

Sensor-Agnostic Satellite Chlorophyll Model Based on Transformer

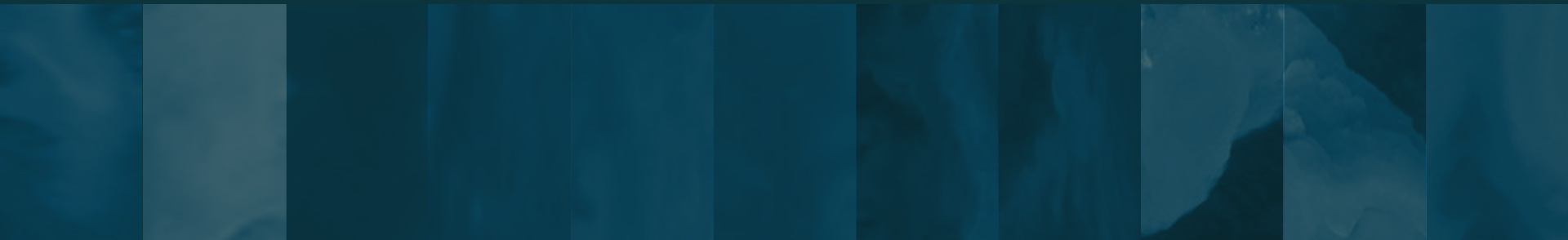
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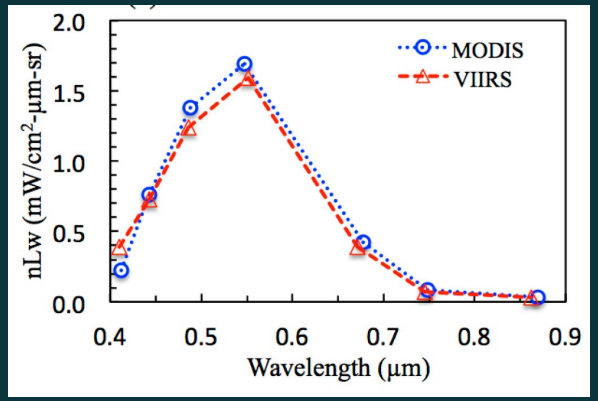
Motivation

- Large-scale, long-term, cost-effective monitoring
- A variety of satellite ocean color sensors
- Need for harmonized multi-sensor datasets
- Extant, sensor-specific, bio-optical algorithms
    - e.g., OC-CCI
    - Uncertainties introduced by assumptions
- Challenges in optically complex waters



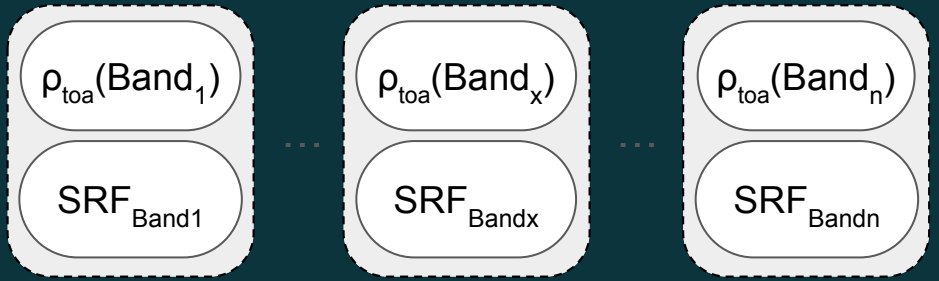
What Do Different Sensors' Data Have in Common?

Traditional Perspective



nLw: normalized water-leaving radiance

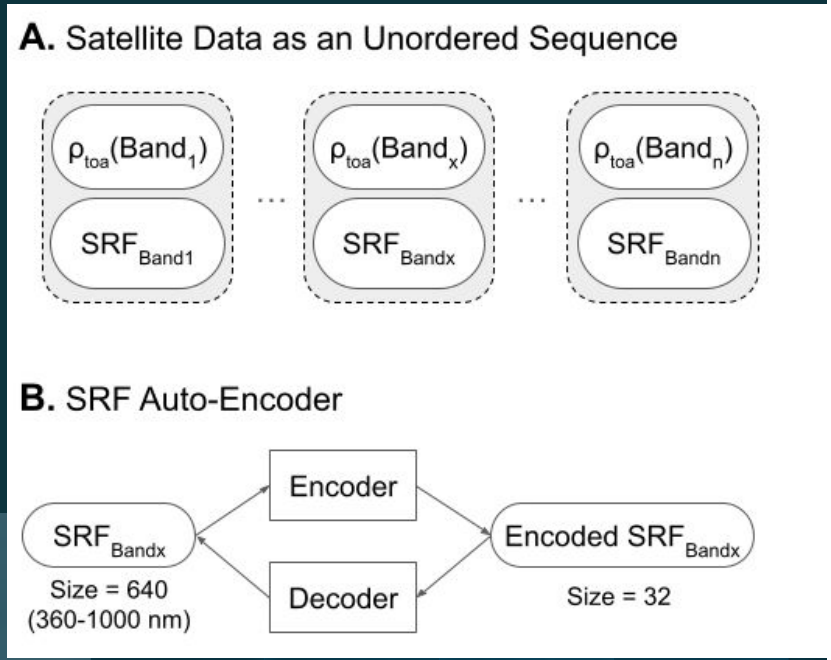
New Perspective

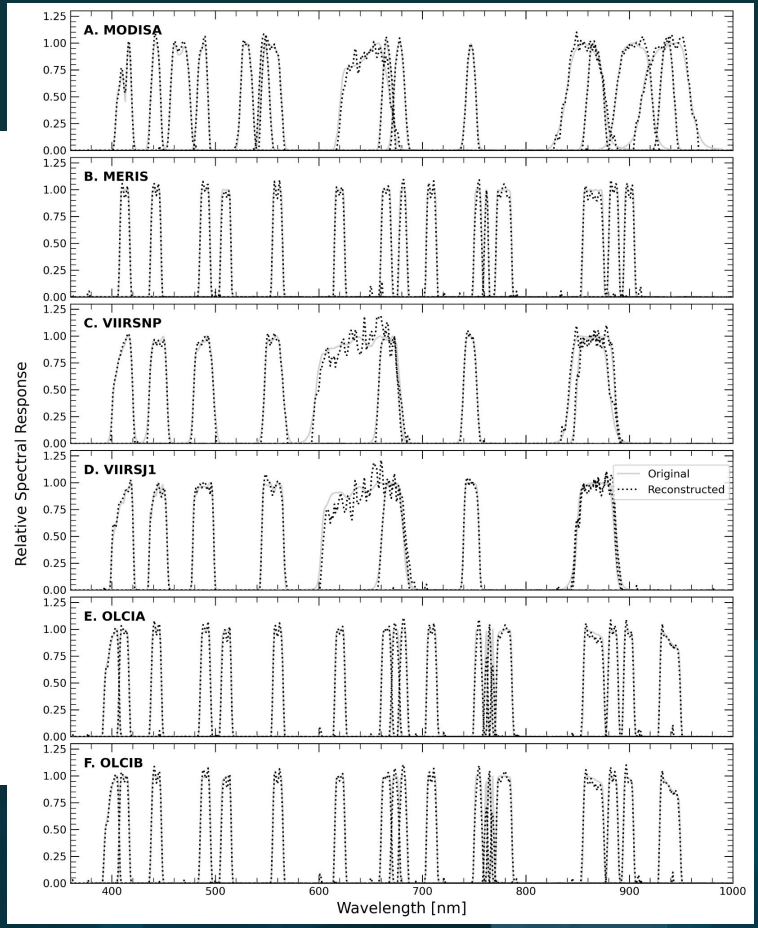


ρ_{toa}: Top-of-Atmosphere reflectance

SRF: Spectral Response Function

Harmonize Multi-Sensor Spectra with Transformers

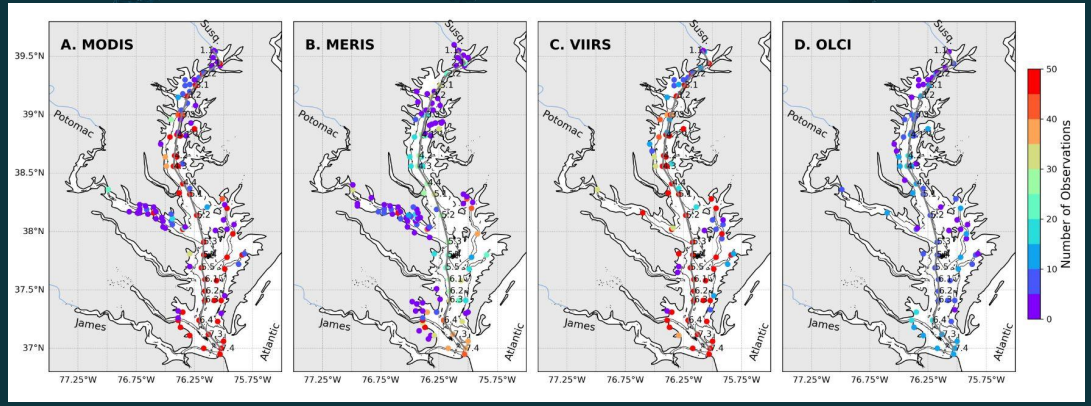




Data

- Matchups in the Chesapeake Bay:
  - 6 sensors: MODIS-Aqua, MERIS, VIIRS-SNPP, VIIRS-J1, OLCI-S3A, and -S3B
  - 2002-2020

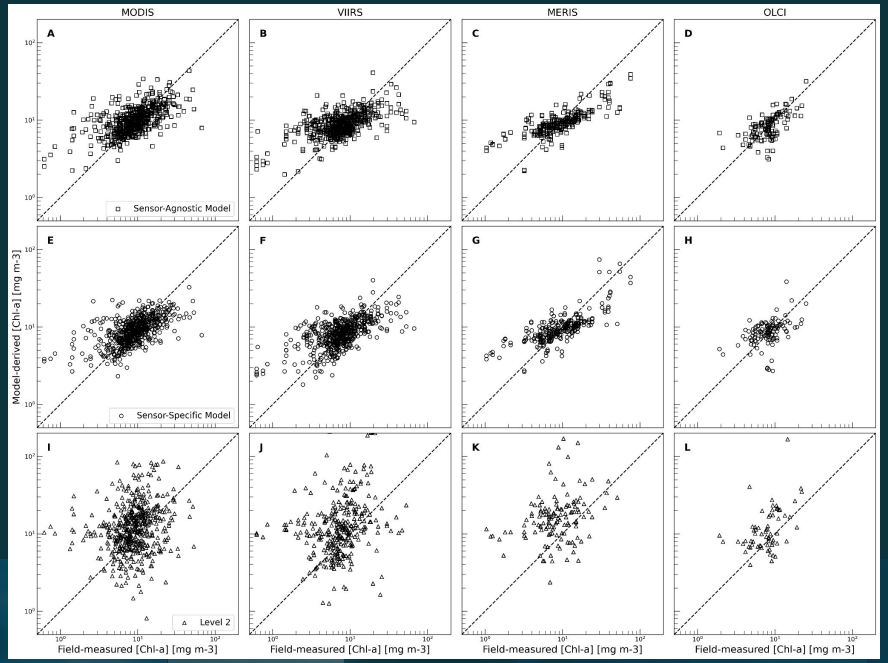
- Data Augmentation
  - Linear combinations
  - Between data in the same spatial-temporal bins
  - Outcome: ~23x for MODIS, 10x for MERIS, 10x for VIIRS, 4x for OLCI



Data Split

Sensor	Training	Validation	Test
MODIS (*N* = 4063)	2002-2016 (73.3%)	2017, 2018 (12.1%)	2019, 2020, 2021 (14.6%)
MERIS (*N* = 1773)	2002-2009 (71.8%)	2010 (12.0%)	2011, 2012 (16.2%)
VIIRS (*N* = 3396)	2012-2019 (74.0%)	2020 (9.1%)	2021 (16.9%)
OLCI (*N* = 617)	2016, 2017, 2019 (71.5%)	2018 (9.4%)	2020 (19.1%)

Model Evaluation on Testset



Error statistics

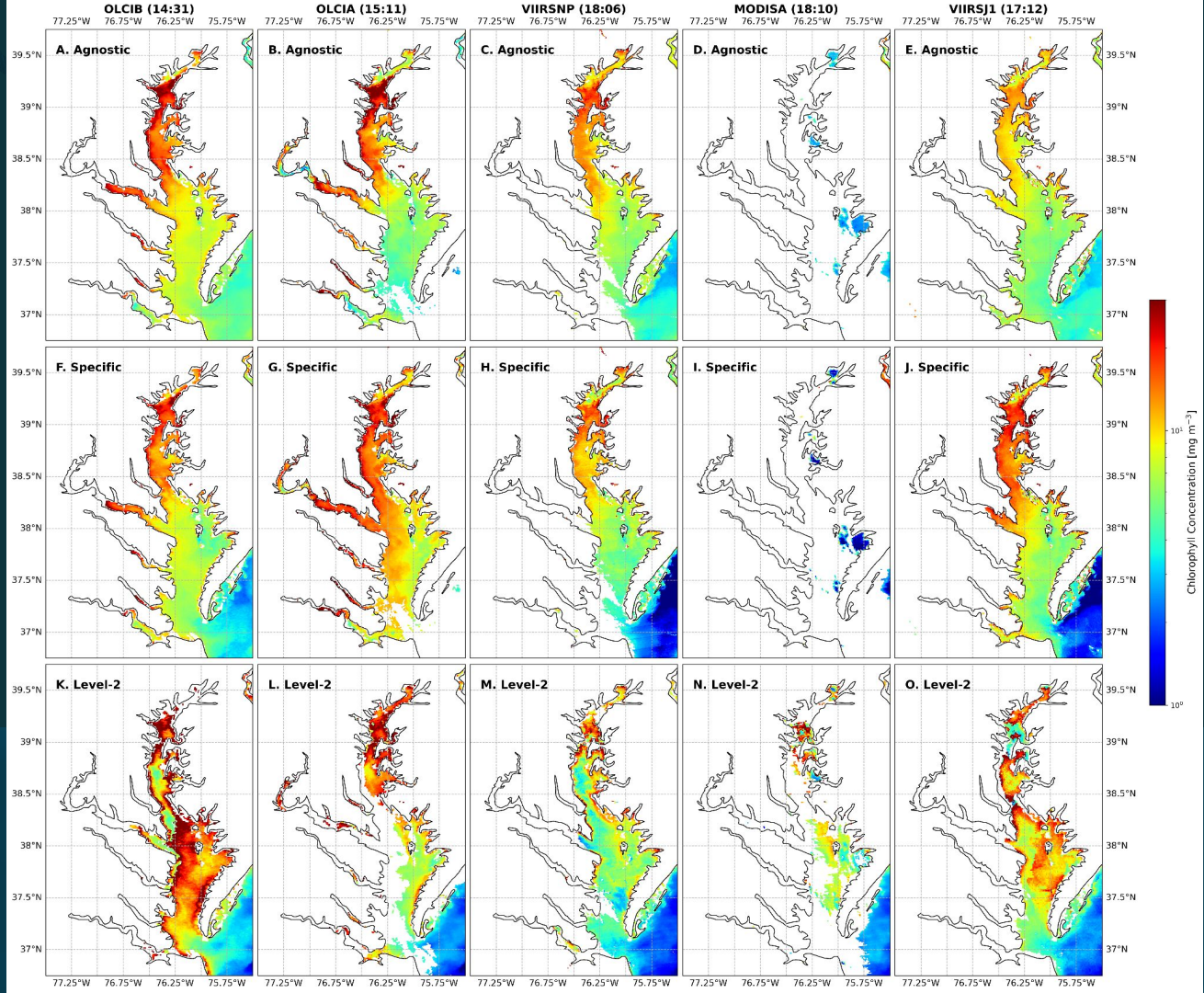
Sensor	Model	RMSE [mg m^{-3}]	R^2	Slope	MAE [mg m^{-3}]	MAPE	Bias [mg m^{-3}]	Log_MAE	Log_Bias	*N*
	Agnostic	6.02	0.28	0.35	3.58	45.4	-0.09	1.410	1.092	595
MODIS	Specific	6.07	0.26	0.29	3.60	42.6	-1.04	1.423	0.995	595
	NASA Level-2	14.91	-4.14	0.37	9.08	121.8	5.11	1.985	1.347	494
	Agnostic	7.54	0.48	0.35	4.32	43.7	-2.07	1.457	1.001	287
MERIS	Specific	7.30	0.51	0.54	4.33	44.2	-1.28	1.456	1.028	287
	NASA Level-2	72.58	-86.98	4.52	22.59	203.2	20.48	2.375	1.967	242
	Agnostic	6.22	0.26	0.25	3.56	55.7	-0.07	1.495	1.161	573
VIIRS	Specific	6.13	0.28	0.28	3.49	51.1	-0.44	1.482	1.088	573
	NASA Level-2	33.24	-23.34	0.97	14.05	199.6	11.01	2.262	1.703	515
	Agnostic	2.89	0.44	0.67	2.21	28.0	-0.16	1.309	0.996	117
OLCI	Specific	4.05	-0.10	0.47	2.80	34.9	0.28	1.382	1.049	117
	NASA Level-2	80.27	-353.88	8.69	19.50	157.8	18.15	1.816	1.539	79

- Sensor-agnostic model performs as good as or better than sensor-specific models
- Substantial improvements over the standard NASA Level-2 (OCI)

Summer

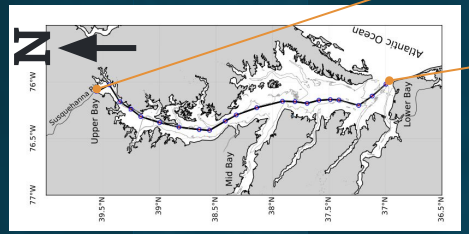
(Jun 22, 2020)

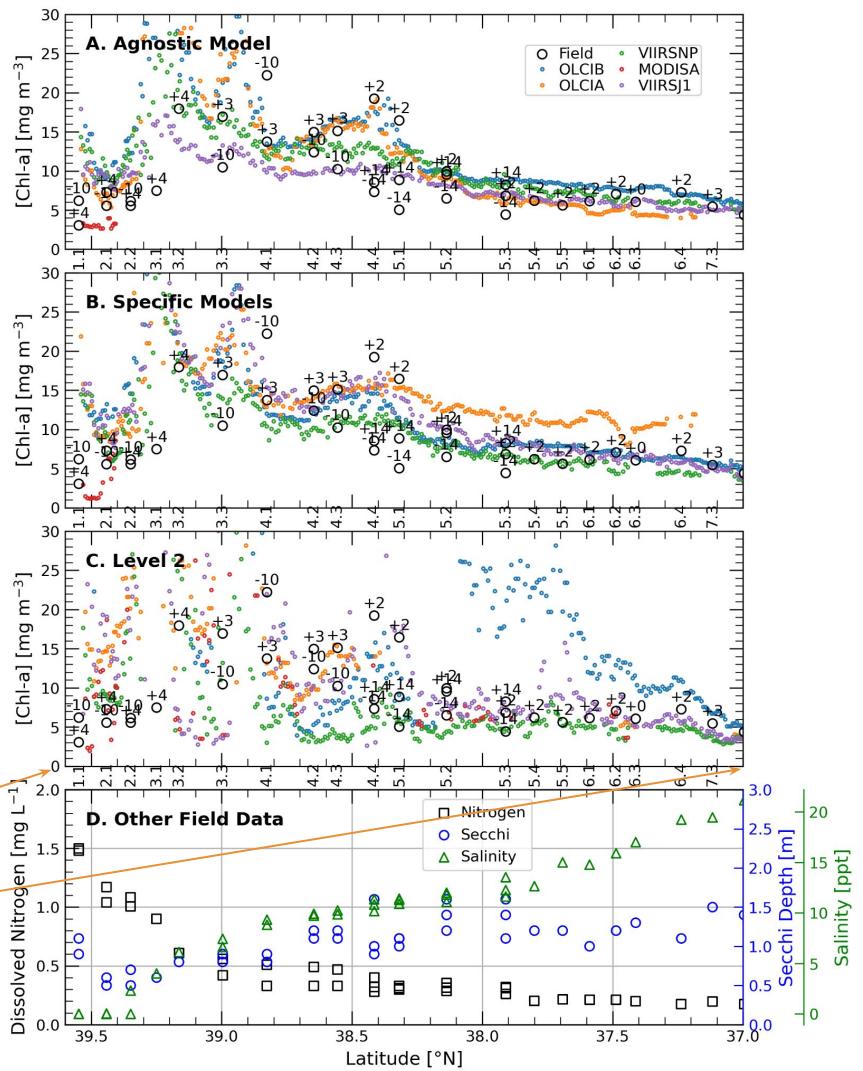
- Consistent front identification
- Greater variability in sensor-specific models
- Low-Chl-a zone agreement in the upper bay



Summer along Transect

- General consistency with field data
- Turbidity maximum/Chl-a minimum
- Chl-a maxima seaward of turbidity maximum
- Inter-sensor consistency, mixed results

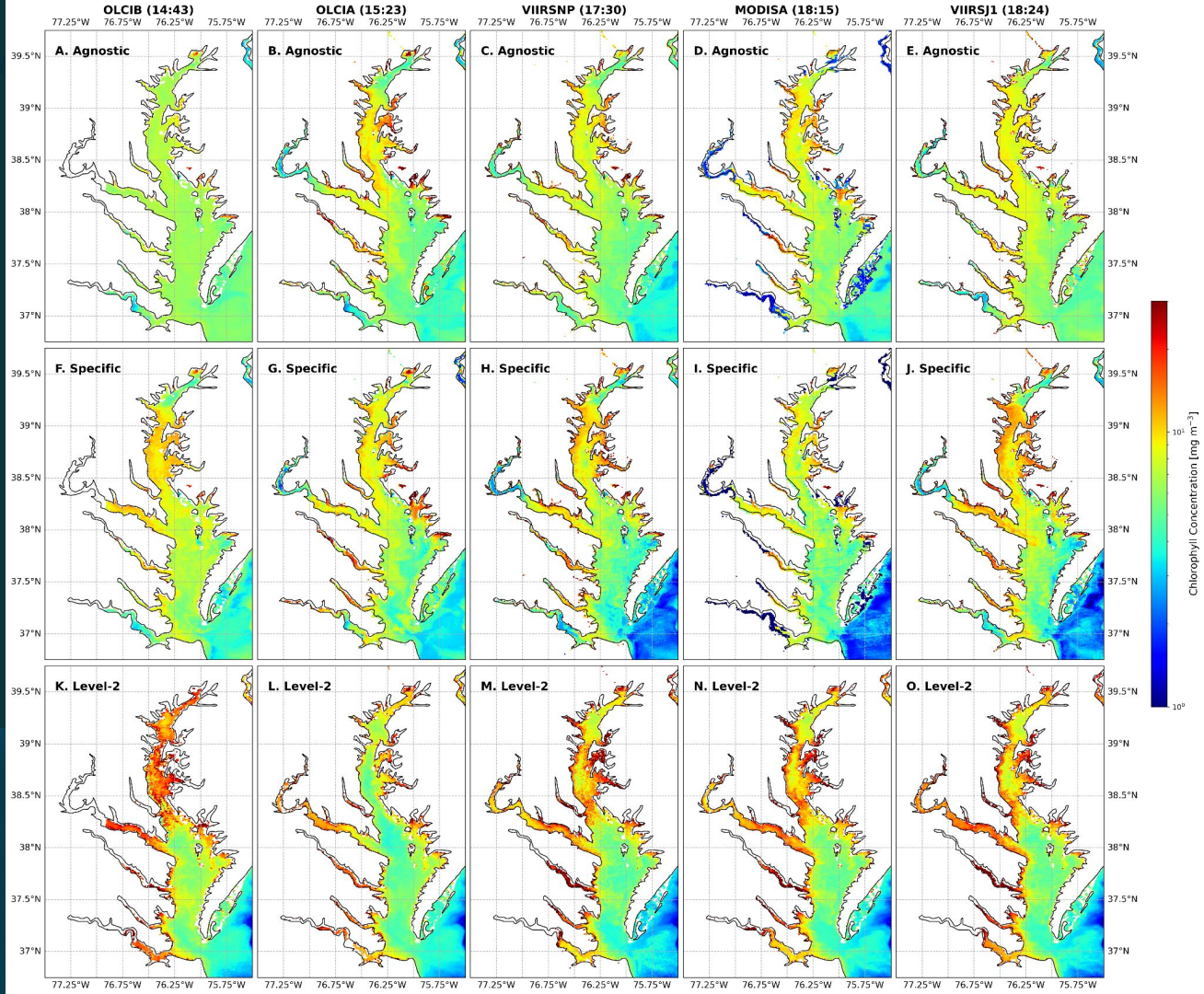




Fall

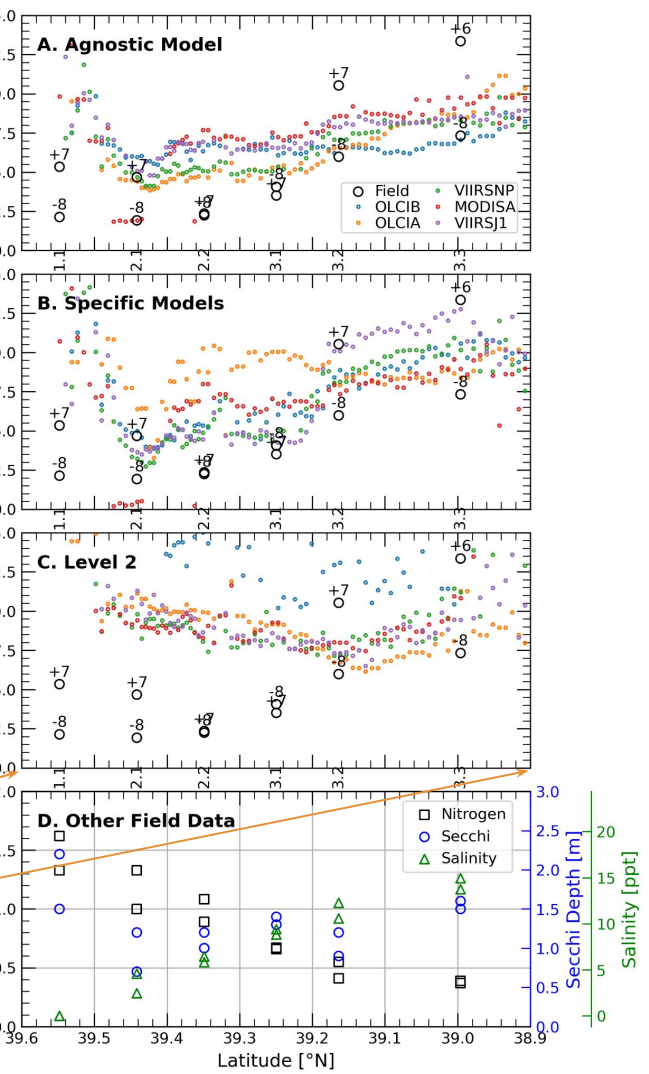
(Nov 4, 2020)

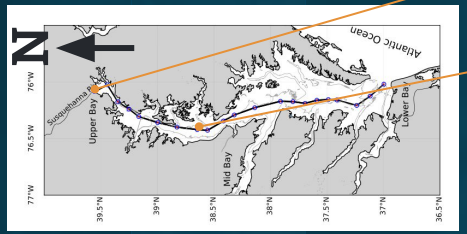
- Chl-a minimum still present in most sensor-agnostic and specific products
- Outlier case: OLCIB
- Level-2 products show a consistent pattern among some sensors



Fall along Transect

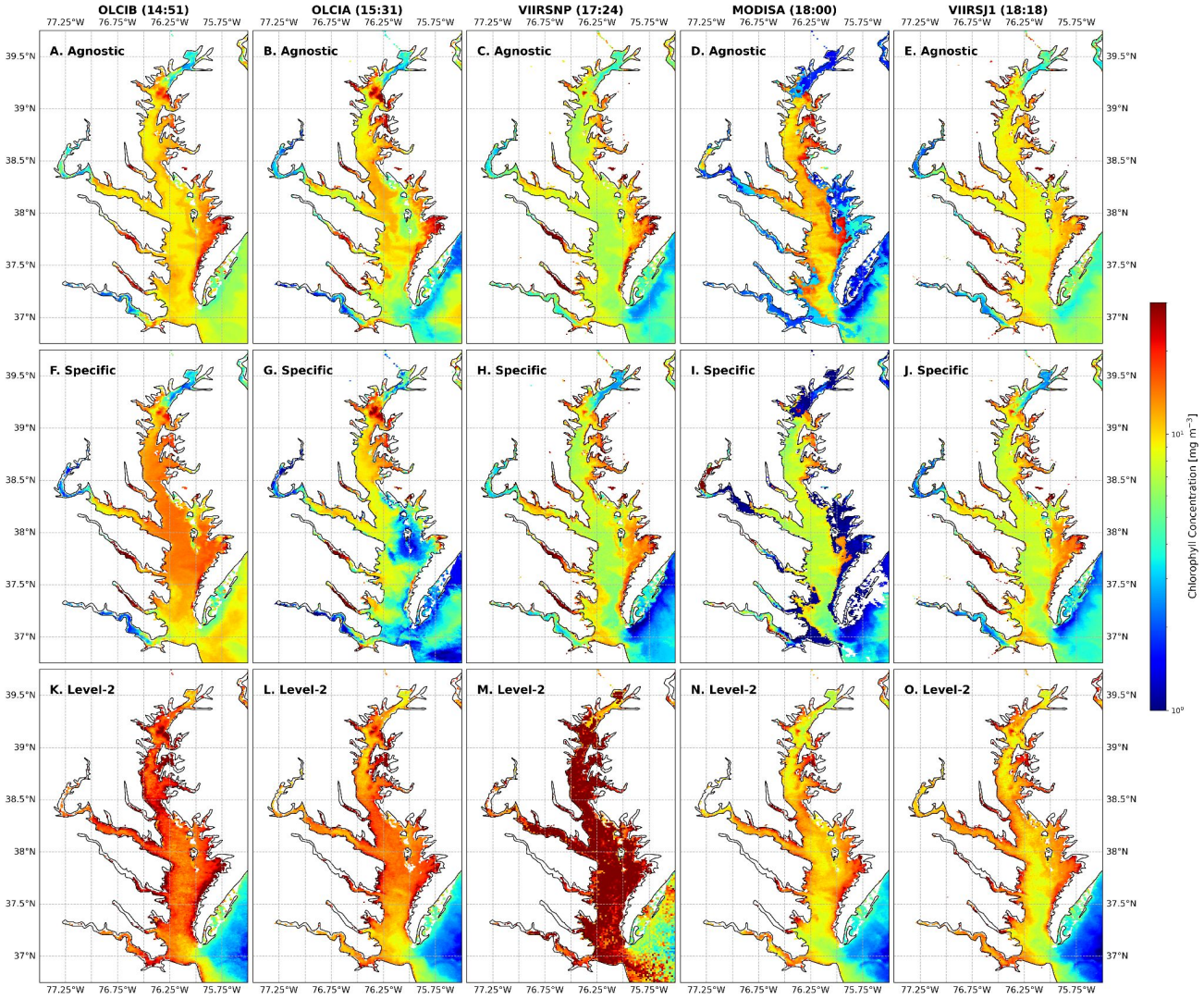
- Chl-*a* minimum alignment with field data
- Inter-sensor consistency
- Level-2 divergence from field data





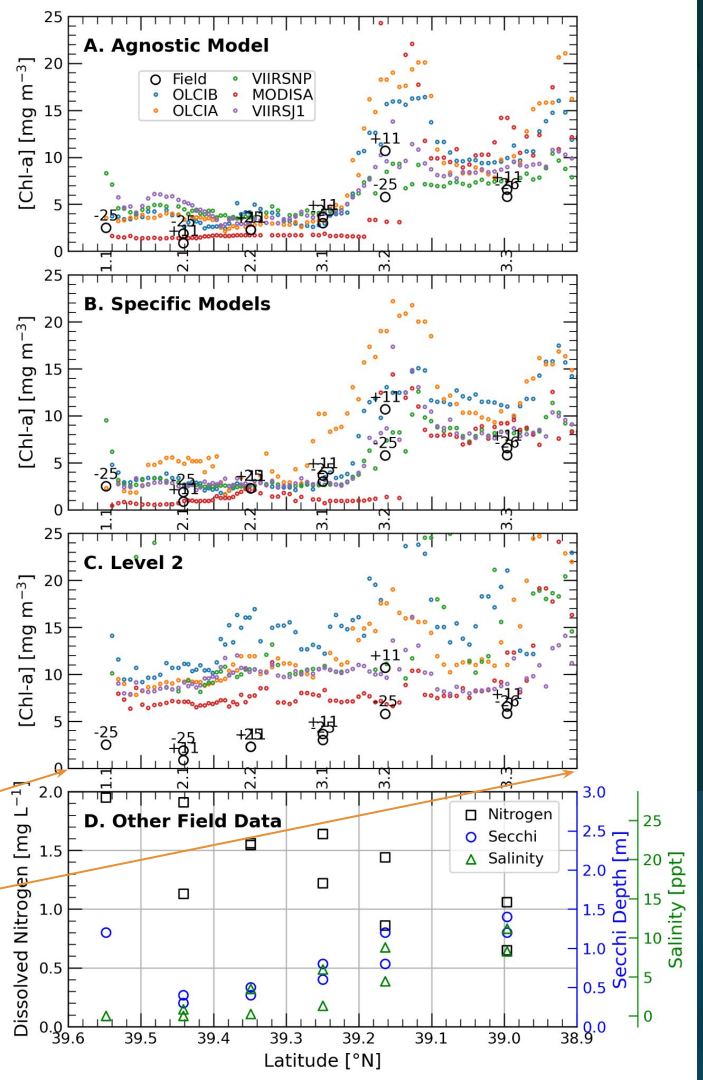
Spring
(Mar 7, 2021)

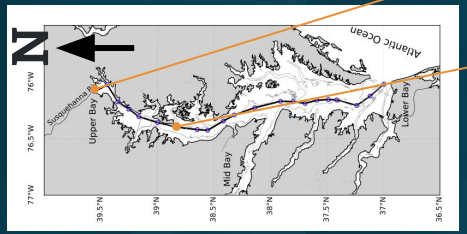
- Most challenging scenario for inter-sensor consistency
- Chl-a minimum still evident in sensor-agnostic and -specific products
- Substantial variation in Level-2 data



Spring along Transect

- General trend consistent with field data
- Turbidity maximum/Chl-a minimum, seaward Chl-a peaks
- Sensor-agnostic data: Superior inter-sensor consistency



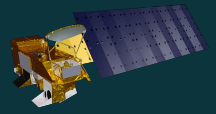
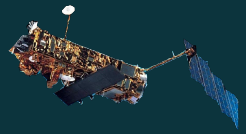
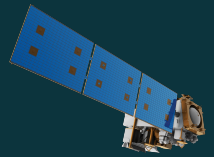
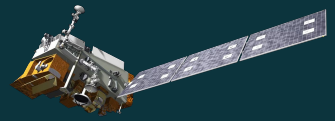
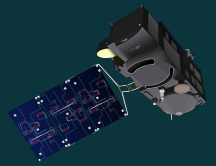


Conclusion

Single Model Outperforms Sensor-Specific Approaches

Latent Semantic Learning

Pre-Trained “foundation models” in ocean color remote sensing?

Acknowledgements

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