

# Influence of horizontal resolution and complexity of aerosol-cloud interactions on marine stratocumulus and stratocumulus-to-cumulus transition in HadGEM-GC3

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# Stratocumulus (Sc)



- Sc clouds cover a large fraction of the world's ocean clouds and cool the climate on average by  $\sim -8 \text{ Wm}^{-2}$ (L'Equyer et al., 2019).
- $\Rightarrow$  A small change in Sc cloud fraction can have a large climate impact. <u>Challenge</u>: Sc clouds are notoriously difficult to represent in general circulation models (GCMs).

# Sc to cumulus transition (SCT)



- Sc clouds are advected by trade winds toward the equator where they eventually break up into trade wind cumuli, so-called stratocumulus-tocumulus transition (SCT).
- A long-term feedback as a result of global warming, with decreased Sc • cloud cover and increased shallow cumulus has been suggested (e.g. Eastman et al., 2011).

<u>Challenge</u>: The amount of change of the different cloud types with a warming is highly uncertain (e.g. Ceppi et al., 2017).



## Question: How to better represent Sc clouds and SCT in GCMs?

The rapid increase in computing power gives us an opportunity to improve models. Would it be beneficial to:

- Increase model resolution?
- $\Rightarrow$  Examine impact of changing horizontal model resolution.
- Improve representation of microphysical processes?
- $\Rightarrow$  Examine impact of using interactive or non-interactive aerosol-cloud parameterization.

We examine four different Sc regions (marked in gray in figure on the right) and transects (marked with diamonds).



- North East Atlantic (NEA)
- North East Pacific (NEP)

# Climatology of low-level cloud cover, winds and surface

### • South East Pacific (SEP) South East Atlantic (SEA)



## **Model setup and experiments**

Simulation	Resolution	Aerosol representation
HiRes-EA	N512 (~25 km)	Non-interactive aerosols (EasyAerosol)
MedRes-EA	N216 (~60 km)	Non-interactive aerosols (EasyAerosol)
MedRes-	N216 (~60 km)	Interactive aerosols (GLOMAP)
GLOMAP		
LowRes-EA	N96 (~135 km)	Non-interactive aerosols (EasyAerosol)

### **General model setup of HadGEM3**:

- Atmosphere-only version of HadGEM3-GC31<sup>1,2,3</sup>.
- Prognostic Cloud fraction Prognostic Condensate (PC2) scheme<sup>4</sup>.
- Prognostic warm rain and advection of rain mass mixing ratios<sup>5</sup>.
- First-order turbulence closure<sup>6</sup>.
- High-resolution daily sea surface temperatures (SSTs)<sup>7</sup> remapped to the different model grids.
- Monthly average output from years 1978 2005.
- Analysis of springtime months (March-April-May in northern and September-October-November in southern hemisphere).

### **Aerosol-cloud interaction representation:** GLOMAP<sup>8,9</sup>:

- Aerosol mass and number for five size modes are simulated.
- These are used to calculate impacts on radiation (direct effects) and warm stratiform cloud formation and precipitation (indirect effects).
- Cloud droplet number concentrations (CDNCs) Köhler theory<sup>10,11</sup>.

### **EasyAerosol:**

- Prescribed monthly mean values of aerosol optical depth (AOD) and CDNC are used to calculate direct and indirect aerosol effects.
- Background AOD and CDNC values come from a HadGEM3 simulation using GLOMAP.
- The MACv2-SP framework<sup>12</sup> is used to perturb the background values of AOD and CDNC..

<sup>1</sup>Williams et al., 2017; <sup>2</sup>Menary et al., 2018; <sup>3</sup>Kuhlbrodt et al., 2018; <sup>4</sup>Wilson et al., 2008; <sup>5</sup>Boutle et al., 2014; <sup>6</sup>Brown et al., 2008; <sup>7</sup>Kennedy et al., 2017; <sup>8</sup>Mann et al., 2010; <sup>9</sup>Bellouin et al., 2013; <sup>10</sup>Abdul-Razzak and Ghan, 2000; <sup>11</sup>West et al., 2014; <sup>12</sup>Stevens, 2017.

are diagnosed based on the aerosol population and



## Simulated aerosol-related parameters over Sc regions



Interactive aerosols (GLOMAP) compared to non-interactive aerosols (EA) result in: Higher AOD (16-28%) and CDNCs (within the main Sc cloud layer) in particular over NH.

\* March-April-May in the NH and September-October-November in the SH





## Simulated cloud and radiation parameters over Sc regions



- Small impact of resolution and aerosol-cloud parameterization over northern hemisphere.
- Over southern hemisphere: higher resolution and non-interactive aerosols (EA) lead to significantly higher liquid water path (LWP) and higher (more negative) short-wave (SW) cloud radiative effect (CRE) at top of the atmosphere.
- Overall small effect on all-sky short-wave radiation at top of the atmosphere.

\* March-April-May in the NH and September-October-November in the SH





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### **HiRes-EA**





## Simulated cloud and radiation parameters along SCT transects



\* March-April-May in the NH and September-October-November in the SH

Similar results in terms of LWP and SW CRE as for the Sc regions: high resolution and noninteractive aerosols gives higher LWPs and higher SW CRE – in particular over the southern hemisphere. No clear impact on SCT transition – possibly a somewhat faster transition in the LowRes-EA simulation.



# Conclusions

- Our results suggest that a change in horizontal resolution from low (~135 km) to higher (less than 60 km) may have a slight influence on the simulated stratocumulus-to-cumulus transition. Otherwise, there is no clear impact of changing the horizontal resolution or the complexity of the aerosol-cloud parameterization.
- A substantial impact on LWP and SW CRE was observed, in particular over regions with high liquid water content and low precipitation rates (i.e. larger effect over the southern hemisphere than the northern hemisphere).
- For these type of regions, the effect of introducing non-interactive (Easy Aerosol) instead of • interactive aerosol-cloud interactions (GLOMAP) was about as large as increasing the horizontal resolution from medium ( $\sim 60$  km) to high ( $\sim 25$  km).
- Higher resolution and non-interactive aerosols (Easy Aerosol) generally led to higher LWP and  $\bullet$ stronger (more negative) SW CRE over the southern hemisphere Sc regions and transects.



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# Thanks for your interest! ③



Greetings from Stockholm