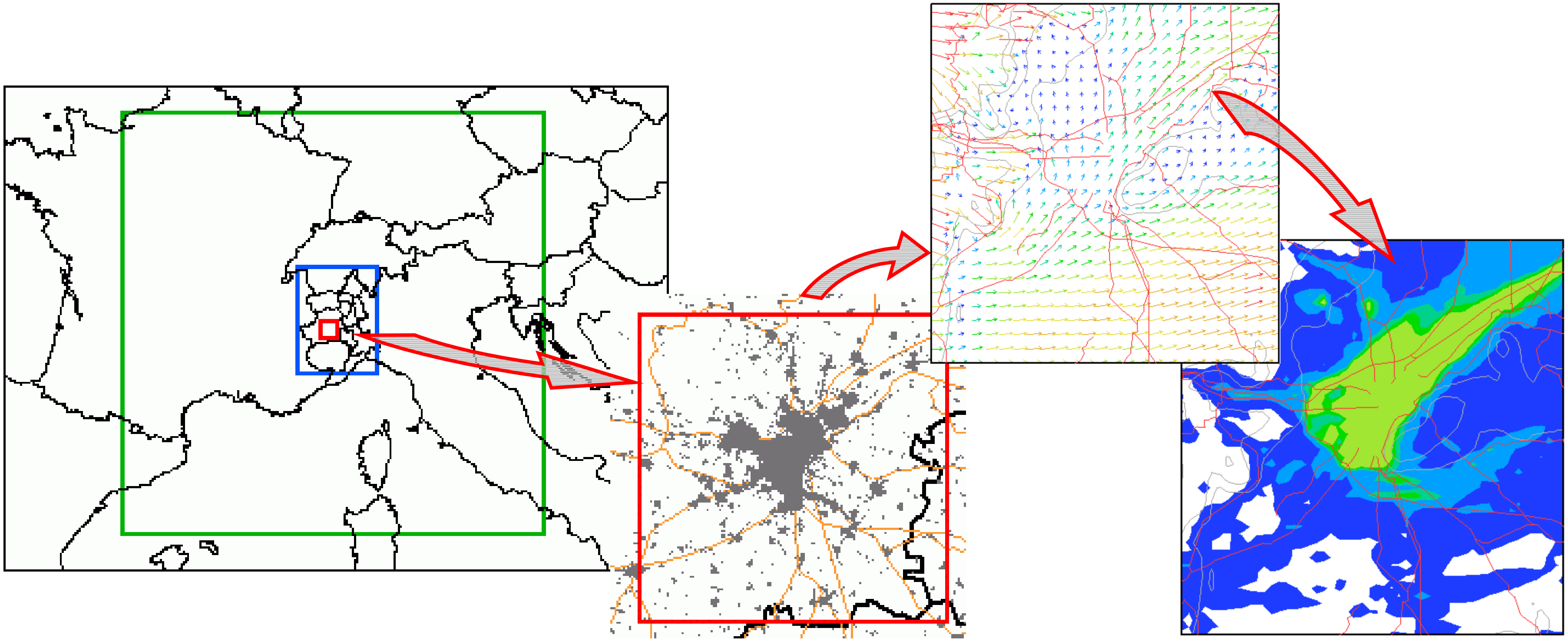
Air quality forecasting system for Torino urban area: meteorological analysis and model sensitivity to dispersion parameterisations



Finardi S., D'Allura A., Calori G., Silibello C., De Maria R., Cascone C., Lollobrigida F.

Summer School FMI – Sodankylä 04-14 Jun 2005

FORECASTING SYSTEM

GTOPO30 DTM

Land use
CORINE & USGS

Geographic and Physiographic Data

RAMS 4.4

Meteorological Model

Large scale forecasts and meteo data

ECMWF forecasts

Interface Module

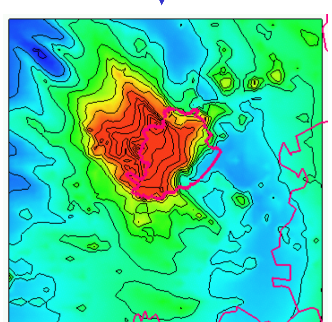
FARM

UAQ Model

Emissions pre-processing

EMEP, CORINAIR and INEMAR emission inventories

IC/BC pre-processing

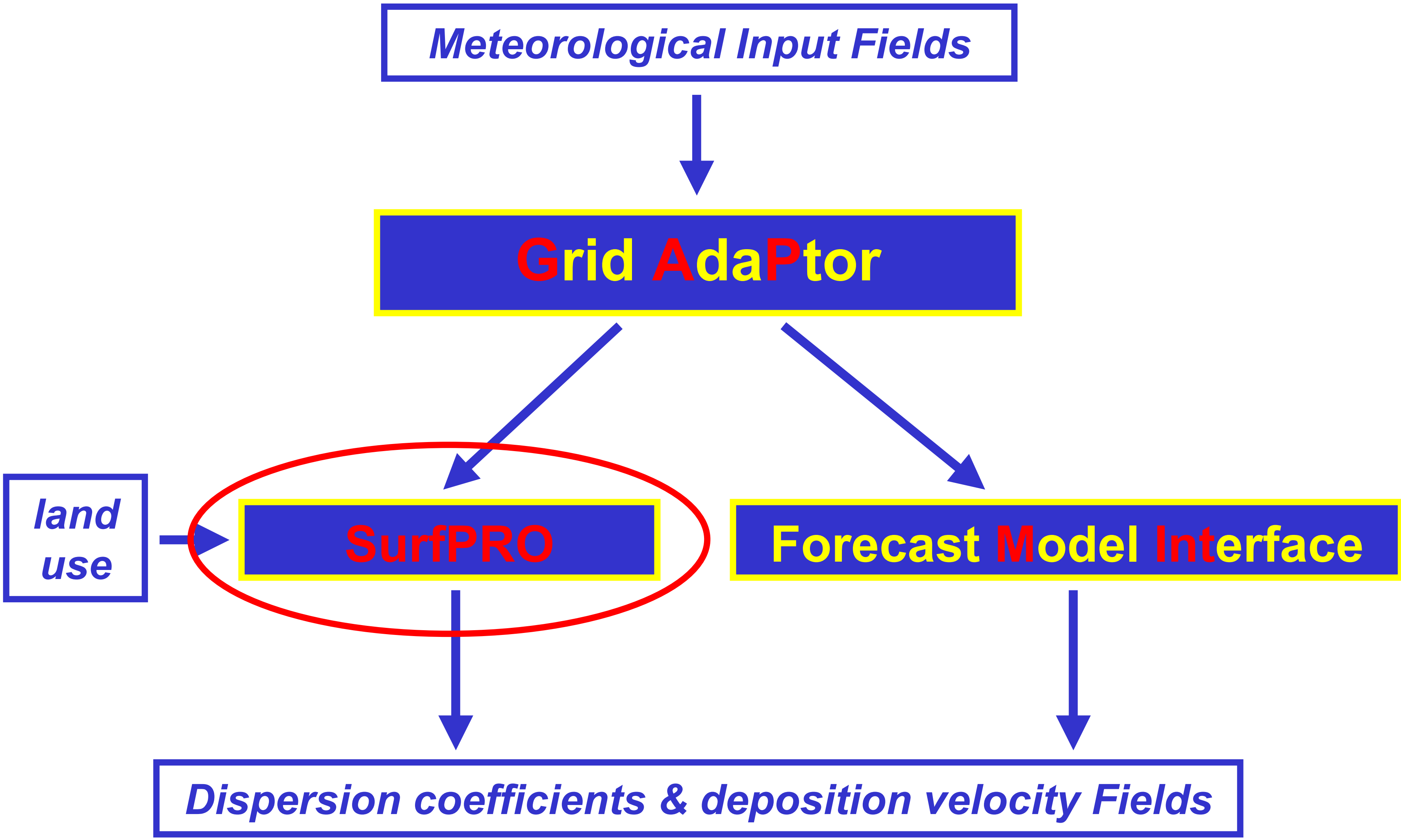


Concentration fields

RAMS features

Basic equations	*3-D, non-hydrostatic, compressible, time-split*
Coordinates	*Horizontal: rotated polar-stereographic transformation* *Vertical: terrain-following height*
Grid nesting	*Two-way reversible, mass-conservative grid nesting, user specified space/time ratios*
Time differencing	*Hybrid (leapfrog for velocity, forward for scalars)*
Turbulence	*Eddy exchange coefficients from prognostic TKE*
Advection	*Second order leapfrog for velocity, second order forward for scalars*
Convection	*Kuo-type deep convection*
Microphysics	*Cloud, rain, and 5 ice species*
Radiation	*Three long and short wave radiative parameterizations*
Surface treatment	*Prognostic soil temperature and moisture model* *Prognostic vegetation and snow parameterization*
Data assimilation	*Four-dimensional data assimilation, "analysis" relaxation*

Interface Module Components



GAP - Grid adapting interpolation tool

Interpolation of 2D and 3D meteo fields

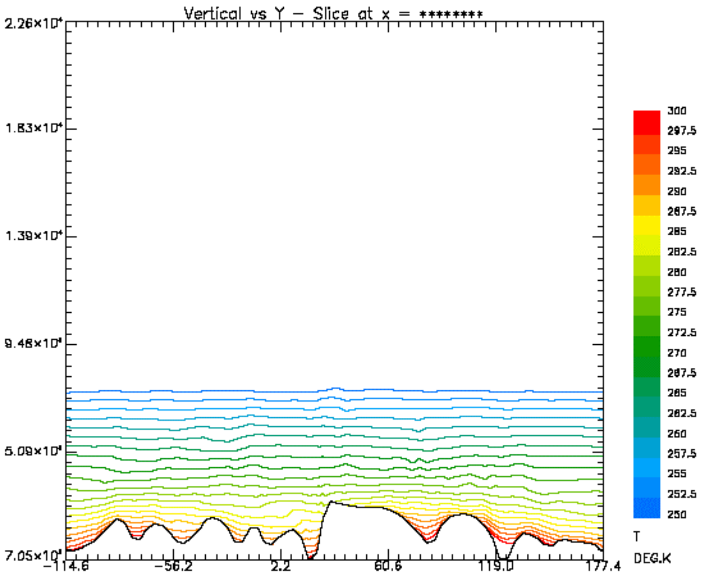
- Vertical interpolation: linear
- Horizontal interpolation: 1) nearest point value,
  2) bilinear,
  3) triangulation + linear,
  4) Cressman;

3D fields horizontal interpolation at constant z heights above sea level.
Input cartographic projection system is assumed to be unknown.
Grid points are identified by latitude, longitude and height.

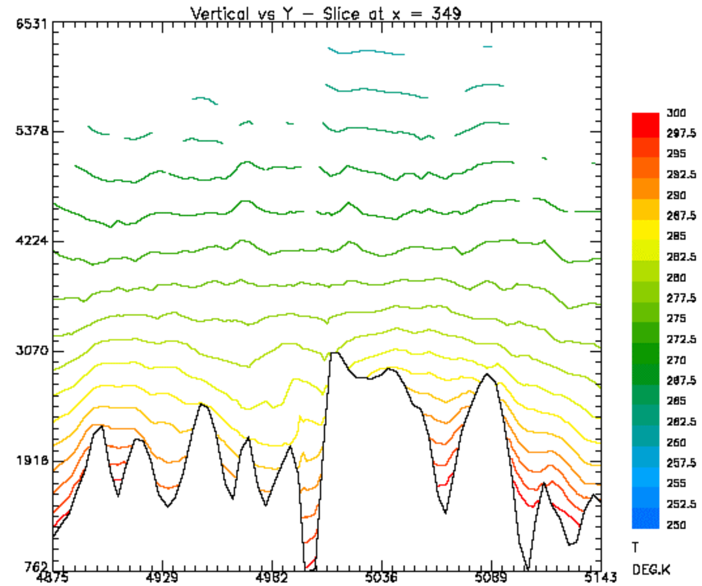
Mass conservation

- Computation of w from continuity equation

GAP - application



RAMS sigma grid system in polar stereographic projection



FARM terrain following grid system in UTM projections

Verified with meteorological fields from:

RAMS, ECMWF, LM.

SurfPRO – Meteorological pre-processor

Meteorological pre-processor for air pollution models based on Monin-Obukhov similarity theory

Input: topography, land-use, average meteorological variables (wind, temperature, humidity, cloud cover and precip.)

Output: turbulence scaling parameters, mixing height, horizontal and vertical diffusivities, deposition velocities.

The processor takes into account water bodies, terrain slopes and related solar shading effects.

Test case simulations

Summer episod

19-21/07/1999 (mo-wed): summertime high pressure

Weak winds and breeze regimes

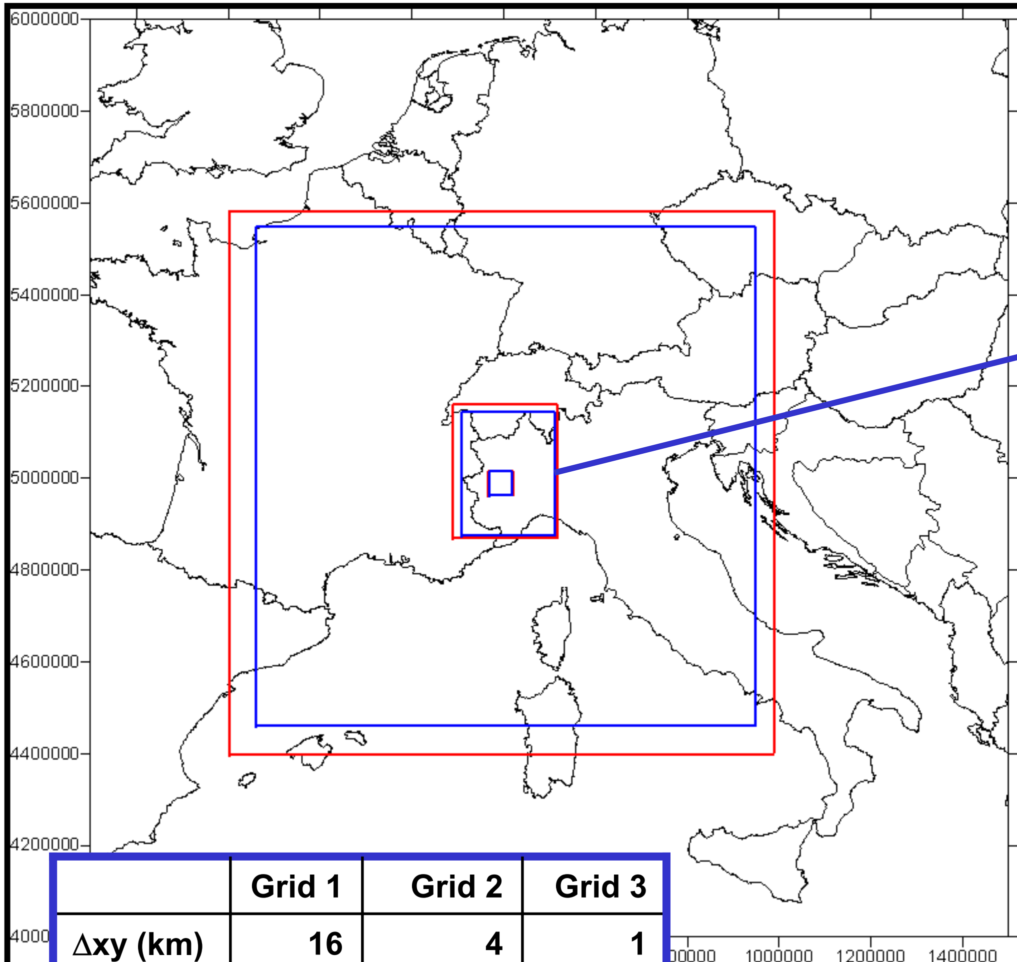
Exceedances of the mean hourly O_3 concentration limit

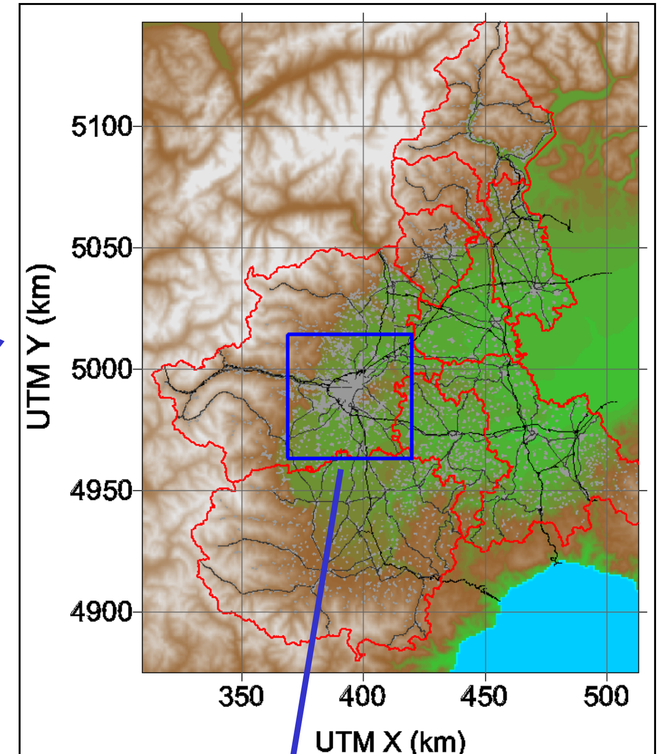
13-15/01/2003 (mon-wed): wintertime high pressure

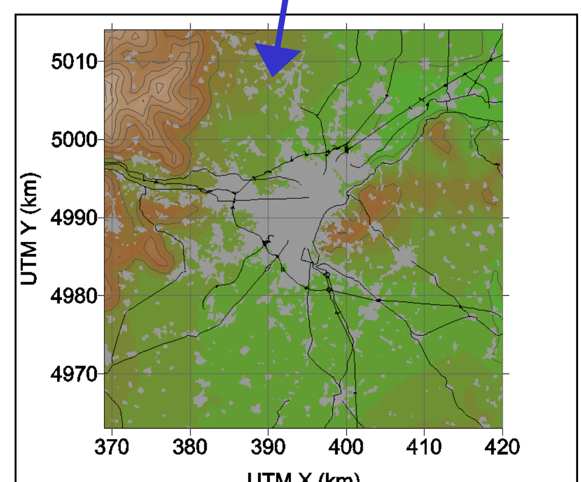
Very weak winds, fog, thermal inversion

Exceedances of the mean hourly PM_{10} concentration limit
Some Exceedances of the mean hourly NO_2 concentration limit

Computational domains

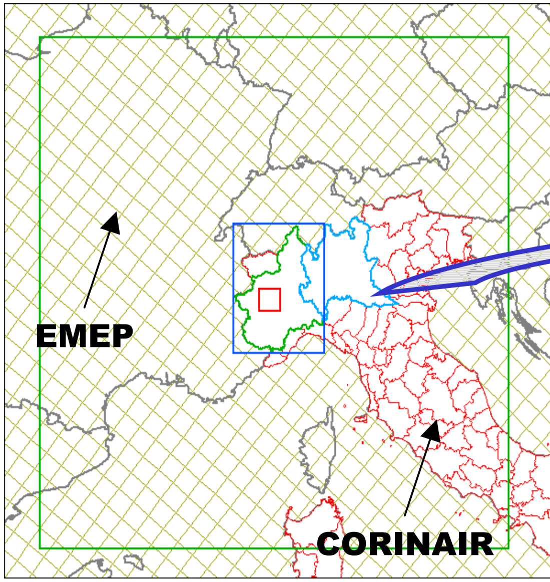


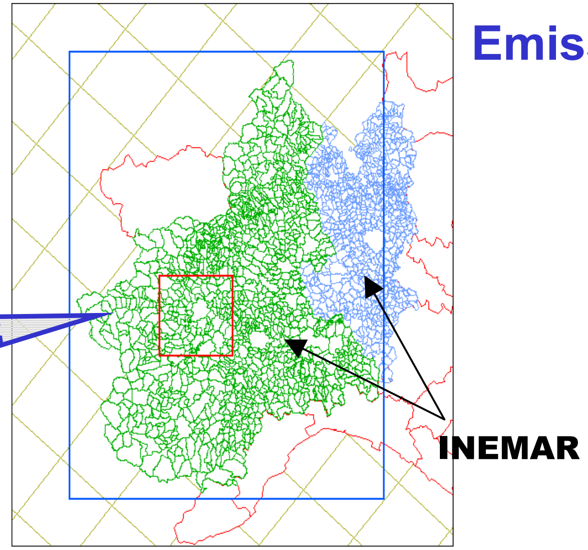




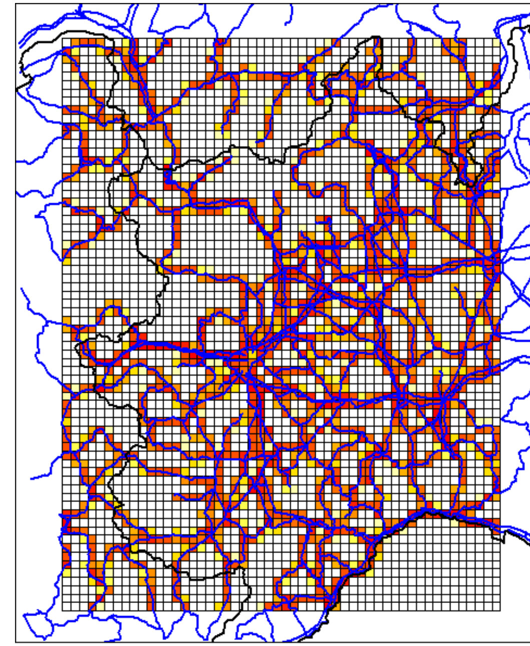
	Grid 1	Grid 2	Grid 3
Δxy (km)	16	4	1
Nx	69	52	52
Ny	69	68	52

Emission Space Disaggregation Major Roads

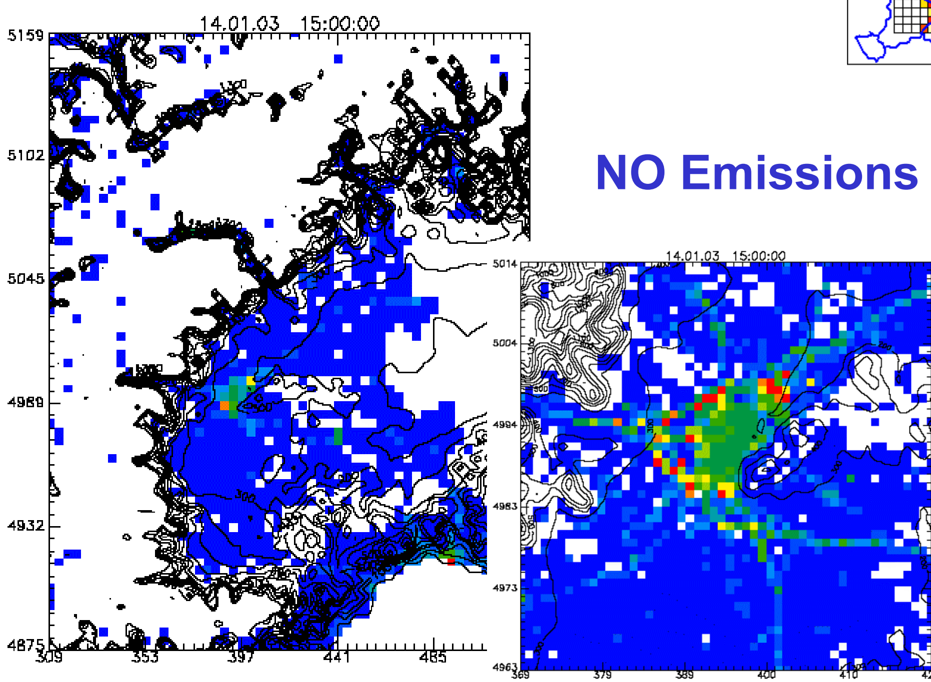




Emission Inventories Space Detail



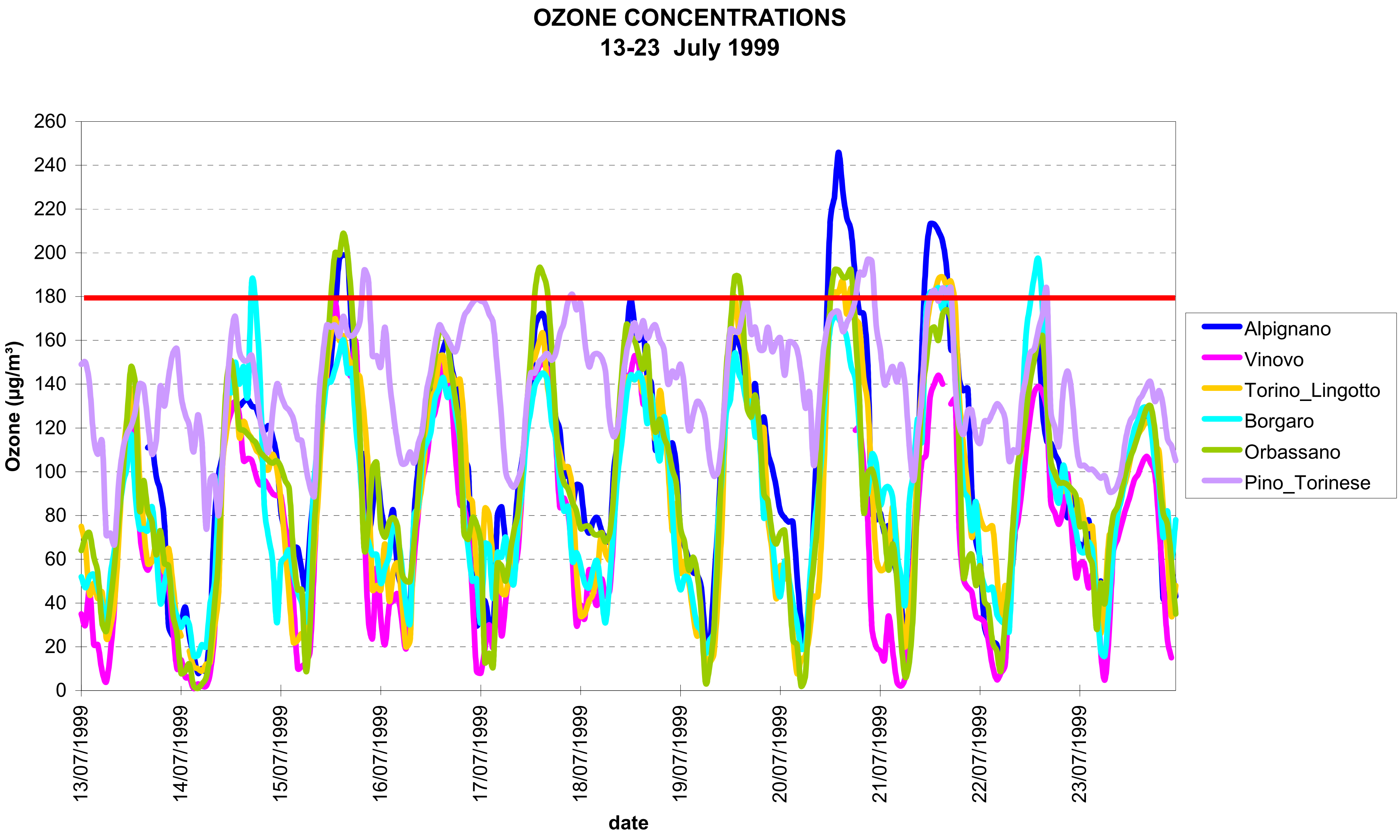
NO Emissions



Summer Episod

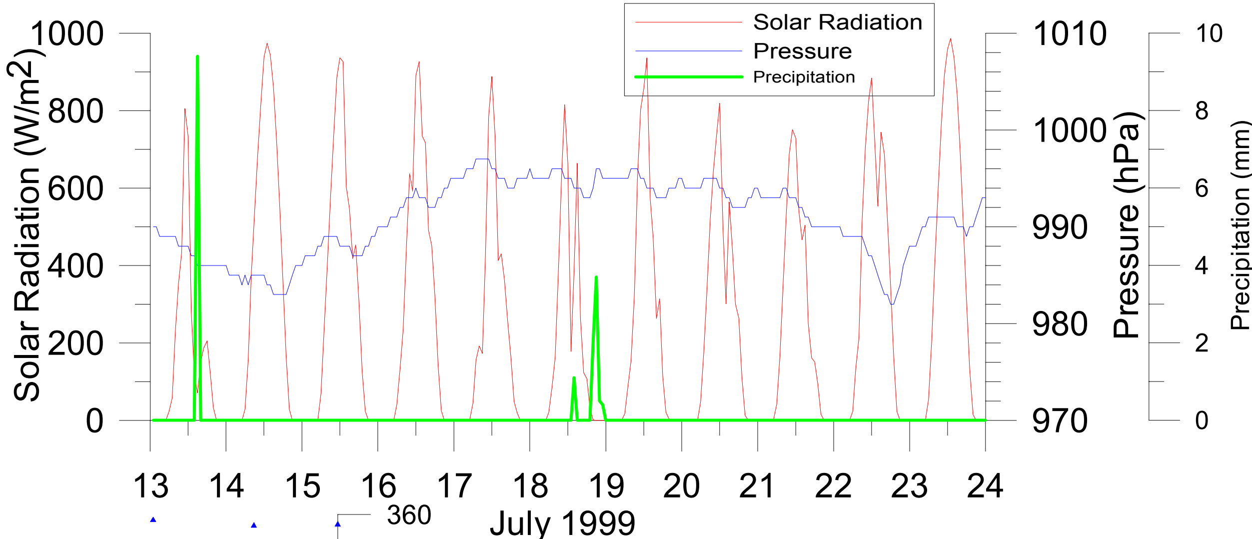
19-21/07/1999

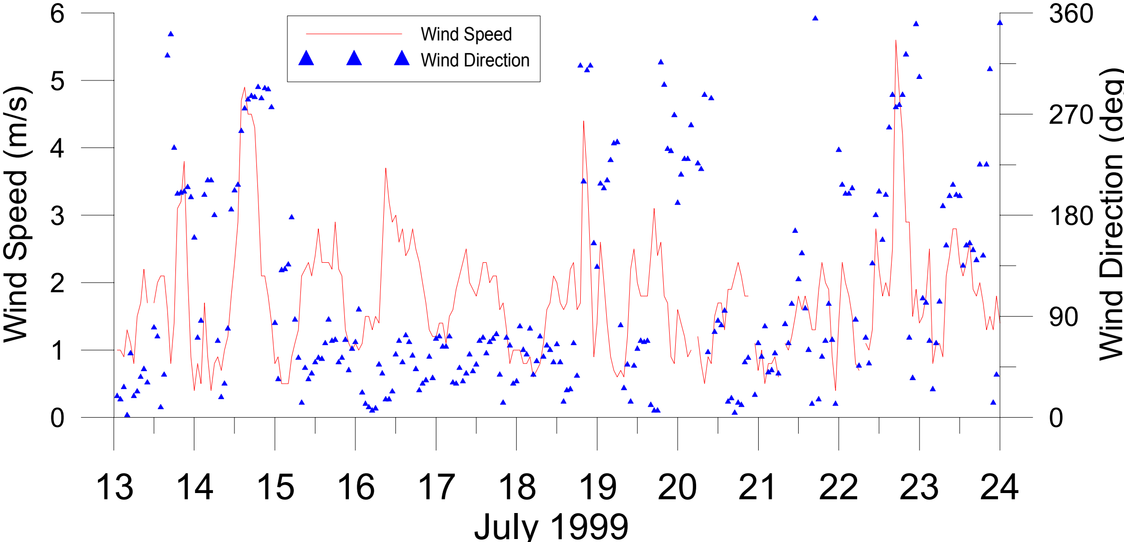
19-21/07/1999 – O_3 - Concentrations

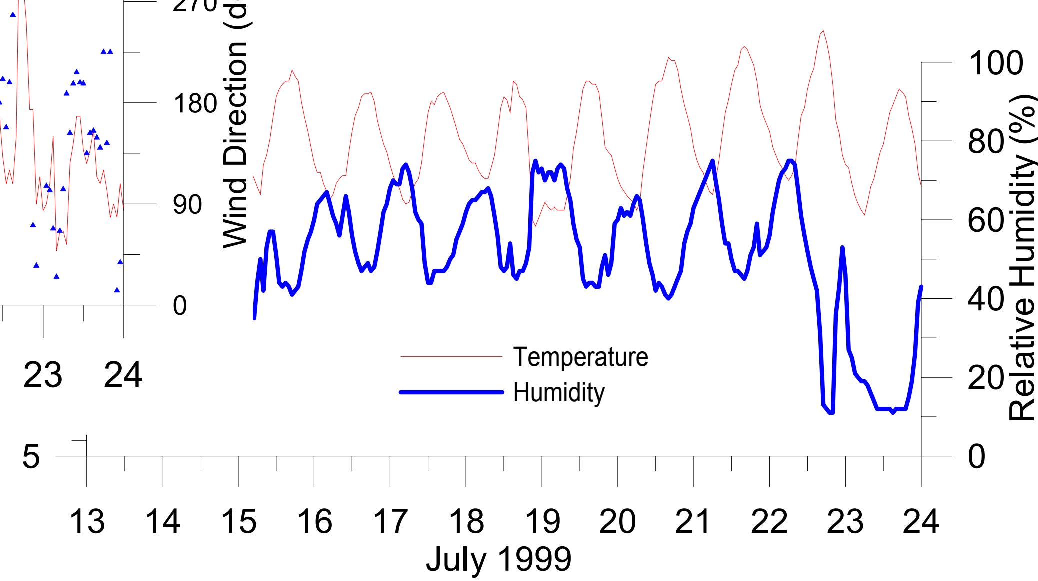


19-21/07/1999 –local meteorology

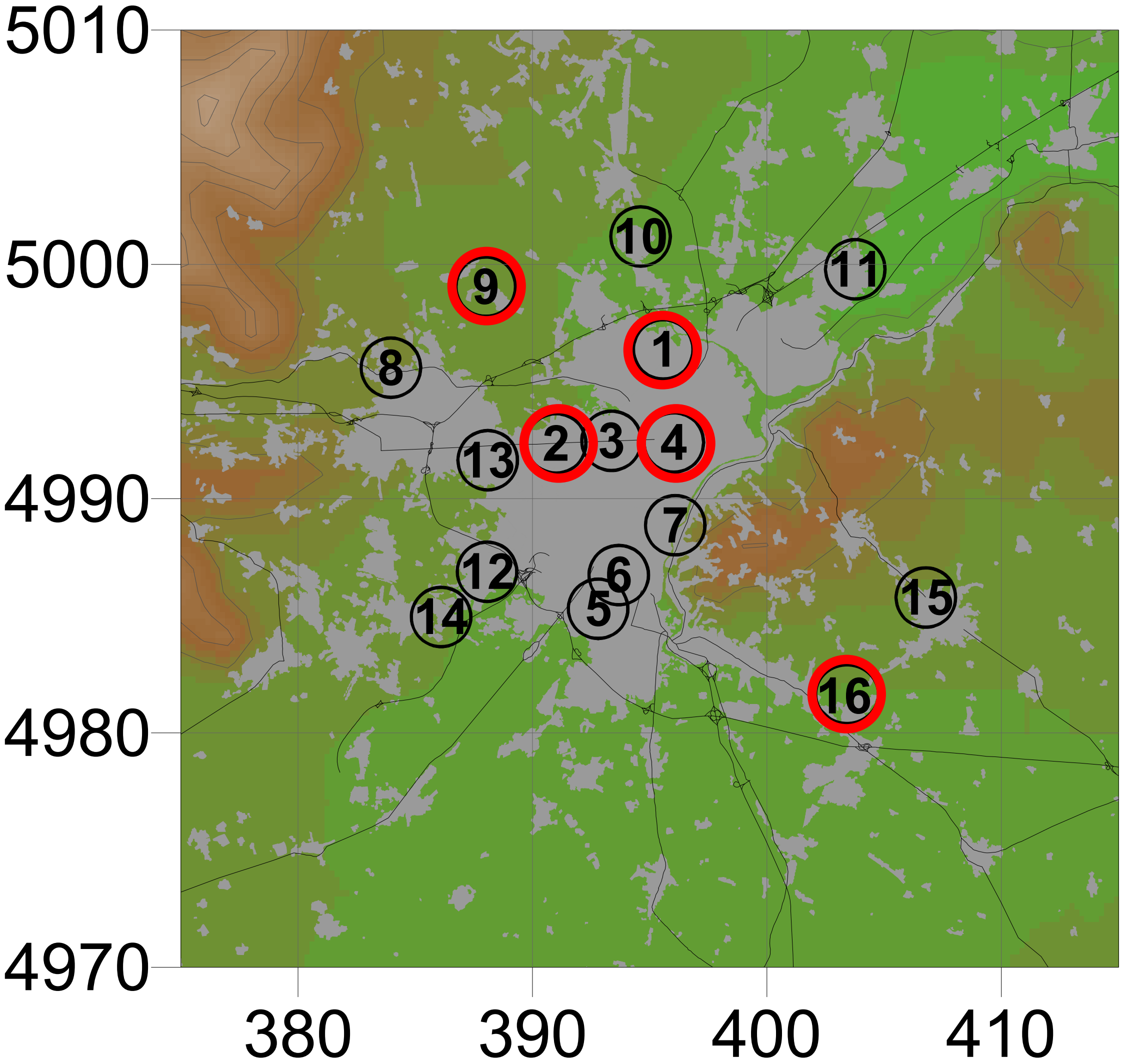
TO - Consolata





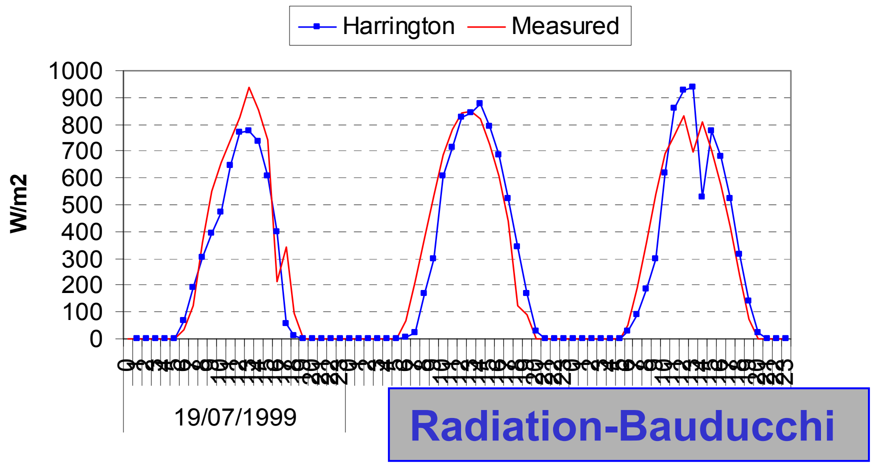


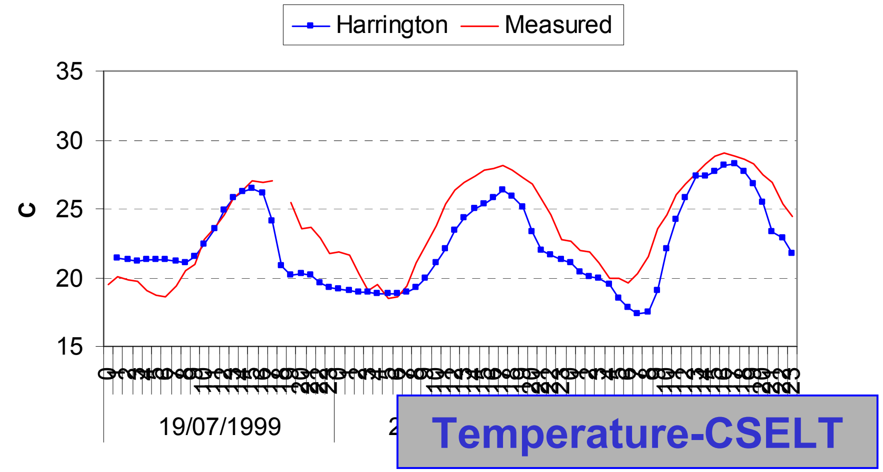
Torino Province monitoring network used meteorological stations

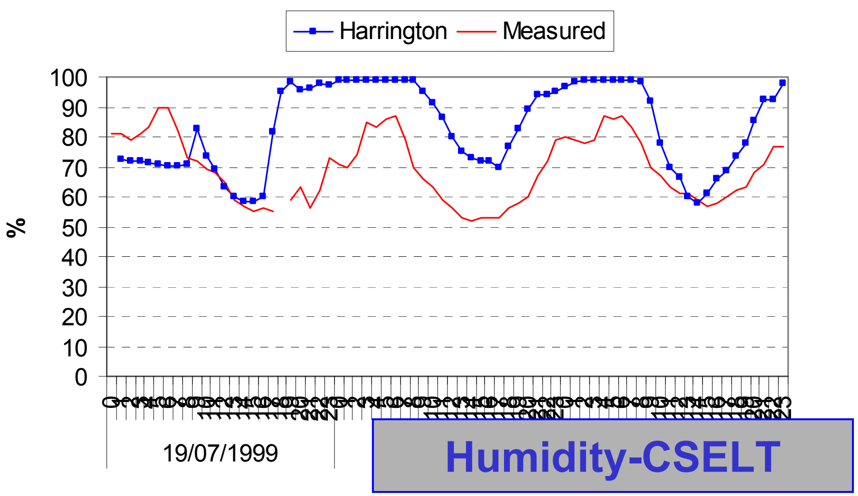


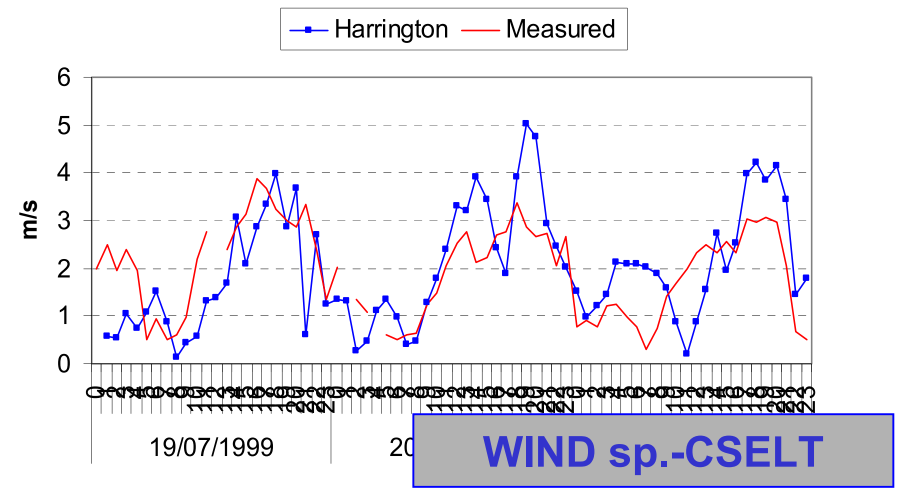
1 CSELT
2 Alenia
3 P.Rivoli
4 Consolata
5 CNR
6 Lingotto
7 LaStampa
8 Alpignano
9 Druento
10 Borgaro
11 Settimo
12 Beinasco
13 Grugliasco
14 Orbassano
15 Chieri
16 Bauducchi

RAMS OUTPUT


Harrington
Measured
W/m2
1000
900
800
700
600
500
400
300
200
100
0
19/07/1999
Radiation-Bauducchi

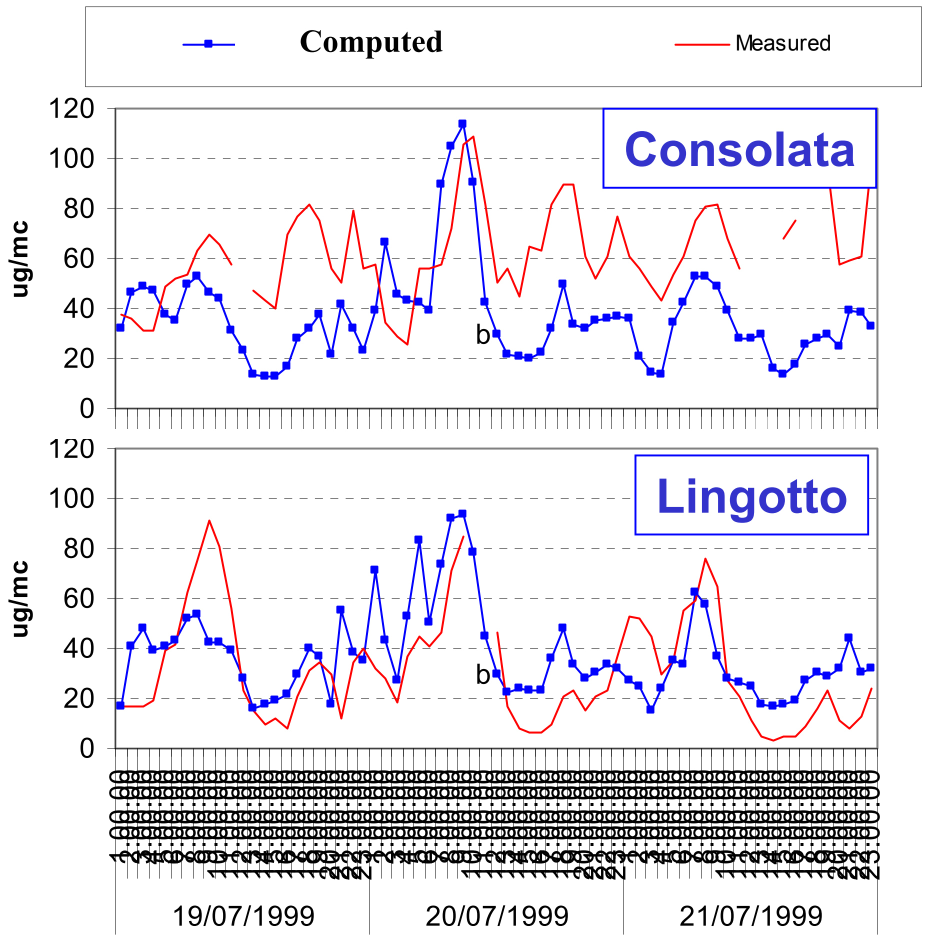

Harrington
Measured
C
35
30
25
20
15
19/07/1999
Temperature-CSELT


Harrington
Measured
%
100
90
80
70
60
50
40
30
20
10
0
19/07/1999
Humidity-CSELT

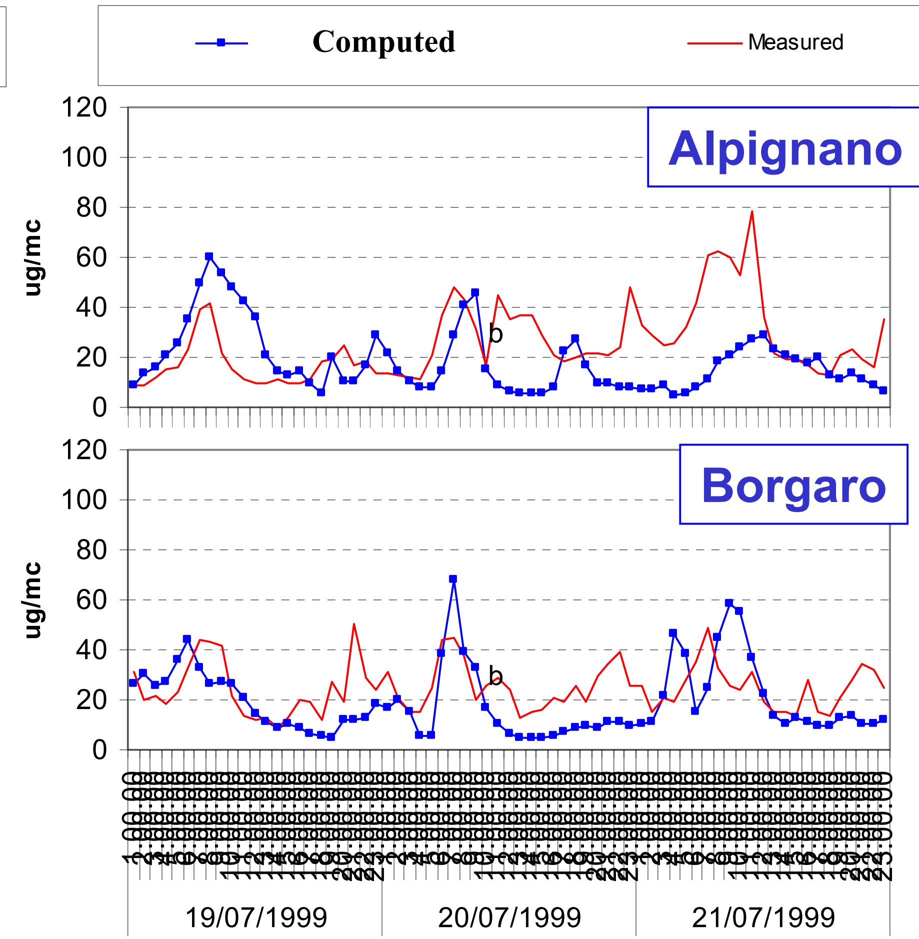

Harrington
Measured
m/s
6
5
4
3
2
1
0
19/07/1999
WIND sp.-CSELT

FARM NO_2 Concentrations

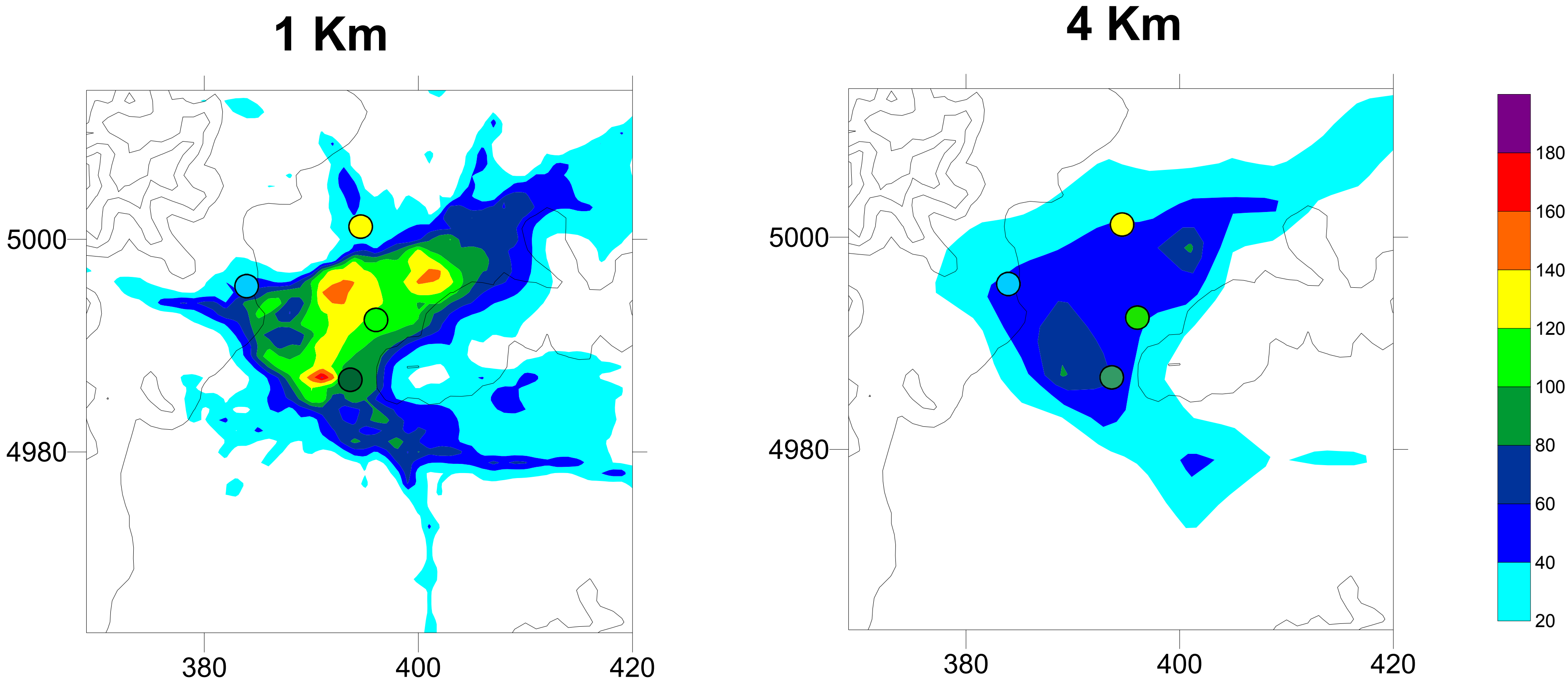
Urban Stations



Suburban Stations



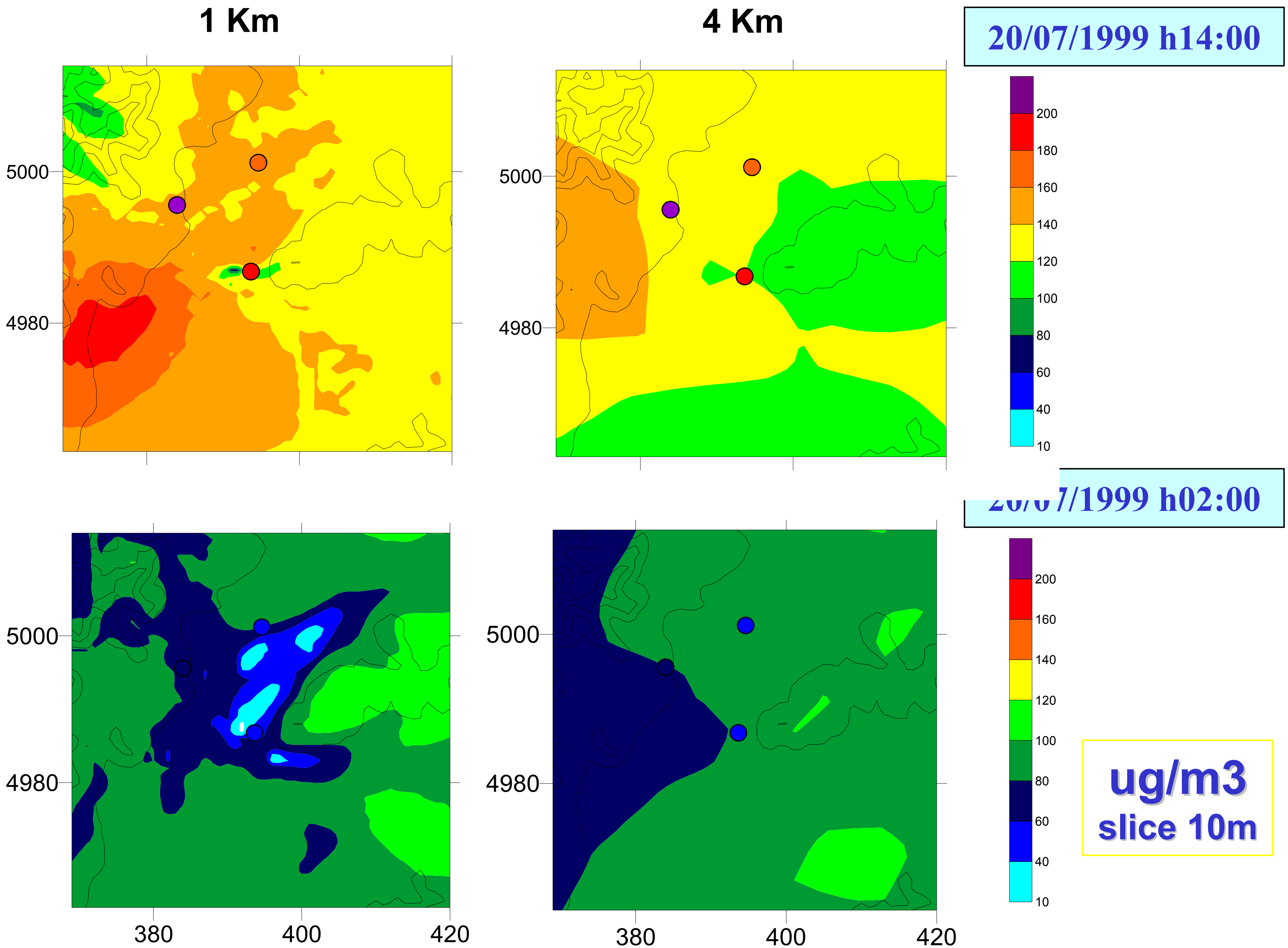
UAQIFS sensitivity to target resolution
NO2 fields



20/07/1999 h.9:00

ug/m3
slice 10m

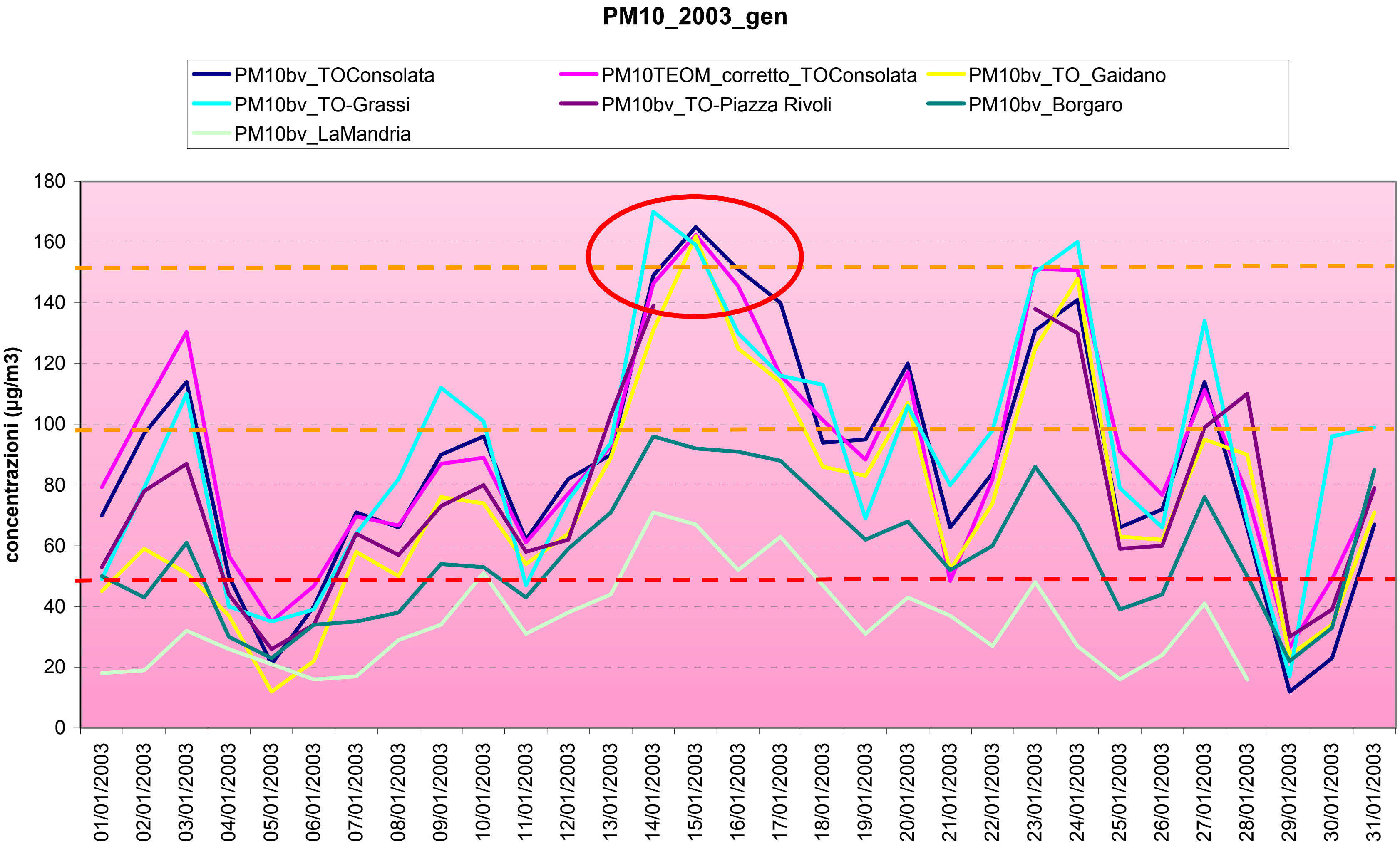
UAQIFS sensitivity to target resolution O3 fields



Winter Episode

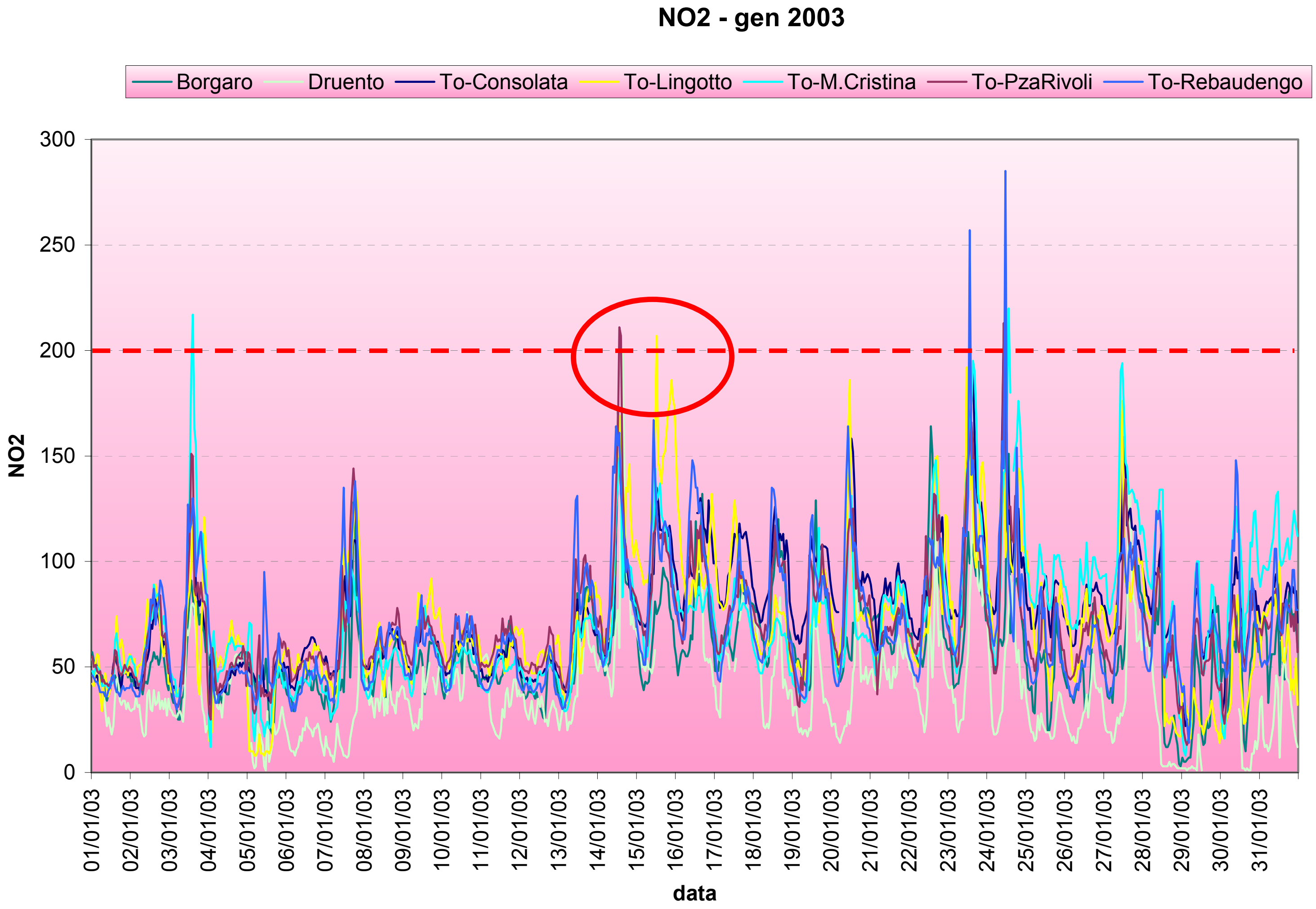
13-15/01/2003

13-15/01/2003 – Concentrations – PM_{10}



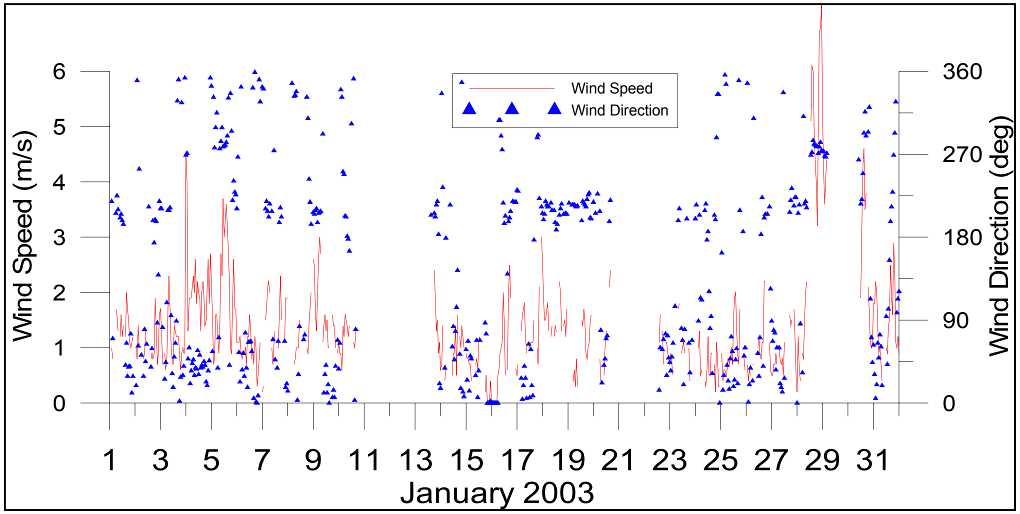
Gennaio 2003

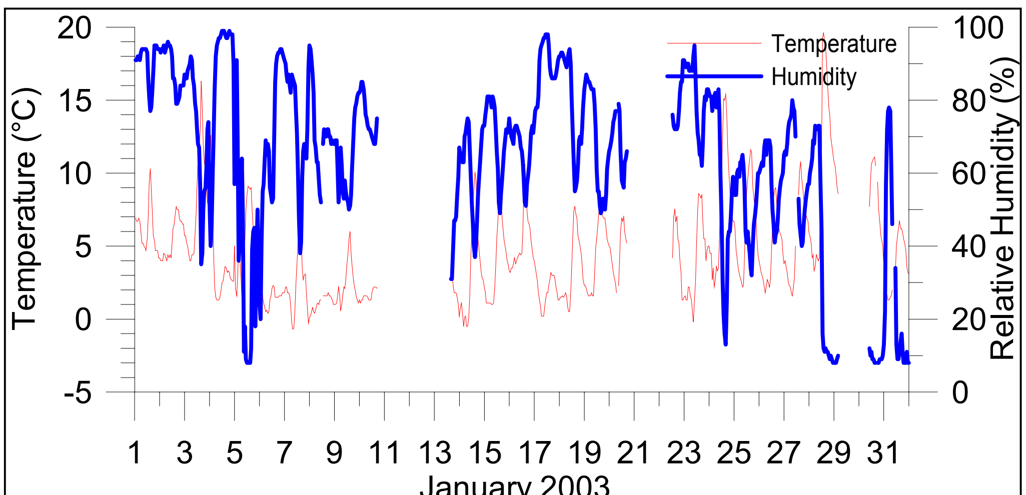
13-15/01/2003 – Concentrations – NO_2

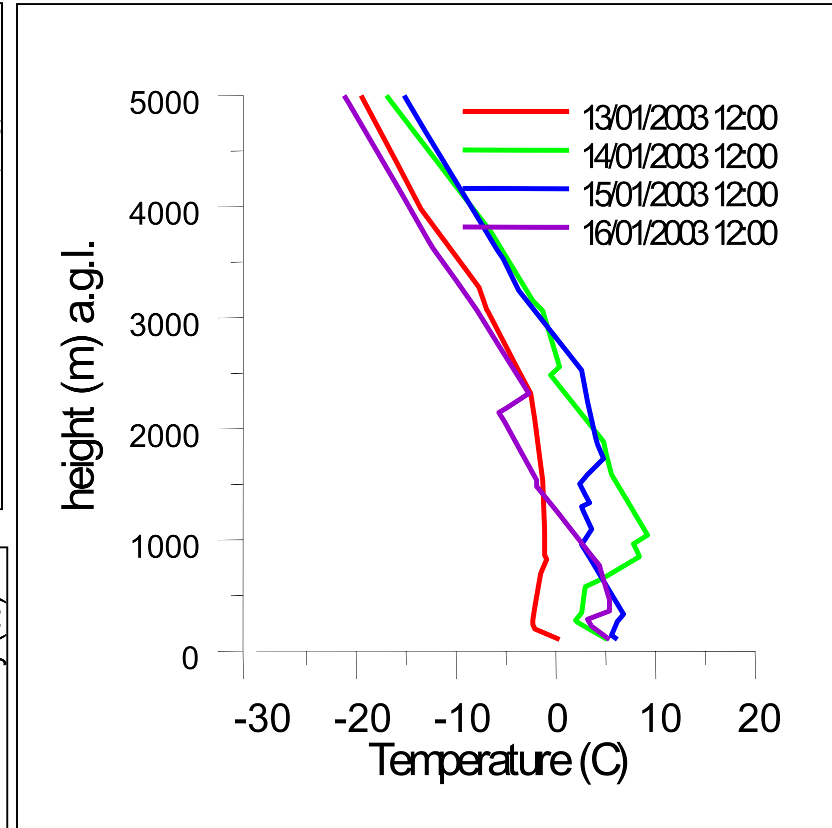


Gennaio 2003

13-15/01/2003





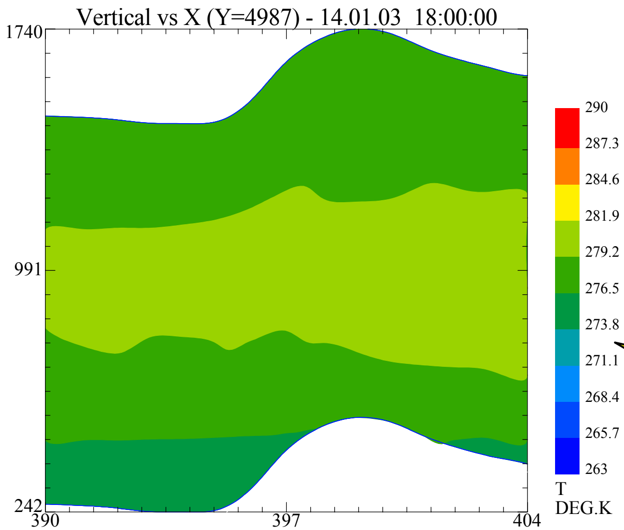


Local Meteorology To - Consolata

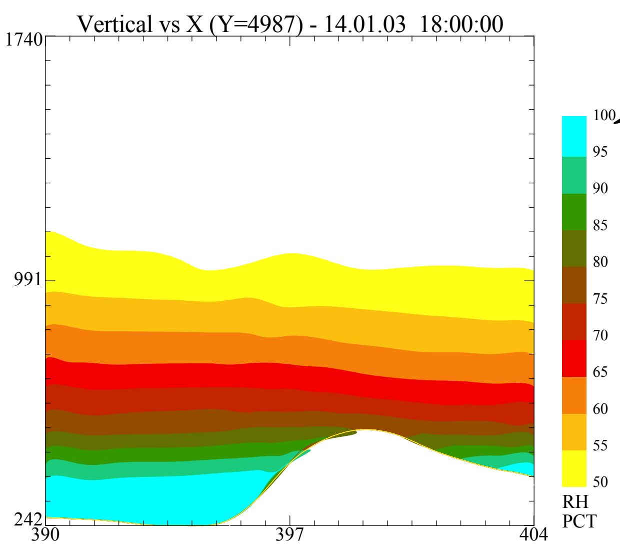
Temperature Soundings Mi - Linate

RAMS Meteorological fields

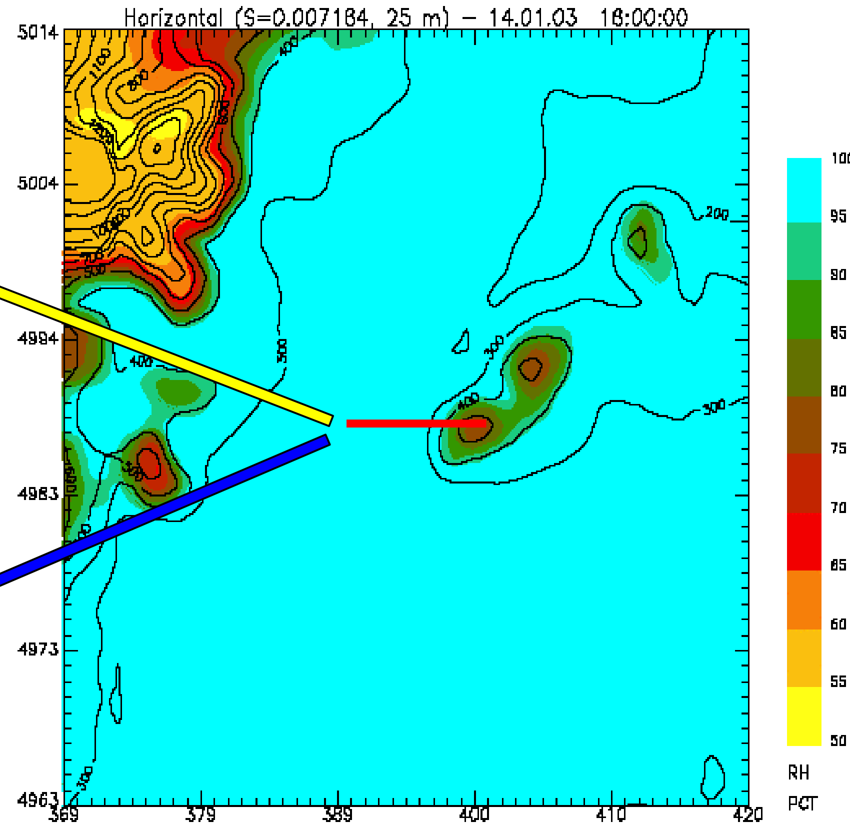
temperature inversion



relative humidity - fog

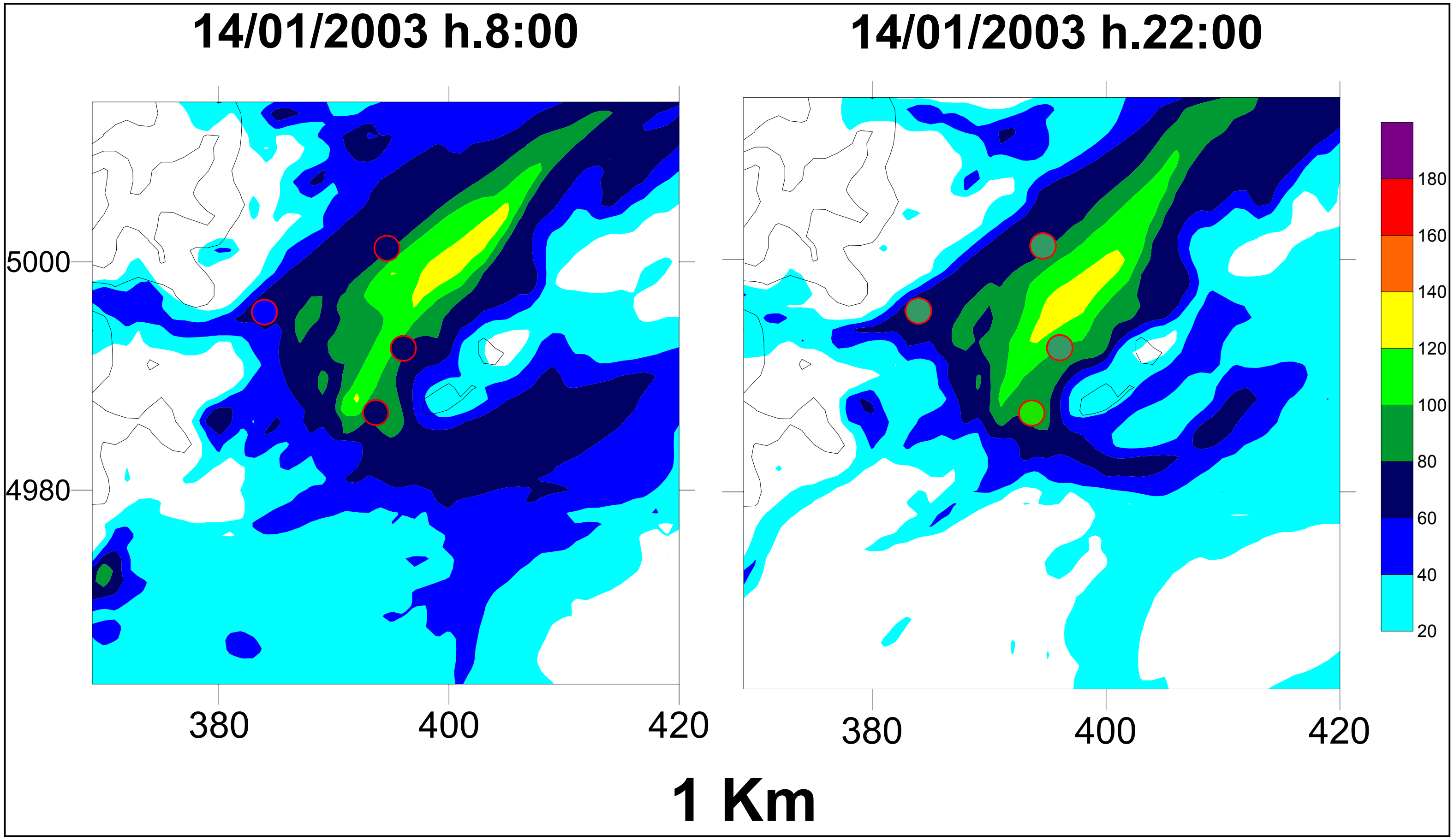


relative humidity (%)



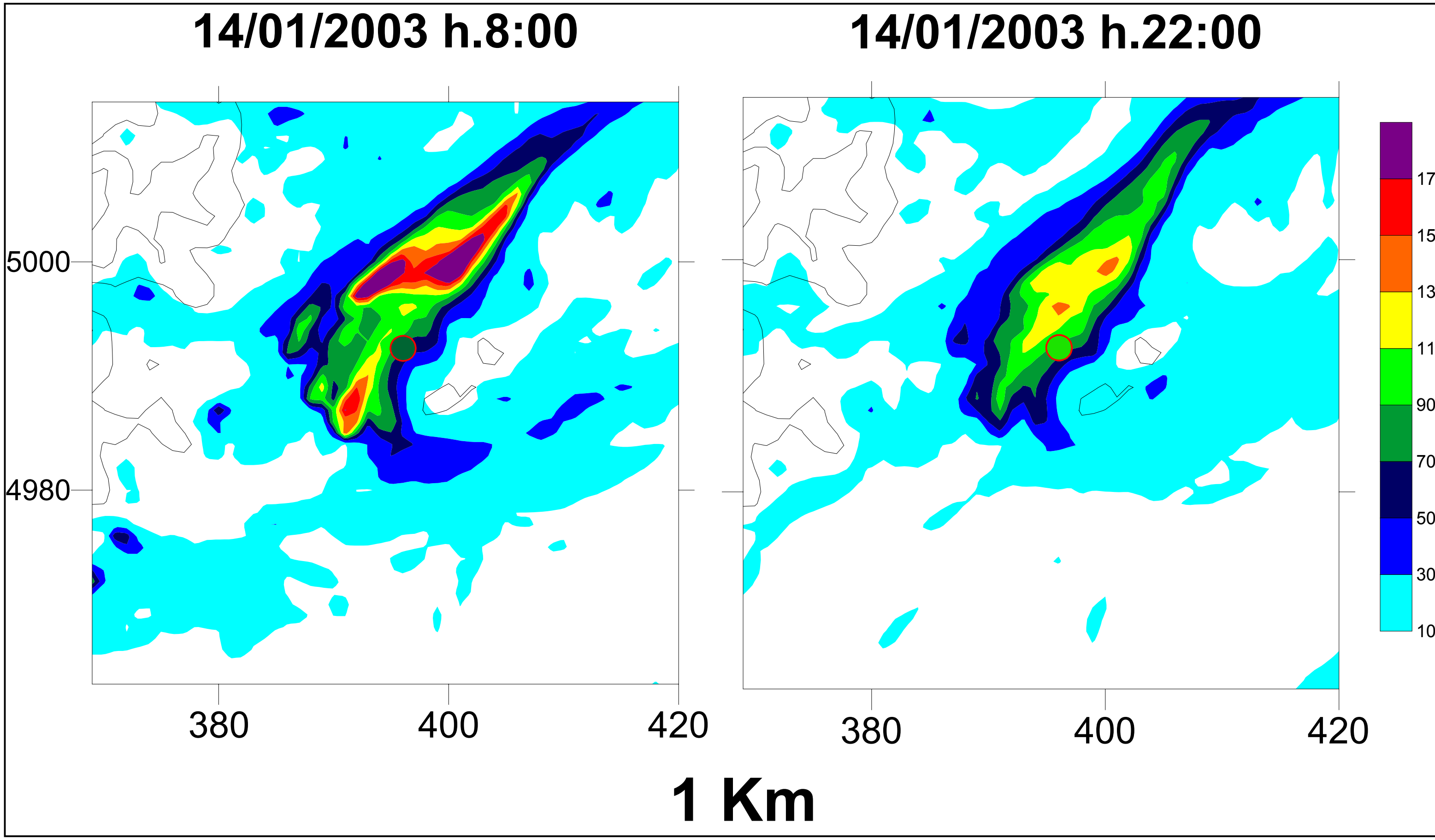
14/01/2003 18:00

FARM NO2 fields



ug/m3
slice 10m

FARM PM10 fields

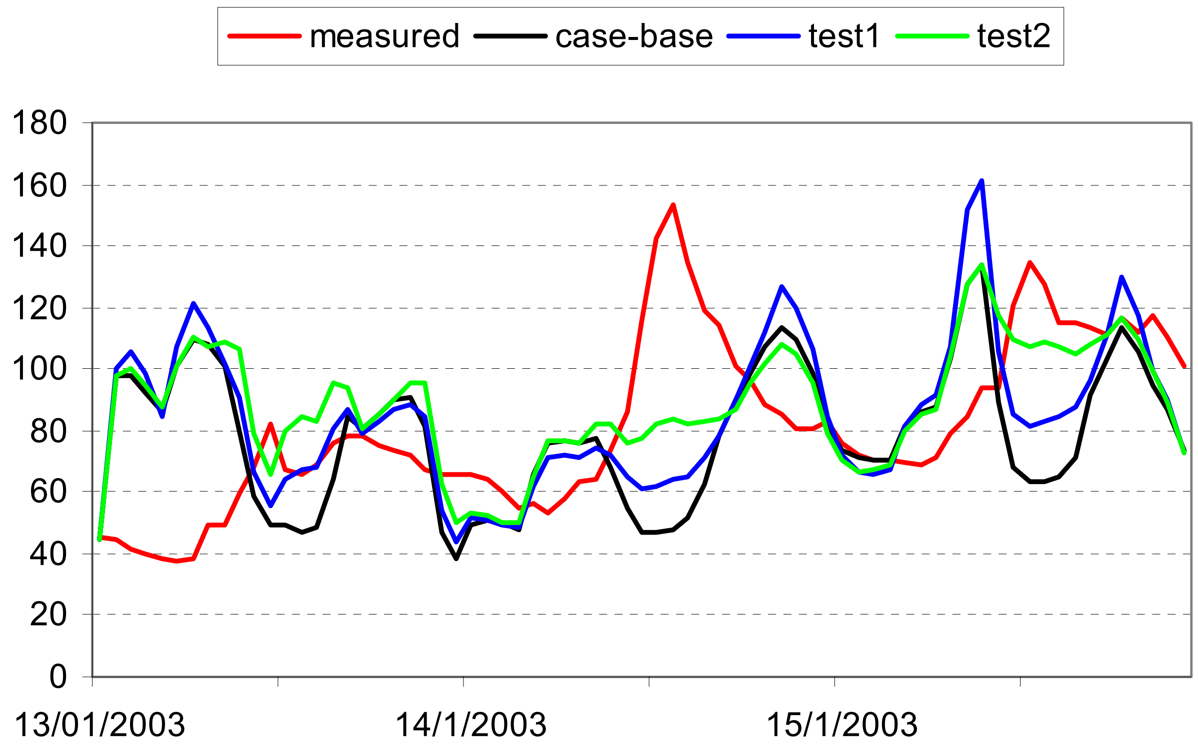


ug/m3
slice 10m

case-base : no max for Hmix - Kz min 0.2 (m^2/s)

test-1 : max for Hmix 150 (m) - Kz min 0.05 (m^2/s)

test-2 : max for Hmix 150 (m) - Kz = 0.2 (m^2/s)



Consolata
NO_2 ug/m_3

Conclusions (1)

Summer episode, sensitivity to horizontal resolution:

- *Variation of results at monitoring sites, slight improvement of performances*
- *Large differences in the general features of meteorological and concentration fields*
- *Large differences in min and max NOx concentrations*

Winter episode

- *General features of atmospheric vertical structure are correctly reproduced even though foggy conditions persist more than expected*
- *Improvements are needed on soil initialization and meteorological parameterizations*
- *A simultaneous reduction of mixing depth and eddy diffusivities clearly improve results, for both NO and NO2 during daytime, confirming the possible overestimation of eddy diffusivities and boundary layer depth for the base case simulation*
- *Improvements are needed on urbanization of turbulent parameters*

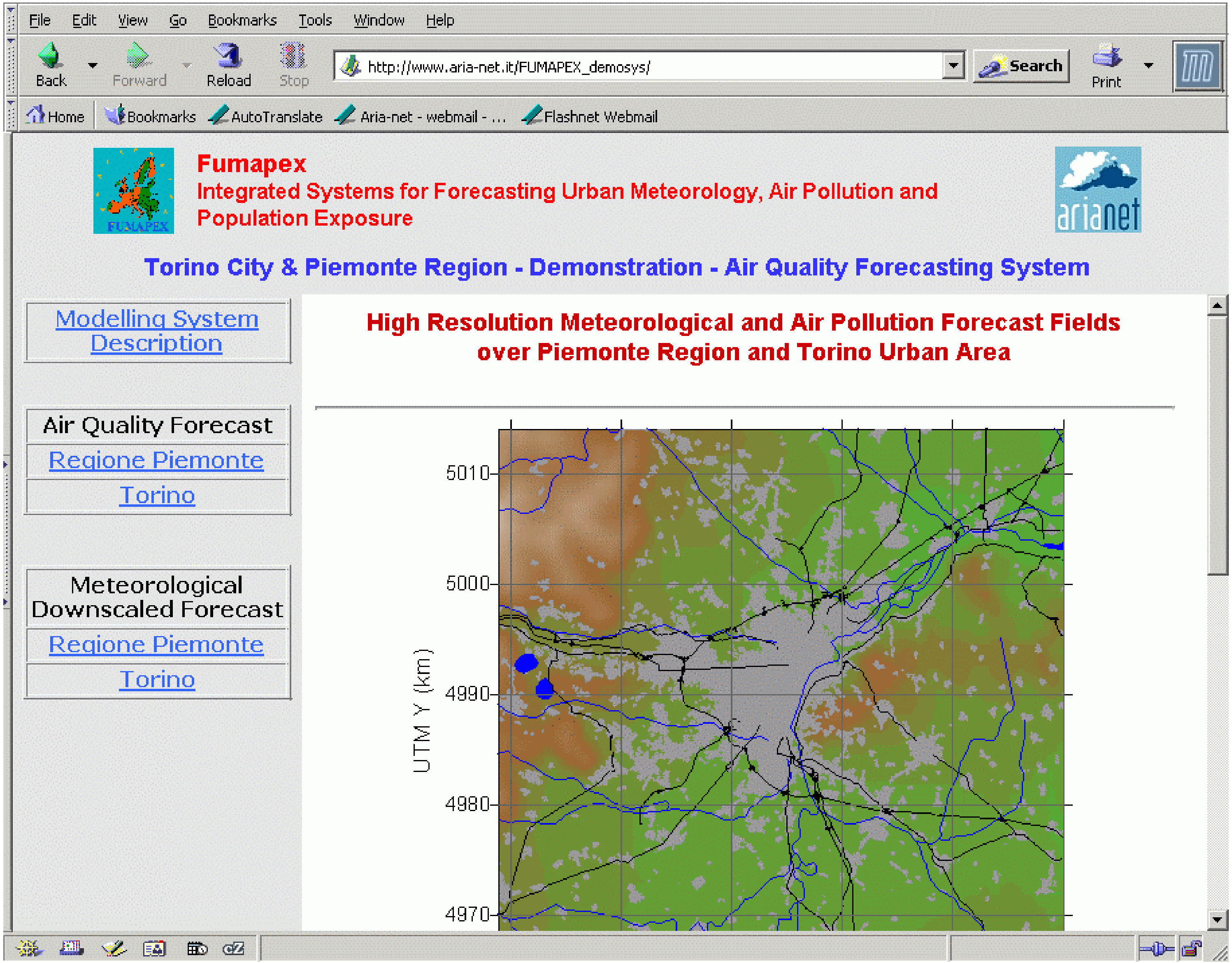
Conclusions (2)

- *The proposed modelling system proved to be a promising tool to support air quality management and for forecast and prevention of severe air pollution episodes in urban areas*

- *The UAQIFS derived from FUMAPEX prototype has been requested for implementation by Novara Province*

Forecast dissemination

http://www.aria-net.it/FUMAPEX_demosys/



Interface Module improvement and urbanisation

Implementation of:

- **new computational schemes for the mixing height**
- **Grimmod and Oke OHM model to describe urban surface energy balance**

Development of SurfPRO 3.0

Mixing height (1)

Surfpro 2.2 computational method:

- **unstable (daytime): modified Carson (1973) method**

$$\frac{\partial\theta}{\partial z} h\, dh = (1+2A)\frac{H_0}{\rho\, c_p}\, dt$$

- **stable (nighttime): Nieuwstadt (1981), Zilitinkevich (1972)**

$$\frac{h}{L} = \frac{0.3 u_* / fL}{1+1.9\, h/L}$$

Mixing height (2)

Richardson number diagnostic schemes:

- **Bulk Richarson number:**

$$\mathrm{Ri}_B \equiv \frac{\beta \Delta \theta_v h}{U^2}$$

$\mathbf{Ri_{Bc} = 0.25}$

$$\mathrm{Ri}_{Bc} = 0.1371 + 0.0024 \frac{N}{|f|}$$

- **Gradient Richarson number:**

$$\mathrm{Ri} = \frac{\beta (\partial \theta_v / \partial z)}{(\partial u / \partial z)^2 + (\partial v / \partial z)^2}$$

$\mathbf{Ri_c = 1.0}$

$$\mathrm{Ri}_c = 0.115 (100 \Delta z)^{0.175}$$

Mixing height (3)

Prognostic computational methods:

- **Gryning & Batchvarova (1996) IBL:**

$$\left\{\frac{h^2}{(1+2A)h-2B\kappa L}+\frac{Cu_*^2T}{\gamma g[(1+A)h-B\kappa L]}\right\}\left(\frac{\partial h}{\partial t}+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}-w_s\right)=\frac{\left(\overline{w'\theta'}\right)_s}{\gamma}$$

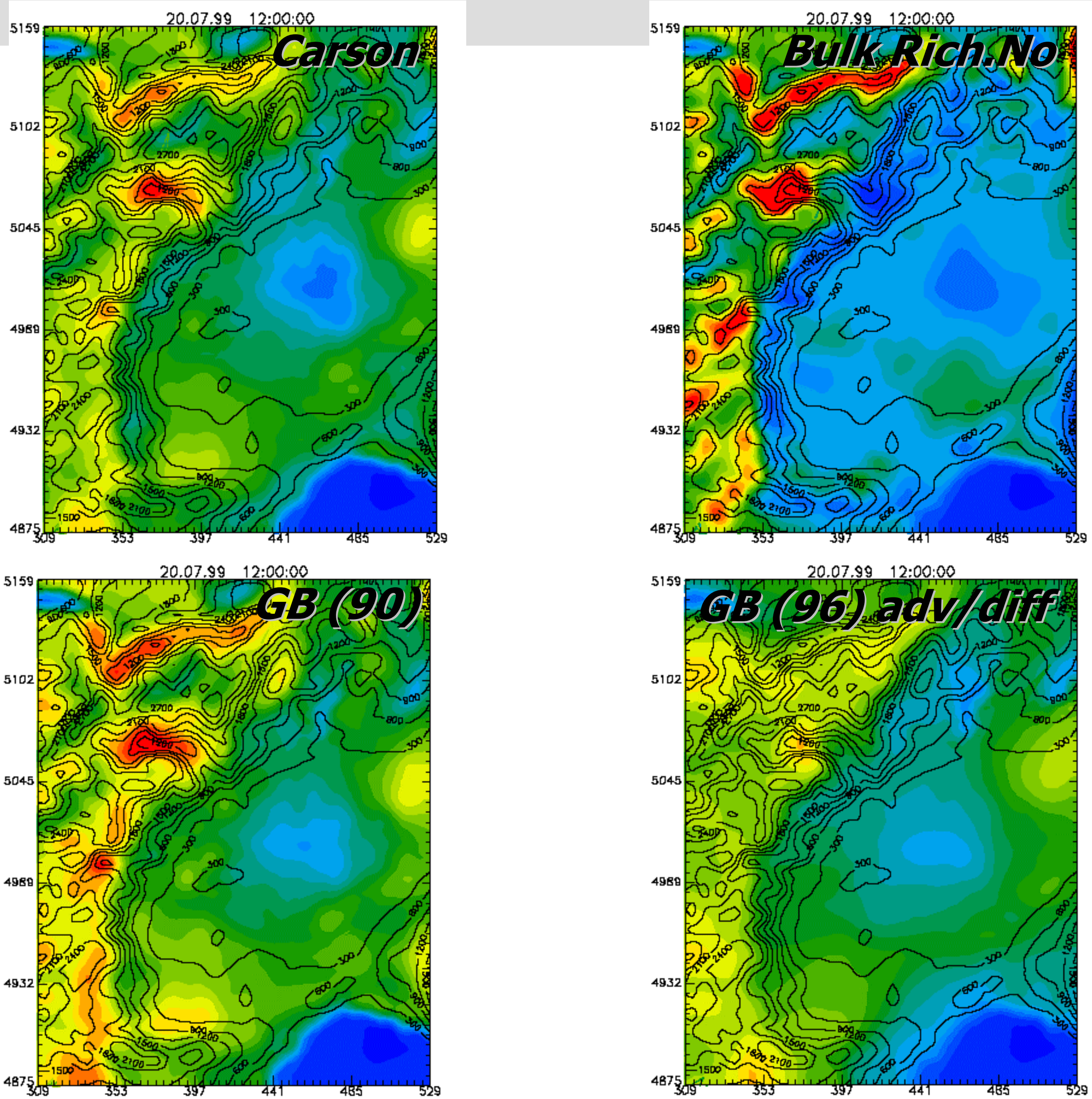
- **Zilitinkevich & Baklanov, (2001):**

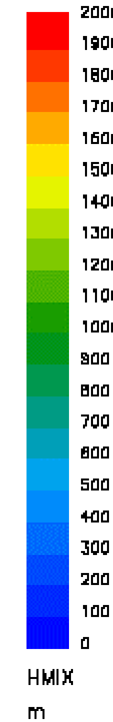
$$\frac{\partial h}{\partial t}+\mathrm{V}\cdot\nabla h=-C_E\,|\,f\,|\,(h-h_{CQE})+K_h\nabla^2 h$$

$$h_{CQE}=\frac{C_R u_*}{|f|}\left(1+\frac{C_R^2 u_*(1+C_{uN}NL/u_*)}{C_S^2 L|f|}\right)^{-1/2}+\frac{w_h}{C_E|f|}$$

Mixing height schemes comparison (1)

Summer daytime (12:00) – convective conditions

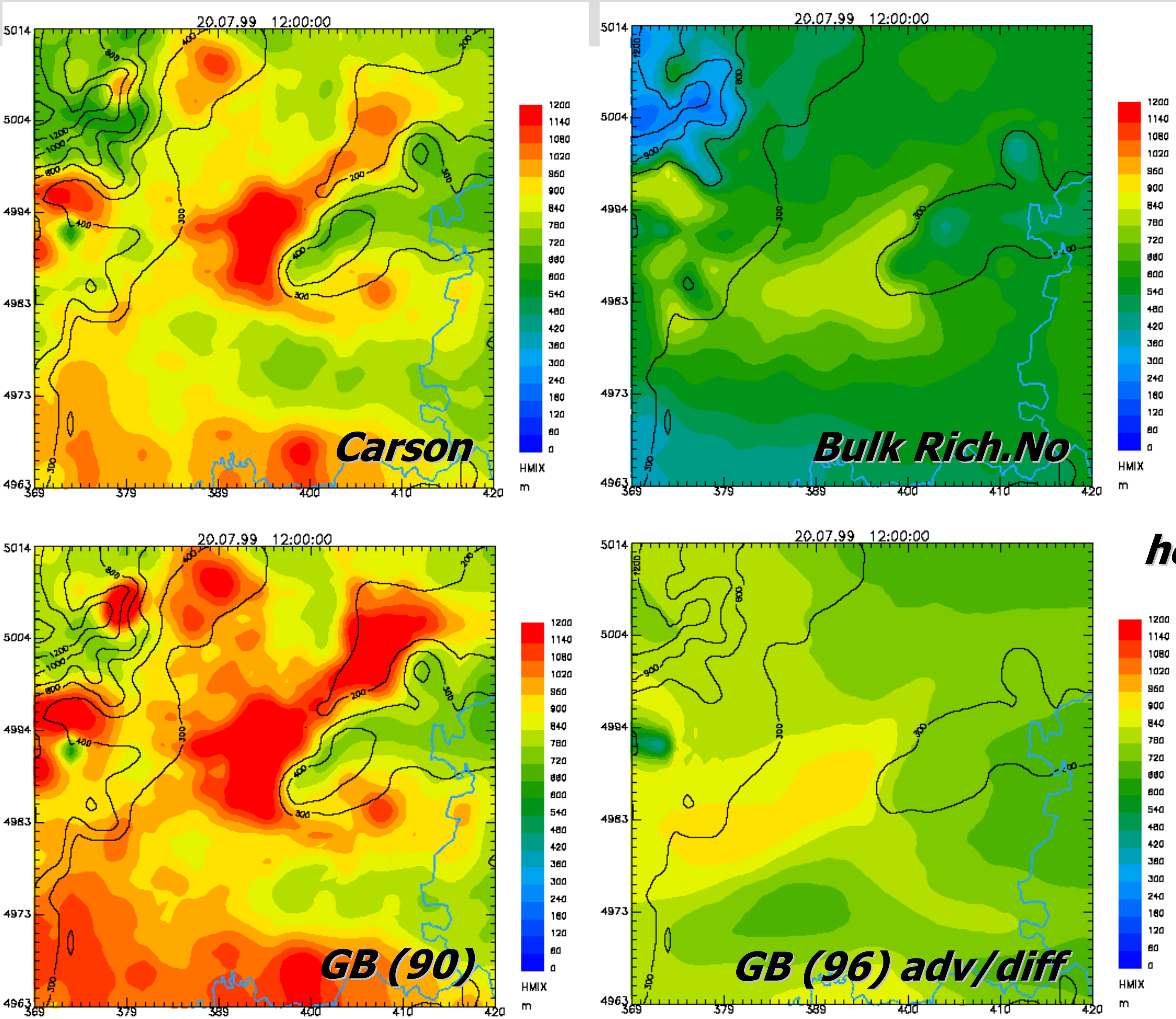




Mixing height (m)

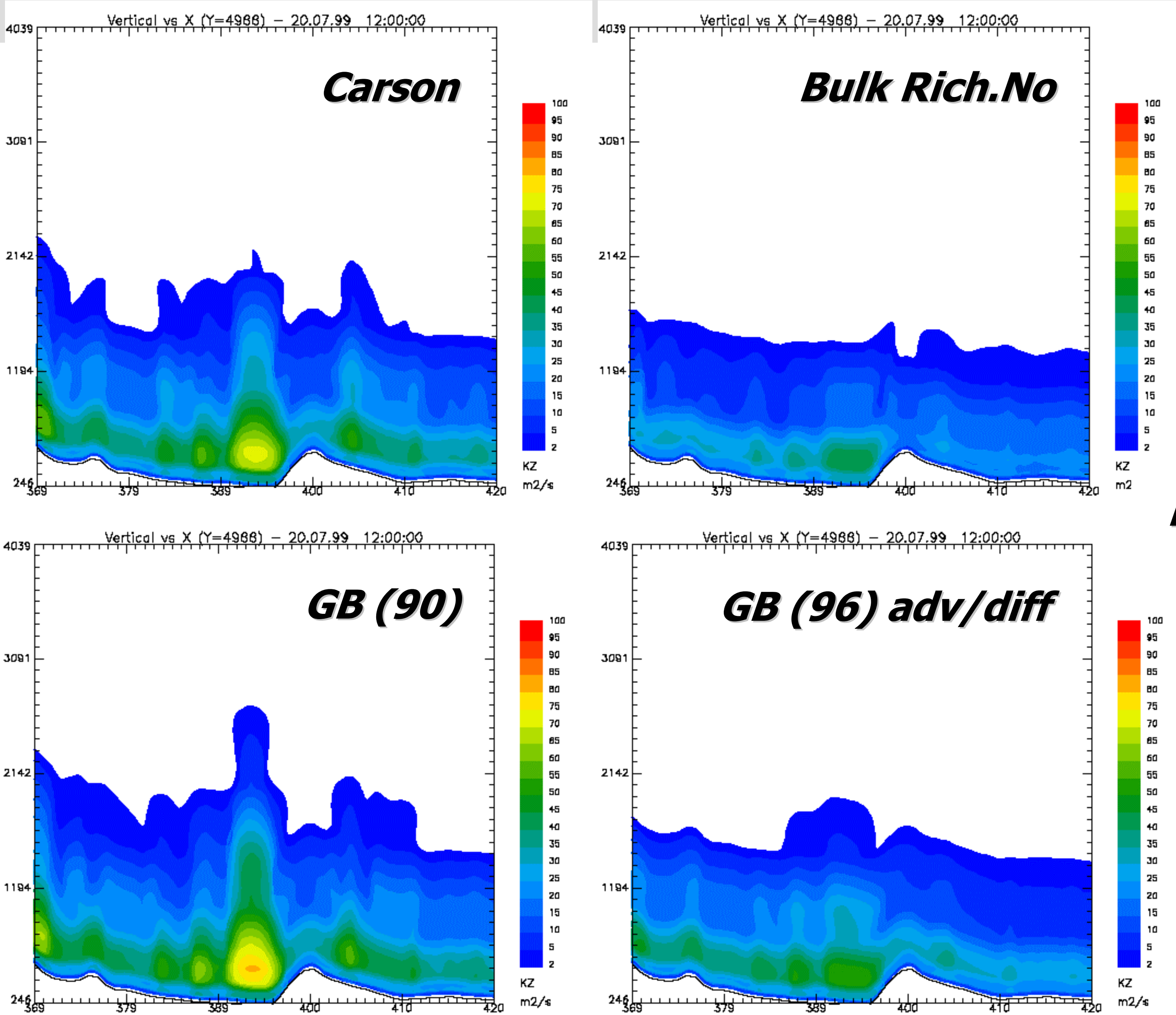
Mixing height schemes comparison (2)

Summer daytime (12:00) – convective conditions



Mixing height (m)

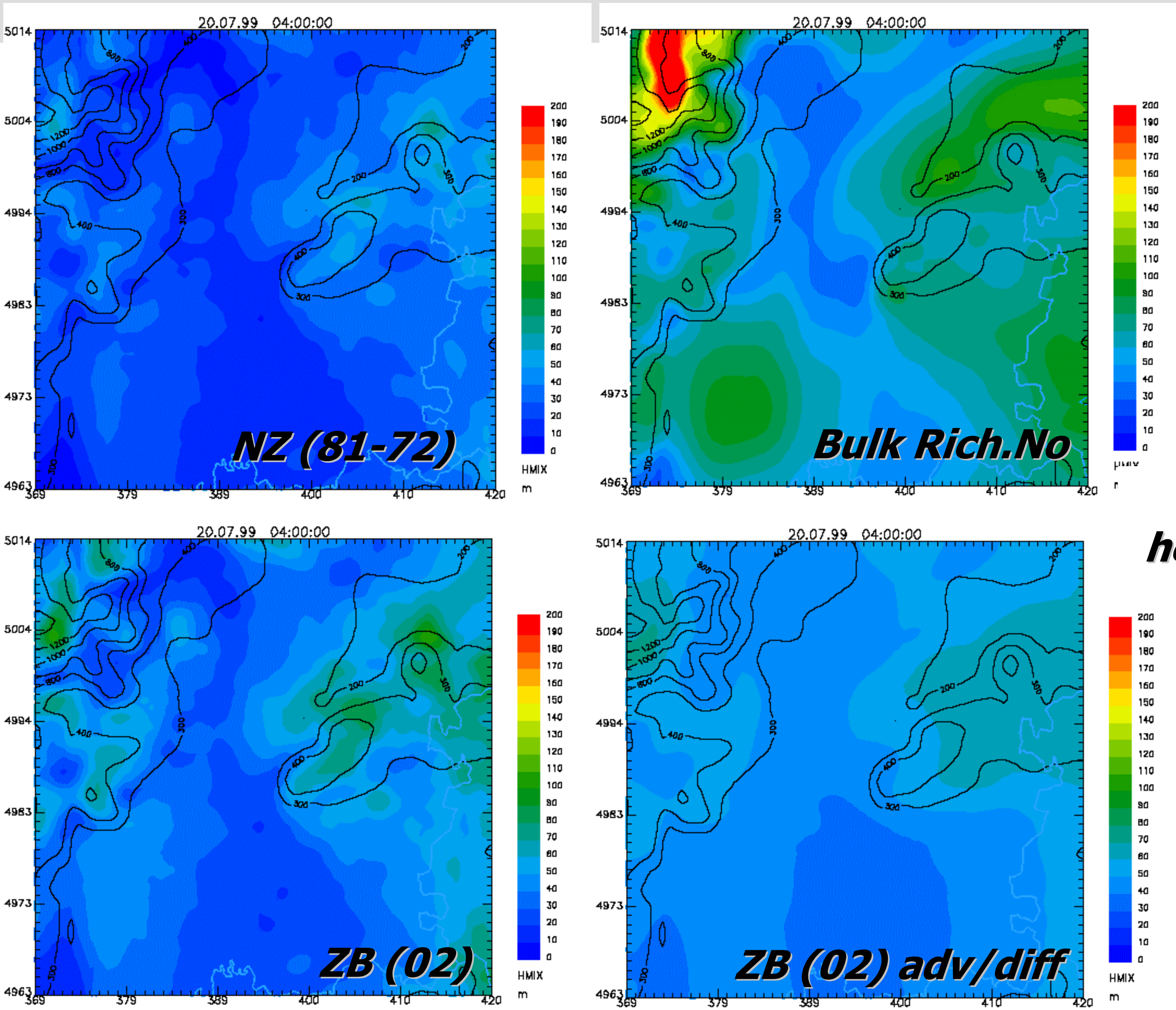
Mixing height schemes comparison (3)
Summer daytime (12:00) – convective conditions



Kz (m^2/s)

Mixing height schemes comparison (4)

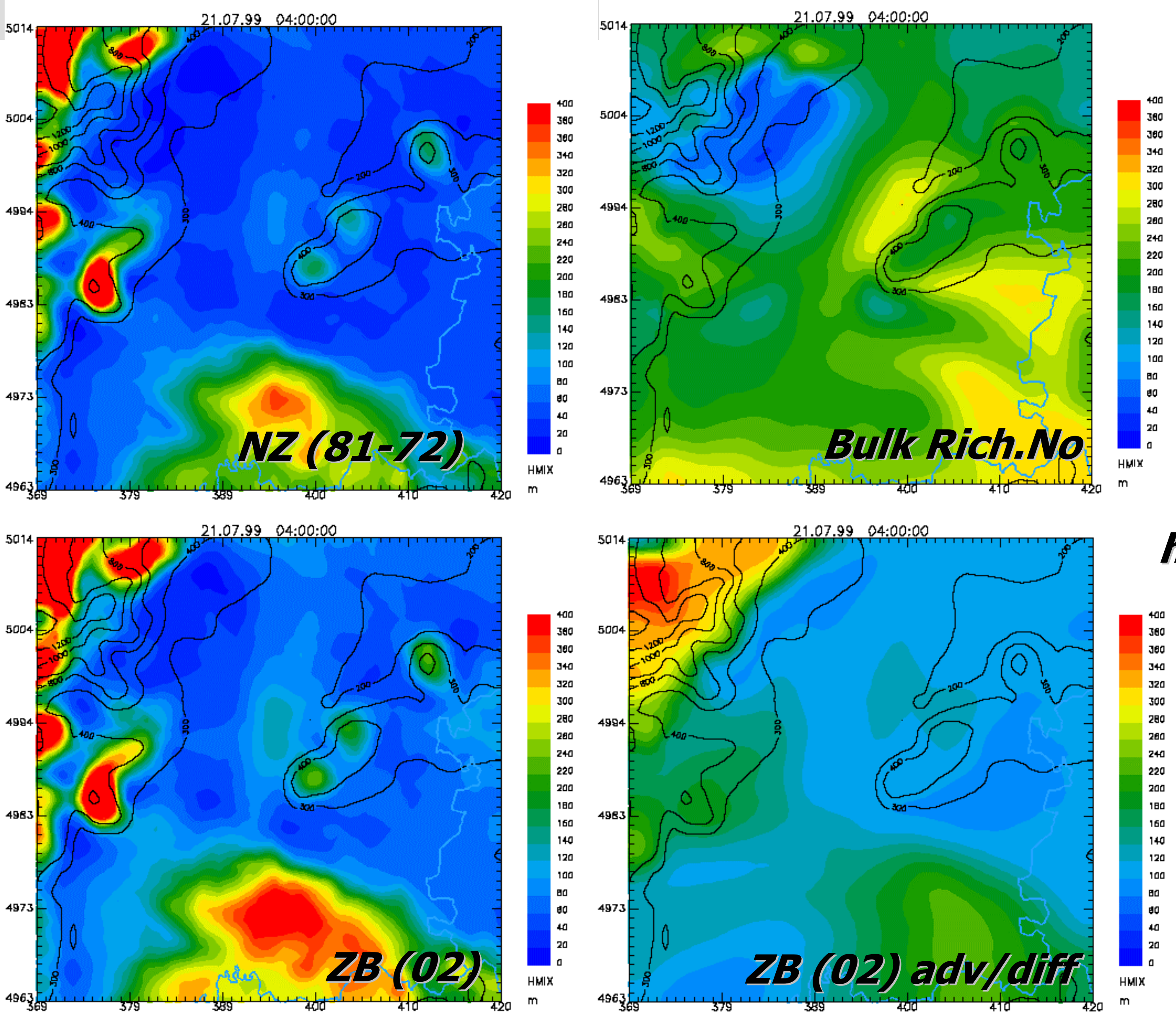
Summer nighttime (4:00) – stable – low wind (<1 m/s)



Mixing height (m)

Mixing height schemes comparison (5)

Summer nighttime (4:00) – stable – windier (>2 m/s)



Mixing height (m)

Urban heat storage model

Objective Hysteresis Model:

- **Heat storage flux, Grimmond & Oke (1999):**

$$\Delta Q_S = \sum_{i=1}^{n} (\lambda_i \alpha_{1i}) Q^* + \sum_{i=1}^{n} (\lambda_i \alpha_{2i}) \left(\frac{\partial Q^*}{\partial t} \right) + \sum_{i=1}^{n} (\lambda_i \alpha_{3i})$$

λ_i plan fractions of: green space/open, paved/impervious, Rooftop

- **Other terms of surface energy balance as in LUMPS, Grimmond and Oke (2000, 2002)**

EVALUATION OF TURBULENT FLUXES IN TORINO URBAN AREA

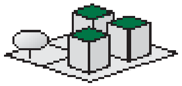
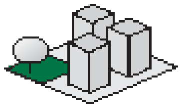
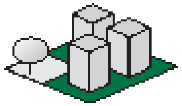
TORINO URBAN AREA

- Detailed surface cover information referred to the Torino urban area

- Surface cover information grouped into classes as defined in Grimmond & Oke (2000, 2002):

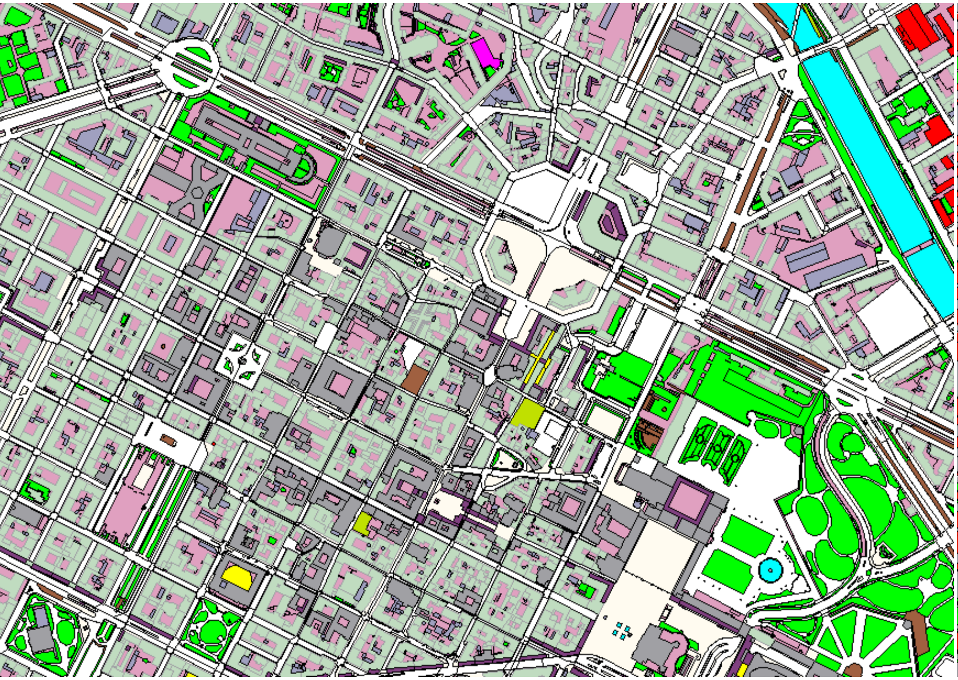
green spaces
paved/impervious
rooftop
water

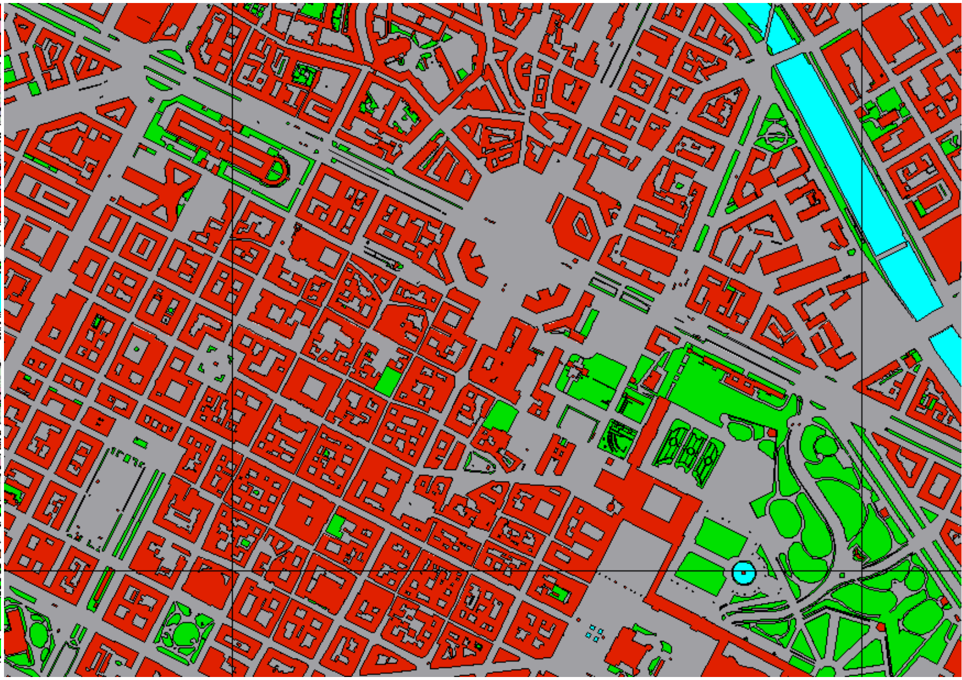
(a) Urban Cover

λ_P	Plan area ratio of buildings		Describes the plan area covered by buildings per total plan area.
λ_V	Plan area ratio of vegetation		Describes the plan area covered by vegetation (and sometimes also unmanaged bare soil) per total plan area.
λ_I	Plan area ratio of impervious surfaces		Describes the plan area covered by impervious surfaces, which are not buildings (e.g. streets, parking lots, pavements) per total plan area.

SURFACE COVER

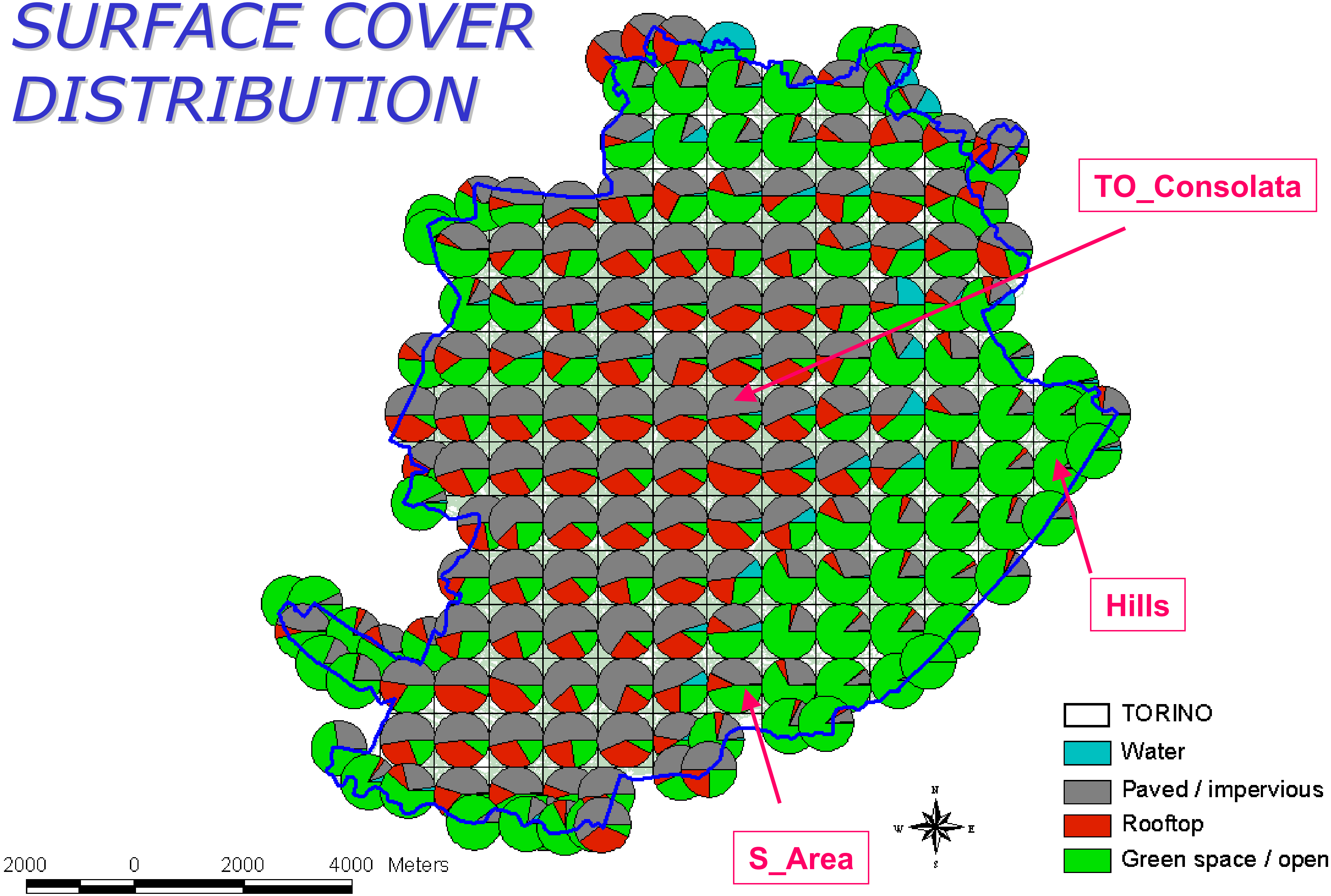
Original thematic layer | **Elaborated thematic layer**





16 classes | **4 classes**

SURFACE COVER DISTRIBUTION



METEOROLOGICAL PARAMETERS

- Meteorological data at the Torino-Consolata station

- Episode studied:

  19 – 21 July 1999

SELECTED POINTS DESCRIPTION

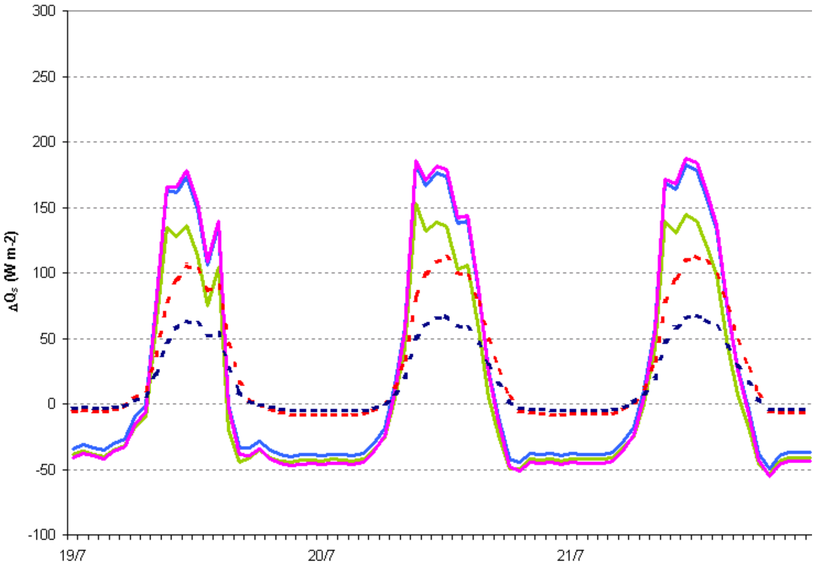
	TO_Consolata	Hills	S area
WATER (%)	2.2	0.3	1.1
GREEN SPACE (%)	9.3	90.4	46.3
PAVED - IMPERVIOUS (%)	51.7	7.7	41.5
ROOFTOP (%)	37.4	1.6	11.2

	α	β (W m-2)
TO_Consolata	0.28	3
Hills	0.76	3
S area	0.50	3

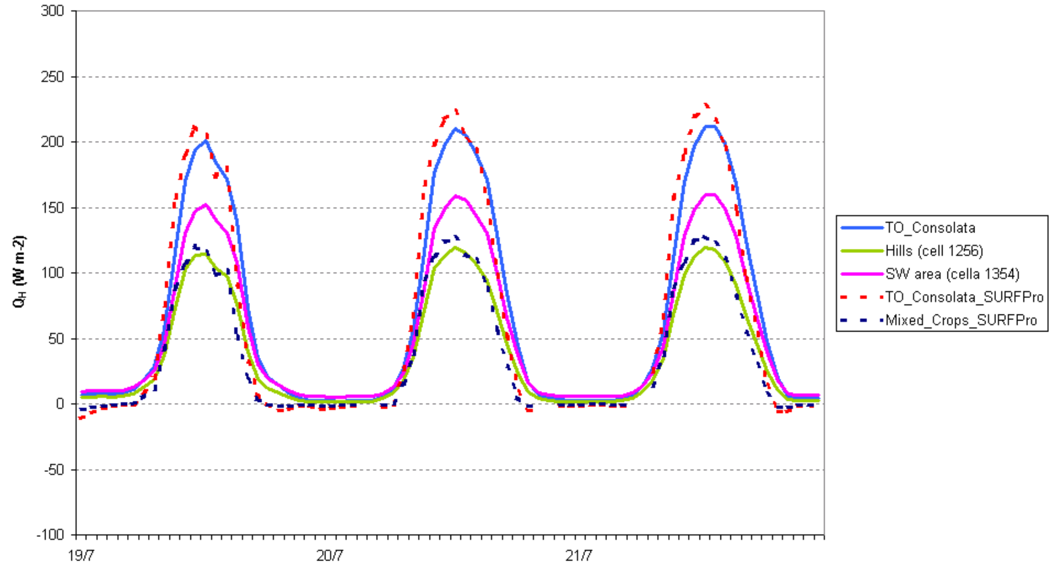
- SURFPro tested with land use Urban and Mixed Crops

Objective Hysteresis Model

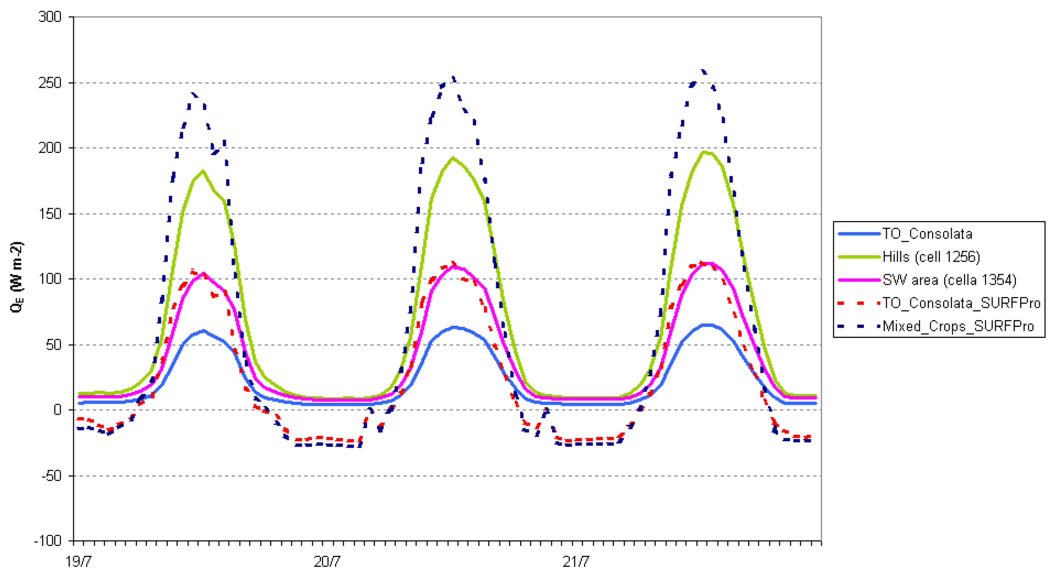
STORAGE HEAT FLUXES (ΔQ_s)

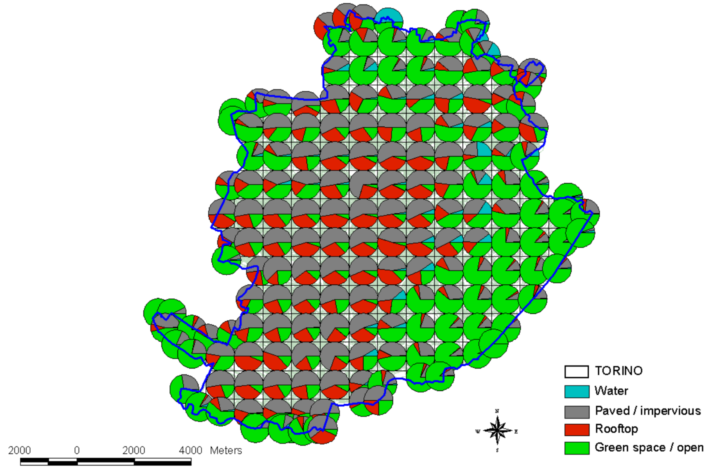


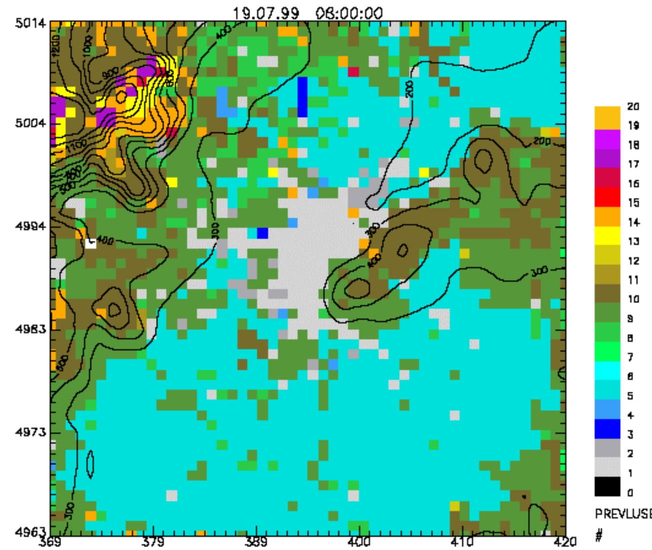
SENSIBLE HEAT FLUXES (Q_H)



LATENT HEAT FLUXES (Q_E)

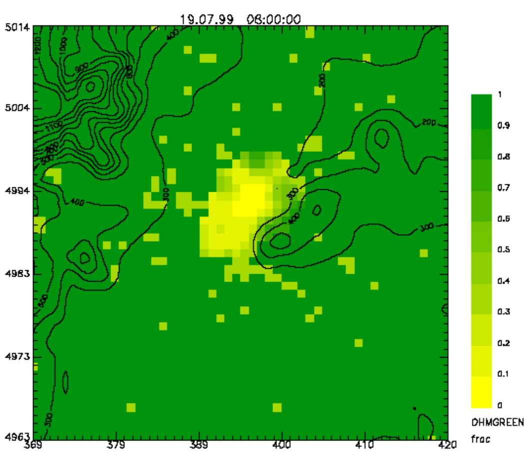




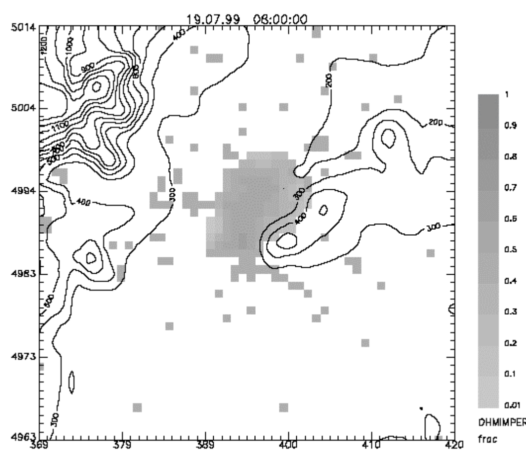


Grimmond & Oke CLASSIFICATION

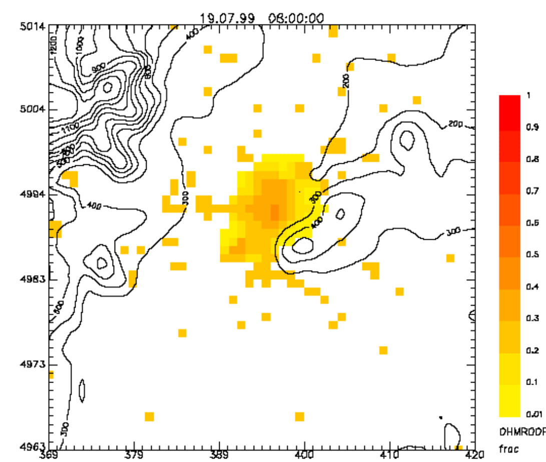
CORINE LANDUSE 21 CLASSES PREVALENT CLASSIFICATION



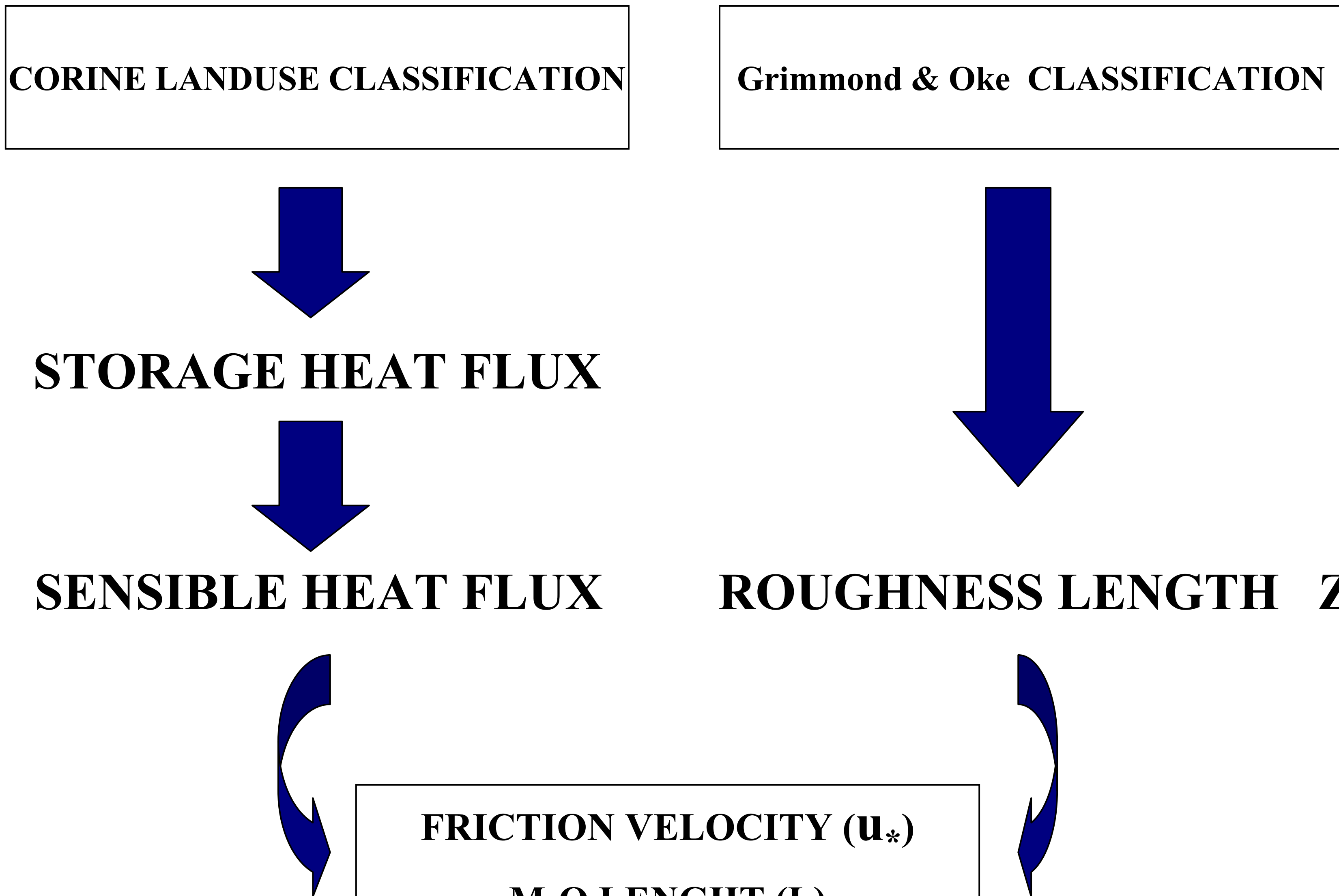
GREEN



INPERVIOUS



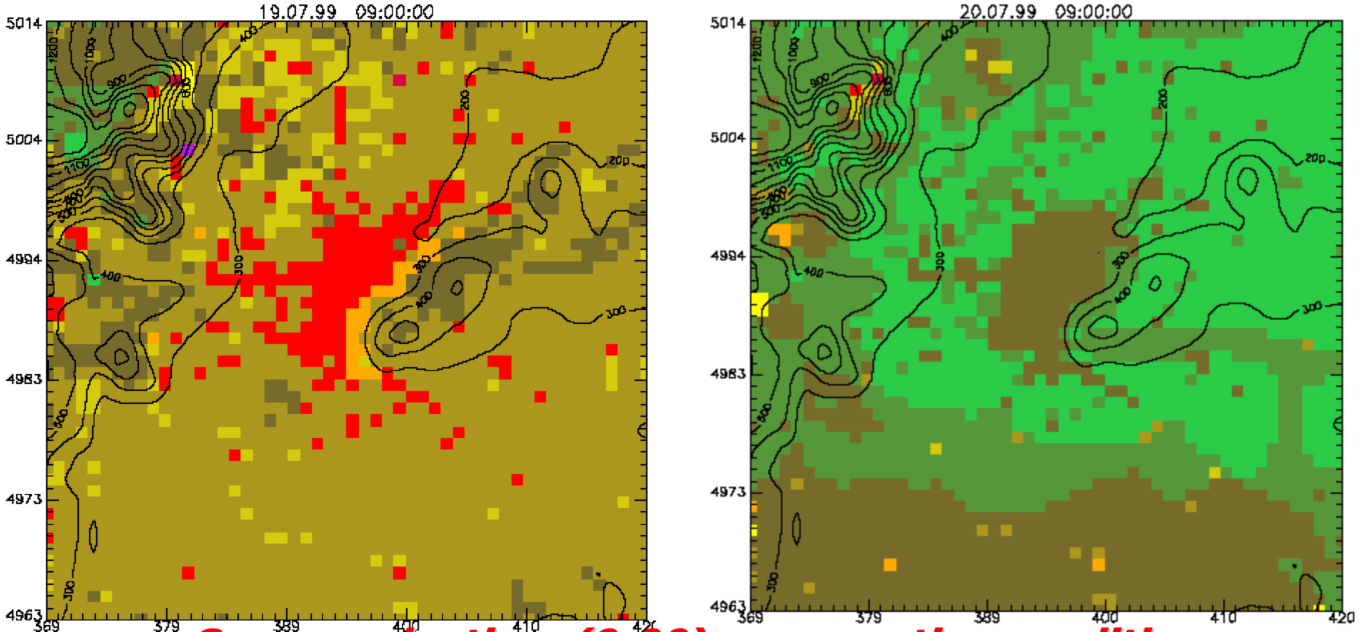
ROOF


CORINE LANDUSE CLASSIFICATION
Grimmond & Oke CLASSIFICATION
STORAGE HEAT FLUX
SENSIBLE HEAT FLUX
ROUGHNESS LENGTH Z_0
FRICTION VELOCITY (u_*)
M-O LENGHT (L)

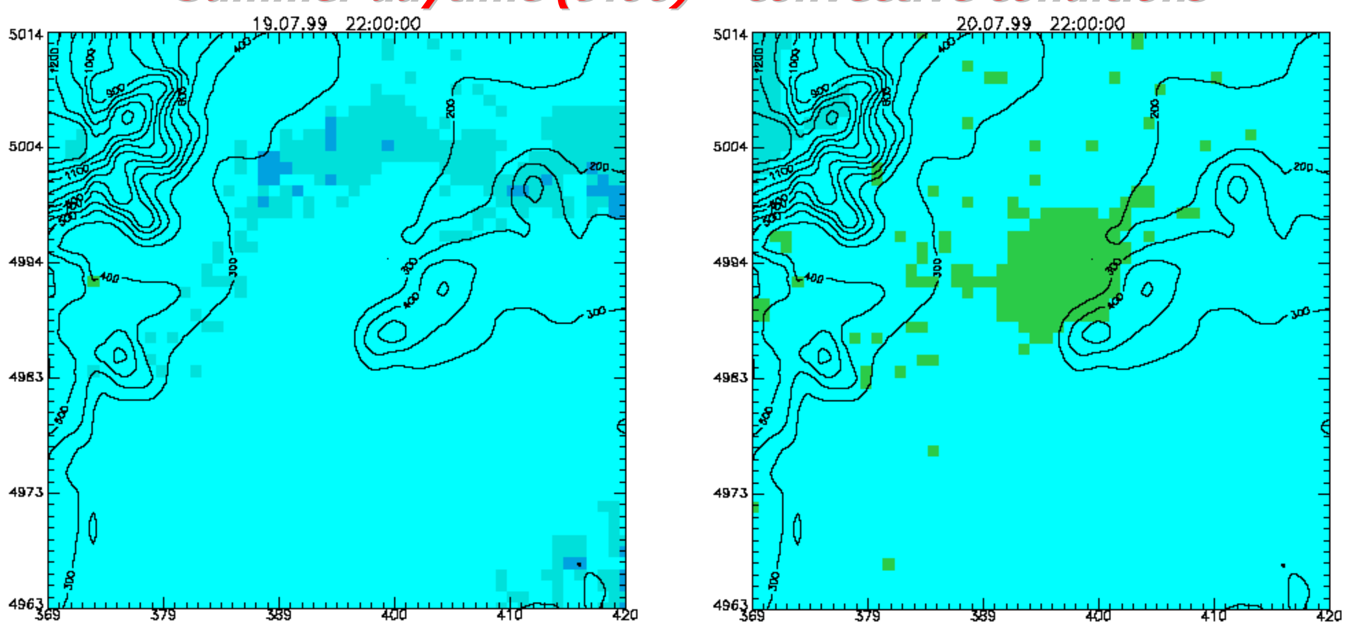
TEST
Objective Hysteresis Model implementation in Surfpro

- **Base case :** no OHM, calculation of PBL height using Nieuwstadt (stable conditions) and Carson (unstable)
- **Test-1 :** OHM, calculation of PBL height using Zilitinkievich Backlanow prognostic scheme (stable conditions) and Gryning and Batchvarova (unstable), taking into account advection-diffusion effects
- **Test-2 :** same as Test-1, except during nighttime, when negative values for M-O length and sensible heat flux are multiplied by minus one.

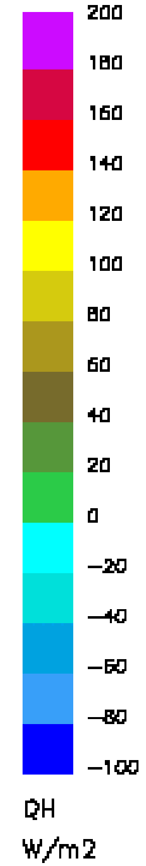
Base case | *TEST-1*



Summer daytime (9:00) – convective conditions



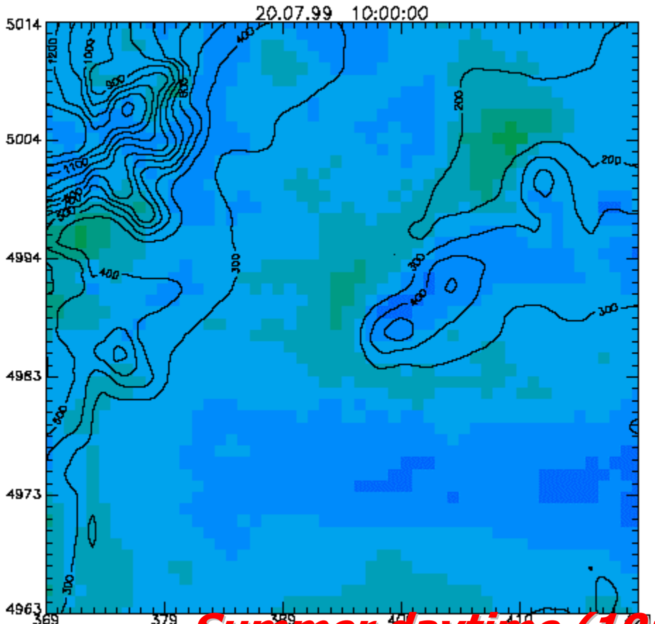
Summer nighttime (22:00) – stable conditions

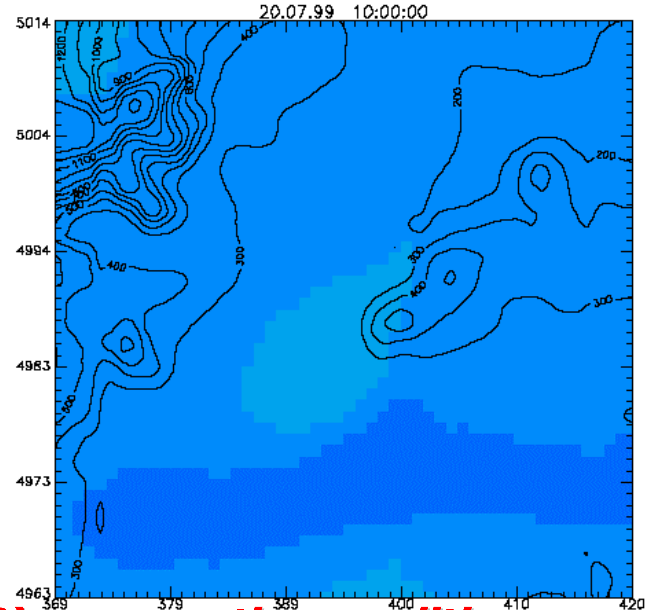


Sensible heat flux (W/m^2)

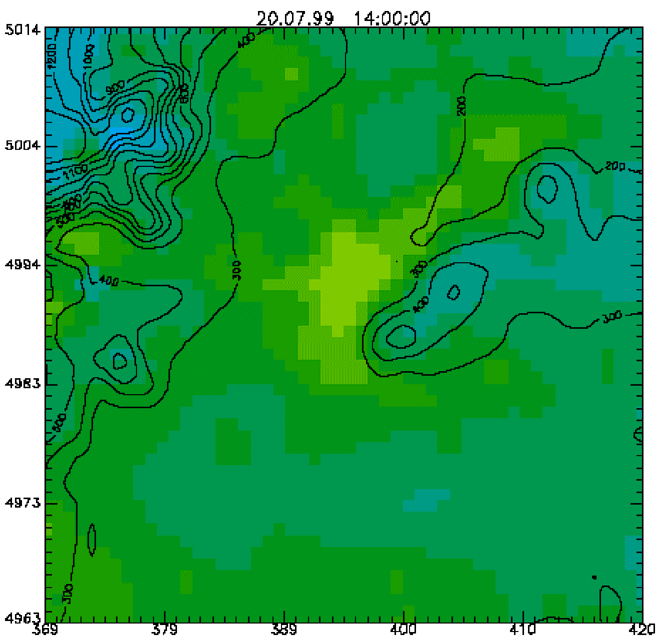
Base case

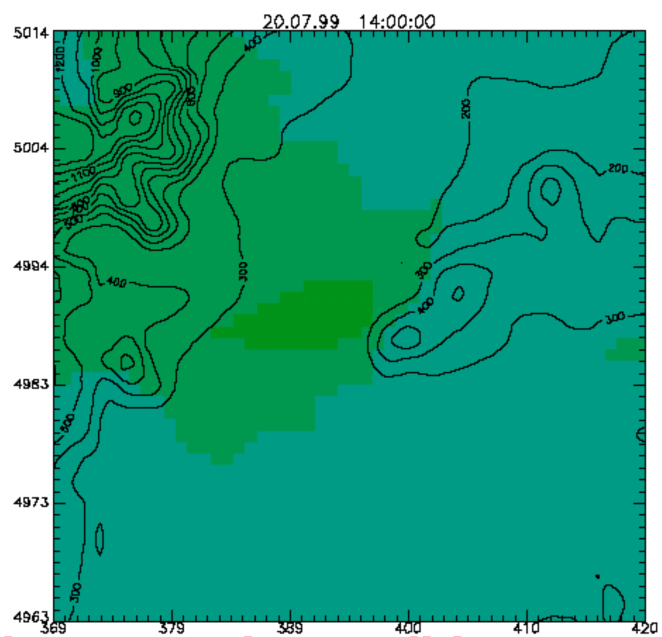
TEST-1



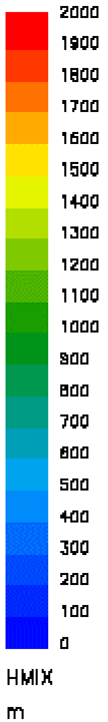


Summer daytime (10:00) – convective conditions



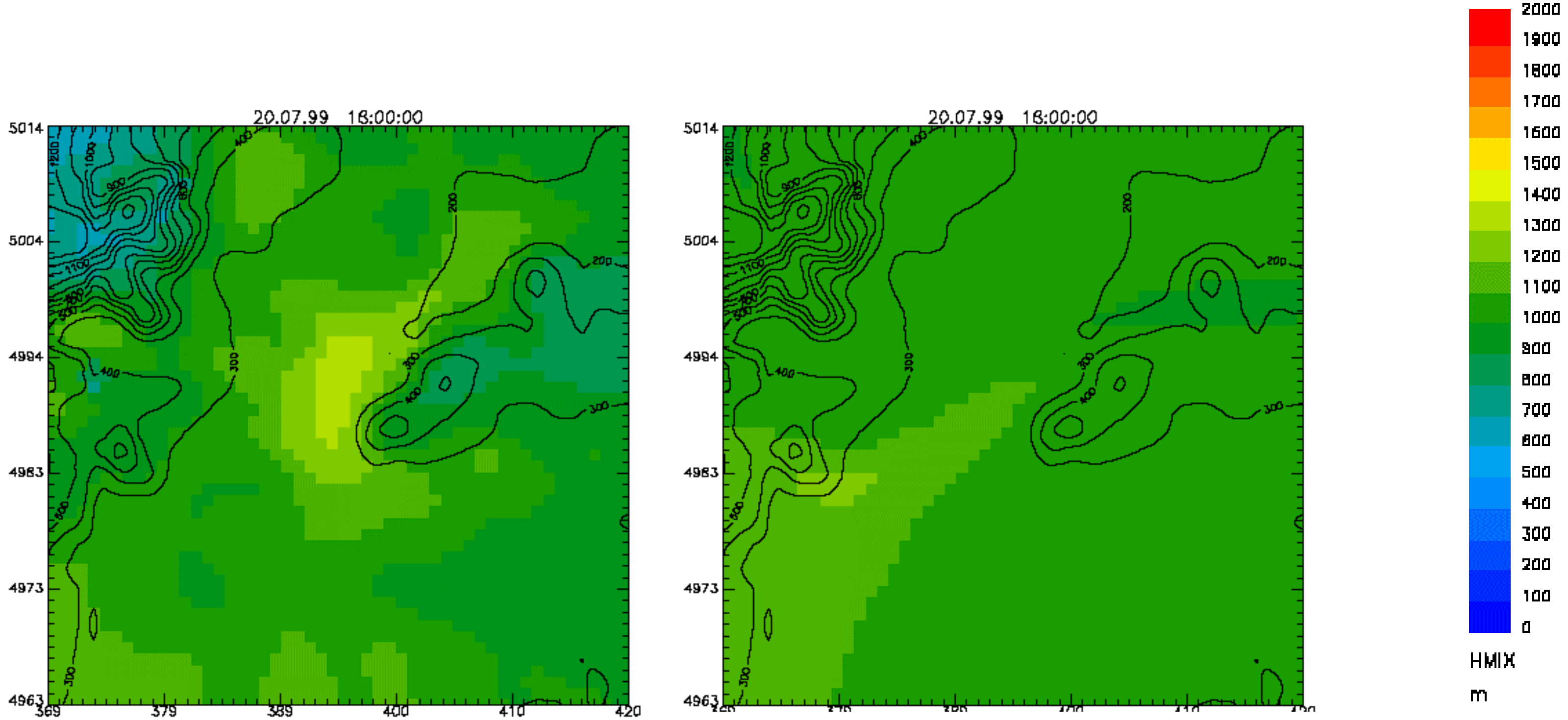


Summer daytime (14:00) – convective conditions



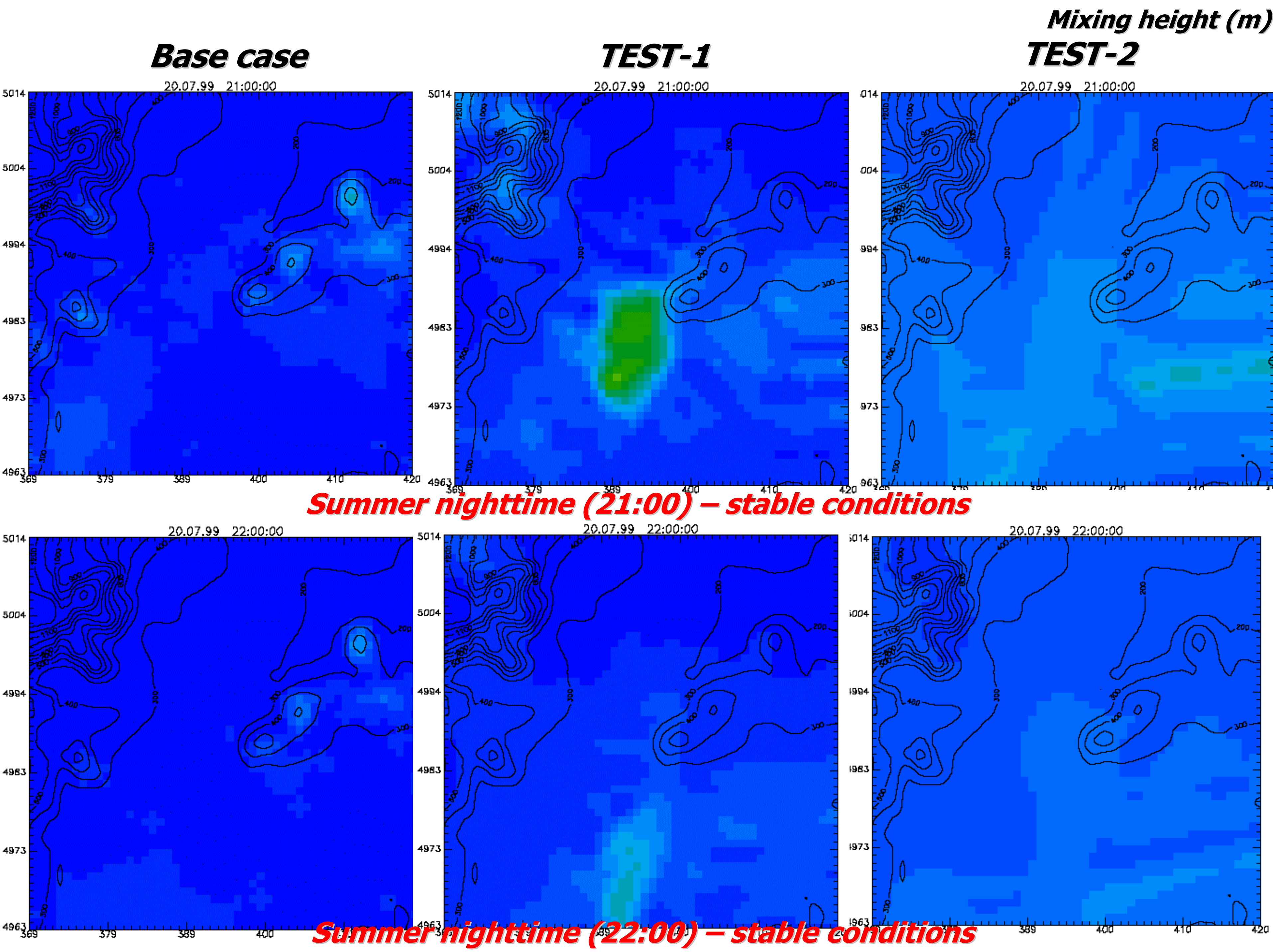
Mixing height (m)

Base case **TEST-1**

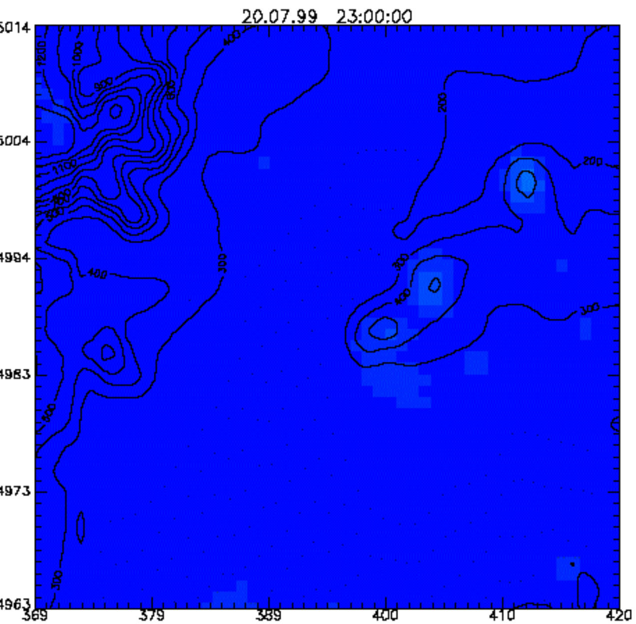


Summer daytime (18:00) – convective conditions

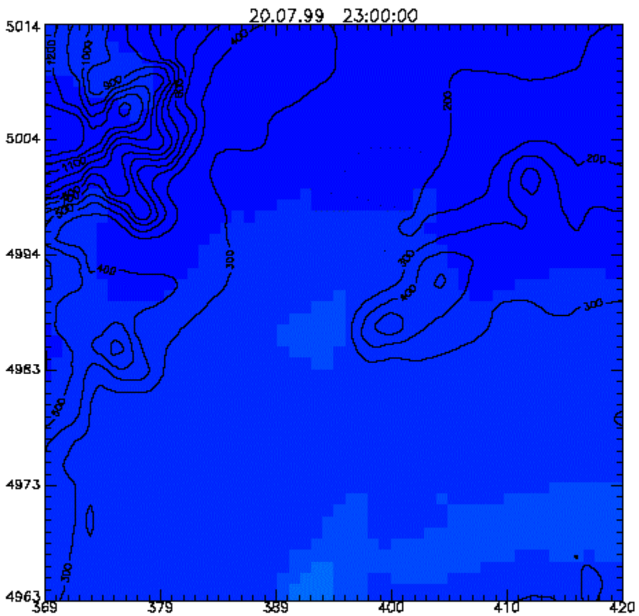
Mixing height (m)


Mixing height (m)
Base case
TEST-1
TEST-2
20.07.99 21:00:00
20.07.99 21:00:00
20.07.99 21:00:00
Summer nighttime (21:00) – stable conditions
20.07.99 22:00:00
20.07.99 22:00:00
20.07.99 22:00:00
Summer nighttime (22:00) – stable conditions

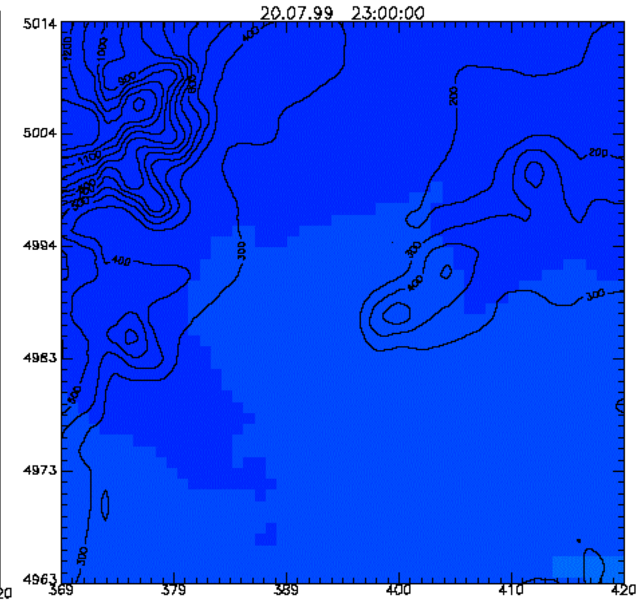
Base case



TEST-1



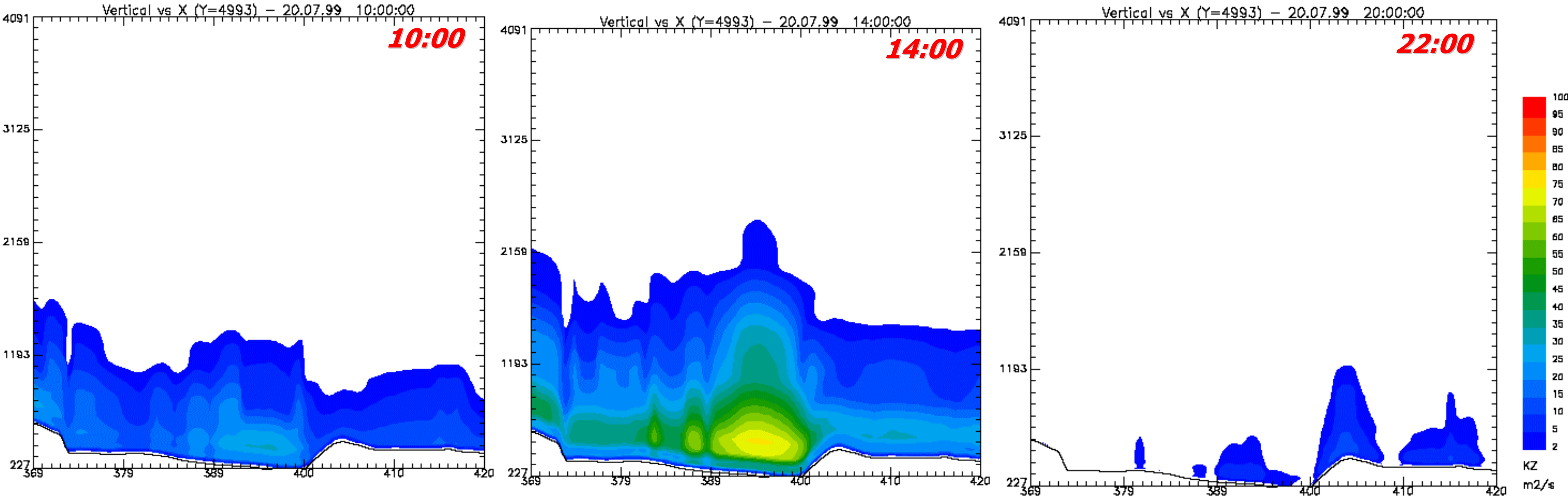
TEST-2



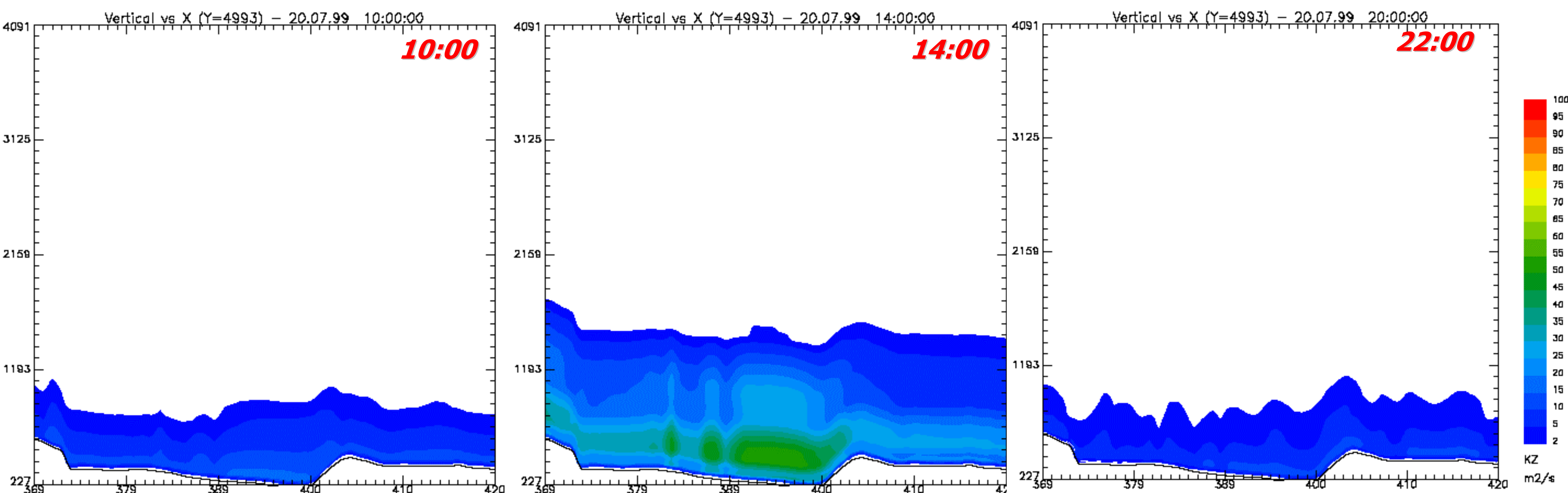
Summer nighttime (23:00) – stable conditions

Base case

Vertical diffusivity (m^2/s)



TEST-1



Conclusions (1)

- ***Diagnostic MH parameterisations based on surface fluxes and M-O similarity theory provide MH fields with similar structure but large differences in local values.***
- ***Computational methods based on Richardson number are more tied to the details of input (NWP) meteorological fields. MH shows values lower than those estimated by other diagnostic parameterisations.***
- ***The calculations are sensitive to the value of Ri_C, that so has to be properly tuned.***
- ***Meteorological forecast errors (e.g. thunderstorms tracks in mountain regions) can have relevant impact on MH values.***
- ***Prognostic MH equations show attractive features, like description of IBL, urban plumes and smoothing of non-realistic space gradients.***

Conclusions (2)

- ***Implementation of the OHM allows to enhance turbulent fluxes modelling in urban environment, especially inducing larger differences between urban and rural surface energy budgets.***
- ***OHM could be effective in improving dispersion simulations, especially in morning and evening hours***

- ***Some key parameters of the OHM, depending on the urban land cover features, should be probably fitted to local data***
- ***Even parameters determining energy partition between sensible and latent heat flux should be probably fitted on local data (not available at the moment), to obtain values suitable for winter stagnation periods in the Po valley.***

Forthcoming work

- ***Verification of the effects on the air quality simulations driven by different interface options and configurations.***
- ***Further investigations and possible implementation of different urbanised computational scheme like, e.g. formulas for wind profile inside the canopy layer***
- ***System testing on operational conditions***
- ***Validation of forecasting system over long periods***