

A Regional Modeling Study of the South China Sea with High Resolution Hydrostatic and Nonhydrostatic Nested Models of the Luzon Strait

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LONG-TERM GOALS

The goal of this work is to better understand the generation, propagation, modal transformations and *interaction of multiple* NLIWs (Nonlinear Internal Waves) on the continental slope and shelf using a nonhydrostatic model embedded in nested hydrostatic models with *realistic forcing* and *bathymetry*. An additional goal is to explore the generation of NLIWs in the Luzon Strait. Accuracy will be assessed by hindcasting and forecasting the temperature, salinity and velocity fields for the SCS (South China Sea) and Luzon Strait experiments of this DRI and for the ASIAEX experiment.

This work will provide the understanding needed to build an operational system to predict the timing, location and intensity of NLIWs as required for tactical planning.

OBJECTIVES

- To identify the mechanisms responsible for the generation of NLIWs in the Luzon Strait using high resolution nonhydrostatic and hydrostatic numerical models with realistic ocean topography and surface forcing and using open boundary conditions provided by the large scale ocean model.
- To provide an understanding of the scales and processes involved in the propagation, modal transformation and interaction of NLIWs on the continental shelf and slope of the South China Sea based on the large scale ocean model simulation with data assimilation and realistic surface forcing.

The global NCOM model will be used to conduct forecasts with data assimilation and a realistic forcing. The output of these forecasts will be used to provide a general description of the circulation for the South China Sea field work and will be used as the initial and boundary conditions for the high resolution Luzon Strait models to study generation mechanisms for and the impact of the Kuroshio on the NLIWs.

High resolution hydrostatic and nonhydrostatic models of the Luzon Strait will be setup with realistic ocean topography, surface forcing and open boundary conditions from the large scale model. Simulations will be conducted varying the topographic and forcing functions to investigate the generation mechanism of the NLIWs. We will investigate scales and aspect ratios that must be resolved to correctly simulate the generation of NLIWs in the Luzon Straits.

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APPROACH

We have used the nonhydrostatic model (NRL-MIT) embedded in a system of multiply nested hydrostatic Navy Coastal Ocean Model (NCOM) models. The forcing consists of surface fluxes from the Coupled Ocean Atmosphere Prediction System (COAMPS) and the Navy Operational Global Atmospheric prediction System (NOGAPS) operational nowcast/forecast system and open boundary conditions from the global NCOM forecasts. The basic bathymetry is the NRL DBDB2 (2 minute) bathymetry which has been enhanced and improved with several additional bathymetry databases. The first tasks were to hindcast the Luzon Strait. Several simulations were done varying the topography in the Luzon Strait and the forcing to understand the mechanisms responsible for generating NLIWs and to determine the generation sites. Then we proceed to the significantly more difficult problem of internal waves which are generated remotely and propagate a significant distance before interacting with the continental slope and shelf and with locally generated NLIWs. An example of this problem is the trans-basin internal waves (IW) that are generated in the Luzon Strait and propagate across the SCS to the Dongsha plateau and the ASIAEX area. In both cases we start by hindcasting existing data sets and then proceed to forecasting (and hindcasting) future experiments.

WORK COMPLETED

We have conducted two dimensional simulations and three dimensional hindcasts of regions in the Luzon Strait and around Dongsha Island (Figure 1) at a variety of resolutions from relatively coarse (2km) to moderately high (100m) resolution.

The domain for the 2D simulations in the Luzon Strait is (20.6N, 121.5E – 122.5E). This domain was chosen because it is thought to be one of the primary generation sites for trans-basin IWs and because the domain contains the site of the WISE/VAN mooring, L1. This provides the opportunity for comparison between the model results and the mooring data.

The simulations in the Luzon Strait used climatological values from Generalized Digital Environmental Model (GDEM V3.0) for initial conditions and to establish the amplitude of the forcing at the open boundaries. The open boundary forcing consisted of idealized diurnal (K1) and semidiurnal (M2) tides. The hindcasts around Dongsha Island used data from the Luzon Strait 1/64th degree NCNFS Nowcast Forecast System (LZS64NFS) for initial conditions and open boundary values. This data was provided by Dong Shan Ko. The domain for the 3D hindcasts around Dongsha Island is (20.5N to 21.5N, 116.5E to 118.5E).

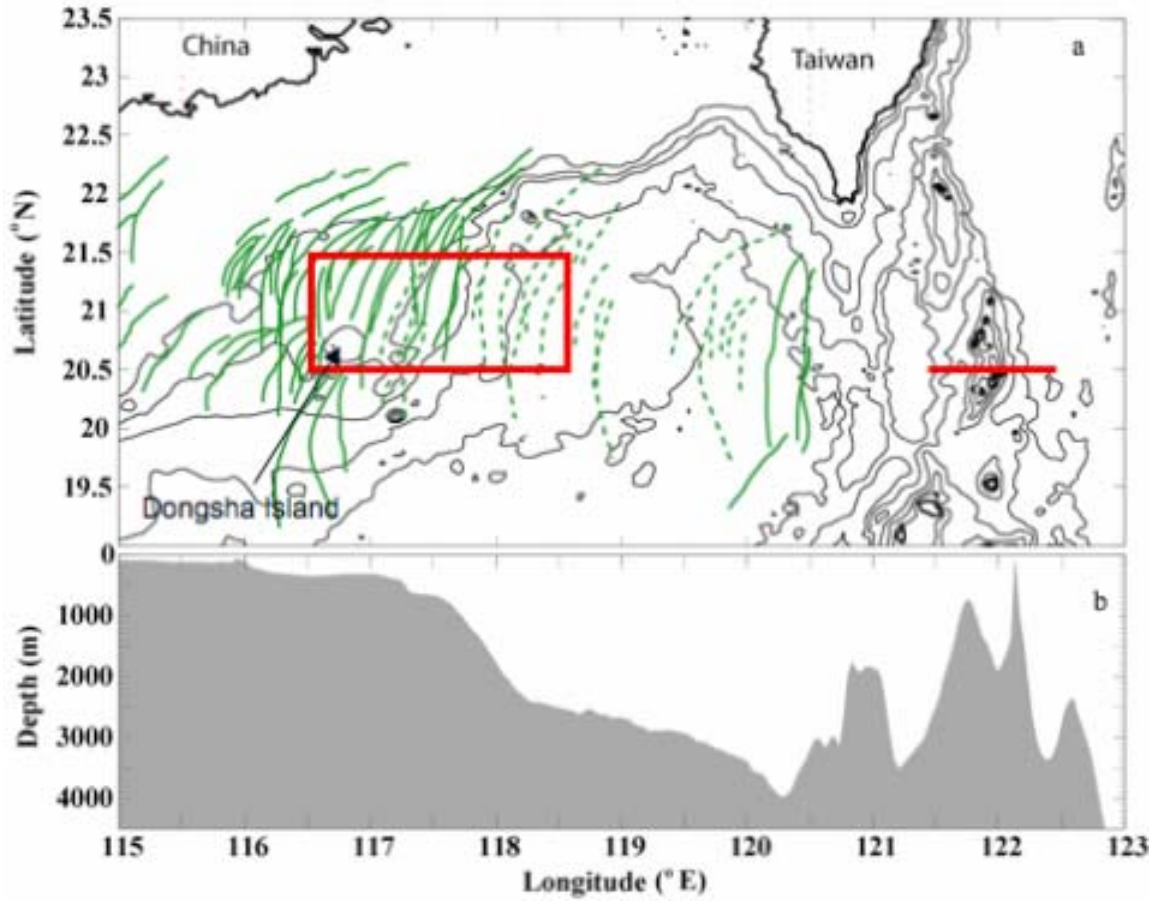


Figure 1. a) Map of the northern South China Sea from 123E (east of the Luzon Strait) to 115E (onto the shelf). The two dimensional model domain in the Luzon Strait and the three dimensional model domain by Dongsha Island are shown in red. Green curves are internal wave packets derived from satellite images by Zhao et al. (2004). Solid green curves indicate multiple-wave packets and dashed green curves single-wave packets. Thick solid green curves west of Luzon Strait represent the big wave event observed on 16 June 1995. Black contours are 200, 500, 1000, 2000, and 3000-m isobaths and b) The bathymetry across the South China Sea. (Based on Lien, R.-C., et al., 2005)

RESULTS

The simulations in the Luzon Strait showed that both K1 and M2 tides generate High Amplitude Internal Waves (HAIWs). These simulations are not sufficient to determine if these are NLIWs or if the HAIWs steepen into NLIWs as they propagate into the SCS. The most active generation sites were the eastern and western edges of the top of the ridge located in the middle of the domain. The K1 tide produces more large amplitude waves west of ridge while the M2 tide produces the largest amplitude HAIWs at east end of ridge. The shorter period of the M2 tide may allow more time for interaction with topography enhancing the generation on the eastern side. M2+K1 produces the largest amplitude waves and most waves are generated at the west side of ridge (Figure 2).

The M2 tides generate significant HAIWs to the east of the Luzon Strait (Figure 2b). However, NLIWs have not been seen to the east of the Strait in SAR images. Limited in situ measurements have indicated, at least occasional NLIW activity east of the Luzon Strait. However, the in situ

measurements are not sufficient to determine the source of the HAIWs. They may be generated in the Luzon Strait or in the East China Sea, where there are several known generation sites of HAIWs

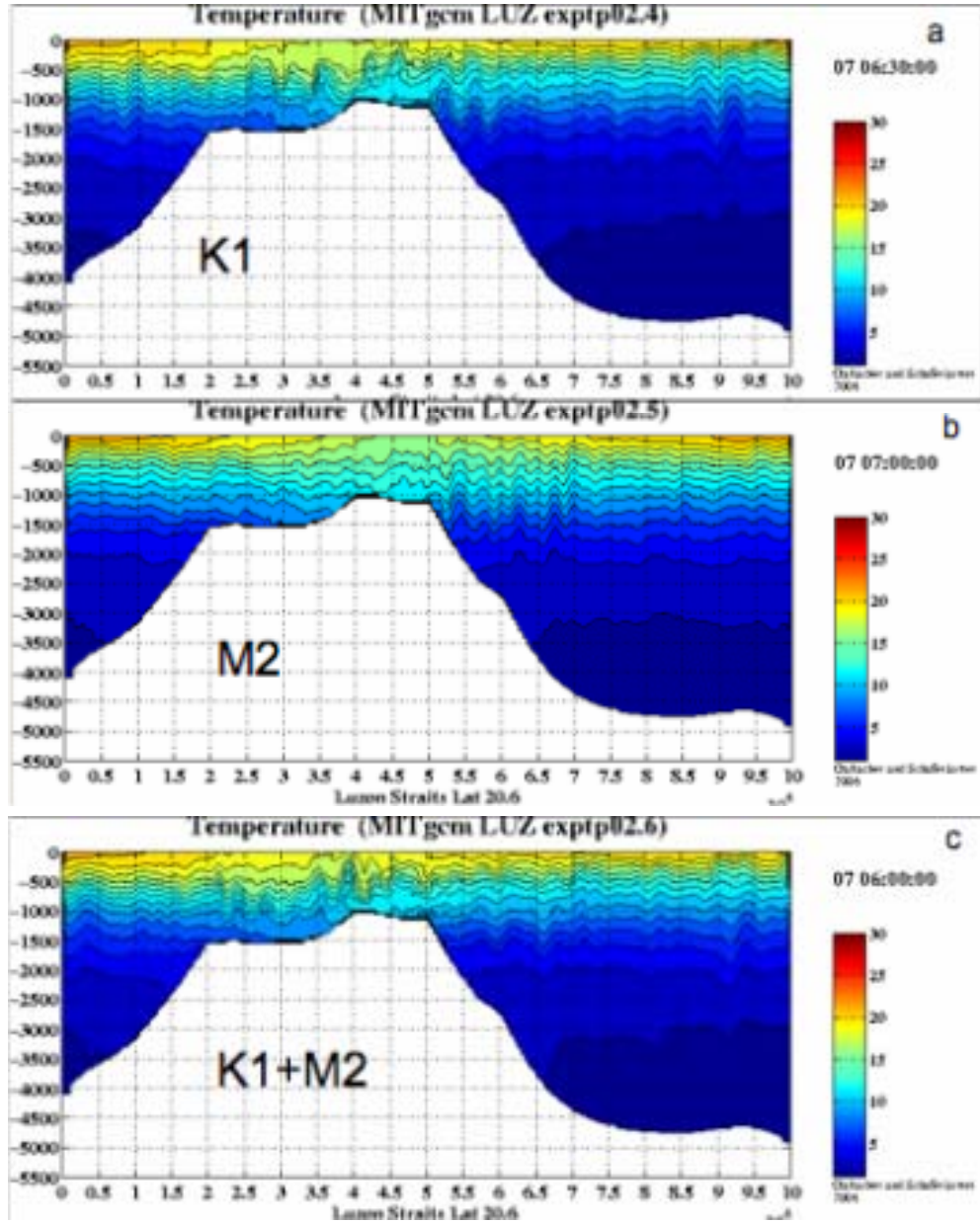


Figure 2. Internal waves generated in the Luzon Strait (20.6N, 121.5E – 122.5E) from climatological K1, M2 and K1+M2 tides. The K1 tide produces more large amplitude waves west of ridge than M2 does. The largest amplitude HAIWs produced by the M2 tide are at east end of ridge. M2+K1 produces the largest amplitude waves and most of those waves are generated at the west side of ridge.

(Liu *et al.*, 1998). The NLIW energy east of the Luzon Strait may be an artifact of the symmetric initial conditions and forcing used in the simulation or the NLIWs are simply not imaged by SAR observations. The later could be due to the Kuroshio, which could drive the NLIWs too deep for significant surface signatures or create enough surface signature to mask the NLIW signature (Steve Ramp, personal communication).

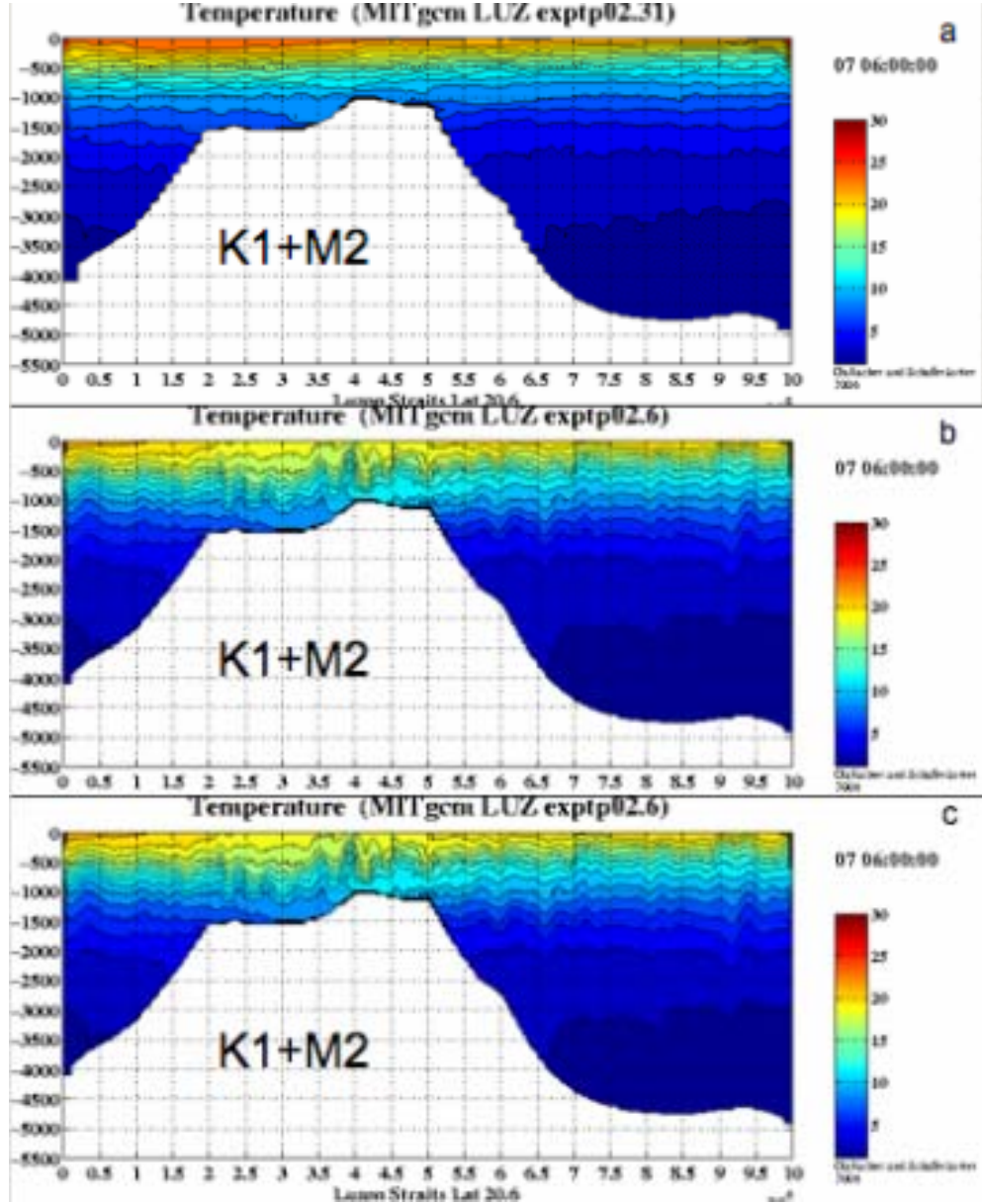


Figure 3. Comparison of identical simulations except that $dx = 1000$ m in 3a, $dx = 500$ m in 3b, $dx = 100$ m in 3c. Results in 3b and 3c are nearly identical whereas the internal wave amplitudes are severely diminished in 3a

We also conducted some resolution sensitivity simulations in the 2D Luzon Strait domain. We found that 500 m resolution was sufficient to generate HAIWs on both sides of the ridge (Figure 3b) with amplitudes comparable to the observations. When the resolution was increased to 100 m there was little apparent improvement of the results (Figure 3c). However, decreasing the resolution to 1000 m dramatically reduced the generation of internal waves (Figure 3a) and their amplitude.

The 3D hindcasts of the Dongsha plateau region were forced at the open boundaries with data from Dong Shan Ko's LZS64NFS hindcasts for April 1 to May 1, 2005. LZS64NFS obtains open boundary conditions from Shelley Riedlinger's East Asian Seas 1/16th degree Nowcast/Forecast system (EAS16NFS). Although the timing of the arrival of the tidal-period, trans-basin IWs is in good agreement with observations, the amplitudes of the waves are too small by a factor of roughly 4 (Dong Shan Ko, personal communication) due to the resolution of the model. Furthermore the structure of the waves with respect to the higher frequency NLIWs (solitary waves and wave packets) is not correct because of the hydrostatic assumption which is employed in the NCOM model.

Nevertheless bands of warm water (possibly waves of depression) can be seen progressing WNW up the slope of the Dongsha plateau in the plan view (Figure 4) of the model domain at 162.5 m (in the thermocline).

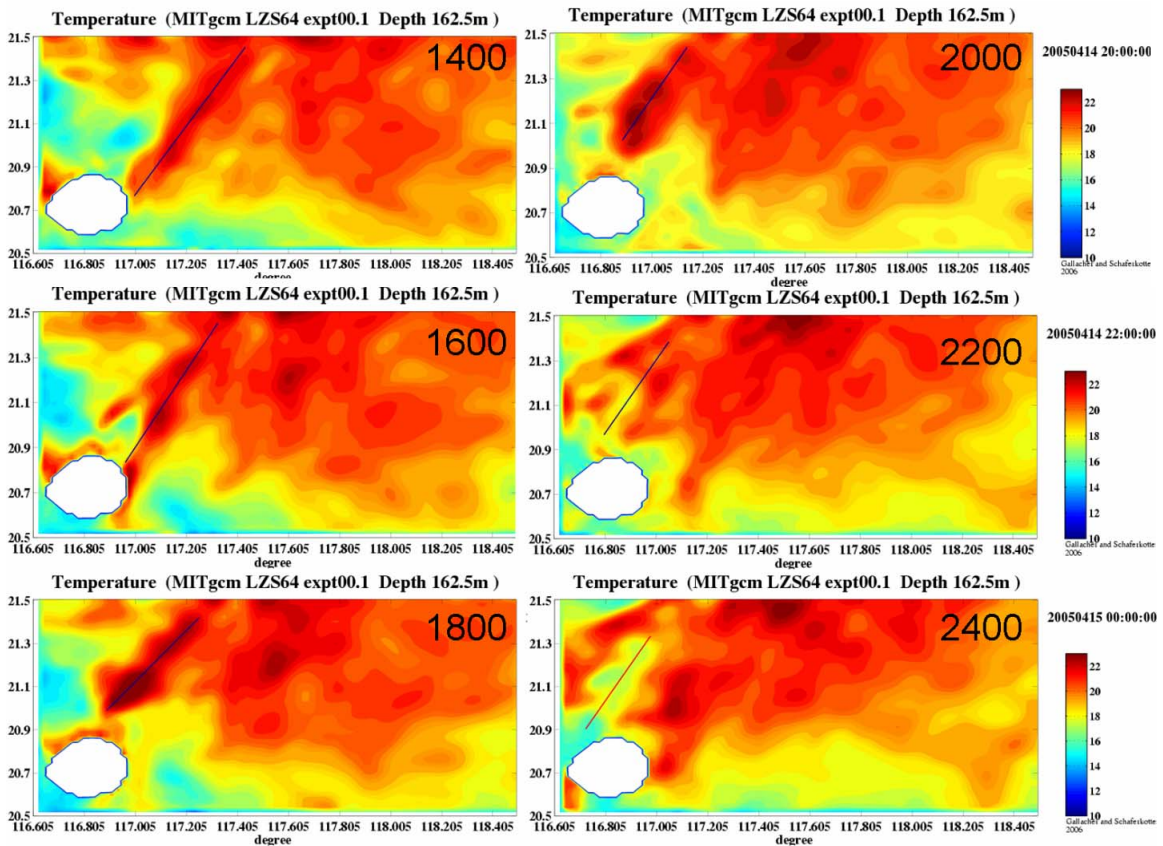


Figure 4. Plan views of a time series of temperature at 162.5 m. The black line highlights a feature which begins as warm water (possible a wave of depression) and propagates WNW up the Donsha plateau. The feature initially warms then cools eventually becoming cooler than the average (possible a wave of elevation).

The strength of the waves appears to diminish and the warm water bands are replaced by bands of cold water (possibly waves of elevation) in the region north and east of Dongsha Island during hours 2200 and 2400.

We increased the amplitude of the original internal waves (Figure 5a) at the eastern boundary by a factor of 4 (Figure 5b) to better represent the trans-basin NLIWs. However, this had virtually no impact on the hindcast results (not shown). This is most likely due to the coarse (2km) resolution in these hindcasts. We are currently working on higher resolution experiments.

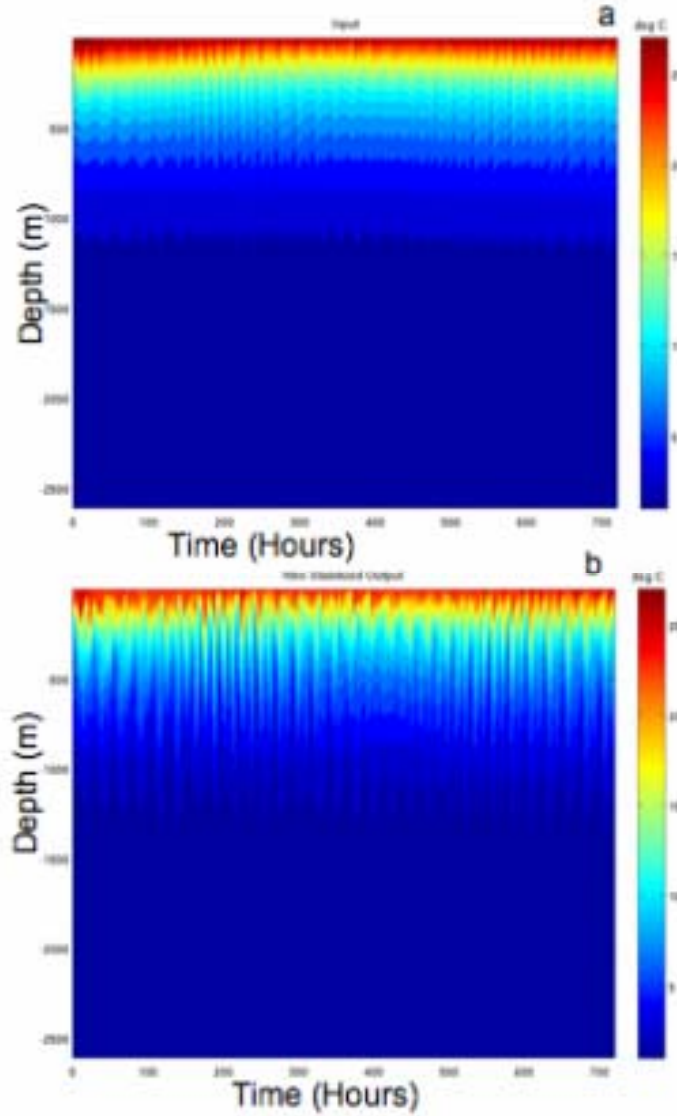


Figure 5. Original time series of temperature profiles from the LZS64NFS at a point on the eastern boundary (a) and the time series after the amplitude of the internal waves had been increased by a factor of 4 (b).

IMPACT/APPLICATIONS

This work will help to determine the importance of and the requirements for nonhydrostatic forecast systems for naval applications. The scales and features which will require nonhydrostatic simulation are being assessed.

RELATED PROJECTS

The NRL project Autonomous Characterization of Environmentally Induced Non-Acoustic Noise and the Adaptation of Multi-Sensor USW Networks. (6.2, Undersea Warfare) is related to this project because it involves nonhydrostatic modeling of the SW06 experimental area and time and comparison with measurements taken during SW06. Components of SW06 are funded through this ONR NLIWI DRI.

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