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The Self-Aggregation of Convection in Idealized Numerical Simulations using Different Cumulus Parameterizations

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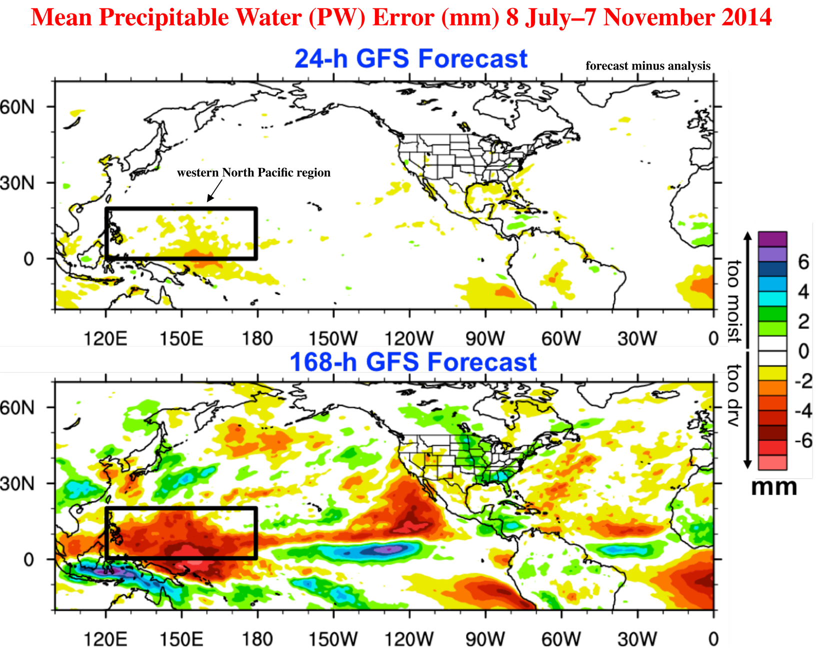
Introduction

Motivation

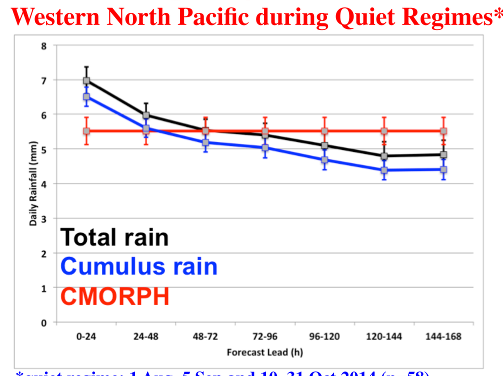
- NCEP Global Forecast System (GFS) model loses atmospheric water vapor over tropical west Pacific during 7-day forecast

Mean Precipitable Water (PW) Error (mm) 8 July–7 November 2014



- PW loss in GFS forecasts is prevalent during quiet regimes (no tropical cyclone present)

Area-Average Daily Rainfall (mm) over Western North Pacific during Quiet Regimes*



*quiet regime: 1 Aug–5 Sep and 10–31 Oct 2014 (n=58)

- GFS produces too much rain in 0–24 h forecast and gradually decreases thereafter
- GFS Simplified Arakawa-Schubert (SAS) cumulus scheme drives burst of convection early in the forecast, contributing to stabilization, drying, and suppression at longer forecast leads
- **We aim to use WRF idealized framework to isolate behavior of SAS cumulus parameterization**

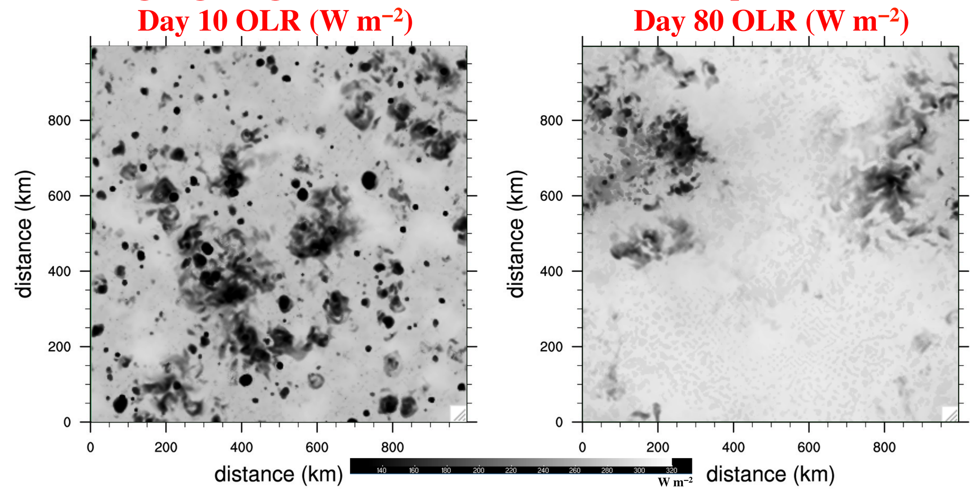
WRF-ARW Idealized Experiments

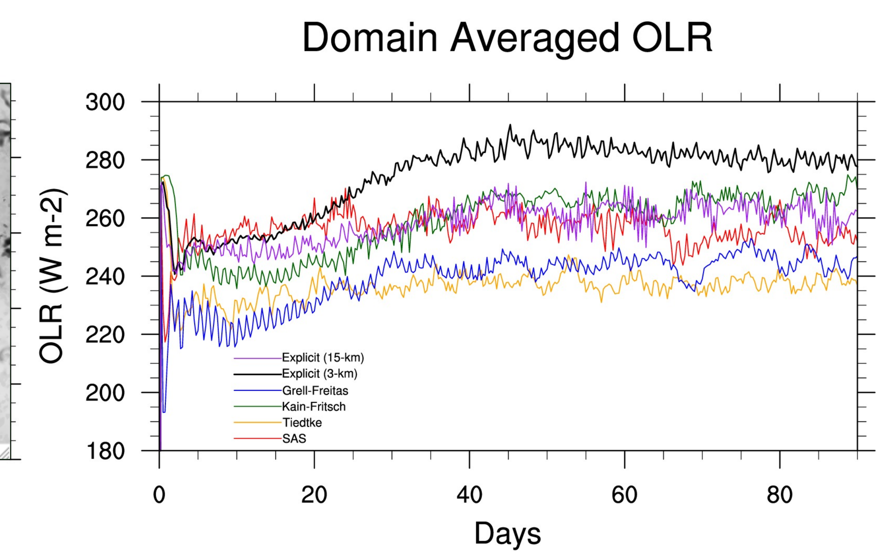
- 90-day WRF-ARW (v3.6.1) simulations
- 15-km horizontal (67×67) grid spacing
- 44 vertical levels to 30 km
- No coriolis; no wind; periodic lateral BCs
- Fixed sea surface temperature = 303 K
- Initial sounding from radiative-convective equilibrium solution of Rotunno and Emanuel (1987)
- Initiate convection with ±0.5 K thermal perturbations in lowest 10 model levels
- Morrison microphysics, RRTMG radiation, YSU PBL, 6th order diffusion
- Test SAS, Tiedtke, Kain-Fritsch, and Grell-Freitas cumulus schemes at 15-km
- Compare results with explicit runs at 15 km and 3 km horizontal (334×334) grid spacing

Results

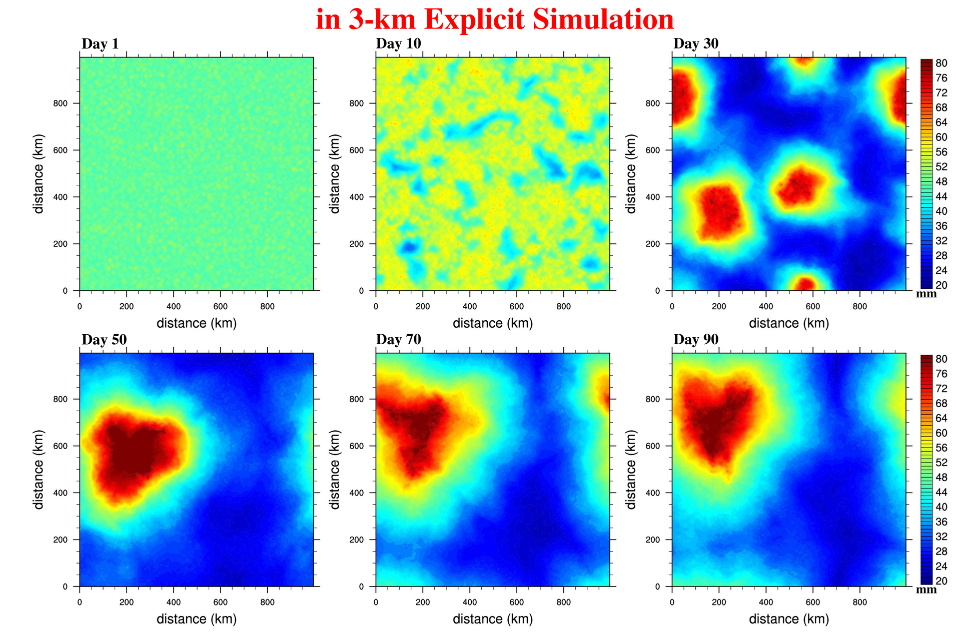
Aggregation in Idealized Simulations

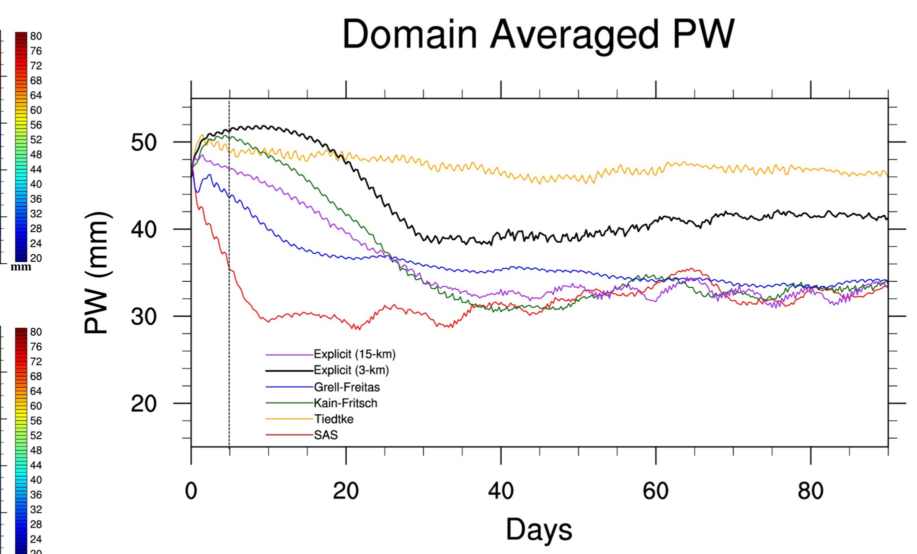
Outgoing Longwave Radiation (OLR) in 3-km Explicit Simulation
Day 10 OLR ($W m^{-2}$) Day 80 OLR ($W m^{-2}$)



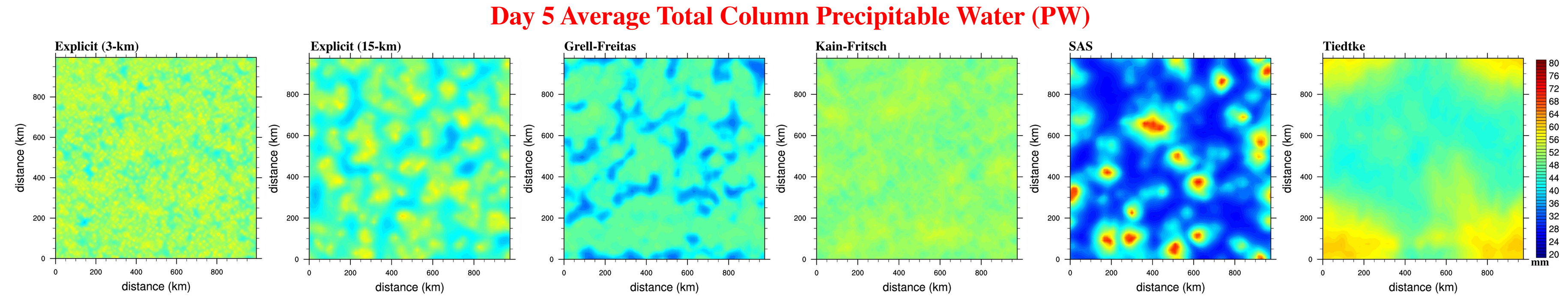


Daily Average Total Column Precipitable Water (PW) in 3-km Explicit Simulation



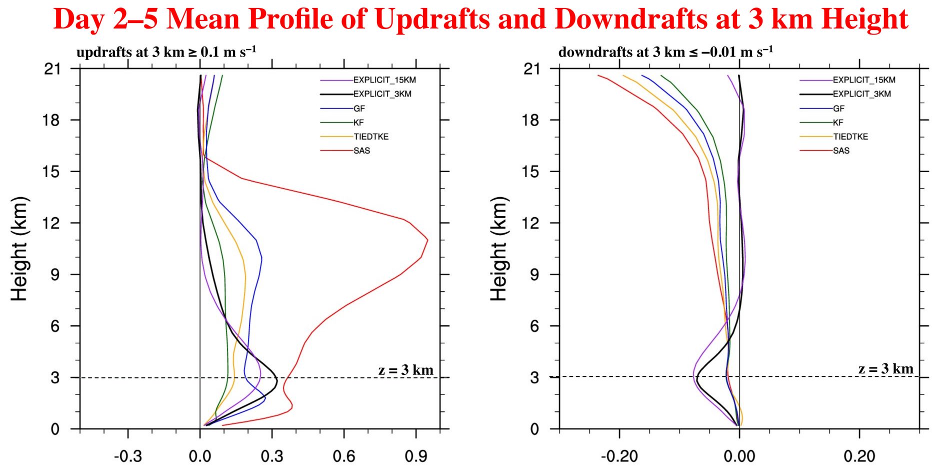


Day 5 Average Total Column Precipitable Water (PW)

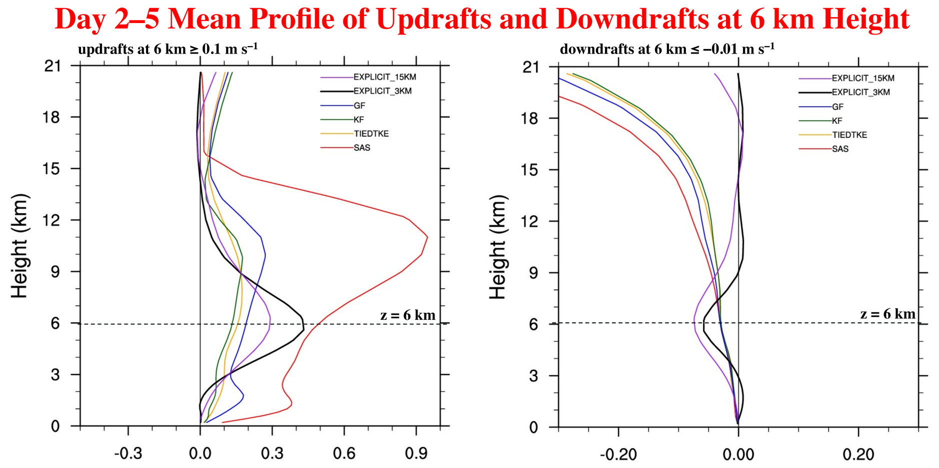


- The 3-km explicit WRF simulation reaches radiative-convective equilibrum (RCE; aggregated convection) by day 40, similar to previous studies
- The 15-km explicit and Kain-Fritsch simulations behave similar to the 3-km simulation, while Tiedtke and Grell-Freitas reach RCE by about day 30
- The SAS is an outlier, reaching RCE by day 20 and characterized by rapid domain-average drying during the first 10 days of the simulation

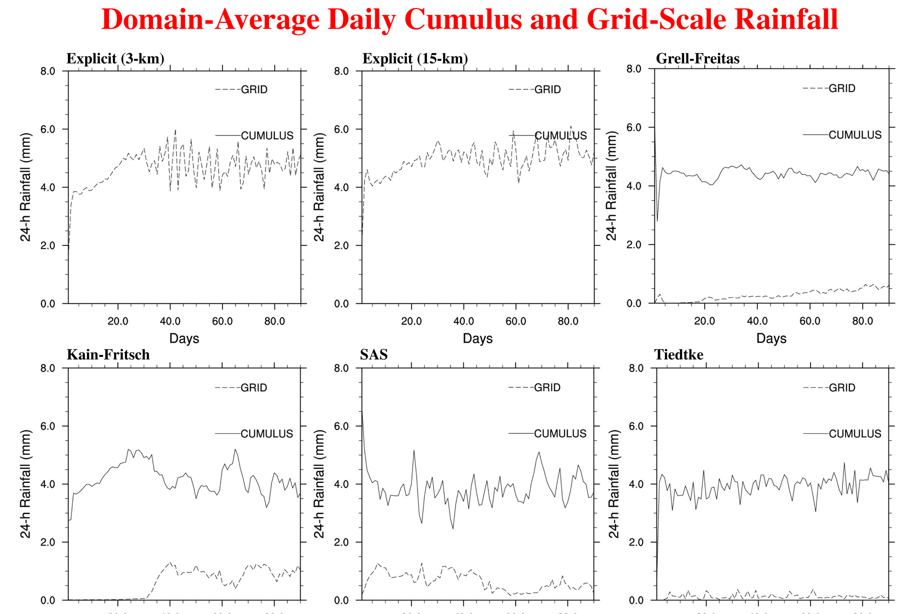
Day 2–5 Mean Profile of Updrafts and Downdrafts at 3 km Height



Day 2–5 Mean Profile of Updrafts and Downdrafts at 6 km Height



Domain-Average Daily Cumulus and Grid-Scale Rainfall



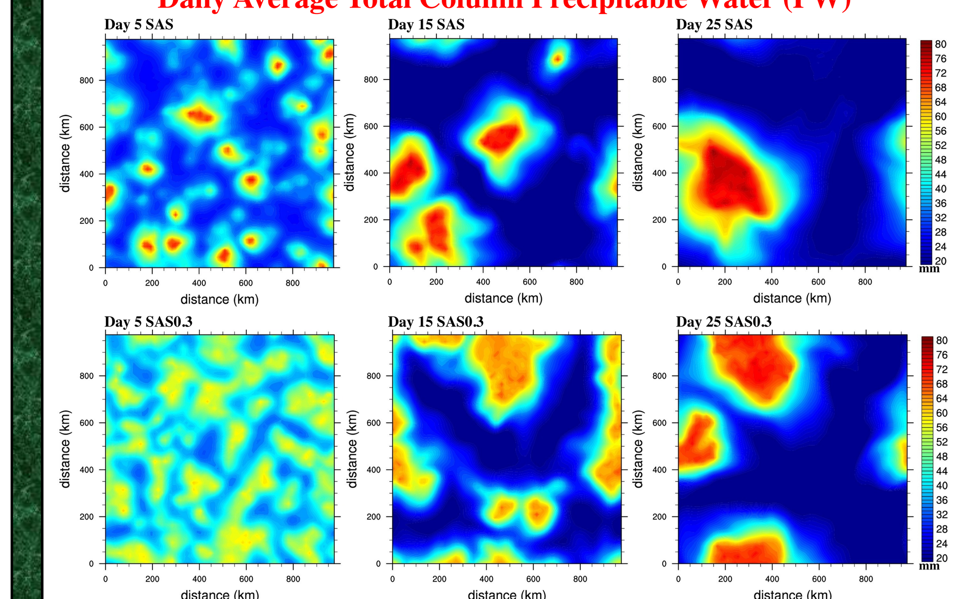
- SAS produces more intense updrafts through a deep layer compared to the explicit and other cumulus parameterizations in the first 5 days of the simulation
- SAS produces more cumulus rainfall compared to the other simulations through day 5
- Compensating subsidence stronger with SAS and likely contributes to rapid drying throughout domain, enhancing the aggregation rate

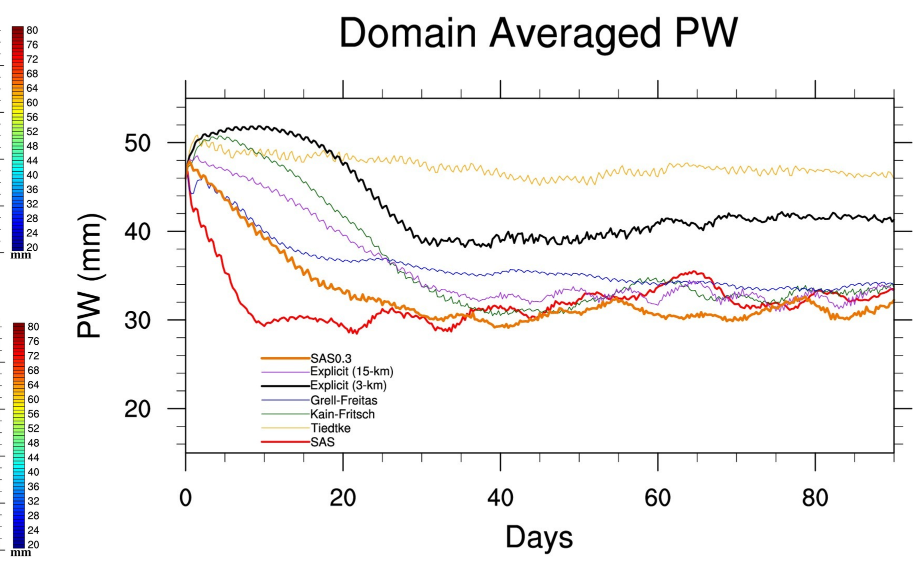
Results

Test Modification to SAS Entrainment Parameter

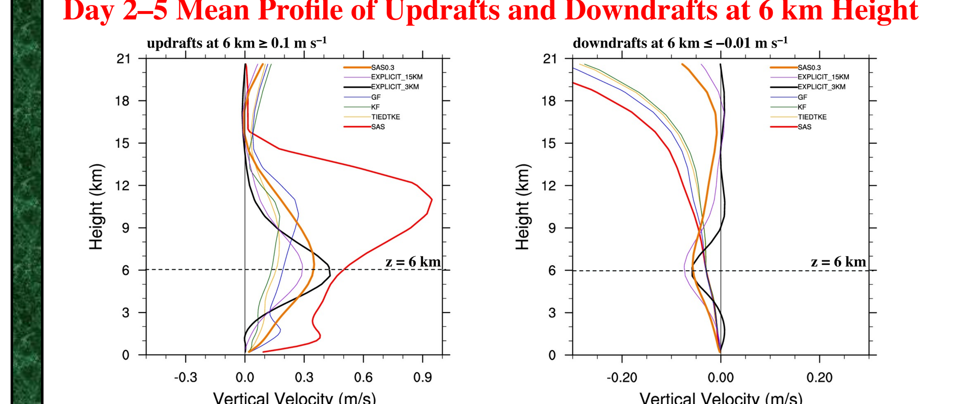
- Bassill (2015) noted sensitivity of track forecasts of Hurricane Sandy to the deep convective entrainment parameter in SAS
- Increasing the entrainment parameter reduces deep convection driven by SAS, which produces less drying and allows for more grid-scale saturation
- As a preliminary test, we increase the SAS entrainment parameter to 0.3 (simulation referred to as "SAS0.3") from the default value of 0.1

Daily Average Total Column Precipitable Water (PW)

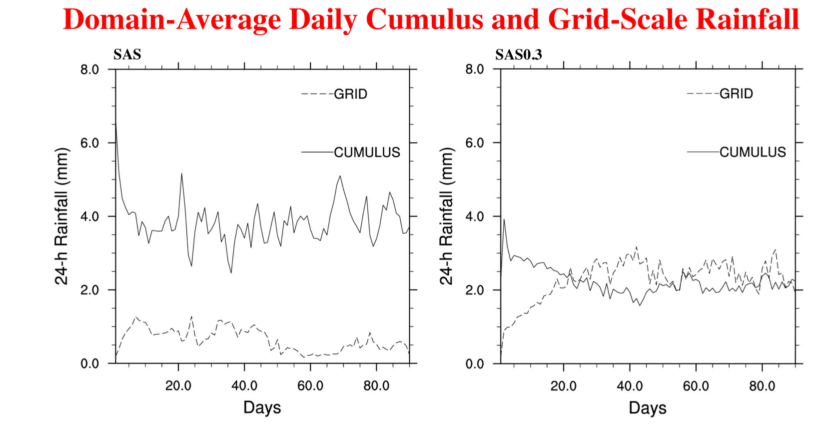




Day 2–5 Mean Profile of Updrafts and Downdrafts at 6 km Height



Domain-Average Daily Cumulus and Grid-Scale Rainfall



- Increasing the deep convective entrainment parameter in SAS acts to dampen the domain-average drying rate during the first 10 days of the simulation
- SAS0.3 has weaker updrafts on average and reduced subsidence in upper-levels, both with a vertical profile that resembles the explicit WRF simulations
- RCE is delayed in SAS0.3 compared to SAS, but reaches similar climatic state as the other simulations using cumulus schemes (except Tiedtke) by day 30
- Cumulus rainfall is reduced in SAS0.3, with grid-scale precipitation more active particularly in the RCE stage of the simulation

Conclusions

- Compared to WRF simulations that utilize explicit convection or other cumulus parameterizations, SAS produces more intense convection early in the simulation that enhances the domain-average drying and aggregation of convection
- Increasing the deep convective entrainment parameter in SAS "dampens" the rate of drying/aggregation in the first 10 days, but does not change the model "climatic state" after day 30 compared to other cumulus schemes
- Behavior of SAS in WRF simulations is somewhat consistent with operational GFS forecasts over the west Pacific, but with caveat that SAS may behave differently in simulations using the WRF versus GFS modeling systems

Acknowledgements

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- We thank Jimy Dudhia for his guidance on running idealized WRF in a RCE configuration and for discussions on aggregation in different model configurations