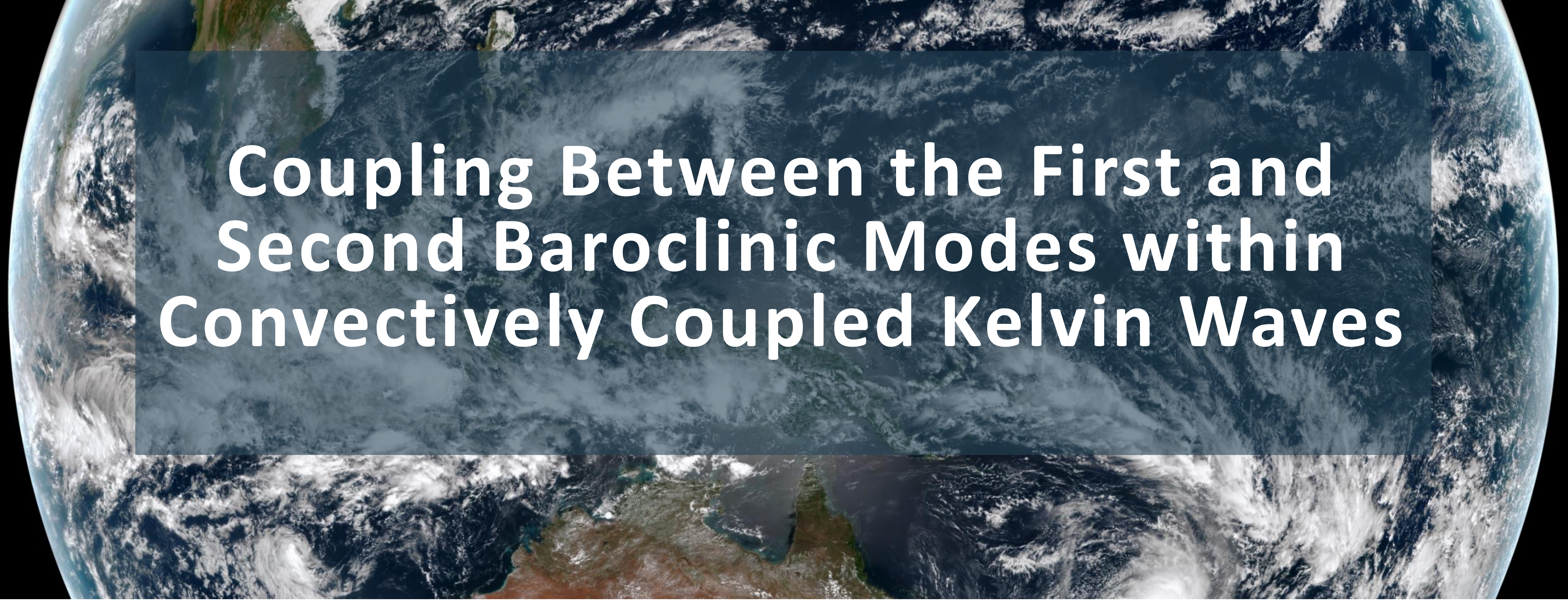
Coupling Between the First and Second Baroclinic Modes within Convectively Coupled Kelvin Waves



2024 AMS Tropical Conference

Acknowledgement: NOAA CVP, NCAR supercomputer Cheyenne and Derecho

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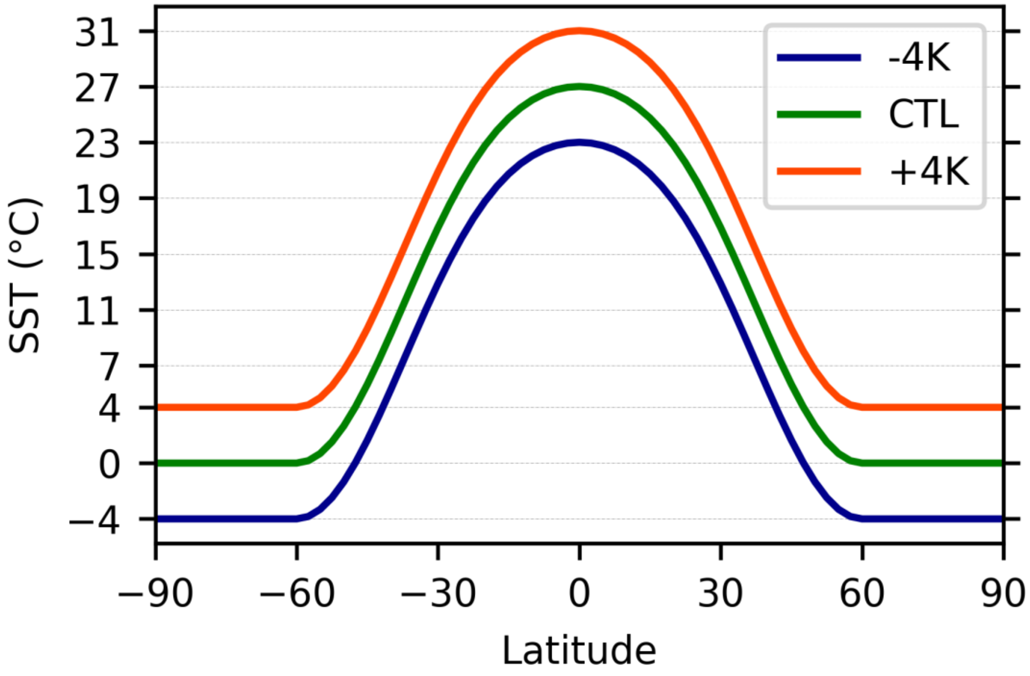
Response of convectively coupled Kelvin waves (KWs) to surface warming and cooling in aquaplanet simulations

Aquaplanet version of CAM6 with prescribed zonally symmetric SST

	-4K	CTL	+4K
SST_max (℃)	23	27	31

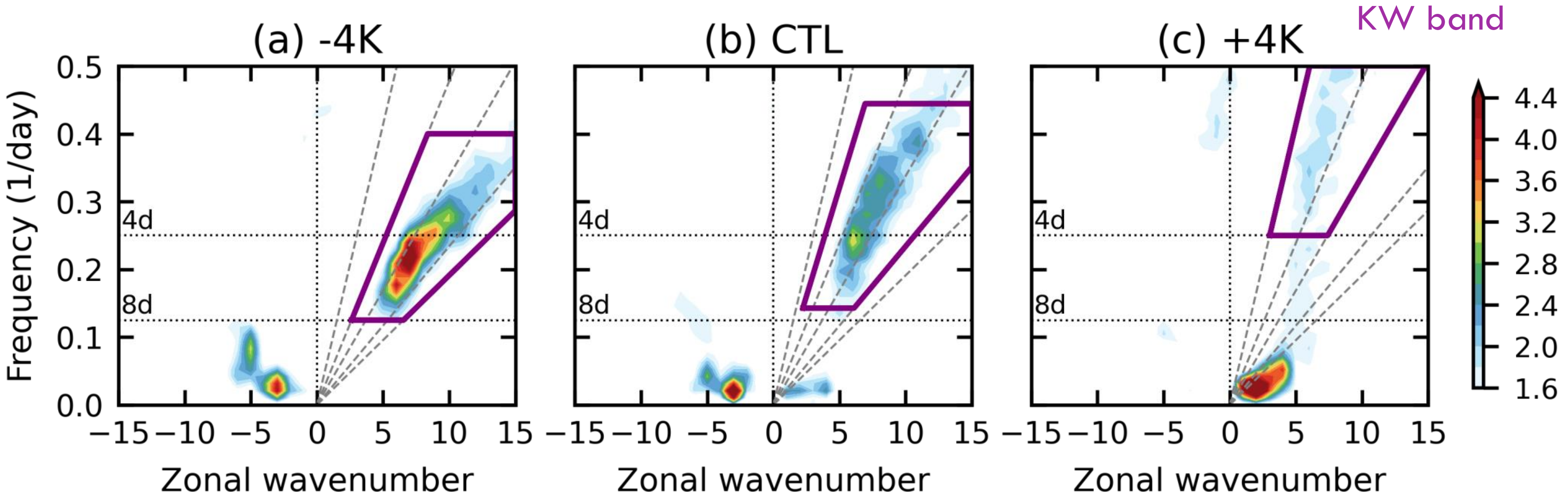


- Run for 12 years, use the later 10 years for analysis.
- 1.9° lat × 2.5° lon
- Deep convection scheme: Zhang and McFarlane (1999).
- Shallow convection scheme: Cloud Layers Unified by Binormals (CLUBB).

(Chien and Kim, submitted)

KWs weaken and accelerate with warming

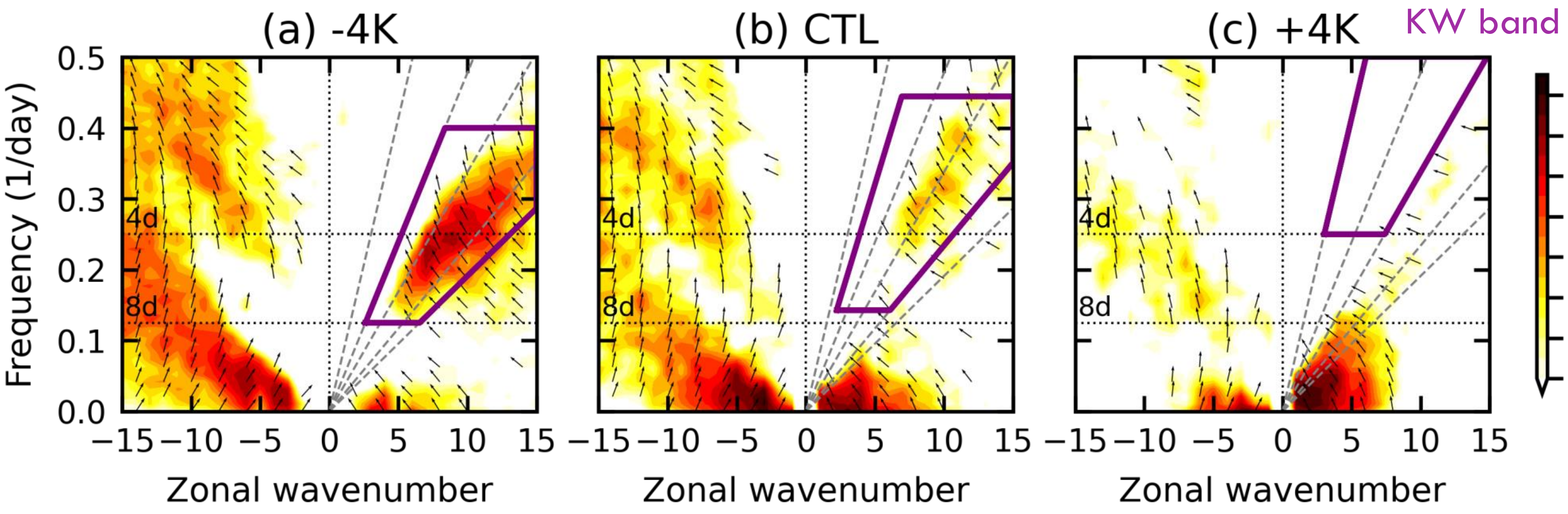
Normalized power spectrum of precipitation anomalies (signal strength)

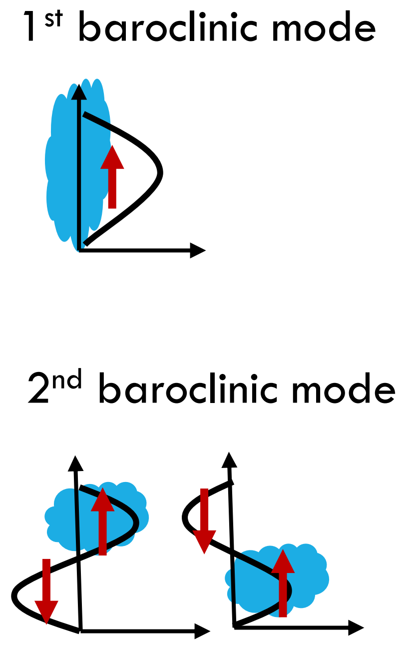


(Chien and Kim, submitted)

Weakening and acceleration of KWs are associated with weaker coupling between the first and second baroclinic modes

Coherence squared between first and second baroclinic modes





Why does the coupling between the two modes weaken?

What controls the coupling?

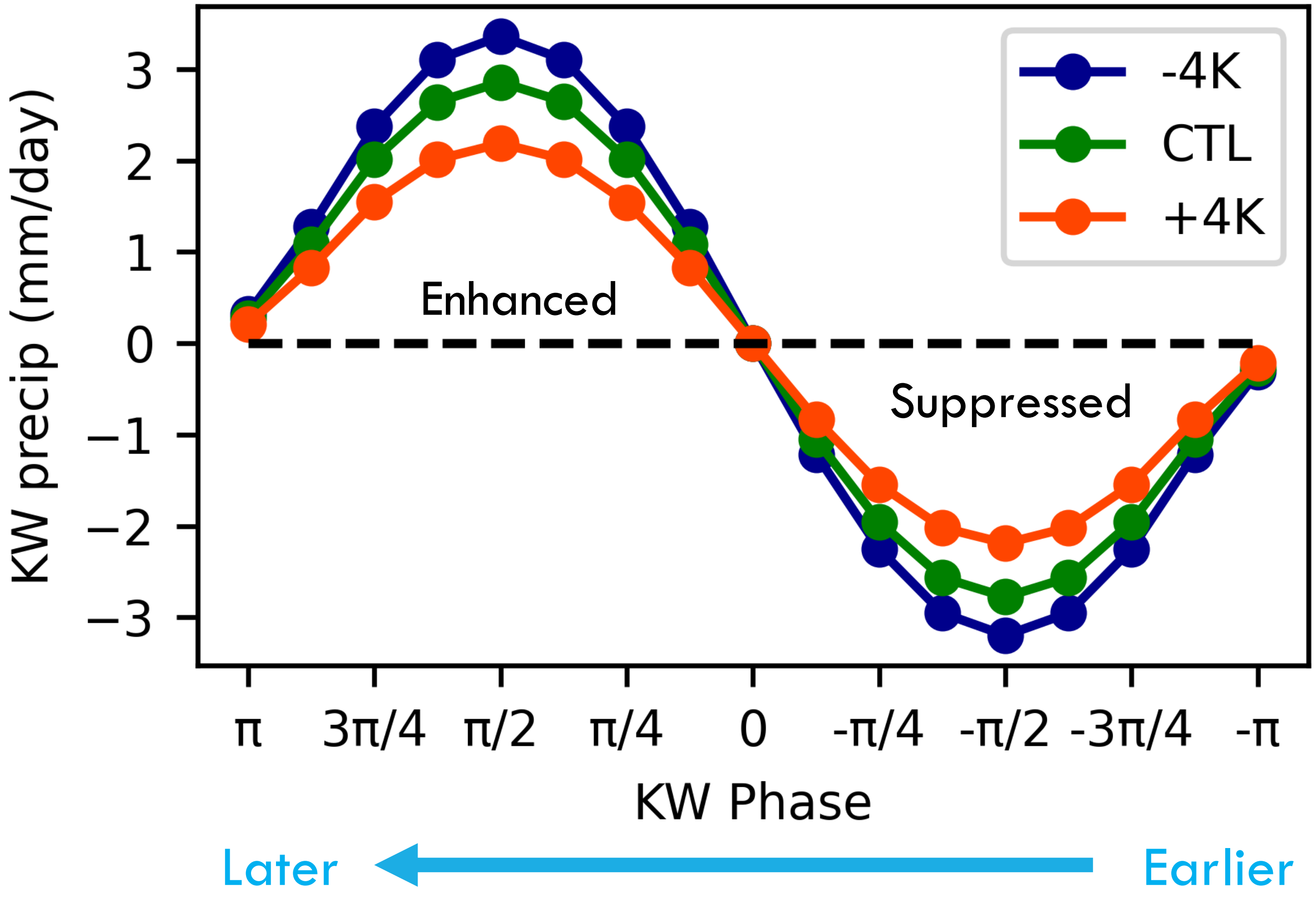
(Chien and Kim, submitted)

Research objectives:

Investigate how the first and second baroclinic modes are coupled within KWs using aquaplanet simulations.

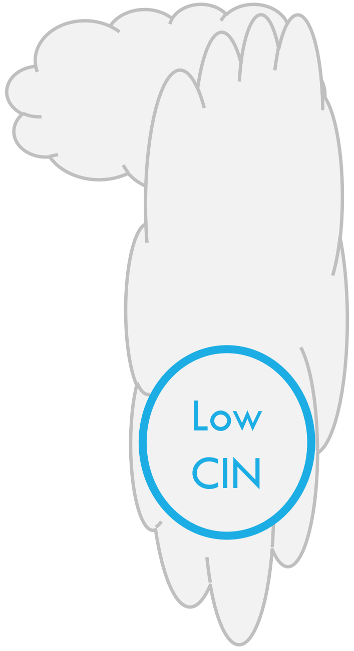
Hypothesize why the coupling between the two modes may weaken with warming which lead to the weakening and acceleration of KWs.

Method: KW composite



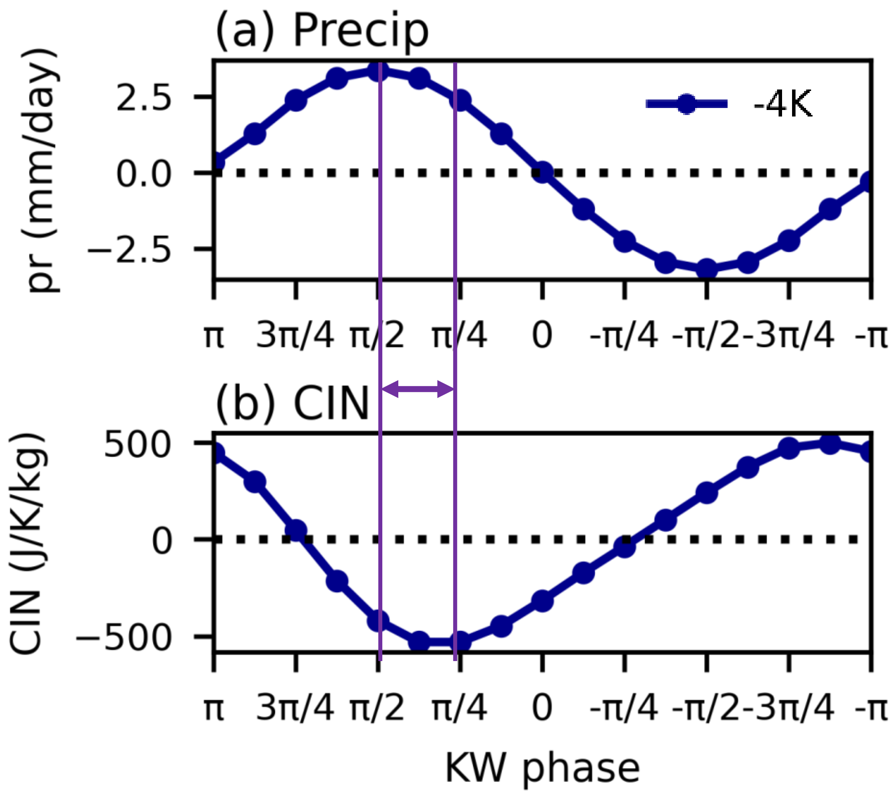
Previous theories on the two-mode coupling not consistent with our simulations

Mapes (2000)



Deep convection is triggered when convective inhibition (CIN) is lowest.

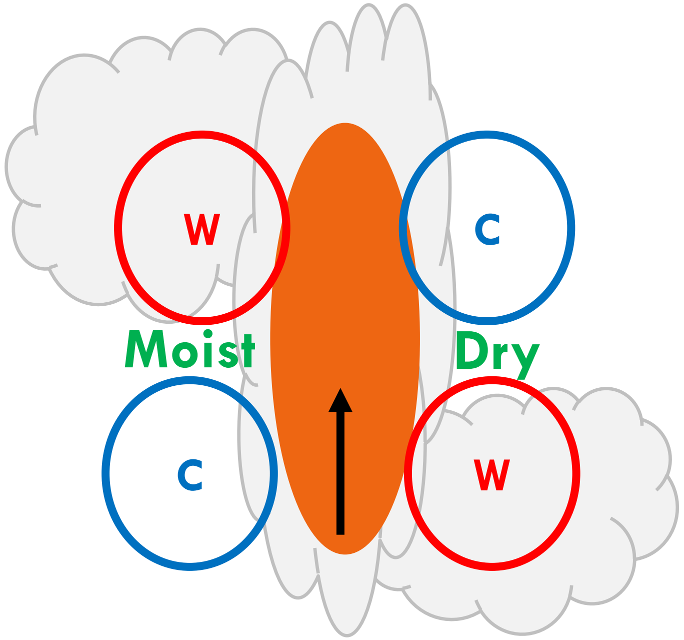
Stratiform heating lags deep convection by 3 hours.



Phase Lag between precipitation and CIN suggests our simulation results do not fully match this model.

Previous theories on the two-mode coupling not consistent with our simulations

<u>Kuang (2008)</u>



W: Warm anomalies

C: Cold anomalies

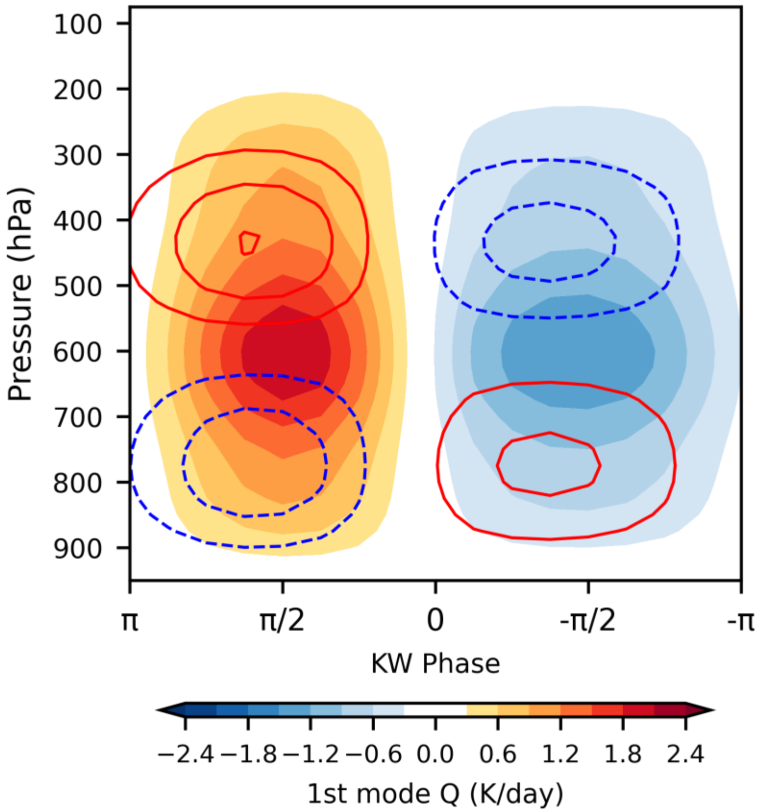
Shading: Diabatic heating

Deep convection is triggered when lower tropospheric temperature decreases (quasi-equilibrium is perturbed).

Mid-tropospheric moisture determines the depth of convection.

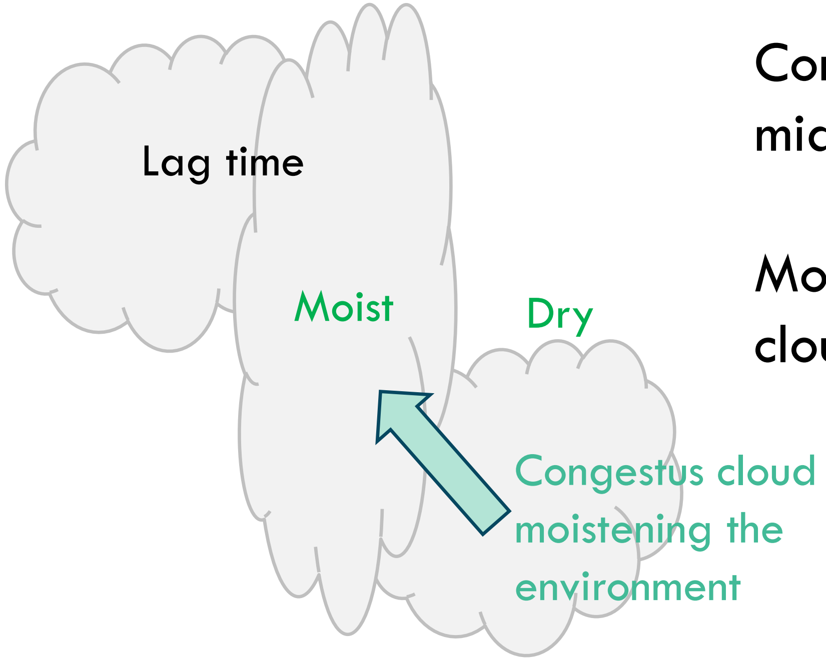
Phase Lag between deep convection and the temperature tendency of the second mode suggests our simulation results do not match this model.

KW composite 1st mode diabatic heating (shading) and 2nd mode temperature (contours) in -4K



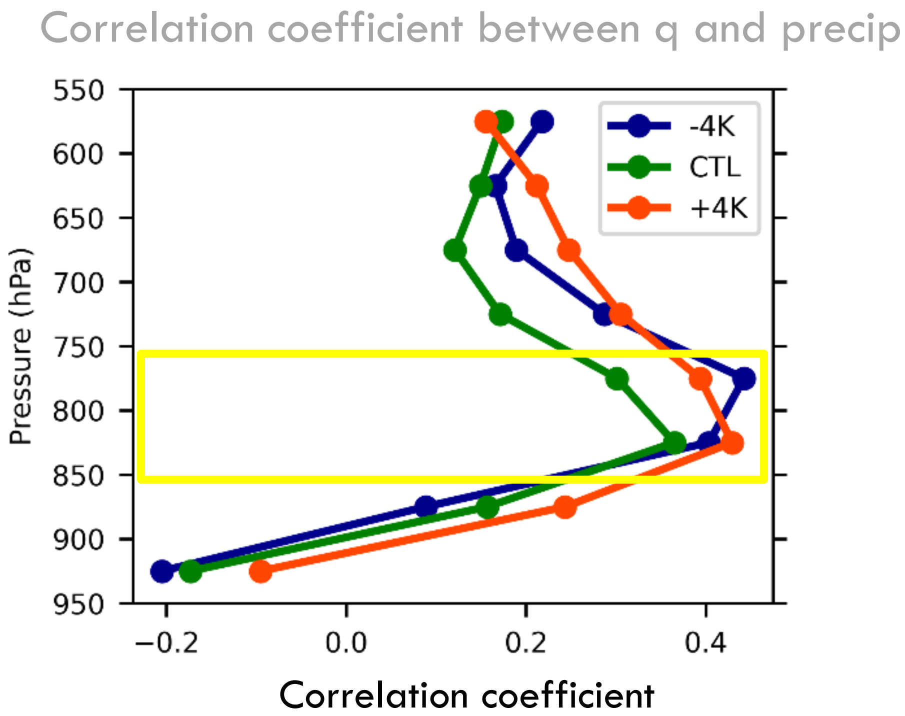
Previous theories on the two-mode coupling not consistent with our simulations

<u>Khouider and Majda (2006)</u>



Convection occurs when the midtroposphere is moist.

Moistening of congestus cloud is essential.



Precipitation is most strongly correlated with lower tropospheric moisture (750-850 hPa) in our simulations.

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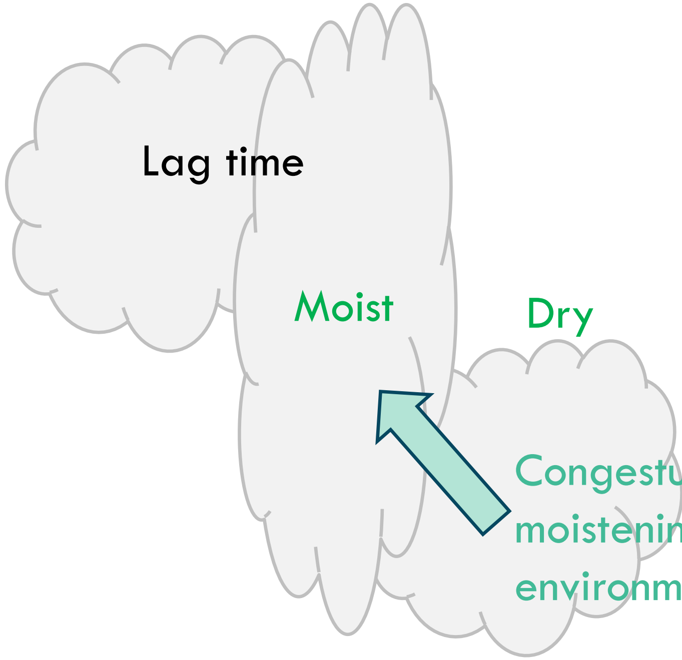

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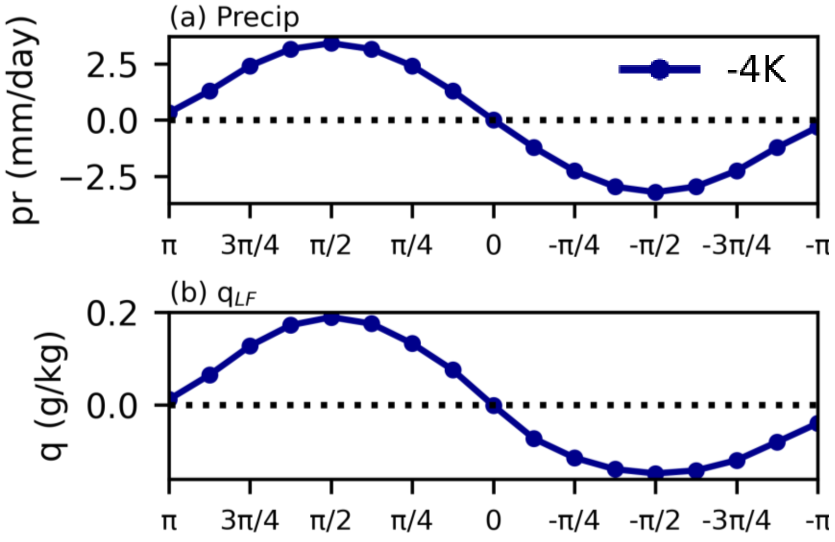
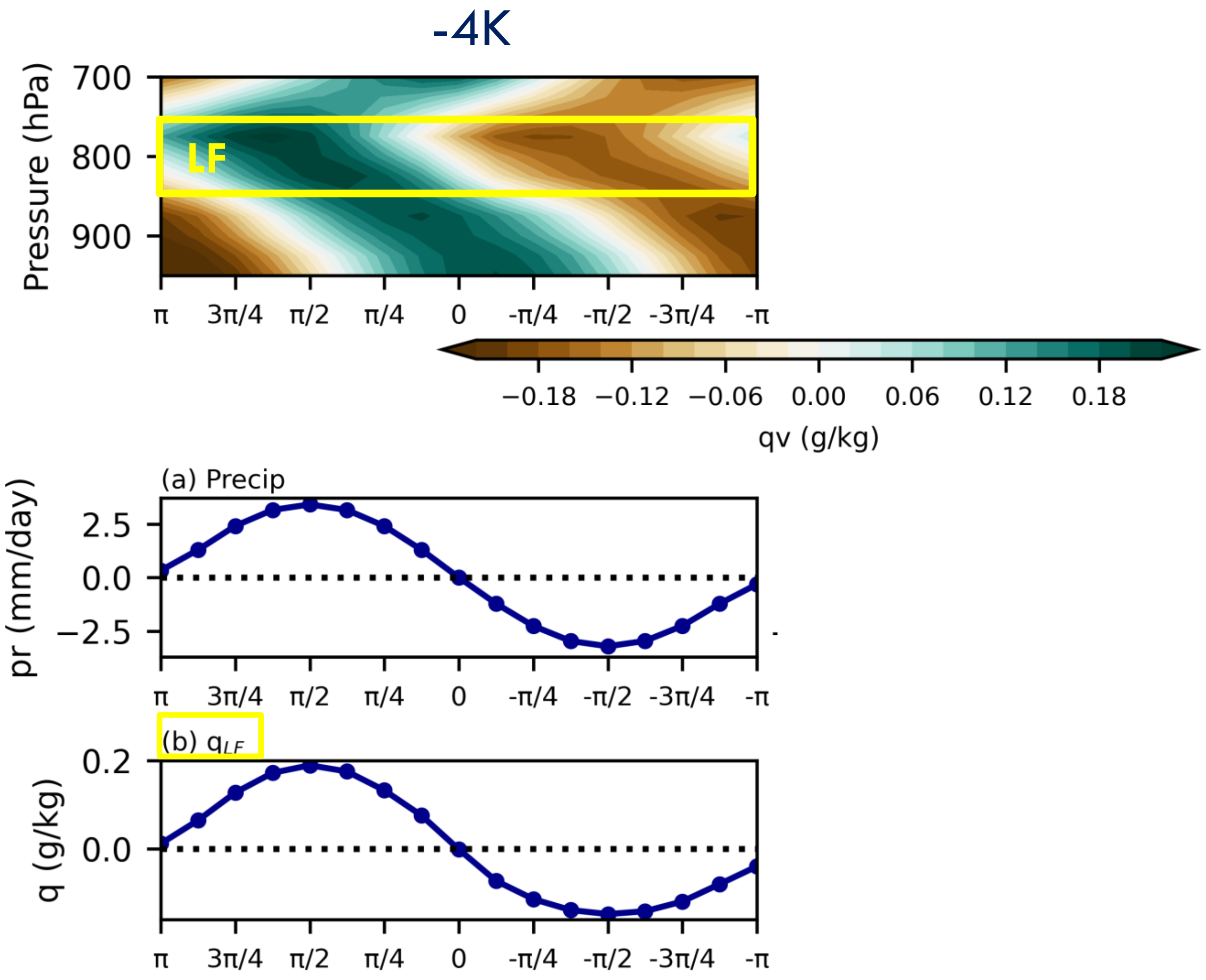


Precipitation is most strongly correlated with lower tropospheric moisture (750-850 hPa) in our simulations.

Shading: Specific humidity



Moisture increases in the free troposphere follows the increases in the boundary layer

Shading: Specific humidity

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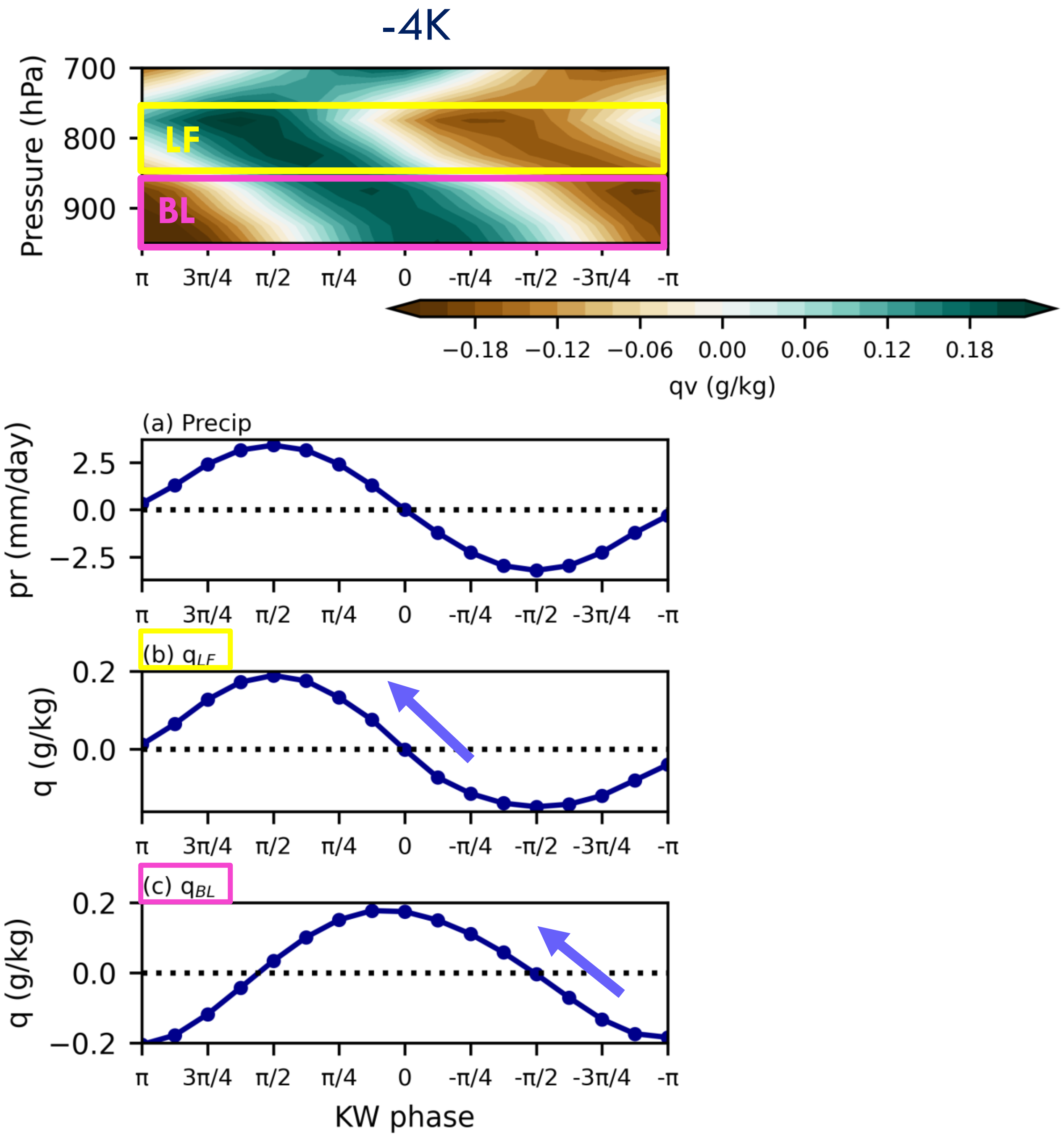

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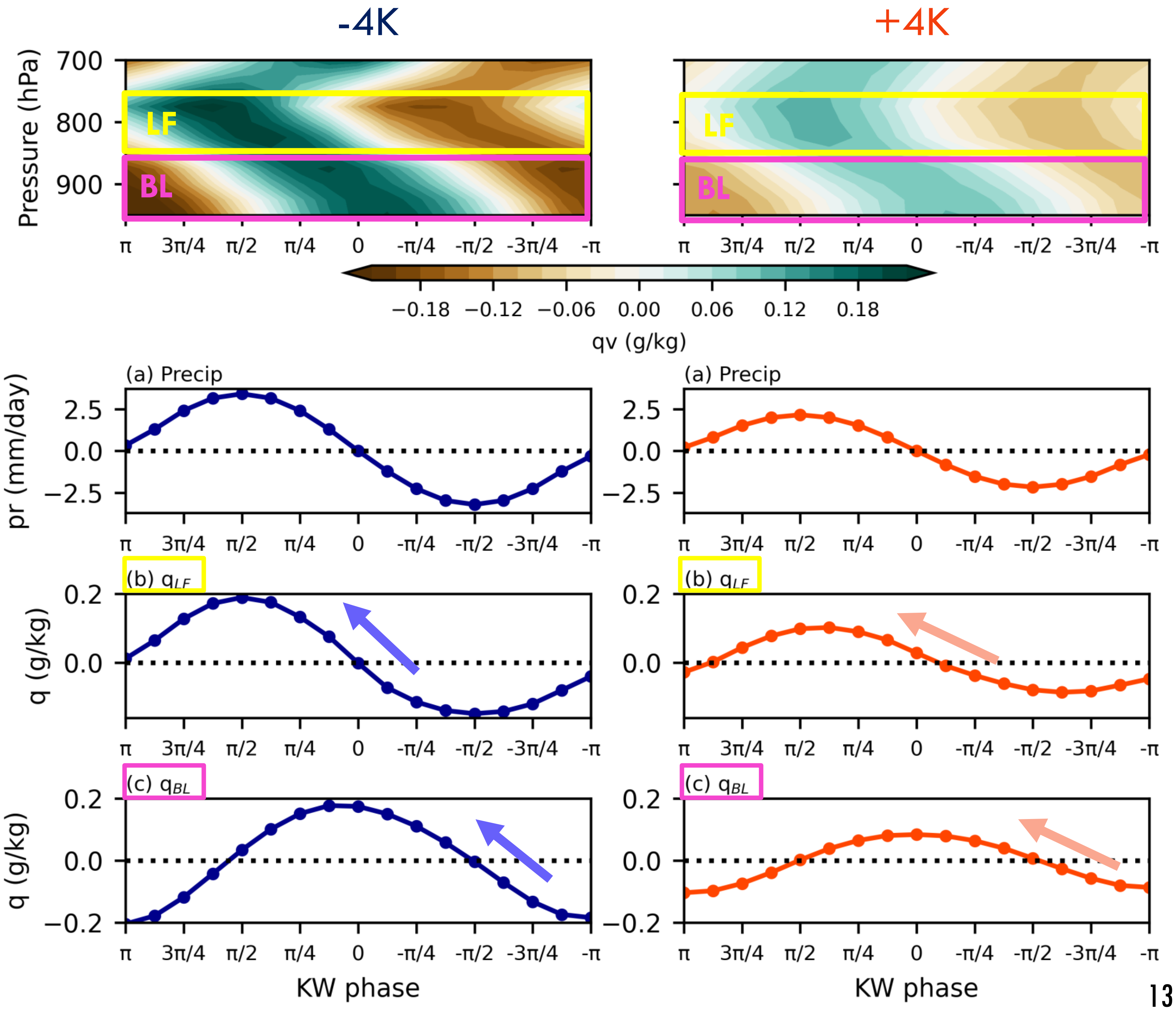
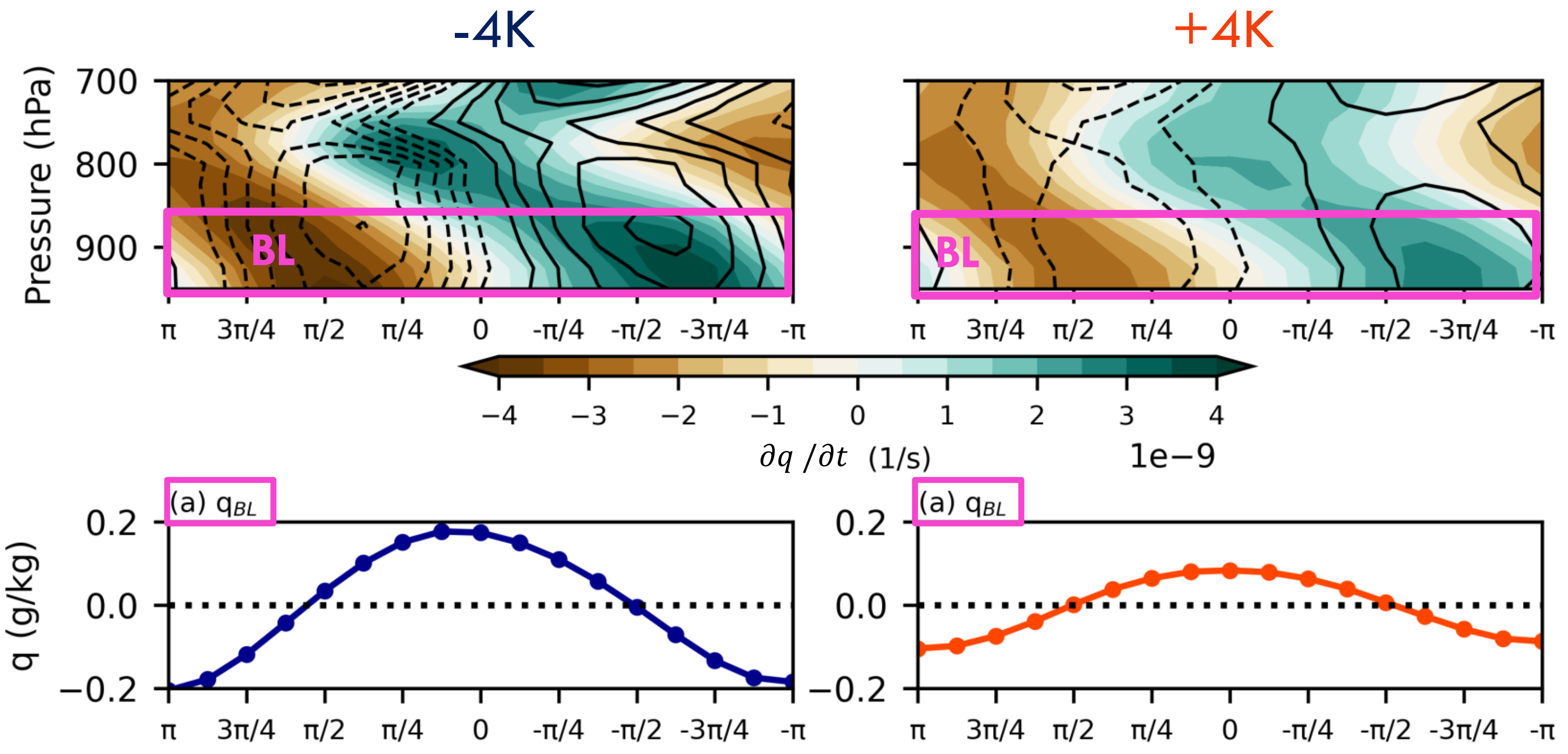


Shading:

Specific humidity tendency $\frac{\partial q}{\partial t}$

Contour: -Q2



Boundary layer moisture comes from evaporation

$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial p} - \mathrm{Q2}$$

Apparent moisture source (Yanai 1973)

Shading:

Specific humidity tendency $\frac{\partial q}{\partial t}$

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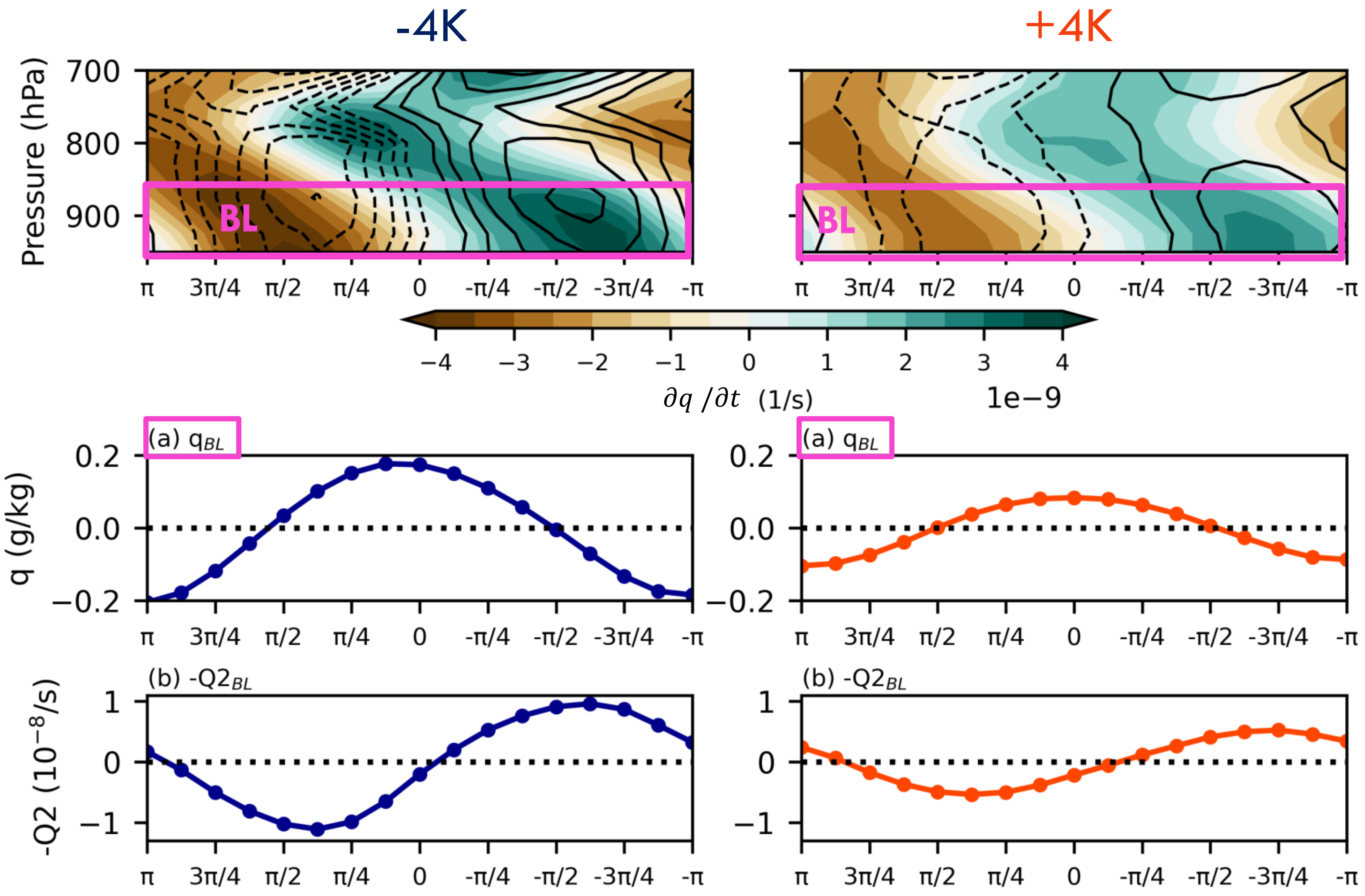

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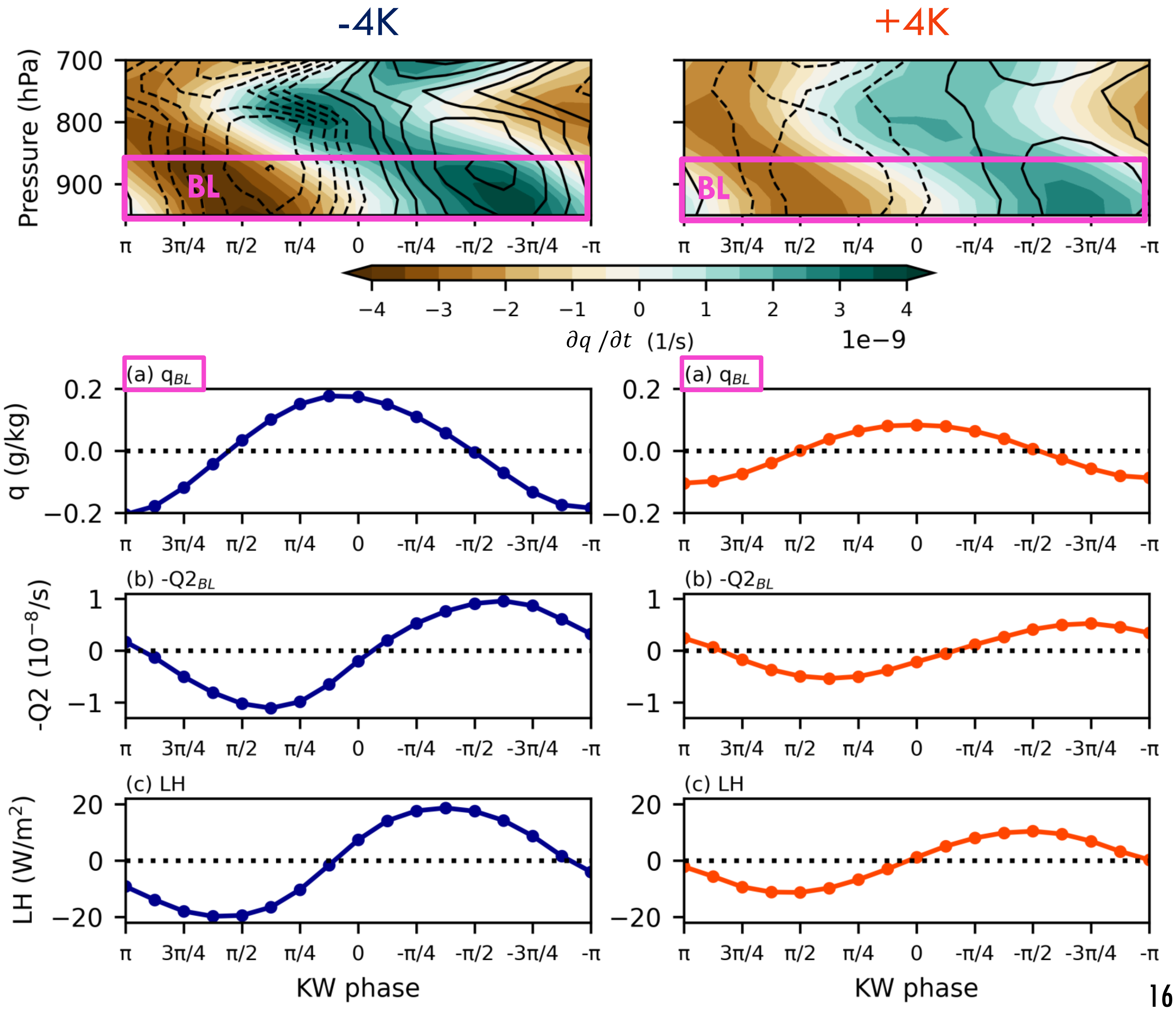
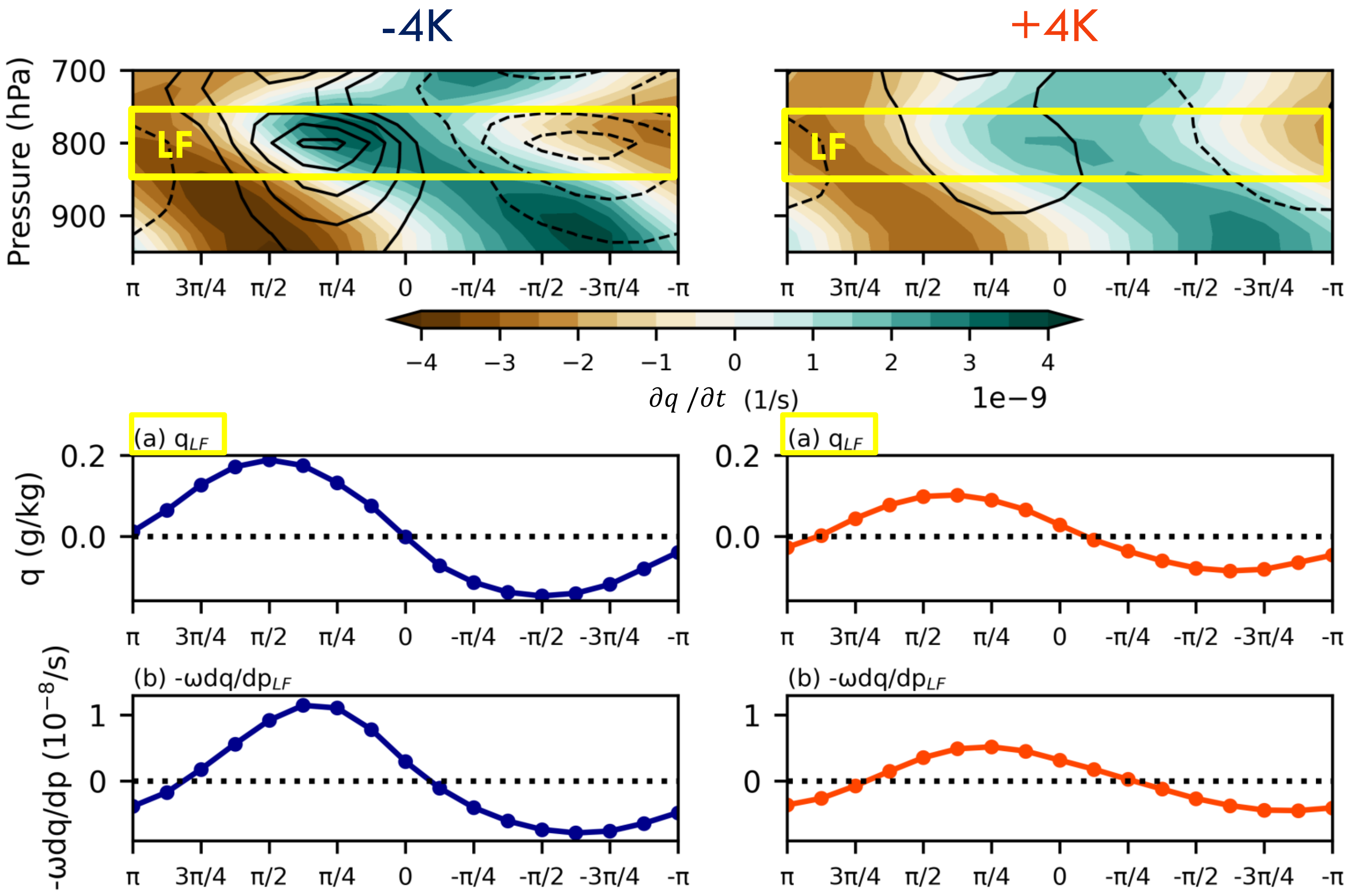


Shading:

Specific humidity tendency $\frac{\partial q}{\partial t}$

Contour: $-\omega \frac{\partial q}{\partial p}$



Lower free tropospheric moisture comes from vertical advection

$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial p} - Q2$$

Vertical advection

Shading:

Specific humidity tendency $\frac{\partial q}{\partial t}$

Contour: $-\omega \frac{\partial q}{\partial p}$

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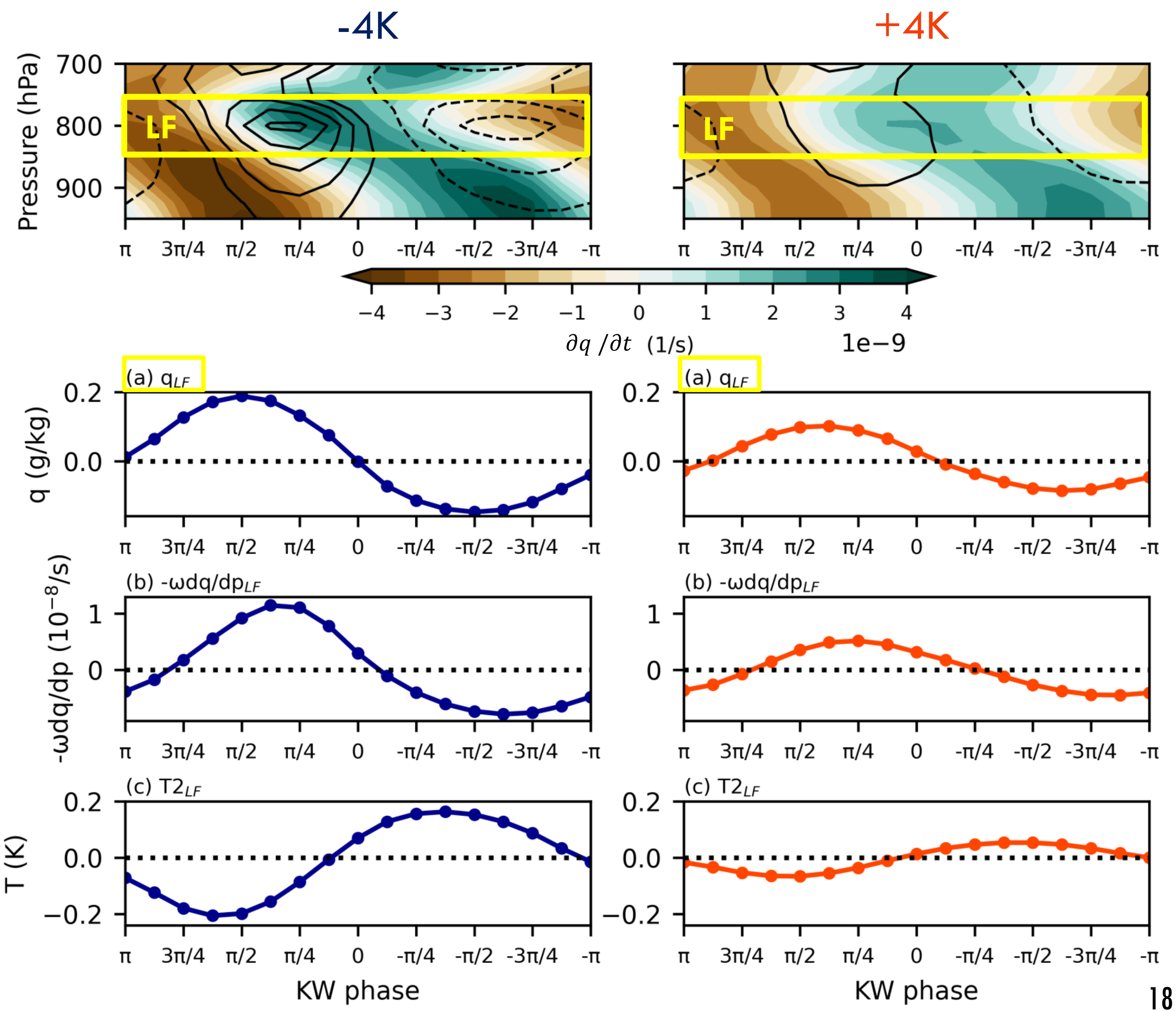
Vertical advection



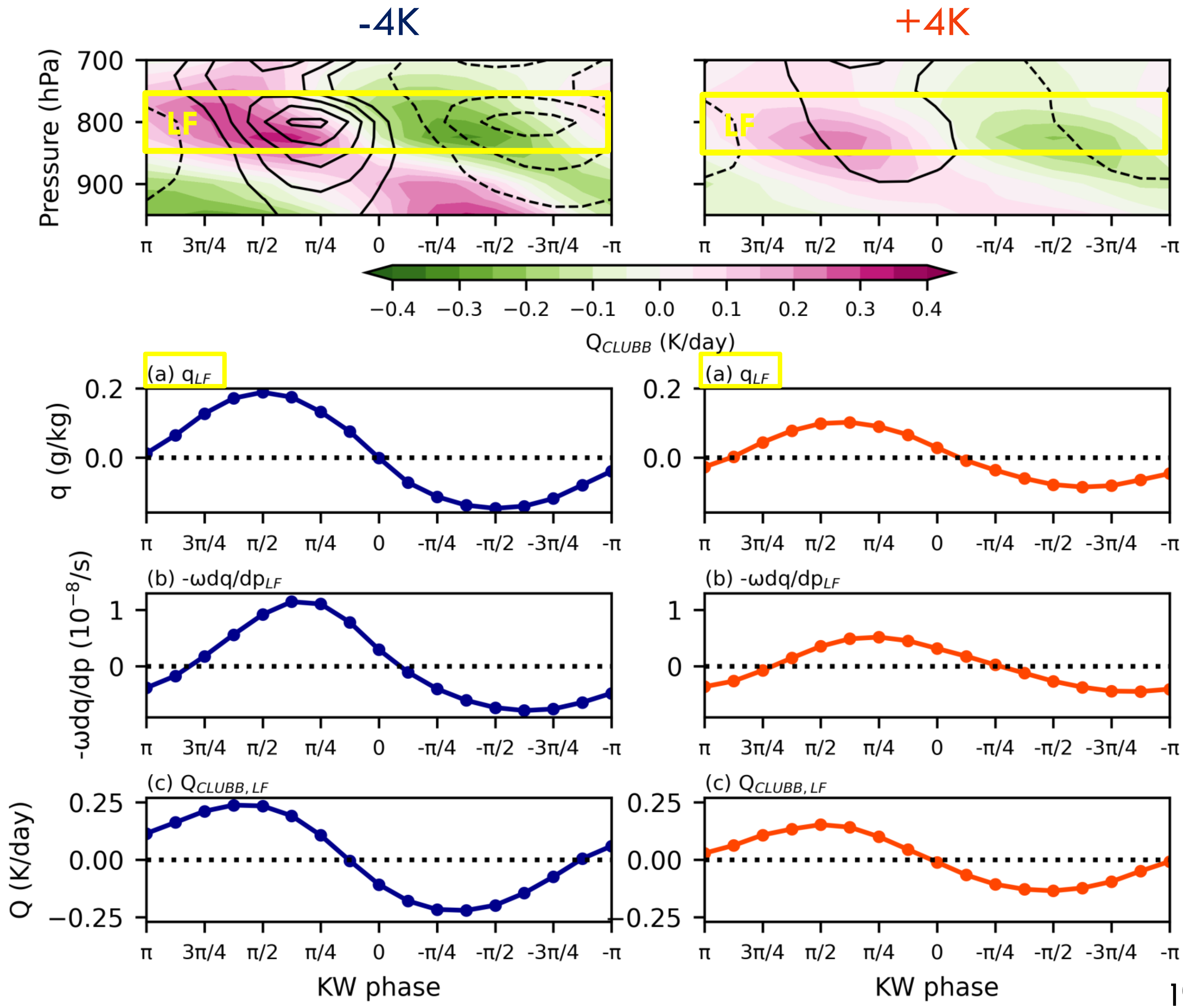
Shading: Diabatic heating from shallow convection scheme

Contour: $-\omega \frac{\partial q}{\partial p}$

Vertical advection of moisture is associated with shallow convection

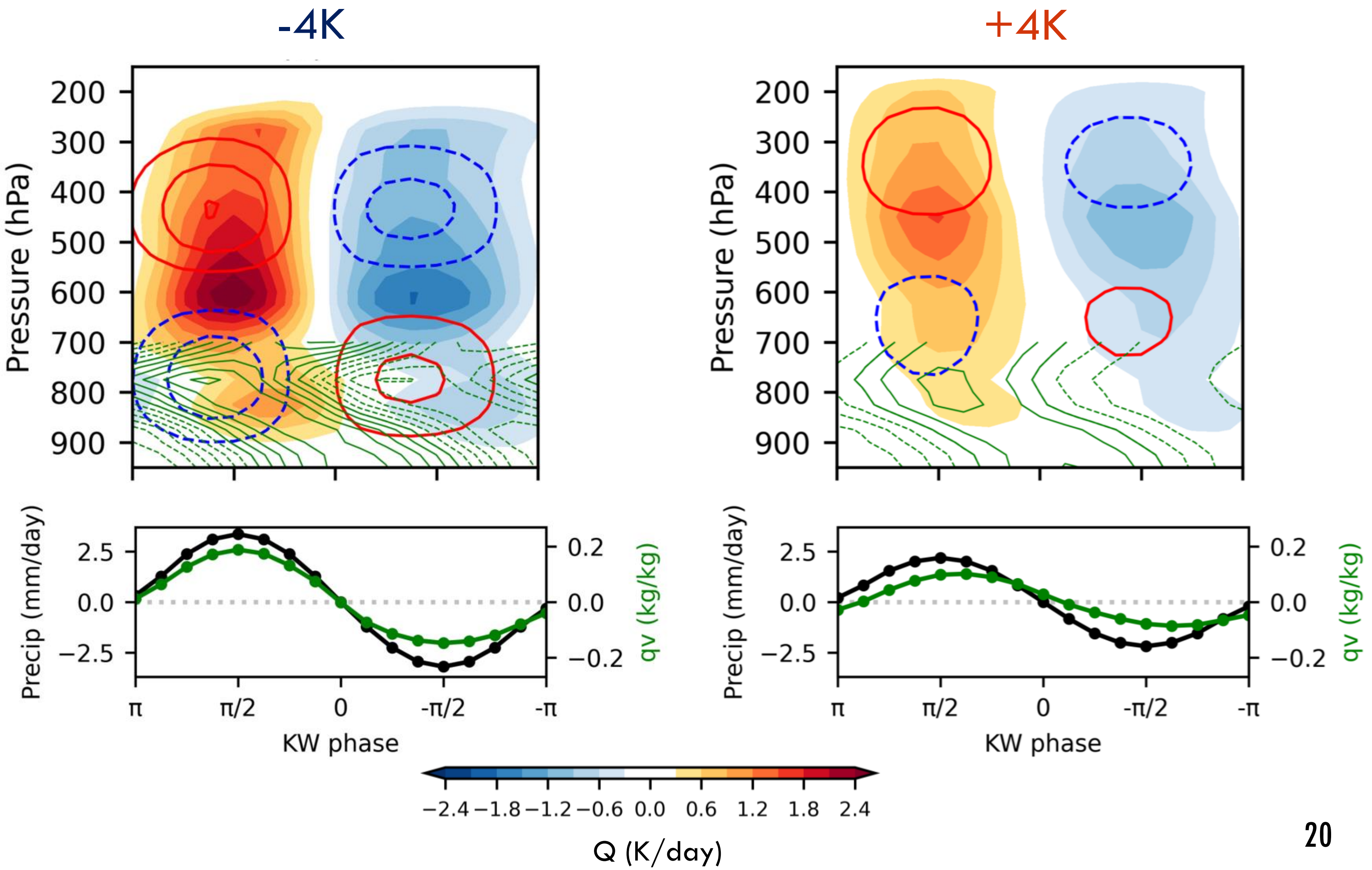
$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial p} - Q2$$

Vertical advection



Hypothesis on how the two modes are coupled and why the coupling weakens with warming

- Precipitation is in quasi-equilibrium with lower tropospheric moisture.
- Lower tropospheric moisture mostly comes from vertical transport from the boundary layer associated with shallow convection.
- Shallow convection weakens in a warmer climate, likely related to the rise of the melting level.



Summary, future work, and implications

1. We found that shallow convection which transports moisture upward from the boundary layer to the lower free troposphere is a key to the coupling between the first and second baroclinic modes. Weaker shallow convection in a warmer climate may be responsible for the decoupling of the two modes, which leads to the weakening and acceleration of KWs.

2. To test our hypothesis, we will run numerical experiments with nudging of moisture and temperature to the climatology in -4K.

3. Shallow convection moistening is neglected in previous simple models of KWs. We may need to incorporate this process in the simple model.