11.8 COMPARISON OF METHODS TO INFER GAS FLUXES OFF A LAGOON

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1 INTRODUCTION

Agricultural waste lagoons emit gases that may impact on the environment, not only locally (eg. odour), but also at larger scales (eg. the greenhouse gas methane). Scientists from many disciplines have an interest in the quantification of such emissions, and we wish here to emphasize that the *spatial-variability* of the microclimate over a lagoon, or for that matter any other distinct component of the landscape, *invalidates* some of the familiar methods that can be used to measure gas emissions over uniform surfaces; ie. flow over a lagoon is a *disturbed* flow, and so if source strength (Q) is deduced by the application of theories or hypotheses or models whose derivation and validity hinges on the assumption of horizontal-uniformity of the flow, then there are likely to be errors.

But how big? To answer that question we compare various common estimators of the flux Q, from *modelled* spatial fields of windspeed, temperature and gas concentration (U, T, C) over a lagoon.

2 SYNTHETIC LAGOON FLOW

We programmed the Rao et al. (1974; RWC) second-order closure model of local advection, and confirmed its satisfactory performance relative to previous observations (Bink, 1996) of flow from arid to moist land. We added a scalar conservation equation

$$\frac{\partial}{\partial x}\left(UC+\overline{u'c'}\right)+\frac{\partial}{\partial z}\left(WC+\overline{w'c'}\right)=0 \qquad (1)$$

for our "lagoon gas," and budget equations for the turbulent fluxes patterned after the RWC treatment of humidity. Calculated concentration fields for a source in the *undisturbed* surface layer were found to be completely consistent with the observations of Project Prairie Grass, provided the turbulent Schmidt number (defined below) S_c=0.63.

We calculated synthetic lagoon microclimates (U,T,C) for very unstable, neutral, and very stable approach flows, and specified a (fixed) lagoon surface temperature T_{lag} that (in many cases) differed greatly from the surface temperature T_{up} of the approach flow. In all cases, roughness lengths were z_{up}=0.01m, z_{lag}=0.001 m. Flux estimators (as could be used in the field) were then applied to infer the (in this case, known) tracer flux Q, from the synthetic profiles at fetch x=50 m over the lagoon.

3 FLUX ESTIMATORS

Standard Flux-Gradient (FG) Select a pair of heights ($z_1 < z_2$), and measure differences $\Delta C=C_2-C_1$, $\Delta U=U_2-U_1$, and $\Delta T=T_2-T_1$. Using Monin-Obukhov similarity theory it can be reasoned that:

$$Q^{FG} = -\frac{1}{S_c}\,k_v^2\,\frac{z_g^2}{\Delta z^2}\,\frac{1}{\varphi_c\ \varphi_m}\,\Delta C\ \Delta U \qquad (2)$$

where $z_g=(z_1 z_2)^{½}$, the φ's are the similarity functions (unit value in neutral stratification) for the tracer gas and for momentum, and the turbulent Schmidt number $S_c=k_v/k_{vc}=(K_m/K_c)^{neutral}$ is the ratio of von Karman constants for momentum (k_v) and mass (k_{vc}), ie. the ratio of the eddy viscosity to the eddy diffusivity in neutral stratification.

Mass Balance (IHF): Pre-supposing a source of infinite crosswind (y) extent, the source strength must balance the upwind-downwind difference in

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the horizontal flux of mass. Then provided we may neglect the turbulent contribution to the horizontal flux,

$$\int_{x-}^{x+} Q^{IHF}\, dx =$$

$$\int_{z=0}^{\infty} \left[\, U(x+,z)\ C(x+,z)\ -\ U(x-,z)\ C(x-,z)\, \right] dz$$

where (x+, x-) denote locations (downstream, upstream) from the source. The "integrated horizontal flux" (IHF) method is theory-independent, and valid even if the flow is disturbed. If the flow *is* uniform, then

$$Q^{IHF} = \frac{1}{L} \int_{z=0}^{\infty} U(z) \left[\, C(x+,z)\ -\ C(x-,z)\, \right] d: \qquad (3)$$

where Q^{IHF} is now the *mean* emission rate over the width (L) of the source. The "background" C(x-, z) vanishes in many cases.

Backward Trajectory (bLS): Flesch et al. (1995) introduced the "backward Lagrangian stochastic" (bLS) source-receptor method, applicable to a source of *any* geometry. One measures the gas concentration at a *single* point, C_P, and those variables defining the state of the surface layer (at a minimum, a single wind speed U_{ref} and wind direction; for improved accuracy, one adds atmospheric stability). In conjunction with these field inputs, a trajectory model is applied by generating an ensemble of (N) trajectories from the point P *backward* in space and time, and where any trajectory touches ground, one records the triplet (x,y,w), touchdown position and vertical velocity. Q^{bLS} is inferred from those touchdowns as

$$Q^{bLS} = \frac{U_{ref}\, C_P}{N} \sum \left(\frac{w}{U_{ref}} \right)^{-1} \qquad (4)$$

where the summation runs over all touchdowns on the source. Being based on a dispersion model, the bLS method is *not* theory- and flow-independent, and we deduced source strengths Q^{bLS} using an LS model that *did not* account for flow inhomogeneity.

4 QUALITY OF FLUX ESTIMATES

The accompanying Table compares the quality (Q^{est}/Q) of various estimators ($Q^{est}=Q^{FG}$, Q^{IHF} or Q^{bLS}) of the lagoon emission rate.

T_{up} (C)	L_{up} (m)	T_{lag} (C)	FG z_1=0.15 z_2 = 0.4	FG z_1=0.4 z_2 = 1.4	IHF	bLS
25	-23	25	0.91	0.72	1.09	0.89
25	-23	30	0.94	0.79	1.08	0.87
25	-23	20	0.85	0.63	1.10	0.89
25	-23	15	0.82	0.52	1.09	0.88
25	48	25	0.61	0.36	1.03	0.86
25	48	30	0.69	0.53	1.03	0.89
25	48	20	0.51	0.19	1.03	0.87
25	48	15	0.43	0.09	1.03	1.15
20	-2300	30	0.92	0.85	1.05	0.94
20	-2300	10	0.61	0.23	1.06	0.87

5 CONCLUSION

Not surprisingly, serious errors *can* arise using the flux-gradient technique in disturbed flow (worst case: stable IBL within stable approach flow). The IHF method proves the most accurate (errors are due to discretization and neglect of turbulent flux), but demands more field instruments than bLS, even when 2d symmetry of the source prevails - and is impractical otherwise. The bLS estimates are also quite good (not worse than 15%), even though the LS model ignored flow disturbance (had we taken the trouble to adopt an LS model that admits horizontal inhomogeneity, and "fed" it with the disturbed flow properties generated by the advection model, we should presumably have had near perfect agreement, Q^{bLS}=Q). We conclude that bLS is a suitable indirect technique for assessing surface emissions in (this) disturbed flow.

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