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Evaluation and Improvements to the WRF’s Multilayer Urban Scheme

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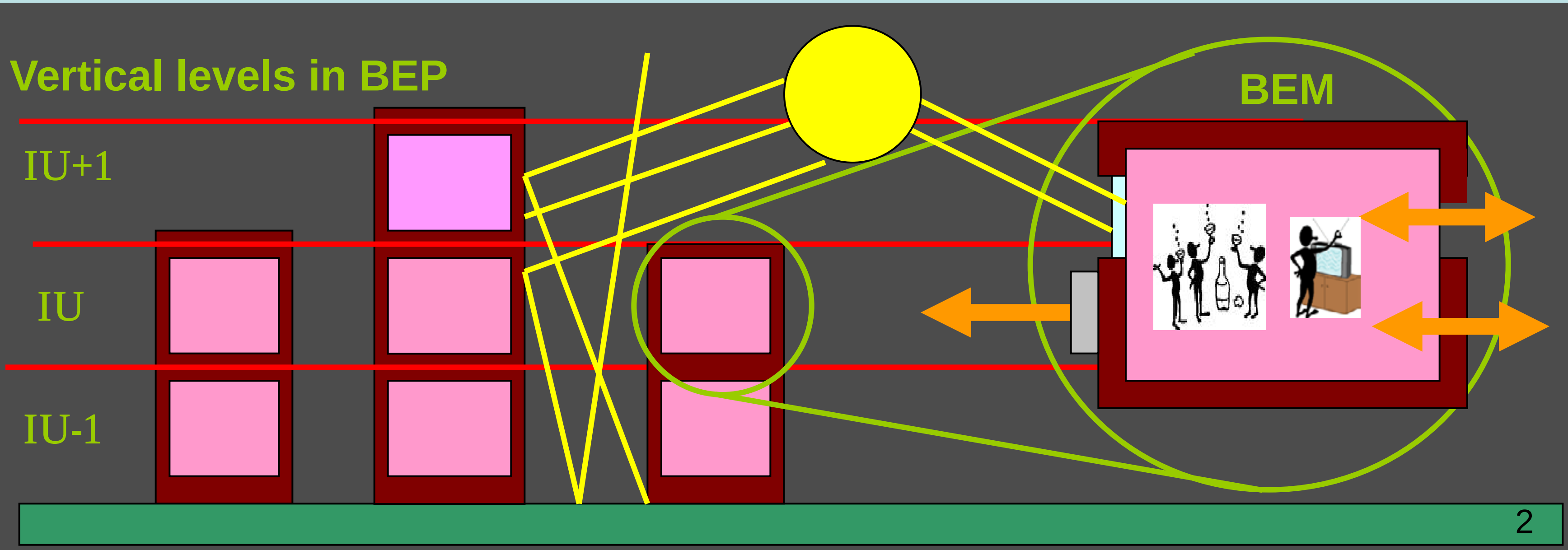
uWRF-A High Resolution City Scale Model

- **BULK** is a simple bulk scheme that defines a roughness length and thermal parameters to represent the effect of the urban areas.
- **UCM** is a single layer urban scheme (with the possibility to add a diurnal profile of the anthropogenic heat AH) that recognizes three different urban surfaces (walls, roofs, and roads).
- **BEP** is a multiple layer urban scheme (without the possibility to add AH) that permits a direct interaction with the PBL, and recognizes three different urban surfaces.
- **BEP+BEM** is a simple building energy model (BEM) linked to BEP:

  a) The time evolutions of floor air temperature and air humidity are estimated separately.

  b) Natural ventilation, heat generated by equipments and occupants, the convective heat through the walls, and the radiation through the windows are considered in the model.

  c) The heat needed for cooling/heating the indoor air temperature can be computed considering an air conditioning (AC) system model w/COP of 2.8.



BEP+BEM

Building Energy Model (BEM) (Martilli & Salamanca, 2009)

Time Evolution of room air temperature and humidity:

$$Q_B \frac{dT_r}{dt} = H_{in} - H_{out}$$

$$l\rho V_B \frac{dq_{Vr}}{dt} = E_{in} - E_{out}$$

H_{in} and E_{in}: Sensible and Latent Heat Load

H_{out} and E_{ot}: Sensible and Latent Heat needed for Cooling/Heating the Indoor Air

Heat Loads:

Heat exchange Windows/Indoor Air

Heat exchange Walls-Roof/Indoor Air

$$H_{in} = \sum_j A_j^{wind} h_{wind,j} (T_{wind,j} - T_r) + \sum_i A_i^{wall} h_{wall,i} (T_{wall,i} - T_r) +$$
$$+ (1 - \beta) C_p \rho V_a (T_a - T_r) + A_f q_E + A_f P \varphi_p q_{hs} ,$$

Ventilation

Heat generation by equipments and occupants

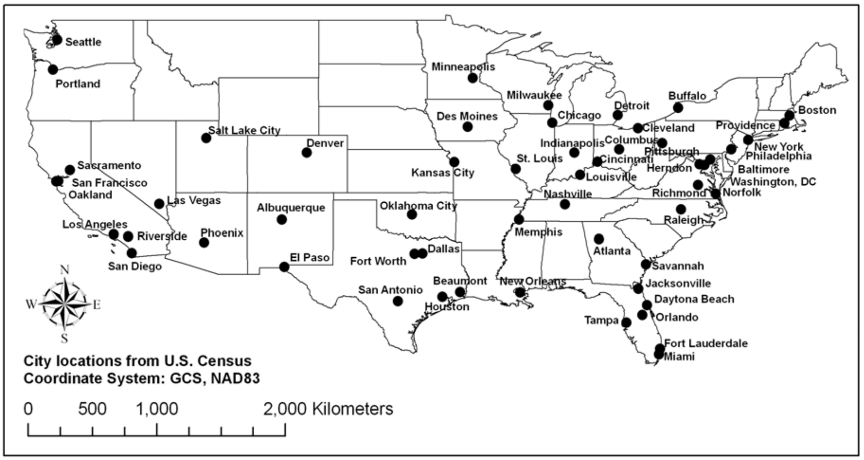
$$E_{in} = (1 - \beta) l \rho V_a (q_{Va} - q_{Vr}) + A_f P \varphi_p q_{hl} .$$

Water Vapor Mixing through Ventilation

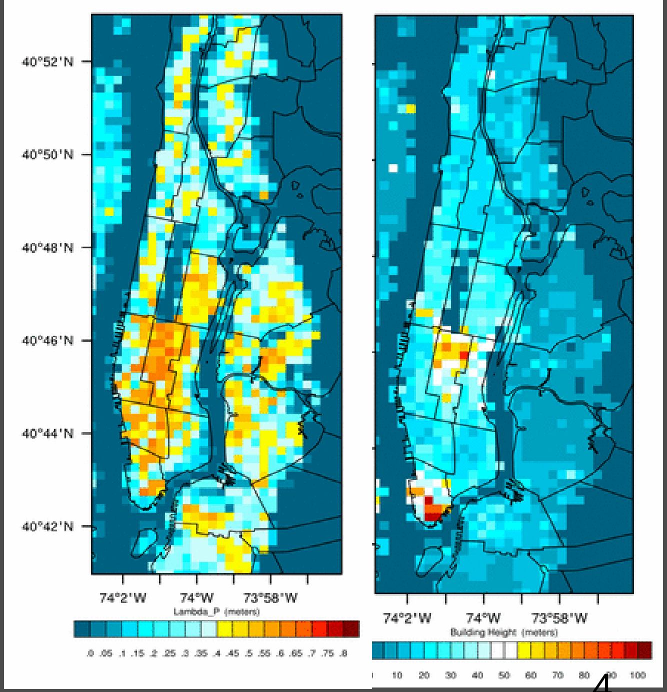
Evaporation from occupants

National Building Statistics Dataset (NUDAPT):

The NBSD2 consists of 13 building statistics computed from airborne Lidar data and other sources of information by the National Geospatial-Intelligence Agency (NGA) at 250-m and 1-km horizontal spatial resolutions from three-dimensional building data for 44 metropolitan areas in the US (Burian *et al.,2008).*

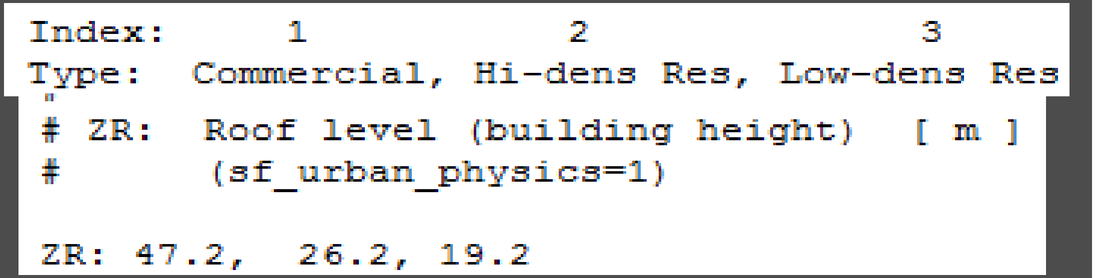


Gridded NUDAPT Parameters



Building Area Fraction Building Height

Example of NUDAPT ingestion by table:



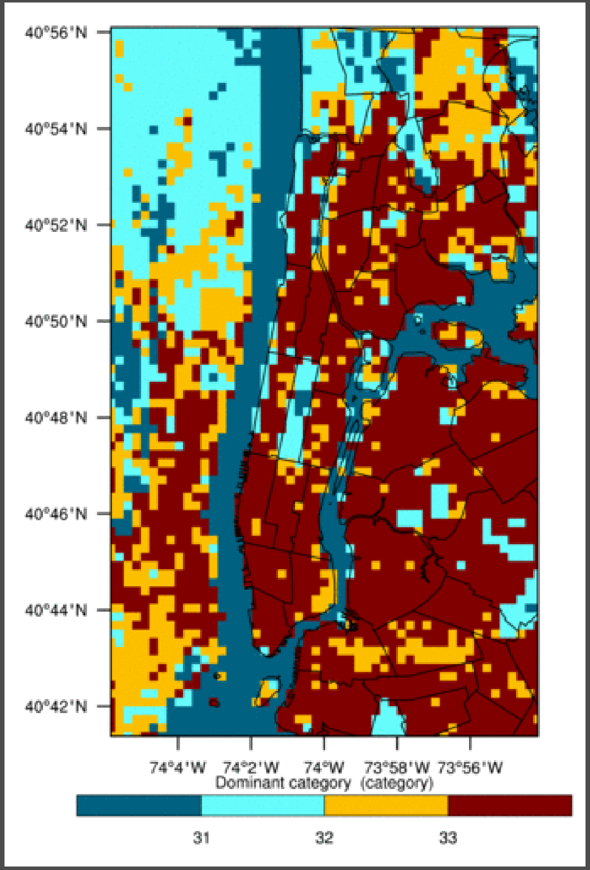
```
Index:     1              2                3
Type:   Commercial, Hi-dens Res, Low-dens Res
"
 # ZR:   Roof level (building height)   [ m ]
 #        (sf_urban_physics=1)

 ZR: 47.2,  26.2, 19.2
```

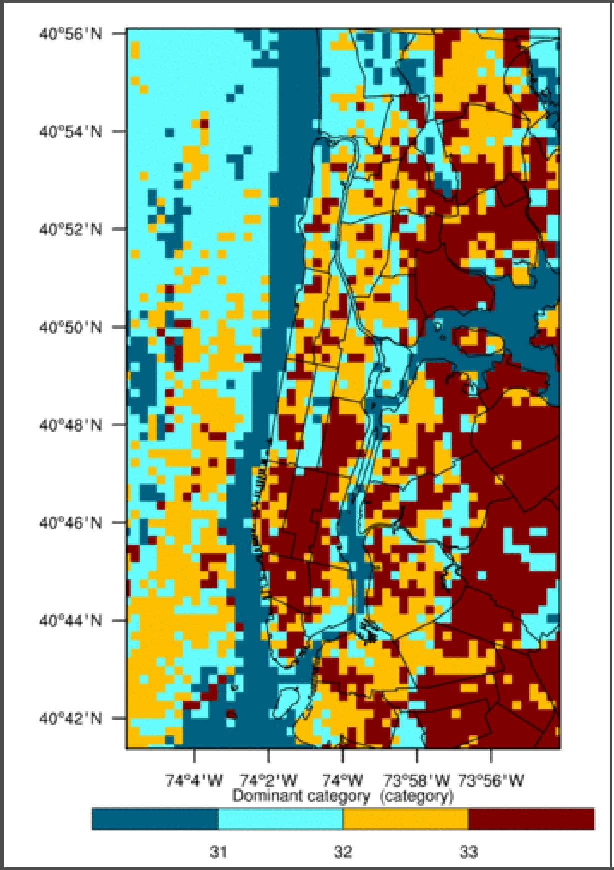
National Land Cover Data (NLCD)

Classes: Low Residential:31, High Residential: 32, Commercial: 33

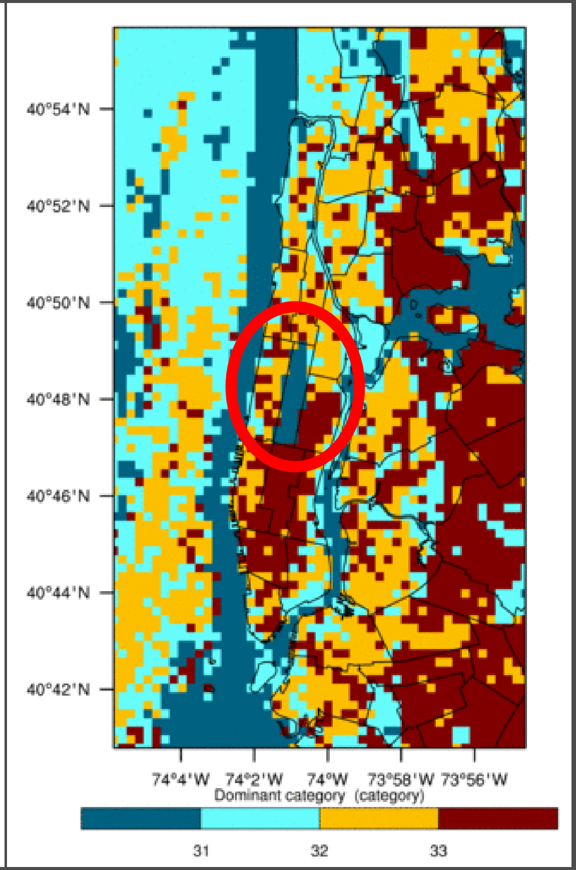
Original NLCD



NUDAPT Classes based on λp



Central Park Corrected



Model Setup

- Four two-way nested domains with a grid spacing of 9, 3, 1 and 0.333 km were defined. Initial and boundary conditions from NAM (resolution: 12 km). NCEP/MMAB data at 0.5 degree were employed to update the sea surface temperature every 24-h.

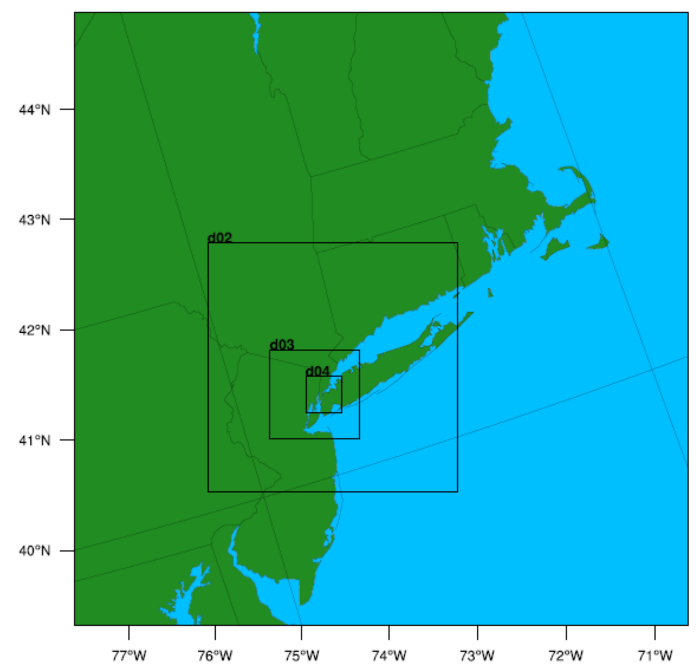
- Vertical resolution of 51 terrain following sigma levels (33 levels in the lowest 1.5 km, first level ~10m).

- PBL Parameterization: Bougeault and Lacarrère (BouLac).

- Urban classes were derived from the National Land Cover Data (NLCD).

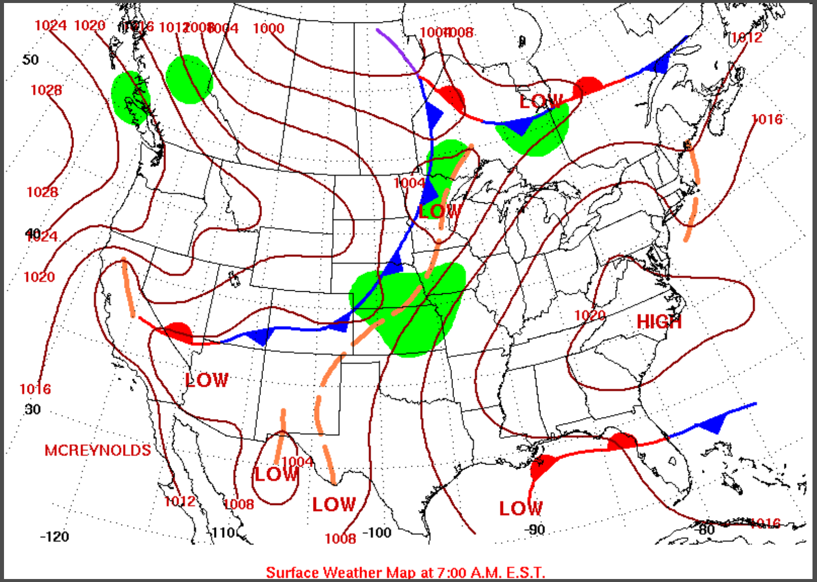
- Urban canopy parameters from National Urban Database and Access Portal Tool (NUDAPT) are assimilated in WRF on a GRIDDED basis.

- Two albedo values were defined to represent dark and white roofs. An albedo of 0.2 was assigned to the dark roofs and for the white roofs the albedo was increased to 0.8.

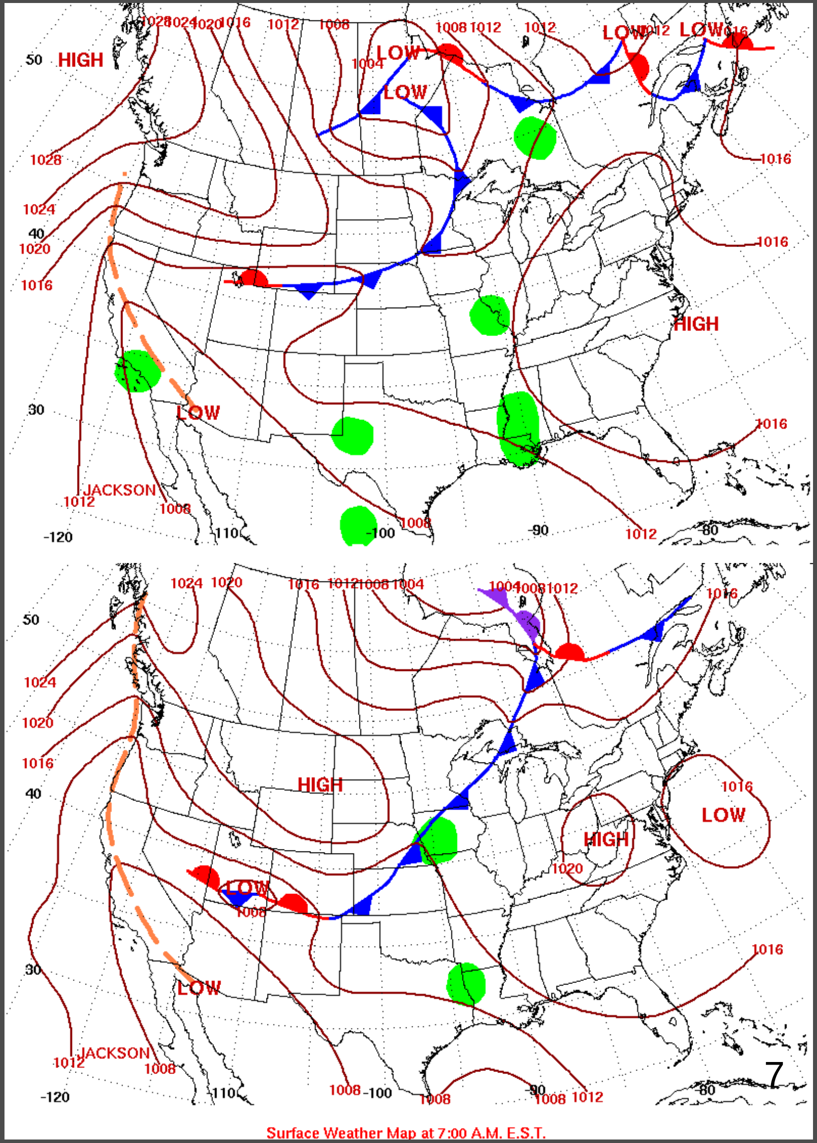


Model Domains

Synoptic Conditions during 4,6 & 7 July 2010 NYC heat wave



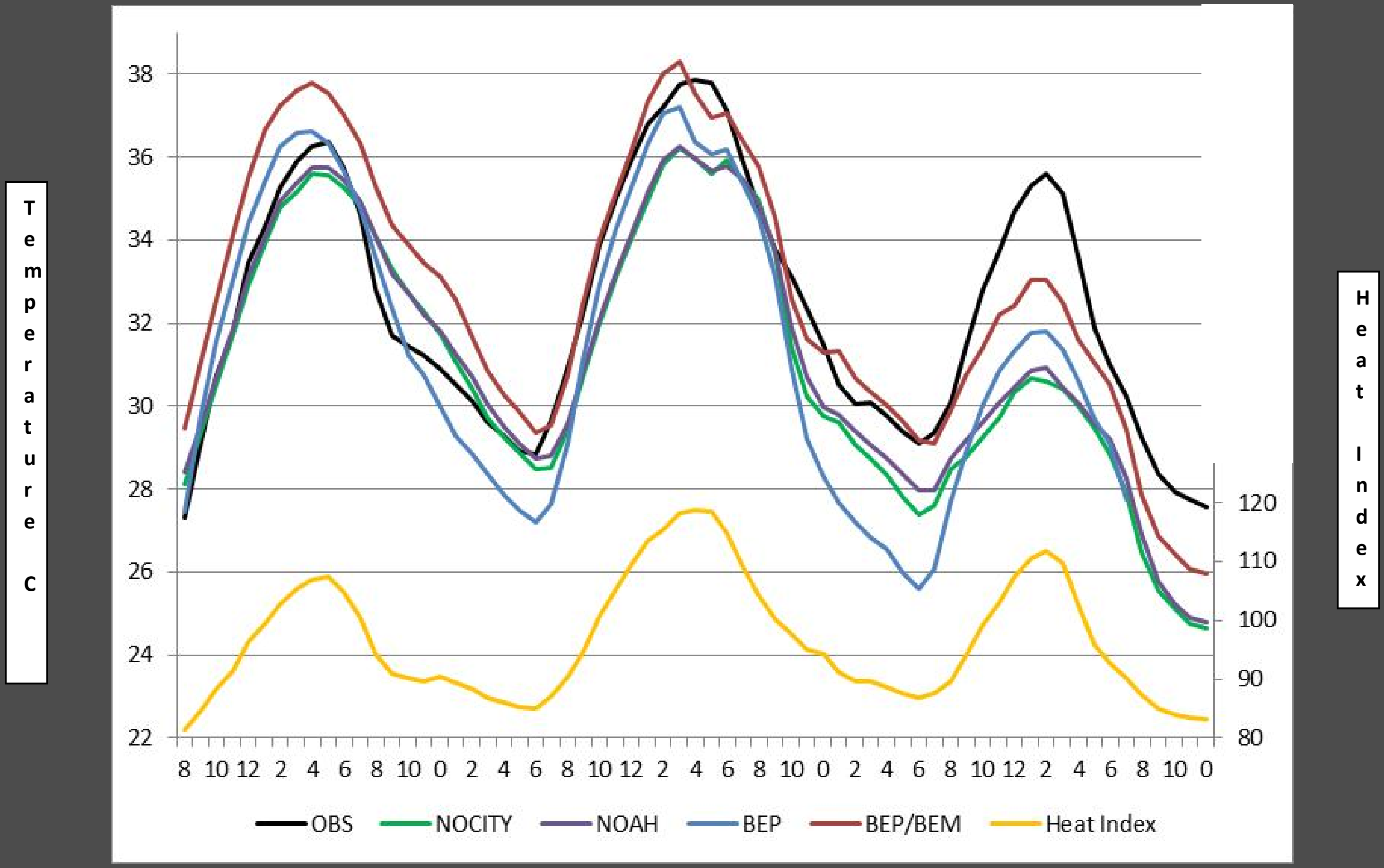
Surface Weather Map at 7:00 A.M. E.S.T.



Surface Weather Map at 7:00 A.M. E.S.T.

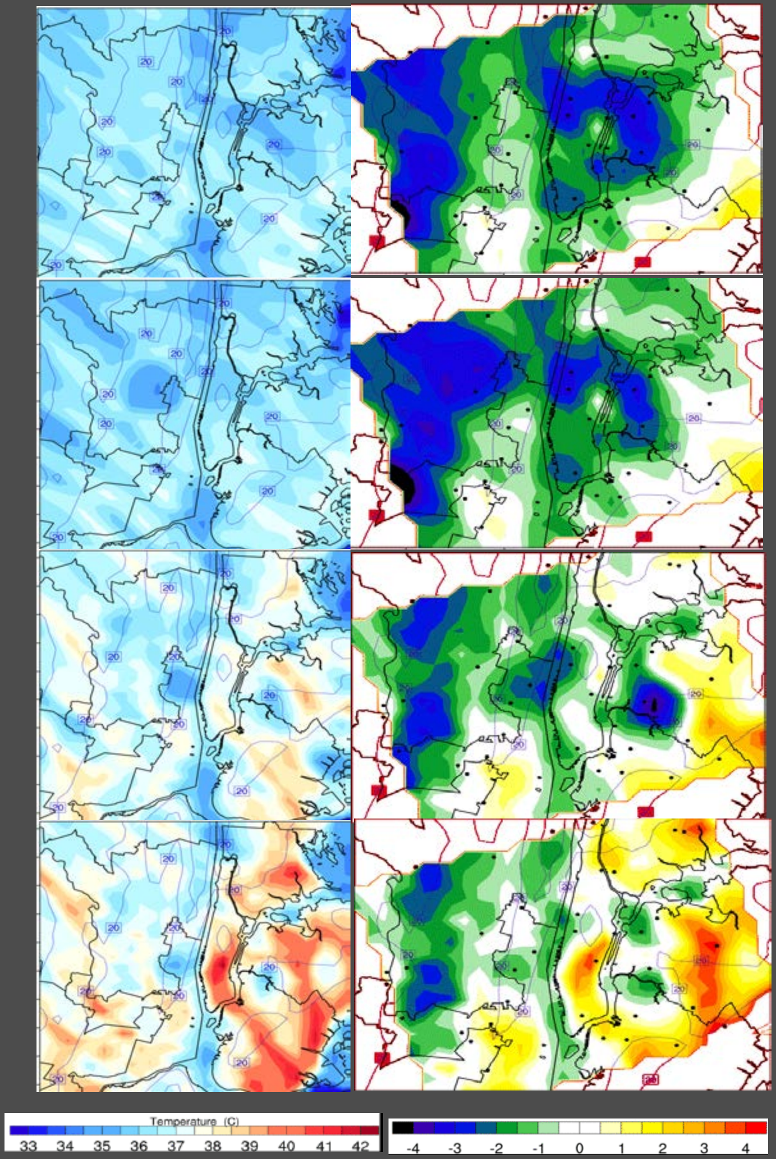
SFC High forms over VA, reaches peak on 4th
& remains until 7th

SFC temperatures at downtown Manhattan during heat-wave event July 2010

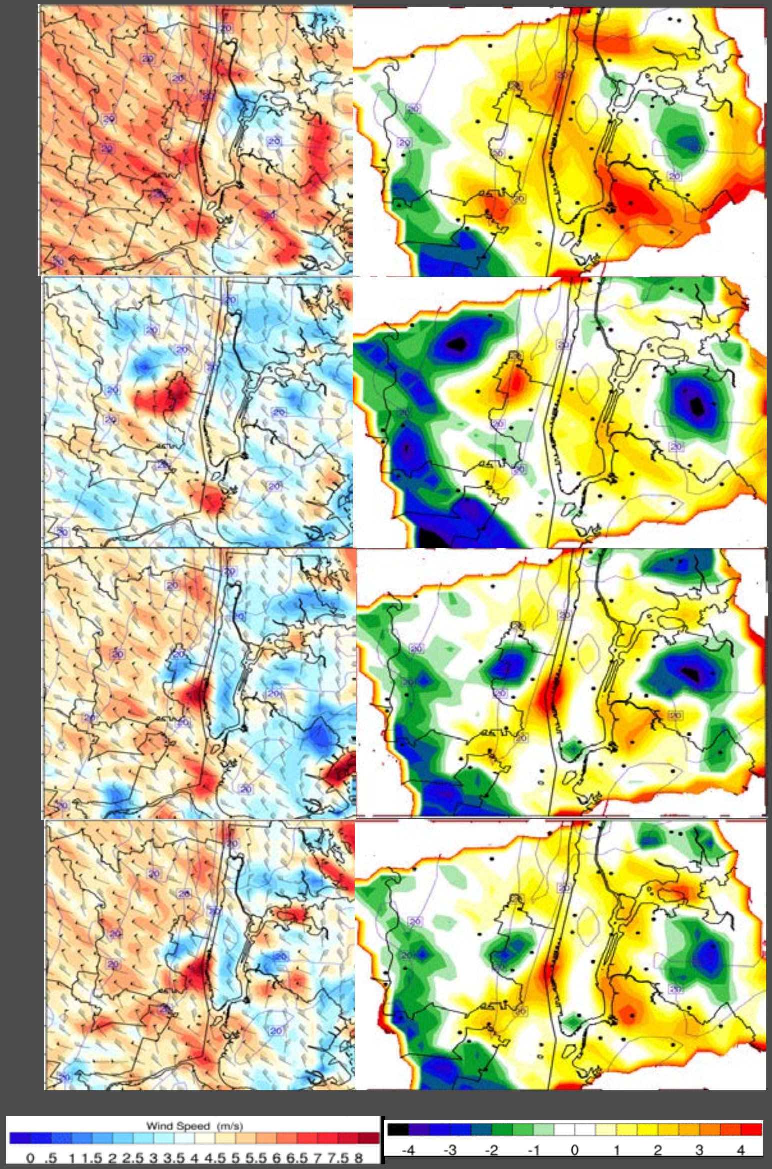


Heat Wave Results (Surface Parameters Errors)

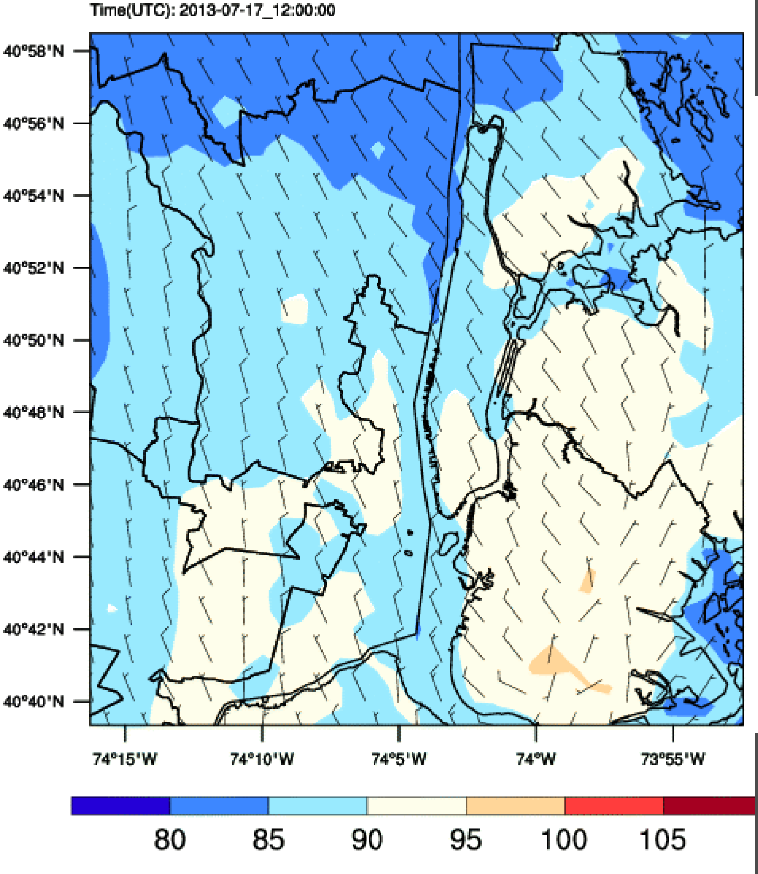
Temperature 3 PM

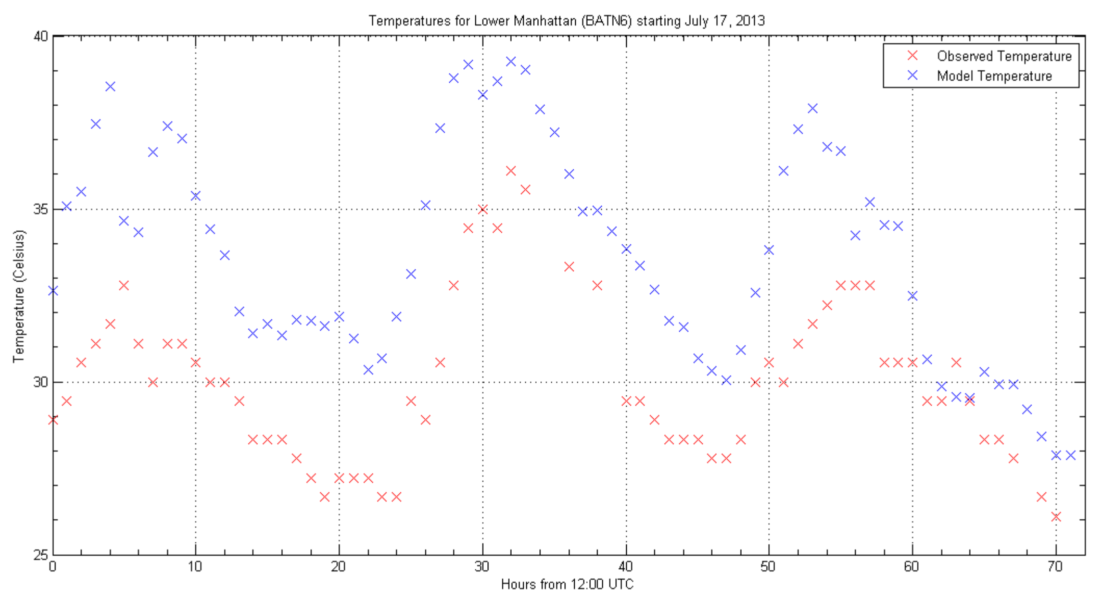


Wind Speed 3 PM

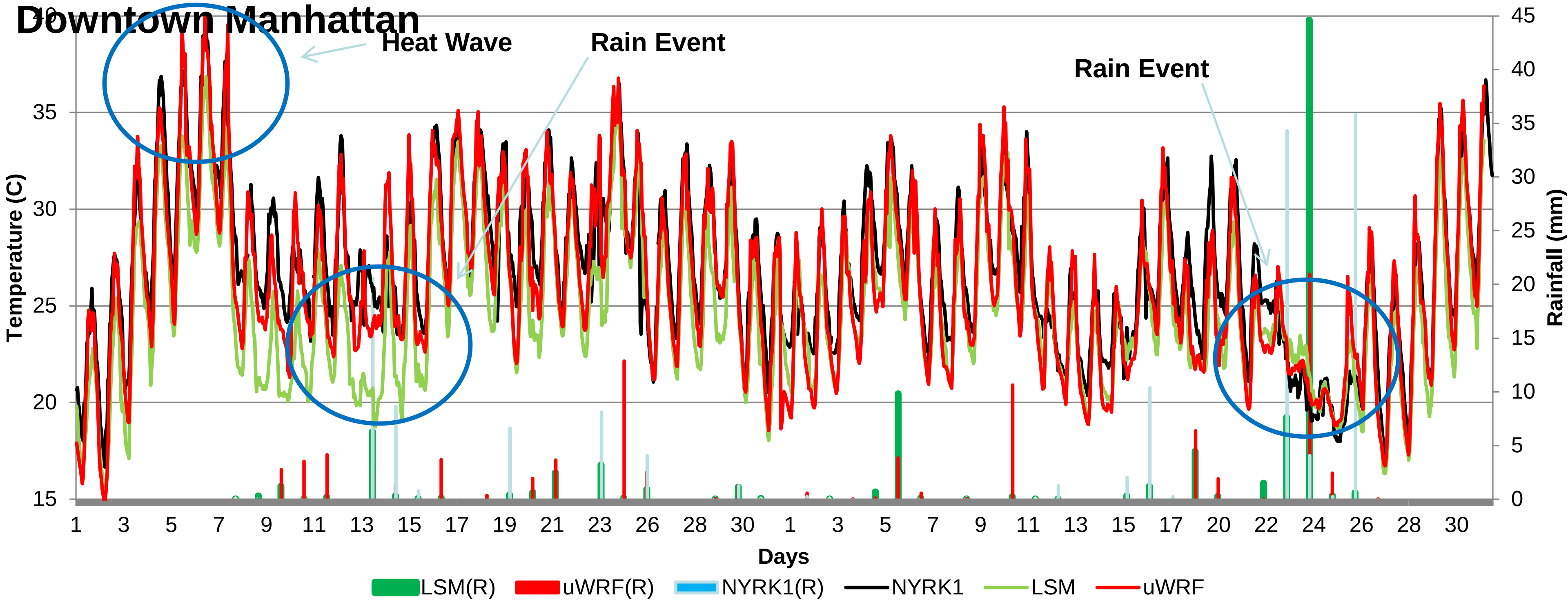


Heat Wave July 2013

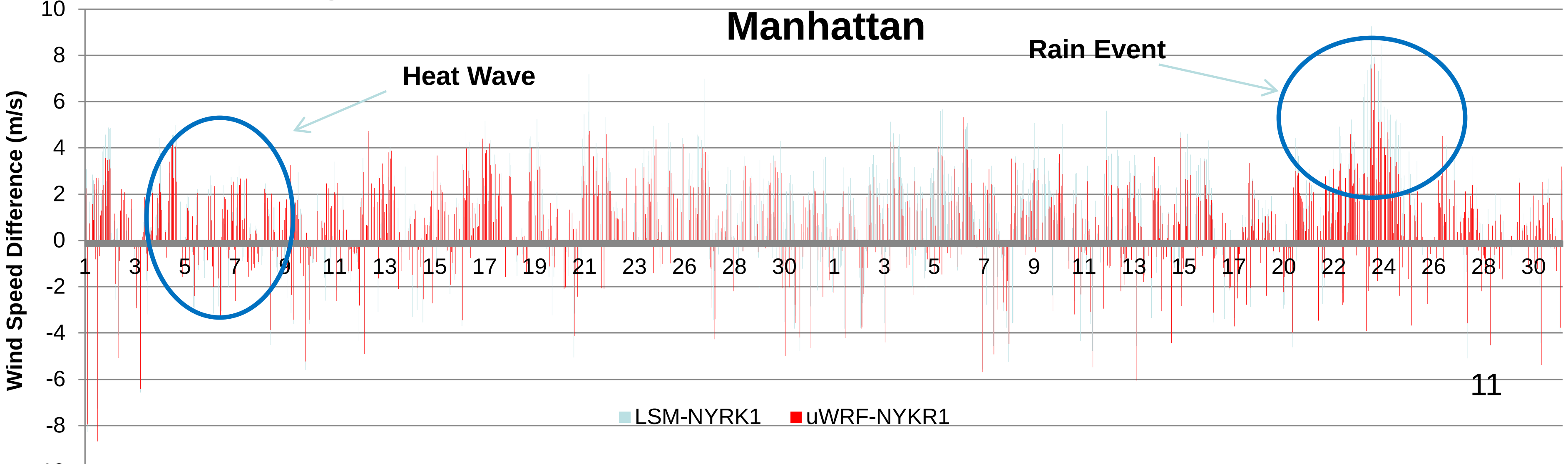




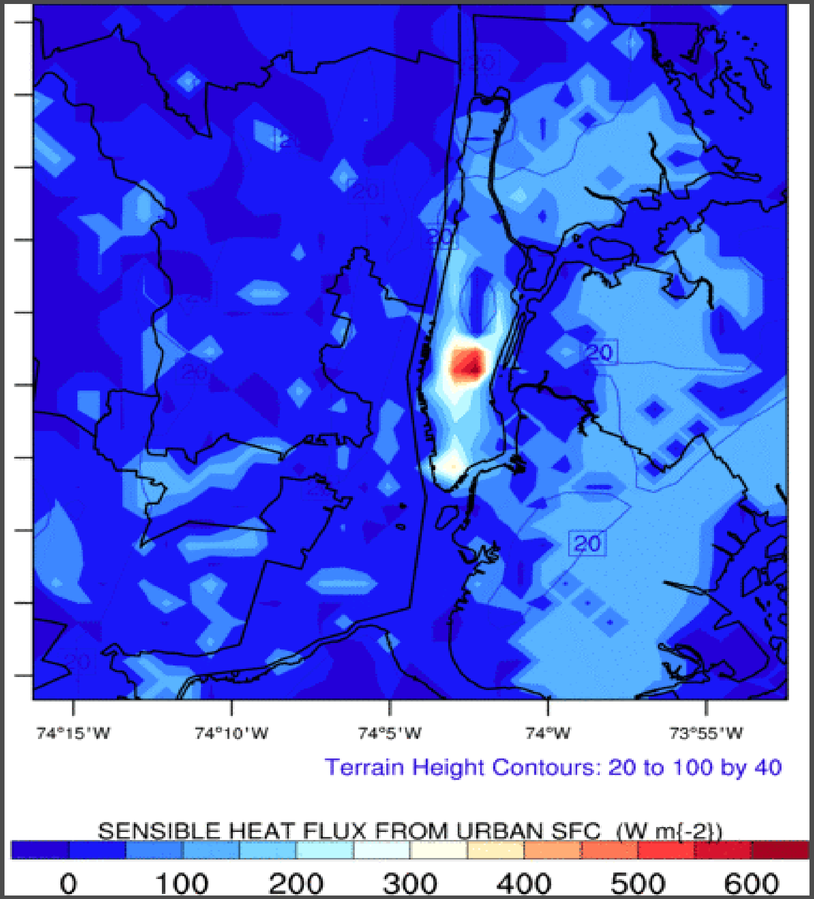
July & August Hourly Surface Temperature (C) and Daily Rainfall (mm) at Downtown Manhattan

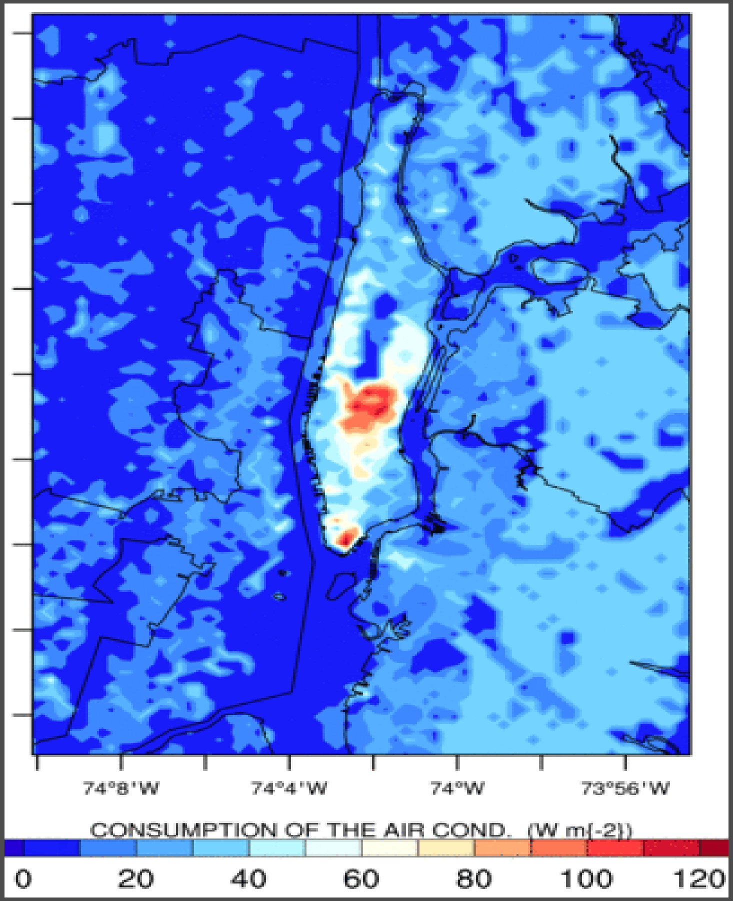


July & August Hourly Surface Wind Speed Difference (m/s) at Downtown Manhattan



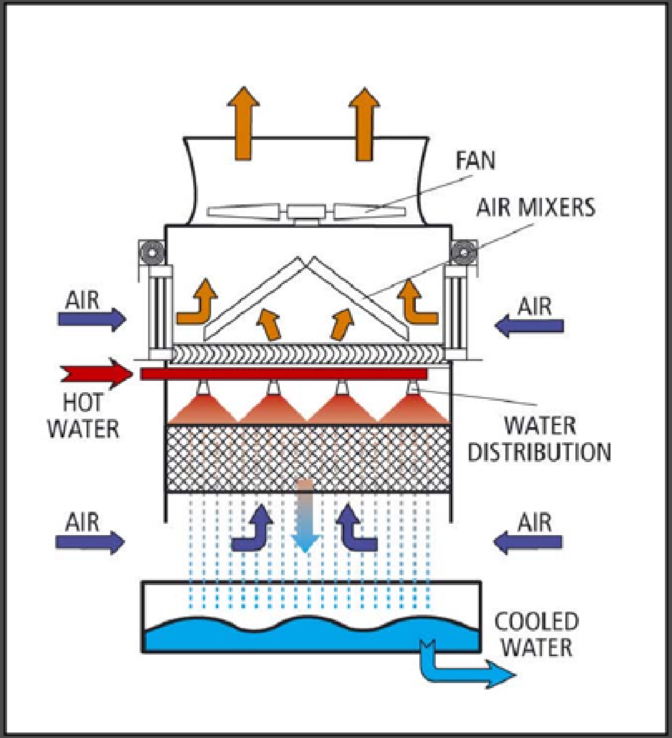
Sensible Heat Flux and A/C Consumption



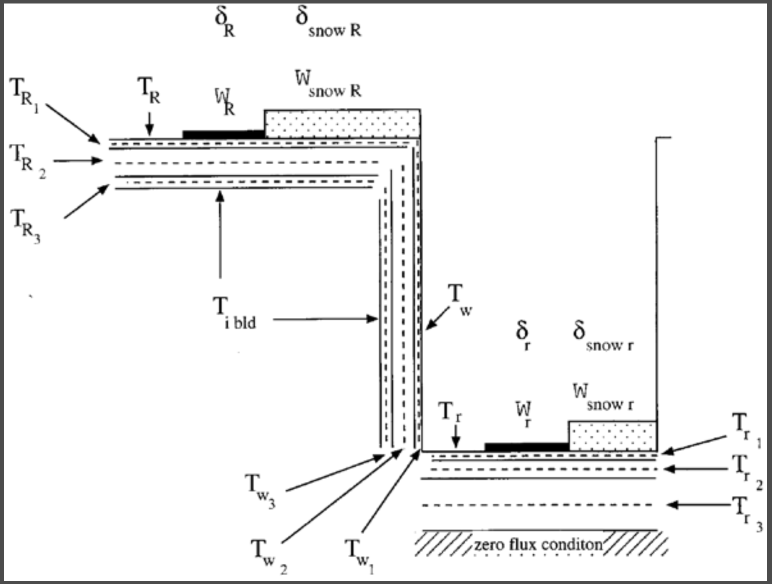


Model Improvements

- Cooling Tower Model:
  - Latent heat release by cooling towers at commercial buildings.

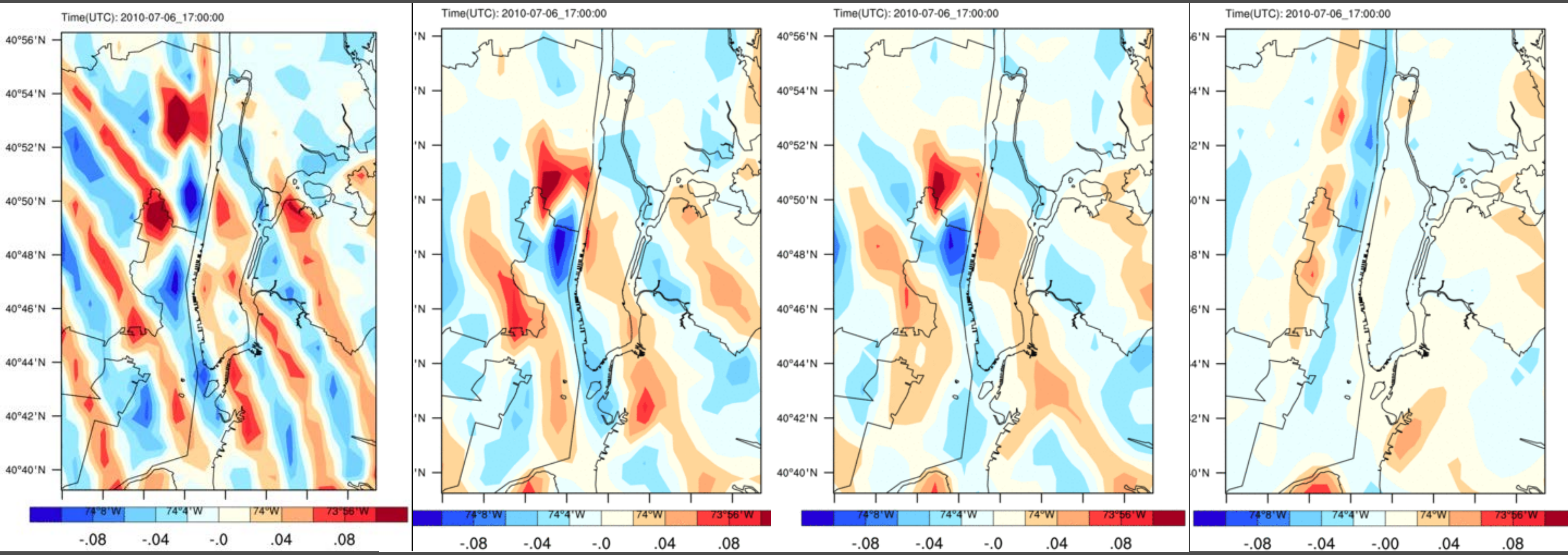


- Water Reservoir:
  - Latent heat from evaporation in roofs and streets (Masson, 2000)



Vertical Velocity at z= 12 m on 07/06/10 at 13 EST for **Δt=6,** 1, 0.66, & 0.11 s

Rolls tend to dissipate when Δt is decreased. A Δt of 0.11 s represents 1/54 the recommended value. WRF developers recommend a Δt of 6Δx for course domain, then reductions of 3 for each finer nest



Run 3: Δt=6 s **Run 4: Δt=1 s** **Run 5: Δt=0.66 s** **Run 6: Δt=0.11 s**

SUMMARY & CONCLUSIONS

- BEP(Table)+BEM and BEP(NUDAPT)+BEM improve the simulation of surface temperature with respect to Bulk scheme.

- The drag effect of the buildings is captured by BEP with a decrease of the wind speed over Manhattan. A better representation of the city’s morphology using the NUDAPT information improves the spatial representation of the surface temperature.

- Extreme heat events (e.g. heat waves) are represented well by (BEP+NUDAPT+BEM), not so for summer precipitation events. Further research is needed to improve water balance at the surface

- Surface temperature simulations over the suburban regions is an area to improve. Solving this issue is essential in order to have an accurate representation of the UHI over NYC

- The temperature spatial distribution shows the presence of convective rolls vortices. Further investigation is needed to determine if the vortices are formed due to numerical instabilities.

ACKNOWLEDGEMENTS

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