# Assessment of the ECMWF Model Cloudiness and Surface Radiation Fields at the ARM SGP Site

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## Abstract

The cloud and radiation fields produced by the operational European Centre for Medium-Range Weather Forecasts (ECMWF) forecasts are assessed using observations from the Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) site over the April through May 1999 period.

Over the first 36 hours of the forecasts, most of the model fields, taken over a 24-hour time window (either 0 to 24, 6 to 30, or 12 to 36-hour) are generally consistent with each other. Comparisons of model fields taken from any such 24-hour time window with observations are therefore representative of the quality of the ECMWF model physical parameterizations.

The surface radiation fluxes are assessed separately for clear-sky, overcast, and whole-sky situations. For clear-sky fluxes, differences between model and observations are linked to differences in humidity and temperature profiles, the characterization of aerosols, and systematic errors in the shortwave (SW) radiation scheme.

Model cloud occurrences and boundaries over the Central Facility are compared with similar quantities derived from radar and Micropulse Lidar (MPL) observations. Model cloud water is tentatively assessed through comparisons with the radar reflectivity measurements. Systematic deficiencies in the surface radiation fields in the presence of clouds are discussed with respect to differences between the model and observed cloud characteristics.

Given the $T_L319$ resolution of the ECMWF model at the time of the comparisons, both the day-to-day and temporal variability within the day are reasonably well captured by 24-hour forecasts including cloud-radiation interactions with 1-hour time resolution. However, most of the differences with observations can be traced back to either deficiencies in the clear-sky SW radiation scheme or problems in the cloud fraction and/or cloud water content.

## Methodology

The study covers the entire months of April and May 1999. A spring period was preferred because spring had, in the past, not been a particularly good period for ECMWF forecasts. Moreover, for somewhat average conditions of temperature and humidity, a large temporal variability can be expected at the latitude of the ARM SGP site (Lamont, Oklahoma, 36.605°N, 97.485°W), depending on the flow direction of the prevalent air mass. In the following, use is made of measurements by the observational systems located at the Central Facility.

The ECMWF fields correspond to outputs every hour for all 36-hour forecasts starting 24 hours apart between 19990331 12 Universal Time Coordinates (UTC) and 19990531 12 UTC. The analyses from which the forecasts were started are obtained through a four-dimensional (4D) variational assimilation of all the observations during a 6-hour window centered around the analysis time. The model used in this study is the so-called cycle 23R1 of the ECMWF Integrated Forecast System, operational between June 27 and November 11, 2000. Among the modifications introduced with cycle 23R1 are the replacement of the previous longwave (LW) scheme (Morcrette 1991) by the Rapid Radiation Transfer Model (Mlawer et al. 1997) and the introduction of a tiling scheme for the surface processes. The Morchette (1991) scheme included cloud effects using maximum-random overlap of effective cloud layers through an effective emissivity approach. The ECMWF version of the Rapid Radiative Transfer Model (RRTM) LW scheme also includes a maximum-random overlap assumption but keeps the cloud fraction and cloud optical thickness as two separate quantities.

The rest of the package of physical parameterizations follows Gregory et al. (2000). All cloudy fluxes are computed from cloud optical thicknesses derived from the prognosed liquid and ice cloud water content weighted by a 0.7 inhomogeneity factor following Tiedtke (1996). The dynamical part of the model includes the two-time-level semi-Lagrangian scheme (Hortal 2000) on a linear grid of Hortal and Simmons (1991), which keeps roughly the same dimension going towards the poles.

In the study presented here, the $T_L319$ L60 model (about 60-km horizontal resolution and 60 levels in the vertical) is run with a 20-minute time-step. The 60-level vertical resolution includes about twelve levels between the surface and the average top of the planetary boundary layer (PBL). The full radiation computations (i.e., those using updated cloud fraction and cloud water) are called every hour.

## Comparisons at the Central Facility

### Total Column Water Vapor and Cloud Water

The model total column water vapor (TCWV) and total column cloud water (TCCW) are compared for April 1999, with quantities derived from Microwave Radiometer (MWR) observations in Figure 1 (top and bottom, respectively). The agreement in TCWV is quite good, especially for the low values. For the highest values, some uncertainty might exist in the observations, due to moisture condensing on the observing device. The periods over which such a problem occurs are given by the wet index at the bottom of Figure 1a and top of Figure 1b.

The TCCW (Figure 1 bottom) is much more difficult to assess. The model TCCW includes both the liquid and ice water, whereas the retrieved TCCW based on the difference between observations at 23.8 and 31.4 GHz is really cloud liquid water only. The peaks in the observations obviously correspond to clouds above the MWR. They are also usually flagged as wet, so the observations are likely to include precipitation.

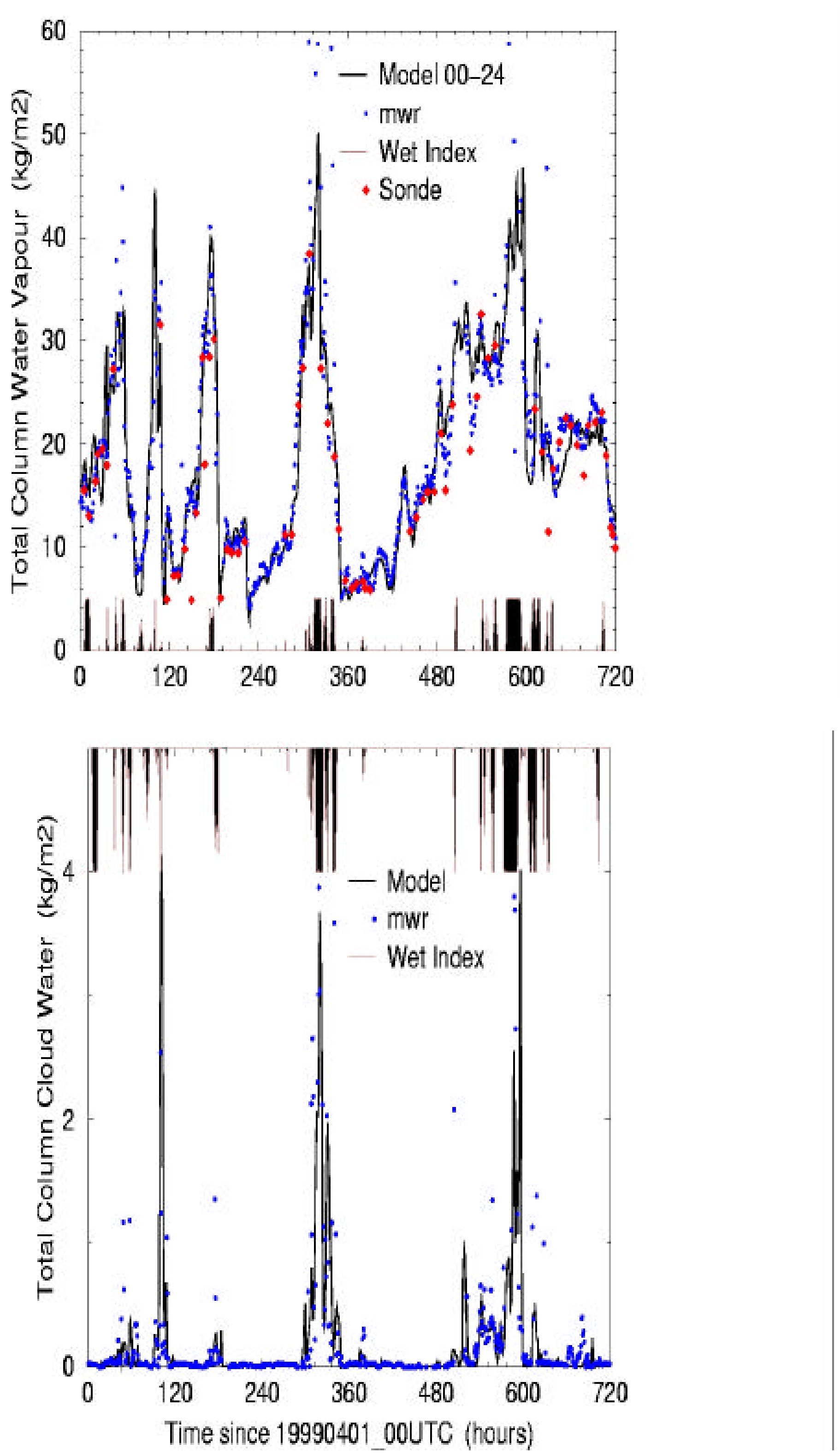


**Figure 1**. The vertically integrated water vapor (top) and vertically integrated cloud water (bottom) over the ARM SGP Central Facility. Measurements are from the MWR.

## Downward Radiation

The corresponding surface downward SW and LW radiation (referred to as SSRD and STRD, within the ECMWF model and archive) are presented in Figure 2 (top for SSRD, bottom for STRD) as measured from two sets of radiometers located at the Central Facility (C1 and E13) and as represented by the model forecasts. For all the time slots for which both the E13 and C1 measurements are available over the April through May period, the correlation between the two stations is better than 0.999 for both SSRD and STRD. Some uncertainty arises from the (small) negative values usually reported by the pyranometers during nighttime. Statistics for SSRD were computed in three different ways—the first set corresponding to all observations during the period, the second set to all observations with nighttime values set to zero, and the third set to daytime observations only. Over the 2-month period of the observations, the difference between the first two approaches is at most 2.5 $Wm^{-2}$. In both cases, the correlation is practically unity, and the slope higher than 0.998. Therefore, the slight disagreement between these two approaches is unlikely to be of concern for evaluating the model behavior.

In clear-sky atmosphere, the STRD is between 240 $Wm^{-2}$ and 290 $Wm^{-2}$. Only when clouds are present, does STRD get over 300 $Wm^{-2}$, with the values over 360 $Wm^{-2}$ corresponding to the presence of low level cloudiness. There is a reasonable agreement between model and observed STRD (Figure 2, bottom), reflecting the ability of the model to produce the cloud events at the right time, with cloud base close to the proper height.

From the 1464 (= 61 days x 24) one-hour slots in April through May 1999, 168 clear-sky situations have been extracted (only 164 such situations are for daytime conditions, and are thus used for the SW). This extraction is based on the following set of conditions: a model total cloud cover < 1%, no return from the Multi-Mode Cloud Radar (MMCR), no cloud base from the Micropulse Lidar (MPL), and a zero wet index from the MWR. Over this set of profiles, there is a very good agreement between the MWR-observed and model TCWV and STRD. The agreement for STRD is within the range obtained when comparing C1 and E13 SIRS measurements. In contrast, even on these selected clear-sky cases, the model SSRD overestimates the observed SSRD by 31.2 $Wm^{-2}$ over the 164 daytime situations. This reflects a likely bias in the SW radiation scheme and with possibly a small contribution from an improper specification of the aerosol optical thickness.

In the presence of cloudiness, the discrepancies between model and observed surface radiation fluxes are as likely to come from incorrect atmospheric profiles, incorrect definition of the cloud parameters (cloud base height and optical properties) produced by the forecasts as from the radiation schemes used in the model. Therefore, a set of 59 overcast situations (25 during daytime are used for SSRD) has been extracted, for which the model total cloud cover (TCC) is > 99%, with presence of clouds during all intervals making the one-hour slot in the MMCR, Beaufort Laser Ceilometer (BLC), and MPL observations. These cases show an agreement on both the cloud cover and the cloud base height. However, the comparison between MWR-observed and model TCWV is certainly affected by moisture condensating (dew) or precipitating on the observing device. The agreement in STRD is again good (with a 2 $Wm^{-2}$ model overestimation). Again, the model SSRD overestimates the observed SSRD by 26.4 $Wm^{-2}$. The overestimation is consistent with the deficiency already seen for the SW radiation scheme in clear-sky conditions, but problems in the definition of the cloud optical parameters (optical thickness in particular) cannot be ruled out and are as likely to increase as decrease the clear-sky error.

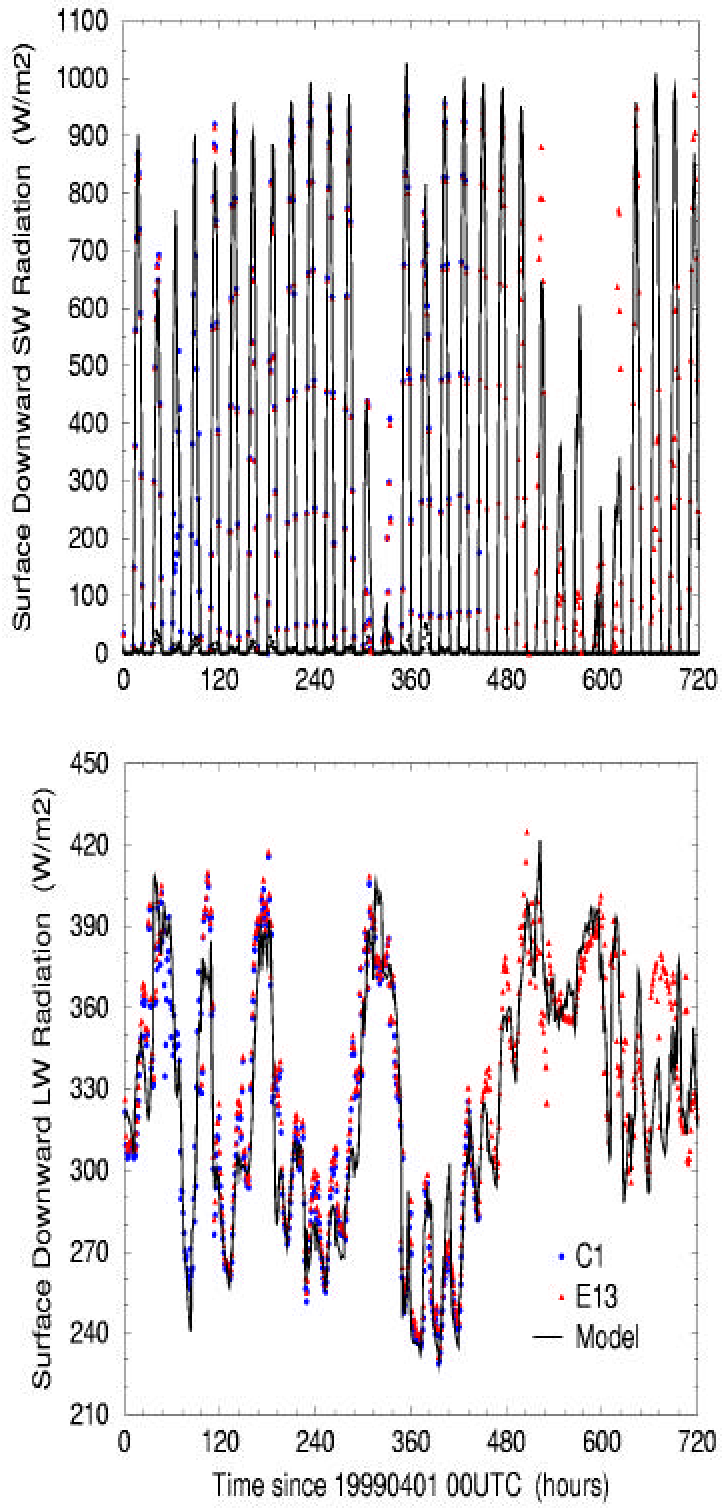


**Figure 2**. The surface downward shortwave (top) and longwave radiation (bottom) from the SIRS-C1 and E13, and from the 00-24-hour model. Measurements are from Solar Infrared Radiation stations C1 and E13.

Over the 1436 LW comparisons, the model underestimates the observations by 2 $Wm^{-2}$. The SW comparisons are restricted to 821 daytime comparisons and show a 17 $Wm^{-2}$ overestimation by the model.

The net radiation (SWdown - SWup + LWdown -LWup), for April 1999, as produced by the model, was compared to observations by the Energy Balance Bowen Ratio system at station E13. In the model, the often large overestimation of the SSRD, the slight underestimation of STRD, and the too large skin temperature at night all contribute to the model producing too much energy input to the surface during daytime, and too much energy output from the surface at night.

## Cloudiness

The temperature and humidity in the first 3000 m above the surface forecasted by the ECMWF model were compared to the temperature and humidity derived from the AER interferometer (AERI). There is an overall good agreement between model and observations, with the range of differences going from -11.0 K to 11.6 K for temperature and from -5.2 g $kg^{-1}$ to 8.3 g $kg^{-1}$ for humidity. However, the average bias over the first 3000 m of the atmosphere varies between -1.6 K at the surface and 0.7 K at 3000 m for temperature, and between -0.2 g $kg^{-1}$ at 300 m and 0.3 g $kg^{-1}$ at 1800 m.

The capability of the ECMWF model to produce cloudiness at the proper time and height can be also judged by comparing the model cloud fraction with a so-called cloud mask produced from radar measurements and/or the height of clouds detected by the MPL or the BLC. When a large amount of clouds, with substantial low-level cloudiness, is present (April 2-3, 7, 13-14, 24-25), the agreement for cloud base height between BLC measurements and the model is generally good. At other times, the agreement is much poorer, and the cloudiness derived from MMCR measurements often does not support the BLC measurements. A Ze-reflectivity, simulated using IWC-Ze and LWC-Ze relationships from the model IWC and LWC fields, is presented in Figure 3 (top panel). Details of the procedure follows Beesley et al. (2000). The corresponding Ze-reflectivity derived from MMCR measurements by Clothiaux et al. (2000) are presented in the bottom panel of Figure 3. The effect of heavy precipitation on the radar reflectivity data can be seen on April 2, 7, 13, and 24. The observed reflectivity saturates at these times corresponding to a wet index of 1 in the MWR measurements.

The comparison of the two panels in Figure 3 shows that, in terms of reflectivity, the model is in the ballpark of the measurements, particularly for the higher-level (ice) clouds. The results are obtained using the IWC-Ze relationship of Atlas et al. (1995) for a 100-mm equivalent particle diameter Do, within the range 60 mm to 120 mm diagnosed by the model from temperature following Matveev (1984). However, as seen in an intercomparison of Ze-reflectivities derived from the same model ice content, differences up to several dBZ exist between the various IWC-Ze relationships or when Do is allowed to vary between 100 mm and 900 mm in Atlas et al.'s relationships. So the obtained agreement between model and observations cannot be taken as a sure proof of the adequacy of the model cloud ice water content.

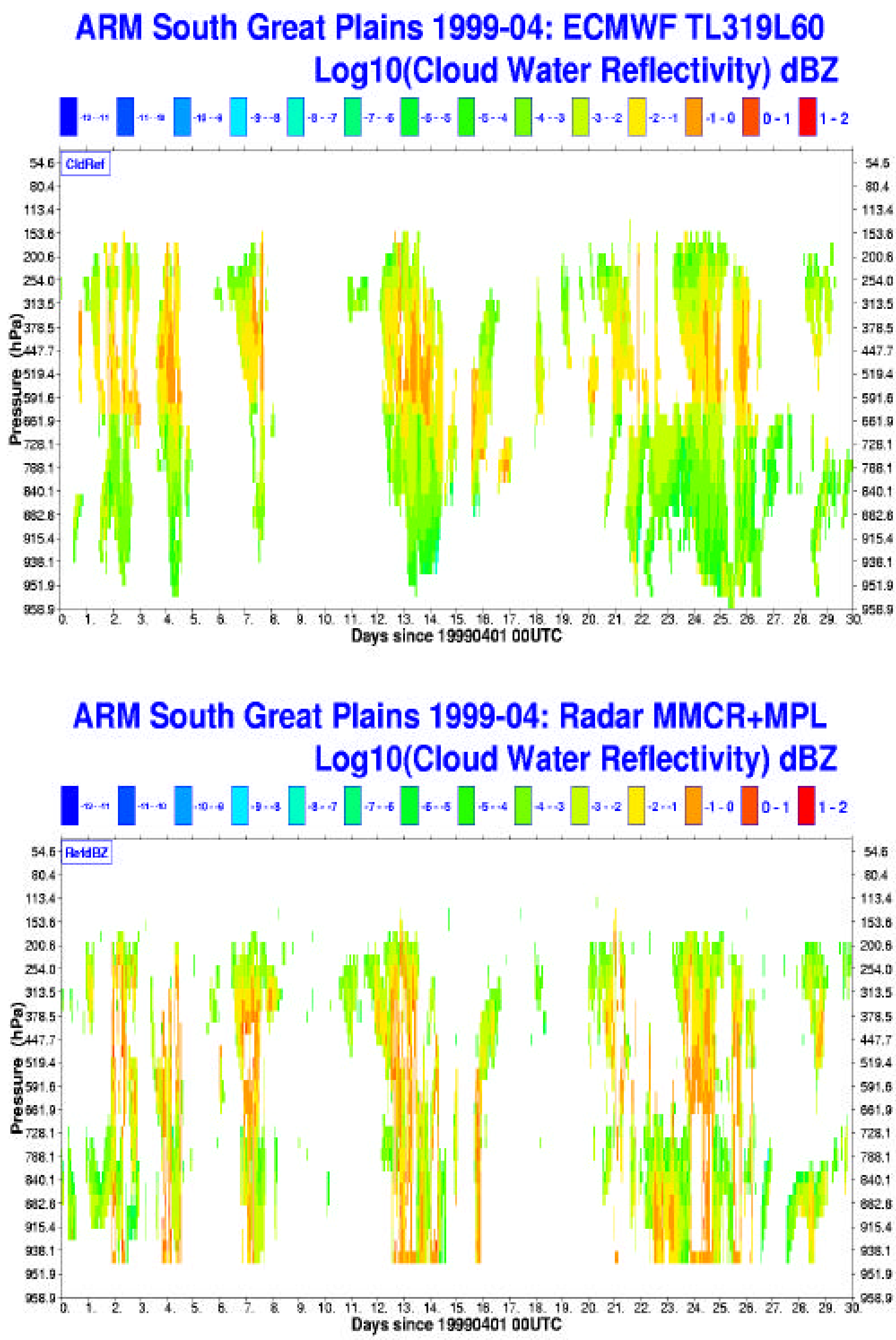


**Figure 3**. The pseudo-radar reflectivity computed from the ECMWF model using the relationships from Frisch et al. (1995) for LWC-Ze, and Atlas et al. (1995) for IWC-Ze (top panel) and the radar reflectivity actually measured at the ARM-SGP site. The reflectivity is the best estimate as discussed in Clothiaux et al. (2000). Step is 10 dBZ.

For LWCs, the agreement between the various theoretical relationships is much better, so a disagreement between model and observations is likely to indicate a problem in the distribution of the model cloud LWC. As seen in a similar intercomparison of Ze-reflectivities from the same model LWC, the LWC-Ze curves remain within 2 dBZ of each other. The agreement is down to 1 dBZ for Frisch et al.'s relationships when the particle number concentration varies between 150 and 900 $cm^{-3}$, which corresponds to the concentrations implicitly assumed for ocean and land in the ECMWF model. A comparison of the lower parts of clouds in Figure 3 indicates that, for LWCs, the model reflectivity is generally too low.

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