CLIMATE FORECAST SKILL

ENSO AND THE SOUTHEASTERN UNITED STATES

The goal of this education module is to present the current state of climate forecasting, including forecast skill, how forecasts are made, and how one should interpret them. After reading this article, you should be able to understand official climate forecasts, how reliable they are, and how they should be used to make informed decisions.

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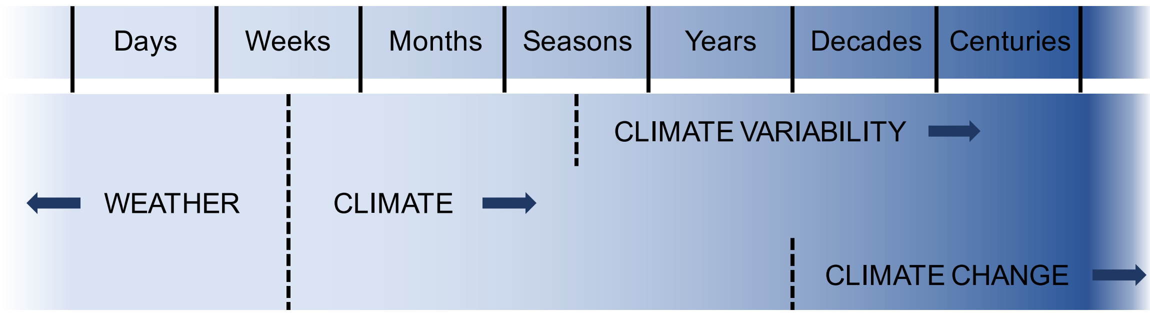
What is a Climate Forecast?

If a weather forecast is unreliable beyond 5 to 7 days, how can a climate forecast, which spans months, years, and even decades into the future have any reliability at all? The answer is found in the definitions of weather, climate, climate variability, and climate change. Each has a specific meaning, and it is important to know these in order to understand climate forecast skill. **Weather** refers to the state of the atmosphere at a given location and time (e.g. precipitation events, temperature, etc.). **Climate**, on the other hand, is a summary of prevailing weather conditions for a given area over an extended period of time (usually many years). **Climate variability** and **climate change** refer to changes in these weather states over varying periods of time. Variability indicates that the changes are temporary, and that they oscillate between strong and weak patterns. Climate change indicates a more permanent change due to a shift in atmospheric conditions, especially when we have not observed those shifts before. An example of this would be the increasing concentration of greenhouse gases in the atmosphere, which evidence suggests alters weather, climate, and climate variability patterns. The following figure is provided to help communicate the different time scales associated with these terms.

There is some confusion about the current capabilities of both weather and climate forecasts and the reliability of their predictions. We may not be able to know exactly when and where major storm events will occur, but we are able to observe atmospheric conditions that are known to produce severe storms.

Understanding these patterns forms the basis of climate-related research. Weather forecasts tend to focus on high and low pressure systems as well as cold and warm fronts, which drive most of the weather we experience. Weather is difficult to predict more than a few days into the future. Climate, on the other hand, relies on ocean-atmosphere circulation patterns (e.g. wind and current patterns driven by heat transfer) to predict likely weather occurrences (e.g. increased or decreased rainfall, severe events, temperature, drought, length of frost season, etc.).



Typical time scales associated with weather and climate terminology. The dashed lines indicate loose bounds for the use of these terms. Note the overlap between climate, climate variability, and climate change.

Why We Forecast Climate

Climate forecasting was thrust into the global limelight in 1997. This primarily resulted from a large number of extreme weather events that were accurately predicted months prior to their arrival. In early 1997, there were indications of a strong El Niño phase of the El Niño Southern Oscillation (ENSO)—explained later—which had been linked to specific weather patterns in different areas of the globe. These predictions were confirmed by observations while El Niño conditions continued, including:

"…water shortages, fires, and crop failure in Central and South America; fires in Southeast Asia; major storms in South America and California; tornadoes that killed more than 120 in the United States; and increased rainfall in the U.S. Southwest that fostered vegetation growth and increased the potential for serious wildfires…." — an excerpt from *Making Climate Forecasts Matter* (Stern and Easterling, 1999).

Such events (of varying types and severity) are regionally specific, and therefore, they have unique stakeholders with vested interests in their impacts. If climate forecasts could provide relevant information to stakeholders in these regions, then those stakeholders could make better-informed decisions to lessen the impacts of these events on communities. Since 1997, forecasts have been getting better. Benefits of climate forecasts include:

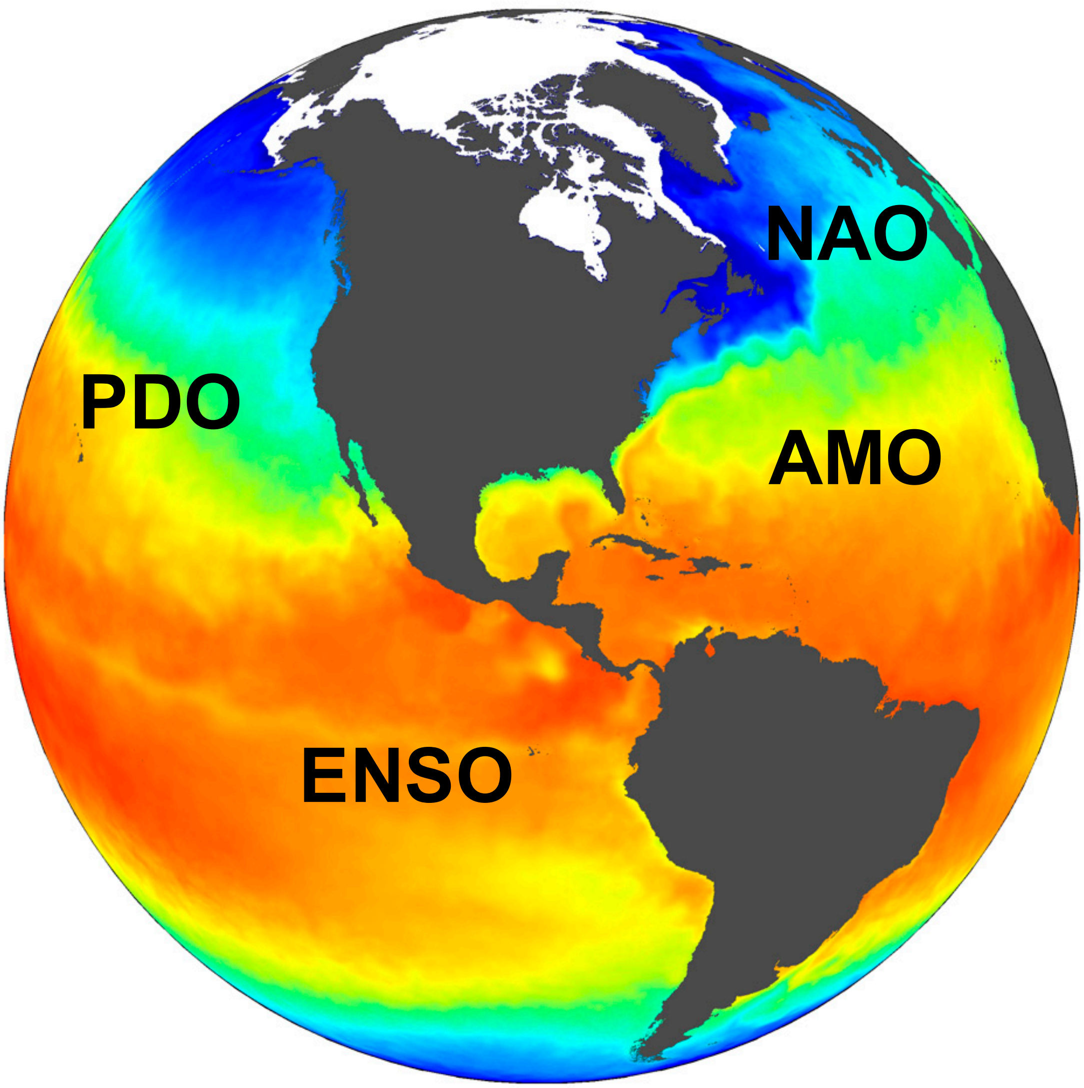
- providing advanced warning
- coordinating response efforts
- supporting long-term resource planning
- satisfying simple scientific curiosity

Known Climate Oscillations

Most known climate oscillations are tied to fluctuations in sea-surface temperature (SST) and pressure differences for various oceans, especially at or near the equator but also in other areas. See the following figure for the geographic locations of at least four climate oscillations known to impact the climate of North America, and more specifically, that of the southeast United States.

It is also important to understand the cycle frequency of oscillations in the climate system, which can range from seasonal to inter-annual to decadal and even to hundreds of thousands of years and beyond. Most are familiar with short cycle oscillations (like seasonal climate variability) since they impact our everyday lives frequently, but the familiarity drops with increasing cycle duration. And, why would the public need to know about cycles longer than their life span? Therefore, we focus on the climate cycles that would be observed in the lifetime of a typical human for this module.

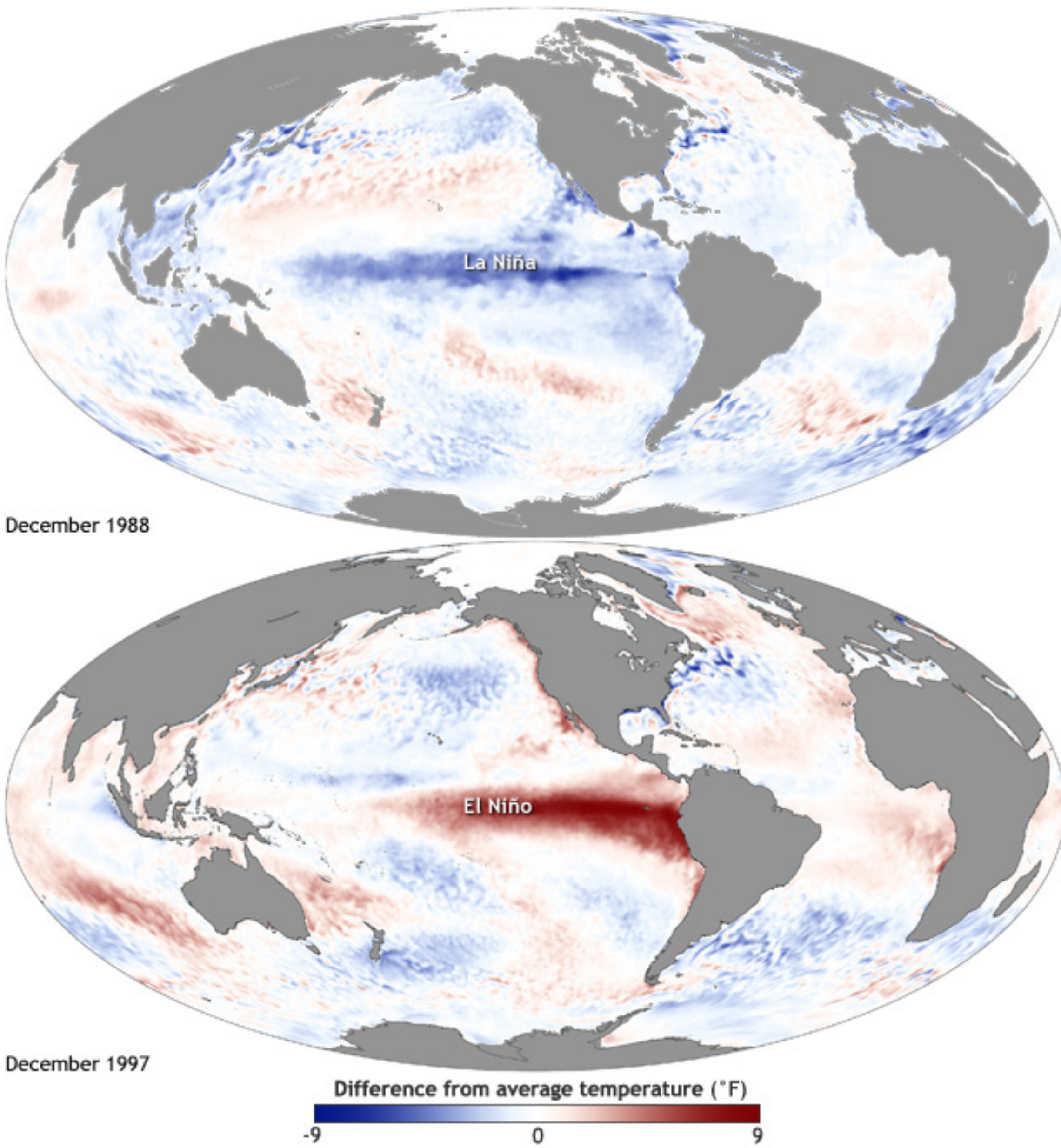
Everyone is familiar with the seasons, which are caused by Earth's rotation as it orbits the sun, leading to uneven heating of the northern and southern hemispheres. Seasons have an obvious impact on weather and climate, and they are consistent: they arrive every year at the same time, with generally the same effect (although some seem stronger than others). Most people can reflect back on a particular winter or summer that was warmer or cooler than normal, but usually they do not know why this happened. Stronger or weaker seasons can actually be caused by other climate cycles such as ENSO (and the other climate cycles) acting subtly behind the scenes.



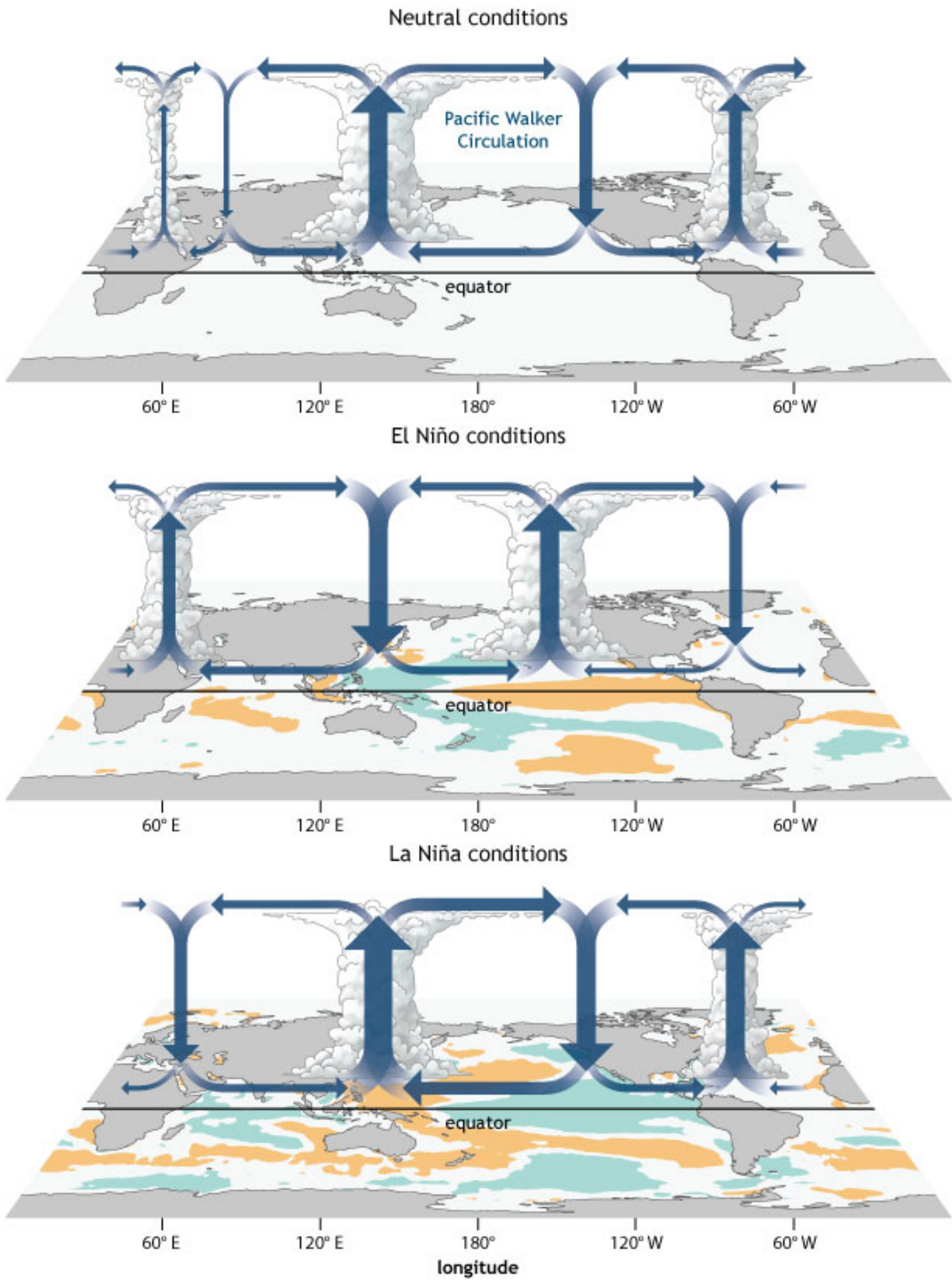
The geographic location of four climate cycles known to impact the climate of North America and the southeastern United States. Cycles pictured include the following: El Niño Southern Oscillation (ENSO), Atlantic Multidecadal Oscillation (AMO), Pacific Decadal Oscillation (PDO), and North Atlantic Oscillation (NAO). Relative ocean SSTs, indicated by warmer and cooler colors, shown for reference (highlighting some circulation of the oceans). Figure adapted from NOAA Climate.gov.

The El Niño Southern Oscillation (ENSO)

The most publicized of the climate cycles is the El Niño Southern Oscillation (ENSO), which refers to the heating and cooling cycle of SST along the equator (west of Peru) in the Pacific Ocean. The figure below shows an example of historically strong ENSO phase SSTs. Warmer or cooler ocean surface temperatures affect atmospheric circulation, which in turn impacts where precipitation occurs, how much, and how frequently (causing flooding and drought), in addition to other weather events and climate patterns. Why does this happen? When warm air rises it cools, condenses, forms clouds, and then converges into droplets large enough to fall as precipitation. Other factors determine when and where moisture actually converges into droplets before falling. Generalized Walker Circulation (warm and cool air circulation) for the phases of ENSO (neutral, El Niño, and La Niña) are shown on the following page.



Sea surface temperature (SST) differences from normal during a strong La Niña (top, December 1988) and strong El Niño (bottom, December 1997). Maps by NOAA Climate.gov, based on data provided by NOAA.



Generalized Walker Circulation (Dec. to Feb.) for ENSO-neutral conditions (top), ENSO-El Niño (middle), and ENSO-La Niña (bottom). NOAA Climate.gov drawing by Fiona Martin.

There are at least two potentially confusing aspects of ENSO-related forecasts, which are also true for other climate forecasts. First, the ENSO cycle typically lasts 1 to 2 years, and it does not always cycle from positive (El Niño) to negative (La Niña). ENSO can change from positive to neutral and back to positive without having a negative phase (phase determination explained later). Second, although ENSO can and probably does impact the climate of the entire year at a given location, it will almost always impact part of the year more strongly than other parts. For the southeastern United States, ENSO has the largest impact in winter. Stakeholders should be careful not to confuse southeastern ENSO impacts with those for other locations and seasons of the year, which can be and usually are different.

Forecasted Climate Cycles

Forecasting climate cycles like ENSO becomes relatively simple. Accurately predict the SST for the critical location for an extended period of time, and atmospheric circulation patterns will follow well-known laws of thermodynamics, which produce climate and weather patterns we have observed. Yet, therein lies the crux of the matter—accurately predicting SSTs for fairly extended periods of time. It is relatively simple to observe SSTs and to determine the resulting circulations they cause, but it is a separate issue to forecast them. For this reason, there are many identified climate cycles but not nearly as many forecasted cycles.

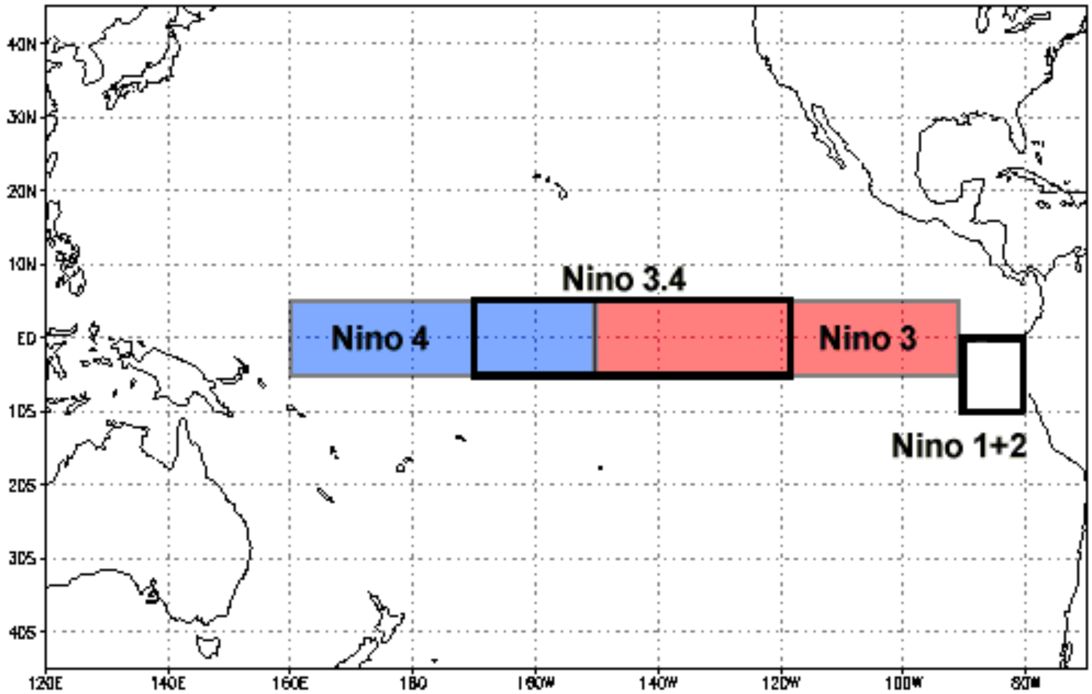
The National Oceanic and Atmospheric Administration (NOAA) provides forecasts of many climate cycles on their Climate Prediction Center (CPC) website. The climate cycles for which they provide forecasts include: the El Niño Southern Oscillation (ENSO), the Madden Julian Oscillation (MJO), the Arctic Oscillation (AO), the North Atlantic Oscillation (NAO), the Pacific North American Pattern (PNA), and the Antarctic Oscillation (AAO). All of these cycles are simultaneously impacting the climate of North America and the United States. You can see how complicated this can get!

Furthermore, these are just the cycles we can predict with relative accuracy. There are several others that are not forecasted but that we know also impact our climate including: the Atlantic Multidecadal Oscillation (AMO), the Interdecadal Pacific Oscillation (IPO), the Pacific Decadal Oscillation (PDO), the North Pacific Oscillation (NPO), and others. Although all climate oscillations are important to consider for a complete understanding of the entire Earth system, some are more important for each region than others.

ENSO was discussed earlier as one of those forecasted cycles with large bearings on the Southeast, but one that is of particular interest to the southeastern United States that is not currently forecasted is AMO. The AMO has been shown to affect the number of tropical storms that become hurricanes (Dong et al., 2013), and some have even proposed that AMO may influence where these hurricanes make landfall on the U.S. East Coast and Floridian Peninsula (Klotzbach and Gray, 2008). This is important to understand since the AMO could significantly impact the southeastern climate independently of the current ENSO phase. Therefore, even if ENSO forecasts were perfect, they could not account for ***all*** climate variability. This is why climate science must focus on all climate cycles rather than ENSO forecasts alone.

How Forecasts Are Made

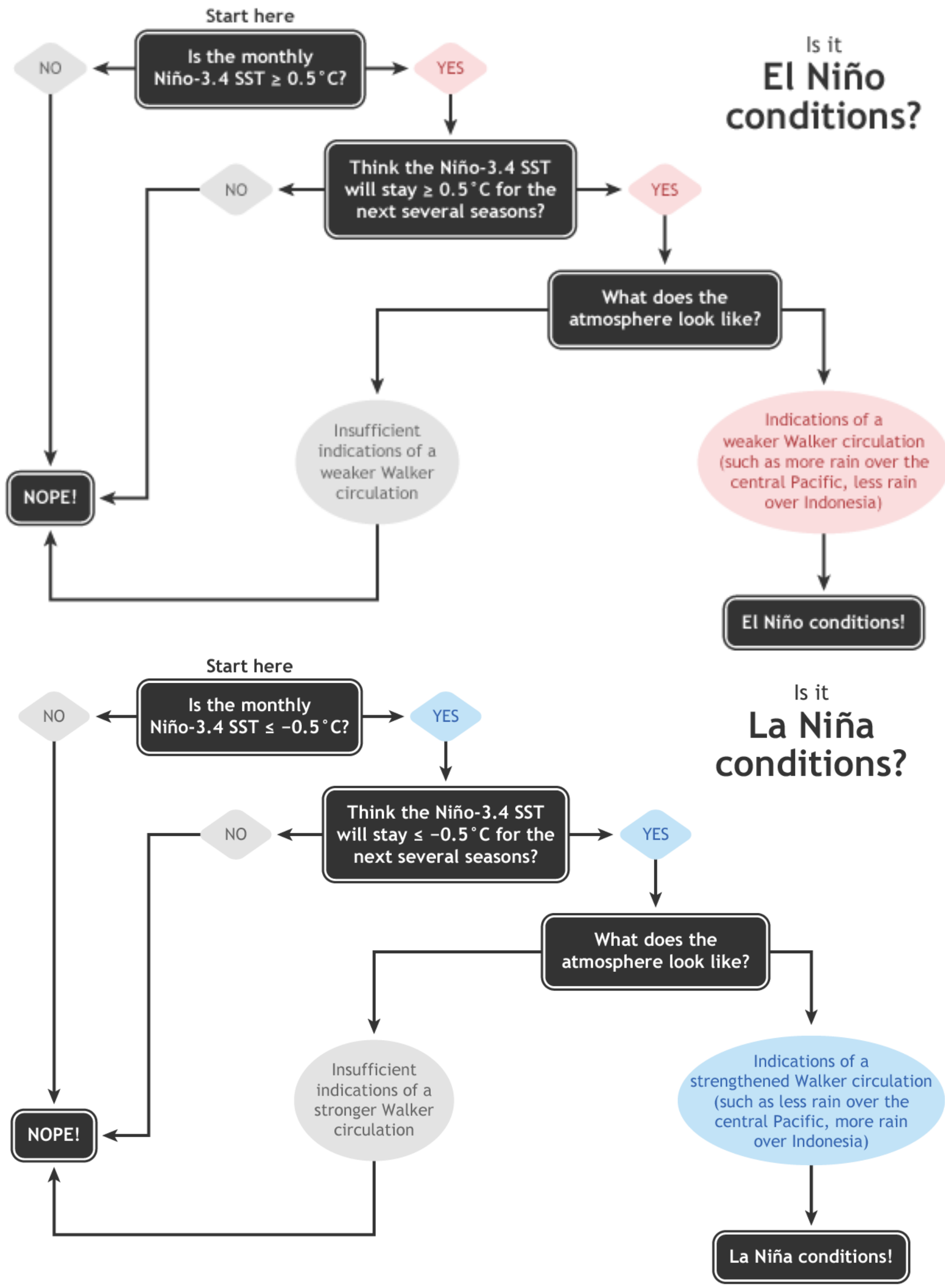
Every climate cycle forecast is prepared differently, but all have similar components. As mentioned before, most of these rely on the accurate prediction of SSTs (and therefore pressure differences) at particular geographic locations. This is also the case for ENSO. The specific geographic location used to make ENSO observations and forecasts is called the 'Niño 3.4 box' (figure follows). SSTs (either observed or forecasted) are averaged for the entire geographic area for 3 months at a time. As time moves forward, so does the 3-month interval over which SSTs are averaged. This is called a moving-time average. See the following figure for an explanation of the Niño 3.4 box and the role of other 'Niño boxes' in ENSO forecasts.



Geographic locations called 'Niño boxes' used in observing and forecasting SSTs for observing and forecasting ENSO phases. The Niño 3.4 box is most commonly used to make conclusions of how ENSO will affect global climate. The Niño 1+2 box may be the first to warm (and could be used for early warning of ENSO. The Niño 3 box is the most variable box, and the Niño 4 box is used to predict precipitation in Indonesia. Credit: NOAA and IRI.

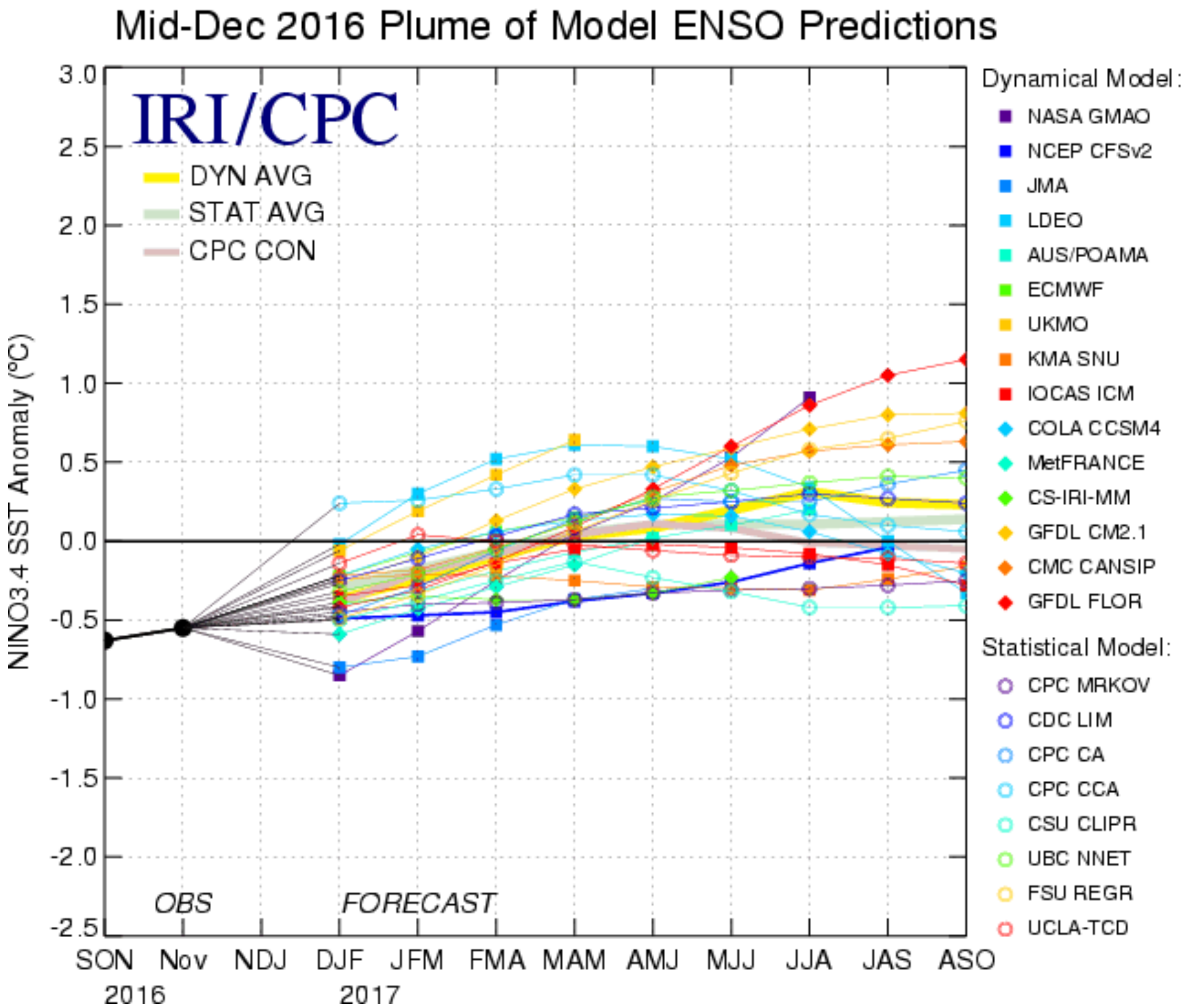
If the moving-time averaged values are either above 0.5 °C or below -0.5 °C they advocate for either an El Niño or La Niña prediction, respectively. Larger anomalies are associated with stronger circulation patterns (and their effects). An ENSO forecast will be issued only if the anomaly has some permanence (lasting at least 5 months) and the appropriate Walker circulation patterns. It is possible to develop the temperature anomalies but not develop atmospheric circulation patterns associated with ENSO. In these cases, a neutral phase forecast would be issued. See the following figures (next page) for the decision tree for determining whether we are in the positive (El Niño) or negative (La Niña) phase of ENSO.

So where do these forecasted SST values come from? The short answer is climate models. The longer answer is that forecasts are derived from a mixture of different models and model types. SST forecasts are derived from a number of models—all of which are based on different assumptions producing different results. No model is perfect because we do not definitively know how to account for everything that has been observed in our climate. So, scientists and science-based organizations apply their own ideas of how the climate system operates into different models, and we report all their results as one. This allows us to show a range of possible values, given different assumptions, as well as when models agree or disagree concerning the forecast objective. Therefore, it is not only the mean value reported by models that is important, but the convergence (or the agreement) of the models must be considered in making the final prediction. Generally, the multi-model mean value is used for ENSO predictions, but models are only aids to forecasters, and they are not the forecast itself.



ENSO forecast decision tree for El Niño (top) and La Niña (bottom). Note some of the more vague language used for the atmospheric component of ENSO predictions. Credit: NOAA.

An example forecast of SST values in the Niño 3.4 box is shown below. This figure shows an example of what a forecaster would use to issue a prediction. In this figure, the observed SST in the Niño 3.4 box (black line) for the fall of 2016 was below -0.5 °C. If Walker Circulation patterns were strong (see previous figures) and the SST had been below this threshold for at least 5 months, then it would have been declared a [weak] La Niña phase of ENSO (it was). Since an increase in SST was predicted, the forecast would automatically change from La Niña to neutral because the SST forecast would have been higher than the threshold value of -0.5 °C and the Walker circulation patterns would have weakened. At that time, there was no strong SST anomaly predicted in either direction, so the forecast would have remained neutral (it did).



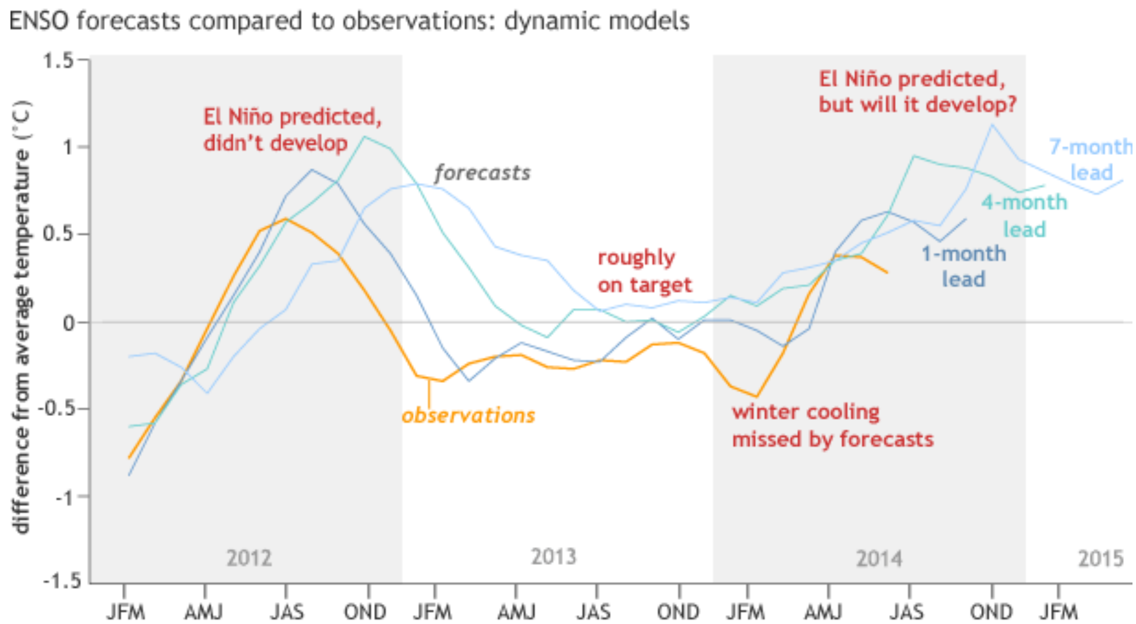
Niño 3.4 SST anomaly forecasts from the International Research Institute for Climate and Society (IRI) and NOAA CPC. Generally the model means are used to issue a prediction (along with other factors shown in the previous figures).

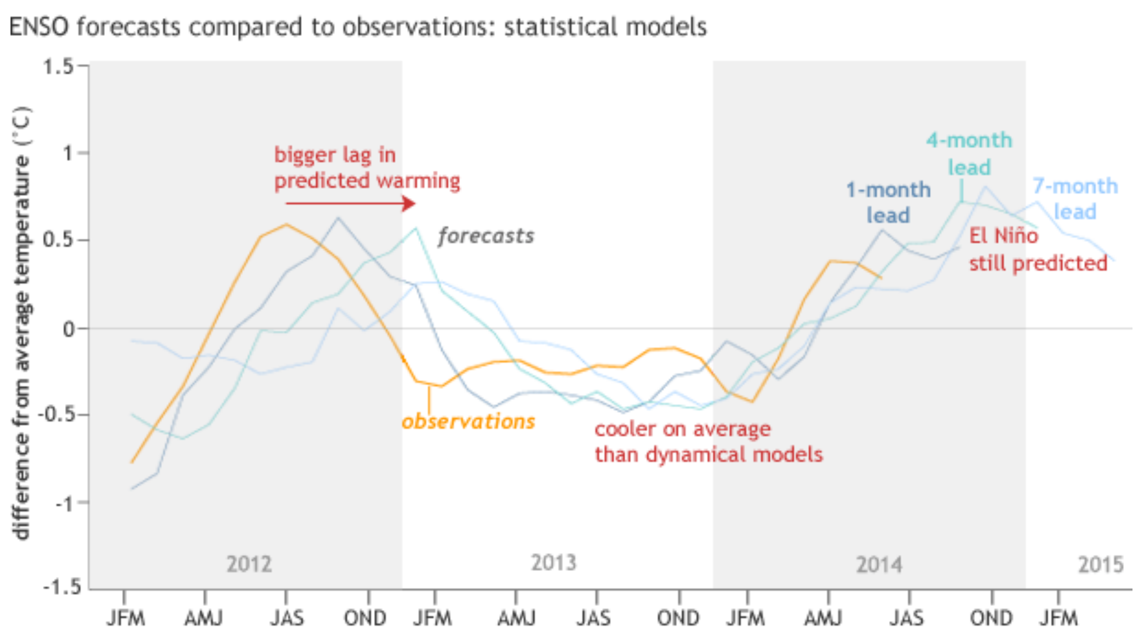
The State of the Science

ENSO forecasts have only been around since about 1997. Forecasts have been improving since that time, but they are far from what they will become in time. Two questions regarding climate forecasts remain: What is the 'skill' of the forecast? And, what can be expected from them in the near future?

When using the word 'skill' we are referring to the usefulness and reliability of a forecast. It can be a difficult question to answer because forecasts must be evaluated at different lead times. Lead time refers to the time ahead of the present through which the forecast is issued. The reliability of forecasts decreases as the lead time increases, but the usefulness increases for longer lead times. In other words, more lead time means more response time, if enough accurate information can be gleaned from the forecast and used in decision-making.

The International Research Institute for Climate and Society (IRI) produces three SST forecasts at three different lead times (1, 4, and 7 months). As one may expect, the shorter lead times have much greater reliability, but all seem to capture the SST signal fairly well, although the strength and timing of the signal can vary quite a bit with longer lead times. Here 'signal' refers to a forecast's ability to predict a real event in the future, although the forecast may under- or overestimate the timing and magnitude of that event significantly. One can imagine however, that if the signal for a La Niña phase is present in a 7-month lead time forecast (which has been linked to drought in the southeast U.S.), then even though La Niña may not fully develop, it would provide enough time to take action and begin preparing for the possibility of its occurrence. The following figures and table communicate the forecast skill of dynamical and statistical models for ENSO-related SST. Mathematical measures are more objective, but graphic measures help modelers understand potential sources of forecast error.





Comparison of observed and model averaged forecasted SSTs for dynamical models (top) and statistical models (bottom) from February 2012 to August 2015. Credit: IRI/CPC.

For mathematical performance, we usually report measures such as correlation coefficient or the mean absolute error (see the following table). The closer the correlation coefficient is to 1, it means that there is a strong positive relationship between the two. The mean absolute error is a quantity used to measure how close forecasts are to actual outcomes. A value of 0 would mean a perfect forecast.

Mathematical performance of model averaged forecasted SSTs for dynamical and statistical model types at different lead times (February 2012 to August 2015). Credit: IRI/CPC.

Model Type	Correlation Coefficient			Mean Absolute Error		
	Lead 1	Lead 4	Lead 7	Lead 1	Lead 4	Lead 7
Dynamical	0.89	0.6	0.14	0.17	0.32	0.44
Statistical	0.79	0.46	0.12	0.22	0.29	0.31

Note: Lead 1, 4, and 7 correspond to 1, 4, and 7-month lead times in the forecast.

From the mathematical and graphical measures of the different lead times, we can say that a forecast with up to 4 months lead time is reliable. Less lead time is more reliable but not as useful, and a longer lead time is the opposite.

The Future of Climate Forecasts

What can we expect from future models and forecasts? The most certain future development of models will be the focus on interpretation, specifically that of end users and not even necessarily the scientists. Climatology (a study of climate), climate variability, and climate change may be among the most misunderstood science topics of our modern world. It can be expected that forecasts will improve both in their accuracy and complexity as models become more representative of the physical sciences driving climate. The public will probably be more attentive to climate models and forecasts as more major events are correctly predicted and observed, especially when forecasts are issued but not heeded.

On a more technical note, forecasts will begin to incorporate longer-term climate variability, such as those oscillations which are known but not currently forecasted, particularly AMO and PDO, which have been correlated to climate patterns across the United States. Barnston and Tippett (2014) concluded that future forecast efforts may even attempt to specify the explicit contribution of different climate cycles or time scales on predictions, which are not independent of one another. Even with the incorporation of other climate cycles (especially longer duration cycles), inter-annual cycles are still expected to be the dominating factor. Efforts specifically targeting decadal forecasts will almost certainly be better served by including ENSO forecasts along with other cycles (Barnston and Tippett, 2014).

Probabilistic Climate Forecasts and How to Interpret Them Correctly

A recurring problem with forecasting in general is the accurate interpretation of forecasts. A ***forecast, no matter how accurate it is, if it does not invoke the correct response is worth nothing***. This has been discussed in climate literature as well as the centers that produce these forecasts, but there are not many 'silver bullet' solutions to this issue. ***Barnston and Tippett (2014) recommend recurring communication, face-to-face stakeholder meetings with an emphasis on decision-making as the preferred solution.*** Those that have tried this approach know that it is a lot of hard work, and it is difficult to maintain over long periods of time. Yet, that is exactly the meaning and purpose of research-instruction-extension (a critical partnership for discovering, demonstrating, and disseminating information to those who can use it).

The primary issues arise out of a general misunderstanding of probability. Those who are either able or willing to spend the time needed to understand a forecast must avoid two major pitfalls. First, a stakeholder should not simply take the most likely outcome and accept that as the forecast. If the forecast claims a 75% chance of El Niño for a season, this means that 1 out of 4 times it will not develop into El Niño. The second most common mistake is to minimize the value of the forecast and to not make decisions based on the most likely outcomes. In the same example, over a long period of time, 3 out of 4 times El Niño will develop and if the appropriate decisions are made, property, profits, environment, and lives can be saved (Barnston and Tippett, 2014).

Summary

Every decision that accurately interprets and utilizes climate forecasts is inherently a better decision. There are at least two limitations to the impact of climate forecasts on those decisions including 1) the technological skill of forecasts and 2) understanding and interpretation of those forecasts. As each of these limitations improve, we will find these forecasts as an increasingly relevant and reliable part of everyday life. Individuals will have a greater understanding of the many factors influencing climate that are relevant to their past experiences and future plans. Cities and corporations will be able to better manage resource consumption, supply chains, operations, etc. in the face of a dynamic climate. And, governments at state, national, and international levels will have a better idea of how to prepare for, respond to, and mitigate forthcoming weather events and climate states.

The number of identified climate cycles and the number of those forecasted will increase in the future. Forecasts will be presented with both better skill and communication than is currently practiced. The methods of their derivation will likely change, but they may not change that drastically, especially since SSTs have been reliable indicators of atmospheric patterns with which they are associated.

A likely future development is that we will understand more about what causes SST fluctuations, even though we do not at present (NOAA NCEI, El Niño Southern Oscillation (ENSO) Technical Discussion). This anticipated knowledge would permit better SST forecasts, which in turn would improve ENSO predictions. It is conceivable that one day we might be able to predict weather events 3 or 4 weeks ahead with relative accuracy, and climate states, such as the ENSO phase, 1 or 2 years in advance of their occurrence.

Scientific developments such as these would provide a significant boost to our decision-making capabilities. However, until such things come to pass, our society should focus on stewarding the knowledge and resources we have at our disposal to make the best possible decisions today. We would submit that the best decision, whatever that may be, will be one that relies on the guidance of skillful climate forecasts such as those in existence today.

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