Towards a Modular Model of Tropical-Cyclone Structure

Abstract

Insurance companies correlate tropical-cyclone-inflicted loss with the cube of the peak low-level sustained wind speed, i.e., the intensity. Accordingly, attention here is focused on tropical cyclones of at least depression strength. Nature is left to sort these from among the many disturbances that arise. Few residuals of early history mark later stages.

Available operational-forecasting aids for tropical-cyclone intensity include: (1) quickly executed semi-empirical regressions, based largely on observed environmental parameters; and (2) computationally demanding, comprehensive numerical simulations, in which the accurate parameterization of cumulatively important subgrid-scale processes (typically including turbulent mixing, cumulus convection, cloud microphysics, radiative transfer, mass/momentum/energy transfer at the air/sea interface, spray dynamics, interfacial-wave dynamics, etc.) is regarded as crucial to accuracy. Unfortunately, even accepting that adequate parameterizations are possible, they are unknown, and detailed observations to assist formulation/validation of parameterization are sparse, and likely to remain so. Adopting successively more intricate parameterizations in response to inaccurate intensity predictions may result in the computational demands increasing faster than computer-processing power increases. In practice, “tuning” of flawed parameterizations converts the simulations to just elaborate curvefits to the same data base supporting the simple explicit curvefits, so the two categories of forecast aids perform comparably (poorly).

As an alternative, to reconcile the desiderata of fine resolution and large ensembles in real time, a simplistic, quickly executed, readily modifiable, portable modular model is undertaken, initially for steady axisymmetric conditions. By use of self-consistent scaling applied to a dimensionless formulation, only the locally dominant processes and gradients are retained in each of several mathematically and physically distinct subdivisions. The semi-autonomous solutions for the modules are fused to form an overall composite by enforcing continuity of fields and fluxes at the interfaces (or in strips of overlapping validity) between contiguous subdivisions. The computational tasks, owing to this semi-analytic/semi-numerical treatment, are reduced sufficiently to be met by Mathematica. Adoption of an approximate, asymptotic methodology (singular perturbation) of this type is commonplace in applied mechanics and other engineering disciplines, but is evidently uncommon in tropical-cyclone modeling.

For a depression/tropical storm, the three logical modules are: the bulk outer vortex; the near-ocean-surface boundary layer; and the central swirling updraft/upper-tropospheric outflow. A key challenge is identifying the position and properties of the vortex-sheet/contact-surface interface between the core/outflow and the bulk-vortex modules. For a hurricane, a fourth module, the eye, is added, along with the challenge of identifying the position and properties of the vortex-sheet/contact-surface interface between the eye and the eyewall. Appearance of an eye is regarded not as an idiosyncrasy of nature, but as essential to the achievement of the greater pressure anomaly necessary to support the greater intensity of hurricanes, especially major hurricanes. This role seems often mistakenly attributed entirely to convection.

A steady model gives a sea-level pressure anomaly and low-level peak swirl that are in equilibrium, for a given environment. The pressure anomaly and/or peak swirl may overshoot/undershoot an equilibrium relationship for a given environment, and this implies forthcoming structural adjustment, together with intensification/weakening. Anticipation of adjustment toward equilibration affords a basis of prediction. Moreover, in the Atlantic and eastern North Pacific, statistically about half of tropical storms intensify to hurricanes, and nearly half of hurricanes intensify to major hurricanes. Perhaps the modular model, in conjunction with soundings of sufficient horizontal and vertical resolution through the depth of the troposphere from a platform supporting sustained monitoring (such as the Global Hawk), may assist identification of accessible observable(s) that portend which one in two.

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