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Meteorological Analysis Laboratory

Introduction to the Unified Forecast System

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https://openclimate.org/

Unified Forecast System: Outline of Talk

- Background
  - U.S. science culture
  - U.S. science policy
- What is the Unified Forecast System (UFS)?
- Some specifics
  - Case study
  - Subseasonal prediction
- Summary

The Unified Forecast System

- For more than 20 years the U.S. operational numerical weather prediction capabilities have been the subject of public criticism. The criticisms are:
  - The forecasts are deficient to those of the European Center for Medium-range Weather Forecasts.
  - The forecasts do not provide the U.S. with what it has paid for to provide state-of-the-art protection of life and property.

Is the criticism justified?

- Yes and no: For example:
  - My analysis in Washington Post
  - The criticism has been focused on the global medium-range forecast model. This is only part of the information used in forecasting.
  - For professional forecasters, model information is used as “guidance.” It is only part of the knowledge suite.
  - An important consideration is how forecasts are used by practitioners – do we effectively use increased skill?

U.S. and global forecasts

- Objectively, the U.S. benefits from excellent and improving weather forecasts, which include severe storms, hurricanes, storm surge, air quality, space weather, etc.
  - The global interests of the U.S. require global forecasts.
- Objectively,
  - the suite of models is too complex
  - the cost of our forecasts is too high
  - the model guidance is not as good as it could be

The Unified Forecast System

- The Unified Forecast System was proposed after several external advisory panels to NOAA called for
  - Developing a community-based approach to improve the benefit to operational centers from broader research investments
  - Addressing known scientific deficiencies – strive for scientific excellence
  - Addressing known computational and infrastructure deficiencies
  - Reducing the complexity and cost of the operational suite
  - Adhering to evidence-based decision making in system development

My role in the Unified Forecast System (UFS)

- I was asked to take a leadership role because of successes and skills in management of large scientific organizations.
  - I focus on systems.
  - I have knowledge of organizations.
  - I value strategic goals and the management to achieve those goals.
  - I have been described as able to execute “bureaucratic aikido.”
- I am not an expert in weather prediction

To be clear

- The deficiencies in U.S. weather modeling are related, first and foremost, to organizational issues which lead to fragmentation of efforts.
  - This is at the core of our scientific culture.
  - This is supported by our science policy.
  - There are political interests intertwined with our scientific policy.
  - Individuals and institutions are invested in the fragmentation.
  - This is an enormously difficult problem.

Unified Forecast System

- After a couple of years of planning and pre-work, the Unified Forecast System was initiated in winter-spring of 2018.

There were a set of defining decisions

- Dynamical Core (Dycore): Selection of the FV3 dynamical core for the GFS (Global Forecast System)
- Modular, community-based systems architecture for the coupled model
- Infrastructure:
  - Coupling (ESMF, NUOPC)
  - Data Assimilation (JEDI)
  - CCPP Framework (Atmospheric Physics)
  - METplus
- NCAR-NOAA Memorandum of Agreement
  - ~50 % shared code in models and infrastructure
- System-based planning: Strategic Implementation Plan (SIP)
  - Continuity in planning

Seven UFS Applications

- Medium-Range Weather
  - Atmospheric behavior out to about two weeks
- Subseasonal-to-Seasonal (S2S)
  - Atmospheric and oceanic behavior from about two weeks to about one year
- Hurricane
  - Hurricane track, intensity, and related effects out to about one week
- Short-Range Weather/Convection Allowing
  - Atmospheric behavior from less than an hour to several days
- Space Weather
  - Upper atmosphere geophysical activity and solar behavior out to about one month
- Coastal
  - Storm surge and other coastal phenomena out to about one week
- Air Quality
  - Aerosol and atmospheric composition out to several days

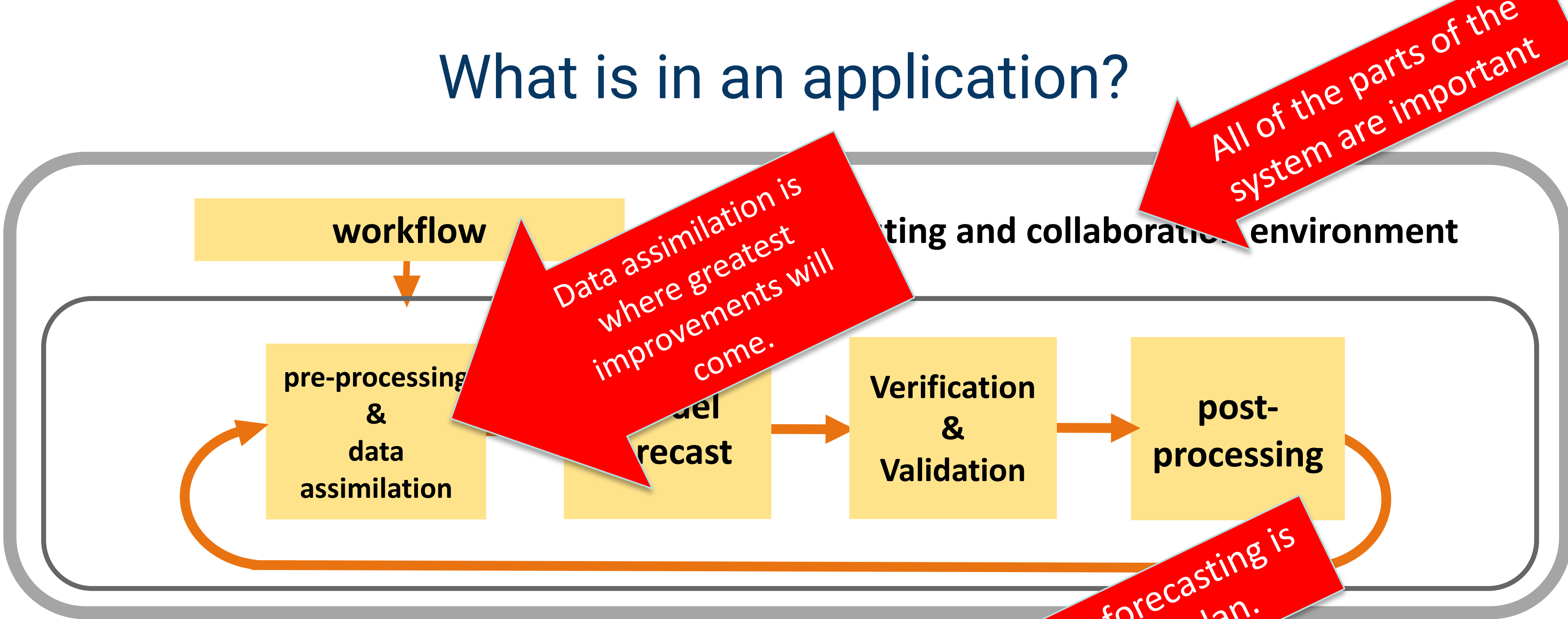
Central role of Medium-Range Weather

- The global medium-range weather receives greatest attention because all the other applications rely on the performance of the global model.
  - Historically, this is the “atmospheric” model
  - Presently, moving to coupled atmosphere, ocean, land, sea ice, aerosol & composition
- Even on scales as short as five days, there are important benefits from coupled models

Short-Range Weather/Convection Allowing & Hurricane Applications

- Short-Range Weather/Convection Allowing
  - Tornadoes, derechoes, extreme thunderstorms, fire weather, etc.
- Hurricane
  - Set of models especially focused on hurricanes
- These might be called regional or mesoscale models

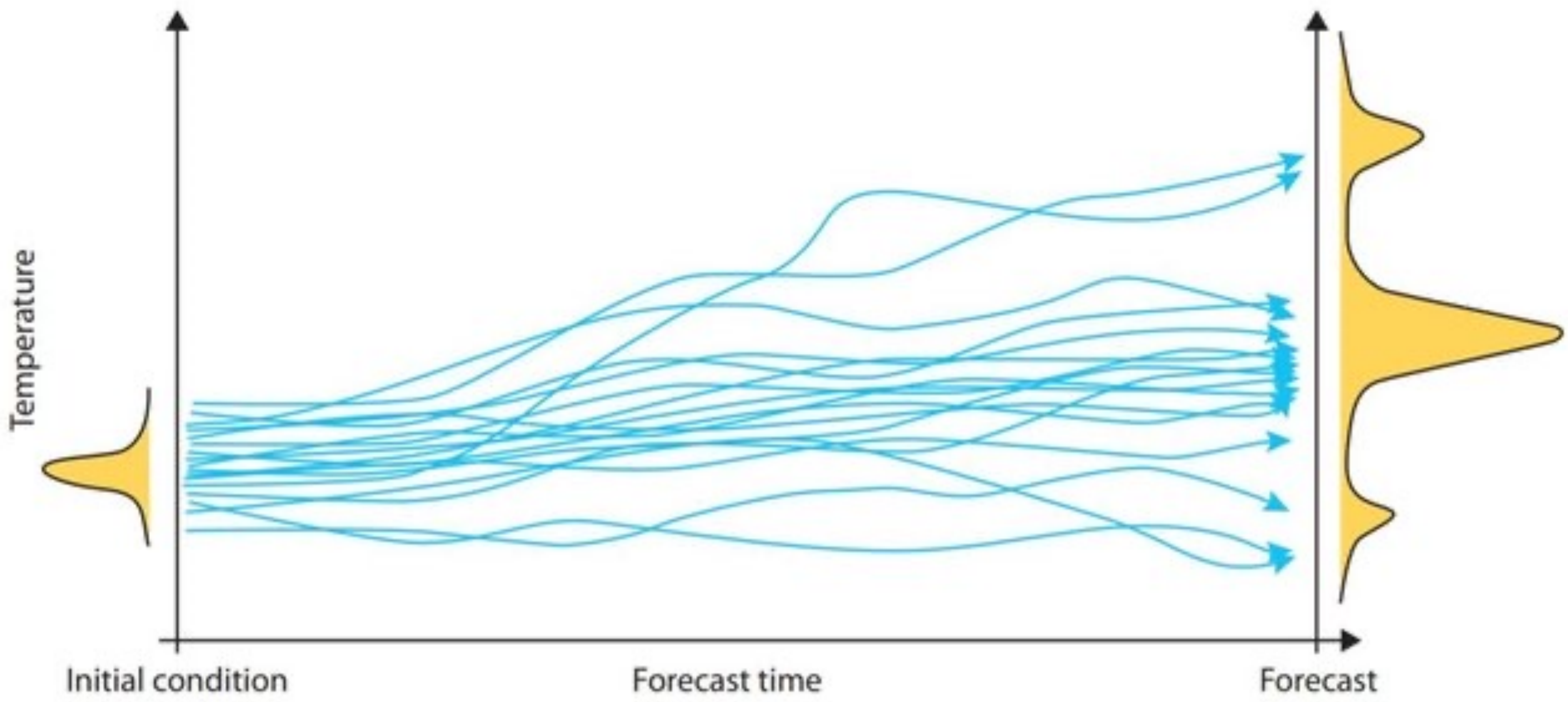
What is in an application?



Pre-processing and data assimilation	Stages inputs, performs observatio[illegible] prepares an analysis
Model forecast	Integrates the model or ensemble o[illegible]dels forward
Verification & Validation	Assesses skill and diagnoses deficiencies in the model by comparing to observations
Post-processing	Tailors forecast guidance based on known model errors
Workflow	Executes a specified sequence of jobs
Computing and collaboration environment	• May be different for research (experiment focus) and operations (forecast focus) • Provides actual or virtualized hardware, databases, and support

Ensemble (Figure from ECMWF)

- Increasingly, we focus on an ensemble of forecasts to provide probabilistic guidance, rather than a single, deterministic forecast.



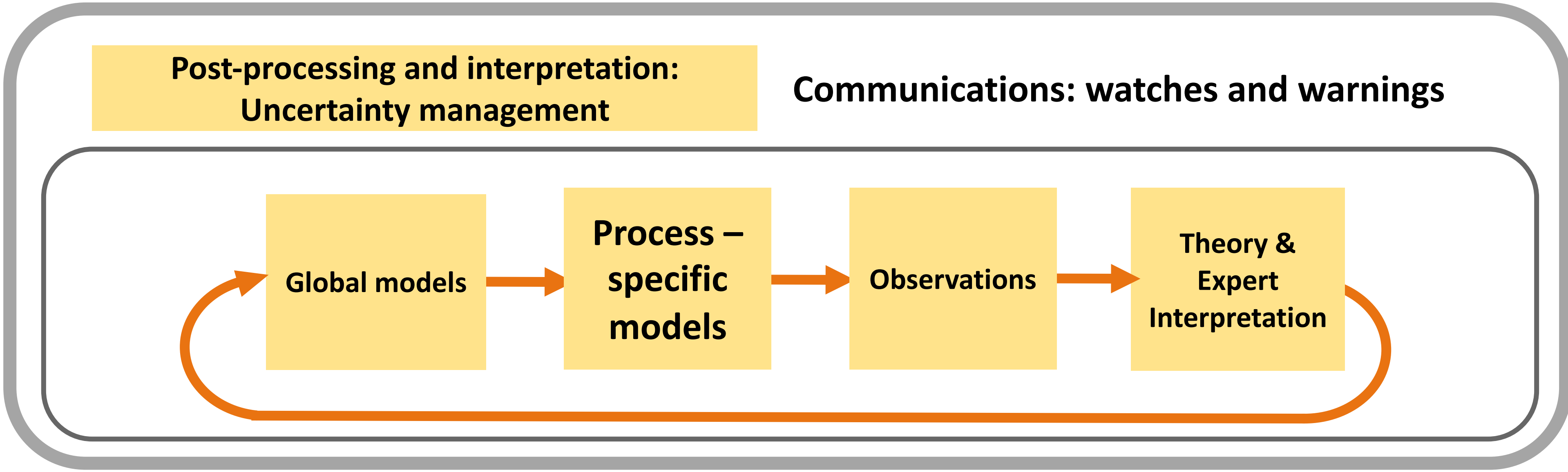
What is the UFS?

- The UFS is a community-based, coupled, comprehensive Earth modeling system.
  - This system includes computer code, governance rules, and the community of individuals composed of researchers, developers and users from NOAA, educational institutions, federal agencies, and the private sector.
  - The UFS is designed to support the weather enterprise and to be the source system for NOAA's operational numerical weather prediction applications.

Guidance

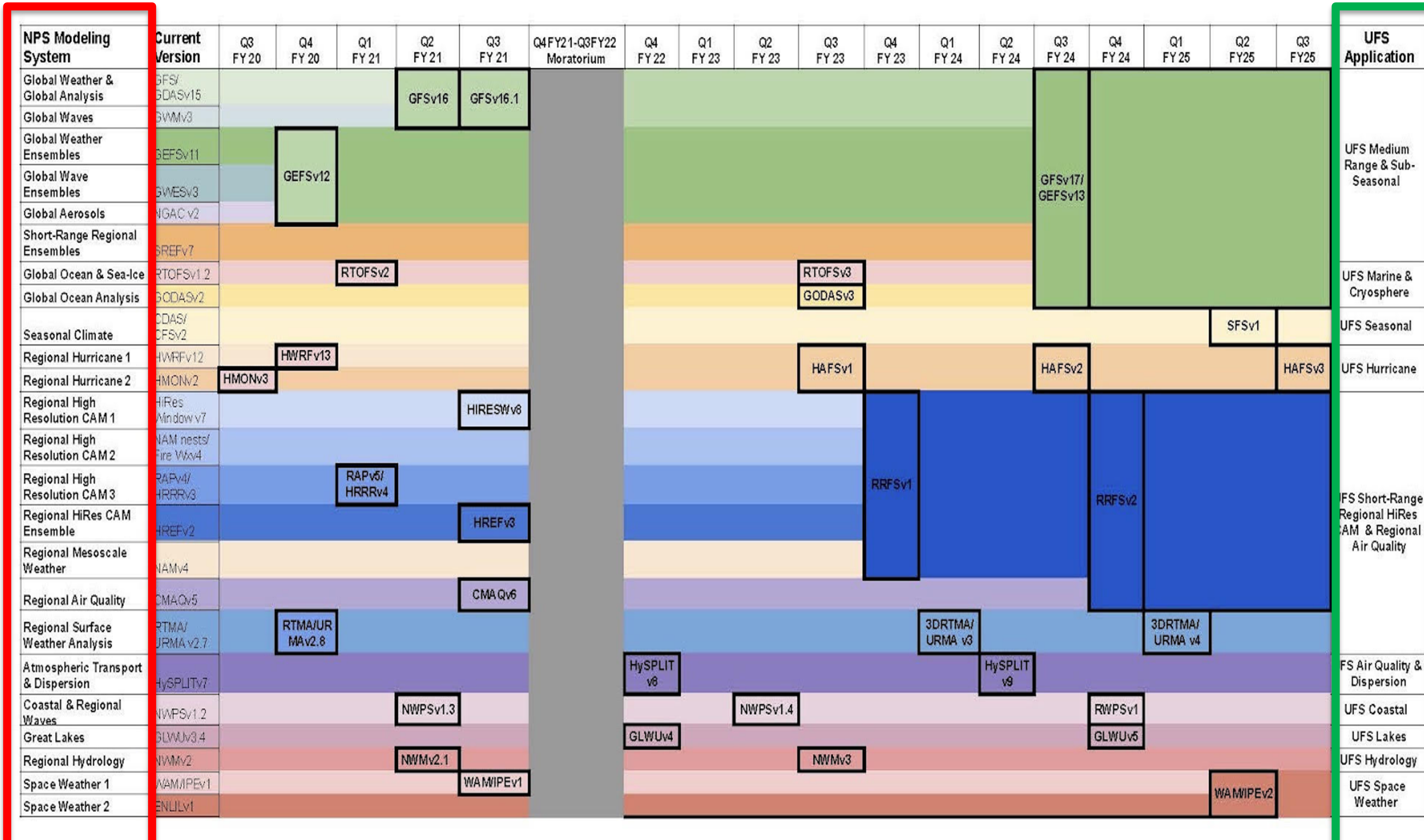
- Numerical weather prediction models, the "model forecasts," do NOT define the "forecast" issued by the weather service.
  - Model forecasts provide guidance to forecasters.
  - There is a lot of model information available on the web and a lot of people read off model simulations and call them "forecasts."

Model Guidance?



Process – specific models	For example, hurricanes, storm surge, air quality, storm resolving
Ensemble	• Multiple runs with same models • Models from different organizations • Research models
Observations	Focus on specific observations or additional observations that bring local focus
Theory	For example: Does the moisture content and precipitation make sense with the temperature
Expert interpretation	How do I interpret different types of precipitation? The lake we are on?

Scope of the challenge schedule



How many we run today (already reduced)

How many we want to run in 2025

Progress

- 1st order improvements in medium-range forecasts and more to come
- 1st order improvements in global ensemble performance
  - Inclusion of ocean wave model and aerosols
- Substantial progress on simplification of short-range weather/convection allowing
- Transfer of space weather WAM-IPE to operations

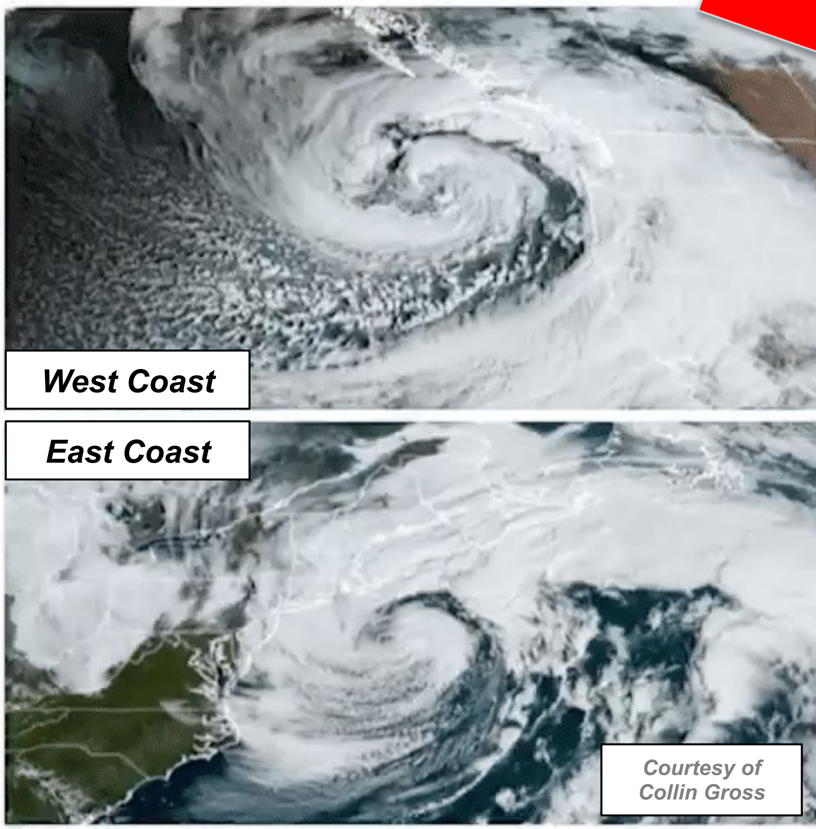
Some specifics

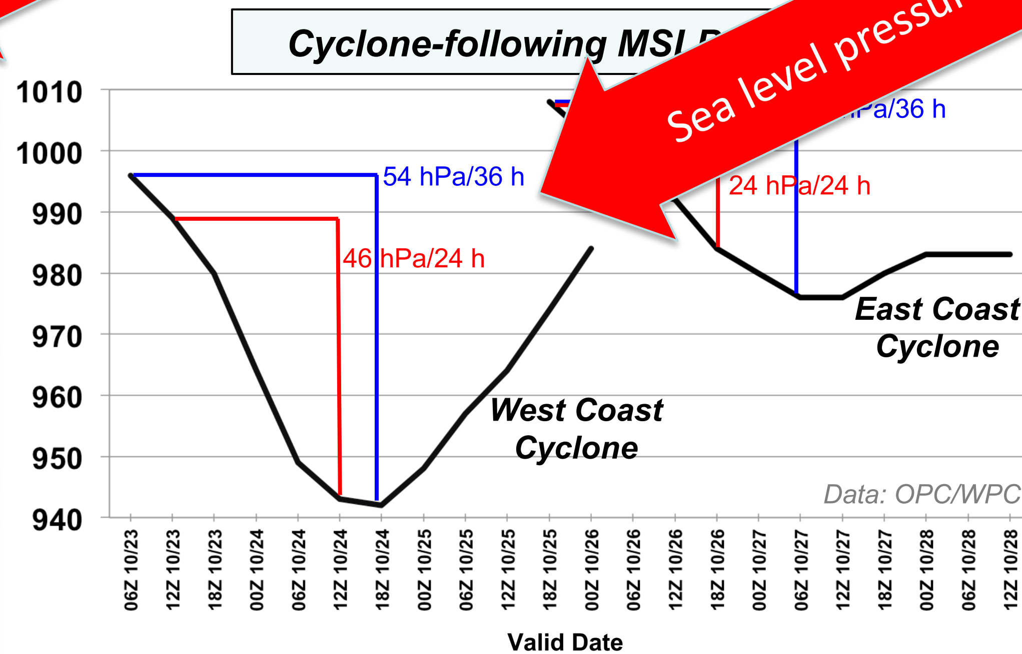
- Focuses on global systems
- Shows how model forecasts inform the forecast process
- Suggests how experts might use model forecasts as guidance to describe and manage uncertainty
- GFS uses UFS Medium-range Weather

NATIONAL OCEANIC AND ATM MINISTRATION

Recap of Octo "Bomb" Cyclones

This one





The West Coast cyclone had a higher deepening rate and lower central pressure than the East Coast cyclone. Both cyclones qualified as "bomb" cyclones according to their 24-h deepening rate and latitude (φ).

X hPa/24 h = sin(φ)/sin(60˚) (Ex. ~20 hPa/24 h is a "bomb" at 45ºN)

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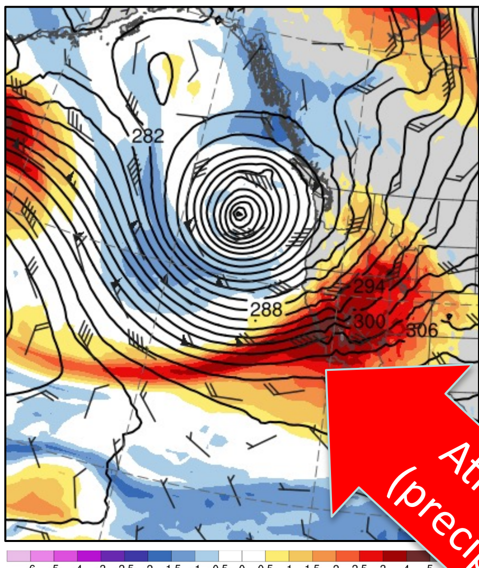
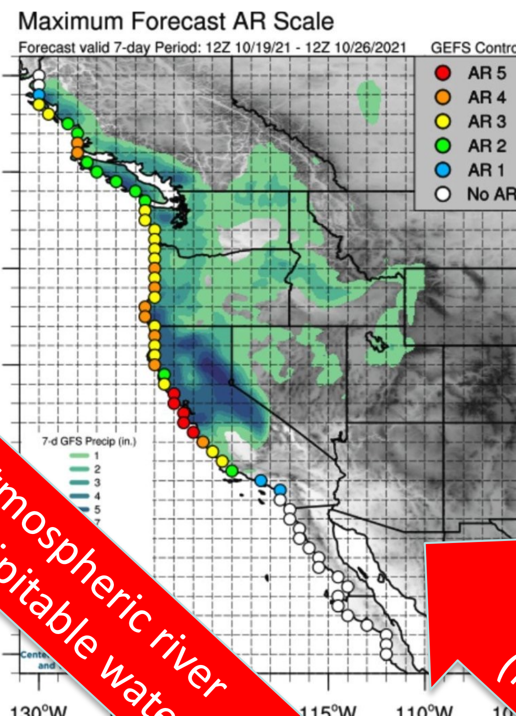
Recap of October 2021 "Bomb" Cyclones

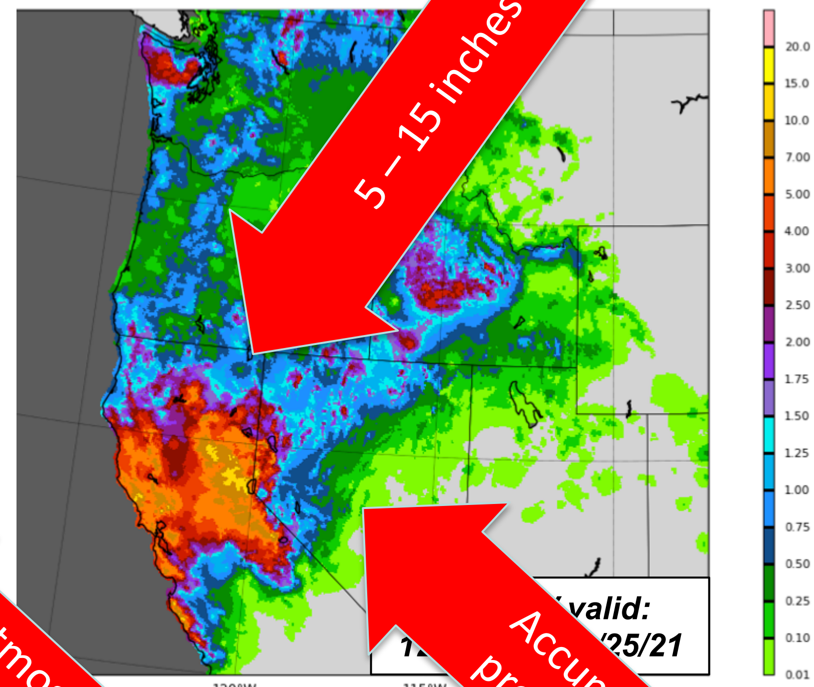
Atmospheric River assoc. w/ West Coast Cyclone



700-hPa geo. height/wind and standardized PW anomalies
Init.: 06Z 10/21/21
Valid: 00Z 10/25/21



24-h Accumulated Pr…n



What happened?

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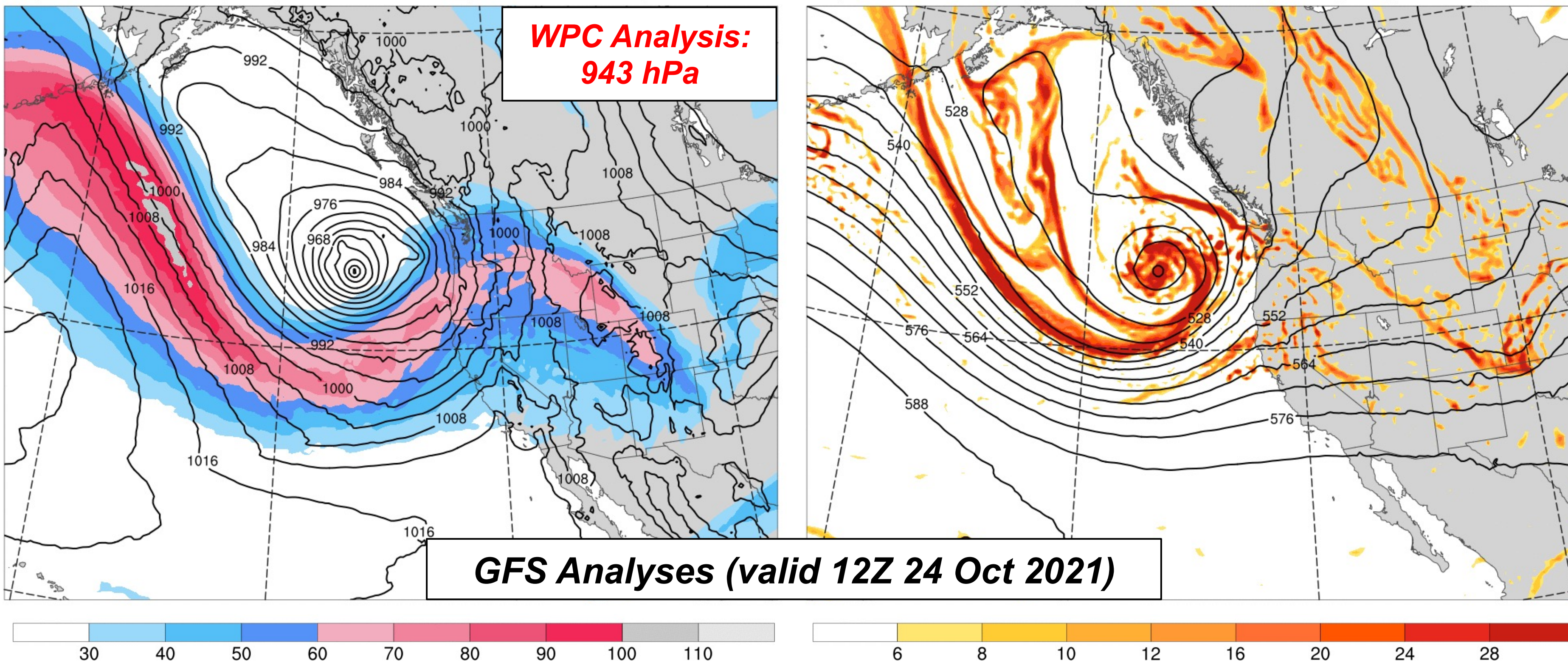
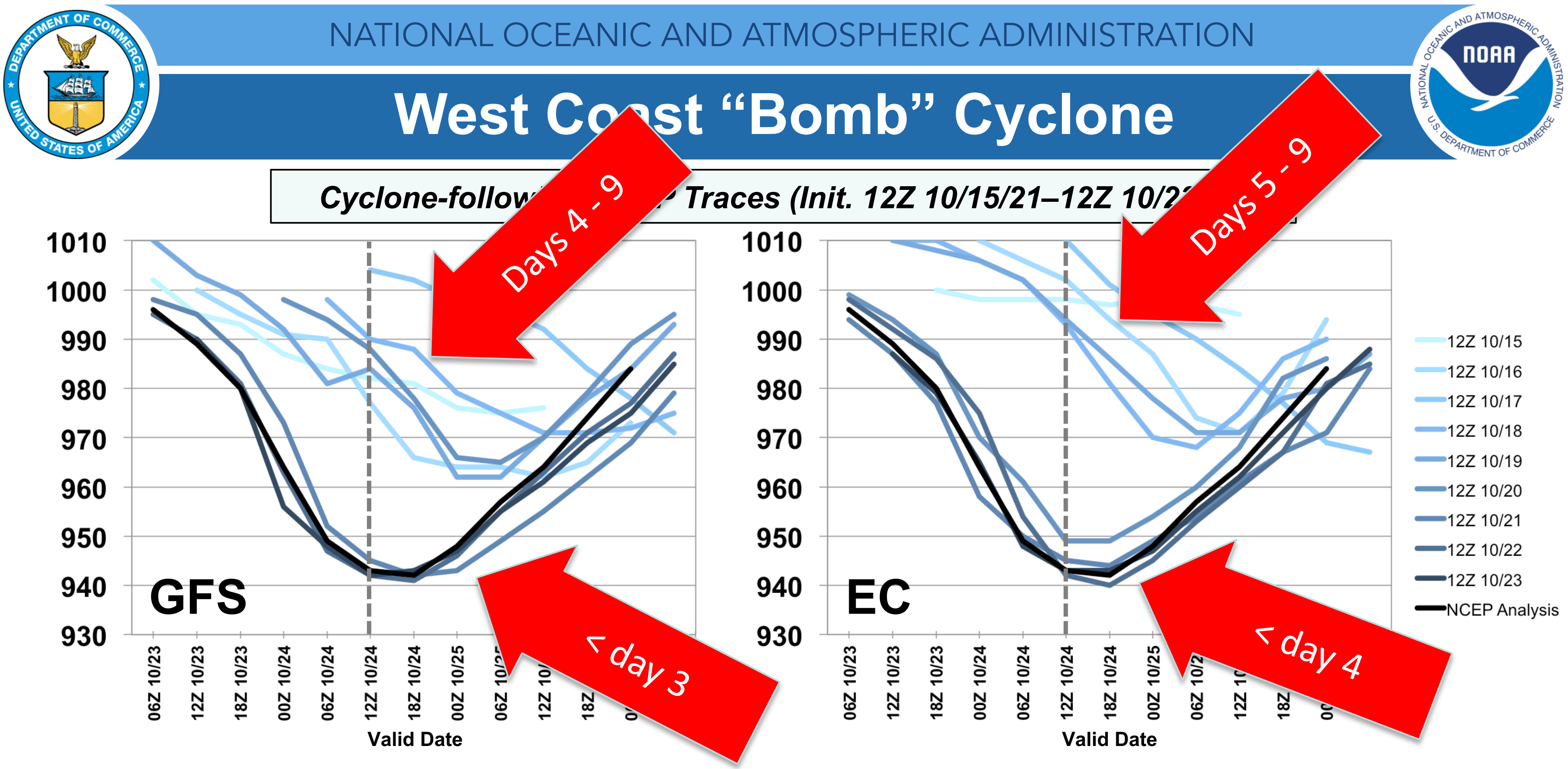
West Coast “Bomb” Cyclone

GFS | Init.: 1200 UTC 24 Oct 2021 | Fhr: 0 | Valid: 1200 UTC 24 Oct 2021 | MSLP and 250-hPa wind speed

GFS | Init.: 1200 UTC 24 Oct 2021 | Fhr: 0 | Valid: 1200 UTC 24 Oct 2021 | 500-hPa geo. height and vorticity



model forecast pressure minimum



- GFS and EC forecasted ≤980-hPa cyclones at Days 5–8, but deepening was delayed (and cyclones too weak)
- EC forecasted the correct deepening by Day 4, whereas the GFS forecasted the correct deepening by Day 3

6-day model forecast

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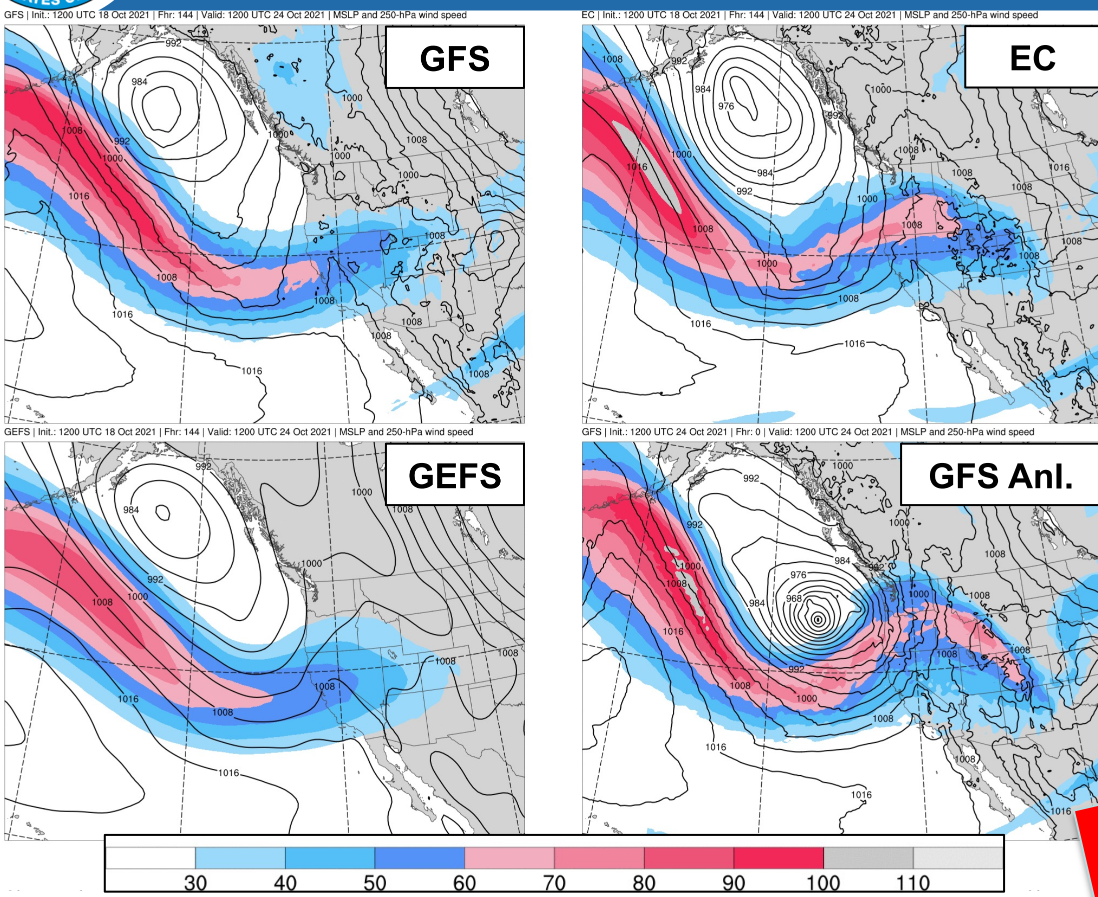
West Coast “Bomb” Cyclone



Init.: 12Z 10/18/21 (F144)
Valid: 12Z 10/24/21

- GFS and EC delayed the formation and deepening of the West Coast cyclone (a strong cyclone was not located off of the WA/OR coast until hours later)
- GFS and EC ultimately forecasted cyclones that were considerably weaker than analyzed (~970 hPa vs. 943 hPa)
- GEFS mean did not depict a cyclone off of the WA/OR coast during this cycle (only an elongation of low MSLP values to the southeast, toward the coast)

verification

5-day model forecast

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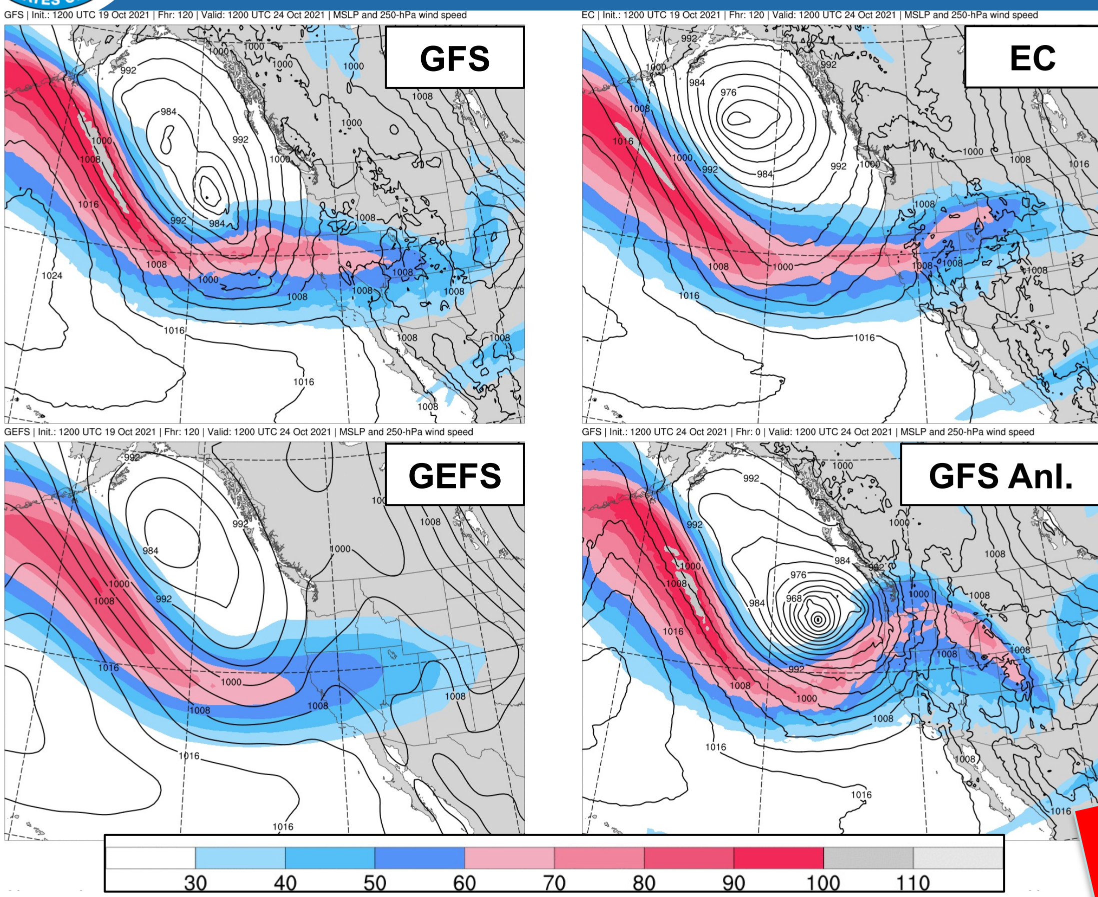
West Coast “Bomb” Cyclone



Init.: 12Z 10/19/21 (F120)
Valid: 12Z 10/24/21

- GFS forecasted a cyclone further south than the EC on Day 5, but delayed its deepening and was still ultimately too weak (962 hPa vs. observed 943 hPa)
- EC delayed the formation/deepening of the West Coast cyclone (forecasting a 971 hPa cyclone 18-h later)
- GEFS mean did not depict a cyclone off of the WA/OR coast during this cycle (a few GEFS members showed a deep cyclone hours later than observations)

verification

4-day model forecast

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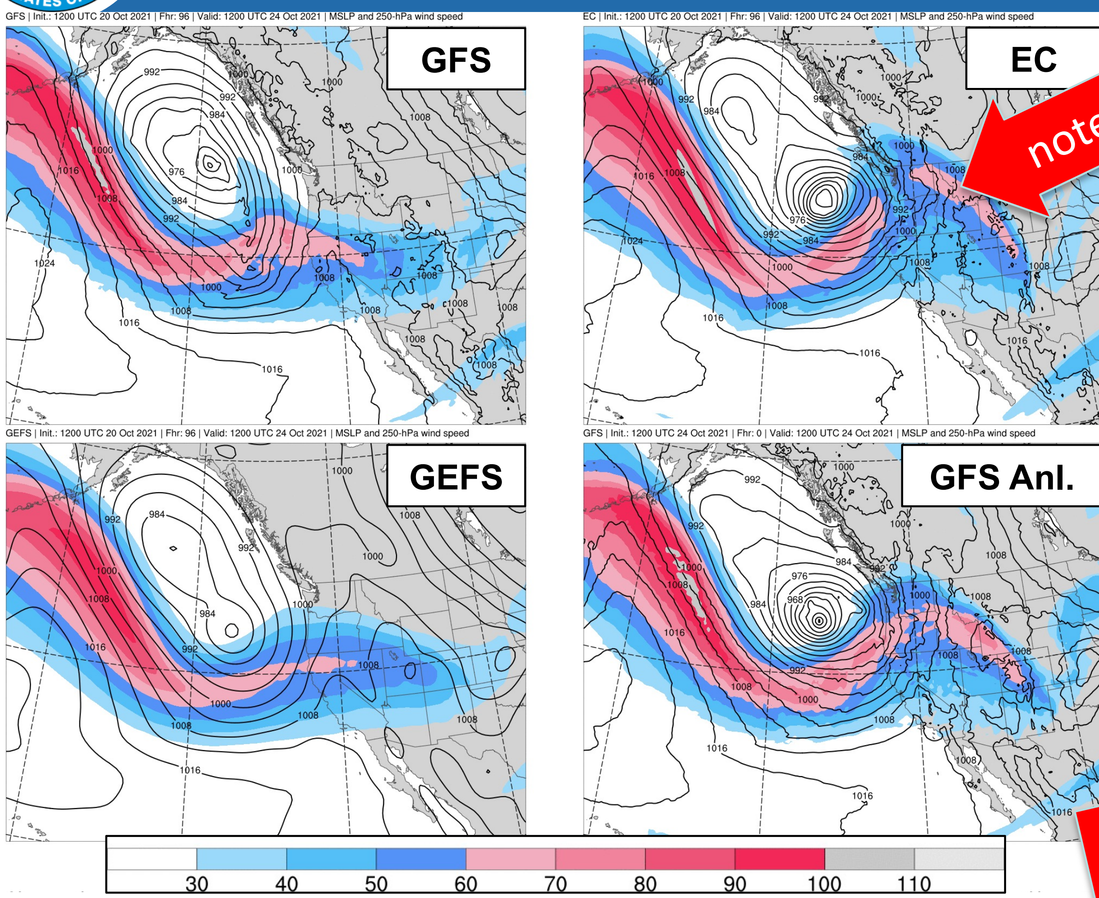
West Coast "Bomb" Cyclone



note jump in quality

Init.: 12Z 10/20/21 (F096)
Valid: 12Z 10/24/21

- GFS continued to delay the formation/ deepening of the West Coast cyclone (a 966-hPa cyclone was present off of the WA/OR coast 12-h later)
- EC captured the formation/deepening of the West Coast cyclone by Day 4, with a 949-hPa cyclone off the WA/OR coast
- GEFS mean began to depict a cyclone off the WA/OR coast by Day 4, although there was also a delay in its formation/ deepening (similar to the GFS)

verification

3-day model forecast

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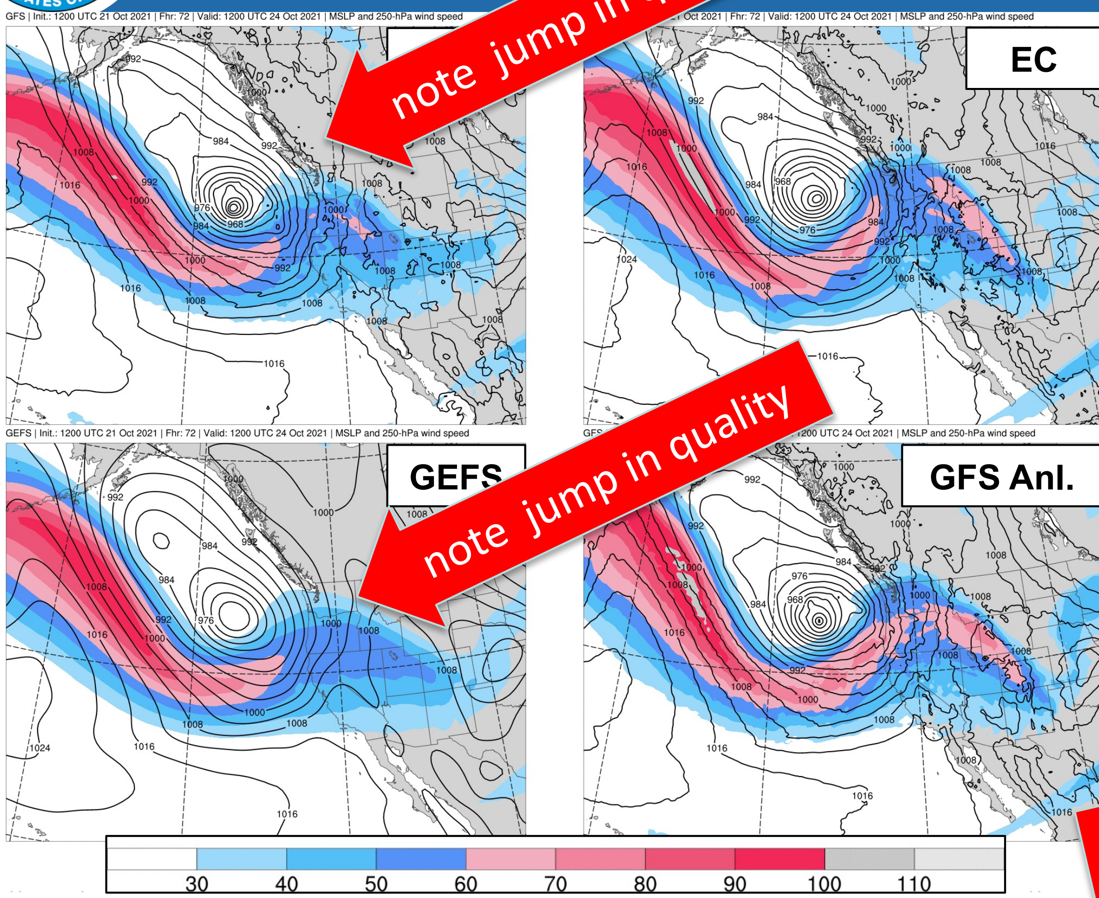
West Coast “Bomb” Cyclone



verification

Init.: 12Z 10/21/21 (F072)
Valid: 12Z 10/24/21

- GFS forecasted the timely formation/ deepening of the West Coast cyclone as forecasts of the 500-hPa cutoff low of the WA/OR coast improved (945 hPa)
- EC continued to forecast a <950-hPa cyclone off the WA/OR coast at Day 3, refining its location and structural details
- GEFS mean also captured a strong cyclone off the WA/OR coast (966 hPa), with all GEFS members forecasting a strong cyclone by Day 3 (not shown)

Can we figure out something more substantive?

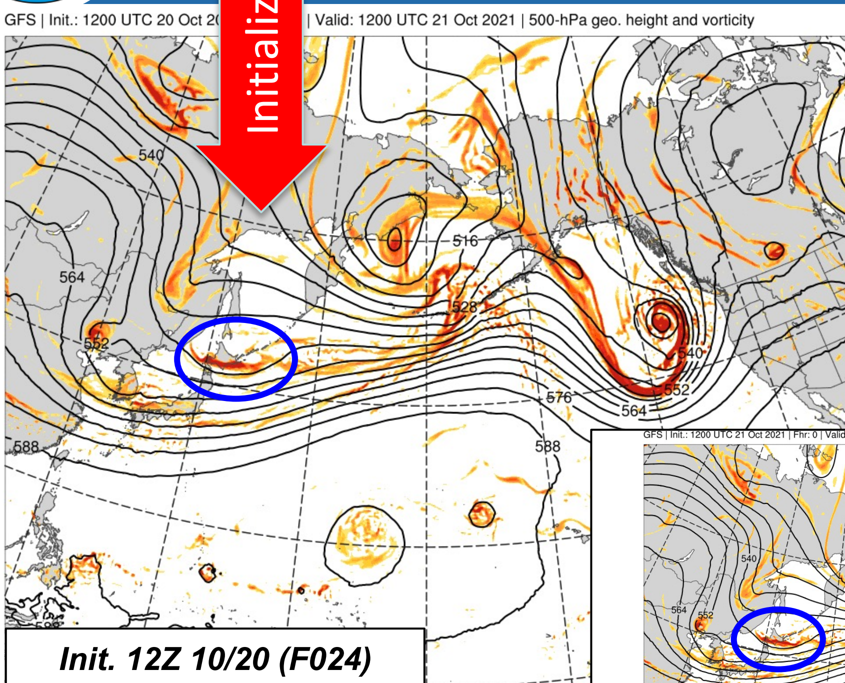
- We are going to look at a series of figures of GFS model forecasts.
- They are initialized 24 hours apart
  - 4-day
  - 3-day
- Note role of the “short-wave”

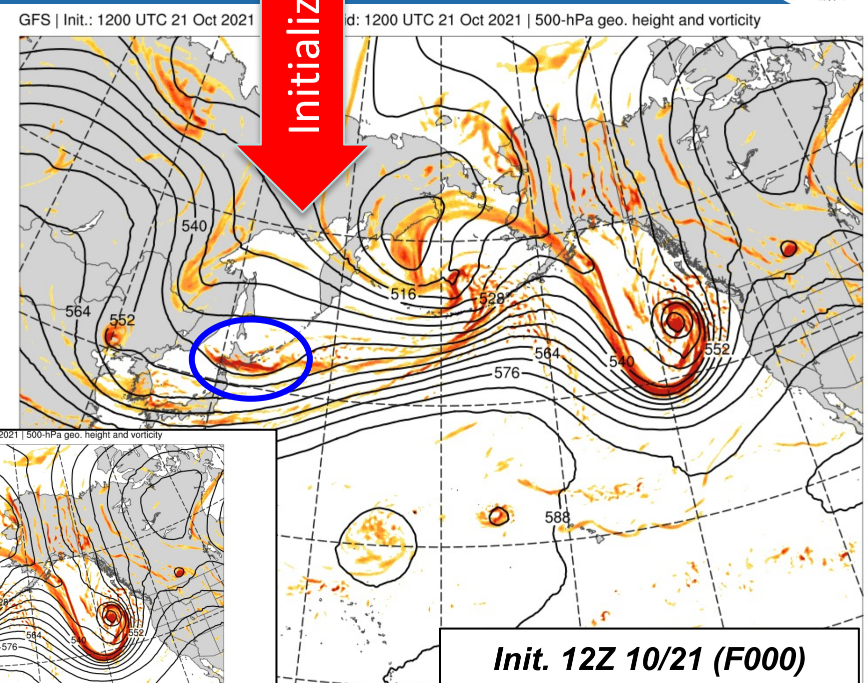
NATIONAL OCEANIC AND ATMOSPHERIC AD ISTRATION

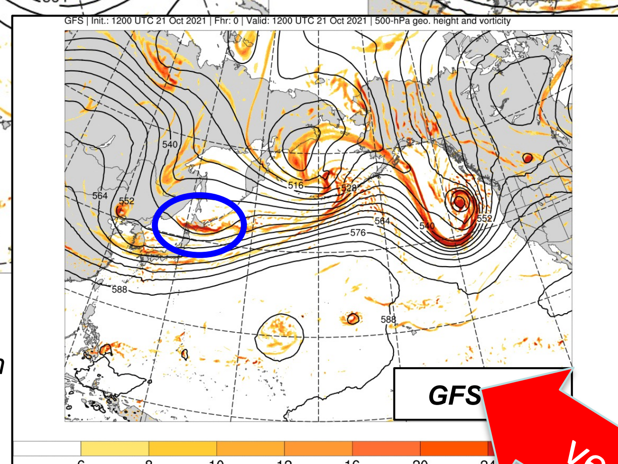
Ru Differences (Init. 12Z 10/20 . 12Z 10/21)

Initialized 4 days earlier

Initialized 3 days earlier







Subtle/e differences in structure of a shortwave turbance over pan resulted in different adv tion speeds ac s the NPAC and different off low structur ver EPAC

Initial time

Forecast length

verification

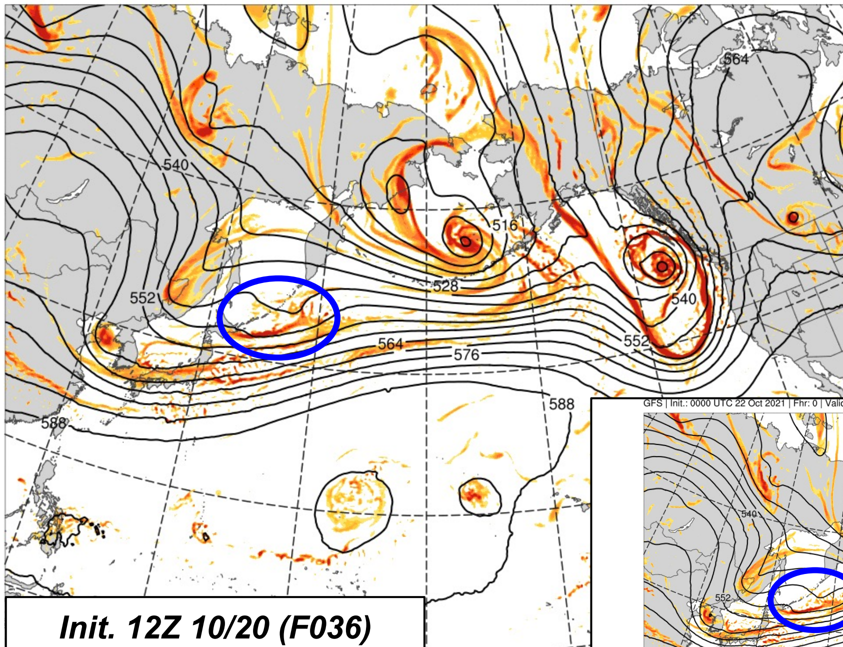
Initial time

Forecast length

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Run Differences (Init. 12Z 10/20 vs. 12Z 10/21)

GFS | Init.: 1200 UTC 20 Oct 2021 | Fhr: 36 | Valid: 0000 UTC 22 Oct 2021 | 500-hPa geo. height and vorticity



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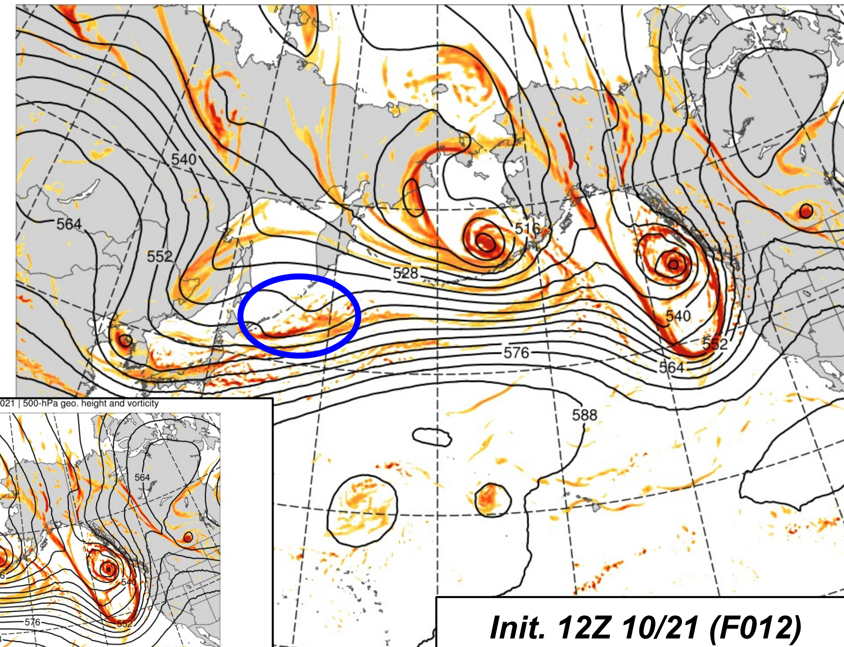
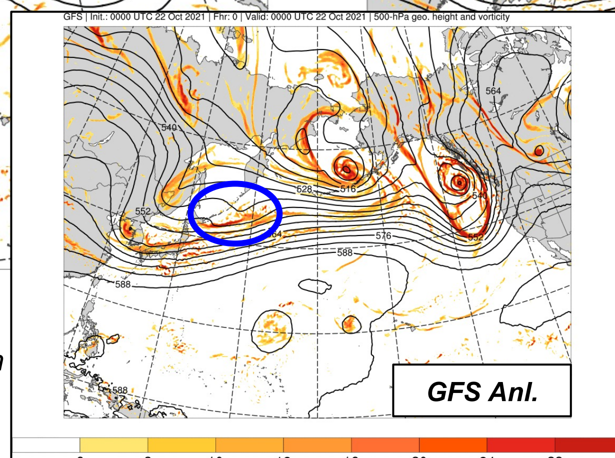
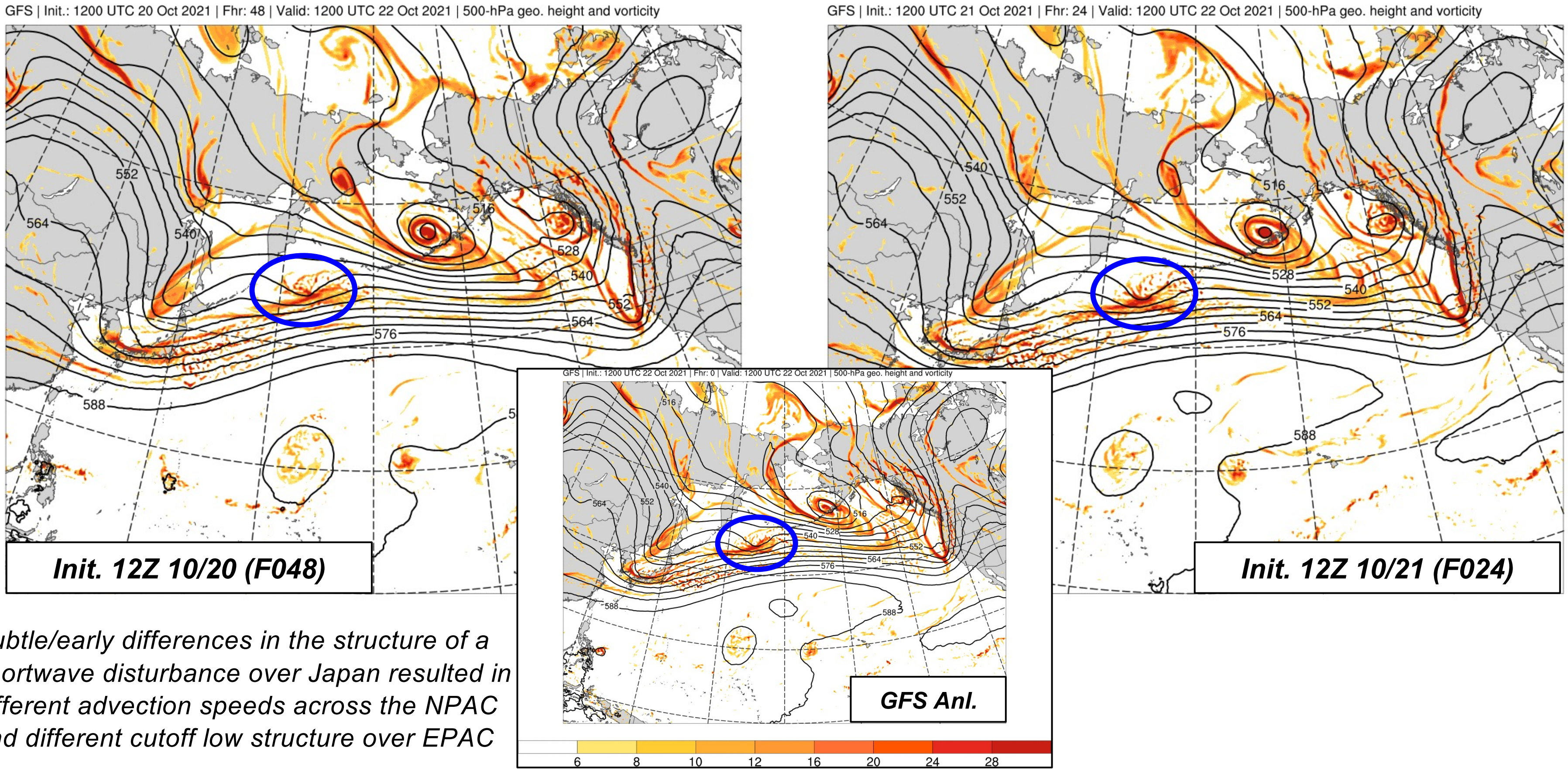




Subtle/early differences in the structure of a shortwave disturbance over Japan resulted in different advection speeds across the NPAC and different cutoff low structure over EPAC

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Run Differences (Init. 12Z 10/20 vs. 12Z 10/21)



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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Run Differences (Init. 12Z 10/20 vs. 12Z 10/21)

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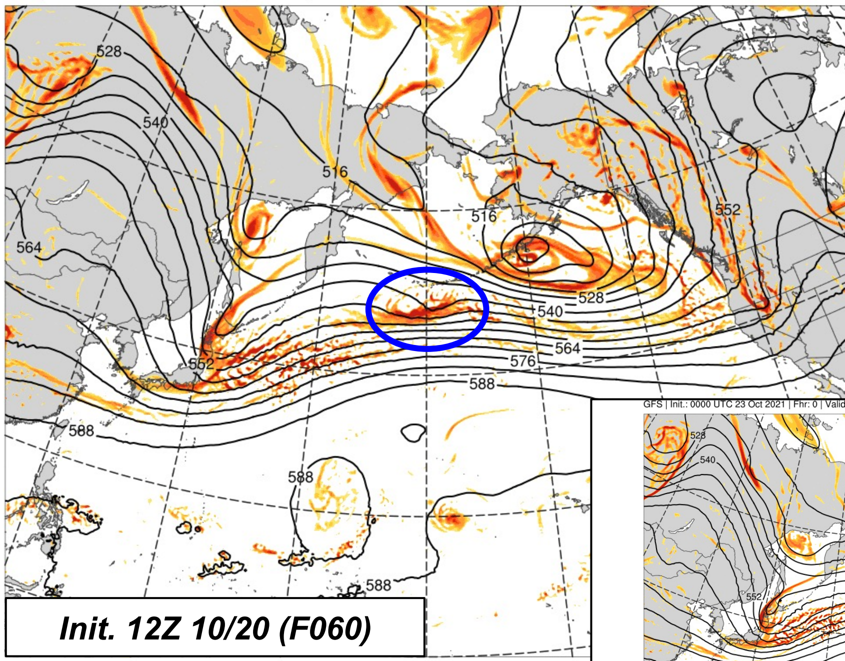
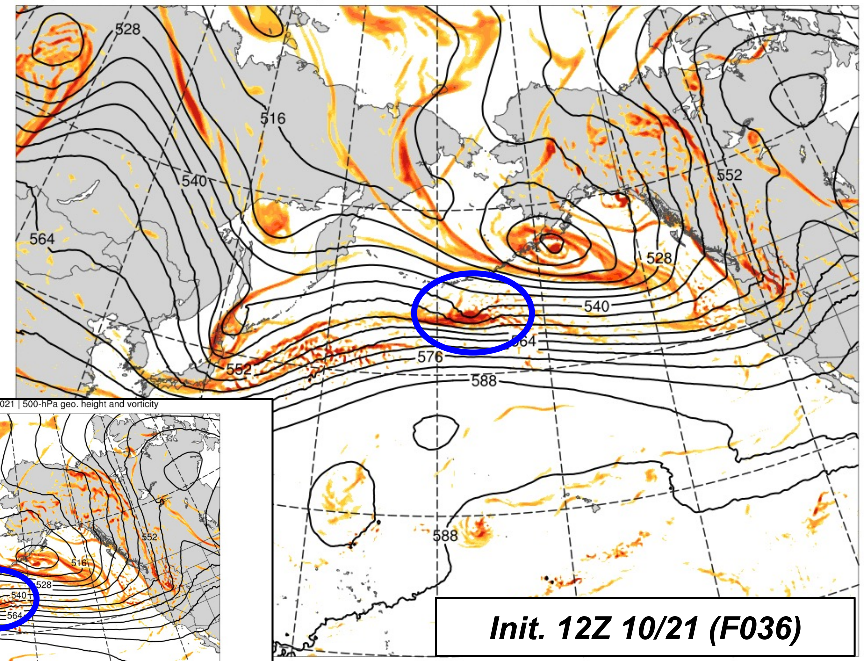
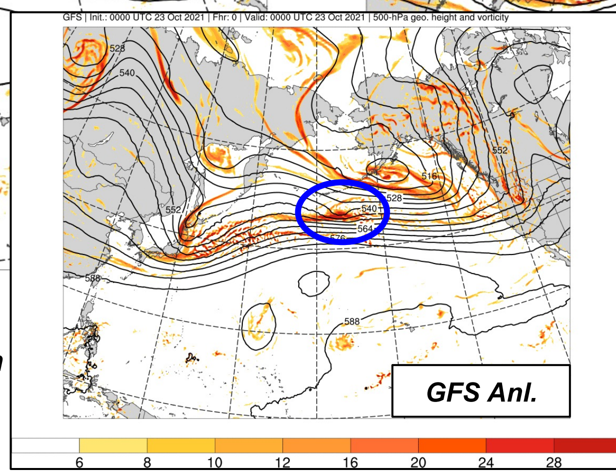


GFS | Init.: 1200 UTC 21 Oct 2021 | Fhr: 36 | Valid: 0000 UTC 23 Oct 2021 | 500-hPa geo. height and vorticity

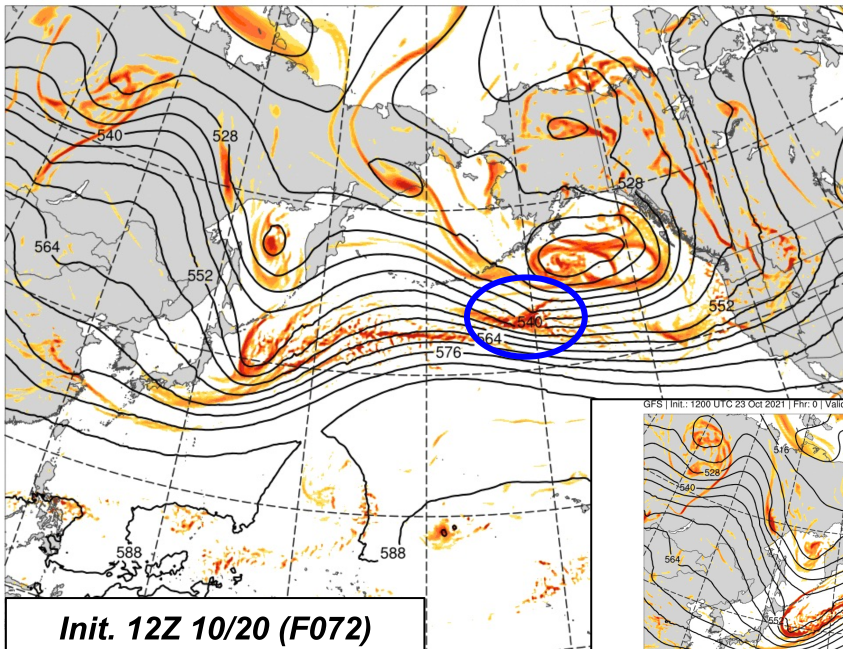




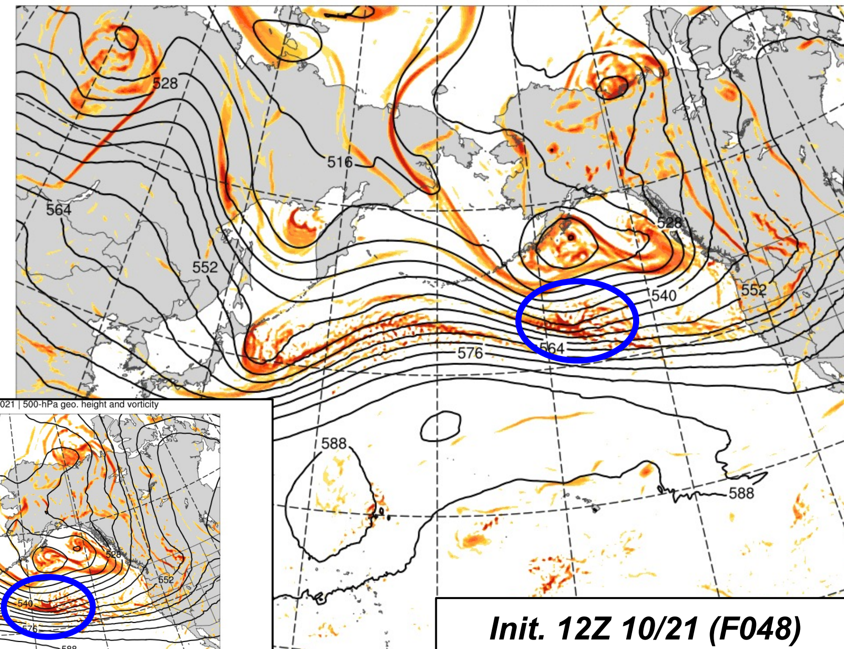
Subtle/early differences in the structure of a shortwave disturbance over Japan resulted in different advection speeds across the NPAC and different cutoff low structure over EPAC

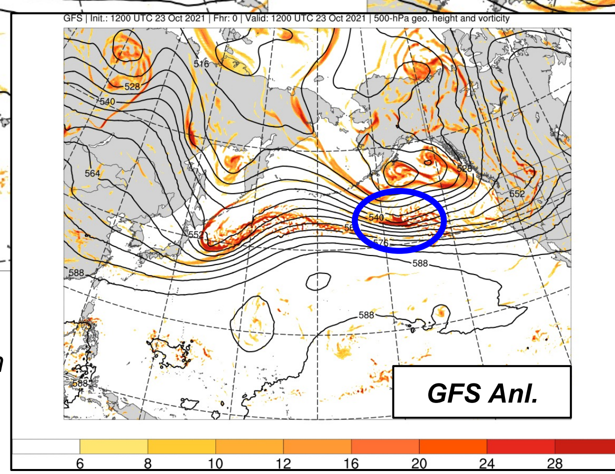
Run Differences (Init. 12Z 10/20 vs. 12Z 10/21)

GFS | Init.: 1200 UTC 20 Oct 2021 | Fhr: 72 | Valid: 1200 UTC 23 Oct 2021 | 500-hPa geo. height and vorticity



GFS | Init.: 1200 UTC 21 Oct 2021 | Fhr: 48 | Valid: 1200 UTC 23 Oct 2021 | 500-hPa geo. height and vorticity





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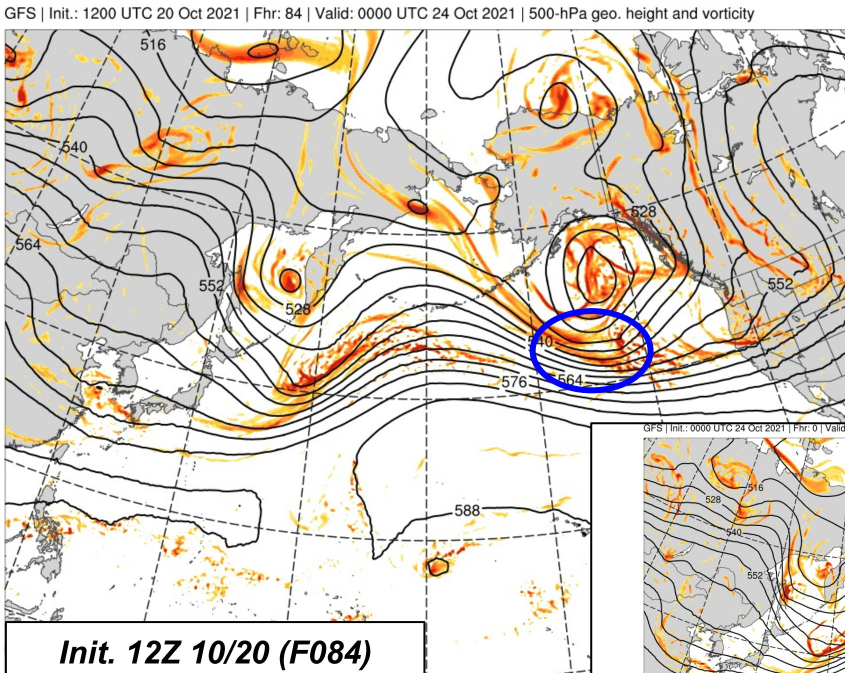

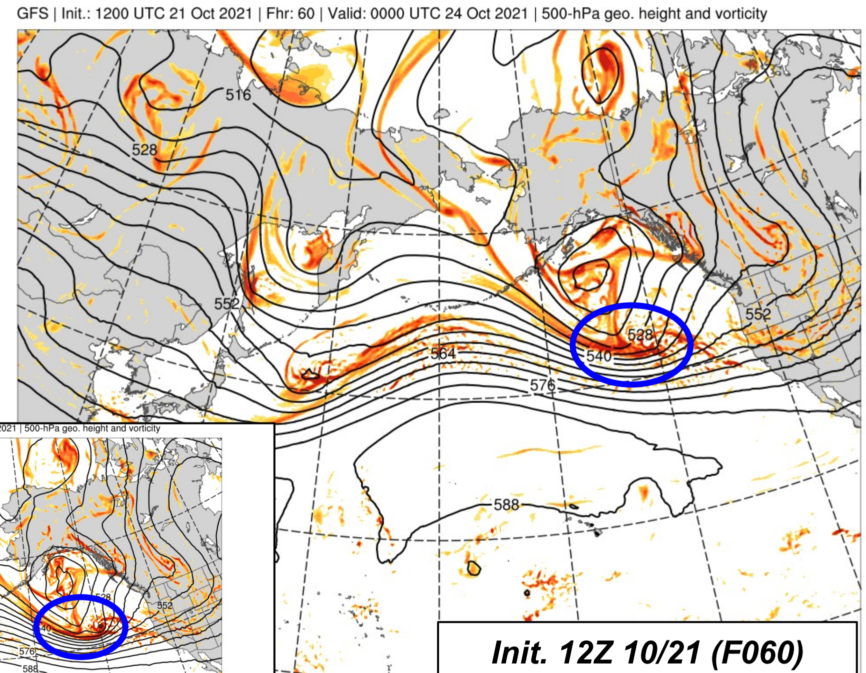

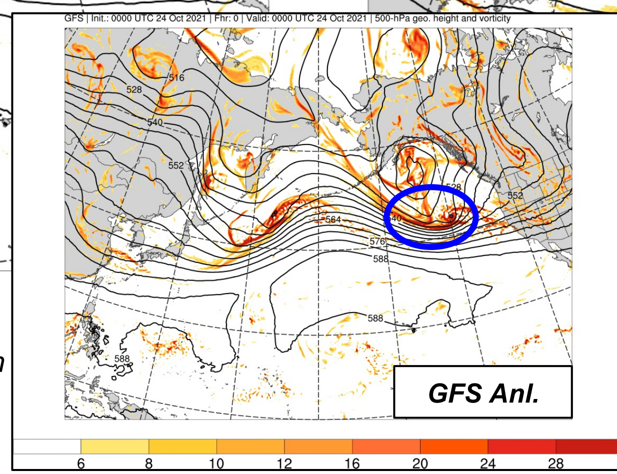

Subtle/early differences in the structure of a shortwave disturbance over Japan resulted in different advection speeds across the NPAC and different cutoff low structure over EPAC

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Run Differences (Init. 12Z 10/20 vs. 12Z 10/21)

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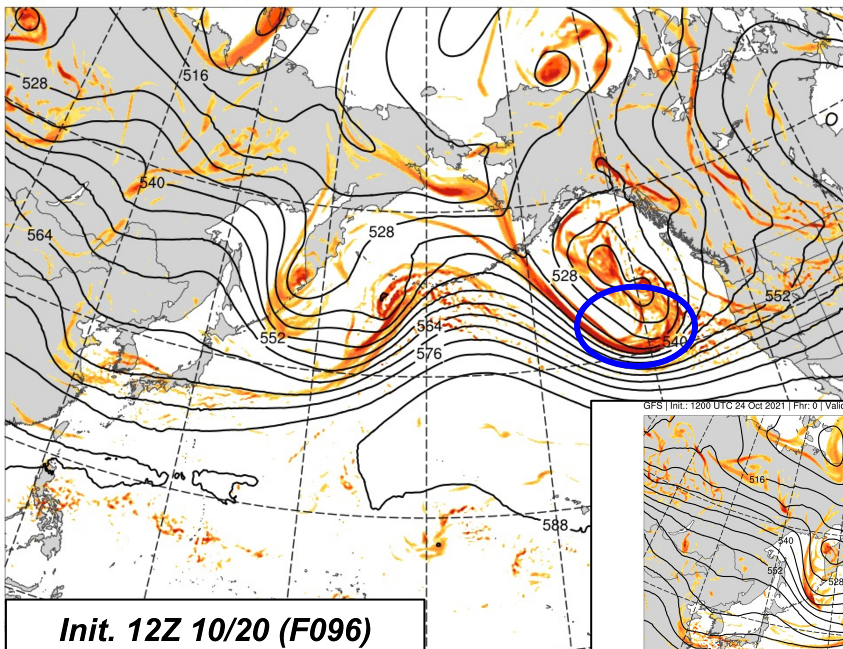
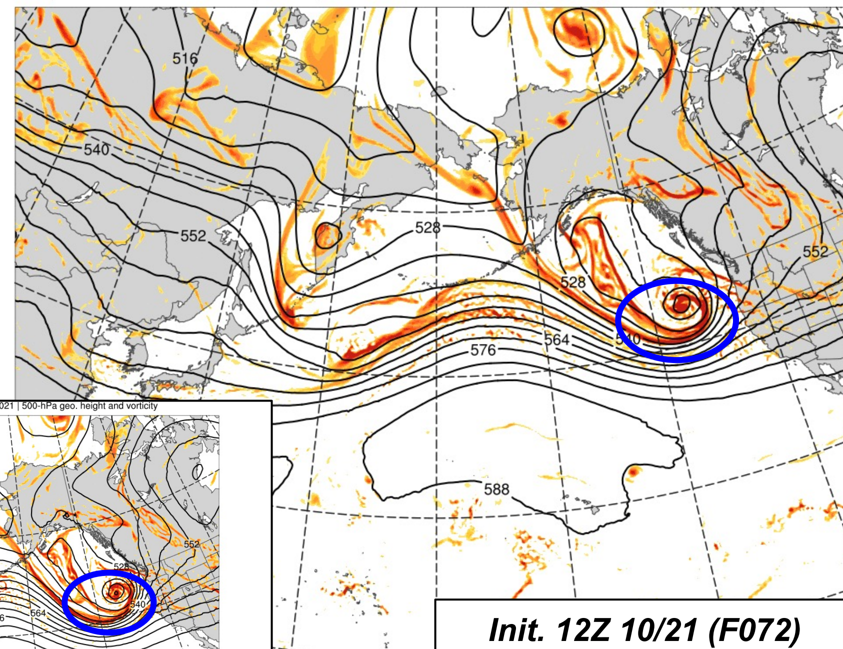
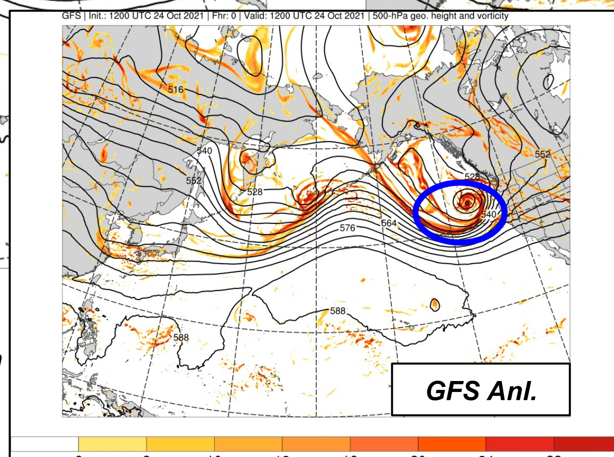


Init. 12Z 10/20 (F096)

GFS | Init.: 1200 UTC 21 Oct 2021 | Fhr: 72 | Valid: 1200 UTC 24 Oct 2021 | 500-hPa geo. height and vorticity



Init. 12Z 10/21 (F072)



GFS Anl.

Subtle/early differences in the structure of a shortwave disturbance over Japan resulted in different advection speeds across the NPAC and different cutoff low structure over EPAC

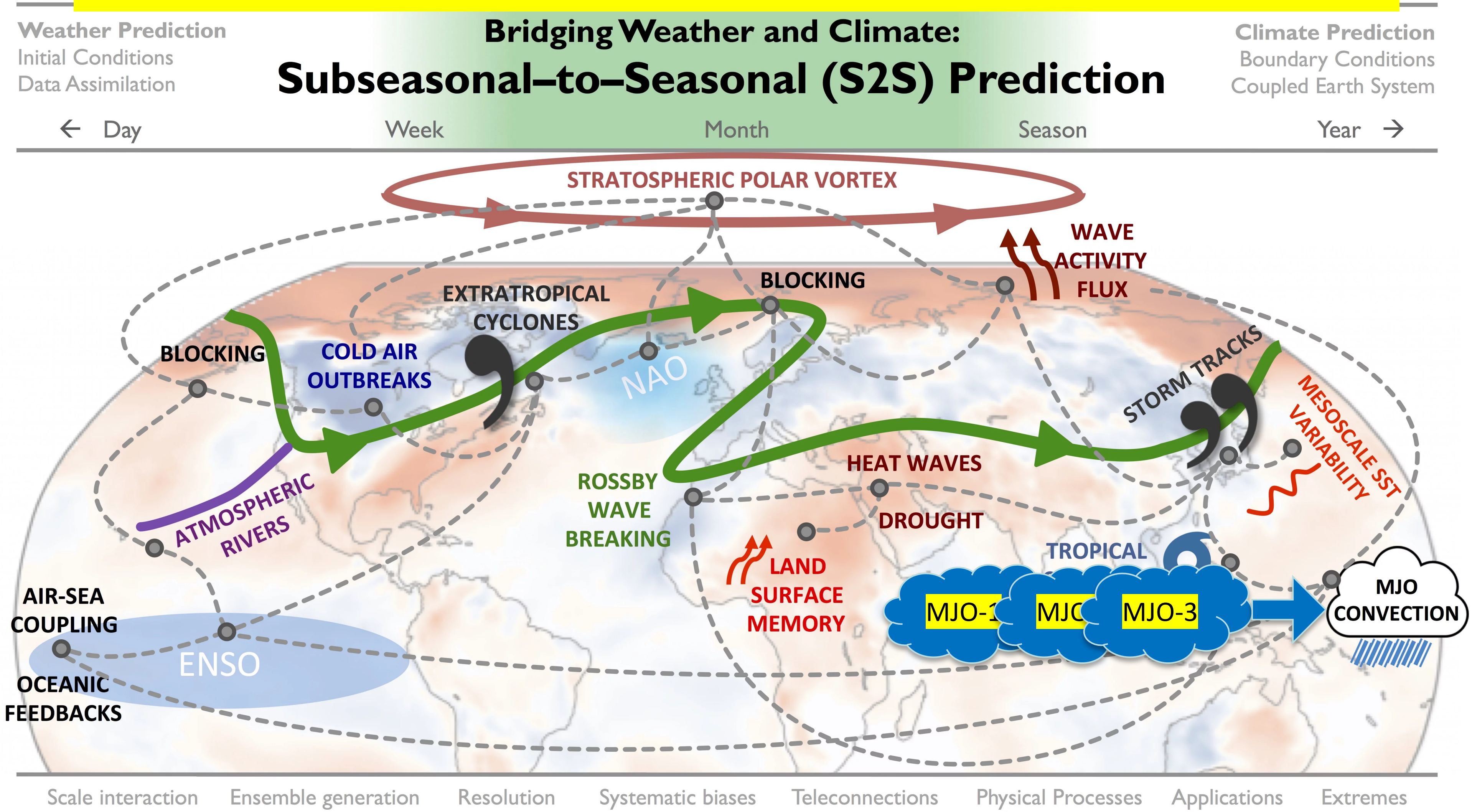
W. Coast Cyclone: Medium-Range Forecasts

- GFS and EC forecasts delayed the formation/deepening of the West Coast cyclone at Days 5–8, producing weaker cyclones than analyzed
- EC forecasts captured the formation/deepening of the West Coast cyclone by Day 4 due to a better handling of the 500-hPa geopotential height pattern over the NPAC and the cutoff low off of the WA/OR coast
- GFS forecasts did not capture the timing of the formation/deepening of the West Coast cyclone until Day 3 (when forecasts of a 500-hPa shortwave trough traversing the NPAC and the cutoff low off of the WA/OR coast improved)
- GEFS mean struggled to forecast the West Coast cyclone until Day 4, and did not capture the timing of its formation/deepening until Day 3 (similar to GFS)

The role of models

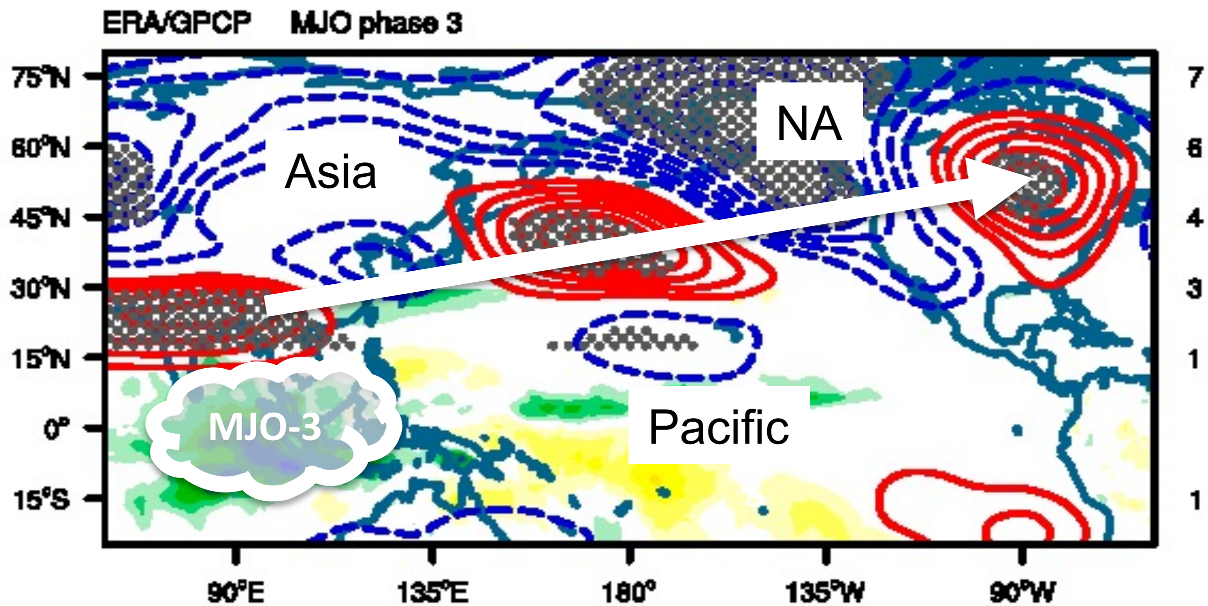
- The differences between model forecasts are used to explore and describe uncertainty in the generation of forecasts.
  - They provide context.
- Some models prove, with sufficient statistics, to be more reliable than others.
  - In medium-range, ECMWF, verifies with highest skill.
- Regional and process models contribute to the uncertainty exploration close to forecast time.
  - Bring information unavailable from global models
  - Often, provide improved model forecasts

The motivation for subseasonal prediction



Often looking for information on persistent anomalies:
Heat waves, polar vortex events, flooding, drought, blocking

Role of Madden-Julian Oscillation (Henderson et al., 2017)



Phase 1 – Enhanced convection (rainfall) develops over the western Indian Ocean.
Phase 2 and 3 – Enhanced convection (rainfall) moves slowly eastwards over Africa, the Indian Ocean and parts of the Indian subcontinent.
Phase 4 and 5 – Enhanced convection (rainfall) has reached the Maritime Continent (Indonesia and West Pacific)
Phase 6, 7 and 8 – Enhanced rainfall moves further eastward over the western Pacific, eventually dying out in the central Pacific.
-- The next MJO cycle begins.

Summary

- The UFS is a cultural change in how the U.S. addresses operational environmental modeling.
  - There has been substantial progress with improved forecasts, simplification of the modeling suite, addressing issues of cost, and engagement of forecaster community.
  - There is much left to be done, and continuity must be maintained.
    - That is, we need to build off successes, towards strategic goals. We need to fight the organizational inertia that promotes fragmentation.
- Infusion of new capacity with Earth Prediction Innovation Center (EPIC)

Student Involvement

- The Graduate Student Test: One accomplishment is that the code is far more accessible.
  - Medium-range weather
  - Short-range weather/Convection allowing
- Many NOAA opportunities
  - Lapenta Internships
- UFS at the AMS meeting

References

- UFS Resources
  - Portal: https://ufscommunity.org
  - Strategic plan
  - Neil Jacobs: BAMS Community Modeling
  - Rood: White Paper on UFS Priorities

References

- Model Evaluation Group (MEG) @ Environmental Model Center
  - Headline Scores
  - Official Evaluation of GFSv16
  - Official GEFSv12 Evaluation
- There are amazing weekly analysis by MEG. The presentations are online, but you have to request access.

References

- Subseasonal to Seasonal (S2S)
  - NOAA Weeks 3-4/S2S Webinar Series
    - Eric Maloney Webinar on MJO
  - CPO S2S Task Force
  - What is the Madden-Julian Oscillation
  - National Academy of Science: S2S Strategy

End: Introduction to the UFS

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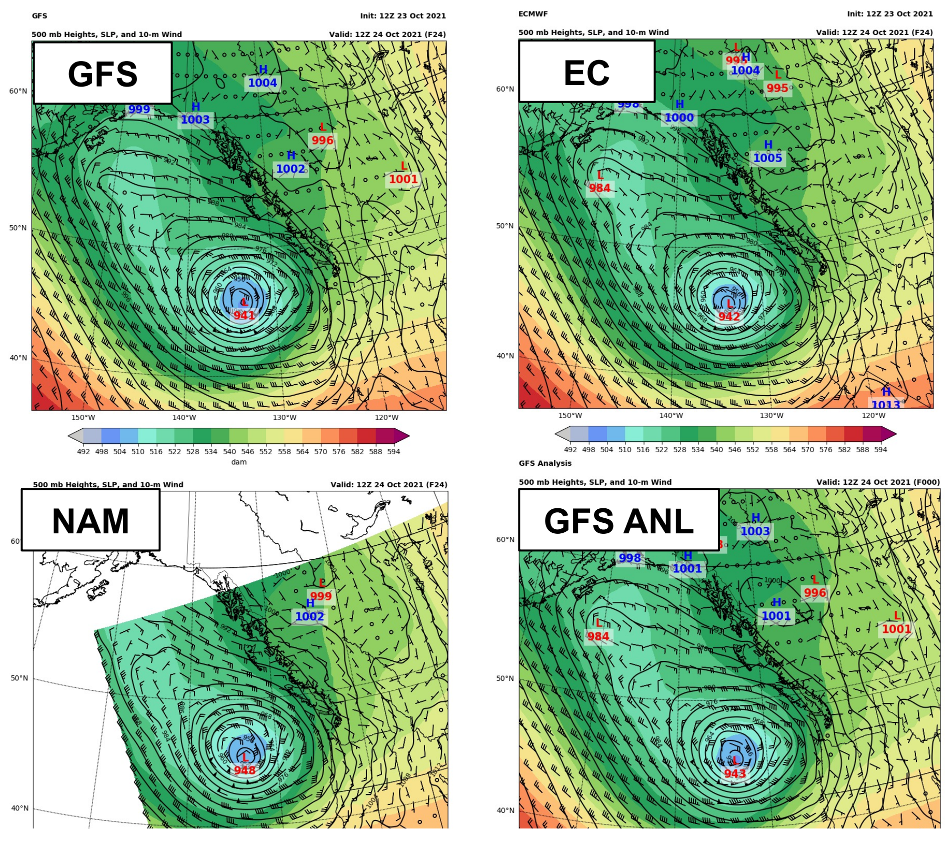
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

West Coast "Bomb" Cyclone

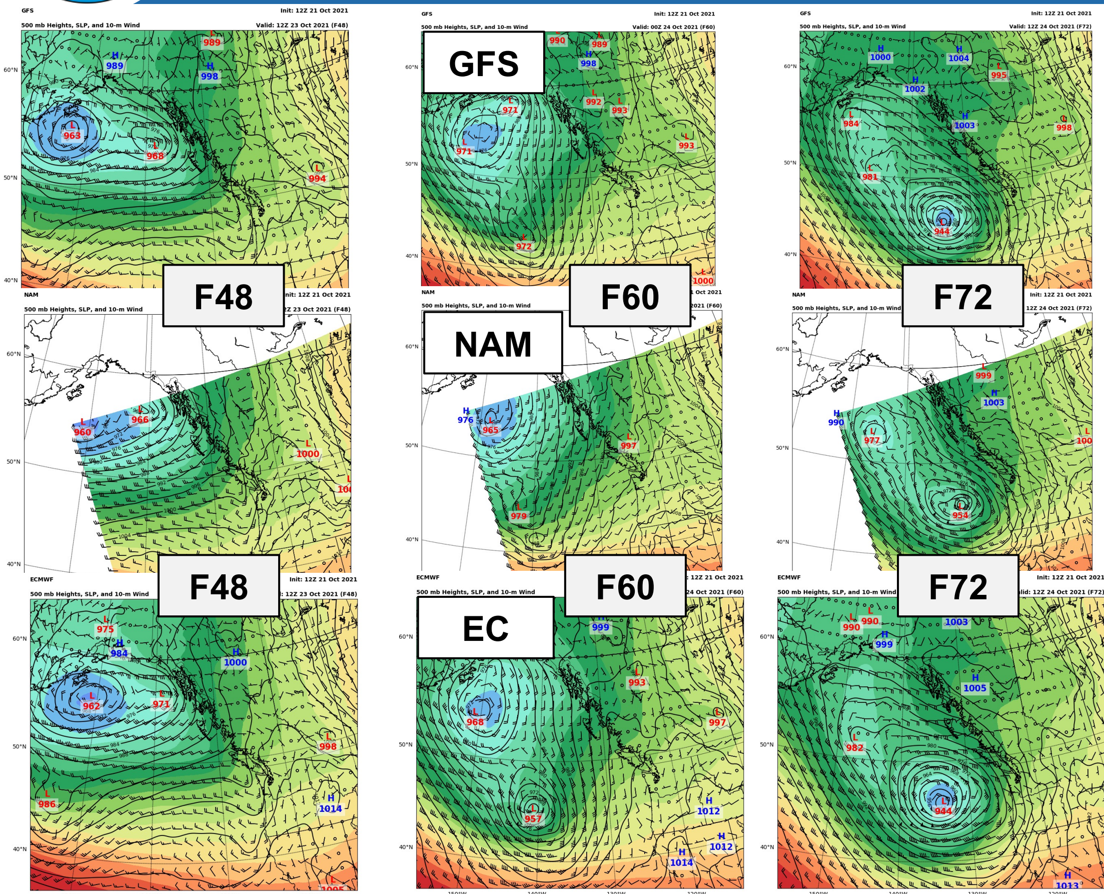


Init.: 12Z 10/23/21 (F024)
Valid: 12Z 10/24/21

- The GFS, EC, and NAM Day 1 forecasts of the position and intensity of the primary sfc low were all very good
- NAM was still several mb too weak with the central pressure of the low
- GFS again didn't show a closed circulation with the low that was further northwest, although it again did show a circulation earlier (through F18 - not shown)

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

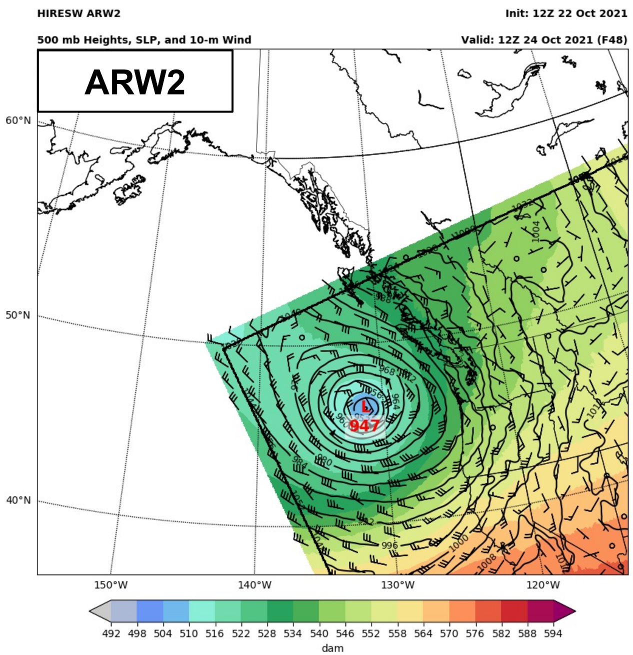
Examining the Rapid Deepening

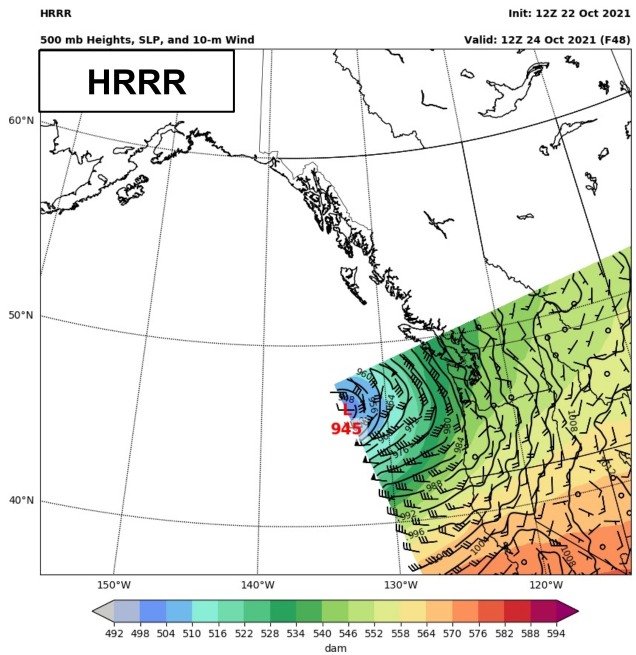


Init.: 12Z 10/21/21

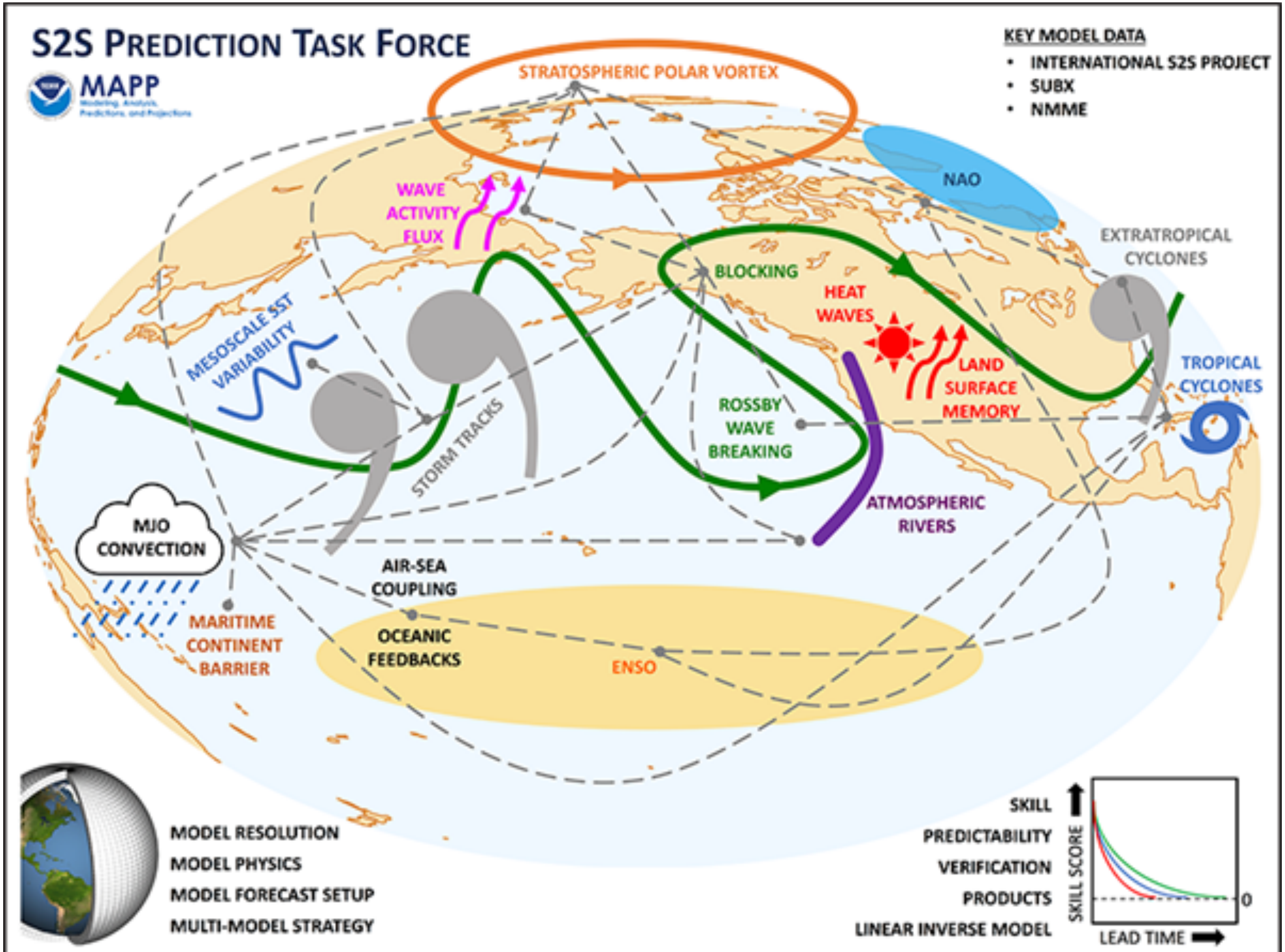
- The rapid deepening of the southern low (and weakening of the northern low) was overall handled quite well by the GFS, EC, and NAM
- The EC was a bit too fast with the rapid deepening (based on observed central pressures, as shown earlier in this presentation)
- And, as previously mentioned, the NAM didn't deepen the primary low quite enough

CAMs





- Won’t examine CAM performance for the rapid deepening, as this process occurred either on or just off of the western boundary for those model domains


S2S PREDICTION TASK FORCE
MAPP
KEY MODEL DATA
• INTERNATIONAL S2S PROJECT
• SUBX
• NMME
STRATOSPHERIC POLAR VORTEX
NAO
WAVE ACTIVITY FLUX
EXTRATROPICAL CYCLONES
BLOCKING
HEAT WAVES
MESOSCALE SST VARIABILITY
LAND SURFACE MEMORY
TROPICAL CYCLONES
ROSSBY WAVE BREAKING
STORM TRACKS
ATMOSPHERIC RIVERS
MJO CONVECTION
AIR-SEA COUPLING
MARITIME CONTINENT BARRIER
OCEANIC FEEDBACKS
ENSO
MODEL RESOLUTION
MODEL PHYSICS
MODEL FORECAST SETUP
MULTI-MODEL STRATEGY
SKILL
PREDICTABILITY
VERIFICATION
PRODUCTS
LINEAR INVERSE MODEL
SKILL SCORE
0
LEAD TIME