Dynamical Polar Warming Amplification and a New Climate Feedback Analysis Framework

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Historically, only the thermodynamic processes (e.g., water vapor, cloud, surface albedo, and atmospheric lapse rate) that directly influence the TOA radiative energy flux balance are considered in climate feedback analysis. One of my recent research areas is to develop a new framework for climate feedback analysis that explicitly takes into consideration not only the thermodynamic processes that the directly influence the TOA radiative energy flux balance but also the local dynamical (e.g., evaporation, surface sensible heat flux, vertical convections etc) and non-local dynamical (large-scale horizontal energy transport) processes in aiming to explain the warming asymmetry between high and low latitudes, between ocean and land, and between the surface and atmosphere.

In this talk, I will begin with a brief review on the partial radiative perturbation (PRP) method, the primary climate feedback analysis method used in the IPCC AR4 report. To demonstrate the need for developing a new framework, I will present a theoretical evidence showing the change in the atmospheric poleward energy transport is one of the leading factors causing the polar warming amplification. The theoretical proof resolves the seemingly paradox, namely, “how can the warming in high latitude be greater than the low latitude warming by the atmospheric poleward heat transport given the fact the atmospheric poleward heat transport itself is driven by the poleward decreasing temperature profile?”

Next, I will propose a coupled atmosphere-surface climate feedback-response analysis model (CFRAM) as a new framework for estimating climate feedback and sensitivity in coupled general circulation models with a full physical parameterization package. The formulation of the CFRAM is based on the energy balance in an atmosphere-surface column. In the CFRAM, the isolation of partial temperature changes due to an external forcing alone or an individual feedback is achieved by solving the linearized infrared radiation transfer model subject to individual energy flux perturbations (external or due to feedbacks). The partial temperature changes are addable and their sum is equal to the (total) temperature change (in the linear sense). The decomposition of feedbacks is based on the thermodynamic and dynamical processes that directly affect individual energy flux terms. Therefore, not only those feedbacks that directly affect the TOA radiative fluxes but also those feedbacks that do not directly affect the TOA radiation are explicitly included in the CFRAM. The differences between the CFRAM and PRP will be illustrated using a radiative-convective climate model.

In the end, I will present some results obtained with an idealized GCM model that does not include the hydrological cycle (therefore, cloud and ice-albedo feedbacks are not included). The objective is to confirm the theoretical finding that in the absence of the ice-albedo feedback, the dynamical feedback alone via an increasing in the poleward energy transport can lead to a surface warming that is stronger in high latitudes. The CFRAM is used to isolate the partial temperature changes due to the external forcing, due to water vapor feedback, local vertical convection and non-local dynamical feedbacks. The sum of these partial temperature changes is responsible for the (total) atmospheric and surface warming patterns derived from the climate perturbation simulations using the simple GCM. The feedback analysis using the CFRAM shows that the stronger polar warming in this idealized GCM is solely due to the non-local dynamical feedback, as in the theoretical model.