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Comparison of 30 Day Integrations with and without Interactive Clouds

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A cloud-radiation interaction parameterization package has recently been incorporated into a global spectral GCM used for extended range prediction studies at GFDL. The elements of this package are summarized. Analysis of the time mean radiative and dynamical responses suggests that cloud-radiation interaction has a favorable impact, overall, on systematic errors. The possible relevance of this sensitivity study to FIRE is mentioned.

Fractional cloud amount is predicted empirically in a manner similar to J. Slingo (1987), although the humidity threshold is reduced to 70%, the relationship between cloud fraction and relative humidity is linear, and a shallow convective cloud type is predicted for radiative purposes. The optical depth of sub-freezing, cold clouds varies quadratically with temperature following Platt and Harshvardhan (1988). Otherwise, distinct constant values are specified for high, middle and low clouds. The long- and shortwave cloud optical properties are linked to the cloud optical depth, employing an algorithm of V. Ramaswamy (1987, personal communication).

The GCM's sensitivity to interactive clouds is investigated for the extended forecast range, by performing two sets of 30 day integrations for 3 winter and 3 summer cases (referred to by the respective dates of the initial conditions): (i) CLDRADI employs the above package of parameterizations; (ii) LONDON utilizes the GCM's standard specification of zonal mean cloud amount, absorptivity, reflectivity and **blackbody** emissivity. The CLDRADI and LONDON GCM's are identical in all other respects. The model resolution is R21L18, denoting rhomboidal spectral truncation at wave number 21 and 18 sigma levels in the vertical. The usual physical parameterizations are retained - Mellor-Yamada turbulence closure, Monin-Obukhov surface boundary layer, water bucket hydrology, Fels-Schwarzkopf radiation, moist convective adjustment and orography; and linear mountain gravity wave drag is incorporated. A few auxilliary integrations are performed for a single case to help clarify the results. For example, parameterized shallow convection in the spirit of Tiedke et al. (1988) is added in KSHLCNV; and the Platt-Harshvardhan temperature dependence of cloud optical depths is suppressed in WARM τ.

The 30 day mean CLDRADI total cloud amount for one winter and one summer case are shown in Fig. 1, and the CLDRADI, LONDON and observed OLR (winter case only) in Fig. 2. The GCM-predicted cloud amount fields and corresponding OLR fields are plausible in many respects, especially in the tropics, where they exhibit ITCZ-like and SPCZ-like features. In contrast, the OLR fields from the control integrations do not. The CLDRADI OLR fields agree better, overall, than LONDON with NIMBUS 7 earth radiation budget data. The tropical OLR minima are nonetheless too weak, especially over the Amazon. Some stratus may be noted off the west coasts of South America and Africa in January. Moving on to longwave radiative heating/cooling rates (not shown), the CLDRADI cirrus level

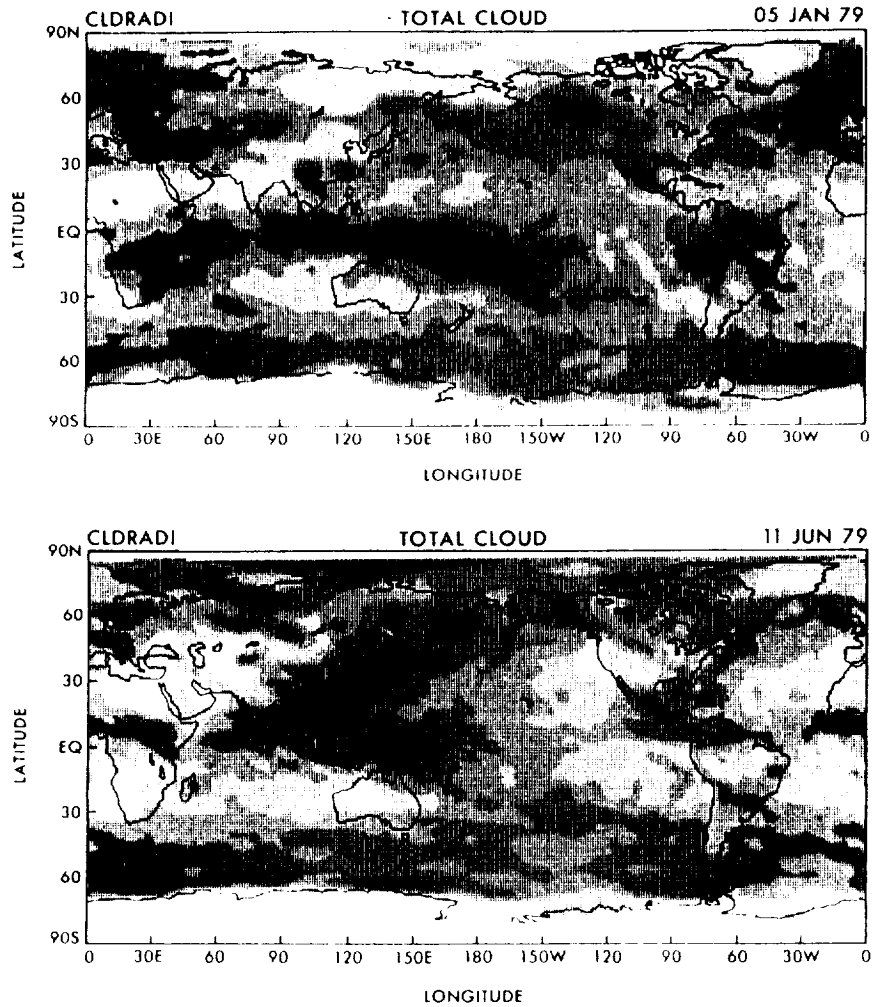

Fig. 1 Day 0-30 30 day mean CLDRADI total cloud amount for 05 Jan 1979 (top) and 11 June 1979 (bottom) cases. Blank = 0-20%; progressively darker shades of stippling for 20-100% in intervals of 20%.

heating is moderately stronger in amplitude, is much more zonally asymmetric, and occurs ~75 hPa higher in the atmosphere, compared to LONDON. Meanwhile, at low cloud top level (e.g., at ~700 hPa in the tropics), the longwave cooling is dramatically reduced in CLDRADI, accompanied by weaker latent heating and adiabatic cooling. The response is considerably enhanced, because the longwave cooling for clouds more than 1 layer thick is not smoothed. LONDON low clouds are particularly sensitive to this adjustment, being always 2 layers thick and zonally symmetric.

The zonal mean OLR tropical bias is positive and surprisingly similar (~7 or 8 Wm^{-2}) for both CLDRADI and LONDON. The higher tops of LONDON vs. CLDRADI low clouds apparently tend to compensate for the higher tops of CLDRADI high clouds. But the CLDRADI tropical bias can be almost eliminated, by suppressing the temperature-dependent Platt-Harshvardhan parameterization of cloud optical depth (not shown). Conversely, we were able to increase the OLR 5 to 6 Wm^{-2} by incorporating shallow convection and another 2 to 4 Wm^{-2} by confining the shallow convective cloud tops beneath 800 hPa instead of 750 hPa.

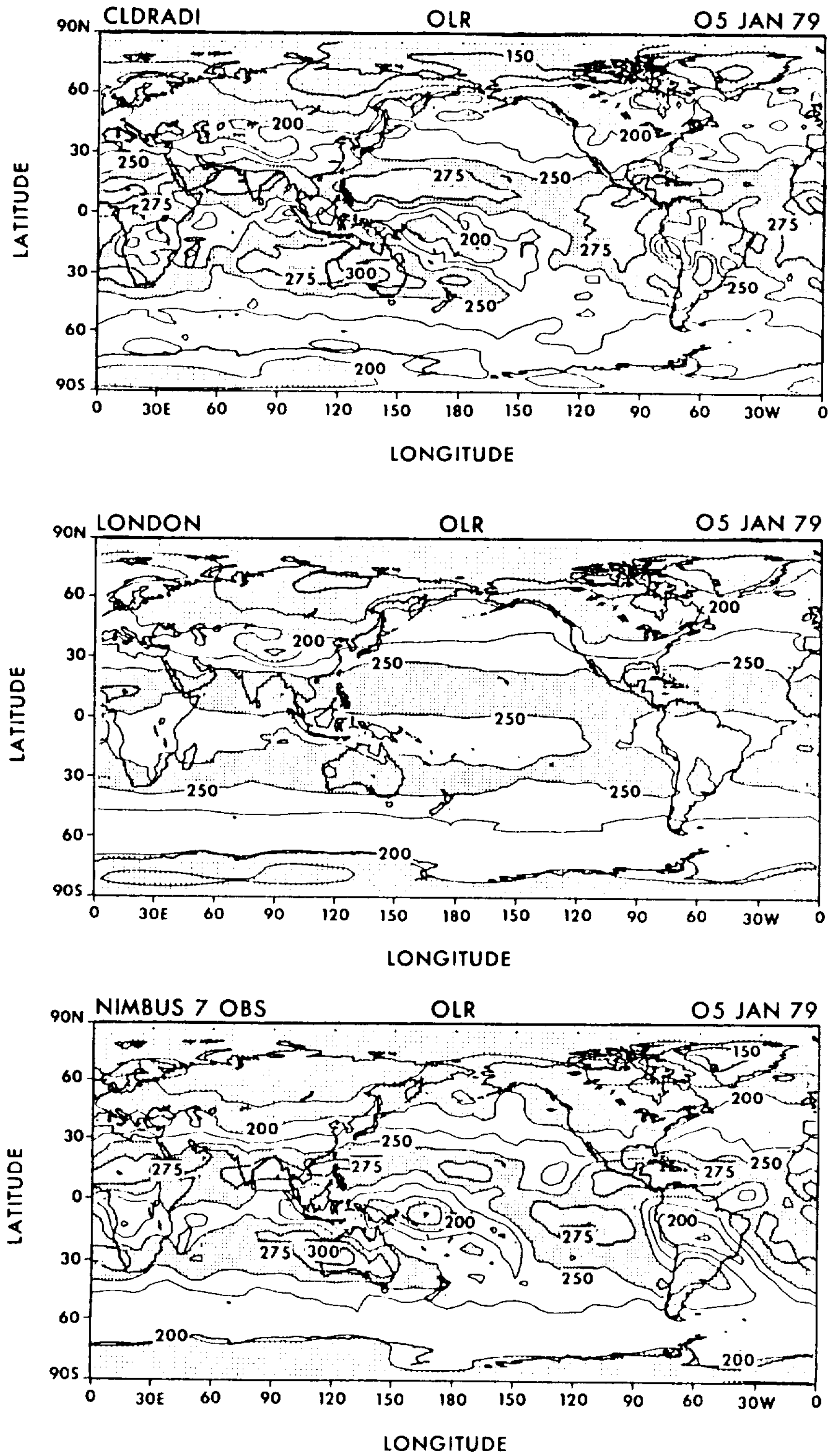

Fig. 2 Day 0-30 30 day mean outgoing longwave radiation. CLDRADI (top) and LONDON (middle) for case of 05 Jan 1979; NIMBUS 7 NFOV Obs (bottom). Contour int. = 25 wm^{-2}.

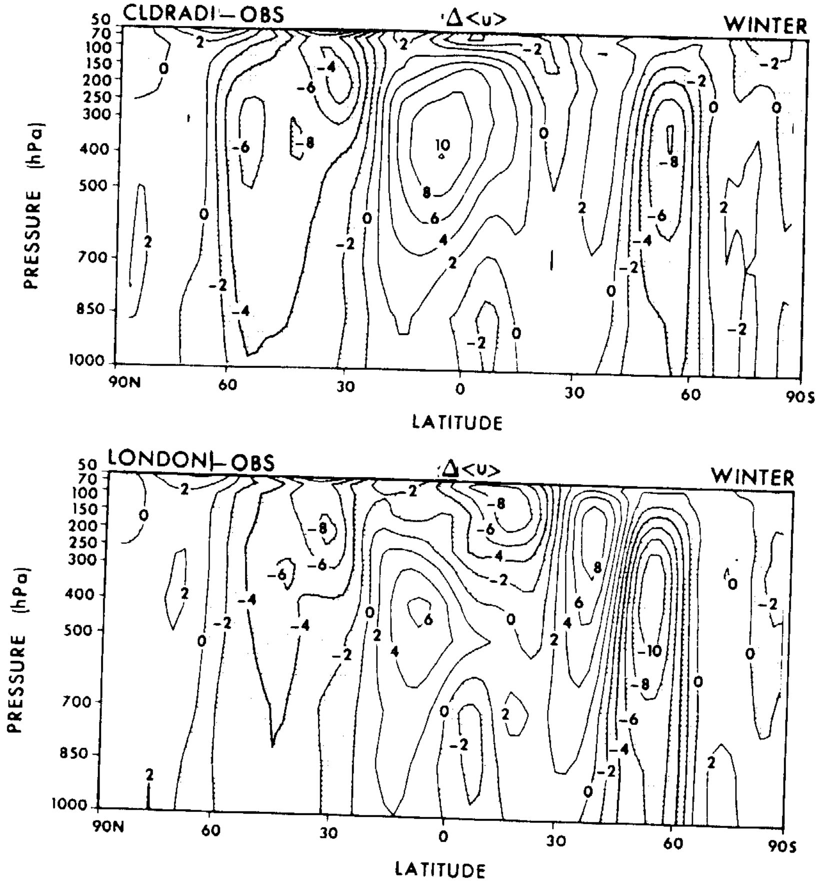

Fig. 3a Day 10-30 20 day winter ensemble mean, zonal mean zonal wind error in the latitude-pressure plane. CLDRADI (top), LONDON (bottom). Contour int. = 2 m s^{-1}.

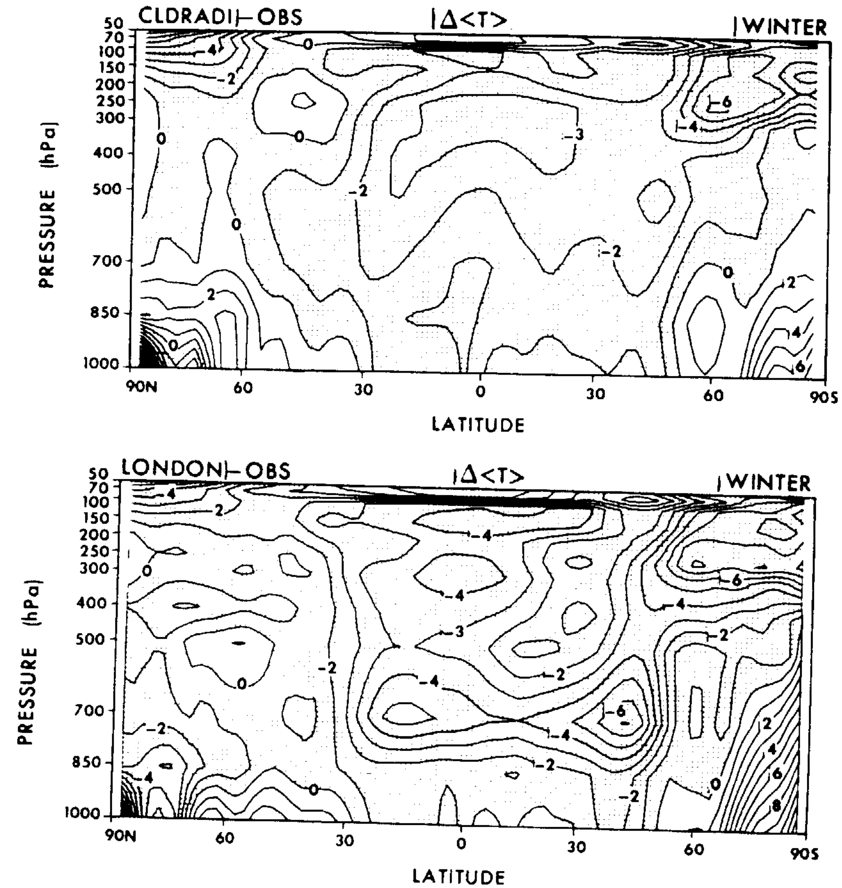

Fig. 3b As in Fig. 3a, for zonal mean temperature error. Contour int. = 1°k.

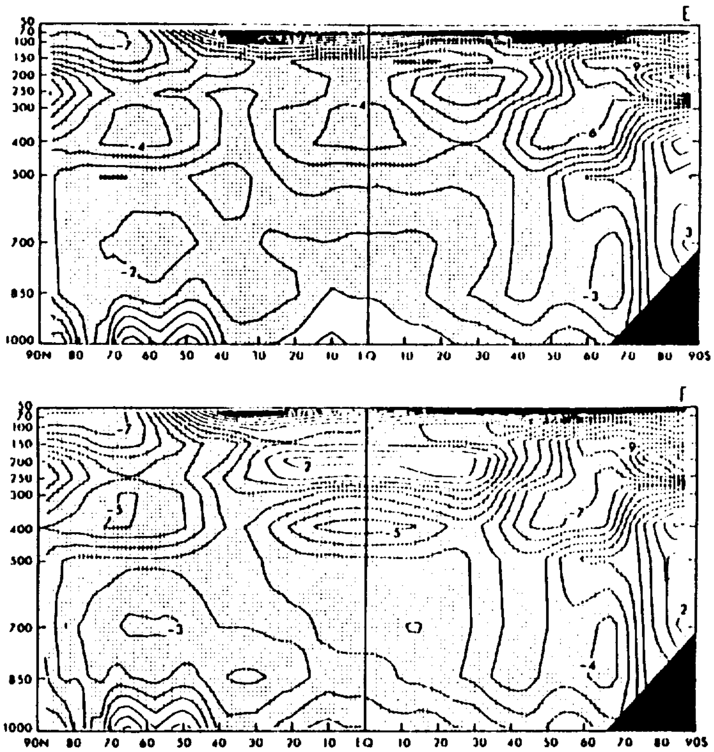

Fig. 4 30 day, 8 case ensemble mean, zonal mean temperature error in the latitude-pressure plane for N48L9 GCM with moist conv. adj. (top) and Arakawa-Schubert (bottom) parameterizations. Contour int. = 1°k. After Sirutis and Miyakoda.

Since contributions to OLR come from various vertical levels, it would be useful to have observations of cloud top and cloud base pressure in the subtropics and tropics as well as the observed vertical profiles of radiative flux and water vapor.

To assess the GCM's dynamical response to cloud-radiation interaction, we shall focus on systematic errors (with respect to NMC observation) and CLDRADI-LONDON differences of the zonal mean temperature and wind fields, because the CLDRADI-LONDON differences (not shown) tend to be statistically significant. The 3-case winter ensemble mean, zonal mean zonal wind and temperature errors are illustrated in Figs. 3a and 3b. The following features of the CLDRADI distributions compare more favorably with observation: a weaker cold bias, i.e., ~2k warmer, centered near the tropical tropopause, and weaker easterlies in the tropical lower stratosphere; weaker SH mid-latitude westerly jet and slightly stronger westerlies poleward of the jet during SH summer; a weaker cold bias in the tropical middle troposphere, and tropical and mid-latitude lower troposphere. In particular, the cold bias near the 700 hPa level in the 30°N-30°S latitude belt is ~4k. Near the South Pole, the lower troposphere is considerably warmer during SH winter and colder during SH summer, in closer agreement with observation, when cloud-radiation interaction is incorporated. The latter responses are essentially radiatively driven by a relative reduction in cloud cover. During NH winter, the CLDRADI zonal mean wind in the tropical upper troposphere is westerly, like observation, but too

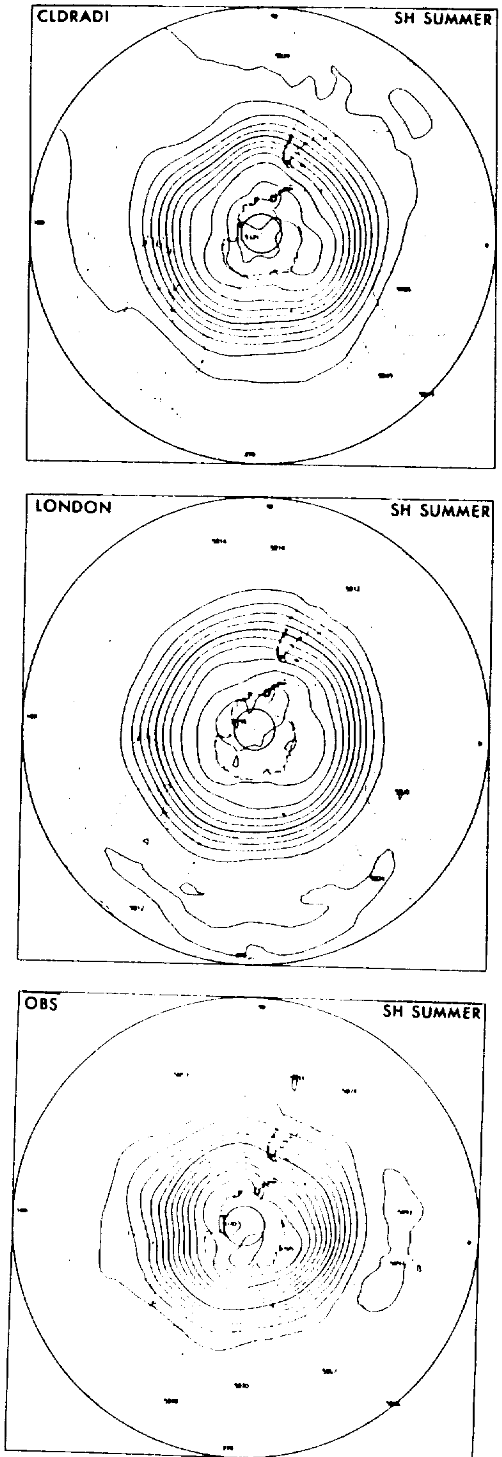

Fig. 5 Day 10-30 20 day ensemble mean 500 hPa geopotential height, for SH summer. CLDRADI (top), LONDON (middle) and NMC observation (bottom). Contour int. = 60 m.

strong, while the corresponding LONDON winds are easterly. Fig. 3b indicates that these westerly and easterly wind errors are of comparable magnitude.

The sensitivity of the systematic temperature error of a 30 day mean forecast by a 2° resolution 9 level GCM to the parameterization of cumulus parameterization is illustrated in Fig. 4. The results are based on an 8 case study by Sirutis and Miyakoda (1989). Note the dipole error structure associated with the Arakawa-Schubert (AS) parameterization in the tropical upper troposphere and the sign reversal near tropopause level when moist convective adjustment is replaced by AS. While the result may not surprise anyone, it illustrates that the systematic temperature error may not be a good indicator of the performance of a cloud-radiation parameterization. Clearly, some pairs of cumulus + cloud-radiation parameterizations are more effective than others at minimizing the systematic temperature error in the upper troposphere. Our present cloud prediction scheme tends to compensate for the apparent cold bias of the moist convective adjustment scheme. Similarly, the anvil cirrus parameterization of Randall et al. (1988), which promotes radiative cooling at tropopause level and warming at ~400 hPa, would tend to oppose the dipole structure of AS in Fig. 4. Conversely, the combination of Randall et al. + moist convective adjustment would probably increase the cold bias in our GCM. Under these circumstances, observed vertical profiles of radiation fluxes in the tropics or subtropics would be a useful verification tool.

The phase and amplitude prediction of geopotential height troughs and ridges at 500 hPa in SH summer is discernably improved when cloud-radiation interaction is incorporated into the model (Fig. 5). Also note the amplification of wavenumber 3. It may be primarily forced by stronger (radiative) diabatic heating in the SH tropics near the tropopause in the presence of more favorable zonal winds. In particular, the CLDRADI upper tropospheric zonal mean westerlies may favor wave propagation to the SH extratropics, whereas the LONDON easterlies may inhibit it. In addition, radiatively induced warming in the tropics, and hence, a strengthening of the equator-to-pole temperature gradient could play a complimentary role, in analogy to Meehl and Albrecht (1988). Their GCM predicted a stronger circumpolar trough in SH summer, in response to enhanced tropical diabatic heating associated with a new parameterization of cumulus convection. Meanwhile, in the NH, where there is more background asymmetric forcing, the 500 hPa ridges tend to be stronger and troughs weaker; and there is no visible evidence of improved phase prediction, at least at R21 resolution.

The relevance of a global GCM sensitivity study to FIRE is not immediately obvious. But perhaps, the favorable impact of cloud-radiation interaction on systematic forecast error in our GCM is at least reassuring. More importantly, awareness gained of the limitations of OLR and temperature data for validating cloud prediction schemes, from the perspective of a GCMer poses a challenge to FIRE II or ASTEX. Namely, can their future observational programs measure vertical profiles of radiative cooling rates, cloud-related variables, water vapor and temperature over the entire troposphere for a region the size of a GCM grid box 250 km square? Horizontal means, computed from these measurements for a range of horizontal scales, could prove valuable for the development and validation of meso-scale and GCM scale cloud parameterizations.

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