ISOS|2023

Simposio Internacional sobre Sistemas de Emisarios 2023

International Symposium on Outfall Systems 2023

IAHR AIRH International Association for Hydro-Environment Engineering and Research

Hosted by Spain Water and IWHR, China

IWA the international water association

Coupled wave-current modeling of outfall sediment dynamics in shallow coastal waters

DIEGO A. CASAS, TOBIAS BLENINGER, MAURÍCIO F. GOBBI AND SILENE C. BAPTISTELLI

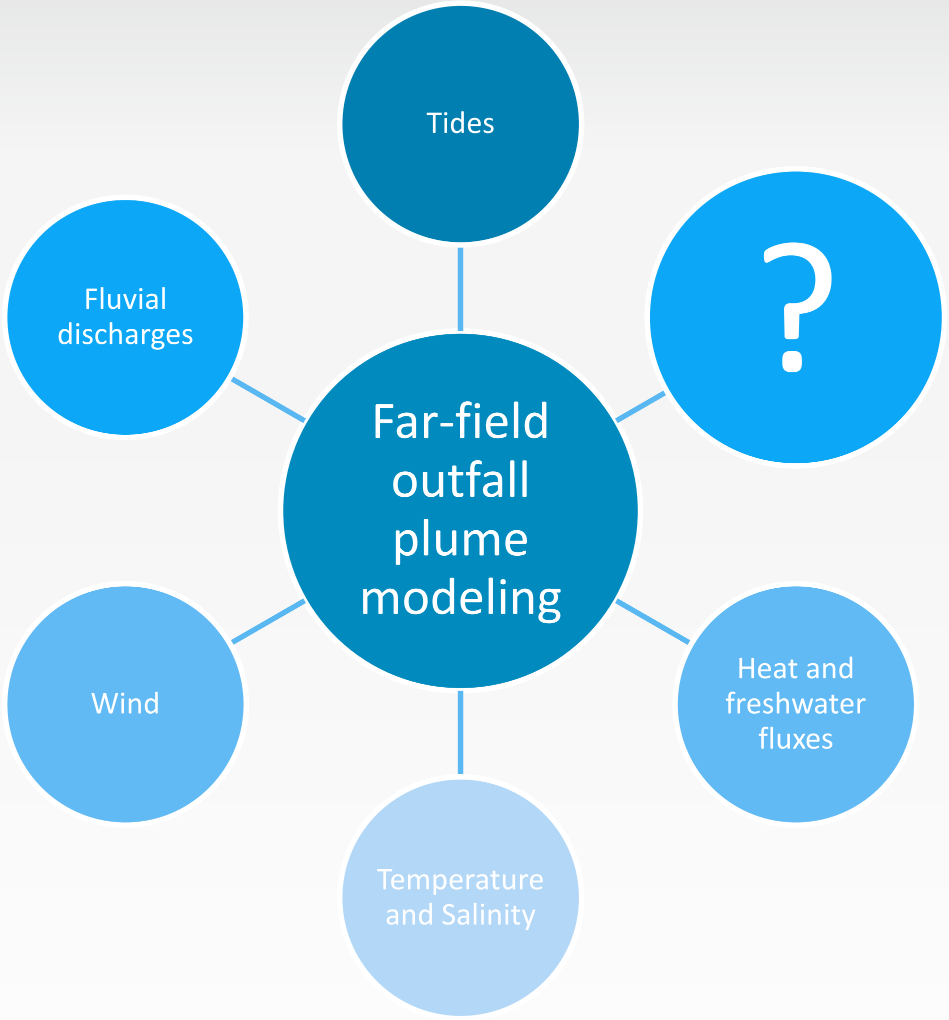
aysa Lo bueno del agua llega.

COFES

Ministerio de Obras Públicas Argentina

INTRODUCTION

- The effects of several physical processes on far-field outfall plume behavior have been extensively examined both in 2D and 3D models such as MIKE21/3, ROMS, MOHID and Delft3D
- Despite the understanding of outfall plume behavior under a variety of coastal and oceanic forcings, there are still processes whose effects have not been properly investigated.



INTRODUCTION

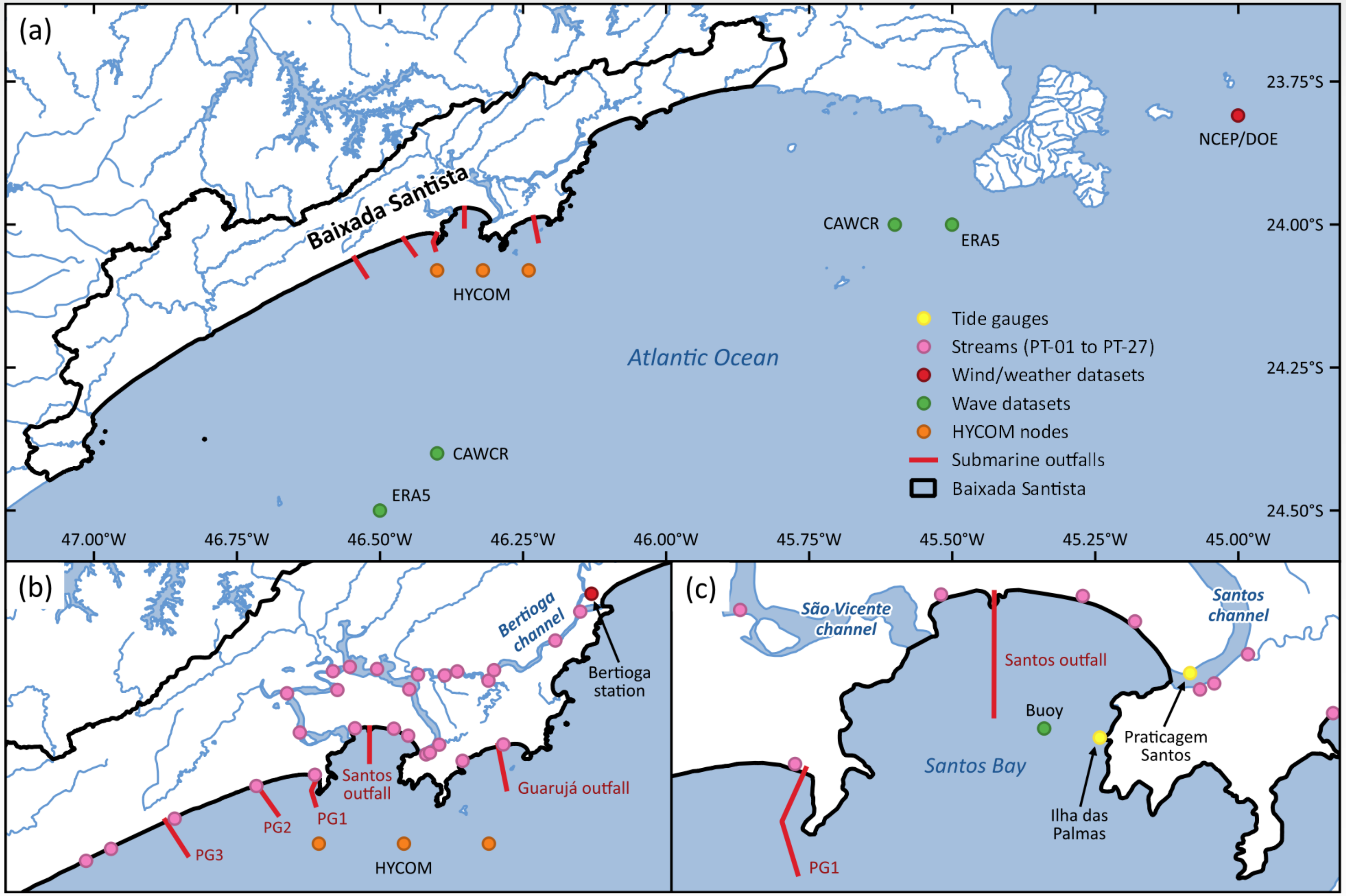
- One of those processes is ocean waves, as it has been pointed out by several authors.
- Furthermore, including waves in far-field outfall models is not common in the current practice

Wu et al. (1991)	Lee et al. (2003)	Neves (2006)	Bleninger (2006)	Terfous et al. (2016)
Observed current-induced resuspension Suggested that waves may contribute to resuspension in the vicinity of outfalls	Concluded from site measurements that waves were a dominant process for resuspension in some parts of the shelf	Associated wave measurements to: 1.- Sediment resuspension 2.- Prevention of deposition around diffusers 3.- Impacts on local benthic system	Proposed future work on settling and resuspension of particles (attached pollutants) Mentioned the interaction of particles with waves	Modeled sediment deposition from outfall jets Proposed the inclusion of wave motion effects as future work

OUTFALL SYSTEMS

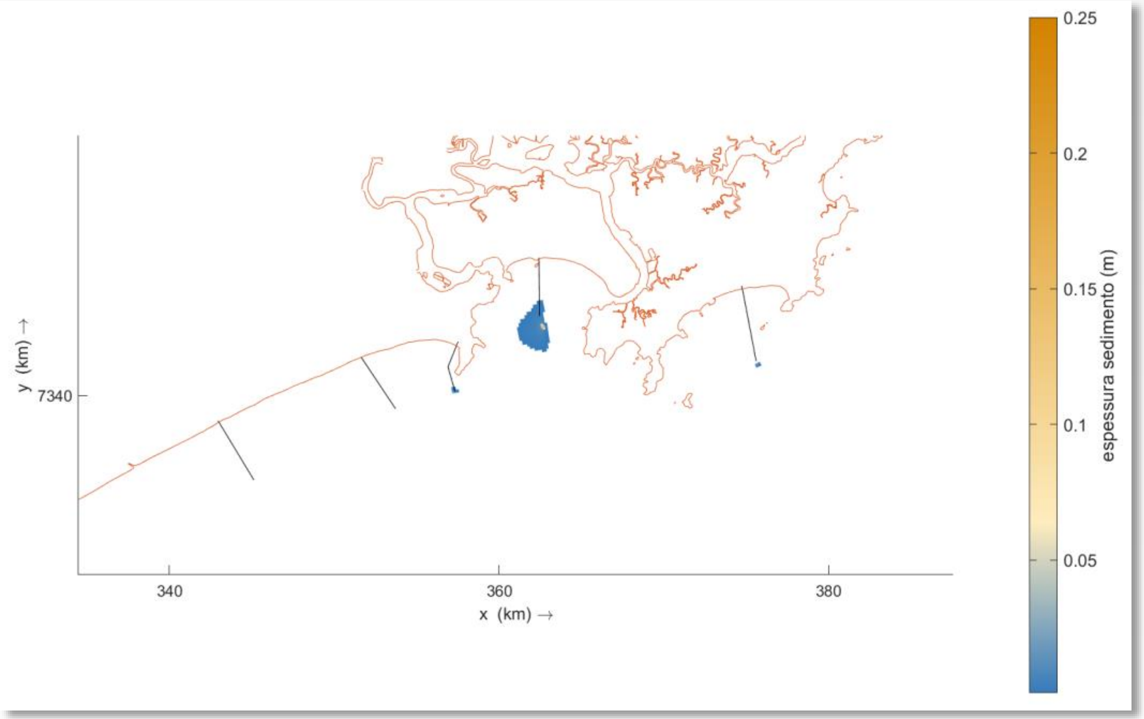
- 5 submarine wastewater outfalls
- Baixada Santista, SP, Brazil
- Outfalls operated by Sabesp
- Data for 2019

Outfall	Length (km)	Depth (m)	Mean discharge (m^3/s)
Santos	4.4	11.5	2.08
Guarujá	4.5	14	0.59
PG1	3.3	14	0.55
PG2	3.3	14	0.52
PG3	4.1	13	0.15

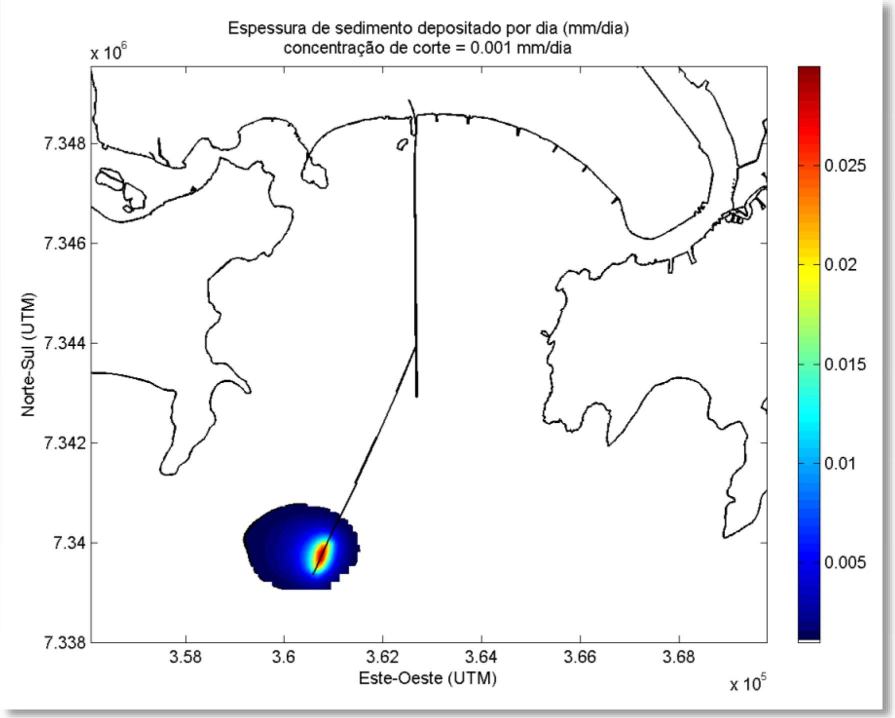


OUTFALL SYSTEMS

- 2021 – Consulting service by Consórcio Integração CAGM for Sabesp
- Sediment deposition of ~25 cm/year (?) in Santos Bay



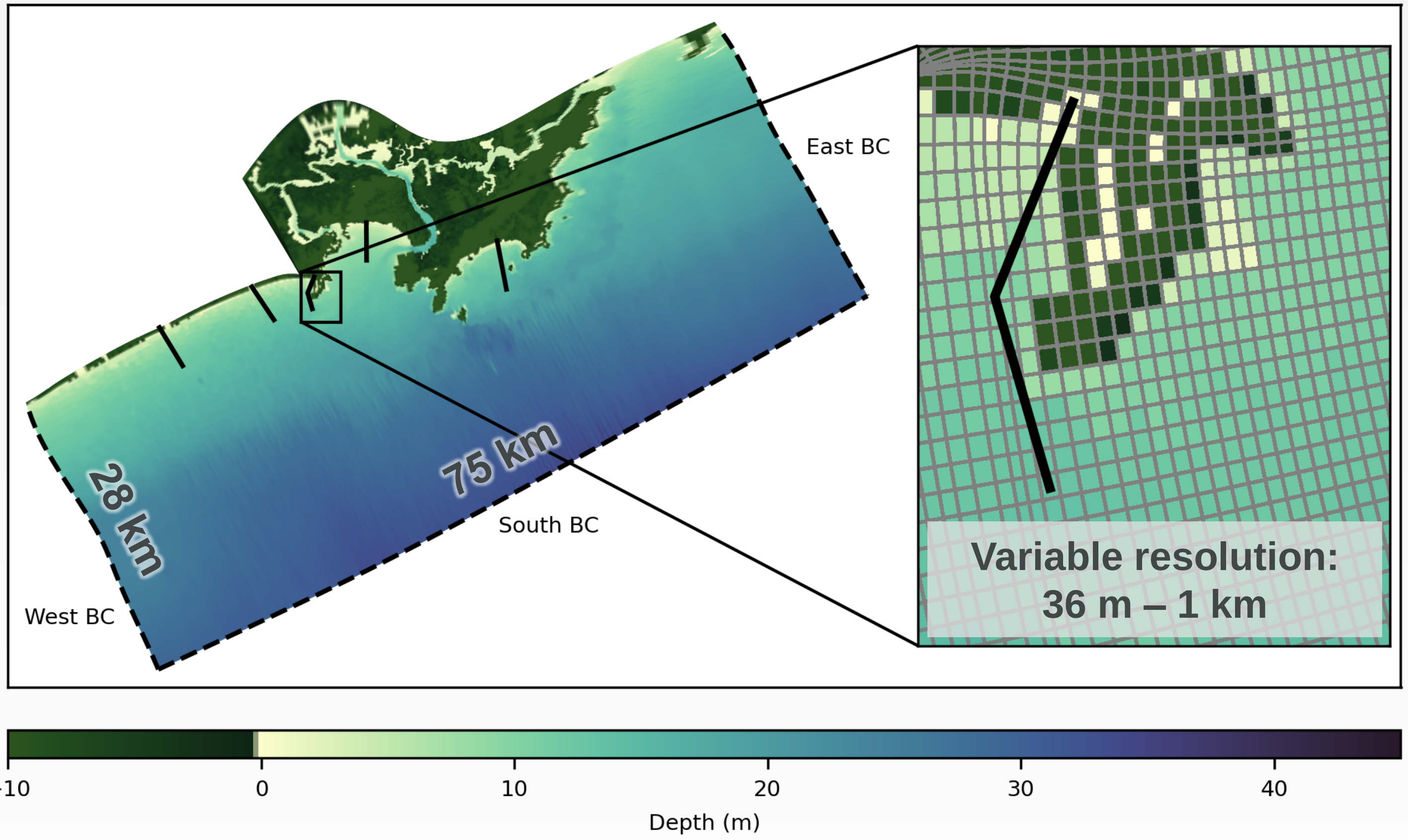
- 2017 – Consulting service by Consórcio Partner-TetraTech for Sabesp
- Decreased deposition by stronger offshore currents



IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China
IWA the international water association
aysa Lo bueno del agua llega.
COFES
Ministerio de Obras Públicas Argentina

METHODOLOGY – HYDRODYNAMIC MODEL

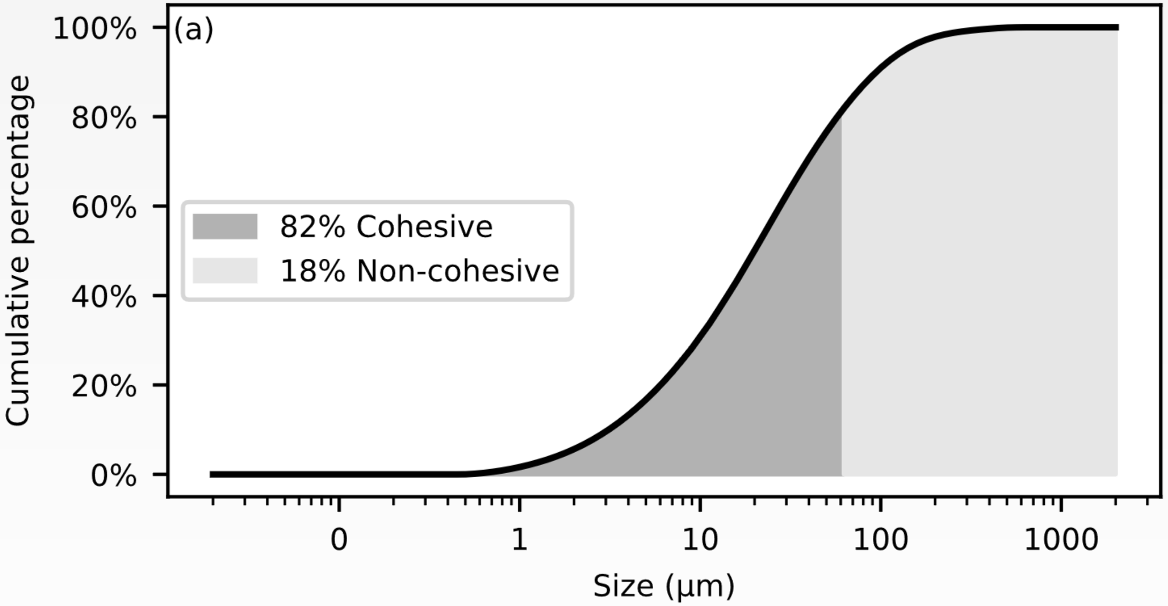
- Hydrodynamic model:
  - Delft3D-FLOW
  - Depth-averaged
- Calibration and validation (2012)
- Actual study (2019)
- 2012/2019: Tides, salinity, temperature, wind, heat flux, Coriolis, freshwater discharges and outfall discharges
- **2019: + Suspended solids from outfalls**

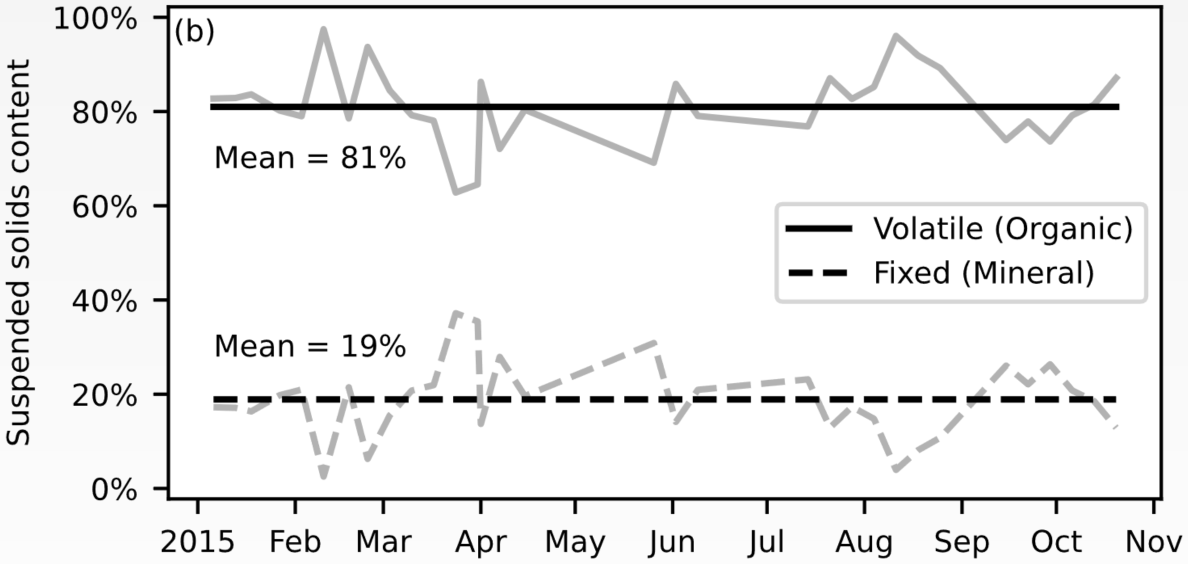


METHODOLOGY – SEDIMENT TRANSPORT

Outfall	TSS (kg/m³)
Santos	0.278
Guarujá	0.128
PG1/2/3	0.134

- Two sediment fractions: cohesive and non-cohesive
- Sediment density corrected for organic content (2650 kg/m³ ➞ 1513 kg/m³)





IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China

IWA the international water association

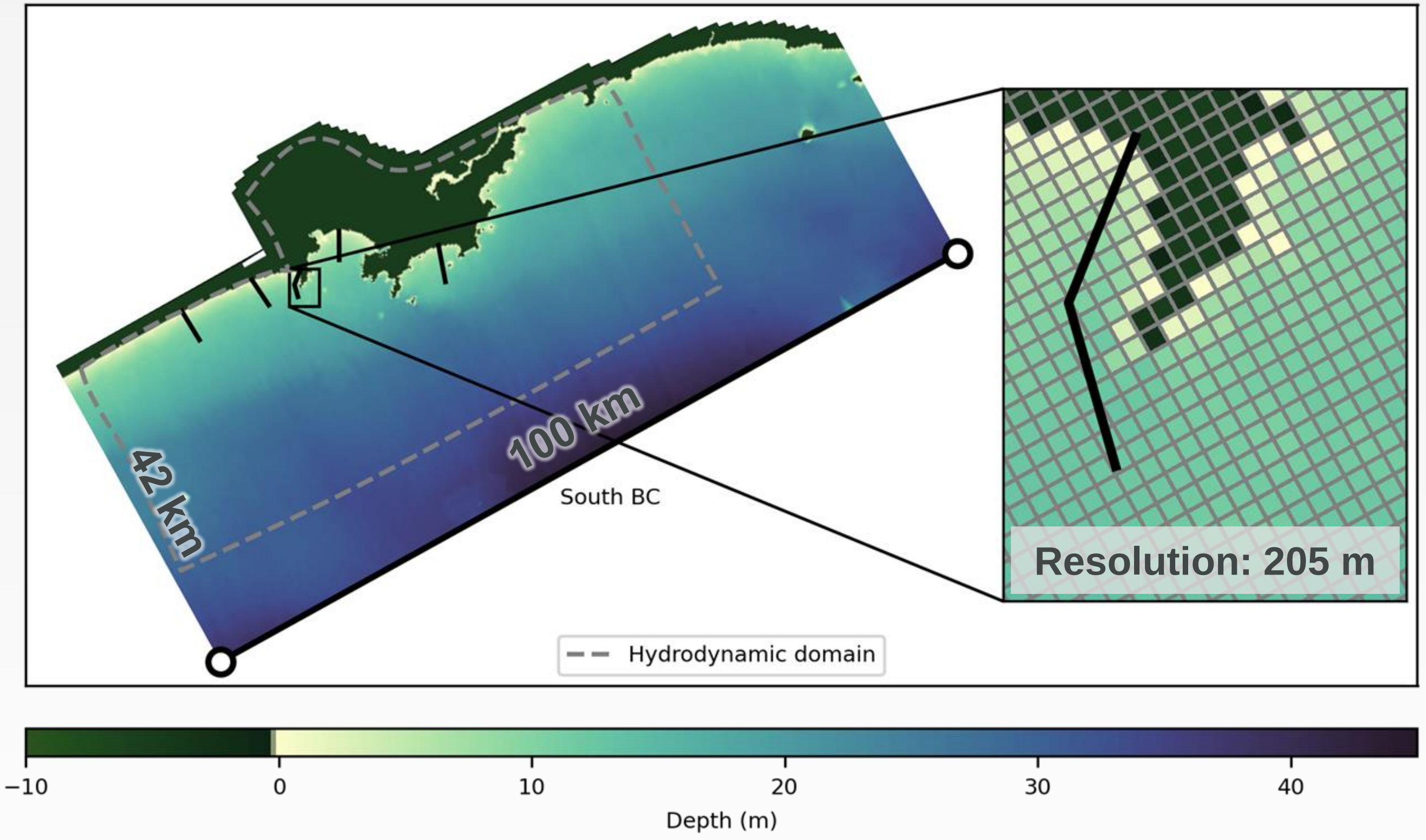
aysa Lo bueno del agua llega.

COFES

Ministerio de Obras Públicas Argentina

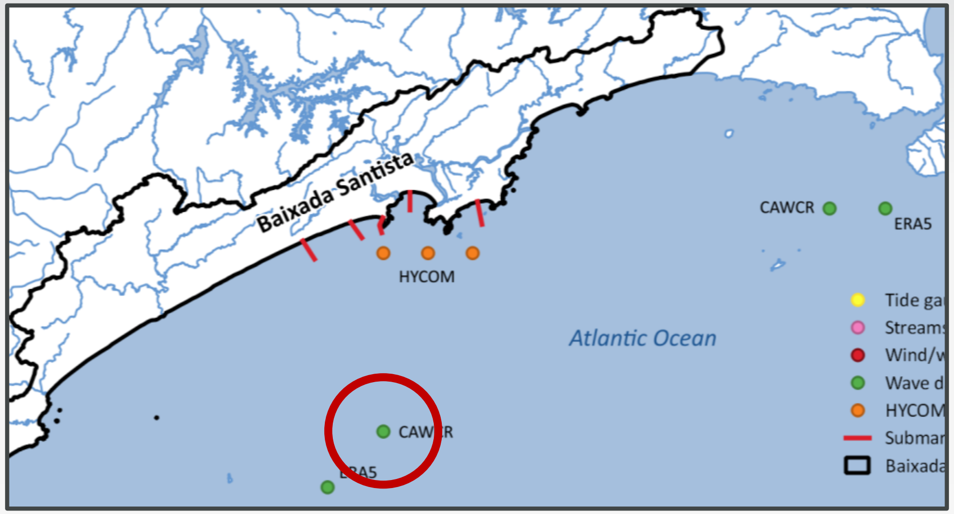
METHODOLOGY – WAVE MODEL

- Wave model
  - Delft3D-WAVE (SWAN)
  - Spectral description of waves
- Validation (2016)
- Actual study, wave-current coupling (2019)
- 2016/2019: Energy input by wind, non-linear wave-wave interactions, bottom friction, depth-induced breaking and whitecapping
- **2019: + Wave-current interaction**

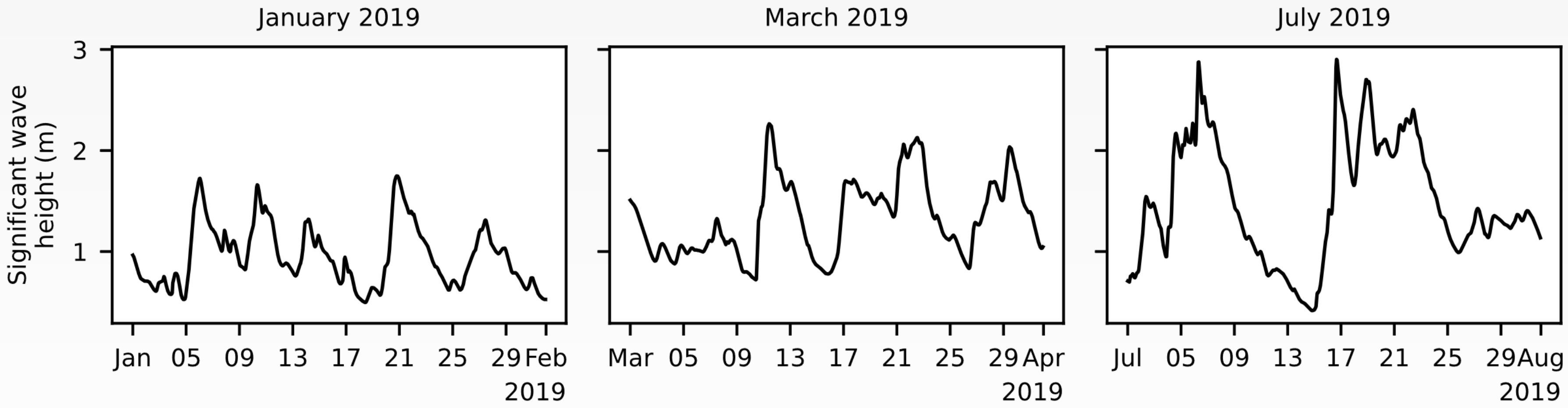


METHODOLOGY

- Analysis of wave height and period (2019)
- January – mild
- March – mean
- July – strong



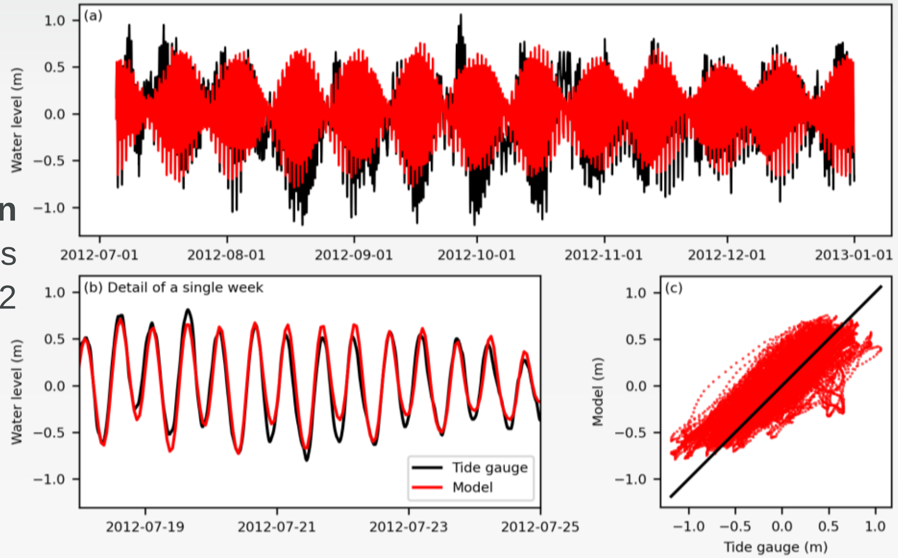
H_s



CALIBRATION AND VALIDATION

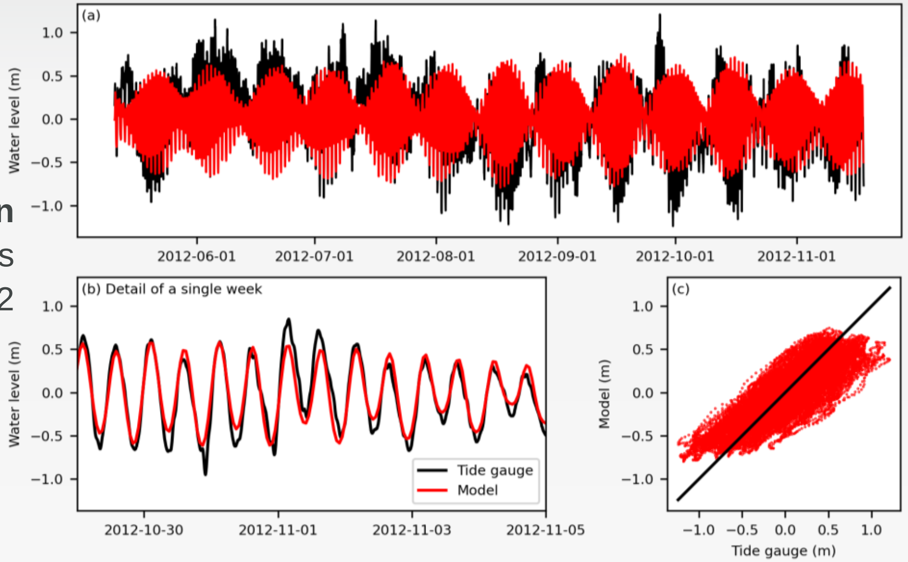
Calibration
Praticagem Santos
July–December 2012

71%

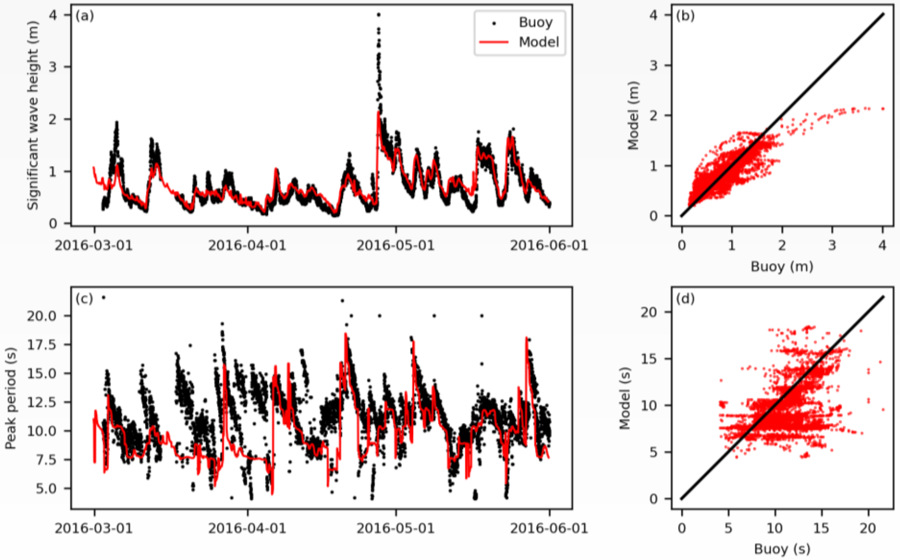


Validation
Ilha das Palmas
May–November 2012

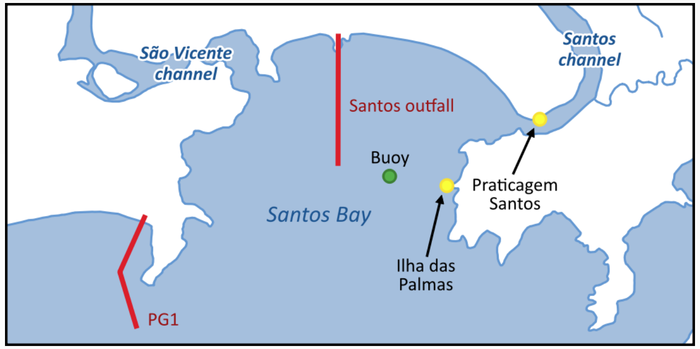
72%



Wave model
Mid Santos Bay
March–May 2016



H_s: 78%
T_p: 43%



* Index of model performance by Willmott et al. (2011)

IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China
IWA the international water association
aysa Lo bueno del agua llega.
COFES
Ministerio de Obras Públicas Argentina

SUSPENDED SEDIMENT

- Temporal mean of total sediment concentration
- The Santos outfall has the largest sediment plume
- Waves ➞ + suspended sediment
- Sediment advected by currents

Effluent: $O(10^{-1}$ kg/m3)

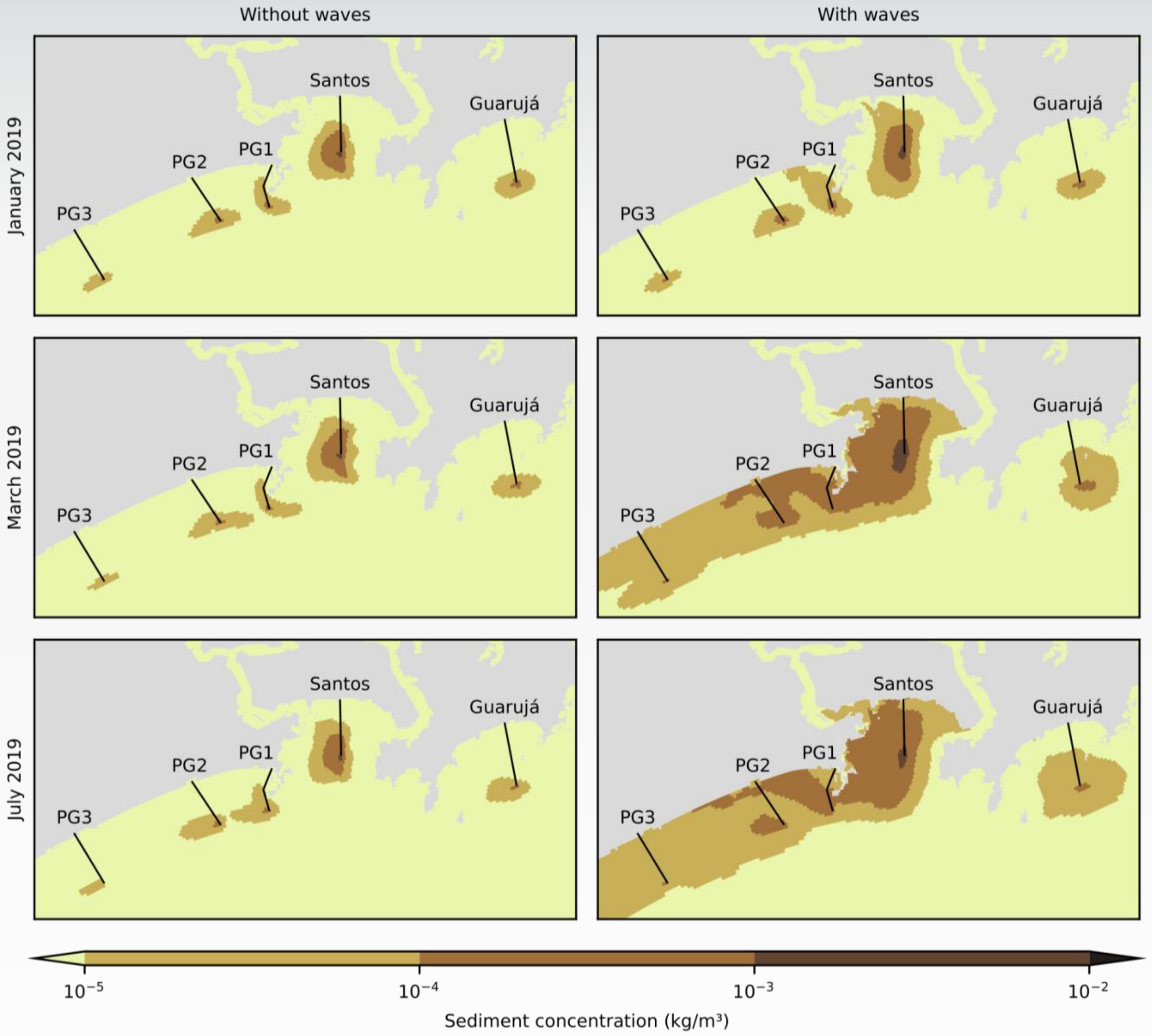
After release: $O(10^{-3}$ kg/m3) and lower

Environment: $O(10^{-2}$ kg/m3) (Berzin, 1992)

January
Mild

March
Mean

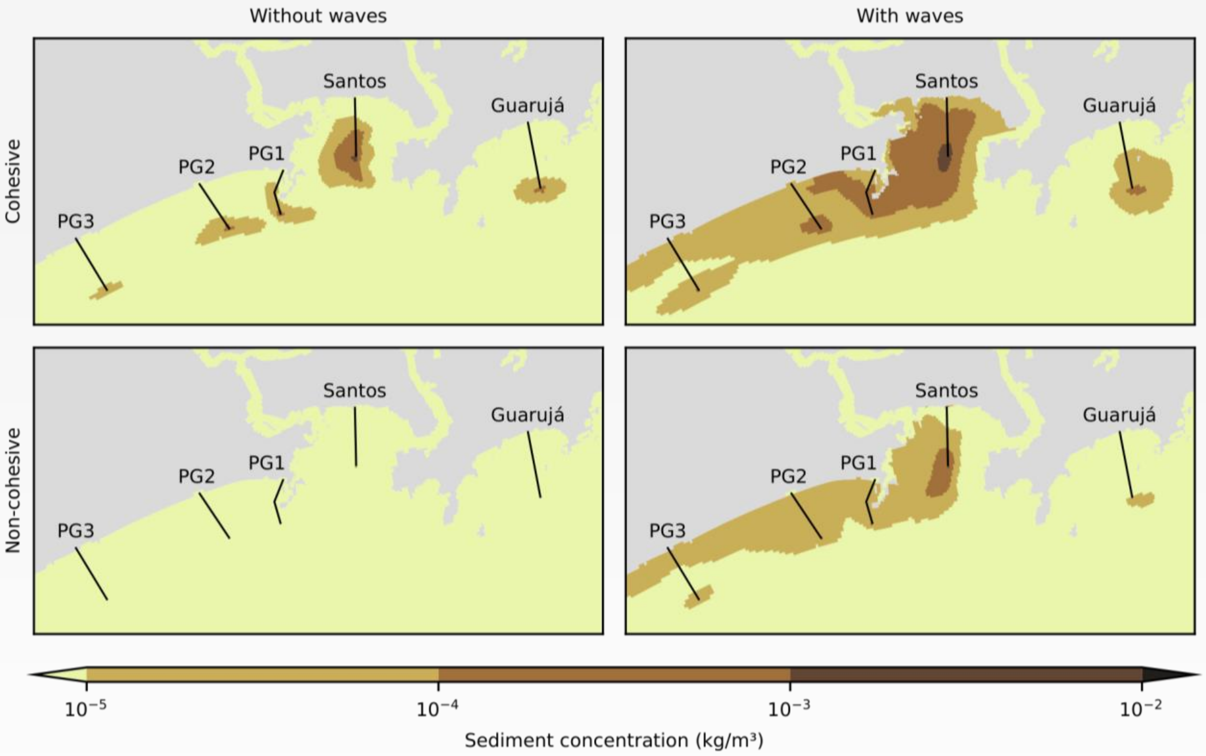
July
Strong



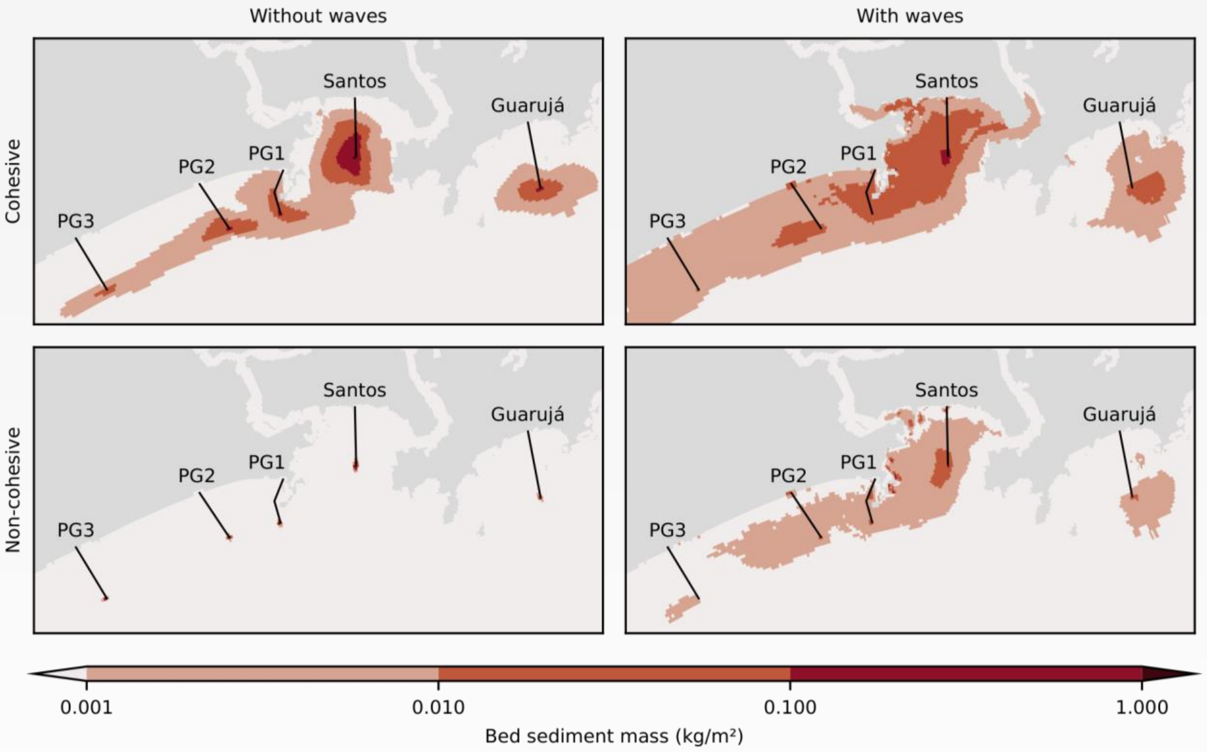
IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China
IWA the international water association
aysa Lo bueno del agua llega.
COFES
Ministerio de Obras Públicas Argentina

COHESIVE AND NON-COHESIVE FRACTION

Mean sediment concentration (kg/m³)



Bed sediment mass (kg/m²)



IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China

IWA the international water association

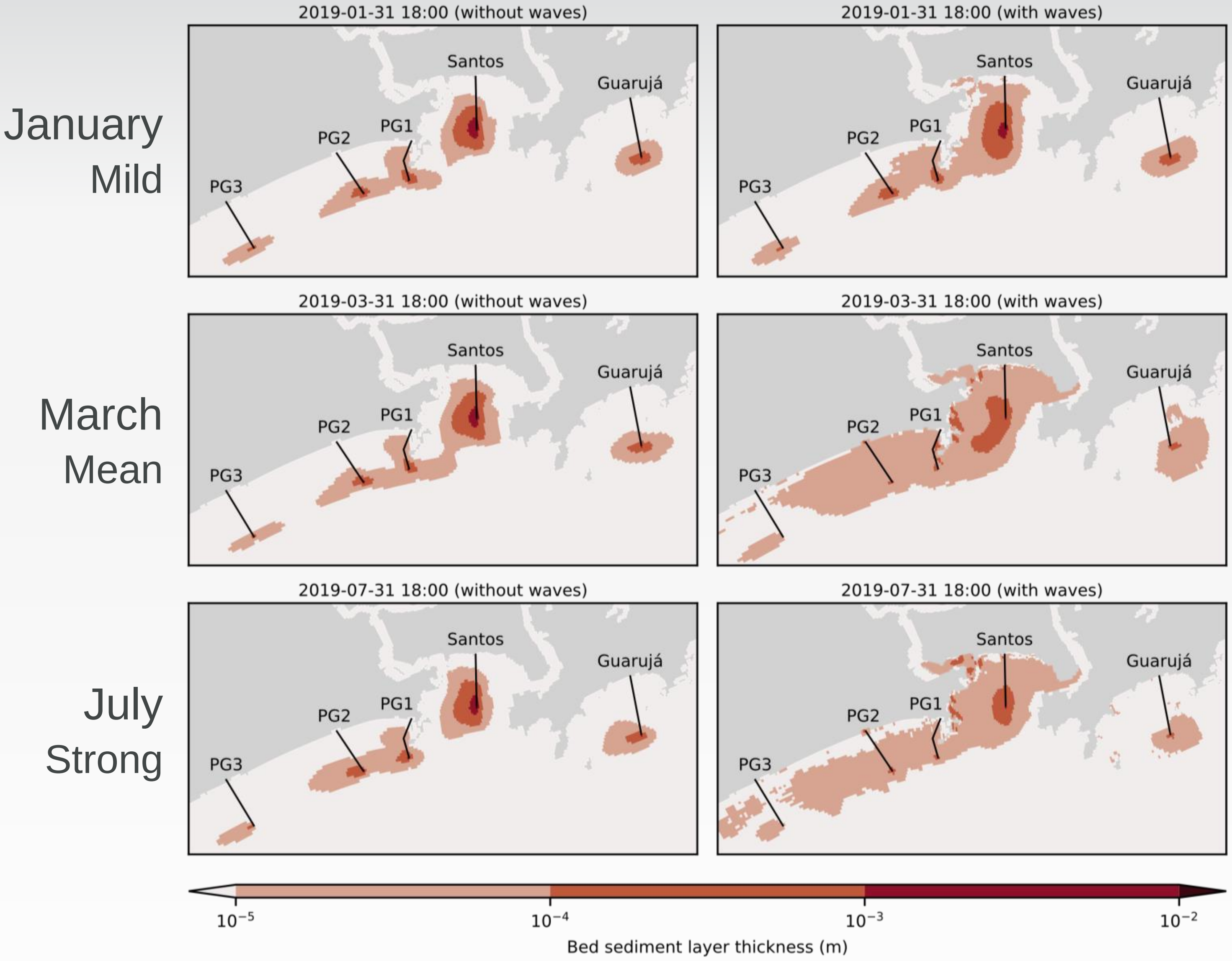
aysa Lo bueno del agua llega.

COFES

Ministerio de Obras Públicas Argentina

SEDIMENT DEPOSITION

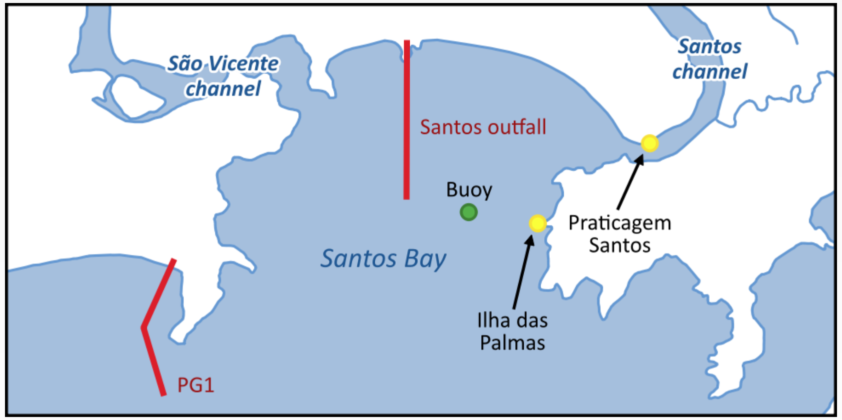
- Bed sediment layer thickness
- Waves disperse sediment over larger extents
- The advected sediment settles far from the discharge location
- Sediment reaches channels and nearby coasts

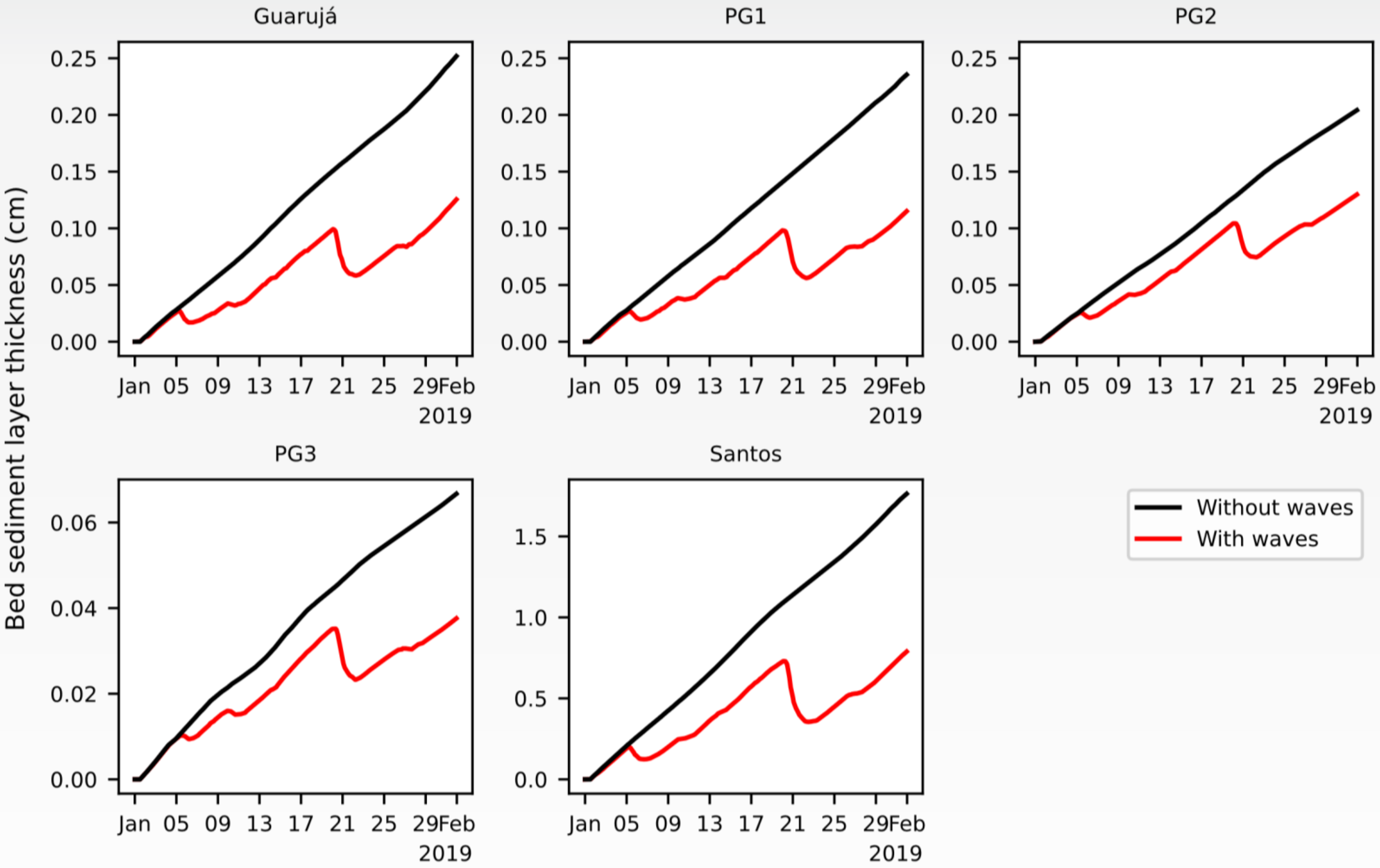


SEDIMENT DEPOSITION (JANUARY / MILD WAVES)

Resuspension around
January 5, 10 and 20

Santos: 1.76 cm ➞ 0.79 cm **(55%)**
PG3: 0.07 cm ➞ 0.04 cm **(44%)**





IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China

IWA the international water association

aysa Lo bueno del agua llega.

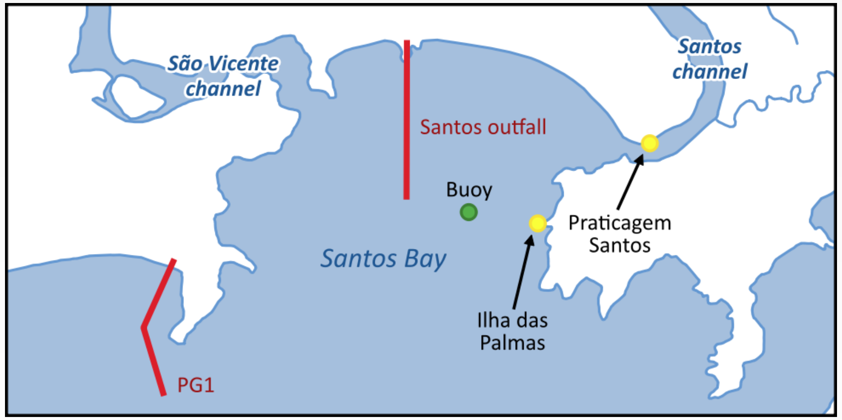
COFES

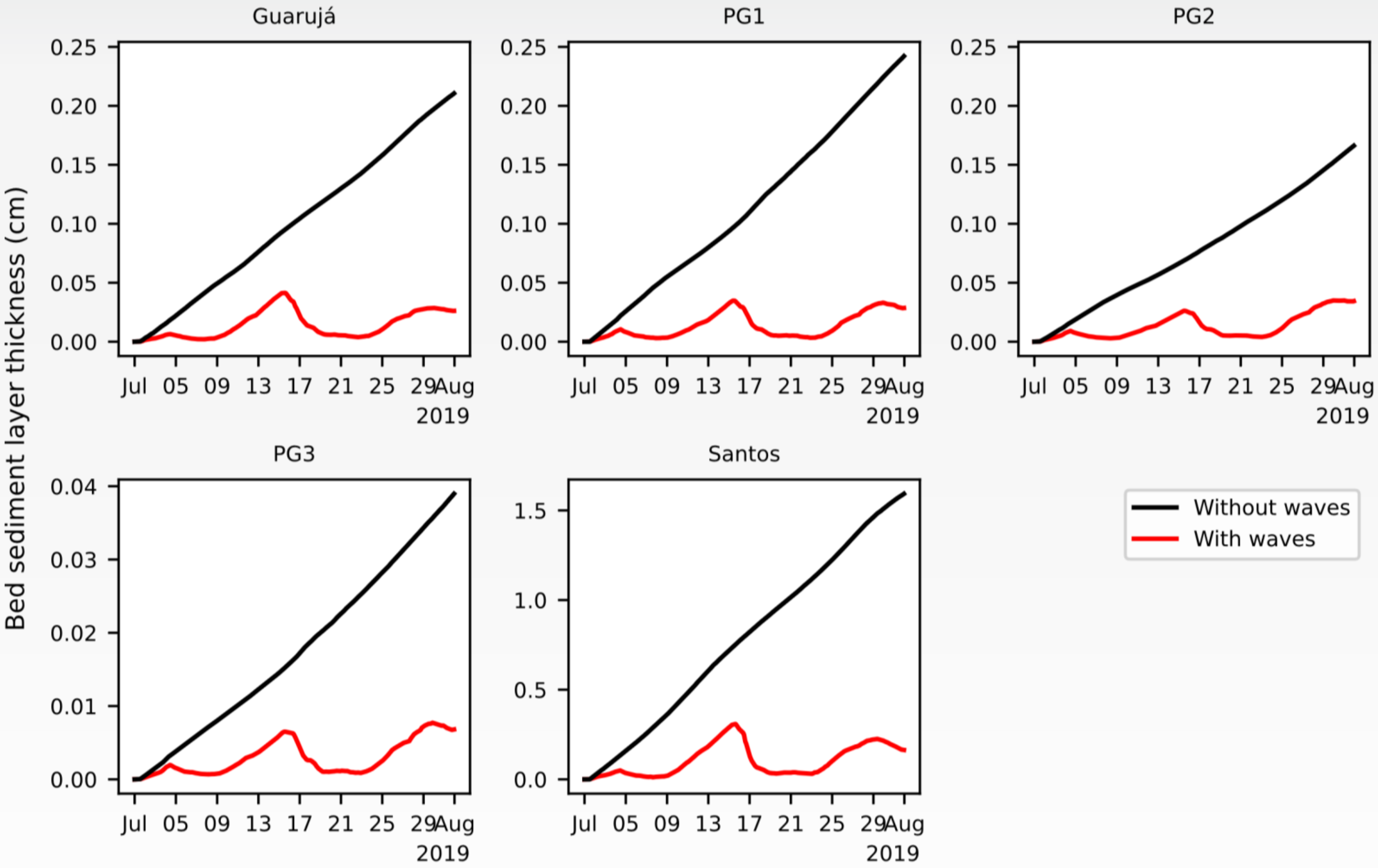
Ministerio de Obras Públicas Argentina

SEDIMENT DEPOSITION (JULY / STRONG WAVES)

Resuspension most of the time

Santos: 1.59 cm ➞ 0.16 cm **(90%)**
PG3: 0.04 cm ➞ 0.01 cm **(83%)**





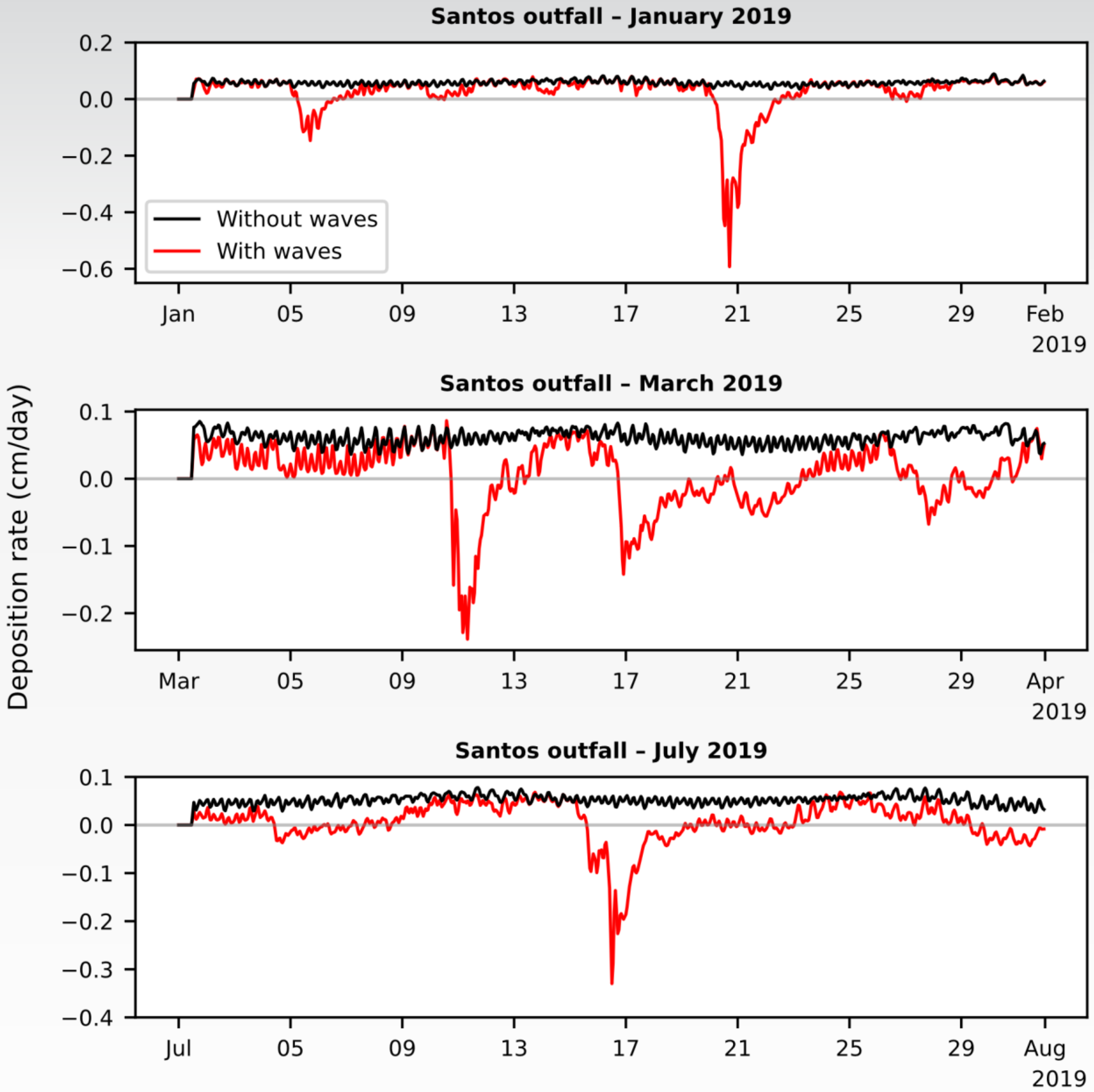
DEPOSITION RATE (SANTOS)

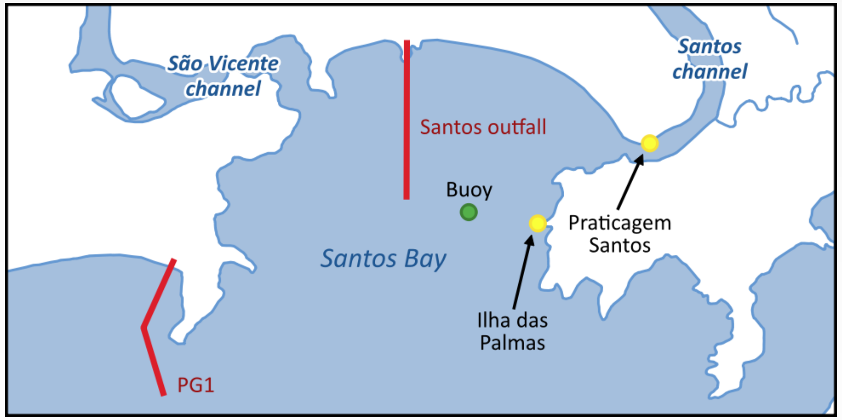
- Undisturbed deposition:
  0.06 cm/day ➞ **~20 cm/year** (unrealistic)
- Waves ➞ resuspension and reduced rate

January
Mild

March
Mean

July
Strong





DEPOSITION RATE
(SANTOS / MARCH / MEAN WAVES)

Current-alone stress

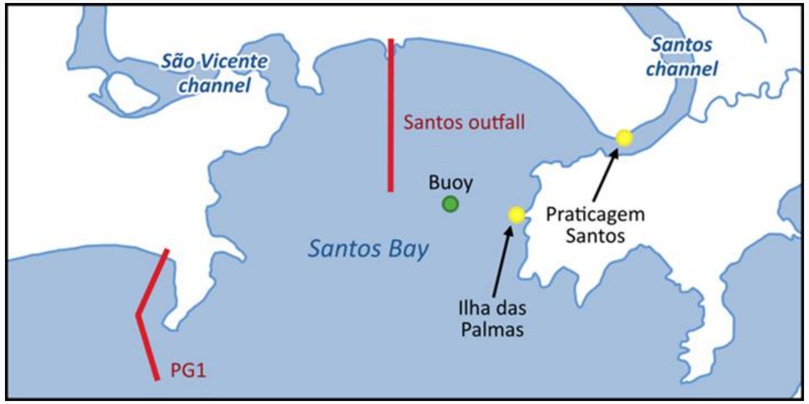
+

Wave-alone stress

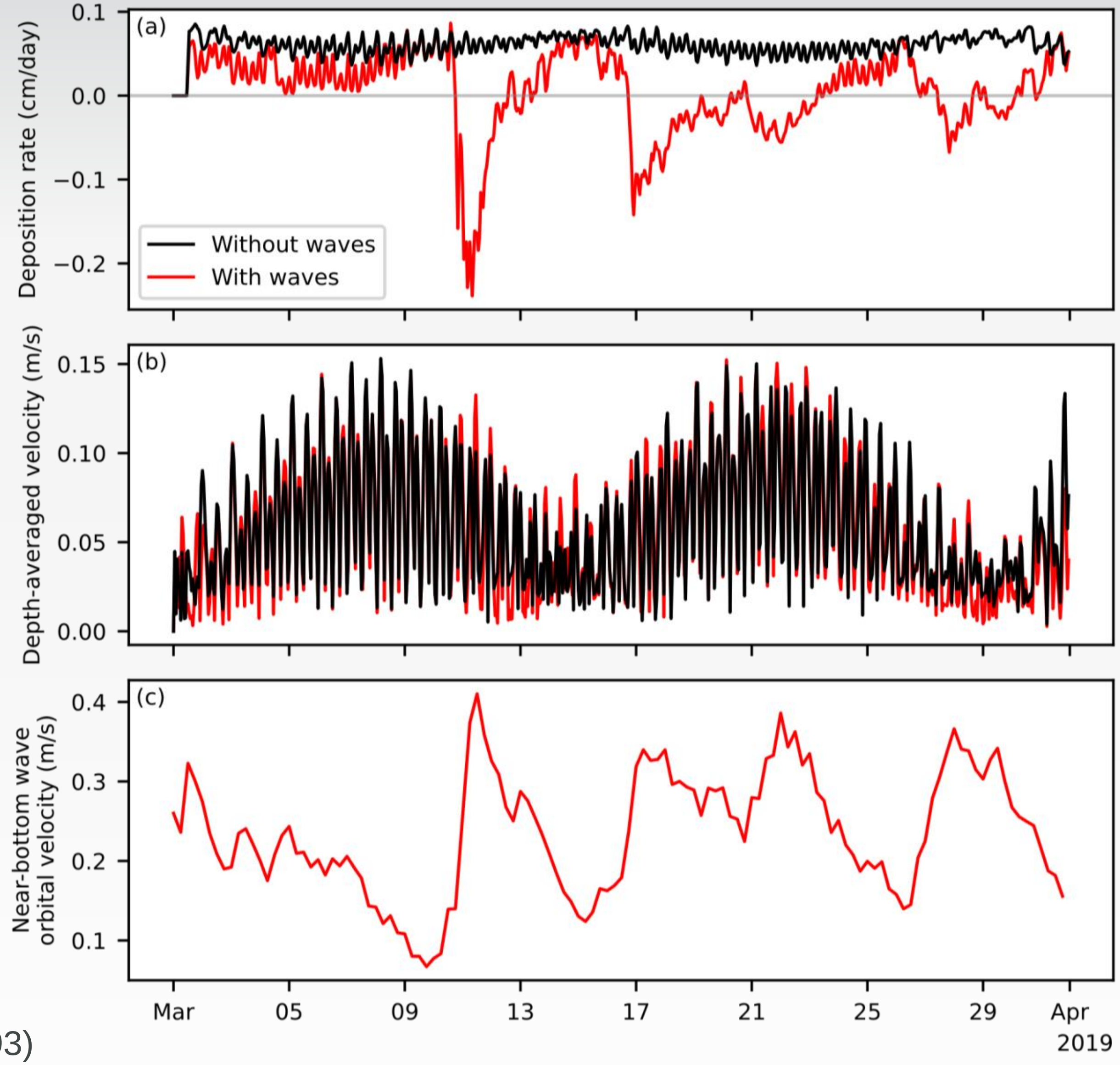
=

Oscillatory stress*

(time-mean, **maximum**)



* Soulsby et al. (1993)



International Association for Hydro-Environment Engineering and Research

Hosted by Spain Water and IWHR, China

the international water association

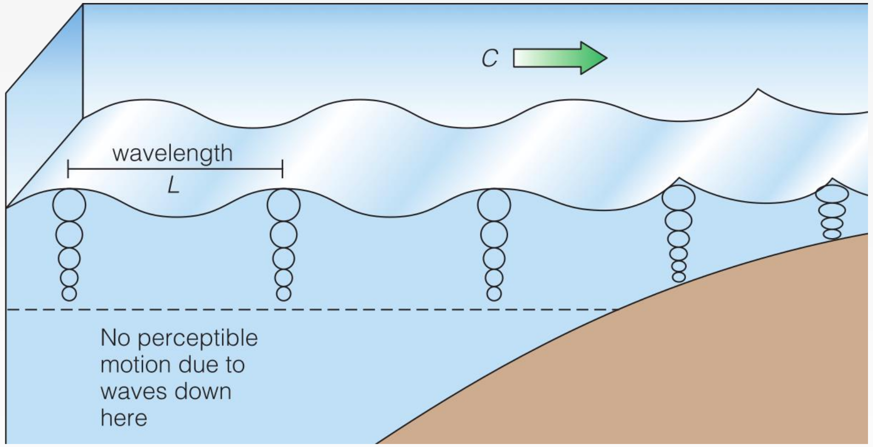
aysa Lo bueno del agua llega.

COFES

Ministerio de Obras Públicas Argentina

WAVE REGIME

- Depth-wavelength* ratio
- Lower limit of wave action (0.5)
- Wave-bed interaction



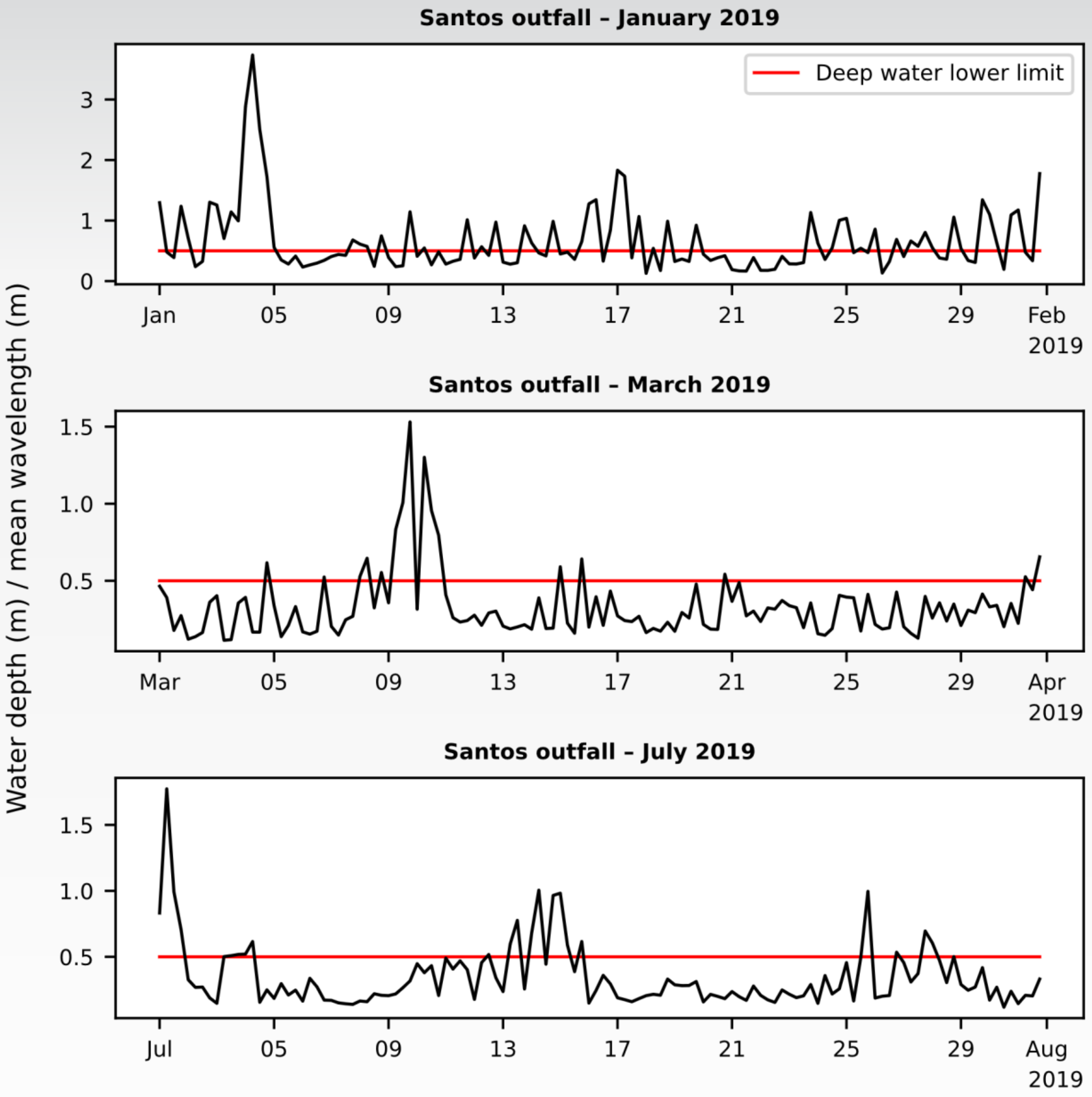
Garrison & Ellis (2016). Oceanography: An Invitation to Marine Science, 9th edition. Cengage Learning.

* Mean spectral wavelength

January
Mild

March
Mean

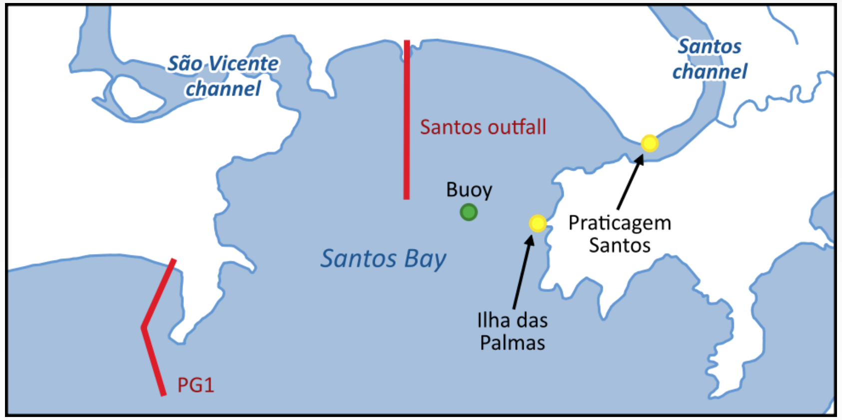
July
Strong



WAVE REGIME

- Near-bed orbital velocity is directly proportional to wave height:

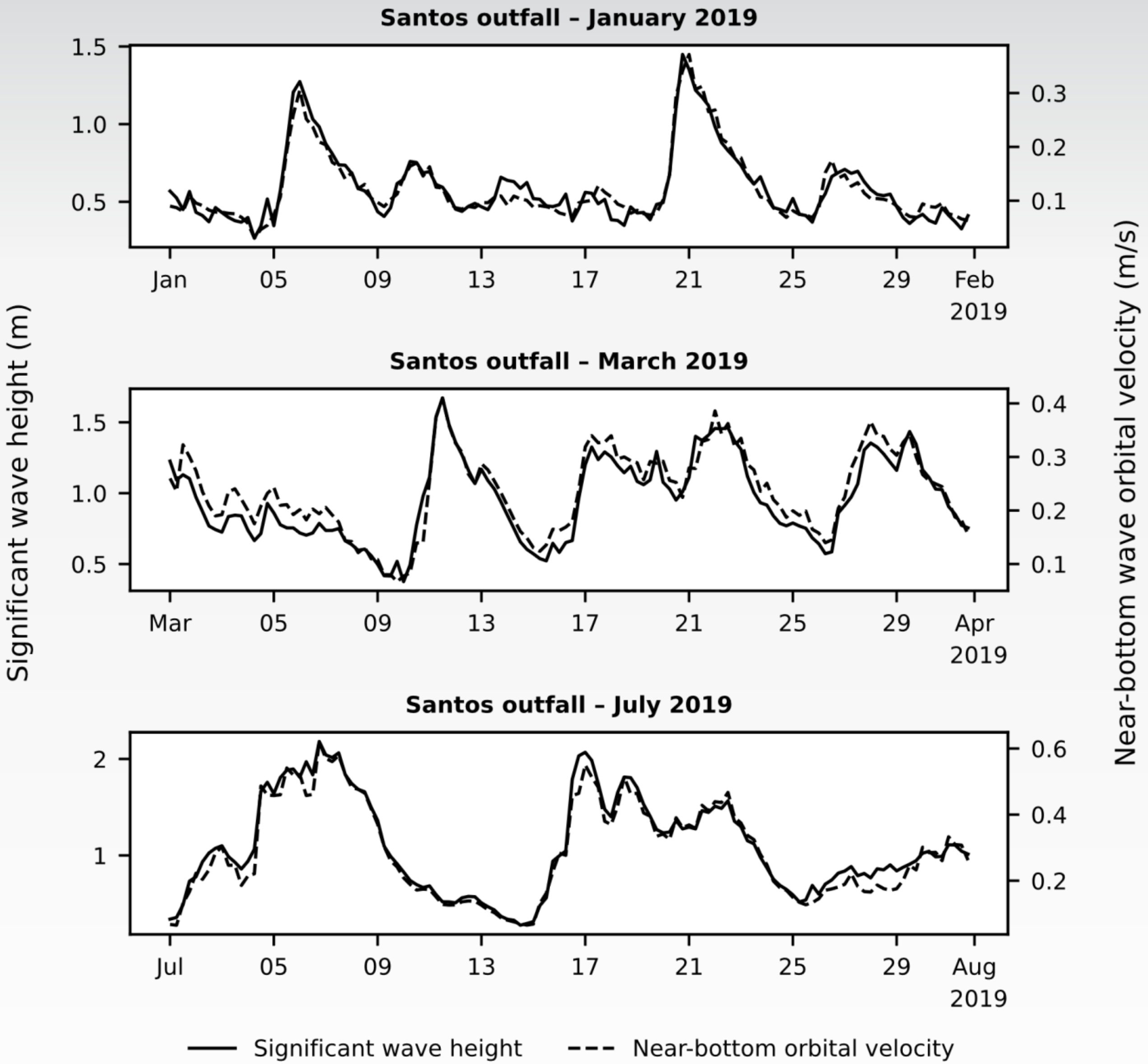
$$u_b = \frac{H\pi}{T \sinh kh}$$



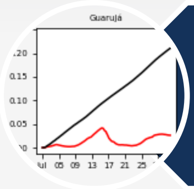
January
Mild

March
Mean

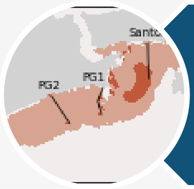
July
Strong



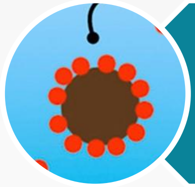
CONCLUSIONS



The consideration of waves avoids unrealistic sediment deposition in the long term (~20 cm/year)

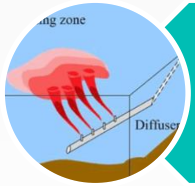


Resuspended sediment can be transported further, reaching the coastline and channels



Using coupled wave-current models for outfall plume modeling allow us to:

- Understand the fate of sediment-attached contaminants
- Identify areas of potential environmental concern



Future studies must consider the potential effects of waves on the design and operational conditions of outfalls

Acknowledgements

CAPES

sabesp

REFERENCES

- Wu, Y., L. Washburn, and B. H. Jones. 1991. “Mixing and dispersion processes in the vicinity of an ocean outfall system in Southern California.” In Coastal Zone ’91: Proceedings of the Seventh Symposium on Coastal and Ocean Management, edited by O. T. Magoon, H. Converse, V. Tippie, L. T. Tobin, and D. Clark. Long Beach, CA: American Society of Civil Engineers. https://cedb.asce.org/CEDBsearch/record.jsp?dockey=0071341.
- Lee, H. J., M. A. Noble, and J. Xu. 2003. “Sediment Transport and Deposition Processes Near Ocean Outfalls in Southern California.” In Contaminated Sediments: Characterization, Evaluation, Mitigation/Restoration, and Management Strategy Performance, ASTM STP 1442, edited by J. Locat, R. Galvez-Cloutier, R. C. Chaney, and K. R. Demars, 253–265. West Conshohocken, PA: ASTM International. isbn: 978-0-8031-3466-9. https://doi.org/10.1520/STP11567S.
- Neves, R. 2006. “Modelling Applied to Waste Disposal Systems. Application of Mohid for Simulating Trophic Activity in The Tagus and for Assessing the Impact of Costa do Estoril Submarine Outfall.” In Submarine outfalls: design, compliance and environmental monitoring, edited by C. C. Lamparelli and J. P. Ortiz, 147–169. São Paulo, Brazil: Secretaria do Meio Ambiente do Estado de São Paulo. isbn: 85-86624-49-7.
- Bleninger, T. 2006. “Coupled 3D hydrodynamic models for submarine outfalls: Environmental hydraulic design and control of multiport diffusers.” PhD diss., University of Karlsruhe, June. https://doi.org/10.5445/KSP/1000006668.
- Terfous, A., S. Chiban, and A. Ghenaim. 2016. “Modeling sediment deposition from marine outfall jets.” Environmental Technology 37 (15): 1865–1874. https://doi.org/10.1080/09593330.2015.1135988.
- Willmott, C. J., S. M. Robeson, and K. Matsuura. 2011. “A refined index of model performance.” International Journal of Climatology 32, no. 13 (September): 2088–2094. https://doi.org/10.1002/joc.2419.
- Berzin, G. 1992. “Monitoring of the Santos Submarine Outfall, São Paulo, Brazil, 10 Years in Operation.” Water Science and Technology 25, no. 9 (May): 59–71. https://doi.org/10.2166/wst.1992.0206.
- Soulsby, R. L., L. Hamm, G. Klopman, D. Myrhaug, R. R. Simons, and G. P. Thomas. 1993. “Wave-current interaction within and outside the bottom boundary layer.” Coastal Engineering 21, nos. 1-3 (December): 41–69. https://doi.org/10.1016/0378-3839(93)90045-a.

IAHR AIRH International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China

IWA the international water association

ISOS|2023

Simposio Internacional sobre Sistemas de Emisarios 2023

International Symposium on Outfall Systems 2023

aysa Lo bueno del agua llega.

COFES

Ministerio de Obras Públicas Argentina