Upscale Energy Transport in the Tropical Atmosphere

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It is long hypothesised that convection can drive upscale effects in the atmosphere, especially in the tropics.

Can we use **convection-permitting** models to diagnose **upscale responses** to convection?

How might we isolate the effect of convection on atmospheric evolution?

1. Compare CP and parameterised simulations.

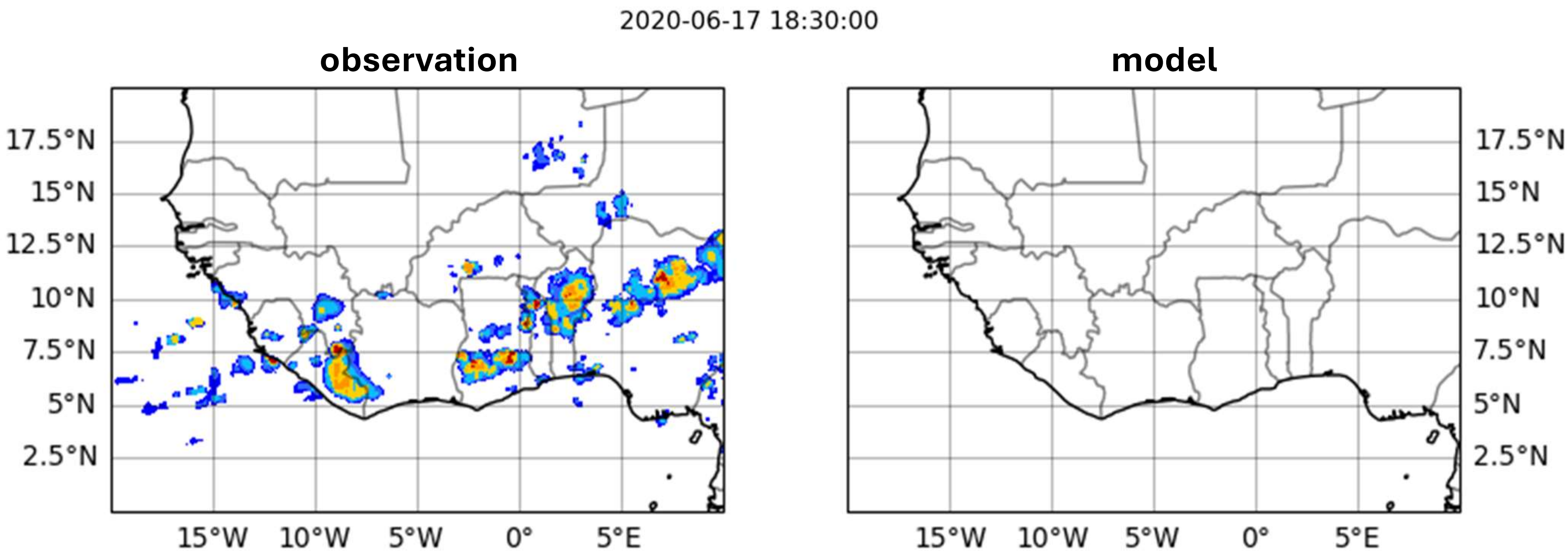
↳ ...but how justifiable is it to take CP simulations as a "truth"?

2. Artificially add or suppress signatures of convection.

↳ ...but how physically consistent are artificial signatures?

Warm-Starting

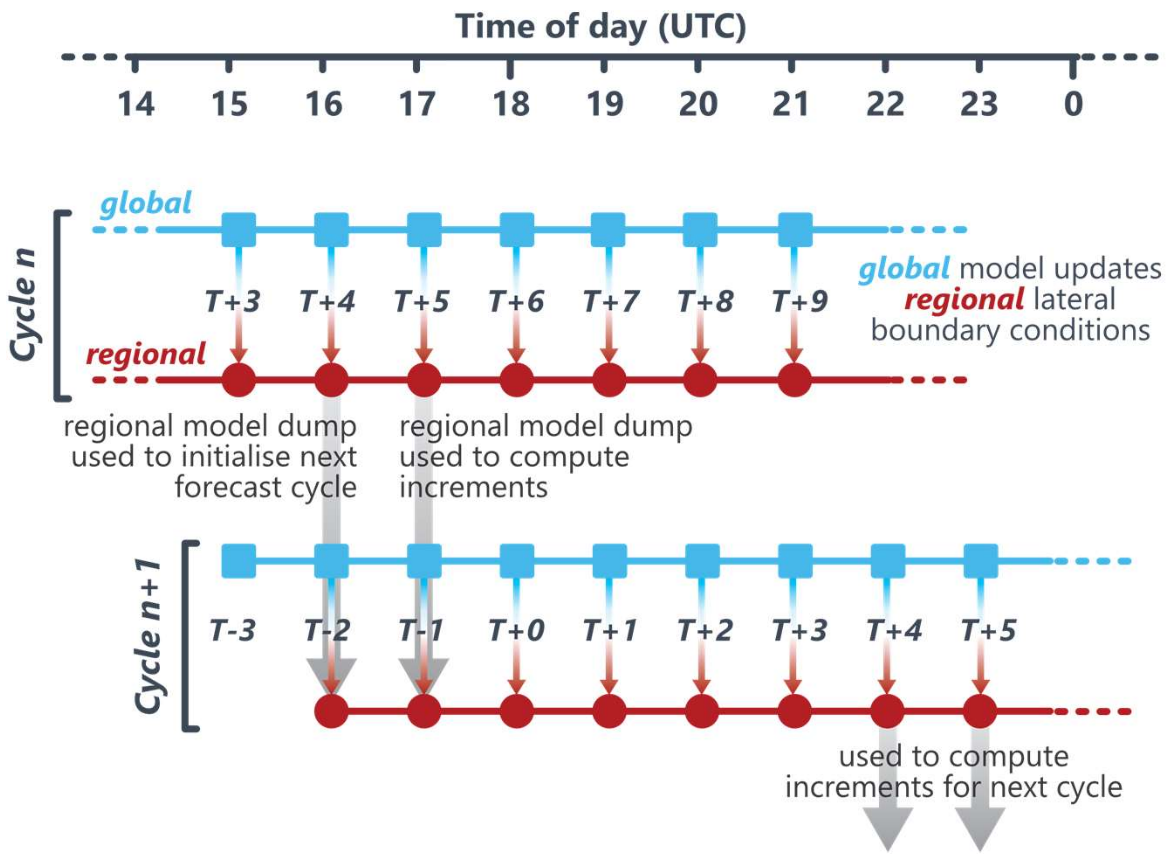
Convective-scale simulations take some time (12-18 hours) to spin up realistic precipitation structures when initialised operationally.



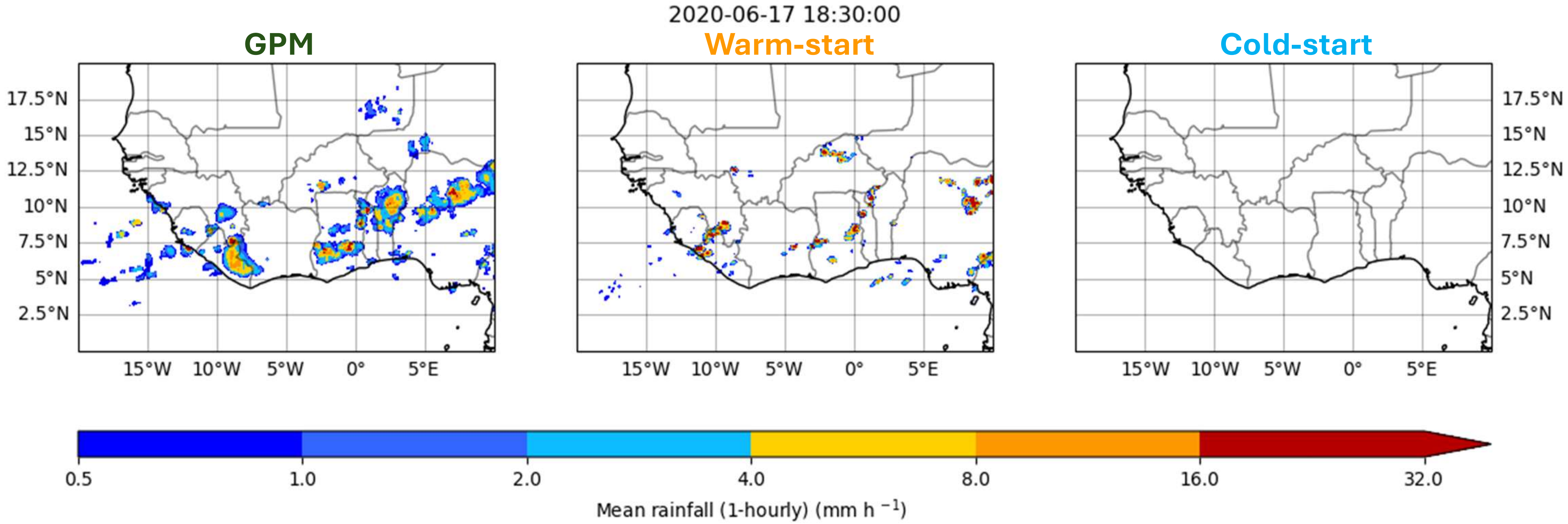
Warm-Starting

Sixth-order implicit tangent filter combines **small-scale information** from the **previous cycle** of the regional simulation with **large-scale information** from global model with DA.

Experiments carried out by James Warner (UKMO) over Tropical Africa domain with a filter length of 200km (see *Short and Petch, 2020*).



For the first 24 hours after initialisation, warm-started simulations generate **organised MCSs** which **more closely resemble reality** (compared to GPM).



Case study: gifs show mean hourly **rainfall rate** (mm h^{-1}) following initialisations at 18Z on June 17th, 2020.

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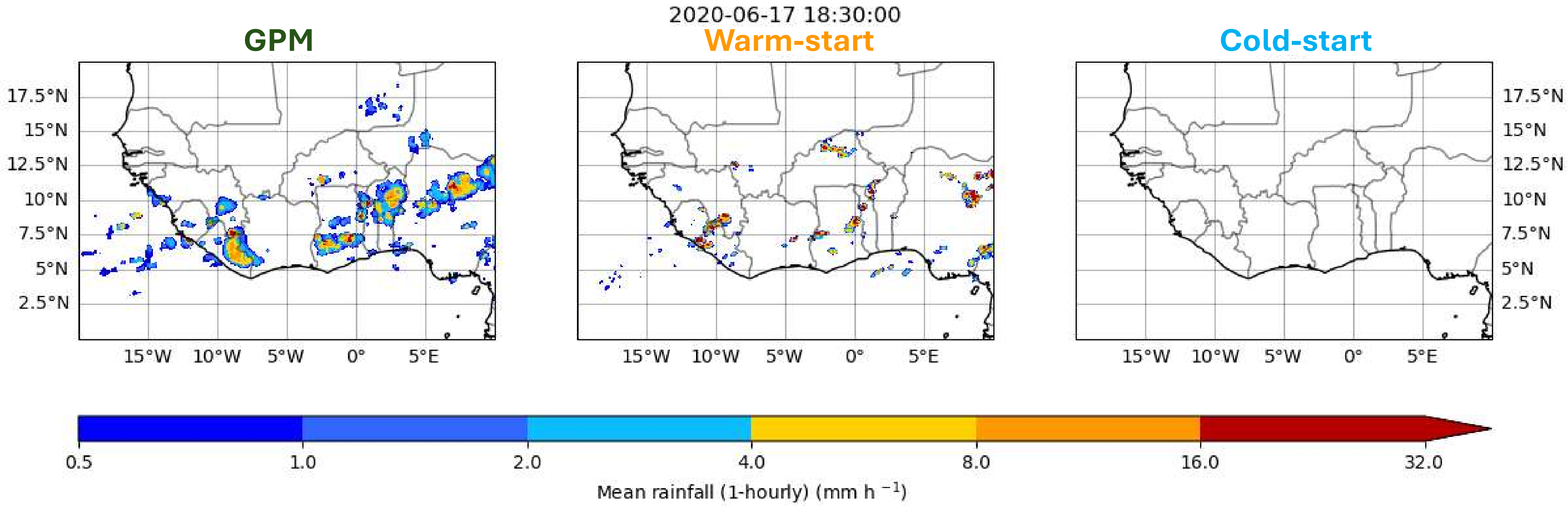

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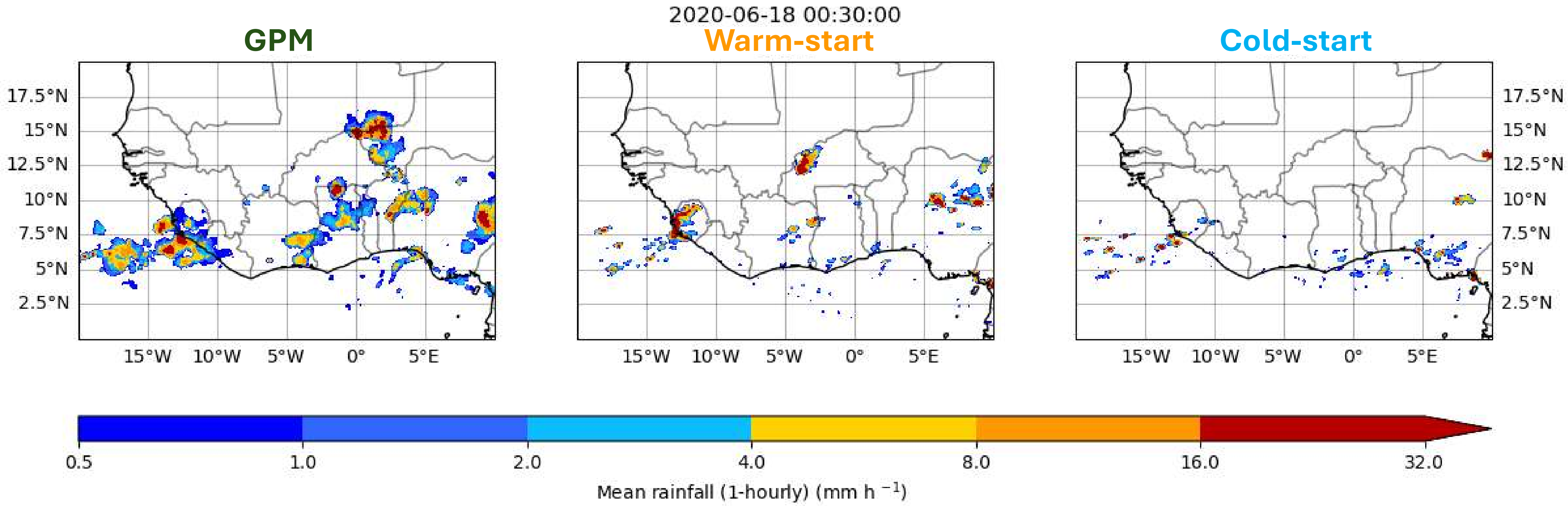

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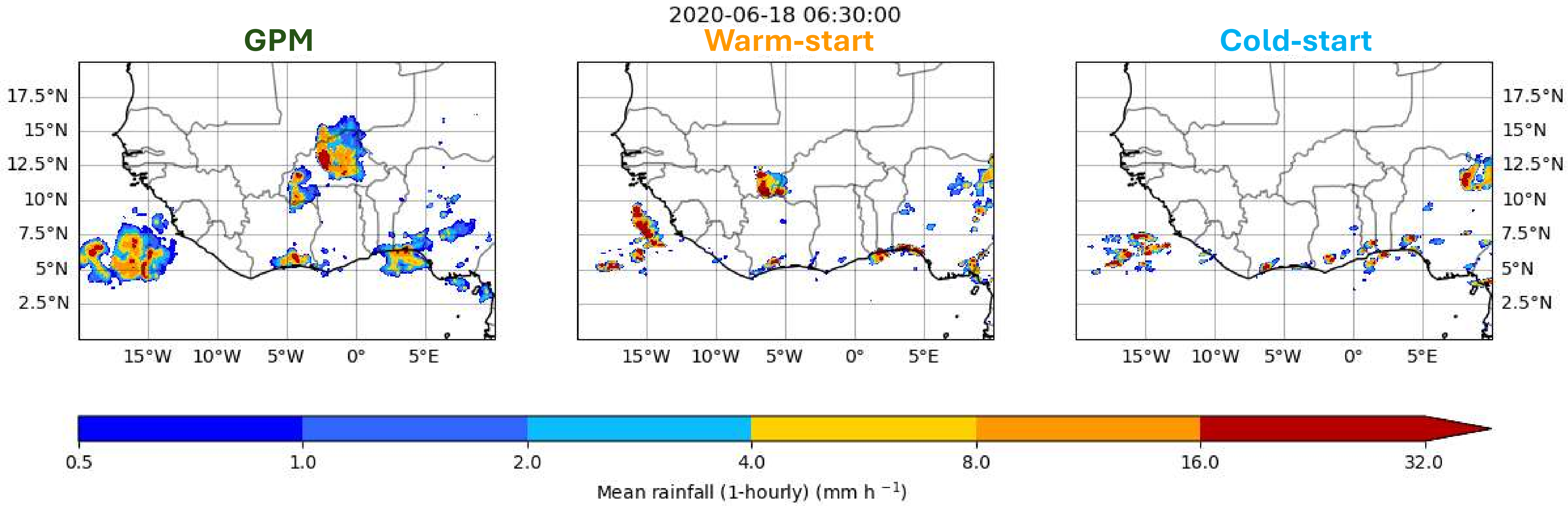

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more realistic representation of rainfall

Precipitation in the warm-started simulation is increased for the first 12-18 hours of the model, which usually is considered "spin-up" time.

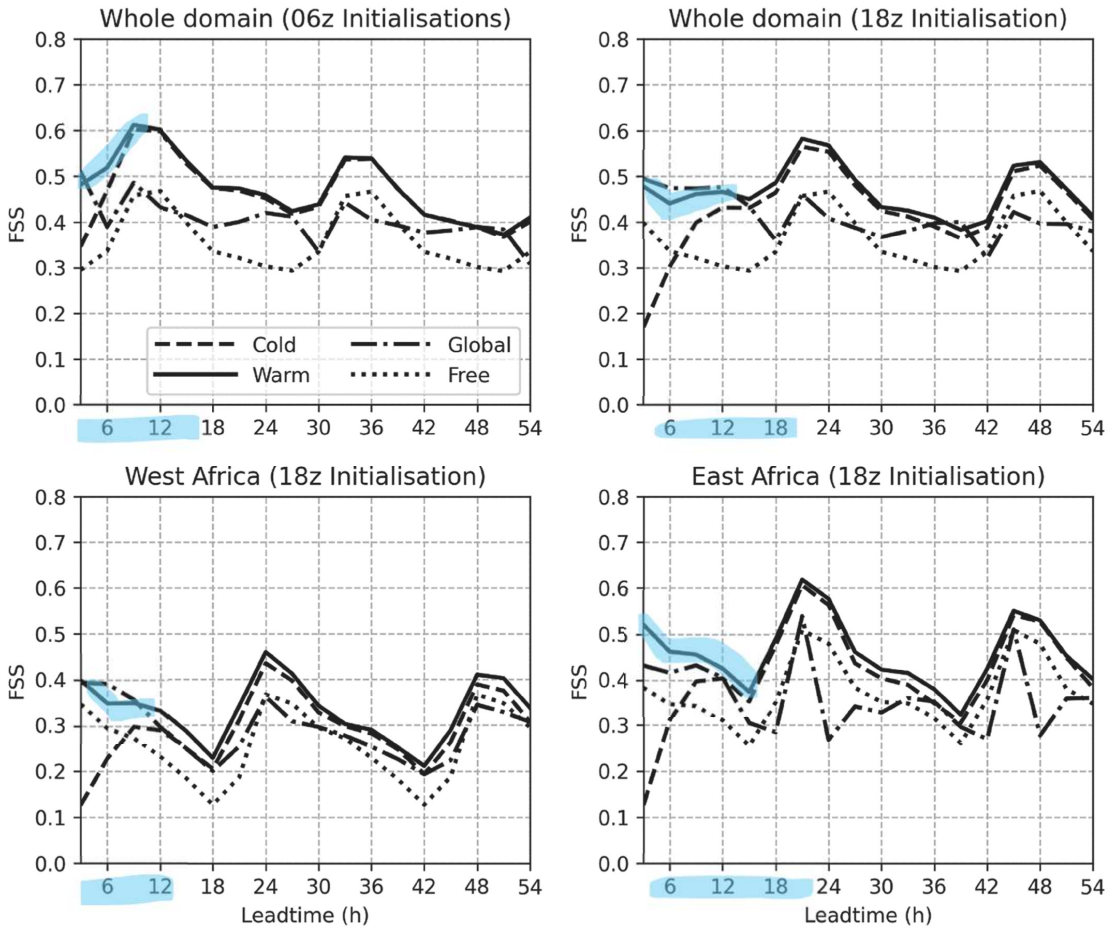


Figure 5 from **Warner et al., 2023**

Not only a **more realistic representation of rainfall**

Even 24-36 hours into the forecast, error in wind speed (relative to ERA5 analysis) is significantly ($p<0.05$) reduced in the warm-started simulation.

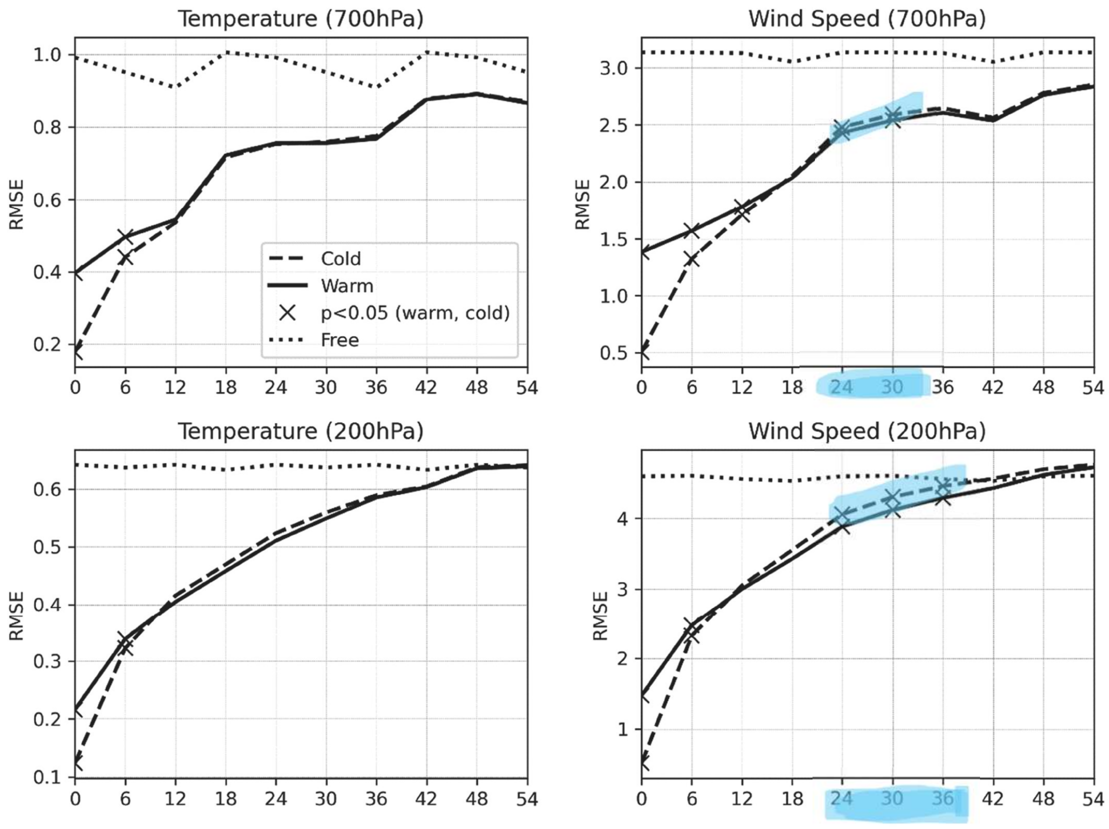
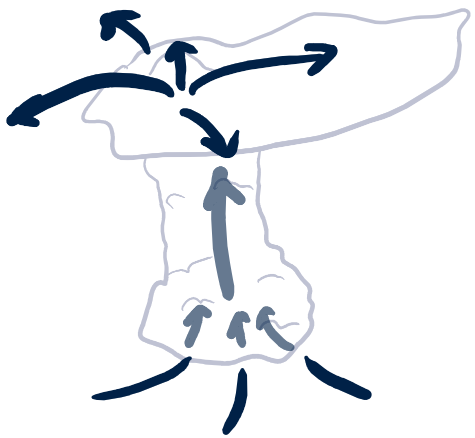
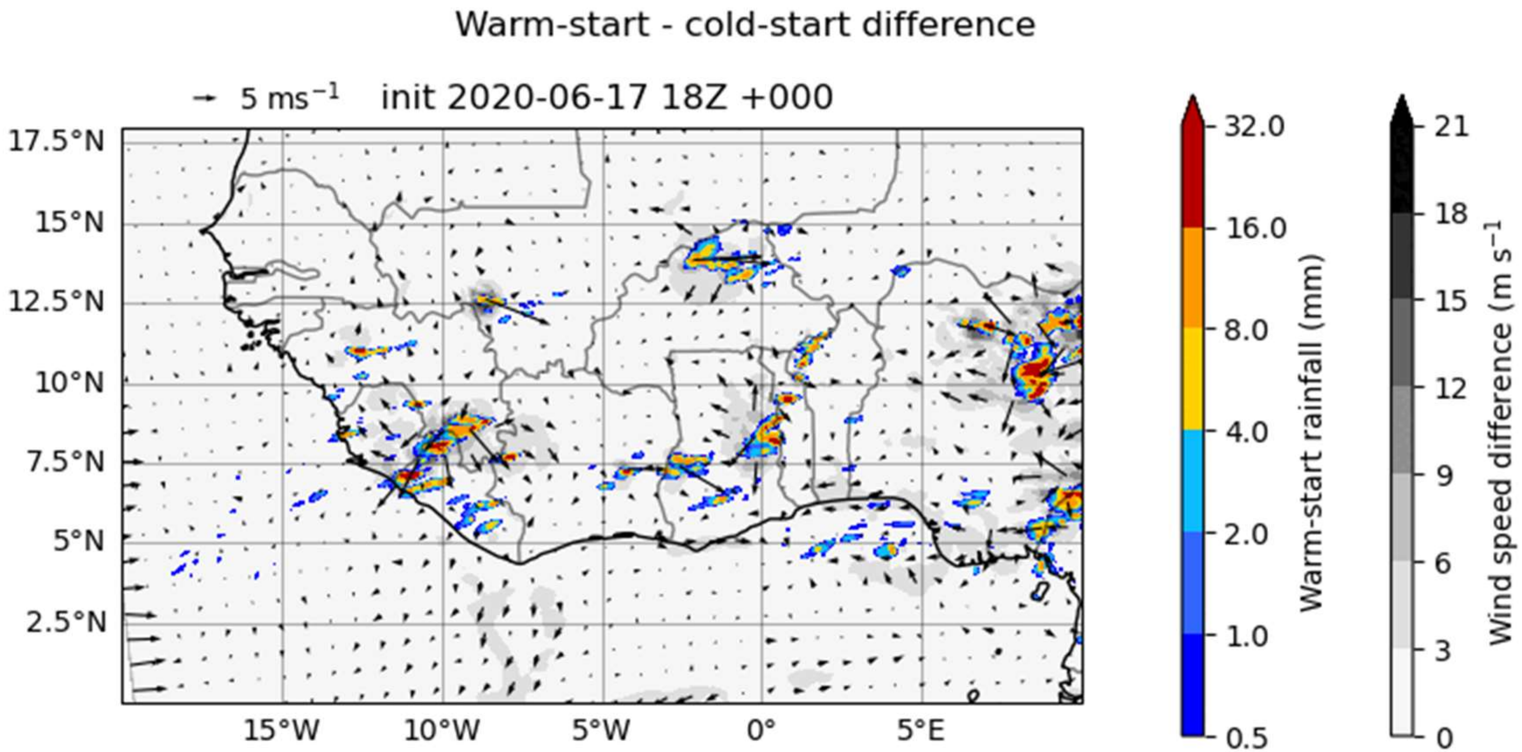


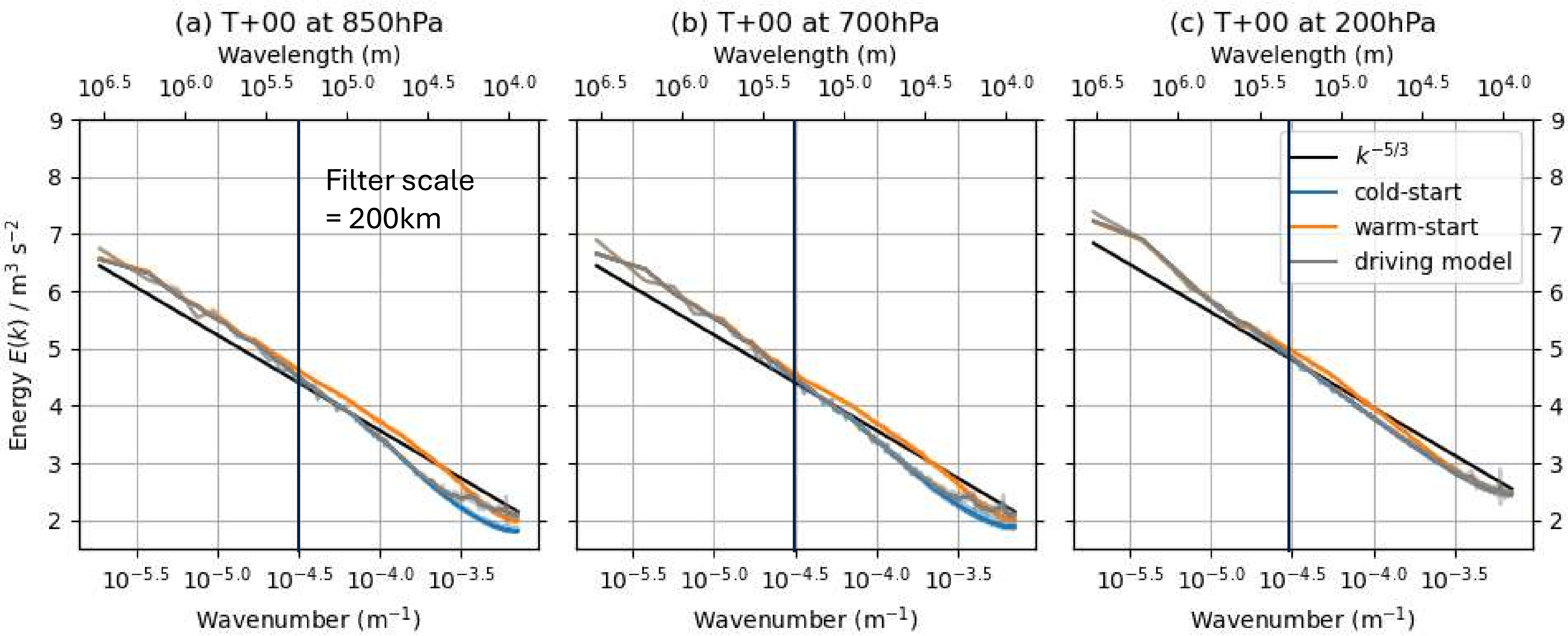
Figure 6 from **Warner et al., 2023**

Warm-start wind – cold-start wind at 200hPa (vectors) and **warm-start rainfall** (mm) (17 June case)





Kinetic energy spectra (17 June case)



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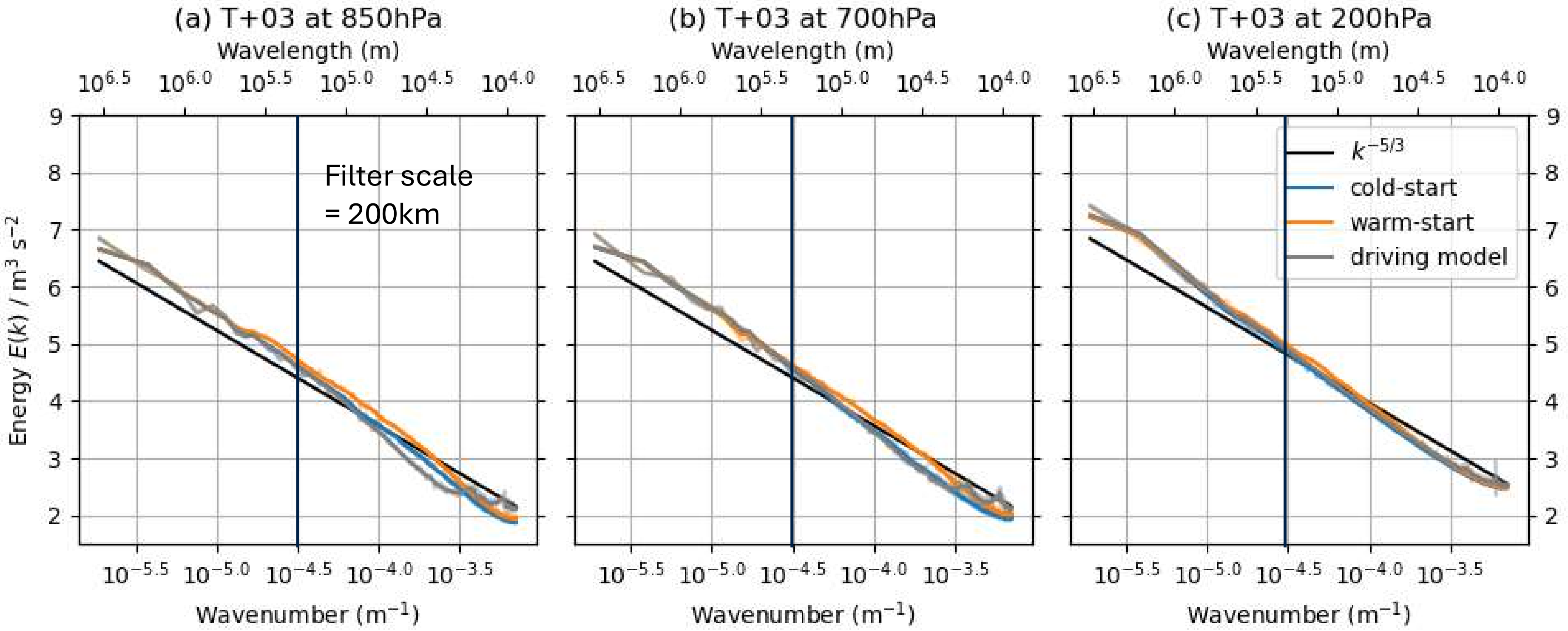

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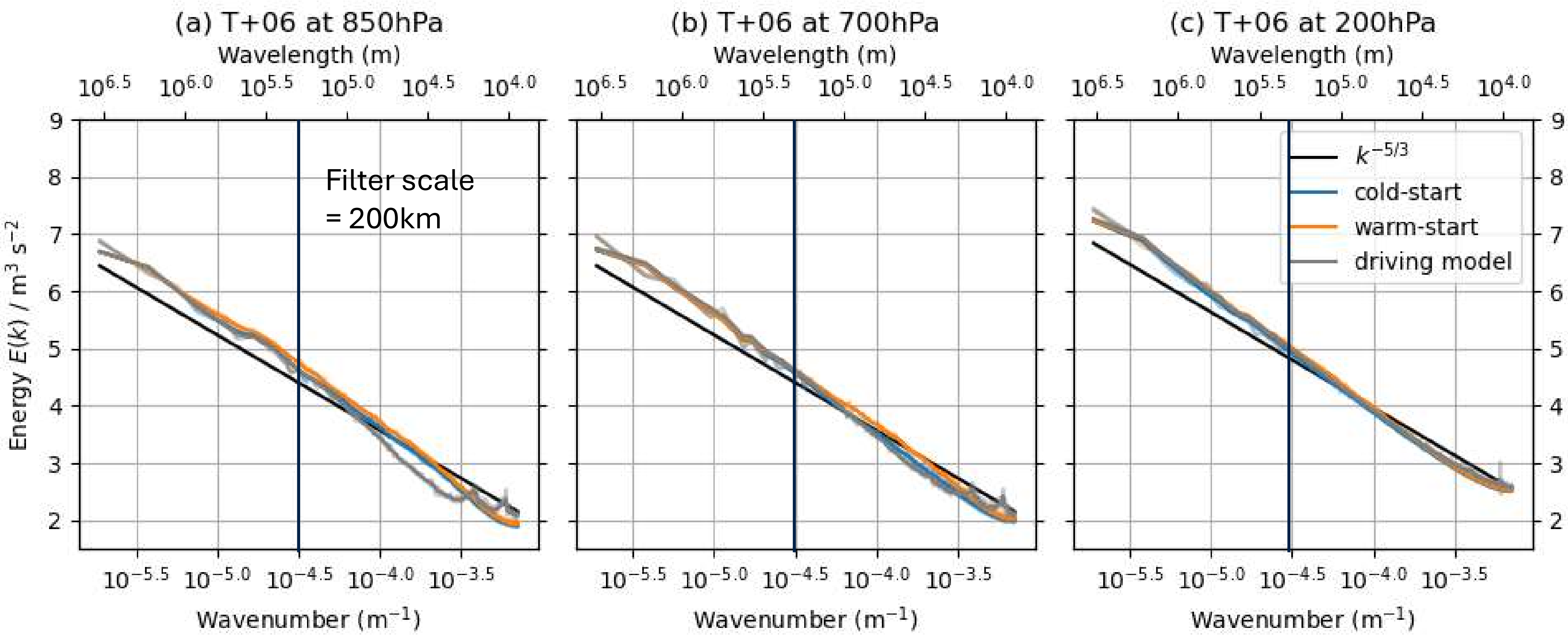

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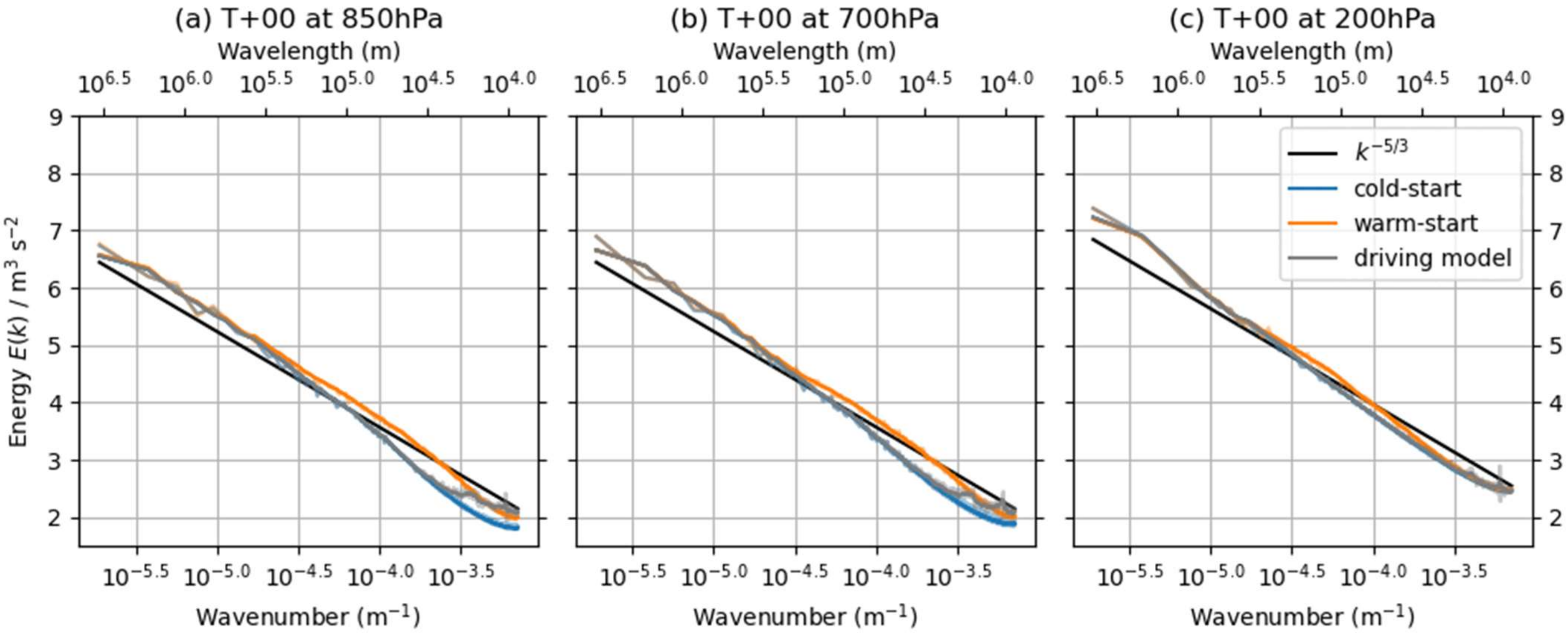
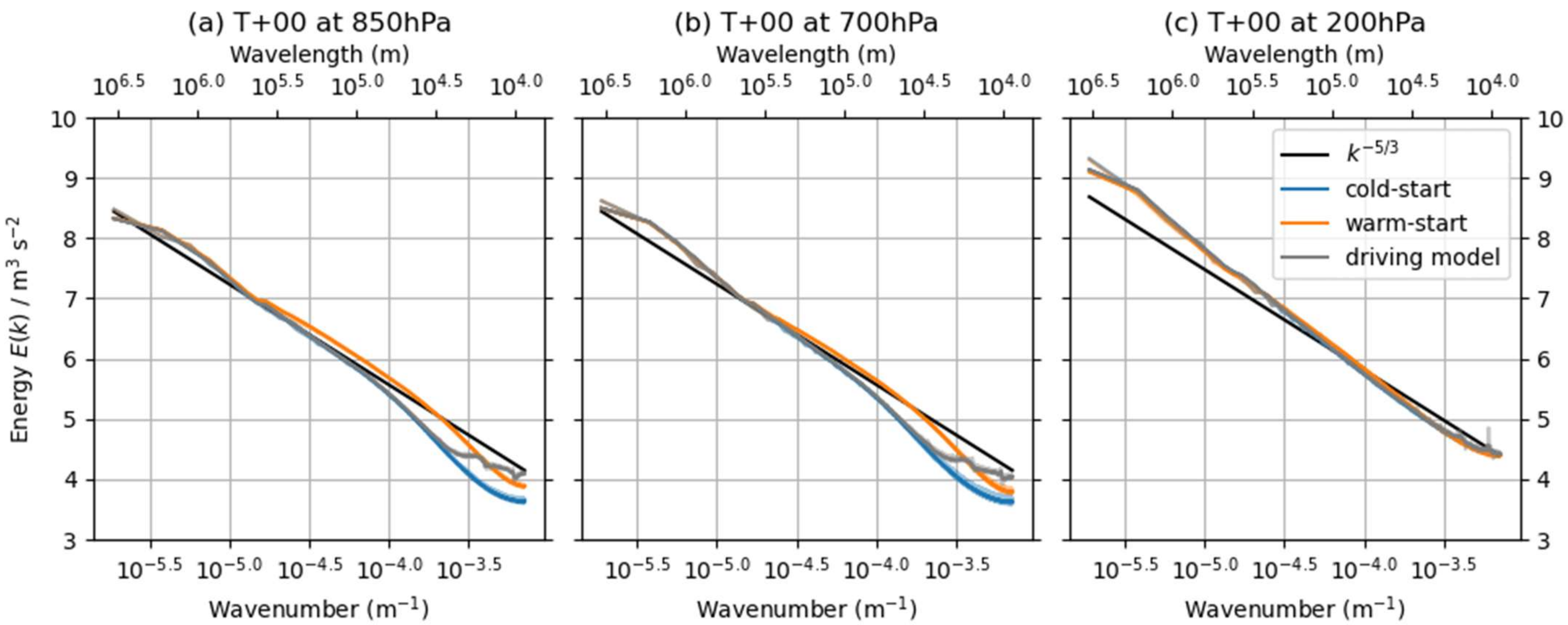


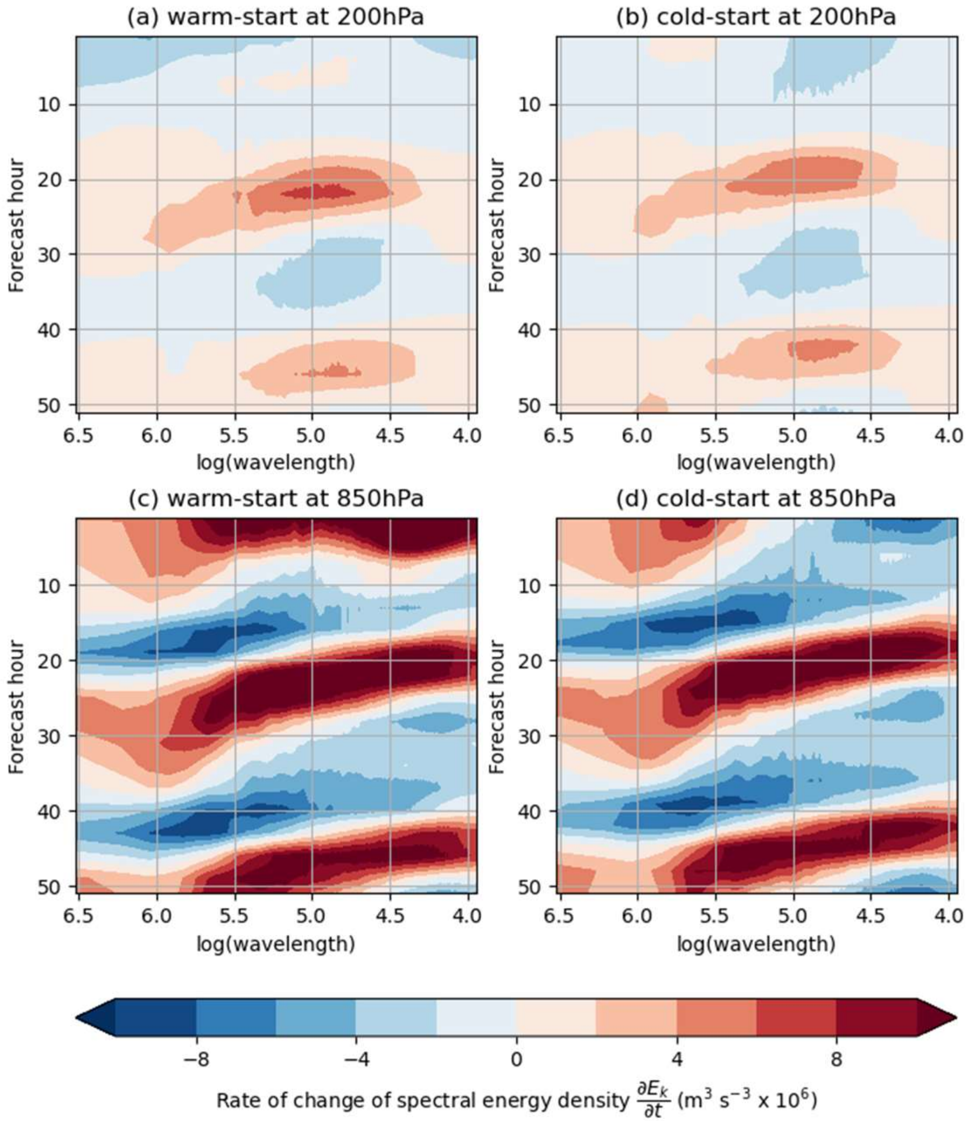
Kinetic energy spectra (all 18Z inits)



Rate of kinetic energy change across scales

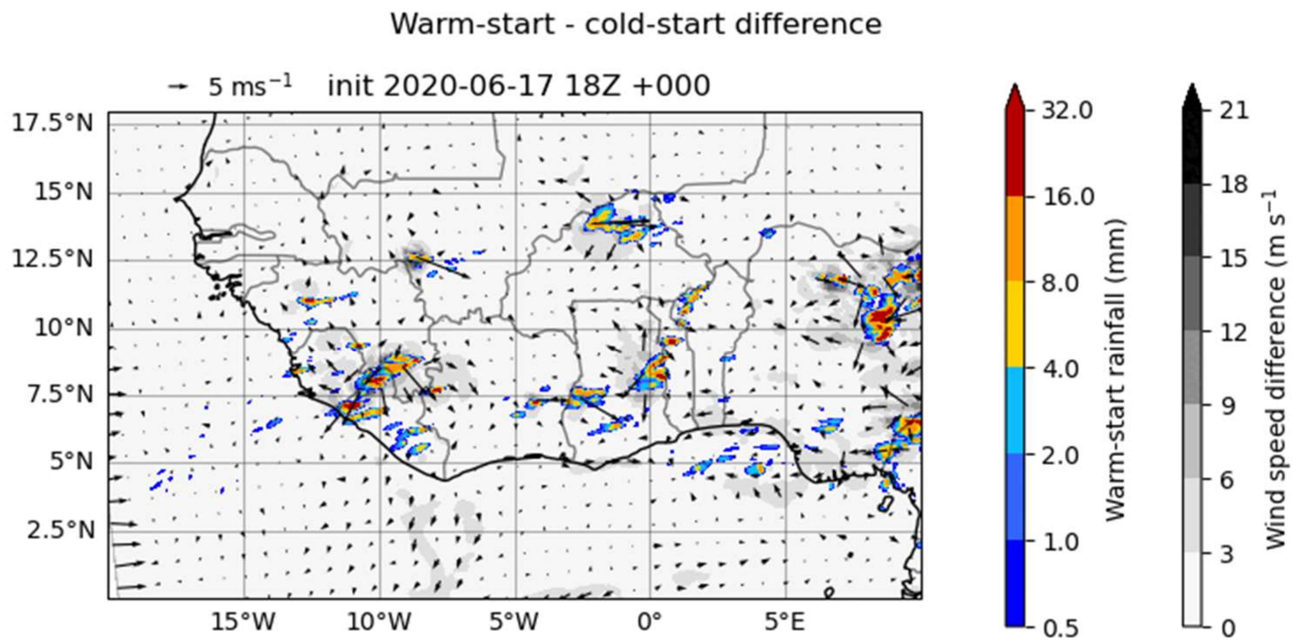
(18Z initialisations)

- **Distinct diurnal cycle**: at T+20 (12Z next day) energy increases at smaller scales then steadily starts to increase at larger scales
- More small-scale energy in warm-start simulation at start
- More energy at scales up to 10^6m (1000km) at T+40 in warm-start



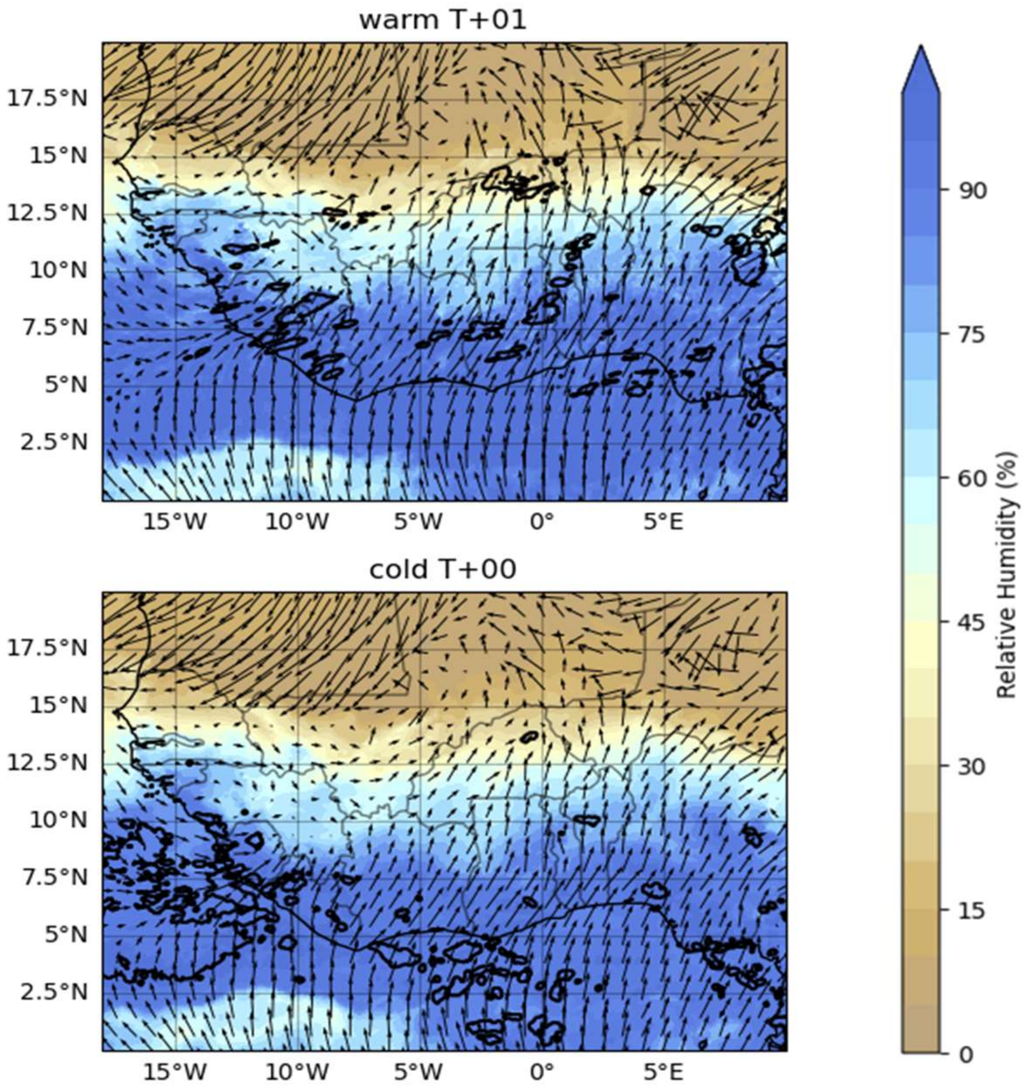
Introduction Warm-Starting Atmospheric Differences **Mechanisms** Conclusions

With different rainfall conditions at the start of the forecast, **different structures** emerge **later**. What **mechanisms** drive this?



Relative humidity @ 925hPa filled contours and **0.5 mmh^{-1} rain** line contour

- Large storms use up low-level moisture in the atmosphere
- Redistributed to
  - Upper atmosphere
  - Moisture in soil via precipitation



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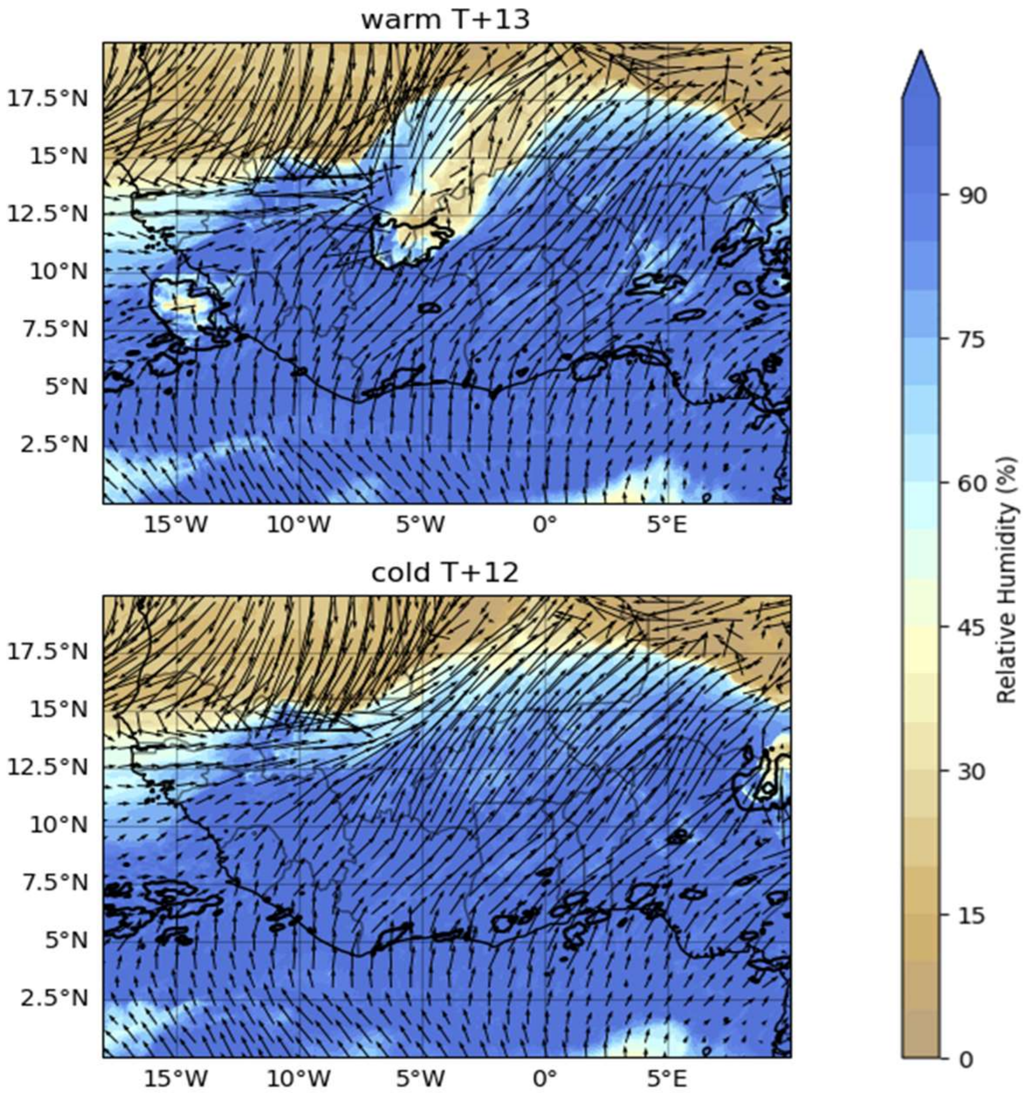
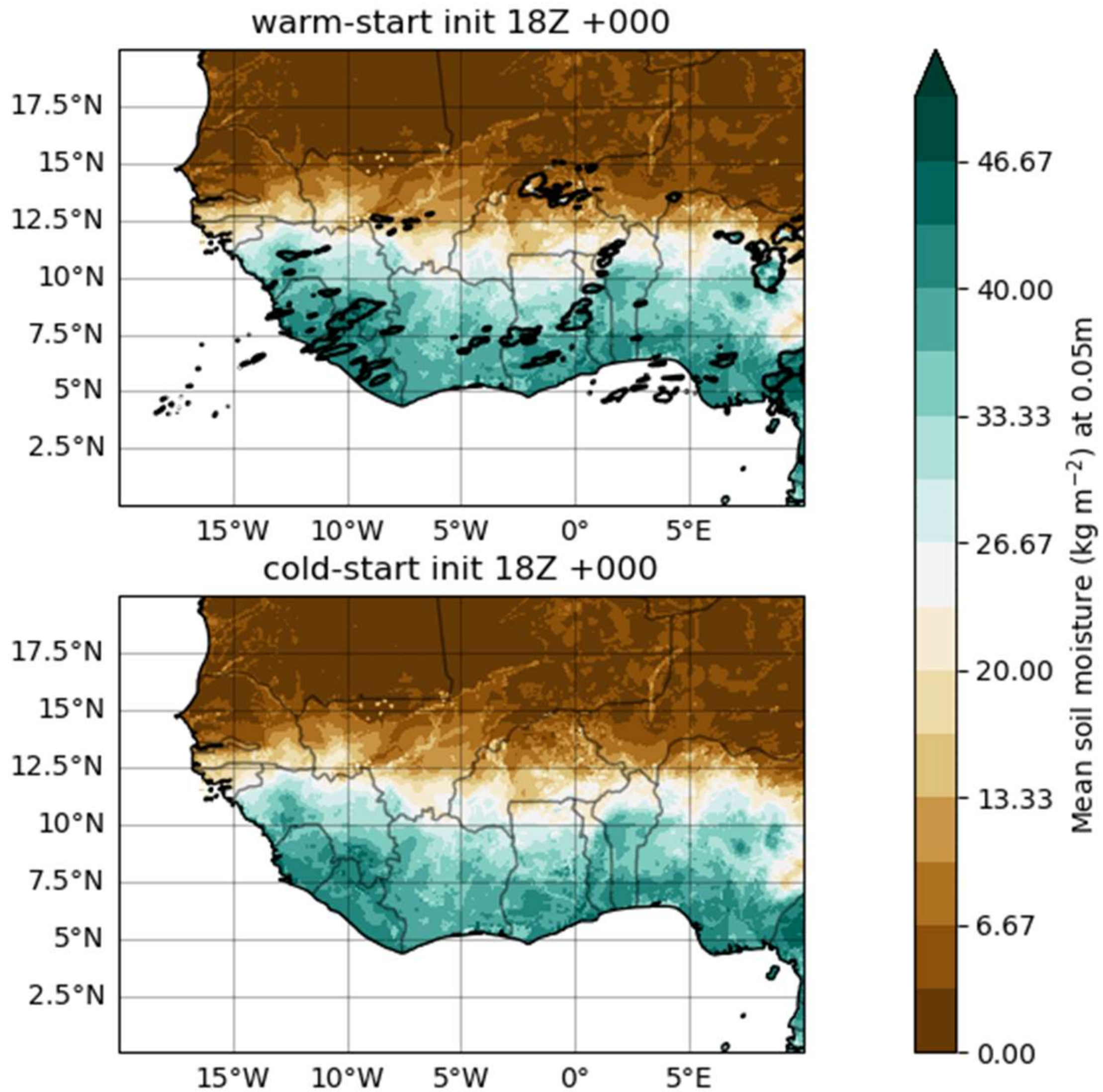


Soil moisture filled contours and **0.5 mmh^{-1} rain** line contour

- Trail of damp upper-level soil left behind storm tracks
- Dry soil intensifies storms (e.g. Klein 2020)
- Remaining dry patches lead to more intense MCSs later in cold-start forecast?



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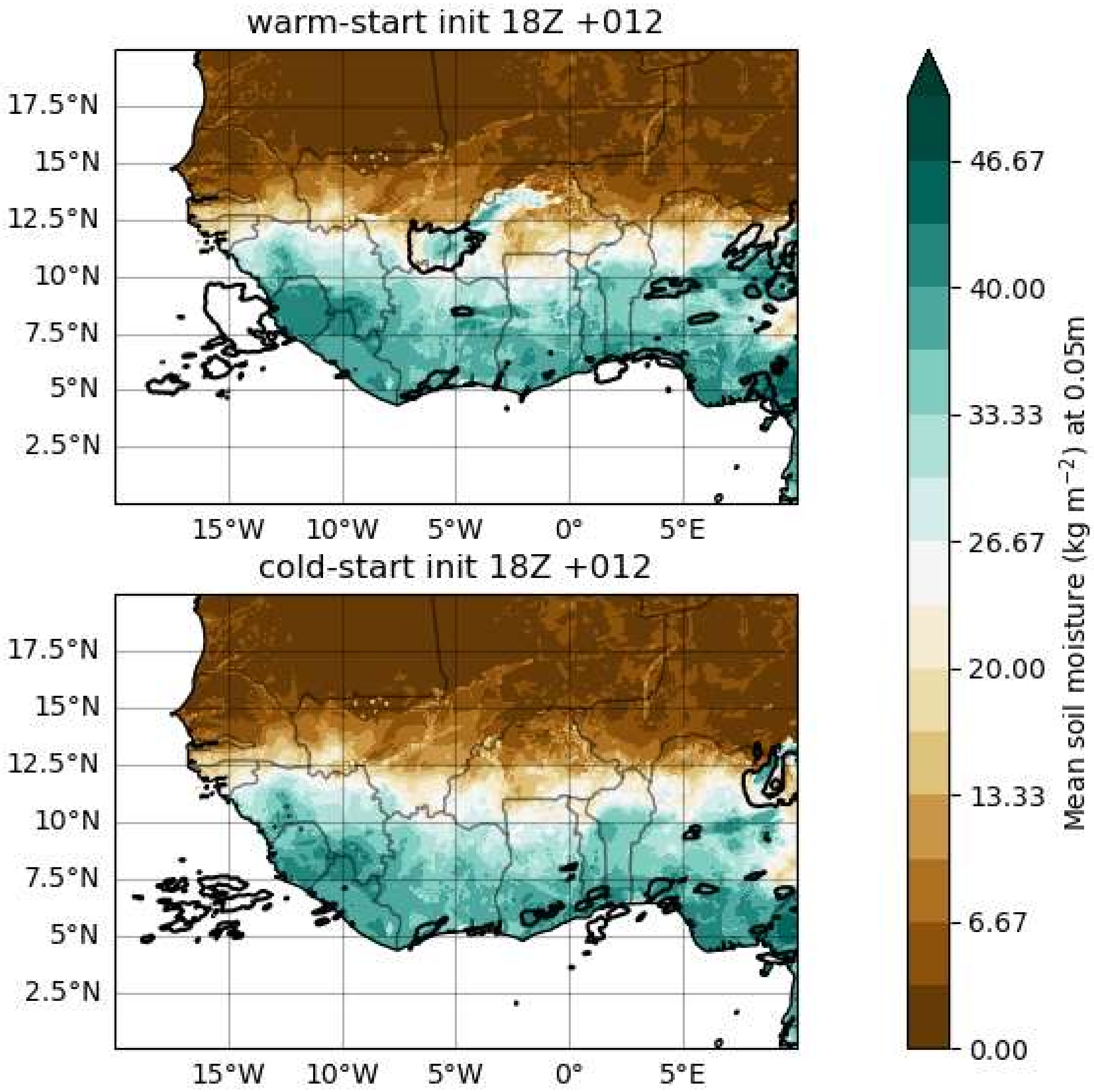

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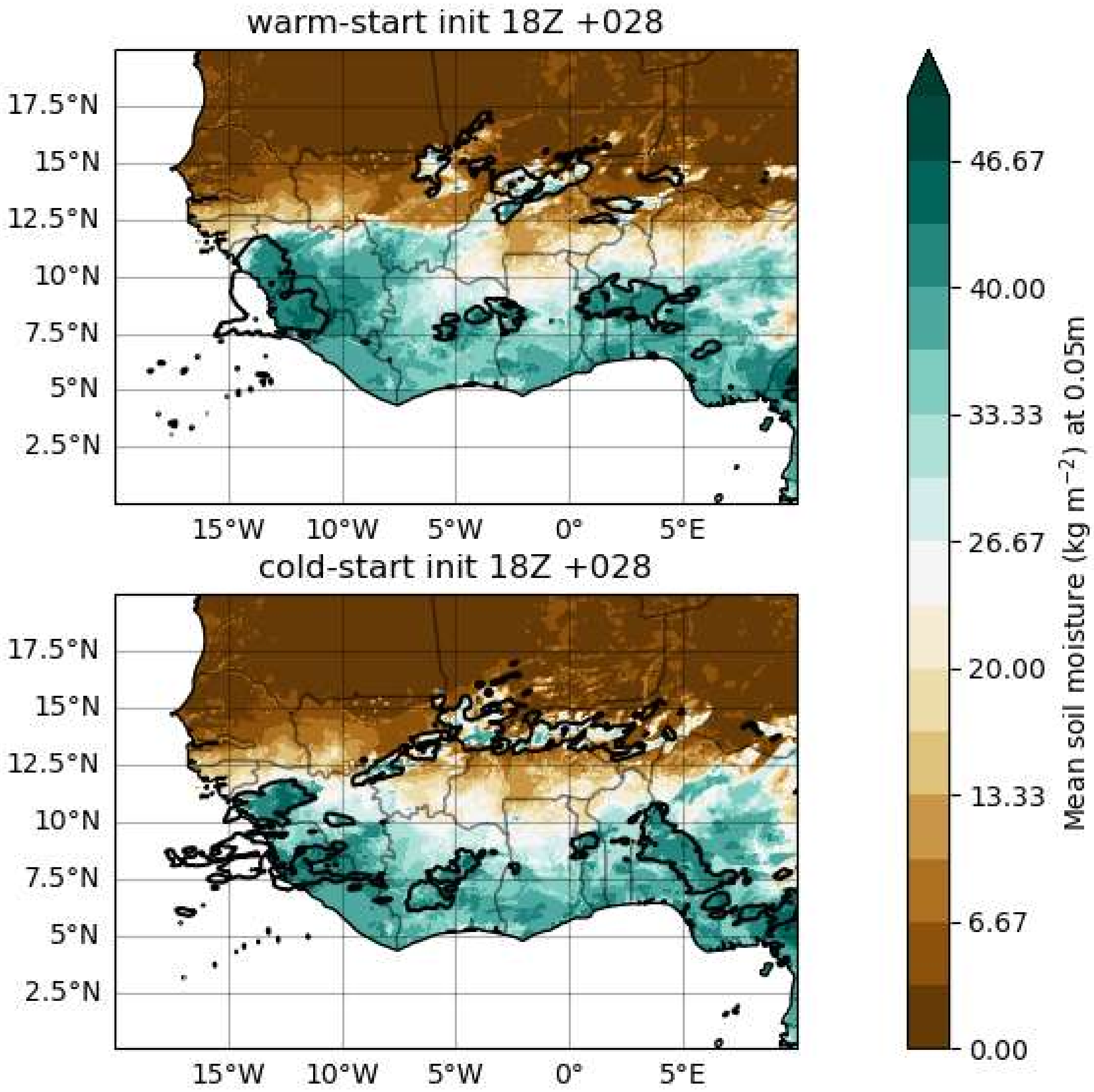
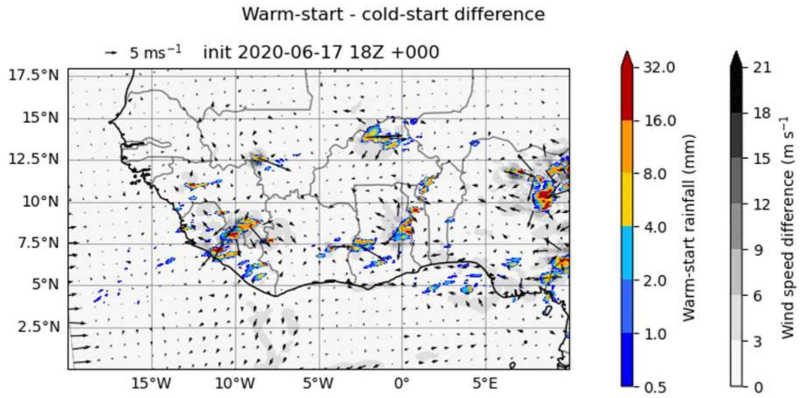
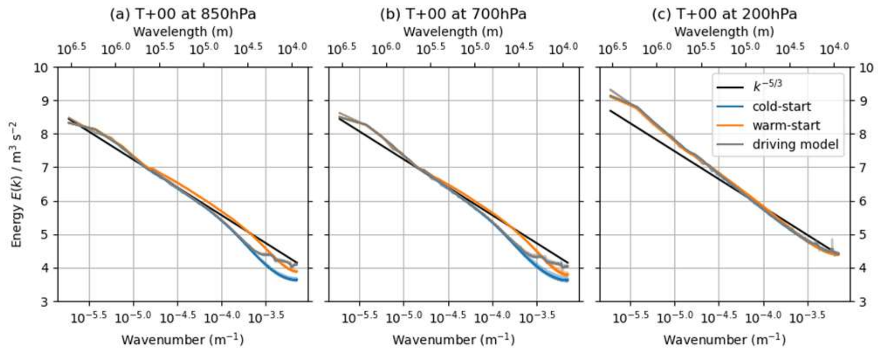


Summary

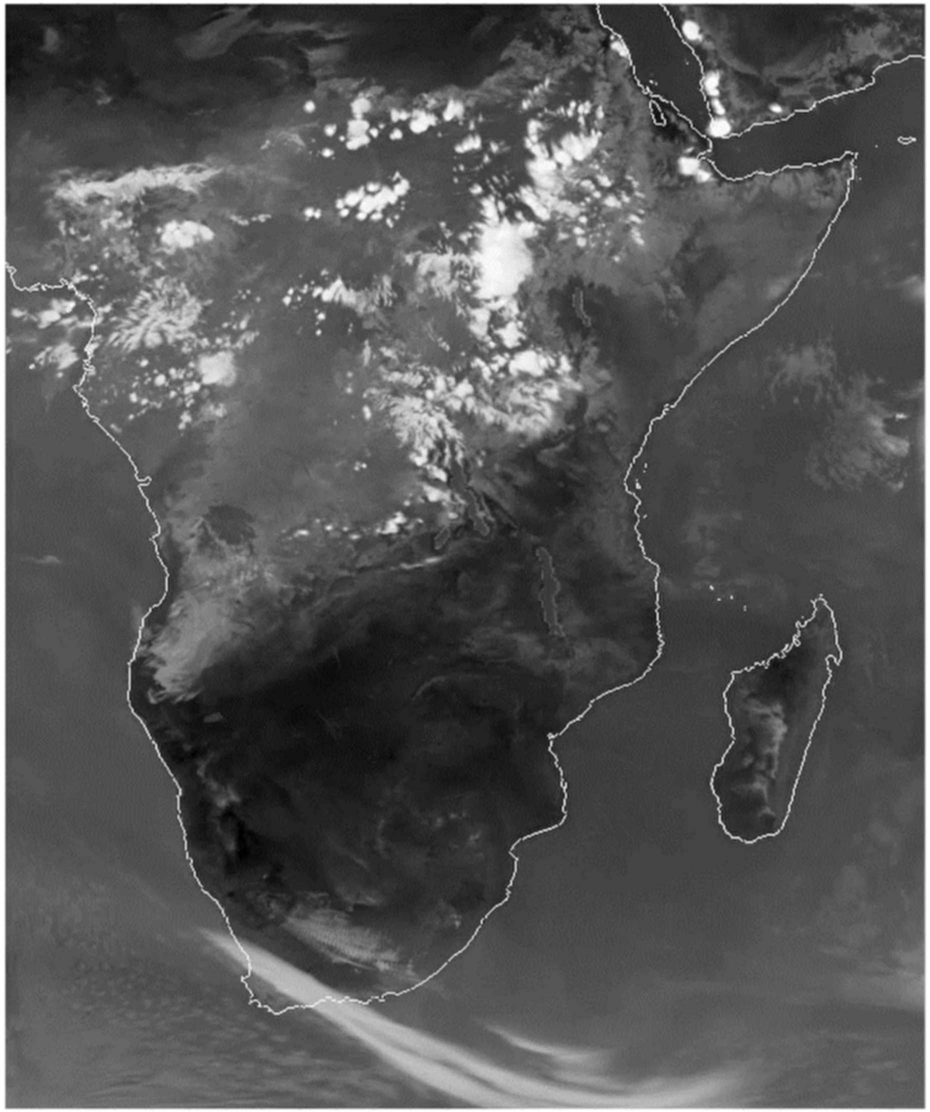
- **Novel initialisation method** provides comparison of simulations initialised with and without convective structure
- Comparing the simulations illustrates an **upscale energy transfer associated with moist convection**
- Mechanisms for scale propagation include **soil moisture** and **atmospheric humidity** feedbacks

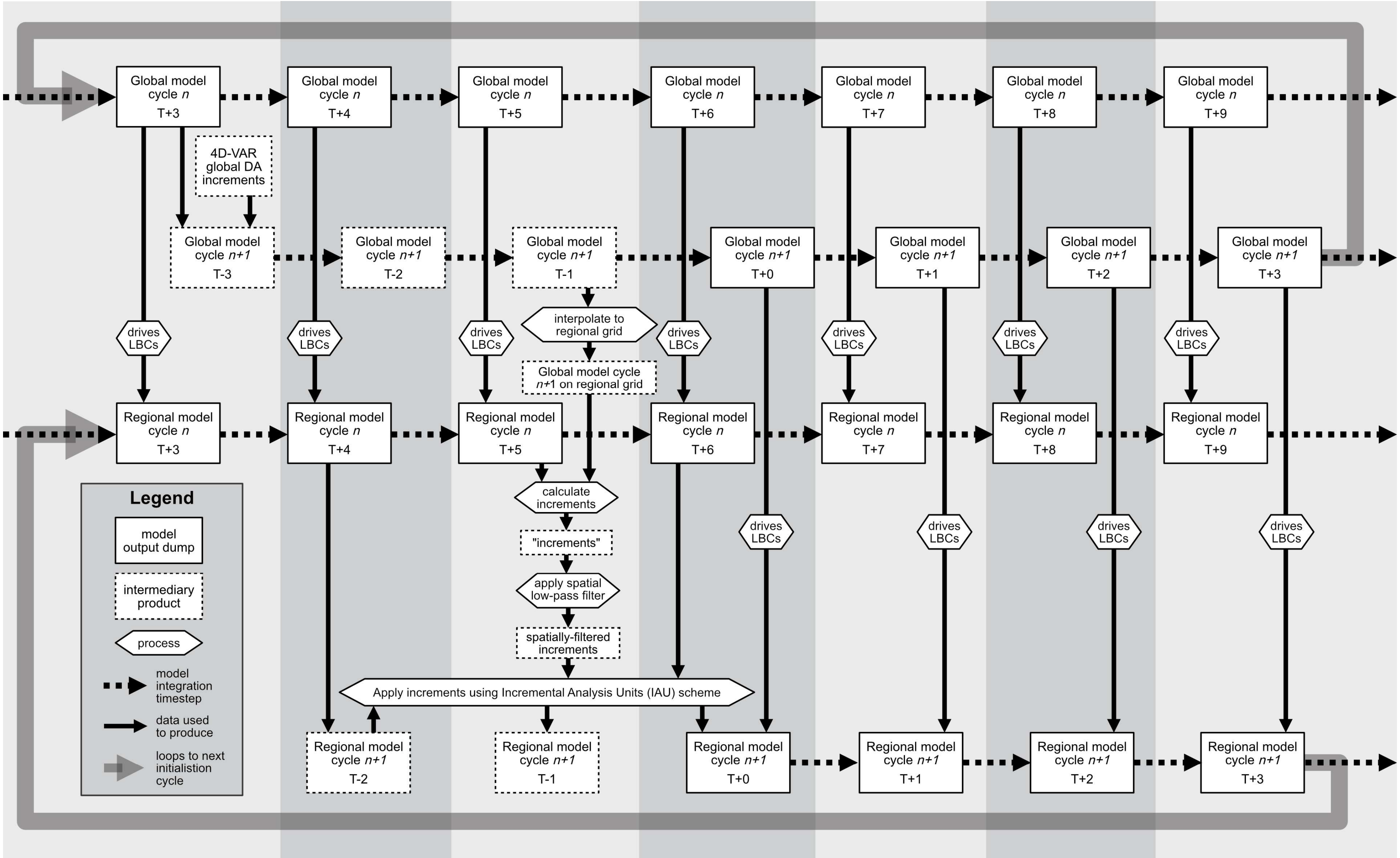




Future Work

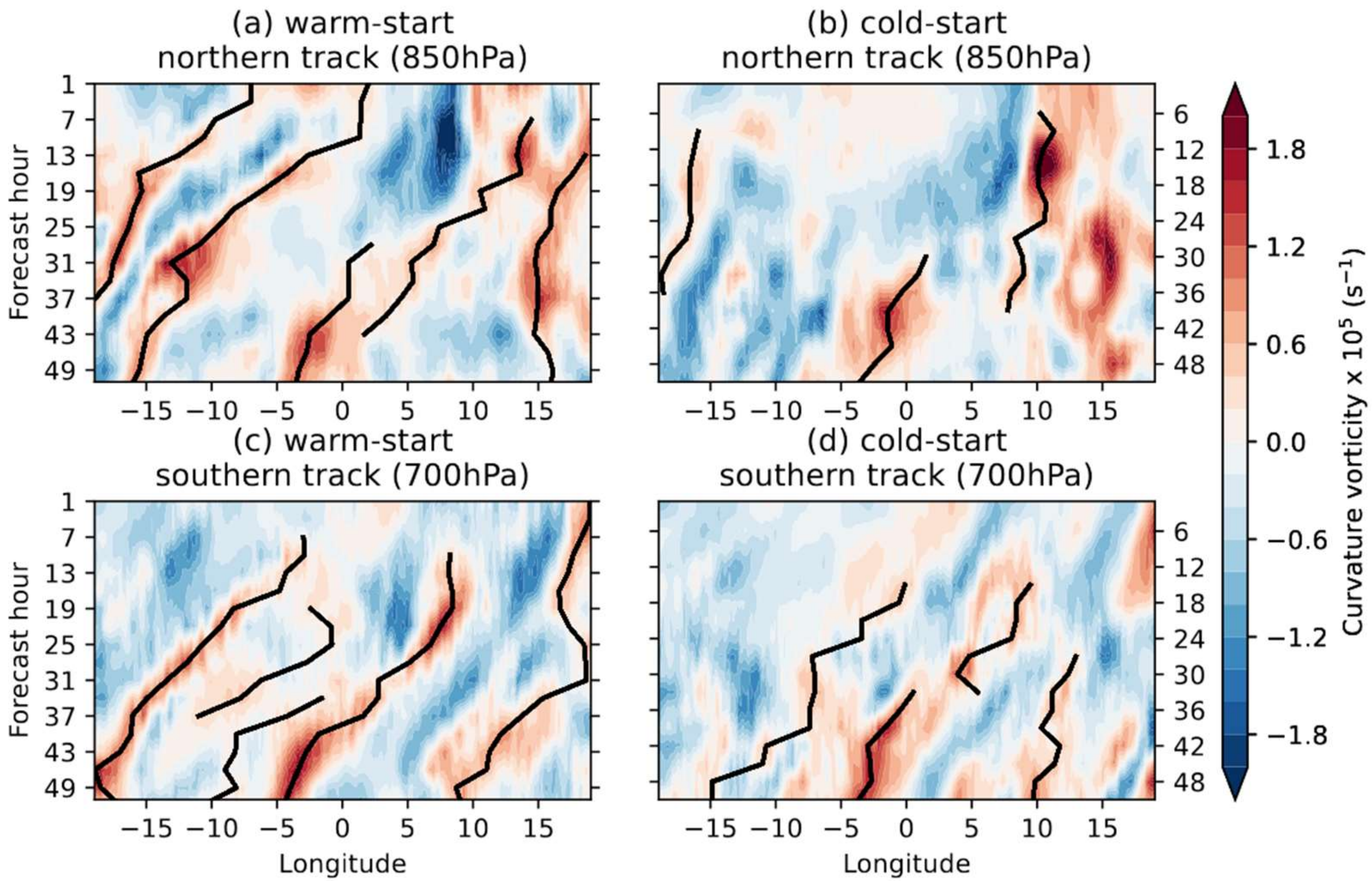
- Natural extension to this work would examine **larger k-scale simulations** (e.g. Met Office tropical channel) or…
- Currently my postdoc role is running a **convective-scale ensemble** over a large regional African domain to investigate predictability of Southern African Monsoon onset, as part of **First Rains** (PI Dr Neil Hart, Oxford)





Global model cycle n T+3
Global model cycle n T+4
Global model cycle n T+5
Global model cycle n T+6
Global model cycle n T+7
Global model cycle n T+8
Global model cycle n T+9
4D-VAR global DA increments
Global model cycle n+1 T-3
Global model cycle n+1 T-2
Global model cycle n+1 T-1
Global model cycle n+1 T+0
Global model cycle n+1 T+1
Global model cycle n+1 T+2
Global model cycle n+1 T+3
interpolate to regional grid
Global model cycle n+1 on regional grid
drives LBCs
Regional model cycle n T+3
Regional model cycle n T+4
Regional model cycle n T+5
Regional model cycle n T+6
Regional model cycle n T+7
Regional model cycle n T+8
Regional model cycle n T+9
calculate increments
"increments"
apply spatial low-pass filter
spatially-filtered increments
Apply increments using Incremental Analysis Units (IAU) scheme
Regional model cycle n+1 T-2
Regional model cycle n+1 T-1
Regional model cycle n+1 T+0
Regional model cycle n+1 T+1
Regional model cycle n+1 T+2
Regional model cycle n+1 T+3
Legend
model output dump
intermediary product
process
model integration timestep
data used to produce
loops to next initialisation cycle

AEWs change characteristics



How do we know it's convection?

- Split KE spectra of warm-started forecasts by fraction of domain which precipitates
- More rain cover is > 8 x 10^{-6} %
- More energy in 200hPa signature
- More large-scale energy in later parts of forecasts where less rain cover at initialisation