Consolidated Recommendations - Working Group 4

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Ensemble size:
1. Let ensemble size be limited by computational resources (the bigger the better, reconsider settling for ~100-member ensembles).
2. Dedicate efforts to the careful generation of ensembles – aiming to span the broadest state-space possible. The quality of the model and ensemble generation is important, as well as the quantity.
3. Recommend more research on resolution, quality and independence of ensemble members versus ensemble size.

Model resolution:
1. Let model resolution be guided by the spatial resolution of the observing system and the relevant physical processes. Specifically, sufficient model resolution is required to resolve physical processes such as current separation and eddy shedding in WBCs and tidal mixing that modulates water masses.
2. To benefit from novel observations, model resolution may need to be increased.
3. Recommend more research on two-way nesting for dynamically important regions requiring higher resolution.

Best practice:
1. Remember to regularly update your historical Argo data as QC is repeated every 12 months when new data becomes available.
2. Best practice is to compare with independent data, but the challenge is deciding what to withhold. JMA, for example, withhold ~20% of Argo data for validation in the development phase, then assimilate all observations in operations. A good option is data that we are not yet ready to assimilate.
3. Observing system evaluation should be done together with the observational community so that we can contribute to the design of our future observing system and strengthen our relationship with global ocean observing community.
4. Common frameworks for evaluation of systems are needed, and regional collaboration already exists. Broader collaboration should be encouraged, although time consuming it will give consistency. We recommend to make use of international programs or communities, such as UN decade for Ocean Sciences and OceanPredict, for such collaboration.

DA methods:
1. Advances in DA methods needs to prepare us for the assimilation of novel observations (SWOT, HF radar, gliders) and for coupled atmosphere-ocean DA.
2. Recommend more research on hybrid variational and ensemble methods, specifically flow dependent covariance in 4D-Var using ensembles.
3. For coastal and regional applications, we recommend more research on parameter estimation and model tuning versus DA.

Infrastructure:
1. Shared infrastructure is a great opportunity to enhance scientific development of DA, and could really benefit from an easy-to-use user interface.
2. Shared infrastructure is feasible for EnKF applications, but not straight-forward for 4D-Var applications (as a model specific adjoint is required). This makes it more challenging for centres using or looking to use variational methods to 'out-source' their research. We recommend that centres using NEMO for operational forecasting look for a way to develop 4D-Var applications for NEMO and find a better way to bring together the operational developers, researchers and academia.

Entraining and retaining young experts:
1. We recommend an International Centre of Excellence in Data Assimilation to encourage and fund the training of young experts and to retain early career researchers to work on advancing DA. Online international collaboration could allow this to be a 'global' centre.