REQUEST FOR A SPECIAL PROJECT 2020–2022

MEMBER STATE: …Italy…………………………………………………...…

Principal Investigator[1]**:** …Fred Kucharski……………………………………………

Affiliation: The Abdus Salam ICTP…………………………

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Other researchers: …Franco Molteni (scientific consultant of ECMWF and Staff Associate of ICTP, and the OpenIFS team at ECMWF) ……………………………….……

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Project Title: Development of a 3-layer thermodynamic model of the upper ocean for studies on teleconnections from the tropical oceans.

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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2020	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2020-2022: (To make changes to an existing project please submit an amended version of the original form.)		**2020**	**2021**	**2022**
High Performance Computing Facility	(SBU)	950000	950000	950000
Accumulated data storage (total archive volume)[2]	(GB)	900	900	900

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

In recent years, studies on teleconnections and tropical-extratropical interactions have discussed the importance of the relationship between heating anomalies occurring in different parts of the tropical oceans. The impact of both Pacific-Atlantic and Pacific-Indian ocean connections have been explored in numerous studies, with focus on either the mechanisms linking anomalies in different basins (e.g. Cai et al., 2019, Kucharski et al 2016; Bracco et al. 2005), or on the effect of teleconnections with tropical continents (Kucharski et al. 2007) and the extratropical circulation (Molteni et al. 2015).
While the "classical" response to ENSO anomalies from the central-eastern Pacific can be treated as a forced atmospheric response to boundary forcing, teleconnections from the Atlantic and especially from the Indian ocean are substantially affected by atmospheric feedbacks on the upper-ocean temperature caused by variations in radiative and latent heat fluxes. This implies that coupled model are expected to provide better results than atmosphere-land-only models in reproducing such teleconnections (eg Wang et al. 2005). However, the relationship between variations in surface heat fluxes and the resulting SST anomalies depends crucially on the properties of the ocean mixed layer; model biases in mixed-layer depth or the intensity of upper-ocean mixing can affect the strength of the atmospheric feedbacks and modify the intensity and/or propagation of organised tropical convection.
State-of-the-art ocean models have multiple levels in the ocean mixed layer, and include sophisticated parametrization for vertical mixing. Still, such a complexity does not necessarily guarantee an improvement in the simulation of teleconnections with respect to simulations with prescribed SST (see the results for Indian Ocean teleconnections in the ECMWF new seasonal forecast system SEAS5, discussed in Johnson et al. 2018 and Stockdale et al. 2018).
The goal of this project is to develop a simplified model of the upper ocean where mixed layer depth is prescribed and the vertical mixing is controlled by a small number of parameters. This model will be suitable for coupling with atmospheric models of both intermediate and state-of-the-art complexity: in particularly, we plan to first couple it to the ICTP intermediate-complexity AGCM (SPEEDY: see Molteni 2003; Kucharski et al. 2006, 2013) and then to the latest version of OpenIFS (Carver 2017).
Since teleconnections from the tropical oceans act on scales spanning from the subseasonal to the decadal, the model includes three layers of increasing depth, whose heat content typically varies on sub-seasonal, seasonal and multi-year time scales. The model only represents interactively variations due to thermodynamic processes (namely, convergence of vertical heat fluxes), while the effects of horizontal heat transport are simulated by a climatological, seasonally varying heat flux source (the so-called Q-flux term). This source term can also be modified in order to relax the model temperature towards prescribed regional anomalies, as in "pacemaker" experiments.

The model will be referred to as TOM3 (for Thermodynamic Ocean Model, 3 layers). The typical depth of the three layers is 10m, 50m, and 240m respectively. The depth of the second layer can be specified as a function of the annual-mean surface wind speed, and the total model depth can range between 150m and 300m depending on the actual ocean depth. The 300m maximum depth has been chosen to be able to compare the total-column heat content of the model with the 300m heat content from ECMWF ocean re-analyses. Heat fluxes between the ocean layers are assumed as proportional to the vertical temperature gradient, with coefficients depending on the sign of the gradient itself and the surface wind speed. The inclusion of a thermodynamic sea-ice component is also being considered.
At the moment, the TOM3 model has been tested in forced mode using downward energy fluxes and atmospheric variables from ERA-Interim. In this setting, the Q-flux term has been computed and the forced model has successfully reproduced monthly-mean temperature tendencies as diagnosed from the World Ocean Atlas 09 dataset (see Fig. 1).
The proposed Special Project is planned in two phases. The first phase, which is expected to last one year and is covered by the 2020 proposal, will include:
a) re-tuning and testing the model in forced model with energy fluxes and PBL variables from ERA5;
b) testing the model in coupled mode with the SPEEDY AGCM and perform multi-decadal historical runs in both free and pacemaker mode;
c) coupling TOM3 to OpenIFS and test the coupled system on seasonal to multi-year (~5yr) scale.
At the end of this first phase, it is expected to have an 'optimal' set of model parameters which provide a suitably realistic representation of thermodynamically driven ocean variability.

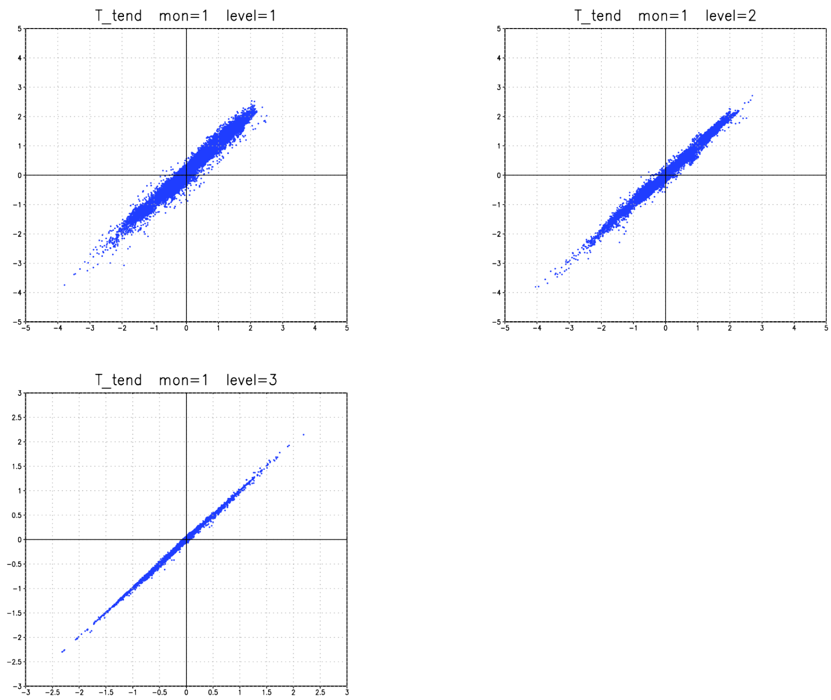

Fig. 1: *Scatter diagram of climatological 30-day tendencies of sub-surface ocean temperature in January, at the 3 levels of the TOM3 model: WOA09 data on x-axis, TOM3 data on y-axis. The model data are derived from a one-year run forced by ERA-interim fluxes and atmospheric variables.*

In the second phase of the project, to be covered by a follow-up Special Project request for 2021-2022, the OpenIFS-TOM3 coupled system will be used to investigate a selected number of scientific issues, exploring the sensitivity of coupled phenomena to upper-ocean properties, as controlled by the model parameters. Among the phenomena to be investigated, we foresee the following:

- MJO intensity and propagation;
- teleconnections from Indian Ocean rainfall to the North Atlantic circulation on seasonal to decadal scale;
- connection between tropical Atlantic and Pacific SST variability.

The exact priority for these investigations will be set at the end of the first phase, based on the fidelity of the simulated ocean variability at different time scales and different ocean domains as diagnosed from phase-1 experiments.
Both phases of the project with be performed in collaboration with Franco Molteni (currently scientific consultant of ECMWF and Staff Associate of ICTP) and the OpenIFS team at ECMWF.

References

1. Bracco, A., F. Kucharski, F. Molteni, W. Hazeleger and C. Severijns, 2005: Internal and forced modes of variability in the Indian Ocean. *Geophys. Res. Lett.*, **32** , L12707, doi:10.1029/2005GL023154.
2. Carver, G., 2017: OpenIFS users explore atmospheric predictability. ECMWF Newsletter no. 153, 6-7.
3. Cai, W. et al., 2019: Pantropical climate interactions. *Science*, **363**, 944
4. Johnson, S. J., Stockdale, T. N., Ferranti, L., Balmaseda, M. A., Molteni, F., Magnusson, L., Tietsche, S., Decremer, D., Weisheimer, A., Balsamo, G., Keeley, S., Mogensen, K., Zuo, H., and Monge-Sanz, B., 2018: SEAS5: The new ECMWF seasonal forecast system, *Geosci. Model Dev.*, doi: 10.5194/gmd-2018-228.
5. Kucharski, F., F. Molteni and A. Bracco, 2006: Decadal interactions between the western tropical Pacific and the North Atlantic Oscillation. *Climate Dyn.*, **26**, 79-91.
6. Kucharski F, A. Bracco, J-H Yoo and F. Molteni, 2007: Low-frequency variability of the Indian Monsoon-ENSO relationship and the Tropical Atlantic: the “weakening” of the 1980s and 1990s. *J. Climate*, **20,** 4255-4266.
7. Kucharski F., F. Molteni, M.P. King, R. Farneti, I-S. Kang, and L. Feudale, 2013: On the need of intermediate complexity General Circulation Models: a “SPEEDY’’ example. *Bull. Amer. Met. Soc.,* **94**, 25-30; doi:10.1175/BAMS-D-11-00238.1
8. Kucharski, F, F. Ikram, F. Molteni, R. Farneti, I-S. Kang, H.H. No, M.P. King, 2016: Atlantic forcing of Pacific decadal variability. *Climate Dyn.* **46**, 2337-2351; doi:10.1007/s00382-015-2705-z
9. Molteni, F., 2003: Atmospheric simulations using a GCM with simplified physical parametrizations. I: Model climatology and variability in multi-decadal experiments. *Climate Dyn.*, **20**, 175-191.
10. Molteni F., T.N. Stockdale and F. Vitart, 2015: Understanding and modelling extra-tropical teleconnections with the Indo-Pacific region during the northern winter. *Climate Dyn.* **45**, 3119-3140; doi:10.1007/s00382-015-2528-y
11. Stockdale, T., and co-authors, 2018: SEAS5 and the future evolution of the long-range forecast system. ECMWF Technical Memorandum no. 835.
12. Wang, B., Ding, Q., Fu, X., Kang, I.-S., Jin, K., Shukla, J. and Doblas-Reyes, F.J., 2005: Fundamental challenge in simulation and prediction of summer monsoon rainfall. Geophysical Research Letters, 32, L15711. doi: 10.1029/2005GL022734.