

The Collaborative Historical African Rainfall Model (CHARM)

(Updated by Chris Funk, July 2004)

One substantial limitation to studying rainfall in Africa is the limited number of gauge observations available internationally. To overcome this limitation, USGS/UCSB FEWSNET collaborators have developed the Collaborative Historical African Rainfall Model (Funk et al., 2003). The two key sources of data for the CHARM are the NCAR/NCEP reanalysis (Kalnay et al., 1996) time-series and the University of Delaware gridded station data (Willmott and Feddema, 1994; Willmott and Robeson, 1995). The daily estimated precipitation fields from the reanalysis are smoothed with a specialized spatial filter. This generates a set of 'synoptic' rainfall fields at a resolution of 0.1 degree. The gridded monthly precipitation fields are then used to provide a monthly bias correction of the daily rainfall fields.

Both the reanalysis and University of Delaware precipitation fields vary smoothly in space. Compared to rain gauge data, they often under-represent total precipitation values in regions with significant topography. These areas experience increased rainfall due to several compounded effects. Orography provides a source of vertical lifting, but can also block, channel and heat the surrounding atmosphere. We model the first effect, lifting, through the use of a single column diagnostic model (Funk and Michaelsen, 2004). The diagnostic model uses the terrain-gradient, surface wind vector, and a simplified gravity wave model (Durran, 1990; Holton 1992) to determine the vertical velocity (ω) profile. This ω profile can then be used linked with Sinclair's (1994) diagnostic VDEL model to estimate orographic precipitation. This model begins with an at-surface vertical velocity estimate

$$\omega_s \approx \rho g \mathbf{v}_s \cdot \nabla z_s$$

where ω_s is the vertical velocity in pressure coordinates [pa s^{-1}], ρ the density of air [kg m^{-3}], g the acceleration due to gravity [m s^{-2}], \mathbf{v}_s is the two-dimensional wind vector at the surface [m s^{-1}] and ∇z_s the regional two-dimensional gradient of the terrain [m m^{-1}]. The internal gravity wave-based vertical velocity profile and rainfall efficiency parameterizations are then used to derive estimates of orographic rainfall on a 0.1-degree grid.

The scale analysis used to derive the internal gravity wave equations shows that topographic gradients with characteristic lengths of less than approximately 15 km create evanescent (imaginary) solutions within stable atmospheric conditions. The magnitude of these waves are determined by the terrain-induced vertical motion at the surface (ω_s), while the frequency of non-evanescent waves will be a function of wind speed and the brunt-vaisailla (buoyancy) frequency

$$\omega_p = \omega_s \sin\left(\frac{N}{|\mathbf{v}_s|}(p_s - p)\right)$$

Where ω_p is the terrain-induced vertical motion at pressure level p, $|\mathbf{v}_s|$ is the wind-speed orthogonal to the slope and N is the atmospheric buoyancy frequency [s^{-1}]. This equation may be used to determine the orographic rainfall (R_{VDELB}) at a given location, and this rainfall may be merged with spatially smoothed reanalysis rainfall (R_{reanal}) according to

$$R_{CHARM} = \alpha R_{reanal} + \beta R_{VDELB}$$

where α and β are unitless weights used to combine the reanalysis and VDELB rainfall surfaces. β has been set to 0.5, based on hydrologic mass balance considerations, and α is estimated from interpolated rainfall fields:

$$\alpha_t = \frac{R_{Interp}}{R_{reanal}}$$

The α parameter grids are calculated for each month over the period 1961-1996 by constraining the average reanalysis precipitation totals to equal the equivalent grid cell from the interpolated GHCN rain gauge data. These α parameter grids can be used to perform a monthly bias correction of the reanalysis precipitation fields. These estimates tend to underestimate the actual rainfall amounts in areas of Africa with significant orography, as estimated by hydrologic models and stream gauge data. This results from the extremely low station data density of the Global Historical Climate Network, and the fact that most stations follow population distributions, which tend to be in valley bottoms. The modeling process generates 0.1 degree/daily precipitation fields for all of Africa for the period 1961-1996.

Accuracy Assessment and Known Data Problems

The CHARM article contains detailed error assessments for Mali and Western Kenya based on independent high-density gauge networks. These validation exercises suggest that at synoptic scales (areas of $\sim 10,000 \text{ km}^2$ or greater) the CHARM represents rainfall variability effectively at monthly, dekadadal and even daily time-steps, with mean absolute errors of less than half a standard deviation. These accuracy levels are comparable with regionally averaged satellite-based rainfall estimates (Funk and Verdin, 2003), and comparison between CHARM and satellite-based rainfall estimates (Herman et al., 1997) at 0.1° resolution show correlations of greater than 0.8 for most of sub-tropical Africa.

One known problem with the CHARM (Seid, 2003) has to do with the ‘frozen’ β parameter controlling the orographic correction. This parameter setting appears to be realistic for most of southern Africa (where the CHARM was originally calibrated). In areas of the Greater Horn, however, where higher elevations are preferentially selected for habitation and monitoring, the orographic correction causes the CHARM model to overestimate. Future research will correct this tendency, and our more recent article (Funk and Michaelsen, 2004) describes a possible approach based on matched filter regression.

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