Quantifying sources of inter-model diversity in the cloud albedo effect

Laura Wilcox[1,2] | Ellie Highwood[2] | Ben Booth[3] | Ken Carslaw[4]

l.j.wilcox@reading.ac.uk

1. NCAS-Climate, University of Reading 2. Department of Meteorology, University of Reading 3. Met Office Hadley Centre 4. School of Earth and Environment, University of Leeds

National Centre for Atmospheric Science
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There is large diversity in the simulated aerosol forcing in CMIP5 models, particularly related to aerosol-cloud interactions. There is also large diversity in the global load and spatial distribution of sulphate aerosol.
We use simple models to quantify the main sources of uncertainty in the magnitude of the cloud albedo effect.

Diversity in aerosol load and distribution

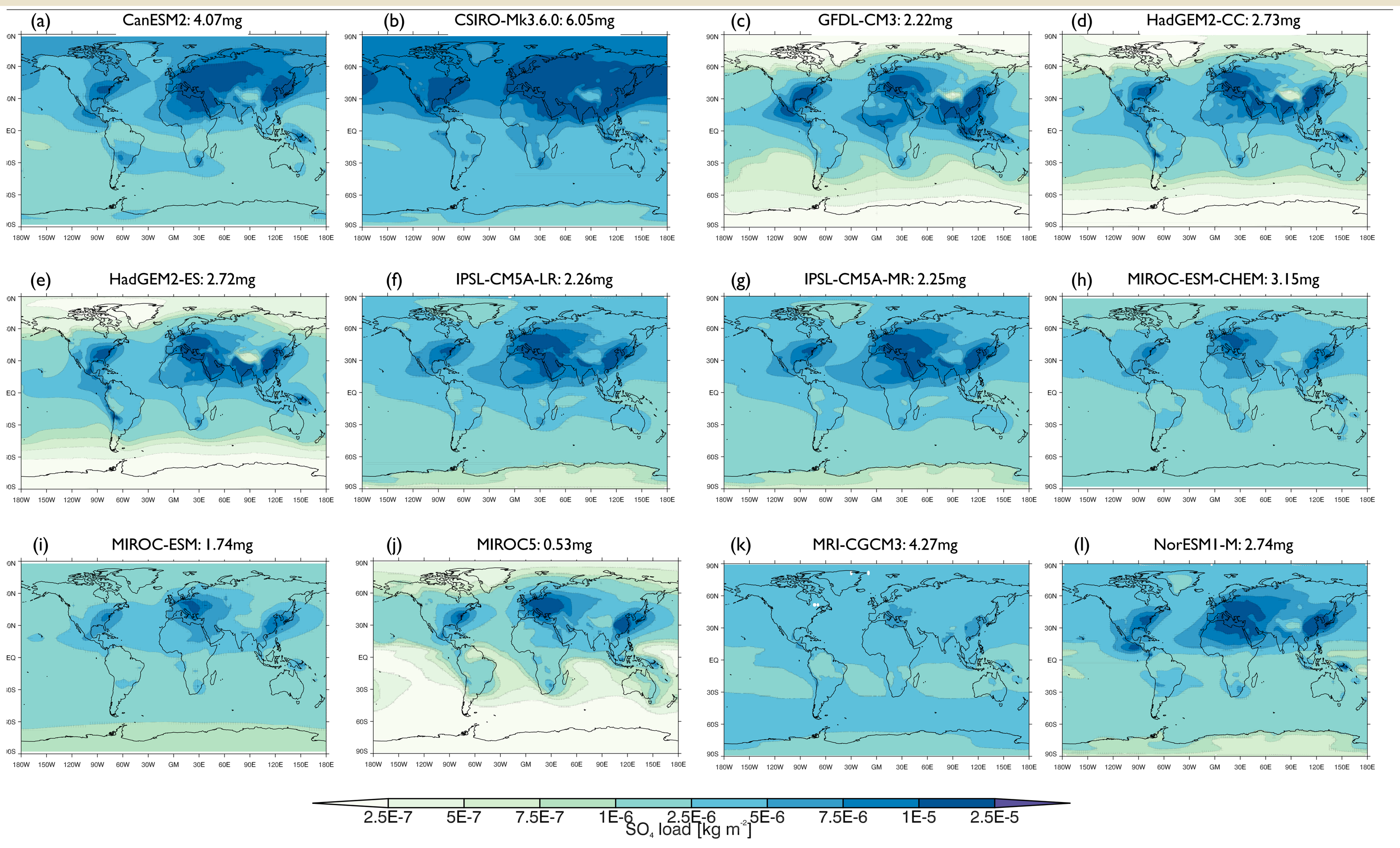

Figure 1: *1986-2005 column total sulphate load for (a): CanESM2, (b): CSIRO-Mk3.6.0, (c): GFDL-CM3, (d): HadGEM2-CC, (e): HadGEM2-ES, (f): IPSL-CM5A-LR, (g): IPSL-CM5A-MR, (i): MIROC-ESM-CHEM, (j): MIROC-ESM, (k): MIROC5, (l): MRI-CGCM3, (m): NorESM1-M.*

- Considerable diversity in load and distribution, despite standardised anthropogenic emission
- Diversity is present in both pre-industrial (PI) and present-day periods

Relationship between PI values and historical changes

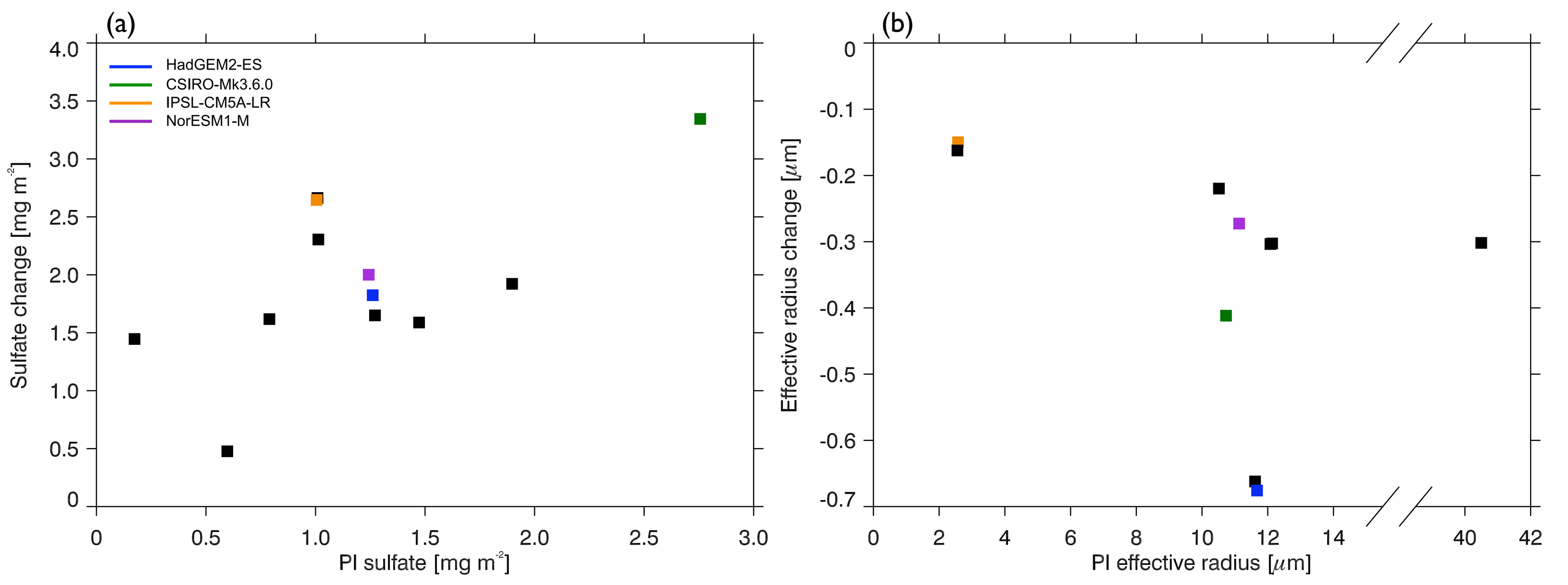

Figure 2: *Change over the historical period of (a): sulfate load for 12 CMIP5 models, (b): cloud-top effective radius for 9 CMIP5 models, compared to pre-industrial values. Focus models for the remainder of the poster are highlighted.*

- Factor of 15 spread in global-mean sulphate in 1860. Factor of 16 in effective radius (r_e)
- Weak linear relationship between PI load and historical change suggests the causes of model spread in 1860 likely differ from those that account for diversity in historical changes

Simple models of effective radius

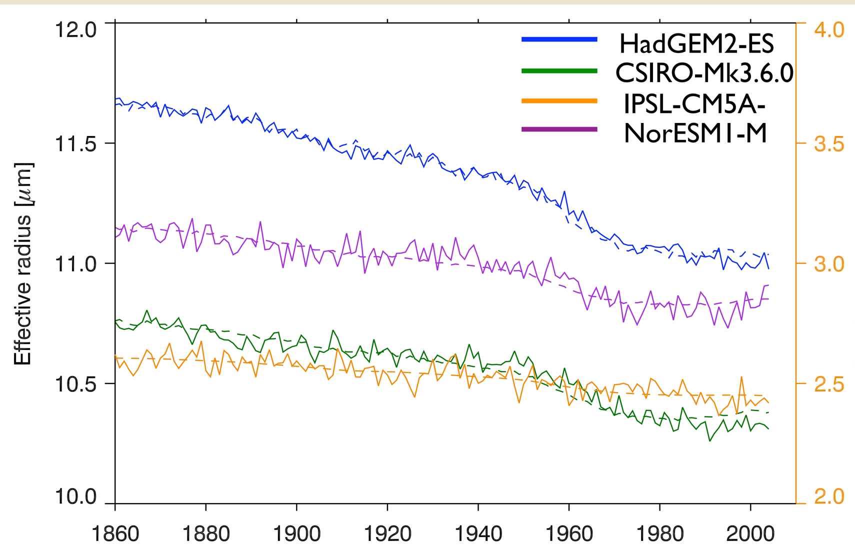

Figure 3: *Global-mean annual-mean r_e output from CMIP5 models (solid lines), and produced using simplified equations in terms of sulphate load (dotted lines).*

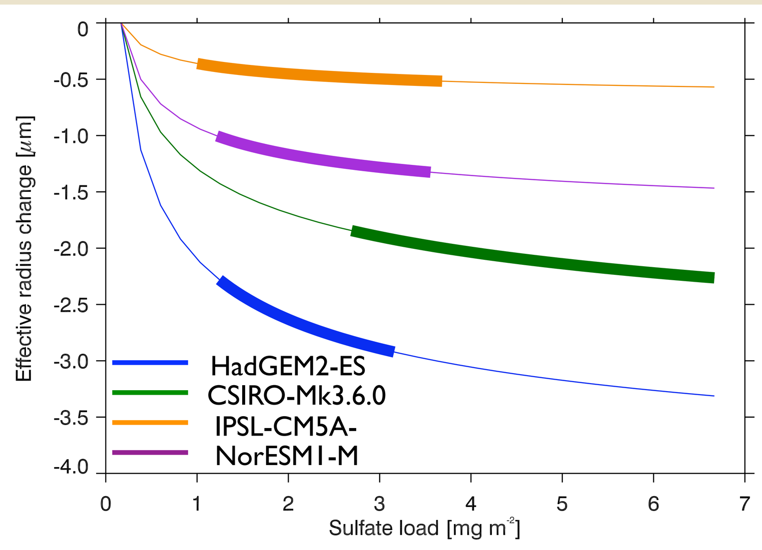

Figure 4: *Schematic showing the r_e change for a given sulphate load. Thin lines use the simple models to show r_e for the whole CMIP5 range of global mean sulphate load. Thick lines highlight the sulphate loads used in each full model.*

- Simple models provide a good approximation to full model output
- For a given change in sulphate load, global-mean r_e is most sensitive to sulphate load changes in the HadGEM2-ES parameterisation
- Different models have different loads, making inter-model diversity less than would be expected from parameterisations alone

PI load and historical temporal structure

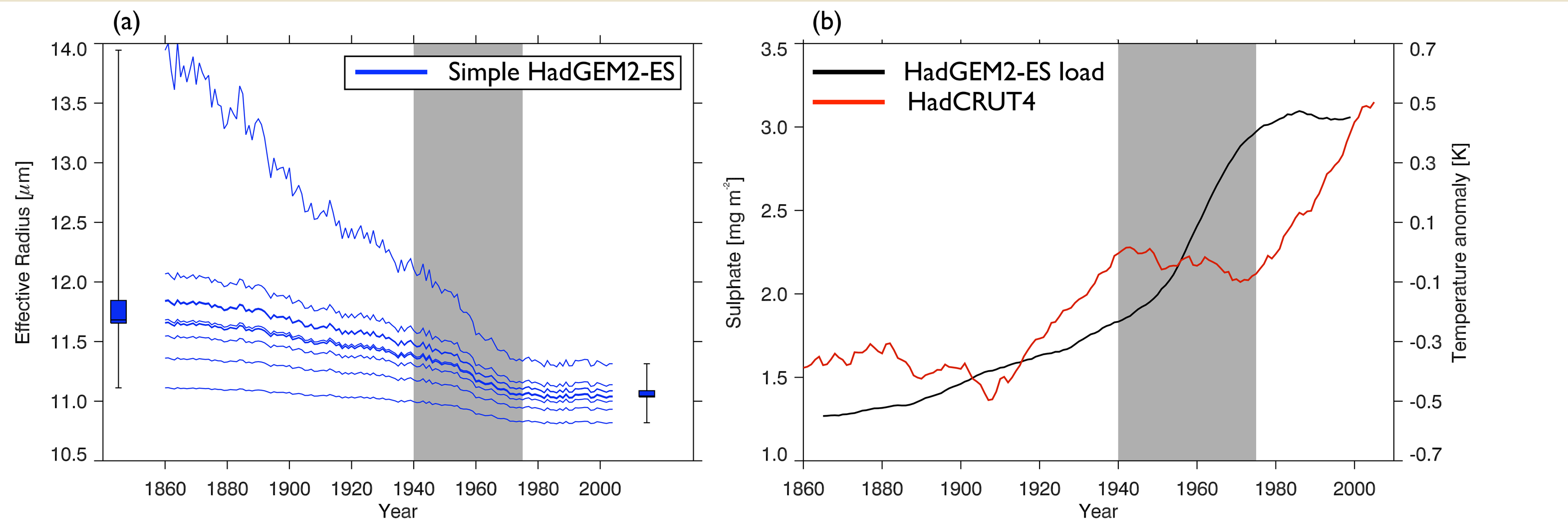

Figure 5: *(a): Global-mean annual-mean r_e in the HadGEM2-ES simple model, when the model sulphate is offset to be equal to the 1860 load from 11 CMIP5 models; (b): 11-year running means of global-mean annual -mean sulphate load from HadGEM2-ES, and temperature anomalies from HadCRUT4. The period previously shown by [1] to be sensitive to aerosol is highlighted.*

- Figure 4 shows that for a given historical sulphate change, the magnitude of the cloud albedo effect will be larger in cases with small pre-industrial loads (e.g [2])
- Figure 5 shows this sensitivity in the HadGEM2-ES simple model
- Multi-decadal variability in sulphate load still plays an important role in multi-decadal variability in modelled twentieth century r_e

Sources of diversity in radiative forcing

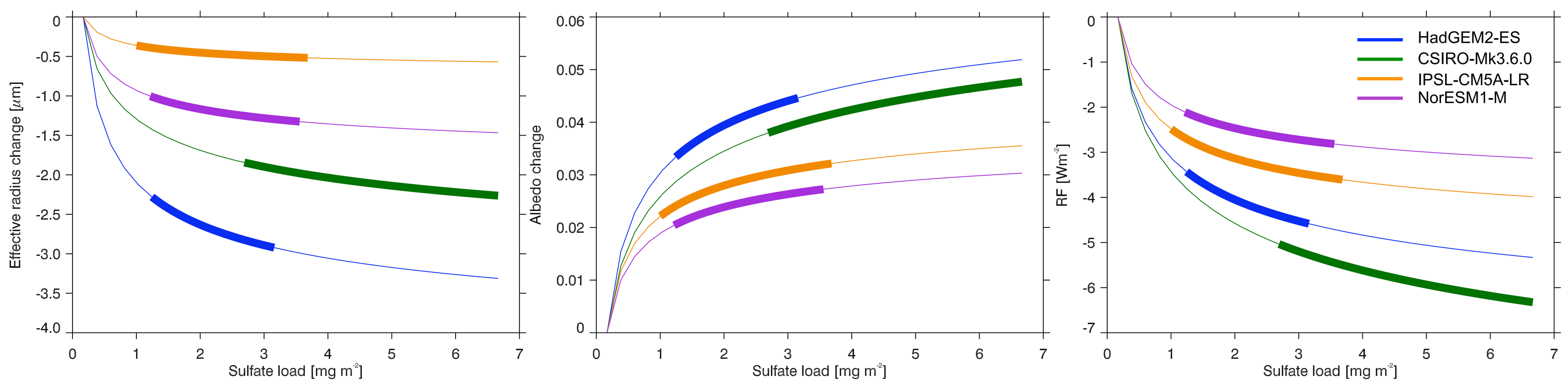

Figure 6: *Schematic showing (a): the change in global-mean r_e, (b): cloud albedo, and (c): radiative forcing relative to their minimum values for a given sulphate load. Thin lines use the simple models to show the whole CMIP5 range, thick lines highlight the sulphate loads used in each full model.*

- Use the relationships given in [2] to calculate radiative forcing, assuming that all cloud is low
- Differences in model climatology result in different relative sensitivities of the models to sulphate load for different metrics

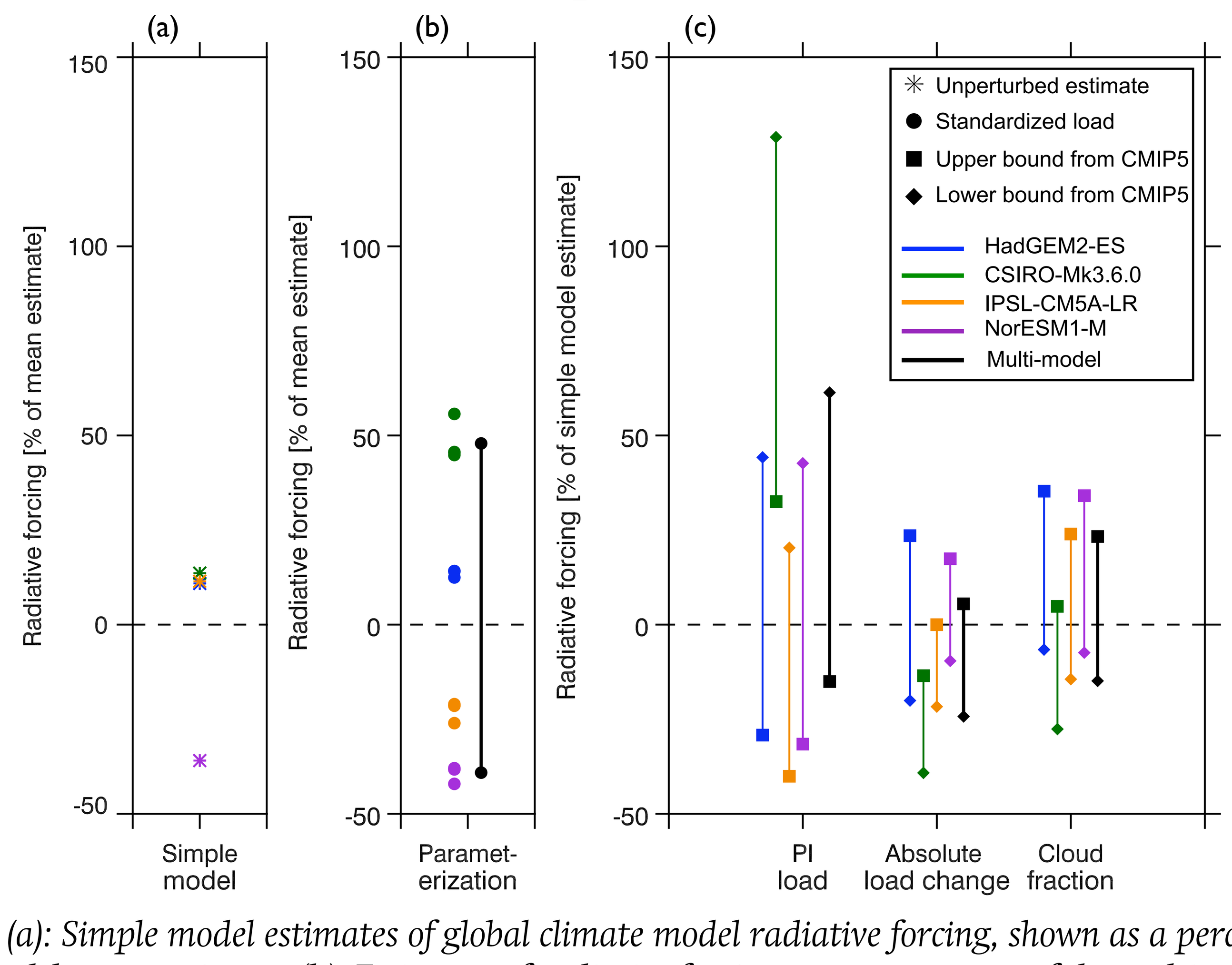

Figure 7: *(a): Simple model estimates of global climate model radiative forcing, shown as a percentage of the multi-model mean estimate. (b): Estimates of radiative forcing, as a percentage of the multi-model mean estimate, when all models are driven with the same sulphate load, showing uncertainty associated with the parameterisation of the relationship between r_e and CDNC. The experiment was repeated four times, corresponding to the four data points shown for each model. (c): Estimates of radiative forcing as a percentage of the corresponding simple model estimate when (i): pre-industrial load and (ii): the absolute change in load over the historical experiment are perturbed within the bounds of the central 9 CMIP5 values, and when (iii): total cloud fraction is perturbed within the bounds of 11 CMIP5 models.*

- The use of different parameterisation schemes for the relationship between cloud-top effective radius and CDNC is the largest potential source of inter-model diversity
  - -39% and +48% about the baseline estimate
  - Actual inter-model differences are less than would be expected from parameterisation alone
- Driving the simple models with 9 CMIP5 pre-industrial loads results in radiative forcing estimates between -15% and +61% about the baseline estimate
  - Perturbing the absolute change in sulphate load results in a range of -24% and +5% about the baseline
- Perturbing cloud fraction within the range of 11 CMIP5 models changes multi-model mean radiative forcing by between -15% and +23%

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www.met.reading.ac.uk/~laura

[1] Wilcox et al., (2013). *Environmental Research Letters*, **8**, 024033, [2] Carslaw et al., (2013). *Nature*, **503**, 67-71.

University of Reading