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Sensitivity analysis of WRF for integrated assessment modelling in Spain

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Seoul National University. Seoul, Korea.

Alexandrov, V., Borge, R.*, Lumbreras, J., Rodríguez, E.

* rborge@etsii.upm.es

Universidad Politécnica de Madrid

OUTLINE

1. INTRODUCTION

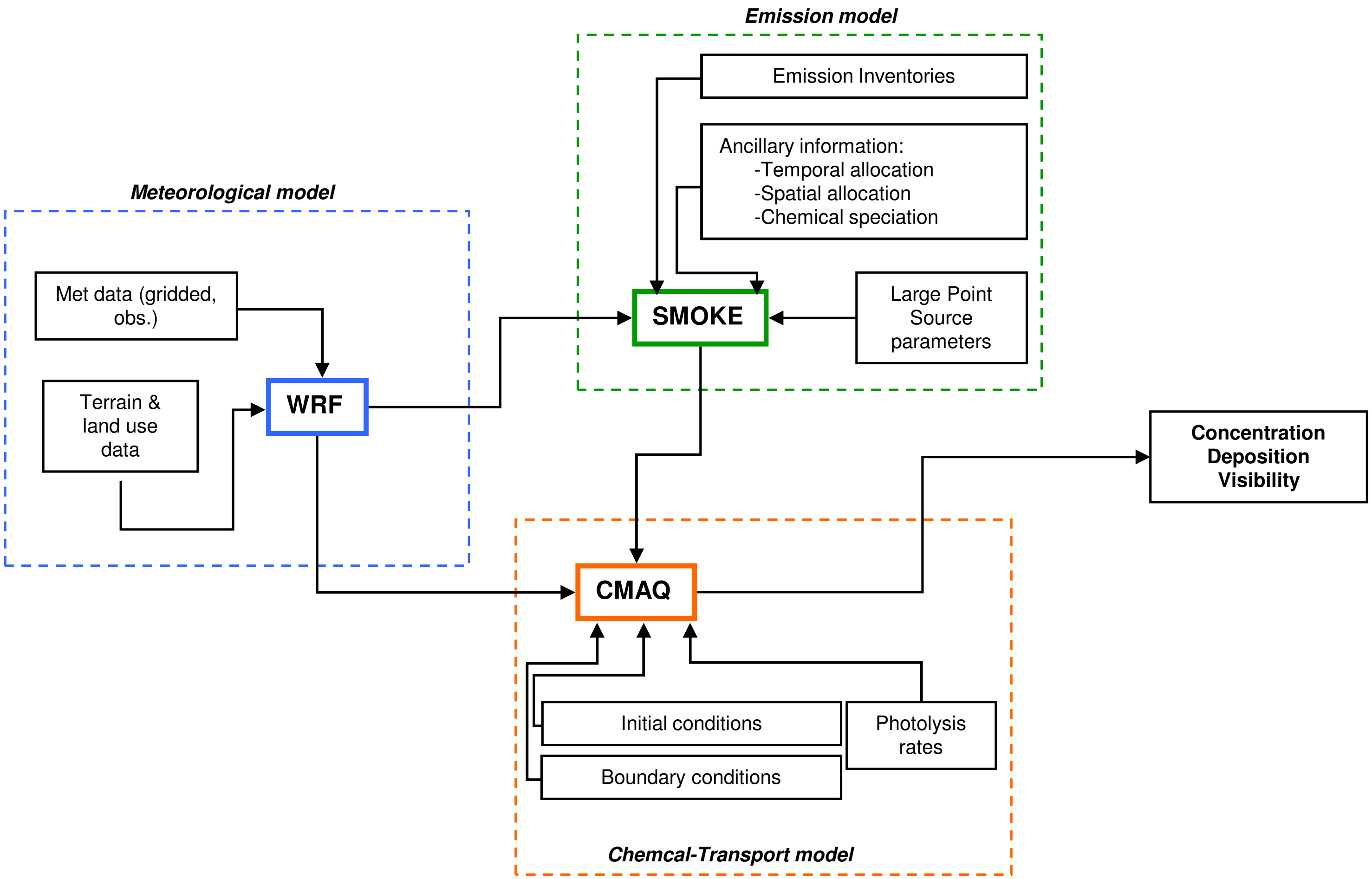
The SIMCA project

- SIMCA (Air quality integrated assessment modelling system for the Iberian Peninsula) is a research project funded by the Spanish Ministry of Environment

GOBIERNO DE ESPAÑA MINISTERIO DE MEDIO AMBIENTE

- Assessment and comparison of environmental policies and control strategies
- Multiscale and multipollutant approach
- Based on national projections from the Spain's Emission Projection (SEP) project

Modelling system overview



The need for a meteorological sensitivity analysis

- Critical input for air quality modelling

→ Uncertainty and errors in the final AQ results

- Non-deterministic approach: future-year runs based on 6 meteorological years (2000-2005)

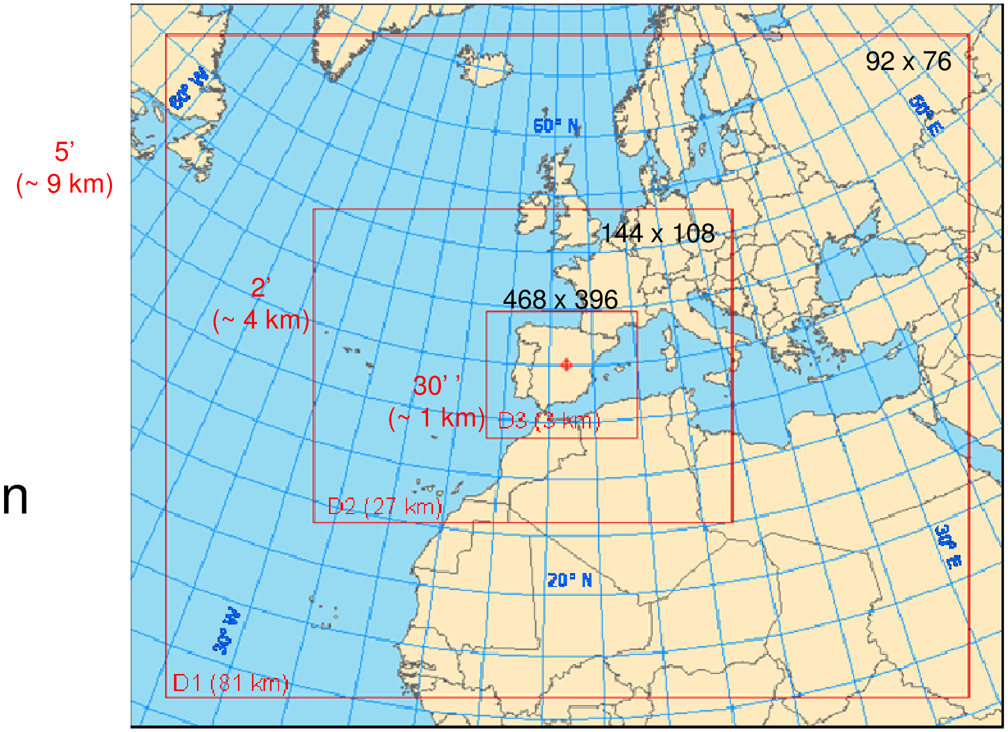
→ Extensive computational (time) resources

~ 1600 h WRF running time / year

(128 IBM PPC 2.2 GHz processors)

2. METHODOLOGY

Modelling domains and inputs



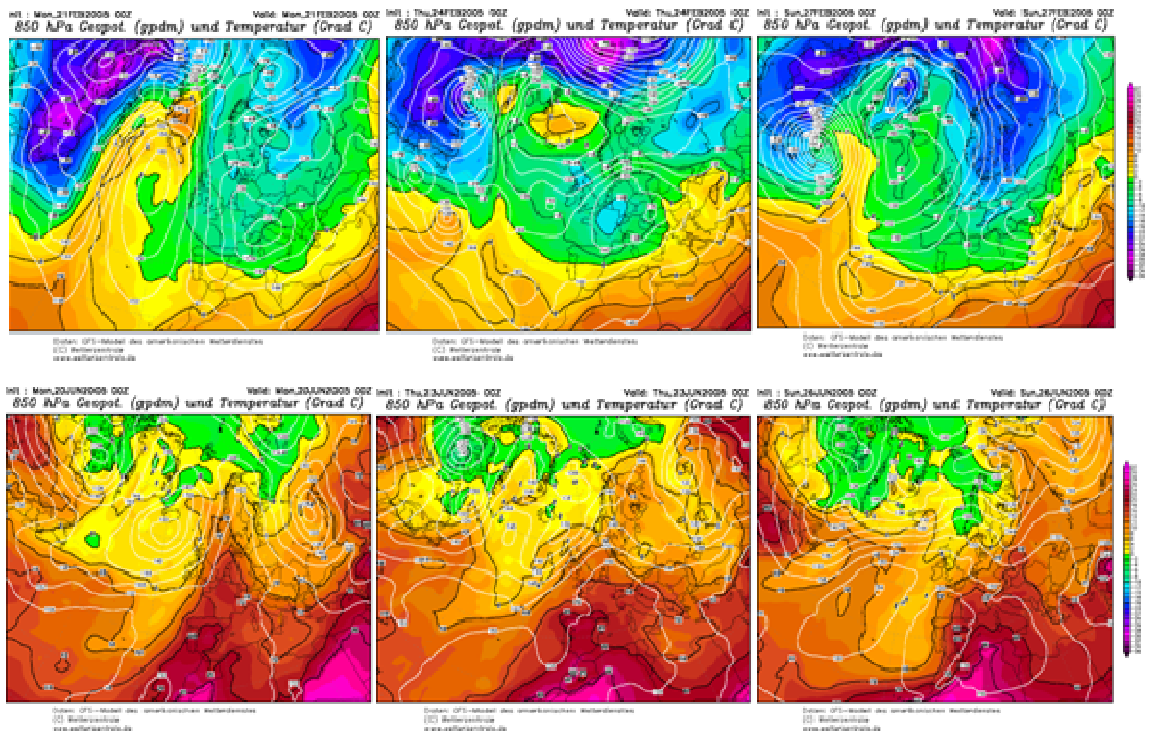
- Lambert conformal projection
- Three nested domains
- 30 layers
- Initializacion from NCEP Global Tropospheric Analyses with 1º x 1º spatial resolution and temporal resolution of 6 hours

Episodes

- Two 7-day (9) episodes. Winter and summer 2005

21-28 February

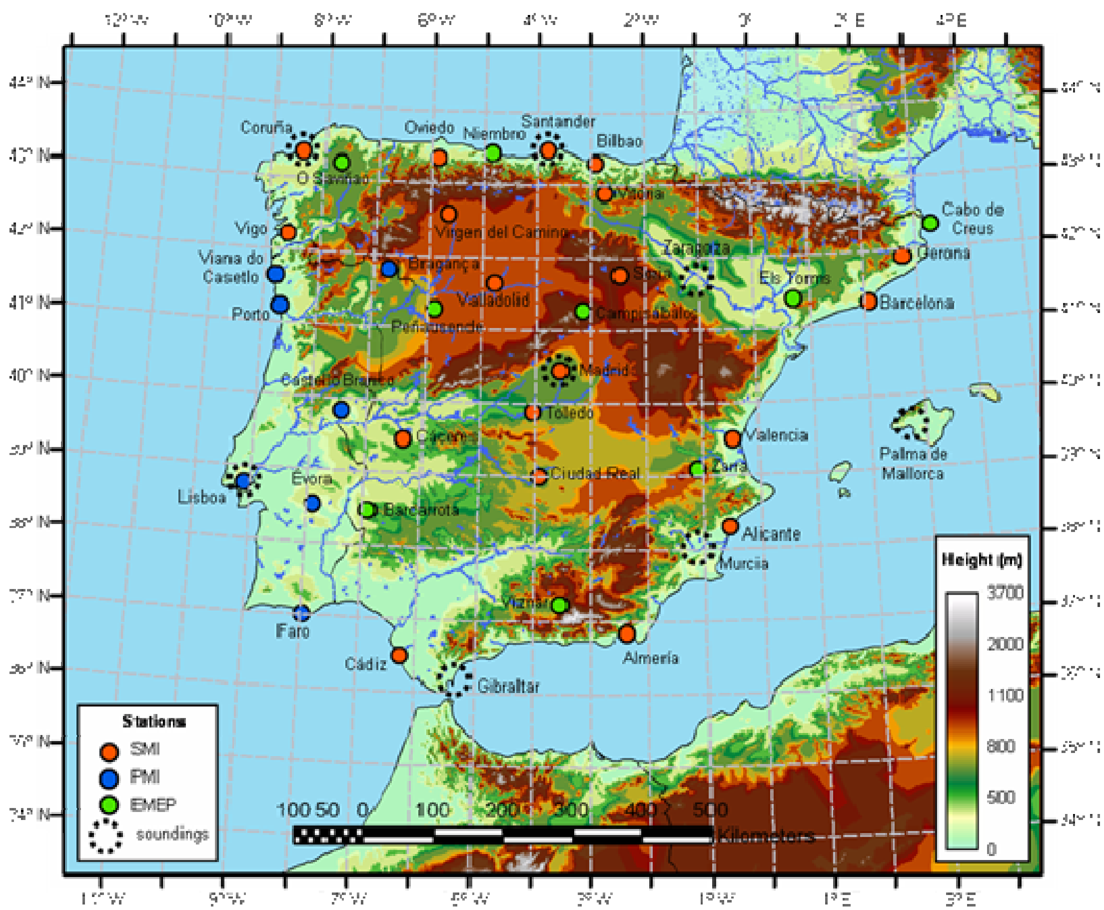
20-27 June



- Generalized high pollution levels over the Iberian Peninsula (SO_2 and $PM_{2.5}$ in winter and O_3 in summer)

Observational datasets

- 39 monitoring stations (met & AQ) representative of geophysical conditions across the Iberian Peninsula



- Surface meteorological variables (1-h resolution)
  - Temperature (2 m)
  - Wind speed and direction (10 m)
- Observations from 3 monitoring networks:
  - Spain's Meteorological Insititute (SMI) – 19 stations
  - EMEP – 9 stations
  - Portugal's Meteorological Insititute (PMI) – 7 stations
- Upper air measurements (12-h resolution)
  - Vertical profiles from routinely soundings in 8 locations

Evaluation methodology

- Classical approach (measurements Vs model predictions)
- Statistics from Emery et al., 2001 (specific methodology for mesoscale model evaluation for air quality purposes)

$$B = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - O_j^i\right)$$

Bias error

$$E = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left|P_j^i - O_j^i\right|$$

Gross error

$$RMSE = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - O_j^i\right)^2\right]^{1/2}$$

Root mean square error

$$IOA = 1 - \left[\frac{IJ \cdot RMSE^2}{\sum_{j=1}^{J}\sum_{i=1}^{I}\left(\left|P_j^i - M_o\right| + \left|O_j^i - M_o\right|\right)^2}\right]$$

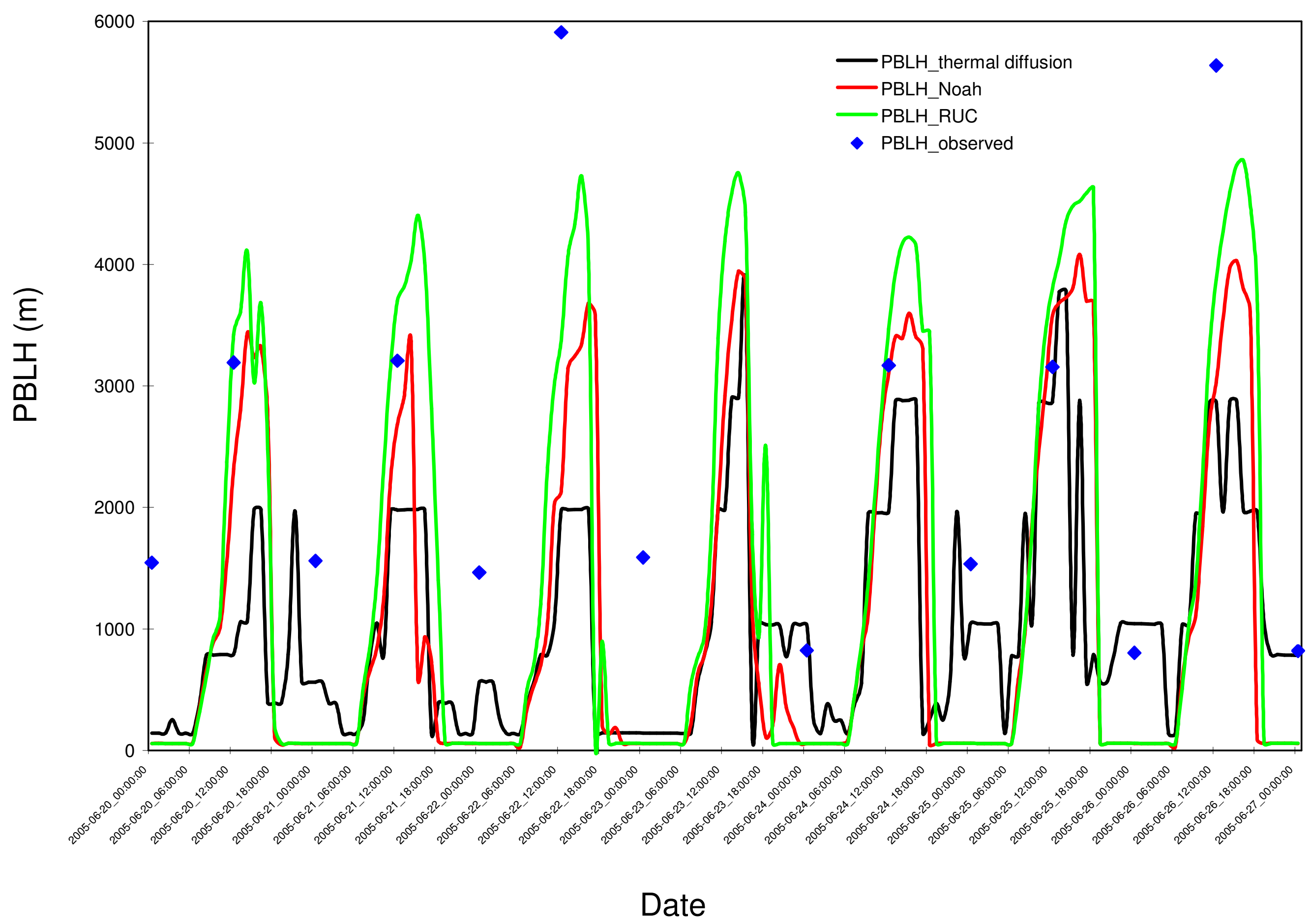
Index of agreement

- Most-relevant surface variables for AQ modelling
- Benchmarks not considered explicitly
- Comparative (relative) analysis

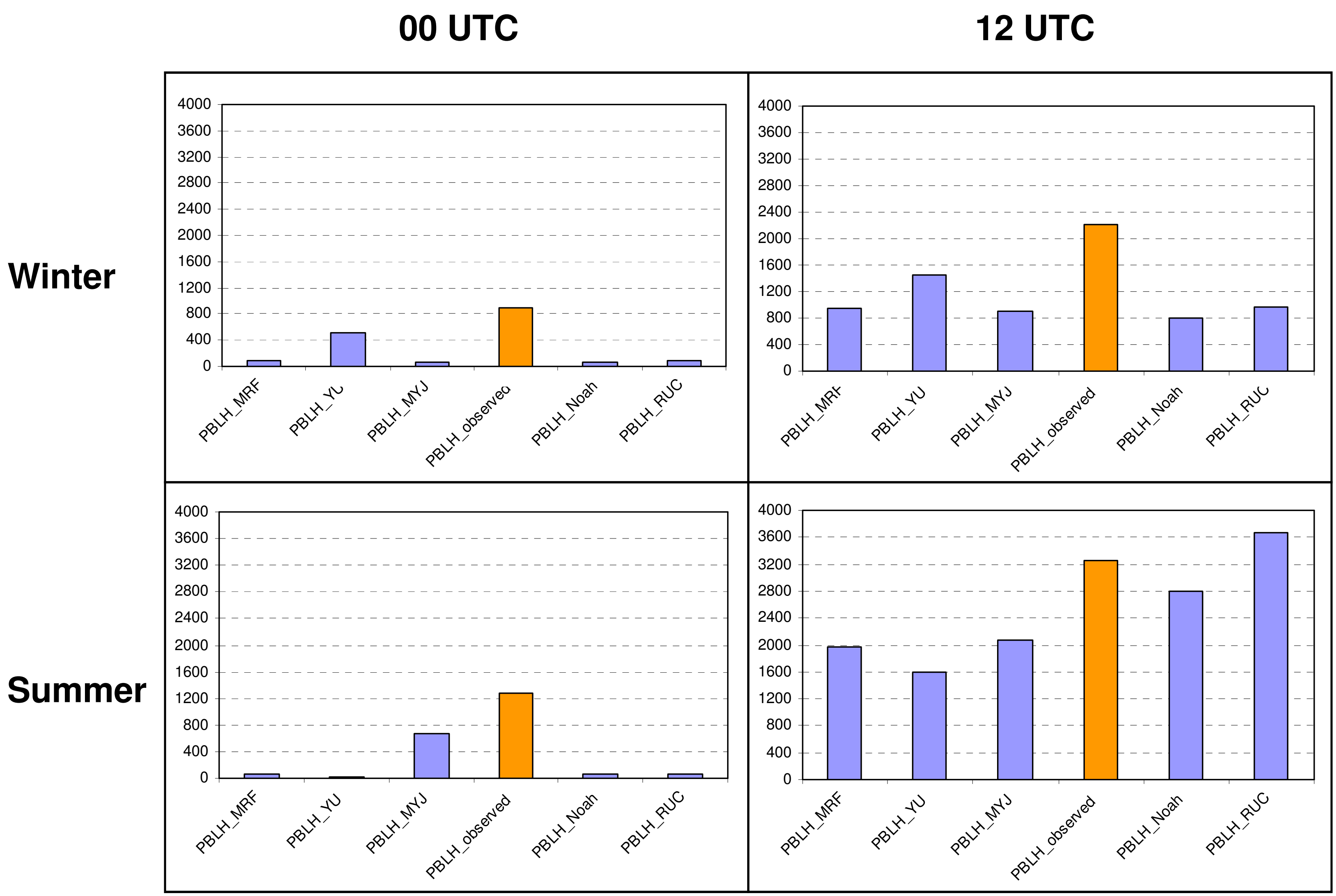
Statistic	Temperature	Wind speed	Wind direction	Humidity
RMSE	-	≤ 2 m/s	-	-
B	≤ ± 0.5 K	≤ ± 0.5 m/s	≤ ± 10º	≤ ± 1 g/kg
E	≤ 2 K	-	≤ 30º	≤ 2 g/kg
IOA	≥ 0.8	≥ 0.6	-	≥ 0.6

Statistic-variable relations and reference values
(for annual runs computed from 24-h averages)

- Upper-air measurements used for PBL height evaluation
- "Observed value" estimated with Bulk Richardson number



- Comparison for combined PBL-LS models



Sensitivity runs

- Main physics options and other user-defined important parameters in WRF v.2.2
- Base case from previous experiences (MM5)

Parameter	Option
Planetary Boundary Layer (PBL) scheme – Surface layer scheme	Medium Range Forecast Model (MRF) PBL – MM5 surface layer scheme
	Yonsei University (YSU) PBL – Eta surface layer scheme
	Mellor-Yamada-Janjic (MYJ) PBL – MM5 surface layer scheme
Microphysics	WSM5 scheme
	Purdue Lin scheme
	WSM6 scheme
	Eta Grid-scale Cloud and Precipitation (2001) scheme
Land-Surface Model	5-layer thermal diffusion
	Noah LSM
	Rapid Update Cycle (RUC) Model LSM

Sensitivity runs 1/2

Parameter	Option	
Sea Surface Temperature (SST)	Time-varying	
	Constant	
Radiation scheme	Longwave	Rapid Radiative Transfer Model (RRTM)
		Eta Geophysical Fluid Dynamics Laboratory (GFDL)
		Community Atmospheric Model (CAM)
	Shortwave	Eta Geophysical Fluid Dynamics Laboratory (GFDL)
		MM5 (Dudhia) Shortwave
		Goddard
Four-Dimensional Data Assimilation (FDDA)	Nudging	Analysis (grid)
		Stations (observational)
		Both (grid + observational)
	Without nudging	

Sensitivity runs 2/2

3. RESULTS

PBL scheme

- Yonsei University (YSU) PBL
  - Best performance for T in every network
  - T underestimated for SMI, overestimated for EMEP and PMI
  - Overall IOA ~ 0.9, gross error < 2.5 K
  - Best results for wind speed (IOA ~ 0.7)
  - Some seasonal differences
  - No appreciable effect on wind direction
  - PBLH not very sensitive on PBL scheme (YSU slightly better)

details

Land-surface model

- 5-layer thermal diffusion (Dudhia, 1996)
  - Similar performance to Noah LSM for T (slightly lower IOA)
  - Best results for wind speed predictions B=0.2 m/s, IOA=0.65 and direction B < 18º
  - Sensibly better performance for SMI stations
  - Seasonal differences; T performs better in summer, wind is better predicted in winter
  - Bigger influence in PBLH than PBL schemes (RUC scheme performs slightly better)

details

Microphysics

- WSM6 scheme
  - Best B results for T (no differences for E and IOA)
  - Best B results for wind speed (no differences for RMSE and IOA)
  - Best performance for SMI stations
  - Not very influencial on temperature and wind
  - Computationaly expensive (40% more than WSM5)

details

Sea surface temperature

- SST values from global NCEP SST analysis (dayly, 0.5º resolution)
- During the selected periods, no significant difference was found from variable SST values overall (Vs fixed SST)
- Clear improvement of the IOA for temperature in PMI stations (predominantly by the coast)
- Expected to have a stronger impact on annual simulations

details

Radiation: longwave

- Eta Geophysical Fluid Dynamics Laboratory (GFDL)
  - Sensitive parameter for T prediction
  - Underprediction of T
  - RRTM provides better results for some stations (SMI) / statistics
  - Overall better performance except for wind direction B (RRTM). Both schemes provided much better results for SMI than for PMI
  - Seasonal differences; T performs better in summer, wind is better predicted in winter

details

Radiation: shortwave

- MM5 shortwave scheme (Dudhia, 1989)
  - Slightly better than GFDL
  - Not uniform behaviour in time/space
  - Goddard scheme provided the best results for EMEP network but the worst overall performance

details

Four-Dimensional Data Assimilation (nudging)

- FDDA grid + observations
  - Combined nudging towards grid and observations provided the best results for most of the statistics / locations
  - However, FDDA grid provided better results for wind speed RMSE
  - The lower B values for wind directions were obtained when no nudging was applied

details

Best case summary

- Similar results for temperature
- Best results for all wind speed statistics for all the stations
- Better results for wind direction in some other experiments

Variable	Statistic	SMI	EMEP	PMI	TOTAL
T (K)	BE	-0.82	0.70	-0.30	-0.33
	GE	2.24	2.89	2.12	2.38
	IOA	0.91	0.83	0.88	0.88
WS (m/s)	BE	-0.10	-0.02	0.09	-0.04
	RMSE	2.35	2.86	1.98	2.42
	IOA	0.65	0.76	0.71	0.71
WD (º)	BE	-19.42	-17.39	-35.53	-22.99
	GE	59.97	59.69	65.57	63.17

- Worse performance for PBLH than other combinations (underprediction)

4. CONCLUSIONS

- Usually no single scheme performs better than others for all the locations / periods
- Promising results overall
- Poorer results for wind direction, especially in Portugal
- Model performance seems to be sistematically worse for the EMEP network
- PBLH performance hard to evaluate through routinely soundings
- The “best case” actually performs better
- FDDA (grid+observations) to be applied in all domains

5. NEXT STEPS

- Analyze PBLH sensitivity to radiation schemes
- Incorporation of humidity observations in the analysis

- Refinement of IC/BC through WRF-VAR (V 3.0)
- Full performance evaluation (6 years)
- Optimal setup for particular regions / subdomains
- Influence of meteorological variability on future-year annual air quality simulations

Thank you for your attention!

Any question / suggestion?