Some GOAPP terminology

GOAPP attempts to analyze and predict the global state of the ocean-atmosphere-land-cryosphere system using coupled global models on timescales from days to decades. GOAPP brings together researchers from different disciplines (e.g., atmospheric scientists and oceanographers) and this brief document is an attempt to clarify terminology and avoid confusion where the disciplines interact.

System state (GB): The state of the coupled system which may be thought of as a multi-dimensional vector $\mathbf{X}(\lambda, \phi, z, t) = (T, V, q, \ldots)$ containing the variables needed to characterize the system (such as the temperature, velocities and the very many other quantities needed) at a particular time t. The values are often specified over the globe (ϕ, λ) and in the vertical (z) for the atmosphere, ocean, cryosphere and land.

Governing equations (GB): A mathematical representation of the system which conceptually has the form $d\mathbf{X}/dt = \mathbf{F}(\mathbf{X}, \mathbf{B})$ where the rate of change of the system state vector $\mathbf{X}$ is a function of the current system state and other specified information $\mathbf{B}$ which may include, for instance, boundary conditions.

Numerical model (GB): An approximation to the governing equations where the system state is typically specified over a grid of points in both the horizontal and vertical and the analytic governing equations are replaced by discretized approximations thereto. In this process, grid-scale processes are *resolved* while sub-grid scale processes are *parameterized* as functions of the resolved values. Symbolically $\left(\frac{\delta X_{ijk}}{\delta t}\right)^{\tau} = D(X^{\tau}_{ijk}, B^{\tau}_{ijk}) + P(X^{\tau}_{ijk}, B^{\tau}_{ijk})$ where D and P represent the resolved (dynamical) and parameterized (physical) processes and the (i, j, k) subscripts signify the discretized position in the horizontal and vertical and τ denotes time.

Numerical solution (GB): The discretized model equations are stepped forward in time where, for instance $X^{\tau+1}_{ijk} = X^{\tau-1}_{ijk} + 2\Delta(D^{\tau}_{ijk} + P^{\tau}_{ijk})$ represents a single timestep. The process is repeated for many timesteps to provide an evolving time dependent numerical solution which is an approximation to the solution to the governing equations. The numerical solution will depend on the initial conditions X^{o}_{ijk} representing the state of the system at some time $\tau = 0$ and on the boundary conditions B^{τ}_{ijk} which provide information external to the domain of the solution. For a fully coupled ocean-atmosphere model these would include solar radiation values at the top of the atmosphere, the atmospheric composition and topographic and bathymetric information among other information for instance.

Analyses (GB): The generation of observation-dependent approximations to the state of the system X^{τ}_{ijk}. These values may be used as initial conditions for forecasts and as the verification data against which to measure the *skill* of a forecast.

Forecast (GB): A time-dependent numerical solution to the model equations Y^{τ}_{ijk} where the initial conditions are (usually) from an *analysis* of the system state at a particular time and for which the boundary conditions are known or independently forecast. In particular, a true ***forecast*** contains ***no information from the future***. The actual forecast product may be some derived quantity or statistic such as a seasonal mean.

Hindcast (GB): a forecast but made for a period in the past and where ***no use is made of information from the future with respect to the forecast***. The purpose of a sequence of hindcasts is usually to investigate the skill of a new or modified forecast system on past cases so as to justify its use. The results also provide an indication of *expected skill* for forecasts made subsequently.

Simulation (GB): A simulation is a time-dependent numerical solution to the model equations where the initial conditions may or may not come from an *analysis* of the system state at a particular time and for which the *boundary conditions* may contain information from the future. An example is an AMIP simulation where observation-based sea-surface temperatures and sea-ice cover are specified in the integration of an atmospheric model or an ocean-only simulation where observation-based surface energy fluxes and stresses drive an ocean model.

Two-tier forecast (GB): Typically a forecast in which the SST is independently predicted (the first tier) and then imposed as a boundary condition for a forecast with an atmospheric model (the second tier).

One-tier forecast (GB): A forecast of the *coupled* ocean-atmosphere system where both atmosphere and ocean components are initialized and evolve together.

Forecast error (GB): The forecast error for a deterministic value forecast is $e^{\tau}_{ijk} = Y^{\tau}_{ijk} - X^{\tau}_{ijk}$ and the *mean square error* (MSE) $\overline{e^2} = \overline{(Y - X)^2}$ is the average over many independent forecasts (symbolized by the overbar) to give a measure of average *forecast skill*.

Forecast skill (GB): is generally measured by one or more statistics such as the MSE, the correlation between X and Y, $r = \overline{XY}/\sigma_X\sigma_Y$ and the mean square skill score MSSS $S = 1 - \overline{e^2}/\overline{e^2_r}$ where $\overline{e^2_r}$ is the MSE of some reference forecast. Forecast skill measures require a sufficient number of independent forecasts to provide stable statistics

Predictability (GB): A feature of the physical system which characterizes its instability and non-linearity and hence its "ability to be predicted" in the presence of even small errors in initial and boundary conditions. This is in contrast to the "ability to predict" the future of the system which depends on current abilities and which is measured by *forecast skill.*

General Circulation Models (GCMs) (DW): numerical models of the general circulation of the global ocean, atmosphere or coupled system often including additional components such as representations of the cryoshere or bioshere. The equations solved are based on the Navier-Stokes equations with various parameterizations used to represent the effects of processes not resolved by the numerical grid or not explicitly included in the model formulation. For example, bulk formulae are used to parameterize air sea exchange and eddy diffusion coefficients are used to represent unresolved mixing processes. Cloud cover, convection (in the ocean and the atmosphere) and land surface processes also require parameterization. ***Atmospheric and Oceanic General Circulation Models*** (AGCMs and OGCMs) are important components of the ***Coupled Atmosphere-Ocean General Circulation Models*** (CGCMs or AOGCMs) used in global climate models. Sea ice and land surface models are also important components of these models. General Circulation Models are also used for weather forecasting, typically with finer resolution and modified parameterizations reflecting the differences in resolved processes.

Numerical Model "grids"(DW): The equations used by GCMs are discretised using a variety of different approaches. Finite difference methods represent numerical derivatives by difference quotients on a regular grid that converge to the true values as the grid resolution tends to zero. Geopotential models, isopycnal models, sigma coordinate models, level models, layer models are all examples of finite difference models. Spectral methods approximate the solution of a system as linear combination of continuous functions that are generally nonzero over the full domain of interest. Derivatives are then calculated as a linear sum of analytical derivatives of the basis functions and tend to the true values as the number of basis functions increases. Simple sinusoids provide one example of a possible set of basis functions for use in spectral methods, but other options (e.g. Chebyshev polynomials) have been used to meet application requirements. Finite element and finite volume models have aspects in common with both finite difference and spectral models since they work in terms of basis functions (like spectral models), but these are typically simple functions defined over limited domains (like finite difference models).

Hindcast (DW): A numerical or other simulation that makes use of past information to provide a "best estimate" of conditions during a past event. A hindcast is normally used to provide information on conditions during a period of interest or to test the reliability of a simulation procedure. If the hindcast produces results consistent with observations that are not used in the simulation, it would be considered to be successful. Note that depending on the intended usage, the formulation of a hindcast can use information that was not available at the time of the event of interest. For example, a model might be tuned based on information from the 60s and the 90s and then used to simulate particular properties during the 70's during which observations might be more limited. A hindcast may, of course, also be performed using only information from before the event of interest, but this is not essential.

Reanalysis (DW): A reanalysis is the same as an analysis except that it is not done in real time and a single methodology (including the numerical model providing an initial state and the analysis methods used to blend model and data) is used throughout the analysis period. The method will typically provide superior results to the original analysis for two reasons. First, data collected prior to the analysis but not yet available at the time of the original analysis may be included. Second, variability in archived results associated with changes in analysis techniques that may occur in NWP centers will not contribute to reanalysis results.

Ocean Reanalysis (DW): A procedure by which historical ocean observations are combined with ocean model results, frequently from an OGCM, using a data assimilation algorithm to reconstruct historical changes in ocean conditions. The ocean model is normally driven by historical estimates of surface winds, heat, and freshwater. The combination of typically sparse historical observations and sophisticated numerical models of the ocean permit a more accurate reconstruction of past oceanic conditions than would be possible from either models or data alone.

A question raised by GOAPP investigators is what atmospheric forcing fields may be used in an ocean reanalysis. The question centers around whether future information can be used in the reanalysis. This question is irrelevant for the actual reanalysis since use of any information from before the analysis is obviously permitted and use of information from a time after the analysis would never be done.

The question of interest is not really whether future information can be used in a reanalysis, but whether it is legitimate to use future atmospheric information in ocean prediction studies aimed at determining the predictability of ocean conditions. The answer to this question obviously depends on the purpose of the prediction studies. If the goal is to determine the current ability to predict changes in ocean conditions, then all information on future atmospheric conditions should be obtained from an atmospheric (or other) prediction system. However, if the goal is to determine the limits to predictability associated with the ocean model itself (either for academic purposes or assuming that atmospheric predictions will continue to improve in the future), then the best available information of atmospheric conditions should be used. This naturally introduces questions regarding "artificial skill" or "false skill" in the forecast results. These need to be considered in such studies.

Artificial or False Skill (DW): Formally, this is the overestimate of the true skill of a forecast system that occurs when data used in the development and tuning of a model is also used to evaluate the forecast skill of the model. Artificial skill is frequently reduced by withholding portions of a data set or full data sets from the tuning and assimilation procedures to provide an independent evaluation. Artificial skill also occurs due to the presence of long-term trends in the data.

Another form of artificial skill of relevance to GOAPP investigators can occur if data that is not available at the time that an ocean forecast is initiated are used in the determination of the atmospheric forcing fields used to force the ocean model. Although this approach can help to determine the limits to predictability associated solely with the limitations of the ocean model, the possibility of introducing artificial skill needs to be understood and evaluated when true prediction skill is of interest. Unfortunately, there does not appear to be a generally accepted name for an ocean forecast that uses forcing fields that were not available at the time corresponding to the initialization of the forecast.