Annual and diurnal variation of precipitable water over California and Nevada

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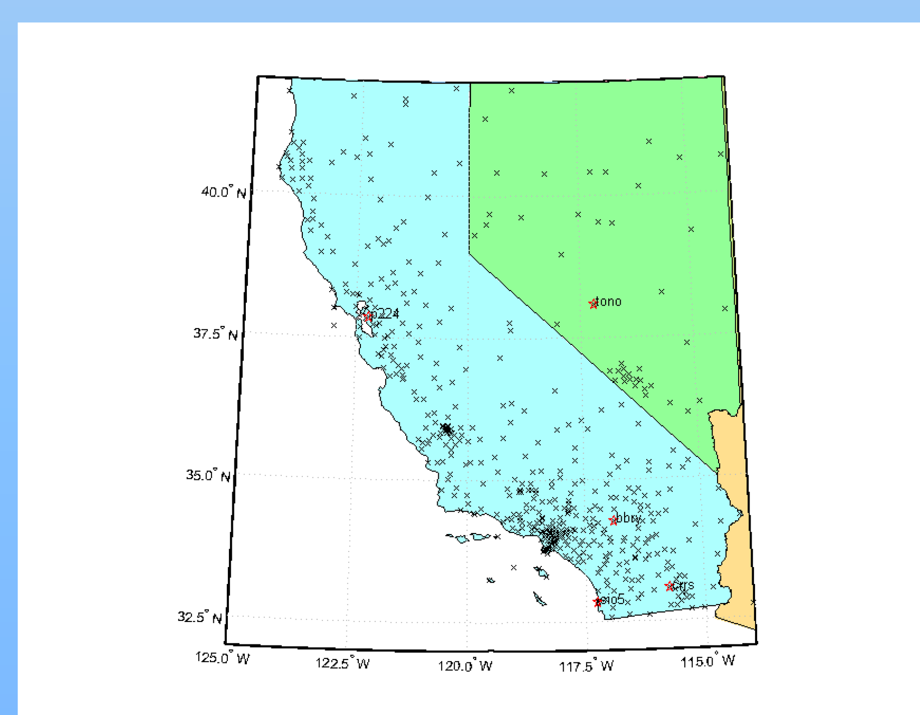
Introduction

Diurnal cycles are widespread in climate studies. Temperature, pressure, and wind speed are all quantities that are known to exhibit diurnal cycles. A diurnal cycle of moisture would be an important facet of California and Nevada's climate—both to humans and ecosystems. It may be important to landward moisture transport, through the sea breeze, and it may show the daily cycle of evapotranspiration induced by solar heating.

However, evidence has been lacking, since the most obvious data source, the balloon soundings, is only available at a few sites and then just twice per day. We have been able to overcome this limitation by using archived Global Positioning System (GPS) delays combined with pressure and temperature from reanalysis to calculate the precipitable water corresponding to those delays. A seven year (2003-2009) data set of precipitable water (integrated water vapor) values obtained from more than 500 GPS sites has been used to examine diurnal variation in precipitable water over California and Nevada. Most sites show a clear diurnal variation, with small values near the coast increasing rapidly inland. The temporal variation is used to fit a sinusoidal curve to the data for each site; the maximum of the sinusoid gives the peak local time of daily cycle. The peak of the diurnal cycle generally occurs earlier in sites near the ocean and other water bodies, and later away, suggesting that the peak in the water vapor diurnal cycle may be determined by peak heating of adjacent water bodies, and then modified by the travel time of sea breezes from the water to the land.

This map shows the locations of the 520 GPS sites that have been used in this study of precipitable water. Precipitable water is calculated from zenith delays, which are archived by the Scripps Orbit and Permanent Array Center (SOPAC). Specific sites referred to in this study are designated by red stars.

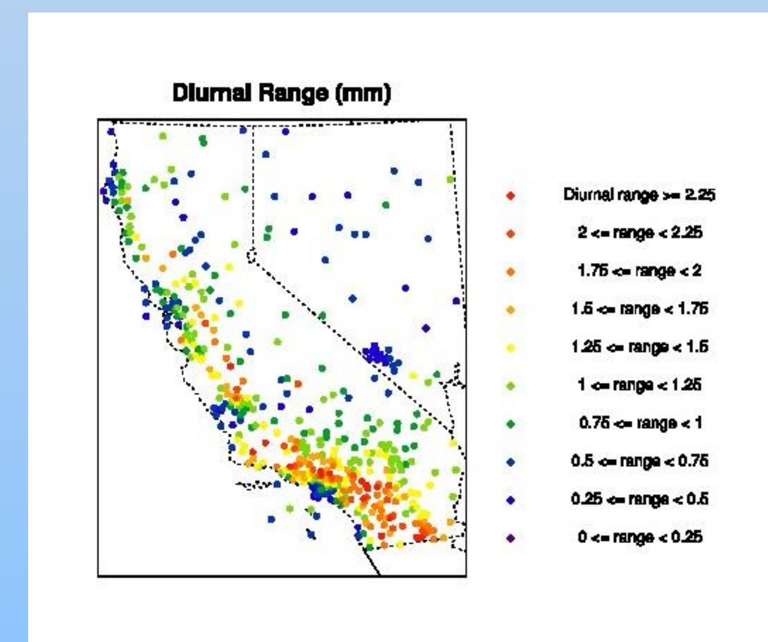


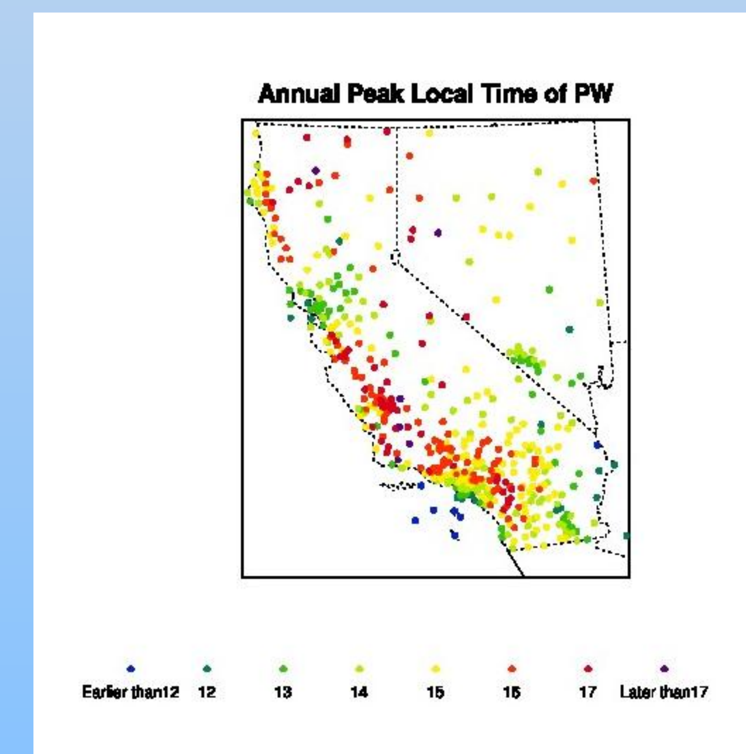
What can cause a diurnal variation?

As seen in the following equation, evaporation, condensation, transpiration, moisture convergence, and advection all contribute to changing the precipitable water vapor,

$$\frac{\partial PW}{\partial t} = \frac{g}{\rho_w}\left(\bar{E} - \bar{C}\right) - \frac{1}{\rho_w}\left(\int_0^{p_s}\left(q\nabla\cdot\mathbf{V}_h + \mathbf{V}_h\bullet\nabla q\right)dp\right)$$

Translated into the climate of the region, moisture may evaporate from the ocean or water bodies, condense as marine stratus, be advected inland, evaporate with the daily rise in temperature and be mixed with vapor transpired from vegetation. During the evening processes may reverse—a dry land breeze carries drier air toward the ocean, dew condenses on the ground, etc. A complex combination of all of these no doubt determines the diurnal cycle at a particular location.



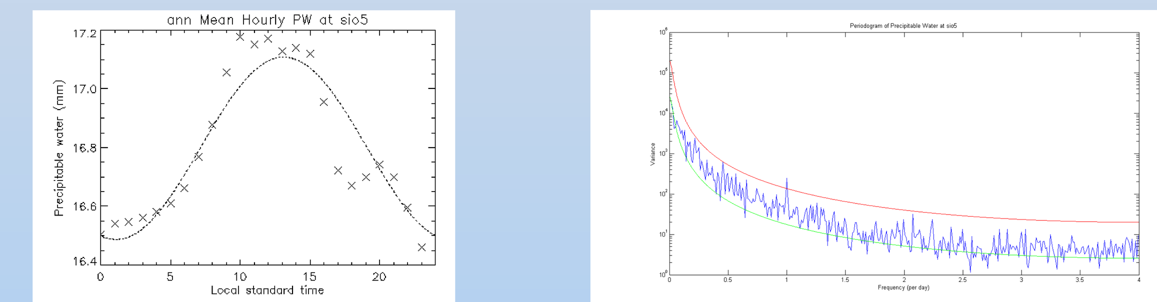


Diurnal range and peak time of PW

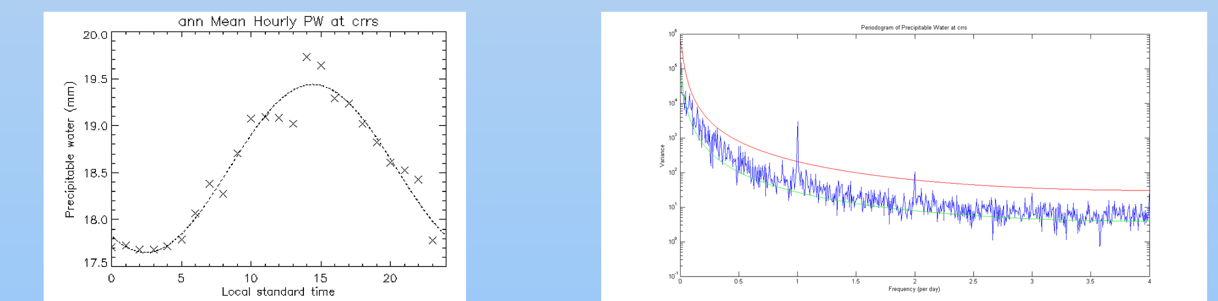
The mean daily range at a site and peak time determined from the complete GPS precipitable water climatology have a definite geographic variation, with the diurnal range increasing from the coast inland, and also from north to south. The time of peak precipitable water varies also, with lower sites having precipitable water peak earlier in the day than more elevated sites.

Diurnal variation and power spectra

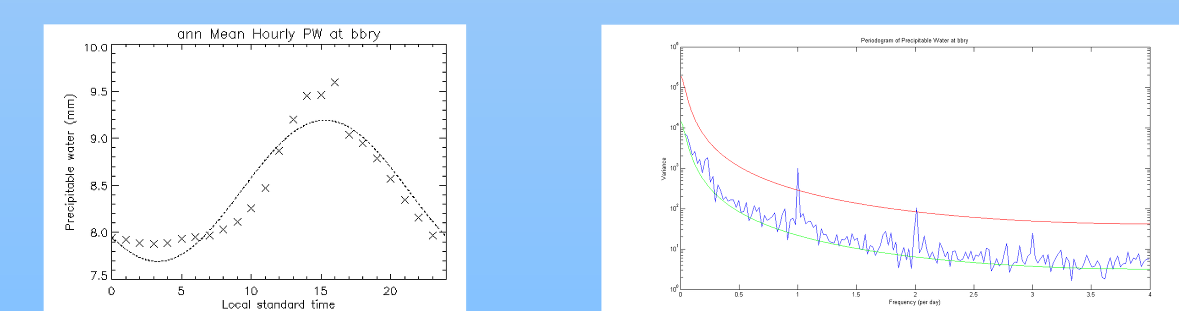
Examples of daily mean time series and power spectra are shown in the following plots. PW is modelled as an autoregressive type 1 process. AR(1). We calculate a theoretical spectrum from the process variance and the lag 1 autocorrelation. From that we can calculate the spectral amplitude that must be exceeded for a particular significance level. On the power spectra that follow we have plotted curves corresponding to both the theoretical AR(1) spectra and the 95% significance level. To improve the signal-to-noise ratio we have binned frequencies and summed the results.



Southern coastal site SIO5 shows a diurnal variation of small amplitude



Southern desert site CRRS shows a large diurnal variation with a semidiurnal component



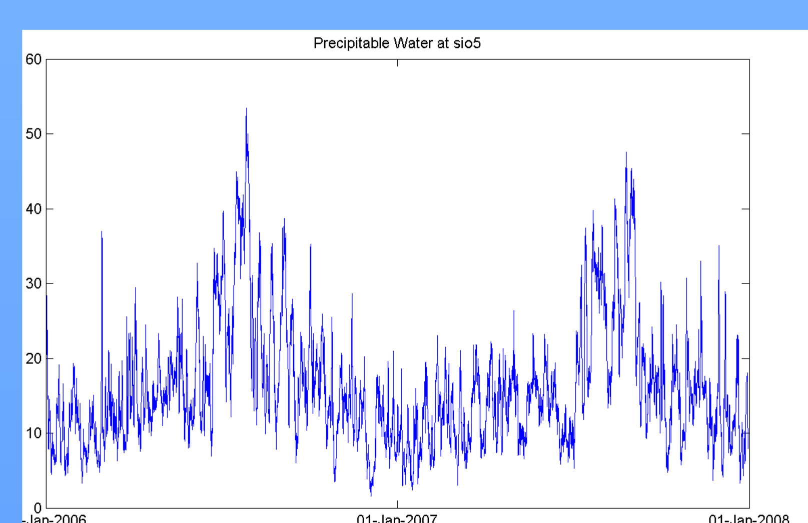
Southern mountain site BBRY shows a proportionally large and complex diurnal variation

Conclusion

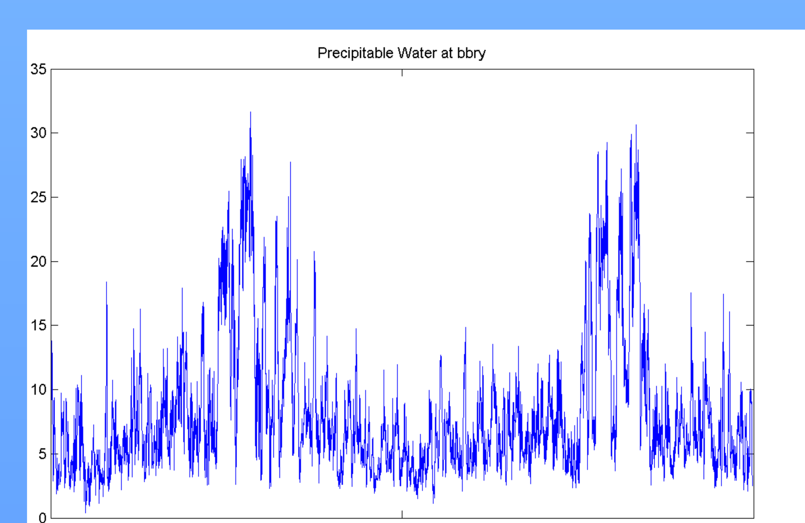
Our study of precipitable water has shown that most locations have both a strong annual variation in precipitable water, as well as a diurnal variation. The diurnal variation can range from a few percent at coastal locations to over ten percent at higher elevation inland sites. Further study is needed to determine the moisture budget that drives the diurnal cycle at a particular location.

Two Years of Annual Variation 2006--2007

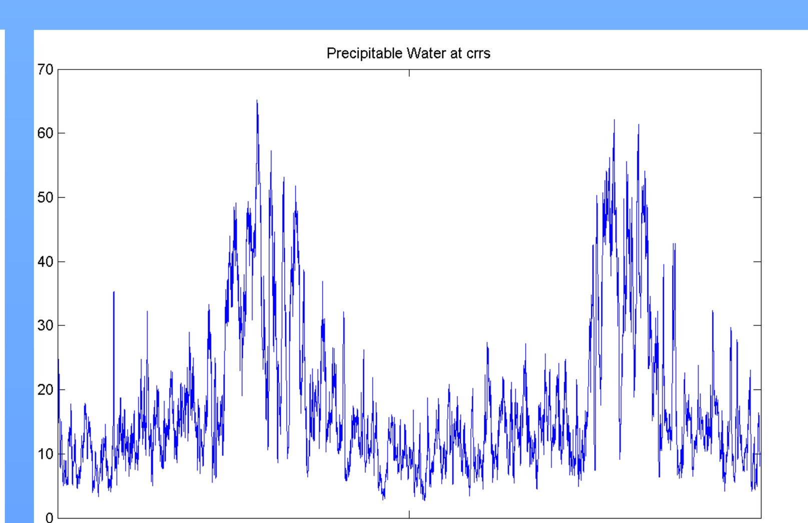
The plots to the right show time series of precipitable water for the 2006—2007 time period at a variety of stations across the region. Most show a strong annual cycle with precipitable water peaking in late summer. There is also a clear dependence on latitude and elevation, with southern lowland stations showing greatest precipitable water and the northern and mountain stations showing the least.



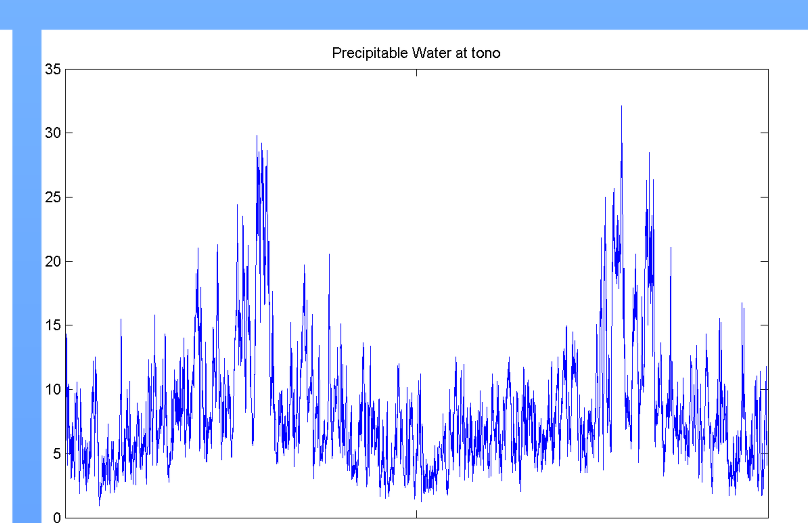
Southern coastal site SIO5 shows a strong summer increase with PW values over 50 mm during intrusions of monsoonal air. Peaks during winter season corresponding to baroclinic storm passage.



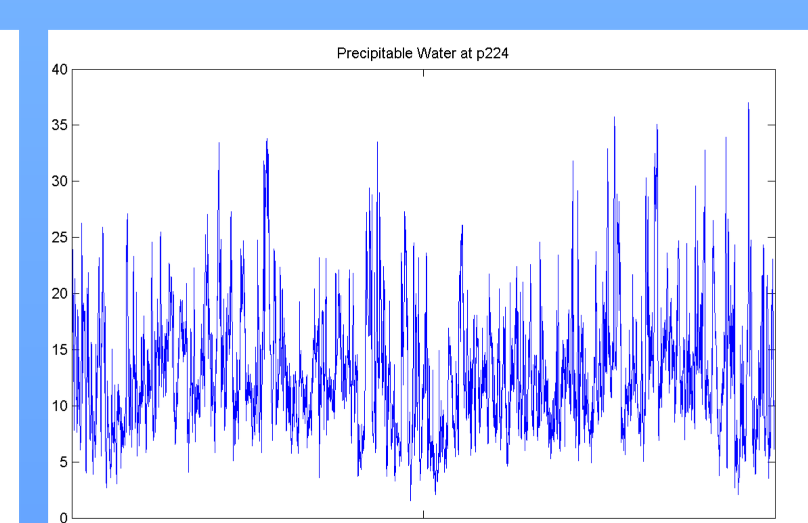
Southern mountain site BBRY has a similar annual cycle to SIO5, but much smaller amplitude due to its elevation (> 2000 m). There is a high degree of correspondence with nearby sites SIO5 and CRRS.



Southern desert site CRRS has a similar annual cycle to SIO5, but with much large summer amplitude because it's in the monsoon region.



Great basin site TONO has a similar annual cycle to BBRY, with small amplitude also due to its elevation (> 2000 m) and interior location.



Northern coastal site P224 shows much less seasonal dependence than other sites, at least partially because its more northern location puts it near the storm track year-round.