

# 15B.5 DESIGN, IMPLEMENTATION, AND OPERATION OF A MODULAR INTEGRATED TROPICAL CYCLONE HAZARD MODEL

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## 1. INTRODUCTION

The **Arbiter of Storms** (TAOS) is a meteorological hazard model that is integrated, scalable, and modular. It is intended to assist emergency managers, land use planners and meteorologists in assessing the risks associated with meteorological hazards. TAOS is designed using an object-oriented approach which allows a user to select the methods most appropriate to the problem, or the use of multiple methods to create an ensemble approach. TAOS is in order to enable the rapid integration and testing of new or experimental techniques. The underlying complexity of storm hazard modeling is hidden from users with minimal numerical modeling background using a graphical user interface. More experienced users have the option to interact with the model at a detailed level.

Typical applications include real-time tracking, track forecasting, and modeling of storm effects including probabilistic aspects for assessing real time, seasonal, and overall historical risks. Fundamental to the flexibility of TAOS is its integration of Geographic Information System (GIS) technology as both the input and output management basis for the model. In particular, this allows rapid incorporation of hazard data with existing planning data such as building structure type, value, location, population, and zoning. Verification exercises are briefly indicated for various aspects of the model. TAOS has been used operationally for projects in Central America, the Caribbean, and the United States, most recently for the Florida High Resolution Tropical Cyclone Hazard Mapping Project.

The assessment of hazards from meteorological phenomena is fraught with difficulties for the emergency management and land planning communities. Sophisticated numerical modeling is required, due to the uniqueness of individual storm events, time constraints with approaching storms and the lack of substantial historical observational data at most locations. Hazards associated with Tropical Cyclones (TC's), such as wind, wave, storm surge, and rainfall, are generally modeled separately, often with different underlying assumptions. For example, the NWS SLOSH program (Jelesnianski et al,1992) based hurricane hazard maps are event driven, whereas the FEMA WHAFIS model (FEMA, 1988) and flood insurance maps are return period based.

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Many local users who would like to have real-time guidance have neither the access nor the platform to obtain it. Resolution presents additional difficulties, with users requiring higher resolution than many models can provide. Finally, risk assessment by definition necessitates a probabilistic approach, whereas many physical models lack the built-in tools to accomplish this in an integrated fashion.

TAOS represents a comprehensive effort to create a modeling system that attempts to overcome these difficulties. This paper outlines the background, design philosophy, and model physics options utilized by the current TAOS system, representing an update to Watson (1995) and a summary of Watson and Johnson (1998). The emphasis here is on the scientific literature underlying TAOS.

## 2. BACKGROUND

The present configuration of TAOS has its origins in the need to create a hurricane recovery plan for the town government of Hilton Head Island, SC. Existing FEMA hazard zones and SLOSH paper maps were completely inadequate to account for the local situation (e.g., major gaps in the dunes). A high-resolution (10-30 meters) tool was needed to translate anticipated meteorological events with the effects of wind, wave, storm surge and debris generation into local impacts (both building damage and shoreline erosion).

The Organization of American States recognized the potential of TAOS and incorporated it into the Caribbean Disaster Mitigation Project (CDMP). Particularly attractive was the use of GIS as the basic front end, eliminating the need to develop custom data sets (which would be prohibitively expensive in the Caribbean). TAOS has evolved to include near real-time assessments of active storms, currently in use at the Caribbean Meteorological Institute, and by the Met Departments of Jamaica and Belize. High resolution projects have been conducted for Jamaica, Antigua, St. Lucia and Dominica. In summary, TAOS or one of its variants is in use throughout the Caribbean and is the basis of ongoing projects for Florida and Hawaii. Other clients relying on TAOS output products include the World Bank, USAID and numerous industrial clients.

TAOS can simulate tropical systems on a variety of scales, from 1 arc second (30.8 meters) per cell through 5 arc minutes (9850 meters/cell). Version TAOS/C models wind, wave, and rainfall, including orographic effects, and wind damage. Another variant,

TAOS/R, is the ultra-high resolution research version of the model that also simulates non-tropical storm systems, rainfall runoff and riverine flooding, coastal erosion, and tsunamis.

### 3. MODEL DESIGN PHILOSOPHY

TAOS is based on the object oriented model (OOM) approach (Farley, 1985). Although originally written in Fortran, TAOS is now written entirely in C++, thus enhancing the OOM design philosophy. As illustration of the flexibility, three distinct statistical modules were installed, validated and operational in less than two weeks, performing hundreds of thousands of distribution fits throughout the Atlantic Basin. Religious adherence to OOM principles is paramount in the single programmer environment at WTC. Some additional design decisions are now briefly indicated. Further elaboration can be found in

Watson and Johnson (1998).

*Intermodule data access.* Each TAOS system module is independent, yet has access to the other modules (e.g., wind, wave, topography, land cover, etc.). Such module independence permits customized application runs.

*GUI and batch mode processing.* TAOS supports both a friendly Graphical User Interface (GUI) and a more sophisticated batch mode capability to address the needs of different types of users. Figure 1 shows the TAOSmenu screen for Tropical Storm Georges (1998), with various track models selected.

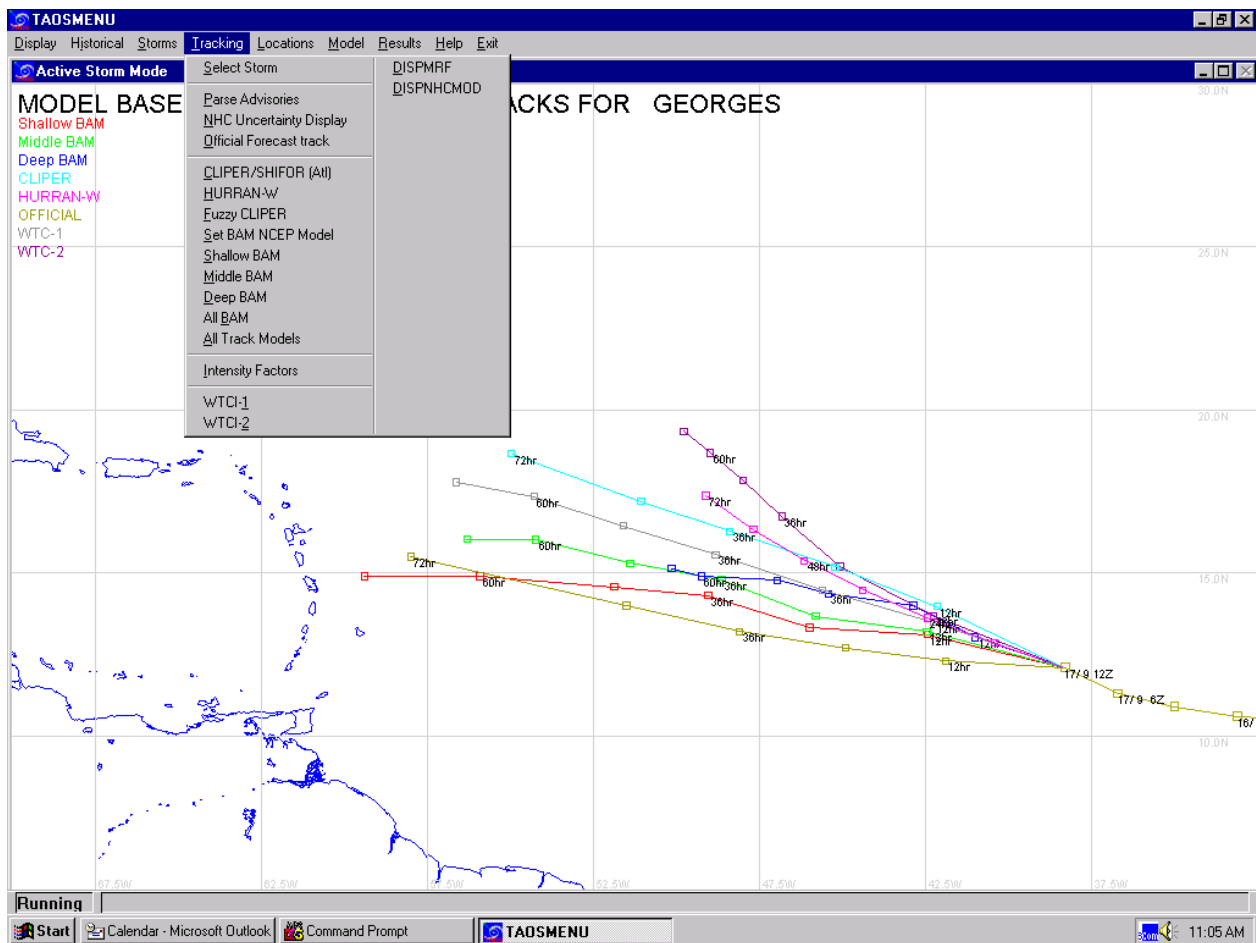


Figure 1: TAOSMENU Forecast Track Model Screen

*Coordinate system.* TAOS uses a moving, variable extent, variable time-step, storm centered grid. Hence, boundary effects are minimized and stability is ensured while maintaining computational efficiency.

Moreover, as a storm proceeds, necessary data is drawn from the master GIS data sets and output results are produced as the storm grid passes. TAOS can run at 30 meter resolution (the Florida project) or at much coarser resolutions, depending on the supporting data

bases. Therefore, a storm run may start at a 30sec(980m) resolution in the Caribbean, increase to 1 arc second (30m) over Florida, then finish at 6 arc seconds (180m) as the storm moves up the US east coast.

#### 4. INPUT AND OUTPUT DATA SETS

TAOS is designed to read from and write to standard Geographic Information System data formats as input data sets. This obviates the need for specialized data assimilation code, and gives users the ability to overlay hazard data with complex land use, demographic, and zoning data.

#### 5. TAOS MODULES

TAOS consists of numerous user configurable modules such as, wind, wave, tide, hydrology, rainfall, damage, statistical, and forecast. Each module may have user selected components. In view of space limitations, this section provides the basic components of the modules with an emphasis on the primary references. Additional details can be found in Watson and Johnson (1998).

*Wind Modules.* TAOS includes five wind models for simulating tropical cyclones. These are based on the following papers: Miller (1962) and Miller and Moore (1960), Jelesnianski et al (1992), Davenport et al (1985), Cardone, et al (1992), and Emanuel (1995). TAOS can also accommodate wind and other variables provided externally using MM5 (Anthes, Hsie, and Kuo, 1987), CCM3 (Kiehl et al., 1996), and various NCEP models: MRF, AVN, ETA, RUC. TAOS can also accommodate a variety of schemes for bringing winds down to the surface level depending on the chosen boundary layer model. The methodology from NWS-23 (Schwerdt et al., 1979) suitably modified is included as well as that inherent to the external modules mentioned above. Inland decay may be modeled through the use of various techniques including that of Kaplan and DeMaria (1995).

*Wave Modules.* A simple parametric wave model (Lyons, 1997) and a full spectral wave model based in part on the Corps of Engineers WISWAVE model (USACE, 1994) are available. Other components handle wave breaking, run-up, setup, and related effects (i.e., coastal erosion). One such module is based on Vellinga (1986).

*Tide Module.* It is erroneous to treat tides in a model as a post-simulation addition, as tidal effects have non-linear interactions with other forces. TAOS employs the University of Texas Center for Space Research Tide Model version 3.0 to compute tide stresses (Cartwright and Ray 1990).

*Hydrology Modules.* TAOS contains three modules for computing water flow: (1) a vertically integrated form derived from Harris (1958); (2) a hybrid form derived by Watson, which allows for multiple layers; (3) a module based on the Princeton Ocean Model (POM; Mellor, 1992). Two methods are internally implemented for rainfall runoff: (1) one based

on traditional civil engineering techniques; (2) a finite element module based on Viex and Gaur (1990).

*Rainfall Modules.* TAOS accommodates both external rainfall rates (e.g., from NCEP or MM5 runs) and internal (user-specified rate function). Orographic effects are handled using the model described in Sinclair (1995).

*Damage Module.* The TAOS damage modules take the outputs of the various physical modules and convert them into estimated damage levels for various structure types. TAOS contains 5 damage modules: four specific structure types traceable to Simiu and Scanlan (1996) and a programmable module which can accept individual characteristics for virtually any structure, including bridges, infrastructure, antenna towers, etc. TAOS also includes damage functions due to Leicester and Beresford (1978), Friedman (1984), and Stubbs (1997).

*Statistical Module.* The statistical module is designed for use in estimating return periods of hurricane phenomena. Additional details can be found in Johnson and Watson (1998). Internally, TAOS processes the HURDAT data set (Neumann et al, 1993) applying techniques from Ho et al (1987) to account for incomplete parameters. Annual maxima are fit to Weibull, lognormal or inverse Gaussian distributions. Graphical displays support the goodness of fit summary calculations. For the Florida project, over a billion data sets were fit to produce estimates of return periods and upper prediction limits to reflect uncertainty.

*Forecast module.* A recent enhancement to TAOS has been the inclusion of real time forecast capabilities, in response to client requests who require "customized" forecasts. TAOS offers several track and intensity forecast modules for real time track forecasts, also useful for creating realistic tracks for exercises and scenario evaluation. These modules include HURRAN (Anthes, 1982), CLIPER (Hope and Neumann, 1970), various BAM models (Marks, 1992), and two WTC developed long range track and intensity models. An additional capability parses the NHC Objective Guidance messages, convert the data to digital format, and displays the storm tracks. TAOS also incorporates uncertainty in storm characteristics in the track forecast modules. For example, the uncertainty in the initial storm position may be used to create an ensemble forecast using a single (or multiple) track model.

#### 6. VERIFICATION

Extensive verification data for the various modules has been produced on dozens of storms worldwide, and is available from the authors. Due to the modular nature of TAOS, an important issue to keep in mind is at the batch mode processing level, various combinations of distinct modules can be selected, producing varying results. This issue is addressed more fully in Watson and Johnson (1998). For tropical cyclones, the hybrid surge model, the Jelesnianski (1992) wind field, and the NWS-23 boundary layer methodology, TAOS/C at 30 arc seconds appears to generate water level results within 0.3 meters (less than

1 foot) 80% of the time, and less than 0.6 meters (about 2 feet) 90% of the time.

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