2015 US CLIVAR Summit
Updates on Research Challenges

Mike Patterson
USCPO Director

Research Challenges

Decadal Variability & Predictability	Climate & Extreme Events	Polar Climate Changes	Climate & Carbon/ Biogeochemistry

Key Questions:

- What is the scope for each?
- What activities have been undertaken and what progress has been made?
- What future directions should US CLIVAR pursue and how?

US CLIVAR
Climate Variability & Predictability

Research Challenge: **Decadal Variability & Predictability**

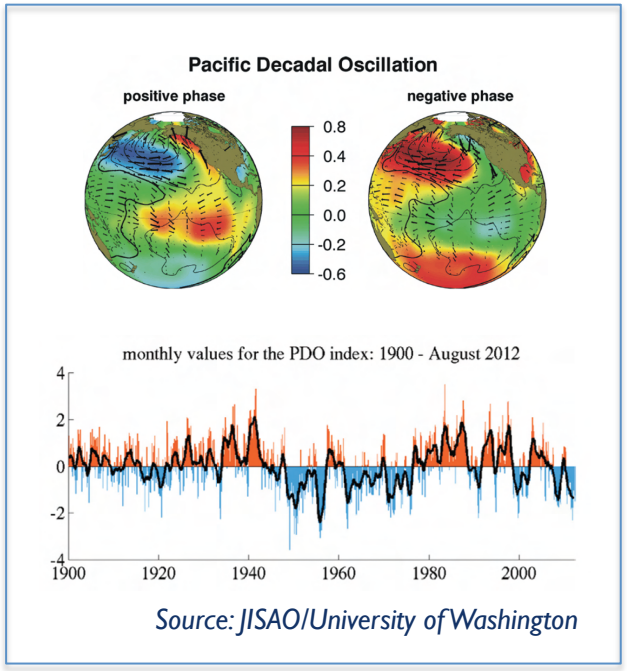
Described in terms of large-scale modes, the dominant patterns of variability that oscillate at decadal timescales

Societally important impacts (e.g., on terrestrial precipitation)

Obfuscates climate trend

Likely origins in coupled ocean-atmosphere interactions

Other factors: deep soil moisture, vegetation, snow cover, anthropogenic aerosols, stratospheric water vapor



US CLIVAR
Climate Variability & Predictability

Decadal Variability & Predictability Activities

- Decadal Predictability WG (2010-2013)
  - Defined a **framework to distinguish natural variability from anthropogenically forced** decadal variability (Solomon et al. 2011)
  - Developed a **set of metrics for assessing the skill of initialized decadal predictions** and their comparison to uninitialized projections (Goddard et al. 2013)

- US AMOC Science Team (2008-2020)
  - Estimating state, variability, and change of AMOC across timescales, understanding mechanisms, predictability, and impacts
  - Analyzing model CMIP5 and future decadal prediction experiments will verify the ability to capture past decadal-scale events, such as North Atlantic 1960s cooling, mid-1990s subpolar gyre warming in the North Atlantic, and the sudden decrease in AMOC strength during 2009-2010

- CMIP5 hindcast and decadal predictability experiments
  - Agency funding of projects to evaluate CMIP5 initialized decadal hindcasts (2011 on)

- Workshops and meetings
  - Aspen Global Change Institutes, June 2008, June 2011, & June 2015
  - CLIVAR Seasonal-to-Decadal Prediction, Toulouse, May 2013
    - Reviewed externally forced and initialized forecasting system results

US CLIVAR
Climate Variability & Predictability

Decadal Variability & Predictability Sessions & Workshops

Warming hiatus sessions at Summit, Fall 2015 AGU, 2016 Ocean Sciences

NRC Frontiers in Decadal Climate Variability, Woods Hole, September 2015

- Establish **observational evidence** of decadal variability and potential forcings**, utility and accuracy of various observations for tracking climate variability, anticipating haitus regimes, and closing heat budgets**
- Examine our understanding of the **processes** governing decadal-scale variability in key climate parameters
- Consider **model-based experiments** to explore possible factors affecting decadal variations
- Consider how best to **communicate current understanding of climate variability**, including potential causes and consequences, **to non-expert audiences**

CLIVAR/ICTP Decadal Climate Variability & Predictability, Trieste, November 2015

- Address the relevant phenomena, their modeling, and their predictability

US CLIVAR Connecting Paleo and Modern Oceanographic Data to Understand AMOC over Decades to Centuries, Boulder, May 2016

- Explore how **paleoceanographic tools/experience** can be deployed to better **understand AMOC variability and its climate impacts** on decadal to centennial timescales

US CLIVAR
Climate Variability & Predictability

International Decadal Variability & Predictability Plans

- Link with CLIVAR Decadal Climate Variability & Predictability Research Foci
  - Explaining, understanding, and predicting the modulation – **accelerations and slowdowns** – of the global temperature average and their regional expression
  - Determining the **role of volcanic eruptions** in decadal climate variability, global and regional, and their impact on the decadal climate prediction

- Link with WCRP CMIP6 Decadal Climate Prediction Project
  - Experiments include **hindcasts, forecast, and predictability/mechanisms/case studies**
  - Pacemaker experiments for understanding **mechanisms of climate shifts, internal modes** of variability and predictability
  - Perturbation experiments on the **impact of volcanoes** on predictability and predictions

- Possible WCRP Grand Challenge on Decadal Predictability
  - Concept Group formed to draft short concept document outlining the focus and remit for Decadal GC and how to make substantial progress in 5-10 years
  - Arun Kumar on Group

US CLIVAR
Climate Variability & Predictability

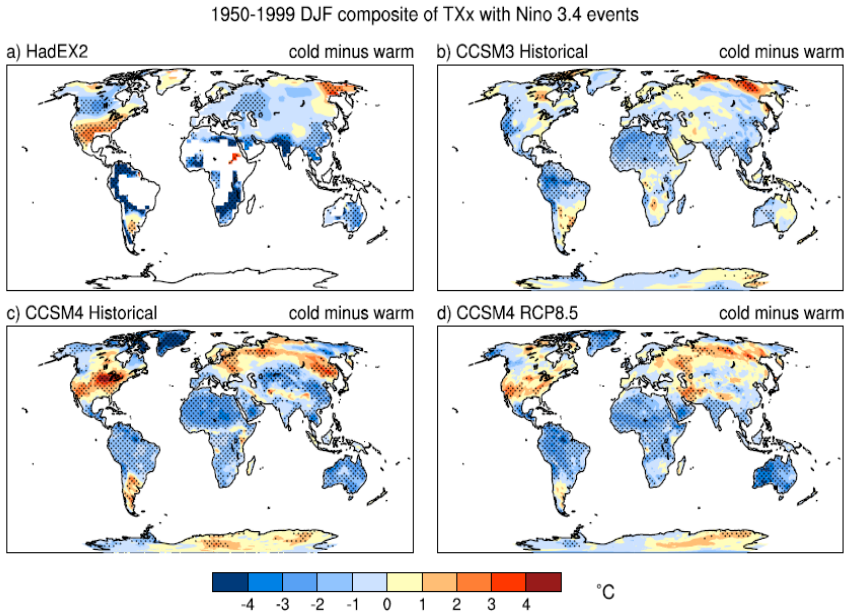
Research Challenge: **Climate and Extreme Events**

Events that occur rarely or exceed a threshold

- Tropical cyclones and hurricanes
- Heavy wave and storm surge events
- Heavy precipitation and related floods
- Drought
- Cold snaps and heat waves

SST and upper ocean heat content influences on atmospheric heating and circulation

Other factors: soil moisture and terrestrial evaporation, water availability, vegetation, snow cover & sea ice



Source: Arblaster and Alexander (2012)

US CLIVAR
Climate Variability & Predictability

Climate and Extreme Events Activities

- Working Groups
  - Drought (2006-2008); WCRP Drought Interest Group (2008-Present)
  - Hurricane (2011-2014)
  - Atmospheric Patterns Assoc. w/ Extreme T and P (2012-2015)
  - New Artic-Midlatitude Interactions (2015-2018)

- Evaluation of CMIP5 experiments
  - Drought, precip extremes, statistics of daily weather extremes, extreme Arctic cyclones

- Workshops and meetings
  - NCAR ASP Extremes Summer School/Wksp, Boulder, July 2011
  - WCRP Extremes Summer School, Trieste, Sep. 2014
  - WCRP Drought Workshops, recent-Pasadena, Dec. 2014
  - US CLIVAR Virtual Wksp on Climate Var. in IntraAmericas Seas, Sep. 2015

US CLIVAR
Climate Variability & Predictability

Future Climate and Extreme Events Plans

- NMME evaluation of extremes (NOAA, DOE, ONR Joint Call)
- CMIP6 extremes experiments
  - High Resolution Model Intercomparison Project
  - Global Dynamical Downscaling Experiment
- NRC Fast-Track Study on Extreme Weather Events and Climate Change Attribution
  - Assess current scientific understanding and capabilities for attribution of specific extreme weather events to climate change
  - Provide guidance about the robustness of extreme event attribution science
  - Identify research priorities for further development of the approaches
- Develop links with
  - US GEWEX (when established)
  - CLIVAR Understanding & Predicting Weather & Climate Extremes Research Foci
  - WCRP Extremes Grand Challenge

US CLIVAR
Climate Variability & Predictability

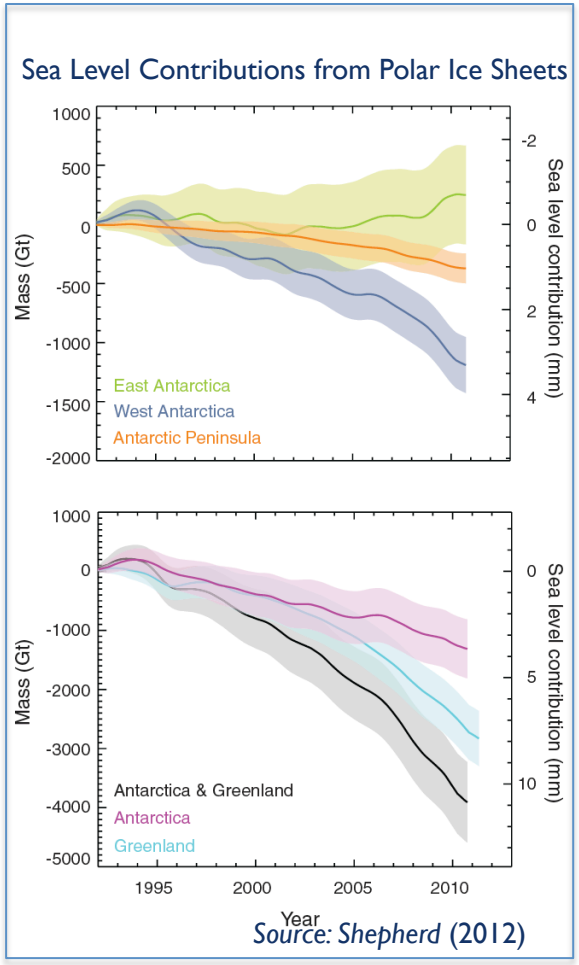
Research Challenge: **Polar Climate**

Changes in SH atmospheric circulation and SO eddies on SO/ACC stratification and meridional transport of heat, salt, and carbon

Changes in NH subpolar gyre and inter-basin exchanges of heat and salinity

Feedbacks of Antarctic and Greenland ice shelf response to warming ocean – strengthening ocean stratification, reducing vertical mixing, inhibiting convection

Potential impact of warming and sea ice changes on mid-latitude extremes



US CLIVAR
Climate Variability & Predictability

Polar Climate Activities

- Working Groups
  - High Latitude Surface Fluxes (2009-2013)
  - Greenland Ice Sheet-Ocean Interactions (2011-2014)
  - Southern Ocean Heat & Carbon Uptake (2012-2015)
  - New Arctic-Midlatitude Interactions (2015-2018)

- Workshops and meetings
  - CLIVAR Sea Level Rise, Ocean-Ice Shelf Int., Hobart, Australia, Feb. 2013
  - US CLIVAR Understanding the Response of Greenland's Marine Terminating Glaciers to Oceanic and Atmospheric Forcing, Beverly, MA, June 2013
  - US CLIVAR/OCB/PCPI Ocean's Carbon and Heat Uptake/SO Session

- Process studies
  - Diapycnal and Isopycnal Mixing Experiment (DIMES), Marginal Ice Zones (MIZ)

- Expanding observing networks (SOOS/SOCCOM, OSNAP, AON)

US CLIVAR
Climate Variability & Predictability

Future Polar Climate Plans

- CPTs on sea ice and land ice?
- CMIP6 Experiments
  - Ice Sheet Model Intercomparison Project for CMIP6
  - Sea-Ice Model Intercomparison Project
- A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research (Aug. 2015)
- Developing links with
  - Studies of Environmental Arctic Changes (SEARCH)
  - CLIVAR Southern Ocean Panel (transition metrics from US Southern Ocean WG)
  - Possible CLIVAR Arctic Panel?
  - WCRP Climate and Cryosphere (CliC)
  - WMO Polar Prediction Project & Year of Polar Prediction (2017-2019)

US CLIVAR
Climate Variability & Predictability

Research Challenge: **Climate & Marine Carbon/Biogeochemistry**

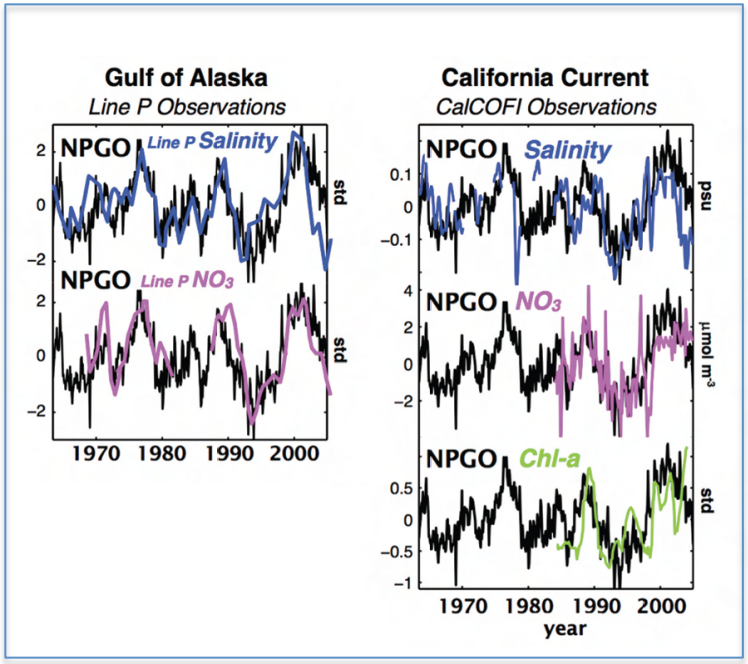
Understand the coupled physical/biogeochemical processes that maintain oceanic sources and sinks of carbon and the marine ecosystem and accurately predict how they will evolve in response to climate variability and change

Carbon cycle sensitivity

- to ocean overturning and stratification, wind forced mixing. and upwelling

Marine ecosystem sensitivity

- to surface mixed layer thickness, upper ocean stratification, processes that lift nutrients



US CLIVAR
Climate Variability & Predictability

Climate and Carbon/Biogeochemistry Activities

- Joint physical/biogeochemical observing systems (e.g., GO-SHIP, TPOS, SOCCOM)

- Working Groups (joint with OCB)
  - Ocean Carbon Uptake in CMIP5 (2012-2015)
  - Southern Ocean Heat and Carbon Uptake (2012-2015)

- Workshops and meetings
  - US CLIVAR/NCAR ASP – Carbon/Climate School/Wksp, Boulder, Aug. 2013
  - OCB/Future Earth – North Atlantic/Arctic Planning, Arlington, April 2014
  - US CLIVAR/OCB Ocean's Carbon & Heat Uptake, San Francisco, Dec. 2014

- US AMOC Science Team – TT4: Impacts on Carbon Cycle and Marine Ecoystems of N. Atl

US CLIVAR
Climate Variability & Predictability

Future Climate & Carbon/Biogeochemistry Activities

- CMIP6 experiments: OMIP includes Carbon/Biogeochem
- Next steps with OCB? Regional foci: North Atlantic, Southern Ocean, Tropics?
- Develop links with CLIVAR Research Foci on Biophysical Interactions and Dynamics of Upwelling Systems
  - Goal is an updated study of the dynamics of eastern boundary upwelling regions, beginning to address known warm biases in the climate models and their impacts on biogeochemistry and fisheries.
- CLIVAR Workshop on CLIVAR Marine Biophysical Interactions & Dynamics of Upwelling, Ankara, Oct. 2015
  - Review state of science and opportunities to scope future research directions
  - Produce a draft plan for this CLIVAR Research Foci

US CLIVAR
Climate Variability & Predictability

Research Challenges

Decadal Variability & Predictability	Climate & Extreme Events	Polar Climate Changes	Climate & Carbon/ Biogeochemistry

Key Questions:

- What is the scope for each?
- What activities have been undertaken and what progress has been made?
- **What future directions should US CLIVAR pursue and how?**

Panels are encouraged to identify needs and suggest approaches

US CLIVAR
Climate Variability & Predictability

Thank You

US CLIVAR
Climate Variability & Predictability

Research Challenge: **Decadal Variability & Predictability**

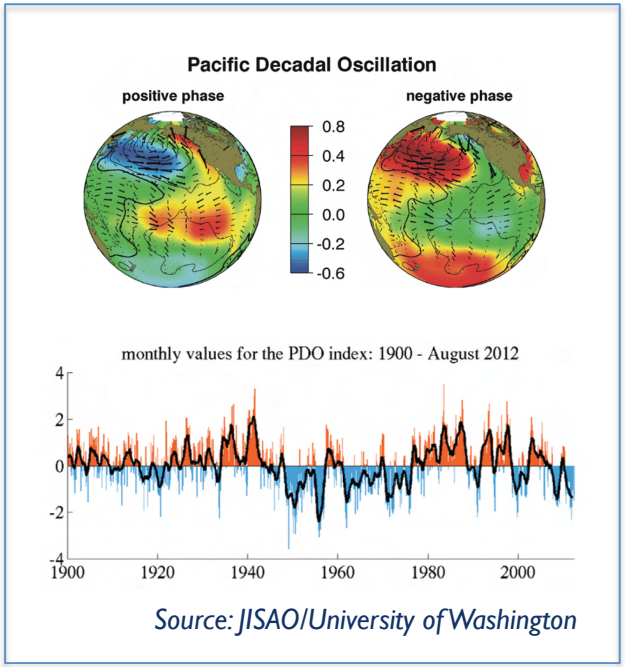
Described in terms of large-scale modes, the dominant patterns of variability that oscillate at decadal timescales

Societally important impacts (e.g., on terrestrial precipitation)

Obfuscates climate trend

Likely origins in coupled ocean-atmosphere interactions

Other factors: deep soil moisture, vegetation, snow cover, anthropogenic aerosols, stratospheric water vapor



Source: JISAO/University of Washington

<u>Future research</u>

- Identify optimum method for initialization, given imperfect and incomplete observations and assimilation systems
- Determine the added skill in predictions with initialization
- Assess the impact of small ensemble size on the spectrum of decadal means
- Establish what predictions should be attempted, and how they could be verified

US CLIVAR
Climate Variability & Predictability

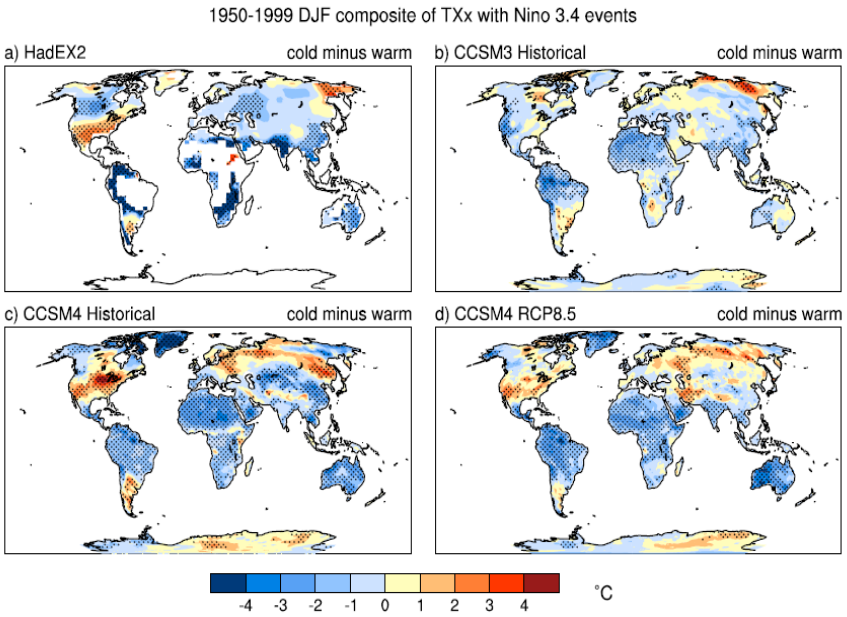
Research Challenge: **Climate and Extreme Events**

Events that occur rarely or exceed a threshold

- Tropical cyclones and hurricanes
- Heavy wave and storm surge events
- Heavy precipitation and related floods
- Drought
- Cold snaps and heat waves

SST and upper ocean heat content influences on atmospheric heating and circulation

Other factors: soil moisture and terrestrial evaporation, water availability, vegetation, snow cover & sea ice



Source: Arblaster and Alexander (2012)

<u>Future research</u>

- Identify dynamical processes that underlie precipitation and temperature extremes
- Investigate how short-term processes interact with the larger-scale, slower, and potentially-predictable climate fluctuations linked to the ocean
- Determine metrics and analysis tools most relevant for extremes
- Investigate what properties of extremes, if any, are changing under global warming

US CLIVAR
Climate Variability & Predictability

Research Challenge: **Polar Climate**

Changes in SH atmospheric circulation and SO eddies on SO/ACC stratification and meridional transport of heat, salt, and carbon

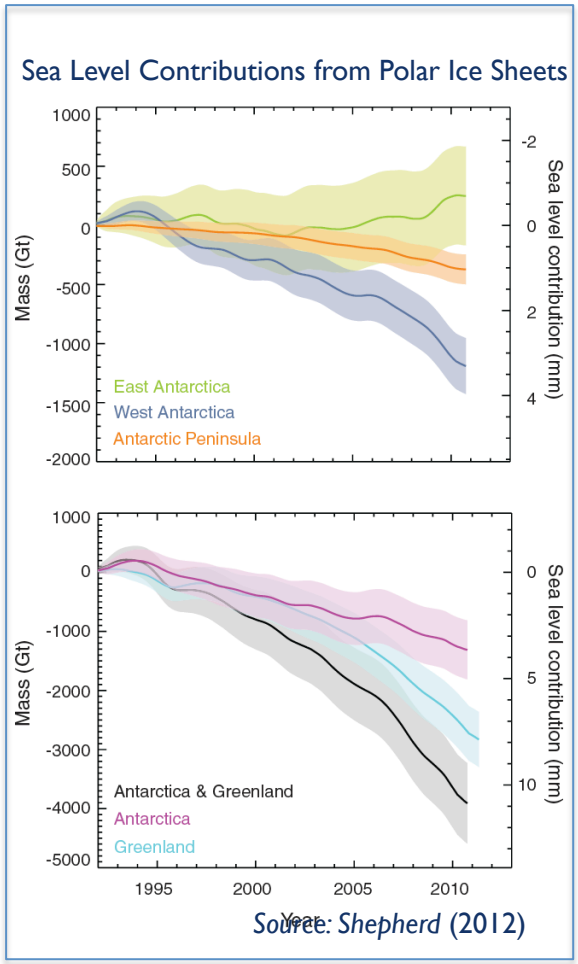
Changes in NH subpolar gyre and inter-basin exchanges of heat and salinity

Feedbacks of Antarctic and Greenland ice shelf response to warming ocean – strengthening ocean stratification, reducing vertical mixing, inhibiting convection

Potential impact of warming and sea ice changes on mid-latitude extremes

<u>Future research</u>

- Expand observational basis for monitoring variability/change and understanding mechanisms
- Synchronize data quality control and processing
- Identify processes that models need to capture to improve simulation and predictability



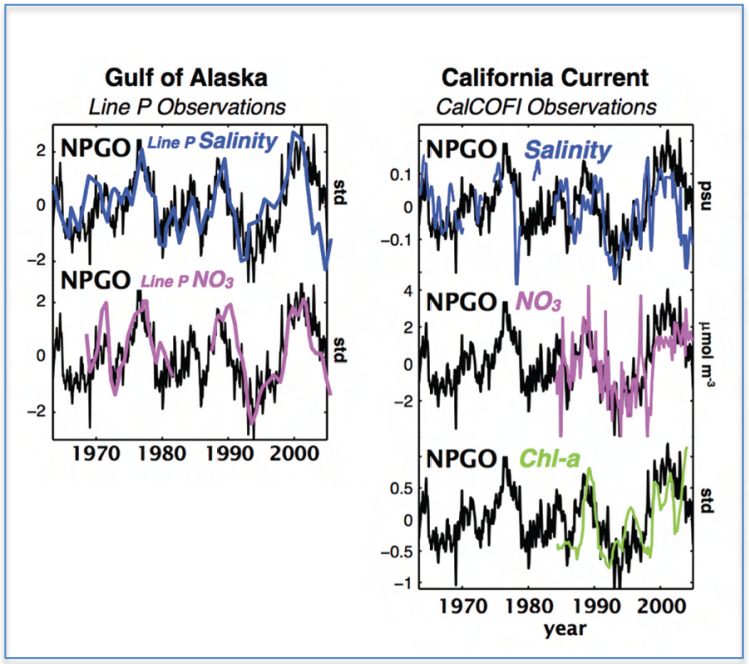
US CLIVAR
Climate Variability & Predictability

Research Challenge: **Climate and Marine Carbon/ Biogeochemistry**

Understand the coupled physical/biogeochemical processes that maintain oceanic sources and sinks of carbon and the marine ecosystem and accurately predict how they will evolve in response to climate variability and change

Carbon cycle sensitivity
- to ocean overturning and stratification, wind forced mixing and upwelling

Marine ecosystem sensitivity
- to surface mixed layer thickness, upper ocean stratification, processes that lift nutrients



Future research

- Develop and deploy multi-purpose ocean-observing systems, exploiting innovation in oceanographic instrumentation – e.g., autonomous technology
- Develop, evaluate, and compare coupled physical/biogeochemical models and support improvement of model interoperability
- Undertake integrated ecosystem process studies to gain mechanistic understanding of the biological responses to climate variations and change

US CLIVAR
Climate Variability & Predictability

Research Challenges – Activities

Decadal variability and predictability

- Decadal Predictability WG (2010-2013)
- US AMOC Science Team (2008-2020)
- Workshops and meetings
  - Aspen Global Change Institutes, June 2011 & June 2015
  - CLIVAR Seasonal-to-Decadal Prediction, Toulouse, May 2013
  - CLIVAR/ICTP Decadal Climate Variability & Predictability: Challenge and Opportunity, Trieste, November 2015
- CMIP5 evaluation and feedback
- CMIP6 decadal experiments
- Developing links with CLIVAR DCVP RF & WCRP DCPP

Climate and extreme events

- Working Groups
  - Hurricane (2011-2014)
  - Atmospheric Patterns Assoc. w/ Extreme T and P (2012-2015)
  - New Artic-Midlatitude Interactions (2015-2018)
- Workshops and meetings
  - NCAR ASP Extremes Summer School/Wksp, July 2011
  - WCRP Extremes Summer School, Trieste, Sep. 2014
  - WCRP Drought Workshops, recent-Pasadena, Dec. 2014
  - US CLIVAR Virtual Wksp on Climate Var. in IntraAmericas Seas
- NMME evaluation of extremes
- CMIP6 extremes experiments
- Develop links with US GEWEX; CLIVAR & WCRP Extremes GC

Polar climate

- Working Groups
  - High Latitude Surface Fluxes (2009-2013)
  - Greenland Ice Sheet-Ocean Interactions (2011-2014)
  - Southern Ocean Heat & Carbon Uptake (2012-2015)
  - New Arctic-Midlatitude Interations (2015-2018)
- Workshops and meetings
  - Sea Level Rise, Ocean-Ice Shelf Int., Hobart, Feb. 2013
- Process studies (DIMES, MIZ, OSNAP)
- Expanding observing networks (SOOS/SOCCOM, AON)
- CPTs on sea and land ice?
- Developing links with SEARCH & IARPC, CliC, WMO YOPP

Climate and carbon biogeochemistry

- Observing systems (e.g., GO-SHIP, TPOS, SOCCOM)
- Working Groups (joint with OCB)
  - Ocean Carbon Uptake in CMIP5 (2012-2015)
  - Southern Ocean Heat and Carbon Uptake (2012-2015)
- Workshops and meetings
  - NCAR ASP Carbon/Climate School/Wksp, Aug. 2013
  - North Atlantic/Arctic Planning, Arlington, April 2014
  - US CLIVAR Ocean's Carbon and Heat Uptake, San Francisco, Dec. 2014
- US AMOC Science Team – TT4: Impacts
- CMIP6 experiments
- Develop links with CLIVAR Upwelling/Ecosystems RF

US CLIVAR
Climate Variability & Predictability

SSC Implementation Considerations

- How will we **measure and demonstrate the progress** and success of US CLIVAR?
- How will the SSC ensure that implementation **addresses the goals** of the program?
- **What mechanisms** will be used to enable implementation?
- How will the SSC foster and review **progress on the research challenges**?

US CLIVAR
Climate Variability & Predictability

Measuring Progress

Reviews of 5-year Project Office proposal called for defining approaches for evaluating scientific and programmatic progress

- Establish metrics to measure
  - Improved depth of understanding; improved observing systems; improved models; improved analyses; improved predictions
  - Improved quantification of uncertainty in observations, analyses, predictions, projections
  - Effectiveness of integration across sciences (e.g., interdisciplinary engagement; linking observations and models)
  - Lessons learned and best practices employed
  - Transition of practices from research to operations
  - Impact on capacity building and training, including diversity
  - Community engagement and communication efficacy
  - Effectiveness of international partnerships; of inter-program partnerships
- Conduct external program reviews
  - Of 5-year proposals
  - Through NRC
  - Through ad-hoc committees

US CLIVAR
Climate Variability & Predictability