

Estimate of sediment settling velocities from a theoretically guided data-driven approach

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Sediment Settling Velocity Affects

- sediment transport process
- reservoir and harbor designs
- wetland reclamation and restoration
- waterways navigation
- more ...

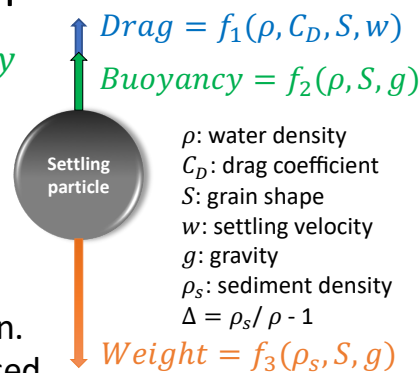
Previous Studies

Process-based approach

$$\text{Weight} = \text{Drag} + \text{Buoyancy}$$

$$w = f(S, C_D, \rho_s, \rho, g)$$

- C_D is a function of particle Reynolds number (Re).
- Laboratory experiments were conducted for $C_D - Re$ relation.
- Many models have been proposed.
- Comparisons of different models within integrated data are rare.**
- Uncertainty remains in real applications.**



Parametric data-driven approach

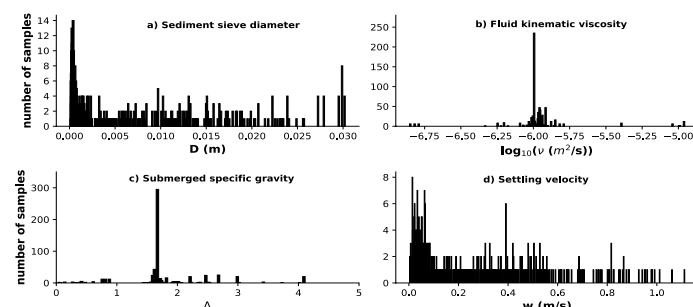
Goldstein and Coco (2014):

- Compiled a multi-source database from literature w , D (grain size), ν (water kinematic viscosity) and Δ
- Trained $w = f(D, \nu, \Delta)$ in a genetic programming software
- Picked the best fit from all candidate solutions
- Need pre-specify mathematical operators.**

This Study

Aggregated database

- 13 distinct experimental data sources
- 756 non-cohesive sediment settling data in water



Random forest regression model

Model Development

Parameter tuning and model selection

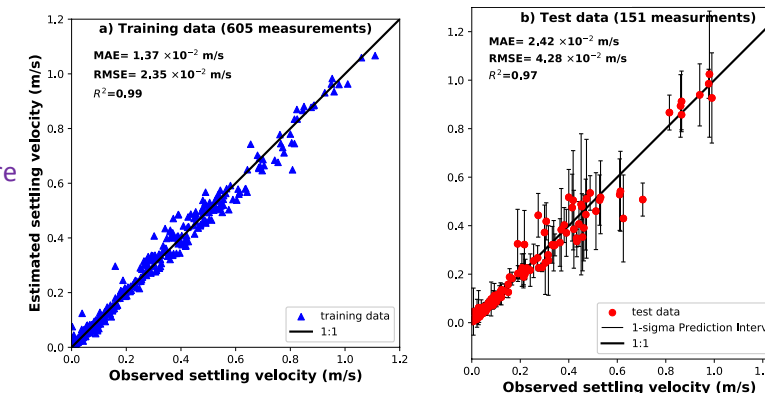
- test data size, number of trees, maximum depth
- grid search with 5-fold cross validation

Scenario	Tuning parameters			Training data			Test data		
	test_size	ntrees	max_depth	MAE*	RMSE*	R ²	MAE*	RMSE*	R ²
1	0.1	100	8	1.57	2.67	0.99	2.54	4.81	0.97
2	0.2	150	9	1.37	2.35	0.99	2.42	4.28	0.97
3	0.3	100	9	1.35	2.30	0.99	2.44	4.38	0.97
4	0.4	350	11	1.17	2.13	0.99	2.60	4.64	0.96
5	0.5	400	13	1.16	2.15	0.99	2.55	4.65	0.96
6	0.6	400	5	2.05	3.31	0.98	3.06	5.55	0.95
7	0.7	150	6	1.62	2.34	0.99	3.30	6.14	0.93
8	0.8	100	5	1.66	2.50	0.99	3.68	6.66	0.92
9	0.9	150	9	1.31	2.29	0.99	3.77	6.78	0.92

* 10^{-2} m/s

Scenario 2

- High accuracy
- No overfitting
- Simple structure



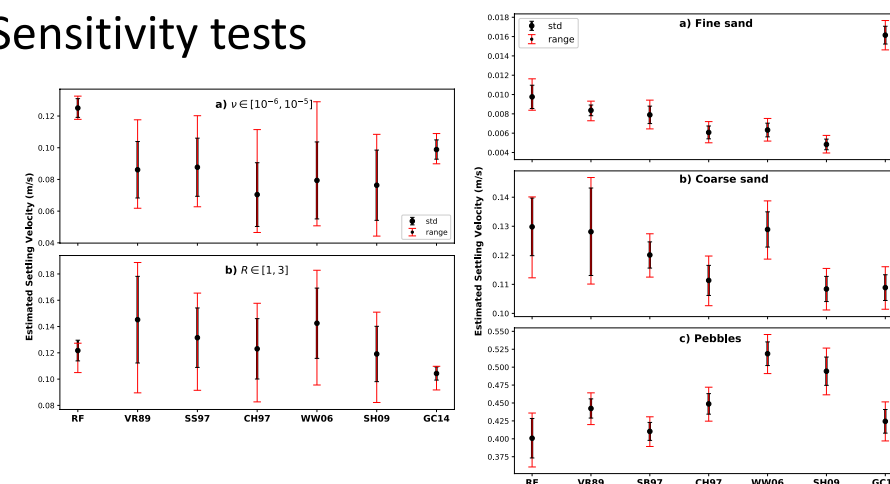
Model Comparisons

Accuracy on test data

Model Name	sand			gravel			sand & gravel		
	MAE*	RMSE*	R ²	MAE*	RMSE*	R ²	MAE*	RMSE*	R ²
Van Rijn 1989 (VR89)	1.18	1.62	0.92	7.65	10.60	0.78	3.44	6.39	0.93
Soulsby 1997 (SB97)	1.36	1.93	0.89	8.17	11.40	0.75	3.73	6.90	0.91
Cheng 1997 (CH97)	1.12	1.76	0.91	7.95	10.62	0.78	3.51	6.43	0.92
Wu and Wang 2005 (WW05)	0.96	1.35	0.94	10.34	13.34	0.65	4.23	7.96	0.88
Sadat-Helbar 2009 (SH09)	1.40	2.10	0.86	10.47	13.51	0.64	4.56	8.16	0.88
Goldstein and Coco 2014 (GC14)	1.56	2.23	0.85	6.67	8.60	0.86	3.34	5.39	0.95
This study (RF)	0.87	1.21	0.96	5.31	7.07	0.92	2.42	4.28	0.97

* 10^{-2} m

Sensitivity tests



Model Update

Theoretical data

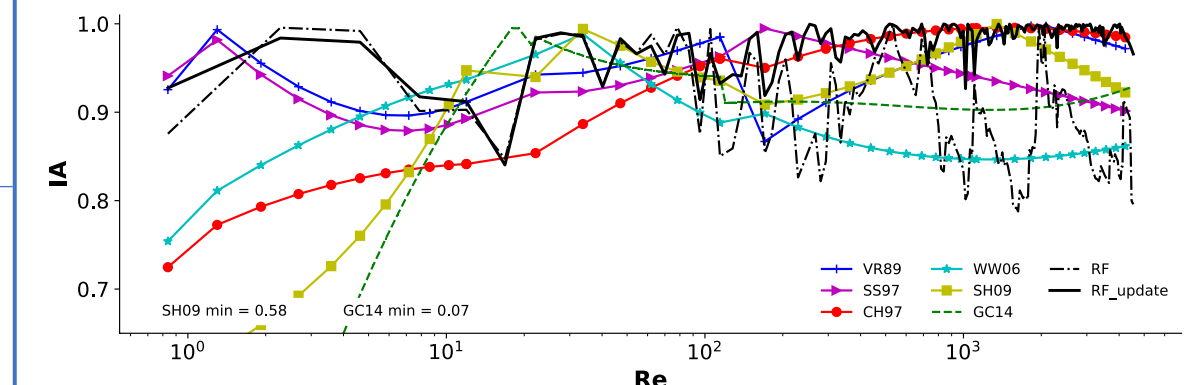
- Select 1000 sediment particles with fixed density (2650 kg/m^3) and varying grain sizes evenly distributed between $[10^{-4} 10^{-2}] \text{ m}$.
- Estimate the particle settling velocities in water using the process-based equations (VR89, SB97, CH97, WW05 and SH09).
- Average the estimate values of each particle as theoretical data.

Integration of theoretical data

- Randomly pick 10% of the theoretical data to retrain RF and get RF_update
- Evaluate model performance on the rest theoretical data via an individual

$$IA_{i,j} = 1 - \frac{|w_{new}^i - w_j^i|}{w_{new}^i}$$

where w_{new}^i is the theoretical value of the i th particle, w_j^i is the estimated value of the i th particle by the j th model.



Conclusions

- Non-parametric data-driven approach reduces the uncertainty in estimating sediment settling velocities under various physical regimes.
- The data-driven model has an easy-implemented update capability by integrating theoretical data.
- Leveraging experimental and theoretical knowledge to enhance estimate performance provides an alternative framework for sediment transport study.

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