Global Coupled Modelling at NCMRWF

Model Components

The current coupled configuration implemented at NCMRWF include the Unified Model (UM) as the atmospheric model and the Joint United Kingdom Land Environment Simulator (JULES) to represent land-surface. Nucleus for European Modeling of the Ocean (NEMO) is adopted as ocean model and seaice dynamics and thermodynamics are computed by subroutines in Los Alamos National Laboratory community-driven sea ice model (CICE). The land and atmospheric models are combined as single executable while ocean and seaice models are combined into separate executables. This choice of separating and combing different models stems from the development cycles of the coupled systems. For example, land-atmosphere modeling system followed the development cycles of the United Kingdom Met Office operational models. Similarly, patches to both NEMO and CICE models are applied to enable transfer of data within the ocean-seaice executable and to enable coupling with the UM-JULES executable. Each of the model-components have ever-evolving science configuration associated with it. In this section, we briefly describe scientific configurations adopted here for each model component: Global Atmosphere 6.0 (GA6.0) and Global Land 6.0 (GL6.0), Global Ocean 5.0 (GO5.0) and Global Sea Ice 6.0 (GSI6.0). Together these are known as Global Coupled configuration, and we adopt GC2 version of it. GC2 shows improvements over earlier configuration particularly for simulation of temperature and climate modes like El-Nino and Southern Oscillations (ENSO) and the North Atlantic Oscillation (NAO).

The Atmospheric Model

The UM is a non-hydrostatic, fully compressible deep atmospheric model discretized on Arakawa C-grid in horizontal and uses Charney-Phillips vertical staggering having semi-implicit semi-lagrangian scheme for time-stepping. The Terrain-following hybrid-height coordinate in model has maximum height of 85 km with 85 levels. Horizontal model resolution is defined as N216 which is a regular grid with grid size ~65 in mid-latitudes. The dynamical core of the model called ENDGame (Even Newer Dynamics for General atmospheric modeling of the environment). The nested approach of ENDGame has improved stability of the model which allows implementation of near semi-implicit numerical scheme which is more accurate than earlier dynamical core called New Dynamics. Improved stability also allowed discontinuation of polar filtering, making the code more scalable. Physical processes are represented by a set of parameterization schemes. A modified version of mass flux-based convection scheme is adopted. Unresolved turbulent motions in both free troposphere and boundary layer are represented. In addition, model has extensive parameterization schemes to represent large-scale precipitation, prognostic cloud fraction and prognostic condensate (PC2), drag due to sub-grid orography and effects of gravity waves.

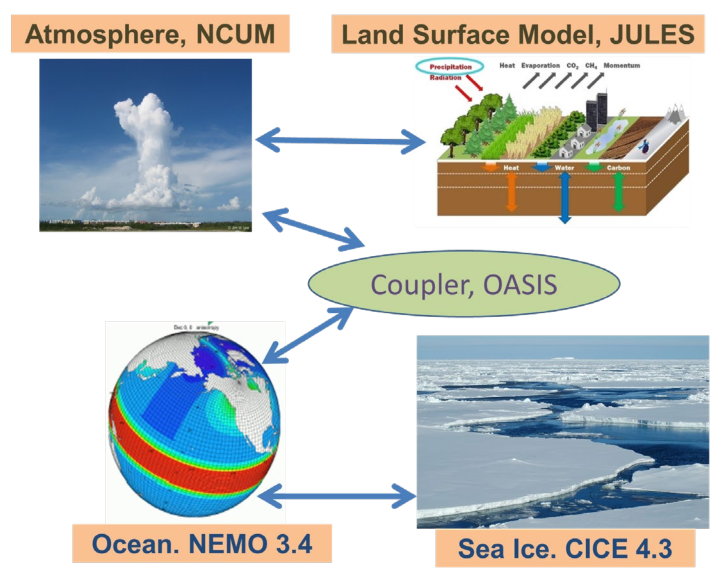

Figure 1: Block diagram of NCMRWF UM Coupled Modelling System

The Land-surface Model

JULES is a community land surface model developed by United Kingdom researchers and Centre for Ecology and Hydrology available freely for non-commercial use. Here a configuration GL 6.0 is adopted; the horizontal grid is same as that of atmospheric model with 4 vertical levels. 9 types of vegetations are represented in each grid point by tiles of different properties. The surface similarity functions are used to parameterize surface heat and momentum fluxes. GL 6.0 also includes a hydrological model to represent rainfall-runoff relationship and sub-surface water flow. The excess runoff is routed via river-routing routines.

The Ocean Model

NEMO ocean model used in current coupled configuration is at eddy-permitting resolution of 1/4*o* having a tripolar orthogonal curvilinear grid, ORCA025, in horizontal and 75 vertical levels reaching a depth of 6000 m with higher resolution of 1 m in the upper ocean. The spatial discretization is based on centered second-order finite difference approximation. The generalized Arakawa C-grid is used to represent the variables in which the scalars are located at cell's center and vectors are located at the center of faces of the cell. The model solves the prognostic equations in their vector invariant form in which Coriolis and advection terms are decomposed into vorticity, kinetic energy, and vertical advection terms. Other forces include horizontal and surface pressure gradients, and contributions from lateral and vertical diffusion. For diffusive terms, a backward (or implicit) time differencing scheme is used. Non-diffusive forcings are solved using well known leapfrog time-differencing with some modifications. Surface layer height is a diagnostic variable and is computed by integrating the linear surface kinematic condition. Explicit filtering of fast gravity waves is implemented to allow reasonable time-step for model integrations. Diapycnal mixing is parameterized using a modified version of turbulent kinetic energy scheme. The effect of energy transfer from barotropic tides to internal tides and internal tide breaking due to rough topography is parameterized, with enhanced tidal dissipation efficiency in the region of Indonesian Throughflow to account for trapped internal waves in the Indonesian Archipelago. An advective and diffusive bottom boundary layer scheme is also included.

The Sea-Ice Model

The seaice surface temperatures and surface fluxes need to dynamically evolve in a coupled model. Traditionally, UKMO coupled models are coupled every 24-hour. This prevents the diurnal cycle of key variables at the atmosphere-seaice interface from being resolved. Thus, in HadGEM family of models, the sea ice computations related to seaice thermodynamics is split between atmosphere and ocean. The UM-JULES model computes atmosphere-ice radiative and heat fluxes, the diffusive heat flux through the ice, and the ice surface temperature. Unlike ocean treatment of solar heat fluxes, where solar fluxes are partitioned into penetrative and non-penetrative fluxes, atmospheric computation of surface fluxes over seaice assume all solar fluxes to be absorbed and thus none passes through ice to the ocean. To allow such sub-daily treatment of surface fluxes over seaice when coupling frequency is sub-optimal to resolve diurnal variability, the GC2 uses a modified version of CICE. Note this is not the issue with standalone CICE as it can update surface fluxes depending on forcing data available. The CICE code used here implements zero-layer thermodynamics to calculate the growth and melt of sea ice, with one layer of snow and one layer of ice. The land-atmosphere model also computes seaice albedo as a function of temperature, snow cover and melt ponds. The surface heat flux, latent heat flux, and conductive flux through ice determine the growth or melt rates of seaice. The heat is also exchanged between ocean and seaice at the bottom surface of seaice and when frazil ice forms in ocean. These are then linearly remapped to transport the ice between thickness categories. Five categories of seaice based on thickness are included in GO5.0 with elastic-viscous-plastic ice dynamics and energy- conserving thermodynamics. Note that CICE has multi-layer thermodynamics which cannot be used here as seaice surface temperatures and the conductive heat fluxes into seaice are computed by atmosphere-land model and not seaice model for the reasons specified above. This dependency on UM for computing seaice surface temperatures and heat fluxes through seaice will not be necessary in sub-daily coupling frequency and thus later versions of the coupled configurations are expected to use multilayer seaice thermodynamics.

Remapping algorithm for exchange of fields at coupling interface

One of the advantages of coupling different models is that it allows the forcings and boundary conditions at the model interfaces to be updated during simulation instead of being represented as static fields. To exchange fields between different component models, a remapping algorithm with desired accuracy is required when the component models are defined on different grids. The interpolation of fields from source to destination model grids thus allows the fields computed in source model to be made available to the destination model. However, interpolation of fields on discrete grids is susceptible to numerical errors which could amplify during longer runs. Component models are designed to conserve mass and energy within a known range of accuracy. However, errors in fields received the coupling interface can introduce mass and energy imbalances in the component models. Thus, heat, momentum and freshwater fluxes need to be conserved for the stability of long runs. Here, we use the first order conservative remapping for all scalar fields exchanged from atmosphere to ocean and second order conservative remapping for all scalar fields exchanged from ocean to atmosphere. Because the second order conservative remapping can introduce over- and under-shoots near sharp gradients in the source fields, such a scheme cannot be used for atmospheric variables such as shortwave fluxes, precipitation, runoff, wind speed etc. which are defined to be positive numbers. The remapping of vector fields, such as ocean currents and wind stress, is done by bilinear remapping due to technical difficulties in interpolating vector grids between arbitrary grids. The lack of conservation of momentum during remapping has not been found to create serious issues during climate simulations using earlier versions of this coupled modeling framework. SCRIP software is used for creating and remapping files. It needs locations of center and corners of each grid point in input and output grids, the remapping weights are generated using user defined algorithm (bilinear, conservative etc.). The area of each cell is also computed for conservative remapping. There are 6-different grids in current implementation; these are U, V, and T, each for land-atmosphere ocean-seaice component models. Creating remapping weights using SCRIP takes several minutes and thus a performance penalty. Thus, while OASIS3 coupler used here can generate online weights during runtime, remapping weights generated apriori are used here. OASIS3 also has several routines for pre-processing of fields, such as but not limited to time averaging over the coupling frequency. Since the ocean grid is curvilinear, the vectors are rotated within the ocean model before being sent to atmosphere and after receiving fields from atmosphere. The coupling sequence is fixed apriori to avoid any deadlock in model simulation, such as when models involved in coupling wait for the exchange of fields at the same execution time. The models are initialized using their respective dumps, coupling fields are then exchanged before model simulation, and then each of component models run up to coupling period. The simulation continues beyond each coupling event only after the fields are thus exchanged. Coupling frequency is set to every 3 hours.

Initialization of Forecasts and Hindcasts

Each of the component models: atmosphere, land, ocean, and seaice, are initialized from respective startdumps. The initialization strategies are different for the re-forecasts and forecasts and have been described below. Choices for initialization of boundary conditions are described in detail for both hindcasts and forecasts particularly for amount of snow, soil temperature, soil moisture, surface temperature (over land, ocean, snow and seaice) and seaice concentration.

Atmosphere Initialization

Many fields are required to be initialized as needed by dynamic and physical parameterization routines in UM. A complete list of initialized variables in both forecasts and hindcasts is provided in Appendix A. The forecasts are initialized from NCMRWF atmospheric analysis which is produced operationally using a hybrid-4DVar data assimilation system. The assimilation system uses a large number of observations and model background to optimally estimate dynamically consistent state of atmosphere by minimizing the departure of the forecasts from observations over the assimilation window using weighing functions based on observations and model background error covariance matrices. Hybrid-4DVar is an advanced data assimilation system which is coupled to the ensemble forecasting system at NCMRWF by combining errors estimated from ensemble of daily forecasts with climatological model background errors to compute the error covariance matrix. However, many variables are left undefined as the estimation of their current values is either not available or not of interest. Many such important variables, particularly those related to boundary parameters and aerosols concentrations, are initialized from climatology and some are updated at regular intervals during model simulations. All the ancillary files can be broadly categorized into those representing a) land parameters: orography, mean and standard deviation of the topography, land mask, land fraction and albedo); b) vegetation parameters: fraction of surface types, leaf area index, canopy height; c) soil parameters: saturated soil conductivity, volumetric soil moisture at saturation etc.; d) river parameters: river sequence, direction and storage; e) aerosols: sulphate (accumulation, aitken, and dissolved modes), sea salt (film and jet modes), dust (6-types), black carbon (fresh and aged); e) Emissions: from biogenic sources, fresh, aged, in-cloud modes from biomass burning and combustion of fossil fuel (organic carbon); and g) ozone. Other initialized variables are either set to zero, a constant, a missing value or computed from other fields in the startdump.

The hindcasts are initialized using ECMWF ERA-Interim reanalysis. The ERA-Interim reanalysis used here is at 60 levels and at 0.75-degree resolution. It is reconfigured to L85 vertical grid (reaching 85 km) and N216 regular grid for running atmospheric model. As discuss above many variables are initialized from operational startdumps for the forecasts. However, only a small subset of variables is initialized from reconfigured ECMWF analysis. The remaining fields are either set to zero or some constant values. It is useful to note that the hindcasts use exactly same ancillary data as used by the forecasts. Further many of other variables are initialized consistently between forecasts and hindcasts.

Land-surface Initialization

For the realtime coupled runs up to 15-days, soil temperature and soil moisture are initialized from land-surface analysis from simplified extended Kalman filter land-surface data assimilation system which uses ASCAT soil wetness and other surface temperature and humidity observations. However, soil moisture from the realtime analysis cannot be used in the current extended range prediction system, as the soil moisture climatology from UKMO based assimilation system differs significantly from the ERA-Interim. This prevents use of soil moisture from ERA-Interim in hindcast-initialization and use of NCMRWF soil moisture analysis for the forecast system. Thus, a soil moisture monthly climatology developed by UKMO is used to initialize both the forecasts and hindcasts. Snow-depth and soil temperature are taken respectively from satellite estimates and NWP analysis for the forecasts and ERA-Interim for the hindcasts.

Ocean and Seaice Initialization

The ocean and sea-ice initial conditions are produced at NCMRWF using NEMOVAR which is an incremental 3D-Var data assimilation system using first guess at approximate time (FGAT) as background field. The system assimilates both satellite and in situ observations of SST, sea-level anomaly, sub-surface temperature and salinity profiles, and satellite observations of sea-ice concentrations over 1-day assimilation cycle. The ocean-sea-ice model is same in both the data assimilation system and forecast model. The startdumps for the hindcast initialization are taken from GloSea Ocean and Sea Ice Analysis, which is from the same system as used in the realtime ocean data assimilation system but with ERA-Interim forcings.