Modeling Approaches for Scenario Forecasts of Gulf of Mexico Hypoxia

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A. Abstract

Management efforts focused on mitigating the size and impacts of the northern Gulf of Mexico hypoxic zone have been primarily informed by a limited number of statistical models used to make scenario forecasts of nutrient management. To improve the scientific foundation of management decisions, additional modeling approaches have been developed over the last decade that range from statistical models to fully mechanistic hydrodynamic-biogeochemical models. With advancement of a new suite of models, a Modeling Technical Review Panel was convened at the *Forum for Gulf of Mexico Hypoxia Research Coordination and Advancement* on April 17-19, 2013 at Stennis Space Center, MS to assess the state of scenario forecast models and develop conclusions on approaches to most effectively meet needs of management efforts such as the Gulf of Mexico Hypoxia Task Force. Models were assessed based on their ability to address key management questions, their infrastructure, observational and remaining research needs, and their state of development. Based on modeler presentations and Forum discussions, this white paper assesses the status of several empirical and deterministic models capable of characterizing Gulf hypoxia. The Panel concluded that several empirically-based models are ready for transition to operational use in scenario forecasts of nutrient reduction goals required for hypoxia mitigation. Conversely, deterministic modeling efforts were considered to have made considerable recent advancements, but not fully ready for use in an operational environment for scenario-based hypoxia forecasts. Remaining needs for the deterministic models include: 1) additional calibration/validation against refined estimates of the spatial and temporal extent of hypoxia within the Gulf and against more process-based data sets (primary production, respiration, sediment oxygen demand, nutrient flux, etc.), and 2) the presentation of model sensitivity to key model parameters. Continued refinement of the deterministic modeling efforts is emphasized, with the ultimate goal of developing an ensemble (multiple) modeling approach (empirical and deterministic models) to inform managers of required nutrient reduction goals, both in the short term and under longer climate change scenarios.

B. Background

B.1 Introduction

Scenario forecast models provide decision makers with the ability to examine the effect of multiple management scenarios on resources of concern. For coastal hypoxia, this often involves the ability to examine the relative influences of climatological (e.g. winds, currents, salinity) and land-based (e.g. nutrient and freshwater inputs) factors on the formation and maintenance of coastal hypoxia. Scenario forecast models have been used to inform the interagency Mississippi River/Gulf of Mexico Watershed Nutrient Hypoxia Task Force ("Hypoxia Task Force") of watershed nutrient reduction targets needed to achieve its Coastal Goal to reduce the areal extent of the northern Gulf of Mexico hypoxic zone to 5,000 km^2 by 2015. The EPA Science Advisory Board report (USEPA 2007) that provided guidance for the Hypoxia Task Force's (HTF) 2008 *Action Plan* (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2008) used model estimates from two references to recommend 45% TN and 45% TP reductions needed to achieve the 5,000 km^2 Coastal Goal:

- Scavia et al. (2004): results from an ensemble of models suggested a 40-45% reduction in N loading needed to meet the Coastal Goal: 1) Bierman et al.'s (1994) complex 3-D, food-web-nutrient-oxygen dynamics model, 2) Justic´ et al.'s (1996, 2002) box model simulating two-layer, time-dependent, oxygen dynamics, and 3) Scavia et al.'s (2003) model simulating summer steady-state, one-dimensional horizontal dynamics of nutrient-dependent production, respiration of organic matter, and resulting oxygen balance.

- Scavia and Donnelly (2007): updated Scavia et al. (2004) model results for TN using new USGS loading data, concluding that a 37-45% reduction of TN load was needed to reach the 5,000 km^2 Coastal Goal; also this paper estimated that a 40-50% reduction of TP was needed.

The HTF's Coastal Goal will not be met by 2015, and deliberations are underway to develop alternatives and options for hypoxia mitigation goals and watershed nutrient reduction targets. The ability to develop an operational quantitative framework for the development of nutrient reduction targets, and reassessment of goals and targets using an adaptive management approach, are critical HTF needs.

In order to provide independent guidance on modeling approaches for an operational hypoxia scenario modeling framework, NOAA in partnership with the Northern Gulf Institute convened the Gulf Hypoxic Zone Modeling Technical Review Meeting as part of the Forum for Gulf of Mexico Hypoxia Research Coordination and Advancement April 17-19, 2013 at Stennis Space Center, MS. The goal of the meeting was to assess the state of scenario forecast models targeting hypoxic zone dynamics in the Northern Gulf of Mexico, and develop conclusions on modeling approaches to most effectively meet the HTF management directive to mitigate hypoxia. The Forum Steering Committee selected a Modeling Technical Review Panel charged with assessing existing models based on:

- ability to address key management questions;
- infrastructure, observational, and remaining research needs;
- state of development – are they ready for transition to operation?

The specific charge to the Panel and key management questions are located in Appendix 1. In general, however, key management questions revolved around the need to improve quantitative nutrient reduction targets for use in goal setting and implementation of nutrient reduction strategies through the HTF. The report represents Panel input on which modeling approaches are presently best suited for addressing HTF needs.

B.2 Review of Hypoxia Modeling Approaches

The USEPA (2007) SAB report (heretofore referred to as "SAB Report") provided an overview of the then state-of-the-science tools available for understanding the factors influencing the extent and duration of hypoxia in the northern Gulf of Mexico. The report included a review of empirical and deterministic or mechanistic modeling capabilities and limitations. There has been significant progress in refining and improving these tools in the years since the SAB Report and much of this progress was presented at the Gulf of Mexico Hypoxic Zone Modeling Technical Review Meeting. Presentations included both empirical modeling approaches, deterministic modeling approaches, and a mixed Bayesian-deterministic approach. Presentations were also made on models assessing the effects of hypoxia on living marine resources. Other than to note that these latter research efforts are of key interest to living resource managers of the northern Gulf and that they should be continued and expanded, we will not comment further on them, as the charge to the Panel was "to assess the state of the science on scenario forecast models targeting hypoxic zone dynamics, and develop conclusions on modeling approaches to most effectively meet the Hypoxia Task Force management directive to mitigate hypoxia".

Empirical models, noted for their simplicity, are largely structured by observed relationships or correlations between experimental or observed data. These models can be used to develop relationships for describing trends and for forecasting. However, as noted by the SAB Report, correlation does not imply causation, nor do correlations between variables explain why variables are correlated or the mechanisms of these relationships. They can, however, provide useful predictive capability, if they are not applied far outside of the range of observed data under which they were developed. The Vollenweider (1976) model is perhaps the best known of the empirical models that have long been used in lakes to understand the relationships between chlorophyll concentration and phosphorus loadings.

Deterministic or mechanistic models are based on an explicit representation of the physical, biological, and/or chemical processes of an ecosystem. These models attempt to quantify ecosystem behavior and phenomena by their underlying causal mechanisms. Deterministic hypoxia models tend to be more complex than empirically-based models of hypoxia, and they also require larger data sets and greater time and effort to calibrate and validate. They can provide an additional capability that empirical models cannot offer; that is, they can forecast the time to recovery or the time to achieve a new state of equilibrium after implementation of a management action. Again, however, as noted in the SAB Report, it should be recognized that the complexity of deterministic models requires estimation of a much larger set of model coefficients and parameters, and recognition that there may be large uncertainty in some of these model coefficients and parameters. Hence, these types of model may not improve forecasting capabilities significantly. However, the more process data (e.g. measurements of primary production, community respiration, water column nitrification, sediment oxygen demand, sediment nutrient flux, etc.) that can be used to specify or constrain model parameters and coefficients, the more confidence that living resource managers will have in model forecasts or predictions.

C. Panel Conclusions on Modeling Approaches

C.1 Modeling Approaches to Inform the Hypoxia Task Force of Progress toward Meeting Coastal Goal

The Modeling Technical Review Panel reviewed empirical and deterministic models used to assess and predict hypoxia properties in the Gulf of Mexico, based on the presentations and discussions at the Forum (Appendix 2). The empirical model developed by Turner (Appendix 2, #8) continues to show improved or increasing coefficient of determination (r^2), with the latest r^2 achieving values of 0.99 for the period 1994 to 2000 and 0.97 for the period 2001 through 2012. The current model formulation still includes the variable “Year” in the multiple regression, which was of concern to the SAB Report because “the addition of one more year will cause prediction of a positive increase in hypoxia with time”. However, an alternative interpretation to the variable “Year” may reflect a carryover of a large pool of sediment organic matter delivered to the sediment in a year (Year X) of high Mississippi/Atchafalaya nutrient load that does not undergo diagenesis or mineralization in Year X, but rather is carried over and undergoes diagenesis in Year X+1. Of course, the variable “Year” would reflect little or no carryover of organic matter from Year X to Year X+1 under conditions of low nutrient loading from the Mississippi/Atchafalaya River. Also, as acknowledged by Turner, the empirical model does not recognize the role of storms and their influence on vertical mixing and reventilization of hypoxic bottom water in the Gulf. The Streeter-Phelps Bayesian Model developed by Scavia et al. (Appendix 2, #7) was also well validated: 93% of their model predictions of hypoxic area were within the 95% confidence limits of the estimated area of hypoxia when a 3-year calibration window was used (Evans and Scavia 2011). The model included some assessment of the influence of phosphorus on hypoxic area as well as the potential need for additional load reduction that may be required as a result of climate change. The results of two newly developed empirical models were also encouraging. Forrest's multivariable regression model (Appendix 2, #15) confirmed the strong relationship between May nitrate loading and hypoxic zone areal extent, and the importance of wind stress (Forrest et al. 2011), and its future application to seasonal and scenario forecasts was acknowledged. Obenour's Bayesian multiple mixed reactor model (Appendix 2, #16) and mixed Bayesian/deterministic modeling efforts (presentation at Forum – "A parsimonious mechanistic model for assessing multiple drivers of Gulf hypoxia") showed promise in incorporating a more mechanistic modeling approach into the Bayesian model to yield more robust areal extent estimates and uncertainties while retaining rapid turnaround for addressing management questions.

A number of deterministic models, representing a coupling of physically-based three-dimensional hydrodynamic models and biogeochemically-based water quality models, were presented. While these models represent a significant improvement over those reviewed by the SAB Report, there were a number of weaknesses identified. In particular, a number of the models did not explicitly include a sediment diagenesis/nutrient flux compartment or sub-model. This is surprising in that sediment diagenesis/nutrient flux models (Soetaert et al. 1996, DiToro 2001) have been used in a number of estuarine and coastal systems (Cerco and Cole 1993, Cerco 1995, Brady et al. 2013) for more than a decade. Those models that lack a deterministic sediment diagenesis/nutrient flux framework lack a predictive capability to determine changes in sediment oxygen demand (or sediment oxygen consumption) and nutrient flux in response to changes in nutrient loading (e.g. through management actions). It is also worth noting that in the two modeling presentations that included explicit sediment diagenesis compartments, the sediment diagenesis submodels may have been overly complicated with respect to the number of vertical layers needed to represent the sediment bed, and may be causing undue computation burden as compared to similar models with simpler vertical structure. However, the fact that a sediment diagenesis/sediment flux compartment has been included is an important step forward towards providing predictive or forecast capabilities to these deterministic frameworks.

Another limitation to be noted in most of the presentations is that, while most of the presenters provided calibration results comparing observed and computed chlorophyll and bottom water dissolved oxygen, they did not provide model versus data comparisons of primary production, community respiration, or sediment oxygen consumption (or sediment oxygen demand). However, following the meeting, Hetland et al. provided model results comparing primary production, respiration, and sediment oxygen consumption. These results were encouraging in that they reproduced some of the spatial features of primary production and respiration in the Gulf, although the model appeared to underestimate respiration by about a third. In general, the model of Hetland (Appendix 2, #1) over-predicted sediment oxygen consumption, particularly in the late summer months, but again the results are encouraging.

At this point, the Modeling Technical Review Panel, while encouraged by the results of the deterministic modeling efforts, felt that they were not quite ready to be used to provide information concerning necessary load reductions required to achieve the goal of reducing the areal extent of hypoxia in the northern Gulf of Mexico to 5,000 km^2 nor are they fully ready to be considered for use in an operational environment for scenario-based hypoxia forecasts. Additional calibration/validation against refined estimates of the spatial and temporal extent of hypoxia within the Gulf and against more process-based data sets (primary production, respiration, sediment oxygen demand, nutrient flux, etc.), and the presentation of model sensitivity to key model parameters are suggested before these models can be considered operational. Rather, it is concluded that the empirically-based models (Turner, Scavia et al., Forrest, and Obenour – after publication) are presently capable of informing living resource and water quality managers of nutrient reduction goals for the Gulf. Moving into the future, however, it is suggested that funding continue to refine the deterministic modeling efforts and that consideration be given to using information from an ensemble (multiple) modeling approach (empirical and deterministic models) to inform managers of required nutrient reduction goals, both in the short term and under longer climate change scenarios.

C.2 Modeling Approaches to Inform Additional Management Decisions

The specific issue addressed here is the ability of alternative modeling approaches to evaluate restoration management actions (e.g. Mississippi River diversions) or climate change. Deterministic modeling offers the only practical approach to informing the restoration management actions framed in this document. The empirical models are useful, especially in addressing questions of the gross system response to nutrient loads; however, they are not designed to address changes in timing of riverine inputs. The ability of models of reduced dimensionality to examine alteration in the location of river inputs is limited. Three-dimensional models with realistic forcing functions, appropriate spatial extent, and extensive application period are required. These models can eventually supply computations to ecological models, which may provide insight into the response of fish and other organisms to restoration management actions.

Specification of the future climate and framing of climate change scenarios are key issues in model application to address climate change. Empirical models may have some applicability to climate change scenarios; e.g. if climate change affects nutrient loads, then a model that relates hypoxia to loading can be useful. Empirical models may also address increasing temperature, to the extent that temperature is included in the empirical relationships. However, detailed, mechanistic models are necessary to address a number of climate-related factors that extend beyond the capability of empirical models; e.g. temperature and salinity effects on stratification and circulation, and their subsequent impacts on hypoxia.

C.3 Applications to Living Resource Modeling

Currently, the management target of reducing the size of the northern Gulf of Mexico hypoxic zone to 5,000 km^2 was established in the 2001 Action Plan as representative of the hypoxic zone size in the early- to mid-1970s, prior to the increase in TN loads in the 1970s and 1980s that stimulated a dramatic increase in hypoxia (supported by hindcasts, Scavia et al. 2004, Scavia and Donnelly 2007). Whether this target will result in vastly improved ecosystem functioning is difficult to predict. While the demographic rates, and hence, population dynamics of sessile organisms are affected directly by exposure to low dissolved oxygen (DO), the effects on mobile marine organisms are mostly indirect and can be difficult to detect. Reproductive biomarkers show that some mobile species (e.g. Atlantic croaker) are exposed to low DO, indicating that the assumption that mobile organisms always avoid hypoxia is an oversimplification (Thomas and Rahman 2010, Tan and Thomas 2011, Thomas and Rahman 2012). Indeed, trawl surveys in the Gulf of Mexico demonstrate that mobile organisms in both benthic and pelagic assemblages may preferentially utilize hypoxic edge habitats (Craig 2012) and that distance from the hypoxic edge is a significant predictor of species composition (Craig and Bosman 2013). The stability of the hypoxic edge, the spatial and temporal dynamics of hypoxia, and the ecophysiology of marine organisms all serve to modulate the energetic cost-benefit trade-off involved in residing in these habitats. Therefore, any model that purports to quantify not only hypoxic volume/area but also the attendant effects on living resources should almost certainly capture within-season spatial and temporal DO dynamics and not just interannual variability. Understanding within-season hypoxia dynamics in relation to the distribution and movements of mobile organisms is critical to both understanding low DO exposure, a major uncertainty in current models of upper trophic levels, and in understanding the indirect effects that result from altered spatial distributions. Relationships between hypoxic area, hypoxic edge effects, and the behavior and physiology of resident marine organisms are critical to developing empirically-based models of effects on living resources. Ongoing mechanistic modeling efforts that focus on (1) predicting the severity of hypoxia from underlying physical and biogeochemical processes and (2) hypoxia effects on the population and community dynamics of upper trophic levels have largely proceeded in parallel, and are not well-integrated. Integrating these two modeling approaches is challenging given the complexity of ecosystem modeling, the differing spatial and temporal scales on which organismal and water quality modeling is typically conducted, and the expertise needed to integrate these efforts. However, this integration is necessary to develop a better predictive understanding of how nutrient enrichment and associated hypoxia influence the capacity of the Gulf ecosystem to support upper trophic levels that are the primary source of economic value in the Gulf of Mexico.

D. Transitioning Hypoxia Models to Operations

D.1 Generalized Operational Infrastructure Requirements

Observations: Observations are required for model initialization, model forcing, model evaluation, and data assimilation. All data must contain the appropriate metadata. All data used to force the model must be made available (e.g. in the data tanks at the National Weather Service/National Centers for Environmental Prediction, NWS/NCEP), and must be placed on the implementation schedule well in advance of operational model implementation. A backup data strategy must be identified for each data type used in the model if the primary data stream is unavailable (e.g. climatology, model forecast, etc.).

Physical: These include physical observations of water levels, currents, temperature, and salinity for initialization, evaluation, and data assimilation in hydrodynamic circulation models in the Gulf of Mexico. These operational physical models will form the basis (gridded fields of the 3-dimensional circulation and stratification) for coupling to hypoxia models.

In addition, observations are required of the forcing parameters for the physical models that would include atmospheric wind, heat fluxes, moisture fluxes, river inputs of fresh water, and large-scale oceanic boundary conditions for the regional Gulf of Mexico domains (water levels, currents, temperature, and salinity).

The same suite of physical model observations is required for model evaluation and data assimilation. For data assimilation, the observational data must be available in real-time and accessible via operational data tanks where the operational physical models are run (e.g. at NWS/NCEP).

Hypoxia: Biochemical observations are required for initialization, evaluation, and data assimilation in hypoxia models too. These could include observations of nutrients, DO, respiration estimates, and sediment transports, as well as the physical observational data referenced above (i.e. water levels, currents, temperature, and salinity).

Computer: The ability to run on either a cluster or high performance computer, such as at an operational center like NWS/NCEP, or to run locally where regional expertise is available, is required. Operational computational considerations should include the necessity for access to real-time observations to initialize, drive, and evaluate the models (as well as for data assimilation into the models). Also, the computational capacity is necessary for ensemble modeling to obtain probabilistic solutions. Consideration should be given to the model run time and the number of cycles the model will be run each day; e.g. the National Ocean Service (NOS) is only given finite-duration time windows by NCEP within which to complete its model runs. If models run outside these time windows, the run will be terminated.

Personnel:

- 24x7 model operational coverage (e.g. at NCEP's National Computing Center, NCO - 1 person at 50%);
- 24x7 model and product coverage (e.g. at the Center for Operational Oceanographic Products & Services, CO-OPS, and the National Center for Coastal Ocean Science, NCCOS, - 1 person at 50%);
- local/regional personnel for dissemination of products - 1 person at 50%;
- research (e.g. academic) & development (e.g. Coast Survey Development Laboratory, CSDL, personnel to be available for trouble shooting and updating - 1 person at 50%).

NOS personnel need to be very responsive (less than 24 hours) to model failures that occur on the NCEP computers. When products are disseminated to users, NOS personnel must also be available to answer any questions and respond to user requests.

Total operational personnel requirements are, at a minimum, equal to 2 FTEs at 100%. This is probably a serious underestimate. As more ecological models are delivered to operations, more time must be allocated to address the operations and maintenance of these models, which will impact the development of new models or products.

D.2 Model Initialization and Implementation

For a hypoxia model developed in academia, for example, there is the necessity for developing the links for transition (e.g. by CSDL) to operations (e.g. CO-OPS and NCEP/NCO). These links (research to operations) need to be established early on in the process so that the research version of the forecast system can be developed knowing the constraints of the operational environment. These links include considerations of standardized infrastructure, inputs and outputs, formats, access to real-time observational data, access to other models (or model outputs) necessary to run a hypoxia model, standardized methods (including skill assessment of model results), and the products that will be developed and disseminated.

NOAA recognizes the significant modeling expertise in the oceanographic community and how it can be an asset in meeting NOAA mission requirements. Over the past several years, NOAA modeling efforts have greatly expanded with modern community-based models and presently, for example, NOS operates hydrodynamic model-based forecast systems in all five Great Lakes, the Port of New York and New Jersey, the Chesapeake, Delaware, San Francisco, and Tampa Bays, the St. Johns River, Galveston Bay, the northern Gulf of Mexico, and the Columbia River and Estuary. This expansion has put strains on the NOS modeling resource and has illuminated the gap in upgrading the existing legacy models.

To complement existing resources, NOS would like to be able, in the future, to ingest external model guidance outputted by the operational oceanographic community. To this end, NOS CO-OPS has developed a set of requirements that external operators must satisfy before NOS will ingest and display these data.

D.3 Interpretation and Dissemination of Model Outputs

Model forecasts (outputs) must be translated into model-based forecast guidance that can then be disseminated and used for making management decisions by a variety of different users. This requires interaction with the users early on to know what their needs are (how they will use the guidance to make their decisions) so that the guidance provided is intelligible and in a form that is useful to a variety of coastal management entities. For example, the requirements to run seasonal forecasts will be very different from those for daily/weekly forecasts, so it is imperative to understand how the model will perform under each of these scenarios early in the development process.

D.4 Options for Development of Ensemble Forecasts

Ensemble forecasting is a method to generate a representative sample of the possible future states of a dynamical system (e.g. Leith 1974). In general, multiple numerical predictions are conducted using slightly different forcing, initial, or boundary conditions to account for the two usual sources of uncertainty in forecast models: (1) the errors introduced by the use of imperfect initial, boundary, or forcing conditions, amplified by the chaotic nature of the dynamical system, which is often referred to as sensitive dependence on the initial, boundary, or forcing conditions, respectively; and (2) errors introduced because of imperfections in the model formulation and parameterizations. One approach to reduce the second source of errors is to apply many different forecast models to generate a forecast; the approach is termed multi-model ensemble forecasting, and has been shown to improve forecasts when compared to a single model-based approach. While the ensemble forecasting method has been widely adopted in weather and ocean circulation forecasting by operational prediction centers worldwide, including the NCEP and the European Centre for Medium-Range Weather Forecasts (ECMWF), its application in biogeochemical modeling is still in its infancy.

Roiha et al. (2010) reported an ensemble forecasting application on harmful algal blooms (HABs) in the Baltic Sea. Ensembles were produced by running a biogeochemical model several times and forcing it on every run with a different set of seasonal weather parameters. The ensembles were then analyzed by statistical methods, and the median, quartile, minimum, and maximum values were calculated for estimating the probable amounts of algae. To evaluate the forecast method, final results were compared against available and valid in-situ HAB data. The study showed that quantitative HAB forecasts are possible, but verifications of ensemble forecasting will require expanded observational networks. Similar ensemble forecasting exercises for hypoxia prediction using various hypoxia models developed for the northern Gulf should be encouraged.

It should be noted that physical and biogeochemical ocean dynamics are intermittent and highly variable, and involve interactions on multiple temporal and spatial scales. For efficient forecasting, the structures and parameters of models should evolve and respond dynamically to new data injected into the executing prediction system. The concept of adaptivity (e.g. Lermusiaux et al. 2004) should be considered within an interdisciplinary prediction system. Model-data misfits and data assimilation schemes should be used to provide feedback from measurements to applications and modify the runtime behavior of the prediction system. This line of research should be encouraged in parallel to the ensemble forecasting efforts.

D.5 Considerations for Operational Scenario versus Short-term Forecast Models

Most of the operational forecasts currently issued by NOS are for current conditions or for short-term warnings and alerts. Hypoxia is more scenario-based with longer time frames throughout. The use of hypoxia modeling is not usually for hourly or daily conditions, but for seasonal or annual projections. Goal-setting for nutrient reduction is the primary end use, and decision points may happen annually, or only once in several years, when nutrient targets are re-evaluated. This may necessitate a different approach than that traditionally used for short-term operations.

In hypoxia forecasting, there is not always a linear pathway from observations to model to forecast all within the NOAA umbrella. Some hypoxia forecasts may be based on a hybrid of NOAA and other agency forecasts. Others are strictly empirical or statistical without using a NOAA operational physical forecast. A forecast can go through several iterations, including feedback from users/decision makers along the way. Delivery to the end user is an iterative process, which can take a year or more of consultation. Outreach is also different for many hypoxia forecasts – these can be directed not only to targeted users but also to media outlets to raise public awareness.

The scenario aspect of hypoxia modeling requires archiving of many different runs of the models that portray different scenarios, as well as archives for different model runs under the same scenario to get statistics on the models. These models may be used in a decision process that can take several years, and then may not be revisited until several years later when targets are re-assessed. Long-term archiving is necessary, when the forecast models are not being run on a daily basis. This will be important to facilitating the Hypoxia Task Force adaptive management process; e.g. the models will not need to be re-created each time targets are re-assessed.

Verification and skill assessment for hypoxia forecasts may be years from now, not done between the generation and dissemination of a forecast. Hindcasts may be used as skill assessment mechanisms, but verification of a model may be annual - e.g. did the forecast predict the size of the hypoxic zone? If yes, then it may be appropriate to use the same process the following year; if no, then there may be a need to modify the model or approach. This long time lag between the forecast and the validation is quite different than traditional weather or hydrodynamic forecasts.

Finally, for many hypoxia models, multiple loops exist in generating different forecasts. One forecast may be used to drive another – for example, climate assessments may drive future hypoxia projections, which then drive living marine resource projections. Any framework that is set up to operationalize hypoxia forecasts must take these loops into account, in addition to the feedback loops with users.

E. Advancing Modeling Applications

E.1 Priority Needs

The SAB Report called for: (1) the continued use and development of a range of modeling approaches from the simple to the complex, (2) incorporation of nitrogen, phosphorus, and their interactions given the importance of P-limitation, (3) development of more comprehensive monitoring in coordination with model development, (4) development of simple mass balance models for organic carbon, dissolved oxygen, and nutrients, and (5) design of Gulf hypoxia models to be compatible with watershed models. Regarding items (1) – (3), it was clear from the 2013 Forum for Gulf of Mexico Hypoxia Research Coordination and Advancement that these activities have all been to a large degree accomplished since the SAB Report. A continually expanding range of hypoxia models of varying complexity have been developed for the Gulf (see above). Many of these models include both N and P cycling and their impacts on primary production, and recently funded projects by NOAA's Northern Gulf of Mexico Ecosystems and Hypoxia Assessment Program (NGOMEX) and external programs have provided additional data useful for model assessment, although we will address this further below. We discuss (4) in more detail in the next paragraph. Item (5) was not a focus of the 2013 Forum and will not be addressed here.

E.2 On the Utility of Mass Balance / Budget Models

The SAB Report called for an additional area of modeling research focused on development of seasonal material budgets and/or mass balance models that are essentially input-output accountings of materials such as O_2, C, or nutrients. This did not appear to be a major focus of current work presented at the 2013 Forum, so we echo the SAB's conclusion that "mass balance models should be used to provide a checklist of needed measurements for future NGOM hypoxia research/monitoring." We also suggest that these budgets can provide both valuable heuristic understanding of how the Gulf hypoxic zone functions as well as information useful to managers.

E.3 Needs for Advancing Model Development

The suite of Gulf hypoxia models is under continual development and there is certainly more to do with respect to items (1) – (2) above in the coming years. Particularly we embrace the SAB Report's recommendation that "… a diverse ensemble of models is needed, including both relatively simple and more complex ones. … management of Gulf hypoxia is best served by having multiple models with multiple outputs." We agree that use of multiple models developed in parallel provides the greatest opportunity for robust recommendations for management. Predictions on which the models agree provide managers with confidence when making decisions, while areas in which the models diverge provide a focal point for future research (both empirical and numerical) and monitoring.

Regarding model development, focus should continue to be placed on including multiple nutrients (at least N and P, and perhaps Si). There currently exists a wide variety of approaches for modeling deposition of carbon to the sediments and subsequent sediment oxygen consumption and nutrient recycling. Approaches include instant remineralization to specification of relatively constant rates of consumption to a variety of empirical and relatively simple mechanistic functions (e.g. Seitzinger and Giblin 1996, Van Cappellen and Wang 1996, Hetland and DiMarco 2008, Murrell and Lehrter 2011, Lehrter et al. 2012), and new efforts are underway to couple more detailed, often highly parameterized sediment flux models (Morse and Eldridge 2007, Soetaert et al. 2007). While this array of approaches is commendable, we note that no model appears to use the widely applied DiToro (2001) sediment flux model being used in Total Maximum Daily Load (TMDL) applications around the country. It also appears that only one sediment flux model includes production by microphytobenthos, which have been shown to be important in the northern Gulf.

There also seems to be a disconnect between the empirical regression models presented by Turner and Hetland (Appendix 2, #8 and #15, respectively). These models use different input parameters and have widely different r^2 values. It would be useful to attempt to rationalize results from these two efforts.

E.4 Needs for Advancing Model Skill and Predictability

The SAB Report found that "… model development, calibration, and verification are hampered by the relative paucity of data on the duration and extent of hypoxia and on rates of important biogeochemical and physical processes that regulate hypoxia." While this may continue to hold true to some degree, recent NOAA NGOMEX projects together with a variety of external efforts have clearly provided additional and highly valuable data for use in model assessment. Arguably the greatest need for advancing existing models, however, still has to do with the availability and use of data, particularly when moving the models towards operational status. Specifically, the SAB Report concluded that "… modeling efforts, ranging from the simple to complex, be conducted in parallel *wherein there is the opportunity for cross-testing of results* …." For this cross-testing to happen, and in order to move towards operational models, there is a need to ensure the availability of a consistent set of data across all modeling projects and to assess the same model outputs with a consistent set of data. This is true whether the data are being used for calibration (i.e. model tuning to fit the data) or validation/verification (i.e. evaluation against an independent dataset without tuning).

Currently different modeling groups appear to be using different types of data, different time periods, and different datasets to conduct calibration/validation. While this is acceptable for individual modeling efforts, it makes it difficult if not impossible to compare relative model skill as one moves towards operational capability. Some datasets currently used in model calibration/validation of key outputs are listed below. The Panel did not specifically ask for information on datasets being used to calibrate/validate predicted phytoplankton biomass and nutrient concentrations, but these are also key outputs to assess.

- Oxygen: annual LUMCON survey; biweekly to monthly LUMCON cruises (transects C to F); time series at buoy C6 (Rabalais); DiMarco ACROBAT surveys; SEAMAP cruises; EPA Gulf Ecology Division data
- Chlorophyll *a* (partial listing): annual LUMCON survey; biweekly to monthly LUMCON cruises (transects C to F); time series at buoy C6 (Rabalais); DiMarco ACROBAT surveys; SEAMAP cruises; EPA Gulf Ecology Division data; satellite-derived values
- Primary production: Lohrenz et al. (1999); Lehrter et al. (2009); Quigg et al. (2011); Sinclair (unpub, LUMCON)
- Water column respiration: Murrell and Lehrter (2011); Murrell et al. (2013); Roberts (unpub, LUMCON)
- Sediment respiration: Rowe et al. (2002); Murrell and Lehrter (2011); Roberts (unpub, LUMCON)
- Stratification (primary and secondary pycnocline): annual LUMCON survey; biweekly to monthly LUMCON cruises (transects C to F); time series at buoy C6 (Rabalais); DiMarco ACROBAT surveys

Given the diversity of datasets being used in model assessment and other issues discussed above, we make the following suggestions, particularly if the goal is to conduct cross-testing of model results as suggested by the SAB Report and/or move towards operational models:

- It is critical to derive consistent areal extent estimates of the hypoxic zone from the annual LUMCON survey. A workshop or other venue to compare interpolation methods would be a timely next step.
- While all models appear to use the annual LUMCON survey of hypoxic areal extent as a key assessment benchmark, this is a single snapshot in time and may not necessarily capture the full extent or severity in a given year, especially if hypoxia is tied to timing of flow events. We therefore suggest that additional oxygen datasets be used in assessment of all models, particularly time series of oxygen concentrations (e.g. biweekly to monthly LUMCON cruises, C6 buoy). It will be more difficult to address this issue with the statistical models that predict annual areal extent; in this case time series data may be useful in estimating uncertainty around the deterministic result.
- Calibration of and/or validation to states (oxygen, chl-a, nutrients) and key rates (primary production, water column, and sediment respiration) is critical to ensure that models are getting the right result for the right reason. Rates of denitrification would be another desirable calibration target although data may not be available. Regarding model physics, a key parameter to calibrate/validate is the strength of stratification, both in the primary and secondary pycnoclines.
- It would be highly advantageous to produce a single database with all available observations for use by all modeling groups.
- It would also be highly advantageous for the various modeling groups to agree upon a standard set of data drawn from the list above to be used in calibration/validation of all models. This seems especially critical before models are transitioned to operational mode.
- In that same vein, it would be advantageous to agree upon a standard use of data for calibration and/or validation. Some models appear to compare output to the observations without any tuning of parameters (i.e. validation) while others adjust parameters (objectively or subjectively) to maximize the fit to the data (i.e. calibration). This is another discrepancy that makes it hard to cross-test the models.
- For data management and quality control, we emphasize the need for standardized data sets(s) and adequate data access.

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Appendix 1. Gulf of Mexico Hypoxic Zone Modeling Technical Review Meeting Guidelines for Gulf Modelers

Developed by the Modeling Technical Review Panel:

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Introduction

The *Gulf of Mexico Hypoxic Zone Modeling Technical Review Meeting* has an overarching goal to provide perspectives to NOAA re. the next potential steps in hypoxia modeling in the Gulf in support of management efforts to mitigate the hypoxic zone. The Modeling Technical Review Panel will work with Gulf Modelers to assess the state of forecast models that can be applied to hypoxic zone dynamics in the northern Gulf of Mexico, and develop conclusions on current modeling approaches to most effectively meet the Hypoxia Task Force management directive to mitigate hypoxia.

The Panel, in collaboration with Gulf Modelers, is tasked with assessing modeling approaches for improving the predictive understanding of the quantitative relationship between nutrient loading and hypoxic zone size. We are looking for models to inform nutrient reduction targets to mitigate hypoxia, to monitor management progress toward achieving hypoxia mitigation through nutrient reduction, and to conduct hindcast simulations to understand past events. We are also looking for models to produce seasonal and synoptic scale forecasts, for the important outreach purpose of alerting the public and managers to the state of the hypoxia problem and the role of nutrients in causing the problem - but in future these types of forecasts could be used to inform fishing activities and fishery management strategies.

The Steering Committee for the *Modeling Technical Review Meeting* developed a *Terms of Reference* to provide a framework for the charge to the Modeling Technical Review Panel. Based on that framework, this *Guidelines for Gulf Modelers* is intended to guide the presentations of Gulf modelers to provide the information necessary to do a thorough assessment.

Overview of presentation and working session expectations:

1. Presentations: Gulf Modeler Presentation" Session (Day 2, 10:15-12:00 and 1:00-2:50)
    a. 15 min per model

b. Q&A will be held until later session (3:30-4:45 – see below)
c. ~10 slides: these should address the following topics but does not have to be constrained to one slide per topic:

    i. What **management questions** are addressed? See “Key Management Questions” below.

    ii. What key **assumptions** are made for the physical and biological components of the model? For physical models, assumptions include turbulence closure, surface fluxes, river flows, … For biological models assumptions may include N and P flows, biology, bottom interactions, light and nutrient interactive effects on phytoplankton growth…

    iii. **Inputs:** On what input information is the system dependent (e.g. river flow, nutrient loads, offshore boundary conditions, observations types, initial conditions, surface fluxes, biological conditions)? What data are available to support these inputs?

    iv. **Outputs**: What are the outputs or state variables of the physical and biogeochemical components in the model? What are not represented?

    v. What is the **scalability** of the model? This is important because one researcher’s implementation of a model may be constrained by available computer resources. So a domain may be small or of low resolution. How well does the model scale when going to a larger domain or finer resolution? For statistical models, what are the regression variables?

    vi. **How applied so far:** What historical re-analyses, hindcasts, or forecasts have been done relative to hypoxic zone size? What management outcomes have been achieved?

    vii. **Skill assessment:** Prior performance evaluations (references) for tides, wind-driven events, density-driven events, mesoscale events, and biological properties; What is the statistical significance of the skill that has been evaluated? Over what range of hypoxic events has prediction been demonstrated, and what is the skill over that range? If relevant, what is the skill of the ancillary variables, such as phytoplankton biomass, nutrients, etc.?

    viii. **Remaining needs:** Given the available resources, research systems are what they are. What existing capabilities (things the science community generally knows how to do) remain to be implemented in the research system? How are those remaining components expected to change the hypoxic forecast skill? What are the fundamental shortcomings in basic understanding of physics, biology, parameterizations, input data, etc. that remain to be addressed to enable skillful predictions?

ix. **Transition to operations:** What is the user cycle for operation? How much interaction is required to construct a forecast? What inputs must be constructed vs what is automatically pulled in from operational sites? What skill set would a user be required to have? Must the user have a complete understanding of model numerics and biology? What level of training would be required for a user to be able to spot a 'bad' forecast?

2. Working Sessions:

   a. Session 1: Day 2, 2:50 to 3:15 p.m.: Modeling Technical Review Panel Session: The Modeling Panel will be deliberating in a short closed session and developing questions in preparation for the Q&A session with the Gulf modelers at 3:30.

   b. Session 2: Day 2, 3:30 to 4:45 p.m.: Modeling Panel & Gulf Modelers: Q&A between Panel and Modelers to clarify talking points from slides, followed by group discussion on modeling vision.

Key Management Questions:

1. What is the quantitative relationship between the size of the hypoxic zone (areal extent and volume) and nutrient loadings from the Mississippi/Atchafalaya Watershed? Is there a critical period or season during which nutrient loading has a relatively greater impact on the size and persistence of the hypoxic zone than other seasons or periods within the year?
2. What is the influence of freshwater flows, as it affects stratification, on the size of the hypoxic zone (areal extent and volume)?
3. What nutrient reduction levels are required to meet the goal to reduce the size of the hypoxic zone to a 5-year running average of 5,000 km^2?
4. What is the minimal amount of sustained nutrient reduction required to obtain a reduction in the size of the hypoxic zone that can be quantified and statistically verified? How long will reduced nutrient inputs need to be sustained before this reduction in size is realized?
5. If interim nutrient reduction targets are developed, what will be their resultant reduction in hypoxic zone size and over what time frame?
6. In addition to nutrients and river flow, what is the influence of ocean and weather conditions on the measured size of the hypoxic zone?
7. What is the effect of coastal restoration activities, such as large-scale river diversions, on the spatial and temporal extent of the hypoxic zone?
8. What is the long-term effect of climate change on the spatial and temporal extent of the hypoxic zone?

9. What are the linkages between the predicted size of the hypoxic zone and the resultant impacts to living resources?

Considerations for next steps in modeling approach:

1. ***Forecasts* –** Current goals of the Gulf Hypoxia Task Force emphasize the need to reduce Mississippi/Atchafalaya nutrients (N, P) fluxes into the Gulf of Mexico by 45% in order to meet the goal of reducing the size of the hypoxic zone to 5,000 km^2. The ability to refine these reduction targets and evaluate them in the context of additional ecosystem drivers is required to advance restoration efforts within the Gulf of Mexico and Mississippi River watershed. Characteristics of the modeling approach may include:

    a. quantitative assessment of nitrogen flux, especially nitrate, as well as phosphorus, and the relative role of their loading (amount, timing) on the formation and maintenance of the hypoxic zone;

    b. capabilities for discriminating the relative roles of physical characteristics such as river discharge, winds, episodic tropical storms, and currents;

    c. ability to inform the development of interim nutrient reduction targets and goals;

    d. capabilities for assessing the influences of restoration management actions (e.g. Mississippi River diversions) or climate change on the timing and spatial characteristics of the hypoxic zone;

    e. seasonal to synoptic-scale forecasting capabilities.

2. ***Model Requirements* –** Consideration of model requirements is a significant factor in balancing the ability of a model to address management needs with operational requirements. Key questions include:.

    a. What are the observational requirements for the initiation and validation of scenario forecasting models? What key processes need to be included in model? Which observations are required to objectively assess model skill?

    b. What are the infrastructure requirements for each modeling platform? Infrastructure needs include, but are not limited to:

        i. Computing needs and time;

        ii. Personnel time for initiation, validation, and system administration;

        iii. Output analysis and dissemination.

c. Does the model output have quantifiable uncertainties, and if so, what are those uncertainties?

d. What additional research is required prior to the transition of forecast models to operations?

e. Are there priority research needs required to improve model performance after they are transferred to operations?

Appendix 2. Gulf of Mexico Hypoxia Model Inventory

1. Hetland ROMS	
Model Developer/Institution:	Rob Hetland /Texas A&M
Contact/Institution:	Rob Hetland /Texas A&M
Water Body:	Gulf of Mexico
Model Name:	Regional Ocean Modeling System (ROMS)
Model Type:	3D dynamically coupled
Model Domain:	The Texas-Louisiana continental shelf from the TX/LA boarder to about the MS/AL boarder
a) Inshore distance:	0 km
b) Nearest offshore distance:	0 km
c) Farthest offshore distance:	200 km
d) Alongshore distance:	700 km
Year of Model Development/Application:	1990 to 2011
Model Grid:	
a) Grid type:	Curvilinear
b) Grid resolution (min, avg, max):	940 m / 21 km / ~ 2 km in the areas of interest.
Purpose of Model:	Examine physical controls on the formation and destrucion of seasonal hypoxia on the TX-LA shelf.
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, dissolved oxygen
Dissolved/Particulate Parameters Available in Model Code:	Detritus and noncohesive sediment, River discharge and atmospheric and solar parameteres (wind speed and direction, air temp, cloudiness, etc,)
Data Used for Model Forcing:	Nutrient load, Sediment load
Data Assimilated:	None
Data Needs:	For forcing, data described above (already obtained by us). For validation, any data Is useful.
Simulation Period:	20 yr
Validation with Data?:	Hydrography, moored currents and tracers, satellite derived Chla, some sediment accumulation rates.
Used for Forecasting?:	In 2009.
What kind of review has model undergone?:	Published in the Journal of Marine Research.
Reference:	Hetland, R. D. and S . F. DiMarco, (2007) How does the character of oxygen demand control the structure of hypoxia on the Texas-Louisiana continental shelf? J. Mar. Sys.,doi:10.1016/j.jmarsys.2007.03.002.
	Laurent, A., Fennel, K., Hu, J., Hetland, R. (2012) Simulating the effects of phosphorus limitation in the Mississippi and Atchafalaya river plumes, Biogeosciences 9, 4707-4723, doi:10.5194/bg-9-4707-2012;
	Hetland, R. D. and S. F. DiMarco (2012) Skill assessment of a hydrodynamic model of circulation over the Texas- Louisiana continental shelf, Ocean Modelling, 43-44, 64-76, doi:10.1016/j.ocemod.2011.11.009

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	Xu, K., C. K. Harris, R. D. Hetland, J. M. Kaihatu (2011) Dispersal of Mississippi and Atchafalaya Sediment on the Texas-Louisiana Shelf: Model Estimates for the Year 1993, Cont. Shelf Res., 31(15), 1558-1575, doi:10.1016/j.csr.2011.05.008
Is GIS shapefile of modeled area available?:	No
Comments:	Developed as part of the NOAA funded Mechanisms Controlling Hypoxia program.
Note: If modeler or contact name is being submitted	Robert Hetland, 3146 TAMU, College Station, TX 77843-3146, 979-458-0096, hetland@tamu.edu
for the first time, please enter contact information here	
(e.g. address, phone number, e-mail address).	
2. Fennel ROMS	
Model Developer/Institution:	Katja Fennel /Dalhousie University and Rob Hetland /TAMU
Contact/Institution:	Katja Fennel /Dalhousie University
Water Body:	Gulf of Mexico
Model Name:	Regional Ocean Modeling System (ROMS)
Model Type:	3D dynamically coupled
Model Domain:	The Texas-Louisiana continental shelf from the TX/LA boarder to about the MS/AL boarder
a) Inshore distance:	0 km
b) Nearest offshore distance:	0 km
c) Farthest offshore distance:	200 km
d) Alongshore distance:	700 km
Year of Model Development/Application:	1990 to 2009
Model Grid:	
a) Grid type:	Curvilinear
b) Grid resolution (min, avg, max):	940 m / 21 km / ~ 2 km in the areas of interest.
Purpose of Model:	Examine physical and biogeochemical mechanisms for the formation and destrucion of seasonal hypoxia on the TX-LA shelf.
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, nutrients (N+P), phytoplankton, zooplankton, small- and large-particle detrital pools, dissolved oxygen
Dissolved/Particulate Parameters Available in Model Code:	same as previous field
Data Used for Model Forcing:	Nutrient load, freshwater discharge
Data Assimilated:	None
Data Needs:	For forcing, data described above. For validation, many different data types are needed and useful (see below).
Simulation Period:	20 yr

Validation with Data?:	Hydrography, temperature, salinity, Chla, Primary Productivity, inorganic nutrients, dissolved oxygen, respiration rates in water column and sediments, exchange fluxes of nutrients and oxygen between sediments and water column, etc.
Used for Forecasting?:	Not yet.
What kind of review has model undergone?:	Two papers published in Biogeosciences (Fennel et al. 2011, Laurent et al. 2012). Two papers are accepted in Journal of Geophysical Research (Fennel et al. 2013, Mattern at al. 2013).
Reference:	Fennel, K., Hetland, R., Feng, Y., DiMarco, S. (2011) A coupled physical-biological model of the Northern Gulf of Mexico shelf: Model description, validation and analysis of phytoplankton variability, Biogeosciences 8, 1881-1899, doi:10.5194/bg-8-1881-2011;
	Laurent, A., Fennel, K., Hu, J., Hetland, R. (2012) Simulating the effects of phosphorus limitation in the Mississippi and Atchafalaya river plumes, Biogeosciences 9, 4707-4723, doi:10.5194/bg-9-4707-2012;
	Fennel, K., Hu, J., Laurent, A., Marta-Almeida, M., Hetland, R., Sensitivity of hypoxia predictions for the Northern Gulf of Mexico to sediment oxygen consumption and model nesting, Journal of Geophysical Research-Oceans (in press);
	Mattern, P., Fennel, K., Dowd, M.: Uncertainty in hypoxia predictions for the TX-LA shelf, Journal of Geophysical Research-Oceans (accepted pending minor revisions)
Is GIS shapefile of modeled area available?:	No
Comments:	Developed as part of the NOAA funded Mechanisms Controlling Hypoxia program with additional support from US IOOS Coastal and Ocean Modeling Testbed (COMT).
Note: If modeler or contact name is being submitted	Katja Fennel, Dalhousie University, PO Box 15000, Halifax NS, B3H 4R2, CANADA, +1-902-494-4562, katja.fennel@dal.ca
for the first time, please enter contact information here	
3. Justic´NGOMEX Box Model	
Model Developer/Institution:	Dubravko Justic´, Louisiana State University
Contact/Institution:	Dubravko Justic´, Louisiana State University
Water Body:	Northern Gulf of Mexico
Model Name:	Gulf Hypoxia Model
Model Type:	Box model
Model Domain:	Station C6 located in the core of the Gulf hypoxic zone (-90.2768; 28.5144)
a) Inshore distance:	
b) Nearest offshore distance:	
c) Farthest offshore distance:	
d) Alongshore distance:	
Year of Model Development/Application:	1996, updated 1997-2005
Model Grid:	
a) Grid type:	
b) Grid resolution (min, avg,	

max):	
Purpose of Model:	Predict changes in surface and bottom DO at a single station
Dissolved/Particulate Parameters Simulated:	surface and bottom DO, total organic carbon
Dissolved/Particulate Parameters Available in Model Code:	same as previous field
Data Used for Model Forcing:	Mississippi River discharge and nitrate flux, ambient surface and bottom temperatures, surface winds
Data Assimilated:	
Data Needs:	Same as for model forcing + surface and bottom DO for validation
Simulation Period:	45 years
Validation with Data?:	Yes
Used for Forecasting?:	Yes
What kind of review has model undergone?:	Published in peer review journals (see below).
Reference:	Justic´, D., Rabalais, N. N., Turner, R. E. 1996. Effects of climate change on hypoxia in coastal waters: a doubled CO2 scenario for the northern Gulf of Mexico. Limnology and Oceanography 41: 992-1003.
	Justic´, D., Rabalais, N. N., Turner, R. E. 1997. Impacts of climate change on net productivity of coastal waters: Implications for carbon budgets and hypoxia. Climate Research 8: 225-237.
	Justic´, D., N. N. Rabalais and R. E. Turner. 2002. Modeling the impacts of decadal changes in riverine nutrient fluxes on coastal eutrophication near the Mississippi River delta. Ecological Modelling 152: 33-46.
	Justic´, D., Rabalais, N. N., Turner, R. E. 2003. Simulated responses of the Gulf of Mexico hypoxia to variations in climate and anthropogenic nutrient loading. Journal of Marine Systems 42: 115-126.
	Justic´, D., N. N. Rabalais and R. E. Turner. 2005. Coupling between climate variability and coastal eutrophication: Evidence and outlook for the northern Gulf of Mexico. Journal of Sea Research 54: 25-35.
Is GIS shapefile of modeled area available?:	No
Note: If modeler or contact name is being submitted	Dubravko Justic´, 2221 Energy, Coast and Environment Bldg., Louisiana State University, Baton Rouge, Louisiana 70803; Tel: 225-578-6394; Email: djusti1@lsu.edu
for the first time, please enter contact information here	
(e.g. address, phone number, e-mail address).	
4. Justic´ et al. Barataria Bay Model	
Model Developer/Institution:	Dubravko Justic´, Anindita Das, Masamichi Inoue, Dongho Park and Asif Hoda, Louisiana State University
Contact/Institution:	Dubravko Justic´, Louisiana State University
Water Body:	Northern Gulf of Mexico
Model Name:	Barataria Bay Model
Model Type:	2-D coupled hydrology-hydrodynamics-water quality model
Model Domain:	Barataria Bay Estuary/ coastal northern Gulf of Mexico
a) Inshore distance:	0 km

b) Nearest offshore distance:	0 km
c) Farthest offshore distance:	60 km
d) Alongshore distance:	100 km
Year of Model Development/Application:	2008 - present
Model Grid:	
a) Grid type:	Structured grid
b) Grid resolution (min, avg, max):	100 m; 1.3 million elements
Purpose of Model:	Investihgate the importance of estuarine carbon sources for GOM hypoxia development
Dissolved/Particulate Parameters Simulated:	Water levels, salinity, fluxes of N, TOC, DOC, POC and Chl a
Dissolved/Particulate Parameters Available in Model Code:	Salinity, N, Chl a
Data Used for Model Forcing:	Wind speed and direction, air temp, precipitation, river diversion discharges
Data Assimilated:	None
Data Needs:	Data used for model forcing + calibration/validation data (water levels, salinity, N, Chl a)
Simulation Period:	1999-2002
Validation with Data?:	Extensive
Used for Forecasting?:	No
What kind of review has model undergone?:	Published in peer review journals (see below).
Reference:	Inoue, M., Park, D., Justic´, D., Wiseman, W. J., Jr. 2008. A High-Resolution Integrated Hydrology-Hydrodynamic Model of the Barataria Basin System. Environmental Modelling and Software 23: 1122-1132.
	Das, A., Justic´, D., Swenson, E., Turner, R. E., Inoue, M., Park., D. 2011. Coastal land loss and hypoxia: The 'outwelling' hypothesis revisited. Environmental Research Letters 6: 025001 (9 pp); doi:10.1088/1748-9326/6/2025001.
	Das, A., Justic´, D., Inoue, M., Hoda, A., Huang, H., Park., D. 2012. Impact of Mississippi River diversions on salinity gradients in a deltaic Louisiana estuary: Ecological and management implications. Estuarine, Coastal and Shelf Science 111: 17-26.
Is GIS shapefile of modeled area available?:	No
Comments:	Model development was funded in part by NOAA-CSCOR and NGI
Note: If modeler or contact name is being submitted	Dubravko Justic´, 2221 Energy, Coast and Environment Bldg., Louisiana State University, Baton Rouge, LA 70803; Tel: 225-578-6394; Email: djusti1@lsu.edu
for the first time, please enter contact information here	
(e.g. address, phone number, e-mail address).	
5. Quinones-Rivera et al. Daul-Budget Hypoxia Model	

Model Developer/Institution:	Zoraida Quinones-Rivera, Bjoern Wissel, Brian Fry and Dubravko Justic´, Louisiana State University
Contact/Institution:	Dubravko Justic´, Louisiana State University
Water Body:	Northern Gulf of Mexico
Model Name:	Daul-Budget Hypoxia Model
Model Type:	Box model
Model Domain:	Originally developed for station C6 located in the core of the Gulf hypoxic zone (-90.2768; 28.5144); subsequently applied to the Louisiana-Texas shelf
a) Inshore distance:	
b) Nearest offshore distance:	
c) Farthest offshore distance:	
d) Alongshore distance:	
Year of Model Development/Application:	2007
Model Grid:	
a) Grid type:	
b) Grid resolution (min, avg, max):	
Purpose of Model:	Quantify oxygen sources and sinks based on stable oxygen isotopes and conventional DO budgets
Dissolved/Particulate Parameters Simulated:	GPP, NPP, P/R, water column and benthic respiration
Dissolved/Particulate Parameters Available in Model Code:	Same as previous field
Data Used for Model Forcing:	Temperature, Mississippi River discharge, air-sea oxygen flux
Data Assimilated:	None
Data Needs:	temperature, salinity, sigma-t, wind speed, pH, POC, PON, DO,δ18O, Chl a
Simulation Period:	2001-2003
Validation with Data?:	Yes
Used for Forecasting?:	No
What kind of review has model undergone?:	Published in peer review journals (see below).
Reference:	Quiñones-Rivera, Z. J., Wissel, B., Justic´, D., Fry. B. 2007. Partitioning oxygen sources and sinks in a stratified, eutrophic coastal ecosystem using stable oxygen isotopes. Marine Ecology Progress Series 342:69-83.
	Quiñones-Rivera, Z.J., Wissel, B., Justic´, D. 2009. Development of productivity models for the northern Gulf of Mexico based on oxygen concentration and stable oxygen isotopes. Estuaries and Coasts 32: 436-446.
	Quiñones-Rivera, Z. J., Wissel, N. N. Rabalais, Justic´, D. 2010. Effects of biological and physical factors on seasonal oxygen dynamics in a stratified, eutrophic coastal ecosystem. Limnology and Oceanography 55: 289-304.
Is GIS shapefile of modeled area available?:	No
Comments:	Model development was funded in part by NOAA-CSCOR

Note: If modeler or contact name is being submitted	Dubravko Justic´, 2221 Energy, Coast and Environment Bldg., Louisiana State University, Baton Rouge, Louisiana 70803; Tel: 225-578-6394; Email: djusti1@lsu.edu
for the first time, please enter contact information here	
(e.g. address, phone number, e-mail address).	
6. Justic´and Wang FVCOM-LATEX	
Model Developer/Institution:	Dubravko Justic´and Lixia Wang, Louisiana State University
Contact/Institution:	Dubravko Justic´, Louisiana State University
Water Body:	Northern Gulf of Mexico
Model Name:	FVCOM-LATEX
Model Type:	3-D coupled hydrodynamics-water quality model
Model Domain:	Louisiana-Texas continental shelf, from Mobile, AL, to Galveston, TX
a) Inshore distance:	0 km
b) Nearest offshore distance:	60 km
c) Farthest offshore distance:	240 km
d) Alongshore distance:	680 km
Year of Model Development/Application:	2002 - present
Model Grid:	
a) Grid type:	Unstructured grid
b) Grid resolution (min, avg, max):	550m - 10km, ~ 1.5 km across the hypoxic zone
Purpose of Model:	Examine physical and biological controls on hypoxia on the TX-LA shelf
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, dissolved oxygen, NH4, NO3+NO2, PO4, ON, OP, BCOD
Dissolved/Particulate Parameters Available in Model Code:	Same as previous field
Data Used for Model Forcing:	River discharge and atmospheric parameteres (wind speed and direction, air temp, cloudiness, etc)
Data Assimilated:	None
Data Needs:	Data used for model forcing + calibration/validation data (ambient water temperature, salinity, currents,dissolved oxygen, nutrients, Chlorophyll a, MODIS imagery)
Simulation Period:	2002 was used for calibration/validation; 2003-present in works
Validation with Data?:	Extensive
Used for Forecasting?:	No
What kind of review has model undergone?:	Published in the Continental Shelf Research
Reference:	Wang L. and D. Justic´ (2009) A modeling study of the physical processes affecting the development of seasonal hypoxia over the inner Louisiana-Texas shelf: Circulation and stratification. Continental Shelf Research (29):1464-1476

	Justic´, D. and L. Wang (2009) Application of unstructured-grid Finite Volume Coastal Ocean Model (FVCOM) to the Gulf of Mexico Hypoxia Zone. Proceeding of the Oceans 2009 MTS/IEEEE BILOXI conference & Exhibition (Biloxi, Mississippi, October 26-29, 2009MTS-IEEE)
Is GIS shapefile of modeled area available?:	No
Comments:	Model development was funded in part by NOAA-CSCOR and NGI
Note: If modeler or contact name is being submitted	Dubravko Justic´, 2221 Energy, Coast and Environment Bldg., Louisiana State University, Baton Rouge, LA 70803; Tel: 225-578-6394; Email: djusti1@lsu.edu
for the first time, please enter contact information here	
(e.g. address, phone number, e-mail address).	
7. Scavia Streeter-Phelps Bayesian Scenario and Forecasts Model	
Model Developer/Institution:	Donald Scavia/University of Michigan
Contact/Institution:	Donald Scavia/University of Michigan or Mary Anne Evans/USGS-GLSC
Water Body:	Northern Gulf of Mexico coastal waters
Model Name:	Streeter-Phelps Bayesian Scenarios and Forecasts Model
Model Type:	1D long-shore dissolved oxygen model
Model Domain:	Coastal region west of the Mississippi River mouth
a) Inshore distance:	10km
b) Nearest offshore distance:	60km
c) Farthest offshore distance:	60km
d) Alongshore distance:	600km
Year of Model Development/Application:	2003/2004,2006-2013
Model Grid:	
a) Grid type:	Linear
b) Grid resolution (min, avg, max):	Continuous
Purpose of Model:	Assess impact of nutrient loads on hypoxia
Dissolved/Particulate Parameters Simulated:	Organic Matter, Dissolved Oxygen
Parameters Available in Model Code:	Organic Matter, Dissolved Oxygen
Data Used for Model Forcing:	Nutrient Loads from MS basin
Data Assimilated:	Parameter estimation and forecasting done through Bayesian data assimilation mode
Data Needs:	nutrient loads, historic hypoxic area (for calibration)
Simulation Period:	57 years (1955-2012)
Validation with Data?:	Yes
Used for Forecasting?:	Yes
What kind of review has model undergone?:	Published in Limnol. Oceangr.,Estuaries, Env. Sci. Technol., and Environ. Res. Letters. journals
Reference:	Scavia, D., Rabalais, N.N., Turner, R.E., Justic´, D., Wiseman Jr., W.J. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. Limnol. Oceanogr. 48:951–956.

	Donner, S.D. and Scavia, D. 2007. How climate controls the flux of nitrogen by the Mississippi River and the development of hypoxia in the Gulf of Mexico. Limnol. Oceanogr. 52:856-861.
	Scavia, D., Donnelly, K.A. 2007. Reassessing hypoxia forecasts for the Gulf of Mexico. Environ. Sci. Technol. 41,8111–8117.
	Liu Y, Evans M A and Scavia D 2010 Gulf of Mexico hypoxia: exploring increasing sensitivity to nitrogen loads Environ. Sci. Technol. 44 5836–41.
	Evans. M.A. and D. Scavia. 2011. Forecasting hypoxia in the Chesapeake Bay and Gulf of Mexico: Model accuracy, precision, and sensitivity to ecosystem change. Environ. Res. Lett. 6: 015001
Development Stage:	Used for scenario analysis and annual forecasts since 2002
Boundary Conditions:	Assumes oxygen saturation at model origin
Model Time-Step:	Steady state, model updated annually
Management Application:	Annual forecasts of hypoxic area and scenarios to estimate nutrient load limits for desired hypoxic areas
Comments:	Model has also been used successfully for the Chesapeake Bay (Estuaries and Coasts 29(4) 674-684; Estuaries and Coasts 33:629–639)
	Results from the model applications have been used to guide nutrient reduction goals for the hypoxia task force
	Both the oringinal applications and hindcasts with respect to N and P loads were used in the EPA SAB reassessment and 2008 Action Plan
	Scenarios on P load impacts were used in NRC study of sediment loads issues in the MO River
	NRC 2010: Missouri River Planning: Recognizing and Incorporating Sediment Management
Note: If modeler or contact name is being submitted for the first time, please enter contact information	Donald Scavia, University of Michigan, 440 Church St., Ann Arbor, MI 48103; 734-615-4860; scavia@umich.edu;
	Mary Anne Evans, U S Geological Survey - Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI 48105; 734-214-7221, maevans@usgs.gov
8. Turner Statistical Model	
Model Developer/Institution: Contact/Institution:	R.E.Turner / Louisiana State University
Water Body:	nothern Gulf of Mexico
Model Name:	none
Model Type:	statistical
Model Domain:	
a) Inshore distance:	shoreline
b) Nearest offshore distance:	200 m isobath
c) Farthest offshore distance:	100 km
d) Alongshore distance:	300 km
Year of Model Development/Application:	
Model Grid:	
a) Grid type:	NA
b) Grid resolution (min, avg,	NA

max):	
Purpose of Model:	predict the size of the summertime hypoxic zone
Dissolved/Particulate Parameters Simulated:	oxygen
Dissolved/Particulate Parameters Available in Model	
Code: *Data Used for Model Forcing:*	nitrate nitrate;
Data Assimilated:	na
Data Needs:	monthly flux of ntrate in the Mississippi River watershed to the GOM
Simulation Period:	1 prediction for July/August; mulitple forecasts under development
Validation with Data?:	yes
Used for Forecasting?:	yes
What kind of review has model undergone?:	
Reference:	Turner, R. E., N. N. Rabalais, and D. Justic´. 2006. Predicting summer hypoxia in the Northern Gulf of Mexico: Riverine N, P and Si loading. Marine Pollution Bulletin 52: 139-148.
	Turner, R. E., N. N. Rabalais, and D. Justic´. 2008. Gulf of Mexico hypoxia: Alternate states and a legacy. Environmental Science and Technology 42: 2323-2327.
	Turner, R.E., N.N. Rabalais and D. Justic´. 2012. Predicting summer hypoxia in the northern Gulf of Mexico: Redux. Marine Pollution Bulletin 64: 318-323.
Is GIS shapefile of modeled area available?:	na
Comments:	prediction is done 1-3 months before the hypoxia cruises. Accuracy was 99% in 2006; model is updated annually, to include other variabiles, which have not proved useful over 10 years;
Note: If modeler or contact name is being	RETurner Coastal Ecology Institute, SCE, Nicholsen Extension, LSU, Baton Rouge, LA 70803; euturne@lsu.edu; 225 578 6454
submitted for the first time, please enter contact	
information here (e.g. address, phone number, e-mail address).	
9. Patchen NOS NGOM (formerly PDOM-A)	
Model Developer/Institution:	Richard Patchen, NOAA/NOS/CSDL (formerly Dynalysis of Princeton)
Contact/Institution:	Richard Patchen, NOAA/NOS/CSDL
Water Body:	Gulf of Mexico
Model Name:	NOS Gulf of Mexico (NGOM) - formerly PDOM-A
Model Type:	Princeton Ocean Model (POM)
Model Domain:	Entire Gulf of Mexico, including Northern Caribbean and Straits of Florida
a) Inshore distance:	
b) Nearest offshore distance:	
c) Farthest offshore distance:	
d) Alongshore distance:	

Year of Model Development/Application:	Continued Development and Application from 1992 to present
Model Grid:	
a) Grid type:	Stuctured Grid (BF Curvilinear)
b) Grid resolution (min, avg, max):	2-6 Km
Purpose of Model:	Nowcast/Forecast System to support NOS and others needs for the physical processes in the Gulf
Dissolved/Particulate Parameters Simulated:	Salinity
Dissolved/Particulate Parameters Available in Code:	Salinity
Data Used for Model Forcing:	COAMPS Winds & Atm Pres; USGS &USACE Rivers; and MODAS T&S
Data Assimilated:	T&S derived for SSTs and Altimetry
Data Needs:	See above
Simulation Period:	Each day an Update/Nowcast, then a 48 hr Forecast; once a week a two month Long range Forecast
Validation with Data?:	Extensive comparisons
Used for Forecasting?:	Yes
What kind of review has model undergone?:	NOS, MMS and Navy Scientific reviews
Reference:	Blaha, J.P., G. H. Born, N.L. Guinasso, Jr., H. J. Herring, G. A. Jacobs, F. J. Kelly, R. R. Leben, R. D. Martin, Jr., G. L. Mellor, P. P. Niiler, M. R. Parke, R. Patchen, K. Schaudt, N. W. Scheffner, D. K. Shum, C. Ohlmann, W. Sturges, III, G. L. Weatherly, D. Webb, and H. J. White. 2000. Gulf of Mexico Ocean Monitoring System. Oceanography , 13, 2, 10-17.
Is GIS shapefile of modeled area available?:	NO
Comments:	http://nauticalcharts.noaa.gov/csdl/op/dgom.m.html
Note: If modeler or contact name is being	Richard Patchen NOAA/NOS/Coast Survey Development Lab SSMC3, Room 7826 1315 East West Hwy Silver; Spring MD 20910; 301-713-2650 x118; rich.patchen@noaa.gov
submitted for the first time, please enter contact	
information here (e.g. address, phone number, e-mail address).	
10. Wei and Xu FVCOM	
Model Developer/Institution:	Eugene Wei and Jiangtao Xu at NOAA/NOS/CO-OPS
Model Developer/Institution:	NOAA/NOS/OCS/CSDL
Contact/Institution:	Eugene Wei and Jiangtao Xu at NOAA/NOS/OCS/CSDL
Water Body:	Northern Gulf of Mexico (from Choctawhatchee Bay, AL to Texas)
Model Name:	Northern Gulf of Mexico Operational Forecast System (NGOFS)
Model Type:	FVCOM
Model Domain:	
a) Inshore distance:	0m

b) Nearest offshore distance:	70km
c) Farthest offshore distance:	200km
d) Alongshore distance:	1200km
Year of Model Development/Application:	undergoing
Model Grid:	
a) Grid type:	unstructured triangular grid
b) Grid resolution (min, avg, max):	200m-10km
Purpose of Model:	Component of NOS' backbone of circulation models in US waters. Nowcast and forecast are provided for water levels, currents, salinity and temperature. These nowcast and forecast support safe and efficient navigation, with emerging ecological forecast capabilities.
Dissolved/Particulate Parameters Simulated:	temperature, salinity, DIN, phytoplankton, chlorophyll, zooplanton, detritus , oxygen
Dissolved/Particulate Parameters Available in Code:	temperature, salinity, DIN, phytoplankton, chlorophyll, zooplanton, detritus , oxygen
Data Used for Model Forcing:	NAM surface wind, atmospheric pressure and heat fluxes; Open-ocean boundary conditions specified from either NGOM or NCOM for elevation, transport, salinity, and temperature; USGS river inflow and nutrient loads; climatology at the open-ocean boundary for biology
Data Assimilated:	None in FVCOM; both NGOM and NCOM assimilate satellite data
Data Needs:	gaps in data for model validation
Simulation Period:	2008-2009; Nov. 2010 to Jan. 2011; other time periods are possible
Validation with Data?:	water levels, currents, salinity, temperature, oxygen, DIN, phytoplankton
Used for Forecasting?:	Operational forecast for water level, currents, salintity and temperature in March 2012
What kind of review has model undergone?:	physical component of the model will be objectively evaluated using NOS established skill matrics before going operational
Reference:	Chen C, R. H. Liu, and R. Beardsley, 2003. An Unstructured Grid, Finite-Volume, Three-Dimensional Primitive Equations Ocean Model: Application to Coastal Ocean and Estuaries. J. Atmos Oceanic technol., 20, 159-186.
	Zhang, A., K.W. Hess and F. Aikman III. 2010. “User-based Skill Assessment Techniques for Operational Hydrodynamic Forecast Systems.” Journal of Operational Oceanography, Volume 3, Number 2, August 2010 , pp. 11-24(14).
Is GIS shapefile of modeled area available?:	Yes
Coupling with other models?:	NGOM/NCOM for open ocean boundary
Development Stage:	modeling implementation and vetting
Model Time-Step:	External mode: 12 second; internal mode: 3 seconds
Note: If modeler or contact name is being	1315 East West Highway, Silver Spring, MD 20910, 301-713-2809 eugene.wei@noaa.gov, jiangtao.xu@noaa.gov, and aijun.zhang@noaa.gov

submitted for the first time, please enter contact information	
here (e.g. address, phone number, e- mail address).	
11. Ko and Lehrter EPACOM_GEM	
Model Developer/Institution:	Dong S. Ko/Naval Research Laboratory; John Lehrter/EPA- ORD
Contact/Institution:	ko@nrlssc.navy.mil; lehrter.john@epa.gov
Water Body:	Louisiana Coastal Water
Model Name:	EPACOM_GEM
Model Type:	Fully 3D hydrodynamic biogeochemical hypoxia model
Model Domain:	From coast to deep water and from TX/LA boarder to MS/AL boarder
a) Inshore distance:	
b) Nearest offshore distance:	
c) Farthest offshore distance:	~ 300 km
d) Alongshore distance:	~ 600 km
Year of Model Development/Application:	2007 - 2011
Model Grid:	
a) Grid type:	Structured lat-lon grid
b) Grid resolution (min, avg, max):	~2 km
Purpose of Model:	Fully 3D simulation of physical and biogeochemcial processes including dissolved oxygen
Dissolved/Particulate Parameters Simulated:	Temperature, salinity, NO3, NH4, PO4, DIC, six groups of phytoplanktons, zooplankton, six types of OMs and DO
Dissolved/Particulate Parameters Available in Code:	All above
Data Used for Model Forcing:	Synoptic 3D circulation including tides, river flow, solar radiation, wind speed and seasonal river nutrient load
Data Assimilated:	Circulation model assimilates satellite altimeter data and MCSST
Data Needs:	All data are collected for the model simulations but need better initial conditions. All data that can be used for validation is useful. For running the model: same as Data Used for Model Forcing. We also need credible lateral boundary condition data for each bio-geo_chemistry species. Additional CDOM data for running the model as well as validation. Need obs data at more horizontal locations and time-periods.
Simulation Period:	2003 - 2009
Validation with Data?:	EPA in-situ observation
Used for Forecasting?:	Not yet
What kind of review has model undergone?:	Original water column-sediment model published (Eldridge and Roelke, 2010)
Reference:	Ko, D.S., P.J. Martin, C.D. Rowley, and R.H. Preller, A real-time coastal ocean prediction experiment for MREA04, J. Marine Systems, 69, 17-28, doi:10.1016/j.jmarsys.2007.02.022, 2008. (for circulation model).

	Eldridge, P.M. and D.L. Roelke, D.L., Origins and Scales of Hypoxia on the Louisiana Shelf: Importance of Seasonal Plankton Dynamics and River Nutrients and Discharge, Ecol. Model., 221, 1028-1042, 2010.
Is GIS shapefile of modeled area available?:	No
Coupling with other models?:	Coupled to the Louisiana Coastal circulation model
Development Stage:	in development
Boundary Conditions:	Use regional IASNFS prediction
Model Time-Step:	300 seconds
Management Application:	After 3-D version of model has been validated, the model results will be used by EPA to help guide their efforts to reduce N and P coming into the Gulf.
Note: If modeler or contact name is being	Dong S. Ko/ NRL Code 7320/ Stennis Space Center, MS 39529/ ko@nrlssc.navy.mil ;
submitted for the first time, please enter contact	John Lehrter, EPA Gulf Ecology Division, Gulf Breeze, FL 32570, 850-934-9255, lehrter.john@epa.gov
information here (e.g. address, phone number, e-mail address).	
12. EPA ORD GoMDOM	
Model Developer/Institution:	U.S. EPA, Office of Research and Development, National Health and Evironmental Effects Research Laboratory -- (Mid-Continent Ecology Division (MED) and Gulf Ecology Division (GED)). *Collaborators include the U.S. Navy Research Laboratory, U.S. EPA Environmental Modeling and Visualization Laboratory, and the U.S. EPA*
Contact/Institution:	Russell G. Kreis, Jr. (MED) and John C. Lehrter (GED)
Water Body:	Gulf of Mexico/Louisiana coastal shelf
Model Name:	GoMDOM (Gulf of Mexico Dissolved Oxygen Model)
Model Type:	3D mechanistic water quality model (based on LM3 and CE-QUAL-ICM)
Model Domain:	
a) Inshore distance:	0 km
b) Nearest offshore distance:	~ 20 km
c) Farthest offshore distance:	~ 180 km
d) Alongshore distance:	~ 450 km
Year of Model Development/Application:	2008 - present
Model Grid:	
a) Grid type:	structured lat-lon grid
b) Grid resolution (min, avg, max):	~ 6 km (potential for 2km grid)
Purpose of Model:	Will be used to evaluate the relationship between nutrient loads and area of hypoxia
Dissolved/Particulate Parameters Simulated:	dissolved oxygen, carbon, nutrients, phytoplankton, zooplankton,salinity and tracer
Dissolved/Particulate Parameters Available in Code:	dissolved oxygen, carbon, nutrients, phytoplankton, zooplankton, salinity and tracer

Data Used for Model Forcing:	nutrients, carbon, and dissolved oxygen loads; wind speed, solar radiation
Data Assimilated:	none
Data Needs:	loads and field data for nutrients, dissolved oxygen, phytoplankton, zooplankton and carbon
Simulation Period:	one year per simulation, will simulate 2003-2007
Validation with Data?:	Yes
Used for Forecasting?:	The model will be used for forecasting
What kind of review has model undergone?:	Oral presentation at Aquatic Sciences Meeting, 2013, a manuscript in preparation. GoMDOM is based on LM3 which has been reviewed (underwent a formal EPA expert panel review and in literature).
Reference:	GoMDOM reference: Development, Calibration, and Sensitivity Analyses of a High-Resolution Dissolved Oxygen Mass Balance Model for the Northern Gulf of Mexico (Timothy J. Feist, Wilson Melendez, James J. Pauer, Phillip A. DePetro, Amy M. Anstead, John C. Lehrter, Russell G. Kreis, Jr. Oral Presentation at ASLO (2013) Aquatic Sciences Meeting, New Orleans, LA
	LM3 references:
	Pauer, J.J., A.M. Anstead, W. Melendez, R. Rossmann , K.W. Taunt, and R.G. Kreis, Jr. 2008. The Lake Michigan Eutrophication Model, LM3-Eutro: Model Development and Calibration. Water Environ Res., 80(9): 853-861.
	Melendez, W., M. Settles, J. J. Pauer, and K. R. Rygwelski. 2009. LM3: A High-Resolution Lake Michigan Mass Balance Water Quality Model. U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Mid-Continent Ecology Division, Large Lakes Research Station, Grosse Ile, Michigan. EPA/600/R-09/020, 329 pp.
	Pauer, J.J., A.M. Anstead, W. Melendez, K.W. Taunt and R.G. Kreis Jr. 2011. Revisiting the Great Lakes Water Quality Agreement phosphorus targets and predicting the trophic status of Lake Michigan. J. Great Lakes Res. 37:26–32
	Lake Michigan Mass Balance Study - PCB Modeling Report. EPA Report EPA-600/R-04/167 December 2006; on http://www.epa.gov/med/grosseile_site/LMMBP/pcb-report.html Part 2: LM3-Eutro
Is GIS shapefile of modeled area available?:	Yes
Coupling with other models?:	Uses hydrodynamic output from the NRL EPACOM model and atmospheric loads from CMAQ
Development Stage:	calibration/corroboration
Boundary Conditions:	from field data
Model Time-Step:	5 minutes
Management Application:	Estimate the nutrient loading necessary to reduce the five-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 square kilometers
Comments:	
Note: If modeler or contact name is being	kreis.russell@epa.gov and lehrter.john@epa.gov
submitted for the first time,	

please enter contact	
information here (e.g. address, phone number, e-mail address).	
13. Ko MsLaTex Ocean Nowcast/Forecast System	
Model Developer/Institution:	Dong S. Ko/Naval Research Laboratory
Contact/Institution:	ko@nrlssc.navy.mil
Water Body:	NW Gulf of Mexico (TX/LA/MS) Coastal Water
Model Name:	MsLaTex Ocean Nowcast/Forecast System
Model Type:	Coastal circulation
Model Domain:	
a) Inshore distance:	
b) Nearest offshore distance:	
c) Farthest offshore distance:	~ 300 km
d) Alongshore distance:	~ 700 km
Year of Model Development/Application:	
Model Grid:	
a) Grid type:	Structured lat-lon grid
b) Grid resolution (min, avg, max):	~ 2 km
Purpose of Model:	Full 3D ocean prediction
Dissolved/Particulate Parameters Simulated:	
Dissolved/Particulate Parameters Available in Model Code:	
Data Used for Model Forcing:	Wind, tides, river flow, solar radiation and heat fluxes
Data Assimilated:	Yes
Data Needs:	Altimeter ssh and satellite sst
Simulation Period:	Started from 2002 up-to-date
Validation with Data?:	Yes
Used for Forecasting?:	Yes
What kind of review has model undergone?:	
Reference:	D'Sa, E., M. Korobkin, and D.S. Ko, 2011: Effects of Hurricane Ike on the Louisiana-Texas coast from satellite and model data, Remote Sensing Lett., 2, 11-19, doi: 10.1080/ 01431161.2010.489057.
Is GIS shapefile of modeled area available?:	
Coupling with other models?:	Coupled to the NRL Intra-Americas Sea Nowcast/Forecast System (IASNFS)
Development Stage:	In real-time operation at NRL
Boundary Conditions:	From IASNFS
Model Time-Step:	120 seconds
Management Application:	
Comments:	http://www7320.nrlssc.navy.mil/IASNFS_WWW/LSUNFS_WWW/

Note: If modeler or contact name is being submitted for the first time, please enter contact information here (e.g. address, phone number, e-mail address).	Dong S. Ko/ NRL Code 7320/ Stennis Space Center, MS 39529/ ko@nrlssc.navy.mil
14. Ko Regional Ocean Prediction System	
Model Developer/Institution:	Dong S. Ko/Naval Research Laboratory
Contact/Institution:	ko@nrlssc.navy.mil
Water Body:	Gulf of Mexico and Caribbean Sea
Model Name:	Intra-Americas Sea Nowcast/Forecast System (IASNFS)
Model Type:	Regional ocean prediction system
Model Domain:	
a) Inshore distance:	
b) Nearest offshore distance:	
c) Farthest offshore distance:	~ 2500 km
d) Alongshore distance:	~ 4000 km
Year of Model Development/Application:	
Model Grid:	
a) Grid type:	Structured lat-lon grid
b) Grid resolution (min, avg, max):	~ 6 km
Purpose of Model:	Full 3D ocean prediction
Dissolved/Particulate Parameters Simulated:	
Dissolved/Particulate Parameters Available in Model Code:	
Data Used for Model Forcing:	Wind, river flow, solar radiation and heat fluxes
Data Assimilated:	Yes
Data Needs:	Altimeter ssh and satellite sst
Simulation Period:	Started from 2002 up-to-date
Validation with Data?:	Yes
Used for Forecasting?:	Yes
What kind of review has model undergone?:	
Reference:	Ko, D.S., R.H. Preller, and P.J. Martin, 2003: An experimental real-time Intra-Americas Sea Ocean Nowcast/Forecast System for coastal prediction, Proceedings, AMS 5th Conference on Coastal Atmospheric and Oceanic Prediction and Processes, 97-100. Plus more than 10 papers.
Is GIS shapefile of modeled area available?:	
Coupling with other models?:	Coupled to the NRL Global NCOM
Development Stage:	In real-time operation at NRL
Boundary Conditions:	From NRL Global NCOM
Model Time-Step:	360 seconds

Management Application:	
Comments:	http://www7320.nrlssc.navy.mil/IASNFS_WWW/
Note: If modeler or contact name is being submitted for the first time, please enter contact information here (e.g. address, phone number, e-mail address).	Dong S. Ko/ NRL Code 7320/ Stennis Space Center, MS 39529/ ko@nrlssc.navy.mil
15. Forrest Multivariable Regression	
Model Developer/Institution:	David Forrest, VIMS
Contact/Institution:	Robert Hetland, TAMU
Water Body:	Northern Gulf of Mexico
Model Name:	Multivariable regression
Model Type:	Multivariable regression
Model Domain:	Northern Gulf of Mexico
a) Inshore distance:	n/a
b) Nearest offshore distance:	n/a
c) Farthest offshore distance:	n/a
d) Alongshore distance:	n/a
Year of Model Development/Application:	2011
Model Grid:	n/a
a) Grid type:	n/a
b) Grid resolution (min, avg, max):	n/a
Purpose of Model:	Prediction of hypoxic area based on a variety of environmental factors, including nutrient load and summertime winds
Dissolved/Particulate Parameters Simulated:	Nitrogen load, Various wind parameters, various secular time terms, River Discharge, Nitrogen concentration, SST anomaly.
Parameters Available in Model Code:	Nitrogen load, Various wind parameters, various secular time terms, River Discharge, Nitrogen concentration, SST anomaly.
Data Used for Model Forcing:	Nitrogen load, Various wind parameters, various secular time terms, River Discharge, Nitrogen concentration, SST anomaly.
Data Assimilated:	Nitrogen load, Various wind parameters, various secular time terms, River Discharge, Nitrogen concentration, SST anomaly.
Data Needs:	None
Simulation Period:	1985 - present
Validation with Data?:	Yes.
Used for Forecasting?:	Yes.
What kind of review has model undergone?:	Peer reviewed publication.
Reference:	Forrest, D. R, R. D. Hetland, S. F. DiMarco (2011), Multivariate statistical regression models of the areal ex- tent of hypoxia over the Texas-Louisiana continental shelf, Env. Res. Letters., 6, 10pp, doi:10.1088/1748- 9326/6/4/045002
Development Stage:	Mature.
Boundary Conditions:	None
Model Time-Step:	n/a

Management Application:	Used for scenario predictions of changing nitrogen load, examined time of system response to management actions to reduce nitrogen.
Comments:	
Note: If modeler or contact name is being submitted	
for the first time, please enter contact information	
16. Obenour Bayesian Multiple Mixed Reactor Model	
Model Developer/Institution:	Daniel Obenour/ University of Michigan
Contact/Institution:	Daniel Obenour/ University of Michigan
Water Body:	Louisiana-Texas Shelf, Gulf of Mexico
Model Name:	Bayesian multiple mixed reactor model
Model Type:	Bayesian multiple mixed reactor model
Model Domain:	
a) Inshore distance:	0 km
b) Nearest offshore distance:	approximately 0 km (3 m minimum depth)
c) Farthest offshore distance:	170 km
d) Alongshore distance:	500 km
Year of Model Development/Application:	currently 1985-2011
Model Grid:	
a) Grid type:	4 reactors (east and west shelf, upper and lower layer)
b) Grid resolution (min, avg, max):	
Purpose of Model:	explore and predict temporal variability of hypoxia on east and west shelf
Dissolved/Particulate Parameters Simulated:	dissolved oxygen
Dissolved/Particulate Parameters Available in Model Code:	vertical fluxes of oxygen demand
Data Used for Model Forcing:	Flow, load, wind velocity
Data Assimilated:	SOD from other studies, mean dissolved oxygen from geostatistical model (with uncertainties)
Data Needs:	better rate information for reaeration and organic matter decomposition
Simulation Period:	1985-2011
Validation with Data?:	Cross validation planned
Used for Forecasting?:	Not yet
What kind of review has model undergone?:	None yet, manuscript in preparation
Reference:	*None yet.*
Is GIS shapefile of modeled area available?:	Yes
Comments:	

Note: If modeler or contact name is being submitted	Daniel Obenour, U. Michigan, obenour@umich.edu
for the first time, please enter contact information here	
(e.g. address, phone number, e-mail address).	
17. NRL AMSEAS RNCOM	
Model Developer/Institution:	Naval Research Laboratory / multiple scientists
Contact/Institution:	frank.bub@navy.mil / Naval Oceanographic Office
Water Body:	Gulf of Mexico and Caribbean Sea
Model Name:	American Seas Regional Navy Coastal Ocean Model (AMSEAS RNCOM)
Model Type:	Regional ocean prediction system
Model Domain:	5.0N to 32.0N, 98.0W to 55.0W
a) Inshore distance:	
b) Nearest offshore distance:	
c) Farthest offshore distance:	
d) Alongshore distance:	
Year of Model Development/Application:	2010-present
Model Grid:	
a) Grid type:	Structured lat-lon grid
b) Grid resolution (min, avg, max):	~3 km
Purpose of Model:	Full 3D, real-time ocean prediction
Dissolved/Particulate Parameters Simulated:	N/A
Dissolved/Particulate Parameters Available in Model Code:	
Data Used for Model Forcing:	COAMPS wind, river flow, solar radiation and heat fluxes
Data Assimilated:	SSH and satellite SST, temperature and salinity from buoys, floats, gliders, ships
Data Needs:	Same
Simulation Period:	MAY 2010 to present
Validation with Data?:	Yes
Used for Forecasting?:	Yes
What kind of review has model undergone?:	Standard Navy verification & validation process
Reference:	
Is GIS shapefile of modeled area available?:	No, data served as NetCDF
Comments:	Operational Navy data served via NOAA sites:
	Real Time: http://ftp.opc.ncep.noaa.gov/grids/operational/NCOM/regional/
	Archive: http://ecowatch.ncddc.noaa.gov/amseas/
	or http://www.northerngulfinstitute.org/edac/NCOM_AmSeas.php

Note: If modeler or contact name is being submitted	Frank L. Bub, Ocean Modeling Technical Lead (NP3M), Naval Oceanographic Office, 1002 Balch Blvd.,
for the first time, please enter contact information here	Stennis Space Center, MS 39529, 228-688-4758, frank.bub@navy.mil
(e.g. address, phone number, e-mail address).	