Outline of the coordinated experiments for studying tropical basin interaction (TBI CoEx)

1. Integration period

The core integration period is 1982-2021 for all experiments. For the standard pacemaker experiments, the integration period 1870-2021 is recommended. 2015-2021 is important due to the strong 2015/2016 El Nino (and the poor predictions for 2014/15), and the strong 2019 IOD, and 2019 and 2021 Atlantic Niños.

2. Restoring fields

Restore to model climatology plus observed anomalies ("anomaly-restoring") for the experiments in Tier 1. Additional experiments in Tier 2 will restore to full-field observed SST. The target for the SST restoring will be the CMIP6 AMIP SST boundary conditions prepared by Paul Durack: https://esgf-node.llnl.gov/search/input4mips/ (variable tosbcs). The current version is 1.1.9, which extends to Dec 2022. Please use this version. The data can also be found here: https://drive.google.com/file/d/1xCdUbrtlNZ-XSwO-estLHXIOxSFF-1mJ/view?usp=sharing
These monthly mean boundary conditions are centered on the middle of each month and should be linearly interpolated to the model time step. They are specifically modified such that the monthly mean observed value is recovered from the model output. See here for details: https://pcmdi.llnl.gov/report/pdf/60.pdf
Sea-surface salinity will also have to be restored in the global SST restoring experiment (CTRL_REST) to avoid AMOC collapse and other undesirable model drift.
Sea-ice restoring is optional. A reference for sea-ice restoring is here: (https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019GL085788).
The restoring time scale should be 15 days over a 50m deep layer.
While SST restoring is recommended, groups may also use 3D data assimilation.
Please use the following **basin mask** to separate individual basins:
https://drive.google.com/file/d/1iuxXgTmEaNphvve_o0t9fdcC3ZTgEO9R/view?usp=drive_link
In this mask, the Atlantic is 1, the Pacific is 2, and the Indian Ocean is 3.

3. Radiative forcing, aerosols etc.

Forcing data should follow those of the CMIP6 experiment "historical", available via the ESGF website. Please see here for more information:
https://pcmdi.llnl.gov/CMIP6/Guide/modelers.html
The CMIP6 forcing is only available until 2014. Use future forcing for 2015-2021 (e.g. experiment ssp585).

If a GCM does not support varying radiative forcing (e.g. seasonal prediction models) climatological forcing may be used.

4. Model spin-up
Where a pre-industrial control simulation (e.g. piControl in CMIP6) exists a random year from that simulation should be chosen to initialize experiments. It is recommended to follow the CMIP6 protocol for experiment “historical”, if possible.

5. Ensemble members
A minimum of 10 ensemble members should be used for all experiments, including the pacemaker hindcasts. Groups are free to decide how they generate perturbations for the ensemble integrations.

6. Initialization of hindcast experiments
The following concerns the pacemaker hindcast branch of the proposed experiments.
<u>a) Initialization method</u>
We recommend using global SST restoring as a “poor man’s” initialization scheme. This method has shown reasonable performance for seasonal prediction in the tropics and is easy to implement for groups that do not have data assimilation at their disposal. While more sophisticated initialization techniques are likely to yield somewhat higher prediction skill, what is more important for our experiments than optimized skill is the comparability across models.
Nevertheless, these are only recommendations. Groups are free to use the initialization scheme of their choice.

<u>b) Initialization month</u>
February 1 should be used by all groups. Additionally, May, August and November are recommended. March may be useful to assess prediction skill in the Atlantic, but this is optional.

7. Long-terms storage of the data
We will aim to become part of CMIP6Plus (or CMIP7, depending on when the experiments are completed). This will require a technical paper describing the experiment design. Once the manuscript has been submitted and been made available on a preprint server, we should be able to upload the “cmorized” data to the ESGF. This is not expected to happen until the end of 2023. Spring 2024 is more realistic. Until then, groups should expect to store the necessary model output on their own storage systems.

8. Timeline for completion of experiments

Test runs have been performed by several groups. We should aim to start production runs in the summer of 2023 and to have some results by the end of 2023. All Tier 1 experiments should be completed by the end of 2024. The completion of Tier 2 and Tier 3 experiments will depend strongly on the interests and resources of individual modeling groups.

9. List of experiments

The experiments aim to achieve a better understanding of both the mechanisms of TBI and its potential importance to seasonal predictions. These aims are addressed in two separate branches of experiments: standard pacemaker experiments and pacemaker hindcast experiments. Groups can choose whether they would like to participate in only one or both branches.

Tier 1

Branch 1: Standard pacemaker experiments (full basin)

CTRL

This is a fully coupled CGCM integration that uses historical radiative forcing. The core integration period is 1982-2021, but it is recommended to use the longer period 1870-2021. For groups who participated in CMIP6 this will be identical to experiment "historical" but extended to 2021. Groups who did not participate in CMIP6 should use the radiative forcing provided by CMIP6. Since the CMIP6 experiment "historical" only extends to 2014, forcing from experiment ssp585 should be used to extend simulations to 2021.

PACE_P_ANOM

This is a pacemaker experiment that restores SSTs to model climatology + observed anomalies over the whole width of the tropical Pacific, from 15S to 15N. The restoring should be linearly tapered off poleward to 25S and 25N. Outside the restoring regions, the model will be fully coupled. No tapering will be performed at the lateral boundaries (including the Maritime Continent). SST restoring is recommended, but 3D data assimilation may also be used. The **basin mask** to use can be found here: https://drive.google.com/file/d/1iuxXgTmEaNphvve_o0t9fdcC3ZTgEO9R/view?usp=drive_link

The model climatology should be calculated from the above CTRL experiment using the period 1982-2019. SST anomalies are calculated from the CMIP6 AMIP SST boundary conditions: https://esgf-node.llnl.gov/search/input4mips/ (variable tosbcs). The base period for calculating the SST anomalies is 1982-2019.

The current version is 1.1.9, which extends to Dec 2022. Please use this version. The data can also be found here: https://drive.google.com/file/d/1xCdUbrtlNZ-XSwO-estLHXIOxSFF-1mJ/view?usp=sharing

PACE_A_ANOM
Similar to PACE_P_ANOM, but for the tropical Atlantic. The restoring latitude range is 10S-10N, with linear tapering to 20S/20N.

PACE_I_ANOM
Similar to PACE_P_ANOM, but for the tropical Indian Ocean. The restoring latitude range is 15S-15N, with linear tapering to 25S/25N.

Branch 2: Pacemaker hindcast experiments

CTRL_REST_ANOM
Like CTRL_REST from Tier 2, but restore SST to model climatology + observed anomalies. This is meant to serve as an anomaly initialization scheme and can also serve as a reference, in combination with CTRL_REST. If another initialization scheme is used (3DVAR etc.) this experiment is not needed.

HIND_CTRL_ANOM
Hindcast experiment with anomaly initialization. This is only needed if CTRL_REST_ANOM is used.

HIND_P_ANOM
If CTRL_REST_ANOM is used for initialization: Like CTRL_REST_ANOM, but continue restoring to observed SST anomalies in the tropical Pacific only.
If another initialization method is used: Restore to drift climatology, i.e., the climatology of the hindcast as a function of lead time and calendar month. This is to account for the fact that the model will start from observed climatology and gradually drift toward its own climatology.
Restoring region and base period for calculation of SST anomalies are the same as in PACE_P_ANOM.

HIND_A_ANOM
Like HIND_P_ANOM, but for the tropical Atlantic. Restoring region as in PACE_A_ANOM.

HIND_I_ANOM

Like HIND_P_ANOM, but for the tropical Indian Ocean. Restoring region as in PACE_I_ANOM.

Tier 2

Branch 1: Standard pacemaker experiments (full basin)

PACE_P
This is a pacemaker experiment that restores SSTs to full-field observations over the whole width of the tropical Pacific, from 15S to 15N. The restoring should be linearly tapered off poleward to 25S and 25N. Outside the restoring region, the model will be fully coupled. No tapering will be performed at the lateral boundaries (including the Maritime Continent). SST restoring is recommended, but 3D data assimilation may also be used.
The target for the SST restoring will be the CMIP6 AMIP SST boundary conditions prepared by Paul Durack: https://esgf-node.llnl.gov/search/input4mips/ (variable tosbcs). The current version is 1.1.9, which extends to Dec 2022. Please use this version. The data can also be found here: https://drive.google.com/file/d/1xCdUbrtlNZ-XSwO-estLHXIOxSFF-1mJ/view?usp=sharing
The basin mask to use can be found here:
https://drive.google.com/file/d/1iuxXgTmEaNphvve_o0t9fdcC3ZTgEO9R/view?usp=drive_link

PACE_A
Similar to PACE_P, but for the tropical Atlantic. The restoring latitude range is 10S-10N, with linear tapering to 20S/20N.

PACE_I
Similar to PACE_P, but for the tropical Indian Ocean. The restoring latitude range is 15S-15N, with linear tapering to 25S/25N.

Branch 2: Pacemaker hindcast experiments

CTRL_REST
This is meant to serve as a poor-man's initialization scheme for the hindcast experiments.

Global SSTs are restored to observations for the period 1982-2021. In addition sea-surface salinity should be restored as well. Restoring sea-ice is optional.
For those groups that do use this experiment as an initialization scheme, the ocean will have to be spun up. This can be achieved in the following way (following Luo et al. 2005):
1) Force the atmosphere component of the model with SST for the period 1971-1981. Save hourly output of the atmospheric surface forcing (wind stress, diabatic fluxes).
2) Use the hourly output from above to force the ocean component of the model for the same period, 1971-1981.
For those groups who want to use a different initialization scheme, the ocean spin-up described here is not necessary and the entire experiment is optional.
Reference: Luo, J., S. Masson, S. Behera, S. Shingu, and T. Yamagata, 2005: Seasonal climate predictability in a coupled OAGCM using a different approach for ensemble forecasts. *J. Climate*, **18**, 4474–4497, https://doi.org/10.1175/JCLI3526.1.

HIND_CTRL
Initialize hindcast experiments for every year from 1982-2021. February 1 is mandatory, May 1, August 1, and November 1 are recommended. March 1 is optional.
Using CTRL_REST for initialization is recommended, but other initialization schemes may be used.
Hindcasts should be run up to and including lead month 12.

HIND_P
Like HIND_CTRL, but continue restoring SST in the tropical Pacific through the forecast period. Restoring region as in PACE_P.

HIND_A
Like HIND_P, but for the tropical Atlantic. Restoring region as in PACE_A.

HIND_I
Like HIND_P, but for the tropical Indian Ocean. Restoring region as in PACE_I.

Tier 3
Experiments to be performed are still open for discussion. The outcome from Tiers 1 and 2 will likely indicate which additional experiments may be important. Below are some suggestions.

PACE_X_CLIM

Where X stands for P, A, or I. Similar to PACE_X, but restores to observed climatology in the basin of interest. This could serve as an additional reference to the PACE_X experiments.

PACE_X_CLIM_MOD
Like PACE_X_CLIM, but restores to model climatology.

PACE_AI
Restore the Atlantic and Indian Oceans simultaneously to study their combined effect.

PACE_EP
Restore only the eastern tropical Pacific (say, west of the date line) to study how this region can influence global climate variability. Inspired by Kosaka and Xie (2013).

10. Output variables
The following lists output variables we are interested in, using the CMIP nomenclature (see also this simpler list from CMIP3). If not otherwise noted, the output type is monthly means. Vertical pressure levels for 3D atmospheric variables should follow the standard CMIP format (hPa): 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10, 5, 1.
The variables are grouped into three importance levels:
1) necessary (the absolute minimum requirement)
2) desirable (supply if possible)
3) optional (would be useful for further analysis)
Note that CMIP6 has official data requests that specify all the variables that should be provided for a given experiment. We will also have to provide data requests for our experiments in order to become part of CMIP6Plus. I believe the variables listed below should be sufficient for our purposes. Most CMIP6 experiments specific additional variables, such as atmospheric trace gas concentrations, but I believe these are not necessary for us. For your reference, here are links to the data requests for CMIP6 experiment historical monthly mean AGCM output (https://clipc-services.ceda.ac.uk/dreq/u/0bb7eb9e-7f05-11e6-b027-ac72891c3257.html), and monthly mean OGCM output (https://clipc-services.ceda.ac.uk/dreq/u/efc154f6-5629-11e6-9079-ac72891c3257.html).

Atmospheric variables

Level 1	2D: ts, uas, vas, pr, ps, psl, hfls, hfss, rsus, rsds, rlus, rlds, rlut, rsdt, rsut, tauu, tauv, cld, tas, sfcWind, hfcorr 3D: ta, ua va, wap, zg, hus

Level 2	2D: daily mean: ts, uas, vas, pr, ps, ua200, va200, wap500
Level 3	3D: cl, tntmp; 2D: mrso, prw, huss, hurs, sic, snd; daily mean: ta, ua, va, wap, zg, hus (reduced levels: 850, 500, 200, 100, 50 hPa) Additional variables: individual diabatic heating terms, i.e., the components of tntmp (latent, sensible, shortwave, longwave)

Oceanic variables

Level 1	2D: thetao, zos, tos, hfcorr, z20 (depth of the 20C-isotherm)
Level 2	3D: uo, vo, wo, so; 2D: uos, vos, mlotst, tauuo, tauvo, hcont300; daily mean: zos, uos, vos, z20
Level 3	3D: rhopoto; 2D: msftbarot, msftmz, hfbasin; daily mean: sos Additional variables: ocean heat budget terms (3D), or mixed-layer heat budget terms (2D)