The Cryosphere Discuss., 6, C2426–C2436, 2012
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The Cryosphere Discussions

TCD

6, C2426–C2436, 2012

Interactive Comment

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.

V. Zunz et al.

violette.zunz@uclouvain.be

Received and published: 13 December 2012

The authors thank Anonymous Referee #1 for the careful reading and for the constructive comments on the manuscript. They helped us to re-structure our ideas and to present them more clearly.

The present answer gives a point-by-point response to the comments of Anonymous Referee #1. 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.

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Interactive Discussion

Discussion Paper

Response to Anonymous Referee #1's comments

The paper evaluates the CMIP5 models and their ability to simulate historical Antarctic sea ice extent. The hypotheses is that the model's internal variability and/or an inadequate initialization are the reason for the models' inability to simulate a correct trend. The paper is generally well written and raises an important question. However, the authors mention the possibility that internal variability may play a significant role for the observed trend, but never analyze this. Therefore, before publishing the authors should also include the role of internal/interannual variability in their analysis.

Main points

1. *As illustrated by the authors, internal or interannual variability is an important factor for this region. The fact that some models have ensemble members with positive trends and negative trends should raise the question, whether the observed trend is more than just noise. Because if this is true, there would be no reason for the models to agree on the sign of the trend. Tebaldi et all. illustrate this concept in their paper (Mapping model agreement on future climate projections, 2011). An other nice illustration of how important variability can be is given by Deser et al. (http:// www.cgd.ucar.edu/ cas/ cdeser/ Docs/ submitted. deser.communicating_uncertainty.jan1). In Section 3.2 the authors give a trend of 150'000km2, however the standard deviation shown in Figure 2b for this time of the year is of about that magnitude. This could be an indication that the trend might as well be noise.*

   Response: The satellite observations of sea ice extent in the Southern Ocean start in 1979. The time period they span is thus too short to properly investigate how the trend in sea ice extent evolves over longer time periods (at multi-decadal

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timescales). The observed increase in sea ice extent could indeed arise from the internal variability and be not more than noise. Unfortunately, the limited available observations prevent us from confirming this hypothesis. In our study, we use climate models to test this hypothesis. Nevertheless, if we want to trust their results, these models must agree with the real system for what we know from observations. The available observations tell us informations about the mean state, the interannual variability and the trend of the sea ice extent in the Southern Ocean, from 1979 to present. We have shown that none of the analyzed models has both a mean state and an interannual variability that fit the ones of the observations. This thus rises the question whether we can reasonably use these models to investigate the internal variability in the Southern Ocean. Regarding the trend in Southern Ocean sea ice extent, thanks to their large internal variability, some models can provide positive values that agree with what is observed. These results seem to favor the hypothesis that the positive trend is due to the internal variability. However, one has to keep in mind that these models do not provide a reasonable estimate of the main characteristics of the sea ice extent in the Southern Ocean (i.e. the mean state and the interannual variability). In conclusion, we do not exclude the hypothesis linking the recent increase in sea ice extent to the internal variability. However, neither the observations nor current general circulation models can be used to confidently confirm this hypothesis.

Action: "Introduction" and "Summary and conclusions" sections have been rewritten to better present the issues we dealt with and the conclusions we can draw from our study, citing and discussing the references proposed by the referee. Details about the analyses of results have been added in Sect. 3.2. In particular, we now present a figure summarising the range of the trends provided by each model's ensemble historical simulation.

2. *How exactly was the trend computed?*

Response: The trend of summer (winter) sea ice extent has been computed through a linear regression of the yearly values of summer (winter) extent, between 1979 and 2005.

Action: A brief explanation has been added in Sect. 3.2.

Minor points

1. *Page 3542: If the variability is large, what does out of phase mean? Is it then necessary that the models are in phase with the observations?*

   Response: If the observed positive trend is actually due to internal variability, a correct initialization of the models may put the system in a state that favors the formation of sea ice (e.g., a more stratified or a colder ocean). Even if the variability is large in this region, idealized models studies have pointed out high potential predictability there (e.g. Latif et al., 2010). This means that models have deterministic decadal variability. We thus think it was necessary to check if this potential predictability could lead to reliable prediction of the sea ice extent in real conditions, i.e. when a model is initialized with some observed fields.

   Action: We have added a paragraph at the beginning of Sect. 4 to make this point clearer.

2. *Page 3543: Not sure whether it is fair to say the models are failing for the reasons mentioned in the main points.*

   Response: The point of this paragraph is to explain why we have chosen to present our analyses for the sea ice extent over the whole Southern Ocean rather than discussing the results for the individual sectors. The reason is that there is no better agreement with observations if we consider sectors of the Southern Ocean individually. However, the spatial structure of the observed trend might also arise from internal variability. If this is true, there is indeed no need for models to reproduce this spatial structure. Since this hypothesis has not been

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validated yet, it seems important to us to mention that we keep in mind the different behaviour of sea ice in the different sector of the Southern Ocean, even if we do not discuss these results in our paper.

Action: We have modified the last paragraph of the introduction to better explain our approach.

3. *Page 3546: the multi-model mean overestimates the sea ice cover. Could this be due to a few models? At least for CMIP3 most models had to little sea ice compared to observations.*

   Response: In September, 10 of the 24 models underestimate the whole Southern Ocean sea ice extent (see Fig. 2a). Regarding the different sectors of the Southern Ocean, it seems that, in each individual sector, there are approximately as many models that overestimate the sea ice extent as models that underestimate it but we do not discuss it in the paper.

   Action: We have added a sentence in Sect. 3.1 to precise that 10 of the 24 models underestimate the Southern Ocean sea ice extent in summer.

4. *Page 3554: Same point again; if variability is large how much information can a correlation tell you?*

   Response: See the answer given for the minor point 1.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/6/C2426/2012/tcd-6-C2426-2012-supplement.pdf

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Interactive Comment

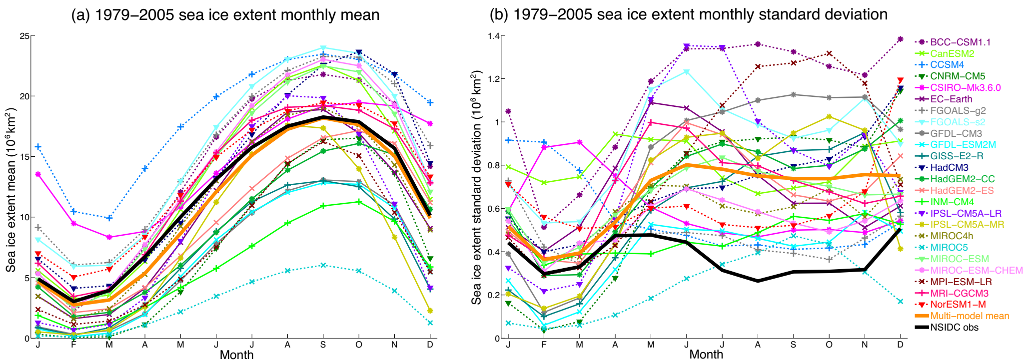

Fig. 2. **(a)** Monthly mean of Southern Ocean sea ice extent, computed over the period 1979–2005. **(b)** Standard deviation of detrended Southern Hemisphere sea ice extent, computed over the period 1979–2005 for each month of the year. Colors correspond to the ensemble mean of historical simulations 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

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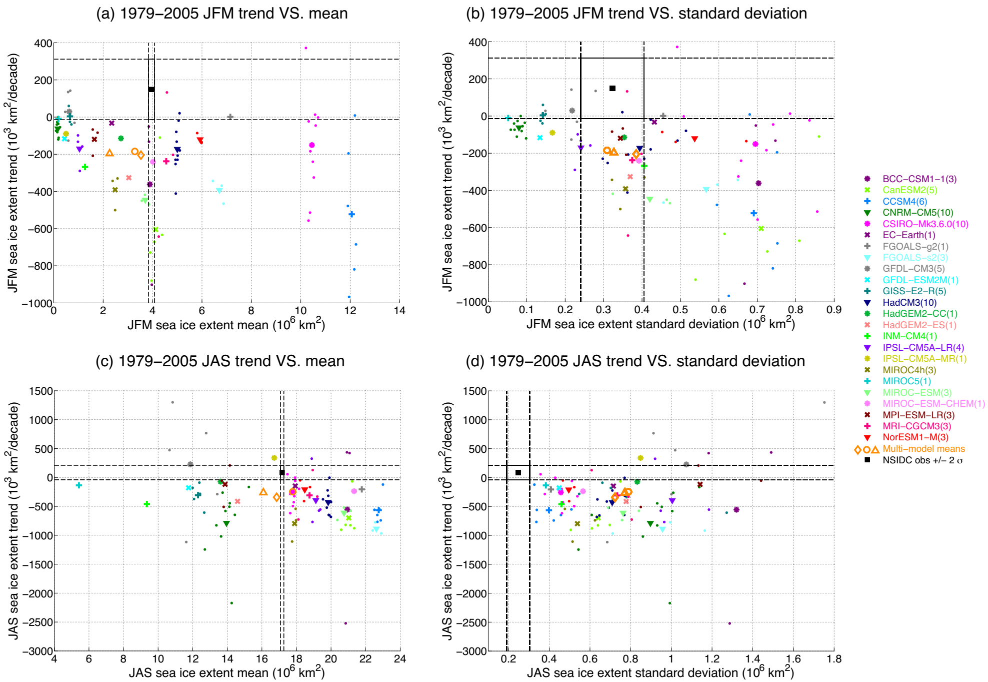

Fig. 3. Sea ice extent trend for the period 1979–2005 over the whole Southern Ocean vs. mean **(a, c)** and standard deviation **(b, d)**. The first row corresponds to summer (JFM), the second to winter (JAS). The different colors correspond to the historical simulations from 24 different models. For 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

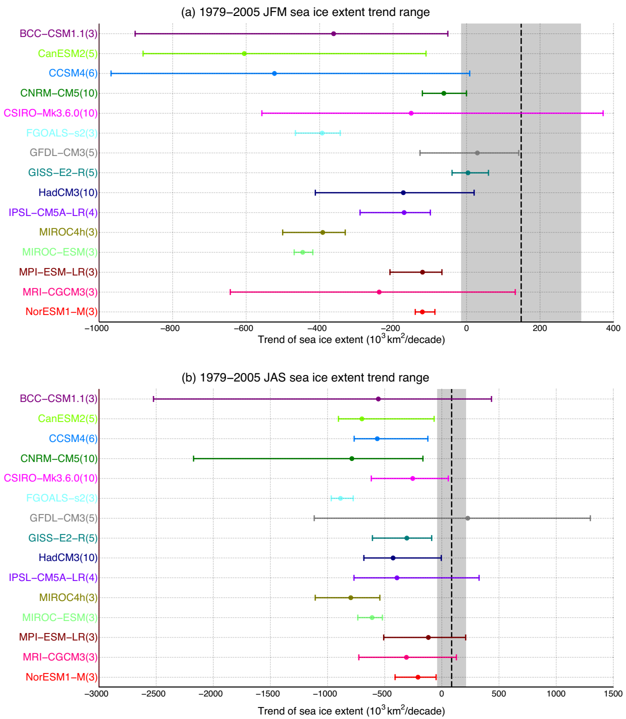

Fig. 4. Ensemble mean, minimum and maximum value of the sea ice extent trend for the period 1979–2005 over the whole Southern Ocean for summer **(a)** and winter **(b)**. The different colors correspond to the historical simulations from the 15 models that have at least 3 members in their ensemble. Dots 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

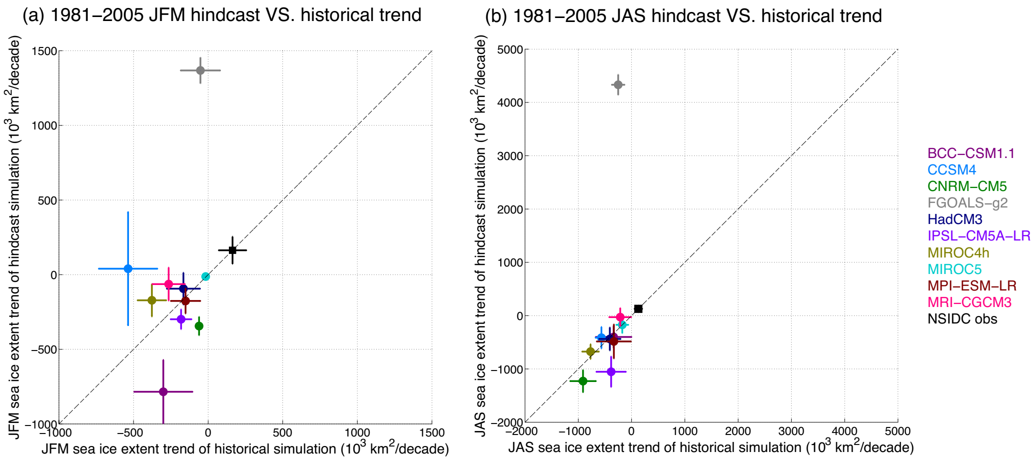

Fig. 5. Hindcast vs. historical Southern Ocean sea ice extent trend for summer **(a)** and winter **(b)**, computed over the period 1981–2005. The different colors refer to the different models. For each model, the dot refers to the ensemble mean of the trends and the horizontal (vertical) bar shows 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)

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	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	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

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	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