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The Cryosphere Discussions

Interactive comment on "How does internal variability influence the ability of CMIP5 models to reproduce the recent trend in Southern Ocean sea ice extent?" *by* V. Zunz et al.

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The authors thank Anonymous Referee #2 for the constructive suggestions and the encouraging comments on the manuscript. We are pleased that Anonymous Referee #2 found that our work will make a valuable contribution to the literature.

The present answer gives a point-by-point response to the comments of Anonymous Referee #2. The referee's comments are in italic font and the author's response in upright font.

We also provide a new version of the manuscript (with changes highlighted in red) as a supplement to this comment.

Response to Anonymous Referee #2's comments

General Comments:

The authors do an excellent job examining the sea ice capabilities of 24 CMIP5 GCMs, mainly focusing on the ability of the models to simulate the observed Antarctic-wide summer and winter trends. While I like the paper I have two fundamental suggestions that may help the presentation:

1. *I found this paper laborious to read. From my experience that usually suggests an organizational issue, though the paper does seem to be organized in a logical manner. I believe some of this difficulty arises from: (1) too many times I had to search back earlier in the paper to better understand what I was currently reading. For example, when dealing with the historical and then hindcast simulations, it was clear I had al- ready forgotten what the difference between these two were (though I obviously did not memorize it when explained earlier in the text). For that particular case, a brief reminder of the differences when introducing the results would have been useful (just saying "initialized" did not do it for me, a simple sentence or two, such as those appear- ing on pages 4 and 5 would have been ideal reminders). (2) The prose is sometimes laced with lengthy technical detail which I think would have fared better in tables. For example, take much of the discussion of atmospheric ozone from page 6 and move into Table 2 with other ozone information âĂŤ as it is, it is a bit of distraction when additional details of ozone appear here and there throughout the text.*

   Action: As suggested by the referee, we have modified the structure of the manuscript. In particular, paragraphs have been added at the beginning of Sect. 3 and Sect. 4 to remind what are the characteristics of these simulations and our goals. We have removed the details about the representation of the atmospheric ozone in models that were given in Sect. 2.

2. *Regarding figures 2-4; I found that while I could differentiate the various colors of the models in the graphs, I could not successfully match those colors to the colors of the models they represent in the legend. This was because there were 7 subtly different shades of green and of blue and it was difficult to pick which was which in the very short line segments next to the acronyms (Figure 2) and the colored letters of the acronyms (Figures 3 and 4; though 4 was easier since there were not as many subtle shades given fewer models in the graphs). Perhaps the authors could use more dramatically different colors (or limit the shades to just a couple per color âĂŤ e.g., light green and dark green), or adding different shaped symbols to the lines (cross, squares, etc.). Not sure best fix, but even blown up full screen it was difficult. I think addressing the above would make reading and comprehending the paper much easier.*

   Action: Figures 2, 3 and 4 have been re-drawn. We have modified the colors and added symbols that should help differentiating the models. Furthermore, two tables including all the information displayed on figures 2 and 3 have been added as supplementatry material. All the information for each model is thus easily obtained if needed.

Specific comments:

1. *P4L3-7: The Liu and Curry mechanism mentioned is relevant to perennial ice, which represents a trivial contribution to the sea ice extent or trends in the Antarctic, where seasonal ice is the issue. On seasonal ice, more snow leads to seawater flooding which leads to thicker ice, but that extra thickness is still so thin that its impact on the length of survival during melt is in the noise level.*

   Action: To be more precise, we have modified the description of the mechanism proposed by Liu and Curry (2010) given in the introduction.

2. *P4L7-9: Could you say what low frequency internal variability you are talking about (or give a reference)?*

   Response: By low frequency internal variability, we meant the variability at multi-decadal timescales, that could for instance trigger a decrease of sea ice extent during some decades and an increase during other decades.

   Action: In order to avoid misinterpretation of what we have in mind, we have re-written this paragraph.

3. *P5L17: Should the word "rapid" be "initial"?*

   Action: The word "rapid" has been changed to "initial".

4. *P5L18-21: I understand the practical reason for looking at the whole Southern Ocean, but given the regional trends, it does make me worry that some models may be getting the right answer for the wrong reason (e.g., uniformly increasing tend everywhere). Did any models get increasing trend in the west, and decreasing in the east? Figure 1 was very encouraging! Figures 2-4: results are quite interesting, but as men- tioned above, I sure wish I could more clearly figure out which models were performing best with more unique color coding.*

   Response: The models that have a positive trend in sea ice extent over the whole Southern Ocean generally do not have the right sign of the trend in the individual sectors of the Southern Ocean compared to the observations. However, none of the analyzed model has an uniformly increasing trend everywhere. We did not add details about this comment in the paper because the conclusion remains the same, i.e. the models have such a large internal variability that they can simulate much varying behaviour in the Southern Ocean. These behaviours sometimes agree with the observations but this agreement seems to occur randomly, due to the internal variability.

5. *Section 3 and higher: The analyses, results and interpretations are excellent,*

I would like to be able to quickly access this information for future use, but for that, a table summarizing the performance results for each model would be very helpful.

Action: 2 tables have been added to the supplementary material of the paper. They summarize the results for each model historical simulations, for summer and winter sea ice extent.

6. *P12L10-15: Regarding ozone, a simple hypothesis is that the lack of ozone keeps the Antarctic continent cold while the rest of the planet warms, thus intensifying the meridional temperature gradient, driving stronger westerlies, leading to the Antarctic Circumpolar Current migrating closer to the continent. Since the ACC limits the equa- torward extent of polar waters capable of growing sea ice, wouldn't we expect to see a decreasing ice extent with better ozone simulation? Or is this one of those easy to recite, but overly naïve scenarios? In the text (P12L10-15) it is noted that models with interactive chemistry and those with higher vertical resolution underestimate ice extent, but we are not told if those models better simulate the ozone? Perhaps they would have overestimated the ice if not for good ozone.*

   Response: Recent studies tend to demonstrate that the sea ice extent does not increase in response to the stratospheric ozone depletion (e.g. Sigmond and Fyfe, 2010; Smith et al., 2012; Bitz and Polvani, 2012). The conclusion of our analyses does not differ from the one of these studies. However, investigating in details the mechanisms linking the ozone and the sea ice production in the Southern Ocean is out of the scope of our study.

   Action: We have added a sentence in the introduction to precise that discussing the mechanisms that link the sea ice extent and the stratospheric ozone variations is out of the scope of our paper.

7. *Section 4.1, P13-15: There is often a desire to present all of the impressively*

detailed analyses that lead to a consistent interpretation. Seems that much of the discussion here is leading to the rather reasonable solution that if a hindcast simulation is initialized to produce less sea ice than the model's climatological solution, the trend will naturally be positive, or vice-versa. I don't think we need the analysis details of various sets of models leading to this general result. More words, more laborious reading.

   Action: As we cannot reach firm conclusions from available information, we have removed the analysis details of the analysis related to the initial shock that is sometimes trigerred by the initialization with observations.

Technical comments:

There are a number of minor English mistakes that I leave to the journal editor.

1. P16: *I am concerned about the validity of correlation significance here. How was the autocovariance included to determine the effective degrees of freedom taken into account in the t-test. And, with so few points in the test, even allowing for this with the small sample size t-test, 1 or 2 points passing a 5% significance test is a stretch. One can actually compute the significance to the significance, but I think that would be taking this too far. But, if the effective DOF was handled properly, I do think the results were presented responsibly.*

   Response: The degrees of freedom used in the t-test is related to the number of members in one ensemble and the number of ensembles performed with one model. The anomaly correlation coefficient computed here is not the correlation generally used between two time series. The anomaly correlation coefficient consists in computing, for the first year of all the hindcasts, the correlation between the values of the different hindcasts in their first year and the corresponding value of the observations. The same procedure is applied for the second year, the third year, etc. Values for different years of one simulation are thus not included in the same computation. As a consequence, there is no need to take into account the autocorrelation to determine the effective number of degrees of freedom, this latter being unrelated to the lenght of the time duration of the hindcasts.

Despite my numerous though minor criticisms, I do think this paper will make an excellent contribution to the literature. I do hope the authors try to address my 2 general comments.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/6/C2437/2012/tcd-6-C2437-2012-supplement.pdf

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Interactive comment on The Cryosphere Discuss., 6, 3539, 2012.

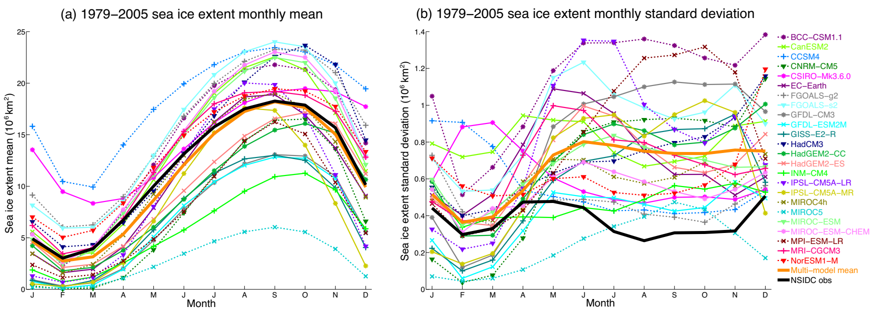

Fig. 2. **(a)** Monthly mean of Southern Ocean sea ice extent, computed over the period 1979–2005. **(b)** Standard deviation of detrended Southern Hemisphere sea ice extent, computed over the period 1979–2005 for each month of the year. Colors correspond to the ensemble mean of historical simulations from 24 different models. Dotted lines refer to models that provide both historical and hindcast simulations but here, results are only from historical simulations. Orange bold line is the multi-model mean. Black bold line refers to observations (Cavalieri and Parkinson, 2008).

Fig. 1. New version of Fig. 2

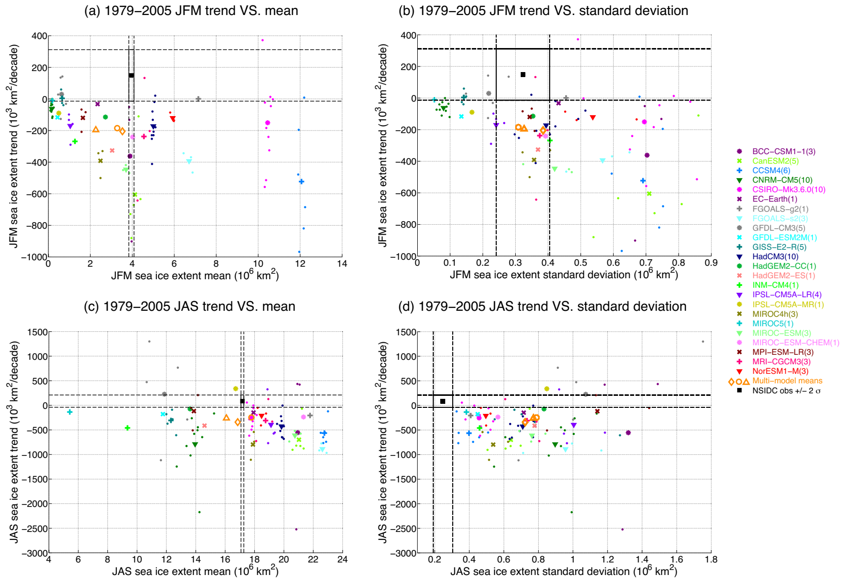

Fig. 3. Sea ice extent trend for the period 1979–2005 over the whole Southern Ocean vs. mean **(a, c)** and standard deviation **(b, d)**. The first row corresponds to summer (JFM), the second to winter (JAS). The different colors correspond to the historical simulations from 24 different models. For each color, the small dots refer to model individual members and the symbol specified in the legend is for the model ensemble mean. The number of members in each model is indicated in brackets in the legend. Orange refers to multi-model means: diamond sign is for the average over all the models, circle sign is for the mean of models with interactive chemistry (in bold in Table 2) and triangle sign is for the mean of models with 35 atmospheric levels or more on the vertical. Black square is for the observations (Cavalieri and Parkinson, 2008), surrounded by 2 standard deviations (black dashed lines).

Fig. 2. New version of Fig. 3

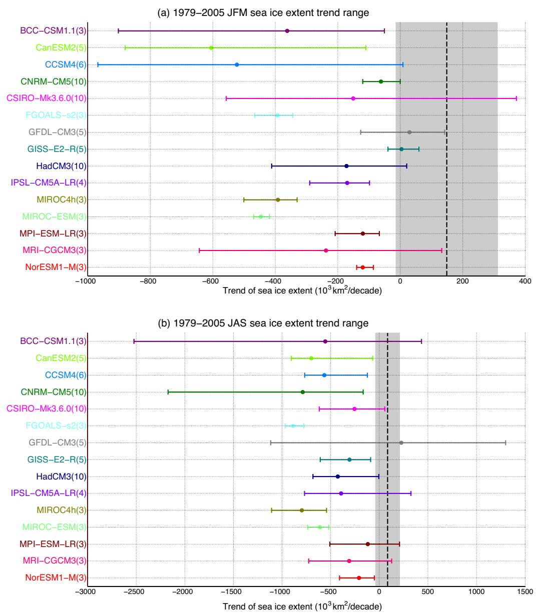

Fig. 4. Ensemble mean, minimum and maximum value of the sea ice extent trend for the period 1979–2005 over the whole Southern Ocean for summer **(a)** and winter **(b)**. The different colors correspond to the historical simulations from the 15 models that have at least 3 members in their ensemble. Dots refer to the ensemble means of the trends. Horizontal bars show the minimum and the maximum value of the trend reached by the members of one model ensemble. Black dashed line is for the trend of the observations (Cavalieri and Parkinson, 2008) surrounded by 2 standard deviations (grey shade).

Fig. 3. New figure

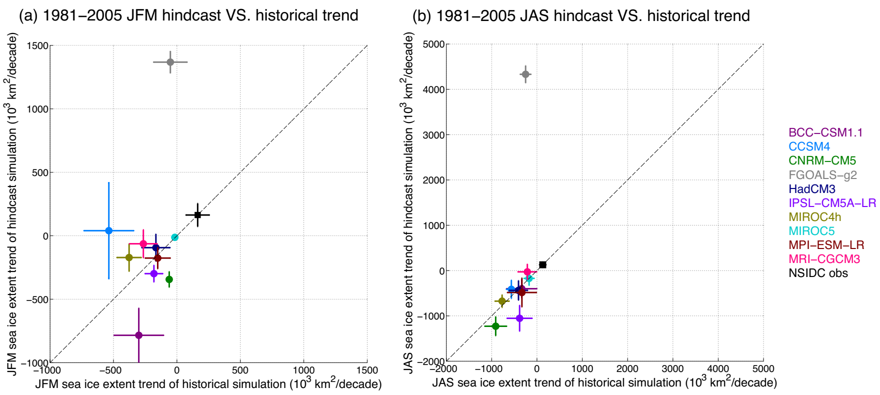

Fig. 5. Hindcast vs. historical Southern Ocean sea ice extent trend for summer **(a)** and winter **(b)**, computed over the period 1981–2005. The different colors refer to the different models. For each model, the dot refers to the ensemble mean of the trends and the horizontal (vertical) bar shows the ensemble mean of the standard deviations of the trends in the historical (hindcast) simulations. Black square is for the trend of the observations (Cavalieri and Parkinson, 2008). The vertical and the horizontal black bars are for the standard deviation of the observed trend. Dashed line represents the line $y(x) = x$.

Fig. 4. New version of Fig. 4 (now Fig. 5)

	1979-2005 sea ice extent (10^6km^2)		**1979-2005 trend in sea ice extent (10^3km^2/decade)**		
	Ensemble mean of seasonal means	Ensemble mean of seasonal standard deviations	Individual members	Ensemble mean	Ensemble standard deviation
BCC-CSM1.1	3.89	0.70	**-902.03** -132.44 -50.97	-361.81	469.61
CanESM2	4.13	0.71	**-880.51** **-728.81** **-671.28** **-634.06** -110.28	-604.99	292.07
CCSM4	12.06	0.69	**-967.65** **-819.56** **-685.12** **-478.24** -195.45 8.56	-522.91	375.18
CNRM-CM5	0.16	0.08	**-120.24** **-111.03** **-80.98** **-73.90** **-73.72** **-54.79** **-40.41** -36.38 -26.56 -0.19	-61.82	37.54
CSIRO-Mk3.6.0	10.45	0.70	**-557.15** **-514.10** **-325.14** -240.38 -183.97 -45.54 -23.27 -2.12 13.01 **371.72**	-150.69	276.07
EC-Earth	2.35	0.43	-32.41	-32.41	–
FGOALS-g2	7.15	0.46	0.83	0.83	–
FGOALS-s2	6.71	0.57	**-465.78** **-369.16** **-343.86**	-392.93	64.34
GFDL-CM3	0.63	0.22	**-126.66** -31 27.83 134.95 **142.06**	29.44	113.84
GFDL-ESM2M	0.44	0.13	**-116.49**	-116.49	–
GISS-E2-R	0.66	0.14	-39.52 -25.73 10.50 14.65 59.69	3.92	38.84
HadCM3	5.00	0.39	**-411.58** **-252.60** **-229.59** **-229.57** **-207.29** -179.35 -132.36 -79.55 -19.43 20.64	-172.07	125.76
HadGEM2-CC	2.72	0.35	-114.61	-114.61	–
HadGEM2-ES	3.04	0.37	**-326.27**	-326.27	–
INM-CM4	1.27	0.41	**-268.62**	-268.62	–
IPSL-CM5A-LR	1.04	0.24	**-289.85** **-158.40** **-132.87** -98.51	-169.91	83.64
IPSL-CM5A-MR	0.50	0.17	**-89.76**	-89.76	–
MIROC4h	2.48	0.36	**-500.60** **-343.58** **-330.13**	-391.43	94.78
MIROC5	0.19	0.05	-10.94	-10.94	–
MIROC-ESM	3.7	0.42	**-469.10** **-450.42** **-418.50**	-446.01	25.59
MIROC-ESM-CHEM	4.02	0.39	**-240.84**	-240.84	–
MPI-ESM-LR	1.64	0.34	**-208.42** -83.99 -67.01	-119.81	77.21
MRI-CGCM3	4.55	0.37	**-643** **-203.22** 132.63	-237.86	388.98
NorESM1-M	5.93	0.54	-139.58 -135.12 -86.09	-120.27	29.68
Observations	3.96	0.32	**148.69**	–	–

Table S2: Summer (JFM) sea ice extent: 1979-2005 seasonal mean and trend, computed from the historical simulations. The ensemble mean of seasonal means is the average over all the JFM extents of the individual members of one model historical simulation. The ensemble mean of seasonal standard deviations is the mean of all the seasonal standard deviations of the individual members. The ensemble mean of the trends is a mean of all the trends of the individual members and the ensemble standard deviation of the trend is the standard deviation of the trend between members. Trends that are significant at the 90% level are in bold. Details about the observations are given in in Cavalieri and Parkinson (2008).

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Fig. 5. New table in the supplementary material

	1979-2005 sea ice extent ($10^6 km^2$)		1979-2005 trend in sea ice extent ($10^3 km^2$/decade)		
	Ensemble mean of seasonal means	Ensemble mean of seasonal standard deviations	Individual members	Ensemble mean	Ensemble standard deviation
BCC-CSM1.1	20.94	1.32	**-2522.87** 422.24 434.57	-555.35	1703.93
CanESM2	21.02	0.64	**-904.52** **-878.38** **-826.56** **-819.50** -67.45	-699.28	354.99
CCSM4	22.76	0.40	**-767.07** **-741.68** **-649.03** **-559.13** **-551.02** -122.50	-565.07	234.58
CNRM-CM5	13.95	0.90	**-2172.40** **-1245.13** **-1019.92** **-827.53** **-646.85** **-580.44** **-506.43** -445.84 -262.46 -165.47	-787.25	587.27
CSIRO-Mk3.6.0	17.81	0.46	**-617.24** **-494.90** **-427.46** **-323.45** **-285.16** -201.11 -196.83 -58.77 -3.14 56.81	-255.13	218.47
EC-Earth	17.93	0.72	-147.14	-147.14	–
FGOALS-g2	21.78	0.41	**-205.75**	-205.75	–
FGOALS-s2	22.62	0.96	**-967.45** **-917.19** **-775.29**	-886.64	99.66
GFDL-CM3	11.86	1.07	**-1116.57** -288.07 **472.70** **766.19** **1299.64**	226.78	945.00
GFDL-ESM2M	11.76	0.45	-178.78	-178.78	–
GISS-E2-R	12.31	0.78	-607.23 **-373.34** **-282.37** -179.70 -88.96	-306.32	199.3
HadCM3	19.84	0.71	**-682.10** **-654.18** **-647.19** **-521.33** **-424.63** **-414.32** **-377.90** -317.35 -222.93 -4.44	-426.64	213.14
HadGEM2-CC	13.61	0.83	-72.26	-72.26	–
HadGEM2-ES	14.60	0.78	**-412.92**	-412.92	–
INM-CM4	9.35	0.46	**-459.18**	-459.18	–
IPSL-CM5A-LR	19.12	1.00	**-768.83** **-573.81** **-553.79** 325.71	-392.68	488.65
IPSL-CM5A-MR	16.72	0.85	338.9	338.90	–
0 MIROC4h	17.89	0.54	**-1107.68** **-740.15** **-542.24**	-796.69	286.93
MIROC5	5.42	0.38	-135.04	-135.04	–
MIROC-ESM	20.75	0.76	**-735.34** **-575.80** **-519.86**	-610.33	111.82
MIROC-ESM-CHEM	21.33	0.57	-237.01	-237.01	–
MPI-ESM-LR	13.87	1.14	**-509.02** -53.14 208.48	-117.89	363.11
MRI-CGCM3	18.75	0.73	**-726.16** -330.31 127.28	-309.73	427.09
NorESM1-M	18.48	0.50	**-409.14** -166.62 -50.12	-208.63	183.16
Observations	17.17	0.25	85.57	–	–

Table S3: Winter (JAS) sea ice extent: 1979-2005 seasonal mean and trend, computed from the historical simulations. The ensemble mean of seasonal means is the average over all the JAS extents of the individual members of one model historical simulation. The ensemble mean of seasonal standard deviations is the mean of all the seasonal standard deviations of the individual members. The ensemble mean of the trends is a mean of all the trends of the individual members and the ensemble standard deviation of the trend is the standard deviation of the trend between members. Trends that are significant at the 90% level are in bold. Details about the observations are given in in Cavalieri and Parkinson (2008).

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Fig. 6. New table in the supplementary material