A Semi-Empirical Model of the Stratosphere in the climate System

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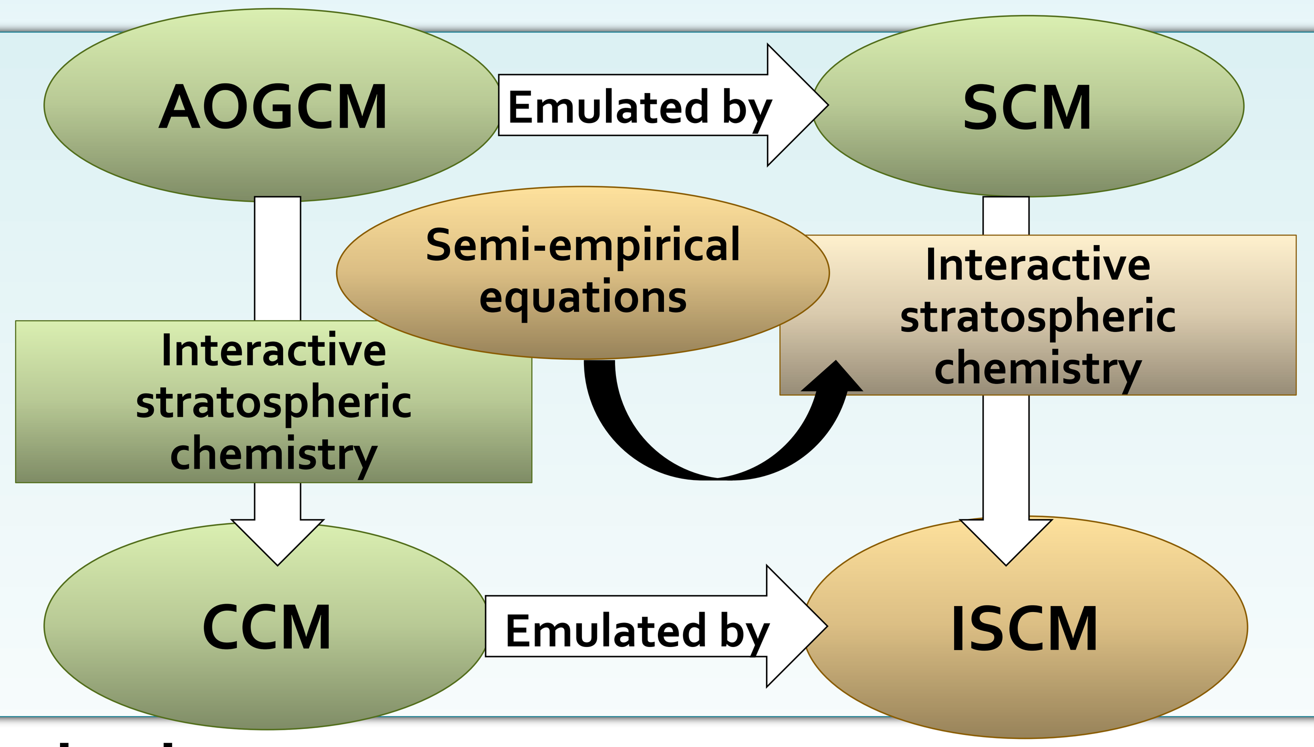
The problem

Chemistry Climate models (CCMs) currently used to project changes in stratospheric ozone are (i) highly complex, (ii) computationally demanding and (iii) uncertain due to lack of knowledge of future greenhouse gas (GHG) & ozone depleting substances (ODSs) emissions and parameterizations within the models. Therefore projections should be based on ensembles of simulations to cover the uncertainties. This is not possible today, due to the complexity of the CCMs.

Our solution

- We have developed a fast method to simulate the evolution of the stratospheric ozone layer and its coupling to the climate system by building a fast emulator of complex Atmospheric-Ocean Global Climate Models (AOGCMs) and Chemistry-Climate Models (CCMs).
- We have implemented an interactive stratosphere using our developed method into the simple climate model (SCM) MAGICC (Ref.s 1 ,2).
- With this method it will be possible simulate the evolution of the ozone layer for a wide range of GHG and ODSs emissions scenarios, and to calculate ensembles of simulations to cover the uncertainties related to climate simulations. MAGICC is tuned to 19 different AOGCMs and 10 different carbon cycles which gives us an ensemble of 190 simulations.



Method

Radiative Forcing

We use a pattern scaling technique to determine the functional dependence of radiative forcing (RF) on Stratospheric Column Ozone anomalies (hereafter referred to as SCO′, the ozone column above the tropopause), using the following concept:

$$RF = \alpha SCO_{90\text{-}60}' + \beta\, SCO_{60\text{-}30}' + \delta\, SCO_{30\text{-}0}' + \eta \qquad (1)$$

The fit coefficients α, β, δ, γ and η are derived by fitting the equation to CMIP5 (Ref. 3) output. The SCO anomalies (w.r.t. 1960) are averaged over three latitudinal zones 90-60°. 60-30° and 30-0° (south and north).

Stratospheric Ozone

The SCO′ fields in Eq. 1 are calculated with a similar pattern scaling technique where the dependence of SCO on CO_2′ and EESC′, for each latitude *i*:

$$SCO_i = \alpha_i CO_2' + \beta_i CO_2'^2 + \delta_i EESC' + \gamma_i EESC'^2 + \eta \qquad (2)$$

The fit coefficients α, β, δ, γ, and η are derived by fitting the equation to chemistry climate model output from EMAC and CO_2′ and EESC′ are the anomalies w.r.t. 1960.

Because of the vertical dependence of stratospheric ozone on RF, it is necessary to use vertically weighted SCO in Eq. 1. The weighted SCO (expSCO) are calculated as follows:

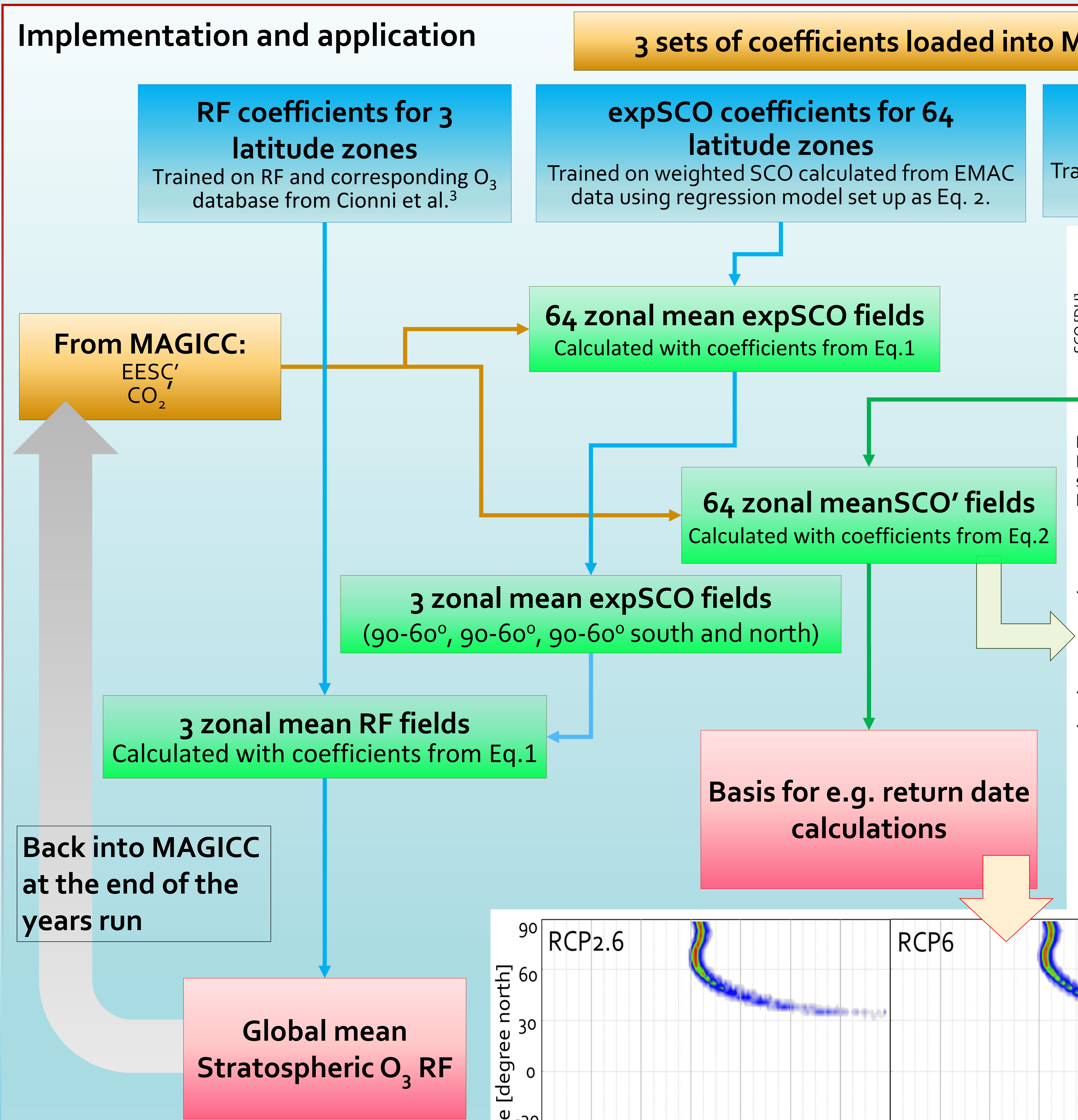
$$expSCO_i = \frac{\sum O_{3\,l}\, exp^{-\frac{z_l - z_0}{5}}}{\sum exp^{-\frac{z_l - z_0}{5}}} \qquad (3)$$

Where O_3 is the ozone at each level in the stratosphere, *z* is the altitude and z_0 is the tropopause height in km and *l* represents the atmospheric level. To catch the seasonal variations of SCO and expSCO the coefficients are expanded as a Fourier series, i.e.,

$$\alpha(t) = \alpha_0 + \sum_{k=1}^{M}\left[\alpha_{2k-1}\sin\left(2\pi k\frac{t}{365}\right) + \cos(2\pi k\frac{t}{365})\right] \qquad (4)$$

Where *t* is the number of steps per year and *M* is the number of Fourier pairs in which the fit coefficients are expanded.

Implementation and application



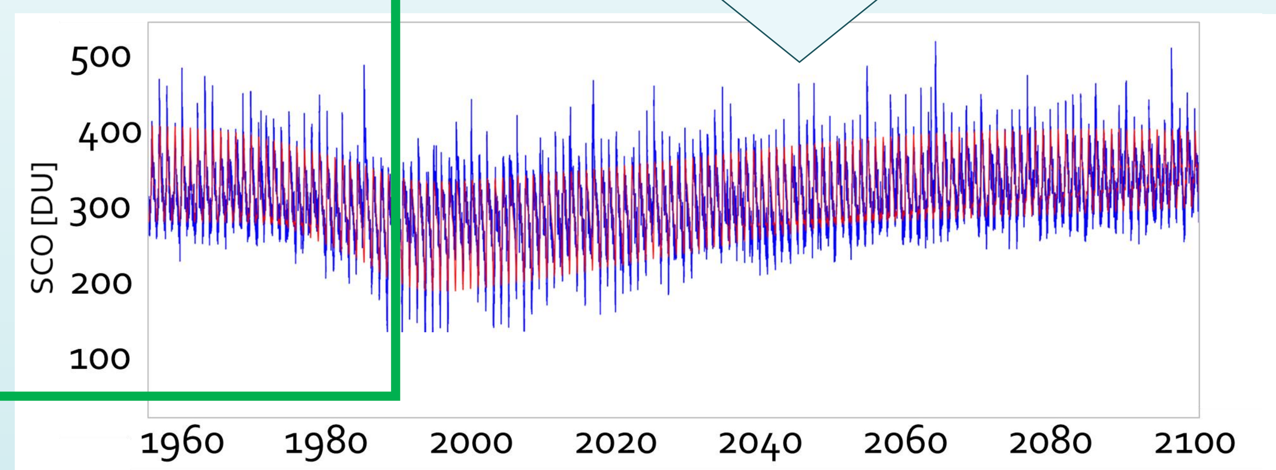


Figure 1. Daily SCO at 87° S calculated with coefficients obtained from Eq. 2, trained on EMAC data following the RCP8.5 scenario (red line) and stratospheric column ozone calculated from EMAC output (blue line). Here M in Eq. 4 is set to 4 for ε and 2 for the other coefficients.

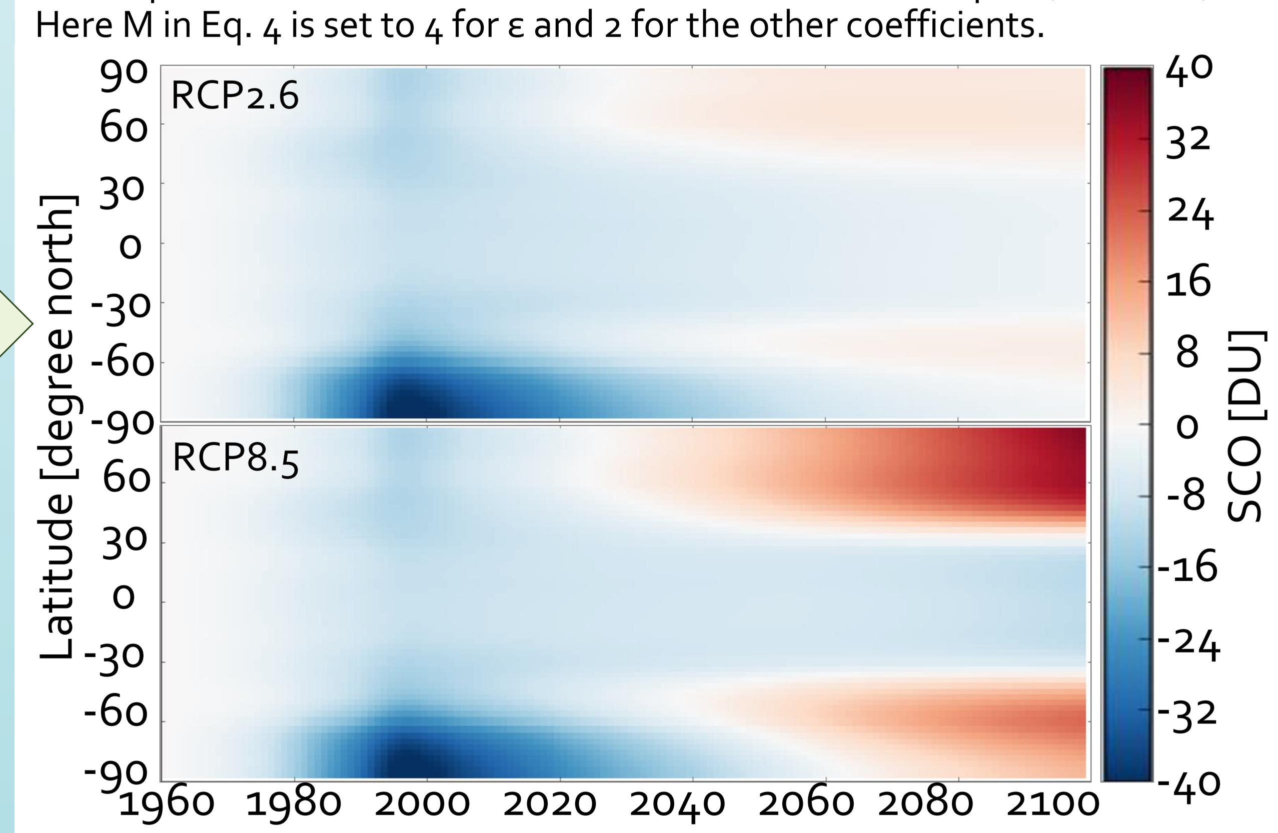


Figure 2. SCO anomalies calculated with MAGICC following the RCP2.6 (top) and RCP8.5 (bottom) scenarios .

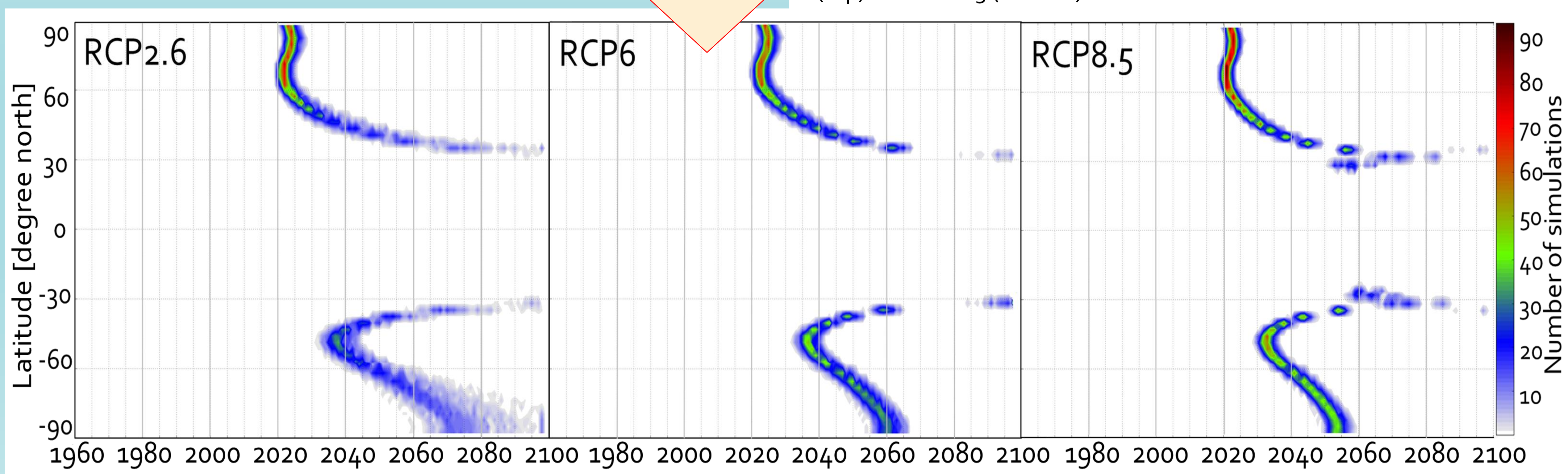


Figure 3. Probability calculations of the return of SCO to 1960 levels for 190 simulations calculated with MAGICC, following the RCP2.6, RCP6 and RCP8.5 scenarios.

[1] Meinshausen, M.; Raper, S.; Wigley, T. M. L.: *Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6-Part 1: Model description and calibration*. Atm. Chem. Phys. Vol. 11.p.1457-1456 (2011)

[2] Meinshausen, M.; Wigley, T. M. and Raper, S. C. B.: *Emulating atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6-Part 2: Applications*. Atm. Chem. Phys. Vol. 11. p.1457-1471 (2011)

[3] Cionni, I.; Eyring, V.; Lamarque, J. F.; Randel, W. J.; Stevenson, D. S.; Wu, F.; Bodeker, G. E.; Shepherd, T. G.; Shindell, D. T.; Waugh, D W.: *Ozone database in support of CMIP5 simulations: results and corresponding radiative forcing*. Atm. Chem. Phys. Vol.11. p. 11267-11292 (2011)