Stretched-mesh simulations are useful for studying convection on exoplanets

The impact of the explicit representation of convection on the climate of a tidally locked planet in global stretched-mesh simulations with LFRic-Atmosphere

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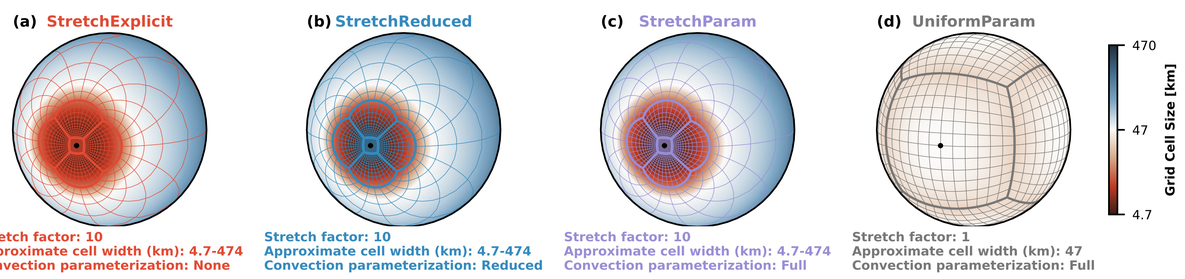
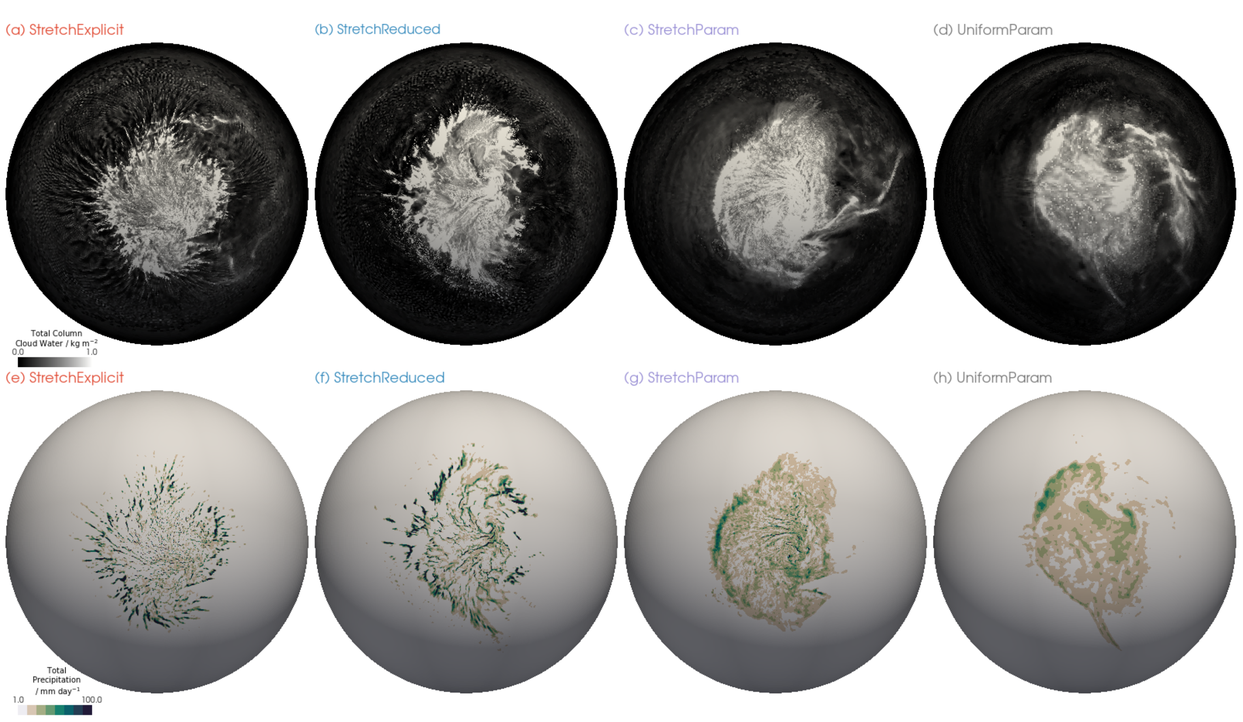
What motivated us?

- **Convection** is a key process in exoplanetary atmospheres
- **Convection** is typically subgrid-scale for general circulation models (GCMs)
- How to simulate the **global effect of convection**?
  - ✗ Convection-resolving GCMs: too computationally expensive
  - ✗ GCMs with a nested grid: boundary artefacts, one-way interaction
  - ✓ **Stretched-mesh** GCMs: gradual localised increase in resolution
- **Tidally locked exoplanets** are a perfect application for stretched-mesh GCMs

How did we set up the stretched-mesh model?

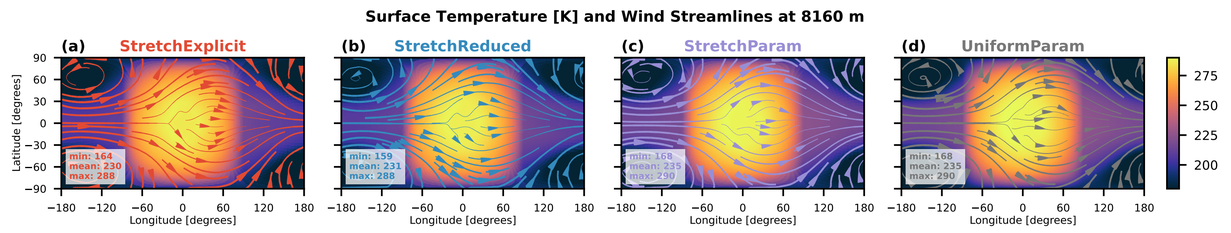


- **LFRic-Atmosphere**, the next-generation model of the Met Office
- Non-hydrostatic **cubed-sphere** dynamical core
- Simulations with **stretched** and **non-stretched** mesh
- **Convection:** parameterised, reduced, or explicit
- Tidally locked aquaplanet with a moist, nitrogen-dominated atmosphere
- Base setup: **THAI** (TRAPPIST-1 Habitable Atmosphere Intercomparison)
- Rotation period: increased to **12.2 days** to avoid circulation bistability

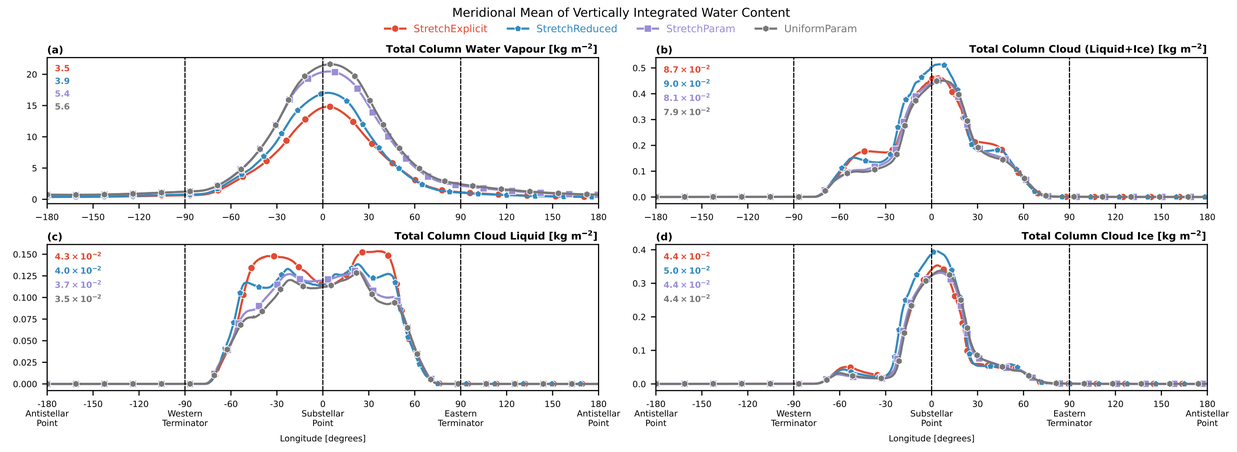


What did we find?

- Stretched-mesh model captures the **small-scale cloud features** on the day side
- **Precipitation** is more intense and localised



- The StretchExplicit run produces **a colder (by 5 K) and drier (by 25%) climate**, but with more cloud condensate compared to StretchParam and UniformParam
- Main reason: **stronger shortwave reflection by clouds** in the StretchExplicit case (by $\approx 10\ \mathrm{W\,m^{-2}}$), i.e. higher cloud albedo (by about 4%)
- Additionally: less water vapour and thus weaker greenhouse effect



- Moving from parameterised convection (StretchParam and UniformParam) to reduced/explicit convection (StretchReduced and StretchExplicit), the global-mean low cloud fraction increases by up to 6 %
- This happens mostly in the substellar region and due to the increase in liquid cloud

How significant is this?

- **Novelty:** 1st example of a stretched-mesh GCM for a tidally locked exoplanet
- **Habitability estimates:** explicit convection makes the climate colder and drier
- **Fidelity:** the global circulation is similar to coarse-grid GCMs
- **Numerics:** no significant numerical artefacts
- **Stability:** LFRic-Atmosphere is stable even with a stretching factor of 10
- **Savings:** ~500 cheaper than a global convection-permitting model
- **More to explore:** scale-aware parameterisations, impact of microphysics, sensitivity to the degree and the location of the focal point of stretching
- **Future applications:** mixing in tidally locked **hot Jupiters**, dust storms on **Mars**, moist convection on **Titan**, and much more!

Read the paper:
Sergeev et al., 2024
Astrophys. J.
https://arxiv.org/abs/2402.19277

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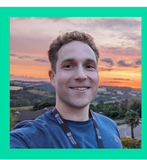

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