EUCLIPSE

EU Cloud Intercomparison, Process Study & Evaluation Project

Grant agreement no. 244067

Deliverable D0.15:	Policy brief on implications of the project results on the climate decision making process.
Delivery date:	54 months
Responsible partner:	KNMI

EUCLIPSE Policy Brief

A. P. Siebesma, S. Bony, and B. Stevens

July 17, 2014

Synopsis: *The FP7 European Union Cloud Intercomparison, Process Study and Evaluation Project (EUCLIPSE) helped propel European climate science to the forefront of the field internationally. EUCLIPSE germinated one of the most important new international climate science initiatives, the World Climate Research Programme's grand science challenge on clouds, circulation and climate sensitivity, and made major scientific contributions which underpinned, and in some cases have already eclipsed, the fifth assessment report of the IPCC (AR5). As a result of EUCLIPSE it is now understood why climate sensitivity, a simple measure of the expected average warming of the Earth from a doubling of atmospheric* CO_2*, remains the most vital issue in climate science. Cloud feedbacks have ceased to be a riddle rapped in a mystery inside an enigma, and by linking cloud processes to the structure of the atmospheric circulation and its propensity to change, a foundation has been laid for understanding regional climate changes. Building on the legacy of earlier EU projects (EUClouds and EUROCS) EUCLIPSE has bridged the gaps between distinct cultures, irreversibly linking experts in atmospheric processes to broader questions of climate change, in so doing it has helped develop a uniquely European expertise on some of the most critical questions in climate science, by organically linking activities and interests of Europe's leading climate research laboratories with one another, and with broader expertise within the university community.*

Scientific Advances

Climate sensitivity is still the most vital question in climate science

It is easy to think that the question of the equilibrium climate sensitivity, that is the globally averaged warming Earth's surface required to balance the radiative forcing from a doubling of the concentration of atmospheric CO_2, is passé, an academic abstraction largely irrelevant to policy makers, planners, or the broader society. EUCLIPSE has made important contributions to helping us understand that this is far from the case. Many of the more fine-grained aspects of the climate system appear to be directly related to the equilibrium climate sensitivity. For instance, projections of changes in European temperatures, particularly during the summer, are directly proportional to the climate sensitivity. More broadly, although different models predict different patterns of changes, the amplitude of a particular models projected climate change pattern scales remarkably well with the change in the globally averaged surface temperature. Finally uncertainty in changes in globally averaged precipitation have been shown to be dominated by uncertainty in globally averaged surface temperature changes, i.e., the equilibrium climate sensitivity. This work, through EUCLIPSE, contributes to work by others in the broader community, which shows that the climate sensitivity is associated with physiological limits to adaptation, and that the transient climate response is both proportional to and controlled by the same factors as that of the equilibrium climate sensitivity. Hence narrowing climate sensitivity remains the single most vital question of climate science, as no other single number conditions so many aspects of climate change. [1, 2, 3]

Clouds feedbacks are no longer a riddle wrapped in a mystery inside an enigma

Of the major feedbacks on radiative forcing, most (like the surface albedo or water vapor feedback) were identified more than a century ago, when scientists first begin thinking about climate change. The idea that clouds might be an important in determining the equilibrium climate sensitivity really only was raised a few decades ago, and even then there were no clear ideas why clouds should change with a changing climate – a point that gains emphasis when it is realized that then, and now, it has been widely assumed that relative humidity will not change markedly with warming. EUCLIPSE is responsible for the most important new ideas in decades as to why and how climatologically important low-clouds might change in a changing climate, even if the processes that regulate the large-scale patterns of relative humidity change little. EUCLIPSE investigators showed how water vapor fluctuations, an important driver of turbulent mixing in the lower troposphere, increase with warming if the relative humidity stays constant, and that this implies more efficient lower tropospheric mixing which would tend to deepen and dry the lower layers of the troposphere, reducing cloudiness over the ocean, and amplifying warming. Such a situation is also thought to be energetically favored because a constant relative humidity implies a larger vertical gradient in absolute humidity, and so less radiative cooling is required by clouds to balance the energy budget of the troposphere. These ideas have proven powerful in understanding the response of climate models to forcing, and helped break a long-standing deadlock in our understanding of the climate system, namely whether or not clouds are contributing to or mitigating against forced changes in the climate system. Because of work in EUCLIPSE it is now thought that clouds act to amplify warming, although to what degree remains open. Before EUCLIPSE it was not understood why cloudiness might depend on Earth's surface temperature, let alone in which sense. Clouds, once a riddle wrapped inside a mystery inside and enigma, are no longer enigmatic, and while riddles remain, even some of the mystery has been removed. [4, 5, 6, 7, 8]

Clouds matter for more than warming

The overall distribution of dry and wet areas over the globe is primarily related to the large-scale atmospheric circulation. In the tropics for instance, wet areas are located in the moist, ascending branches of the tropics (associated with what are known as the Hadley and Walker Circulations) where moisture converges and rises, giving rise to precipitation, while dry areas are located in the descending branches of this circulation. A reason why climate models exhibit great difficulties in predicting the regional distribution of tropical rainfall over a large range of timescales is that they fail to represent this large-scale circulation properly. EUCLIPSE helped understand why this is so, and proposed ways to improve models. The long-standing tendency of models to produce a double ascending branch of the tropical circulation over equatorial oceans instead of a single one as shown by observations (sometimes called the 'double-ITCZ' problem) could be alleviated by increasing the amount of turbulent mixing between clouds and the environmental air around them, and better capturing their coupling to patterns of surface evaporation. These studies, and others supported by EUCLIPSE, also showed that a more realistic representation of the tropical convergence zones also improved the representation of important modes of tropical variability, including phenomena such as the Madden-Julian Oscillation and ENSO, both of which are critical to patterns of weather well away from the tropics. EUCLIPSE studies also showed how low-cloud radiative effects play an important role in determining the aridity of the arid regions of the tropics, and the strength of the tropical circulation and its response to external forcing, such as might accompany an increase in aerosols in the northern hemisphere as a result of human activity. Few aspects of the climate system matter as much for humankind as the large-scale distribution, amount and variability of rainfall over the globe, EUCLIPSE has greatly contributed to understanding how and why the representation of cloud and cloud-radiative processes in models is so critical for predicting these aspects of the large-scale circulation, and hence why models have struggled to represent such changes more robustly. [9, 10, 11, 12, 13, 14]

CO_2 also directly controls rainfall

For decades, CO_2 has been thought to influence the climate system mostly through its impact on surface temperatures. An important contribution from EUCLIPSE has been to show that CO_2 can also influence climate independently of its influence on surface temperature. In particular, EUCLIPSE demonstrated that higher CO_2 amounts in the atmosphere weaken the strength of large-scale rising and sinking motions of the atmosphere, hence affecting the amount and distribution of rainfall at the regional scale, even in the absence of global-mean surface temperature changes. This "direct" effect of CO_2 on the atmosphere, which is reproduced by most models and can be physically understood from basic physics principles, occurs very fast (within just a few days after an increase in CO_2) but contributes significantly to the long-term change in circulation and rainfall. An understanding of this direct effect has changed the way we now interpret regional precipitation changes, their dependence on the nature of anthropogenic forcing, and the reasons why some aspects of regional projections are robust while others differ across models. This work shows that not only changes in global precipitation, but also changes in patterns of precipitation, will be a residue of increasing concentrations of CO_2. As is the case for ocean acidification, changes in precipitation will remain, even if efforts to mitigate against surface warming are successful but fail to address rising concentrations of atmospheric CO_2. [3, 15, 16]

Legacy

The Grand Science Challenge on Clouds Circulation and Climate Sensitivity To guide its efforts over the coming decade the World Climate Research Programme launched an initiative of six Grand Science Challenges. One of these, on Clouds Circulation and Sensitivity germinated from the EUCLIPSE project, as its two lead coordinators are EUCLIPSE work-package leaders, and of the twelve coordinators, five are from Europe, and of these four formed the core team within EUCLIPSE. This particular Grand Science Challenge will be the focus of WCRP attempts understand the physical climate system, as such it is helping prioritize new satellite missions, experimental strategies within projects such as CMIP (the coupled model inter-comparison project) and activities within the core projects of WCRP, through its leadership of the Grand Science Challenge EUCLIPSE has helped give European scientists a leading role within the initiative.

Guidance for parameterization: EUCLIPSE developed new parameterizations, new approaches for parameterizations, and a deeper understanding of some of the critical issues facing parameterization. For future parameterization EUCLIPSE demonstrated how important the coupling's among parameterizations are, whether it be between circulation and convection, convection and clouds, turbulence and convection, or clouds and radiation. As a rule, the couplings among the parameterizations were shown to plays as much, or more, of a role than the specifics of any particular parameterization. EUCLIPSE demonstrated the power of numerical weather prediction techniques, single column model approaches, and high-resolution process modeling for advancing parameterization.[17, 18, 13]

New Frameworks for studying climate change EUCLIPSE advanced the integration of existing frameworks, and the development of new frameworks, to study climate change. The use of a hierarchy of models, from single column models, to high-resolution process models, to short time integrations of advanced climate models EUCLIPSE has shown how this hierarchy of models must be used in combination to solve important problems in climate science. EUCLIPSE advanced the use of new diagnostic techniques to better link observations to modelling, both through the development of simulators that are now routinely imbedded in climate models, but also through the development of high frequency grid-point output for comparison with ground stations. Finally EUCLIPSE advanced the model hierarchy by showing the power of new idealizations, ranging from three dimensional calculations of radiative convective equilibrium using Earth System Models, to the applicability of reduced frameworks like aqua planets for studying climate change. [13, 19, 20, 21, 22, 23]

Training of a new generation of climate scientists In addition to training a new generation of scientists, EUCLIPSE has helped advance the question of the role of clouds, circulation and climate more broadly – both through a book, and through a summer school. The book, entitled *Clouds and Climate* will be published by Cambridge University Press in 2016, consists of thirteen chapters authored by EUCLIPSE investigators, and will help define the background and challenges for the next generation of climate scientists. The summer school was designed to help develop the chapters within the book and attracted fifty-five advanced PhD students and young postdocs for a two week period in the French Alps in the summer of 2013. Through these activities, and through its contribution to Chapter Seven in the AR5, EUCLIPSE has helped define a new, and increasingly recognized, sub-discipline within climate science more broadly.

Contribution to the IPCC Fifth Assessment Report (AR5) EUCLIPSE PIs and science featured very prominently in the IPCC report. The EUCLIPSE community was fundamental in establishing clouds and aerosols as one of the new process chapters to be included in the AR5. EUCLIPSE contributions featured prominently in this report, with figures developed through EUCLIPSE projects featuring directly in the report, and some of the major findings, i.e., mechanisms for positive low cloud feedbacks which supported the IPCC assessment of a likely positive cloud feedback, or the effect of CO_2 on regional patterns of precipitation change, arising directly from research within EUCLIPSE.

References

[1] Cattiaux, J., Douville, H. & Peings, Y. European temperatures in CMIP5: origins of present-day biases and future uncertainties. *Climate Dynamics* **41**, 2889–2907 (2013).

[2] Stevens, B. *et al.* Atmospheric component of the MPI-M Earth System Model: ECHAM6. *J. Adv. Model. Earth Syst.* **5**, 146–172 (2013).

[3] Popke, D., Popke, Mauritsen, T. & Stevens, B. Inter-model spread in hydrological sensitivity is small. *J. Adv. Model. Earth Syst.* In preparation (2014).

[4] Brient, F. & Bony, S. Interpretation of the positive low-cloud feedback predicted by a climate model under global warming. *Climate Dynamics* **40**, 2415–2431 (2013).

[5] Rieck, M., Nuijens, L. & Stevens, B. Marine Boundary Layer Cloud Feedbacks in a Constant Relative Humidity Atmosphere. *J. Atmos. Sci* **69**, 2538–2550 (2012).

[6] Webb, M. J. & Lock, A. P. Coupling between subtropical cloud feedback and the local hydrological cycle in a climate model. *Climate Dynamics* **41**, 1923–1939 (2012).

[7] Sherwood, S. C., Bony, S. & Dufresne, J.-L. Spread in model climate sensitivity traced to atmospheric convective mixing. *Nature* **505**, 37–42 (2014).

[8] Gesso, S. D., Siebesma, A. P., de Roode, S. R. & van Wessem, J. M. A mixed-layer model perspective on stratocumulus steady states in a perturbed climate. *Quarterly Journal of the Royal Meteorological Society* n/a–n/a (2014). URL `http://dx.doi.org/10.1002/qj.2282`.

[9] Oueslati, B. & Bellon, G. Tropical precipitation regimes and mechanisms of regime transitions: contrasting two aquaplanet general circulation models. *Climate Dynamics* **40**, 2345–2358 (2012).

[10] Möbis, B. & Stevens, B. Factors controlling the position of the Intertropical Convergence Zone on an aquaplanet. *J. Adv. Model. Earth Syst.* **4**, 1–16 (2012).

[11] Oueslati, B. & Bellon, G. Convective Entrainment and Large-Scale Organization of Tropical Precipitation: Sensitivity of the CNRM-CM5 Hierarchy of Models. *J. Climate* **26**, 2931–2946 (2013).

[12] Crueger, T., Stevens, B. & Brokopf, R. The Madden–Julian Oscillation in ECHAM6 and the Introduction of an Objective MJO Metric. *J. Climate* **26**, 3241–3257 (2013).

[13] Fermepin, S. & Bony, S. Influence of low-cloud radiative effects on tropical circulaton and precipitation. *J. Adv. Model. Earth Syst.* 1–34– in press (2014).

[14] Voigt, A., Bony, S., Dufresne, J.-L. & Stevens, B. The radiative impact of clouds on the shift of the inter-tropical convergence zone. *Geophys. Res. Lett.* 1–27– in press (2014).

[15] Bony, S. *et al.* Robust direct effect of carbon dioxide on tropical circulation and regional precipitation. *Nature Geoscience* **6**, 447–451 (2013).

[16] Sherwood, S. *et al.* Adjustments in the forcing-feedback framework for understanding climate change. *Bull. Amer. Meteorol. Soc* 1–41 submitted (2014).

[17] Neggers, R. A. J. & Siebesma, A. P. Constraining a system of interacting parameterizations through multiple-parameter evaluation. *J. Climate* **26**, 6698–6715 (2013).

[18] Brient, F., Bony, S., Schneider, T. & Tan, Z. On the antagonist role of convection and turbulence on trpical-low-cloud feedback in climate models. *Climate Dynamics* in press.

[19] Bodas-Salcedo, A., Williams, K. D. & Ringer, M. A. Origins of the Solar Radiation Biases over the Southern Ocean in CFMIP2 Models*. *Journal of ...* (2014).

[20] Webb, M. J. *et al.* The diurnal cycle of marine cloud feedback in climate models . *Climate Dynamics* 1–37– in press (2014).

[21] Popke, D., Stevens, B. & Voigt, A. Climate and climate change in a radiative-convective equilibrium version of ECHAM6. *J. Adv. Model. Earth Syst.* **5**, 1–14 (2013).

[22] Nuijens, L., Medeiros, B., Sandu, I. & Almgren, A. S. The behavior of trade-wind cloudiness in observations and models. Part I: the major cloud components and their variability. *J Geophys Res-Atmos* to be submitted. (2014).

[23] Medeiros, B., Stevens, B. & Bony, S. Using aquaplanets to understand the robust responses of comprehensive climate models to forcing. *Climate Dynamics* (2014).