Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2017-82
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 10 August 2017


# 31 years of hourly spatially distributed air temperature, humidity, and precipitation amount and phase from Reynolds Critical Zone Observatory

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**Abstract.**

Thirty one years of spatially distributed air temperature, relative humidity, dew point temperature, precipitation amount, and precipitation phase data are presented for the Reynolds Creek Experimental Watershed, which is part of the Critical Zone Observatory network. The air temperature, relative humidity, and precipitation amount data are spatially distributed over a 10m Lidar-derived digital elevation model at an hourly time step using a detrended kriging algorithm. This dataset covers a wide range of weather extremes in a mesoscale basin (237 km$^2$) that encompasses the rain-snow transition zone and should find widespread application in earth science modeling communities. Spatial data allows for a more holistic analysis of basin means and elevation gradients, compared to weather station data measured at specific locations. Files are stored in the NetCDF file format, which allows for easy spatiotemporal averaging and/or subsetting. Data are made publicly available through an OPeNDAP-enabled THREDDS server hosted by Boise State University Libraries in support of the Reynolds Creek Critical Zone Observatory (http://doi.org/10.18122/B2B59V).

## 1 Introduction

Spatially distributed air temperature, relative humidity, dew point temperature (Td), precipitation amount, and precipitation phase data are presented from the Reynolds Creek Experimental Watershed (RCEW) from 1 Oct. 1983 to 30 Sept. 2014 (31 water years, where a water year extends from 1 Oct. to 30 Sept.) (Fig. 1). These data provide a whole-catchment view of the dynamic weather conditions that occur in a mountainous catchment that encompasses the rain-snow transition zone. The rain snow transition zone is of specific importance as warming trends are expected to shift the current precipitation regime toward being rain-dominated and move the rain-snow transition to higher elevations (Klos et al., 2014; Nayak et al., 2010). The rain snow transition zone may approach sea level at high latitudes (Feiccabrino et al., 2012), but can frequently extend above 2000 m at lower latitudes (Cayan et al., 2001). In the interior Pacific Northwestern US, where RCEW is located, the rain-snow transition typically occurs in mid-elevations ranging from 1500 - 1800 m (Nayak et al., 2010).

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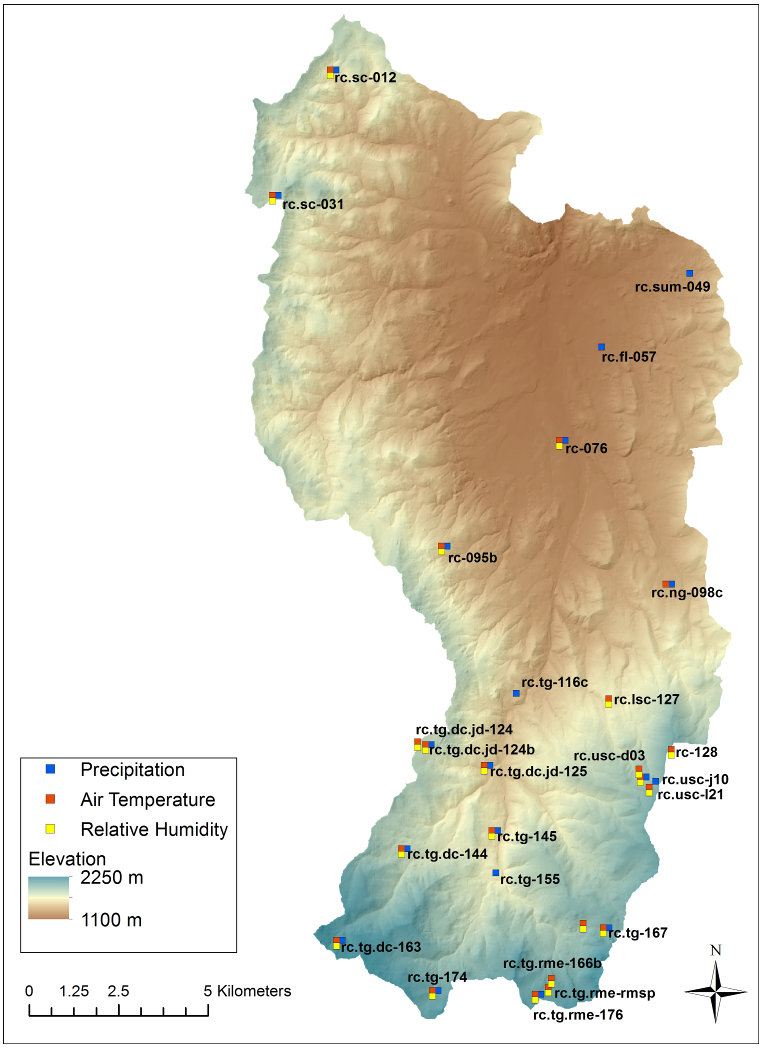


**Figure 1.** Location map of Reynolds Creek Experimental Watershed showing the elevation (m.a.s.l.) and the location of instruments used to measure precipitation, air temperature, and relative humidity.

RCEW was established in 1960 to address water yield, flood flow, and sedimentation problems of the Northwestern United States. Today, RCEW monitors 11 weirs, 23 dual gage precipitation stations, and 22 weather stations (relative humidity, air temperature, wind, and incoming solar radiation as a minimum), many of which have been continuously monitoring for decades (Fig. 2).

RCEW became a Critical Zone Observatory in 2014, with the purpose of improving the prediction of soil carbon storage and flux. Part of that goal is met by the creation of these high spatiotemporal resolution data, which addresses a strategic priority to develop an integrated modeling framework. These data will be used in conjunction with soil carbon and other environmental variables in land surface models with the end goal of watershed scale biogeochemistry modeling (model development, model

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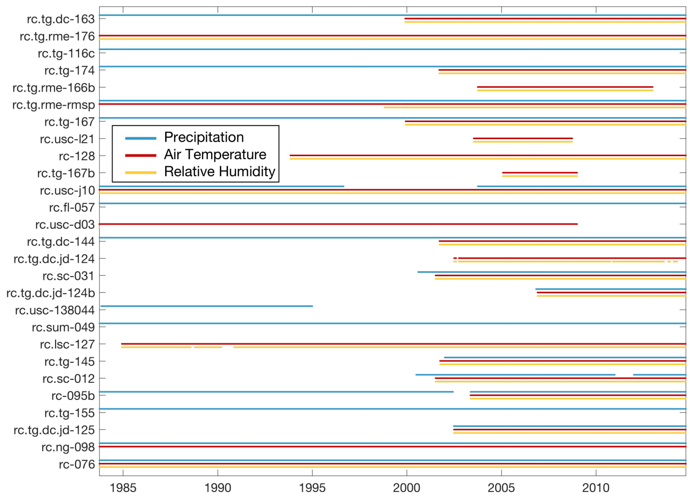


**Figure 2.** Measurement sites and the corresponding time periods that data from that site were used in the construction of the spatial data.

validation, total carbon and nitrogen storage estimation). In addition to biogeochemical modeling, this dataset provides the weather variables commonly used to force models from disciplines ranging from hydrology and snow melt to ecology and biogeochemistry.

This dataset meticulously describes weather variables in a mountain rain-snow transition zone, which provides pertinent information for analyzing climate warming trends. The snow cover in this zone is sensitive to climate warming trends because it is generally warm and thin (less than 1m for most of the snow season). Since precipitation can be deposited as either rain that is rapidly transmitted to the soil, or snow that delays the delivery of liquid water to the soil, changes in the precipitation phase translate directly to changes in the timing of water inputs to catchment soils. Previous studies have documented historic changes in mountain snow cover due to climate warming trends (Mote, 2003), but most of these studies rely on point data (Nayak et al., 2010) or model results (Brown and Mote, 2009). Spatially distributed data derived from measured data, such as this data set, are essential for diagnosing changes in snow regime in the mountain west US. Weather data sets have been published from rain-dominated (Western and Grayson, 1998) and snow-dominated areas (Reba et al., 2011; Morin et al., 2012), but there is a general lack of weather data from the rain-snow transition zone (Kormos et al., 2014); Enslin et al. in prep).

The combination of 1) length of record, 2) high spatial resolution, 3) high temporal resolution, 4) the availability of supporting data, and 5) meticulous maintenance and upkeep of weather station data at RCEW makes it an ideal location for the development of a detailed dataset of this magnitude.

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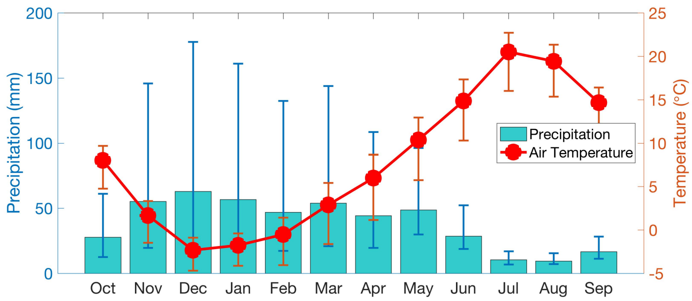


**Figure 3.** Mean monthly precipitation and air temperature showing that warm temperatures are out of phase with high precipitation. Red and blue vertical bars show the range in monthly data for the 31 years of this dataset.

## 2 Site Description

The Reynolds Creek Experimental Watershed (RCEW) is a 239 km$^2$ catchment located in the Owyhee Mountains in southwest Idaho, USA (Fig. 1). Catchment elevation ranges from 1100 to 2244 masl with a mean of 1529 masl and, along with aspect, controls several important environmental gradients, including a strong precipitation gradient, vegetation community gradients and land use gradients (Figs. 1, 5a) Mean annual precipitation is approximately 200 mm for the lowest elevations and 1140 mm for the highest elevations, with a basin mean value of 462 mm. The majority of precipitation falls in the winter, spring, and fall, with low precipitation during summer months (June July August). (Fig. 3). The upper elevations or RCEW are snow dominated and the lower elevations are rain dominated. The dominant wind direction during storms is out of the southwest, and snow drifts form on the lee side of slopes. The mean annual air temperature is 7.8°C, with the warmest month being July (20.5°C) and the coldest month being December ( -2.3°C) (Fig. 3).

Vegetation cover in the lower elevations of RCEW are characterized by sparse shrub and grasslands, while upper elevations are characterized by mixed conifer woodlands. More northerly aspects are commonly more productive and have denser vegetation. There exists a strong snow-vegetation feedback, where drift areas commonly support denser shrub and aspen communities. The spatial distribution of vegetation, soils, and geology, and that data availability are described in Seyfried et al. (2001).

## 3 Instrumentation

Precipitation, air temperature, and relative humidity have been measured at multiple locations within RCEW at different time periods (Figs. 1 and 2). Since many of the measurement locations in RCEW have been operating for long time periods, changes in instrumentation have been necessary. Instruments have always been carefully calibrated. Precipitation is measured with a dual gauge system described by Hanson et al. (2001). This arrangement measures alter shielded and unshielded precipitation in Belfort-type precipitation gauges and allows for wind correction of the data in the absence of wind speed data (Hanson

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et al., 2004). Air temperature and relative humidity data have been measured using Vaisala HMP series sensors, and have been upgraded as improved models became available.

## 4 Data preparation and spatial distribution

Measured data from precipitation gauges and weather stations were error checked in a number of steps. Precipitation amount, air temperature, relative humidity, and calculated vapor pressure were plotted simultaneously month by month to visually inspect for erroneous measurements, instrument failures, and instrument icing. Coincidentally, measured data from the individual stations were plotted separately and missing data were flagged. Early time shifts resulting from clock synchronization errors were fixed.

Erroneous data in air temperature and relative humidity time series were identified by visual inspection and removed. Short data gaps were filled by either linear interpolation, or multiple linear regressions to surrounding stations. Data gaps longer than a day were filled with multiple linear regression using up to four surrounding stations if a strong relationship existed. Data gaps that were longer than a day and lacked this relation were left as missing data. All available weather stations that had air temperature or relative humidity were used in the spatial distributions of that variable.

Precipitation data were filtered following Nayak et al. (2008) and wind-corrected following Hanson et al. (2004). Precipitation station data were included based on 1) the degree of topographic and vegetation sheltering and 2) the spatial arrangement of measurement locations. Wind-sheltered precipitation gauges were preferentially used over wind exposed sites following Winstral et al. (2013) and Winstral and Marks (2014). However, some exposed precipitation stations were used because they were the only ones representing large portions of RCEW (eg. 057, 049, and 127). We note that figure 2 represents the data used in the spatial distribution of variables, and not necessarily the data available. For example, lower sheep creek (rc.lsc-127) has precipitation measurements, but we did not use them because they did not meet our wind sheltering requirements. Based on this criteria, 19 precipitation locations were selected.

Detrended kriging was used to spatially distribute measured air temperature, relative humidity, and precipitation for each hour (Garen et al., 1994; Garen, 1995). The detrended kriging method first fits an elevation model to measured data using a least absolute deviations regression. That model is used to spatially distribute the variable over a user supplied digital elevation model (DEM). Residuals from that elevation model were then kriged to obtain a spatial distribution of deviations from the elevation model, and added to the elevation distribution to get the final distributed variable. The linear elevation model is constrained to have a negative slope with elevation for air temperature, positive slope with elevation for precipitation, and has no constraints for relative humidity.

An exercise was conducted to choose the spatial resolution of this data set. The area of the rain snow transition zone was compared when distributing all variables over a 5, 10, 30, 50, and 100m DEM for January 2002. We define the rain-snow transition zone as areas of the watershed that receive 7 percent or more of the precipitation as mixed events during this time period (Fig. 4). Although the areal extent of the rain snow transition zone was not sensitive to the grid sizes evaluated, the detail of the spatial patterns degrades quickly at lower resolutions in smaller subcatchments (e.g. Reynolds Mountain East, shown

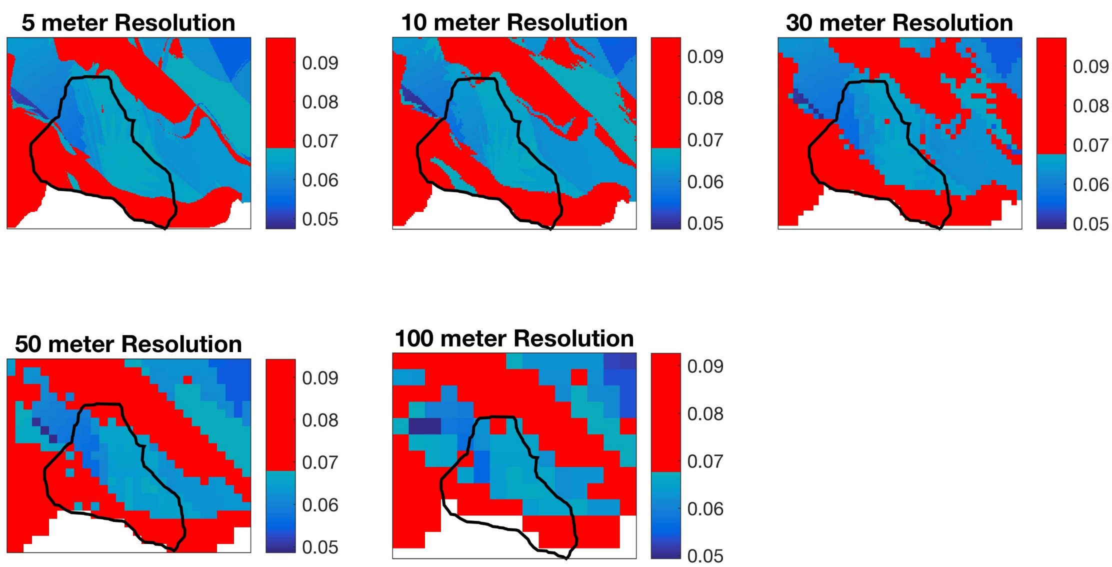


**Figure 4.** Maps of the percent of precipitation received as mixed precipitation at the Reynolds Mountain East subcatchment from January 2002 to compare different spatial resolutions.

in figure 4). Based on a cost benefit analysis of computational expense and realistic representation of the rain snow transition zone at small subcatchments, we chose 10 m grid cells (100 m$^2$).

Dew point temperature (Td) was calculated from distributed air temperature and relative humidity using methods developed by (Marks et al., 1999). Precipitation that fell with Td less than -0.5°C is assumed to be 100% snow and precipitation that fell with Td greater than 1.0°C is assumed to be 0% snow (all rain) (Marks et al., 2013). Percent snow for mixed phase precipitation is linearly interpolated from 0% at Td of -5°C to 100% at Td of 1.0°C.

## 5 Example Data

As an example of the type of detailed information that can be extracted from this dataset, we look at one hour of a mixed phase precipitation event that occurred on 21 January 2002 at 13:00 mountain standard time (Fig. 5). Distributed air temperature and relative humidity were used to calculate distributed Td, which was in turn used to classify precipitation as rain, snow, or mixed phase. We then divided the basin elevation in to 10% quantiles to get a more detailed description of where it was raining and where it was snowing (Fig. 5a. and f.). Precipitation data do not account for wind redistribution of snow.

As an example of the type of weather summary that can be extracted from this dataset, we replicate Fig. 5, but replace the one-hour data with the 31 year mean values in Fig. 6.

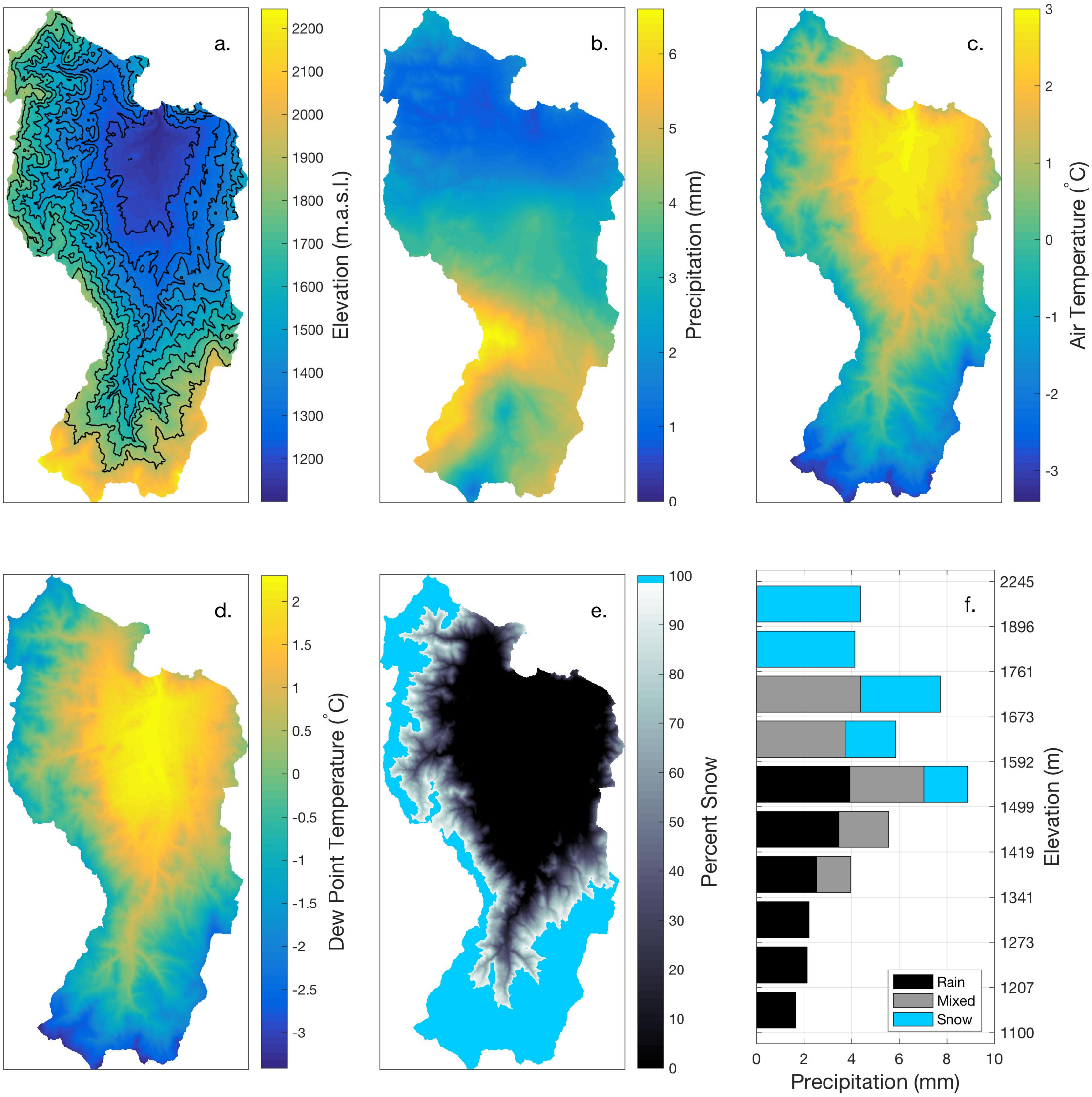


**Figure 5.** Example data from a mixed phase precipitation event that occurred on 21 January, 2001 at 13:00 mountain standard time showing a) the digital elevation model with black lines showing the delineation of bands that precipitation phase was extracted for subplot f., b) the distributed precipitation amount, c) the distributed air temperature, d) the distributed dew point temperature, e) the distributed precipitation phase, and f) the amount and phase of precipitation that fell in each elevation band described in a). Air temperature and dew point temperature are very similar because this time period is during a precipitation event.

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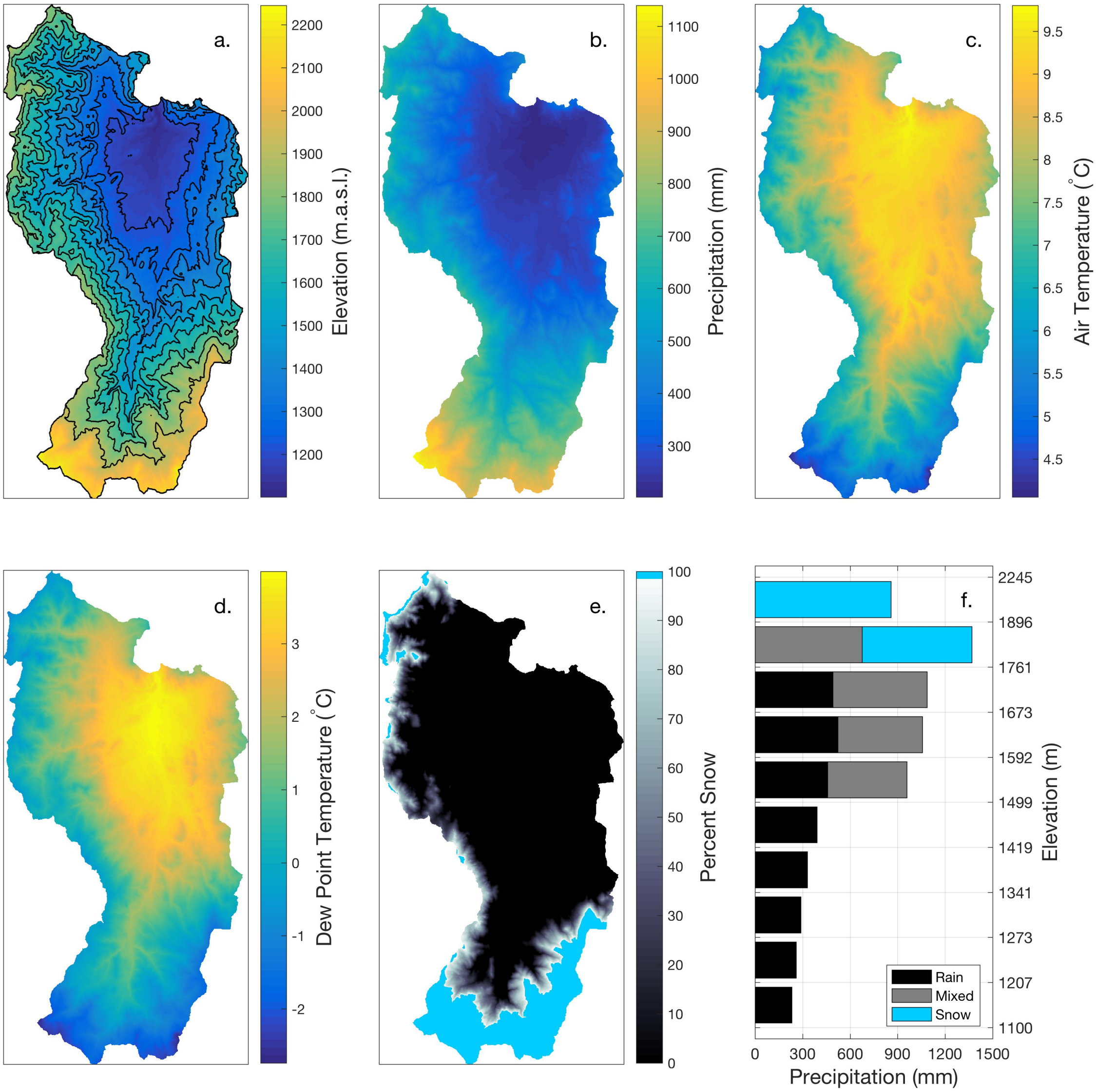


**Figure 6.** Example summary data from the 31 year dataset showing a) the digital elevation model with black lines showing the delineation of bands that precipitation phase was extracted for subplot f., b) the mean water year distributed precipitation amount, c) the mean water year distributed air temperature, d) the mean water year distributed dew point temperature during precipitation, e) the mean distributed precipitation phase, and f) the amount and phase of precipitation that fell in each elevation band described in a).

## 6 Data Provenance and Structure

All data are publicly available through an OPeNDAP-enabled THREDDS server hosted by Boise State University Libraries in support of the Reynolds Creek Critical Zone Observatory (Kormos et al., 2016). The server allows users to download subsets of the data by variable, and in space and time. Calls to the OPeNDAP portal can be made directly from a number of scientific programming languages, including Matlab, Python, and R. An example Python script is made available in the ARS-Snow GitLab repository (https://gitlab.com/ars-snow/RCZO_spatial_data_code). Spatial reference information are all in the projection UTM, NAD83, Zone 11. Weather data are stored in the NetCDF file format using conventions CF-1.6 (http://cfconventions.org/Data/cf-conventions/cf-conventions-1.6/build/cf-conventions.pdf). Files are organized by variable and water year. Each file contains a three dimensional array of the distributed variable of size 1395 (grid cells east-west) by 2813 (grid cells north-south) by 8760 (hours or 8784 for leap years). In addition, each file contains the digital elevation model used to distribute the spatial data, masks of the subwatersheds within the larger Reynolds Creek Experimental Watershed, the eastings and northings of the center of each grid cell in meters, the latitudes and longitudes of the center of each grid cell in decimal degrees, and the time vector corresponding to the distributed variable. Precipitation mass, air temperature, and relative humidity files also contain the measured time series data, names, and coordinates (easting, northing) of the weather stations used to distribute the data for that water year. Additional supporting data for RCEW, including streamflow data, vegetation, geology, and soils data, is available from ftp.nwrc.ars.usda.gov/publicdatabase/reynolds-creek/geographic-information/.

## 7 Summary

31 years of spatially distributed air temperature, relative humidity, dew point temperature, and precipitation mass and phase are presented for the Reynold Creek Experimental Watershed. This fine spatial (10m grid cells) and temporal (hourly) data set facilitates 1) analysis of "whole catchment" weather data opposed to point measurement data, and 2) hydrological and ecological modeling of a mesoscale catchment in the rain snow transition zone. Data are relevant to studies exploring historic climate changes in one of the most sensitive environments in the mountain western U.S; the rain snow transition zone.

## 8 Acknowledgements

We thank the scientists and support staff at the Agricultural Research Service - Northwest Watershed Research Center for the careful collection of weather station data at the Reynolds Creek Experimental Watershed. This work was funded in part by the NSF Critical Zone Observatory (2052-13610-010-08R), NASA Jet Propulsion Laboratory (2052-13610-010-09T), Bureau of Reclamation (2052-13610-010-05I), and the Natural Resources Conservation Service (2052-13610-010-10I). USDA is an equal opportunity provider and employer.

## References

Brown, R. D. and Mote, P. W.: The Response of Northern Hemisphere Snow Cover to a Changing Climate, Journal of Climate, 22, 2124–2145, doi:10.1175/2008JCLI2665.1, http://dx.doi.org/10.1175/2008JCLI2665.1, 2009.

Garen, D. C.: Estimation of spatially distributed values of daily precipitation in mountainous areas, in: Mountain Hydrology: Peaks and Valleys in Research and Applications, pp. 237–242, Canadian Water Resources Association, Cambridge, Ont., Canada, 1995.

Garen, D. C., Johnson, G. L., and Hanson, C. L.: MEAN AREAL PRECIPITATION FOR DAILY HYDROLOGIC MODELING IN MOUNTAINOUS REGIONS, JAWRA Journal of the American Water Resources Association, 30, 481–491, doi:10.1111/j.1752-1688.1994.tb03307.x, http://dx.doi.org/10.1111/j.1752-1688.1994.tb03307.x, 1994.

Hanson, C., Burgess, M., Windom, J., and Hartzmann, R.: New Weighing Mechanism for Precipitation Gauges, Journal of Hydrologic Engineering, 6, 75–77, doi:10.1061/(ASCE)1084-0699(2001)6:1(75), http://dx.doi.org/10.1061/(ASCE)1084-0699(2001)6:1(75), 2001.

Hanson, C., Pierson, F., and Johnson, G.: Dual-Gauge System for Measuring Precipitation: Historical Development and Use, Journal of Hydrologic Engineering, 9, 350–359, doi:10.1061/(ASCE)1084-0699(2004)9:5(350), http://dx.doi.org/10.1061/(ASCE)1084-0699(2004)9:5(350), 2004.

Klos, P. Z., Link, T. E., and Abatzoglou, J. T.: Extent of the rain-snow transition zone in the western U.S. under historic and projected climate, Geophysical Research Letters, 41, 4560–4568, doi:10.1002/2014GL060500, http://dx.doi.org/10.1002/2014GL060500, 2014.

Kormos, P. R., Marks, D., Williams, C. J., Marshall, H. P., Aishlin, P., Chandler, D. G., and McNamara, J. P.: Soil, snow, weather, and sub-surface storage data from a mountain catchment in the rain–snow transition zone, Earth Syst. Sci. Data, 6, 165–173, doi:10.5194/essd-6-165-2014, http://www.earth-syst-sci-data.net/6/165/2014/, 2014.

Kormos, P. R., Marks, D. G., Seyfried, M. S., Havens, S. C., Hedrick, A., Lohse, K. A., Masarik, Matt, F., and N., A.: 31 Years of Spatially Distributed Air Temperature, Humidity, Precipitation Amount and Precipitation Phase From a Mountain Catchment in the Rain-snow Transition Zone, doi:10.18122/B2B59V, http://scholarworks.boisestate.edu/reynoldscreek/1/, 2016.

Marks, D., Domingo, J., Susong, D., Link, T., and Garen, D.: A spatially distributed energy balance snowmelt model for application in mountain basins, Hydrological Processes, 13, 1935–1959, 1999.

Marks, D., Winstral, A., Reba, M., Pomeroy, J., and Kumar, M.: An evaluation of methods for determining during-storm precipitation phase and the rain/snow transition elevation at the surface in a mountain basin, Advances in Water Resources, 55, 98–110, 2013.

Morin, S., Lejeune, Y., Lesaffre, B., Panel, J. M., Poncet, D., David, P., and Sudul, M.: An 18-yr long (1993–2011) snow and meteorological dataset from a mid-altitude mountain site (Col de Porte, France, 1325 m alt.) for driving and evaluating snowpack models, Earth Syst. Sci. Data, 4, 13–21, doi:10.5194/essd-4-13-2012, http://www.earth-syst-sci-data.net/4/13/2012/, 2012.

Nayak, A., Chandler, D. G., Marks, D., McNamara, J. P., and Seyfried, M.: Correction of electronic record for weighing bucket precipitation gauge measurements, Water Resources Research, 44, doi:10.1029/2008WR006875, http://dx.doi.org/10.1029/2008WR006875, 2008.

Nayak, A., Marks, D., Chandler, D. G., and Seyfried, M.: Long-term snow, climate, and streamflow trends at the Reynolds Creek Experimental Watershed, Owyhee Mountains, Idaho, United States, Water Resources Research, 46, 15, 2010.

Reba, M. L., Marks, D., Seyfried, M., Winstral, A., Kumar, M., and Flerchinger, G.: A long-term data set for hydrologic modeling in a snow-dominated mountain catchment, Water Resources Research, 47, n/a–n/a, doi:10.1029/2010WR010030, http://dx.doi.org/10.1029/2010WR010030, 2011.

Seyfried, M., Harris, R., Marks, D., and Jacob, B.: Geographic Database, Reynolds Creek Experimental Watershed, Idaho, United States, Water Resources Research, 37, 2825–2829, doi:10.1029/2001WR000414, http://dx.doi.org/10.1029/2001WR000414, 2001.

Western, A. W. and Grayson, R. B.: The Tarrawarra Data Set: Soil moisture patterns, soil characteristics, and hydrological flux measurements, Water Resources Research, 34, 2765–2768, doi:10.1029/98WR01833, http://dx.doi.org/10.1029/98WR01833, 1998.

Winstral, A. and Marks, D.: Long-term snow distribution observations in a mountain catchment: Assessing variability, time stability, and the representativeness of an index site, Water Resources Research, 50, 293–305, doi:10.1002/2012WR013038, http://dx.doi.org/10.1002/2012WR013038, 2014.

Winstral, A., Marks, D., and Gurney, R.: Simulating wind-affected snow accumulations at catchment to basin scales, Advances in Water Resources, 55, 64–79, 2013.