Discussion 1

UK wave science: research priorities, knowledge gaps, and collaborations

Jean: Are we now reaching the limit of high resolution to do spectral wave modelling. New options in the data-driven world, so is there a way for the new generation to combine the physical modelling in a smart way to best incorporate new and growing datasets. Trying to do this so called digital-twin which means running system at very high resolution (kilometre-scale globally.) Digital-twins are supposed to be used as practical tools, to make decisions on very critical issues. Q to Engineers: what information you need about the waves? Are there smarter techniques that can do the down-scaling much more efficiently than deterministic models?

Lucy: A wealth of models and reanalysis that maybe we haven't made the best use of yet and there's a lot of scope for sort of statistical emulation and of what we've already got. Skipping the wave model out completely using it only as a training data set? Based on deterministic models and go for some emulators. So can you see a space for that in the wave field as well?

Breo: Met Office there is there are efforts to replace part of the model with machine learning approaches we haven't gone for the wave model as a thought yet: been more focused on things like the atmospheric model. But yes, I'm sure there is applications there for some parts of the model.

Paul: Digital twins are useful for circumstances you've seen already. They have no ability to predict extremes that we haven't seen before

Peter: All science is empirical. We can know more about physics, but physics always remains and model. Maybe simple data driven model and be good that well.

Lucy: Spectral wave modelling is 'good enough' for a lot of the day-to-day work. But how can we include any new developments? To update our practical approach of the spectral modelling?

Jean: You have to move away from what spectrum with modelling was designed for in the first place. Perfectly suitable for Hs, but directional representation, especially at the high frequency from the model, is not right. There is room for improvement around a high frequency tail and you do the full 2D distribution of it. Also, nonlinear wave-wave interactions.

Jana: I think there is some work to be done on the use of satellite data for training data-driven models. I think by using deterministic models to train a data-driven, AI/ML model what is being learned is the underlying physics of the deterministic model. Can a better AI/ML model be developed by training on ONLY satellite data? The idea being that nearshore areas which are hard to measure accurately using wave buoys may be better represented. Interesting research question could be using AI or deep learning models which are trained only from satellite or kind of measured data. Danger of basing machine learning on a model, is that it can only represent the behaviour of the spectral model. Use of satellite data would help to eliminate those issues and I wonder as well if it would make the wave model and AI wave model resolve more effective because it would be able to kind of consider the nonlinear mechanisms which aren't included in term missing models.

Tianning: Satellite data can lack a lot in the temporal resolution so that would need to be taken into account.

Paul: Issue with horizontal displacement of buoys means an uncertainty in where they are recording data. All measurement techniques need to be treated with a certain amount of scepticism!

David Woolf: More practical than pure research, but many questions around the operability of offshore wind and other offshore and coastal infrastructure. Not knowing wave conditions can be expensive (for offshore operations), so there is a lot of room to work. Anything that includes predictions/projections from almost instantaneous "next wave" prediction to 30 years + operating lives of wind farms. There are now also lots of data streams (buoys and altimeters and all sorts, and there's also lots of forecasts.) Users may only go to one source, but there is a lot more data available, and great value in trying to use more than one stream of data or more than one forecast. This problem perhaps needs a data scientist to identify how to make the best use of multiple data streams.

Lucy: Agree. Operations thresholds, safety, ship design, and coastal defences are often based on quite old datasets that probably do need a bit of updating. The responsibility should be on us (the people doing the latest wave science) to push that out to the end-users, policy guidance.

Bahareh:The possibility of replacing numerical modelling with AI. Recently we have established a centre for doctoral training (funded by Strathclyde) on "AI-based ocean forecast for marine operation" and PhD students are working on developing AI models for operational wind and wave forecast. Trying to understand if we can find the relationship between the wind and wave in the past based on the available data and if we can apply that to the future projections. And the second topic that now we have like a long-term data access to long term (ECMWF ERA5 for 60 years. and long-term satellite data). So we are taking this opportunity to define the climate stability, but mainly for marine operation or design. Defining criteria for climate stability of wind and wave in long-term using long-term available data (various resources)

Lucy: long-term ocean atmosphere models which are not currently taking waves into account. So is there is there an opportunity to make use of the latest generation of CMIP driven wave-climate models to improve the ocean-atmosphere interface? E.g. mixed-layer depth / sea-surface temperature.

Jean: Recent work looking at long-term climate projection to try to get a wave climate signals. There's been a lot of work recently by the group is Spain in Cantabria and it is very impressive. No doubt that you can use, you know, let's call them higher level statistical methods in which data driven would be to derive this. There's a workshop in ECMWF in April on this: https://events.ecmwf.int/event/364/

Jean: with regards to the atmos-ocean coupling**.** I believe waves should be everywhere, and are necessary in global climate models. But there is a reluctance to spend the extra computational cost on wave modelling. We have to demonstrate that we need the process understanding better first, because even the science is still a bit limited. Until we have a stronger framework to really say that's the process that is missing to go sell it to these people running the CMIP systems, they will take a while. How do we work across different communities that historically have treated one as the and inputs as a boundary condition to the other? So, the atmosphere, things that they only need SST and sea-ice cover and then the ocean only think they only need the winds. But in reality, they are part of the same system. It is a PR issue! Need to bring together knowledge from ocean / atmos / wave communities to combine this knowledge. Waves are at work on 2/3rds of the worlds surface.

Breo: Data assimilation needs to resolve the problem with missing processes at the surface. Modify lower troposphere, and upper ocean at the same time. Traditionally you used to do DA in the wave and atmosphere independently. Coupled data assimilation aims to update these two fields at the same time in a consistent way, in order to propagate into meaningful changes in the model.

Jean: Yeah, I agree. It's just couple days if you want to enhance the use of wave data, you have to use the waves to change the forcing. This has been overlooked / by passed by jumping directly to the SST. Altimetry / SAR data are under-used. If the waves are wrong, then usually it is because the winds are wrong. S there is opportunity for coupled DA (of waves) to improve the skill of the atmosphere.

David Woolf: air-sea transfer of gases and particles (aerosol) also have a sensitivity to waves, therefore there maybe common purpose with atmospheric chemists and chemical oceanographers in pushing for inclusion of waves within coupled climate models. There is a case for including waves and at least some sort of understanding of how she said affects transfer rates. So that may give sort of the common purpose in terms of atmospheric chemistry, to have waves integrated a bit more into climate models so they don't just run with some sort of wind speed or wind stress parameterization.

Lucy: wave ice interactions really need to be considered as well, especially if we're getting that breakdown in the marginal ice zone and that is going to be more important. Increased compute resource mean, we can now start to include all these processes in properly like a true Earth system model.

Jean: I'm still amazed that you know this full nonlinear simulation are inherently so costly? Effort is in solving FFTs -hard to upscale / parallelise this part. Finally, we are missing the step between ‘’users’ who see the actual sea state (not an integrated spectrum). How hard is it to make that step to predict/provide a real-time sea state, rather than an integrated spectrum?

Tiang: The problem can be that a lot of energy is dissipated in the wave breaking that is then not accounted for.
Can this be addressed through parameterisation?

Breo: 2 things from operational centre perspective: interested in improving momentum transfer between atmosphere and ocean. Mean wave conditions are captured well, but the extreme wave heights / tails of the distribution need more work. Second is improving wave approximation in the nearshore; missing processes in <10m water depth, that are resolved in radar, but not seen in the wave models. This would improve the quality of forecasts. Finally, another research question might be around the impact of offshore wind installations: increased drag at the sea surface is likely to not affect waves directly, but reduce wind speed, and thus wave conditions indirectly. E.g. in North Sea. **Lucy**: yes, impacts of currents generated around infrastructure will also interact with the waves.

Importance of directional spreading. Relevant to survival of rigs / infrastructure, and also design of wave-energy convertors for extraction frequency (but also needs to survive very long waves / high-tail / severe sea states). Important to make directional wave spreading available to download with wave data. Wave climate is also relevant for installing new infrastructure: can build in the North Sea whilst it is calm, but e.g. Australian coast permanently exposed to long-swells. There are some installations have been designed so that the platform moves into the inverse of the of the wave, but these are costly. E.g. experimental devices off the coast of Portugal being installed and they have those fairly aggressive conditions. Wave power is also particularly sensitive to directionally