



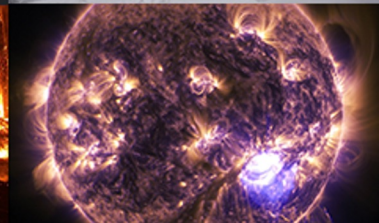
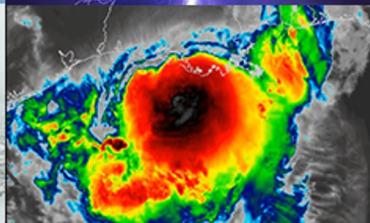
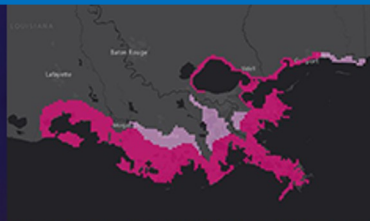
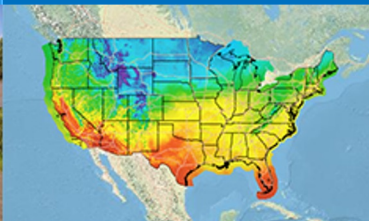
**NATIONAL
WEATHER
SERVICE**

NWS numerical weather prediction Research to Operations (R2O) process and perspectives

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Youngsun Jung, Judy Ghirardelli, Sarah Perfator, Phil Shafer

Friends & Partners in Aviation Weather Spring 2023, Kansas City, MO May 16-18, 2023





NWS Mission



*"Provide weather, water and climate **data, forecasts, warnings, and impact-based decision support services** for the protection of life and property and enhancement of the national economy."*

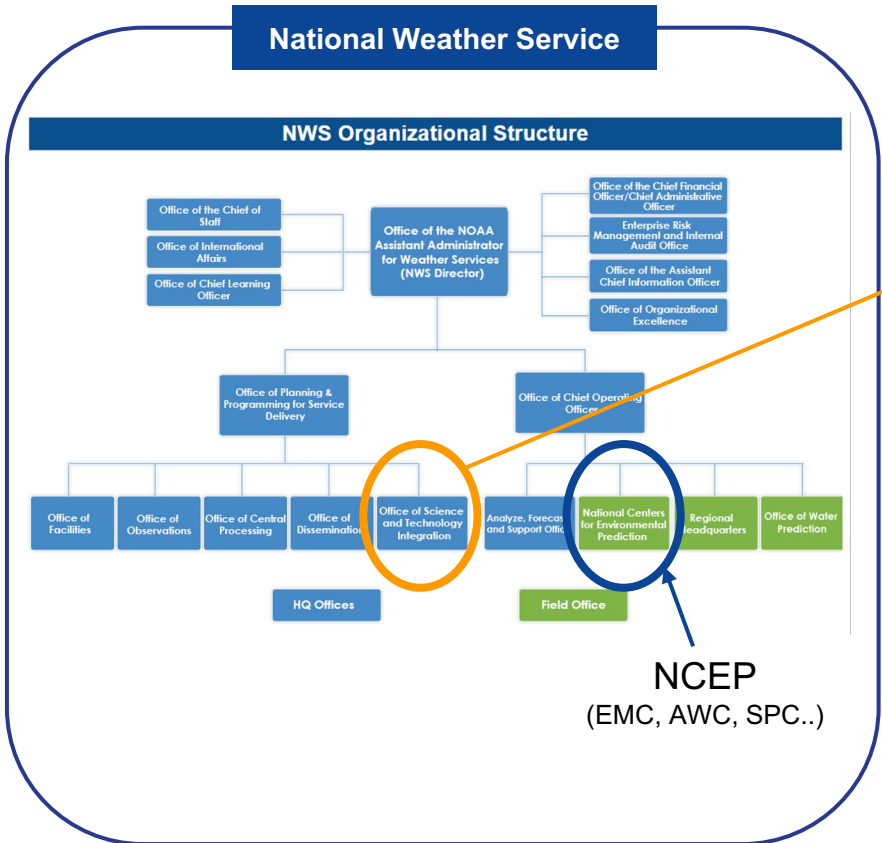


What is Transition?



"The transfer of an R&D output to an operation, application, commercial product or service, or other use." - NAO 216-105B

NWS Office of Science and Technology Integration

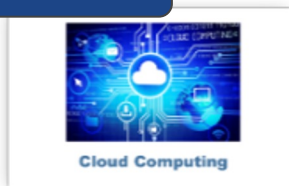


NWS/OSTI Modeling Program

Programs

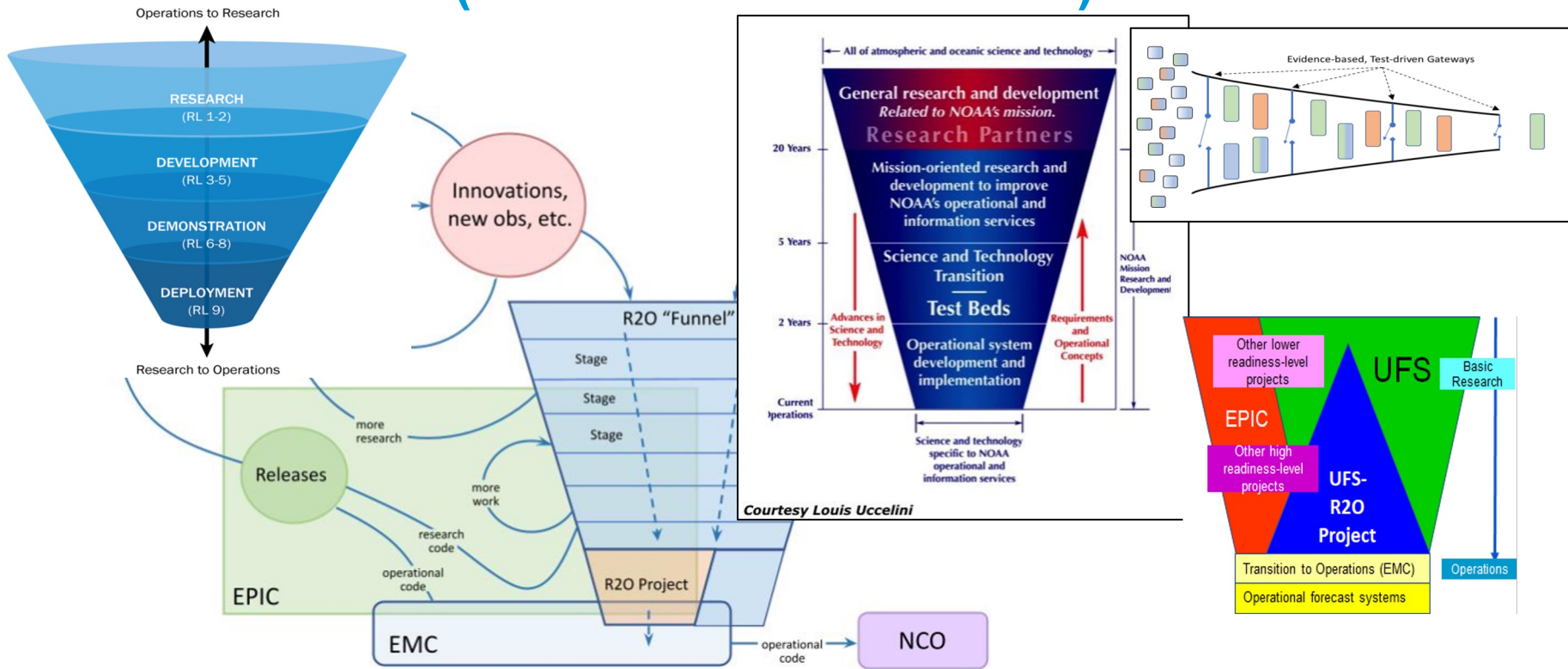


Projects



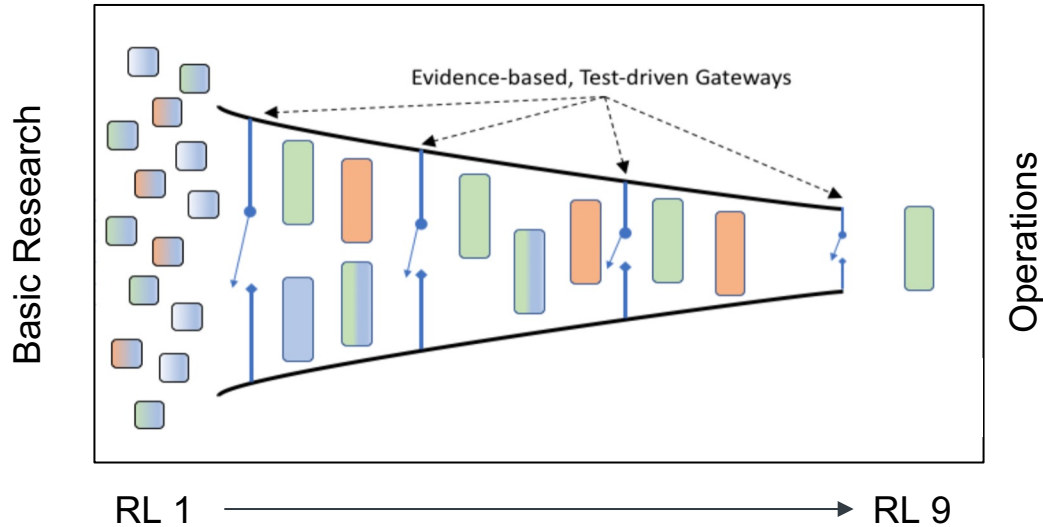
- Support NWS modeling and research initiatives to accelerate operational model development and improve forecast accuracy (*transitioning to the Unified Forecast System, UFS*)
- Foster collaboration among NOAA research scientists, federal labs, operational forecasters and the academic community

Research to Operations (R2O) Process (NOAA has 'funnel-itis')



Courtesy Louis Uccellini

R2O In (Basic) Theory



- Capture needs/requirements
- Identify solution space
- Begin development ([Readiness Levels](#) (RLs) 1-5)
- Advance through RLs (stages and gates)
- Operational acceptance
- Operational transition

R20 In Detail



Initial Development

- Map user requirements to possible solutions
- Develop requirements of the system
- Engage Modeling community (Academia, OAR)
- Begin system development

Prototypes

- Establish metrics and benchmarks
- Hierarchical Testing
- Development and Operational communities interface
- Engage operational forecasters
- Transition plans

Tested in Operational-like System

- Integrate Testing and Evaluation in Testbeds
- Engage operational forecasters
- Engage users and stakeholders
- Refine and iterate

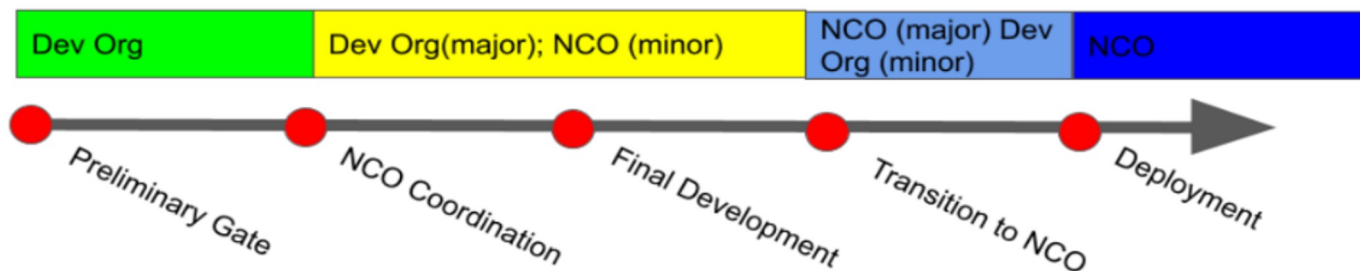
Operations

- Rollout plan
- Public notices and feedback period
- NCEP acceptance
- Service change notice
- Operational integration
- Production

Constants: standards, QC, documentation, open development

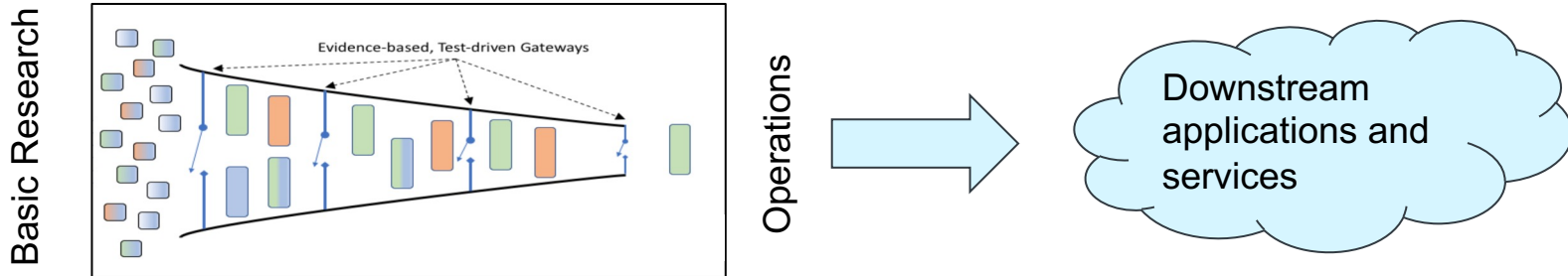
T2O Timeline

- Preliminary Gate: 1-3 years Prior To Implementation (PTI)
- NCEP Central Operations (NCO) Coordination Gate: 1 year PTI
- Final Development Gate: 6-12 month PTI
- NCO Deployment Gate: 0-3 months PTI
- Postmortem Gate: Optional, 1 month after implementation
- *Considerations: Computational cost, production timelines, data flows and archive*



Source: EMC Implementation Plan FY23-27

What's missing?



Model upgrades can be trivial, or major.

User/stakeholder engagement is needed to prepare downstream applications *well in advance*

Applies both internal and external to NOAA

★ Data format

★ Data Dissemination

★ Products (new or removed)

★ Error characteristics

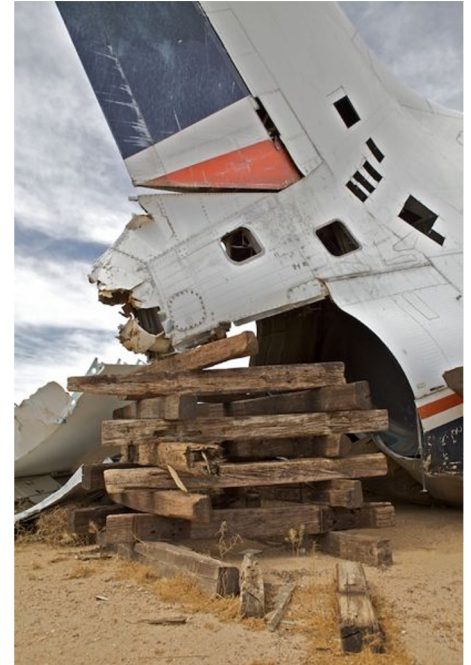
What else is missing?

Code retirement

The objective is to develop applications with shared components and infrastructure
(see transition to UFS)

Legacy systems will be retired
(not scalable to meet NWS mission needs)
(there are not enough resources to sustain O&M of multiple systems)
(more compute is needed for next generation, high resolution, coupled, ensemble systems)

Example: Rapid Refresh Forecast System
(will replace RAP/HRRR, NAM, HiRes Window/HREF, AQM)



5-Year Transitioning NCEP Production Suite to UFS Application (Notional!!)

NPS Modeling or Product System	Current Version	Q2 FY 23	Q3 FY 23	Q4 FY 23	Q1 FY 24	Q2 FY 24	Q3 FY 24	Q4 FY 24	Q1 FY 25	Q2 FY 25	Q3 FY 25	Q4 FY 25	Q1 FY 26	Q2 FY 26	Q3 FY 26	Q4 FY 26	Q1 FY 27	Q2 FY 27	UFS Application	
Global Weather, Waves & Global Analysis	GFS/ GDASv16.3									GFSv17/ GDASv17/ GEFSv13/ GODASv3	SFS Development GFSv18/GEFSv14 Development Coupled Reanalysis and S2S Reforecast Production								UFS Medium Range & Sub-Seasonal (w/Marine and Cryosphere)	
Regional Weather (Parent Domain)	NAMv4																			
Regional Weather (Parent Domain)	RAPv5																			
Global Ocean Analysis	GODASv2																			
Global Weather and Wave Ensembles, Aerosols	GEFSv12	Coupled SubX Reforecasts w/Replay																		
Short-Range Regional Ensembles	SREFv7																			
Seasonal Climate	CDAS/ CFSv2																			UFS Seasonal
Global Ocean & Sea-Ice	RTOFsv2																			
Regional Hurricane 1	HWRFv13	HAFsv1				HAFsv2				HAFsv3				HAFsv4				UFS Hurricane		
Regional Hurricane 2	HMONv3																			
Regional High Resolution CAM 1	HiRes Window v8							RRFSv1						RRFSv2/ WoFsv1						UFS Short-Range Regional HiRes CAM & Regional Air Quality
Regional High Resolution CAM 2	NAM nests/ Fire Wxv4																			
Regional High Resolution CAM 3	HRRRv4																			
Regional HiRes CAM Ensemble	HREFv3																			
Regional Air Quality	CMAQv6	AQMV7																		
Atmospheric Transport & Dispersion	HySPLITv8									HySPLITv9								UFS Air Quality & Dispersion		
Regional Surface Weather Analysis	RTMA/ URMA v2.8	RTMA/URMA v2.10				3DRTMA/URMA v1				3DRTMA/URMA v2				UFS Regional Analysis						
Coastal & Regional Waves	NWPSv1.3									RWPSv1								UFS Coastal		
Great Lakes	GLWUv1.0.3	GLWUv2				GLWUv3								UFS Lakes						
Regional Hydrology	NWMv2.1	NWMv3								NWMv4				UFS Hydrology						
Space Weather 1	WAM/IPEv1									WAM/IPEv2								UFS Space Weather		
Space Weather 2	ENLILv1																			





R2O Governance/Directives

- 10-102: Products and Services Change Management
 - Development, demonstration, review, implementation
- 10-103: Capabilities and Requirements Decision Support (CaRDS) Process
 - Acquiring and Validating Field Requirements
 - Request (need, idea, or opportunity) should be validated as “Requirements.”
 - Originator may be Internal (NWS), or External (Executive / Legislative Branch, International, Partner, other organization or agency)
 - Validated by the Mission Delivery Council (MDC)
 - Development of the necessary capability to meet the validated requirement is based on priority and resource availability

Impact of NWP upgrades downstream

- Examples
 - GFSv16.3 -> WAFS products
 - HYSPLITv8 -> Ensemble dispersion capability (volcanic ash)
 - RAPv4/HRRRv5 -> NBM, LAMP
- Systems need to be robust in handling changes to upstream models

HRRR 3km HIResARW 2.5km HIResARW2 2.5km HIResFV3 2.5km RIOPS 5km HWRF 2km HMON 2km	RAP 13km NAM 12km RDPS 10km(CMC) NAMNest 3km SPC-POST wTCM (NHC)
Mesoscale	
SREF Ens 16km (CO) 30km (AK) GFS 0.25 deg REPS 15km GEPs 0.5 deg (CMC) NAVGEN 0.5 deg ECMWF 0.5 deg GEWPS 0.25 deg REWPS 0.022x0.031 deg ACCESSE 0.3x0.45 deg	
Ensembles	
GFS 0.117 deg GDPS 0.25 deg (CMC) NAVGEN 0.5 deg (FNMOG) ECMWF 0.25 deg ACCESSG 0.12x0.18 deg-res chg RTOFS 0.3 deg	
Global	
GFS-MOS (station) GFS GMOS 2.5km LAMP (station) GLMP 2.5km NAM GMOS 2.5km ECMWF MOS ECMWF MOS	
MOS	

National Blend of Models Inputs





Downstream impacts example (LAMP)

- Model upgrade impacts on Localized Aviation MOS Program (LAMP)
 - Retrospective data are needed to assess impact on LAMP. Retrospective LAMP data would need to be created, verified, and the impact assessed. The majority of the impacts have been minor historically, with some impacts requiring later redevelopment.
 - Sometimes, model improvements lead to LAMP improvements without redevelopment.
 - Redevelopment is not an agile process (i.e., it is time-consuming and resource intensive). To mitigate this, LAMP has now developed in a two step process, with the more changeable HRRR incorporated in the second, broader development step, which makes the process more agile when redevelopment is needed (i.e., only the second step may need to be redeveloped).
 - Long term goals are to create a self-updating system using AI/ML techniques.

In short, changes to input models can have both positive and negative impacts on LAMP guidance



Example of a recent LAMP upgrade to incorporate the HRRR and updated GFS MOS

- LAMP v2.5*: Updated station-based temperature (T), dew point (Td), wind speed (WS), wind direction (WD), and wind gust (WG) guidance. Redeveloped to:
 - incorporate recently redeveloped GFS MOS,
 - incorporate input from the High Resolution Rapid Refresh (HRRR) model,
 - extend forecast projections from 25 hours out to 38 hours,
 - and incorporate input from the Rapid Refresh (RAP) model for stations outside the CONUS
- 
- 
- 
- 

*LAMP/GLMP v2.5 is scheduled to be implemented on June 6, 2023

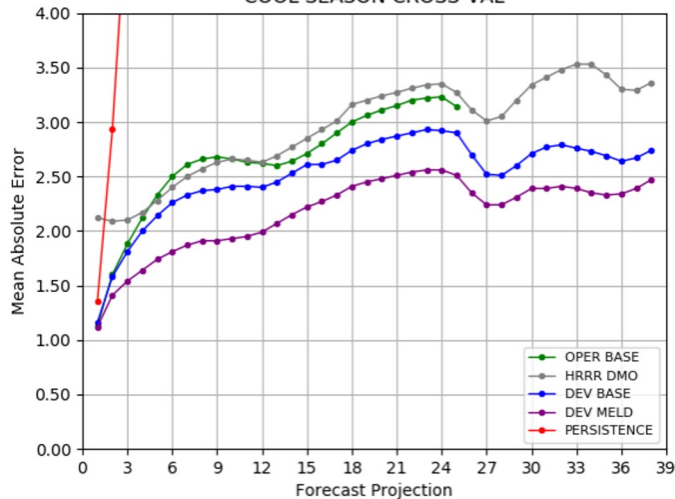


LAMP Meld (V2.5) Independent Verification

1-38 h Temperature MAE 12 UTC cycle

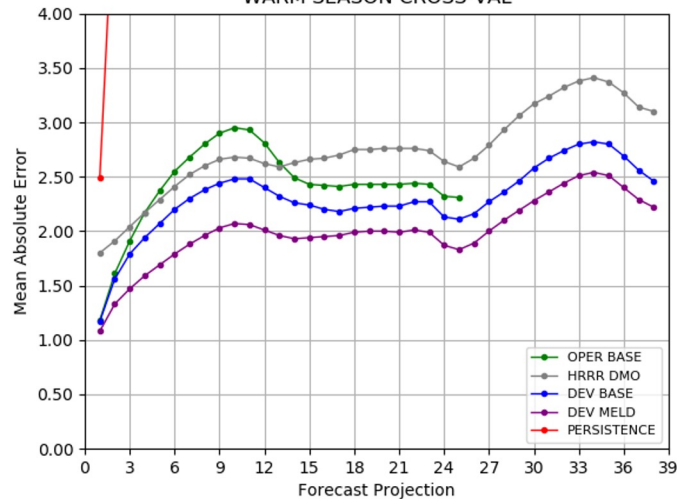
Cool Season

12Z MELD LAMP TEMPERATURE
COOL SEASON CROSS-VAL



Warm Season

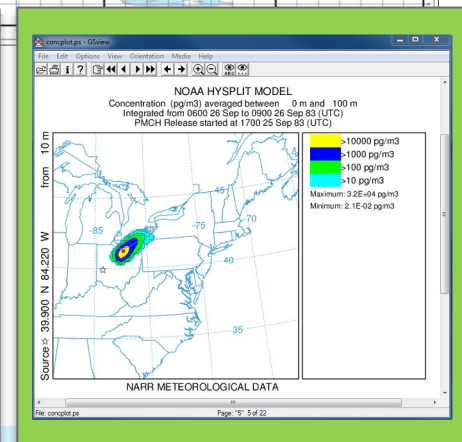
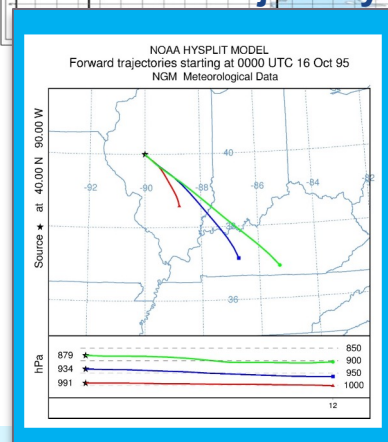
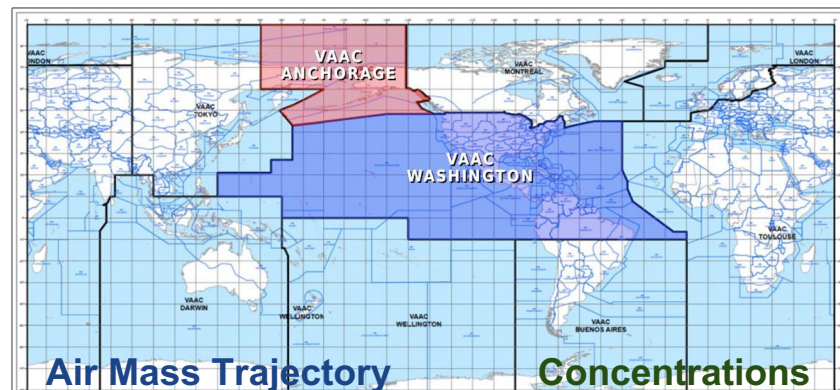
12Z MELD LAMP TEMPERATURE
WARM SEASON CROSS-VAL



NEW LAMP Meld (purple) shows improvement over Base LAMP (blue) and Operational LAMP (green) and HRRR (gray)

Volcanic Ash Forecasting (HYSPLIT)

- Support volcanic ash advisory centers (VAACs)
- To support improved volcanic emissions advisories and warnings for aviation
- Ensemble-based volcanic ash -> quantitative probabilistic forecast
- Future enhancements
 - Incorporation of satellite data



Planned Enhancement with RRFs

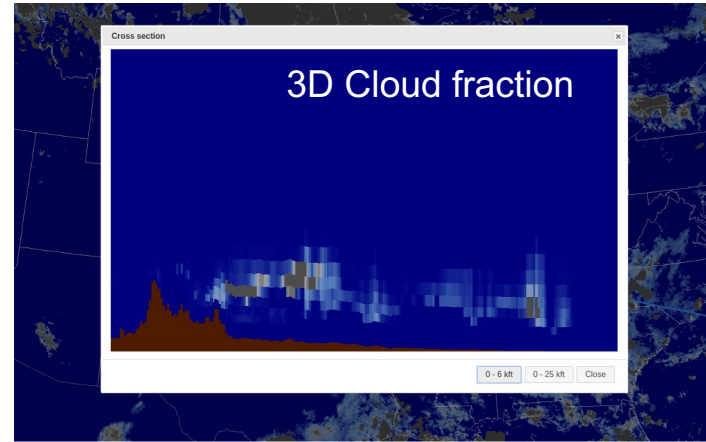
- Based on the FV3 dynamical core Limited Area Model (LAM) capability
- Rapidly updated
- Convection-allowing (~3 km grid spacing)
- 65 vertical layers
- Hybrid 3DEnVar assimilation (30-36 members)
- Deterministic forecasts to 18h every hour
- Ensemble forecasts to 60h every 6 hours
- Implementation: ~Q4 FY24



RRFs_{v1} Computational Domain

Planned Enhancement with 3D RTMA

Precipitation P-Type Snow	Convection Severe Wx	Surface Fields	Cloud SIC Fluxes	Upper Air Fields	SPC Fields
Percent Frozen Precip	0-3 km Storm Relative Helicf	2-m Temperature	Precipitable Water	850 mb Theta-e	Composite Reflectivity
Snow Depth	0-1 km Storm Relative Helicf	2-m Dew Point Temperature	Low/Mid/High Cloud Cover	700 mb Omega & RH	2-m Temperature
Hybrid Lvl 1 Cloud Water	Most Unstable CAPE	Surface Pressure	Cloud Base Height	500mb Heights, Winds, & V0	2-m Dew Point Temperature
Hybrid Lvl 1 Rain	Surface-Based Cape	Surface Wind Gusts	Cloud Ceiling Height	250 mb Winds	MLCAPE+Shear
Hybrid Lvl 1 Snow	Mixed-Layer Cape	10-m Wind Speed	Cloud Top Height		SBCAPE+Shear
	Reflectivity (1 km)	Terrain Height	EMC Surface Visibility		MUCAPE+Shear
	Reflectivity (4 km)	0-10 cm Soil Temperature	Latent Heat Flux		Effective Tornado Parm
	Composite Reflectivity	2-m Max Temperature	Sensible Heat Flux		Effective Helicity
	Reflectivity (-10 C isotherm)	2-m Min Temperature	Ground Heat Flux		Most Unstable CAPE
		2-m Max Relative Humidity	Skin Temperature		Most Unstable CIN
		2-m Min Relative Humidity	Downward Shortwave		Most Unstable Lifted Index
		2-m Temperature Obs	Upward Shortwave		0-1 km Storm Relative Helicity
		Surface Pressure Obs	Downward Longwave		0-3 km Storm Relative Helicity
		10-m U obs	Upward Longwave		Downdraft CAPE
		10-m V obs			Mixed Layer CAPE
		10-m Wind Speed Obs			Mixed Layer CIN
		Specific Humidity Obs			Mixed Layer Lifted Index
		2-m Temperature Used Obs			3 km Mixed Layer CAPE
		Surface Pressure Used Obs			Effective Surface
		10-m U Used Obs			Effective Top
		10-m V Used Obs			Effective Depth
		10-m Wind Speed Used Obs			Equilibrium Temp
		Specific Humidity Used Obs			U-Shear
					V-Shear
					Bulk Shear
					U Bunkers Storm motion
					V Bunkers Storm motion
					Fixed Tornado Parm
					Supercell Parm



- 3-Dimensional analysis
- More variables
- Improved Obs processing and QC
- Implementation: ~Q1 FY25



Summary and other thoughts

- Requirements are important- drive model development
 - Close coordination across NOAA line offices, forecasters, external users/stakeholders
- Principles based on community modeling
 - Criteria for advancing toward operations needs to be well known and resourced
- Testbeds play a critical role in model T&E
 - Need more coordination across testbeds, and ensure users/stakeholders have adequate lead time
- The R2O process for models (even minor upgrades) is thorough, but long
 - Need agility to accelerate innovation into operations



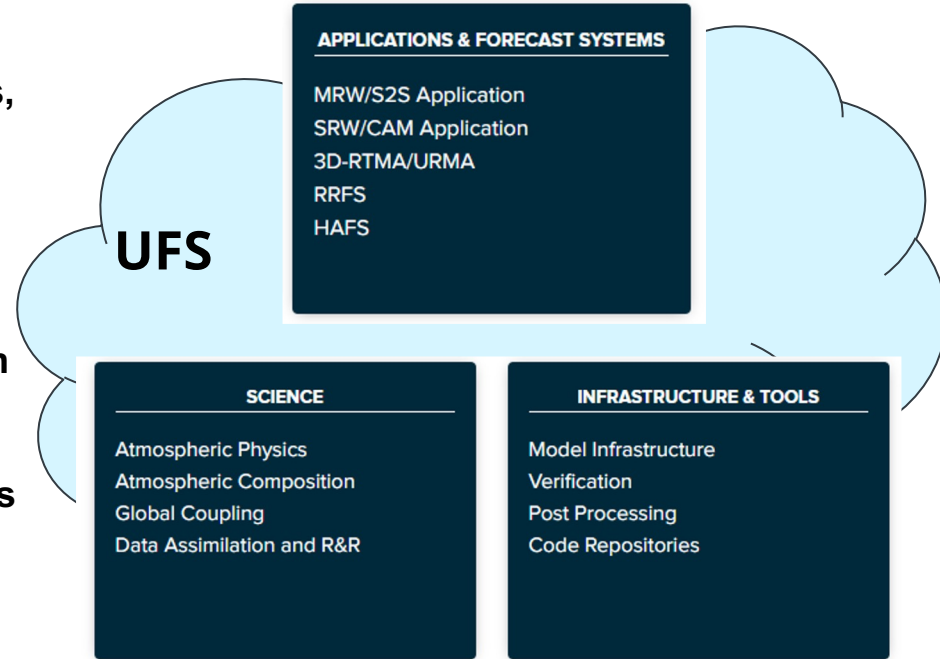
Backup slides



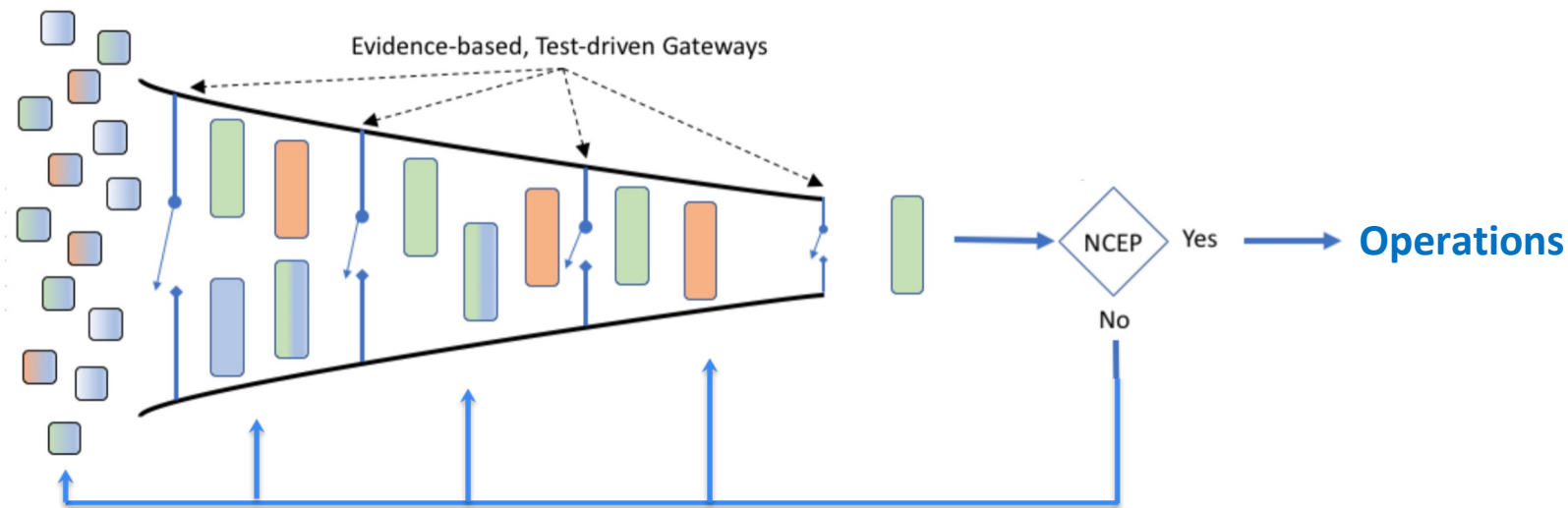
What is the *UFS-R20* project?



- Formal kickoff in 2020
- Transition UFS applications, components, and infrastructure into NWS operations (integrated, fully-coupled Earth system model)
- Direct partnerships with UFS community members and Earth Prediction Innovation Center (EPIC)
- Focus on high readiness-level capabilities
- Co-managed by NWS/Office of Science and Technology Integration and OAR/Weather Program Office



Stages and Gates



Schematic adapted from
'Describing R2O Interface' by UFS-SC, SIP
WGs



Research to Operations Process

