Physics Assessments by DTC in Support of the Upcoming GFS and GEFS 2024 Implementations

Weiwei Li[1,3], Man Zhang[2,3,4], Tracy Hertneky[1,3], and Ligia Bernardet[2,3]

[1] *National Center for Atmospheric Research/Research Applications Laboratory/Joint Numerical Testbed*
[2] *NOAA Global Systems Laboratory*
[3] *Developmental Testbed Center*
[4] *Cooperative Institute for Research in Environmental Sciences, University of Colorado*

Part of the UFS R2O Physics Subproject

Unifying Innovations in Forecasting Capabilities Workshop

20 July, 2022

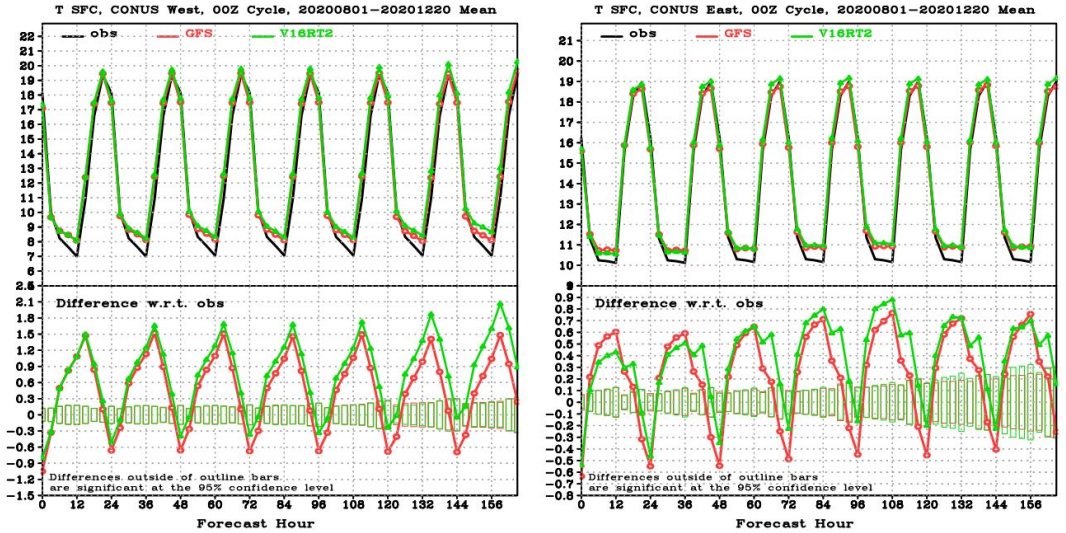
Accomplishments in Year 1 and Year 2

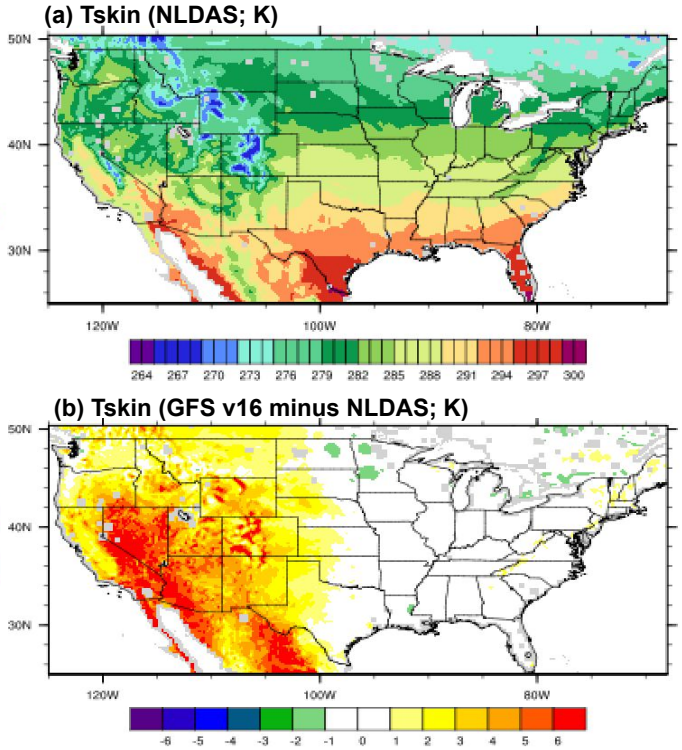
- Conducted several rounds of model assessments: experiments, performance-level verifications, and process-level diagnostics
- Provided holistic understanding of model performance, and effectively informed model physics development/improvement in connection with the forecast/prediction improvement, through
  - Employing multiple tiers in the "Physics-focused" Hierarchical System Development (HSD), with UFS weather model, CCPP and CCPP SCM, METplus, DTC's in-house metrics, reliable benchmark datasets, and carefully selected cases
  - Assessing at a rapid pace in close collaboration with developers
- Assisted EMC and project leads, and contributed to decisions for physics configurations and pre-operational implementations (i.e., P7, P8 and beyond)

Accomplishments in Year 1 and Year 2 (cont'd)

- **Generated an evaluation baseline at the beginning of Year 1**
  - Conducted a comprehensive assessment of CCPP-based operational GFS v16
  - Assessed convection, precipitation, cloud-radiation, land surface processes, etc
  - Adopted case studies from UFS Case Study platform and the LES-based LASSO product
- **Assessed multiple physics updates and innovations in Year 1 and Year 2**
  - UGWD, CCAA (surface, PBL, cumulus and cellular automata) for P7, and RRTMGP for P8
  - Ascertained proposed physics implementations not to adversely affect overall model performance
  - Pinpointed possible issues in model physics and their interactions
  - Identified bugs in source code leading to bugs fixed by developers, e.g., issues with duplicated temporal averages of cloud fraction in cloud diagnostic calculations
  - Expanded capacity of physics-focused HSD with new CCPP SCM cases added (e.g., ARM LASSO, AWARE and MAGIC) to evaluate processes under different weather/climate regimes, and promote further improvement of model physics
- **Engaged with the broader community**
  - Presentations and sessions on applying physics-focused HSD at both AGU and AMS for each year
  - Published one work (for MAGIC case study) on WGNE Blue Book, and another one (for LASSO case study) to be submitted to *Mon. Wea. Rev.* on demonstrating HSD

Benchmark Evaluation for GFS v16 - CONUS warm bias



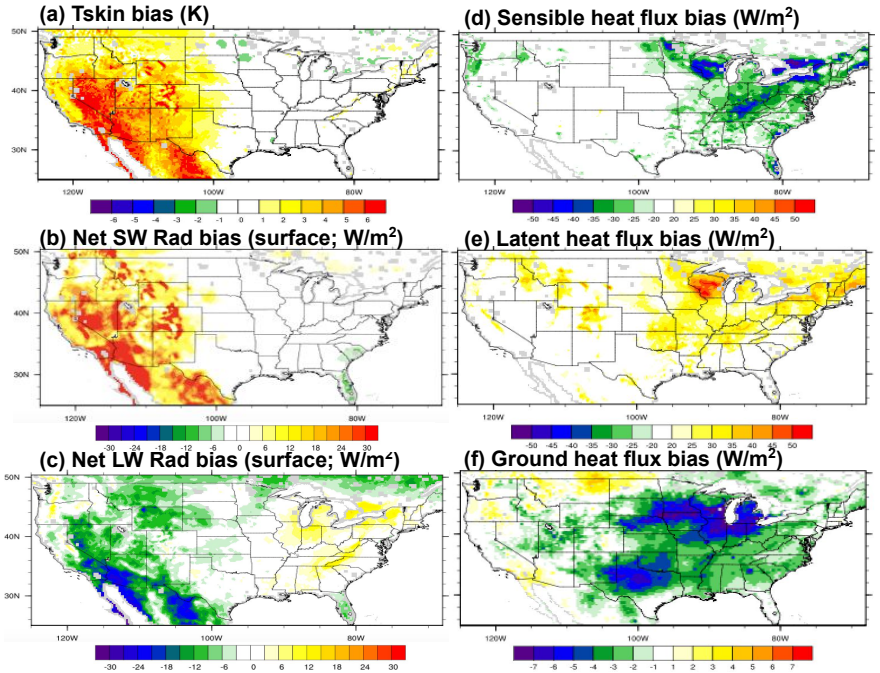


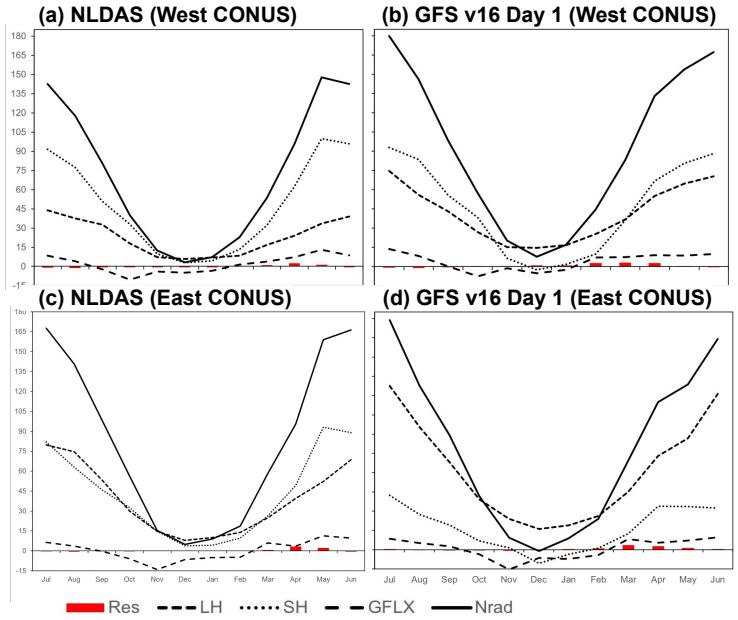
We distilled EMC VSDB results and selected benchmark dataset and diagnostics to identify problems

Surface Energy Budget: Res = H_R - H_S - H_L - H_G

Res - Residual
H_R - Net surface irradiance (LW+SW) (+ values denote downward flux; gain of energy by surface from radiation)
H_S - Surface sensible heat flux (+ values denote upward flux; loss of energy from surface to atmosphere by heat transfer)
H_L - Surface latent heat flux due to evaporation (+ values denote upward flux; loss of energy from surface to atmosphere due to evaporation)
H_G - Ground heat flux into the subsurface medium (+ values denote downward flux; loss of energy from surface to ground due to heat conduction)

Seasonality of surface energy budget (GFS v16 vs NLDAS)





West CONUS

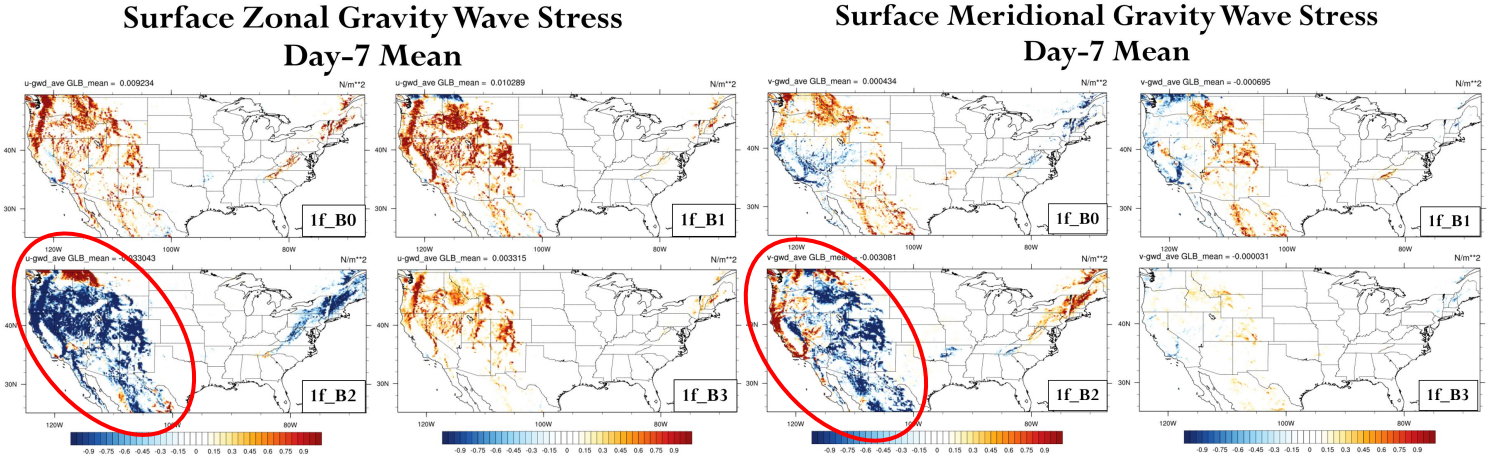
East CONUS

Possible attributions of the warm bias over CONUS

- **West**: too much insolation
- **East**: less upward longwave radiation (related to emissivity) and too much ground-to-surface heating
- **Problematic Bowen ratio**, possibly incorrect initialization of soil moisture, which surface heat fluxes are quite sensitive to (e.g., Trier et al. 2004)

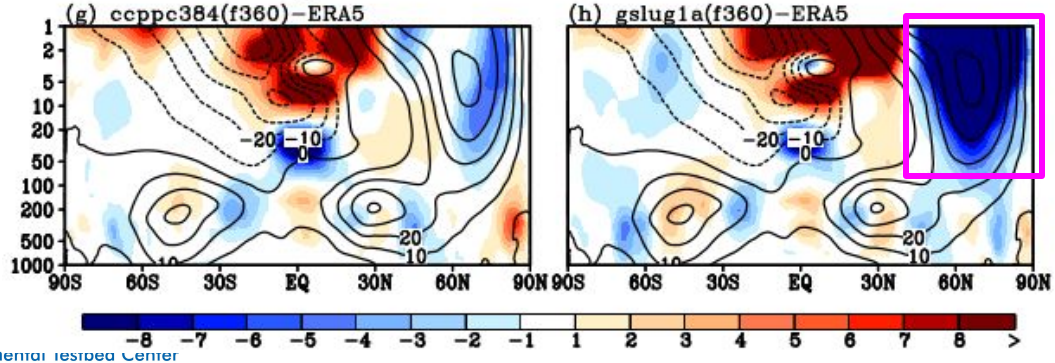
Testing and Evaluation for uGWD configurations

Identified an issue of **opposite sign of surface GW stress** in GSL drag scheme



***B0**: GFSv16 (uGWPv0; ctrl)*

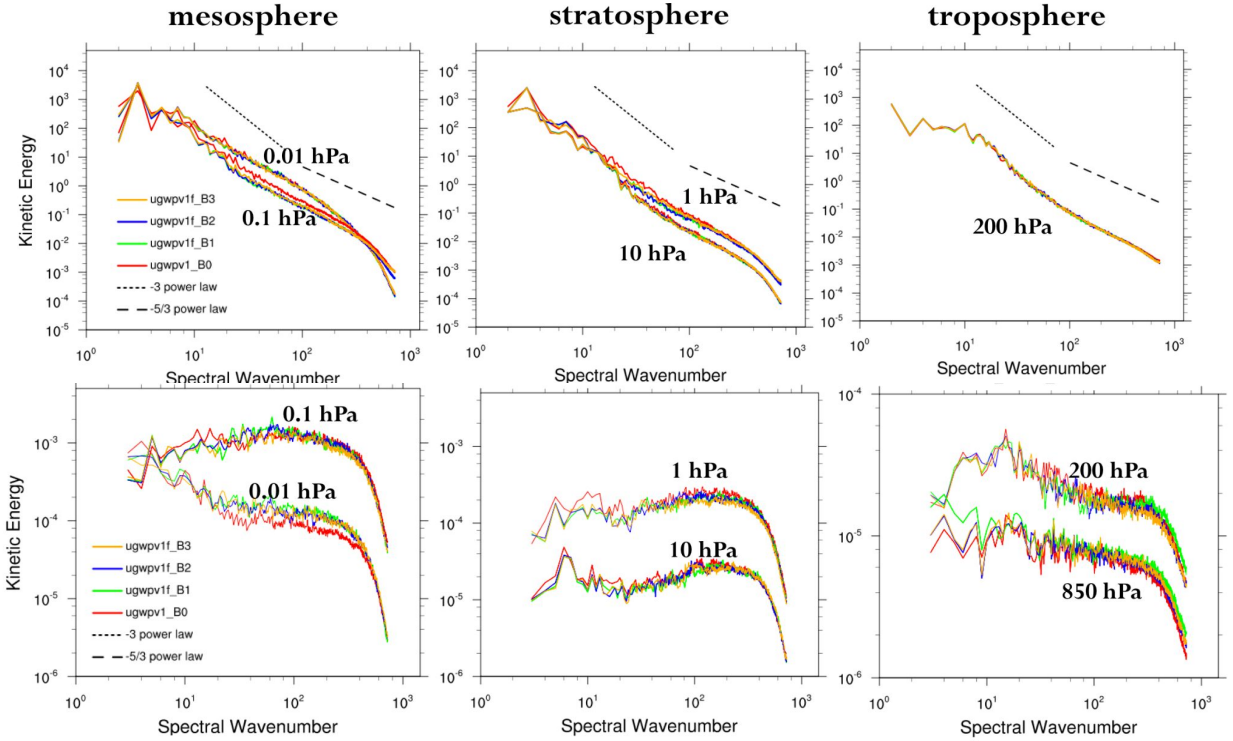
***B1, 2, 3**: uGWPv1 + GSL orographic GWD by Mike Toy (NOAA/GSL)*



UGWD physics innovation led to forecast improvements (not shown) **but still too weak polar night jet** (negative bias of zonal mean zonal wind in day-15 fcst vs ERA5)

Testing and Evaluation for uGWD configurations

Contributed kinetic-energy spectra evaluations to ascertain the new configuration did not adversely affect the canonical distribution of energy among various scales of motion.



Horizontal KE spectra based on horizontal winds (m^2 s^2)

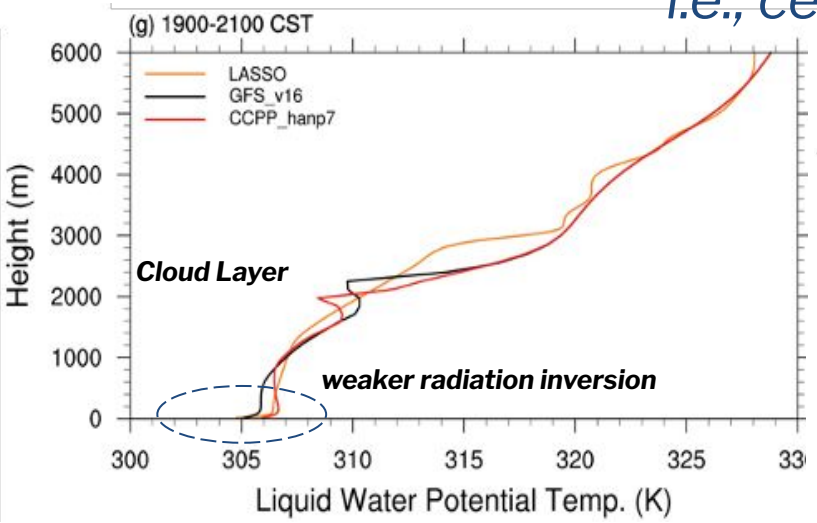
Vertical KE spectra based on vertical velocity (m^2 s^2)

Evaluation of CCAA for P7
(updated cumulus, PBL, sfc layer, plus stochastic innovation, i.e., cellular automata)

Summary (vs GFS v16)	West CONUS	East CONUS
Both winter & summer	• Nighttime dry bias - Improved • Weaker-than-observed near-sfc winds - Degraded • Excessive clouds - Neutral • Positive bias of latent heat flux - Neutral	• Nighttime warm bias (related to surface-based inversion) - Improved but issue remains • Stronger-than-observed near-surface winds (may be related to weaker surface-based inversion) - Slightly improved but issue remains • Excessive clouds - Degraded
Winter	• Nighttime warm bias - Neutral	• Afternoon cold bias - Degraded • Near-surface moist bias - Degraded • Positive (negative) bias of latent (sensible) heat flux; negatively biased Bowen ratio - Degraded • Positive bias of LW↓ (related to more cloud cover) - Degraded
Summer	• Nighttime warm bias - Slightly improved	• Afternoon cold bias - Improved • Early-morning dry bias - Improved

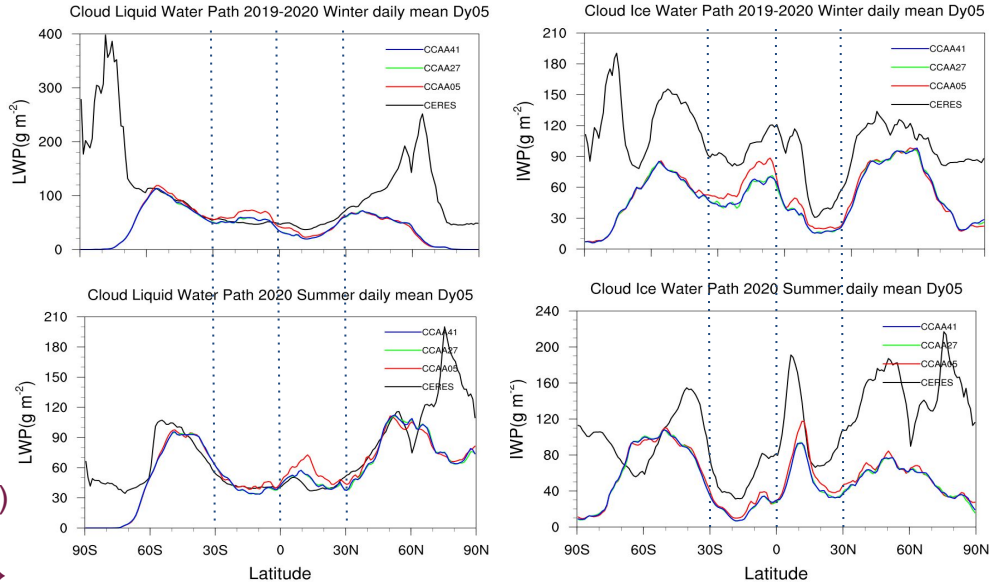
Evaluation of CCAA for P7

(updated cumulus, PBL, sfc layer, plus stochastic innovation, i.e., cellular automata)



HSD approach (CCPP SCM simulation vs. LASSO LES) pinpointed **key processes leading to weak radiation inversion**: 1) stronger entrainment/capping inversion → excessive clouds; 2) windy lower levels, stronger entrainment, not warm enough surface →weak nocturnal radiation inversion

(Courtesy to Dr. Dan D'Amico)



Identified biased microphysical properties (more liquid less ice)→ biased radiation at the surface

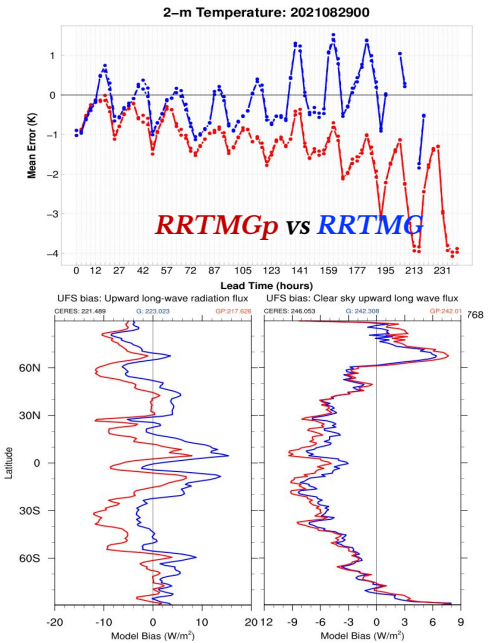
(Courtesy to Dr. Xia Sun)

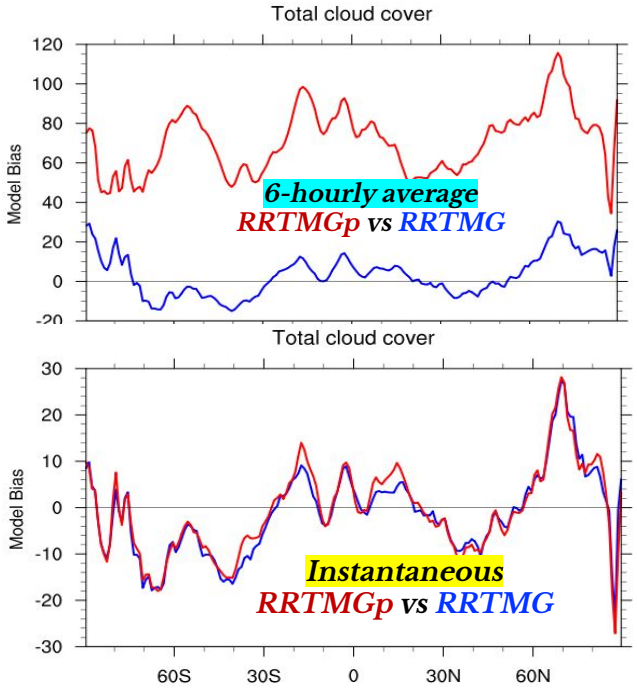
Testing and Evaluation of RRTMGP for P8

Two rounds of testing and evaluation on two global forecast cases (warm and cold seasons):

- Conducted comprehensive evaluation against observations and reanalysis dataset.
- Pinpointed coupling issues between RRTMGP and the microphysics parameterization→ stimulated further work with more cases conducted by EMC.
- Identified a bug resulting in duplicated temporal averages of cloud fraction in cloud diagnostic calculations → led to a bugfix by the physics developers.

Applied standard metrics (e.g., METplus and in-house diagnostics) to global forecasts





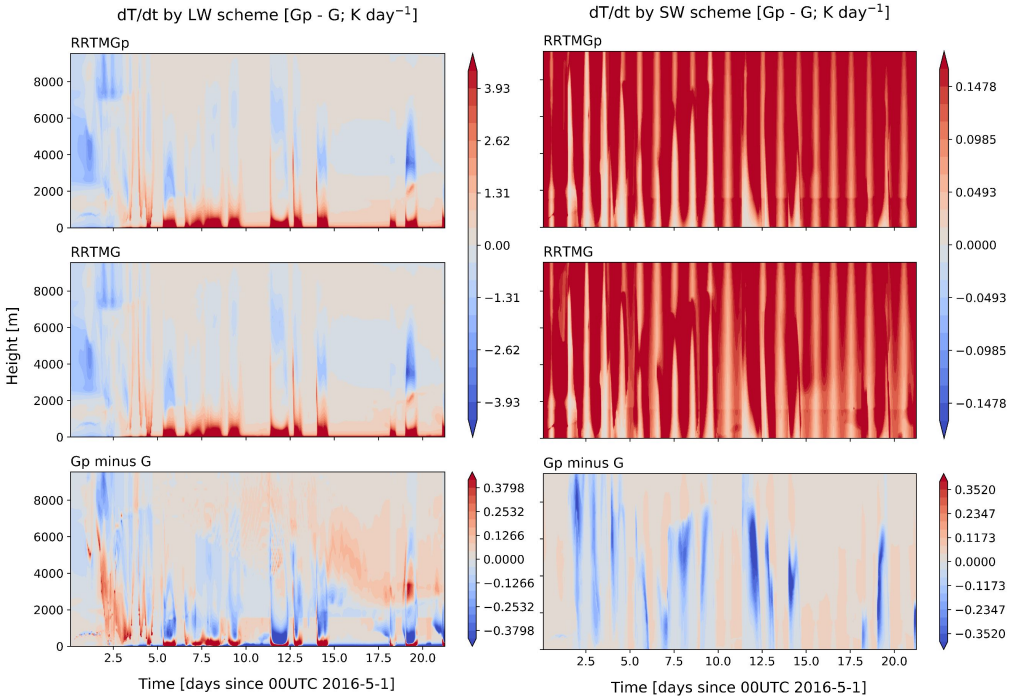
Identified errors in physics source code, i.e., overcounting cloud diagnostics in RRTMGp led to bugfix by developer

Testing and Evaluation of RRTMGP for P8

HSD-type of testing and evaluation

- Conducted and analyzed CCPP SCM experiments (RRTMGP vs RRTMG) for three field campaign cases (LASSO, TWP-ICE, and ARM AWARE) to investigate cloud and radiation processes under conditions with land ice where forecast issues exist, and pinpointed possible cloud-radiation interaction issues
- Results are expected to impact P8 and pre-operational implementation decisions.

RRMTGP is associated with excessive LW heating near the surface, related to processes such as thermal blanketing due to longwave heating by optically thick cloud cover or fog



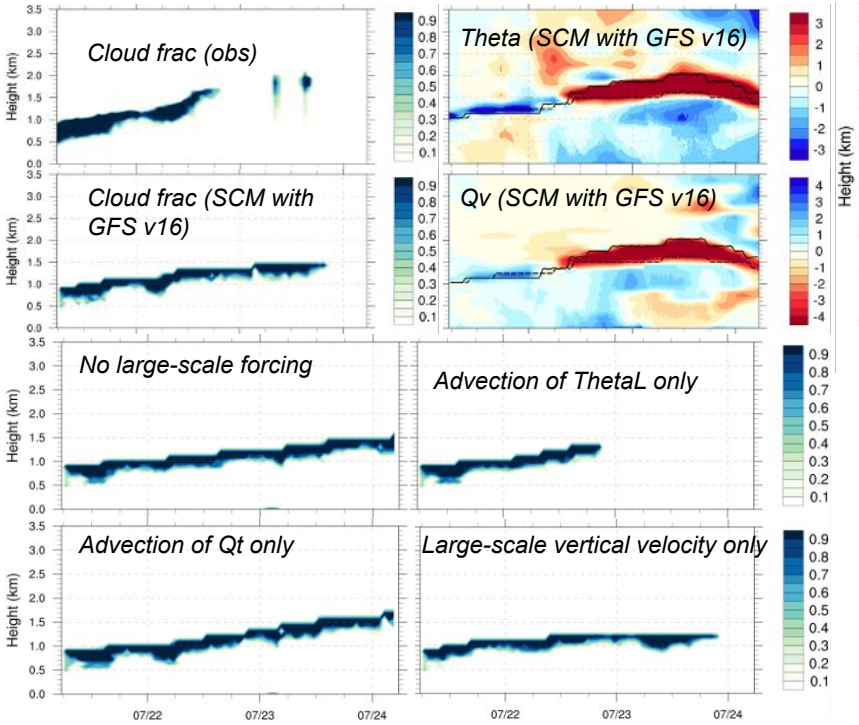
Gp has less SW heating than G across a deep layer of troposphere.

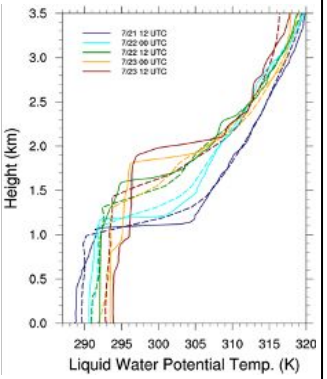
New SCM cases added to expand HSD capacity and evaluate processes under different weather/climate regimes

Example: a new SCM case ARM MAGIC

- Diagnosed bias of GFS v16 for stratocumulus (Sc) to scattered shallow cumulus (Cu) transition
- Investigated the role of different components of large-scale forcing in leading to thermodynamic and cloud biases

- A negative bias of Sc in global forecasts is well known - but in CCPP SCM simulation (ship-following large-scale forcings from ECMWF forecast), Sc is <u>not</u> largely underestimated but thinner and grows more slowly.
- Weaker entrainment & stronger capping inversion → cold, moist bias on day 1 → a slower growth of PBL and cloud base on days 2-3.
- When only advecting potential temperature, Sc breakup occurred at a similar time compared to obs, indicating that other forcings may negatively contribute to the cloud bias (e.g., too much moisture advection and inhibiting effects by large-scale vertical motions).





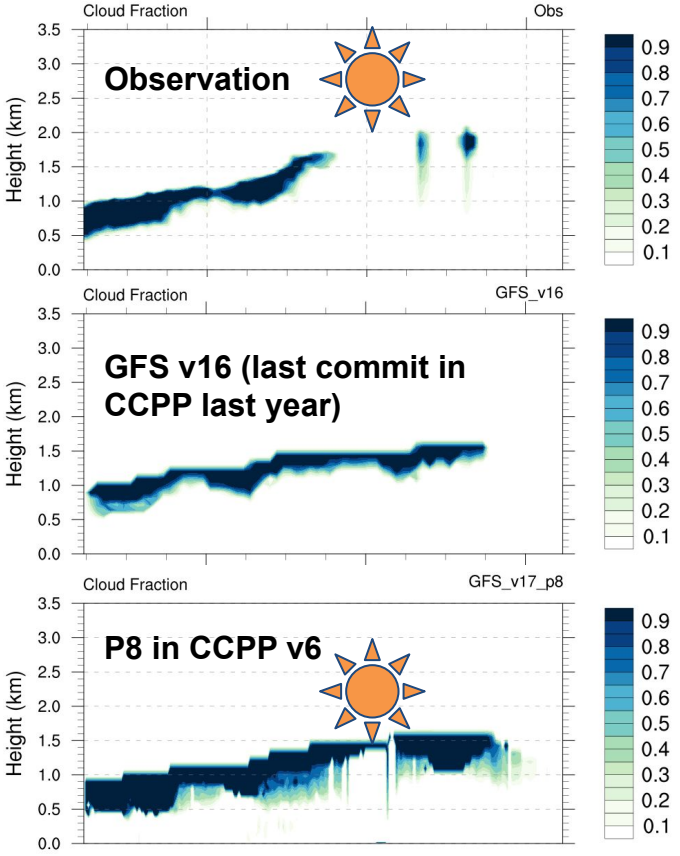
Solid: Observations
Dashed: CCPP SCM

Hertneky et al. (2022)

Outlook for Year 3

Maintain a close collaboration with EMC and developers

- **Main task:** Testing and evaluation of physics for upcoming operational global UFS configurations
- **Targeted application, system**: MRW/S2S, GFS/GEFS
- **Deliverable**: Briefings on the evaluations of developmental physics suites for GFSv17/GEFSv13
- **Dependence:** Code readiness and availability of physics innovations in CCPP
- **Datasets and physics suites to evaluate:** datasets of interest to the UFS-R2O Physics Subproject, and continuously evolving prototype schemes and suites for the global coupled model, i.e., P8 and beyond for GFS v17/GEFS v13.
- **Evaluation**: complement standard verification performed by EMC and other partners, and focus on reapplying established cases, metrics, and tools.



P8 for ARM MAGIC: improved skill of capturing Sc-to-Cu transition and breakups, despite cloud overestimation