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Moisture budget of tropical cyclones in HighResMIP: large-scale balance and sensitivity to resolution

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PRIMAVERA

Motivation

- Increasing the horizontal resolution of atmospheric global climate models (AGCMs) to around 0.25º leads to an increase of tropical cyclogenesis and gives rise to tropical cyclones (TCs) of stronger intensity (e.g. Strachan et al 2013, Roberts et al. 2020).
- Recent studies have shown the value of process-oriented studies in a multi-model framework have been undertaken to understand to role of model configuration in TC formation (Kim et al 2008, Wing et al 2019, Moon et al 2019). The comparison is not straightforward because simulation do not follow a single protocol.
- The energy and moisture budget are intertwined in tropical cyclones as moist processes play a key role in intensification. What can we learn about TCs in GCMs by looking at their moisture budget?

Overview of PRIMAVERA / HighResMIP

- 5 GCMs following a single protocol
- Here, we look at AMIP simulations over the period 1950-2014 and forced by HadISST2 daily at 0.25º.
- HighResMIP protocol requires to keep retuning at each resolution to a minimum (may mean higher resolution is not as good as it could be).
- Limitations : simplified design and models (e.g. prescribed MACv2 aerosols)
- Comparison against :
  - IBTrACS tropical cyclone tracks.

	CMCC-CM2	CNRM-CM6-1	EC-Earth3P	ECMWF-IFS	HadGEM3-GC31
LR	1x1 (100 km)	Tl127 (156 km)	Tl255 (78 km)	Tco199 (50 km)	N96 (208 km)
HR	0.25x0.25 (28 km)	Tl359 (55 km)	Tl511 (39 km)	Tco399 (25 km)	N512 (39 km)
Dyn. core	Finite volume	Spectral	Spectral	Spectral	Finite difference
Convective param.	Neale (2010)	Bougeault (1985)	Bechtold (2001)	Bechtold (2001)	Gregory (1990)

Description of HighResMIP protocol in Haarsma *et al* (2016 GMD)

Tropical cyclone tracking

Tracking algorithm :

Typical number per year and globally

- TRACK (Hodges, 2017) : objective tracking algorithm
- Same parameters in all regions
- Identification stages :

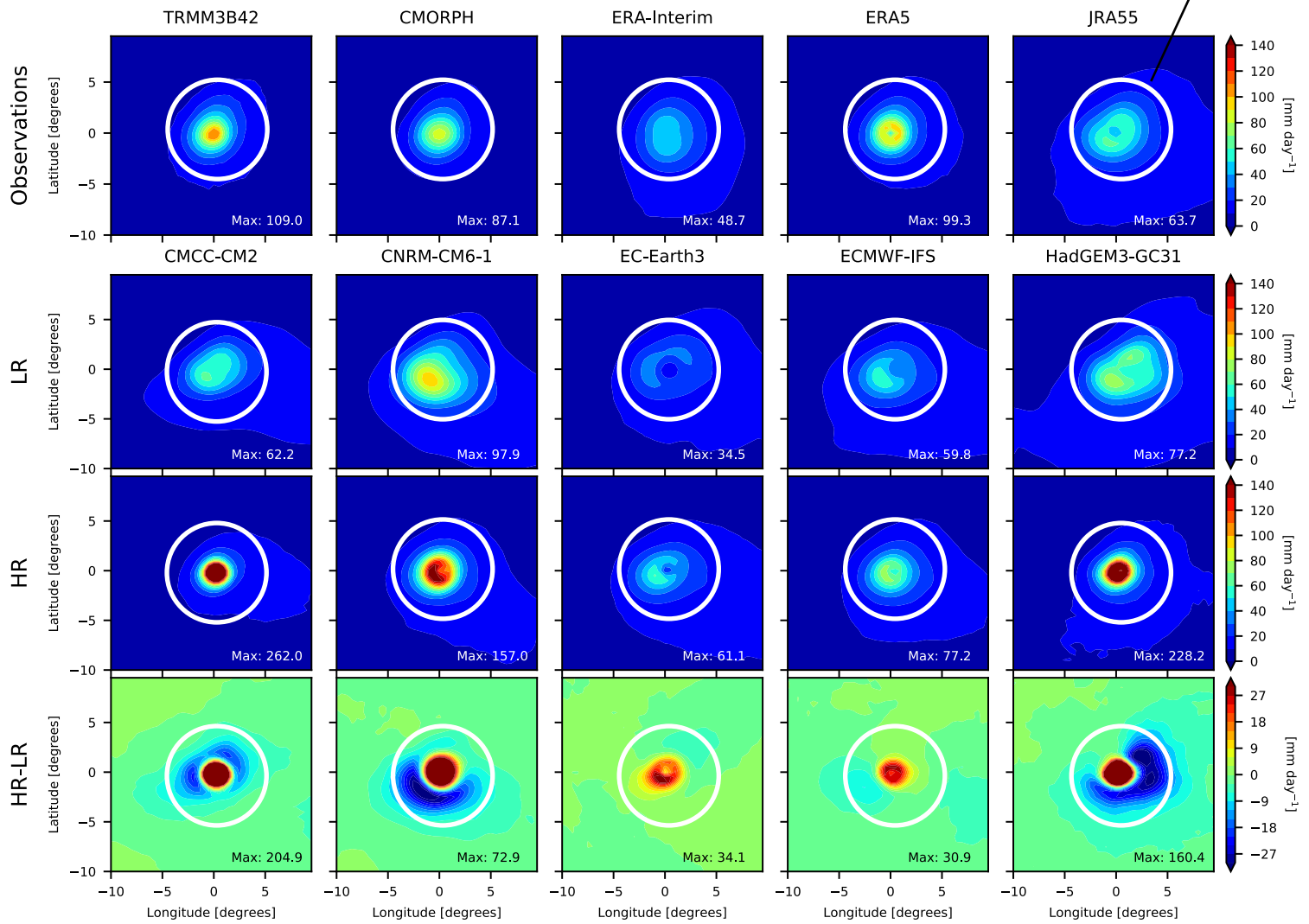
1. Locate high relative vorticity every 6-hours on T63 grid, tropical vortices → 30,000
   - ✓ T63 is relatively low resolution so that the tracking is not sensitive to the resolution of the model on which it is performed!
2. Select duration longer than 2 days → 8,000
3. Scans the vertical structure to retain warm-core TCs → 120

Roberts *et al* (2020 JClim) discuss the impact of resolution on TC in the HighResMIP ensemble.

Tropical cyclone precipitation

- Tropical cyclones in HR models exhibit a more compact structure with more intense precipitation rates near the core and a decrease of precipitation in the outer region of the storm.

- 200 strongest TC in NH over 18 years
- P averaged over the whole lifetime

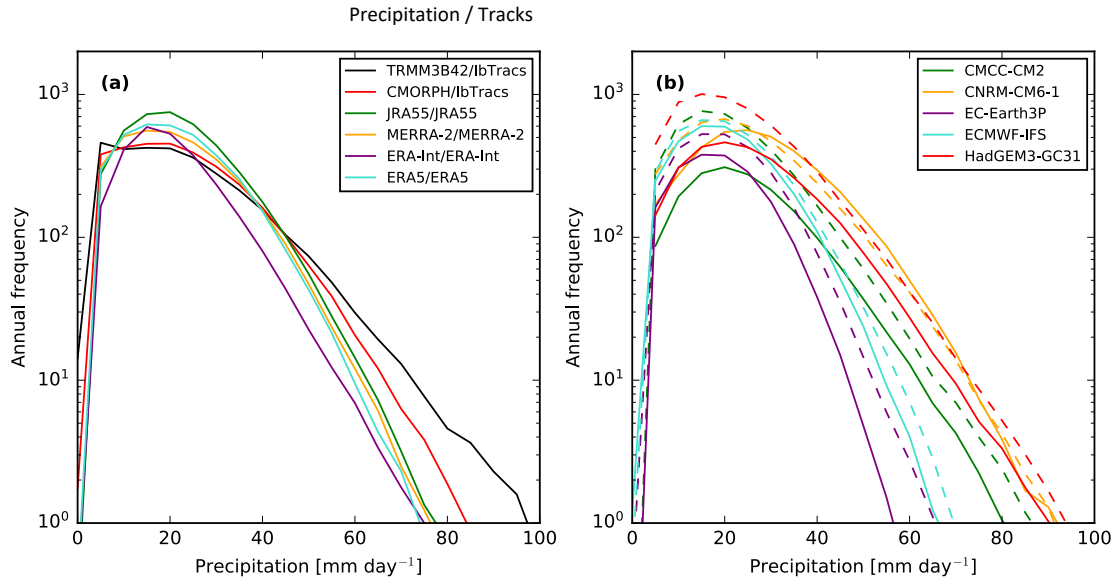


Vannière et al. Submitted to *J Clim*

Distribution of tropical cyclone precipitation

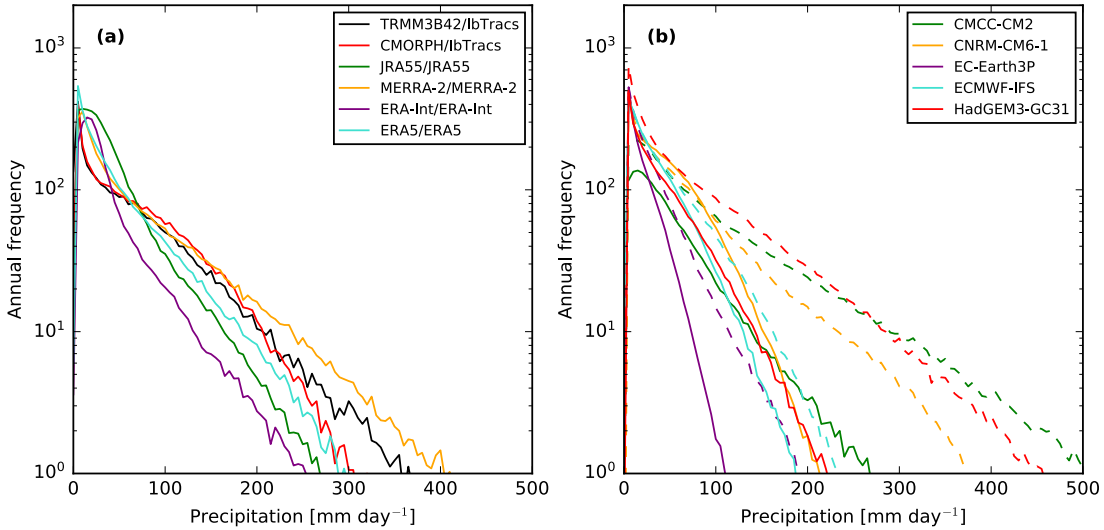
Each 6-hourly observation counts for 1

TC Precipitation in 5º radial cap = TCP5º



- Models are in the range of uncertainty of observational estimates and reanalysis.
- The inter-model spread of TCP5º is larger than the sensitivity to resolution for each model.

TC Precipitation in 1º cap

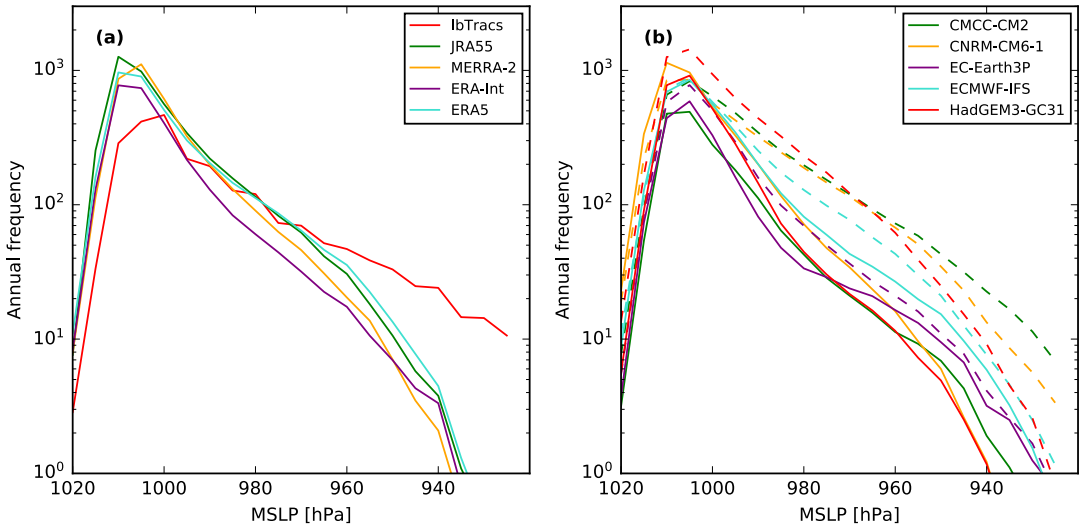


- Core precipitation is sensitive to resolution
- Several models predicts precipitation rates larger than any observational dataset and reanalysis.

Vannière et al. in revision for *J Clim*

Distribution of tropical cyclone intensity

Minimum SLP



- The distribution of MSLP has a clear sensivity to resolution as is already well known.

Why do LR models can get the TCP5º distribution right if they systematically underestimate TC intensity?

Vannière et al. in revision for *J Clim*

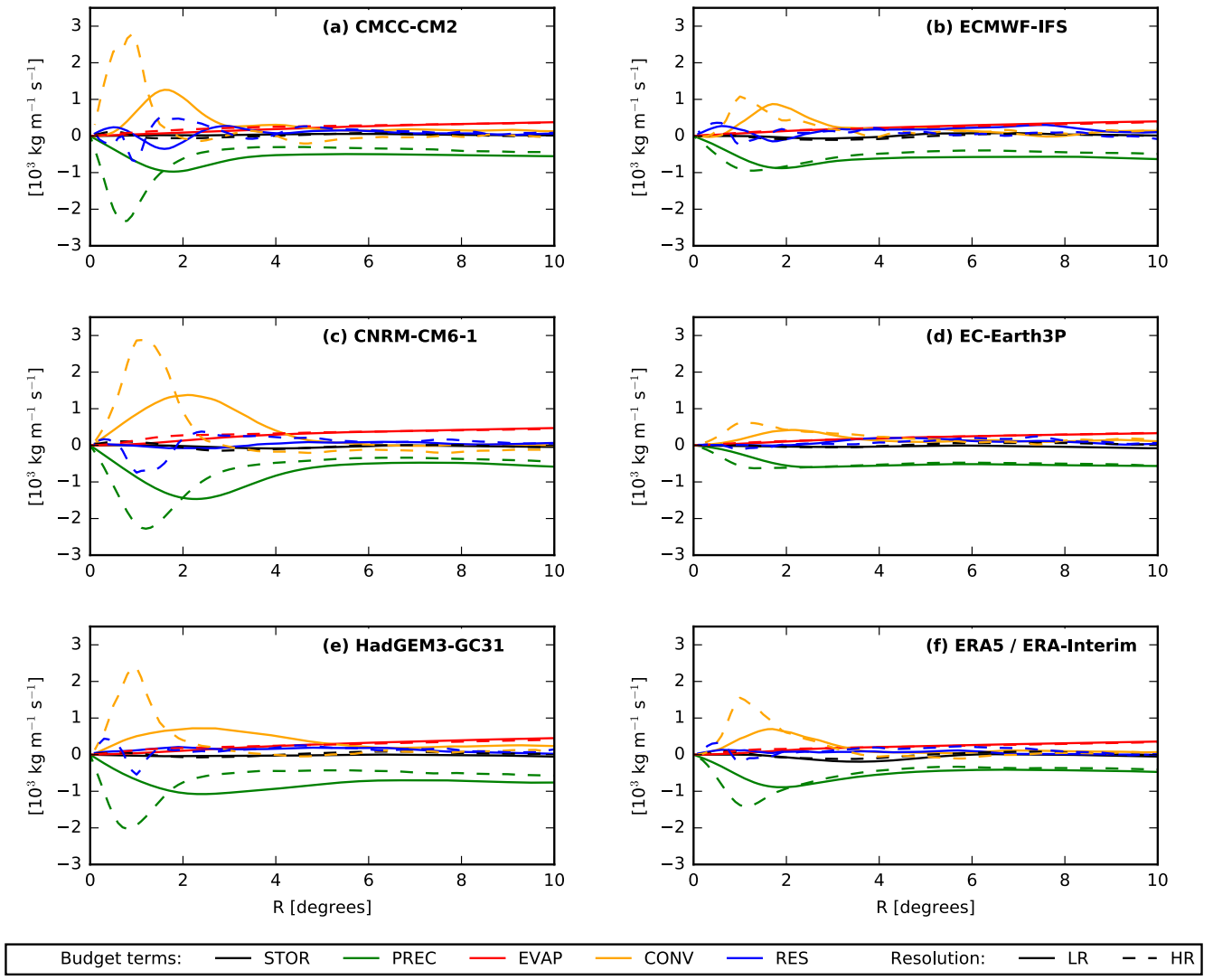
TC moisture budget

200 strongest TC in NH over 18 years

Azimuthally averaged moisture budget at a distance r for a ring of width dr :

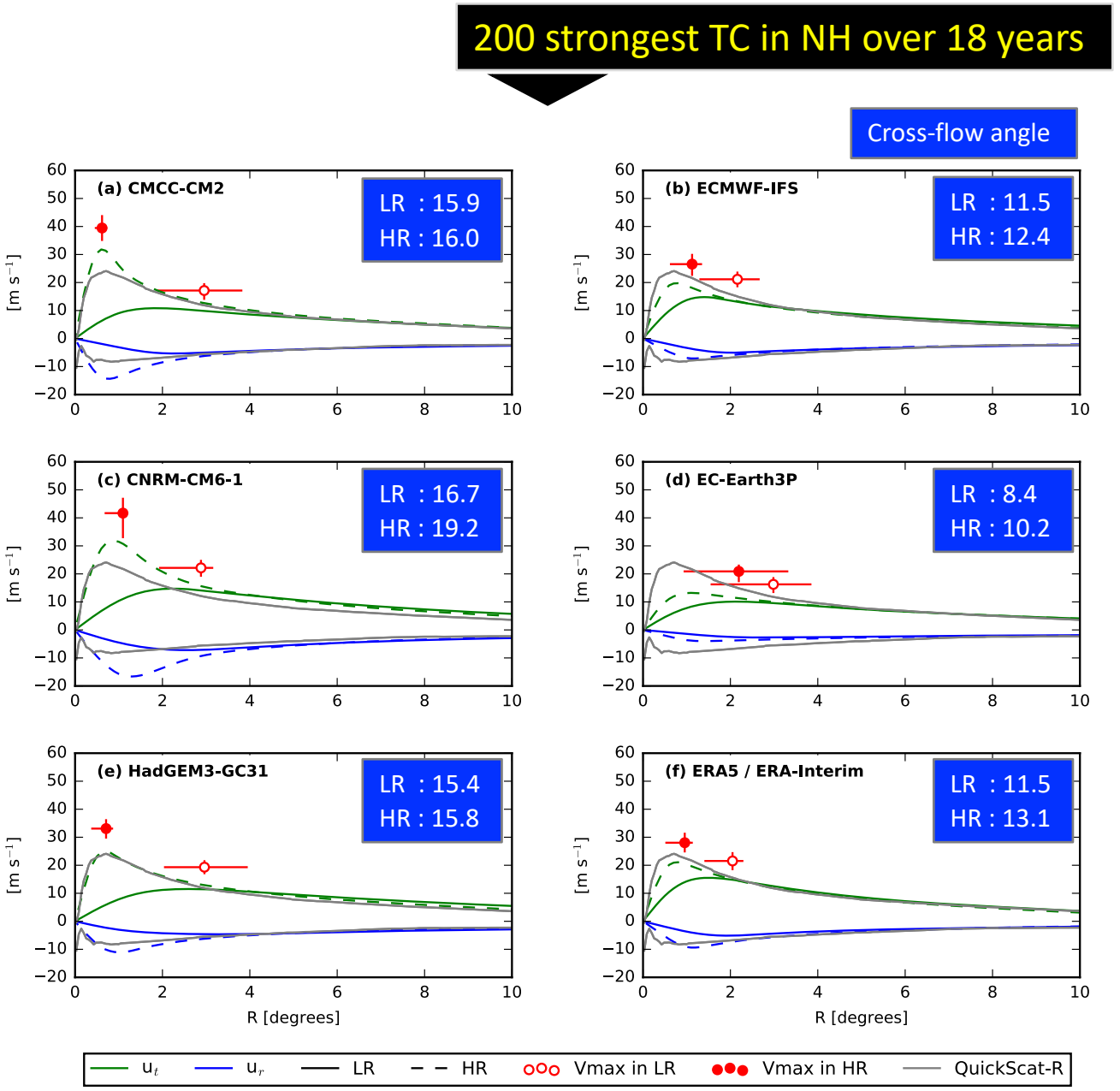
$$\int_p 2\pi r \frac{\partial q}{\partial t}\frac{dp}{g} = 2\pi r \times \left(- \int_p \frac{1}{r}\frac{\partial r q u_r}{\partial r}\frac{dp}{g} + E - P \right) + \epsilon$$

- First oder balance between moisture flux convergence and precipitation consistent with Trenberth *et al* (2007) for case studies in WRF 4km. Secondary role of in TC surface evaporation.
- At HR displacement of P and moisture flux convergence with no net change of total P between 0 and 500 km.
- Too little intensification of moisture flux convergence in the inner core region at HR in IFS based models.



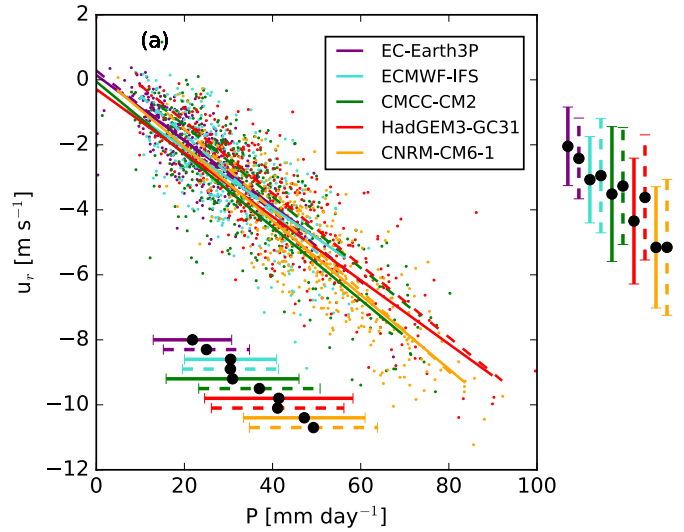
TC moisture budget

- Radial wind profile at HR is more intense in the core region with Vmax getting closer to the center of the storm.
- The wind profile converge in LR and HR at around 5º and independently of Vmax.
- The cross-flow angle is more model dependent than sensitive to resolution. It is underestimated in IFS based models, which means :
  - Less moisture will be brought overall in the TC.
  - Moisture is not brougth close enough to the warm core hampering intensification.

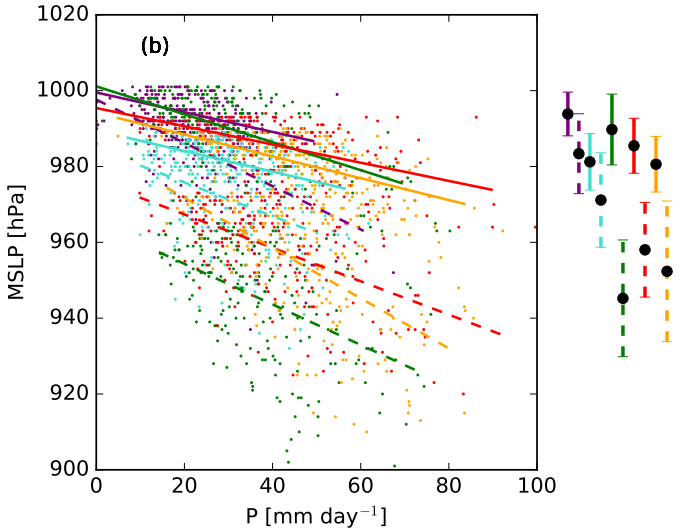


The large-scale balance of the moisture budget

TCP5º vs V_{radial} at 5º



TCP5º vs MSLP



- TCP5º is the result of a large scale balance with moisture originated well beyond 5º.
- We find that surface evaporation must be integrated from 12 to 15º depending on GCMs to balance TCP5º.
- How does this balance relates to the atmospheric moisture budget closure found by Dagan et al (2019) and RCE spatial scales Jakob et al (2019)?

- TC intensity is not a very good predictor of the amount of precipitation (for a given intensity more P at LR than HR!)
- This motivated us to look at composite of 200 strongest storms rather than composites stratified per intensity.

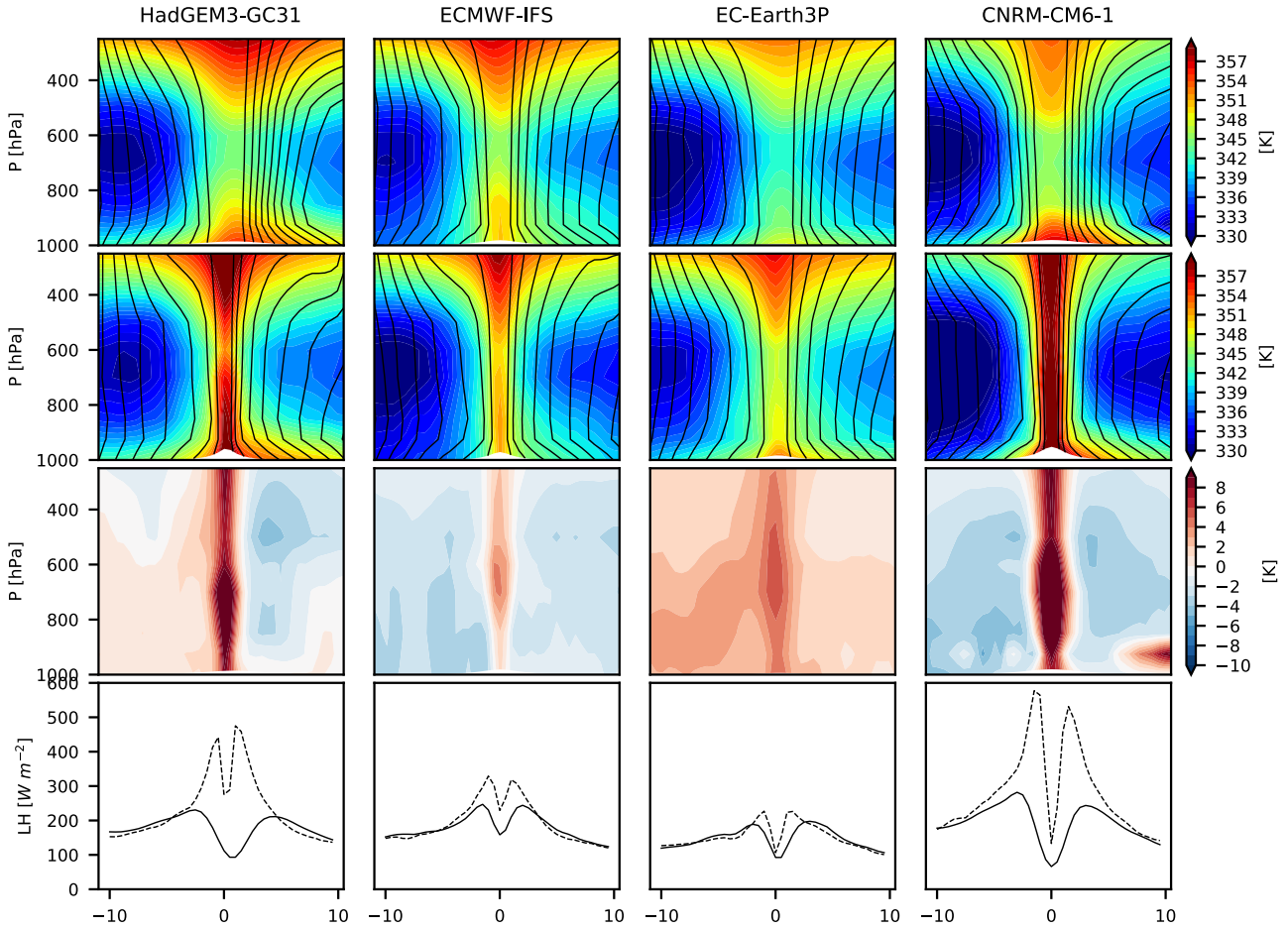
Vannière et al. Submitted to *J Clim*

Role of moist processes in intensification

θ_e (colors)
M (lines)

$\Delta\theta_e$

LH



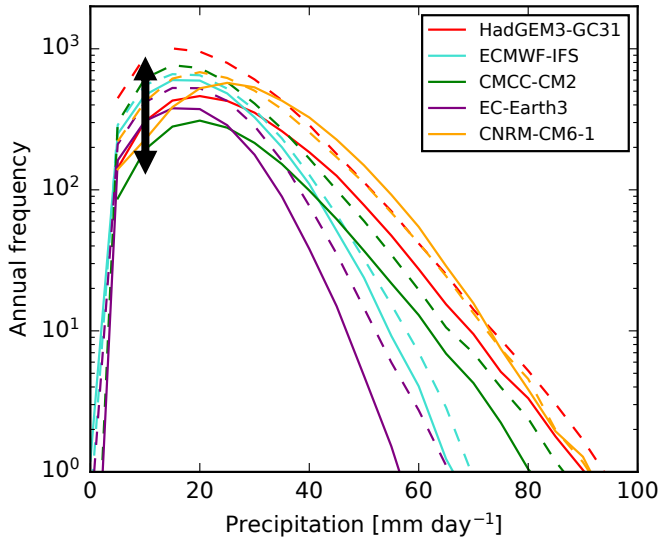
- We should insist on the fact that although in-TC surface evaporation plays little role in the moisture budget, it does play a crucial role in the intensification.

- The feedback loop is consistent with enhanced WISHE feedback at HR : stronger winds near the eye wall generate more surface evaporation, leading to larger theta_e, warmer core anomalies and stronger winds.

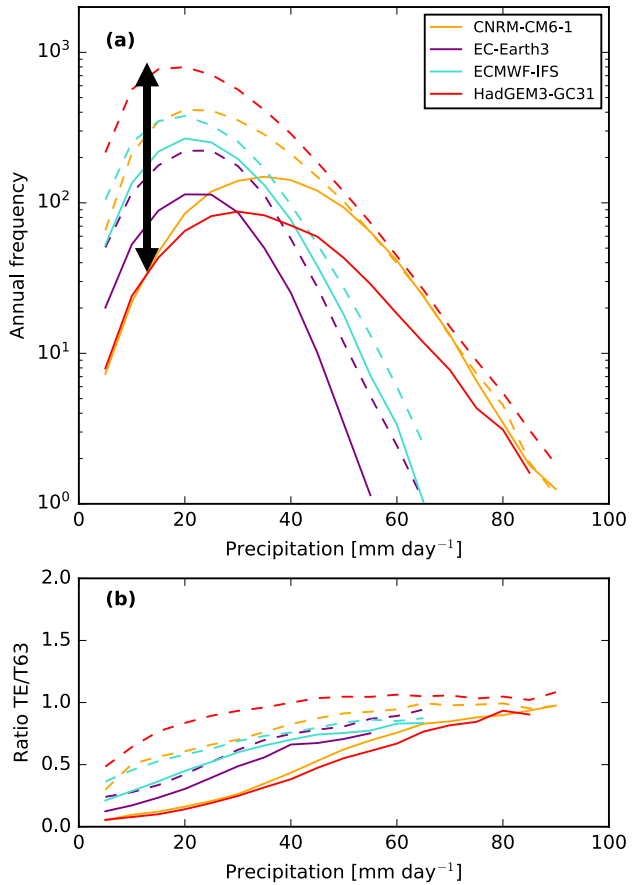
Role of the tracking algorithm

TC Precipitation 5º

TRACK (T63)



Tempest Extreme (TE)



LR HR

- TCs also have been tracked with *Tempest Extreme* which is based on MSLP.
- The choice of the tracking algorithm does matter for extreme precipitation but less so for intense precipitation.
- There is a strong sensitivity of grid-point feature tracking algorithm to resolution.

Conclusions

- The **amount of precipitation in a TC is the result of a the large-scale balance** between precipitation and moisture flux convergence in TC, the latter being equally well represented in LR and HR models.
- **Model formulation plays an important role in the sensitivity to resolution** of the TC moisture budgets (little change when resolution is increased in IFS models) : this is an opportunity to use HighResMIP as a development lab for parameterisations.
- Importance of the choice of the **tracking algorithm** which itself might be sensitive to resolution!
- Our results also suggest that when **limited area models** are used to understand physical processes underlying the intensification of tropical cyclones, a domain large enough should be considered so that lateral boundary conditions do not constrain the TC moisture budget.