Overview of National Academy Studies on Decadal Prediction

Scott Sandgathe
University of Washington
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Genesis 41

(29) "Behold, seven years of abundance are coming throughout the land of Egypt, but seven years of famine will follow them. Then all the abundance in the land of Egypt will be forgotten and the famine will devastate the land."

Decadal prediction is not a new idea!

Outline???

- Weather and Climate: The Report (1975)
- Ocean-Atmosphere Observations Supporting Short-Term Climate Predictions (1994)
- Decade-to-Century-Scale Climate Variability and Change: A Science Strategy (1998)
- Improving the Effectiveness of U.S. Climate Modeling (2001)
- Report of a Workshop on Predictability and Limits-To-Prediction in Hydrologic Systems (2002)
- Fair Weather: Effective Partnership in Weather and Climate Services (2003)
- Groundwater Fluxes Across Interfaces (2004)
- Knowledge-Action Systems for Seasonal to Interannual Climate Forecasting: Summary of a Workshop (2005)
- Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts (2006)
- Assessment of Intraseasonal to Interannual Climate Prediction and Predictability (2010)
- The Effects of Solar Variability on Earth's Climate: A Workshop Report (2012)
- A National Strategy for Advancing Climate Modeling (2012)
- Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report (2014)
- Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts (2016)
- Frontiers in Decadal Climate Variability: Proceedings of a Workshop (2016)

Weather and Climate: The Report (1975)

LONG-RANGE WEATHER AND CLIMATE PREDICTION

It now appears that the ability to predict determinately the state of the atmosphere cannot be extended beyond approximately 2 weeks. Hence, the ability to make longer-range forecasts, if possible, may have to be handled in a statistical manner. This implies that meteorology will have to develop a different set of mathematical and descriptive tools if it is to attack the problem of long range weather and climate prediction. This effort is now in its infancy.

A treatise is not undertaken here concerning the vital importance of the ability to predict weather on the time scales of months, seasons, and years. Suffice it to say, the consensus of the Panel is that this capability is <u>desperately needed</u> by a growing civilization that has seriously strained its food supplies, natural resources, and distribution systems. Substantial efforts in long-range weather and climate prediction must now begin in order to aid man in coping with the consequences of climatological vagaries (e. g., failure of food and fiber crops).

Decade-to-Century-Scale Climate Variability and Change: A Science Strategy (1998)

The Dec-Cen panel recommends that the United States initiate a Dec-Cen Program designed to increase understanding of climate variability on decade-to-century time scales, and determine its predictability.

Report of a Workshop on Predictability and Limits-To-Prediction in Hydrologic Systems (2002)

“Because policy decisions are often forward-looking, they are, in part, based on predictions. In the Workshop Roger Pielke, Jr. discussed the makings of an effective research and application program. Under this model there is a parallel undertaking of research and use of predictive models, linked by the communication between researchers and users of predictions. Success in prediction depends on the effective communication between these groups, leading to predictions which, 1) provide the most skill possible given the available data and modeling capabilities, 2) account for the stated needs of prediction users, and 3) have effectively communicated and understood uncertainties.

Absolute success in the cycle occurs when a skillful prediction is communicated efficiently, and used effectively in formulating a decision that has a value to society.”

Knowledge-Action Systems for Seasonal to Interannual Climate Forecasting: Summary of a Workshop (2005)

The area of seasonal to interannual climate forecasting was chosen because: (1) climate variability has significant impact on decision making for sustainability; (2) there have been important advances in the science of climate forecasting in the last two decades; and (3) there is active experimentation underway in that area, involving various institutional approaches to producing and using climate forecasts.

In addition, the nature of seasonal to interannual climate forecasting, which involves complex, rapidly changing, interdisciplinary science at scales ranging from local, to regional, national, and supranational, makes it particularly relevant to other areas of sustainability science, which often involve similar complexities.

Climate application efforts have been targeted at such areas as emergency preparedness, agriculture, food security, tourism, public health, and fisheries, with the goal of bringing a suite of benefits to society including decreases in mortality and morbidity, increased economic profit, improvements of agricultural harvests, more efficient operations of reservoirs, and better planning for natural hazards.

Knowledge-Action Systems for Seasonal to Interannual Climate Forecasting: Summary of a Workshop (2005)

Attributes of an effective forecast system:

- Salience relates to the perceived relevance of information: Does the system provide information that decision makers think they need, in a form and at a time that they can use it?
- Credibility addresses the perceived technical quality of information. Does the system provide information that is perceived to be valid, accurate, tested, or, more generally, at least as likely as alternative views to be “true”?
- Legitimacy concerns the perception that the system has the interests of the user in mind or, at a minimum, is not simply a vehicle for pushing the agendas and interests of other actors.

Assessment of Intraseasonal to Interannual Climate Prediction and Predictability (2010)

Three categories of sources of interseasonal to interannual climate variability:

- Inertia/Long term memory
  - e.g. Groundwater, ocean heat content, soil moisture, vegetation, land heat content, polar ice…
- Patterns of variability or feedback
  - e.g. ENSO, PDO, NAO, QBO…
- External forcing
  - e.g. volcanic aerosols, anthropogenic aerosols, solar variability, greenhouse gases, land use… and human mitigation.

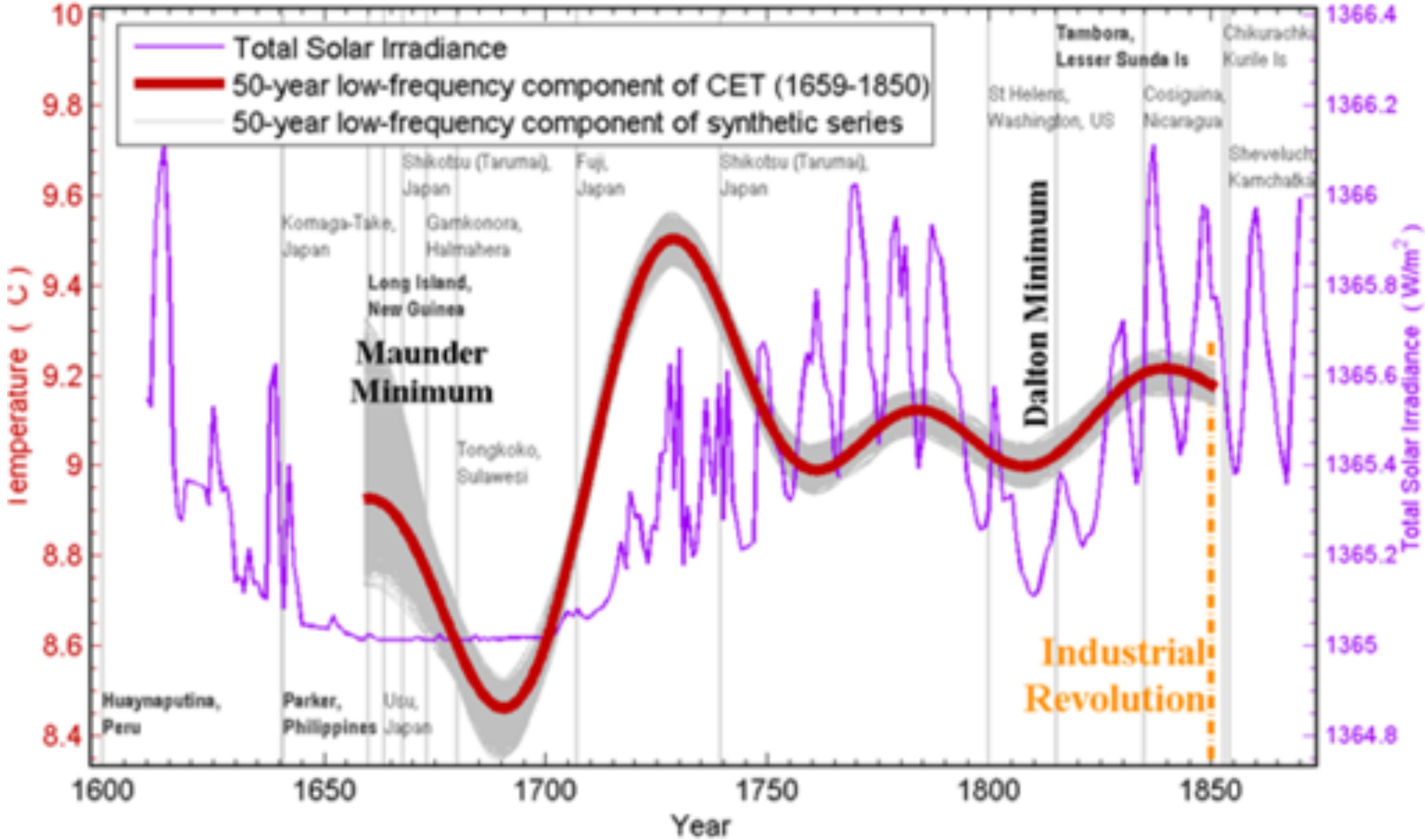


FIGURE 2.5 The low-frequency portion of the Central England temperature record, which could represent the Northern Hemisphere mean, is plotted along with the solar total solar irradiance (TSI) index and the occurrence of known large volcanic explosions. The figure indicates that the warming at the end of the Maunder Minimum around 1700 leads the increase in TSI by about 20-30 years and suggests that the warming may instead be a recovery from the cooling produced by the aerosols from a series of large volcanic eruptions between 1660 and 1680. SOURCE: Courtesy of K.K. Tung and J. Zhou, University of Washington, "Climate Response at Earth's Surface to Cyclic and Secular Forcing," presentation to the Workshop on the Effects of Solar Variability on Earth's Climate, September 9, 2011.

The Effects of Solar Variability on Earth's Climate: A Workshop Report (2012)

- The Sun may vary by as much as 0.1 percent over the 11-year solar cycle and perhaps by 0.05 to 0.3 percent over centennial timescales.
- When observed sea surface temperature data are composited using only sunspot peak years, the tropical Pacific shows a pronounced La Niña-like pattern, with a cooling of almost 1°C in the equatorial eastern Pacific.
- 10 times what might be expected from solar heating
- Supported by climate model studies but exact mechanisms unknown
- Difficult to separate other external forcing (volcanic activity, aerosols) from solar forcing in the historical record

Groundwater Fluxes Across Interfaces (2004)

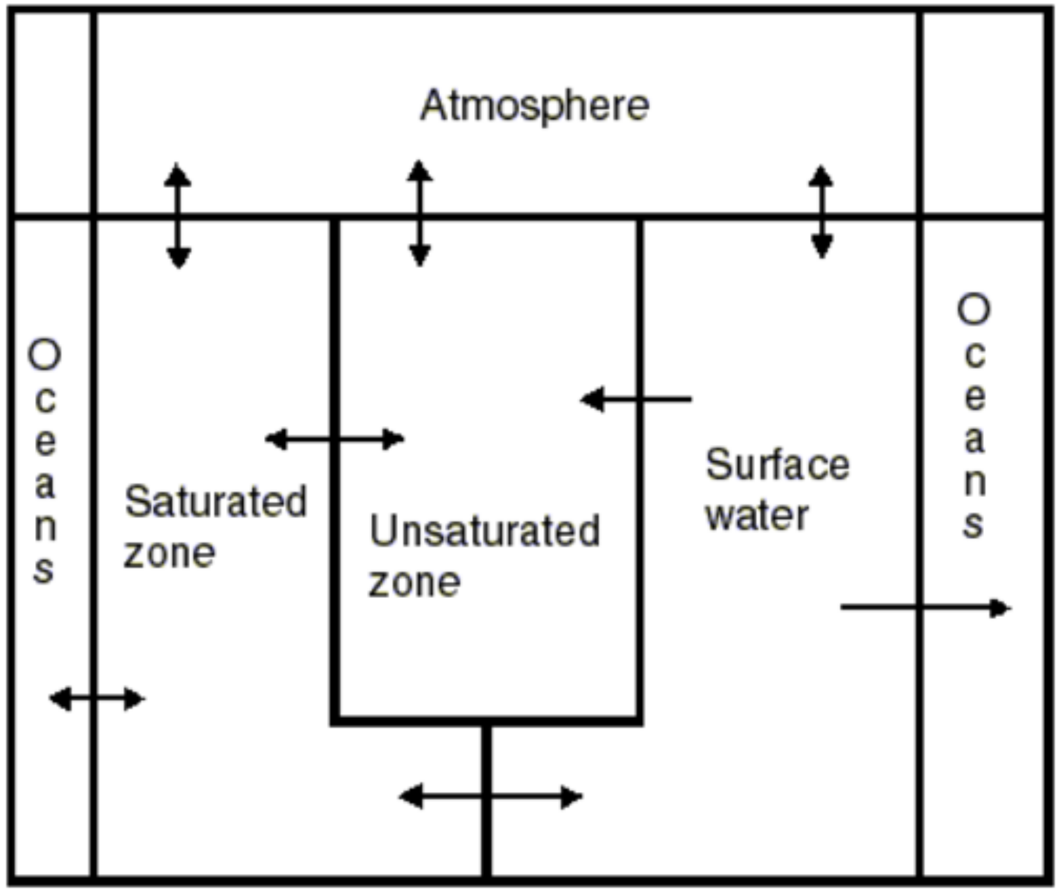


FIGURE 1-1 Global water reservoirs. Arrows show the interchange between reservoirs. The arrows connecting the saturated zone to the other reservoirs represent groundwater recharge and discharge and are the subject of this report. SOURCE: Guido Salvucci, Boston University, written communication, May 2002.

Groundwater Fluxes Across Interfaces (2004)

Finding 1
Our ability to quantify spatial and temporal variability in recharge and discharge is inadequate and must be improved given the importance of groundwater in the hydrologic cycle, the contribution of groundwater to base flow in streams and inflow to lakes, and society's reliance upon groundwater for water supply.

Finding 2
The roles of groundwater storage, and recharge and discharge fluxes in the climate system are under- appreciated and poorly understood. Because groundwater is the largest reservoir of fresh water in the hydrologic cycle, characterization of the linkage between groundwater and climate is crucial.
Groundwater plays an important role in the carbon cycle and related subsurface biogeochemical processes, and therefore the variability and fluctuation in groundwater levels can influence climate.

Finding 3
Groundwater measurements are needed across a range of temporal and spatial scales; measurements at one scale are often needed to address questions at another scale.

Groundwater Fluxes Across Interfaces (2004)

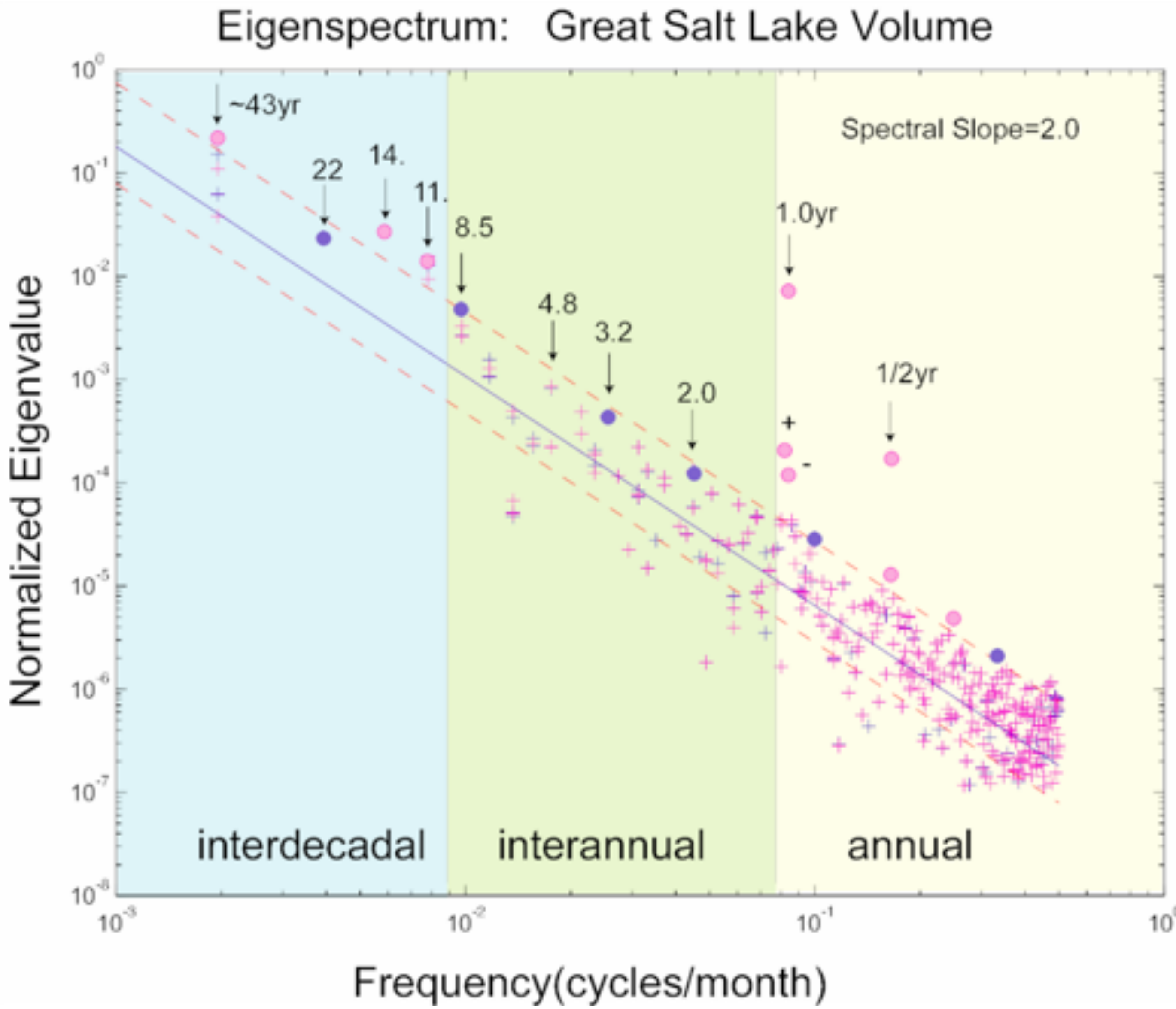


FIGURE 3-1 The spectrum for the historical record of the Great Salt Lake produced from bimonthly volume time series 1847-1997.

Assessment of Intraseasonal to Interannual Climate Prediction and Predictability (2010)

ISI forecasting systems are composed of several “building blocks:” observations, statistical and dynamical models, and data assimilations systems.

Based on its examination of the literature, the committee concludes that incremental increases in ISI forecasting quality are to be expected as the building blocks of ISI forecast systems are improved and upgraded. The committee also concludes that there are no “silver bullets;” there is no single action that will lead to a revolutionary leap forward in ISI predictions. As past improvements to ISI predictions and weather predictions have shown, progress forward can be achieved by a concerted effort to address the shortcomings of the various building blocks of forecast systems.

Assessment of Intraseasonal to Interannual Climate Prediction and Predictability (2010)

Recommendations:

1. Best Practices aim to improve the delivery and dissemination of forecast information for both decision makers and researchers.
2. Improvements to the Building Blocks of ISI Forecast Systems pertain to continued development of observations, statistical and dynamical models, and data assimilation systems.
3. Research for Sources of Predictability constitute specific goals for current and future academic exploration of ISI processes.

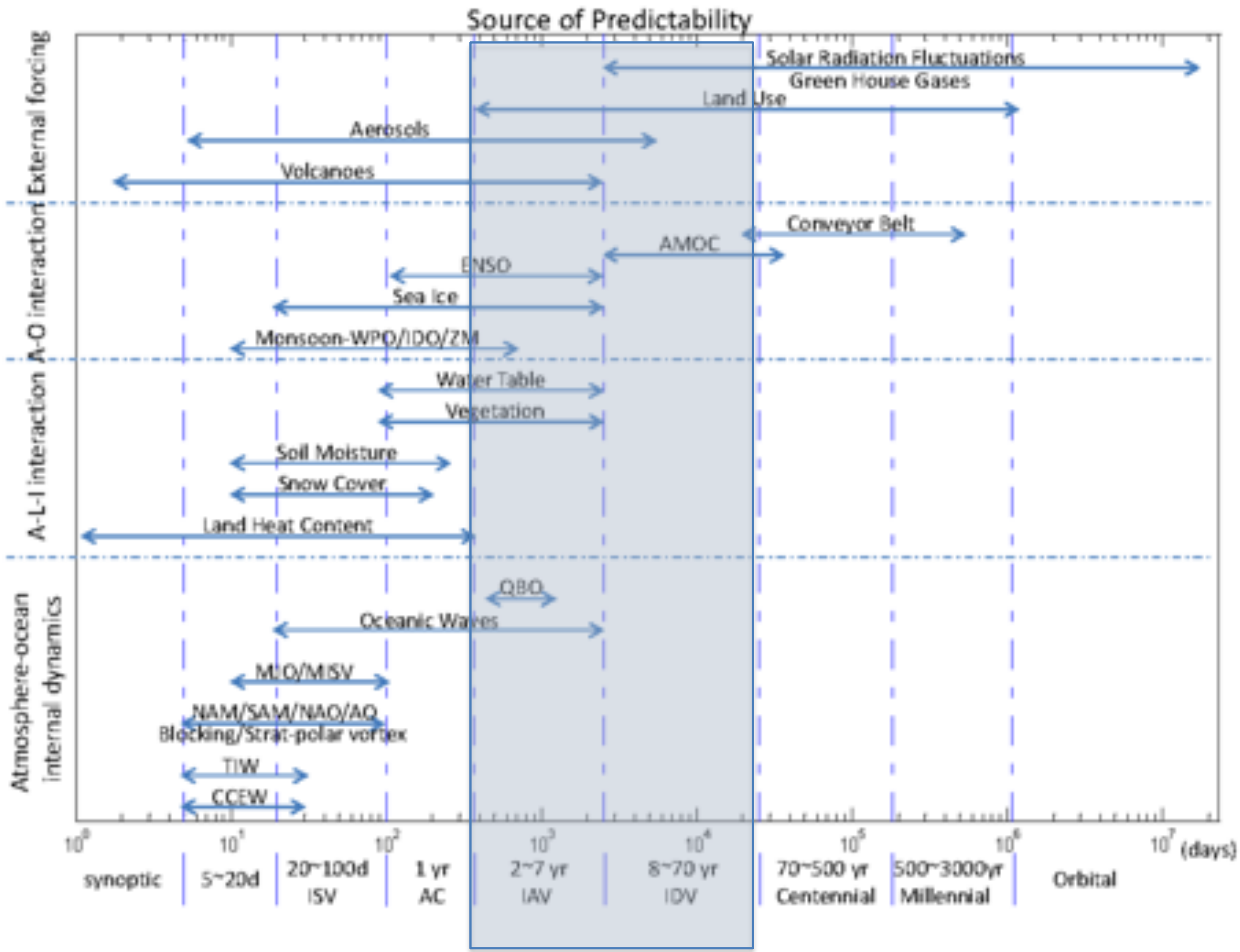


FIGURE S.1 Processes that act as sources of ISI climate predictability extend over a wide range of timescales and involve interactions among the atmosphere, ocean, and land. CCEW: convectively coupled equatorial waves; TIW: tropical instability wave; MJO/MISV: Madden-Julian Oscillation/Monsoon intraseasonal variability; NAM: Northern Hemisphere annular mode; SAM: Southern Hemisphere annular mode; AO: Arctic oscillation; NAO: North Atlantic oscillation; QBO: quasi-biennial oscillation, IOD/ZM: Indian Ocean dipole/zonal mode; AMOC: Atlantic meridional overturning circulation. For the y-axis, “A” indicates “atmosphere;” “L” indicates “land;” “I” indicates “ice;” and, “O” indicates “ocean.”

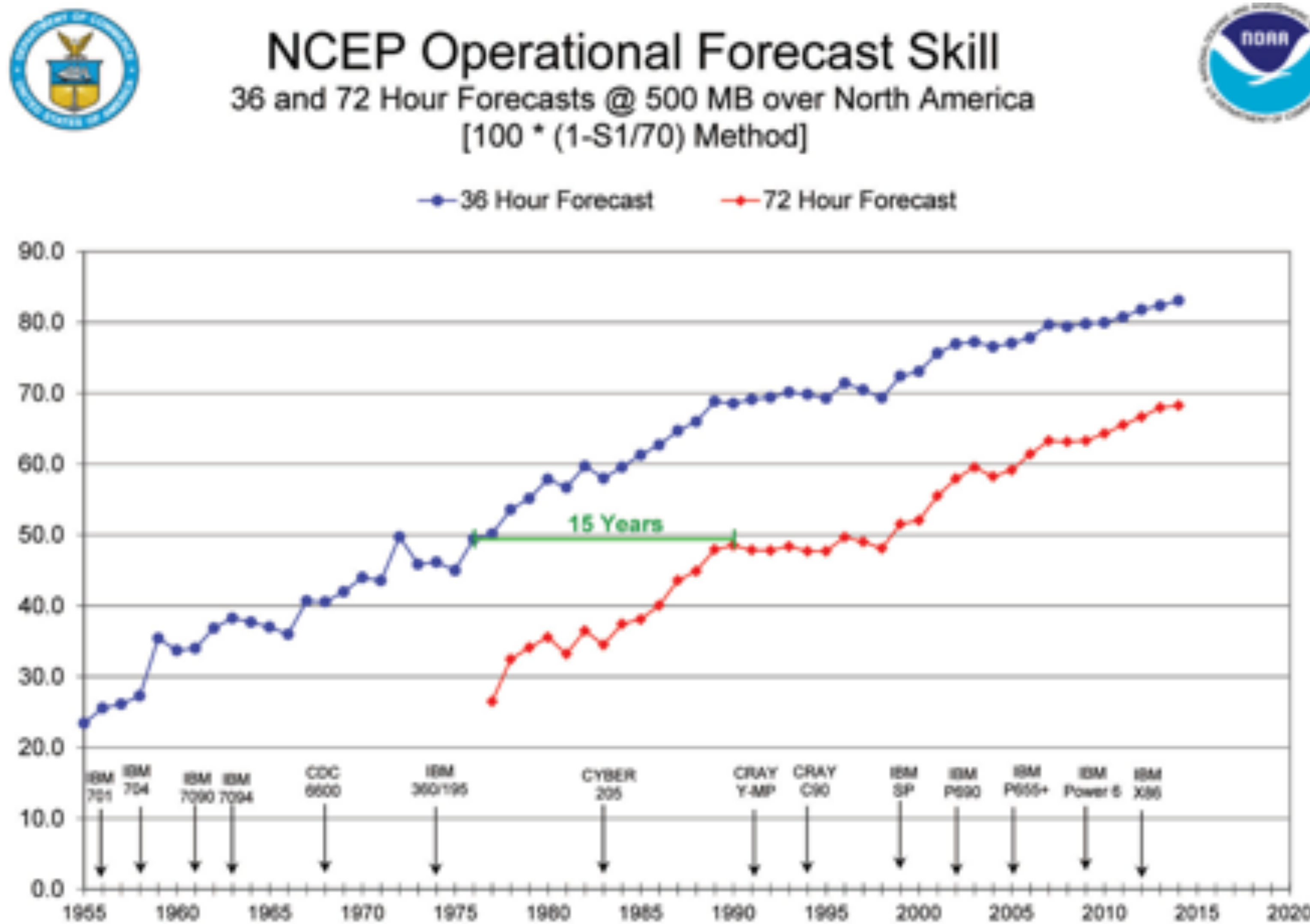


FIGURE 2.1 Forecast verification for 36- and 72-hour forecasts for the Global Forecast System (GFS) model. NOTES: The skill (S1) is based on the mean error of the 500 mb heights in the forecasts relative to radiosonde measurements over North America. This quantity is shown as 100*(1-S1/70). A perfect forecast is 100. Dates of computer hardware upgrades are shown with arrows along the x-axis. SOURCE: National Center for Environmental Prediction, http://www.nco.ncep.noaa.gov/sib verification/s1_scores/s1_scores. pdf, accessed July 20, 2015.

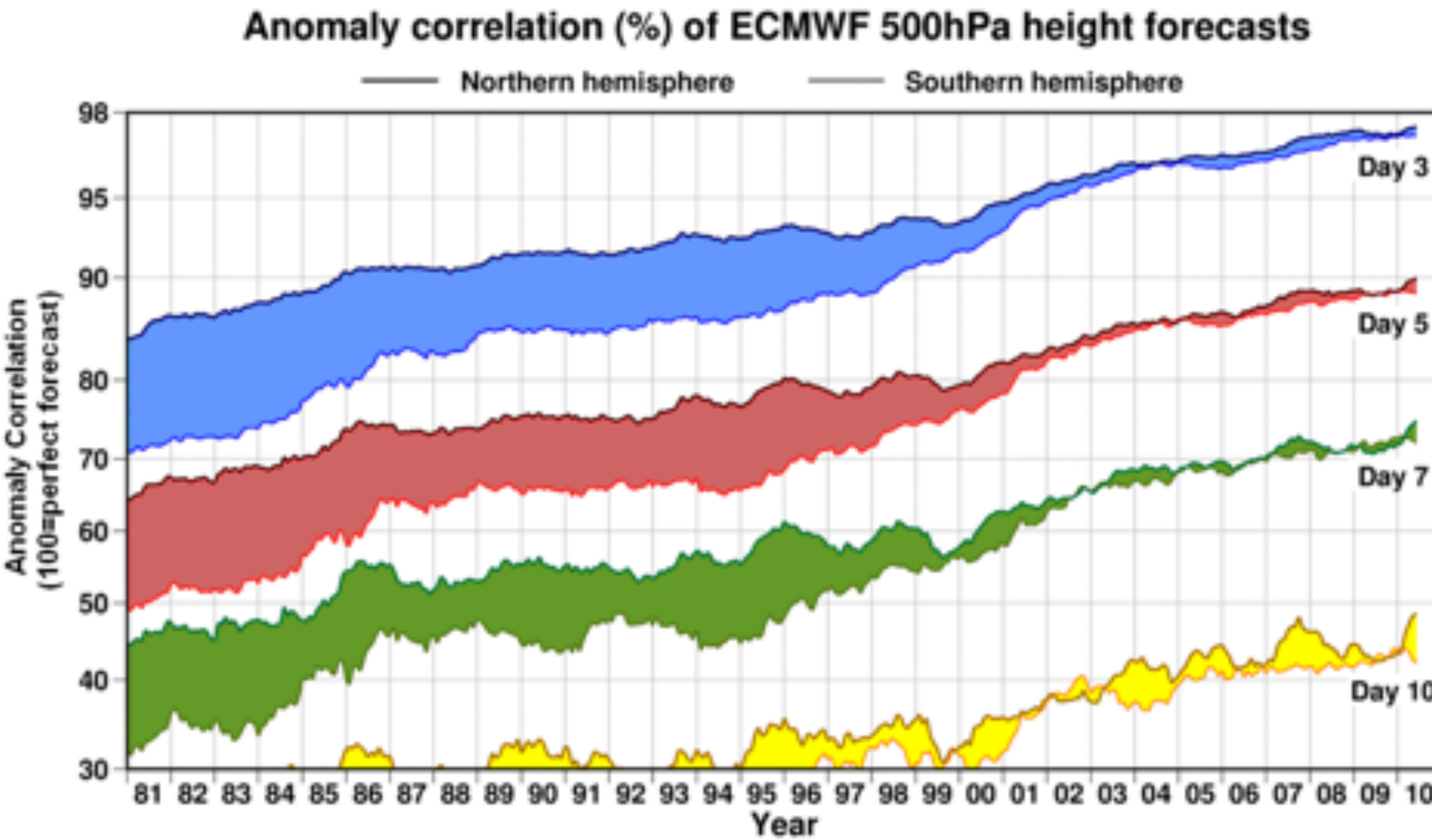


FIGURE 2.1. Evolution of ECMWF forecast skill for varying lead times (3 days in blue; 5 days in red; 7 days in green; 10 days in yellow) as measured by 500-hPa height anomaly correlation. Top line corresponds to the Northern Hemisphere; bottom line corresponds to the Southern hemisphere. Large improvements have been made, including a reduction in the gap in accuracy between the hemispheres. SOURCE: courtesy of ECMWF, adapted from Simmons and Hollingsworth (2002).

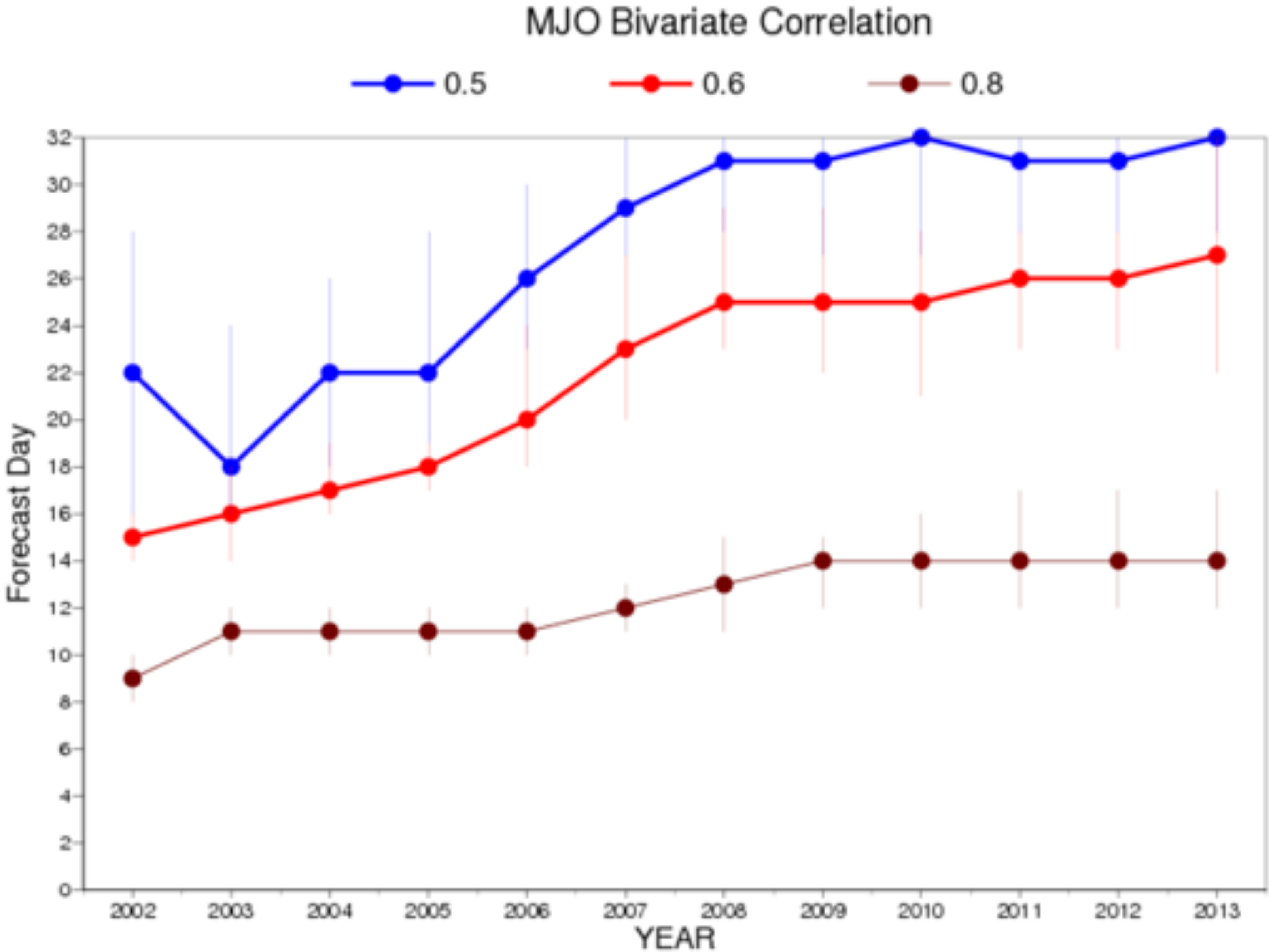


FIGURE 2.3 Evolution of the MJO skill scores since 2002, calculated as bivariate correlations applied to the Real-time Multivariate MJO (RMM) index of Wheeler and Hendon (2004). NOTES: The MJO skill scores are computed on the ensemble mean of the ECMWF retrospective forecasts produced during a complete year. The blue, red, and brown lines indicate respectively the day when the MJO bivariate correlation skill drops to 0.5, 0.6, and 0.8. SOURCE: Modified from Vitart (2014).

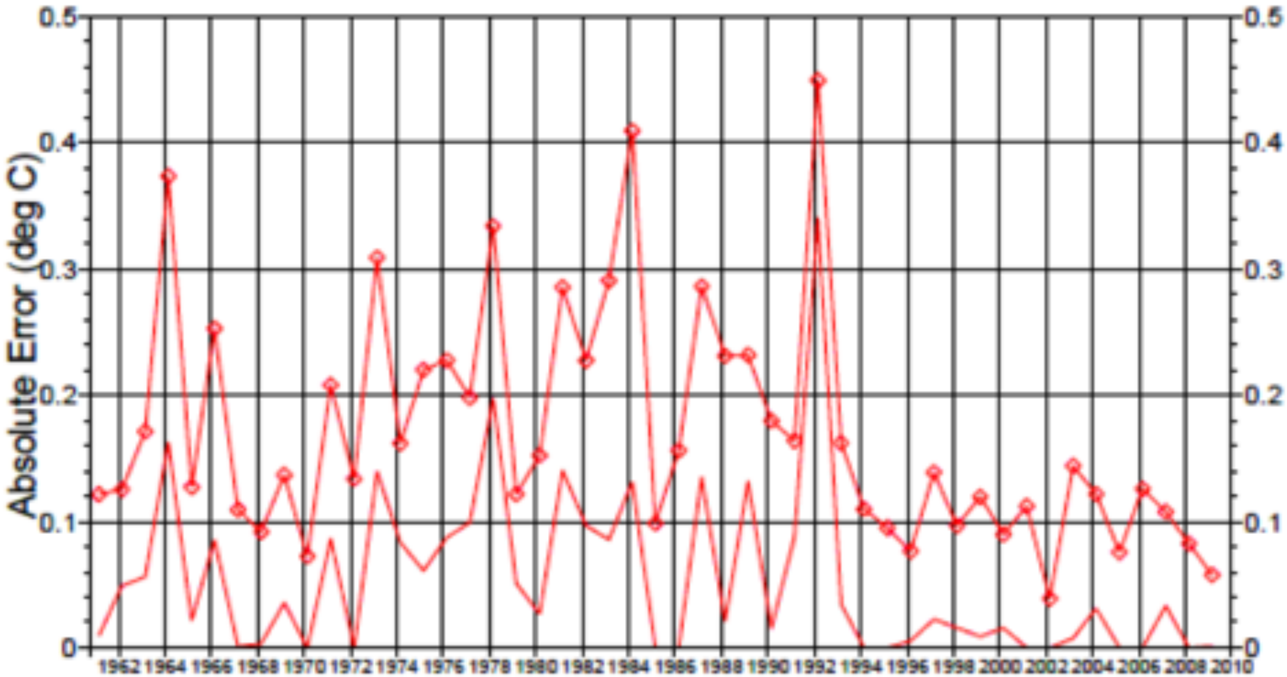


FIGURE 1.1 Time series of Mean Absolute Error (MAE) (thicker line with symbols) for the first three months of NINO3.4 predictions starting 1st February each year. Also shown (thin line, no symbols) is what is referred to as the Best Absolute Error (BAE), which is defined at each lead time as either zero (if the observations lie within the predicted range) or the distance between the observed value and the closest ensemble member, and then averaged over lead times. For a perfect forecasting system with a modest ensemble size, the BAE would be mostly zero, with occasional small positive values. The step change in skill after 1993 is evident. SOURCE: Stockdale et al. (2010), Fig 7a.

A National Strategy for Advancing Climate Modeling, 2012

The two principles underlying the committee's vision for U.S. climate modeling a decade hence are that

- U.S. climate modeling groups need to work together more closely, while fully engaging the user, academic, and international communities; and
- taking full advantage of exascale computing will be critical to progress on both longstanding and new climate science frontiers.

A National Strategy for Advancing Climate Modeling, 2012

‘The way forward includes improvement of the mechanistic understanding of the processes and drivers (both internal and external) that contribute to decadal climate variability, assessment of this understanding, followed by development of prediction and attribution capabilities.’

“Both the prediction of decadal climate variability and attribution of specific climatic events and trends can be used to better inform decision makers.”

‘To facilitate the grand challenges of climate modeling in support of U.S. national interests, increased model resolution and complexity will be required, which in turn will result in the need to exploit enhanced computing power, including:
(1) a common software infrastructure shared across all U.S. climate modeling groups
(2) a strategic investment in advanced climate-dedicated supercomputing resources and in designing climate models to exploit new computational capabilities; and
(3) a global data-sharing infrastructure that is operationalized.

Frontiers in Decadal Climate Variability: Proceedings of a Workshop (2016)

Patterns of Internal Variability

The El Niño–Southern Oscillation (ENSO) … ENSO “events” (phases) persist for 6 to 18 months. ENSO variability is mostly interannual (in the 3- to 7-year range), although analyses also suggest decadal scale shifts in its variability.

Pacific Decadal Variability (PDV) is dominated by the Pacific Decadal Oscillation (PDO) and Interdecadal Pacific Oscillation (IPO).

 The PDO describes an ENSO-like decadal pattern of variability in sea surface temperature (SST) of the North Pacific Ocean (poleward of 20° N). The PDO phases persist for 20 to 30 years.

 The IPO is a variability pattern of SST fluctuations and sea level pressure changes in the entire Pacific basin; the IPO can be thought of as the Pacific-wide expression of the PDO.

The North Atlantic Oscillation (NAO) is the Atlantic expression of the Arctic Oscillation (AO), which is the dominant mode of atmospheric variability in the extratropical Northern Hemisphere. The NAO has a large impact on storm tracks. The NAO varies on all timescales from days to years.

The Atlantic Multidecadal Oscillation (AMO) pattern describes variability in SSTs averaged over the entire North Atlantic Ocean. The AMO index reveals warmer and cooler periods spanning several decades (20-40 years).

Conclusions from 45 years of NAS Reports

- There are clear climate variations/signals on 2 to 70 year time scales.
- We don't understand them all or all the interactions, but we need to move forward in order to achieve incremental progress.
- We need to involve researchers, developers, operations, and users in the process in order to achieve success.

FIGURE 3.1 S2S forecasts (shown in blue and green) fill a gap between short-term weather and ocean forecasts (shown in red) and longer-term Earth system projections (shown in black). NOTES: They inform critical decisions (also shown in blue and green) across many different sectors by providing information about likely conditions in between these more established prediction times. SOURCE: Modified from the Earth System Prediction Capability Office.

BACK UP SLIDES
&
REJECTS

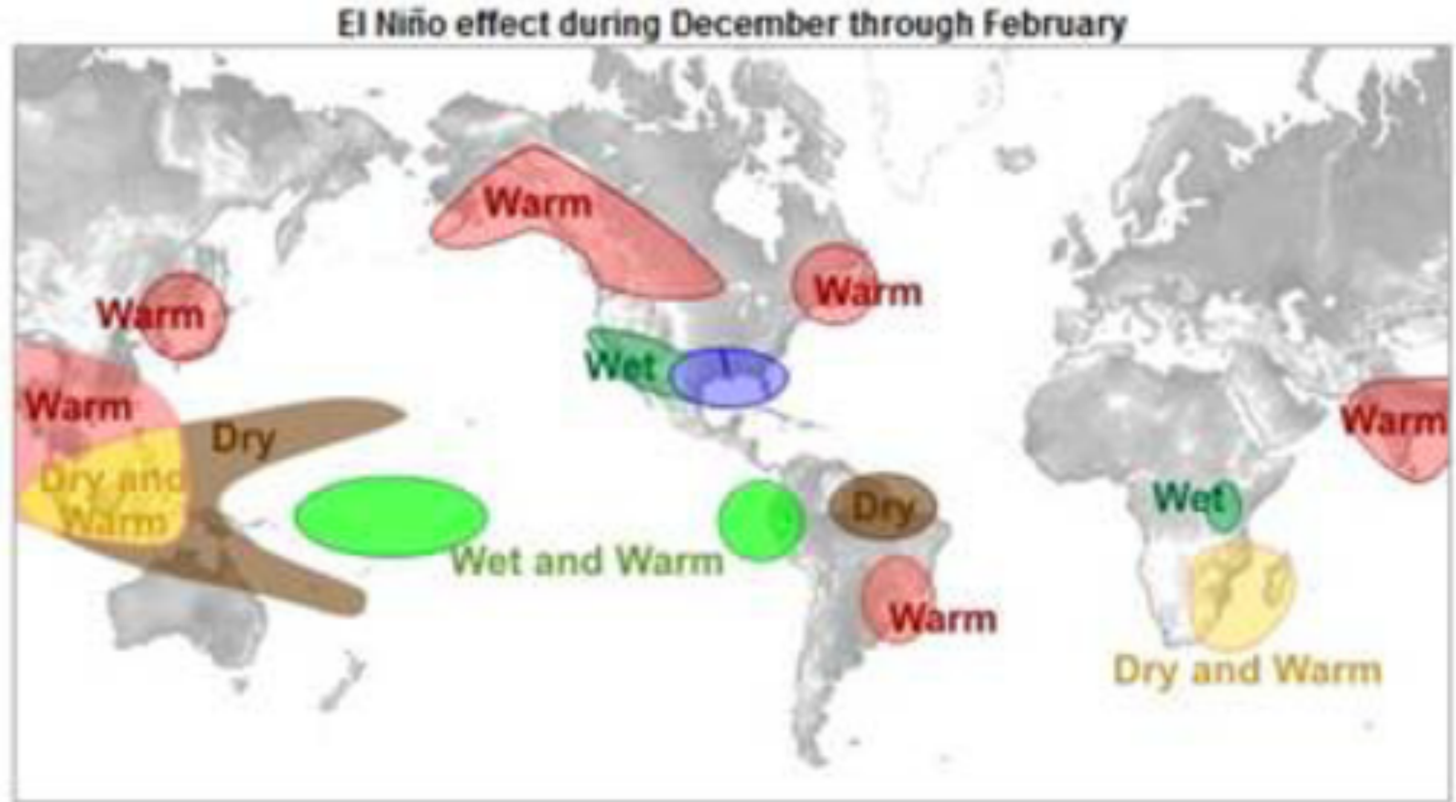
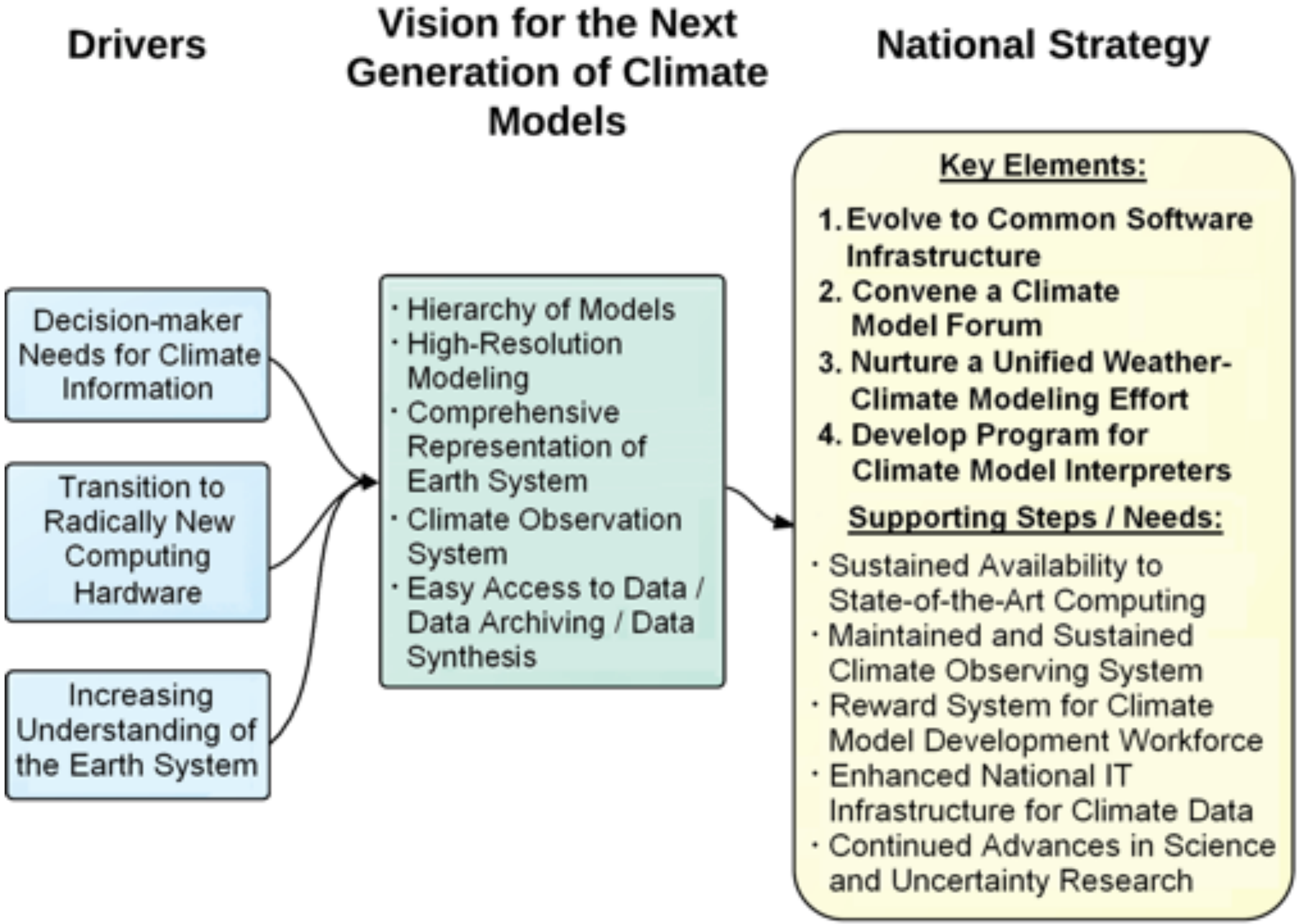


FIGURE 1.3 Patterns of anomalous temperature and precipitation during an El Niño episode for the Northern Hemisphere winter. SOURCE: Adapted from CPC/NCEP/NOAA.



Drivers
Vision for the Next Generation of Climate Models
National Strategy
Decision-maker Needs for Climate Information
Transition to Radically New Computing Hardware
Increasing Understanding of the Earth System
· Hierarchy of Models
· High-Resolution Modeling
· Comprehensive Representation of Earth System
· Climate Observation System
· Easy Access to Data / Data Archiving / Data Synthesis
Key Elements:
1. Evolve to Common Software Infrastructure
2. Convene a Climate Model Forum
3. Nurture a Unified Weather-Climate Modeling Effort
4. Develop Program for Climate Model Interpreters
Supporting Steps / Needs:
· Sustained Availability to State-of-the-Art Computing
· Maintained and Sustained Climate Observing System
· Reward System for Climate Model Development Workforce
· Enhanced National IT Infrastructure for Climate Data
· Continued Advances in Science and Uncertainty Research

Frontiers in Decadal Climate Variability: Proceedings of a Workshop (2016)

Fox-Kemper concluded that these uncertainties in the air-sea exchange rates, and consequently the global heat budget, should be reduced if we are to make robust predictions of decadal variability into the future.

Predicting GMST over the next two decades will require determination of the fate of heat that has been stored in the Pacific and Indian Oceans as a result of planetary warming.

Key Uncertainties:

- Ocean heat budget
- Air-sea energy fluxes
- Top of Atmosphere fluxes

Fox-Kemper also noted that moving toward really useful decadal climate prediction would require a change of culture and orientation in the research community from exploration to operational forecasting (including the designation of forecast skill scores, validation, etc.).

Frontiers in Decadal Climate Variability: Proceedings of a Workshop (2016)

What if decision makers knew they had 30 years versus 10 years to prepare for the large shifts in drought frequency and intensity expected in western North America as a consequence of global warming?

Many participants pointed out that the ability to predict climate on decadal timescales, if possible, would help to direct investments in climate adaptation and more generally to guide longer-range planning.

Although much progress has been made, predictive power is still generally lacking. For example, the Interdecadal Pacific Oscillation (IPO) phase could explain much of the slowdown in GMST (global mean surface temperature) rise, but it is not yet understood what triggers changes in IPO phases.

Without a deeper understanding of the mechanisms that cause patterns such as the Pacific Decadal Oscillation (PDO), IPO, and Atlantic Multidecadal Oscillation (AMO), it will be difficult to predict how and when slowdown-like features will occur, and how these features will manifest regionally.

A National Strategy for Advancing Climate Modeling, 2012

There is a growing demand for climate products for decision making by user communities other than national decision makers…they need to be able to find and work with someone that has the knowledge of the present state of the science and an ability to access climate data, interpret it in the context of a specific user's need, and to help that user to understand the…attendant uncertainties.

Finding 12.2: While there is a great deal of climate model output available, there is a growing need for more user-accessible information and tailoring of information to specific user needs.

National Climate Modeling Forums would provide regular interactions between scientists from the various U.S. regional and global modeling activities, including operational modeling. The Forum should also include end users of climate model output.

Report of a Workshop on Predictability and Limits-To-Prediction in Hydrologic Systems (2002)

Water and energy are freely exchanged among the continents, the atmosphere, and the oceans, and these exchanges are, in many ways, the defining characteristics of climate. Groundwater is by far the largest unfrozen stock of fresh water. In some cases, the physical processes of interaction between groundwater systems and climate are well understood qualitatively, but quantitative and practical consequences are unknown. In other cases, interactions may be speculative or yet undiscovered. Climate and the hydrogeologic environment are the joint controls of groundwater recharge, discharge and storage. Amounts and pathways of aquifer recharge differ greatly from humid to arid climatic regions, with consequent influences on groundwater storage and discharge. Temporal changes in climate are reflected in groundwater fluxes, albeit with dampening of high-frequency variations Not so obvious is that groundwater fluxes may have significant reciprocal impacts on climate and climate-related aspects of the Earth system. Groundwater fluxes are a component of the surface water balance, which is tightly coupled to atmospheric processes and, thus, to climate. Because groundwater is one of the major reservoirs in the hydrosphere, changes in its volume would also be reflected ultimately by changes in sea level. Groundwater may also play an important, indirect role in determining climate by affecting atmospheric composition. Atmospheric concentrations of radiatively active gases such as carbon dioxide and methane are determined partially by exchanges with the continents. Such exchanges may be affected by water fluxes between the atmosphere and land and by biogeochemical processes near the land surface. The latter can be strongly influenced by soil moisture, which may be influenced by groundwater (e.g., high water tables), with consequences for soil aeration, microbiological activity, and greenhouse gas emissions. This is particularly true for northern peatlands. The location of the water table determines whether the peat is subjected to aerobic or anaerobic decomposition rates, which are substantially different, and the subsequent release of methane and carbon dioxide." This chapter focuses on three topics

BOX 5.1 2025 Vision of Weather and Climate Forecasts

An NRC report A Vision for the National Weather Service: Road Map for the Future a looked ahead to the year 2025 to much improved weather and climate forecasts and how information derived from these forecasts would be increasingly valuable to society. The report envisions weather forecasts approaching the limits of atmospheric predictability (about two weeks) and new forecasts of chemical and space weather, hydrologic parameters and other environmental parameters. It describes the use of ensemble forecasts that project nearly all possible future states of weather and climate and how these ensembles can be used in a probabilistic way by a variety of users. It asserts that as the accuracy improves and measures of uncertainty are better defined, the economic value of weather and climate information will increase rapidly as more and more ways are found or created to use information profitably. New markets, such as the weather derivatives market, will be created. Some markets will be strengthened (e.g., forecasting for transportation, energy, and agriculture). Other markets may diminish, such as the role of human forecasters in adding value to numerical forecasts beyond one day or in preparing graphical depictions of traditional weather forecasts.
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National Research Council, A Vision for the National Weather Service: Road Map for the Future

Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts (2016)

- Although it is increasingly recognized that many sources of predictability exist in the Earth system on S2S timescales, representing these sources of predictability in Earth system models is challenging.

Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts (2016)

- Challenges:
  - Cost vs value vs skill
  - Long range, high expense
  - Low skill, political risk
  - Insurance companies and legal challenges
  - Low confidence