The influence of orographic flows on PICO-NARE trace-gas measurements

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Geography

The PICO-NARE station is a mountaintop observatory in the Azores islands. This remote, elevated location is ideal to study transatlantic transport of air pollution[1] (see poster AS1D-0108). We have characterized upslope flow on Pico using a 3.5 year climatology of CO measurements at Pico-NARE. Meteorological measurements conducted during summer 2004 for the purpose of assessing the role of physical flow processes on CO concentrations. Measurements at the PICO-NARE station are significantly affected by both types of flows, with mechanically driven uplift dominating during winter and buoyant uplift during the summer. However, our analysis indicates that on most days FT air is sampled at the station throughout the day.

Mountain Winds

Mechanically forced lifting

Strong synoptic winds can lift stable air over a mountain. In particular, three factors determine the behavior of an approaching flow: the stability of the air (Brunt-Vaisala frequency N), the synoptic wind speed (U), and topographic characteristics (mountain height h). The non-dimensional mountain height $h_{0.5}$ is used to predict the dividing streamline height $z_t$.

Buoyantly forced lifting

Diurnal mountain winds are caused by temperature differences between the mountain and the surrounding air. Upslope flow is caused by solar heating of the mountain during daytime, while downslope flow occurs due to radiative cooling of the surface at night [4].

Mechanical Forcing 4

Dividing streamline height $z_t$

Based on Bernoulli's law, Sheppard [5] postulated that the reduction in kinetic energy along a streamline over a mountain is balanced by the resulting increase in potential energy. We use FNL data of wind speed and potential temperature profiles in Sheppard's formula to derive the minimum altitude of air lifted over the mountain ($z_t$), and an annual cycle that is opposite that of the marine boundary layer (MBL) height. During winter, the higher wind speeds and reduced stability in the lower atmosphere result in a greater degree of mechanically forced uplift (smaller $z_t$), while lower winds and a more stable lower FT during summer result in less uplift (larger $z_t$).

Buoyant Forcing – Case Study

During summer 2004 the FAAM BAe-146 aircraft obtained profiles around Pico mountain on four days. The aircraft measurements of $O_3$ and potential temperature on August 1, 2004, are shown in the right figure. The potential temperature profiles indicate a nearly neutral MBL capped by a stable region. Multiple layers with varying $O_3$ levels were present in the lower FT, all with greater mixing ratios than in the MBL. The PICO-NARE measurements were consistent with the sampling of air between $z_t$ and the actual station altitude, but were not consistent with sampling of air from the region below $z_t$.

Buoyant Forcing

The mean diurnal variation of solar radiation R, atmospheric stability z/L, vertical wind speed w, and water vapor mixing ratio qv are shown in the left figure below. If air from the populated regions of the island reached the station during buoyant upslope flow periods, afternoon enhancements in CO and nitrogen oxides would be expected. Alternatively, if clean MBL air were sampled, reductions in $O_3$ and $O_3$ would be expected on average. The right figure shows the mean diurnal variation of trace gas mixing ratios on upslope flow days (solid lines) and non-uptake days (dashed lines) at the PICO-NARE station.

References


Acknowledgments

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Field Experiment

Measurements at remote mountain observatories can be influenced by orographic flows. Upslope flow and marine boundary layer air has been observed in daytime at high altitude stations on Mauna Loa, Hawaii (photo A) and Izaña, Canary Islands (photo B). To study airflow around Pico, an array of meteorological sensors was deployed along the western slope of the mountain (see figure above). Design of field measurements

Over heterogeneous surfaces, fine spatial and temporal resolution is necessary to describe stability and to detect duration and extent of upslope flows.

Equipment

Four meteorological towers with dataloggers and five Crossbow wireless sensor stations were deployed. Photograph A shows a met station with instrumentation to measure pressure, temperature, relative humidity, wind speed and direction, and turbulence. Photograph B shows a radiation shield. Inside the radiation shield (photo C) is a Crossbow Technology Mica2 processing board with MT6300 sensor board including a temperature sensor. Photograph D shows the Crossbow Mica2 data collected at 5 minute intervals to assess the impact of downslope flow on trace gas measurements.

July 5 was a typcial buoyant upslope flow day in many respects, but the MBL was unusually deep. A radiosounding showed unstable conditions to 900 m and a weakly stable but well mixed layer with RH exceeding 90% to 1000 m. Upslope flow impacted the PICO-NARE station around 1155h, when the temperature ratio (R) there rose rapidly. Throughout the day, qV exhibited rapid variations. However, the upper limit of qV remained significantly below that at the mountainside station. Thus, drier air was sampled at the PICO-NARE station than was observed on the mountainside, but upslope flow contributed to the mountain-top composition. $O_3$ was strongly anticorrelated with $qV$, and declined by up to 16 ppbv relative to conditions prior to the onset of upslope flow. This demonstrates that $O_3$ levels were significantly lower in the wet lower altitude air that was intermittently sampled.

Conclusions

We have characterized upslope flow on Pico mountain using a 3.5 year climatology of CO measurements at Pico-NARE. Meteorological measurements conducted during summer 2004 for the purpose of assessing the role of physical flow processes on CO concentrations. Measurements at the PICO-NARE station are significantly affected by both types of flows, with mechanically driven uplift dominating during winter and buoyant uplift during the summer. However, our analysis indicates that on most days FT air is sampled at the station throughout the day.

- **Mechanically forced uplift** on Pico mountain is most important during October through April. During this period, our calculations indicate that upslope flow is strong enough to carry MBL air to station altitude 30-50% of the time. In contrast, mechanically forced upslope flow carries MBL air to station altitude less than 10% of the time during May-August.

- **Buoyant upslope flow** occurred on approximately 30% of the summer days studied. This indicates that daytime FT measurements are possible at this station on the other ~70% of the summer days, in sharp contrast to Mauna Loa and Izaña where buoyant upslope flow is important on most days and all daytime observations are typically dissolved. On most buoyant upslope-flow days, there was no evidence of significant impacts of uplift on station chemical measurements. In particular, afternoon enhancements in CO and NO2 were not significant and the afternoon decline in CO was small and not significant.

- **The observations on July 5 demonstrate that uplift of air over a vertical distance of 1 km or more and from within the MBL does occur during some buoyant upslope flow events.** However, on July 5 the day on which variations in trace gas mixing ratios could be unambiguously attributed to buoyant uplift.

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