The Influence of Orography on Synoptic Weather Systems in Tropical Southern Africa

Emma Howard, Richard Washington
School of Geography and the Environment

University of Oxford

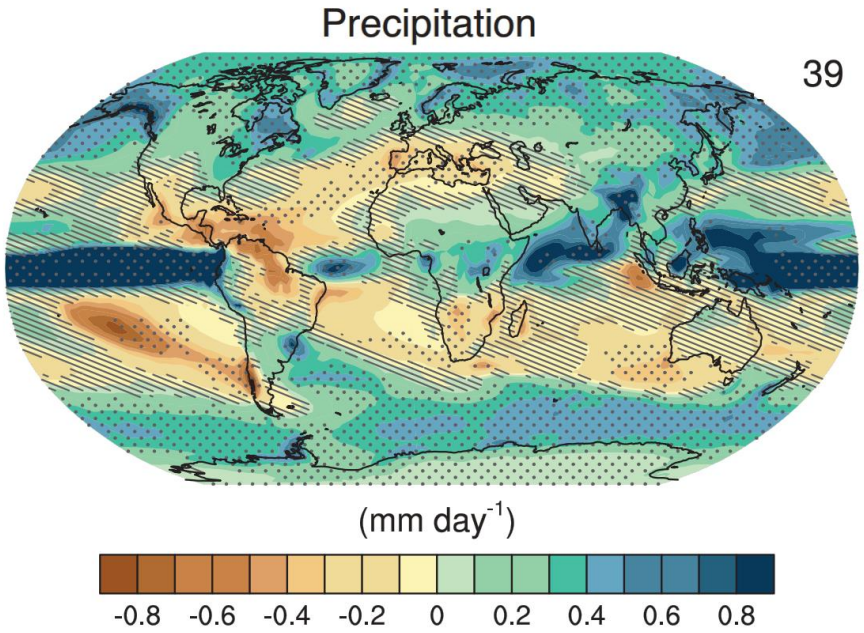
With thanks to Callum Munday, Fabien Desbiolles, Rondrotiana Barimalala, Neil Hart, Rachel James, Ross Blamey and Chris Reason

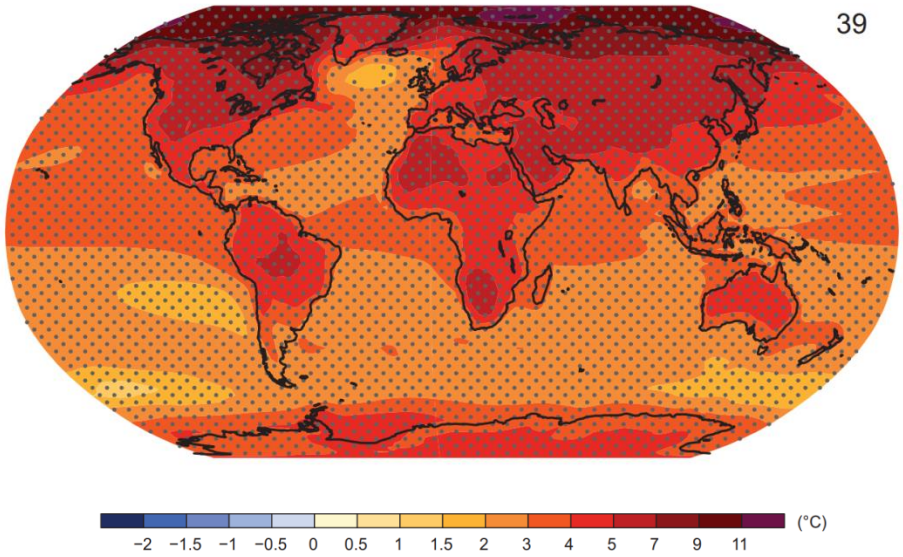
FUTURE CLIMATE FOR AFRICA UMFULA

UNIVERSITY OF OXFORD

Motivation: Why Southern Africa?

RCP8.5 Precipitation and Temperature Change (1986-2005 to 2081-2100)





Southern Africa is one of the few places (on land) where most models agree on future drying, and it is a hotspot for global warming with Botswana warming at 4 times the global average rate.

Source: IPCC AR5

Present Day Rainfall Bias

However, there is a significant rainfall bias over the whole region in present day CMIP Models

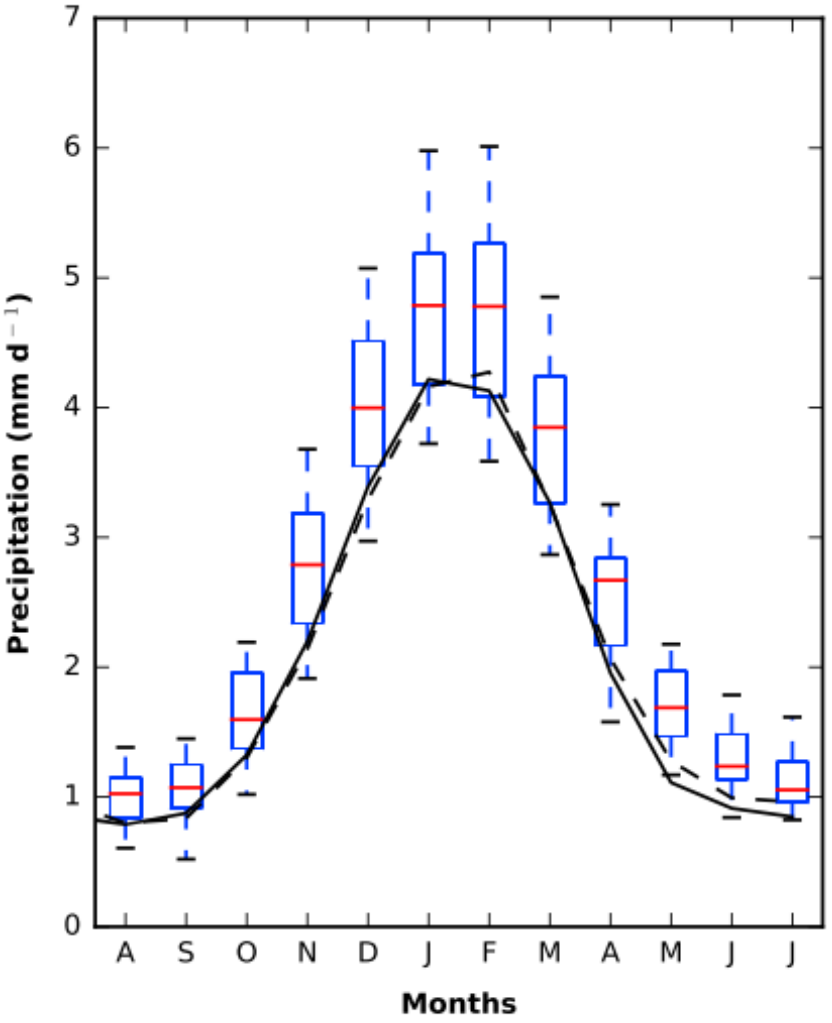


Figure 1. Mean (1979–2005) annual cycle of southern African rainfall (averaged over 10–52°E,10–35°S) in CMIP5 models (box plots) compared to CMAP (dashed line) and GPCP (solid line). The red lines show the median model for each month, the box encompasses the interquartile range of models, and the tails represent the full range.

Motivation: Why Orography?

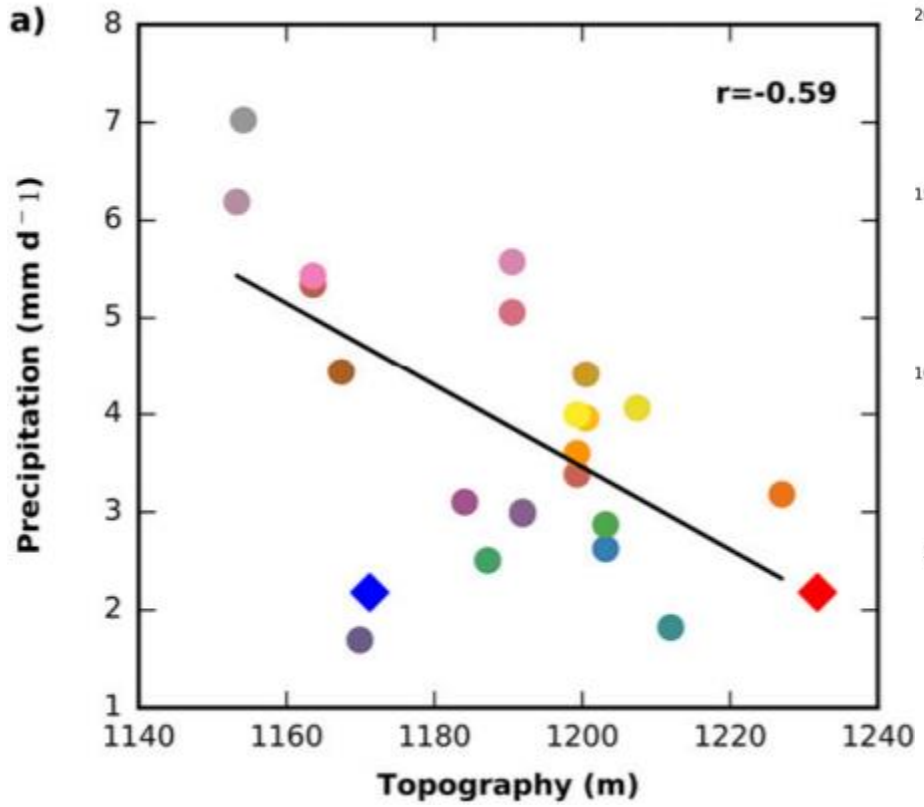
Orography provides moisture flux blocking and elevated heating to the southern African Atmosphere

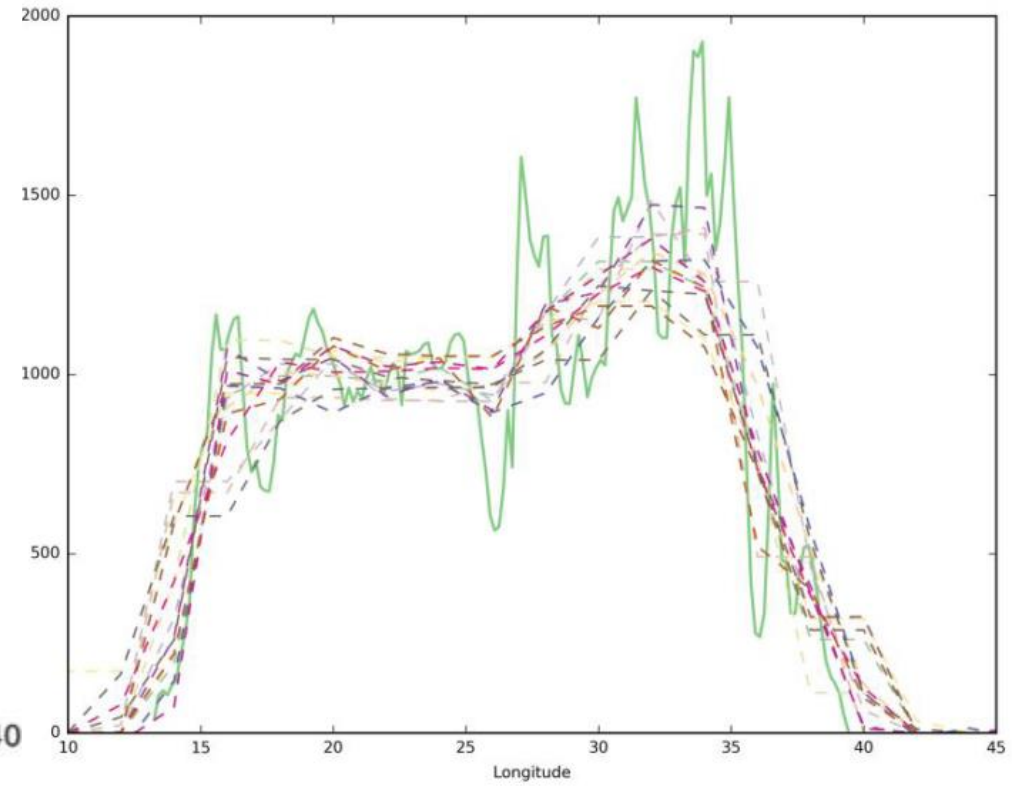
Systematic Climate Model Rainfall Biases over Southern Africa: Links to Moisture Circulation and Topography

C. MUNDAY AND R. WASHINGTON

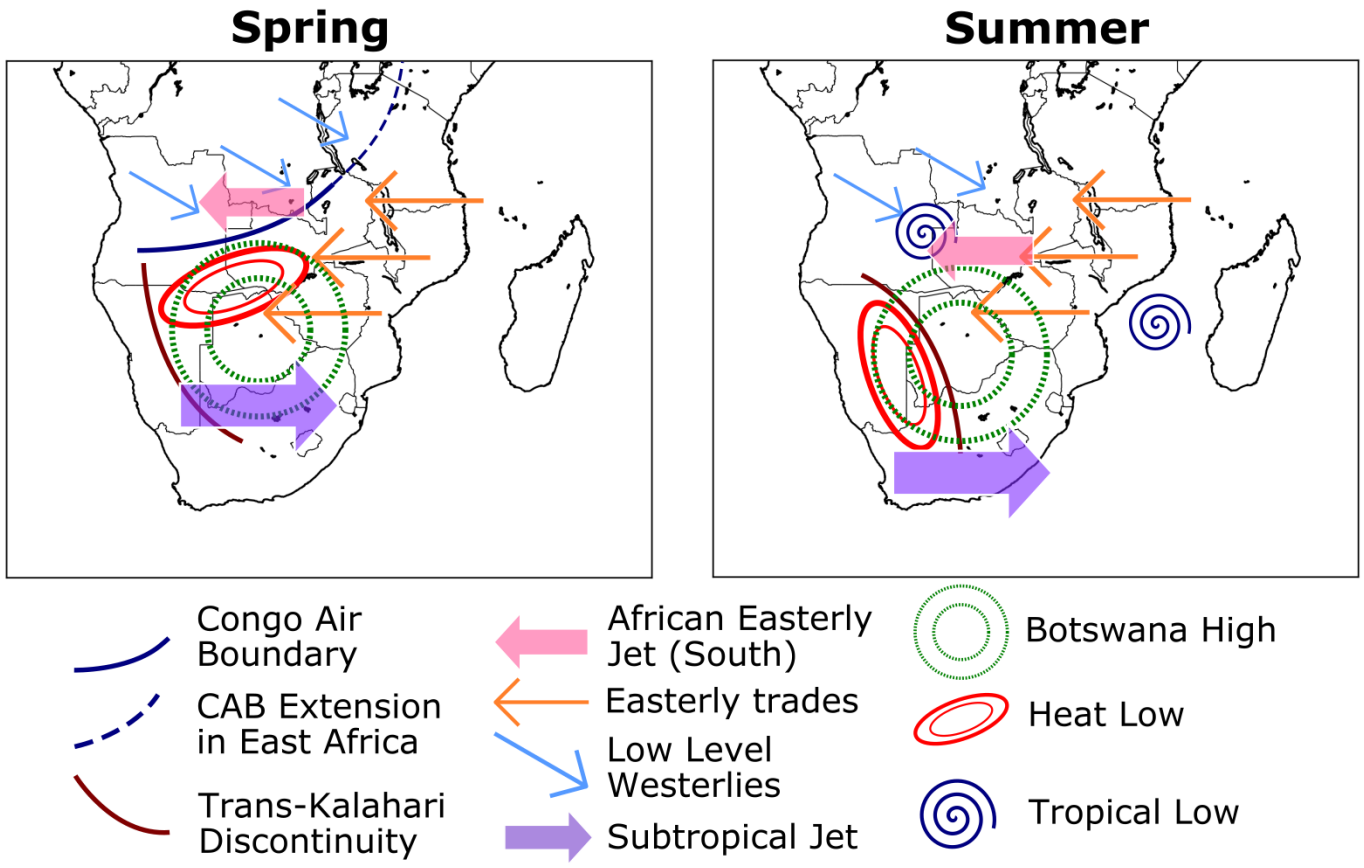
School of Geography and Environment, University of Oxford, Oxford, United Kingdom

(Manuscript received 9 January 2018, in final form 14 June 2018)





Background: Key Processes in Southern Africa (Spring and Summer)



ALSO:

- St. Helena High (Atlantic Ocean)
- Mascarene High (Indian Ocean)
- Angola-Benguela Frontal Zone

Figure from Howard and Washington (submitted to JCli) *Dry-lines in Southern Africa: Rediscovering the Congo Air Boundary*

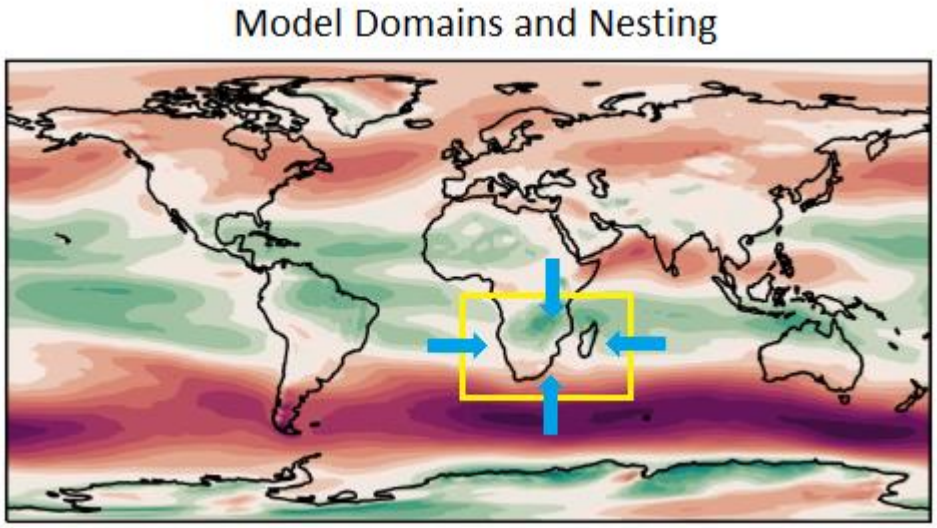
Experimental Design

OpenIFS (Global)

- Cy40r1v1.1
- Run at 75 km resolution (T255) with 60 vertical levels.
- 45 minute time-step
- 8 ensemble members with differences derived from different initialisation dates and stochastic physics.

WRF (Regional)

- National Centre for Atmospheric Research (USA)
- V3.7.1
- 18 km resolution, 40 vertical levels (lower model top)
- 1 minute time-step
- Initial and boundary conditions derived from OpenIFS – so model differences carried through.



3 experiments with 8 ensemble members each:

- Full Topo
- Half Topo
- No Topo

Run from August 2006 to March 2007

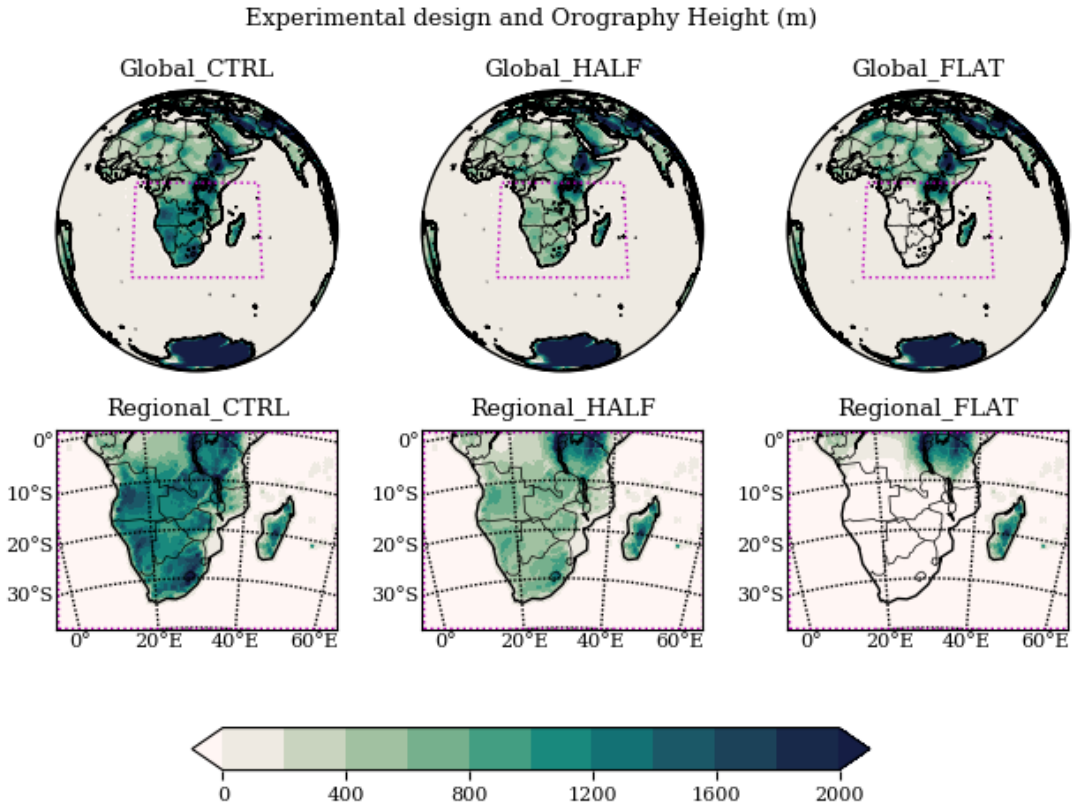
Global model, downscaled over southern Africa

1 month Spin up

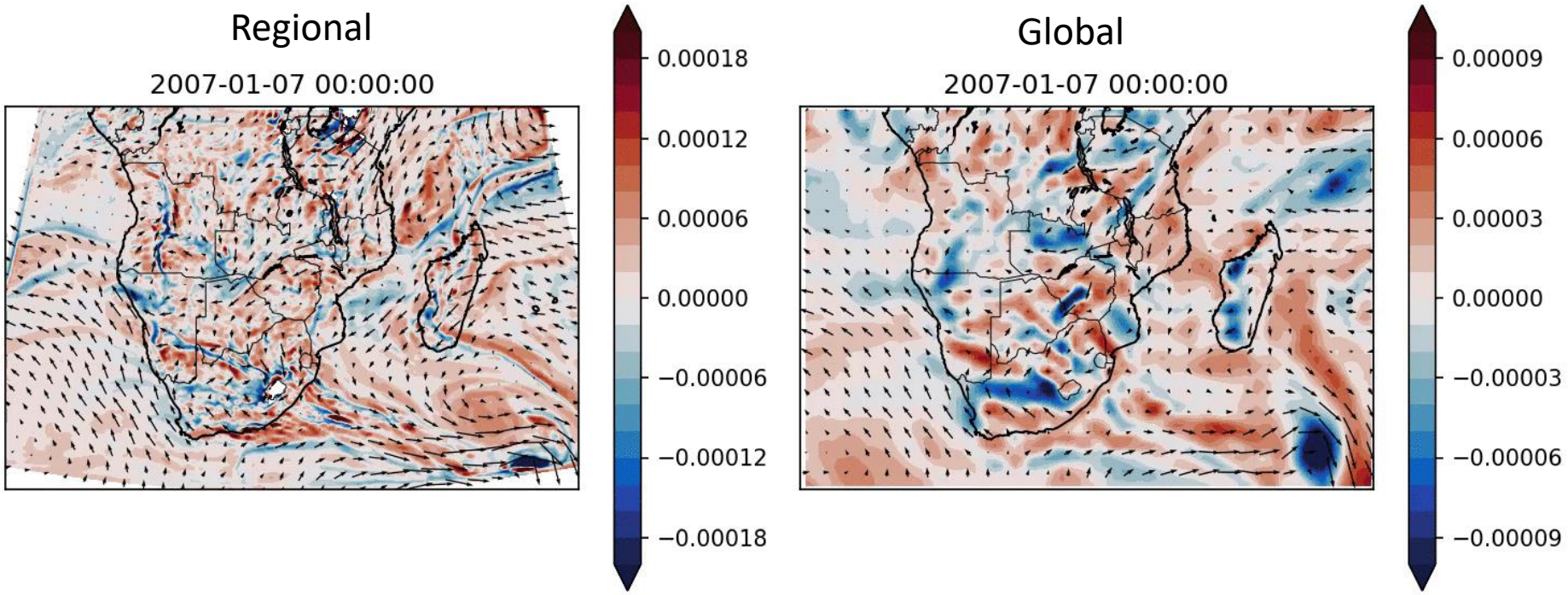
Experimental Design

Research Question:

- What are the climate impacts of removing the topography from Southern Africa from atmospheric models?
  - Impacts on global circulation
  - Impacts on local processes
  - Impacts on local rain-bearing weather systems
  - Local impacts on convection
- Elevated Heating
- Orographic Blocking



Example output – pretty tropical low



800 hpa Vorticity in one ensemble member of the control run. (Regional left, Global right)
Blue: Cyclonic; Red: Anti-Cyclonic

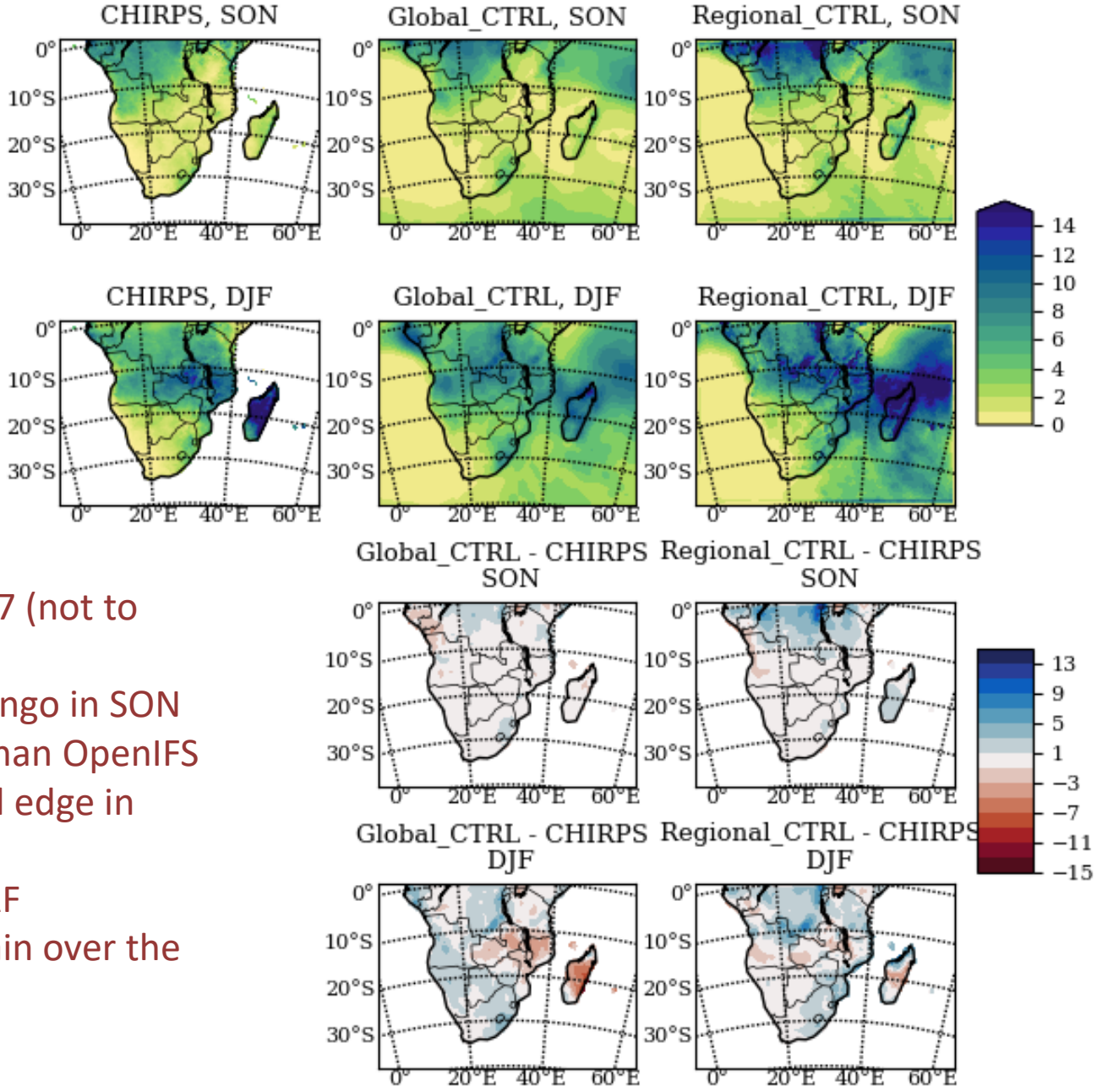
Continental features are better resolved in the regional model. The large scale flow over the oceans are similar in the two models.

Sea breeze interacts with Angola Low in the regional model.

OpenIFS -> WRF

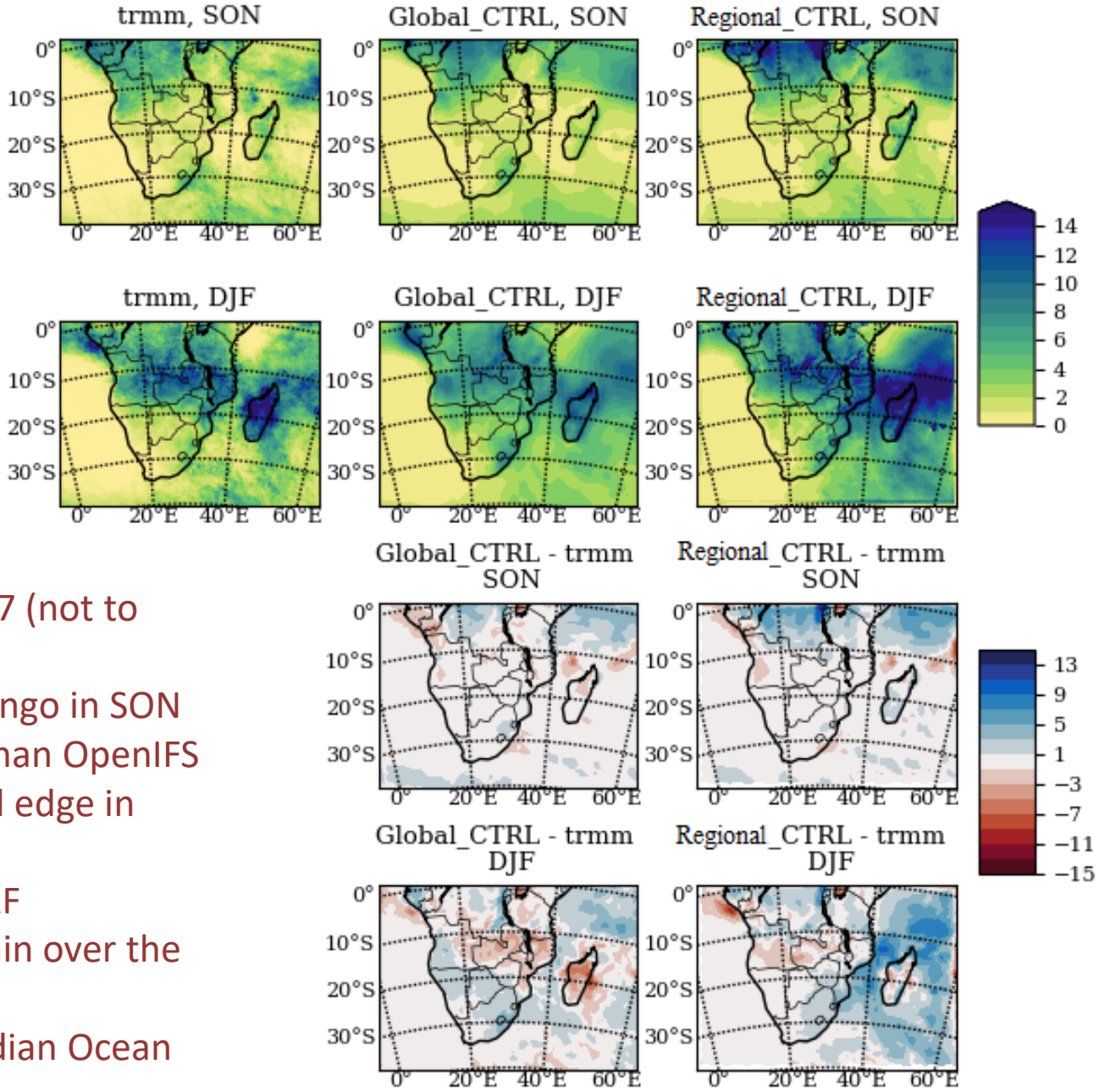
- Set name-list variables in fort.4 to output appropriate WRF inputs on model-level and surface/subsurface grids
- OpenIFS outputs GRIB files
  - Mixed type 1 and type 2
  - Multiple vertical coordinate types
  - Reduced Gaussian Grid and Spectral Grid
- WRF Pre-processing system (WPS) reads GRIB files
  - But is a little bit fussy
  - Must be all same type (type 2)
  - Regular lat-lon grid
  - Geopotential -> Geopotential Height
- Only minor formatting changes needed
- Plus some small bug fixes/modifications to the WPS

Model Validation – Rainfall (CHIRPS)



- Compared to 2006-07 (not to climatology)
- Wet bias over the Congo in SON
  - Worse in WRF than OpenIFS
- Dry bias over tropical edge in OpenIFS in DJF
  - Improved in WRF
- Both models don't rain over the lakes

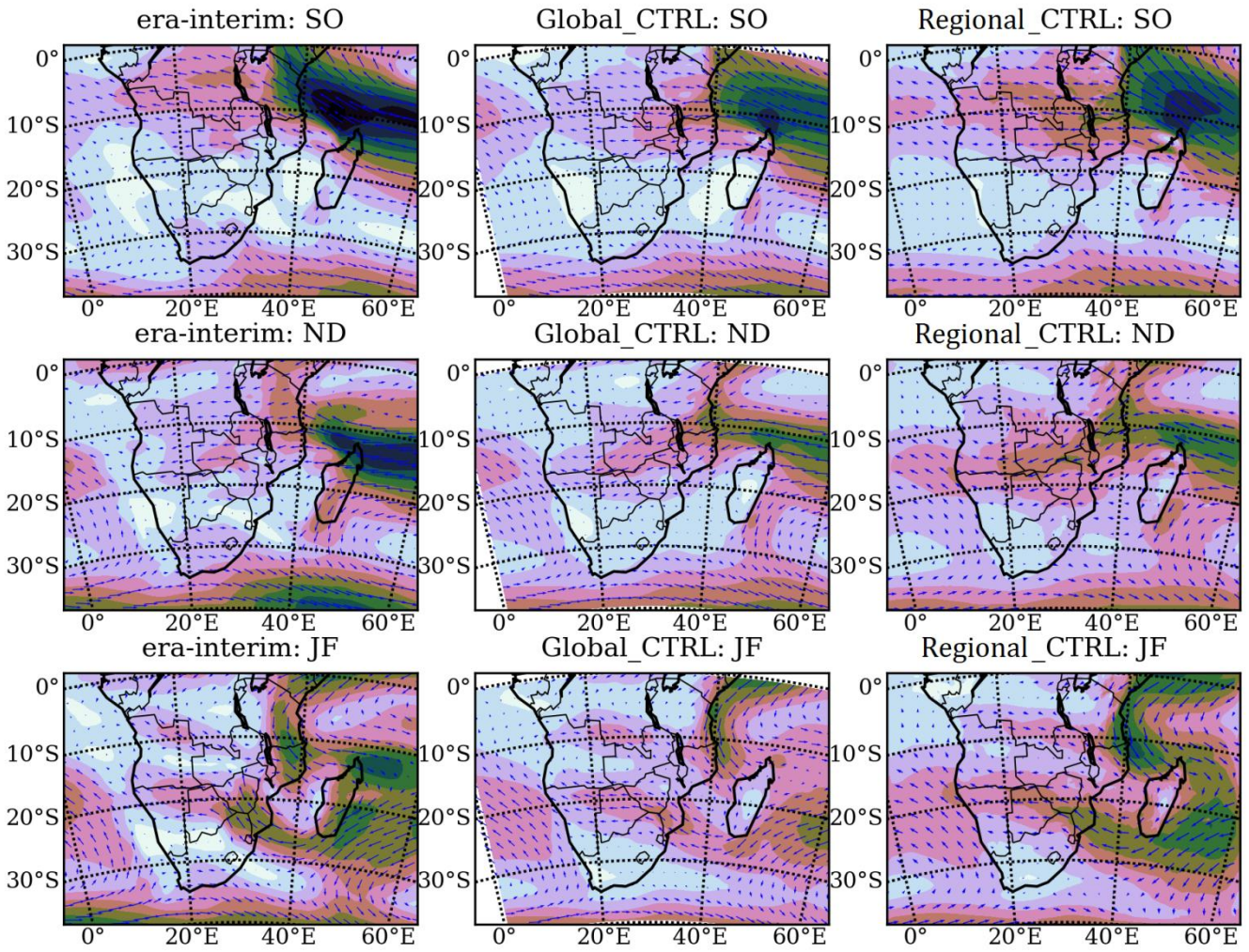
Model Validation – Rainfall (TRMM)



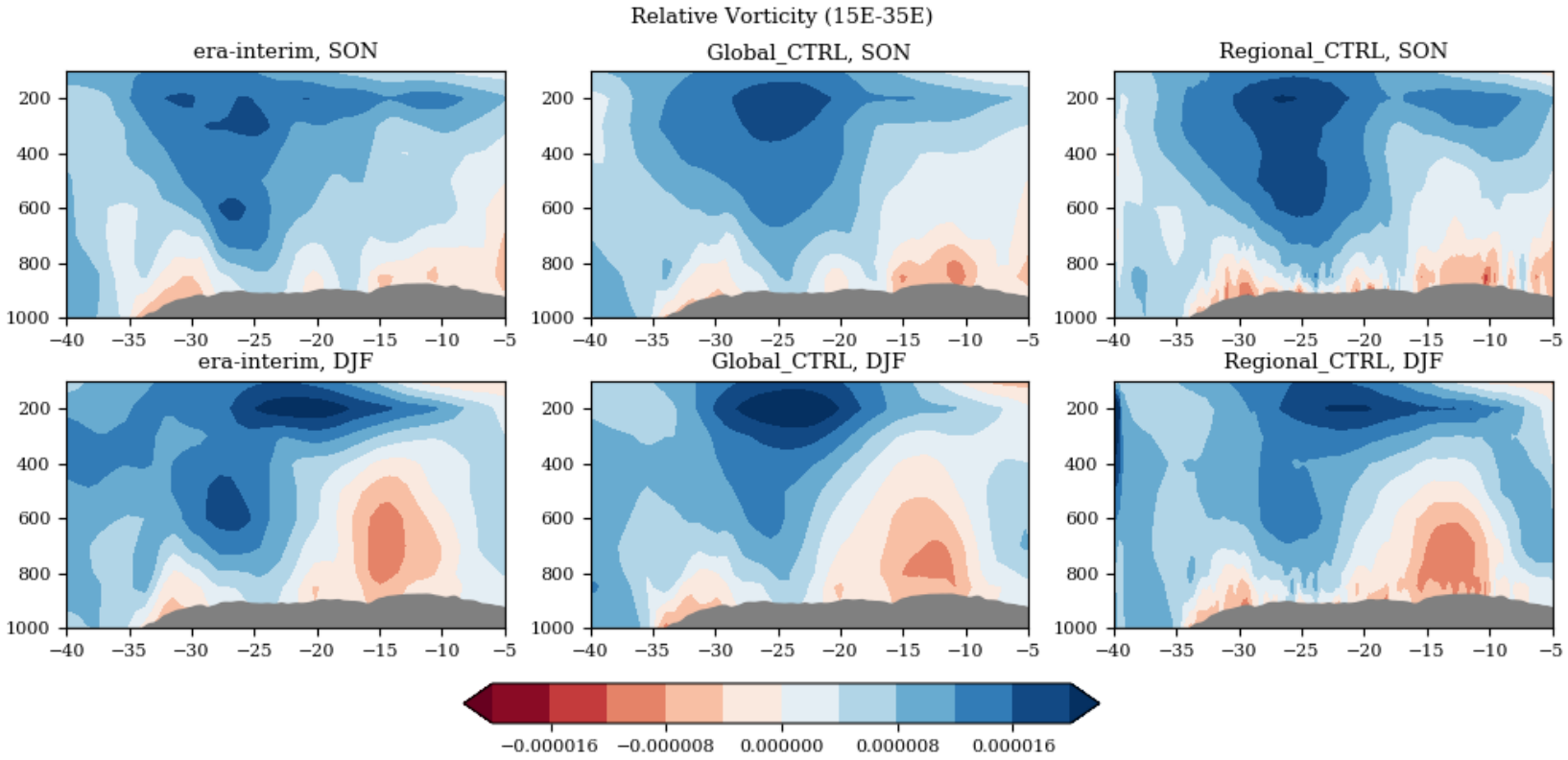
- Compared to 2006-07 (not to climatology)
- Wet bias over the Congo in SON
  - Worse in WRF than OpenIFS
- Dry bias over tropical edge in OpenIFS in DJF
  - Improved in WRF
- Both models don't rain over the lakes
- Wet bias over SW Indian Ocean

Model Validation: Moisture Flux

- Overall Structure of Moisture flux is good
- There is an improved moisture flux across the escarpment in the regional model



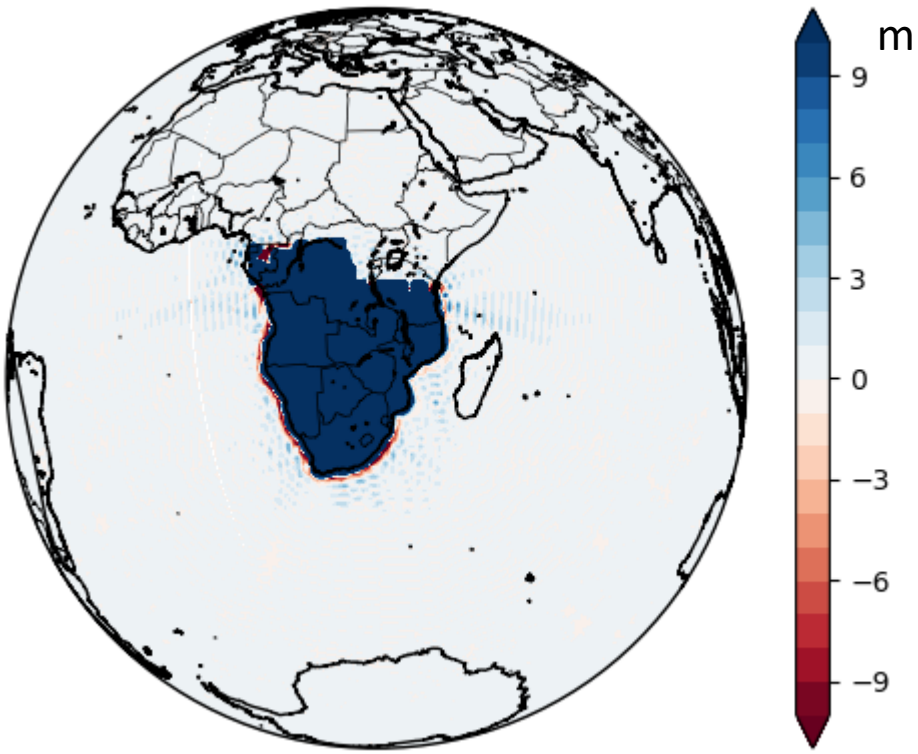
Model Validation: Vertical Structure



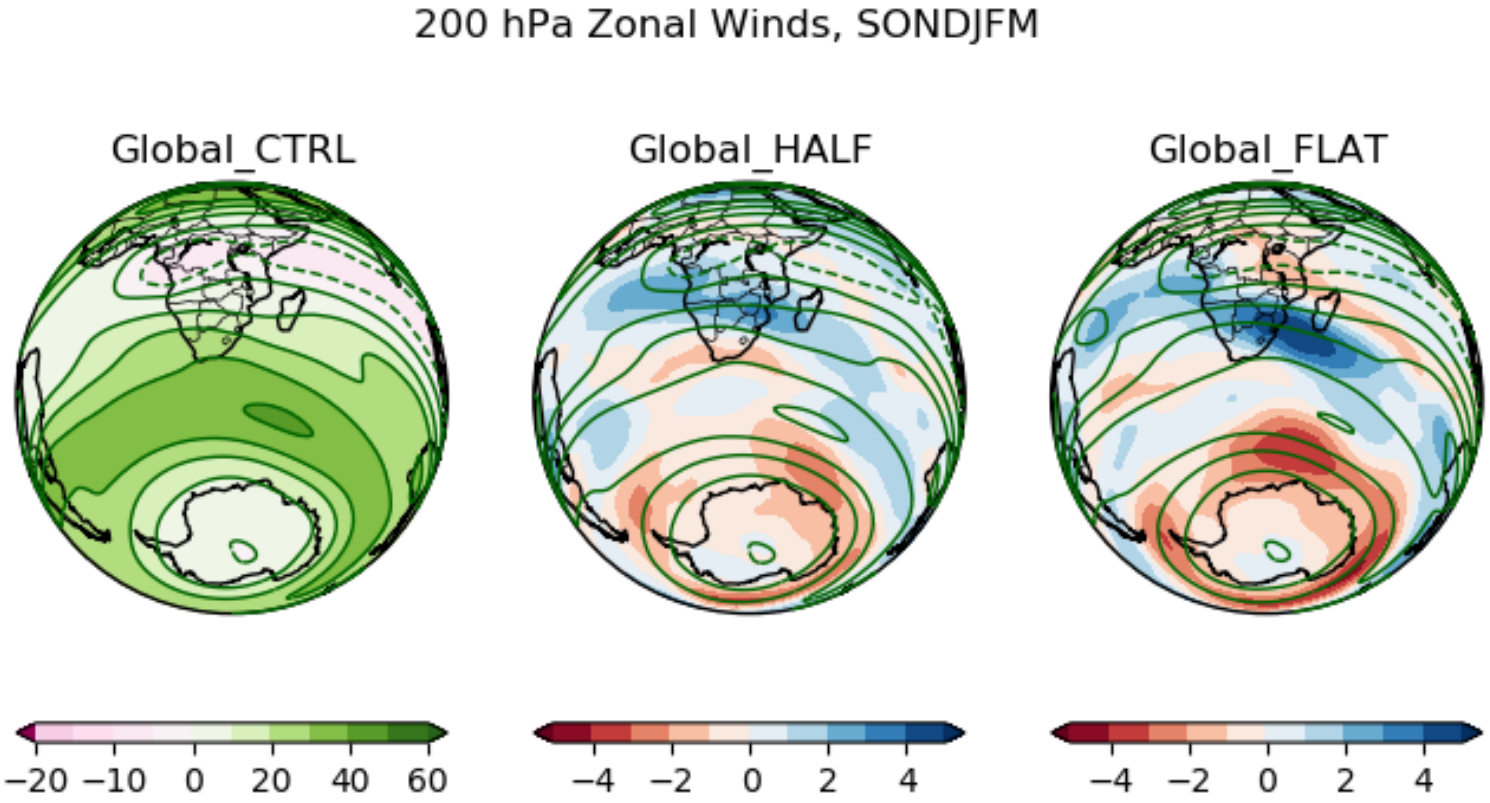
- Botswana High, Angola Low, Upper Level High, heat lows are all captured
- Separation of highs is better in Regional Model

Topography Removal Process

- Convert surface z and lnsp in ICMSH*INIT from sp to gp, modify, interpolate lnsp, convert back to spectral
- Run with 5 min time-step for 3 days as gravity waves disperse, temperatures adjust.



Results: Global Circulation



The Subtropical Jet shifts northwards – towards southern Africa and away from Antarctica

Results: Global Circulation

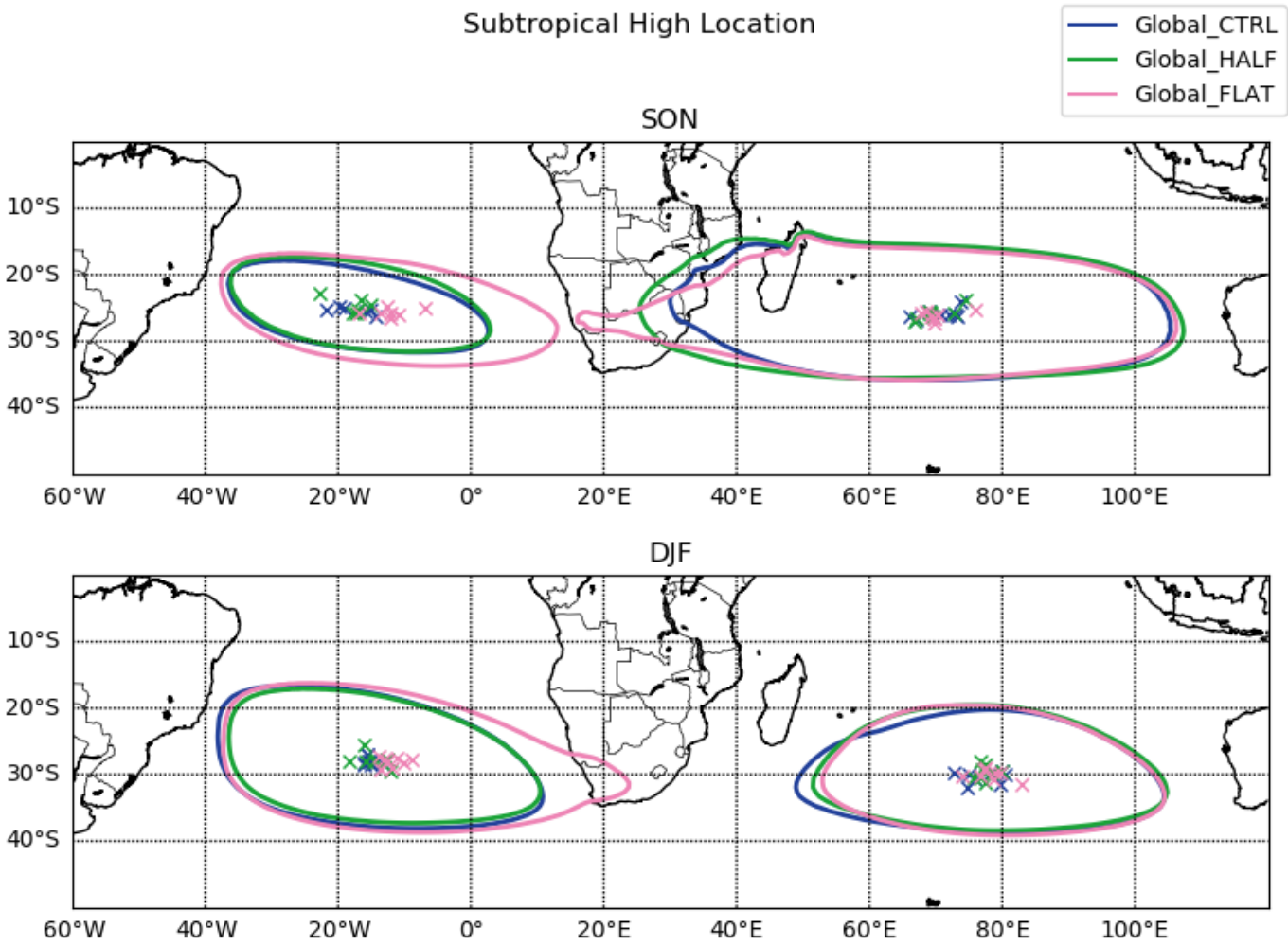
Contours: High location: 850 hPa, fixed contour of geopotential height.

Dots: ensemble subtropical high centroids.

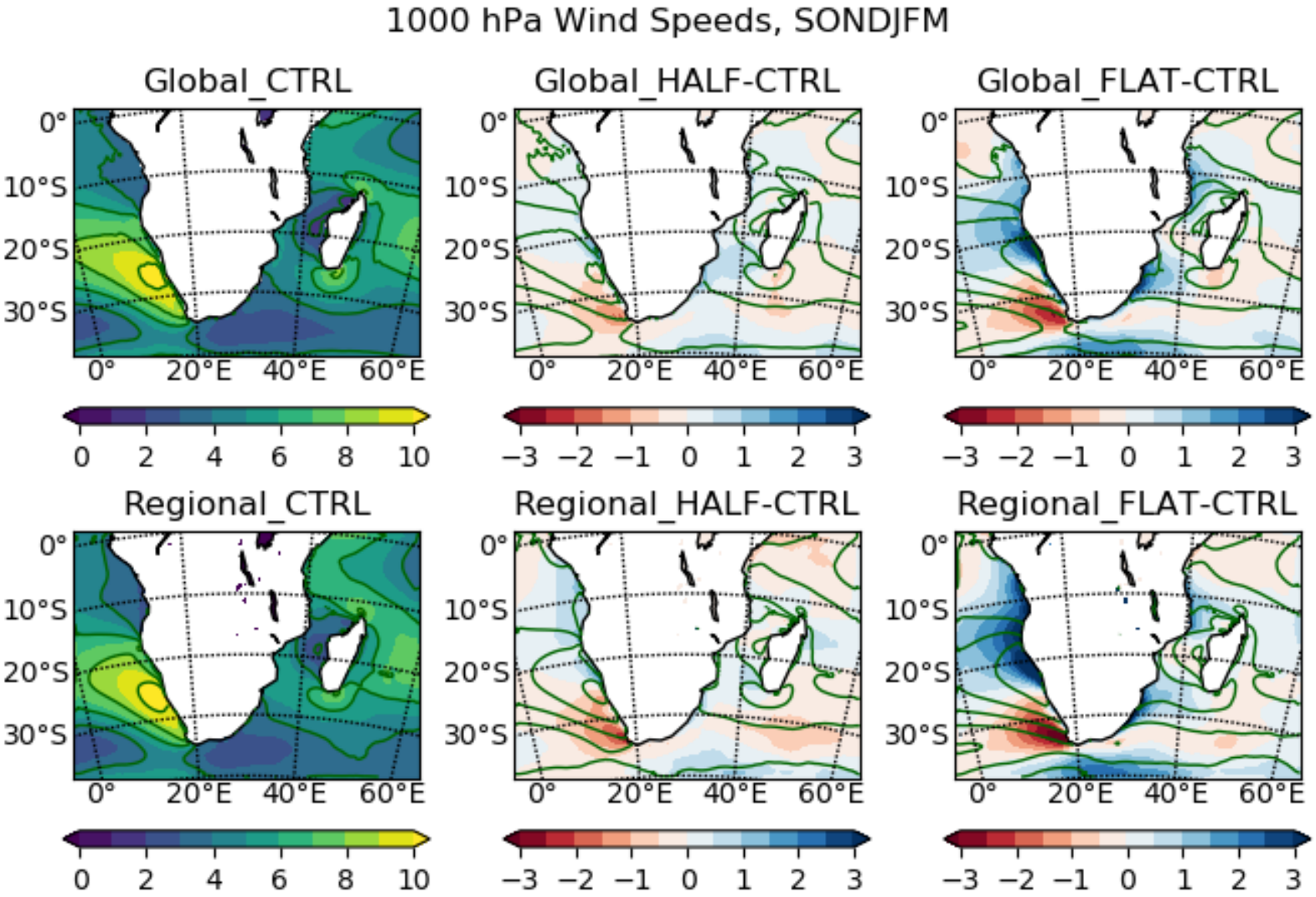
The St. Helena High shifts towards Southern Africa, and expands in SON.

Change is all in FLAT, not in HALF.

The Mascarene High doesn't change much – perhaps due to Madagascar.



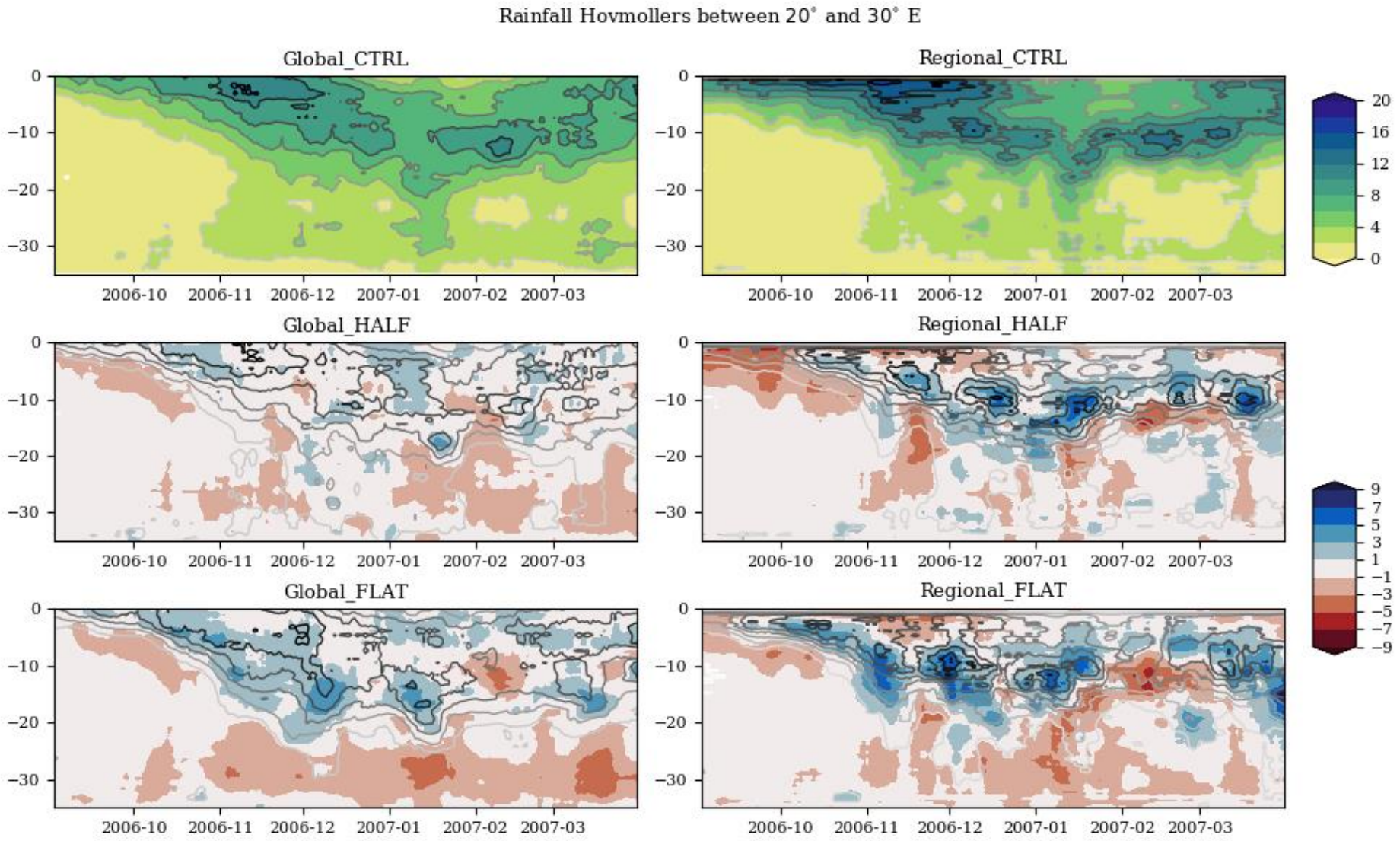
Near-Sea Winds



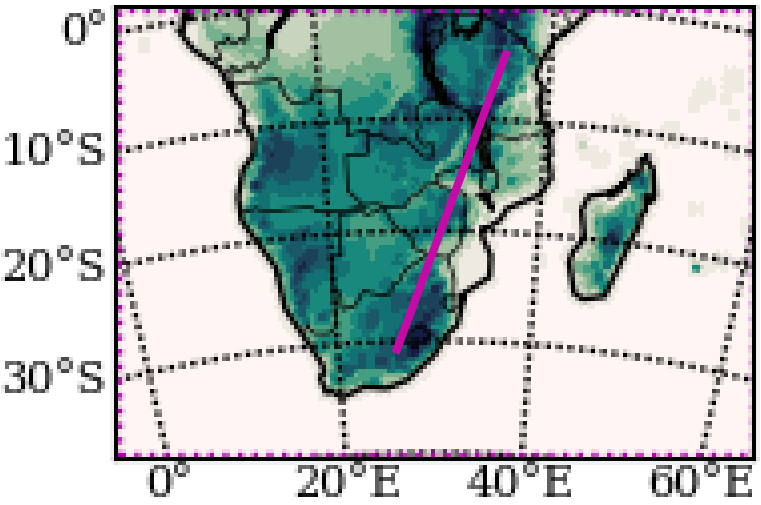
Colberg and Reason (2006) A model study of the Angola Benguela Frontal Zone: Sensitivity to atmospheric forcing (GRL)

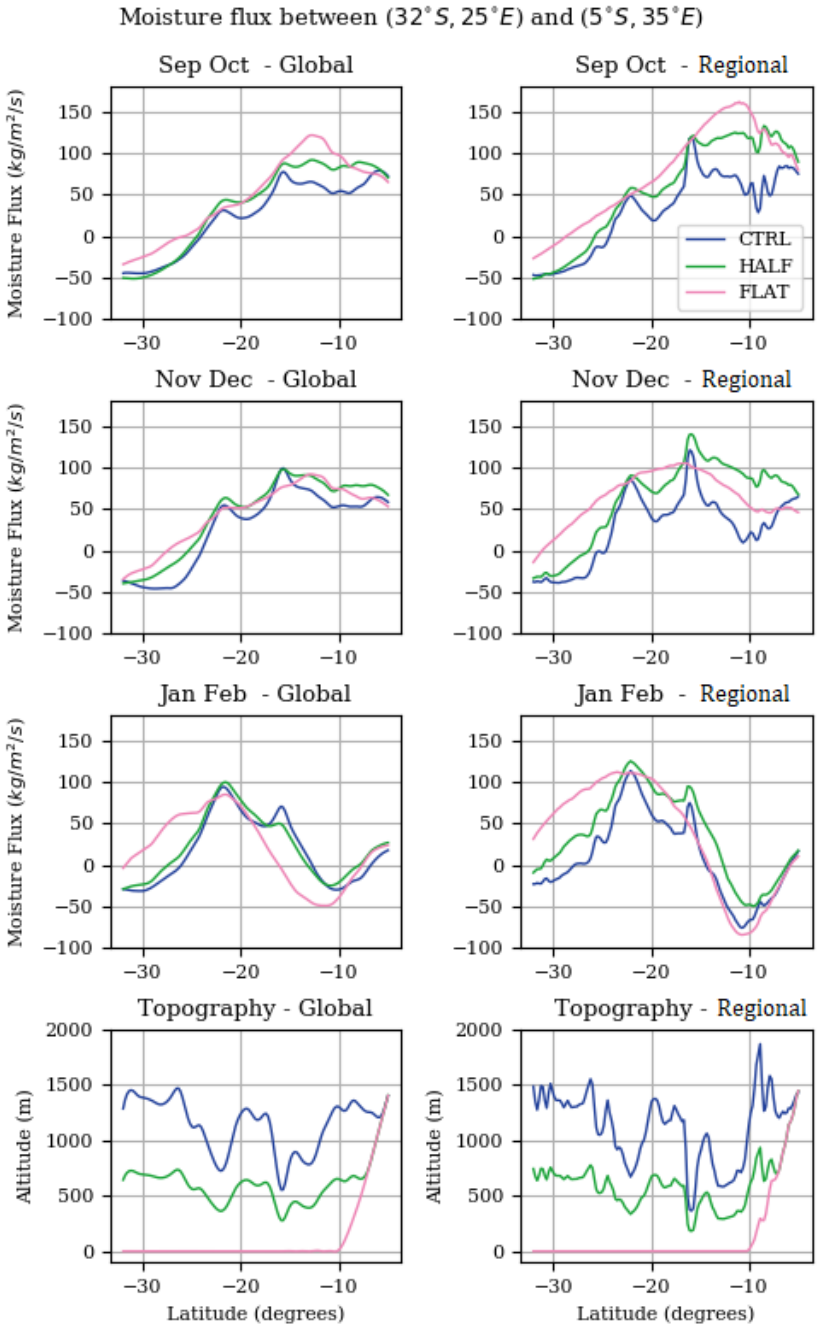
Results: Rain

- Becomes more intense at centre of rain-belt
- Rain-belt shifts south more slowly in Sept and Oct
- Much less rain at subtropical latitudes – increased subsidence associated with stronger subtropical highs

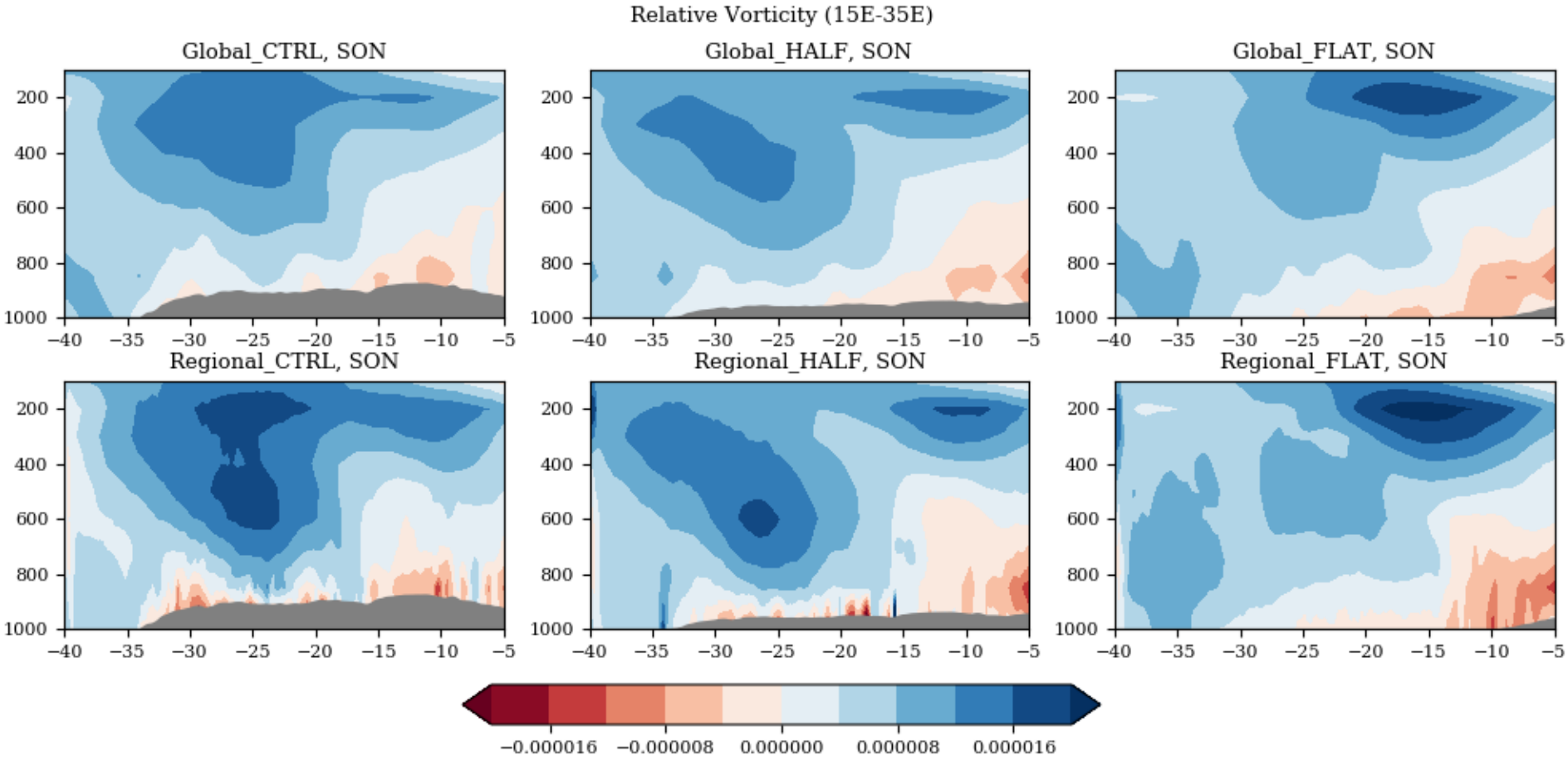


Results: moisture flux

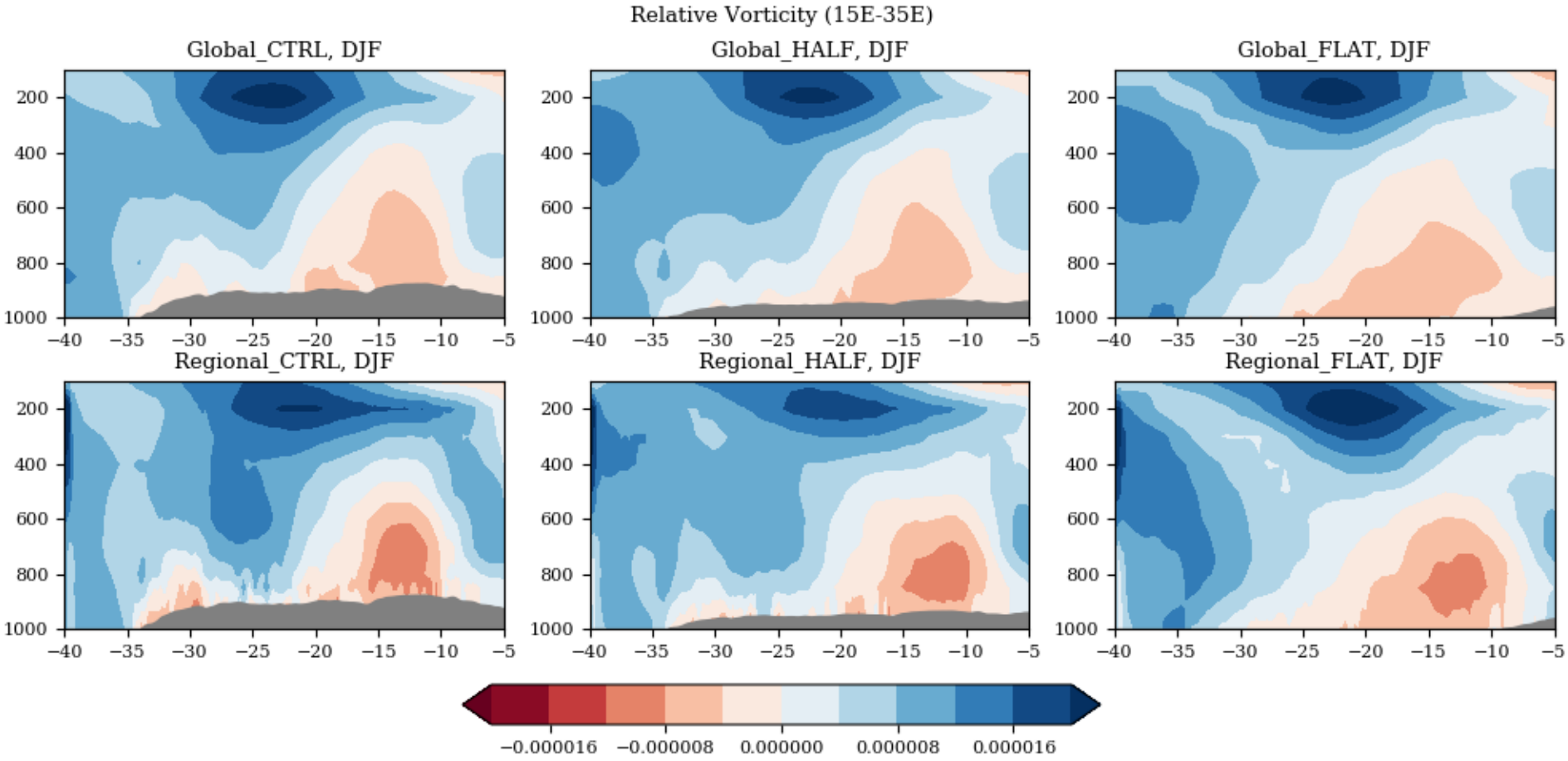




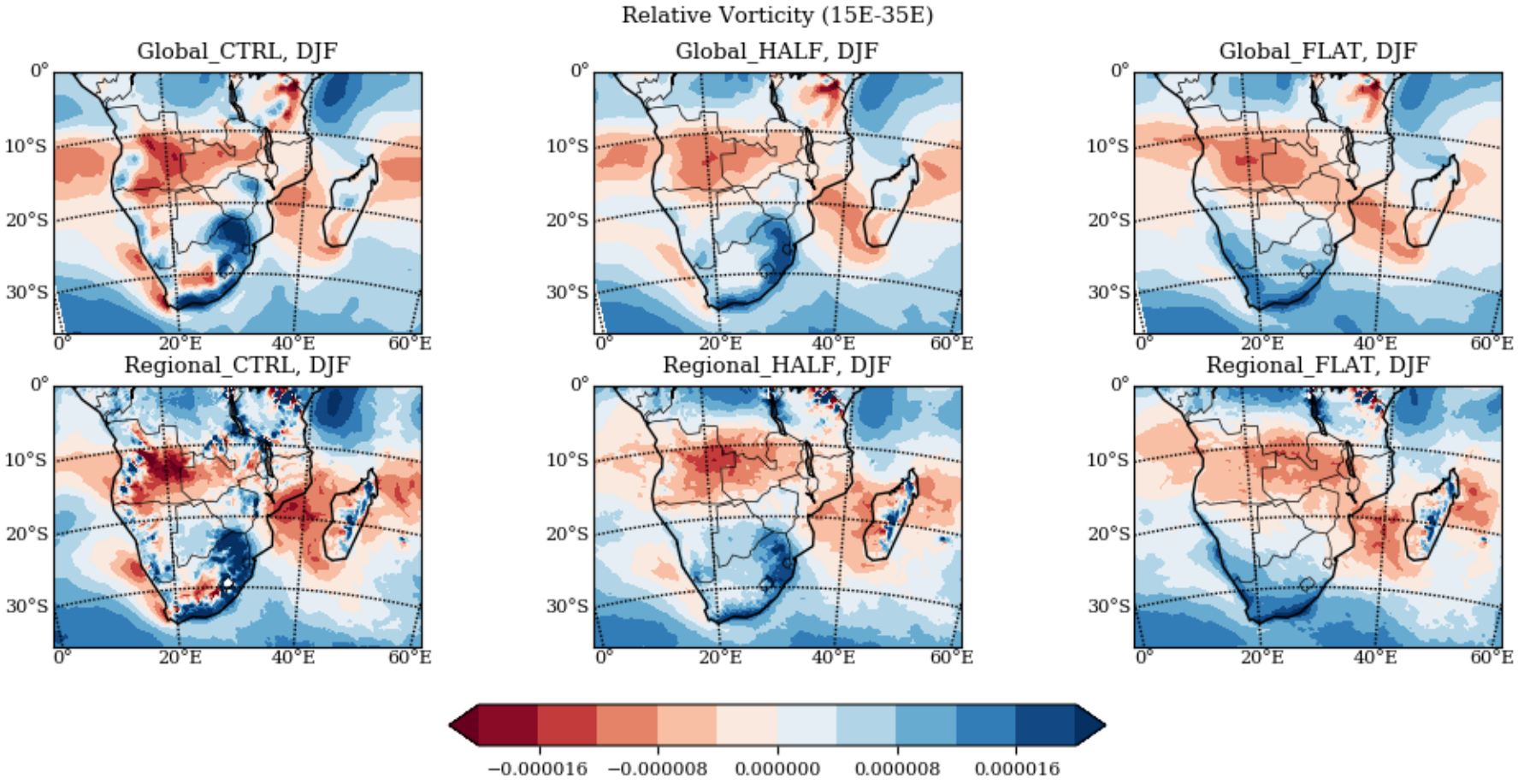
Vertical Structure



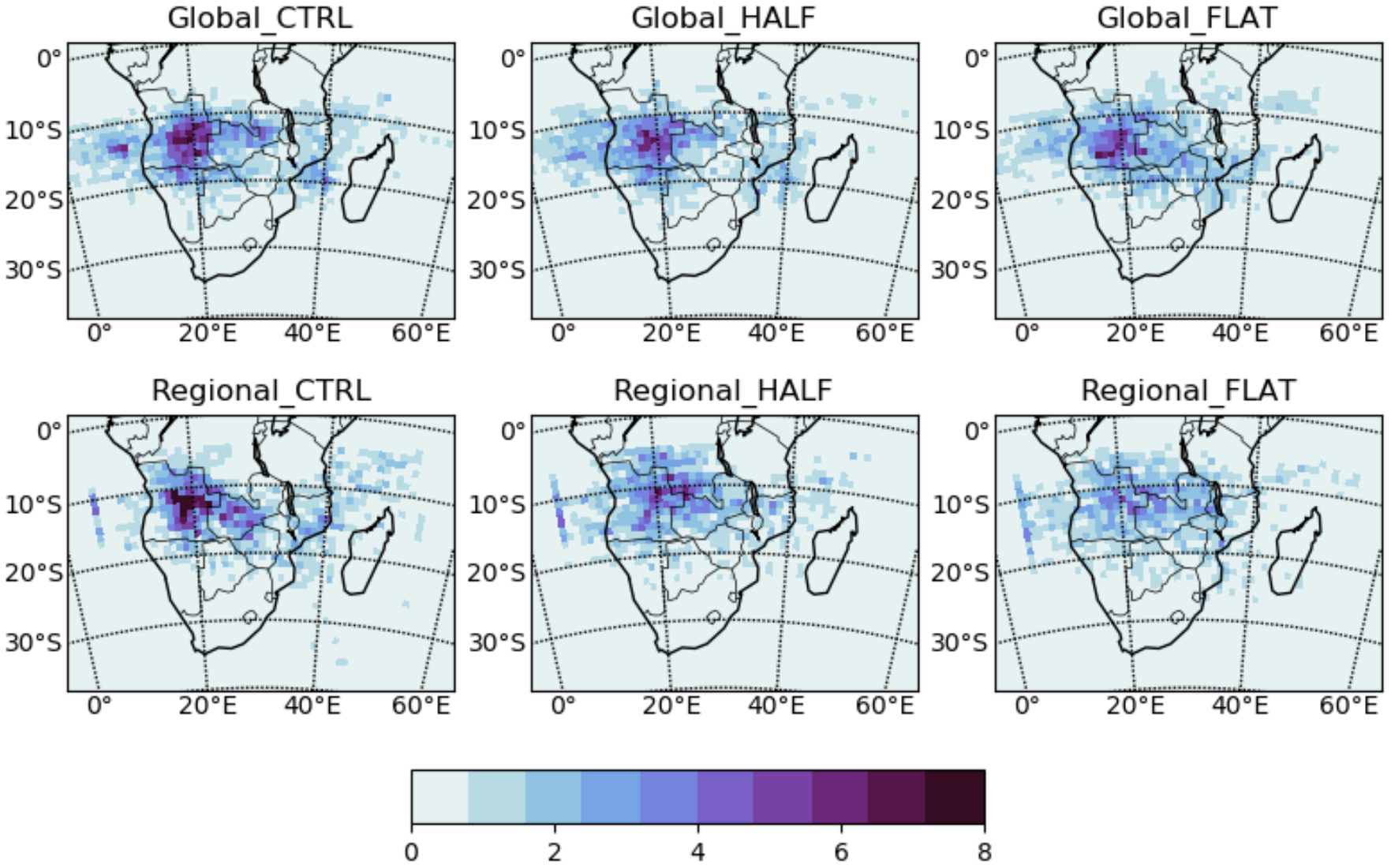
Vertical Structure



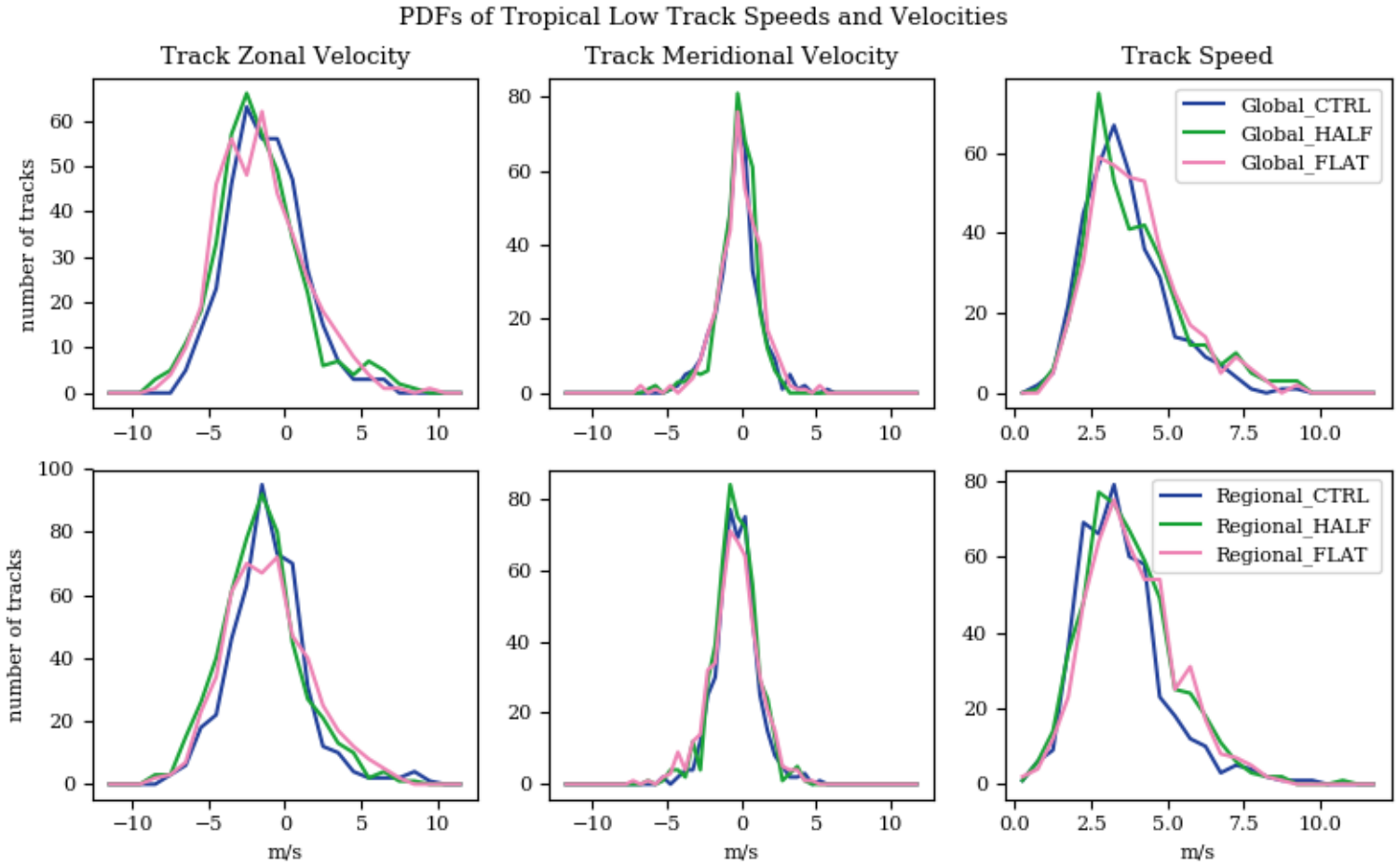
MCT: 800 hPa Vorticity



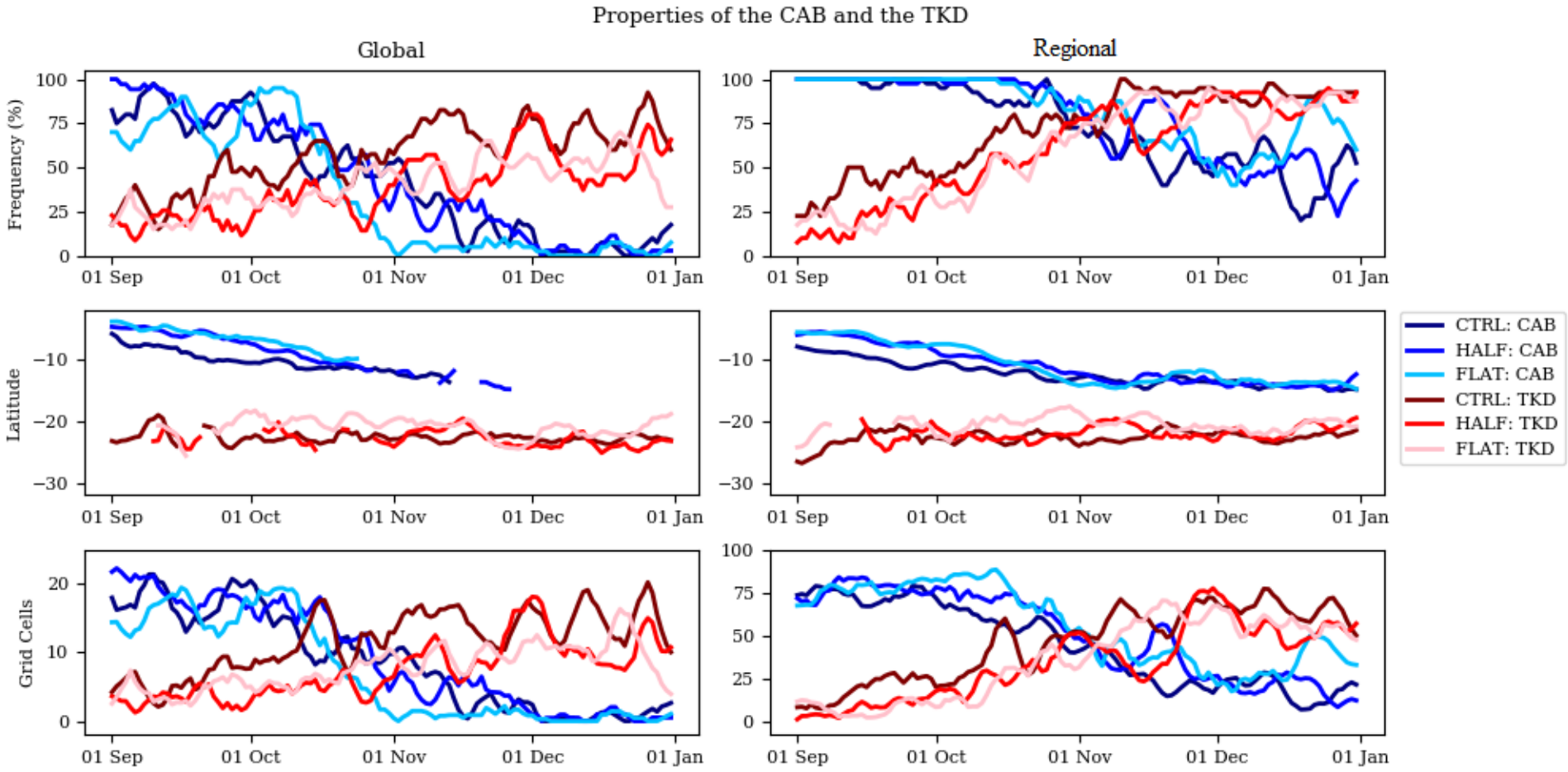
Results: Tropical Low locations



Results: tropical low track speeds

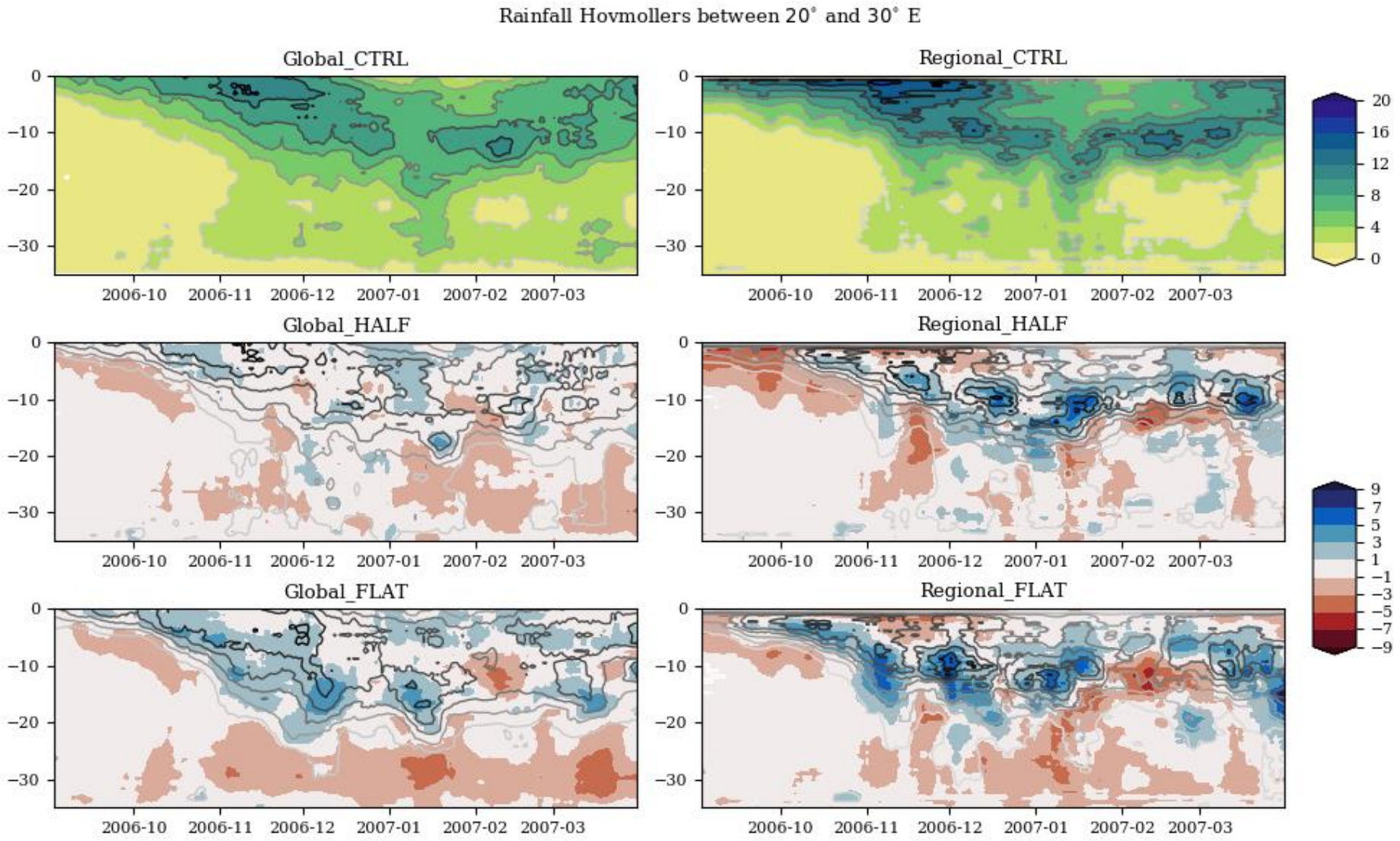


Congo Air Boundary

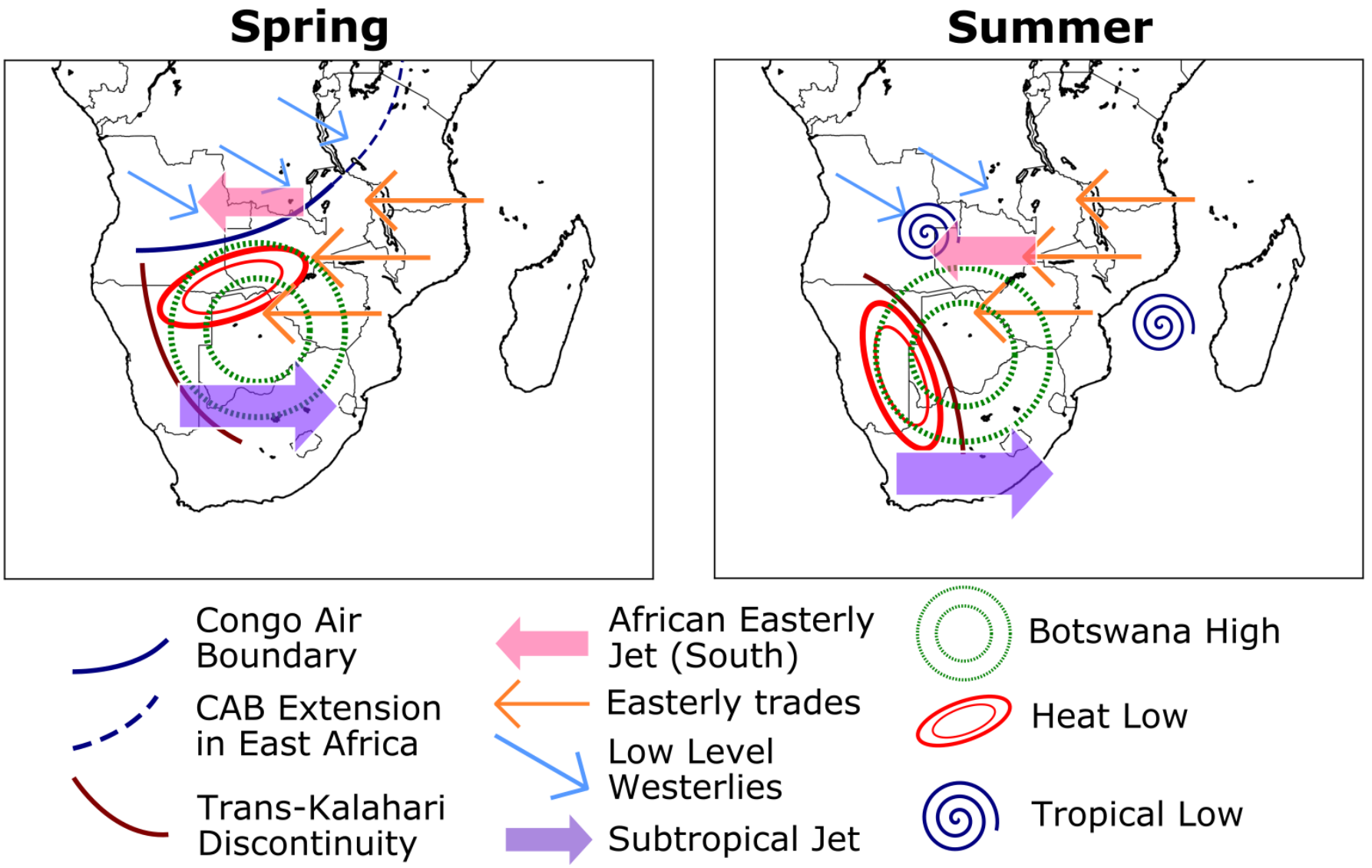


Results: Rain

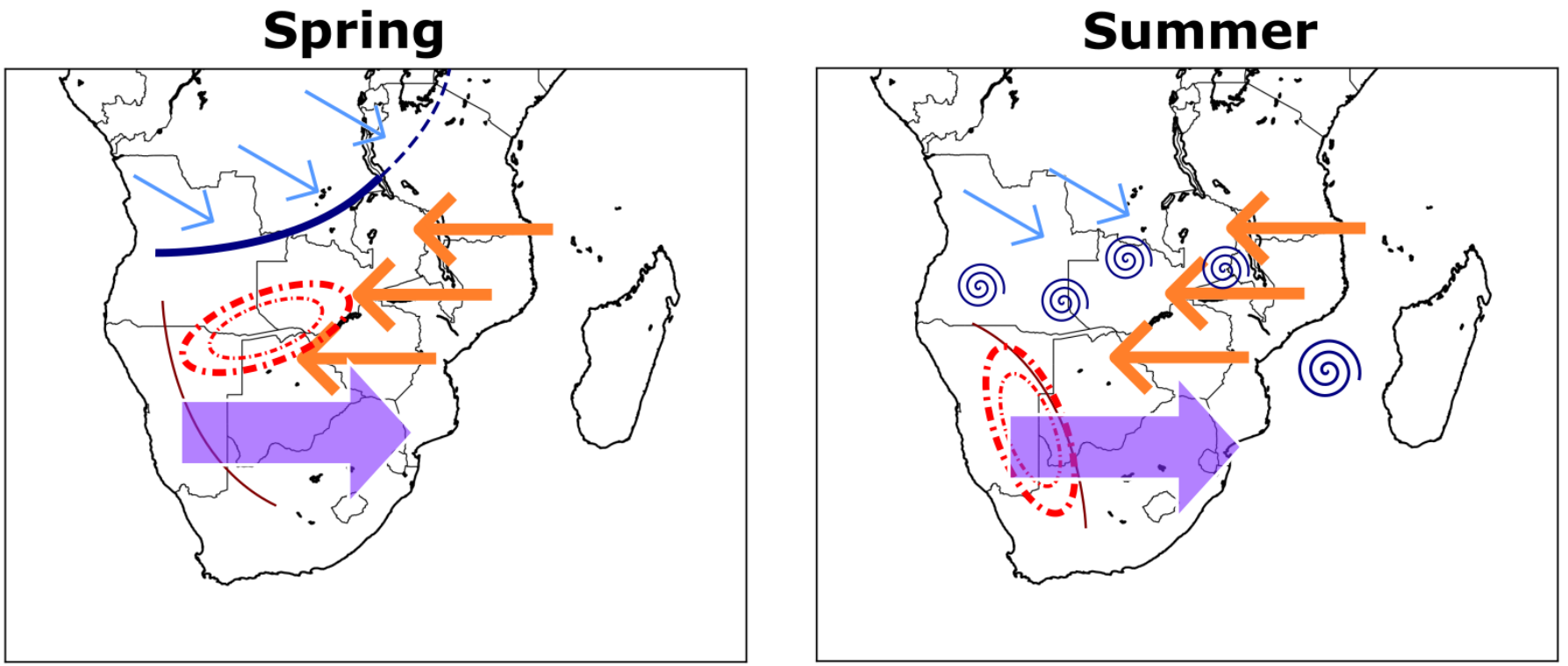
- Becomes more intense at centre of rain-belt
- Rain-belt shifts south more slowly in Sept and Oct
- Much less rain at subtropical latitudes – increased subsidence associated with stronger subtropical highs



Summary: Key Processes



Summary: Key Processes



Summary: Key Processes