Conference Paper, Published Version

Baills, Julien; Dugor, Jérémy; Rihouey, Didier

Numerical modelling of released dredged sediment dispersion from Pandop harbour (New Caledonia)

Numerical modelling of released dredged sediment dispersion from Pandop harbour (New Caledonia)

Julien Baills, Jérémy Dugor, Didier Rihouey
CASAGEC Ingénierie
Anglet, France
baills@casagec.fr
dugor@casagec.fr
rihouey@casagec.fr

***Abstract*— The Pandop harbour is located in the New Caledonia North-West lagoon. This site is subject to sedimentation processes requiring dredging operations in order to maintain its activities. The present work aims to evaluate the released sediment impact on outside coral reef.**

The first step of this work consists in evaluating oceano-climatic conditions impacting the study site, i.e. tide, global circulations, waves, wind and upwelling phenomena. Offshore wave conditions were analysed from WW3 numerical model over a 23 years period. The tide is taken into account using the TPXO database (Egbert et al., 2002). The offshore general currents around New Caledonia are studied from results of Mercator model (Brasseur et al., 2005) at different depths over a 10 years period. Circulations along the west coast of New Caledonia show a seasonal variability in terms of intensity and direction (weaker currents during austral winter). These circulations are used to force the TELEMAC3D model.

The mesh covers the North-West part of New Caledonia and is refined in the lagoon, on the coral barrier and around the disposal zone. The vertical mesh is only composed of 10 planes (fixed and sigma planes) to limit computation time and is refined in the upper part of the water column. The numerical model is calibrated and validated with tide gauge measurements from SHOM and ADCP campaign. Friction coefficients are assigned depending on the bottom type especially on the coral reef.

To model the sediment disposal, a simplistic but realistic solution was used following the bibliography (KBR (2002), Alzieu (2000), Boutin (2000)). Indeed, in order to represent the sediment resuspension during the fall, sediments are injected in the water column at different depths and especially at the pycnocline. The results allowed to define a disposal zone that gives the best compromise between a relatively close disposal area and a low impact on the coral reef. Moreover, the cumulative impact of successive disposals is studied with long-term simulations. Finally, the currents around the disposal zone are relatively low and thus sediment transport is limited.

I. Introduction

A. General context and goals of the study

The Pandop harbour is subject to sedimentation processes requiring dredging operations in order to maintain its activities. The dredge project consists of about 114 000 m³ of sediments to be dredged to reach a bathymetry of -4,50 m Chart Datum in the harbour. A solution for the dredged sediments consists in dumping them in the sea.

A modelling work is needed in order to:

- Characterize the oceano-climatic conditions impacting the study site.
- Evaluate the released dredged sediment dispersion in order to define a disposal zone that gives the best compromise between a relatively close disposal area and a low impact on the coral reef.
- Study the cumulative impact of successive disposals by means of long-term simulations.

A three-dimensional hydrosedimentary model has been developed to represent the different processes impacting the study site. Two specific modules have been created or modified to force the model with global circulations and to represent the sediment disposal.

B. Geographic situation

The Pandop harbour is located in the Northern Province of New Caledonia at the tip of Koumac. In order to dump the dredged sediment, the barges have to cross the lagoon for about 11,5 km to the Koumac inlet. The bathymetry decreases quickly from 15m in the lagoon to 1000m of depth at 3 km of the Koumac inlet. In front of the Koumac inlet, the barrier reef represents a 9 km diameter bay with two inlets: the Koumac inlet and the Deverd inlet.

Fig. 1 Study site (North-West of New Caledonia)

II. OCEANO-CLIMATIC CONDITIONS

A. General climate

The New Caledonia climate is characterized by two main seasons:

- The hot season characterized by the passage of depressions and tropical cyclones and a wind regime from South-East to East (south-east trade wind).
- The cool season characterized by wind from East-South-East sector but also cold fronts accompanied by abundant rainfall and West sector winds that can blow in storm (shots from West).

The tide is semi-diurnal and the maximum tidal range is about 1,67m at the Pandop harbour.

B. Wind climate

The wind climate around the study site was studied thanks to two years measurements at the Duroc inlet done during the Koniambo project in 2001 and 2002.

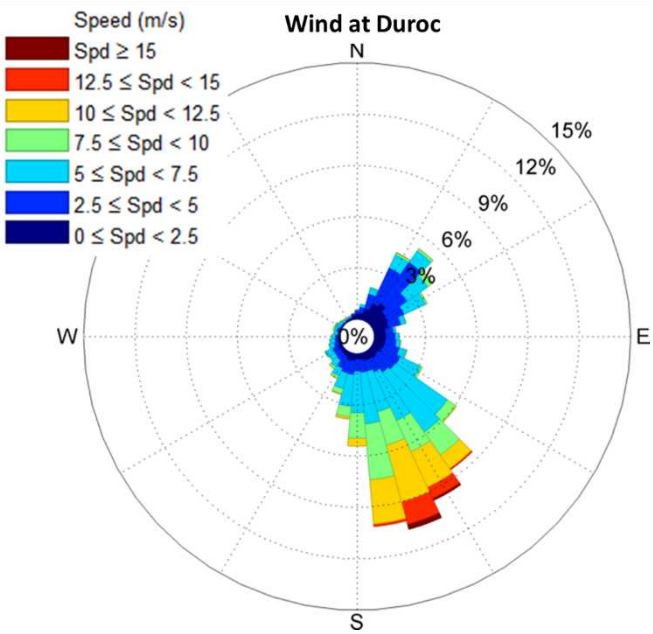

Fig. 2 Wind rose at the Duroc inlet.

The mean velocity is about 5,73 m/s and the wind originates mostly from South-East. Indeed, the strongest winds come from South and South-East.

The wind velocities measured are below 5,5 m/s during 26% of the time and below 10,5 m/s during 79% of the time.

During the cool season, westerly sea breezes can be observed.

C. General wave conditions

Offshore wave conditions were studied from a WW3 numerical model from IFREMER over a 28 years period from 1990 to 2018. The wind forcing comes from ECMWF (European Centre for Medium-Range Weather Forecasts) model.

The Mean wave conditions can be summarized as follow:

- Waves preferentially originate from South-East (135°N) to South-South-West (210°N).
- The significant wave height is lower than 1,5m for 23% of the time, lower than 2m for 55% of the time and lower than 3m for 92% of the time.
- Sea states below 3.0 m usually have peak periods of the order of 9 to 14 s. More rarely, some sea states can reach significant heights of more than 6m and long periods up to 20s.

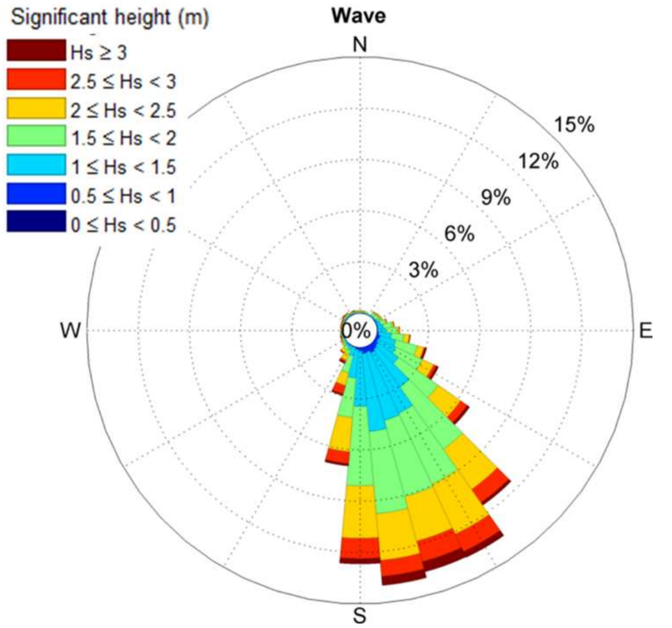

Fig. 3 Wave rose from the WW3 model.

D. Offshore general current

The global circulations around New Caledonia are complex and difficult to characterize ([1],[2],[3]). Current circulations have been extracted from the Mercator ([4]) model over a 10 years period (2007-2016). Moreover, these velocities are recuperated for several depths (surface, 100m, 400m and 1000m).

The velocities are studied for a point located off the Koumac inlet. The global currents are mostly parallel to the coast.

With these data, velocity roses (Fig 4) have been constructed for the different depths and seasons and thus analysed.

These figures show a strong seasonal variability.

Indeed, during the hot season (from November to April), currents are mainly directed towards South-East with intensities of about 0,15 to 0,5 m/s at the surface. Moreover, current directions are homogeneous in the water column and velocities are lower near the bottom.

However, during the cool season (from May to October), currents are still directed towards South-East but with lower velocities of about 0,05 to 0,3 m/s. Otherwise, opposite currents toward North-West can be observed under the pycnocline.

Moreover, global velocities of about 1 m/s can be observed during cyclonic events.

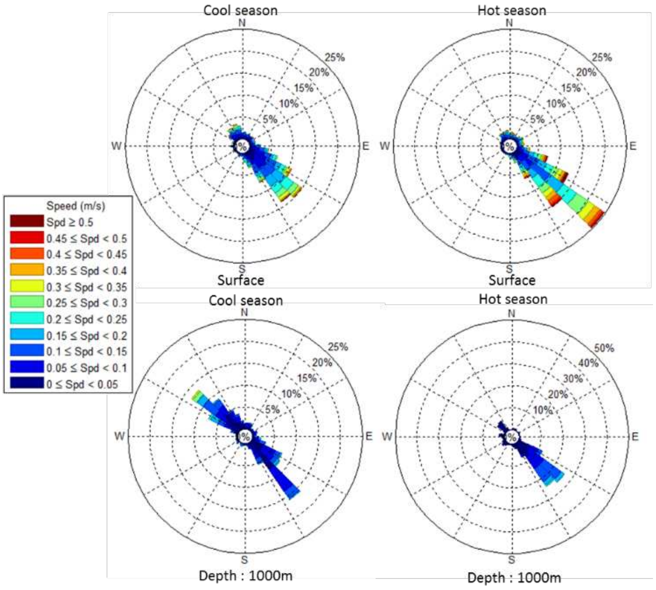

Fig. 4 Velocity roses off the lagoon from Mercator model

III. Numerical model description

A. Mesh and forcings

The Telemac software using Finite Element Method was used to model the three-dimensional hydrodynamic processes and the dredged sediment dispersion. The 2D mesh covers the North-West part of New Caledonia (about 100km from North to South), it is refined in the lagoon, on the coral barrier and around the disposal zone and is composed of about 41 200 nodes. The mesh size is about 1000m off the lagoon to 500m in the lagoon and 100m at the reef. The mesh size is minimal around the disposal zone (mesh size of about 50m).

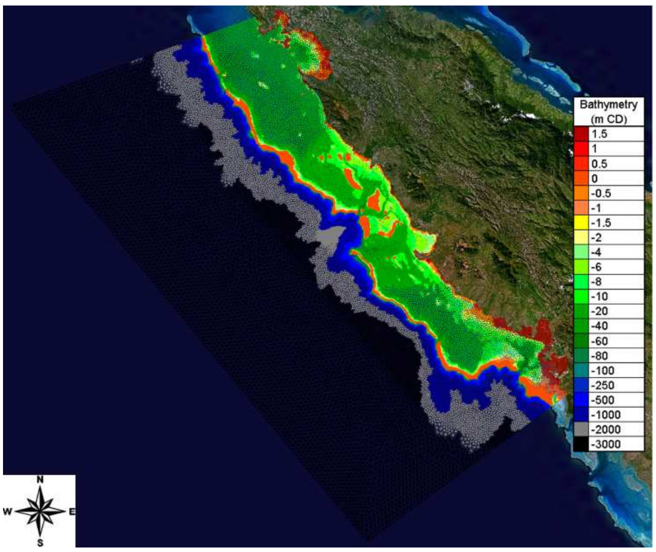

Fig. 5 Mesh and bathymetry

The vertical mesh is only composed of 10 planes (fixed and sigma planes) due to computation time and it is refined in the upper part of the water column.

Different bathymetric data were used to generate the digital depth model:

- GEBCO (General bathymetric Chart of the Oceans) 2014 30 arc-second grid for the offshore part.
- ZONECO bathymetry (Zone économique de Nouvelle-Calédonie) for the lagoon part of the model.
- Digitalisation of SHOM maps for the missing part of the lagoon.

The reef bathymetry is imposed to +0,3 m Chart Datum.

The model is forced on its oceanic boundaries by the global oceanic tide model TPXO ([5]). The tide model gives water depth and velocities at the ocean limit allowing to have a good reproduction of the tidal phenomenon.

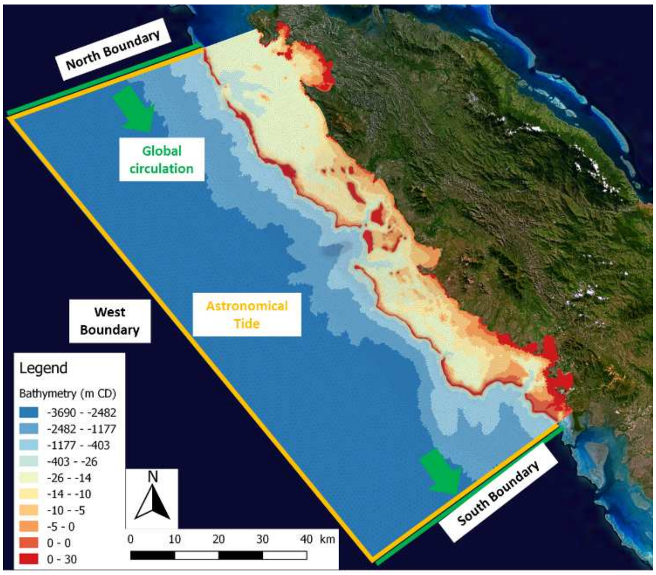

Fig. 6 Forcing scheme

To impose velocity profiles related to the Mercator model at the boundaries, a specific module has been developed. The velocities are imposed to the different boundaries at the different layers. The wind is imposed with a time series and is considered constant in space. The k-epsilon turbulence model ([6]) is used for this study.

The friction is computed with the Manning law and the friction coefficients are assigned depending on the bottom type (sand, mud, reef). The coefficients values given according to the Koniambo project ([7]) are the following:

- 0,02 $m^{-1/3}s$ for the ocean,
- 0,024 $m^{-1/3}s$ for the sandy part of the lagoon,
- 0,035 $m^{-1/3}s$ for the muddy part of the lagoon,
- 0,083 $m^{-1/3}s$ for the reef.

B. *Calibration and validation*

The model is firstly calibrated in terms of water levels comparing with the SHOM predictions at the Paagoumène harbour located at the north part of the model. The comparison is done for two weeks (one in May 2015 and one in August 2015). The water levels are well reproduced by the model with a bias of about 1-2cm (cf. Fig 7).

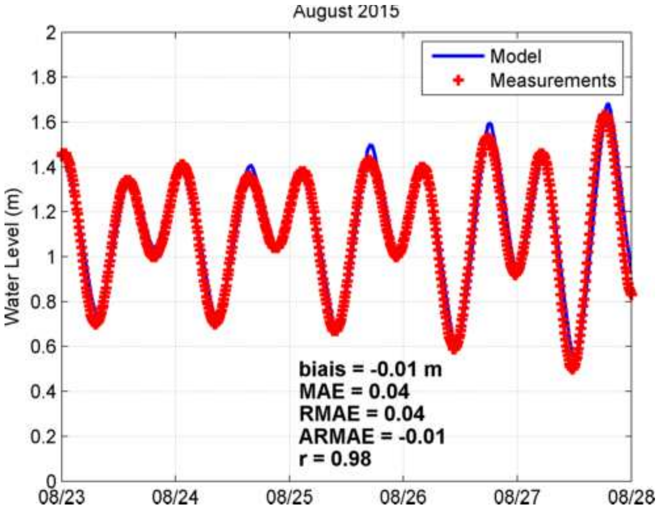

Fig. 7 Comparison of water levels modelled and measured at Paagoumène

The 3D model is then validated in terms of currents with aDcp measurements (measurement campaign of the Koniambo project at the Duroc inlet cf. Fig 8). The comparison between the measured and modelled velocities also shows good results with correct statistical indices (bias of about 7 cm/s).

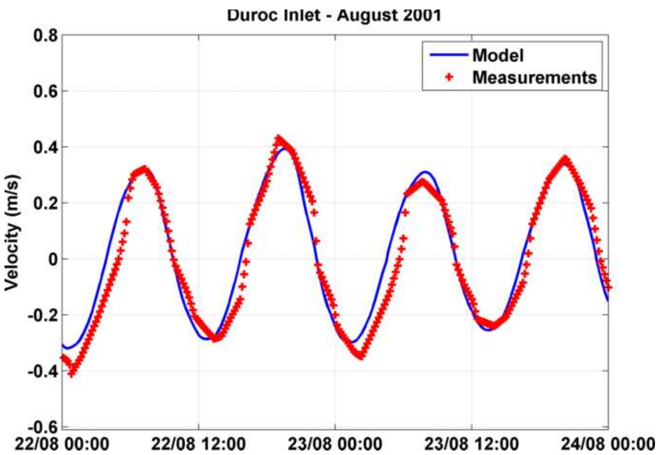

Fig. 8 Comparison of modelled and measured velocities at the Duroc inlet during the campaign of August 2001

These differences can be explained by the bad bathymetric resolution of this part of the mesh due to the lack of data.

IV. MODELLING STRATEGY AND RESULTS

A. *Hypothesis*

To model the sediment disposal, a simplistic but realistic solution was used following the bibliography ([7], [8], [9]). Indeed, in order to represent the sediment resuspension during the fall, sediments are injected in the water column at different depths and especially at the pycnocline.

Depending on the current velocities, 5% for calm conditions and 10% for agitated conditions of the dumped sediments are injected at the surface and also at the pycnocline (layer of density change). The convective descent of the majority of the dumped sediment is not represented in the model.

Grain size measurements show that the sediment dumped are mostly mud (grain size inferior to 63 µm). Due to the sediment size, the fall velocity is estimated with the Stokes formula to be about 0,1 mm/s (neglecting flocculation effects). To only observe the dumping impact, no sediments are considered at the bottom at the beginning of the simulation. The critical shear stress for deposition and erosion were adapted linked to the state of art.

The impact threshold for the reef is considered regarding to the state of art ([3], [10]). Indeed, the reef is considered as impacted for sediment concentrations higher than 10 mg/l (for depth less than 100m).

Concerning the position of the dumping site, similar constraints of the Koniambo project are taken into account i.e. the zone must be located at more than 3,5 km of the reef and for depth higher than 1000m. Therefore, two disposal zones were defined at 4,5 km and 6,5 km of the coral reef. Due to the number of dredges, their capacities and the position of the disposal zone, the dumping occurred about every 3 hours and are considered to last 5 minutes. Therefore, 0,16 m³ of sediment are injected at each time step.

Three scenarii defined with the analysis of the oceano-climatic conditions were modelled on fifteen days:

- Scenario 1 - Calm conditions: weak wind (1 – 5 m/s), low sea state (0,5 m) from South and general current of 0,2 m/s from North-West to South-East.
- Scenario 2 - Agitated conditions of the cool season: waves of 1,8m from South, wind time series of trade wind and westerly sea breezes and no general circulation.
- Scenario 3 - Agitated conditions of the hot season: waves of 1,8m from South, strong south-east trade wind and a general current of 0,4 m/s from North-West to South-East.

B. *Results*

In order to respect the Courant condition, a time step of 5 seconds had been chosen. With a sixteen-core computer, simulations of fifteen days had a computation time of about twenty-four hours.

The different simulations show that the currents around the disposal zone are relatively low (< 0.3 m/s). The strongest currents are observed at the inlets of the lagoon with velocities of about 0,8 m/s especially during the flood and the ebb tide.

A gyre can be observed around the dumping zone generated by the global circulation impacting the bay and the two inlets. The velocities of the gyre are linked to the global circulation.

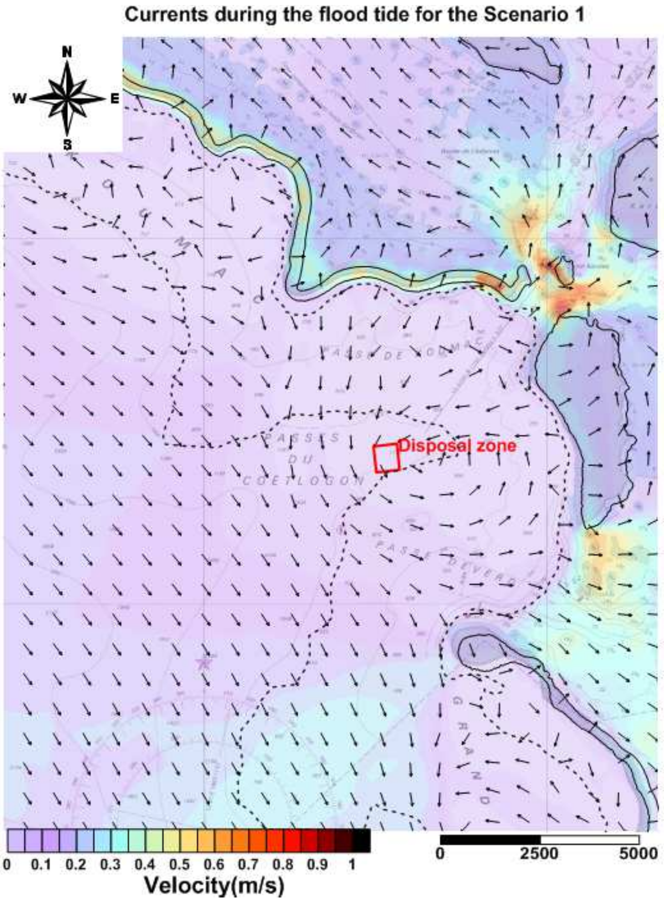

Fig. 9 Map of current during the flood tide for the scenario 1 conditions. The red square shows the position of the disposal zone.

Indeed, due to the low velocities, sediment transport is limited, the sediments fall in the water column and stay close to the disposal site (cf. Fig. 10 and Fig. 11). After a dumping, the sediment concentration in the disposal zone decreases quickly.

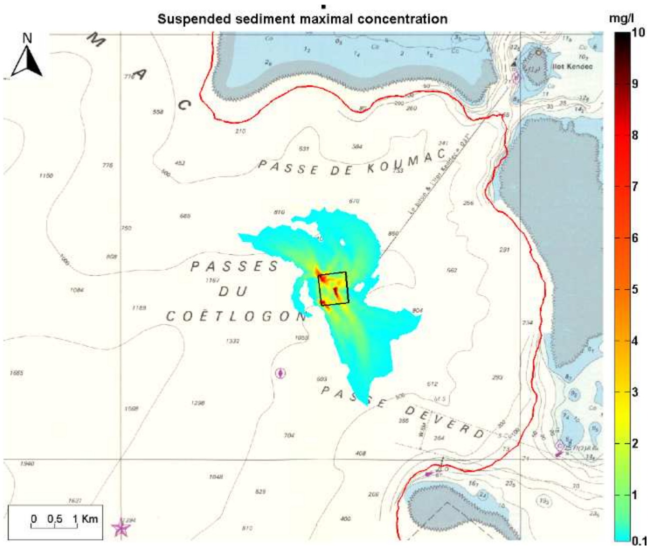

Fig. 10 Map of maximal sediment concentration for the scenario 1. The red line is the isobath -100m Chart Datum. The black square shows the disposal site position.

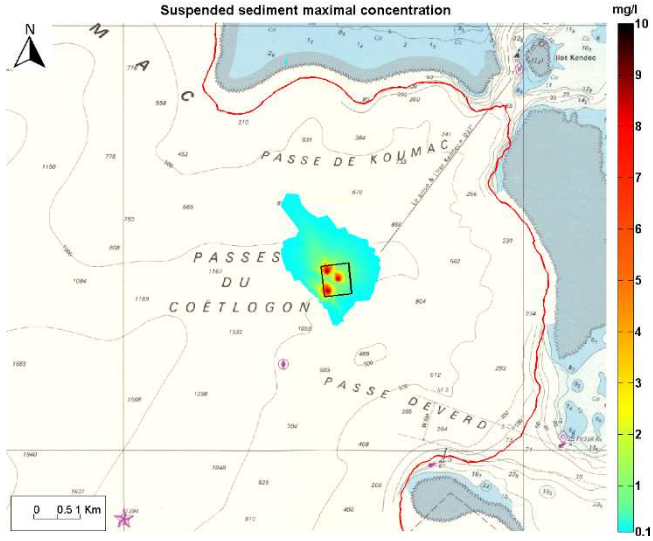

Fig. 11 Map of maximal sediment concentration for the scenario 3. The red line is the isobath -100m Chart Datum. The black square shows the disposal site position.

The maximal sediment concentration modelled are about 15-20 mg/l in the disposal zone and less than 5 mg/l out of the dumping zone. The influence of wind or wave is limited due to the depths around the disposal zone. However, the sediment plume for the scenario 3 is mostly propagated to the North-North-West due to South-South-East winds.

The simulations show that the reef should not be impacted for the different modelled conditions. The sediment concentrations are relatively low near the reef. The scenario 3 for agitated conditions of the hot season is the worst one with concentrations at the reef of about 0,13 mg/l. The maximal concentration at the reef for the calm scenario is about 0,075 mg/l and 0,02 mg/l for the cool season simulation. These simulations show that the concentrations observed at the reef are one hundred times lower than those who could impact the reef.

A second disposal site has also been studied at 6,5 km of the reef. The site is more sensible to the global current. Indeed, this site is located out of the gyre. Therefore, the reef is less impacted by the dumping. For the scenario 3, the maximal sediment concentration at the reef is about 0,085 mg/l which is twice as low as for the closest site.

Long term simulations of one month has also been carried out to observe the cumulative impact of successive disposals. This work showed that the cumulative impact of successive dumpings is negligible. The dumping impacts are temporary and punctual.

V. Conclusion

The Pandop harbour requires dredging operations to maintain its activities due to important sedimentation processes. The aim of this study is to evaluate the impact of the dumped sediment dispersion especially on the coral reef.

For this purpose, a 3D hydrosedimentary model has been developed to reproduce the different hydrodynamic processes on the North-West part of New Caledonia. Some specific modules have been added or modified to represent the dumping in the model and to impose velocities profiles at the different boundaries.

Thanks to this work, the dispersion of released dredged sediment has been modelled for different oceano-climatic conditions to estimate their impact on the reef. The studied disposal site is located in a "bay" where a gyre can be observed. The site configuration leads to low currents resulting in limited sediment transport. For the different modelled oceano-climatic conditions, the suspended sediment concentrations at the reef caused by the dumping are relatively low and do not impact the coral reef.

Moreover, the cumulative impact of successive disposals is limited and negligible especially on the reef.

A second disposal site has also been studied leading to a diminution of the impact but a cost rise (rise of the distance with the harbour and need of a supplementary dredge to keep the same work rate).

REFERENCES

[1] S.Cravatte, E. Kestenare, G. Eldin, A. Ganachaud, J. Lefèvre, F. Marin, C. Menkes and J. Aucan, “Regional circulation around New Caledonia from two decades of observations,” Journal of Marine Systems, vol. 148 pp. 249–271, 2015.

[2] C. Hénin, J. M. Guillerm and L. Chabert, "Circulation superficielle autour de la Nouvelle-Calédonie," in Océanographie Tropicale, pp. 113-126, 1984.

[3] NSR, "Koniambo Project, Physical Marine Investigations," NSR Environmental Consultants, 2002, unpublished.

[4] P. Brasseur, P. Bahurel, L. Bertino, F. Birol, J. M. Brankart, N. Ferry, S. Losa, E. Remy, J. Schröter, S. Skachko, C. E. Testut, B. Tranchant, P. J. Van Leeuwen and J. Verron, "Data assimilation in operational ocean forecasting systems: The Mercator and Mersea developments", Q.J.R. Met. Soc., Vol. 613, C, pp 3561-3582(22).

[5] G. D. Egbert and S. Y. Erofeeva, "Efficient inverse modelling of barotropic ocean tides". Journal of Atmospheric and Oceanic Technology, Vol. 19, pp 183-204, 2002.

[6] B. E. Launder and D.B. Spalding, "Lectures in Mathematical models of Turbulence", Academic Press, 1972.

[7] KBR, 'Koniambo Port Project," Dredge spoil disposal report, 2002.

[8] C. Alzieu, "Dragages et environnement marin. Etat des connaissances," Editions Ifremer, 225 p. 2000.

[9] R. Boutin, "Dragage et rejets en mer. Les produits de type vase", Presses de l'ENPC, 307p. 2000.

[10] P. L. A. Erftmeijer, B. Riegl, B. W. Hoeksema and P. T. Todd, "Environmental impacts of dredging and other sediment disturbances on corals: A review," Marine Pollution Bulletin, vol. 64. Pp 1737-1765. 2012.