Cataloging large precipitation events associated with atmospheric rivers in the Upper Colorado River Basin

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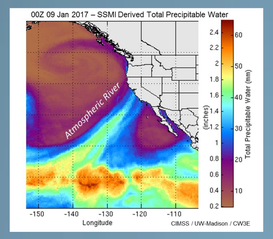
Abstract

Many watersheds rely on atmospheric rivers (ARs) to contribute significant proportions of annual water supply, often from only a few events. In California, for example, ARs contribute 30-50% of annual precipitation and 40% of Sierra Nevada snowpack (Anderson 2016). This study characterizes the role of ARs as moisture sources for the Upper Colorado River Basin (UCRB), by cataloging ARs coinciding with large precipitation events (LPEs) observed across the UCRB from 1981-2014. ARs coincide with 10% of LPEs and generally produce wetter than normal events, but the relationship between integrated vapor transport (IVT) and LPEs is weak, suggesting that ARs are not uniquely dominant sources of yearly water supply. Despite topographic decay, ARs reach the UCRB through particular pathways, suggesting that certain synoptic conditions may enhance moisture advection into the region. Since LPEs have been shown to be strong predictors of streamflow in the basin, further awareness of moisture sources, especially at sub-AR criteria, is needed when considering hydroclimatic conditions of inland watersheds.



Data and Methods

LPE Database:

- Selected 15 SNOTEL sites among headwater regions of the UCRB. The sites represent drainage areas which yield 16% of annual streamflow, draining 2% of total UCRB area.
- LPE days are defined by snow-water equivalent or accumulated precipitation exceeding the 80th percentile of all days: ≥ 7.6-12.7 mm. (0.3-0.5 in.).
- LPEs produce 56% of all precipitation at the selected sites and are significant predictors of streamflow.

AR Database:

- ARs identified by Rutz et al. (2014), using 6-hr NCEP/NCAR Reanalysis 1. ARs must be ≥ 2000 km long, IVT ≥ 250 kg m^{-1} s^{-1}. AR dataset is provided in an online archive.
- An AR day occurs on an LPE day if the AR criteria are met for any 6-hr interval on that day at the nearest reanalysis grid point to each SNOTEL site.

Results

On average in the UCRB, LPEs occur on 9.5% of all days annually. AR conditions occur on 10% of LPE days, representing 1.5% of all days, and yield 10% of annual LPE precipitation, typical fractions found for the continental interior (e.g. Rutz et al. 2014). Overall, 44% of ARs yield LPEs, suggesting that AR-level moisture does not always result in heavy precipitation. ARs most frequently lead to LPEs towards the south in the basin (48%) and less so in the central and northern portions (35%; 30%, respectively). Basin-wide, on average, AR-LPEs yield 21 mm of daily precipitation, as compared to 16 mm in non-AR LPEs.

IVT over the UCRB varies widely (Fig. 1), with higher values more common towards the south and lower towards the north. ARs account for as many as 27% of all LPEs, as in the north, and as little as 4% in the central UCRB. LPEs occur during both high and low IVT, suggesting the importance of factors other than moisture transport. AR-associated LPEs coincide with higher IVT values by definition, but many of the wettest events occur with IVT values well below traditional AR thresholds, suggesting either AR decay or other contributing factors to precipitation.

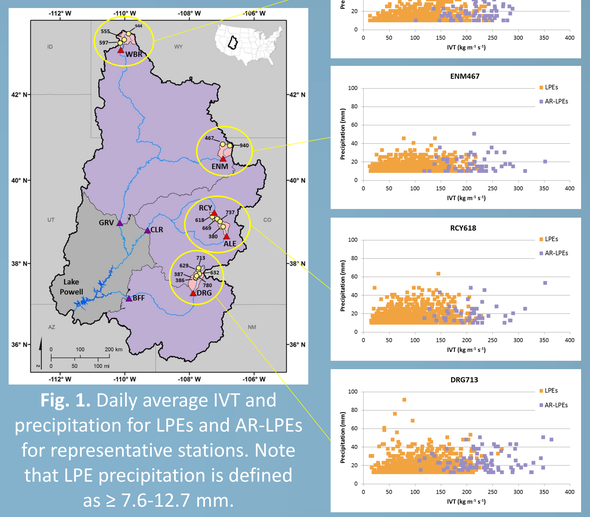


Fig. 1. Daily average IVT and precipitation for LPEs and AR-LPEs for representative stations. Note that LPE precipitation is defined as ≥ 7.6-12.7 mm.

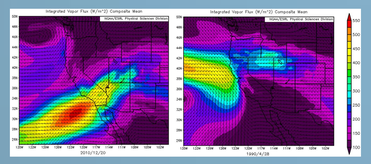


Fig. 2a (left) and 2b (right). Examples of ARs which resulted in LPEs in the UCRB

Topography is a major obstacle for the inland penetration of ARs. Despite this, a few pathways exist for Pacific moisture to reach into the interior (Rutz et al. 2015). Figures 2a and 2b illustrate two AR events that were recorded in the UCRB, each producing LPEs at the SNOTEL sites featured in this study. Fig. 2a depicts an AR which registered as an LPE at all of the selected SNOTEL sites, except in the northernmost subbasin, and resulted in major flooding (Werner and Yeager 2013). Fig. 2b illustrates a more northern corridor for an AR to penetrate into the interior, which resulted in an LPE for UCRB stations towards the north. The Sierra Nevada represent the most significant topographic barriers for inland AR penetration to the UCRB, thus the proportions of AR-associated LPEs tend to be lower in the central basin, in the lee of the mountains.

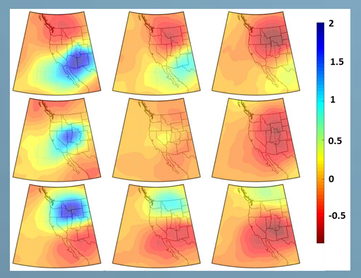


Fig. 3. Self-organizing map (SOM) pattern classification of standardized IVT anomalies in the UCRB

Research is currently being conducted on synoptic conditions leading into LPEs. The pathways identified in Fig. 2 emerge as separate classifications in Fig. 3, with plumes of positive IVT anomalies centered at differing latitudes. These patterns reflect those produced in Swales et al. (2016), which found two dominant synoptic patterns associated with extreme events:

(1) Troughs with landfalling extratropical cyclones moving into the US interior, with accompanying moisture advection pushing south into southern portions of the Colorado River Basin

(2) Persistent coastal ridges directing moisture from the southwest to northeast, resulting in high IVT oriented towards the Pacific Northwest and northern reaches of the UCRB.

The ridge pattern is more common due to its persistence and may be contributing to the higher proportions of AR-associated LPEs observed here for the northern UCRB.

Conclusions

On average, AR conditions exist on 7 days in the UCRB each year. While individual ARs can produce extreme precipitation in the basin, based on this study, links between LPEs and IVT are weak, thus ARs are not particularly dominant sources of precipitation year-to-year in the basin. ARs are known to rapidly decay as they penetrate into the interior western US, but it is likely that residual moisture, below traditional AR definitions, still contributes to LPEs. Research on moisture pathways has identified corridors for AR penetration into the UCRB, evidenced here by the higher proportions of LPEs linked to ARs observed in the north and south of the UCRB, outside of the lee of the Sierra Nevada. Additional analysis of LPE moisture sources is needed to further characterize basin hydroclimatology.

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AMS 2017 – Observations Lead the Way

"To measure is to know." To improve some areas of hydroclimatology, consider the following:

- Support and expand USGS stream gage network
- Fully upgrade SNOTEL network with soil moisture sensors
- Expand Pacific coast network of Atmospheric River Observatories to improve sensing of moisture transport (Ralph et al. 2014)
- Facilitate interagency collaboration to efficiently utilize existing data infrastructure and improve salience and legitimacy of next-gen observation strategies (Cash et al. 2003)
- Keep an open mind – contemporary problems require creative solutions

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