# Reports

## Turbidity Trends at Tucson, Arizona

Abstract. *Variations in atmospheric turbidity at Tucson, Arizona, since 1956 are similar to those at Mauna Loa in Hawaii, especially before January 1970. The turbidity at both locations increased markedly in 1963 after the Bali eruption. Since January 1970, the turbidity has returned to its pre-1963 level at Mauna Loa, but has remained relatively high at Tucson.*

I report here turbidity values for Tucson, Arizona (32°08′N, 110°57′W). These are based on pyrheliometric observations taken almost continuously since mid-1956, but only partially published (*1*). For comparison, values for Mauna Loa (19°32′N, 155°35′W) are also given (*1*).

Controversy presently exists concerning the matter of an increase in atmospheric turbidity and its possible long-range effects on world climate. Ellis and Pueschel (*2*), using selected turbidity measurements, concluded that man-made pollutants have not significantly increased turbidity at Mauna Loa over the last 13 years. Studies of turbidity in the Antarctic by Fischer (*3*) showed that no significant change occurred during the 16 years before 1966. McCormick and Ludwig (*4*), however, using data from Davos, Switzerland, and Washington, D.C., implied that there has been a large increase in worldwide turbidity over the last 50 years. They hypothesized that such an increase in turbidity would eventually cause a decrease in world temperatures. Studies by Mitchell (*5*) indicated that such a decrease could be caused by the presence in the atmosphere of large clouds of particulate matter from volcanoes. Charlson and Pilat (*6*), Mitchell (*7*), and Ensor *et al.* (*8*), however, proposed that increasing aerosol concentrations could lead to either heating or cooling trends.

Turbidity is defined by the following expression (*9*):

$$I = (1/S)I_0 \exp[-T\bar{a}_R(m)m] \qquad (1)$$

where $I$ is the normal incident solar radiation at the ground (insolation); $S$ is a reduction factor for the mean solar distance; $I_0$ is the extraterrestrial solar radiation at the mean distance of the earth from the sun; $\bar{a}_R(m)$ is the mean value of the extinction coefficient over all wavelengths in a clean dry Rayleigh atmosphere, weighted according to the spectral distribution of the transmitted energy; $m$ is the optical air mass (a function of the solar elevation angle and the altitude of the station); and $T$ is the Linke turbidity factor. The method essentially involves determining the turbidity $T$ from the slope of the curve obtained by plotting isolation as a function of air mass. It has the advantage of being insensitive to errors in the calibration constant of the pyrheliometer.

From the logarithm of Eq. 1,

$$T = P(m)(\log I_0 - \log I - \log S)$$

or

$$\log I = \log (I_0/S) - TX \qquad (2)$$

where

$$P(m) = [m\bar{a}_R(m) \log e]^{-1} = 1/X$$

Equation 2 has the form $y = b + ax$. By using measured values of $y$ ($\log I$) and appropriate values of $x$ [$X$ or $P(m)^{-1}$], a linear regression between $y$ and $x$ can be computed and the slope $a(-T)$ obtained.

For Mauna Loa, the turbidity for the period November 1957 through December 1967 was calculated from average monthly values of the normal incident radiation at four air-mass times (that is, four path lengths of solar radiation through the atmosphere, for each of which there is a certain mass of air between the sun and the point of observation) (*1*). Morning and afternoon values at a given air-mass time were weighted and averaged according to the number of observations available. For the period January 1958 through January 1972, data for four air-mass times, but only for the mornings of completely cloudless days, were also used to compute the turbidity (*10*). The sample size is quite small. In some months, especially during the spring, no data at all are available; this is especially true for the period before January 1968. Monthly average turbidities computed from the two sets of data for the overlapping period (January 1958 through December 1967) generally agree quite closely. However, the values for cloudless days average about 1 percent lower than the values based on all available data and were adjusted accordingly.

The Tucson data were analyzed in essentially the same manner, by using data for six air-mass times before July 1970 and for four air-mass times thereafter. The values were read directly off the original pyrheliometer charts for clear days. A later analysis showed no significant difference between turbidities computed with four and six air-mass times. Average monthly turbidity values for Mauna Loa for the period from November 1957 to January 1972 and for Tucson for the period from June 1956 to January 1972 are given in Table 1. The data for each location are plotted in Fig. 1, where they are expressed as departures from the monthly mean and smoothed by using a 12-month running average. Each point on the curves represents the average turbidity anomaly for the preceding 12 months. In addition, the monthly values for Tucson were smoothed by using a three-point binomial smoothing and are plotted in Fig. 1 as departures from the monthly mean.

Some trends can be seen by comparing the average data for Tucson and Mauna Loa in Table 1. The Tucson readings are generally larger and vary more through the year than do the Mauna Loa readings. Both locations have maxima in the late spring or summer. Tucson, however, has two maxima, one in April and one in July. The April maximum is due to dust raised by comparatively high winds in the Southwest, which is dry at that time of year. The July maximum, during the Tucson rainy season, is probably due to increased water vapor concentration.

The eruption of Mt. Agung on the island of Bali (8°S, 115°E) on 17 March 1963 and the resultant spread of volcanic aerosols in the stratosphere have been studied (*11*). The arrival of the stratospheric dust cloud over a region was indicated by a sudden sharp increase in turbidity for the region. Such an increase occurred at Mauna Loa in May 1963 and at Tucson between July 1963 and January 1964 (Fig. 1). This indicates a lag time of 3 to 8 months between the arrival of stratospheric dust over Mauna Loa and its arrival over Tucson.

Of course, other factors are involved in determining the turbidities of the two locations. This is especially true of Tucson, where the turbidity is influenced strongly by local effects. Several copper smelters are near enough to affect Tucson's measured turbidity. The locations and distances from Tucson are: San Manuel, 80 km; Douglas, 170 km; Miami, 130 km; Hayden, 140 km; and Ajo, 180 km. Attempting to separate out turbidity variations due to Tucson's urban locale from those due to the smelters is almost impossible; however, there were two extended periods, August 1959 to January 1960 and August 1967 to March 1968, when the smelters were closed because of strikes. During both, Tucson's turbidity values were predominantly below normal. The negative anomalies were considerably larger than at Mauna Loa. This is not unusual for periods of 3 to 4 months, but it does appear to be unusual for longer periods, such as the strike periods. This suggests that the smelters do have a small significant effect on Tucson's turbidity, increasing its values by 5 to 10 percent.

Table 1. Average monthly values of the Linke turbidity factor for Mauna Loa from November 1957 to January 1972 and for Tucson from June 1956 to January 1972.

| Month | Linke turbidity factor | |
|---|---|---|
| | Mauna Loa | Tucson |
| January | 1.543 | 2.114 |
| February | 1.601 | 2.190 |
| March | 1.612 | 2.320 |
| April | 1.683 | 2.709 |
| May | 1.755 | 2.613 |
| June | 1.670 | 2.657 |
| July | 1.590 | 2.868 |
| August | 1.560 | 2.687 |
| September | 1.569 | 2.343 |
| October | 1.579 | 2.144 |
| November | 1.554 | 2.060 |
| December | 1.563 | 2.004 |
| Annual average | 1.607 | 2.401 |

If the effect of the Bali eruption and also of smaller eruptions in the Philippines, Celebes, and Galápagos is taken into account, turbidity variations at Tucson and Mauna Loa have been similar, at least until the early part of 1970. Since that time, the turbidity at Mauna Loa has returned to its pre-1963 level, which indicates little, if any, increase in global dustiness. At Tucson, however, the turbidity has been increasing rather steadily since the end of the 1967–1968 smelter strike. There is no obvious explanation for this. Global stratospheric effects seem to be ruled out because of the turbidity decrease at Mauna Loa.

The population of Tucson has grown in the last few years, but not as much as it did between 1957 and 1963, when the average turbidity remained almost constant. In July 1968, the pyrheliometer used to measure the solar intensity was moved 3 km south, from the roof of a one-story building in a residential area to the roof of a six-story building on the campus of the University of Arizona. Although there has been quite a bit of construction work in the area, there is no obvious indication that this is responsible for the turbidity increase. In fact, the biggest increase in turbidity did not occur until the pyrheliometer had been at the new site for a year.

This leaves the possibility that the increase is the result of a climatic trend, perhaps short-lived, toward more humid summers and drier and dustier winters and springs. The available climatic data, however, only marginally support this conclusion. Precipitation in Arizona during the first 5 months of 1970, 1971, and 1972 has averaged only 43 percent of the 30-year normal. It may take several more years of data gathering before the true cause of the turbidity increase at Tucson can be established.

Although this analysis does not yield any specific conclusions concerning turbidity trends at Tucson, it does show that Tucson as an urban locale is significantly affected by natural volcanic turbidity. This natural effect is not damped out by local influences and must be taken into consideration when analyzing turbidity in urban areas.

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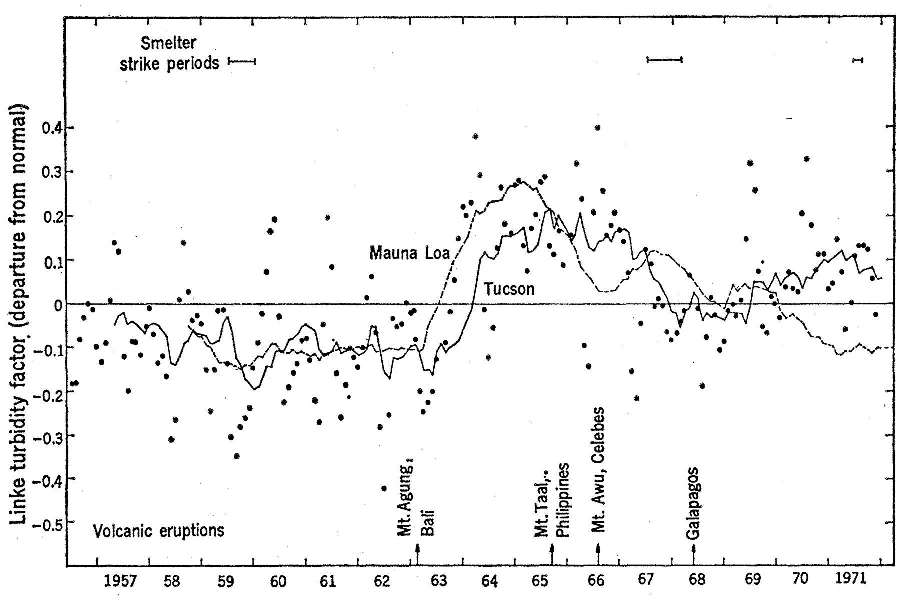


Fig. 1. Turbidity variations at Tucson, Arizona, and Mauna Loa, Hawaii. Each point on the solid and dashed lines indicates the average turbidity for the preceding 12 months. The dots represent the monthly turbidity values for Tucson; these have been smoothed by using 1-2-1 binomial coefficients.

### References

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