Available online at www.sciencedirect.com

ScienceDirect

Agriculture and Agricultural Science Procedia 1 (2010) 204–211

Agriculture and Agricultural Science Procedia

International Conference on Agricultural Risk and Food Security 2010

Managing Typhoon Related Crop Risk at WPC

Craig W. Tillman[a], Joel K. Sivillo[a], Sergei A. Frolov[a*]

[a]WeatherPredict Consulting Inc., 3200 Atlantic Ave, Suite 114, Raleigh, NC 27604, USA

Abstract

Risk management of crop related exposures in coastal regions can be enhanced through a program of hazards modeling and real-time forecasting. As one component in the yield distribution of selected crops, typhoon-related hazards are a critical factor. Natural typhoon occurrence rates accentuate the extreme parts of the yield distribution, causing severe and correlated financial disruptions to invested interests. This paper outlines a suite of techniques focused on building a probabilistic understanding of crop risk from tropical cyclones. Several foundational technologies are discussed, including: Numerical Weather Prediction (NWP) of tropical cyclones; statistical consensus forecast models, such as the WeatherPredict Superensemble™; and the application of flood modeling techniques to typhoon landfall scenarios.

Keywords: Agricultural Risk; Typhoon Hazards; Typhoon Flooding; Numerical Weather Prediction; Crop Risk

* Corresponding Author. Tel: +1-919-876-3633;
E-mail Address: Craig.Tillman@weatherpredict.com

2210-7843 © 2010 Published by Elsevier B.V.
doi:10.1016/j.aaspro.2010.09.025

1. INTRODUCTION

WeatherPredict Consulting Inc. (WPC) is a U.S. affiliate of RenaissanceRe. Focusing on atmospheric hazards and vulnerability, WPC's team of advanced scientists draws upon expertise in oceanography, meteorology, remote sensing, wind engineering, aerodynamics and computer simulation. WPC provides intelligence on atmospheric perils to clients that must anticipate the occurrence and outcome of weather events, including crop insurers. In this paper WPC's tropical cyclone and digital agriculture expertise is the backdrop to the support of a crop risk management program that considers typhoon hazards.

1.1 Crop Related Hazards and Exposures in Coastal Regions

Tropical cyclones create multiple environmental characteristics that can adversely affect the production and distribution of agricultural commodities. These characteristics may include excessive rainfall, powerful winds, inland flooding, coastal surging and associated salinity. Adjacent to the world's major tropical cyclone basins, a number of crops are exposed to typhoon and hurricane hazards. In Table 1, one sees examples of major crops that can be impacted by tropical cyclones.

Table 1. Partial list of crops in major tropical cyclone basins

Cyclone Basin	Crop Commodity Impacts
Western Pacific	Rice, Palm Oil, Corn, Soybean, Sugarcane, Cotton
Atlantic	Corn, Soybean, Sorghum, Citrus, Sugarcane, Cotton
South Pacific	Sorghum, Cotton, Sugarcane
North Indian Ocean	Corn, Sugarcane, Rice, Sorghum, Millet, Groundnuts, Cotton
Southeast Indian Ocean	Rice, Corn

1.2 Risk Management Programs

The impacts of typhoons on coastal crop exposures present a challenging problem for risk managers who need to quantify crop yield potentials for investors, insureds, and markets anticipating the season's harvest. Random arrivals of typhoons can inhibit production due to over conservative planting decisions and alternatively, increase the propensity for failed harvests when producers underestimate the risk associated with typhoon-related floods and damaging winds. This paper describes a risk management system that allows producers to develop a probabilistic basis for crop exposure decisions. The system employs a number of foundational technologies developed to quantify different aspects of this risk management problem, each of which will be described below. With these foundational technologies integrated into a probabilistic simulation framework, objective decisions can be made about crop exposures dynamically, in the context of forecast time-frames and long-run probably distributions of typhoon climatology.

2. TYPHOON HAZARDS IN CROP RISK

2.1 Typhoon Occurrence Rates

Overall frequency-severity rates of typhoons are established through the use of Numerical Weather Prediction (NWP) models, which are informed by historical observations and enhanced by integrating the physical constraints of extreme typhoon events. To support the overall probabilistic description of the risk, a stochastic set of events is constructed to span the parameter space with sufficient density. The stochastic set accounts for variations in geography, central pressure, maximum winds, forward speed, radius to maximum winds, and angle of landfall incidence. For modeling storm surge phenomena, randomizations that exercise the radius to maximum wind and angle of landfall incidence provide crucial refinements for this goal. Historical counts of land falling storms provide an important calibration for the frequency-severity depiction across the region of geographic interest. However, this must be augmented with an understanding of the physical processes governing typhoons so that the extreme limits of this parameterization may be realized. Normally, a stochastic event set requires thousands of individual events to competently derive dense descriptions of the exceedance probability distribution for loss exposures as well as capture event realizations at the extremes not yet observed in the historical experience.

2.2 Relationship of Typhoon Occurrence to Crop Losses

The stochastic depiction of typhoon hazard is necessarily an event-wise collection of realizations that include depictions of the temporal-spatial distribution of winds, rain, and storm surge. Each realized event must describe the geographic correlation of hazard effects on different production areas. Also, with respect to crop exposures, the chronological unfolding of the hazard can be critical to understanding loss potentials. For instance, damaging winds may arrive prior to typhoon-related flood waters and so, for selected crops, compromised structural ductility may increase damageability to subsequent flood inundation. In some coastal regions the synchronization of tides with storm surge related flooding will increase the likelihood of flood-related losses to crops. Similarly, the coincidence of hydrodynamic loading of drainage basins with the onset of typhoon generated storm surge may aggravate flooding problems and increase predicted flood heights. This latter example highlights the importance of examining “multi-event” scenarios to understand the aggregate effects of typhoons over the course of a growing season.

3. FORECASTING TOOLS FOR TYPHOON RISK MANAGEMENT

This section discusses three predictive technologies that can lead to the risk manager’s improved understanding of the typhoon hazard. The optimization of deterministic and probabilistic typhoon forecasts couples with proper understanding of crop exposures and vulnerabilities in order to create a dynamic crop risk management platform.

3.1 Numerical Weather Prediction (NWP) of Tropical Cyclones

NWP models render each event realization using mathematical simulations of the system’s physical dynamics. NWP models simulate the interactions of the typhoon with the atmosphere and the ocean. All typhoon tracks are derived using a NWP approach based on the NOAA’s GFDL Hurricane forecast system. This simulation approach solves data scarcity issues that plague other methods; it guarantees that each track has a combination of translation speed and approach angle at landfall, which is possible in nature. As the typhoon makes landfall, NWP models are critical to model the interaction of the typhoon with natural and man-made land surfaces so that cumulative wind speeds (as averages and peak-gusts) can be correctly characterized. Among other elements, descriptions of land surface roughness, coastline geography and coastal topography are important to achieve accurate depictions of wind hazards with these simulations models.

3.2 Statistical Consensus Forecasting

In addition to the detailed physical information that is provided with NWP models, accurate forecasting of key parameters, such as typhoon strength and track, can assist the risk manager’s decision making. Statistical consensus forecasts, particularly those from the WPC Superensemble™, extract valuable information from an ensemble of objective forecasts, resulting in highly accurate deterministic forecasts, plus estimates of forecast uncertainty.

The Superensemble™ technique has significant advantages over simple ensemble averaging, as it corrects for biases in individual objective forecasts. It also uses an optimization and weighting scheme that captures the strongest predictive components of the ensemble members whose skills may vary regionally or at different lead times.

3.3 Flood Modeling Techniques

Typhoon-related storm surge and inland flooding models provide extended characterizations of the individual events described above. These models are driven by NWP-based simulation of the typhoon, as it translates across the ocean and over land, which is critical in building a robust description of the flooding hazard. Similar to the use of NWP models to describe the physics of the typhoon systems, the Advanced Circulation Model (ADCIRC) coupled with a hydrological/hydraulic model is used to simulate the resultant storm surge and inland flood [2]. ADCIRC is a sophisticated storm surge model that has been successfully applied to the coastal flood simulations in a number of scientific and engineering studies (see [4] for an example). The principal advantage of the ADCIRC comes from an adaptable finite element approach that allows very flexible assignment of grid density, according to the complexities of geography, bathymetry or loss exposure density. The advantage of using a fully dynamical storm surge model (compare to a parametric model) is illustrated in Figure 1. Depending on the geometry and bathymetry of coastlines, vastly different storm surge levels can be realized according to the angle of landfall incidence. The effect of these location-specific and storm-specific details can be captured in a robust fashion only in a fully dynamical simulation.

In order to simulate the combined effect of the storm surge and inland (rainfall-related) flooding, the ADCIRC storm surge model is coupled to a proprietary WeatherPredict Consulting hydrological/hydraulic model. The WPC hydrological/hydraulic model is capable of simulating overland water flows in a variety of frictional regimes allowing simultaneous representation of rainfall-related and storm surge flooding. Figure 2 illustrates the advantage of the WPC model built to capture both hurricane-related storm surge and inland flooding. Note that a critical element of this technology is the linkage between the hydrologic model for inland flooding and the flows simulated by ADCIRC related to storm surge. The WPC model is successful in predicting the critical peak of the flooding related to both aspects, as well as in capturing tidal effects that further modify that peak flood level.

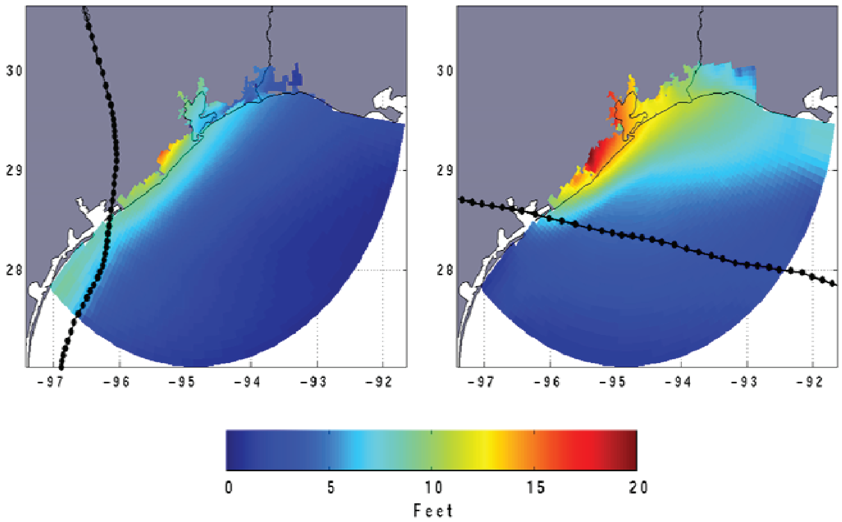

Figure 1. Credible storm surge simulation has to take into account the typhoon's angle of incidence

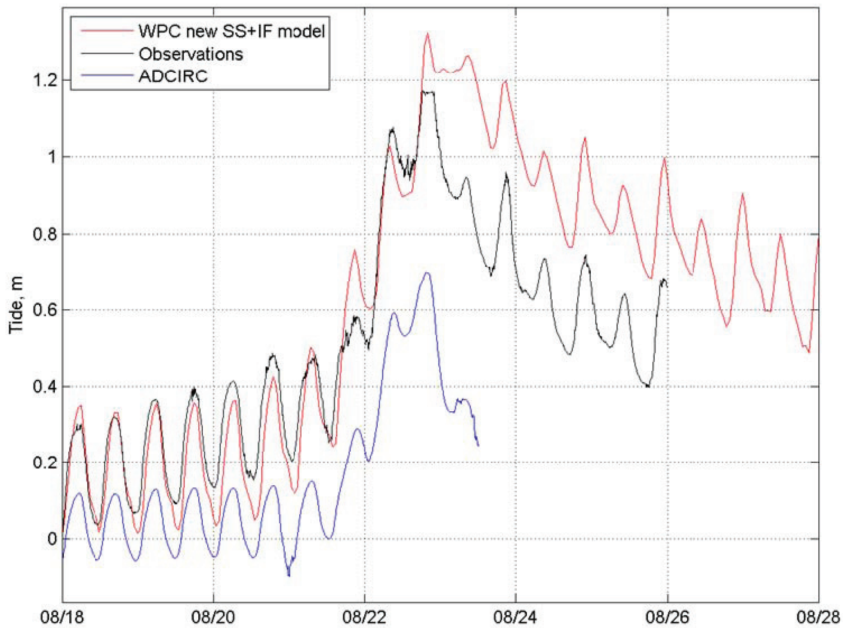

Figure 2. Typical storm surge estimation using ADCIRC coupled with NWP-generated typhoon simulation.

4. DYNAMIC CROP RISK MANAGEMENT

Risk managers are faced with multi-tiered decisions with respect to crop loss exposures. Decisions normally have two components: the spatial correlation between loss exposures, and the temporal refinement of loss distributions as the decision framework moves from planning, planting, field management, and finally to harvest. Using probabilistic characterizations of the hazard integrated with crop inventory and vulnerability, managers are best equipped to anticipate both positive and negative outcomes in a quantitative manner. The tools and models described above are collapsed into a dynamic crop risk management system, which is characterized by a family of exceeding probability distributions (Figure 3). The base exceedance probability distribution captures the multi-location, multi-event, risk signature of the portfolio of crop exposures. The mathematical process for building this loss distribution involves building ranked event loss tables and transforming these tables into exceedance probability distributions (see [1], [3]). Its reliability is driven by the robustness of the underlying simulations and their dense coverage of all geographic regions that might be affected by any particular typhoon in the stochastic catalog.

4.1 Crop Risk Management Prior to Onset of Typhoon Season

Prior to the onset of typhoon season, a risk manager selects the content of a portfolio of crop exposures. In order to enhance the stability of profits within the portfolio, the manager must anticipate both the likelihood of losses and the levels of catastrophic loss that can be financed. The first step is to consider the exceedance probability distributions that correspond to the long-run climatology of typhoons. Additionally, the probability distribution can be disaggregated to identify the largest contributors to the overall portfolio risk. With this in mind, one can quantify the benefits of selected crop loss mitigation measures for wind or storm surge, investigate selected typhoon scenarios for disaster planning exercises, and determine the levels of loss correlation among different crops and individual crop exposures. In conjunction with other risk management tools, this probabilistic assessment allows the risk manager to apportion investments and efforts so as to increase the likelihood of favorable outcomes for the crop exposures in which they invest.

4.2 Intraseasonal Crop Risk Management

With the advent of skillful seasonal forecasts for typhoons, managers are better able to refine decisions based on a distribution that is conditional on the most current forecast of tropical activity. While the reliability of such a seasonal forecast determines its applicability, a conditional exceedance probability distribution further informs the risk manger about the benefit of actions, such as risk financing or risk trading, which can be beneficial to the current portfolio investment. This tuning of the risk position accounts for the elapsed time to harvest, and the forecasted tropical activity for the balance of the exposure period. Options for refining the risk position of the portfolio with this "mark-to-forecast" information are only limited by the cost of alternatives, whether market-based or mitigation-based. Depending upon the region of interest, forecasts can offer skill improvements for the 2 to 24-week time frame. Special emphasis might be given to key crop growth epochs, e.g., pod-filling for soy beans, to emphasize the criticality caused by externalities like typhoon-related flooding. Knowledge of these seasonal forecasts allows the risk manager to maximize the likelihood of favorable investment results.

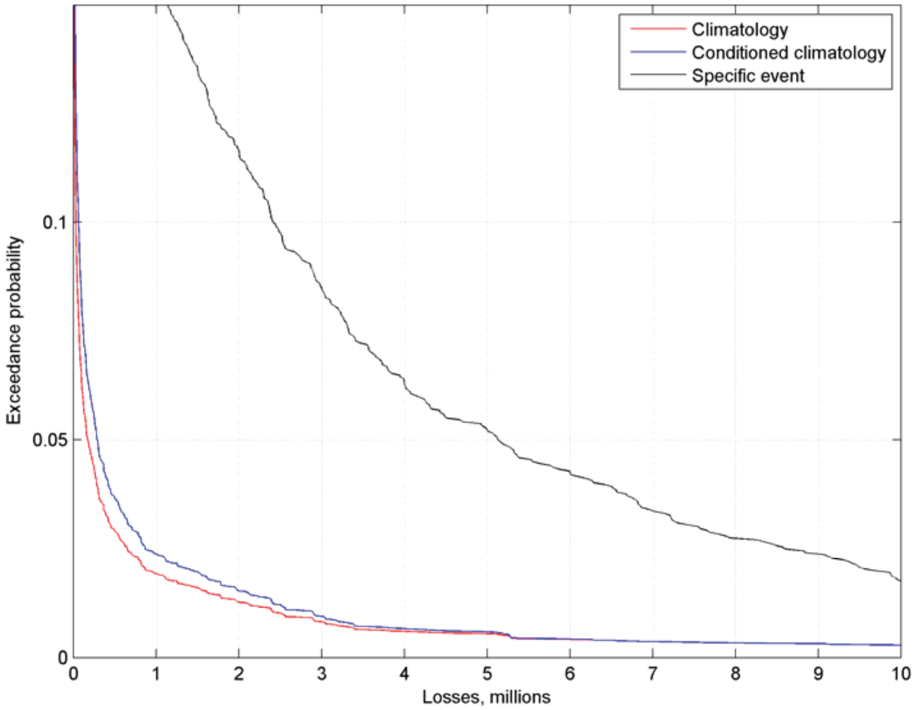

Figure 3. Exceedance probability distribution: Evolved as forecast information becomes more specialized. Exceedance Probability equals 1 (one) minus the cumulative probability.

4.3 Crop risk management when landfall is imminent

A special case of the conditional view occurs when landfall of a typhoon is imminent. Techniques such as the Superensemble^{TM} methodology described above allow forecasters the ability to provide updated probabilistic estimates of portfolio performance. Risk managers can use this information to adjust invested positions, obtain more risk financing, and alert producers about special mitigation measures that should be considered to reduce potential losses. Similar to adjustments of the loss exceedance distribution to reflect seasonal forecasts, Superensemble^{TM} results allow the depiction of forecast skill as part of the modification of the exceedance probability distribution. As this is a short-term adjustment, the prospective loss distribution would revert to the seasonally adjusted mode, after the typhoon makes landfall.

4.4 Execution of Post Landfall Impact Assessments

Through the coordination of a number of scientific disciplines and real-time track and intensity forecasts provided by Superensemble^{TM} technology, results can be quickly augmented to assess the range of impacts in the early hours after typhoon landfall. By initializing NWP models with the observed parameters of the typhoon before landfall, accurate depictions of the cumulative wind field can be determined. Simultaneously, storm surge impact models can be initialized with typhoon observations and in situ hydrodynamic loads on drainage basins, as well as observations of precipitation levels, to calculate flood levels and inundation persistence. These data may be integrated with crop loss algorithms based on local parameters for crop damageability and soil absorption qualities. Economic estimates of crop impacts are directly calculable from these model results.

5. CONCLUSIONS

Many coastal crops are exposed to tropical cyclone and typhoon hazards. Accordingly, a comprehensive crop risk management program will consider and plan for such hazards. Tropical cyclone forecasting and analysis tools permit better risk management through the understanding of hazards at seasonal, intra-seasonal, and landfall-imminent time scales. Timely planning at the seasonal timescale allows for short-fused risk management actions to be taken during critical periods of crop growing seasons

Dynamic management of crop exposures in typhoon hazard regions involves focusing on conditional aspects of the risk as seasonal and real-time information become available. Further, rapid post-landfall assessments of impacts must be planned and executed. When managed with an appropriately calibrated stochastic model that describes the physical processes involved, insurers can apply intelligent measures towards managing retained risk. Such a management system also provides for collaboration between atmospheric scientists and the risk managers in supporting decisions under the risk and uncertainty of crop-related typhoon losses.

6. REFERENCES

1. W. Dong, P. Grossi,. Insurance Portfolio Management, in: P. Grossi and H. Kunreuther, (Eds.), Catastrophe Modeling: A New Approach to Managing Risk, Springer, New York, 2005, pp. 119-133.
2. R. Luettich, J. Westerink. Formulation and Numerical Implementation of the 2D/#D ADCIRC Finite Element Model Version 44.XX , University of North Carolina at Chapel Hill, Dec. 8, 2004.
3. C. Taylor, C. Tillman, 1990. Seismic Risk Methods for Earthquake Insurance, Fourth U.S. National Conference on Earthquake Engineering, May, 1990.
4. J. Westerink, J.C. Feyen, J. H. Atkinson, R. A. Luettich, C. N. Dawson, M. D. Powell, J. P. Dunion, H. J. Roberts, E. J. Kubatko, H. Pourtaheri, A New Generation Hurricane Storm Surge Model for Southern Louisiana, University of Notre Dame, Sept. 4, 2004.