25th Workshop
Troposheric Chemical and Transport Modelling
6-7 November 2014 – University of Aveiro

INVESTIGATING AEROSOL - RADIATION - CLOUD FEEDBACKS UNDER EMISSION CONTROL STRATEGIES

A. Balzarini, G. Pirovano, G. M. Riva and A. Toppetti

AIM OF THE WORK

- Models are important tools to explore the effects of emission-control strategies on air quality
- In recent years the modelling community in moving toward the so-called coupled on-line approach
- The existence of interactions between aerosols and meteorology (*"feedbacks"*) has been well documented in past years, but only few studies considered them in air quality simulations
- Moreover, the impact of feedback effects on emission-reduction strategies needs to be addressed

Investigating interactions between aerosol and meteorology through the WRF-Chem coupled model in order to understand the implication of feedback mechanisms on ground concentrations either when emission control strategies are applied

MODEL SET UP

- WRF-Chem version 3.4.1 (September 2012)
- **Period:** July 2010
- **Computational domain:**

1) **Italy** – 1290x1470 km^2, 15 km grid step, 86x98 cells, 30 vertical levels (50 hPa)

- **Meteorology – IC & BC:**
  ECMWF meteorological fields (0.5 deg, 6 hours)
- **Chemistry - IC & BC:**
  MACC-II project (1.125 deg, 3 hours)
- **Emissions:**
  1) ANTHROPOGENIC: SMOKEv2.6 (ISPRA + EMEP)
  2) ON-LINE NATURAL: sea salt (Gong et al., GBC, 2003)
  MEGANv2.4 (Guenther et al., ACP, 2006)
  DUST (Shaw et al., AE, 2008)

BASE: without feedback effects

FBS: with feedback effects

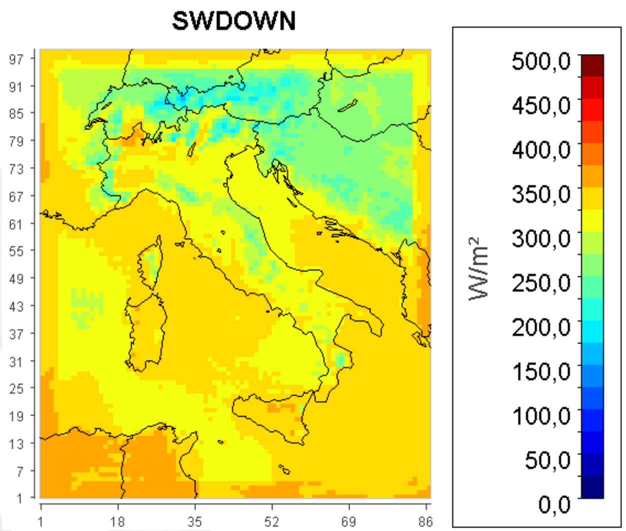
MODELING CONFIGURATIONS

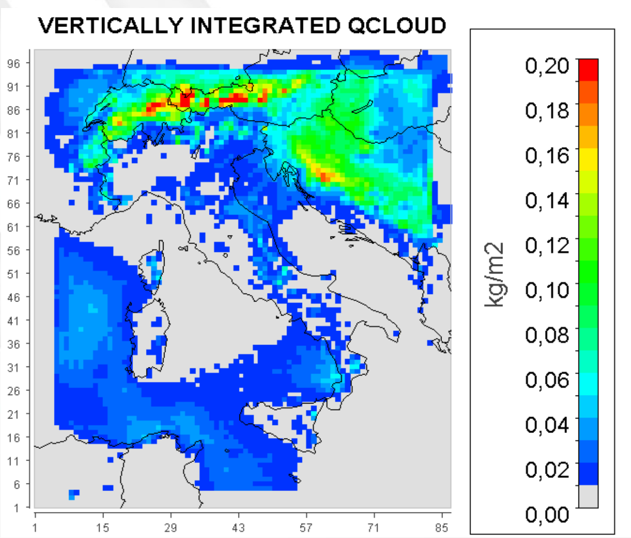
CHEMISTRY OPTIONS	BASE	FBS
GAS CHEMISTRY	CBMZ	CBMZ
AEROSOL CHEMISTRY	MOSAIC	MOSAIC
Aqueous reactions	-	**Fahey and Pandis**
Dry and wet deposition	Included	Included
Aerosol dynamic	4 bins – sectional approach	4 bins – sectional approach
Radiation feedack	**off**	**on**
Indirect feedback	**off**	**on**

PHYSICS OPTIONS	
Microphysics	MORRISON 2-mom
PBL	YSU
LSM	Noah
Cumulus scheme	New Grell 3D scheme
Shortwave radiation	RRTMG
Longwave radiation	RRTMG

RESULTS

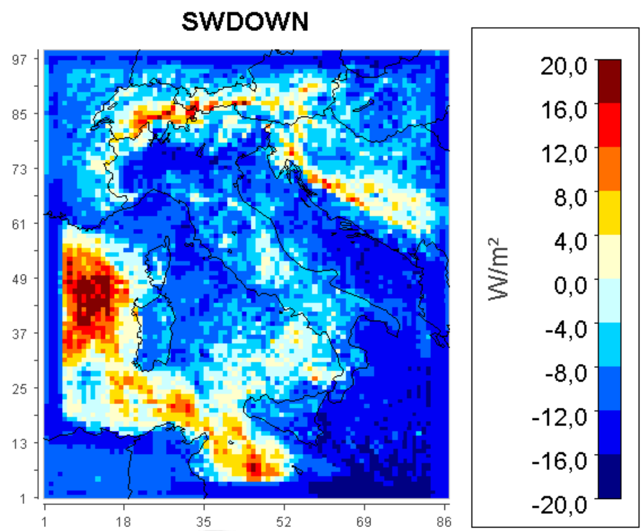
BASE CASE

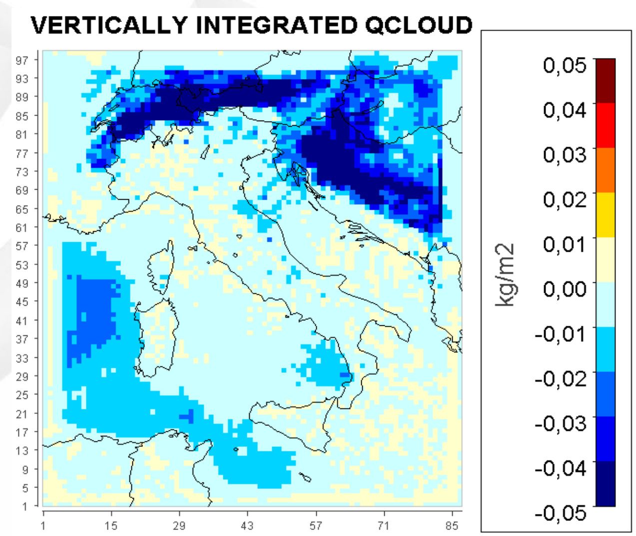




Differences with respect to the Base Case
FBS - BASE

FEEDBACKS - BASE

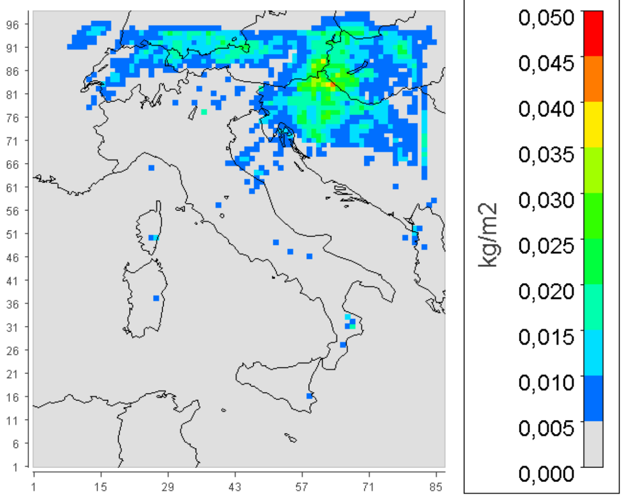




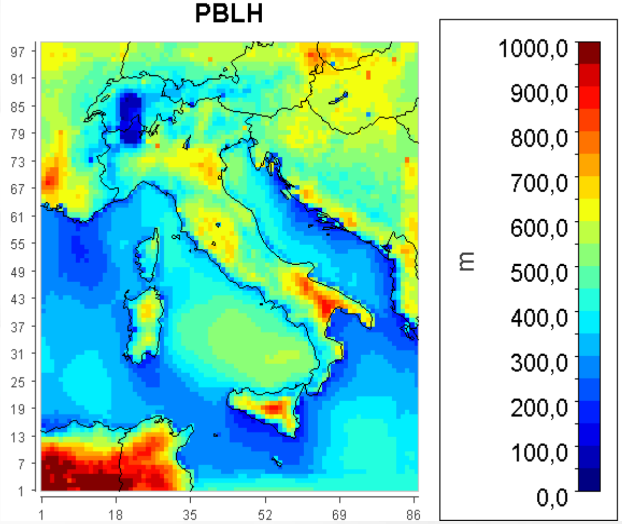
RESULTS

BASE CASE

VERTICALLY INTEGRATED QRAIN



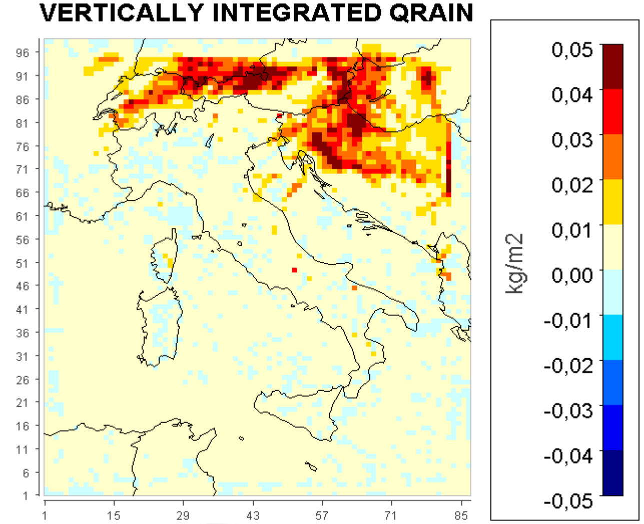
PBLH



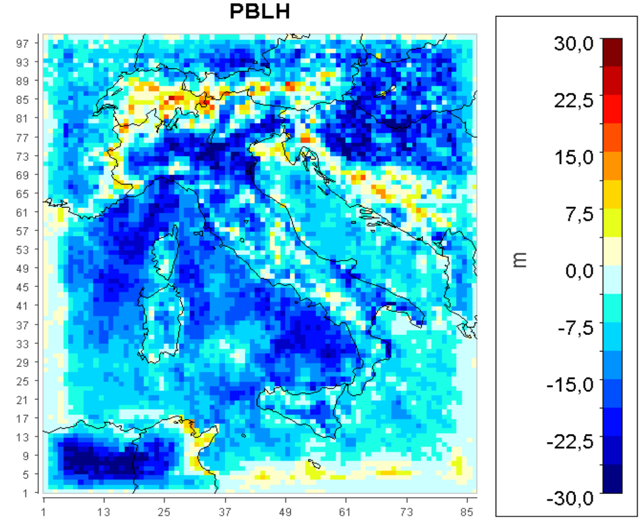
Differences with respect to the Base Case
FBS - BASE

FEEDBACKS - BASE

VERTICALLY INTEGRATED QRAIN

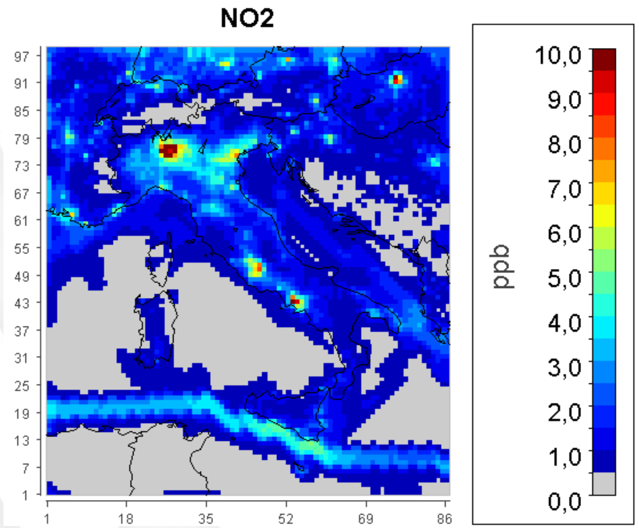


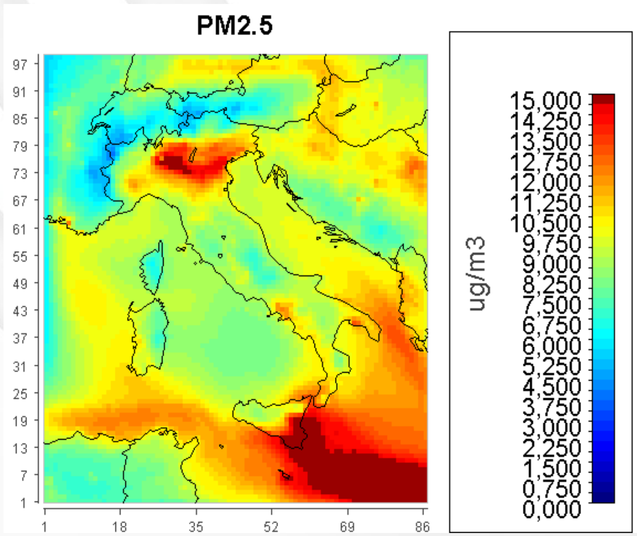
PBLH



RESULTS

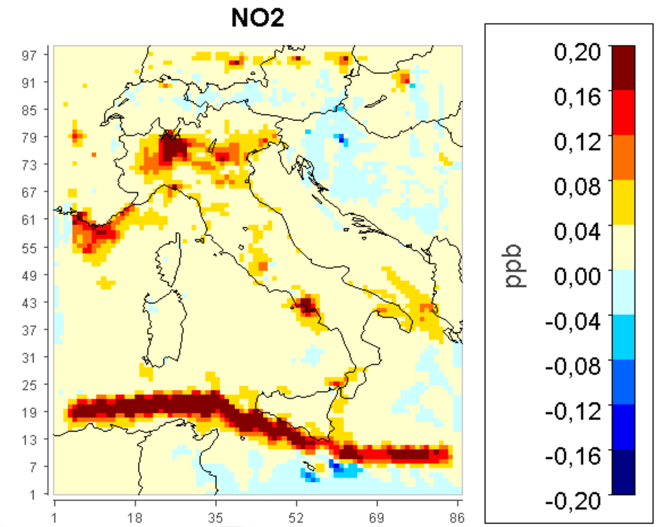
BASE CASE

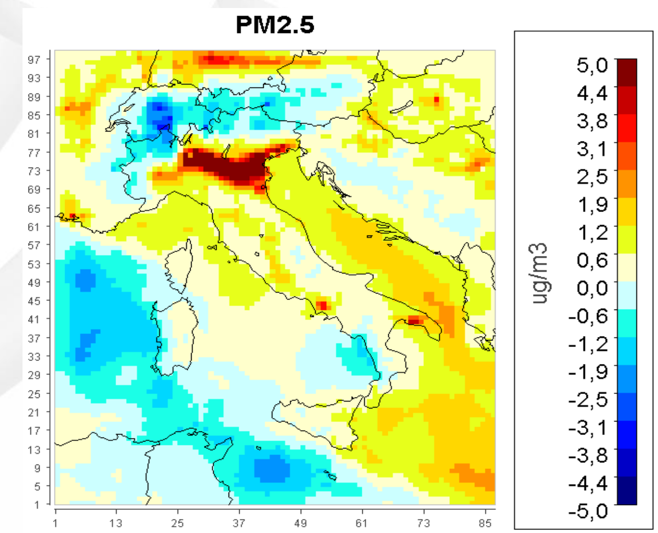




Differences with respect to the Base Case **FBS - BASE**

FEEDBACKS - BASE

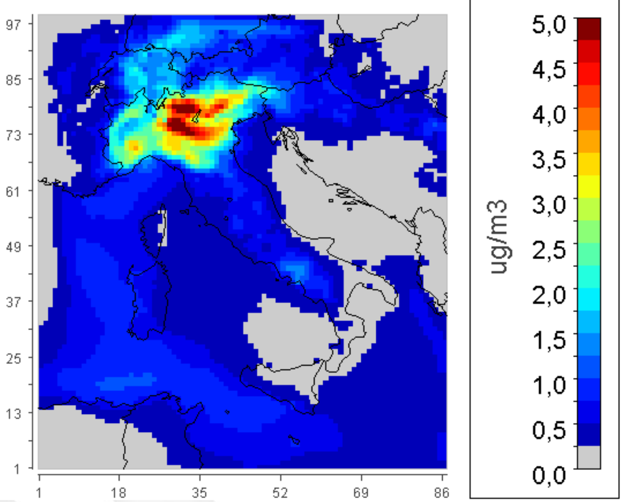




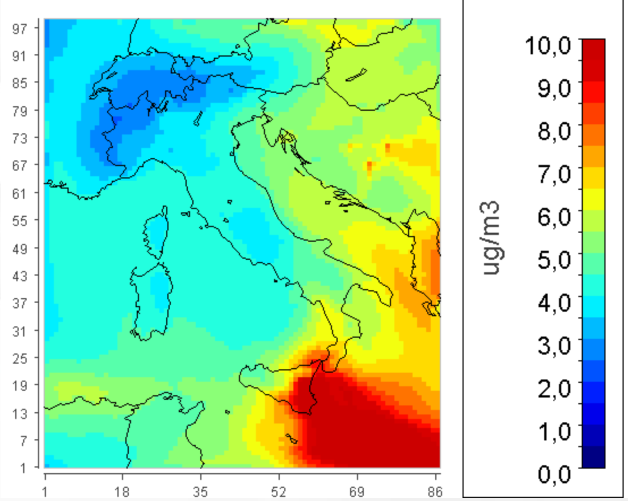
RESULTS

BASE CASE

NO3



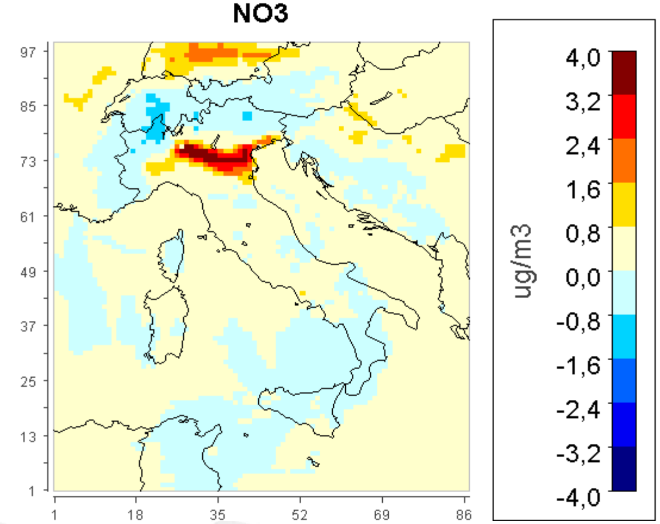
SO4



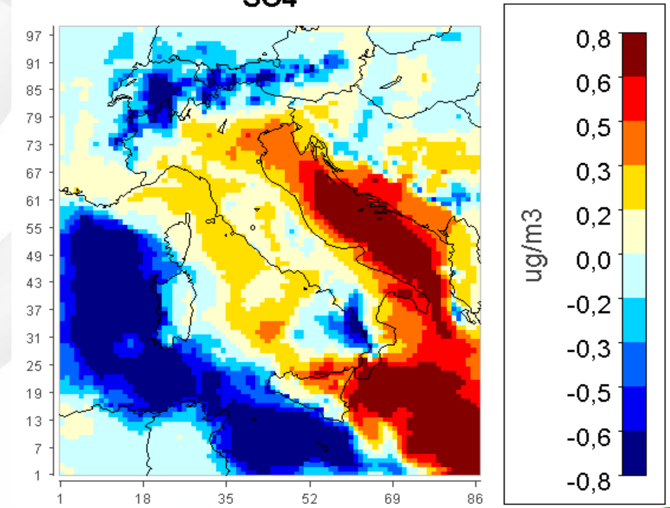
Differences with respect to the Base Case
FBS - BASE

FEEDBACKS - BASE

NO3

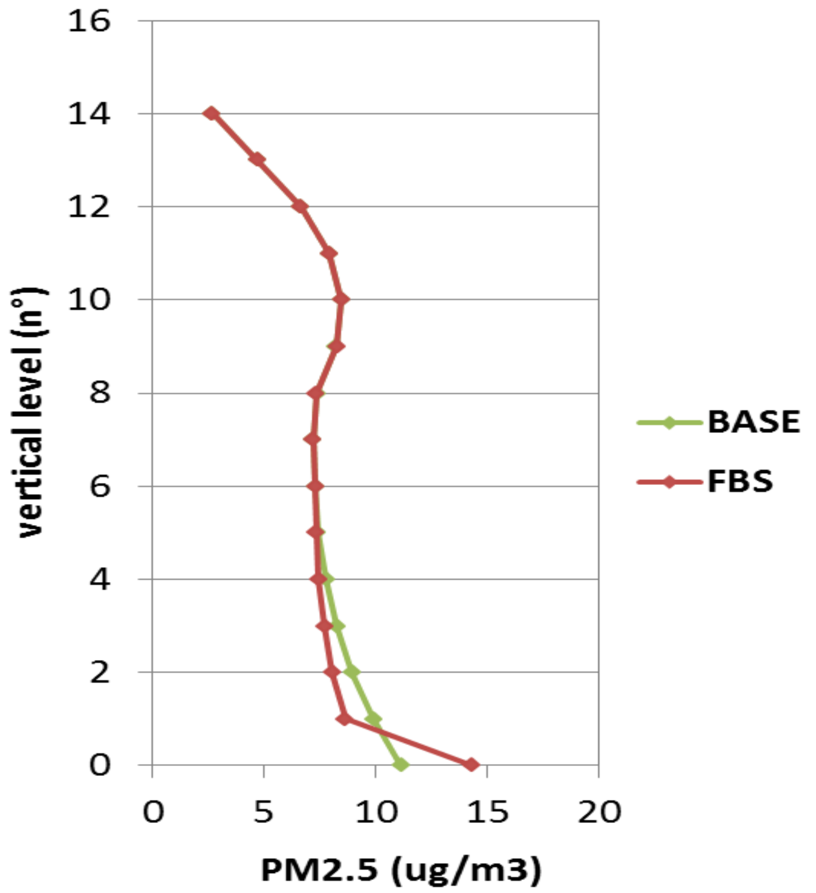


SO4



RESULTS

- PM2.5 concentration vertical profiles on 25/06/2010 at 01 UTC in the city of Milan



COMPARISON TO OBSERVATIONS

a) Monthly performances at 72 WMO stations

Variables	Mean Obs	BASE					FBS				
		Mean Mod	NMB %	NME %	RMSE	AC	Mean Mod	NMB %	NME %	RMSE	AC
Temperature (K)	298.68	296.80	-0.63	0.97	3.63	0.75	296.86	-0.61	0.96	3.58	0.76
Mixing ratio (g/kg)	14.38	13.32	-7.36	17.21	3.19	0.62	13.36	-7.13	17.21	3.18	0.63
Wind speed (m/s)	3.45	3.54	2.76	46.93	2.15	0.46	3.52	2.24	46.71	2.15	0.46

b) Monthly performances at 134 Rural Background stations

Compound	Mean Obs	BASE					FBS				
		Mean Mod	NMB %	NME %	RMSE	IOA	Mean Mod	NMB %	NME %	RMSE	IOA
NO_2 (ppb)	4.95	2.40	-51.57	55.71	4.00	0.51	2.46	-50.25	54.66	3.95	0.52
O_3 (ppb)	44.13	42.55	-3.56	18.92	10.66	0.48	42.52	-3.64	18.97	10.69	0.47
SO_2 (ppb)	0.78	0.35	-54.36	70.49	0.76	0.59	0.34	-56.25	71.82	0.77	0.63
PM10 ($\mu g/m^3$)	20.62	11.84	-42.57	45.48	12.19	0.72	12.99	-37.01	42.12	11.51	0.79
PM2.5 ($\mu g/m^3$)	14.06	10.72	-23.74	35.30	6.58	0.41	12.64	-10.09	33.28	6.23	0.41

FIRST SCENARIO ANALYSIS - 2030

- **Scenario analysis of emission reduction based on GAINS Italy outcomes (ENEA, 2013):**
  - Energy scenario developed by ISPRA using MARKAL (MARKet ALlocation; http://www.iea-etsap.org/)
  - Other-sectors scenario developed by ENEA
  - Control strategy that follows National and European legislations (e.g. LCPD 2001/80/CE; Dir. 692/2008/CE; Dir. 595/2009/CE; Dir. 2004/42/CE)

Unit: ton/domain/year
Region: Italy+EMEP

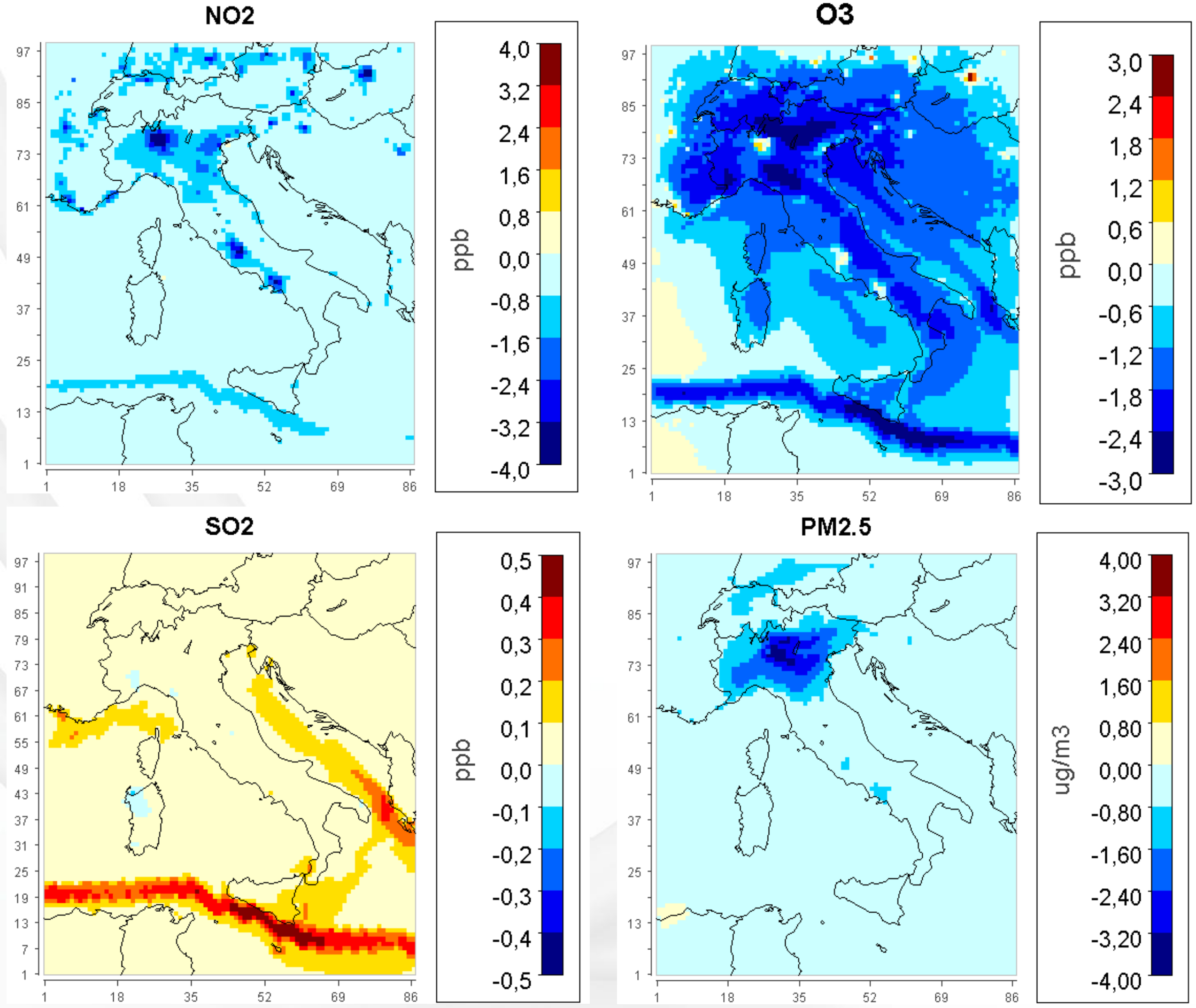
	NOx	VOC	NH_3	SO_2	PM10	PM2.5
EMISSIONS - BASE CASE 2010	2.9E+06	2.0E+06	8.8E+05	1.6E+06	6.1E+05	4.5E+05
EMISSIONS - SCENARIO 2030	2.3E+06	1.9E+06	8.9E+05	1.6E+06	5.8E+05	4.4E+05
VARIATION WITH RESPECT TO THE BASE CASE (%)	**-19%**	**-9%**	**1%**	**1%**	**-5%**	**-3%**

SCENARIO: without feedback effects

SCENARIO_FBS: with feedback effects

D'Elia and Peschi, LO SCENARIO EMISSIVO NAZIONALE NELLA NEGOZIAZIONE INTERNAZIONALE, ENEA Report, 2013

RESULTS

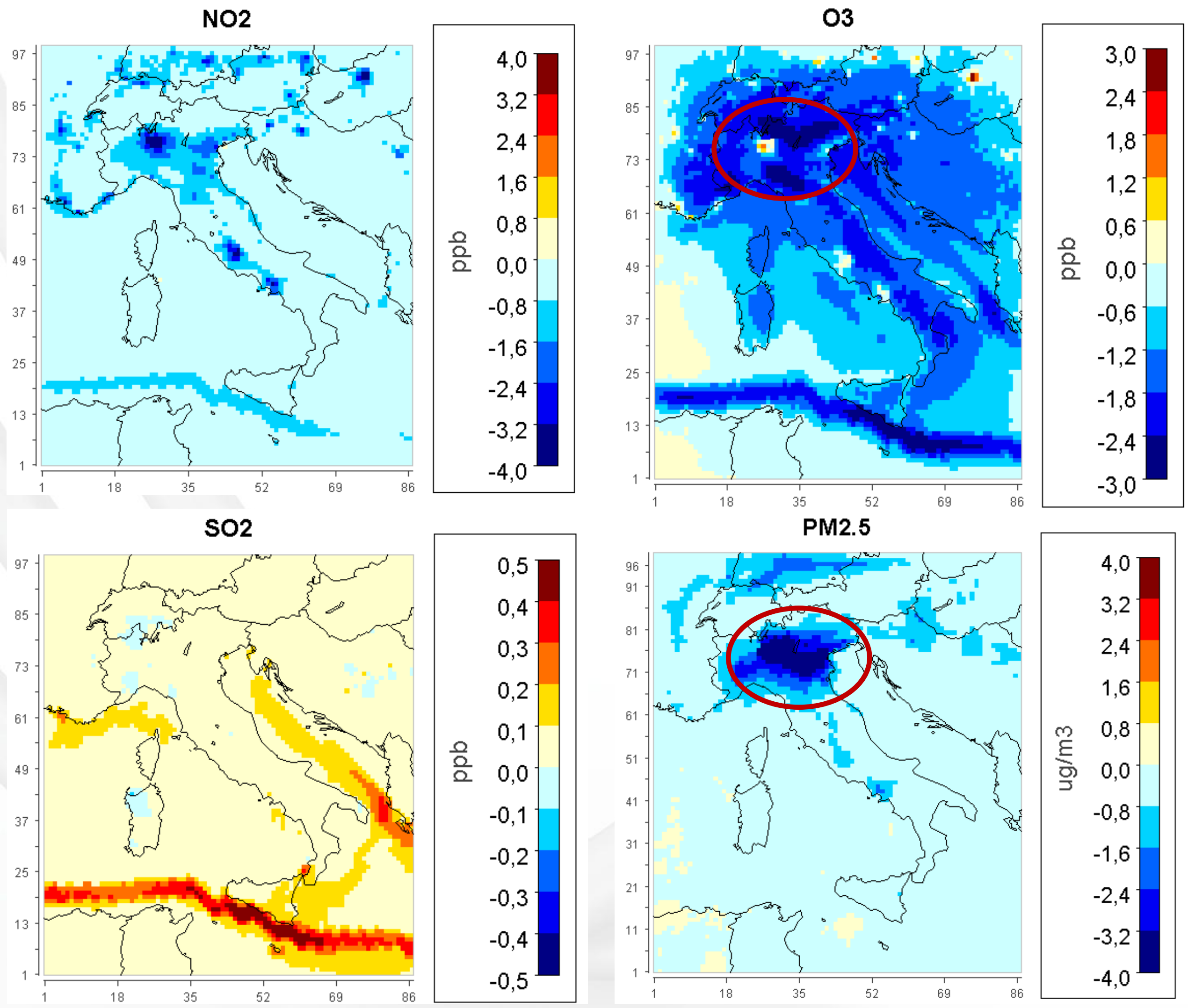


Differences with respect to the Base case

SCENARIO - BASE

without Feedbacks

RESULTS



Differences with respect to the Feedback case

SCENARIO_FBS - FBS

with Feedbacks

CONCLUDING REMARKS

- The coupled approach tends to improve the skill of model in reconstructing both meteorological fields and aerosol concentrations especially in complex circulation systems
- Direct feedbacks are found to have the following effects in the Po valley:

  1) Incoming solar radiation decreases at the ground up to 20 W/m^2 (5%)
  2) Planetary Boundary Layer height reduces up to 5% (30 m)

- Indirect feedbacks reduce cloud droplet number concentrations up to 40% and increase rain droplet number concentrations
- Feedbacks have minor influence on gas species (2-4%), in line with meteorological variations, while a strong impact was shown for aerosols (PM2.5) and their main components, that increases of about 30% due to the induced reductions of turbulent vertical mixing that concentrated particles in the first atmospheric layer
- It was demonstrated the effectiveness of using WRF-Chem to analyze future scenarios that explore the impact of emission control strategies on air pollution either when feedbacks are turned on
- Feedbacks effects are found to further improve the effectiveness of emission control strategies over the main polluted areas of Italy

THANKS FOR YOUR ATTENTION!

alessandra.balzarini@rse-web.it

FEEDBACK EFFECTS

- **Direct effect:** scattering (sulfate, OC) and absorption (BC) of shortwave incoming radiation depending on aerosol type and size

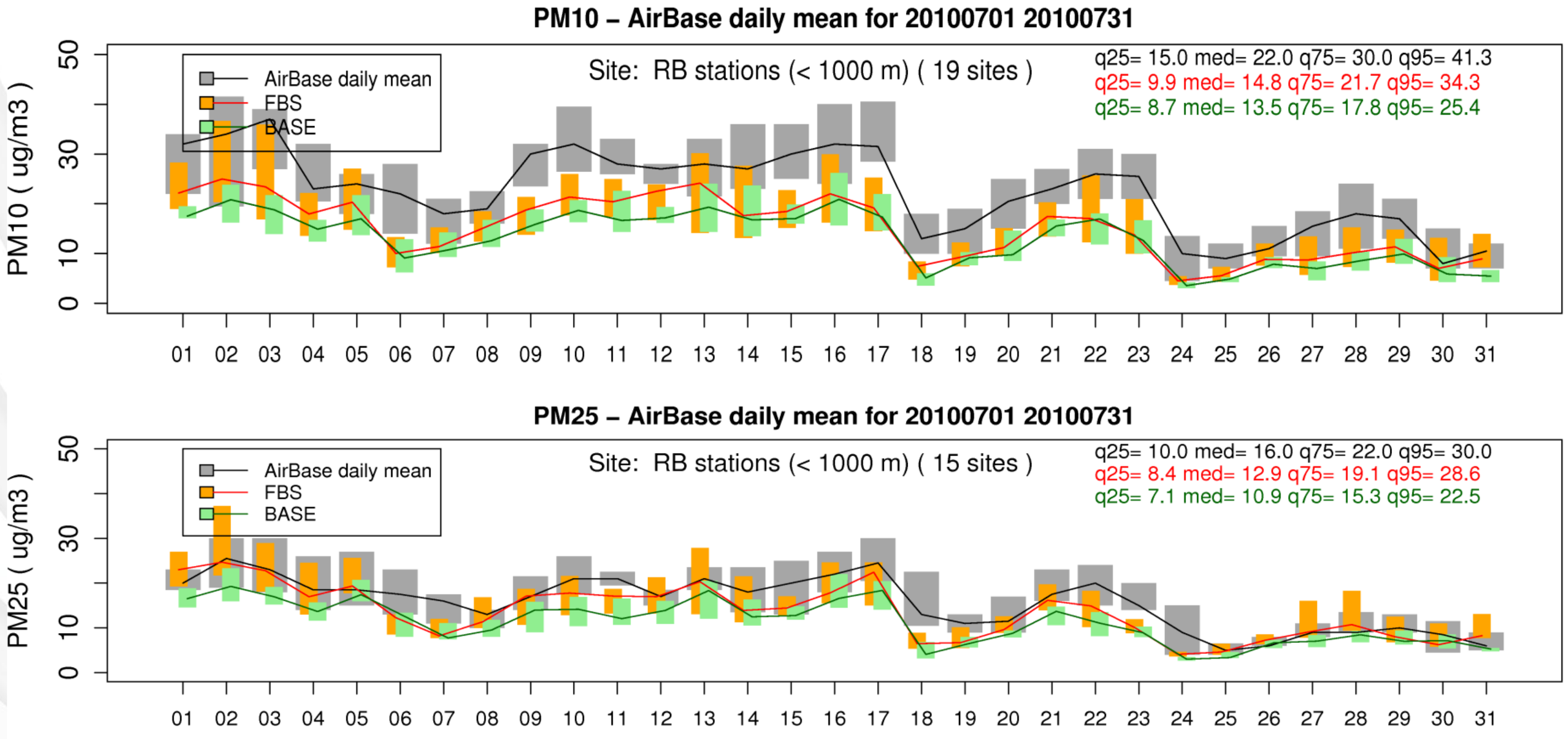
- **Semi-direct effect*:*** aerosol shortwave absorption (BC) reduced cloud cover by reducing relative humidity into the atmospheric layer

- **First indirect effect**: increase cloud droplet number concentrations with lower mean droplet size, that affect cloud cover and then cloud albedo

- **Second indirect effect:** influence on effective radius and hence cloud lifetime and initiation of precipitation

COMPARISON TO OBSERVATIONS

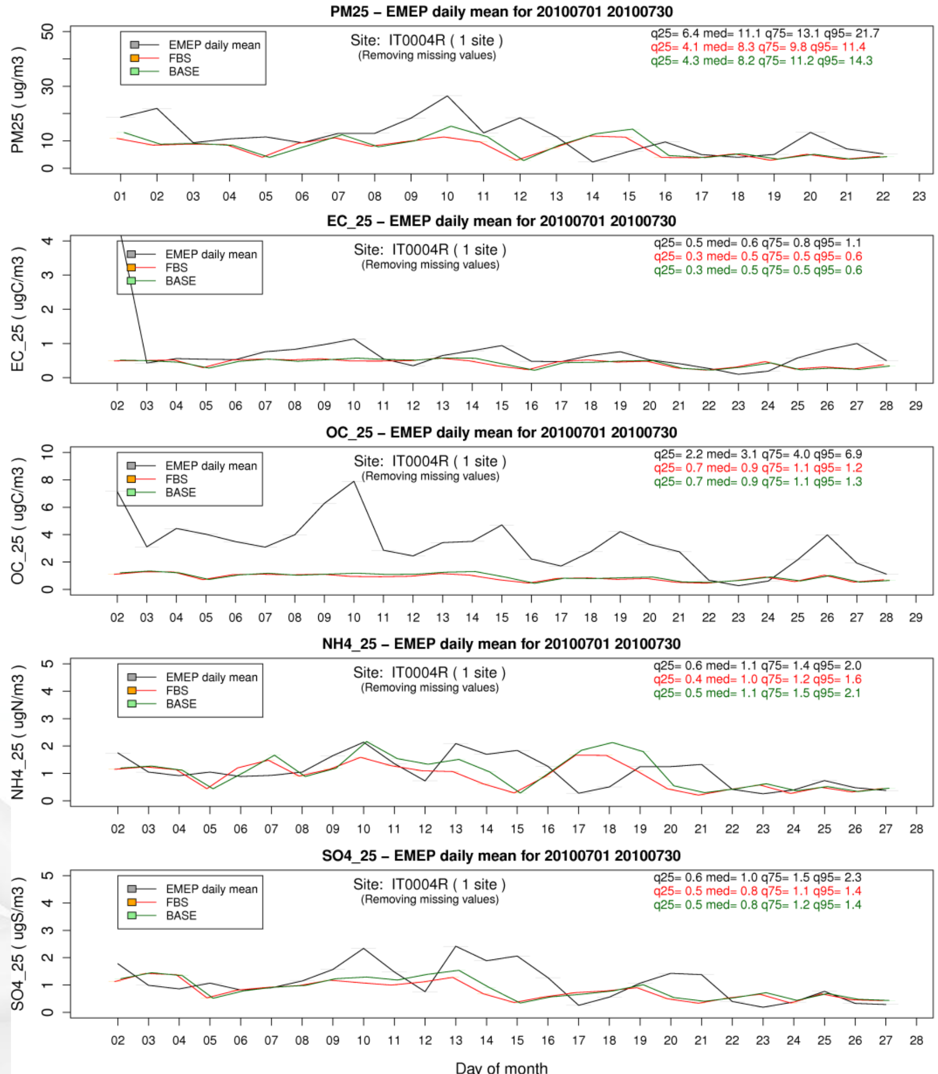
- Daily Box-whisker plots at rural background stations of the Po Valley



FEEDBACKS BASE Observed

COMPARISON TO OBSERVATIONS

- Time series of daily data at EMEP station of Ispra (IT0004R)



VERTICAL PROFILES