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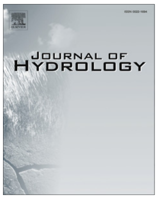

The dependence of precipitation types on surface elevation and meteorological conditions and its parameterization

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SUMMARY

Precipitation types (rain, snow, and sleet) have great impacts on the surface runoff and energy balance. However, many weather stations only record precipitation amount without discriminating its type. Based on CMA (China Meteorological Administration) station data over 30 years, this study investigates the relationship of precipitation types with surface elevation and meteorological variables. Major findings are (1) wet-bulb temperature is a better indicator than air temperature for discriminating precipitation types; (2) precipitation types are highly dependent on surface elevation, and a higher threshold temperature is needed for differentiating snow and rain over a higher-elevation region; and (3) precipitation types are also dependent on relative humidity, and the probability of sleet event rises greatly with the increase of relative humidity. Based on these findings, a new parameterization scheme is developed to determine the precipitation type, with input of daily mean wet-bulb temperature, relative humidity, and surface elevation. Evaluations for China territory show that the new scheme gives better accuracy than 11 other schemes that are used in hydrological and land surface models.

1. Introduction

Precipitation is one of the most important components in water and energy cycle, and the precipitation types (rain, snow, and sleet) have great impacts on the land surface mass and energy balance (Loth et al., 1993). Snowfall can accumulate at the land surface while rainfall usually infiltrates into soils and converges into rivers or groundwater (Clark et al., 2006). The surface albedo increases greatly when snowfall occurs, which can substantially alter the surface energy budget, whereas the effect is opposite when rainfall occurs (Box et al., 2012). Besides, precipitation type is needed for the correction of precipitation gauge data, as the catch ratio of precipitation gauges depends on precipitation type (Yang et al., 1988, 1995; Rasmussen et al., 2012). Therefore, the differentiation of precipitation types is important for land hydrological process studies (Anderson and Mackintosh, 2012).

However, precipitation types are often not observed or not accessible. For example, the data of precipitation amount at more than 700 CMA (China Meteorological Administration) weather stations since 1950s can be obtained via the CMA National Meteorological Information Center (NMIC), but the data of precipitation types is not available for the years after 1979 (Han et al., 2010). So the discrimination of the precipitation types for the recent three decades mainly relies on empirical or semi-empirical relationships derived from other observations. Generally, the discrimination schemes are categorized into two classes according to the used variables.

One class is based on the temperature profile and other atmospheric conditions (e.g. Bocchieri, 1980; Ryzhkov and Zrnic, 1998; Rauber et al., 2001; Lundquist et al., 2008). Czys et al. (1996) presented a non-dimensional parameter (i.e. the ratio of the available time for melting to the required time for complete melting) to differentiate between freezing rain and ice pellets by using air temperature profile. Bourgouin (2000) used the area between the air temperature profile and the 0 °C isotherm on aerological diagrams to diagnose precipitation types. Schuur et al. (2012) employed the vertical profile of wet-bulb temperature derived from the rapid update cycle model (Benjamin et al., 2000) and polarimetric radar retrievals to classify the precipitation types. A challenging issue that hinders the applications of the above schemes is that air temperature profile is generally not available at weather stations.

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The other class of empirical schemes mainly employs surface air conditions. Their inputs are accessible and thus they are widely used for hydrological and land surface modeling. Among them, surface air temperature-based methods are most widely used for the identification of precipitation types (e.g. Auer, 1974; Kang et al., 1999; Gustafsson et al., 2001), including single threshold methods (Yang et al., 1997; Clark et al., 2006) and dual-threshold methods (Kang, 1994; Wigmosta et al., 1994; Chen et al., 2008). A single threshold method differentiates rain and snow with only one critical temperature. A dual-threshold method uses two critical temperatures to differentiate rain, snow, and sleet: rain occurs when air temperature is higher than an upper critical temperature; snow occurs when air temperature is lower than a lower critical temperature; sleet (as a mixture of rain and snow) occurs when air temperature is between the two critical temperatures. In addition, some schemes are developed to calculate the ratio of snow (or rain) amount to total precipitation amount (Zhang et al., 2013), instead of determining the precipitation type. Yamazaki (2001) used a scheme with the wet-bulb temperature as an indicator to calculate the ratio of snow amount to total precipitation amount for modeling land surface processes in Eastern Siberia. Dai (2008) proposed a method to calculate the frequencies of rain, sleet, and snow from their relationships with both surface air temperature and pressure over land and ocean. Table 1 shows the critical temperatures of nine schemes in the literature and the calculations of snow ratio of the above two schemes; clearly, the critical temperature values are not unique in different regions, and all these schemes need validations for different climate regimes. Particularly, we have little knowledge on how elevations impact the precipitation types.

This study aims at developing a new scheme to discriminate precipitation types, based on more than 400,000 samples of precipitation types collected from different climate regimes and elevations in China. The remaining parts of this paper are organized as follows. Section 2 introduces the dataset and the data quality control procedures. Section 3 presents the dependence of precipitation types on surface wet-bulb temperature, relative humidity, and elevation. Based on their relationships, a new parameterization scheme is developed in Section 4 and its evaluation is presented in Section 5 by comparisons with 11 schemes in the literature. The results are summarized in Section 6.

2. Data

The dataset used in this study is the Version 3.0 of "Daily Surface Climate Variables of China", which is provided by CMA NMIC. This dataset covers the period from 1951 to 1979, with precipitation type information available at daily scale. Therefore, daily weather data are used in this study, including daily mean air temperature (T_a), daily mean relative humidity (RH), daily mean surface pressure (p_s), daily total precipitation (P_r), and precipitation type of 824 stations. Elevation (Z) is also used so as to understand its role in the formation of precipitation.

Generally, the precipitation type is recorded as one of three types (rain, sleet, and snow). Although the data quality has been preliminary controlled by the data provider, some stations recorded all precipitation events as rain throughout all years or some years, without discriminating precipitation types. In addition, erroneous or suspected classifications occur occasionally, since the precipitation type is based on manual judgment and recording. Therefore, the following data quality control procedures are adopted to remove erroneous and suspicious data.

1. Select qualified data according to the original quality control flag in the dataset. Herein, data are selected if the quality control flags of T_a, RH, p_s, and P_r are simultaneously marked as correct.
2. Search for erroneous and suspicious data records. A data record is regarded as abnormal if rain occurs when $T_a < 0$ °C, snow occurs when $T_a > 8$ °C, or sleet occurs when $T_a < -1.6$ °C or $T_a > 9.6$ °C, according to statistical results of the precipitation types; otherwise, the data record is regarded as a normal one. Then, we counted for each year of each station (i) the numbers of all samples of rain, snow, and sleet, recorded as N_{rain}, N_{snow}, and N_{sleet}, respectively; and (ii) the numbers of all abnormal samples of rain, snow, and sleet, recorded as $N_{rain,wrong}$, $N_{snow,wrong}$, and $N_{sleet,wrong}$, respectively.

Table 1
Nine schemes of discriminating precipitation-type and two schemes of calculating snow ratio to total precipitation in the literature.

Scheme	Thresholds of T_a or snow ratio	Model	Region and period being applied
Y97 (Yang et al., 1997)	2.2 °C	BATS model	Yershov, Uralsk, Ogurtsovo, Kostroma, Khabarovsk and Tulun (48°N–57°N, 41°E–135°E), 1978–1983
L93 (Loth et al., 1993)	−1 °C, 4 °C	Snow cover model	German meteorological station Potsdam (52°23′, 13°04′), 1975–1980
W94 (Wigmosta et al., 1994)	−1.1 °C, 3.3 °C	DHSVM model	Middle Fork Flathead River basin in northwestern Montana (114°00′W, 48°29′N, 900 m–3000 m), Oct 1988–Oct 1991
K94 (Kang, 1994)	2.8 °C, 5.5 °C	Energy, water, mass balance and hydrological discharge model	Tianshan Mountain, China (43°06′N, 86°50′E, 3539 m–4010 m), 1986–1990
L97 (Lindström et al., 1997)	−1 °C, 1 °C	HBV model	Ten basins in Sweden, 1969–1989
C04 (Collins et al., 2004)	−5 °C, 0 °C	NCAR CAM3.0	
HH05 (Hock and Holmgren, 2005)	0.5 °C, 2.5 °C	Mass balance model	Storglaciären, Sweden (67°55′N, 18°35′E, 1120 m–1730 m), 1993–1994
G10 (Gao et al., 2010)	−0.5 °C, 2 °C	Degree-day mass balance model	Tarim River Basin, China (35°N–43°N, 73°E–93°E, 2780 m–4800 m), 1961–2006
W11 (Wang et al., 2011)	0 °C, 2 °C	Degree-day mass balance model	Qiyi Glacier in Qilian Mountains, China (39.5°N, 97.5°E, 4304 m–5158.8 m), Jun 30–Sep 5, 2010
Y01 (Yamazaki, 2001)	Snow ratio dependent on T_w	One dimensional land surface model	Lena River basin in Eastern Siberia, 1986–1994
D08 (Dai, 2008)	Snow ratio dependent on T_a and p_s		15,000 land stations global and many ships, 1977–2007