REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE: **UK**……………….…………………………………………….....…

Principal Investigator[1]**:** **Prof V.I. Shrira**……………………………………………….……

Affiliation: **Keele University**………………………………………………….……

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Other researchers: **Dr Sergei Annenkov**…………………………………………….……

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Project Title: **Role of finite non-gaussianity in the evolution of wind wave fields, with applications to freak wave prediction**

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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPGBSHRI**______________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	**2022**	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2022-2024: (To make changes to an existing project please submit an amended version of the original form.)		**2022**	**2023**	**2024**
High Performance Computing Facility	(SBU)	**1000000**	**1000000**	**1000000**
Accumulated data storage (total archive volume)[2]	(GB)	**100**	**100**	**100**

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

Modelling of wind wave fields in the ocean, including operational forecasts, is based on the Hasselmann kinetic equation, which describes energy exchange between wave motions of different scales and directions, energy input from wind and dissipation through wave breaking and other mechanisms. The nonlinear interaction term, responsible for redistribution of energy between spectral components, is considered to be established, since it is derived from first principles using plausible assumptions. Until now, there were no alternatives to the Hasselmann equation or its generalisations or simplifications.

Previously, direct numerical simulations (DNS) were only possible for short-term evolution (at most a few hundred characteristic periods). The DNS algorithm based on the Zakharov equation (Annenkov & Shrira 2013, 2018), capable of long-term (up to tens of thousands of periods) simulations of random water wave fields, for the first time made possible a direct comparison of wind wave evolution modelled with the Hasselmann equation with DNS obtained by averaging over an ensemble of realisations, without invoking any statistical hypotheses.

In the previous Special Project (2019-2021), simulations of wind wave evolution by DNS and Hasselmann equation were compared with high quality airborne measurements of spectra performed during GOTEX experiment off the coast of Mexico and HYMEX experiment in the western Mediterranean sea. For both sets of measurements, the direct comparisons showed that while the bulk characteristics of wind wave evolution (e.g., significant wave height, wave steepness, downshift of the spectral peak) were captured by all models sufficiently well, there were large differences in spectral shapes and characteristics of angular distribution. In these respects, the DNS results were found to be in much better agreement with the measurements than the results obtained with the Hasselmann equation. Thus, it was demonstrated that the discrepancy between the spectral shapes of mature oceanic waves and solutions of the Hasselmann equation, long known as a major problem in wind wave modelling, can be overcome with DNS, pointing to the nonlinear interaction term of the Hasselmann equation as the origin of the discrepancy. Although the discrepancy mostly concerns spectral shapes, rather than spectral integrals, it has huge significance for many applications, including freak wave prediction. In particular, it was shown that the demonstrated difference in spectral shape corresponds to an order one change of kurtosis, which dramatically affects the freak wave probability estimates. On the other hand, since the existing wind wave models are optimised against the available measurements, knowledge of systematic errors in models can drastically improve the quality of such optimisations, and thus improve the quality of predictions even for spectral integrals like significant wave height.

The origin of the discrepancy has been identified as the neglect of non-gaussianity in the derivation of the Hasselmann equation (Annenkov & Shrira 2021). It was shown by DNS that although non-gaussianity is weak, in the long term it leads to a considerable distortion of the spectral shape. While the Hasselmann equation takes into account finite nonlinearity, it assumes infinitesimal non-gaussianity, since in its derivation the six-point correlator is expressed in terms of two-point ones, neglecting the four-point cumulants in the expansion. Although this approximation, which takes into account only the leading term in the expansion of the correlator, is a prerequisite for obtaining the kinetic equation for spectral amplitudes in the closed form, it leads to the equation with the right-hand side being a homogeneous function of the spectrum, thus neglecting all effects of finite nonlinearity. For the range of wave steepness of real oceanic waves (0.05 and higher) this is an order one effect, which cannot be neglected.

In the new project, we plan to study the role of the terms describing the finite non-gaussianity effects, by extending the existing algorithm for the generalised kinetic equation, created earlier during the

Special Project "Direct numerical simulation of wind wave fields in a rapidly changing environment". The algorithm is fully tested, highly parallelised and optimised for the supercomputing environment. The existing algorithm will be extended by adding a new module, which will involve the solution of a very large system of linear equations for four-point cumulants, and will also be parallelised.

Specific objectives include:

1. To create, for the first time, the numerical model of wind waves within the kinetic theory with the account for weak nonlinearity and weak non-gaussianity.

2. To perform direct comparisons with the DNS

3. To examine implications for the probability of freak waves

4. To get new insights into the input and dissipation functions

5. To formulate recommendations for wind wave modelling

We will start with relatively small discrete models, consisting of $O(10^2)$ harmonics (this will require the numerical solution of a system of $O(10^4)$ linear equations). The target will be to find out the threshold level of wave steepness ε, above which the non-gaussianity effects become significant. We expect this value to be quite small (below 0.05).

Then, we will create the numerical model for continuous wave fields, extending the existing code for the generalised kinetic equation, and perform detailed comparisons with the DNS results, with and without wind forcing. We will also perform a direct comparison of higher statistical moments, in particular kurtosis. Results of the project will have fundamental significance for the progress in wave forecasting.

References

Annenkov, S.Y. & Shrira, V.I. 2013 Large-time evolution of statistical moments of wind wave fields. J. Fluid Mech. 726, 517-546.

Annenkov, S.Y. & Shrira, V.I. 2018 Spectral evolution of weakly nonlinear random waves: kinetic description versus direct numerical simulations. J. Fluid Mech. 844, 766-795.

Annenkov, S.Y. & Shrira, V.I. 2021 Effects of non-gaussianity on evolution of a random wind wave field. Phys. Rev. Letters, submitted.