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Low modeled ozone production suggests underestimation of precursor emissions (especially NO_x) in Europe

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Table S1. Summary of WRF parameterizations (http://wrf-model.org).

Parameter	Option
Microphysics	WRF Single-Moment 5-class (WSM5).
Longwave and Shortwave Radiation	Rapid Radiative Transfer Model for general circulation models (RRTMG).
Surface Layer	Revised version of the fifth generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model (MM5) parameterization.
Land Surface	Noah land surface model (LSM).
PBL	Yonsei University non-local closure scheme (YSU).
Cumulus Parameterization	Kain-Fritsch.
Dynamics & FDDA	Recommendations of WRF user's guide.

Table S2. Description of SNAP source categories in TNO-MACC-III (as in Kuenen et al., 2014).

SNAP	SNAP sector description
1	Energy industries
2	Non-industrial combustion
34 (3+4)	Industry (combustion and processes)
5	Extraction and distribution of fossil fuels
6	Product use
7	Road transport
8	Non-road transport and other mobile sources
9	Waste treatment
10	Agriculture

Table S3. Overview of ozonesonde stations.

Station	Longitude (deg)	Latitude (deg)	Elevation (m)	Daily Records	UTC time
Valentia	10.25 W	51.93 N	14	7	11:00–12:00
Barajas	3.58 W	40.47 N	631	12	10:00–11:00
Legionowo	20.97 E	52.40 N	96	9	11:00–12:00
Hohenpeissenberg	11.00 E	47.80 N	976	25	04:00–06:00
Payerne	6.57 E	46.49 N	491	36	11:00–12:00
Uccle	4.35 E	50.80 N	100	40	11:00–12:00

Table S4. Overview of stations used for ozone–temperature correlation analysis in Fig. 7.

Station	Longitude (deg)	Latitude (deg)	Elevation (m)
Payerne	6.95 E	46.81 N	489
Kucharovice	16.09 E	48.88 N	334
Kocelovice	13.84 E	49.47 N	519
Kramolin-Kosetice	15.08 E	49.57 N	535
Meiningen	10.38 E	50.56 N	450
Nice	7.20 E	43.65 N	2
Cabauw	4.93 E	51.97 N	-1
Leba	17.53 E	54.75 N	4

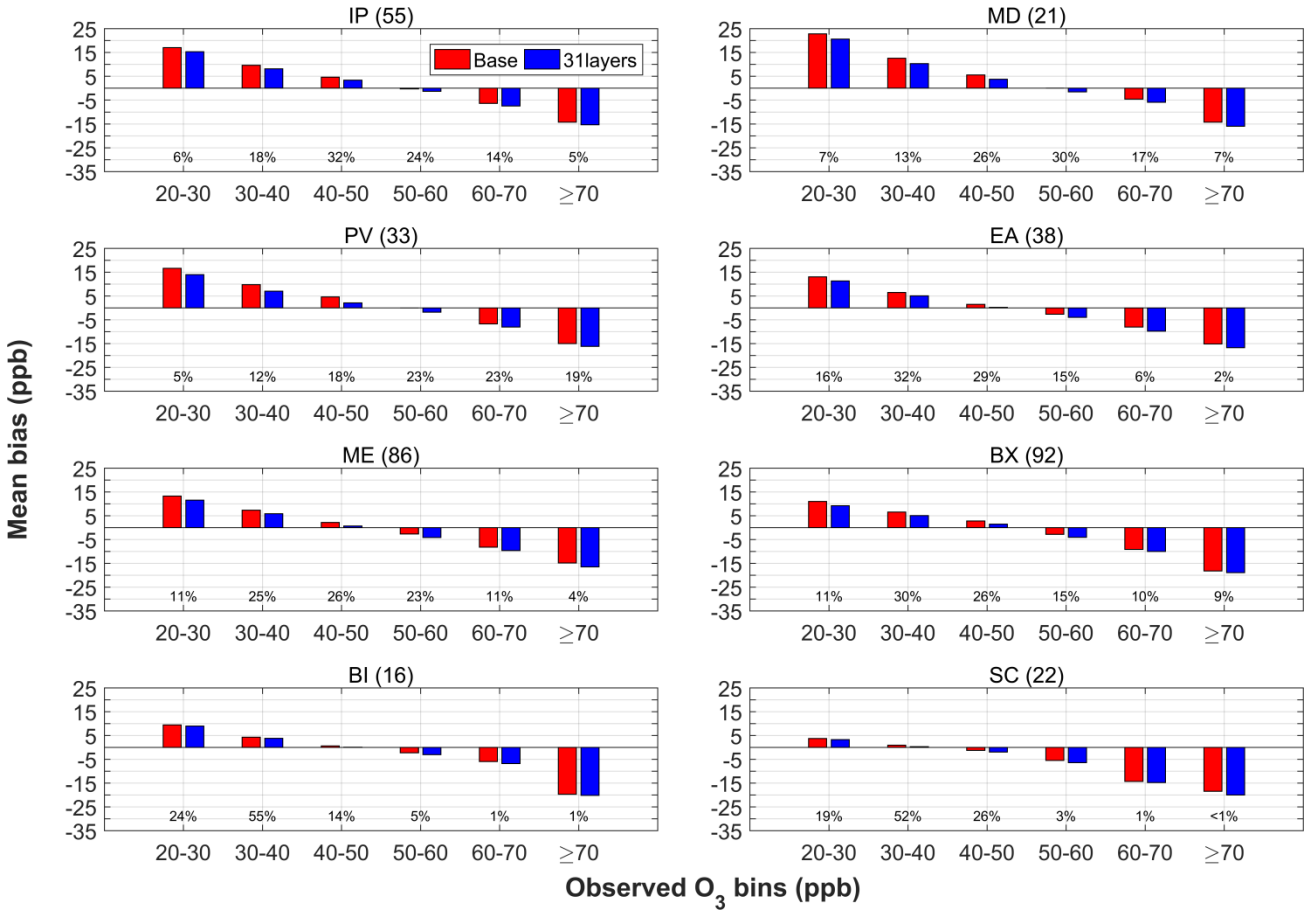

Figure S1. Effect of increasing vertical resolution (31 layers up to 100 hPa instead of 14 layers up to 460 hPa) on the mean afternoon (12:00–18:00 UTC) bias for surface O_3 mixing ratios in 8 European regions in June 2010. Percentage values below the bars indicate the fraction of the values assigned to each bin for each region. The number of stations available for each region is reported in parentheses at the top of each panel. A definition of the regions is given in Fig. 1.

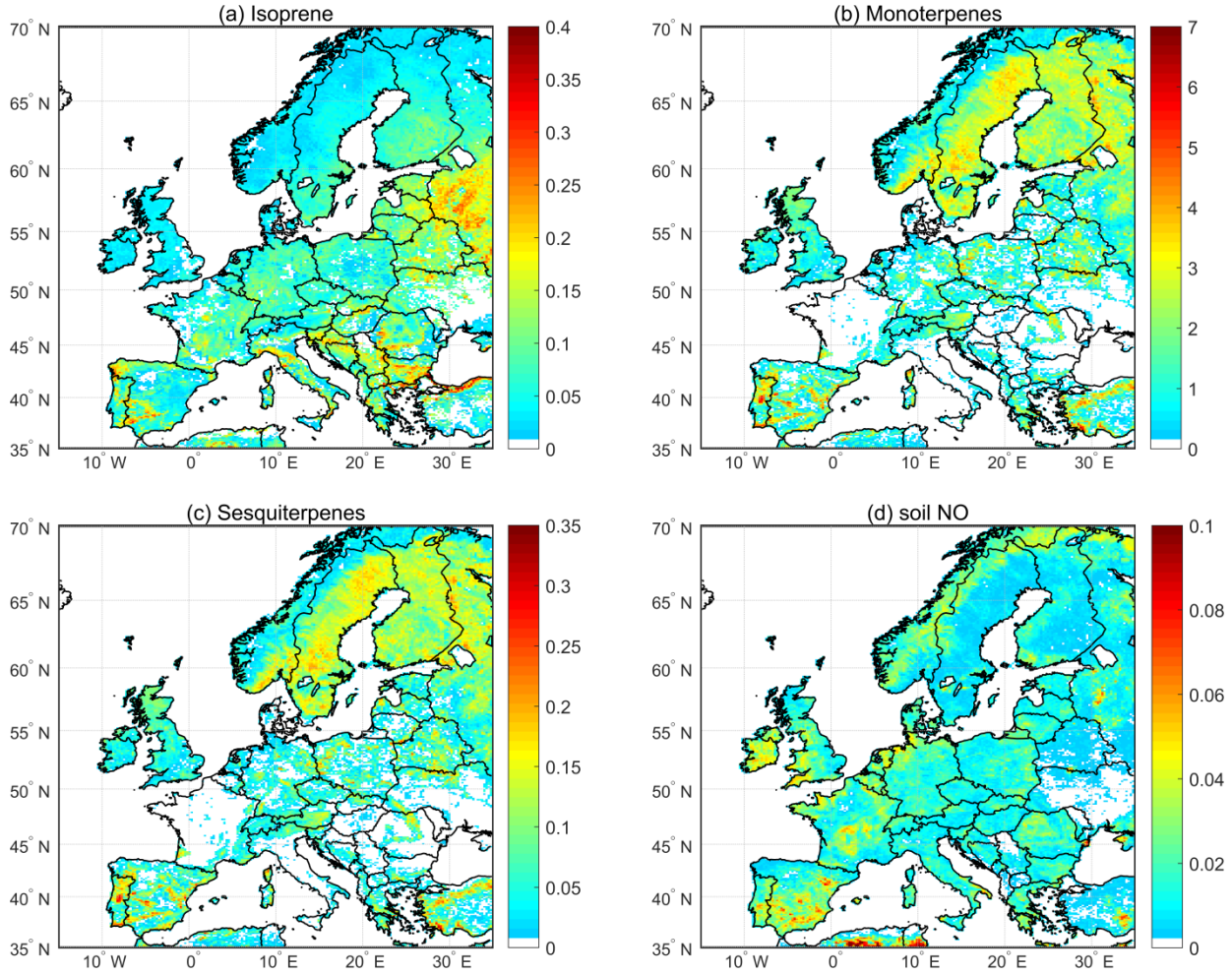

Figure S2. Spatial distributions of total (a) isoprene, (b) monoterpene, (c) sesquiterpene and (d) soil NO emissions (t km^{-2}) integrated over the summer (JJA) of 2010 in Europe.

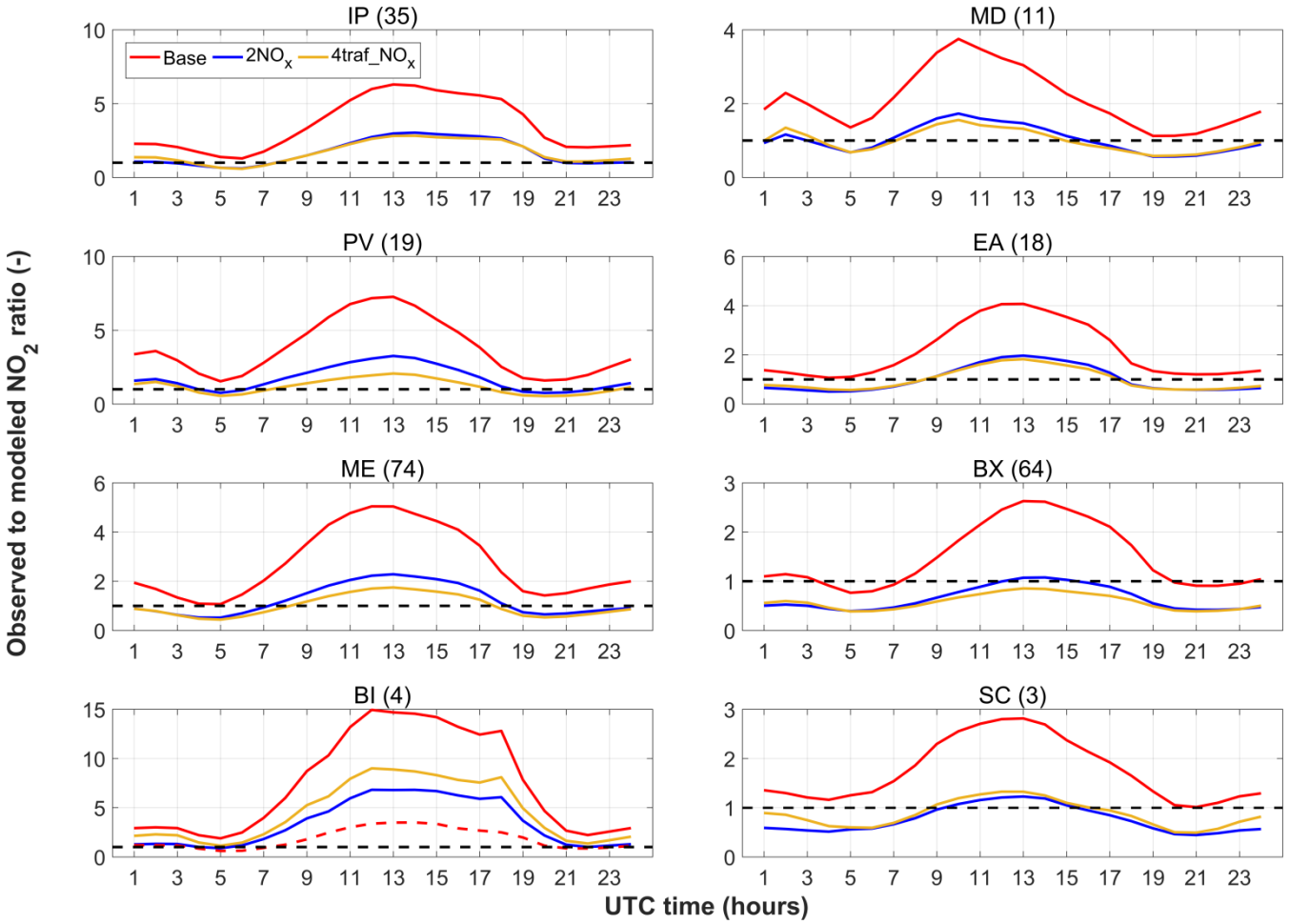

Figure S3. Diurnal profile of the ratio of observed to modeled surface NO_2 mixing ratios in 8 European regions in summer 2010. The number of stations available for each region is reported in parentheses at the top of each panel. The dashed black line is the ratio of 1. Red line shows the base case, blue line shows the scenario with doubled NO_x emissions ($2NO_x$) and yellow line shows the scenario with quadrupled traffic NO_x emissions ($4traf\_NO_x$). The dashed red line shows the base case averaged over 3 stations instead of 4, excluding the station Fort William in northern UK (GB0885A; 5.10W, 56.82N) which was considered to be an outlier. A definition of the regions is given in Fig. 1.

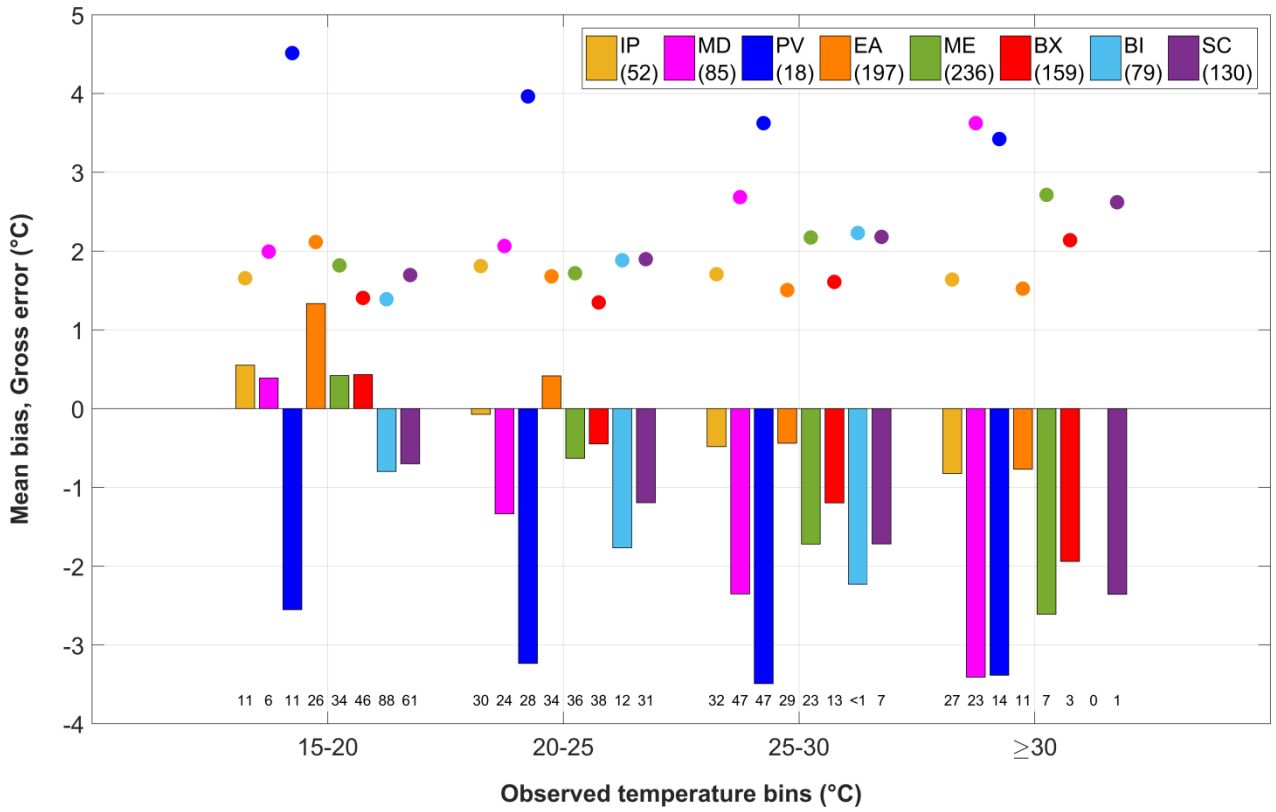

Figure S4. Temperature (2 m) mean bias (bars) and gross error (dots) for observed afternoon (12:00–18:00 UTC) temperature bins in 8 European regions in summer 2010. Values below the bars indicate the fraction (%) of the values assigned to each bin for each region. The number of stations available for each region is reported in parentheses in the legend. A definition of the regions is given in Fig. 1.

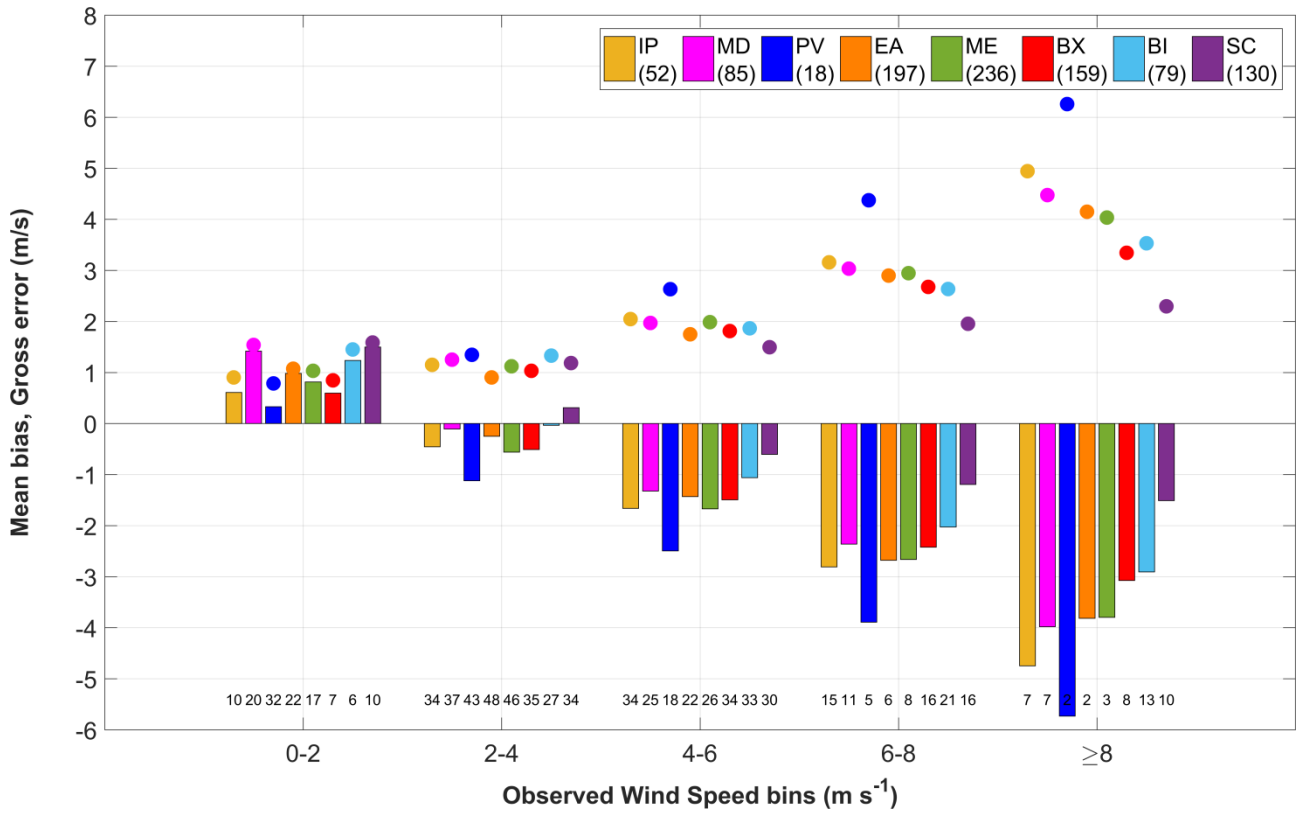

Figure S5. Wind speed (10 m) mean bias (bars) and gross error (dots) for observed afternoon (12:00–18:00 UTC) wind speed bins in 8 European regions in summer 2010. Values below the bars indicate the fraction (%) of the values assigned to each bin for each region. The number of stations available for each region is reported in parentheses in the legend. A definition of the regions is given in Fig. 1.

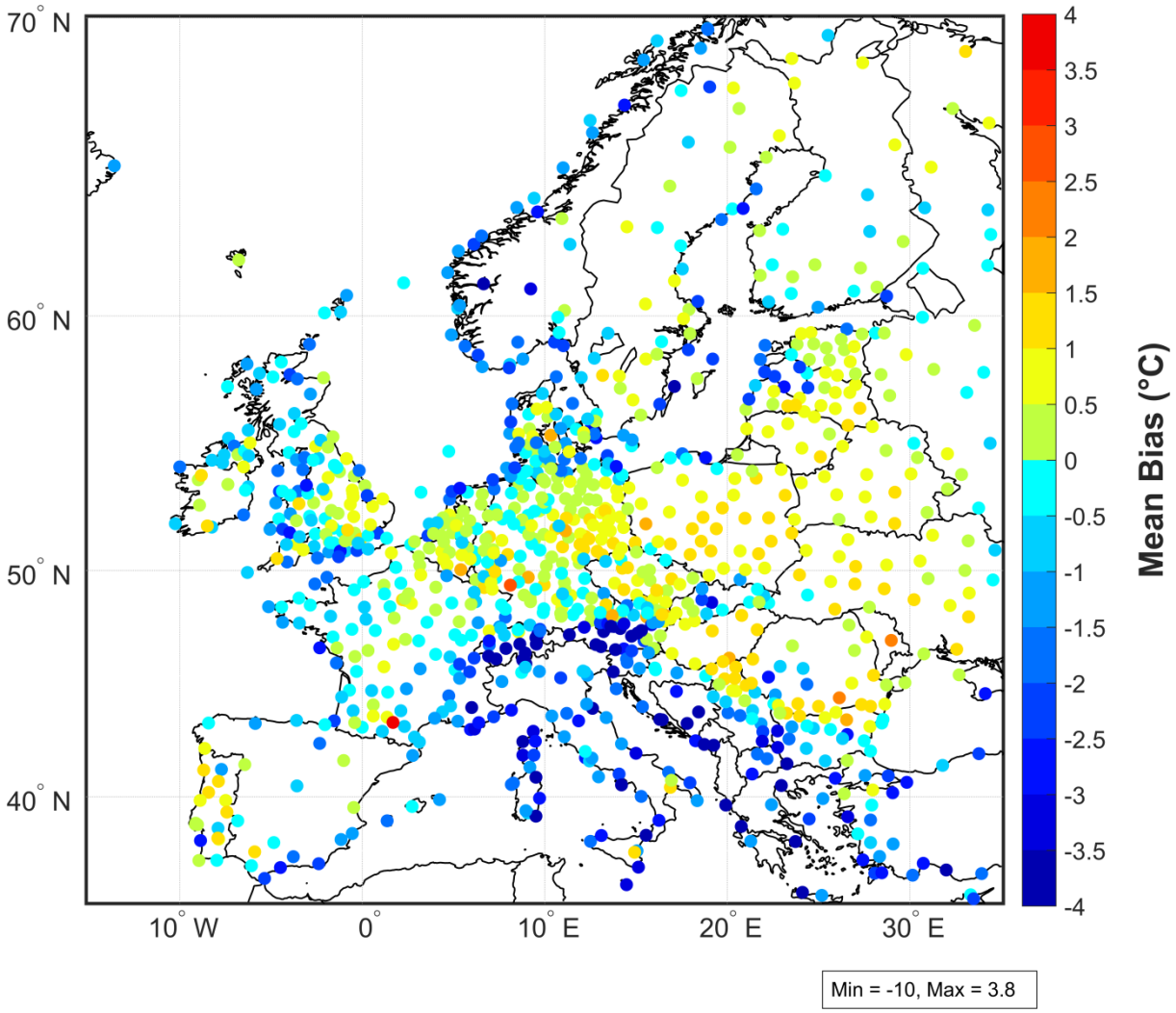

Figure S6. Temperature (2 m) afternoon (12:00–18:00 UTC) mean bias for each station in Europe for the summer of 2010. There are 18 stations outside the color scale.

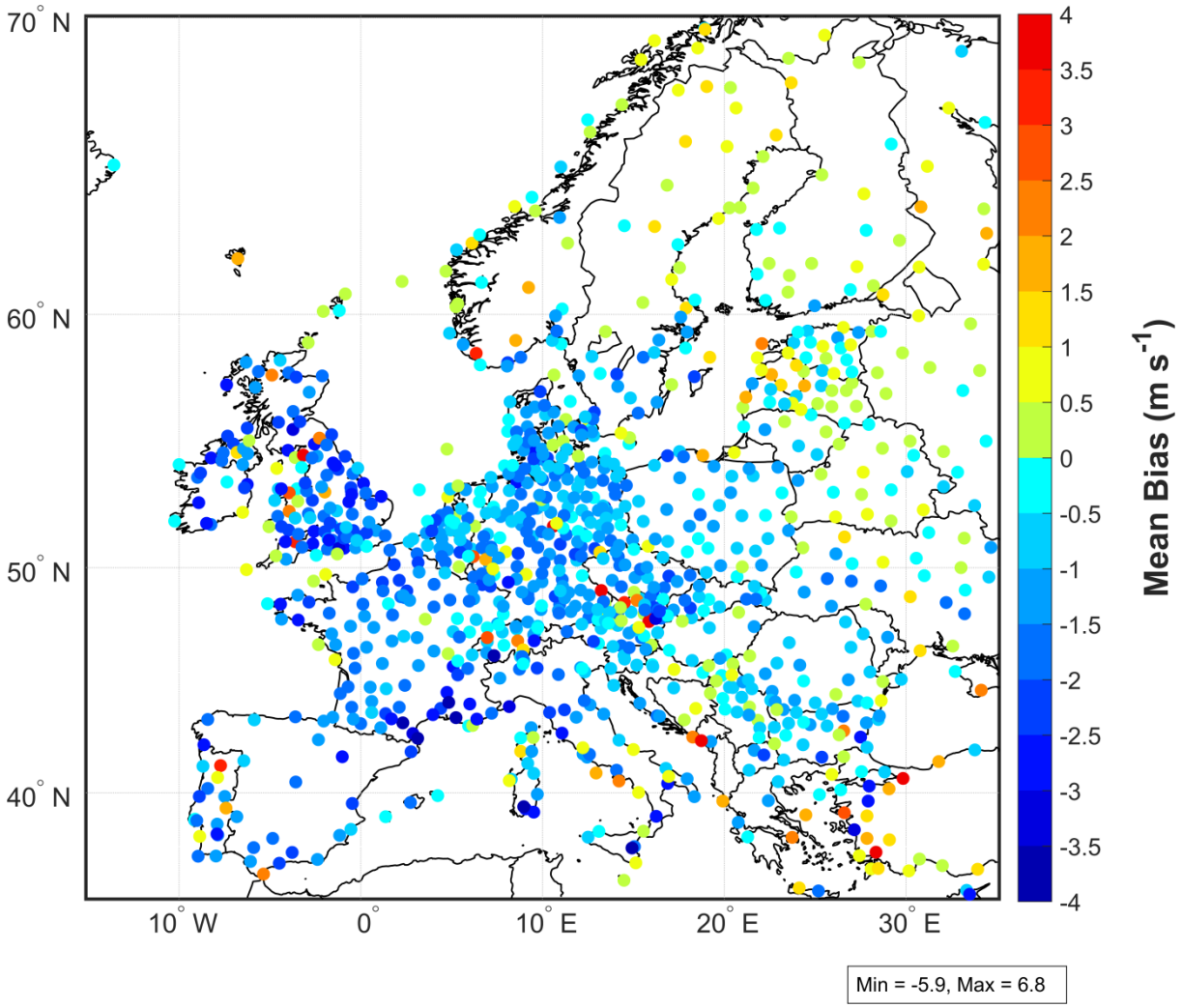

Figure S7. Wind speed (10 m) afternoon (12:00–18:00 UTC) mean bias for each station in Europe for the summer of 2010. There are 8 stations outside the color scale.

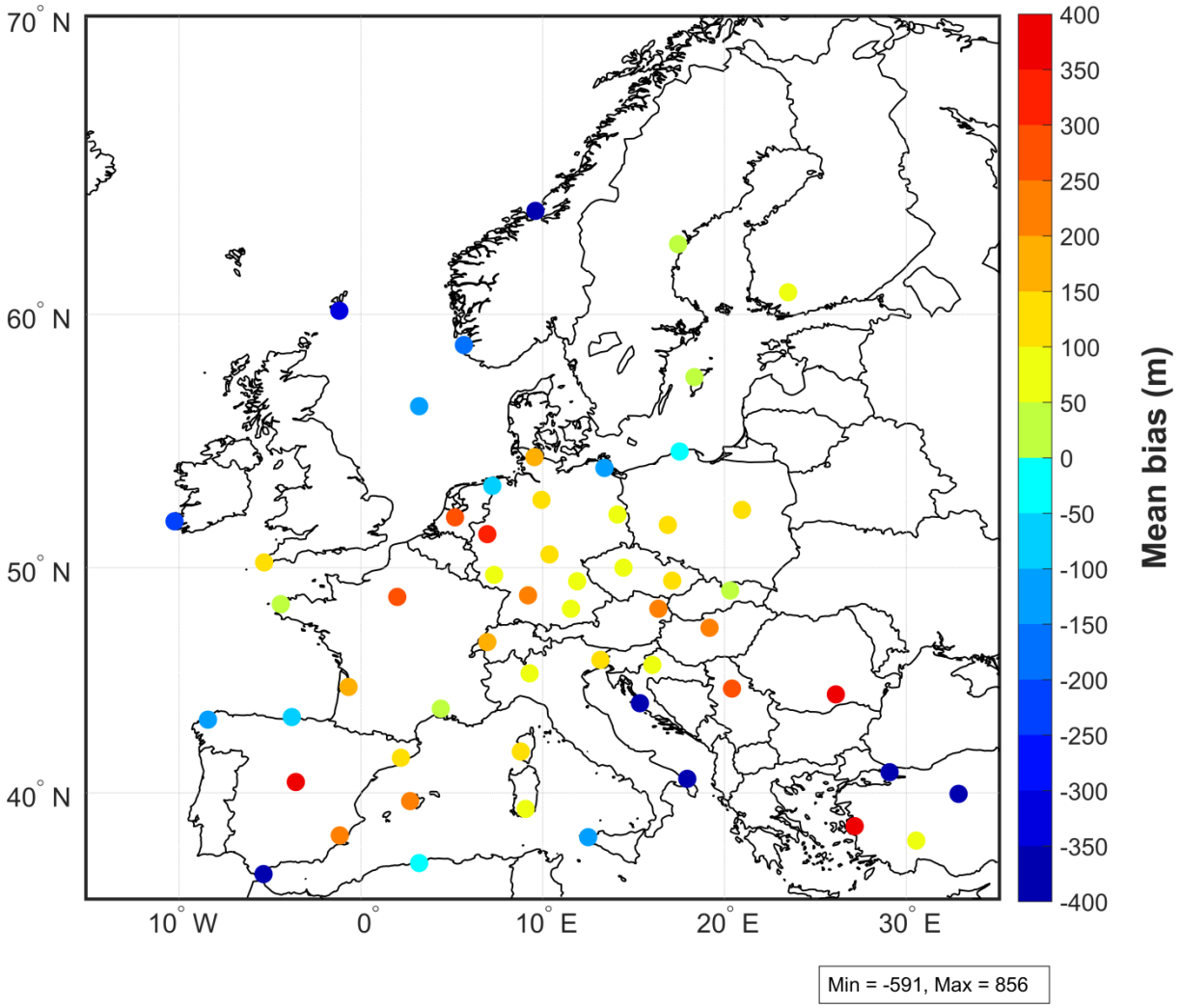

Figure S8. PBLH mean bias at 12 UTC for each station in Europe for the summer of 2010. There are 5 stations outside the color scale.

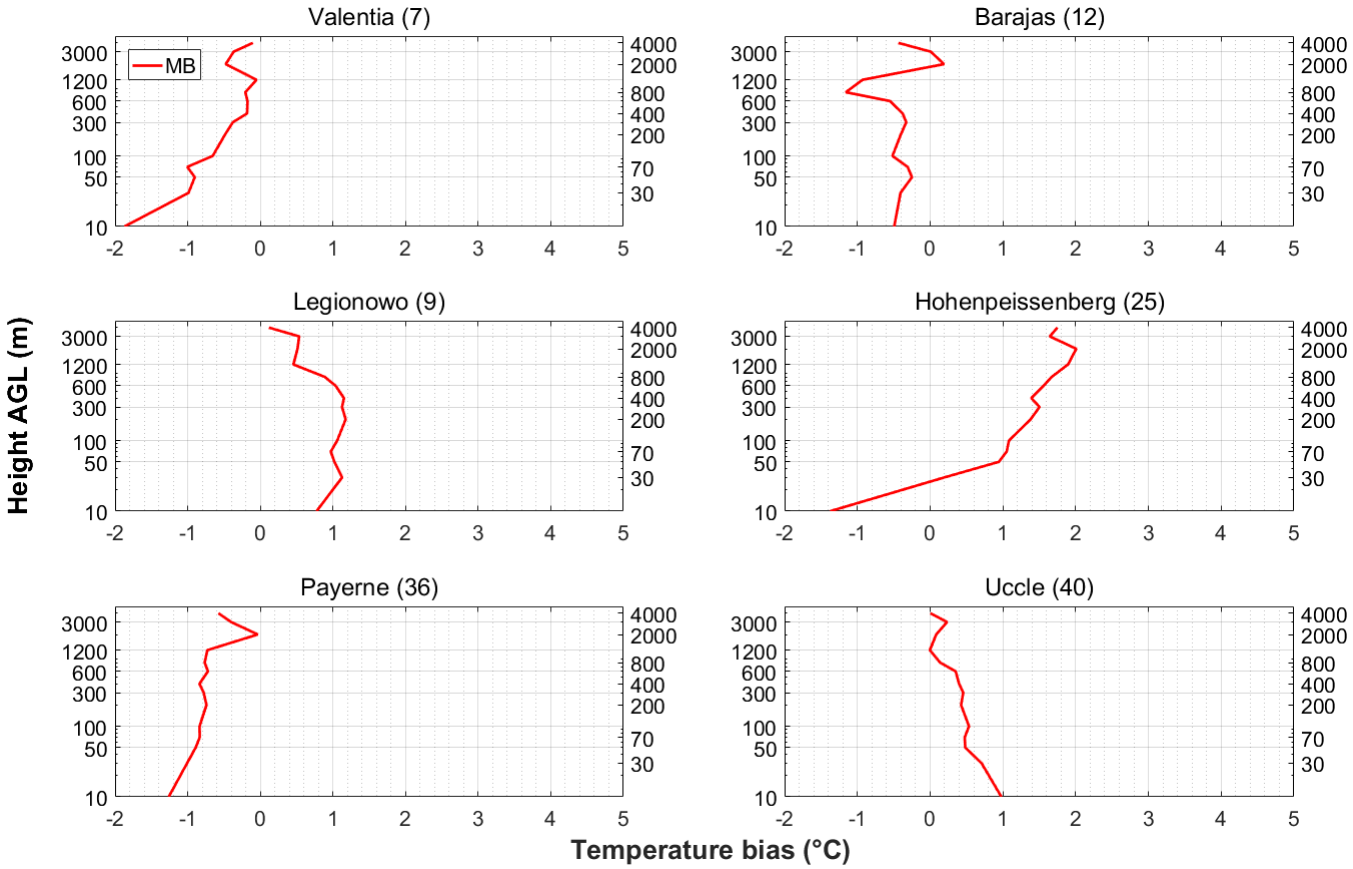

Figure S9. Vertical profiles of temperature mean bias for 6 stations for the summer of 2010. The number of ozonesondes available for each station is reported in parentheses at the top of each panel. Heights of 14 model layers are shown on both y-axes which are in logarithmic scale.

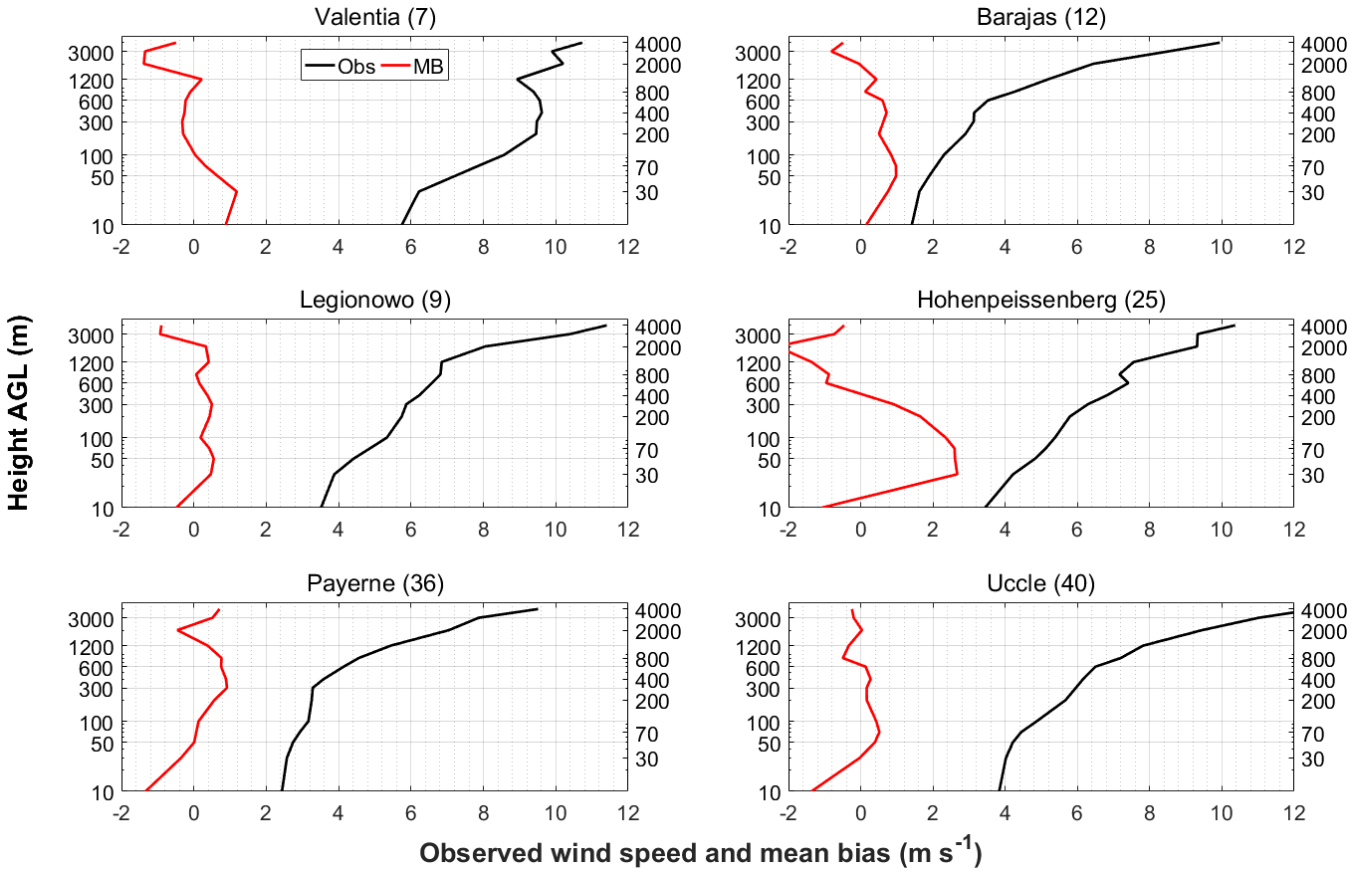

Figure S10. Vertical profiles of observed wind speed and mean bias for 6 stations for the summer of 2010. The number of ozonesondes available for each station is reported in parentheses at the top of each panel. Heights of 14 model layers are shown on both y-axes which are in logarithmic scale.

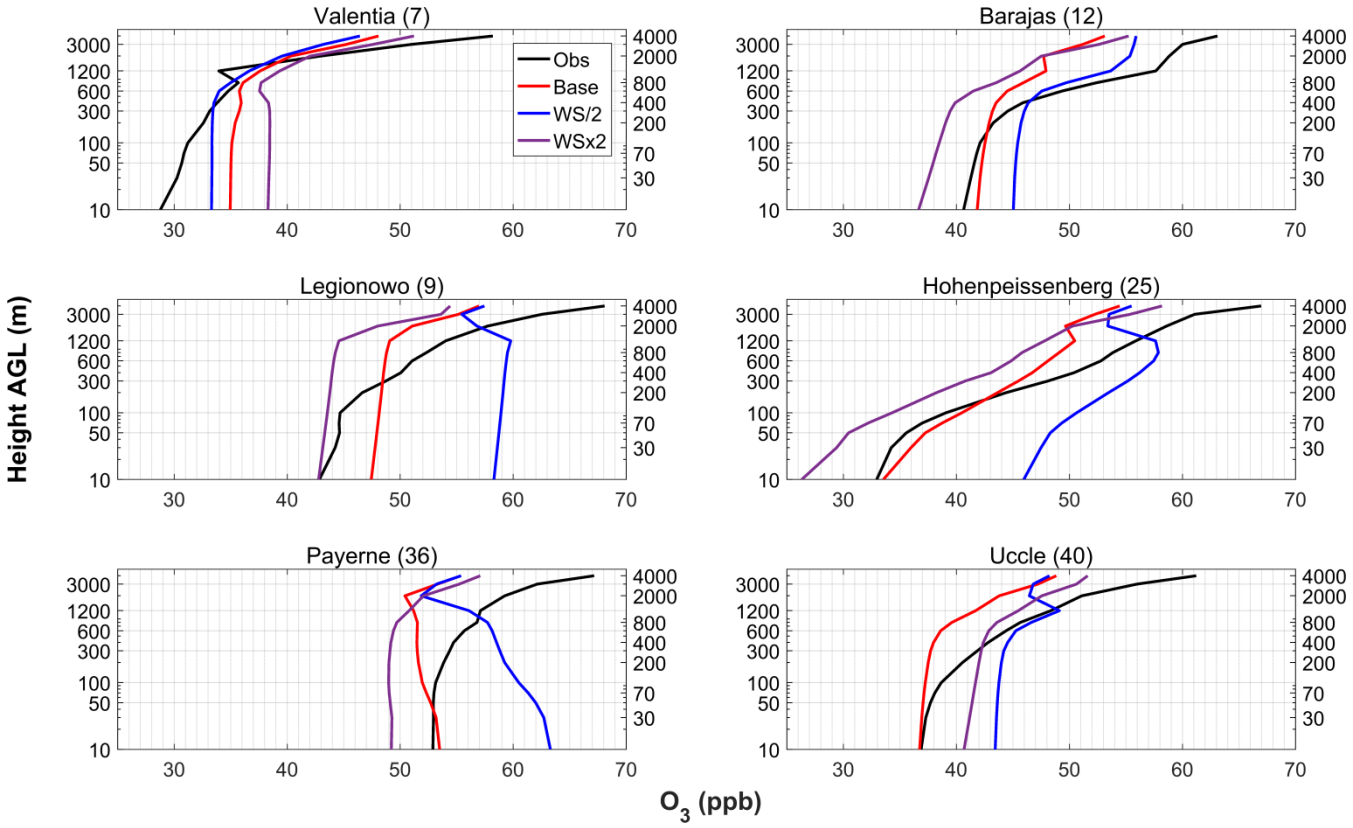

Figure S11. Observed and modeled O_3 mixing ratio vertical profiles for 6 stations for the summer of 2010. The number of ozonesondes available for each station is reported in parentheses at the top of each panel. Heights of 14 model layers are shown on both y-axes which are in logarithmic scale.

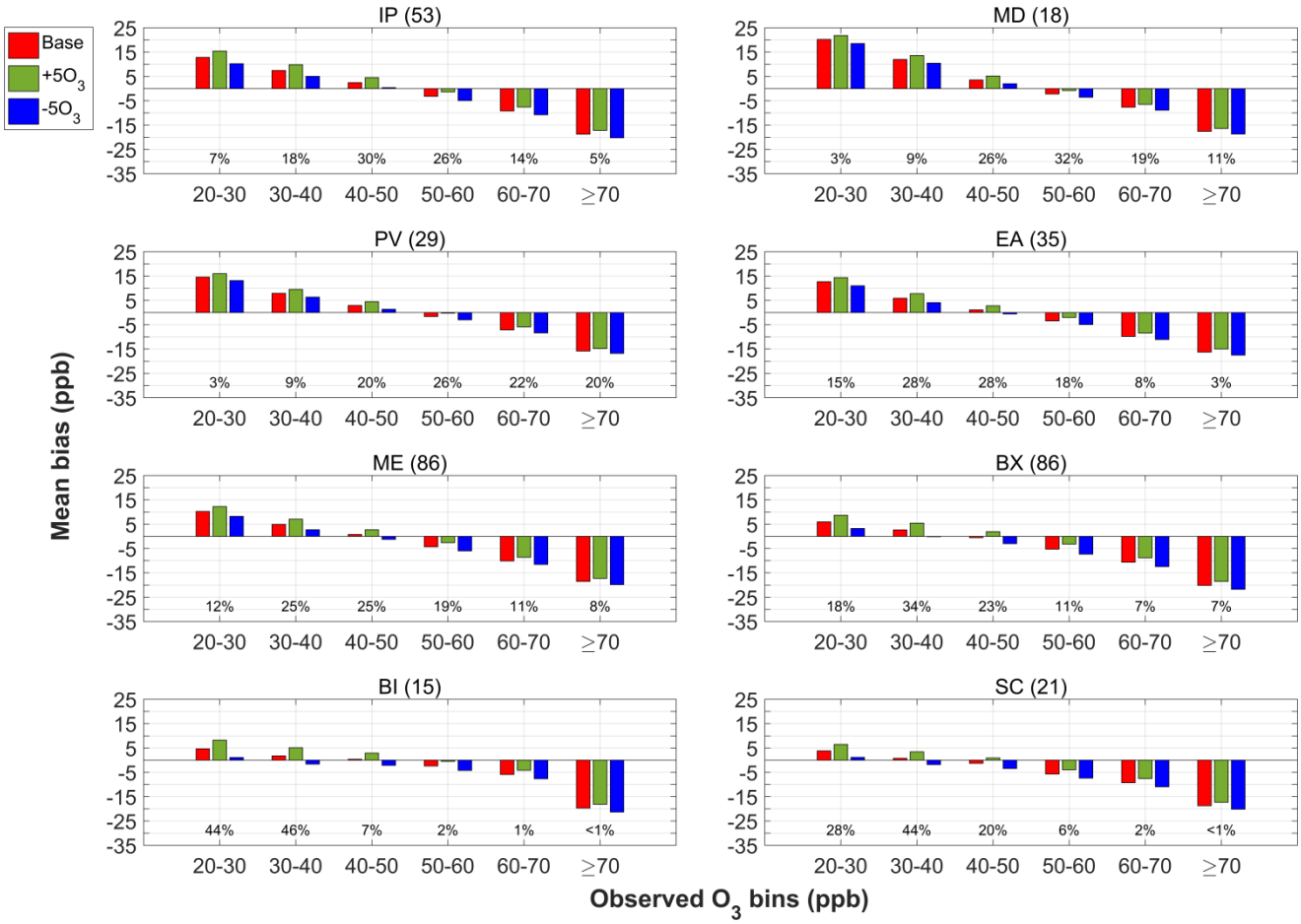

Figure S12. Mean bias of the afternoon (12:00–18:00 UTC) surface O_3 mixing ratio for each bin of observed surface O_3 mixing ratios for various O_3 ICBC scenarios in 8 European regions in summer 2010. Percentage values below the bars indicate the fraction of the values assigned to each bin for each region. The number of stations available for each region is reported in parentheses at the top of each panel. A definition of the regions is given in Fig. 1.