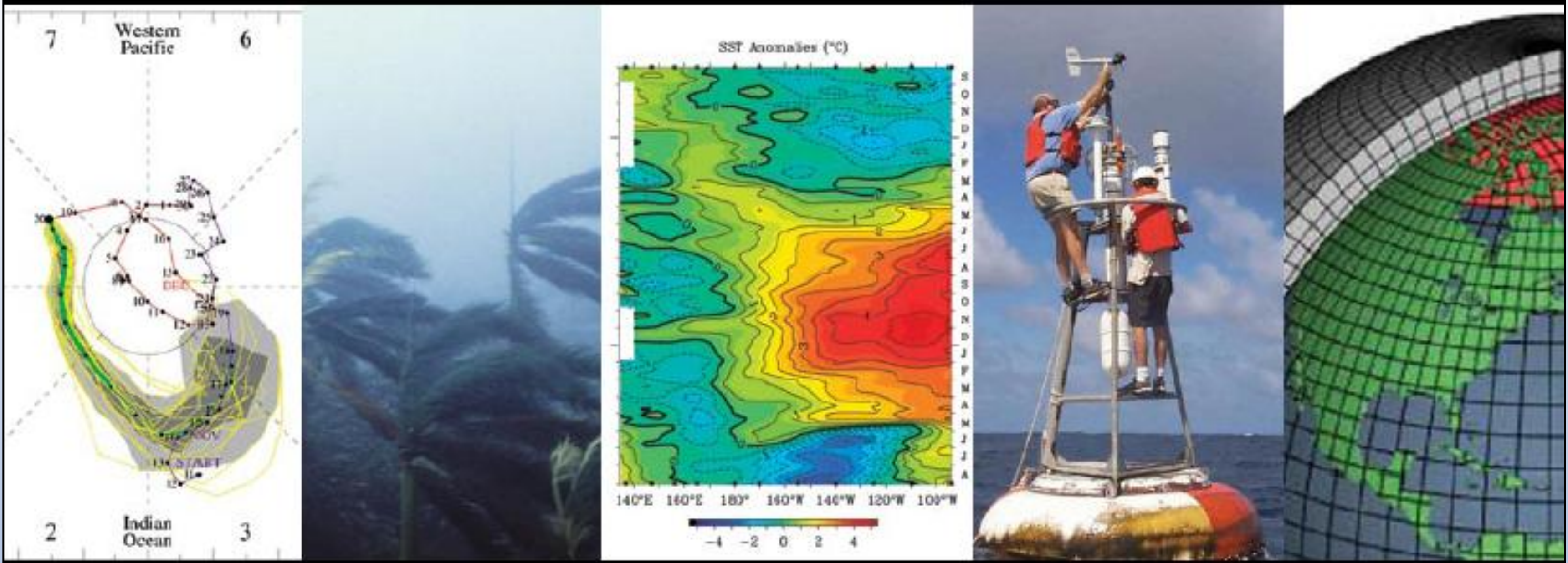
Assessment of Intraseasonal to Interannual Climate Prediction and Predictability



Bob Weller, Woods Hole Oceanographic Institution
Ben Kirtman, University of Miami

September 2, 2010
National Oceanic and Atmospheric Administration

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Outline

1) Committee Membership and Charge
2) Motivation and Committee Approach
   - Why Intraseasonal to Interannual (ISI) Timescales?
   - What is "Predictability?"
3) Framework for Report
   - Sources of Predictability
     Research Goals
   - Building Blocks of ISI Forecast Systems
     Improvements to Building Blocks
   - Procedures for Operational Centers
     Best Practices

Committee Membership

ROBERT A. WELLER (Chair), Woods Hole Oceanographic Institution

ALBERTO ARRIBAS, Met Office, Hadley Centre

JEFFREY L. ANDERSON, National Center for Atmospheric Research

ROBERT E. DICKINSON, University of Texas

LISA GODDARD, Columbia University

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RANDAL D. KOSTER, NASA

MICHAEL B. RICHMAN, University of Oklahoma

R. SARAVANAN, Texas A&M University

DUANE WALISER, Jet Propulsion Laboratory, California Institute of Technology

BIN WANG, University of Hawaii

Charge to the Committee

The study committee will:

1. Review current understanding of climate predictability on intraseasonal to interannual time scales;

2. Describe how improvements in modeling, observational capabilities, and other technological improvements have led to changes in our understanding of predictability;

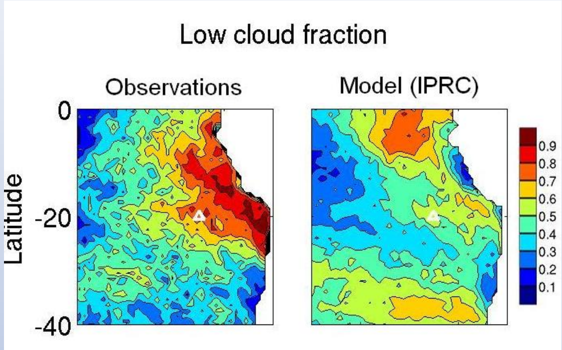
3. Identify key deficiencies and gaps remaining in our understanding of climate predictability and recommend research priorities to address these gaps;

4. Assess the performance of current prediction systems;

5. Recommend strategies and best practices that could be used to assess improvements in prediction skill over time.

Why Intraseasonal to Interannual (ISI) Timescales?

- "ISI" - timescales ranging from a couple of weeks to a few years.



- Errors in ISI predictions are often related to errors in longer term climate projections

- Useful for a variety of resource management decisions

- Many realizations/verifications possible.

What is “Predictability?”

- “The extent to which a process contributes to prediction quality.”
- Literature provides variety of interpretations; committee agreed on qualitative approach.

<u>Key aspects of committee approach</u>

- Quantitative estimates of a *upper limit* of predictability for the real climate system are not possible.
- Verification of forecasts provide a *lower bound* for predictability.
- Traditional predictability studies (e.g., twin model studies) are qualitatively useful.

Framework for Analyzing ISI Forecasting

Performance of ISI forecasting systems is based upon:

1) Knowledge of Sources of Predictability
How well do we understand a climate process/phenomenon?

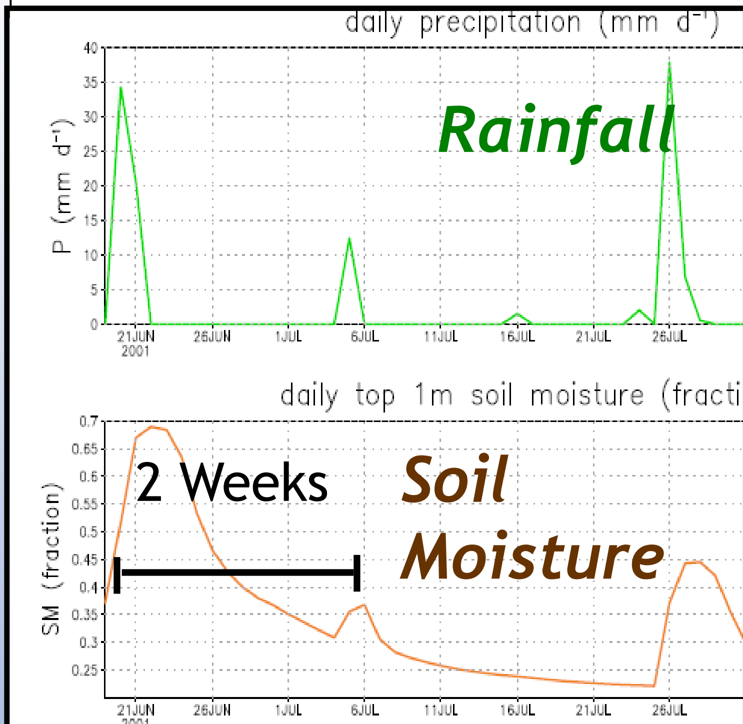
2) Building Blocks of Forecasting Systems
To what extent do observations, data assimilation systems, and models represent important climate processes?

3) Procedures of Operational Forecasting Centers
How do these centers make, document, and disseminate forecasts?

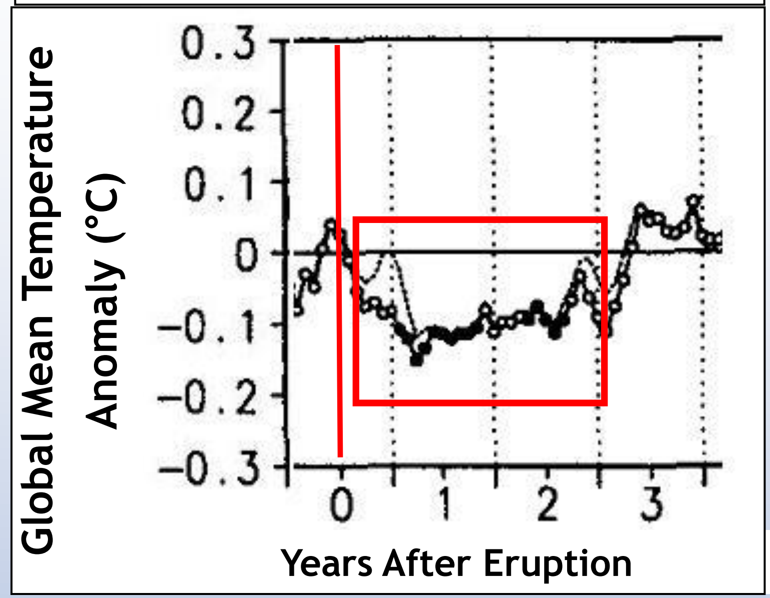
"Operational Forecasting centers" – e.g.,
Climate Prediction Center (CPC)
European Centre for Medium-Range Weather (ECMWF)

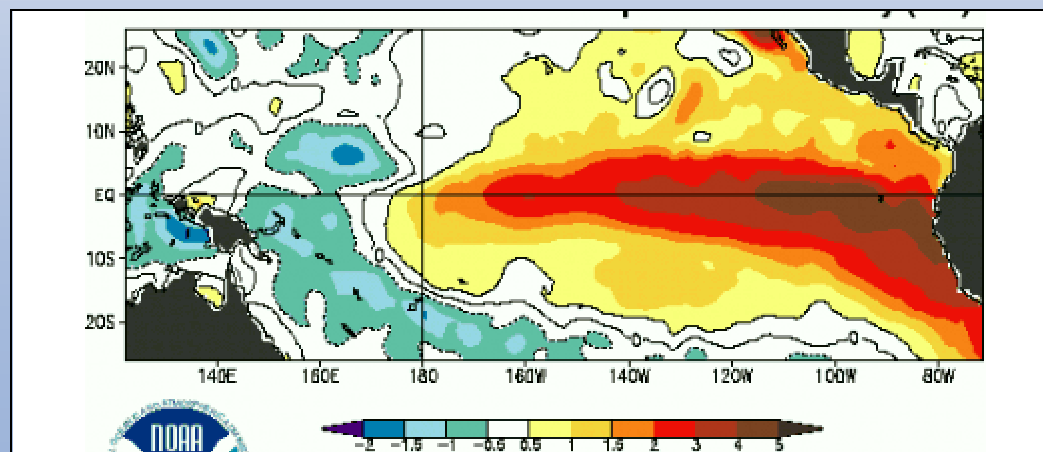
Example Sources of Predictability

Soil Moisture



Volcanic Eruptions





El Niño - Southern Oscillation (ENSO)

Recommendations Regarding Sources of Predictability

Many sources of predictability remain to be fully exploited by ISI forecast systems.

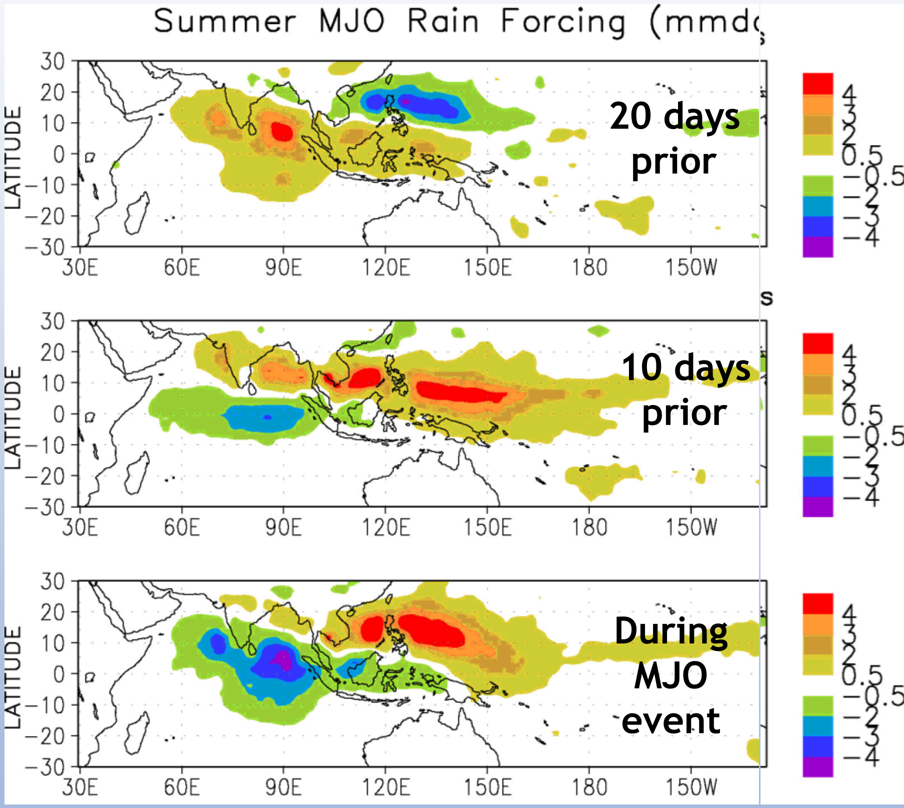
Criteria for identifying high-priority sources:

1) Physical principles indicate that the source has an impact on ISI variability and predictability.
2) Empirical or modeling evidence supports (1).
3) Identifiable gaps in knowledge/representation in forecasting systems.
4) Potential social value.

Six Research Goals for Sources of Predictability

1) Madden-Julian Oscillation (MJO)

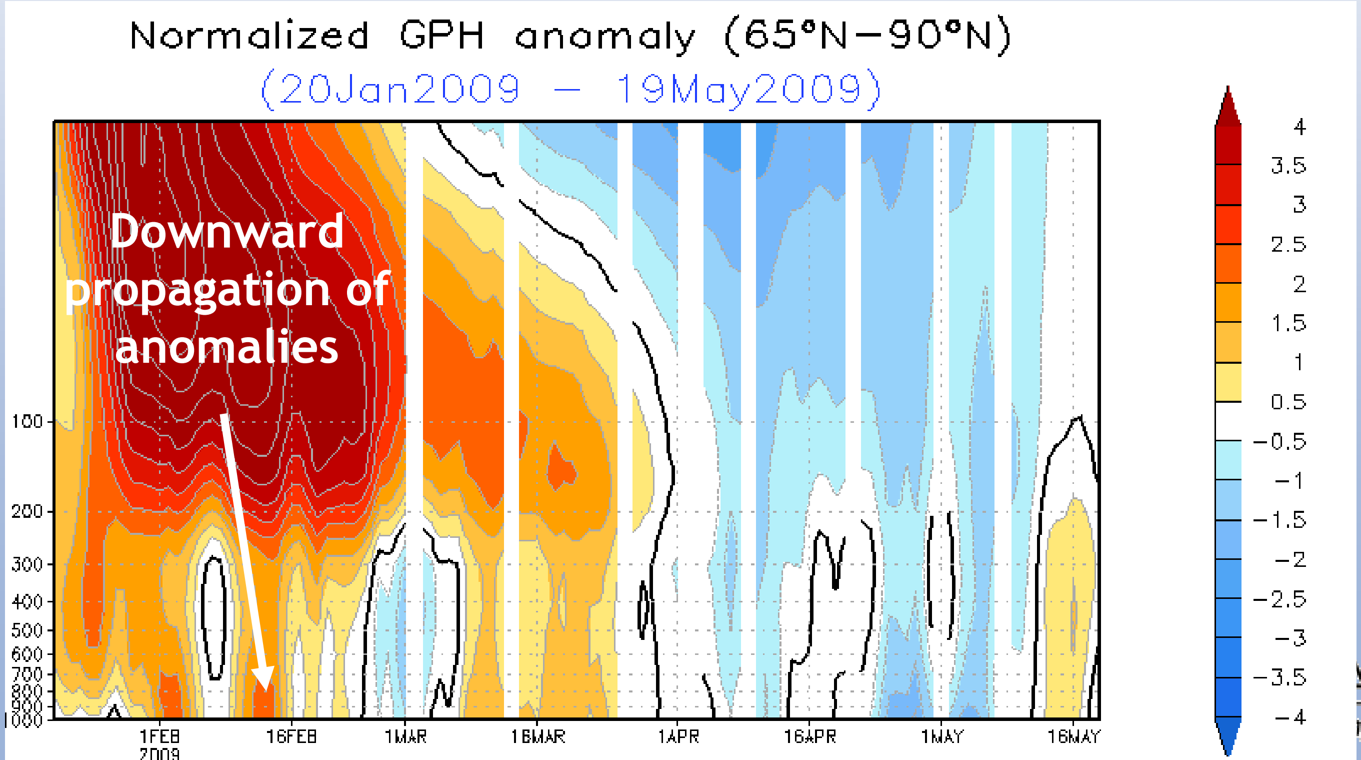
Develop model diagnostics. Expand process knowledge (e.g. MJO Task Force) regarding ocean-atmosphere coupling, convection, cloud processes.



Six Research Goals for Sources of Predictability

2) Stratosphere-troposphere interactions

Improve understanding of link between stratospheric processes and ISI variability. Successfully simulate/predict sudden warming events and subsequent impacts.



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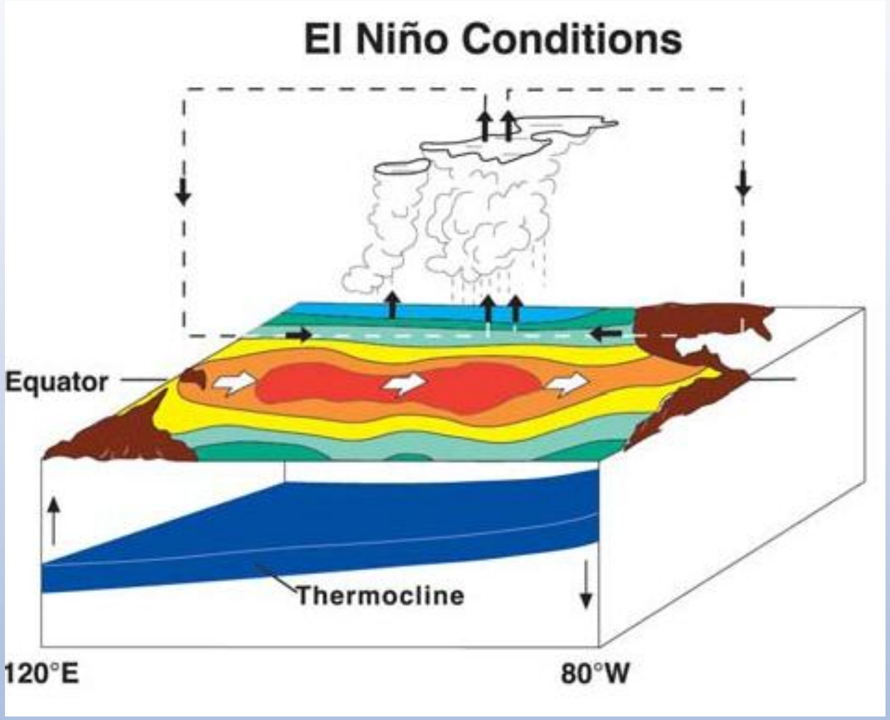
Six Research Goals for Sources of Predictability

3) Ocean-atmosphere coupling

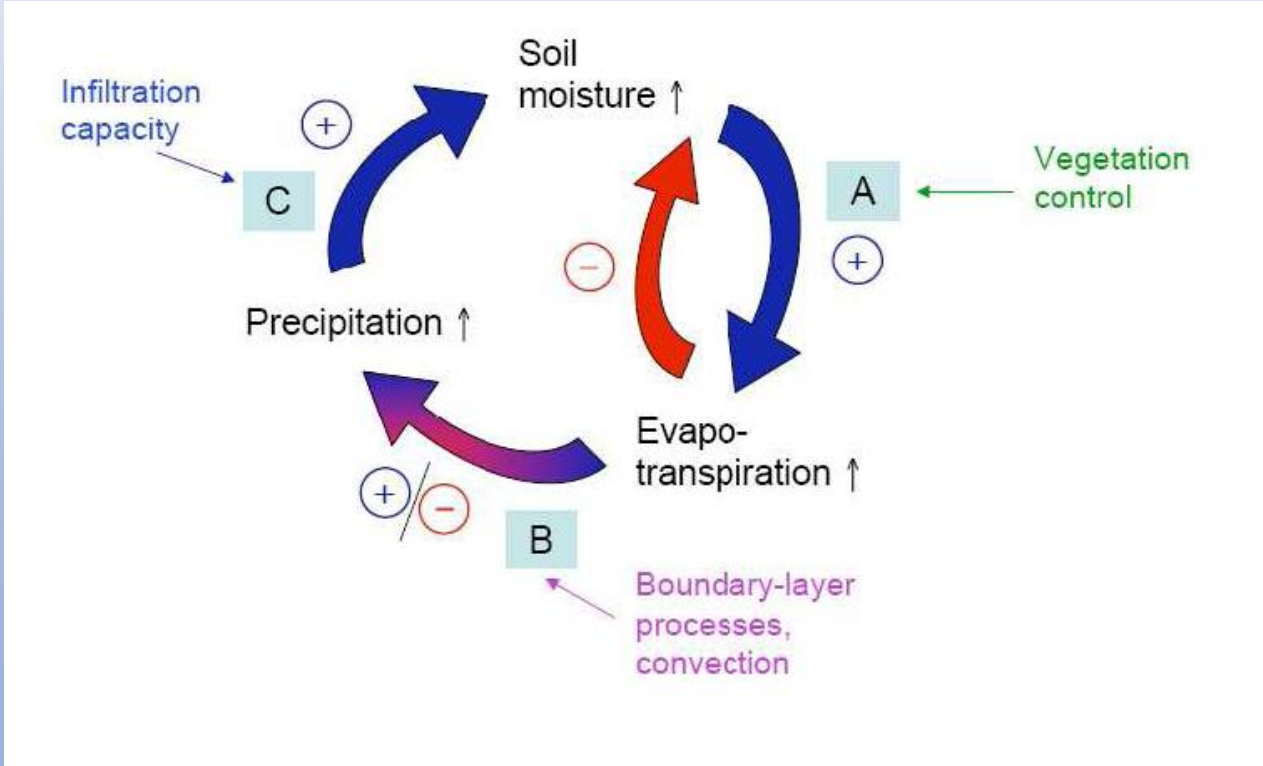
Understanding of sub-grid scale processes should be improved.



Six Research Goals for Sources of Predictability

4) Land-atmosphere feedbacks

Investigate coupling strength between land and atmosphere. Continue to improve initialization of important surface properties (e.g., soil moisture).



Six Research Goals for Sources of Predictability

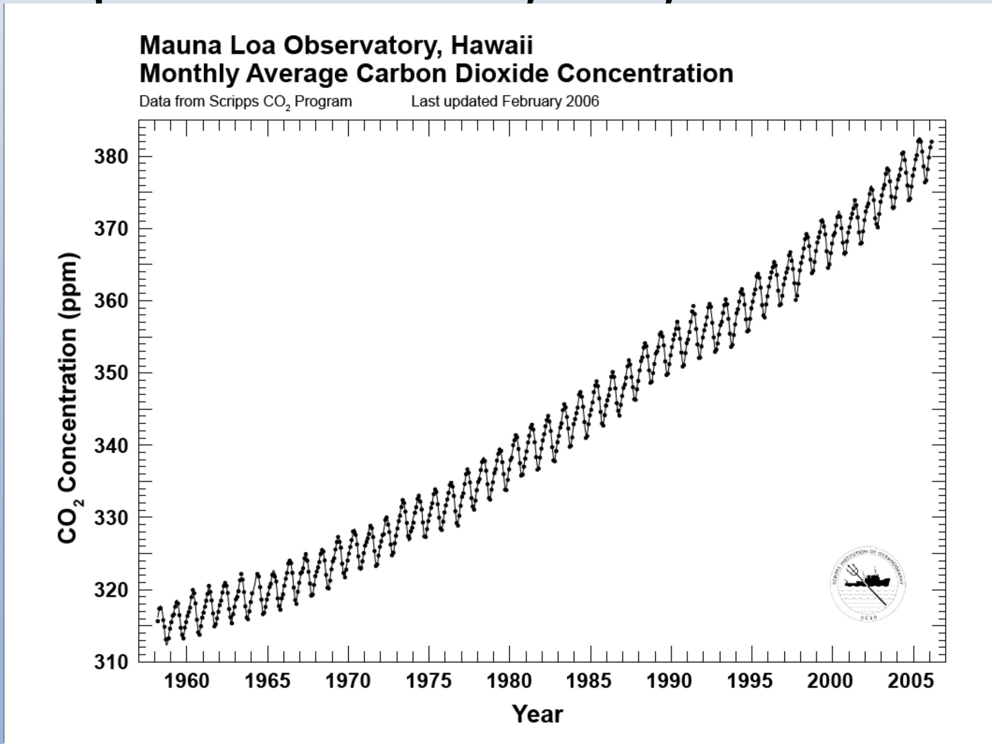
5) High impact events (volcanic eruptions, nuclear exchange)

Develop forecasts following rapid, large changes in aerosols/trace gases.

Six Research Goals for Sources of Predictability

6) Non-stationarity

Long-term trends affecting components of climate system (e.g., greenhouse gases, land use change) can affect predictability and verification techniques. Changes in variability may also be important.



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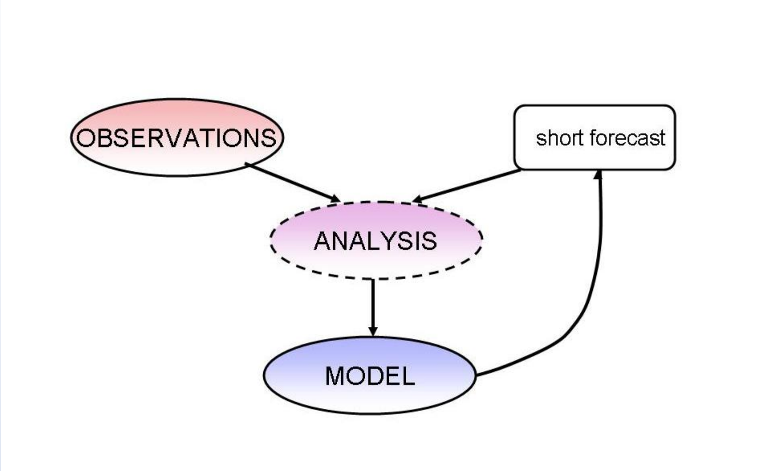
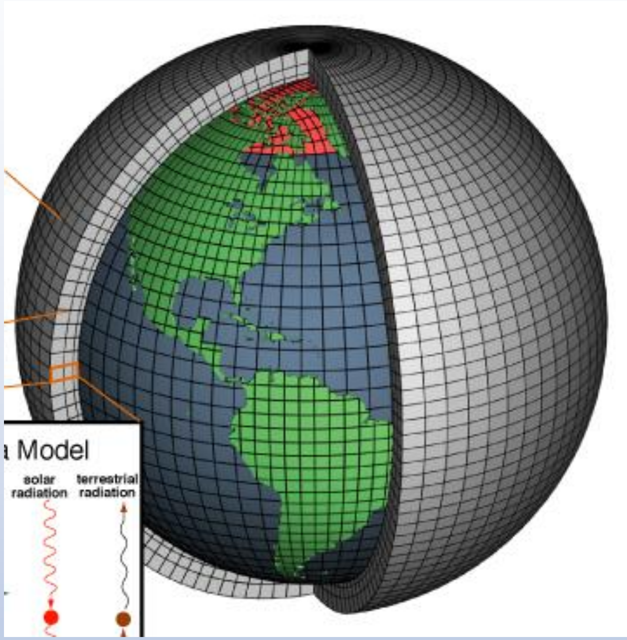
What are Building Blocks?

Data Assimilation Systems



Statistical/ Dynamical Models

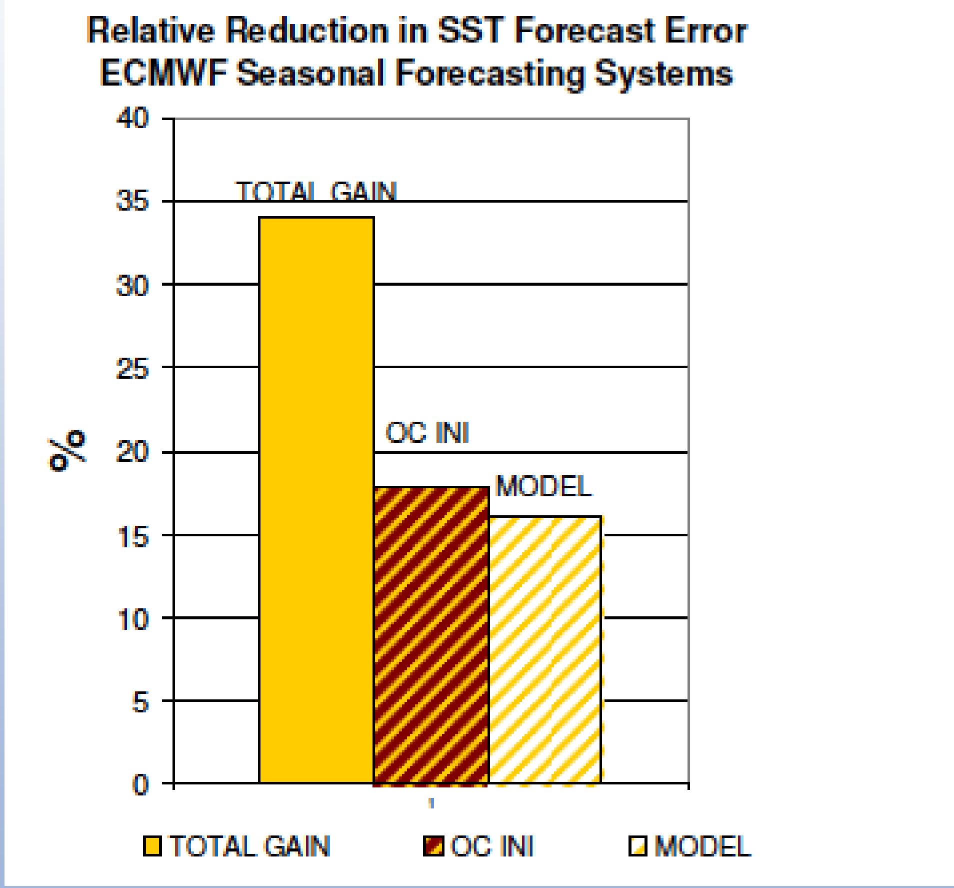


Observational Networks

Forecast Improvements involve each of the Building Blocks

Past improvements to ISI forecasting systems have occurred synergistically.

(e.g., with new observations comes the need for model improvement and expansion of DA system)

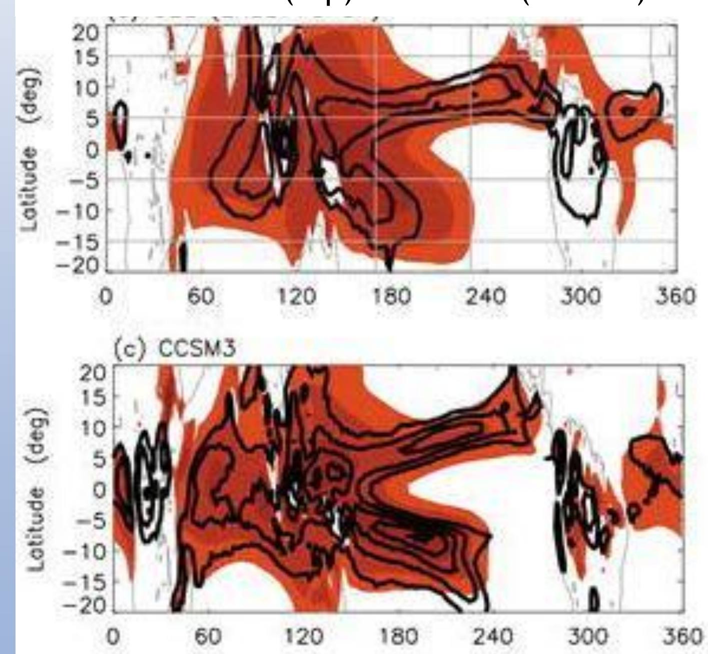


Improvements to Building Blocks

1) Errors in dynamical models should be identified and corrected. Sustained observations and process studies are needed.

- Examples:
  * *double intertropical convergence zone*
  * *poor representation of cloud processes*
- Climate Process Teams serve as a useful model for bringing together modelers and observationlists
- Other programmatic mechanisms should be explored
  (e.g. facilitating testing of increased model resolution)

Observations (top) and Model (bottom)



SST (shading); precipitation (contours)

Improvements to Building Blocks

2) Continue to develop and employ statistical techniques, especially nonlinear methods.

Statistical methods are useful in making predictions, assessing forecast performance, and identifying errors in dynamical models. Cutting-edge nonlinear methods provide the opportunity to augment these statistical tools.

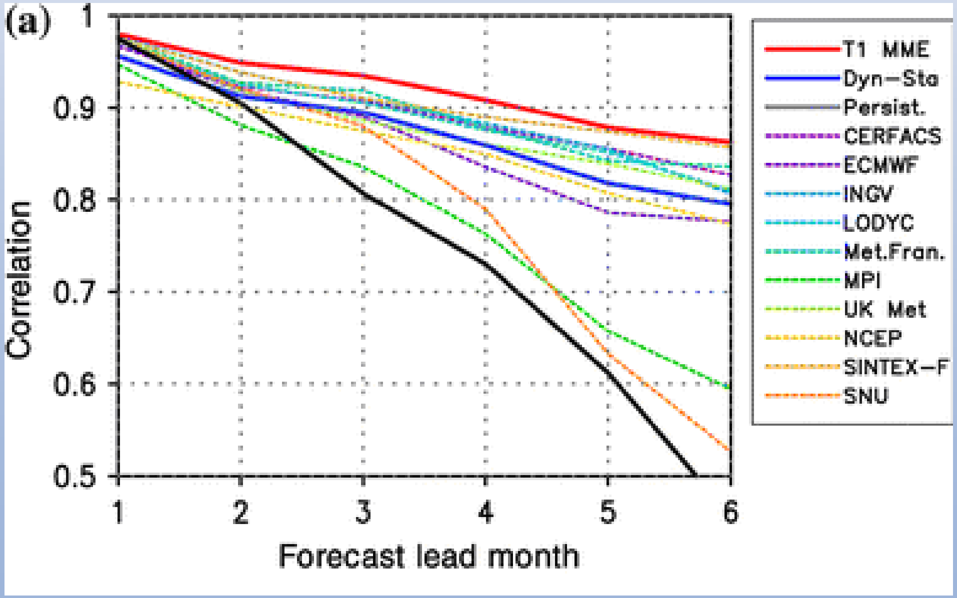
3) Statistical methods and dynamical models are complementary and should be pursued.

Using multiple prediction tools leads to improved forecasts. Examples of complementary tools:

- *Model Output Statistics*
- *Stochastic Physics*
- *Downscaling techniques*

Improvements to Building Blocks

4) Multi-model ensemble forecast strategies should be pursued, but standards and metrics should be developed.

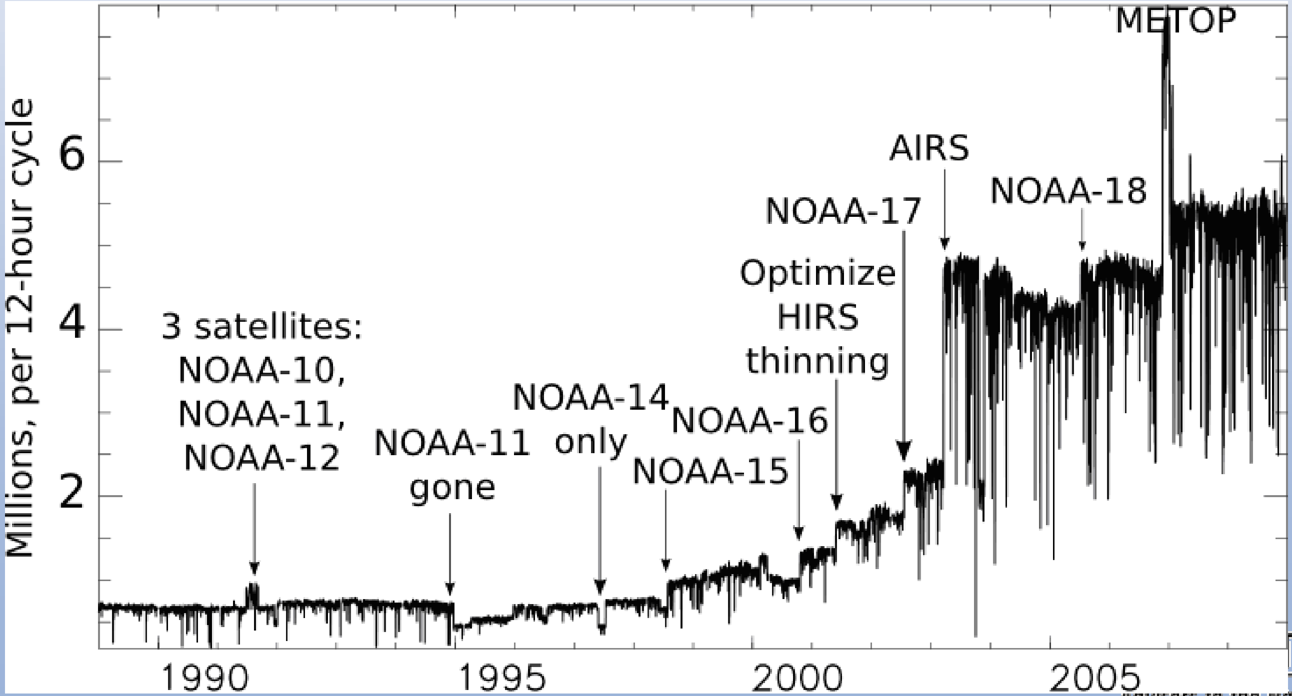


MME mean (in red) outperforms individual models (other colors).

Black is persistence (baseline forecast).

Improvements to Building Blocks

5) For operational forecast systems, state-of-the-art data assimilation systems should be used (e.g. 4-D Var, Ensemble Kalman Filters, or hybrids). Operational data assimilation systems should be expanded to include more data, beginning with ocean observations.



Number of satellite observations assimilated into ECMWF forecasts.

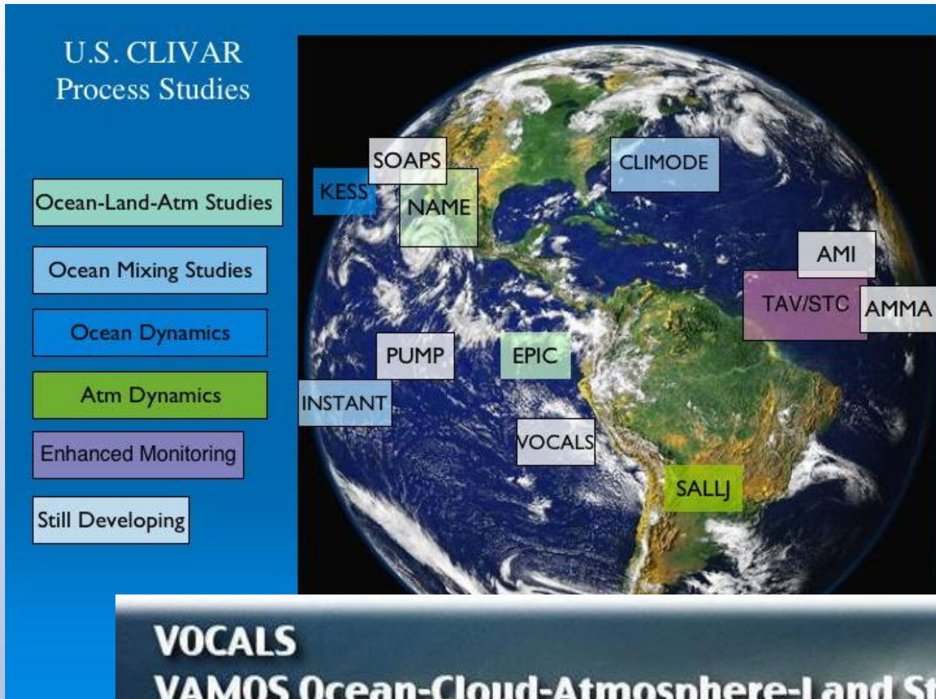
Relationship between Research and Operations

Collaboration has expanded knowledge of ISI processes and improved performance of ISI forecasts.

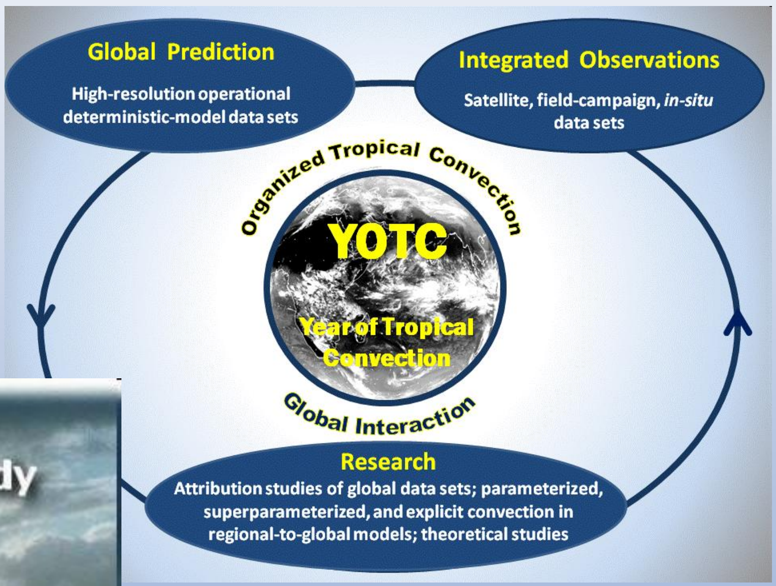
Collaboration is necessary BOTH:

- *between research and operational scientists*
- *among research scientists; linking observations, model development, data assimilation, and operational forecasting.*

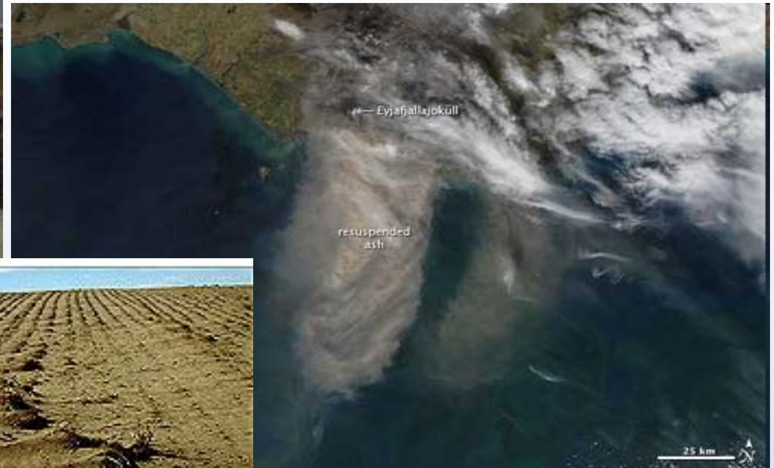
Examples of Collaborative Programs



ECMWF



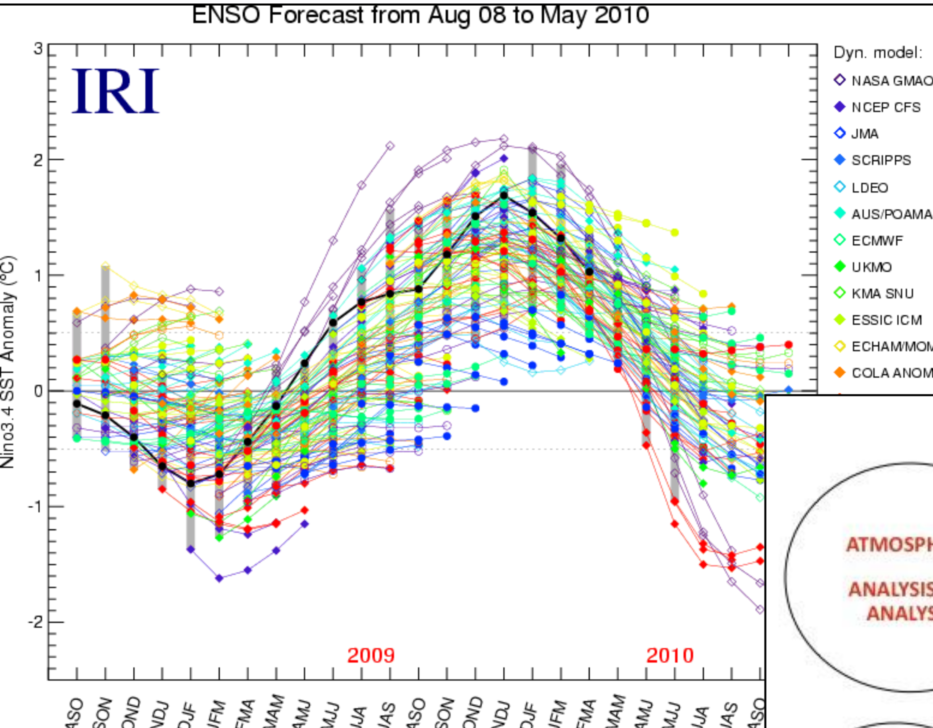
Making Forecasts More Useful

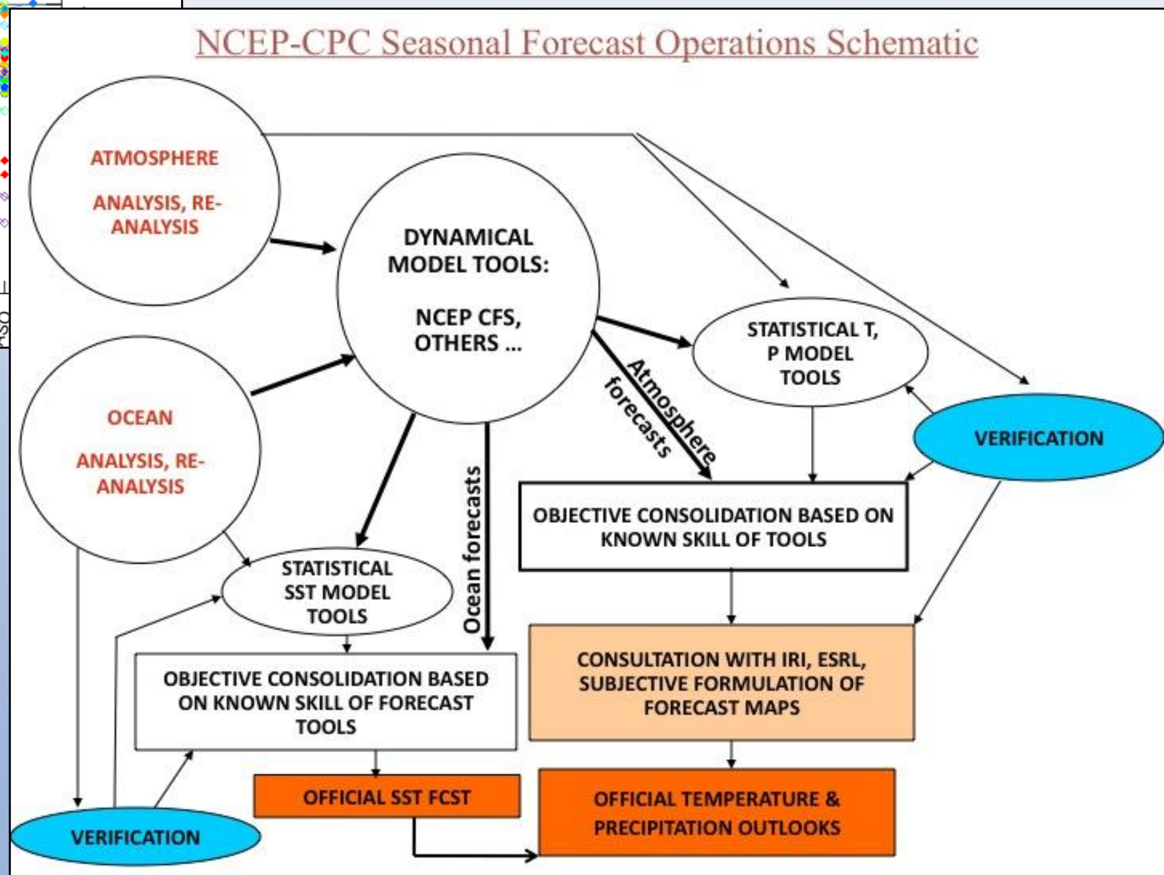


Value of ISI forecasts for both researchers and decision makers can be tied to:

- *Access*
- *Transparency*
- *Knowledge of forecast performance*
- *Availability of tailored products*

…but the process of and products associated with ISI forecasting can be complex.





Best Practices

1) Improve the synergy between research and operational communities.

- Workshops targeting specific forecast system improvements, held at least annually
- Short-term appointments to visiting researchers
- More rapid sharing of data, data assimilation systems, and models
- Dialog regarding new observational systems

Best Practices

2) Establish publically-available archives of information associated with forecasts

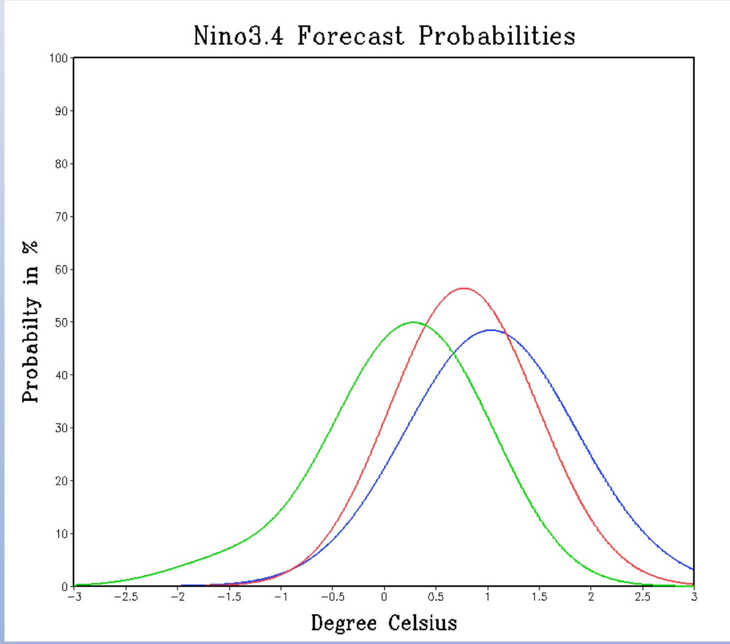
- Includes observations, model code, hindcasts, forecasts, and verifications.
- Will allow for quantification and tracking of forecast improvement.
- Bridge the gap between operational centers and forecast users involved in making climate-related management decisions or conducting societally-relevant research.

3) Minimize the subjective components of operational ISI forecasts.

Best Practices

4) Broaden and make available forecast metrics.

- Multiple metrics should be used;
  No perfect metric exists.
- Assessment of probabilistic information is important.
- Metrics that include information on the distribution of skill in space and time are also useful.



Examples of
probability density functions
representing forecasts for ENSO

Case Studies

El Niño-Southern Oscillation (ENSO) **Madden-Julian Oscillation (MJO)** **Soil Moisture**

Case studies illustrate how **improvements of building blocks** of ISI forecasting system led to an **improved representation of a source of predictability**.

Also illustrate **collaboration** among researchers and operational forecasting centers.

Summary of Recommendations

Research Goals

Improve knowledge of sources of predictability

- MJO
- Ocean-atmosphere
- Land-atmosphere
- Stratosphere
- Non-stationarity
- High impact events

Long-term:
years to decades; mainly the research community

Improvements to Building Blocks

- Identify and correct model errors
- Implement nonlinear statistical methods
- Use statistical and dynamical prediction tools together
- Continue to pursue multi-model ensembles
- Upgrade data assimilation schemes

Medium-term:
coming years; shared responsibility of researchers and operational centers

Summary of Recommendations

Best Practices

- Improved synergy between research and operations
- Archives
- Metrics
- Minimize subjective intervention

Short-term:
related to current and routine activities of operational centers

Adoption of Best Practices:

- requires stable support for research gains to be integrated into operations;
- establishes an institutional infrastructure that is committed to doing so;
- will establish “feedbacks” that guide future investments in making observations, developing models, and aiding decision-makers (i.e., BEYOND “traditional” operations);
- represents a continuous improvement process.

Closing Thoughts

- Empirically, few revolutionary jumps in forecasting performance
- Best Practices are "enabling" mechanisms
- Improvements should be "synergistic;" they should be designed to encourage and enable strong feedbacks among operations, research, model development, observations, and decision science

For more information:

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Report is available online at www.nap.edu.

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6 Grand Coolee Dam – Bonneville Power Administration; Wheat field – USDA; Cloud fraction image - M. Wyant, R. Wood, C. Bretherton, C. R. Mechoso, *Pre-VOCA*

9 soil moisture – Vinnikov and Yeserkepova, *J..Climate*, **4**, 66-79 (1991); Volcano impact – Robock and Mao, *J. Climate*, **8**, 1086-1103 (1995); ENSO – CPC/NCEP/NOAA

11 MJO – Waliser et al., *BAMS*, **87**, 425-431 (2005)

12 Stratosphere – Mark Baldwin, NWRA

13 ENSO - McPhaden (2004), BAMS, **85**, 677–695

14 Soil moisture – Seneviratne et al., *Earth-sci. Reviews*, **99**, 3-4, 125-161 (2010)

15 Volcano – USGS

16 Keeling curve – Scripps Institute of Oceanography

17 Buoy – NOAA; Model globe - NOAA

18 SST graph – Balmaseda et al., *Proceedings of Oceanobs'09*, ESA Pub. WPP-306, (2009)

19 Double-ITCZ - Lin (2007) *J. Climate*, **20**, 4497–4525.

21 MME – Jin et al., *Climate Dynamics*, **31**, 647-664 (2008)

22 Satellite obs - ECMWF

24 Sources are from the respective organizations

25 Flooding – NRCS; Volcano – NASA; Drought – NESDIS; Moscow sun - BBC

26 ENSO curves – IRI; NCEP flow chart – Jon Gottschalck, NCEP

28 National Archives

29 Pdf's - IRI