Advancing Earth System Prediction

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Executive Summary

- In alignment with NOAA's operational and legislative mandates to expand the breadth of Earth system modeling and extend the infrastructure and user support for UFS to full Earth system coupling.
- CWG is providing recommendations to enhance NOAA's Earth system prediction by increasing process understanding that:
  - leads to more sources of predictability and thus,
  - predictive skill for the development of a seamless forecast system across timescales
- The guidance and recommendations will be organized into the following topics:

1. Observations (Land/Atmospheric Chemistry/Ocean & Coastal Shelf)
2. Ice and Inundation
3. Operational Oceanography / Ocean Forecasts
4. Decision Maker Needs
5. Enhancing Coordination
6. Model Technology

1. Motivation: Enhance NOAA’s observational network to improve Earth System Prediction

- Incorporate additional sources of predictability and increased predictive skill through addressing the merits of targeted observations and process studies versus sustained observation systems to improve process understanding.

- Advance the initialization of prediction through assessment of ongoing observation systems, preventing degradation of observational networks, and expanding and improving observational networks where Earth system prediction requires additional measurements.

Land Observations: Recommendations

1) Lead the coordination, through multi-agency collaborations, of the observation of surface, deep soil and groundwater, as well as the atmospheric boundary layer and free troposphere, clouds and precipitation profiles, which are mostly available, but not coordinated in space and time.

2) Develop and improve gridded snow mass datasets, including investment in quality check of the citizen science measurements, over U.S. and globally for improving model initialization in weather and S2S prediction, especially for stream and river flows and floods over snow-covered regions.

Atmospheric Chemistry Observations: Recommendations

3) Enhance land observations with focus on land impacts on atmospheric boundary layer structure, and biogenetic, dust and biomass burning aerosols, and their interaction with clouds and precipitation, either by initiating NOAA's own or contributing to joint efforts; and realign some of the "chemistry" measurements capabilities to address the issue of boundary layer meteorology that will enhance weather prediction, deposition process understanding, and climate change science.

4) Enhance and refocus the NOAA infrastructure (people; heavy-lift aircraft; chemical, aerosol, and radiation measurements, etc.) to improve weather forecast, emission quantification to inform societal action, climate change quantification to inform mitigation and adaptation, and reducing impacts of wildland fires.

Ocean/Coastal Observations: Recommendations

5) Target major gaps in the ocean observing system (shelf seas, deep and polar oceans, and living ocean). Expand the use of new and improved drifters, buoys, and autonomous instruments to facilitate a cost-effective expansion of the observing network below the ocean surface.

6) Ensure capability through robust observing system design projects and implement experiments to design networks of integrated observations and platforms including satellites, ships, floats, gliders and moorings for both physical and biogeochemical parameters.

7) Assess the utility of a nationwide shallow-water network of autonomous platforms (like gliders and floats) for physical and biogeochemical measurements for the shelf and coastal oceans and under-ice.

8) Build out the Argo network, including deep Argo and floats with biogeochemical sensors. Plan to enhance the fleet of global ocean observing ships.

2. Motivation: Ice & Inundation

- Ice and snow across Earth's surface have a major impact on the amount of solar heating on Earth. Extreme weather and ocean turbulence are often connected to strong temperature gradients, which occur in proximity to ice and snow.

- Meltwater from land and sea ice and river runoff are known to alter ocean stability, and therefore Sea Surface Temperature, through ocean mixing and circulation. Meltwater and runoff are also of concern for coastal inundation through sea level rise.

- Coastal inundation depends on other factors, like storm surge, which may compound the threat of inundation from meltwater and runoff – the modeling issues are related.

Ice & Inundation: Recommendations

9) Create a strategic plan to implement global predictions, projections and scenarios coupling dynamical sea ice and ice-derived runoff components with the atmosphere, ocean, and land in global models. Sea ice and ice sheet components must have high quality initializations for ice sheet and sea ice mass and coverage through advanced data assimilation means.

10) Work towards using an ensemble of predictions from a global model for stakeholder products. Regional modeling for calculating inundation should be nested within boundary conditions from global model simulations with coupled sea ice and ice sheets for consistency in treating variability and meltwater and its influences on ocean stability and circulations.

3. Motivation: Operational Oceanography & Forecasting

- The US needs a NOAA-led ocean forecasting system that produces regional and global products to support ocean and weather prediction, the blue economy (including shipping, ports and commerce) and fisheries and ecosystem prediction applications.

- NOAA is clearly positioned to take the lead in this effort as other agencies' missions are limited to coastal regions – only NOAA's mission includes the blue ocean. In addition, NOAA's mandate, unlike any other agency, includes prediction.

- Applying earth system prediction to operational oceanography will improve ocean forecasts and weather forecasts, especially hurricanes. Assimilating ocean data, including biogeochemistry, will support fisheries applications. Ocean reanalyses, especially those including carbon, will support NOAA's predictive capability with respect to ever-evolving initial conditions as well as supporting verification of international carbon and other pollution emissions.

Ocean Forecasts: Recommendations

11) Implement an open-source operational ocean forecast system using MOM6 as soon as possible (on an accelerated timeline, i.e. not waiting until 2025). Include Earth system prediction benchmarks that quantify ocean pH, carbon, nutrients, with the intent of enabling consistent regional downscaling of ocean transport and ecosystems.

12) The NOAA ocean forecast system (based on MOM6) should include development and implementation of ocean data assimilation, ocean reanalysis and the framework for coupled ocean-atmosphere assimilation & reanalysis.

13) Current NOAA capability in regional ocean forecasting benchmarks and skills test should be applied to evaluate MOM6 global and regional simulations to accelerate transition to robust climate-relevant timescale boundary conditions.

4) Motivation: Decision Maker Needs

- With climate change, there are decision maker needs that are not being met, and the development of earth system prediction can answer many of these.

- Decision maker needs to address longer climate scale decisions are distinct from immediate hazard mitigation, the response to warnings, and other weather response decisions. These longer-term decisions are increasing in importance as climate change manifests.

- There are sector-specific needs to understand what to adapt to and when. Rates of change, deep uncertainty, and abrupt changes are key elements of this decision space. These issues are also essential to understanding the limits of current hazard mitigation strategies.

Decision Maker Needs: Recommendations

14) Enhance product specifications to include the distinctive dimensions of decision requirements for infrastructure and investment decision making that are influenced by progressive and abrupt change in climate processes and timescales and how advances in Earth system prediction can meet those needs across sectors.

15) Develop plans to foster the continued refinement of model information and derived products, at multiple time scales and spatial scales. In order to better characterize decision spaces, the Earth system prediction model output should be made available in combination with other decision-relevant information.

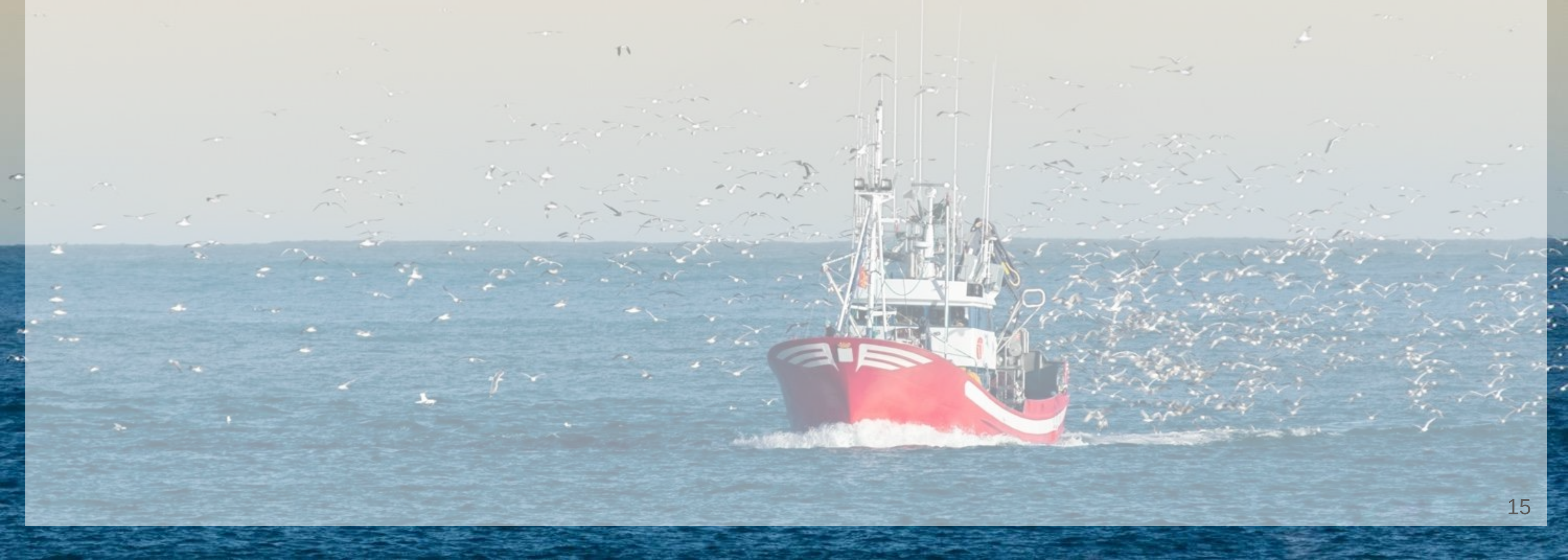
Decision Maker Needs: Recommendations

16) Develop a framework for incorporating research and development needs as informed by the end user decision spaces. This should include systematic, regularized opportunities for collaborative exploration based on decision-centric benchmarks of data and product performance of new components of Earth system prediction.

17) In conjunction with planning for the implementation of the Service Delivery Network, evaluate the appropriate level of specialist support needed to maximize benefits of advanced Earth system predictions. Coordinate these activities within NOAA so they can integrate feedback from decision makers and users’ applications into continuing Earth system prediction improvements.

4) Enhancing Coordination - Motivation

- Earth system prediction requires interdisciplinary and cross-workforce collaboration and coordination to be successful. Historically, the substructures within NOAA have made change difficult to implement.



5) Enhancing Coordination: Recommendation

18) Every NOAA Strategic Implementation Plan related to Earth system prediction should include a line that addresses the goals, objectives, responsible parties and metrics of assessment relevant to the collaboration and coordination between:

1) responsible line offices within NOAA
2) NOAA and other Federal agencies
3) NOAA and State agencies
4) NOAA and other partners – academic and industry
5) NOAA and stakeholders

6) Motivation: Model Technology

- Enable Earth system prediction extension beyond 10 day forecasts with better skill and similar, or increased, confidence, including new forecasts of different Earth system areas.

- Inform NOAA’s accelerating adoption/adaptation of technologies to optimize model forecast performance, while implementing a “do no harm” approach.

- Research to operations transitions would benefit from benchmarking improvements prior to operational use by allowing competition for model performance demonstration from academic and industry teams within a pseudo-operational environment using cloud environments and advanced observations.

Model Technology: Recommendations

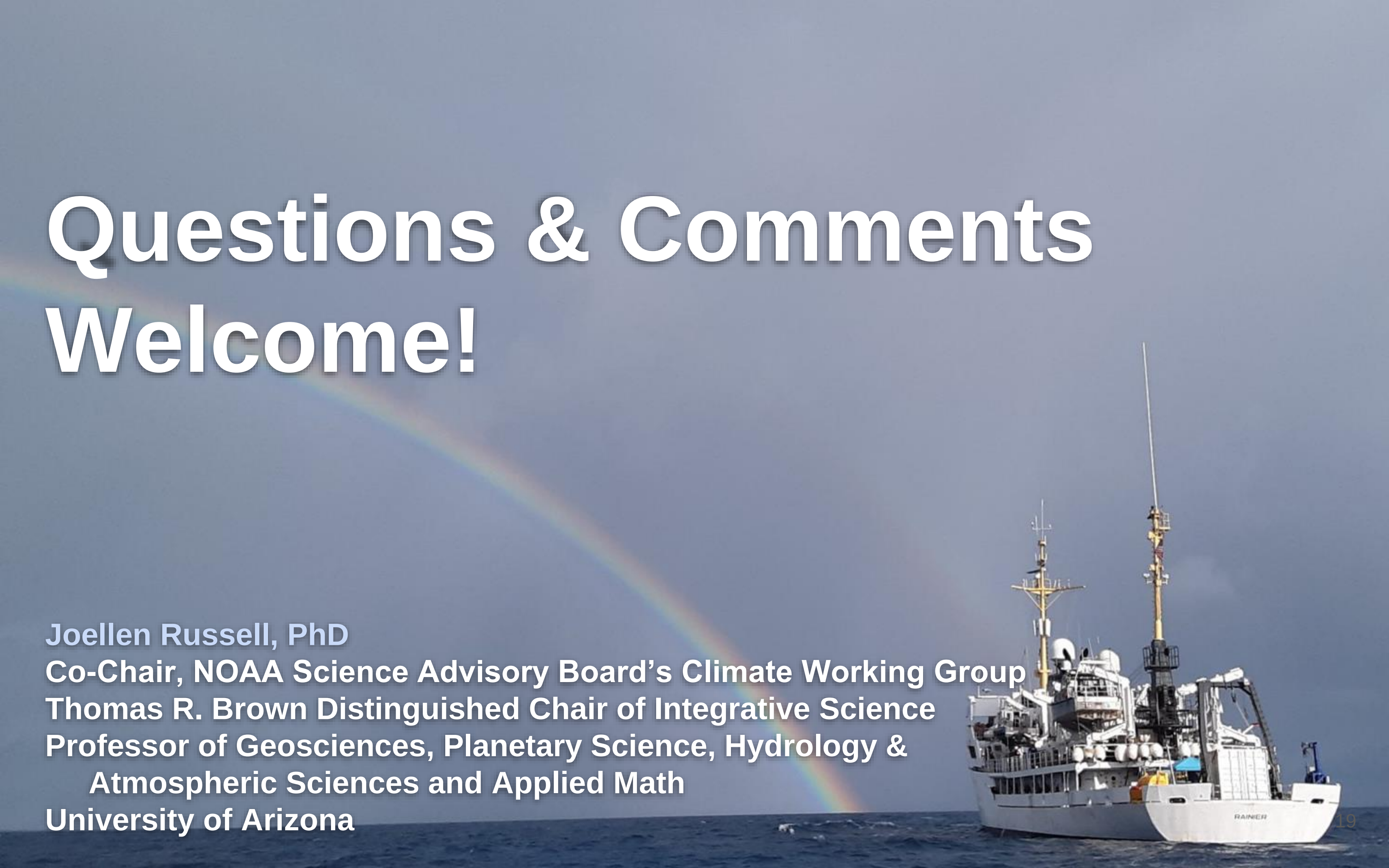
19) Establish agreements with Cloud Service Providers and members of the Earth system value chain to realize benefits of cloud technology for advancing predictions.

20) Establish accurate, high-quality, historical training datasets and indicators for trust in applying Artificial Intelligence/Machine Learning technologies to advance Earth system predictions.

21) Accelerate acquisition and assimilation of commercial sources of data and delivery systems along with development of Earth Science Decadal recommended observing systems.

22) Benchmark performance quality, productivity, and cost using proven methodologies to quantify improvements to close gaps, identify root causes for deficiencies, and inform actionable improvement opportunities.

Questions & Comments Welcome!



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