Homework #3/4/5 – Modeling the Urban Surface Energy Balance ME EN 7710 Environmental Fluid Dynamics Due 2/12/2013

The goal of this project is to obtain a working understanding of the Surface Energy Balance (SEB) for urban areas. For this project, you will model the urban SEB for a tower located in a suburban neighborhood in the Salt Lake Valley (Murray, UT) using the so-called LUMPS (Local-scale Urban Meteorological Parameterization Scheme) model. At the end of the project you have a working simulation tool. This "project" will be worth 3 homework assignments.

The basic path for this homework is to:

- 1. Familiarize yourself with the LUMPS model by reading Grimmond and Oke 2002.
- 2. Write and validate a sub-module to determining the net radiation balance (see description below).
- 3. Write the code for the LUMPS model and integrate the net radiation module into the LUMPS model.
- 4. Utilize the provided surface cover and morphometry data as well as basic meteorological data from the flux tower in Murray to calculate the full SEB.
- 5. Compare the calculated Sensible and Latent Heat Fluxes to those actually measured in the field. Note, you will get full diurnal solutions.
- 6. Please present your results in the form of a well-written AMS conference paper that includes a brief introduction and methods section. Use the Grimmond and Oke 2002 paper as a model. Your paper should be limited to 7 pages;

This project should be done individually, but cooperation amongst students is encouraged.

Radiation Sub-Module (Due 2/5/2013)

Using the equations presented in class, in the handouts and in the textbook, write a computer program to do the following: calculate the incoming direct beam solar radiation at any point in the northern hemisphere, at any time of the day, at any latitude (ϕ), and for sloping terrain (slope angle - $\hat{\beta}$ and slope azimuth - $\hat{\Omega}$). In doing this, assume the atmosphere has a net transmissivity that can modeled using the parameterization given in class for low, middle and high cloud cover fractions or using a more advance model that you might find in the literature. <u>Please hand in your computer code as well as answering the questions below.</u>

- 1) Determine the incoming solar radiation on a segment of horizontally homogeneous unobstructed flat terrain in Salt Lake City, UT on September 21, 2002 at 2 pm local time with no cloud cover (use the airport coordinates: $\phi = 40.788^{\circ}$ North and $\lambda_e = 111.978^{\circ}$ West).
- 2) For the same latitude, generate a contour plot of incoming solar radiation as a function of time of day and slope angle for (a) a north-facing slope ($\hat{\Omega} = 0$) on December 21 and (b) a south-facing ($\hat{\Omega} = 180$) slope on June 21.

- 3) Determine the incoming solar radiation for the same day and time as in problem 1, for a slope on the Oquirrh mountains (assume $\hat{\beta} = 5$ degrees and $\hat{\Omega} = 90$ degrees)
- 4) Determine the incoming solar radiation for the same day and time as in problem 1, along the Wasatch front (assume $\hat{\beta} = 20$ degrees and $\hat{\Omega} = 270$ degrees)
- 5) Compare to supplied incoming solar radiation data from the Dugway Proving Grounds $(\hat{\beta} = 0; \phi = 40.142^{\circ} \text{ North and } \lambda_e = 113.267^{\circ} \text{ West})$. Note that the time series is in UTC +6 hours.
- 6) Compare to supplied incoming solar radiation data from the BLLAST experiment in Lannemezan, France ($\hat{\beta} = 0$; $\phi = 43^{\circ}$ 6' 32.9'' North and $\lambda_e = 0^{\circ} 21' 32.1''$ East). Note that the time series given on the website for this is in UTC.

Land Surface Cover Data



Figure. Satellite image of (*left panel*) the central portion of the SLV with a box (~1km x 1km) indicating the approximate region directly surrounding the tower and (*right panel*) the area surrounding the suburban flux tower.

Average Building Height	4.4 m
Average Tree Height	6.5 m

Table 1. Average heights for suburban site in Murray, UT.

	Area	Area	
Surface Type	(m ²)	(Acres)	fraction
Grass	373592.2	92.33	0.193159
Trees	200178.8	49.47	0.103494
Residential			
Rooftops	179834.7	141.8	0.296653
reflective rooftop	6430.262	1.58	0.003305
Parking Lot	15386.32	3.8	0.00795
Industrial Rooftops	34538.78	8.53	0.017845
Bare Soil	79901.81	19.74	0.041297
Asphalt Road	128578.3	31.78	0.066485
Other		128.97	0.269812
Total		478	

Table 2. Land cover fractions for suburban site in Murray, UT.

Murray Tower Met and Flux Data

See www.mech.utah.edu/~pardyjak/

Site Location: Latitude: 40° 39.11 N Longitude: 111° 55.19 W Elevation: 1306 m Average Site Albedo: 0.18

Slope of the saturation vapor pressure temperature curve:

$$\frac{de_s}{dT} \cong \frac{L_V}{R_V} \frac{e_s}{T^2}$$
 (kPa/K)

The psychrometric constant (Brunt 1952):

$$\gamma = \frac{C_p}{L_v} \frac{P}{\varepsilon}$$
 (kPa/K)

Where the Latent heat of vaporization can be calculated as function of air temperature as (Stull, 1988):

$$L_{V} \cong \left[2.501 - 0.00237 \cdot T\left({}^{\circ}C\right)\right] \cdot 10^{6} \text{ (J/kg)}$$

Grimmond, C.S.B. and Oke, T.R., 2002: Turbulent Heat Fluxes in Urban Areas: Observations and a Local-Scale Urban Meteorological Parameterization Scheme, *J. Appl. Meteorol.* 41, 792-810.