Toward Improved Numerical Weather Prediction Though Advancing Model Capabilities in the Unified Forecast System

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Thank You!!

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Session Description

- Overview of the Unified Forecast System (UFS)
- Overview of the UFS Research to Operations Project and OSTI/Modeling Division
- Overview of the Earth Innovation Prediction Center Program

Inherent barriers to solutions with the status quo

- Fractured internal strategy and growing requirements
- Fractured external strategy across agencies/industries with different priorities
- Obtuse HPC procurement process (both hard iron builds and cloud)
- Security clearance procedures for visiting scientists
- Cultural (internal and external)
- Funding allocation process disincentivizes collaboration
- Risk aversion (incentive not to fail >> incentive to improve)
- Too many committees with overlapping and conflicting input
- Lack of documented, supported, and portable community code

Forcing Factors

WAFIA

Leadership

People
Process
Product

T-2 years

Today

5 Years

ESPC → Contractor support
JCSDA
DTC
UFS → SC
UMC
CMAC
SIP

ESPC (?)

A → B

- Too many modeling systems & OPS
- Community codes are too small in number
- NOAA Global NWP } Difficult to work with community
  Fractured
- NOAA labs - Culture People
- NIM
- FIM
- FIM-HYcom
- Fractured Strategy
- Stove Pipe thinking

- UFS Adopted in NOAA
- Moving away from Spectral
- Engaged community in a Strategic sense
  - UMAC (2015) NWS
  - SIP
  - CMAC ← NWS - mixing OAR/NWS cultures
- OAR/NWS better aligned
  - SLA - Cross Lo projects to work on
- NCAR-NOAA MOA
  - Infrastructure
- JCSDA + New business model (UCP)
  - In-kind (Contract) → Gov't control
  - Core (Ucp) → Tom Control
- NCW
- Satellite DA
- DTC - GMTB
  - NGGPS

MOB
ET

SC

UFS

- NOAA #1 Global NWP } Includes DA, Conv allowing, Coupled, ENS
- Community based modeling System (End-to-End)
- Scientific VSP, Development (flexibility Same sharing)
- Scientifically Credible Toolset → PI's want to use it in Research (Documented Supported)
- (computationally flexible/efficient - Community accessible HPC ← Cloud Hardware
- Governance - Decision making Process CONTROL??
- Agencies (NOAA, NASA, NSF, DoE, USAF, USN) are jointly developing AO's based on Scientific priorities to advance the UFS.
- Unified Vision
- Agile/Nimble test environment with Resources (Innovation)

Engage Community ($)

- Agency players at the Table
- NSF - ($)
- NASA - ($)
- NOAA - ($)
- DoE -
- USAF -
- USN - → ($)

member states

C - 2yrs 5 10

MOB
DIR
ET

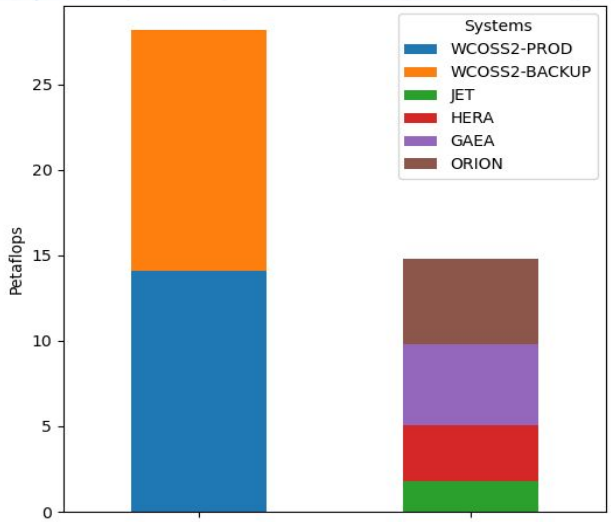
Govt
Community

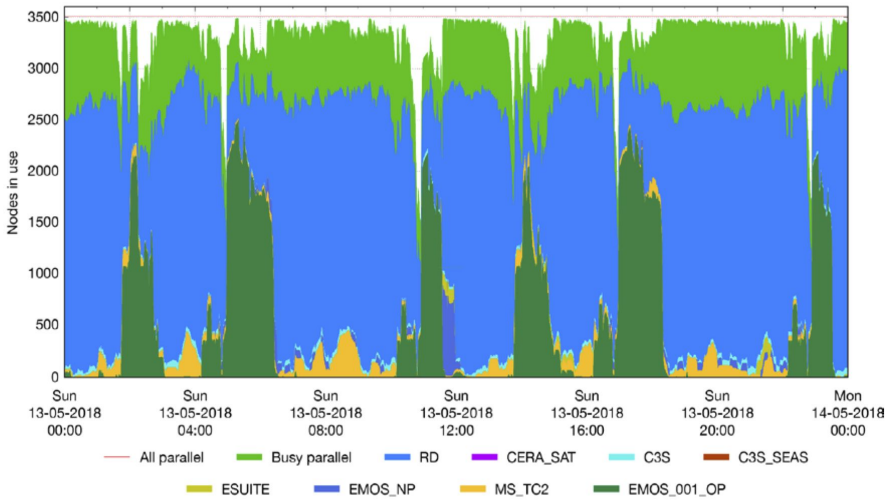
EPIC (Partnership)

Value to All Participants

Cloud HPC and community modeling

- Cloud HPC for on-demand parallel “surge” development
- More innovations than NWS can implement (because personnel/HPC)
- NOAA scientists have long queue to run jobs
- NOAA research : operations compute = 1:1 (1:2?) ECMWF roughly 5:1
- VMs: X:1 (X=scalable on demand)
- Costing per core hour (spot pricing options)
- Antibodies to "cloud” are cultural (not technical)
- Lift and shift, cloud native tools, and vendor lock





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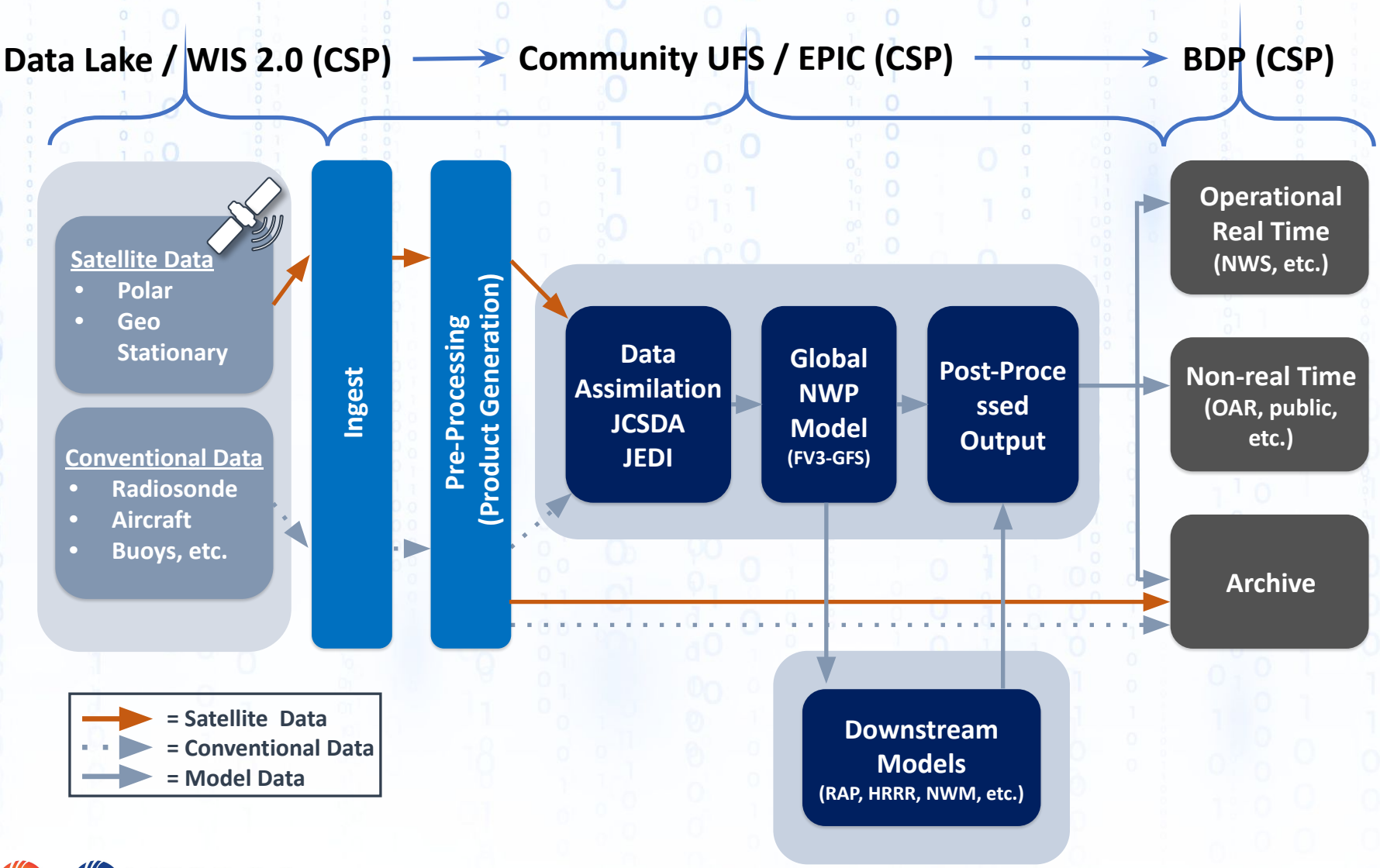
Cloud HPC and community modeling



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National Integrated Drought Information System Reauth. Act of 2018

SEC. 4. EARTH PREDICTION INNOVATION CENTER.

(a) WEATHER RESEARCH AND FORECASTING INNOVATION.—Section 102(b) of the Weather Research and Forecasting Innovation Act of 2017 (15 U.S.C. 8512(b)) is amended by adding at the end the following:

"(4) Advancing weather modeling skill, reclaiming and maintaining international leadership in the area of numerical weather prediction, and improving the transition of research into operations by

"(A) leveraging the weather enterprise to provide expertise on removing barriers to improving numerical weather prediction;

"(B) enabling scientists and engineers to effectively collaborate in areas important for improving operational global numerical weather prediction skill, including model development, data assimilation techniques, systems architecture integration, and computational efficiencies;

"(C) strengthening the National Oceanic and Atmospheric Administration's ability to undertake research projects in pursuit of substantial advancements in weather forecast skill;

"(D) utilizing and leverage existing resources across the National Oceanic and Atmospheric Administration enterprise; and

"(E) creating a community global weather research modeling system that—

"(i) is accessible by the public;

"(ii) meets basic end-user requirements for running on public computers and networks located outside of secure National Oceanic and Atmospheric Administration information and technology systems; and

"(iii) utilizes, whenever appropriate and cost-effective, innovative strategies and methods, including cloud-based computing capabilities, for hosting and management of part or all of the system described in this subsection.".

(b) UNITED STATES WEATHER RESEARCH PROGRAM.—Section 108(a) of the National Oceanic and Atmospheric Administration Authorization Act of 1992 (15 U.S.C. 8520(a)) is amended—

(1) in paragraph (10), by striking "; and" and inserting a semi-colon;

(2) in paragraph (11), by striking the period at the end and inserting "; and"; and

(3) by adding at the end the following:

"(12) carry out the activities of the Earth Prediction Innovation Center as described in section 102(b)(2) of the Weather Research and Forecasting Innovation Act of 2017 (15 U.S.C. 8512(b)(2)).".

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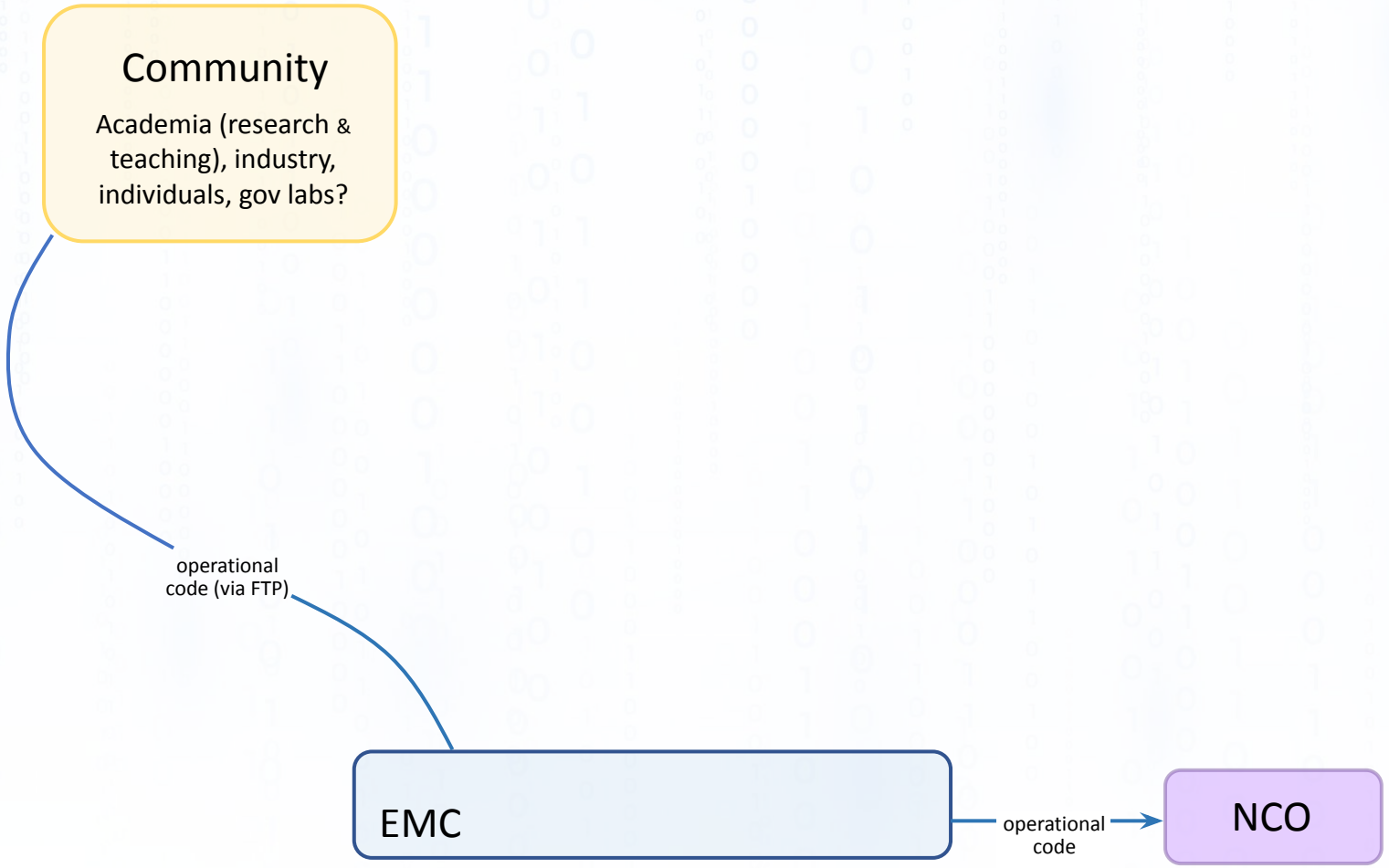
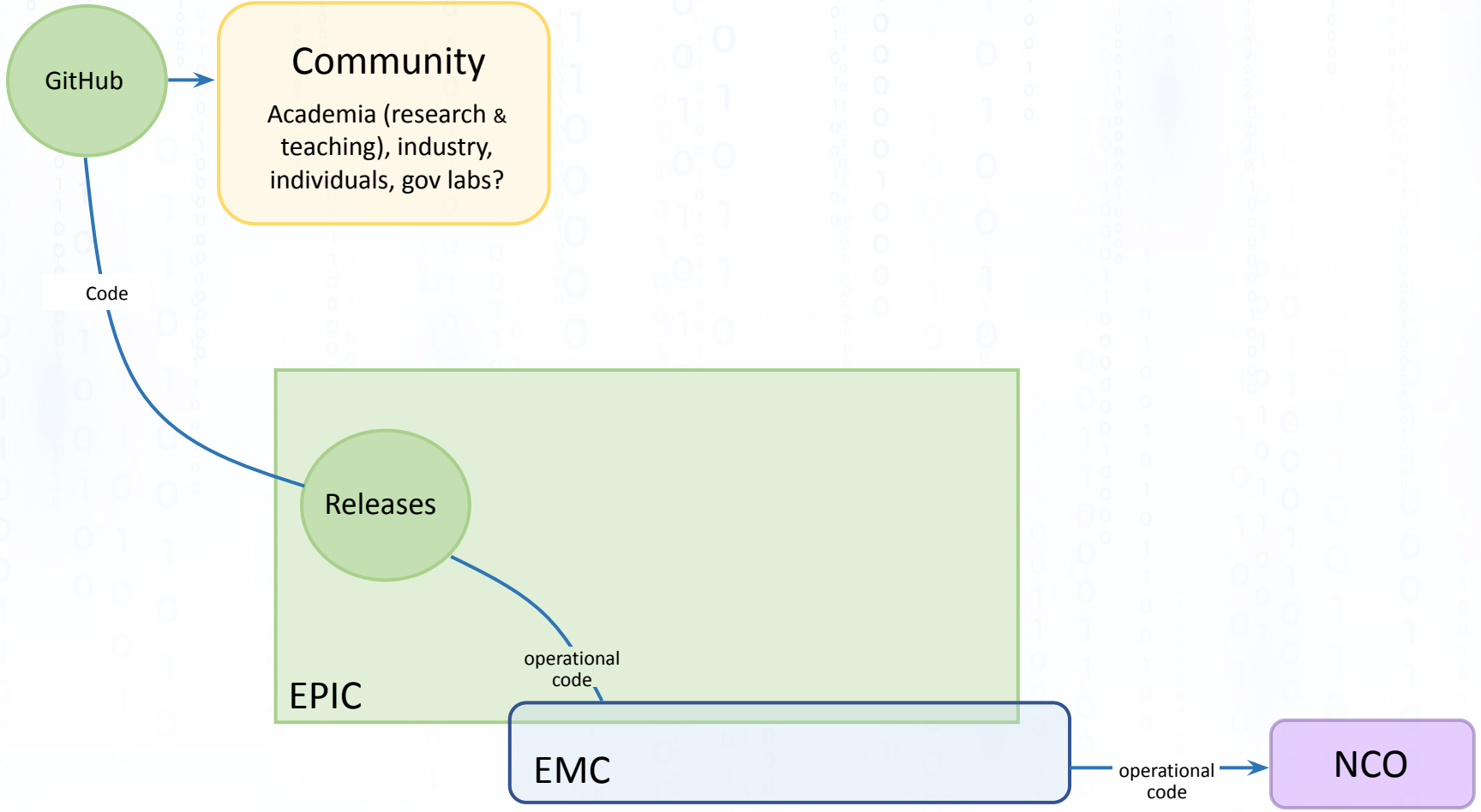
Process: circa 2015

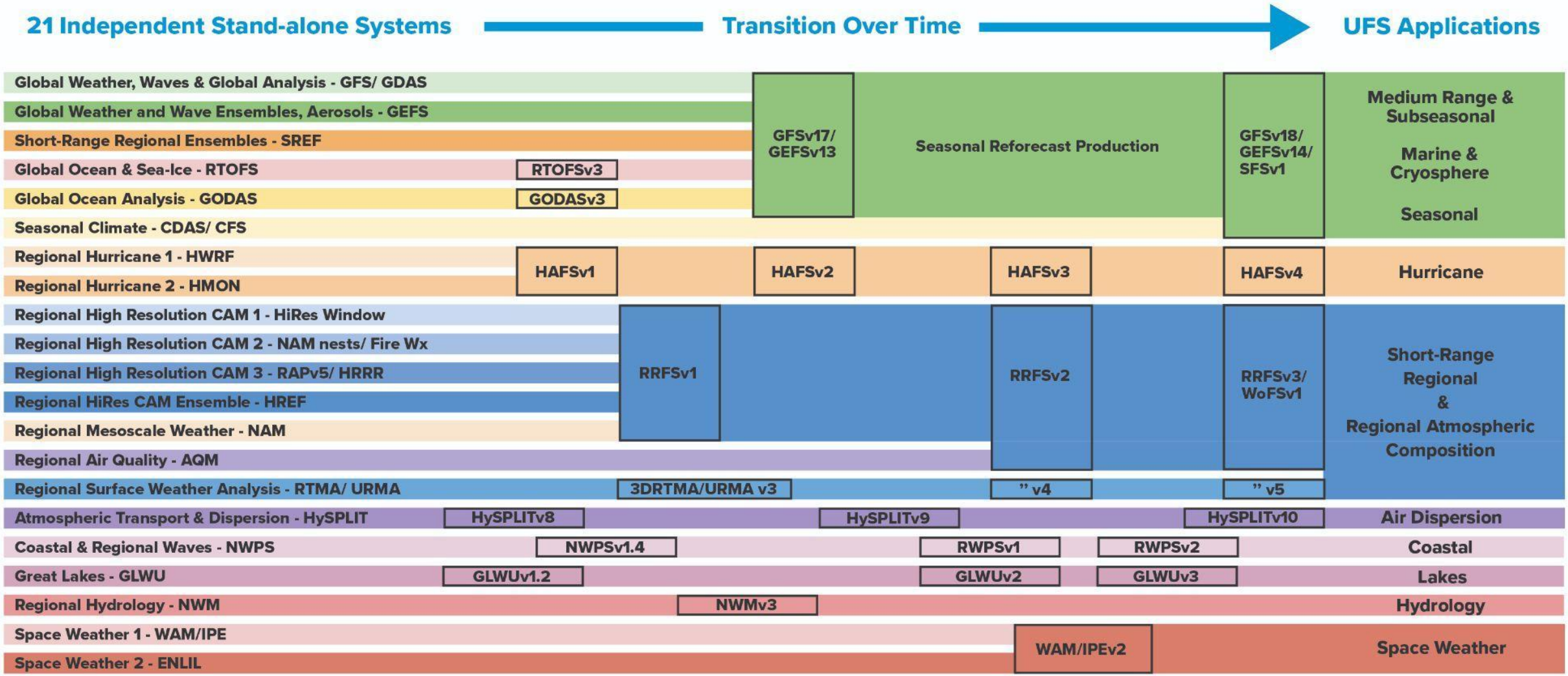


Process vision: managing community releases

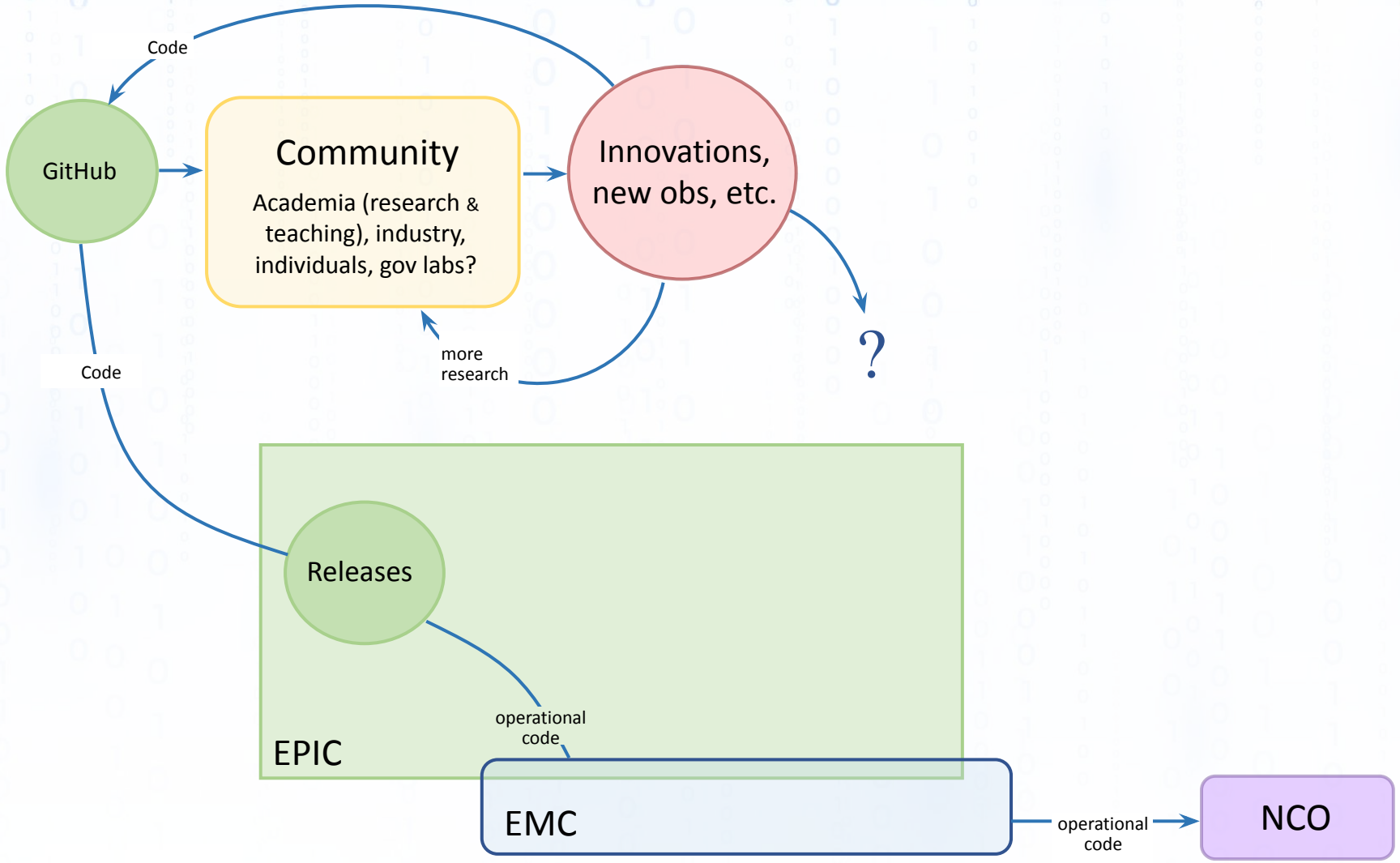


Simplifying NOAA's Operational Forecast Suite

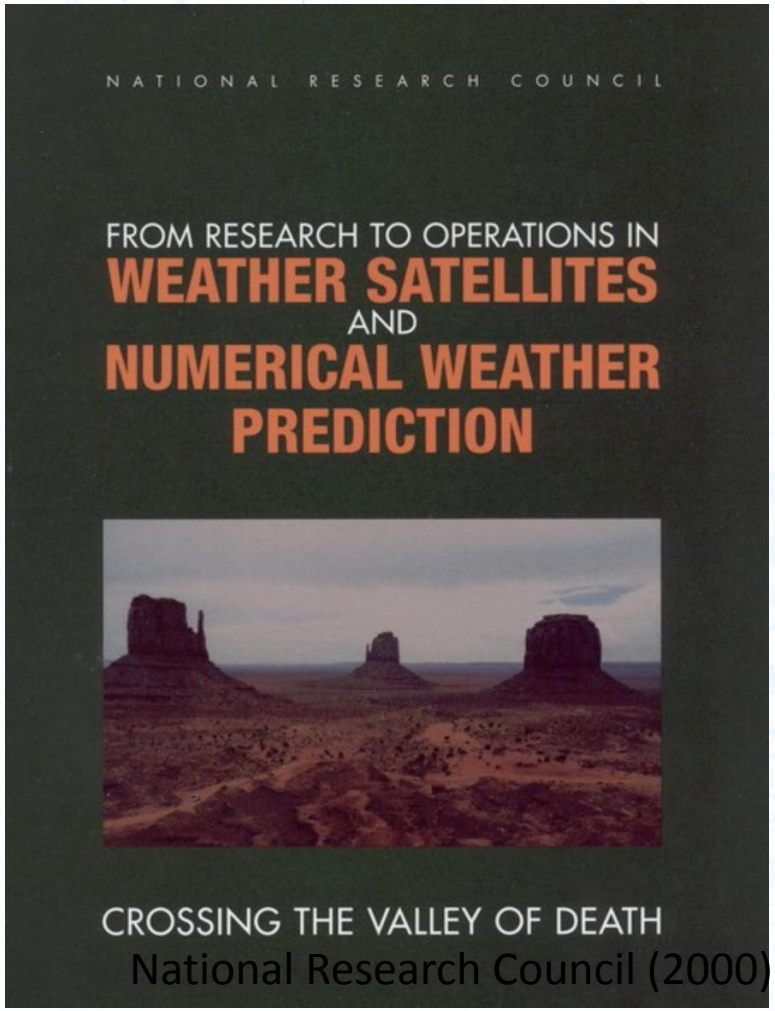
Reducing the 21 Stand-alone Operational Forecast Systems into Eight Applications



Process vision: enabling community innovation



R2O, Valley of Death, and *The* Funnel



National Research Council (2000)

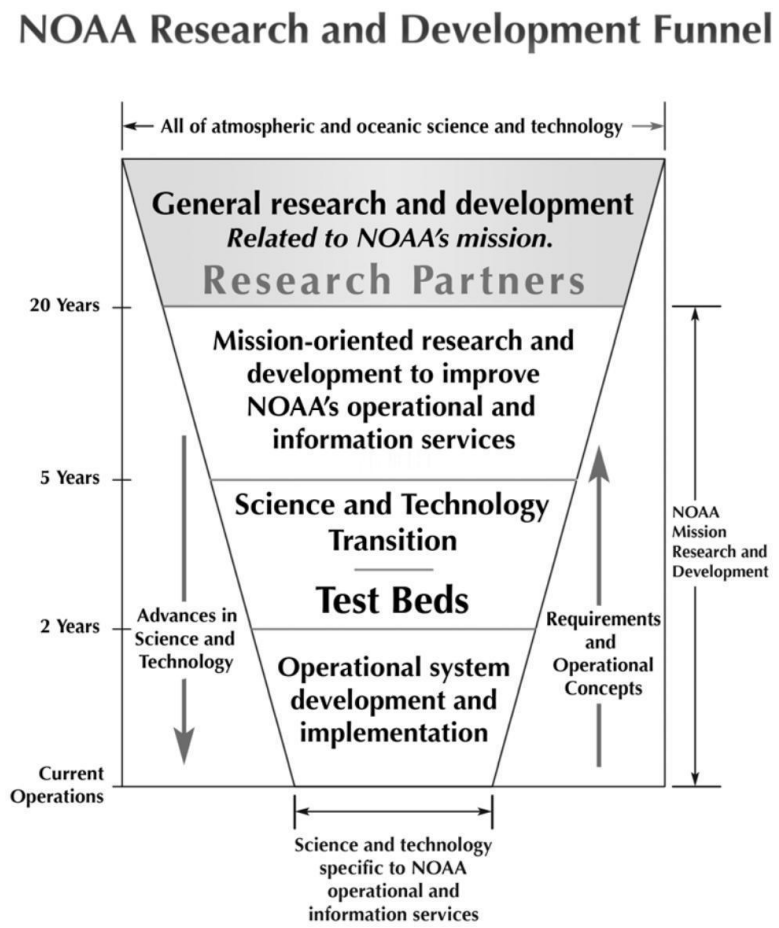
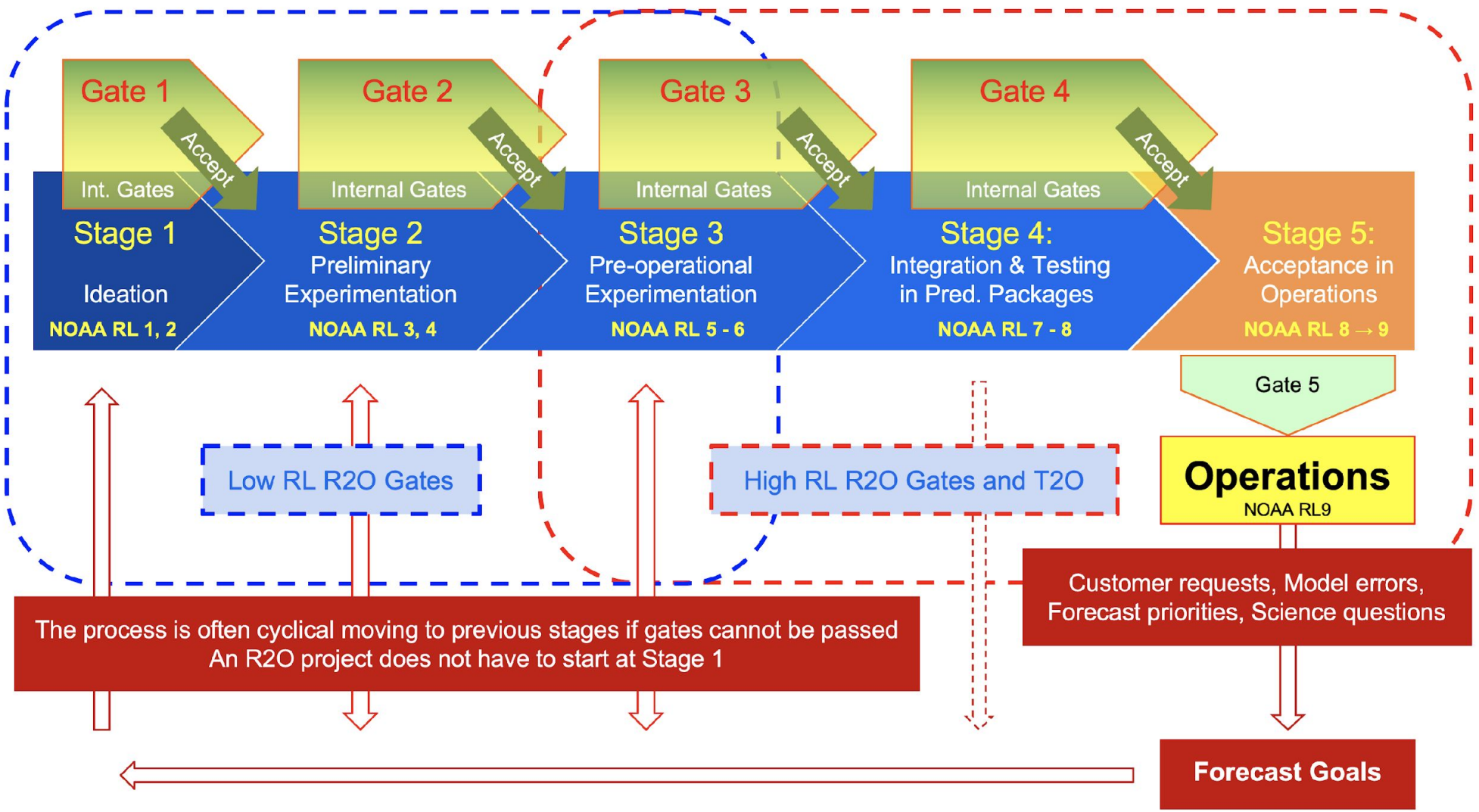


Fig. 1. The "research and development" funnel. This schematic gives an overview of how NOAA's mission-based research and development can be organized to keep its operational and information services at the state of the art in science and technology.

Alexander MacDonald , Richard Fulton, Maureen Kenny, Steven Murawski, Peter Ortner, Alfred Powell, Avery Sen, and Louis Uccellini, 2006: *Research Location in NOAA: Physical and Social Sciences*

UFS stages and gates



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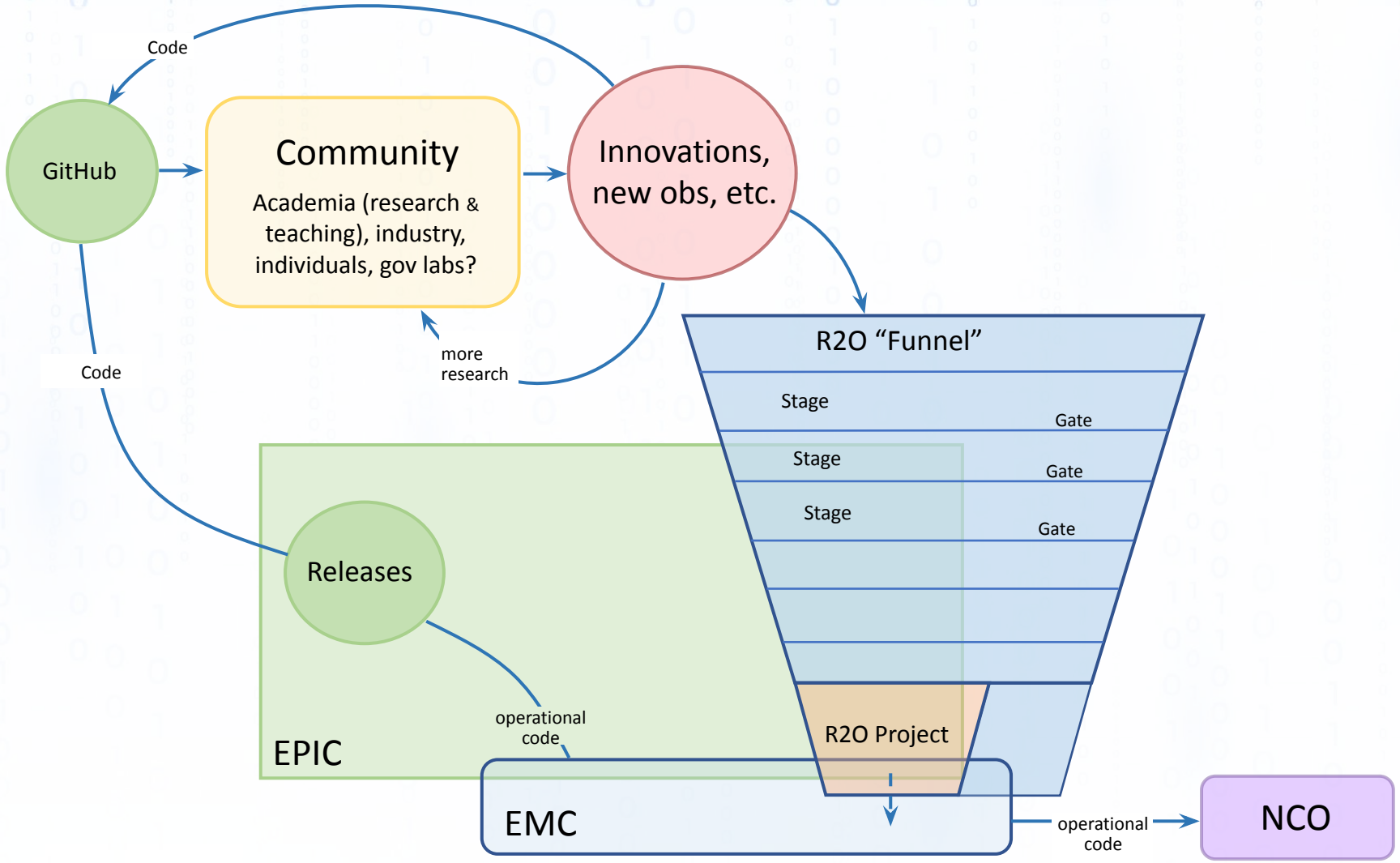
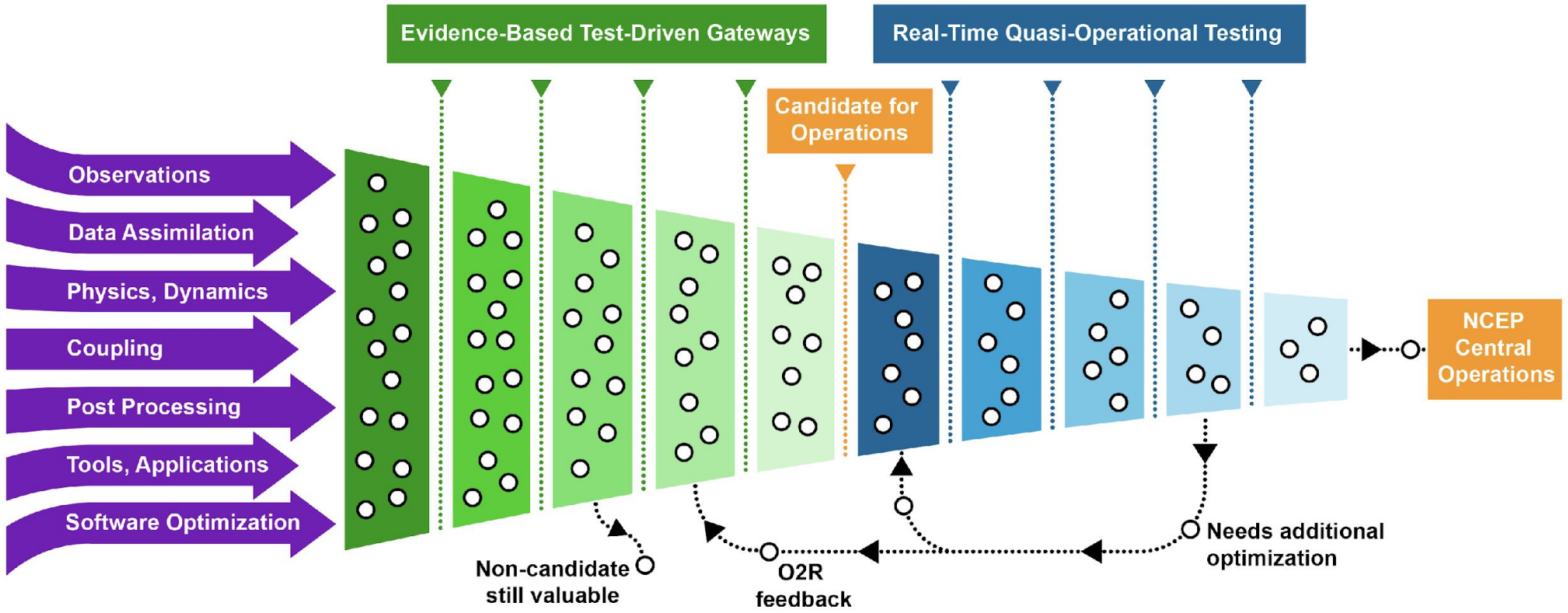
Process vision: “the funnel”



Formalizing the R2O “funnel”

- Initial baseline requirements with operations in mind (stages and gates)
- O2R! - R needs to better understand and appreciate O
- Objective evaluation process to transition though gates
- UMAC: ONLY “evidence-based decisions”
- No playing favorites / not invented here
- Verification / agreed-to evaluation metrics
- Parallel production environment (possibly many) and common workflow
- Software engineers brought in at initial stages
- EMC involved throughout the process (avoid forklift approach)

Formalizing the R2O "funnel"



Jacobs, N. A., 2021: Open Innovation and the Case for Community Model Development. *Bull. Amer. Meteor. Soc.*, 102(10), 2002-22.

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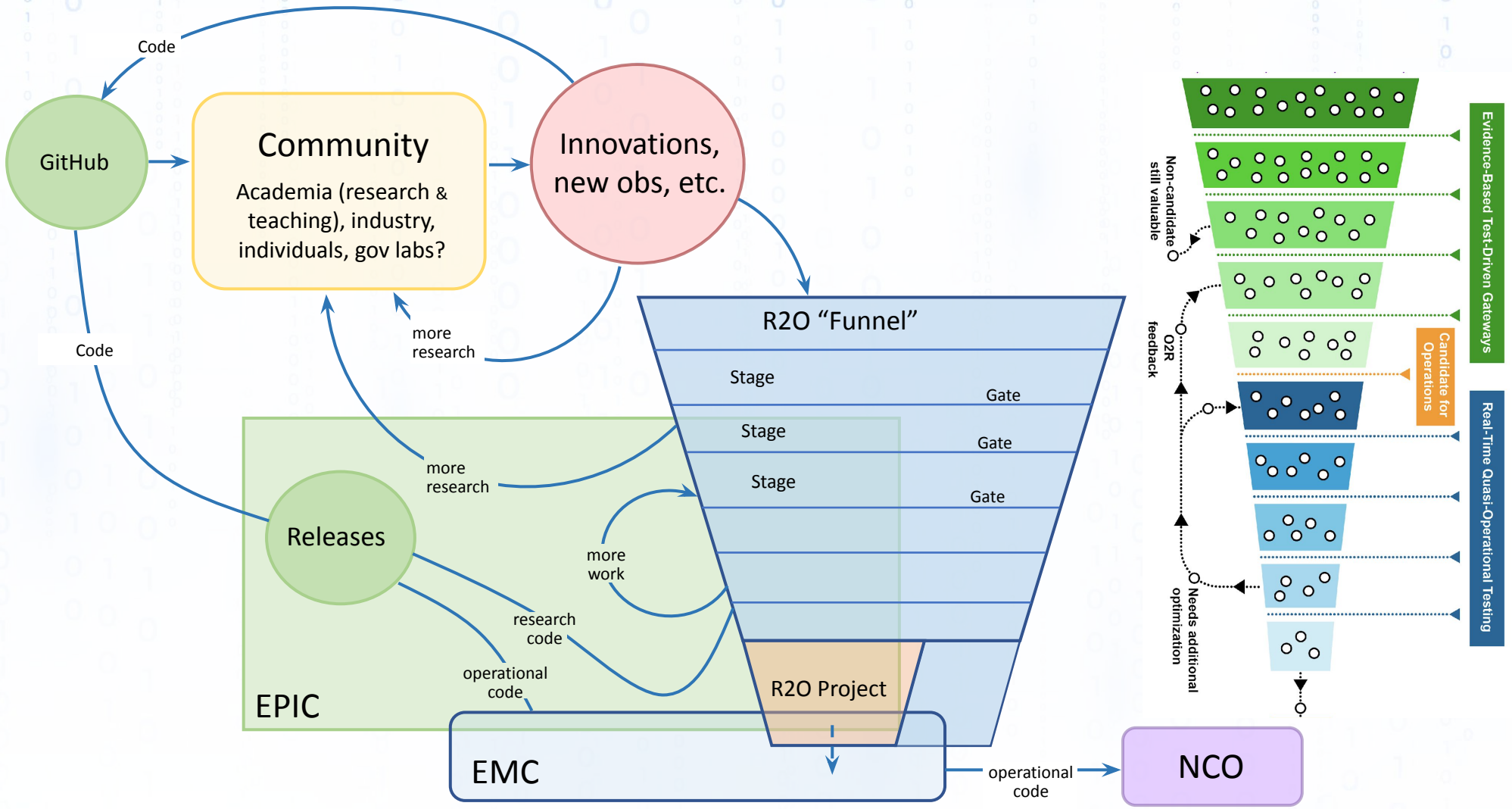
Process vision: transitioning to operations



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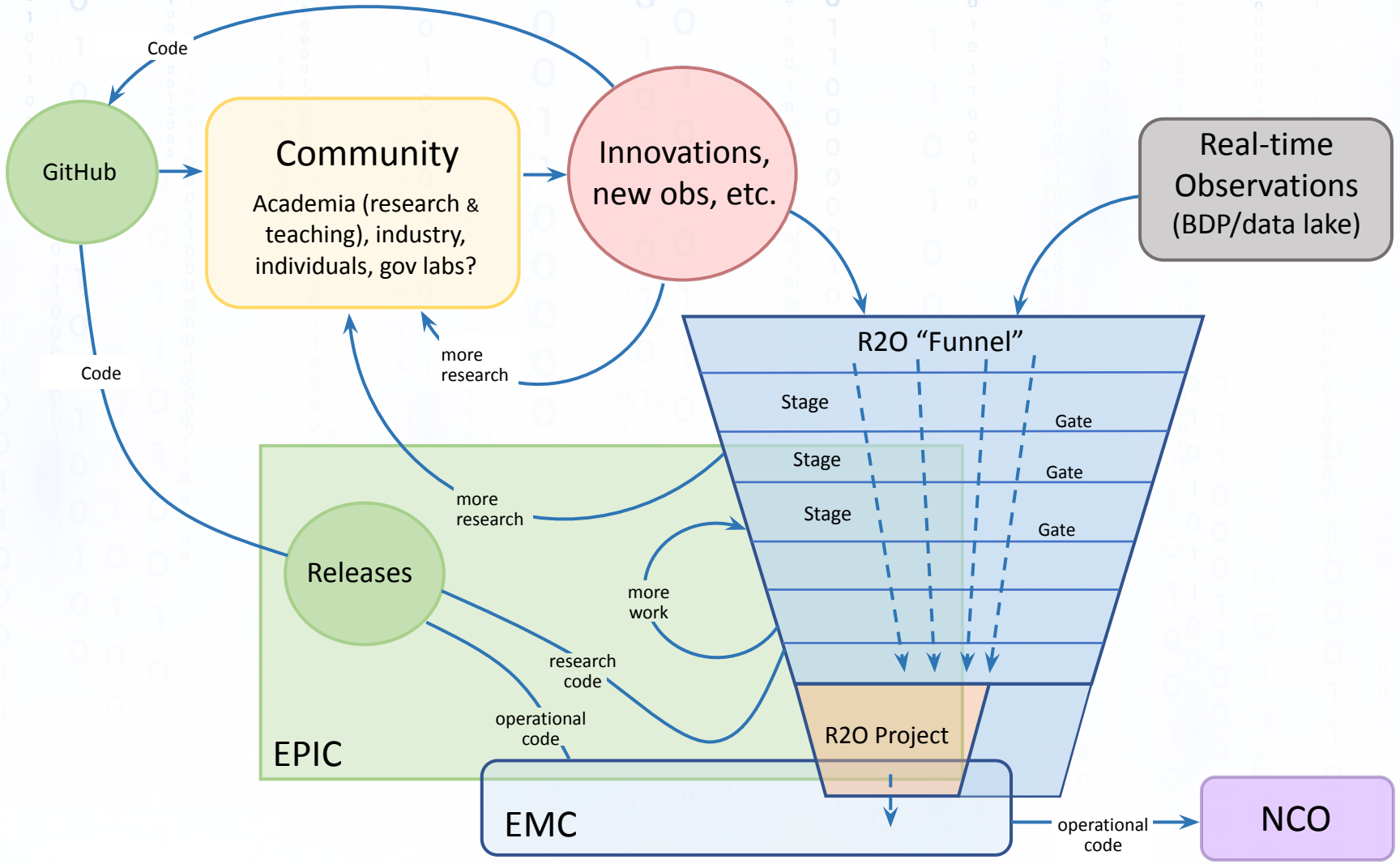
UFS matrix and roles

UFS Application Teams (ATs): Responsible for developing and delivering each UFS product

	Medium-Range Weather	S2S	Hurricane	Short-Range Weather	Space Weather	Marine and Cryosphere	Coastal	Air Quality
UFS TOB	Representatives of organizations contributing resources to UFS.							
UFS-SC	Overall leads for each application, responsible for identifying forecast skill priorities, determining science strategies, and developing release schedules, plus representation from cross-cutting teams and topical working groups.							
Cross-Cutting Teams	Leads and points of contact for cross-cutting teams focused on communication and outreach, release preparation, system architecture and infrastructure, and V&V.							
Topical Working Groups	Leads and points of contact for topical working groups focused on aerosols and atmospheric composition, data assimilation, ensembles, dynamics and nesting, land, marine, physics, and post-processing.							

Process vision: data lake, observations, and parallel testing



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What's in it for NOAA?

- Leveraging broad external expertise accelerates model development
- Streamlines the R2O process in a transparent and objective way
- Common code base and dependencies simplifies production suite
- Hardware-agnostic code commoditizes HPC and drives down costs
- Private investment is aligned with public mission
- Community model removes the "us versus them" public-private competition
- Community engagement doubles as training and recruitment
- Private sector advocacy for congressional support
- Better balance of risk burden

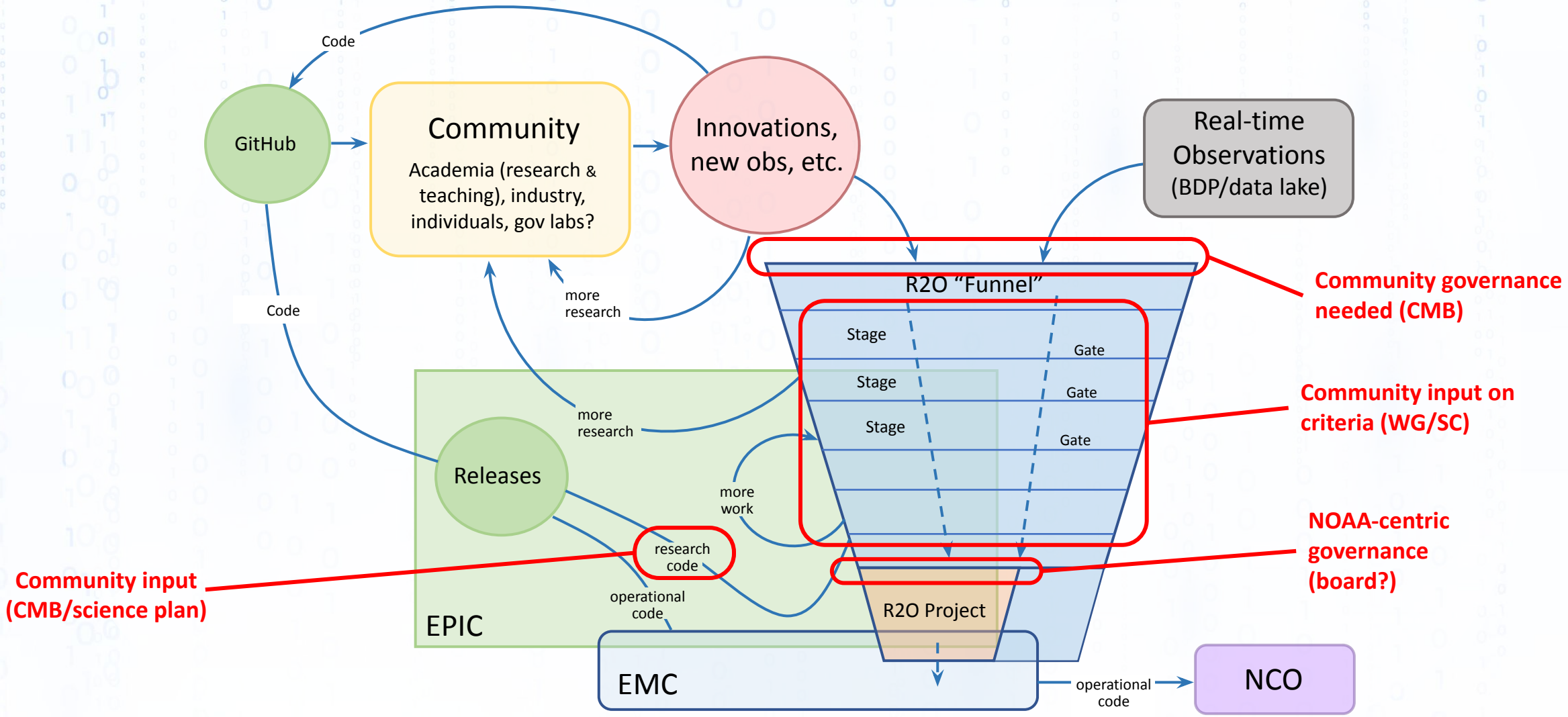
What's in it for academia?

- Researchers can contribute to operational system
- Experiments can be apples-to-apples using production code
- Funding opportunities benefit research, education, and public at same time
- Community offers collective support for getting up and running
- Open source, hardware-agnostic code is user friendly and inexpensive to run
- Cloud HPC is a cost-effective way to handle fluctuating demand
- Basic research (NSF) and applied research (NOAA/industry) use same code base
- Multiple entry points into the development process for different interest areas
- Foreign nationals can now work on production code
- UFS doubles as both a research tool and teaching tool

What's in it for industry?

- Better forecast means better products and services
- Open source, hardware-agnostic code is user friendly and cheap to run
- Creates more opportunity for customized NWP B2B solutions
- Government investment spurs innovation consistent with market direction
- Better forecasts mean greater cost avoidance
- Competition drives down costs of compute
- Enables rapid innovation
- Indirect economic benefits go well beyond Weather Enterprise

Process vision: governance and decision points



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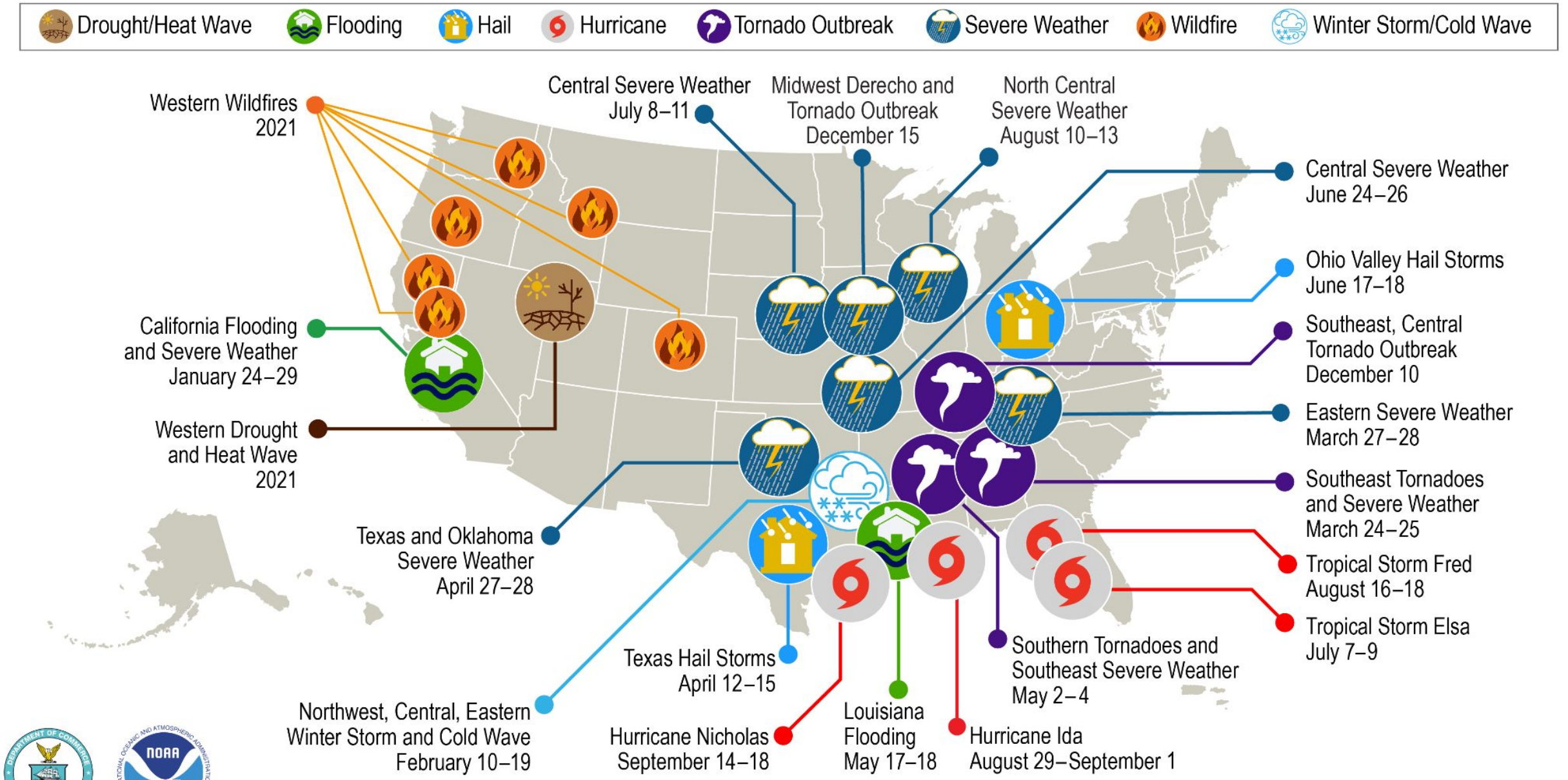
Overview of NWS/OSTI Modeling Program and the UFS-R2O Project

Jamese Sims, Ph.D., Director, National Weather Service (NWS) Office of Science and Technology Integration (OSTI) Modeling Program

U.S. 2021 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the **20 separate billion-dollar weather and climate disasters that impacted the United States in 2021***

ncdc.noaa.gov/billions

Modeling programs and projects

Programs

Projects

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NOAA MODELING PROGRAM GRANTS


Cloud Computing


Land Modeling

- Support NWS modeling and research initiatives to accelerate operational model development and improve forecast accuracy
- Foster collaboration among NOAA research scientists, federal labs, operational forecasters and the academic community

[OSTI Modeling Program]

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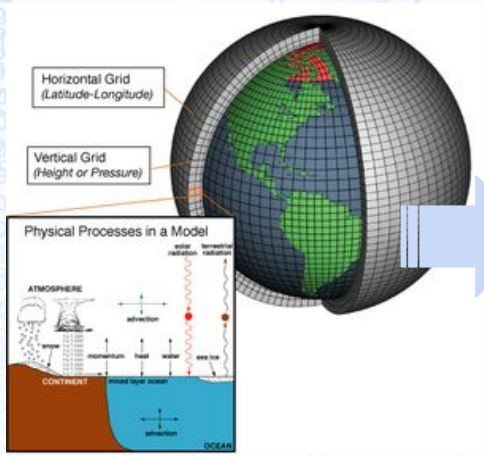
OSTI Modeling Program – What we do

Deliver world's best modeling capabilities through development and integration of science and technology improvements for a Weather-Ready Nation



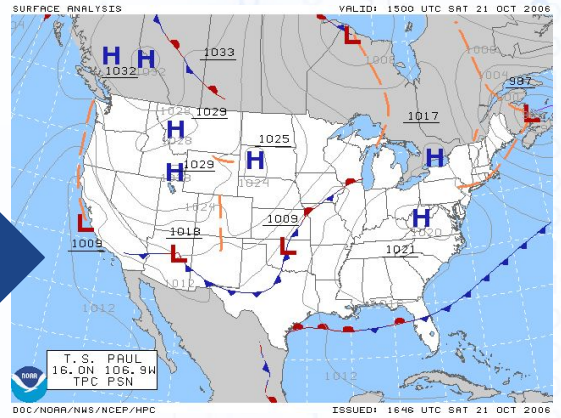
Research to Operations

WE ARE HERE

Basic Research

Applied R&D

Operational Deployment



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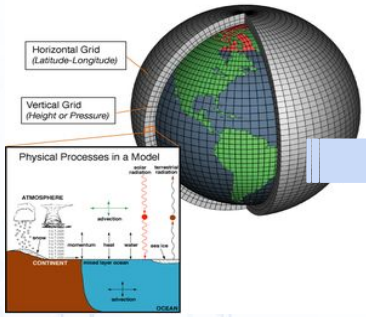
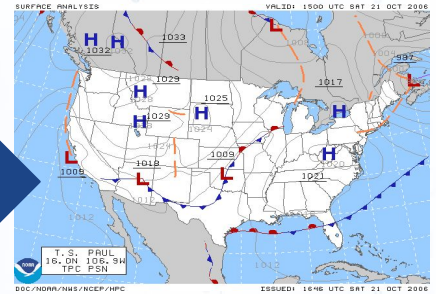
OSTI Modeling Program – What we do



Research to Operations



Basic Research **Applied R&D** **Operational Deployment**

Research

Cutting-edge research is being conducted by NOAA and non-NOAA labs and university partners

Ensuring innovations are in pipeline for implementation

“Valley of Death”-
Strengthening R2O bridge and making the transition pathways quicker and more efficient is key

Operations

NCEP Centers, NWS Regional Offices whose mission is to issue accurate and timely forecasts on a variety of weather, water and climate events

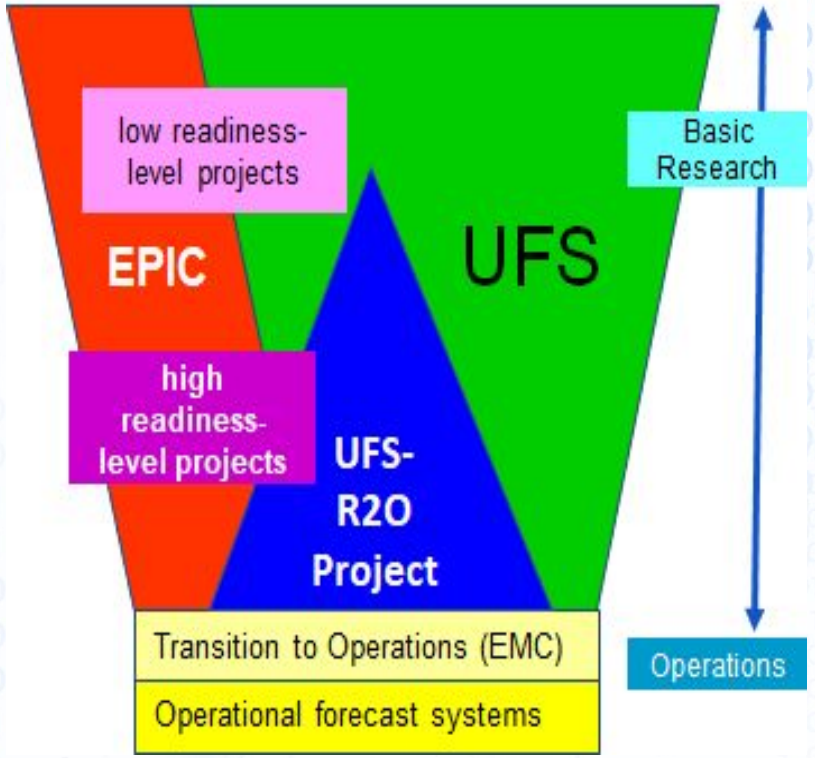
Priorities - Meeting Operational considerations, implementation schedule, Forecast accuracy, Forecasters and user needs

EPIC UFSR2O

UFS – Research-to-Operations Project (UFS-R2O)

UFS-R2O Project: Accelerating a pathway for community innovations into operational weather and climate modeling systems

- The UFS R2O Project began in 2020 as a NOAA-supported UFS community project, jointly supported by NOAA Operations (NWS) and Research (OAR), to develop three major UFS forecast application systems targeted for operational implementation.
- Unification and modernization of NWS operational models is a major effort underway at the NWS
- A community-based, modeling system, to support the Weather Enterprise is the future of operational models at NWS
- Collaborative efforts with research community, open development, and documented, community codes will be key
- Currently this effort is active through [UFS-R2O Project]



EMC, PSL, GSL, CSL, NSSL, ARL, GFDL, AOML, NESDIS

UFS-R2O Sponsors:
Sims (UFS-R2O PM, NWS), Kondragunta (JTTI, OAR), Huang (EPIC, OAR)

UFS-R2O Project Leads
Whitaker, Tallapragada, Kinter

Project Engineers

Medium-Range Weather, Subseasonal-to-Seasonal Coupled Global Model
Stan, Yang, Mehra, Jablanowski
Whitaker, Kinter

Rapid Refresh Forecast, 3D Real-Time Mesoscale Analysis & Warn-on-Forecast
Alexander, Carley
Tallapragada, Whitaker

Hurricane
Mehra, Zhang
Tallapragada, Kinter

Atmospheric Composition
Stajner, **Frost**

Atmospheric Physics
Bao, Bengtsson

Data Assimilation, Reanalysis & Reforecast
Kleist, Tremolet, Penny, Frolov

Cross-Cutting Application Support
Wolf, Wang

Cross-Cutting Modeling
Dunlap, Chawla

Verification and Post-Processing
Jensen, **Levit**

NOAA program focus areas

NWS/NGGPS Focus Areas
- Medium Range Application
- Atmospheric Physics
- Data Assimilation and Observations
- Stochastic Physics
- Physics Infrastructure (CCPP)
- Verification Infrastructure (METplus)

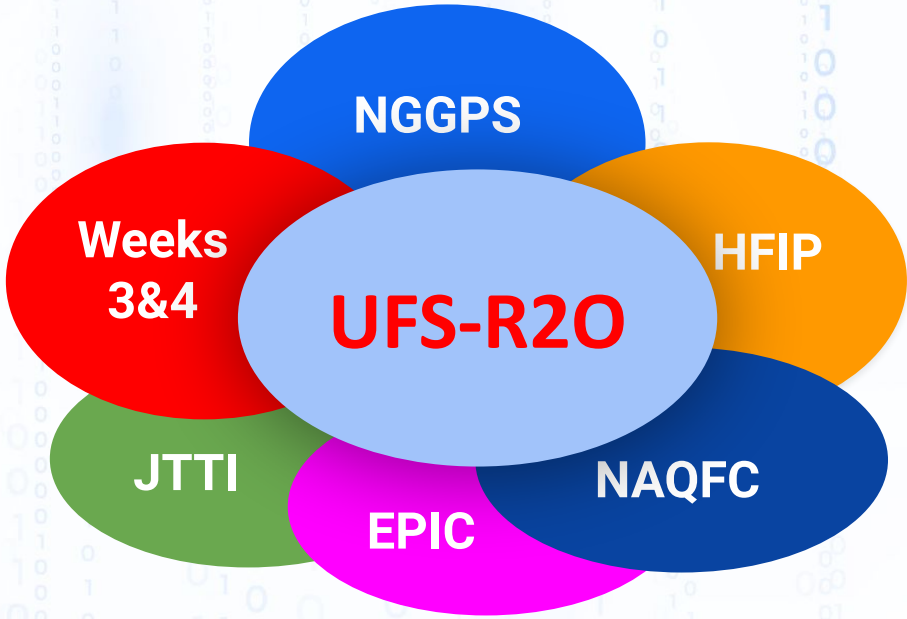
NWS/Week 3&4 Focus Areas
- S2S Application
- Coupling Infrastructure

NWS/HFIP Focus Areas
- Hurricane Modeling

NWS/NAQFC Focus Areas
- Atmospheric Composition

OAR/EPIC Focus Areas
- Data Assimilation
- Coupling Infrastructure

OAR/JTTI Focus Areas
- Short Range Application
- 3DRTMA/URMA



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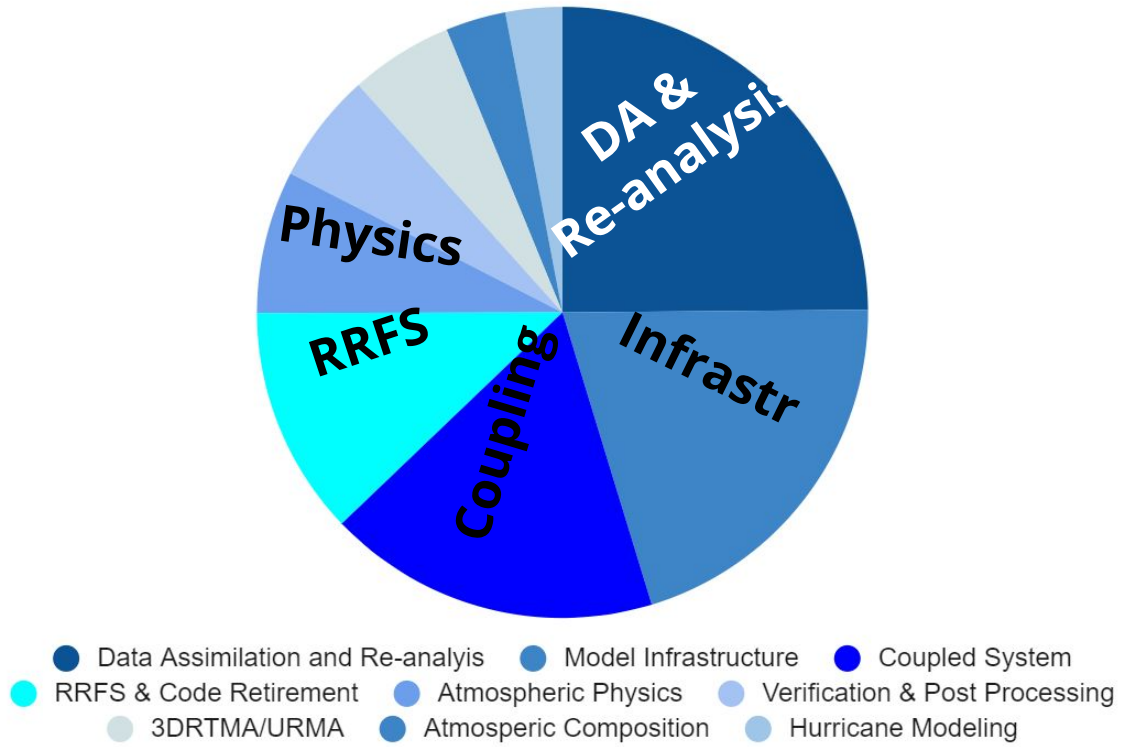
Aligning UFS-R2O priorities to investment areas

Key UFS-R2O Priorities

- Reduce near-surface biases
- Implement a coupled ensemble prediction system
- Advance initialization through improved use of observations and advances in data assimilation algorithms
- Develop a unified regional system and retire legacy regional systems

Key Investment Areas for UFS-R2O

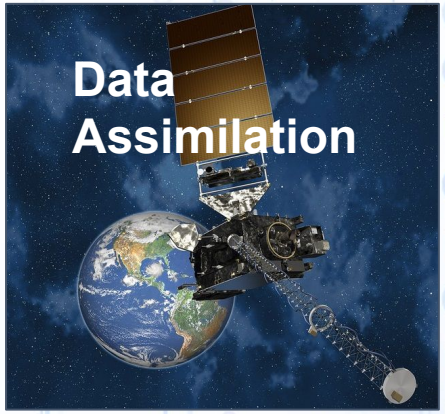
- Model Infrastructure (Physics, Coupling, and Verification)
- Coupled system
- Data Assimilation, Observations, and Reanalysis
- RRFS & Code Retirement
- Physics parameterization

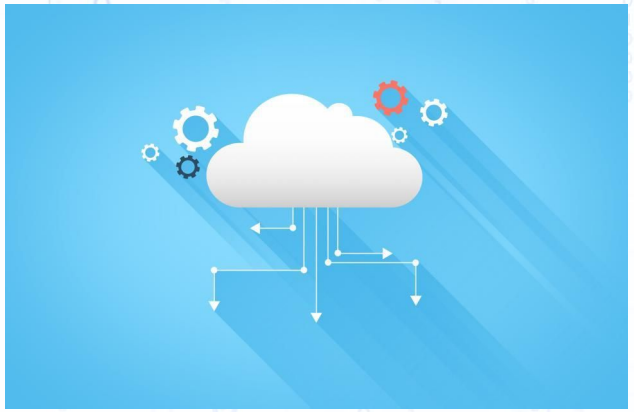


UFS-R2O future programmatic goals

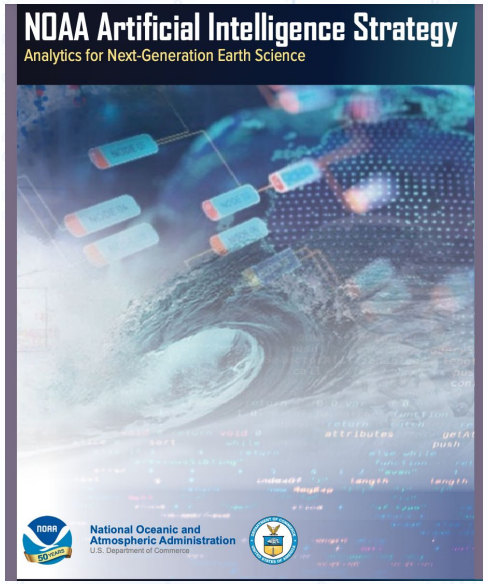
- Provide scope, priorities and guidance for UFS-R2O Project FY23-25
- Align project priorities with operational forecaster needs
- Continue engagement with the UFS Steering Committee, EPIC program, and the NOAA Modeling board
- Develop and finalize strategic resource plan for compute resources need
- Invite additional sponsors and programs
- Invite additional collaborators
- Incorporate new applications such as Seasonal, Coastal, and space weather applications

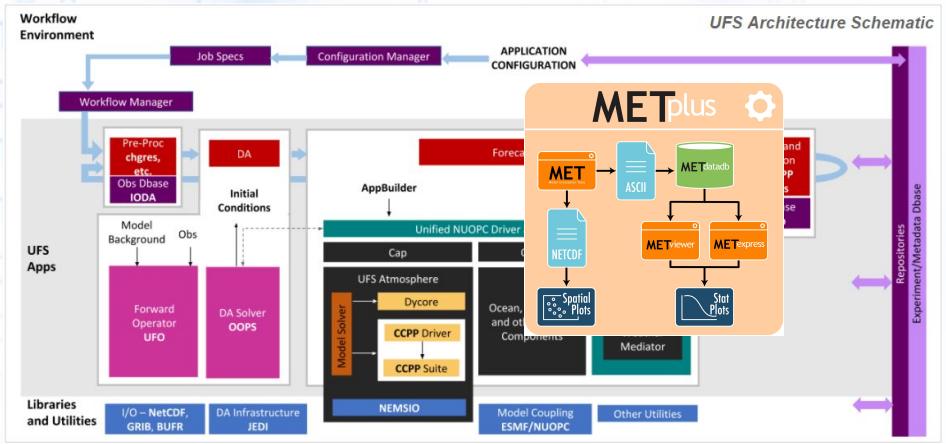
Unifying Innovations in Forecasting Capabilities





Emerging Technologies - Cloud computing, AI/ML





Infrastructure, V&V and Post-processing

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Partnering with the Community for the Benefit of the Nation

How the Earth Prediction Innovation Center (EPIC) will accelerate NOAA's community modeling efforts & the Unified Forecast System (UFS)

Maoyi Huang, Ph.D., EPIC Program Manager, NOAA/OAR/Weather Program Office

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EPIC - Partnering with the community for the benefit of the nation

Vision: *Enable* the most accurate and reliable operational numerical forecast model in the world.

Mission: To be the *catalyst* for community research and modeling system advances that continually inform and accelerate advances in our nation's operational forecast modeling systems.

What EPIC is….

- A virtual community model development environment
- Management of cloud- ready code
- Community access to NOAA observations, data & tools
- Community support & engagement
- Clear research & model transition to operations priorities
- Expected expansion to other additional model components
- EPIC: focus on the Unified Forecast System (UFS)

Community Engagement

UFS
UNIFIED FORECAST SYSTEM

Cloud Use

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How Will NOAA Incorporate Community Code

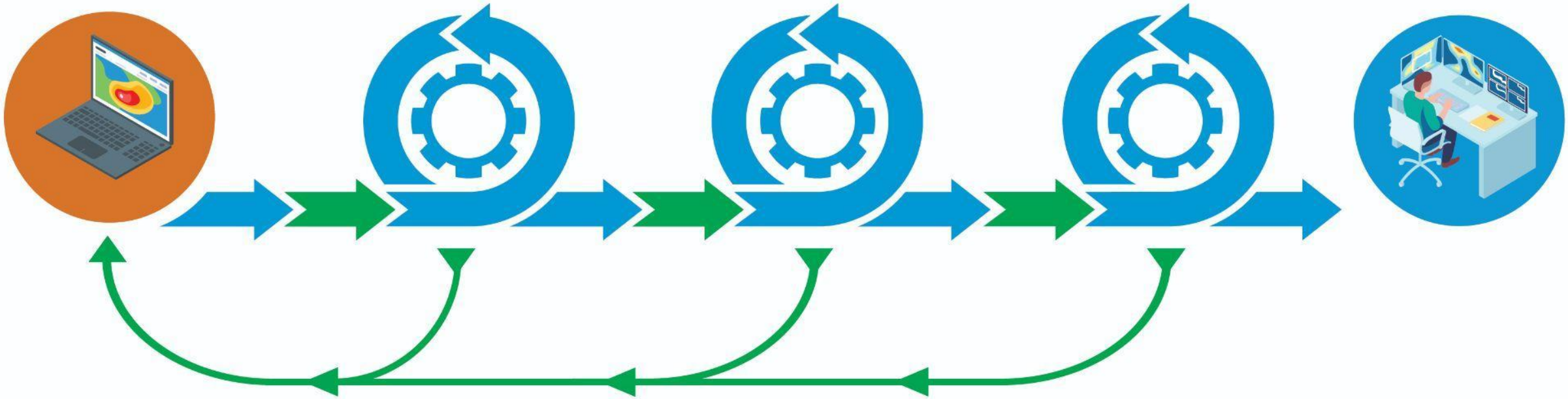
Community Innovation
Access to code, datasets, tools, and user support to assist with initial code validation

Office of Oceanic and Atmospheric Research
Developmental testing in a quasi-operational framework among researchers and operational scientists

Environmental Modeling Center
Code is adapted to the operational environment and tested more rigorously

NCEP Central Operations
Parallel model run is compared side-by-side with the current operational model

Operational Implementation
Code is used by the Weather Enterprise to address societal needs



EPIC Program | Process / Budget / Communications / Legislative Affairs designed to accelerate the R2O process

NOAA Line Offices | Scientific, technical, and engineering processes to ensure operational readiness

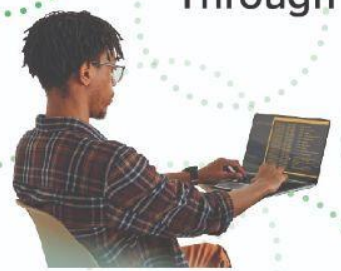
EPIC Innovation Flow

Creating an Environment for Co-development and Inclusion

Modeling Community

Innovation to Research

INNOVATION PROCESS
Through User Support



User Forums

Code Repository

Documentation

Building a Community

Bringing greater alignment between NOAA, academia, private industry, and research centers

Creating the next generation of scientists

Supporting agencies' environmental modeling mission needs

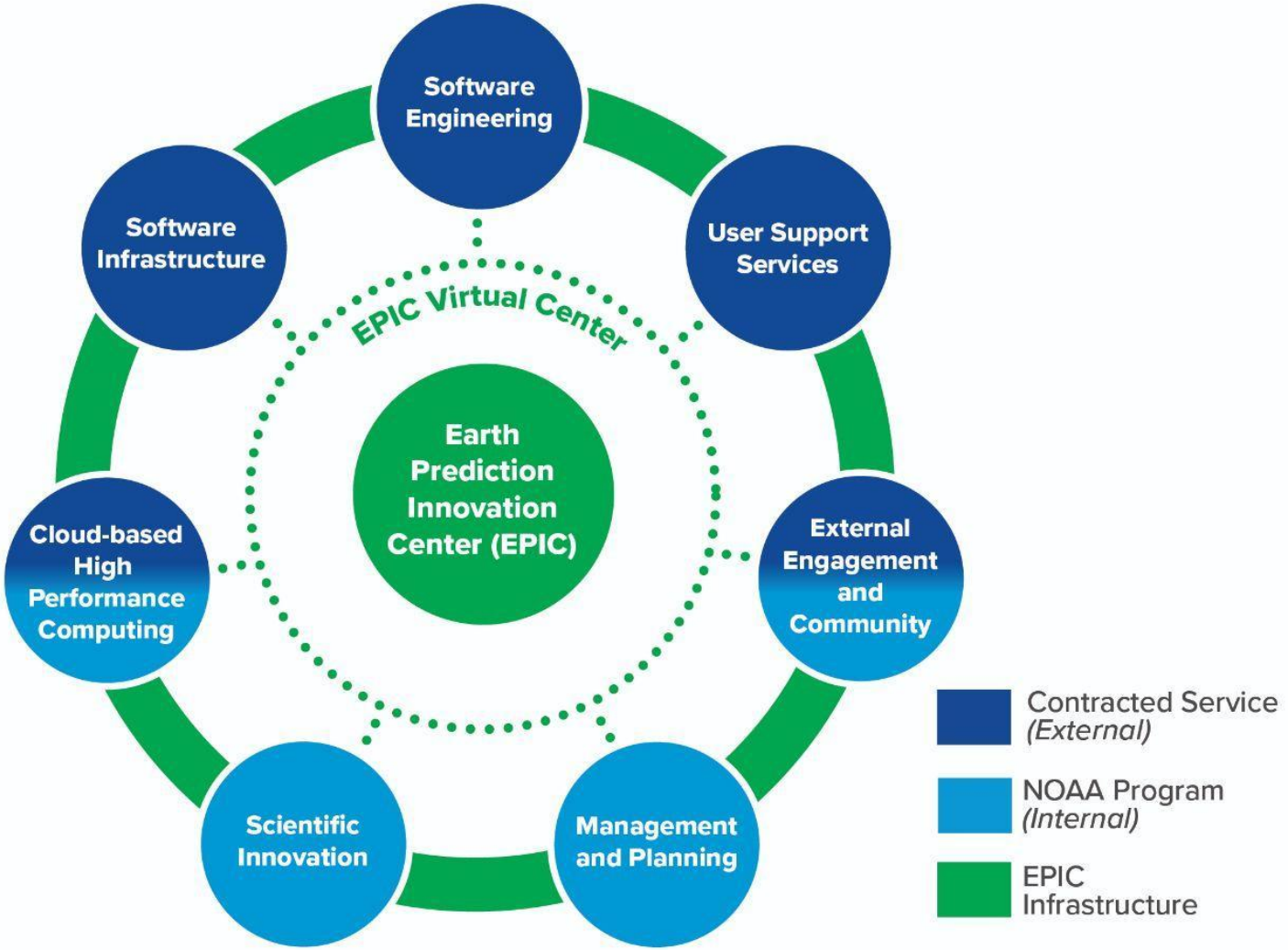
Transition to Operations

Protecting life and property

Bolstering the economy and industry

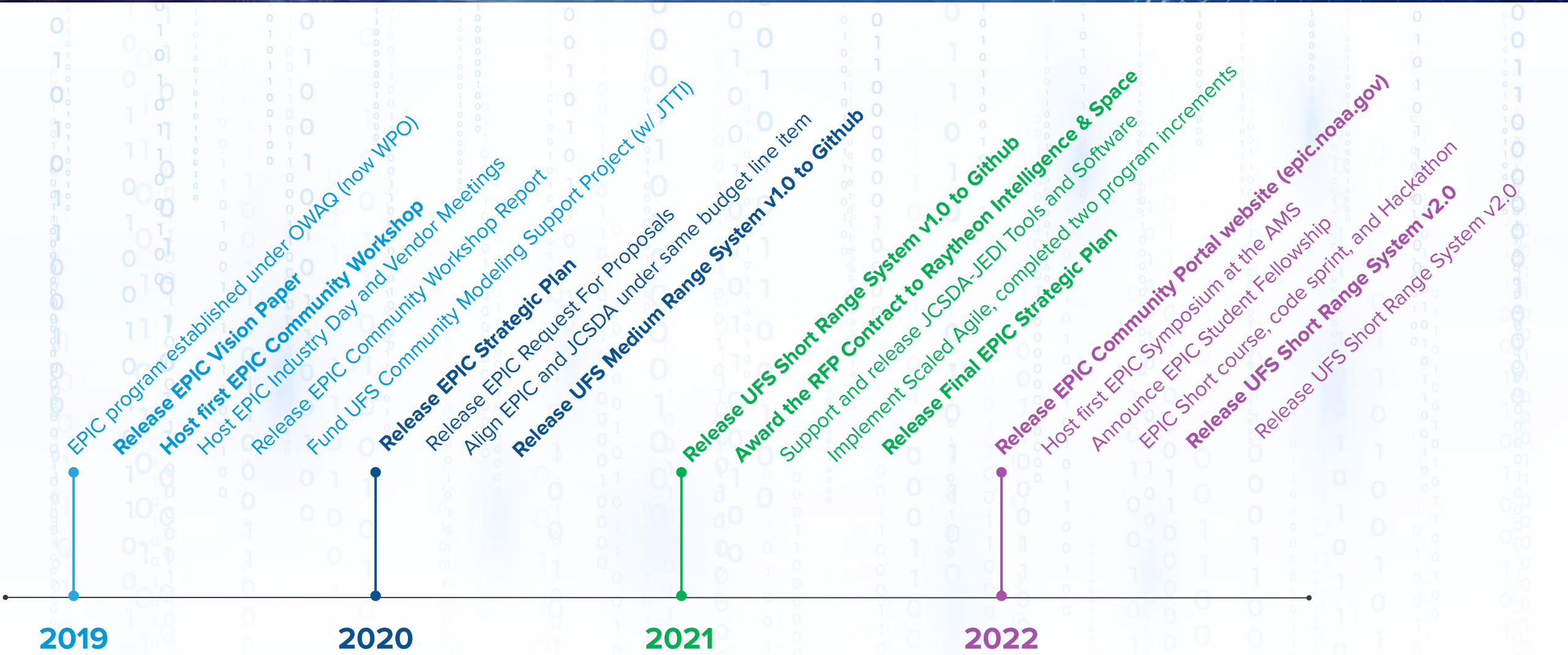
EPIC's Seven Investment Areas

1. External Engagement and community
2. Software engineering
3. Software infrastructure
4. User support services
5. Cloud-based high performance computing
6. Scientific innovation
7. Management and planning

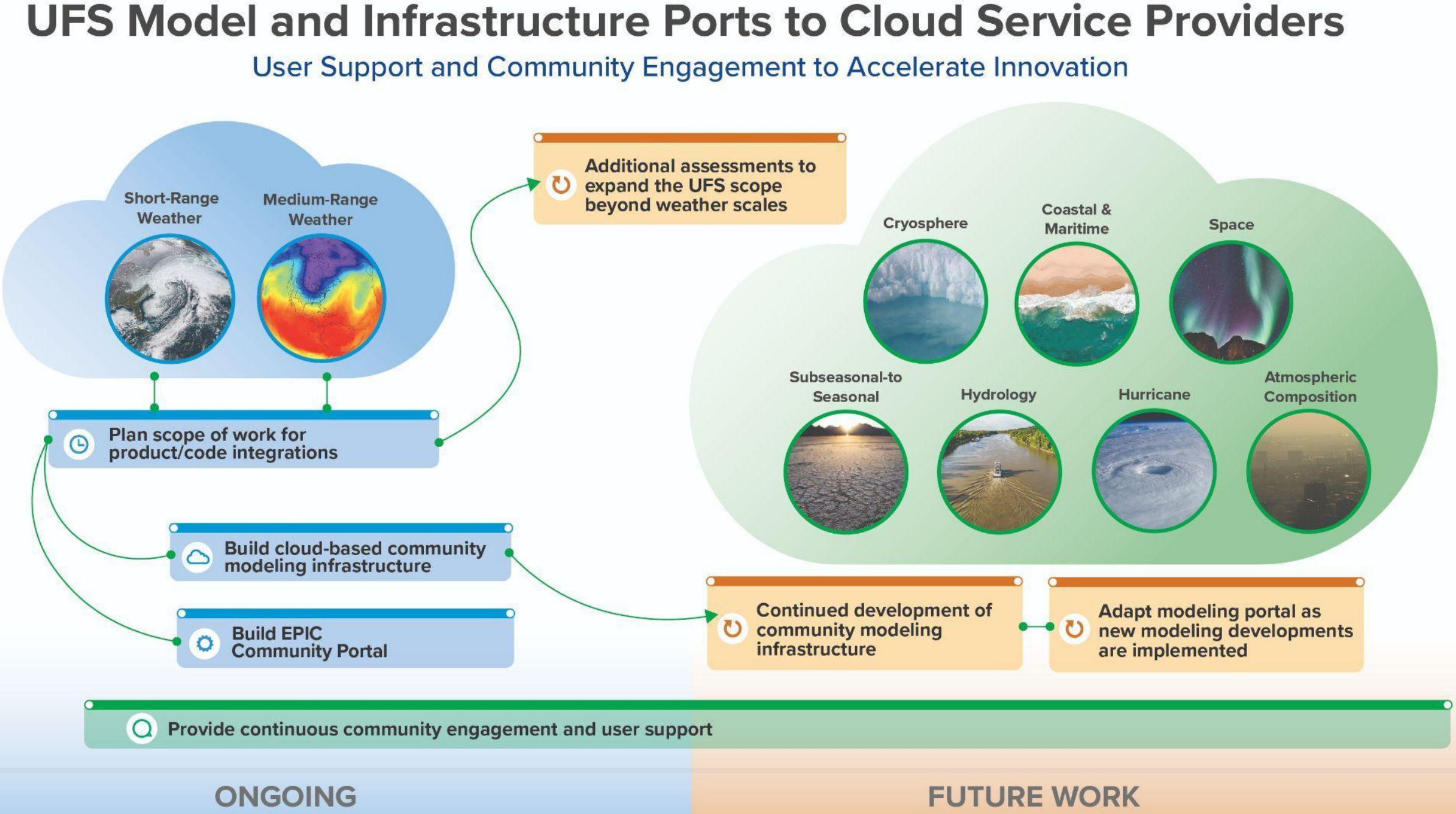


UFSR20

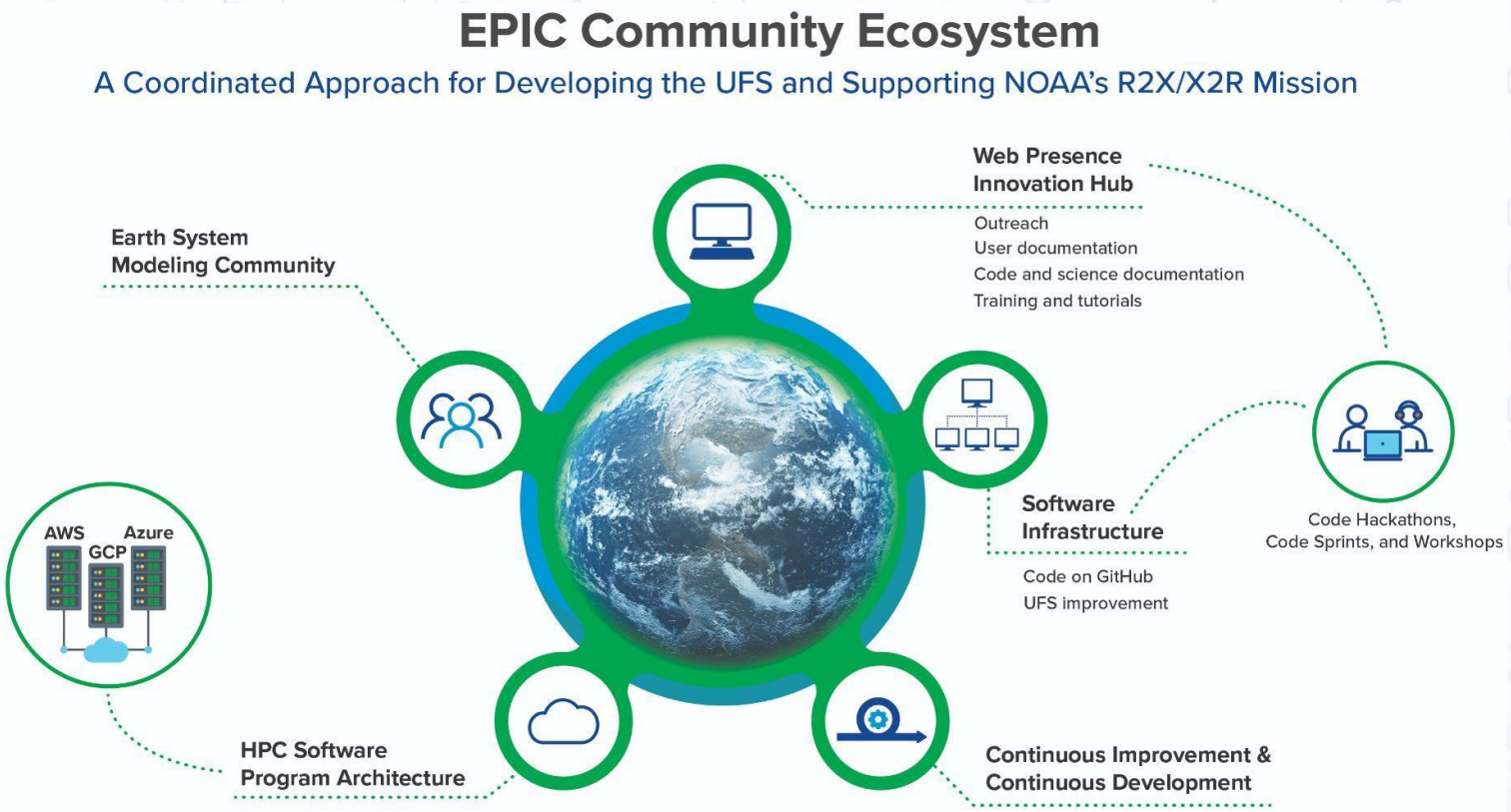
Timeline and Accomplishments



Near- and long-term EPIC Contract outcomes



EPIC Community Center



Uccellini et al., in review for BAMS

- **Web presence.** The EPIC Community Center (ECC) portal provides engagement opportunities via centralized access to UFS code repositories integrated with CI/CD pipelines, EPIC content (e.g. tutorials, social media, events), dashboards showing UFS build and test results
- **Multi-Platform Portability.** Platform-agnostic versions of the UFS on Cloud and on-prem HPCs.
- **Advanced User Support.** Documentation, tutorials, and forums with dedicated user support via a help desk, providing opportunities for co-development and community innovation.

Projects supported by EPIC Program 2019-2022

Scientific Innovation

- FV3 Medium Range - S2S Prediction at convective Scales
- UFS R2O MER/S2S DA R&R
- Advances in physics/microphysics parameterization for UFS/Hurricane models
- Coupled Ensemble Prediction and Data Assimilation (DA) for UFS
- Community Radiative Transfer Model for UFS
- Land DA for UFS
- Convection Allowing Model Ensembles for short and longer time scales and Multi-grid Background error covariance model enhancements
- Process-level parameterizations of model uncertainty in the GFS/GEFS ensemble system
- Improving boundary layer parameterization and cloud systems at all scales

Management & Planning

- EPIC Program Office
- JCSDA Directors Office
- Lapenta Interns

Cloud-based High Performance Computing

- EPIC Program supports OAR Cloud Tiger Team
- OAR OCIO Cloud Utility Contract
- Developed OAR Cloud Strategy Document

External Engagement & Community

- EPIC Community Workshop
- UFS Workflow Workshop
- UFS Community Modeling Support
  - UFS Weather Model code base/applications
  - CICE
  - Stochastic Physics
  - ESMF
- JCSDA core-funding for DA observations, DA Algorithms - Joint Efforts in Data Assimilation Integration (JEDI), Coupled DA, JEDI framework, Sea-Ice Ocean and Coupled Assimilation
- 2020 International Symposium on Data Assimilation

EPIC UFSR20

Thank You!!!