The sensitivity of ocean-bottom gravimeters at deep waters to mass changes in a synthetic hydrocarbon reservoir

André Defendi Arelaro* (Observatório Nacional – Petrobras S.A.)

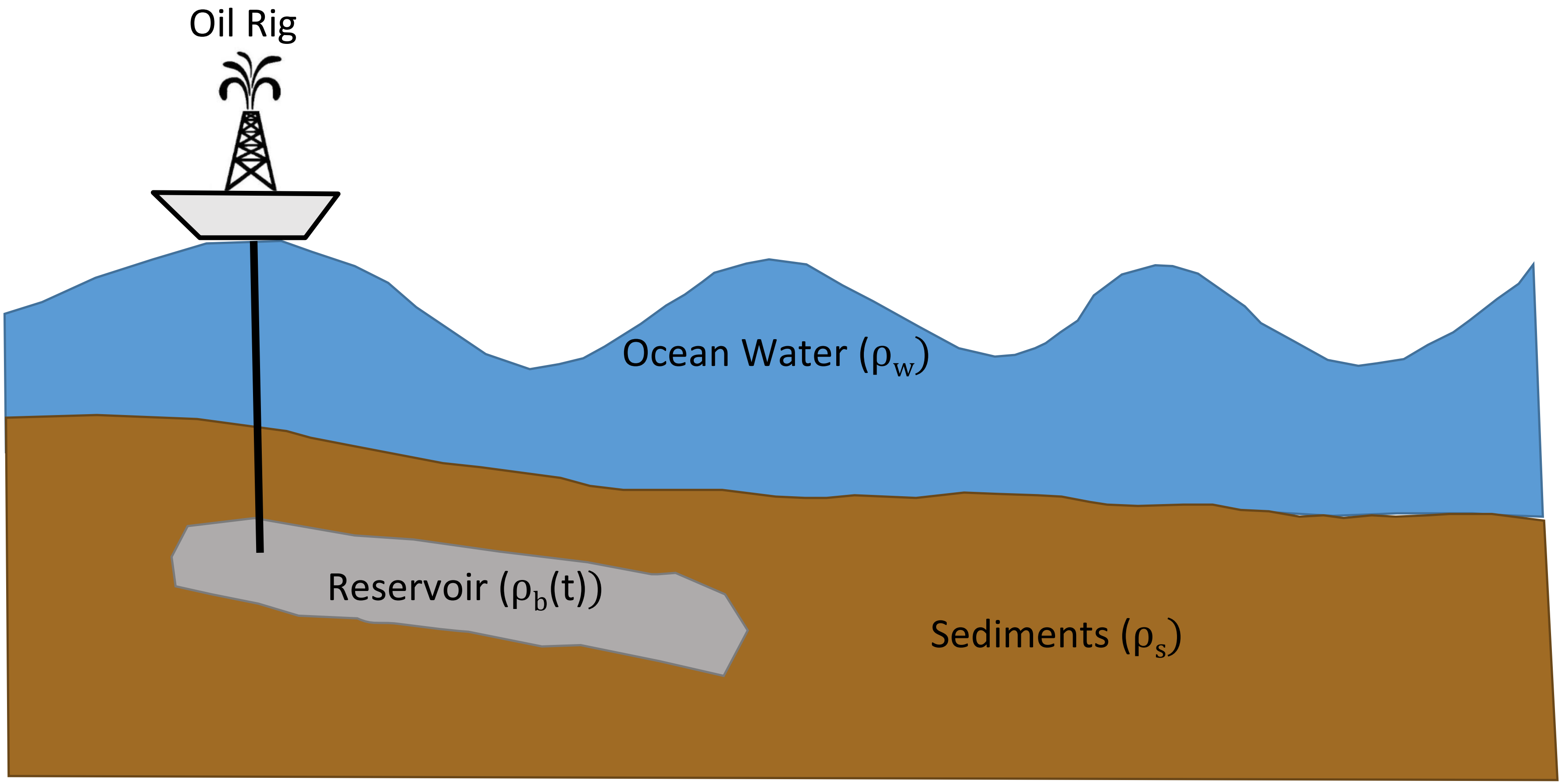
Valéria Cristina Barbosa (Observatório Nacional)

Vanderlei Cordeiro de Oliveira Jr (Observatório Nacional)

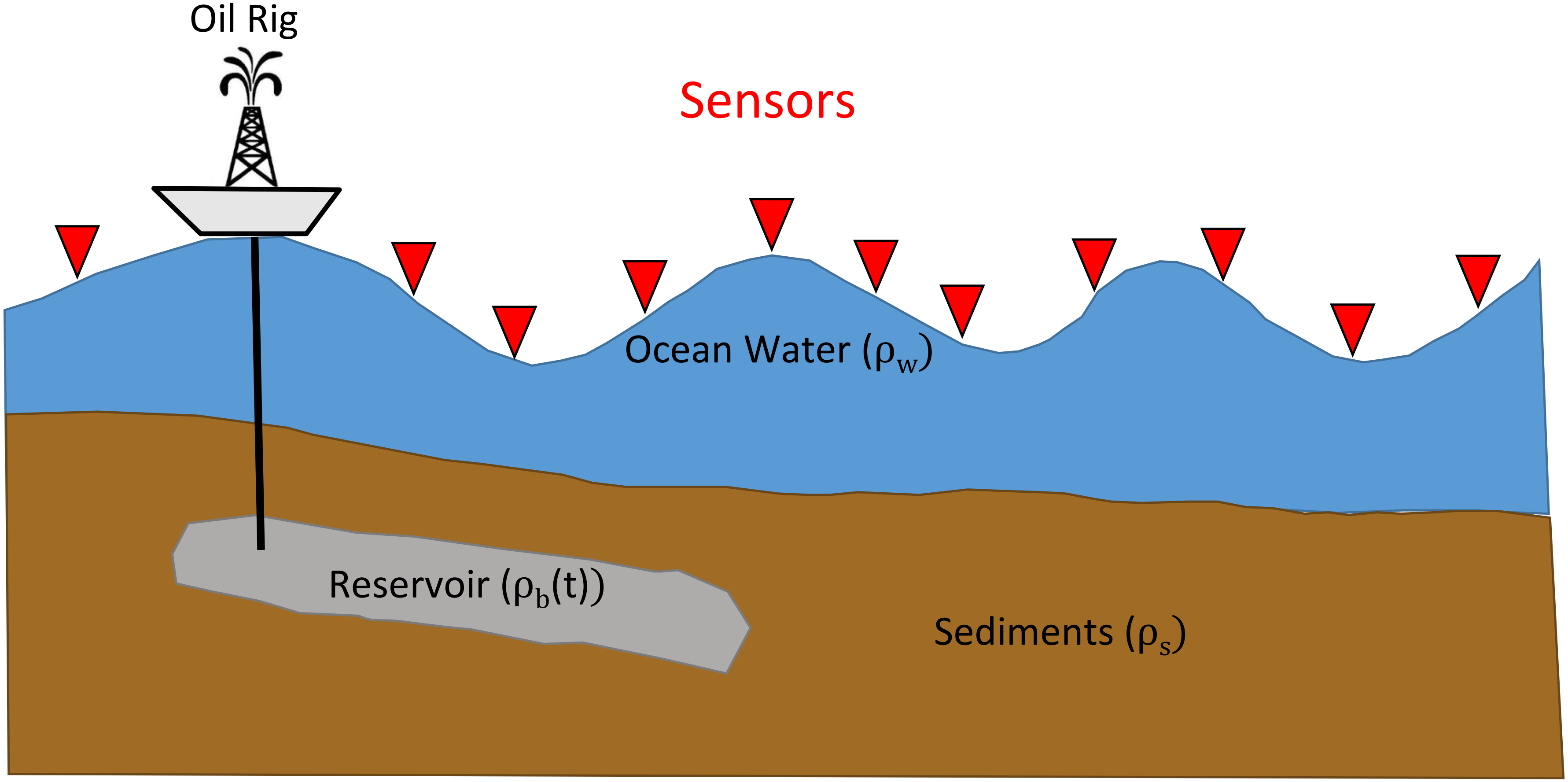
Summary

- Introduction
- Objectives
- Methodology
- Results
- Conclusion
- Acknowledgements

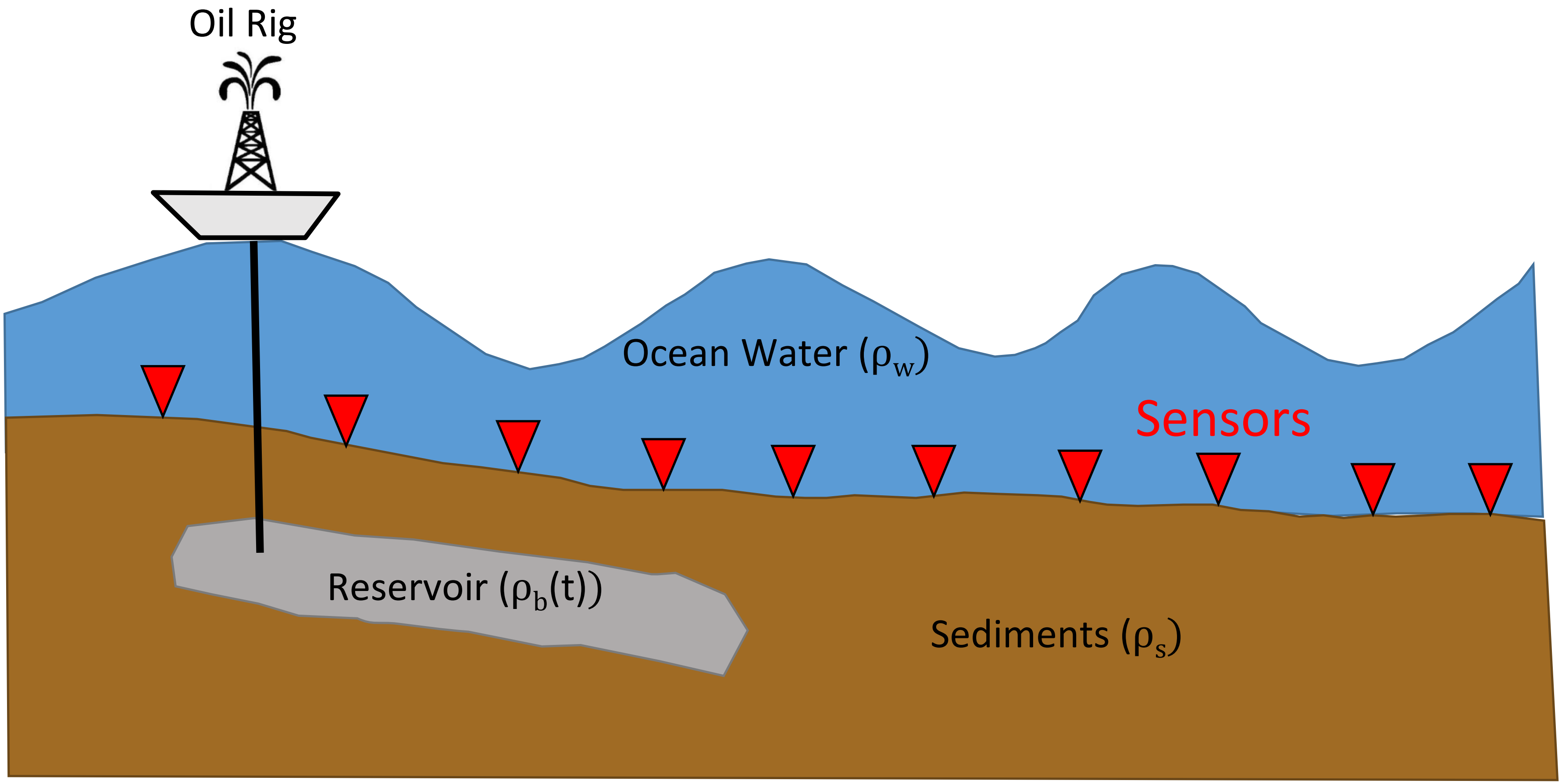
Introduction



Introduction

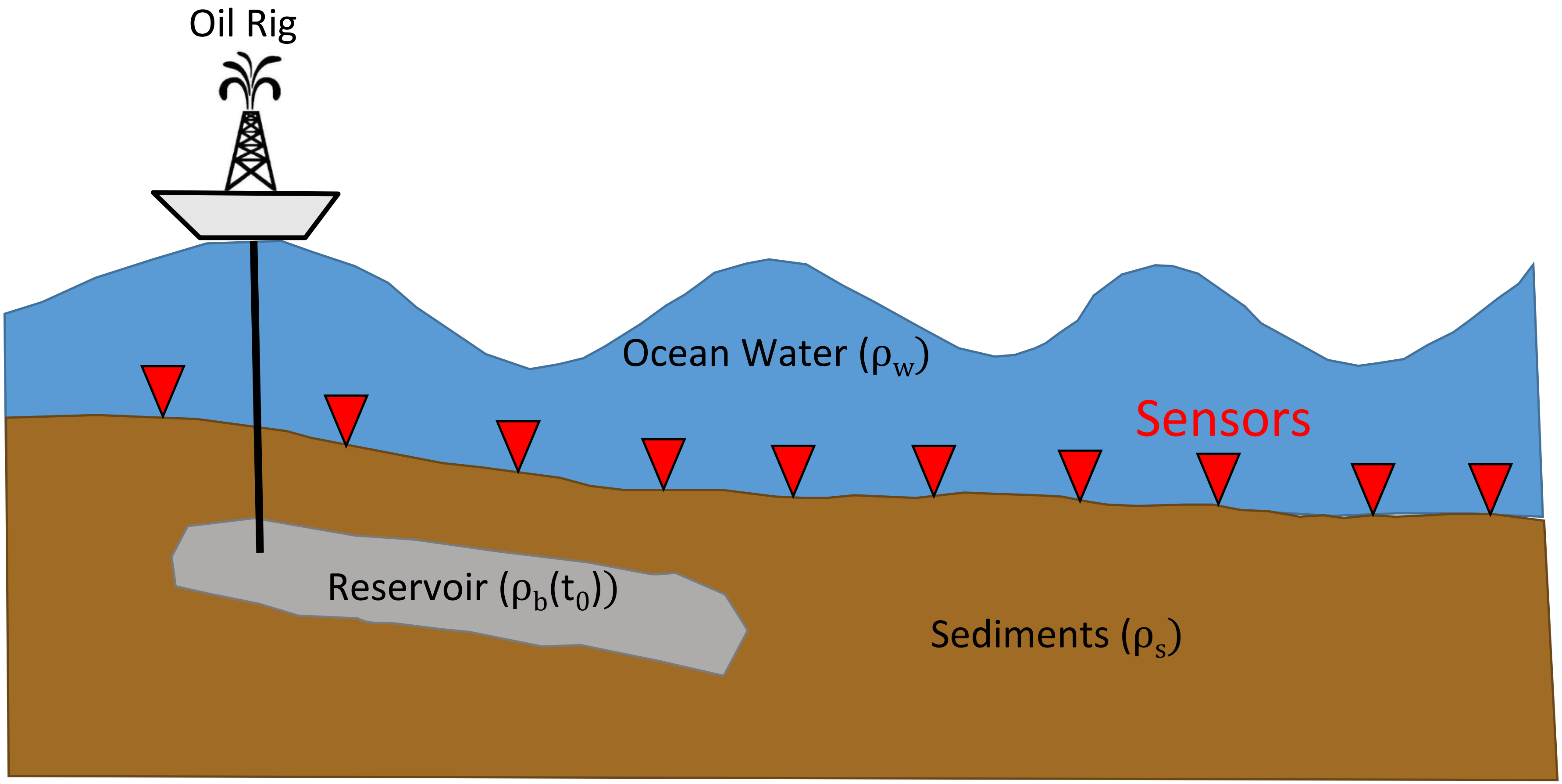


Introduction

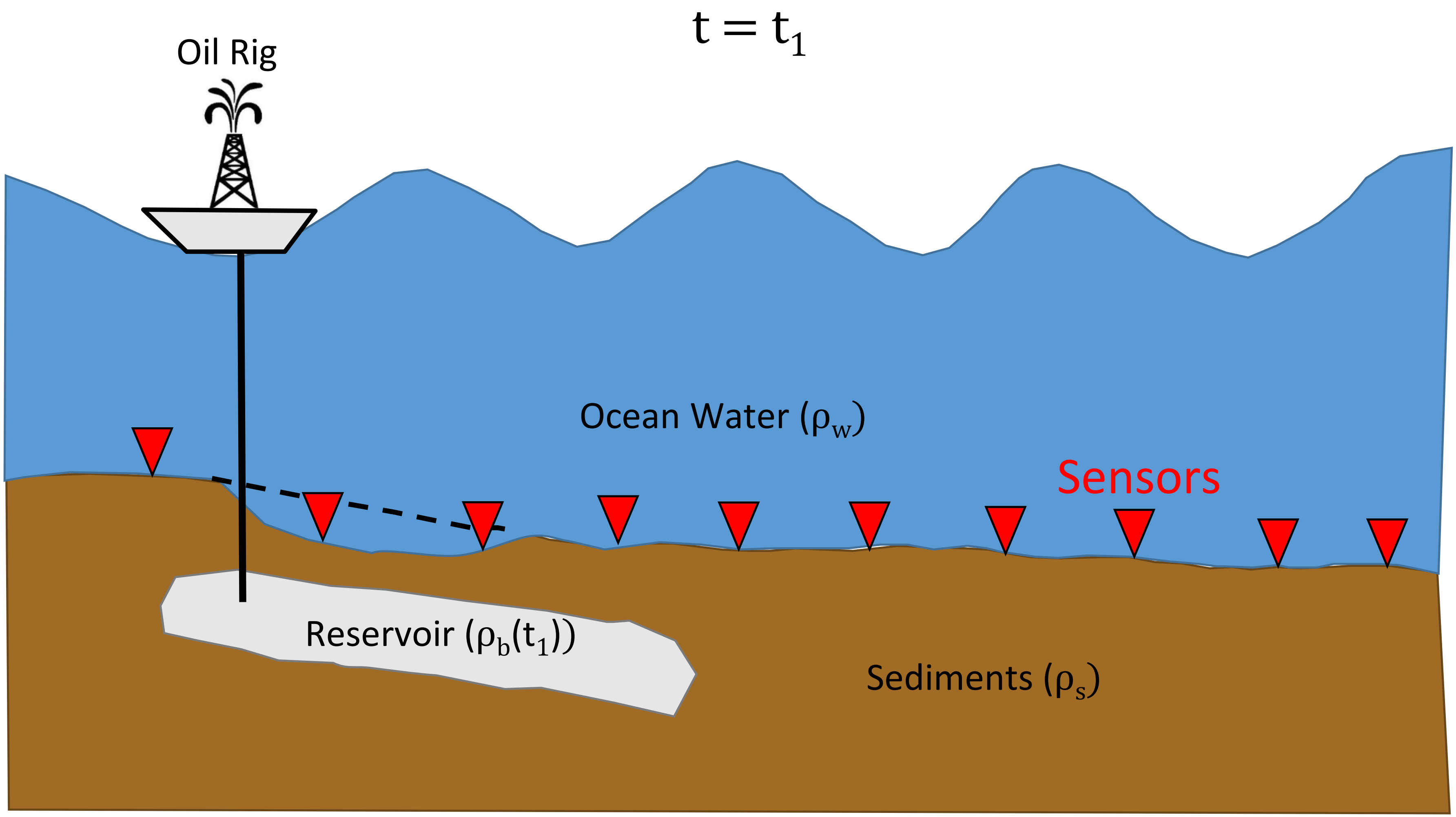


Introduction

$t = t_0$



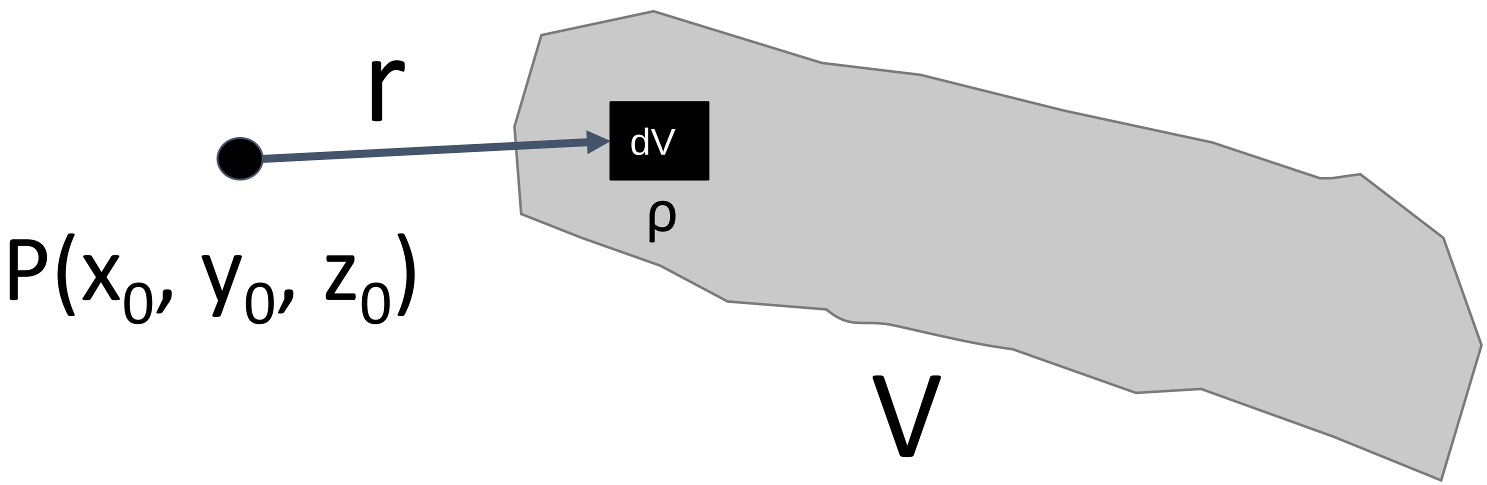
Introduction



Objectives

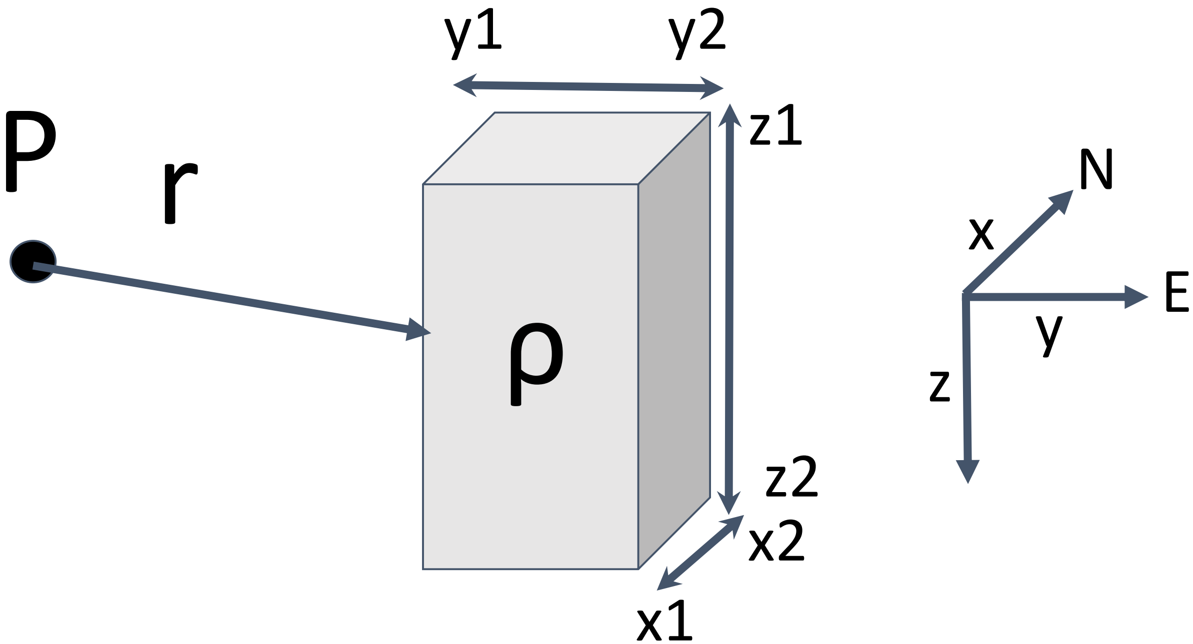
Main Objective	Study the parameter sensitivity (3 μGal) of a 4D ocean-bottom gravity acquisition via forward modelling.	
	Studied Parameters:	Water thickness
		Ocean-bottom subsidence
		Reservoir fluid substitution

Methodology



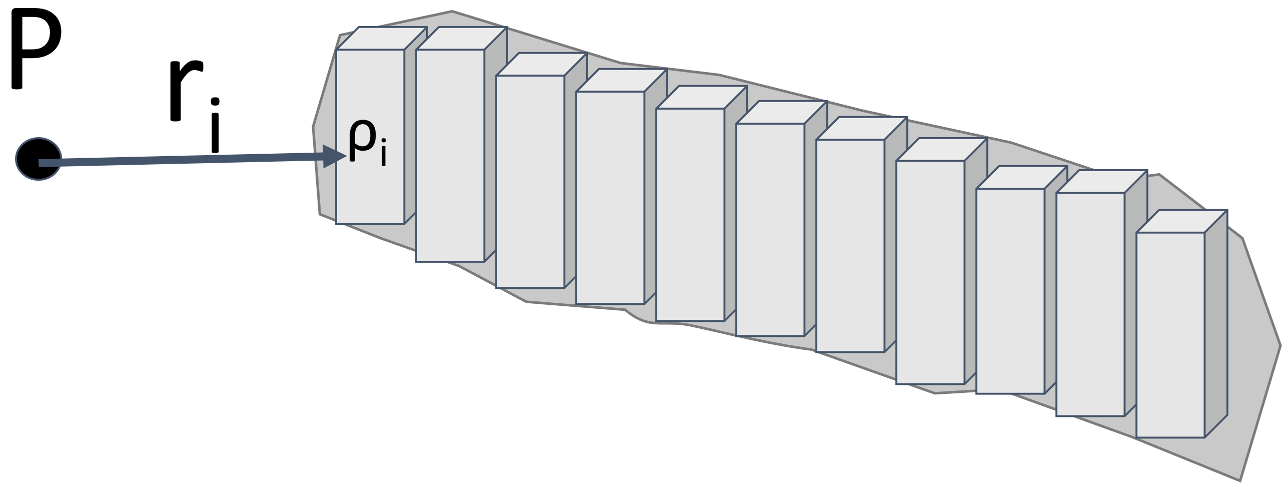
$$g_z(P) = \gamma\rho \int\int\int_V \frac{z - z_0}{r^3} dV$$

Methodology



$$g_z(P) = \gamma\rho \left[x ln(y+r) + y ln(x+r) - z tan^{-1}\left(\frac{xy}{zr}\right) \Big|_{x_1}^{x_2} \Big|_{y_1}^{y_2} \Big|_{z_1}^{z_2} \right]$$

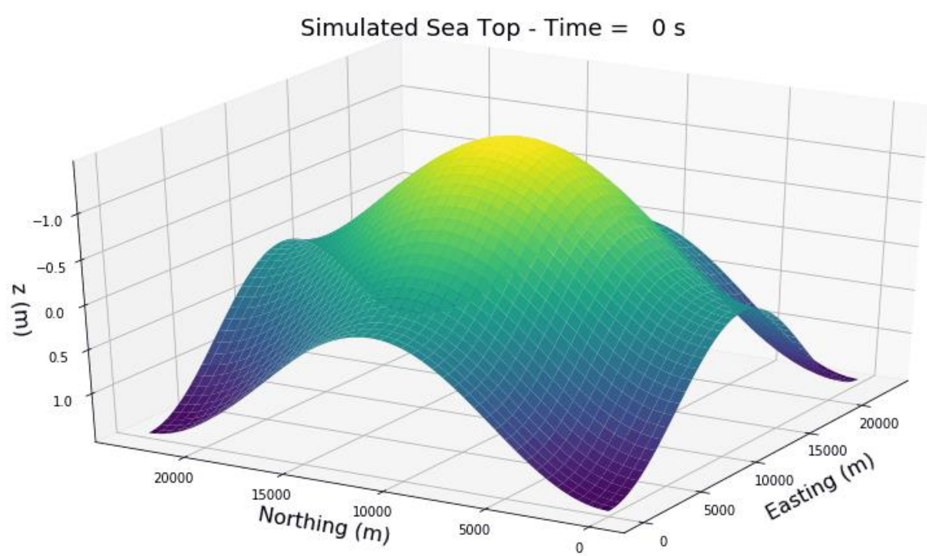
Methodology



$$g_z(P) = \gamma \sum_{i=1}^{N} \rho_i \left[x ln(y + r_i) + y ln(x + r_i) - z tan^{-1}\left(\frac{xy}{z r_i}\right) \Big|_{x_{1i}}^{x_{2i}} \Big|_{y_{1i}}^{y_{2i}} \Big|_{z_{1i}}^{z_{2i}} \right]$$

Methodology - Water Top

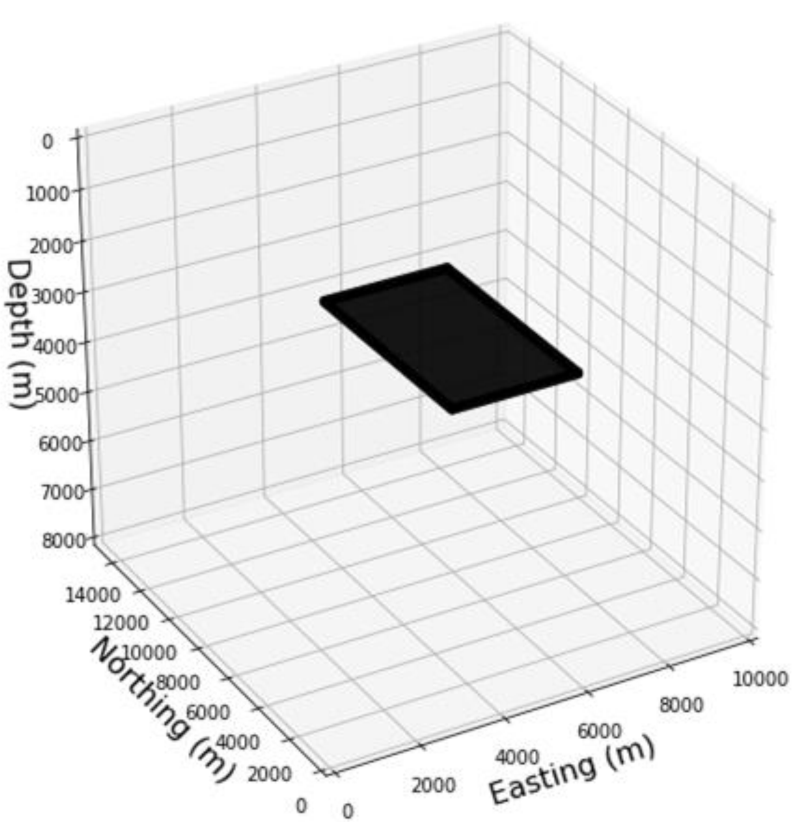
$$z_W(x,y,t) = \frac{A}{2}\left\{cos\left(\frac{2\pi}{L_x}x + \frac{2\pi}{T}t\right) + cos\left(\frac{2\pi}{L_y}y + \frac{2\pi}{T}t\right)\right\}$$



- A: amplitude;
- Lx: Model size in x;
- Ly: model size in y;
- T: period.

Methodology - Fluid Substitution

$$\rho_b(t) = \phi[\alpha(t)\rho_f + (1 - \alpha(t))\rho_o] + (1 - \phi)\rho_r$$

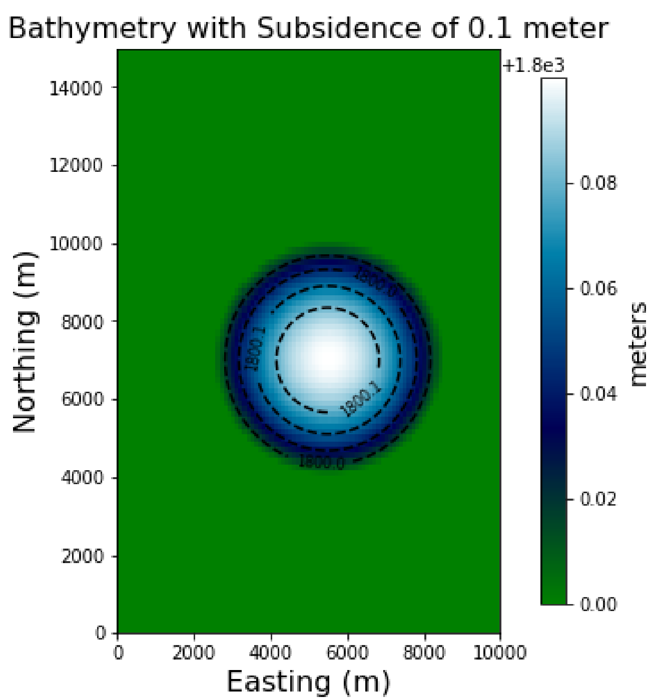


- $\rho_b(t)$: bulk density;
- φ: porosity;
- $\alpha(t)$: fluid substitution percentage;
- ρ_f: fluid density;
- ρ_o: oil density;
- ρ_r: rock density.

Methodology - Subsidence

$$z(t_1) = -[\frac{(x - x_c)^2}{a^2} + \frac{(y - y_c)^2}{b^2}] + z_{max}$$

$$a = \frac{-R_x}{\sqrt{z_{max} - z(t_0)}} \qquad b = \frac{-R_y}{\sqrt{z_{max} - z(t_0)}}$$

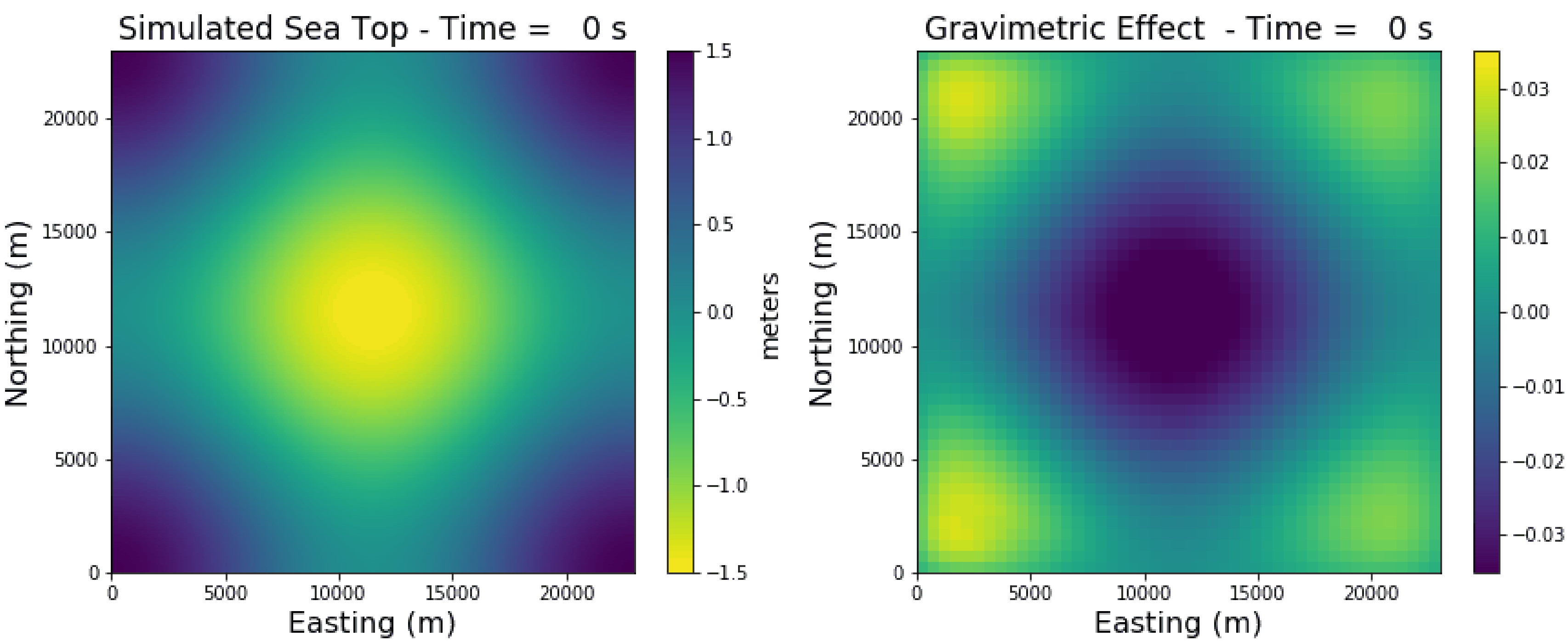


- $z(t_1)$: bathymetry after subsidence.
- x_c: central point in x;
- y_c: central point in y;
- z_{max}: maximum subsidence;
- R_x: subsidence radius in x;
- R_y: subsidence radius in y;
- $z(t_0)$: original bathymetry.

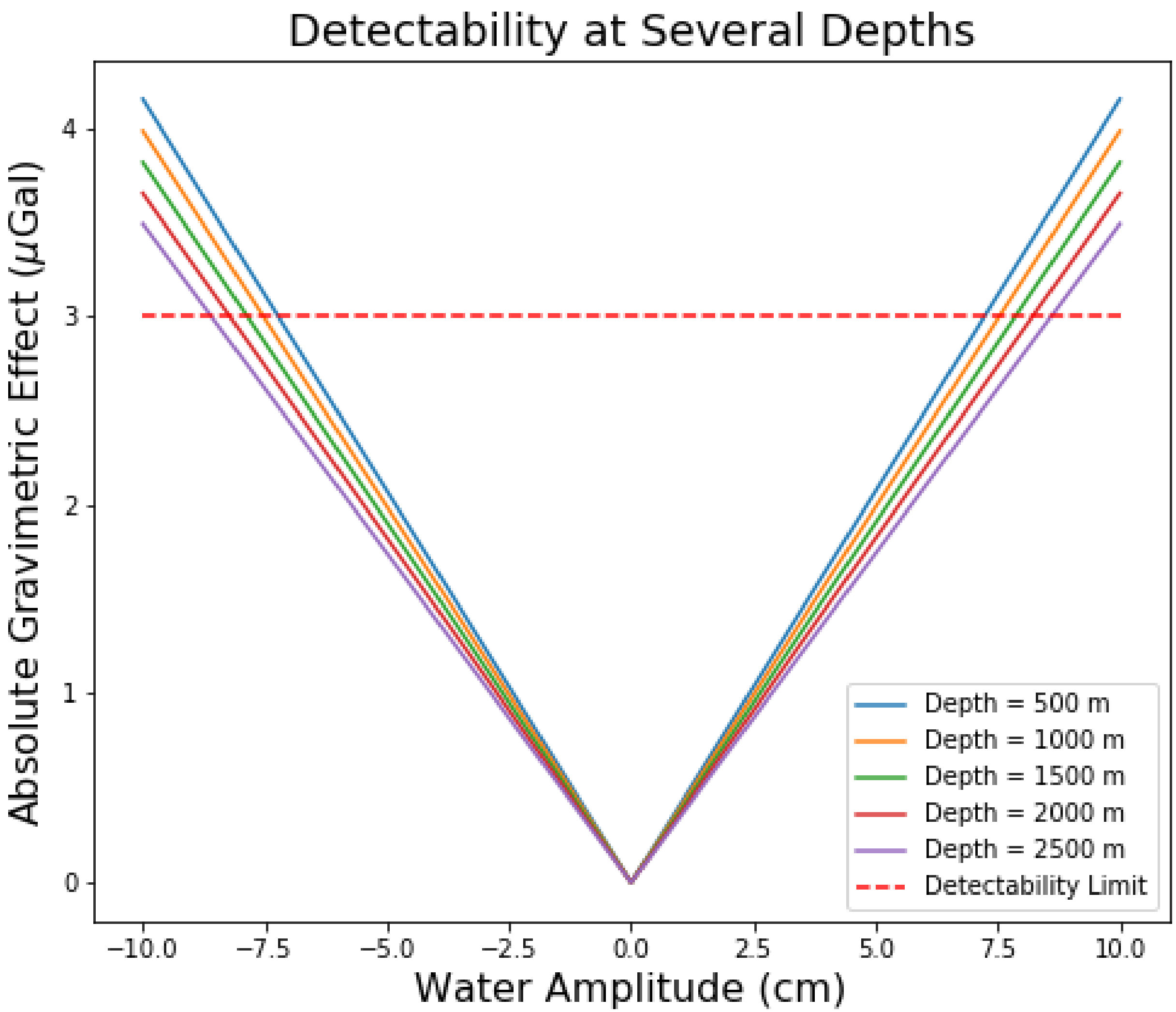
Results - Water Effect

$$z_w(x,y,t) = \frac{A}{2}\left\{cos\left(\frac{2\pi}{L_x}x + \frac{2\pi}{T}t\right) + cos\left(\frac{2\pi}{L_y}y + \frac{2\pi}{T}t\right)\right\}$$

- A = 1.5 m
- Lx = Ly = 23,000 m
- T = 7,500 s



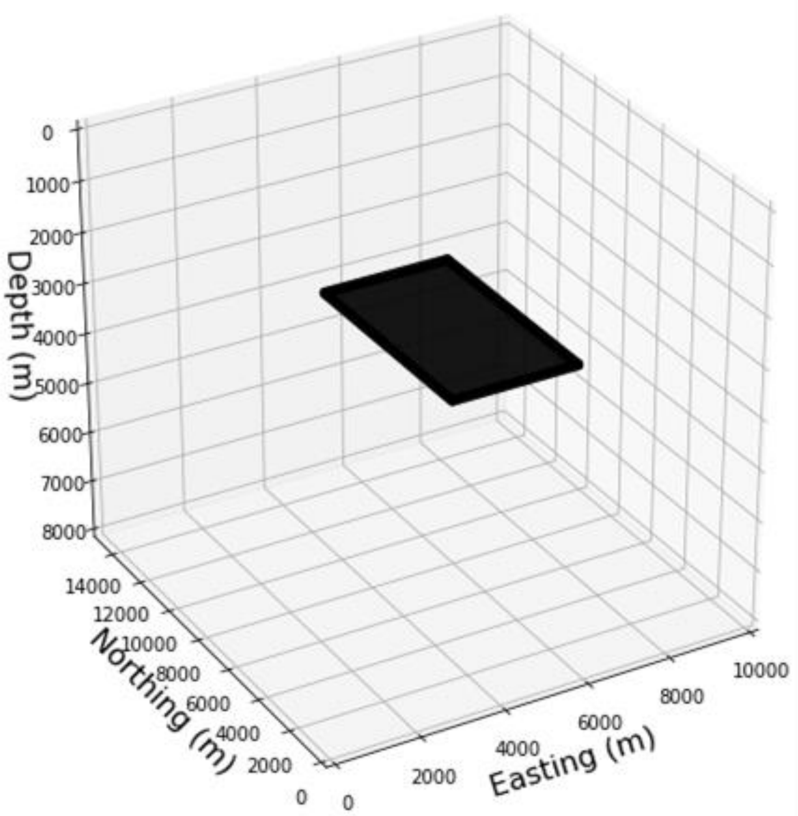
Results - Water Effect



- $x = y = 11{,}700$ m
- $L_x = L_y = 23{,}000$ m
- $T = 7{,}500$ s

Results - Density Changes in Reservoir

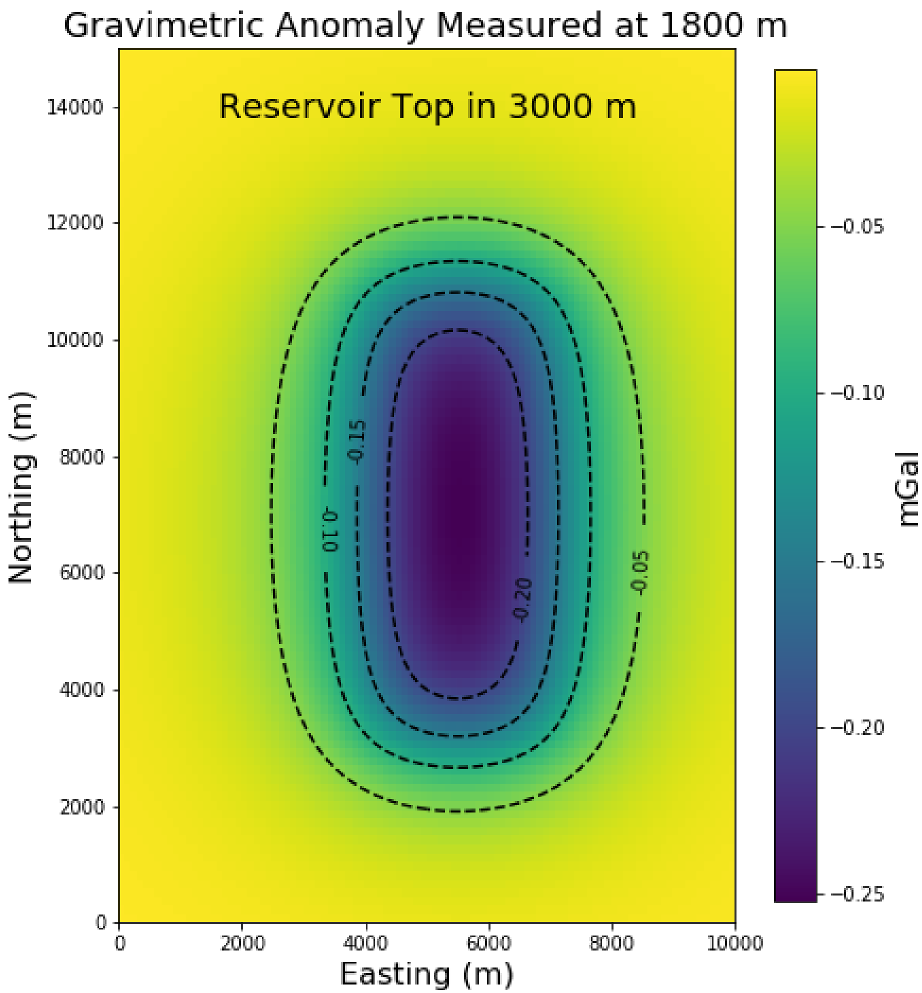
$$\rho_b(t) = \phi[\alpha(t)\rho_f + (1 - \alpha(t))\rho_o] + (1 - \phi)\rho_r$$



- φ: 20%
- $\alpha(t_0)$: 0% (before production)
- ρ_f: 1060 kg/m³ (brine)
- ρ_o: 850 kg/m³ (oil)
- ρ_r: 2350 kg/m³ (sandstone)
- $\rho_b(t_0)$: 2050 kg/m³

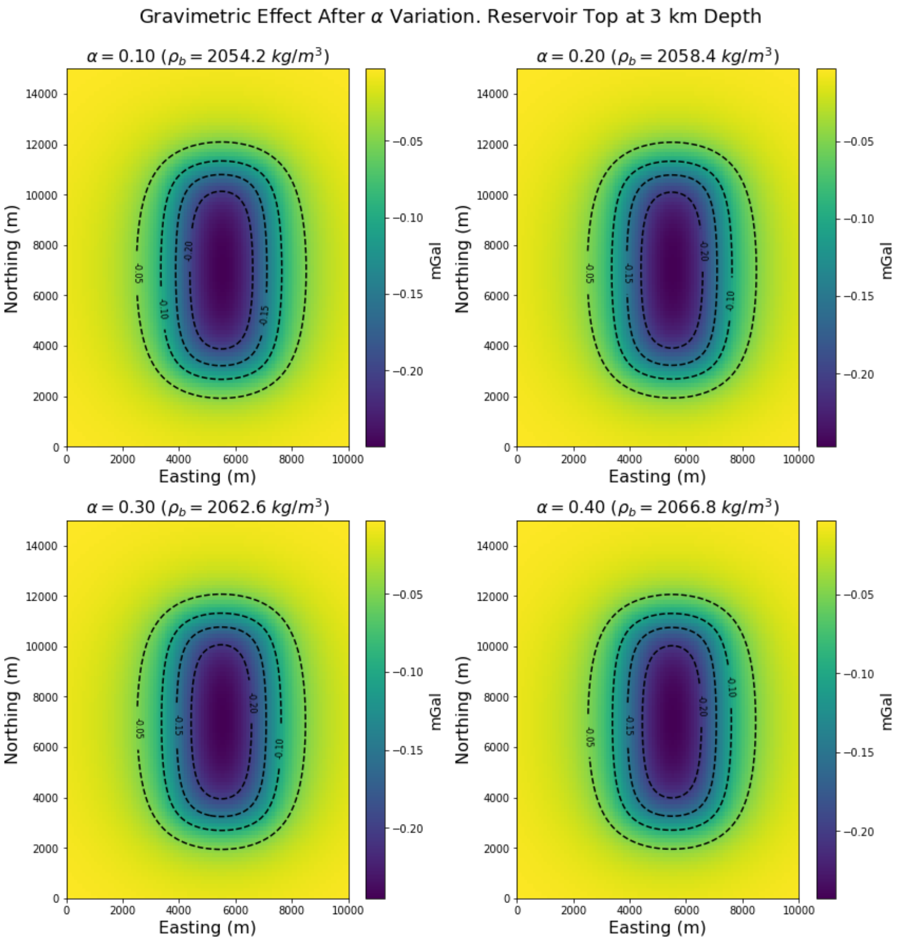
Results - Density Changes in Reservoir

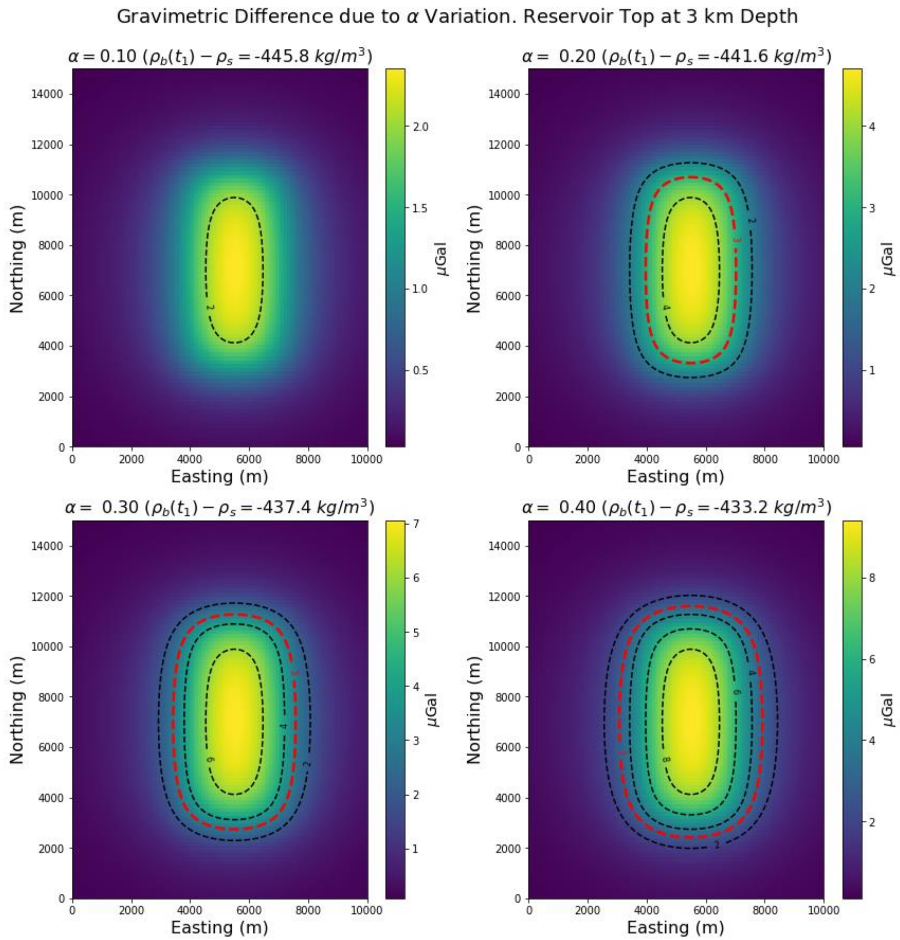
$$\rho_b(t) = \phi[\alpha(t)\rho_f + (1-\alpha(t))\rho_o] + (1-\phi)\rho_r$$



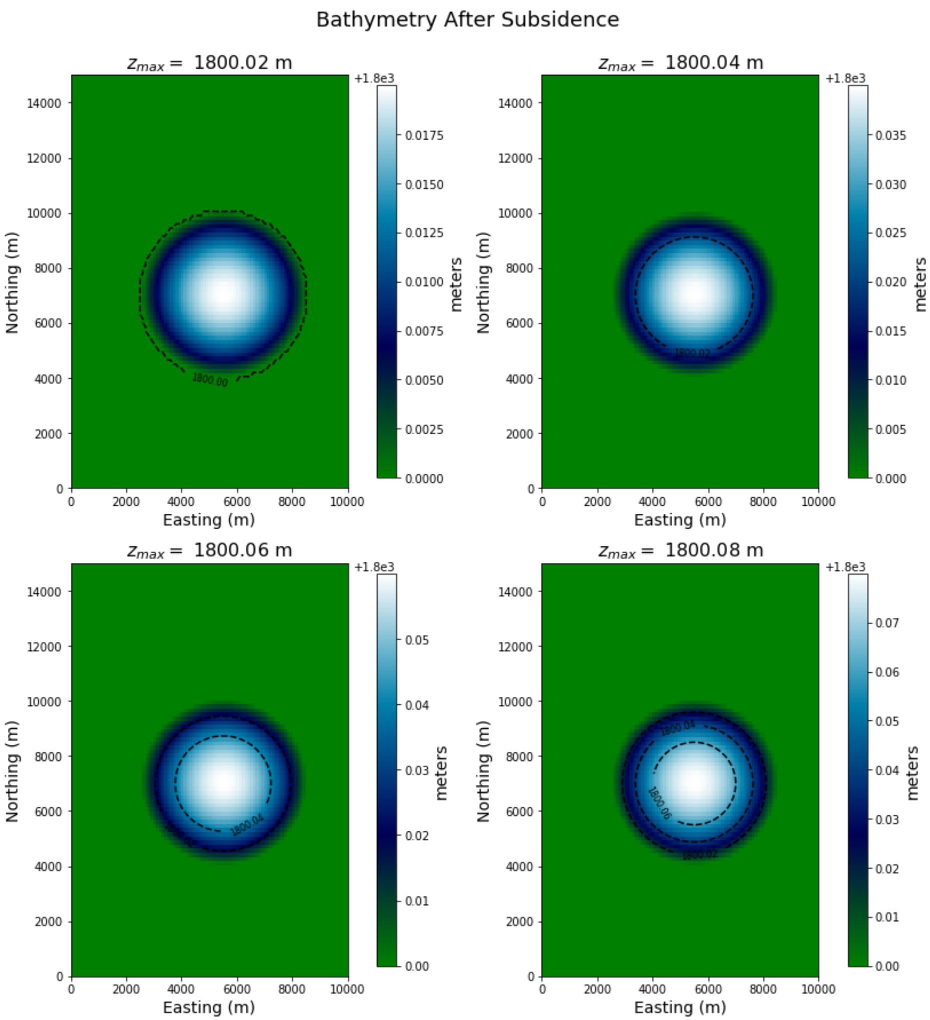
- φ: 30%
- $\alpha(t_0)$: 0%
- ρ_f: 1060 kg/m³
- ρ_o: 850 kg/m³
- ρ_r: 2350 kg/m³
- $\rho_b(t_0)$: 2050 kg/m³
- ρ_{back}: 2500 kg/m³

Results - Density Changes in Reservoir





Results - Subsidence Effect

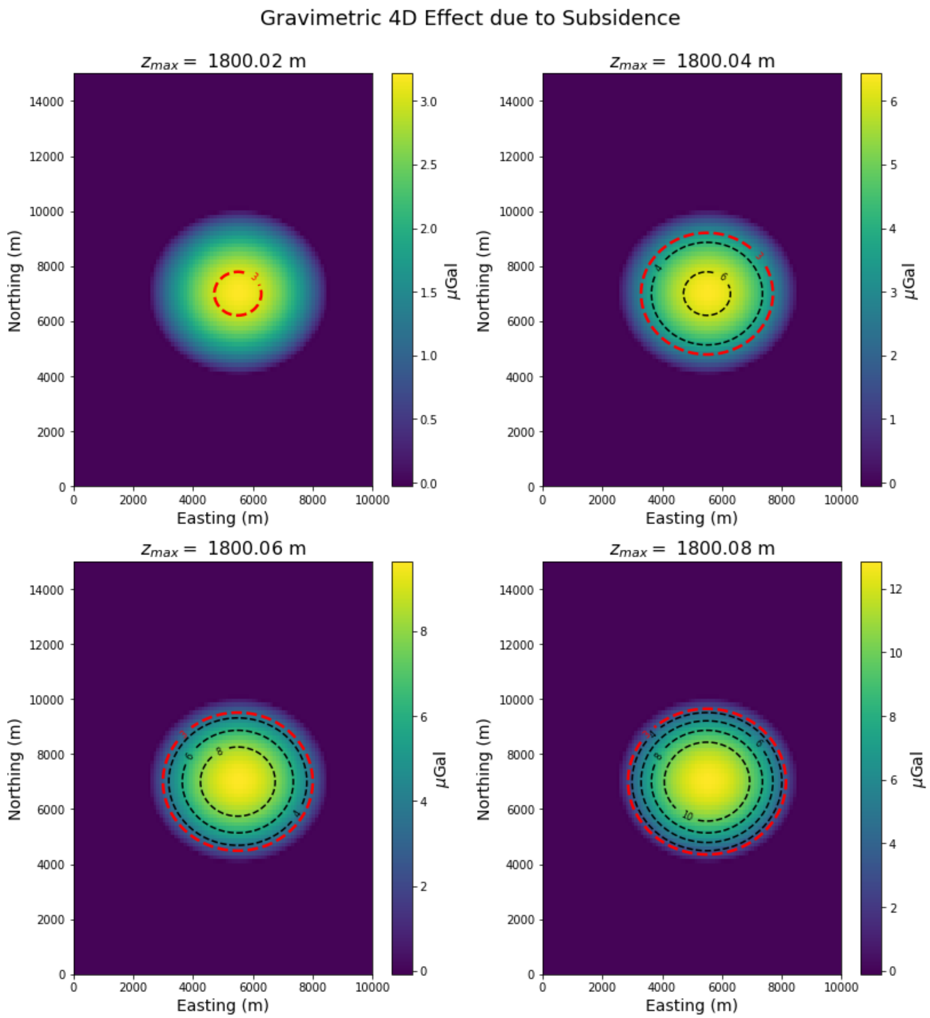


$$z(t_1) = -[\frac{(x-x_c)^2}{a^2} + \frac{(y-y_c)^2}{b^2}] + z_{max}$$

$$a = \frac{-R_x}{\sqrt{z_{max} - z(t_0)}} \qquad b = \frac{-R_y}{\sqrt{z_{max} - z(t_0)}}$$

- x_c: 7,000 m
- y_c: 5,500 m
- $R_x = R_y$: 3,000 m
- z_{obs}: 1,800 m

Results - Subsidence Effect



$$z(t_1) = -[\frac{(x - x_c)^2}{a^2} + \frac{(y - y_c)^2}{b^2}] + z_{max}$$

$$a = \frac{-R_x}{\sqrt{z_{max} - z(t_0)}} \qquad b = \frac{-R_y}{\sqrt{z_{max} - z(t_0)}}$$

- x_c: 7,000 m
- y_c: 5,500 m
- $R_x = R_y$: 3,000 m
- z_{obs}: 1,800 m

Conclusions

- Variations in water surface in a magnitude of few cm could affect the data.
- For the reservoir model used, detectability is reached when the substitution from oil to salty water is between 10% and 20%.
- For a sea-bottom originally flat in 1,800 m, a subsidence of few cm could be detected.
- This methodology can be very useful in reservoir monitoring and in guaranteeing the safety of offshore oil facilities in Brazil.

Acknowledgements

BR PETROBRAS

Observatório Nacional

PINGA
Grupo de problemas inversos em geofísica

fatiando a terra
open-source library for modeling and inversion in geophysics

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

FAPERJ
Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro

THANK YOU