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Sensitivity of simulated hydrological processes to GCM's resolution

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Introduction

The atmospheric moisture transport from ocean to land constitutes the moisture input to the continental freshwater cycle. Liepert and Previdi (2011) suggested that a few models could bias considerably the ensemble mean for variables like precipitation or E-P when a multi-model approach is used. A better understanding of the variability of land to ocean moisture fluxes simulated by models is thus crucial. Demory *et al.* (2014) have demonstrated, in two different versions of the UK Met Office HadGEM model, that the global water cycle is sensitive to global climate model (GCM)'s horizontal resolution, up to about 60 km, where the results converge. They found that while ocean precipitation decreases with higher resolution, land precipitation increases due to higher moisture convergence over land. The contribution of moisture transport to land precipitation also increases, whereas moisture recycling, a quantity that is known to be overestimated by state-of-the-art GCMs, tends to decrease.

- **Do these results still hold true in other climate models?**
- **What are the role of model formulation and the effect of ocean coupling?**

Data and method

In the present study, we analyse an ensemble of four GCMs, using different degrees of coupling and various modelling methods.

Model	Ocean coupling	Modelling method	Resolution and equivalent resolution at 50N
HadGEM3-GA3	No	Finite diff.	N96 (135km) N216 (40km) N512 (25km)
HadGEM3-GC2	Yes	Finite diff.	N96 (135km) N216 (40km) N512 (25km) +ORCA025 +ORCA025 +ORCA025
EC-EARTH3.01	No	Spectral	T159 (125km) T255 (80km) T319 (62km) T511 (39km) T799 (25km) T1279 (16km)
EC-EARTH3.1	No	Spectral	T255 (80km) T799 (25km) T1279 (16km)
EC-EARTH3.1/ORCA	Yes	Spectral	T255 (80km) T511 (39km) +ORCA1 +ORCA025
MRI3.2	No	Spectral	T95 (210 km) T319 (60km) T959 (20km)
CAM5.1	No	Finite vol.	2deg(143km) 1deg (72km) 0.25deg (17km)

Conservation of moisture

- Spectral models show larger biases in the closure of the moisture budget, as they do not conserve moisture. An artificial sink of up to 15 10^3 km^3 $year^{-1}$ occurs in EC-EARTH3.01.
- In spectral models moisture budget closure worsens as resolution increases.
- In finite difference/volume models : there is no significant effect of resolution on P-E.

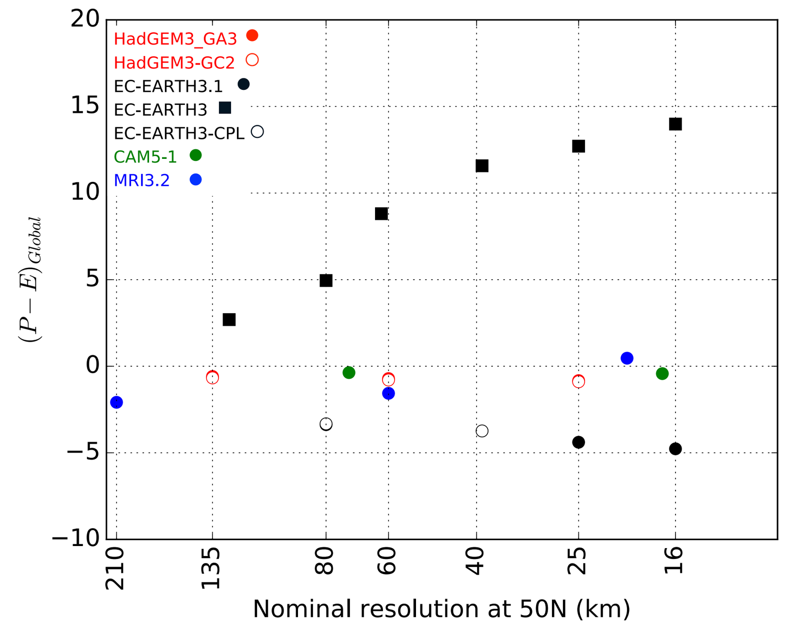

Figure 1 Precipitation minus evaporation averaged globally (units 10^3 km^3 $year^{-1}$). Plain circles are for atmospheric only and empty circles for coupled models.

Continental water cycle

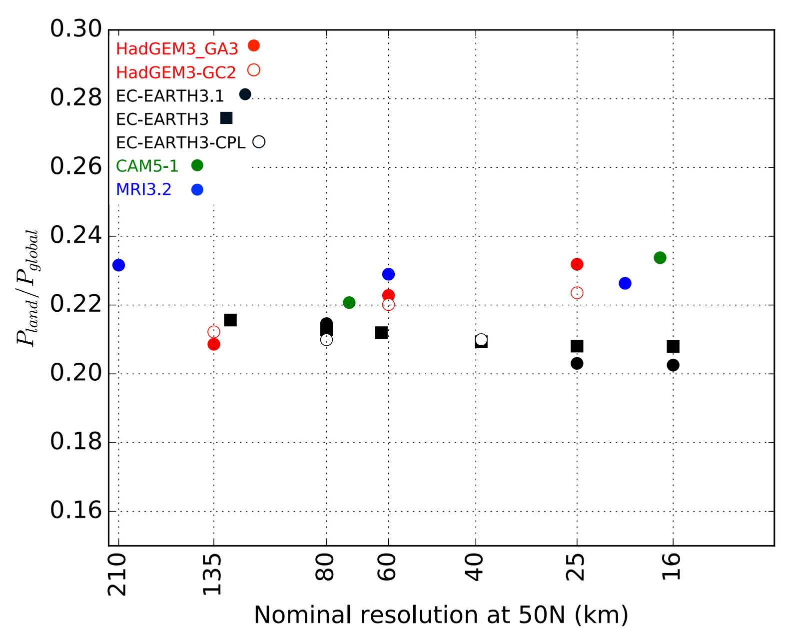

Figure 2 Same as Fig. 1 but for the ratio of land precipitation to total precipitation.

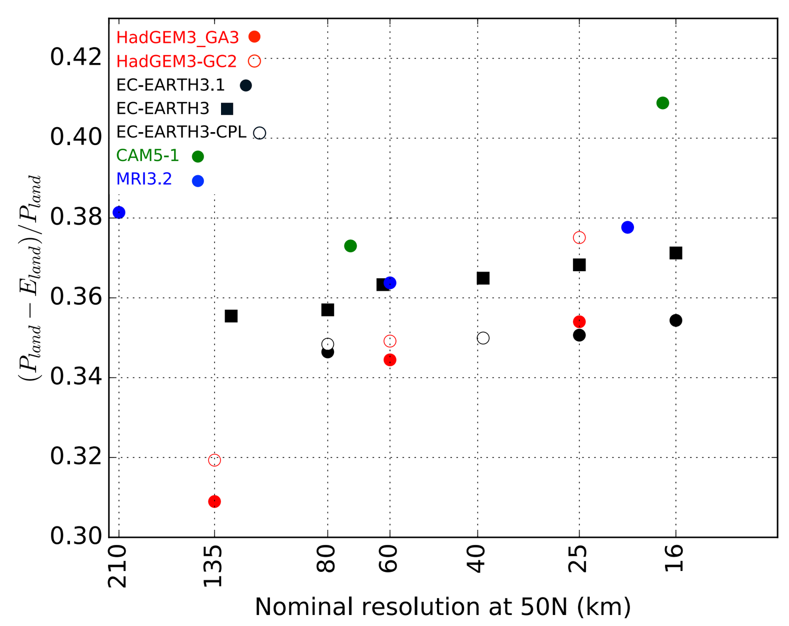

Figure 3 Same as Fig. 1 but for the ratio of E-P over land to land precipitation. This ratio measures the percentage of land precipitation due to moisture advection from ocean to land.

- Spectral models tend to show a decrease of the ratio of land to total precipitation when resolution increases, whereas models using finite differences/volumes method show an increase of this ratio (Fig 2)
- Spectral models tend to show a slight (~1%) increase of (E-P)/P over land when resolution increases, whereas model using finite differences/volumes show a larger increase of this ratio (~5%) (Fig 3)
- Coupling does not modify this behaviour (Figs. 2 and 3)

References

1. Liepert, Previdi (2011), 'Intermodel variability and biases of the global water cycle in CMIP3 coupled climate models', *Env. Res. Lett.*
2. Demory et al. (2014), 'The role of horizontal resolution in simulating drivers of the global hydrological cycle', *Clim. Dyn.*.

Mechanisms of moisture advection

Model	Res.	*P-E* *land*	$\nabla.uq$	$\nabla.\bar{u}\bar{q}$	$\nabla.u'q'$	$\nabla.\bar{u}_{N96}\bar{q}$	$\nabla.\bar{u}\bar{q}_{N96}$
HadGEM3-GA3	N96	36.55	38.7	27.17	11.5	27.17	27.17
	N216	43.55	45.5	33.99	11.5	26.83	32.22
	N512	46.85	47.7	34.53	13.2	26.25	31.58
Model	**Res.**	*P-E* *land*	$\nabla.uq$	$\nabla.\bar{u}\bar{q}$	$\nabla.u'q'$	$\nabla.\bar{u}_{T255}\bar{q}$	$\nabla.\bar{u}\bar{q}_{T255}$
EC-Earth3.1	T255	38.81	na	26.04	na	26.04	26.04
	T799	38.47	na	22.32	na	27.17	20.93
	T1279	38.95	na	22.76	na	27.22	21.33

Table 1 Ocean to land moisture fluxes (units 10^3 km^3 $year^{-1}$)

Conclusions

- The moisture transport over land and land precipitation to model resolution are found to be strongly dependent on the model formulation. Thus model formulation should be taken into account when evaluating ocean to land moisture transport in multi-model studies.
- The variations of P-E over land with resolution are to first order explained by the advection of moisture by the mean circulation. Whether the model uses spectral methods or methods based on the strong form of partial differential equations, the wind sensitivity to resolution accounts for most of the moisture transport change. This response is believed to be dominated by the tropics and current work is undertaken to analyse this behaviour in midlatitudes only.
- The little sensitivity of moisture convergence over land to spectral models resolution could be explained by the relatively good representation of the dynamics even at low resolution in those models.
- Models based on finite differences or finite volumes offer a better conservation of moisture at the global scale. However, high resolution is needed to accurately represent the mean large scale circulation and moisture transport.

Acknowledgements

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