U.S. NAVAL RESEARCH LABORATORY

Diagnosing and Addressing Systematic Errors in the Navy's NEPTUNE Modeling System

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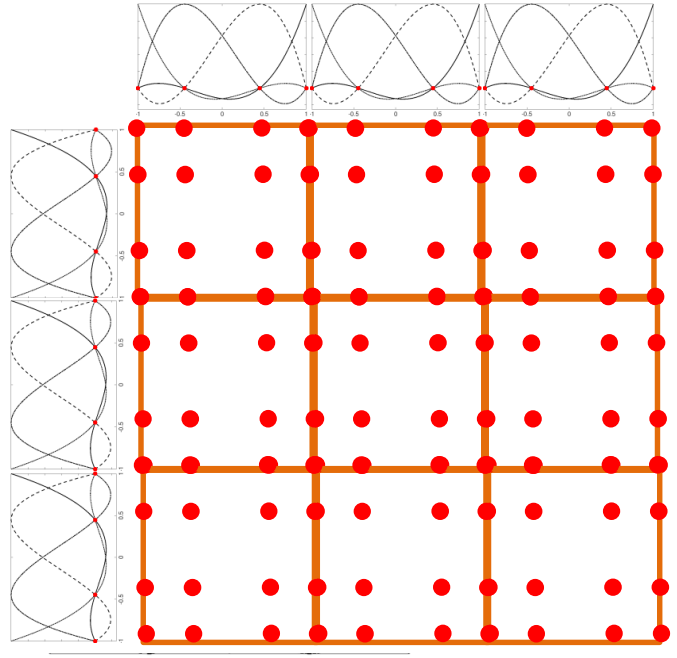
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NEPTUNE Background

- NEPTUNE Numerics
  - Numerical solution is represented by a local polynomial expansion
  - Flexible numerics allow for high-order and mesh refinement options
  - Excellent scaling and dense floating point computations (for accelerators)
  - Initial transition ~9 km resolution (E96P6) in Jan. 2024 using NAVGEM Hybrid 4D-Var initial conditions
- Common Community Physics Package (CCPPv6)
  - Optimizing the NEPTUNE physics suite selected from components in CCPP
  - NRL tested many physics components and selected Suite 7
- NEPTUNE Testing
  - NEPTUNE (9 km 104L) using NAVGEM Hybrid 4D-Var ICs
  - 5-day forecasts every 24 h; March 2021 – February 2022
  - Mitigate forecast biases through iterative physics testing
  - Verify and compare with NAVGEM forecasts for same period



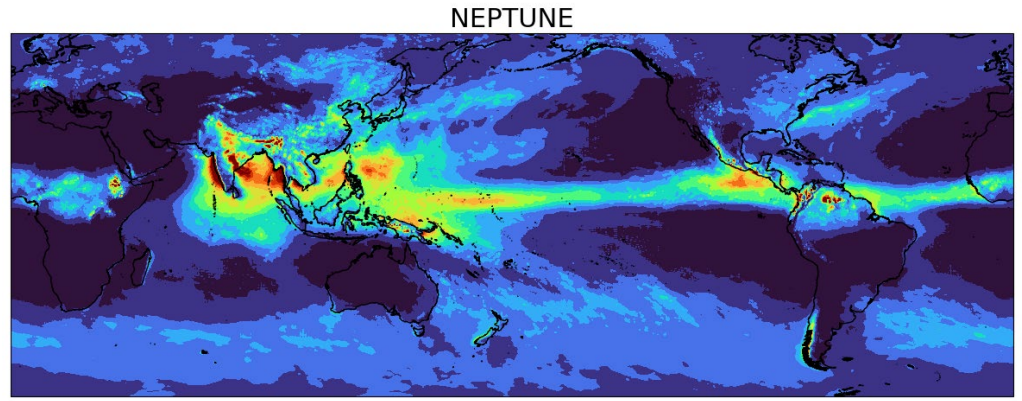
NRL Suite 7 Physics

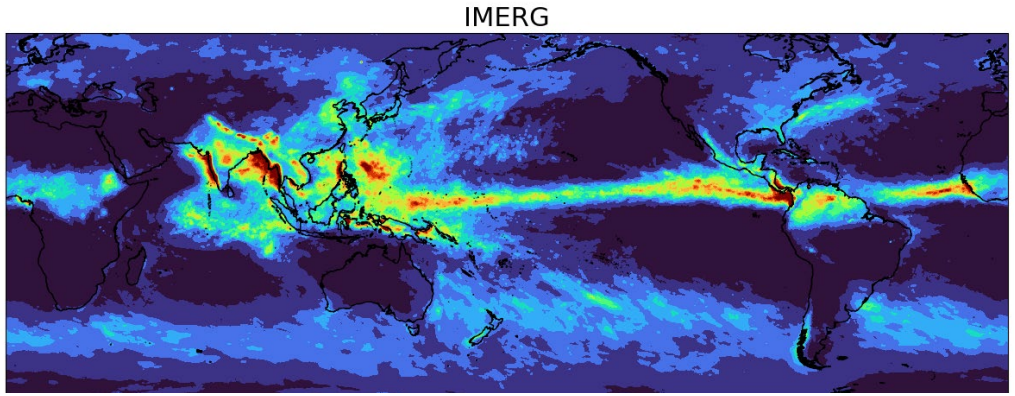
Microphysics	Thompson
PBL and Turbulence	MYNN-EDMF
Surface Layer	MYNN
Deep Convection	Tiedtke
Shallow Convection	Tiedtke
Radiation	RRTMG
Gravity Wave Drag	CIRES uGWP
Land Surface Model	Noah

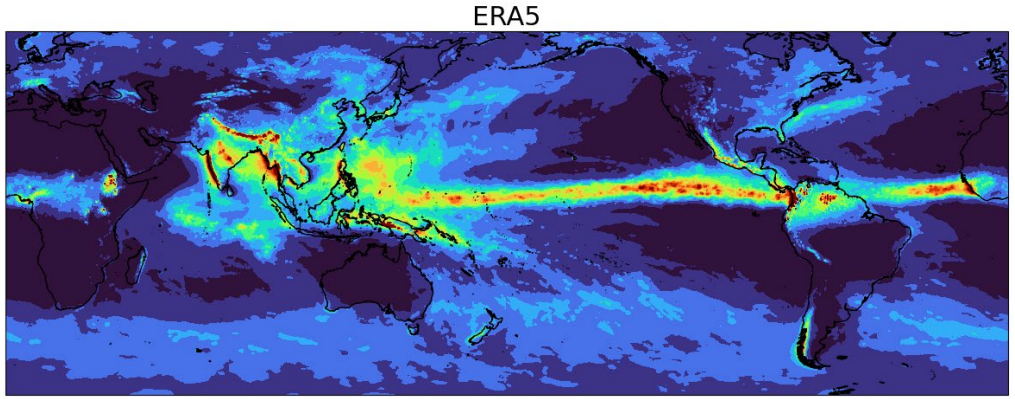
***NEPTUNE**: **N**avy **E**nvironmental **P**rediction sys**T**em **U**tilizing a **N**onhydrostatic **E**ngine*

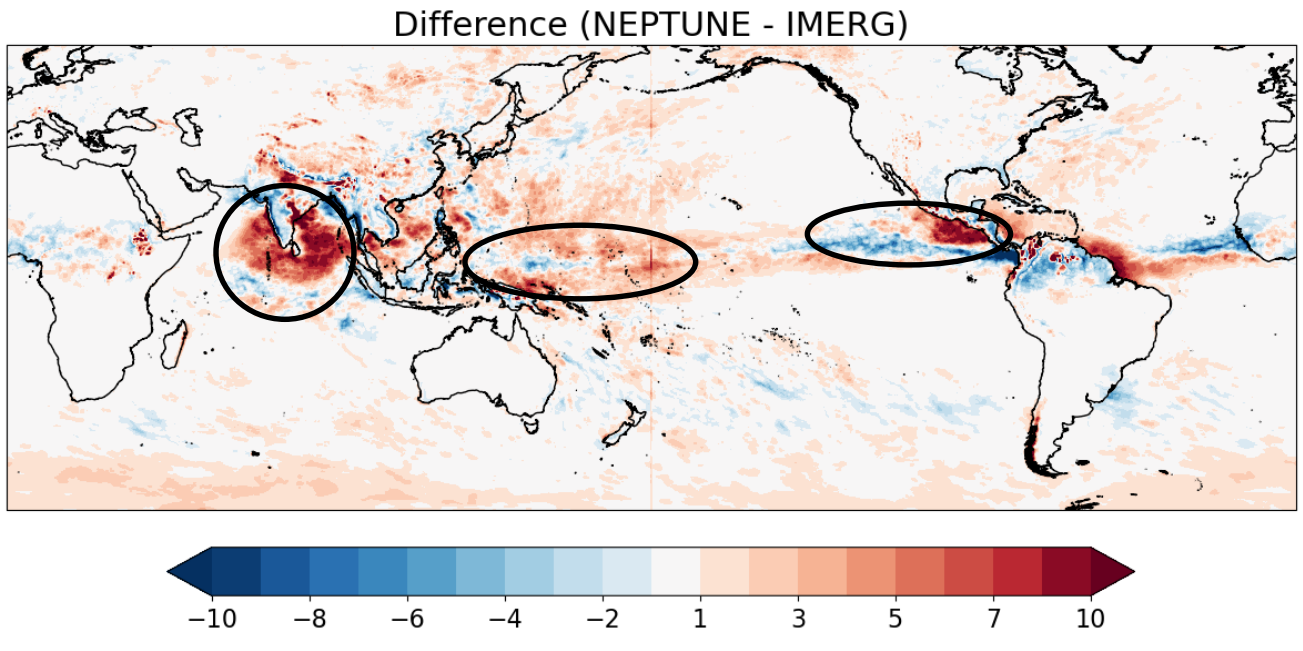
Tropical Precipitation Bias

- Monthly Mean Precipitation for July 2021/2022/2023 (mm/day)
- 12 different 48-120 hour forecasts per month to represent monthly rainfall (36 total forecasts)
- Too much precipitation over northern Indian Ocean
- ITCZ misplaced in Atlantic and Pacific



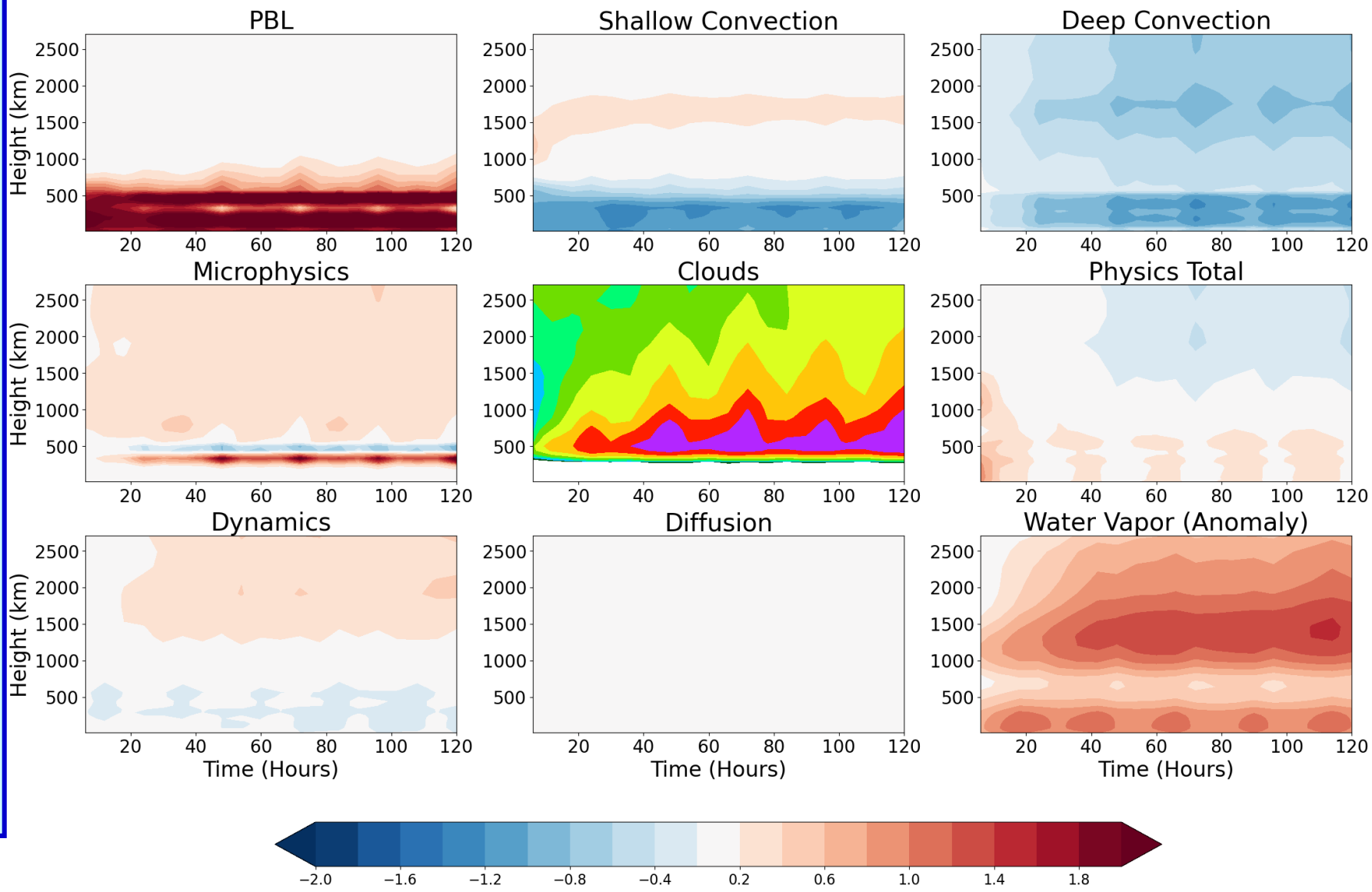






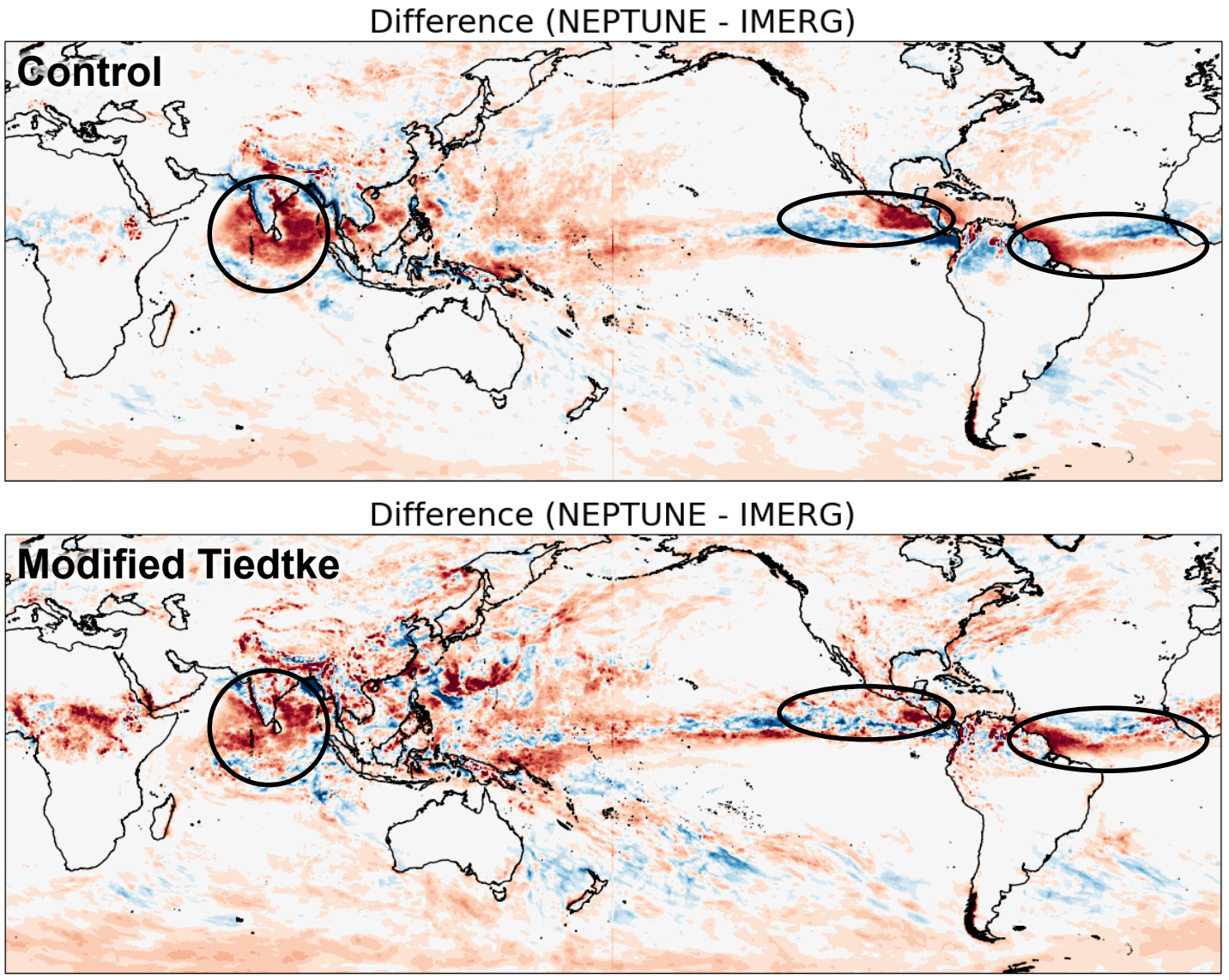
Parameterization Moisture Tendencies

- Tiedtke shallow convection entrains moisture out of PBL
- MYNN PBL responds by adding even more moisture
- Increasing moisture leads to clouds with larger liquid water content
- Moisture tendencies above PBL via shallow convection are converted to clouds
- Microphysics adds excess moisture to the grid scale through evaporation
- Tiedtke shallow convection mass flux is an order of magnitude larger than SAS



Reducing the Tropical Precipitation Bias

- Increased the updraft entrainment rate coefficient in the Tiedtke deep convection
- Decreased the shallow cumulus threshold: 200 hPa to 150 hPa
- Monthly mean precipitation for July 2021/2022/2023 (mm/day) using ~18 km resolution (E96P4)
- Overall improvements in the northern Indian Ocean and Pacific/Atlantic ITCZ



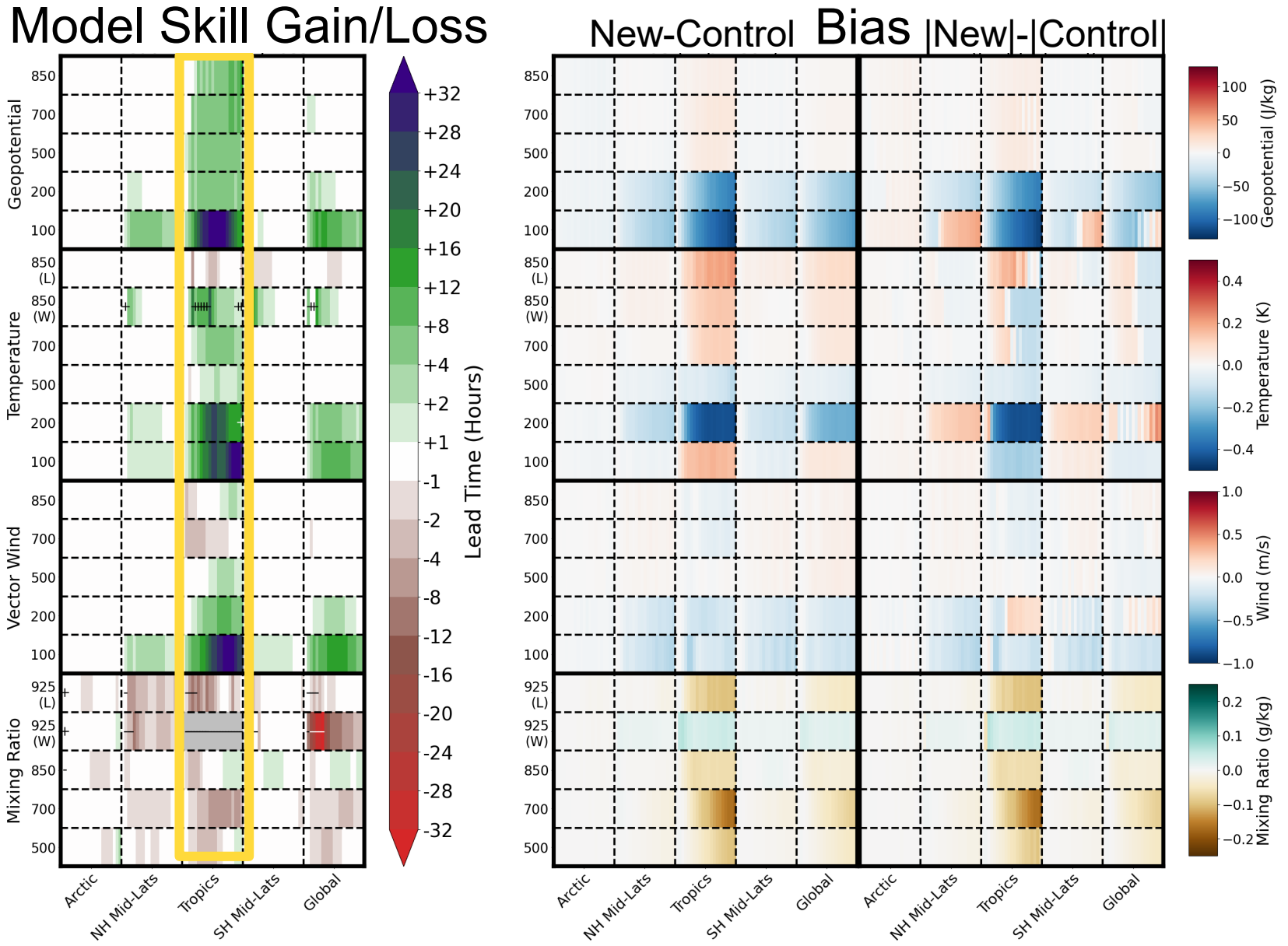
Reducing the Tropical Precipitation Bias

- Verification with ERA-5
- Improvements mainly in the tropics
- Increased entrainment counteracts the excessive moisture, since the convection is more exposed to the lower humidity of the ambient environment

Red/Brown:
worse skill for experiment

Indigo/Green:
better skill for experiment

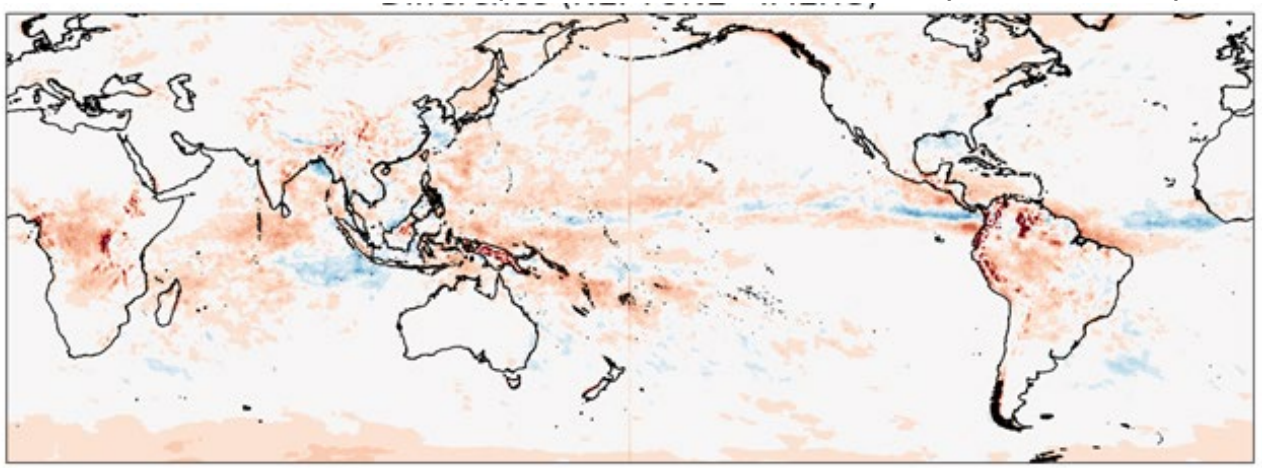
Comparison of Model Skill and Mean Bias



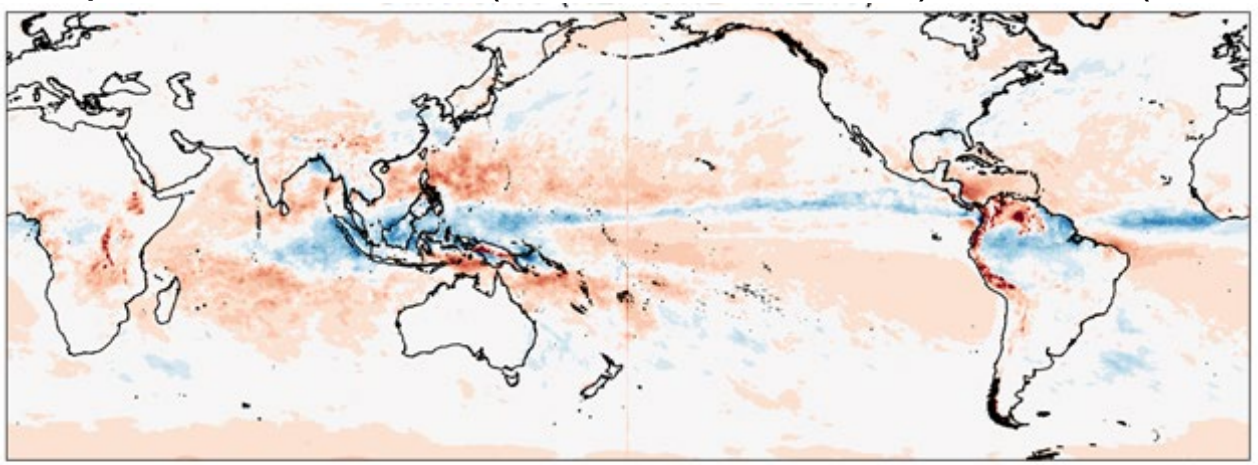
NEPTUNE and NAVGEM Precipitation Forecasts

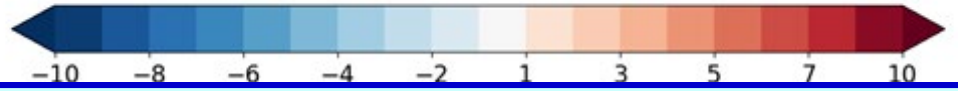
9-km Forecasts
E96P6
March 2021 to
February 2022

Precipitation Difference (NEPTUNE – IMERG) 96-120h (mm/day)

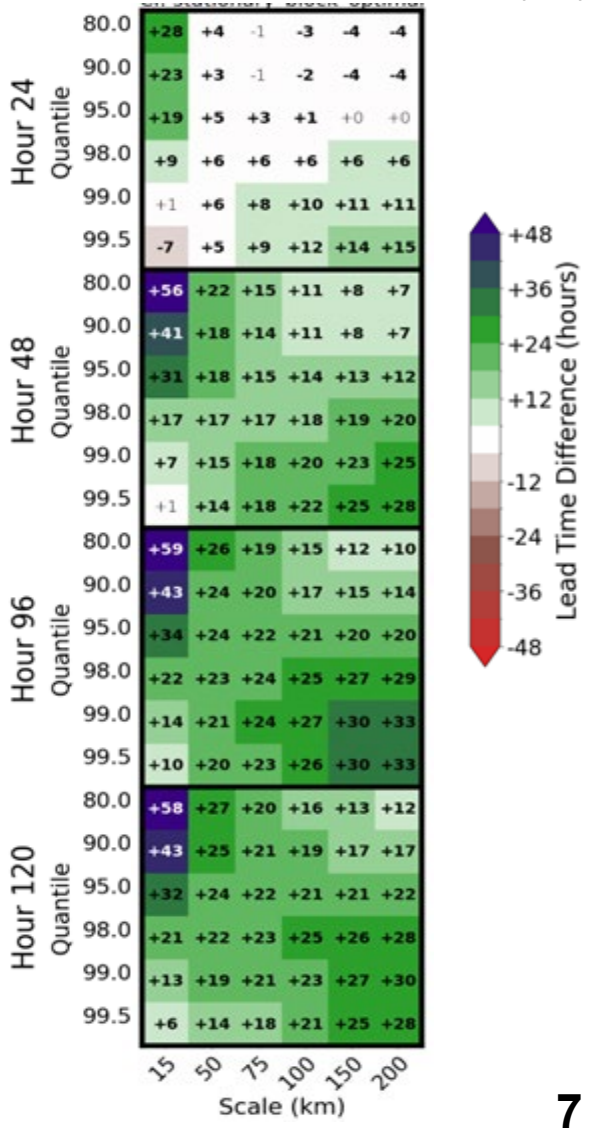


Precipitation Difference (NAVGEM – IMERG) 96-120h (mm/day)





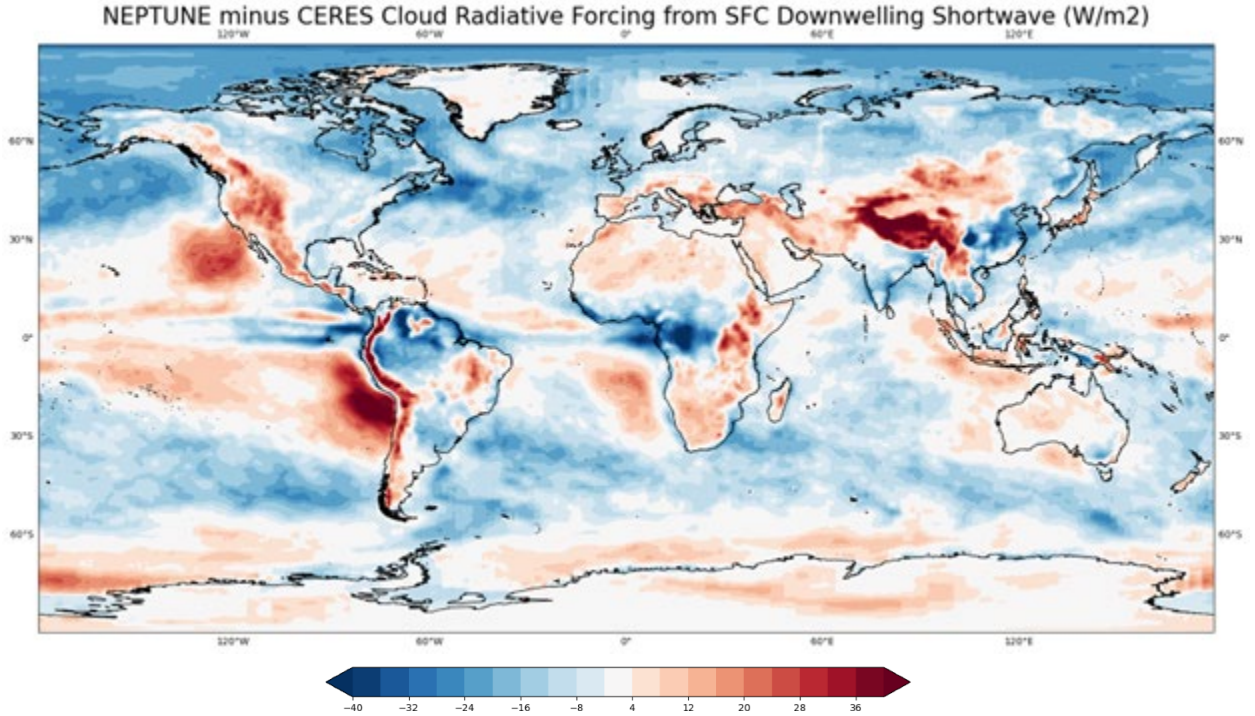
NEPTUNE and NAVGEM Evaluation
Lead Time Gain/Loss (hours)
Bold>95%; Fractional Skill Score Scale (km)

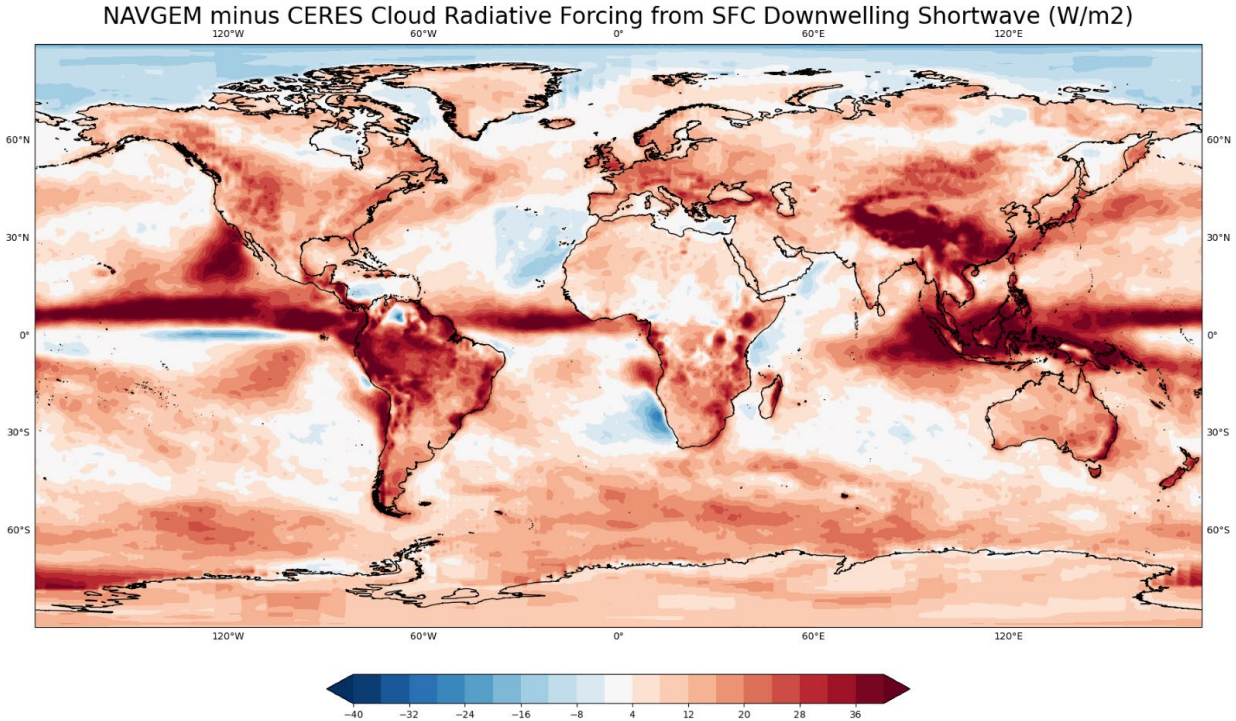


NEPTUNE shows broad improvements in the precipitation forecasts, particularly in the tropics compared to NAVGEM (verified with IMERG)

NEPTUNE and NAVGEM Cloud Forecasts

Fraction of Surface Downward Shortwave Blocked by Clouds



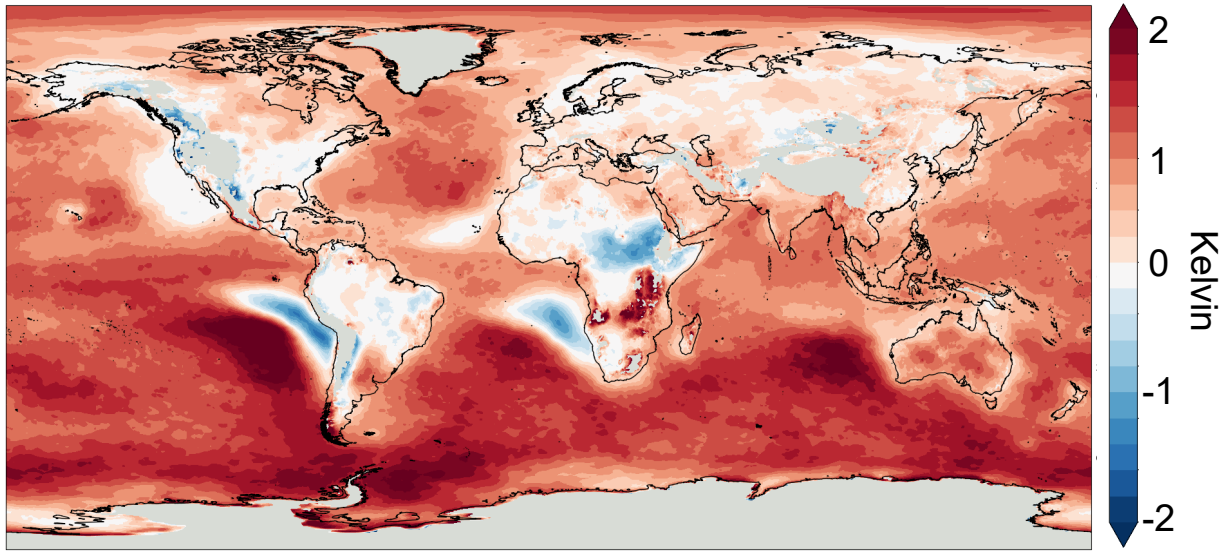


9-km Forecasts (E96P6)
March 2021 to February 2022

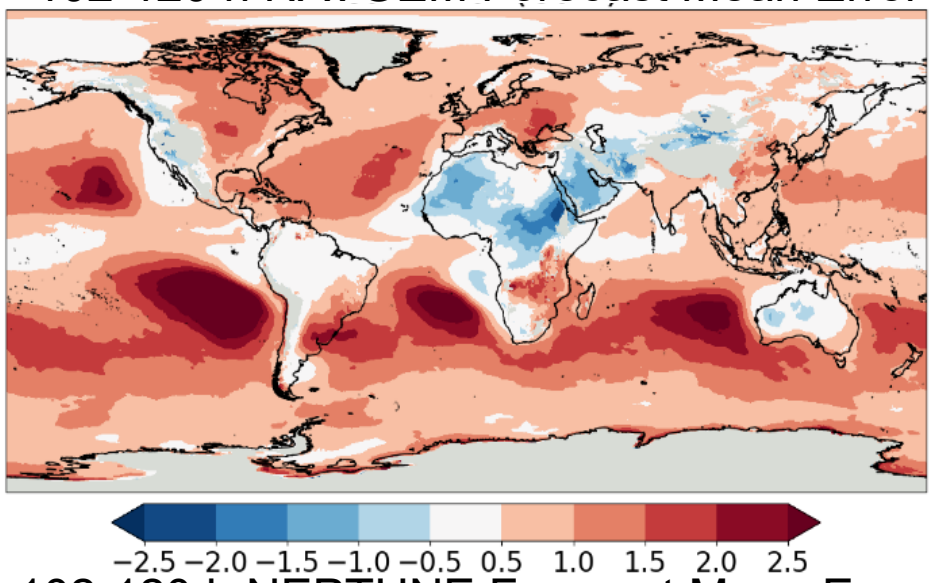
- Evaluated 9-km forecasts with NASA Clouds and the Earth's Radiant Energy System: CERES
- NEPTUNE shows improvements in the cloud forecasts, particularly low-level clouds over oceanic regions compared to NAVGEM

NEPTUNE and NAVGEM Low-Level Temperature Bias

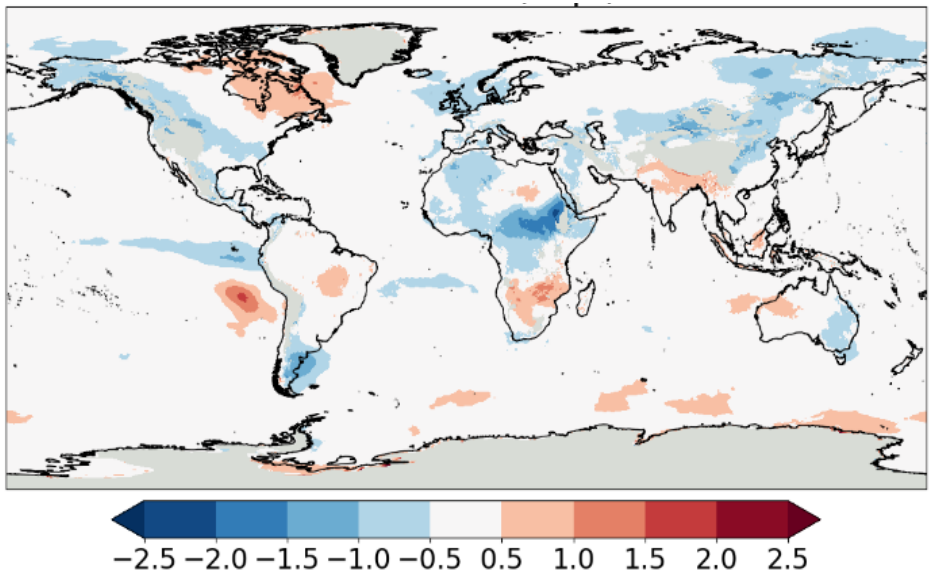
NAVGEM / NEPTUNE Initial Condition



102-120 h NAVGEM Forecast Mean Error



102-120 h NEPTUNE Forecast Mean Error



9-km Forecasts (E96P6) initialized from NAVGEM
March 2021 to February 2022
Verified with ERA-5

- NAVGEM has a significant tropospheric warm bias
- NEPTUNE is able to recover skill, however, further tuning physics is challenging with biased ICs

NEPTUNE Summary and Future Plans

Summary

- Tested various Physics Suites in CCPPv6.0 in NEPTUNE and selected NRL Suite 7
- Improvements to the tropical precipitation accuracy and bias by increasing the entrainment rate in the convective parameterization and decreasing the shallow convection threshold
- NEPTUNE 5-day forecasts are overall superior to NAVGEM, not only for clouds and precipitation metrics, but also for a wide range of verification metrics weighted by Navy mission

Component	Max. Points	Points 72h	96h	120h
OpsTest	9.0	3.0	2.0	2.0
TC Position	9.0	0.0	0.0	0.0
Cloud	9.0	8.8	8.8	8.7
Precipitation	3.0	2.4	2.2	2.1
Land stations	2.2	1.9	1.9	2.2
Over-Ocean	60.8	39.2	38.2	39.2
EAAMF	6.0	6.0	6.0	2.0
Total	99.0	61.3	59.2	56.3

Future Plans

- Operational transitions to Navy FNMOC:
  - NEPTUNE Global 9-km atmosphere model (Jan 2025)
  - FALCON 4D-Var data assimilation (Jan 2027)
- NEPTUNE Unified Prediction System
  - NEPTUNE atmosphere in Navy ESPC global coupled system
  - High altitude capability
  - Limited area and tropical cyclones capabilities