A Distributed Model Coupling Environment for Geophysical Processes

Matthew T. Bettencourt and Shahrdad G. Sajjadi, Center of Higher Learning, Stennis Space Center, MS
Patrick Fitzpatrick, Mississippi State University, Stennis Space Center, MS

In the realm of geophysical modeling the current state-of-the-art models have the capability to run at very high spatial resolutions. This capability has led to a drastic increase in the accuracy of the physics being predicted. Due to this increased numerical accuracy, once neglected effects, such as non-linear feedback between different physical processes, can no longer be ignored.

The ocean's deep water circulation, surface gravity waves, and the atmosphere above can no longer be treated as independent entities and must be considered a single coupled system.

One solution to this problem is to link models together through a series of surface variables. An example would be the evaporative cooling of the ocean, which, at a simple level, requires sea surface temperature, humidity, and temperature of the atmosphere, and would return the mass and heat flux into the atmosphere.

The Model Coupling Environmental Library (MCEL) was developed to simplify the coupling process for models that exchange data at most every time step. Traditionally, model coupling is performed in three ways: file Input/Output (I/O), subroutinization, or Message Passing Interface (MPI).

The traditional way of model coupling is through file I/O as shown by Blain[1] and Hodur.[2] In this case the models are left relatively unaltered and are executed for a very short length of time. Model preprocessors then transform the output files from one model into input files for the second model. Depending on the frequency of coupling, this can be a very costly alternative.

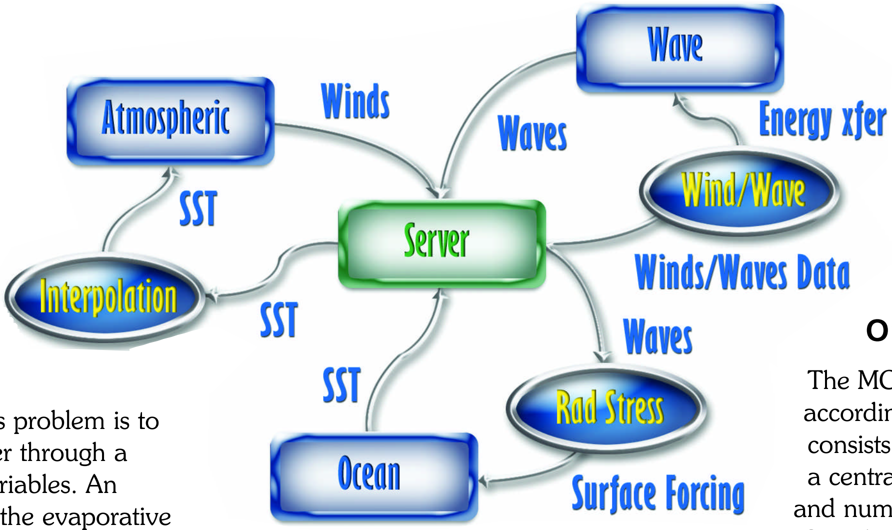


Figure 1. A hypothetical example of a three-model MCEL system.

The second method of model coupling, subroutinization, requires one of the models to be written as a subroutine of the other model. While this can provide the fastest program, it can, however, be quite difficult to implement and maintain such a large multi-physics application.

The final common method for model coupling is through an MPI interface, where calls are added to both applications to send data to each other as demonstrated by Welsh[3] or in an abstract form with the Model Coupling Toolkit.[4]

This approach has the benefit that applications are executed only once, as in the subroutinization method, and the applications are left as independent entities, as in the file-based approach.

However, because MPI uses two-sided communication, it is required that each model be modified explicitly for the set of applications running in a coupled suite.

OVERVIEW

The MCEL infrastructure, according to Bettencourt,[5] consists of three core pieces: a centralized server, filters, and numerical models. MCEL, by utilizing a data flow approach, stores coupling information in a single server or multiple centralized servers.

Upon request these data flow through processing routines, called filters, to the numerical models, which represent the clients. These filters represent a level of abstraction for the physical or numerical processes that join different numerical models. The extraction of the processes unique to model coupling into independent filters allows for code reuse for many different models.

The communication between these objects is handled by the Common Object Request Broker Architecture (CORBA). In this paradigm, the flow of information is fully controlled by the clients. Figure 1 represents a hypothetical example of how such a system might be used.

Figure 1 shows three numerical models: Ocean circulation model, atmospheric model, and surface gravity wave model. Each model provides information to the centralized server: sea surface temperature (SST), wave height and direction, and wind velocities at 10 meters above the surface, respectively.

SST is used by the atmospheric model; however, it must first be interpolated onto the atmospheric model's grid. Therefore, the data passes through an interpolation filter prior to delivery. The wave information is transformed into stresses by the RadStress filter using the algorithm by Longuet-Higgins and Stewart.[6]

The final transformation uses the algorithm by Sajjadi and Bettencourt[7] which calculates energy transfer from wind and wave information. The filters represent application-independent processes and can be used to process inputs for any wave or circulation application. With the proper combination of filters and models, arbitrarily complex modeling suites can be developed.

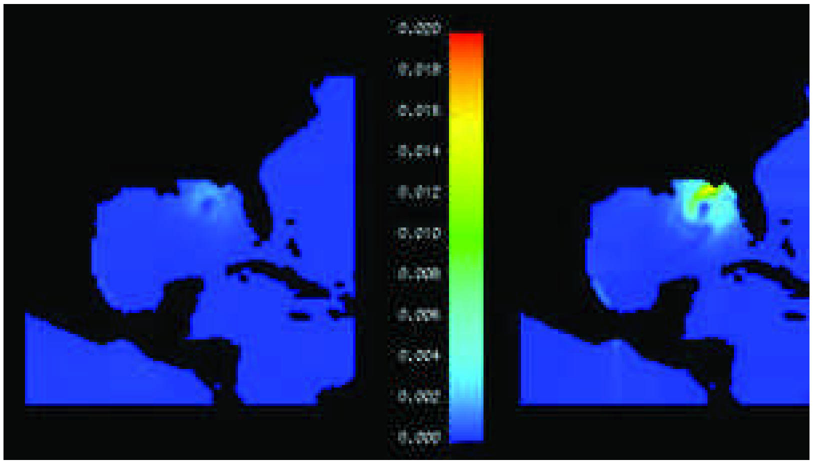


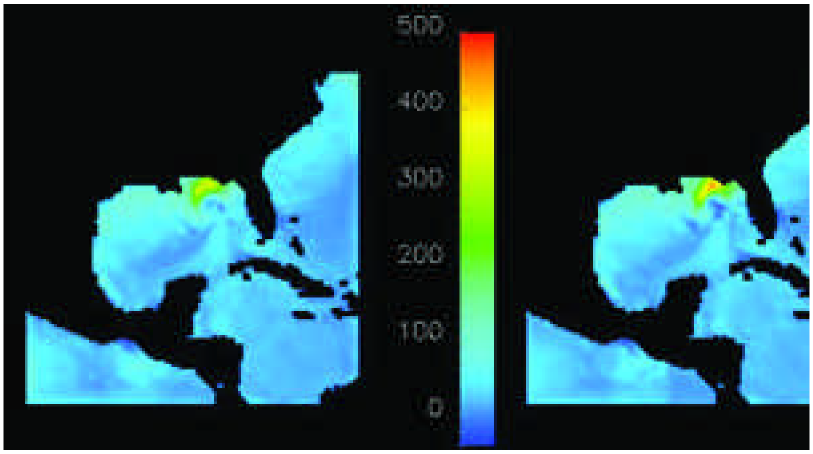
Figure 2. Roughness length for Hurricane Gordon at 9/18/00 22:00. Left: Utilizing Charnock parameterization within COAMPS. Right: Utilizing WaveWatch Parameterization.

RESULTS

The coupling infrastructure has been incorporated into several different models listed below:

- ADvanced CIRCulation model (ADCIRC)
- Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)
- Navy Coastal Ocean Model (NCOM)
- REFraction DIFfraction model (REF/DIF)
- WAve Model Cycle 4 (WAM)
- WaveWatch

Figure 3. Sensible latent heat flux for Hurricane Gordon at 9/18/00 22:00. Left: Utilizing COAMPS roughness length calculation. Right: Utilizing WaveWatch Parameterization of roughness length.



The work with the COAMPS coupled to the WaveWatch model will be used to illustrate the potential of the coupling infrastructure. COAMPS is a non-hydrostatic atmospheric model that incorporates many physical parameterizations and numerical techniques.

One of these parameterizations is the calculation of the roughness length. COAMPS utilizes the Charnock relationship, which assumes that the waves are in equilibrium with the wind. While this relationship is valid for "old" seas, wind direction and speed changes can throw the system out of equilibrium.

These cases produce much steeper waves and much larger roughness lengths. WaveWatch contains a more sophisticated roughness length approximation that takes into account wave age and produces a more physical roughness length. In the coupling scheme for these two models, COAMPS provided 10-meter wind velocities to WaveWatch every hour of simulation. In return, WaveWatch provided roughness lengths over the ocean.

Tests of this coupling were conducted on Hurricane Gordon, which struck the coast of Florida on 18 September 2000. The event was chosen because it represented a weak storm, where the WaveWatch roughness length parameterization was believed to be valid.

The unaltered version of COAMPS under-predicted the intensity of the storm and predicted a path too far to the west of what was actually observed.

COAMPS used 9-kilometer grid spacing over a 121x121 grid with 30 vertical levels. WaveWatch used an 81x81 grid. The model runs were compared between the two-way coupled version versus WaveWatch being forced without feedback.

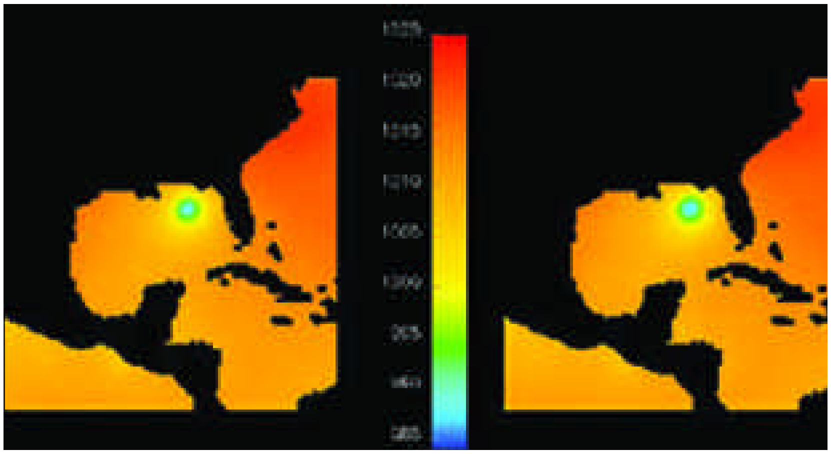


Figure 4. Sea surface pressure for Hurricane Gordon at 9/18/00 22:00. Left: Utilizing COAMPS roughness length calculation. Right: Utilizing WaveWatch Parameterization of roughness length.

Roughness lengths were compared between the two formulations as shown in Figure 2. Over the range of the simulation, the roughness length predicted by COAMPS was typically about ten percent of the value predicted by WaveWatch.

The increased roughness length has two major effects on the storm. First, it increases the kinetic energy transfer from the atmosphere to the ocean. This has a tendency to slow the storm. However, increased roughness length also increases the heat flux to the storm, as shown in Figure 3, which has the tendency to increase the intensity of the event.

These effects combine into a net increase in the storm intensity as seen by the pressure plot in Figure 4. This figure shows a 3-millibar deepening of the pressure at the center of the storm. While this more closely represents what was actually observed with the pressure, it did not improve the track of the storm.

The MCEL infrastructure allows these two models to run concurrently, which can drastically decrease the time until a solution is achieved.

For the problem described above, a one-way coupled mode required 348 seconds per hour of simulation for the COAMPS model and 249 seconds for the WaveWatch model, or a total of 597 seconds. However, in a coupled mode the two jobs could be split onto two different computers, and the solution obtained in 374 seconds, or a speedup of 1.6.

Furthermore, this approach allowed for a more physically accurate solution than the two models running independently. The incorporation of the MCEL resulted in the modification/addition of only a few hundred lines of the two models. This approach simplifies the maintenance of these two models when compared to a single model containing both sets of physics.

Acknowledgements

This work is supported by the Department of Defense High Performance Computing Modernization Office (HPCMO) Common HPC Software Support Initiative (CHSSI) and Programming Environment and Training (PET) programs as well as the Office of Naval Research's supported project Distributed Marine Environment Forecast System.

References

1. Blain, C. and M. Cobb, “Wave-Current Interaction in a Wave-Breaking Environment,” Recent Advances in Marine Science and Technology 2000, 2001.
2. Hodur, R. M., “The Naval Research Laboratory's Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS),” Monthly Weather Review, 1996.
3. Welsh, D. J. S., K. W. Bedford, R. Wang, and P. Sadayappan, “A Parallel-Processing Coupled Wave/Current/Sediment Transport Model,” Technical Report PET 00-20, ERDC MSRC Technical Report, The Ohio State University, Columbus, OH, 2000.
4. Larson, E. O. J., and R. Jacob, “MCT - The Model Coupling Toolkit,” http://www-unix.msc.anl.gov/acpi/mct/
5. Bettencourt, M. T., "Distributed Model Coupling Framework," Proc. 11th IEEE Symposium on High Performance Distributed Computing, 284-290, 2002.
6. Longuet-Higgins, M. and R. Stewart, “Radiation Stress in Water Waves,” Deep Sea Research, II:529-562, 1964.
7. Sajjadi, S. G. and M. T. Bettencourt, “An Improved Parameterization for Energy Exchange from Wind to Stokes Waves,” To appear Proc. 2nd Wind-Over-Waves Conference, Ellis Horwood Publishing Co., 2002.