Understanding and Testing the Aerosol Radiative Forcing Responses of a Global Model for the North Atlantic Region as Part of ACSIS

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEEDS

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1) Motivation

- **Aerosol cloud interactions represent the largest uncertainty in climate change predictions.**
- **Sea-surface temperature variability in the N. Atlantic has been linked to droughts in the African Sahel and Amazonian regions, and hurricane activity.**
- **Cloud-aerosol interactions have been implicated as a driver of SST variability in global models.**

2) Do aerosol-cloud relationships drive N. Atlantic SST variability?

- **Booth et al. (2012) suggests that cloud-aerosol interaction forcing may have driven the recent variability in N. Atlantic SSTs in the HADGEM2 climate model :-**

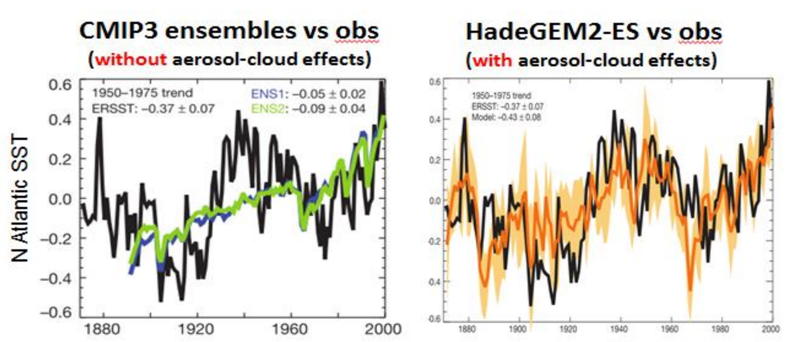


Figure 1 : N. Atlantic mean SST anomalies. Left: models that do not include cloud-aerosol interactions. Right: the HadGEM2-ES model that does include them. The black line shows the observed anomalies.

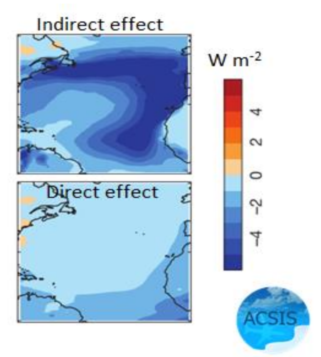


Figure 2 : Surface SW forcing from the indirect aerosol effect (top) and the direct effect (bottom).

3) Questions

- **Do we trust the climate model predictions of the aerosol-cloud forcing?**
- **Where, when and in what types of clouds and meteorology is the aerosol-cloud forcing coming from?**
- **How accurately does the global model simulate spatial and temporal cloud distributions and how important is this for aerosol-cloud forcing?**
- **How important is aerosol scavenging/removal and how well do the models capture this process?**
- **What are the other important processes?**

4) The complexity of the North Atlantic

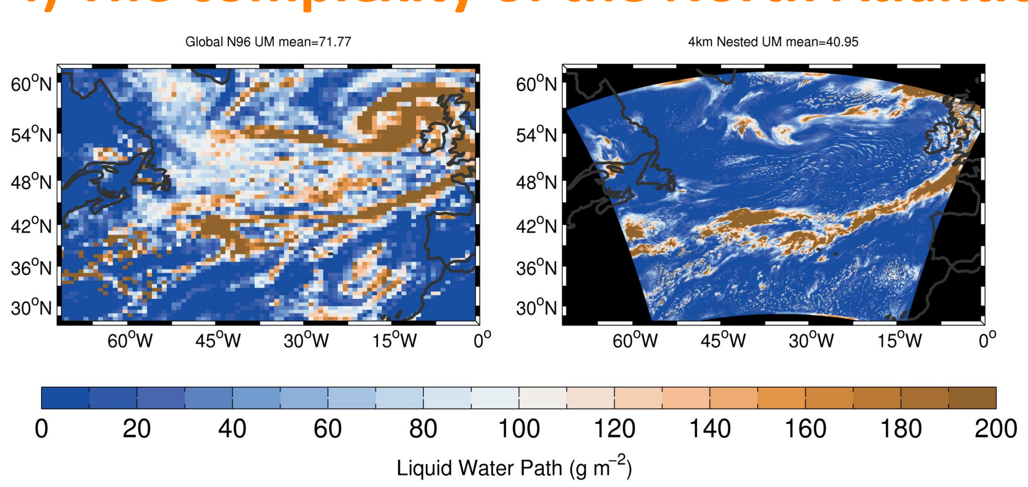
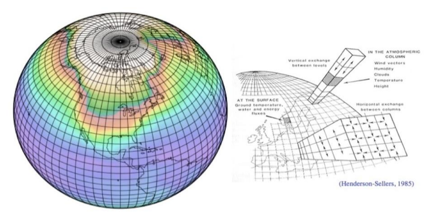


Figure 3: Demonstrative Liquid Water Path plot for two simulations. Left: N96 climate model resolution (approx. 140x210km resolution). Right: 4km resolution nested simulation.

- The North Atlantic region is dynamically complex making assessments of aerosol-cloud effects difficult.
- There are likely to be additional important processes compared to stationary stratocumulus for example.
- What is the effect of the low resolution of climate models?

5) Global modelling approach

- UKCA global model, v10.3 with nesting capability
- "N96" horizontal resolution (1.875° x 1.25°) at equator
- Run from 1st March 2009 – 28th Mar, 2010
- 2 nudged runs (same meteorology, offline oxidants):-
  - 1) Pre-industrial (PI) aerosol emissions
  - 2) Present day (PD) aerosol emissions
- 3D instantaneous output every 27 hours to capture diurnal cycle



UKCA = UM + GLOMAP aerosol

6) Model cloud evaluation

- **Getting the model clouds right is likely vital for getting the aerosol-cloud forcing correct.**
- **Shown are annual mean comparisons against satellite instruments :-**

SW TOA vs satellite

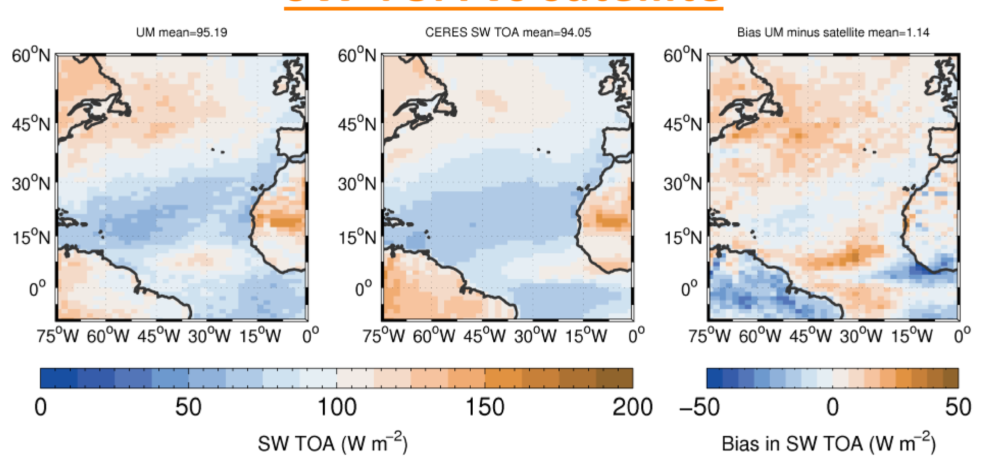


Figure 4 : Annual averages in Top-of-the Atmosphere (TOA) Shortwave (SW) radiative fluxes for the model (left) vs CERES-EBAF satellite data (middle) with the bias on the right.

- Model has a slight high bias in the NW Atlantic

Low cloud fraction vs satellite

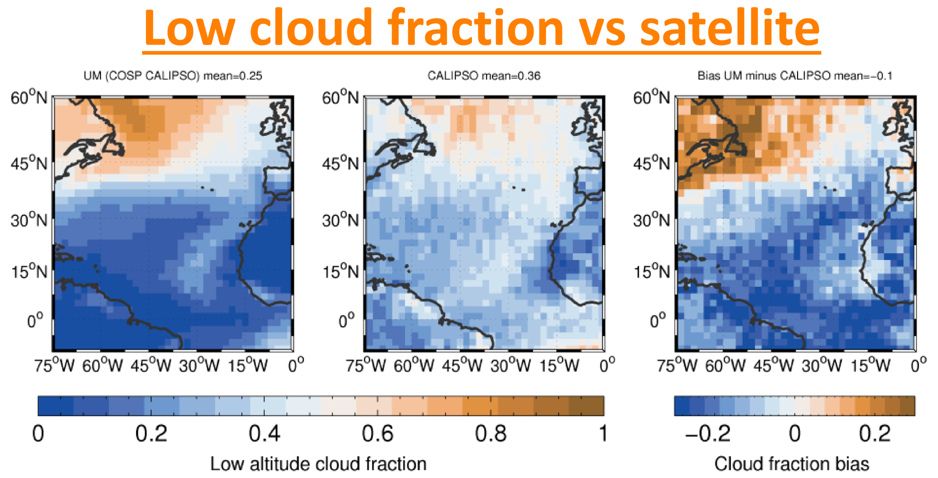


Figure 5 : As for Figure 4 except vs the CALIPSO satellite for low cloud fraction. The model field is from the COSP satellite simulator to account for the cloud detection threshold and overlying layers.

- Model pattern looks good
- Positive bias, though, that approximately correlates with the SW TOA bias

Liquid Water Path vs satellite

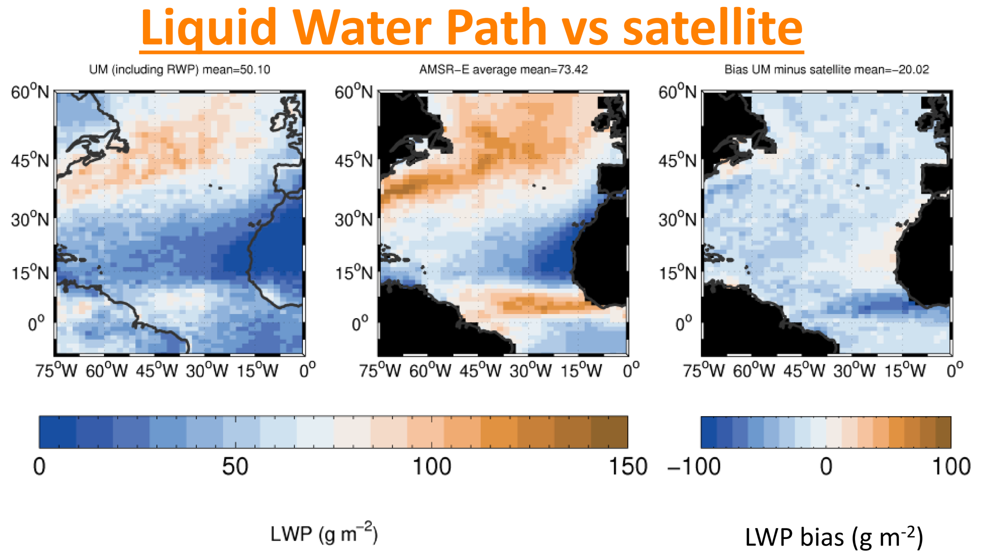


Figure 6 : As for Figure 4 except vs the AMSR-E satellite instrument for Liquid Water path (LWP).

- Good spatial pattern, but a negative model bias.

6)... Cloud Droplet Number Concentration vs satellite

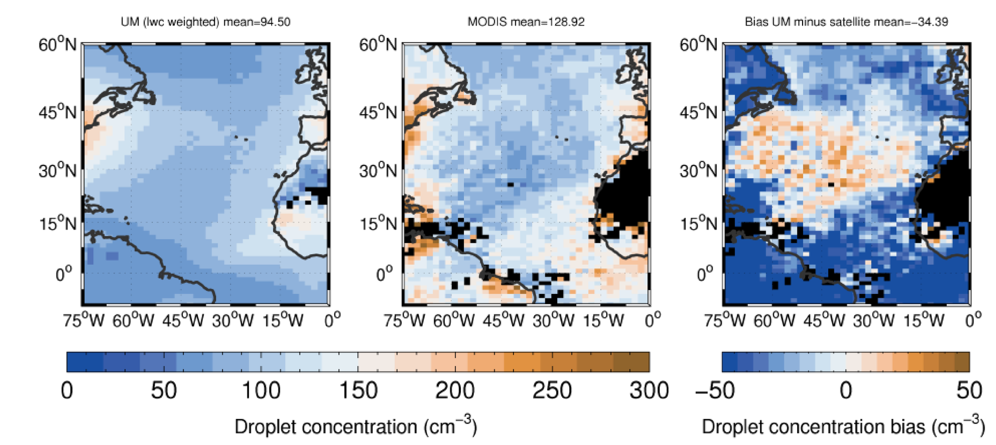


Figure 7 : As for Figure 4 except vs the MODIS satellite instrument.

- Good spatial pattern, but quantitative biases.

7) Surface SW aerosol forcings

UM has triple-calls to the radiation using :-

- All aerosol + cloud (SW_{tot})
- Reference state "clean" aerosol + cloud (SW_{clean})
- Reference state aerosol, no cloud ($SW_{clean+clear}$)

Indirect cloud radiative effect, $CRE = SW_{clean} - SW_{clean+clear}$
Indirect forcing = $CRE_{PD} - CRE_{PI}$
PD = Present Day, PI = Pre-industrial

N. B. – these forcings include cloud feedbacks (cloud fraction, LWP changes, etc.)

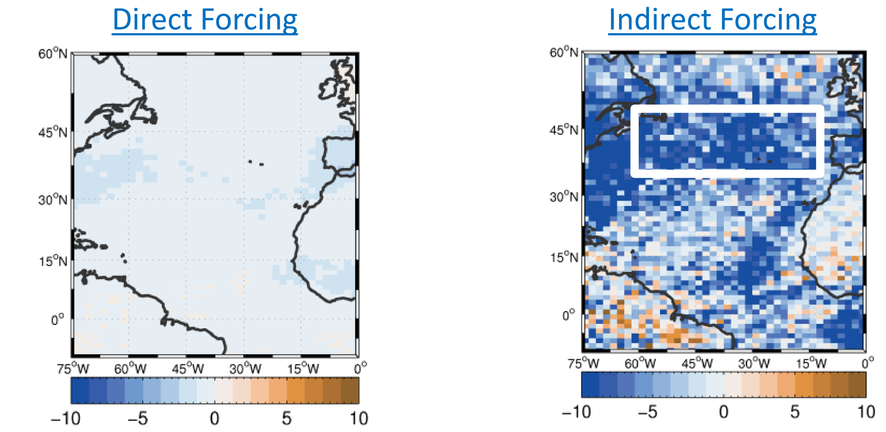


Figure 8 : Annual averages surface shortwave direct (left) and indirect (right) forcings.

- The direct forcing is very small
- Indirect forcing shows similar pattern to that in Booth (2012, see Fig. 2), but is more negative

9) Changes in cloud properties due to aerosol

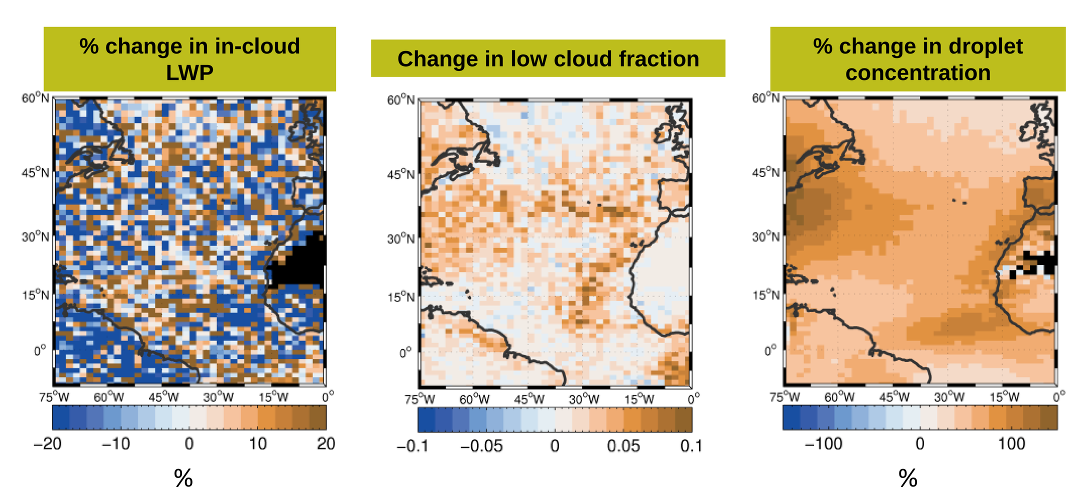
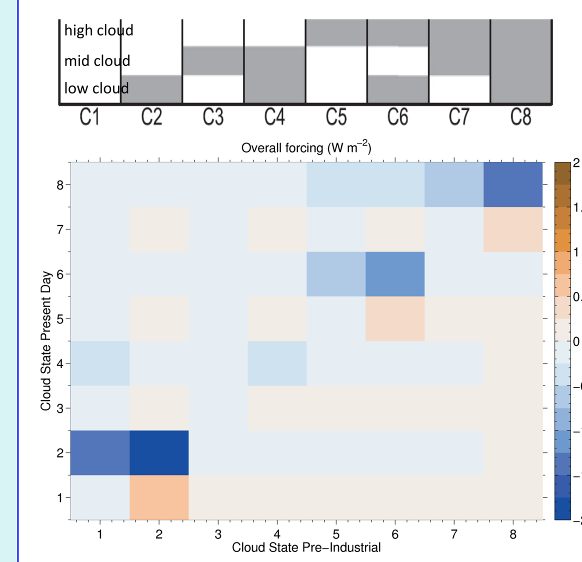


Figure 9 : Changes between Pre-Industrial (PI) and Present Day (PD) runs for cloud properties. Positive means higher values for PD.

- Significant cloud fraction changes in a pattern similar to forcing.
- Droplet concentrations mostly change near the continents.

8) Which situations are most important for forcing?

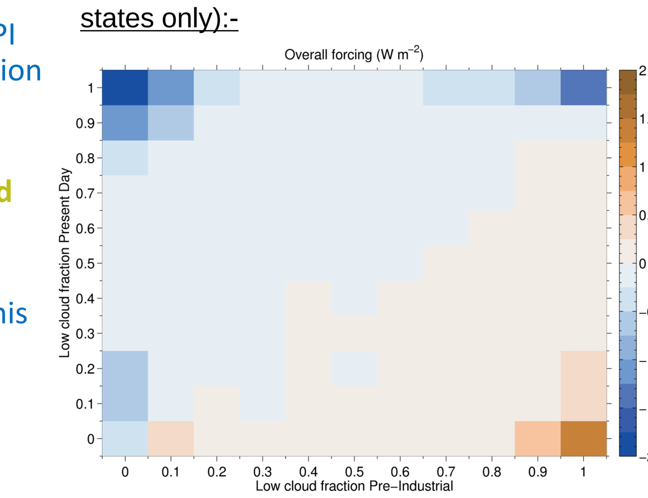


Indirect forcing separated into different cloud states for white box region in indirect plot (Fig. 8).

- Low-only clouds in Pre-Industrial (PI) and Present Day (PD) dominant
- Followed by PI-to-PD transitions from clear to low-only
- Then low+mid+high and low+high in both PI and PD.
- I.e., low clouds are the most important!

Figure 10 : Surface indirect forcing contribution from Pre-Industrial and Present Day combinations of each cloud state (taking into account frequency of occurrence).

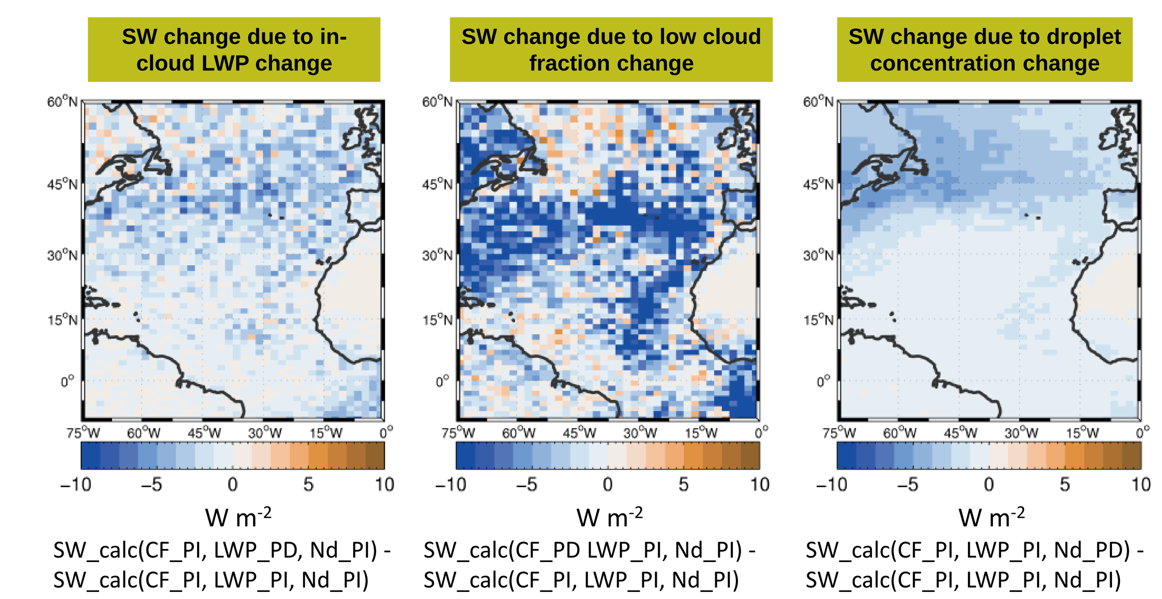
Contribution to overall forcing for different PI and PD cloud fraction combinations (C1 and C2 states only):-



- Forcing is highest when clear-sky PI turns into overcast PD (cloud fraction feedbacks).
- Also high when have overcast clouds in both PI and PD (no cloud fraction feedback).
- Indicates that cloud feedbacks are very important for this model in this region.
- Stratocumulus (high areal cloud fractions) likely more important than cumulus (lower fractions).

10) Forcing contribution from cloud change types

- SW surface downwelling flux estimated using simple method :-
  1) Estimate cloud optical depth from in-cloud LWP and droplet concentration assuming adiabatic clouds.
  2) Calculate cloud albedo from optical depth using analytical equation.
  3) Combine with low cloud fraction to calculate downwelling SW.



- Significant contribution from cloud fraction changes in a pattern similar to forcing.
- Droplet concentration changes mostly important further north and near the continents.

Conclusions

- Climate resolution UKCA model reproduces observed spatial patterns of low cloud fraction, cloud droplet concentration and liquid water path well.
- Low cloud is the most important cloud type for forcing in this model.
- Cloud fraction changes give rise to the largest forcing, followed by droplet concentration changes.
- The formation of overcast clouds in the Present Day from the clear state in Pre-Industrial gives rise to the largest forcing.
- Cloud feedbacks are important for this model, but are difficult to evaluate.