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Climate Feedbacks: Some Conceptual and Physical Issues (Vilhelm Bjerknes Medal Lecture)

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Discussion of feedbacks in the climate literature is hampered by a lack of clear distinction between the many different senses in which the term climate feedback is used. In a recent non-exhaustive study of this topic (Bates, QJRMS, 2007, 545-560, Erratum, p. 1071), four categories of feedback have been delineated: categories F1 (control theory definition), F2 (electronics definition), F3 (stability-altering definition) and F4 (sensitivity-altering definition). It was shown that these four categories, often regarded as synonymous, are conceptually distinct and that any pair of them can have conflicting signs when applied to an appropriately chosen system.

In this presentation, the above results will be discussed and the investigation will be further extended. The system used for the extended investigation is a two-zone (tropics and extratropics) hemispheric climate model incorporating a linearized version of the Iris mechanism of Lindzen et al. (BAMS, 2001, 417-432) in the tropical zone, and dynamical heat transport between the tropical and extratropical zones. This model is based on top-of-the-atmosphere energy balance. The Iris feedback is in the first instance a local stability-altering (F3) feedback, being based on satellite observations that indicate how cloud-radiative effects cause a tropical SST perturbation about the equilibrium climate to decay back to zero. The observations were used by Lindzen et al. in conjunction with a simple one-zone hemispheric model to estimate the influence of the Iris mechanism as a global sensitivity-altering (F4) feedback. In the context of their model, the Iris feedback necessarily has the same sign as an F3 and an F4 feedback, strongly stabilizing local SST perturbations and strongly diminishing the equilibrium sensitivity of the global-mean surface temperature to a CO2 doubling. It will be shown that when the more complete two-zone model involving dynamical heat transport is used, the equivalence in sign between the Iris feedback according to the definitions F3 and F4 no longer necessarily holds. Even if the signs happen to be the same, the quantitative effects are no longer necessarily the same: the Iris mechanism can act as a strong local stabilizing feedback while providing only a weak global sensitivity-diminishing feedback.

The two-zone Iris model is also used to investigate another common assumption, viz., that separate F4 feedbacks are linearly additive. It is shown that, contrary to the case of the one-zone model, the longwave and shortwave Iris F4 feedbacks are no longer linearly additive in the two-zone model; with appropriately chosen parameters, it is even possible for the individual feedbacks to be of the same sign while their combined feedback is of the opposite sign. It is stressed that his holds despite the fact that the governing equations are linearized.

It will be argued that there is an urgent need for the introduction of internationally-agreed standardised definitions in the area of climate feedbacks and for a realization that some common assumptions regarding climate feedbacks are not generally valid.