STORM SURGE MODELLING IN THE SOUTH CHINA SEA

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Abstract

Sea level anomalies (SLA) due to different phenomena have been observed in various parts of the South China Sea (SCS). Excluding tsunamis, the largest anomalies are classified as storm surges. Storm surges in the most southwestern part of the SCS are associated with a strong persistent wind blowing along the longest axis of the sea, roughly passing through Taiwan and Singapore. The phenomenon is very dynamic, may last for 2-3 days, and is modulated by larger scale geostrophic forces and smaller scale astronomic tides.

This paper describes the relationship between SLA events observed along the eastern Malaysian coast and in Singapore waters in response to typical seasonal winds over deep water regions in South China Sea. Further on, the methodology of simulation of such events is presented. Since data analysis has determined wind over the whole SCS as a key factor in building of SLA, it is important to have a numerical model covering the entire SCS region with meteorological forcing.

The research has shown that typical and extreme scenarios of storm surges at South China Sea can be described accurately using a numerical ocean model with wind input from numerical weather prediction models. The next stages of the research could be to use the model in a forecasting mode and to zoom it at Singapore Strait to study SLA impact on local hydrodynamics.

Keywords: Sea level anomaly, storm surges, South China Sea

1. INTRODUCTION

Barotropic sea level variability is caused by various geostrophic, astronomic, as well as meteorological parameters such as wind and atmospheric pressure variation. Following periodic driving forces (astronomic tides in particular) the sea level may oscillate with a wide range of periods ranging from hours to years, whereas non-periodic sea level anomalies may be due to the meteorological forces. Some extreme coastal flood events can occur when several driving phenomena coincide, such as it happened on 23 December 1999 in the southwest part of the South China Sea (SCS), when the spring tide was modulated by the galactic eclipse event, and coincided with a strong Northeast (NE) wind off Vietnam.

In the last decades, several studies on sea level variation in the SCS (Fig. 1) have been carried out using tide gauge and more recently altimetry data. Compared to the gauge readings, modern altimetry data is denser in space but sparser in time, while it is more accurate in open seas than near the coast. Even though tide gauge data is more accurate for coastal regions, satellite altimetry can still be very useful to get the broader picture of sea level anomalies in the region and to assess how the two measurements agree with each other to obtain a robust characterisation of SLA behavior. Nearly 15 years of merged altimetry data sets, such as Topex/Poseidon (T/P), ERS- I & II, Jason-1, and ENVISAT are available now for the analysis. Using altimetry data several studies on trends and seasonal water level variation have been carried out for SCS (Shaw et al., 1999; Ho et al., 2000; Liu et al., 2001; Cheng and Qi, 2007; Tkalich et al., 2009b), while SLA have been simulated using a depth-averaged model (Tkalich et al., 2009a), but additional work is required to quantify all major involved phenomena.

Fenoglio-Marc (2002) used T/P sea surface heights (SSHs) and tide gauge data for different locations in the Mediterranean Sea and computed correlations between tide gauge SLAs and atmospheric pressure, wind speed and sea surface temperature (SST), showing that merging of the data sets is beneficial.

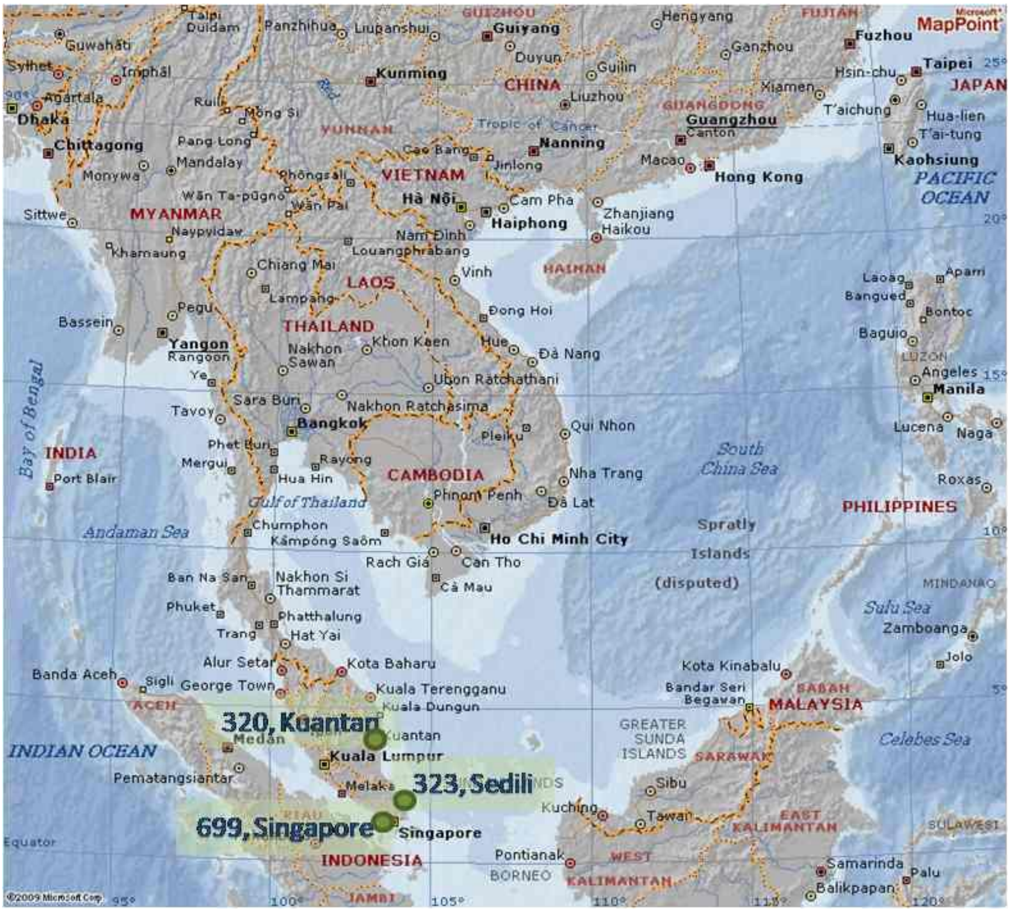


Fig. 1. South China Sea domain

This paper concerns with resolving storm surge related sea level anomalies in SCS region and comprises two parts. The first part describes data analysis of SLA observed in the Singapore Strait and their correlation with wind events over South China Sea while the second part describes modeling activity that has been carried out to reconstruct SLA events based on meteorological forces.

2. DATA ANALYSIS

Tkalich at el. 2009b has analyzed available data on wind generated anomalies for a period of more than 15 years. The focus was placed on extreme sea level anomalies (> 30cm) in the Singapore Strait and correlating them to large scale wind patterns over the entire SCS. The de-tided residual heights from a long term (23.5 years) tidal record available at the Tanjor Pagar station (this station is also addressed as 699 Singapore in UHSLC data center, see Fig. 1) has been used as well as TOPEX/Poseidon satellite altimetry. It is shown that the wind is one of the primary factors responsible for anomalous sea levels in the Singapore Strait. The most important seasonal wind patterns over the SCS, namely Northeast (NE) and Southwest (SW) monsoons were found responsible for the strong seasonality of storm surges in SCS, with NE wind being responsible for positive anomalies in Singapore Strait. It is shown that time series of sea level anomalies extracted from satellite data are well correlated with sea level anomalies extracted from tidal gauge records (after application of de-tiding procedures). Some discrepancies are attributed to the fact that tide gauge data represents water level taken at a fixed location when satellites average over area few km^2. Also, tidal gauges are generally located in the coastal area where the level of uncertainty of satellite measurements is higher.

Grouping the hourly measured SLAs by month over the measurement period shows a correlation of its mean values with the monsoons. Positive anomalies are more typical for the NE monsoon period while negative anomalies mostly occur during the SW monsoon period (see Fig. 2). Also, December and March show a higher variability of anomalies than the other months, when they are typically banded within a 20 cm range. Also, detailed analysis of wind-SLA relationship during North-East monsoon shows a strong correlation between wind magnitude observed over deep water area of South China Sea between Borneo and the coast of Viet Nam and SLA events occurring in Singapore Strait. The correlation coefficients vary from 0.514 to 0. 541 when an optimum time lag in a range of 36 to 42 hours (varied from area to area) is applied. The analysis also points out that these areas are located along a straight line towards Singapore Strait where there is no any significant land mass obstruction for the anomaly to travel along, while the impact of storm surges generated in other areas of the South China Sea is often blocked by land.

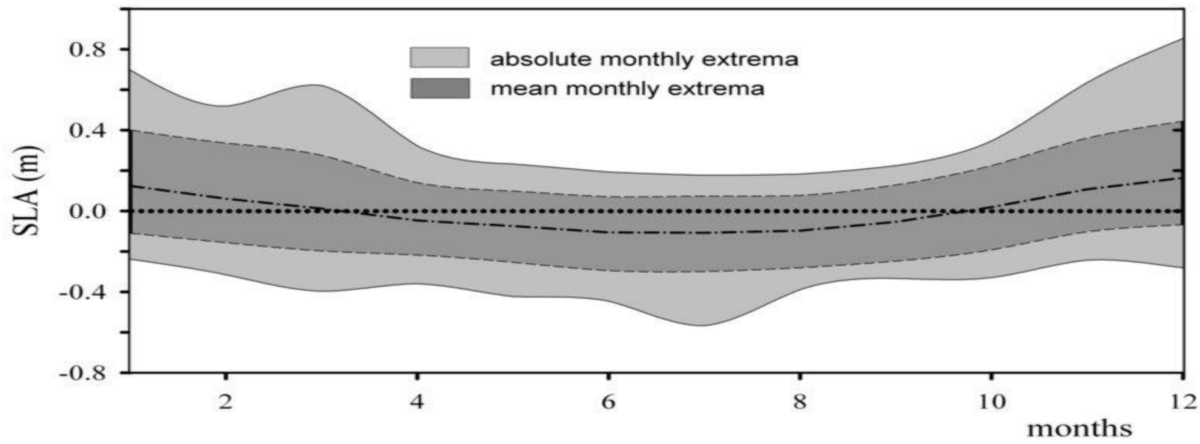


Fig. 2 Monthly frequency distribution of SLAs, 1984-2007 (adopted from Tkalich at el. 2009b)

3. THE SOUTH CHINA SEA MODEL

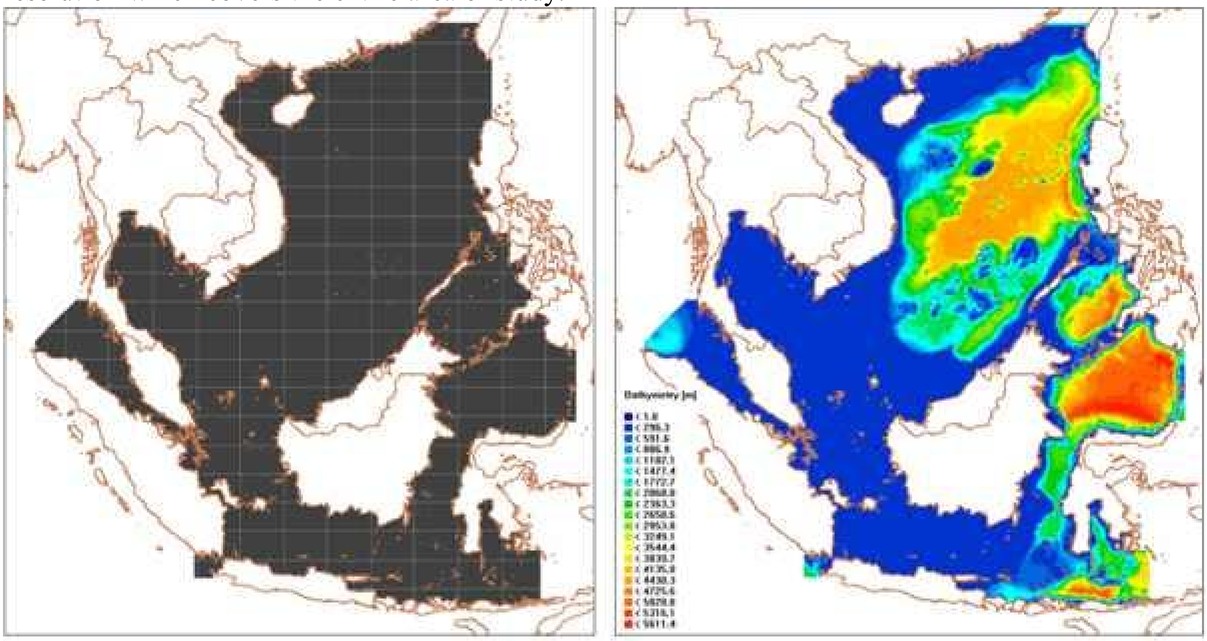
3.1 Hydrodynamic model set up

The SCS model domain covers the whole South China Sea and connected basins such as Java Sea and Indonesian waters (Fig. 3b) and has been chosen for simulation of non-tidal water motions of large scale. The model area consists of a complicated combination of several deep water basins with interconnection shallow sills and shelves between them. Each basin has its own specific characteristic length and a wide range of depths is present. The central part of the South China Sea has depths in the order of 5000m while typical depths of connected Sunda Shelf and Java Sea are in order of 100m. The latter area is known as an area where tides from the Pacific Ocean interact with tides from the Indian Ocean entering via Malacca Strait and a number of openings between the islands which adds extra complexity to the water motion in the system.

For the SLA simulation two similar model set ups have been used. Both are based on solving the depth-integrated shallow water equations for barotropic flow. The first one is the original set up the South China Sea model (SCSM), which was initially developed for depth-integrated barotropic tidal modelling and is described in (Gerritsen et al., 2003). It features a uniform spherical latitude-longitude grid with resolution 1/4 degrees. The second model set up is a refined version of SCSM with uniform spherical grid of 1/12 degrees, and is called the South China Sea Refined (SCSR) model. The models cover the area from 95º – 126º E.L. and from 8º S.L.– 24º N.L., and use similar bathymetry schematization (see Fig. 3a).

3.2 Meteorological forcing

According to previous analysis as well as observations, the non-tidal contribution to water level in Singapore waters can be significant. In the period January – April 2004 three strong water level increase events of non-tidal nature happened with maxima of ~50 cm. Wind and pressure results of fine scale atmospheric modelling have being used as SCSM model inputs to simulate water movement within the SCS basin with the aim to reconstruct those events. Here, the 4-months wind and pressure hindcast database from a local Weather Research and Forecasting (WRF) model suite nested in the Global Forecasting System (GFS) model has been used (Zelle, 2008). In the South China Sea area the WRF model has 40.5 km. spatial resolution and it has been chosen since this is the finest available resolution which covers the entire area of study.



a) b)

Fig. 3 Computational grid (a) and bathymetry schematization (b) of South China Sea Refined model

We note that more fine resolutions of the same nested WRF model system were used to force the Singapore Regional Model (SRM) which has significantly less spatial coverage and focuses on the simulation of local hydrodynamics in Singapore Strait (Ooi and el. 2009).

3.3 Results of the simulation

The simulation set up is similar for both SCSM and SCSR – simulations have been done with wind forcing only without external or internally generated tide forces. The simulation period was identical for both cases and represented the period 1 January – 31 March 2004. The 40.5 km WRF model results are used as atmospheric forcing. Application of atmospheric forcing implies volume forcing by surface winds and pressure gradients, plus application of the inverted barometer effect at open boundaries.

The two sets of simulated SLA time series are compared with observations at three stations obtained from the University of Hawaii Sea Level Center (UHSLC). The stations are denoted as 320 Kuantan, 323 Sedili and 699 Singapore (see Fig. 1). A 25-hours running mean filter has been applied for the time series with the aim to reduce the noise level. The time series results for stations 320, 323 and 699 are shown in Fig. 4. Three well-recognizable SLA events occurred in the simulated period (peaks at or near 25th of January, 13th of February and 8th of March) and it is clearly seen from the results that the wind driven water levels can be captured by both SCSM and SCSR models, but it is also seen that the models do not approximate the amplitudes of the event accurately.

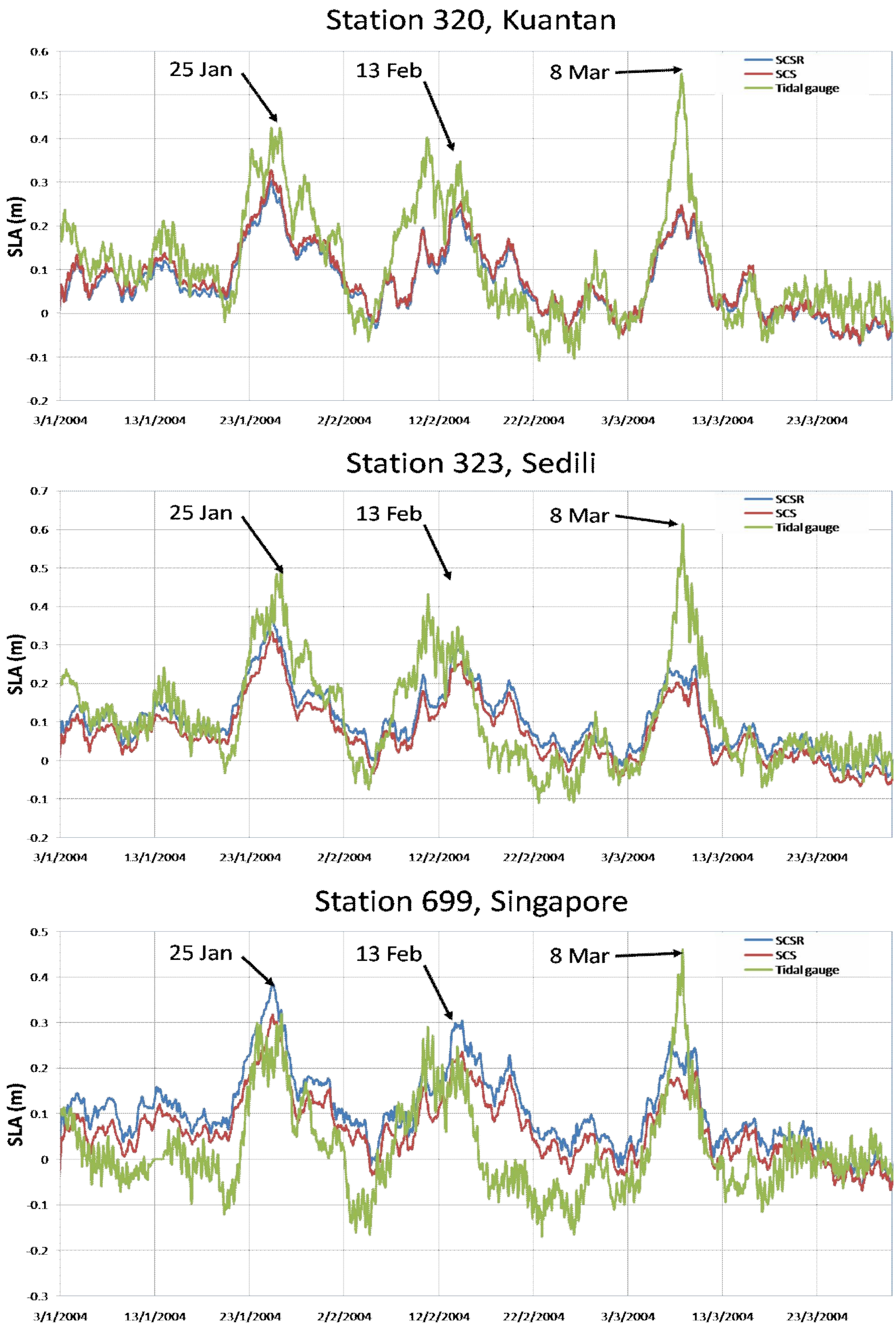


Fig. 4 Comparison between modeled and measured SLAs

The spatial distributions of SLAs for each of the events mentioned above are shown in Fig. 5. As one can see, both models succeed in reconstructing a general pattern of events and provide confident results in most of the areas except the complicated coast line zones and within Calamian Islands where the lack of spatial resolution of SCSM becomes significant.

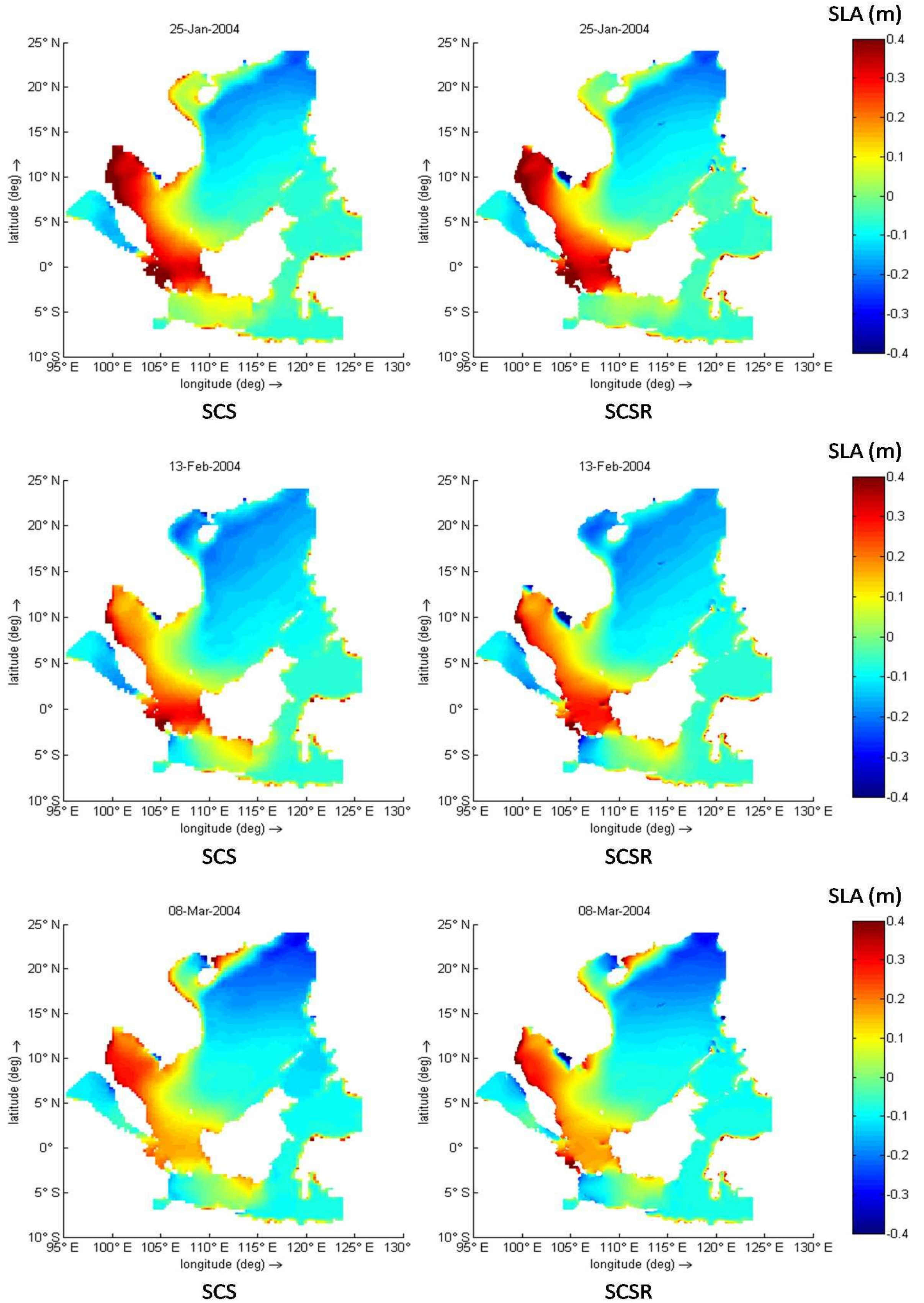


Fig. 5 Spatial distribution of the sea level anomaly for the 3 major SLA events occurring in the 1st quarter of 2004 at the times of the peak value in Singapore

4. CONCLUSIONS

The model has been verified using past storm surge cases and demonstrated adequate behaviour. A typical seasonal case respecting NE monsoon (Jan, Feb and March) 2004 is explored using two grids of different spatial resolution, 1/4° and 1/12°, respectively. For stations Kuantan and Sedili, along the open coast directly open to forcing from the central South China Sea, the results or the two models are not essentially different. The sensitivity analysis shows a superiority of the finer-scale grid model for the station Singapore, which lies shielded from the South China Sea. The observed discrepancy between the model and data could be attributed to poor resolution of atmospheric forces, missing interaction with astronomic tides and large scale dynamics and seasonal phenomena in the South China Sea. This is the subject of further rinvestigation.

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