EAS372 Assignment 3 Due: 9 April, 2015

Format: Please submit a tidy, organized report covering the exercises below (preferably as a single PDF file), double spaced with font size 12 pt. The page limit is **four**, not counting figures and tables.

A. Q-vector formulation of the QG omega equation (5%)

The QG vertical velocity (w) equation may be written in qualitative form as a proportionality

$$[\,\overline{w}_{\rm nbrs} - w_{\rm P}\,] \propto \nabla \cdot \mathbf{Q} \;, \tag{1}$$

where the left hand side "compares" vertical velocity at a point **P** with the average value nearby and the right hand side is the divergence of the "**Q**-vector." According to this formula, wherever **Q**-vectors are *convergent* (i.e. $\nabla \cdot \mathbf{Q} < 0$) a local maximum in vertical velocity can be expected (i.e. $w_{\rm P} > \overline{w}_{\rm nbrs}$).

Present a snapshot of a storm, based on CMC analyses or 0h progs (and possibly other relevant data, e.g. satellite cloud images). Demonstrate whether the pattern of vertical motion is (or is not) qualitatively consistent with the pattern of the **Q**-vectors (maps of the latter may found at `http://www2.mmm.ucar.edu/people/tomjr/files/realtime/qg_diag/Qvect700-NorAmer/res3.html`). Focus on a few regions of dramatic **Q**-vector convergence or divergence.

B. Computation of turbulence statistics (10%)

The ascii text file "aug16_1500_1530_rot_DOS.csv" (also provided as an Excel file) contains turbulence signals in six columns: (1) alongwind velocity $u\,[\mathrm{m\,s^{-1}}]$, (2) crosswind velocity $v\,[\mathrm{m\,s^{-1}}]$, (3) vertical velocity $w\,[\mathrm{m\,s^{-1}}]$, (4) temperature $T\,[^{\circ}\mathrm{C}]$, (5) carbon dioxide concentration $\rho_c\,[\mathrm{mg\,m^{-3}}]$ and (6) absolute humidity $\rho_v\,[\mathrm{g\,m^{-3}}]$. These signals, recorded at 10Hz, span 15:00-15:30 MDT on 16 Aug. 2011, and were recorded over a wheat crop at St. Albert by a sonic anemometer at height $z_m = 2.5$ m (Wilson 2013) . The coordinate system has been rotated such that $\overline{v} = \overline{w} = 0$.

Using whatever computing environment you wish (e.g. Excel or Matlab or your own code), calculate and report the following statistics[1]:

1. mean value for each of the six columns (i.e. $\overline{u}$,...)
2. all components of the Reynolds stress matrix[2] $\mathbf{R} = \overline{u_i'\, u_j'}$, where a prime designates the fluctuation (i.e. deviation from the mean value)
3. the friction velocity
$$u_* = \left[\, (\overline{u'w'})^2 \;+\; (\overline{v'w'})^2 \,\right]^{1/4}$$
and the mean drag of the wind on the surface (plants and ground), given by $\tau = \rho u_*^2\,[\mathrm{N\,m^{-2}}]$
4. the Obukhov length
$$L = \frac{-u_*^3\, \overline{T}_\mathrm{K}}{k_v\, g\, \overline{w'T'}}$$
(where $k_v = 0.4$ and $\overline{T}_\mathrm{K}$ is the mean temperature in Kelvin) and the dimensionless stratification parameter z_m/L
5. 30-min average vertical flux density of sensible heat Q_H $[\mathrm{W\,m^{-2}}]$
6. 30-min average vertical flux density of water vapour E $[\mathrm{kg\,m^{-2}\,s^{-1}}]$ and of latent heat Q_E $[\mathrm{W\,m^{-2}}]$
7. 30-min average vertical flux density of carbon dioxide F_c $[\mathrm{kg\,m^{-2}\,s^{-1}}]$
8. the standard deviations σ_{ρ_c}, σ_{ρ_v} of the CO_2 and H_2O concentrations and the correlation coefficient $R = \overline{\rho_c'\, \rho_v'}/(\sigma_{\rho_c}\, \sigma_{\rho_v})$

Assume the pressure $P = 91$ kPa, in order to compute a mean air density ρ. Compute the fluxes as (e.g.)
$$Q_H = \rho\, c_p\, \overline{w'T'}\ .$$

References

Wilson, J.D. 2013. Turbulent Schmidt numbers above a wheat crop. *Boundary-Layer Meteorol.*, **148**, 255–268.

[1] A common subscript notation is used to identify the three coordinate directions, i.e. $u_1 \equiv u$, $u_2 \equiv v$, $u_3 \equiv w$.

[2] $\mathbf{R}$ is a 3×3 matrix, where i is the row index and j the column index. Thus (for example) the bottom right entry $R_{33} = \overline{w'^2} \equiv \sigma_w^2$, the variance of the vertical velocity.