SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Effects of aerosols reduction on the Asian summer monsoon prediction skill: the case of summer 2020 with COVID-19 confinements
Computer Project Account:	spitcher
Start Year - End Year :	2022 - 2022
Principal Investigator(s)	Annalisa Cherchi
Affiliation/Address:	CNR-ISAC
Other Researchers (Name/Affiliation):	Andrea Alessandri (CNR-ISAC), Danila Volpi (CNR-ISAC), Paolo Davini (CNR-ISAC), Pablo Ortega (BSC), Juan Acosta Navarro (BSC), Etienne Tourigny (BSC), Twan van Noije (KNMI)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The main objective of this special project is to evaluate the effects of the detected decreased atmospheric emissions during the boreal spring of 2020 on the monsoon precipitation over Southeast and East Asia during the subsequent summer and in its seasonal prediction skill.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

In the first half of the year, we mostly worked on the setup of the model and the autosubmit configuration. Then in the second half we started and completed the simulations as planned. No specific problem encountered, only we had to speed up during summer 2022 to complete everything before cca shutdown in fall 2022.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

Our experience with the administrative aspects has been positive. The few issues experienced during the duration of the project were quickly solved with the technical support provided.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

1. Workflow manager configuration and setup

In collaboration with the colleagues at Barcelona Supercomputing Centre (BSC), the Autosubmit workflow manager has been employed. Like what implemented by BSC for Marenostrum 4 for the control seasonal hindcasts a semi-automated procedure to produce the retrospective seasonal forecasts has been setup. In particular, the EC-Earth runtime scripts have been modified to perform parallel scheduling of the seasonal predictions for 2020, including associated post-processing, and by setting up the required running environment, including preparation and transfer in the working directory of the initial and boundary conditions needed by the model.

2. *System set-up for initial and boundary conditions*

The same initialization strategy used in the control seasonal hindcasts that have been performed at BSC (CTL-2020) is here employed for our experiments. It consists of initializing the coupled model on May 1st, 2020, from a known reference state (the same as in CTL-2020 ensemble performed at BSC). Initial conditions for IFS/HTESSEL have been prepared from ERA-Interim/ERA-Land reanalysis (Dee et al 2011; Balsamo et al 2015). ICs for NEMO come from ORAS5 reanalysis, and sea-ice conditions for LIM3 have been produced by BSC. As atmospheric forcing we used the ones from SSP2-4.5 scenario for the control experiment, and the scenario called ssp245-covid prepared for the COVID-MIP coordinated simulations (Jones et al 2021). The two scenarios differ as in the latter from January 1st, 2020, the emissions are changed with the observed reductions (Forster et al 2020).

3. Experiments performed

Using EC-Earth3.3 in its seasonal hindcast configuration (Fig 1) we produced two sets of 60-member ensemble seasonal forecast started May 1st, 2020, with atmospheric forcings and boundary/initial conditions as described above. We produced the CTRL ensemble with same conditions as the CTL-2020 ensemble produced by BSC, and COVID ensemble with the modified atmospheric forcing and emissions changed as in the observation for that spring-summer, following the COVID-MIP protocol (Jones et al 2021). A summary of the experiments performed and related descriptions is summarized in Table 1.

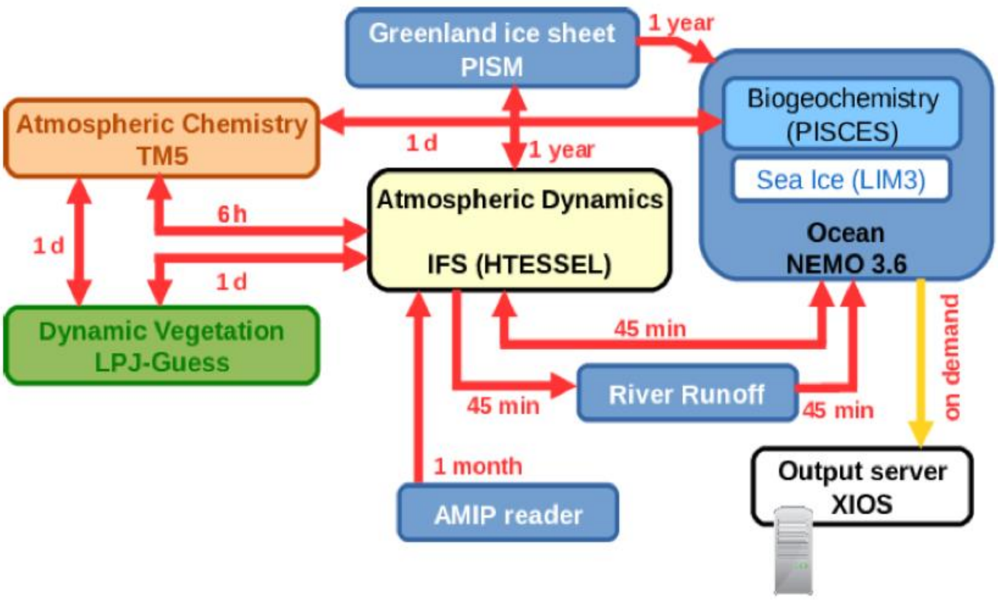

Fig 1: Schematic of the EC-Earth3.3 model configuration used in this project. The model has been used in its seasonal prediction system setup. For more details see Dosher et al 2022.

NAME	Available/produced	DATES	START DATE	LENGTH (months)	MEMBERS (#)	ATM forcing (origin)
CLIM	BSC available	1993-2019	May 1st	6	30	HIST+SSP2-4.5
CTRL	SP produced	2020	May 1st	6	60	SSP2-4.5

COVID	SP produced	2020	May 1st	6	60	COVID-19

Table 1: Characteristics and names used in this report of the EC-Earth3.3 seasonal prediction experiments considered in the analysis below (BSC available is the 1993-2019 climatology and produced within this SP are the 2020 seasonal forecasts).

The model results are compared with observed dataset and atmospheric re-analyses. Observed precipitation data are taken from GPCP (Adler et al 2016) available with global coverage from 1979 to 2020. Winds and other atmospheric variables are taken from the ERA5 atmospheric reanalysis (Hersbach et al 2020) covering the globe for the period 1979 to present.

4. Effects of anthropogenic emissions on the Asian summer monsoons seasonal predictions skill

Before the statistical analysis to verify the changes in the prediction skills, we verified how the model can represent the mean climatological features of the summer over the regions of interest and how the summer 2020 differ in COVID ensemble compared to CTRL ensemble as JJA mean anomalies.

Fig. 2 shows the JJA mean climatology of precipitation (shaded colors) and of wind at 850 hPa (vectors) for the observations (panel a) and for the EC-Earth model (panel b). As mentioned in the methodology section, the climatology is computed for the period 1993-2019 that is the common period between observations/reanalysis and available seasonal prediction hindcasts (CLIM). The main features of the summer mean over the Asian sector are maxima of precipitation over India (mostly in the western Ghats) and over the East Asian continent, as well as over the eastern equatorial Indian Ocean and the Maritime Continent sector, and a strong southwesterly wind from the eastern equatorial Indian Ocean toward India and extending to east Asia (Fig 2a). These two features are the main manifestations and characteristics of the Asian and East Asian summer monsoon. The EC-Earth3 model can reproduce these main features in a realistic way with some larger maxima in terms of precipitation mostly related to orographic structures (Fig. 2b).

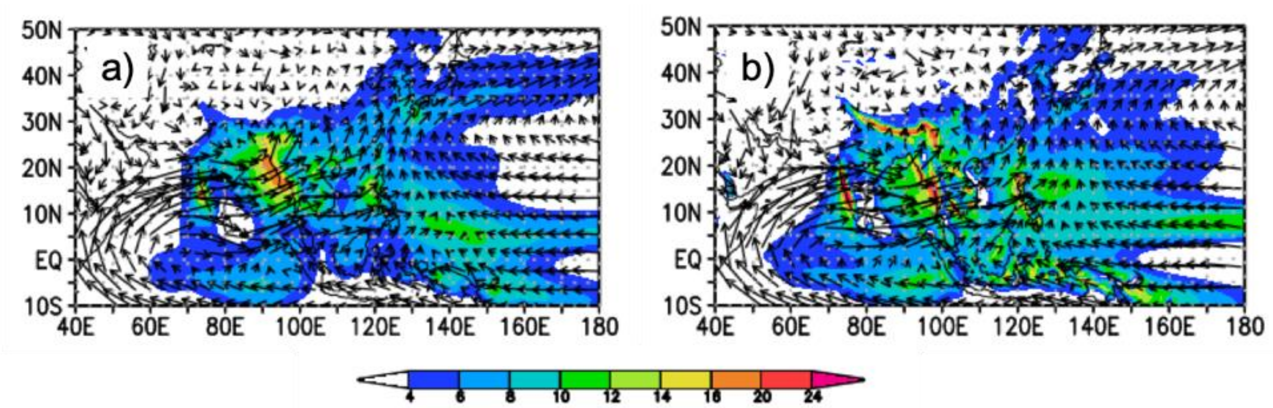

Fig 2: JJA mean precipitation (mm/d, shaded) and 850 hPa wind (m/s, vectors) for (a) observations (GPCP and ERA5) and for (b) EC-Earth3 hindcasts for the period 1993-2019

Figure 3 shows the 2020 anomalies (JJA mean) of precipitation over the region of interest for the observation (GPCP, panel a) and for the two ensembles considered. Panel b shows the ensemble mean of the CTRL while panel c shows the ensemble mean of the COVID experiments. For construction, the two ensembles differ just for the atmospheric forcing that in COVID corresponds with the actual reductions in atmospheric emissions recorded in spring-summer 2020 all over the world. In the observations, the main features of the summer 2020 are positive precipitation anomalies over India (mostly west of the continent) and over East Asia, Korea and south Japan, and negative precipitation anomalies over the Maritime Continent and in the western Pacific region (Fig 3a). In the model these characteristics are reproduced but with some differences, and in particular both set of experiments have smaller positive precipitation anomalies either over India or east Asia compared to GPCP (Fig 3b,c). The objective of the present analysis is to verify whether the differences between the two set of experiments are significant and whether considering a more realistic atmospheric forcing can improve the skill of the summer monsoon precipitation over the region.

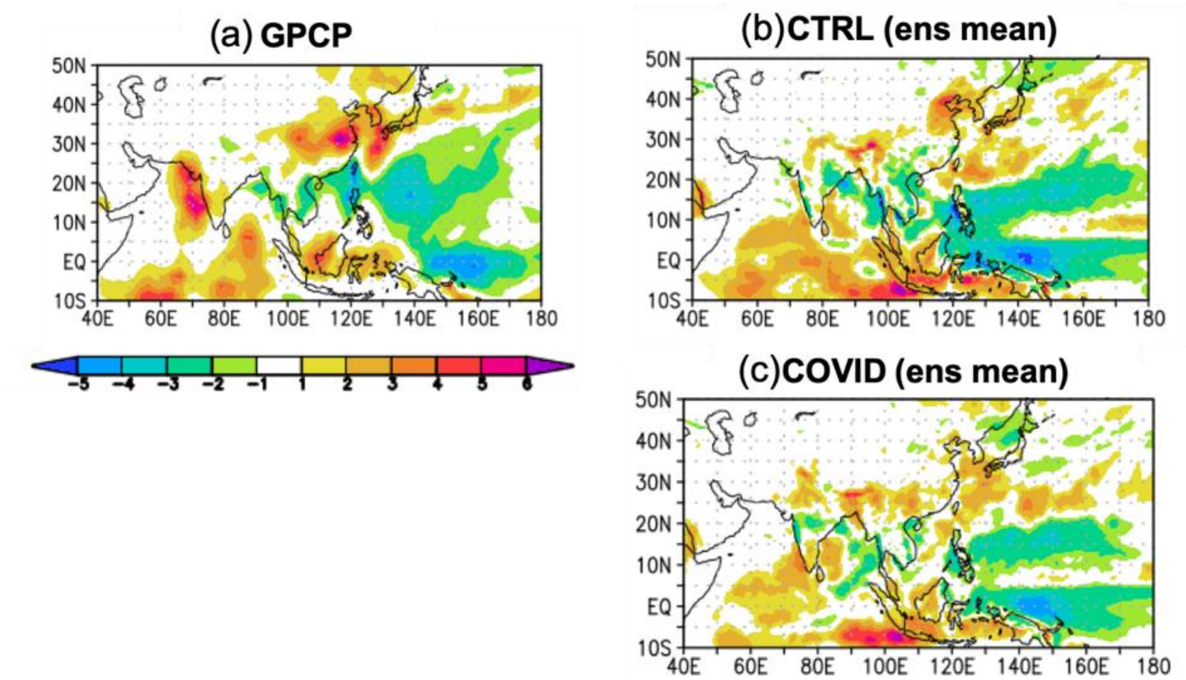

Fig 3: JJA mean 2020 precipitation anomalies (mm/d) for (a) GPCP, (b) CTRL and (c) COVID experiments. In the model the values are shown in terms of ensemble mean for both set of experiments

Fig 4 shows the JJA precipitation anomalies in 2020 as observed from GPCP dataset (a) and how the difference between the JJA 2020 anomalies between the COVID and the CTRL ensemble differs from what has been observed. The COVID minus CTRL difference has positive precipitation anomalies in areas over the Asian and East Asian regional summer monsoon sectors (Fig 4a,b). In the lower troposphere, at 850 hPa, the eddy streamfunction shows a clear positive anomaly over the Western Pacific sector with anticyclonic 850 hPa wind anomalies as indicated by the vectors (fig 4c). The COVID minus CTRL 2020 anomalies (Fig 4d) shows similar features, with a positive streamfunction anomaly in the western Pacific and weaker anticyclonic winds. Also, the anomalies over the Indian subcontinent are in phase with the pattern represented from the atmospheric reanalysis (Fig 4c,d), indicating that the COVID ensemble better represent (and hopefully forecast) the summer 2020 characteristics over the Asian and East Asian regional summer monsoon sectors.

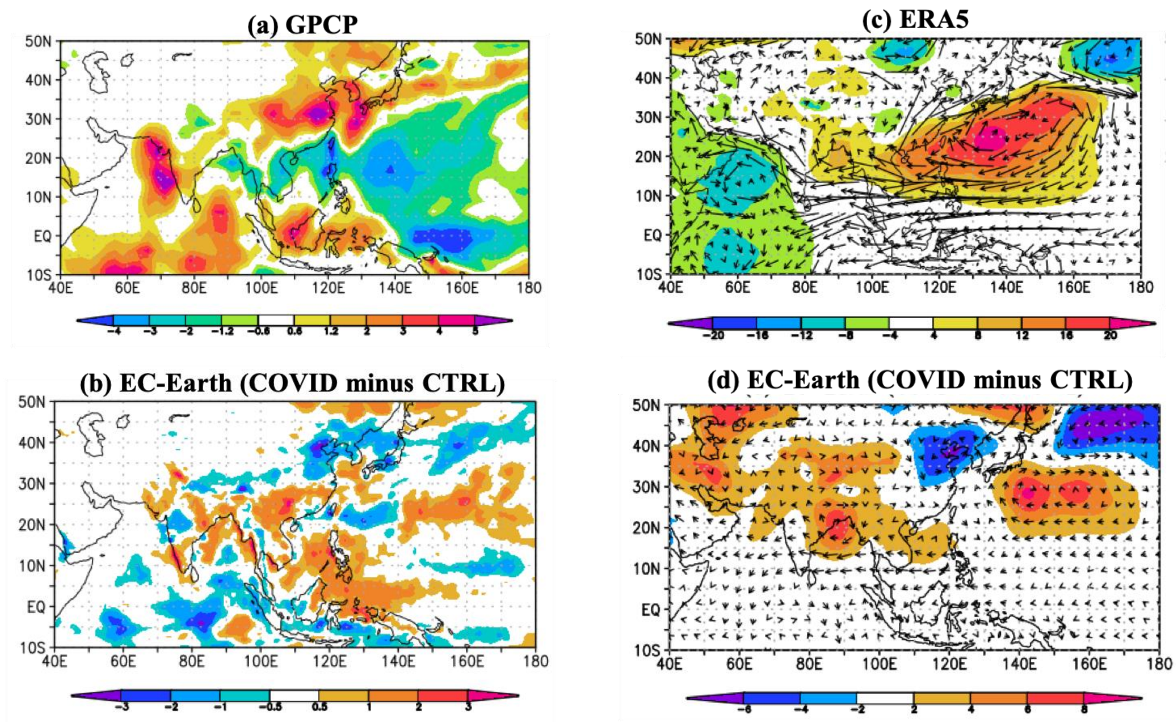

Fig 4: JJA 2020 precipitation anomalies (mm/d) for (a) GPCP and (b) as difference between COVID and CTRL ensemble means. JJA 2020 850 hPa eddy streamfunction (m, shaded) and 850 hPa wind (m/s, vectors) for (a) ERA5 and (b) as difference between COVID and CTRL ensemble means

One of the most widely used metrics for the verification of spatial patterns in prediction framework is the anomaly correlation coefficient (ACC). The ACC is the spatial correlation between the forecasted and the verified anomalies. In our case it is the correlation between spatial field in panel b and c with the spatial field in panel a. Table 2 shows the ACC for some selected regions in the domain considered in Fig. 3 and it mostly evidence that the values in the two ensembles are not statistically different in some areas but may largely differ in others.

ACC (2020 JJA mean)	CTRL	COVID
R1 (40°-180°E, 10°S-50°N)	0.43	0.43
R2 (100°-120°E, 23°-30°N)	-0.29	0.11
R3 (65°-85°E, 5°-15°N)	-0.27	-0.27
R4 (130°-160°E, 10°S-5°N)	0.44	0.59

Table 2: ACC values computed for JJA 2020 anomalies for CTRL and COVID ensembles in different areas of the domain shown in Fig. 2

To infer more in terms of probabilistic performance some other statistical metrics have been identified and used. To characterize the overall probabilistic performance of the predictions we use the Brier skill score (BSS) as recognized metric to estimate the improvement of the accuracy of a prediction against a reference. The BSS is defined as

$$BSS = 1 - \frac{BS}{BS_{ref}} \qquad (1)$$

where BS is the Brier score of our prediction and BS_{ref} is the Brier score of the reference (observations). In our case, the Brier Score (Wilks, 2011) is defined as the squared difference between the forecast probability (y) and the occurrence (o) of the dichotomous event under consideration (see Eq. 2)

$$BS = \frac{1}{N}\sum_{k=1}^{N}(y_k - o_k)^2$$

The value of the occurrence o_k can be 1 (if the event has been observed) or 0 (if the event has not been observed). As defined BSS is 1 for perfect forecasts, and it is 0, or less than 0, when forecast is less skillful than the reference chosen.

In this analysis we evaluate the probabilistic events of precipitation being above the upper quartile of the sample climatological distribution. To keep a broader view on the possibility to have an increased skill, the BSS is applied to the whole domain. Fig 5 shows the June 2020 precipitation anomalies in the COVID ensemble that we already discussed above in terms of differences compared to CTRL (Fig 3, 4 and related description) but black dots are included to inform on the BSS performance. In particular, black dots correspond to grid point where the BSS difference between COVID and CTRL is positive and statistically significant (at 5%). The values in Fig 5 are indicative of the fact that in COVID forecasts the skill is potentially increased compared to CTRL. Considering the experiments analyzed and how they have been designed this suggests that the increased skill is associated with using more realistic atmospheric forcing, including anthropogenic aerosols, in the predictions. In fact, the areas where the signature and the difference are more evident correspond to the area where the reduction in aerosol optical depth has been recorded as the largest in the spring 2020.

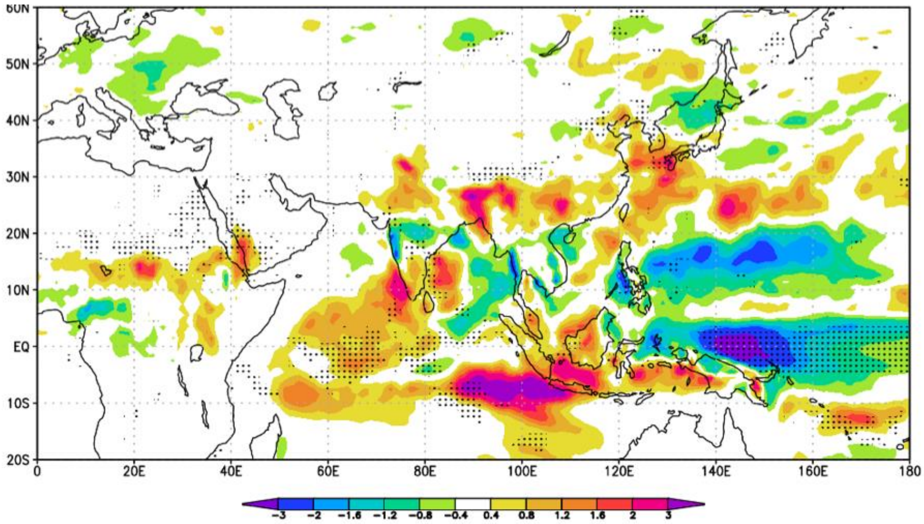

Fig 5: JJA precipitation anomalies (shaded, mm/d) in COVID ensemble mean. Black dots indicate where the BSS difference with respect to CTRL ensemble mean is positive and statistically significant at 10% level.

5. *Final remarks*

The outcome of the main analysis described here and obtained from this special project is an important potential contribution to the understanding of the role of atmospheric emissions, including anthropogenic aerosols, on the predictability (and predictions) of the summer monsoon precipitation over Asia. An important take-home message is that including more realistic atmospheric forcing conditions in the spring preceding the forecasted summer can be convenient. Overall, it is part of the ongoing research on seasonal forecasting, including its usefulness and applicability for society. The importance and applicability of this type of research goes beyond the region selected for the analysis performed.

References:

Adler R, Wang JJ, Sapiano M, Huffman G, Chiu L, Xie PP, Ferraro R, Schneider U, Becker A, Bolvin D, Nelkin E, Gu G, and NOAA CDR Program (2016) Global Precipitation Climatology project (GPCP) Climate Data Record (CDR), Version 2.3 (Monthly). National Centers for Environmental Information https://doi.org/10.7289/V56971M6

Balsamo G et al (2015) ERA-Interim/Land: a global land surface reanalysis dataset. Hydrol Earth Syst Sci 19 389-407 https://doi.org/10.5194/hess-19-389-2015

Dee DP et al (2011) The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Quart J Roy Meteor Soc 137(656) 553-597 https://doi.org/10.1002/qj.828

Doscher R, Acosta M, Alessandri A, Anthoni P, Arsouze T, Bergman T, Bernardello R, Boussetta S, Caron LP, Carver G, Castrillo M, Catalano F, Cvijanovix I, Davini P, Dekker E, Doblas-Reyes FJ, v. Hardenberg J, Hieronymus J, Karami MP, Keskinen JP, Koenigk T, Makonnen R, Massonet F, Menegoz M, Miller PA, Moreno-Chamarro E, Nieradzik L, van Noije T, Nolan P, O'Donnell D, Ollinaho P, van den Oord G, Ortega P, Prims OT, Ramos A, Reerink T, Rousset C, Ruprich-Robert Y, Le Sager P, Schmidtd T, Schrodner R, Serva F, Sicardi V, Madsen MS, Smith B, Tian T, Tourigny E, Uotila P, Vancoppenolle, Wang S, Warlind D, Willen U, Wyser K, Yang S, Yepes-Arbos X, Zhang Q (2022) The EC-Earth3 Earth system model for the coupled model intercomparison project 6. Geophys Model Develop 15(7) 2973-3020 https://doi.org/10.5194/gmd-15-2973-2022

Forster PM et al (2020) Current and future global climate impacts resulting from COVID-19. Nat Clim Ch https://doi.org/10.1038/s41558-020-0833-0

Hersbach H, Bell B, Berrisford P, Hirahara S, and co-authors (2020) The ERA5 global reanalysis. Quart J Roy Meteor Soc 146 (73) 1999-2049 https://doi.org/10.1002/qj.3803

Jones CD et al (2021) The climate response to emissions reductions due to COVID-19: Initial results from CovidMIP. Geophys Res Lett 28 e2020GL091883 https://doi.org/10.1029/2020GL091883

List of publications/reports from the project with complete references

Cherchi A, Alessandri A, Tourigny E, Acosta Navarro JC, Ortega P, Davini P, Volpi D, Catalano F, van Noije T and Annamalai H (2022) Effects of anthropogenic emissions reduction on the Asian summer monsoon prediction: the case of summer 2020 (in preparation)

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

This specific analysis can be considered as concluded, and there is no specific follow up to implement. The scientific report to be submitted as peer-reviewed publication is under drafting and it will be completed soon. The experience gained with this special project has been highly valuable for other activities and another special project submitted by the same principal investigator and just started in January 2023.