Evaluating Climate Model Simulations of Clouds, Radiation, and Precipitation

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From forecast skill…

Weather forecasts have improved steadily since the advent of NWP in the 1980s. We know this because forecast skill has been measured uniformly over time using simple metrics.

Forecasts are verified
- using low-order statistical measures: bias, RMS error, anomaly correlation
- against 1) analyses and 2) point observations
- using aspects of the flow: temperature and winds on select levels; sea-level pressure; geopotential height

Clouds and radiation are not part of forecast verification (and precip. scores are not exchanged)
- Verifying datasets are harder to come by:

1) clouds are a by-product of the analysis (cloud observations aren't assimilated),
2) point measurements are subject to large sampling errors
- cloud processes feed back on the flow fairly slowly

… to cloud metrics

Climate models have not been evaluated consistently across time or across models
- Climate models are built to project change but can only be evaluated against the present day climate
- Evaluation is necessarily statistical, but it's not known which statistics are relevant for climate change
- There is no routine context for climate models.

Climate models have changed a lot since 1990, but the range of climate sensitivity has not decreased much. Are we making progress? How can we show progress?

Climate model evaluation would likely include clouds and radiation
- Clouds and cloud feedbacks drive much of the range in climate response between models
- Observations for statistical evaluation are very good

This poster describes a set of metrics for evaluating the simulation of present-day clouds, radiation, and precipitation by climate models. We show these scores for the models that participated in IPCC AR4.

Scoring the IPCC AR4 models

Quantities and datasets (primary/secondary)
- Net, SW, LW cloud radiative effect vs. CERES (ERBE)
- Cloud fraction vs. ISCCP (MODIS)
- Surface precipitation vs. GPCP (Xie-Arkin)
- Net, SW, LW fluxes vs. CERES (ERBE)

Low-order statistical summaries
- RMS error; bias; centered RMS error; correlation; $\sigma_{model}/\sigma_{obs}$
- Statistics computed over space (area-weighted) and mean annual cycle

Time and space domain
- Datasets averaged, re-grided to form mean annual cycle on 2.5° grid
- Models evaluated using 1979-1999
- Ensemble are averaged

Participating models
- 20th Century and AMIP runs from IPCC AR4 archives
- "IPCC mean model:" average across all models
- "Super-parameterized" CAM (1986-1999)
- ERA-40 24 hr. accumulated fields from 12Z analyses

2nd Obs. data set	bccr bcm2.0	cccma cgcm3.1	cccma cgcm3.1 t63	cnrm cm3	cnrm cm3 (amip)	csiro mk3.0	gfdl cm2.0	gfdl cm2.1	giss aom	giss model e h	giss model e r	giss model e r (amip)	iap fgoals1.0g	iap fgoals1.0g (amip)	inmcm3.0	inmcm3.0 (amip)	ipsl cm4	ipsl cm4 (amip)	miroc3.2 hires	miroc3.2 hires (amip)	miroc3.2 medres	miroc3.2 medres (amip)	miub echo-g	mpi echam5	mpi echam5 (amip)	mri cgcm2.3.2a	mri cgcm2.3.2a (amip)	ncar ccsm3.0	ncar ccsm3.0 (amip)	ncar pcm1	ukmo hadcm3	ukmo hadgem1	ukmo hadgem1 (amip)	all model mean	all model mean (amip)	csu mmf (amip)	ecmwf		
6.81	20.1	20.2	19.9	21.7	20.9	19.6	18.4	18.6	16.8	19.8	20	19.1	19.1	17.7	18	16.6	18.5	16.9	19.6	18.3	21.2	20.8	17.9	16.8	15.6	19.2	20.2	16.6	16.3	22.4	18.1	15.2	14.2	13.1	12.7	18.9	25.9		Net flux	RMSE
6.79	19.9	19.8	19.3	21.3	19.5	19.3	18	18	16.7	19.6	19.8	18.7	19.1	17.6	17.9	16.6	17.5	15.5	19.1	17.9	20.9	20	17.8	16.3	15.3	19.1	19.6	16.2	15.9	22	17.6	14.5	13.3	12.5	11.8	18.1	22.4			Cent. RMSE
−0.558	−2.64	−4.02	−4.76	−3.92	−7.48	−3.23	−4.06	−4.4	−1.69	−2.88	−2.64	−3.69	−0.403	−1.81	−2.33	1.36	−5.95	−6.76	−4.37	−3.74	−3.58	−5.66	−0.588	−3.81	−3.22	−1.36	−4.83	−3.6	−3.7	−4.43	−4.27	−4.7	−4.9	−3.81	−4.53	−5.43	−12.9			Bias
0.998	0.976	0.977	0.977	0.973	0.978	0.978	0.98	0.979	0.983	0.977	0.977	0.98	0.977	0.981	0.982	0.984	0.982	0.986	0.977	0.98	0.972	0.975	0.981	0.983	0.985	0.977	0.976	0.984	0.984	0.969	0.982	0.988	0.989	0.991	0.992	0.981	0.968			Correlation
0.965	0.933	0.978	0.983	0.914	0.908	0.915	0.955	0.974	0.979	0.965	0.955	0.957	0.942	0.937	0.965	0.984	0.972	0.967	0.976	0.97	0.958	0.95	0.96	0.972	0.971	0.961	0.95	0.956	0.96	0.987	0.942	0.947	0.958	0.945	0.943	0.926	0.939			$\sigma_{model}/\sigma_{obs}$
8.56		24.7	24.5	24.2	25.9	23.7	21.8	20.9		24.5	27.4	27.2	25.9		21.1	19.2	21.6	20.3	22.5	21.9	23.7	23.9	21	20.1	19.3	22.9	24.2	20.1	19.1	24.6	24.1	19.9	17.2	17.8	17.1	23.1	30.9		Net CRE	RMSE
8.34		24.6	24.3	20.9	20.1		23.1	21.7		24.5	27.4	27.2	25.1		20.6	19	21.8	20	22.5	21.9	23	23.4	21	19.9	19.1	22.1	22.2	19.8	18.7	24.4	22.9	19.9	17.2	17.7	16.9	21.6	26.2			Cent. RMSE
1.94		2.12	2.67	−2.3	−2.37	5.28	−6.34	−5.73		0.2	0.358	−0.132	6.5		4.59	2.86	0.952	3.61	−1.28	−0.02	−5.53	−4.43	0.046	−3.18	−2.73	−5.73	−9.47	−3.33	−3.67	−3.19	−7.48	−0.126	0.629	−1.91	−2.72	−8.19	−16.5			Bias
0.96		0.667	0.634	0.685	0.645	0.687	0.749	0.76		0.709	0.634	0.644	0.596		0.801	0.841	0.814	0.821	0.703	0.717	0.737	0.723	0.77	0.797	0.811	0.769	0.786	0.781	0.808	0.688	0.753	0.771	0.831	0.816	0.837	0.765	0.584			Correlation
0.978		0.722	0.754	0.942	0.96	0.882	0.907	0.852		0.839	0.852	0.87	0.701		0.876	0.973	1.03	1.04	0.886	0.881	1.03	1.02	0.77	1.04	1.02	1.07	1.14	0.95	0.97	0.979	0.994	0.896	0.898	0.824	0.907	1.02	0.854			$\sigma_{model}/\sigma_{obs}$
6.25	15.4	12.7	13.3	16	14.2	16.5	12.7	12.4	15	15.6	13.9	11.9	16.3	17.3	16.6	12.7	14.3	13	12.7	10.5	14	12.5	12.8	13.5	12	12.3	13.3	14.9	14.6	18.7	12.1	13.9	13.1	9.84	8.45	10.1	10.7	OLR	RMSE
5.16	14.2	12.6	13.1	14.6	13.7	15.6	11.9	12.3	12.9	15.5	13.9	11.9	14.5	14.7	15.9	12	14.2	13	12.7	10.5	12.8	11.9	11.8	11.9	10.4	11.5	12.9	14.2	14.2	18.6	12.1	13.8	12.7	9.22	8.08	10.1	8.76			Cent. RMSE
−3.53	−5.97	−1.23	−2.42	−6.67	−3.67	−5.58	−4.43	−1.16	−7.82	1.35	−0.461	0.147	−7.39	−9.19	−4.83	−4.23	−2.04	−0.05	0.05	−0.16	−5.63	−3.62	−4.86	−6.2	−5.97	−4.23	−3.5	−4.36	−3.37	−2.07	0.222	1.57	3.24	−3.44	−2.49	−0.83	6.11			Bias
0.988	0.916	0.945	0.938	0.908	0.926	0.899	0.936	0.933	0.931	0.903	0.924	0.945	0.905	0.901	0.893	0.939	0.925	0.943	0.931	0.953	0.93	0.942	0.941	0.936	0.951	0.943	0.928	0.916	0.917	0.881	0.946	0.934	0.941	0.962	0.971	0.959	0.965			Correlation
1	1.03	1.1	1.11	1.01	1.07	1.05	0.989	1.01	0.861	1.01	1.04	1.04	1.02	1	0.965	0.961	1.08	1.12	1.03	1.04	1.01	1.05	0.975	0.992	0.974	1.01	1	1.06	1.05	1.16	1.08	1.14	1.11	0.99	1	1.04	0.972			$\sigma_{model}/\sigma_{obs}$
6.56		11.5	11.7	14.9	13.8	15.9	11.1	11.6		13.8	12.6	11.6	12.5		14	11.6	13.4	12.8	11.4	10	11.8	10.9	11.2	10.6	9.76	11.7	12.3	13.5	13.6	16.1	12.1	11.6	11	9.25	8.61	10.5	12.4		LW CRE	RMSE
6.22		11.5	11.7	13.4	12.7	14.6	10.7	10.8		13.6	12.4	11.4	12.5		14	11.6	12.8	12.4	11.4	9.93	11.8	10.9	11.2	10.6	9.73	10.4	11.4	13.3	13.2	16	10.5	11.3	10.9	9.25	8.61	9.74	9.77			Cent. RMSE
2.08		−0.283	0.181	6.5	5.32	6.26	−2.85	−4.2		−1.83	−2.27	−2.22	0.852		0.443	0.412	2.91	2.98	−0.795	−1.15	−0.155	−0.33	0.069	0.556	0.757	−5.42	−4.55	2.74	3.32	1.84	−6.09	−2.37	−1.79	−0.027	0.027	−3.88	−7.62			Bias
0.931		0.724	0.723	0.673	0.714	0.693	0.77	0.762		0.559	0.64	0.698	0.681		0.62	0.728	0.713	0.744	0.754	0.805	0.749	0.777	0.733	0.785	0.818	0.774	0.727	0.725	0.731	0.618	0.763	0.75	0.763	0.829	0.854	0.881	0.807			$\sigma_{model}/\sigma_{obs}$
1.03		0.884	0.888	1.02	1.04	1.2	0.886	0.848		0.808	0.815	0.817	0.9		1.02	0.981	1.08	1.12	0.959	0.901	1.02	0.996	0.839	0.95	0.94	0.811	0.823	1.13	1.15	1.19	0.831	0.929	0.893	0.844	0.868	0.909	0.814			$\sigma_{model}/\sigma_{obs}$
8.99	25.6	22.2	22.4	27	24.9	24.3	22.2	21.1	22.3	23.1	22.9	21.6	24.2	25.6	23.1	19.5	23.2	20.4	20.6	20	25	24.2	21	22	20.1	24	26.2	22.1	21.6	24.9	20	16.9	15.8	16.6	15.8	21.2	25.9		Net SW	RMSE
8.03	24.1	21.3	21.2	24.9	22.8	22.6	20.5	20.3	20.1	23	22.7	21.3	22.9	23.2	22	19.3	21.8	19.3	20.2	19.7	23.2	22.4	20.3	19.6	17.8	23.3	24.8	20.6	20.4	24	19.6	16.6	15.8	14.9	14.1	20.2	25			Cent. RMSE
−4.05	−8.61	−6	−7.11	−10.6	−11.1	−8.79	−8.48	−5.55	−9.54	−1.48	−3.05	−3.51	−7.75	−11	−7.17	−2.88	−7.98	−6.76	−4.32	−3.89	−9.21	−9.27	−5.45	−10	−9.22	−5.61	−8.35	−7.95	−7.07	−6.47	−4.02	−3.08	−1.62	−7.24	−7	−6.27	−6.82			Bias
0.997	0.976	0.983	0.982	0.975	0.98	0.981	0.982	0.983	0.985	0.98	0.981	0.983	0.978	0.978	0.983	0.986	0.982	0.986	0.983	0.984	0.978	0.98	0.984	0.984	0.987	0.977	0.975	0.982	0.983	0.976	0.985	0.988	0.99	0.991	0.992	0.983	0.974			Correlation
0.977	0.963	0.995	1	0.935	0.943	0.916	0.967	0.982	0.971	0.977	0.976	0.975	0.962	0.931	0.952	0.972	1	1	0.973	0.974	0.958	0.96	0.968	0.977	0.975	0.988	0.978	0.967	0.964	1	0.974	0.993	0.997	0.961	0.96	0.957	0.941			$\sigma_{model}/\sigma_{obs}$
11.2		26.9	26.7	29.9	31.4	27.1	23.8	22.4		26.4	29	28.6	30.2		25.5	22.5	25.8	24.1	25.6	25.9	27.3	27.7	24.1	23	21.9	26.1	27.5	25.7	24.8	27.3	25.2	22.8	20.7	20.8	20.2	25.1	30.1		SW CRE	RMSE
11.2		26.8	26.6	28.5	30.4	27	23.6	22.3		26.3	28.8	28.5	29.7		25.2	22.4	25.7	24.1	25.6	25.8	26.8	27.4	24.1	22.7	21.6	26.1	27.1	25	23.8	26.8	25.1	22.7	20.5	20.7	20	24.7	28.8			Cent. RMSE
−0.07		2.4	2.52	−6.78	−7.74	−1.04	−3.46	−1.45		2.23	2.83	2.27	5.64		4	2.2	−2.93	2.26	−0.43	1.2	−5.33	−4.07	−0.06	−3.8	−3.57	−0.314	−4.93	−4.07	−7	−5.26	−1.27	2.3	2.47	−1.88	−2.74	−4.32	−8.75			Bias
0.947		0.692	0.669	0.674	0.64	0.656	0.754	0.772		0.733	0.679	0.69	0.572		0.761	0.821	0.779	0.787	0.695	0.688	0.71	0.696	0.766	0.799	0.815	0.753	0.753	0.735	0.761	0.711	0.757	0.772	0.813	0.805	0.823	0.764	0.649			Correlation
1.01		0.766	0.754	0.989	1.02	0.837	0.913	0.848		0.861	0.868	0.884	0.777		0.896	0.962	1.09	1.02	0.837	0.839	0.98	0.98	0.869	1.05	1.03	1.08	1.14	0.97	0.973	0.985	0.966	0.915	0.906	0.832	0.898	1.02	0.97			$\sigma_{model}/\sigma_{obs}$
8.53	15.8	16.4	15.4	16.8	16.3	14.6	14.5	15.8	16	19.9	19.2	18.9	19.1	20	16	14.3	16.8	17.7	18.5	18.6	19.4	19.6	17.7	14.5	13.6	21.8	21.5	17.2	17	20.6	23.1	17.5	17.5	12.5	13.6	26.1	12.1	CF	RMSE
8.53	15.7	14.9	14.5	15.3	15.2	14.5	14.5	15.3	15.5	18.5	18.2	17.9	19.1	19.9	16	14.3	16.5	16.9	12.8	12.2	14.4	14.3	16.7	14.1	13.3	15.4	15.7	13.4	13.5	19.3	13.7	12.4	11.9	10.9	10.5	13.1	11.8			Cent. RMSE
0.335	1.28	−6.86	−5.23	6.94	5.91	−1.16	−0.933	−3.93	−3.81	−7.24	−5.89	−5.95	−1.21	−2.23	0.172	−0.247	−3.13	−5.12	−13.4	−14	−13	−13.4	−6.04	−3.02	−2.75	−15.4	−14.7	−10.8	−10.3	−7.23	−18.6	−12.4	−12.9	−6.21	−8.72	−22.6	−2.85			Bias
0.912	0.686	0.673	0.692	0.683	0.702	0.657	0.692	0.692	0.718	0.532	0.543	0.579	0.331	0.294	0.577	0.66	0.687	0.693	0.784	0.811	0.747	0.764	0.544	0.712	0.738	0.692	0.679	0.678	0.673	0.494	0.704	0.813	0.823	0.795	0.811	0.732	0.802			Correlation
1.19	1.24	1.14	1.13	1.19	1.23	1.04	1.13	1.22	1.31	1.23	1.22	1.25	0.909	0.935	1.07	1.06	1.33	1.38	1.2	1.22	1.25	1.29	1.04	1.14	1.12	1.22	1.22	0.95	0.945	1.2	1.08	1.24	1.22	0.972	0.983	1.07	1.14			$\sigma_{model}/\sigma_{obs}$
1.29	1.97	1.77	1.86	2.14	2.19	1.84	2.05	2.09	1.9	2.27	2.07	2.02	1.79	1.8	2.31	1.86	1.92	1.71	1.79	1.78	1.73	1.68	1.67	2.15	2.04	1.64	1.92	2.09	2	2.84	2.13	2.3	2.3	2.19	1.55	1.55	1.9	2.04	PR	RMSE
1.29	1.93	1.77	1.86	2.04	2.04	1.84	2.04	2.07	1.89	2.25	2.05	2	1.75	1.79	2.31	1.84	1.92	1.71	1.76	1.75	1.72	1.67	1.67	2.13	2.01	1.64	1.92	2.08	1.98	2.8	2.11	2.26	2.13	1.53	1.51	1.89	1.87			Cent. RMSE
0.069	0.392	0.056	0.133	0.651	0.784	−0.09	0.149	0.274	0.21	0.279	0.221	0.25	0.394	0.128	0.163	0.246	−0.01	0.023	0.336	0.317	0.08	0.126	0.095	0.313	0.318	−0.026	0.027	0.216	0.28	0.481	0.268	0.435	0.505	0.256	0.314	0.198	−0.815			Bias
0.867	0.665	0.72	0.716	0.632	0.684	0.69	0.702	0.69	0.62	0.531	0.628	0.649	0.676	0.662	0.519	0.655	0.664	0.713	0.754	0.734	0.74	0.762	0.737	0.665	0.72	0.765	0.705	0.664	0.669	0.501	0.7	0.699	0.697	0.778	0.786	0.741	0.581			$\sigma_{model}/\sigma_{obs}$
1.16	1.13	1.17	1.19	1.14	1.26	1.09	1.28	1.27	1.08	1.22	1.25	1.26	0.966	0.973	1.23	1.12	1.16	1.09	1.19	1.13	1.14	1.16	1.13	1.26	1.3	1.14	1.21	1.22	1.16	1.43	1.38	1.42	1.33	1.05	1.07	1.27	0.789			$\sigma_{model}/\sigma_{obs}$

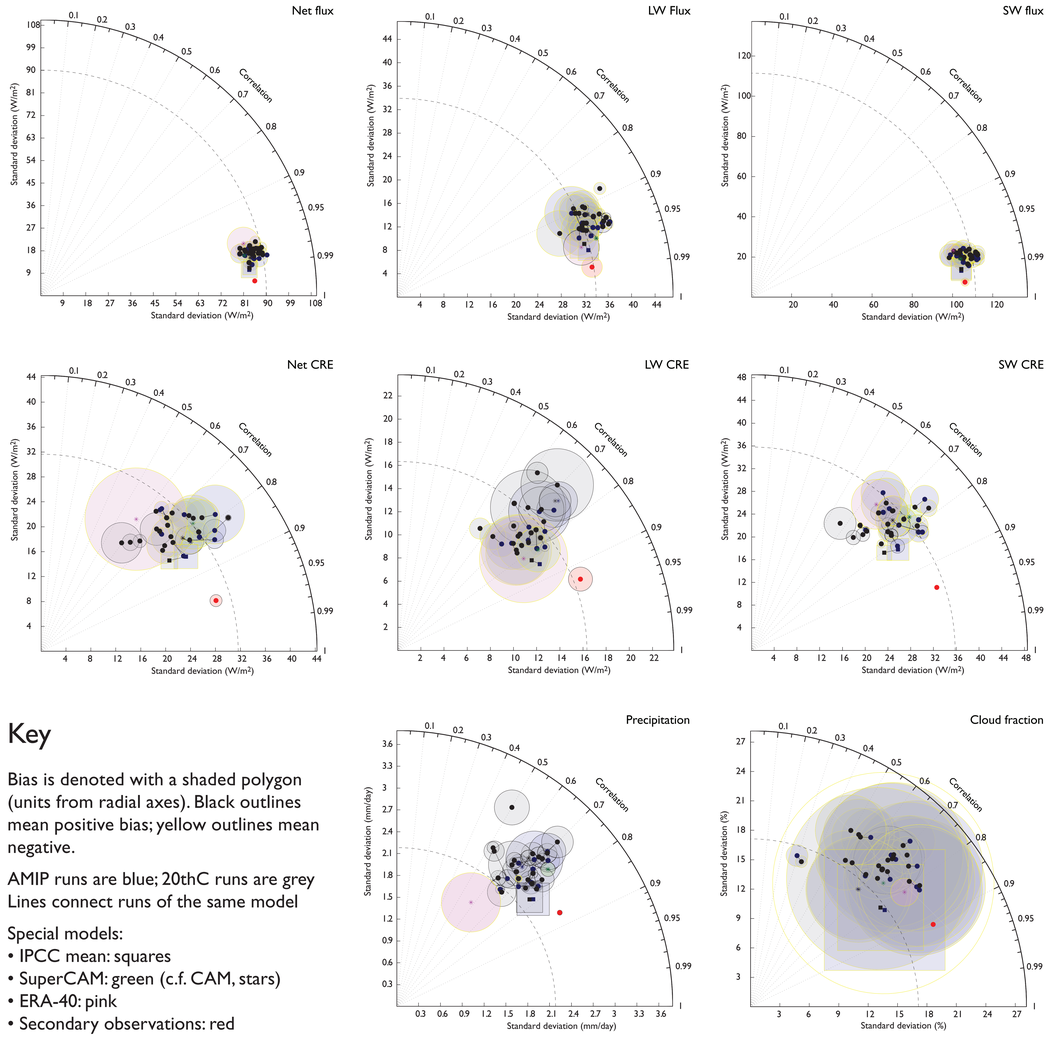
Don't try to read the numbers

Results in each row are shaded linearly to denote distance from perfect agreement: runs closest to the observations are blue; furthest from the observations are red
The second set of obs is shaded on the same scale

Notice:

- In almost all cases models are further from the observations than the secondary data set
- No model does best on all scores, though some do well on many
- The "IPCC mean model" is closer to the observations than any individual model on many scores
- There is no dramatic change in relative skill between 20thC and AMIP runs of the same model
- The SuperCAM is not uniformly closer to the observations then the CAM, according to these measures
- ERA-40 is further from the observations than most climate models

Taylor diagrams for cloud metrics



Key

Bias is denoted with a shaded polygon (units from radial axes). Black outlines mean positive bias; yellow outlines mean negative.

AMIP runs are blue; 20thC runs are grey
Lines connect runs of the same model

Special models:
- IPCC mean: squares
- SuperCAM: green (c.f. CAM, stars)
- ERA-40: pink
- Secondary observations: red