How parameterised deep convection generates model biases for the West African Monsoon system: A seamless assessment

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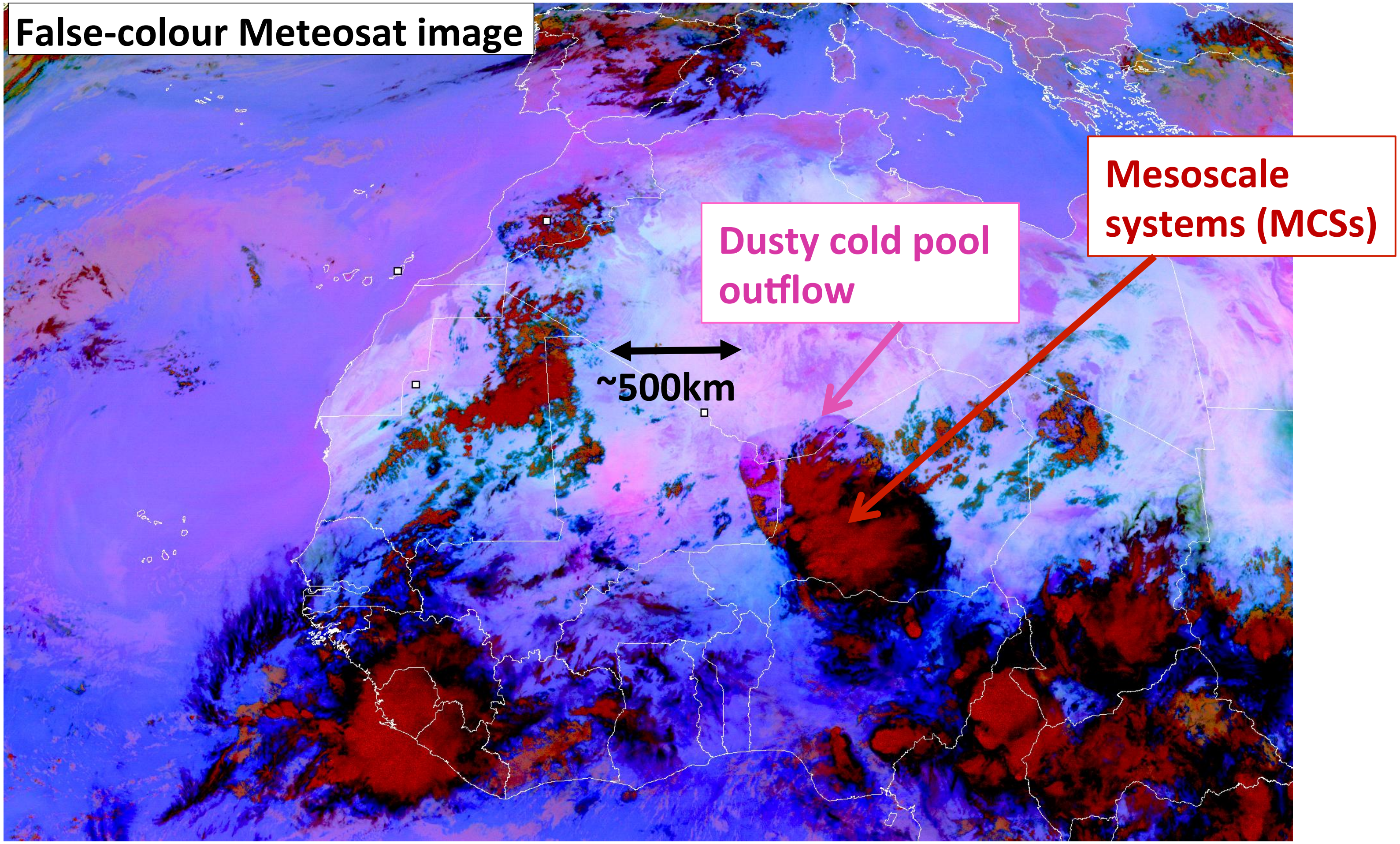
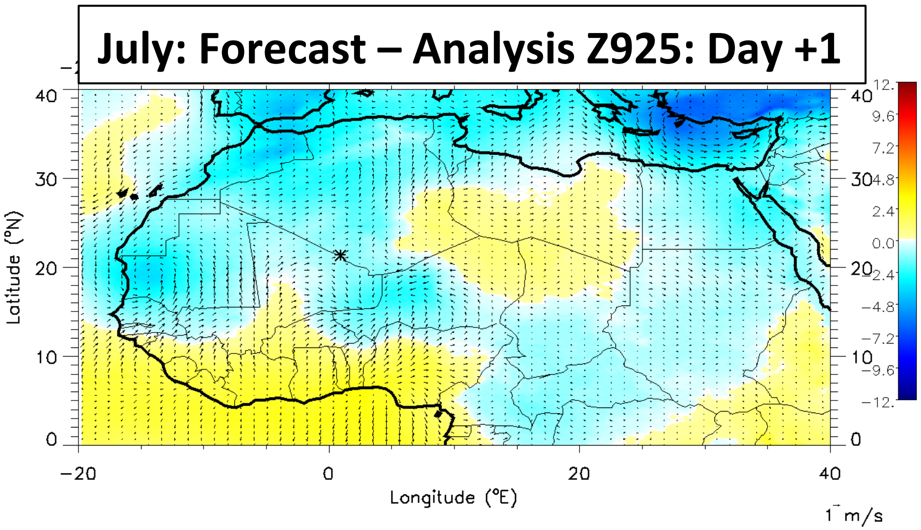
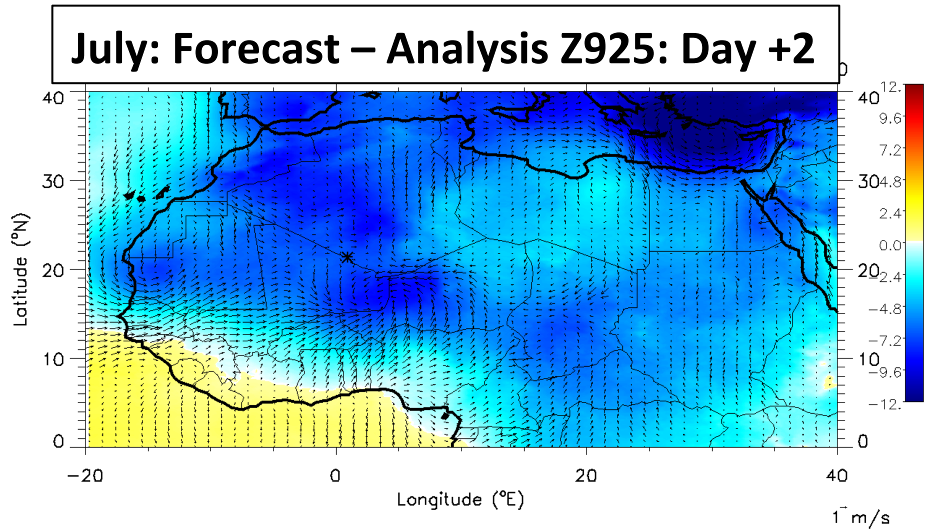
Convection in the West African Monsoon



- Summer monsoon brings annual rains to the Sahel.
- MCSs bring 80% of rainfall in some parts of the Sahel.
- Monsoon winds maximum at night (Parker *et al*., 2005)

Global Unified Model forecast bias for the West African Monsoon

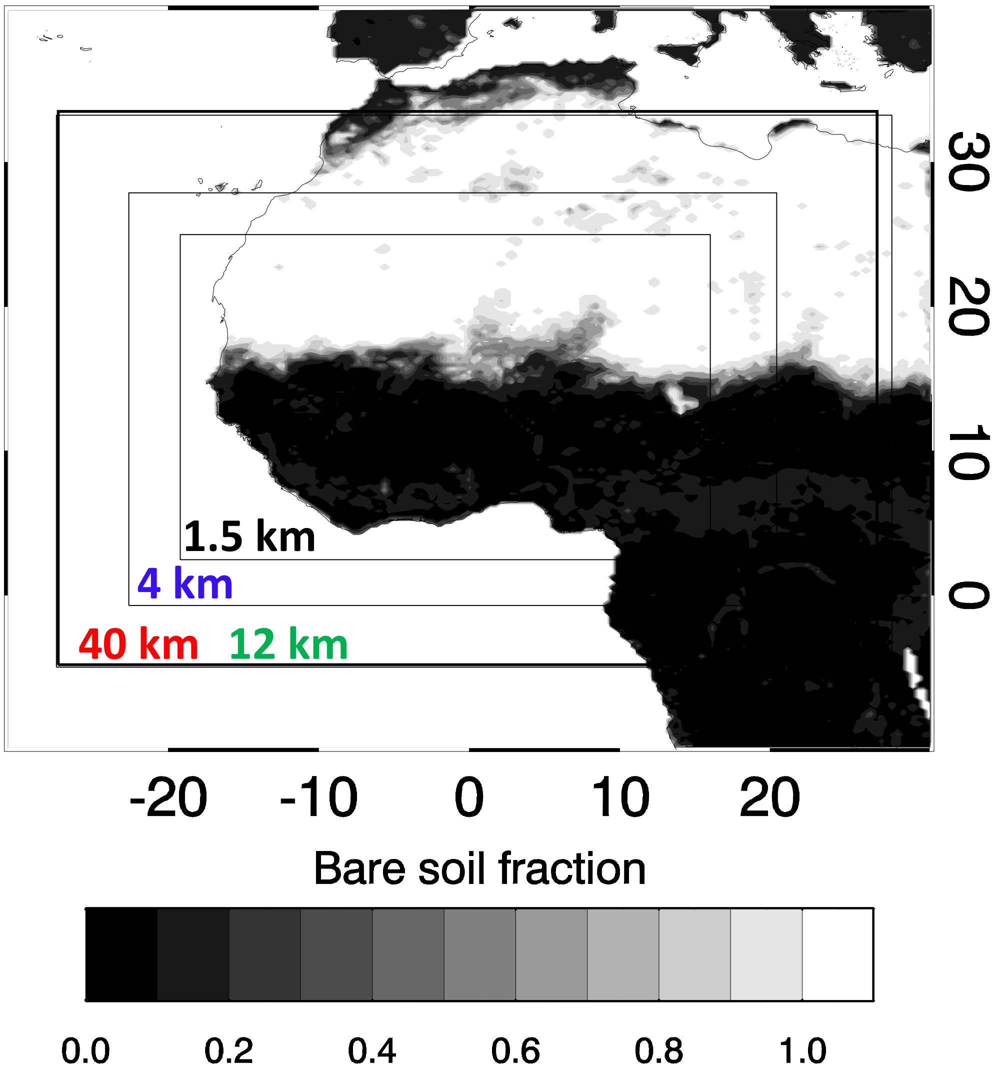




- Systematic error in West African Monsoon appears within one day
- Too strong a Sahel-Sahara pressure gradient gives too strong a monsoon flow
    - Errors in Saharan heat low region known to be important (e.g. Tompkins et al, 2003; Rodwell and Jung, 2008)
    - But here we focus on role of moist convection

Cascade simulations

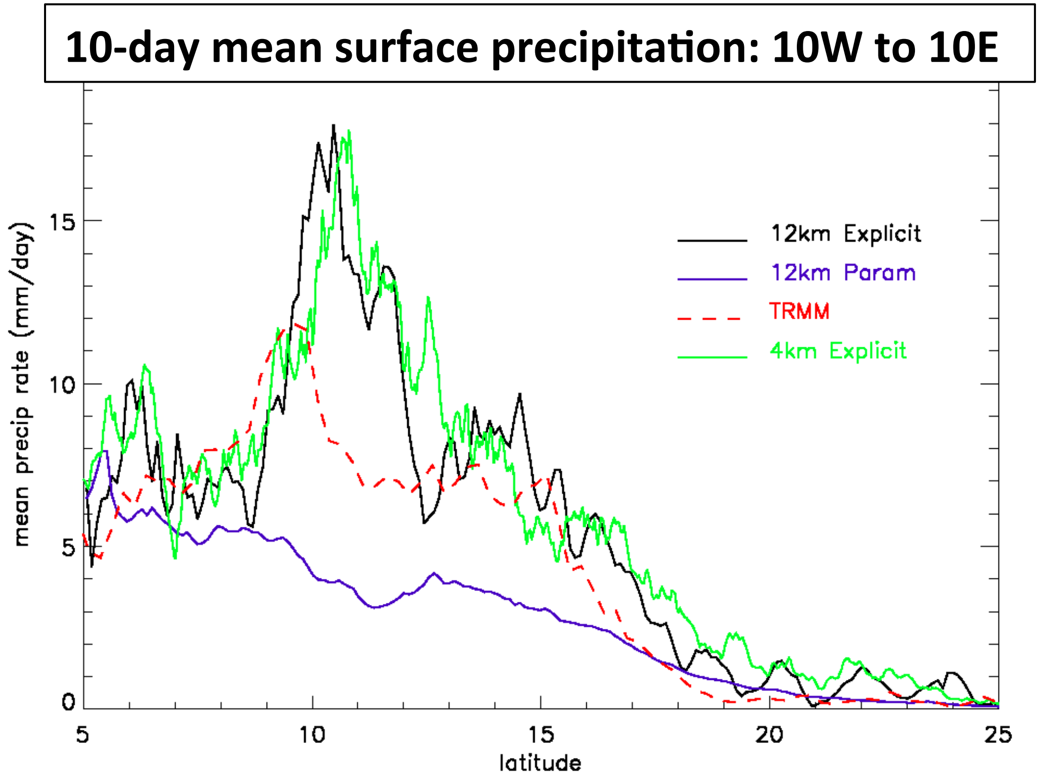
Multi-day continental-scale convection-permitting simulations



- Nested **40-km**, **12-km**, **4-km** and **1.5-km** simulations.
- 25th July to 3rd August 2006 (only 2 days at 1.5 km).
- Parameterised convection: 40 km, 12 km.
- Explicit convection: 4km, **1.5km** and 12km.

- 12km explicit *versus* 12km parameterised allows us *to isolate the role of the representation of convection on the continental scale.*
- 12km explicit is coarse, but can give reasonable squall-lines (Weismann *et al.*, 1996).

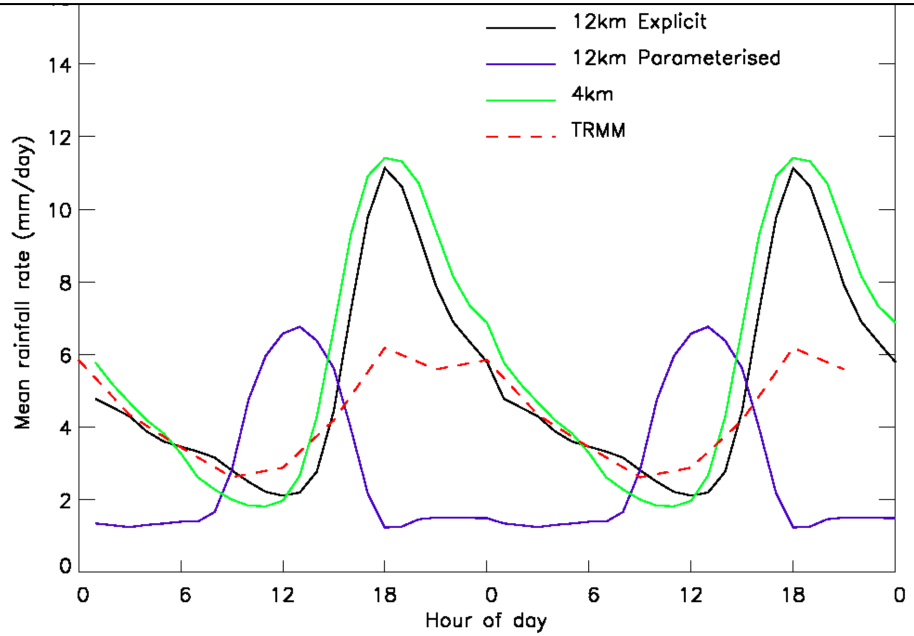
Cascade: Spatial distribution of rainfall



- Explicit (**12** and 4km) runs most similar to TRMM retrievals
  - But have more rain than TRMM at 11N
- 12km parameterised has too little rain, which is too far south

Diurnal Cycle in rainfall

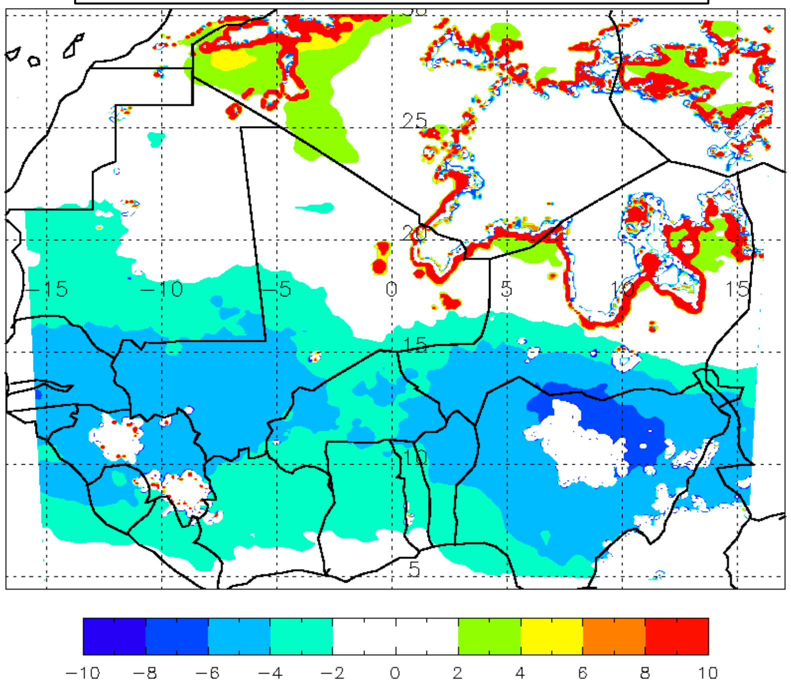
Mean diurnal cycle in surface precipitation: 10W to 10E



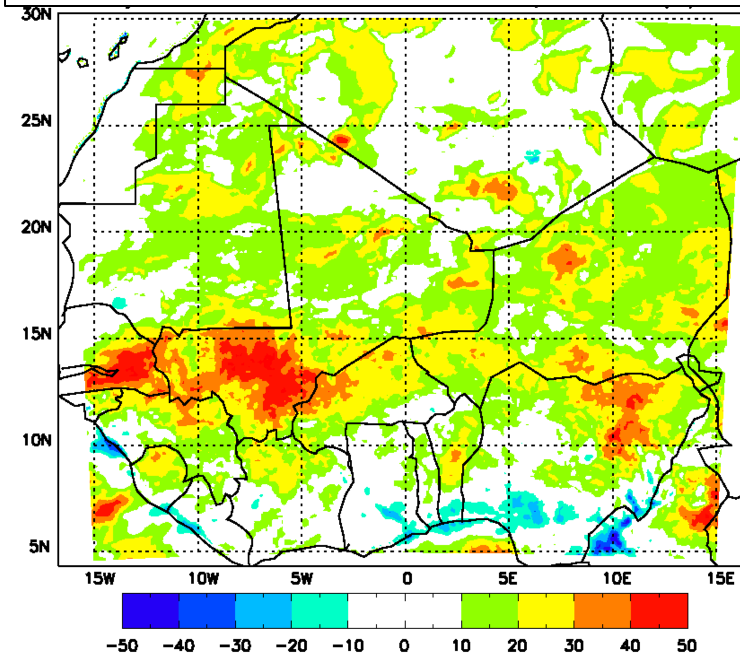
- Parameterised convection gives rain too early in the day.
- Explicit convection gives timing close to observations, with maximum around 18Z.
- Spatial "patchiness" of rain also better at 12kmExp (not shown).

Differences in mean state

Z925: Explicit-Paramaterised



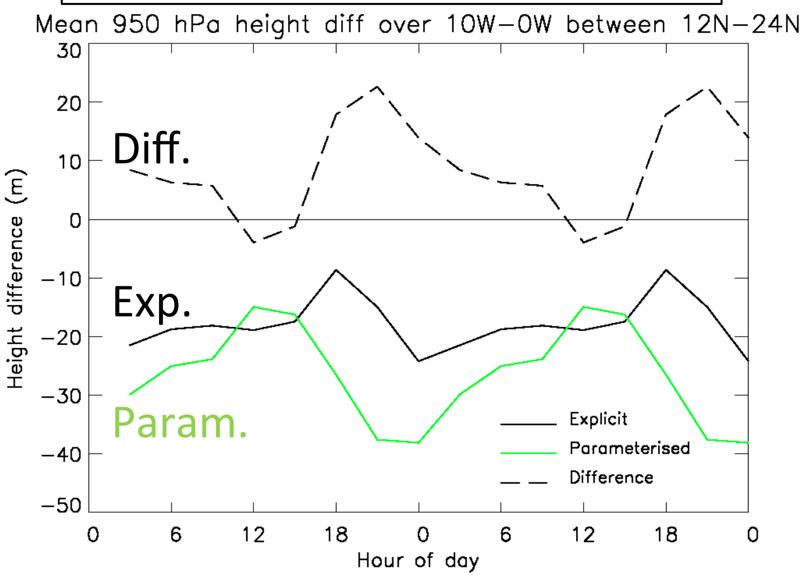
Net surface radiation: Explicit-Paramaterised



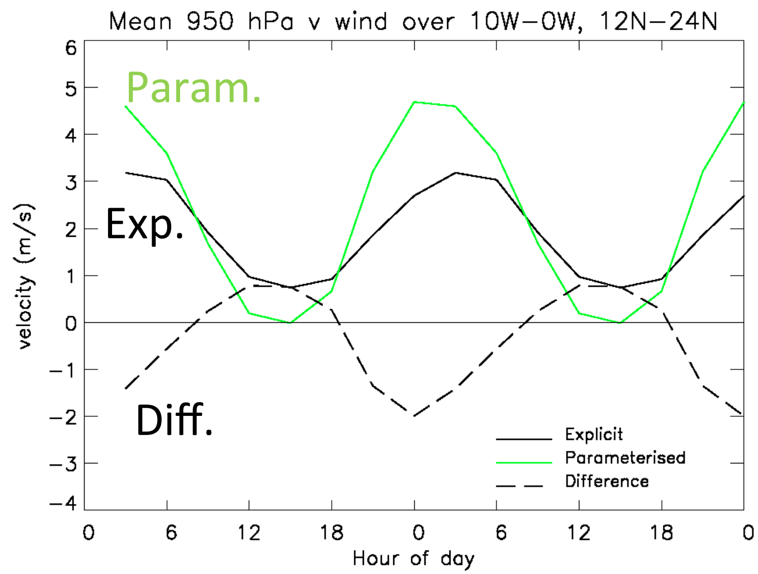
- Increased rain in explicit run over the Sahel gives greater convective heating (mean = 5.2mm/day vs 2.8 mm/day ~ 64 Wm^{-2})
  - Lowers pressure over the Sahel, weakening the Sahel-Sahara pressure gradient.
- Less midday cloud in explicit increases solar heating (mean = 14Wm^{-2})
- Both occur within 24 hours

Diurnal cycle in model differences

Sahel-Sahara pressure gradient



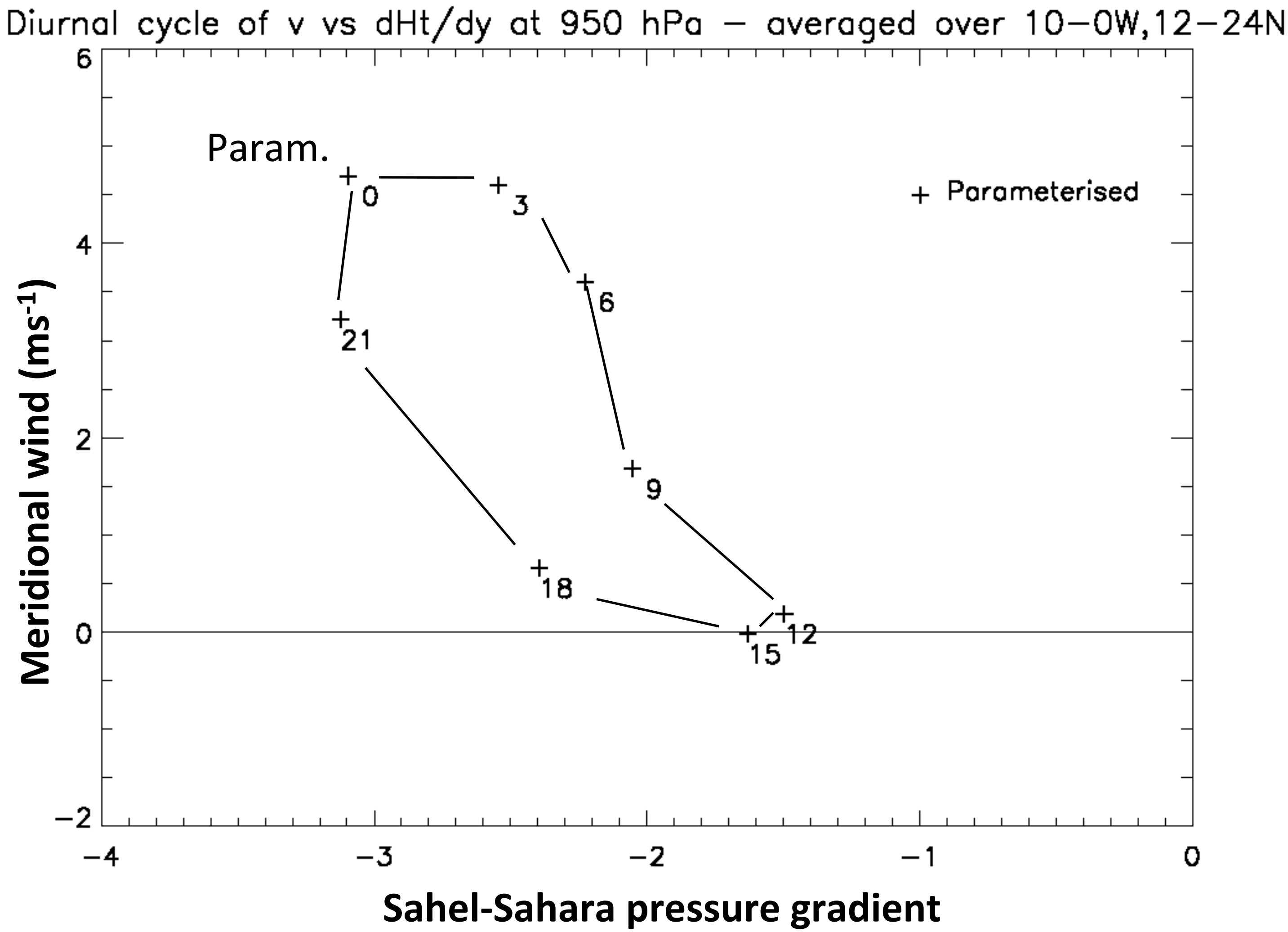
Meridional wind



- Diurnal cycle in pressure gradient consistent with diurnal cycle in rain.
  - Later rainfall in explicit run gives later minimum in Sahel-Sahara pressure gradient.
- Lengthens “dissipation phase” and shortens “building phase”

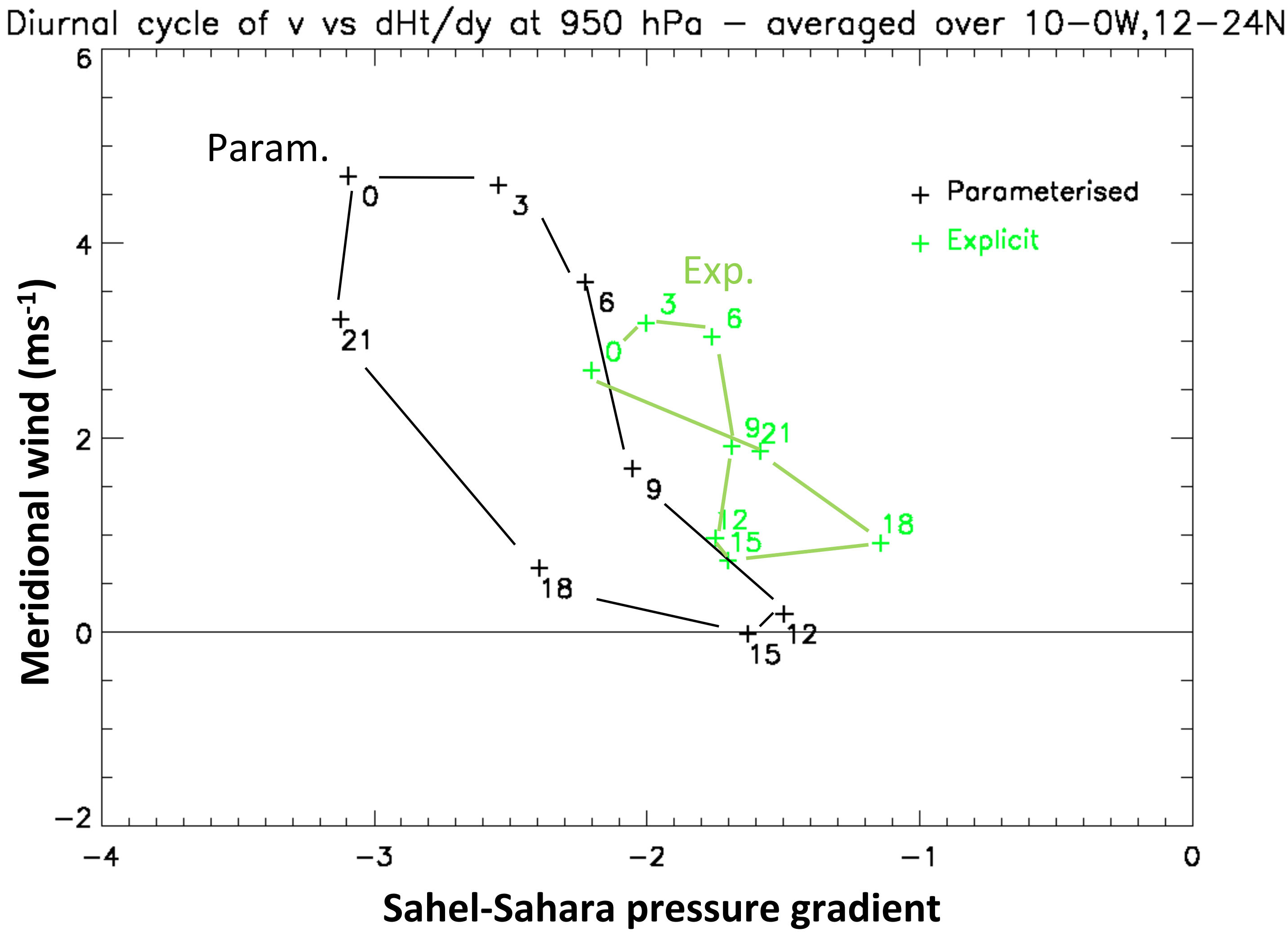
- Gives stronger pressure gradient (~10m at Z925 hPa) and stronger monsoon winds (~2 m/s) in parameterised run

Diurnal cycle in monsoon flow



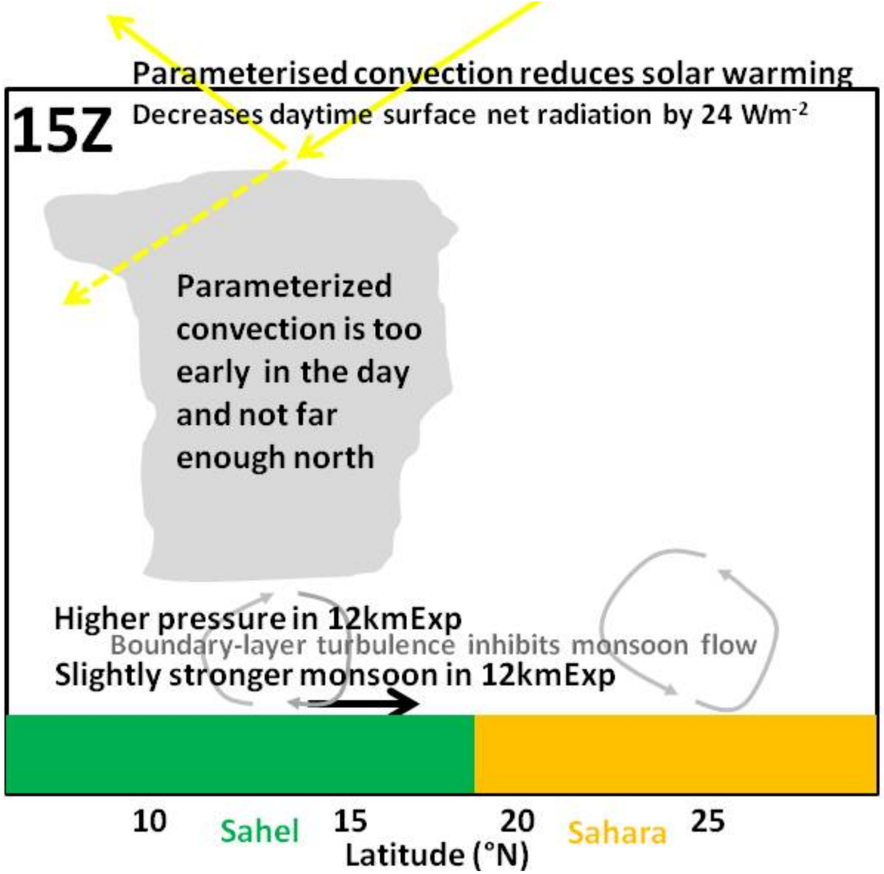
- Meridional wind lags pressure gradient by about three hours
- BL convection inhibits winds in the daytime

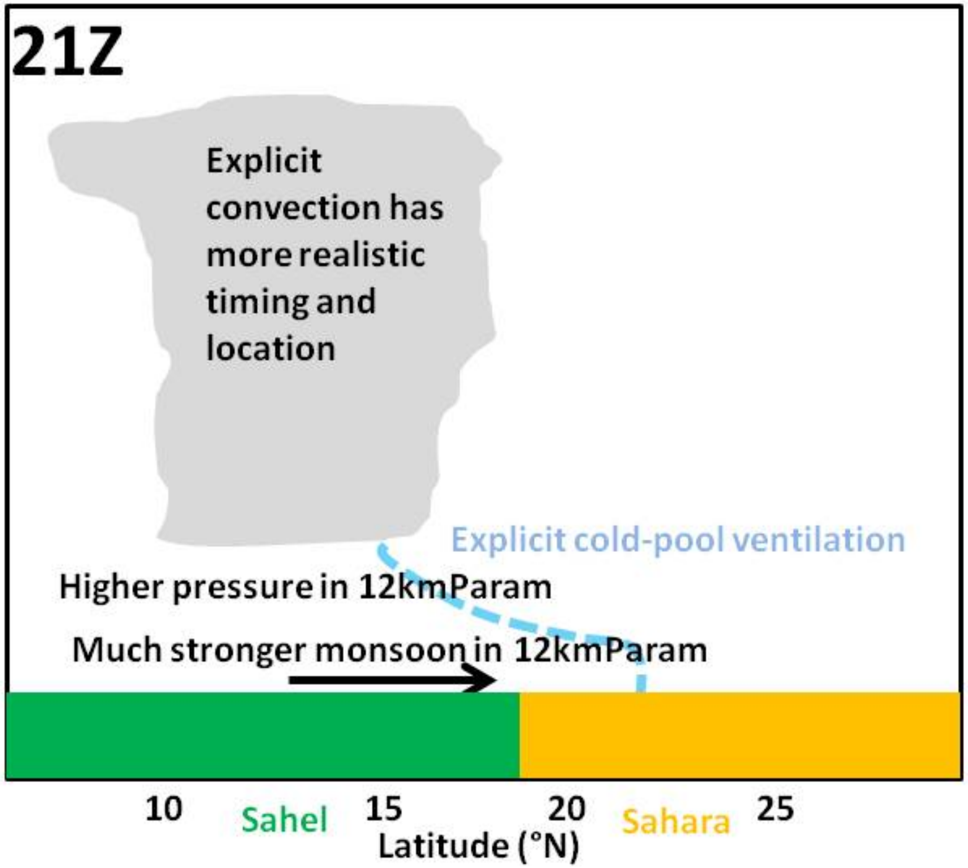
Diurnal cycle in monsoon flow



- Timing of minimum pressure gradient and BL convection now offset

Summary of Processes

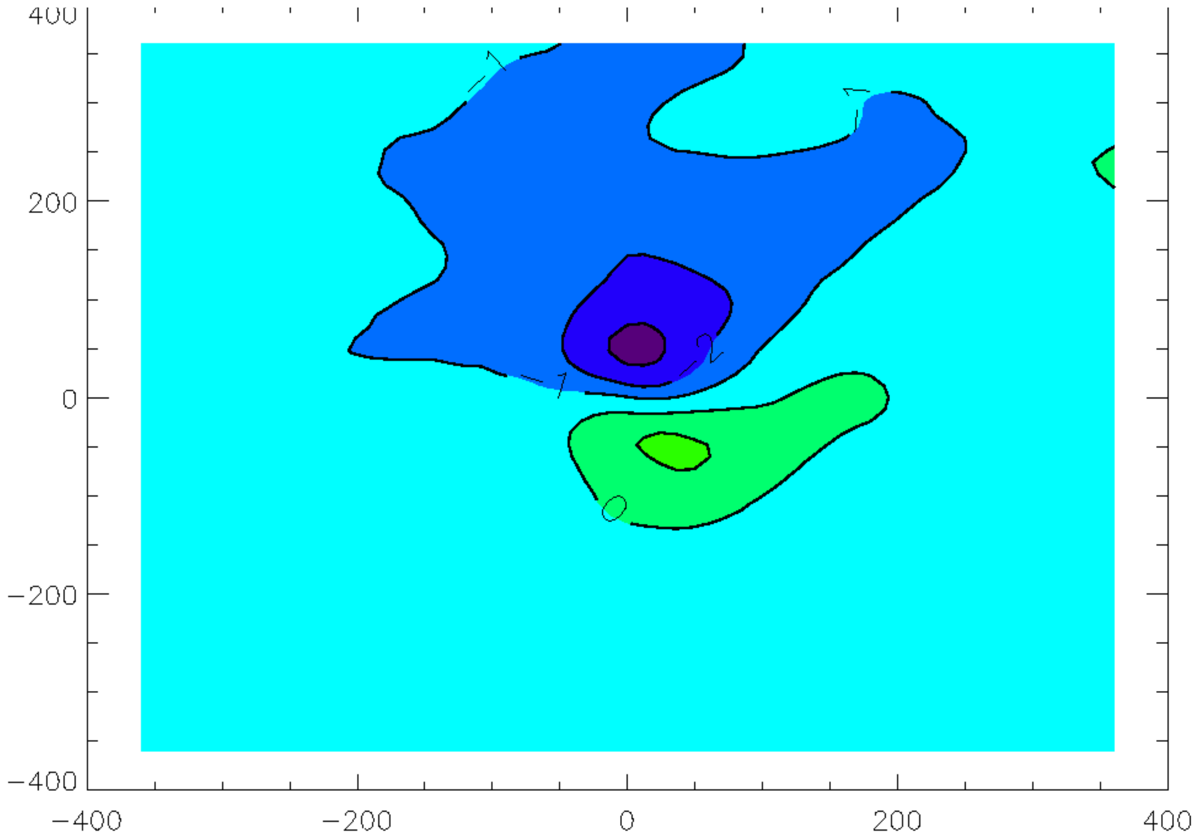




(1) Great net heating over Sahel in 12kmExp, from more intense convection (and from solar radiation)
(2) Convective heating occurs later in diurnal cycle in 12kmExp
(3) Cold pool ventilation

Ventilation by cold pools

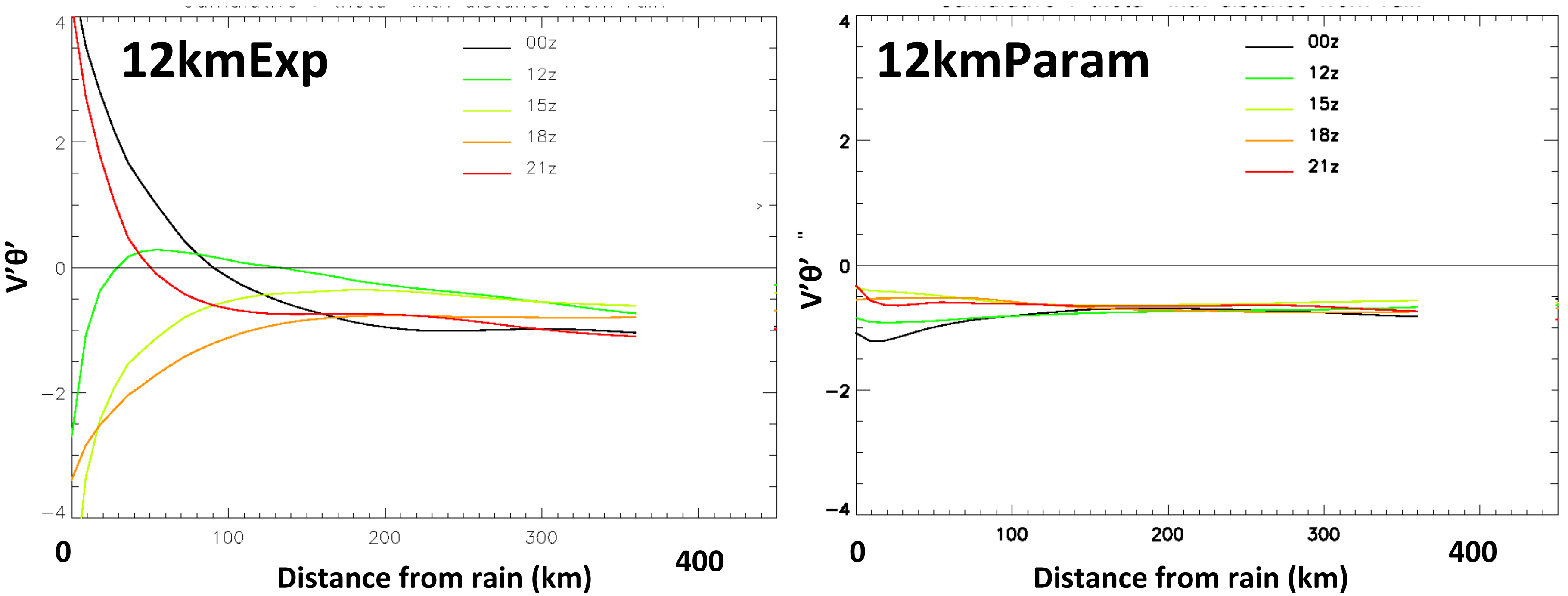
Composite of v' θ' around rainfall (12kmExp)



- Explicit cold pools move cold air northwards

Ventilation by cold pools

Cumulative pdfs of v' θ' as a function of distance from rain



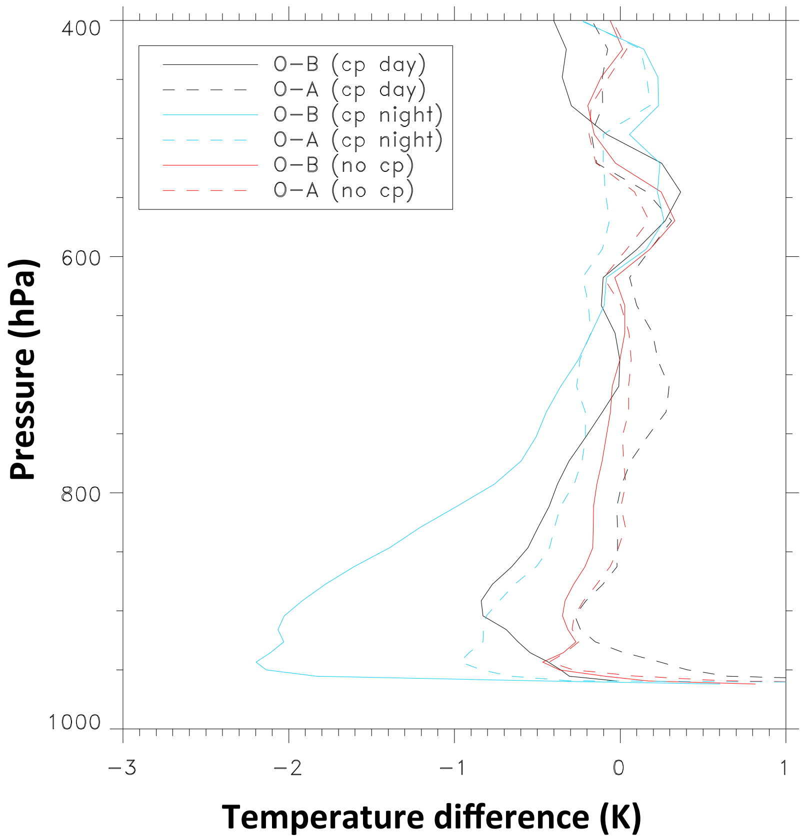
- Explicit cold pools move cold air northwards (12, 15, 18 UTC)
- Moist convection can inhibit monsoon winds at night

(like dry convection during the day, Parker *et al*., 2005)

- Largely missing in parameterised model

NWP biases from cold pools: *Fennec* data from the Sahara

(Luis Garcia-Carreras *et al.*)



0-B: Obs – Model first guess (solid)

O-A: Obs– Analysis (dashed)

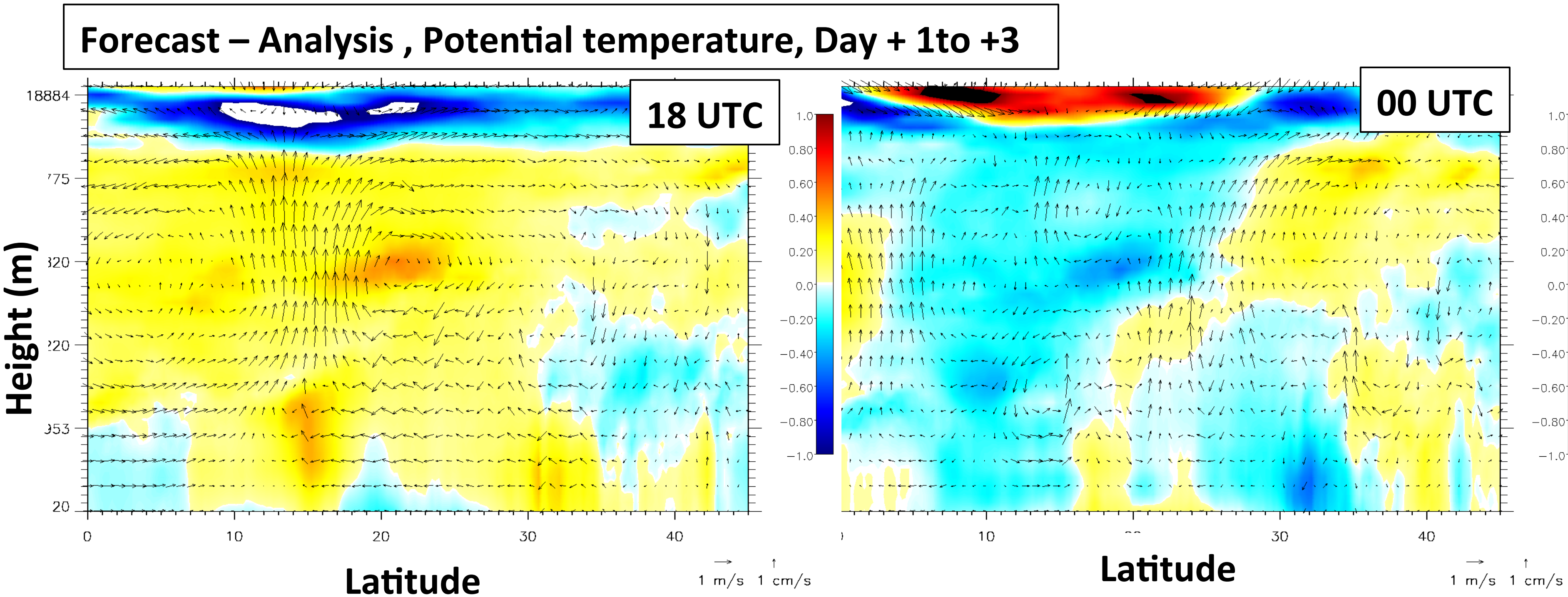
Night-time cold pools: 13 profiles

Day-time cold pools (07 to 18Z): 7 profiles

No cold pools: 104 profiles

- NWP model errors (solid lines) much larger when there are cold pools/night-time cold pools seen in *Fennec* data
  - Assimilation impacts (solid *versus* dashed) small for no cold pools, large for (day-time) cold pools
  - Analysis errors (dashed) significant for temperature in night-time cold pools

Relationship to UM forecast bias



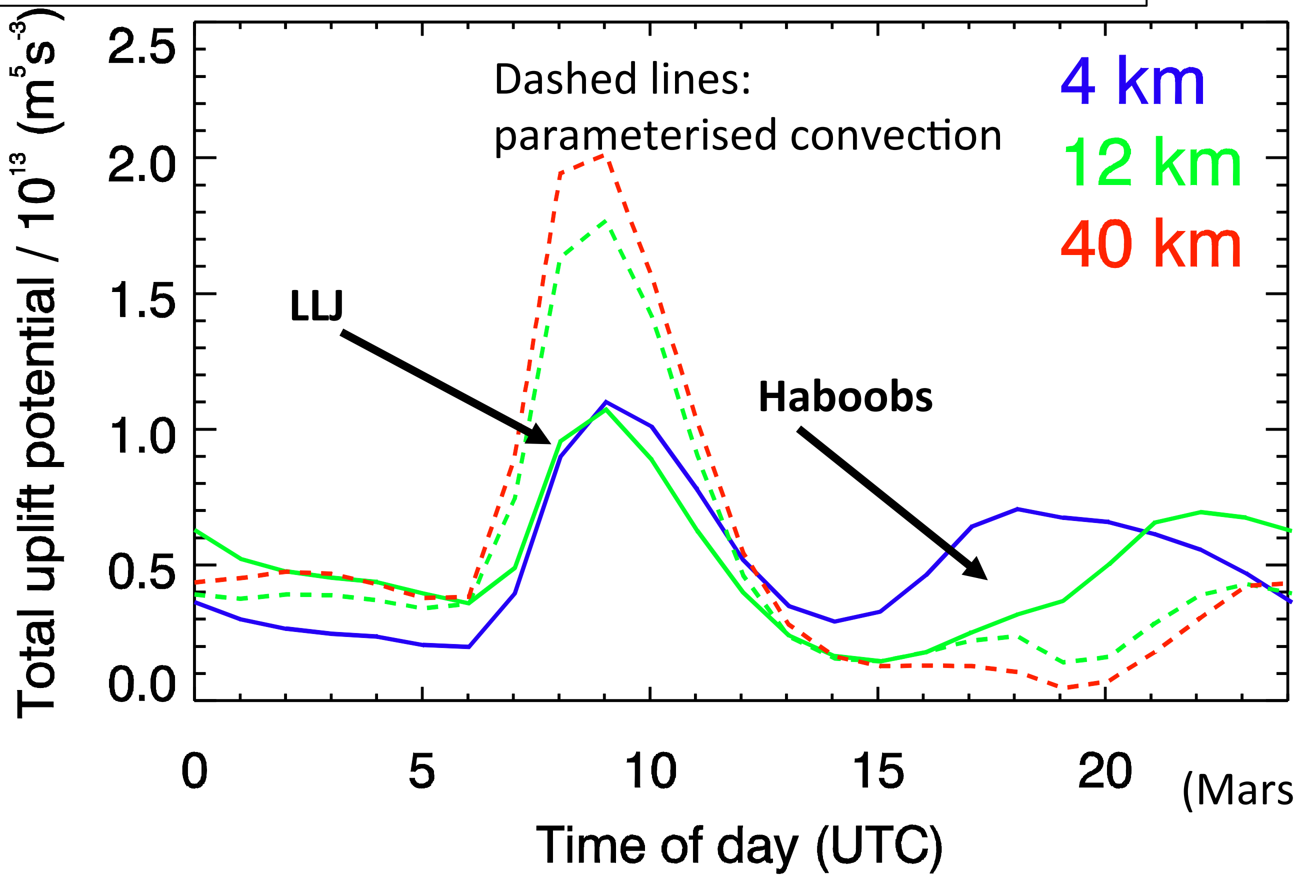
- Forecast too warm at mid-levels at 18 UTC (after parameterised convection)
- Forecast too cold at mid-levels at 00 UTC (after observed convection)
- All consistent with effects of parameterised convection.

Conclusions

- Climate models disagree on the whether many parts of the West African Monsoon region will get wetter or drier.
- *Cascade* runs show a weaker monsoon in explicit run, caused by:
  - Increased precipitation further north
  - Convection being later in the diurnal cycle
  - Explicit representation of cold pools
- Consistent with UM forecast errors (mean biases, and biases in observed cold pools), which have been the same for many years (Thorncroft *et al*., 2003, JET2000)
- Improved parameterisations of deep convection required to predict the WAM.
- Convection acts as a "governer" to the WAM
  - The monsoon flow allows the moist convection
  - The moist convection inhibits the monsoon flow

Implication for dust modelling

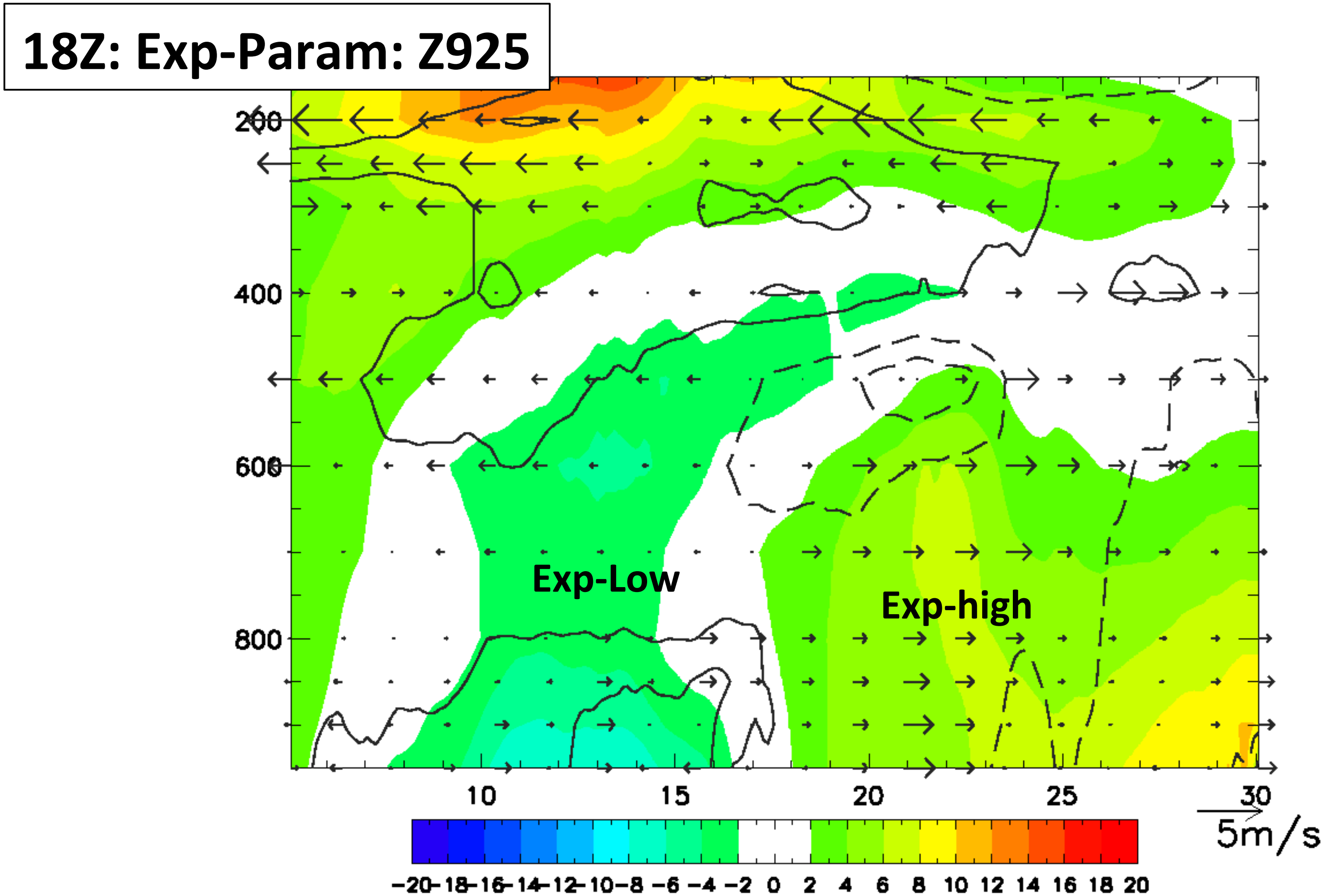
***Cascade*: 10-day mean diurnal cycle in dust-generating winds**



(Marsham *et al.*, *GRL*, 2011)

- Parameterised runs have stronger low-level jet and nocturnal monsoon, but are missing haboobs (dusty cold pool outflows, Marsham *et al.*, 2011)
    - Role of haboobs confirmed by *Fennec* observations, important for seasonal cycle (Marsham et al., 2008, Marsham *et al.*, 2012;Heinold *et al.*, 2012)

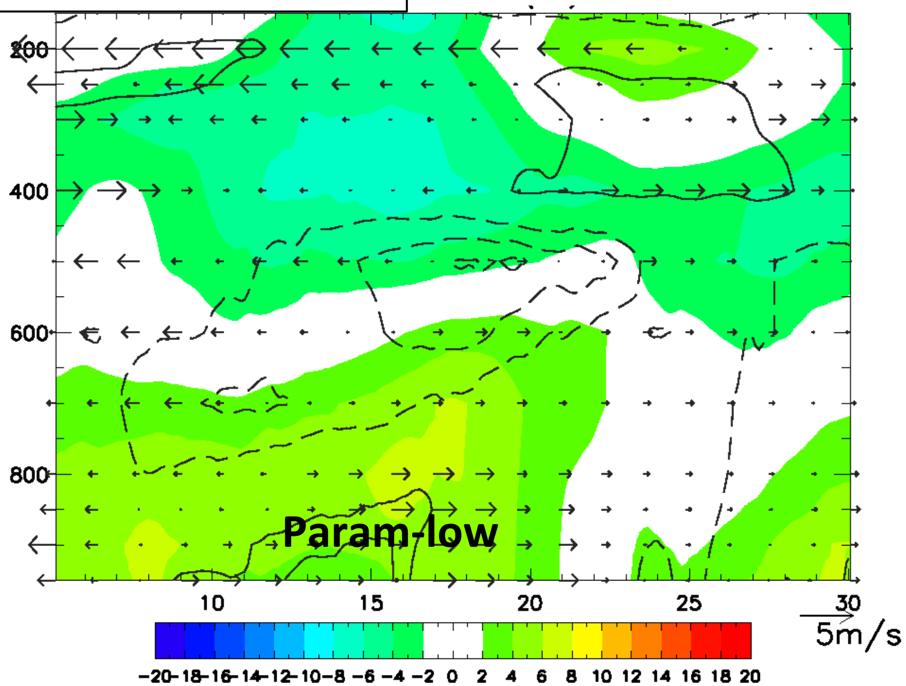
Cold pool ventilation: 18Z



(3) Explicit winds from Explicit Low to Explicit High – cold pools outflows from moist convection?

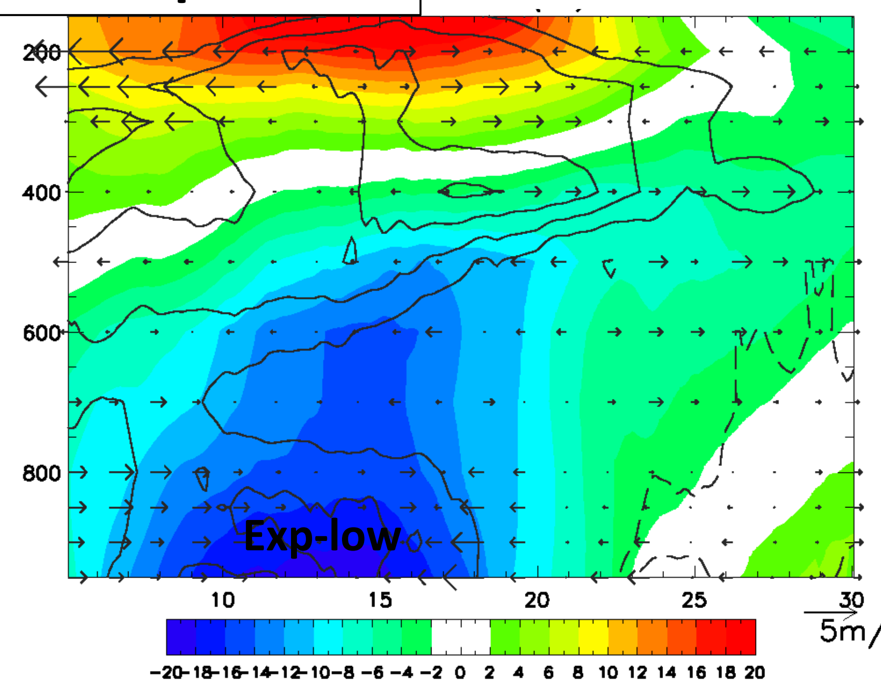
Diurnal cycle in model differences

15Z: Exp-Param



Colours: geopotential
Lines: potential temperature

21Z: Exp-Param

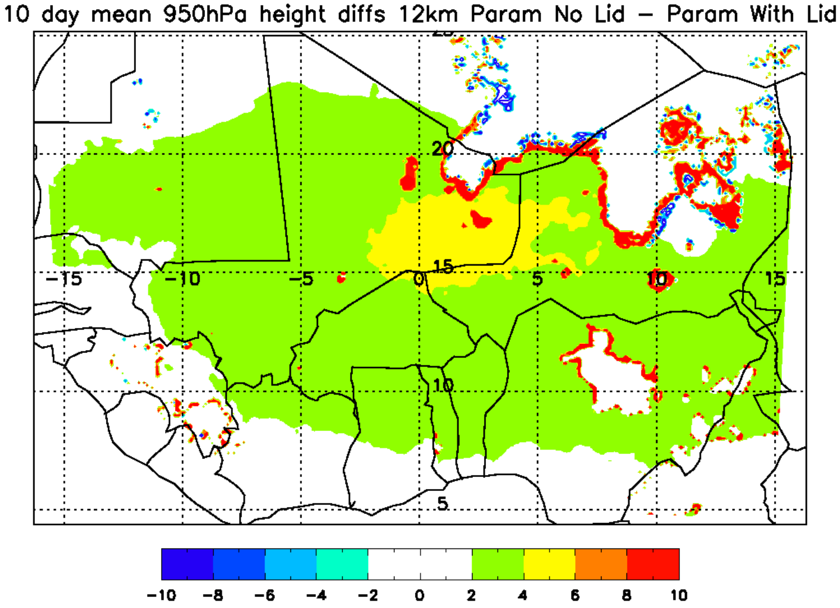


Over the Sahel:

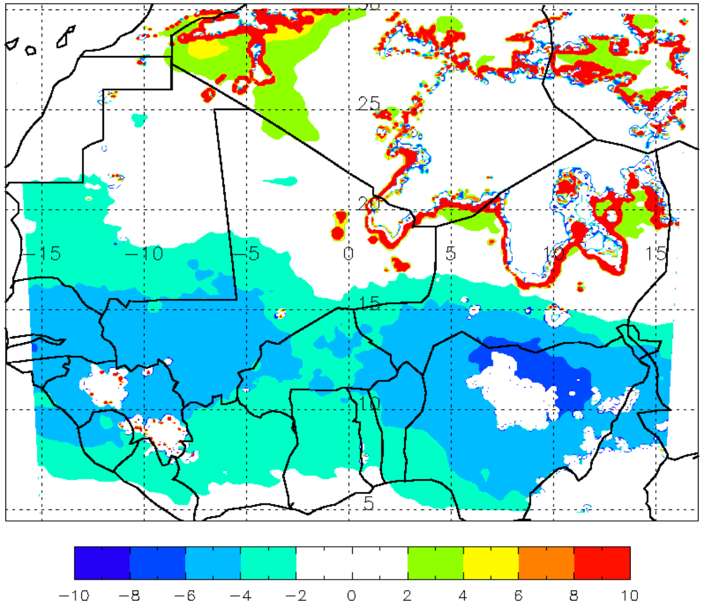
- Daytime heating from parameterised convection leads to a "Parameterised-low"
- Evening/night-time heating from explicit convection leads to an "Explicit-low"

Impact of resolution

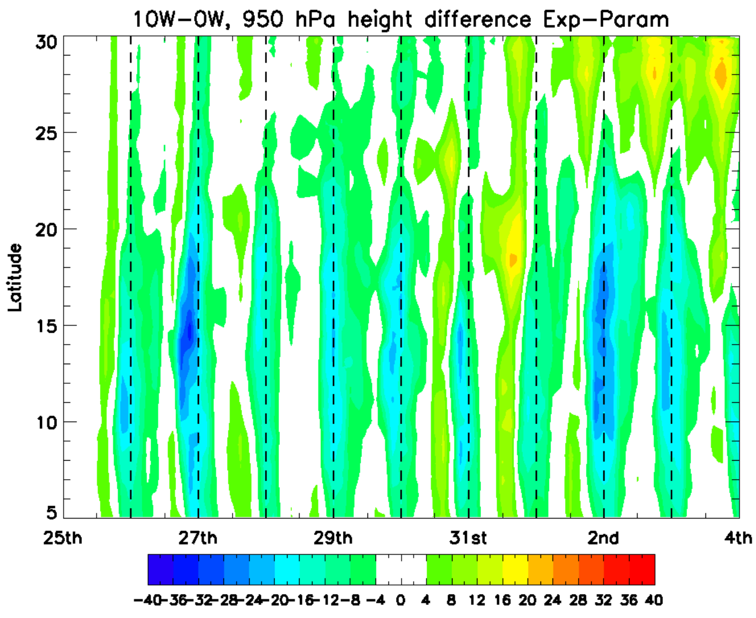
Z950: 12kmExp-4kmExp



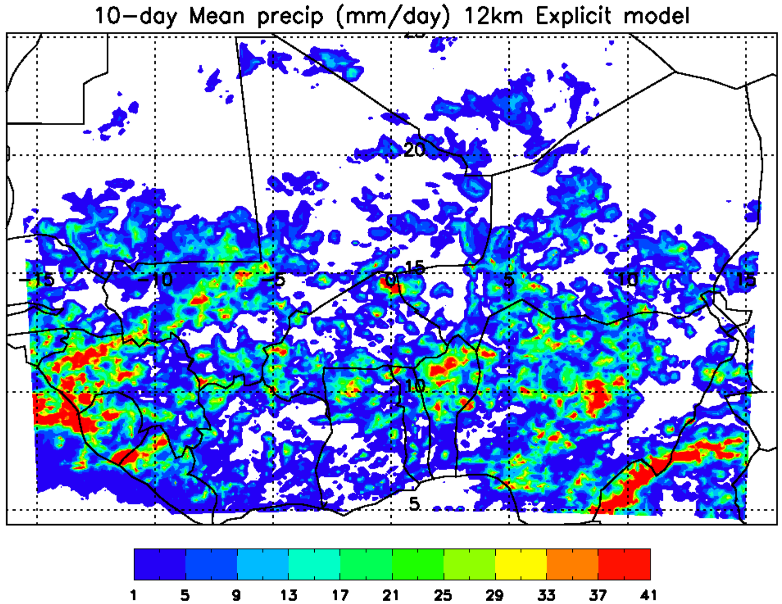
Z950: 12kmExp-12kmParam

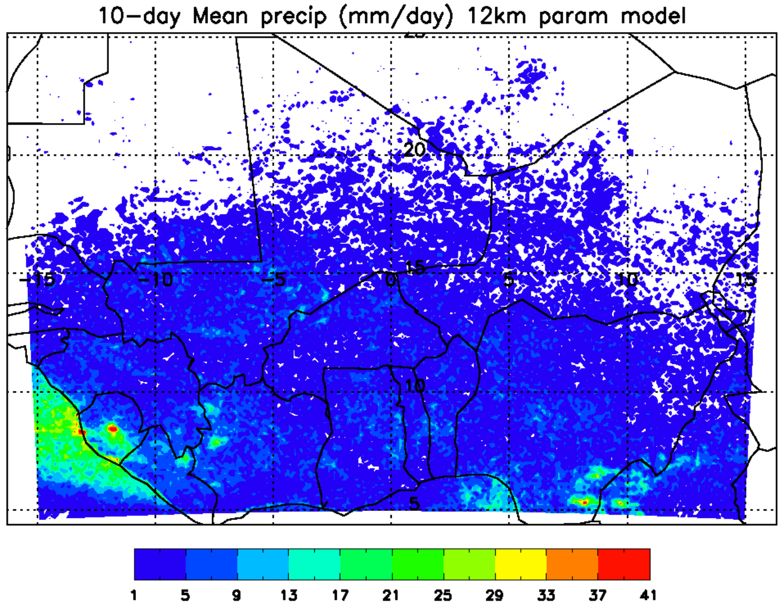


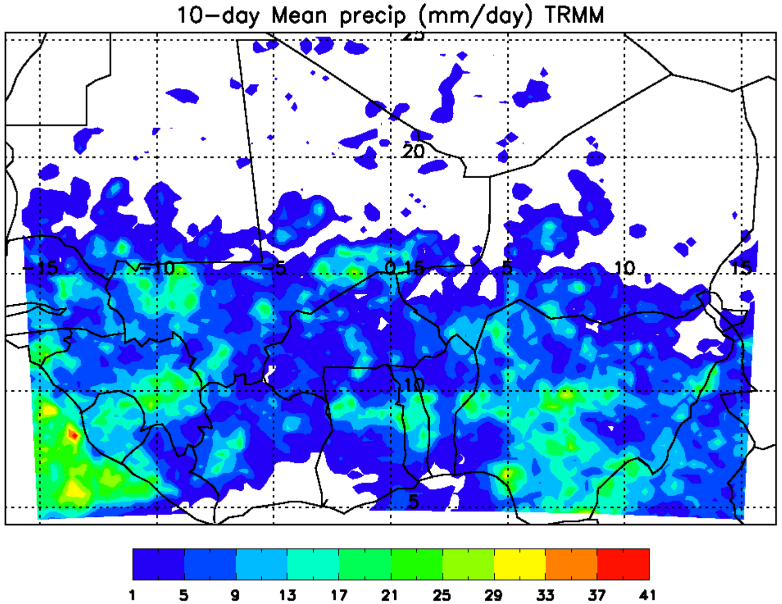
- Time-latitude Hovmöller of differences in 950 hP height (12kmExp – 12km Param) evolving through the simulation period.



Spatial distribution of rain

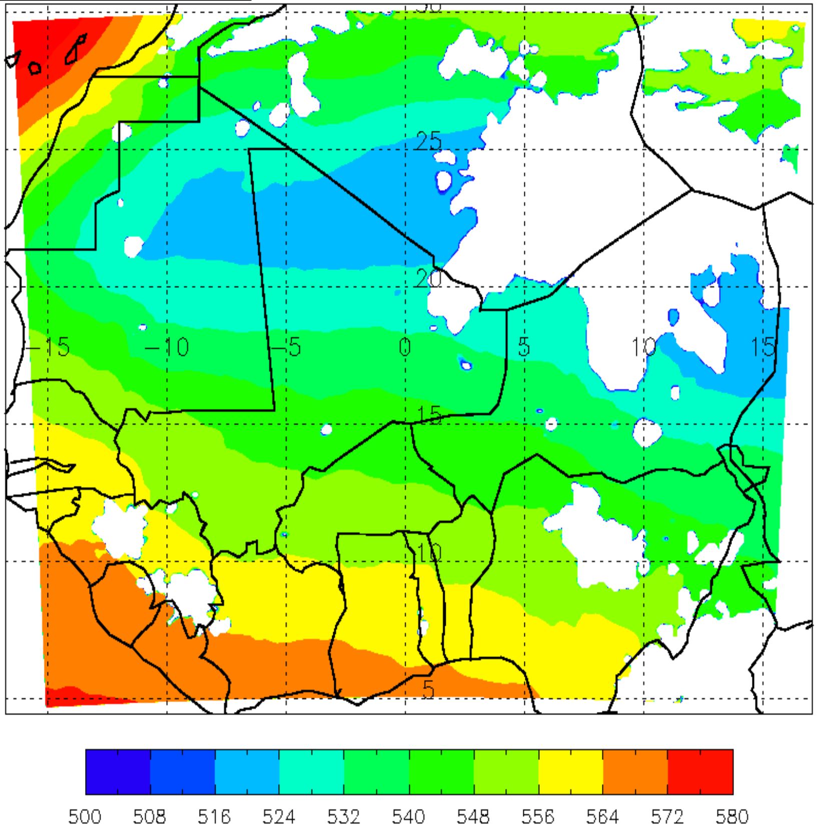




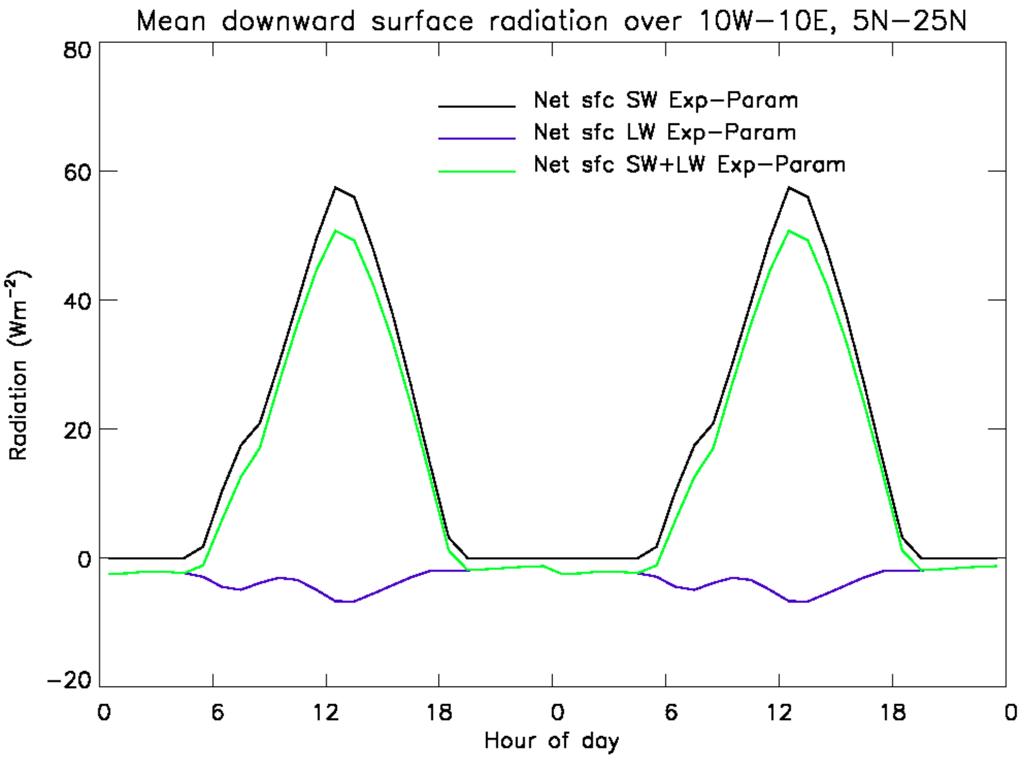


The West African Monsoon

Z925: Day +1



Diurnal cycle in radiation



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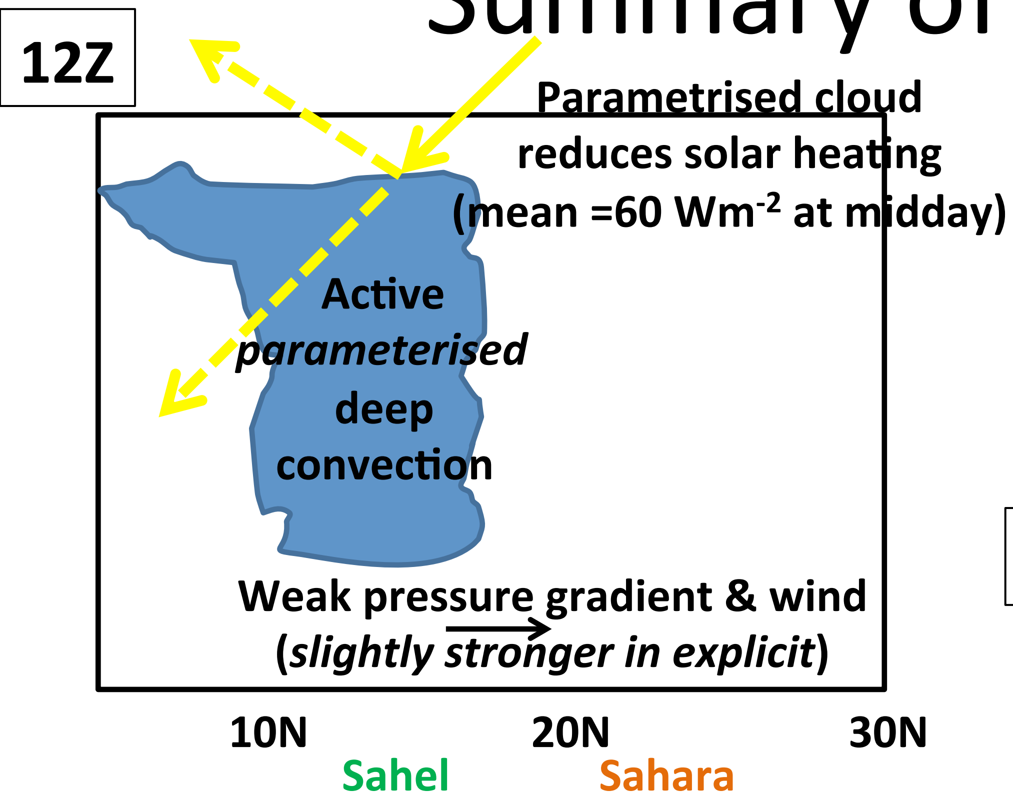

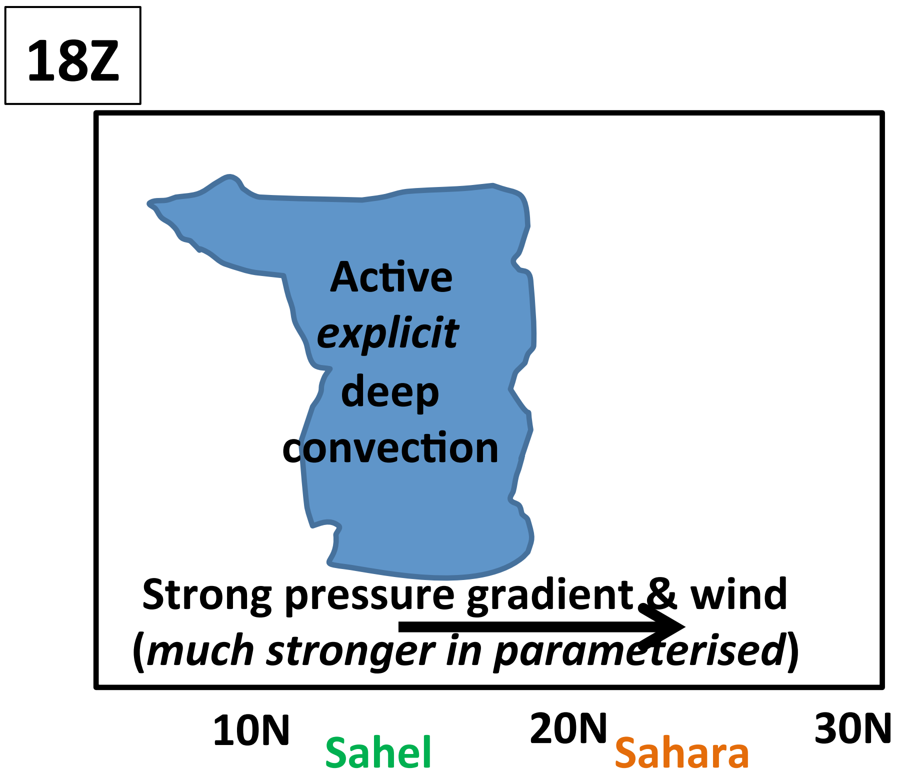

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