The InaCAWO Metocean **Operational Forecast System**

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The atmosphere-ocean interface is one of the most difficult and challenging environments to predict well. At this interface, lower atmospheric and upper oceanic/surface-ocean waves impact the planning and execution of maritime activities. Nothing could be more representative than the Indonesian archipelago, which consists of more than 17,000 islands – each of which depends on shipping or aviation to enable economic/social connections and, indeed, to obtain life-sustaining resources.

The Indonesian National Meteorological and Geophysical Agency (Badan Meteorologi Klimatologi dan Geofisika, BMKG) is tasked with providing official and accurate "metocean" forecasts, alerts, and warnings within this enormously complex region. But now, due to the recent operational implementation of Baron's novel metocean model, the ability for BMKG to issue more timely and accurate maritime forecasts is becoming a reality.

The **Modeling System** and **Computational Requirements**

Together with our partners at Fathom Science Inc. located at North Carolina State University, the "InaCAWO" (Indonesian Coupled-Atmosphere-Ocean) was designed, operationally deployed, and validated over the last two years on premises at BMKG in Jakarta. Along with a model coupler (MCT), the InaCAWO consists of three advanced "single-media" modeling systems configured to communicate with each other. The Weather Research and Forecasting Model (WRF), the Regional Ocean Modeling System (ROMS), and the Simulating Waves Nearshore (SWAN) model are all deployed on a common 3km spatial grid depicted in **Figure 1**.

Together, they forecast the weather, waves, and ocean conditions simultaneously. WRF is implemented with forty-eight atmospheric layers, ROMS with seventy ocean layers, and SWAN with thirty-six spectral bins. Fluxes at the metocean interface are passed between all three models in parallel through MCT (**Figure 2**). This novel feature allows InaCAWO to represent the exchange of heat, moisture, and momentum at the atmosphere/ocean interface in a fully conservative manner, as in nature. The computational requirements are severe.

Baron's testing showed that the optimal performance was gained by running on ~8,500 AMD EPYC cores, resulting in a 10-day forecast run taking less than 3 hours of wall-clock time to complete on average. This accomplishment makes the overall InaCAWO operationally feasible on the HPC now deployed on-site at BMKG.

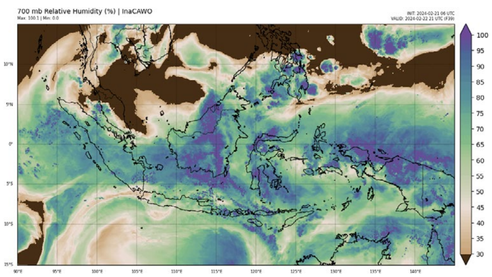

Figure 1. The InaCAWO forecast domain as portrayed by an operational InaCAWO-WRF 700mb relative-humidity forecast valid on February 22, 2024, at 21UTC

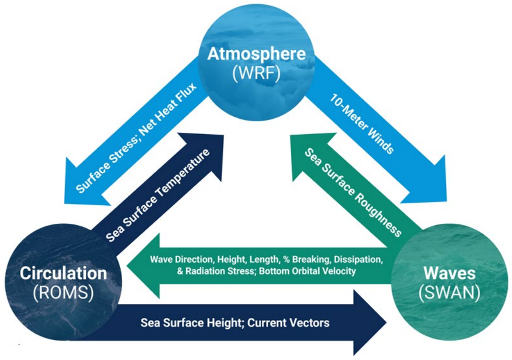

Figure 2. Atmospheric – Ocean Interface Coupling in the BMKG InaCAWO modeling system

Validation Against Observations

The model was validated following a design study approved by BMKG. Data supplied by the Agency over a “validation year” included surface synoptic and MAWS observations, drifter-based ocean-current speed, drifter-based sea-surface temperatures, satellite-derived significant wave heights, and tide gauges. Baron ran three-day re-forecast runs (as if in real-time) for the period Sept 1, 2021 – August 31, 2022. The validation occurred at three-time horizons (forecast days 1, 2, and 3), clustering observations into unique Indonesian sub-climate zones. On a global basis, it was found that InaCAWO validates to a combined aggregate accuracy of 86.14%, well above the 80% threshold mark expected by the Agency.

Operational Design

InaCAWO provides four forecast cycles per day on the HPC at BMKG. The 00UTC and 12UTC runs execute with a 10-day forecast horizon, while the off-cycle (06UTC, 18UTC) runs provide a 90-hour forecast horizon. Since the timing/availability of global model data for ingest is critical to the overall workflow, it has been found that these forecast lengths “fit” well on the HPC resources while meeting forecaster needs for frequent, albeit deterministic, model forecast updates. Each of the three regional models comprising InaCAWO must have its own initial and boundary conditions, and, like all regional models, these must be obtained from “host” global models. For the primary (00UTC, 12UTC) cycles, IC/BCs for InaCAWO-WRF are obtained from the ECMWF IFS, IC/BCs for InaCAWO-SWAN are obtained from the ECMWF IFS Wave model, and the IC/BCs for InaCAWO-ROMS are provided by the MERCATOR global ocean model. For the off-cycle runs, InaCAWO-WRF is driven by NOAA’s GFS. As the InaCAWO-WRF can/is driven by two different sources for global model inputs, the other two models also have backup global model options – for InaCAWO-ROMS, the backup used is the US Naval HYCOM global model, and for InaCAWO-SWAN, it is the US NOAA GFS-Wave global model based on Wavewatch III. Model spin-up is also important, especially in the ocean, such that InaCAWO-ROMS and InaCAWO-SWAN are both spun-up for three days using 6-hourly meteorological analysis forcing data prior to coupled model forecast launch. Model outputs are generated via web pages and other visualization systems and include time series, thermodynamic diagrams, and many other prognostically animating forecast fields, including ocean, waves, and atmosphere.

Forecast Examples

Several illustrative examples from a recent InaCAWO forecast issued on January 16th at 00Z, valid at 18UTC on 17 January 2024, are shown in the following figures. On that and during previous days, tropical cyclone Anggrek was developing southeast of Jakarta. By 18UTC on the 17th, Anggrek was forecast to be centered near the Cocos Islands, as shown in the lower left-hand corner of **Figure 3**. **Figure 4** presents the InaCAWO-ROMS ocean temperature forecast, in which the cooling effect of Anggrek on SST'S is quite obvious. While surrounding ocean temperatures are in the 80s, forecast ocean temperatures within the storm's core are >10F cooler. **Figure 5** presents the simultaneous Significant Wave Height (SWH) forecast, whereby the most dangerous waves are proposed to occur on the eastern flank of the storm (at that time). Finally, **Figures 6** and **7** show zoomed-in views, focusing on the dangerous maritime conditions (unrelated to Anggrek) that often form in the channels along the island chain to the east of the main island of Java.

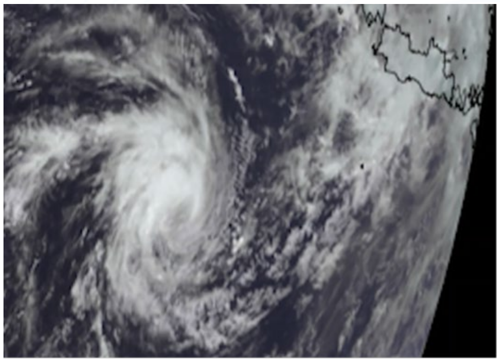

Figure 3. Meteosat-9 Image of Tropical Cyclone Anggrek near the Cocos Islands Southeast of Jakarta, Indonesia, valid 12UTC, January 18th, 2024. At that time, the cyclone was moving quite slowly.

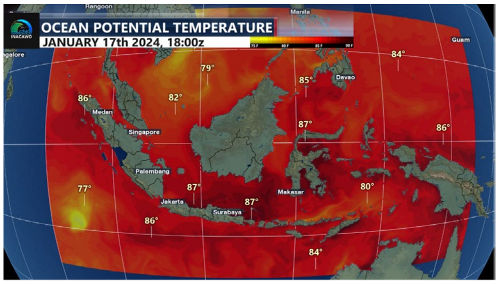

Figure 4. InaCAWO-ROMS forecast of ocean "potential" temperature – i.e. sea-surface temperature – showing the forecast impact of tropical cyclone SST cooling resulting from the developing TS Anggrek

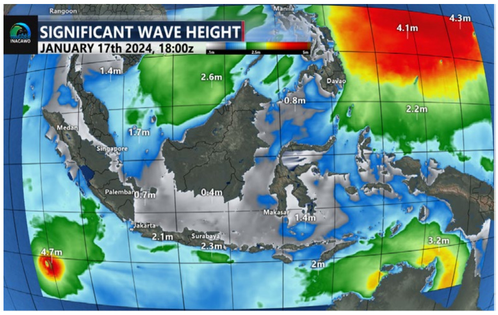

Figure 5. Same, but for InaCAWO-SWAN significant wave height. Clearly, the forecast impact of the TS on oceanic waves is only possible with a tightly coupled 3-WAY modeling system such as InaCAWO, whose atmospheric winds and oceanic heat contents are fully consistent with the SWH forecast.

Conclusions

The MMS program at BMKG is designed for long-term sustainability. In the first phase, the InaCAWO model has been developed, validated, and deployed operationally as the largest high-resolution regional implementation of a 3-way coupled atmosphere-ocean-wave model currently available (to our knowledge). The Baron team has provided several informative training sessions to build competency among the already excellent staff at BMKG. In the second phase, data assimilation and ensembles are expected to be implemented to provide additional skills. This is planned to further enhance the capabilities of the Agency to deliver reliable, actionable forecasts to this very complex archipelago. Full references and additional details are available from the authors.

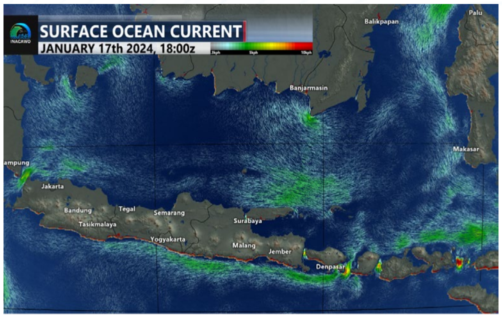

Figure 6. Zoomed in view of forecast oceanic currents at the island scale. Note the presence of three current "jets" near/adjacent to Denpasar. Never before, at least in this region, have such forecast jets (current speeds at/above 10km/hr) been available with such detail to maritime forecasters in this region.

Figure 7. Forecast Peak Wave period, same zoomed view as in Figure 6. Here, waves in the channels where the jet currents are flowing southward are migrating with long-wave lengths northward, presenting a significant danger to maritime operations attempting to cross the straights.