Journal of Hydrology: Regional Studies 5 (2016) 20–32

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Discriminating types of precipitation in Qilian Mountains, Tibetan Plateau

Junfeng Liu[a,b,*], Rensheng Chen[a,b]

[a] Qilian Alpine Ecology and Hydrology Research Station, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China
[b] Heihe Key Laboratory of Ecohydrology and Integrated River Basin Management, Chinese Academy of Sciences, Lanzhou 730000, China

ARTICLE INFO

Article history:
Received 4 May 2015
Received in revised form 1 November 2015
Accepted 15 November 2015
Available online 28 November 2015

Keywords:
Precipitation type
Threshold air temperature
Hulugou river basin
Qilian Mountainous
Tibetan Plateau

ABSTRACT

Study region: Hulugou River Basin (HRB) of Qilian Mountains, eastern edge of Tibetan Plateau.
Study focus: Traditional manual observations only record point-scale precipitation rather than regional-scale precipitation. Automatic weather stations just record precipitation amount without discriminating by type of precipitation. This study observed precipitation types all over the HRB and analyzed air temperature and humidity conditions at daily and half-hour resolution.
New hydrological insights for the region: Combined observations of air temperature and precipitation type indicate that, at daily resolution the threshold air temperature between rain and snow is 0 °C and the air temperature at rain/snow boundary is from 0 °C to 7.6 °C, which means the rain and mixed precipitation threshold air temperature can shift more than 7.0 °C in the HRB. At half-hour resolution, air temperature is above 0 °C during rainfall, under 0 °C for snowfall, and above 0 °C at the rain/snow precipitation boundary, and could either be above 0 °C or fluctuate around 0 °C for mixed precipitation. Corresponding relative humidity observations indicate that rainfall and mixed precipitation events correspond with high humidity conditions in warm season of the HRB. Snowfall events correspond with low humidity conditions in the HRB.

1. Introduction

Observation of precise precipitation amount and type of precipitation are critical for reliable stream flow forecasts (Fassnacht et al., 2006). Precipitation amount has been widely observed, but precipitation type is rarely observed by automatic weather stations. Type of precipitation has great impact on the land surface energy balance (Loth et al., 1993; Ding et al., 2014), as snowfall can increase the surface albedo, and rainfall can decrease the surface albedo (Box et al., 2012). Land surface hydrological processes are also different for different precipitation types, i.e., rainfall usually converts into underground or surface water stream systems, while snowfall may accumulate during the cold season and melt in warm season. Observation of precipitation type is important, because some forms of cold season precipitation can pose a threat to human safety or disrupt travel and commerce (Reeves et al., 2014). It has been widely recognized that gauge measured precipitation

* Corresponding author at: Qilian Alpine Ecology and Hydrology Research Station, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China
E-mail address: jfliu121@163.com (J. Liu).

http://dx.doi.org/10.1016/j.ejrh.2015.11.013

Table 1
Precipitation measurements intercomparison experiment.

Gauge	Abbreviation	Size	Start date	End date	Measure time
China standard precipitation gauge	CSPG	ϕ=20 cm, h=70 cm	June, 2009	April, 2014	20:00 and 8:00, local time
CSPG with Alter shelter	Alter	ϕ=20 cm, h=70 cm	June, 2009	April, 2014	20:00 and 8:00, local time
Pit gauge with a CSPG	Pit	ϕ=20 cm, h=0 cm	September, 2010	April, 2014	20:00 and 8:00, local time
Pit with a larger diameter bucket	Pit500	ϕ=25 cm, h=0 cm	September, 2010	April, 2014	20:00 and 8:00, local time
Double-Fence International Reference (Tretyakov wind shield + CSPG)	DFIR	ϕ=20 cm, h=3.0 m	September, 2012	April, 2014	20:00 and 8:00, local time

has systematic errors mainly caused by wind-induced undercatch (Sugiura et al., 2003). When the wind speed is very high, the catch ratio of precipitation gauges depends on precipitation type (Yang et al., 1995). In this case, the precipitation type data deficit will greatly affect measured precipitation calibration and precision.

However, most of the time precipitation type data are not available because these depend on manual observation and automatic precipitation type discrimination sensors are not precise enough to be used widely. For example, the World Meteorological Organization arranged an intercomparison of weather sensor abilities (Present Weather Sensors/Systems Intercomparison; PREWIC, 1993–1995) in the field of precipitation detection and precipitation type discrimination (Leroy and Bellevaux, 1998). Sensors like the Vaisala FD12P performed the best of all optical sensors in PREWIC, but it is known that the discrimination of precipitation type is not precise (Haji, 2007). Manual observations of precipitation type are limited at certain altitudes. A study by Thériault et al. (2010) indicated that small variations in temperature profiles and precipitation rate can have major impacts on the types of precipitation formed at the surface. It was also found that precipitation type varies widely over space and time in mountainous regions (Harder and Pomeroy, 2013), where the rain/snow boundary often formed at certain altitudes.

Little knowledge is available of how elevation impact the precipitation types, and no systemic precipitation type observations have been undertaken at watershed scale in mountainous regions. To address this shortfall, a systemic precipitation type observation experiment was carried out in the Hulugou River Basin (HRB) of the Qilian Mountainous. The observations include manual observations since 2009 as a reference at the outlet of the HRB. Two time-lapse cameras have been used to photograph precipitation types in the HRB at two different locations since 2012. Through photographic interpretation, precipitation types which include rainfall, snowfall and mixed precipitation are acquired at basin scale. If the rain/snow boundary is visualized in a precipitation event, the elevation of the rain/snow boundary is obtained by georeferencing the image. On the basis of automatic land surface meteorological observations at different altitudes, the air temperature and humidity were determined for each precipitation event at daily and half-hour resolution. Specifically, in this study, the meteorological conditions at the rain/snow boundary were determined during each mixed precipitation event, which can be used as the threshold air temperature to differentiate rain and mixed precipitation.

2. Study area and data

The HRB is located in the Qilian Mountains along the northeastern margin of the Tibetan Plateau (38°15′54.9″N, 99°52′53.5″E; Fig. 1). The basin forms the headwaters of the Heihe River and has a catchment area of 23.4 km^2. Elevations in the basin range from 2980 m to 4800 m above sea level. The landscape zones include glaciers at mountain top, subnival, marsh meadows, alpine shrub, and mountain grassland. The annual precipitation ranges from 376 to 650 mm, and the annual mean temperature varies from approximately 3.1 °C at 3000 m to −4.0 °C at 4200 m. The river basin faces north with inclines from 5° to 85°. The steep north facing slope experiences less solar radiation and lower ground surface temperatures, combined with the large elevation ranges, these conditions cause mixed precipitation events to frequently appear at high altitudes during the warm season. Consequently, the rain/snow boundary is often visualized on north facing aspects of the HRB.

Field precipitation measurement intercomparison experiments (Fig. 1, Table 1) were conducted near the outlet of the HRB (2980 m). Manual observations (rain, snow and mixed) are three time per day. In September 2008, four ENVISs (Environmental Information Systems) were installed at 2980 m, 3382 m, 3710 m, and 4166 m in the HRB. Measurements include air temperature, humidity, wind speed and direction, radiation, amount of precipitation (weighing gauge), snow depth, number of hours of sun, ground surface temperature, soil temperature at eight depths, and three ground heat fluxes. The weighting gauge was used to determine the total rain using a weighting sensor TRwS500 with a resolution of 0.001 mm. Other sensors installed in each of the ENVISs include the temperature and relative humidity sensor of Campbell CS215-L, the wind speed and direction sensor of Campbell Wind sonic Two-Dimensional Sonic Anemometer, the radiation sensor of Campbell four-component radiometer, the Campbell snow depth sensor of SR50 Sonic Ranging Sensor with a precision of 1 cm, the Campbell soil water content sensor of Enviro SMART Soil Water Content Profile Probes, the Campbell soil temperature sensor of 107_L Sensor, the CSD3sun time hour sensor, and the soil heat flux sensor of HFP01SC-L Self-Calibrating Soil Heat Flux Plate sensor.

In June 2012, two automatic weather stations (AWSs) were installed on the western tributary of the HRB (3839 m). Another AWS was installed at a higher site (4496 m) on the Shiyi glacier. Each AWS measures air temperature, relative