Description of “triangle” precipitation disaggregation scheme

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Abstract

This document describes a non-stochastic “triangle” method of disaggregating daily precipitation to sub-daily time scales. Each day’s precipitation is modeled by a single event, whose temporal distribution has the shape of an isosceles triangle, symmetric about the time of peak intensity. The triangle is determined by two seasonally- and geographically-varying parameters: the time of peak intensity and the event duration. The magnitude of peak intensity is determined geometrically such that the area of the triangle equals the daily total precipitation. Climatological average values of the two parameters at all points in the CONUS domain were computed from the NLDAS data set. This method has been added as a new option in the MetSim meteorological disaggregation tool.

Motivation

Hydrological models require meteorological fields at sub-daily temporal resolution to properly simulate moisture and energy fluxes at the land surface. For models running in offline mode (uncoupled from atmospheric models), these fields are typically taken from gridded station observations [1–5], atmospheric model outputs or reanalyses[6–8], or estimates based on remote sensing[9,10]. Where station densities are sufficiently high, gridded station observations are often the product of choice due to their long record lengths and greater accuracy, but they generally are restricted to daily temporal resolution due to the sparsity of stations that record sub-daily observations. For most meteorological fields, deterministic algorithms using a small number of spatially and temporally invariant parameters can disaggregate daily values into their diurnal cycles with acceptable accuracy[11]. These algorithms have been employed widely as an embedded disaggregation step within the Variable Infiltration Capacity (VIC) model[12] and more recently as the stand-alone tool MetSim[13].

However, the highly heterogeneous nature of precipitation (P) has hindered development of a similarly simple deterministic disaggregation algorithm. P disaggregation efforts have focused on primarily stochastic, multi-parameter approaches that require localized calibration to achieve acceptable accuracy[14,15]. Because derivation of these parameters is unwieldy at large (continental to global) scales, VIC and MetSim have, up to now, disaggregated P by distributing the daily total evenly over all of the day's time steps (i.e., a rectangular hyetograph). This yields an unrealistic diurnal cycle of P, particularly in summer convective regimes, where the daily total P may be concentrated into a single event of brief duration. This mischaracterization of the hyetograph is problematic given the strong non-linear dependence of runoff on the differences between instantaneous P intensity and other fluxes such as canopy evaporation and soil infiltration.

Here we present a non-stochastic, two-parameter method of disaggregating daily P to sub-daily resolution, for use within MetSim. This method approximates the each day's hyetograph with an isosceles triangle, whose duration and time of peak intensity are uniformly set to their average values from a historical reference period. Triangular hyetographs have been employed in numerous studies, in conjunction with intensity-duration-frequency curves[16]. However, in our case, we are ignoring variability in duration. This method represents a compromise between the erroneous simplicity of uniform disaggregation and the complex accuracy of multi-parameter stochastic methods.

Methods

Here we use a simple two-parameter (per month) algorithm to disaggregate daily P into a single event per day, describing the event's duration, time of occurrence, and distribution of within-event intensities. We approximate each P event with an isosceles triangle, with base equal to the event duration and apex located at the event's midpoint, with peak intensity such that the area of the triangle equals the day's total P:

$$P_{sub}(d,t) = P_{daily}(d)k(t) \qquad (1)$$

Where P_{sub} (mm h^{-1}) is the sub-daily P at time t within day d, P_{daily} (mm) is the daily total P on day d, and k (h^{-1}) is the kernel function (unit hyetograph) describing the isosceles triangle (Fig. 1):

$$k(t) = \begin{cases} \frac{2}{D} + \frac{4}{D^2}\left(t - t_{pk}\right), t_{pk} - 0.5D < t < t_{pk} \\ \frac{2}{D} - \frac{4}{D^2}\left(t - t_{pk}\right), t_{pk} < t < t_{pk} + 0.5D \\ 0\,, all\ other\ t \end{cases} \qquad (2)$$

Where t_{pk} is the time of day of peak intensity (h) and D is the event duration (h). The kernel (also called a unit hyetograph) spans 48 hours (-12 h > t > +36 h), to account for triangles that cross a day boundary. Sub-daily P values are therefore the sum of contributions from both the current day and either the previous or following day. Thus, for events that occur sufficiently close to midnight, the daily totals of disaggregated P might not match the input daily totals, due to "bleeding" of P into neighboring days. However, the inaccuracies of total P become negligible at monthly and annual scales.

Values of the two parameters t_{pk} and D were determined for all points over the CONUS domain using the North American Land Data Assimilation System (NLDAS-2)[17,18] dataset at spatial resolution of 1/8º over the period 1981-2014. For each pixel, the hourly P data were extracted for the entire period and grouped by month of year (for a total of 12 groups). Next, for each of the 12 months, the mean frequency, $F(t)$, of rainfall occurrence in each hour $h = 0, \ldots, 23$ was calculated. Following Mascaro (2017)[19] the harmonic analysis was applied on $F(t)$:

$$F(t) = F_0 + F_1 \cos(\omega t - \phi_1) + \text{residual} \qquad (3)$$

In (3), the coefficients F_0 and F_1 are the amplitude of the zeroth and first harmonic components, respectively, which are related to the mean and diurnal cycles; ω is the angular frequency equal to $2\pi/24$, where 24 is the number of hours in a day; and ϕ_1 is the phase angle. Parameters F_0, F_1 and ϕ_1 were estimated via the least squares method and used to compute the time of day of peak t_{pk} and the amplitude of the cycle. In general, the larger the amplitude, the more significant the presence of a significant diurnal cycle. Values of t_{pk} were expressed in local (sidereal) time.

Average event duration D was computed at each pixel as follows: (1) each group of contiguous hours of nonzero precipitation was labelled as a distinct event; (2) for days with multiple events, only the largest event (largest total P) was retained for computing statistics; (3) for each of the 12 months, the mean duration of these largest events was computed.

To eliminate large discontinuities at the Canada-US and US-Mexico borders (due to NLDAS-2 using the CMORPH[9] product to disaggregate daily P over areas where the Doppler Stage II radar product is unavailable[18]), values of D over Canada and Mexico were estimated as a linear function of the natural logarithm of the mean monthly P of the Livneh et al. (2015)[4] dataset over the period 1981-2010, derived via linear regression over the US. Although this substantially improved the consistency of values across the borders, relatively small discontinuities still exist, particularly along 49° N latitude.

For points in Mexico south of 25° N latitude (the southern boundary of the CONUS domain), parameter values of t_{pk} were estimated as the average of their values within the rectangle bounded by 25° and 27° N latitude and -115° and -95° E longitude.

Maps of t_{pk} and D for the months of February and July are shown in Fig. 2.

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Figures

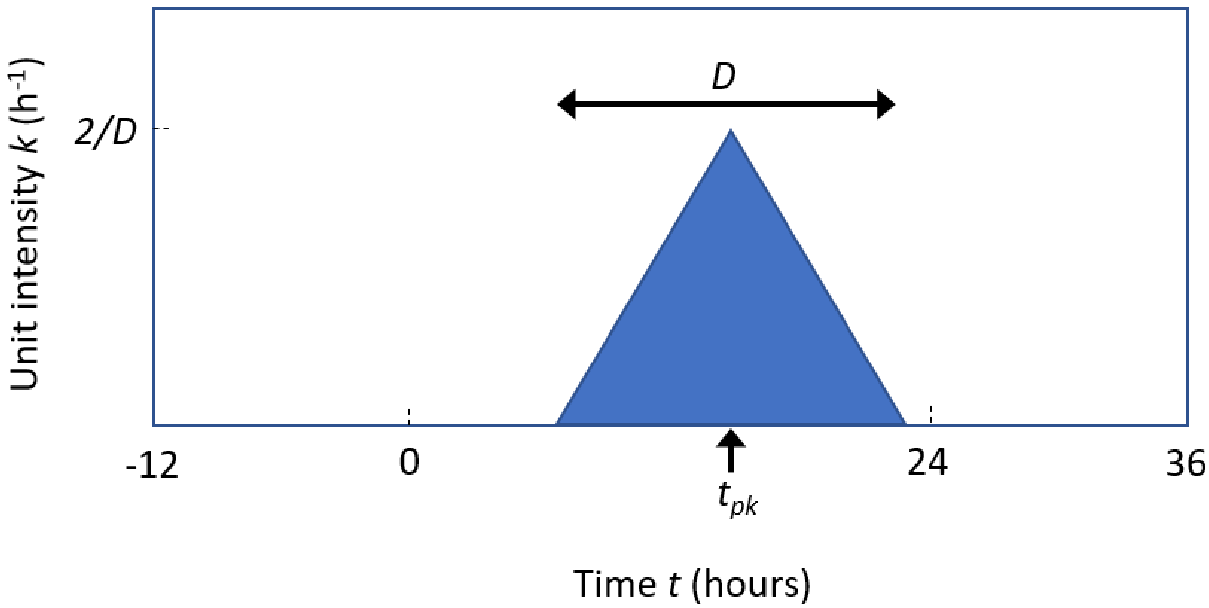

Fig 1. P disaggregation kernel (unit hyetograph). Time values are expressed in local (sidereal) time.

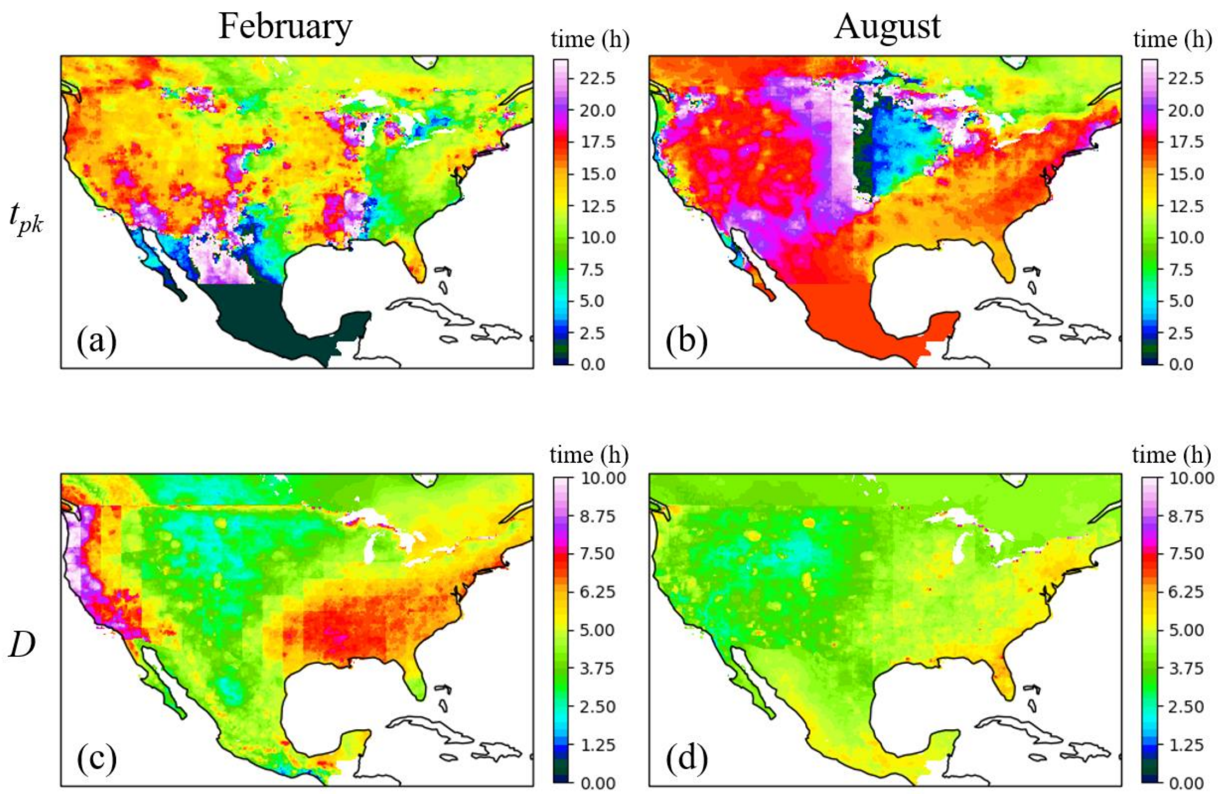

Fig. 2. Maps of P disaggregation parameters t_{pk} and D, for February and August. Values of t_{pk} are expressed in local (sidereal) time.