Rossouw M, Luger S, Kuipers J, Patel S. Development of a Virtual Wave Buoy System for the Port of Cape Town, South Aarica. InFifth International Symposium WAVES 2005 (pp. 1-10).

DEVELOPMENT OF A VIRTUAL WAVE BUOY SYSTEM FOR THE PORT OF CAPE TOWN, SOUTH AFRICA

Marius Rossouw[1], Stephen Luger[2], Jan Kuipers[3] and Sahil Patel[4]

Abstract: The Port of Cape Town is located in Table Bay on the south-west coast of South Africa. Since the port experiences adverse weather conditions, especially during the winter period, the monitoring of marine weather and wave conditions forms an integral part of the daily port operations. The port receives real-time offshore wave data, representing the deep-sea wave conditions. To meet a request for wave information inside the bay, a real-time wave transformation model was set up for Table Bay. The SWAN wave generation and refraction model was used for this application. The output from this model is provided at six locations in the bay. These six locations, in essence represent imaginary wave buoys or "Virtual Wave Buoys".

INTRODUCTION

The Port of Cape Town is located in Table Bay on the south-west coast of South Africa (Figure 1). Information on the prevailing weather and wave conditions is vital to port operations, especially with regard to ships entering and leaving the harbour. Thus, monitoring of the marine weather and the wave conditions forms an integral part of the port operations, particularly in winter when intense low pressure systems approach Cape Town from the west/south-west, often resulting in severe weather and wave conditions.

The CSIR has operated a wave-recording buoy off the Cape coast since the early 1980s. This buoy, known as the Slangkop wave buoy, is located some 5 km offshore in 70 m water depth (Figure 1). During the 1990s this system was extended to provide real-time data for the National Ports Authority (NPA) for application in the Port of Cape Town.

---

1 CSIR, P O Box 320, Stellenbosch, 7599, South Africa, mrossouw@csir.co.za
2 CSIR, P O Box 320, Stellenbosch, 7599, South Africa, sluger@csir.co.za
3 CSIR, P O Box 320, Stellenbosch, 7599, South Africa, jkuipers@csir.co.za
4 PRDW, P O Box 50023, Waterfront, 8002, South Africa, spatel@prdw.co.za

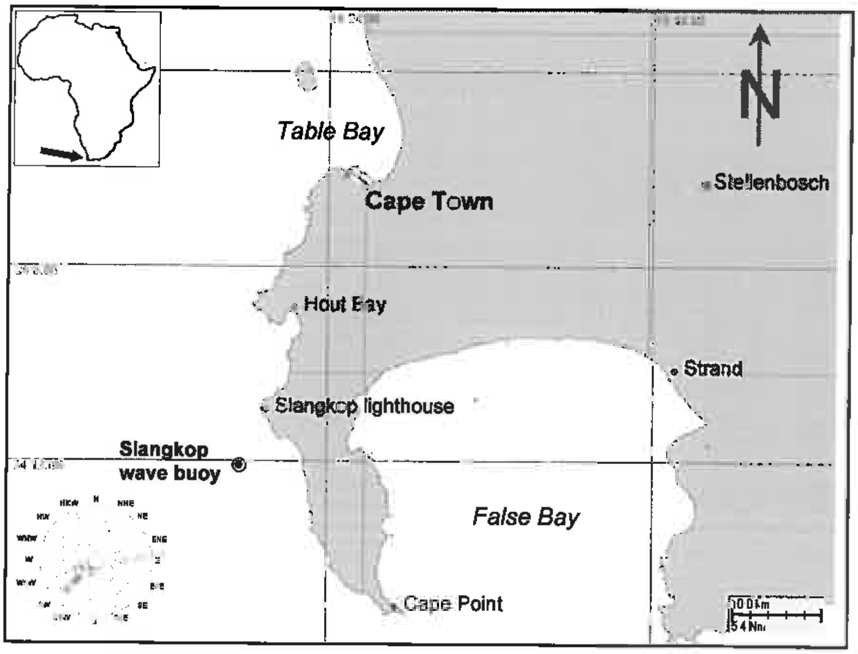

Fig. 1. Location of the Port of Cape Town and the Slangkop wave buoy

MONITORING WAVE CONDITIONS IN TABLE BAY

Deep-sea waves approach the Cape coast from the south-west to the north-west, resulting in a considerable variation in wave conditions inside the bay, mainly because south-westerly waves are reduced significantly as a result of refraction. Although the port is sheltered from the dominant south-westerly waves, it was realised that wave information inside the bay would be valuable during low visibility conditions, e.g. at night-time or during a major storm. Reliable wave information would, for example, assist pilots in deciding whether a large vessel could be brought safely into the harbour.

The basic information on the offshore wave height and period from the non-directional Slangkop buoy were inadequate for port operations and in 2001 the buoy was replaced with a directional Datawell Waverider. This, however, did not meet the need for wave information in Table Bay itself.

A number of options were identified for providing data on the wave conditions inside Table Bay. The first option was the deployment of a wave-recording buoy within the bay. However, the cost of an additional wave buoy and the high risk associated with having it within the shipping-lanes, made this option unattractive. The chance of a ship colliding with the buoy was relatively high.

Another option was to deploy an Acoustic Doppler Current Profiler (ADCP) on the sea-bed. The data would be transmitted to Port Control using an acoustic modem and/or cables. Depending on how the data are transmitted, an ADCP is also a high risk option and the cost of maintaining the underwater instrument also needs consideration. Therefore, another solution, avoiding instrument deployment, was required.

NUMERICAL WAVE TRANSFORMATION MODEL

The solution adopted entailed the numerical transformation of the offshore Slangkop data to nearshore wave conditions inside Table Bay on a real-time basis. This wave transformation was achieved through the third-generation wave generation and refraction SWAN (Simulating WAves Nearshore) model, as described by Booij, et al. (1999).

Since SWAN is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequency), it was ideally suited for this application. The wave processes modeled with SWAN included wave refraction, shoaling, bottom friction and breaking. The absence of strong currents in Table Bay permitted the omission of the wave-current interactions. Furthermore, the generation of local wind-waves was not accounted for in the model since it was assumed that the energy of wind-waves were included in the boundary specification as based on the Slangkop Waverider measurements (Smith and Luger, 2003).

Model setup and calibration

The SWAN model for the greater Table Bay area was already in place since it had been used in earlier studies (e.g. Luger et al., 2004). The model consisted of two grids: the large coarse grid covering the area which included the Slangkop wave buoy location, and a nested grid covering the Table Bay area (Smith and Luger, 2003). The layout of these grids is shown in Figure 2.

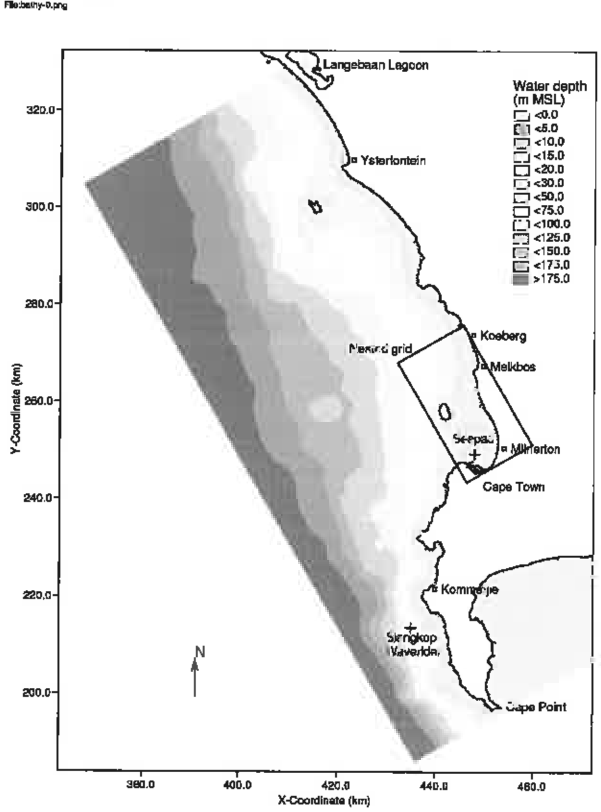

Fig. 2. Layout of large and nested SWAN grids with the positions of the Slangkop and Seapac stations (from Smith and Luger, 2003)

The model was calibrated using wave data measured simultaneously by the Slangkop wave buoy and a Seapac electromagnetic current meter inside Table Bay (Figure 2). The Seapac was deployed in a water depth of about 17 m. The 1-dimensional (1-D) wave energy spectral data from the Slangkop buoy was applied at the boundary for calibrating the model. The 1-D spectrum is defined by the variance density (m^2/Hz), the corresponding direction and associated directional spreading, all as a function of frequency.

The calibration results in the form of time-series of the significant wave height (Hmo), the wave direction and peak wave period are presented in Figure 3. The time-series of the measured and simulated data for both the Slangkop and Seapac locations are shown in Figure 3, while the scatterplots of the wave parameters are presented in Figure 4. The correlation between the measured and simulated data was generally good: the model followed the Seapac measurements reasonably well.

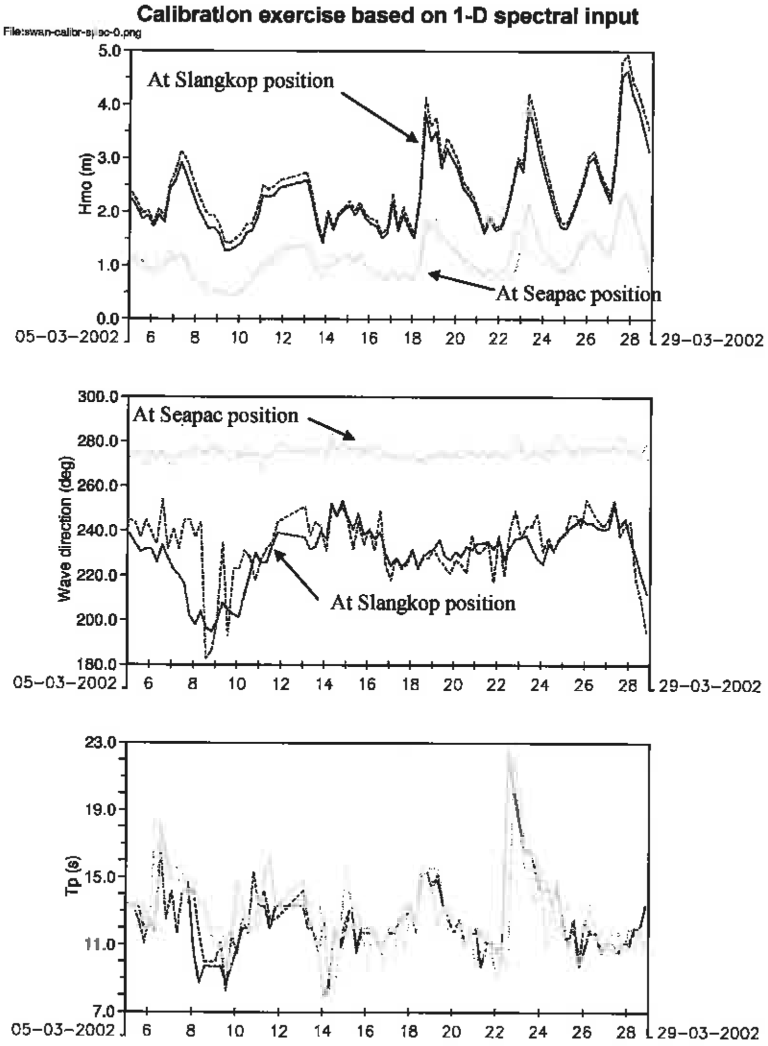

Fig. 3. **Time-series of measured (dotted line) and modeled (solid line) data at Slangkop (red) and Seapac (green) locations. (from Smith and Luger, 2003)**

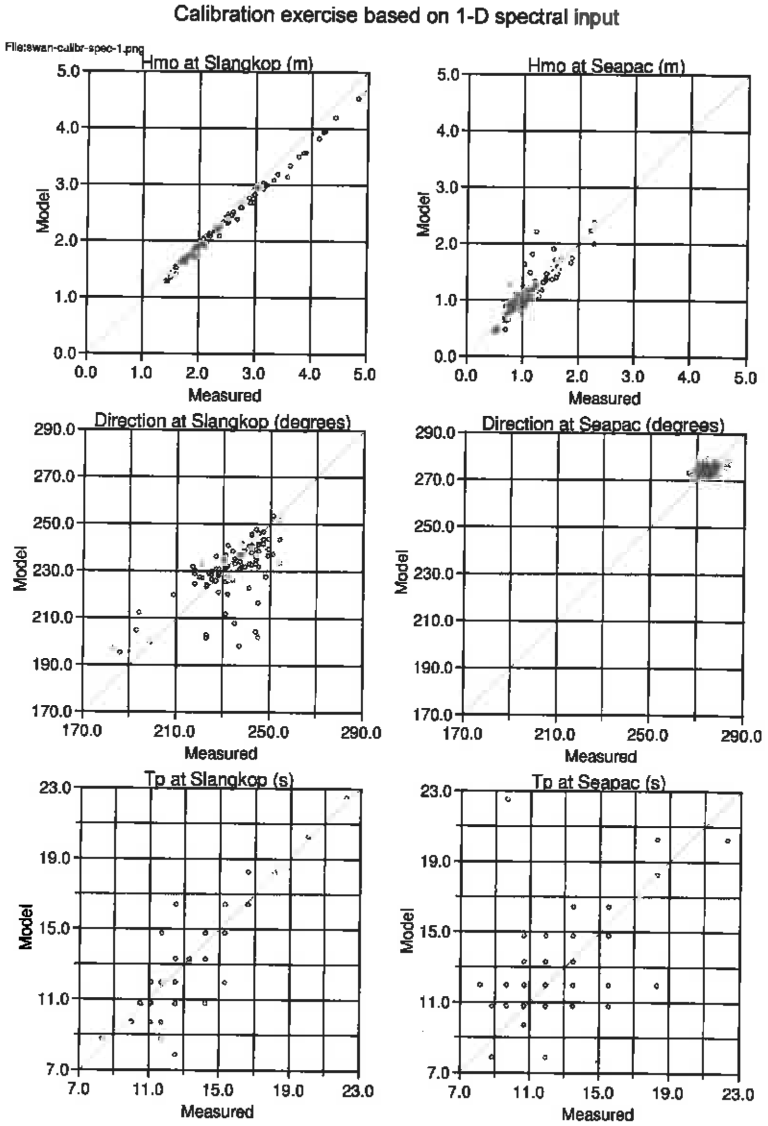

Fig. 4. Scatterplots: Measured versus simulated Slangkop and Seapac parameters (from Smith and Luger, 2003)

The underestimation of the wave heights at Slangkop, as indicated in Figures 3 and 4, may be attributed to the model only accounting for energy propagating into the model domain, while the measurements include energy propagating in an offshore direction. Also note that the boundary of the model domain was not aligned with the position of the Slangkop wave buoy, but placed slightly further offshore to match the model boundary with the approximate parallel depth contours. Therefore, bottom friction also affects the energy arriving at the Slangkop location from the edge of the boundary.

Verification of SWAN model

A comparison exercise, to validate the model setup, was undertaken using data from an ADCP current meter located about 1 km south-west of the Seapac (Figure 5). The ADCP, originally set up to collect current data, sampled data at 2 Hz for 10 minutes, giving 1 200 samples per record. These records provided only half the number of samples generally used to derive reliable and consistent wave parameters. Consequently, the measured ADCP data would inherently result in additional scatter in the estimates of the wave parameters.

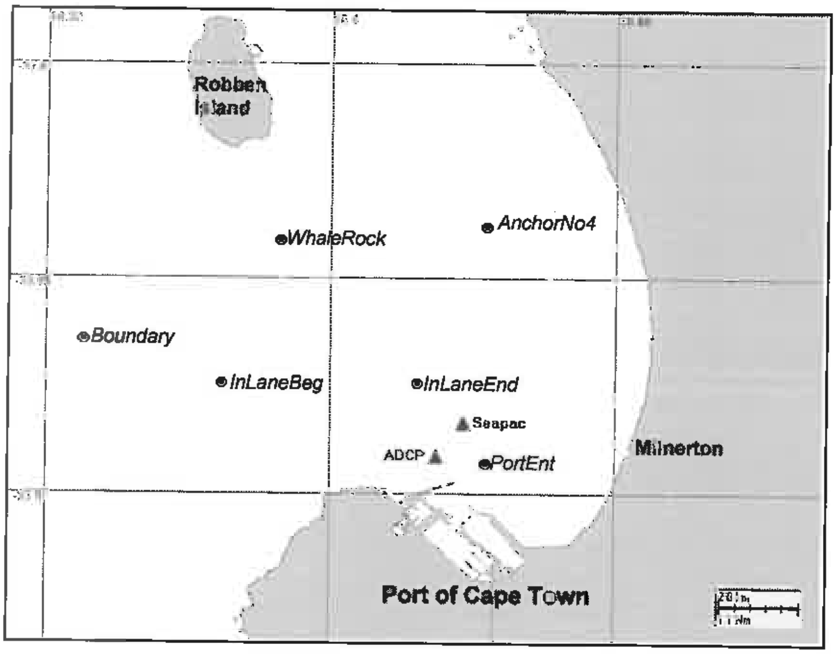

Fig. 5 Position of the Seapac and ADCP instruments (▲) and the six SWAN output locations (◉)

Time-series of the measured and simulated data for the ADCP location are presented in Figure 6. The period simulated with the model represents a major storm on 3 July 2004 with significant wave heights reaching almost 9 m. Taking the limitation of the record length into consideration, the model results nevertheless compare reasonably well with the measurements.

Since the focus of this modeling system is to simulate the wave conditions inside Table Bay, the correlation found with the Seapac data and the July 2004 storm indicates that the model setup is sufficiently accurate and reliable for use in port operations.

IMPLEMENTATION OF REAL-TIME WAVE MODEL

In order to operate the Table Bay SWAN model in a real-time mode, the appropriate input data were required. The two options considered were the 1-D spectrum and the full 2-D spectrum, defined by the variance density as a function of frequency and direction.

Although the 2-D spectrum was preferred as the input data source, it was not available as a standard output from the wave buoy, which only provided the wave parameters and the 1-D spectrum. To determine if the 2-D spectral input was indeed required for an operational modeling system, a comparison exercise was undertaken whereby simulations were done using the 1-D and the corresponding 2-D spectral input.

Three sets of simulation tests were done. The first set comprised simulations with Slangkop waves greater than 4 m to ensure reasonable levels of energy propagating into the bay. The results of these tests for the Slangkop and Seapac locations are illustrated in Figure 7.

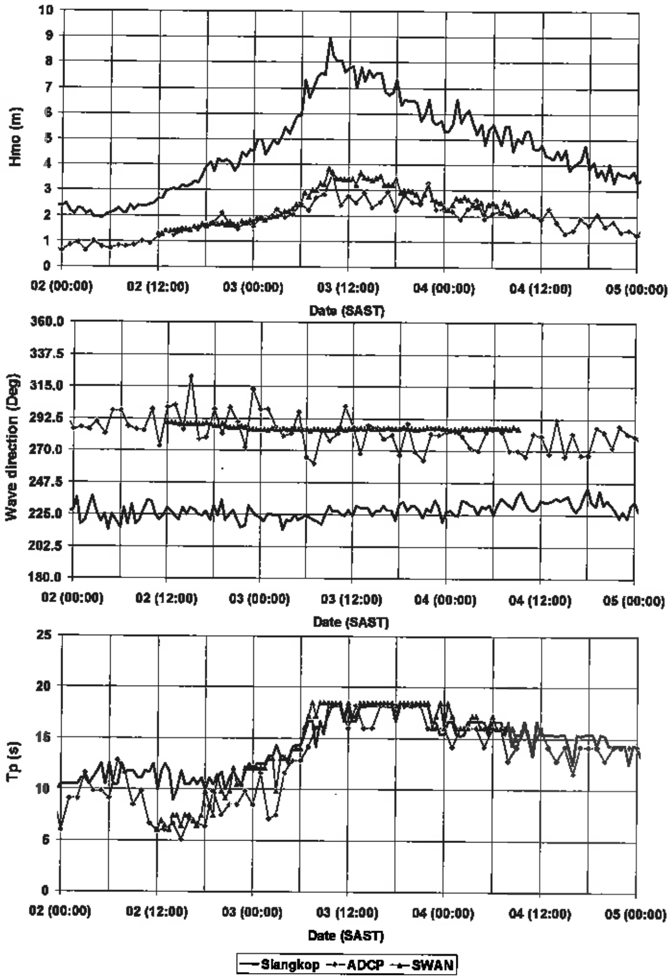

Fig. 6. Storm of 3 July 2004: comparison between ADCP and simulated data also showing the time-series of the Slangkop data

The second set of tests consisted of Slangkop records that indicated bimodality with regard to wave direction. The bimodal data records were identified using the spectral analysis routines of Van Tonder (1994), and using the sea mode definition of Nwogu et al. (1987). As with the first set of tests, the results of these simulations indicated little difference. Based on these results, the 1-D spectrum from the Slangkop Datawell Waverider was selected for input to the Table Bay model.

A third set of tests was performed to investigate the effect of tidal variation. The maximum spring tidal range in Table Bay is in the order of 2 m. Since the differences in results were found to be insignificant, it was decided that the model be operated at a constant mean water level.

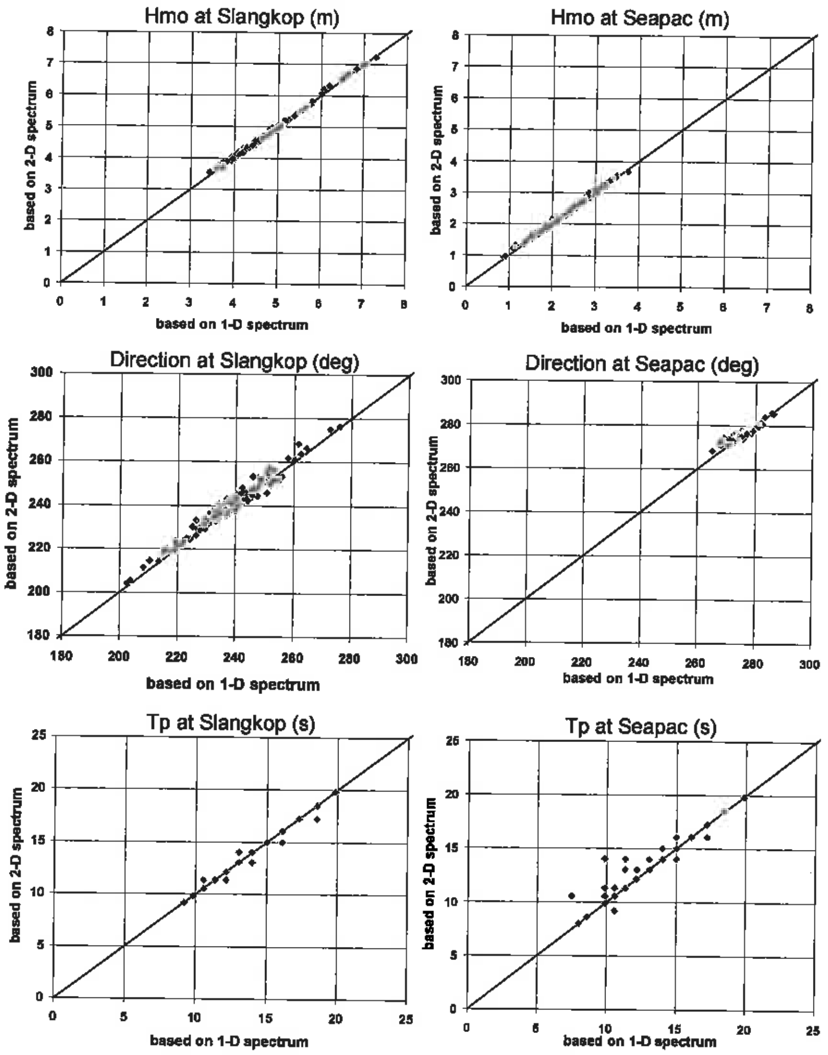

Fig. 7 Scatterplots: Slangkop and Seapac parameters based on 1-D spectrum vs 2-D spectrum simulations

Operational mode

The wave data from the Slangkop wave buoy are transmitted by radio to a base station at Slangkop lighthouse from where it is sent by telephone modem to Cape Town Port Control (Figure 1). At Port Control the offshore wave data are displayed with the weather and tide information on the PC-based Integrated Port Operation Support System (IPOSS). The data collected by the IPOSS are also sent to the CSIR in Stellenbosch via modem for monitoring and archiving.

The operational SWAN model runs on a dedicated PC which is directly linked to the IPOSS, thereby ensuring minimum computational time. The automated routine captures the incoming data record from the IPOSS PC and processes the data with the SWAN model. Once the output is available (after approximately 5 minutes), the wave parameters are transferred back to the IPOSS PC and displayed jointly with the offshore (Slangkop) wave data, the weather and tidal information.

At present the SWAN system outputs the wave parameters for six locations in Table Bay. These locations (Figure 5) have been selected to represent areas of activity within the boundaries of the port jurisdiction. Since the output from the system is similar in appearance to that of the measured offshore data, the six locations are in essence imaginary wave buoys or "Virtual Wave Buoys". An example of the IPOSS display, showing the virtual buoy data, is presented in Figure 8. The time-series of significant wave height for a 24 hour period at each of the six locations are shown.

A relatively simple quality control procedure is presently embedded in the system. Aspects taken into consideration with respect to both the Slangkop input data and the SWAN output data include a limit on wave height (Hmo and Hmax), a reasonable range for the peak wave period and wave direction.

It is recognised that the Virtual Buoy system will not provide data as accurate as measured data. However, since this system needs to provide general information on the wave conditions in Table Bay for daily operational use, the calibration and validation exercises indicate the present output represents the actual conditions reasonable well.

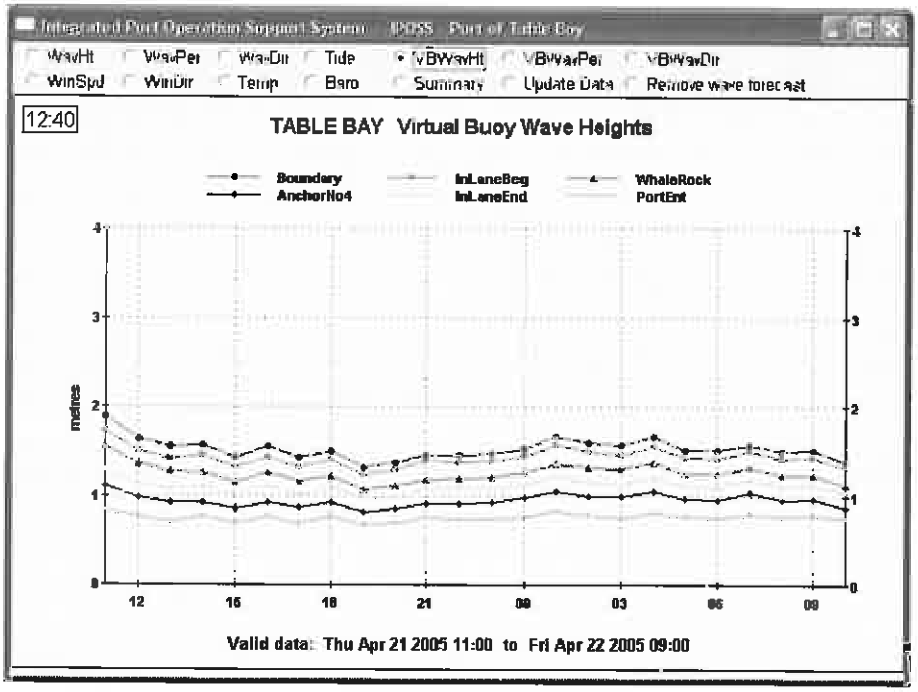

Fig. 8. Example of IPOSS display showing the Virtual Buoy output at the six selected locations in Table Bay (refer to Fig. 5 for locations)

CONCLUSIONS

A system was developed for the Port of Cape Town to provide real-time information on the wave conditions in Table Bay, South Africa. The system comprised linking the present offshore wave recording buoy at Slangkop with the third-generation wave generation and refraction SWAN model.

The model produced outputs for six locations in Table Bay. Since these model outputs are similar in appearance to that from the Slangkop wave buoy, the six locations are in essence imaginary wave buoys and are thus referred to as "Virtual Wave Buoys".

Calibration and validation exercises indicated that the simulated data compare reasonably well with the measured data. The Virtual Buoy system, therefore, is considered a realistic alternative to an additional wave recording buoy in Table Bay, when the operational costs and high risk to which the buoy would be exposed to in an area with a high volume of ship traffic are considered.

ACKNOWLEDGEMENTS

The development of the Virtual Buoy system was partially funded by the National Ports Authority of Cape Town. The ADCP data was supplied by the South African based Institute for Maritime Technology, a Division of Armscor Business PTY Ltd.

REFERENCES

Luger, S., Smith, G. and Schoonees, J.S. (2004). Minimising the Impacts of Reclaimation Dredging at Cape Town. *Proceedings of the 29th International Conference on Coastal Engineering*, Lisbon, Portugal, 2004

Nwogu, O.U., Mansard, E.P.D., Miles, M.D. and Isaacen, M. 1987. Estimation of Directional Wave Spectra by the Maximum Entropy Method. *Proceedings IAHR Seminar on Wave Analysis and Generation in Laboratory Basins*, Lausanne.

Rossouw, M, Davies, J, Coetzee, L. and Kuipers, J. (1999). The Wave Recording Network around the South African Coast. *Proceedings of the Fifth International Conference on Coastal and Port Engineering in Developing Countries.* Cape Town, South Africa, April 1999.

Smith, G and Luger, S (2003). *EIA Secialist Study on the Impacts of the Container Terminal Expansion on Shoreline Stability.* CSIR Report ENV-S-C 2003-087, August 2003.

Van Tonder, A. (1994). *The Development and Testing of a System for the Measurement of Directional Wave Spectra in the Nearshore Coastal Zone.* Phd Thesis, University of Stellenbosch, South Africa, December 1994.