# EFFECTS OF NOCTURNAL THERMAL CIRCULATION AND BOUNDARY LAYER STRUCTURE ON POLLUTANT DISPERSION IN COMPLEX TERRAIN AREAS

*Mireia Udina, Maria Rosa Soler, Raúl Arasa, Miriam Olid*

Department of Astronomy and Meteorology, Universitat de Barcelona, Barcelona, Spain

UNIVERSITAT DE BARCELONA

Mesoscale and Microscale Atmospheric Modelling and Research

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- Stable boundary layer present a challenge for mesoscale models (MM5, WRF).

- Errors in meteorological forecasts have consequences for atmospheric transport and dispersion predictions and for other air quality applications.

- Difficulties in a complex terrain area with heterogeneities in flow and thermal structures.

- Mesoscale systems and local effects become important in nocturnal SBL (forced by night-time temperature gradients): mountain and valley breeze regimes, including drainage and down-valley winds (Whiteman, 2000).

## Aims of the study

- Check MM5 and WRF simulations in a complex terrain in the nocturnal stable boundary layer with available data from the a 100m height meteorological tower.

- Examine the performance of different PBL schemes in MM5 and WRF to simulate the mesoscale systems at night time: drainage winds, down valley winds, low level jets and turbulence episodes.

- Couple meteorological simulations with photochemical model CMAQ under different PBL schemes

- Analyze distribution patterns of air pollutant concentrations placing different virtual sources at interesting areas.

**Overview**

1. Introduction
   *Aims of the study*

2. Experimental design and model description
   *Area and data description*
   *Meteorological characteristics of the simulation period*
   *Numerical model configuration*

3. Meteorological results and evaluation
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   *Vertical temperature gradient*
   *CIBA tower data*
   *Temporal and vertical variations within the BL*

4. Distribution of pollutants
   *Virtual source placements*
   *$SO_2$ field distribution at P1: CIBA*
   *Wind speed at steep terrain area*
   *$SO_2$ field distribution at P2: steep terrain area*
   *$SO_2$ distribution differences*

5. Conclusions

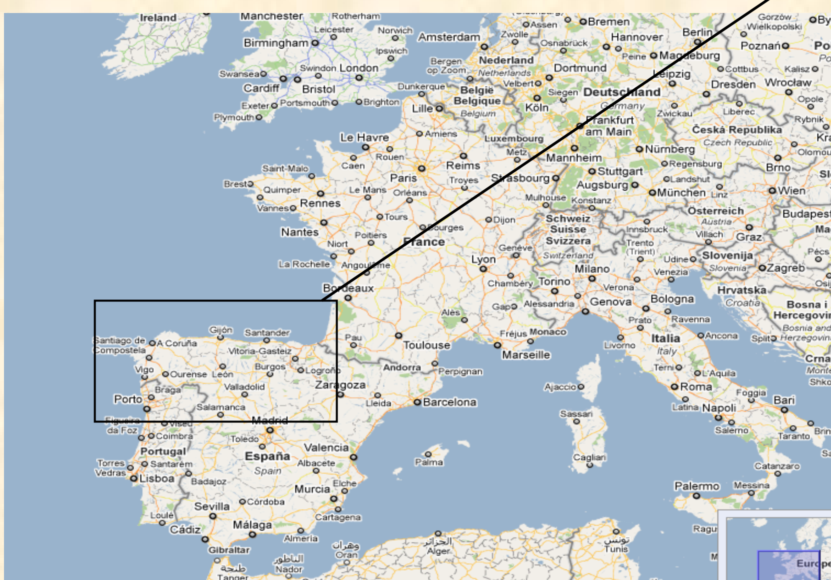
## Area and data description

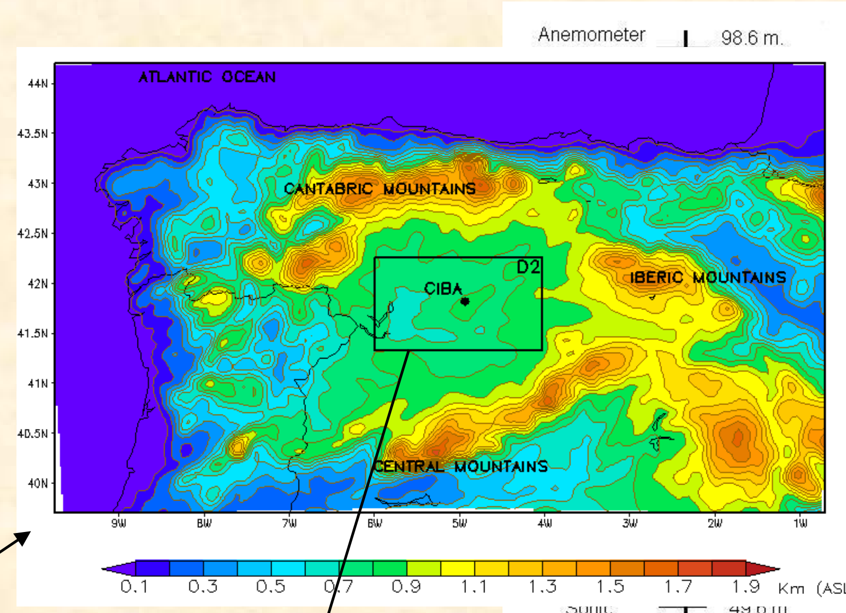
Northern Castillian plateau, Iberian Peninsula, Spain

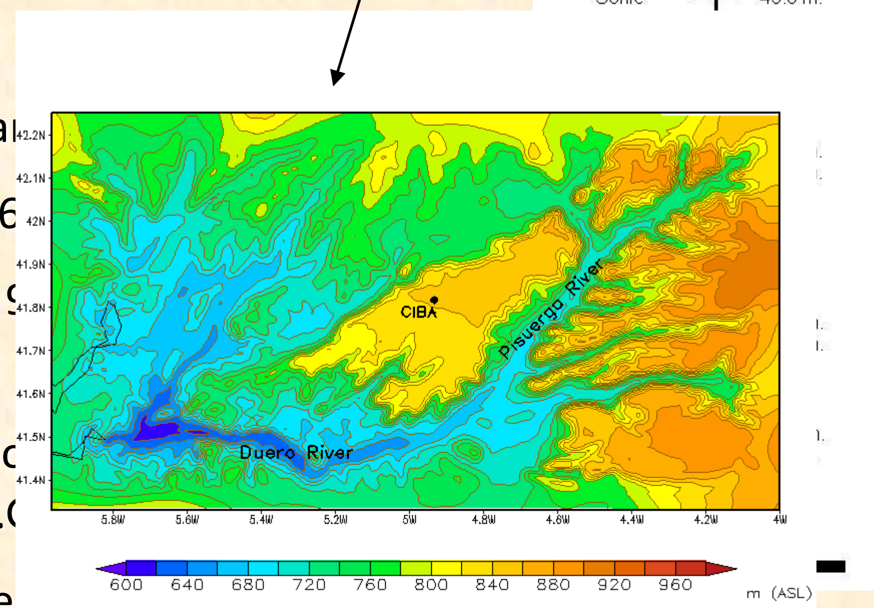
Mountains 2000 m ASL
Duero River

Montes Torozos 840 m ASL
**CIBA** meteorological tower: 100m height

Database at different heights:






2. EXPERIMENTAL DESIGN AND MODEL DESCRIPTION

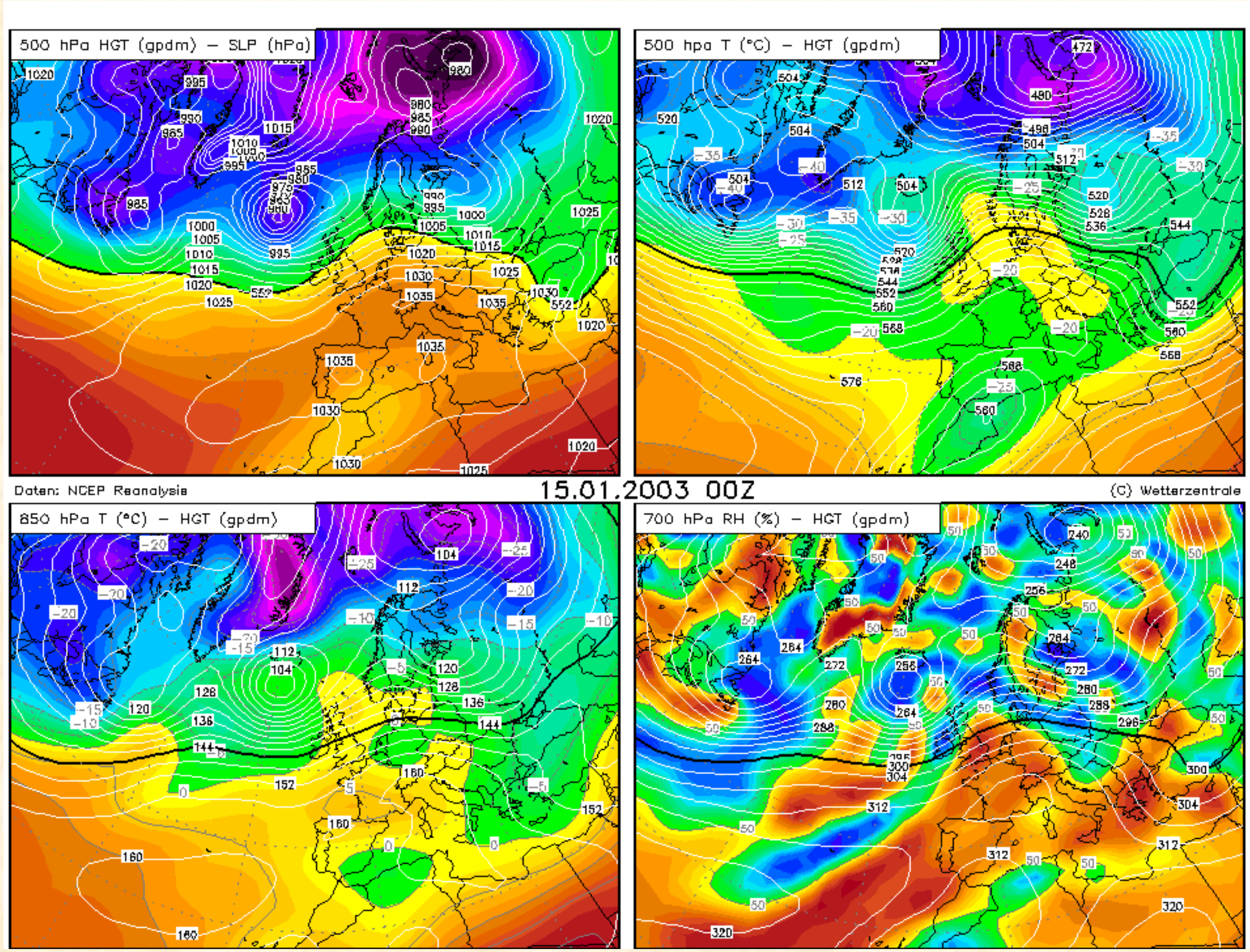
## Meteorological characteristics of the simulation period

Simulation period: 12th -15th January 2003

**Night between 14-15th January 2003**

- Hight surface pressure 1025hPa
- Stability at heigh
- Little humidity

Clear skies and weak winds




Mesoscale systems:

-Valley and drainage winds

-Low level jets

-Intermittent turbulent episodes

# Numerical model configuration

Two meteorological models:

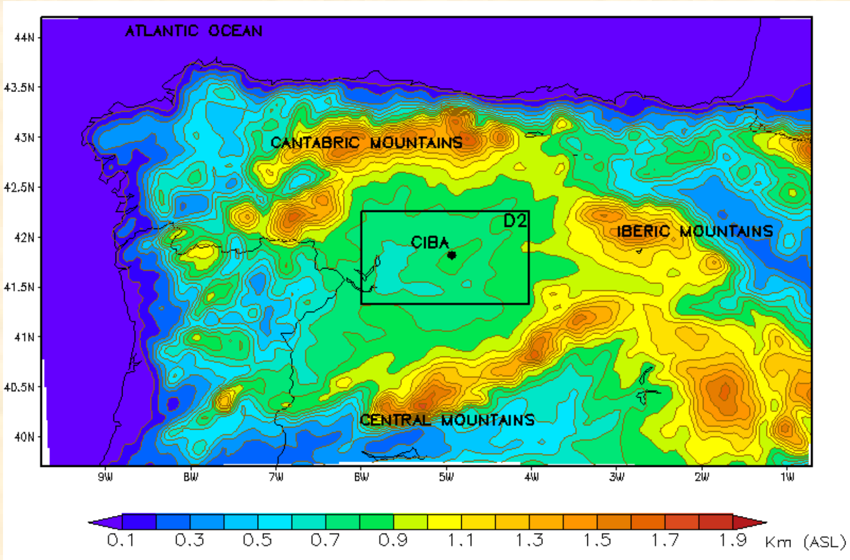
- PSU/NCAR mesoscale model **MM5** v3.7
- Weather Research and Forecasting model **WRF-ARW** v3.1.1

Two nested domains (one way nesting):

| | |
|---|---|
| Outer domain – D1 | Inner domain – D2 |
| 5 Km horizontal resolution | 1 Km horizontal resolution |
| Initial boundary coniditions from ECMWF | One way nesting |
| 150x100 grid cells | 161x101 grid cells |
| 24 h long → 1200 UTC 14th - 1200 UTC 15th January | 12 h long →1800 UTC 14th– 0600 UTC 15th January |

86 vertical sigma levels
2m close to the surface
First 100 meters in 23 first levels

Domain top at 100hPa



## Numerical model configuration

3 sets of model experiments:

- MM5 with ETA PBL scheme → **MM5** — Experiment 1
- WRF with MYJ PBL scheme → **WRF-MYJ** — Experiment 2
- WRF with QNSE PBL scheme → **WRF-QNSE** — Experiment 3

| **Physics** | **MM5** | **WRF-MYJ** | **WRF-QNSE** |
|---|---|---|---|
| Microphysics | Reisnel graupel (Reisner2) | New Thompson | New Thompson |
| Atmospheric Radiation | Cumulus radiation scheme | Short wave:Dudhia<br>Long wave:RRTM | Short wave:Dudhia<br>Long wave:RRTM |
| Surface Layer | ETA similarity (Monin Obukhov) | ETA similarity (Monin Obukhov) | ETA similarity (Monin Obukhov) |
| Land Surface | Noah Land-Surface Model | Noah Land-Surface Model | Noah Land-Surface Model |
| Planetary Boundary Layer | **ETA scheme** **$TKE_{MIN}$= 0.2 $m^2s^{-2}$** | **Mellor-Yamada-Janjic (MYJ)-ETA scheme $TKE_{MIN}$= 0.1 $m^2s^{-2}$** | **Quasi-Normal Scale Elimination (QNSE) $TKE_{MIN}$= 0.01 $m^2s^{-2}$** |
| Cumulus | Grell | Grell 3D | Grell 3D |

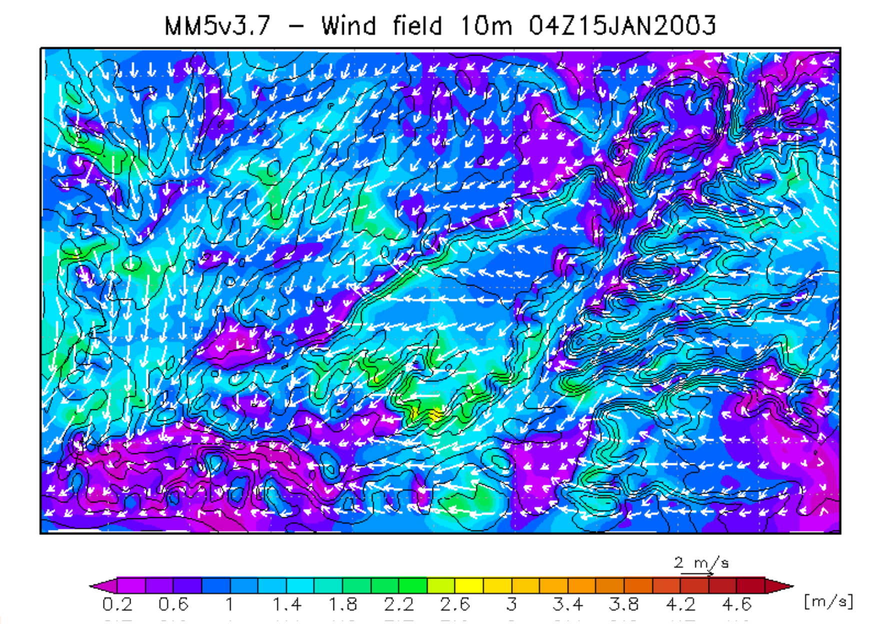
Photochemical model **CMAQ v4.6** with virtual industry source of emissions
No initial boundary conditions are considered

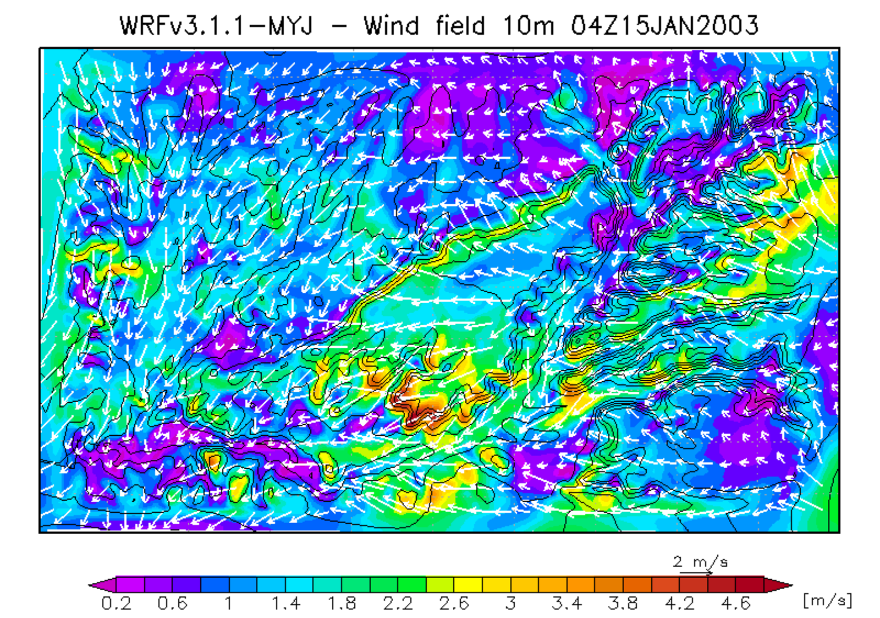
## Results and evaluation

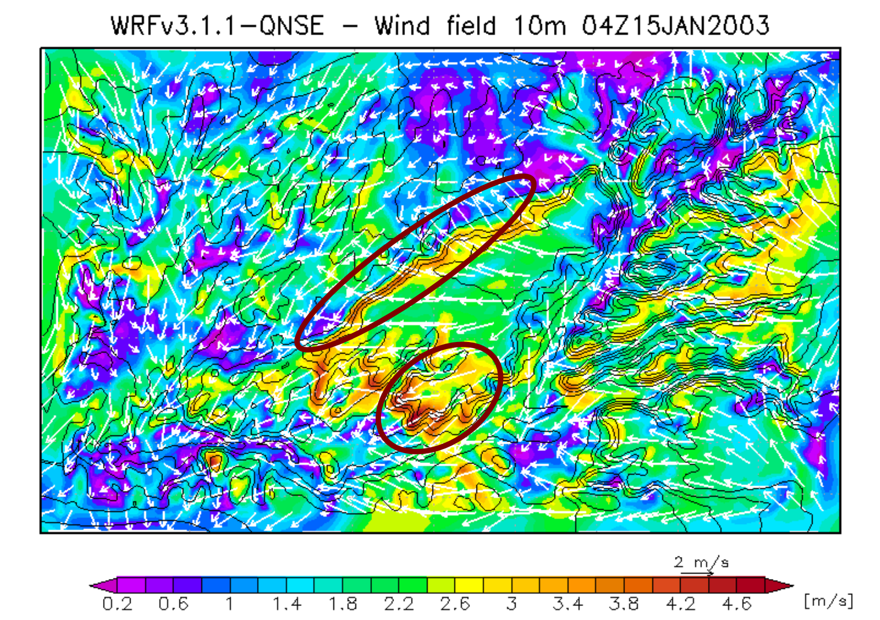


- Wind field at 10m
- Vertical temperature gradient
- CIBA tower data
- Temporal and vertical variations within the BL

# Wind field 10m



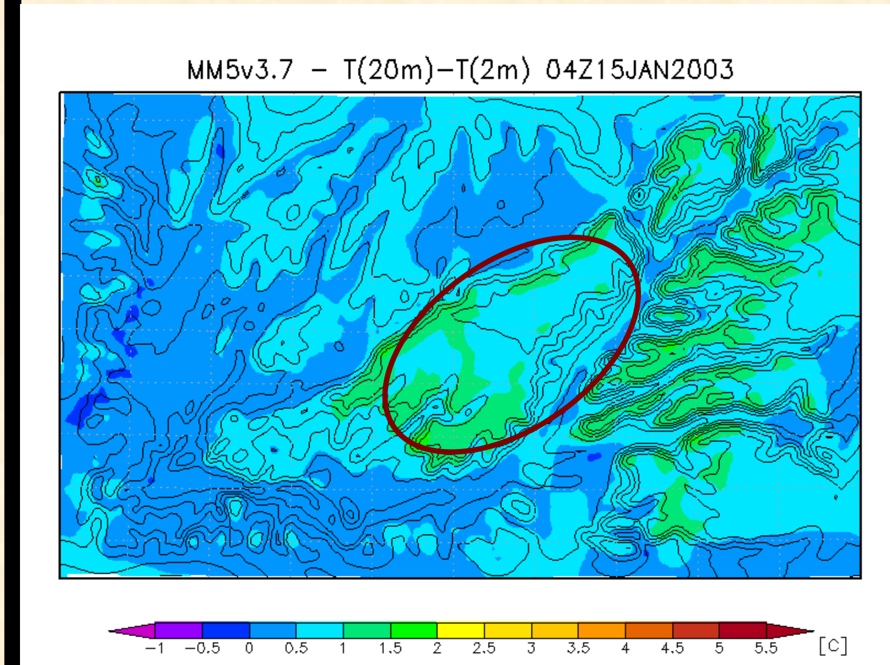



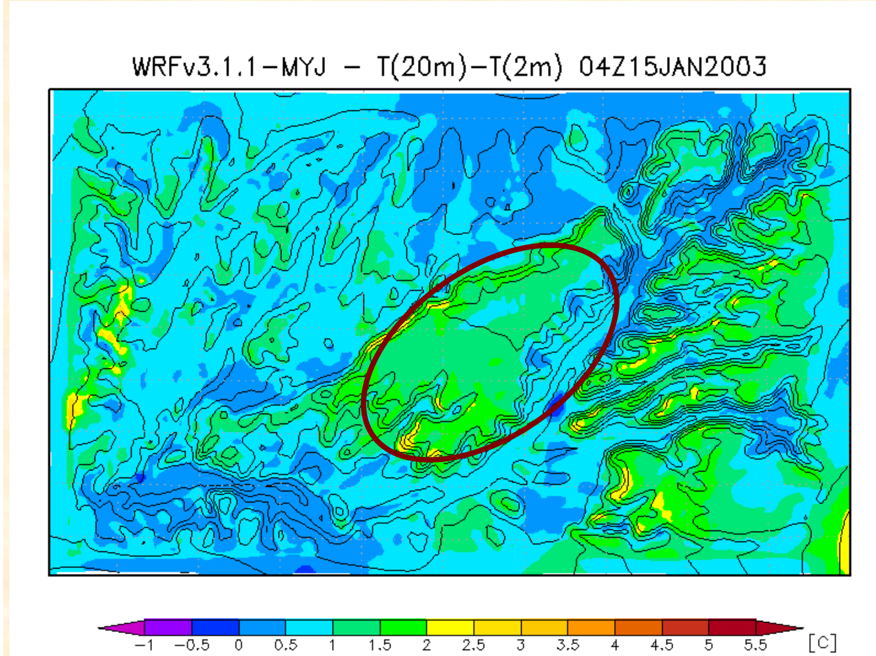



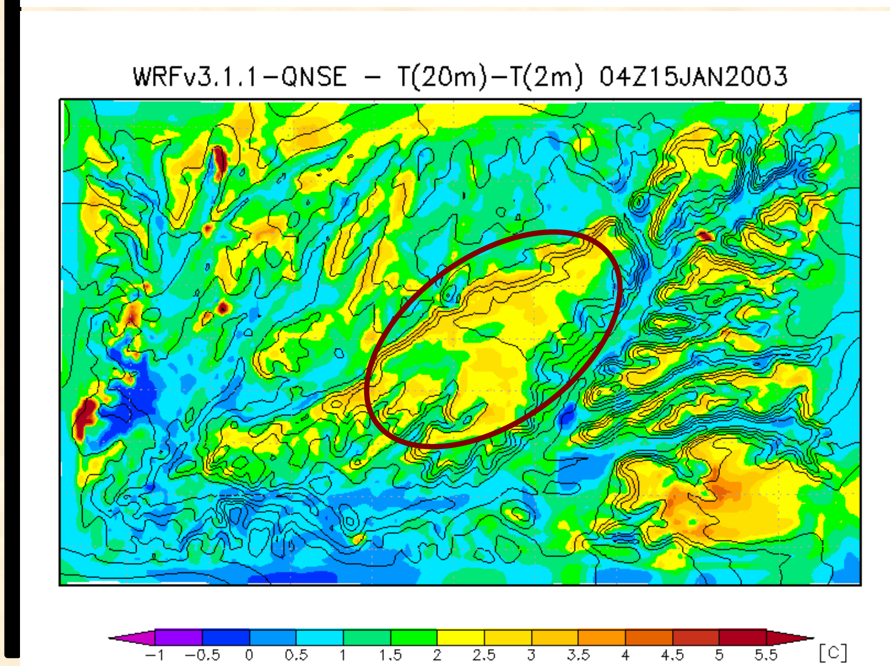

2300 UTC: stronger winds in steep terrain areas → drainage winds

0400 UTC: QNSE experiment forecasts the strongest winds

# Vertical Temperature gradient




Big differences in temperature gradient between models

QNSE forecasts the highest gradients at CIBA plateau and at steep areas

# CIBA tower data

Temperature at different levels

*Cold air at surface*

Wind speed

*Jet at the end of the night*

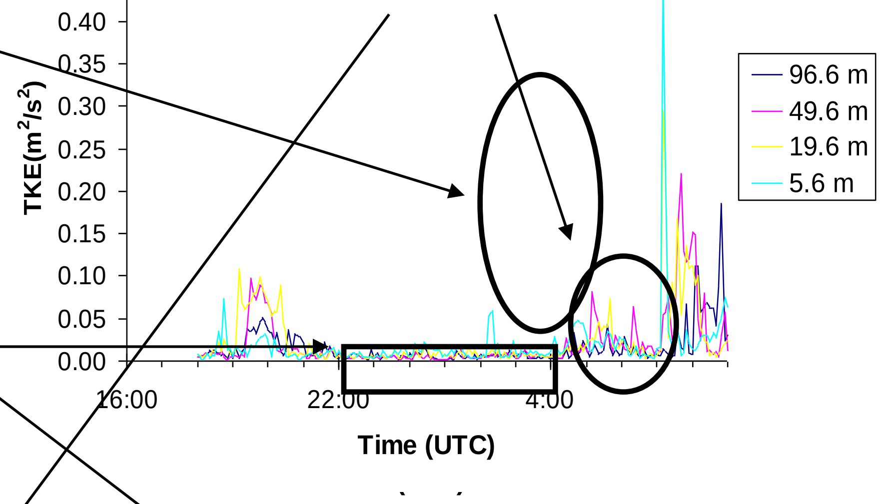
Turbulent variables

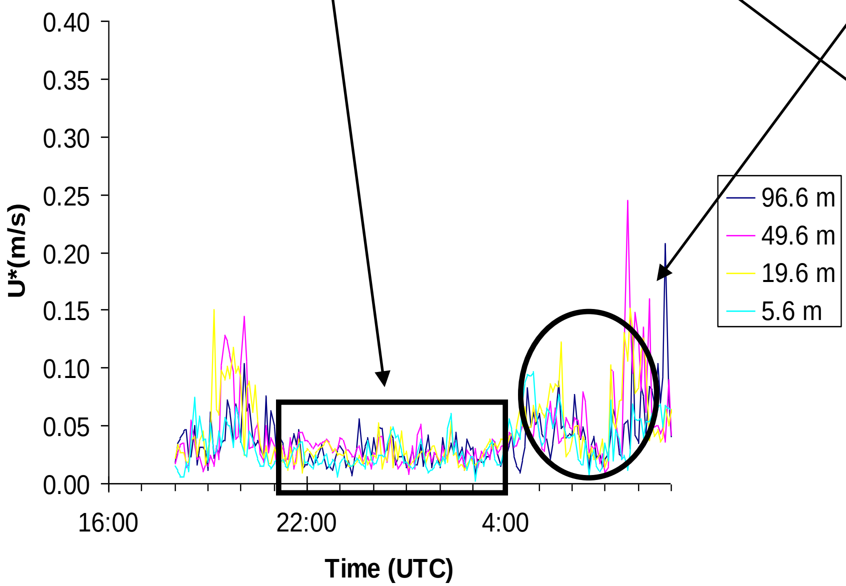
TKE ~ 0

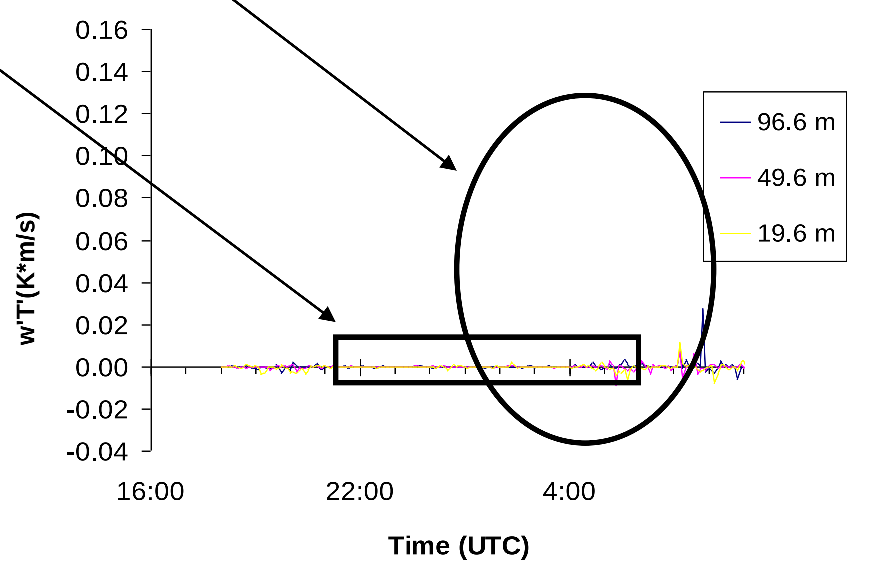
Heat flux ~ 0

U* ~ 0

Turbulence at the end of the night due to wind shear at CIBA tower



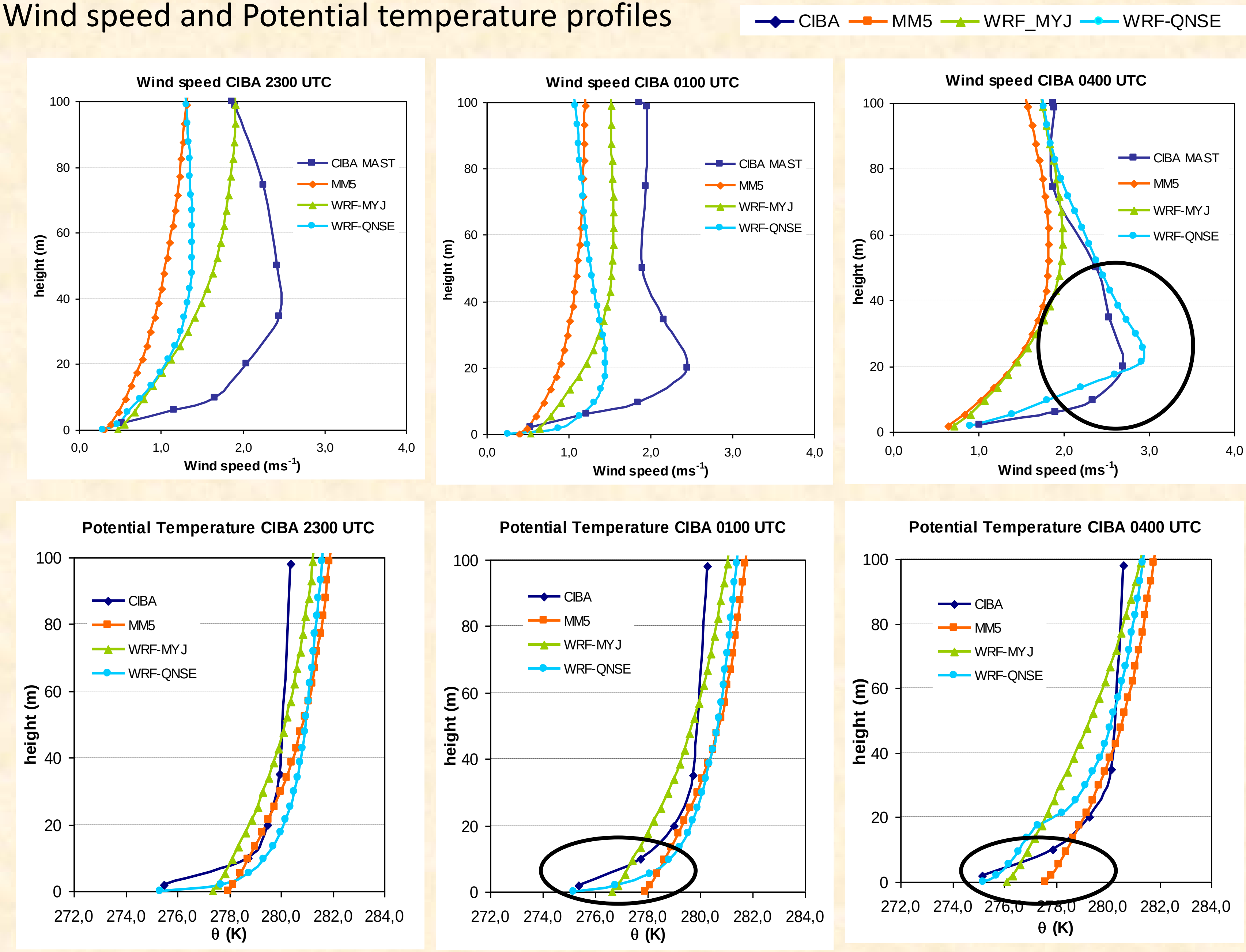



# Temporal and vertical variations within the BL



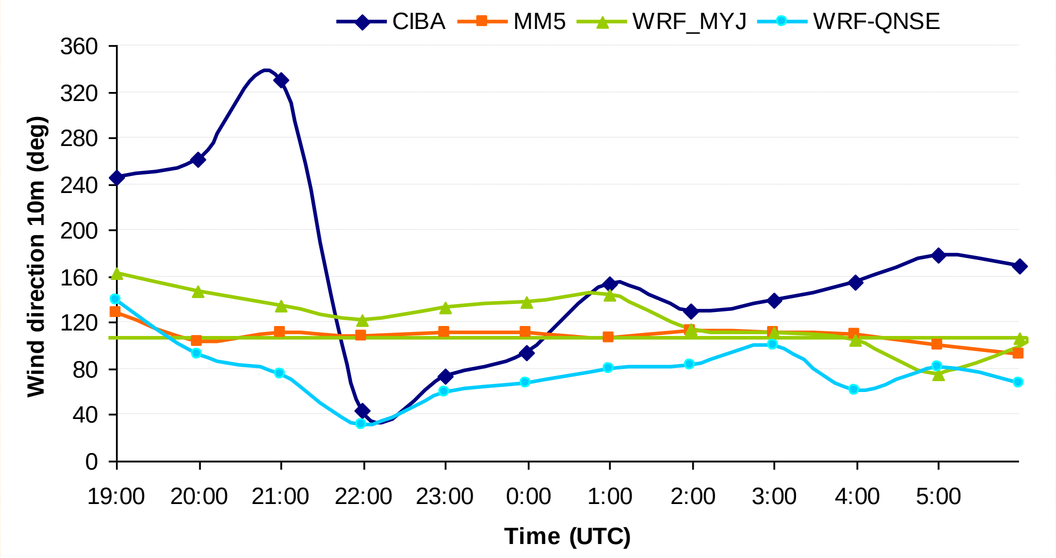
## Wind speed and Potential temperature profiles

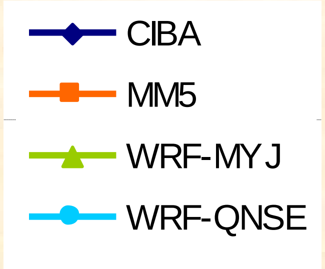


# Temporal and vertical variations within the BL

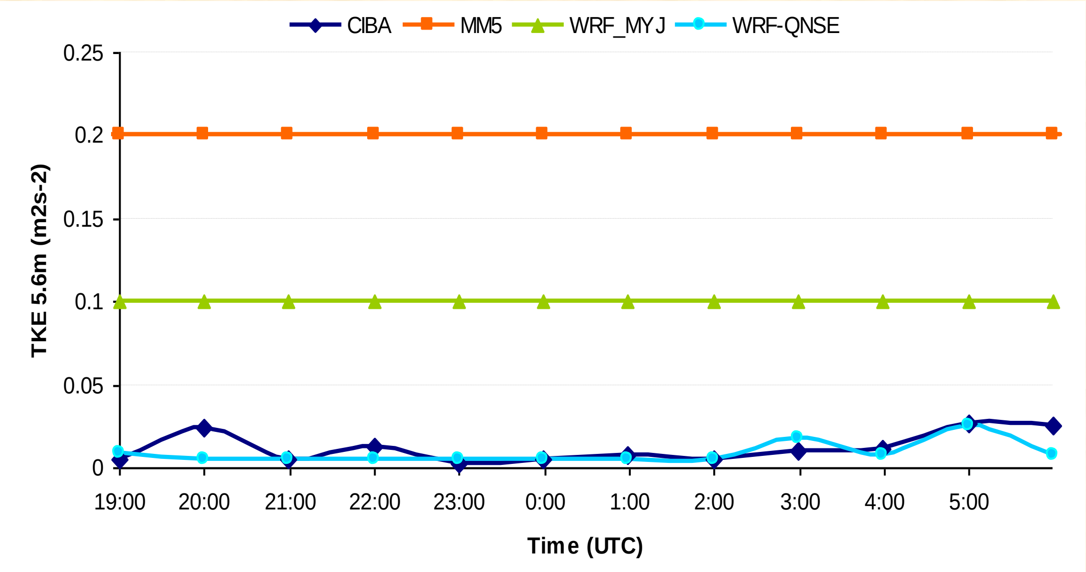


Wind direction




TKE



# Temporal and vertical variations within the BL



Statistics values at 6 vertical levels of 3 model experiments

| ***Temperature*** | ***Wind speed*** | ***Wind direction*** |
| --- | --- | --- |
| MAGE < 2K | RMSE < 2ms-1 | MAGE < 30 deg |
| MB 0.5 K | MB 0.5 ms-1 | MB 10 deg |

*Source: EPA Draft Guidance*

| Height | | Statistic | **Temperature (ºK)** | | | **Wind velocity (ms-1)** | | | Wind direction (deg) | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **T** | **WV-WD** | | MM5 **Exp. 1** | WRF-MYJ **Exp. 2** | WRF-QNSE **Exp. 3** | MM5 **Exp. 1** | WRF-MYJ **Exp. 2** | WRF-QNSE **Exp. 3** | MM5 **Exp. 1** | WRF-MYJ **Exp. 2** | WRF-QNSE **Exp. 3** |
| 2m | 10m | MB | 3.14 | -0.62 | 0.43 | -1.44 | -0.35 | -0.94 | -25.95 | 3.66 | -56.27 |
| | | MAGE | 3.14 | 0.64 | **0.55** | 1.44 | 0.47 | 0.97 | 69.11 | 67.78 | 73.84 |
| | | RMSE | 3.15 | 0.78 | 0.71 | 1.46 | **0.56** | 1.05 | 82.7 | 80.14 | 86.68 |
| 10m | 20m | MB | 0.70 | -0.21 | 0.51 | -1.46 | -1.0 | -0.58 | 5.65 | -6.41 | -1.83 |
| | | MAGE | 0.70 | **0.41** | 0.82 | 1.46 | 1.0 | 0.68 | 61.78 | 73.82 | 73.49 |
| | | RMSE | 0.83 | 0.49 | 0.86 | 1.5 | 1.07 | **0.82** | 74.09 | 85.03 | 86.05 |
| 20m | 35m | MB | 0.30 | -0.34 | 0.48 | -1.60 | -1.04 | -1.00 | -10.46 | -3.36 | 0.373 |
| | | MAGE | **0.36** | 0.70 | 0.70 | 1.60 | 1.04 | 1.04 | 63.51 | 69.82 | 69.85 |
| | | RMSE | 0.56 | 0.84 | 0.81 | 1.67 | **1.10** | 1.20 | 77.80 | 82.80 | 83.03 |
| 35m | 50m | MB | 0.30 | 0.46 | 0.36 | -1.45 | -0.86 | -1.14 | 3.06 | 6.98 | 9.51 |
| | | MAGE | **0.42** | 0.70 | 0.60 | 1.45 | 0.86 | 1.14 | 56.47 | 68.83 | 67.31 |
| | | RMSE | 0.54 | 0.86 | 0.70 | 1.60 | **0.97** | 1.41 | 68.47 | 82.49 | 81.95 |
| 98m | 75m | MB | -0.83 | 0.53 | 0.52 | -1.24 | -0.68 | -1.06 | -3.19 | 23.20 | 3.30 |
| | | MAGE | 0.84 | **0.48** | 0.54 | 1.24 | 0.68 | 1.07 | 58.52 | 68.61 | 73.75 |
| | | RMSE | 0.92 | 0.61 | 0.70 | 1.43 | **0.82** | 1.30 | 71.43 | 83.38 | 90.70 |
| ------- | 98m | MB | | | | -0.88 | -0.35 | -0.72 | 12.90 | 12.85 | 36.09 |
| | | MAGE | | | | 0.98 | 0.51 | 0.84 | 59.65 | 76.65 | 75.74 |
| | | RMSE | | | | 1.15 | **0.64** | 1.00 | 75.31 | 98.72 | 95.21 |

## Distribution of pollutants

- Virtual source placements
- $SO_2$ field distribution at P1: CIBA
- Wind speed at steep terrain area
- $SO_2$ field distribution at P2: steep terrain area
- $SO_2$ distribution differences

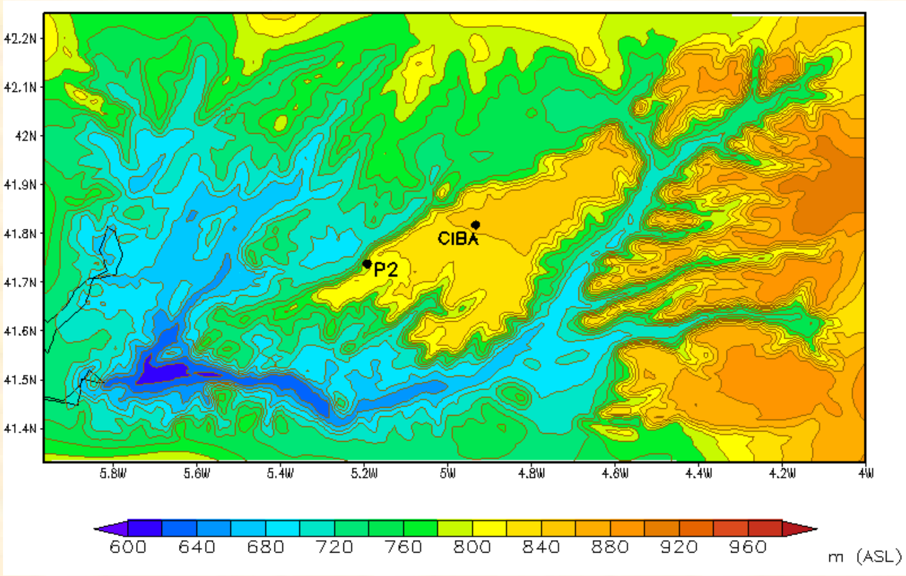
Virtual industry as an emission source

$SO_2$ emission rate 2537 t·year$^{-1}$

$SO_2$ immission results

**- P1**: **CIBA** - 20m above ground level

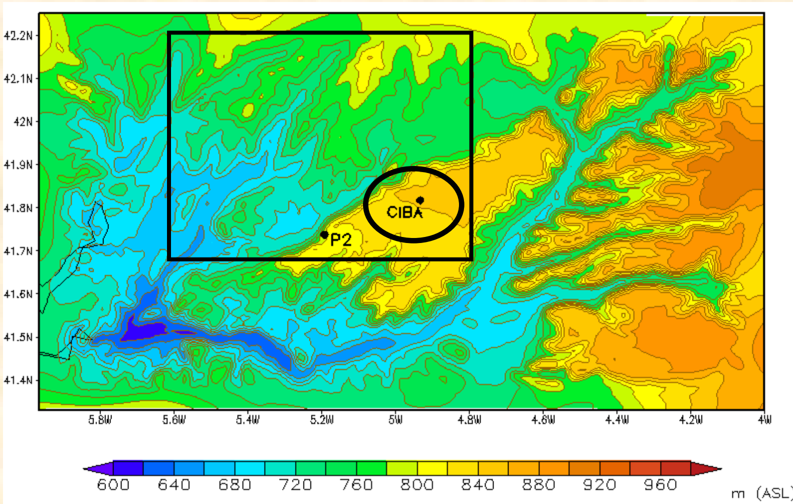
- **P2**: Drainage wind - 10 m above ground level

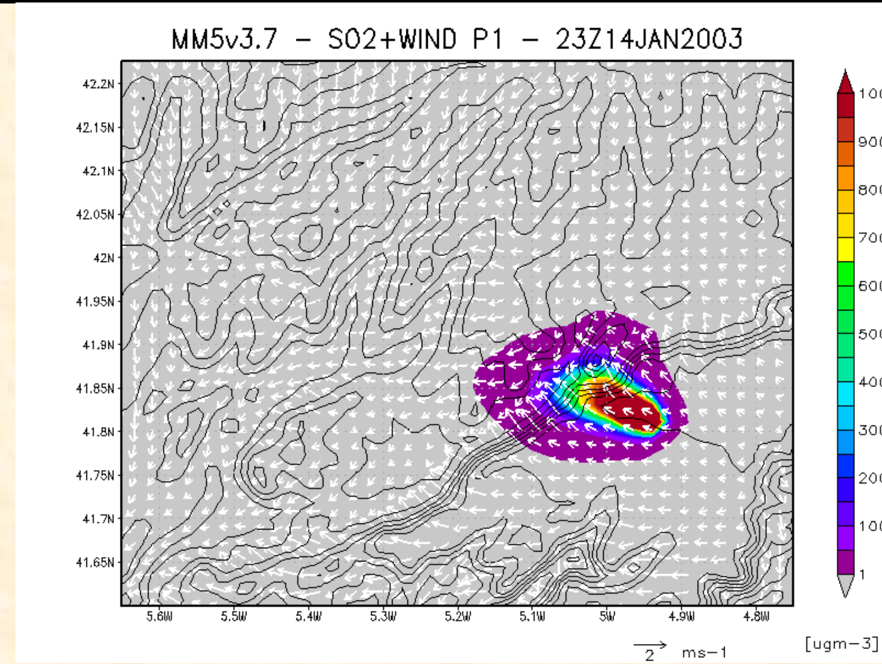


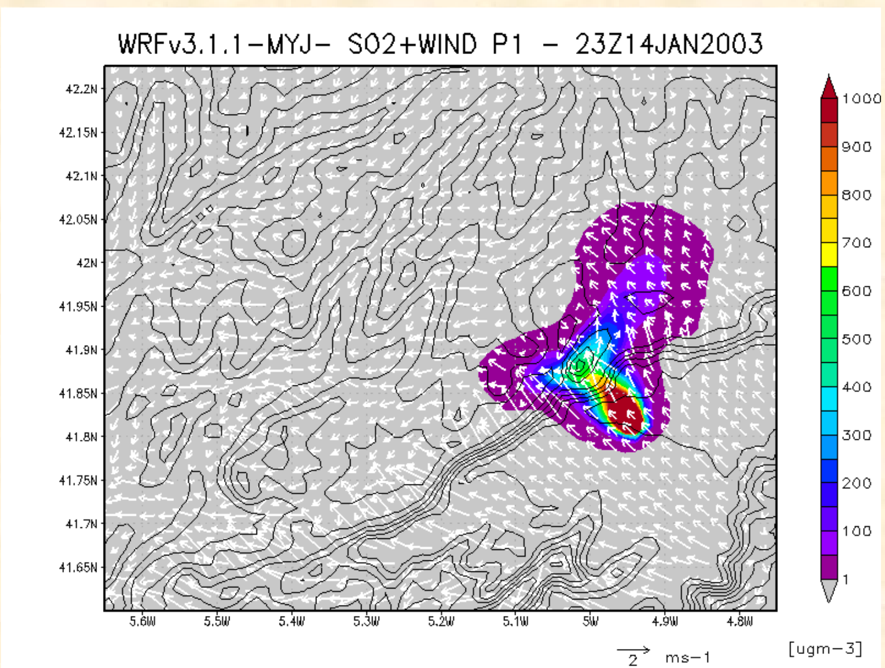
# $SO_2$ field distribution at P1: CIBA

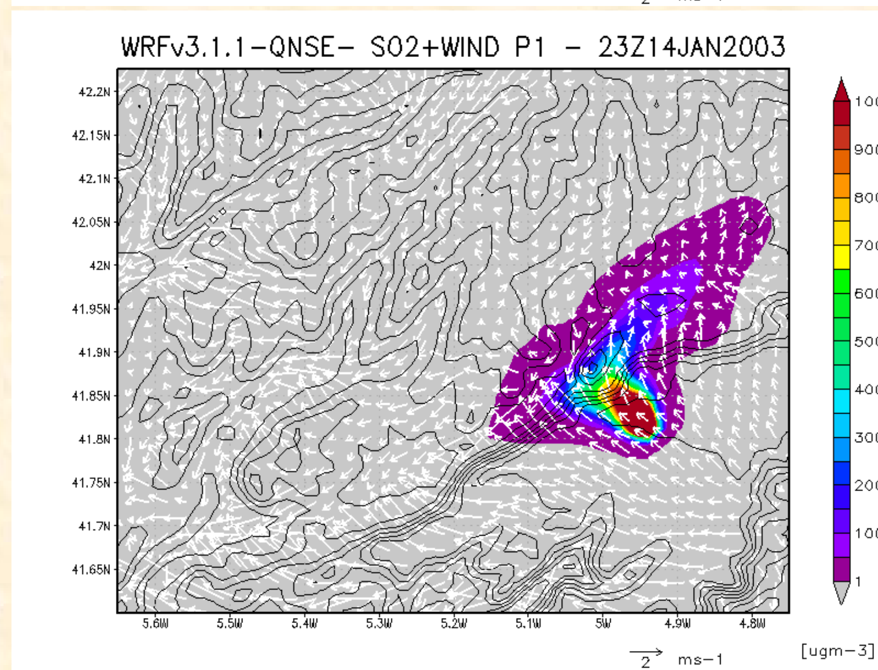
4. DISTRIBUTION OF POLLUTANTS

## $SO_2$ evolution during night time



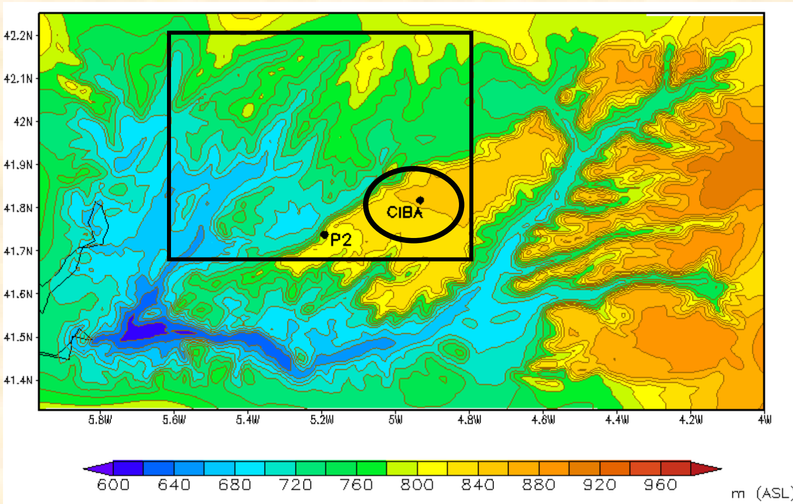



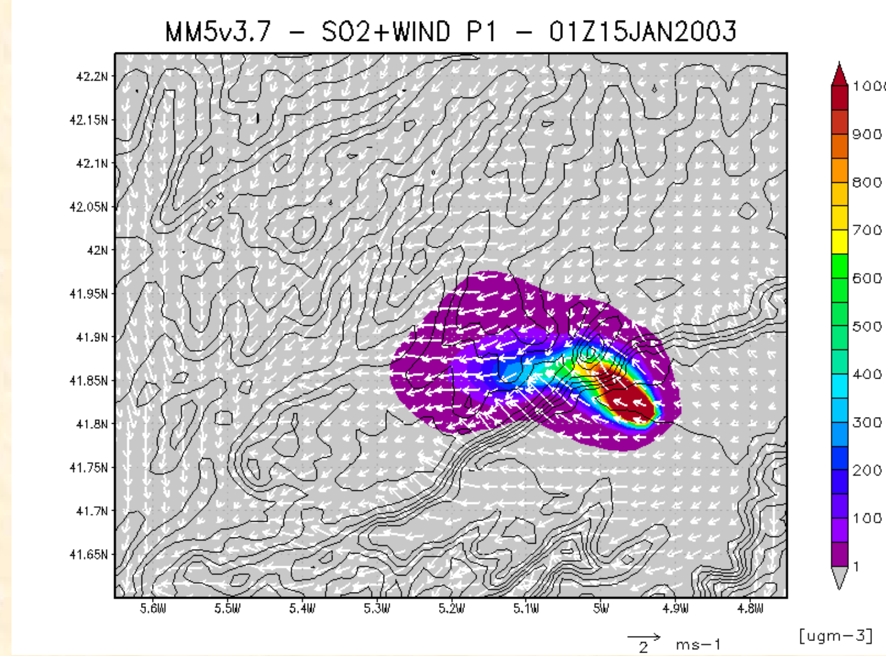



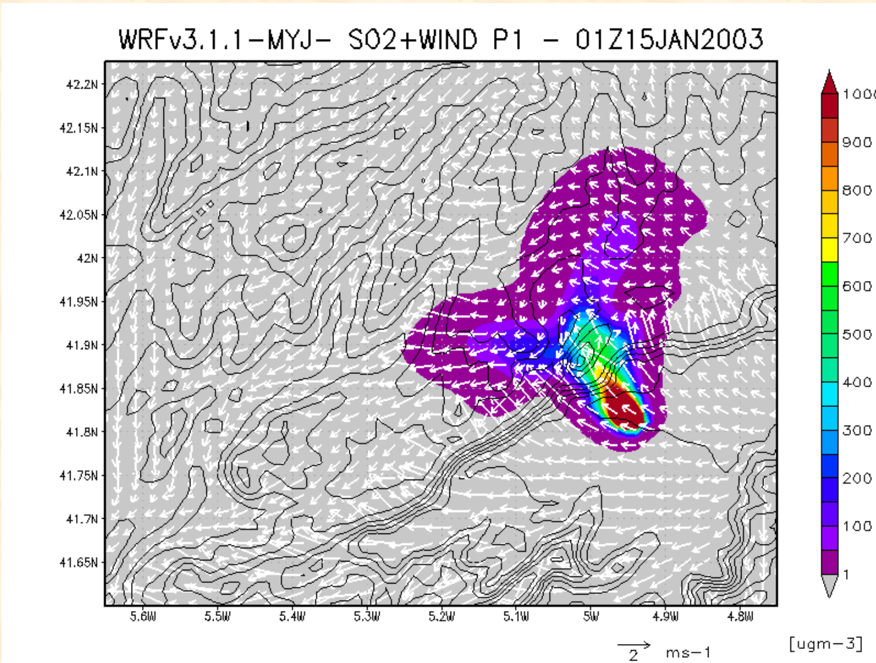



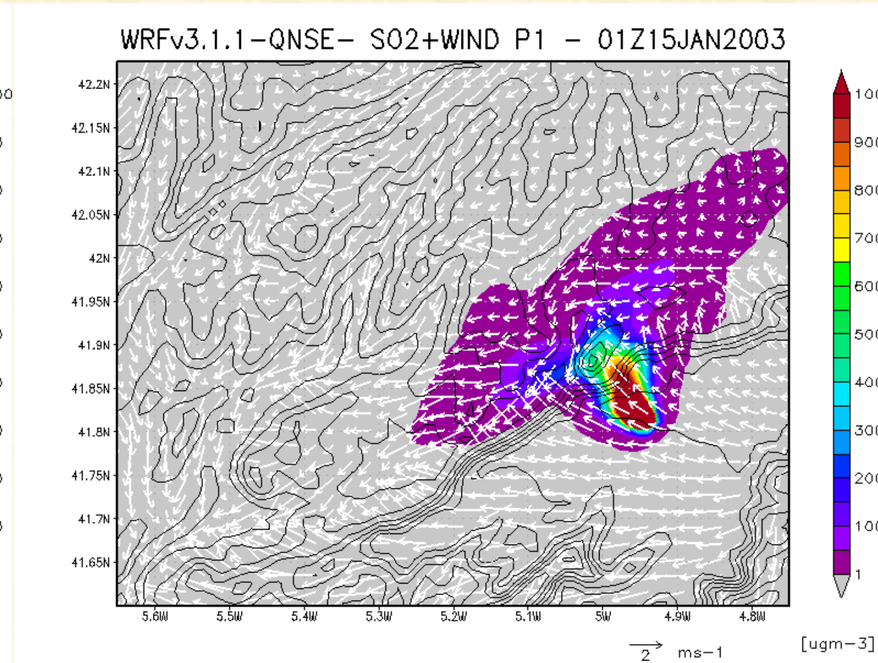
# $SO_2$ field distribution at P1: CIBA





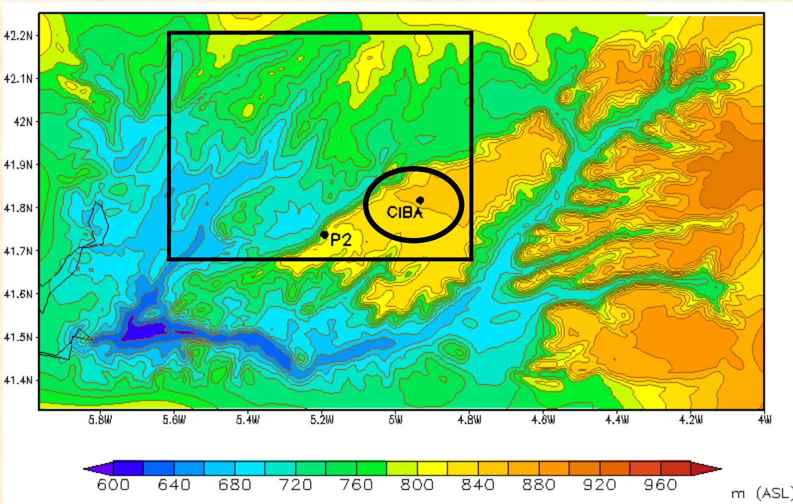



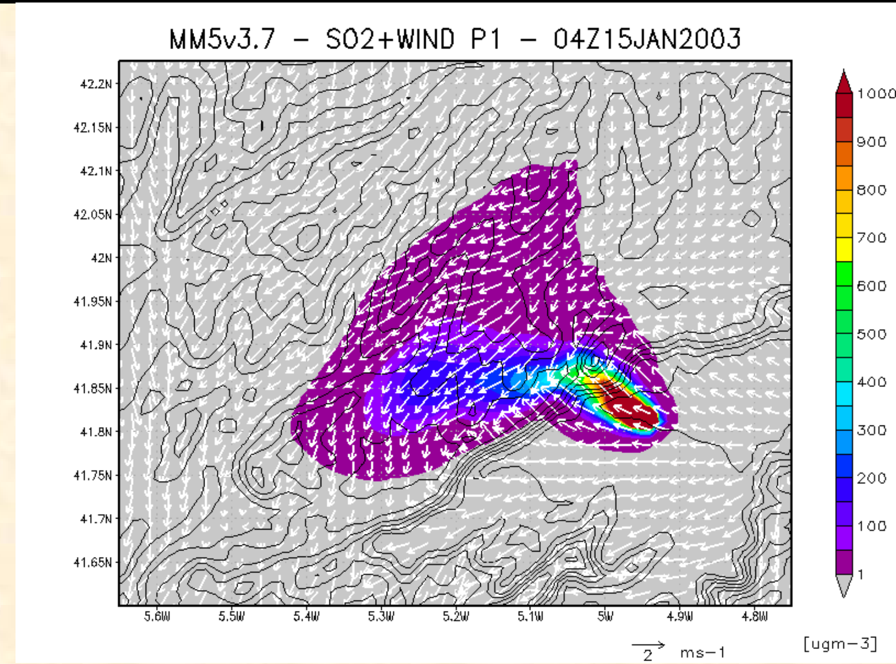



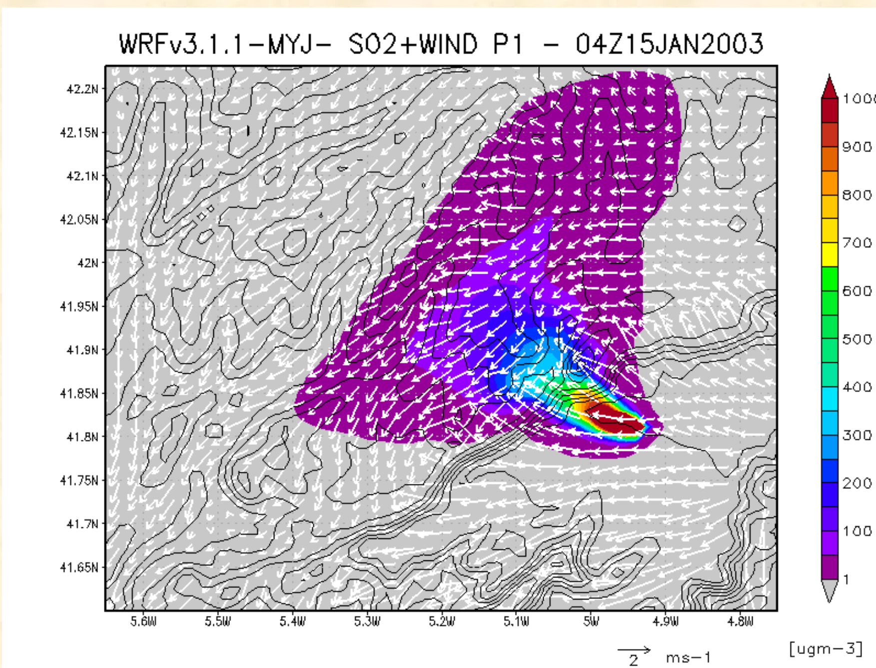



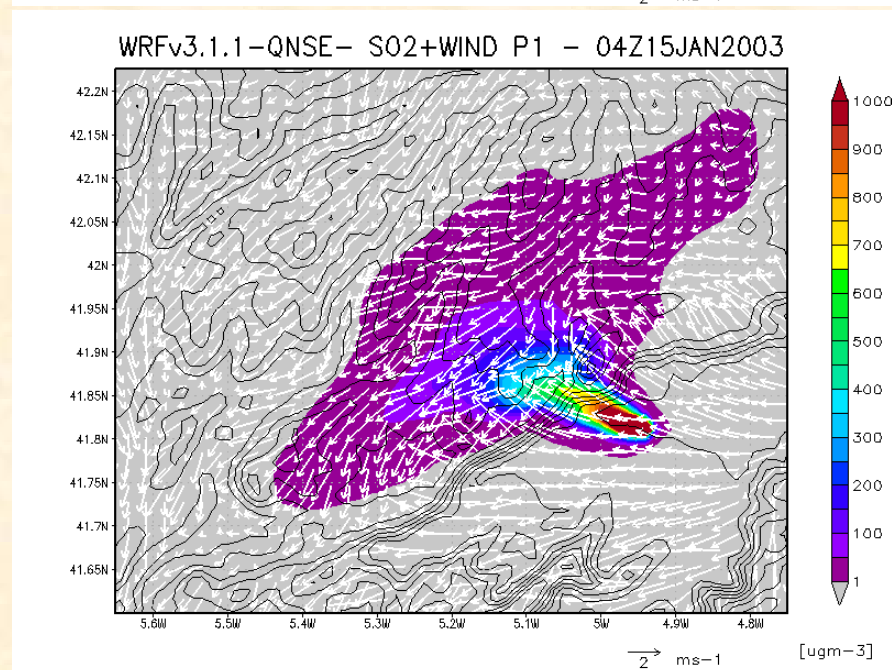
# $SO_2$ field distribution at P1: CIBA

4. DISTRIBUTION OF POLLUTANTS

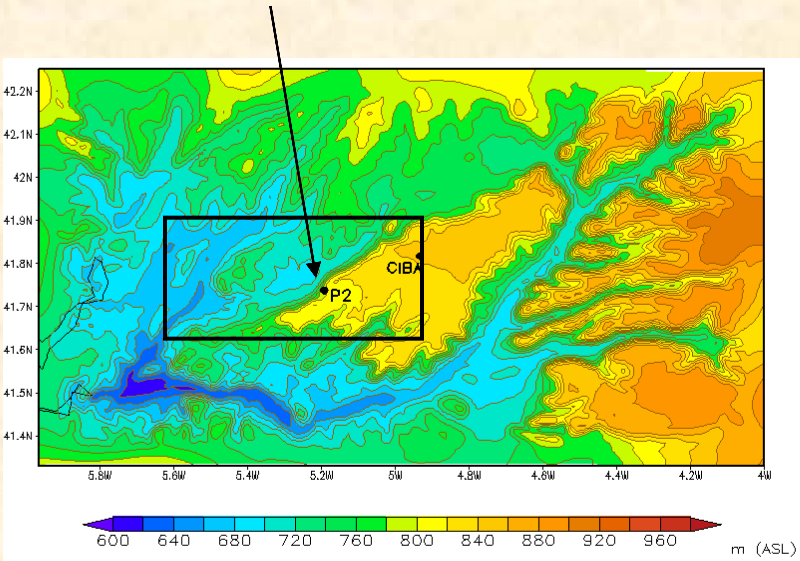


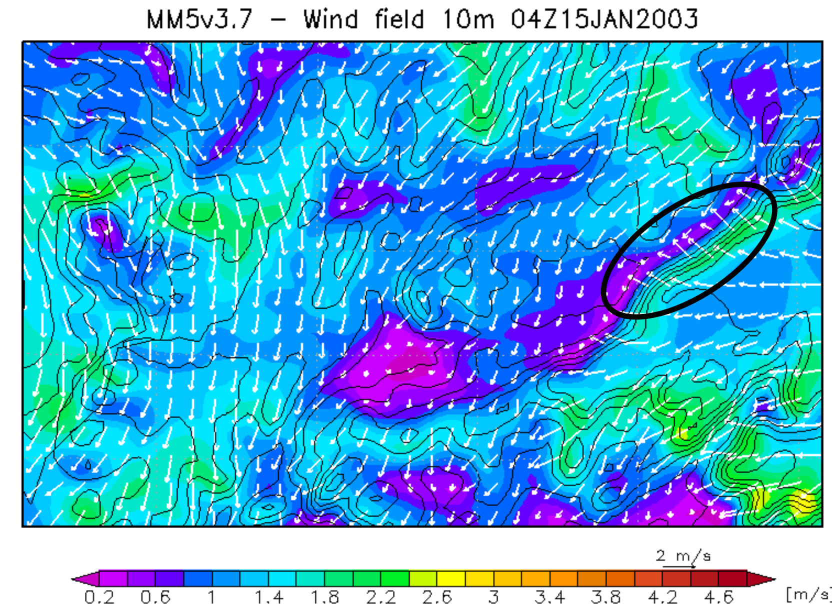



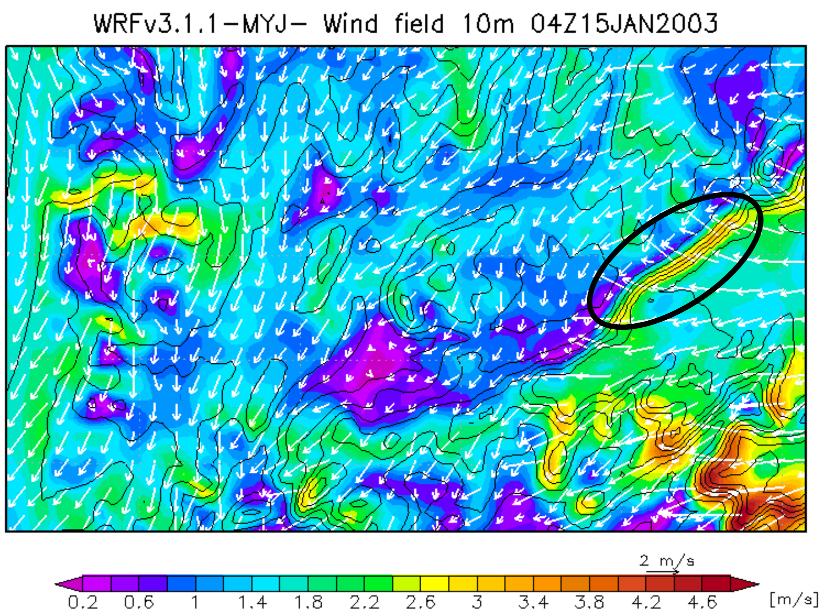



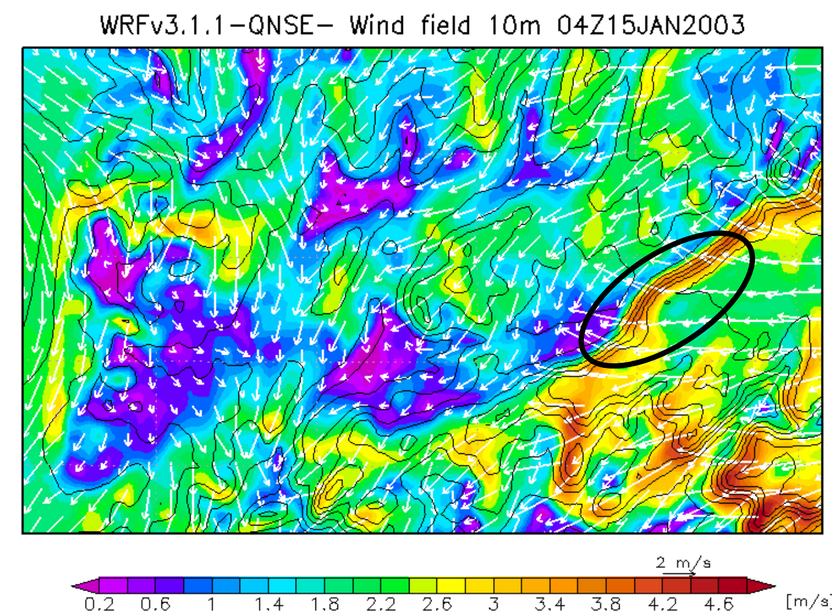



# Wind speed at steep terrain area



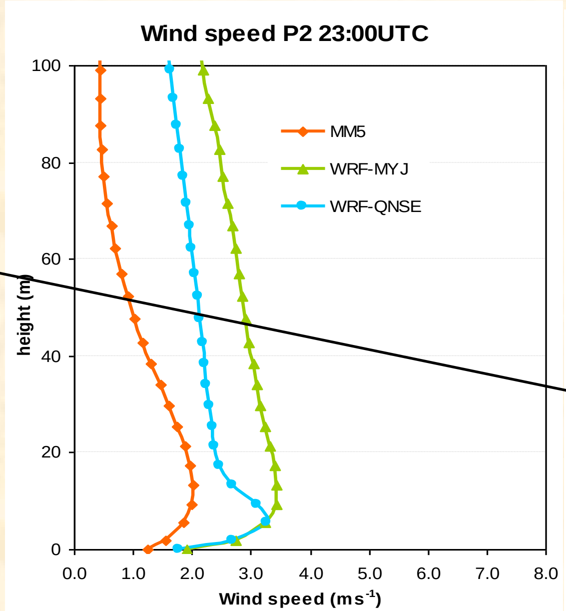
# Wind speed at steep terrain area

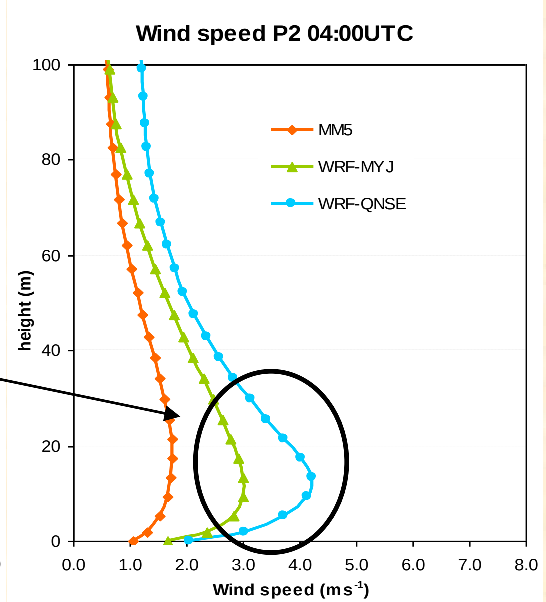
4. DISTRIBUTION OF POLLUTANTS

Profiles at P2

Wind speed

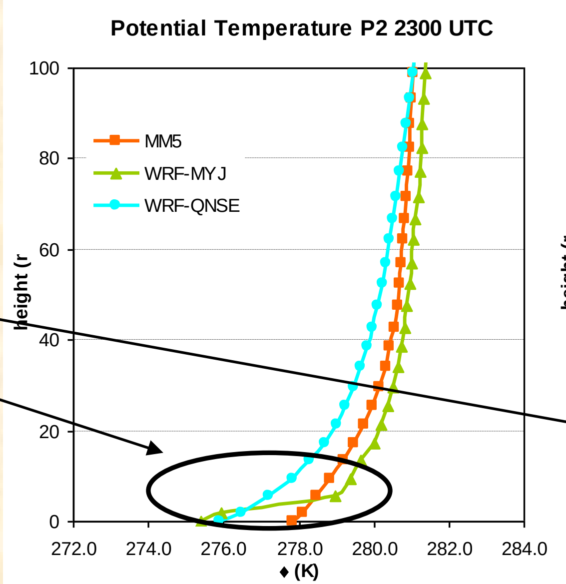
WRF → Strong LLJ

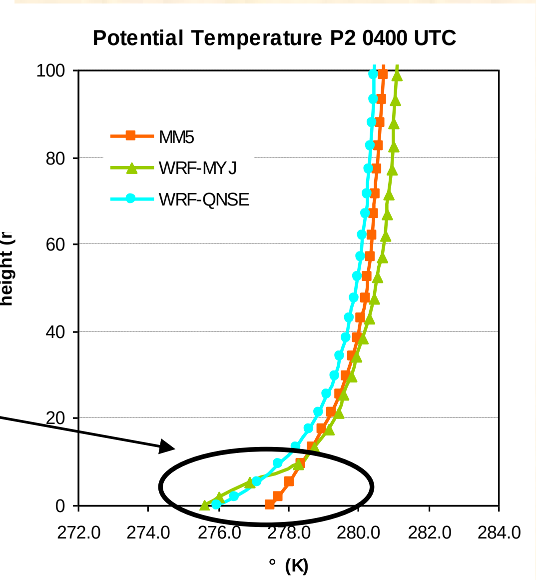



Potential temperature

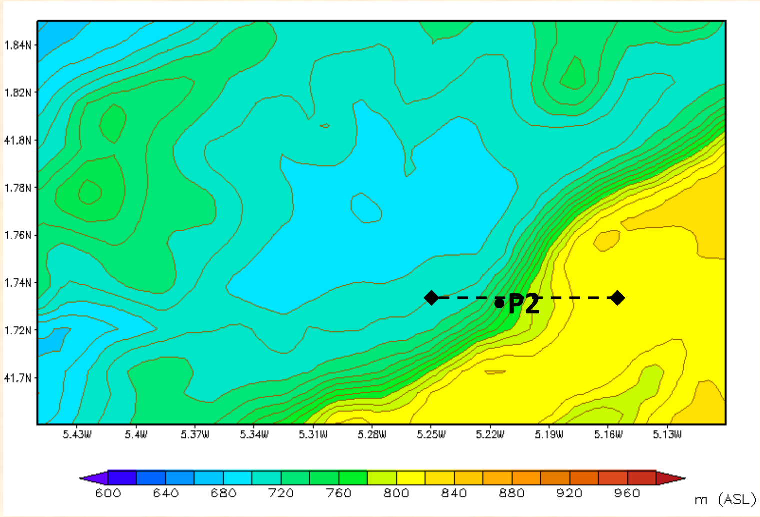
WRF → surface cooling

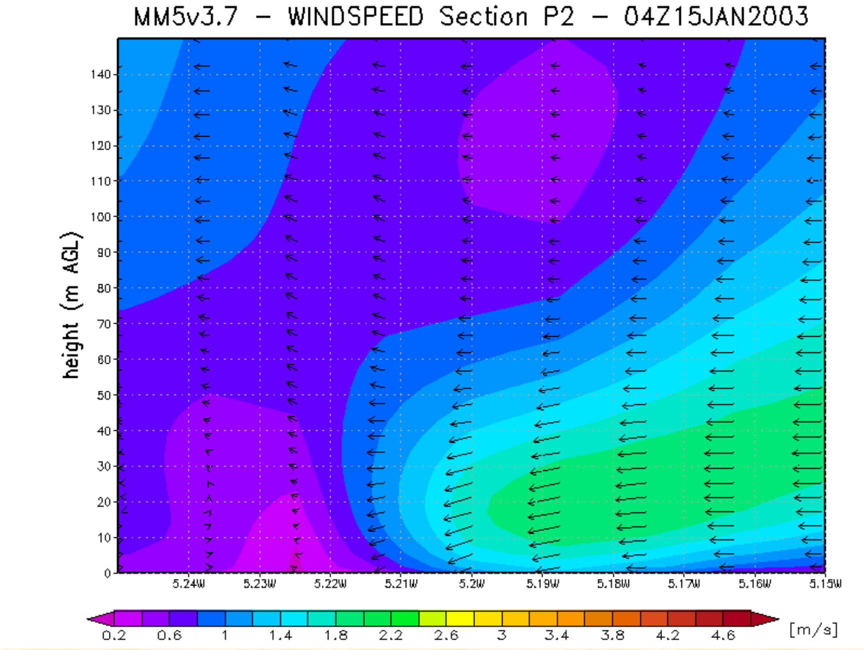


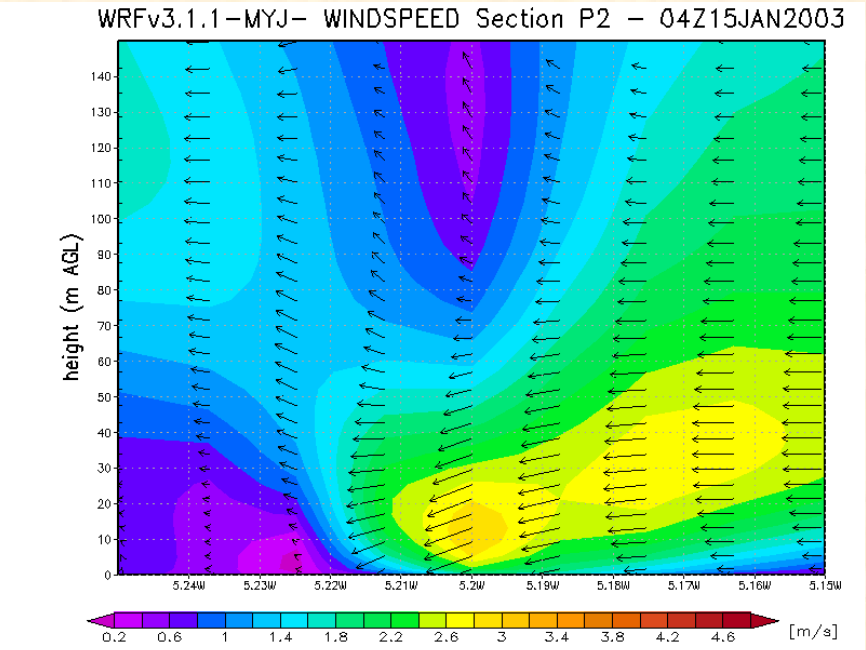



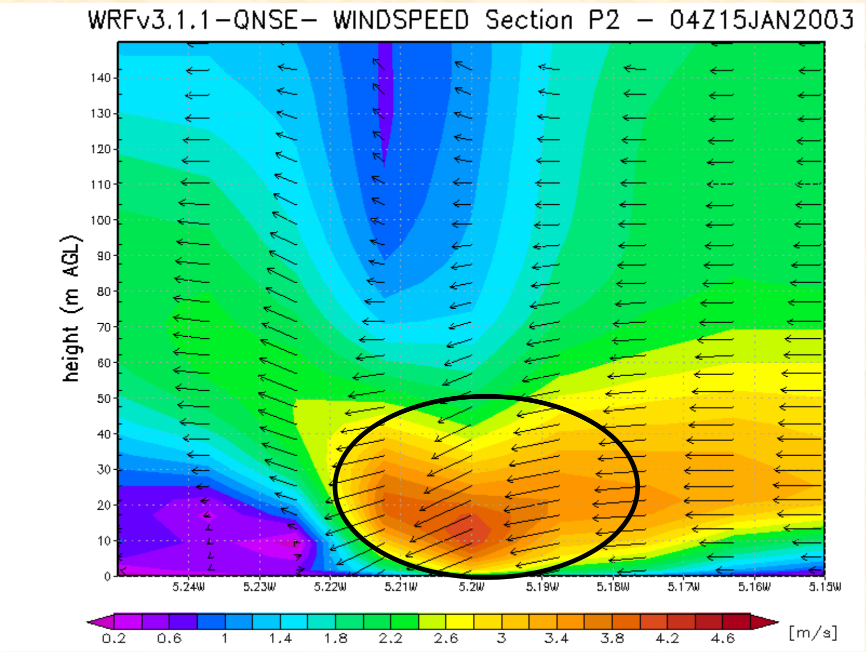
# Wind speed at steep terrain area

4. DISTRIBUTION OF POLLUTANTS



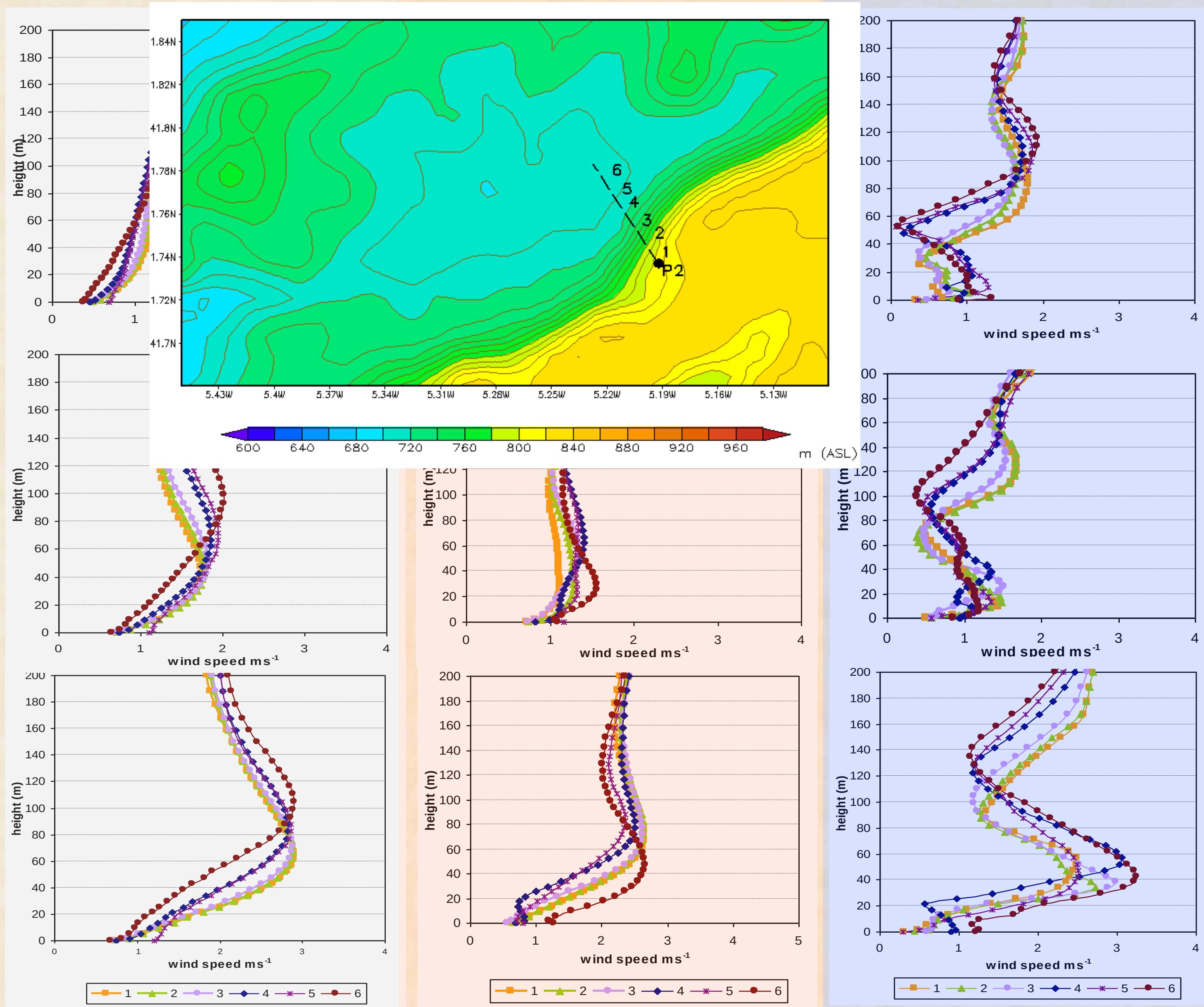



# Wind speed at steep terrain area

4. DISTRIBUTION OF POLLUTANTS

| | MM5 | MYJ | QNSE |
|---|---|---|---|
| 23:00 UTC | | | |
| 01:00 UTC | | | |
| 04:00 UTC | | | |



# Wind speed at steep terrain area

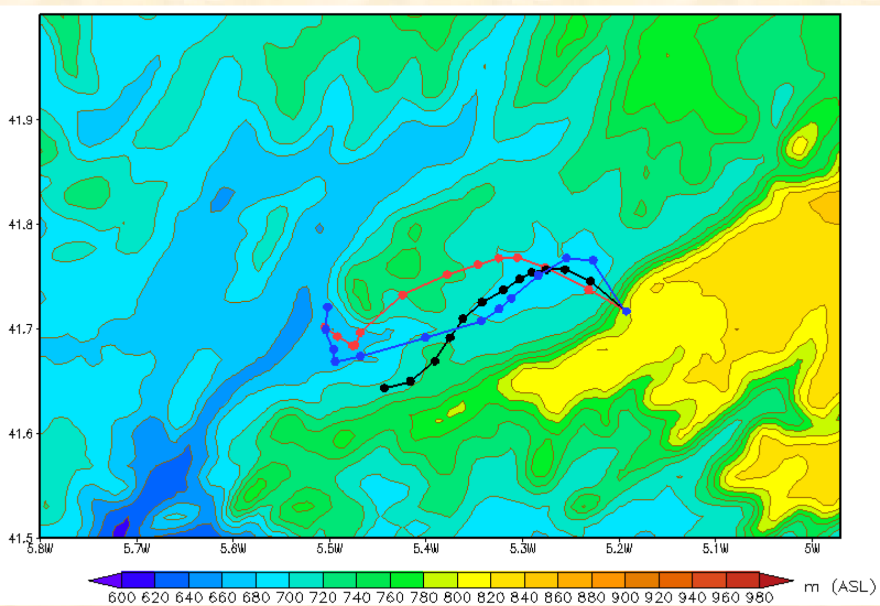
Trajectories of a parcel over P2

- MM5
- WRF-MYJ
- WRF-QNSE

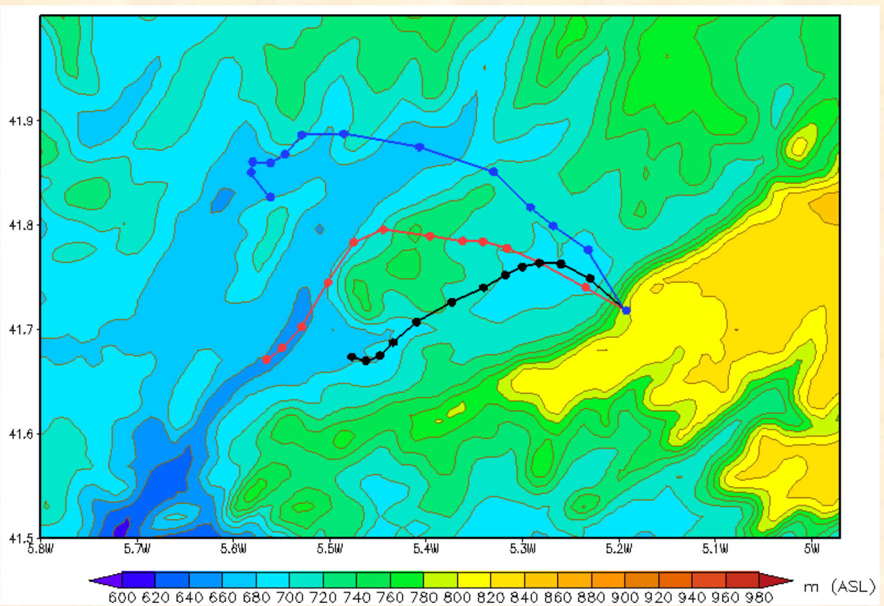
Big differences at 20 meters AGL

WRF parcels move further dragged by drainage winds

10m AGL

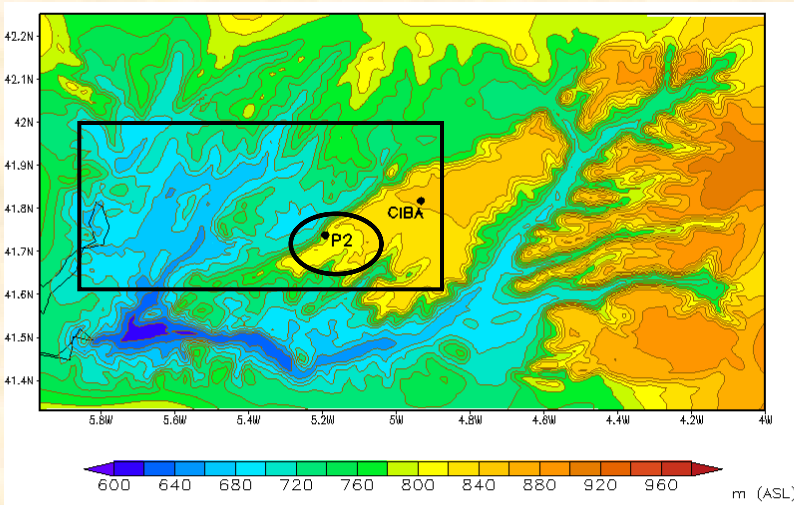


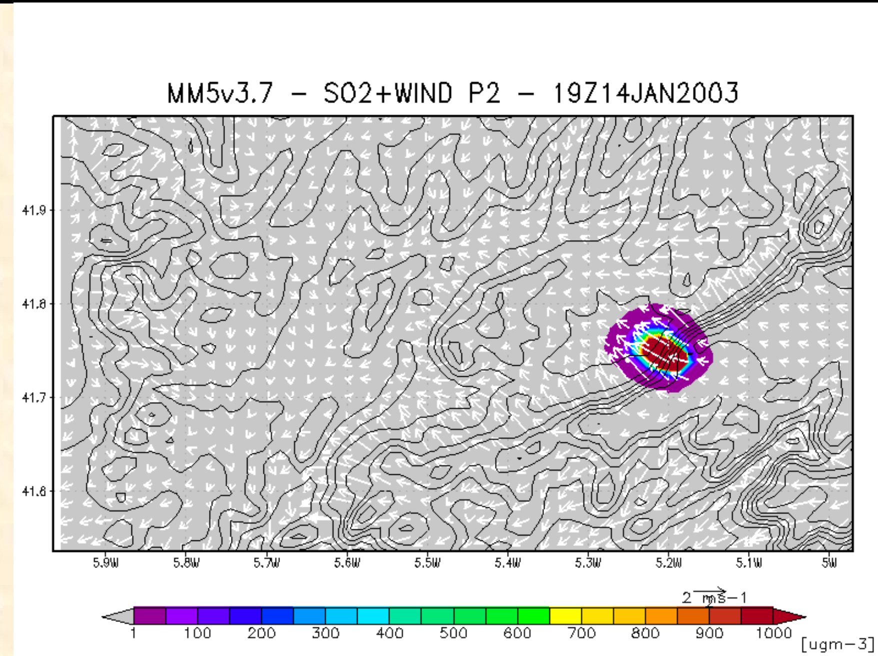

20m AGL

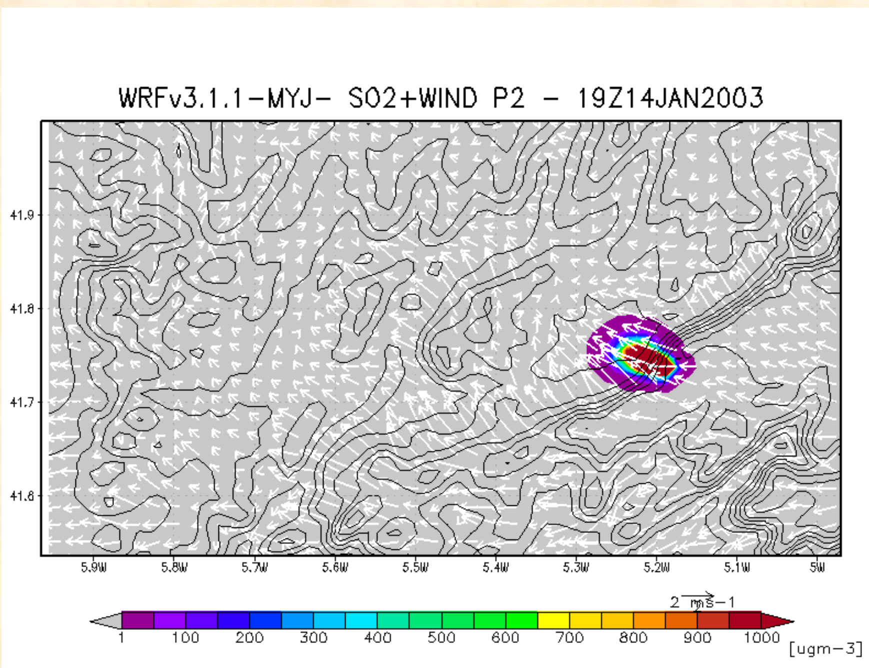


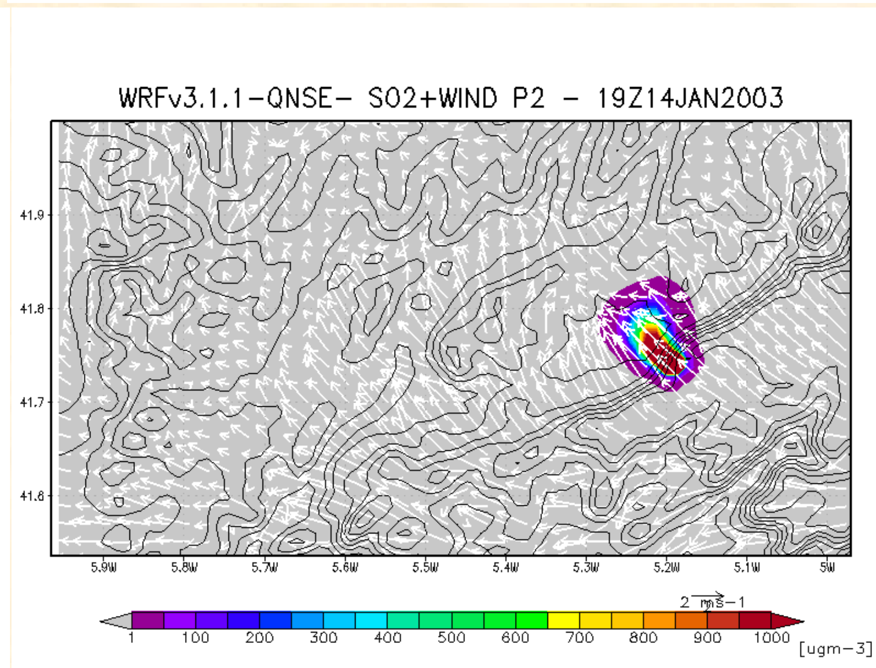
# $SO_2$ field distribution at P2

4. DISTRIBUTION OF POLLUTANTS



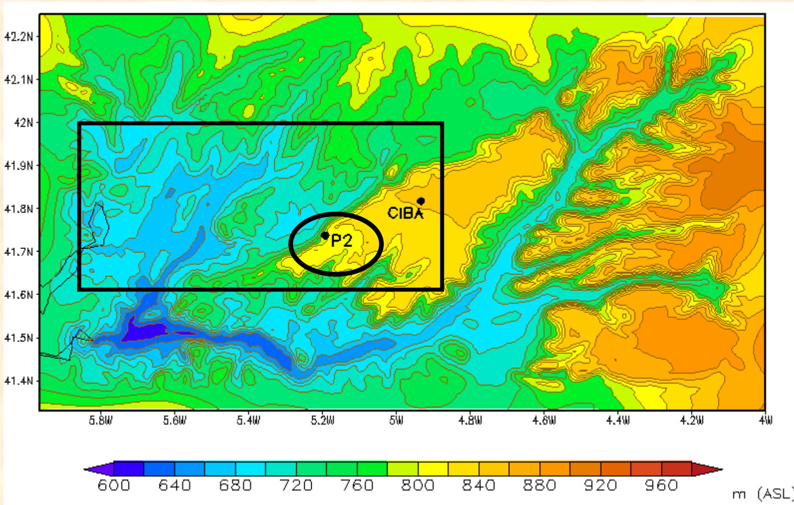



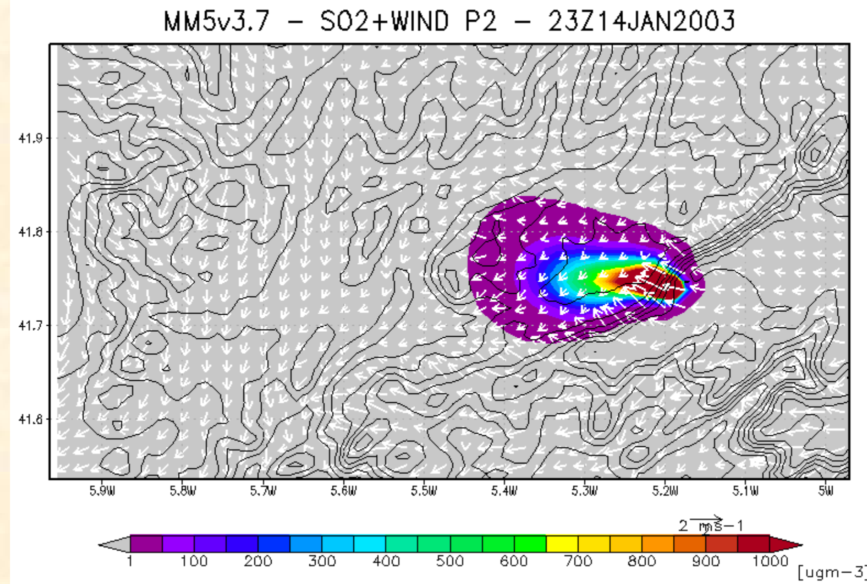



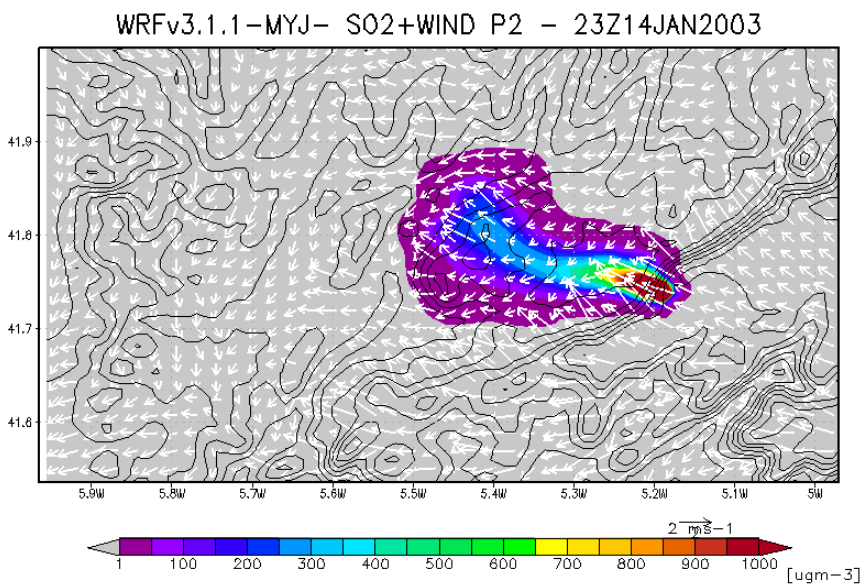



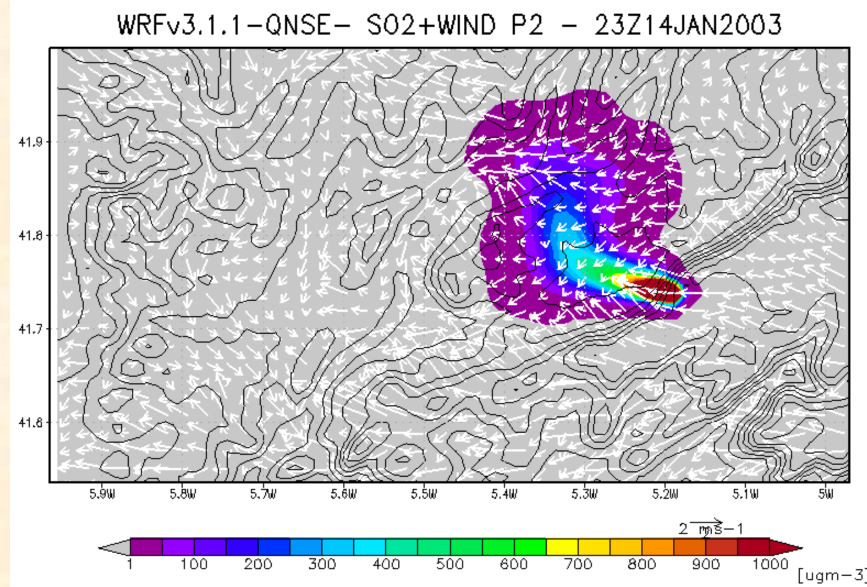
# $SO_2$ field distribution at P2

4. DISTRIBUTION OF POLLUTANTS



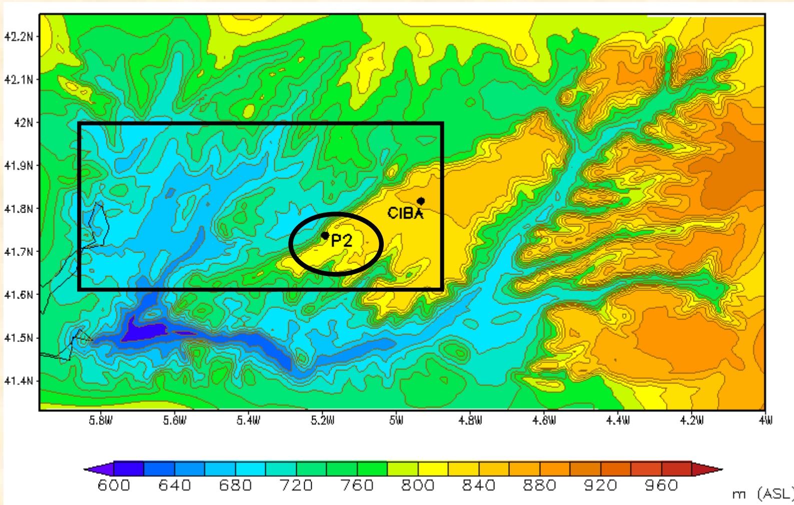



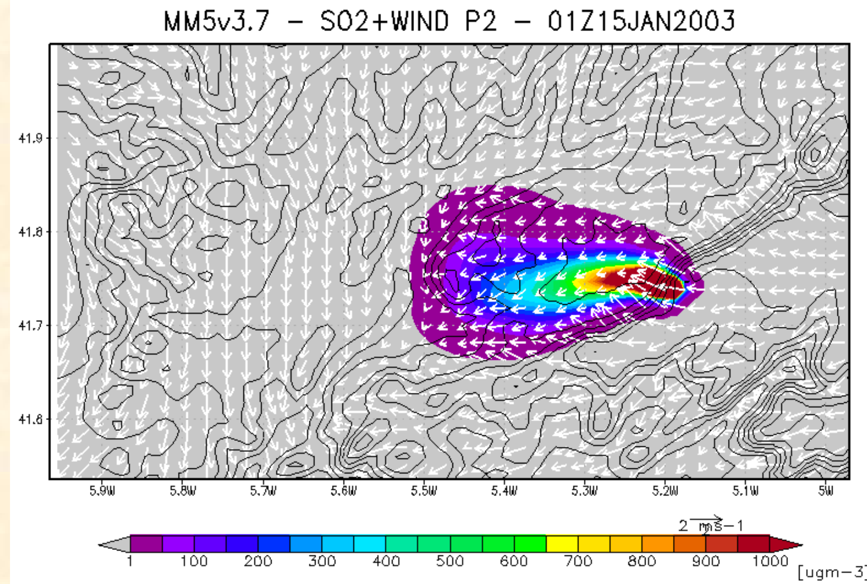



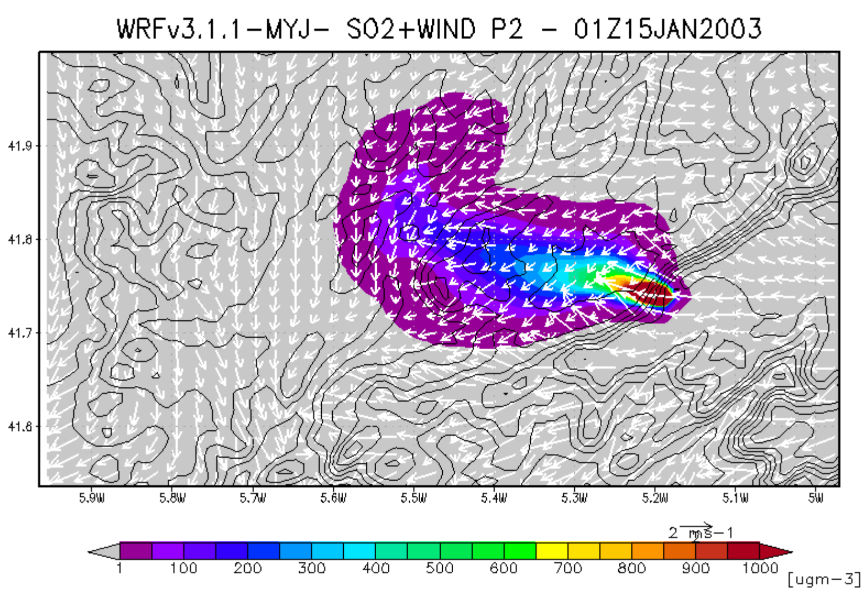



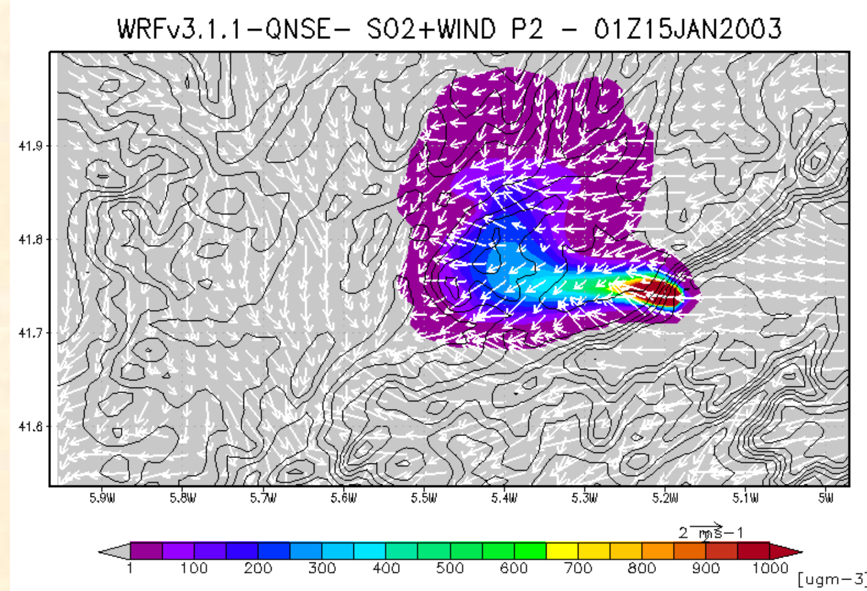
# $SO_2$ field distribution at P2

4. DISTRIBUTION OF POLLUTANTS



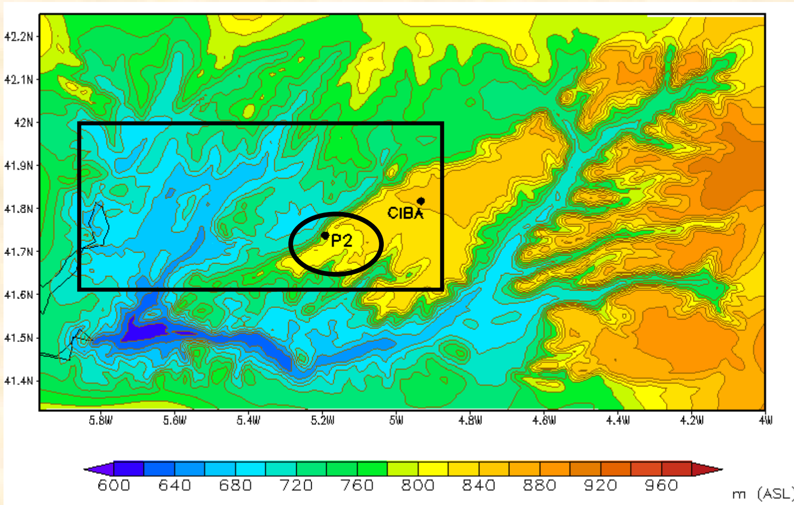



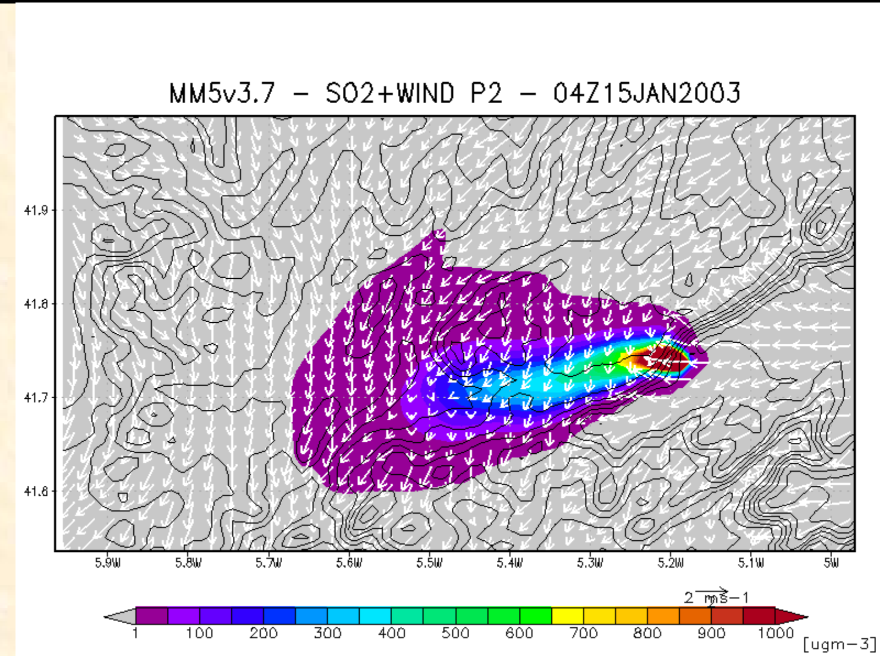



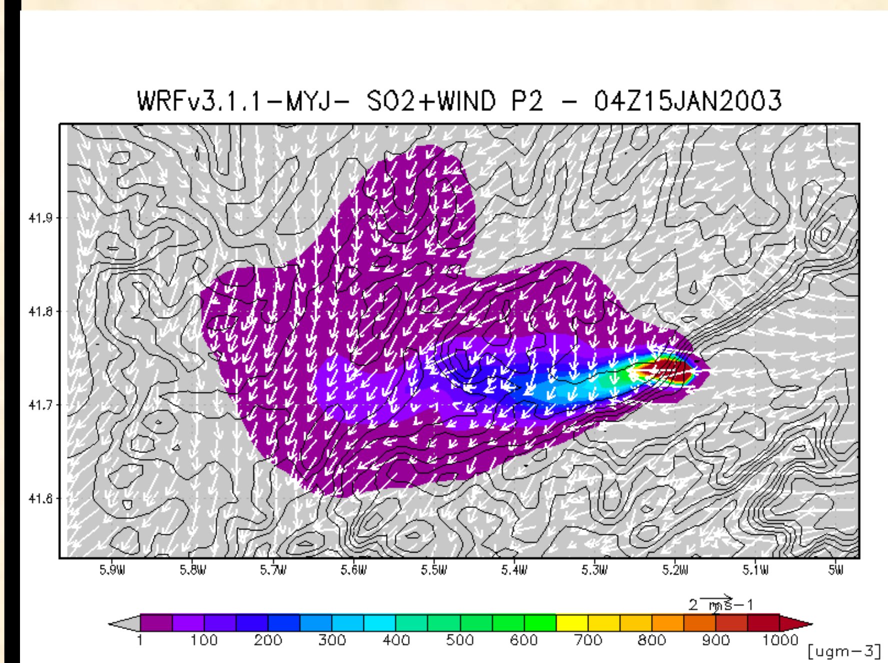



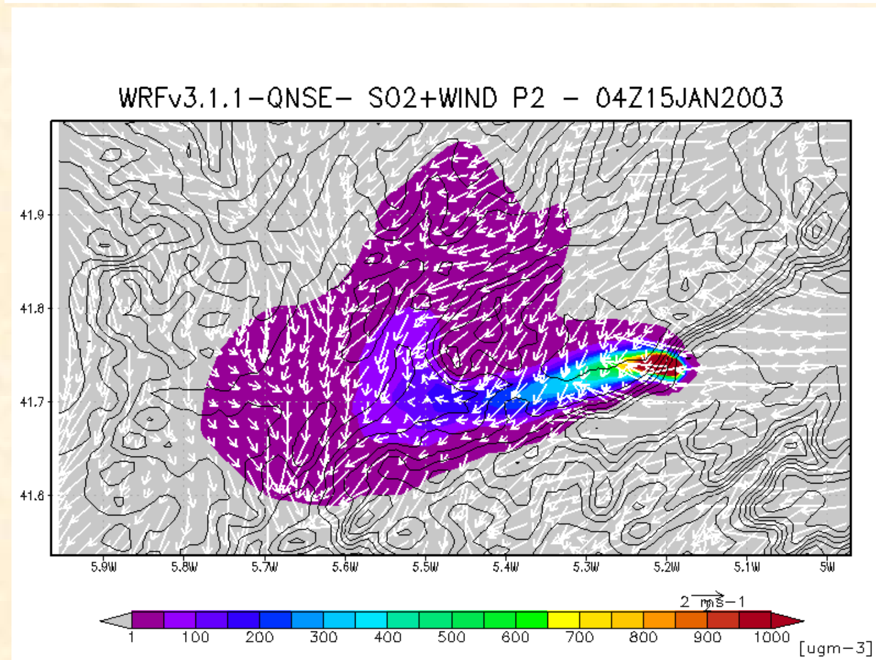
# $SO_2$ field distribution at P2

4. DISTRIBUTION OF POLLUTANTS



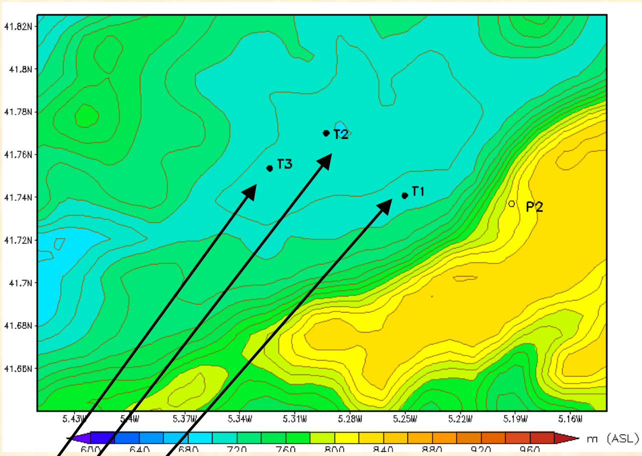



# $SO_2$ distribution differences

Point T1: 5 Km far from source of pollutants

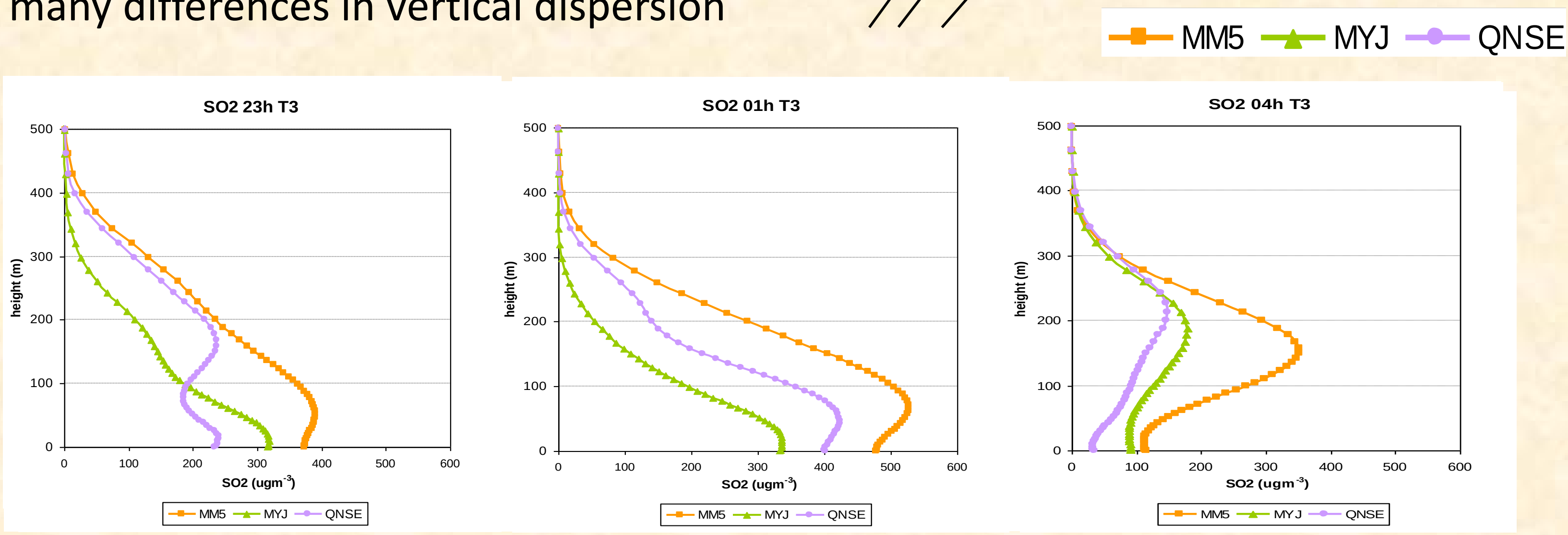
Point T2: 9 Km far from source of pollutants following WRF trajectories

Point T3: 11 Km far from source of pollutants following WRF trajectories




Higher $SO_2$ concentrations in MM5 model → dilution of air pollution is inhibited by low wind speeds

No many differences in vertical dispersion



## Conlusions

Two meteorological mesoscale models have been run using different PBL schemes over Duero basin under very stable conditions

WRF provides more realistic meteorological forecast in lower atmospheric region

MYJ experiment gives better statistical results, mostly for wind speed throughout all night

A development of a LLJ was fairly well captured by WRF-QNSE scheme at CIBA plateau

QNSE experiment forecasts strong drainage winds mostly at steep terrain areas

WRF experiments forecast more effective transport than MM5 experiments in 2 analyzed scenarios: at CIBA and an area near a slope.

## *THANK YOU FOR YOUR ATTENTION*

# EFFECTS OF NOCTURNAL THERMAL CIRCULATION AND BOUNDARY LAYER STRUCTURE ON POLLUTANT DISPERSION IN COMPLEX TERRAIN AREAS

*Mireia Udina, Maria Rosa Soler, Raúl Arasa, Miriam Olid*

Department of Astronomy and Meteorology, Universitat de Barcelona, Barcelona, Spain

Mesoscale and Microscale Atmospheric Modelling and Research

**HARMO 13**. 13th International Conference on Harmonization within Atmospheric Dispersion Modelling for Regulatori Purposes

Paris, France 1-4 June 2010.