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The wind field in a cattle feedlot: measurements and simulations

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ABSTRACT

Cup and sonic anemometers were operated in and about an empty pen (60 m × 68 m) on the outer (south) edge of a large cattle feedlot in southern Alberta. Mean wind speed, measured at constant height above ground, varied by more than a factor of four across the pen, the spatial transects being distinct for different wind directions—implying (for instance) that efforts to quantify feedlot gas emissions by micrometeorological methods will be prone to error, unless the drastic lateral inhomogeneity of wind statistics is accounted for. A subset of the observations, selected for southerly winds and weak thermal stratification, were aggregated and compared with steady-state, three-dimensional numerical simulations using "ASL3D", a Reynolds-averaged Navier–Stokes model with eddy viscosity closure that represents the influences both of feedlot windbreak fences and of topography (Wilson, 2018). Simulations confirm that wind drag on the tall ($H \approx 3$ m), low porosity (25%) slatted wooden fences was by far the dominant aerodynamic disturbance at this site. Various options were tested for the placement of computational domain boundaries, and it was found that the influence of fences at the faraway edges of *neighbouring* pens is practically negligible in comparison with that of the fences lying immediately upwind—that is, the transect of *relative* mean wind speed within the instrumented pen was largely determined by the nearest upwind fence(s). It is also concluded that when the mean wind is obliquely incident on low porosity fences of this type, simulations are improved if the horizontal wind component tangential to the fence is forced to vanish (at the fence).

1. Introduction

In western North America cattle feedlots experience a harsh winter climate, often motivating the provision of shelter for the animals (e.g. Bond and Laster, 1974; Dronen, 1988; Olsen and Wallander, 2002), and in western Canada this typically takes the form of a network of wooden slatted shelter fences bordering the pens. Scientists measuring the contribution of feedlots to methane (and other) budgets must therefore work in what is, from the micrometeorological perspective, a wind environment that could hardly be more different from the horizontal uniformity required if Monin–Obukhov similarity theory were to be posited as descriptive framework for the meteorology. This means, for instance, that if using eddy covariance the flux footprint would or could be very different from the available estimates, that invariably are based on a horizontally uniform wind regime. Similar difficulties attend the flux-gradient and the mass balance approaches, as well as the inverse dispersion approach (Denmead, 1995; Wilson et al., 2012) that is perhaps most widely used in the context of agricultural gas emissions.

Irrespectively of which micrometeorological method one may exploit for determining feedlot gas fluxes, correct application hinges on at least a qualitative assessment of the wind field, and if one were confident in being able to describe the wind regime quantitatively, there is the prospect of refining some of the available methods, e.g. one would be capable of computing the flux footprint over the feedlot, and put more generally, of bringing to bear a description of atmospheric transport attuned to the circumstances—correctly treating wind statistics as varying on all three spatial axes. Consequently it is pertinent to establish the potential accuracy of wind simulations of the feedlot environment, because it will never be feasible to quantify such a complex wind regime by measurement alone.

It is in this context, and in anticipation of pending inverse dispersion trials to measure cattle methane emissions differentially as a function of diet, that over an interval of a week we operated eleven cup anemometers and three sonic anemometers to monitor wind statistics in and about an empty pen on the outer edge of a cattle feedlot. In what follows we will describe the feedlot wind experiment, briefly outline a simple computational model of that flow, and compare the measured winds with model solutions.

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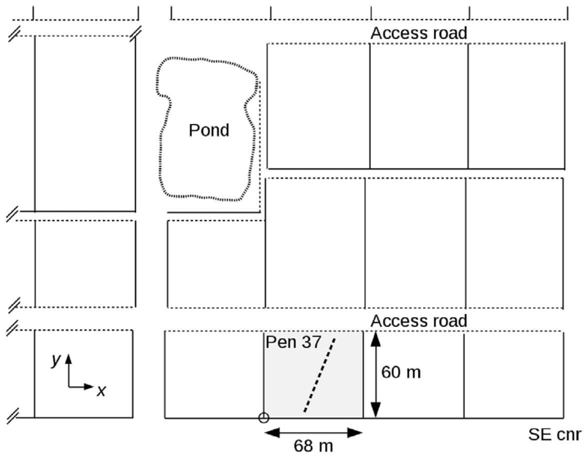

Fig. 1. Schematic of the southeast area of the feedlot (eastern-most five pens of the three southern-most rows). A further nine rows of pens stood further north, while a further three columns of pens stood west of those shown. Sketch is approximately to scale, but gateways have not been shown. Solid lines are windbreak fences (height ~3 m), while light dashed lines are low stock barriers fabricated in steel pipe: these offered minimal impediment to the wind. Narrow alleys are stock routes. The coordinate origin, at the SW corner of pen 37, is shown by a circle. The heavy dashed line in pen 37 identifies the cup anemometer transect.

2. Experiment

The experiment took place 11–18 July 2017 at a prairie cattle feedlot (approximately 1 km × 1 km in areal span) a few kilometers from Nanton (Alberta, Canada). Pen 37, which for the purposes of the experiment was emptied of cattle, lay at the south edge of the feedlot, and not far from its south-east corner (see Fig. 1): it was flanked to its east by two and to its west by more numerous occupied pens. Figs. 2 and 3 give a view of pen 37, and the instrument layout: it can be seen that the amplitude of the topography across the pen was very modest, as confirmed by the elevation contours of Fig. 4. In this paper the coordinate system has been aligned with the fences of the pens, the origin $(x, y) = (0, 0)$ lying in the SW corner of pen 37 (at the farther end of the gate visible in Fig. 2). The alignment of the (nominally) east-west running fences (thus, the x-axis in this paper) deviated by only 3.4° from latitude lines, and pen 37 spanned distances $(X, Y) = (68, 60)$ m on respectively the (x, y) axes.

More than 50 m south of pen 37 and the feedlot as a whole, lay two small (lateral span ~5–10 m), low (height ~2–3 m), weed-covered hillocks of material scraped from the pens, while to the south-west at a distance of at least 150 m from pen 37 a berm (height ~3 m) surrounded a water reservoir. These features were not represented in the wind simulations to be described below.

Seven cup anemometers (Climet, Inc., 011-4) were disposed (at height above ground $\eta = 1.15$ m) along a line crossing pen 37 obliquely, at the positions given in Table 1. A further four Climet cup anemometers measured the profile of mean wind speed on a 6 m mast near the N end of pen 37. Two 3-dimensional sonic anemometer-thermometers (Campbell Scientific Inc., CSAT3) were operated within the pen, always at $\eta = 2$ m. One was mounted on the mast, the other sited either near the middle ('mid', $y \sim Y/2$) of pen 37, or near $y \sim Y/4$. A further CSAT3 sonic was operated south of the south boundary of pen 37. Table 1 gives the coordinates of all instruments.

Shelter fences, forming a network about the feedlot, bounded pen 37 on the west, south and east sides, and were composed of vertical wooden slats of cross-section 9.5 × 1.1 cm ($3\frac{3}{4} \times \frac{7}{16}$ in) with an average gap space of 4.4 cm ($1\frac{3}{4}$ in), the resulting porosity being 25%. The height of the shelter fences relative to ground varied somewhat, and was determined at 10 m intervals. For the purpose of the simulations below each fence was attributed a constant height. The south boundary fence ($H_S = 2.9$ m) ran along the entire $y = 0$ axis (excepting the interval $0 \le x \le 8$ m, the opening for the SW gate). The west fence ($H_W = 2.4$ m) ran northward (only) along $x = 0$, and the east fence ($H_E = 2.65$ m) northward along $x = X = 68$ m. At its north edge, pen 37 was bounded only by a low concrete berm and a highly porous steel pipe fence (see Fig. 3), whose aerodynamic effect (over pen 37, during southerly winds) has been assumed negligible.

A Campbell Scientific Inc. (CSI) CR7 datalogger averaged the cup anemometer windspeeds over 15 min intervals, while each sonic anemometer was equipped with a CSI CR10X logger computing mean wind and turbulence statistics over the same 15 min intervals.

2.1. Data analysis

In order to aggregate the mean wind speeds, and in order (also) to allow comparison of measured and computed fields, it was necessary to choose a reference wind speed from a single instrument and normalize using that value. Here the uppermost instrument ("T4", at 5.08 m above ground) on the mast near the N end of pen 37 has been used, thus S/S_{T4} denotes a normalised mean wind speed. (Note: to a first approximation, cup anemometer overspeeding error cancels out in these *ratios* S/S_{T4} of mean speeds; e.g. Wilson (2004a,b).)

A Fortran program aggregated the anemometer data for wind direction sectors of angular width ± 10° or ± 15° about the SE, S and SW compass directions; this narrow sector width was chosen because shelter flows within windbreak networks exhibit a strong "corner effect" (e.g. Wilson and Flesch, 2003); results were not very different, however, with wider ± 22.5° sectors. To avoid periods when one or more anemometers may have intermittently stalled, any run with $S_{T4} < 1.5\ \mathrm{m\,s^{-1}}$ was discarded, and a further criterion on the Obukhov length L was imposed (the latter was deduced from the north sonic anemometer, and can be interpreted only as being *broadly* indicative of the prevailing stratification).

Fig. 2. View towards (roughly) the SSW across pen 37. Transect of seven cup anemometers all at $\eta = 1.15$ m above ground level (referred to in the text by number, no. 7 being the closest to camera). Anemometer no. 5 stood some 0.8 m below the mean level of the plot. Beyond the gate in the SW corner of the pen can be seen higher ground: the nearby berm of a feedlot reservoir, and (barely distinguishable) the foothills some 20–30 km distant.