO is also the second most "disruptive" influence on global and regional climates. Specifically, ENSO's warm and cold extremes are major disruptors of the expected natural flow of the seasons.

ENSO is a perennial quasi-periodic cycle of air-sea interactions across the tropical Pacific. The United States monitors the Niño 3.4 region in the ocean for clues of the developing onset of an El Niño (Fig. 1). Other countries consider sea surface temperature (SST) changes in the other Niño regions, based on the statistical correlations that they consider more relevant to their specific geographic locations.

NOAA's Climate Prediction Center website (NOAA/CPC 2021) uses the 3-month running mean to develop the Oceanic Niño Index (ONI) as one way to measure and monitor SST variations in the Niño 3.4 region of the central tropical Pacific. El Niño, ENSO's warm SST extreme, has been defined as follows:

> An El Niño state occurs when the central and eastern equatorial Pacific sea-surface temperatures (SSTs) are substantially higher than usual. The National Oceanic and Atmospheric Administration (NOAA) defines an El Niño event when the Niño 3.4 area has sea-surface temperatures at least 0.5°C higher than normal for five consecutive three-month-averaged periods.

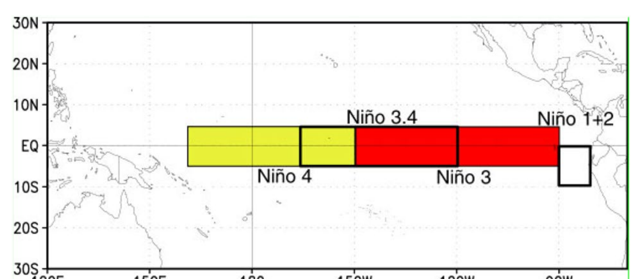

Fig. 1 The five regions across the equatorial Pacific. *Source* CPC (2005).

3 La Niña, ENSO's Cold Sea Surface Temperature Extreme

Over the past few decades, El Niño captured the lion's share of attention of researchers, policymakers, funding agencies, and perhaps most importantly the media about ENSO. However, La Niña is now receiving more attention, because it is accompanied by its own set of anomalous seasonal precipitation and temperature patterns with associated costly societal and environmental consequences. In the United States, for example, La Niña has become more interesting, because it influences the Atlantic's hurricane season. As Fig. 2 shows, during a typical El Niño episode fewer than average Atlantic hurricanes form, whereas during a typical La Niña, an above average number of hurricanes in the region are to be expected.

During a La Niña, an above average number of hurricanes form that make landfall along the coasts of the Atlantic and Gulf of Mexico and in the Caribbean. The 2020 La Niña was exceptional to this general rule. That year, an unprecedented number of tropical cyclones (that is, named tropical storms and hurricanes) that formed forced the US Weather Service for the first time ever to resort to numerous backup letters of the Greek alphabet to name all of the events (Fig. 3). All

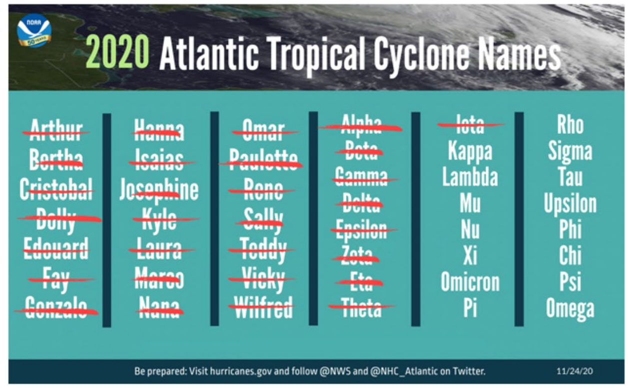

Fig. 3 The list is of 30 named storms that occurred during the 2020 Atlantic hurricane season as of 24 November 2020. The season officially ended on 30 November. The 2020 season surpassed 2005 as the busiest one on record. *Source* NOAA (2020).

21 names that had been designated for events that year had already been used by mid-September, nearly two and a half months before the end of the hurricane season.

It appears that La Niña events are becoming stronger, wetter, more destructive and may become more frequent. Some researchers (for example, Changnon 2000) have argued that

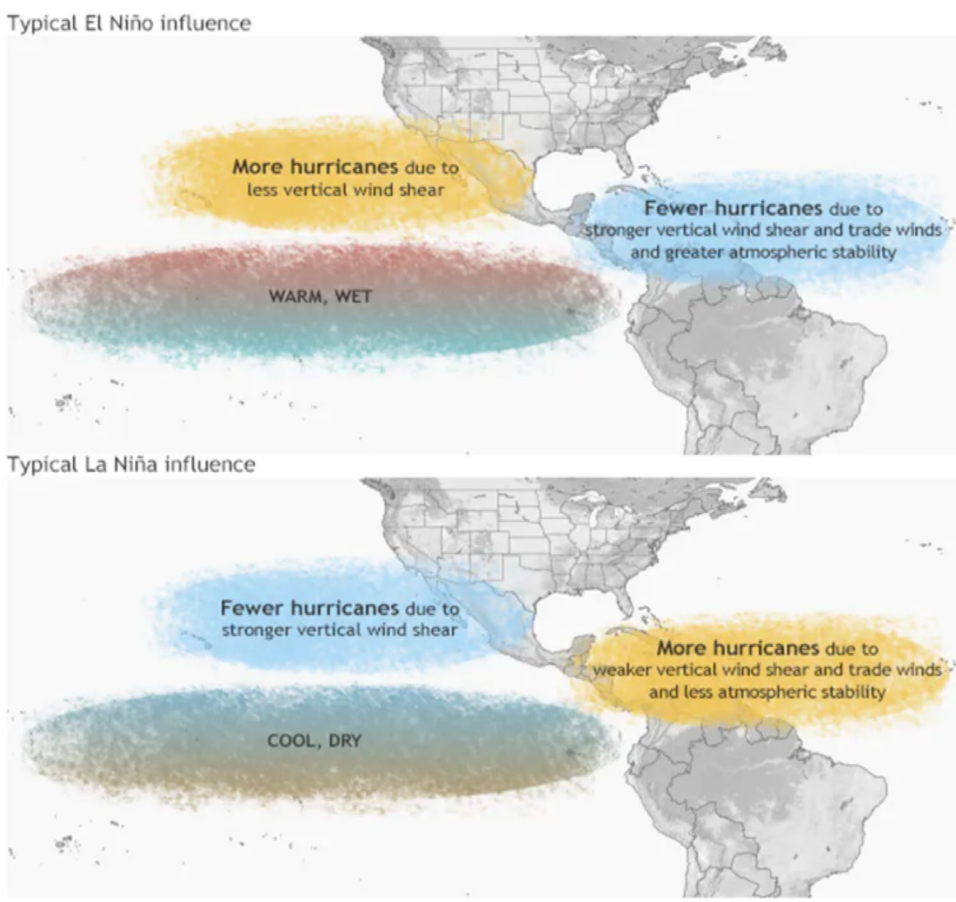

Fig. 2 During an El Niño episode fewer than average Atlantic hurricanes form, whereas during La Niña more than average form in the region. For additional examples see Encyclopedia Britannica, Inc. (1996). *Source* NOAA Climate.gov (2014)

over time the cumulative costs of the socioeconomic impacts of La Niña events already outweigh the cumulative costs associated with those of El Niño events. More recently, Bowen (2016) reported:

> When breaking down historical weather catastrophe loss data from Aon Benfield's database, a distinct trend is recognized. La Niña years have clearly shown greater average annual losses on both an economic and insured basis in comparison to El Niño and Neutral phases. The results indicate that there is a 42 percent difference in annual economic losses alone between La Niña ($77 billion) and El Niño ($45 billion) years when using inflation-adjusted dollar values.

4 Seasonality, or Seasonal Climatology

While ENSO is a continually recurring, inter-annual 3-phase process, El Niño manifests as a sub-decadal, quasi-periodic cycle. As one of ENSO's extremes, an El Niño event generally starts in the summer of one year (Year 0) and ends 9−12 months later, by late spring of the following year (Year +1). Because this does not follow the annual calendar year (Fig. 4), we refer to an El Niño year as an "El Niño non-calendar year," which occurs from July to the following June.

El Niño creates its own seasonal climate, which is notably a different non-calendar year seasonal climate and quite different from the Köppens-Geiger calendar-year climate classification (Naranjo et al. 2018). An El Niño year comes with its own temperature and precipitation patterns and

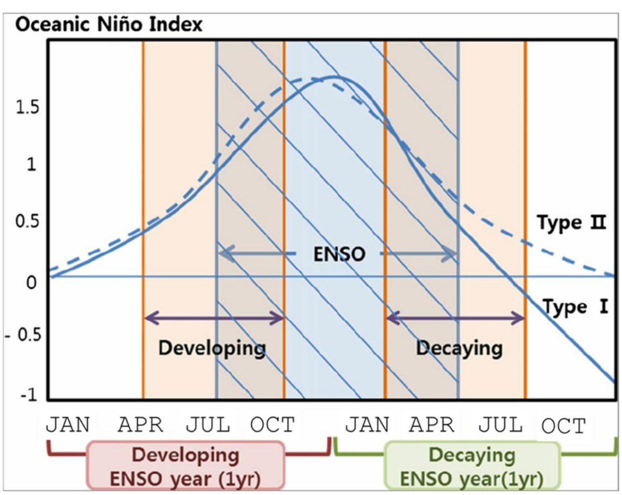

Fig. 4 Schematic diagram of the Oceanic Niño Index for developing El Niño conditions, decaying El Niño conditions, and Type I and Type II years. Type I case of the decaying El Niño is one where El Niño shifts to La Niña. Type II El Niño returns to neutral condition as it decays. *Source* Modified from Jang and Ha (2008).

socioeconomic and ecological impacts that depart from expected ("normal") seasonal climate. Figure 5 shows what are generally considered primary El Niño hotspots, though other regions are directly or indirectly affected.

The socioeconomic impacts of El Niños vary from event to event and country to country. From a financial perspective, Kenton (2019) distinguishes between seasonality and seasonal effects in the following way:

> Seasonality is a characteristic of a time series in which the data experiences regular and predictable changes that recur every calendar year. Any predictable fluctuation or pattern that recurs or repeats over a one-year period is said to be seasonal.
> Seasonal effects are different from cyclical effects, as seasonal cycles are observed within one calendar year, while cyclical effects can span time periods shorter or longer than one calendar year.

What Kenton's useful definitions imply is that when it comes to disaster preparedness and risk reduction, benefits are to be had by governments that have strategically planned in consideration of seasonal climate anomalies and their different effects during each of ENSO's three distinct phases. A forecast of El Niño, for example, is likely to provide an attentive government one of the earliest possible warnings of expected disruptions to be caused by shifts in seasonal climate regimes.

In this regard, three intervening variables deserve specific mention because they can impact favorably or unfavorably the temporal pattern of an El Niño's formation, development, and decay and so its subsequent ecological and societal impacts. These intervening variables are other atmospheric and oceanic oscillations, climate change, and surprises.

4.1 Oscillations

El Niño's characteristics and behavior as well as the severity and location of its impacts near and far are influenced to varying degrees by various other atmospheric and oceanic oscillations (Fig. 6). Since Bjerknes (1969) first identified ENSO's warm extreme as a basin-wide phenomenon with global consequences, further research has shown that the various oscillations adjacent to the oceanic processes that lead to an El Niño also need to be considered when forecasting for and issuing early warnings about a developing event.

One example of an adjacent oscillation known to affect El Niño's impacts is the Indian Ocean Dipole (IOD). First identified only 20 years ago, the IOD is formed by an east-west shifting of pools of warm and cool surface sea water. Its movement is graphically depicted in Fig. 7. The IOD's importance as a variable affecting the formation, development, and impacts of an El Niño event in the Indian Ocean region is captured by Johnson (2021) in his wittily titled blog

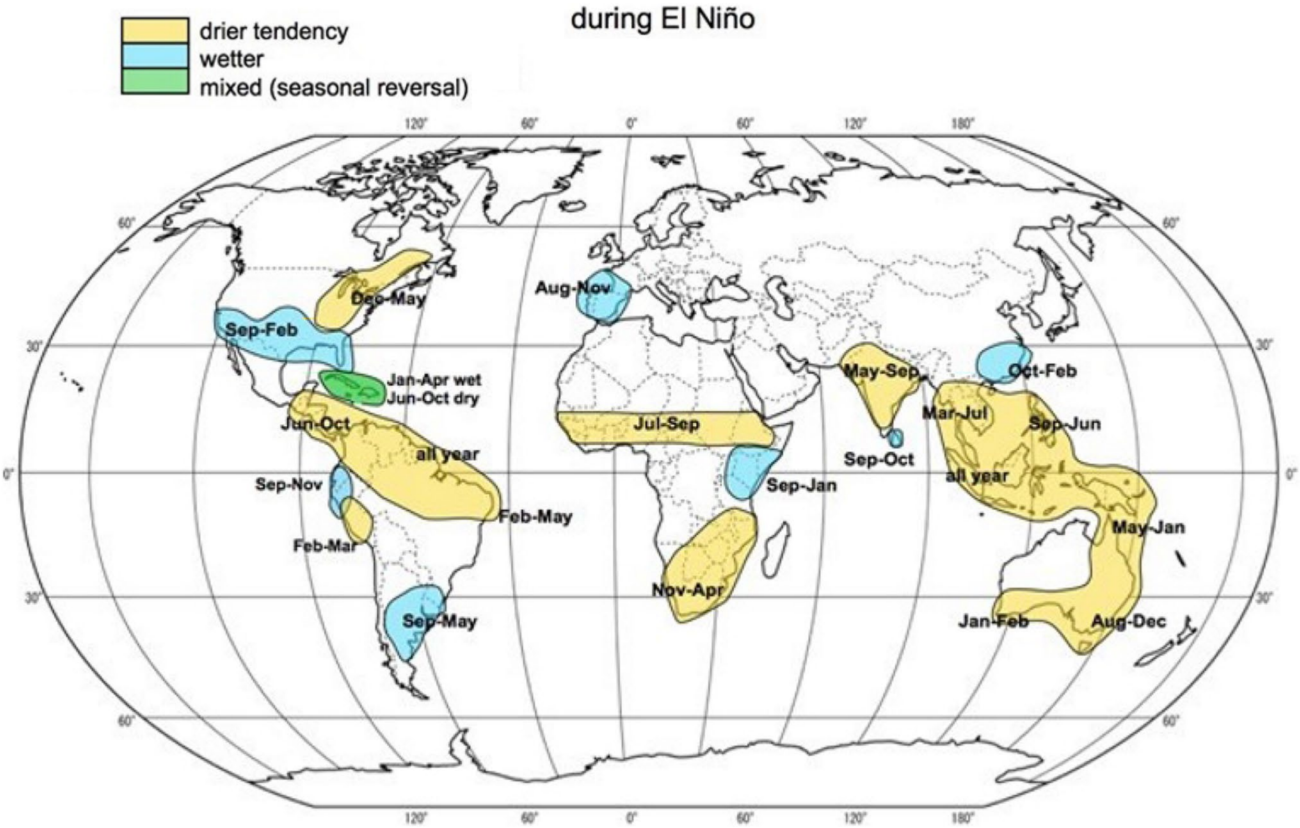

Fig. 5 This map identifies El Niño "hotspots" as well as the months (seasons) during which El Niño's influence on societies and managed and unmanaged ecosystems are likely to be affected. *Source* UK Met Office (2019).

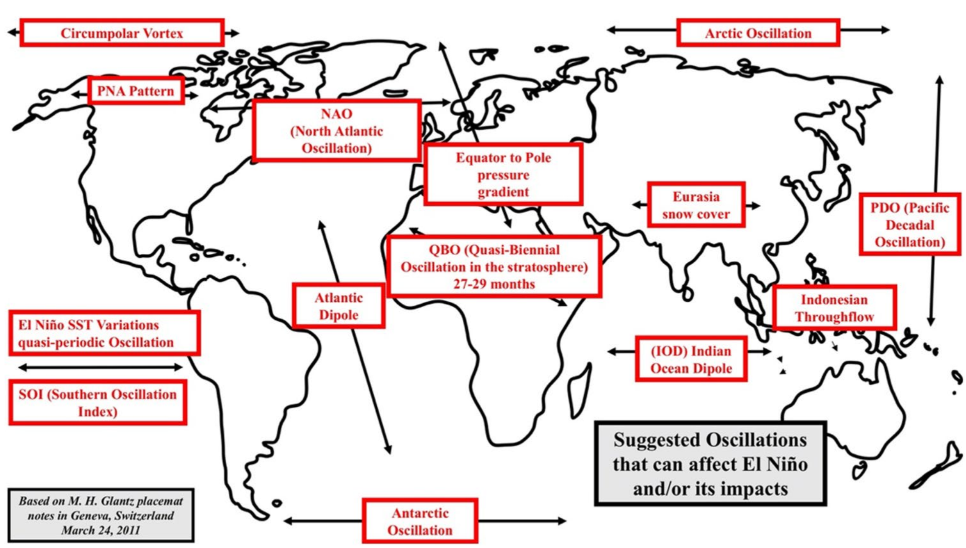

Fig. 6 Oscillations that can affect the societal and ecological impacts of ENSO's extremes. *Source* Ross (2021).

post: "Meet ENSO's neighbor, the Indian Ocean Dipole." As Feba et al. (2021) noted, the IOD "is an inter-annual coupled ocean-atmosphere phenomenon in the tropical Indian Ocean that peaks during the boreal fall season (September to November; SON). Positive IODs are associated with anomalously warmer western Indian Ocean and anomalously cooler eastern Indian Ocean. Negative IOD events are associated with opposite anomalous sea surface temperatures (SSTs) across the Indian Ocean."

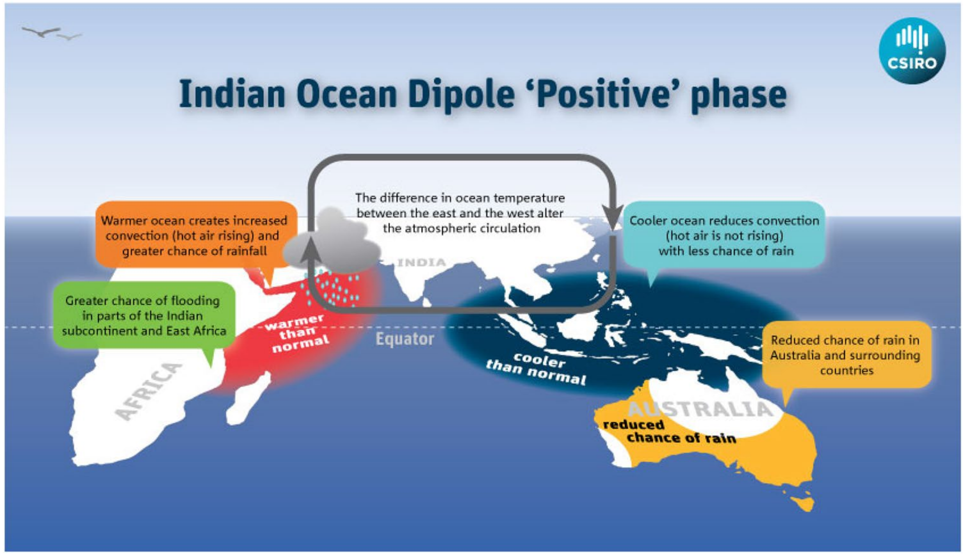

Fig. 7 Positive Indian Ocean Dipole (IOD) event. *Source* CSIRO (2013).

Another example is the Pacific Decadal Oscillation (PDO), although its influence on the ENSO cycle has remained only speculative since its discovery in the mid-1990s (Mantua et al. 1997; Di Liberto 2016). Located in the northern Pacific Ocean, PDO has a return period for a north-south shift between warm and cold surface water on the order of two decades. Tracking new research on PDO specifically regarding its influences on the ENSO cycle and especially regarding its impact on the hazards ENSO tends to generate will be important as the global climate continue to change.

4.2 Climate Change

The global climate began slowly heating as an unintended consequence of industrialization in northern Europe in the mid-1700s; in recent decades, this heating has only accelerated as modernizing economies like China and India began to rapidly industrialize. Decades worth of evidence clearly show that this rapid warming of the atmosphere and oceans is directly attributable to such human-caused increases in greenhouse gas emissions. Today's policymakers are now on a steep learning curve about what to expect from and how to respond to an uncertain climate future, even as researchers grow increasingly certain that specific extreme climate, water, and weather events are direct outcomes of atmospheric warming (IPCC 2012, 2021).

No scientific consensus exists at present about how continued atmospheric warming will influence ENSO's extreme phases (Lian et al. 2018). Different modeling exercises have led to dramatically different predictions. Kohyama et al. (2017) proposed that future global climate regimes will be more like those observed during current El Niño events, while Kohyama (2017) independently hypothesized that future global climates will be more La Niña-like. Even as the climate science community seeks greater certitude in the coming years, this major research "debate" must be brought to the attention of policymakers today and especially to the attention of youth and young professionals who will soon become tomorrow's advisers and eventual policymakers. They will especially have to strategize ways to cope with global issues of warming over the next several generations.

4.3 Surprises

There are two types of climate surprises: Type A surprises are associated with the occurrence of an event, while Type B surprises have to do with the impacts resulting from such events. These general types can be further subdivided. Problems arise because we do not know the precise timing, location, intensity, or magnitude of type A climate surprises. Type B surprises arise from how people deal with hydrometeorological information (probabilities, forecasts of rare events, historical disaster records, and the variable climate system). With type B surprises, individual perceptions of reality play a significant role in whether an event is viewed as surprising and unprecedented or not. Myers (1995) called recurrent Type A climate surprises "anticipatable." By looking at analogous historical events, many of the societal impacts resulting from Type A climate surprises should also have been "foreseeable" (Glantz et al. 1998).

Valuable to keep in mind here is that the calculus of surprise can also change over time, sometimes in unanticipated or even surprising ways. In this regard, Myers (1995, p. 1) writes that:

> It might seem fruitless to speculate about seemingly unknown problems in the environmental field. But

> recall that at the time of the first major international conference on the [human] environment in Stockholm in 1972, there was next to no mention of what have now become established as front-rank problems: global warming, acid rain, and tropical deforestation.

As with societal responses to human-induced global warming, surprising changes should be expected of the ENSO phenomenon and within its 3-phase cycle. Especially in the last decade, for example, unanticipated El Niño-related surprises have been observed. Such examples include the destructive out-of-season 2017 appearance of a "Niño Costero" off the Peruvian coast (Ramirez and Briones 2017) and the still-mysterious unusually warm water pool, referred to as the "BLOB," that formed in the northeastern Pacific in 2014 and did not disperse for two years (Gaworecki 2019). Reflective of the surprising nature of the latter anomaly, Mass (2016) notes: "In early 2014, the BLOB was terrifying in its strength, with sea surface temperatures (SST) more than 2C (about 4F) above normal" (Fig. 8).

The increasing warming of the global atmosphere is slowly affecting ENSO and adversely affecting the "normal" seasonality that communities around the globe have come to expect and rely on. Societies must make decisions in the face of climate changes that have created a different "new normal," one that has not yet been witnessed by living generations. In this regard, youth and young professionals may have a decision-making advantage over older generations whose responses to new surprises will likely be bound to, and so constrained by, the social, cultural, and hydrometeorological norms they are used to that are no longer as effective.

It is easy to theorize about ways to enhance societal awareness about all aspects of the full ENSO cycle. Effectively applying such theory would make DRR planning at all levels of government more effective for coping with changes in seasonal hydrometeorological variability. In practice, however, it is not so easy to carry out such theoretical enhancements. For one reason the return period for El Niño is between two to seven years is beyond the attention span of a large segment of the public and of most governments (Downs 1972; Gupta and Jenkins-Smith 2015). Also, once any forecaster suggests to the media that an El Niño event has peaked, interest in it rapidly dissipates and it disappears from media headlines for some years until the next El Niño forecast has been issued—"Out of sight, out of mind."

5 Readiness

Though readiness and preparedness are often used interchangeably, they are not synonymous. Readiness suggests shorter-term tactical responses with less lead time, while preparedness implies longer-term strategic responses with more lead time for planning in the face of an impending hydrometeorological threat.

Like so, the comment appended to the United Nations International Strategy for Disaster Reduction (UNISDR) definition of "preparedness" refers to "readiness" only as an afterthought in the final sentence of the paragraph. The comment states:

> Preparedness action is carried out within the context of disaster risk management and aims to build the capaci-

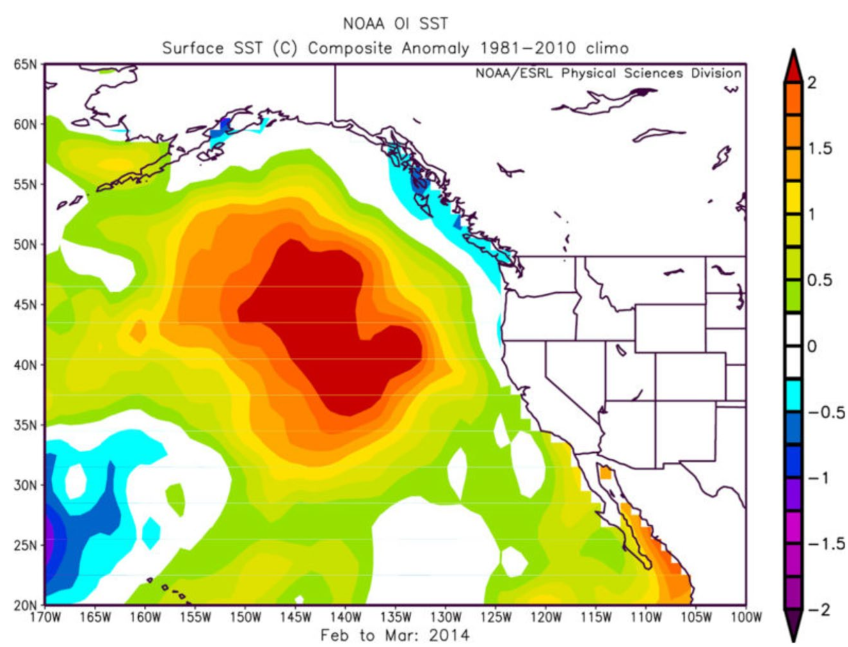

Fig. 8 Sea surface temperature (SST) anomalies' differences from normal for February to March 2014. *Source* Mass (2016).

> ties needed to efficiently manage all types of emergencies and achieve orderly transitions from response to sustained recovery […]. The related term “readiness” describes the ability to quickly and appropriately respond when required. (UNISDR 2009)

Perceptions about what it means for a particular society to be hazard-ready are influenced by past and current trends about the hazard(s) of concern as well as by relevant socio-economic factors, cultural elements, secular and religious beliefs, political structure, and so on. These variables differ from one country or culture to another. Because there is no universally accepted definition of readiness, different regions, countries, and communities have the responsibility to determine its own desired acceptable or achievable level of readiness. Furthermore, a country’s level of readiness is typically known to vary from one year or decade to the next. These temporal variations tend to fall on what might be called a Spectrum of Readiness, a typology that can describe specific country’s or community’s respective levels of readiness. In other words, there are shades of readiness: not at all ready, partly ready, almost ready, somewhat ready, hardly ready, and fully ready.

6 The Meaning of El Niño Readiness

Considered in its entirety, a full ENSO cycle can be described as an inter-annual, continuously shifting, quasi-periodic, multi-year-long recurring phenomenon. ENSO’s warm El Niño extreme phase is a sub-decadal phenomenon that usually overlaps two calendar years, July to June. El Niño Ready Nations (ENRNs) is a multi-national, multi-disciplinary initiative proposed to raise the awareness of individual governments, respective national meteorological and hydrological services (NMHS), and the public at large about the importance of El Niño readiness. While climate, water, and weather anomalies that are spawned by El Niño cannot be prevented, their impacts are in many cases foreseeable and can, therefore, be warned about, prepared for, and mitigated through strategic and tactical best practices.

Although the core of the ENRN initiative is El Niño, the overarching goal is to develop fully ENSO-ready nations, meaning that to be considered truly El Niño Ready a government must take the entirety of the ENSO cycle seriously as a recurring national threat that must be planned and continually monitored in order to protect at-risk citizens, livelihoods, and properties. Policies for each ENSO phase—El Niño, La Niña, and Neutral—must be implemented and regularly updated, and each respective country’s NMHS must be tactically if not also strategically prepared to effectively broadcast usable information about foreseeable El Niño impacts and potential surprises. Becoming an ENRN will enable decision makers to:

Alert different foreseeably affected populations about the potential of teleconnected hydrometeorological threats;
Encourage forethought about being ready strategically as well as tactically;
Identify El Niño (and La Niña) as a non-calendar year anomaly;
Provide adequate lead time to prepare for disruptions in seasonal expectations; and
Focus on early warnings of related climate, water, and weather hazards and their likely socioeconomic effects.

Preparedness for and response to El Niño impacts are linked to disaster risk reduction (DRR), climate change adaptation (CCA), and sustainable development (SD). While DRR, in general, focuses on current to mid-term circumstances, CCA and sustainable development focus on a period from mid-term circumstances to the relatively distant future. El Niño can thus serve as a steppingstone to DRR while also providing a bridge between DRR and sustainable development goals.

7 Striving to Be Fully Ready: Linking ENSO Readiness and Weather Readiness

> NOAA’s Weather-Ready Nation (WRN) initiative is about helping our nation become more resilient to increasing extreme weather, water, and climate events. NOAA is working to keep these threats from becoming disasters with greater accuracy in forecasts and warnings, evolving services to community decision makers, and better ways to communicate risk to stakeholders and the public. (STCOEMA 2021)

This laudatory statement is valid for other countries as well. Through WRN, NOAA has not only provided timely weather, water, and climate information in the form of forecasts and early warnings but has also fostered public awareness about seasonal and sub-seasonal hydrometeorological conditions at local and community levels. As the WRN website states:

> NOAA’s Weather-Ready Nation is about readying your community for extreme weather, water, and climate events […]. The devastating impacts of extreme events like record breaking snowfall, violent tornadoes, destructive hurricanes, widespread flooding, and devastating drought can be reduced by taking advanced action, which is why the Weather-Ready Nation initiative is so important. (NOAA/WRN n.d.)

The original goals specific to the US WRN include: Goal 1: Improve weather decision services for events that threaten lives and livelihoods; Goal 2: Deliver a broad suite of improved water forecasting services to support management of the nation's water supply; Goal 3: Enhance climate services to help communities, businesses, and governments understand and adapt to climate-related risks; Goal 4: Improve sector-relevant information in support of economic productivity; Goal 5: Enable integrated environmental forecast services supporting healthy communities and ecosystems; Goal 6: Sustain a highly-skilled, professional workforce equipped with the training, tools, and infrastructure to meet our mission (NOAA 2011).

In line with these goals, WRN tends to highlight El Niño only every few years or so, when a forecast of an event's likely onset has been issued. We contend, however, that "mainstreaming ENSO" information continuously—at the seasonal, or even monthly—level would be more beneficial to the WRN "ecosystem" as a whole. Awareness of the constant influence of the full ENSO phenomenon—not only of the anomalous impacts of its extremes on a country's expected seasonal climate but of its Neutral phase—would be a valuable addition to the existing US WRN program. It would plug the mid-level gap in monitoring and so help achieve the primary WRN goal of educating and encouraging communities to better understand, prepare for, and respond to official forecasts of high-impact weather, water, and climate anomalies.

8 Striving to Become an International Weather-Ready Nation (WRNi)

The primary responsibility of the US National Weather Service (NWS) and of NMHSs worldwide is to serve their respective national interests. A few years after establishing the US WRN program in 2011, the International Affairs Office of NOAA's National Weather Service formally embarked on developing an international dimension of its WRN program. In 2014 the NWS Director mentioned the value of such an international program of the US WRN, which here we refer to as WRN International or WRNi) (Uccellini 2015).

For its part, the US NWS has a tradition of sharing equipment, expertise, research findings, and operational experience with the World Meteorological Organization (WMO) and its many NMHS members. By partnering with the United States Agency for International Development (USAID) and the WMO, the US worked over the last few years to develop weather-ready nation activities in other countries (NOAA/NWS 2019). The WRN website provides a relevant overview:

> The International Weather-Ready Nations (WRNs) program focuses on strengthening capacity at in-country National Meteorological and Hydrological Services (NMHSs) and National Disaster Management Agencies (NDMAs). Specifically, the goal is to aid in improved use of weather and climate information to save lives, reduce human suffering and lessen economic impacts of hydrometeorological hazards. Many countries are moving towards an Impact-based Forecast and Warning Services approach that translates meteorological and hydrological hazards into sector- and location-specific impacts and the development of responses to mitigate those impacts. (NOAA/NWS 2019)

The World Meteorological Congress (WMO 2015) also actively supported the WRNi initiative. As a first step, the US NWS support for WRNi focused on modeling and forecasting quick-onset flash flood events using a Flash Flood Guidance System. It also made strides in providing help with modeling and forecasting heat waves. As the WRN site notes:

> Specifically, the goal is to aid in improved use of weather and climate information to save lives, reduce human suffering and lessen economic impacts of hydrometeorological hazards. Many countries are moving towards an Impact-based Forecast and Warning Services approach that translates meteorological and hydrological hazards into sector- and location-specific impacts and the development of responses to mitigate those impacts. Recognizing the transformative role of impact-based forecasting in disaster risk reduction, the NMHSs and NDMAs of Barbados, South Africa, El Salvador, Costa Rica, Guatemala, and Indonesia are currently in the process of implementing a Weather-Ready Nations (WRNs) approach to building weather, water and climate-resilient countries. (NOAA/NWS 2019)

Recently, discussions about becoming a Weather-Ready Nation have been initiated with Fiji, the Bahamas, and Jamaica (S. Tokar, USAID, personal communication, 17 November 2022).

At the same time as the NWS's international program was being developed in 2015, the University of Colorado's Consortium for Capacity Building (CCB) was developing its El Niño Ready Nations (ENRN) initiative for, and with funding from, USAID (El Niño Ready Nations 2015). The ENRN initiative, though originally developed in direct response to the major 2015–2016 El Niño event, in fact complements the WRNi initiative, potentially to the benefit of both initiatives (Glantz et al. 2022).

Beyond their common goal of fostering societal readiness, ENRN and WRNi have several shared areas of interest. Two of these areas are: (1) improving early warning systems (EWSs); and (2) enhancing multi-sectoral preparations for and responses to extreme meteorological events through impact-based decision support systems (IDSS).

8.1 Improving Early Warning Systems

Early warning systems are a central concern of ENRN, the US WRN, and WRNi activities.

The contrast between Fig. 9a and b makes an important point about early warning systems. Figure 9a represents a generalized perception about the role (and value) of EWSs in any given society. In this case, society is perceived as existing in a stable state, and early warning systems for hydrometeorological hazards (located graphically at the apex of the pyramid) are thought to act as searchlights that constantly shed light on the base of the pyramid in search of potential threats to societal stability. This common perception, however, distorts the true value of EWSs. The reality is that the stability of a society rests on the levels of efficiency and effectiveness of choices made based on how well warning systems and response mechanisms have been monitored and maintained.

As suggested in Fig. 9b, all societies, represented graphically in this case by an upside-down pyramid resting on its point, are really in unstable equilibrium clarifying the importance of ongoing investment in response mechanisms and dedicated monitoring by early warning systems. As forecasting and response mechanisms and monitoring improve, the point on which the inverted societal pyramid rests flatten slightly, indicating an increase in overall societal stability. Like this are EWSs revealed as integral to all three readiness initiatives—WRN, WRNi, and ENRNs.

Early warning systems associated with ENSO, especially El Niño, can provide WRNs with their earliest possible seasonal warnings of foreseeably threatening hydrometeorological hazards. In this way societies can be forewarned strategically by years (with the use of El Niño climatology) as well as tactically by months (with the use of forecasts derived from the Oceanic Niño Index (ONI)). Whereas WRNs focus on seasonal and sub-seasonal processes, ENRNs focus on processes that are seasonal and sub-seasonal as well as interannual but do so through a sub-decadal lens.

8.2 Enhancing Multi-sectoral Preparations for and Responses to Extreme Meteorological Events Through Impact-Based Decision Support Systems (IDSS)

US WRN, the WRNi, and ENRNs are all social inventions designed to improve the use of hydrometeorological information. They all also intend for hazard forecasts to benefit socioeconomic and culturally relevant decision-making processes. A social invention can be thought of as an idea, notion, or concept that motivates people, communities, and governments to act in a more informed way to achieve desired goals. Impact-based decision support services (IDSS) can also be viewed as a social invention. It encourages bringing together those involved in making hazard forecasts with those responsible for coping with the societal impacts of those forecasted hazards. In line with this ultimate goal, NOAA's strategic plan (NWS 2019) specifically "call[s] for the NWS to shift to the impact-based decision support services [IDSS] approach." Lazo et al. (2020, p. 1) notes:

> In 2011, the NWS formalized their approach to provide impact-based decision support services (IDSS) to help core partners better understand and utilize NWS forecasts and warnings in the face of upcoming extreme events. IDSS encourages weather forecasters to better consider societal impacts from weather events. This shift in emphasis toward impacts ensures NWS information and services are more relevant to decision-makers, which will allow those decision-makers to use NWS information and services to take proactive mitigating actions to protect life and property.

There are several different views about how exactly IDSS can contribute to a nation's weather readiness. Such views have emerged as part of a more general process of NMHS

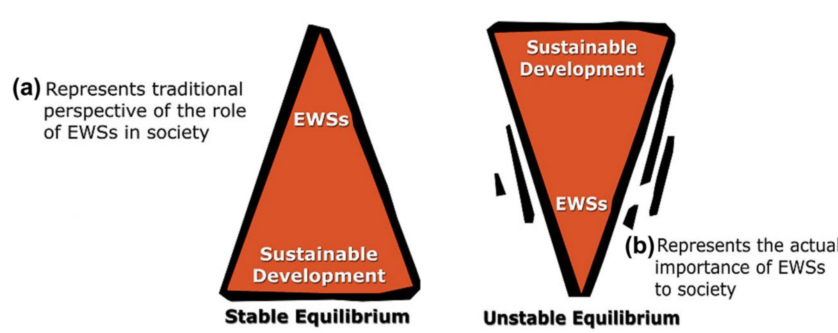

Fig. 9 The role of early warning systems (EWSs). **a** Represents a stable equilibrium and **b** represents an unstable equilibrium. *Source* Glantz (2008).

modernization the aim of which has been to ensure that every society is prepared for and responds to weather-dependent events (for example, Rogers and Tsirkunov 2013). One such view pictures IDSS as making forecasting a more collaborative process. For example, under IDSS, a given WRN would require its NMHS to reach out to interact with users of its forecasts in making their weather-ready decisions. Interestingly, an IDSS-like matrix can be shown in this way to have long played an integral role in applied social science research on ENSO and, more generally, on other aspects of climate, water, and weather impacts. As McPhaden et al. (2006, p. 1740) observe, “ENSO, with its cat’s cradle of interconnected scientific and societal issues, has long been fertile ground for interdisciplinary research.”

WRNi and ENRNs have several other complementary goals. Both programs are, for example, designed to make nations better at anticipating and forecasting high-impact climate, water, and weather anomalies and at preparing for the foreseeable hydrometeorological hazards and potential disasters that are known to recur in a given region or country. Both are also focused on reducing loss of life, livelihoods, property, and infrastructure to extreme hydrometeorological events. Furthermore, an important activity of both initiatives involves identification, learning, and sharing of lessons—both positive and negative—from previous experiences with hydrometeorological events. Table 1 illustrates some observed differences between WRNi and ENRN.

ENRNs research and application activities encompass socioeconomic issues that have often been viewed by scientific researchers as separate from the core science-related tasks of NMHSs. In addition to civil society, ENRN constituents, like those of the WRNi, also include high-level policymakers and NMHSs as well as the ministries of agriculture, water, energy, health, education, civil defense, transportation, and national security.

El Niño is but one phase of the full ENSO cycle. It is important that disaster-related knowledge (from monitoring to forecasting) of ENSO’s three phases be continuously mainstreamed (linked) into Weather-Ready Nation activities. Incorporating ENSO knowledge into Weather-Ready Nation knowledge could reinforce a society’s long-range sustainable development planning for a warming global climate as well as enhance its strategic and tactical planning for coping with seasonal and sub-seasonal hydrometeorological anomalies.

9 Conclusion

Today’s youth and young professionals are inheriting tomorrow’s immensely polluted, deforested, desiccated Earth, the climate of which will continue to grow hotter as past and present human insults and emissions continue to befoul the atmosphere well into the future. Those insults and emissions sharply increased throughout the twentieth century and have only continued to increase in the first fifth of the twenty-first century. As youth become young professionals and young professionals become advisers and then policymakers, they will have the responsibility to cope with, mitigate, and perhaps even eradicate the myriad worldwide sources—both technical and social—of such enduring insults and emissions. Though dire, this is not as yet a hopeless foreshadowing.

The four living generations of decision makers that will be the policy predecessors to the up-and-coming youth and young professional generations must provide those up-and-comers with a toolkit of the knowledge and skills they will need to cope effectively with whatever anomalously

Table 1 Suggested general differences between International Weather-Ready Nation (WRNi) and El Niño Ready Nations (ENRN) with potential for complementary activities

WRNi	ENRNs
The WRNs’ concept focuses on weather at the sub-seasonal to seasonal time scales and, at present, its focus is on quick-onset flash floods in a set of selected countries.	The ENRNs concept focuses on sub-decadal, inter-annual, annual, seasonal time scales. It also focuses on ENSO’s extremes (El Niño and La Niña) and on their specific teleconnected hydrometeorological anomalous impacts.
Top-down approach: The national meteorological and hydrological services (NMHSs) target emergency managers as a country’s official first responders to cooperate with, once a flash flood forecast, for example, has been issued.	Top-down and bottom-up approaches: ENRN is focused on resilient adaptation, requiring constant re-evaluation of societal adaptation or “best practices” in response to past hazards. This identifies changes needed because of a warming climate.
WRNi’s NMHSs are encouraged to “refunction” due to changing political, funding, and decision-making support for impact-based decision support systems (IDSS) that requires closer collaboration with emergency managers.	ENRNs explicitly supports “refunctioning” of NMHSs to better serve society by involving other disciplines within the NMHSs. Social scientists need to be added to the NMHSs’ staff.
IDSS is supported by the US National Weather Service (NWS) in general and by WRNi, driven by the physical sciences.	ENRNs’ efforts have been multidisciplinary, driven by the social sciences. These efforts parallel IDSS.

surprising or ominously changing climate conditions emerge over the course of the twenty-first century's four remaining fifths—that is, over the next almost 80 difficult years of Earth history. Included in this knowledge and skills toolkit should be a clearer understanding of the patterns and irregularities to be expected of the full ENSO cycle. In complement, the full cycle also merits much greater attention than it has been given to date by media professionals and those in civil society outside the scientific community. Linking continuous monitoring of the ever-present, quasi-periodic ENSO cycle in this way can add to a nation's overall weather readiness, providing usable foresights for planning and coping with climate, water, and weather disruptions at seasonal and sub-seasonal scales.

In line with these observations, we propose that a nation striving to become weather ready can benefit greatly by "mainstreaming ENSO" into their decision-making processes. No longer can decision makers be content with taking El Niño or La Niña into account only when either one is forecasted alternately every few years or so. Rather, ENSO information must now be continuously monitored and so blended into a WRN's decision-making processes.

By investing in mainstreaming, ENSO-related multidisciplinary studies (such as those for ENRN) add value by enabling a "re-view" of the effectiveness of present-day societal responses to climate-related anomalies. As such, El Niño studies can also provide a link between sub-seasonal weather anomalies and sub-decadal climate phenomenon. Moreover, they can bridge tactics for coping with weather extremes today with strategies (some still to be developed) for dealing with what future climate change-related hydrometeorological hazards emerge over the coming decades. As McPhaden et al. (2006, p. 1744) note: "By virtue of their recurrence every few years and their distinctive global pattern of environmental impacts, El Niño and La Niña […] provide a unique context for developing testable hypotheses about how various components of the Earth system respond to climate forcing."

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