TSA - a two scale approximation for wind-generated ocean surface waves

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LONG-TERM GOALS

(a) To provide an accurate, efficient, computational model (two-scale approximation, TSA) for the 4-wave interactions, in operational wave forecast models, suitable for global, basin and coastal scale applications, and able to transition seamlessly from deep to shallow water.
(b) Fully test TSA with respect to exact codes for the full Boltzmann integral (FBI), for duration-limited, fetch-limited wave growth, turning winds, swell-windsea, interactions, etc.
(c) Numerically investigate and clarify the basis for TSA, its limitations, errors, enhancements, improvements, self-similarity properties, and spectral flux properties.
(d) Implement TSA in a variety of modern operational wave forecast models, e.g. WAVEWATCH^{TM} (WW3) and SWAN for extensive tests on important, realistic wave conditions.
(e) Derive, adapt and implement new formulations for source terms, S_{in} and S_{ds}, from recent literature and the NOPP partnership, with TSA, in modern wave models, for tests, including veering or accelerating winds, sea and swell interactions, and real storm cases.

OBJECTIVES

For this reporting period:
1) Complete implementation of TSA in operational WAVEWATCHIII (WW3), with comparisons in terms of simulations with Full Boltzmann Integral (FBI) for wave-wave interactions.
2) Conduct standard tests including duration- and fetch-limited wave growth tests for TSA and FBI, using standard S_{in} and S_{ds}, as coded in WW3, e.g. WAMcycle3, Tolman/ Chalicov physics etc.
3) Begin the implementation of TSA in a simple reliable modern operational wave model, for example as developed in USACE, suitable for tests and development of new formulations for wind input and dissipation parameterizations.

APPROACH

We need to do additional basic tests and comparisons. Thus, we need to exercise the TSA code in duration- and fetch-limited cases, and begin to address the issues related to S_{in} and S_{ds}.
1) **TSA put into WW3.** Complete the implementation of TSA in WW3. This is essential in order to later perform a large set of tests (accelerating or veering winds, and combined sea/swell with varying separations of peak frequencies, etc., storm-generated waves; SWAMP, 1985) so that we can test TSA's behavior, with standard source terms S_{in} and S_{ds} available in WW3, and new formulations determined in this project, and compare results with implementations of TSA in a reliable modern relatively simple operational model, e.g. in USACE wave model (see below).

This activity is done by Perrie (BIO), Toulany (BIO), and Resio (UNF).

2) **TSA and duration- and fetch-limited growth.** TSA will be tested against the FBI code and observed data (e.g. JONSWAP, etc.) for duration-limited and fetch-limited wave growth properties. For these tests, the model set-up would assume standard operational formulations for S_{in} and S_{ds}, for example as implemented in WW3, until new formulations for S_{in} and S_{ds} are available in the NOPP project. This test provides numerical estimates for TSA's abilities, providing guidance to understand TSA limitations, and areas where improvements need to be made. This activity is done by Perrie (BIO), Toulany (BIO), and Resio (UNF).
3) **Numerical downshifting for TSA.** Initial indications from Perrie and Resio (2009) are that TSA downshifting is similar to that of FBI, because TSA compares well to FBI in the forward face region of the spectrum. Further tests are needed. Duration-limited tests reveal TSA downscaling properties. Are accepted self-similar laws of spectral peak downshift evident for TSA in both swell and wind-wave cases? It is important that TSA give an accurate spectral downshift for wind-driven waves and swell, because this property is a key to determining spectral development and spectral energy growth relations in time. This activity is done by Perrie (BIO), Toulany (BIO), and Resio (UNF).
4) **Implementation of TSA in modern simple models.** We will put TSA in a reliable modern relatively simple operational (USACE) wave model. These types of models are much easier to work with than WW3, because of its operational parallelized architecture, but they are comparable in standard comparison tests. This implementation allows TSA to be tested thoroughly against a large set of important, realistic conditions (accelerating or veering winds, and combined sea/swell with varying separations of peak frequencies, etc.). This activity is done by Resio (UNF), Long (USACE), and Perrie (BIO).
5) **New S_{in} and S_{ds} parameterizations.** Preliminary development of new wind input and dissipation formulations, S_{in} and S_{ds}, will involve numerical simulations and tests, including USACE data. The approach will consider irst principles, starting from Miles (1957) but develop applicable codes for actual random sea, in conjunction with recent theoretical results and observational data, for wind –waves and swell. Tests include comparisons with S_{in} and S_{ds}. This work is done by Resio (UNF), Perrie (BIO), and Long (USACE).

WORK COMPLETED

The project is moving ahead on schedule.

1) **TSA put into WW3.** This required innovative re-programming of TSA, in order to fit the architecture of WW3. However, now that this was completed, the same approach can be repeated from other models such as SWAN and WAM, having the similar wave model structure. This work activity has involved construction of the diagonal term for nonlinear wave-wave interactions (WAMDIG, 1988) needed for the implicit integration used by WW3.
2) **TSA and duration- and fetch-limited growth.** TSA tested well compared to FBI and DIA codes for nonlinear wave-wave interactions, in terms of simple duration-limited and fetch-limited growth curves, for cases of simple 1-point wave models, as well-as square-box SWAMP-type oceans, with orthogonal constant wind fields. These simulations assume the WW3 default formulations for S_{in} and S_{ds}, which are the Tolman / Chalikov physics. Results compared well with observed data (e.g. JONSWAP, etc.) for duration-limited and fetch-limited wave growth.
3) **Numerical downshifting for TSA.** In simple cases, with constant winds, whether 1-point oceans, or square-box oceans with constant orthogonal winds blowing straight to the coast, results from TSA in WW3 are good. Initial results for more complicated results were less good, for example for

turning winds, or the case of a cyclone moving across the ocean. To obtain reasonable results we had to generalize TSA, to allow the initial "broad-scale term" to be applied more than one time, in order to handle double peaks in frequency spectra, and to let TSA downshift, appropriately. Once these changes were made TSA results were found to compare well to FBI, and to observations.

4) **Implementation of TSA in modern simple models.** To ensure that TSA is computationally efficient it must be re-formulated so that much of the computation occurs prior to the main time-stepping loops of any wave model code. A preliminary version of this formulation has been coded and is presently being checked and tested. This is meant to be the basis for development of numerically efficient operational versions of TSA for implementation in forecast waver models.

5) **New S_{in} and S_{ds} parameterizations.** Preliminary development of new wind input and dissipation formulations, S_{in} and S_{ds}, has also been completed. Ongoing tests are underway, comparing model simulations and characteristics with baseline results and characteristics for well-known formulations, such as WAMcycle3, Tolman/Chalikov physics, etc.

RESULTS

The meaningful technical results achieved in this fiscal year are:

a) In *Resio et al.* (2011) we examine nonlinear fluxes of energy and momentum through wave spectra via an exact integration of the Full Boltzmann Integral. Conclusions are:

i. The bimodal structure observed in studies of the directional distributions of wind-wave spectra (Wang and Hwang, 2001; Long and Resio, 2007; Toffoli *et al.*, 2010) is relatively consistent with the $\cos^{2n}$ angular distributions, at least in a bulk sense, as derived in earlier field studies.

ii. Spectra with a bimodal distribution of energy consistent with recent observations give relatively constant fluxes of both energy and momentum through the equilibrium range which suggests that the role of nonlinear interactions is quite critical to the directional evolution of wave spectral.

iii. Nonlinear momentum fluxes from the spectral peak region through the equilibrium range, from a numerical solution to the Boltzmann integral, agree well with the expected momentum balance.

b) We implemented TSA into WW3 and completed a number of tests for fetch- and duration-limited wave growth. Results are acceptable and compare well with observed data, and runs, using the exact FBI code in WW3. The real challenge has been turing winds, such as generated by a moving cyclone or hurricane, and the generalization of WW3 to accommodate spectral evolution in turning wind cases. This challenge was met be generalizing the manner in which the broad scale of TSA was defined, so that in complicated rapidly changing wave spectra cases, a second broad scale could be defined, in order to handle double peaks, and to let TSA downshift appropriately.

IMPACT/APPLICATIONS

This project is concerned with TSA. The rationale for this project is that nonlinear 4-wave interactions, represented by FBI (Full Boltzmann Integral) have been shown to be central to wave forecast models since Hasselmann (1962) and Zakharov and Filonenko (1966), and accurate numerical formulations have been demonstrated, by Resio and Perrie (2008), and Resio *et al.* (2001). However, these FBI formulations are too slow for operational wave forecasting. The discrete interaction approximation, or DIA (WAMDIG, 1988) is the basis for operational wave models, such as WAM, and it has substantial deviations from FBI in selected parts of the spectrum. Thus, TSA offers a new approach to replace

DIA, outperforming DIA in accuracy, with potentially fast run times for DIA. Therefore TSA is a candidate for implementation in operational wave models.

RELATED PROJECTS

A related project is funded by the Canadian Panel on Energy Research and Development entitled "Waves and Winds in Extreme Storms". Its focus is development of a) new wave model physics, b) improved wind and waves estimates from better atmosphere-ocean coupling, c) improved models for wave-current interactions, d) development of a versatile prototype wave forecast system, e) estimates of biases in wind and wave climatologies. This project is ending on 31 March 2012.

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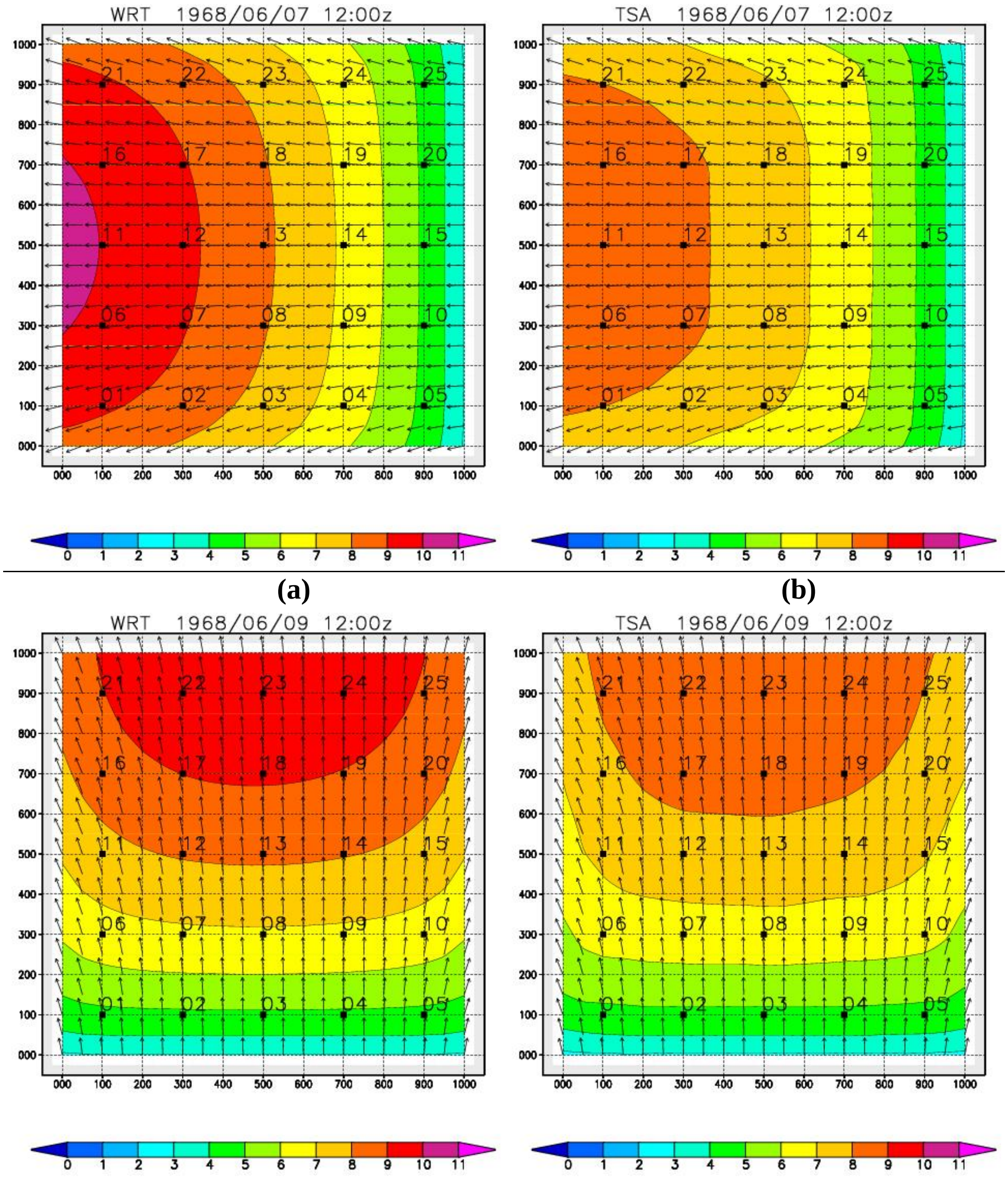

Figure 1. Significant wave height distribution for turning winds: (a) FBI (b) Tsa in WW3, after 36 hr, and (c) FBI (d) TSA in WW3, after reaching saturation, after winds turn by 90^o.