Impacts of the Diurnal Radiation Contrast on the Formation, Intensification and Structure of Hurricane Edouard (2014)

Impacts of the Diurnal Radiation Cycle on the Formation, Intensification and Structure of Hurricane Edouard (2014)

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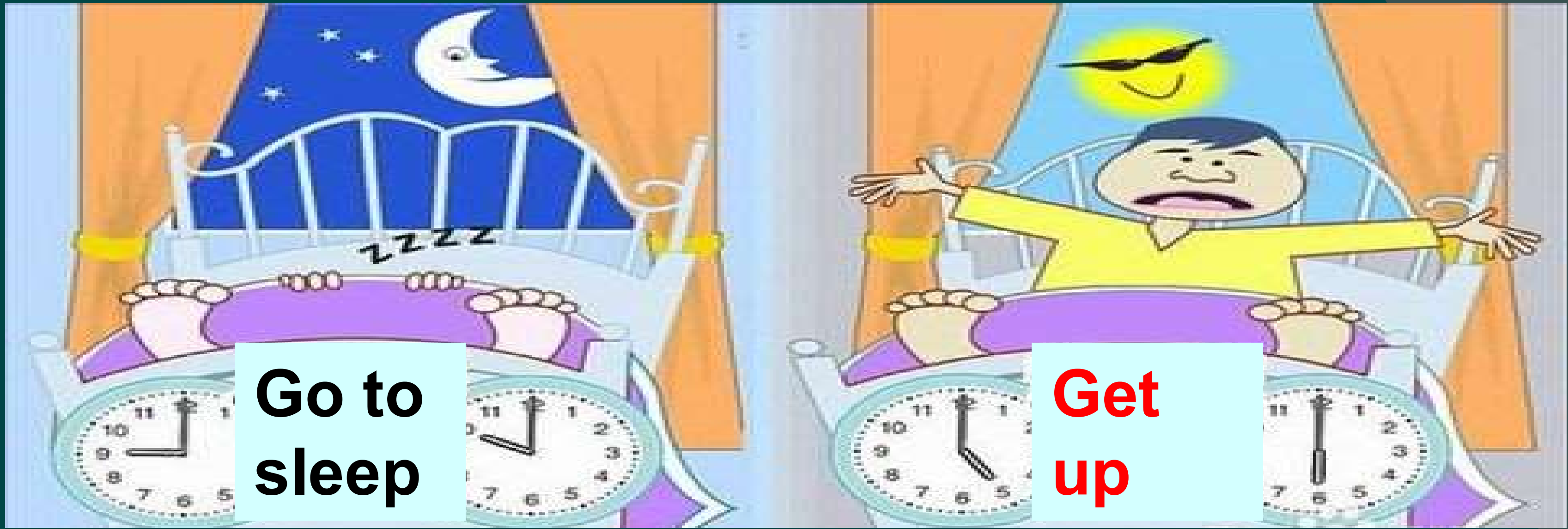
4. *Universities Space Research Association, USA*

28 June, 2018, Nanjing, China



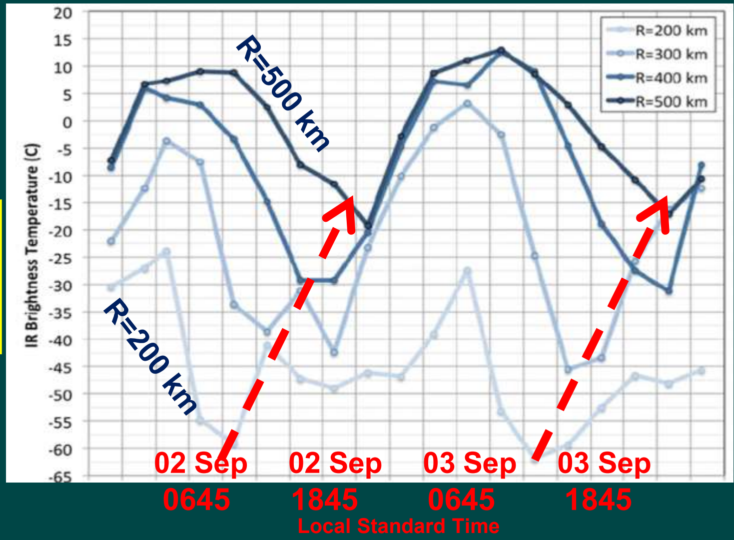
To dance or not to dance, that's the question!

Outline

- Motivation and experimental design
- Verification of diurnal cycle
- Impacts on the TC formation
- Impacts on the RMW contraction
- Impacts on the secondary eyewall formation
- Conclusions

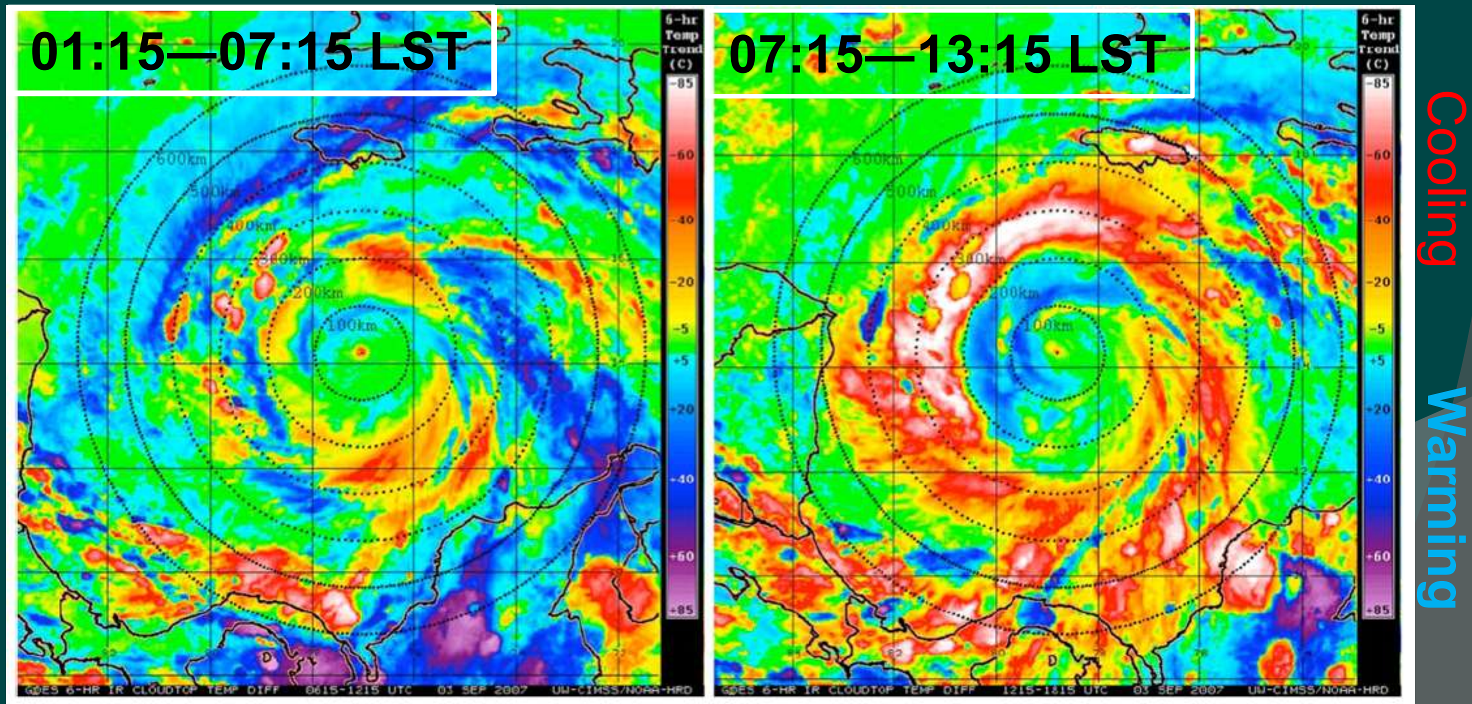
Tropical Cyclone Diurnal Cycle

IR brightness temperature



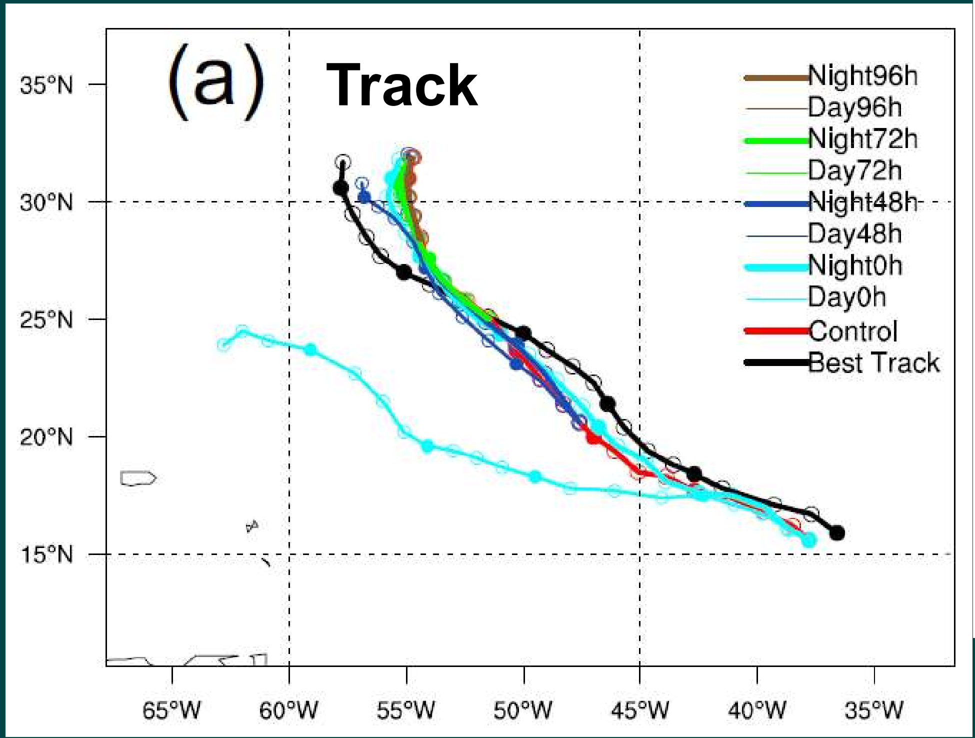
Diurnal pulses begin forming in the inner core near sunset each day, and move outwards overnight, reaching several hundred kilometers away by the following afternoon.

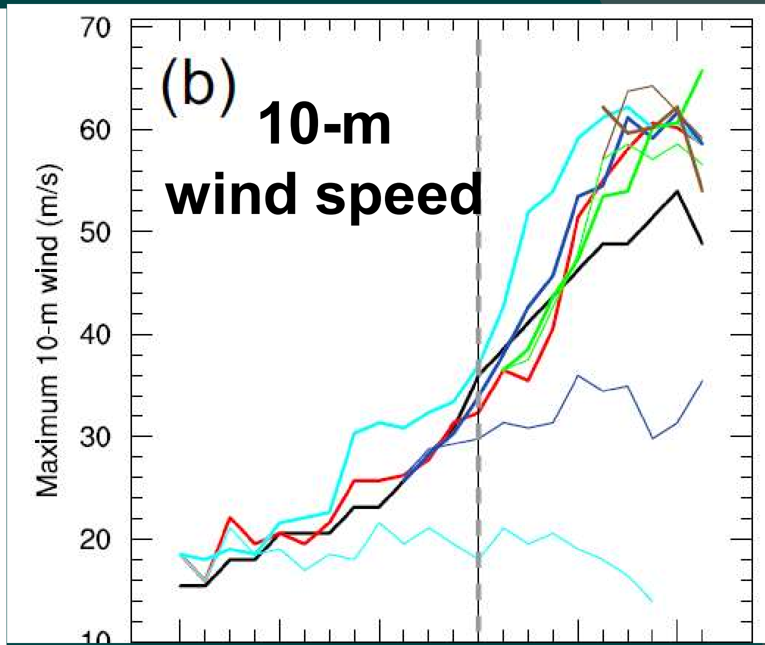
6-hr IR Temperature Trend

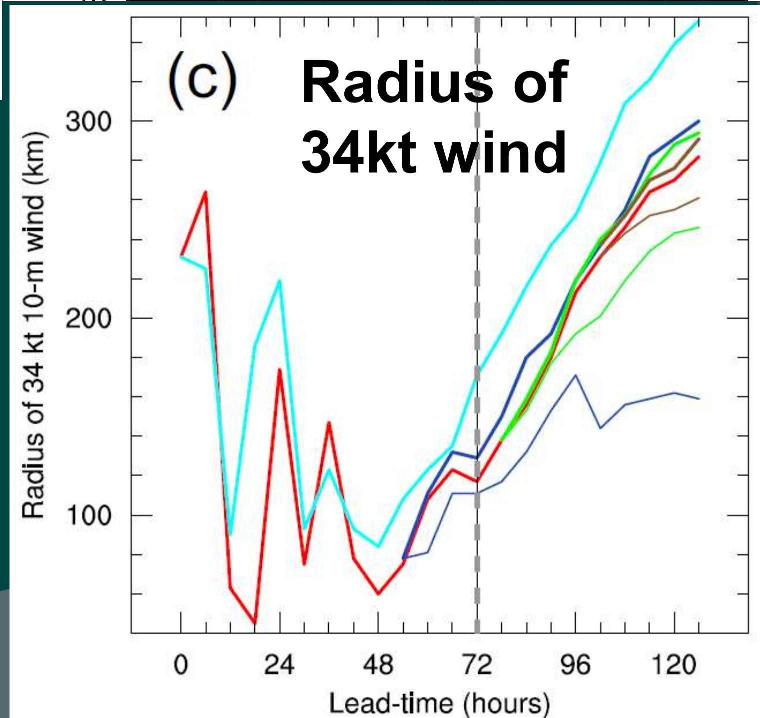


(Dunion et al. 2014) **Hurricane Felix (2007)**

Experimental design







CONTROL: normal diurnal cycle
DayOnly (ConstSolarRad): solar insolation fixed at noon
NightOnly (NoSolarRad): no solar insolation

Outline

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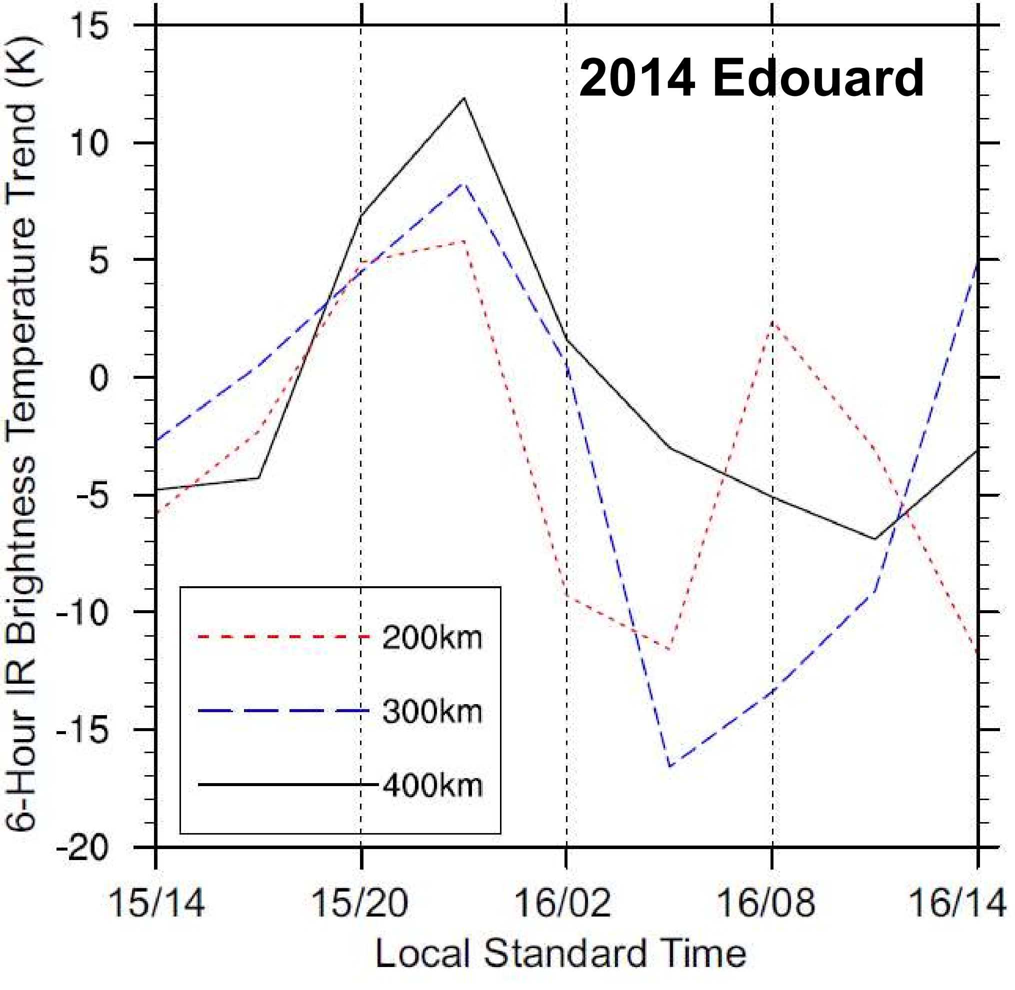
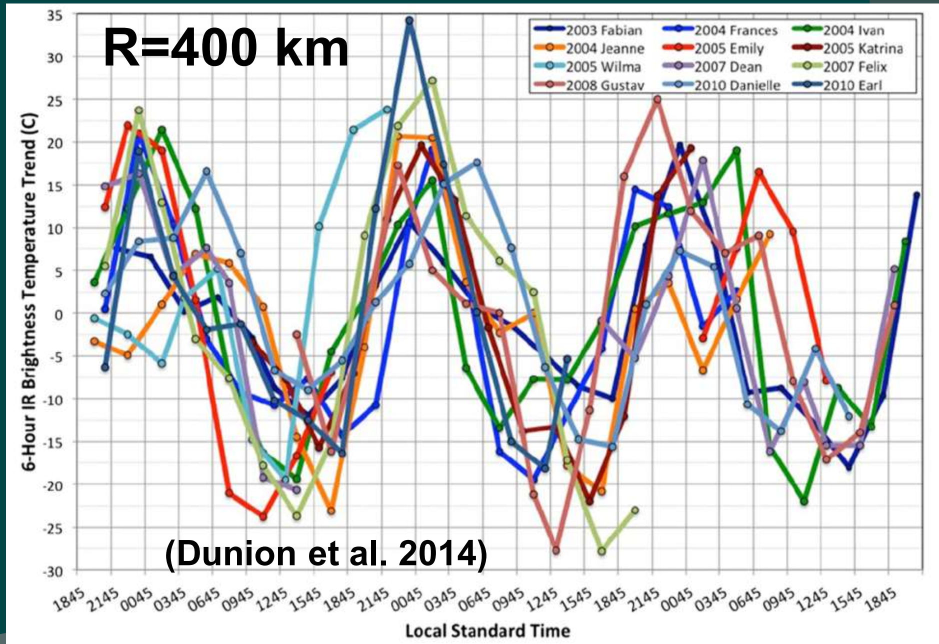
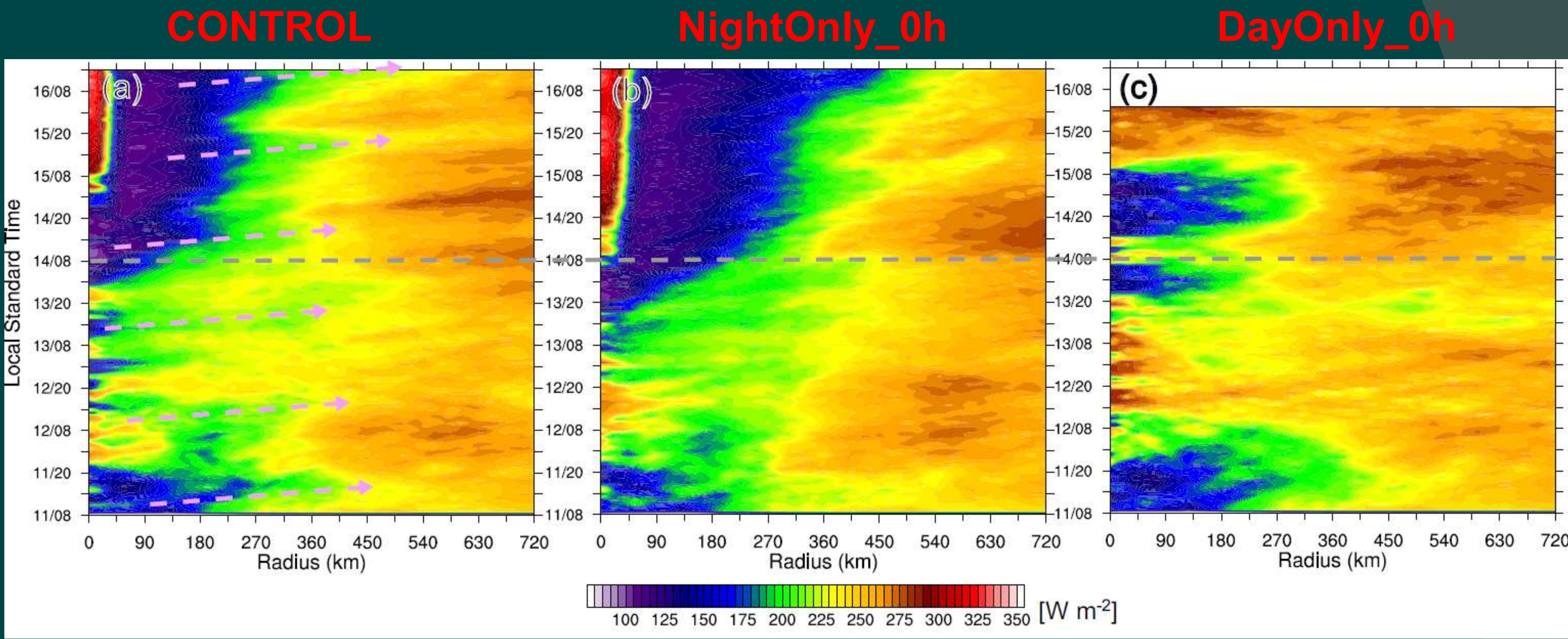
Simulated diurnal cycle of Hurricane Edouard



Diurnal pulses move outwards, reaching several hundred kilometers away by the following afternoon



Diurnal Variation of OLR (Outgoing Longwave Radiation)



✓Apparent outwards propagation of diurnal pulses in CNTL
✓No diurnal cycle in NightOnly or DayOnly experiments

Outline

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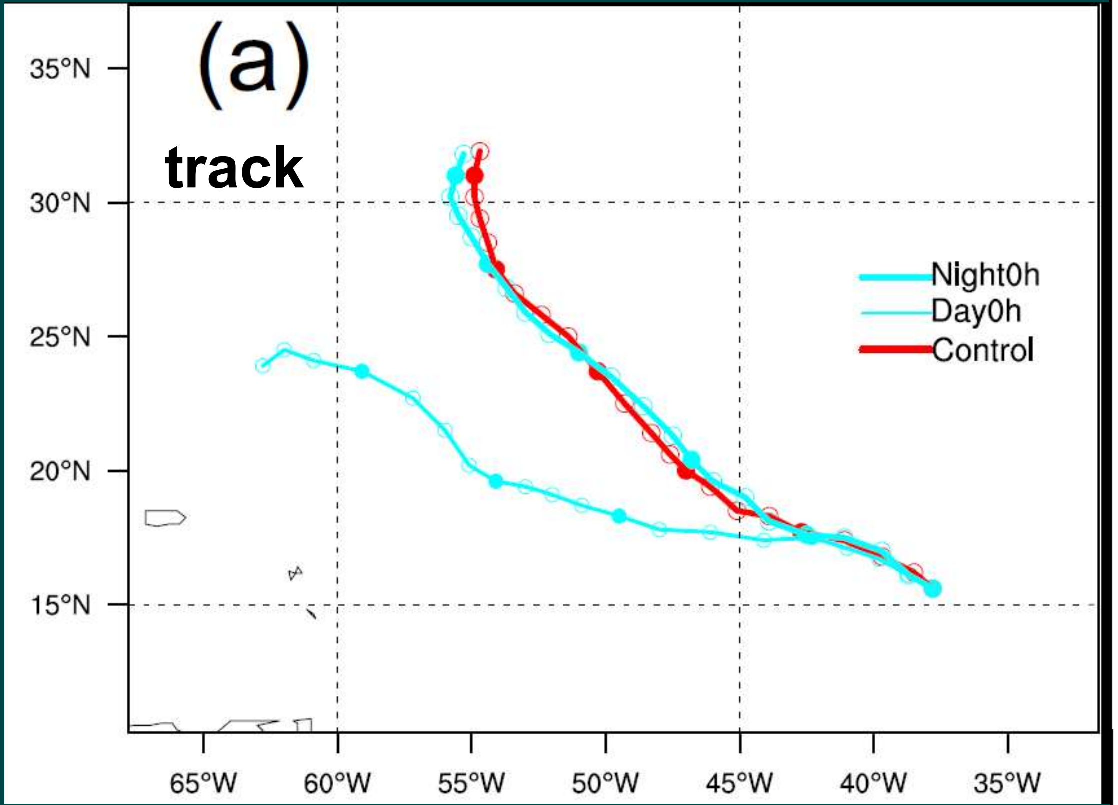
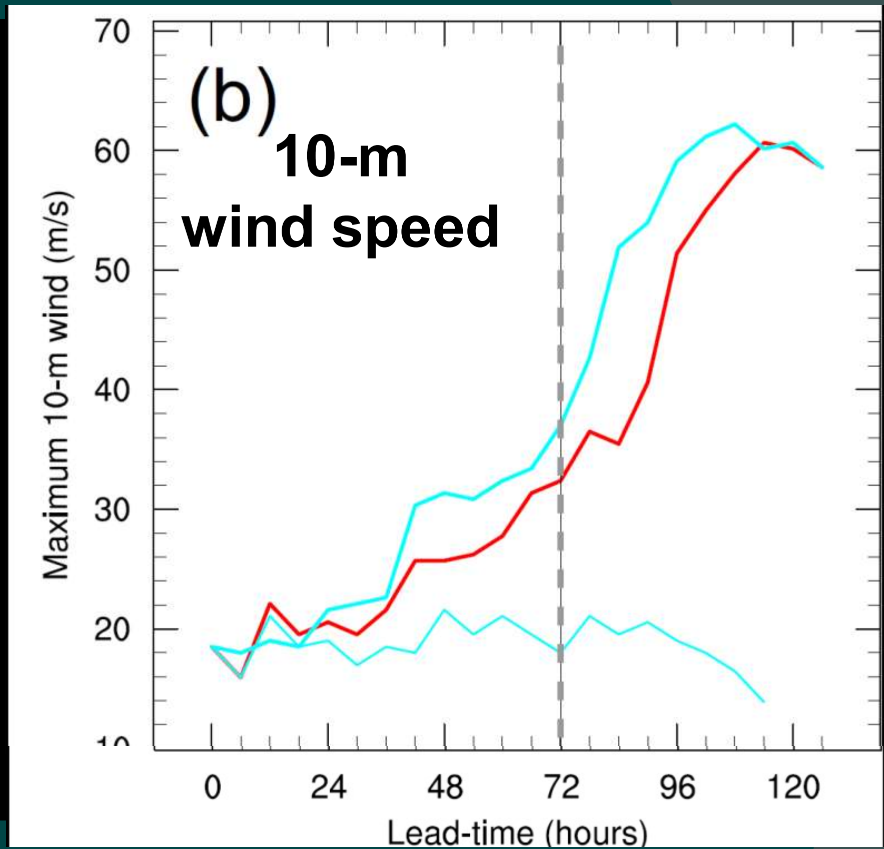
Impact of solar radiation cycle on Edouard's formation



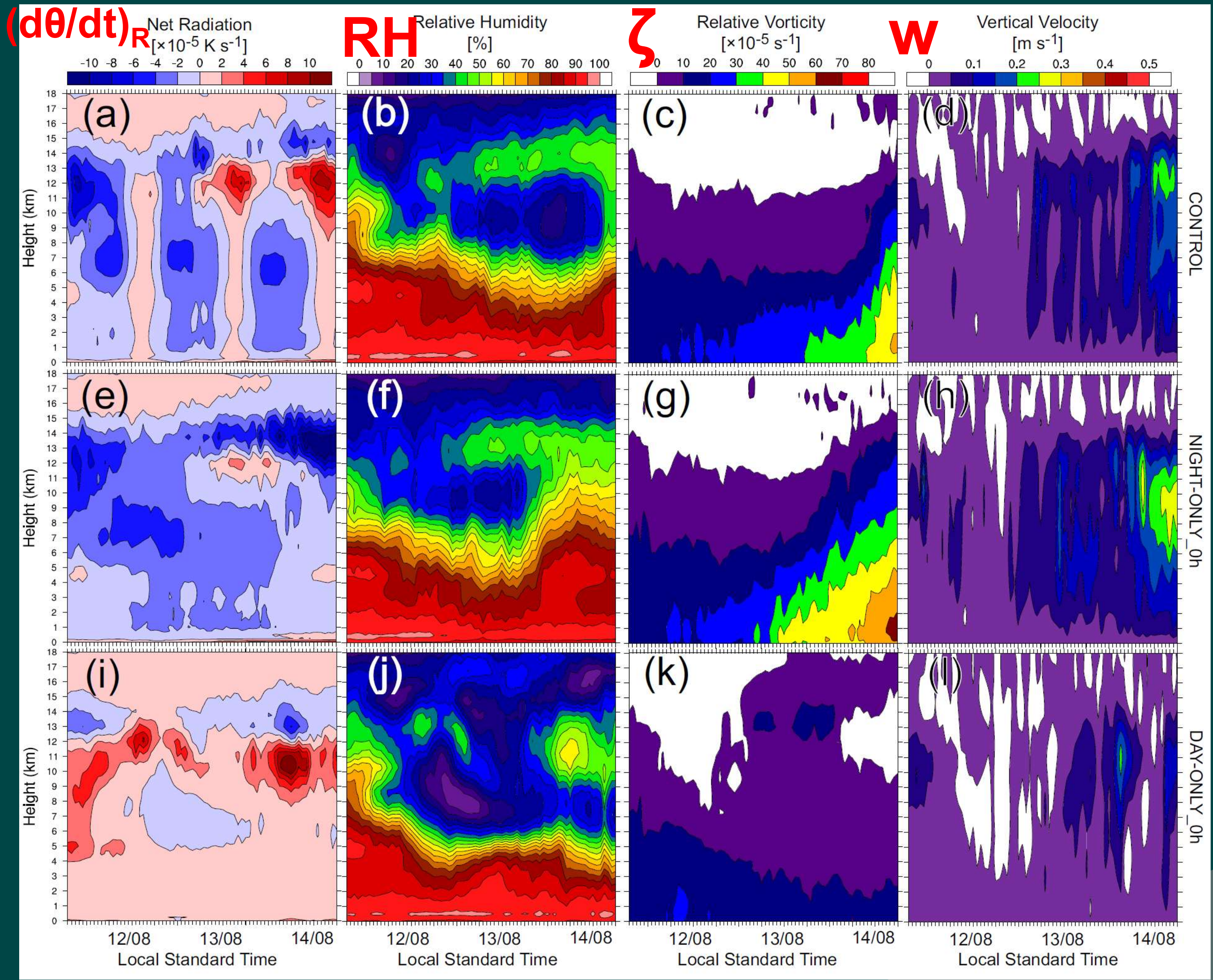


✓DayOnly0h didn't develop, tropical low drifted far leftward of observed track

✓CONTROL and NightOnly0h both develop

✓Net nighttime radiative cooling crucial for the storm's formation

Net nighttime radiative cooling role to the storm's formation



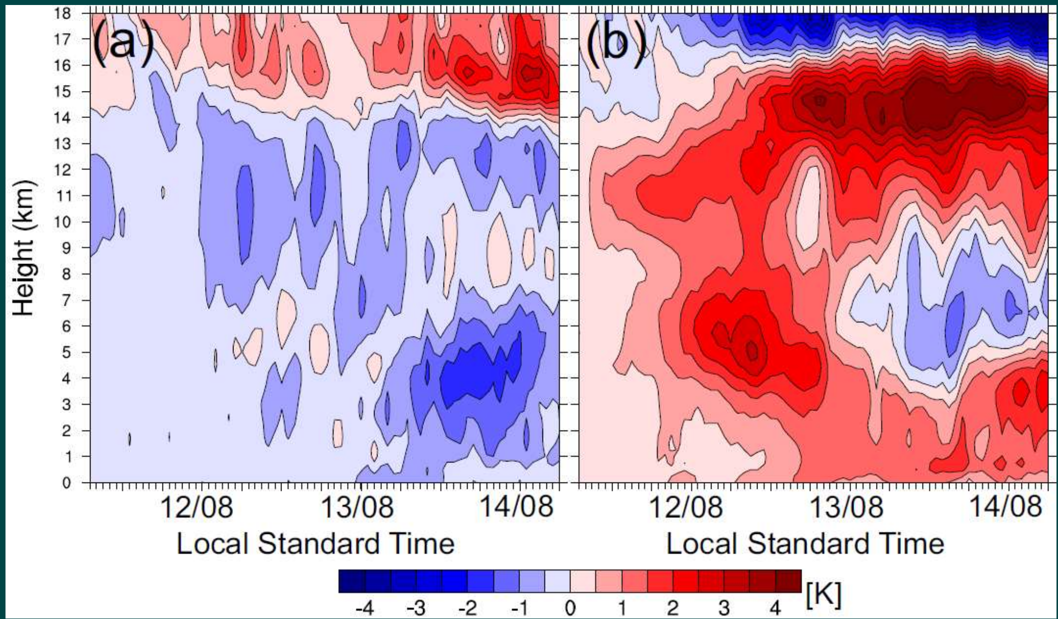
Net nighttime radiation cooling leads to lower T and higher RH

→ Enhancement of moist convection in nighttime

→ Enhancement of the low-level vorticity and upper-level updraft in NightOnly

Net nighttime radiative cooling role to the storm's formation

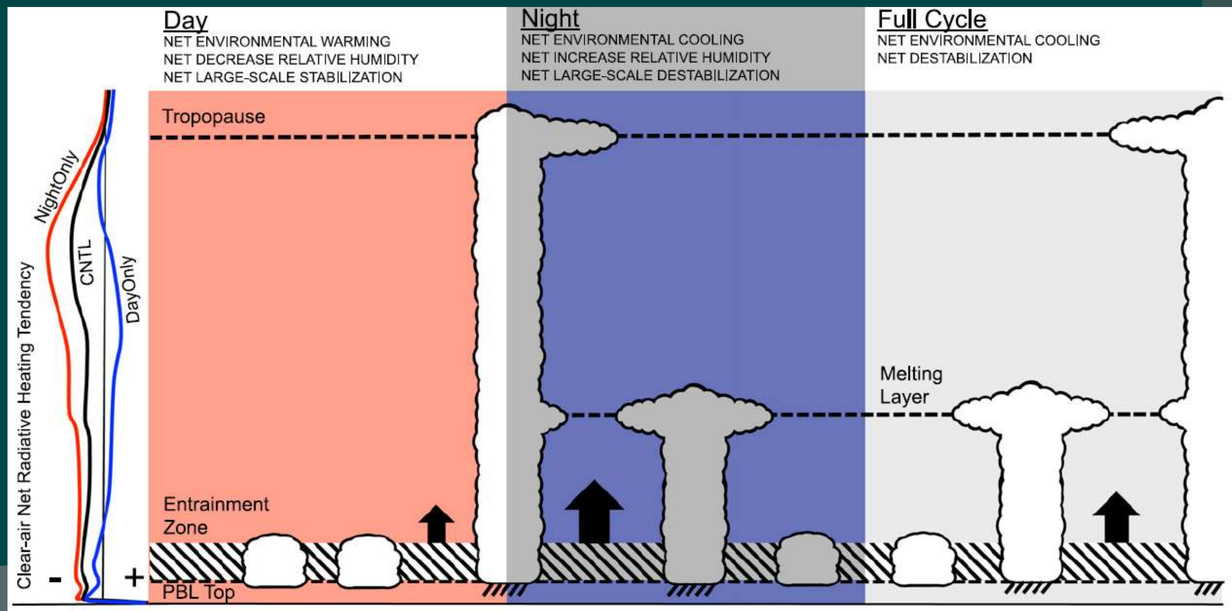
NightOnly_0h **DayOnly_0h**



Temperature difference with CNTL

- **Lower/higher temperature in the low to middle levels for the NightOny/DayOnly.**

Nighttime radiative cooling → destabilize the local and large-scale environment →
deep moist convection →
increase the genesis potential



(Melhauser and Zhang 2014)

Outline

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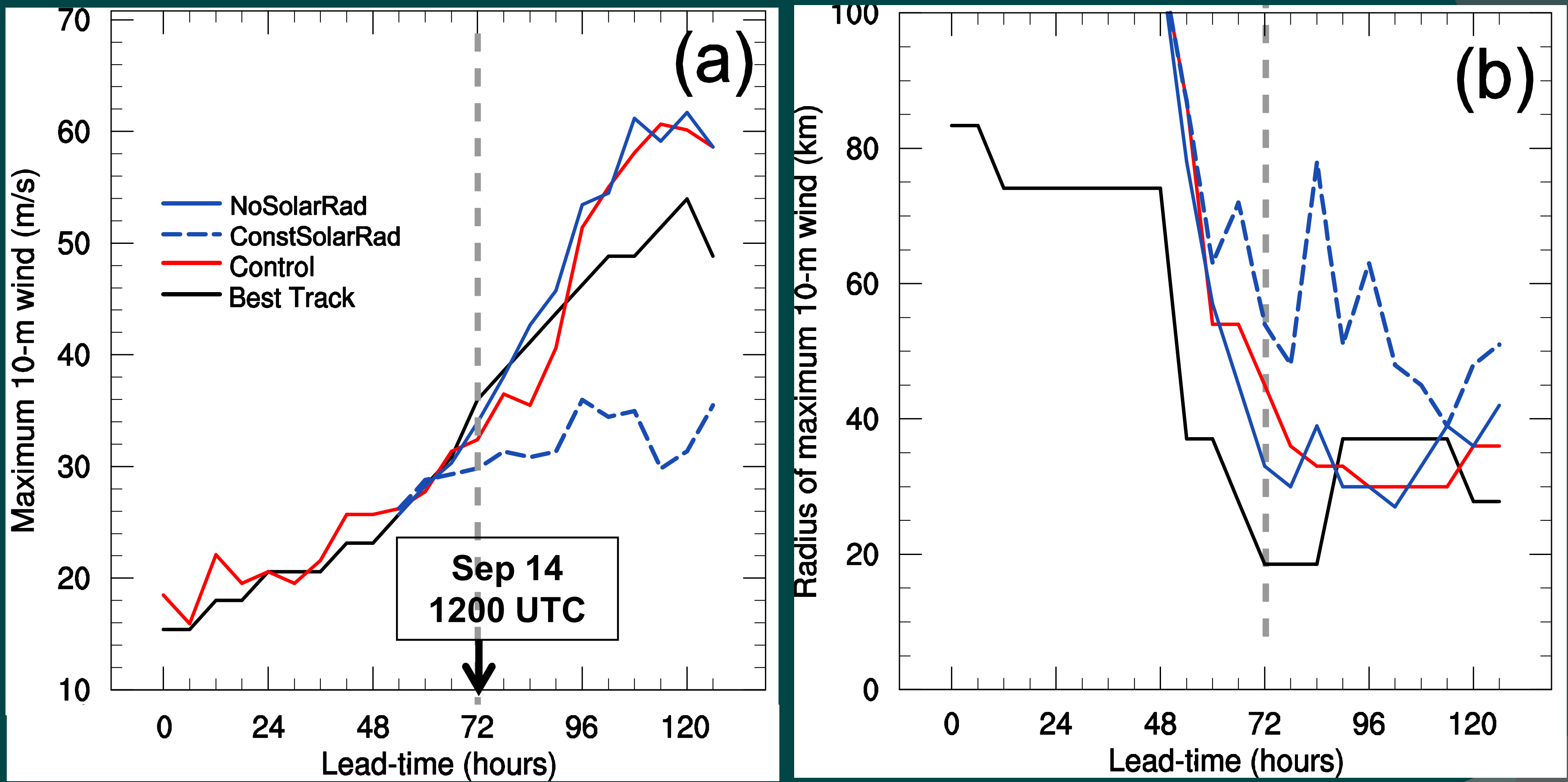
Impact of Diurnal Cycle on RMW Contraction

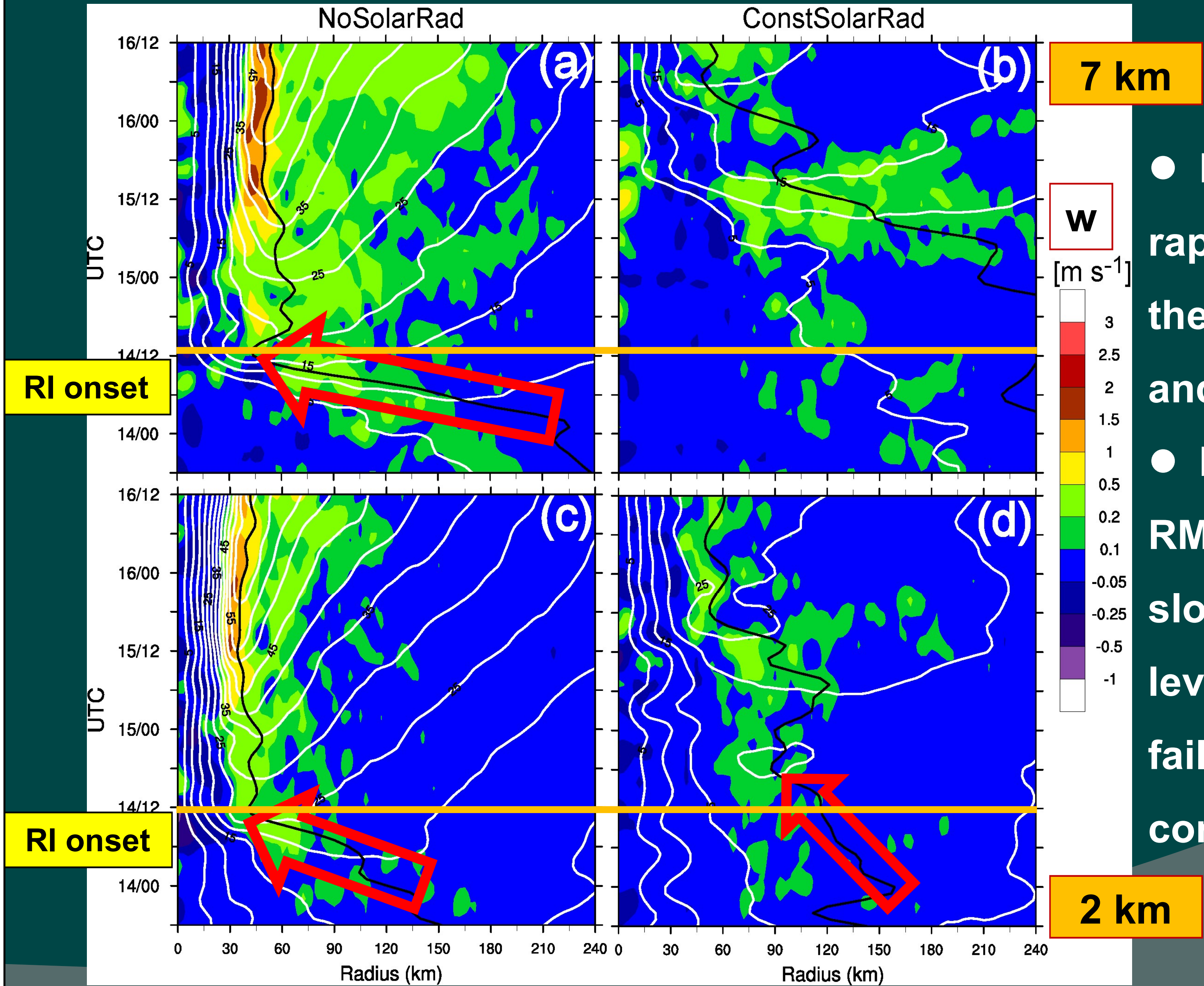


Control: actural diurnal cycle

ConstSolarRad: solar insolation fixed at noon

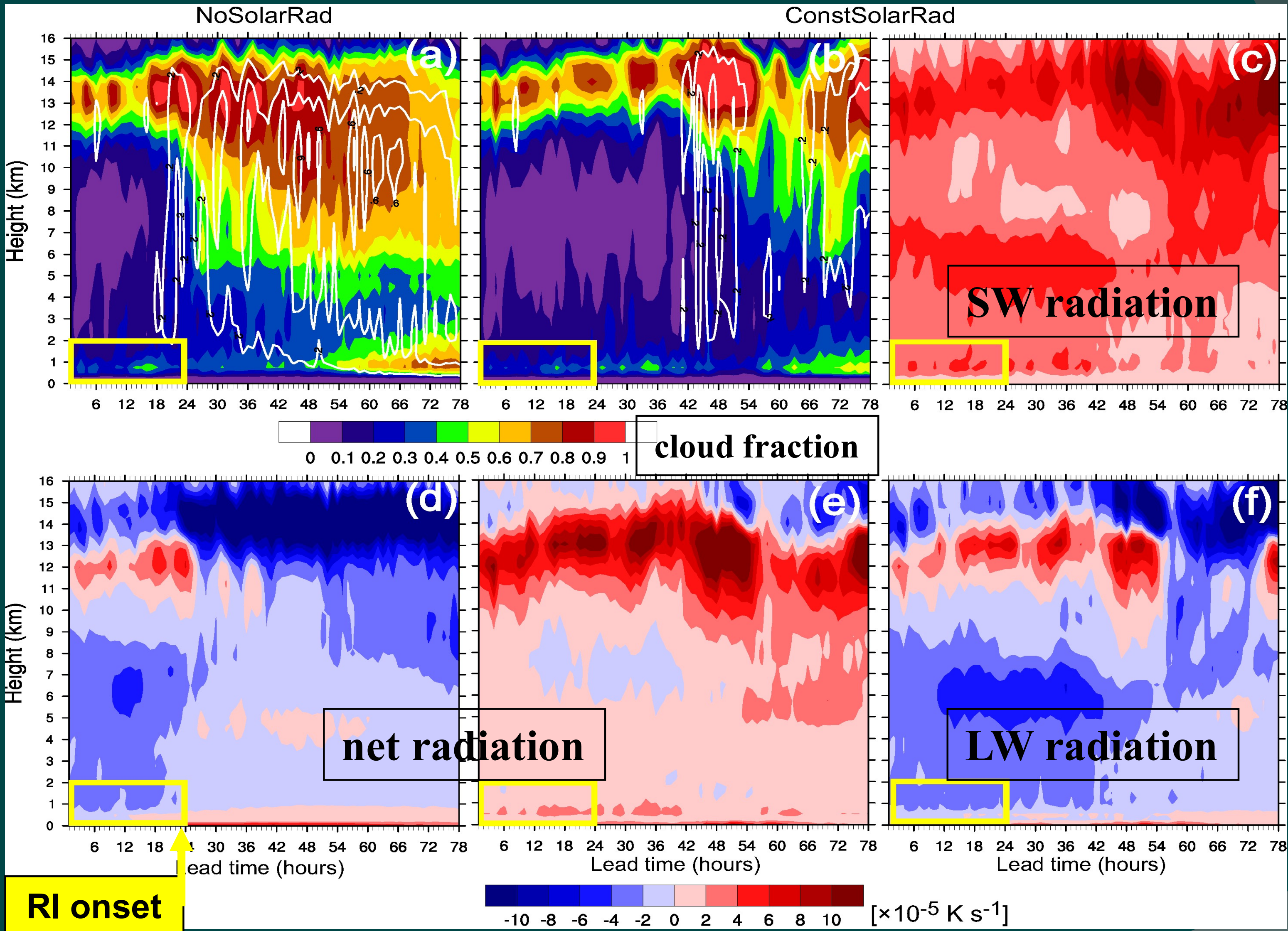
NoSolarRad: no solar insolation

RMW Contraction:
Evolution of vertical and tangential velocity



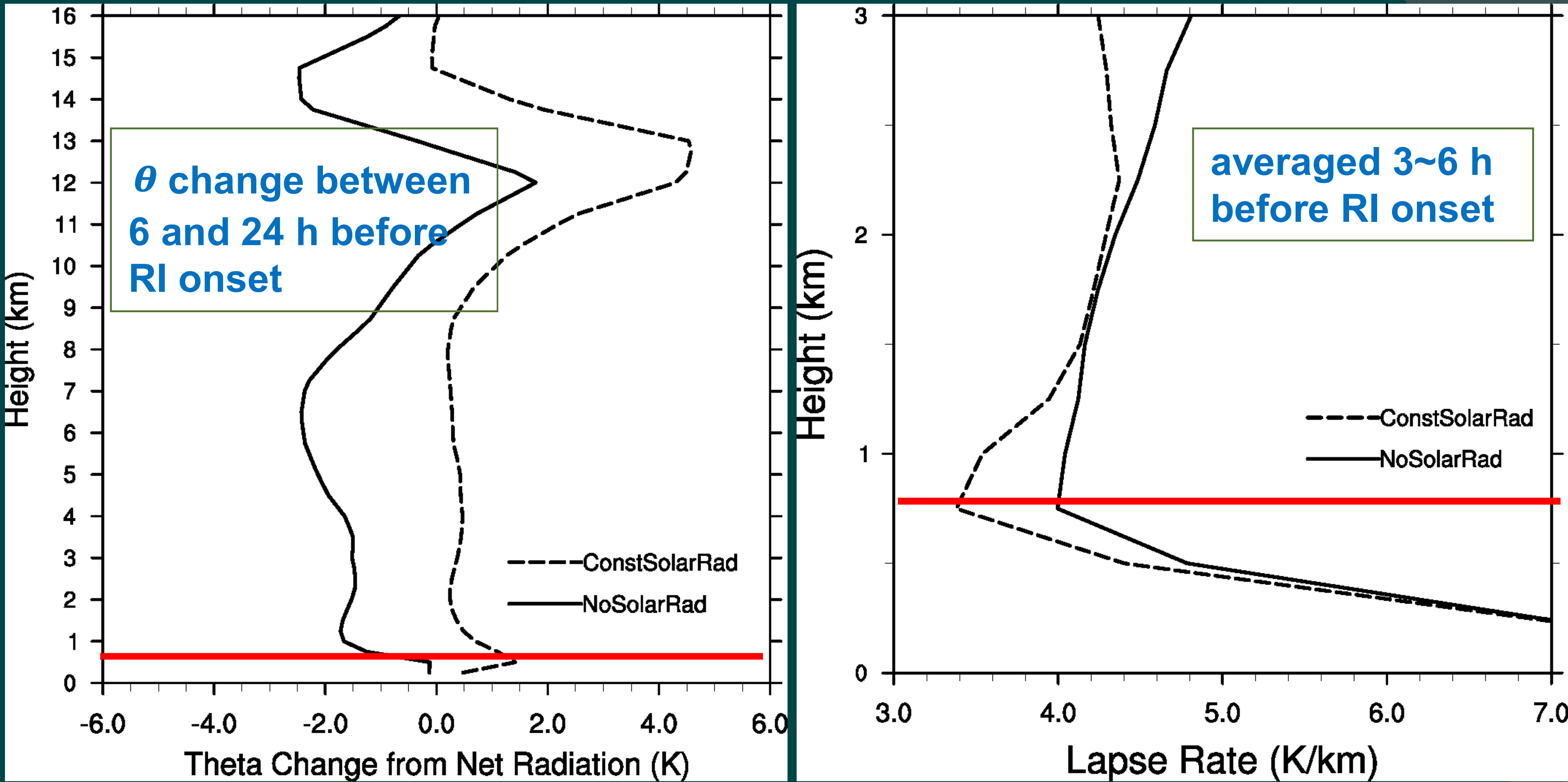
- For NoSolarRad, rapid contraction of the RMW in the low- and mid-levels
- In ConstSolarRad, RMW contracts more slowly only in the low-levels and thereafter fails to intensify continuously

Radiative impacts on inner-core (30 km <R< 90km) convection



- In ConstSolarRad, the clouds at the BL top absorbed solar shortwave radiation at daytime, with net radiative heating
- In the NoSolarRad, net radiative cooling occurred

Radiative impacts on inner-core lapse rate

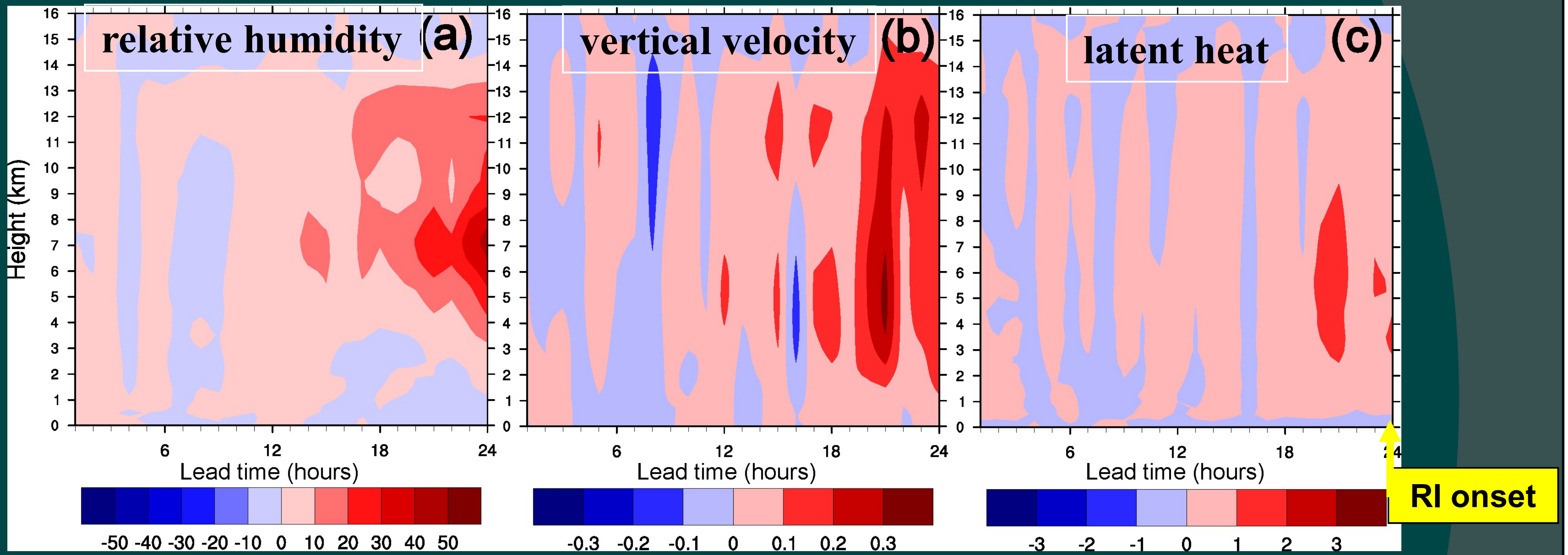


ConstSolarRad:

the vertical gradient of net radiative heating across the BL top →
increasing potential of capping inversion layer (i.e. convective inhibition) →
preventing moist convection

Radiative impacts on difference of inner-core latent heat

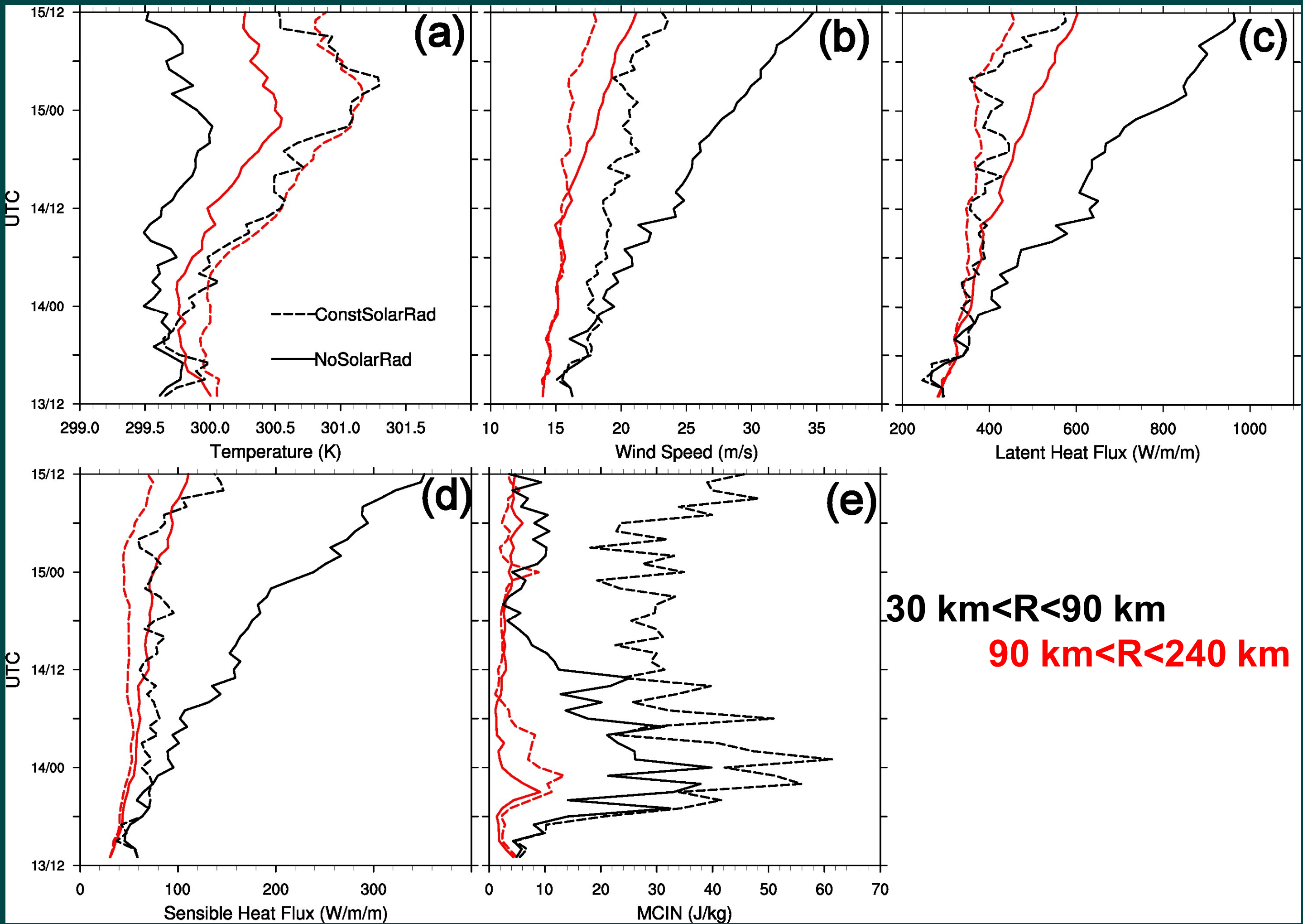
NoSolarRad − ConstSolarRad (30 km < R < 90 km)



NoSolarRad:

lower potential temperature →
greater relative humidity at mid- to upper-levels →
enhancing deep moist convection →
more latent heat release →
more rapid eyewall contraction and intensification

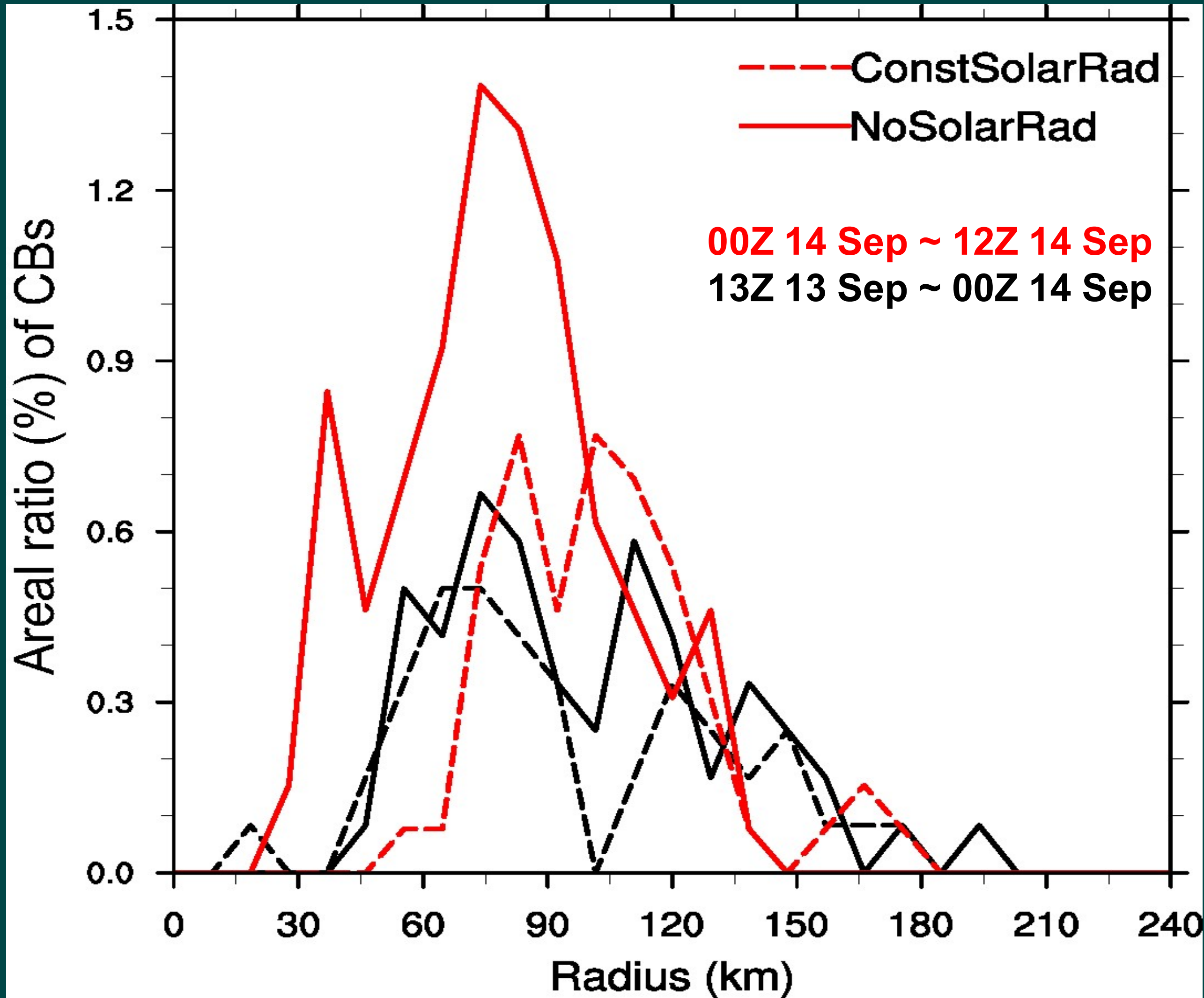
Radiative impacts on WISHE feedback



ConstSolarRad:

- Heated surface air weakens WISHE feedback between the surface fluxes (that promote convection) and the circulation.
- The differences of surface flux and wind speed between NoSolarRad and ConstSolarRad are larger in the inner core
- Convective inhibition is much larger in the inner core

Radiative impacts on convective bursts (CBs)

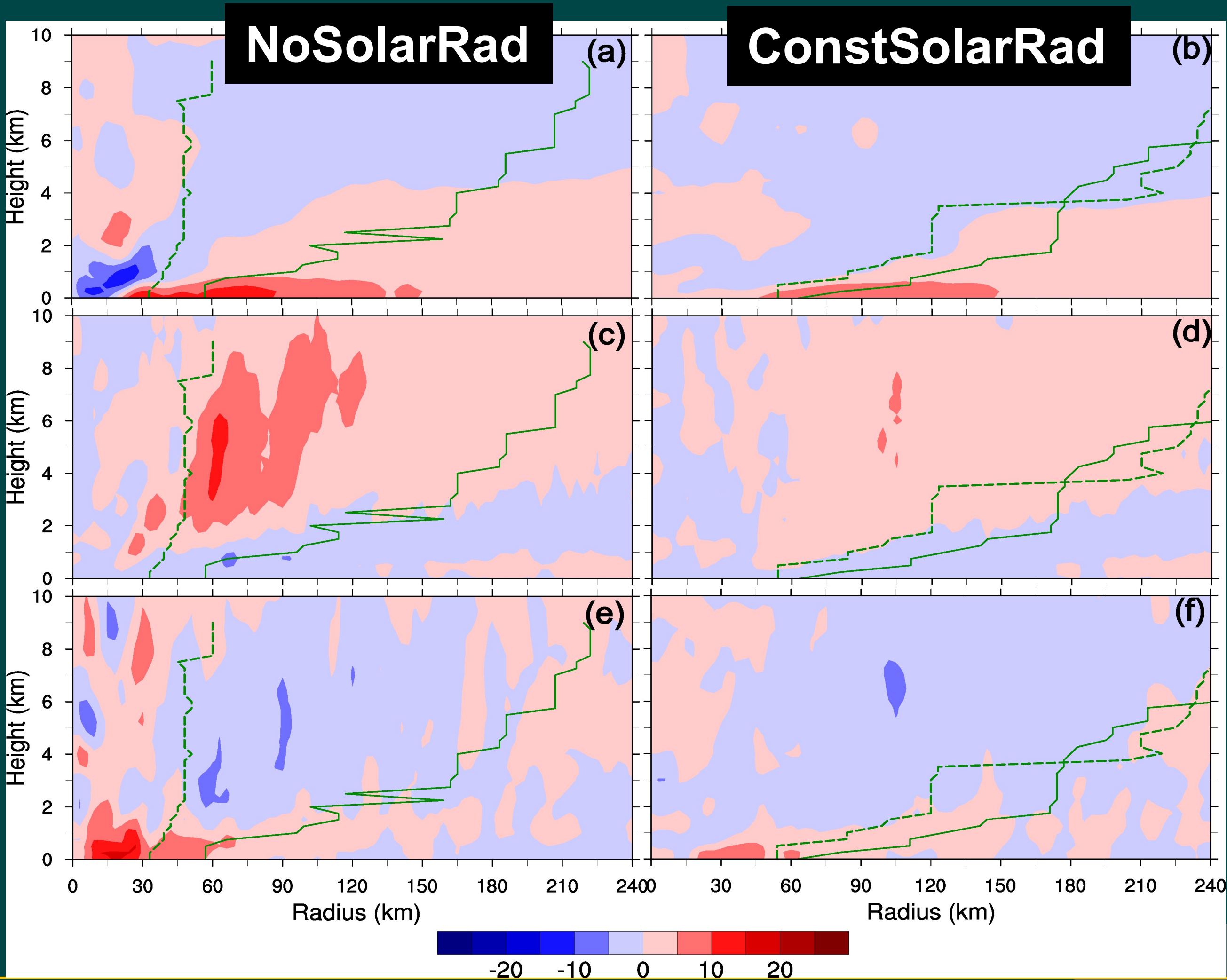


- In NoSolarRad, the areal percentage of CBs increased in the inner core and decreased in the outer core before RI onset
- In ConstSolarRad, the CBs decreased inside 70 km radius, which resulted in the much less CBs inside 90 km

Budget analysis of the tangential wind tendency

$$\frac{\partial \bar{v}}{\partial t} = -\bar{u}(f+\bar{\zeta}) - \bar{w}\frac{\partial \bar{v}}{\partial z} - \overline{u'\zeta'} - \overline{w'\frac{\partial v'}{\partial z}} + \bar{F}$$

00Z 14 Sep ~ 12Z 14 Sep



$-\bar{u}(f+\bar{\zeta})$

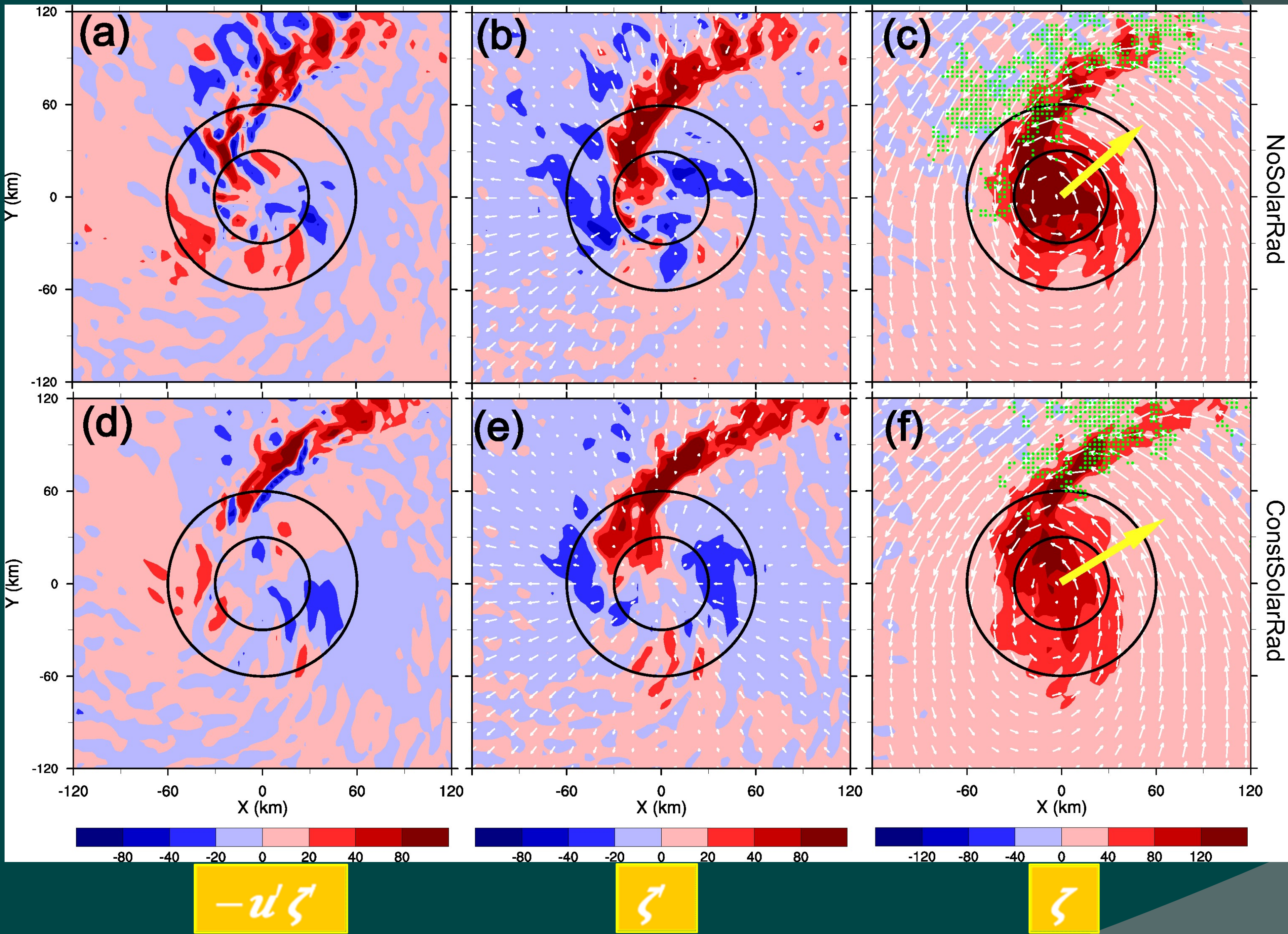
$-\bar{w}\frac{\partial \bar{v}}{\partial z} - \overline{w'\frac{\partial v'}{\partial z}}$

$-\overline{u'\zeta'}$

NoSolarRad:

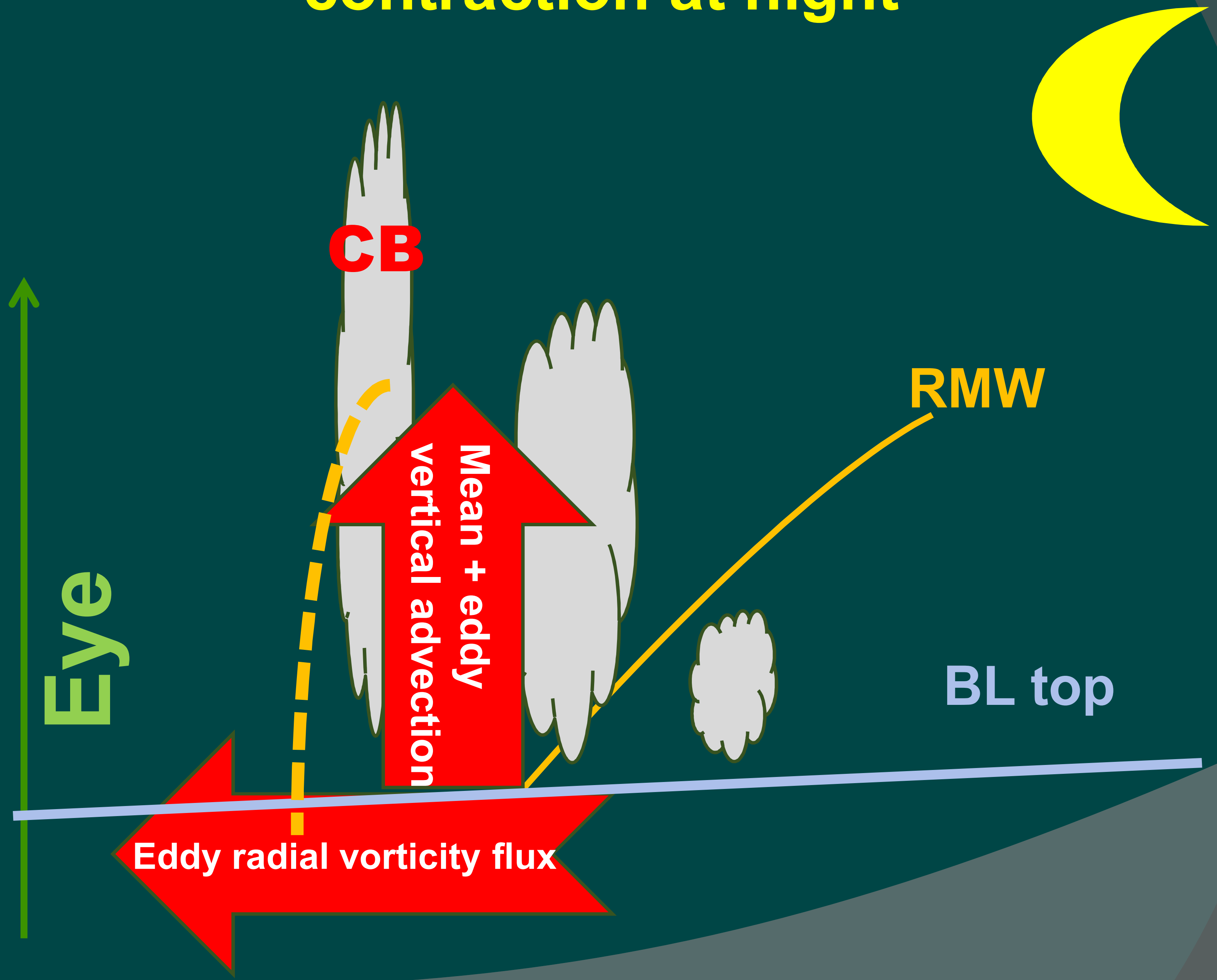
- RMW contraction below about 1 km ← radial eddy vorticity flux
- RMW contraction in the mid-levels ← the sum of mean and eddy vertical advection of tangential wind

Analysis of radial eddy vorticity flux near surface (250 m)



Stronger positive eddy vorticity flux in the downshear-left quadrant inside the RMW of about 60 km for NoSolarRad than ConstSolarRad, collocating with the location of CBs

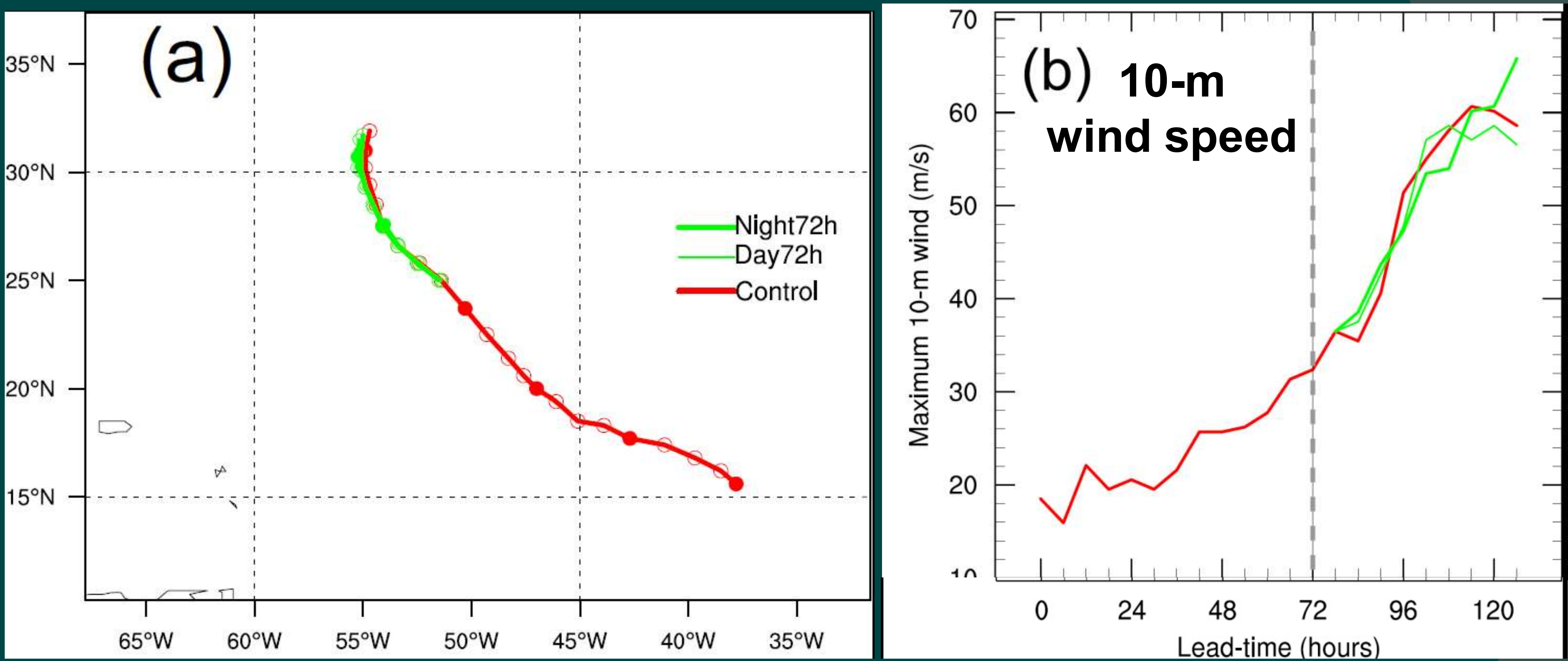
A conceptual model for more rapid RMW contraction at night



Outline

- Motivation and experimental design
- Verification of simulations
- Impacts on the TC formation
- Impacts on the RMW contraction
- Impacts on the secondary eyewall formation
- Conclusions

Impact of diurnal radiation on the mature hurricane

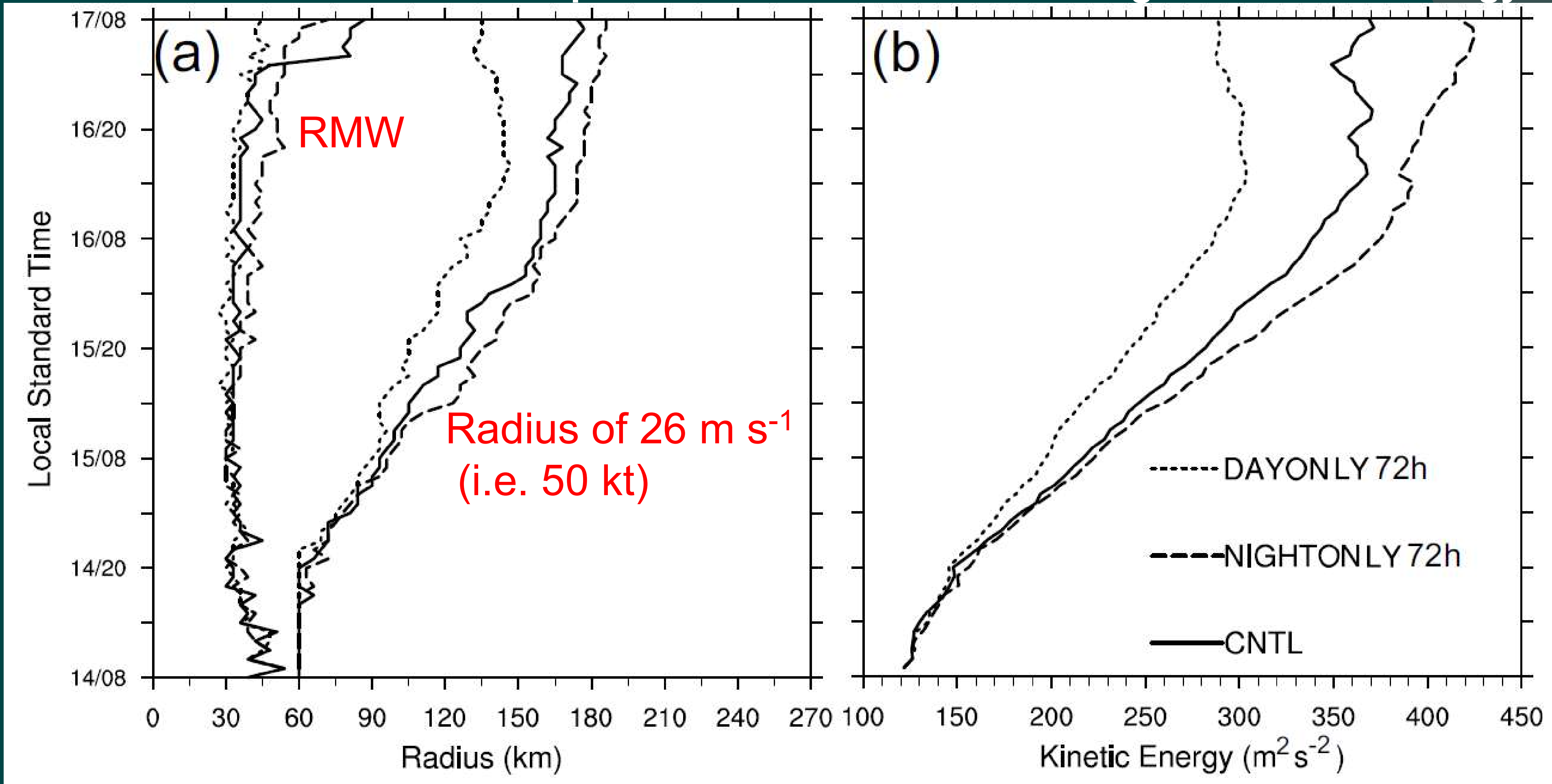


✓**After RI, little impact on track, maximum wind speed and SLP**

✓**However, considerable change in structure and outer rainband (next slides)**

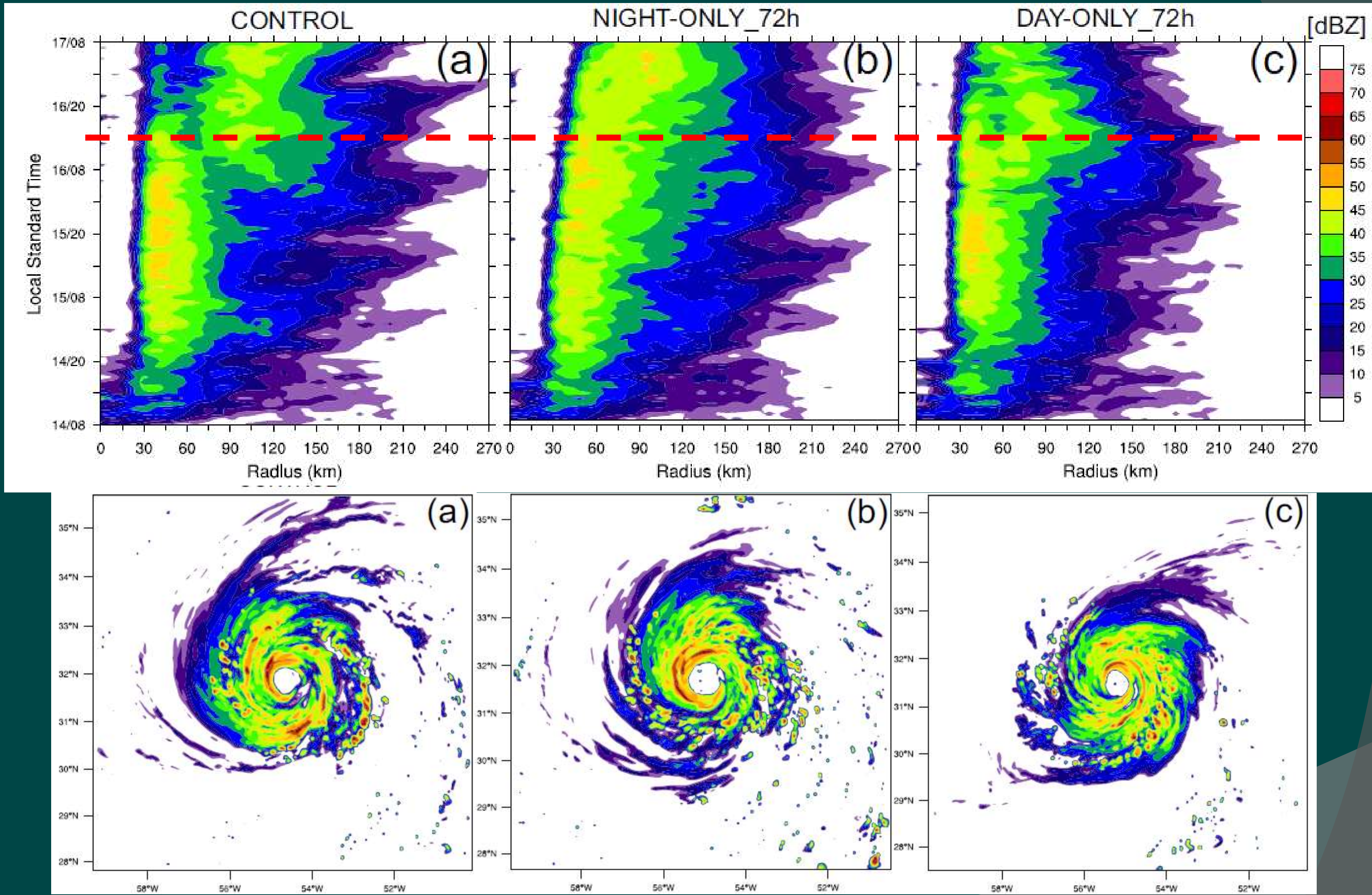
Different size and strength of mature hurricane

Size wrt. 10-m wind speed | **Volume-averaged kinematic energy**



at 10-m level within radius of 270 km

Different structure and rainband of mature hurricane
radar reflectivity

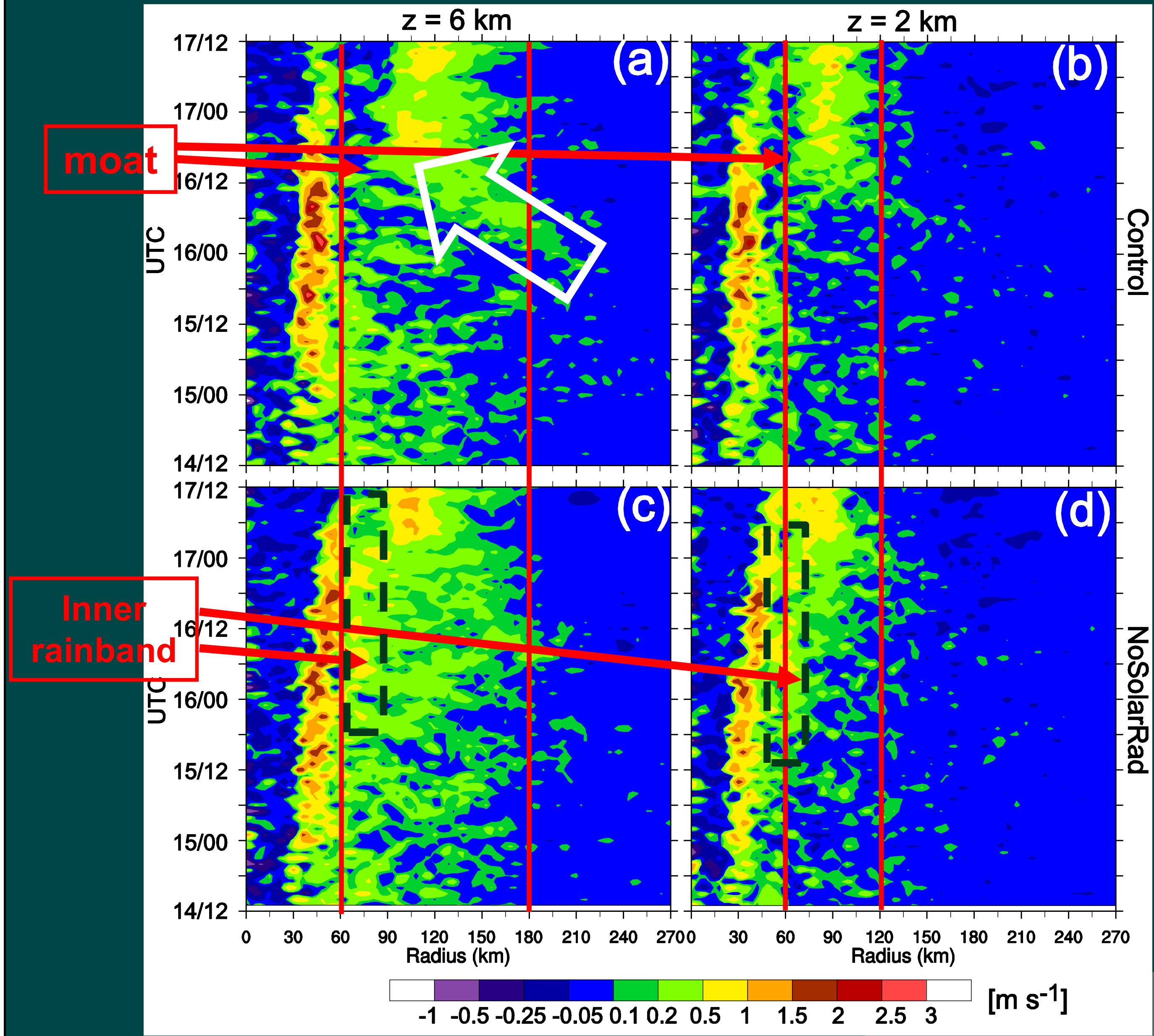


✓**Control run: Secondary eyewall formation as observed**

✓**NightOnly: Stronger strength and bigger size, bigger eye, no SEF**

✓**DayOnly: Narrower moat**

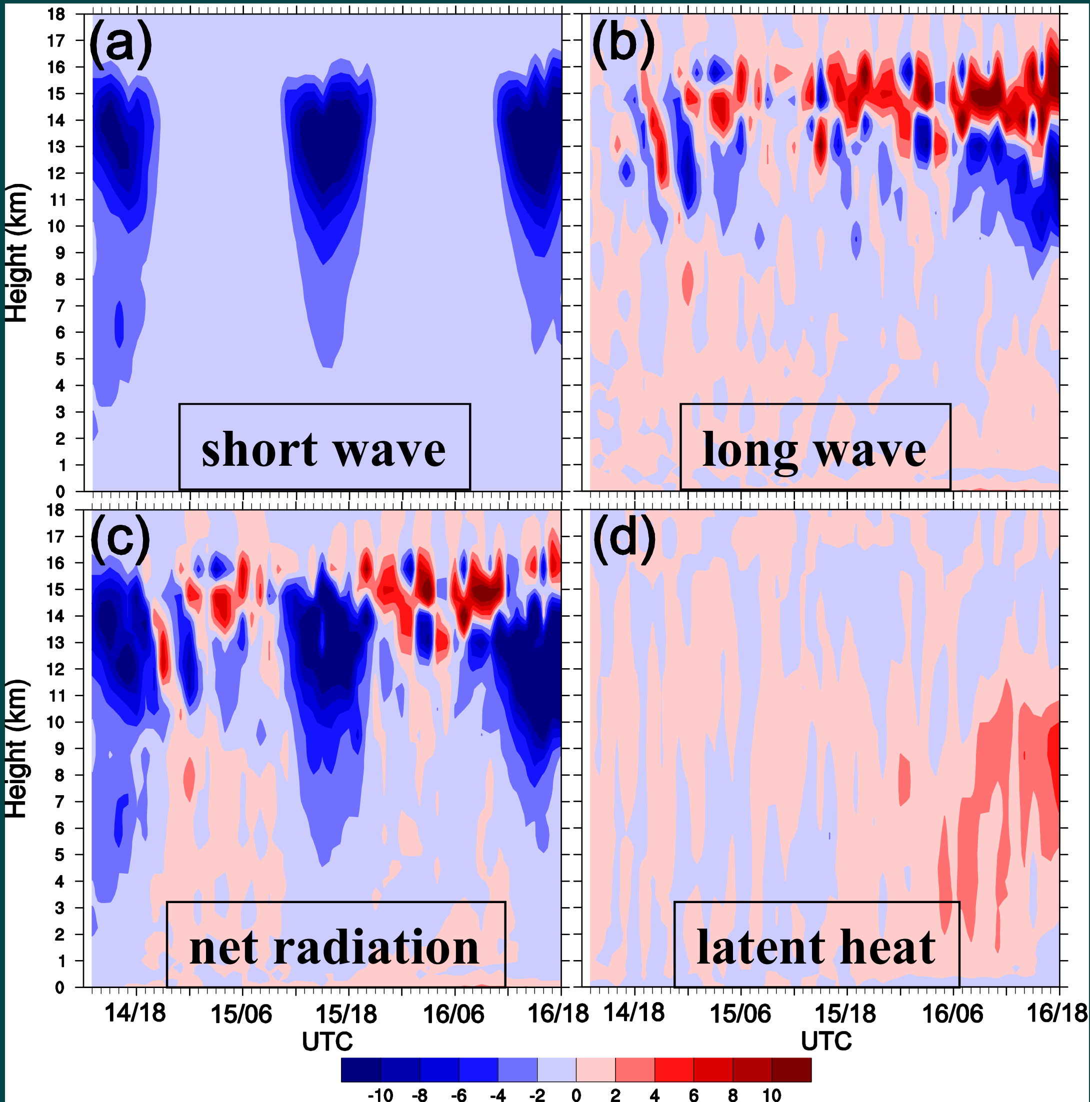
Evolution of vertical velocity



- The outer-core (outside the radius of 150 km) upward motion at mid-level in CNTL became more organized, and began to move inward
- Clear moat formation and SEF
- The latent heating released from more convective activities in the inner rainbands outside of primary eyewall in NoSolarRad

Radiative effects on moat formation and SEF

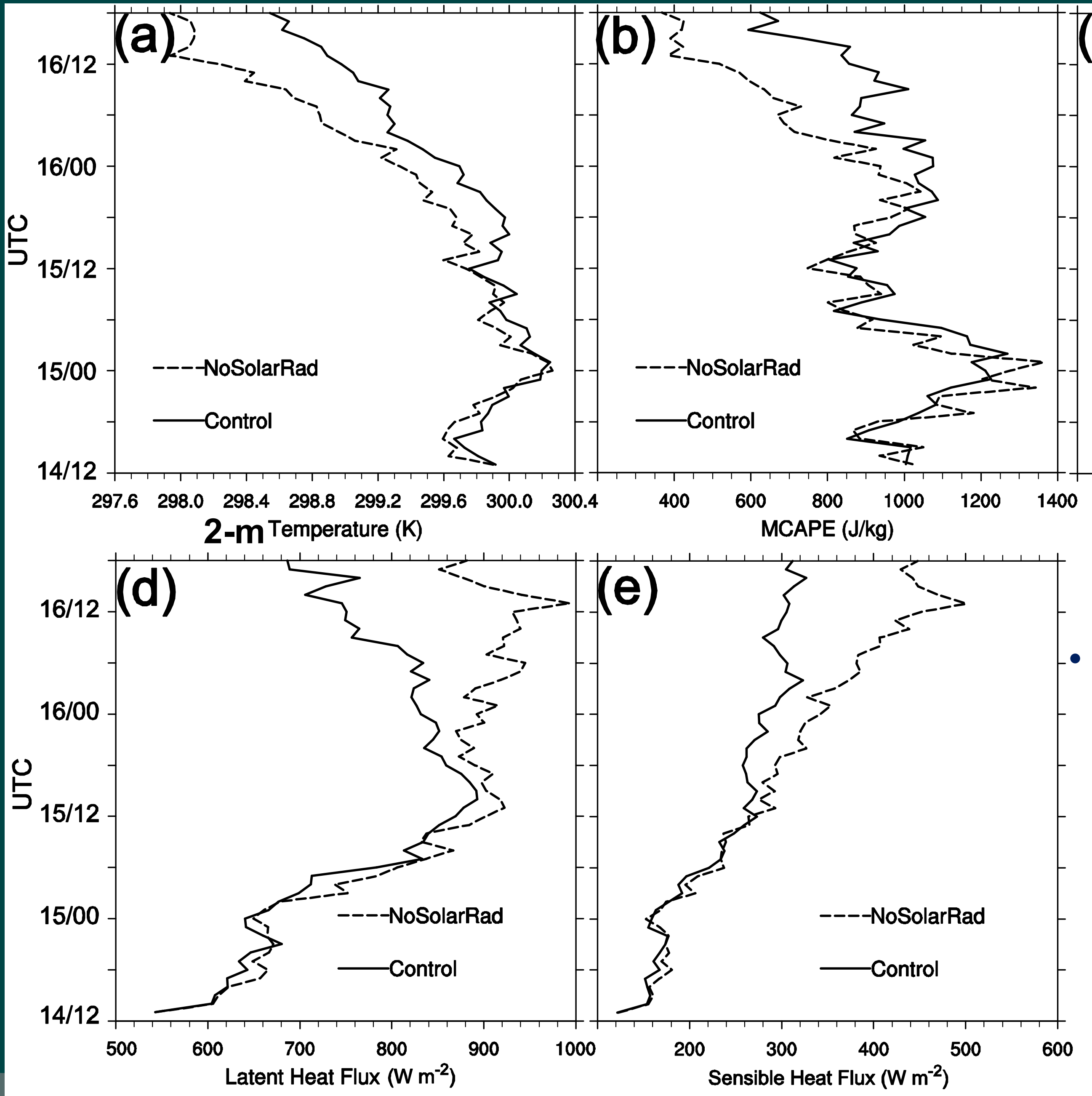
NoSolarRad – CNTL (60 km < R < 75 km)



Unit: 10^{-5} K/s for (a), (b), (c), and 10^{-3} K/s for (d)

- The net radiative heating in CNTL is much stronger due to the solar insolation at daytime.
- Less conducive for deep moist convection in CNTL
- Less diabatic heating due to suppressed convection in CNTL
- Difference: 0.5–1 K/day at the top of the boundary layer

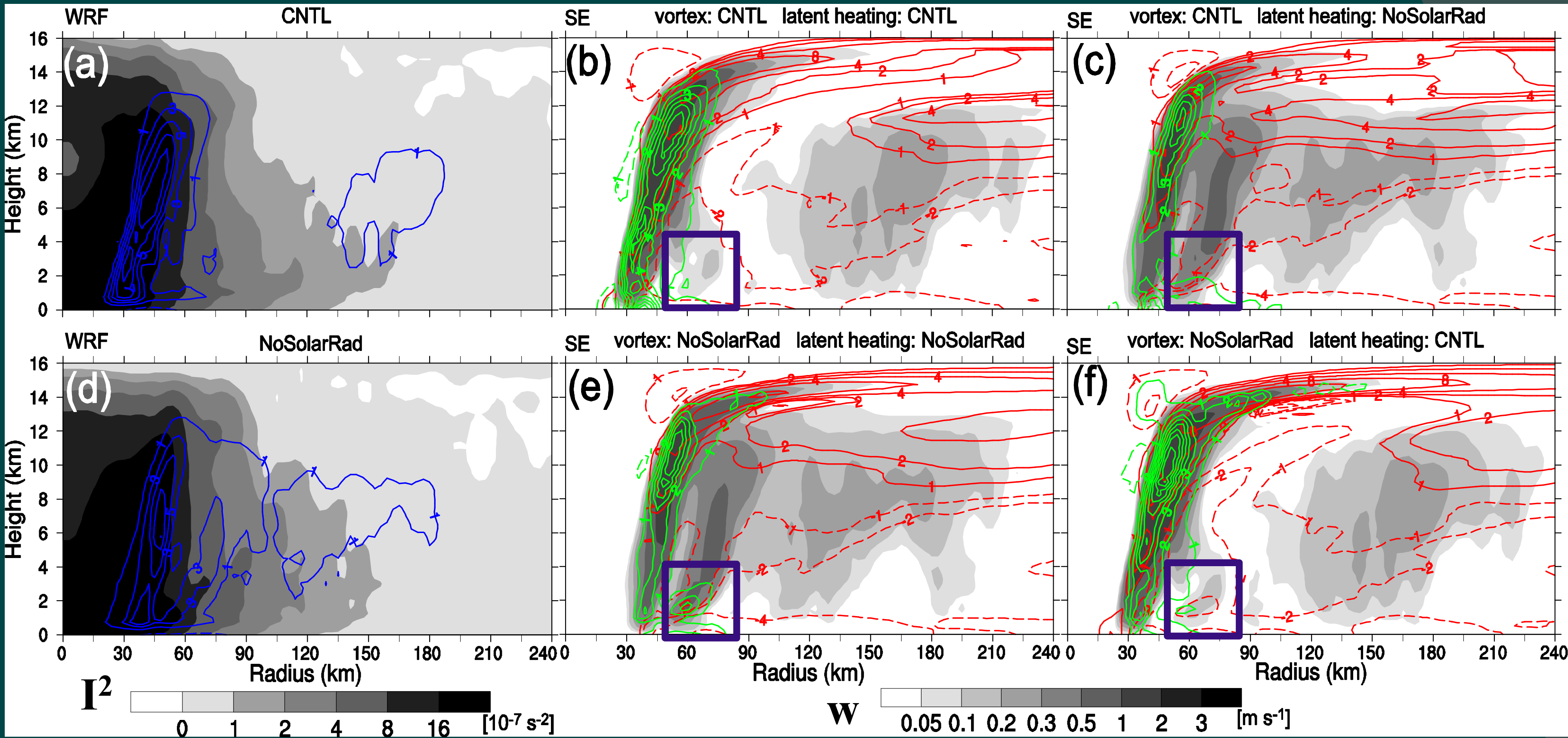
Radiative effects on moat formation



(60 km < R < 75 km)

- **Heated surface air weakens WISHE feedback between the surface fluxes (that promote convection) and the circulation.**

Early stage of SEF



$$\frac{\partial \bar{v}}{\partial t} = -\bar{u}(f + \bar{\zeta}) - \bar{w}\frac{\partial \bar{v}}{\partial z}$$

- **The absence of diabatic heating forcing and resulted smaller *v* in the moat region in CNTL is more important for moat formation in the early stage of SEF**

Conclusion

- Formation stage: nighttime radiative cooling → humidification and destabilization → promote deep moist convection → storm genesis
- Intensification stage: nighttime→ favoring more deep convection inside the RMW
  - RMW contraction in low levels: the greater positive radial eddy vorticity flux inside of the RMW is key
  - RMW contraction in mid-levels: the greater positive vertical advection of tangential wind inside of the RMW dominates
- Mature stage: Moat region is highly sensitive to the solar shortwave radiative heating mostly in the mid- to upper-level at daytime, which leads to a net stabilization effect and suppresses convective development.
- The heated surface air weakens WISHE feedback between the surface fluxes (that promote convection) and convective heating (that feeds to the secondary circulation and then the tangential wind).

Ongoing work

- **Diurnal impact on multi-scale wave –cloud–radiative interaction during TC genesis**
- **The impacts of the diurnal radiation cycle to the timing of RI onset**
- **The robustness of the sensitivity of SEF to diurnal solar insolation cycles← TC with different intensities and sizes**
- **……**

Thanks for attention

References:

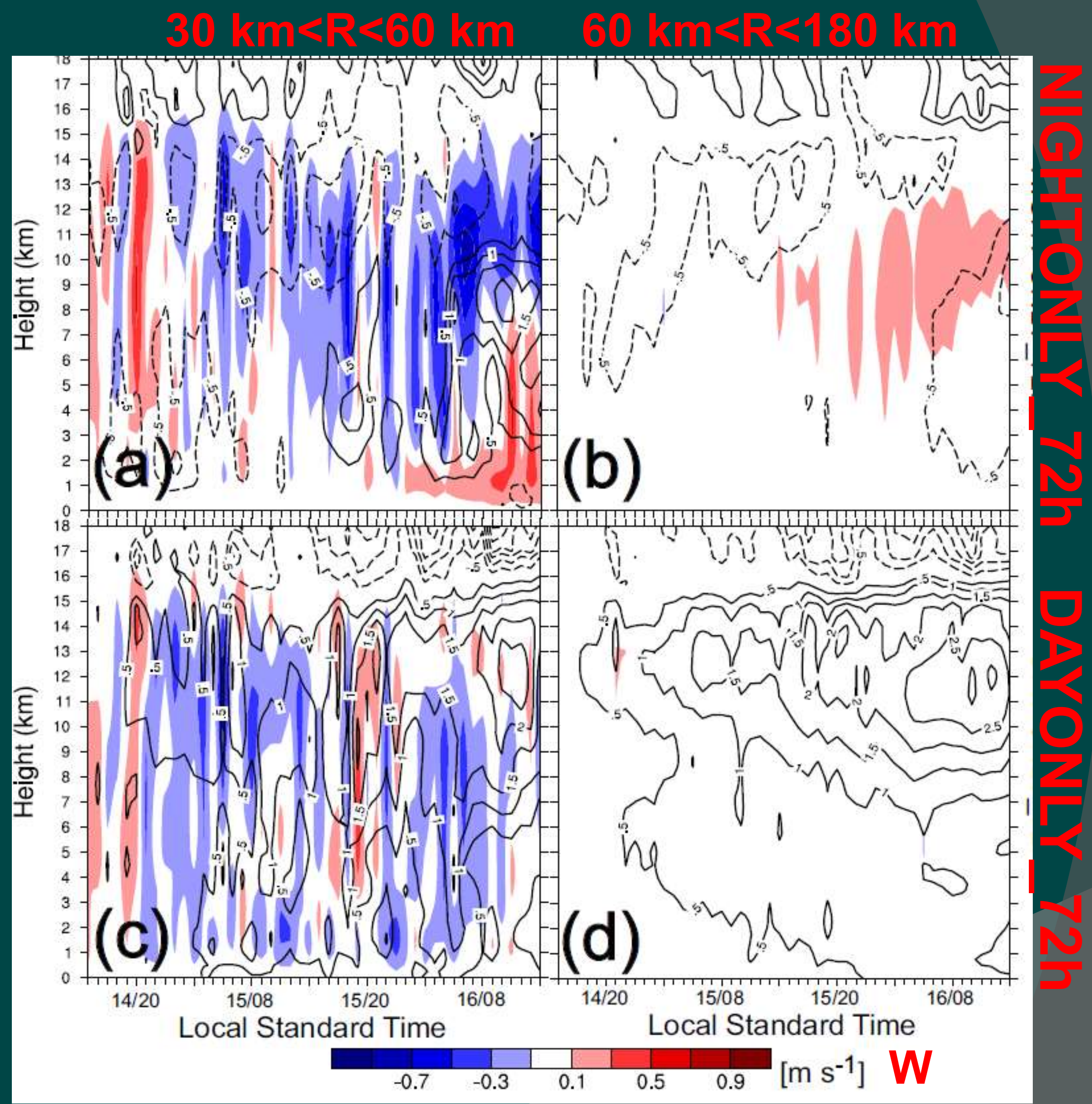
Tang, X., and F. Zhang, 2016: Impacts of the Diurnal Radiation Cycle on the Formation, Intensity and Structure of Hurricane Edouard (2014), *J. Atmos. Sci.,* 73, 2871-2892.

Tang, X., et al., 2017: Impacts of the Diurnal Radiation Cycle on Secondary Eyewall Formation, *J. Atmos. Sci.,* 74, 3079-3098.

Tang, X., et al., 2018: Impacts of the Solar Insolation on the Radius of Maximum Wind Contraction during the Intensification of Hurricane Edouard (2014), *J. Atmos. Sci., submitted.*

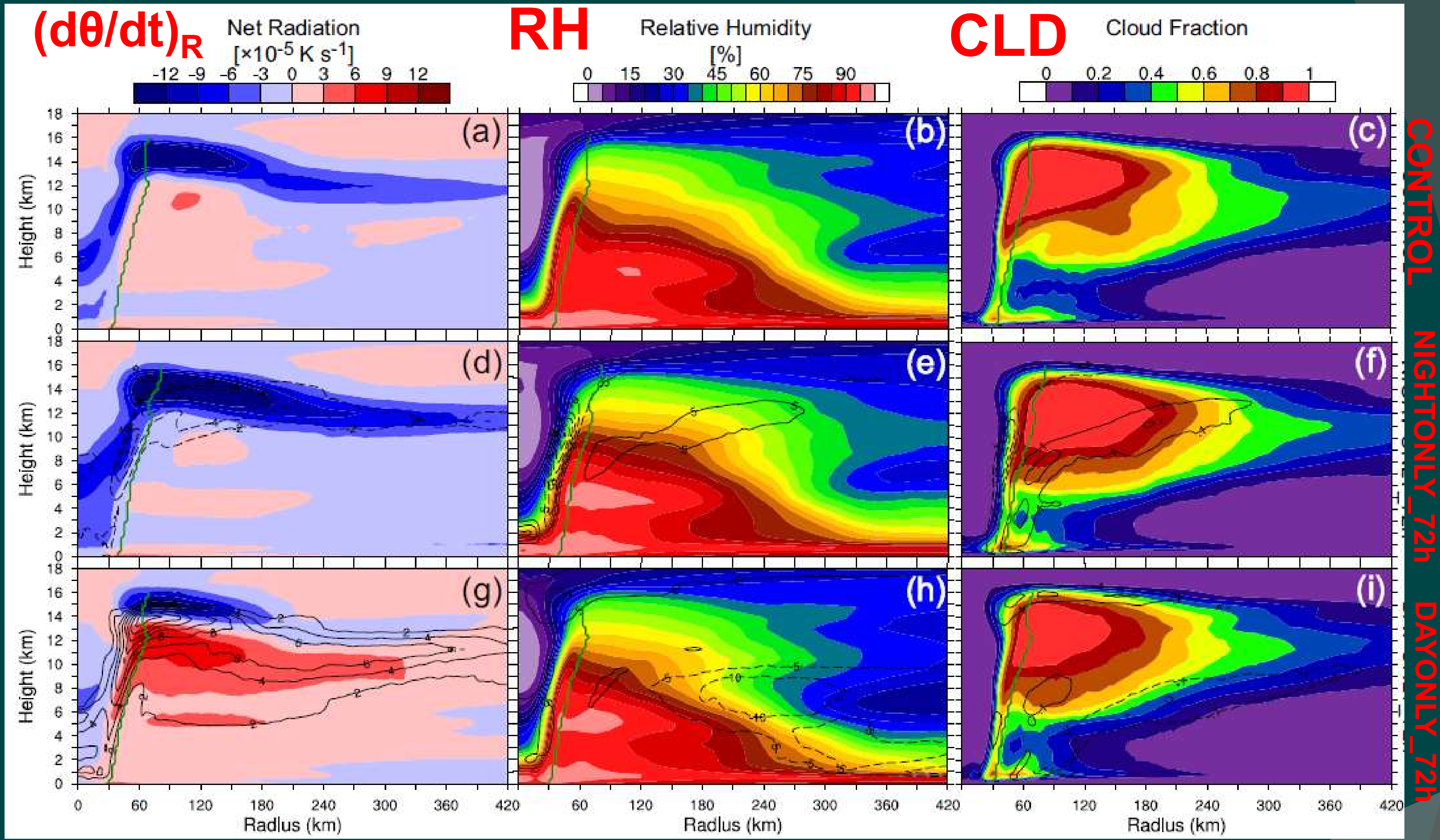
Net nighttime radiative cooling role to mature hurricane

- ✓ Temperature increasing at troposphere in DayOnly
- ✓ Destabilization of outer core, more deep moist convection in the NightOnly
- ✓ The decreasing vertical velocity in (a) is due to the eyewall expanding



Vertical profiles differences of vertical velocity (shading) and temperature (contour)

Different structure induced by radiation



NightOnly :

✓Prominent cooling along the cloud top; higher RH and Cloud Fraction outside;

DayOnly:

✓Warming within the cloud; lower RH and Cloud Fraction in outer region of low level

Radiation's role on convection

NightOnly :

✓Stronger updraft outside of RMW

✓Bigger slope of primary eyewall

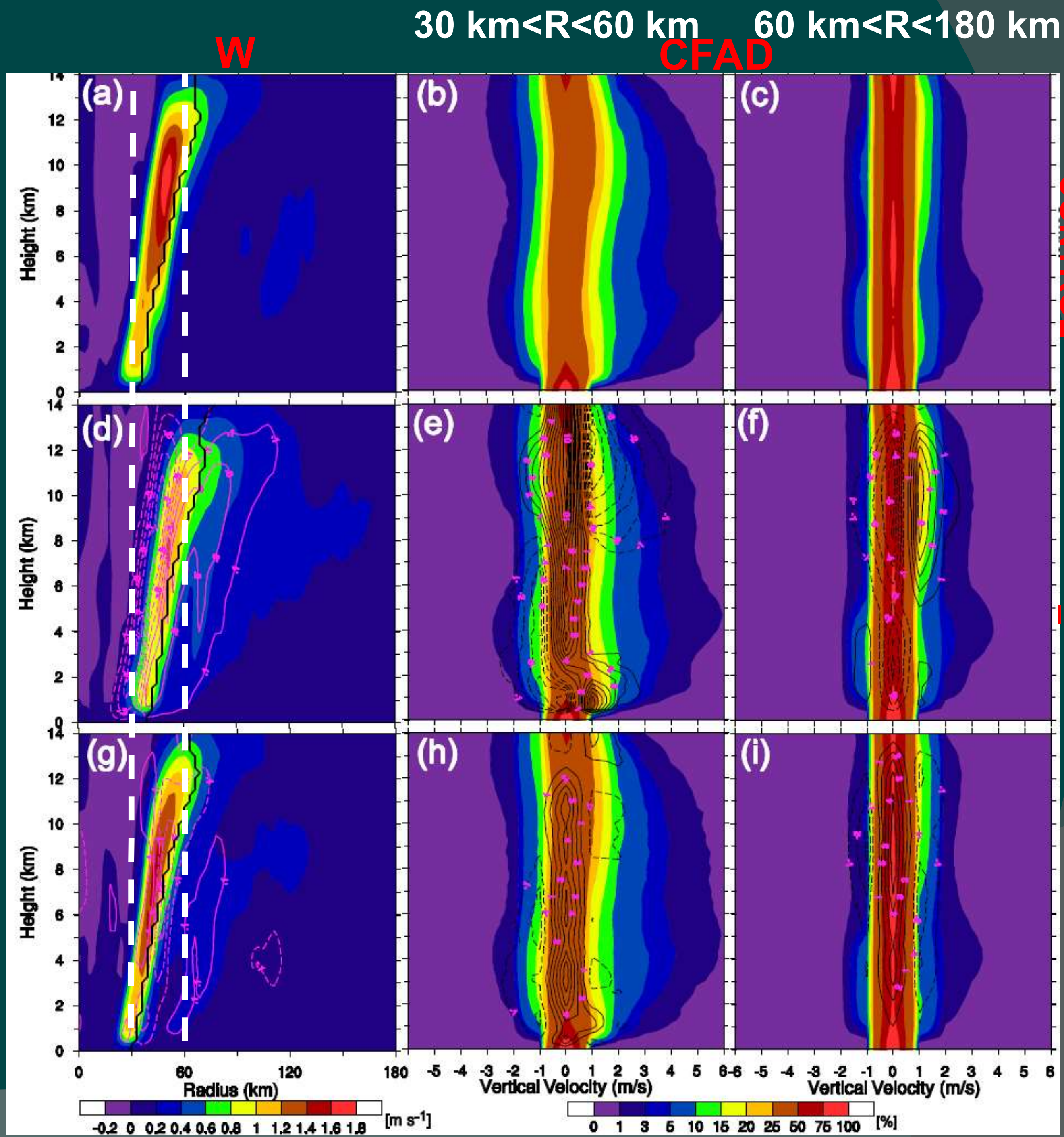
✓Convection increasing outside of eyewall

DayOnly:

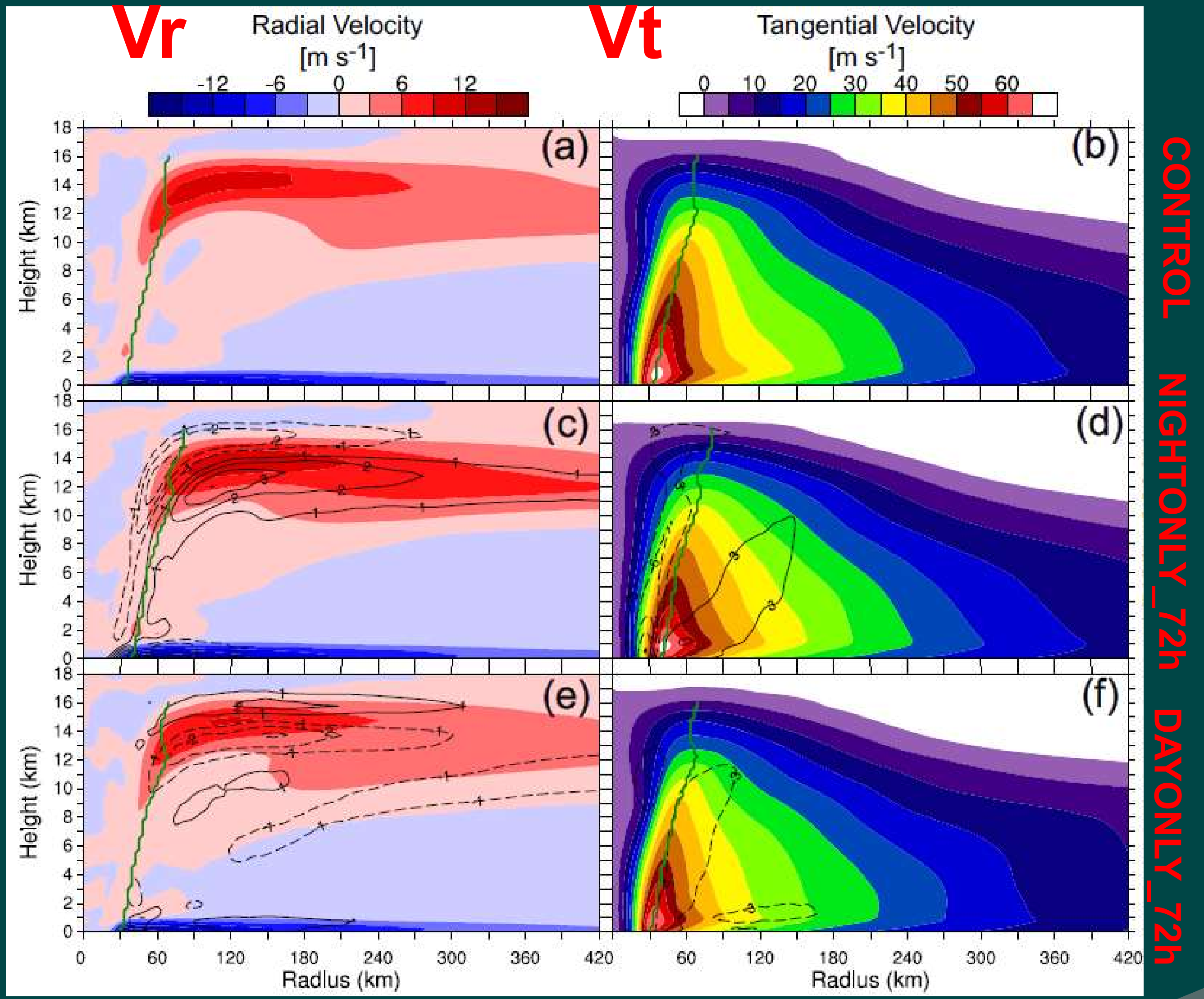
✓Weaker updraft at both sides of RMW

✓More upright primary eyewall

✓Convection decreasing outside of eyewall



Different structure induced by radiation



NightOnly :

✓Stronger upper/low level radial outflow/inflow, and tangential wind outside of eyewalll;

✓Outward slope of primary eyewall increase

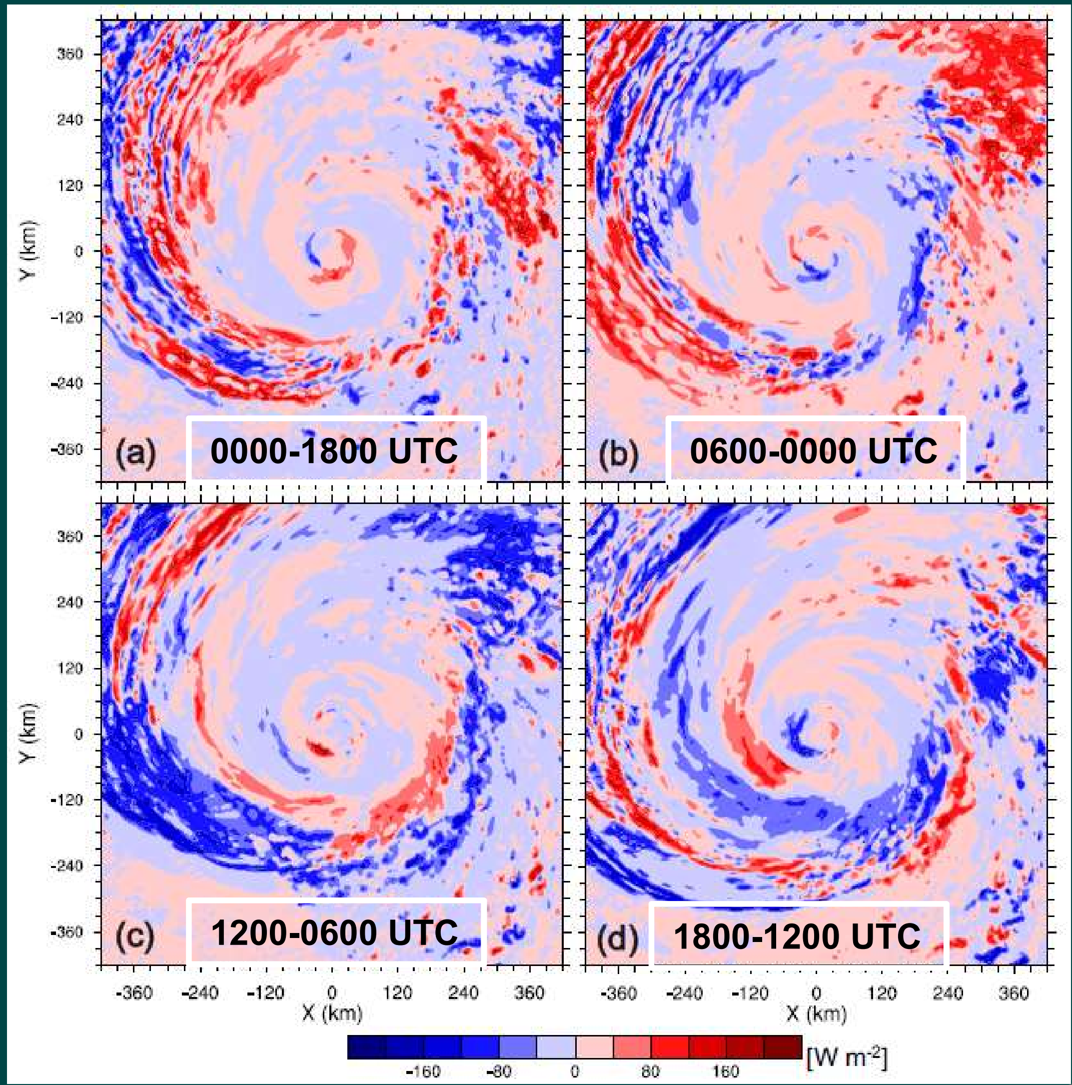
DayOnly:

✓Weeker updraft, upper/low level radial outflow/inflow, and tangential wind besides eyewalll

✓More upright primary eyewall

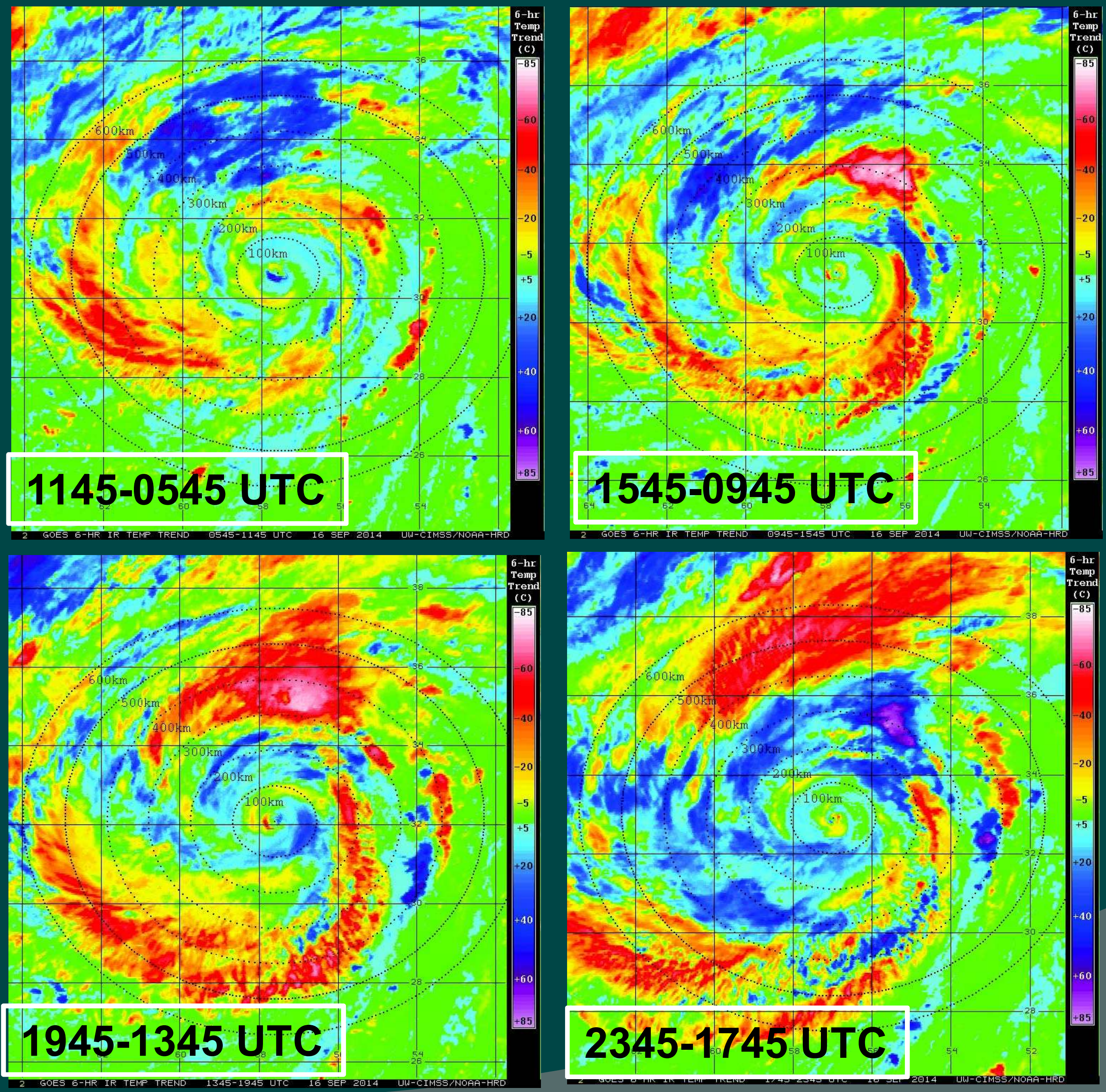
Simulated diurnal cycle of Hurricane Edouard: Sept 16

6-h OLR differencing images for control run



✓**Simulated diurnal cycle in mature stage, which is simliar with observation**

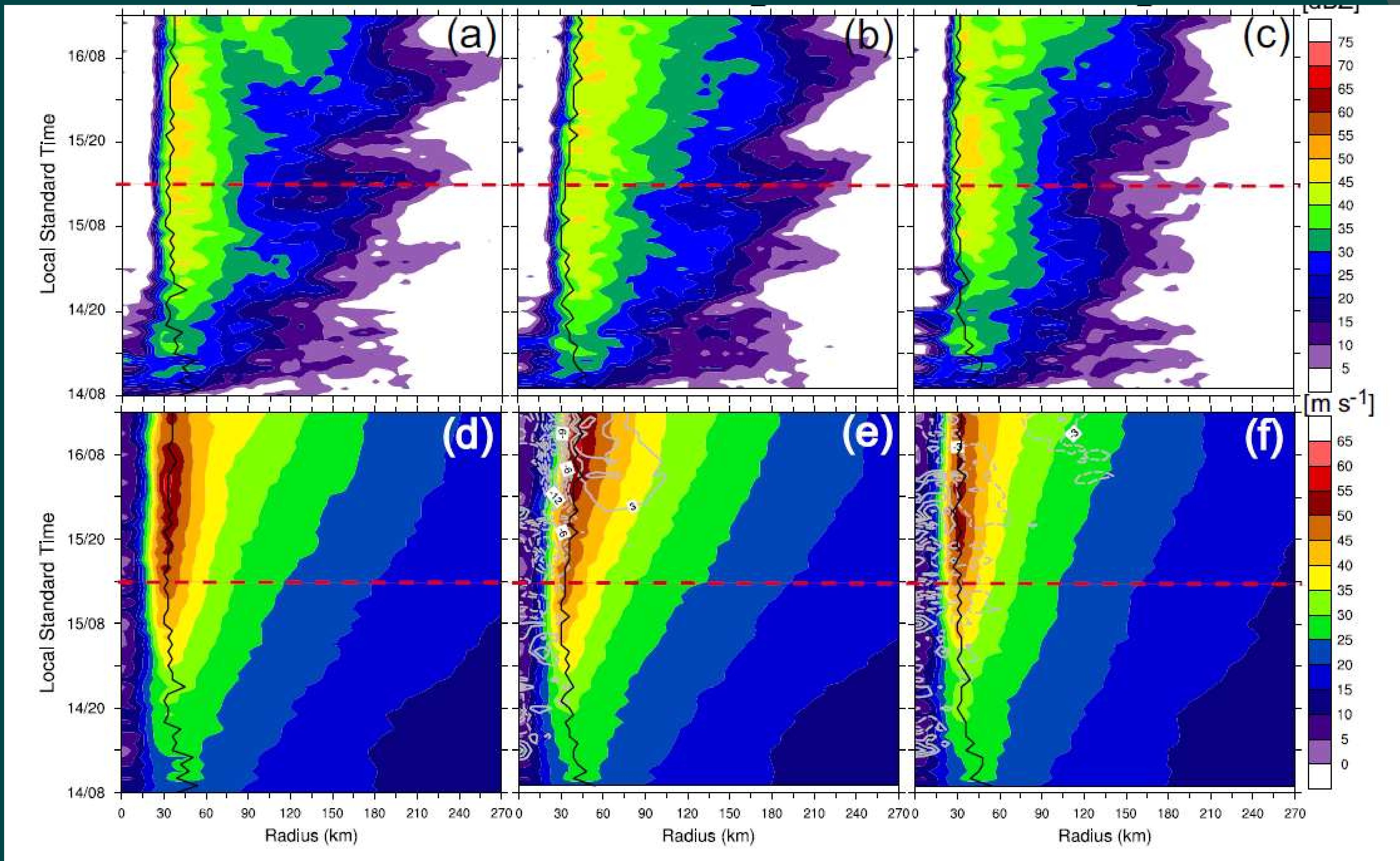
Observed diurnal cycle of Hurricane Edouard: Sept 16



(Courtesy of Jason Dunion)

Different structure and outer rainband of mature hurricane

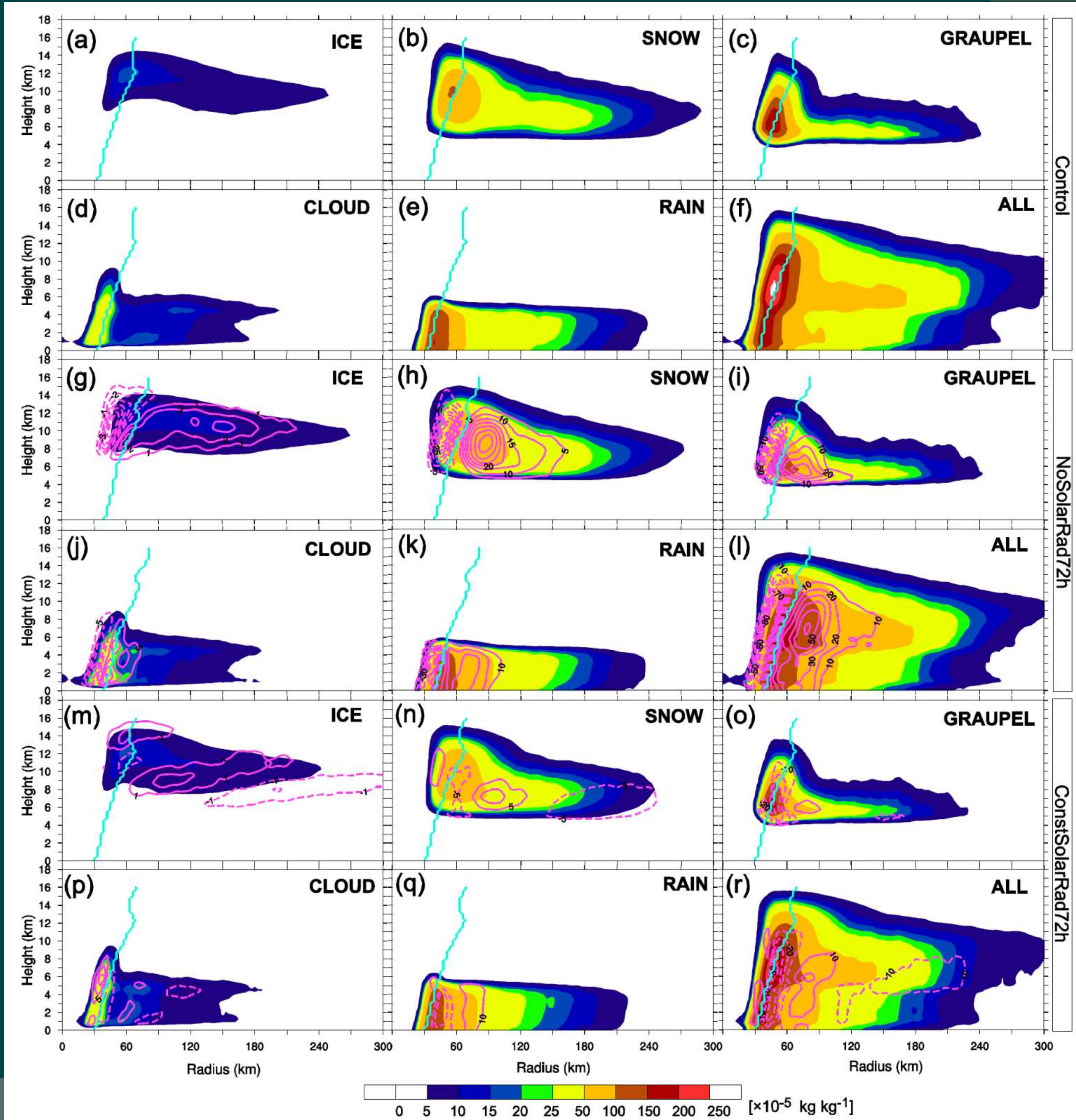
CONTROL **NightOnly_72h** **DayOnly_72h**



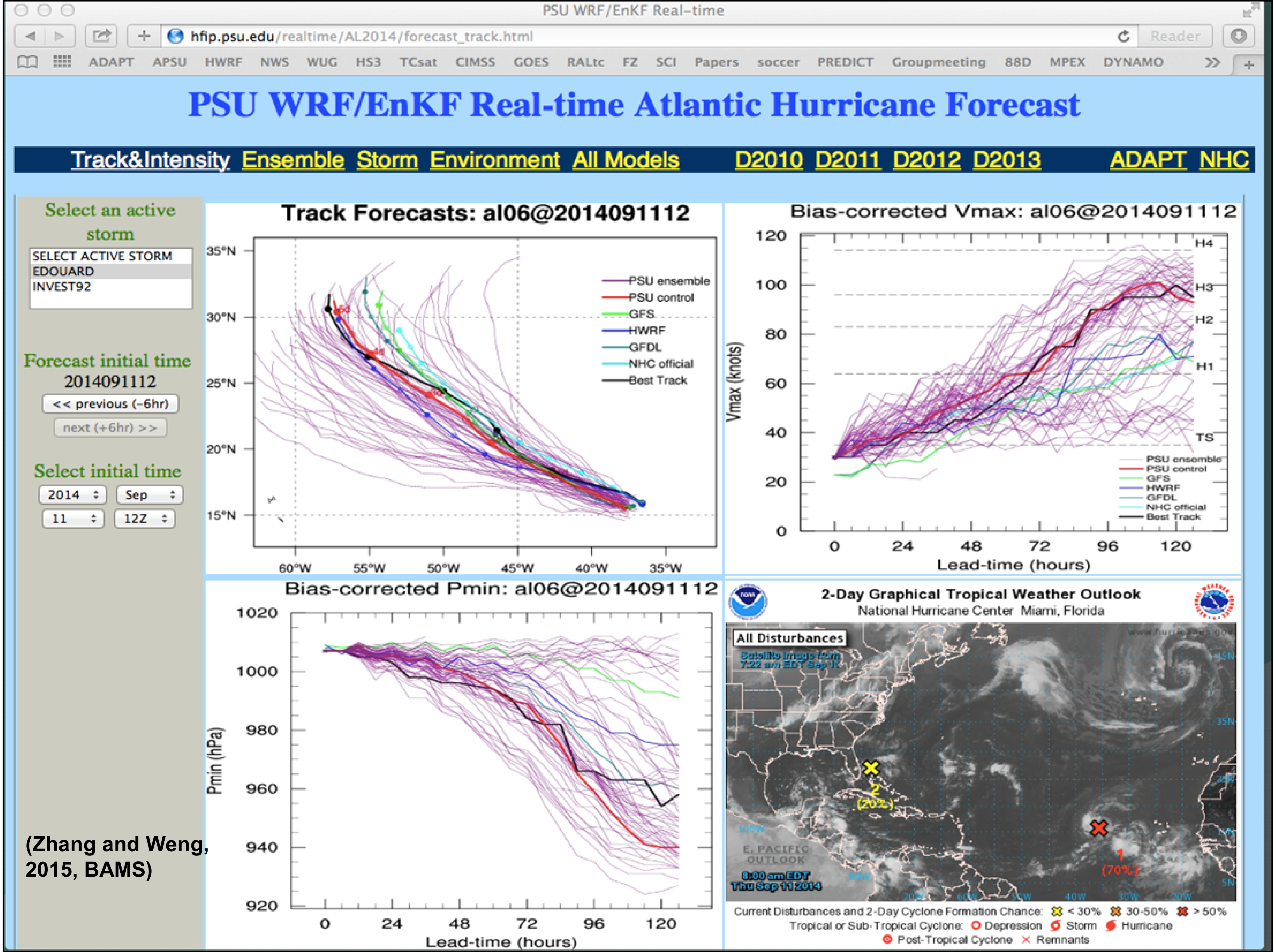
radar reflectivity 10-m wind speed

✓**Control run undergoes secondary eyewall formation as observed**

✓**Stronger strength and bigger size for NightOnly**



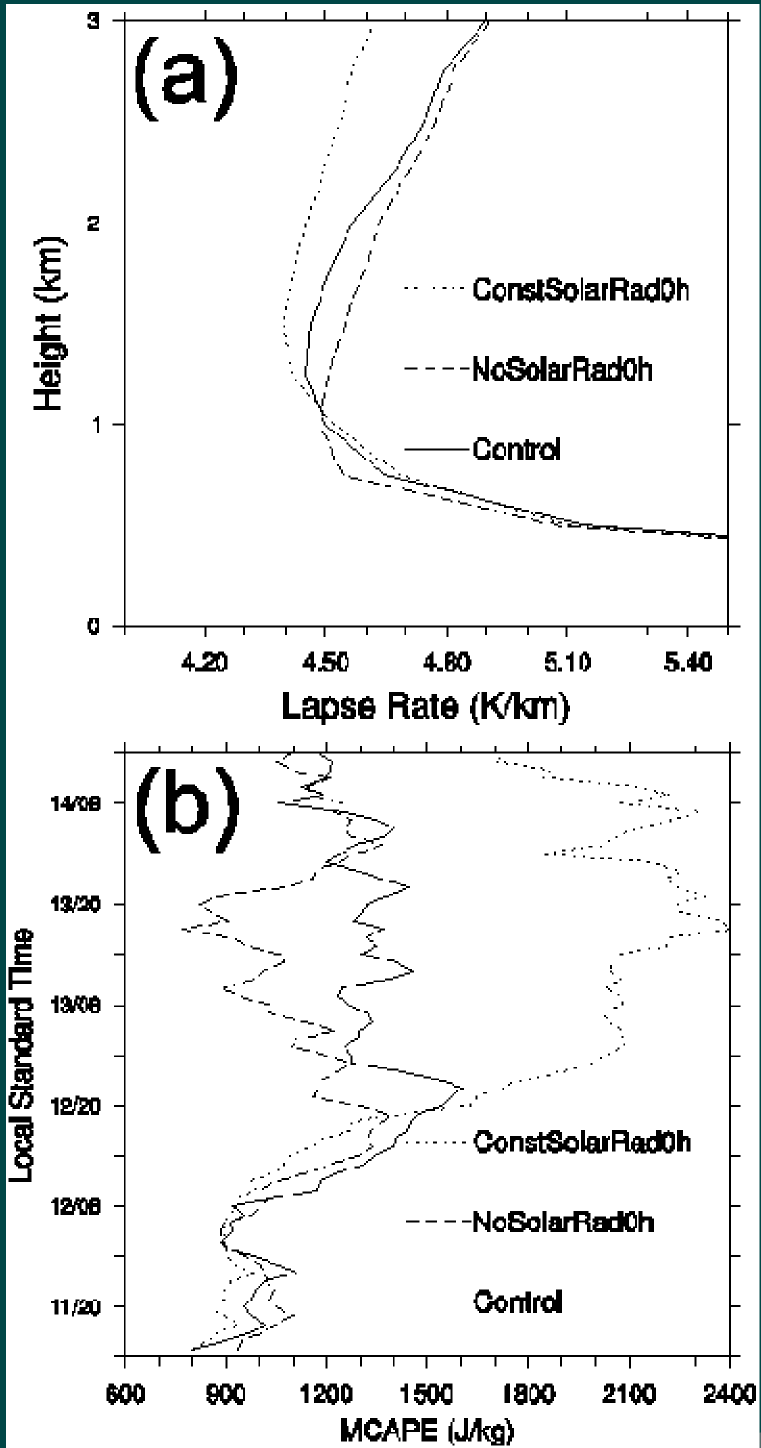
(a) ICE
(b) SNOW
(c) GRAUPEL
(d) CLOUD
(e) RAIN
(f) ALL
(g) ICE
(h) SNOW
(i) GRAUPEL
(j) CLOUD
(k) RAIN
(l) ALL
(m) ICE
(n) SNOW
(o) GRAUPEL
(p) CLOUD
(q) RAIN
(r) ALL
Control
NoSolarRad72h
ConstSolarRad72h
Height (km)
Radius (km)
0 5 10 15 20 25 50 100 150 200 250
[×10-5 kg kg-1]



(Zhang and Weng, 2015, BAMS)

Name	Start time	Integration hours	Radiation	
			Solar shortwave	Longwave
Control	1200 UTC 11 Sept.	168	Normal diurnal cycle	Normal
NoSolarRad0h	1200 UTC 11 Sept.	126	Off	Normal
ConstSolarRad0h	1200 UTC 11 Sept.	126	Fixed at local noon	Normal
NoSolarRad48h	1200 UTC 13 Sept.	78	Off	Normal
ConstSolarRad48h	1200 UTC 13 Sept.	78	Fixed at local noon	Normal
NoSolarRad72h	1200 UTC 14 Sept.	96	Off	Normal
ConstSolarRad72h	1200 UTC 14 Sept.	96	Fixed at local noon	Normal
NoSolarRad96h	1200 UTC 15 Sept.	30	Off	Normal
ConstSolarRad96h	1200 UTC 15 Sept.	30	Fixed at local noon	Normal

$$KE = \frac{1}{2}\int_{z_1}^{z_2}\int_{0}^{2\pi}\int_{0}^{R}\rho(u^2+v^2+w^2)\,r\,dr\,d\theta\,dz$$



(a) Average vertical profiles of the local-environment lapse rate, temporally averaged during 1900 UTC (1500 LST) 11 to 1800 UTC (1400 LST) 13 September, and (b) Evolution of average most unstable convective available potential energy (MCAPE) for a parcel (defined as a 500-m-vertical layer average with the highest equivalent potential temperature below 3000 m AGL) within 180 km of the vortex center for control run and two sensitivity experiments.