



Aerosols, clouds and climate feedbacks in the Southern Ocean

Highlights from New Zealand's Deep South National Science Challenge

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Seamless Modelling Workshop
Bristol 05/06/2025



Deep South National Science Challenge

“Our mission is to enable New Zealanders to adapt, manage risk and thrive in a changing climate. We're achieving this by connecting science with society, through five interlinked programmes”

- Earth System Modelling and Prediction (13 projects)
 - Modelling clouds, aerosols and atmospheric chemistry
 - Clouds and aerosols over the Southern Ocean
- Processes and Observations
- Impacts and Adaptation
- Vision Mātauranga

Concluded: June 2024

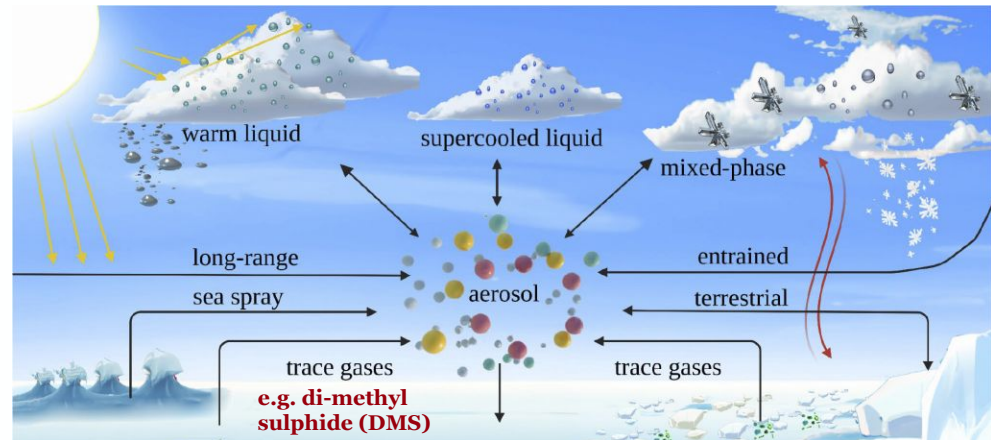
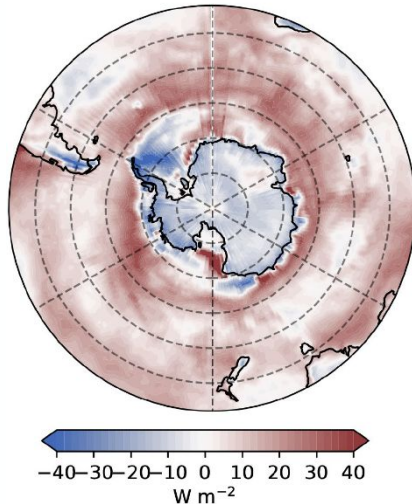


Earth System Modelling and Prediction Programme

- Southern Ocean is a big source of marine aerosol which controls cloud formation in the region.
- Southern Ocean clouds are very important for the global energy budget, but are poorly understood.

The mean austral summer time bias: Incoming shortwave radiation

Multi-model mean - CERES-EBAF



Modelling clouds, aerosols and atmospheric chemistry project

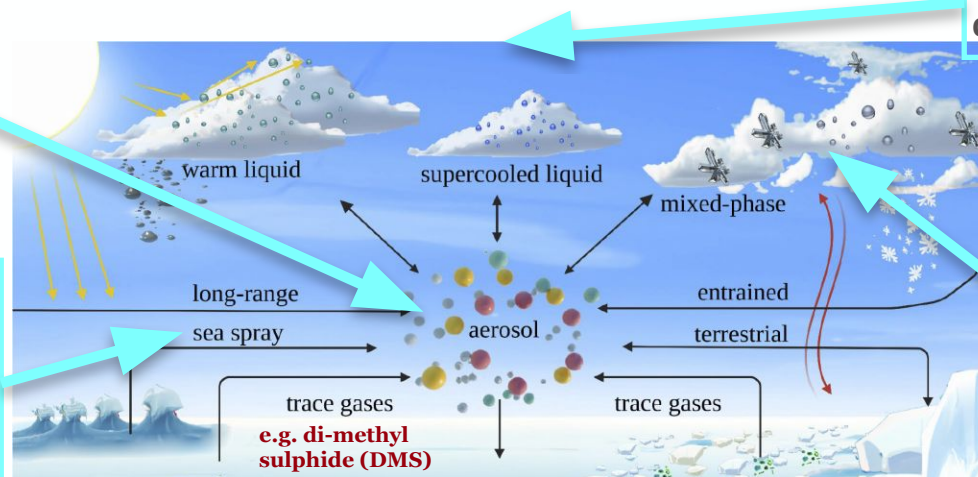
Explored sources of uncertainty in model behaviour using UKESM simulations and observations

2. Aerosol chemistry:

Model uncertainty in sulphur chemistry; new heterogeneous sulphur and bromine chemistry

1. Marine emissions:

Model uncertainty in sea spray aerosol emissions and trace gas (DMS) emissions



3. Stratospheric ozone chemistry

4. Aerosol-cloud coupling:

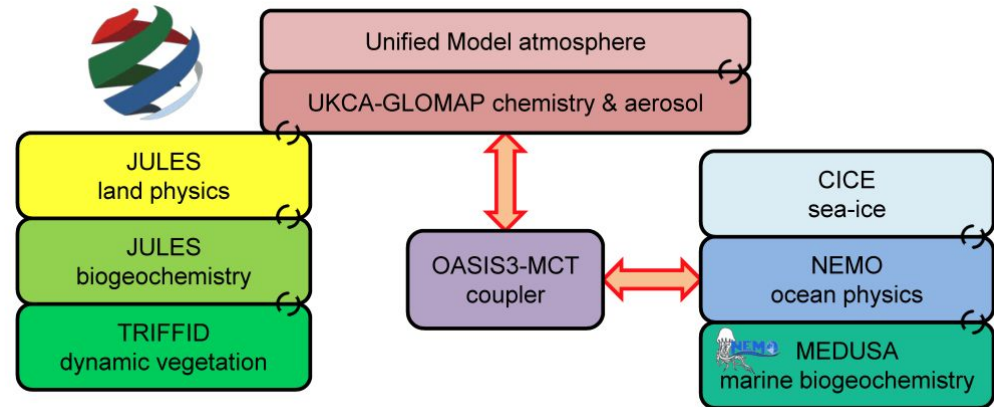
Role of primary marine organic aerosol as ice nucleating particles

- Together with the **Clouds and aerosols over the Southern Ocean** delivered > 20 papers (2018-2023); ~ 5 code commits to the UM trunk; 9 observational campaigns.
- Built great academic partnerships

Modelling clouds, aerosols and atmospheric chemistry project

Model configuration

- UKESM1 atmosphere only (AMIP; sea surface temperatures, ocean biogeochemistry and land cover are prescribed)
- Short run lengths (2-10 years)
- Nudged configuration using ECMWF's ERA5
- => minimise uncertainty in meteorology; compare with observations/shorter model simulations

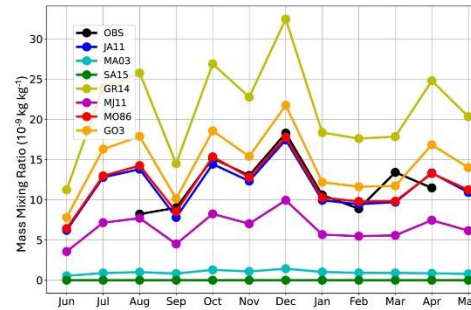


Sea–air fluxes for marine aerosol and trace gases

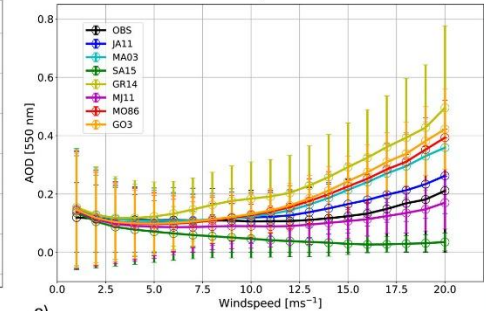
Constraining the uncertainty associated with sea salt sea-air flux parameterizations

- CMIP6 showed that SSA ERF varies from $-0.35 \pm 0.04 \text{ Wm}^{-2}$ to $-2.28 \pm 0.07 \text{ Wm}^{-2}$, with the largest difference over the Southern Ocean.
- “**J11**” reduced model bias in [SSA] and AOD, but cloud properties and radiative forcing are similar to the current UKESM1.1 parameterization (“**G03**”).
- J11 depends on windspeed and sea surface temperature.
- Use of J11 would better position UKESM for future simulations.
- UM #7664/UKCA #184

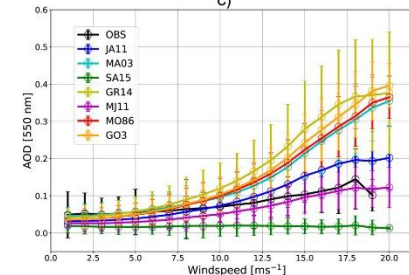
Monthly mean SSA mass mixing ratio



AOD vs windspeed: Global



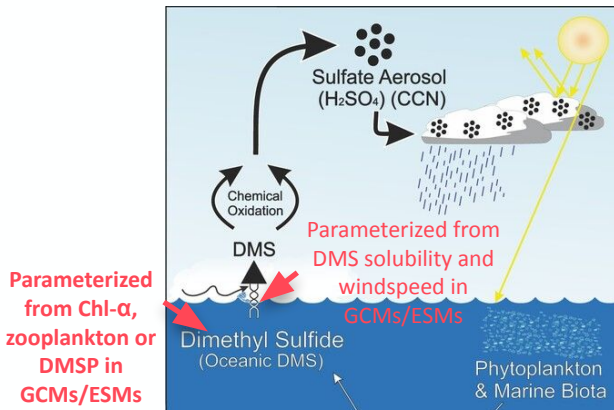
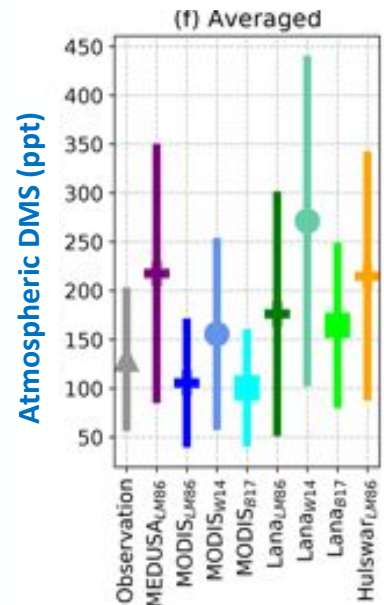
AOD vs windspeed: Southern Ocean



Sea–air fluxes for marine aerosol and trace gases

Constraining the uncertainty associated with di-methyl sulphide (DMS) parameterizations

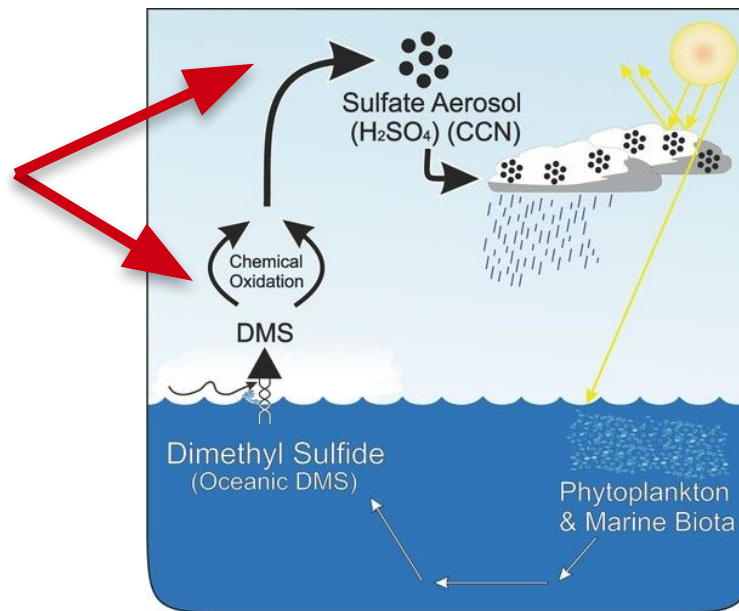
- Explored four oceanic DMS ‘sources’; MEDUSA, MODIS, Lana, Hulswar.
- Explored three sea-air DMS flux parameterisations; quadratic (LM) and linear transfer velocity (W, B)
- UKESM was more sensitive to the oceanic DMS parameterization than to the sea-air flux parameterization*
- Spatial variation in [DMS] is more important than inter-annual variability and the transfer velocity parameterization.
- UM #6973/UKCA #85 included an updated linear transfer velocity parameterization



Aerosol chemistry

Constraining the uncertainty associated with di-methyl sulphide chemistry

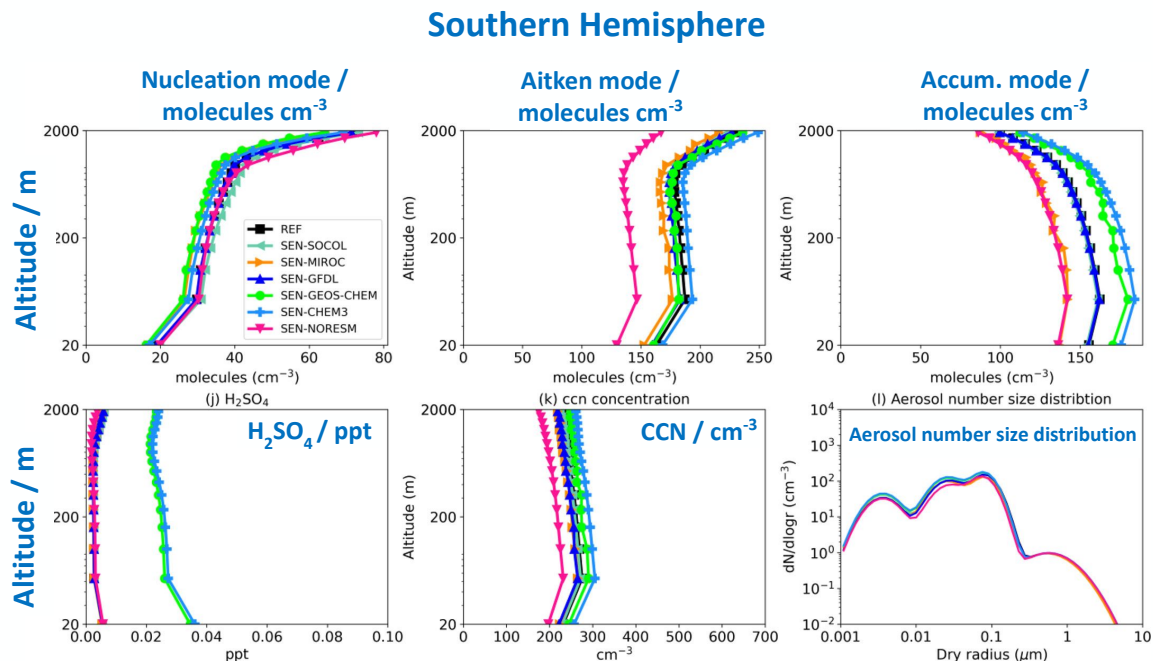
Really
complicated
chemistry



Aerosol chemistry

Constraining uncertainty associated with di-methyl sulphide (DMS) chemistry

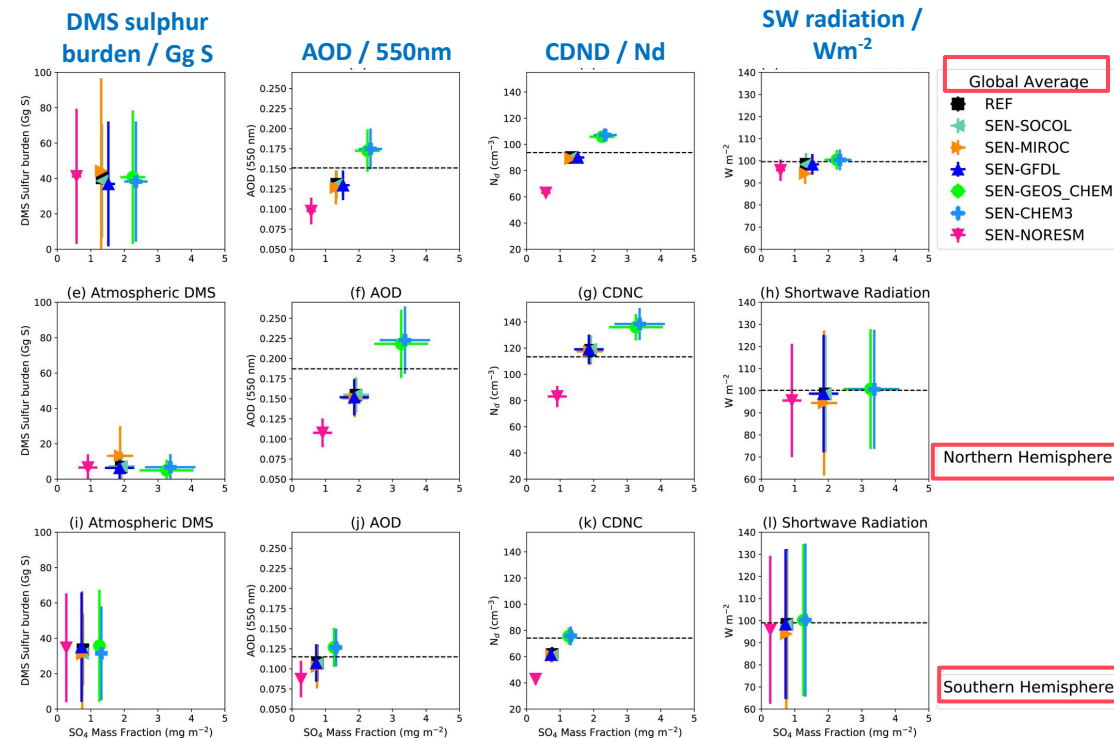
- Different chemistry schemes contribute to variation in atmospheric [DMS].
- Model bias in [DMS] can be reduced, but the 'main' impact is on aerosol size distribution.
- Chemistry schemes with more DMS oxidation and heterogeneous chemistry have more H_2SO_4 and larger aerosol particles.
- Additional heterogeneous chemistry also impacts NH aerosol



Aerosol chemistry

Constraining the uncertainty associated with di-methyl sulphide (DMS) chemistry

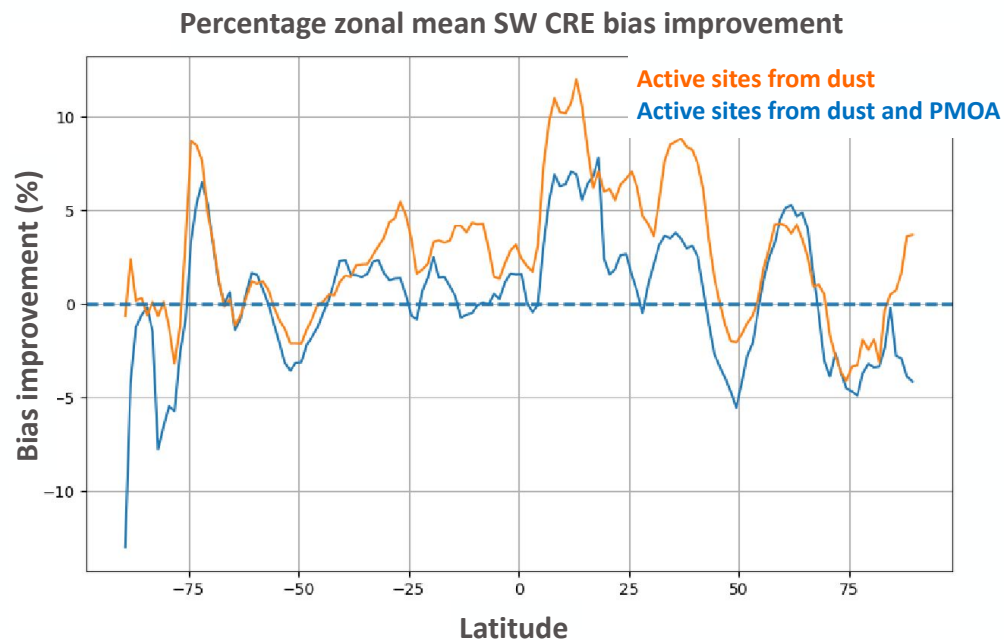
- Different chemistry schemes contribute to model variation in AOD, CDNC and OSWR TOA.
- Additional heterogeneous aqueous phase chemistry does reduce model bias in model bias for AOD and CDNC in the SH.
- It would be nice to lodge the 'CHEM3' DMS chemistry scheme.



Aerosol-cloud coupling in the Southern Ocean

Investigating the role of primary marine organic aerosol (PMOA) as ice nucleating particles (INP)

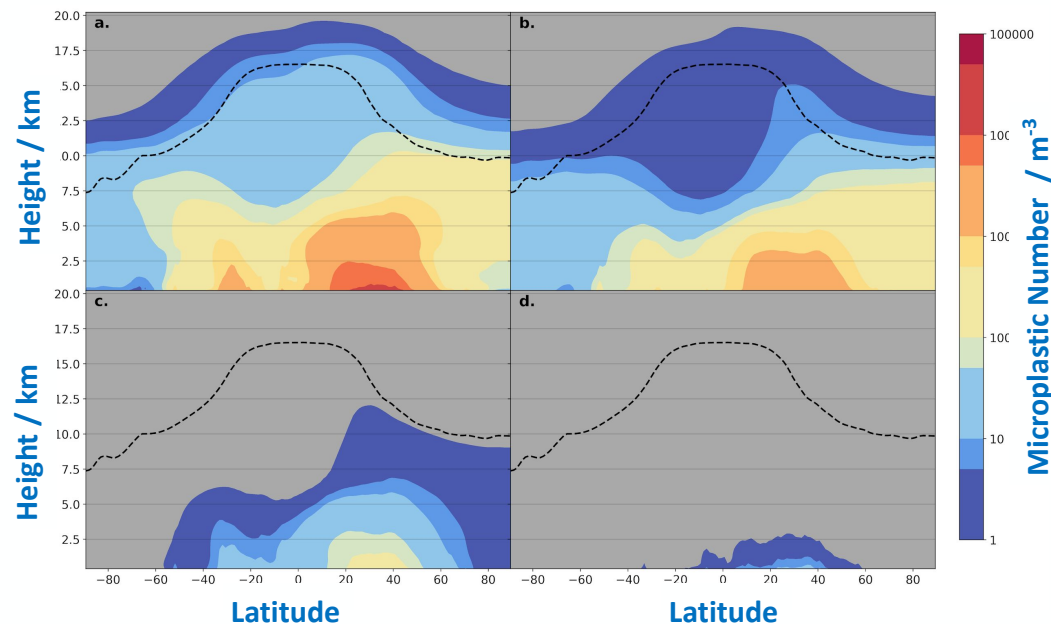
- PMOA emissions are redirected to a new, dedicated insoluble Aitken component.
- Heterogeneous ice nucleating temperature is made a function of the number density of active sites (for dust and PMOA).
- Initial results indicate that the SW cloud radiative effect bias is reduced.
- Work in progress...



Airborne microplastics in UKESM

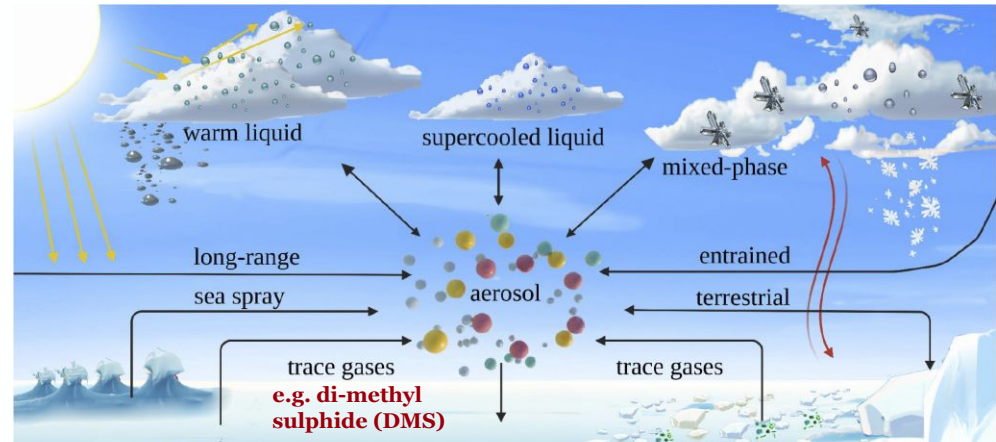
Implementing microplastics in UKESM/GLOMAP-mode

- Microplastic aerosol has been added to GLOMAP-Mode
- There are many uncertainties in the atmospheric microplastic loading.
- Scope for technical development including microplastic fibre behaviour and microplastics as ice nucleating particles.
- Present-day climate impacts are small, but the capability exists for future climate and air quality impact studies.
- UM #7760/UKCA #210



Earth System Modelling and Prediction: Key outcomes

- Improved sea-air fluxes for marine aerosol and trace gases in UKESM.
- Developed new aerosol chemistry in UKESM.
- Improved aerosol-cloud coupling for dust and marine organics
- Improved UKESM's simulation of the Antarctic ozone hole
- Novel evaluation of model simulation of cloud type using satellite data and machine learning.



Clouds, aerosol and climate feedbacks in the Southern Ocean: Outlook

How do we constrain aerosol-cloud interactions (and therefore climate - ECS, meteorology)?

- Cloud type, cloud quantity, location, CCN, INP
- Observations

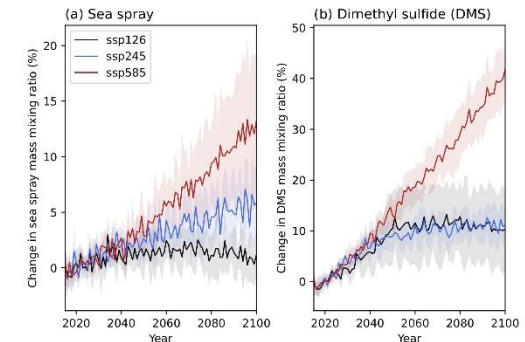


Are there missing or poorly captured sources and processes?

- Cloud water pH, Marine VOCs, chemistry, Antarctic sources?

How will aerosol-cloud-radiation interactions change in the future? (And what were they like in the past?)

- How will increased ocean temperature affect marine emissions?
- How will cloud phase change? E.g. ice -> liquid droplets?





Thank you

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