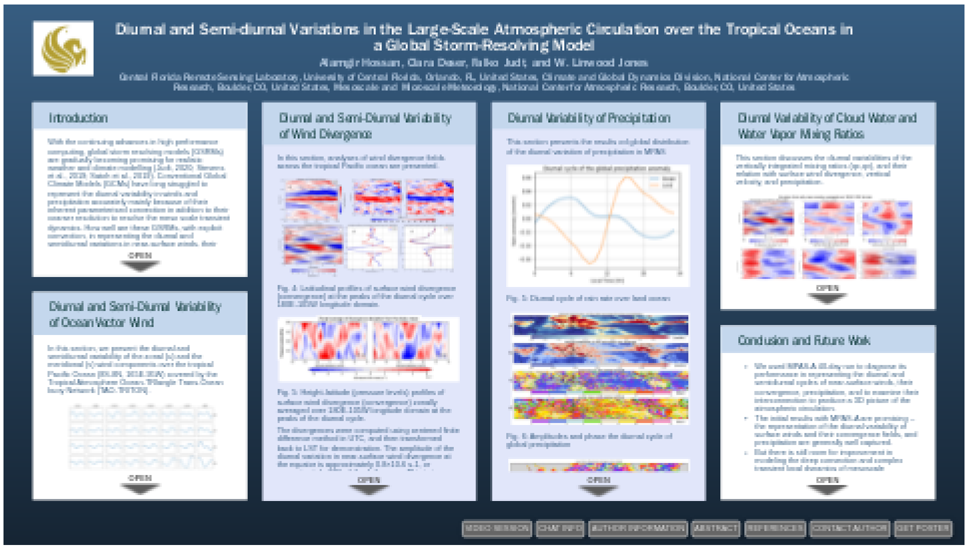
Diurnal and Semi-diurnal Variations in the Large-Scale Atmospheric Circulation over the Tropical Oceans in a Global Storm-Resolving Model



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INTRODUCTION

With the continuing advances in high performance computing, global storm resolving models (GSRMs) are gradually becoming promising for realistic weather and climate modelling (Judt, 2020; Stevens et al., 2019; Satoh et al., 2019). Conventional Global Climate Models (GCMs) have long struggled to represent the diurnal variability in winds and precipitation accurately mainly because of their inherent parameterised convection in addition to their coarser resolution to resolve the meso scale transient dynamics. How well are these GSRMs, with explicit convection, in representing the diurnal and semidiurnal variations in near-surface winds, their divergence fields, cloudiness, and precipitation? In this study, we used the atmospheric component of the Model for Prediction Across Scales (MPAS-A) to investigate this over the tropical ocean basin.

We used 40-day simulation of MPAS-A with 3.75 km horizontal grid spacings and 15 m temporal resolution. This is the same data used in DIAMOND-1 1st intercomparison project (Stevens et al., 2019). For the horizontal discretization, MPAS uses an unstructured spherical centroidal Voronoi tessellation and C-grid staggering. Therefore, the model output variables were first remapped in regular 25 km lat/lon grids, and then a moving average filter of window length of 4 was used to smooth the 15-minute samples, then every fourth sample (hh.00.00) was stored, resulting 24 hourly samples daily for 40 days. Mean daily signals were computed averaging 40 day data which results in a global map of mean hourly winds and precipitation. Finally, an additional 11-point triangular moving average filter was used in the longitude direction for further smoothing. Zonal (u) and meridional wind components (v), vertical velocity (w) at different pressure levels, vertically integrated mixing ratios (qc,qv,qr), and total accumulated precipitation at the surface were analyzed.

DIURNAL AND SEMI-DIURNAL VARIABILITY OF OCEAN VECTOR WIND

In this section, we present the diurnal and semidiurnal variability of the zonal (u) and the meridional (v) wind components over the tropical Pacific Ocean (8S-8N, 165E-95W) covered by the Tropical Atmosphere Ocean-TRIangle Trans-Ocean buoy Network (TAO-TRITON).

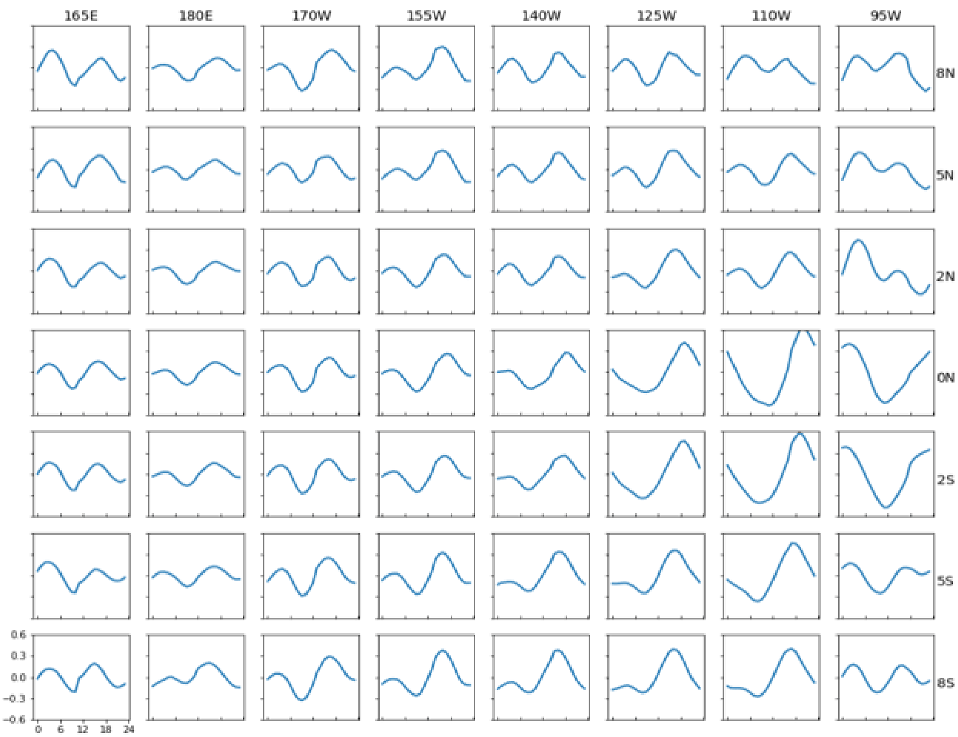

Fig. 1: Zonal Variability over the Tropical Pacific Ocean

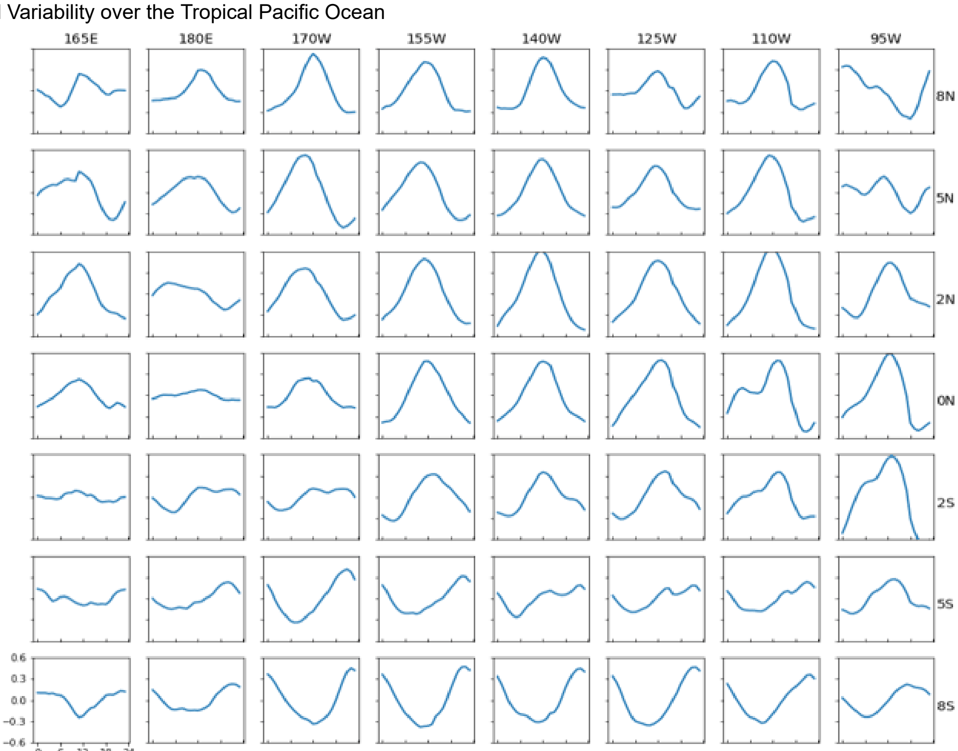

Fig. 2: Meridional Variability over the Tropical Pacific Ocean

Above two figures show the analysis of the u and v wind mode variability in 1-degree regular lat/lon boxes centered at the above-mentioned mooring locations. The x-axis represents the local time (0–24 hr LST) and the y-axis represents the deviation from the daily mean extending between ±0.6 m s−1. All figure panels are drawn on the same scale.

As seen, daily variance of the u component is dominated by semidiurnal mode while it is mostly diurnal for the v component. The semidiurnal variation of the u component is spatially uniform, whereas, for the v component, it is roughly out of phase on either side of the equator. These results generally agree well with the observations (Deser and Smith, 1998; Ueyama & Deser, 2008).

Figure 3 below reveals the mean diurnal wind vector anomaly over the tropical Pacific basin (30N-30S) at local times near the extreme deviations.

Mean wind vector deviations from the daily means

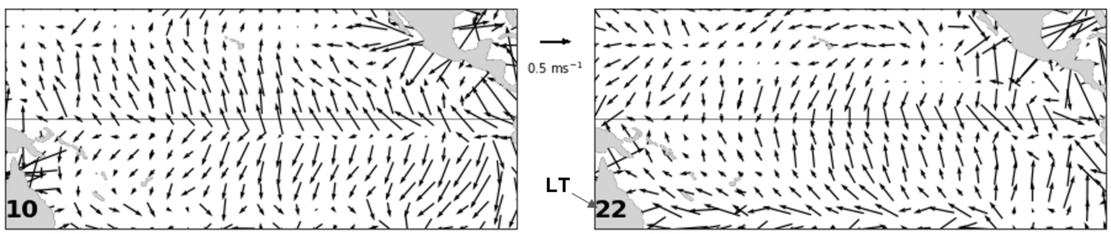

Fig. 3: Mean wind vector deviations from the daily means at 1000 and 2200 LT

DIURNAL AND SEMI-DIURNAL VARIABILITY OF WIND DIVERGENCE

In this section, analyses of wind divergence fields across the tropical Pacific ocean are presented.

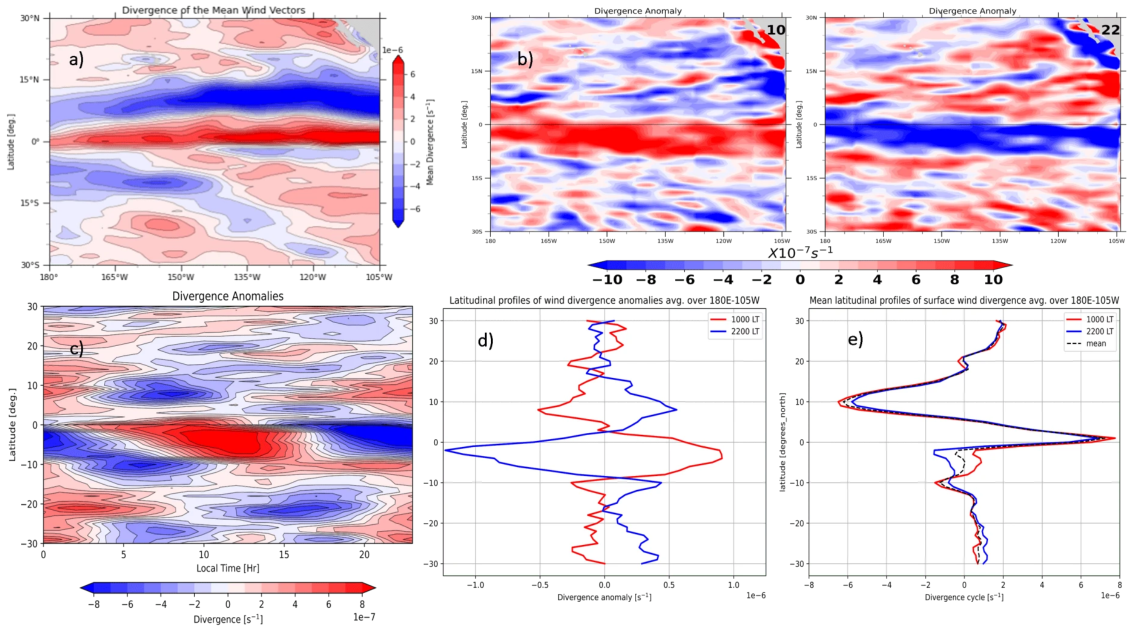

Fig. 4: Latitudinal profiles of surface wind divergence (convergence) at the peaks of the diurnal cycle over 180E-105W longitude domain.

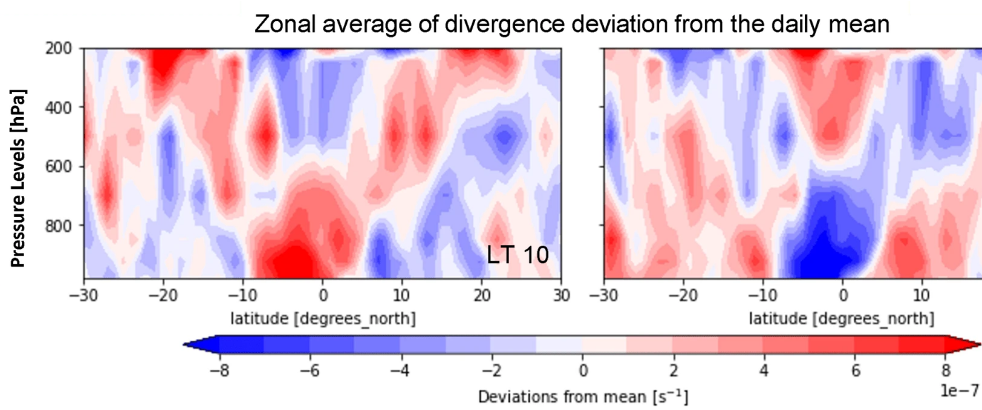

Fig. 5: Height-latitude (pressure levels) profiles of surface wind divergence (convergence) zonally averaged over 180E-105W longitude domain at the peaks of the diurnal cycle.

The divergences were computed using centered finite difference method in UTC, and then transformed back to LST for demonstration. The amplitude of the diurnal variation in near-surface wind divergence at the equator is approximately 0.8×10-6 s-1, or approximately 44% of the daily mean. This is in very close agreement with the previously reported results with buoy observations (Deser and Smith, 1998; Dai and Deser, 1999), but the phase (0900-1200 LT) is little ahead (for ~ 1-3 hr).

Figure 5 shows the height-latitude profiles of the zonally averaged divergence variations at the corresponding local times.

It is clear that, the wind patterns are reversed at the local times 12 apart.

DIURNAL VARIABILITY OF PRECIPITATION

This section presents the results od global distribution of the diurnal variation of precipitation in MPAS

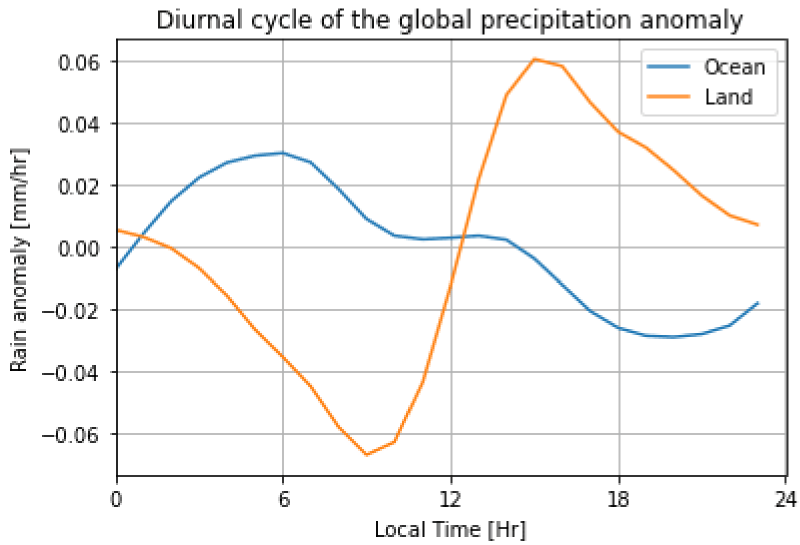

Fig. 5: Diurnal cycle of rain rate over land ocean

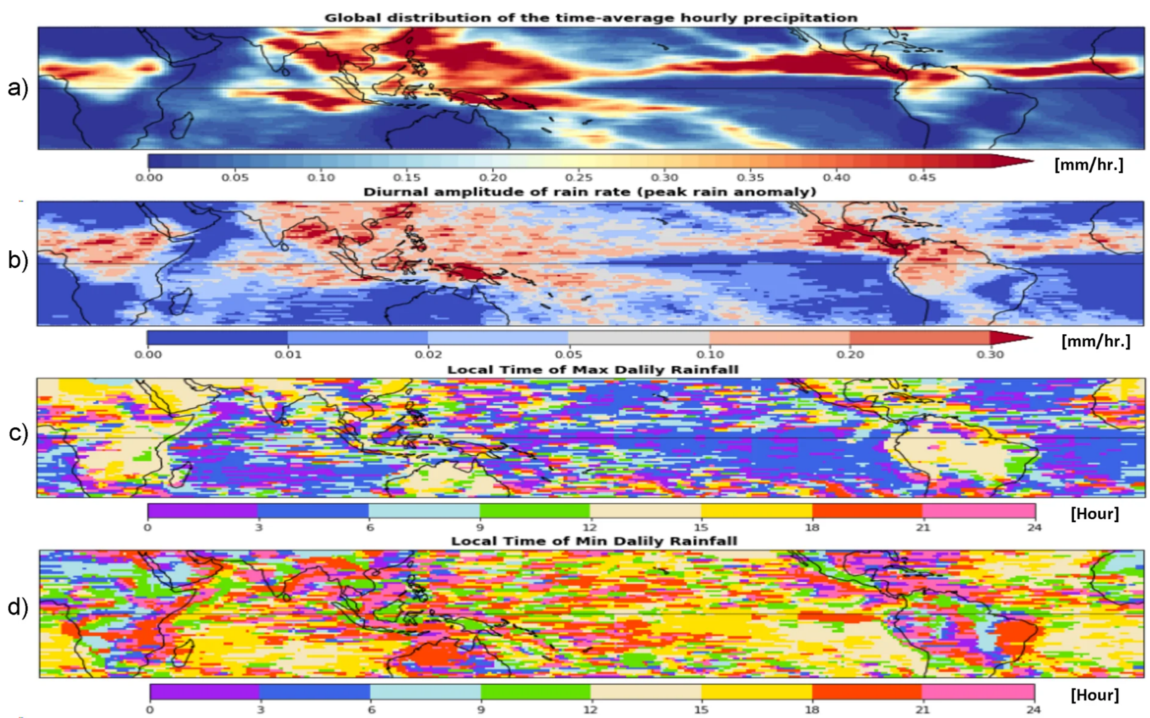

Fig. 6: Amplitudes and phase the diurnal cycle of global precipitation

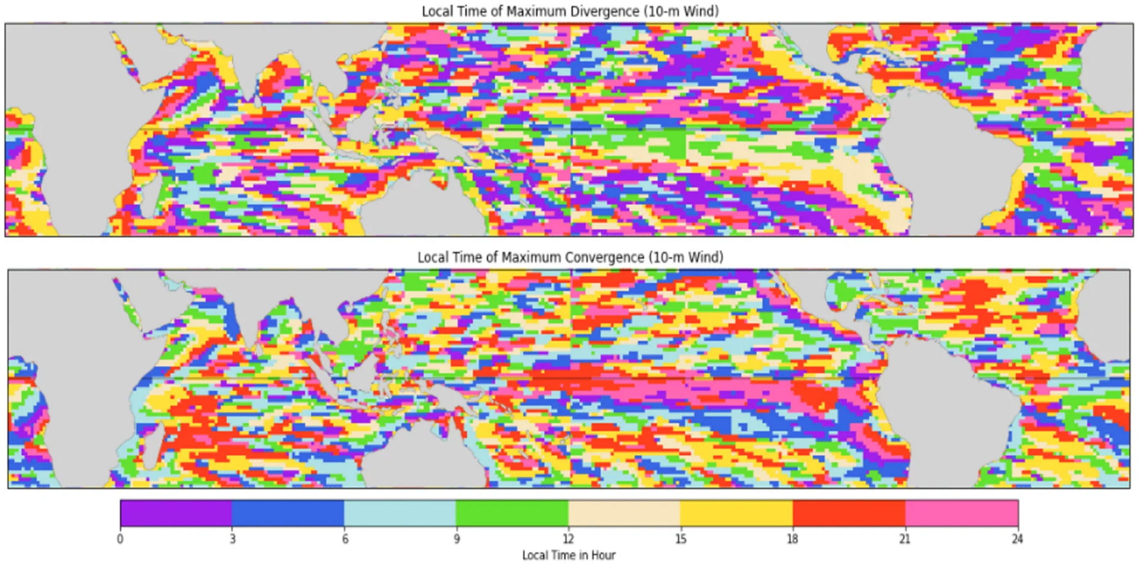

Fig. 7: Phase the diurnal cycle of surface wind divergence (top) and convergence(bottom).

Figure 5 displays the mean diurnal cycle of precipitation over global land and ocean. The land precipitation peaks at ~ 1500-1600 LT, while an early morning peak is found for ocean precipitation. The diurnal cycle of precipitation is in an excellent agreement with satellite observations (Minobe et al. 2020). However, the phase of ocean rainfall is around 2 hours ahead of the observations.

Figure 6 depicts the magnitude a nd phase of the daily variations of precipitation and figure 7 denotes the corresponding phase of the surface divergence (convergence). As seen, there is a clear correspondence between surface convergence and precipitation; the time of maximum convergence leads the time of maximum rainfall by about 5-6 hrs.

DIURNAL VARIABILITY OF CLOUD WATER AND WATER VAPOR MIXING RATIOS

This section discusses the diurnal variabilities of the vertically integrated mixing ratios (qc,qv), and their relation with surface wind divergence, vertical velocity, and precipitation.

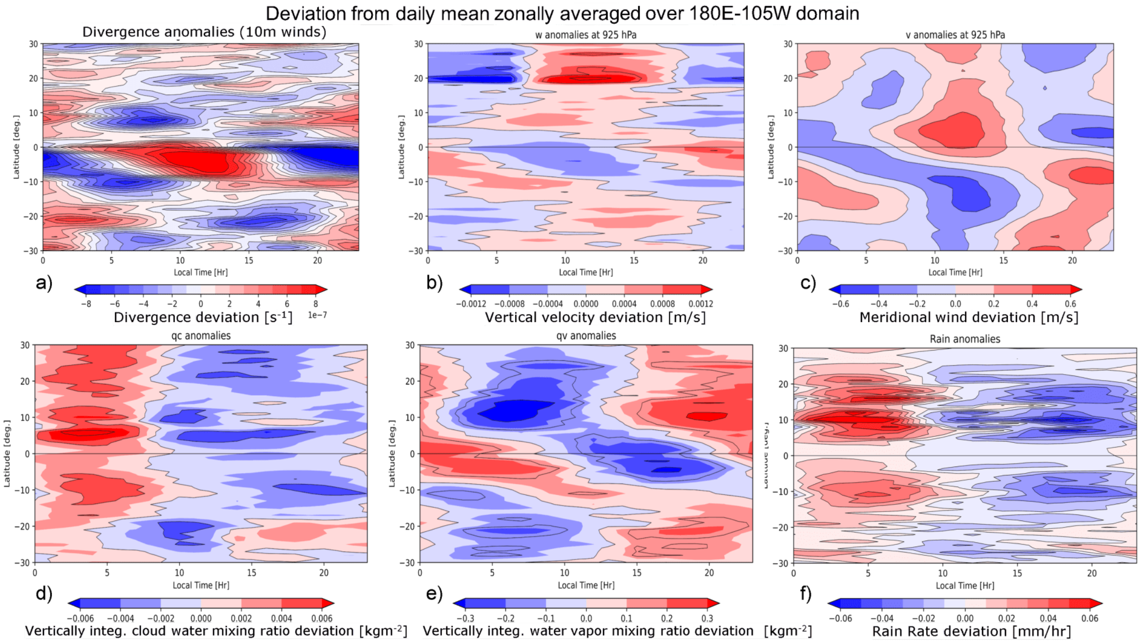

Fig. 8: Diurnal variation of a) surface wind divergence, b) vertical velocity, c) meridional wind component (v), d) qc, e) qv, and f) rain-rate

CONCLUSION AND FUTURE WORK

- We used MPAS-A 40-day run to diagnose its performance in representing the diurnal and semidiurnal cycles of near-surface winds, their convergence, precipitation, and to examine their interconnection to produce a 3D picture of the atmospheric circulation.
- The initial results with MPAS-A are promising -- the representation of the diurnal variability of surface winds and their convergence fields, and precipitation are generally well captured.
- But there is still room for improvement in modeling the deep convection and complex transient local dynamics of mesoscale processes of some regions like over the Maritime Continent and tropical Africa.
- 40-day simulations (DYAMOND-1) are not sufficient to verify seasonal and interannual variabilities; more research and longer records are needed.
- As a future work, we plan to use the 2nd phase of the DYAMOND project (DYAMOND Winter) to leverage the fully coupled atmosphere-ocean version of MPAS, besides MPAS-A, to see how ocean coupling improves the diurnal cycles of both winds and precipitation.

AUTHOR INFORMATION

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ABSTRACT

Studies have long reported the existence of pronounced diurnal and semi-diurnal variations in near-surface winds and divergence over the tropical oceans. Diurnal cycles of convective precipitation and cloudiness in the tropics are also well recognized from in-situ and satellite observations. However, the linkages between diurnal variations in tropospheric circulation, cloudiness and precipitation over the tropical oceans remain to be fully documented and understood. Recently, global storm-resolving models, which do not require convective parameterizations, have created an unprecedented opportunity to investigate the full three-dimensional structure of the diurnal cycle over the tropical oceans. In this study, we used one such model -- the Model for Prediction Across Scales (MPAS) -- for two main purposes: first, to evaluate the model's representation of semi-diurnal and diurnal variations in near-surface winds, precipitation, and cloudiness over the tropical oceans; and second, to extend the analyses to provide a full three-dimensional picture of the daily variations in tropospheric circulation and their linkage with the hydrological cycle.

A 40-day MPAS simulation (the same as used for DYAMOND-1 global storm-resolving models inter-comparison project) was utilized in this study to examine the large-scale geographical patterns and vertical structures of mean daily variations of zonal and meridional wind components, wind divergence, vertical velocity, cloudiness, water vapor mixing ratio and precipitation. The model shows generally good agreement with the previously reported observational results for near-surface winds and divergence. In particular, MPAS exhibits a pronounced large-scale diurnal cycle in the local Hadley Circulation over the Tropical Pacific Ocean, with lower tropospheric divergence (convergence) relative to the daily mean, maximizing around 1000 (2200) LT. The amplitude of the diurnal variation in near-surface wind divergence at the equator is approximately 0.8×10^{-6} s^{-1}, or approximately 44% of the daily mean. The vertical structure of this diurnal circulation, along with its signature in vertical velocity and its association with water vapor, cloudiness and precipitation are presented.

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