Contribution to:

II EULAG WORKSHOP
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IMPLEMENTATION OF SURFACE ENERGY BALANCE FLUXES INTO EULAG MODEL: MADRID CASE STUDY

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- **WRF/NOAH/UCM output with 0.2 km spatial resolution as BC's and IC's will be used for EULAG model simulations with 4 m spatial resolution . Different runs have been done in three cities (Madrid (Spain), Florence (Italy) and Gliwice (Poland) over a 1 km x 1 km model domain.**

- **Surface energy fluxes have been implemented into EULAG code based on the procedures applied in UCM and NOAH/Land-surface model.**

- **A new micro shadow model SHAMO has been developed to calculate shadow areas (including reflections in urban areas) and short wave radiation in high resolution (meters) domains .**

MODELS: WRF

WRF : Next generation mesoscale meteorological model.

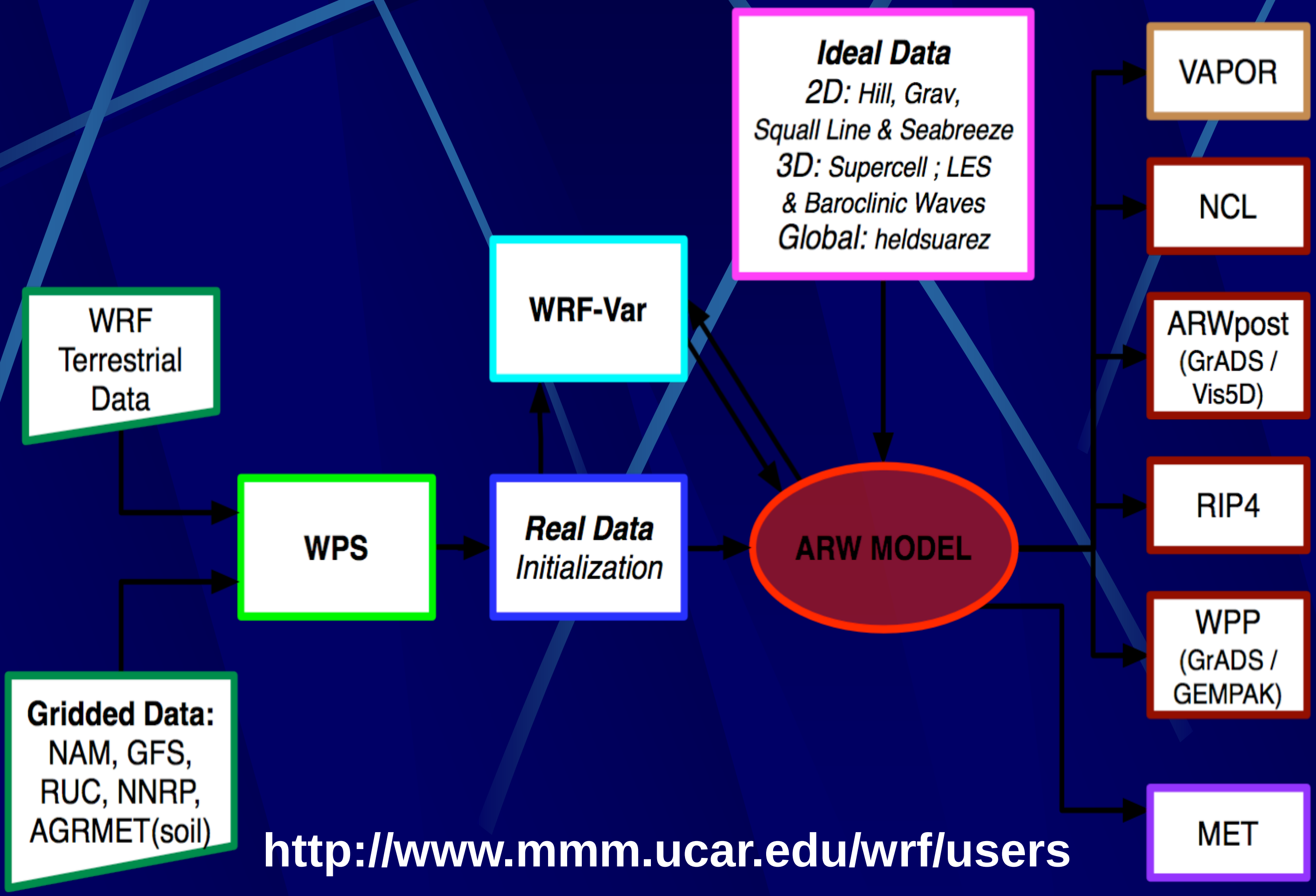
The equation set is fully compressible, Eulerian and nonhydrostatic. It is conservative for scalar variables. The model uses terrain-following, hydrostatic-pressure vertical coordinate with the top of the model being a constant pressure surface.

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)

WRF : Weather Research and Forecasting modeling system.



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

WRF/NOAH/UCM

-**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:

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 **)**

WRF/NOAH/UCM

-**Physics Options used in WRF**:

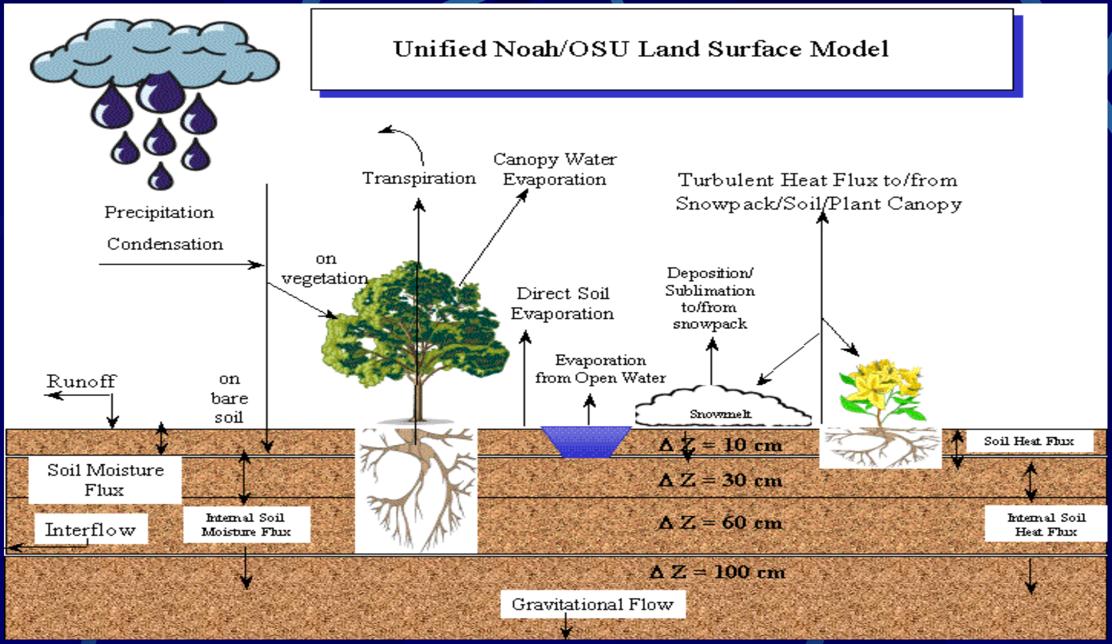
•Radiation Schemes:

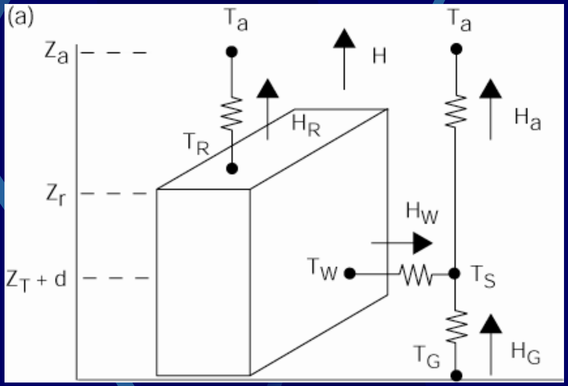
Rapid Radiative Transfer Model (RRTM) longwave radiation *(E.J. Mlawer, S.J. Taubman, P.D. Brown, M.J. Iacono and S.A. Clough, Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave, J. Geophys. Res.* ***102*** *(D14) (1997), pp. 16663–16682* **)**

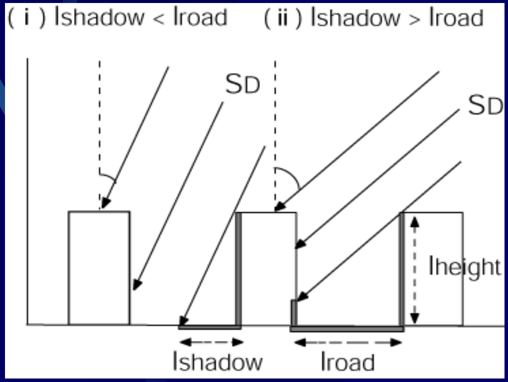
Simple cloud-interactive shortwave radiation scheme Dudhia radiation (Dudhia, Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional Model, *J. Atmos. Sci.* **46** (1989), pp. 3077–3107**)**

WRF/NOAH/UCM

Land surface model: NOAH/UCM

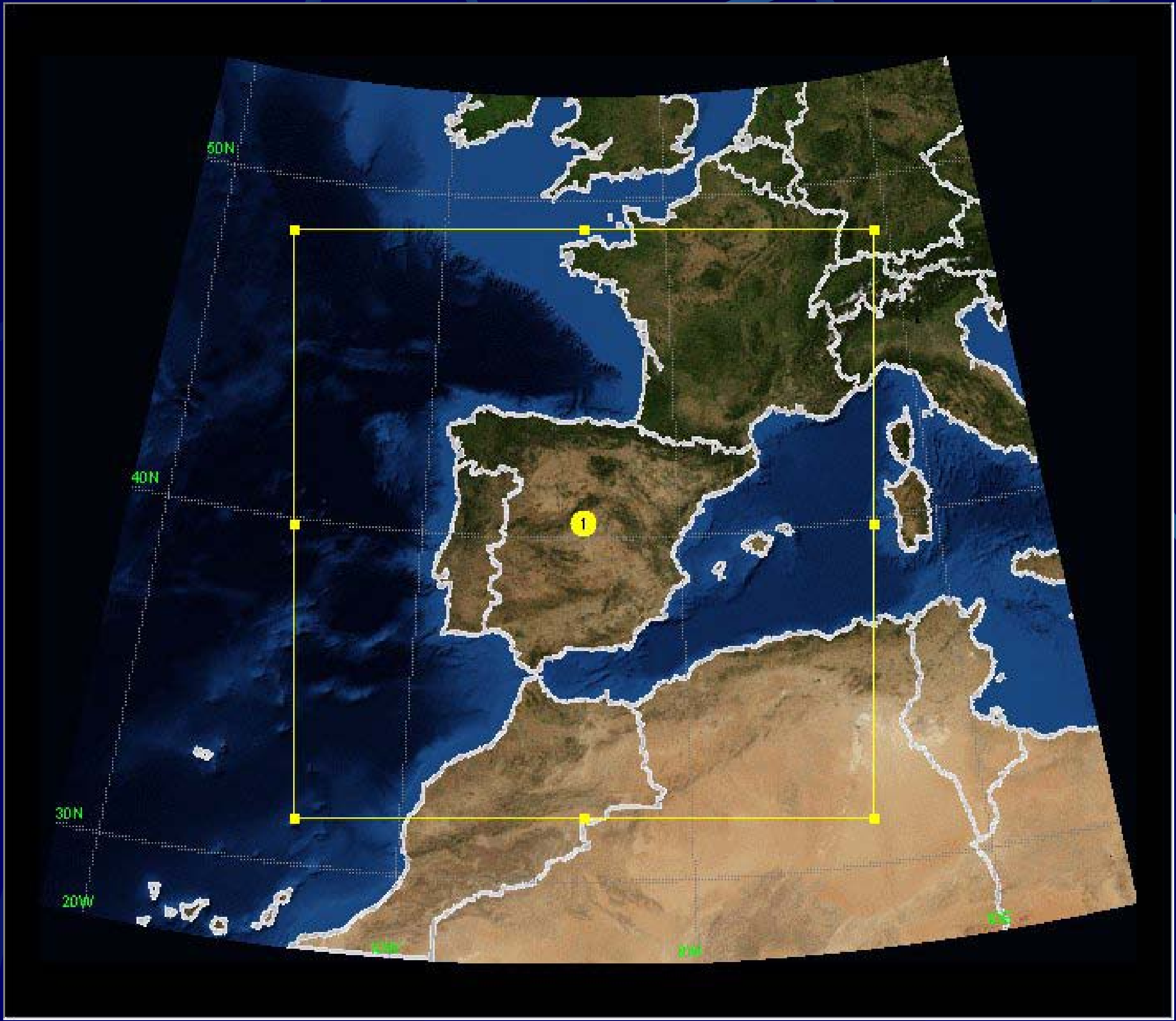






(Chen, F., Kusaka, H., Tewari, M., Bao, J.-W., Kirakuchi, H., 2004. Utilizing the coupled WRF/LSM/Urban modeling system with detailed urban classification to simulate the urban heat island phenomena over the greater Houston area. In: Proceedings of the 5th Conference on Urban Environment, 22–26 August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

DOMAINS. MOTHER DOMAIN



Lambert Conformal Conic

(-3.703, 40.412)

119*119 grid cells

16.2 km. resolution

Lowert left corner (-963900, -963900)

Iberian Peninsula

DOMAINS. 1 LEVEL NESTED DOMAIN

Lambert Conformal Conic

(-3.703, 40.412)

117*117 grid cells

1.8 km. resolution

Lowert left corner (-105300, --105300)

Madrid Community

DOMAINS. 2 LEVEL NESTED DOMAIN

Lambert Conformal Conic

(-3.703, 40.412)

127*127 grid cells

0.2 km. resolution

Lowert left corner (-13500, --13500)

Madrid Municipality

MESOSCALE DOMAINS. WRF ARCHITECTURE

MOTHER DOMAIN

59*59 grid cells

48.6 km. resolution

Lower left corner (-1433700, -1433700)

DT:300 s.

Projection: Lambert Conformal Conic

LEVEL 1:

37*37 grid cells

5.4 km. resolution

Lower left corner

(-121500, -121500)

DT: 30 s.

LEVEL 2:

28*28 grid cells

0.2 km. resolution

Lower left corner

(-2700, -2700)

DT: 0.6 s.

- **Global model data: GFS**
- **One way nesting. (two-way nesting uses higher CPU time in this case)**

MODELS. WRF-NOAH-UCM

The UCM (Urban Canopy Model) is a single layer model, used to consider the effects of urban geometry on surface energy balance and wind shear for urban regions

(H. Kusaka and F. Kimura, Coupling a single-layer urban canopy model with a simple atmospheric model: impact on urban heat island simulation for an idealized case, *Journal of Applied Meteorology* 43 (2004), pp. 1899–1910.)

To better represent the physical processes involved in the exchange of heat, momentum, and water vapor in the mesoscale model, the Urban Canopy Model (UCM) is coupled to the WRF model

(Tewari, M., Chen, F., Kusaka, H.,2006. Implementation and evaluation of a single-layer urban model in WRF/Noah. In: Proceedings of the 7th WRF Users' Workshop, June 2006)

MODELS: WRF-NOAH-UCM

UCM: Take the urban geometry into account in its surface energy budgets and wind shear calculations. Radiative, thermal, moisture effects and canopy flow model are accounted for in the UCM.

Main issues:

- 2-D street canyons that are parameterized to represent the effects of urban geometry on urban canyon heat distribution

- ***Shadowing from buildings and reflection of radiation in the canopy layer***

- ***3D Radiation treatment. Canyon orientation and diurnal cycle of solar azimuth angle***

- ***Wind profile within the urban canopy layer (Swaid 1993)***

MODELS: WRF-NOAH-UCM

Main issues:

-***Multi-layer roof, wall and road models***.

- ***Anthropogenic heat flux***

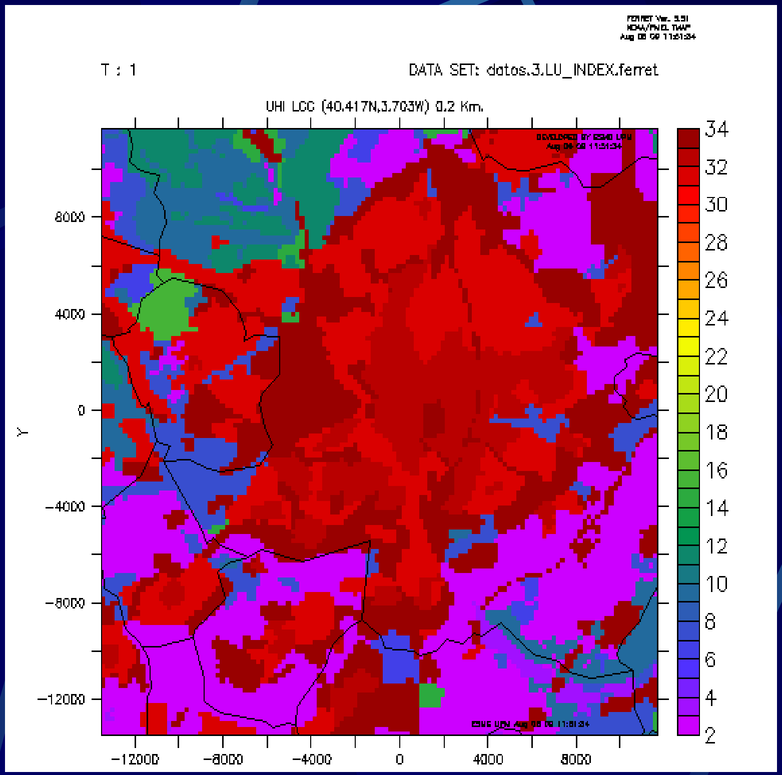
- ***Sensible heat fluxes are calculated from Jurge´s formula (Tanaka 1993) plus Monin-Obukhow similarity theory over urban canopy (Masson 2000 TEB).***

- Surface temperatures are determined from the multilayer heat equation solved numerically

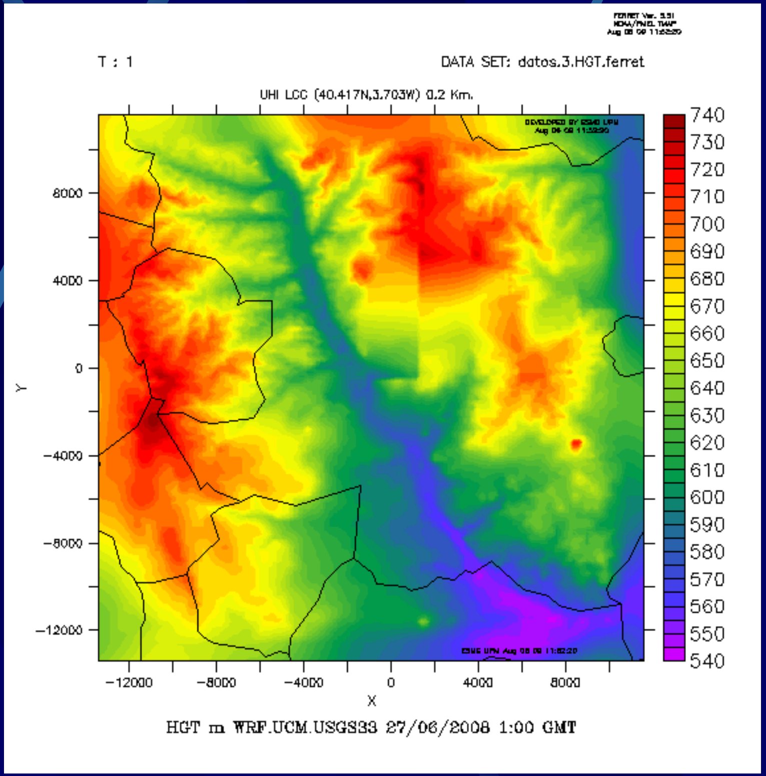
- Roof and road surfaces are impermeable layers.

- ***UCM can be run on-line/ off-line mode.***

WRF/NOAH/UCM. HIGHT RESOLUTION INPUT DATA



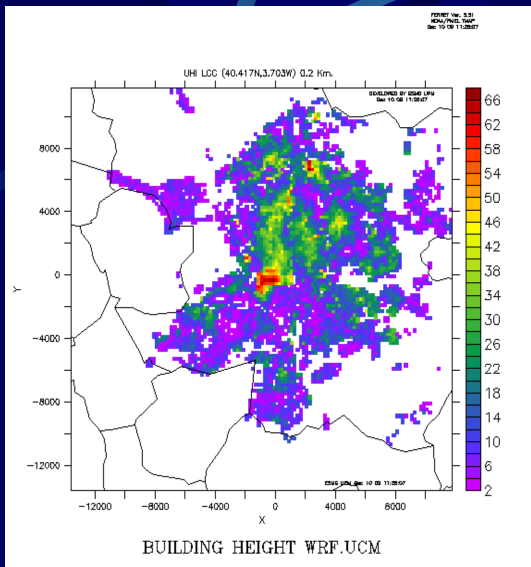
USGS+ 3 UCM CATEGORIES (31,32,33) FROM CLC 2000 (250 m) with 0.2 KM RES.



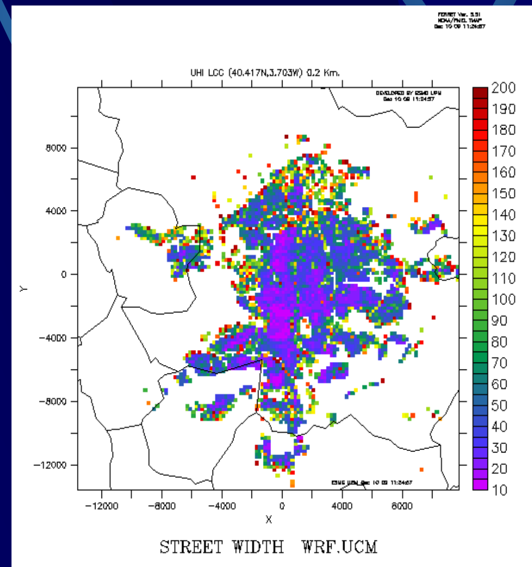
TERRAIN HEIGHT

0.2 KM RES.

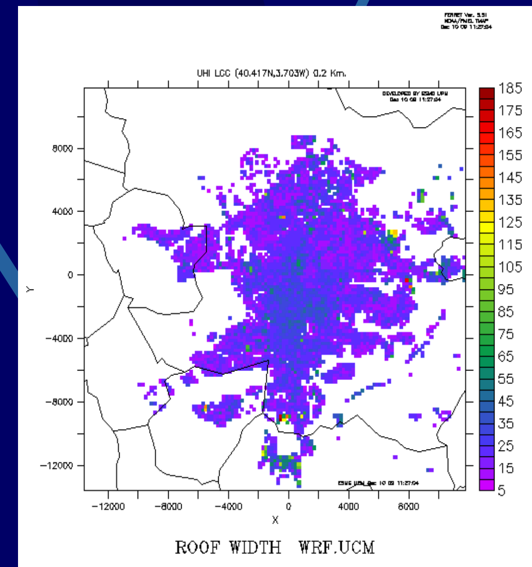
WRF/NOAH/UCM. HIGH RESOLUTION INPUT DATA



Urban Building Height



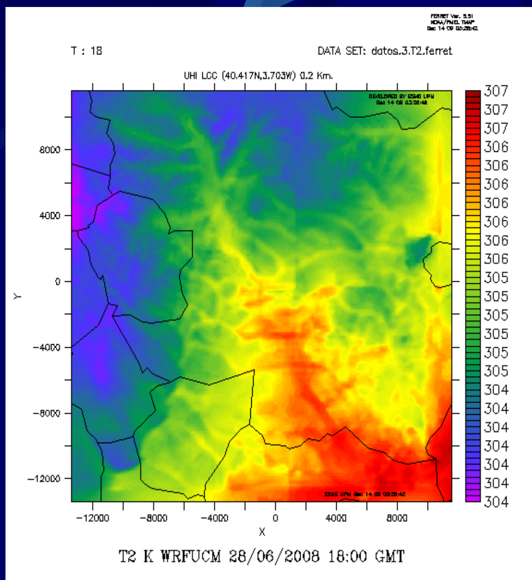
Urban Street Width



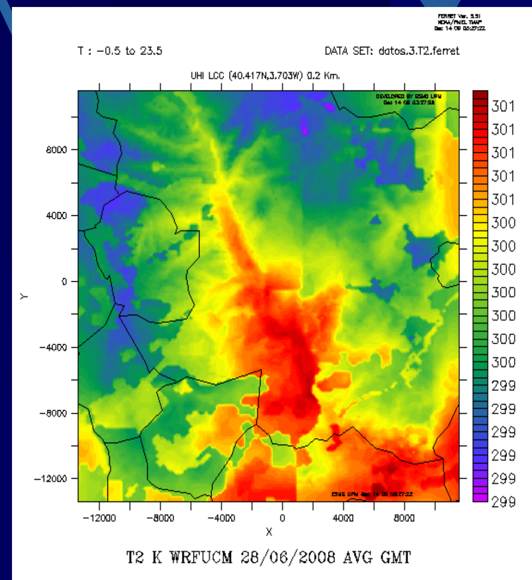
Urban Roof Width

WRF/NOAH/UCM. OUTPUTS

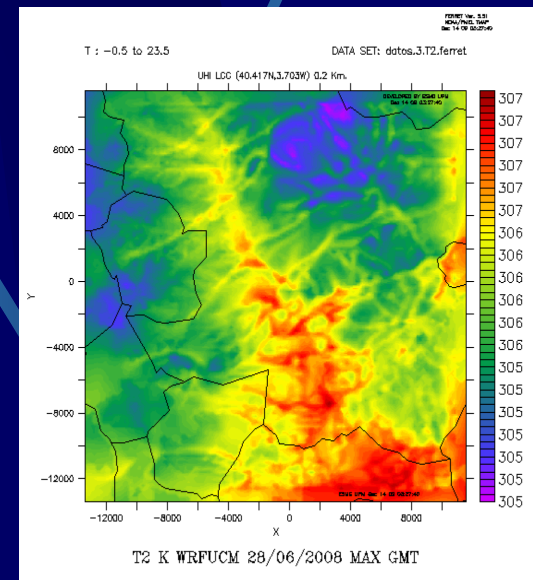
Air Temperature 2M (k) 28/06/2008



18:00 GMT

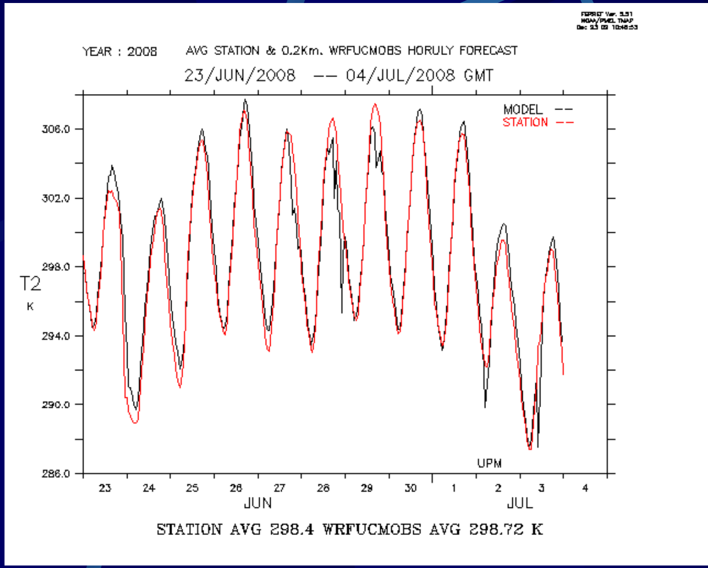


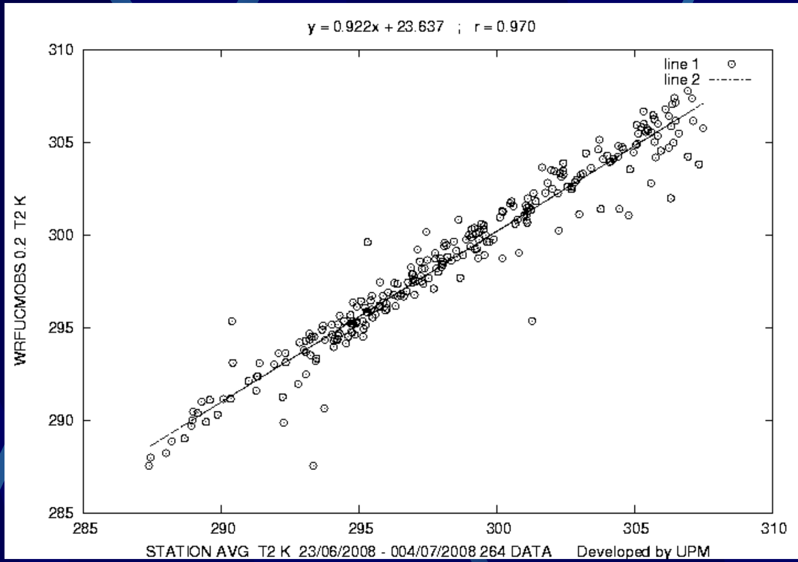
DAILY AVG



DAILY MAX

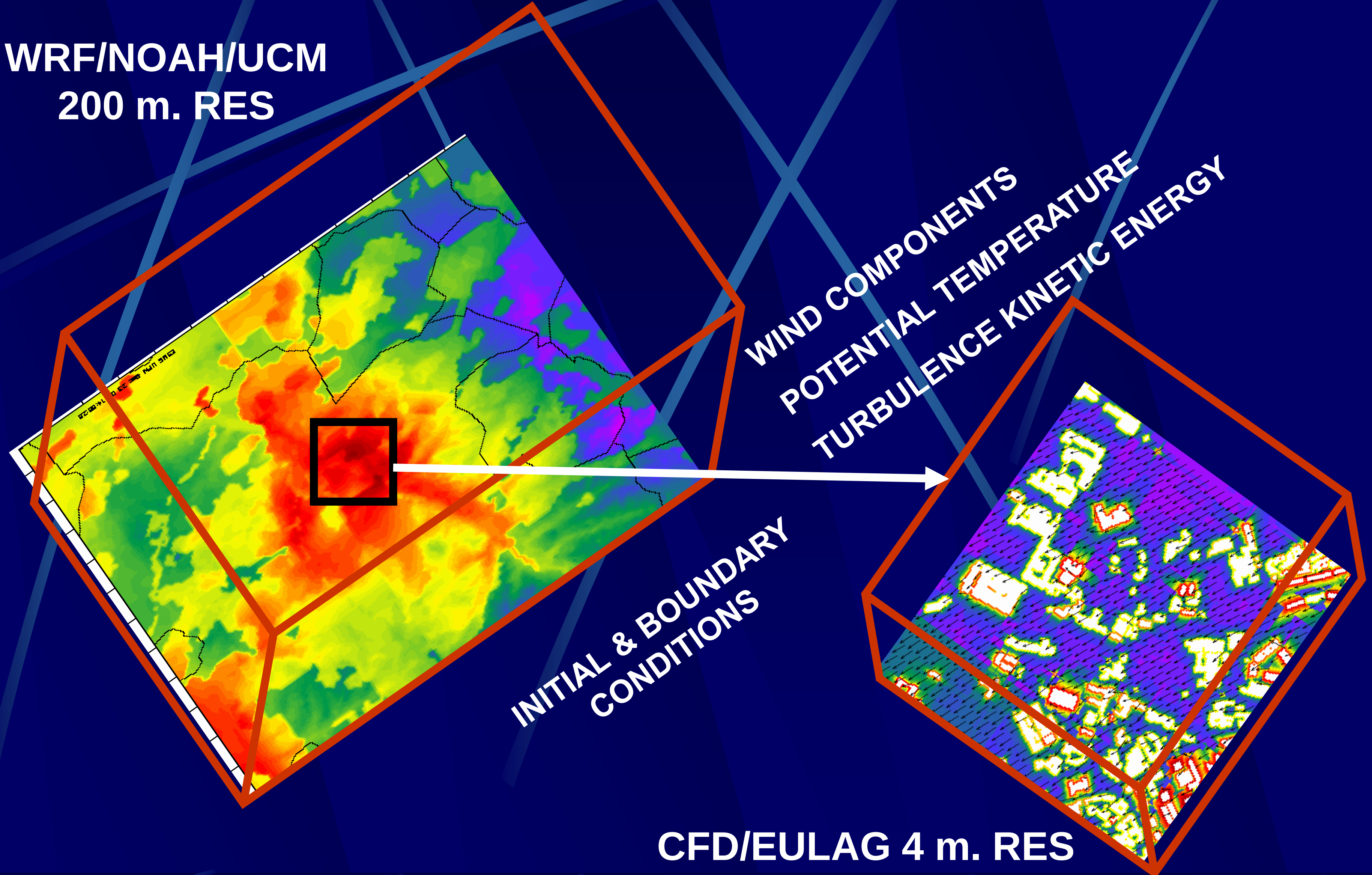
WRF/NOAH/UCM. VALIDATION



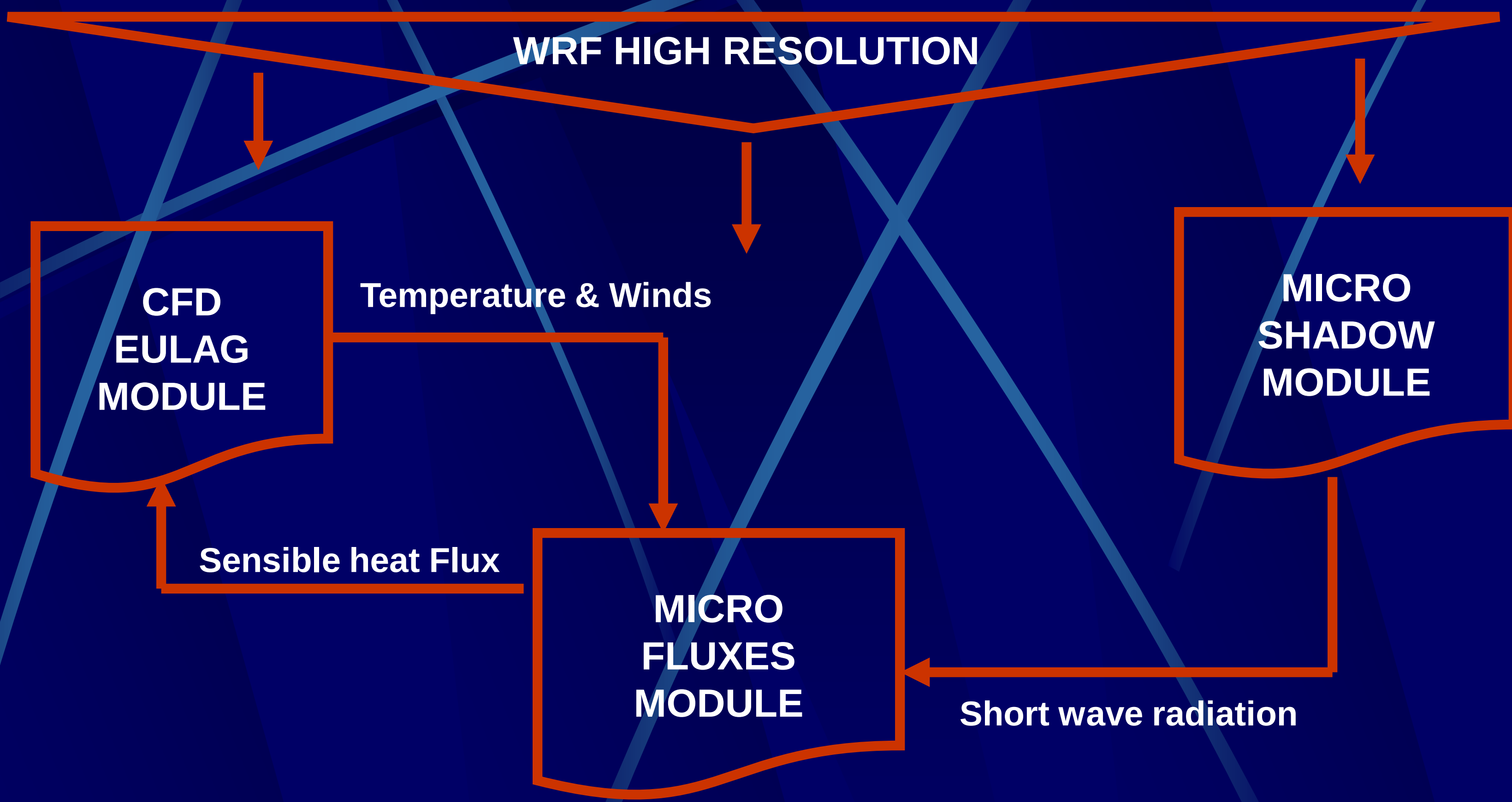


Air Temperature 2M

MESOSCALE TO URBAN SCALE



CFD EULAG – UCM/NOAH MICRO FLUXES- SHADOW MODEL



$$T\_eulag\_new = T\_eulag + (SHF / Rhoo*cpp*CHS)$$

SHF: Sensible heat flux. Rhoo: Air density. CPP=1004. CHS=Surface exchange coefficient f (Wrf)

MICROSYS-EULAG URBAN SIMULATIONS

TIME PERIOD: 28/06/2008 07:00 - 12:00 – 18:00 – 21:00

TIME STEP: 0.01 (7200 time steps)

OUTPUT FREQUENCY: 10 s.

EULAG OPTIONS:

- Numerical approximation: Eulerian conservation law

- Method to represent the edifice-> Immersed boundary

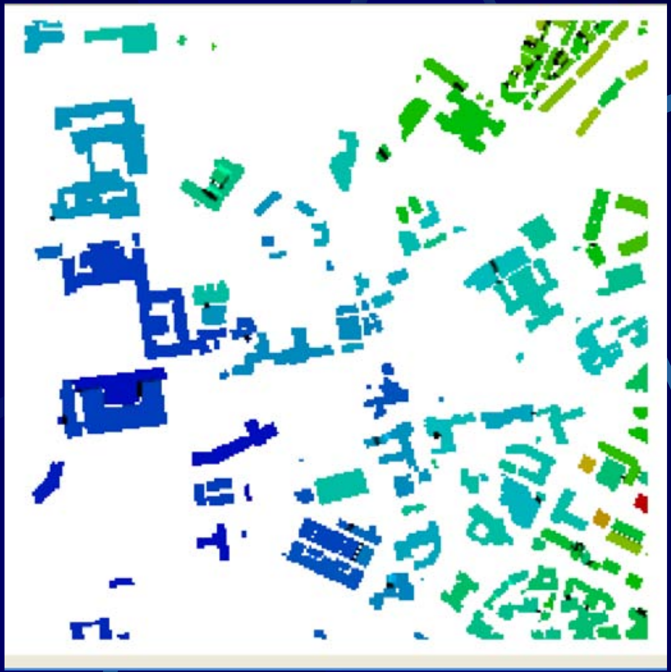
(R. Mittal and G. Iaccarino, Immersed boundary methods, *Ann. Rev. Fluid Mech.* 37 (2005), pp. 239–261.)

- 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

SETUP MICROSYS-EULAG MADRID

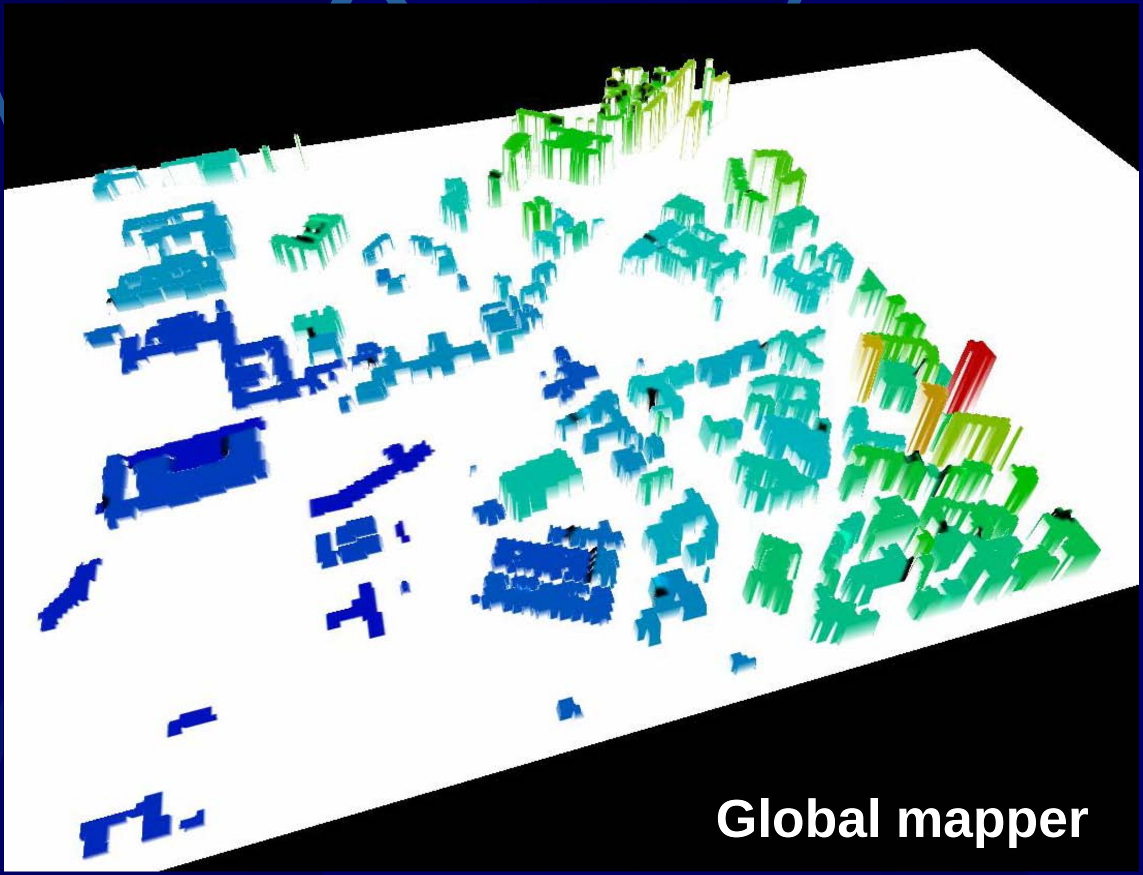


250*250 grid cells 4 m. resolution

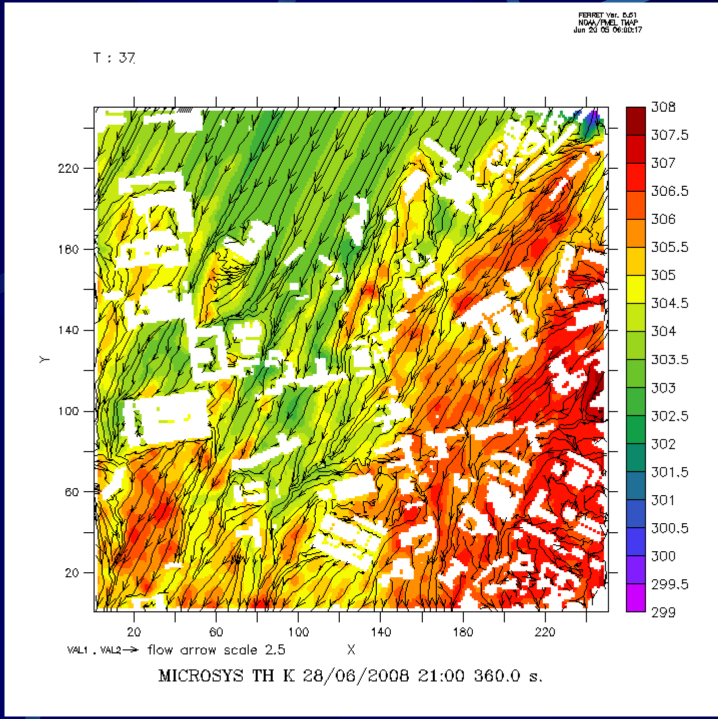
Height 100 m

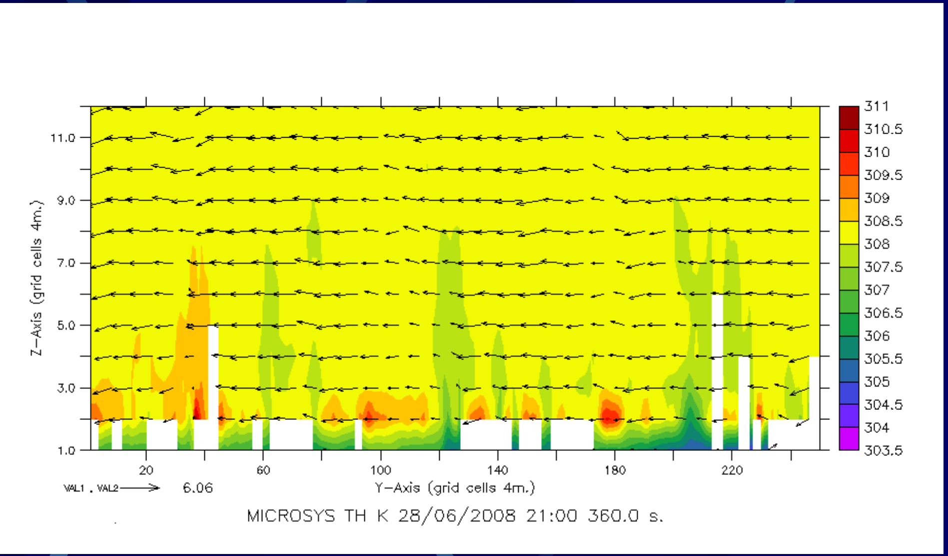
MADRID BUILDINGS

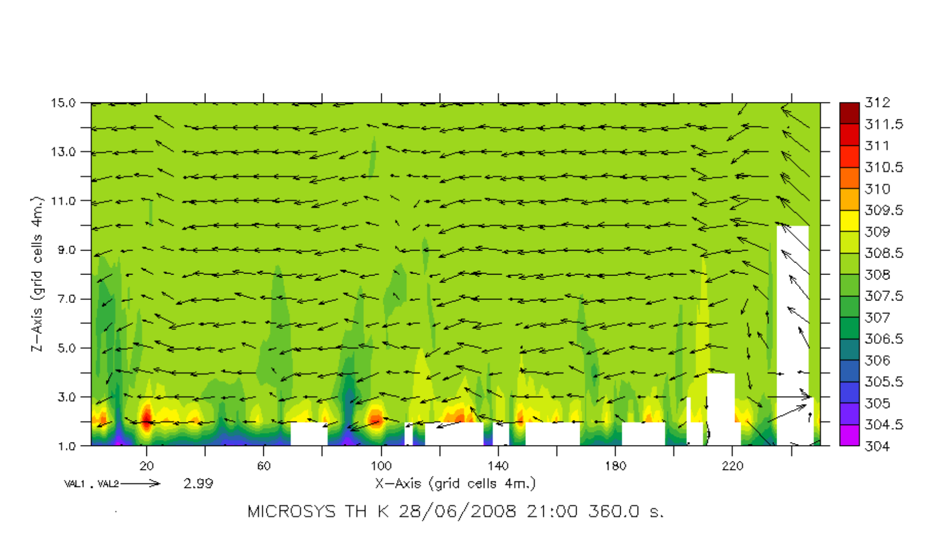
2D & 3D VIEW



MICROSYS-EULAG URBAN SIMULATIONS. RESULTS







POTENTIAL TEMPERATURE (K)

MADRID 28/06/2008 6 Min.

Surface & Vertical planes YZ, XZ

WRF – MICROSYS (EULAG+NOAH/UCM)

ATMOSPHERIC FORCING:

- -Pressure
- - Humidity
- - Precipitation

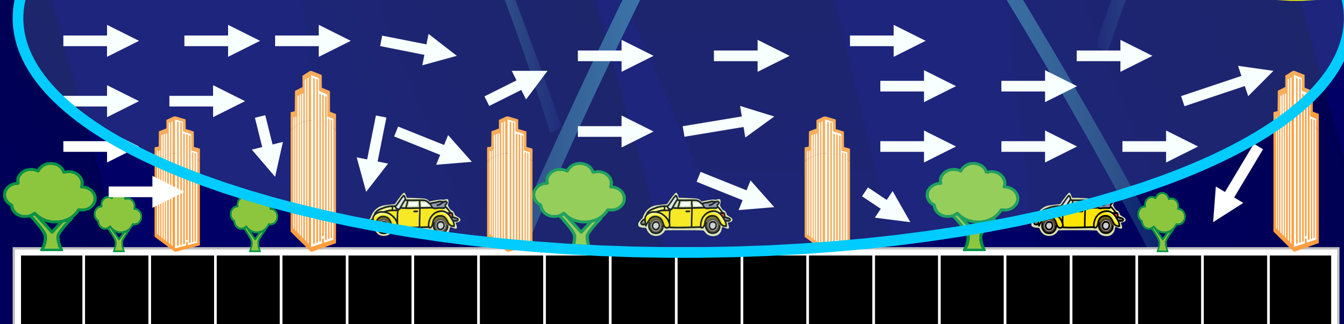
PBL SCHEME

RADIATION FORCING:

- - Long wave
- - Short ware

SURFACE SCHEME : Surface exchange coefficient for vertical turbulent exchange (Monin-Obukov theory)

Wind & Temperature from CFD (EULAG)

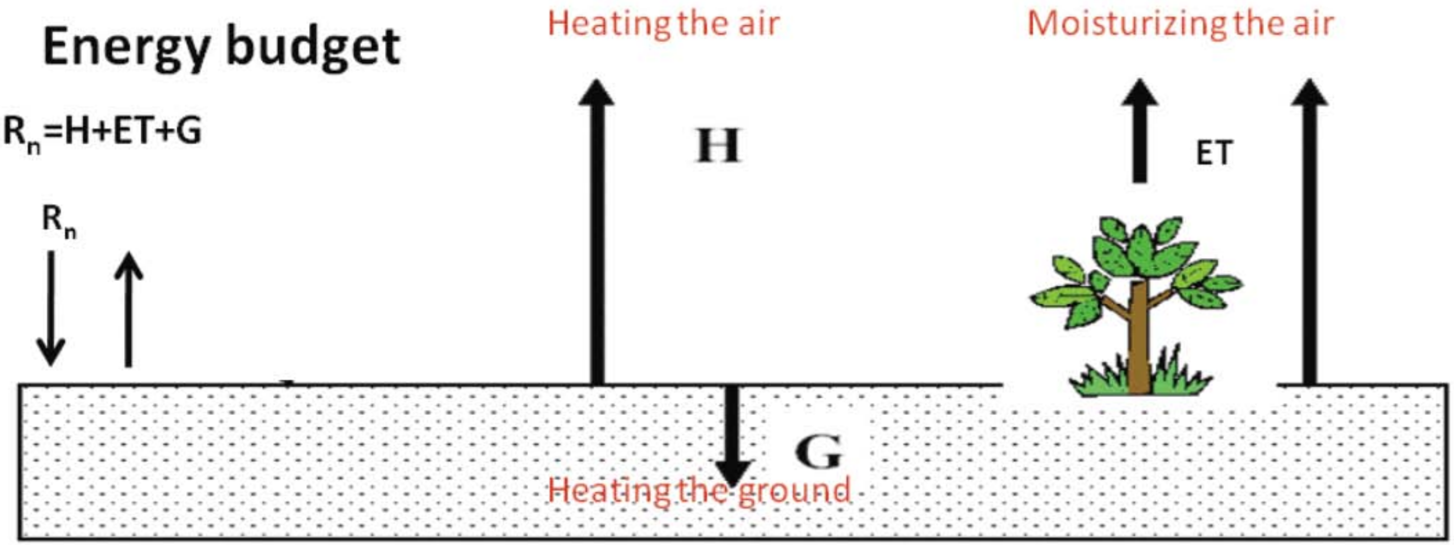


LAND SURFACE SCHEME: NOAH/UCM

High resolution 4m.

Energy budget

$R_n = H + ET + G$



$$R_n = R_n^s + R_n^l = (1-\alpha)F_d^s + \varepsilon F_d^l - \sigma\varepsilon T^4$$

- R_n: Net radiation
- α: albedo
- F_d^s: Insolation
- F_d^l: Longwave downward radiation
- ε: Emissivity
- T: Skin temperature

Radiation budget

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

Implementation of urban flux estimation into EULAG (MICROSYS): SIMPLE SHADOW MODEL

-Simple shadow model using ideal canyons in order to calculate short wave radiation (SWR) by each grid cell (4 meters)

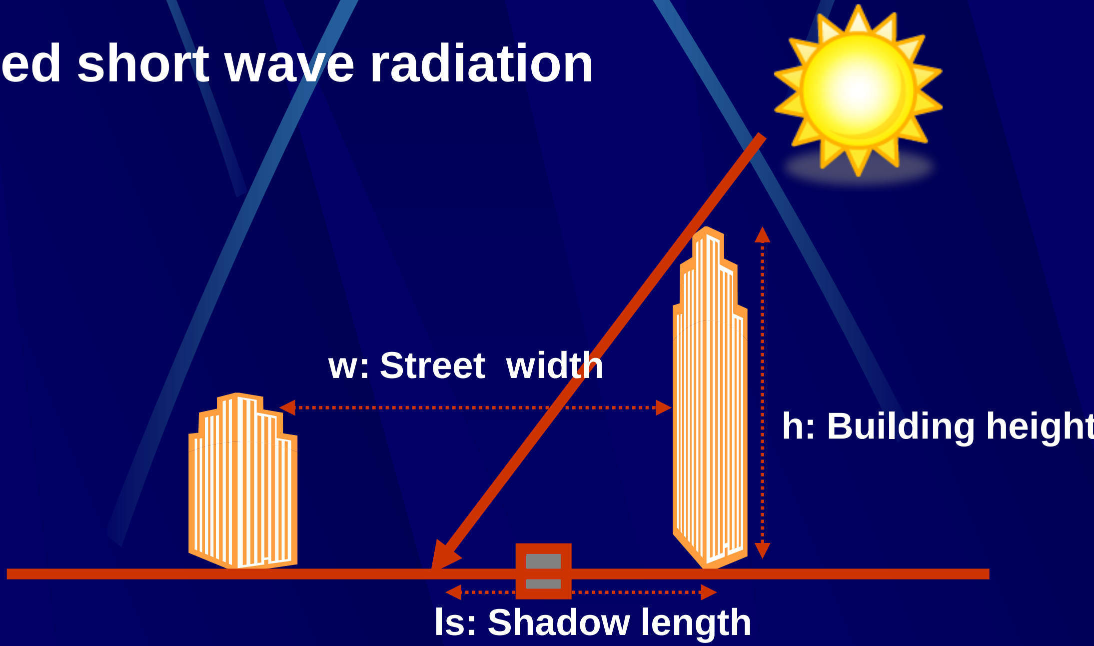
$$SWR = SWR_i + SWR_r$$

i: Incident short wave radiation

r: Reflected short wave radiation

Each grid cell is associated to the closet building to get the “h” parameter.

Data used: City 3d Building GIS



Implementation of urban flux estimation into EULAG (MICROSYS): SIMPLE SHADOW MODEL

Shadow length: ls

$$ls = h * \tan \sigma_z * \sin \sigma_n$$

σ_z : Solar zenit angle (from WRF radiation model)

σ_n : Street orientation (from GIS data)

IF ls > w THEN ls =w (Shadow length <= Street width)

Short wave radiation from WRF is splited into direct(d) & diffuse(q):

$$SWR_d = SWR\_WRF * 0.8$$

$$SWR_q = SWR\_WRF * 0.2$$

Implementation of urban flux estimation into EULAG (MICROSYS): SIMPLE SHADOW MODEL

SWR_i : Incident short wave radiation

$$SWR_i = SWR_d \frac{(w - ls)}{w}(1-\alpha) + SWR_q F_{sky}(1-\alpha)$$

SWR_r : Reflected short wave radiation

$$SWR_r = SWR_d \frac{ls}{2h}\alpha_w F_{walltoground}(1-\alpha) + SWR_q F_{sky}\alpha_w F_{walltoground}(1-\alpha)$$

α : Ground Albedo α_w : Wall Albedo $F_{SKY} = 1 - F_{walltoground}$

$$F_{walltoground} = \int_o^{H\_building} 1 - \frac{h}{\sqrt{h^2 + w^2}}$$

F_{SKY} : Sky view factor **$F_{walltoground}$: Wall view factor**

Implementation of NON urban flux estimation into EULAG (MICROSYS): NOAH/LAND-SURFACE MODEL

GROUND HEAT FLUX (GH)

GH= DF (T – STC(1)) / DSOIL

DF: Thermal diffusivity
T : skin temperature
STC(1) : soil temperature (firs layer)
DSOIL: width layer soil

THERMAL DIFFUSIVITY (DF)

- **SATURATED THERMAL CONDUCTIVITY**
- **DRY THERMAL CONDUCTIVITY**
- **TOTAL SOIL MOISTURE CONTENT**
- **POROSITY**
- **QUARTZ CONTENT**

Implementation of NON urban flux estimation into EULAG (MICROSYS): NOAH/LAND-SURFACE MODEL

SENSIBLE HEAT FLUX (SH)

$$SH = (CH * CP * SFCPRS) / (R * T2V) * (TH2 - T)$$

CH : Surface exchange coefficient (surface scheme)
SFCPRS : Surface pressure
T2V : Virtual temperature (from cfd)
TH2: Potential temperature (from cfd)
CP,R: Constants

LATENT HEAT FLUX (LH)

$$LH = EDIR + EC + ETT$$

EC : Canopy water evaporation
EDIR: Direct soil evaporation
ETT : Total plant transpiration

Implementation of NON urban flux estimation into EULAG (MICROSYS)

POTENTIAL EVAPORATION ETP SPLITTING

EDIR = “SOIL MOISTURE CONTENT (SMC)” * ETP

EC = “CANOPY MOISTURE CONTENT (CMC) ” * ETP

CMC = CMC_old + (RAIN – EC)

ETT = “PLANT COEFFICIENT” * ETP

PLANT COEFFICIENT → CANOPY RESISTANCE

- LAI: leaf area index
– Rc_min ≈ f(vegetation type)
– F1 ≈ f(amount of PAR:solar insolation)
– F2 ≈ f(air temperature: heat stress)
– F3 ≈ f(air humidity: dry air stress)
– F4 ≈ f(soil moisture: dry soil stress)

$$Rc = \frac{Rc\_\min}{LAI\ F_1\ F_2\ F_3\ F_4}$$

Implementation of NON urban flux estimation into EULAG (MICROSYS)

POTENTIAL EVAPORATION ETP (PENMAN)

Potential evaporation: amount of evaporation that would occur if a sufficient water source were available. Surface and air temperature, insolation, and wind all affect this

ETP = EPSCA * RCH / 2.501e+6
EPSCA = (A * RR + RAD * DELTA) / (DELTA + RR)
RCH = (SFCPRS / (287.4*T2V)) * 1004.5 * CH

A → SATURATION SPECIFIC HUMIDITY & 2M SPECIFIC HUMIDITY
RR = [EMISSIVITY * T^4 * 6.48e-8 / (SFCPRS * CH) + 1.0] + “RAIN”
RAD = (TR – EMISSIVITY * T^4 * T – GH) / RCH*TH2-SFCTMP
DELTA → Slope of saturation specific humidity curve at T = surface temperature (SFCTMP)
CH : Surface exchange coefficient (surface model)

Implementation of NON urban flux estimation into EULAG (MICROSYS)

SURFACE WATER BALANCE

dSCM = P - R – ETP

dSMC = change in soil moisture content (SMC)
P = precipitation
R = runoff (Rainfall infiltration rate Schaake & Koren model. Calculations based on hydraulic conductivity and diffusivity)
ETP = Potential evaporation

(P-R) = infiltration

MICROSYS 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)

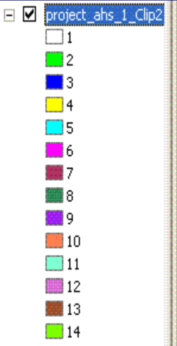
EDIR: Direct soil evaporation (w/m2)

EC: Canopy Water evaporation (w/m2)

ETT: Total Plant Transpiration (w/m2)

FRC_URB: Urban Fraction

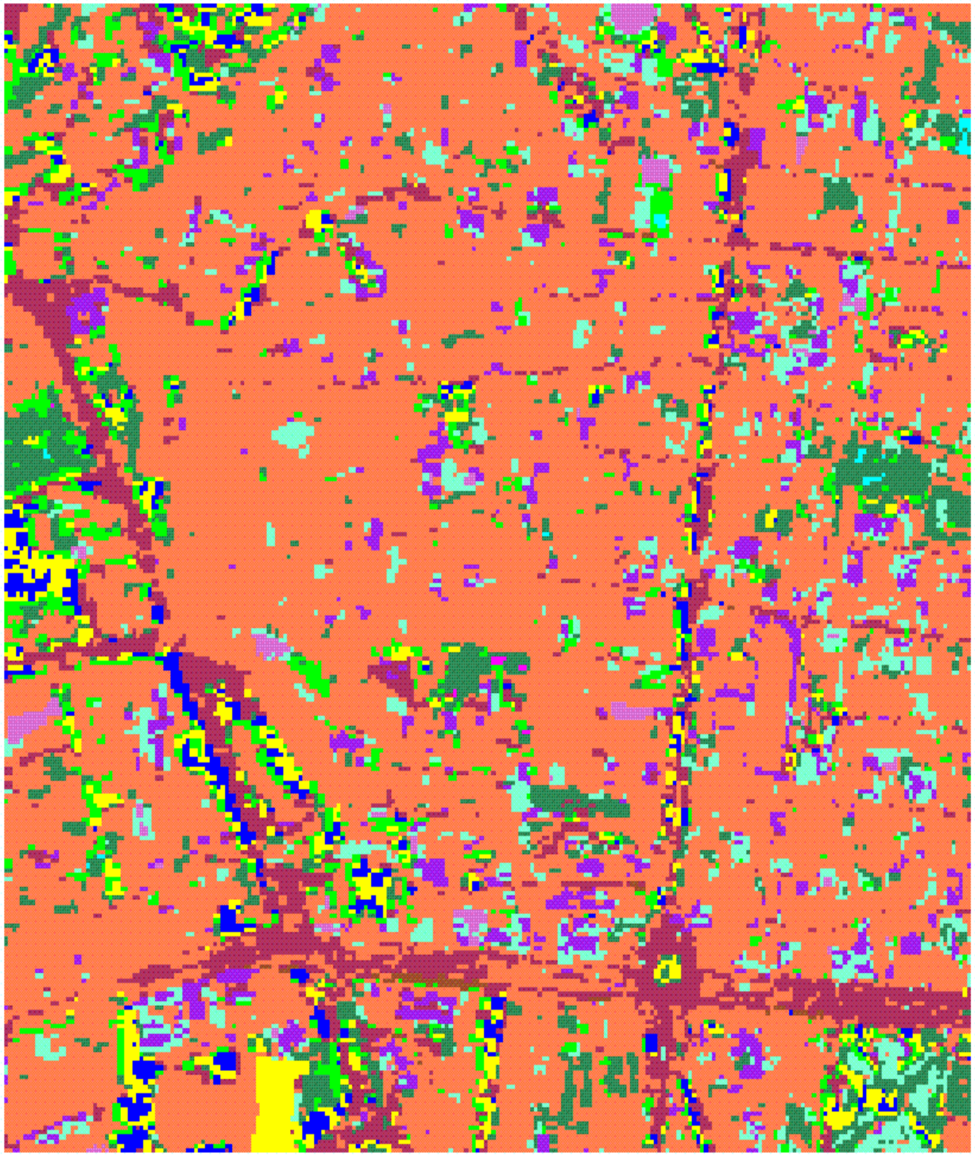
MICROSYS-MADRID- DETAILED LANDUSES



AIRBONE DATA
4m RES
LANDUSE

1: water (lake)
2: water
3: trees
4: green grass
5: bright bare
6:dark bare
7: roads
8: other pavement
9: asphalt roofs
10: tile roofs
11:concrete roofs
12: metal roofs
13: shadows
14: no data

1KM * 1KM



MICROSYS-MADRID-DETAILED LANDUSES

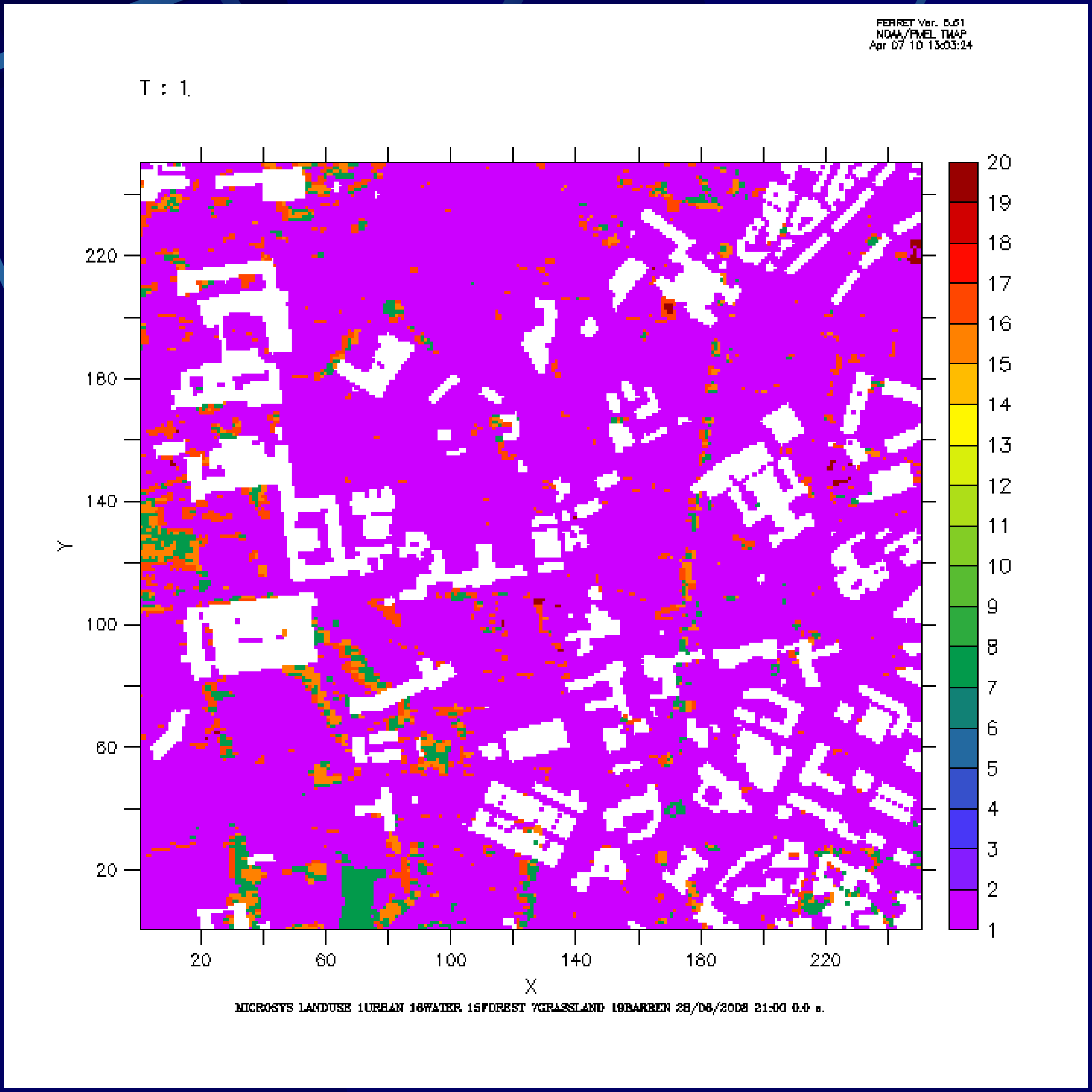
AIRBONE >>> USGS

NOAH 4m RES LANDUSE

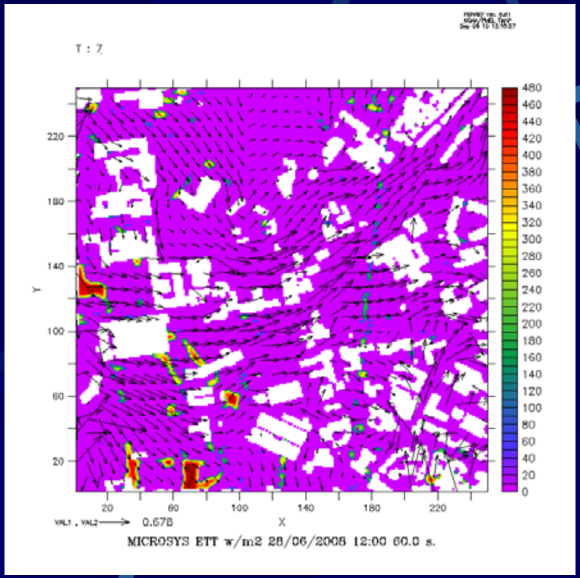
USGS (AIRBONE)

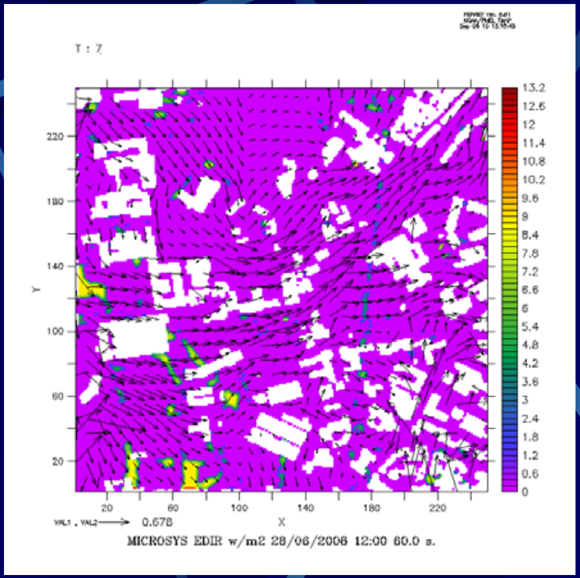
1: urban (7-14 airbone)
7: grassland (4 airbone)
15: mixed forest (3 airbone)
16: water (1,2 airbone)
19: barren (5,6 airbone)

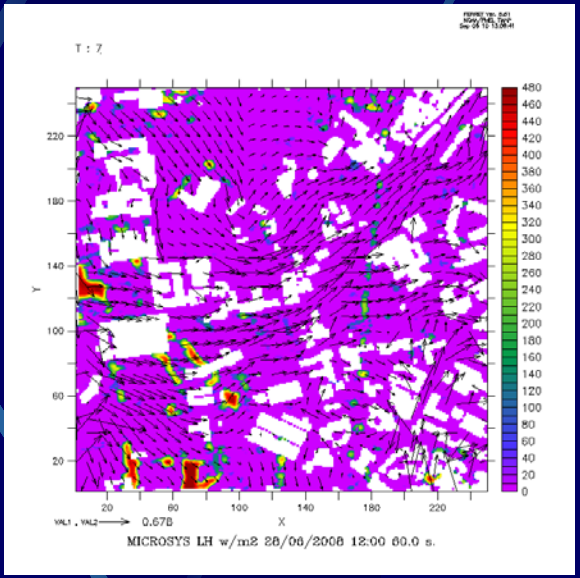
1KM * 1KM

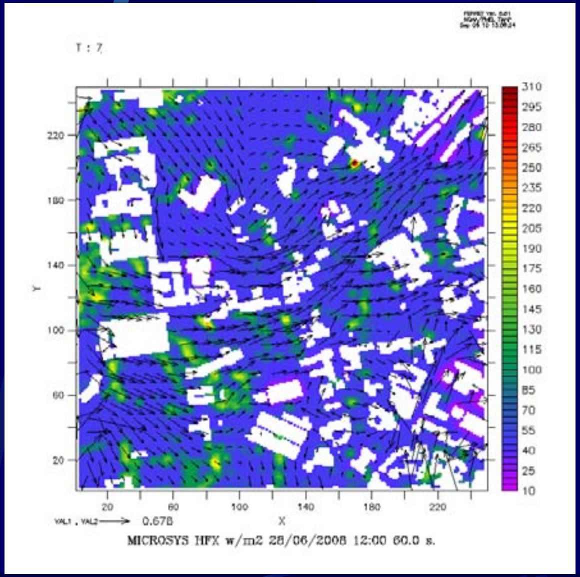


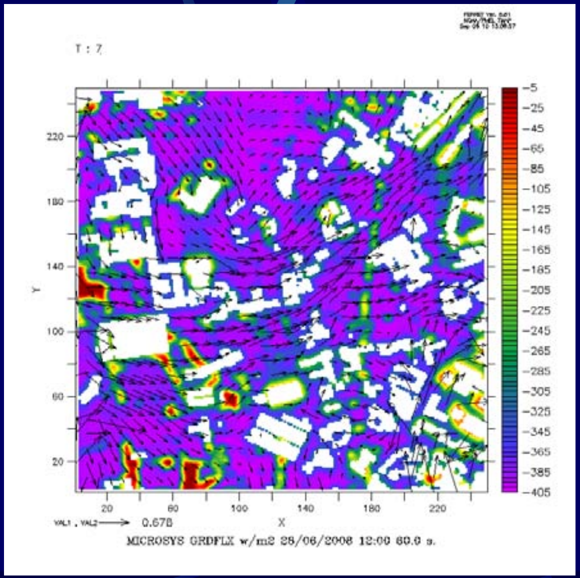
MICROSYS-FLUXES (SIMPLE SHADOW MODEL). MADRID 28/06/2008 12:01

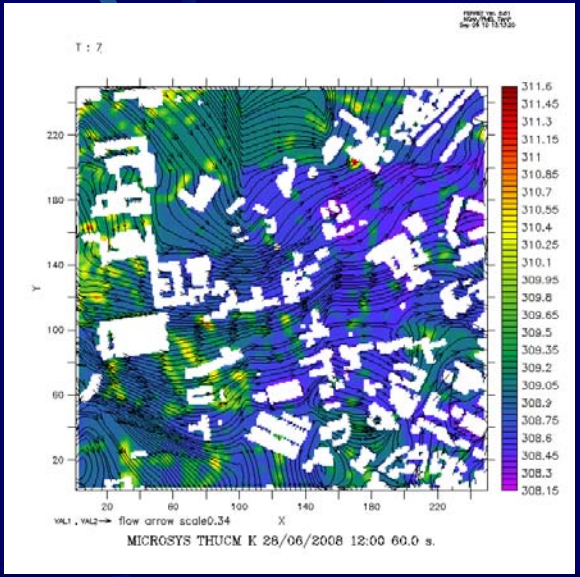










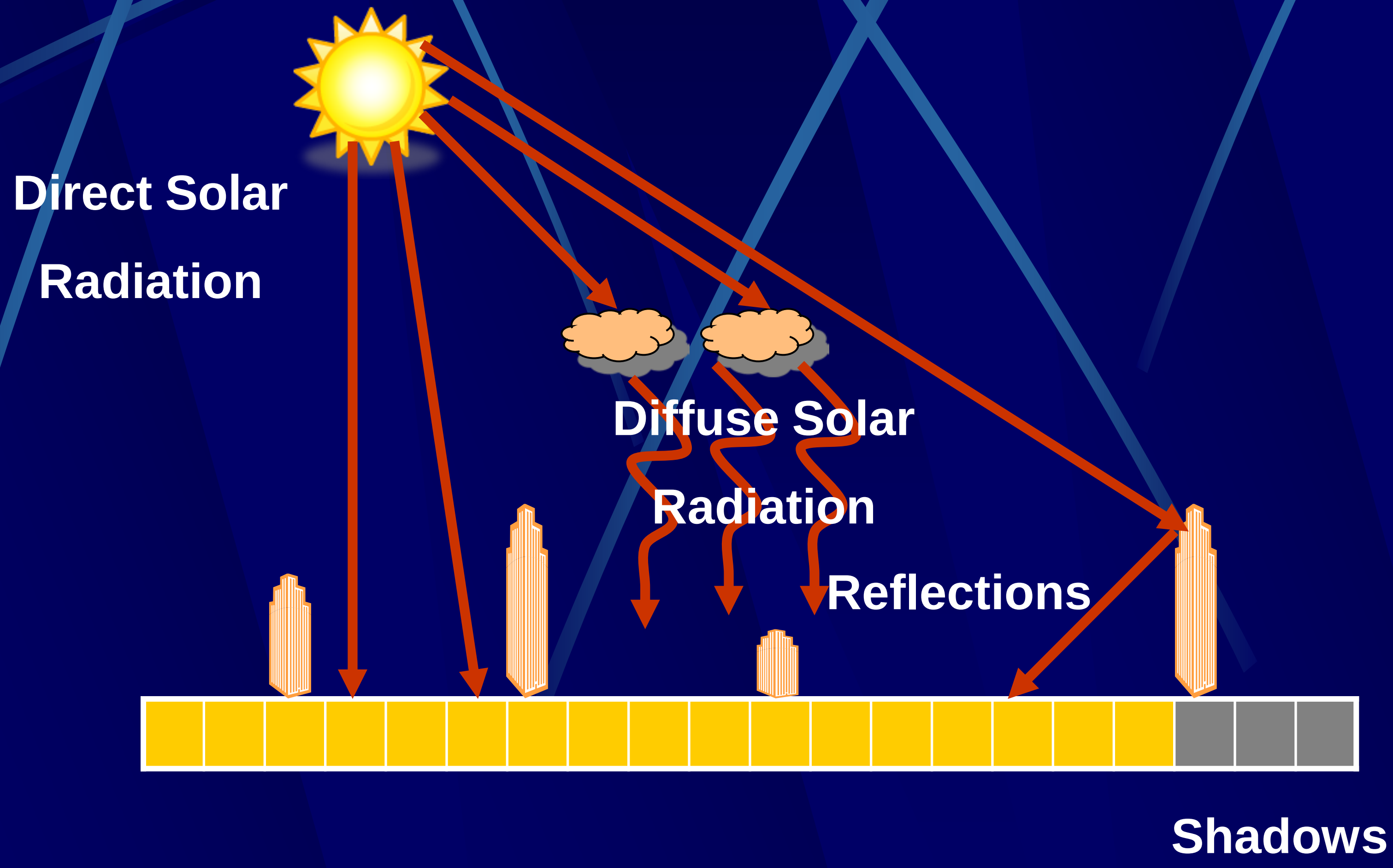


MICRO-URBAN SOLAR RADIATION MODEL

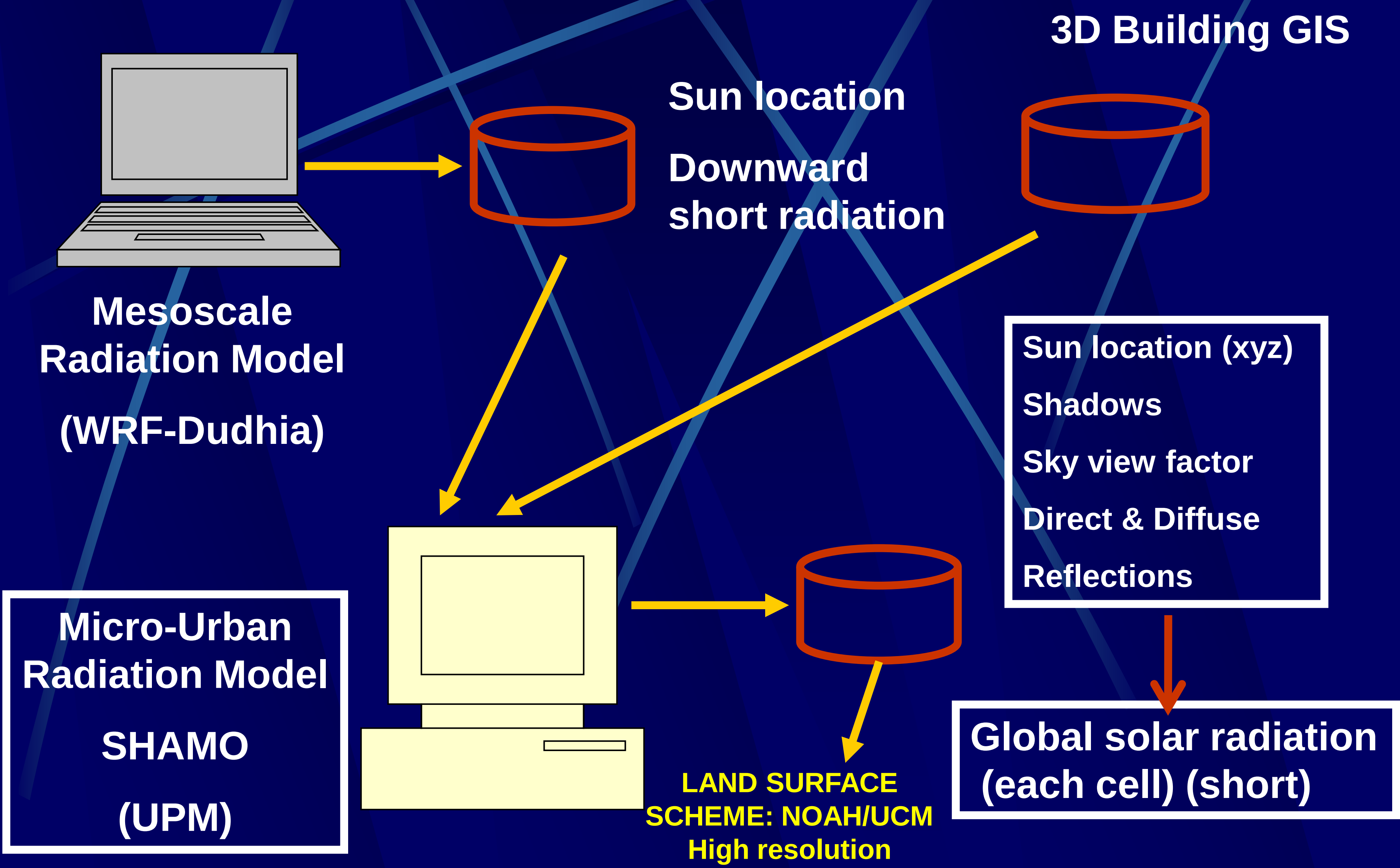
-Multiple reflections

-non idealized canyon street approach

- Direct and diffuse solar radiation are calculated with clouds effects



MICRO-URBAN SOLAR RADIATION MODEL



MICRO-URBAN SOLAR RADIATION MODEL

Final Solar Radiation: (Including m reflections)

$$FSR_{i,m} = \sum_k FSR_{k,m-1} * ALB * FREFLECTION$$

$FSR_{i,m}$: Final Solar Radiation, grid cell i, after m reflections

$FSR_{k,m-1}$: Final Solar Radiation, grid cell j, after m-1 reflections

ALB : Surface Albedo

FREFLECTION : Reflection Factor

m=0 → Initial Solar Radiation ISR (No reflections yet)

Iterative calculations STOP → Reflections Increase FSR < 1% ISR

MICRO-URBAN SOLAR RADIATION MODEL

Initial Solar Radiation: (No reflections)

ISR = FSHADOW * DIRSR + FSKY *DIFSR

FSHADOW: Building shadow effect.

FSHADOW=1 → The grid cell is in the sun

FSHADOW=0 → The grid cell is in the shade

DIRSR: Direct Solar Radiation (W/m2)

DIFSR: Diffuse Solar Radiation (W/m2)

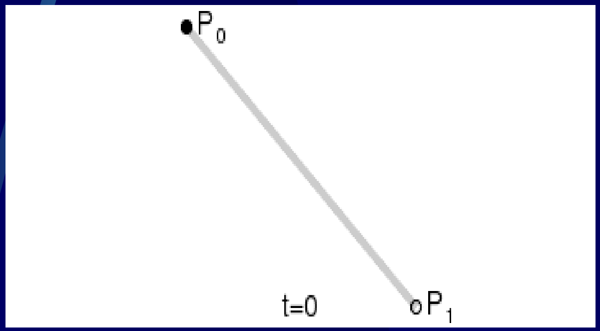
FSKY: Sky View Factor [0-1]

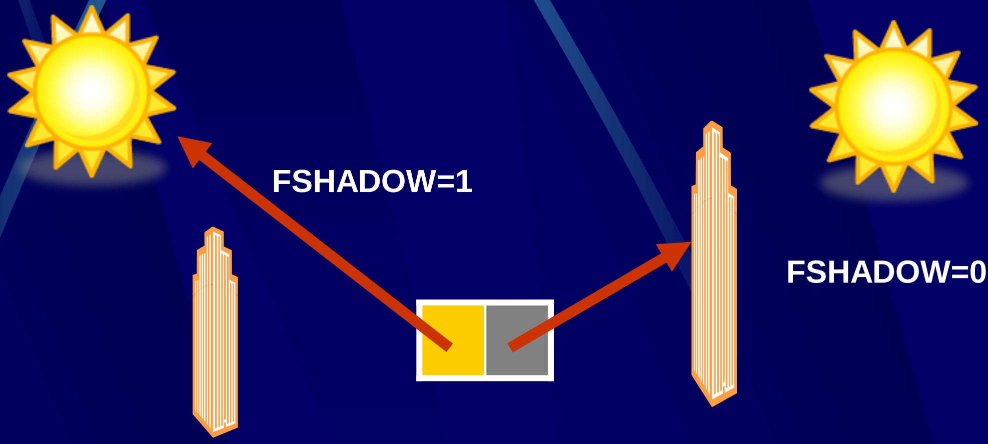
MICRO-URBAN SOLAR RADIATION MODEL. SHADOWS

FSHADOW:

- 3D Straight line from center of the grid cell to the sun

- Follow the straight line, if it collides with a building grid cell then FSHADOW=0 else FSHADOW=1





MICRO-URBAN SOLAR RADIATION MODEL. SHADOWS

SUN´s POSITON:

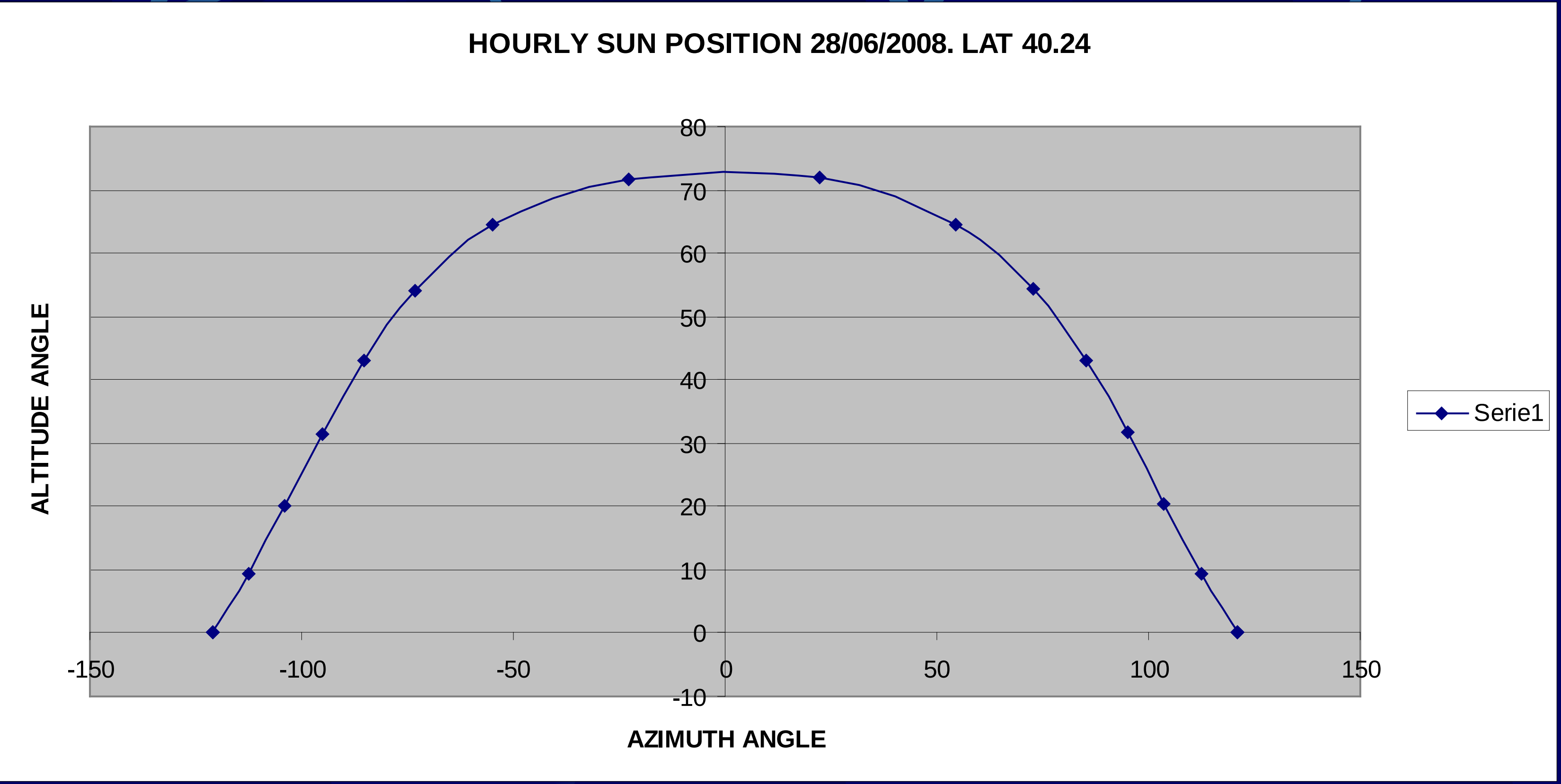
- Inputa data from mesoscale radiation model:
  - * Declination angle (d)
  - * Zenith angle (z)
  - * Hour angle (w)

↓

- Celestial coordinate system:
  - * Solar altitude angle (α): 90º - z
  - * Solar azimuth angle (y): $\cos y = \frac{\sin(\alpha)\sin(w) - \sin(d)}{\cos(\alpha)\cos(w)}$

MICRO-URBAN SOLAR RADIATION MODEL. SHADOWS

SUN´s POSITON:



MICRO-URBAN SOLAR RADIATION MODEL. SHADOWS

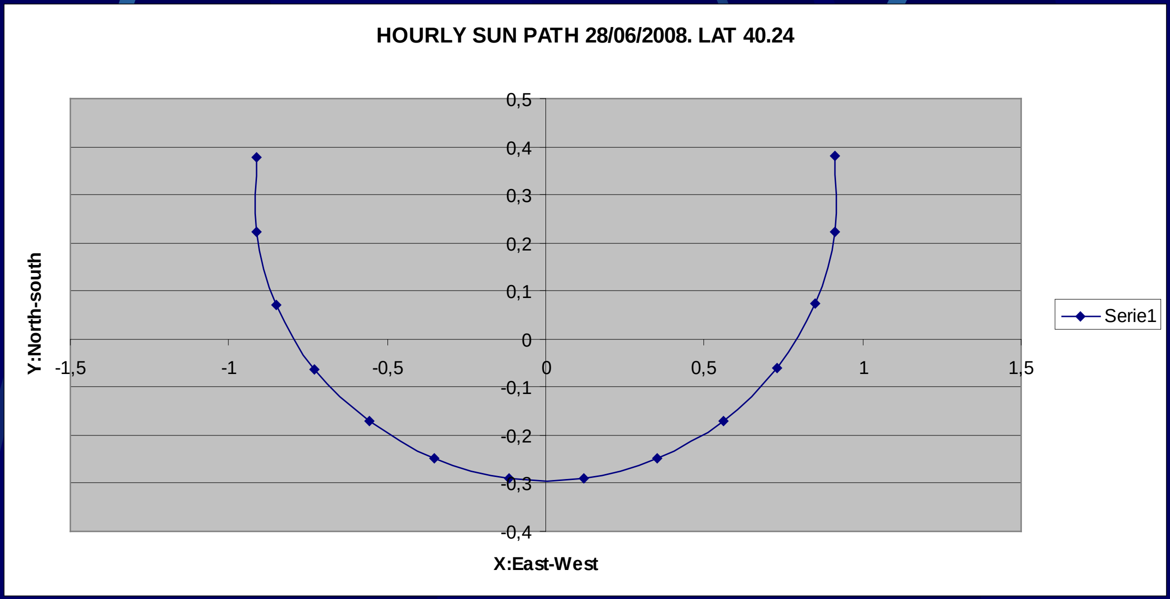
SUN´s POSITON: Cartesian coordinates

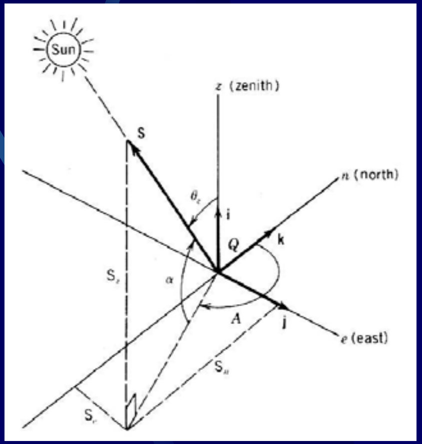
$x = r \ \cos(\alpha) \sin(y)$

$y = r \ \cos(\alpha) \cos(y)$

$z = r \sin(\alpha)$

R: Sphere radius covering the 3d domain



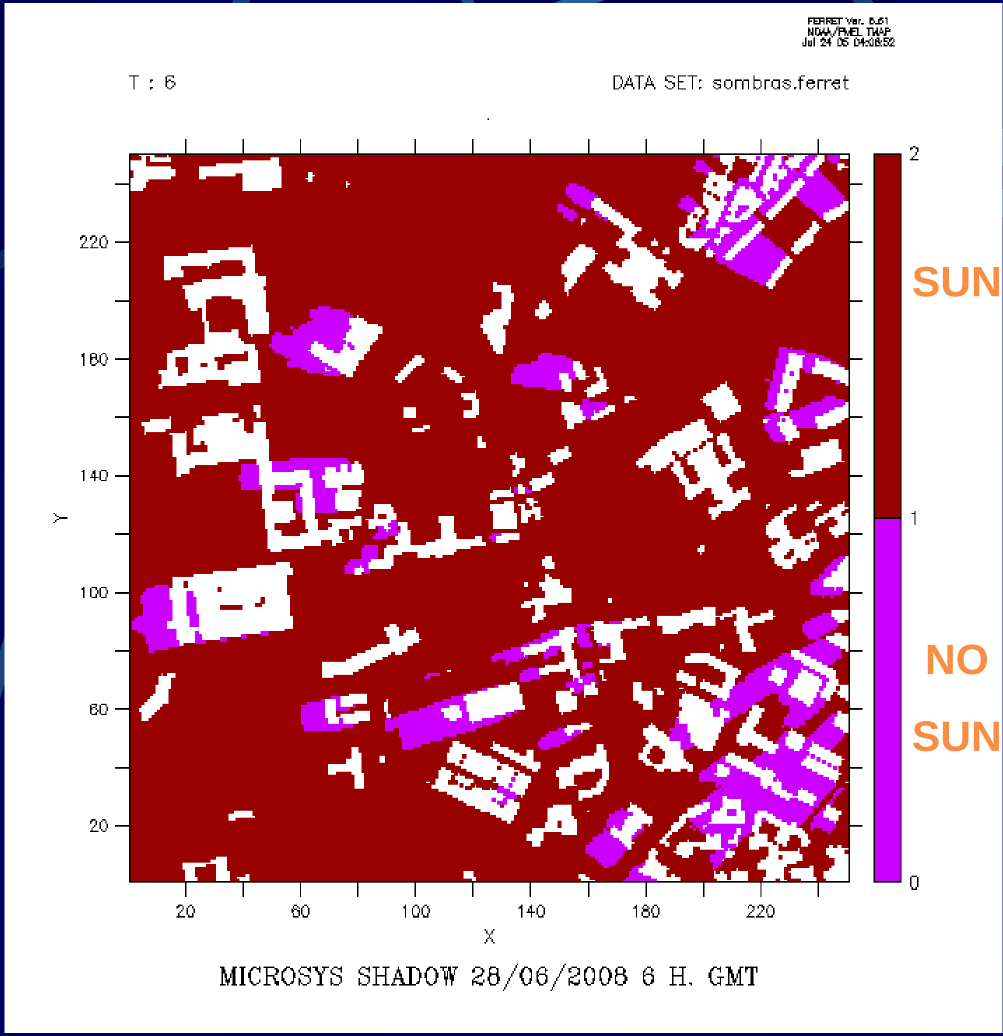


X-axis. East-West direction

Y-axis. North-South direction

(0,0,0) → Center of the grid cell

MICRO-URBAN SOLAR RADIATION MODEL. SHADOWS



MADRID SHADOWS

1km*1km domain

4m resolution grid cells

White areas = buildings

MICRO-URBAN SOLAR RADIATION MODEL. SKY VIEW FACTOR

FSKY & FREFLECTION:

- 3D RAY TRACKING METHOD

- CASTING RAYS FROM A HEMISPHERE LOCATED ON THE CENTER OF EACH GRID CELL

- FINAL POINT OF EACH RAY:

$$X = k \cos(\sigma)$$

$$Y = k \sin(\sigma)$$

$$Z = (r^2 - k^2)^{\wedge(1/2)}$$

σ: Ray direction angle [0,180º]
k : Ray Height [0,r]

- COUNT NUMBER OF RAYS THAT COLLIDE WITH BUILDING GRID CELL

- MINIMUM NUMBER OF RAYS 35000 IN A 1KM*1KM DOMAIN

MICRO-URBAN SOLAR RADIATION MODEL. SKY VIEW FACTOR

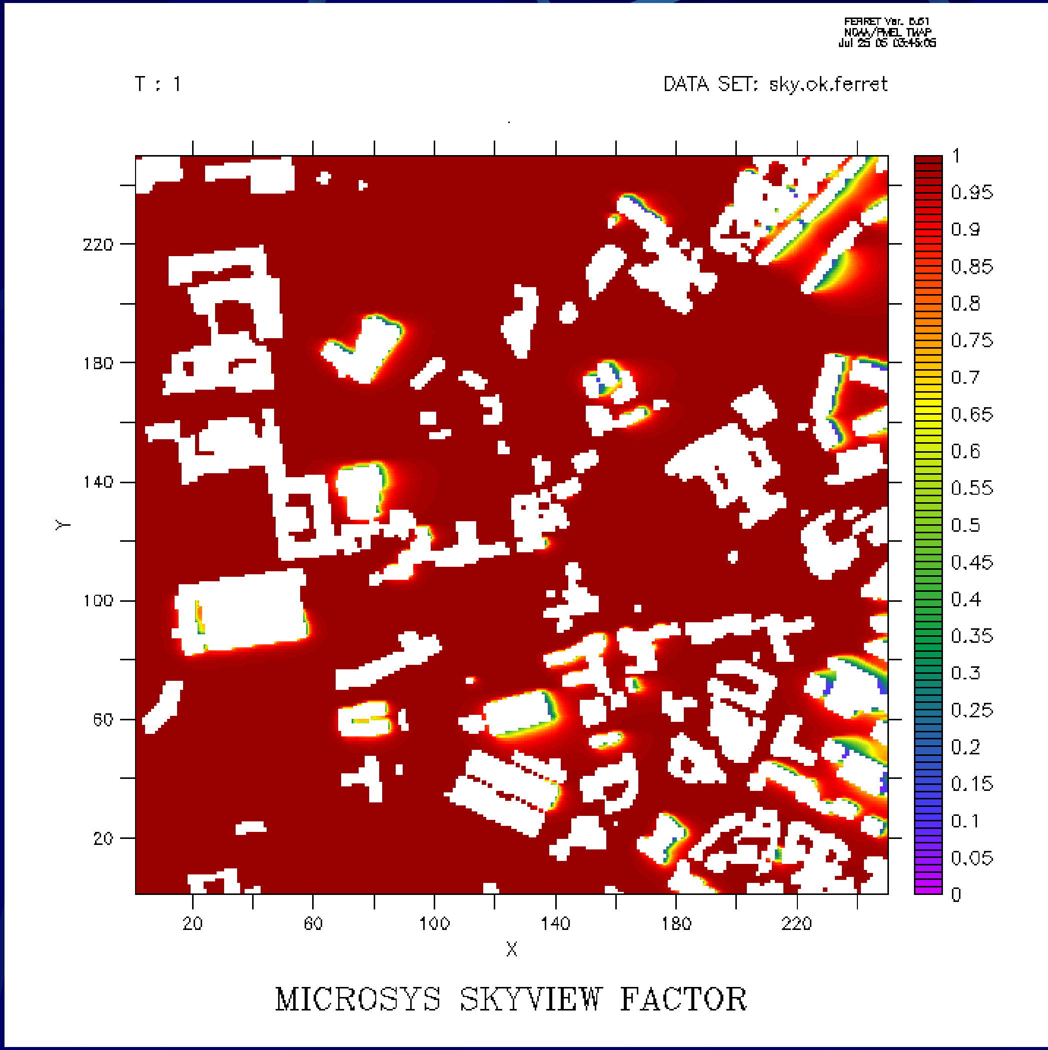
FSKY & FREFLECTION:

- FREFLECTION: FRACTION OF RAYS THAT COLLIDE WITH BUILDINGS GRID CELLS IS THE CORRESPONDING REFLECTION FACTOR.
- FSKY: (1 – FREFLECTION) , RAYS ARE NOT REFLECTED. THIS IS THE SKY VIEW FACTOR
- High computing DEMAND -> PARALLEL APPROACH

MADRID DOMAIN: 1000*1000*100 meters 4m resolution:

* 34752 RAYS 1 CPU → 95 Min.
* 34752 RAYS 50 CPUs → 2.40 Min.
* 135014 RAYS 50 CPUs → 6.50 Min.

MICRO-URBAN SOLAR RADIATION MODEL. SKY VIEW FACTOR



MADRID SKYVIEW

1km*1km domain

4m resolution grid cells

White areas = buildings

MICRO-URBAN SOLAR RADIATION MODEL. DIRECT & DIFFUSE

GLOBAL RADIATION = DIRECT + DIFFUSE

DIFFUSE = TF * GLOBAL (WRF)

TF = Turbidity Factor (Relation between extraterrestrial solar radiation and the incoming solar radiation over horizontal plane)

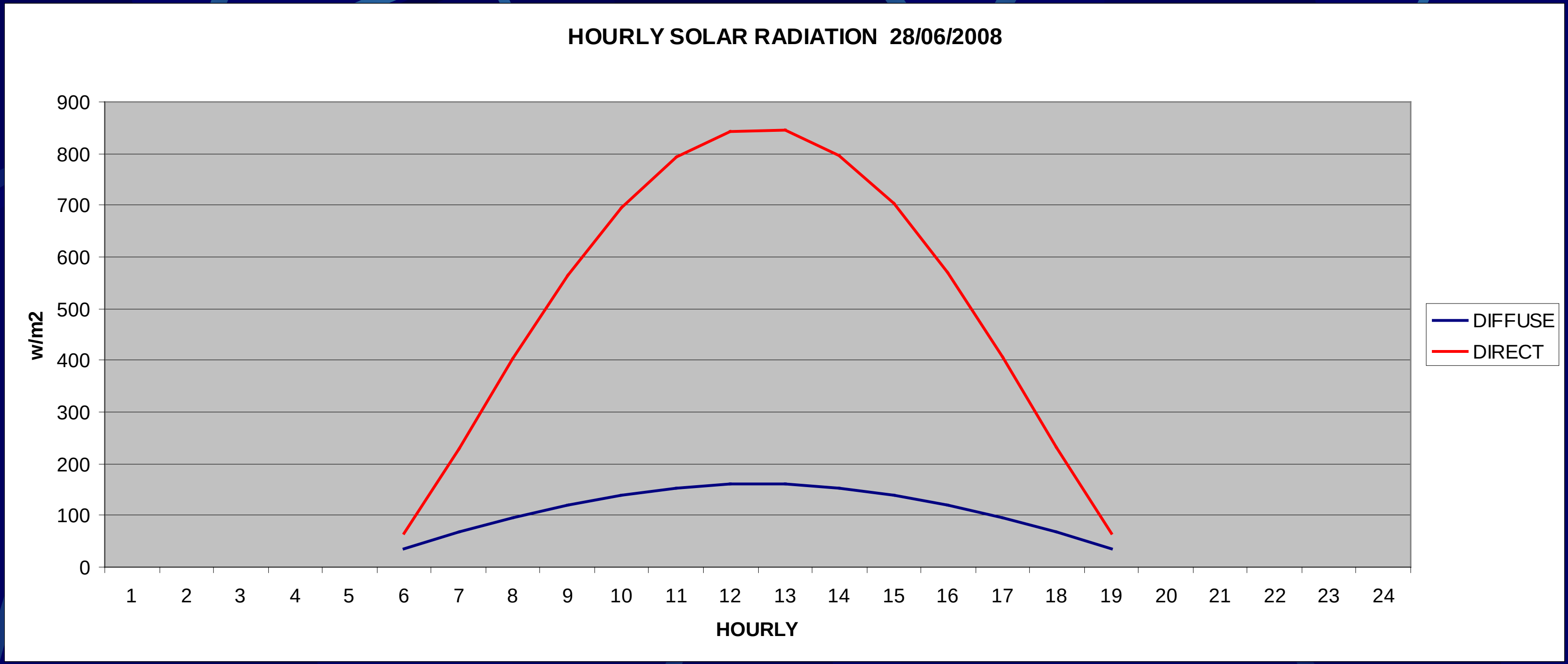
TF = MIN (1,1/A)

A = MAX (0.1,B)

B = 2.1-2.8*LOG(LOG(SOLTOP/GLOBAL))

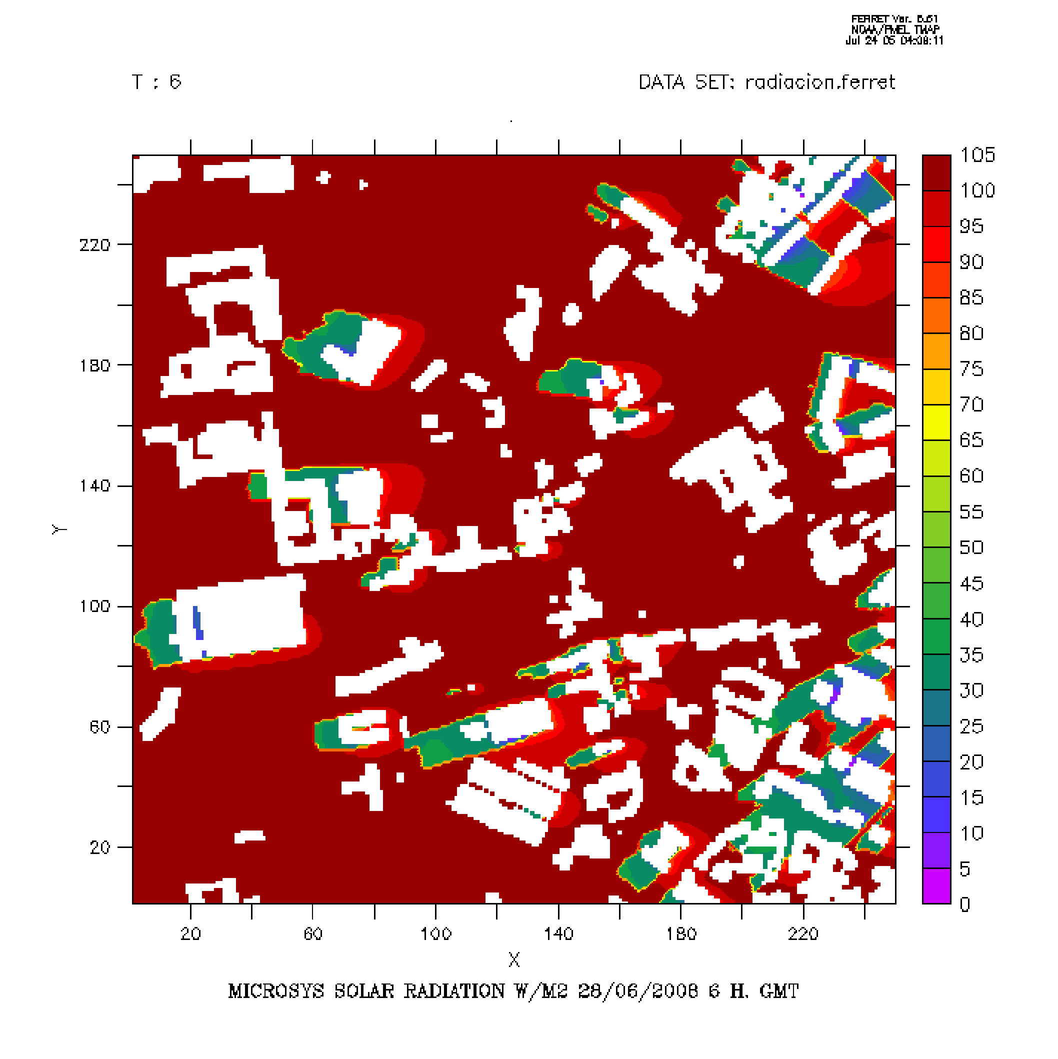
SOLTOP = 1370 * DAYFACTOR*COS(zenith)

MICRO-URBAN SOLAR RADIATION MODEL. DIRECT & DIFFUSE



Ratio *DIRECT/DIFFUSE* depends on solar zenith angle and the sky conditions (clouds) . At cloudless conditions at small solar angles the *D/S* is close to 0.5 and at large solar angles *D/S* is close 0.2

MICRO-URBAN SOLAR RADIATION MODEL. GLOBAL RADIATION



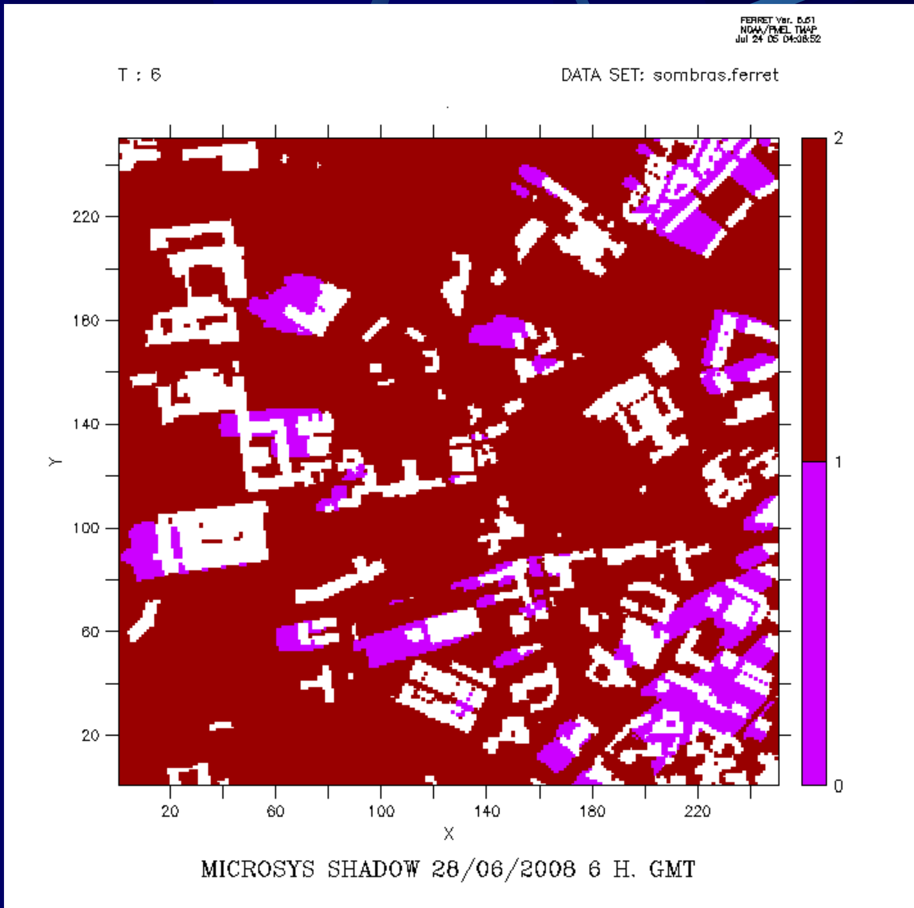
MADRID SOLAR RADIATION

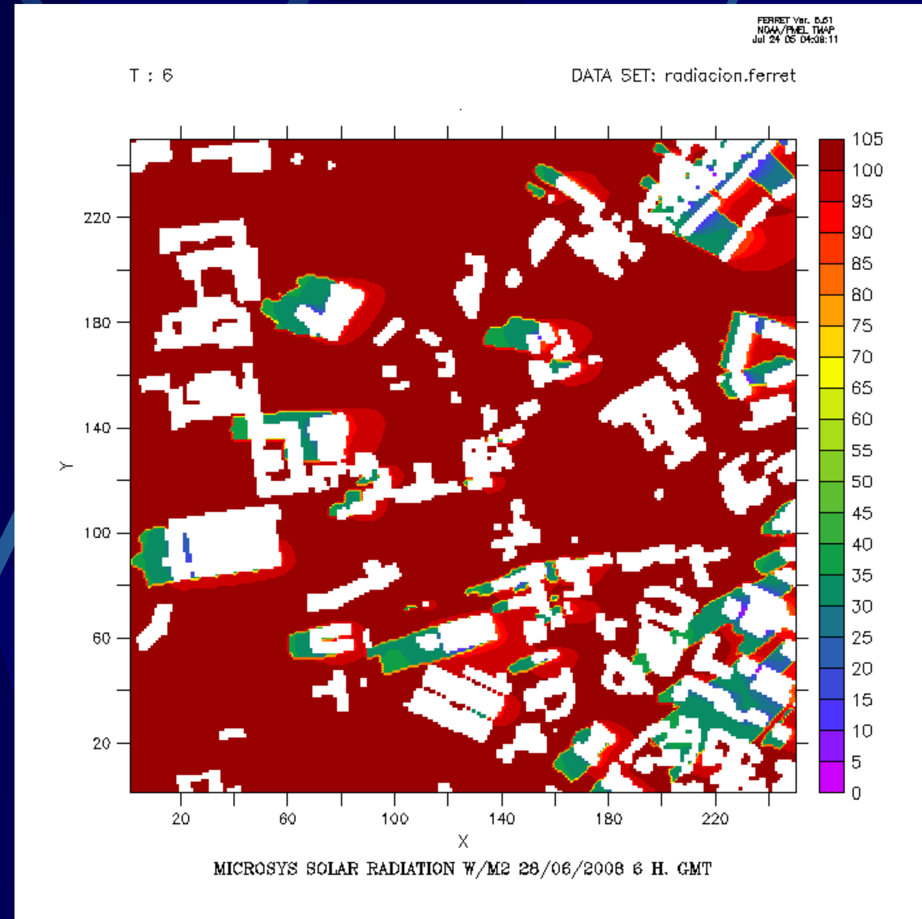
1km*1km domain

4m resolution grid cells

White areas = buildings

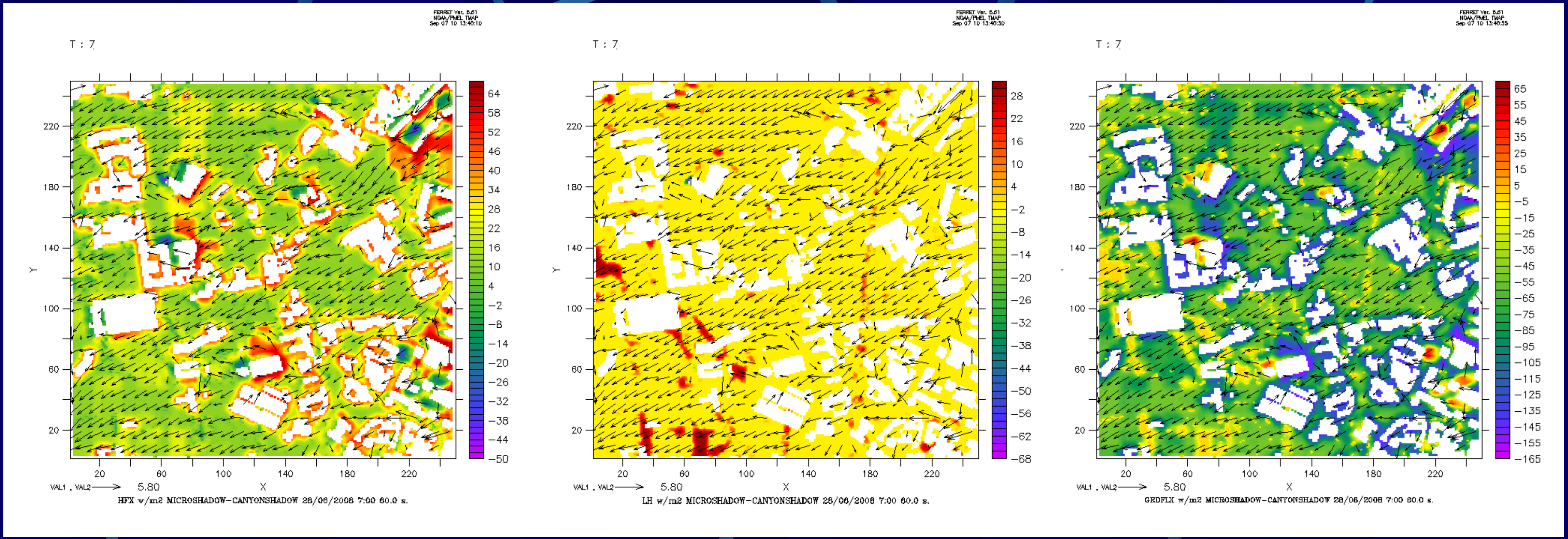
MICRO-URBAN SOLAR RADIATION MODEL. GLOBAL RADIATION





SHAMO MODEL PERFORMANCE

MICROSYS-FLUXES. MADRID SHADOW EFFECTS

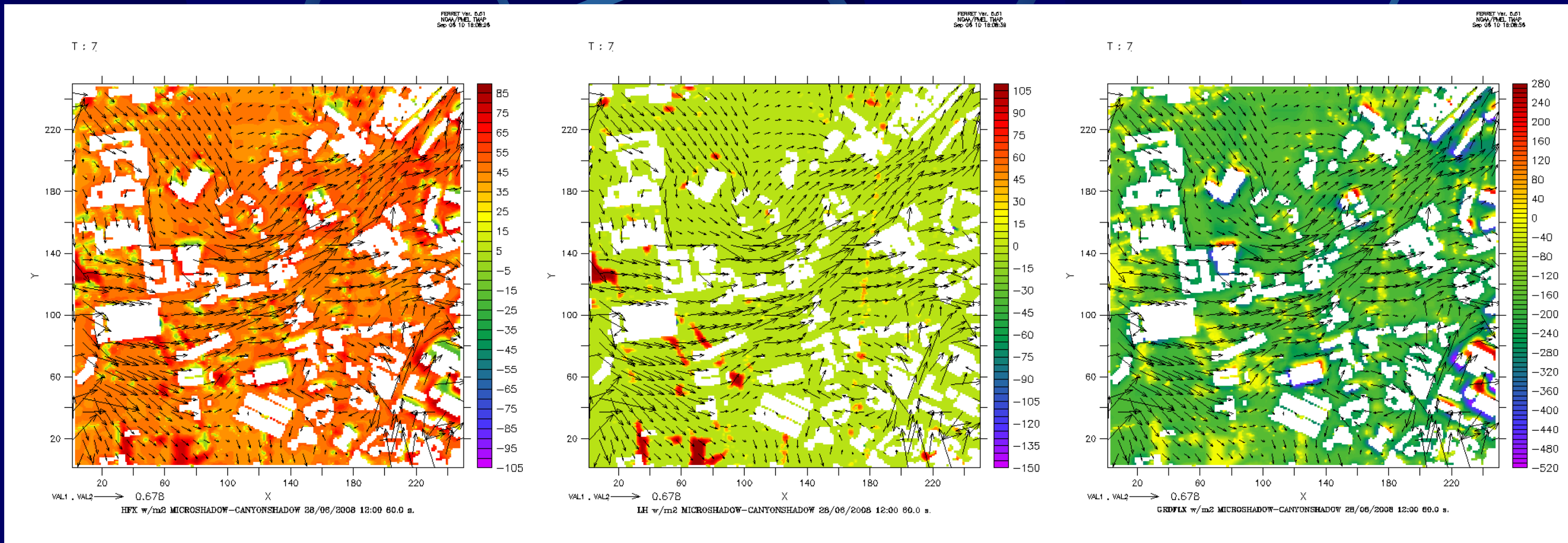


Sensible heat flux **Latent heat flux** **Ground heat flux**

28/06/2008 07:00

DIFERENCES: MICROSHAMO MODEL – CANYON SHADOW MODEL

MICROSYS-FLUXES. MADRID SHADOW EFFECTS

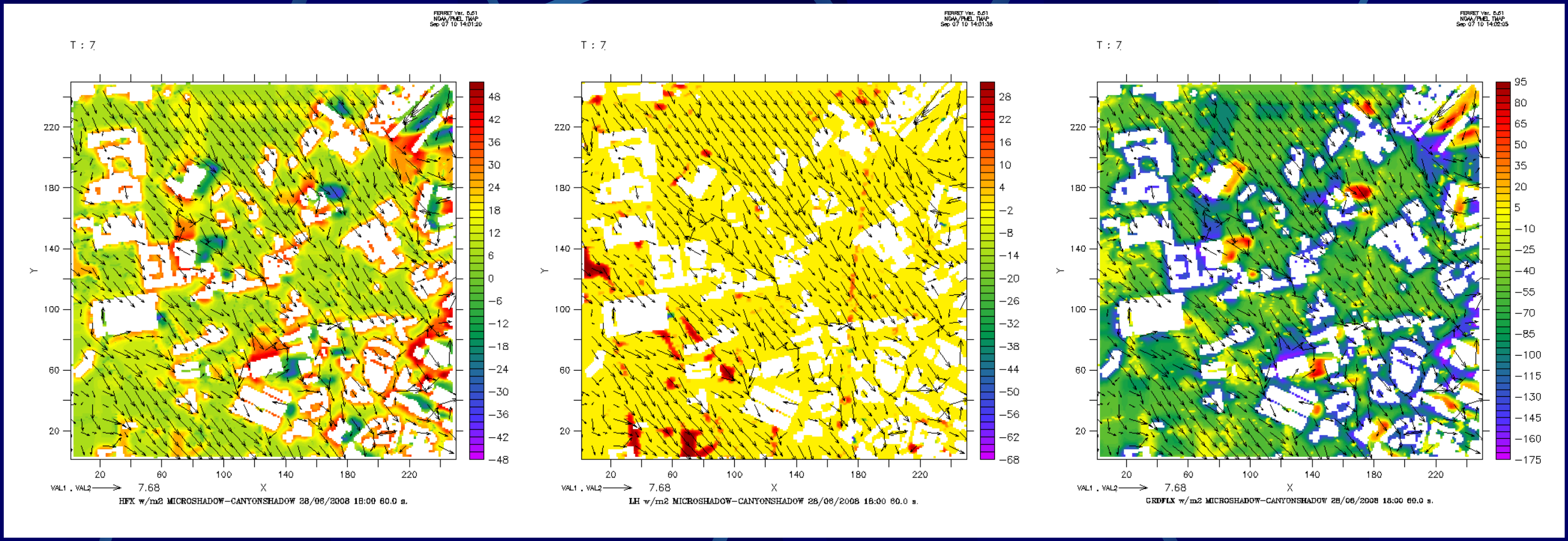


Sensible heat flux **Latent heat flux** **Ground heat flux**

28/06/2008 12:00

DIFERENCES: MICROSHAMO MODEL – CANYON SHADOW MODEL

MICROSYS-FLUXES. MADRID SHADOW EFFECTS



Sensible heat flux **Latent heat flux** **Ground heat flux**

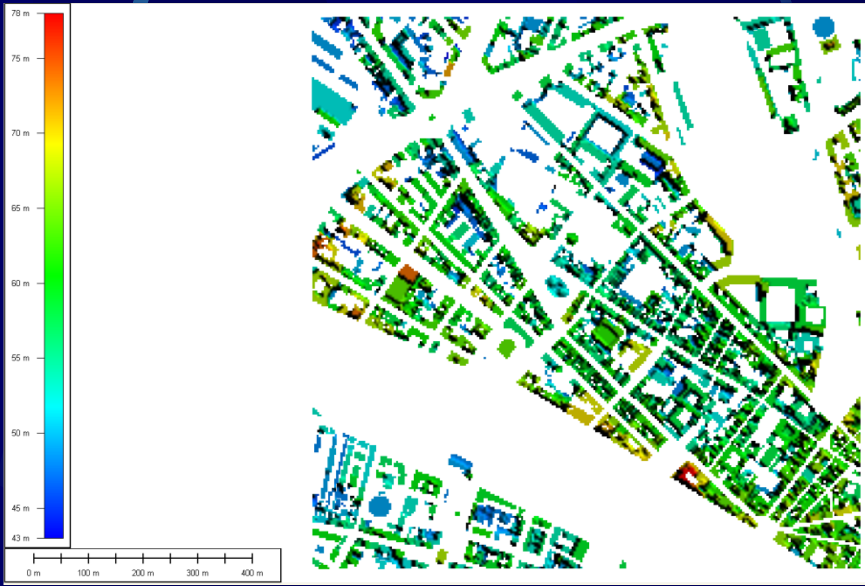
28/06/2008 18:00

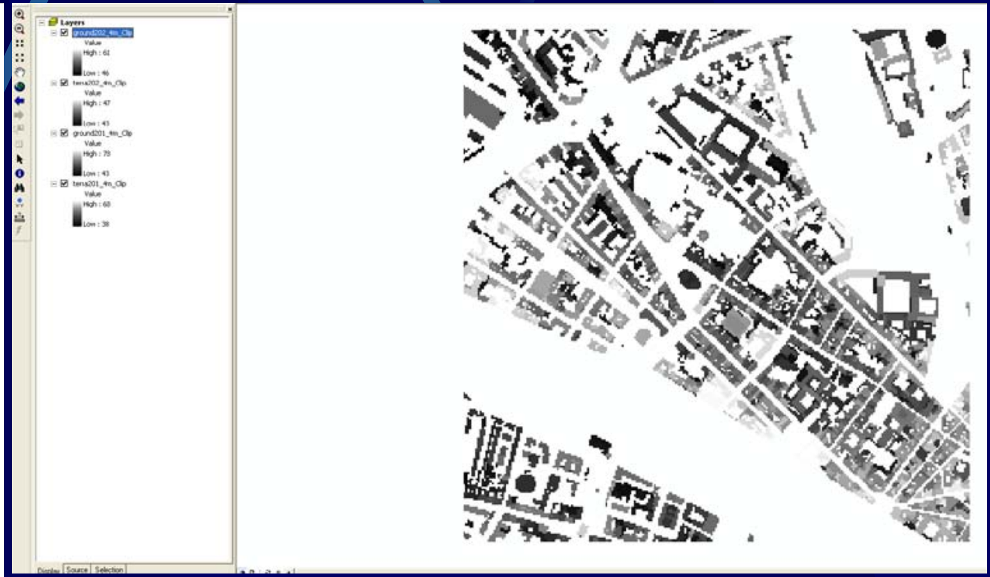
DIFERENCES: MICROSHAMO MODEL – CANYON SHADOW MODEL

SETUP MICROSYS-EULAG FLORENCE (ITALY)

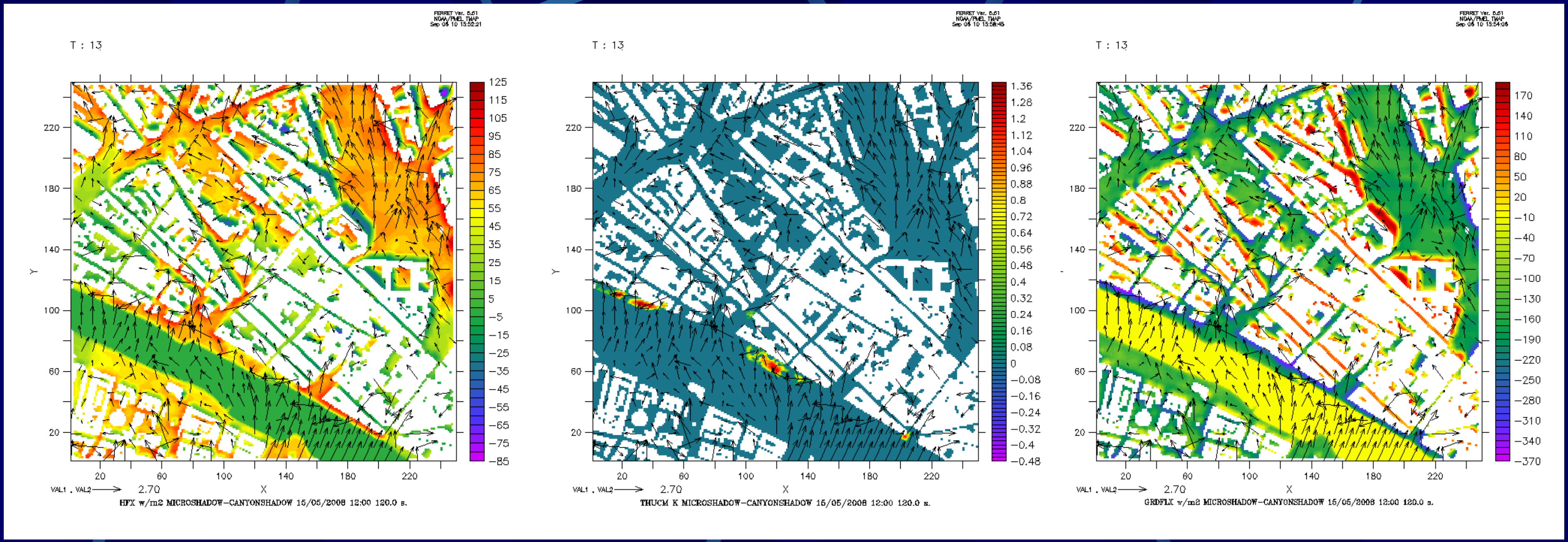
1*1 Km. DOMAIN

4 m. RES.





MICROSYS-FLUXES. FLORENCE (ITALY) SHADOW EFFECTS



Sensible heat flux **Potential Temperature** **Ground heat flux**

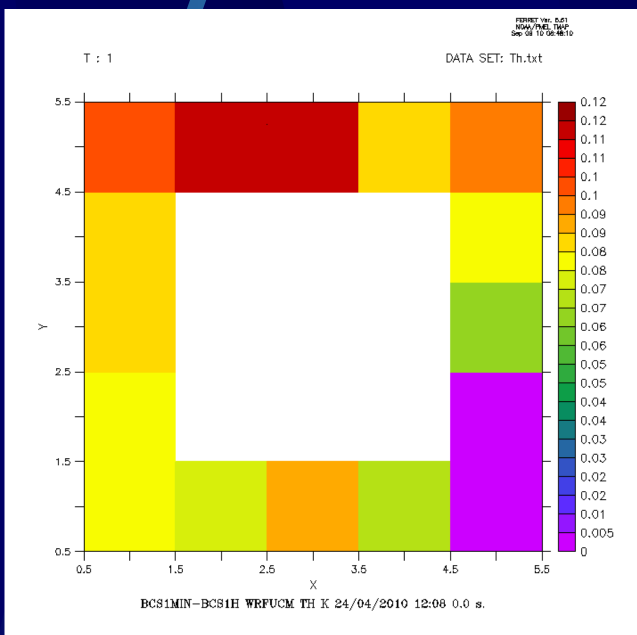
15/05/2008 12:02

DIFERENCES: MICROSHAMO MODEL – CANYON SHADOW MODEL

MICROSYS-EULAG URBAN SIMULATIONS. BCs

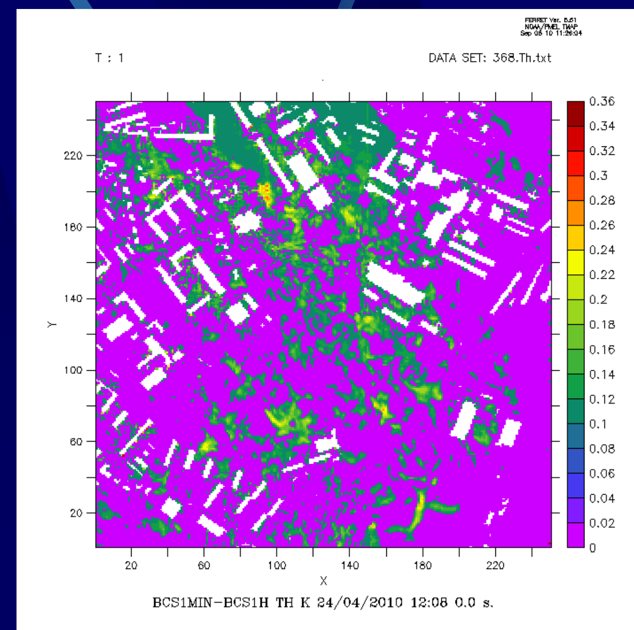
2 CFD-EULAG SIMULATIONS OVER GLIWICE (POLAND)

* Time period: 24/04/2010 12:00 – 12:08
* BC´s 1 Minute : BCs from WRF outputs updated every minute
* BC´s 1 Hour : BCs from WRF output 12:00



WRF BCS 12:08 – 12:00

Potential Temperature Differences



EULAG OUTPUTS 12:08
BCS1MIN-BCS1HOUR

CFD EULAG CPU TIMES (MADRID)

50 PROCESSORS → 10 S. SIMULATION 10.0 CPU HOURS

100 PROCESSORS → 10 S. SIMULATION 7.4 CPU HOURS

125 PROCESSORS → 10 S. SIMULATION 6.3 CPU HOURS

250 PROCESSORS → 10 S. SIMULATION 3.0 CPU HOURS

500 PROCESSORS → 10 S. SIMULATION 2.6 CPU HOURS

Conclusions

1.- Turbulent fluxes have been added to EULAG based on:

a) Simple and ideal street canyon shadow model (UCM shadow model).
b) Complex shadow model (SHAMO) based on building reflections and solar radiation partition (diffuse and direct solar radiation).
c) urban turbulent fluxes based on the Similarity Theory.
d) natural latent heat flux partition based on Noah/Land-surface model.

2.- Comparisons of the results between UCM shadow model and SHAMO model into EULAG simulations show a substantial sensitivity to these changes.

3.- One-way nesting EULAG-WRF model.

4.- Consistent and realistic results which should be validated with specific field campaigns.

ACKNOWLEDGEMENTS

1. INDRA ESPACIO Co. (SPAIN) for the satellite and remote sensing data.

2. BRIDGE EU project ENV.2007.2.1.5.1 for partial funding of this research.

3. UCAR (US) for the EULAG model.

4. Madrid Community.