Urban heat island and human heat-stress values during the July 2006 Portland, Oregon heat wave

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ABSTRACT

The current study uses 12 mesoscale sites around Portland, Oregon to map the urban heat island (UHI) and resulting heat index (HI) fields during the heat wave of 20-24 July, 2006. Past studies have observed UHIs in the area, but temperatures during this heat wave were unusually high due to a combination of synoptic influences: high temperatures aloft and a surface high pressure region. The associated surface southerly flow of moist air also produced high relative humidity (RH) values during both daytime (which raised HI values) and nighttime (which kept minimum temperatures high) periods.

Results showed two separate Portland midday UHI (of up to 16 ^{0}F) centers, divided by the Willamette River that flows through the city. The temperature time series for all 12 mesomet sites and for the NWS site at the Portland Airport shows that the UHI thus produced significant differences in the HI values across the city, with the highest variability during the 22nd of July. HI values from the airport NWS site were much lower (up to 20 ^{0}F) than those from the center of the UHI. An urbanized HI needs to thus be considered when forecasting HI values during heat waves.

Introduction

As part of an NSF grant (Sailor *et al.* 2008) on the "Complex interactions among urban climate, air quality, and adaptive-reactive human responses," an analysis was carried out of urban heat island (UHI) effects on NWS heat index (HI) values across Portland, Oregon during the heat wave of 20-24 July, 2006. Research questions addressed included: What were the synoptic causes of the heat-wave? What were the mesoscale variations across the Portland area of its observed UHI temperatures and calculated HI values? How did mesoscale HI values compare with NWS HI values?

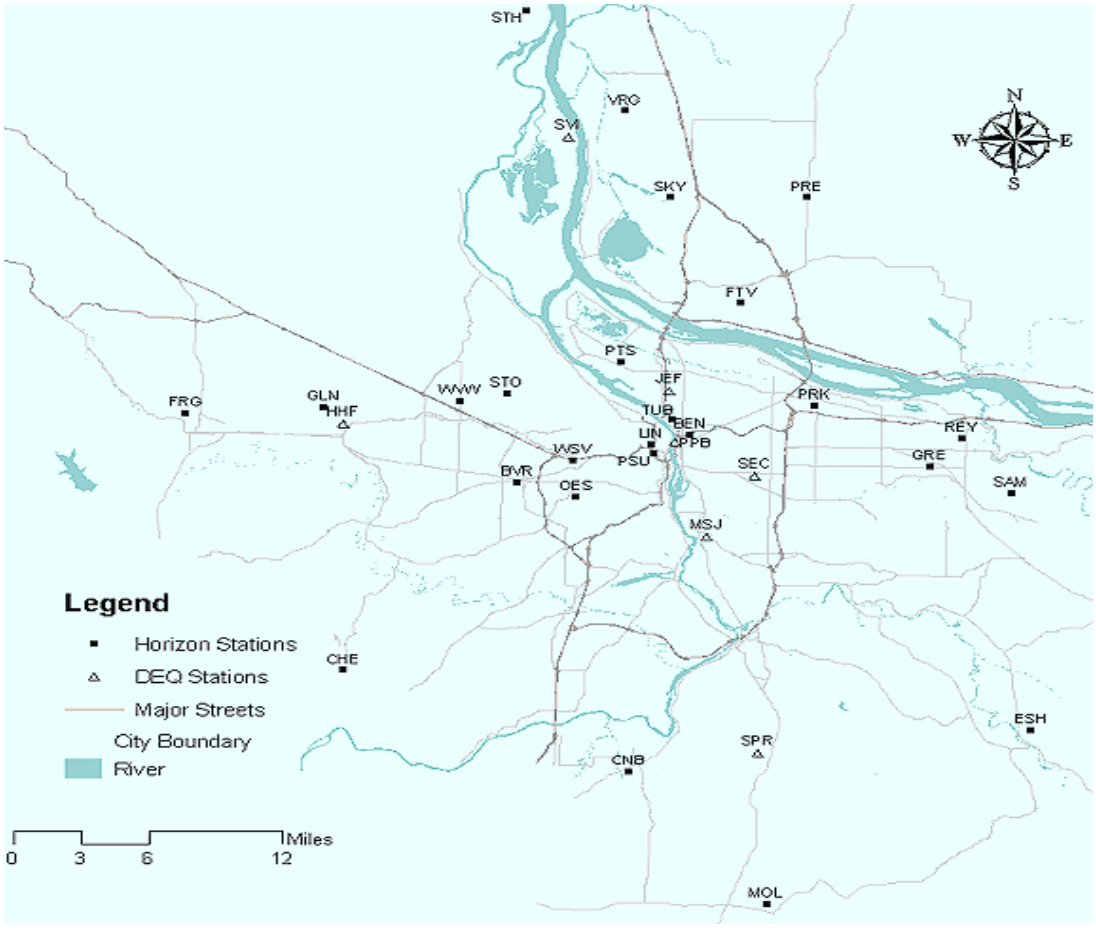
Methodology

Portland lies in the north-central part of the Willamette Valley and has an urban area of 376 km^2. The mean elevation at its NWS airport site is 15 m MSL. Its winter climate is mild, with cloudy and rainy periods with good mixing and southeasterly winds, punctuated by colder stagnant, light winds. High temperatures are mostly in the 30s and 40s (^{0}F). The transitional spring months (March and April) are wet and cool, while May and June are drier, with generally good mixing conditions and high temperatures mostly in the 60s and 70s. Summers have much less rain than the other seasons and are mild to warm, with highs in the 70s to 90s. Persistent

north-west summer afternoon winds bring cleansing, cooling sea breeze flows. Autumn is the reverse of spring, with many warm days in September. By mid-October, rain is increasing, and temperatures are cooling, with afternoon highs in the 50s and 60s. Stagnant periods between storms are frequent, during which fog can persist for several days.

Synoptic and General Circulation forcing that produced the heat wave were evaluated from NWS 850 hPa and surface charts, satellite 250 hPa winds, and surface observations (Fig. 1) from one NWS site (i.e., PRK) and 12 Horizon-network meso-net sites, i.e., Canby CNB, Stoller STO, Reynolds REY, Estacada, ESH, Westview, WVW, Spangler Road SPR, SE Lafayette SEC, Oregon Episopical OES, PSU Portland State, Benson BEN, Greshan GRE, and Sauvie Island SVI. While all 12 meso-net sites yielded temperature measurements, relative humidity at only four of these sites (ESH, STO, GRE, and PSU, plus PRK) measured relative humidity RH.

Fig. 1. Map of Portland, OR showing the NWS site at PRK and Horizon meso-set sites



Simple HI values were calculated from the following empirical relationship, as this is what the NWS uses operationally (the more complex Kalkstein version of HI requires long-term data sets not available for the meso-met sites):

$$HI = c_1 + c_2 \bullet T + c_3 \bullet RH + c_4 T \bullet RH + c_5 \bullet T^2 + c_6 \bullet RH^2 + c_7 \bullet T^2 \bullet RH + c_8 \bullet T \bullet RH^2 + c_9 \bullet T^2 \bullet RH^2 \quad ,$$

where HI is heat index (^{0}F), T temperature (^{0}F), RH relative humidity (%), c_1 = -42.379 (^{0}F), c_2 = 2.04901523, c_3 = 10.14333127 (^{0}F), c_4 = -0.22475541, c_5 = -6.83783×10^{-3} (1/^{0}F), c_6 = -5.481717×10^{-2} (^{0}F), c_7 = 1.22874×10^{-3} (1/^{0}F), c_8 = 8.5282×10^{-4}, and c_9 = -1.99×10^{-6} (1/^{0}F). Note that HI values are only calculated for T > 75^{0}F, and that HI values are less than an observed T value for any combination of RH values at or below 40% and T below 88^{0}F.

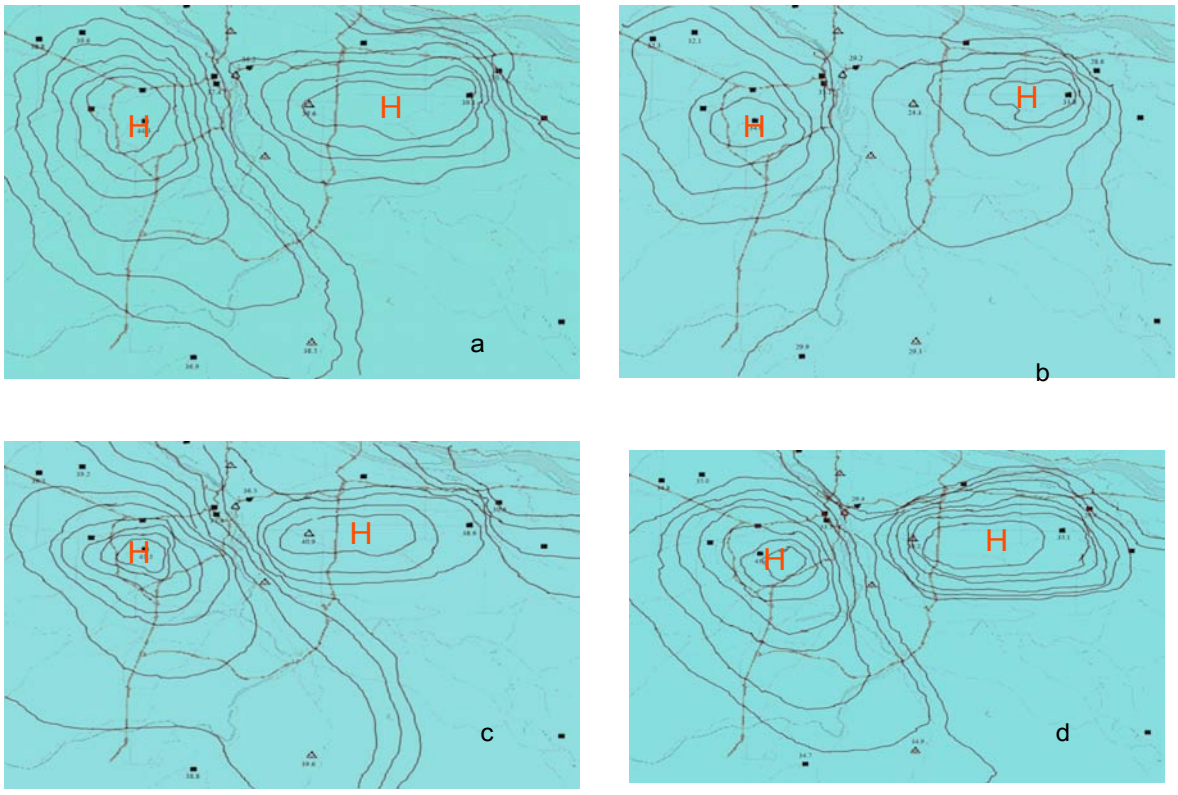
Results

Synoptic Summary

An unusually warm 850 hPa air mass, associated with four-corners High on 20 July at 0000 UTC (= 1600 PDT, Pacific Daylight Savings Time), gradually moved northward past Oregon over the next four days, producing weak onshore flow and subsidence warming at the surface. By 21 July at 0000 UTC, a hot dry cloudless air-mass existed aloft over Oregon. Twenty four hours later, moist air and clouds moved northward to a position over OR, which produced high nighttime temperature and RH values. By the 23rd at 0000 UTC, the moist air had moved north of Oregon.

UHI Spatial-Patterns

Fig. 2. UHI patterns (isotherm interval of 1^{0}F) at 1500 PDT on July (a) 21st, (b) 22nd, (c) 23rd, and (d) 24th

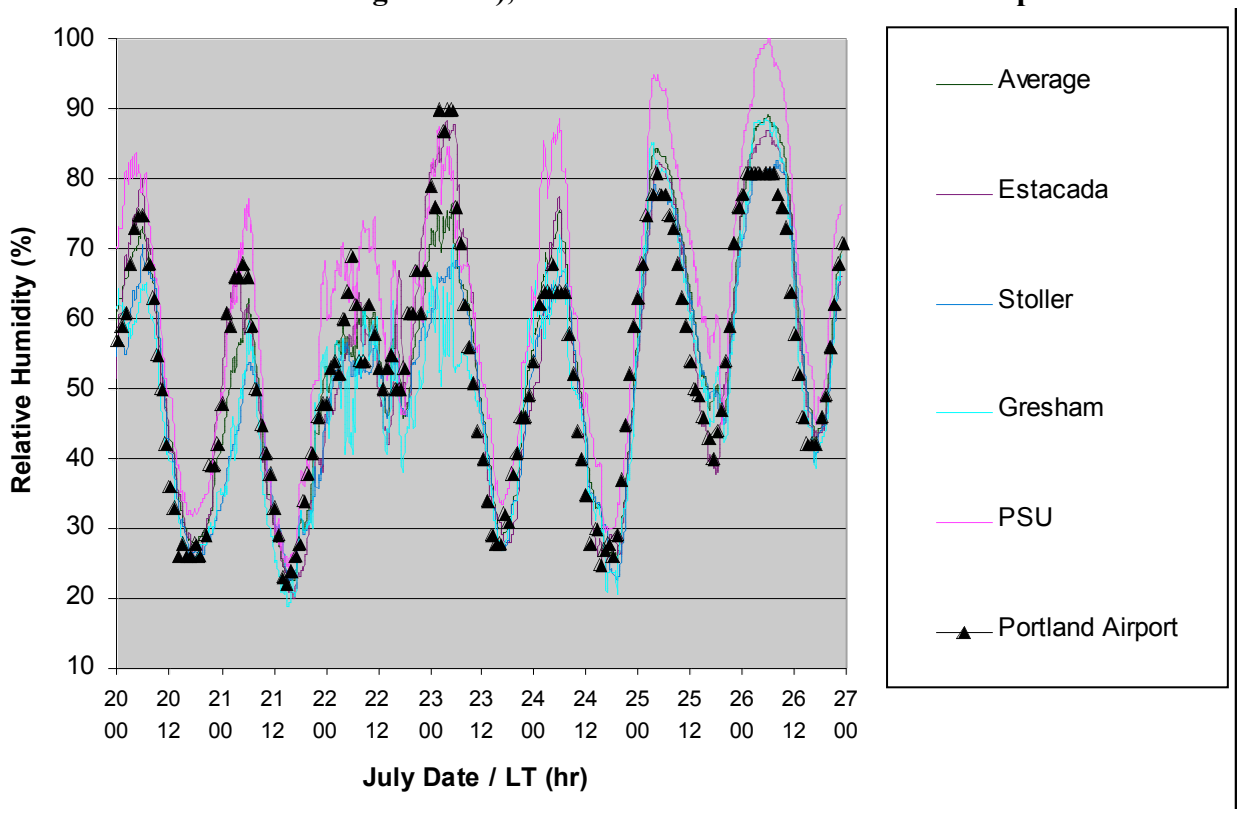


Surface (i.e., 2 m) HUI patterns at 1500 PDT on 21-24 July 2006 (Fig. 2) show that on the 21st, wind speeds were high at 13 mph, the RH was low at 23%, and the maximum UHI of 7^0F was located west of the river, which on all days split the UHI into two lobes. One day later, speeds became calm, the RH rose to 52%, the cloud cover peaked (at "broken" coverage), and the western lobe of the UHI weakened, while the right lobe strengthened. By the 23rd, wind speeds picked up to 8 mph, the RH fell to 33%, only scattered clouds existed, and temperatures had increased. By the final day, speeds were back up to 11 mph, RH values were still at 33%, skies were cloudless, and the left UHI lobe was advected to the south, while the right lobe further intensified.

RH, UHI, and HI Time-Series

The time-series (Fig 3.) for each of the four meso-sites with RH observations (plus the time-series of their average values), as well as that for the NWS site, show fairly uniform low (down to 20 %) daytime values across the sites, with the exception of the relatively high values (40-50%) during the daytime hours of the 22nd. Nighttime vales are much higher (up to 90% on several days) and more variable from site to site. The average RH values were used for calculation of the HI values shown below.

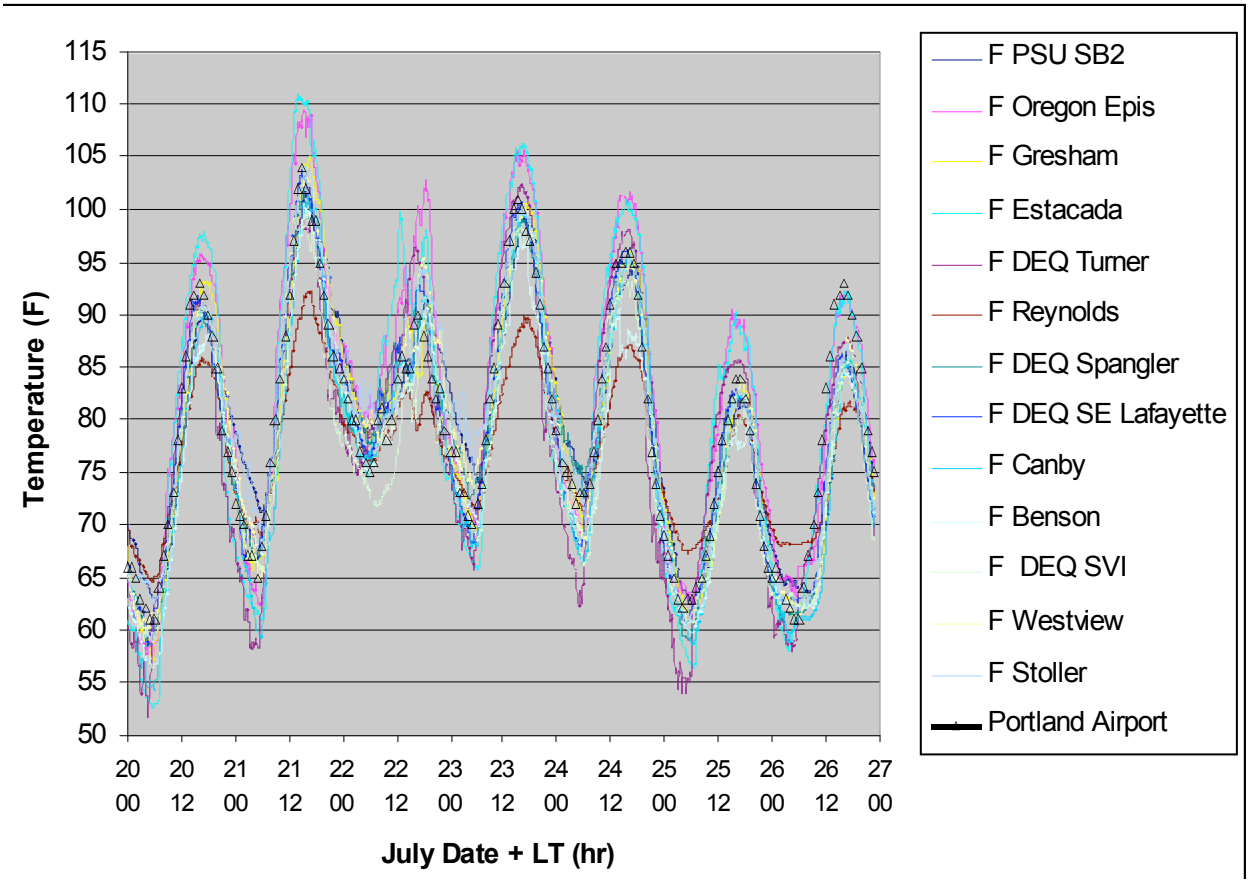
Fig. 3. Time-series for each of the four meso-sites with RH observations (plus the time-series of their average values), as well as that for the PRK NWS airport site



The temperature time-series (Fig. 4) for each meso-site, as well as that for the NWS site, show large site-to-site variations during both daytime and nighttime hours. Daytime values are above 100 ^{0}F at a number of sites on four days, peaking at over 110 ^{0}F the 21st. Values during the night

on the 21st-22nd only fell to 75 ^{0}F at one site because of the high amount of cloud cover, which reduced outgoing long wave radiative loss. The maximum UHI (of 13 ^{0}F) occurred during the mid-day peak temperatures on the 22nd; it was the difference between 90 and 103^{0}F.

Fig. 4. Temperature time-series for each meso-site, as well as that for the PRK NWS airport site



The HI time-series (Fig. 5) for each meso-site, as well as that for the NWS site, again show large site-to-site variations during daytime hours; note that HI values are only (as mentioned above) calculated for T > 75^{0}F. Daytime values at one site never fell below 95^{0}F, are above 110^{0}F at a number of sites on three days, and peaked at over 125^{0}F at one site on the 22nd, when the maximum excess above the NWS (of 30^{0}F) occurred.

The time-series of the differences between the HI values (Fig. 5) and the temperature values (Fig. 4) show generally positive values (Fig. 6), except during several nights (when as mentioned above, HI values are less than an observed T value for any combination of RH values at or below 40% and T below 88^{0}F). The largest difference (i.e., 26^{0}F) again occurs during the day-time hours of the 22nd.

Fig. 5. HI time-series for each meso-site, as well as for the PRK NWS airport site

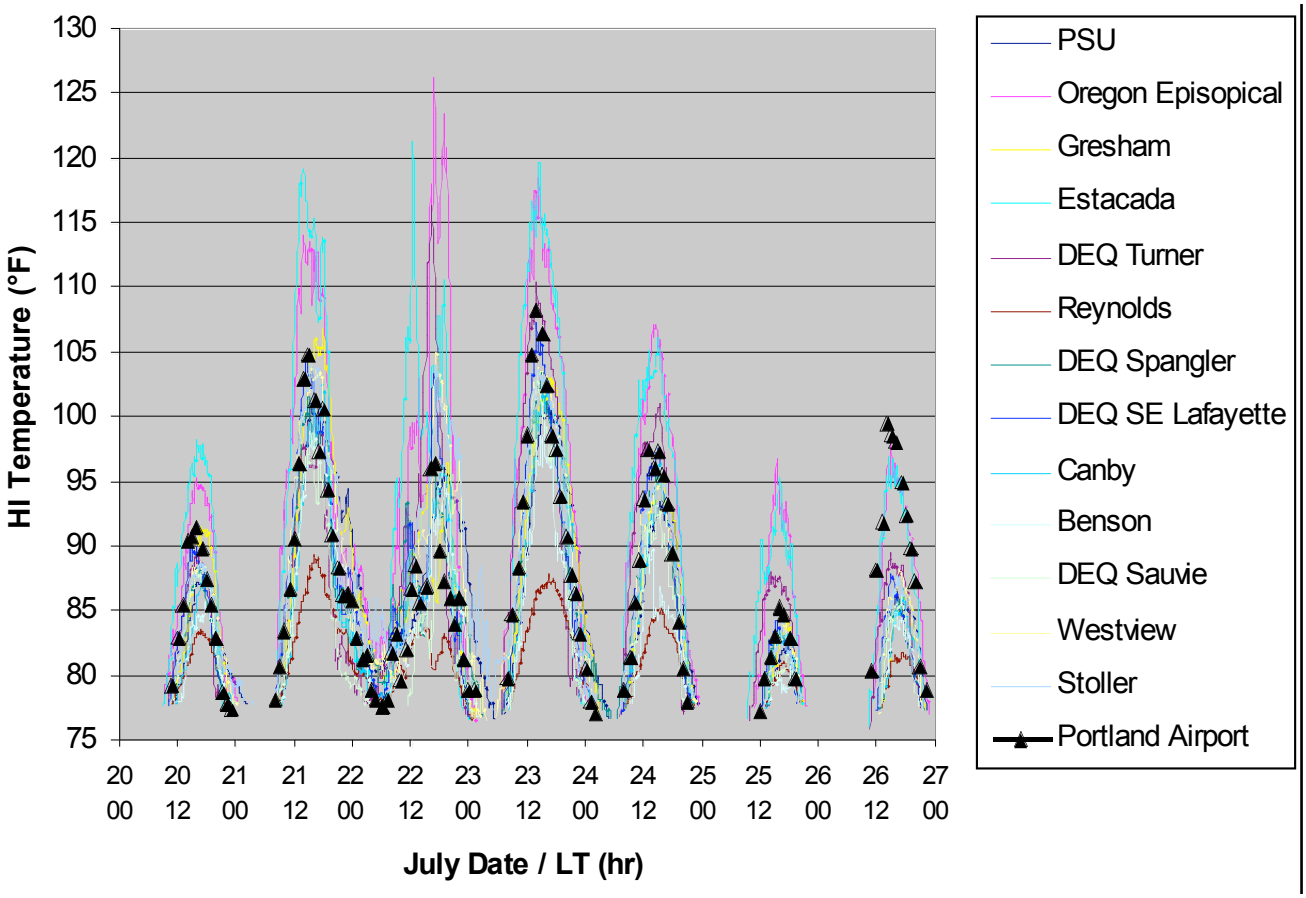
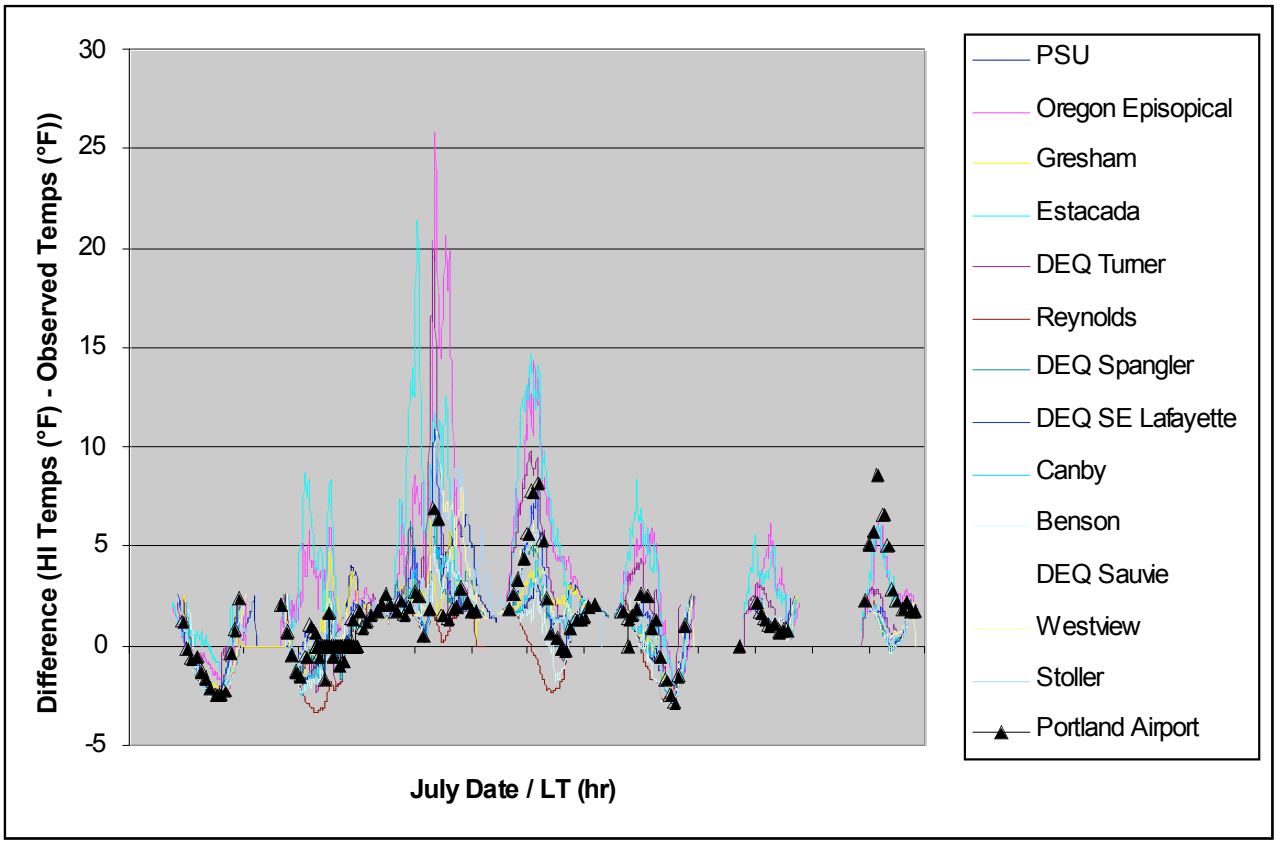


Fig. 6. Difference (HI minus T) time-series for each meso-site, as well as for PRK



Conclusion

Portland, Oregon, generally has mild summer temperatures and good air quality, but synoptic and General Circulation conditions during a four day period in July 2006 produced a heat wave and poor air quality (not discussed). The current study thus used 12 mesoscale sites around Portland, Oregon to map the UHI- and resulting HI-fields during the heat wave.

The upper level factors producing the heat wave included warm and moist air advection, widespread cloud cover, and high nighttime RHs (> 90%). Daytime temperatures were thus high (a maximum of 111^0F), and they remained high during one nighttime period (a minimum of 75^0F) due to an increased cloud cover that prevented long-wave radiative cooling.

The daytime Portland UHIs were bisected by its river, and the largest UHI (on 22 July) was 13^0F. The largest difference between a HI value and a temperature value was 26^0F. Use of the NWS site outside of the city (as is done in the NWS forecasts) produced a maximum under-estimation of a daytime HI value of 30^0F during the study period, i.e., the difference between 126 and 96^0F.

Recommendations for future efforts include the need for NWS temperature forecasts (and forecast models) to be "urbanized," especially so that forecast temperatures will include UHI effects. In addition, urban HI-forecasts must also be "urbanized" by use of mesoscale UHI values.

References

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