Large Precipitation Gradients along the South Coast of Alaska Revealed by Spaceborne Radars

Graduate School of Science, Kyoto University
Shunsuke Aoki and Shoichi Shige

Original paper:
Spaceborne radar can observe precipitation regardless of the ground surface conditions (sea/land) with high resolution (~5km) compared to other sensors. Thus, spaceborne radars are suitable for observing around the coastlines. The 17-yr observations of the Tropical Rainfall Measurement Mission (TRMM) Precipitation Radar (PR) have revealed that large amount of the water vapor flowing inland from the ocean is converted to precipitation around coastal areas. To grasp global land-sea water circulation, it is important to understand precipitation process in coastal areas.
Reveal the precipitation climatology in high-latitude coastal areas (where TRMM PR does not cover) by using products from GPM KuPR.

Distinguish the phase-type of precipitation particles, which is crucial in evaluating precipitation at higher latitudes, by using CloudSat CPR.

The Global Precipitation Measurement (GPM) Dual-frequency Precipitation Radar (DPR) Ku-band precipitation radar (KuPR; 13.6GHz), launched in 2014, cover a mid–high latitudinal area where the TRMM PR does not. By using GPM KuPR, we investigates the spatial patterns of precipitation around the coastline in higher latitudes. Because the temperature is close to the melting point of water at higher latitudes, what characterizes the precipitation climatology along the coastlines is not only the amount of precipitation but also the phase of precipitation particles falling to the surface, which is not much of an issue when referring to tropical precipitation. For example, snowfall at high latitudes and in mountain regions at midlatitudes maintains the mass of glaciers and icefields that play the important role of great freshwater reservoirs, whereas rainfall in these regions increases the flow of rivers to the sea and the melting of ice. W-band radar Cloud Profiling Radar (CPR; 94GHz) onboard CloudSat is far more sensitive in measuring light-to-moderate rainfall and snowfall than the KuPR, and suitable for discriminating phase of precipitation. This study investigates spatial patterns of precipitation climatology and mechanisms for the south coast of Alaska using two spaceborne radars, the GPM DPR and CloudSat CPR.
The south coast of Alaska (45 – 65° N, 125 – 155° W) is selected for analysis in this study because precipitation concentrates along this coast over a long narrow area of > 1000 km. Precipitation along the west coast of North America is usually associated with extratropical cyclones arriving from the Pacific Ocean. CPR is far more sensitive in measuring light-to-moderate rainfall and snowfall than the KuPR due to the CPR’s higher sensitivity and finer horizontal resolution. Each precipitating event is classified into one of three precipitation phases (i.e., a rain, mixed, or snow phase) at the near-surface bin using the precipitation flag from the 2C-PRECIPCOLUMN product. Although suffering from low detectability, the KuPR has a good sampling rate owing to its scanning in the cross-track direction. Furthermore, the KuPR can measure the intensity of modest-to-heavy precipitation, whereas the CPR cannot owing to its large attenuation and multiple-scattering effect.
Data & Methods

- How to show the precipitation distribution by using the limited observation of spaceborne radars?
  ⇒ Show as a function of the distance from the coastline
- Wind vectors from ERA5 reanalysis are decomposed into cross- and parallel-barrier component.

Since these radars are mounted on low-orbit satellites, they can only observe a limited area when the satellite passes over it. Therefore, in order to manage the lack of samples, we performed the analysis by aggregating the data by “the distance from the coastline”. To investigate the relationship between precipitation and wind towards the terrain, wind vectors are decomposed into cross- and parallel-barrier component.
“Precipitation frequency” is defined as the ratio of the number of observations for which precipitation was detected to the total number of observations including no-precipitating events. The KuPR-detected precipitation frequency has a peak above coastal water (from $-20$ to $0$ km). The frequency gradually decreases as the distance from the coast on the seaward side increases to 200 km and drops sharply as the distance from the coast on the landward side increases to 100 km.

As with KuPR, the CPR detects precipitation most frequently near the coastline, however, there is a large difference when cases are divided into the three types of phase. The curves of CPR-detected frequencies of rainfall (dashed blue line) and mixed-phase precipitation (dash-dotted blue line) are similar to the curve of the KuPR-detected frequency (red line). Besides, the CPR snowfall frequency (solid blue line) is completely different in that it has a large value landward of the coastline and a peak in the coastal mountain range (from 20 km to 40 km), more inland from the maximum of the KuPR-detected precipitation frequency.
Precipitation frequencies evaluated by the two spaceborne radars have their maximum values in different regions: the KuPR-detected frequency has its maximum over the coastal waters (-20 to 0 km), and the CPR-detected frequency has its maximum over the coastal mountains (20 to 40 km).
To show how precipitation characteristics differ according to the distance from the coastline, reflectivity data obtained from KuPR and the CPR when precipitation is detected by each radar are aggregated into contoured frequency and altitude diagrams (CFADs; Yuter and Houze 1995). Each CFAD is normalized by the number of observations at each height including non-precipitating events.

On the sea side of the coastline, the ratio of profiles with reflectivity stronger than the 7-dBZ threshold gets higher as the distance from the coastline decreases. The intensity of rainfall & mixed phase precipitation (radar reflectivity) generally increases downward, and this feature is especially clear over the coastal ocean and lowlands (from −80 km to 20 km). Meanwhile, the reflectivity of CPR-detected echoes no longer increases downward; this is because the strong backscattering from liquid particles causes the saturation of attenuation signals in CPR observation.

Inland echoes with reflectivity weaker than 11 dBJ more often appear in layers of the lowest 3 km with increasing distance from the coastline (from 0 km to 60 km). This suggests that light-to-moderate snowfall (with reflectivity lower than 11 dBZ) is dominant there, and precipitation tend to get weaker as these clouds enter the coastal mountains.
Now, we discuss why such a large gradient of precipitation appear along the south coast of Alaska.

The convergence zone of wind at a lower level corresponding to an occluded front proceeded from the ocean and reached the coast on the morning of December 15. Near the coastline, there was another weak convergence zone due to the orographic effect before the front arrived, and it strengthened when the convergence zone from the ocean reached the coastline. The air with a large amount of total-column water moved toward the coastline slightly ahead of the low-level convergence zone. This moist area corresponded to moisture flow in a warm sector of an extratropical cyclone (Fig. 8 of Houze et al. 2017). Low-level winds formed in the parallel-barrier direction rather than in the cross-barrier direction, resulting in a continuous inflow of moisture from upwind of the parallel-barrier flow or lower latitude.
The vertically integrated divergence of moisture flux, which is the superposition of the two values in the figure on last slide, continued to converge from the late night of 13 December to the morning of 17 December. This means that most of the moisture flow from the ocean was blocked by coastal mountains and consumed to produce terrain-enhanced long-lasting precipitation along the coastline (left figure).

The observed brightness temperature of the upper cloud from GOES-15 penetrated inland without being blocked by the terrain (right figure). This indicates that the upper part of the precipitation cloud that strengthened above the coastline was swept away by the upper wind and advected to the coastal mountainous area in contrast with the situation for the lower layer.
We investigated the precipitation climatology and its mechanism precipitation along the south coast of Alaska by using complimentary datasets from GPM KuPR and CloudSat CPR.

1. Precipitation frequencies evaluated by the two spaceborne radars have their maximum values in different region: the KuPR-detected frequency has over the coastal waters (−20–0 km), and the CPR-detected frequency has over the coastal mountains (20–40 km).

2. The difference arises because rainfall and mixed-phase precipitation are dominant over the ocean, whereas light-to-moderate snowfall frequently occur over the mountains.

3. Moisture flows associated with extratropical cyclones from the Gulf of Alaska are blocked by terrain and delayed around the coast, leading to long-lasting precipitation along the coastline.

At high latitudes, discriminating the phase of precipitation, as well as amount, is crucial in grasping the hydrological cycle. This study investigates the horizontal and vertical distribution of precipitation along the south coast of Alaska, using two spaceborne radars: the Dual-frequency Precipitation Radar (DPR) KuPR onboard the Global Precipitation Measurement (GPM) Core Observatory and the Cloud Profiling Radar (CPR) onboard CloudSat. We studied how the horizontal and vertical distributions of precipitation and clouds change with distance from the nearest coastline and made the conclusions.


