How Well do Coupled Models Simulate Present-day Mean Climate?

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A41E-0083

1. Motivation

Recently various modeling groups around the world produced climate change experiments in support of the 4th IPCC assessment report. The question addressed in this study is how the latest model improvements and the full range of external forcings considered in these simulations affect the ability of such models to match the observations of present-day climate. The answer to this question is important to give credible estimates of future climate change.

2. Methodology

We calculate mean climatologies (1979-1999) of various fields to verify model output against observations. We determine the model performance by calculating for each model and field a normalized mean-square error E^2 defined by

$$E^2 = \sum_{n=1}^{N} w_n \left(\frac{\overline{s}_n - \overline{o}_n}{\sigma_{n,o}} \right)^2$$

where $\sigma_{n,o}$ is the interannual standard deviation at grid point n derived from observations, and w_n are appropriate weights.

	Variable	Name	Observations	IPCC	CMIP	Reference
D	temperature (zonal mean)	ta (K)	ERA40	X	X	Simmons + Gibson (2000)
D	zonal wind (zonal mean)	ua (m/s)	ERA40	X	X	
D	meridional wind (zonal mean)	va (m/s)	ERA40	X	X	
D	meridional mass stream function	msv (10^9 kg/s)	ERA40	X		
D	temperature, 250 hPa	t250 (K)	ERA40	X		
D	zonal wind, 250 hPa	u250 (m/s)	ERA40	X		
D	meridional wind, 250 hPa	v250 (m/s)	ERA40	X		
D	zonal wind, 850 hPa	u850 (m/s)	ERA40	X		
D	meridional wind, 850 hPa	v850 (m/s)	ERA40	X		
D	geopotential, 500 hPa	z500 (m^2/s^2)	ERA40	X		
D	stream function, 250 hPa	psi250 ($10^6 m^2/s$)	ERA40	X		
D	velocity potential, 200 hPa	chi200 ($10^6 m^2/s$)	ERA40	X		
D	stationary waves, 500 hPa	twa500 (gpm)	ERA40	X		
D	sea level pressure	psl (hPa)	ECMWF	X	X	Woodruff et al. (1987)
D	zonal surface wind stress	tauu (N/m^2)	ECMWF	X	X	
D	meridional surface wind stress	tauv (N/m^2)	ECMWF	X	X	
F	surface air temperature, 2m	tas (K)	CRU	X	X	Jones et al. (1999)
F	surface skin temperature (over land)	ts (K)	ERA40	X		
F	specific humidity (zonal mean)	hus(g/kg)	ERA40	X	X	
F	total cloud fraction	cl (%)	ISCCP	X		Rossow et al. (1996)
F	outgoing lw radiation, top	rlut (W/m^2)	ISCCP	X		
F	outgoing sw radiation, top	rsut (W/m^2)	ISCCP	X		
F	cloud radiative forcing, lw, top	crlt (W/m^2)	ISCCP	X		
F	cloud radiative forcing, sw, top	crsut (W/m^2)	ISCCP	X		
F	incoming lw radiation, surface	rlds (W/m^2)	ISCCP	X		
F	outgoing lw radiation, surface	rlus (W/m^2)	ISCCP	X		
F	latent heat flux, surface	hfls (W/m^2)	GWFLUX	X		Yu and Weller (2006)
F	sensible heat flux, surface	hfss (W/m^2)	GWFLUX	X		
F	net heat flux, surface	hfns (W/m^2)	ECMWF+ISCCP		X	
F	precipitation	pr (mm/day)	CMAP	X	X	Xie and Arkin (1997)
F	precipitation minus evaporation	pme (mm/day)	CMAP/GWFLUX	X		
F	precipitable water	prw (mm)	NVAP			Randel et al. (1996)
F	snow fraction	snw(%)	NSIDC	X	X	Armstrong et al. (2005)
D	sea surface height	zos (m)	DINACS	X		Tapley et al. (2003)
D	sea surface temperature	tos (K)	GISST	X	X	Parker et al. (1995)
D	sea ice fraction, spatial variance	sic (%)	ISCCP	X	X	Parker et al. (1995)
D	sea surface salinity, spatial variance	sos (‰)	NODC	X	X	Levitus et al. (1998)

For the comparison we renormalize E^2 with the average E^2 over all models:

$$I_m^2 = \frac{E_m^2}{\overline{E^2}^m}$$

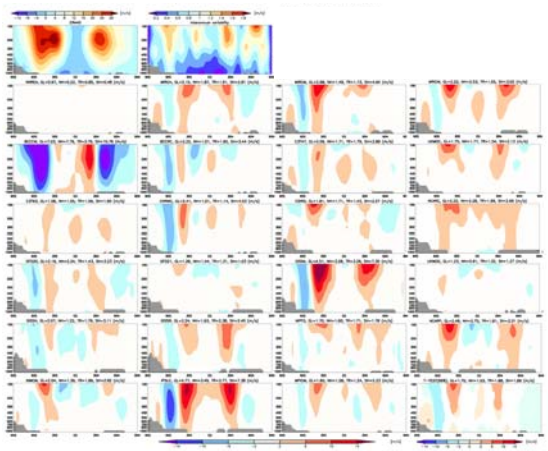
Finally, we aggregate all errors of one model into one single index of model performance:

$$\overline{I_m^2}^v$$

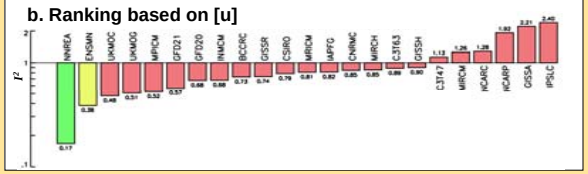
<1: better than average
>1: worse than average

3. Zonal Mean Zonal Wind: IPCC-AR4

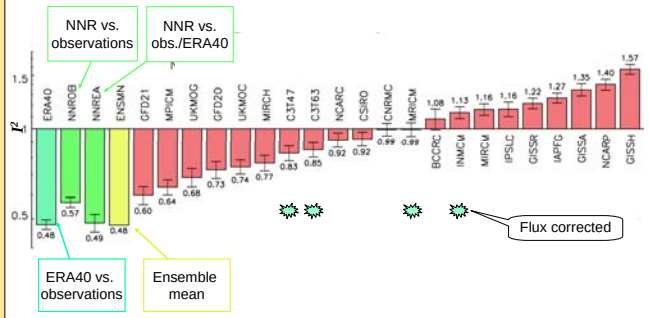
a. Individual models verified against ERA-40



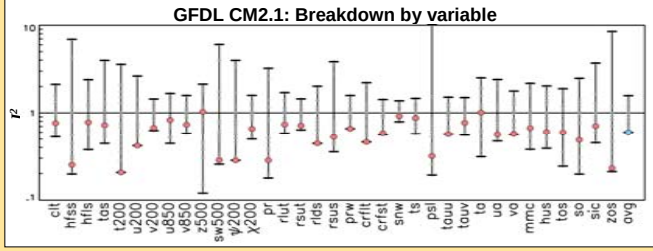
b. Ranking based on [u]



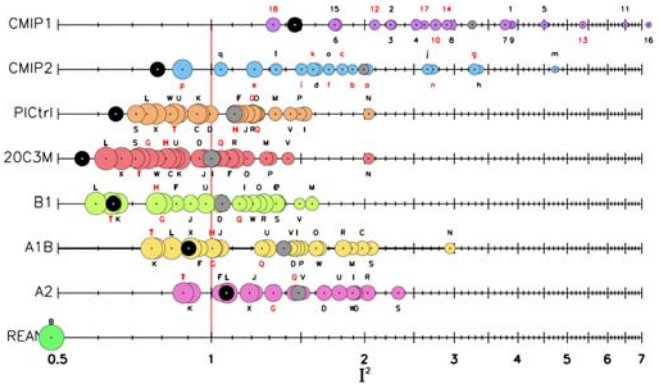
4. IPCC-AR4 (20C3M): 35 Variables



GFDL CM2.1: Breakdown by variable



5. Three Model Generations: 15 Variables

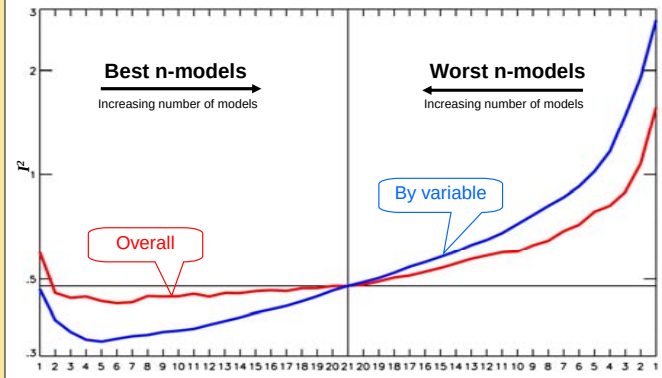


A:ERA40 a:BMRC
Z:NNROB b:CCCM
B:NNREA c:CCSR
C:MIRCH d:CERF
D:MIRCM e:CSIR
E:BCCCM f:ECH3
F:BCCRC g:GFDL
G:C3T47 h:GISS
H:C3T63 i:IAPF
I:CNRMC j:LMDF
J:CSIRO k:MRIC
K:GFD20 l:NCRC
L:GFD21 m:NCRW
M:GISSA n:NRLM
N:GISSH o:PCMD
O:GISSR p:UKMO
P:IAPFG q:UKM3
Q:INMCM
R:IPSLC
S:MPICM
T:MRICM
U:NCARC
V:NCARP
W:UKMOC
X:UKMOG

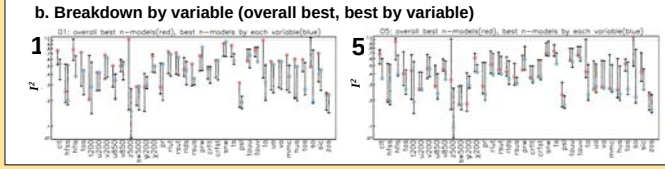
01:BMRC COMMENTS
02:CCCMA PICtrl: NO OUTPUTS (E)
03:CCSR SRESB1: NO OUTPUTS (E,N,X)
04:CERF SRESA1B: NO OUTPUTS (E)
05:COLA SRESA2: NO OUTPUTS (C,E,H,M,N,P)
06:CSIR JRA25: 0.39
07:GFDL JRA25 agoinst OBS: 0.19
08:GISSM ERA40 agoinst OBS: 0.34
09:GISSR NNREA agoinst OBS: 0.36
10:IAPF 20C3M: BCCCM(E): 14.4: Extreme outlier
11:LMDF
12:MPIE3
13:MPIE4
14:MRIC
15:NCRC
16:NCRW
17:NRLM
18:UKMO

6. Performance of the Ensemble Mean

a. Performance of Increasing Number of Models

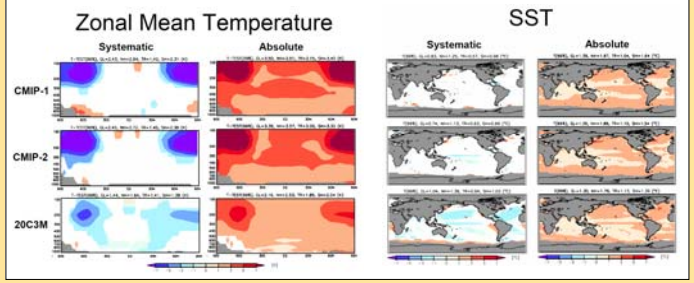
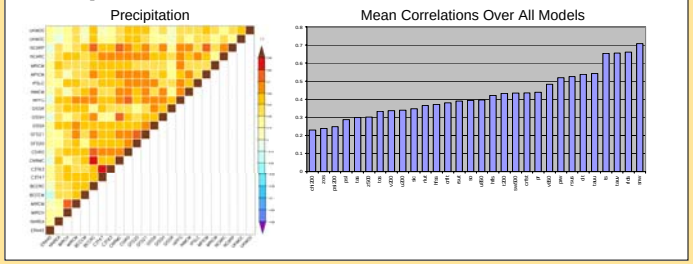


b. Breakdown by variable (overall best, best by variable)



7. Errors by Model Generation

- Systematic $\overline{e_n}^m = \overline{s_n - o_n}^m = \overline{s_n}^m - o_n$
- Absolute $\overline{|e_n|}^m = \overline{|s_n - o_n|}^m$



8. Spatial Correlations of Error Patterns