**Reply to reviewers**

We thank the comments by all the reviewers. We have prepared a new version of our paper addressing the concerns pointed out to the best possible. These improvements include some extra information in new sentences, some rewriting and a few further references. Point by point replies follow next.

**Reply to 'SC1: 'Comments of paper contehnt', Richard Neale, 08 Sep 2019'**

First of all, we thank Dr Neale for taking the time to read our work and provide feedback on it. We have made our best to address the concerns pointed out. Dr Neale states:

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| **I just wanted to comment on the aim and transparency of the work in the paper.The topic of this 'study' certainly has merit as modeling centers are trying to improve their transparency and availability of model code, but it is an ongoing process in the face of certain restrictions that were noted.** |
| We fully agree on this point with Dr Neale and, we are pleased to know that it has become clear in our work. |

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| **I have significant concerns though, regarding its approach and methods and inappropriate speculation. One thing that stood out for me as complete speculation is the line "It is widely acknowledged that some scientists are reluctant to share code because of the perceived potential damage to their reputations". This is quite inappropriate for an academic journal, and I really do not understand what is meant by this. Being pretty intensively involved in CMIP efforts for many years, I have never come across code release reluctance related to 'reputation'.** |
| We fully agree that inappropriate speculation is not right for an academic journal. Unfortunately, our experience does not agree with this view by Dr Neale. We are not unaware of the evaluation processes of climate models. The first author of the work has participated in WMO reports on models, their use for data validation, has published several papers on model evaluation, participated in several workshops on the subject and has been editor and reviewer of multiple papers on climate models. Concerns on the perceived lack of quality of the code of models often appear in the comments of model developers and colleagues during workshops. The problem of the 'reputation' is linked to the quality of the software. Some people think that low-quality software could damage their reputation.<br><br>But beyond our perception, we present evidence that supports informed speculation. Indeed, as we state and show in our submitted work and cited in the text (García-Rodríguez et al.), climate models are inadequate in terms of programming practices (the paper (currently under review) where this evaluation is performed is accessible from this link: http://fortrananalyser.ephyslab.uvigo.es/). This issue happens in some cases to a level that could be embarrassing for a project of an undergraduate student in computer sciences. Also, Barnes (2010) pointed out this issue and Wieters and Fritzsch (2018) – now cited in the text - makes a similar statement.<br><br>However, following the concern raised by Dr Neale and agreeing that the sentence in its current form is probably not enough supported by objective evidence, we have rewritten it as follows:<br><br>'*It is possible to speculate that some scientists could be reluctant to share code because of perceived potential damage to their reputations (Barnes, 2010) because of its quality, perhaps related to a lack of adequate education in computer programming (Merali, 2010). This issue with the quality of the code has been raised for the case of climate models (García-Rodríguez et al., 2020).*'. |

**Furthermore, we simply have no idea how rigorous the investigation is. It quoted a whole raft of comments from various staff at institutions that cannot be attributable to anyone. We have no idea whether they spoke to junio scientist or a senior director.**

We do not understand this claim by Dr Neale. We consider that subsection 2.1, Tables 1 and 2 and Appendix A provide plenty of information on the rigour of our procedures. We have tried to get the access to the code of the different models: use of the CMIP5 webpage, internet search and contact by email in two different languages, several tries to contact by email plus further discussion in a workshop.

The point on attribution is clear: First, we do not decide who reply to the emails or the contact point for each developing model group. How to contact is usually included in the CMIP5 web page or the webpages of the models. We can not decide if it is a junior computer scientist or a senior director. It merely is the contact point that the developing centre/team has chosen. Secondly, who is the contact is irrelevant here, and it is not our fault if it fails to give a reply or the content of the response that we receive. It is the 'official' contact point for the model developing team, and therefore it must be assumed that the reply is 'official'.

A final issue is about the possibility of checking the replies by the different research centres or developing teams. This issue was already pointed out by the editor in a previous version of this manuscript. Of course, we can not publish the replies that we received, because they are subject to communications privacy. However, as in any review process, we offer the possibility to the editor of checking them if he considers it necessary.

**And it is worth pointing out that a little deception was used in the attribution to a researcher as a PhD student in their emails.**

Unfortunately, again, we do not clearly understand this statement by Dr Neale. Does he suggests that we have tried to cheat or mislead the developing teams on our intentions?. It could not be farther from the truth. Mr Michael García Rodríguez is a PhD student at our university. We do not understand what is wrong with it. Indeed, as we pointed it out on page 3, line 12 in the previous version of the manuscript, the code of the models must be available to everybody, not only researchers.

**Don’t get me wrong, easily accessible access to code is important in the whole climate change and climate modeling sphere, but the authors need to rethink this approach quite a bit. Of course I will let the handling editor and reviewers determine whether they agree with me :) Thanks Rich Neale**

We thank all the comments by Dr Neale that we consider constructive. However, concerning this comment, we do not understand what he means by 'need to rethink this approach'. Probably this happens because the word 'approach' is not specific enough. Does it refer to how we have tried to get the code? We will be happy to address any concern relative to our study if it is clarified.

**Reply to “Anonymous Referee #1”**

**Review of “Current status on the need for improved accessibility to climate change models” by Juan A. Añel, Michael García-Rodríguez, and Javier Rodeiro.**

**The manuscript looks into the availability of the source code of models which contributed to CMIP5. The authors basically use a three-step approach to get access to the code (direct download, "anonymous" email and email stating their research). Their results show that more than half of the model source code is not made made available after step three. In addition, they discuss the documentation quality and licensing issues. I find the topic of the manuscript to be highly relevant and the results presented by the authors raise a crucial issue which is of high importance for the climate model community. However, I find the manuscript to have several weaknesses which should be addressed before a possible publication in Geoscientific Model Development as outlined in the comments below.**

We thank the Referee#1 for the supportive comments on our manuscript. Next, we reply point by point to the concerns raised.

**General comments:#1**

**The manuscript contains several generalized statements which I find to need further support by (scientific) literature or the results. I’ve addressed them also in the specific comments but in general I refer to statements like the following: “...it is generally the case that climate models do not comply with what would be the ideal level of programming practice.” (page 1, line 11)**

This sentence is actually on page 2, lines 12-13. We consider that our statement is supported enough by the results of the work cited in the text: García-Rodriguez et al. In this work, climate models are one of the case studies used to prove the usefulness of a Fortran code static analysis tool. It is available through the link http://fortrananalyser.ephyslab.uvigo.es/, something that we make clear now, including the link in the reference. Also, a careful reading of Easterbrook (2014), cited in the sentence that follows the one pointed out by the reviewer, lets to reach a similar conclusion. Moreover, Wieters and Fritzsch (2018) – now cited in the text – pointed out the same conclusion regarding software engineering practice in the field of climate modelling.
Later, in the Conclusions section, we cite now Merali (2010), that includes some further discussion on the topic.

**"...the incidence of comments throughout the code is very low" (p1, l13)**

Again, this is supported by the results in García-Rodríguez et al. We acknowledge that in the previous version of the manuscript, the reviewers could have problems to get access to this information. However, now we link this study submitted for publication.

**“It is widely acknowledged that some scientists are reluctant to share code because of the perceived potential damage to their reputations.” (p4, l14)**

Dr Neale raised concerns about this sentence too in a short-comment. We have modified the sentence to make it less speculative, and now we cite the work by Merali (2010) to provide additional evidence and support. The new sentence reads:
‘*It is possible to speculate that some scientists could be reluctant to share code because of perceived potential damage to their reputations (Barnes, 2010) because of its quality, perhaps related to a lack of adequate education in computer programming (Merali, 2010). This issue with the quality of the code has been raised for the case of climate models (García-Rodríguez et al., 2020).’*.

**#2 I find the discussion about the need to publish model code in the introduction too one-sided. While the authors give several good reasons why code should be made publicly available, there might be equally valid counter-arguments. It would be good to discuss some of them as well and possibly offer solutions. Some things that come to mind:**
**- National or institutional copyright that prevents authors from publishing code**
**- Dependencies of the model on third party code that is under copyright**
**- A lack of funding to set up and maintain a public code repository**
**- Fear that ones property rights might be violated if the code is freely available in the web.**

**This might be particularly true for newer models. An argument could be made that a group developing a model has the right to also publish the results produced with this model (they might even be required to do so by their funding agency).**

The referee makes some good points here but also makes some mistakes, as the incorrect use of 'copyright' to refer to very different legal aspects that could involve intellectual property, redistribution, reuse and modification of software. These comments are in line with usual concerns by many colleagues, and we have made an effort to include them in the text while making clear the most critical issues.

That said, we do not think that the discussion of the points suggested by the referee corresponds to the Introduction, but the Conclusions section. We address the concerns here and in some extra text that, therefore, we have added in the Conclusion.

First of all, respectfully, we do not consider that our discussion in the Introduction is one-sided. It is a mistake to think that there are two equally valid sides here. Someway it is the same fallacy as considering that negationist arguments on anthropogenic climate change deserve to be highlighted to the same level that the scientific consensus on it. The only valid side is complying with the scientific method. If we do not apply the scientific method, what is produced can not be considered science. It is clear that if the access to the code of the models is not provided, we do not comply with the scientific method, as the primary tool used to produce the results is a black box. This problem has been acknowledged many times in the literature. It inspires the editorial policies of many journals. Stodden et al. (2013) (already cited in the previous version of the manuscript) discuss more in deep this issue. However, to better support it, and having into account that it is a pivotal issue for the understanding of the goal of our study, we have modified the first sentence in the paper and added two additional references. The new sentence reads:

"*Reproducibility of results is essential to comply with the scientific method when performing research. This has extraordinary implications in the field of earth system models (Añel, 2019; Gramelsgerber, 2020)*"

The problems with computational reproducibility are evident in some of the works that we already cited in the previous version of the manuscript: Allison et al., 2018; Stodden et al., 2018.

To include the so-called counter-arguments, we have added in the discussion a few paragraphs that read:

"*Some scientists or model development groups could be worried because of issues such as legal restrictions (national or institutional) that prevent from publishing code. Also, because of potential dependencies of the model on third party proprietary software, lack of funding to maintain a public repository or violation of property rights. For all these cases, there is a clear response or solution.*

*In the first case, if it is not possible to make available the code, then any result obtained with such a model should not be accepted as scientifically valid because it is impossible to verify the findings. We acknowledge that this is the case for several models widely used in scientific research nowadays and must be solved by modification of the legal precepts applied to them. Consequently, those working with such models should look for a change in the legal terms so that the model complies with the scientific method.*

*If a part of the model depends on proprietary software, then it harms the possibility to distribute the whole model. Therefore again, the model does not comply with the scientific method. In this case, a good option can be to substitute the part of the model that is proprietary software with one that is free software.*

*Lack of funding to maintain a software repository can not be considered a real problem. There are many options available to host the code. For example, Zenodo is free, widely adopted and assures hosting at least for the next twenty years.*

**#3 The way the authors tried to establish contact is not clearly enough documented and needs clarification. As it is, it seems quite subjective to me. In particular:**
**- How did the authors search for contact information? They mention that they searched the internet.**

To try to clarify the issue of how we search for contact information, we have modified the text in the manuscript. Now it reads:

'*This procedure included the first step using the web addresses for code downloading indicated on the CMIP5 webpage (\url{https://pcmdi.llnl.gov/?cmip5/}). When the code was not directly available to be downloaded, we looked for contact details (emails, on-line formularies, etc.) in the webpage. In some cases, there was an email address to contact. However, in other cases following the information in the CMIP5 website was not enough. In such cases, we searched through the internet using a search engine. We looked for institutional web pages, intending to find open repositories for the corresponding model.*'

**But how easy was it to find the information and at what point (after how much time) did the authors give up? One could for example go as far as looking for publications by the same group investigating the desired model and writing the authors. I was quickly able to find contact information for all five model centres the authors list as "No email or contact phone is available" (see specific comments below).**

It is someway hard to quantify 'how easy' it was to find the information. In some cases, it was direct from the webpage of the CMIP5, for others, as we already explained in the previous version, we had to look for it using a web search actively. However, we do not consider that 'pursuing' the developing teams by looking for contact emails in scientific papers should be assumed as a way of doing it. First of all, many papers continue to be accessible only through paywalls (not open-access) and therefore the information there is not available for most of the people. Secondly, looking for papers, identifying the relevant ones and the appropriate person to contact from an author list requires a knowledge of the modelling groups that only a handful of experts in the field have. And again, availability of the code should be judged having into account that the code of the models must be available to everybody, without being an expert in climate modelling. This is why we did not consider looking through the scientific literature as an appropriate way to assess the availability of the code of the models. In the same vein, to use the metadata in the output NetCDF files of the models, as the referee mentions in the specific comments, is only available to a very specialized small group of people. However, we have introduced a new paragraph in subsection 2.1 to make clear these issues.

'*It could be possible to look for additional contact information in the published scientific literature. However, many papers continue to be accessible only through paywalls (they are not open-access) and therefore they are not available for most of the people. Moreover, identifying the relevant person to contact from an author list requires a knowledge of the modelling groups that only a handful of experts in the field have. Also, additional contact information is available for five models from metadata included in the NetCDF files containing the results of the simulations in the CMIP5 repository. However, the ability to find and manage such data has computational requirements and needs of a knowledge that is beyond what could be considered reasonable for the general public, including part of the scientific community.*'

**The two mails in A1 and A2 are identical. Is that a mistake or did the authors just send the same mail again? In this case they could consider deleting A2.**

We send the same email again. It was already exposed in the previous version of the manuscript just before the content of the email. We assumed that in some cases the contact person could be busy, that the email could get simply buried in the inbox or may be filtered as spam. This is the reason why we did a second try with the same email. As suggested by the referee, we have removed now the second email from the text of the manuscript. To clarify it, we have added in the text a sentence in subsection 2.1 that reads:
"*A second email, equal to the first one, was sent to insist on our request. We intended to minimize the possibility of not getting a reply because of reasons such as the contact person being too busy at the moment of receiving the first email, it was unnoticed or filtered as spam. We waited for a reply for three weeks after sending the first email before sending the second. Finally, three weeks after the second email, we sent a final email, where we identified...*"

**In section 2.1 the authors mention that in "the final email" they identified themselves. After how many mails of type one was that? The "final email" should also be in the appendix.**

This was the third email, as it is listed in Appendix A. It has been already clarified in reply to the previous comment. The 'final email' was in the prior version of the manuscript but as 'Third email'. After the additional explanations included in the text, this is now clearer.

**In table1 only email 1 & 2 are listed. Are these two columns indeed refering to the identical emails from A1 & A2? If yes I'm missing the column for the final email.**

For the final third email, we did not get a single reply. Therefore we did not include a column for it. We have clarified it in the caption of the table.

**The authors mention one specific model for which they got access after direct contact to the developers at a conference. Was this approach tried for all model centres which did not reply to the emails or was it based on a coincidence? If it was only done in this one case, one could argue that this partly jeopardizes the objectivity of the approach.**

We did not make an active approach to get access during conferences. As the referee points out, this would jeopardize the approach. Moreover, it would not be fair for the evaluation, as the general public does not attend scientific conferences. What happened was that the corresponding author of this work was approached by one of the members of the developing team at NASA. Then this person put us into contact with the same colleague that we had already tried to contact before (the contact point for the model) and they sent us the code.
We have modified the relevant sentence in subsection 2.1 to make clear that we did not take an active role to contact groups during conferences and to provide additional details. Now the sentence reads:

"*For the NASA-GMAO model, we failed to get a reply from contact via email. However, we were approached by a member of the institution after a presentation during a conference. After discussing it, the development team granted us access to the model.*"

Moreover, although finally we took the opportunity to analyze the model, NASA-GMAO failed in the availability of the code. This issue is recorded in Table 1, failing to get a third star because of it.

**#4 The manuscript would benefit from proof-reading by a native speaker. There area number of very long and somewhat convoluted sentences. This sometimes makes it hard to follow the authors point as I mention at several occasions in my specific comments.**

We thank this comment. Indeed, our submitted manuscript had already been edited by a professional service, as all of our papers. However, there is always a margin for improvement. The new version of the manuscript has been rechecked.

**Specific comments:**

**Title: Maybe change to “model code” in order to make clear that this is about the source code and not about output? Also I believe that it would be more appropriate to call them “climate models” instead of “climate change models” because they are used to investigate the climate system in general not only climate change.**

We agree with the referee about the title, and we have modified it accordingly. Thank you for pointing it out. However, we have prefered to maintain 'climate change models' in the text. Indeed the models are 'climate models', but our testbed was the CMIP5, therefore models specifically intended to inform on climate change and to serve to the IPCC reports. Because of this reason why we think that 'climate change models' is more accurate here.

**Abstract: “models from the Climate Model Intercomparison Project” Add “fifth”**

Done.

**Page 1, line 13-16: This is a very long sentence and I'm not quite sure what the authors try to say here. Is this addressing the issue of reproducability in general? E.g., subjective judgments (as long as they are properly documented) to not hinder reproducability. So maybe the authors try to say something else? Please clarify, since this seems to be an important point.**

We have rewritten the sentence to try to make it clearer:

“CSR is a problem of high complexity. In some cases, scientists may be unaware of some of the issues that have significant impacts on it, reaching the wrong conclusion that an experiment complies with CSR, when it is not the case, as exposed in Añel (2017). Also, a researcher could decide to use a model based on judgements that have little to do with the most appropriate from a scientific point of view, such as complying with the scientific method (Joppa et al., 2013). All this makes it necessary to consider a range of issues to comply with CSR in the process of design and use of models (Añel, 2017), and climate change models in particular. Some of them are legal aspects of software distribution and intellectual property, usually unfamiliar for researchers.”

**P1, l16: replace “matters” by “CSR”**

Done

**P1, l19: It would be convenient for the reader to have the (most important) recommendations listed here, instead of only quoting Wilson et al. 2017.**

Wilson et al. (2017) include many recommendations that affect different issues. Now we list in the text some of them that we consider representative and relevant for our work.

**P2, l11: “It could be said that adequate sharing and documentation is not necessary if the code used in the models includes appropriate comments,” I’m not sure what the authors try to say here. Why would commenting the code make publishing unnecessary?Also I find the statement that commenting code can replace a proper documentation problematic.**

We fully agree with the referee. Indeed, what we want to say here is that both right code and documentation are needed. We have made our statement clearer, and we cite a paper (in press) by Pascoe et al. that makes some good points on the need for documentation in the CMIP. Now the sentence reads:

"*It can be argued that adequate documentation of the code and the model is not necessary to prevent a potential loss of knowledge if the code used in the models includes appropriate comments. But, indeed, this is not the case of the models contributing to the Fifth Climate Model Intercomparison Project (CMIP5). CMIP models are sophisticated software projects, and they need full documentation of the experiments (Pascoe et al., 2020). Moreover, it is generally the case that climate models do not comply with what would be the ideal level of programming practice.*'.

**P2, l12-15: "...but it is generally the case that climate models do not comply with what would be the ideal level of programming practice." I'd like to see some evidence to support this statement.**

As we have said before, we now include a link to our submitted work García-Rodríguez et al. (2020), a paper on a software tool (FortranAnalyser) that we have designed to evaluate the quality of static code in Fortran. There, it is possible to check how some CMIP5 models perform in terms of programming practice.

**P2, l13-15: "Indeed, the incidence of comments throughout the code is very low, and programmers have tended to perform very badly in this regard in particular (García-Rodríguez et al., 2019)" What code to the authors refer to here? What does low number of comments mean? The citation (García-Rodríguez et al., 2019) is listed as submitted, it should be provided.**

We refer to the code of the CMIP5 models, and it is now clarified in the text. García-Rodríguez et al. (2020) is now provided.

**P2, l21: CMIP 5 I assume?**

Right. We have corrected it.

**P2, l30 I wouldn't call two different emails a "variety of different approaches".**

We have rewritten the sentence to make it more specific:
'*...and contacted research groups where necessary using email, without disclosure of ourselves as climate scientists to full explanation of our interest in studying the code. These approaches are detailed in the following sections*.'

**P3, l3: add "as a first step..."**

Unfortunately, we do not understand this comment by the referee. In P3, l2 it is already said '...a first step...'. If the referee can clarify it, we are happy of addressing the issue in a next round of the review process.

**p3, l3: Could the authors provide a link to the CMIP5 webpage they refer to here?**

Done.

**P3, l5: Why English and French? Several models are developed, e.g., in China it seems to me that for a systematic and objective methodology it should be either only English (the language used in the vast majority of climate model related publications) or all respective native languages of the model centres.**

We sent first the emails in English to all the research centres. From one of the research centres, the IPSL, we did not receive a reply. As one of the coauthors of this work is a French native speaker, we decided to send the second email in French, just in case we had a better chance of getting a reply. We were successful, and we got access to the code of the IPSL model. We have rewritten the relevant part of the text to make clear that sending out emails in French was not the rule. Now the text reads:

"*Still, in others, we had to proceed by making contact with development teams at different levels (emails (see Appendix) (with follow-up emails two weeks after the first contact). To contact the IPSL team after sending the email in English and failling to get a reply we sent the second email in French)*"

**P3, l11-12: "to check whether after it had become obvious that the models were not available easily, institutions and researchers would then share them with someone from the general public." To really represent the general public it would have been better to use a not-university related mail address I assume. Maybe change to something like"with someone from outside the community"?**

Done.

**P3, l18: Why did it take several months? The authors state above that they send an initial email with a follow-up two weeks later. Was it the process of actually getting the code after establishing contact that took so long?**

We have opted to write 'several months' because it was the time that it took from the beginning of the experiment (checking the CMIP5 webpage) to obtaining the last model that we got after contact during a conference, the one contributed by NASA-GMAO. We consider this a minor issue and according to what happened. Therefore, we have not modified it.

**P3, l18: To I assume correctly that "10 out of 26 models" referrers to "models from 10 out of 26 institutions" and "27 out of 61" referrers to multiple models from the same institution (such as GCM and ESM versions)?**

We think so. However, the comment by the referee is not too clear here. We feel that it is evident in the text: There are 26 models, but some of them (as listed in Table 2) have contributed different versions, with a total of 61.

**P3, l23: The percentages refer to the numbers in the first line of the paragraph, I assume. The "they" seems to indicate that only USA, Germany, and Norway are meant.**

Correct. We have modified the sentence to clarify it: «Together, these three countries represent...»

**P3, l24-26: "This analysis is relevant, because in some cases the decision on whether to share the code of the models could have been due to national or regional regulations on software copyright, intellectual property, etc." It would be interesting to detail this point further. Did the authors get concrete answers citing (national) copyright law as response? Did they check the copyright law in countries where they did not get access to any models?**

No, we did not get replies citing national laws. When we got a response with the reason to deny access (five cases), it was claimed that access to the code is only granted to members of the development team. Additionally, in two cases, the reply mentioned that moreover, it would be unfeasible because of the size of the model and that it would involve too much work. This information was already included in the previous version of the manuscript in Tables 1 and 2. Checking the copyright laws that apply to different regions (and probably institutions) is out of the scope of this work. Moreover, in some cases, this could respond to regulations established in confidential information of national laboratories, etc. In this way, it is hard to know if it is possible to perform a proper analysis of this matter.
We agree that our statement is slightly speculative, and therefore, we have modified the sentence to make it clear. Also, we introduce some further discussion:
"*This analysis is relevant. We can speculate that in some cases, the decision on whether to share the code of the models, could have been influenced by national or regional regulations on software copyright, intellectual property, etc.* For example, it is well known that the law in the USA, where for example software can be patented, enables the possibility to enforce a greater level of restrictions to software sharing and distribution than in the EU (van Wendel de Joode et al., 2002; EPO, 2016). However, it is the case that we have been able to get the code for 6 of the 7 models contributed by research centres from the USA and however, for the EU we have only got 3 in 7. The fact that the models developed in the USA can count with the participation of federal employees could partially explain this result. Under the USA copyright law (U.S. Code, 1976), all the work produced by federal employees is in the public domain. Although they are not the same thing, the public domain could be considered closer to openness that lack of licensing of the models. For the case of Norway, we can speculate that the fact that NorESM has been developed using core parts of CESM1 (Knutti et al., 2013) could have facilitated openness of the code through the inheritance of licenses and copyright. In the same way, not sharing the code of the models could be due to inheritance reasons."

**P3, l30: "in six cases" & "in five cases" Table 1 only lists 5 cases with "No email or contact phone is available." and only 4 cases with "No answer".**

We thank the referee for the careful reading and checking of the manuscript that made possible to find this subtle mistake. We have corrected it.

**P4, l3-5: "We considered the level of requirements introduced by the GPLv3 license (https://www.gnu.org/licenses/gpl-3.0.en.html) as the ideal case, or a license under which the model can be shared, modified and used without restriction." This seems to be contradictory. Is the GPL the ideal case or "a license under which the model can be shared, modified and used without restriction"? Because to my knowledge the GPL has very strict requirements that need to be fulfilled to share, modify and use code which is licensed under it (such as: disclosure of source, stating of all changes, further publication only under the same license).**

The GPL is one of the two licenses recommended in the GMD Editorial (GMD, 2019) that we already cited in the manuscript. Exactly the GPL is one of the few licenses (beyond some of the considered as 'GPL compatible') that lets to use the software obtained without limitations.
Some people argue that the GPL imposes limitations. However, this is only the point of view of a developer that wants to restrict sharing of the software. The GPL is the kind of license that better complies with the spirit of science and as Morin et al. (2012) say '*assure the benefits and openness of FOSS in all future derivatives of your work*'. Therefore, to make the reasons for choosing the GPLv3 as the ideal license, we have rewritten the sentence. Now it reads:

"*This is in line with the recent updates to the policy on code availability published by Geoscientific Model Development (GMD Executive Editors, 2019). Moreover, it has been argued that it is the license that better fits to scientific projects to assure the benefits and openness of software (Morin et al., 2012).*"

**P4, l14-15: “It is widely acknowledged that some scientists are reluctant to share code because of the perceived potential damage to their reputations.” Can the authors provide some evidence for this statement?**

This issue has been addressed. Please, check previous replies.

**P4, l20-23: “Barriers to code-sharing through licensing, imposed by e.g., government bodies, cannot be an excuse and when contributing to scientific studies and international efforts where collaboration and trust are critical, such practice is not acceptable.” It seems to me that following the laws of ones country (even when they hinder research and collaboration) is indeed a completely valid excuse for not sharing code.**

We agree that following the laws is a valid excuse for not sharing code. But not doing it means that the results produced are not legitimate science. The scientific method is clear about this: Results have to be reproducible to be considered scientifically valid.
At this point, what should be clear is that the research community should pressure a government or institution to get a change of the laws or licenses that applies to the software developed under their legal framework. In this way, their results could be acknowledged as valid by the research community.

**P4, l22-24: “For cases where we obtained the code of a given model, we were not provided with a reason for the license behind it. In fact, in some cases despite getting the code we did not see a license explaining clearly the terms of use.” It would be interesting indeed to know the rationale behind different licenses (or for the absence of a license), did the authors inquire about this at the groups which provided code?**

We asked for the reasons for not sharing the code in the third email. However, as we explain in the manuscript, we did not get an answer to these emails.
The rationale for the different licenses applied probably embrace from only the license that the first group of developers choose to an imposition by a research institute. However, this is a subject to be discussed more from the point of view of law and psychology. We consider it interesting, but out of the scope of this work.

**P4, l31-32: "we encourage all model developers to improve the availability of the codes of climate models and their CSR practices." As I've mentioned before this might not be only the developers responsibility but also includes institutions, funding agencies and even country copyright laws.**

The referee is right. However, we encourage the developers to make clear to the relevant bodies or agencies that it is not acceptable to comply with the scientific method.

**P4, l33: “which is in some cases very poor (García-Rodríguez et al., 2019)” Again, please provide this paper as it is not yet available.**

Please, see replies above.

**Figure 1a: Maybe delete the axis? (or fix the y-axis, which should run from -90 to 90 I assume?) The percentages are not per country as stated by the caption but by continent I assume? Could the authors find a way to explicitly show that there are now model centres in South America and Africa?**

**Figure 1: I personally would find it more helpful to see absolute numbers of provided/not provided models instead of percentages.**

We have modified the figure according to the suggestions by the referee.

**Table 1: I checked our CMIP5 archive and found all of the contact information flagged as missing in the metadata of the output netCDF files for the respective models. I understand that at this point it is probably too late to include them in the study, yet I'm copying them in here in case they are helpful to the authors.**

**BCC: "contact = "Dr. Tongwen Wu (twwu@cma.gov.cn)"”CSIRO-Mk3.6.0:“contact="Projectleaders:StephenJeffrey(Stephen.Jeffrey@qld.gov.au)&LeonRotstayn(Leon.Rotstayn@csiro.au).Project team:Mark Collier (Mark.Collier@csiro.au:diagnostics & post-processing),StaceyDravitzki(Stacey.Dravitzki@csiro.au:post-processing),CarloHamalainen(Carlo.Hamalainen@qld.gov.au:post-processing),SteveJeffrey(Stephen.Jeffrey@qld.gov.au:modeling&post-processing),ChrisMoeseneder(Chris.Moeseneder@csiro.au:post-processing),LeonRot-stayn (Leon.Rotstayn@csiro.au:modeling & atmos.physics), Jozef Syktus(Jozef.Syktus@qld.gov.au:modelevaluation),KennethWong(Ken-neth.Wong@qld.gov.au:data management), Contributors:Martin Dix (Mar-tin.Dix@csiro.au: tech. support), Hal Gordon (Hal.Gordon@csiro.au: atmos. dy-namics), Eva Kowalczyk (Eva.Kowalczyk@csiro.au: land-surface), Siobhan O\'Farrell(Siobhan.OFarrell@csiro.au: ocean & sea-ice)"”INM-CM4: “contact = "Evgeny Volodin, volodin@inm.ras.ru,INM RAS, Gubkina 8,Moscow, 119333 Russia,+7-495-9383904"”LASG-IAP: “:contact = "Dr. Tianjun Zhou(zhoutj@lasg.iap.ac.cn)" MRI: “contact = "Seiji Yukimoto (yukimoto@mri-jma.go.jp)"”**

We thank the referee for taking the time to look for the information in the NetCDF files. However, as we have discussed previously, dealing with this kind of files is challenging for most of the scientific community and the general public. Therefore, we have not considered in our study NetCDF files as a valid form of providing contact to get the code of the models.

**Table 3: I find the star-rating system slightly in-transparent. Why not just list the criteria in columns and indicate where models passed/failed?**

This suggestion looks reasonable. Admittedly, we did a try with this, with a table including four additional columns for direct download from the CMIP5 webpage, reply to the first email, reply to the second, GPLv3 compatible license, etc. However, the result included leaving blank boxes when emails were not necessary, etc. Moreover, all this information is included in the previous tables and the text. In the end, we did not feel that the result was better than the current version only with the stars. We have decided simply to modify the caption of the table to clarify that the maximum value is three filled stars, something that was not clear before.

**Reply to Anonymous Referee #2**

We thank the referee for the insight provided, and the relevant questions pointed out.

**In the framework of computational scientific reproducibility, this manuscript attempts to explore the status of CMIP5-class climate model accessibility, following a methodology based on web access attempts and emails. The question addressed here is very important, and an appropriate discussion could help the climate model community improving its code sharing practices. Authors show that only very few of these models comply to a full accessibility. Such a result should rock the boat of the climate modelling community and ignite discussion on reproducibility within successive CMIPs. Unfortunately, in its present sate, that is basically the only result this manuscript provides, and the text suffers from a lack of discussion and perspective, together with far too many general and un- or ill-referenced statements. I think the main results should be followed by a discussion both on the relevancy of code sharing policy for CMIPs, an more suggestions to improve it.**

Admittedly, we like the idea of including additional discussion on the topic in the text. We would like to have done it in the previous version of the manuscript. However, this discussion could lead to too much speculation. We are aware (we have discussed this with members of some development teams) that some colleagues are someway reluctant to change how they develop the models. We prefer to avoid strong statements in the manuscript. Already some of them are considered by the referees pretty speculative in the previous version of our paper.

To try to shed some light on how the CMIP can improve this situation, we have included some new suggestions in the text. We have rewritten the last paragraphs of the Conclusions. Among others, we suggest a potential integration of the evaluation of the code of the models in the ESMValTool. Also, now we expose that there are discrepancies between outputs of CMIP5 models, and we discuss how sharing the code would help to address them. This has already been proved in other fields of research and was cited in the previous version of the manuscript (Boulanger, 2005).

**Also an historical perspective of how code availability was considered in the successive CMIP projects would be interesting to evaluate how things are evolving in the climate modelling community.**

Again, this issue raised by the referee is fascinating. However, we think that this is a specific research topic, and therefore it should be the result of future work. Indeed, we aim to do it.

**Many questions come in mind reading the ms, I am not requesting authors to answer them, but I think they could help building a discussion section: I acknowledge authors suggestion to setup “frozen” versions of the codes, but in more details,what could be suggested, at the international level, to improve sharing policy of the codes/experiments? What has been done in the past? Why did it not work until now?**

As we exposed in the previous version of the manuscript and we have tried to make more evident now, it should be done in the same way that it is done for data output. We suggest that each set of outputs from a model has linked the code of the model used to produce it. Other policies could include proper static analysis of the code, integrating it in the ESMValTool as it is suggested.

**Do we have information regarding the ongoing CMIP6 experiments?**

No, we do not have it. At the moment, the CMIP6 webpage only contains some model output data and metadata for the models. This includes email addresses for those involved in the development of each model. However, nothing is said about the code of the models. Also, additionally, ES-DOC includes part of the information that was available directly in the webpage for the CMIP5 (webpage of the development team, the model or institution, associated research paper published and an email for contact). Also, it includes a license for the data but not for the model.
Given that, and having into account that CMIP6 is under development yet, we have decided not to include in our paper a discussion on it, as it would be biased.

**What are the specificities of climate model intercomparison projects when compared to other massive modelling works?**

Admittedly we have not found information about this. Moreover, although we are aware of comparable efforts in others field of research (genomics, particle physics), we do not feel prepared to make a judgement on this topic and discuss it in the paper. Also, this could distract the attention of the reader to the main point that we make: Sharing the code must be done not only because of practical issues or how the climate modelling community compares to other fields but because of scientific integrity and to comply with the scientific method.

**Making codes available is one thing, but does it make sense to make a million-line-ish code available without any support ?**

Yes, it does. It has been proved that merely making the code available improves code reliability. This was already pointed out when we cited Boulanger (2005). In this new version, we have included some extra support citing a report of the US Department of Defense (2009) that says: "The continuous and broad peer-review enabled by publicly available source code supports software reliability and security efforts through the identification and elimination of defects that might otherwise go unrecognized by a more limited core development team." (https://dodcio.defense.gov/Portals/0/Documents/FOSS/2009OSS.pdf). Also, Easterbrook (2010) discussed how 'computer-supported collaborative science' is necessary to tackle the challenge of climate change. In this case, this implies having access to the code of the models. We include this statement now in the Discussion of our manuscript, and we cite the work.

**Can modelling group follow a standard for documenting the setup of a typical CMIP experiment ? Is it possible?**

We are not sure if the referee means here to document the code or to document the experiments. The experiments are already documented. Documentation was already addressed for CMIP5 and has been improved for CMIP6 with ES-DOC (now we cite it in the Introduction (Pascoe et al., 2020)). For comments into the code, some clear standards can be followed, and they are part of the metrics used by García-Rodríguez et al. 2020.

**How the ultimate goal of reproducibility could be reached for CMIP models ? On what machine ? Should the community think of compiling/running all the CMIP models on one single machine? What are the limits of reproducibility in that case ?**

Here the referee seems to be confused. It is not the same reproducibility than replicability. The ACM has made it clear and established the differences between them (https://www.acm.org/publications/policies/artifact-review-badging). The question that the referee has pointed here about dependence on machines and limits are related to replicability. It would good to have the highest level of detail possible, such as supercomputer, architecture, operative system, compiler versions and compilation flags. But, in the end, all this means nothing if the source code is not available.
Partially this could be solved using container technologies. In the new version of the manuscript, we have briefly addressed these issues in the Conclusions section and added three further references to support the exposed ideas. It reads:
"*Reproducibility could not be compromised; however, the simple fact that replicability (note that reproducibility and replicability are different concepts (ACM, 2018)) can not be achieved because of the lack of the code of the model is unfortunate. In this way, frozen versions of the models combined with cloud computing solutions and technologies such as containers can be a step forward to achieve full replicability of results in earth system modelling (Perkel, 2019; Añel et al., 2020)*"

**What was the situation for previous CMIPs, when there were less models involved?**

This question is similar to a previous one by the reviewer about what was done in the past. As we said, it is a complex problem to perform an assessment, and we will try to address it in future work.

**How thoughts on code accessibility did evolve?**

The answer to these questions is something that could be worthy of addressing, but it would imply a more profound analysis and collaboration from the scientific community. As can be seen from the answers that we have already obtained, to obtain cooperation has already been thought sometimes.
However, again, we take note that this can be of interest, and we thank the comment. This will help to shape our future work.

**On the methods: Although I am not an expert in surveying methods, I found it puzzling not to have more details about the emailing methodology, i.e. who was contacted in the different modelling group: engineers, researchers ? Climate/ earth system models are massive codes, developed by many people. Did the authors contact, for each model, responsible for each compartments (vegetation, atmosphere, ocean, etc.) or did they just take one contact from each model web page?**

No doubt we have missed some details and explanations on our methodology. We did not check the role of the person that we contacted (when it was necessary to contact somebody). Usually, when the code was not available to be downloaded, it was listed an email contact address for a person or the institution. When it was available, we used the offered contact address, as it was the official contact point listed by the contributing team. In the same vein, when we had to look for the code repository or model development team, we simply looked for the email address listed in the webpage.
We have tried to clarify this point modifying in the Methods section the following sentence:
"*Using a systematic methodology, we attempted to obtain the codes of all the climate models involved. This procedure included the first step using the web addresses for code downloading indicated on the CMIP5 webpage (\url{https://pcmdi.llnl.gov/?cmip5/}). When the code was not directly available to be downloaded, we looked for contact details (emails, on-line formularies, etc.) in the webpage. In some cases, there was an email address to contact.*"

**On the results : I did not find the geographical (fig 1) approach relevant. What conclusion can be drawn from that ?**

A straightforward analysis can be done based on the comparison of the application of the law to software between the European Union and the USA. We have included some additional information and references in the text now to make clear the benefits of splitting the analysis by regions and centres:

"*This analysis is relevant. We can speculate that in some cases, the decision on whether to share the code of the models, could have been influenced by national or regional regulations on software copyright, intellectual property, etc. For example, it is well known that the law in the USA, where for example software can be patented, enables the possibility to enforce a greater level of restrictions to software sharing and distribution than in the EU (van Wendel de Joode et al., 2002; EPO, 2016). However, it is the case that we have been able to get the code for 6 of the 7 models contributed by research centres from the USA and however, for the EU we have only got 3 in 7. The fact that the models developed in the USA can count with the participation of federal employees could partially explain this result. Under the USA copyright law (U.S. Code, 1976), all the work produced by federal employees is in the public domain. Although they are not the same thing, the public domain could be considered closer to openness that lack of licensing of the models. For the case of Norway, we can speculate that the fact that NorESM has been developed using core parts of CESM1 (Knutti et al., 2013) could have facilitated openness of the code through the inheritance of licenses and copyright. In the same way, not sharing the code of the models could be due to inheritance reasons.*"

**Although it is more complicated, I think having a licensing history of each model would be more relevant to connect to their accessibility.**

We agree that having a licensing history could be interesting, but having into account our knowledge of the field, we speculate that it would be more illustrative than useful. Probably in most of the cases the license was not something relevant when the model began to be developed (mostly for the oldest ones). In the same vein, it is possible that for most of the models when a license was chosen, it was not the result of a profound analysis of the scientific needs and implications, but the result of other issues (requirements from the research centre, etc.). As with the question of how the code has evolved, we take note of this interesting issue, and we will try to address it in subsequent work.

**Specific comments :P1,l7: "There are other reasons that justify the need for access to the codes of climate models used in scientific research. One of the most important is to prevent the loss of knowledge on the cycles of development of these models. Some of them nowadays rely on 'legacy' code that was written up to five decades ago, and new developers must understand why some decisions on implementation were undertaken so long ago. Although I am convinced by the need of improving code sharing policy, I am not sure that it will help reducing loss of knowledge. From my experience it seems that many steps to improve a climate model code are either recorded internally, i.e. within the institutes documents, or through successive publications. I don't see how code sharing will improve that.**

In this regard, the main advantage of code sharing is that it enables the possibility of having more people looking at the code (collective peer-review). Indeed this happens. We agree that it is true that the probability of getting a higher level of lines of code orphaned could not be different between code-shared or not. However, knowledge loss is less probable if more people can access it. We have included two new references in the text (although not in the Introduction) that support this view: DoD CIO (2009) and Easterbrook (2010).

**P1 L13: "The complexity of the problem, where in some cases scientists may be un-aware of some of the determinants, or may make subjective judgements that have little to do with the most appropriate from a scientific point of view (Joppa et al., 2013), or may even fail to make the correct assessment, makes it necessary to consider a range of issues (Añel, 2017), including legal aspects.". I must confess I don't understand this sentence.**

This issue was also pointed out by another referee. We have rewritten the sentence, and we hope that our point is now clearly exposed.

**P2l13 “It could be said that adequate sharing and documentation is not necessary if the code used in the models includes appropriate comments, but it is generally the case that climate models do not comply with what would be the ideal level of programming practice." That is a really strong statement that should be underpinned by appropriate reference.**

We have now included a link to our submitted paper that shows this issue: García-Rodríguez et al. 2020. Indeed, the paper is in collaboration with colleagues from the IPSL and shows as an example how after addressing the most significant problems in the code pointed out by our tool 'FortranAnalyser' the version of the IPSL model for the CMIP6 has significantly improved compared to the CMIP5 version. Moreover, now we cite the work by Wieters and Fritzsch (2018) that makes a similar statement based on their experience.

**“It is widely acknowledged that some scientists are reluctant to share code because of the perceived potential damage to their reputations.” I am really surprised by this statement. Is it supported by any survey ?**

We have rewritten the sentence in this version of the manuscript to make more accurate our statement, and we think that now its intended meaning is more precise and supported with cited literature.

**"Given that many scientists have no formal training as programmers, it may be presumed that they consider that their code may not comply with the standards of excellence that they usually pursue in their main fields of knowledge. Indeed, it has been clearly documented that some climate scientists acknowledge that imperfections in climate models exist, and they simply address them through continuous improvement without paying too much attention to the common techniques of software development(Easterbrook and Johns, 2009). Nevertheless, all scientists must believe that their code is good enough (Barnes, 2010) and that there are thus no reasons not to publish it (LeVeque, 2013)." This paragraph, as the previous sentence, suggest climate scientists, aware of their code imperfections, would be reluctant to share it. It must be supported by a reference or a survey, if not it is just a feeling.**

As said before, we have modified the sentence to make our statement more accurate. Also, we have provided new references to support this 'guess', such as Merali (2010) and García-Rodríguez et al. (2020). Moreover, the references previously cited (Easterbrook and Johns, 2009; Barnes, 2010; LeVeque, 2013) already supported with evidence that the issue exists. We agree that it is felling and we acknowledge it. Indeed, the use of the language here exposes it in this way, as the sentence says '*it may be presumed*’.

**“Barriers to code-sharing through licensing, imposed by e.g., government bodies, cannot be an excuse and when contributing to scientific studies and international efforts where collaboration and trust are critical, such practice is not acceptable.” This sentence is more an open-ed-like statement that what is expected in a scientific journal. Questioning licensing is appreciable but it should be made in a more rigorous way.**

We do not question licensing. It is not the aim of this work to challenge the existence and application of legal frameworks. What we examine is the possibility of complying with the scientific method when code is not shared. We think that it is clear when we say '*when contributing to scientific studies.*' Now we cite at the end Añel (2019), a work about the application of the scientific method that can enrich the debate. However, if the referee considers that this message is unclear, we are open to modifying the sentence in a way that makes it more transparent.

**"For cases where we obtained the code of a given model, we were not provided with a reason for the license behind it. In fact, in some cases despite getting the code we did not see a license explaining clearly the terms of use." Indeed it would have been crucial to obtain, for every model and every component, the license terms used. That would have helped a lot to discuss accessibility.**

We agree with the referee. Indeed it is the case that probably some models do not have a license. Maybe developers think that in this way no restrictions apply to its distribution, but it is not the case. In some legal systems, releasing software without a license means that it is under the umbrella of a kind of copyright by default. Probably, education on the topic is the only way of overcoming this. Hopefully, the work that we present here helps to make research colleagues more aware of the relevance of the issue and to improve the situation on licensing and code sharing in the future.

# Current status on the need for improved accessibility to climate change models code

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**Abstract.** Over the past few years, increasing attention has been focused on the need to publish computer code as an integral part of the research process. This has been reflected in improved policies on publication in scientific journals, including key related issues such as repositories and licensing. We explore the state-of-the-art of code availability and sharing of climate models, using as a testbed the models from the Fifth Climate Model Intercomparison Project (CMIP5), and we include some particular reflections on this case. Our results show that there are many limitations in terms of access to the codes of these climate models ~~,~~ and that the climate modelling community needs to improve its ~~code sharing practice in order~~ code-sharing practice to comply with best practice in this regard, and the most recent editorial publishing policies.



## 1 Introduction

Reproducibility of results is essential ~~in scientific research.~~ to comply with the scientific method when performing research. This has extraordinary implications in the field of earth system models (Añel, 2019; Gramelsberger et al., 2020). Because so much scientific output today relies on the use of computers, there are new requirements in terms of the description of any experiments performed, ~~in order~~ to assure computational scientific reproducibility (CSR). This is widely known (Añel, 2011) and was recently discussed in a Sackler Colloquium on "Reproducibility of Research: Issues and Proposed Remedies" (Allison et al., 2018). ~~The complexity of the problem , where in some cases~~CSR is a problem of high complexity.

In some cases, scientists may be unaware of some of the ~~determinants, or may make subjective~~ issues that have significant impacts on it, reaching the wrong conclusion that an experiment complies with CSR, when it is not the case, as exposed in Añel (2017). Also, a researcher could decide to use a model based on judgements that have little to do with the most appropriate from a scientific point of view ~~(Joppa et al., 2013), or may even fail to make the correct assessment, ~~, such as complying with the scientific method (Joppa et al., 2013). All this makes it necessary to consider a range of issues to comply with CSR in the process of design and use of models (Añel, 2017), ~~including legal aspects~~ and climate change models in particular. Some of them are legal aspects of software distribution and intellectual property, usually unfamiliar for researchers.

Recent examples have revealed some very low levels of CSR (Allison et al., 2018; Stodden et al., 2018). Steps are being taken to improve ~~matters~~CSR, e.g., an increasing number of journals now have computer-code policies (Stodden et al., 2013; GMD Executive Editors, 2015; Nature, 2018), and recommendations have been made to ensure greater reproducibility of results (Wilson et al., 2017). They include to maintain appropriate documentation for the software, split the code into functions and submit it to DOI-issuing repositories, encourage the participation of external collaborators and make it easy for them to collaborate, etc.

The study of climate change relies heavily on the use of large computer simulations with geoscientific models of varying levels of complexity. In projects involving the intercomparison of climate models and in some research papers, it has become increasingly common to provide details of the simulations performed~~, including~~ . These details include initial configurations, which are generally clear, accessible and formalised, in related outputs with digital object identifiers (DOIs) (e.g. Eyring et al. (2016); Morgenstern et al. (2017)). However, it is somewhat perplexing that the codes of the underlying models are not always made available~~or at~~ . At best they are shared informally, using links, repositories without any security regarding long-term availability or access, or email addresses via which it is claimed that the code will be delivered after contact. Especially in a field where heated debates occasionally arise following the publication of results, it seems odd that this core element of the research is not made more widely accessible.

There are other reasons that justify the need for access to the codes of climate models used in scientific research. One ~~of the most important~~ is to prevent the loss of knowledge on the cycles of development of these models. Some of them nowadays rely on 'legacy' code that was written up to five decades ago, and new developers must understand why some decisions on implementation were undertaken so long ago. There is both an educational and practical dimension to this issue. In some cases, different models share sections of code, but its development remains fairly obscure (Knutti et al., 2013). It ~~could be said that adequate sharing and documentation~~ can be argued that adequate documentation of the code and the model is not necessary to prevent a potential loss of knowledge if the code used in the models includes appropriate comments~~, but~~ . But, indeed, this is not the case of the models contributing to the Fifth Climate Model Intercomparison Project (CMIP5). CMIP models are sophisticated software projects, and they need full documentation of the experiments (Pascoe et al., 2020).

Moreover, it is generally the case that climate models do not comply with what would be the ideal level of programming practice~~. Indeed, the incidence of comments throughout the code is very low, and~~ , an idea already pointed out by Wieters and Fritzsch (2018) . García-Rodríguez et al. (2020) show how programmers have tended to perform very ~~badly~~ poorly in this regard in particular~~ (?). The~~ , and the incidence of comments throughout the code of CMIP5 models is very low. Another issue related to the need for code sharing of climate models is the replicability of results~~in~~ . In different computing environments can also be ~~difficult~~ challenging and should not be expected by default (Easterbrook, 2014), even where the same model is used (Massonnet et al., 2019).

Some informal efforts have been made to document accessibility for some climate models (Easterbrook, 2009; RealClimate.org, 2009) and others more formally to check their quality (e.g., ~~Pipitone and Easterbrook (2012); ?~~Pipitone and Easterbrook (2012); ). In light of these efforts, in this study~~our intention was~~ , we intended to test the current status of accessibility to the most commonly used global climate models, in particular those that have contributed to the ~~Climate Model Intercomparison Project~~

~~(CMIP)~~CMIP5. In the sections that follow, we describe our efforts to gain access to these models, the procedures we followed, and a classification of the models according to some metrics related to accessibility, and we also provide a discussion containing reflections on the state-of-the-art.

## 2 Methods

In our attempt to better understand the current status of CSR and the availability of climate models, we used as a testbed the models of CMIP5 (Taylor et al., 2012) ~~in view of~~ given their extensive use in climate research over the last five years. These served as a ~~key~~ vital tool for the last IPCC AR5 (IPCC, 2013), and given the ongoing development of CMIP6, groups of modellers should now be more open to sharing the code, due to the possible depreciation of the earlier version. We followed a standard procedure to obtain the code of each model~~, firstly by checking~~ . First, we checked the information available on each model in the webpage of CMIP5~~, and contacting~~ . Then we contacted research groups where necessary using ~~a variety of different approaches, ranging from non-disclosure~~ email, without disclosure of ourselves as climate scientists to full explanation of our interest in studying the code. ~~These approaches are~~ Our approach is detailed in the following sections.

### 2.1 Survey methods

Using a systematic methodology, we attempted to obtain the codes of all the climate models involved. This procedure included ~~a~~ the first step using the web addresses for code downloading indicated on the CMIP5 webpage ~~. Where this~~ (https://pcmdi.llnl.gov/?cmip5/). When the code was not directly available to be downloaded, we looked for contact details (emails, on-line formularies, etc.) in the webpage. In some cases, there was an email address to contact. However, in other cases following the information in the CMIP5 website was not enough. In such cases, we searched through the internet ~~and~~ using a search engine. We looked for institutional web pages~~for open repositories~~ , intending to find open repositories for the corresponding model. In a few cases, this was sufficient (see Table 1). Still, in others, ~~but in others~~we had to proceed by making contact with development teams at different levels~~(~~, e.g. emails (see Appendix) ~~in English and French (with folow-up~~ (with follow-up emails two weeks after the first contact). ~~)~~ In the case of the IPSL team after sending the email in English and failing to get a reply, we sent the second email in French, and we got an answer. For the NASA-GMAO model, ~~after failing~~ we were unable to get a ~~reply~~ response from contact via email~~, we discussed it at a conferenceand~~ . However, we were approached by a member of the institution after a presentation during a conference. After discussing it, the development team granted us access to the model.

For those cases where we needed to establish contact via email, we provide details in the Table 1 of the different replies that we received. ~~The first email was always sent~~ Michael García-Rodríguez always sent the first email from his student ~~email~~ address (under the domain esei.uvigo.es)~~by Michael García-Rodríguez~~, who had had no previous involvement in the activities of the international climate modelling community. The idea behind this was to check whether after it had become ~~obvious~~ evident that the models were not available easily, institutions and researchers would then share them with someone from ~~the general public~~outside the community. In the end, to assure CSR and accessibility, details of experiments must be open to

everybody, not just to peers or other scientists. ~~In the final emailsent,~~ A second email, equal to the first one, was sent to insist on our request. We intended to minimize the possibility of not getting a reply because of reasons such as the contact person being too busy at the moment of receiving the first email, it was unnoticed or filtered as spam. We waited for a reply for three weeks after sending the first email before sending the second. Finally, three weeks after the second email, we sent a final email, where we identified ourselves and our team, to make clear that we were indeed climate scientists, and thus to check whether we thus had a better chance of obtaining the code. Where access to the code was denied, we sent a survey with a few questions to better understand the reasons for this. All emails sent followed the same template as that given in the Appendix A.

It could be possible to look for additional contact information in the published scientific literature. However, many papers continue to be accessible only through paywalls (they are not open-access) and therefore they are not available for most of the people. Moreover, identifying the relevant person to contact from an author list requires a knowledge of the modelling groups that only a handful of experts in the field have. Also, additional contact information is available for five models from metadata included in the NetCDF files containing the results of the simulations in the CMIP5 repository. However, the ability to find and manage such data has computational requirements and needs of a knowledge that is beyond what could be considered reasonable for the general public, including part of the scientific community.

## 3 Results

After all attempts and several months, we successfully gained access to 10 out of 26 models (27 out of the 61 model versions or configurations) contributing to CMIP5. Table 2 provides a summary of the details of the replies obtained from these centres, teams or contacts that allowed access to the code. In terms of research centres or groups contributing to the CMIP5 project, this also represents 10 out of a possible 26. We found a strong regional bias in terms of the countries where models were made accessible. The USA, Germany and Norway stood out as the best contributors in that we obtained the code for all their models (though Norway only contributes one). Together~~they~~, these three countries represent 38% of the research centres or CMIP5 models and 44% of all the versions. For France, we gained access to one of two models (three out of five versions). This analysis is relevant~~, because~~. We can speculate that in some cases, the decision on whether to share the code of the models, could have been ~~due to~~ influenced by national or regional regulations on software copyright, intellectual property, etc. For example, it is well known that the law in the USA, where for instance software can be patented, enables the possibility to enforce a higher level of restrictions to software sharing and distribution than in the EU (van Wendel de Joode et al., 2003; European Patent Office, 2016). However, it is the case that we have been able to get the code for 6 of the 7 models contributed by research centres from the USA and yet, for the EU we have only got 3 in 7. The fact that the models developed in the USA can count with the participation of federal employees could partially explain this result. Under the USA copyright law (U.S. Code, 1976), all the work produced by federal employees is in the public domain. Although they are not the same thing, the public domain could be considered closer to openness that lack of licensing of the models. For the case of Norway, we can speculate that the fact that NorESM has been developed using core parts of

CESM1 (Knutti et al., 2013) could have facilitated openness of the code through the inheritance of licenses and copyright. In the same way, not sharing the code of the models could be due to inheritance reasons.

Figure 1 shows the percentage of models obtained from a global perspective, with specific plots for Europe and Asia. This makes it easier to visualise the rather narrow distribution of the regions on the maps and because different countries could apply different national laws in order to share the codes of the models.

In some cases, a ~~great~~ high number of email exchanges were required over periods ~~of time~~ longer than one week to receive a reply or the code. In ~~six~~ five cases, there was no obvious way to contact the development teams~~, in five cases~~; in four cases, we received no ~~reply at all, and in seven~~ answer at all. Seven research centres (corresponding to eighteen models) they replied that they did not share the codes of their models. We decided to include in this final group EC-Earth, for which the code is said to be available to a given group of users. Still, in practice, ~~but in practice~~the procedure to access it makes it completely unfeasible for non-members of the regular team involved in its development. In no case did we receive a response to the questionnaire sent asking for the reasons why they did not want to share the code. For the models obtained, we performed a ranking, as shown in Table 3, taking into account licensing issues and availability for reuse by third parties, among other factors. We considered the level of requirements introduced by the GPLv3 license (https://www.gnu.org/licenses/gpl-3.0.en.html) as the ideal case ~~,~~ ~~or~~ for a license under which the model can be shared, modified and used without restriction. This is in line with the recent updates to the policy on code availability published by Geoscientific Model Development (GMD Executive Editors, 2019). Moreover, it has been argued that it is the license that better fits to scientific projects to assure the benefits and openness of software (Morin et al., 2012).

We also addressed other issues relevant for running the models. In some ways, ~~accessiblity~~ accessibility or ability to gain access to the code means nothing if adequate documentation for the model, a description of its components, instructions on how to compile or run it, and basic examples are not provided. This is in line with recommendations contained in the literature (Lee, 2018). The results are shown in Table 4~~and it~~. It can be seen that almost all the models obtained comply with all these criteria, ~~with the exception of~~ except for NICAM.09, which only includes a 'Readme' and a 'Makefile'. For the IPSL, although the link to access the documentation does not work, it is possible to gain access to it by performing an internet search.

## 4 Conclusions

~~It is widely acknowledged that some scientists are reluctant to share code because of the perceived potential damage to their reputations. Given that many scientists have no formal training as programmers, it may be presumed that they consider that their code may not comply with the standards of excellence that they usually pursue in their main fields of knowledge. Indeed, it has been clearly documented that some climate scientists acknowledge that imperfections in climate models exist, and they simply address them through continuous improvement without paying too much attention to the normal techniques of software development (Easterbrook and Johns, 2009). Nevertheless, all scientists must believe that their code is good enough (Barnes, 2010) and that there are thus no reasons not to publish it (LeVeque, 2013). Barriers to code-sharing through~~

~~licensing, imposed by e.g., government bodies, cannot be an excuse and when contributing to scientific studies and international efforts where collaboration and trust are critical, such practice is not acceptable. For~~

In this work, for cases where we obtained the code of a given model, we were not provided with a reason for the license behind it. In fact, in some cases, despite getting the code, we did not see a license explaining clearly the terms of use. Some scientists or model development groups could be worried because of issues such as legal restrictions (national or institutional) that prevent from publishing code. Also, because of potential dependencies of the model on third party proprietary software, lack of funding to maintain a public repository or violation of property rights. For all these cases, there is a clear response or solution:

- In the first case, if it is not possible to make available the code, then any result obtained with such a model should not be accepted as scientifically valid because it is impossible to verify the findings. We acknowledge that this is the case for several models widely used in scientific research nowadays, and this situation must be solved by modification of the legal precepts applied to them. Consequently, those working with such models should look for a change in the legal terms so that the model complies with the scientific method.

- If a part of the model depends on proprietary software, then it harms the possibility to distribute the whole model. Therefore again, the model does not comply with the scientific method. In this case, a good option can be to substitute the part of the model that is proprietary software with one that is free software.

- Lack of funding to maintain a software repository can not be considered a real problem. There are many options available to host the code. For example, Zenodo is free, widely adopted and assures hosting at least for the next twenty years.

- Fears about a violation of property rights usually respond more to a lack of awareness on how the law applies to software distribution than to real issues, as Añel (2017) points out. Intellectual property is usually detached of the norms that apply to the distribution of the model. Unless the developer specifically resigns to the intellectual property, it is generally retained despite if the software is made available and distributed and their contractual obligations. Indeed, under some legal frameworks, it is impossible to resign to intellectual property. The best option is always to get specialised legal advice on these matters.

It is a matter of some regret that we obtained straightforward access to just 3 of the 26 models (7 of the 61 versions) in CMIP5 and that for 16 (34 versions) we were not able to obtain the code at all. For all others, some interaction was required, from email exchanges to personal discussions at workshops. Indeed, we did not get access ~~at all~~ to the codes for more than half of all the versions used in the CMIP5 despite identifying ourselves as research peers. Therefore, we have to report the very poor status of accessibility to climate models, which could generate serious doubts for the reproducibility of the scientific results produced by them. While there is no reason to doubt the validity of the results of the study of climate change obtained using the CMIP5 models (in a similar way to findings for other disciplines (Fanelli, 2018)), we encourage all model developers to improve the availability of the codes of climate models and their CSR practices. Previous work has already shown that there is room for significant improvement in the structure of the codes of the models, which is in some cases very poor ~~(?)~~

(García-Rodríguez et al., 2020), and sharing it could help to alleviate this situation. ~~We suggest the possibility of making available 'frozen' versions of the codes used for research studies in open repositories. Similarly~~ It would be desirable that future efforts on the development of climate models have into account the results here presented. In this vein, scientists starting model development from scratch, without problems with legacy code, are in a great position to care from the beginning about licensing and reproducibility, doing it in the best way possible.

It is possible to speculate that some scientists could be reluctant to share code because of perceived potential damage to their reputations because of its quality (Barnes, 2010). It can be argued that this could be related to a lack of adequate education in computer programming (Merali, 2010). This issue with the quality of the code has been raised for the case of climate models (García-Rodríguez et al., 2020). Given that many scientists have no formal training as programmers, it may be presumed that they consider that their code may not comply with the standards of excellence that they usually pursue in their primary fields of knowledge. Indeed, it has been documented that some climate scientists acknowledge that imperfections in climate models exist, and they address them through continuous improvement without paying too much attention to the common techniques of software development (Easterbrook and Johns, 2009).

Nevertheless, all scientists must believe that their code is good enough (Barnes, 2010) and that there are thus no reasons not to publish it (LeVeque, 2013). Barriers to code-sharing through licensing, imposed by, e.g., government bodies, cannot be an excuse. When contributing to scientific studies and international efforts where collaboration and trust are critical, such practice is not acceptable (Añel, 2019).

We recommend that frozen versions of the climate models later used to support the results discussed in international reports on climate change should be made accessible along with the outputs from simulations in official data portals. ~~Moreover, as~~ Also, this should apply to any other Model Intercomparison Project. It must be had into account that climate models are an essential piece in the evaluation of climate change, and not sharing them can be perceived as a weakness of the methodology used to perform such assessments. Reproducibility could not be compromised; however, the simple fact that replicability (note that reproducibility and replicability are different concepts (ACM, 2018)) can not be achieved because of the lack of the code of the model is unfortunate. In this way, frozen versions of the models combined with cloud computing solutions and technologies such as containers can be a step forward to achieve full replicability of results in earth system modelling (Perkel, 2019; Añel et al., 2020). Also, tools to validate climate models are becoming common. Such tools use metrics to validate the outputs of the models. The ESMValTool (Righi et al., 2020) has been designed with this purpose and evaluation of the accessibility and code of the model could be integrated as a part of the process to measure the performance of the models contributing to the CMIP.

An additional reason to request an open code software policy is that several scientific gaps have been pointed out for the CMIP5 (Stouffer et al., 2017). The lack of availability of the code of the models makes it difficult to address them, as it is not possible to perform a complete evaluation of the source of discrepancies between them. As it has been shown for other fields of software development, ~~this could~~ sharing the code can help to improve the development process of climate models and ~~how these may be expected to work for the scientific research community (Boulanger, 2005). It is clear that funding~~ their reliability (Boulanger, 2005; DoD CIO, 2009). Moreover, it would help to support the collaborative effort necessary to tackle

the challenge of climate change (Easterbrook, 2010) and to do it in a way that complies better with the scientific method and the goals of scientific research (Añel, 2019). Funding should be allocated by agencies and relevant bodies to support such efforts~~, notwithstanding~~ . Notwithstanding that the whole framework of science faces ~~new challenges but~~ challenges related to CSR, at the same time presents opportunities for improvement in such a sensitive field as climate science.

*Code and data availability.* There is no code or data relevant to this paper.

**Figure 1.** Geographical map with ~~percentage~~ the number of the models obtained for each country: a) worldwide; b) Europe (EC-Earth is only included in the worldwide view because it is developed as a consortium of sixteen ~~european~~ European countries); c) Asia. Green colours and ~~percentages~~ fractions represent the obtained models from the total.

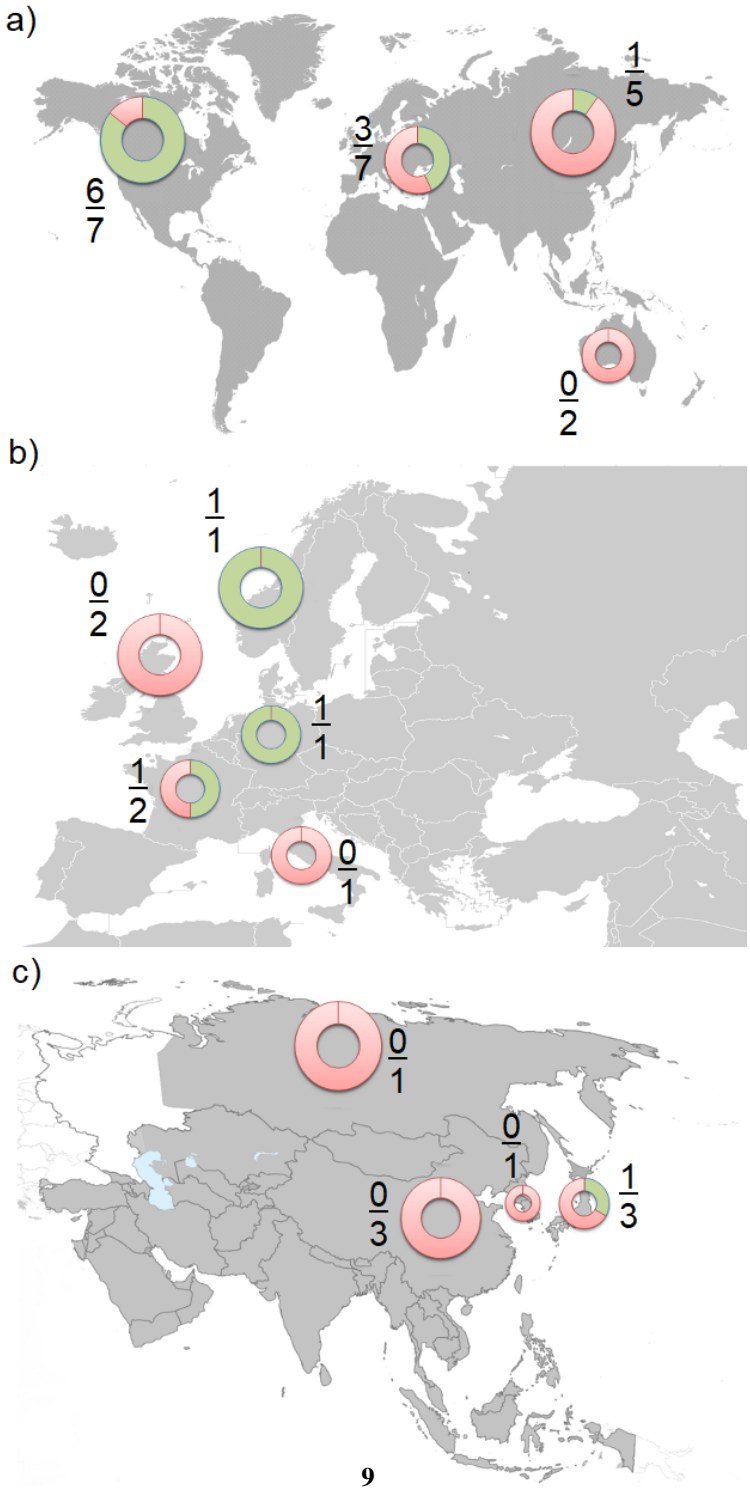

Table 1: CMIP5 model list, research centre responsible for each one and details on the procedure for accessing their code. Email 3 is not listed because we did not receive any answer to them.

| Modeling center | Model | Free download | Answer Email 1 | Answer Email 2 | Comments/Answer |
|---|---|---|---|---|---|
| BCC | BCC-CSM1.1 | No | - | - | No email or contact phone is available. |
| | BCC-CSM1.1(m) | No | | | |
| CCCma | CanAM4 | No | Yes | | The code is not shared. |
| | CanCM4 | No | | | |
| | CanESM2 | No | | | |
| CMCC | CMCC-CESM | No | No | No | No answer. |
| | CMCC-CM | No | | | |
| | CMCC-CMS | No | | | |
| CNRM-CERFACS | CNRM-CM5 | No | No | Yes | The code is not shared. |
| | CNRM-CM5-2 | No | | | |
| COLA and NCEP | CFSv2-2011 | Yes | - | - | Code available from the official web site. |
| CSIRO-BOM | ACCESS1.0 | No | Yes | | The code is not shared. |
| | ACCESS1.3 | No | | | |
| CSIRO-QCCCE | CSIRO-Mk3.6.0 | No | - | - | No email or contact phone is available. |
| EC-EARTH | EC-EARTH | No | - | - | The code is not shared. |
| FIO | FIO-ESM | No | No | No | No answer. |
| GCESS | BNU-ESM | No | No | No | No answer. |
| INM | INM-CM4 | No | - | - | No email or contact phone is available. |
| IPSL | IPSL-CM5A-LR | Yes | Yes | | Available after email exchange. |
| | IPSL-CM5A-MR | Yes | | | |
| | IPSL-CM5B-LR | Yes | | | |
| LASG-CESS | FGOALS-g2 | No | No | No | No answer. |
| LASG-IAP | FGOALS-gl | No | - | - | No email or contact phone is available. |
| | FGOALS-s2 | No | | | |
| MIROC | MIROC4h | No | Yes | | The code is not shared. |
| | MIROC5 | No | | | |
| | MIROC-ESM | No | | | |
| | MIROC-ESM-CHEM | No | | | |
| MOHC | HadCM3 | No | No | Yes | The code is not shared. |

| | | | | | |
|---|---|---|---|---|---|
| | HadCM3Q | No | | | |
| | HadGEM2-A | No | | | |
| | HadGEM2-CC | No | | | |
| | HadGEM2-ES | No | | | |
| MPI-M | MPI-ESM-LR | Yes | Yes | - | Available after email exchange. |
| | MPI-ESM-MR | Yes | | | |
| | MPI-ESM-P | Yes | | | |
| MRI | MRI-AGCM3.2H | No | - | - | No email or contact phone is available. |
| | MRI-AGCM3.2S | No | | | |
| | MRI-ESM1 | No | | | |
| | MRI-CGCM3 | No | | | |
| NASA-GISS | GISS-E2-H | Yes | No | No | Available after email exchange. |
| | GISS-E2-H-CC | Yes | | | |
| | GISS-E2-R | Yes | | | |
| | GISS-E2-R-CC | Yes | | | |
| NASA-GMAO | GEOS-5 | Yes | No | No | Available after meeting during a workshop. |
| NCAR | CCSM4 | Yes | - | - | Code available from the official web site. |
| NCC | NorESM1-M | Yes | Yes | | Available after email exchange. |
| | NorESM1-ME | Yes | | | |
| NICAM | NICAM.09 | No | No | Yes | Available after email exchange. |
| NIMR/KMA | HadGEM2-AO | No | No | Yes | The code is not shared. |
| NOAA-GFDL | GFDL-CM2.1 | Yes | Yes | Yes | Available after email exchange. |
| | GFDL-CM3 | Yes | | | |
| | GFDL-ESM2G | Yes | | | |
| | GFDL-ESM2M | Yes | | | |
| | GFDL-HIRAM-C180 | Yes | | | |
| | GFDL-HIRAM-C360 | Yes | | | |
| NSF-DOE-NCAR | CESM1(BGC) | Yes | - | - | Code available from the official web site. |
| | CESM1(CAM5) | Yes | | | |
| | CESM1(CAM5.1,FV2) | Yes | | | |
| | CESM1(FASTCHEM) | Yes | | | |
| | CESM1(WACCM) | Yes | | | |

Table 2: Summary of reasons behind granting us access to the source code of the models.

| **Modeling center** | **Model** | **Process and reasons to access to the code** |
|---|---|---|
| COLA and NCEP | CFSv2-2011 | A tarball with the source code can be easily accessed from the official web site explaining what the code does and how the climate model works. |
| IPSL | IPSL-CM5A-LR | M. García-Rodríguez identified himself and explained via email the purposes of this research. After a meeting of the developing team and additonal details on this research we were granted access to a tarball with the source code. |
| | IPSL-CM5A-MR | |
| | IPSL-CM5B-LR | |
| MPI-M | MPI-ESM-LR | The access to a tarball with the source code was granted after registration as an user via a web page and approval, without any extra communication or reasoning. |
| | MPI-ESM-MR | |
| | MPI-ESM-P | |
| NASA-GISS | GISS-E2-H | After two weeks, we received the answer to our email. They have provided us directly with a link in which a tarball with the source code can be accessed with the snapshots of the model. |
| | GISS-E2-H-CC | |
| | GISS-E2-R | |
| | GISS-E2-R-CC | |
| NASA-GMAO | GEOS-5 | Initially, they did not answer the emails that were sent to them. After a presentation during a workshop Dr Añel was approached by one of the members of the team and we were put in contact with one of the coders. By contacting this person we obtained access, available as 4073 files in directories retrieved using 'wget'. |
| NCAR | CCSM4 | The code of the model is available through a web page. The dowload proccess is open to anyone but it is hard. Each file of the model has to be individually retrieved (2247 files in total, each in its respective sub-directory). |
| NCC | NorESM1-M | First, we received a reply stating that the code of the model is not shared with anyone outside the NorESM-community, asking if we really needed it. After identifying ourselves and explaining our research, we were granted access to a tarball after registering as users in the 'noresm wiki'. |
| | NorESM1-ME | |
| NICAM | NICAM.09 | Initially, they asked us questions about the purpose of achieving the code. Then, explaining the objectives of the project, they have given us access to a tarball with the code after registering in the nicam user group. |
| NOAA-GFDL | GFDL-CM2.1 | We were granted access to a tarball with the source code in reply to our first request via email. |
| | GFDL-CM3 | |
| | GFDL-ESM2G | |
| | GFDL-ESM2M | |
| | GFDL-HIRAM-C180 | |

| | | |
|---|---|---|
| | GFDL-HIRAM-C360 | |
| NSF-DOE-NCAR | CESM1(BGC) | We had to register to access the Community Earth System Model.<br>After that, we were able to download a tarball with the source code. |
| | CESM1(CAM5) | |
| | CESM1(CAM5.1,FVV2) | |
| | CESM1(FASTCHEM) | |
| | CESM1(WACCM) | |

Table 3: CMIP5 models with code obtained and scores of reproducibility. Maximum value of three filled stars is given to those models it is possible to access through the internet without restriction, with a license that allows full testing and evaluation of the model. The score was reduced by one star when failing for each one of the following criteria: if in order to gain access to the model we had to contact a research centre or development group, to sign license agreements, or if we gained access only after identifying ourselves as scientists undertaking climate research and according to the rights to evaluate and use the model as granted by the license (if applicable). A not-filled star means that the license of the model does not allow modification of the code.

| Institution | Model | Score |
|---|---|---|
| Cola & NCEP | CFSv-2011 | ★★☆ |
| IPSL | IPSL-CM5A-LR<br>IPSL-CM5A-MR<br>IPSL-CM5B-LR | ★★ |
| MPI-M | MPI-ESM-LR<br>MPI-ESM-MR<br>MPI-ESM-P | ★ |
| NASA GISS | GISS-E2-H<br>GISS-E2-H-CC<br>GISS-E2-R<br>GISS-E2-R-CC | ★☆ |
| NASA GMAO | GEOS-5 | ★☆ |
| NCAR | CCSM4 | ★★★ |
| NCC | NorESM1-M<br>NorESM1-ME | ★★ |
| NICAM | NICAM.09 | ★ |
| NOAA GFDL | GFDL-CM2.1<br>GFDL-CM3<br>GFDL-ESM2G<br>GFDL-ESM2M<br>GFDL-HIRAM-C180<br>GFDL-HIRAM-C360 | ★★ |
| NSF-DOE-NCAR | CESM1(BGC)<br>CESM1(CAM5)<br>CESM1(CAM5.1 FV2)<br>CESM1(FASTCHEM)<br>CESM1(WACCM) | ★★★ |

Table 4: Availability of detailed information provided with the source code of the models in order to run them. 'Documentation' refers to full documentation of the model (for IPSL models a web address/link was included to access the documentation but it did not work). 'Readme' corresponds to a file containing basic explanations on the files part of the model and basic instructions. 'Basic example' refers to whether an example to explain the model is included. 'Dependencies' refers to the basic information on libraries, compilers or any other software and its version needed to run the model. 'Makefile' refers to the existence of a single file that manages all the process of compilation and model run.

| **Modeling center** | **Model** | **Documentation** | **ReadMe** | **Basic example** | **Depencencies listed** | **Makefile** |
|---|---|---|---|---|---|---|
| COLA and NCEP | CFSv2-2011 | yes | yes | yes | yes | yes |
| IPSL | IPSL-CM5A-LR | no* | yes | yes | yes | yes |
| | IPSL-CM5A-MR | | | | | |
| | IPSL-CM5B-LR | | | | | |
| MPI-M | MPI-ESM-LR | yes | yes | yes | yes | yes |
| | MPI-ESM-MR | | | | | |
| | MPI-ESM-P | | | | | |
| NASA-GISS | GISS-E2-H | yes | yes | yes | yes | yes |
| | GISS-E2-H-CC | | | | | |
| | GISS-E2-R | | | | | |
| | GISS-E2-R-CC | | | | | |
| NASA-GMAO | GEOS-5 | yes | yes | yes | no | yes |
| NCAR | CCSM4 | yes | yes | no | yes | yes |
| NCC | NorESM1-M | yes | yes | yes | yes | yes |
| | NorESM1-ME | | | | | |
| NICAM | NICAM.09 | no | yes | no | no | yes |
| NOAA-GFDL | GFDL-CM2.1 | yes | yes | yes | yes | yes |
| | GFDL-CM3 | | | | | |
| | GFDL-ESM2G | | | | | |
| | GFDL-ESM2M | | | | | |
| | GFDL-HIRAM-C180 | | | | | |
| | GFDL-HIRAM-C360 | | | | | |
| NSF-DOE-NCAR | CESM1(BGC) | yes | yes | yes | yes | yes |
| | CESM1(CAM5) | | | | | |
| | CESM1(CAM5.1,FVV2) | | | | | |
| | CESM1(FASTCHEM) | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | CESM1(WACCM) | | | | | |

## Appendix A: Templates of emails used to contact the model development teams

### A1 First email

Dear Sir/Madame,

my name is Michael García Rodríguez and I am an MSc Student at the EPhysLab in the Universidade de Vigo, Spain (http://ephyslab.uvigo.es). I am developing my MSc Thesis on the study of qualitative issues of climate models, mostly related to scientific reproducibility and copyright issues.

In order to do it, I have focused my research project on the study of the models that contributed to the last CMIP5 report. For it, I am trying to get access to the code of all the models that reported results of this effort.

Therefore I would like kindly request access to the code of your model, $MODEL-NAME$, namely the version that you used to produce CMIP5 results. Therefore, could you say me how could I get access to it?

Many thanks in advance.

Best regards,

Michael García Rodríguez

EPhysLab

Universidade de Vigo

http://ephyslab.uvigo.es

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### A2 ~~Second email~~

~~The second email was equal to the first one, but a second try:~~

### A2 Third email

Dear Sir/Madame,

We are not trying to understand the code but some way to make qualitative measurements of the code most the focus of copyright use and scientific reproducibility, focusing on how easy it is to get access to the code of the models. Size and complexity of the code is not a problem from my point of view. What you describe is similar to how other models are but for example, the CESM team has provided a tarball file maybe you can do something similar. We are not going to try to understand the physics of the code. If the amount of work is so great that in fact, you can not to deal with it, could you explain me why? It would be of great help, in case of not being able to get the code of the model, know the answer. Please, if it's possible, mark with a cross one or more answers on below:

[ ] Because of restrictions imposed by the institution/s where the model is developed

[ ] Copyright issues (please, if you mark this choice, could you send me a copy of the licenses?)

[ ] Development team policy

[ ] Legal restrictions of your country

[ ] Others reasons (please specify):

_____-

In this case, I will be able to write down the reasons why I was not allowed access to the code and I could document it in my MSc Thesis on the study of qualitative issues of climate models.

thank you for your time, I really appreciate it.

Best regards,

Michael García Rodríguez

EPhysLab

Universidade de Vigo

http://ephyslab.uvigo.es

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*Author contributions.* All the authors participated in the design of the study and writting of the text. MGR and JAA made the attemps to get access to the code of climate models.

*Competing interests.* We do not have competing interest.

*Acknowledgements.* This research was partially supported by the ZEXMOD Project of the Goverment of Spain (CGL2015-71575-P) and the European Regional Development Fund (ERDF). Juan A. Añel is supported by a 'Ramón y Cajal' Grant funded by the Government of Spain (RYC-2013-14560). We would like to thank to Didier Roche, Julia Hargreaves~~and Rolf Sander~~, Rolf Sander, Richard Neale and two anonymous referees for useful comments to improve this paper.

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