Institute for Climate and Atmospheric Science
SCHOOL OF EARTH AND ENVIRONMENT
UNIVERSITY OF LEEDS

The impact of soil moisture and convectively-generated waves on the initiation of a West African mesoscale convective system

C. E. Birch, A. O'Leary, D. J. Parker, J. H. Marsham, C. M. Taylor, P. Harris, G. Lister

Mesoscale convective systems

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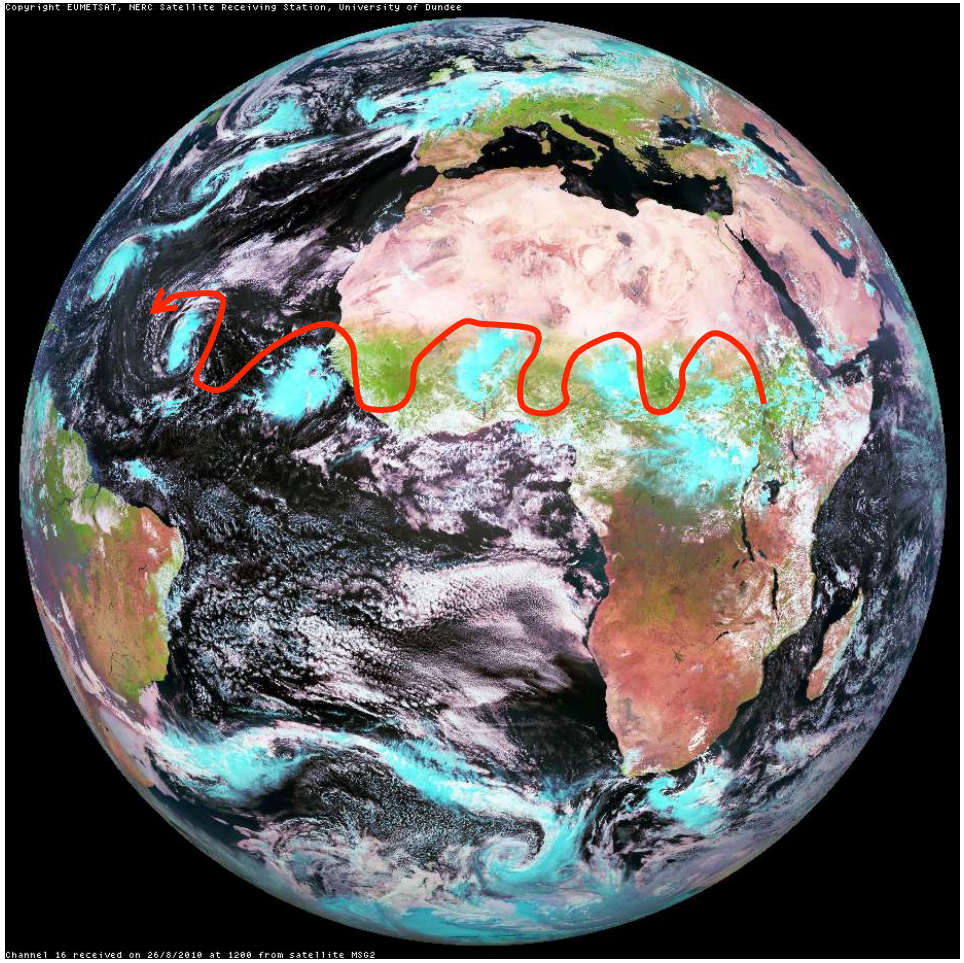
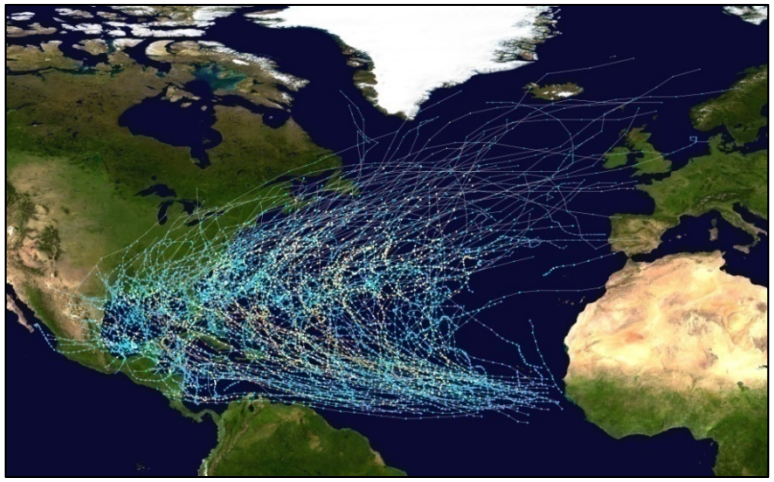


26th Aug 2010, MSG Dundee receiving station

- A mesoscale convective system (MSC) is a large complex of thunderstorms that becomes organised
- These systems provide most of the Sahel's rainfall
- Precursor for Atlantic hurricanes



Case Study

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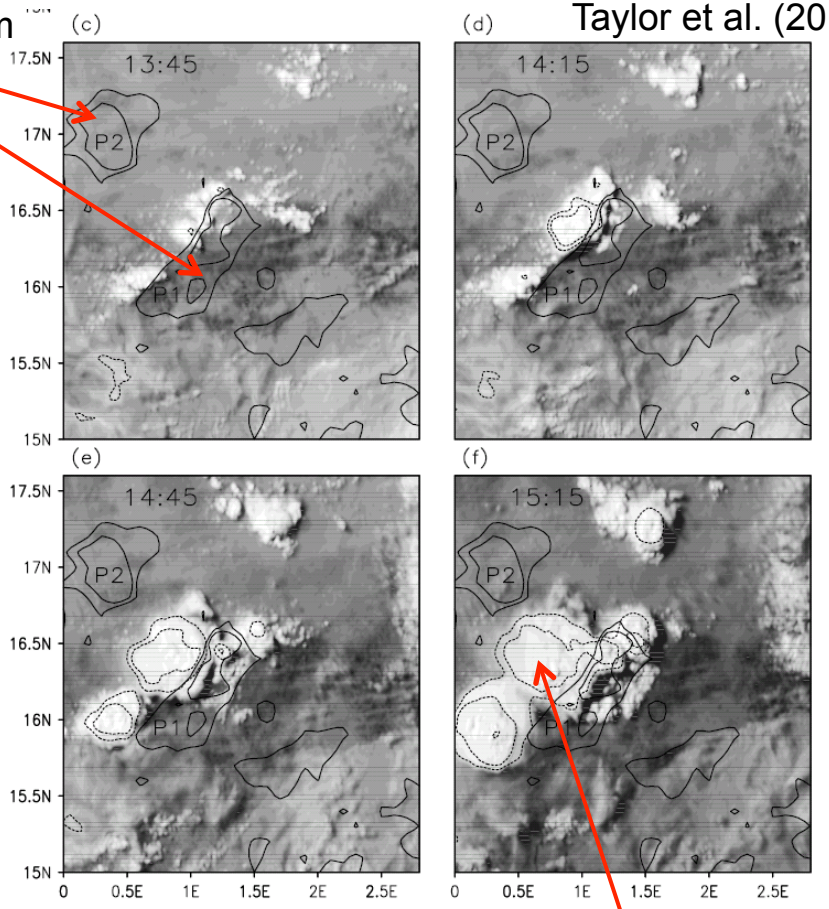
Wet patches created by a storm on the previous day

- Mesoscale convective system case study on 31st July 2006
- Observed during the African Monsoon Multidisciplinary Analysis (AMMA) field campaign

Taylor et al. (2010)



New storm forms on dry soil, upwind of a soil moisture gradient

Case Study

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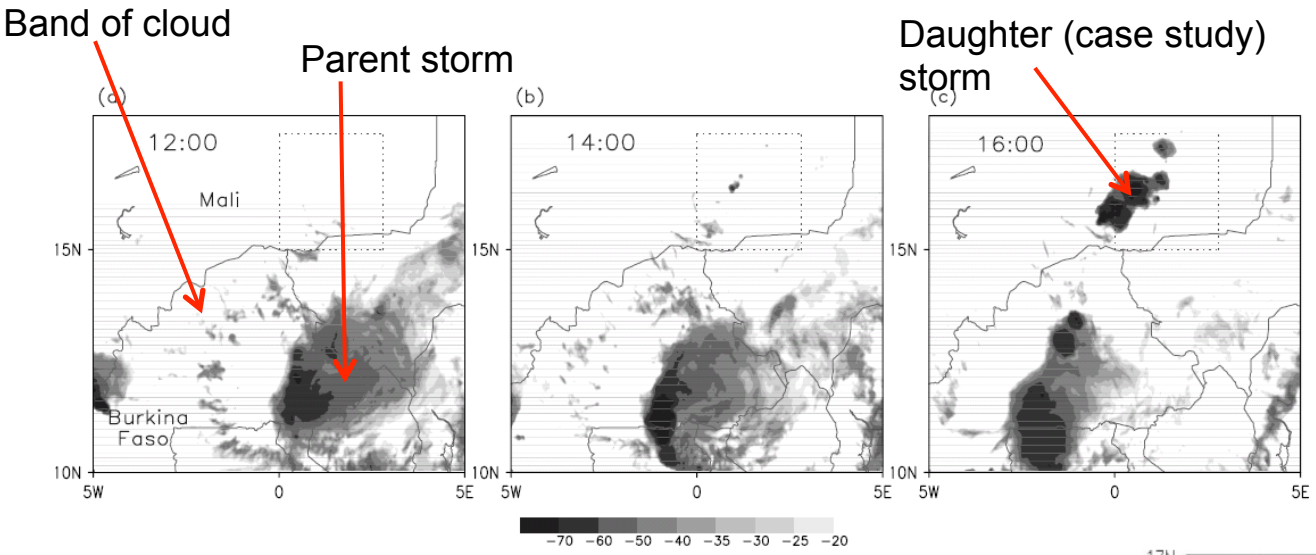

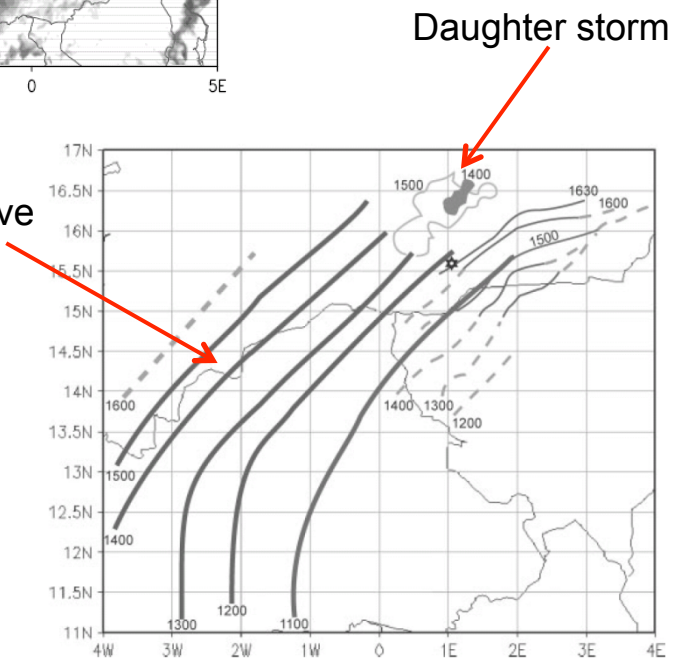

- Gravity wave emitted from the parent storm may have played a role in the development of the daughter storm
- Not clear what form the wave took

Met Office Unified Model (MetUM)

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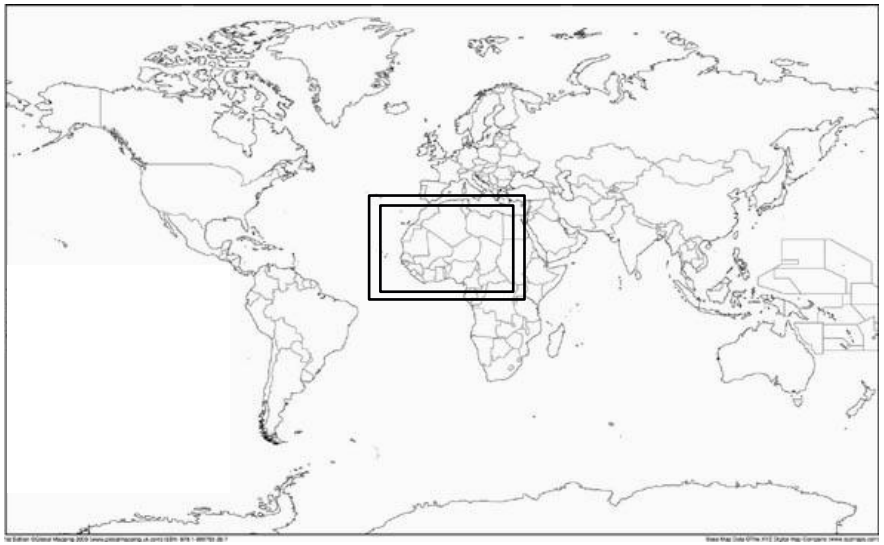

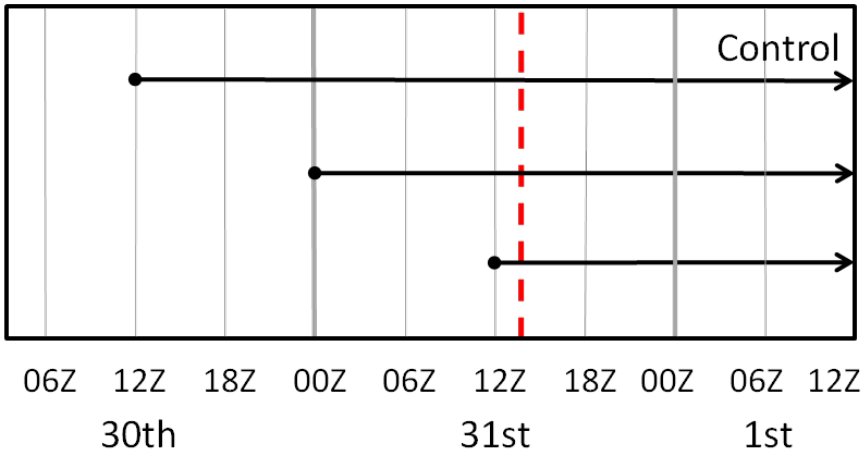

- Met Office Unified Model global-12km-4km
- 4km explicit convection
- 12Z, 30th July 2006 with ECMWF analysis produced best results

Soil moisture and initiation

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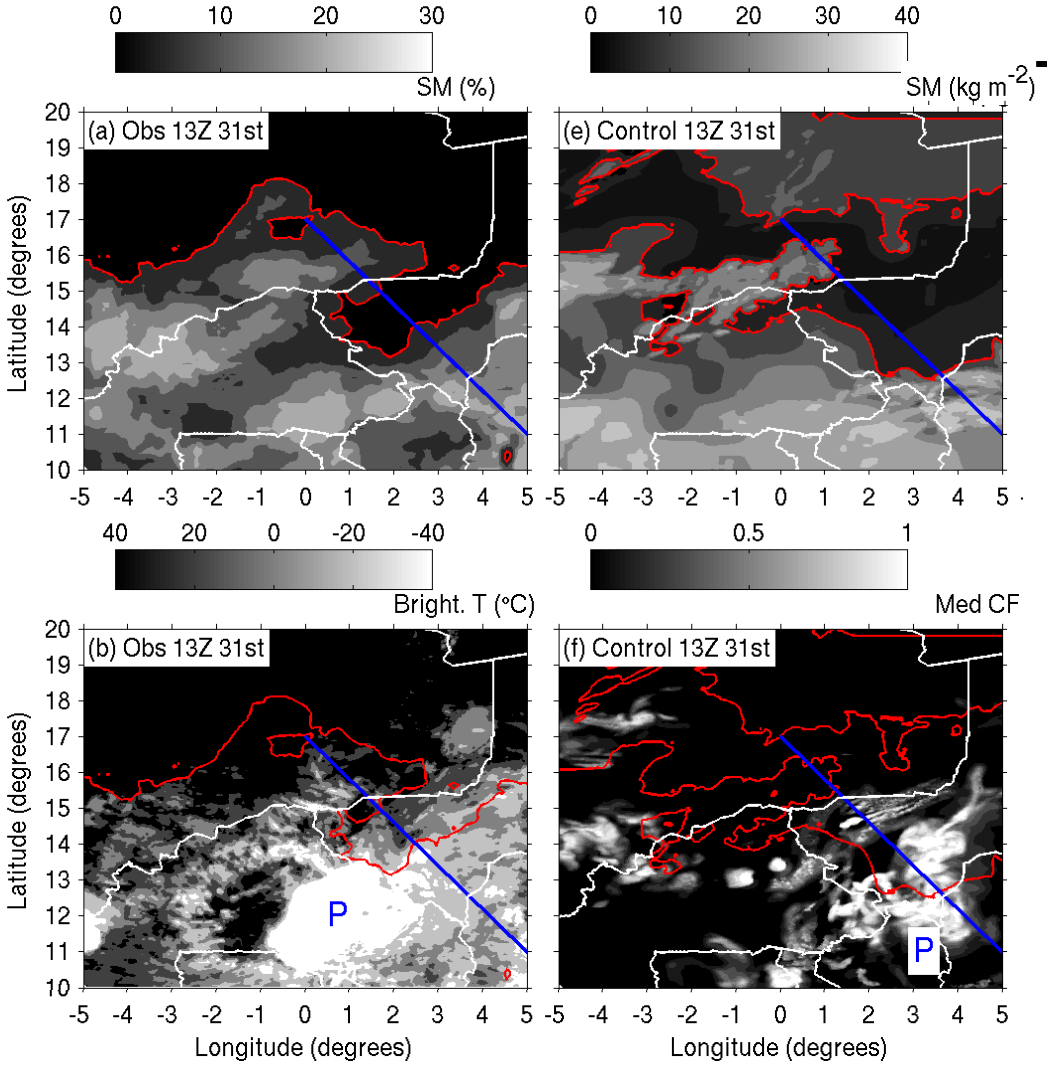

Soil moisture and initiation

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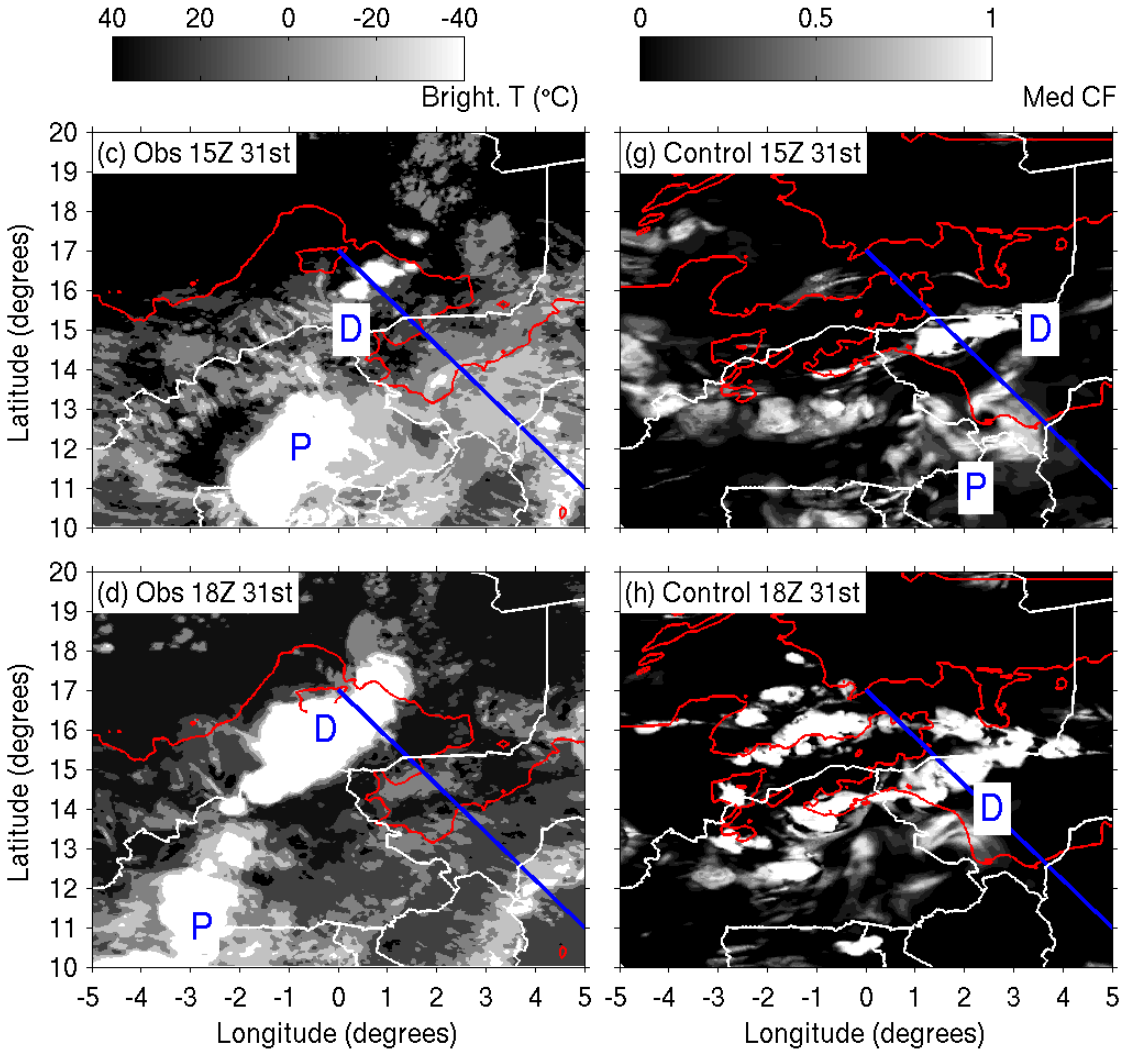

Rainfall rates

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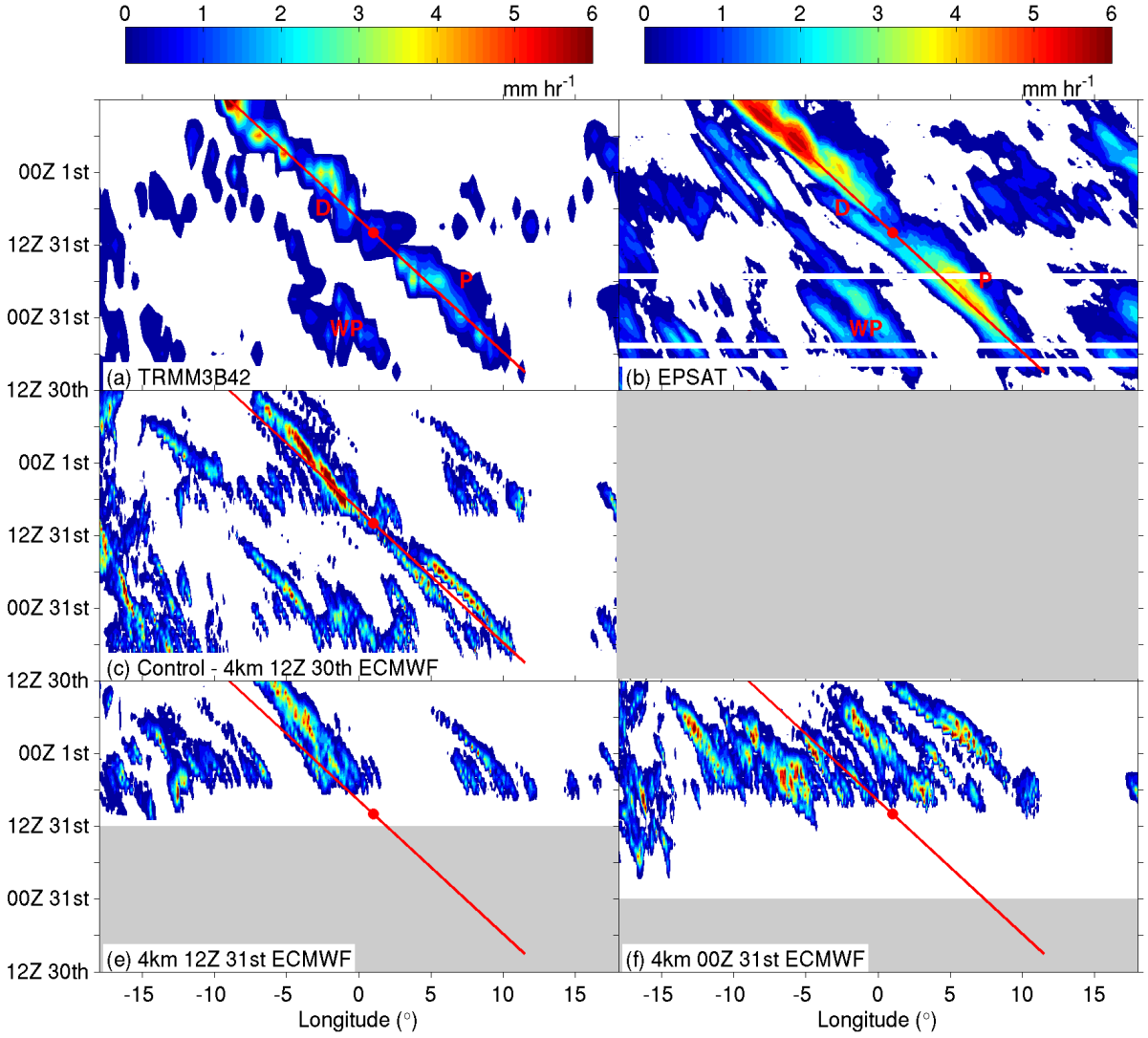

Hovmöller plots averaged between 11 and 18°N

Synoptic-scale circulation

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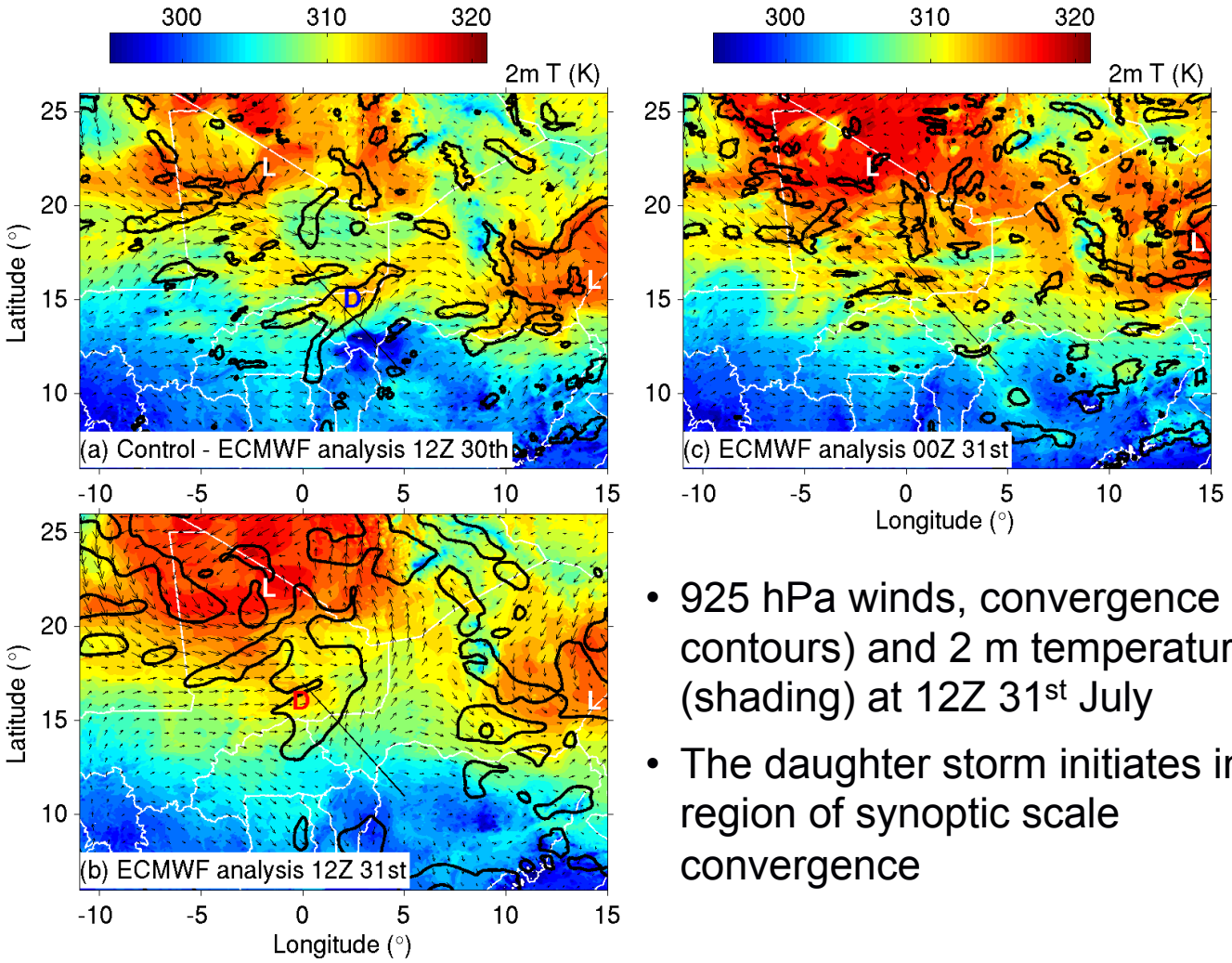

- 925 hPa winds, convergence (black contours) and 2 m temperature (shading) at 12Z 31st July
- The daughter storm initiates in a region of synoptic scale convergence

Gravity waves

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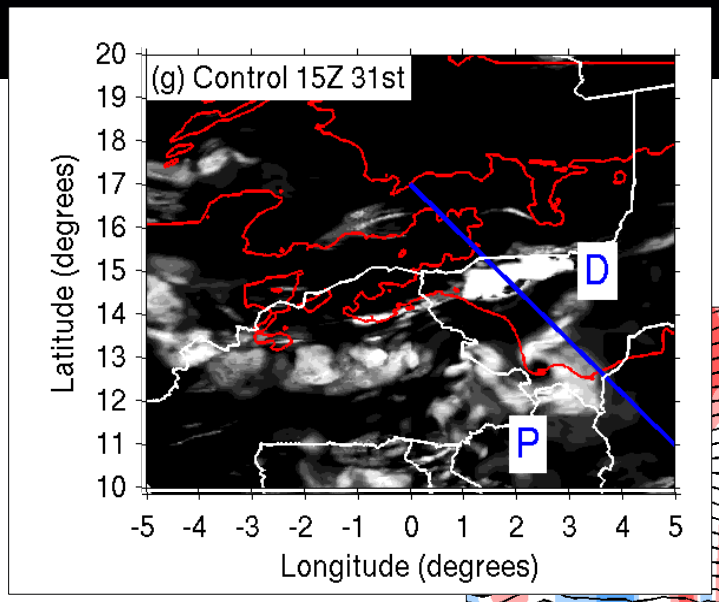

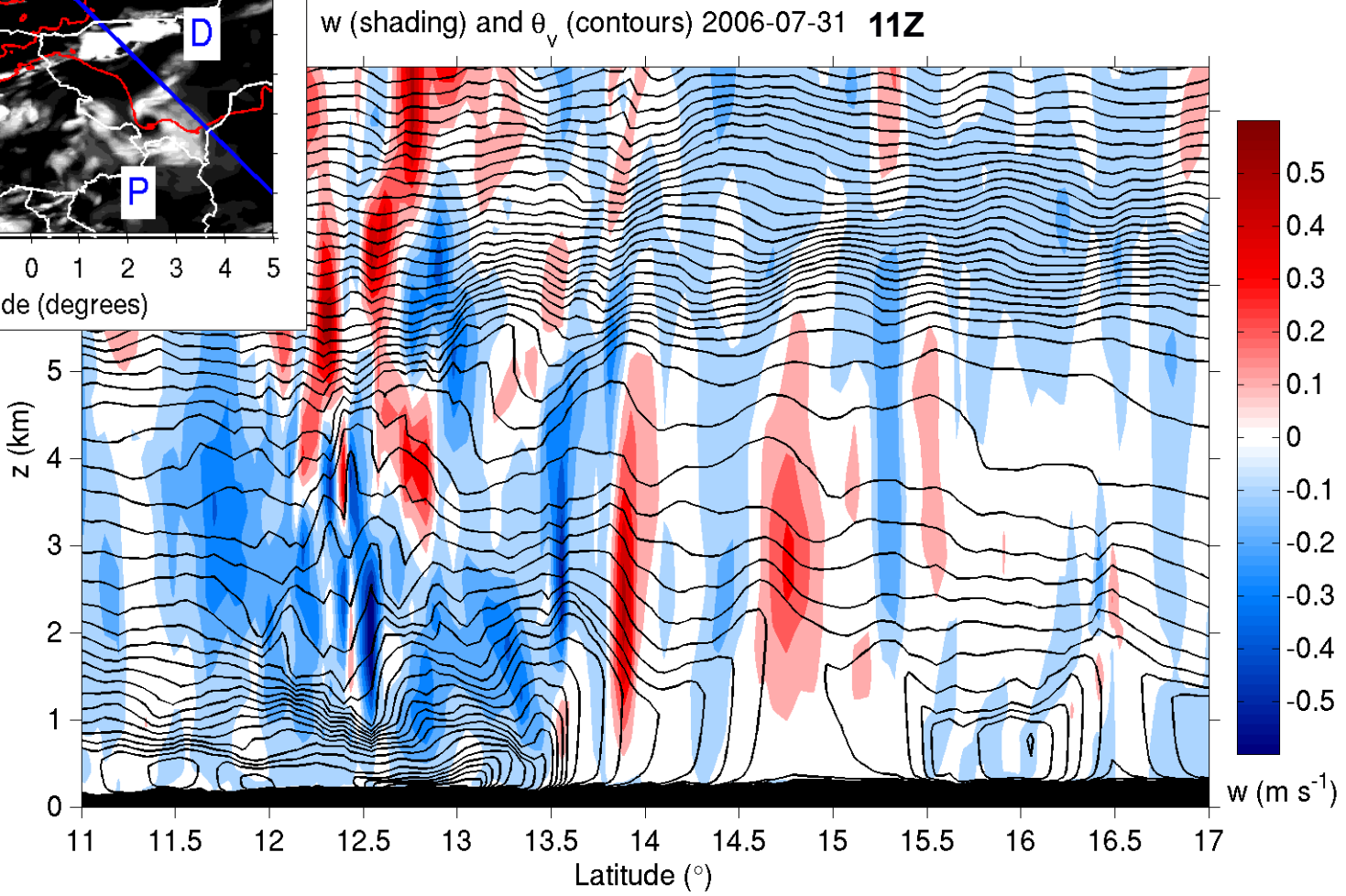

Gravity waves

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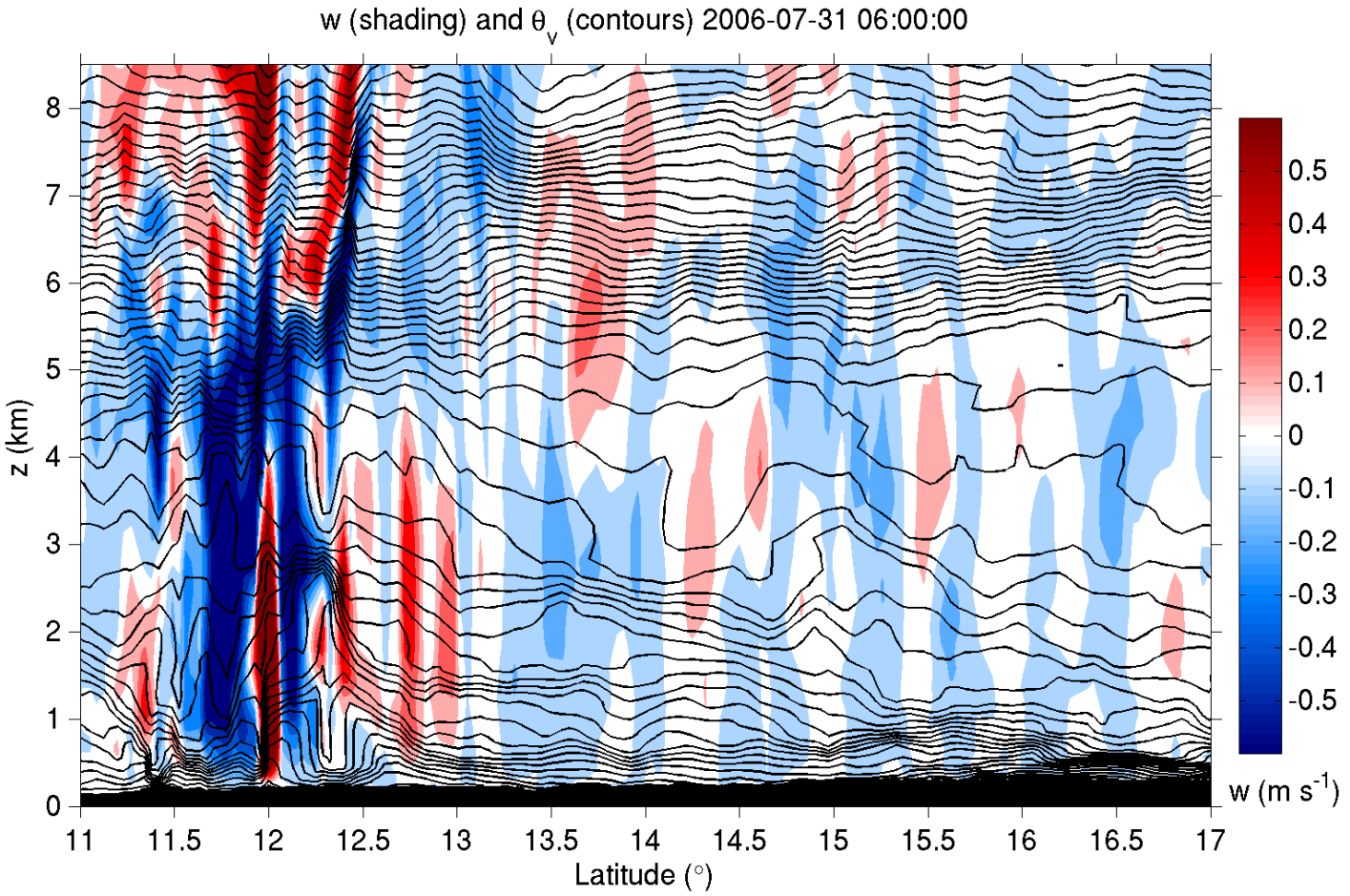

Development without the parent storm

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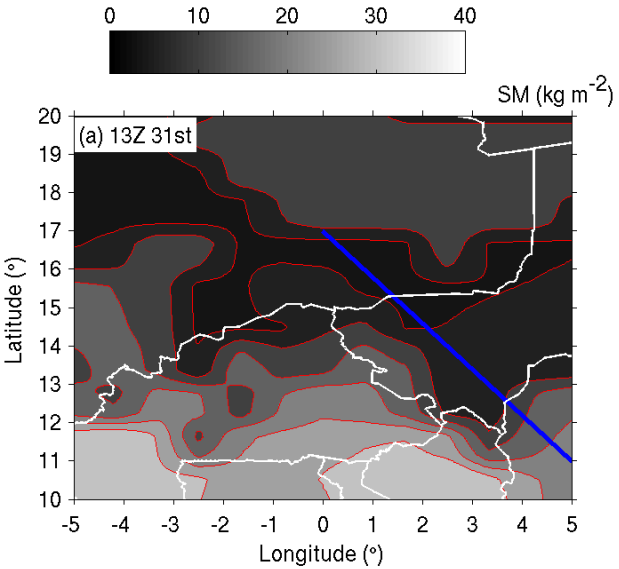
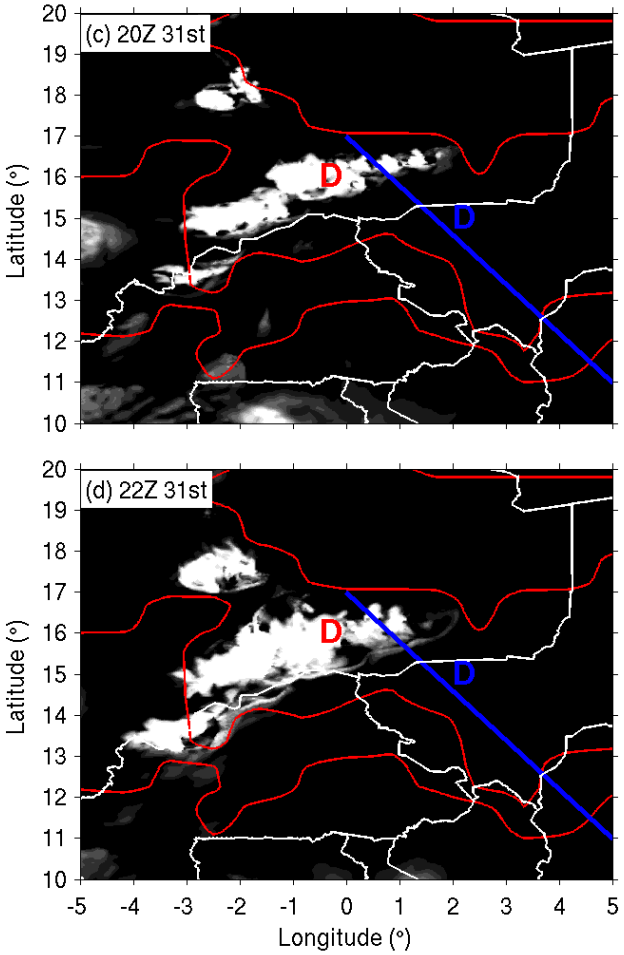


Model initialised 12Z, 31st July (24 hours later)



- Storm is still reproduced but it develops in a different place and too late in the day
- Large-scale circulation (convergence zone) most important

Summary

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- 4 km nest of the model reproduced key aspects of the observed case study
- Daughter storm initiates on dry soil in a region of synoptic-scale low-level convergence
- Two pronounced gravity waves were emitted from the parent storm in the model. The arrival of the second wave coincided with the initiation of deep convection in the daughter storm
- Three key ingredients for successful MCS forecasting:
  1. Synoptic-scale dynamics = storm/no storm
  2. Soil moisture = accuracy of initiation location
  3. Gravity wave = accuracy of timing

Thank you

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Cold pool

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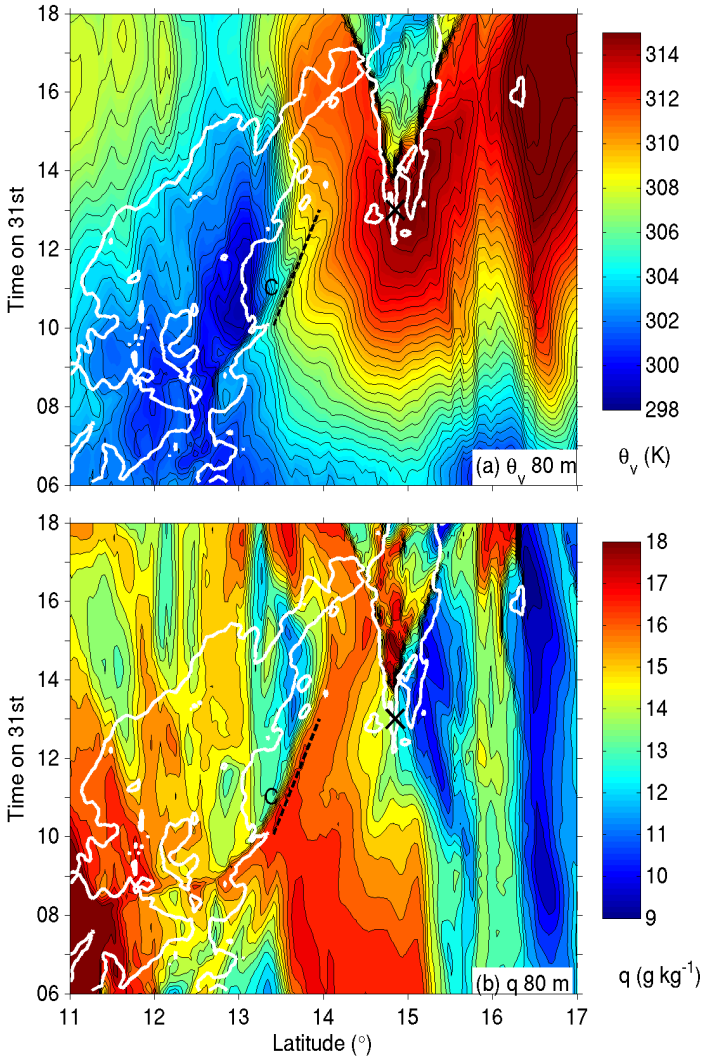

Gravity waves

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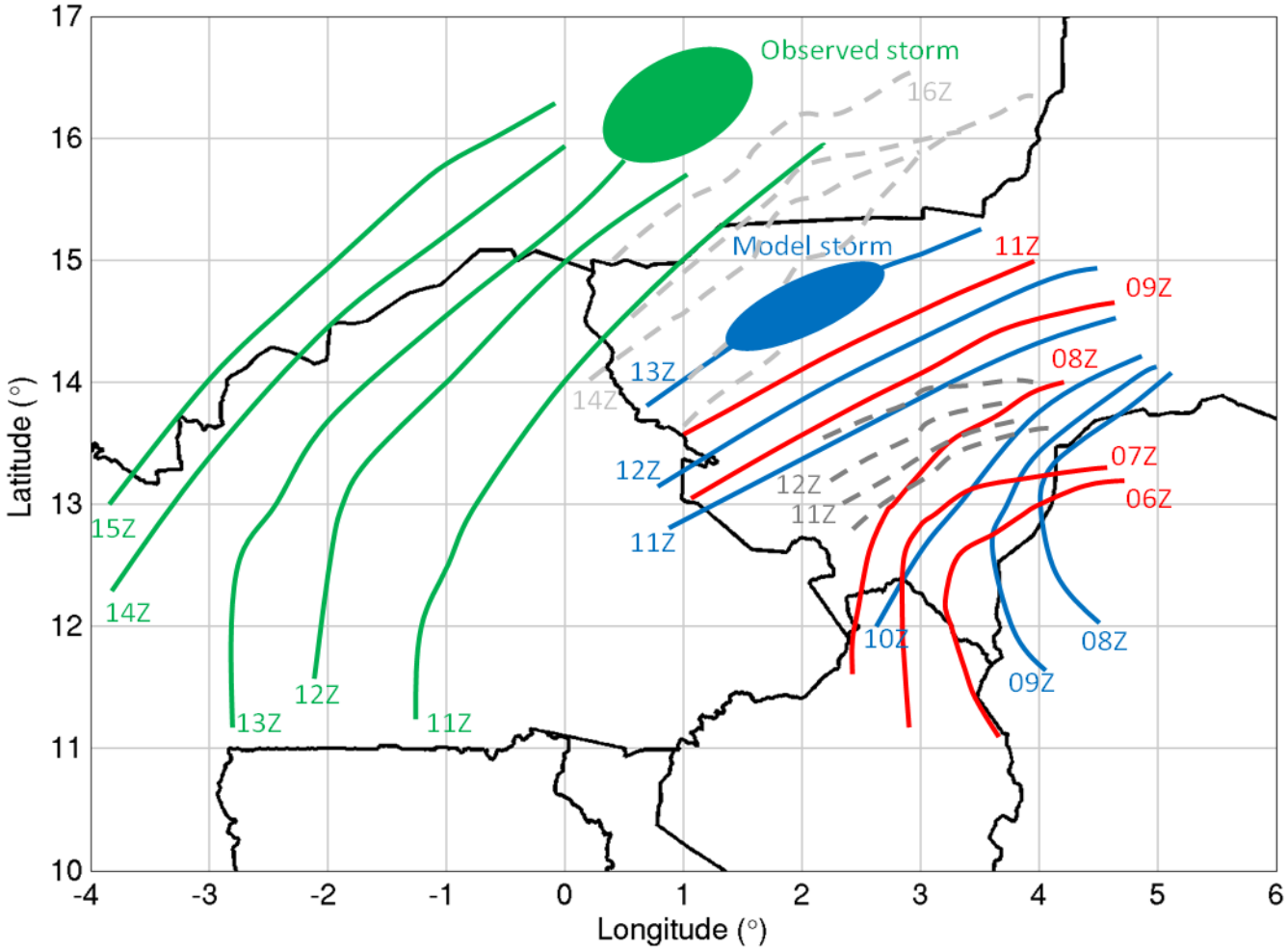

Gravity waves

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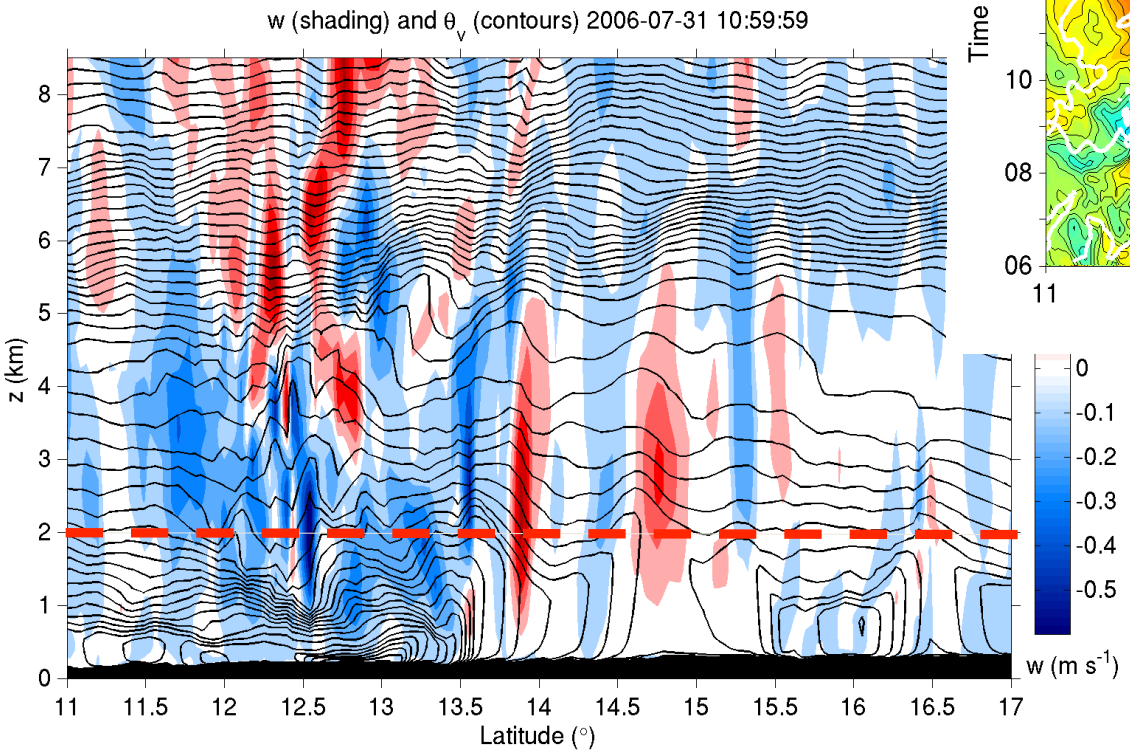

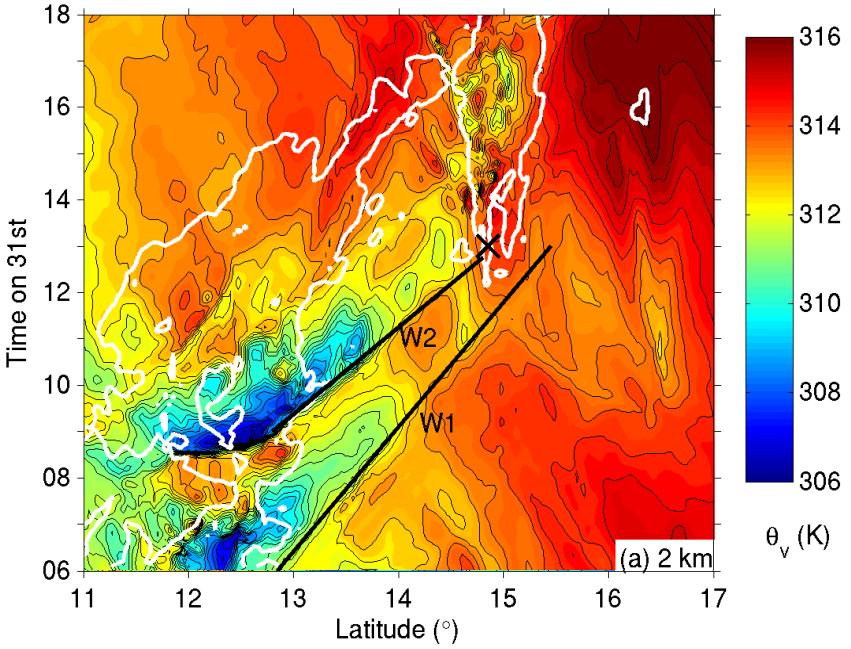

Gravity waves

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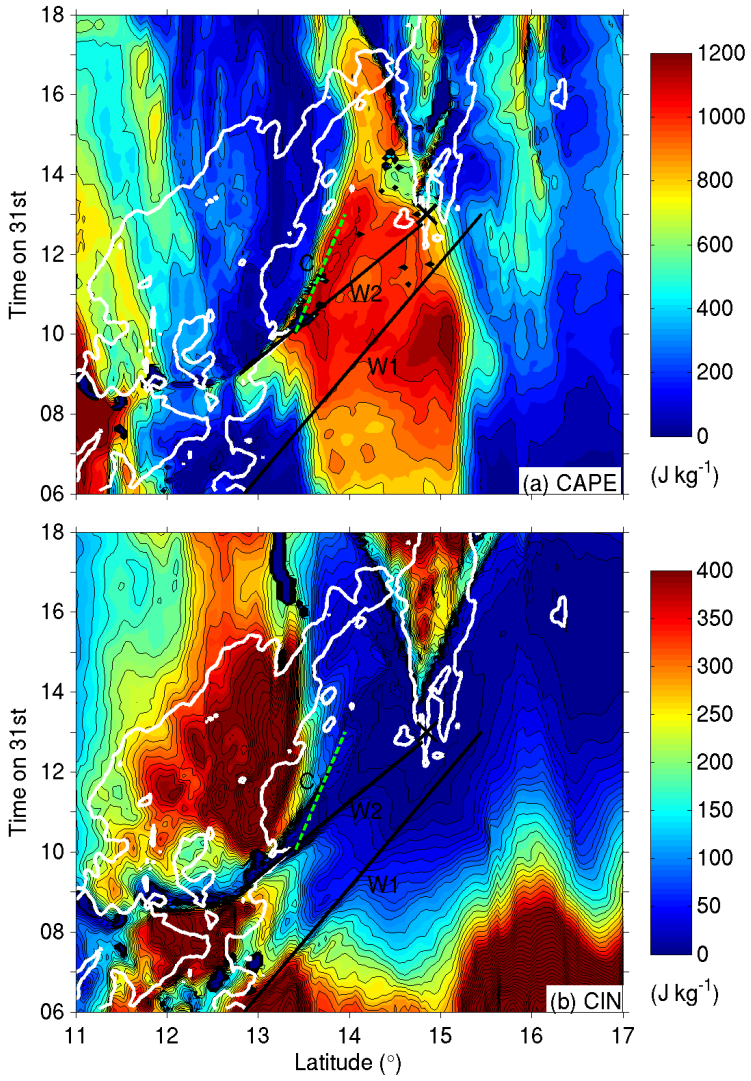

- Waves don't have a significant influence on CAPE but they reduce CIN

Cold pool

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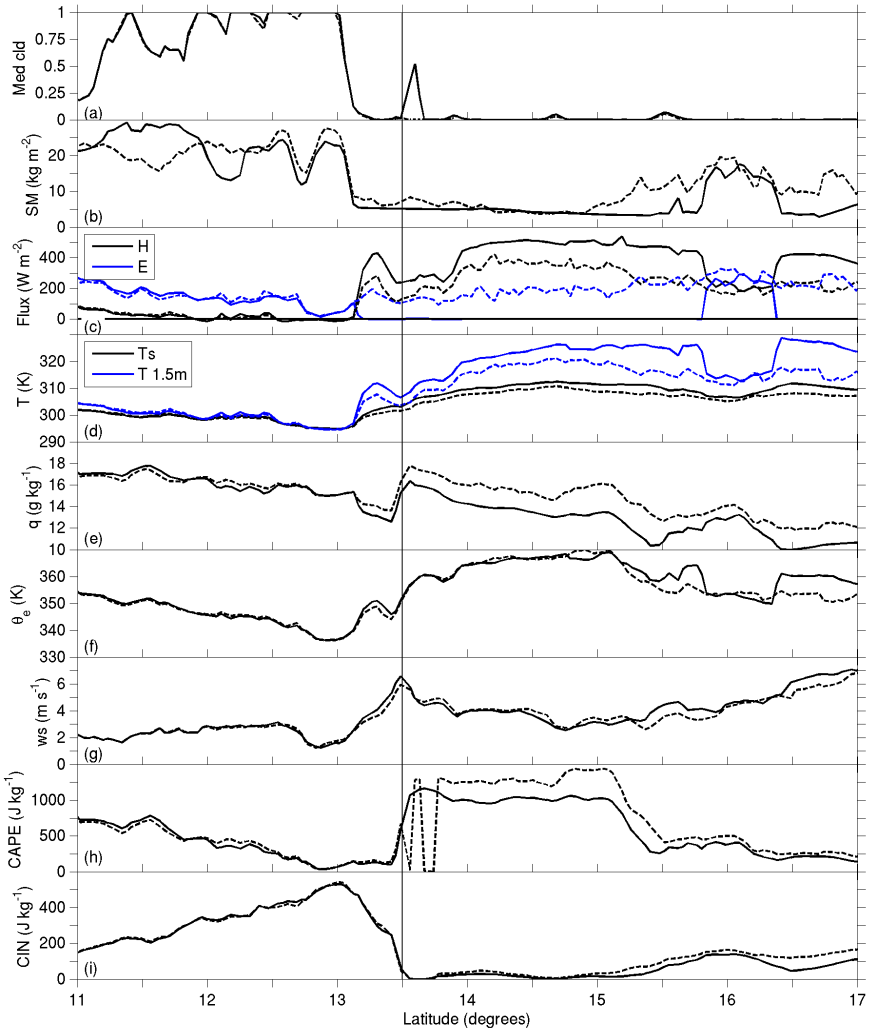
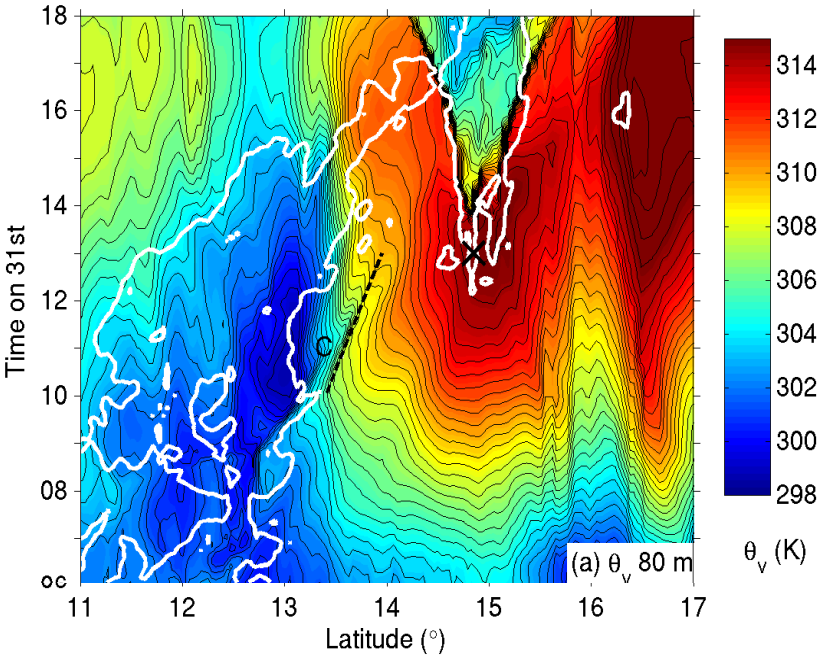


- Model diagnostics at 11Z
- Cold pool at 13.5°N



Land-atmosphere interaction

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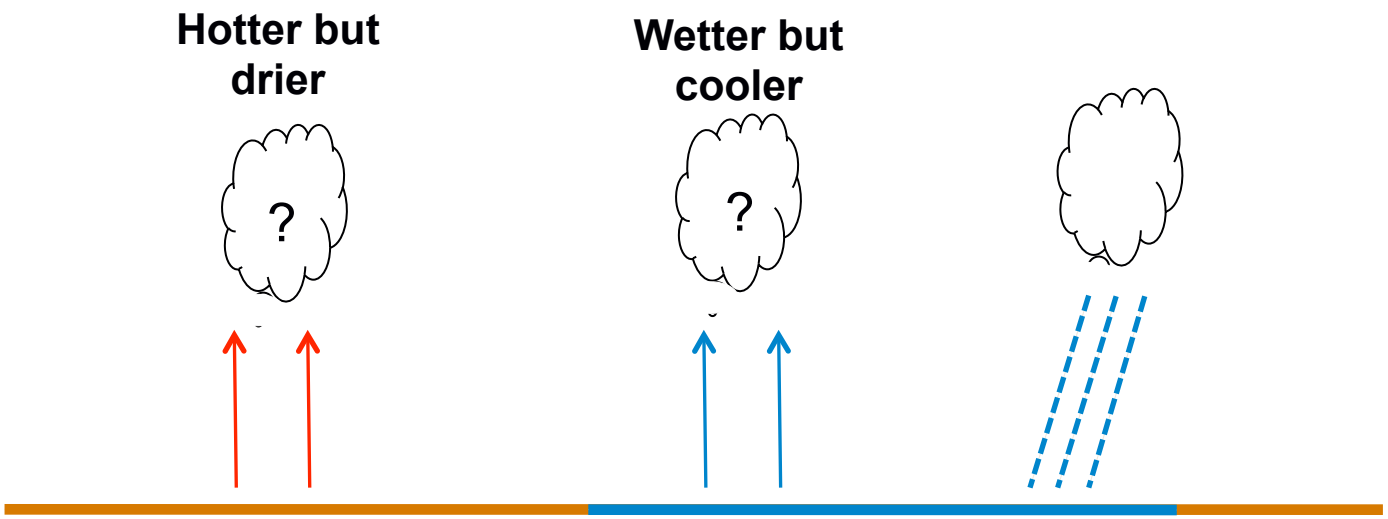

- Moist convection needs heat and moisture

Land-atmosphere interaction

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- Taylor and Lebel 1997:
  - Empirically, rains more on wet soil at the mesoscale

  A positive feedback
- Taylor and Ellis (2006):
  - Empirical composite of many cases, over wet areas there is:

    (i) Reduced cold cloud during late afternoon/early evening

    (ii) Almost no initiation over wet patches

  A negative feedback!

Land-atmosphere interaction

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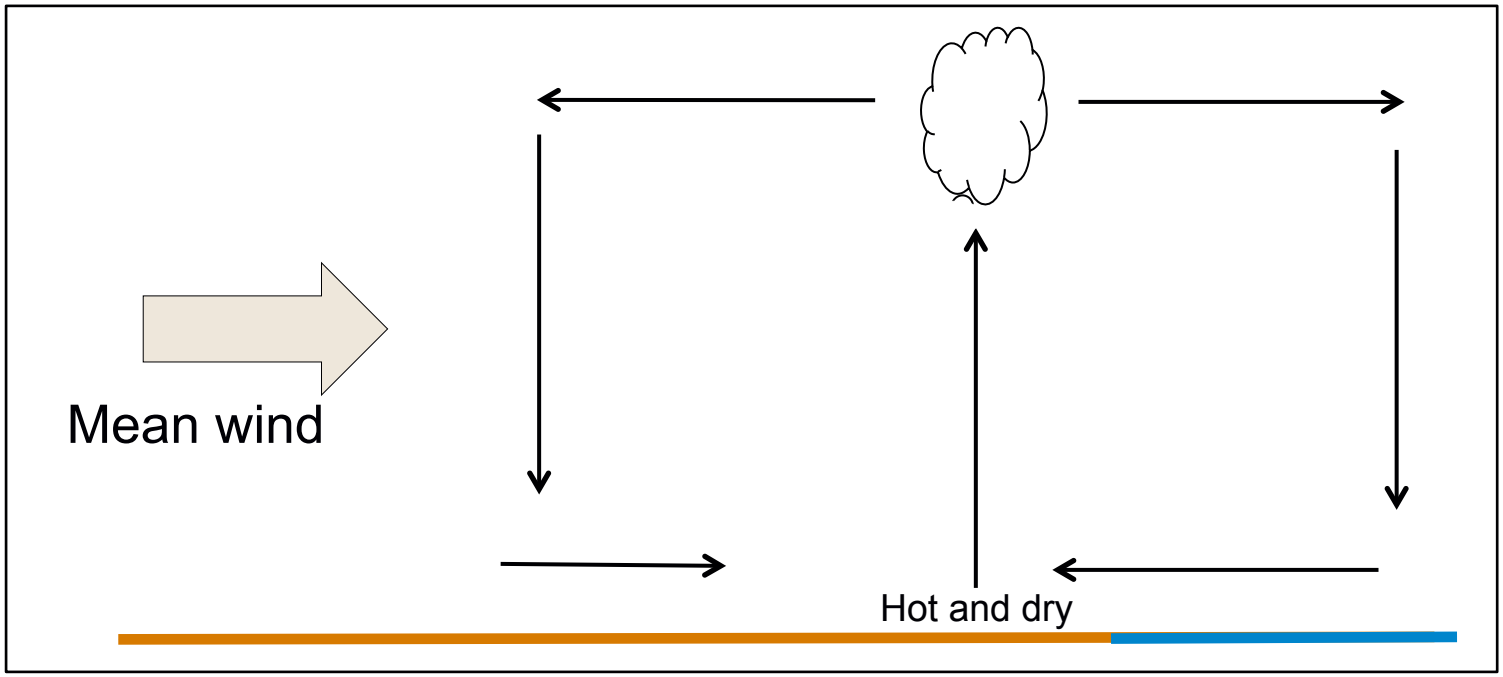

- Current consensus – new convection occurs over dry soil, just upwind of sharp gradients in soil moisture
- But mature systems rain more over wet soil

Wave-fronts

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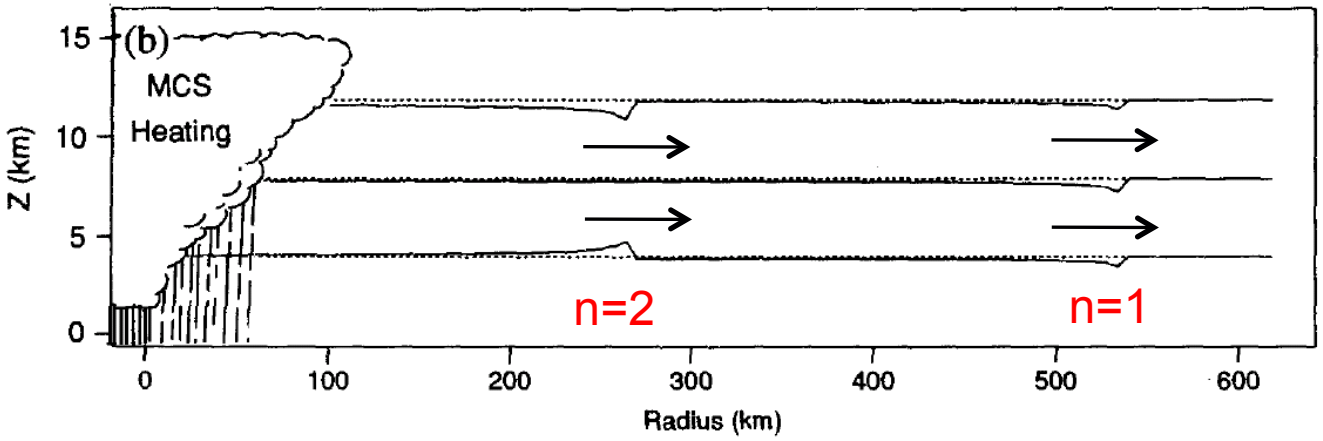

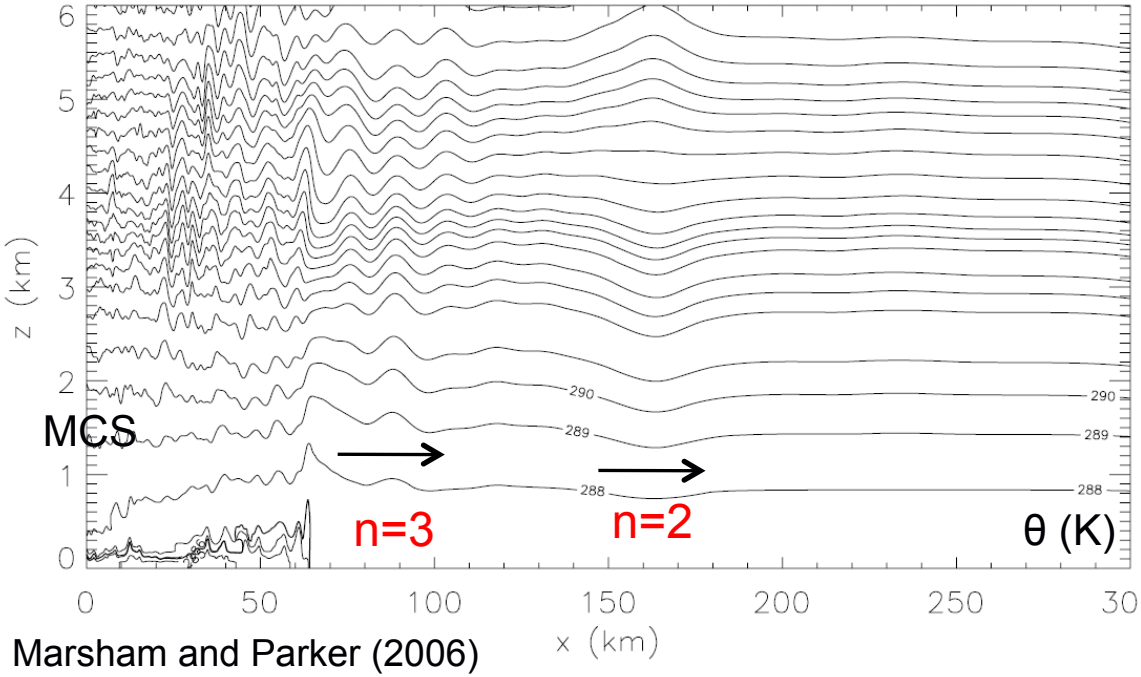

Marsham and Parker (2006)

- The waves extends over the entire troposphere
- n=1 mode travels the quickest
- n=2 and 3 are slower
- Important over the tropics – lots of deep convection and influence of the Coriolis force is lower
- A surprisingly small number of model studies of observed cases (non-idealised), none over west Africa

Storm initiation and development

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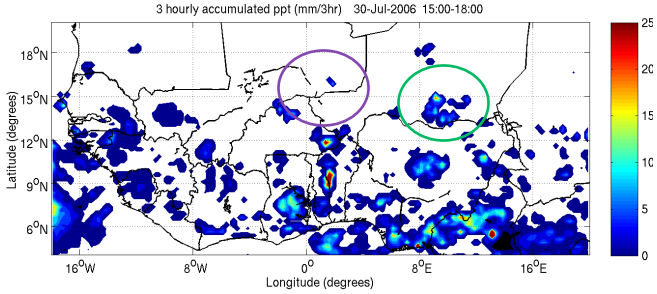
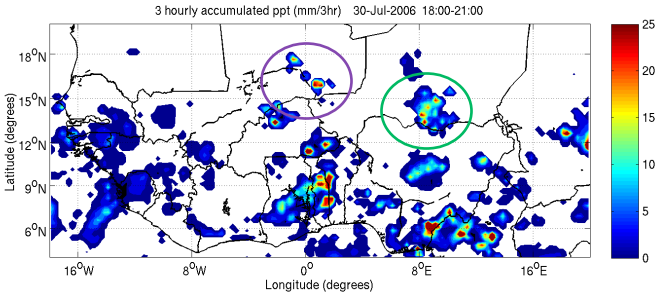
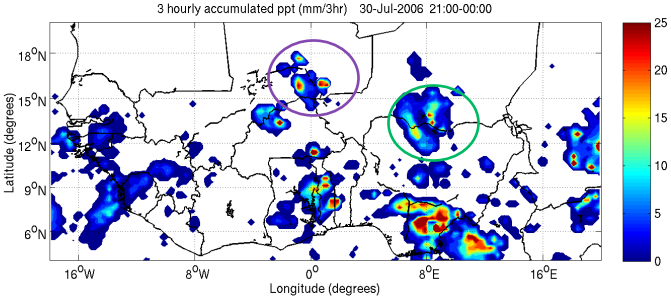
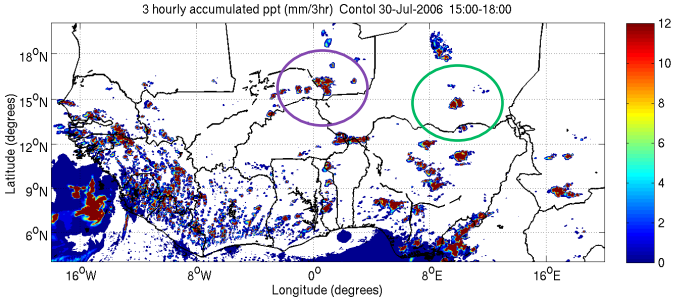
TRMM

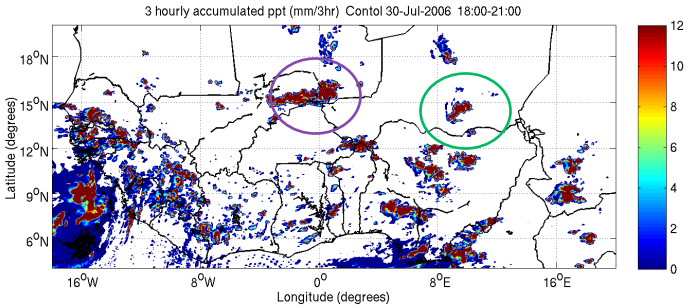


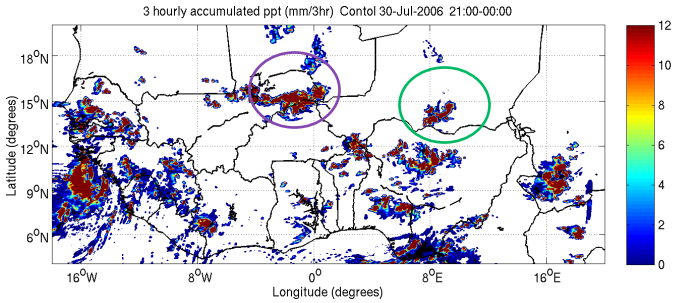




MetUM - control







15-18Z 30th July 2006

18-21Z 30th July 2006

21-00Z 30th July 2006

Storm initiation and development

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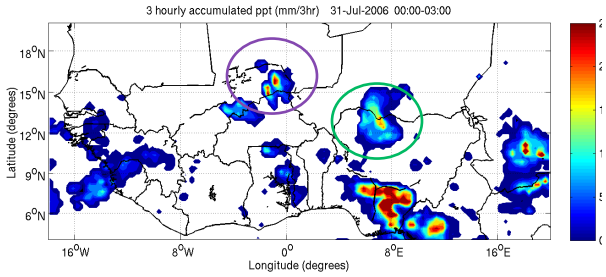
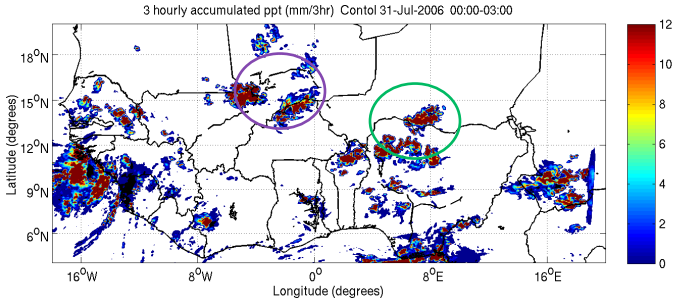
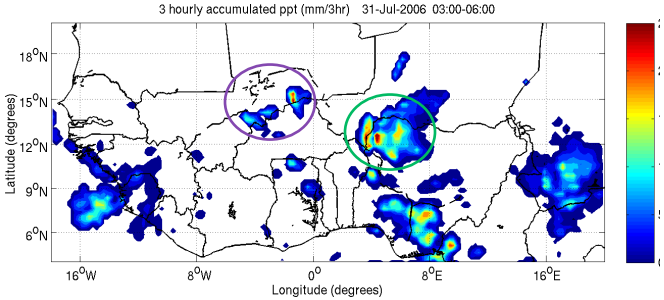
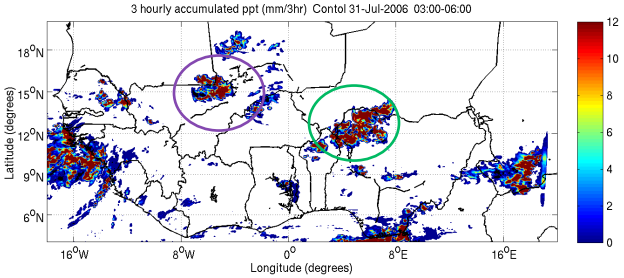




00-03Z 31st July 2006





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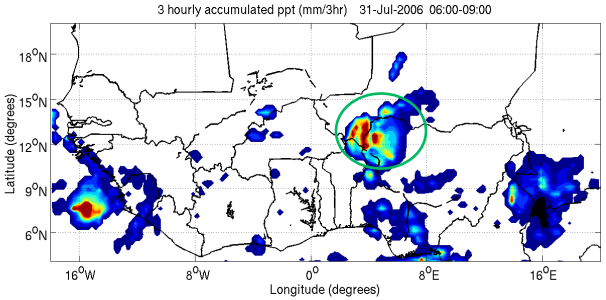

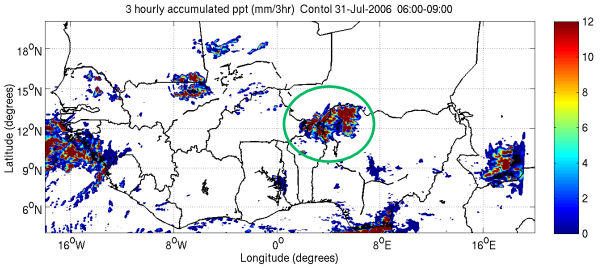

06-09Z 31st July 2006

Storm initiation and development

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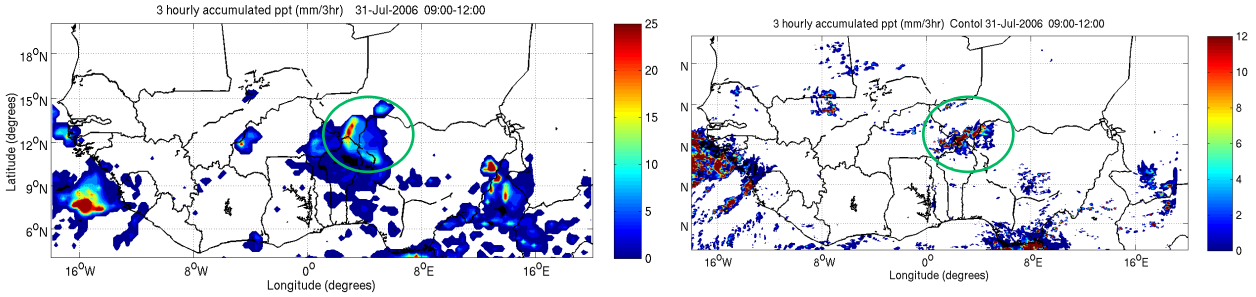
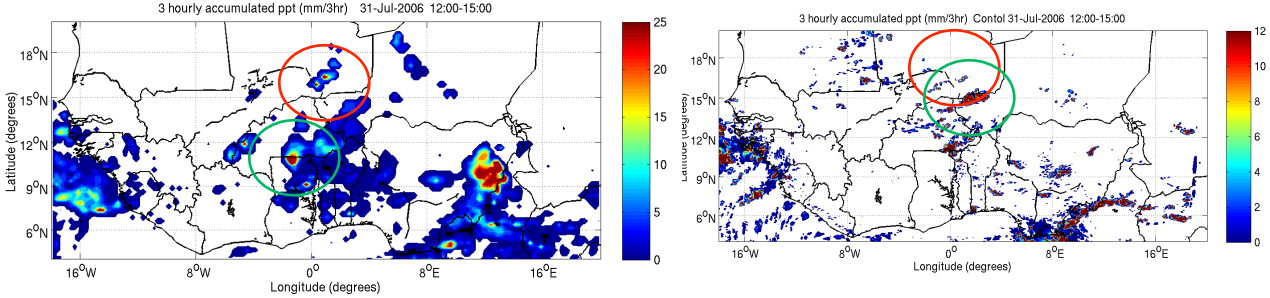
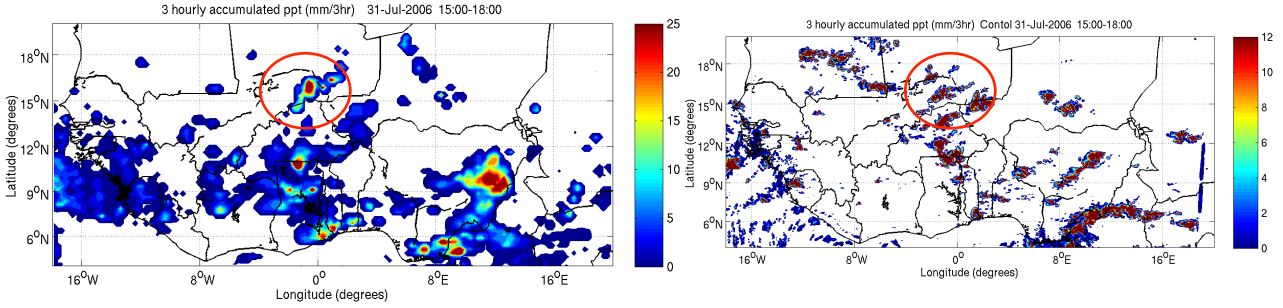


09-12Z 31st July 2006



12-15Z 31st July 2006



15-18Z 31st July 2006

Storm initiation and development

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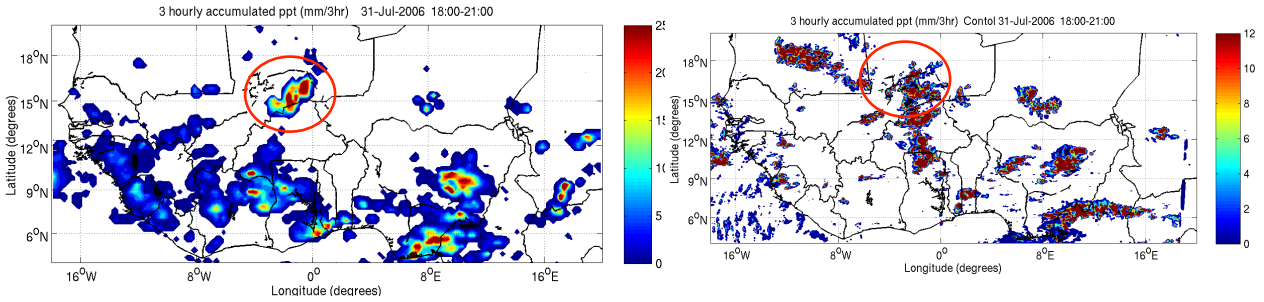
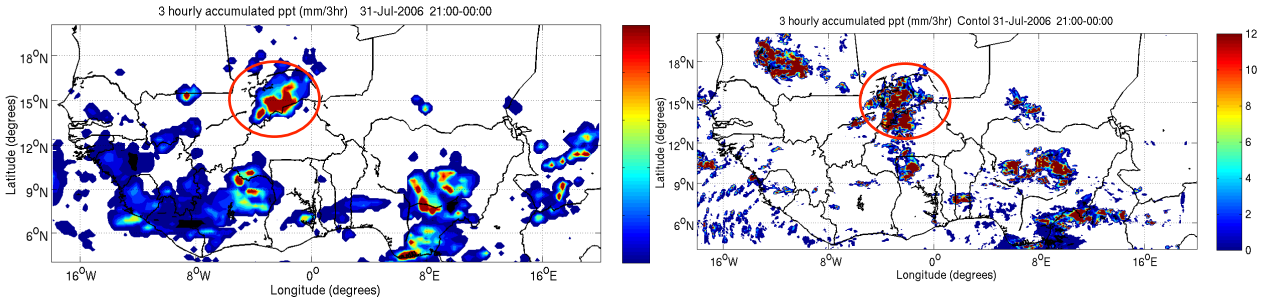
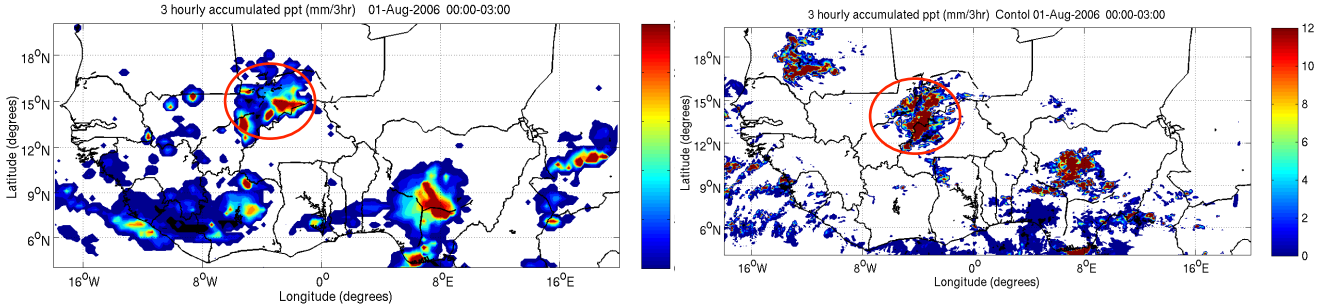


18-21Z 31st July 2006



21-00Z 31st July 2006



00-03Z 1st Aug 2006

Gravity waves

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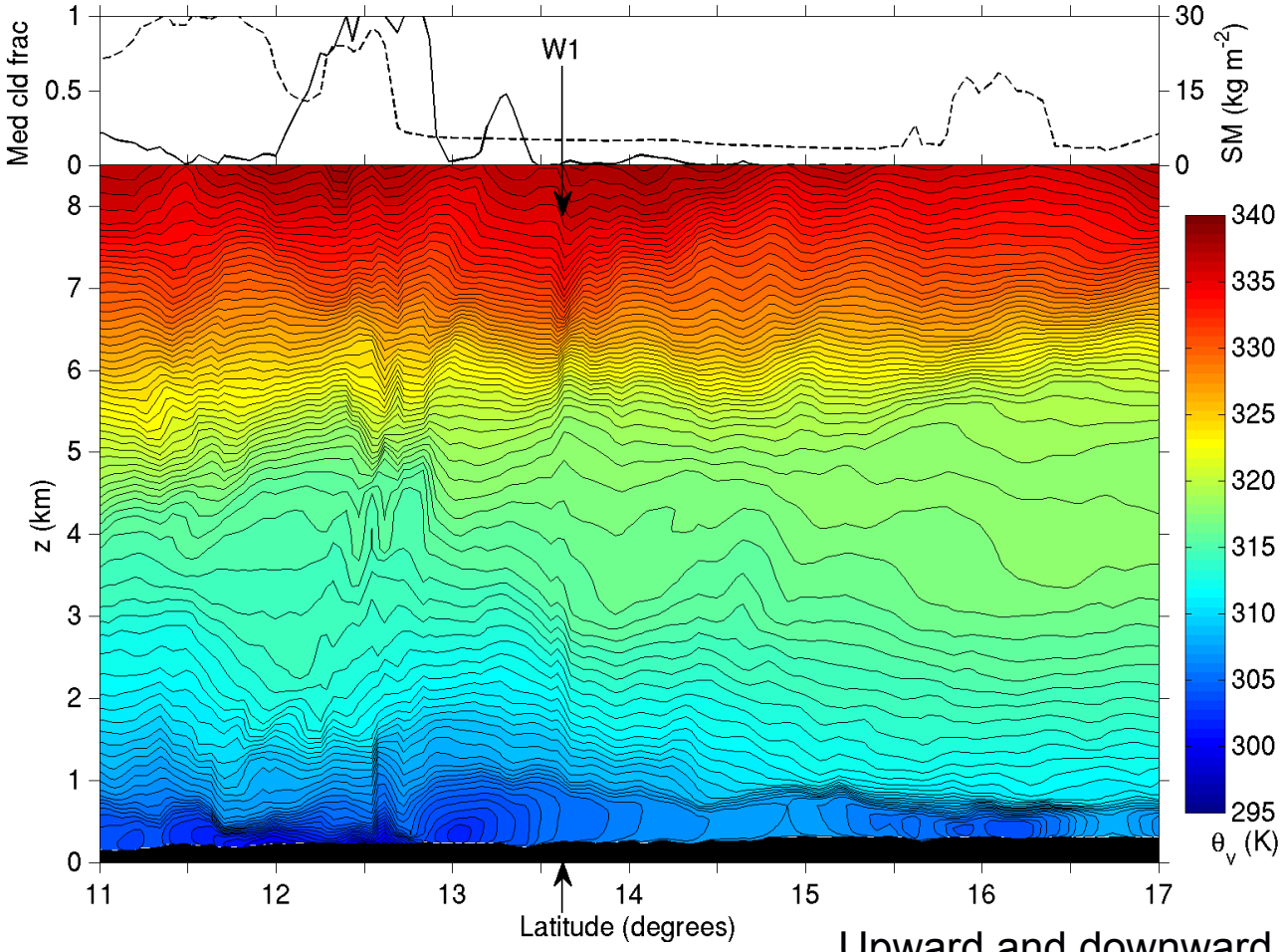
08Z 31st



Upward and downward displacement of air by wave, n=2

Gravity waves

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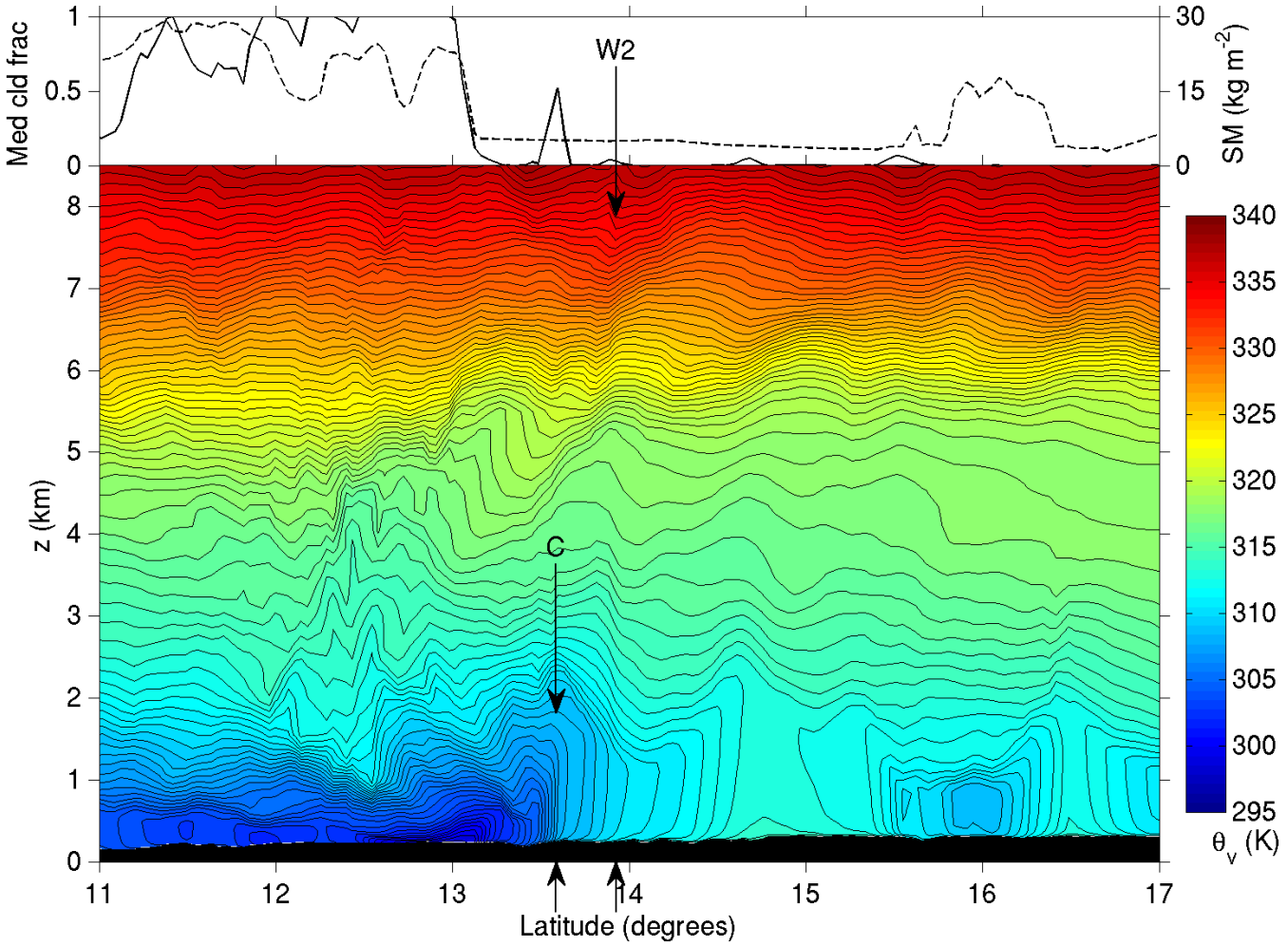

11Z 31st

Upward and downward displacement of air by wave, n=2

Gravity waves

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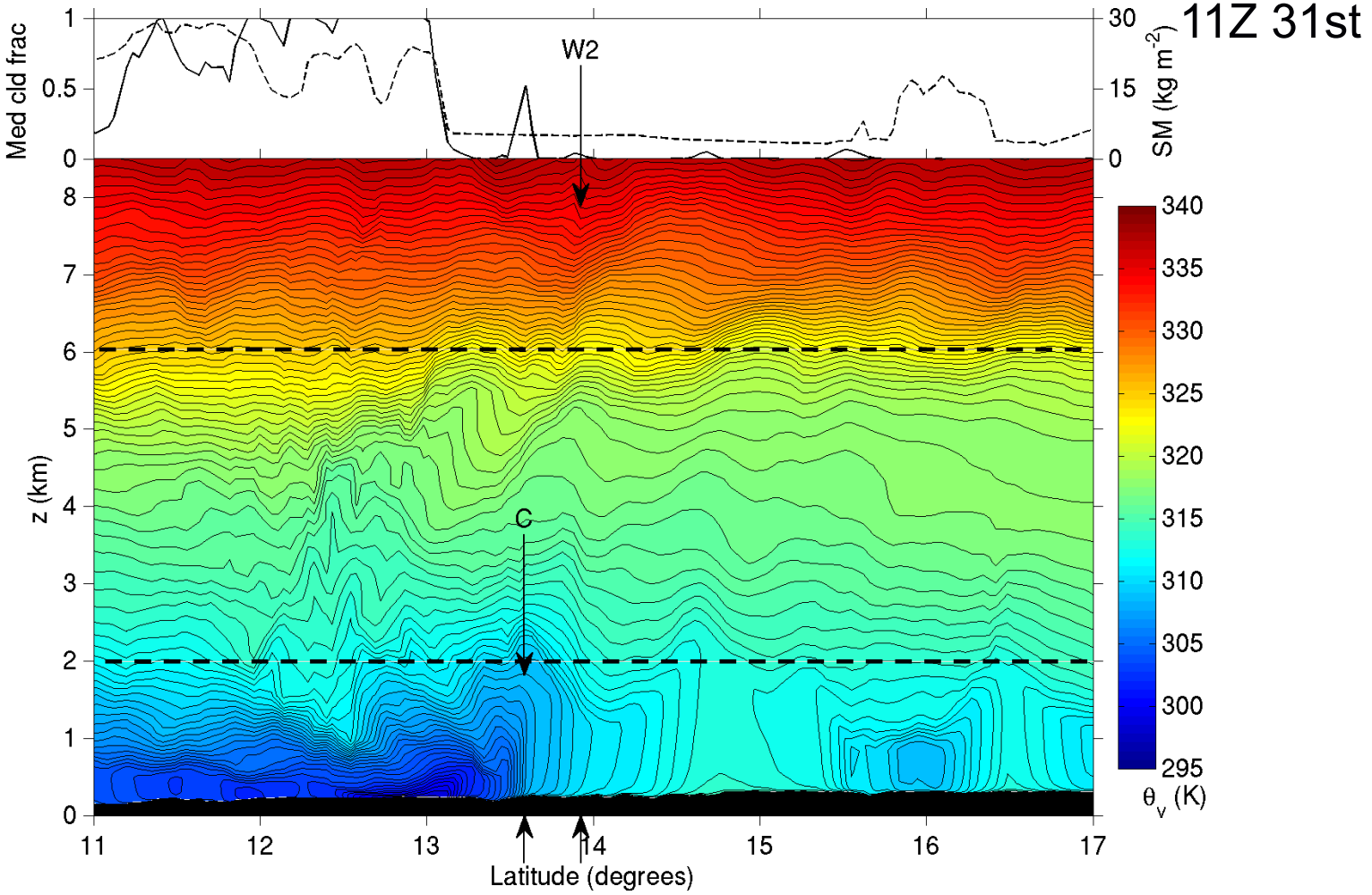

Gravity waves

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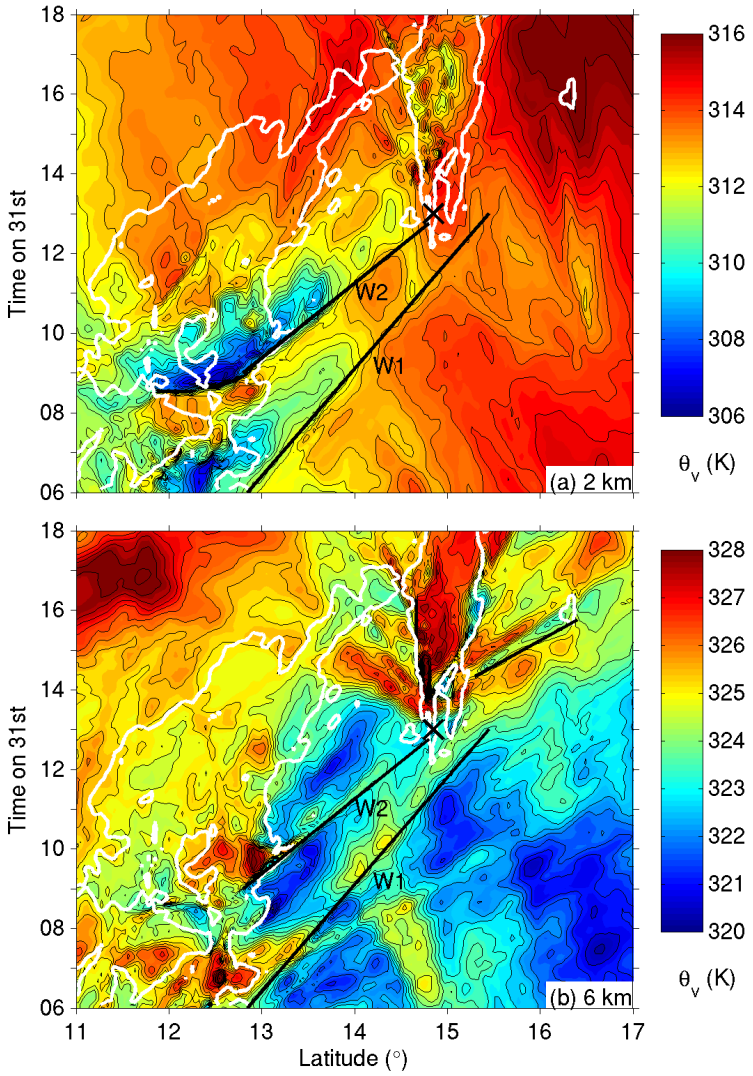

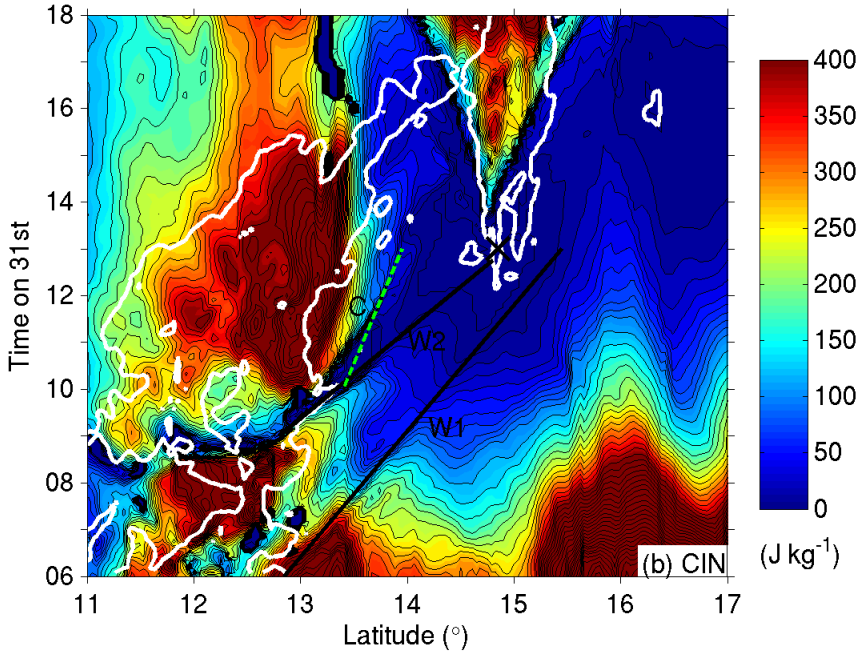

- W1 travels towards the northwest at ~15.7 m s^{-1}
- W2 travels towards the northwest at ~ 20.2 m s^{-1}
- W1 sets up environment for W2
- Second example of initiation by waves

Wave speed calculation

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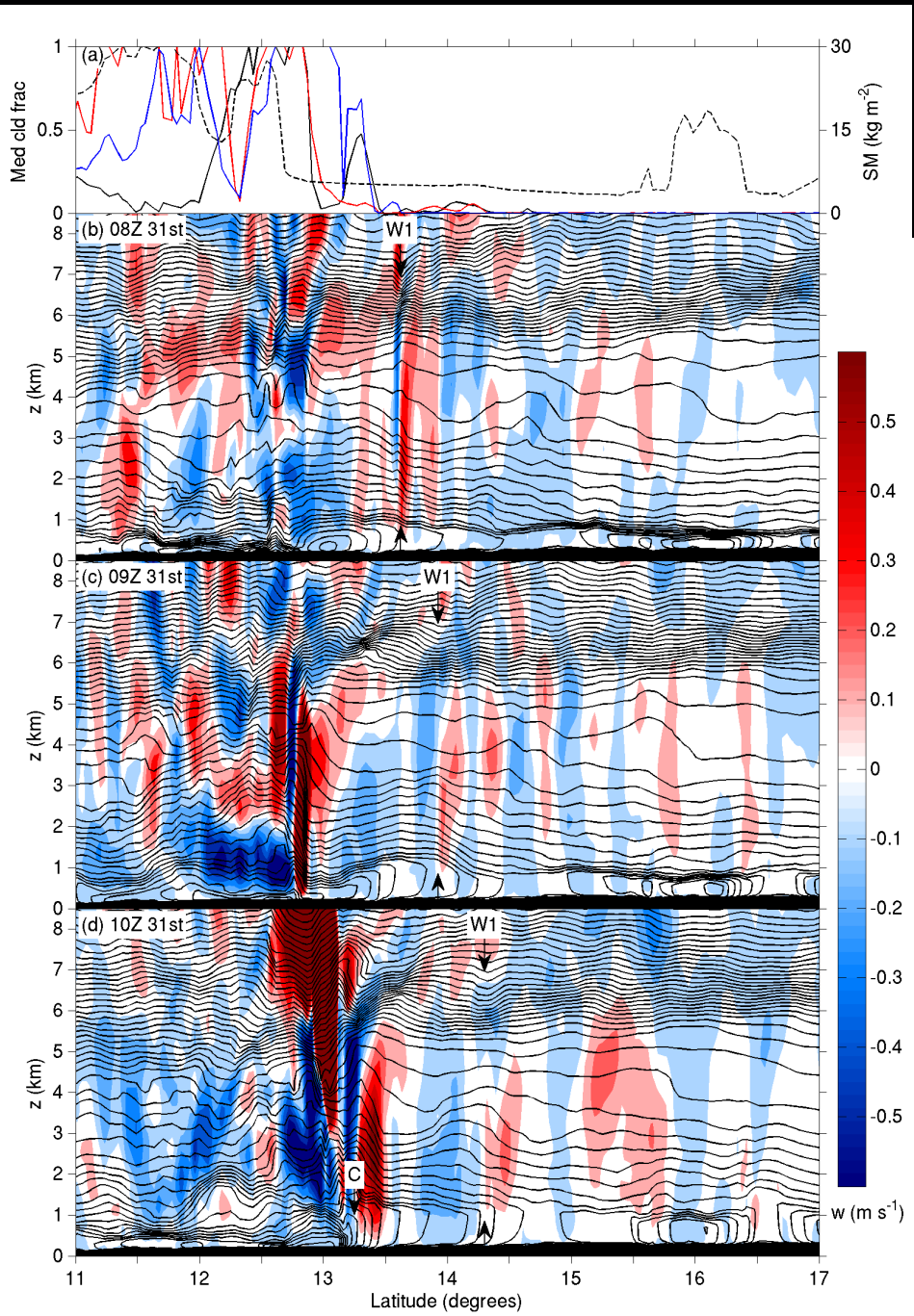
- The waves appear to be wave-fronts rather than bores
- Assuming that the tropopause acts as a rigid lid, the vertical wavelength (λ_z) of the wave can be estimated using the equation:

$$\lambda_z = \frac{n\pi c}{N}$$

where:
n is the wave mode = 2
c is the phase speed = 17.5 m s^{-1}
N is the Brünt-Väisälä frequency = 0.01 s^{-1}

Gives a vertical wavelength of $\lambda_z \approx 11$ km, which is approximately equal to the depth of the troposphere in this case.

Gravity waves



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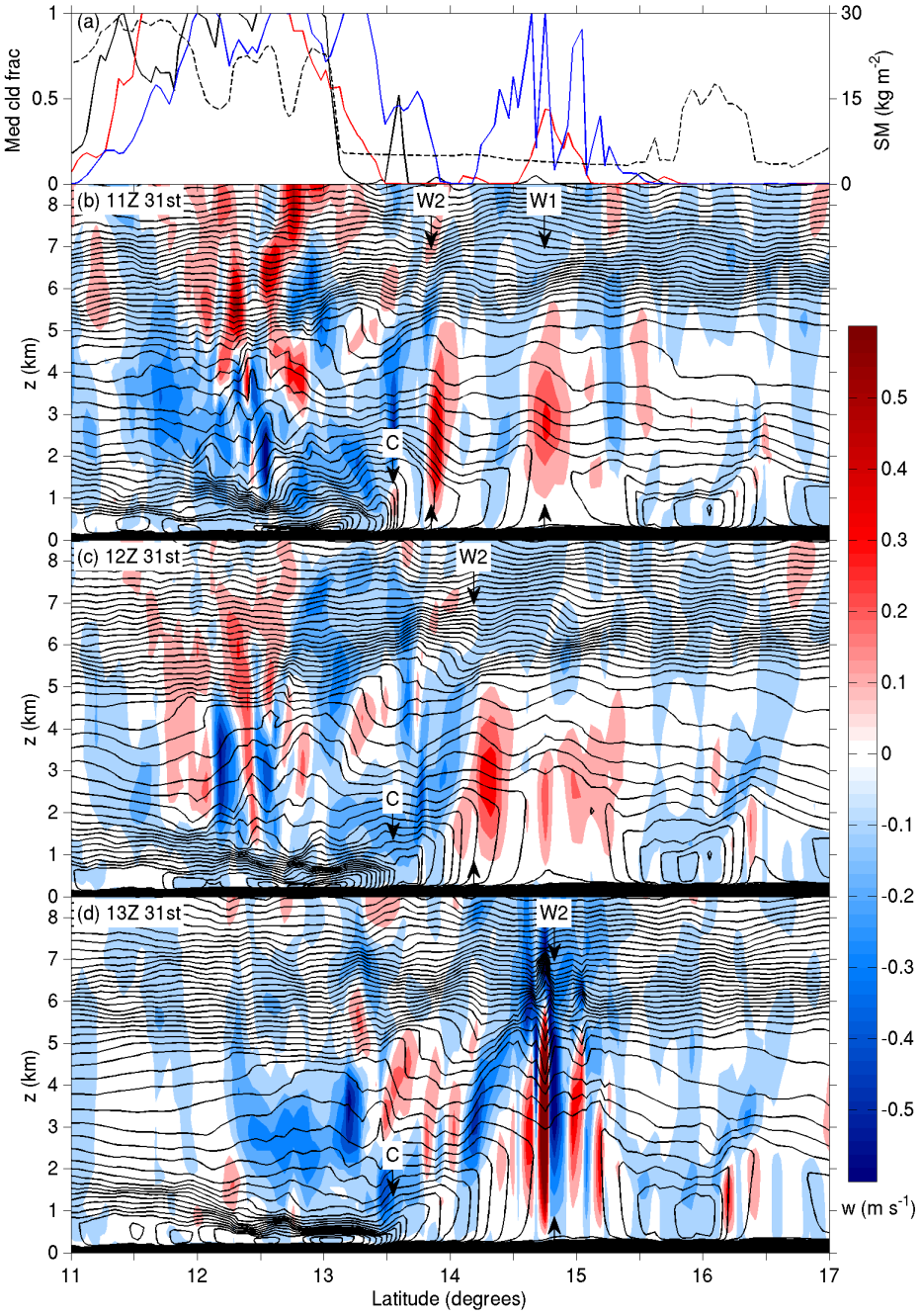
Gravity waves



Land-surface interaction

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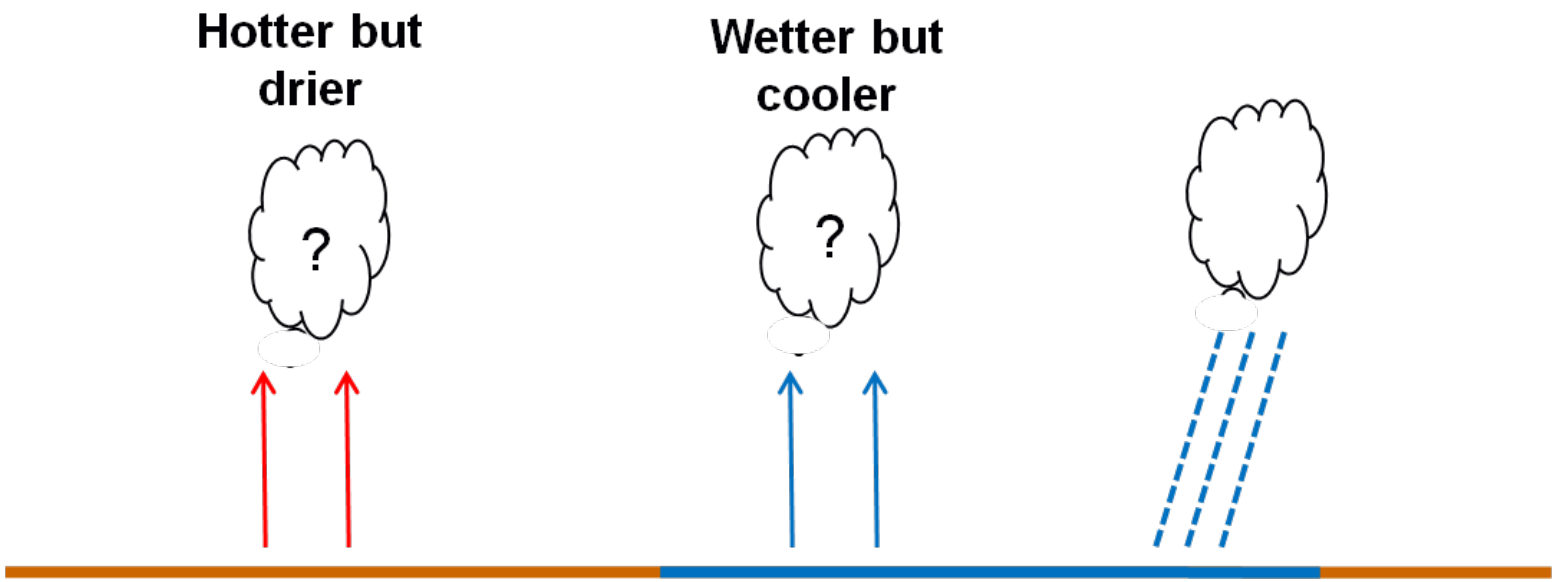

Gravity waves

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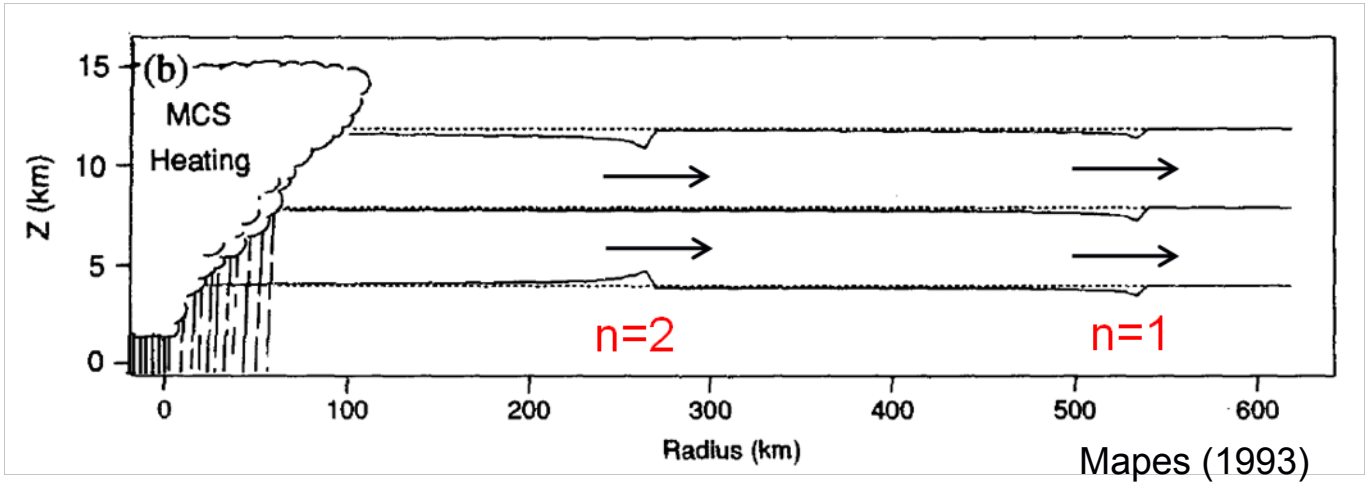

Mapes (1993)