NOTES AND CORRESPONDENCE

A Simple Method for Determining the Standard Deviation of Wind Direction

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ABSTRACT

The discontinuity of the wind direction at 360° complicates automatic calculations of some atmospheric parameters. Various methods were suggested to obtain the standard deviation of the wind direction (σ_θ). They are reviewed and a simple, once through calculation procedure is suggested, giving the exact σ_θ without any hypotheses on the wind direction distribution. The discussion stresses, however, that automatically computed σ_θ values are not always meaningful, in several different situations frequently occurring in the atmosphere.

1. Introduction

The standard deviation of the horizontal wind direction (σ_θ) is an indicator of the horizontal component of the atmospheric turbulence. In the case of atmospheric dispersion of a pollutant, σ_θ may be used to determine the horizontal crosswind standard deviation of the concentration of the plume (σ_y). The relation between σ_y and σ_θ was established in the 1950s. It was reviewed by an AMS panel (Hanna *et al.*, 1977) and was recently used by Sedefian and Bennett (1980) for comparing different dispersion estimation methods. Verrall and Williams (1982) review three methods used to obtain σ_θ directly (from sigma computers, range of wind direction and using the reversal counting method). It can also be obtained from closely-spaced instantaneous digital values of wind direction using a microprocessor-controlled data acquisition system. However, Verrall and Williams (1982) say that in this case a difficulty exists in computing σ_θ directly, according to the standard deviation definition, when the wind direction is distributed around the 360 deg discontinuity point. Their argument is that a decision concerning the range of sampled directions and the necessary transformation of the discontinuity point, can be obtained only from knowledge of the entire wind direction sample, i.e., it requires memory storage of the whole sample. Verrall and Williams (1982) suggest a method for directly obtaining an estimation of σ_θ (using once-through computations) without the need to store the entire sample. Their method is based on the assumption that the wind direction is normally distributed. It requires the storage of the sums of five variables. The Gaussian (normal) distribution is a con-

venient and widely used approximation for many atmospheric variables. It was shown to be a good approximation to the probability distribution of the wind components (e.g., Brooks and Carruthers, 1953; Skibin, 1972). However, Skibin (1972) obtained the probability distribution of wind direction, based on these approximations and showed that it resembles the Gaussian distribution in the cases of horizontal isotropy and small σ_θ . Deviations from Gaussian occur primarily due to nonisotropy and large wind direction range, both in stable and unstable stratification.

Another cause for deviations from Gaussian distribution is the effect of meandering. Changes of wind direction with time, of the order of tens of degrees per hour, are rather frequent in the atmosphere. An ideal stationary flow is hard to find, except under a persistent breeze system (Skibin and Hod, 1979). Under extremely stable (and also unstable) stratification, drastic changes of the average wind direction may occur (90° and even up to 180° within an hour). Nevertheless, stationarity is often used as a convenient approximation. It is justified in the cases where the wind direction changes are not large, or when applied to relatively short time periods. Fluctuating plume models (Gifford, 1968) may be used in the slightly nonstationary cases. Another approach, for the very stable cases, is given by Kristensen *et al.* (1981). Skibin (1983) suggested a procedure to obtain the concentration field from a pollution cloud released to the atmosphere, which is applicable to cases of drastic wind direction changes (of the order of 90°). It may be used in cases of frontal passage etc., even under real-time accident conditions.

A different approach to the wind direction discontinuity problem, not based on the assumption of a Gaussian distribution, is therefore required for use in the major part of the time. This note presents a simple method for directly obtaining the exact σ_θ .

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2. Method

During the sampling period, the sequence of sampled wind directions (θ_i , $i = 1, I$) are obtained, either as the direction from which the wind comes or the direction towards which it blows. Denote the discontinuity point by 360° . The suggested procedure is to distinguish between two groups of samples: $\theta_i \leq 180^\circ$ which will be identified by an index 1, and $\theta_i > 180^\circ$ with index 2. The group is thus determined according to the wind direction and we accumulate

$$A1 = \sum_i \theta_i, \quad S1 = \sum_i \theta_i^2, \quad A2 = \sum_i \theta_i, \quad S2 = \sum_i \theta_i^2$$

and also $N1$ and $N2$ —the number of samples in each group. As a refinement, one may also determine $MIN1$, $MAX1$, $MIN2$, $MAX2$, the minimum and maximum wind directions sampled in the two respective groups.

After termination the sampling and accumulation, the procedure for determining the average and standard deviation of the wind direction is the following:

1) If $N1$ or $N2$ is zero, all the sampled directions are contained in one 180° sector, not containing the discontinuity point. Then if $N2 = 0$

$$\bar{\theta} = \frac{A1}{N1}, \quad \sigma_\theta = [(S1 - A1^2/N1)/(N1 - 1)]^{1/2}. \quad (1)$$

If $N1 = 0$ the indices should be 2.

2) If neither $N1$ nor $N2$ is zero but $(A2/N2 - A1/N1)$ is less than 180° , most of the sampled directions are contained in a semi-circle, not containing the discontinuity point. Then

$$\bar{\theta} = (A1 + A2)/(N1 + N2),$$

$$\sigma_\theta = \{[S1 + S2 - \bar{\theta}^2(N1 + N2)] / (N1 + N2 - 1)\}^{1/2}. \quad (2)$$

An alternative test, perhaps a better one, is to determine if $(MAX2 - MIN1) < 180^\circ$.

3) If neither $N1$ nor $N2$ is zero and $(A2/N2 - A1/N1)$ is greater than 180° , or alternatively if $(MIN2 - MAX1) > 180^\circ$, the average and standard deviation will be given by the procedure:

$$\bar{\theta} = [A1 + A2 - N2(360^\circ)] / (N1 + N2)$$

$$\sigma_\theta = \{[S1 + S2 + N2(360^\circ)(360^\circ - 2A2/N2) - \bar{\theta}^2(N1 + N2)] / (N1 + N2 - 1)\}^{1/2}. \quad (3)$$

If $\bar{\theta} < 0$, 360° must be added to it to yield the conventional wind direction.

3. Summary and conclusions

A simple procedure has been suggested to determine exactly the standard deviation of wind direction. It is a once-through, accumulation procedure that can be conveniently used with computers. No *a-priori* assumptions are made. In particular, the frequency distribution of the sample is not assumed to be Gaussian. It is, however, essential to stress that it is erroneous to calculate the average and standard deviation of a sample which has, for instance, a bi-modal distribution, because in this case it may be that no wind direction even close to the calculated average direction was measured in the sample. Similarly, caution must be used when the spread of the sampled wind directions is too large, e.g., when the standard deviation is $\sim 60^\circ$ or larger. One has therefore to be very careful in analyzing sampling periods during which a large spread, a step change (or other significant changes), occurred in the wind direction. Such phenomena are not infrequent in the atmosphere. However this warning is true for every sampled parameter. It is not specifically connected to the discontinuity problem, which is relevant and disturbing with relation to wind direction measurements, to which this note refers.

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