2010 Gulf of Mexico Hypoxia Forecast and Measurement

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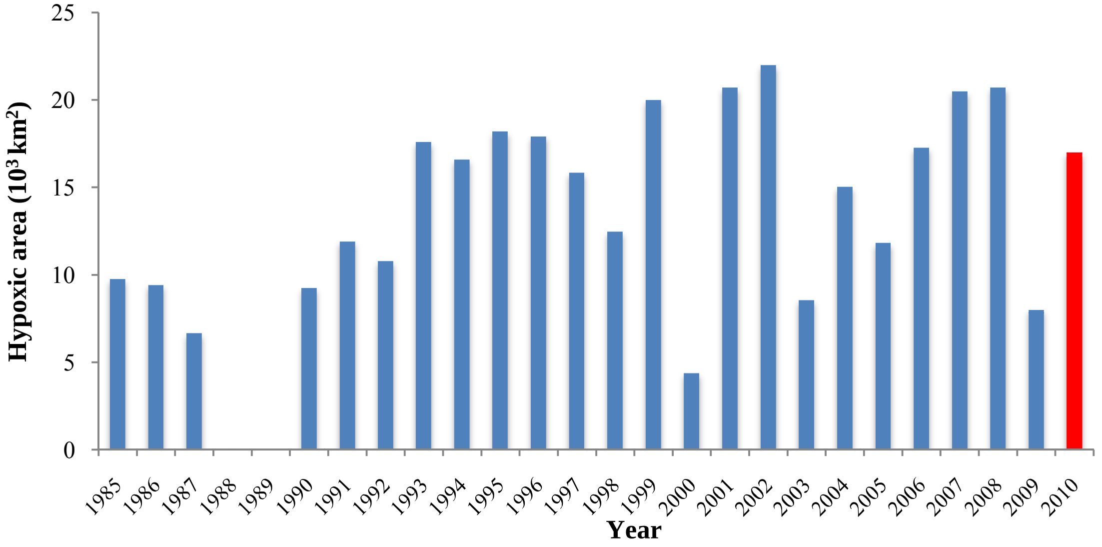
The 2010 Forecast and Observation –

The Gulf of Mexico summer hypoxia forecasts are based on average May total nitrogen (TN) loads from the Mississippi River basin. The load, recently released by USGS, is 5,222 metric tons per day, lower than 2009, and slightly below the average from 1985 to 2009. Based on that estimate, we precict the size of this summer's hypoxic zone to be 17,000 square kilometers (95% credible interval 13,900 to 19,300), the 10th highest since measurements began in 1985.

This year's observed hypoxic is ** square kilometers (to be publisehd after measurments are made in July). See www.gulfhypoxia.net.**

Hypoxia and the Gulf of Mexico – The Gulf of Mexico hypoxic zone (i.e., the area of bottom water with oxygen concentraions below 2 mg/l) is the second largest human-caused zone of hypoxia in the world's coastal waters. Important fisheries are impacted at these low oxygen levels because fish, shrimp and crabs are forced to move from their preferred habitats and animals that cannot move away die. Below is a graph (www.gulfhypoxia.net) showing the changes in hypoxic area since LUMCON's routine measurement began. Support for this work has been provided by NOAA's Center for Sponsored Coastal Ocean Research (http://www.cop.noaa.gov/) since 1990.



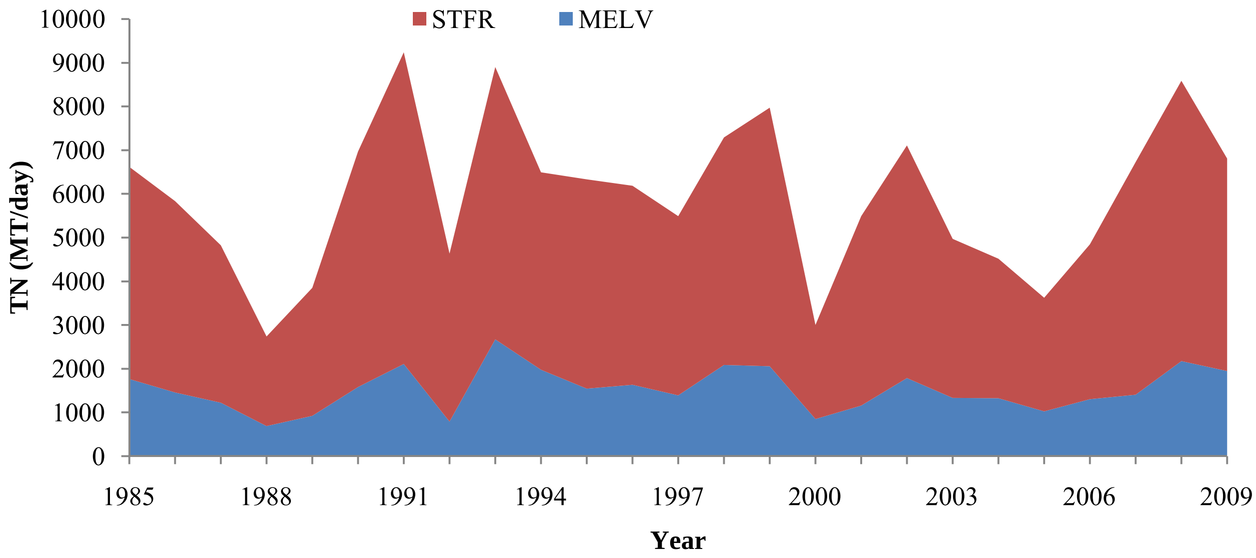
Hypoxic area measured in mid-summer, with 2010 forecast. Source for historical data: N. Rabalais, LUMCON; NOAA/CSCOR

***Nutrient Loads* -** A substantial body of scientific evidence links long-term growth of this hypoxic region to the increased loads of nitrogen from the Mississippi River system.

http://oceanservice.noaa.gov/products/hypox_final.pdf

There is a significant change with our approach to forecasting last year and this year. To provide earlier forecasts, we used May, rather than May-June, loads. The model was recalibrated to historical May loads using a Bayesian estimation procedure described below.

Below are graphs of May nutrient loads from the Mississippi basin between 1985 and 2009 (MELV represents load from the Atchafalaya and STFR from the Mississippi River), LOADEST AMLE Predicted Load from USGS website (http://toxics.usgs.gov/hypoxia/mississippi/oct_jun/index.html).



***Hypoxia Models* –** The forecast was done with a model that was developed to assess the impacts of changes in nitrogen loads on Gulf hypoxia (Scavia et al 2003, 2004, Scavia and Donnelly 2007). While it was originally designed to estimate the extent of nitrogen load reduction needed to reach a particular goal for hypoxia, it can also be used to forecast hypoxic volumes for a given year, based on the average May load.

The model is an adaptation of a river model that predicts oxygen concentration downstream from point sources of organic matter loads using two mass balance equations for oxygen-consuming organic matter, in oxygen equivalents (i.e., BOD), and dissolved oxygen deficits. The equation for dissolved oxygen (DO), solved at steady state is:

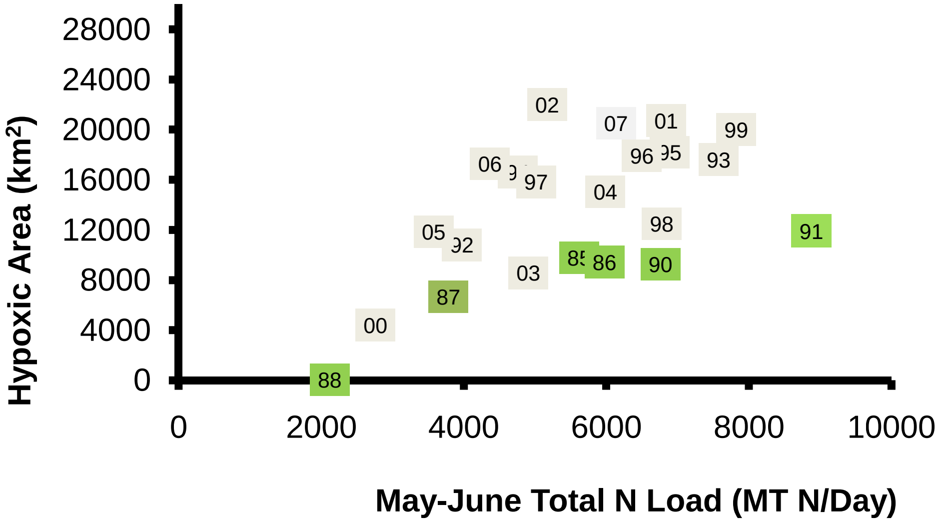
$$DO = DO_S - \frac{k_1 BOD_u}{k_2 - k_1}\left(e^{-k_1 \frac{x}{v}} - e^{-k_2 \frac{x}{v}}\right)$$

where DO = the dissolved oxygen concentration (mg/L), DO_s = the saturation oxygen concentration, k_1 = the BOD decay coefficient (1/day), k_2 = the reaeration coefficient (1/day), BOD_u = the ultimate BOD (mg/L), x = the downstream distance (km), v = stream velocity (km/day). In this application, the parameter v, is a calibration term that integrates all model and data uncertainty. This approach to modeling coastal and estuarine hypoxia has also been used successfully for Chesapeake Bay hypoxia (Scavia et al. 2006).

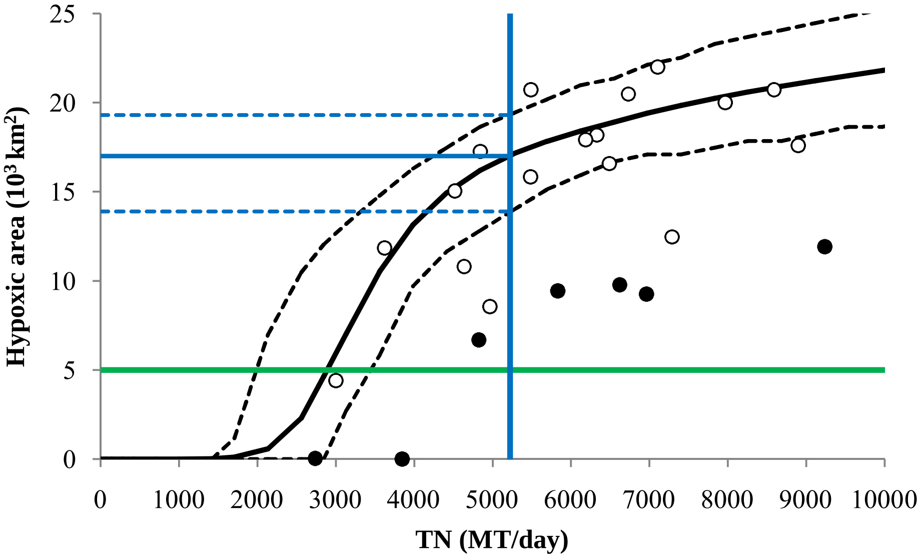
Bayesian Inference – The above hypoxic model was calibrated using Bayesian Inference, an increasingly commonly used method in environmental and ecological modeling (Reckhow 1994; Malve and Qian 2006; Arhonditsis et al. 2007; Stow and Scavia 2009) because it provides a convenient way to combine existing information/past experience (priors) with models and current observations (likelihood) for projecting future ecosystem response (posterior). Markov Chain Monte Carlo (MCMC) algorithm has been applied to obtain the numerical summarization of parameters (Qian et al., 2003) in a Bayesian framework.

We implemented MCMC with Gibbs sampling with WinBUGS (version 1.4.3; Lunn et al., 2000), called from R (version 2.6.0; R2WinBUGS (version 2.1-8; Gelman and Hill 2007). The MCMC sampling was carried out using four chains, each with 20,000 iterations (first 10,000 discarded after model convergence); and samples for each unknown quantity was taken from the next 10,000 iterations using a thin (MCMC sampling interval) equal to 40 to reduce serial correlation. Statistical inference was based on the resulting 1,000 MCMC samples.

The Scenario and Forecast Models - While the originally calibrated model produced a good representation of the large scale changes in hypoxia, recent evidence suggests that persistent hypoxia has caused an ecological shift such that the system has become more sensitive to nutrient loads (Turner et al. 2008). This can be seen in the graph below where it is clear that a given loading rate appears to have produced larger hypoxic regions after 1991 (grey) than before then (green).

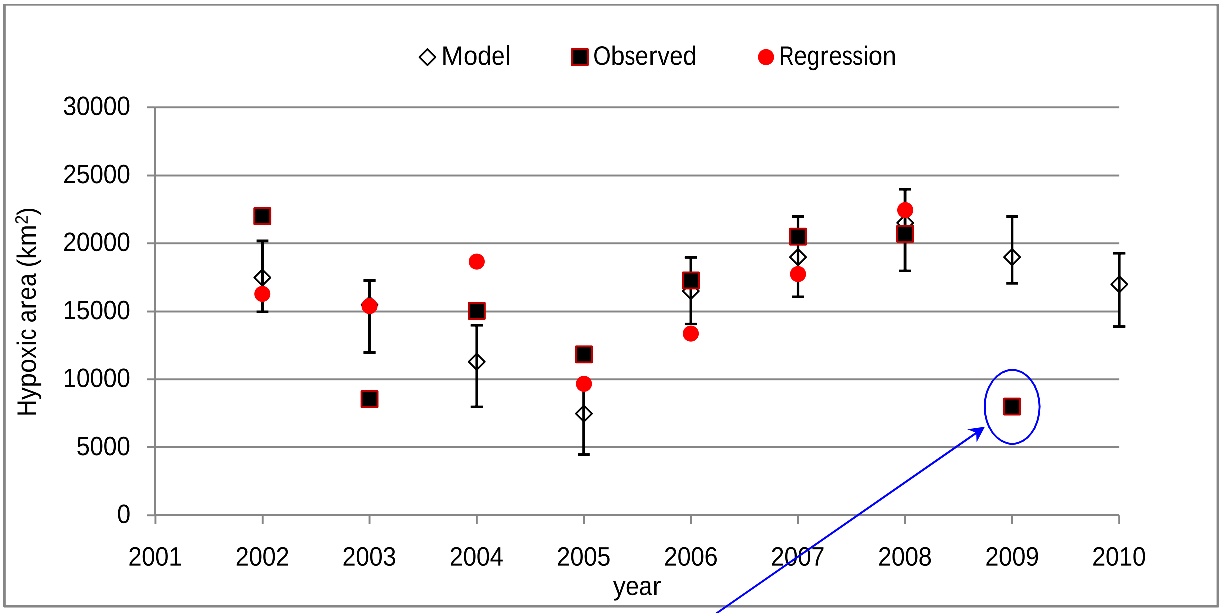


We recalibrated the biophyscial model to the post-1991 data set for forecasts. See results below, including the 2010 values.



Notes: *Solid black curve: Forecasting result (mean value); Dashed clack curves: Forecasting result (2.5 and 97.5% CI); Open circles: observed values in 1992-2008; Dots: observed values before 1992; Green line: target goal of 5000 km^2; Blue lines: 2010 May load=5222 MT/day and forecast (solid horosontal line: mean forecast; dashed horozontal lines 2.5 and 97.5% CI).*

Forecast Track record – Below is a retrospective look at the relationships among forecasts made with the biophysical model calibrated to the post-1991 data (diamonds with error bars), regression-based forecasts using post-1991 data (red dots), and observations (squares).



What contributed to the far smaller observed size of the dead zone than predicated this summer? Dr. Nancy Rabalais, from the Louisiana Universities Marine Consortium, reports that it is likely due to unusual weather patterns that re-oxygenated the waters and other factors, including (a) the re-oxygenation of the bottom layer resulting from the high flow of the Mississippi River falling below average for July; and (b) persistent winds from the west and southwest in the few weeks preceding the mapping cruise likely pushing the low oxygen water mass to the east and 'piled' it up along the southeastern Louisiana shelf (see www.gulfhypoxia.net).

***Additional Background* -** The evolution and management of summer hypoxia in bottom waters of the northern Gulf of Mexico have recently received considerable scientific and policy attention because of the enormous size of the hypoxic zone and because of its implications for watershed management within over 40% of the continental United States -- the Mississippi River Basin (Turner and Rabalais 1994, CENR 2000, Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2001, Mitsch et al. 2001, Rabalais et al. 2002a). Extensive regions of bottom oxygen concentrations below 2 mg L^{-1} form off the Louisiana coast each spring and summer. These regions have recently extended 600 km westward from the mouth of the Mississippi River past the Texas border. These hypoxic regions averaged 8,300 km^2 in 1985 – 1992, and increased to an average of 16,000 km^2 in 1993 – 2001 (Rabalais et al. 2002a). An assessment of the causes and consequences of hypoxia concluded that the almost 3-fold increase in nitrogen load to the Gulf (Goolsby et al. 2001) has driven the long-term increase in hypoxia since the middle of the last century (CENR 2000, Rabalais et al. 2002a). Riverine nitrogen input stimulates coastal algal production and the subsequent settling of organic matter below the pycnocline. Because the pycnocline isolates deeper waters from the surface and inhibits vertical oxygen flux, decomposition of organic matter below the pycnocline consumes oxygen faster than it is replenished and oxygen concentrations decrease dramatically.

Variability in climate and ocean dynamics control much of the interannual variability in hypoxia extent (Rabalais et al. 1999, 2002a), and this can confound the understanding of its response to the management actions being proposed for the basin (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2001, Rabalais et al. 2002a). Here we use a biophysical model to explore the relative influence of nitrogen load and ocean variability on changes in hypoxia, and provide hindcasts and forecasts of hypoxic area in response to changes in loads, bounded by ranges in potential ocean conditions. While efforts to model the interactions between nutrient load and oxygen dynamics have successfully simulated temporal variability within one vertical dimension (e.g., Justić et al. 1996, 1997, 2002) and three dimensions (Bierman et al. 1994), this model is the first one to successfully predict the direct effect of variable nutrient loads on the areal extent of hypoxia on this shelf.

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