Design, evaluation and future projections of the NARCliM2.0 CORDEX-CMIP6 Australasia regional climate ensemble

Supporting Information

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Table S1. Example two- and three-dimensional variables used to force WRF RCM simulations with CMIP6 GCM data

Variable	Description	Units	Frequency
orog	topography	m	fix
sftlf	landsea mask	-	fix
tos	sea surface temperature	K	3, 6 hourly or daily
hus	3D humidity	%	3 or 6 hourly
ta	3D temperature	K	3 or 6 hourly
ua	3D u wind	m s-1	3 or 6 hourly
va	3D v wind	m s-1	3 or 6 hourly
p	3D pressure	Pa	3 or 6 hourly
zg	3D geopotential height	m	3 or 6 hourly
ps	2D surface pressure	Pa	3 or 6 hourly
psl	2D sea surface pressure	Pa	3 or 6 hourly
mrso	3D soil moisture	kg m-2	3 or 6 hourly
ts	skin temperature	K	3 or 6 hourly
tas	2D surface temperature	K	3 or 6 hourly
uas	2D surface u wind	m s-1	3 or 6 hourly
vas	2D surface v wind	m s-1	3 or 6 hourly
huss	2D surface specific humidity	%	3 or 6 hourly
siconc	2D sea ice area percentage	%	3 or 6 hourly
tsl	soil temperature	K	3 or 6 hourly
land cover type / landuse	land cover/land use	-	annual

Table S2. List of WRF parameterisations used in the phase I (N=36) tests. PBL = planetary boundary layer; SW = shortwave radiation; LW = longwave radiation

RCM Configuration ID	PBL	Microphysics	Cumulus	SW Radiation	LW Radiation	Land Surface Model
010601040402	YSU	WSM6	KF	RRTMG	RRTMG	Noah Unified
010601040405	YSU	WSM6	KF	RRTMG	RRTMG	CLM
010602040402	YSU	WSM6	BMJ	RRTMG	RRTMG	Noah Unified
010602040405	YSU	WSM6	BMJ	RRTMG	RRTMG	CLM
010606040402	YSU	WSM6	Tiedtke	RRTMG	RRTMG	Noah Unified
010606040405	YSU	WSM6	Tiedtke	RRTMG	RRTMG	CLM
010801040402	YSU	Thompson	KF	RRTMG	RRTMG	Noah Unified
010801040405	YSU	Thompson	KF	RRTMG	RRTMG	CLM
010802040402	YSU	Thompson	BMJ	RRTMG	RRTMG	Noah Unified
010802040405	YSU	Thompson	BMJ	RRTMG	RRTMG	CLM
010806040402	YSU	Thompson	Tiedtke	RRTMG	RRTMG	Noah Unified
010806040405	YSU	Thompson	Tiedtke	RRTMG	RRTMG	CLM
050601040402	MYNN2	WSM6	KF	RRTMG	RRTMG	Noah Unified
050601040405	MYNN2	WSM6	KF	RRTMG	RRTMG	CLM
050602040402	MYNN2	WSM6	BMJ	RRTMG	RRTMG	Noah Unified
050602040405	MYNN2	WSM6	BMJ	RRTMG	RRTMG	CLM
050606040402	MYNN2	WSM6	Tiedtke	RRTMG	RRTMG	Noah Unified
050606040405	MYNN2	WSM6	Tiedtke	RRTMG	RRTMG	CLM
050801040402	MYNN2	Thompson	KF	RRTMG	RRTMG	Noah Unified
050801040405	MYNN2	Thompson	KF	RRTMG	RRTMG	CLM
050802040402	MYNN2	Thompson	BMJ	RRTMG	RRTMG	Noah Unified
050802040405	MYNN2	Thompson	BMJ	RRTMG	RRTMG	CLM
050806040402	MYNN2	Thompson	Tiedtke	RRTMG	RRTMG	Noah Unified
050806040405	MYNN2	Thompson	Tiedtke	RRTMG	RRTMG	CLM
070601040402	ACM2	WSM6	KF	RRTMG	RRTMG	Noah Unified
070601040405	ACM2	WSM6	KF	RRTMG	RRTMG	CLM
070602040402	ACM2	WSM6	BMJ	RRTMG	RRTMG	Noah Unified
070602040405	ACM2	WSM6	BMJ	RRTMG	RRTMG	CLM
070606040402	ACM2	WSM6	Tiedtke	RRTMG	RRTMG	Noah Unified
070606040405	ACM2	WSM6	Tiedtke	RRTMG	RRTMG	CLM
070801040402	ACM2	Thompson	KF	RRTMG	RRTMG	Noah Unified
070801040405	ACM2	Thompson	KF	RRTMG	RRTMG	CLM
070802040402	ACM2	Thompson	BMJ	RRTMG	RRTMG	Noah Unified
070802040405	ACM2	Thompson	BMJ	RRTMG	RRTMG	CLM
070806040402	ACM2	Thompson	Tiedtke	RRTMG	RRTMG	Noah Unified
070806040405	ACM2	Thompson	Tiedtke	RRTMG	RRTMG	CLM

Fig. S1 WRF namelist settings for the CORDEX-CMIP6 NARCliM2.0 RCMs R3-R5: left panel shows physics settings for each RCM; right panel shows settings universal to the RCMs.

	RCM	R3	R5	R3	R5
physics	mp_physics	8	8	8	8
	ra_sw_physics	4	4	4	4
	ra_lw_physics	4	4	4	4
	sf_sfclay_physics	1	1	1	1
	sf_surface_physics	4	4	4	4
	bl_pbl_physics	5	7	5	7
	cu_physics	2	2	0	0
	sf_urban_physics	1	1	1	1
	radt	10	10	10	10
	cudt	0	0	0	0
	bldt	0	0	0	0
	prec_acc_dt	60	60	60	60
	bucket_mm	1000	1000	1000	1000
	levsiz	59	59	59	59
	paerlev	29	29	29	29
	cam_abs_dim1	4	4	4	4
	cam_abs_dim2	45	45	45	45
	isfflx	1	1	1	1
	surface_input_source	1	1	1	1
	num_soil_layers	4	4	4	4
	sst_update	1	1	1	1
	tmn_update	1	1	1	1
	lagday	150	150	150	150
	sst_skin	1	1	1	1
	usemonalb	.True.	.True.	.True.	.True.
	rdmaxalb	.True.	.True.	.True.	.True.
	slope_rad	1	1	1	1
	topo_shading	1	1	1	1
	shadlen	25000	25000	25000	25000
noah_mp	dveg	2	2	2	2
	opt_crs	1	1	1	1
	opt_sfc	1	1	1	1
	opt_btr	1	1	1	1
	opt_run	3	3	3	3
	opt_frz	1	1	1	1
	opt_inf	1	1	1	1
	opt_rad	3	3	3	3
	opt_alb	2	2	2	2
	opt_snf	1	1	1	1
	opt_tbot	2	2	2	2
	opt_stc	1	1	1	1
	opt_gla	1	1	1	1
	opt_rsf	1	1	1	1
	opt_soil	1	1	1	1
	opt_pedo	1	1	1	1
	opt_crop	0	0	0	0

time_control		
run_days	6	
run_hours	0	
run_minutes	0	
run_seconds	0	
start_year	2016	2016
start_month	5	5
start_day	1	1
start_hour	0	0
start_minute	0	0
start_second	0	0
end_year	2016	2016
end_month	5	5
end_day	7	7
end_hour	0	0
end_minute	0	0
end_second	0	0
interval_seconds	21600	
input_from_file	TRUE	TRUE
history_interval	180	180
frames_per_outfile	8	8
restart	TRUE	
restart_interval	1440	
override_restart_timers	TRUE	
write_hist_at_0h_rst	TRUE	
io_form_history	2	
io_form_restart	2	
io_form_input	2	
io_form_boundary	2	
debug_level	0	
output_diagnostics	1	
auxinput4_inname	"wrflowinp_d<domain>"	
auxinput4_interval	360	360
io_form_auxinput4	2	
auxhist3_outname	xtrm_d<domain>_<date>"	
io_form_auxhist3	2	
auxhist3_interval	1440	1440
frames_per_auxhist3	6	6
auxhist4_outname	fhrly_d<domain>_<date>"	
io_form_auxhist4	2	
auxhist4_interval	60	60
frames_per_auxhist4	144	144
! auxhist8_outname	rfdly_d<domain>_<date>"	
! auxhist8_interval	1440	1440
! io_form_auxhist8	2	
! frames_per_auxhist8	6	6
iofields_filename	"iofields.txt"	"iofields.txt"
domains		
time_step	90	
time_step_fract_num	0	
time_step_fract_den	1	
max_dom	2	
s_we	1	1
e_we	540	616
s_sn	1	1
e_sn	363	501
s_vert	1	1
e_vert	45	45
dzbot	50	
max_dz	1000	
dzstretch_s	1.2	
dzstretch_u	1.05	
p_top_requested	5000	
dx	19567.24	3913.447
dy	19567.24	3913.447
grid_id	1	2
parent_id	0	1
i_parent_start	1	205
j_parent_start	1	90
parent_grid_ratio	1	5
parent_time_step_ratio	1	5
feedback	0	
smooth_option	0	
nproc_x	-1	
nproc_y	-1	
dynamics		
rk_ord	3	
w_damping	1	
diff_opt	1	1
km_opt	4	4
diff_6th_opt	0	0
diff_6th_factor	0.12	
base_temp	290	
damp_opt	1	
zdamp	5000	5000
dampcoef	0.01	0.01
khdif	0	0
kvdif	0	0
non_hydrostatic	TRUE	TRUE
moist_adv_opt	1	1
scalar_adv_opt	1	1
gwd_opt	1	
bdy_control		
spec_bdy_width	5	
spec_zone	1	
relax_zone	4	
specified	TRUE	FALSE
nested	FALSE	TRUE
namelist_quilt		
nio_tasks_per_group	0	
nio_groups	0	

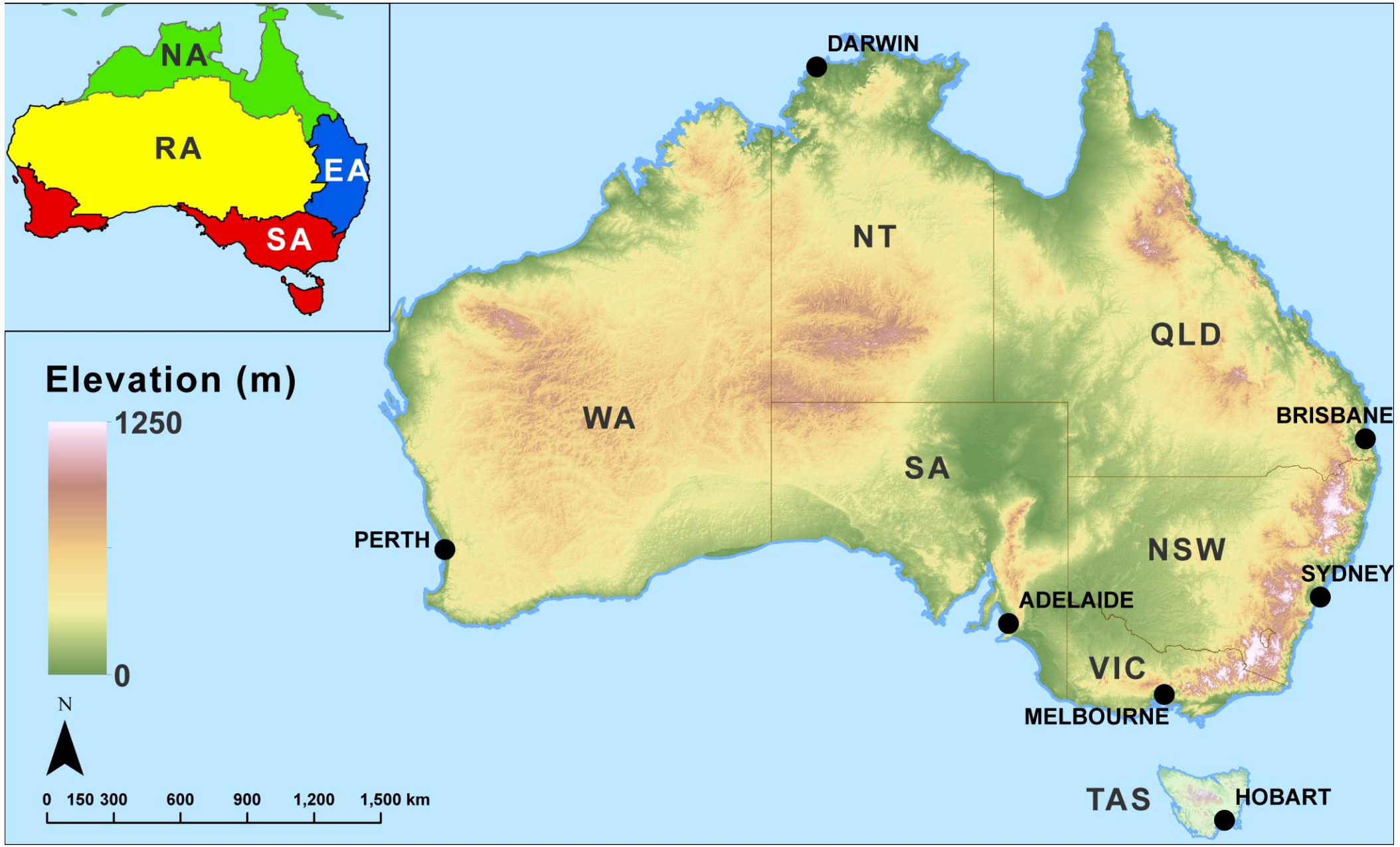
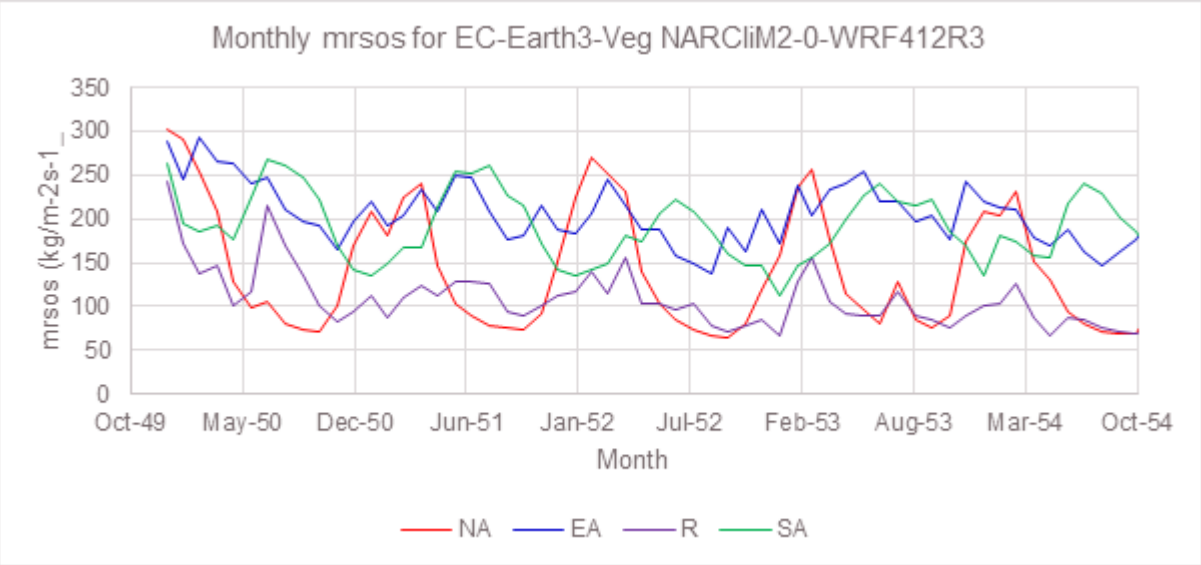


Fig S2. Australia, its states (NT=Northern Territory; QLD=Queensland; NSW=New South Wales; ACT = Australian Capital Territory; VIC = Victoria; SA = South Australia; WA = Western Australia), and major cities. **Inset**: Natural Resource Management (NRM) regions/climate zones (NA = Northern Australia; EA = Eastern Australia; SA = Southern Australia; RA = Rangelands).



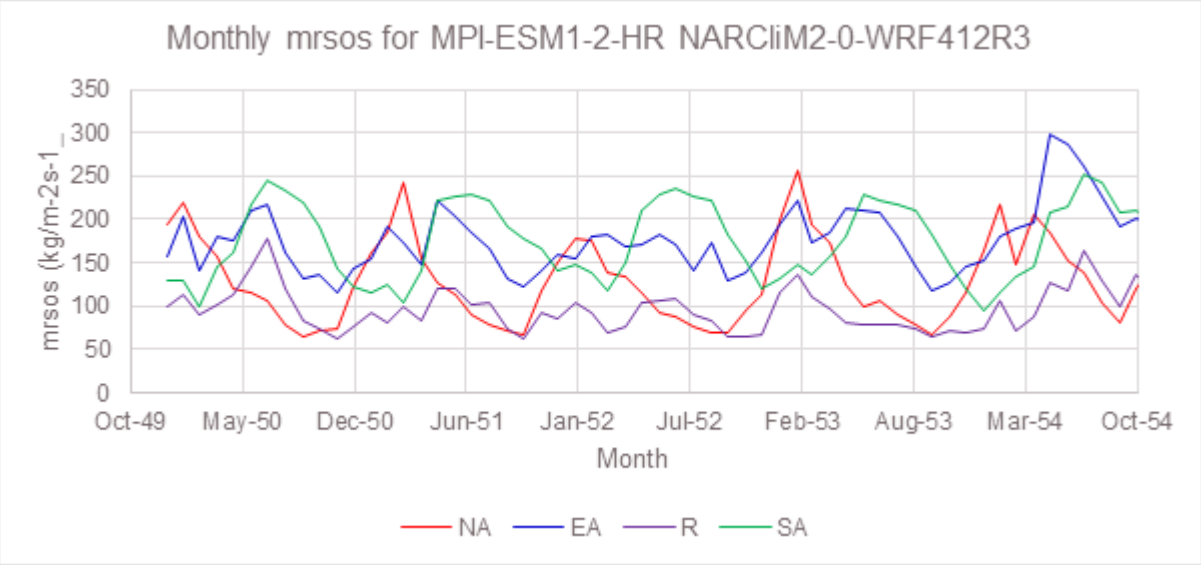


Fig S3. Natural Resource Management (NRM) regionally averaged soil moisture time series (1950-1954) for the EC-Earth3-Veg-forced R3 RCM (top) and MPI-ESM1-2-HR-forced R3 RCM (bottom) simulations. NA=Northern Australia, EA=Eastern Australia, R=rangelands, and SA=Southern Australia

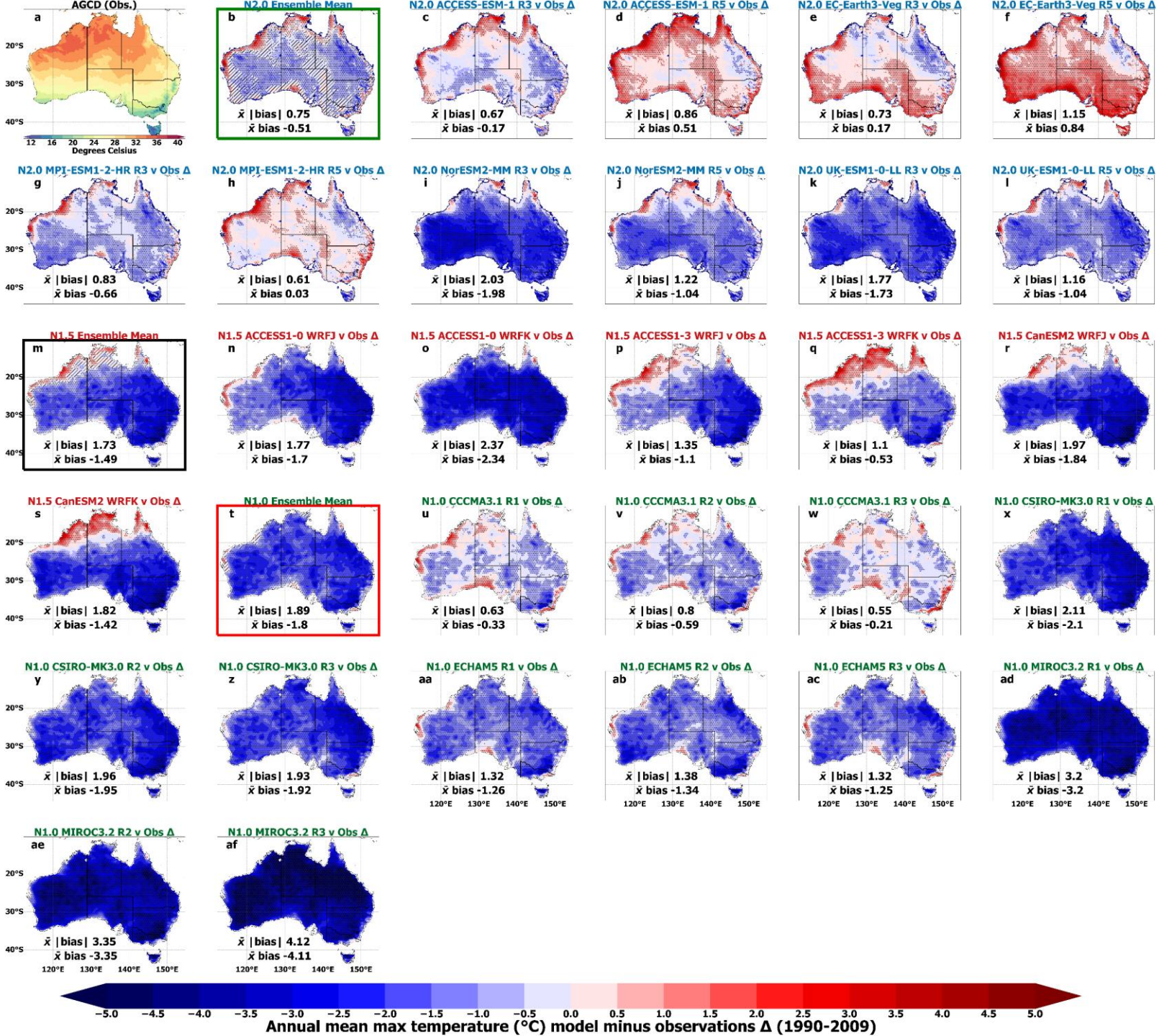


Fig. S4 Annual mean near-surface atmospheric maximum temperature biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Stippled areas indicate locations where an RCM shows statistically significant bias ($P < 0.05$). Significance stippling for the ensemble mean bias follows Tebaldi et al. (2011). Statistically insignificant areas are shown in colour, denoting that less than half of the models are significantly biased. In significant agreeing areas (stippled), at least half of RCMs are significantly biased, and at least 70% of significant RCMs in each ensemble agree on the direction of the bias. Significant disagreeing areas are shown in hatching, which are where at least half of the models are significantly biased and less than 70% of significant models in each ensemble agree on the bias direction. Panel boundaries for ensemble means (b,m,t) in green (red) indicate the RCMs with lowest (highest) area-averaged mean absolute biases.

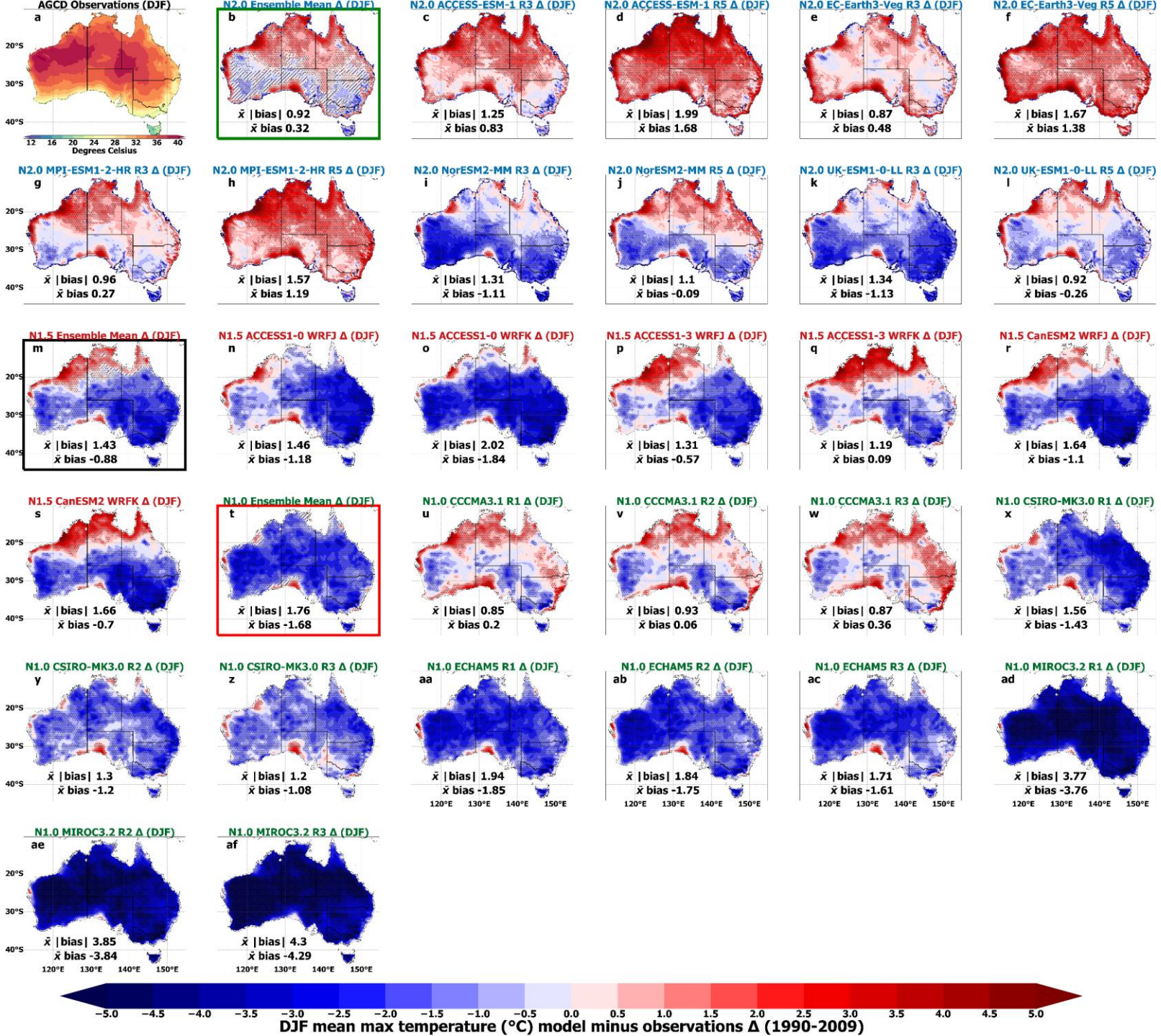


Fig. 5 DJF mean near-surface atmospheric maximum temperature biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Stippling as per Fig.S4.

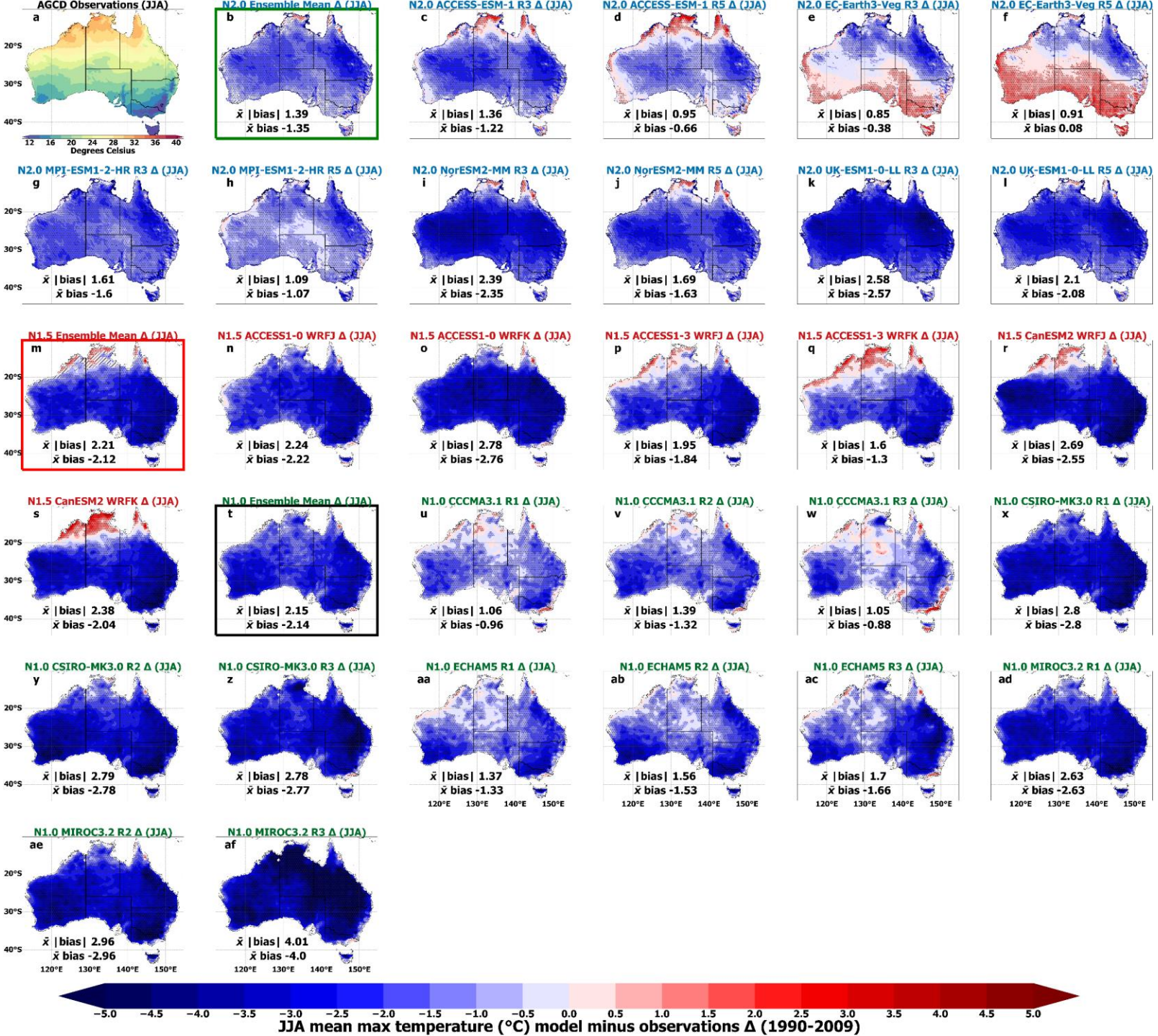


Fig. S6 JJA mean near-surface atmospheric maximum temperature biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Stippling as per Fig.S4.

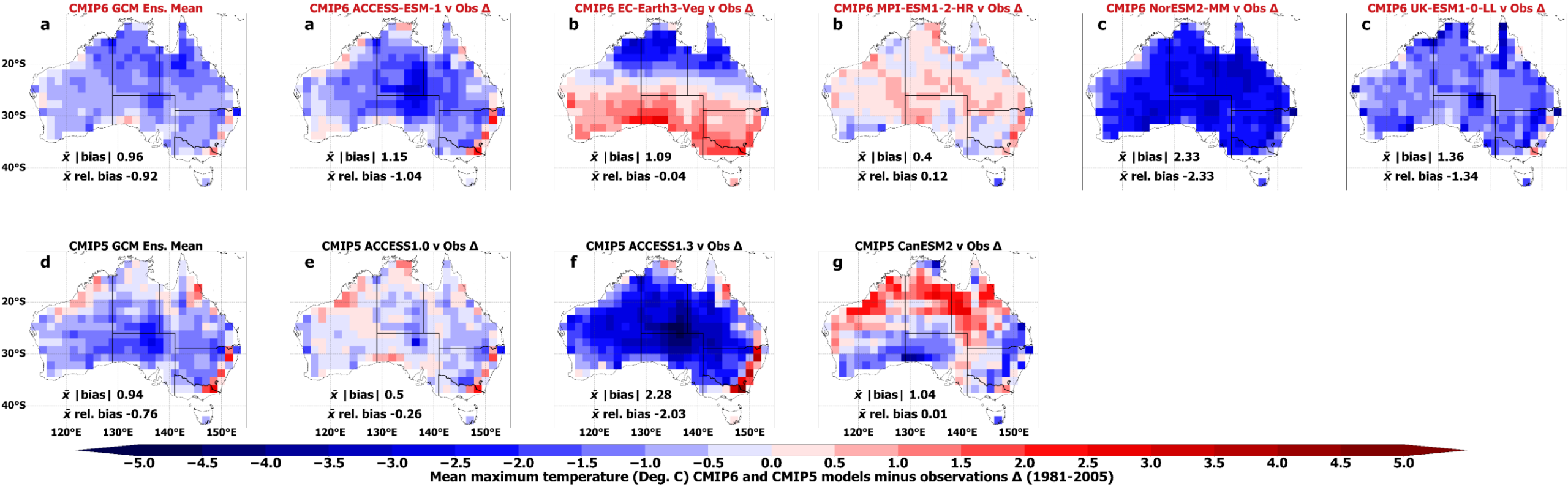


Figure S7. GCM annual mean maximum temperature bias relative to AGCD observations.

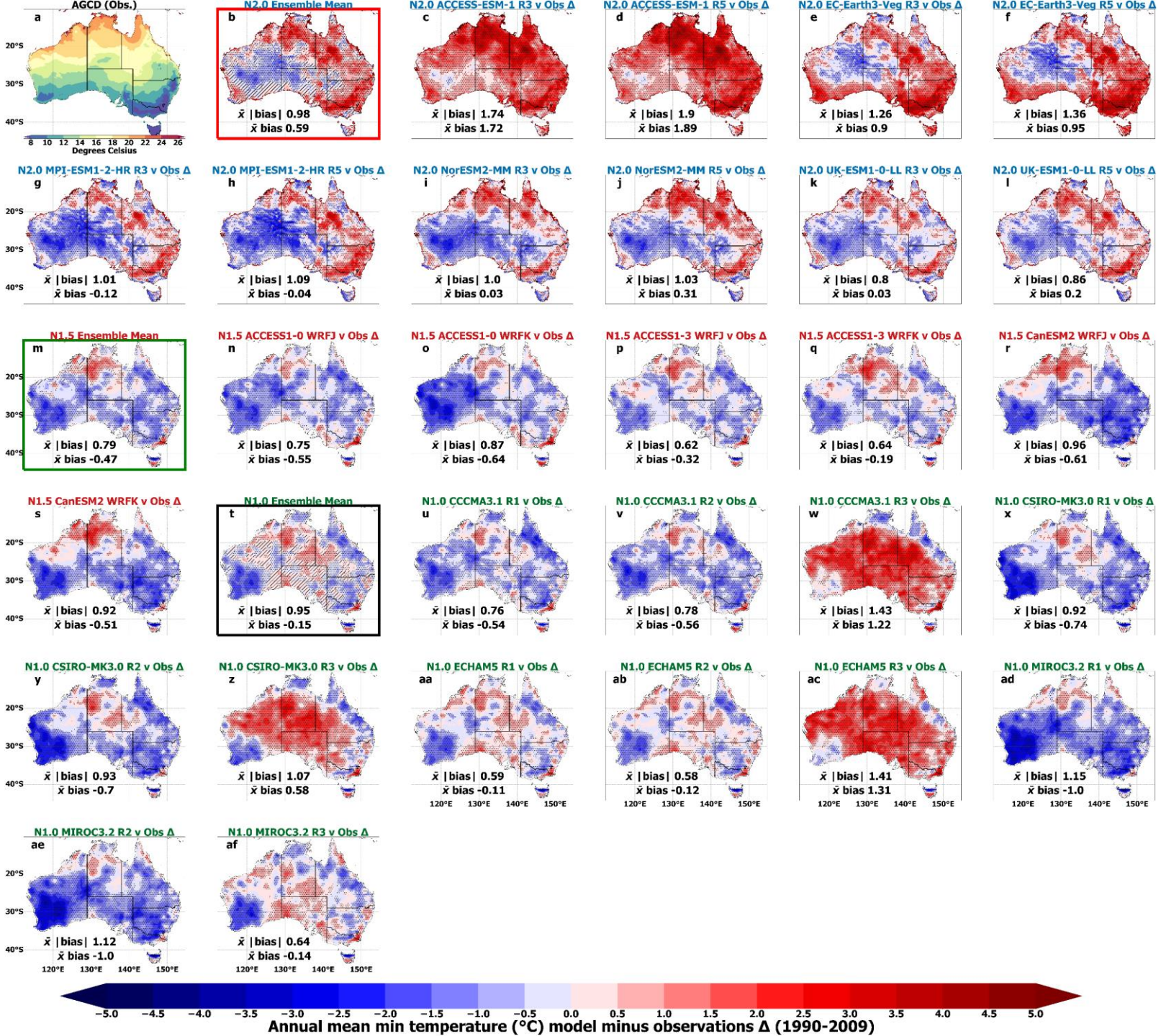


Fig. S8 Annual mean near-surface atmospheric minimum temperature biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Panel boundaries for ensemble means (b,m,t) in green (red) indicate the RCMs with lowest (highest) area-averaged mean absolute biases. Stippling as per Fig.S4.

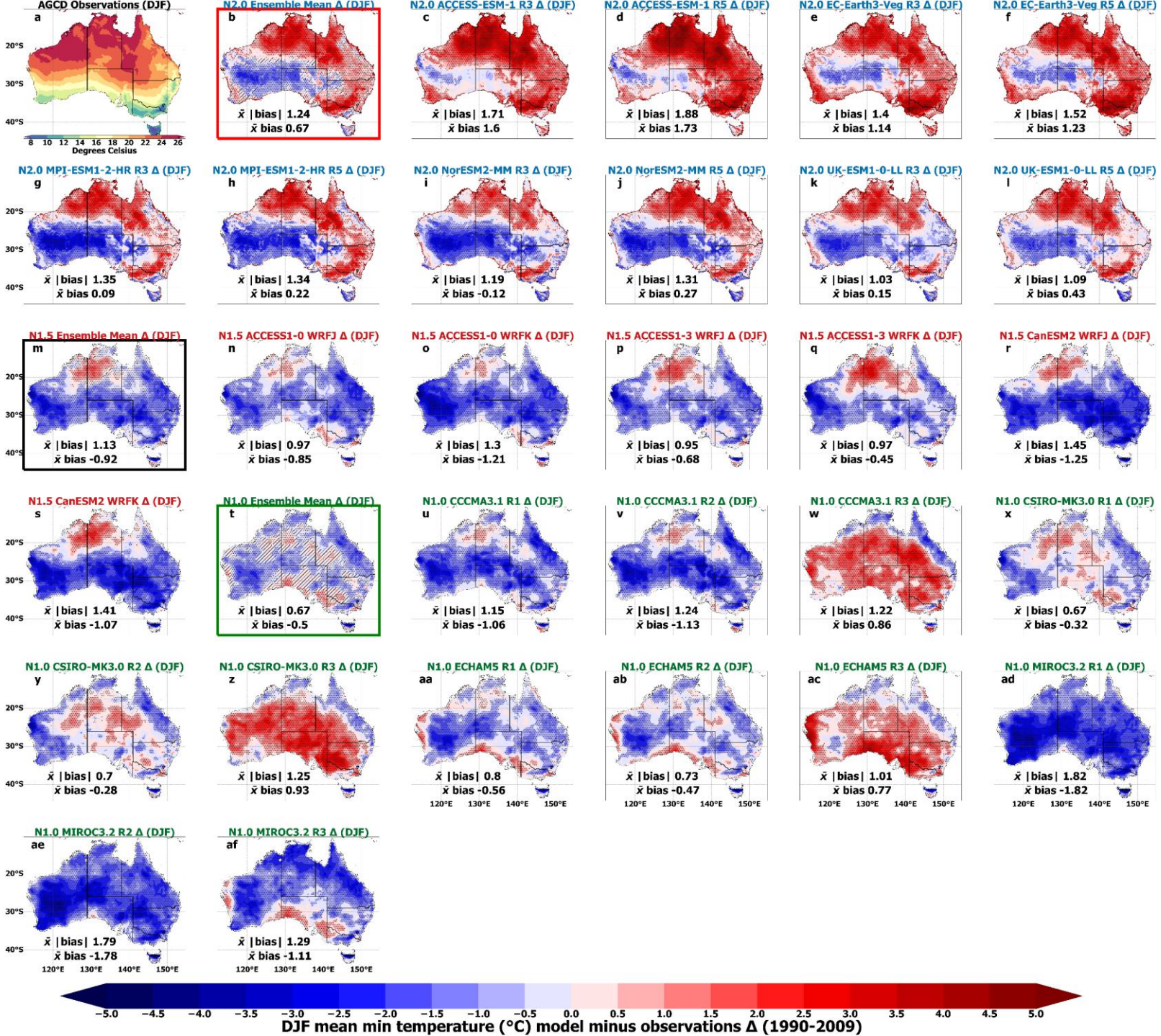


Fig. S9 DJF mean near-surface atmospheric minimum temperature biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Stippling as per Fig.S4.

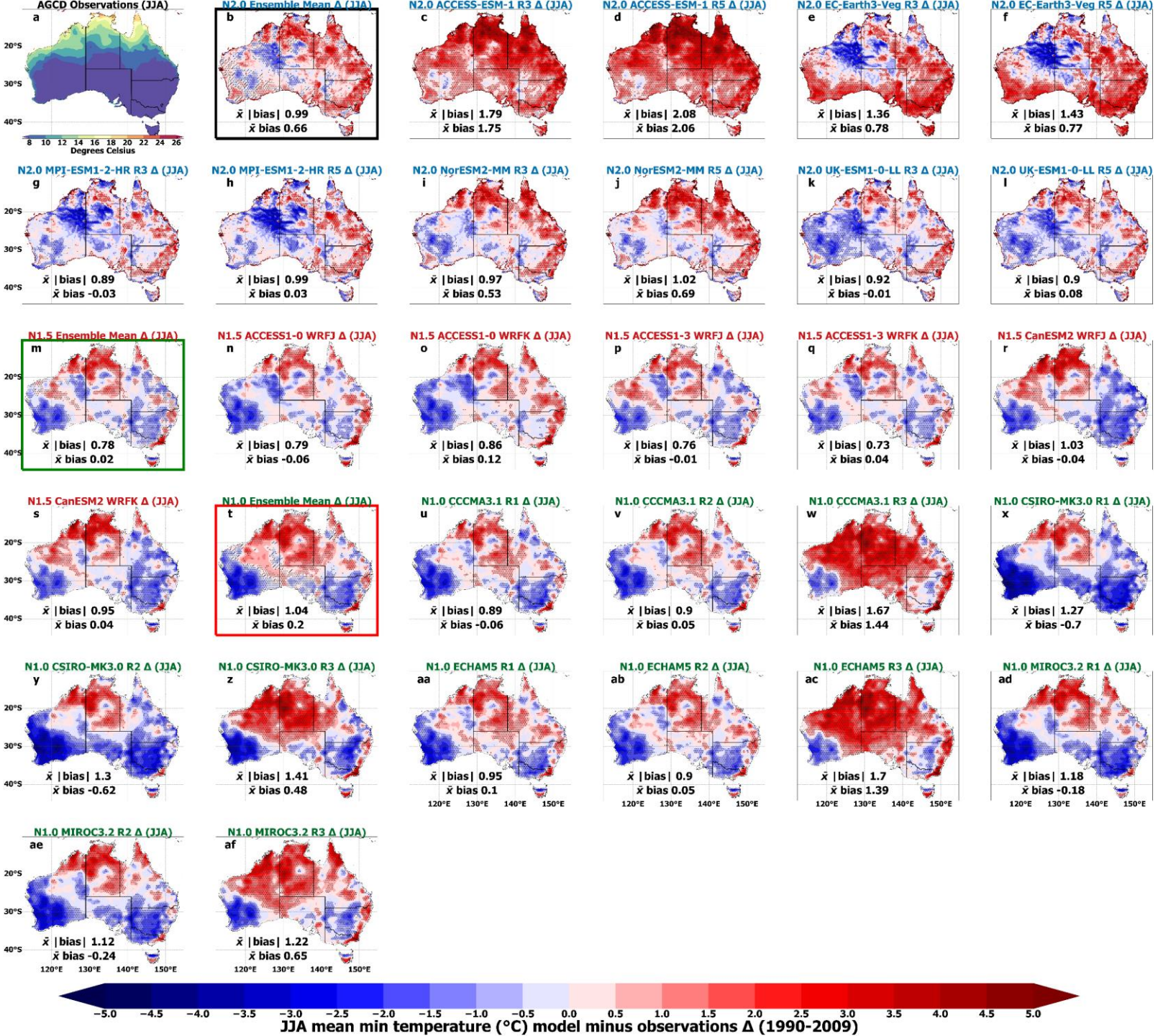


Fig. S10 JJA mean near-surface atmospheric minimum temperature biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Stippling as per Fig.S4.

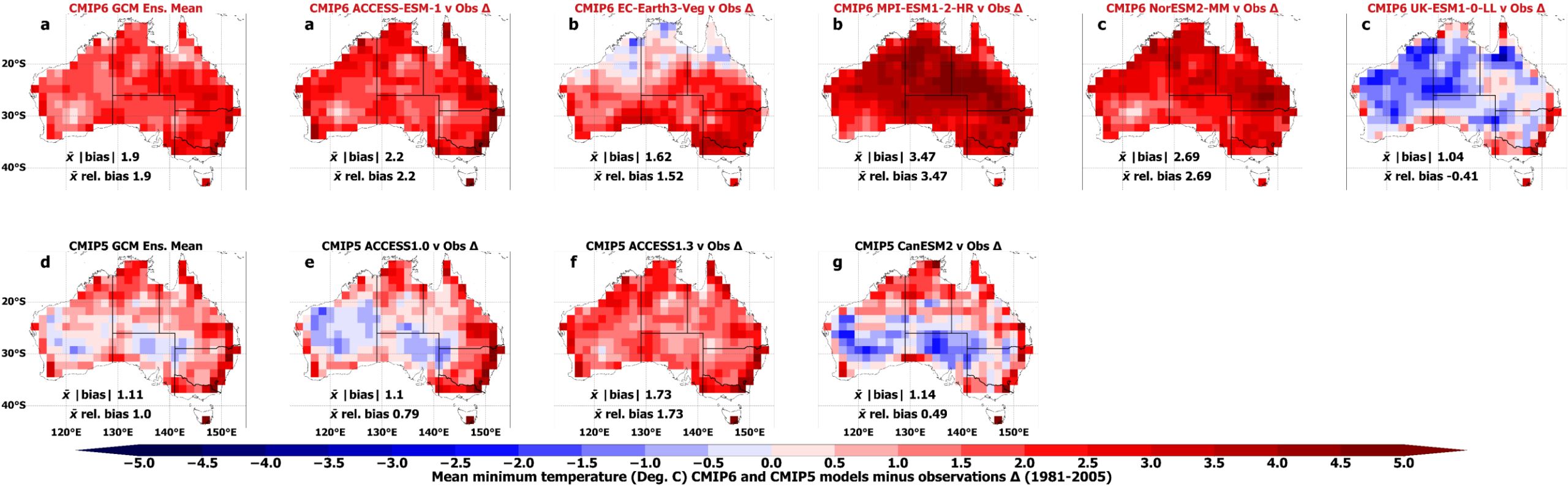


Figure S11. GCM annual mean minimum temperature bias relative to AGCD observations.

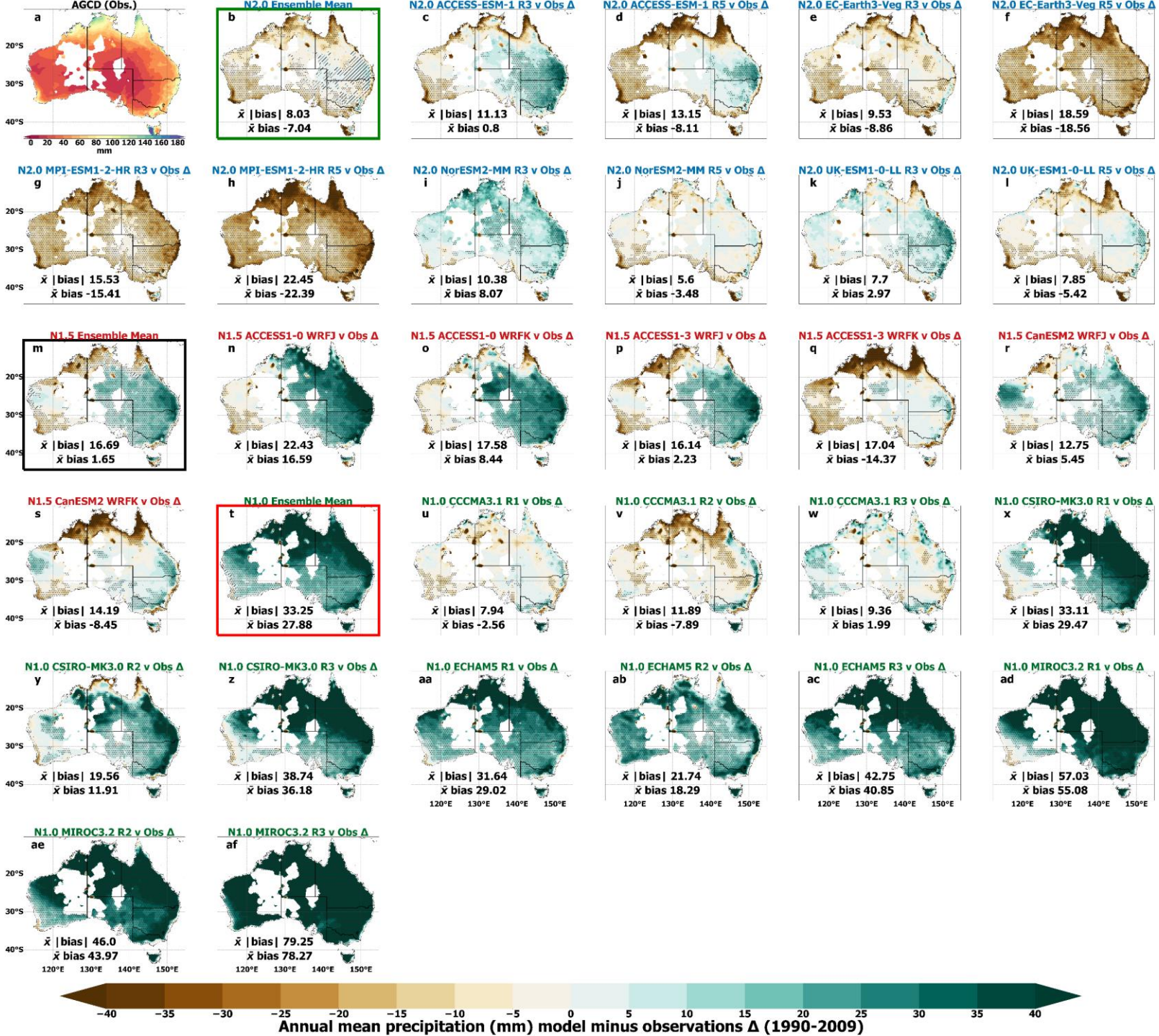


Fig.S12 Annual mean precipitation biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Panel boundaries for ensemble means (b,m,t) in green (red) indicate the RCMs with lowest (highest) area-averaged mean absolute biases. Stippling as per Fig.S4.

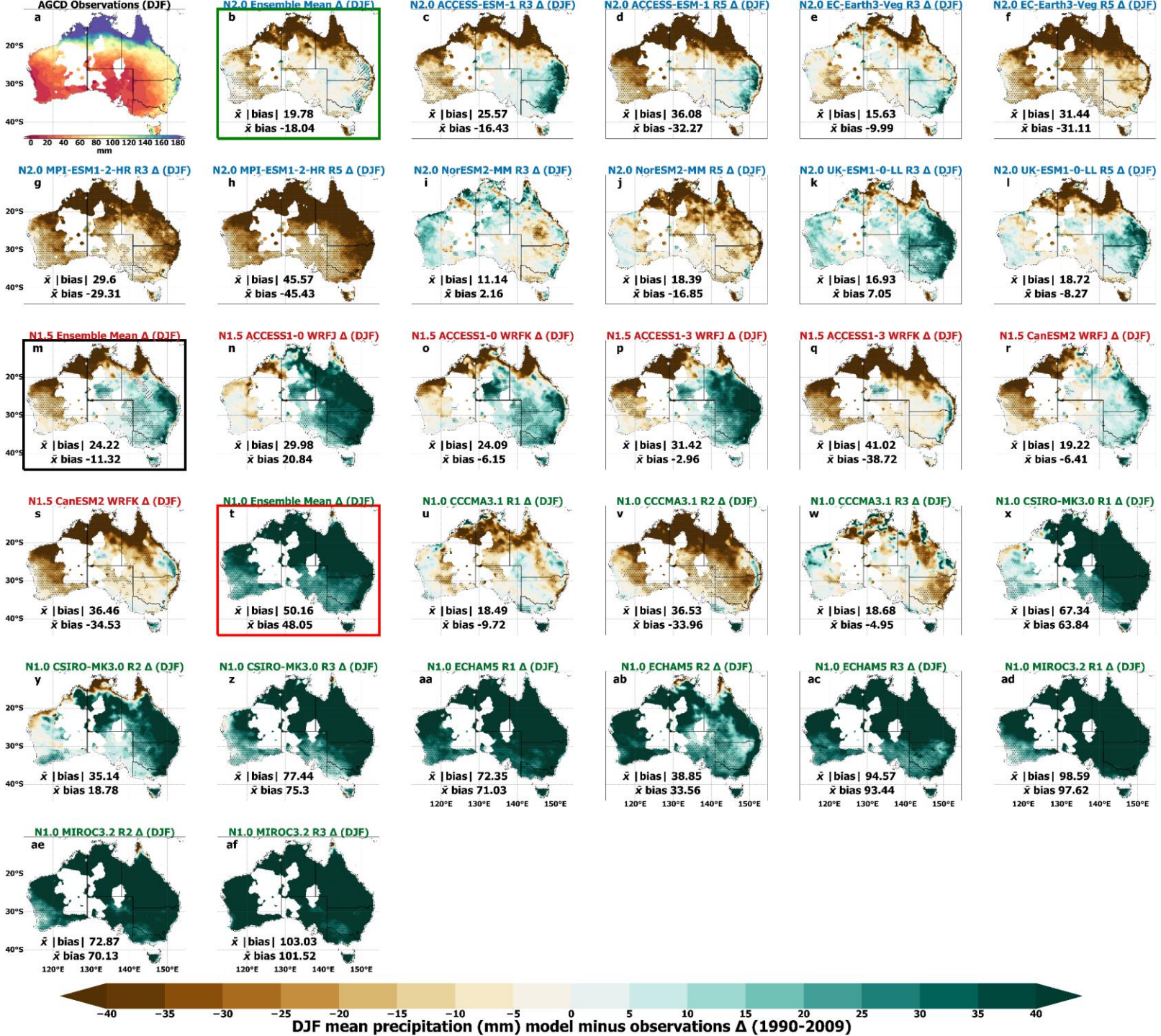


Fig. S13 DJF mean precipitation biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Stippling as per Fig.S4.

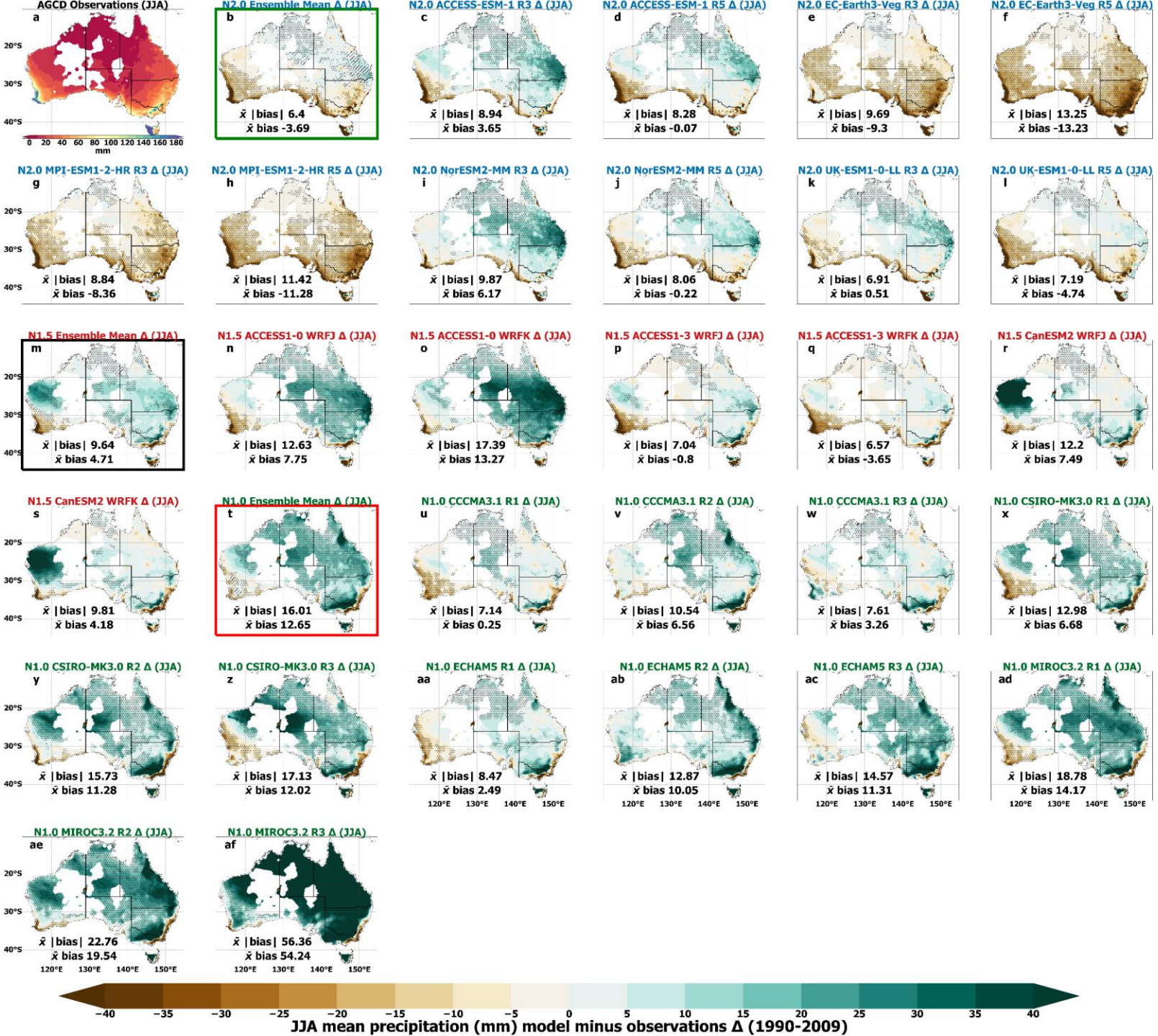


Fig. S14 JJA mean precipitation biases for NARCliM2.0, 1.5 and 1.0 ensemble means and individual ensemble members with respect to Australian Gridded Climate Data (AGCD) observations for 1990-2009. Stippling as per Fig.S4.

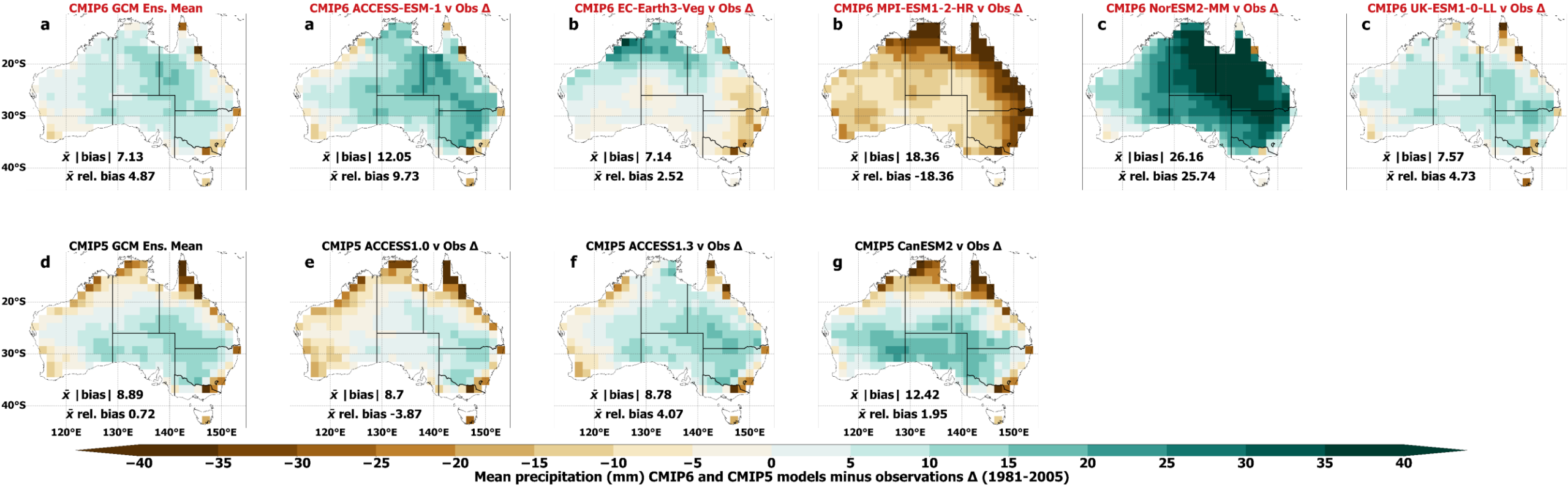


Figure S15. GCM annual mean precipitation bias relative to AGCD observations

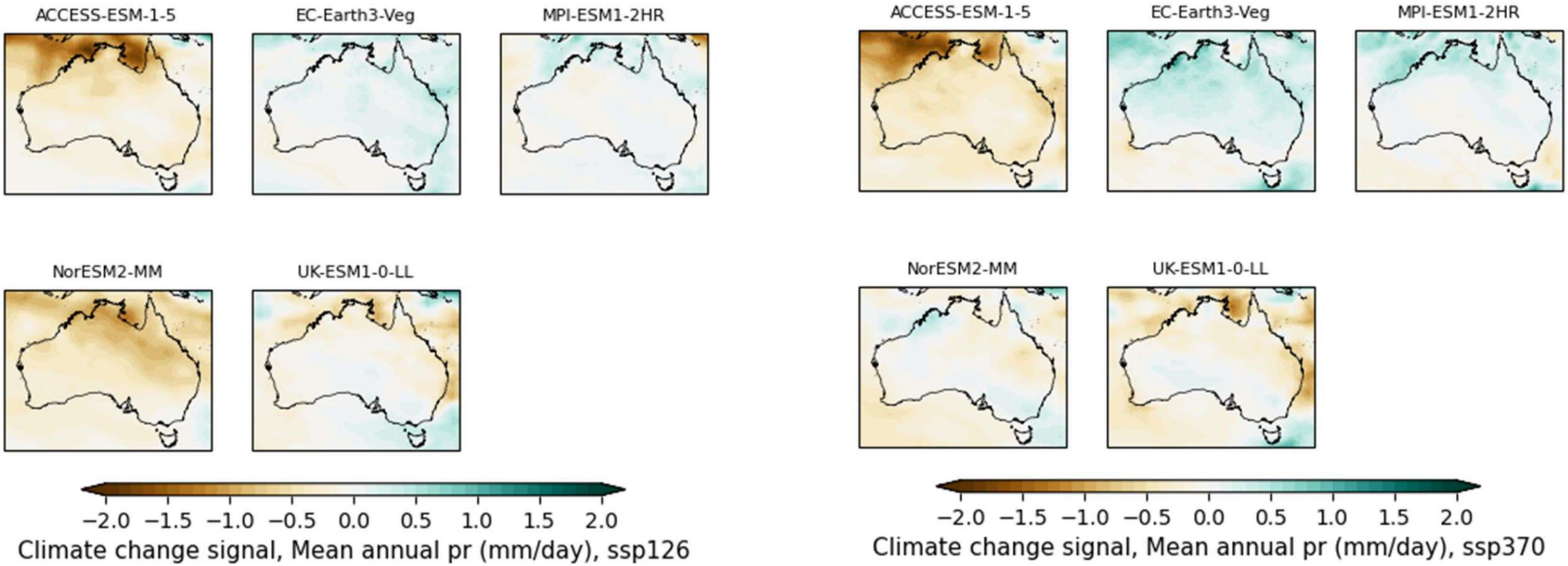


Fig. S16 Climate change signals (1990-2009 versus 2060-2079) for annual mean precipitation for CMIP6 GCMs under SSP1-2.6 (left panel) and CMIP6 GCMs under SSP3-7.0 (right panel) used to force NARCliM2.0 RCMs.