Satellite Remote Sensing of Surface pCO_2 in Coastal Oceans: Evaluation of Different Approaches

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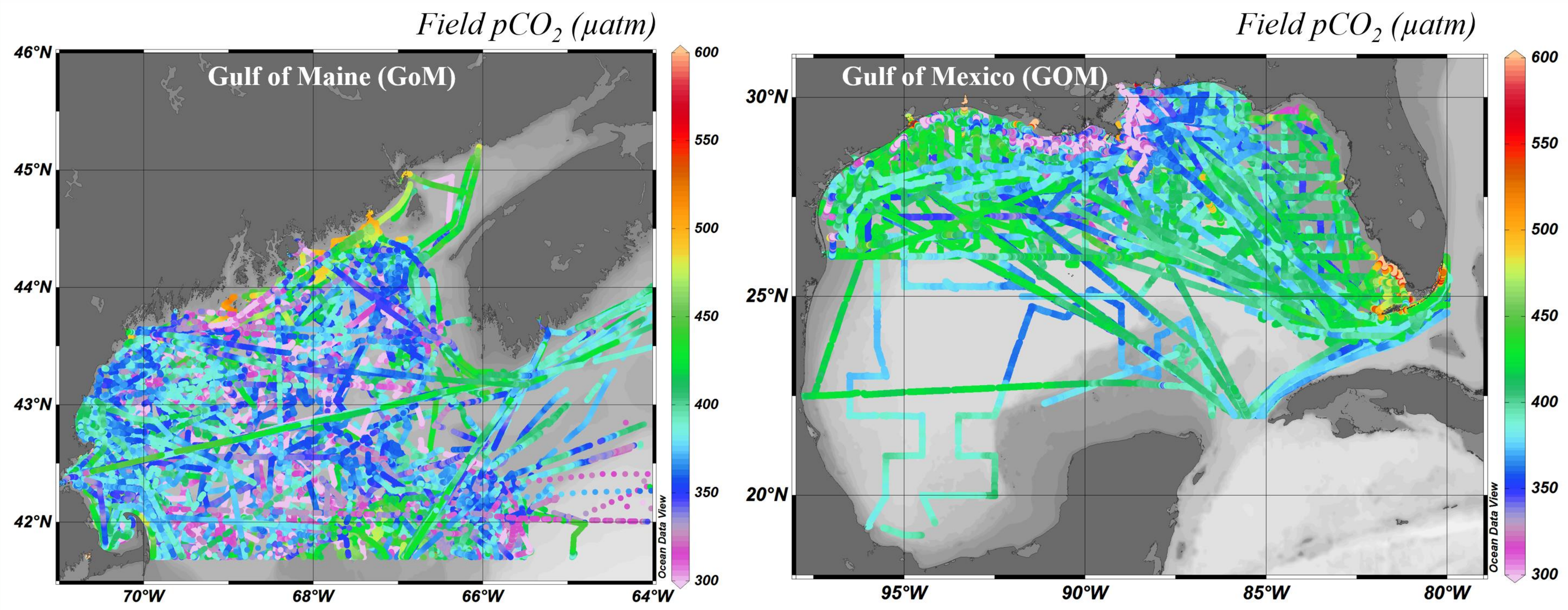
Introduction & Objectives

- Surface partial pressure of CO2 (pCO_2) is a critical parameter in the quantification of air-sea CO2 flux, which plays an important role in the global carbon budget and understanding of ocean acidification. Different approaches have been used to quantify surface pCO_2 from satellites, while the strength, weakness, and general applicability of each in different coastal ecosystems was not evaluated yet.
- The objective of this study is to: 1) develop pCO_2 models for Gulf of Maine (GoM) and Gulf of Mexico (GOM) using different approaches; 2) quantify and compare the performance of each approach; 3) quantify the uncertainties of the generalized approach under various conditions; 4) understand the applicability of the generalized approach through the study of seasonal variation of surface pCO_2 in these two oceanic environments.

Study Area & Data Source



Statistics of Different Approaches

Gulf of Maine

Approach	Statistics	RMSE[g] (μatm)	R^2	MB[h] (μatm)	MR[i]	N	Model Inputs	Study Area
MLR[a]	Model training	47.64	0.36	0.00	1.00	4036	SST, SSS, CHL, Julday	GoM
	Model validation	47.75	0.36	0.07	1.00	4036		
MNR[b]	Model training	40.35	0.54	-0.00	1.01	4036	SST, log_{10}(Kd), log_{10}(CHL), cos(Julday)	GoM
	Model validation	40.45	0.54	-0.13	1.01	4036		
PCR[c]	Model training	54.68	0.19	0.00	1.03	4036	SST, SSS, CHL, Kd, ag440	GoM
	Model validation	54.95	0.18	-0.14	1.03	4036		
MPNN[d]	Model training	11.50	0.95	-0.00	1.00	3040	SST, log_{10}(Kd), log_{10}(CHL), cos(Julday)	GoM
	Model validation	12.23	0.95	-0.24	1.00	1519		
RFRE[e]	**Model training**	**9.12**	**0.97**	**0.06**	**1.00**	**4559**	**SST, log_{10}(Kd), log_{10}(CHL), cos(Julday)**	**GoM**
	Model validation	**12.18**	**0.95**	**0.05**	**1.00**	**4559**		

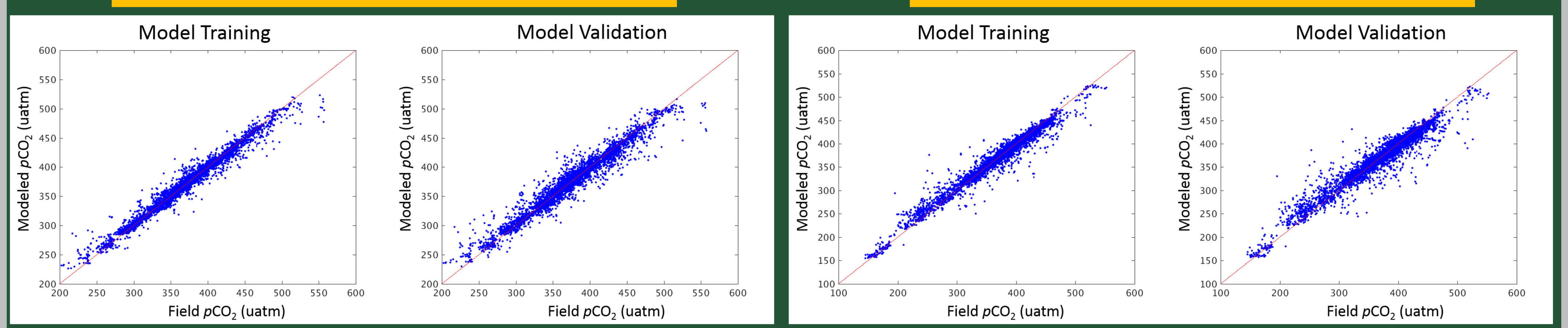
Gulf of Mexico

Approach	Statistics	RMSE (μatm)	R^2	MB (μatm)	MR	N	Model Inputs	Study Area
Stepwise MLR	Model training	14.78	0.75	0.00	1.00	704	SST, SSS, log_{10}(ag440), cos(Julday)	Eastern GOM
	Model validation	15.59	0.73	-0.13	1.00	704		
MNR	Model training	10.51	0.89	0.00	1.00	732	SST, log_{10}(Kd), log_{10}(CHL), cos(Julday)	Eastern GOM
	Model validation	11.79	0.88	0.03	1.00	784		
PCR	Model training	14.69	0.75	0.00	1.00	704	SST, SSS, log_{10}(Kd), log_{10}(CHL), log_{10}(ag440), cos(Julday)	Eastern GOM
	Model validation	15.40	0.74	-0.09	1.00	704		
MeSAA[f]	Model development	12.36	0.78	0.00	1.00	676	SST, SSS, log_{10}(CHL)	Northern GOM
MNR	Model training	10.35	0.84	-0.00	1.00	338	SST, SSS, log_{10}(CHL), cos(Julday)	Northern GOM
	Model validation	10.98	0.83	-0.21	1.00	328		
RFRE	**Model training**	**6.68**	**0.97**	**-0.03**	**1.00**	**17,551**	**SST, SSS, log_{10}(Kd), log_{10}(CHL), cos(Julday)**	**Whole GOM**
	Model validation	**9.12**	**0.94**	**-0.07**	**1.00**	**17,551**		

[a] Multi-linear regression; [b] Multi-nonlinear regression; [c] Principle component regression; [d] Multi-perception Neural Network; [e] Random forest based regression ensembles; [f] Mechanistic semi-analytical approach; [g] Root mean square error; [h] Mean bias; [i] Mean ratio.

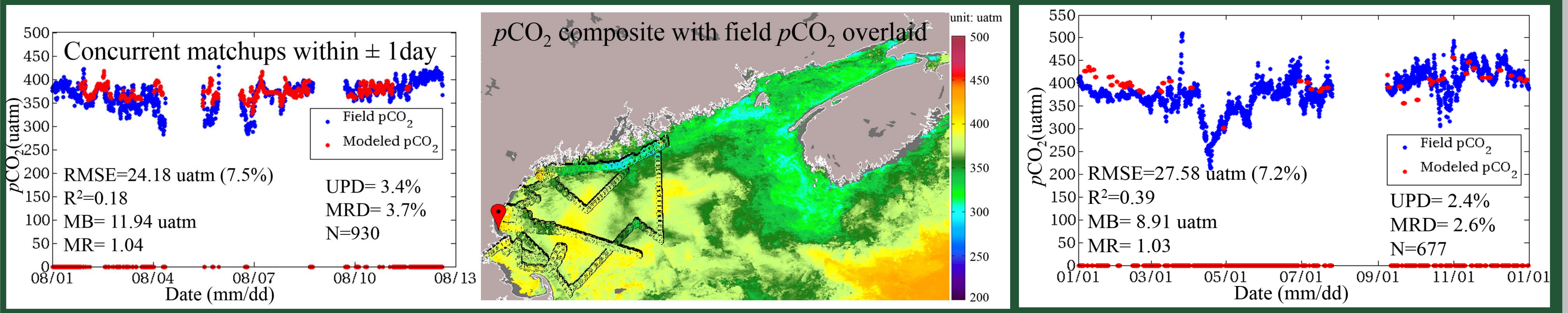
Model performance of the RFRE

Gulf of Maine | Gulf of Mexico



Independent Validation of RFRE in Gulf of Maine

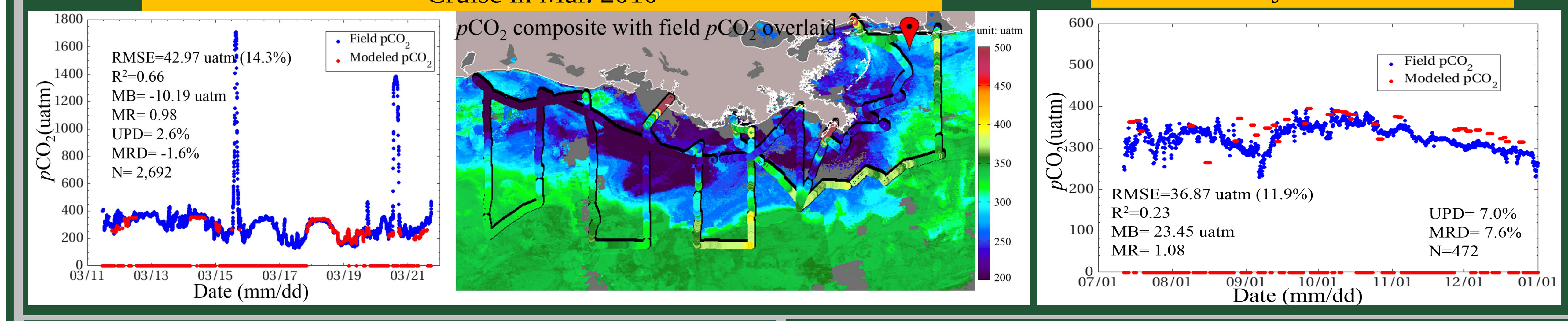
Cruise in Aug. 2004 | Buoy in 2010



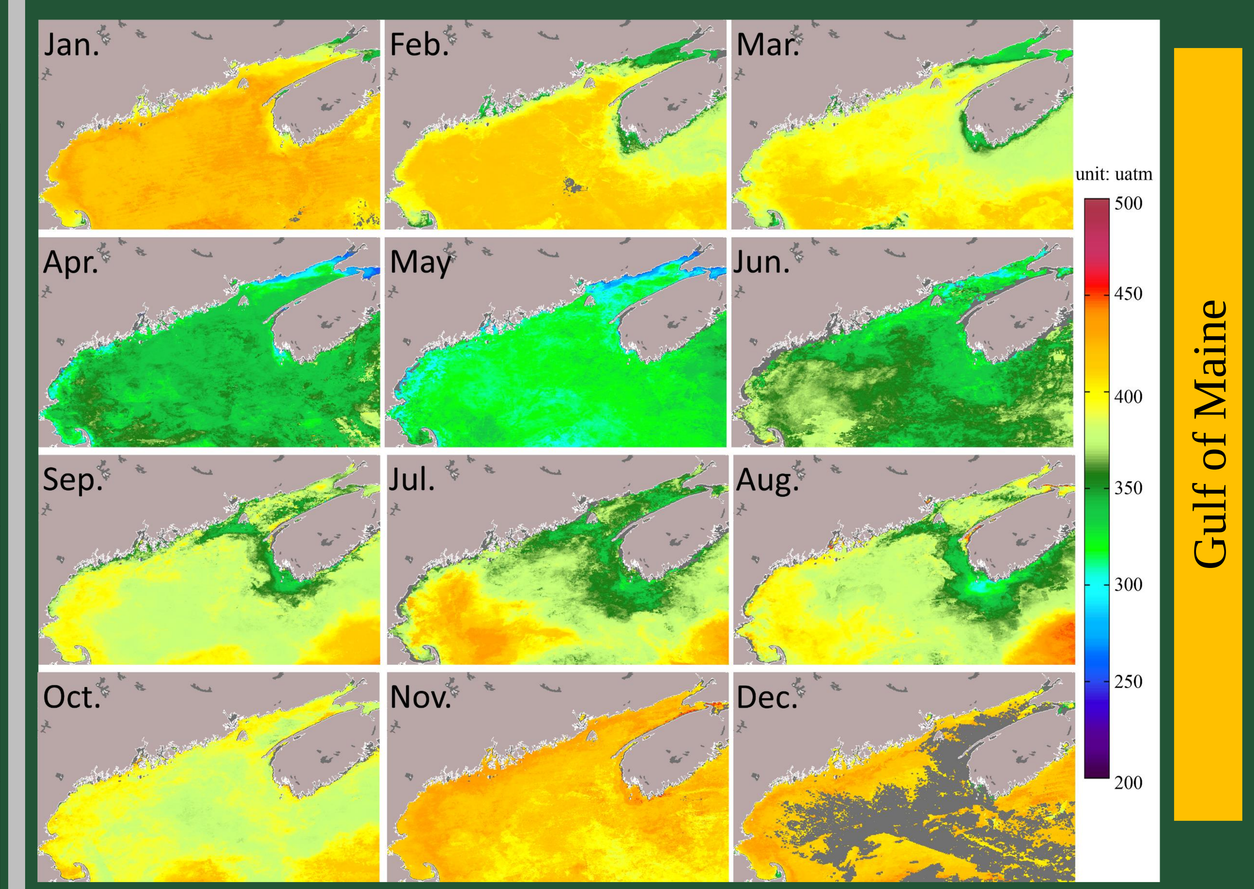
UPD: Unbiased percent difference; MRD: Mean relative difference.

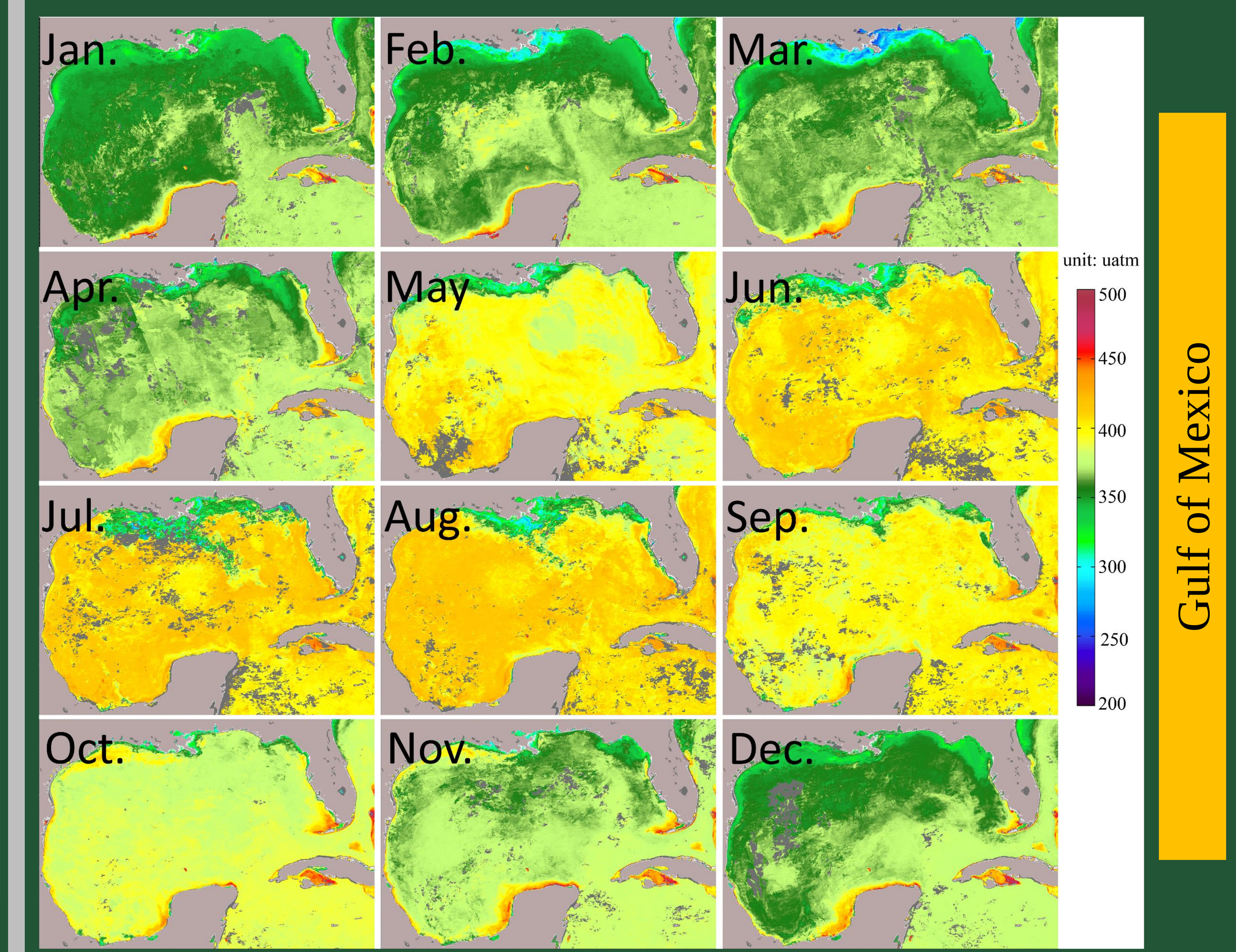
Independent Validation of RFRE in Gulf of Mexico

Cruise in Mar. 2010 | Buoy in 2013



Monthly pCO_2 in 2013





Conclusion

- Comparing to the approaches of MLR, MNR, PCR, MPNN and MeSAA, RFRE is found to have better performance in both GoM and GOM.
- RFRE-based surface pCO_2 models were developed with uncertainty of ~12.18 uatm and pCO_2 of 200~550 uatm for GoM, and uncertainty of 9.12 uatm and pCO_2 of 145~550 uatm for GOM, when applied to MODIS 1-km data.
- The surface pCO_2 model is capable to quantify low pCO_2 around the Mississippi delta and the spatial variation patterns in the GoM and GOM.
- Surface pCO_2 in the GoM and GOM showed the opposite seasonal variation patterns due to different controlling systems.

REFERENCE

[1] Chen, S., Hu, C., Byrne, R. H., Robbins, L. L., & Yang, B. (2016). Remote estimation of surface pCO 2 on the West Florida Shelf. *Continental Shelf Research*, 128, 10-25.

[2] Chen, S., Hu, C., Cai, W. J., & Yang, B. (2017). Estimating surface pCO2 in the northern Gulf of Mexico: Which remote sensing model to use?. *Continental Shelf Research*, 151, 94-110.

[3] Chen, S., & Hu, C. (2017). Estimating sea surface salinity in the northern Gulf of Mexico from satellite ocean color measurements. *Remote Sensing of Environment*, 201, 115-132.

[4] Lohrenz, S. E., Cai, W. J., Chen, F., Chen, X., & Tuel, M. (2010). Seasonal variability in air-sea fluxes of CO2 in a river-influenced coastal margin. Journal of Geophysical Research: Oceans, 115(C10).

[5] Signorini, S. R., Mannino, A., Najjar, R. G., Friedrichs, M. A., Cai, W. J., Salisbury, J., Wang, Z. A, Thomas, H., & Shadwick, E. (2013). Surface ocean pCO2 seasonality and sea-air CO2 flux estimates for the North American east coast. *Journal of Geophysical Research: Oceans*, 118(10), 5439-5460.

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