Metric choice for trading off short- and long-lived climate forcers –
A transdisciplinary approach using the example of aviation

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With advancing climate change there is a growing need to include short-lived climate forcers in cost-efficient mitigation strategies to achieve international climate policy targets. Simple measures, so called climate metrics are required to compare the climate impact of perturbations with distinct different atmospheric lifetimes and atmospheric properties in view of defined policy targets. A multitude of physical and economic emission metrics have been presented in the literature. However, only few scholarly papers exist which consider metrics from a meta-perspective, including atmospheric and economic sciences, and which allow a clearly structured discussion. Further, in particular, metric values for trading-off SLCF and CO2 are highly ambiguous. Choices in climate metric design determine decisively the relative weighting of SLCF and CO2. In aviation, there is a particular need for agreeing on a tool to weigh perturbation with distinctly different atmospheric lifetimes. Short-lived perturbations (linear contrails, contrail cirrus and nitrogen oxide induced ozone) contribute to a significant share to the sector's climate impact.

This dissertation suggests that promoting a transdisciplinary approach to climate metrics has the potential to clarify the role of climate metric choices, particularly for trading-off short- and long-lived climate forcers. The articles assembled in this cumulative dissertation aim at enhancing the understanding of the atmospheric scientific, economic and policy aspects in metric choices: for climate metric design in general, for climate metrics to evaluate short- and longlived climate forcers and for the practical example, the relative weighting of aviation-induced contrails and CO2.

To start, the dissertation presents a physico-economic framework on climate metric design, based on the underlying impact and weighting function of metrics. The framework allows classifying climate metrics from the literature in a straightforward manner. The analysis illustrates that from the economics perspective, the Global Damage Potential can be considered as a first-best benchmark metric since it ensures that the trade-off between different forcing agents is efficient. Virtually all climate metrics can be constructed as variants of the Global Damage Potential. The framework facilitates for the first time a structured discussion on climate metrics since it reveals normative assumptions and simplifications that are implicit to the choice of a climate metric. The evaluation of commonly used metric approaches in terms of uncertainties reveals that the choice of metric is largely coined by trade-offs between different kinds of uncertainties, explicit ones which are directly linked to operational feasibility and implicit structural ones which reflect the degree of policy relevance. A quantitative climate metric assessment focuses on a generic trade-off situation in aviation. An evaluation framework is presented to demonstrate the impact of individual physical metric choices on the preferred mitigation strategy. The concept of a turning point is established, which indicates the point in time where the mitigation of a short-term effect (e. g. line – shaped contrails) at the expense of a counteracting long-term effect (e. g. CO2) becomes preferable. The analysis shows that in the considered generic situation, some physical metrics are better suited than others to trade off short- and long-lived climate effects for obtaining a robust policy recommendation. The preferred mitigation strategy depends particularly on the evaluation horizon, over which climate impacts are to be minimized (cost-benefit approach) and the selected aviation emission type (pulse, sustained, scenario). At any stage, value judgements must guide the required policy decision on metric options. However, including not only linear contrails but

also contrail cirrus in the assessment leads to a situation in which normative decisions become secondary. The mitigation of aviation-induced cloudiness becomes preferable.

Subsequently, the common characteristic of short-lived climate forcers (SLCF), the short atmospheric lifetime is used to present a generic approach for relating the climate effect of SLCF to that of CO2. It is distinguished between three alternative types of metric-based factors to derive CO2 equivalences for SLCF. Within the generalized approach, numerical values for a wide range of parameter assumptions are derived. The practical application is demonstrated using the example of aviation-induced cloudiness. The evaluation of CO2 equivalences for SLCF tends to be more sensitive to SLCF specific physical uncertainties and the normative choice of a discount rate than to the choice of a physical or economic metric approach. The ability of physical metrics to approximate economic-based metrics depends on atmospheric concentration levels and trends. Under reference conditions, physical CO2 equivalences for SLCF could provide an adequate proxy for economic ones. The latter, however, allow detailed insight into structural uncertainties.

A book article, finally, provides a review of the negotiation process in international aviation as background analysis. It explores the political setting for introducing binding, globally harmonised climate targets to limit the aviationinduced contribution to climate change. The policy analysis demonstrates that negotiating climate policies to limit emissions from international aviation has proven to be exceedingly difficult. The article presents possible options to include international aviation in a binding global climate regime and relates them to the negotiation positions of different actors. Special attention is paid to the global sectoral approach. The latter allows to raise revenues for adaptation to climate change in developing countries.

The dissertation reveals that when trading off SLCF and CO2 on the basis of emission-based global- and annual-mean metrics, the basic challenges of metric design persist, some of the critical design challenges, however, reinforce due to the nature of SLCF: the relative weighting of SLCF and CO2 is more sensitive to scientific uncertainties and normative value judgements with respect to the time frame and policy approach than to the selected metric approach (physical, physico-economic). The metrics or CO2 equivalences for SLCF are expected to a large variability when scientific knowledge on the climate system and the small scale climate impacts of SLCF advances and the perceived urgency of near-term mitigation evolves.

Finally, in a climate regime which aims at limiting not only long-term climate change but also controlling the rate of climate change, a multi-gas strategy with a single metric for all types of climate perturbation comes to its limit. While metrics and CO2 equivalences for SLCF treat SLCF and CO2 as substitutes, action on limiting short- and long-lived forcers are rather complements. This could be subject to further research.