# Reply

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Chou and Lindzen (2005, hereafter CL) claim that the long-term *Earth Radiation Budget Satellite* (*ERBS*) nonscanner measurements reflect a strong negative feedback between top of the atmosphere (TOA) radiation and the surface temperature, and is consistent with the Iris hypothesis proposed by Lindzen et al. (2001, hereafter LCH). They disagree with the finding of Lin et al. (2004, hereafter LWWH) that no evidence exists for the Iris hypothesis effect in the long-term *ERBS* data. After examining the decadal *ERBS* data in the context of CL comments, we again conclude that no evidence exists in support of the Iris hypothesis—the strong negative feedback of the climate.

The first CL comment was to derive a set of linear climate feedback equations [their Eqs. (1)–(5)] that relate climate response $F\Delta T$, produced by cloud feedback, to net radiative flux, that is, $F\Delta T = \Delta R_{\rm net}$, where $\Delta R_{\rm net}$ is the ERBS decadal net radiative flux anomaly for the Tropics, $\Delta T$ is the tropical mean SST change, and $F$ is related to the cloud feedback factor. The fact that $\Delta R_{\rm net}$ is $-0.65$ W m$^{-2}$ (LWWH, their Table 2) and indicates anomalous cooling of the Tropics in the warmer 1990s is then used to estimate the cloud feedback factor and to indicate consistency with the Iris hypothesis prediction of a strong negative cloud feedback. There are four implicit assumptions in this overly simple feedback calculation, none of which can be currently justified.

(a) Equations (1)–(5) of CL only apply to global conditions, unless we can assume that there is no horizontal heat transport change between the Tropics and the rest of the globe. The combined ocean and atmosphere heat transport out of the Tropics is roughly 65 W m$^{-2}$ in magnitude (the net radiative imbalance of the Tropics from *ERBS*). Use of their Eqs. (1)–(5) to estimate cloud feedback requires the assumption that the heat transport is constant to within 0.2 W m$^{-2}$ if the small $-0.65$ W m$^{-2}$ tropical net radiation anomaly is to be uniquely related to cloud feedback, and not to the internal variability in heat transport. We are unaware of any observations that demonstrate a climate system with poleward transport stability of better than 0.3%. We conclude that this assumption cannot be justified.

(b) Use of CL's Eqs. (1)–(5) also requires that there be no change in ocean heat storage greater than 0.2 W m$^{-2}$ from the 1980s to the 1990s. The current ocean heat storage data do not support such small variability in ocean heat storage on a 10-yr time scale (Levitus et al. 2001).

(c) Use of CL's Eqs. (1)–(5) assumes that the remainder of the earth (poleward of 20°N and 20°S) has the same net radiative flux anomaly and cloud feedback as the Tropics. This is assumed neither by the Iris hypothesis itself, nor is it assumed in LWWH, and it is not justified. Note that the *ERBS* 20°S–20°N anomaly covers only 1/3 of the globe, and that Eqs. (1)–(5) of CL extrapolate this to the entire earth.

(d) Use of the ratio of $F = \Delta T/\Delta R_{\rm net}$ = (0.144 K)/($-0.65$ W m$^{-2}$) to estimate cloud feedback assumes that the small *ERBS* net flux anomaly of $-0.65$ W m$^{-2}$ is known to better than 0.2 W m$^{-2}$ in order to obtain a 30% uncertainty in $F$. In fact, the discussion in Wielicki et al. (2002) indicated that the uncertainty was estimated as ~0.5 W m$^{-2}$, and that the net flux change was not considered significant. Even without constraints a and b, this uncertainty negates any confidence in the CL cloud feedback estimate from $F$.

We conclude that while the attempt to relate the ERBS net flux anomaly to cloud feedback is interesting, it is not sufficiently accurate or well founded, and cannot support the Iris hypothesis. We did not attempt

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such a feedback analysis in LWWH for the same reasons. Future Tropics-only cloud feedback studies of this type will require additional measurements of interannual ocean heat storage and ocean-plus-atmosphere heat transport at accuracies that are commensurate with the radiation anomalies.

Next, CL comment that it is illogical for LWWH to conclude that the relationship between the tropical high cloud cover and surface temperature of the Iris hypothesis (i.e., $-22\%\ K^{-1}$) is incorrect, based on the fact that the Iris hypothesis–predicted radiation anomalies do not agree with the *ERBS*-measured anomalies. They further argue that 1) the negative cloud–SST relationship is correct, based on the *ERBS* data shown in LWWH, and that 2) the magnitude of the negative slope ($-22\%\ K^{-1}$) is, in fact, not strong enough. When compared to the *ERBS* data, the Iris hypothesis–predicted anomalies are smaller by a factor 1.5–3 for the longwave (LW) anomalies and a factor of 3–8 for the shortwave (SW) anomalies. As well, CL claim that the Iris hypothesis slope needs to be greatly enhanced to be consistent with *ERBS* data.

The only variation of the Iris hypothesis that comes close to the *ERBS* decadal change observations in LWWH's Table 2 would be to double the Iris hypothesis cloud–SST relationship to $-44\%\ K^{-1}$ and modify the original Iris hypothesis to use the Langley Research Center (LaRC) Clouds and the Earth's Radiant Energy System (CERES) radiative properties with gamma = 1. In this case the Iris hypothesis–predicted (LW, SW, net radiation) flux changes from their Table 2 become (2.8, 2.0, and $-0.9\ W\ m^{-2}$), which compare favorably with the *ERBS* values of (3.0, 2.4, and $-0.7$), and are within the 0.5 $W\ m^{-2}$ uncertainty in *ERBS* calibration stability indicated in Wielicki et al. (2002). The Iris hypothesis using the LaRC CERES radiative properties, however, is a small positive feedback for equilibrium climate change, not a strong negative feedback as originally proposed by the Iris hypothesis in LCH, and as argued in CL's comment. Note that if we double the Iris hypothesis cloud–SST relationship and apply it to the original Iris hypothesis radiative properties in LCH with gamma = 0.0, we predict flux changes of (2.9, 0.8, and $-2.1$)—a factor of 2–3 error in the fit to *ERBS*. Because the radiative anomalies change nearly linearly with the cloud–SST slope, there is no way to simultaneously fit both LW and SW anomalies using the original Iris hypothesis radiative properties and scaling the Iris hypothesis gamma = 0 or gamma = 1 Iris hypothesis results in LWWH's Table 2. In all cases, the Iris hypothesis SW effect is a factor of 4 to 5 smaller than the LW effect. This is counter to the *ERBS* results of similar magnitude SW and LW anomalies in LWWH's Table 2. This is also the origin of our conclusion that the Iris hypothesis "exaggerates" the effect of cloud LW changes over cloud SW changes. The ratio of these two cloud radiative effects controls whether the Iris hypothesis feedback is positive or negative.

There also appears to be confusion about the negative *ERBS* net flux anomaly (tropical cooling anomaly) and its relationship to negative or positive cloud feedback in the climate system. First, note that applying the Iris hypothesis to observed SST anomalies in order to predict radiative flux anomalies is not an equilibrium climate solution, and a net flux of zero is not expected. Given the increased SST, and because of the temperature dependence of atmospheric LW radiation, the Iris hypothesis–predicted net flux anomaly without any cloud feedback will still be negative—an increased LW flux but no change in SW flux. Therefore, a negative net flux in the Tropics does not, by itself, imply negative cloud feedback. Instead, negative cloud feedback will increase the magnitude of the negative net flux anomaly. In LWWH's Table 2 this explains the larger negative net flux anomaly that is predicted by the original Iris hypothesis (strong negative cloud feedback), in comparison to the smaller negative net flux anomaly predicted by the LaRC-modified Iris hypothesis (small positive cloud feedback). As mentioned earlier, the net flux anomaly is only directly relevant for cloud feedback if the ocean heat storage and equator-to-pole heat transport remain unchanged.

We conclude that the Iris hypothesis from LCH (strong negative feedback) cannot explain the observational changes in LWWH's Table 2. Further, modifying the original Iris hypothesis to better fit the observations (LaRC, gamma = 1) predicts a small positive cloud feedback, not a strong negative feedback.

Next, CL questioned the analysis of the *ERBS* data used in LWWH. They pointed out that the analysis of *ERBS* data is for both land and ocean, while only sea surface temperature is used in the Iris hypothesis simulations of LWWH. Although it is somewhat difficult to obtain the tropical radiation anomalies over ocean because of the large spatial resolution of the *ERBS* nonscanner instrument, the values for the whole Tropics and ocean-only tropical areas can be estimated from the *ERBS* data using the land percentage within the ERBE 1000-km-scale grid box. As mentioned in LWWH, the averaged differences of the radiation anomalies between whole Tropics and ocean-only data are about 0.01, $-0.07$, and 0.06 $W\ m^{-2}$ for LW, SW, and net radiation, respectively, which are well within the uncertainties of the estimated radiation anomalies. Furthermore, the average difference of surface temperature anomalies between ocean-only and whole Tropics values is only about 0.04 K. Restricting the analysis to ocean areas only would not have changed the result.

Concerning references, CL are concerned that LWWH failed to include some of their references in the literature, in particular, their comments on other papers. The list of references is not meant to be exhaustive, but to gives readers the major starting points. We also did not reference the replies to CL comments, so there was no "bias" in not including literature comments. We felt that the original papers were more compelling and relevant than the comment discussions. We have included a more complete list attached to this note for those who are interested (Baker 2002; Chambers et al. 2002a, b; Chou et al. 2002a,b; Fu et al. 2001; Hartmann and Michelsen 2002a,b; Lin et al. 2002; Lindzen et al. 2001, 2002).

Also, CL were concerned that the Iris hypothesis was taken too literally, and that the cloud brightness temperature thresholds were only meant as examples of how changes in clouds might occur. We agree that this might be the case, so that varying definitions of high cloud need to be examined to fully evaluate the Iris hypothesis. Chambers et al. (2002b, hereafter CLY) addressed exactly this concern by examining the Tropical Rainfall Measuring Mission (TRMM) CERES cloud property and radiation budget data for a wide range of ice cloud definitions, including particle phase, cirrus emissivity, and cloud height/temperature. CLY were unable to find any cases with cloud radiative properties that led to large negative feedbacks as in the original Iris hypothesis. The basic conclusion remains: the difference between the net radiative fluxes of the cloudy moist and clear moist regions should be small. The radiative forcing resulting from a change in tropical high cloud amount is still 1/10, or even smaller, of that modeled by LCH. The key point to remember is that the albedo and LW flux *both* depend on the population of clouds chosen. If the definition of the cloudy moist region is changed, then the area coverage, albedo, and LW flux will all change too.

As well, CL comment on the studies of Chen et al. (2002) and Del Genio and Kovari (2002). LWWH conclude that the observed changes in radiation are more likely due to the intensification of the tropical circulation, following the explanation of Chen et al., and cited the conclusion of Del Genio and Kovari that the Iris hypothesis is inconsistent with their data measured by TRMM. However, CL claim that both the explanation of Chen et al. and the conclusion of Del Genio and Kovari are inappropriate to the evaluation of the Iris hypothesis effect, and further argue that both Chen et al. and Del Genio and Kovari fail to distinguish changes in cloud cover due to increased or decreased cumulus convection from changes due to increased or decreased detrainment from cumulus towers. The cloud feedback arguments in LWWH, CL, and this reply hinge critically on the radiative properties of clouds and the earth–atmosphere system. Convection and detrainment are secondary issues, and are more appropriately replied to by Chen et al., and Del Genio and Kovari.

Finally, CL comment that LWWH, Chen et al. (2002), and Wielicki et al. (2002) provide confirmation for the Iris hypothesis, and claim that it is good news for those who are concerned with global warming. We would also welcome any suggestions of strong negative radiative feedbacks to stabilize the earth's climate system. Unfortunately, as studied by LWWH and the discussions in this reply, there is no evidence found in the decadal *ERBS* data to support the strong negative feedback suggested by the Iris hypothesis.

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