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Physical processes driving mean-state biases in MetUM simulations of the WPSH

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with thanks to G. Martin, K. Furtado and D. Copsey

6th WGNE workshop on systematic errors in weather and climate models

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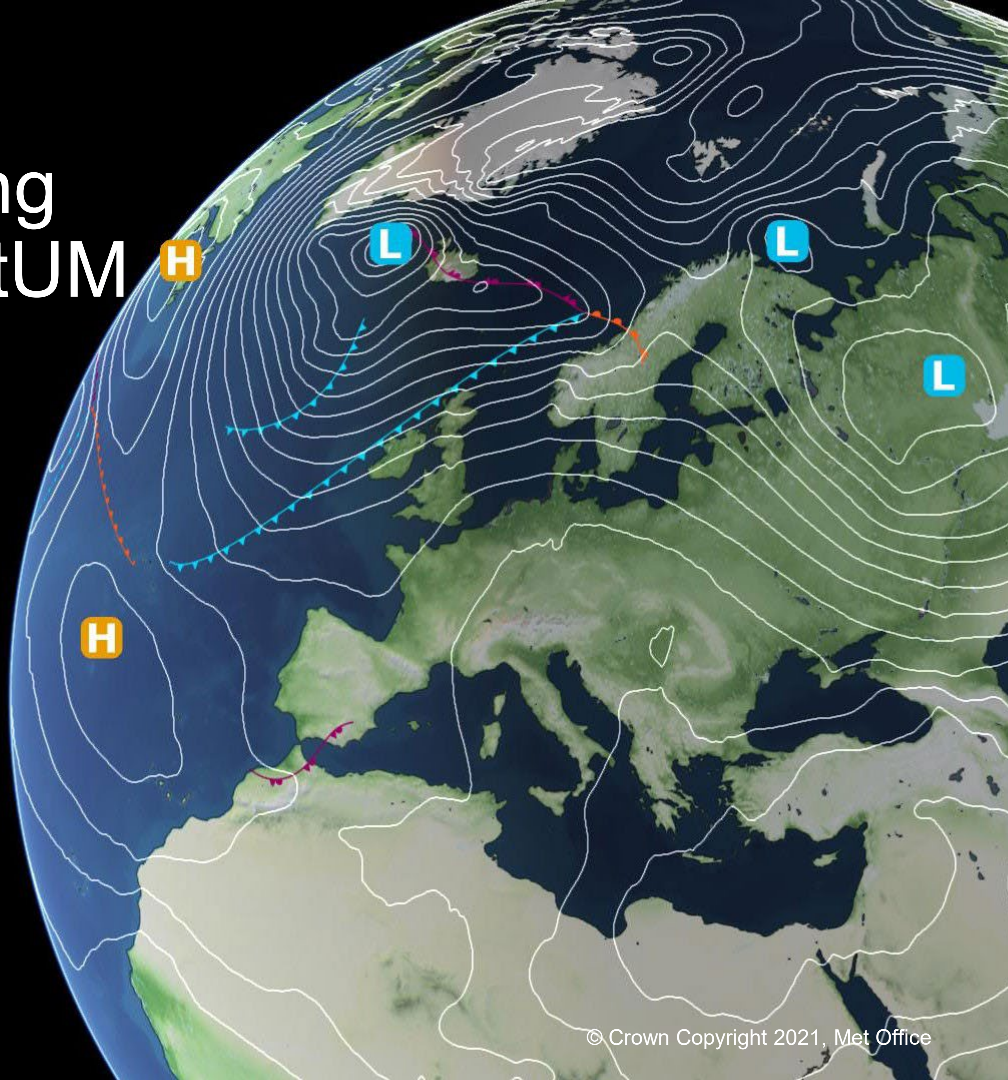

Outline

Origin of circulation biases associated to the mean-state West Pacific subtropical high (WPSH) in the Met Office Unified Model (MetUM).

- Introduction: long-term biases in climate simulations.
- Development of the systematic errors in equivalent NWP hindcasts.
- Use of a semigeotriptic (SGT) balance model to link the circulation errors to physical processes.
- Examine how MetUM's deep convection biases in the region arise.
- Summary

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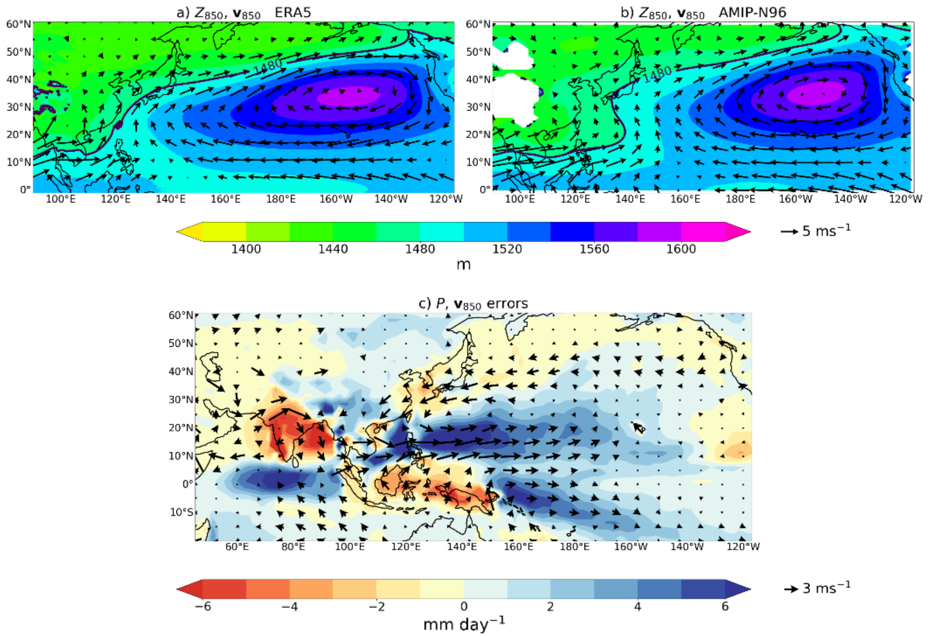
WPSH long-term biases in MetUM climate simulations

JJA



- JJA mean WPSH is too weak, the north edge is located too far north, and '*western border*' located too far east (especially at tropical West Pacific).
- Biases in the location and strength of the WPSH affect moisture transport to East Asia, from Indian monsoon and western tropical Pacific.
- Additionally, distinct precipitation errors:
  - Dry biases over the Maritime Continent and the Indian peninsula.
  - Excessive rainfall in the tropical W. Pacific and erroneous extension of the Asian Monsoon low level flow.
  - Erroneous cyclonic circulation in the Western Pacific subtropics.
- Robust errors also seen at higher model resolutions and in CMIP5 models.

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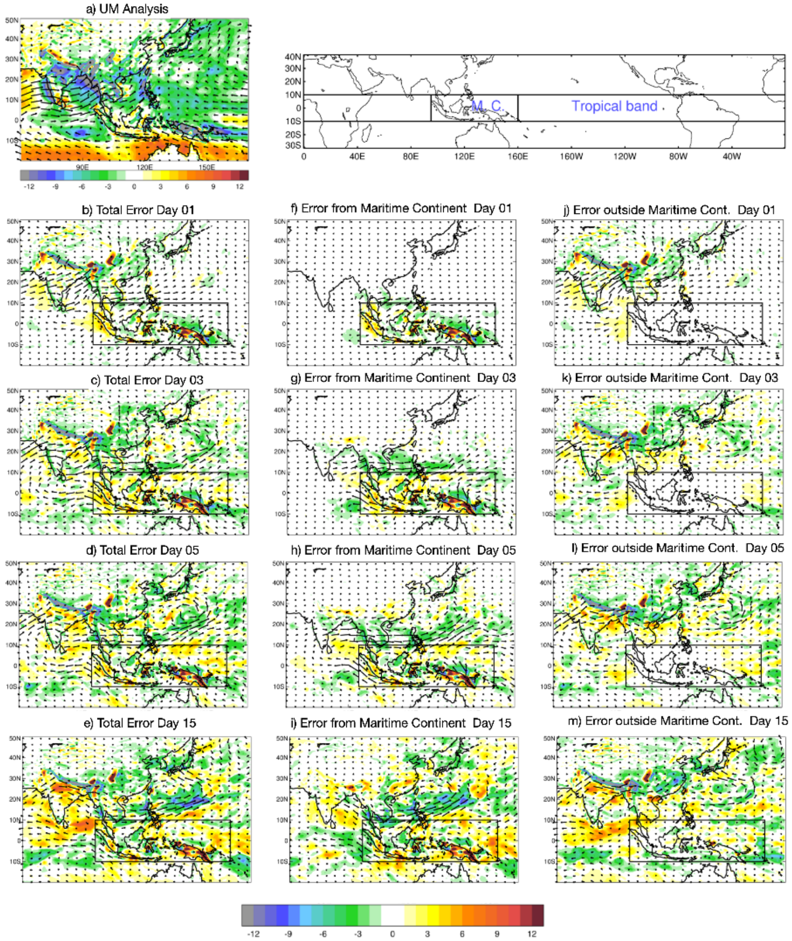
Error development

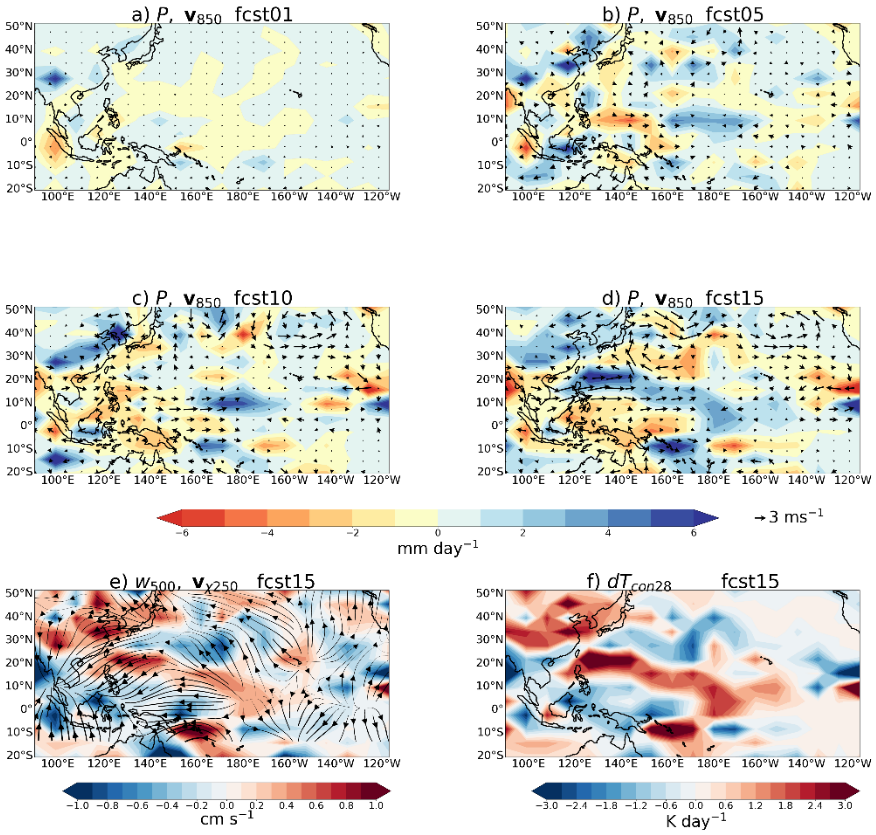


- Climate model biases can develop in the first few days of a simulation, and then persist to climate timescale.
- Studies with nudging methodology in climate simulations and NWP hindcasts:
  - Circulation errors in the Maritime Continent area remotely force excessive westerly monsoon flow into the western Pacific and erroneous cyclonic circulation in the West Pacific.

Rodríguez, J. M. and Milton, S. F. (2019), *Atmosphere*

Martin, G. M. et al, (2021), *Geoscientific Model Development*

Emergence of biases



- Study emergence of circulation biases in ensemble of NWP-N216 hindcasts, ran for 15 days → composite analysis at various lead times during the July 2016 period (31 cases).
- Gradual emergence of P and v_{850} errors consistent with AMIP-N96 simulations: by day 15 the distinct patter is fully formed.
- Diabatic heating errors: convection tendency errors in the tropics from a pattern in agreement with P errors.
- Vertical motion errors in agreement with P and convection tendency errors: deficient upward motion in the MC circumscribed by an area of excessive lift
- Confluence of errors highlights key role played by tropical convection in the development of circulation errors in the western flank of WPSH.

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Using an idealized model to link circulation errors and physical processes

The semigeotriptic model (SGT):

- SGT: SG + Ekman friction → a balance between friction, Coriolis and pressure gradient forces (geotriptic momentum approx.) and advection of all variables with full velocity.
- SGT model is one in a hierarchy of 'balance models' derived from fact that extratropical atmosphere close to geostrophic and hydrostatic balance on scales larger that the Rossby deformation radius.
- Cullen has shown that the full motion in SGT can be deduced from knowledge of the pressure field alone and has developed an inversion tool to solve the model.

$$\mathbf{BQ}'\begin{bmatrix}u-u_e\\ v-v_e\\ w\end{bmatrix} + c_{pd}\theta_v \frac{\partial}{\partial t}(\nabla\pi) = \mathbf{BH}',$$

weight Matrices

ageotriptic wind

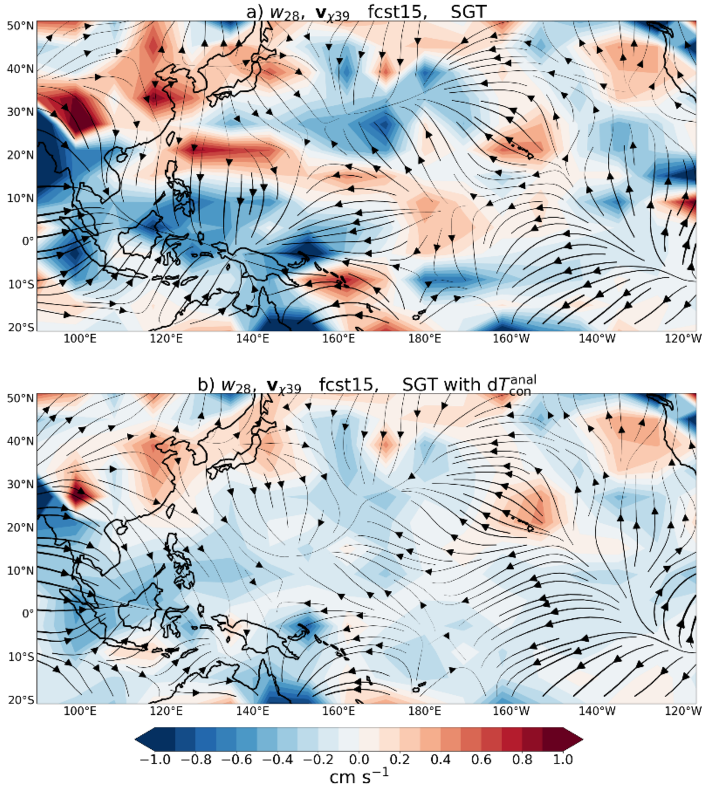
pressure gradient

forcing term

Cullen, M. (2018), *Fluids, 3*(4), 72.

- SGT tool developed to obtain global solutions using data from the MetUM:
  - Numerical approximations are consistent with the formulation of the dynamical core.
  - Diabatic forcing calculated from temperature increments from MetUM parametrizations of SW and LE radiation, large-scale precipitation, convection, boundary layer and cloud processes.
- SGT is a good tool to examine differences between the flow associated with the geotriptic balance and that from the GCM.
- SGT tool can be used to study independently the effect of individual components of the forcing and atmospheric state.
- Tendencies from UM analysis can be transplanted without upsetting SGT balance.

SGT model simulation



- SGT model forced with heating tendencies from MetUM hindcasts simulates well the circulation error.
  Upper air divergent wind: erroneous cell with divergence in W Pacific and convergence in M. C. and consistent with vertical wind errors.

- Use SGT model to examine the individual contributions to circulation error from dynamics and each of diabatic forcings.

- The erroneous cell disappears when using convection increments from UM analysis and the rest from hindcasts, suggesting diabatic heating errors associated with convection as main source of the UM circulation errors in the west flank of the WPSH.

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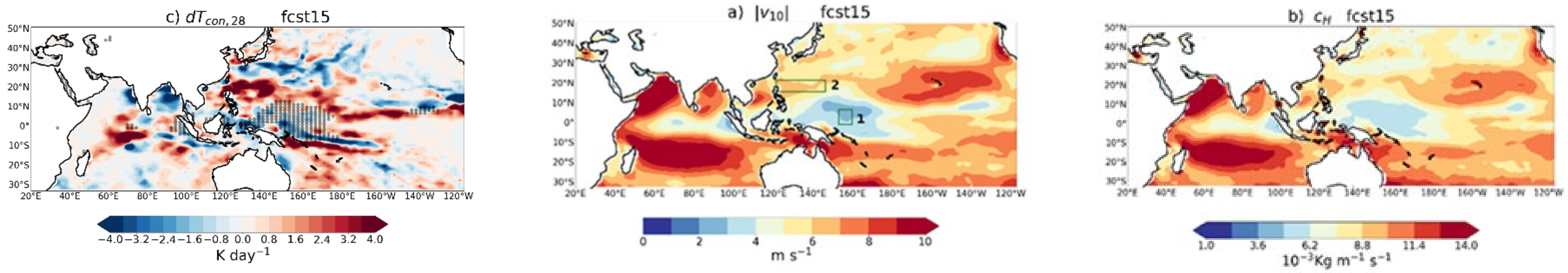
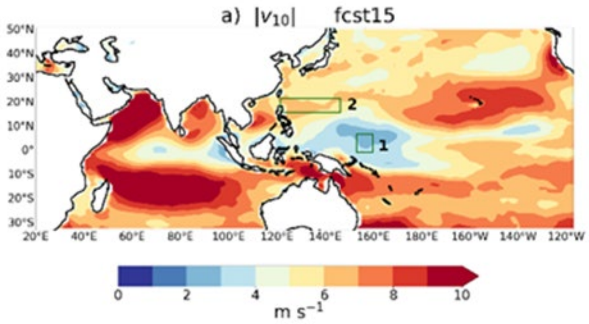
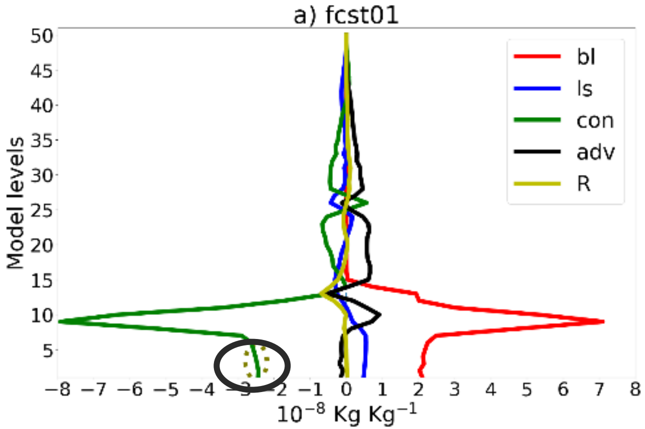
Deep convection over ocean in the UM



- Study convection in tropical region of interest, focusing in ocean points.
- Model convection is deficient in areas of light winds: ocean points surrounding the MC. Once winds sufficiently strong, convection is no longer correlated with wind speed.

Moisture increment budget





- Study in more detail box 1 (region of light wind).
- On timescales considered (1 month), net moisture increment is zero: balance of various components.
- Distinct large convection increment in boundary layer (bl), which is balanced mainly by large bl increment. No positive advection increment in bl.
- **The convection scheme dries the bl and this has to be balanced by bl processes, mainly surface fluxes.**

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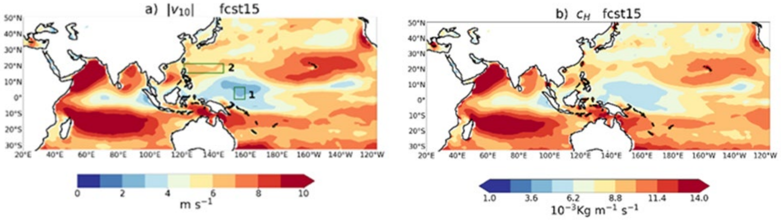
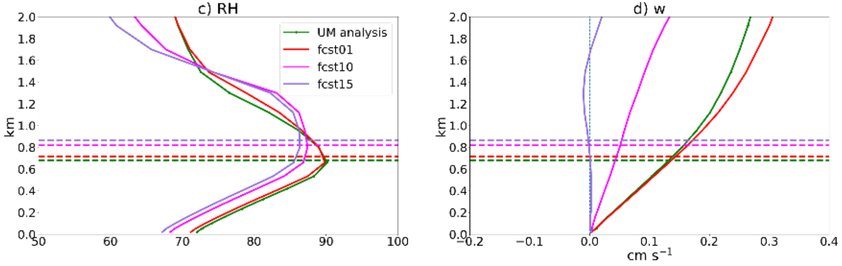
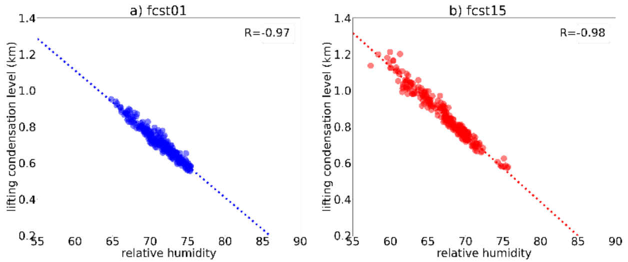
Emergence of convection bias







- Model convection is inhibited on places where exchange coefficient c_H is small.
- Two-step argument to explain how convection is inhibited where c_H is small:
  - in bl there's balance between convection drying and surface fluxes. This is not sustainable in places with low low c_H and RH decreases. $Q = c_H(q^*(\mathrm{SST}) - q_0),$
  - Lifting condensation level linearly related to RH in convection scheme. As RH decreases, lcl. increases → reducing ability to generate deep convection.
- As the lead time increases convection becomes weaker and weaker and the bias is established.

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Summary

- MetUM model circulation errors in WPSH include a weakening of the anticyclone, which is located too far east. This leads to an underestimation of the south westerly monsoon flow over East Asia and contributes to seasonal precipitation errors in the region.

- To make connection between emerging circulation errors and physical processes, we use a semigeotriptic (SGT) balance model that is consistent with the MetUM dynamical core and uses the same diabatic forcings as the GCM's parameterizations.

- Most of the WPSH circulation biases are fixed when the atmospheric convection occurs in the correct place.

- In the model's parameterised convection, a large drying of the boundary layer occurs, balanced only by surface fluxes. The local surface fluxes need to be able to support deep convection over a long period. In places with low exchange coefficient (light surface wind), this is not sustainable and, as the time increases, convection becomes weaker and weaker, and the long-term bias is established.