Dynamical aspects of convectively coupled diurnal rainfall systems in the lee of the Rockies in the Super-Parameterized Community Atmosphere Model v. 3.5

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Introduction

The diurnal physics of organized propagating convection are intimately linked to warm season climate in the lee of mountain chains. Global climate models (GCMs) do not admit these physics, due to the limitations of convection parameterizations. In a recent analysis of the Central US, we have shown that propagating diurnal convection can however be simulated in a GCM that uses the embedded cloud resolving model (CRM) approach. This raises important questions: How are simulated orographic diurnal circulations and thermodynamics altered by the embedded CRM approach? Is the organized convection genesis mechanism in MMFs in line with established conceptual models? How are convective signals transmitted across isolated CRMs in an MMF?

Simulation details:

Simulation output from a GCM and an MMF is analyzed in this poster. The GCM is the Community Atmosphere Model tag 3.5.32 (hereafter CAM3.5; National Center for Atmospheric Research).The MMF is SP-CAM3.5 (SAM6.7.5 CRM embedded in CAM3.5.32; Marat Khairoutdinov, Center for Multiscale Modeling of Atmospheric Processes).

Common settings:
- 3 month simulation (JJA)
- Finite volume GCM dycore
- 1.9 deg x 2.5 deg hor. resolution
- 30 vertical levels
- Climatological SSTs

MMF-specific settings:
- 2D CRM (height-longitude)
- 1 km CRM zonal resolution
- 64 km zonal CRM extent
- 30 levels colocated w/ GCM

JJA mean moisture & stability

How does the embedded CRM approach alter mean climate in the lee of the Rockies? In CAM3.5 the warm season atmosphere is too dry (precipitable water bias ranging from -2 mm to -10 mm). In SP-CAM3.5, there is more moisture available to feed convection (+2 to +4 mm).

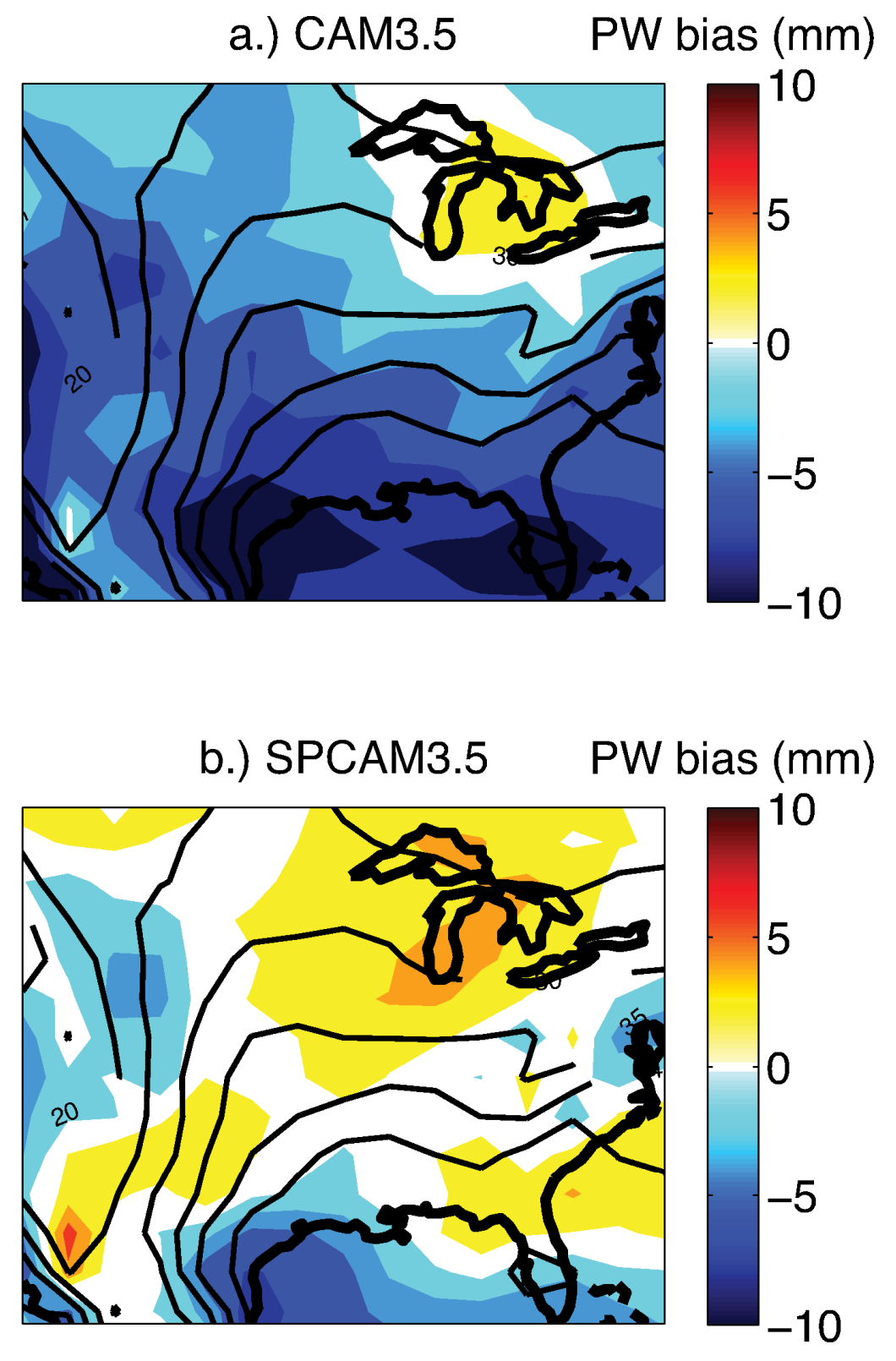

Figure 1: JJA climatological precipitable water anomaly at 0000 UTC (colors; mm) for the single-season a) SP-CAM3.5 and b.) CAM3.5 simulations, relative to the Rapid Uptake Cycle 2003 analysis (contours; interval of 5 mm).

In nature, a capping inversion over the central US traps daytime instability in the boundary layer, where surface flows concentrate energetic air in a narrow region that feeds convective systems propagating off the Rockies (Tripoli and Cotton, 1989). Figure 2 shows that the strength of the capping inversion is too weak in CAM3.5, but is stronger in SP-CAM3.5.

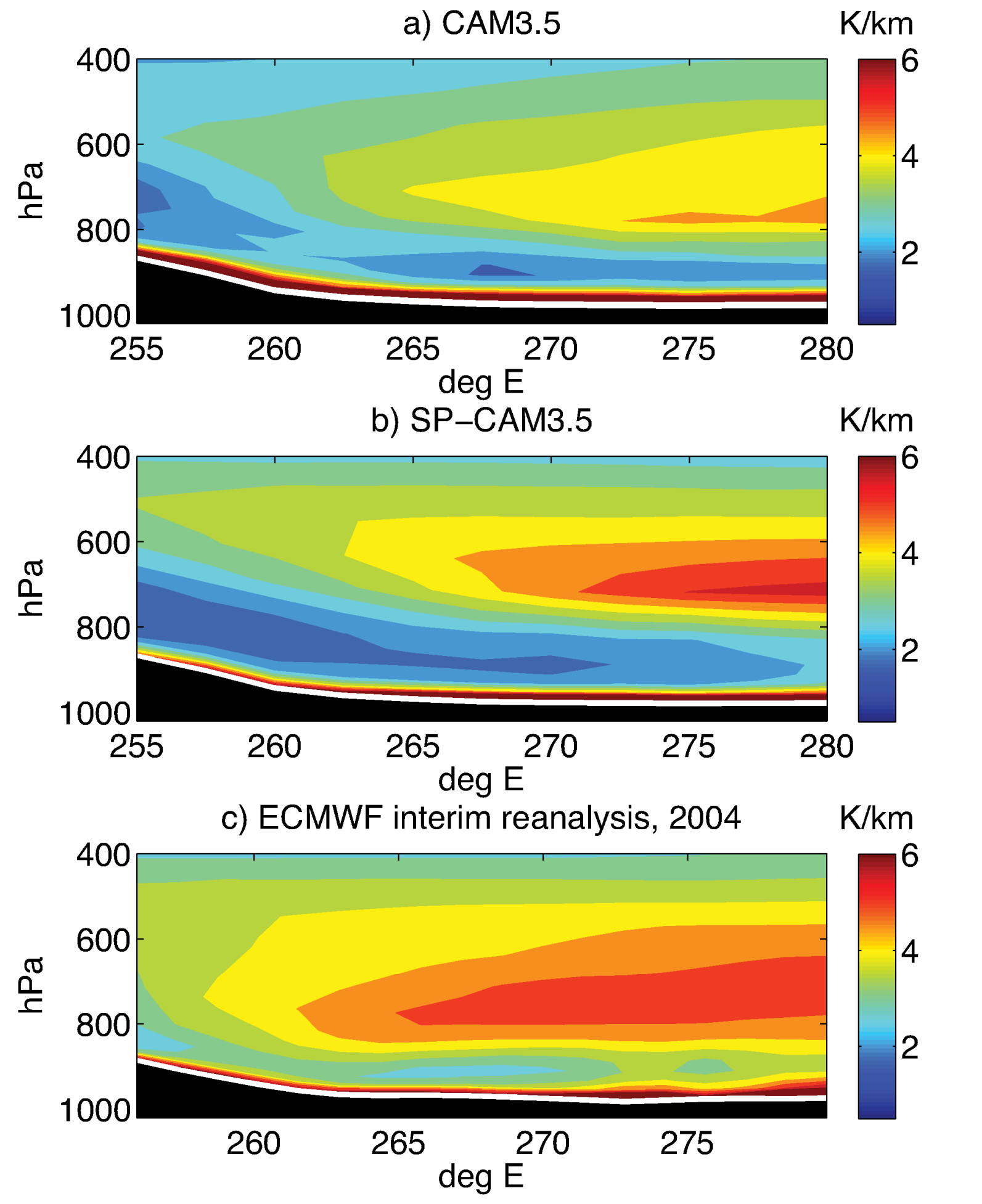

Figure 2: Pressure-longitude section showing JJA climatological static stability (dθ/dz) averaged from 35-45N in the lee of the Rockies for a) CAM3.5, b.) SP-CAM3.5 and c.) ECMWF interim reanalysis. Surface topography is shown in black.

Regional diurnal circulations

What is the effect of the embedded CRM approach on simulated diurnal circulations? Two linked diurnal circulations underly the favorable dynamical environment for organization and nocturnal enhancement of propagating storm systems in the lee of the Rockies - the Great Plains Low-Level Jet (GPLLJ) and the mountain-plains solenoid (MPS).

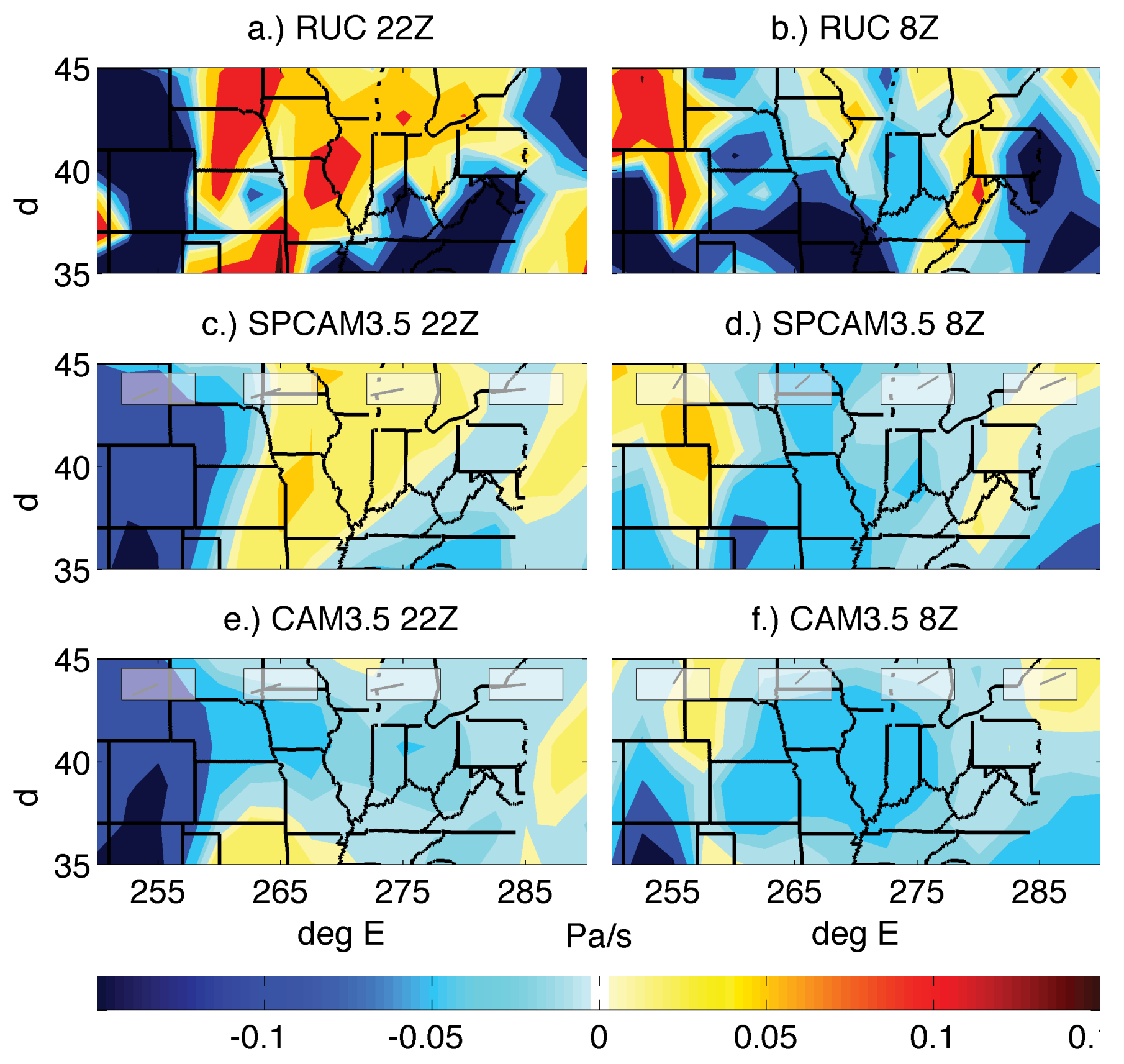

Figure 3: Maps of JJA average vertical pressure velocity at (left) 22Z and (right) 8Z comparing the Central US diurnal mountain-plains solenoidal (MPS) circulation in (top) the Rapid Update Cycle 2003 analysis to (middle) SP-CAM3.5 and (bottom) CAM3.5 simulations.

The western (upward) daytime branch of the MPS circulation is only weakly simulated by both SP-CAM3.5 and CAM3.5 (possibly due to coarse topography; Lee et al. 2008). But the eastern (downward) daytime Plains phase is improved in SP-CAM3.5. (Fig. 3c.) vs. Fig. 3e.), consistent with its stronger capping inversion.

The northern and eastern flanks of the GPLLJ circulation are a source of low level nocturnal moisture convergence, temperature advection, and low-level vertical shear. In nature these zones organize and sustain convective systems in distinct latitude “corridors” (Tuttle and Davis 2006; Trier et al. 2006; Jirak and Cotton 2007; Trier et al. 2010). Figure 4 shows that, like most GCMs, both CAM3.5 and SP-CAM3.5 admit reasonable LLJ dynamics (Ghan et al. 1996). But CAM3.5 has one large nocturnal convergence zone (Fig. 4d.-f.) whereas SP-CAM3.5 has dual zones (Fig. 4g.-i.), which reach farther north and are more consistent with the RUC analysis.

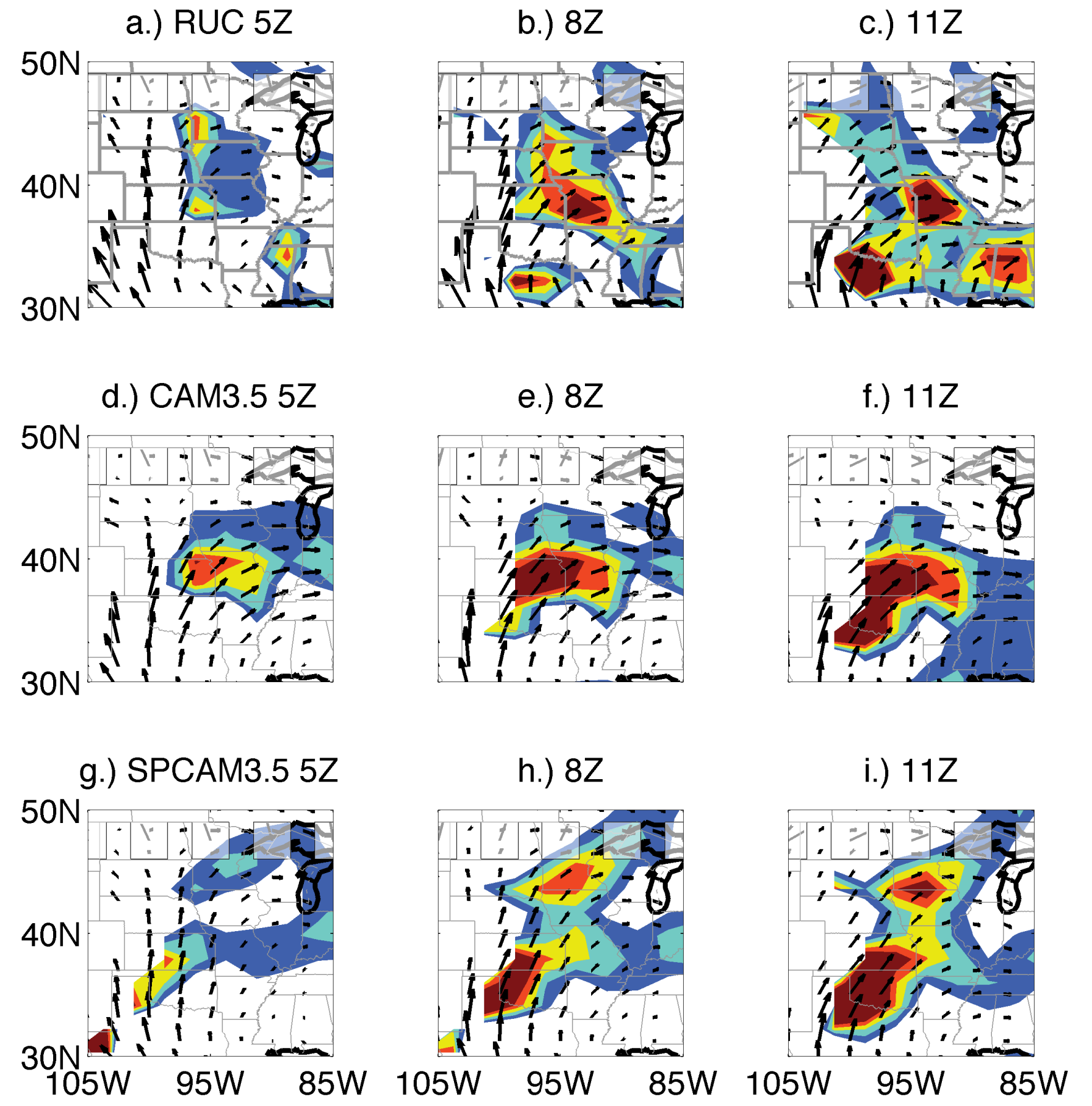

Figure 4: Maps over the central United States comparing the nocturnal evolution of the 850 hPa vapor transport (vector field; *qV*) showing the Great Plains Low Level Jet (GPLLJ) and its associated moisture convergence (colors; *-div(qV)*) in (top) the 2003 Rapid Update Cycle analysis, compared to the (middle) CAM3.5 and (bottom) SP-CAM3.5 simulations.

System propagation

Do the simulated convective systems in SP-CAM3.5 move at realistic speeds? Figure 5a.) shows that the ensemble of simulated propagating orogenic convective events in SP-CAM3.5 move with phase speeds in the range of 7 to 20 m/s. This is within the observed range of zonal phase speed of orogenic mesoscale convection signals in the lee of the Rockies derived from radar (Carbone et al. 2002) as well as cloud-system resolving simulations and theory (Moncrieff and Liu, 2006).

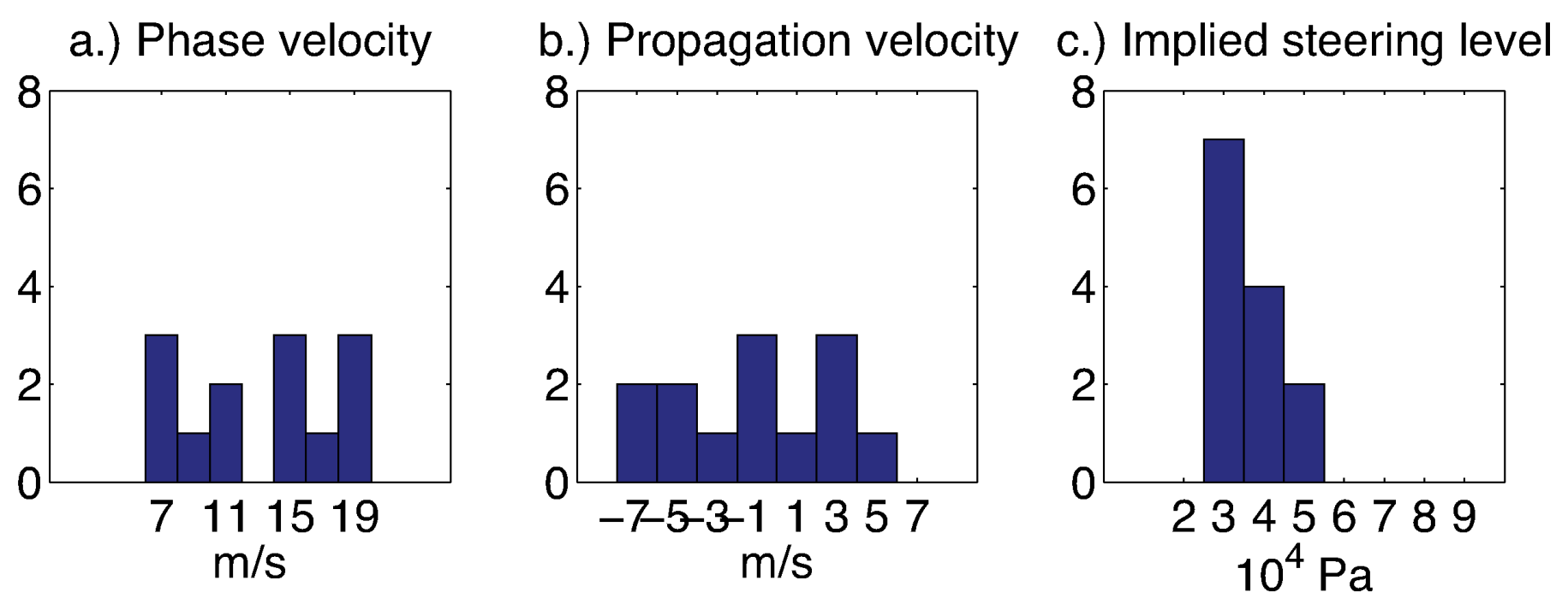

Figure 5: Histograms across the ensemble of simulated propagating convection events in SP-CAM3.5 showing a.) the distribution of the fitted zonal phase speed, b.) the distribution of the implied storm propagation speed relative to the mean buoyancy- and mass- weighted background flow, and c.) the distribution of the implied storm steering level.

In nature the phase speed of mesoscale convective complexes is the result of both an advective and a propagating component. The zonal propagation velocity of the simulated orogenic convective events in SP-CAM3.5 was determined by subtracting the buoyancy- and mass-weighted mean tropospheric zonal wind from the fitted zonal phase speed shown above. Figure 6b.) shows that approximately 70 % of the simulated leeside diurnal convective systems in SP-CAM3.5 propagate in excess of 3 m/s relative to the tropospheric background flow, with steering levels in the 450 hPa to 650 hPa range.

Genesis & Dynamical Balance

Does the chronology of storm genesis and balance agree with conceptual models like Tripoli and Cotton (1989)? Figure 6 investigates the chronology of condensate and large-scale wind evolution during a single propagation event in SP-CAM3.5 as it matures and balances. The zonal westerlies are deeply sheared and a shallow easterly upslope surface wind layer converges near 260E (Fig. 6 a.,c.,e.,g.). Condensate is first produced by locally forced deep mountain convection at 2030Z (Fig. 6a,b; contours). Upscale development occurs around 0000Z when the system reaches the leeside convergence zone (Fig. 6 c.). Convection reduces at 0430Z and re-intensifies by 1130Z, where it coincides with the GPLLJ inflow. A northerly wind component near 500 hPa develops along the western flank, suggesting flow balance on the large scale grid.

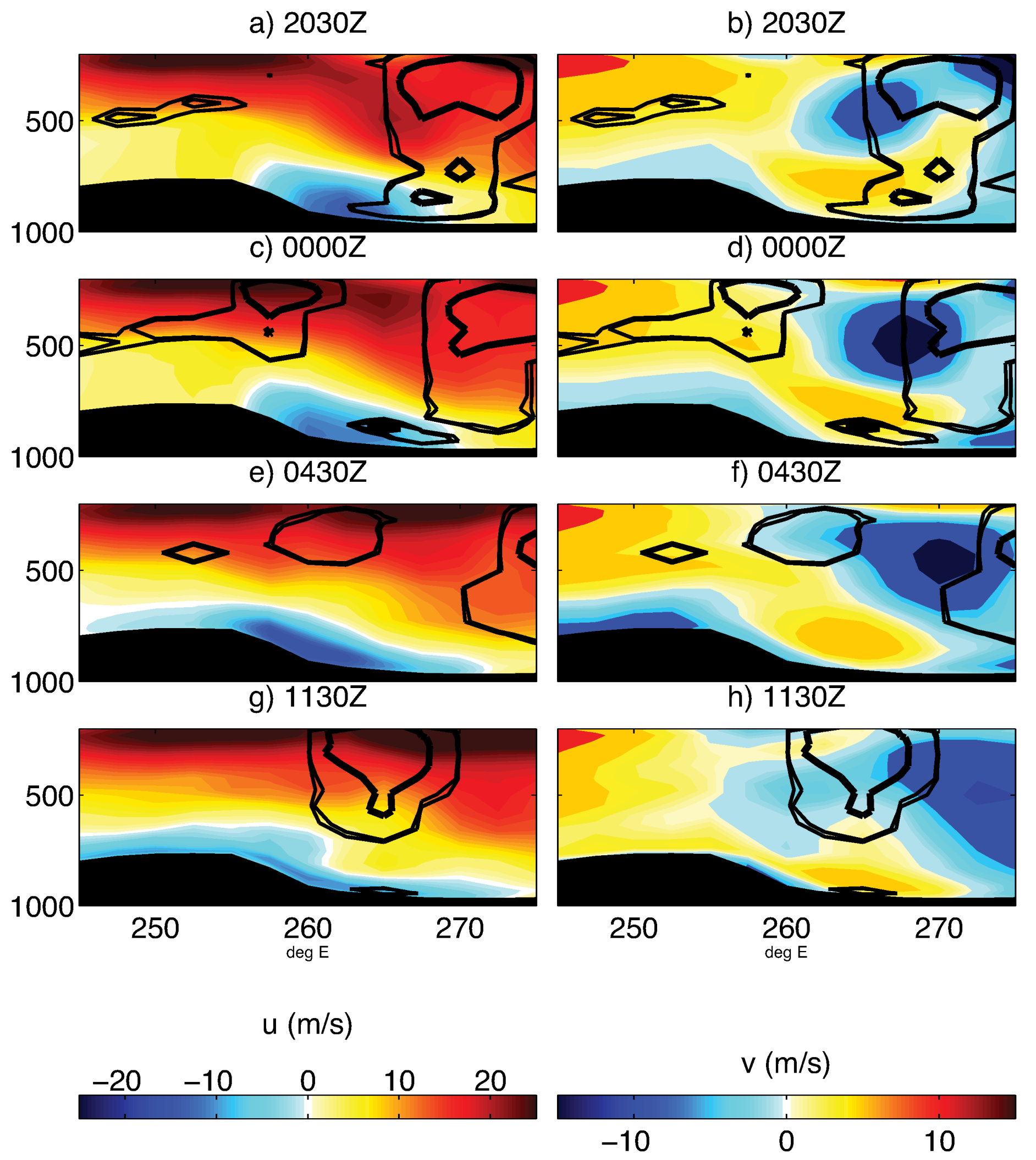

Figure 6: Pressure-longitude structure at 40 N showing the time evolution of (left) zonal and (right) meridional wind dθ/dz during the central of 3 consecutive propagating convective events in SP-CAM3.5. Condensate concentration contours are superimposed for values of (0.005, 0.01, 0.1, 1) g/kg.

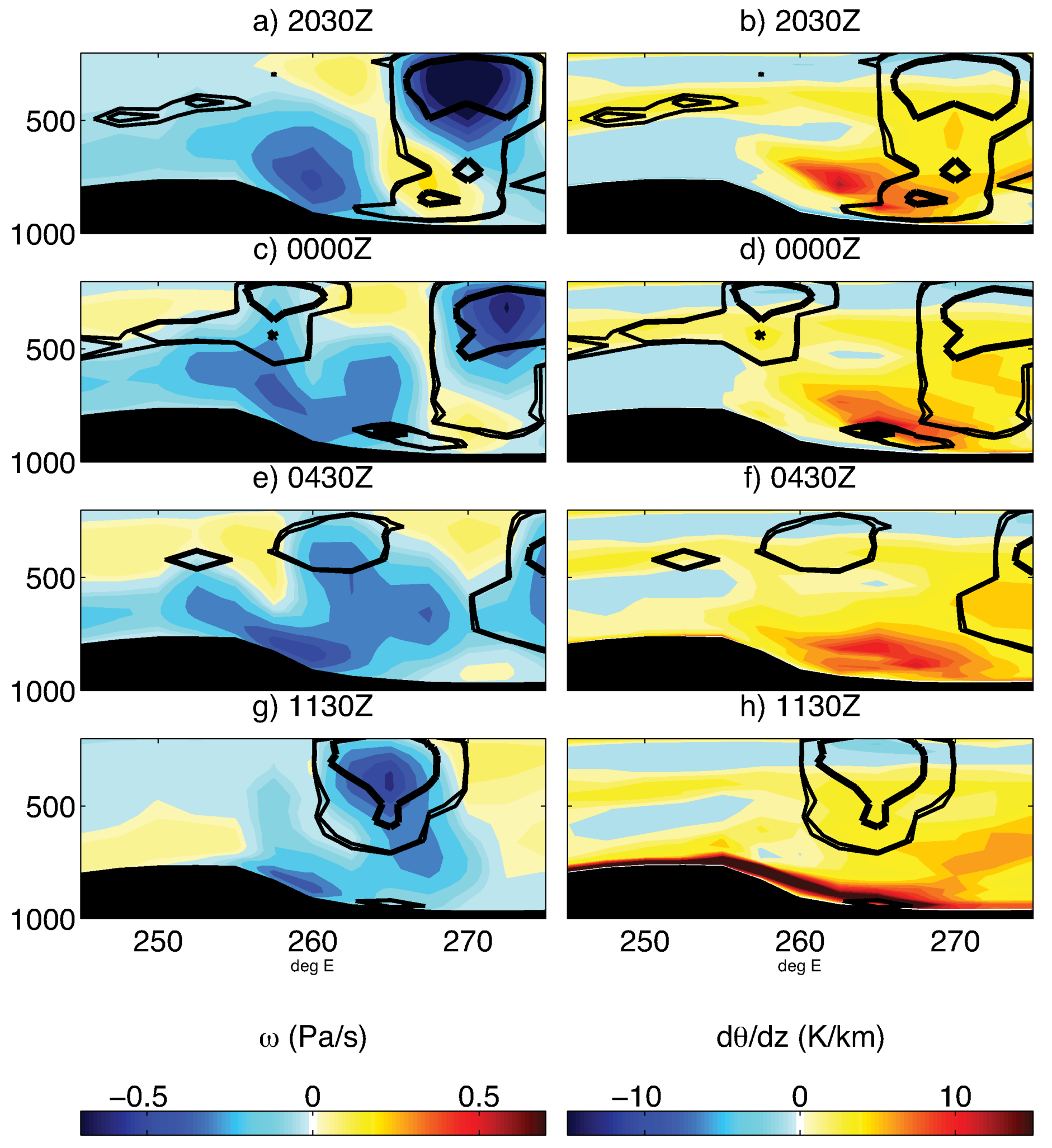

Figure 7: As in Figure 6, but for (left) vertical pressure velocity and (right) dθ/dz.

Figure 7 shows the vertical velocity and stability during the same period. At 2030Z, the Plains inversion traps locally generated surface instability in a thin boundary layer. To the west the cloud topped afternoon boundary layer is deep. The leeside convergence zone causes upward motion near 260E. This plume supplies zonally converged, inversion-trapped Plains instability upwards, feeding convection expansion. Convective heating aloft is straddled by coarse downdrafts. In the mature phase, deep vertical velocity associated with convective heating produces local breaks in the trapping inversion.

Conclusions

The embedded cloud resolving approach to climate simulation improves several aspects of Central US warm season climate in the Community Atmosphere Model v3.5.32. Reduction of a dry bias and enhancement of the daytime Plains subsidence inversion creates an environment that is more favorable for upscale development of convection in the lee of the Rockies. The genesis mechanism and propagation characteristics of diurnally generated convective systems in SP-CAM3.5 appear to be consistent with conceptual models. Flow and thermal anomalies (potential vorticity) induced by CRM convection on the large-scale grid as these systems mature may provide the “glue” that facilitates this long-range diurnal convection propagation signal in SP-CAM3.5.

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