NOAA Response to the Climate Working Group Report
Advancing Earth System Prediction

A Presentation to the
NOAA Science Advisory Board

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Purpose

Provide the SAB with an informational brief on the NOAA response to the recommendations noted in the SAB report *Advancing Earth System Prediction.*

NOAA thanks the members of the SAB and the Climate Working Group for their work on this important task and for providing their collective insight on the agency’s scientific endeavors.

NOAA Coordination & Views

Cross-NOAA coordinated views are provided for each recommendation and have been summarized in this presentation.

Specific notes addressing what has been done and what is intended are provided for each recommendation and are summarized in the back-up slides for each topic area.

Response Team

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SAB Recommendations (22)

- Land Observations (2)
- Atmospheric Chemistry Observations (2)
- Ocean & Coastal Shelf Observations (4)
- Ice and Inundation (2)
- Operational Oceanography and Forecasting (3)
- Decision-maker Needs (4)
- Enhancing Coordination (1)
- Model Technology (4)
  - Cloud Computing (1)
  - Artificial Intelligence / Machine Learning (1)
  - Advanced Remote Sensing Technology (2)

General NOAA Comments

- NOAA agrees with the recommendations.
- The emphasis on land processes and atmospheric chemistry measurements in the context of Earth-system prediction is timely and speaks to important, yet underexplored, research directions.
- Within this report there is confusion in distinguishing between the Finite-Volume Cubed-Sphere Dynamical Core (FV3), the FV3-based Global Forecast System (FV3-GFS), and the Unified Forecast System (UFS), none of which refer to the same thing.
- NOAA agrees with focusing on the MOM6 for appropriate applications. NOAA, however, does not concur with the focus on the single solution of MOM6 for the broad range of ocean applications and challenges.
- The report lacks focus on verification, evaluation, or overall measuring of model performance.

Land Observations

Recommendation 1: NOAA agrees
Recommendation 2: NOAA agrees

NOAA response:

- Surface precipitation observations, versus precipitation profiles, are most important for land applications
- A high-spatiotemporal-resolution surface-type-dynamics data product is critical for consistency checks of other land products and model parameters, in particular to address temporal variability limitations when current weather, water, and climate models employ static surface-type look-up tables.
- Increased observations of land surface and lower-atmosphere conditions could yield increased skill and reliability, if targeted at better predictive understanding of critical air-land fluxes and processes.
- Benefit of gridded snow-mass observations is not limited to weather and S2S model initialization. Also improves and drives hydrologic modeling, drought monitoring, climate monitoring, and the assessment of long-term trends
- Potential exists for improving snow-mass estimates through blending passive microwave, visible, synthetic aperture radar, and ground measurements, with the synthesis addressing gaps and limitations of the individual sources.
- Accurate snow retrieval is challenging because of large spatial variability within a short time window, aerosol deposition on snow that changes its albedo, and heterogeneity of snow cover across different types of vegetation.

Atmospheric Chemistry Observations

Recommendation 3: NOAA agrees
Recommendation 4: NOAA agrees

NOAA response:

- Capabilities for observing atmospheric composition/chemistry need to be enhanced and extended from the surface to the top of the atmosphere to study deposition, anthropogenic, biogenic, biomass burning emissions, air quality, climate, and their linkages, and physical and chemical processes.
- Enhanced observations of boundary layer structure, biogenetics and aerosols, and their interaction with clouds and precipitation can improve the modeling of land-atmosphere and ocean-atmosphere interaction, energy fluxes, convective and large-scale precipitation processes, and, ultimately, overall model prediction accuracy.
- Boundary-layer physics need to be improved in the operational prediction systems.
- Intensive and comprehensive studies on land observation impacts on modeling are needed to understand how to use which land observations to improve numerical Earth-system prediction models.
- Measurement of atmospheric deposition of dust on the ocean surface would help reduce uncertainties in the micronutrients supplied to ocean ecosystems.

Ocean & Coastal Shelf Observations

Recommendation 5: NOAA agrees
Recommendation 6: NOAA agrees
Recommendation 7: NOAA agrees
Recommendation 8: NOAA agrees

NOAA response:

- NOAA's Earth-system prediction modeling and data assimilation activities welcome these recommendations, particularly given that the ocean subsurface is severely under-sampled and has large gaps.
- Coastal/shallow waters are severely under-sampled, and such a network needs to include Blue Sea observations as well, since off-shore ocean currents and dynamics have a large influence on coastal conditions.
- NOAA highlights the need for observations to encompass biogeochemical parameters, as well as physical parameters, to support NOAA's Earth-system prediction objectives.
- NOAA emphasizes the complementary need to observe interface parameters, such as surface winds, ocean waves, and sea ice that inform ocean-atmosphere fluxes of heat, moisture, and momentum and which are critical for coupled Earth-system predictions.
- Observation technology opportunities:
  - With the proven potential of glider measurements, use of the IOOS glider dataset should be expanded.
  - The report contains no mention of new autonomous surface vehicle technology in the report, even though the data from these platforms are already flowing into the Global Telecommunications System (GTS).
  - The build-out of revolutionary robotic sensors and platforms, such as One-Argo, gliders, and uncrewed surface vehicles, requires concurrent enhancement of campaigns on traditional platforms (ships) and improved shipboard and shoreside analytical capabilities for calibration purposes.

Ice and Inundation

Recommendation 9: NOAA agrees

Recommendation 10: NOAA agrees

NOAA response:

- NOAA appreciates the emphasis on coupling sea ice and ice sheets into the global model and recognizes the need for greater investment to address associated challenges for accurately forecasting coastal inundation, maritime safety, and icebreaking parameters, etc.
- NOAA recognizes that the task spans multiple relevant timescales for predictions and projections (near-real-time, medium-range, subseasonal-to-seasonal, and longer), noting that accurate seasonal forecasting requires better physical descriptions of the slowly changing sea-ice processes.
  - Data assimilation improvements for the land, ocean and sea ice states are needed in order to more accurately represent the initial states of those model components that provide the long-term memory of the Earth System.
  - Sea-ice and ice-sheet observations are comparably critical to NOAA's near-real-time Earth-system predictions.
  - Significant developments in sea-ice growth and melt, ocean mixing, land vegetation and groundwater, and atmospheric ozone model components are critical.
  - NMFS notes that sea-ice dynamics are important for some of the most valuable fisheries and would welcome improved model output.
- NOAA envisions greater use of ensemble forecasting to reduce model-specific issues and to provide better estimates of forecast uncertainties.

Operational Oceanography and Forecasting

Recommendation 11: NOAA agrees
Recommendation 12: NOAA agrees
Recommendation 13: NOAA agrees

NOAA response:

- The Nation's and NOAA's strategic priority focus on the Blue Economy, in conjunction with the UN Ocean Decade, provides an opportunity now to coalesce NOAA's operational oceanography enterprise and to apply Earth-system prediction tools and approaches to its operational oceanography endeavors.
- Moving toward clarity on "who has the ultimate leadership for the development of ocean forecasting at NOAA," the NOAA Modeling Board, under the Weather, Water, & Climate Board, initiated a working group on Enhancing Operational Ocean Forecasting to coalesce and integrate efforts.
- NOAA recognizes that greater pan-NOAA coordination between global- to basin-scale ocean modeling approaches and coastal- to local-scale unstructured ocean modeling approaches would be highly beneficial.
- A strongly coupled data-assimilation approach is critical to initializing model prediction systems, along with pairing the ocean forecast system with large-ensemble, high-resolution, multidecadal reanalyses.
- Accelerating MOM6 predictive capabilities needed to address NOAA priorities is challenging due to requiring significant investment in global and regional MOM6 development and evaluation, as well as long development and work force lead times.
- NOAA explicitly looks beyond a nested structured-mesh ocean model framework, highlighting that unstructured-mesh coastal models, such as those currently used operationally by NOS, will continue to play an indispensable role in local ocean forecasts and downscaling (despite reduced efficiency for larger domains) because they better resolve critical complex bathymetric and topographic features.

Decision-maker Needs

Recommendation 14: NOAA agrees
Recommendation 15: NOAA agrees
Recommendation 16: NOAA agrees
Recommendation 17: NOAA agrees

NOAA response:

- Recognizing the need to support informed decision-making, notably with respect to infrastructure and investments, NOAA aims to incorporate sector-specific considerations when developing and extracting knowledge from Earth-system observations.
- NOAA notes that decision-makers need useful tools to access and synthesize information from Earth-system prediction models in conjunction with contextual information; consequently, data and products need to be available in an equitable user-friendly manner, which requires investment in data infrastructure, especially for exploiting high-resolution real-time data.
- NOAA aims to leverage the Earth Prediction Innovation Center (EPIC) to deliver world-class numerical environmental prediction systems, while simultaneously accelerating community scientific research and modeling contributions through sustained engagement to inform and advance NOAA's Unified Forecasting System (UFS).
- NOAA acknowledges the good example provided by the European Center for Medium-range Weather Forecasting (ECMWF), which publishes very clear information about each model upgrade and its products, including extensive metadata, helping end-users optimally use the data without needing extensive support from specialists.

Enhancing Coordination

Recommendation 18: NOAA agrees

NOAA response:

- NOAA is a member of the Interagency Council for Advancing Meteorological Services (ICAMS), which coordinates priorities across the diverse agencies that make up the Federal meteorological services enterprise. NOAA actively engages in the Joint Action Group on Earth System Predictability hosted by the ICAMS Committee on Research and Innovation.
- NOAA co-chairs the US Global Change Research Program that is key to interagency coordination on Earth system process research and climate predictions. ICAMS and USGCRP play complementary interagency coordination roles.
- NOAA actively participates in (and is a principal funder of) the Unified Forecast System, which brings together collaborators from other Federal Agencies and the academic and private sectors, leveraging the entire numerical weather prediction enterprise to improve NOAA's operational numerical environmental prediction systems.
- The NOAA Modeling Board expects to work closely with the Earth-system prediction components of relevant Strategic Implementation Plans to ensure the relevance of the overarching plan, as well as to ensure UFS implementation continues steering towards being a benefit to multiple line offices.
- The UFS Strategic Plan has some gaps concerning broader NOAA modeling needs. The NMB envisions mapping the different components of NOAA and the Enterprise working on components of Earth-system modeling for NOAA, tracking progress of those components, potentially building a new Earth-system modeling plan for NOAA.

Model Technology

Recommendation 19: NOAA agrees
Recommendation 20: NOAA agrees
Recommendation 21: NOAA agrees
Recommendation 22: NOAA agrees

NOAA response:

- Significant strides towards exploiting Cloud computing across the spectrum of NOAA's Earth-system observations value chains are being made, recognizing that this effort requires deliberate resourcing to effectively create and equip the workforce needed. Current resources are insufficient.
- Establishing data readiness, IT, and computing infrastructure to enable innovations and leverage progress in this fast-developing field is critical. Challenges include modernization of data to be AI/ML/Analysis-ready, model and analysis codes and scripts, developing cloud-ready interfaces and data protocols to exploit Artificial Intelligence (AI)/Machine Learning (ML) capabilities.
- Per Executive Order 13960 "Promoting the Use of Trustworthy Artificial Intelligence in the Government", NOAA identified over 260 current and planned AI/ML efforts across NOAA.
- The NESDIS commercial weather program successfully acquires commercial GPS radio-occultation (RO) data and can procure other commercial weather data when they become available and meet performance requirements. NWS recommends that the private sector share in supporting user readiness for the private sector observing systems being developed. Additional cost/benefit/risk analysis of government programs versus commercial data buys is needed.
- One aspect of improvement metrics is peer-reviewed publication, important assessments attesting to the quality of the findings, recognizing its deficiencies and limitations, such that the information can be considered 'actionable' in Earth System predictions and projections.

Desired Outcome

NOAA's response to the SAB's report "*Advancing Earth System Prediction*" and this presentation are informational for the SAB's awareness.

Backup Slides

Land Observations

What NOAA has done:

- Funded work to improve snowfall/snowpack datasets.
- Funding a 3-year project on enhancing S2S predictions of precipitation and drought via improved representation of snowpack processes.
- Developing a satellite & in situ blended snow-water-equivalent product.
  - A satellite & in situ blended snow-depth research is already developed and published

What NOAA intends to do:

- Leverage the ICAMS for coordination efforts
- Continue engagement with the U.S. Global Change Research Program (USGCRP),
  - Participation in the Global Precipitation Grand Challenge, which is coordinated by the USGCRP
- Improve coordination of modeling and data assimilation efforts from hydrological through to fully coupled applications.
- Develop techniques to better leverage novel observations, e.g., from citizen science.
- Properly steward and use gridded snow-mass observations to service climate-scale understanding and use.
- Ingest the highest-quality snow-mass data and use them for product development and model initialization in UFS-based systems.

Atmospheric Chemistry Observations

What NOAA has done:

- Conducted Bedrock-to-Boundary Layer (B2B) Workshops in April 2019 and June 2021
- NESDIS developed a biomass burning emissions product that is ingested by NWS operational global (GEFS-Aerosol) and regional aerosol (CMAQ) models.
- The Community Multiscale Air Quality (CMAQ) modeling system is being coupled to the regional system (RRFS) and studies of feedbacks between chemistry and weather have begun.
- The OAR Air Resources Laboratory (ARL) developed FENGSHA, a dust emission model that has been implemented into the FV3GFS-Chem global aerosol model.

What NOAA intends to do:

- NOAA will continue its long collaboration with NASA and the larger community to obtain the most up-to-date land and biomass emission observations and derived products for improving EMC's modeling suites for weather and S2S predictions.
- NESDIS aims to utilize the fire radiative power, aerosol and trace gas products from geostationary satellite imagers and atmospheric composition sensors to contribute to air quality, cloud physics, chemistry, and climate modeling.
- NWS and OAR intend to:
  - Develop assimilation capabilities for enhanced land observations and improved observations of emissions;
  - Improve the representation of boundary layer physics;
  - Introduce radiatively active aerosols and chemistry into the prediction systems as predictands; and
  - Transition innovation from R&D partners into operational applications based on the Unified Forecast System.

Ocean & Coastal Shelf Observations

What NOAA has done:

- NOAA recently released a five-year Strategic Plan for Uncrewed Systems (UxS) with the objective of coordinating and expanding operation of NOAA's uncrewed aircraft and marine systems across the agency.
  - NOAA operational ocean prediction modeling systems (e.g., RTOFS) ingest all such observations of shelf-sea, deep, and polar waters that are available on the GTS.
  - Autonomous vehicles continue to be evaluated for mission-specific purposes.
- The Tropical Pacific Observing System 2020 (TPOS 2020) Project completed its final report in 2021, providing recommendations for integrating observational approaches (e.g. moorings, satellites, gliders, ships) and further development and evaluation of promising observational technologies, some of which are already being implemented in FY22.
- NOAA has increased deep ocean observations through the Deep Argo program.
- The NOAA Argo Program Office held a cross-line-office workshop in June 2022 to demonstrate the utility of core Argo, deep Argo, and biogeochemical Argo for NMFS applications.
- NMFS has accelerated the integration of data from autonomous platforms into assessing the living components of the coastal and deep ocean and understand their variability.

Ocean & Coastal Shelf Observations

What NOAA intends to do:

- Address stakeholder requirements by filling priority gaps for global ocean and coast observations.
- Leverage grant partners to develop critical baseline infrastructure capability for ecosystem monitoring required for climate-based living marine resource management, along with other necessary added measurements (e.g. acidity, nutrients, acoustics, and genomics) for targeted regional needs and applications.
  - As part of the proposed NOAA CEFI, NOAA will coordinate with IOOS on data management, modeling, and new technology deployments.
  - In conjunction with NWS and NOS, NESDIS plans to develop data products, tools, and techniques to effectively assimilate geostationary ocean color data into NOAA's ocean biogeochemical models and applications.
- Strengthen the value chain between glider observations and NOAA's models, aiming to optimize ocean model performance.
  - Implement an underwater glider field campaign, aiming to improve hurricane intensity forecasts.
  - Plans for the 2022 hurricane season include further testing/evaluation of the Saildrone system.
- Implement the UFS JEDI data assimilation framework, which will accelerate assimilation of new and enhanced ocean observations.

Ice and Inundation

What NOAA has done:

- Continued developing the Unified Forecast System (UFS) global coupled model for the oceans, atmosphere, and sea ice, accounting for ice-derived runoff as part of sea ice-ocean coupling. NOAA has coupled sea-ice/ocean/atmosphere assimilation and prediction activities on multiple fronts (UFS, JCSDA, NOAA-NASA Modeling Team).
- NOAA partners with the Office of Naval Research (ONR), via NOPP, to support higher-resolution global ocean and tide modeling, which should provide information needed for assessing flexure.
- NESDIS is developing new satellite sea-ice observations and products for UFS assimilation, building toward a sea-ice dynamics integrated system (Dynamice).
- OAR's OM4, CM4, and SPEAR model efforts are providing a path for coupling dynamical sea ice and ice-derived runoff components. OAR is actively working on developing ice-sheet components.
- The 2020 realignment of USNIC into NCEP's Ocean Prediction Center (OPC) positions NWS to start planning implementation of a full spectrum of integrated analyses and predictions of polar maritime weather and ice, including improved sea-ice predictions and hazards, and polar seasonal outlooks.

What NOAA intends to do:

- NOAA plans to utilize new technologies to develop an efficient and effective observing enterprise, investing in new deployments of ocean observing technologies and deploying buoys and other observing technologies for Arctic ice information.
- NWS will support strategic and tactical ice analysis services by leveraging data from foreign satellite data purchases and providing support for the International Arctic Buoy Program.
- NWS products will provide upgraded operational inundation maps, upgraded probabilistic storm surge guidance, and operational weekly, monthly, and seasonal sea-ice outlook guidance products for the Arctic Ocean.
- NESDIS is developing a sea-ice dynamics product suite that includes ice motion, divergence/convergence, deformation rate, and sea-ice leads (fractures).
- The NOAA CEFI will develop regionally focused models nested within global models that, for the Arctic and Alaskan domains, will include sea-ice simulations.

Operational Oceanography and Forecasting

What NOAA has done:

- As part of future UFS-based operational applications, global and regional MOM6 simulations are being actively evaluated for future operational use with help from the larger UFS-community.
- On a global scale, the SPEAR climate prediction system, which includes MOM6, has been published and routinely delivers seasonal physical ocean forecasts to the North American Multi-Model Ensemble and corresponding decadal prediction efforts.
- NWS recently completed a 40-year ocean reanalysis employing JEDI-based data assimilation in conjunction with the operational Real-Time Ocean Forecast System (RTOFS).
- Preparations for the CEFI have established prototype high-resolution (1/12th-degree) regional MOM6 implementations covering the east coast, west coast and the Arctic that include both physical and biogeochemical capabilities.
- Development is underway on assimilating satellite ocean color observations of chlorophyll-a into NOAA's Unified Forecast System's (UFS) Real-Time Ocean Forecast System (RTOFSv2) to inform both biophysical feedback and ecosystem representativeness in conjunction with working to implement BLINGv2 biogeochemical modeling within the global RTOFSv2.
- Through by the IOOS Coastal and Ocean Modeling Testbed (COMT), NOS initiated research on assimilating satellite ocean color observations of chlorophyll-a for regional coastal ecological forecasting, targeting support of harmful algal bloom forecasts and National Marine Fisheries Service (NMFS) bycatch avoidance guidance.

Operational Oceanography and Forecasting

What NOAA intends to do:

- In conjunction with the UFS community, NOAA is actively working on establishing foundations for future global coupled forecast systems, which include MOM6 and employ an Earth System Modeling approach for operational prediction.
  - NOAA is developing a UFS-based Seasonal Forecast System (SFS) that employs MOM6 and CICE6 as components. JEDI-based ocean data assimilation and a new ocean reanalysis will set the stage for fully coupled data assimilation, initially weakly coupled, with the target being strongly coupled data assimilation.
  - The long-range UFS vision includes evolving the near-real-time global RTOFSv2, Hurricane Analysis and Forecast System (HAFS), and the Rapid Refresh Forecast System (RRFS) to the MOM6 after appropriate validation, demonstrating the seamlessness of weather and climate prediction.
- The NOAA CEFI aims to implement an end-to-end, operational MOM6 modeling and decision support system that will provide information needed to reduce impacts and increase resilience in a changing climate, aiming to simulate ocean and ecosystem conditions across a range of timescales for all US Exclusive Economic Zones (EEZs).
- NOS plans to develop an East Coast Operational Forecast System, in addition to developing and improving OFSs in the Northeast, Northwest, Southeast, and Gulf of Mexico.
- NESDIS aims to enable assimilating planned observations from hyperspectral ocean color sensors (NASA PACE) and geostationary ocean color sensors (NASA GLIMR and NOAA GeoXO/OCX), as well as enable more frequent observations of water quality and biological assemblages (e.g., phytoplankton types) and biological processes (e.g., primary productivity.
- NESDIS aims to improve the assimilation of satellite altimetry observations into the UFS's modeled ocean's interior through better constraining surface density, thereby enhancing the representativeness of modeled ocean heat content and cascading influences on coupled ocean-atmosphere interactions.

Decision-maker Needs

What NOAA has done:

- NOAA leverages the U.S. Integrated Ocean Observing System (IOOS) and associated Regional associations and partners in identifying user requirements for decision making across temporal and spatial scales and across user sectors.
- The NESDIS National Centers for Environmental Information (NCEI) collects requests identifying needs from a broad spectrum of external users, e.g., the commercial, academic, and even foreign government sectors, each with their own longer-term infrastructure and investment needs and objectives.
- NWS and OAR, with community partners, established key verification and validation metrics for UFS-based applications. These metrics, derived from input by the broader community, will guide evaluating UFS research products and their transition to use.
- NOAA has initiated EPIC, which combines: (1) being a roadmap for research and model priorities, (2) being a development environment, (3) code management, (4) cloud-ready code, (5) observational data and tools, (6) community support, and (7) community engagement.
- For the ocean domain, satellite products, decision-making aids, and specialist support are coordinated, in part, through NOAA CoastWatch/OceanWatch/PolarWatch and their Annual Science Meeting.

Decision-maker Needs

What NOAA intends to do:

- NWS and OAR are developing UFS-based fully coupled subseasonal and seasonal prediction systems to capture processes leading to extreme phenomena, which are of critical importance to infrastructure and investments.
- NOAA's CEFI, designed to support climate-informed decision-making by multiple sectors involved in managing and using marine and coastal resources, aims to deliver essential forecasts (seasonal-to-decadal scales), projections (decadal-to-centennial scales), and assessments of climate, ocean, and marine ecosystems.
- NOAA will fund a robust collaborative research program to understand the responses of marine ecosystems to past climate variability and change and assess NOAA's capacity to predict responses. Priorities for these efforts include enhancing ocean and ecological predictions and decision-support tools, improving scientific understanding of earth-system changes reflected in marine ecosystems, and evaluating alternate resource management strategies.
- NESDIS/STAR will lead the development of innovative derived products that fuse satellite observations of multiple geophysical parameters to meet user needs, exploiting AI/ML learning techniques when appropriate. NESDIS also will pursue consistently processed multiple-mission long-term time-series datasets, initially focusing on mature satellite ocean observations (SST, Ocean Color, altimetry/SSH).
- NWS will continue engaging the R&D and operational communities on refining measures of model skill and valuation of derived products. NWS will pursue development of derived ensemble model products for probabilistic weather prediction to support improving impacts-based, decision-support services.

Enhancing Coordination

What NOAA has done:

- NOAA is a member of the Interagency Council for Advancing Meteorological Services (ICAMS), which coordinates priorities across the diverse agencies that make up the Federal meteorological services enterprise. The ICAMS Committee on Research and Innovation hosts a Joint Action Group on Earth System Predictability, in which NOAA is actively engaged.
- NOAA co-chairs the US Global Change Research Program that is key to interagency coordination on Earth system process research and climate predictions. ICAMS and USGCRP play complementary interagency coordination roles.
- NOAA actively participates in (and is a principal funder of) the Unified Forecast System, which brings together collaborators from other Federal Agencies and the academic and private sectors, leveraging the entire numerical weather prediction enterprise to improve NOAA's operational numerical environmental prediction systems.

What NOAA intends to do:

- The NOAA Modeling Board expects to work closely with the Earth-system prediction components of relevant Strategic Implementation Plans to ensure the UFS implementation continues steering toward being a benefit to multiple line offices, as well as the relevance of an overarching plan.
- The UFS Strategic Plan has some gaps concerning broader NOAA modeling needs. The NMB envisions mapping the different components of NOAA and the Enterprise working on components of Earth-system modeling for NOAA, tracking progress of those components, potentially building a new Earth-system modeling plan for NOAA.

Model Technology

What NOAA has done:

- NOAA's Office of the Chief Information Officer (OCIO) has developed a NOAA Cloud Strategy. Cloud computing and data contracts/programs are established at OCIO and across NOAA Line Offices.
- The NESDIS Common Cloud Framework (NCCF) provides a good example of cloud computing. NESDIS is developing and migrating enterprise algorithms for generating products in the cloud, aiming to provide the NCCF data and products to numerical modeling users.
- NWS initiated multiple projects to run UFS-based applications in the cloud, including the operational Global Forecast System, the ensemble-based Rapid Refresh Forecast System, and Model Evaluations Tools, which provide the basis for all UFS-based model evaluations
- OAR has engaged all three cloud providers in conjunction with the EPIC program and is moving its UFS applications to the cloud for easier community engagement, experimentation, and development.
- NOAA has broadly begun using AI/ML for Earth-system applications, spanning from the retrieval of geophysical parameters to identifying and exploiting Earth-system predictors.
- NESDIS currently ingests commercial RO data in the NCCF and provides RO data to NCEP for assimilation. NESDIS has issued Broad Area Announcements to explore developing new technologies and is working to acquire more data sets for hazard mitigation. NESDIS monitors and validates the quality and performance of remote-sensing data, including commercial data.
- NWS operational forecast systems assimilate commercial radio occultation data, data from commercial aircraft, and ground-based precipitable water from Global Navigation Satellite Systems (GNSS).

Model Technology

What NOAA intends to do:

- EPIC plans to continue fostering collaboration, enabling access to high-performance computing output by porting UFS-based applications to cloud platforms.
- The NOAA Line Offices have extensive plans to exploit AI/MI techniques for a broad spectrum of uses.
- The NOAA Center for Artificial Intelligence (NCAI) will continue collaborating, through the Earth Science Information Partners (ESIP) cluster, to mature the AI-ready data standard to support diverse open environmental data user needs.
- NWS plans to continue upgrading its observation processing to accommodate new observing systems, including those from commercial vendors, e.g., smallsat microwave observations and saildrones.
- NESDIS will facilitate and support Line Office needs for imagery and products for coastal ocean observations derived from high-resolution non-NOAA satellite missions, including Sentinel 2, Landsat and from commercial satellite missions, including synthetic aperture radar missions, "cube sats", "planet", and others.
- With the advanced GEO instrumentation and significantly improved navigation and registration, NOAA and NASA are working closely to further develop a stereo capability (GEO-GEO; GEO-LEO) to offer a direct method of cloud height and wind-vector assignment that relies only on the geometric parallax observed from two different vantage points. NESDIS also will explore the technological development of hyperspectral microwave soundings and 3D winds.