Ice accumulation and the apparent seasonal movement of GPS stations in Alaska

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Summary

Most GPS stations in Alaska move seasonally in response to snowfall and hydrologic loading. These movements are vertical, with an amplitude of 1-3cm.

We found eleven stations which move out-of phase with snowfall. These stations are identified by discontinuous movements in winter, and strongly skewed time-series.

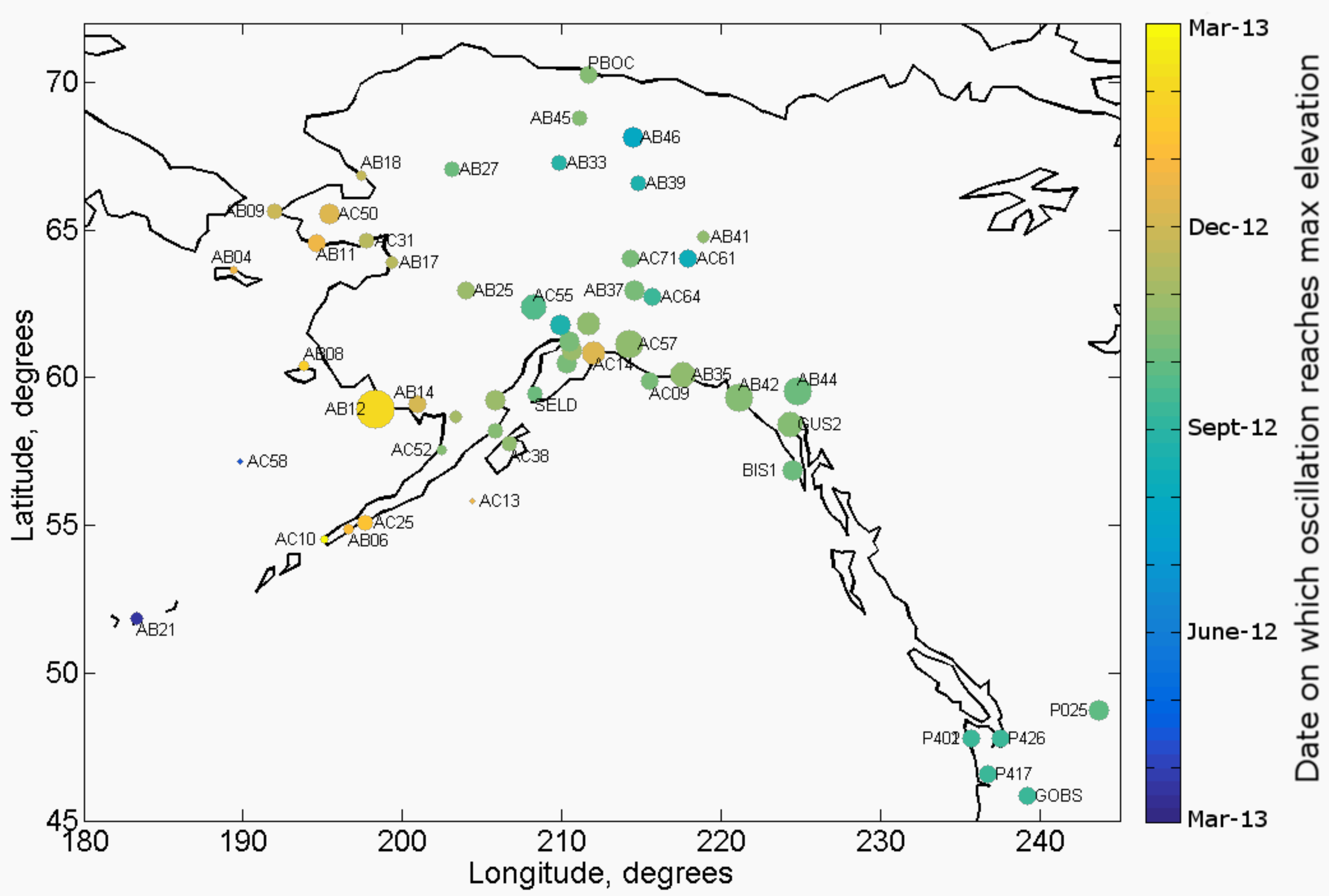
Our analysis indicates that stations AB06, AB11, AB12, AB14, AC16, AC25 and AC50 accumulate ice in winter. Ice delays their signals and causes the stations to report large, non-physical displacements. This reduces the rate of reliable data collection from these stations and completely obscures their seasonal movements.

These results could be confirmed by direct observation of the sites, or by monitoring changes in the stations´ behaviors when their temperatures cross the freezing point.

Most GPS stations in Alaska move downwards during the winter.

The positions of GPS stations oscillate annually. This motion is caused by environmental effects which include, in approximate order of magnitude: hydrologic loading; changes in atmospheric pressure; pole tides; ocean mass movements; ocean tides; and thermal expansion of the bedrock (Dong et al., 2002).

In Alaska, the majority of stations gain elevation during the spring and summer, peak in September or October, then lose elevation in winter. In southeast Alaska, this motion has been attributed to seasonal snow loading on the coastal mountains (Fu et al., 2012).



Vertical seasonal oscillations for fifty GPS stations in Alaska and five in Washington State. The magnitude of the oscillations is proportional to the area of the markers. The phases of the oscillations, expressed as the dates on which each station reaches its highest

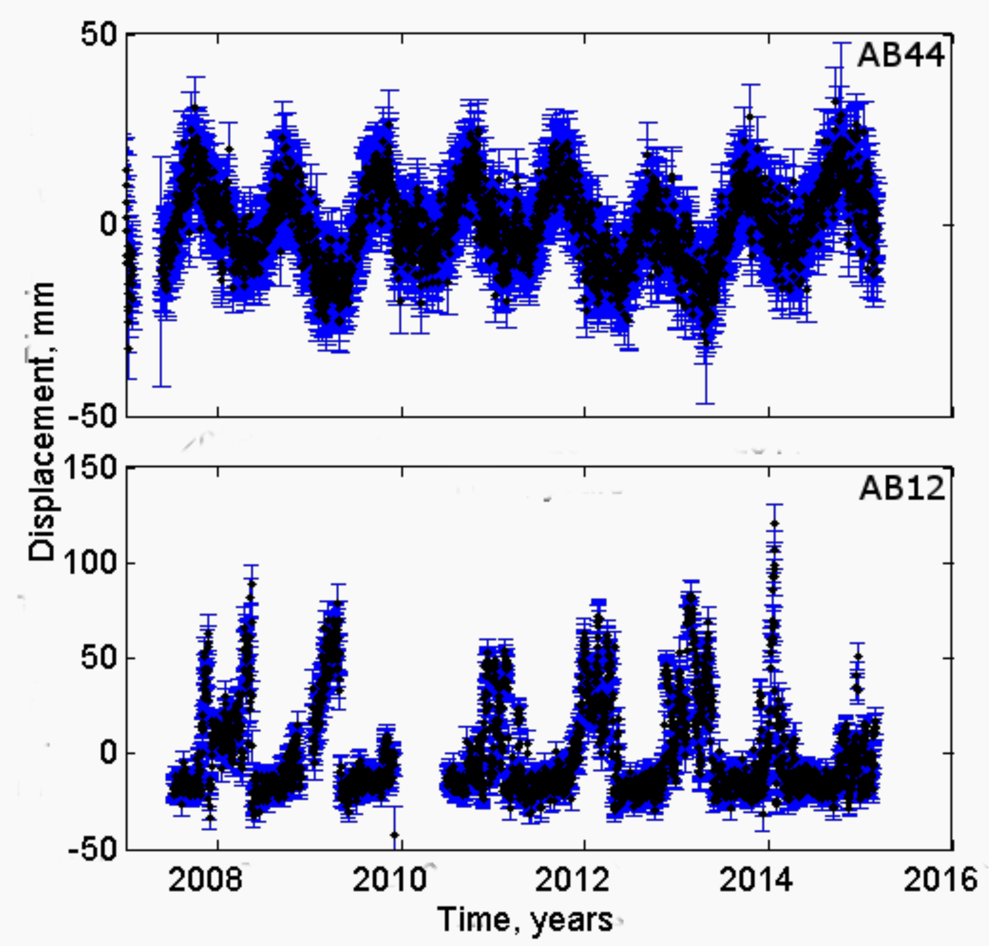
Some stations move up in winter instead.

We surveyed fifty-five GPS stations. The mean date on which they reached their highest elevation was Oct. 26. The standard deviation of that date, however, is ninety days. 44% of that variation is caused by eleven stations. These stations all have time-series, or apparent vertical motions, that are unusually discontinuous and skewed.. They are: AB06, AB11, AB12, AB14, AB33, AB46, AC14, AC16, AC25, AC50, andAC53.

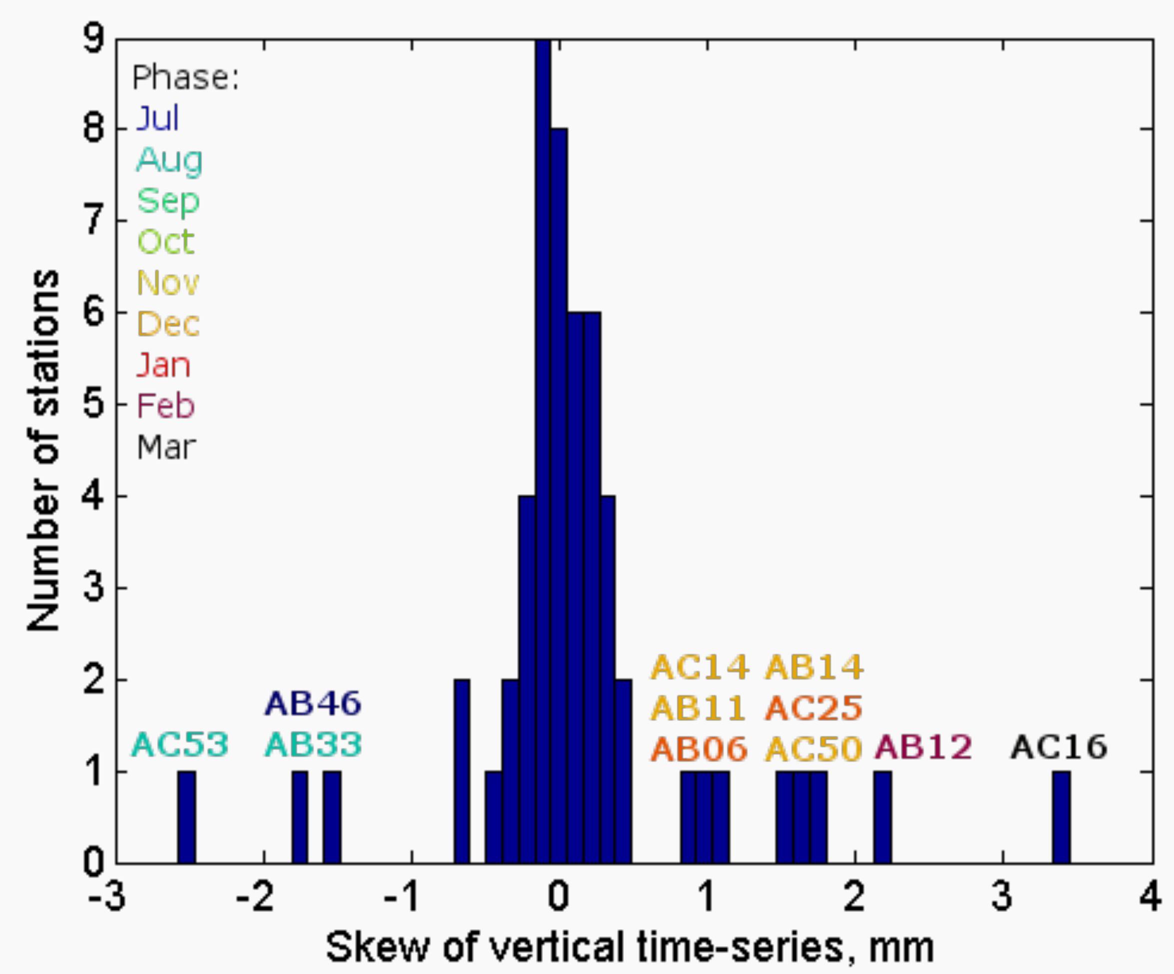
These move discontinuously...

Two example GPS time-series are shown to the right. They show vertical displacement over time. Both series are de-trended. The upper time-series, AB44, has a regular seasonal oscillation that is in phase with snow loading and peaks yearly on average on Oct. 4th.

In contrast, AB12 moves out of phase with snowfall and has the largest seasonal oscillations iin this study. In winter, AB12 moves rapidly and irregularly. Its apparent elevation has jumped by as much as 67mm in one day.



...they have asymmetric time series...



The skew, or asymmetry, of a distribution of values can be calculated as: $\gamma = \mathrm{E}\left[\left(\frac{x-\mu}{\sigma}\right)^3\right]$

where ´E´ indicates an expectation value, μ is the mean of the distribution, and σ is the standard deviation. Each data point must be weighted by the inverse of its uncertainty squared. Sinusoidal time-series have no skew.

The figure above shows the eleven time-series with the greatest skews. These stations are all out - of-phase with snowfall, as indicated by the coloring.

... and they tend to occupy local high points, where winter winds deposit ice.

Station AB14, 40km inland of Bristol Bay. PBO and UNAVCO..

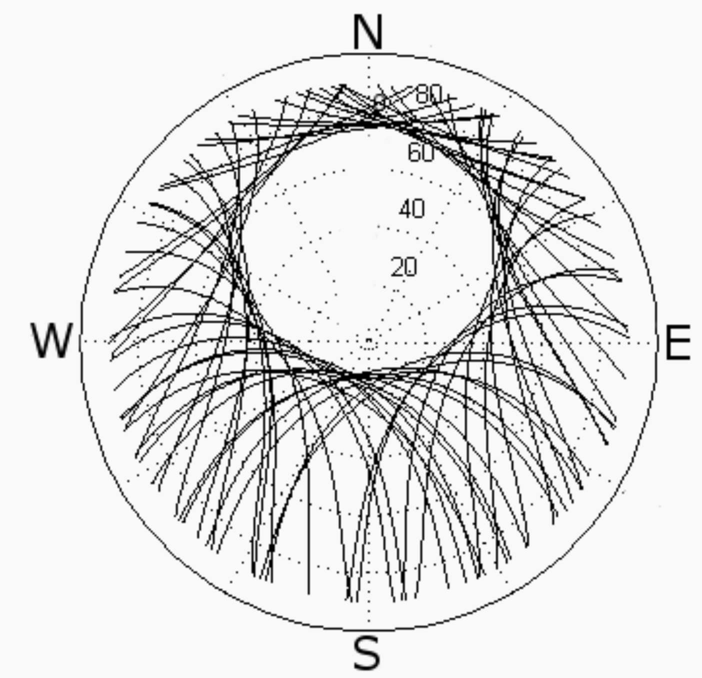
Seven of the eight stations with positively-skewed time series are located on local high points or ridges. Six of these are on the west coast or the Aleutians. The other two stations with skewed time-series, AC14 and AC16, are in Prince William sound.

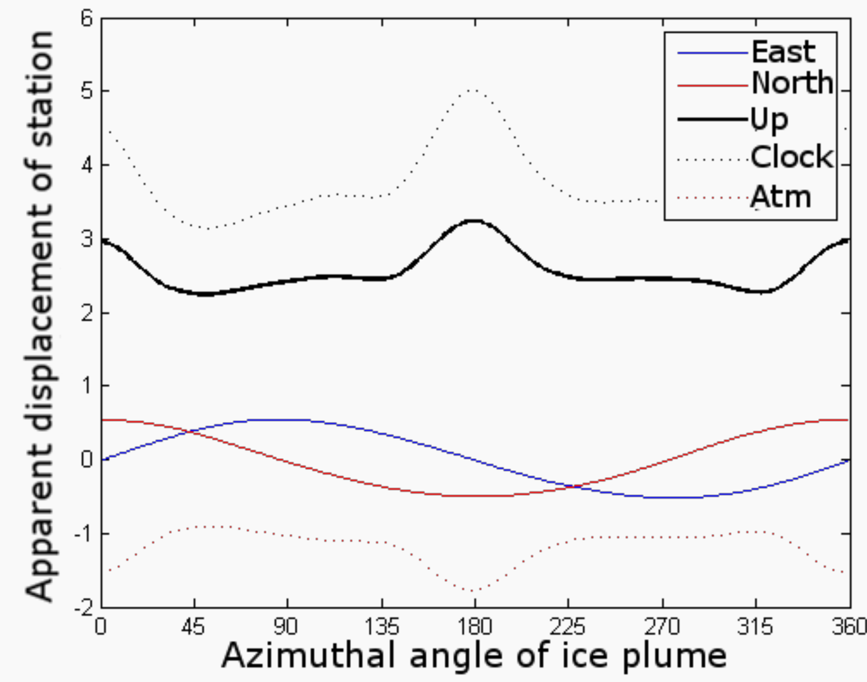
In winter, weather stations in this area experience high humidity and strong, consistent winds along the coast These are ideal conditions to form rime ice.

When wind-borne water hits a cold surface, it freezes into horizontal plumes of rime (photo, right). These feathers are irregularly shaped. They reflect and scatter GPS signals. The positively skewed stations which we identified earlier all have higher multipath values in winter than in summer, which indicates increased signal scattering.

Mt. Washington Observatory 3-Feb-2012, Jesse Ferrell and accuweather.com.

Ice scatters and delays GPS signals, and makes GPS stations appear to move vertically.





We simulated signal delay in a rime plume on a GPS station. We used an idealized geometry in which an ellipsoid of ice clings to a hemispherical GPS station, and used the satellite orbits shown above, and satellites follow the tracks in the figure above left.

The results (figure, right) show the apparent displacement of the station. We observe an apparent motion upwards and towards the rime plume. This demonstrates that ice accumulation can cause the vertical GPS station movements that we observe in the positively skewed stations.

Acknowledgements & References

This material is based on data services provided by the UNAVCO Facility with support from the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) under NSF Cooperative Agreement No. EAR-0735156.

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