Contribution to:

HARMO13: 13TH International Conference on Harmonization within Atmospheric Dispersion Modelling for Regulatory Purposes

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URBAN METBOLISM: MICROSCALE ENERGY SIMULATIONS IN DIFFERENT EUROPEAN CITIES BY USING WRF-UCM AND EULAG MODELS

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URBAN METABOLISM

❑Urban Metabolism is a model to facilitate the description and analysis of the flows of the materials and energy within cities, such as undertaken in a Material flow analysis of a city

❑An urban metabolism analysis is a means of quantifying the overall fluxes of energy, water, material and wastes into and out of an urban region.

❑The urban metabolism provides comprehensive information about the health of a city: energy efficiency, material cycling, waste management and effectiveness of infrastructure.

❑Comparisons between cities show how factors such as urban form, groundwater withdrawals, urban heat islands, nutrient cycles and material supplies impact the urban metabolism.

- In this contribution we will use the WRF/UCM model Combined with several satellite datasets to obtain high Resolution Energy flux maps over Five different cities In BRIDGE EU project: London, Helsinki, Gliwice, Florence and Athens

- In addition we will use the WRF/UCM results with 0.2 km Spatial resolution as BC's and IC's for MICROSYS/EULAF/CFD Model simulations with 4 m spatial resolution for a period Of 6 minutes over a domain of 1 km x 1 km.

- City energy fluxes and vegetation fluxes (NOAA) have been Implemented into the EULAG model (UCAR, US)

MODELS. WRF. UM-UPM

WRF : Next generation mesoscale meteorological model.

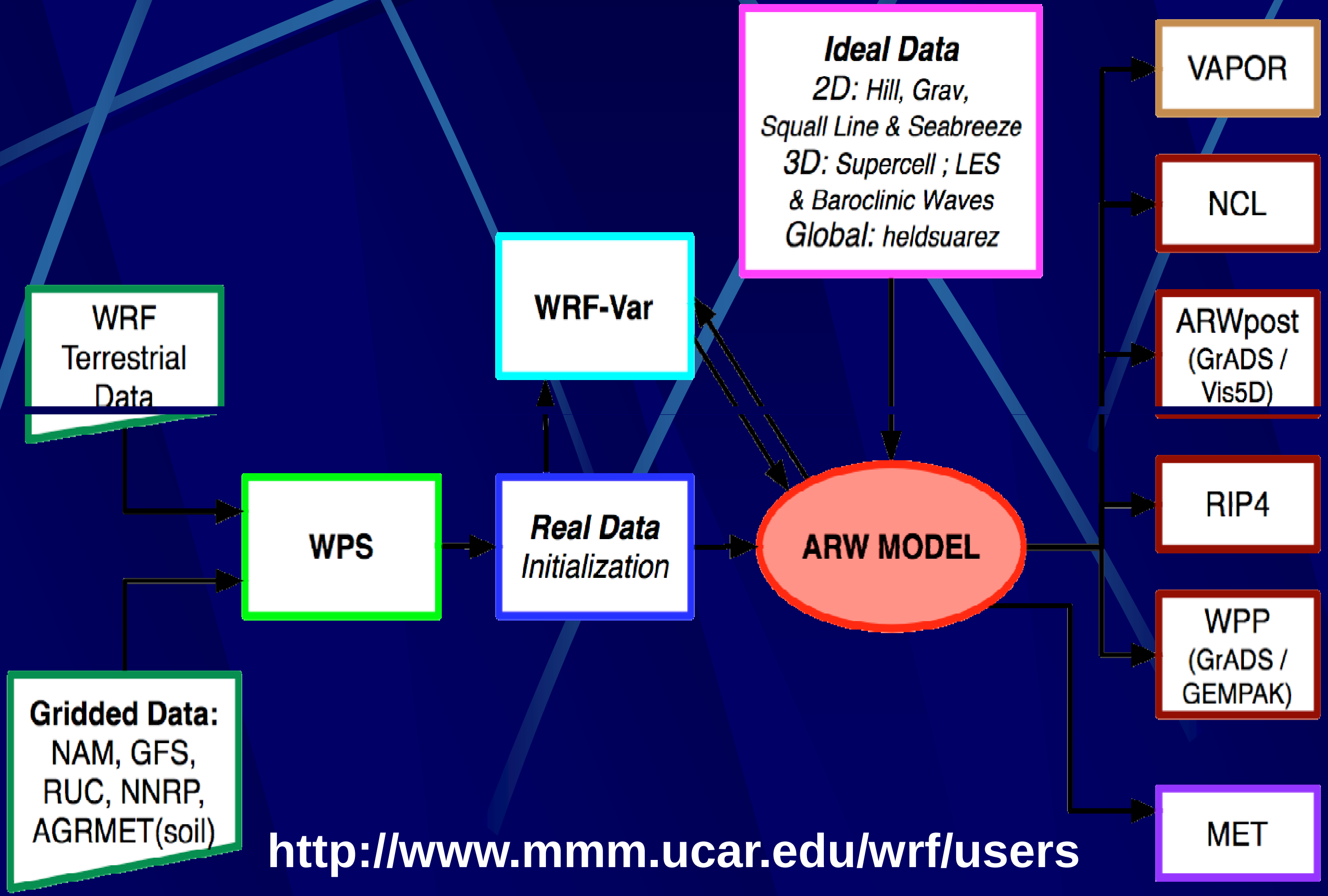
The equation set is fully compressible, Eulerian and nonhydrostatic. It is conservative for scalar variables. The model uses terrain-following, hydrostatic-pressure vertical coordinate with the top of the model being a constant pressure surface.

The horizontal grid is the Arakawa-C grid. The time integration scheme in the model uses the third-order Runge-Kutta scheme, and the spatial discretization employs 2nd to 6th order schemes

(Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Wang, W., Powers, J.G., 2005. A description of the advanced research WRF version 2, NCAR Technical Note. National Center for Atmospheric Research, Boulder, CONCAR/TN-468+STR, 100pp.)

MODELS. WRF (ARW). UM-UPM

WRF : Weather Research and Forecasting modeling system.



http://www.mmm.ucar.edu/wrf/users

MODELS. WRF. UM-UPM

-**Physics Options used in WRF-UM**:

- Cumulus Parameterization:

GRELL-DEVENYI ENSEMBLE SCHEME (Grell, G. A., and D. Devenyi, 2002: A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. Geophys. Res. Lett., **29(14),** Article 1693.**)**

- PBL Scheme and Diffusion:

Yonsei University (*YSU) PBL* (Hong, S.-Y., Dudhia, J., 2003. Testing of a new non-local boundary layer vertical diffusion scheme in numerical weather prediction applications. In: Proceedings of the 16th Conference on Numerical Weather Prediction, Seattle, WA. **)**

- Explicit Moisture Scheme :

LIN et al. scheme microphysics (Lin, Y.L., R. D. Farley, and H. D. Orville, 1983: Bulk parameterization of the snow field in a cloud model. J. Appl. Meteor., **22,** 1065-1092 **)**

- Radiation Schemes:

Rapid Radiative Transfer Model (RRTM) longwave radiation *(E.J. Mlawer, S.J. Taubman, P.D. Brown, M.J. Iacono and S.A. Clough, Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave, J. Geophys. Res.* ***102*** *(D14) (1997), pp. 16663–16682* **)**

Simple cloud-interactive shortwave radiation scheme *Dudhia radiation (* Dudhia, Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional Model, *J. Atmos. Sci.* **46** (1989), pp. 3077–3107**)**

BRIDGE UPM MODELS

SIMULATION DOMAINS. BRIDGE ARCHITECTURE-UPM

Projection: Lambert Conformal Conic

MOTHER DOMAIN

59*59 grid cells

48.6 km. resolution

Lowert left corner (-1433700, -1433700)

DT:300 s.

LEVEL 1:

37*37 grid cells

5.4 km. resolution

Lowert left corner

(-121500, -121500)

DT: 30 s.

LEVEL 2:

28*28 grid cells

0.2 km. resolution

Lowert left corner

(-2700, -2700)

DT: 0.6 s.

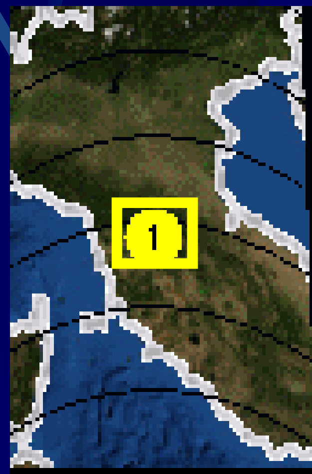
- Global model data: GFS
- One way nesting (two way only tests. Much more CPU time)

DOMAINS. FLORENCE-UPM

Lambert Conformal Conic (11.2436, 43.775)

MOTHER DOMAIN

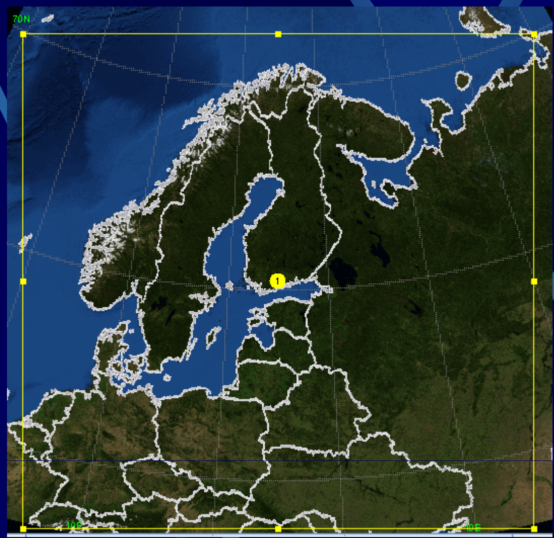
LEVEL 1 DOMAIN



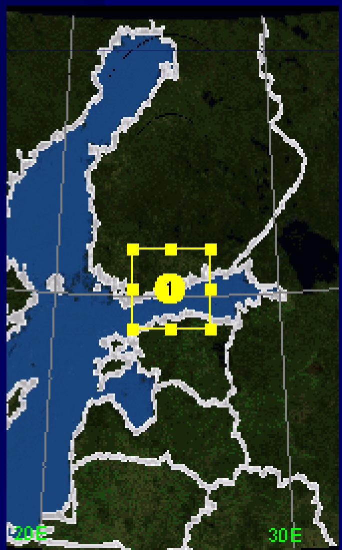
LEVEL 2 DOMAIN

DOMAINS. HELSINKI-UPM

Lambert Conformal Conic (25.1045, 60.1996)



MOTHER DOMAIN

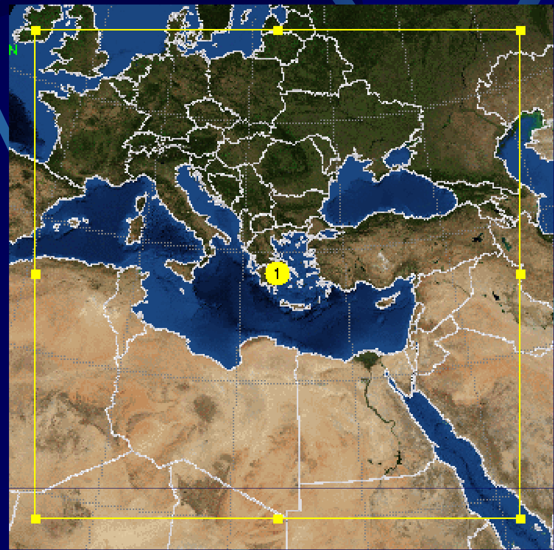


LEVEL 1 DOMAIN

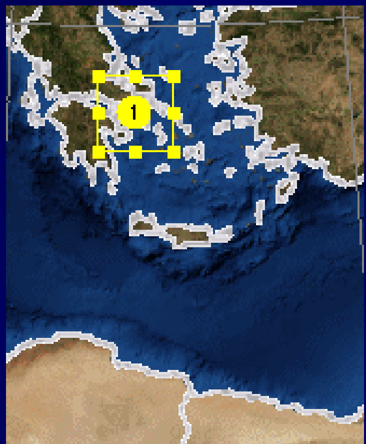
LEVEL 2 DOMAIN

DOMAINS. ATHENS-UPM

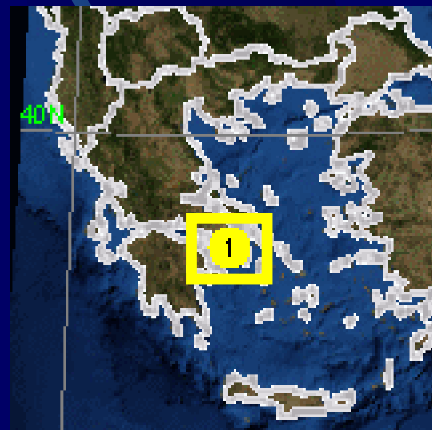
Lambert Conformal Conic (23.6782, 37.9922)



MOTHER DOMAIN



LEVEL 1 DOMAIN

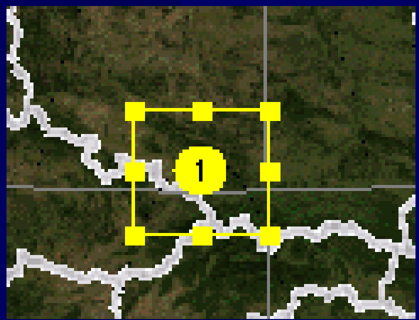


LEVEL 2 DOMAIN

DOMAINS. GLIWICE-UPM

Lambert Conformal Conic (18.6827, 50.2892)

MOTHER DOMAIN

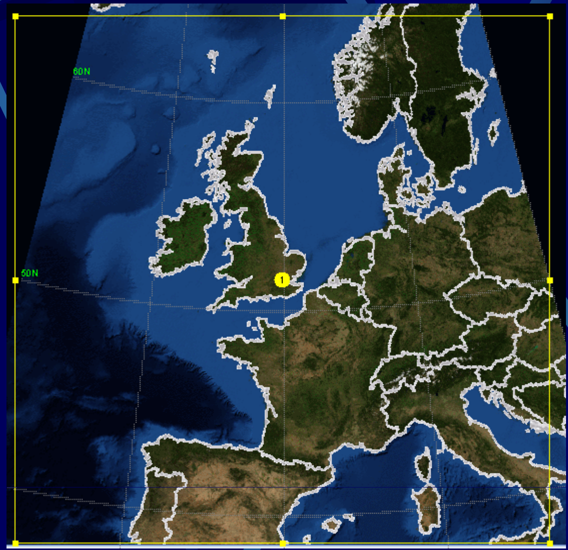


LEVEL 1 DOMAIN

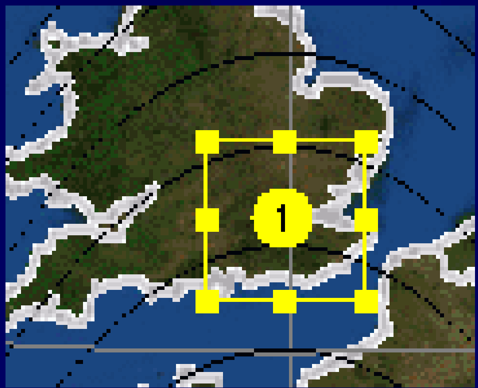
LEVEL 2 DOMAIN

DOMAINS. LONDON-UPM

Lambert Conformal Conic (-0.1262, 51.5004)



MOTHER DOMAIN



LEVEL 1 DOMAIN

LEVEL 2 DOMAIN

WRF/NOAH/UCM. UPM

-**Physics Options used in WRF**:

• Cumulus Parameterization:

GRELL-DEVENYI ENSEMBLE SCHEME (Grell, G. A., and D. Devenyi, 2002: A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. Geophys. Res. Lett., **29(14),** Article 1693. **)**

• PBL Scheme and Diffusion:

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WRF/NOAH/UCM. UPM

-**Physics Options used in WRF-UHI**:

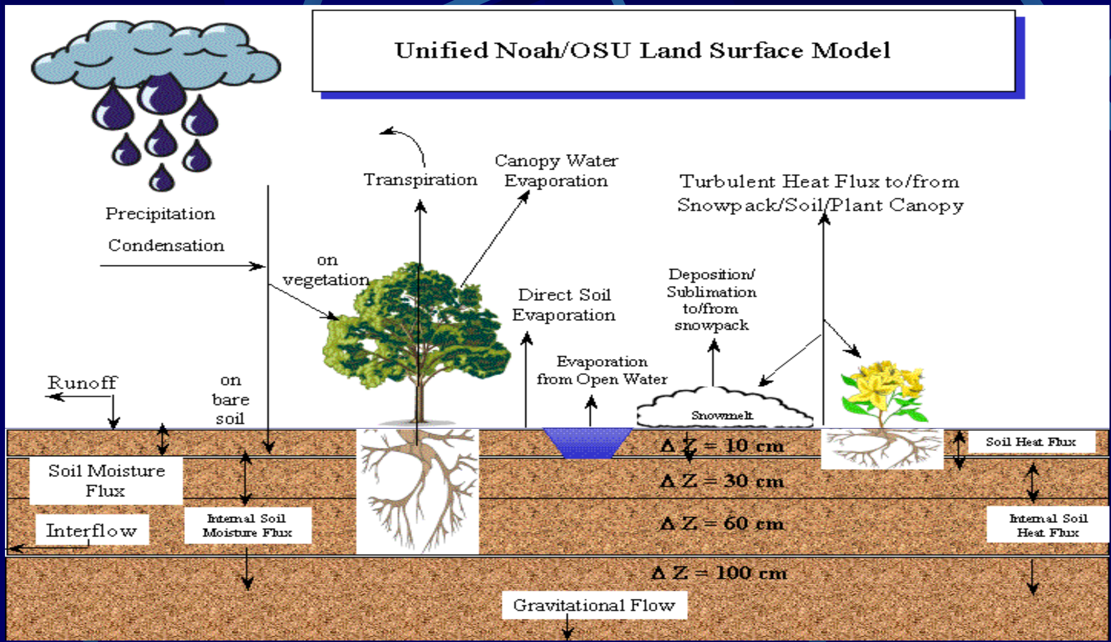
•Radiation Schemes:

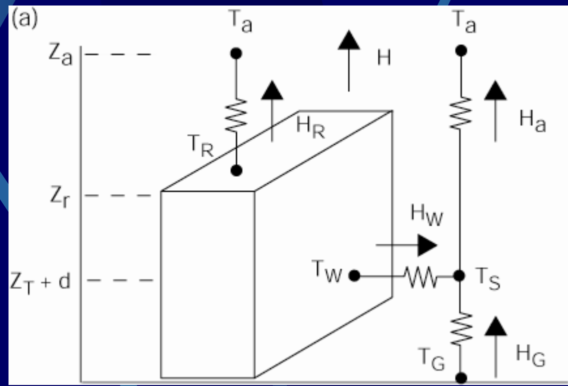
Rapid Radiative Transfer Model (RRTM) longwave radiation *(E.J. Mlawer, S.J. Taubman, P.D. Brown, M.J. Iacono and S.A. Clough, Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave, J. Geophys. Res.* ***102*** *(D14) (1997), pp. 16663–16682* **)**

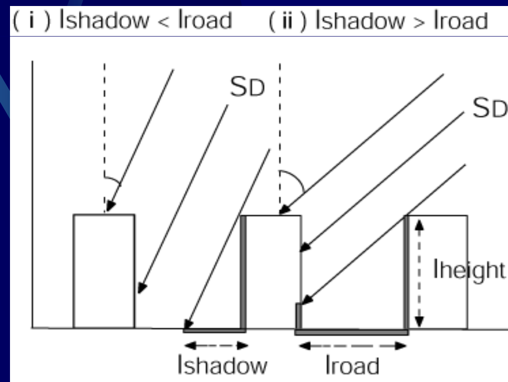
Simple cloud-interactive shortwave radiation scheme Dudhia *radiation (* Dudhia, Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional Model, *J. Atmos. Sci.* **46** (1989), pp. 3077–3107**)**

WRF/NOAH/UCM. UPM

Land surface model: NOAH/UCM (ucm only 0.2 Km resolution)



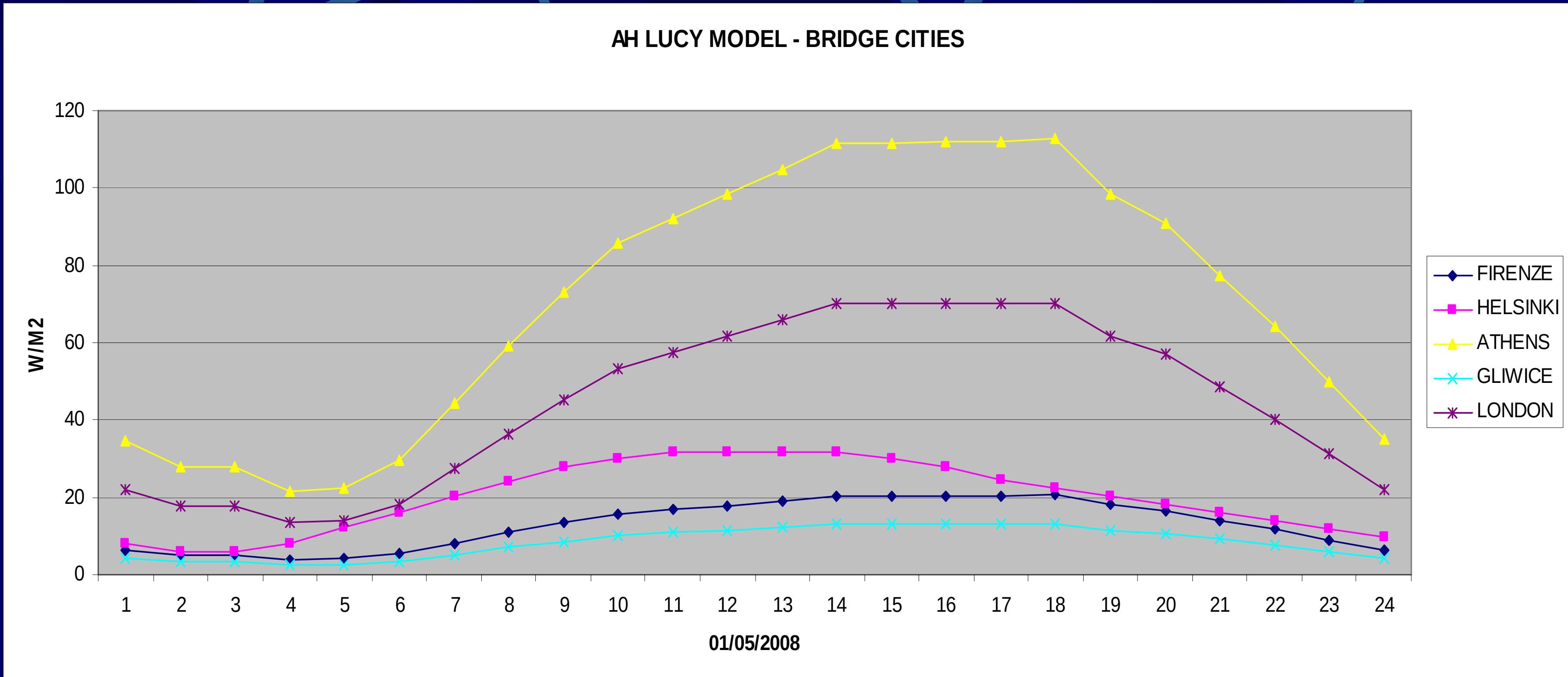




(Chen, F., Kusaka, H., Tewari, M., Bao, J.-W., Kirakuchi, H., 2004. Utilizing the coupled WRF/LSM/Urban modeling system with detailed urban classification to simulate the urban heat island phenomena over the greater Houston area. In: Proceedings of the 5th Conference on Urban Environment, 22–26 August 2004, Vancouver, BC, Canada.)

INPUT DATA. ANTHROPOGENIC HEAT FLUX

AH LUCY MODEL (KCL, Sue Grimmond): Res 0.04167º. Selected Avg speed: 24 km/h



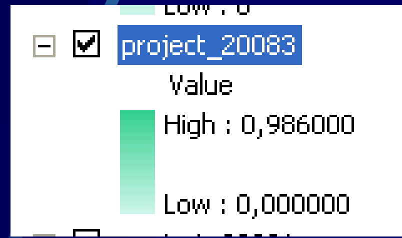
URBAN AREAS: SH (final) = SH (noah/ucm model) + AH (LUCY model)

SH: Sensible heat flux (w/m2)

INPUT DATA. EMISSIVITY

EMISSIVITY SOURCE DATA (FORTH) : GEOTIFF from MODIS

- 1*1 Km. res. 65*65 Km area
- Image each 16 days (Summer 2008)
- No data values because of clouds

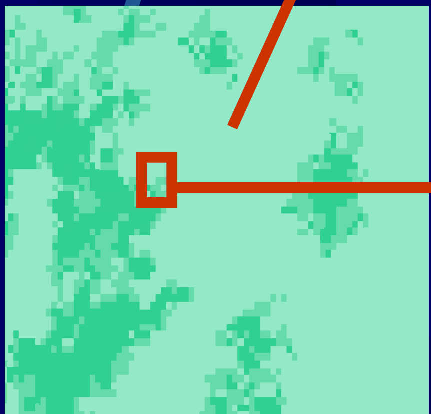


-Projection from Lat-Lon to Lambert Conformal Conic

- Re-sample raster from 1Km to 200 m. resolution

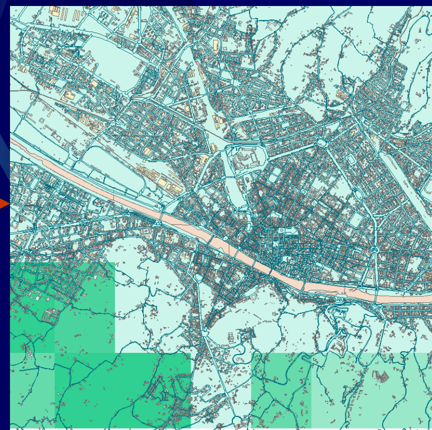
- Clip to domain area

- Average values by each model grid cell to avoid no-data values



Original data

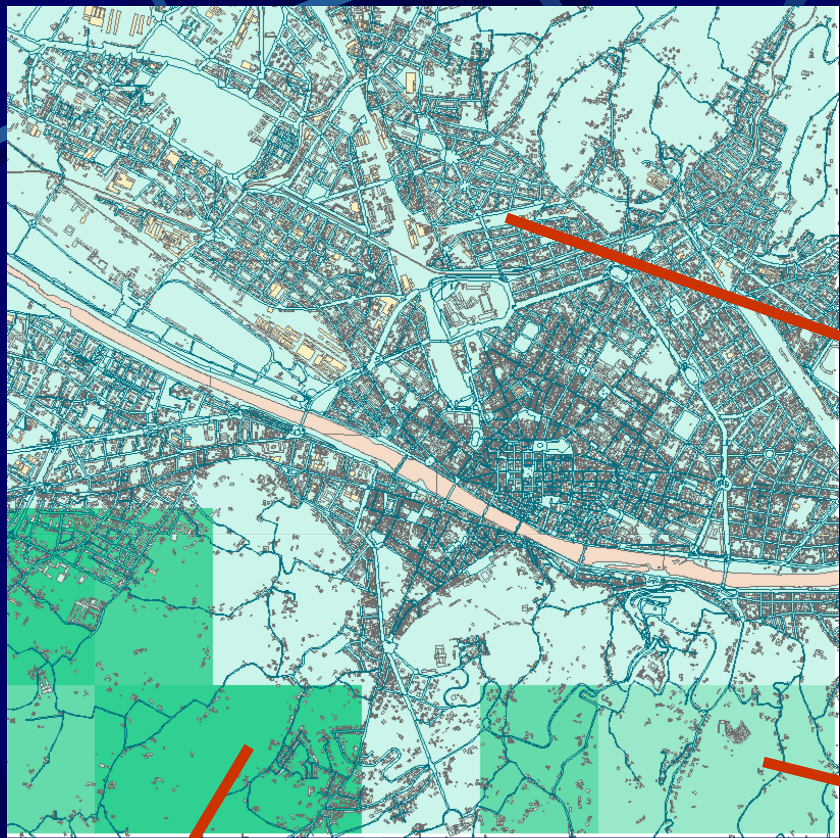
(01/05/2008)



Model input data

INPUT DATA. EMISSIVITY . FLORENCE-UPM

Domain
0.2 KM
res.



Urban area = 0.973

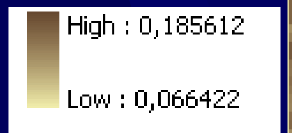
Olive groves
area = 0.975

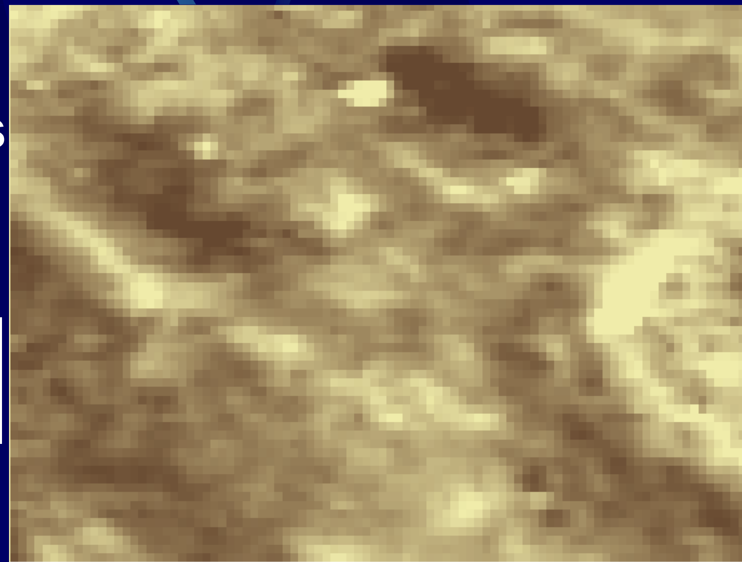
Complex cultivation patterns + Non irrigated
arable land area = 0.983

INPUT DATA. ALBEDO

ALBEDO SOURCE DATA (FORTH) : GEOTIFF from MODIS

- 1*1 Km. res. 65*65 Km area
- 1 Image each 16 days (Summer 2008)
- 3 Fixed AOT (0.1 0.5 0.9). By default we use AOT=0.5
- 10 Solar Zenith Angle (0º,10º,…..,90º) . SZA is calculated by the radiation model.
- No hourly values
- Pre-processed like emissivity maps





Albedo map

08/05/2009 AOT=0.5 SZA=40º

INPUT DATA. ALBEDO . FLORENCE-UPM

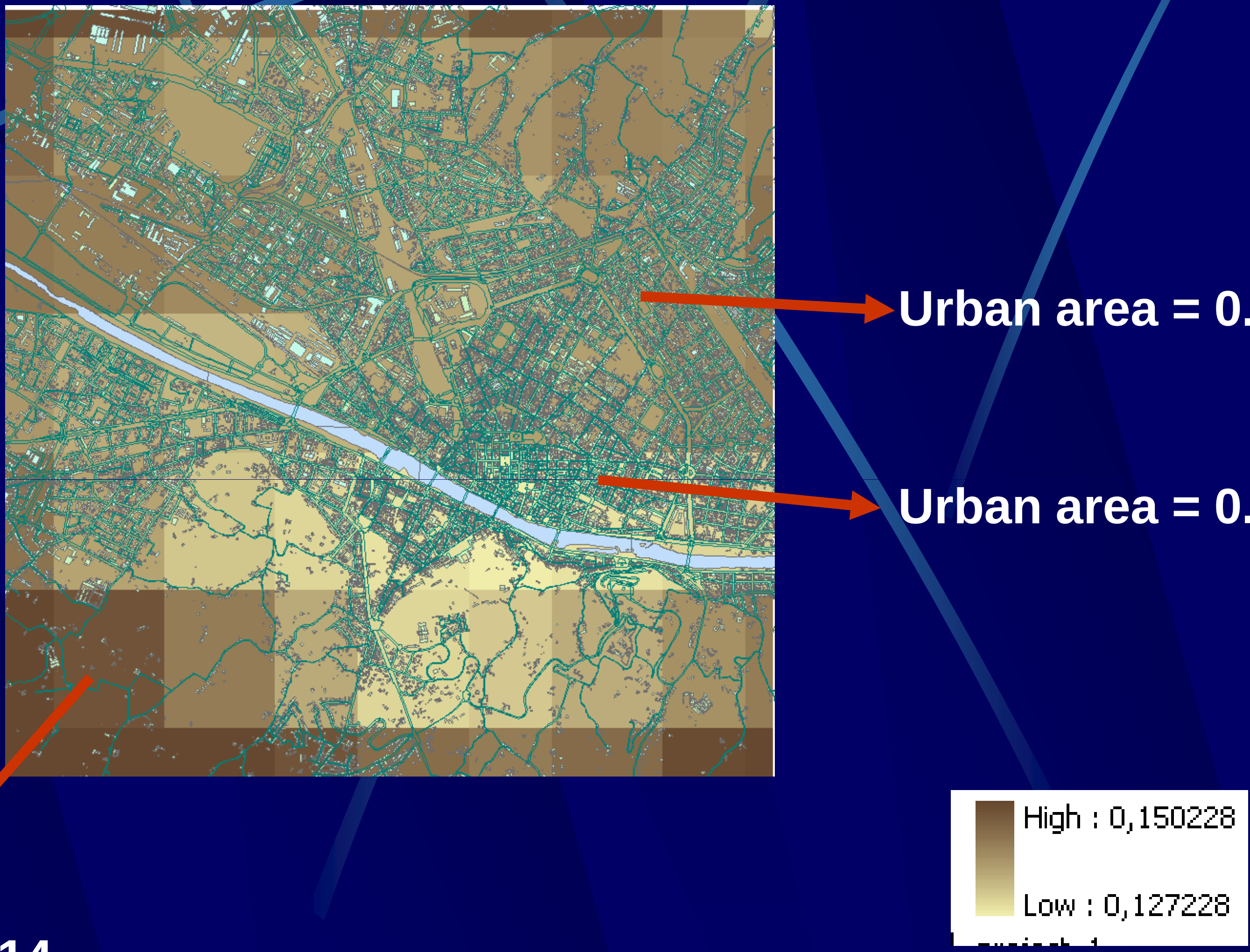
Domain
0.2 KM
res.

Albedo map

08/05/2009

AOT=0.5

SZA=40º



Urban area = 0.13

Urban area = 0.12

Rural area = 0.14

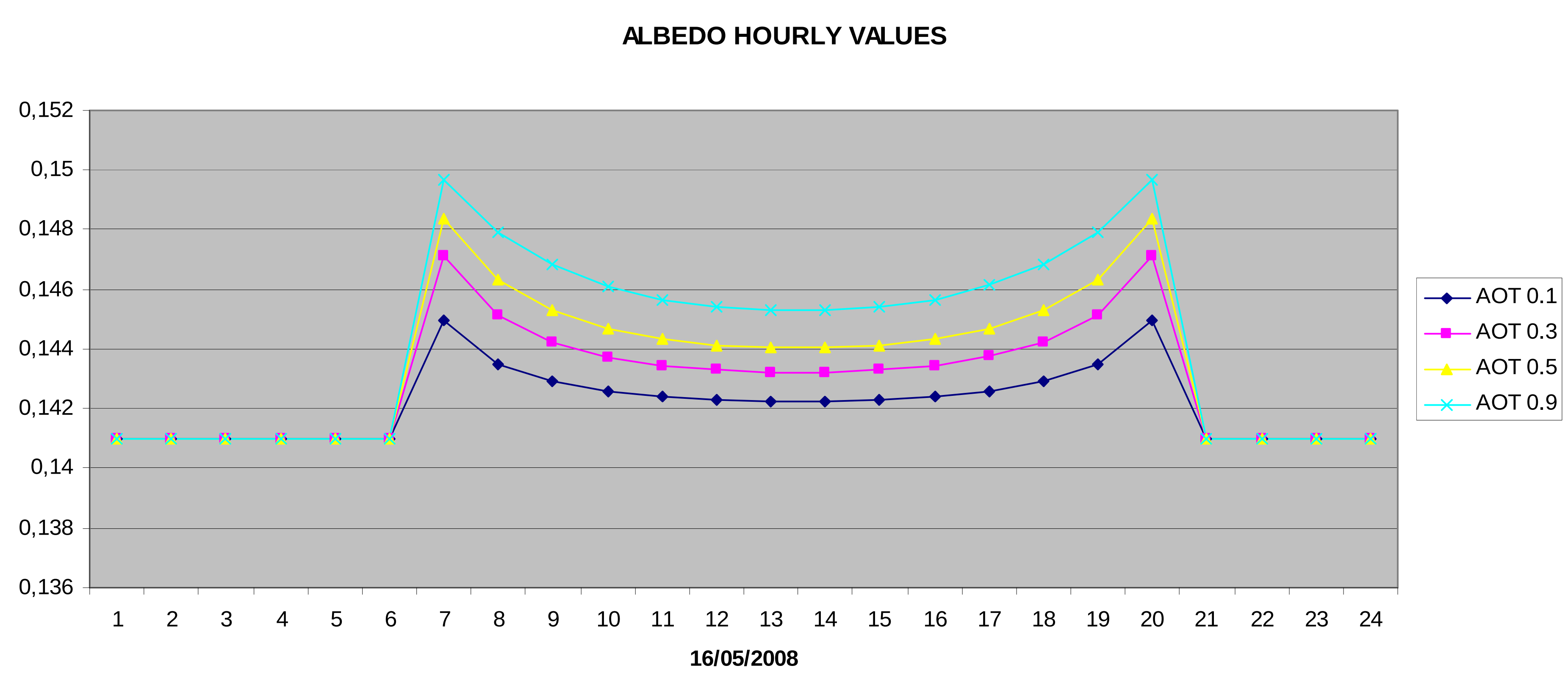
INPUT DATA. ALBEDO

ALBEDO HOURLY VALUES:

$$ALBh = (WSA*0.001) * C + (BSA * 0.001) * (1 - C)$$

- **C : FACTOR FROM A LOOKUP TABLE (continental or marine) DEFINED BY A SELECTED SZA AND AOT**
- **SZA: SOLAR ZENIT ANGLE (from radiaton model)**
- **AOT: AEROSOL OPTICAL DEPTH (under go investigation to apply different relationships between AOT and particles)**
- **BSA: BLACK-SKY ALBEDO VALUE (from MODIS images)**
- **WSA: WHITE-SKY ALBEDO VALUE (from MODIS images)**

INPUT DATA. ALBEDO. FLORENCE-UPM

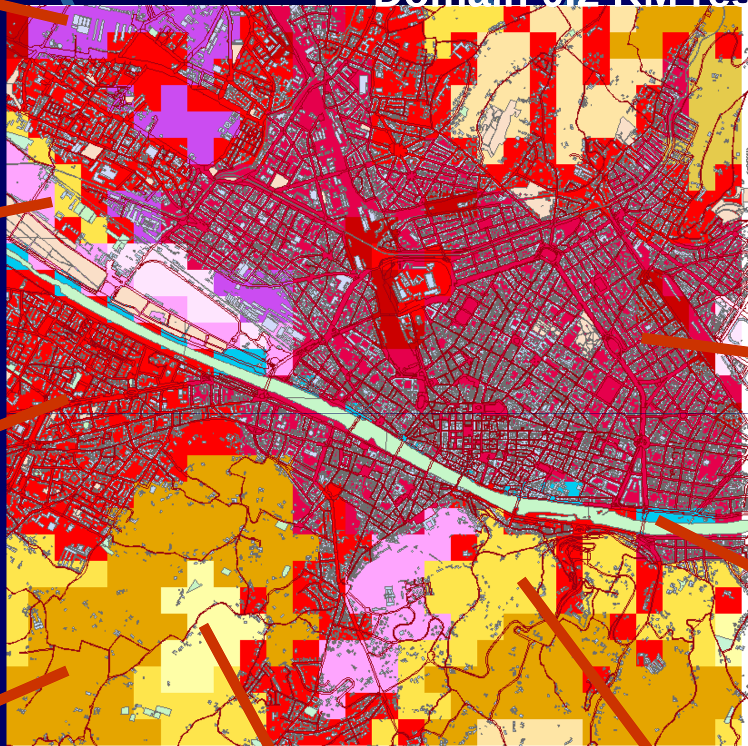


1Km * 1Km grid cell

INPUT DATA. FLORENCE-UPM

Data source: User GIS data (roads,water,gardens) + CLC1002000 (100 m. res)

Domain 0.2 KM res.



Indust. or commercial units (CLC100) →
Com/Indust/Transport urban (USGS/UCM)

Green urban area (CLC100) →
Grassland (USGS/UCM)

Discontinuous urban frabic (CLC100) →
Low density urban (USGS/UCM)

Continuous urban frabic (CLC100) →
Hight density urban (USGS/UCM)

Water courses (CLC100) →
Water bodies (USGS/UCM)

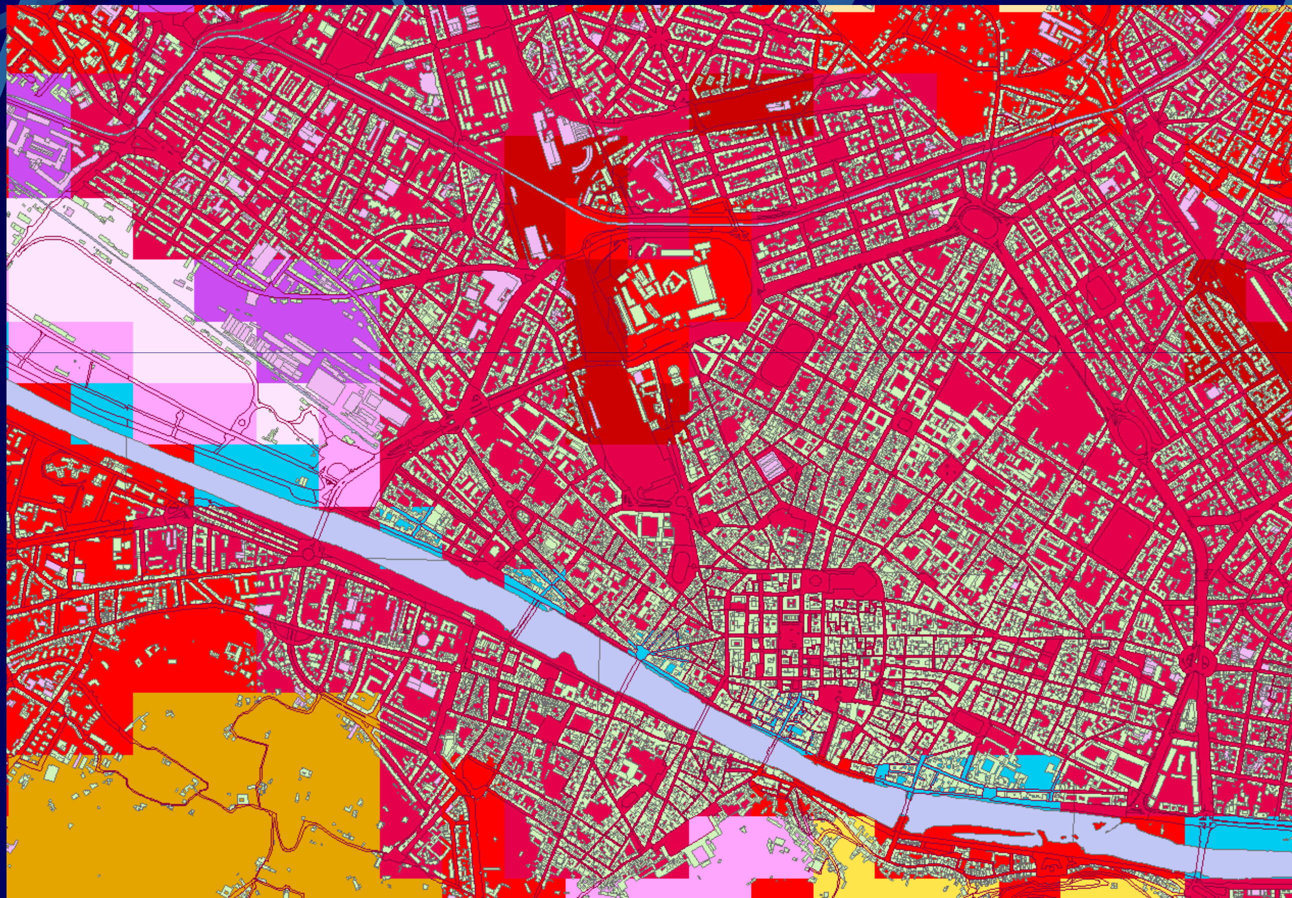
Olive groves (CLC100) →
Deciduous broadleaf forest (USGS/UCM)

Non-irrigated arable land (CLC100) →
Dryland cropland/pasture (USGS/UCM)

Complex cultivation patterns (CLC100) →
Mixed cropland/pasture (USGS/UCM)

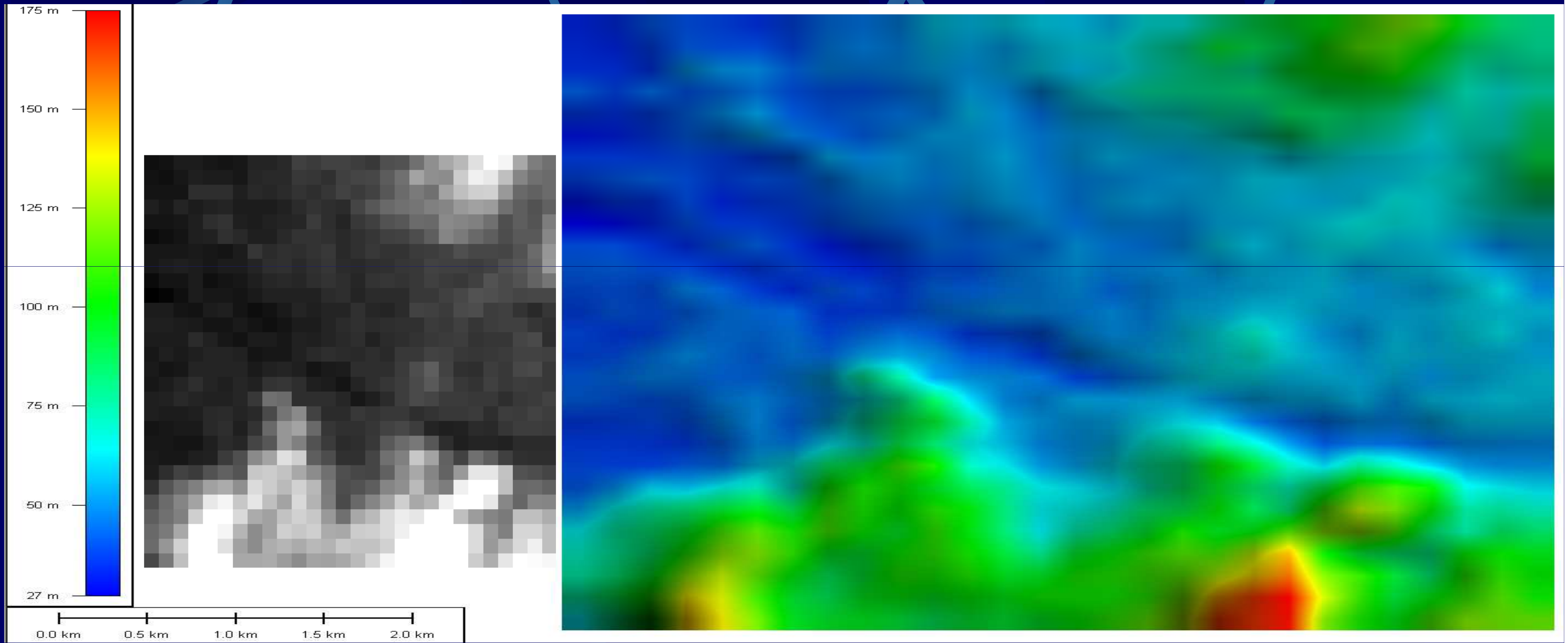
INPUT DATA. FLORENCE-UPM

ZOOM - IN: LANDUSE & BUILDINGS & ROADS



INPUT DATA. TERRAIN HEIGHT. FLORENCE-UPM

Data source: ASTER GDEM (30 m. res.) + User point GIS data
Domain 0.2 KM res.



DATA. URBAN PARAMETERS UCM. FLORENCE-UPM

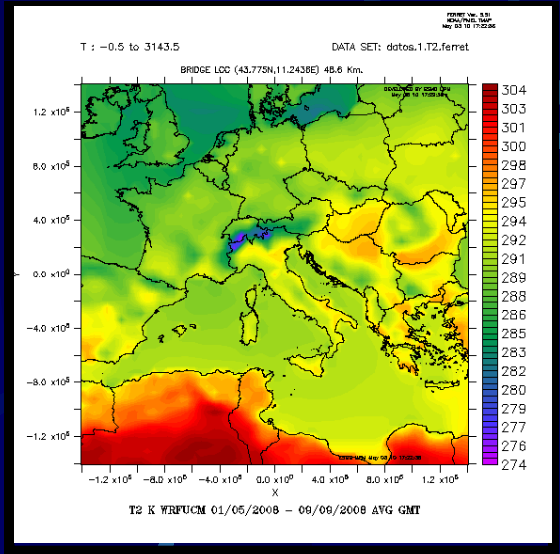
	Urban fraction	Buildings heights	Roof width	Road width
Low Intensity	**0.97**	**6.4 m.**	**19.5 m.**	**32 m.**
High intensity	**0.99**	**6.8 m.**	**19.82 m.**	**27 m.**
Commercial	**0.94**	**7.3 m.**	**22.37 m.**	**25 m.**

No data to derive the following parameters (default values):

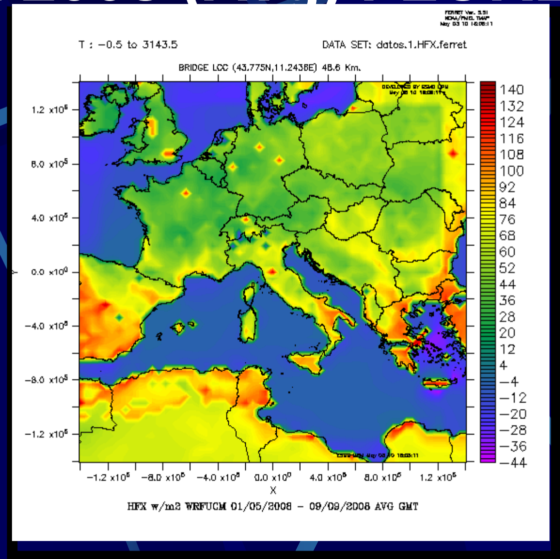
- Heat capacity (roof,road,wall)

- Thermal conductivity (roof,road,wall)

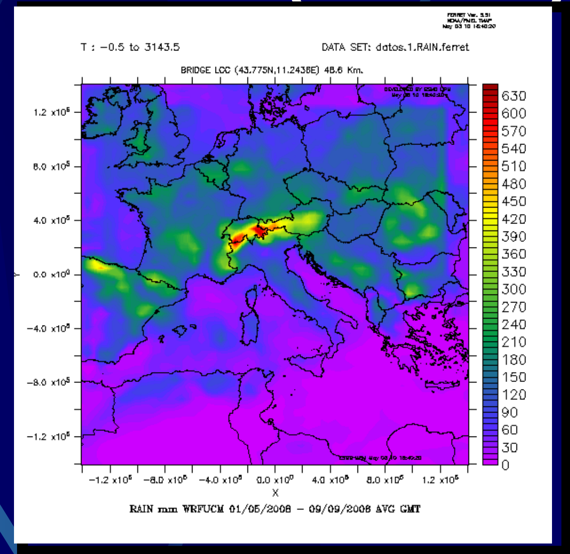
RESULTS. SUMMER 2008 (Avg) FLORENCE-UPM (48.6 KM)



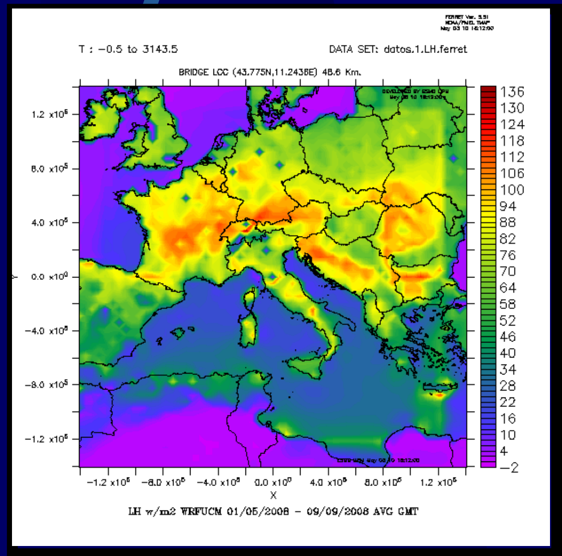
Temperature 2M (K)



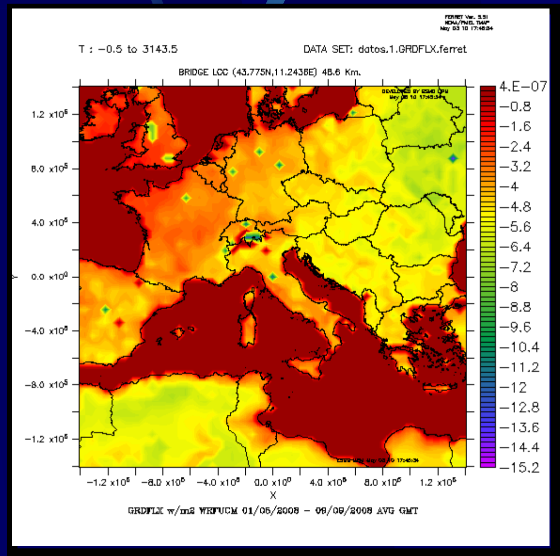
Sensible Heat Flux (w/m2)



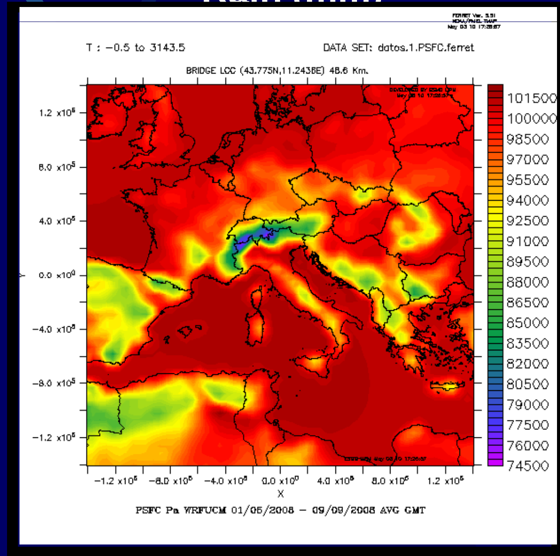
Rain (mm)



Latent Heat Flux (w/m2)



Ground Heat Flux (w/m2)

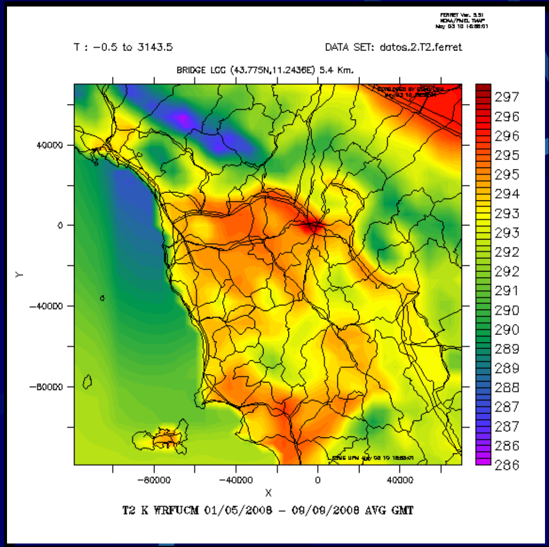


Surface Pressure (Pa)

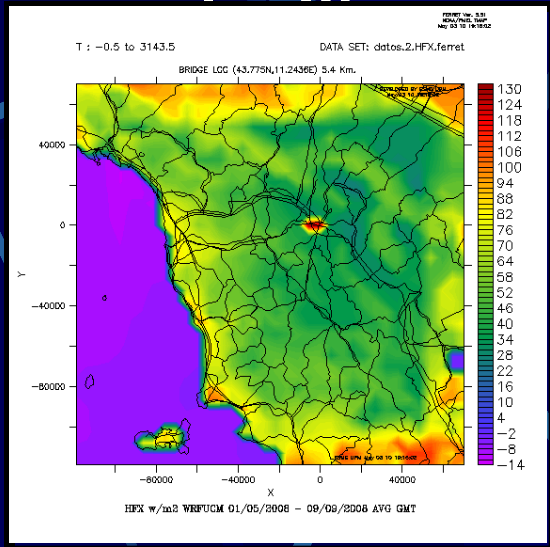
Environmental Software and Modelling Group http://artico.lma.fi.upm.es

upm UNIVERSIDAD POLITÉCNICA DE MADRID

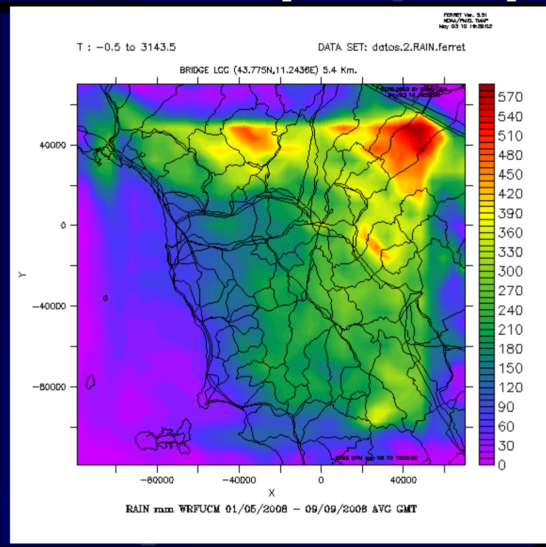
RESULTS. SUMMER 2008 (Avg) FLORENCE-UPM (5.4 KM)



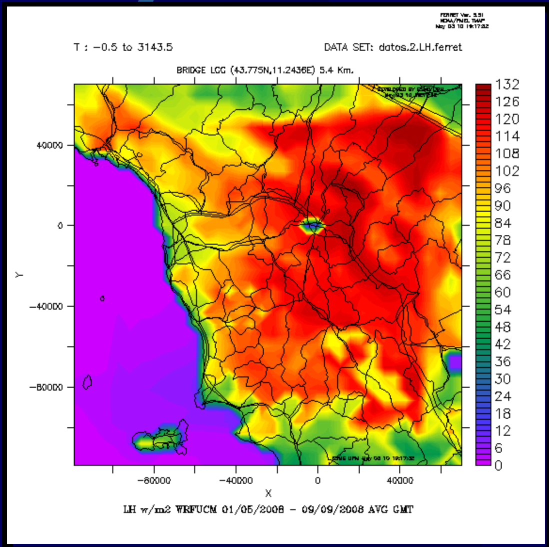
Temperature 2M (K)



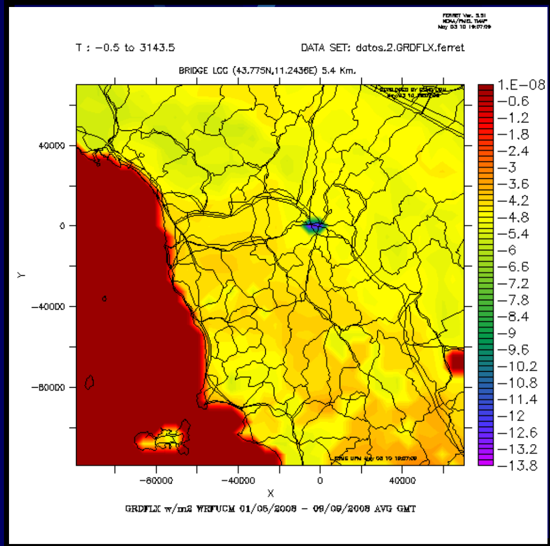
Sensible Heat Flux (w/m2)



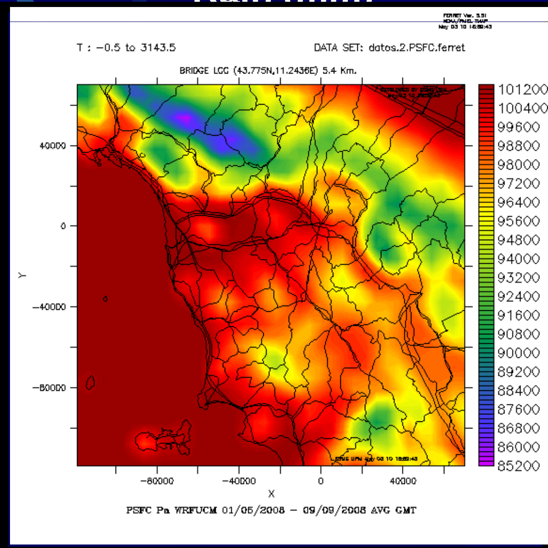
Rain (mm)



Latent Heat Flux (w/m2)

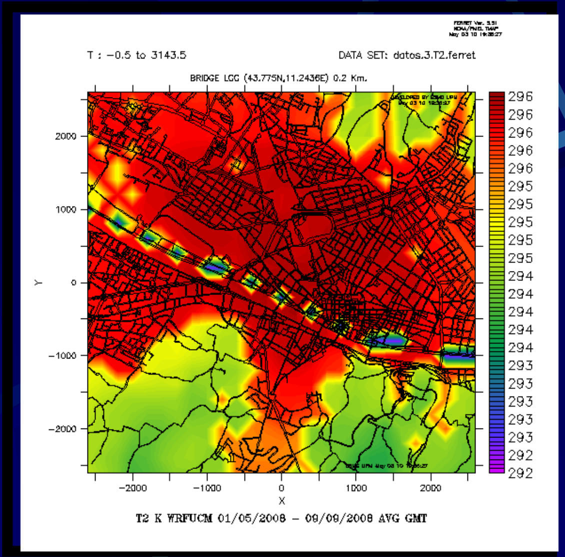


Ground Heat Flux (w/m2)

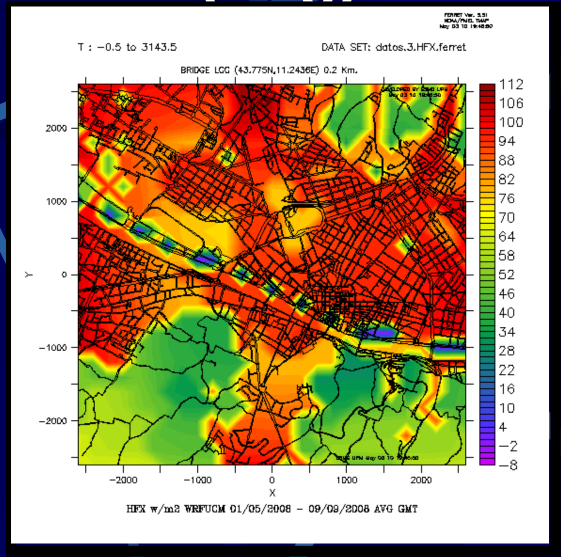


Surface Pressure (Pa)

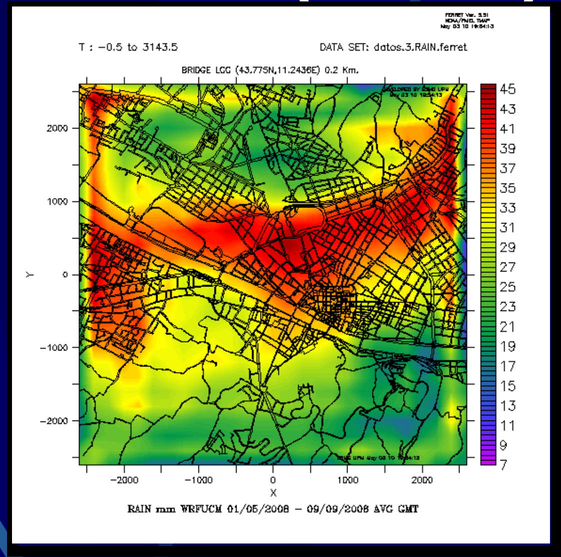
RESULTS. SUMMER 2008 (Avg) FLORENCE-UPM (0.2 KM)



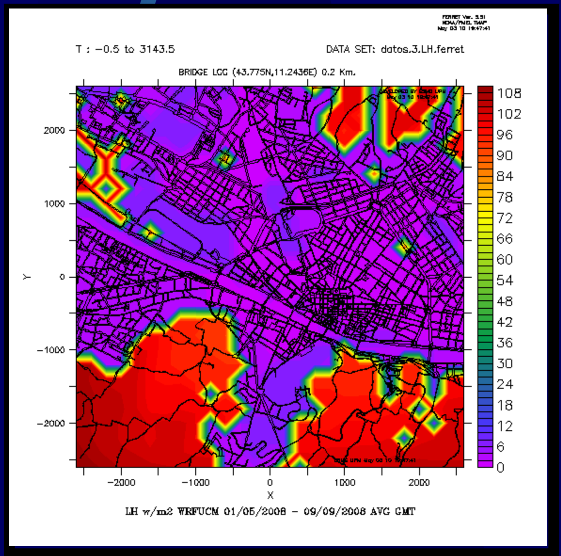
Temperature 2M (K)



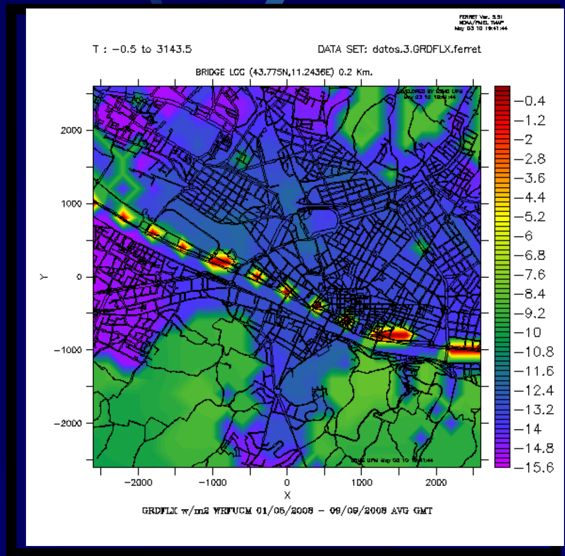
Sensible Heat Flux (w/m2)



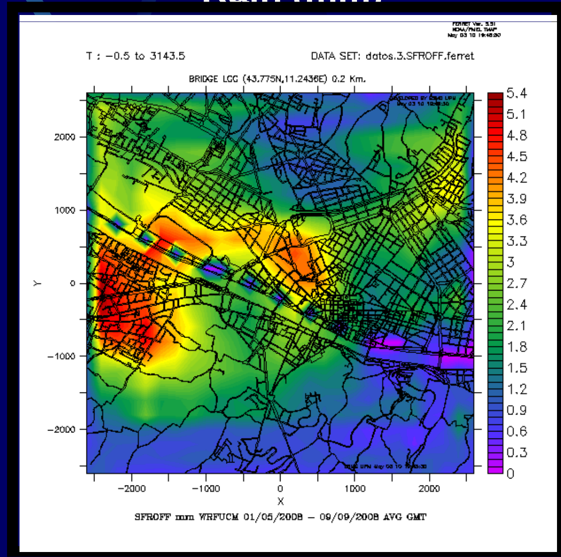
Rain (mm)



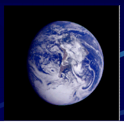
Latent Heat Flux (w/m2)



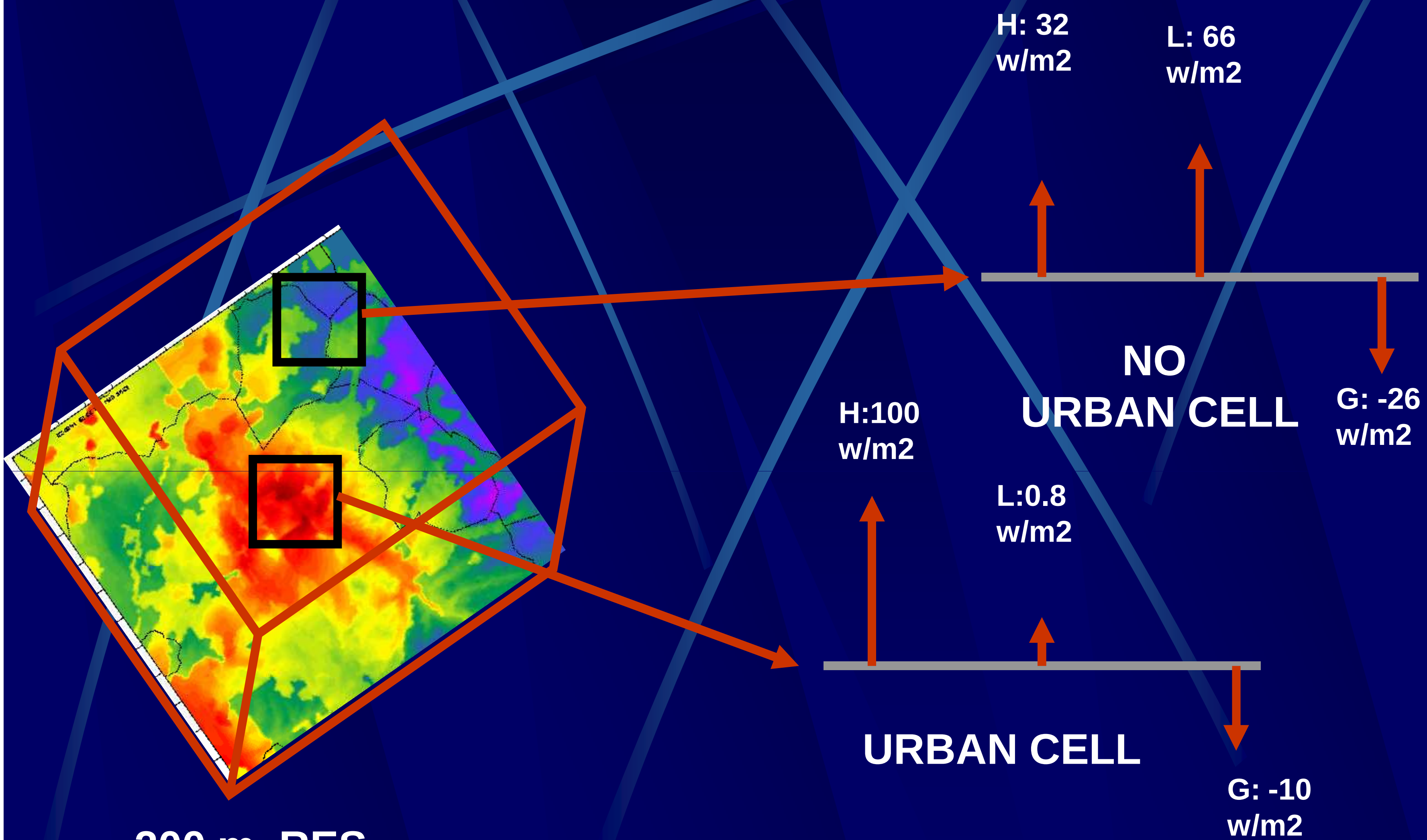
Ground Heat Flux (w/m2)



Surface Runoff (mm)



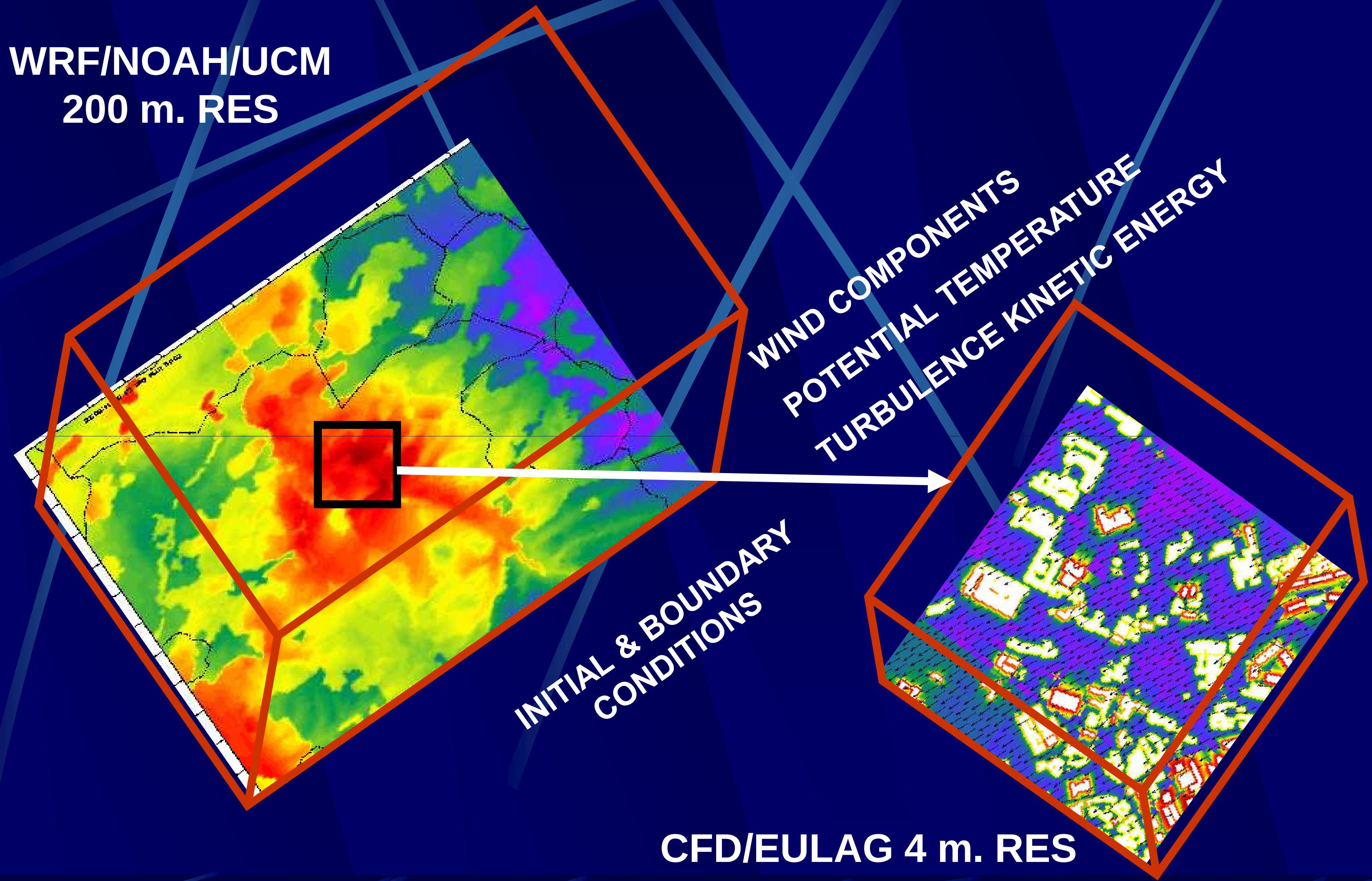
RESULTS. SUMMER 2008 FLORENCE-UPM



200 m. RES

15/05/2008 14:00 GMT

URBAN SCALE TO MICROSCALE. FLORENCE



MICROSYS-EULAG URBAN SIMULATION. FLORENCE

TIME PERIOD: 15/05/2008 12:00 - 12:06

TIME STEP: 0.05 (7200 time steps)

OUTPUT FREQUENCY: 10 s.

EULAG OPTIONS:

- **Numerical approximation: Eulerian conservation law**
- **Method to represent the edifice-> Immersed boundary**

(R. Mittal and G. Iaccarino, Immersed boundary methods, *Ann. Rev. Fluid Mech.* 37 (2005), pp. 239–261.)

- **Turbulence model → Smagorinsky**

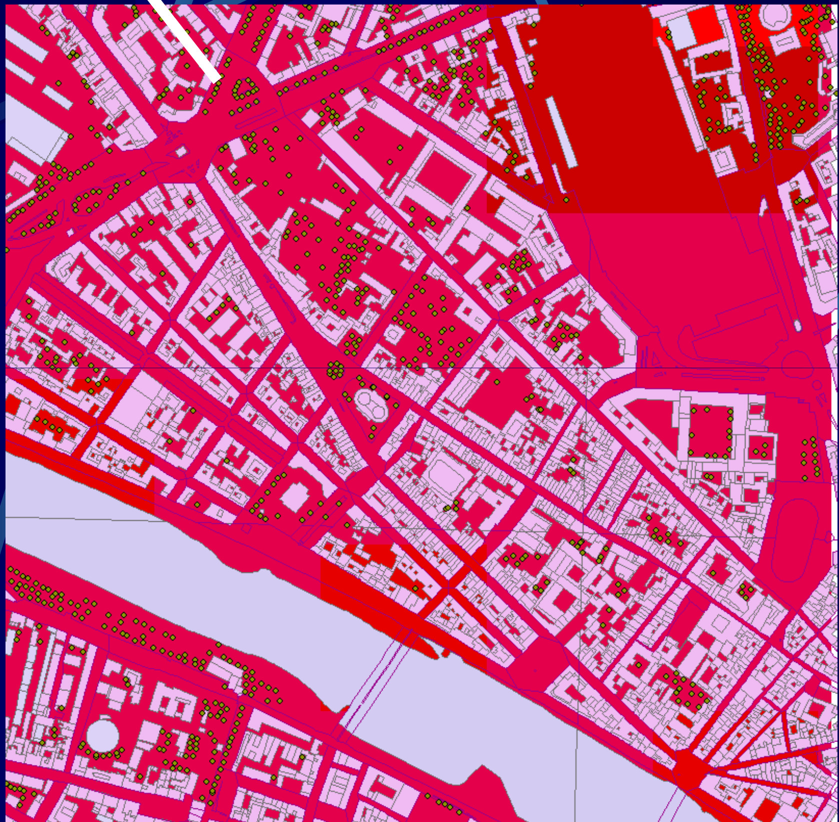
Smagorinsky, J., 1993, "Some Historical Remarks on the Use of Nonlinear Viscosities," *Large Eddy Simulation of Complex Engineering and Geophysical Flows*, Cambridge University Press, Cambridge, UK, pp. 3–36.

- **Moist and simple ice model: ON**

INPUT DATA. LANDUSES. CFD. FLORENCE-UPM

Green dots = Trees

1*1 Km. DOMAIN 4 m. RES.

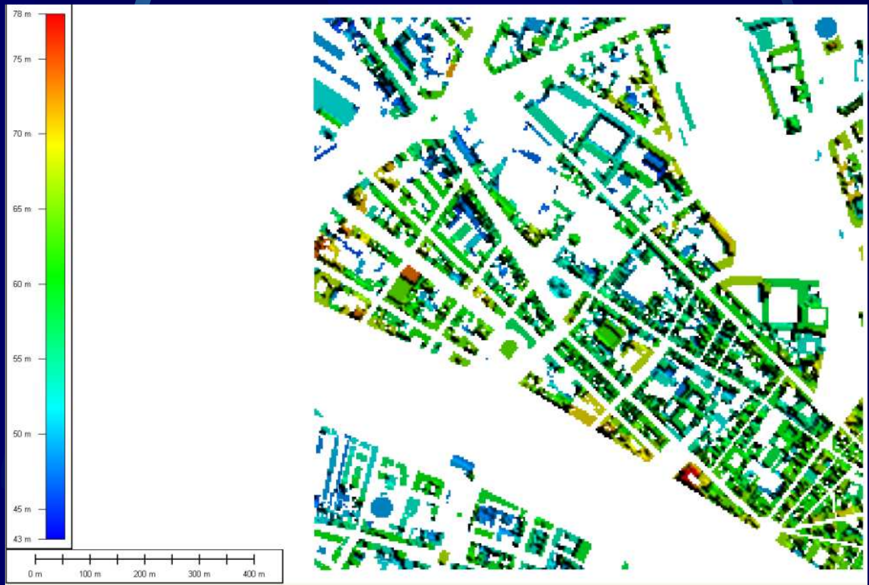


MODEL WORLD REAL WORLD

INPUT DATA. BUILDINGS. CFD. FLORENCE-UPM

1*1 Km. DOMAIN

4 m. RES.



Implementation of flux estimations into EULAG (MICROSYS)

Energy balance equation (roof) :
Rn – H – L – G = 0
Rn (net radiation) includes short and long wave. H is the sensible heat flux, L is the latent heat flux, G is the ground flux. H = $\rho c_p k \frac{u_*}{\Psi_h}(\Theta - \Theta_0)$ ρ = air density Θ = air temperature (K)

Θ_0 = air temperature at roughness length height. c_p = heat capacity of dry air

$k = 0.4$ (*von Karman constant*) Ψ_h = heat integrated universal function

u_* = friction velocity From Similarity Theory, we obtain u_* and Ψ_h using two levels , z_{wrf} - z_{eulag} .

The latent heat flux is calculated as: $L = \rho\, El\, k \frac{u_*}{\Psi_h}(q - q_0)$

ρ = air density. q = specific humidity

q_0 = WRF surface specific humidity (at roughness length)

El = heat capacity of vaporation

$k = 0.4$ (*von Karman constant*)

Ψ_h = heat integrated universal function

u_* = friction velocity

Implementation of flux estimation into EULAG (MICROSYS)

q = 0.622*ES (PS(saturation pressure) -0.378*ES (saturation vapor pressure))
ES = 6.11*EXP (2.5*10**6 / 461.51)* (Θ -273.15)/(272.15* Θ)

G= Thermal conductivity * $\left(\frac{\Theta(\text{surface}) - \Theta(\text{layer } 1)}{(depth/2)}\right)$

Rn= emissivity* (long wave radiation - $\sigma\Theta^4$)

Rn = (albedo, shadow)

Energy balance equation (wall and ground) :

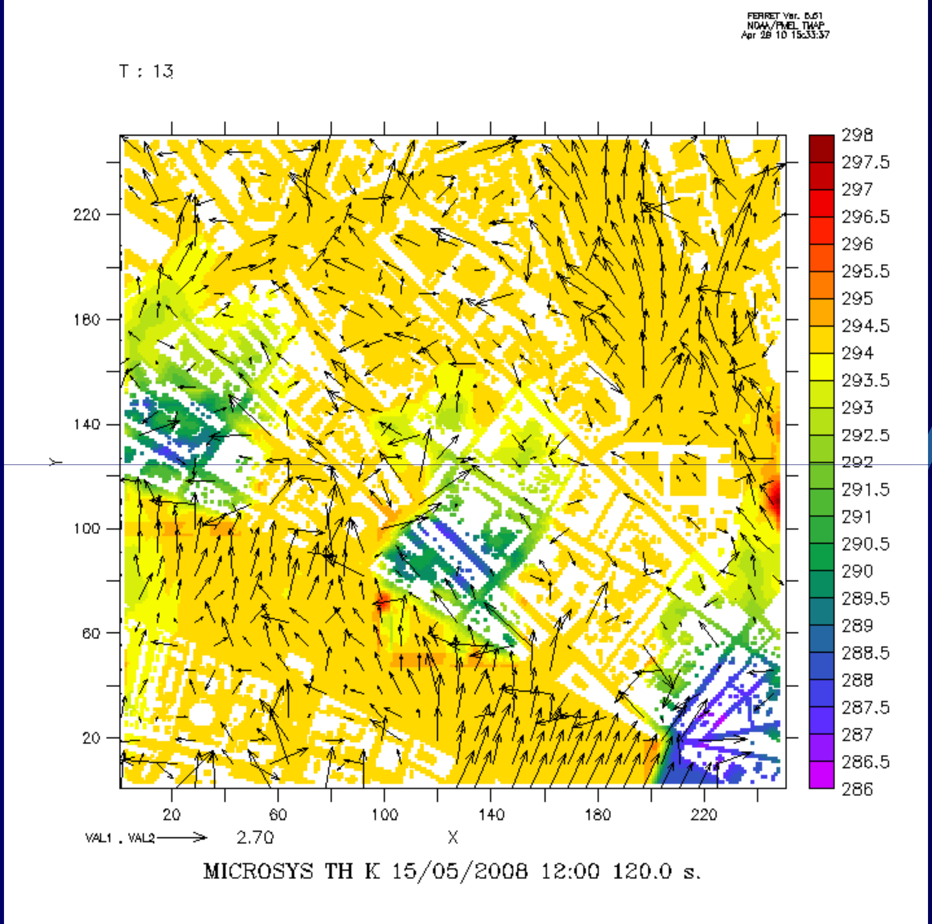
Net radiation (Direct, reflected, sky view factor)

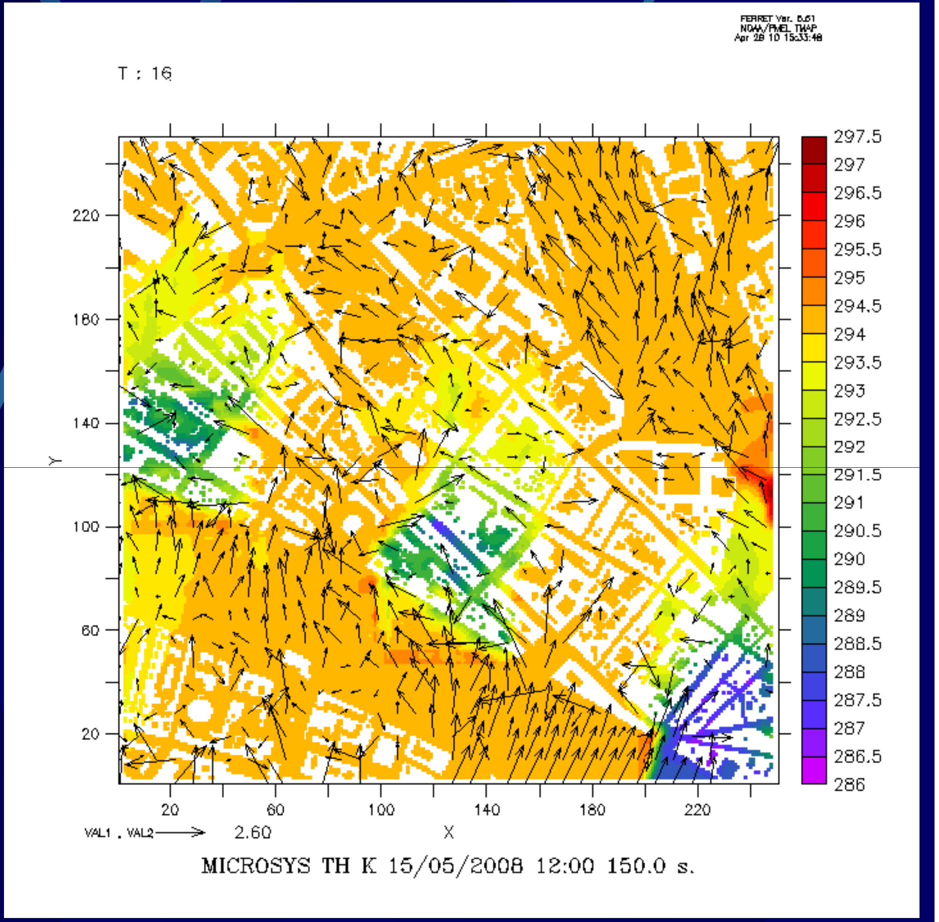
H = $\rho \; c_p\left(6.15 + 4.18 * u_{Eulag}\right)(\Theta - \; \Theta_0)$ (Jurge's formula)

L = $\rho \; El \; \left(6.15 + 4.11 * \; u_{Eulag}\right)(q - q_0)$

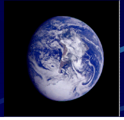
RESULTS. MICROSYS-EULAG.FLORENCE-UPM

POTENTIAL TEMPERATURE (K)





COMPLEX URBAN WIND PATTERNS



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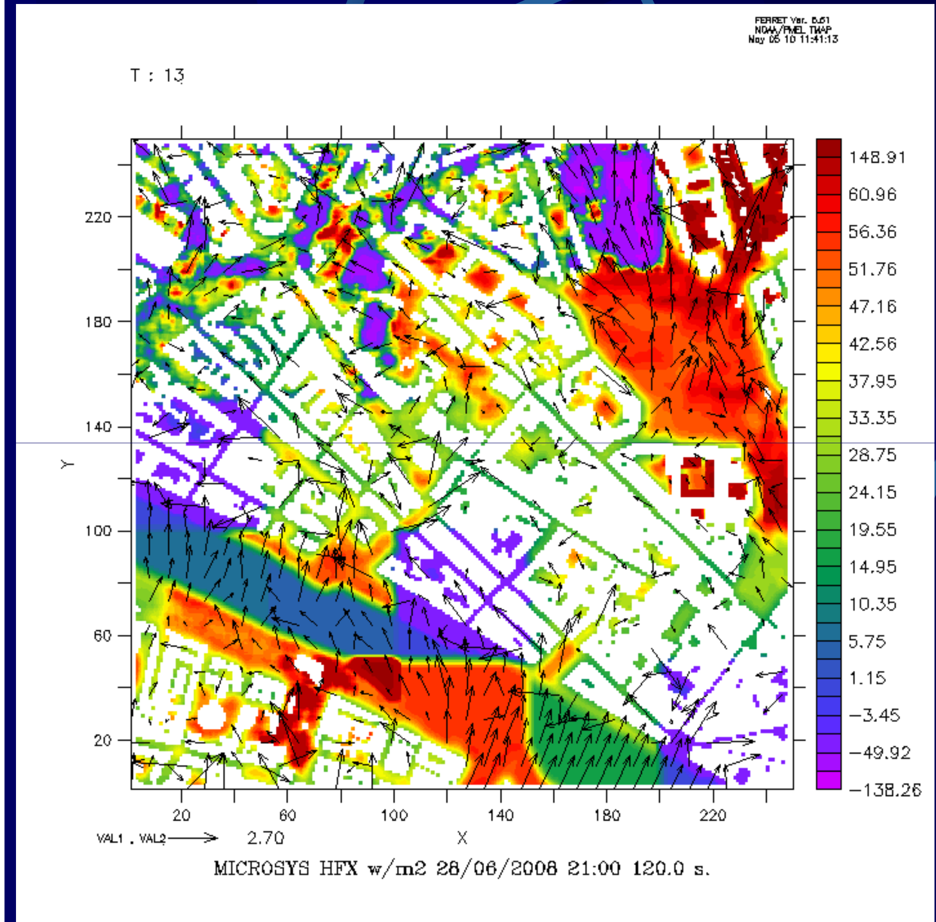
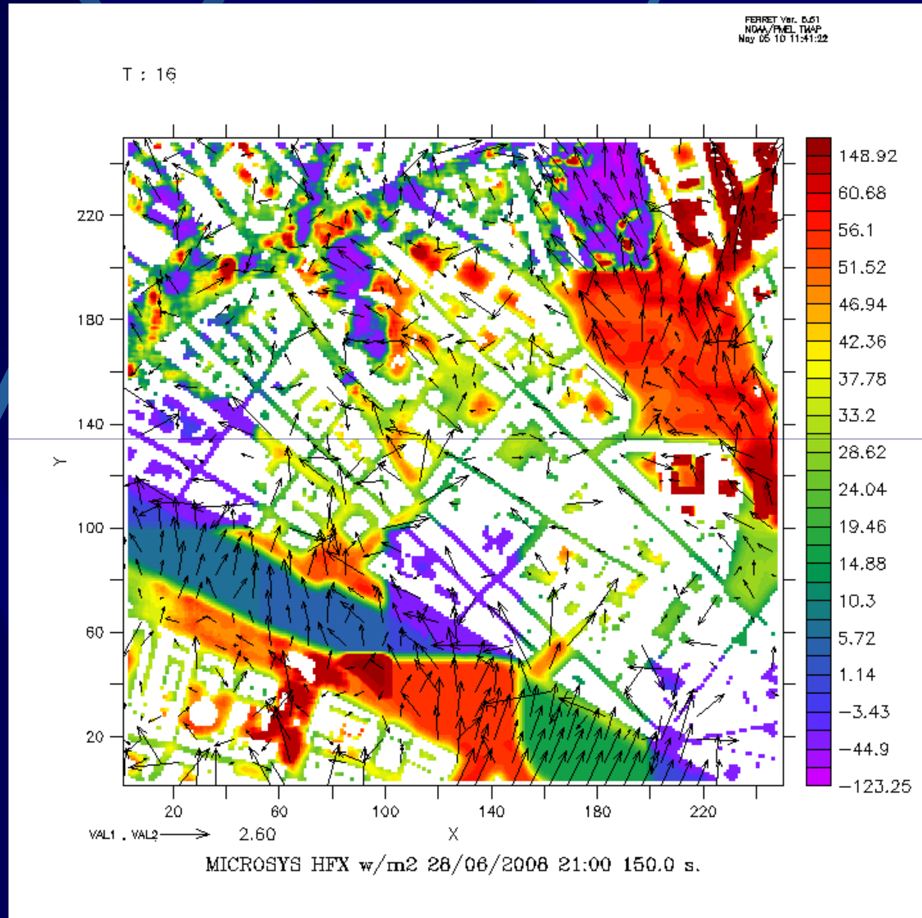
RESULTS. MICROSYS-EULAG.FLORENCE-UPM

SENSIBLE HEAT FLUX (W/M2)

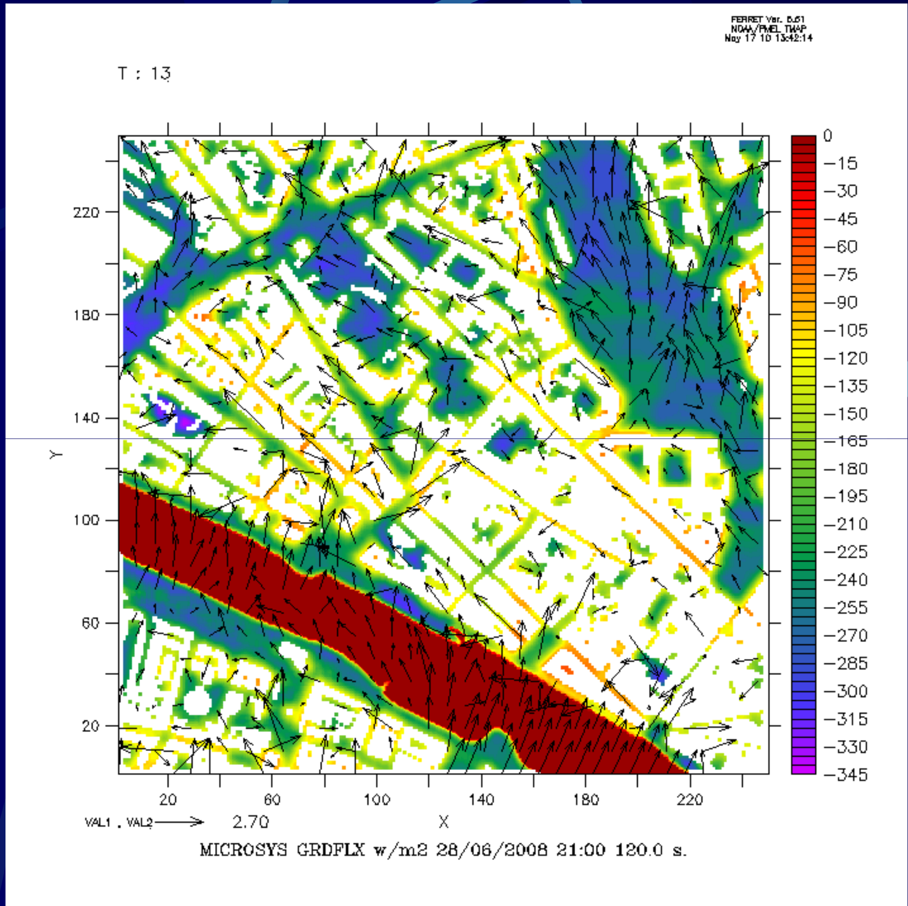


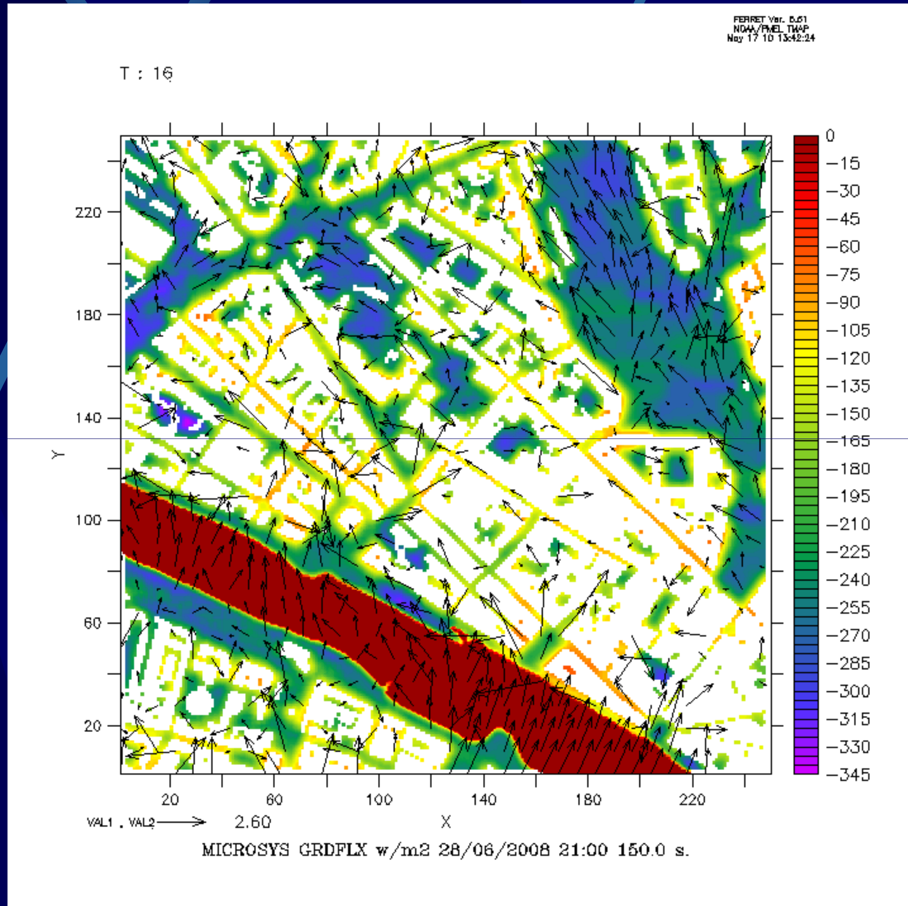


4 METERS RESOLUTION

RESULTS. MICROSYS-EULAG.FLORENCE-UPM

GROUND HEAT FLUX (W/M2)





4 METERS RESOLUTION

WRF/NOAH/UCM LATENT HEAT FLUX: (LH)

1. NO URBAN CELLS

LH = LH_NATURAL (CALCULATED BY NOAH)

LH_NATURAL = ETP (IF ETP < 0)

LH_NATURAL = EDIR + EC + ETT (IF ETP>0)

2. URBAN CELLS

LH=LH_URB (CALCULATED BY UCM) + (1-FRC_URB)
*** LH_NATURAL (CALCULATED BY NOAH)**

LH: Latent Heat Flux (w/m2)

ETP: Potential evaporation (w/m2)

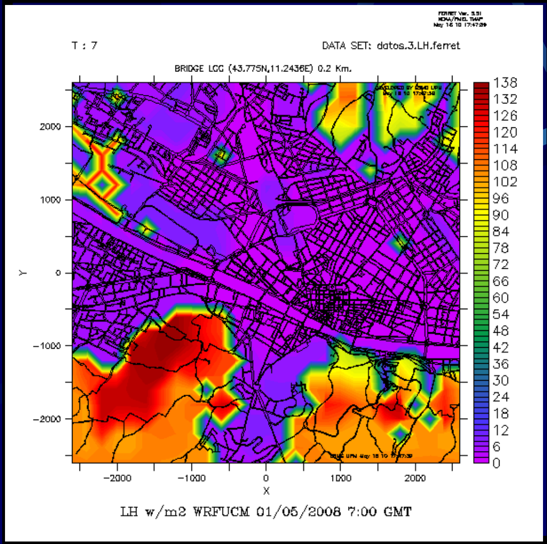
EDIR: Direct soil evaporation (w/m2)

EC: Canopy Water evaporation (w/m2)

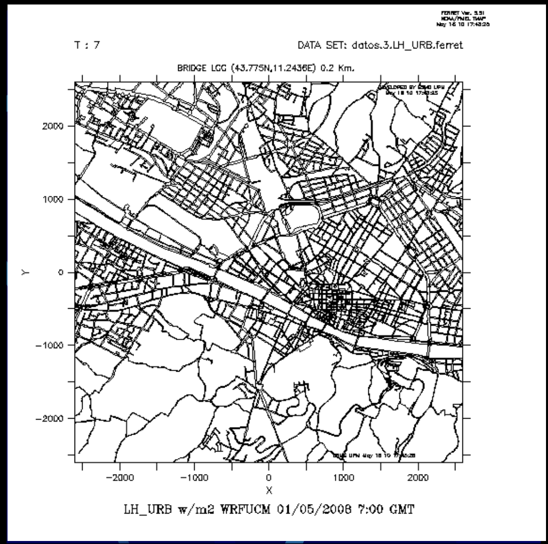
ETT: Total Plant Transpiration (w/m2)

FRC_URB: Urban Fraction

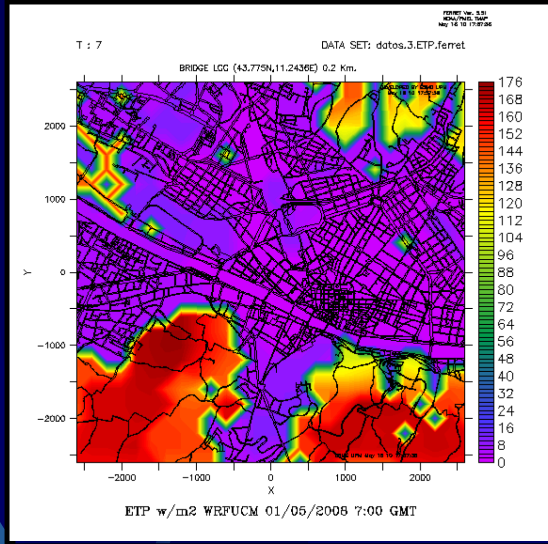
RESULTS. 01/05/2008 07:00 GMT FLORENCE-UPM



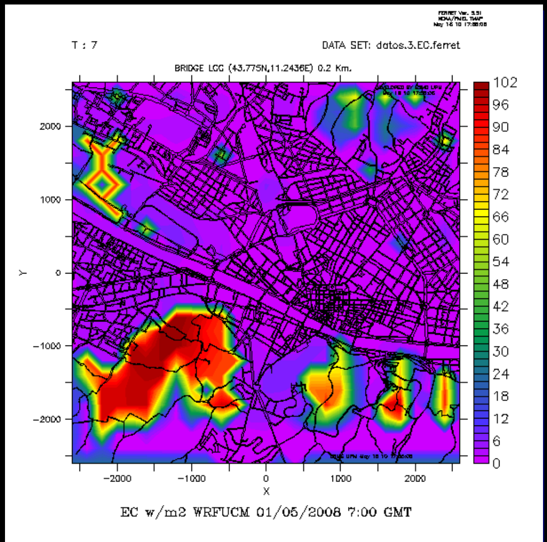
Latent Heat Flux (w/m2)



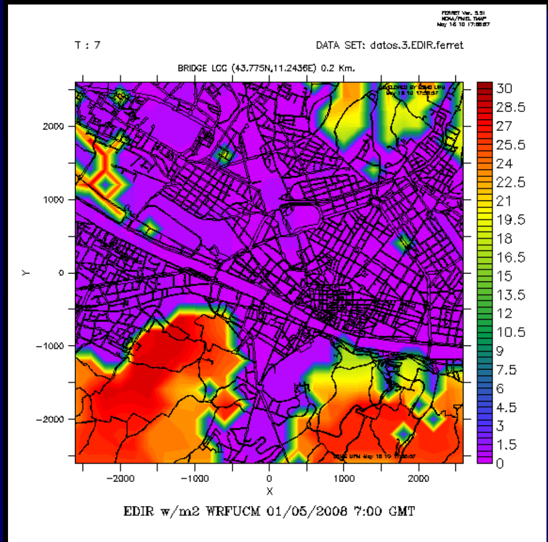
Urban Latent H. F. (w/m2)



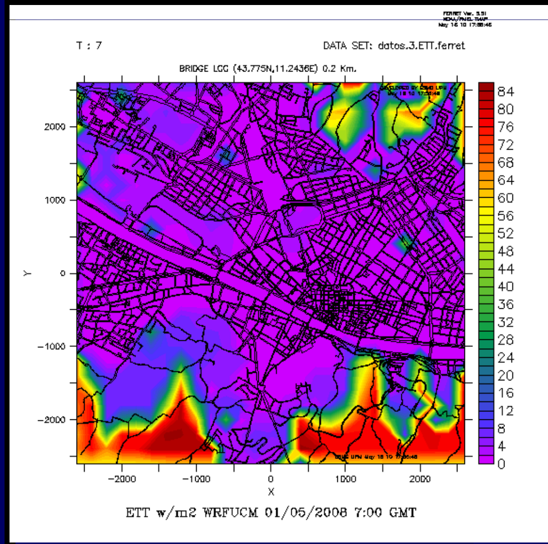
Potential evaporation (w/m2)



Canopy water evap. (w/m2)

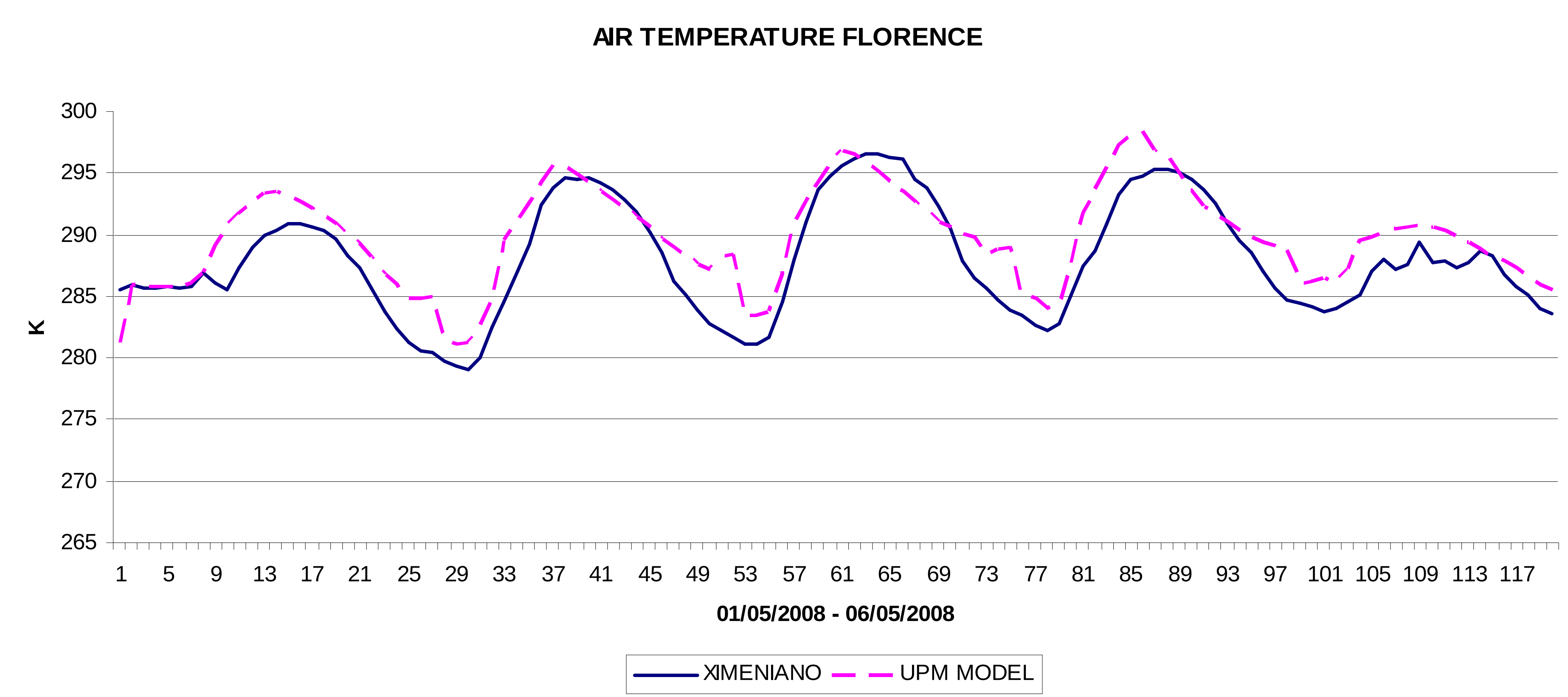


Direct soil evap. (w/m2)



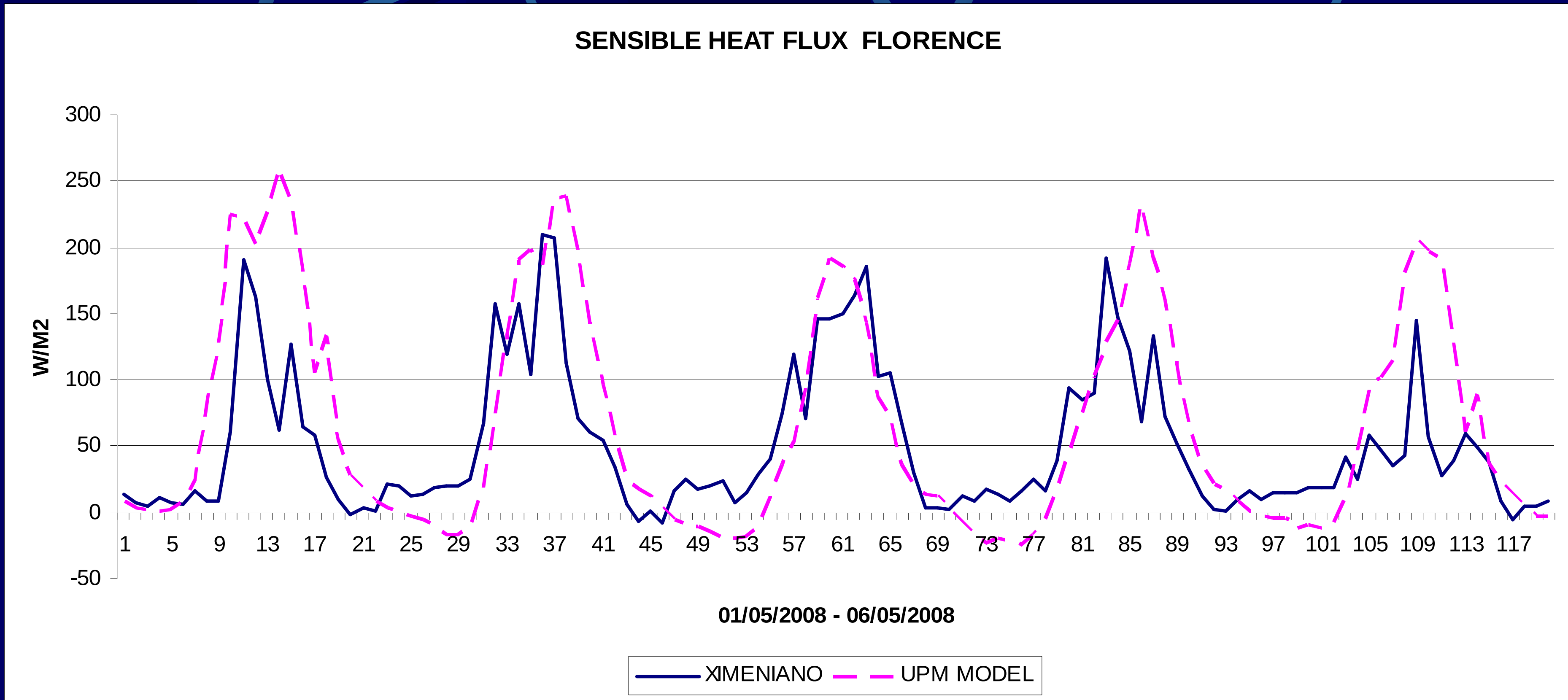
Total plant transp. (w/m2)

RESULTS. VALIDATION. FLORENCE-UPM



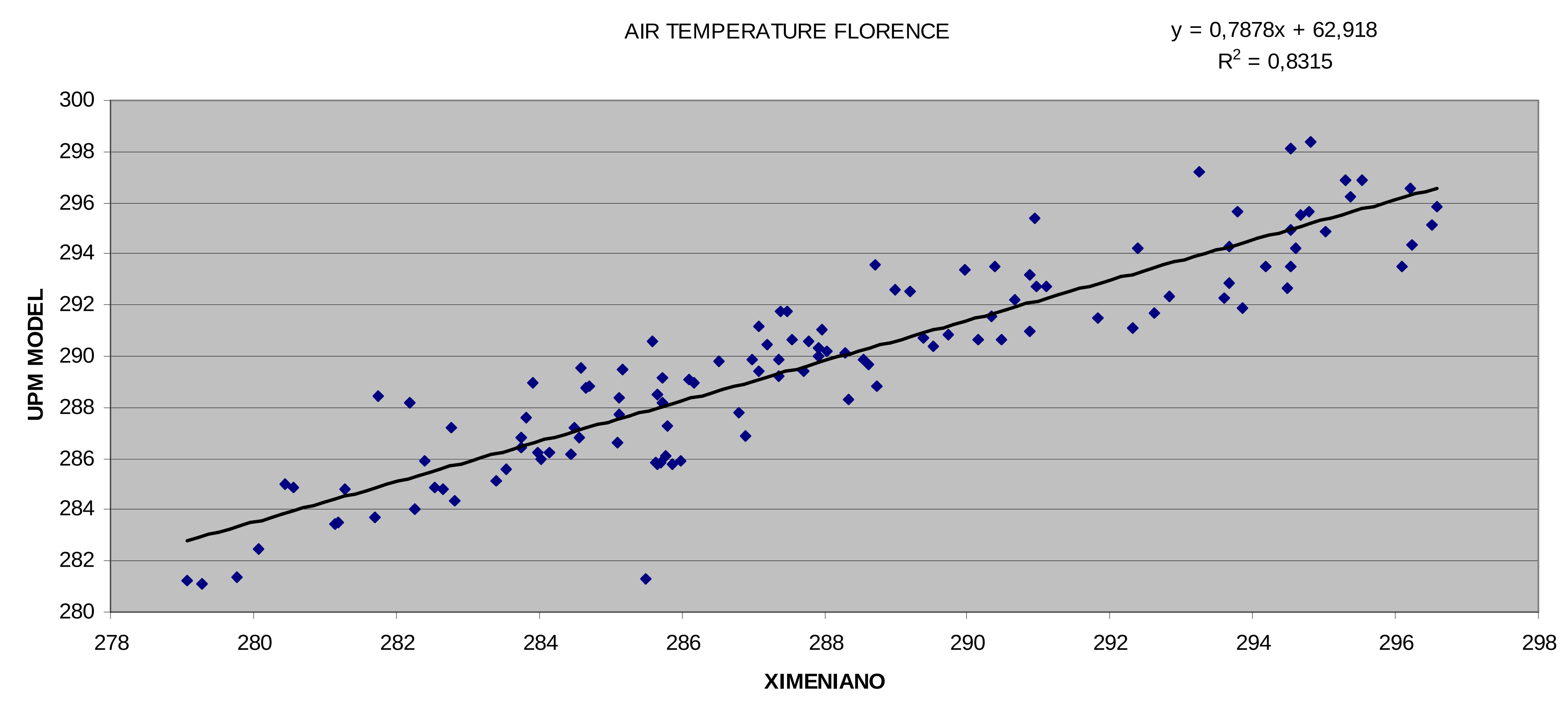
Ximeniano: Eddy covariance (EC) flux station (43°47 ' 70 N, 11°15' E)
UPM Model: WRF/NOAH/UCM 200 meter grid cell

RESULTS. VALIDATION. FLORENCE-UPM



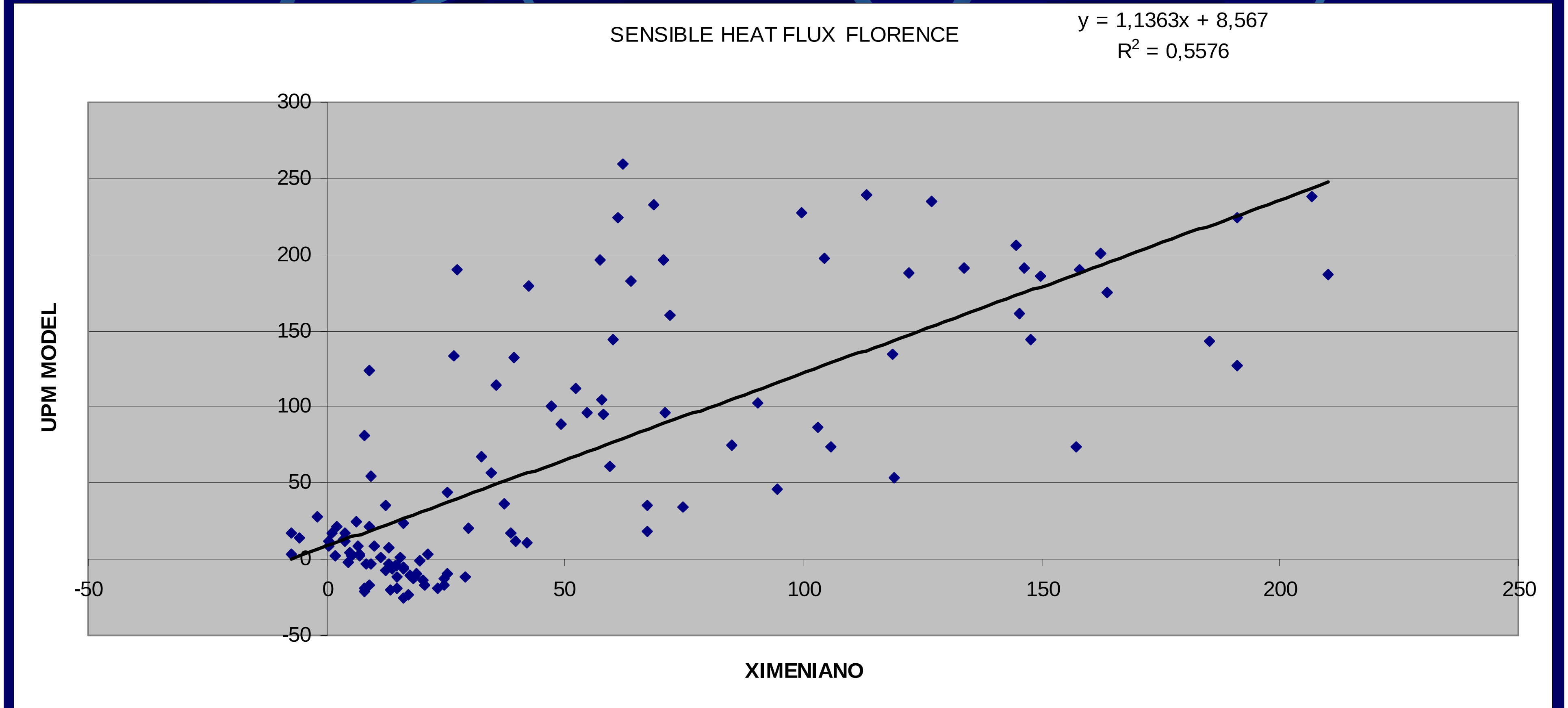
Ximeniano: Eddy covariance (EC) flux station (43º47 ' 70 N, 11º15' E)
UPM Model: WRF/NOAH/UCM 200 meter grid cell

RESULTS. VALIDATION. FLORENCE-UPM



Ximeniano: Eddy covariance (EC) flux station (43°47 ' 70 N, 11°15' E)
UPM Model: WRF/NOAH/UCM 200 meter grid cell

RESULTS. VALIDATION. FLORENCE-UPM



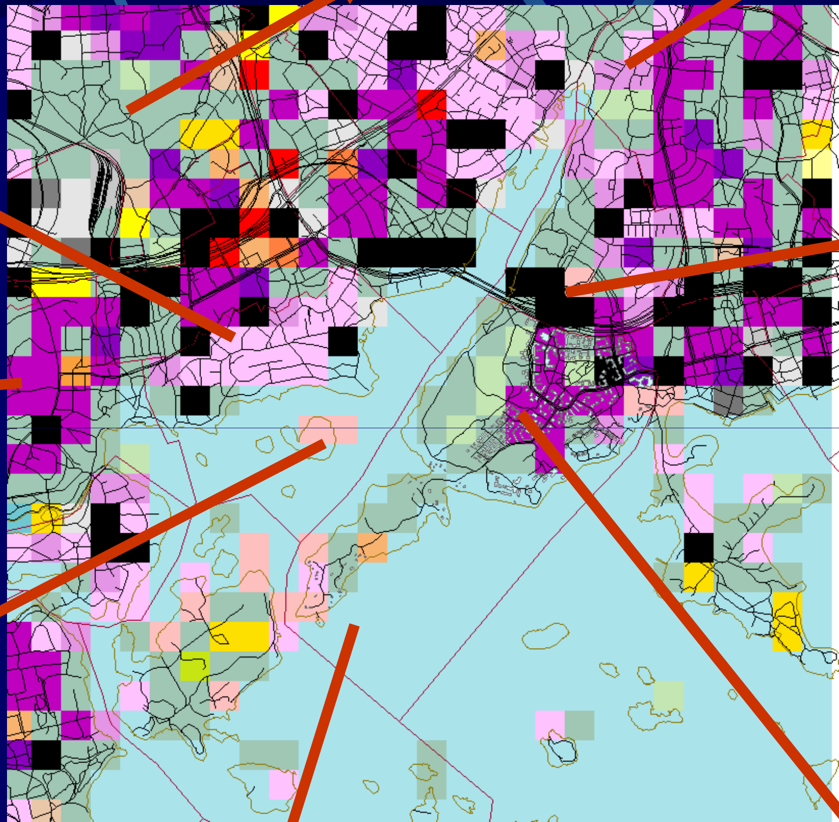
Ximeniano: Eddy covariance (EC) flux station (43°47 ' 70 N, 11°15' E)
UPM Model: WRF/NOAH/UCM 200 meter grid cell

INPUT DATA. HELSINKI-UPM

Forest (user) →
Mixed forest (USGS/UCM)

Detached houses (user) →
Low density urban (USGS/UCM)

Row and attached small houses(user) →
Low density urban (USGS/UCM)



Road transportation area (user) →
Com/Indust/Transport urban (USGS/UCM)

Block house areas (user) →
Hight density urban (USGS/UCM)

Data source: User GIS data (10 m.)

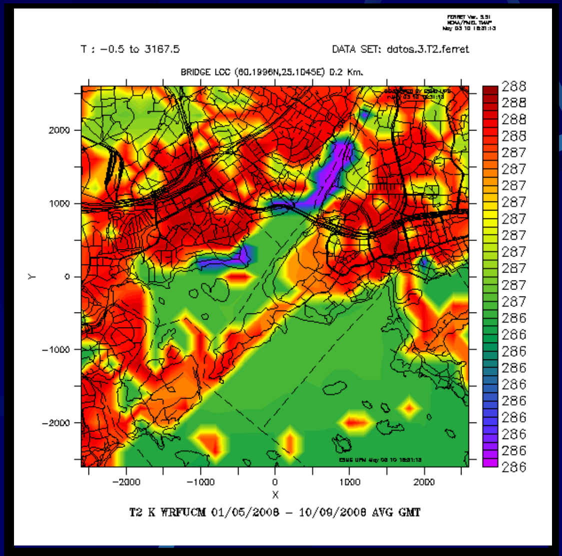
Domain 0.2 KM res.

Holiday resorts (user) →
Low density urban (USGS/UCM)

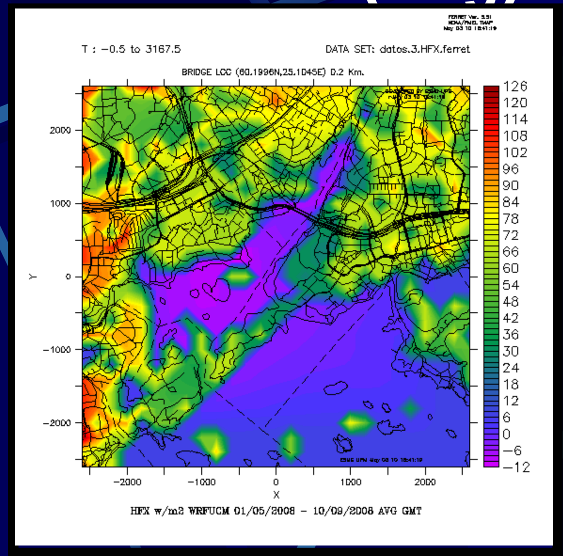
Sea areas (user) →
Water bodies (USGS/UCM)

MR BUILDINGS
2.5 KM *2.0 KM

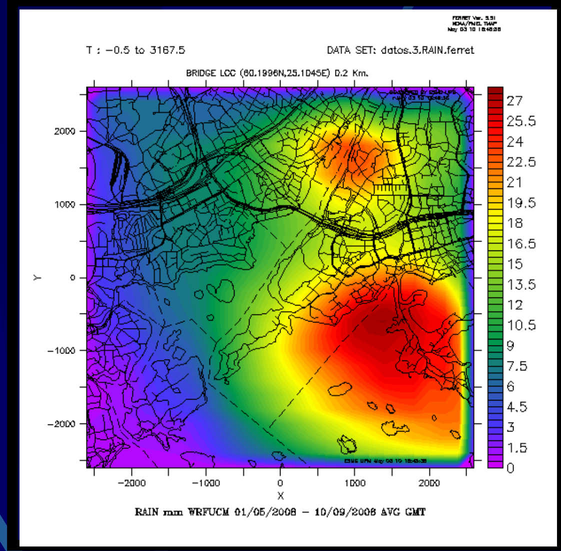
RESULTS. SUMMER 2008 (Avg) HELSINKI-UPM



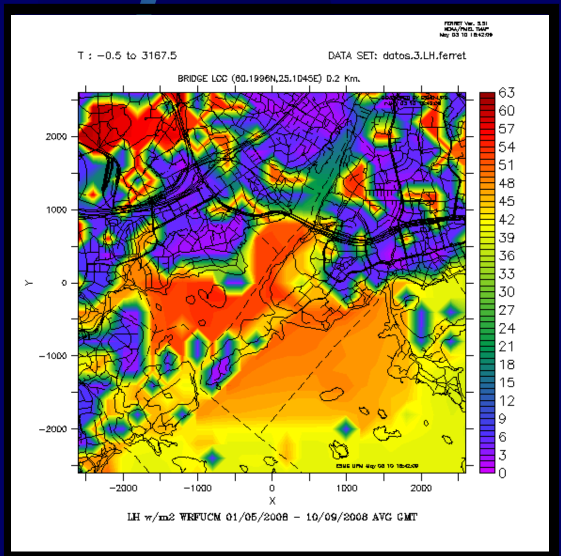
Temperature 2M (K)



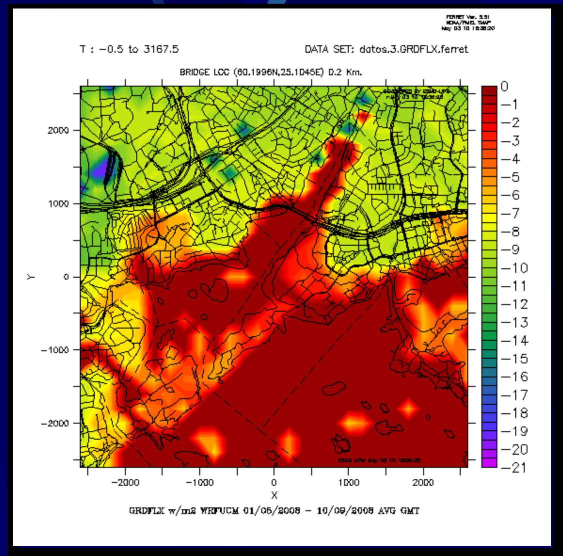
Sensible Heat Flux (w/m2)



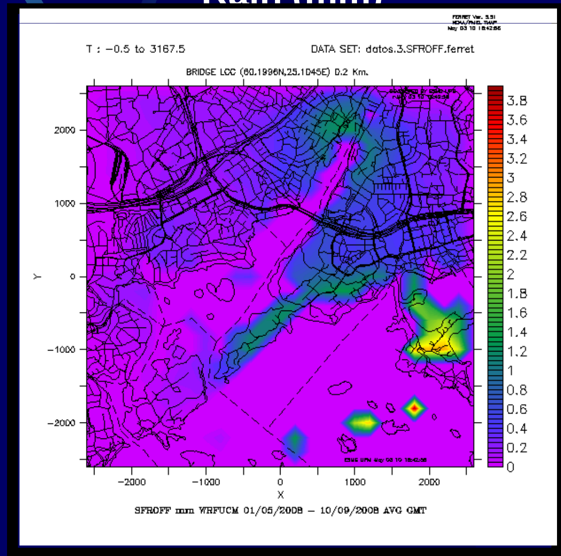
Rain (mm)



Latent Heat Flux (w/m2)

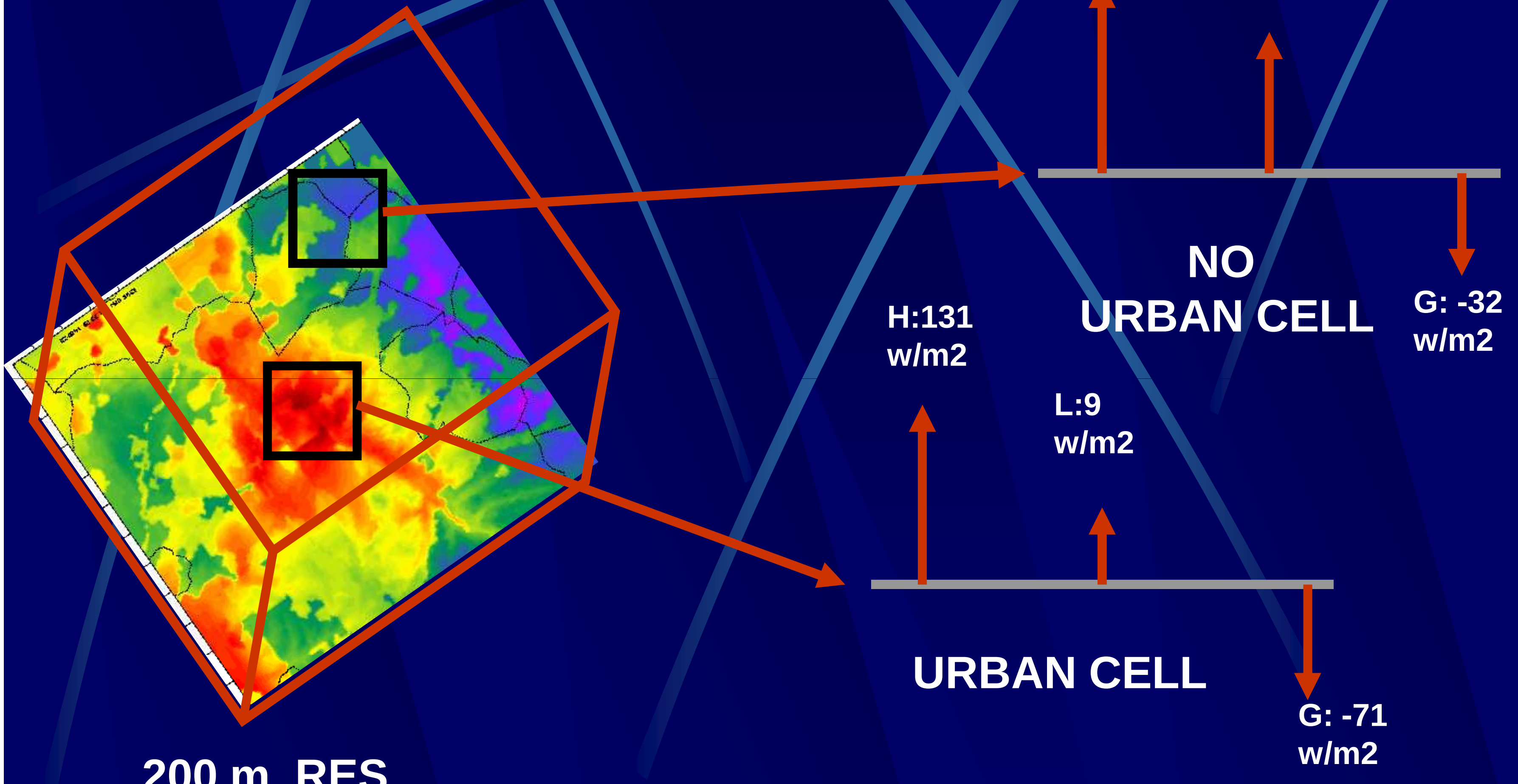


Ground Heat Flux (w/m2)



Surface Runoff (mm)

RESULTS. SUMMER 2008 HELSINKI-UPM



200 m. RES
15/05/2008 14:00 GMT

INPUT DATA. ATHENS-UPM

Data source: User data

Domain 0.2 KM res.

Sport and leisure facilites (CLC100) →

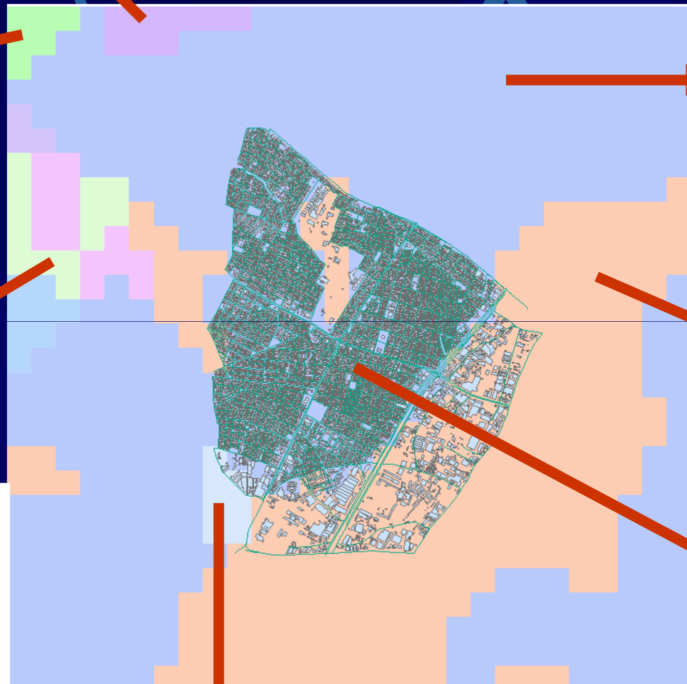
Com/Indust/Transport urban (USGS/UCM)

Discontinuous urban frabic (CLC100) →

Low density urban (USGS/UCM)

Transitional woodland-shrub (CLC100) →

Mixed shrubland/grassland (USGS/UCM)



Continuous urban frabic (CLC100) →

Hight density urban (USGS/UCM)

Indust. or commercial units (CLC100) →

Com/Indust/Transport urban (USGS/UCM)

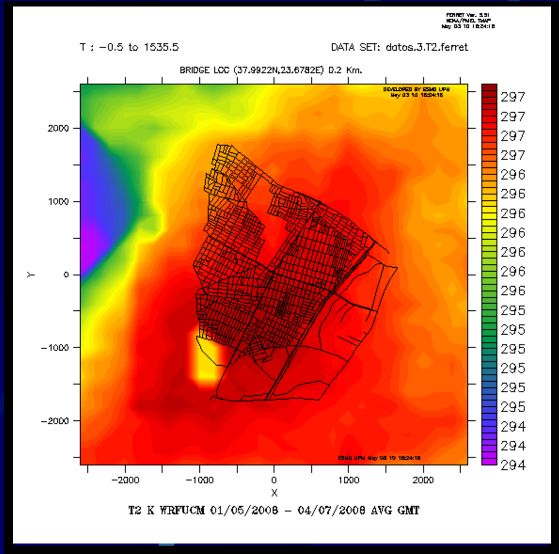
Green urban area (CLC100) →

Grassland (USGS/UCM)

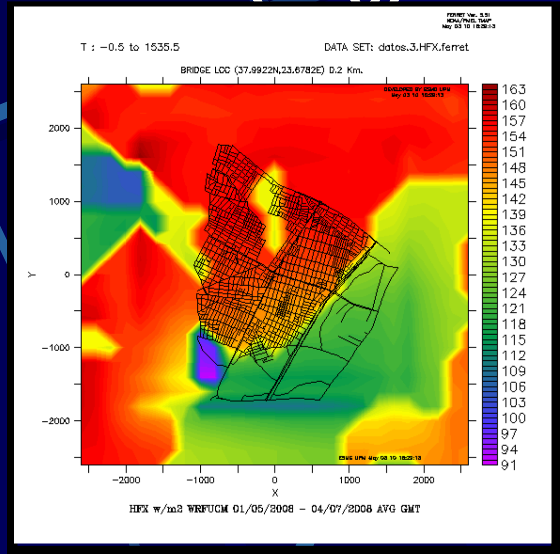
EGALEO BUILDINGS & ROADS

3.0 KM *4.0 KM

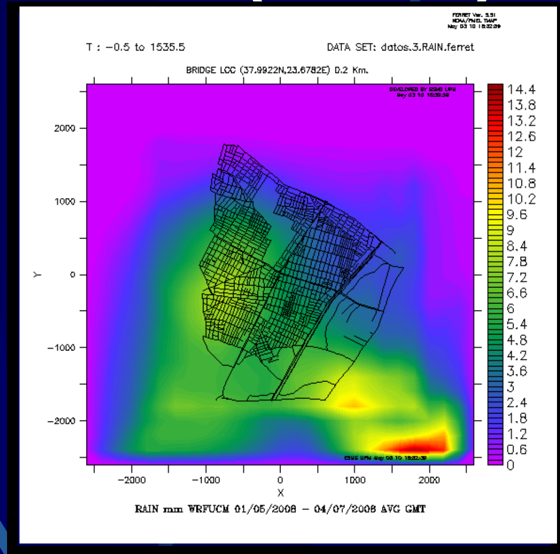
RESULTS. SUMMER 2008 (Avg) ATHENS-UPM (0.2 KM)



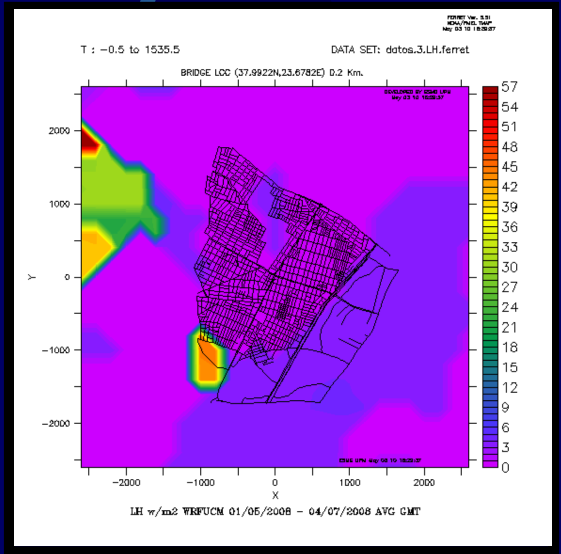
Temperature 2M (K)



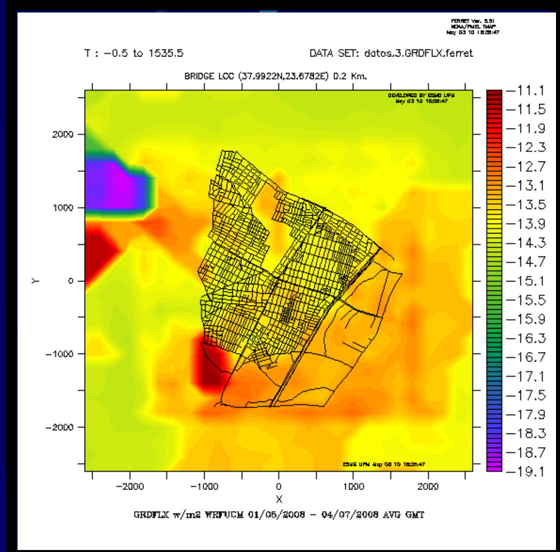
Sensible Heat Flux (w/m2)



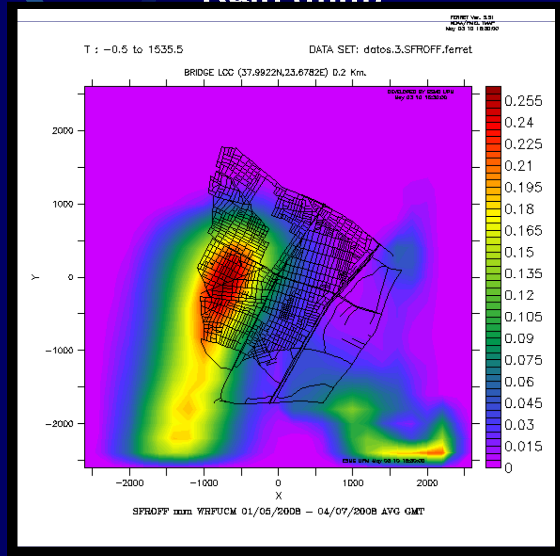
Rain (mm)



Latent Heat Flux (w/m2)

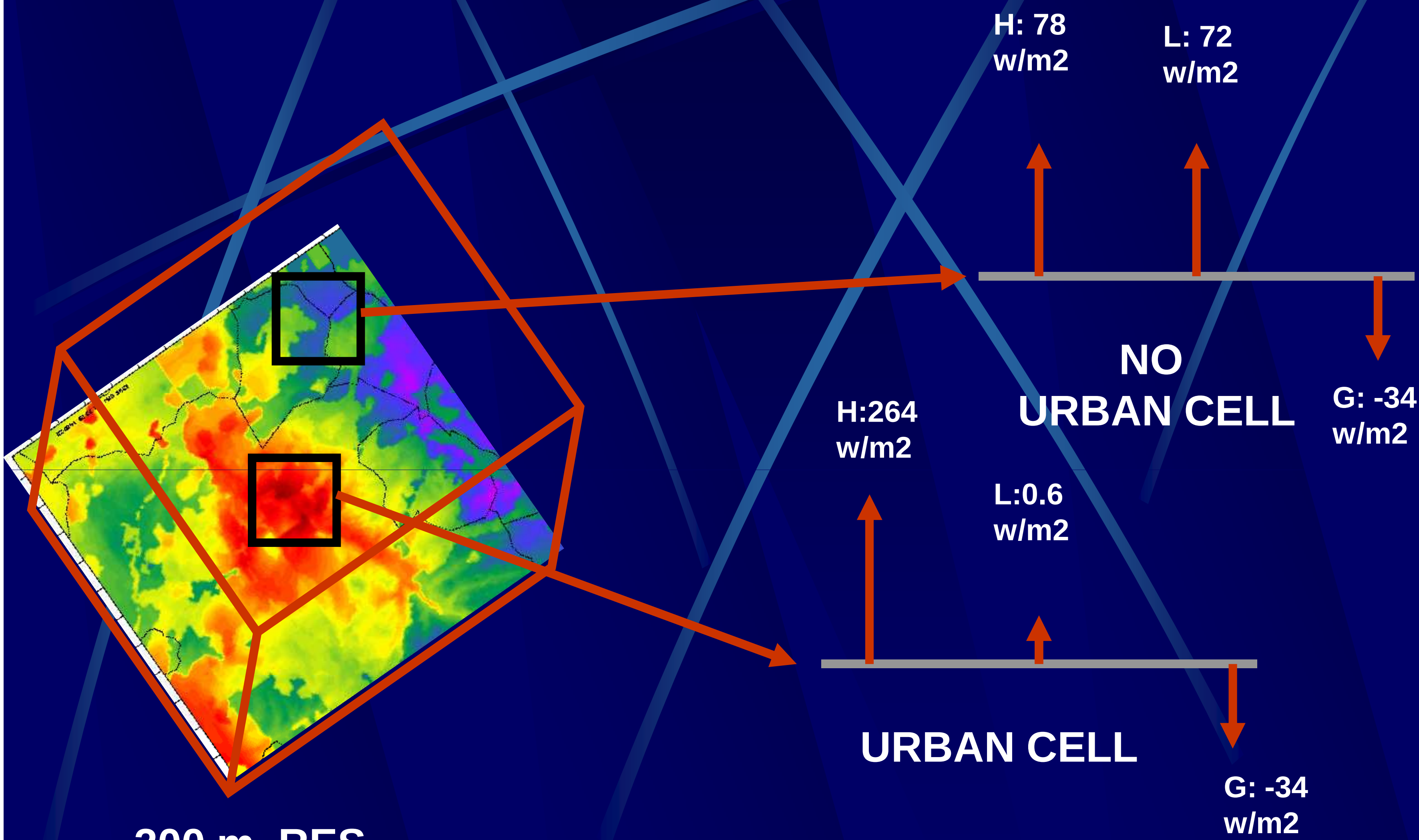


Ground Heat Flux (w/m2)



Surface Runoff (mm)

RESULTS. SUMMER 2008 ATHENS-UPM

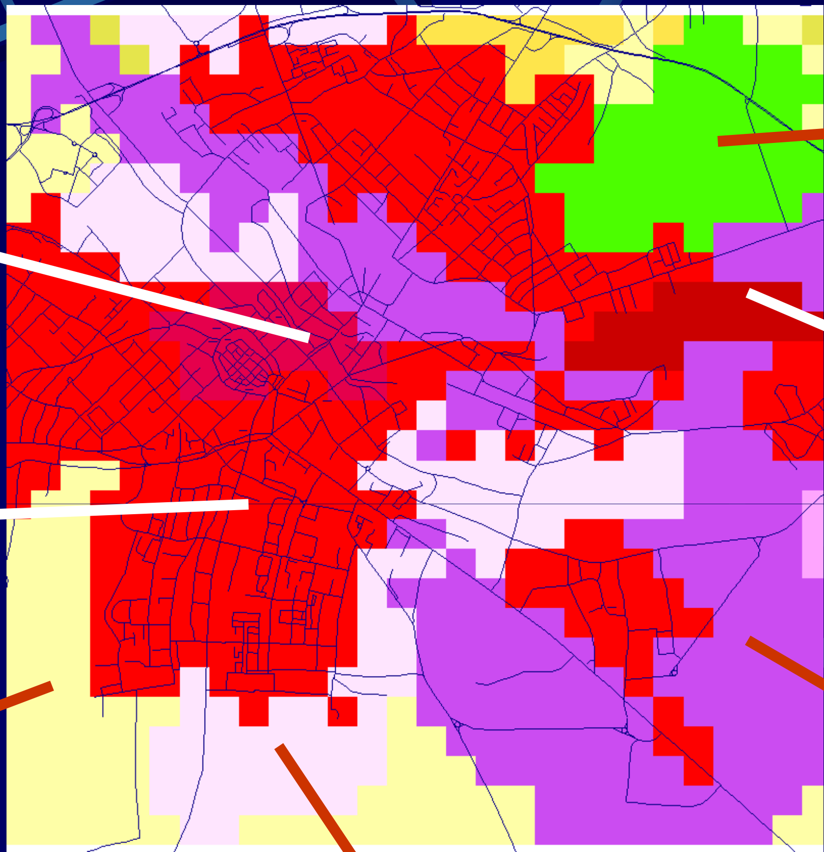


200 m. RES

15/05/2008 14:00 GMT

INPUT DATA. GLIWICE-UPM

Data source: CLC100200 (100 m.) **Domain 0.2 KM res.**



Forest (cls) →
Mixed forest (USGS/UCM)

Continuous urban frabic (CLC100) →
Hight density urban (USGS/UCM)

Road/Rail network (CLC100) →
Com/Indust/Transport urban (USGS/UCM)

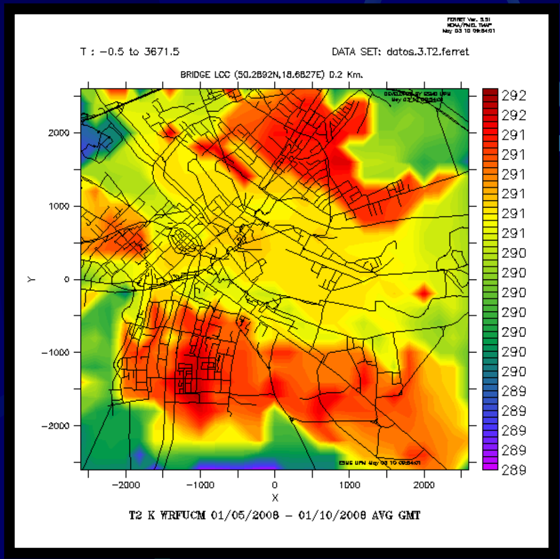
Discontinuous urban frabic (CLC100) →
Low density urban (USGS/UCM)

Indust. or commercial units (CLC100) →
Com/Indust/Transport urban (USGS/UCM)

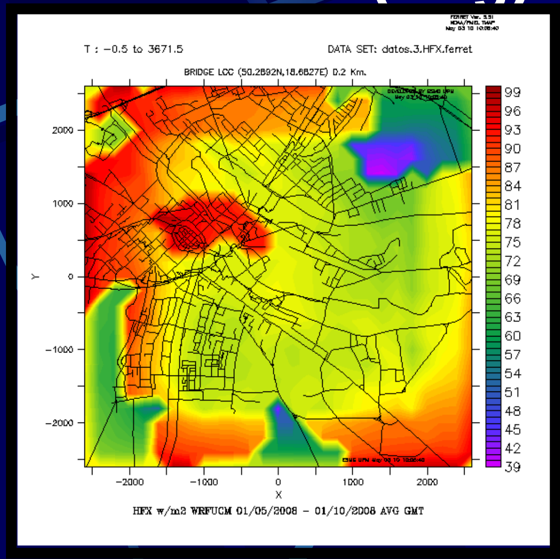
Non-irrigated arable land (CLC100) →
Dryland cropland/pasture (USGS/UCM)

Sport and leisure facilites (CLC100) →
Com/Indust/Transport urban (USGS/UCM)

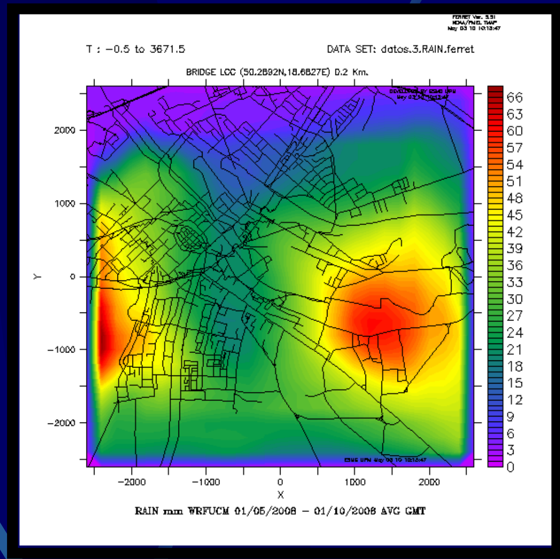
RESULTS. SUMMER 2008 (Avg) GLIWICE-UPM



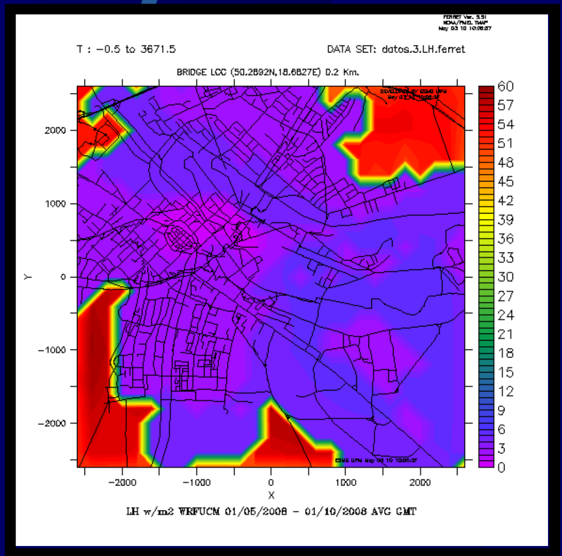
Temperature 2M (K)



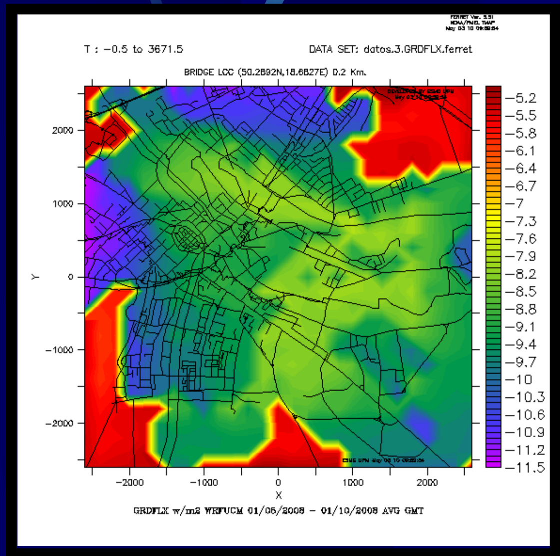
Sensible Heat Flux (w/m2)



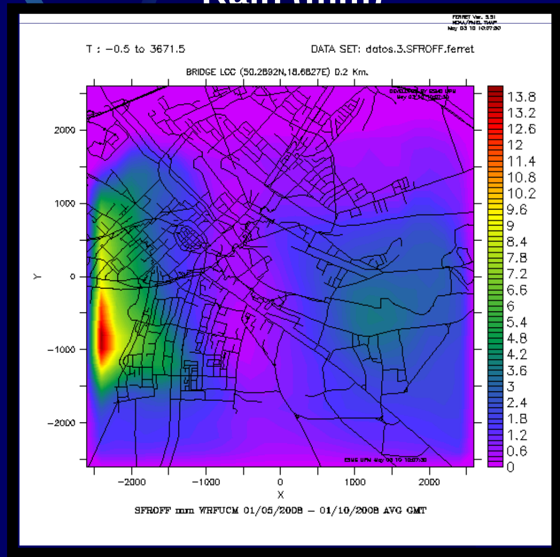
Rain (mm)



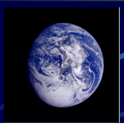
Latent Heat Flux (w/m2)



Ground Heat Flux (w/m2)



Surface Runoff (mm)



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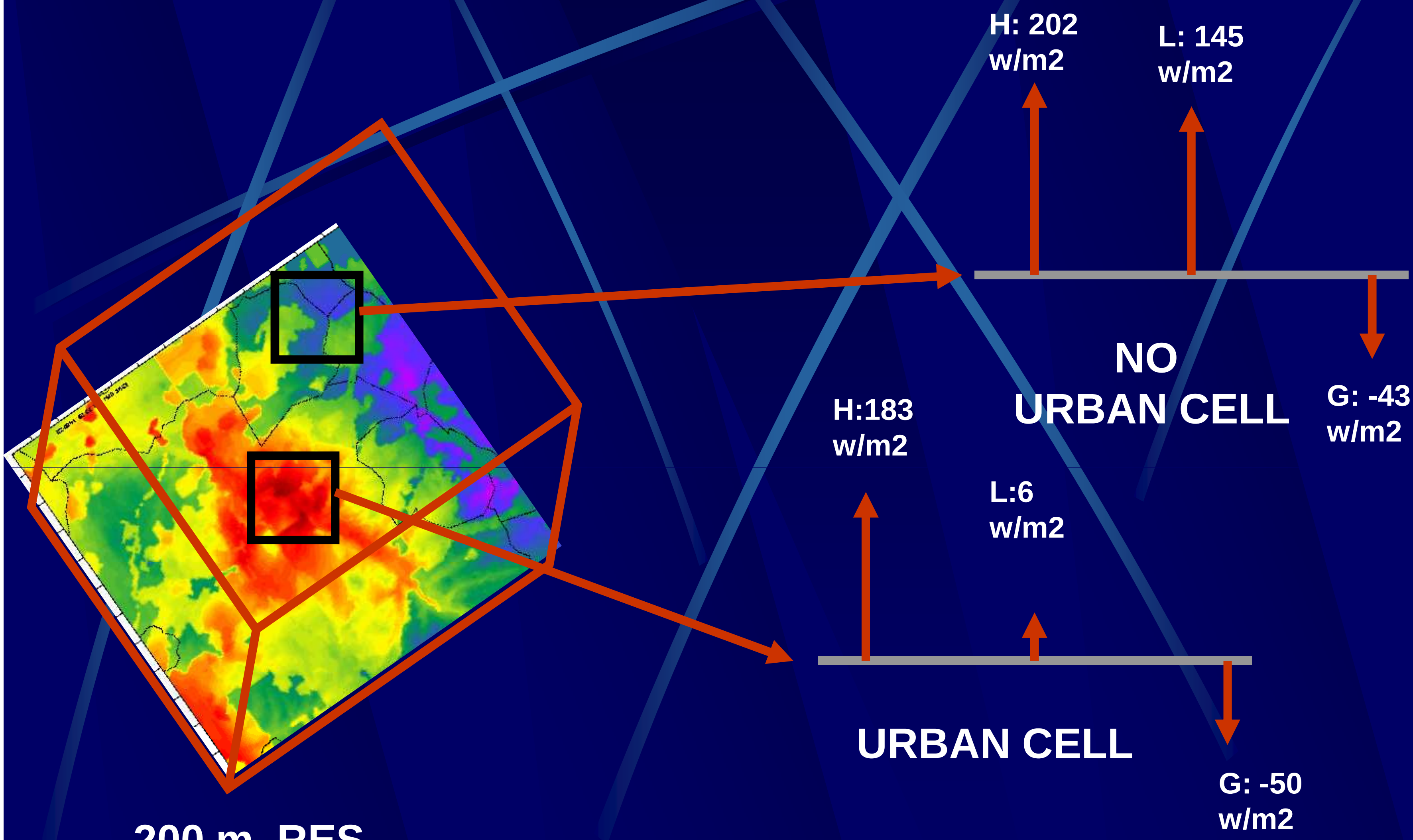
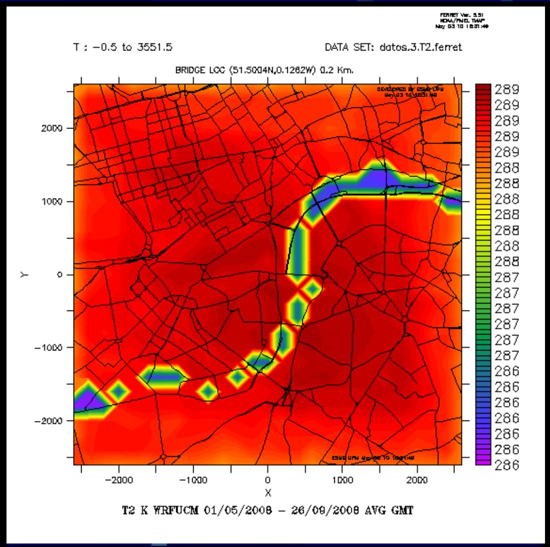
RESULTS. SUMMER 2008 GLIWICE-UPM



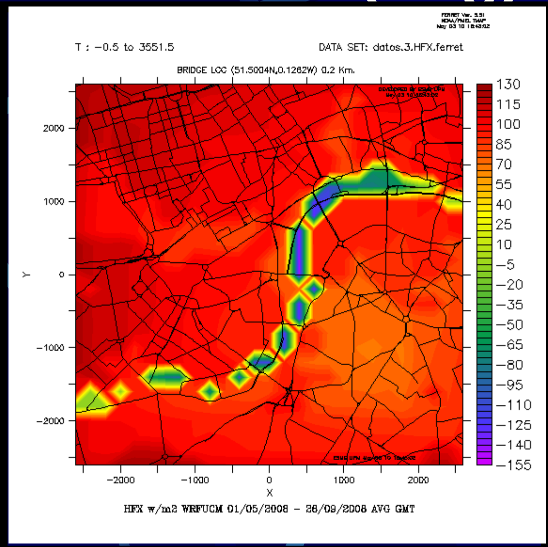
200 m. RES

15/05/2008 14:00 GMT

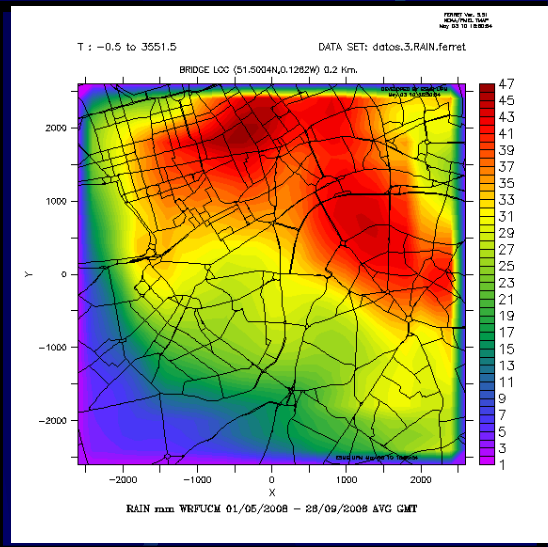
RESULTS. SUMMER 2008 (Avg) LONDON-UPM



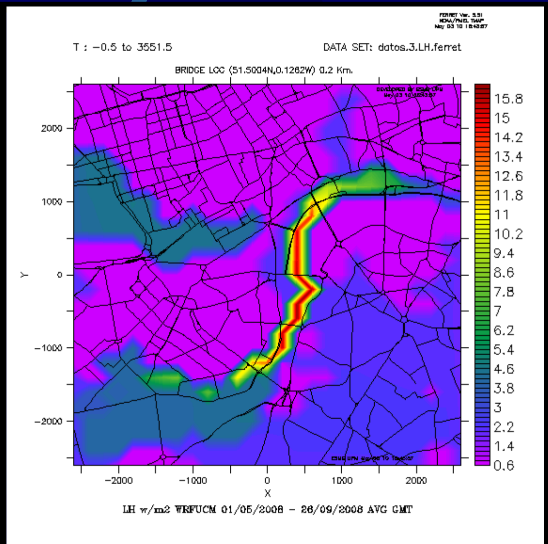
Temperature 2M (K)



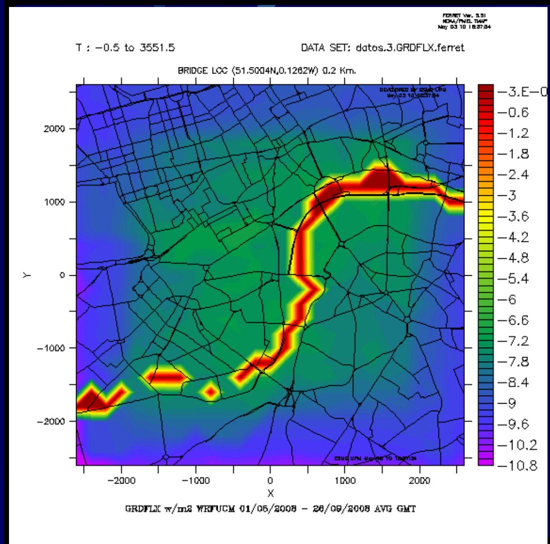
Sensible Heat Flux (w/m2)



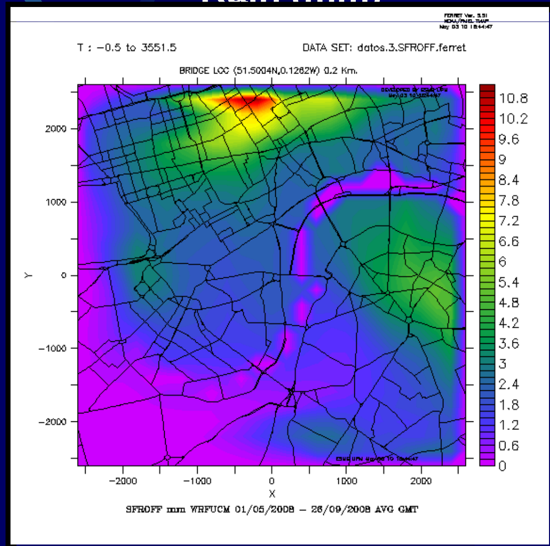
Rain (mm)



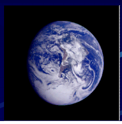
Latent Heat Flux (w/m2)



Ground Heat Flux (w/m2)



Surface Runoff (mm)



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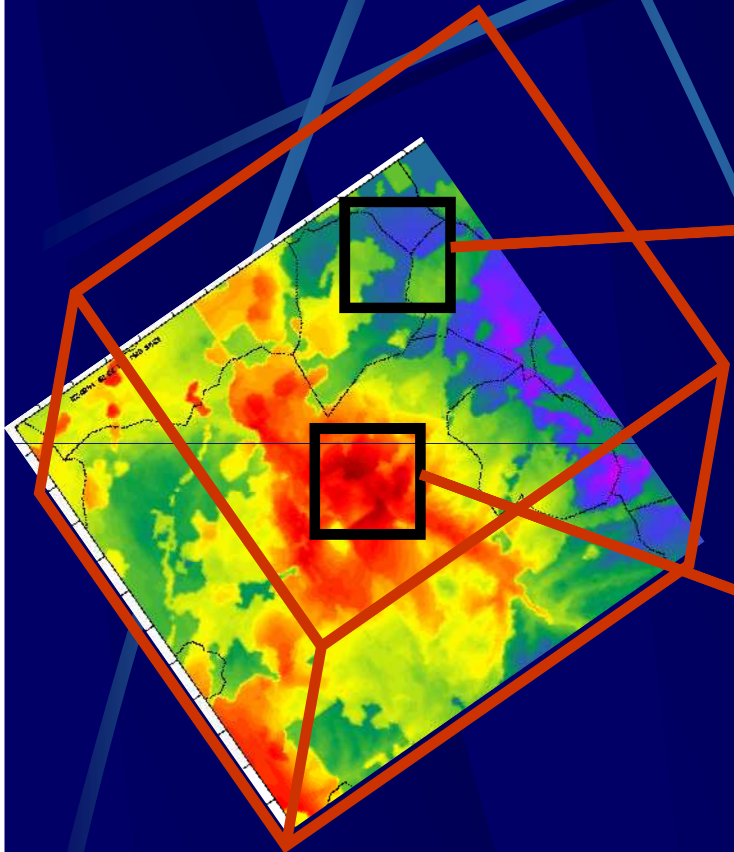

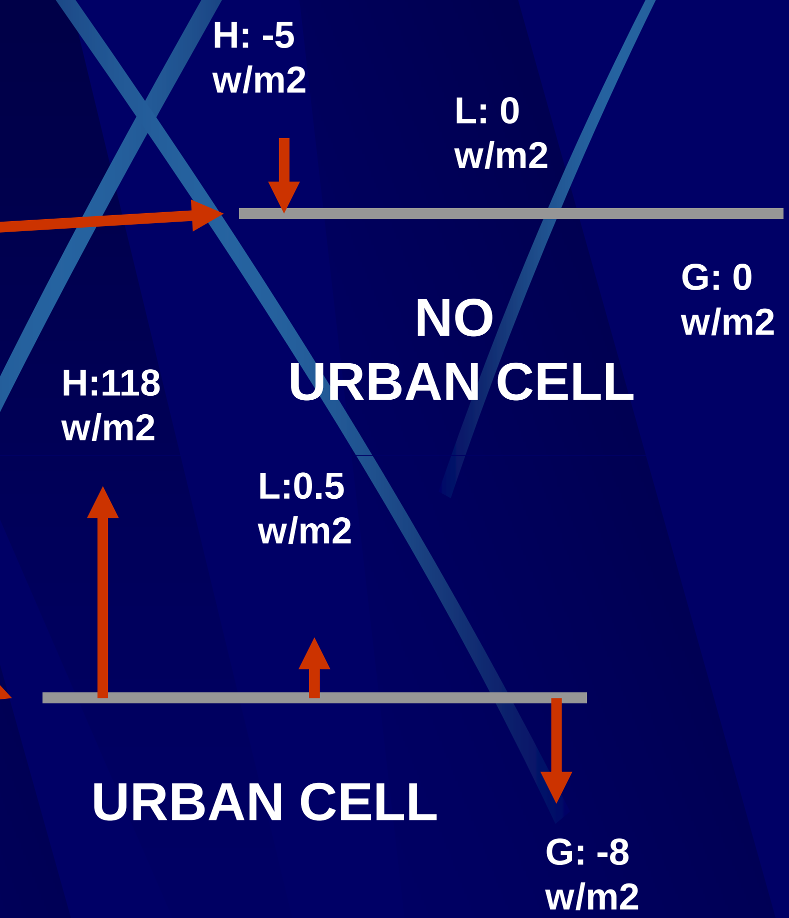

200 m. RES
15/05/2008 14:00 GMT

CPU & SPACE DISK UPM

WRF-UCM-NOAH

64 PROCESSORS	DOMAIN 48.6 KM	DOMAIN 5.4 KM	DOMAIN 0.2 KM	TOTAL DOMAIN
1 DAY 1 CITY	5 MIN 131 MB	10 MIN 49 MB	75 MIN 28 MB	90 MIN 208 MB
SUMMER 2008 1 CITY	13 HOURS 19.6 GB	25 HOURS 7.3 GB	191 HOURS 4.2 GB	9.5 DAYS 31.1 GB
SUMMER 2008 5 BRIDGE CITIES	2.7 DAYS 98 GB	5.2 DAYS 36.5 GB	40 DAYS 21 GB	**48 DAYS** **156 GB**

MICROSYS 1km (4m. RES) 3.6 MIN → 72 CPU HOURS (50 PROC)

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