P1.20 ESTIMATING DIVERGENCE AND VORTICITY FROM AIRCRAFT DATA IN THE STRATOCUMULUS TOPPED BOUNDARY LAYER

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1. INTRODUCTION

One method to estimate the entrainment by stratus topped mixed layers is to evaluate the difference between the growth rate of the layer and the large-scale vertical velocity at the cloud top. Typically the latter is estimated as $W = -Dz_i$, where z_i is the height of cloud top and D is the divergence. Thus estimating W is akin to estimating the divergence. In this paper we present and evaluate a method for estimating both divergence and vorticity from circular flight tracks such as were flown during DYCOMS-II experiment (Stevens et al., 2002). The method is a generalization of one previously proposed by Lenschow et al. (1999) and it allows optimal estimates of the wind field for incomplete flight tracks. Special attention is devoted to assessing how different sources of error might influence the estimates.

2. METHOD

Approximating a steady wind field at a point (x, y) by the first terms in a Taylor series about some point (x_0, y_0) allows us to write the wind as:

$$\vec{v} = \vec{v}_0 + \frac{\partial \vec{v}}{\partial x}\delta x + \frac{\partial \vec{v}}{\partial y}\delta y, \tag{1}$$

where $\delta x = x - x_0$, $\delta y = y - y_0$ and $\vec{v}_0 = \vec{v}(x_0, y_0)$.

During DYCOMS-II the standard flight leg consisted of a circular pattern flown relative to the mean wind. Such legs were chosen to facilitate estimates of the divergence following the method described by Lenschow et al. (1999). For such a pattern (x_0, y_0) can be identified with the center of the circle and

$$\delta x = r\sin(\psi) \quad \text{and} \quad \delta y = r\cos(\psi), \tag{2}$$

where ψ is a time-dependent azimuth which measures the angle (from north) subtended along the circular flight track, and r is the radius of the circle. For a constant airplane angular velocity, ω, $\psi = \psi_0 + \omega t$, where ω is positive for clockwise circles, and ψ_0 is the azimuth of the starting point.

For a linearly varying wind field measured along such a flight path we would expect the zonal and meridional components of the wind to vary in time according to:

$$u, v = a_{u,v} + b_{u,v}\sin(\omega t + \psi_0) + c_{u,v}\cos(\omega t + \psi_0). \tag{3}$$

Here t is the time since the beginning of the flight leg and u, v denotes either u or v. The coefficients b and c can be related to the divergence and vorticity, ζ, as follows

$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{b_u + c_v}{r} \tag{4a}$$

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \frac{b_v - c_u}{r}. \tag{4b}$$

We use these results as a basis for estimating D and ζ across a flight leg. Specifically by regressing the measured wind on to the model given by Eq. (3) we can estimate a, b, and c which is equivalent to estimating $\vec{v}_0$, D and ζ. For a complete circle one could estimate b and c simply from the wave-number one component of the Fourier transform of the measured wind. The regression based method has the advantage of not requiring measurements to be made over a complete circle.

The air-relative flight path is obtained by subtracting the airplane advection by the mean wind from the earth-relative flight path. To obtain the radius, r, and center, (x_0, y_0), of the circular path, a circular regression (Mundhenk et al., 2000) is performed. The circle center is used to calculate the azimuth, which is needed for estimating the starting point and angular velocity in Eq. (3).

Figure 1 presents the flight path and azimuth change along the clockwise cloud top leg from the first research flight (RF01). It illustrates the agreement between DYCOMS-II flights and above stated conditions of circular air-relative path and constant airplane angular velocity.

To check the method and estimate the influence of different sources of error on estimates of D and ζ we construct synthetic wind fields which vary according to Eq. (1) and superimpose either noise, or errors in the flight track. For instance, we explore the effect the shape and closure of the flight path have on the method. Errors associated with small deviations from circular flight paths tend to be small, and errors associated with incomplete time-series (unclosed circles) are effectively zero. The convergence of estimates of D and ζ as a function of distance along a flight circle is illustrated in Figure 2 a).

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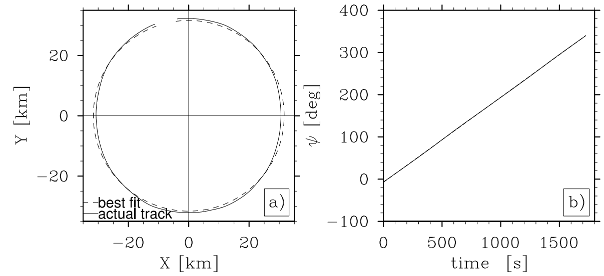

Figure 1: a) The air-relative airplane path and fitted circle. b) A constant change of the azimuth, ψ, imply a constant angular velocity.

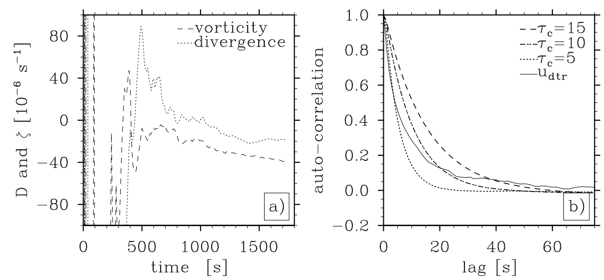

Figure 2: a) Running calculations of divergence and vorticity for the clockwise cloud top leg of the first DYCOMS-II research flight. b) Mean auto-correlation for de-trended zonal wind component for the first DYCOMS-II research flight compared with auto-correlation for synthetic noise.

If the wind field has an acceleration similar to the RMS acceleration estimated from buoy data in the region, the relative error of calculated divergence is in the order of a few tens of %: For instance, for a constant acceleration of $1.5{\cdot}10^{-4}\mathrm{ms}^{-2}$, the relative error of D is 46%.

This error can be reduced to nearly zero (10^{-3}%) by extending the model of the wind, Eq. (1), to include a time change term, $\frac{\partial v}{\partial t}\delta t$, so that Eq. (3) becomes

$$u, v = a_{u,v} + b_{u,v}\sin(\omega t + \psi_0) + \\ + c_{u,v}\cos(\omega t + \psi_0) + d_{u,v}t. \tag{5}$$

Turbulent fluctuations in the wind-field are the most significant source of the error. To estimate their influence the synthetic wind fields are corrupted by adding noise of different amplitudes and integral time scales. The noise is composed by filtering normally distributed white noise of different amplitudes with the low-pass filter (with time-scale τ_c) proposed by Lenschow et al. (2000). The amplitudes and time scales of the noise are chosen to mimic the wind-field as observed during RF01. The amplitudes of the de-trended wind field measured during RF01, calculated as the standard deviations, are less then $1\mathrm{ms}^{-1}$. Figure 2 b) presents the mean auto-correlation of the de-trended wind field measured during RF01 and the auto-correlation for the synthetic noise with three different values of τ_c. It suggests that the actual fluctuations were similar to the synthetic fluctuations with a value of τ_c between 5 and 10s. By analyzing many realizations

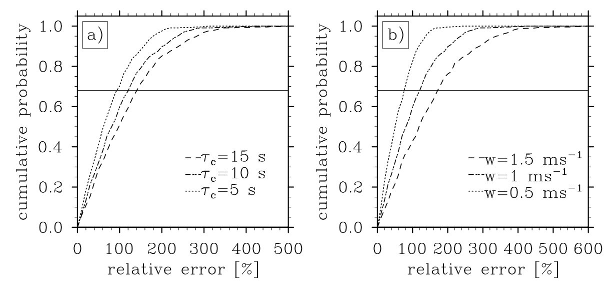

Figure 3: Cumulative probability for the relative error of divergence calculated from synthetic data with fixed: a) amplitude, $w = 1$ ms^{-1} and b) time scale, $\tau_c = 10$ s

of the corrupted synthetic wind-field it is possible to estimate the probability with which one would expect to estimate D within a given error. This probability is illustrated in Figure 3. It demonstrates that for noise with the characteristics of the observed wind, one could expect to estimate D with error less then 100% about 70% of the time.

3. SUMMARY

We present a regression based method for estimating the mean wind and its first derivatives. The method is a generalization of existing methods which allows analysis of flight data from incomplete circular flight patterns. An analysis of the method illustrates that assumptions made in deriving the method should lead to small or negligible errors, but that turbulent fluctuations in the wind itself creates formidable obstacles to accurate estimation of derivatives of the wind field. We estimate that turbulent fluctuations similar to those observed in the actual flight data can lead to errors on the order of 100% in estimates of D (or ζ) for any given flight circle. Because up to eight circles were flown per DYCOMS-II flight mission, flight average errors in estimates of D can be expected to be reduced to about 40%.

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