Assessing Physics Innovations for the Unified Forecast System

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Overview

NOAA's Unified Forecast System goes through periodic upgrades to produce superior guidance:

GFS v16 physics updates upgrade (March 2021):
- PBL/turbulence: K-EDMF=> **sa-TKE-EDMF**
- Orographic Gravity Wave Drag => **Unified Gravity Wave Physics-Version 0**
- Radiation: Updates to cloud-overlap assumptions
- Microphysics: Improvements to GFDL MP

Goal: The Developmental Testbed Center (DTC) is tasked under UFS-R2O physics sub-project to conduct T&E for improving the GFSv17/GEFSv13 physics suite and assess additional physics innovations. DTC, which has the overarching goal of making the numerical weather prediction R2O pipeline more efficient, supports the developmental process by testing "early and often".

Test Configuration

- Operational GFSv16 physics suite (control)

Category	Schemes
Deep CU	Scale-Aware Simplified Arakawa-Schubert (sa-SAS) Deep Convection Scheme
Shallow CU	SAS-based Mass-Flux Scheme for Shallow Convection
Microphysics	GFDL Cloud Microphysics Scheme
PBL/Turb	Scale-Aware TKE-based Moist Eddy-Diffusion Mass-Flux(EDMF) PBL and Free Atmospheric Turbulence Scheme
Radiation	RRTMG Shortwave/Longwave Radiation Scheme
Surface Layer	GFS Surface Layer Scheme
LSM	Noah Land Surface Model
Gravity Wave Drag	Unified Gravity Wave Physics Scheme- Version 0 (uGWPv0)
Ocean	GFS Near-Surface Sea Temperature Scheme
Ozone	NRL Ozone Photochemistry (2015) scheme
Water Vapor	NRL Stratospheric H2O Scheme

- Control tests were conducted by EMC using C768L127 forecasts: spanning the period from Jun 12, 2019- Sep 16, 2020, using a forecast length of 10 days.

- Configuration with **uGWPv0**, **uGWPv1** and **GSL orographic drag suite**


- **SSGWD = small-scale GWD (Tsiringakis et al., 2017)**
- **TOFD = turbulent orographic form drag (Beljaars et al., 2004)**

With a goal of supporting the developmental process by testing "early and often", DTC conducts **pre-tests** with smaller sample size to pinpoint possible issues. The uGWP pre-tests used seven forecasts in January 2020 with lead time of 8 to 10 days

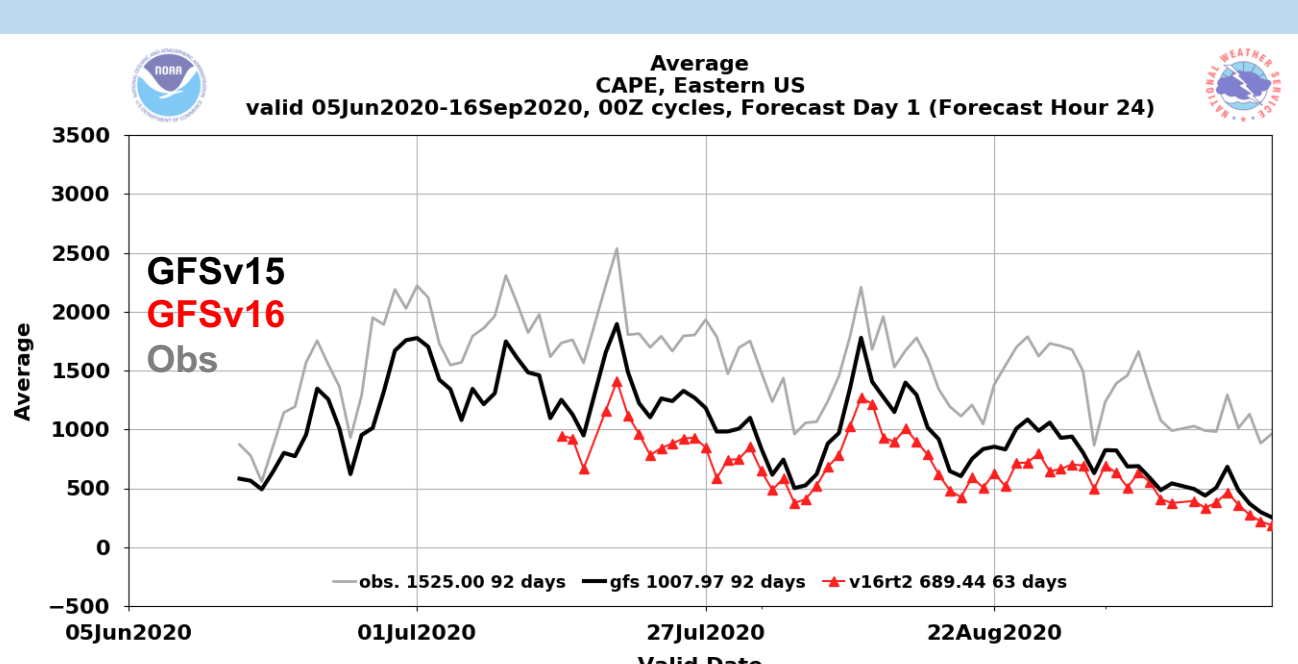## GFSv16 Evaluation by EMC

500-hPa AC scores (NH)

GFSv15 = .891
GFSv16 = .896

Valid: 6/12/19–9/16/20 (Day 5)
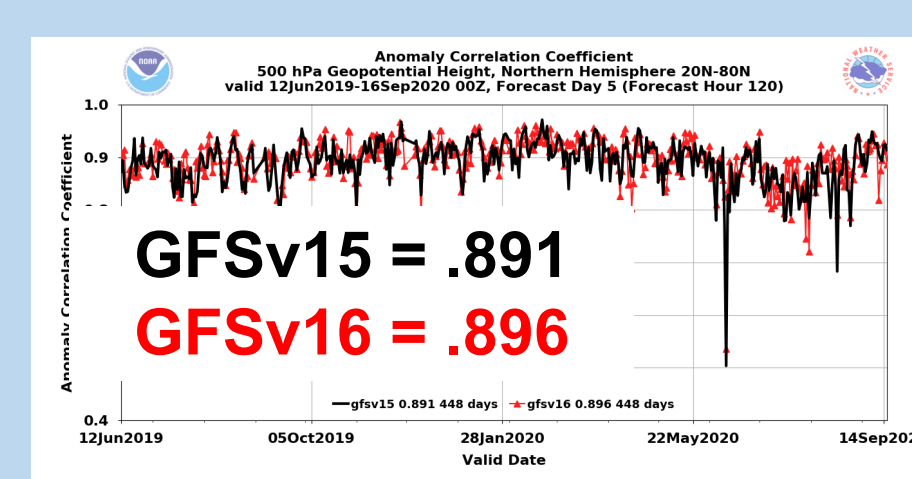
- **GFSv16** had higher AC scores than **GFSv15** at the majority of forecast lead times (Days 1–8)

- **GFSv16** had statistically significantly higher AC scores at Days 2–6

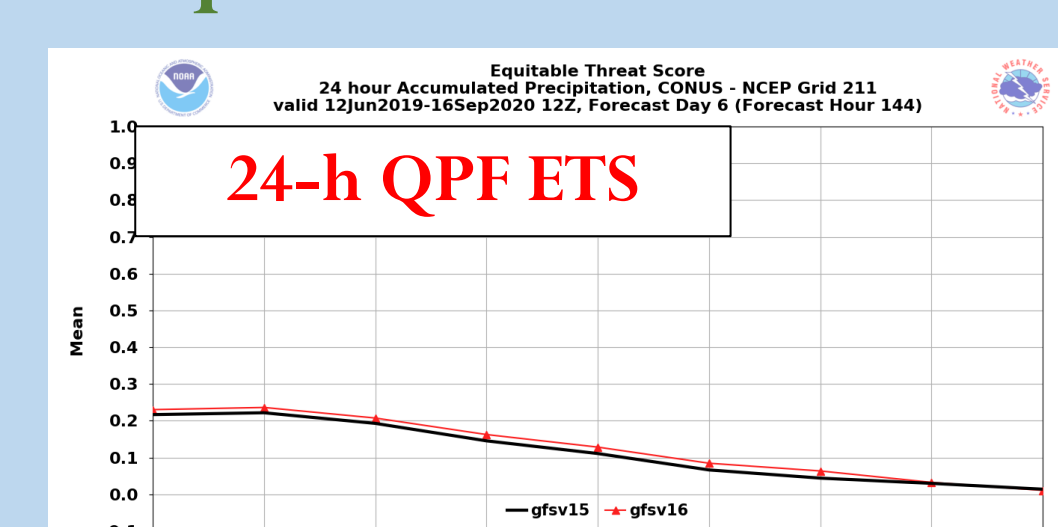> **Larger sample size was deployed in GFSv16 evaluation at EMC**

CONUS QPF Equitable Threat Score

24-h QPF ETS

Statistically Significant

Valid: 6/12/19–9/16/20 (F144)

- 24-h QPF improvements appear the most pronounced in the medium range, which is consistent w/ improved 500-hPa AC scores
- **F144:** Statistically significant improvement at 0.2–35 mm thresholds

CAPE Magnitudes Are Reduced in GFSv16 in the Warm Season
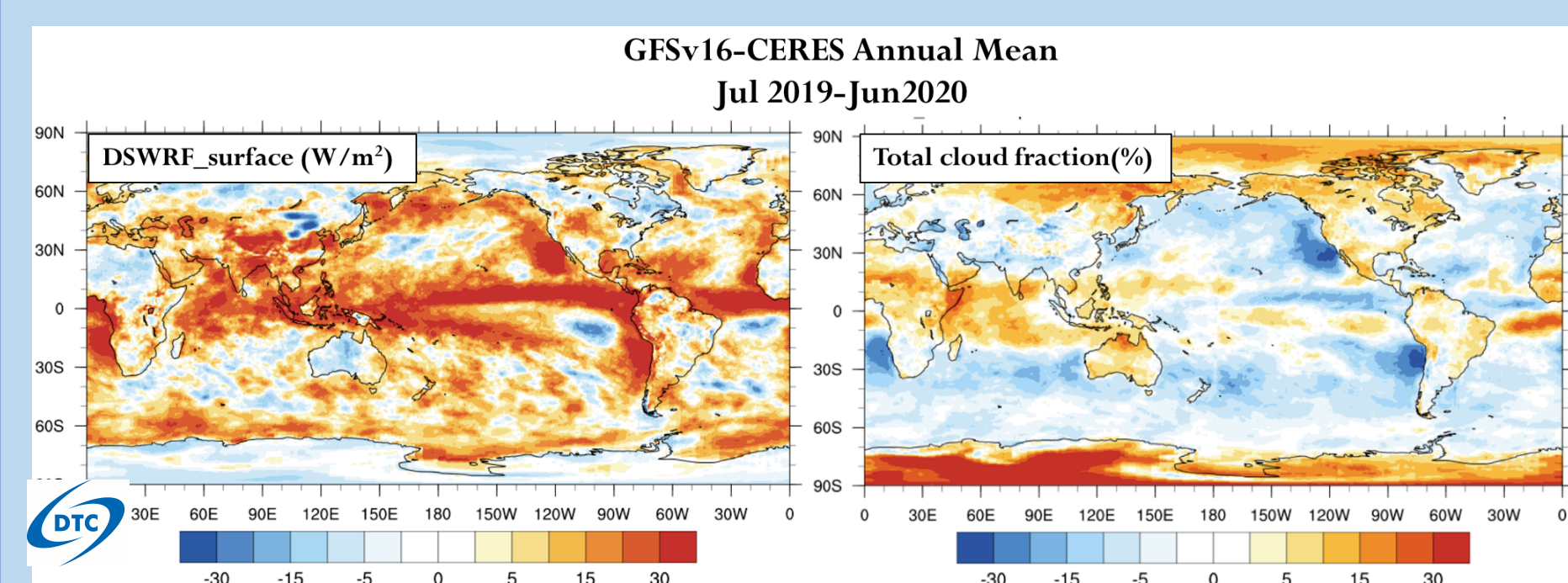

Colder 850-hPa Analysis in the Cold Season
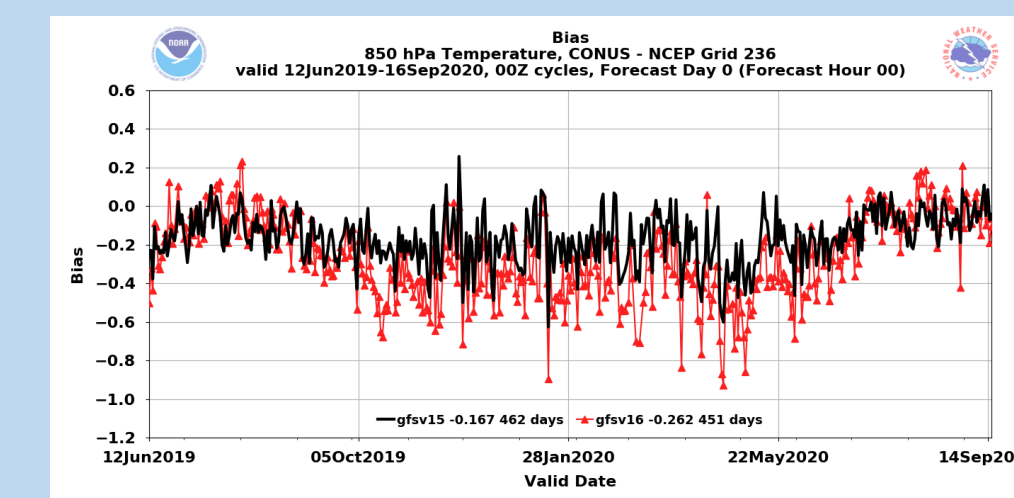
Tropical Rainbelt and ITCZ
in GFSv16/CMORPH/ERA5 Jul 2019-Jun 2020
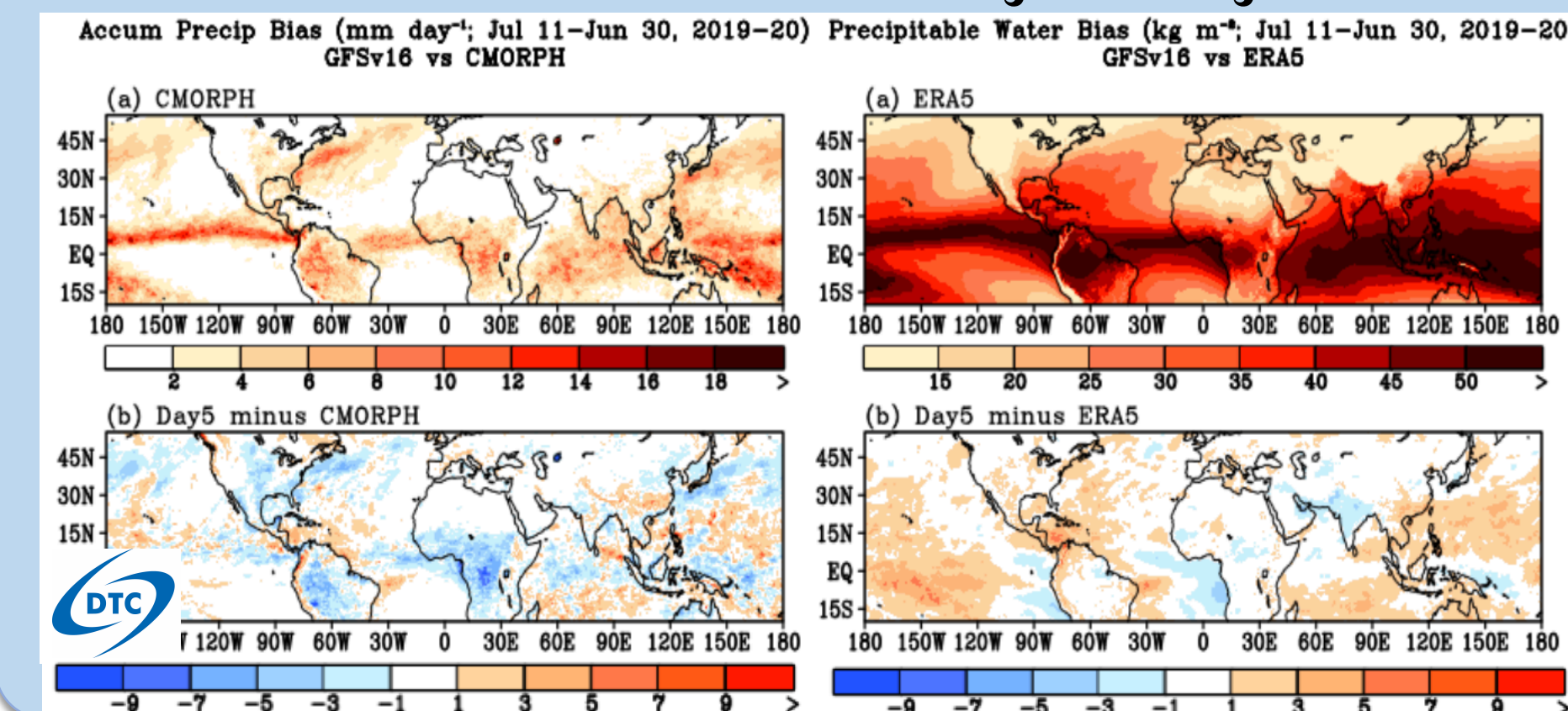
- Moist patches present in some tropical areas, but dry bias exist in the tropical rainforests
- More PW tends to collocate with more precipitation in the tropical oceanic areas

Cloud and Radiation


GFSv16-CERES Annual Mean Jul 2019-Jun2020

- Negative bias of marine stratocumulus off the west coasts of continents (incl. N. and S. America and Africa) as in many GCMs
- Indo-Pacific warm pool: more clouds with positive bias of SW↓ → thinner tropical clouds

Conclusion

- A wide range of verification and diagnostic tool were used at DTC and EMC to decide way forward
- DTC supports the developmental process by testing "early and often", that is, conducting pre-tests with smaller sample size, and by testing hardened configurations
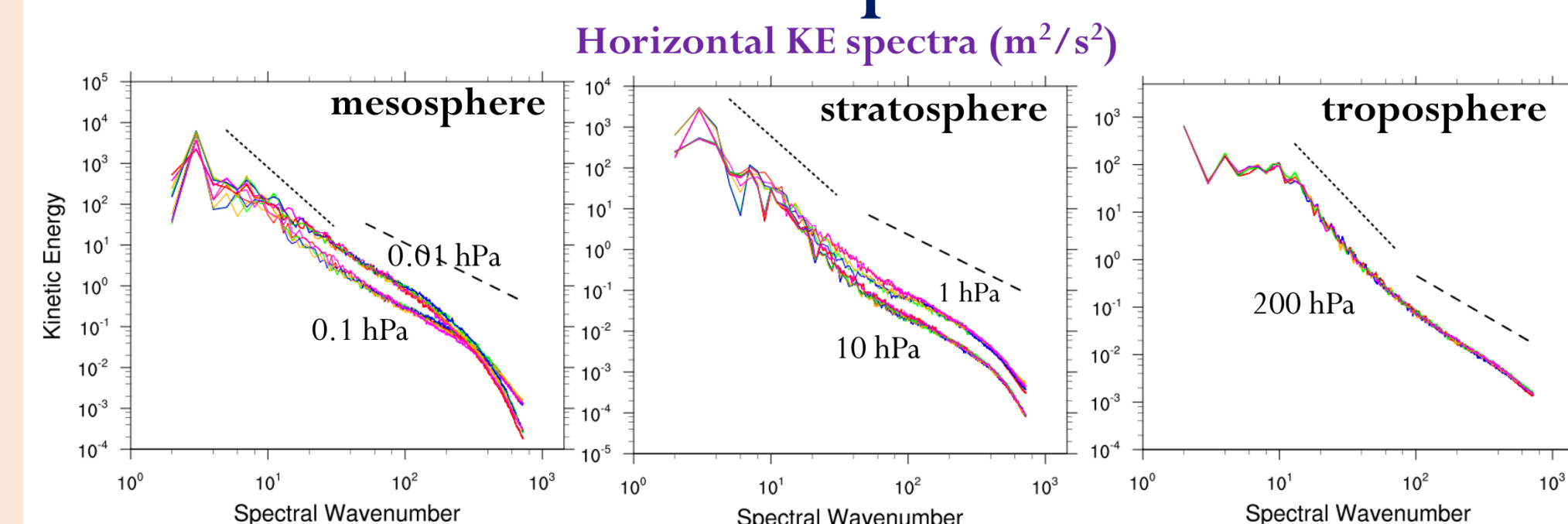- A complete physics test plan developed:

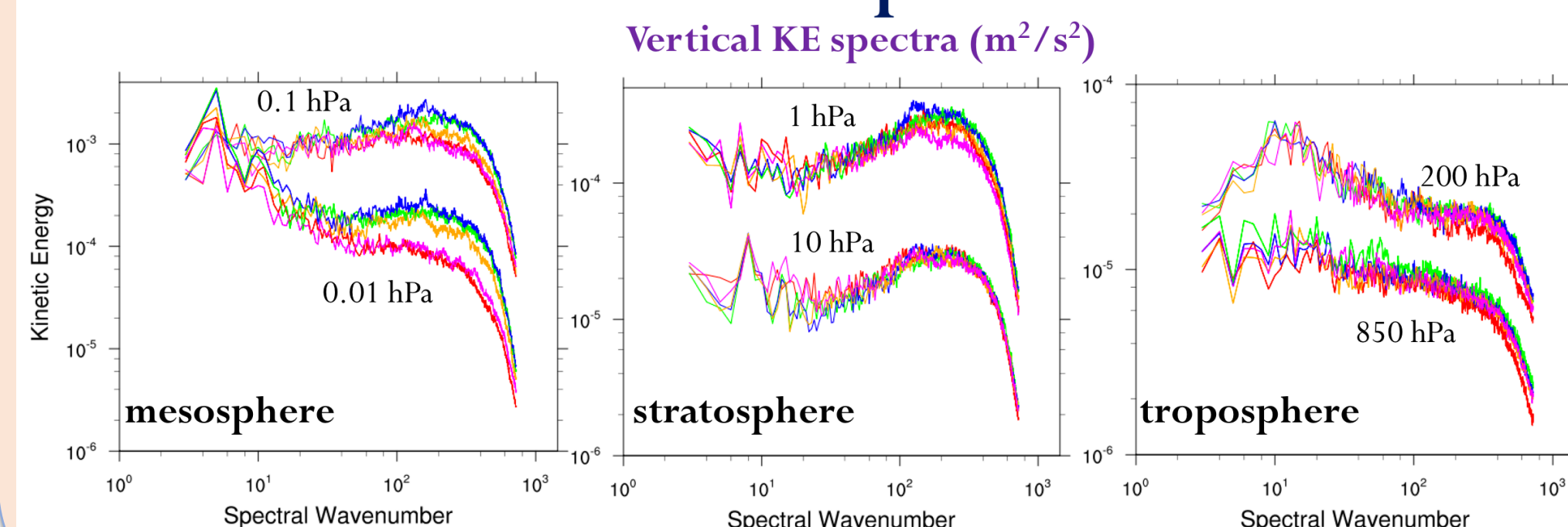|	
• uGWPv1 → uGWPv1	• MERRA-2 aerosol climatology
• GFDL Cloud-MP → Multi-moment microphysics scheme	• Combined test
• RRTMG → RRTMGP	

uGWPv0 Pre-tests

0.01 hPa Vertical Velocity (m/s)

Used as a proxy for GW activity
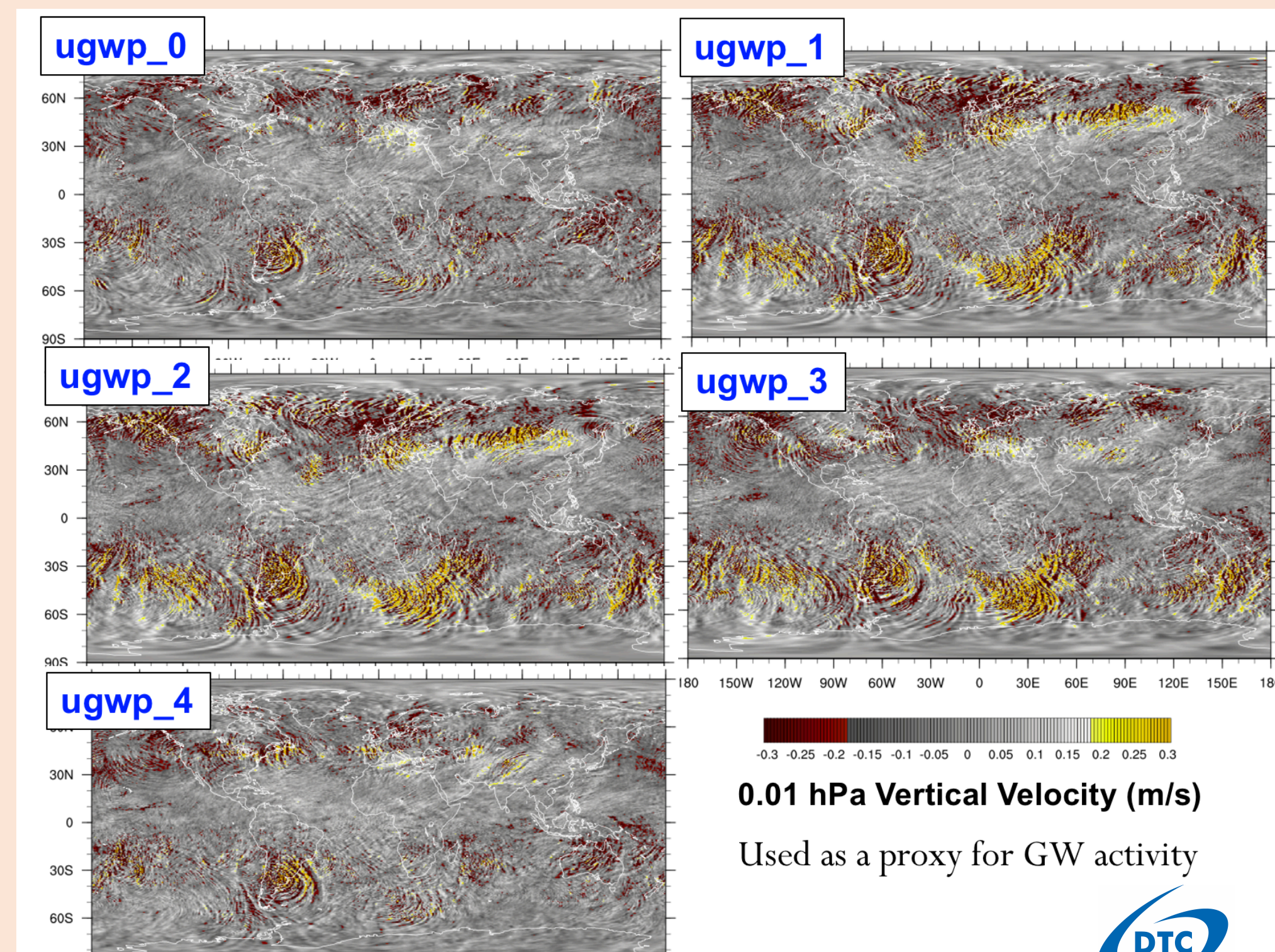
- GWs are small-scale perturbations excited by topography, convection or shear

GFSv16 0p25 f240
Horizontal KE spectra (m²/s²)

GFSv16 0p25 f240
Vertical KE spectra (m²/s²)

- No significant difference of horizontal KE spectra between uGWPv0 Exps.
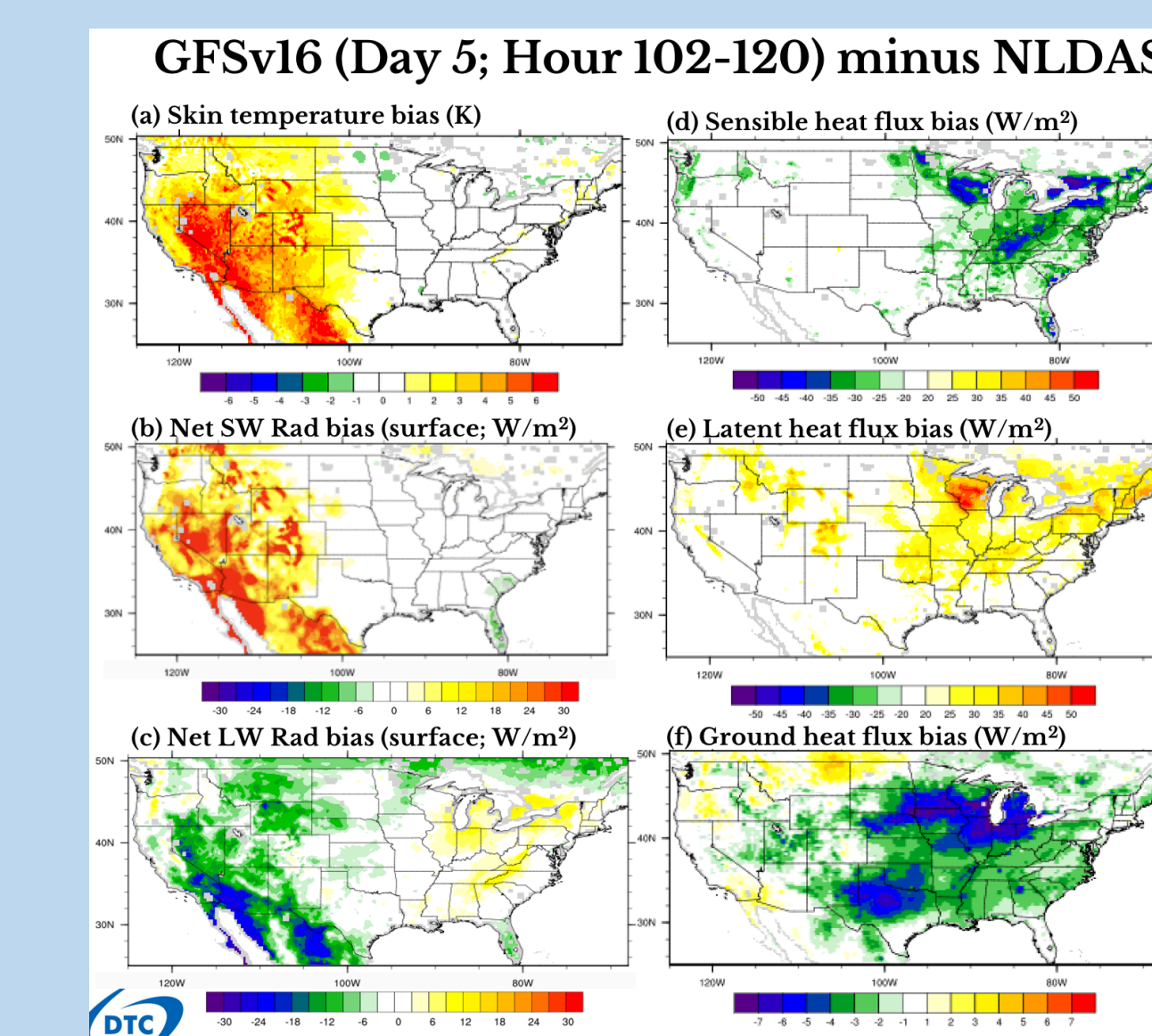- The difference of vertical KE spectra is larger than horizontal KE
- The configurations without representation of non-orographic GWD have increased GWs in mesosphere and stratosphere
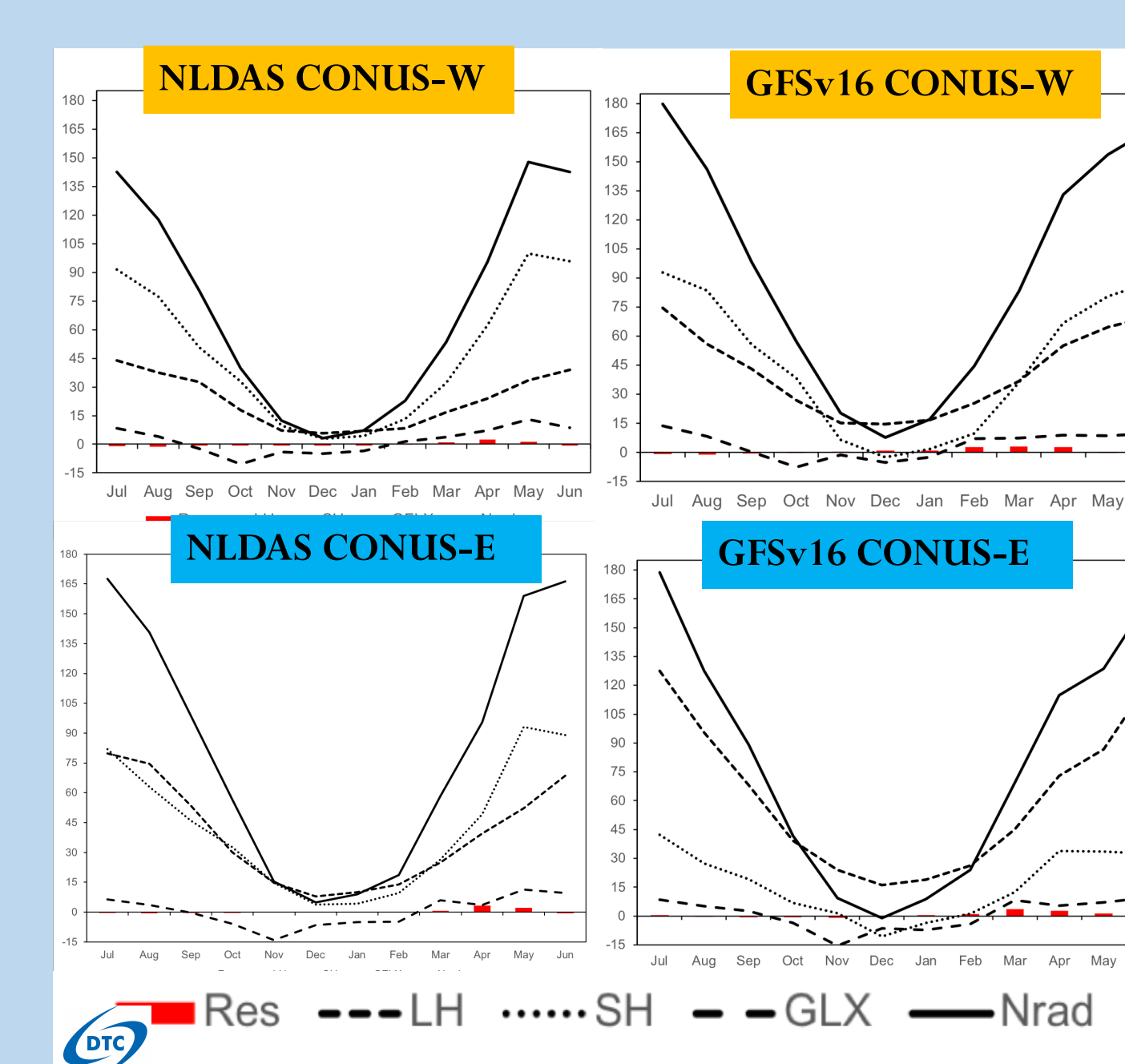
Surface Energy Budget GFSv16 and NLDAS
Jul 2019- Jun 2020

GFSv16 (Day 5; Hour 102-120) minus NLDAS

Seasonality of Jul2019-Jun2020 Area-averaged Surface Energy Balance

- The energy residual averaged over the CONUS is close to zero, implying that both NLDAS and GFSv16ctl close the energy balance very well
- The differences in the seasonal cycle of the ratio of sensible heat/latent heat fluxes are fairly large between these two datasets, implying problematic Bowen ratio on CONUS-E

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