

Grand Canyon Wind Study Aids In Smoke Management

By Joe Boatman and Donald Henderson

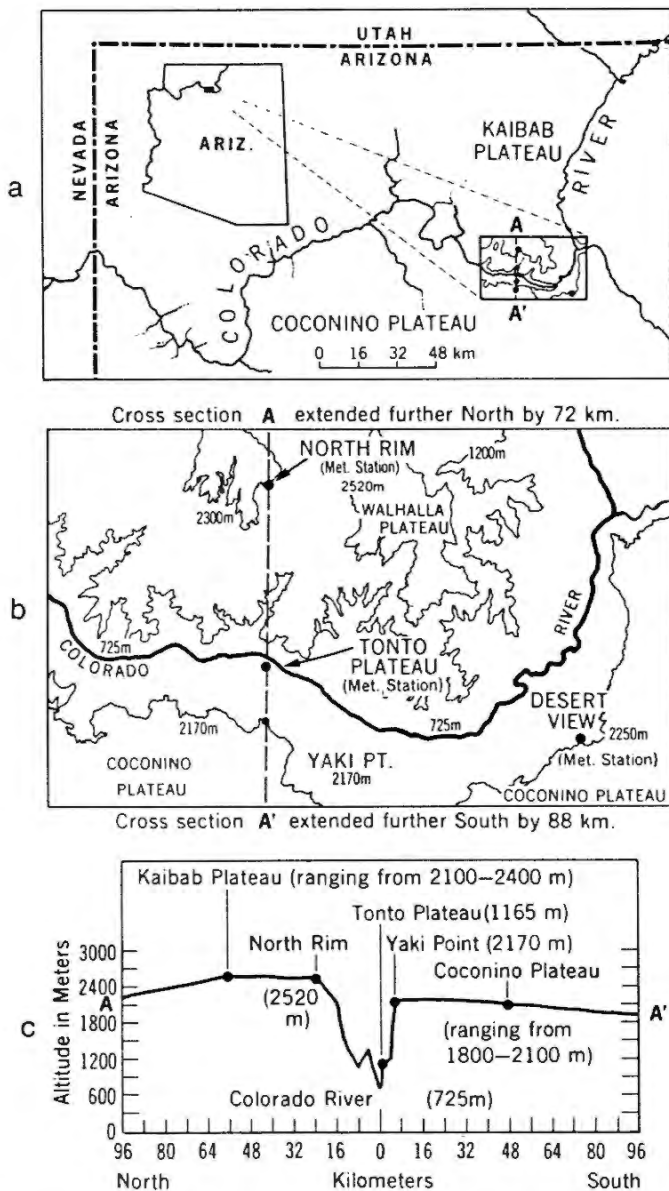


Figure 1. The Grand Canyon and vicinity in plan view (a and b) and cross-section (c).



Figure 2. The research area, looking north from Yaki Point. (Photograph was provided by John Ray, Resource Management Specialist, Grand Canyon National Park).

The Grand Canyon is located in north central Arizona (Fig. 1a). South of the abyss the terrain is relatively flat and averages about 2200 m above mean sea level (MSL); to the north, the terrain is more rolling and has an average elevation of 2500 m MSL. The inner gorge of the Canyon drops to 600 m MSL. This complex topography creates markedly variable winds near and, especially, within the Canyon.

The terrain near both the south and north rims of the Grand Canyon is heavily forested; therefore, controlled burning has become necessary along both rims to meet resource management objectives. This burning is done during the spring and fall of the year when the forest is dry and cool. A significant amount of smoke is produced, creating the potential for reduced visibility and a concomitant decrease in the Canyon's scenic splendor (Fig. 2). Another problem is that the wood smoke, on occasion, could be transported from the burn site into the small town of Tusayan, along the Canyon's south rim, causing annoyance to residents and visitors alike.

The Resource Management personnel at the Grand Canyon requested assistance in developing a weather-dependent plan to minimize these problems by gaining a better understanding of the local winds in and near the Grand Canyon. We have proposed a conceptual model for the winds in the Grand Canyon and made surface, balloon, and aircraft observations in the Canyon in support of the conceptualization.

The climate of the area near the Grand Canyon can be described as sunny and dry throughout most of the year. Winds are predominantly from the southwest; however, during winter months, weak to moderate cold frontal passages do produce periods of northerly winds. It has been shown that visibility near the Canyon averages about 250 km; however, it may drop to less than 80 km on polluted or hazy days. Visibility is best during periods of northerly winds and at its worst during episodes of southerly winds. Variations in visibility result from man-made and natural causes.

Figures 1b and 1c show a plan view and cross-section of the portion of the Grand Canyon studied for this work. Only about 10% of the 300-km-long Canyon was examined. This portion of the Canyon is aligned in a roughly eastward direction and averages 9 km across and 1.7 km deep, giving it a depth-to-width ratio of about 0.2.

The winds in the Grand Canyon have not, to our knowledge, been subject to a quantitative inquiry by other researchers. Figure 1c demonstrates that the Grand Canyon is a large topographic notch, to first order. To date the only laboratory and theoretical studies of fluid flow over notches are for notch height-to-width ratios of 1.0 or greater. A considerable body of knowledge does exist that describes the airflow over cavities and abrupt steps. It is in the case of rectangular cavities and backsteps that the proper aspect ratios (0.2) are simulated.

A conceptual model for the mean air motions in the Grand Canyon was developed using cavity flow. The conceptual model was enhanced after close examination of the Grand Canyon wind data available to us. Conversely, the wind data became more understandable and consistent when placed in this conceptual framework.

Consider first the case of coupled flow (where air from above and below the canyon's rim is interacting) either during the day or at night. We propose that the mean winds in the Grand Canyon, under these conditions, are of the type shown in figures 3a and 3b. Figure 3a is a plan view of the wind pattern; figure 3b is a cross-section view. Figure 3a suggests that air below the level of the Canyon rim moves predominantly parallel to the Canyon itself. The depiction indicates that the direction of this parallel motion is always along the direction of the airflow crossing above the Canyon. That is, air within the Canyon moves eastward (west wind) when the synoptic-scale winds are from the west. The reverse occurs when synoptic-scale winds are from the east. Figure 3a also indicates that the air below the Canyon rim is undergoing a spiral motion. This is due to the secondary cavity flow. Figure 3b depicts this flow in cross-section. The secondary cavity flow is proposed to produce updrafts along the upwind walls of the Canyon and downdrafts along the downwind walls. The air in the center of the Canyon is proposed to have no vertical motion. A secondary air current counter to the prevailing synoptic flow is proposed to occur at the bottom of the Canyon.

Consider second the case of decoupled flow (where air from above and below the canyon's rim is *not* interacting), either during the day or at night. We propose that the mean winds in the Grand Canyon are of the type shown in Figures 4a and 4b under these conditions. Figure 4a is a plan view of the wind pattern. Figure 4b

is a cross-section view. Figure 4a suggests that air below the level of the Canyon rim is undergoing drainage flow. Figure 4b suggests that no secondary canyon flow is present under decoupled conditions. The potentially stable air below the Canyon rim is proposed to drain gently downriver (into the paper in Fig. 4b).

Two data sets were available to test the model we proposed. The first was produced by a set of three wind sensors deployed near to and within the Grand Canyon. The second was a set of 39 pilot balloon launches made from within the Canyon.

The wind sensors consisted of standard wind vanes and cup anemometers. They were deployed atop 10 m towers in each case. Figure 1 shows their locations. Each data collecting system was solar powered and transmitted average wind velocity via satellite to a receiver in Fort Collins, Colo., once per hour. Data collection began during September, 1983. Data for one year were analyzed for this work.

A series of 39 pilot balloon launches were made during Sept. 25-28, 1984, from the Tonto Plateau site depicted in Figure 1b. The balloons were tracked using two theodolites separated by 657 m. Triangulation yielded the horizontal and vertical winds as each balloon rose.

The results we obtained using the two data sets include the following:

- 1) Airflow below the rim level moves predominately parallel to the Canyon during coupled flow conditions which may occur during any month of the year.
- 2) The secondary "cavity flow" suggested in our conceptualization occurs predominately during coupled conditions. These conditions are most often associated with periods of clear days and nights.
- 3) A strong shear layer was often present near the Canyon's rim level. Air below this layer appeared to be draining gently downriver. Above this layer, synoptic-scale forces predominated.
- 4) Winter months appeared more prone to decoupled (or drainage flow) behavior within the Canyon. It may be that potentially cold air from radiative cooling, frontal passages or snow at the rim is responsible for this.
- 5) Shear layers were present at lower levels within the Canyon. They may have been the product of a slow erosion process from above or the establishment of a radiation inversion. They appeared to act as an alternate bottom to the Canyon for airflow purposes.
- 6) At times, scouring occurred instead of secondary cavity flow. This may have been limited to very light wind cases or instances where shear layers established an alternate bottom to the Canyon.

A number of measurements important to understanding the airflow in the Grand Canyon have yet to be made. They include the vertical temperature structure, vertical wind velocities near the rims, and the radiant energy flux from the Canyon walls. An instrumented aircraft is being used to collect the appropriate data.

Final recommendations await further analysis of these additional data. The Pielke mesoscale flow model is being applied in the Grand Canyon area to obtain a better understanding of local wind flow characteristics. If our simplified conceptual airflow model is correct, it would be unwise to burn during periods when stable air fills the Canyon. This could occur during times of synoptic scale subsidence; as the result of cold outflow from passing thunderstorms (as we observed); as the result of cold air outbreaks after frontal passages; during periods of radiative cooling; or finally, as a result of snow along the Canyon rims creating a mechanism for cold air to sink into the Canyon.

To forecast the onset of such adverse conditions adequately we suggest that standard synoptic-scale data plus meteorological information from the Canyon rim and Tonto Plateau would be necessary. Standard forecasting procedures could be used to predict cloudiness, subsidence conditions, cold air outbreaks, frontal passages, or snow. On the days when burning is forecast to be feasible, winds and temperature at the Canyon rim and Tonto Plateau would be scrutinized for the presence of coupled airflow. If coupled flow were present, burning could commence. Burning would be discontinued if decoupled behavior began to appear.

To diminish the annoyance posed by burning, it will be necessary to minimize it at times when winds would carry smoke into the town. Our preliminary suggestion is that only very limited burning be undertaken at the south rim when synoptic-scale northerly flow could carry smoke into Tusayan. If northerly flow were not forecast, burning could commence, but winds at the south rim would need to be monitored for evidence of any switch to a northerly component. If such a switch were detected, burning would need to be discontinued. Burning on the south rim after sunset should be minimized because of the possibility of drainage flow away from the Canyon and into Tusayan.

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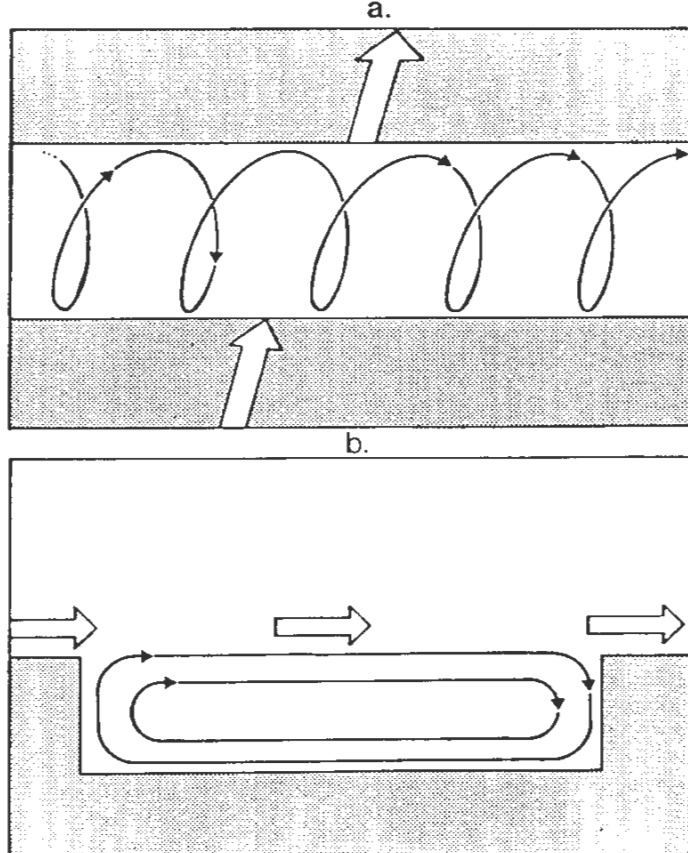


Figure 3. Wind pattern in the Grand Canyon under coupled conditions: (a) a plan view and (b) a cross-section view.

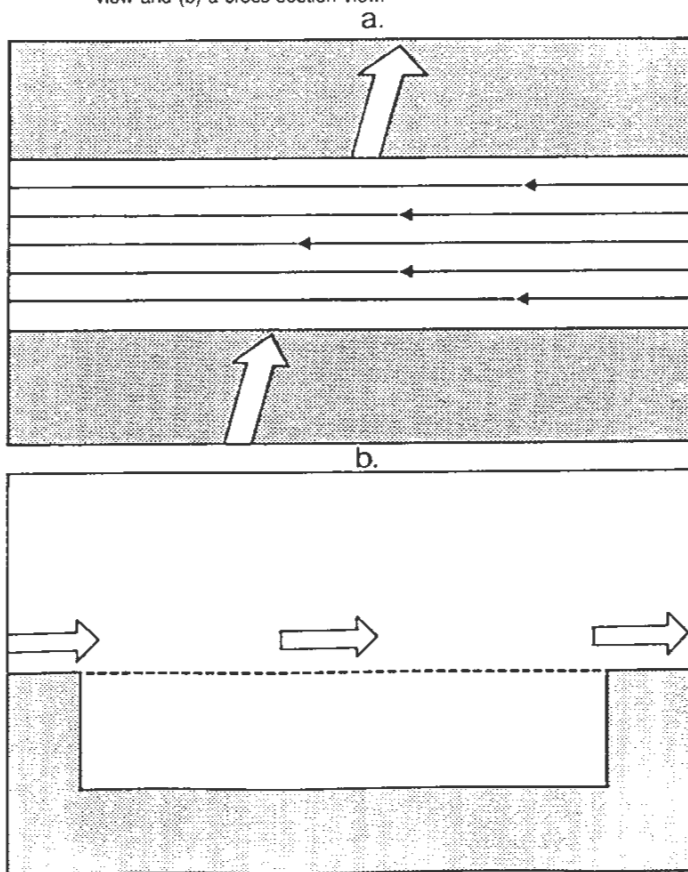


Figure 4. Wind pattern in the Grand Canyon under decoupled conditions: (a) a plan view and (b) a cross-section view.