Usage of the WRF meteorology in the EMEP MSc-W model

Massimo Vieno

INMS

éclaire
Effects of climate change on air pollution impacts and response strategies for European ecosystems

UK-SCAPE

SUNRISE

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Oslo, 2019

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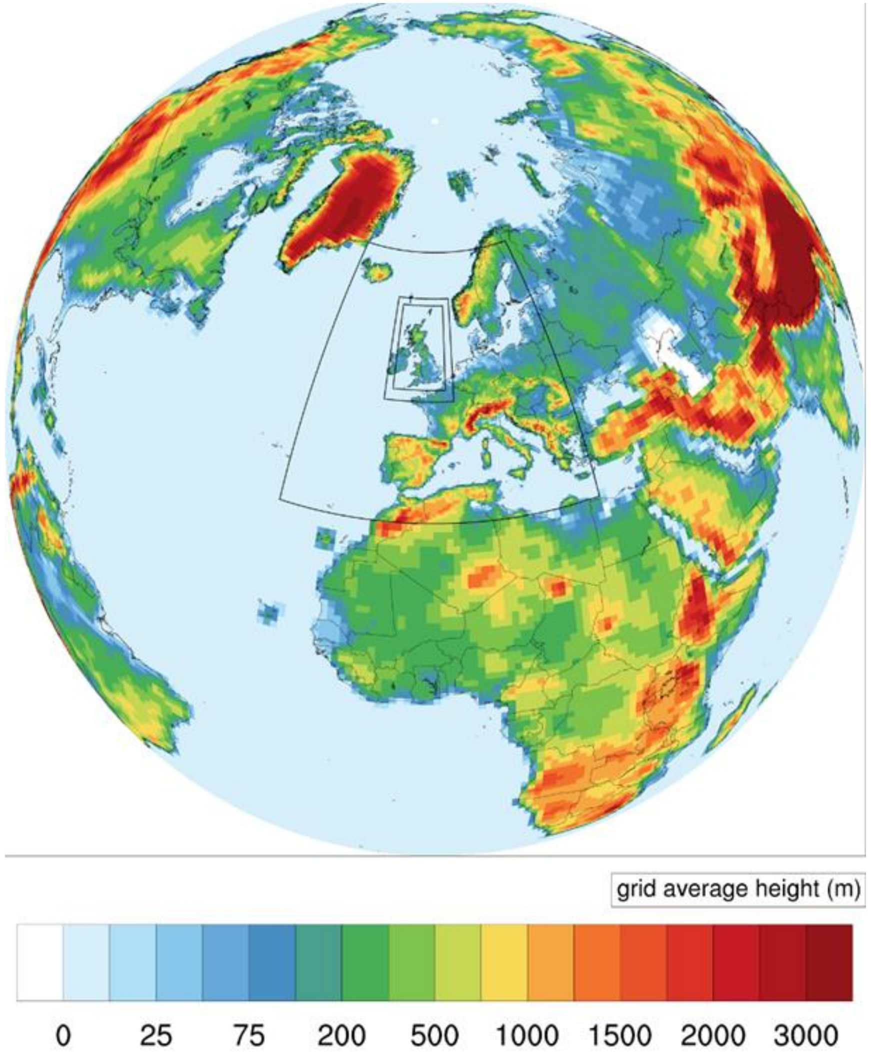
The EMEP-WRF typical setup



- EMEP-WRF is based on the CLRTAP EMEP MSC-w model (rv4.17)
- Eulerian approach
- Meteorology driver is the Weather Research Forecast model (WRF 3.9.1.1 www.wrf-model.org)
- Global to regional scale (~100s km to 1 km)
- Vertical domain from surface (~45 m) up to 100hPa (~16 km)
- Global emissions HTAPv2, EU emission EMEP, UK emissions NAEI, and shipping emissions Finnish Met. Ins.
- 3D meteorology output (wind speed, temperature, …)
- 3D chemistry output of more than 80 species, including:
    - ozone,
    - nitrogen dioxide
    - particulate matter
    - secondary inorganic and organic aerosols

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ACP Vieno et. al, 2010, 2014, 2016 and ERL Vieno et. al, 2016

Core model derived from EMEP MSC-W model (ACP Simpson et al., 2012)

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www.emep4uk.ceh.ac.uk

Overview

- Brief WRF model setup and choice of domain
- The EMEP MSC-w nested setup with WRF model
- Examples of EMEP-WRF model application

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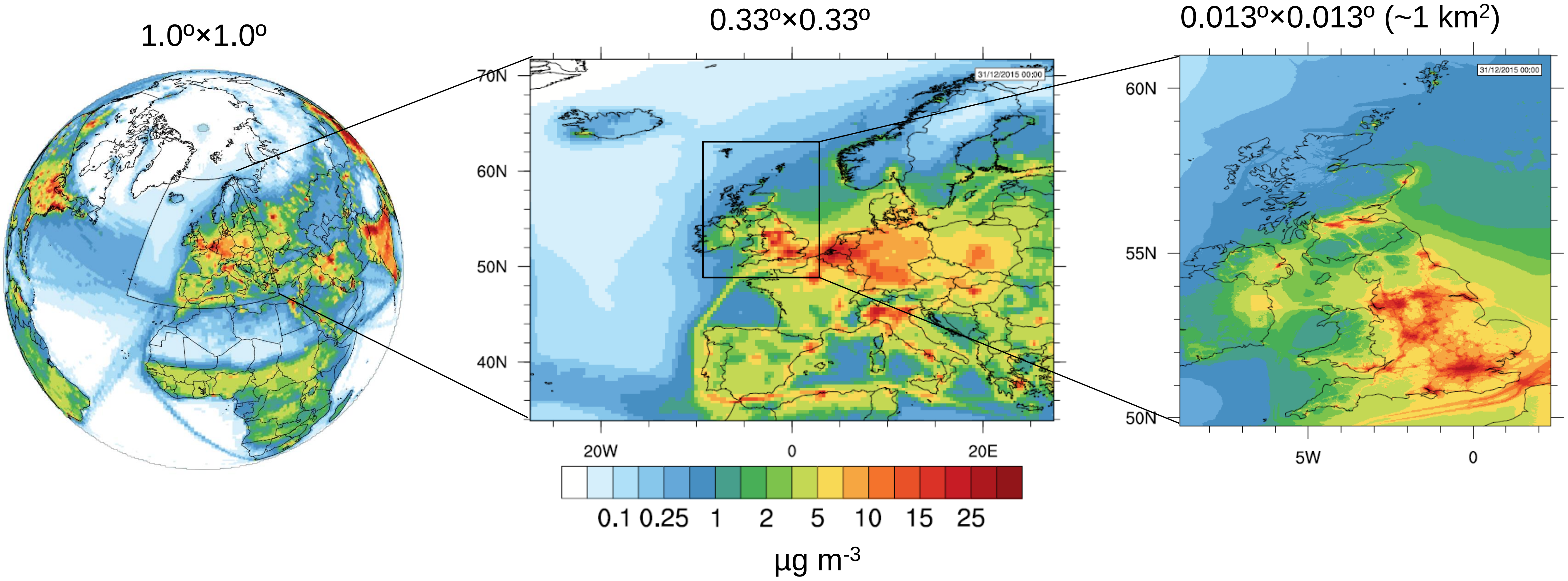
Example of model nesting setup – global to regional

2015 near surface concentration of NO_2



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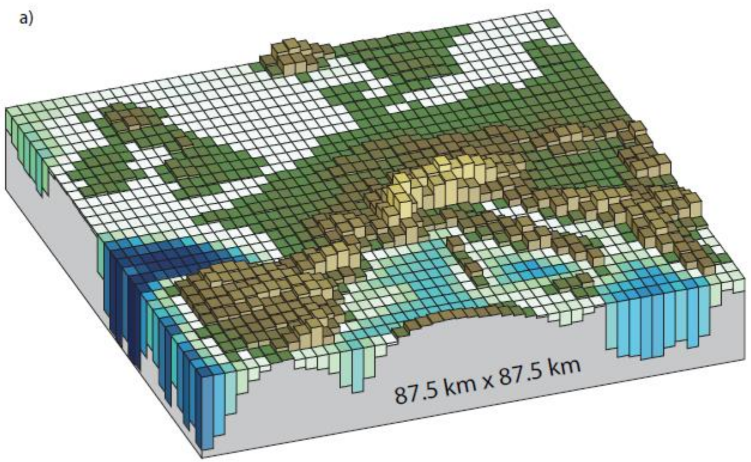
Atmospheric chemistry transport model – reality check

- ACTM models are a numerical approximation of the real world
- The real atmosphere, or part of it, is approximate by a 3D grid
- The left image show how models may approximates elevation



This chapter should be cited as:
Cubasch, U., D. Wuebbles, D. Chen, M.C. Facchini, D. Frame, N. Mahowald, and J.-G. Winther, 2013: Introduction. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

The Weather and Research Forecast model (WRF)

- Mostly I used the 3.9.1.1 version, but recently I updated to the latest 4.0.3 (EMEP works with either)
- WRF can calculate past meteorology and also forecast with nudging or without nudging
- I use the GFS-FNL for the historical and GFS for the forecast
- It is very flexible for the choices of horizontal and vertical domains with varying resolutions
- There is NOT a standard setup and many parameterizations and combinations can be chosen
- It require a relatively large computer (i.e. 100s CPUs)
- It can be temperamental with only “segmentation fault” as an error message

Let assume you had WRF compiled and ready to go…

Lots of help and documentation can be found in the WRF website…(www.wrf-model.org)

WPS setup (WRF pre-porcessor) – Global and nest South Asia

```
&share
 wrf_core = 'ARW',
 max_dom = 3,
 start_date = 'start_simulation', 'start_simulation', 'start_simulation',
 end_date   = 'end_simulation', 'end_simulation', 'end_simulation',
 interval_seconds = 21600,
 io_form_geogrid = 2,
 debug_level = 0,
/

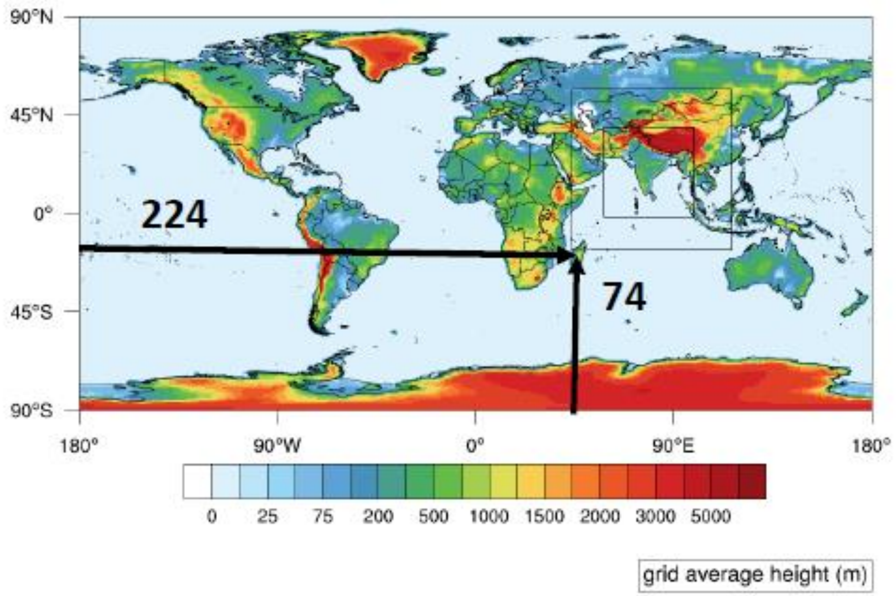
&geogrid
 parent_id         = 1,1,2,
 parent_grid_ratio = 1,3,3,
 i_parent_start    = 1,224,45,
 j_parent_start    = 1,74,45,
 e_we          = 360,220,370,
 e_sn          = 180,220,370,
 geog_data_res     = 'nesdis_greenfrac+default','nesdis_greenfrac+default','nesdis_greenfrac+default',
 geog_data_path = '/air_models/home/mvi/WRF/WRF4.0.3/WPS_GEOG/',
 map_proj =  'lat-lon',
 stand_lon = 180.0,
 pole_lat = 90.0,
 pole_lon = 0.0,
/

geog_data_res = 'default','default','default',

&ungrib
 out_format = 'WPS',
 prefix = 'FILE',
/

&metgrid
 fg_name = 'FILE',
 io_form_metgrid = 2,
/

&mod_levs
 /
```



This domain will set automatically the EMEP model domain too

WRF model domain setup – Global and nest South Asia

namelist.input

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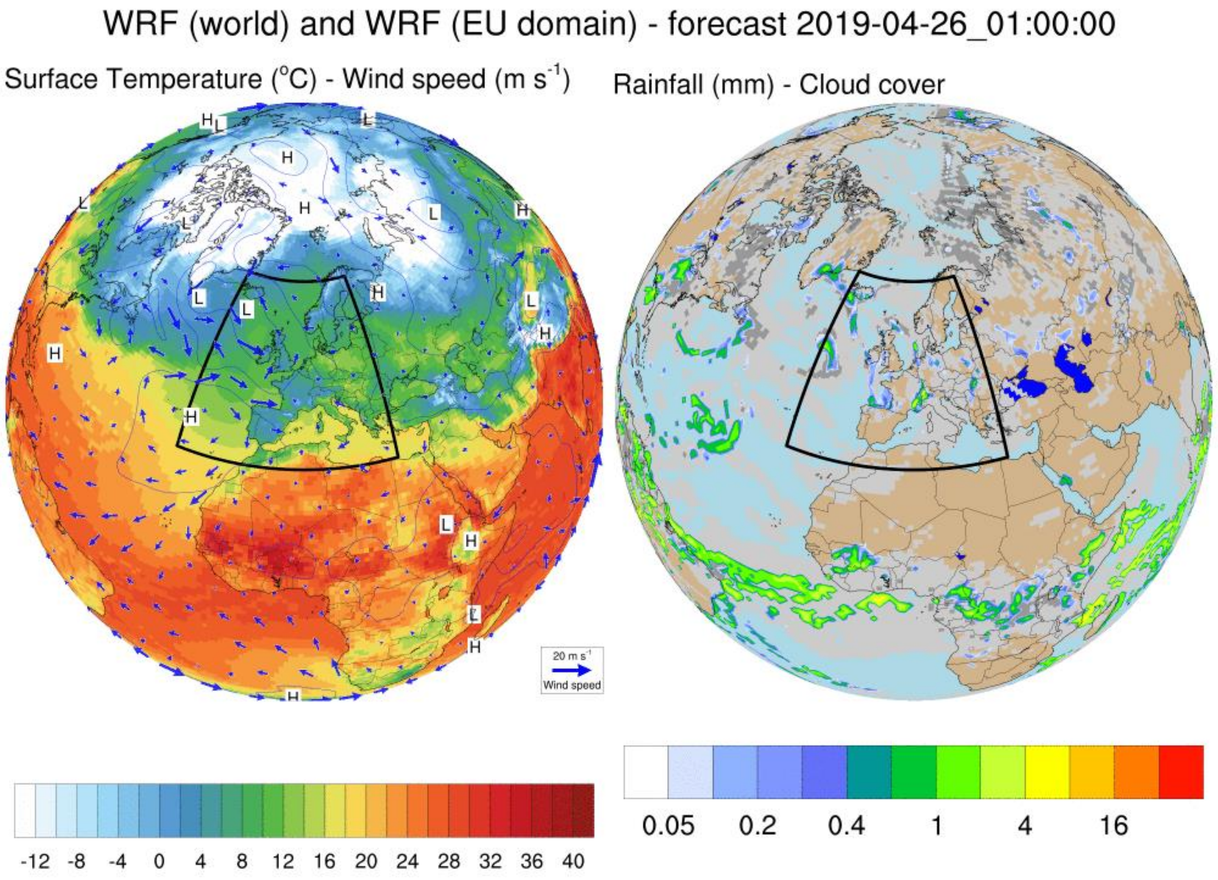
&time_control
run_days                            = 365,
run_hours                           = 0,
run_minutes                         = 0,
run_seconds                         = 0,
start_year                          = 2015,2015,2015,2015,2015,2015,
start_month                         = 01,01,01,01,01,01,
start_day                           = 01,01,01,01,01,01,
start_hour                          = 00,   00,   00,
start_minute                        = 00,   00,   00,
start_second                        = 00,   00,   00,
end_year                            = 2016,2016,2016,2016,2016,2016,
end_month                           = 01,01,01,01,01,01,
end_day                             = 01,01,01,01,01,01,
end_hour                            = 00,   00,   00,
end_minute                          = 00,   00,   00,
end_second                          = 00,   00,   00,
interval_seconds                    = 21600
input_from_file                     = .true.,.true.,.true.,
history_interval                    = 60,60,60,
frames_per_outfile                  = 24,24,24,
restart                             = .false.,
restart_interval                    = 14400,
write_hist_at_0h_rst                = .true.,
override_restart_timers             = .true.,
io_form_history                     = 2
io_form_restart                     = 2
io_form_input                       = 2
io_form_boundary                    = 2
debug_level                         = 1
/

&domains
time_step                           = 360,
max_dom                             = 3,
e_we                                = 360,220,370,
e_sn                                = 180,220,370,
e_vert                              = 22,22,22,
i_parent_start                      = 1,224,45,
j_parent_start                      = 1,74,45,
dx                                  = 111487.2, 37162.39,  12387.46,
dy                                  = 111798.6, 37266.19,  12422.06,
grid_id                             = 1,     2,     3,
parent_id                           = 1,     1,     2,
parent_grid_ratio                   = 1,     3,     3,
parent_time_step_ratio              = 1,     3,     6,
feedback                            = 0,
num_metgrid_levels                  = 27,
eta_levels                          = 1.000, 0.993,0.988, 0.976, 0.958, 0.933,
                                      0.901, 0.862, 0.816, 0.763, 0.703,
                                      0.636, 0.562, 0.481, 0.392, 0.302,
                                      0.225, 0.165, 0.120, 0.080, 0.040,
                                      0.000,
p_top_requested                     = 10000,
/

&physics
mp_physics                          = 3,     3,     3,
ra_lw_physics                       = 4,     4,     4,
ra_sw_physics                       = 4,     4,     4,
radt                                = 30,    30,    30,
sf_sfclay_physics                   = 1,     1,     1,
sf_surface_physics                  = 2,     2,     2,
bl_pbl_physics                      = 1,     1,     1,
bldt                                = 0,     0,     0,
cu_physics                          = 16,   16,     0,
cudt                                = 0,     0,     0,
icloud                              = 1,
num_land_cat                        = 21,
/
```

```
&fdda
grid_fdda                           = 1,      1,      1,
gfdda_inname                        = "wrffdda_d<domain>",
gfdda_end_h                         = 8760,  8760,    8760,
gfdda_interval_m                    = 360,   360,   360,
fgdt                                = 0,      0,      0,
if_no_pbl_nudging_uv                = 0,      0,      0,
if_no_pbl_nudging_t                 = 0,      0,      0,
if_no_pbl_nudging_q                 = 0,      0,      0,
if_zfac_uv                          = 0,      0,      0,
 k_zfac_uv                          = 10,   10,    10,
if_zfac_t                           = 0,      0,      0,
 k_zfac_t                           = 10,   10,    10,
if_zfac_q                           = 0,      0,      0,
 k_zfac_q                           = 10,   10,    10,
guv                                 = 0.0003,     0.0003,  0.0003,
gt                                  = 0.0003,     0.0003,  0.0003,
gq                                  = 0.0,     0.0,   0.0,
if_ramping                          = 1,
dtramp_min                          = 60.0,
io_form_gfdda                       = 2,
/
```

WRF model runs for a Global + European nested domain



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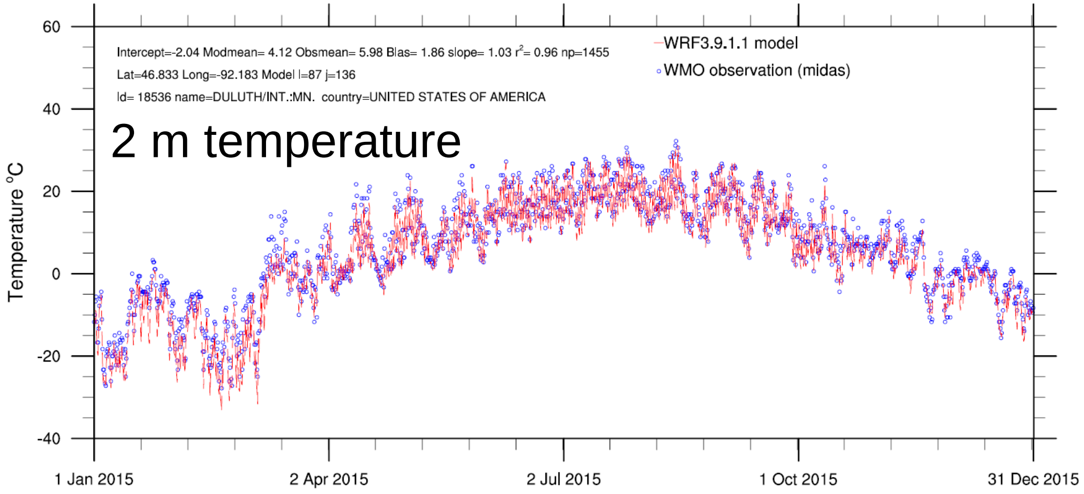
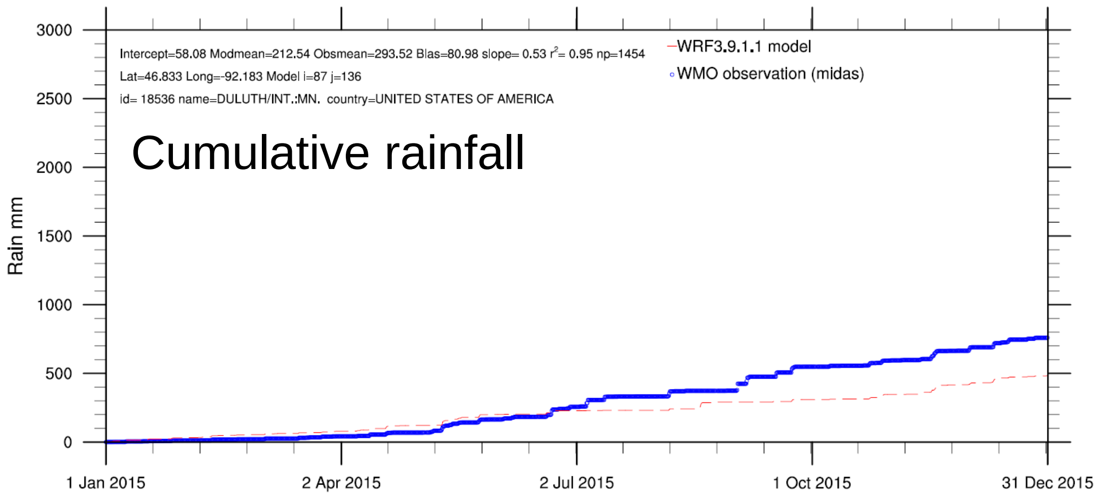
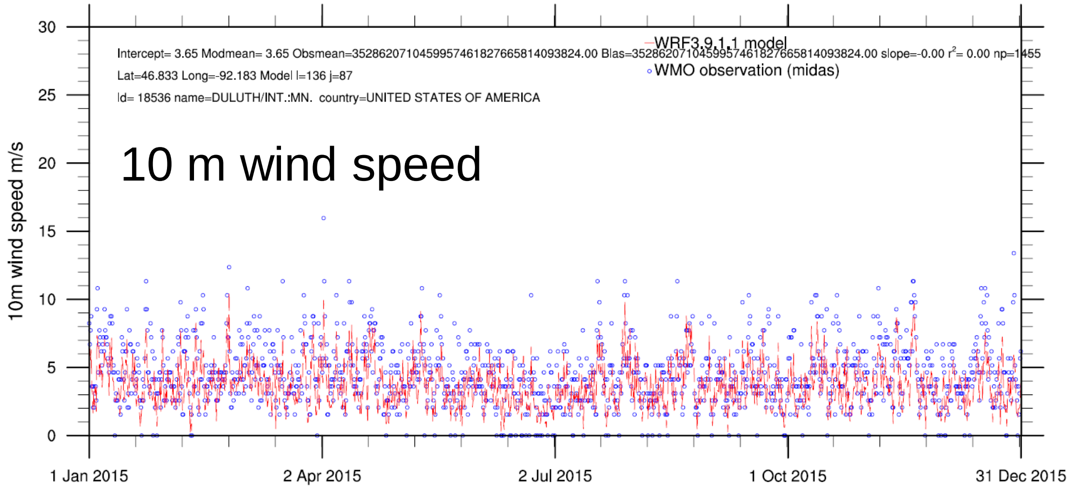
WRF vs WMO evaluation

DULUTH site USA

- WRF 3.9.1.1
- 1º×1º horizontal resolution
- GLOBAL domain





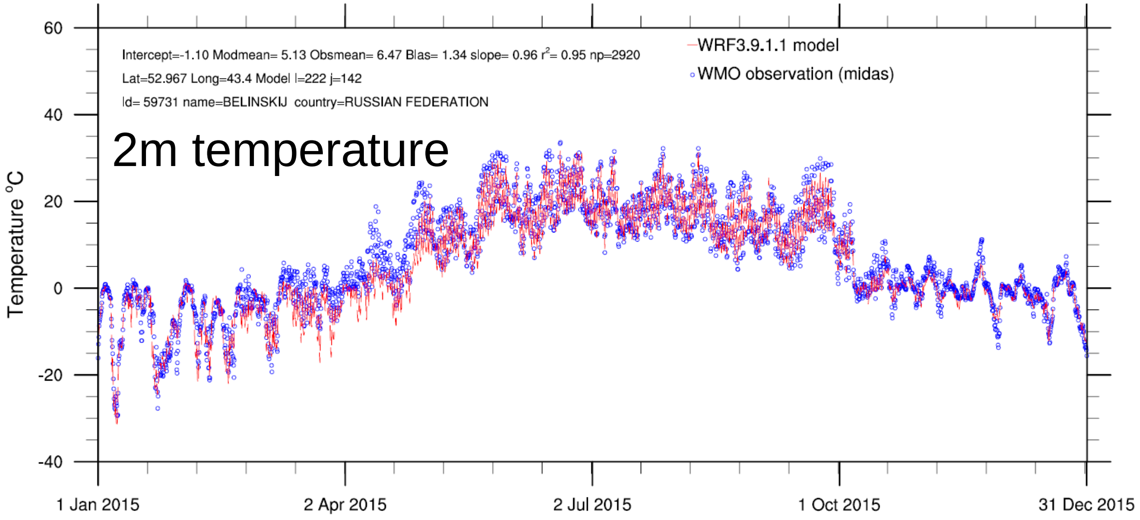


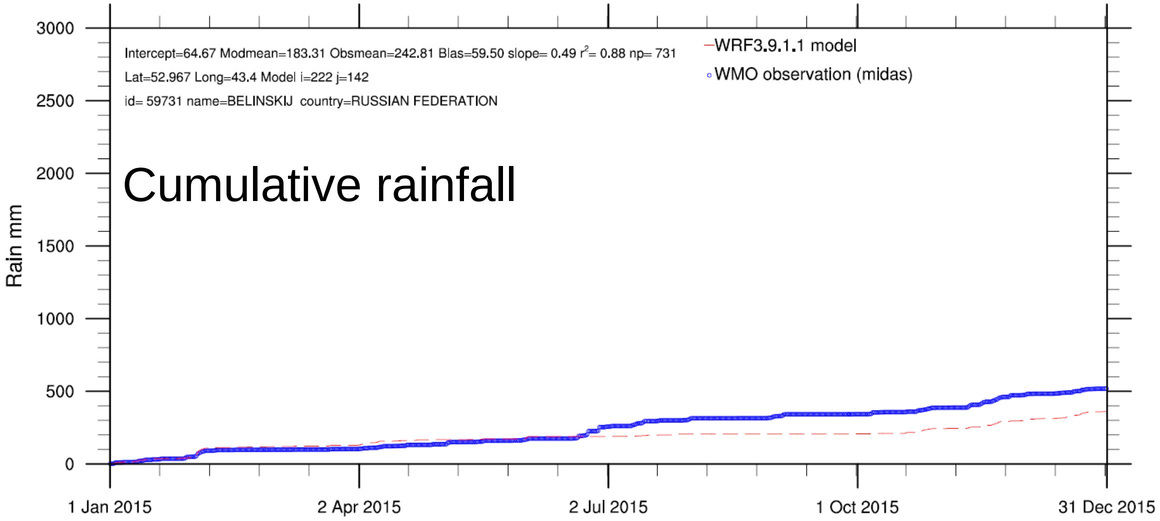
WRF vs WMO evaluation

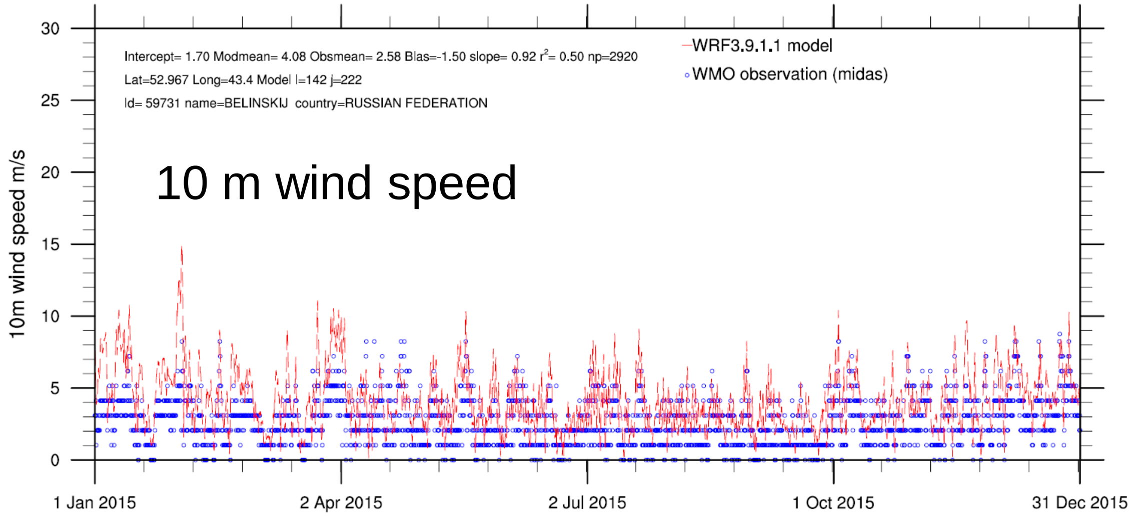
BELINSKIJ site RUSSIAN FEDERATION

Cumulative rainfall

- WRF 3.9.1.1
- 1º× 1º horizontal resolution
- GLOBAL domain





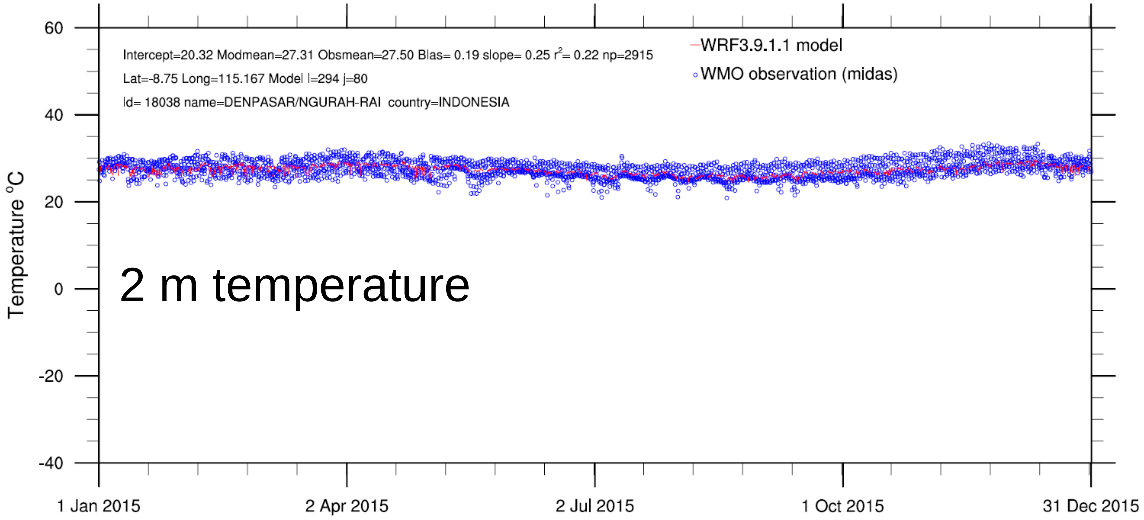


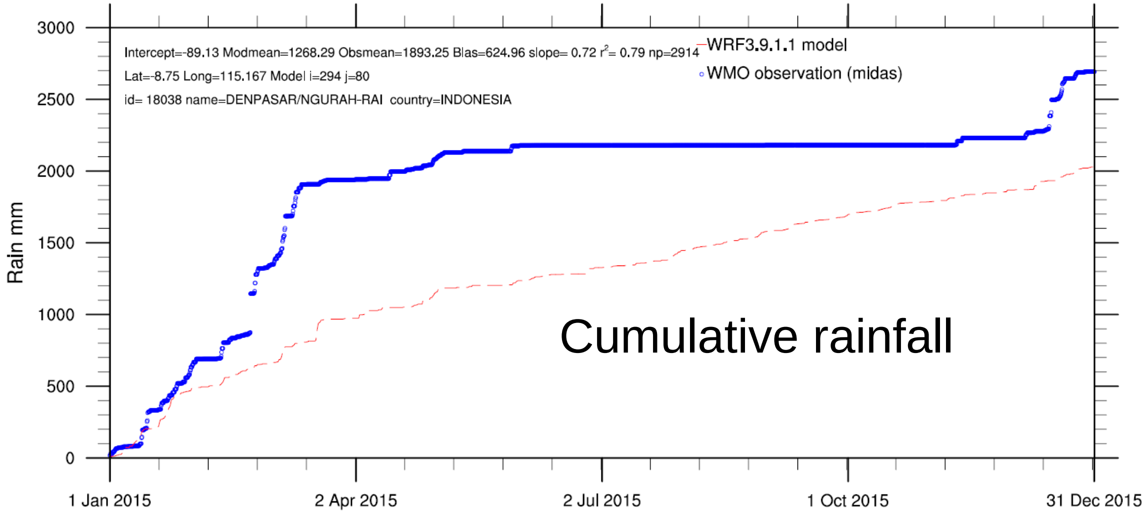
WRF vs WMO evaluation

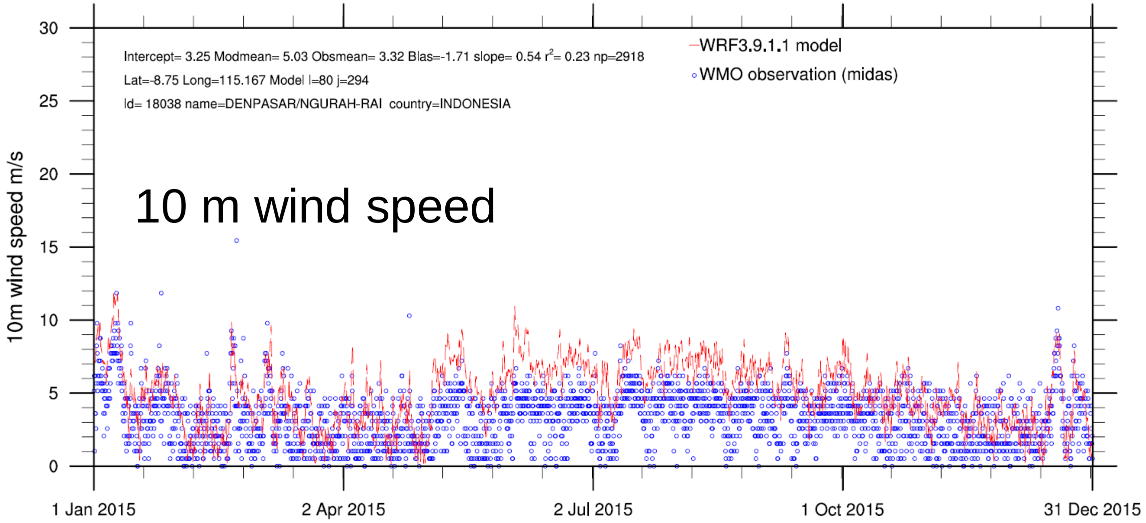
INDIA site (BIJAPUR)

Cumulative rainfall

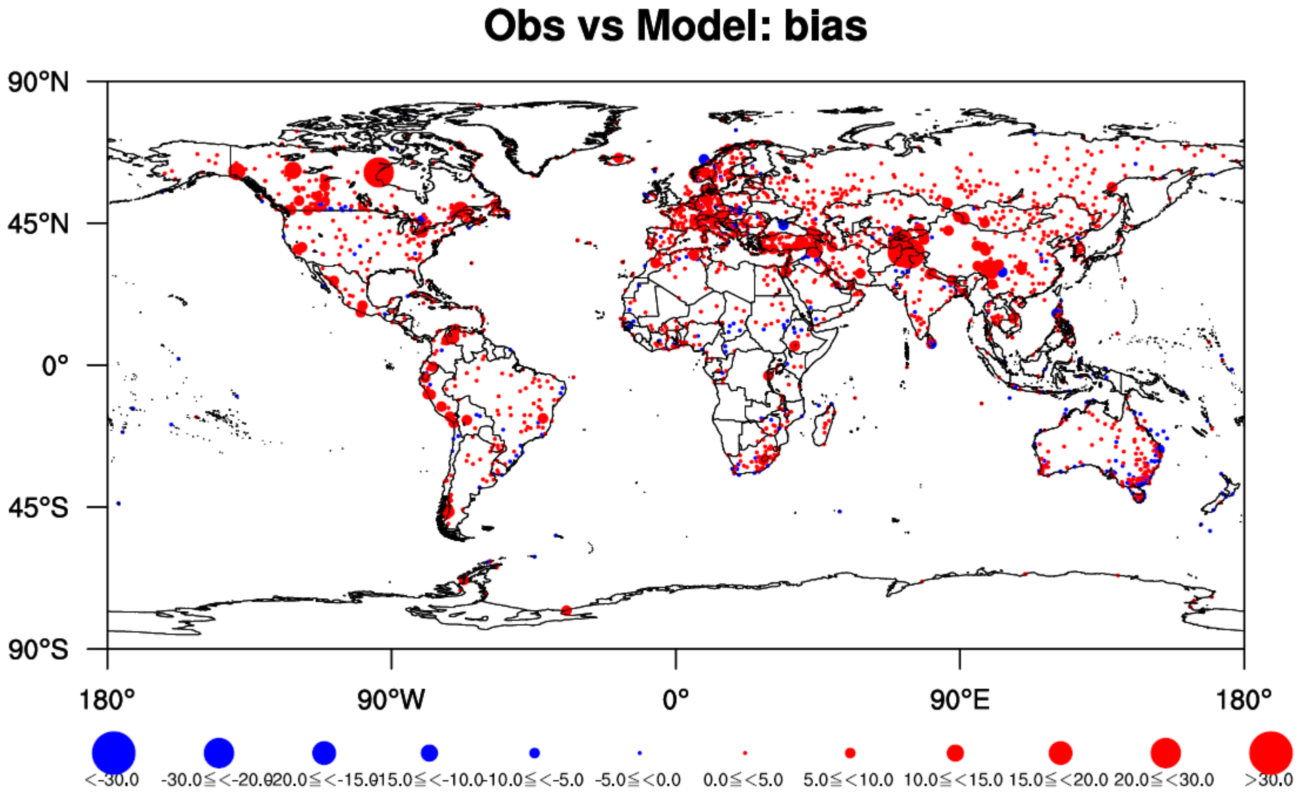
- WRF 3.9.1.1
- 1º× 1º horizontal resolution
- GLOBAL domain







WRF vs WMO evaluation summary



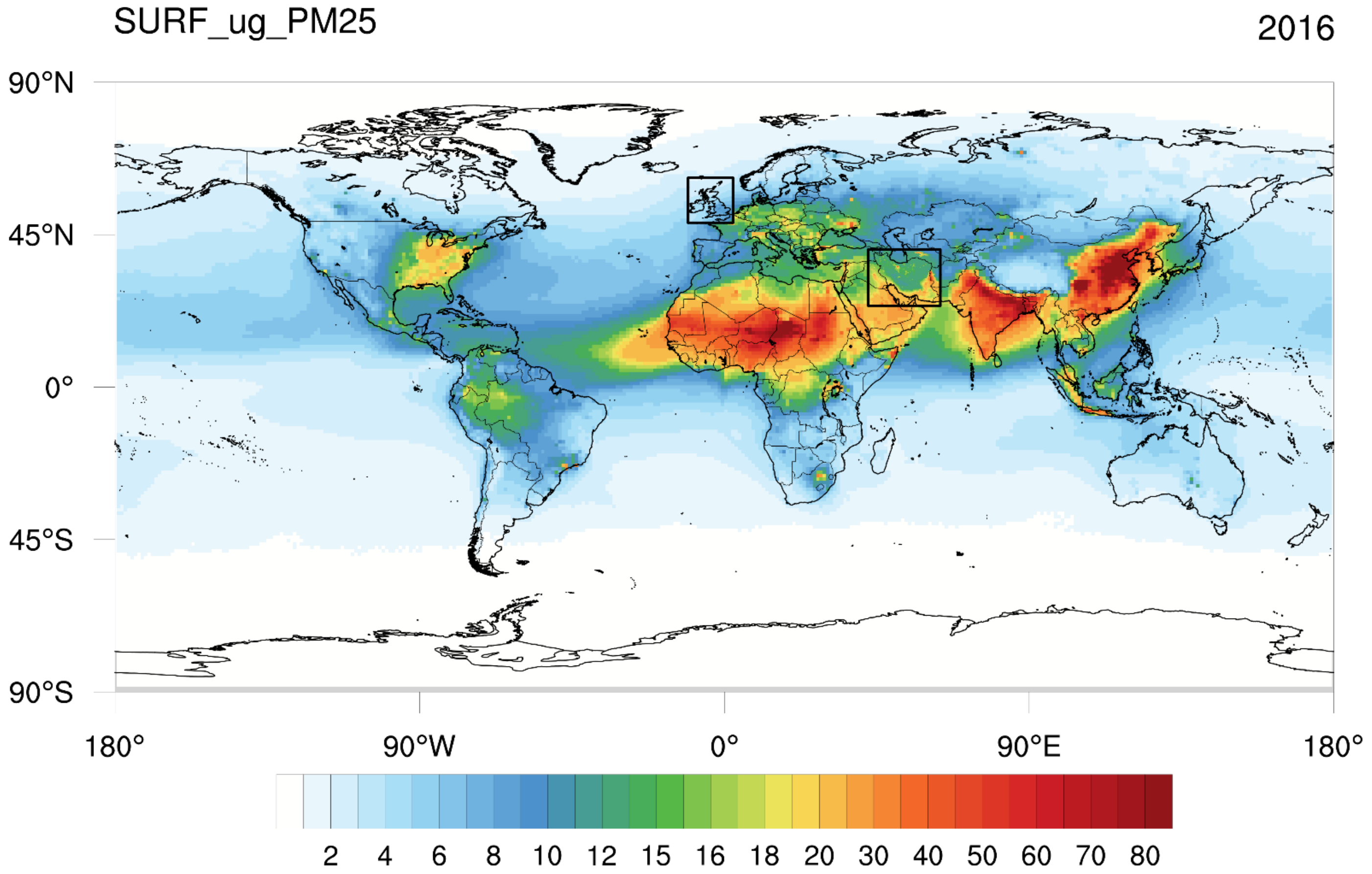
- Mountain terrain at coarse resolution underestimate the elevation and therefore overestimate the temperature
- Coast sites where the dominant land category is sea the modelled temperature is effectively the sea surface temperature
- Different surface scheme, micro physics, and cumulus schemes may have a different performances

The global EMEP-WRF can be applied everywhere on Earth

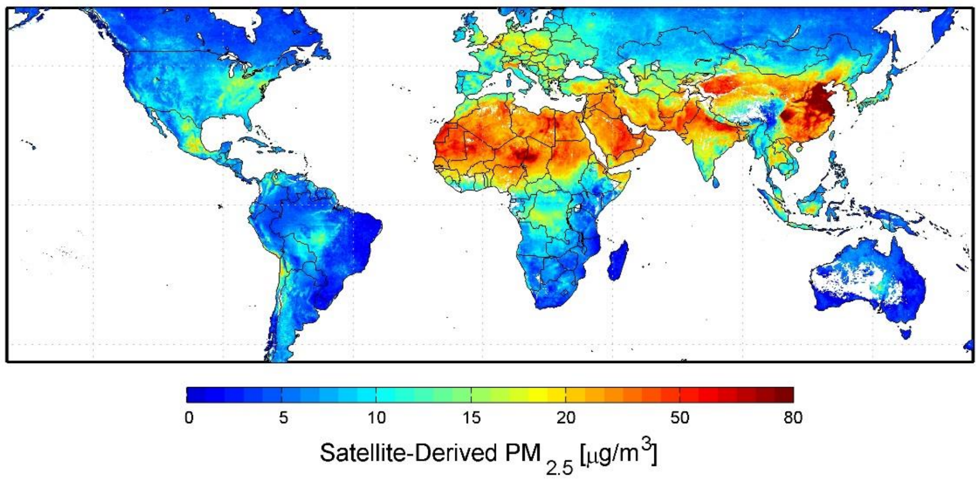
Some application of the EMEP-WRF model

- Regional applications in South Asia (as in the example), Africa, Brazil, China and India
- UK application for specific events
- EU and UK WRF and EMEP-WRF Forecast

EMEP-WRF global spatial distribution of $PM_{2.5}$



Global satellite-derived map of $PM_{2.5}$ averaged over 2001-2006.
Credit: Dalhousie University, Aaron van Donkelaar



https://www.nasa.gov/topics/earth/features/health-sapping.html

Global scale EMEP model results based on 2010 HTAP v2 emissions and 2016 meteorology, compared to earth observations averaged over 2001-2006 for fine particulate matter ($PM_{2.5}$).

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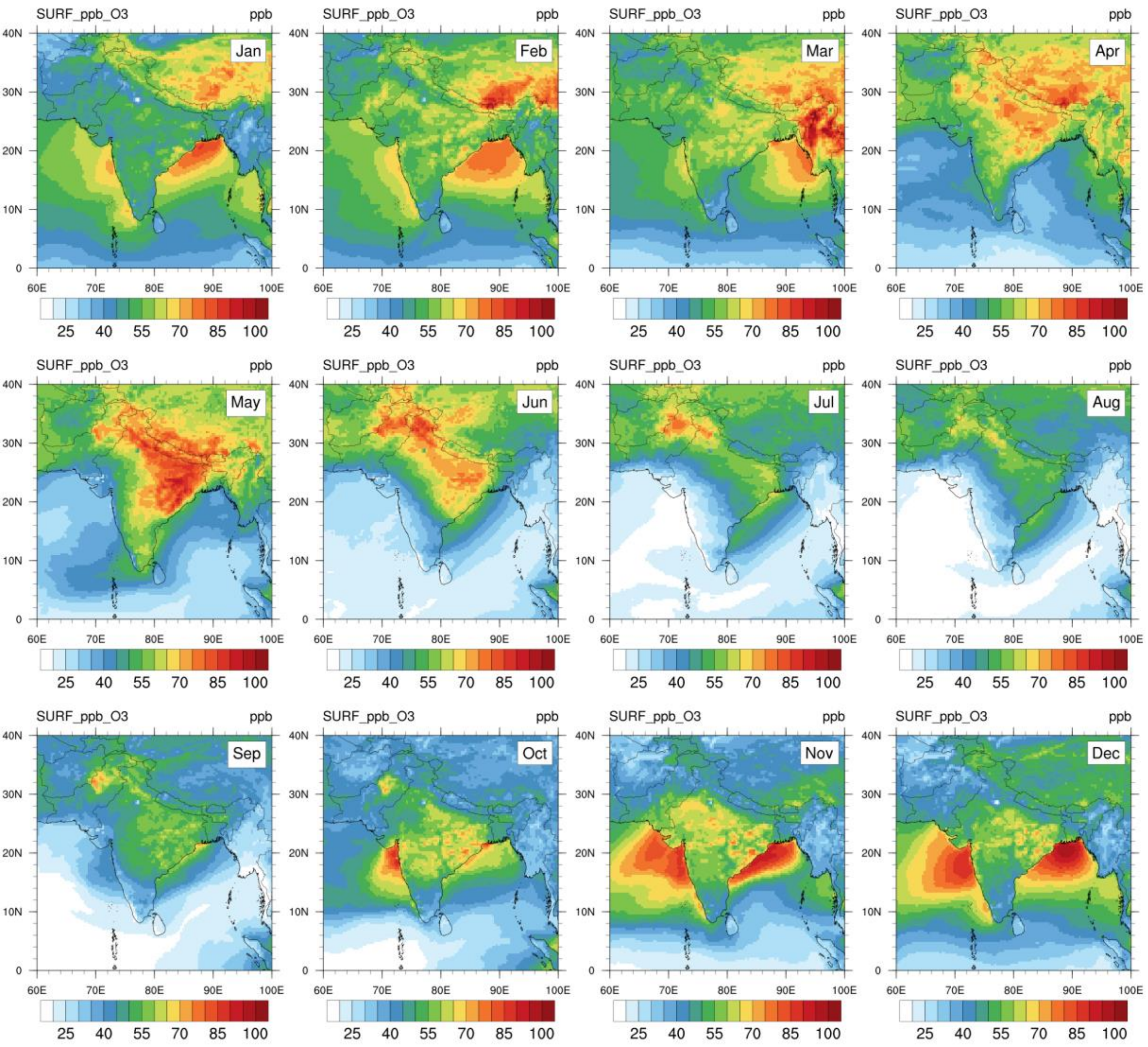
Monthly EMEP-WRF model results (WRF setup example)

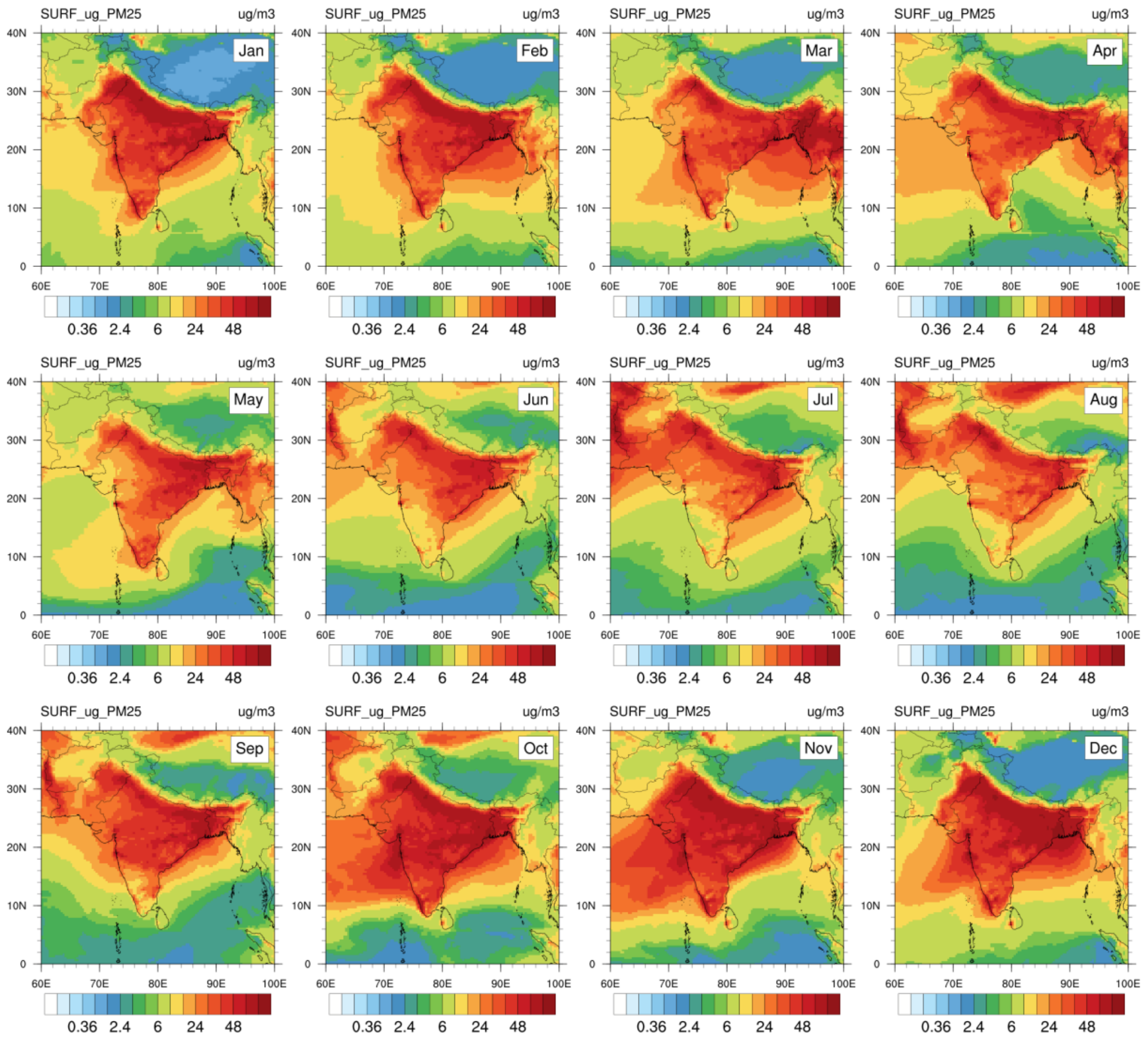
Ozone

EMEP-WRF global (rv4.17) - WRF (4.0.3) 2015

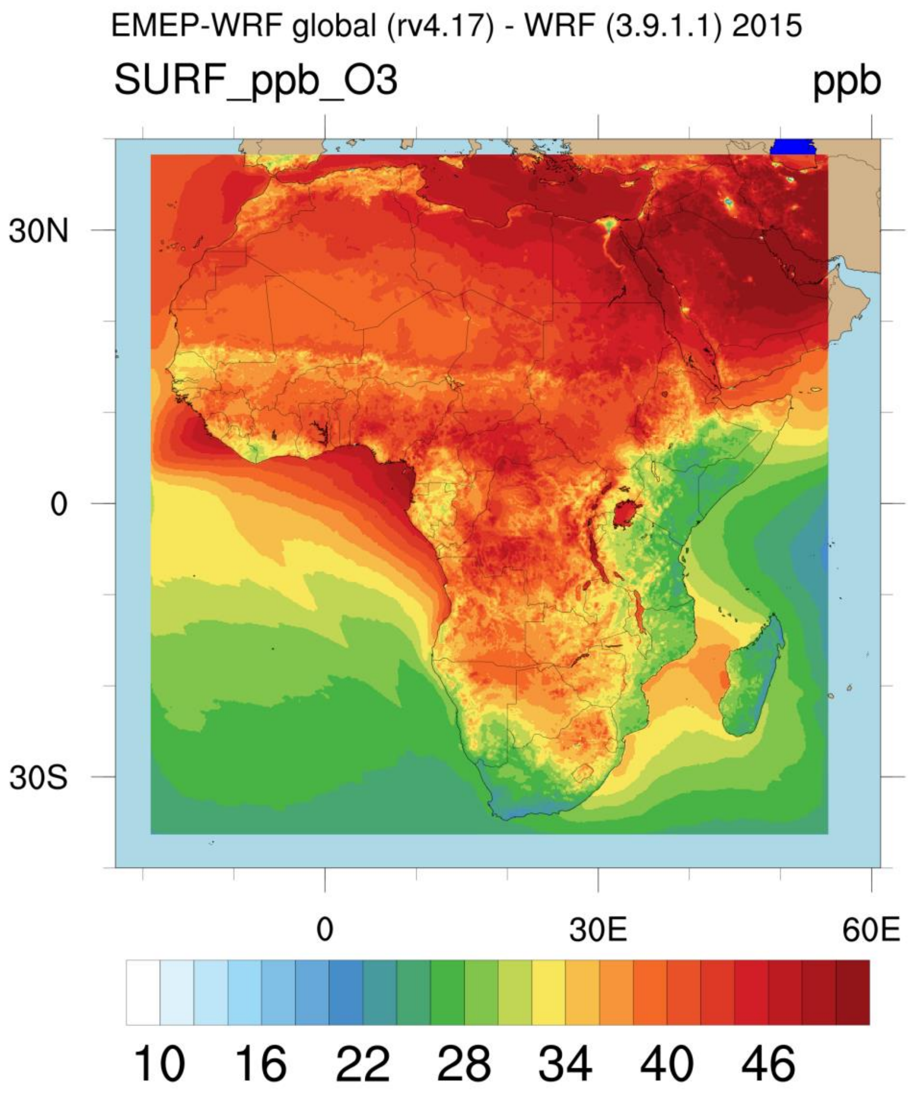


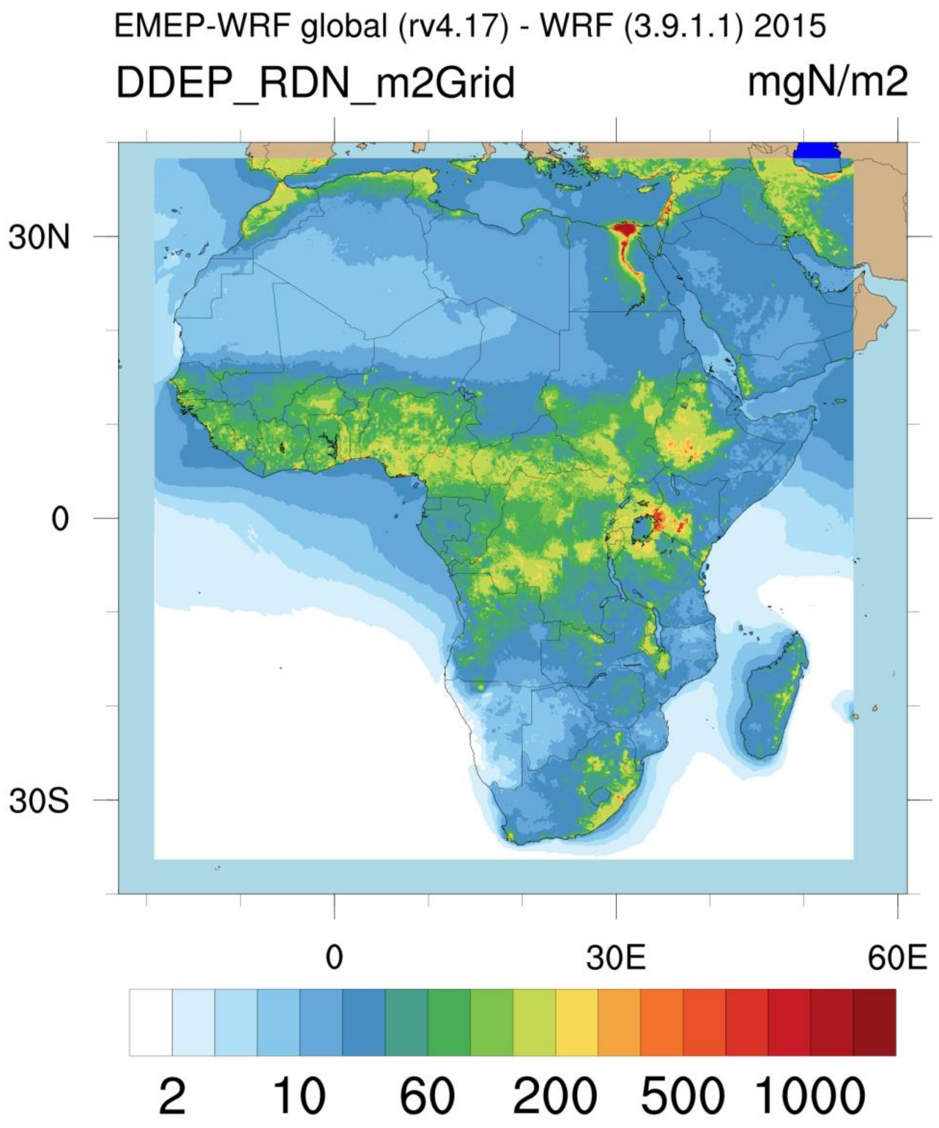
$PM_{2.5}$

EMEP-WRF global (rv4.17) - WRF (4.0.3) 2015



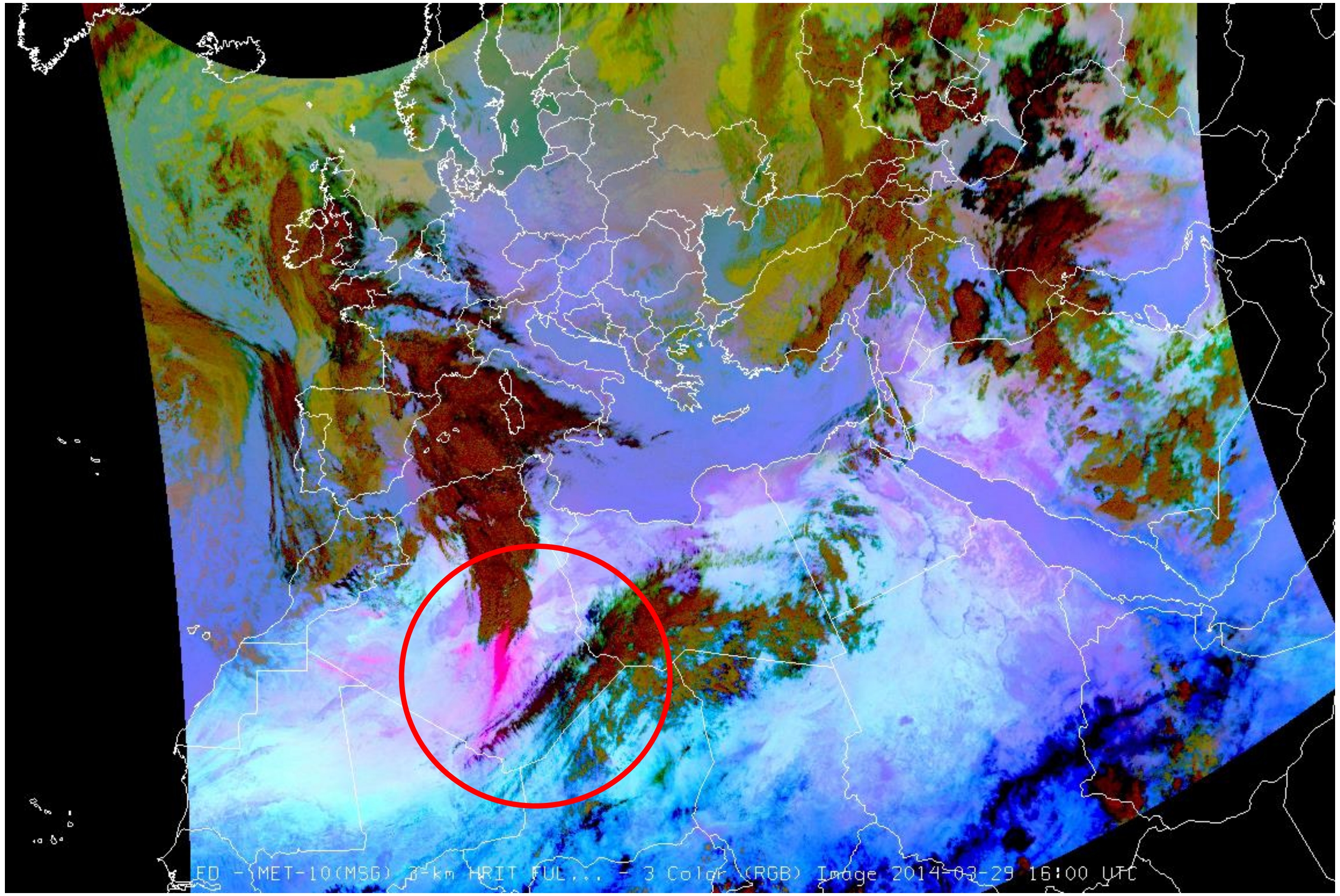
Regional EMEP-WRF Africa 0.1°x0.1°





PM episode in the spring of 2014 EU and UK

2014/03/29
UK Met Office



Saharan dust show in magenta

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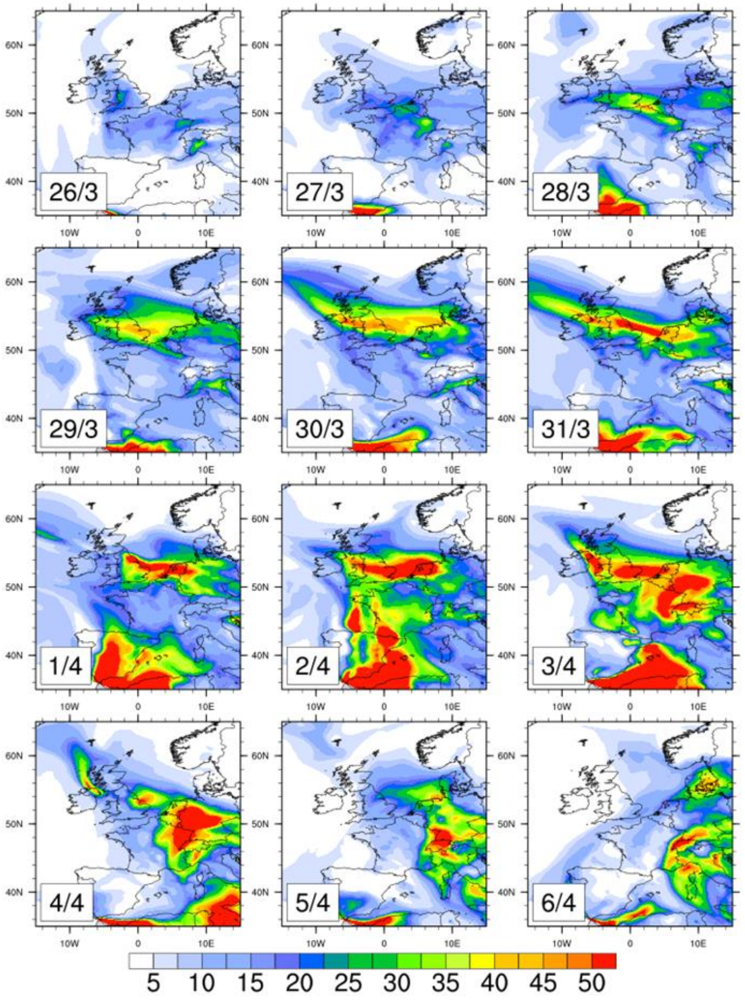
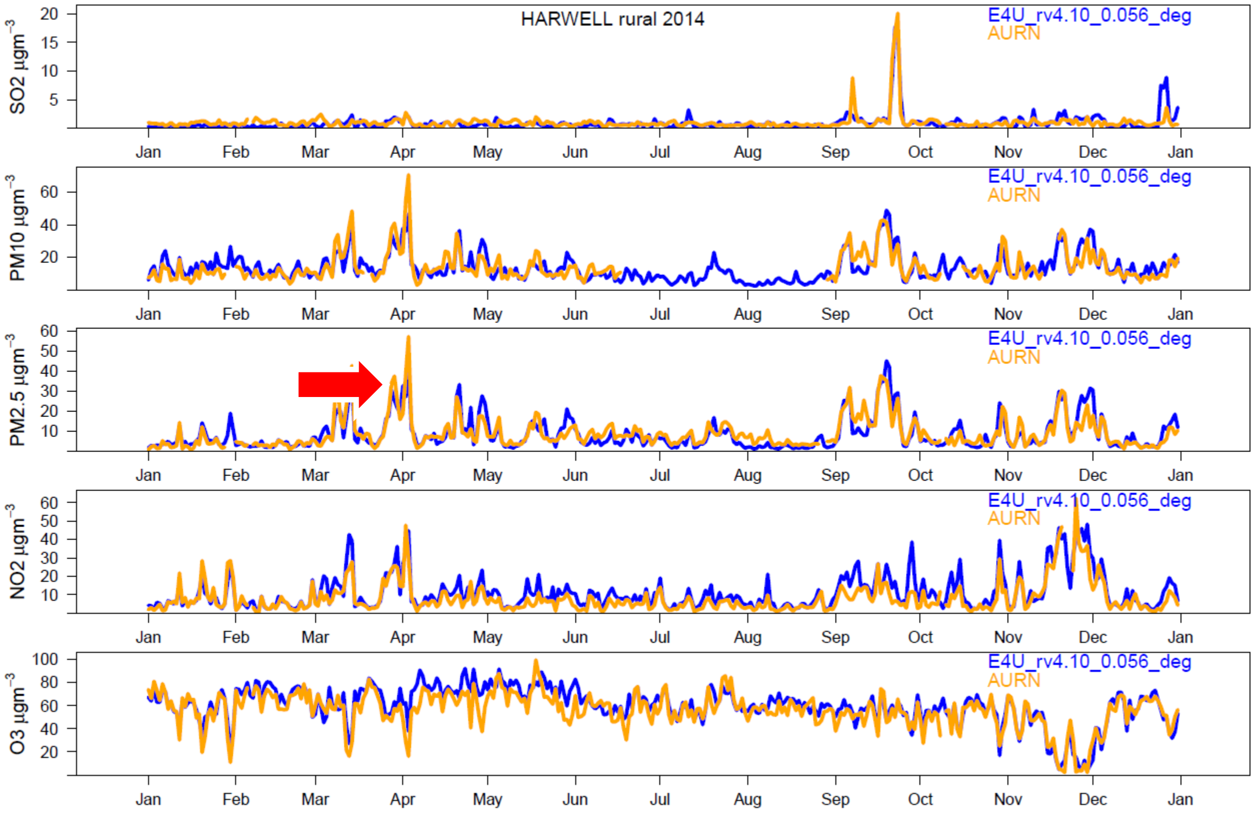
2014 was a busy UK "air pollution year"

Daily $PM_{2.5}$ μgm^{-3}

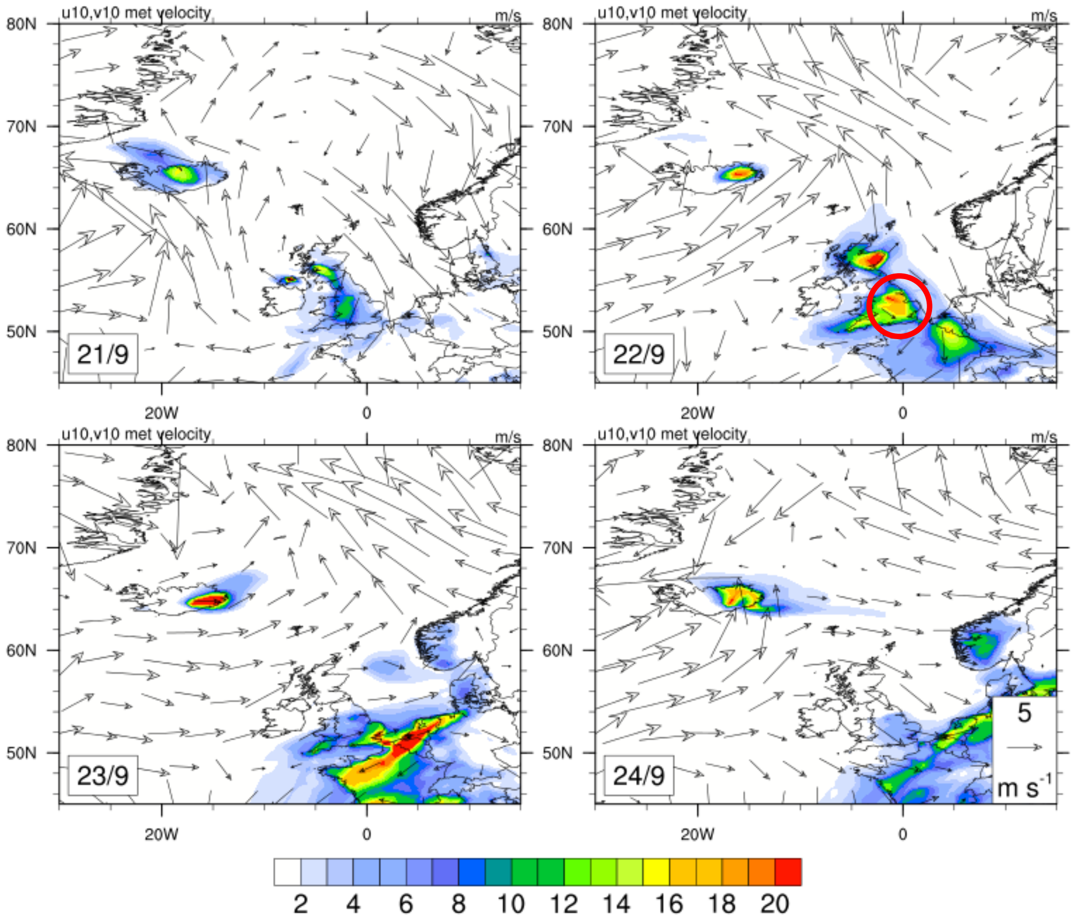


Harwell monitoring site in south England – daily mean

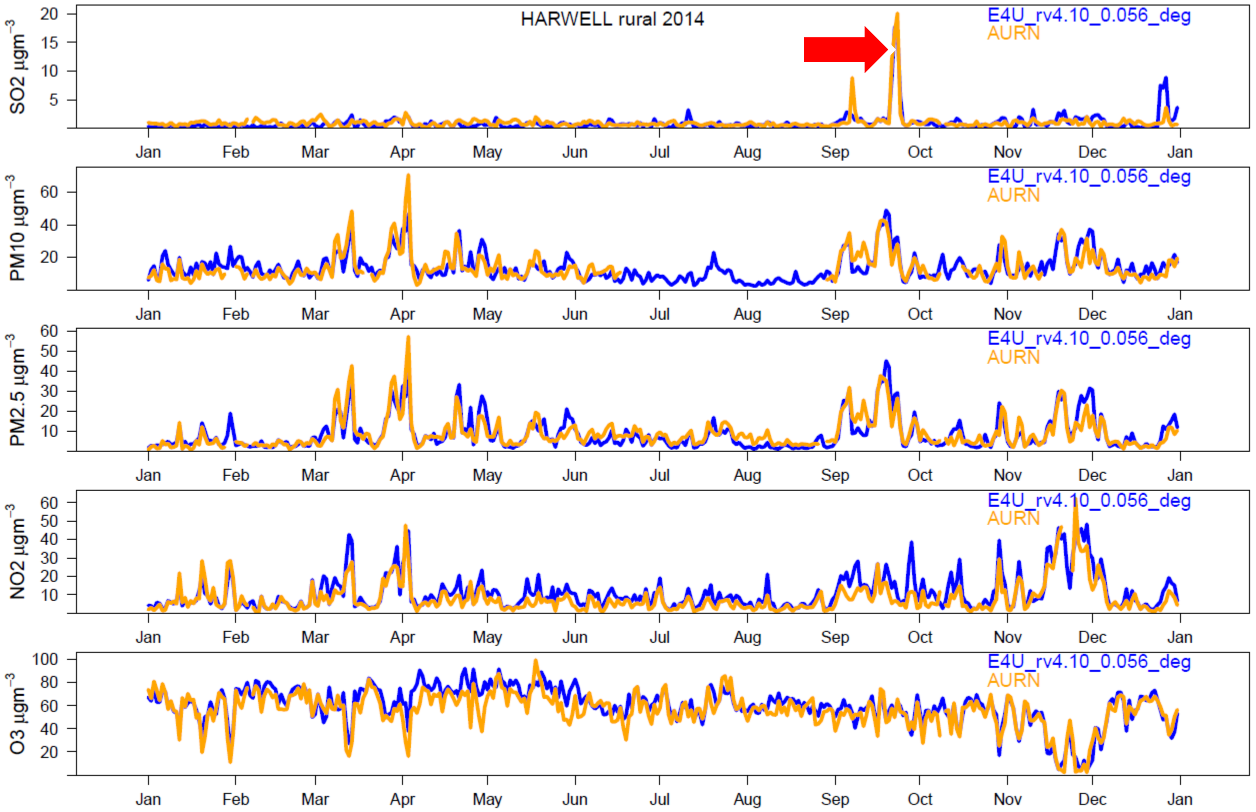


Vieno, M., Heal, M. R., Twigg, M. M., MacKenzie, I. A., Braban, C. F., Lingard, J. J. N., Ritchie, S., Beck, R. C., Móring, A., Ots, R., Marco, C. F. D., Nemitz, E., Sutton, M. A., and Reis, S.: The UK particulate matter air pollution episode of march–april 2014: More than saharan dust, Environmental Research Letters, 11, 044004, 2016.

2014 was a busy UK "air pollution year"



Harwell monitoring site in south England – daily mean



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Twigg, M. M., Ilyinskaya, E., Beccaceci, S., Green, D. C., Jones, M. R., Langford, B., Leeson, S. R., Lingard, J. J. N., Pereira, G. M., Carter, H., Poskitt, J., Richter, A., Ritchie, S., Simmons, I., Smith, R. I., Tang, Y. S., Van Dijk, N., Vincent, K., Nemitz, E., Vieno, M., and Braban, C. F.: Impacts of the 2014–2015 holuhraun eruption on the UK atmosphere, Atmos. Chem. Phys., 16, 11415-11431, 10.5194/acp-16-11415-2016, 2016.

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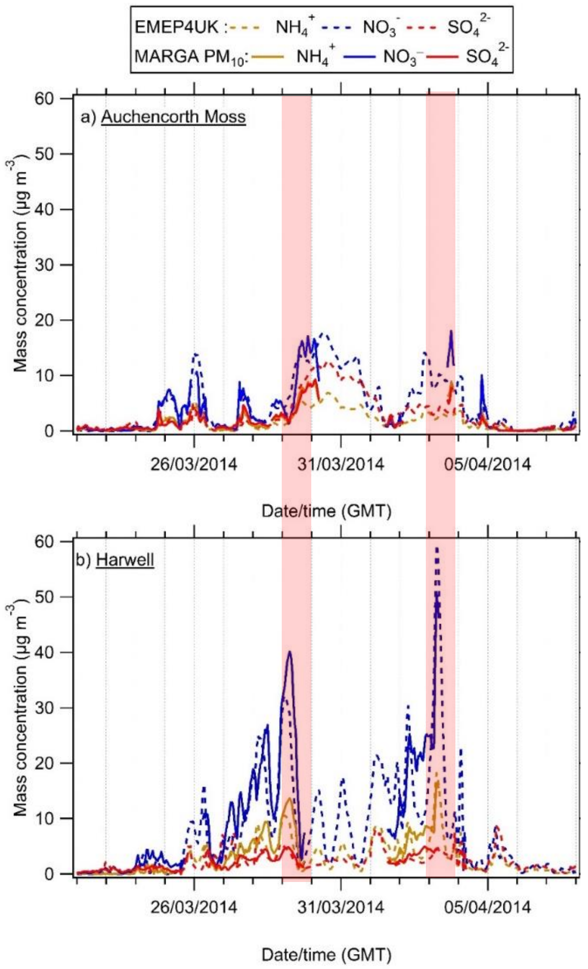
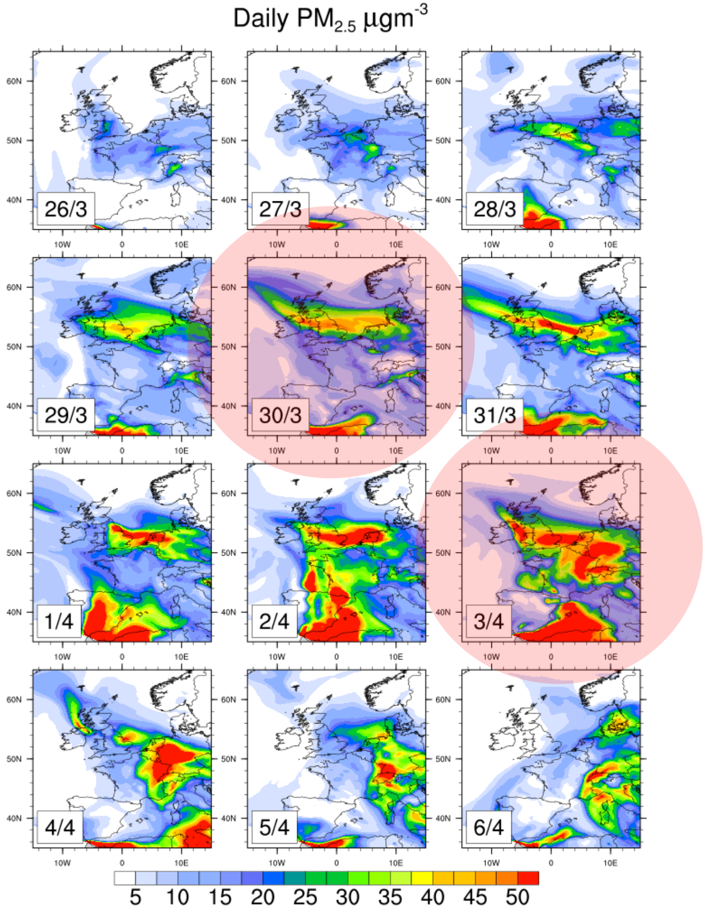
Reactive nitrogen is the cause of the elevated PM in the UK





- The speciated PM2.5 from the MARGA instrument shows a large component of Ammonium nitrate in the plume at two different sites in the UK
- Ammonium nitrate was formed in continental EU by the interaction of ammonia (mainly from agricultural) and nitrogen oxidised (traffic and industry) then advected to the UK
- Saharan dust was a small component to the UK episode but more relevant to continental EU
- Ammonia is a key precursor of UK particulate matter
- Reactive nitrogen have a long range impact

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Interestingly there was evidence of substantial dust washed out by rain in the UK

London smog warning as Saharan sand sweeps southern England

Strong winds and desert storms deposit fine dust on UK streets amid fears of high air pollution levels in capital

▲ The prime minister's car covered in fine dust outside No 10 on Tuesday morning after overnight showers. Photograph: Steve Back politicalpictures.co.uk

The Met Office has forecast one of the year's worst smogs in London this week, following a combination of strong winds and powerful dust storms in the Sahara that has deposited fine red dust on the streets of southern England.

Cars in London, including the prime minister's outside 10 Downing Street

Guardian, 01 April 2014

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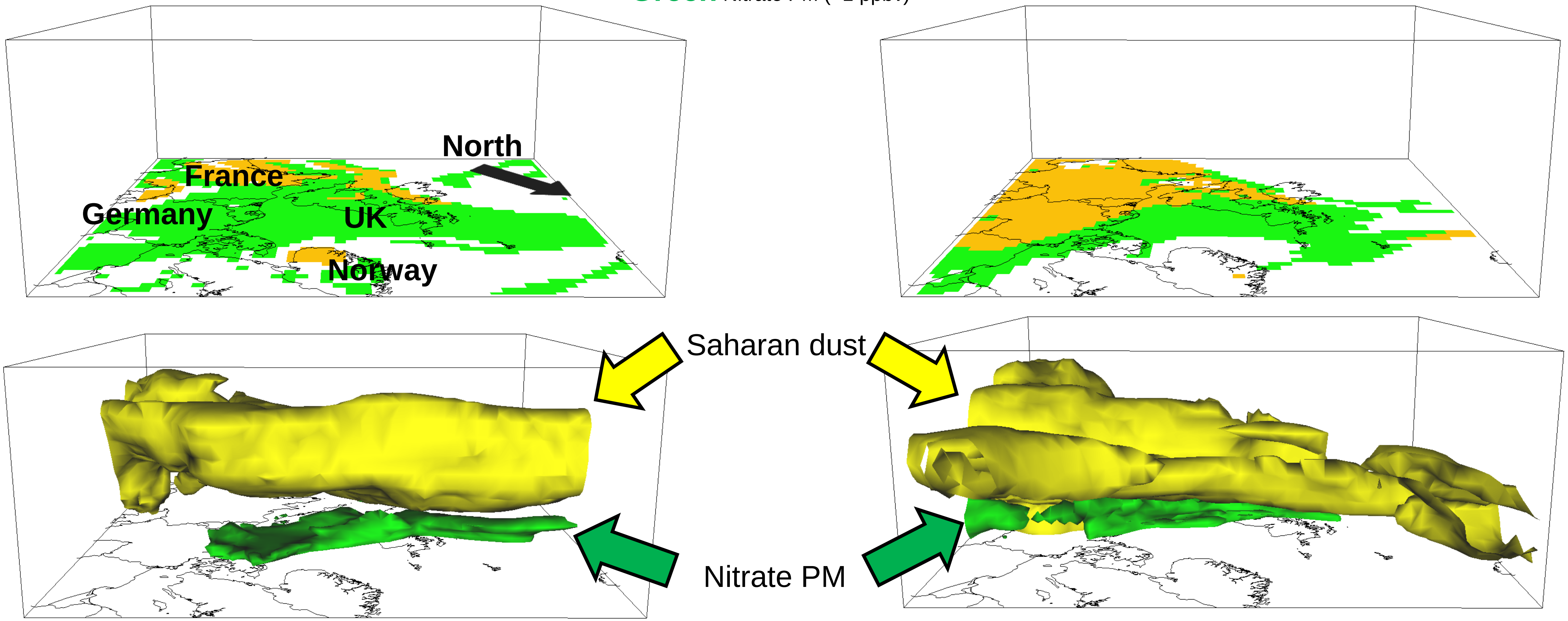
The model results shows a very complex dust vertical structure

12:00 on the 30th March 2014

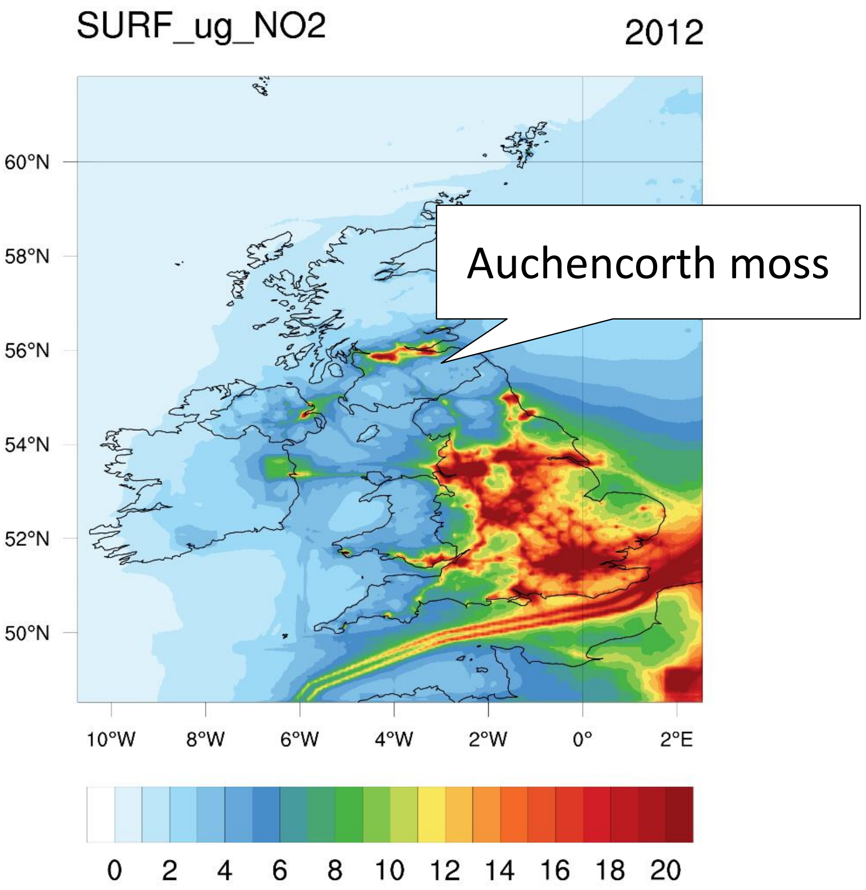
Yellow Saharan dust (>1 ppbv)
Green Nitrate PM (>1 ppbv)

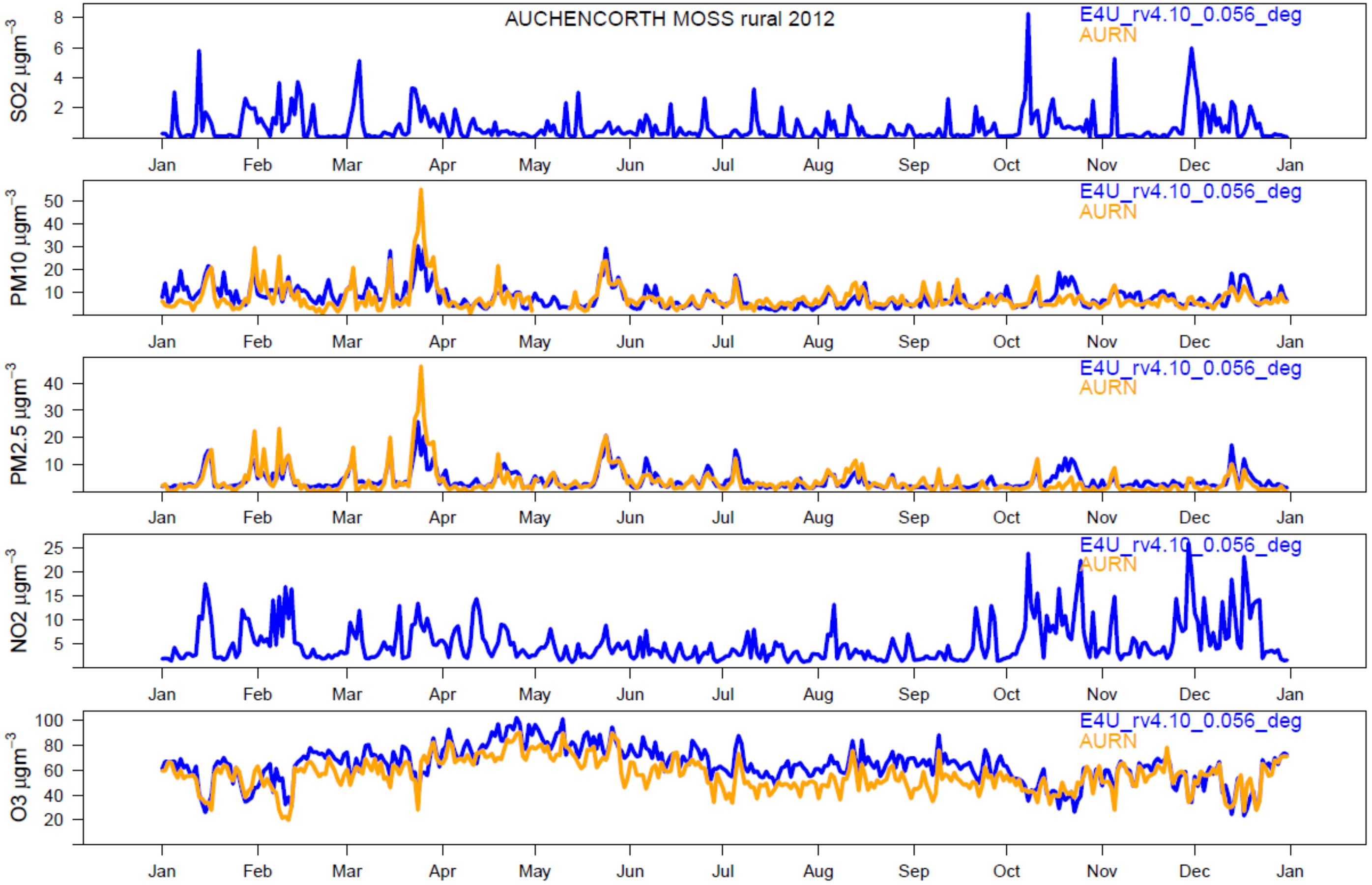
12:00 on the 4th April 2014



3D iso-surface
(5 ppbv)
Aerosol_concentrations = VMR * rho * Mw(aerosol) / Mw(air) * 1e9

EMEP4UK 2012 daily mean vs AURN





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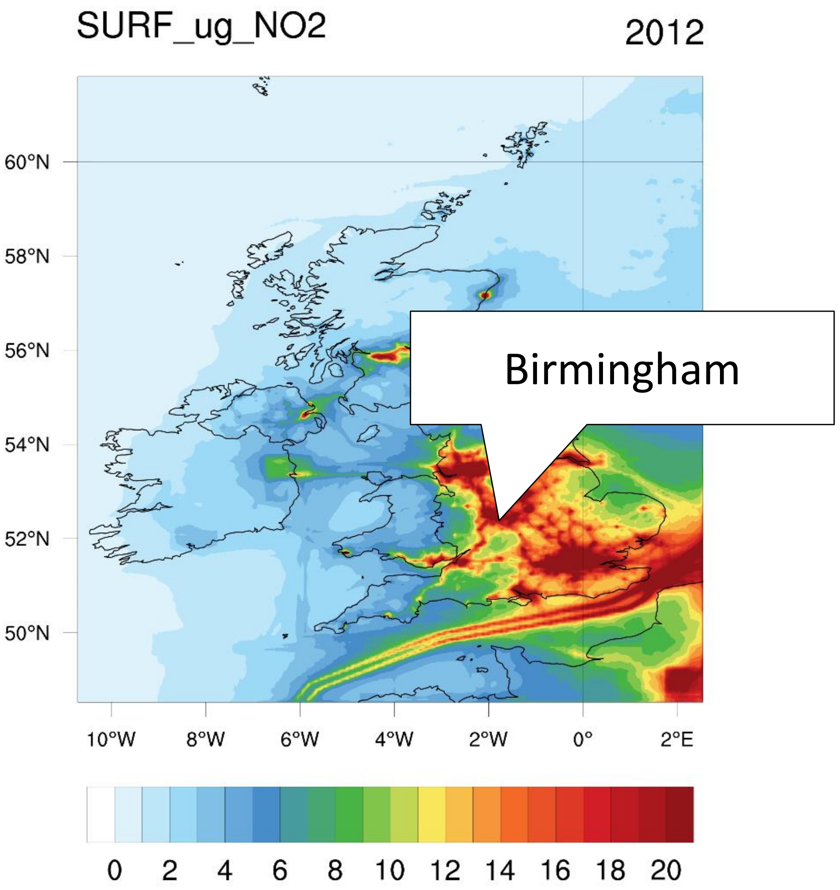
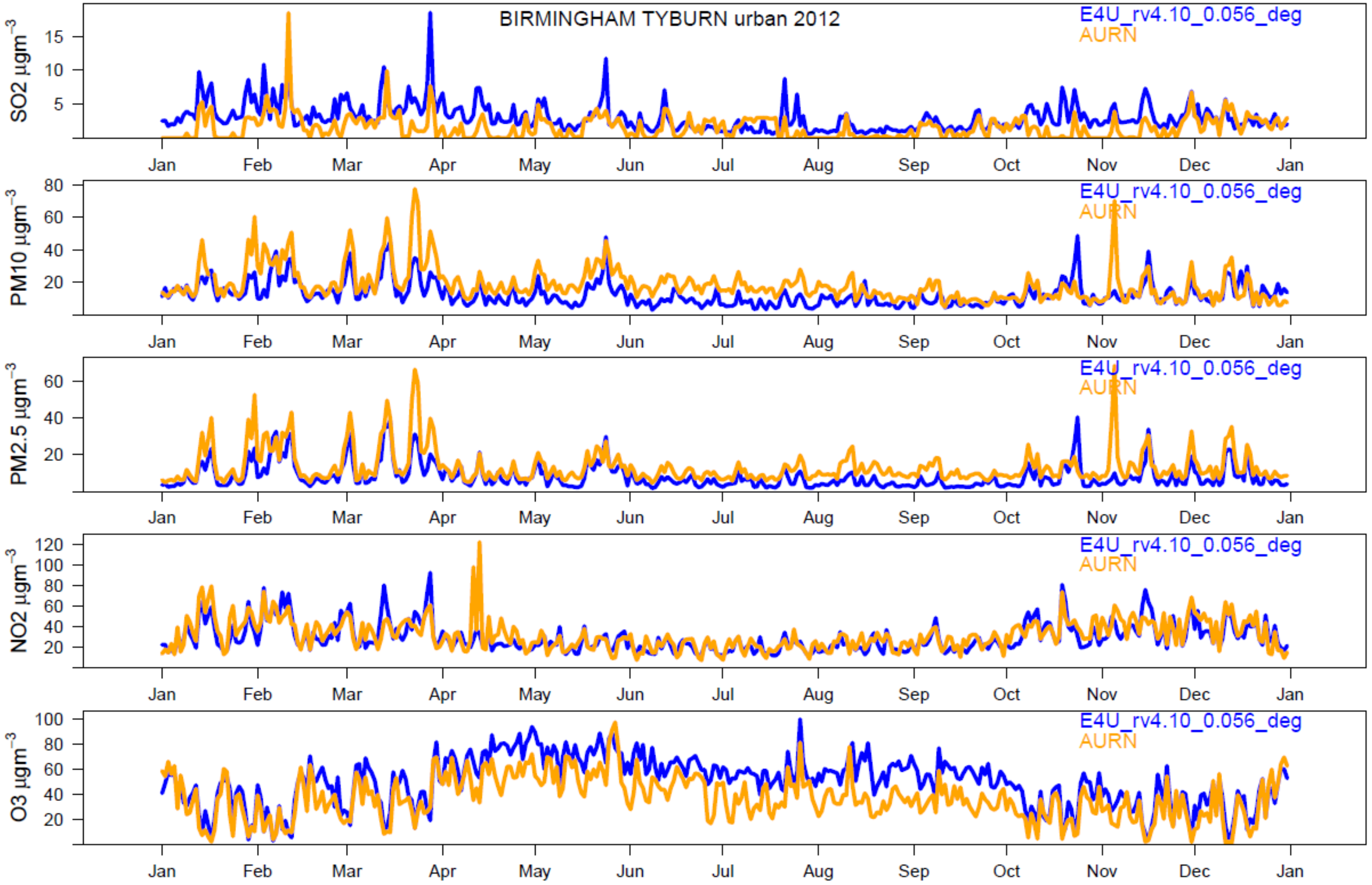
EMEP4UK 2012 daily mean vs AURN





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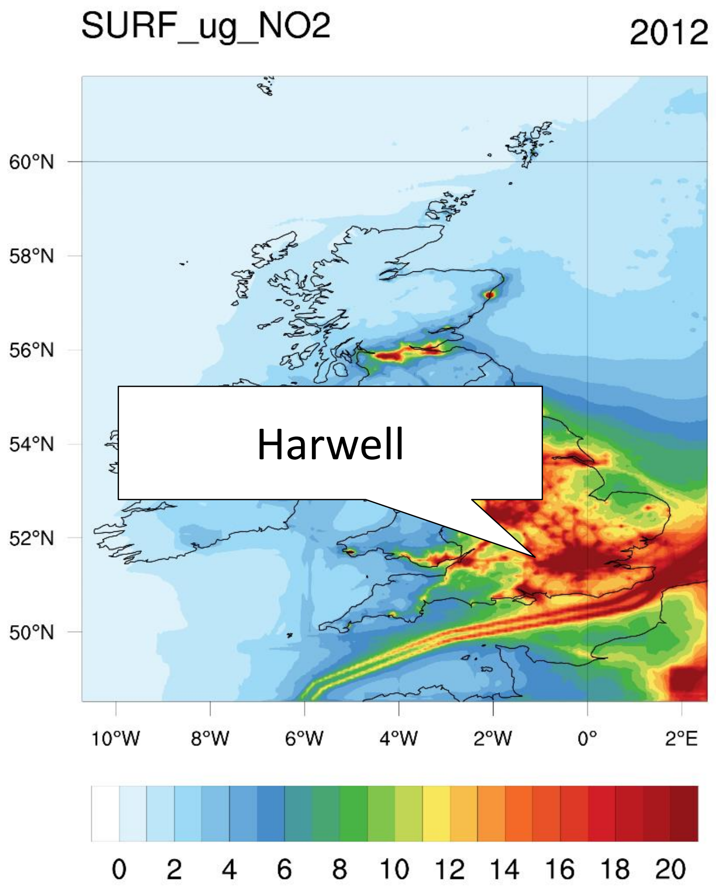
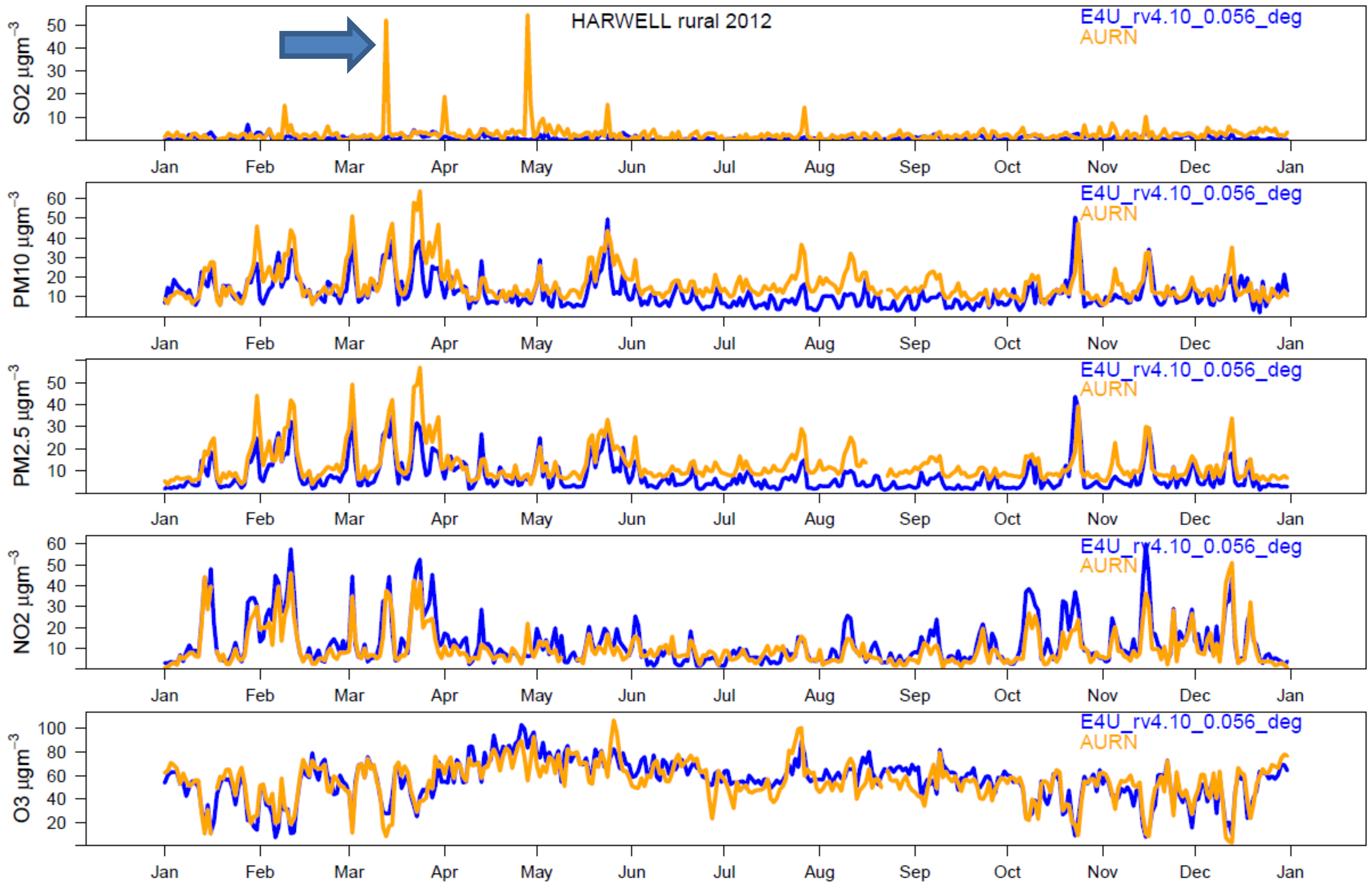
EMEP4UK 2012 daily mean vs AURN

Didcot power plant not working in 2014 – 2014 NAEI base year emissions





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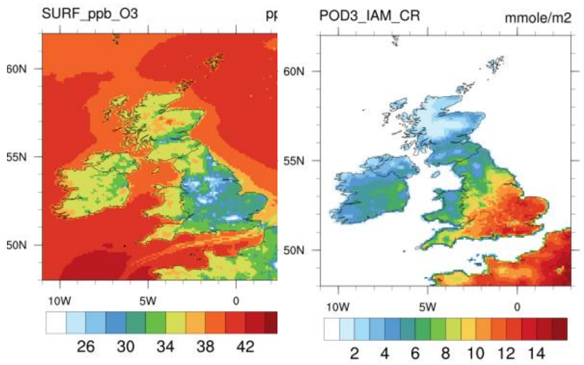
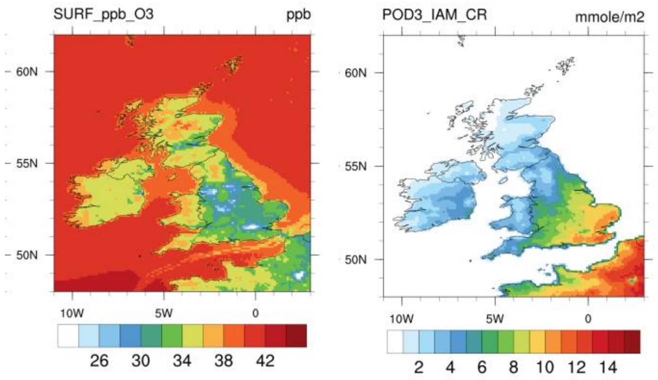
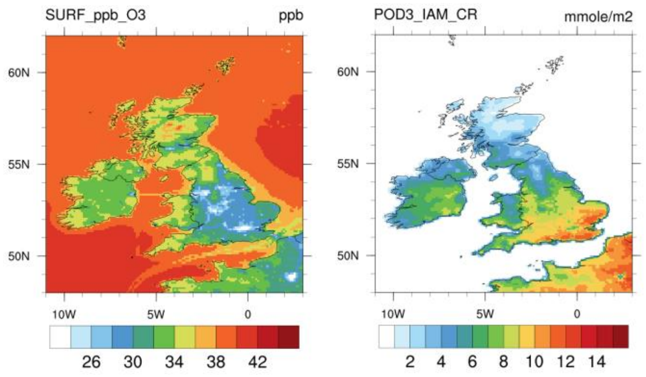
EMEP official results vs. EMEP-WRF

2014 | 2015 | 2016

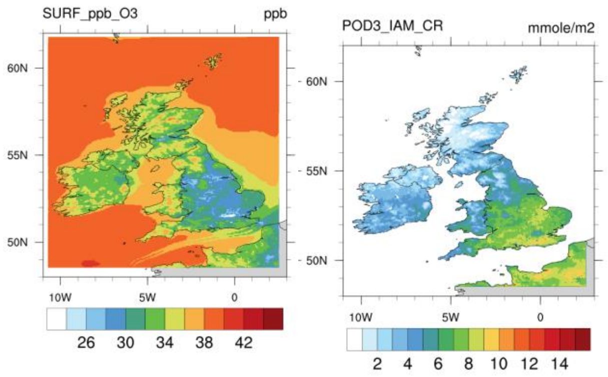
EMEP MSC-W
Rv4.17a_rep2018

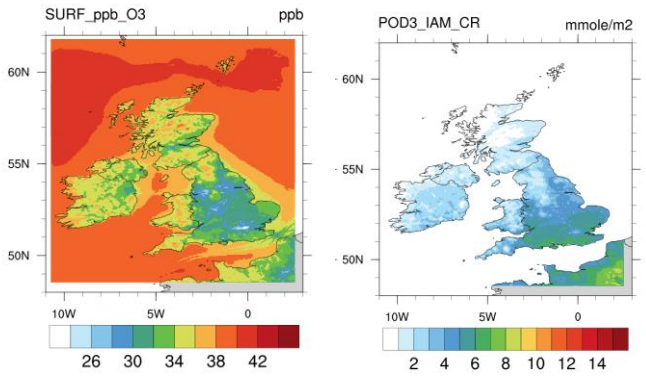


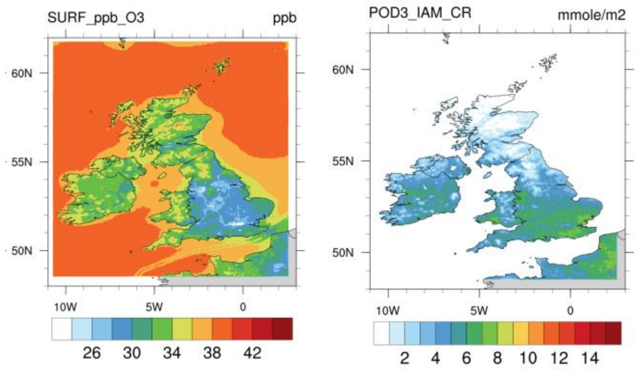




EMEP4UK - WRF
Rv4.17 – 3.7.1







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NERC SCIENCE OF THE ENVIRONMENT

EMEP-WRF three days forecast (very unofficial)

Many thanks

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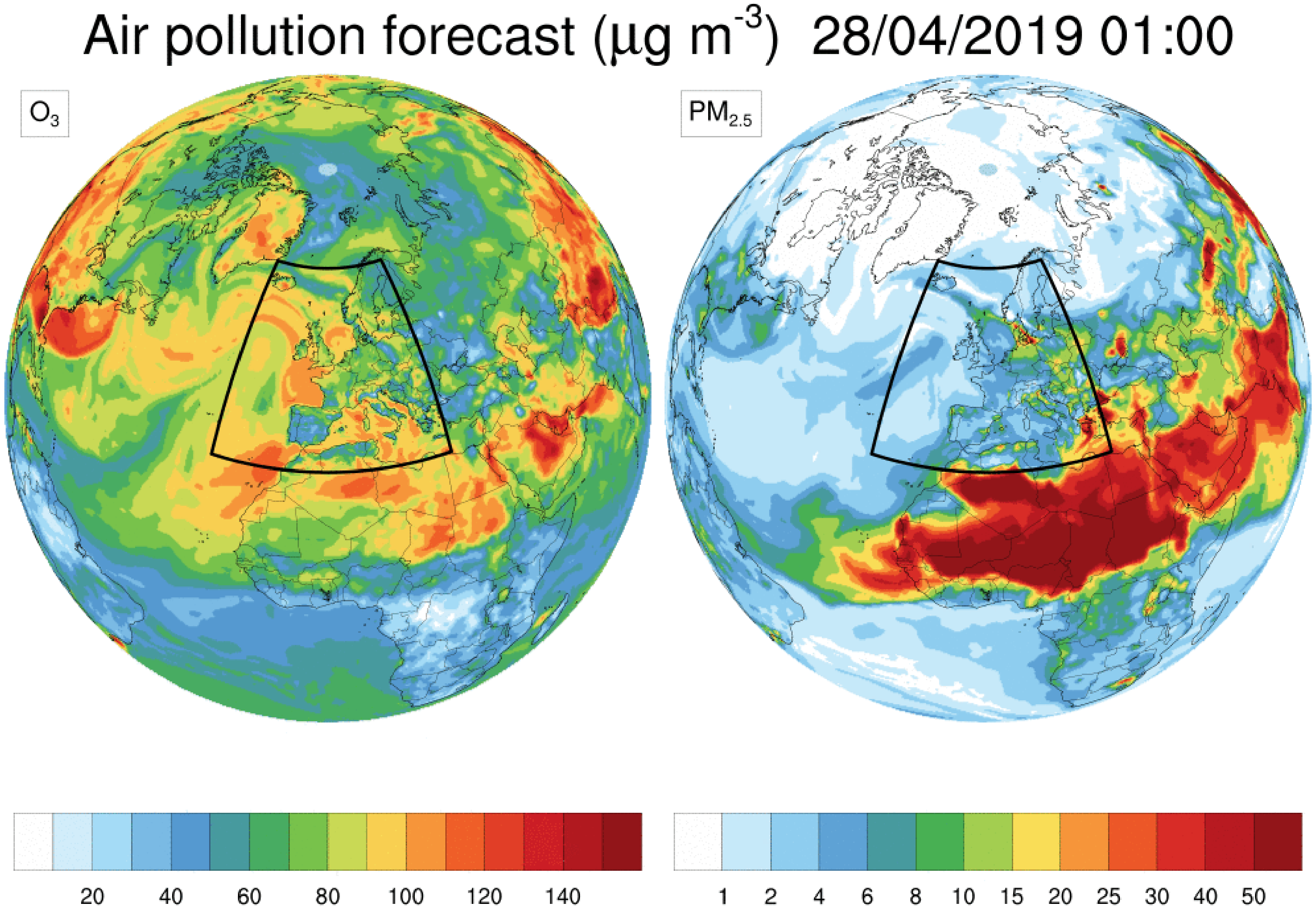

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