Coastal Hypoxia Analysis and Risk Tracking (CHART) through Remote Sensing and Process-Based Modeling in South and Southeast Asia

NASA Interdisciplinary Science Program (Initiated Sept. 2017)

PI: Charles Vörösmarty (CUNY Advanced Science Research Center)

Co-I's: **Zachary Tessler** (CUNY ASRC), Anthony Cak (CUNY ASRC), Peter Groffman (CUNY ASRC), Lucy Hutyra (Boston Univ), Kyle McDonald (CUNY City College), Maria Tzortziou (CUNY City College)

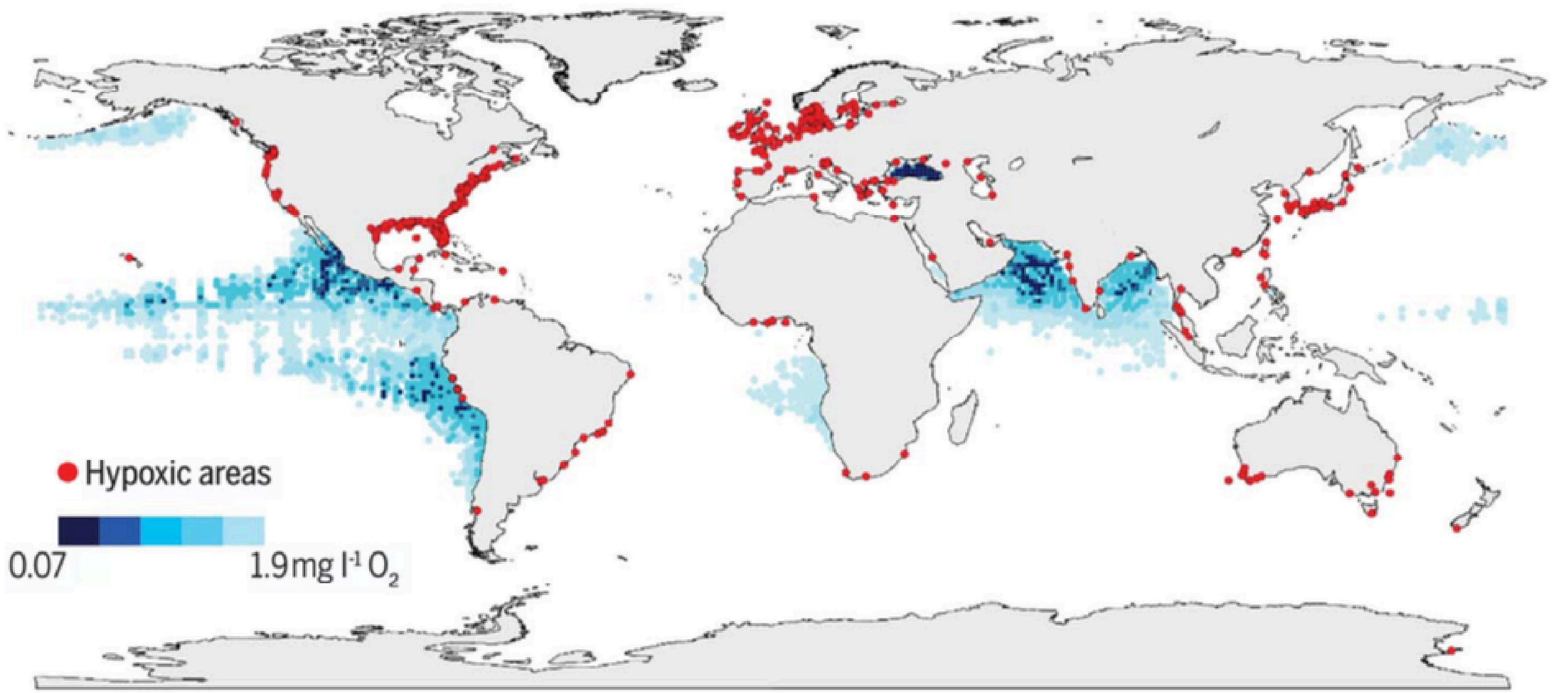
ENVIRONMENTAL SCIENCES INITIATIVE
CUNY ADVANCED SCIENCE RESEARCH CENTER

CUNY The City University of New York

Team

- Charles Vörösmarty (CUNY ASRC)
- Zachary Tessler (CUNY ASRC)
- Peter Groffman (CUNY ASRC)
- Anthony Cak (CUNY ASRC)
- Kyle McDonald (CUNY CCNY)
- Maria Tzortziou (CUNY CCNY)
- Lucy Hutyra (Boston University)

Motivation



Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security. The global map indicates coastal sites where anthropogenic nutrients have exacerbated or caused O_2 declines to <2 mg liter^{-1} (<63 μmol liter^{-1}) (red dots), as well as ocean oxygen-minimum zones at 300 m of depth (blue shaded regions). [Map created from data provided by R. Diaz, updated by members of the GO_2NE network, and downloaded from the World Ocean Atlas 2009].

Breitburg *et al.*, *Science* **359**, 46 (2018)   5 January 2018

Hypoxia is driven by terrestrial and oceanic processes that apply globally, but existing studies suggest it is primarily a North American and European problem.

Our approach is to look at how **known drivers** of hypoxia are changing in the relatively understudied South/Southeast Asia region.

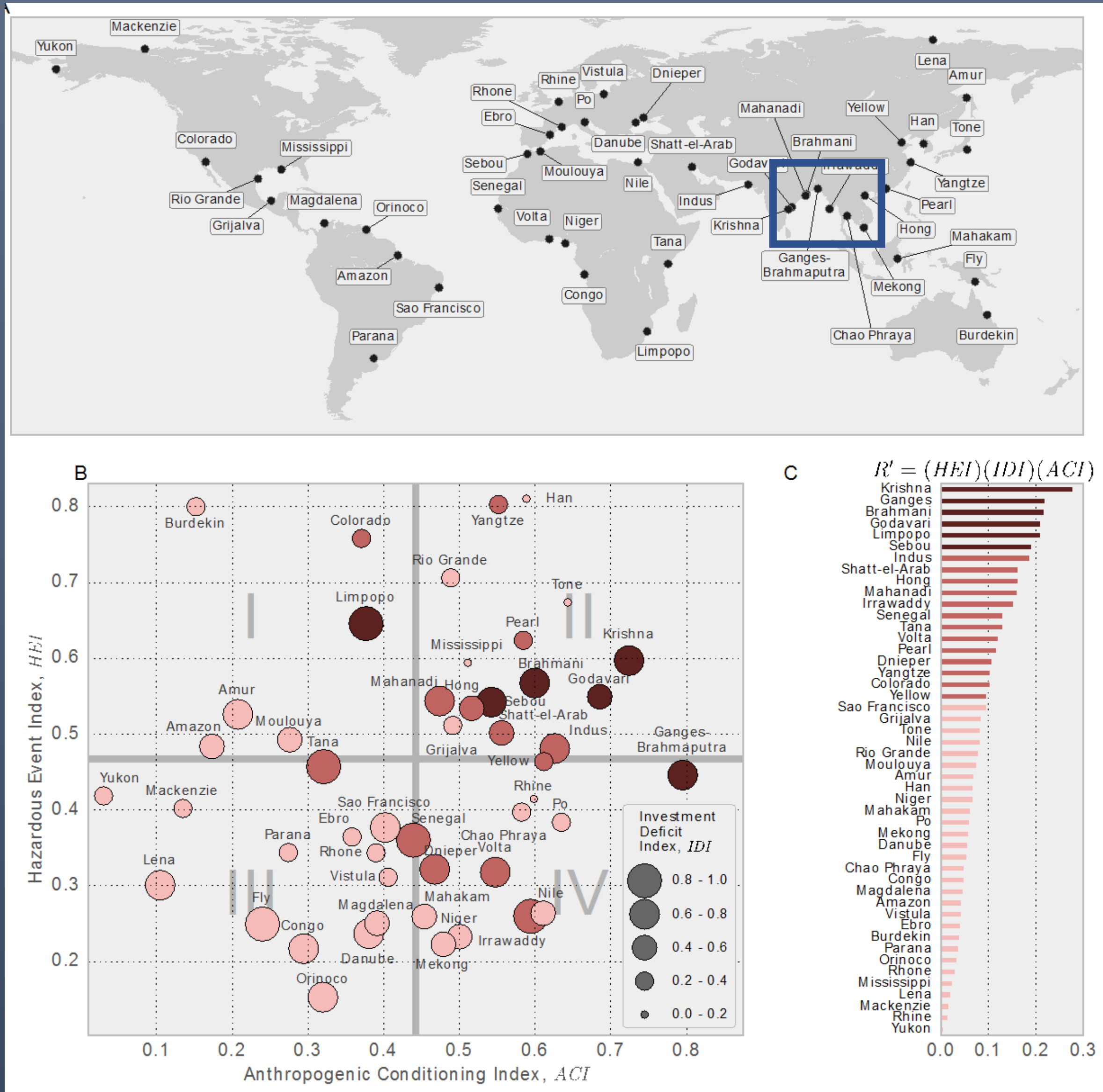
The City University of New York

Anoxia/Hypoxia, driven by:

- Open ocean hypoxia drivers:
  - Warming water decreases oxygen solubility
  - Warming water increases respiration rates
  - Warming surface water and increased precipitation both lower surface density, increases stratification, suppresses downward mixing of oxygen
- Coastal zones also sensitive to nutrient inputs from fluvial runoff

Approach

- Extension and application of results and methods from earlier LCLUC work on coastal deltas (*Global-Scale Assessment of Threatened River Delta Systems*, 2012-2015)

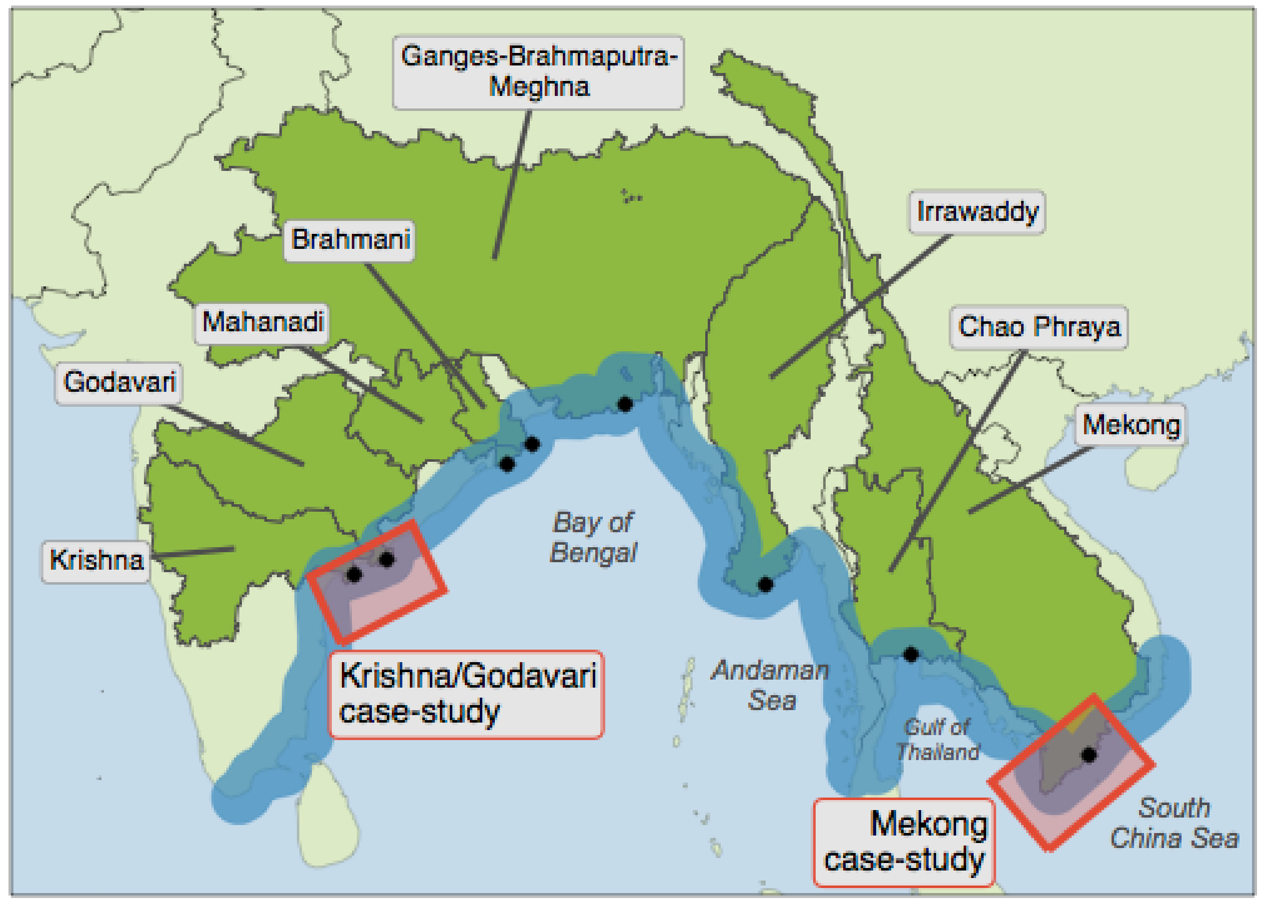


ENVIRONMENTAL SCIENCES INITIATIVE
CUNY ADVANCED SCIENCE RESEARCH CENTER

CUNY The City University of New York

- PROJECT GOAL: Using contemporary and archival optical and radar remote sensing, ***we propose to study how watershed disruption through urbanization and agricultural intensification increases the risk of coastal hypoxia***
- PROJECT HYPOTHESIS: the risk of algae blooms and hypoxia will be elevated offshore of watersheds having the most rapid population and economic growth, relative to more undisturbed land-ocean systems. Further, we expect that loss of natural wetlands of riverine and coastal floodplains – with their documented role in attenuating nutrient pollution – will have a non-linear, amplifying effect on the frequency and intensity of coastal and offshore hypoxia.

Study Region



Analysis domains:

- 8 large watersheds and deltas
- 2 focused offshore case-study sites
- ~800 small watersheds discharging to coast

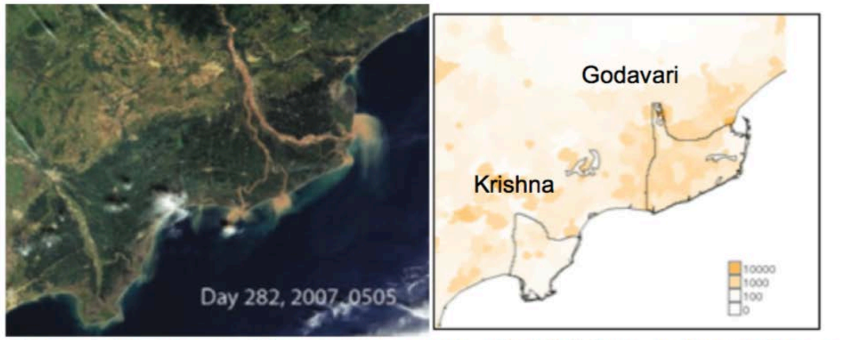


Figure 3: Despite receiving similar amounts of rainfall, large sediment plumes develop offshore of Godavari Delta, but not the Krishna Delta (left panel, MODIS). Reservoir construction along the Krishna traps sediment upstream, and extensive flood controls on the more densly populated Godavari delta (right panel, people/km^2, GRUMPv1) channel river water directly offshore, with less attenuation and modification by wetlands (after Syvitksi et al., 2009).

ENVIRONMENTAL SCIENCES INITIATIVE
CUNY ADVANCED SCIENCE RESEARCH CENTER

CUNY The City University of New York

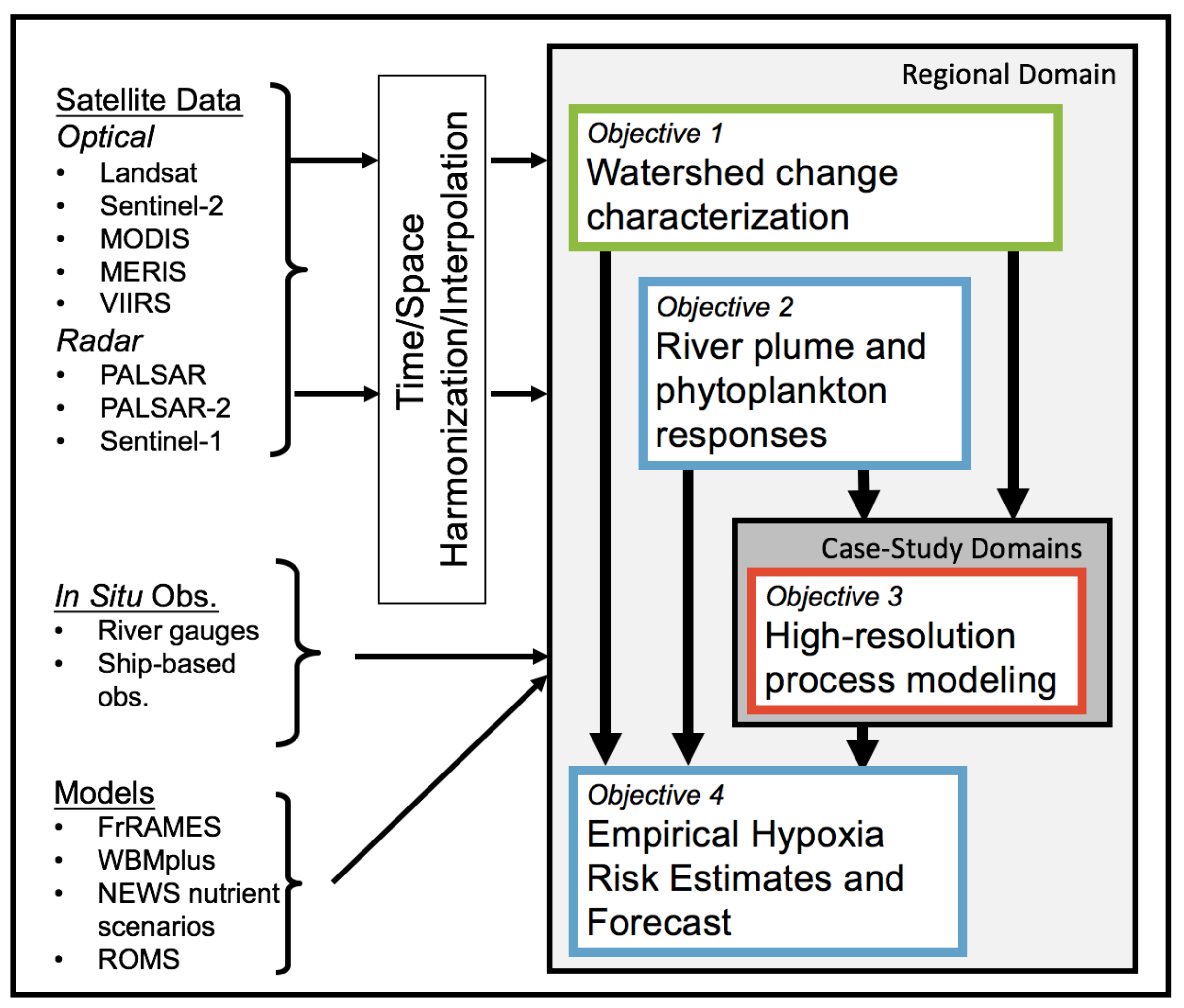
Project structure

Objective 1: Assemble and synthesize all relevant and available optical and radar remote sensing and ground based data to create a land-to-ocean flux change detection system

Objective 2: Characterize variability and trends of coastal ocean phytoplankton abundance and river plume structure using optical remote sensing

Objective 3: Quantify the nature of land-to-ocean linkages between watershed change and coastal ocean plume dynamics using process models; estimate risk factors for coastal hypoxia, with emphasis on the role of wetland losses.

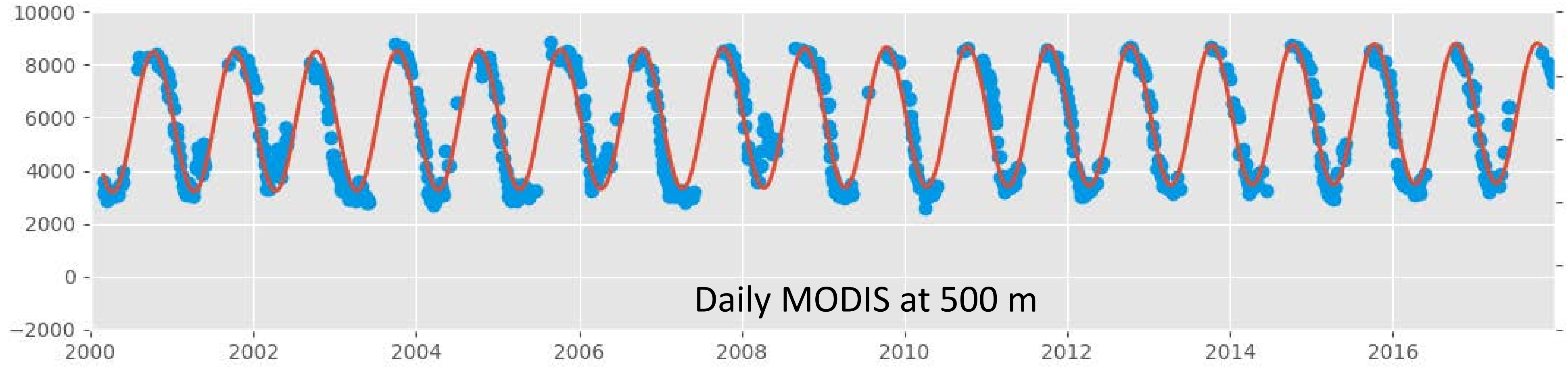
Objective 4: Map contemporary coastal "hotlines" of risk across all river mouths in the South and Southeast Asia study area and construct risk trajectories and near-future forecasts; develop the *PlumeWatch* data dashboard and portal.

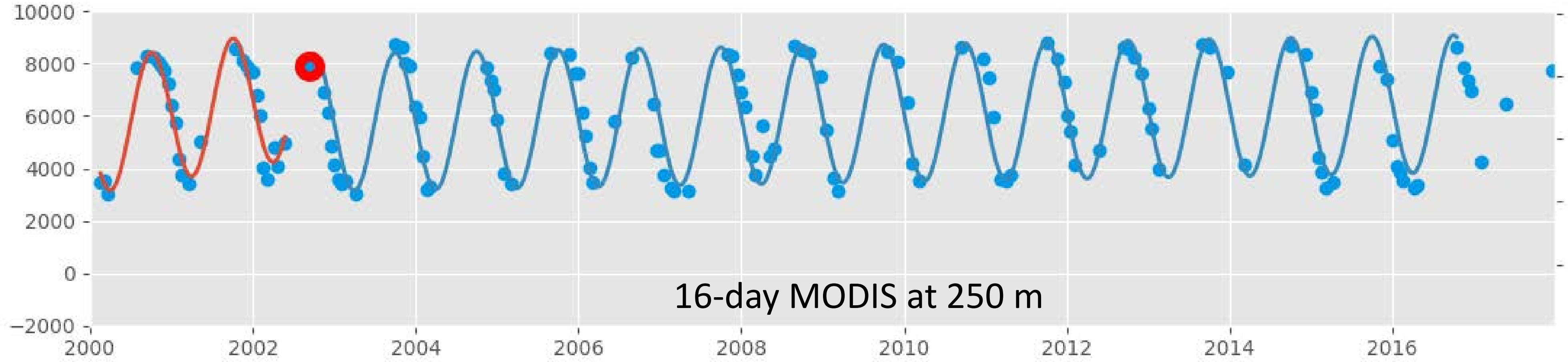


Objective 1: Land-to-Ocean flux change detection system

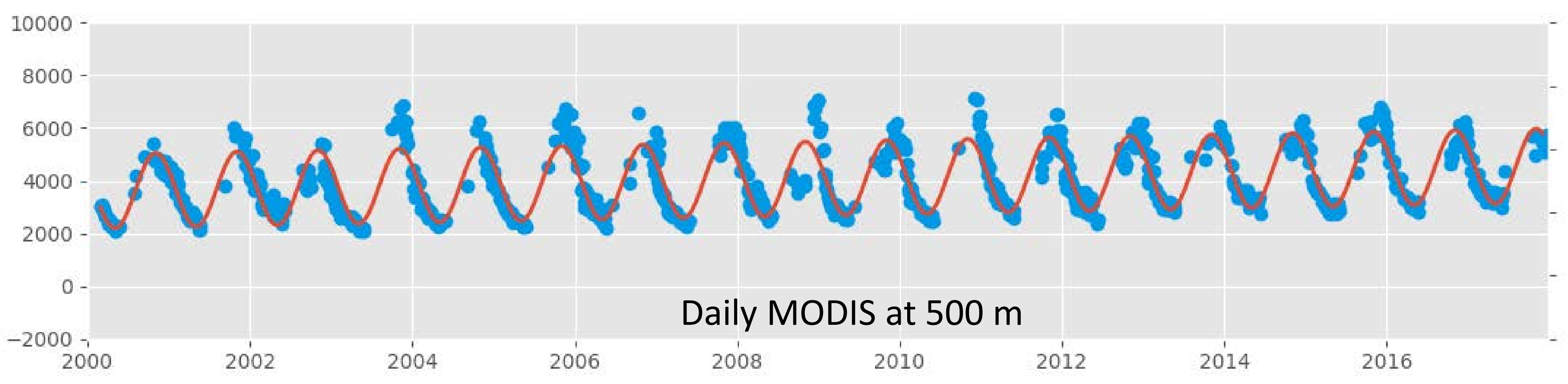
- Watershed LCLUC analysis, 2000-2017, South/Southeast Asia
- Initial effort using 16-day MODIS composites at 250m resolution
  - More computationally tractable than Landsat
  - Sufficient for initial watershed hydrological flux modeling (freshwater, nutrients)
  - CCDC methodology to identify LCLUC transitions
- Targeted higher-resolution validation with Landsat
- Develop regional land cover-to-tree height lookup table using 2005 GLAS canopy height data (Simard et al, 2011)
- Interested in LCLUC-impacts on both river flow dynamics, and water quality

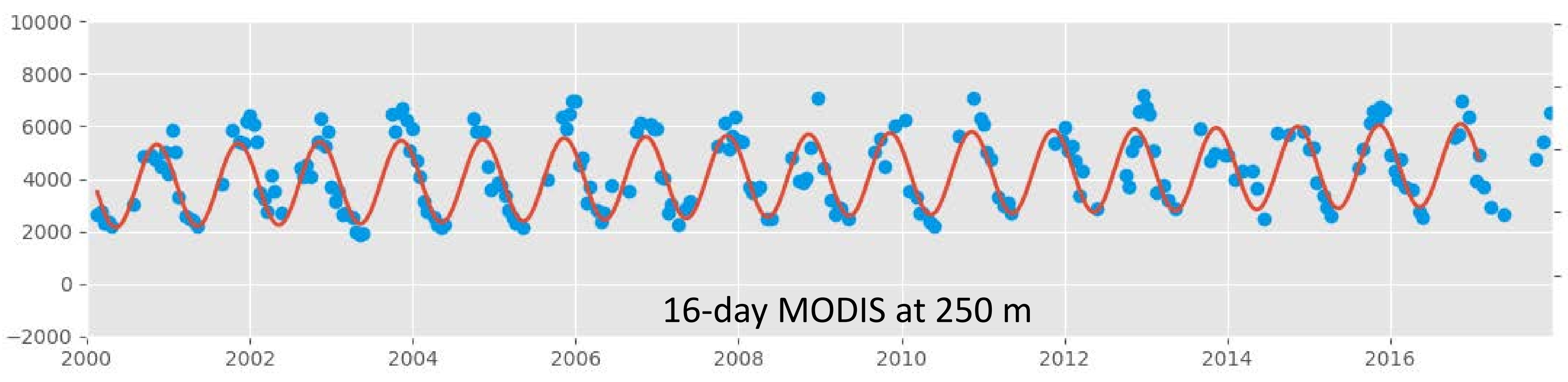
Example 1: Stable Forest



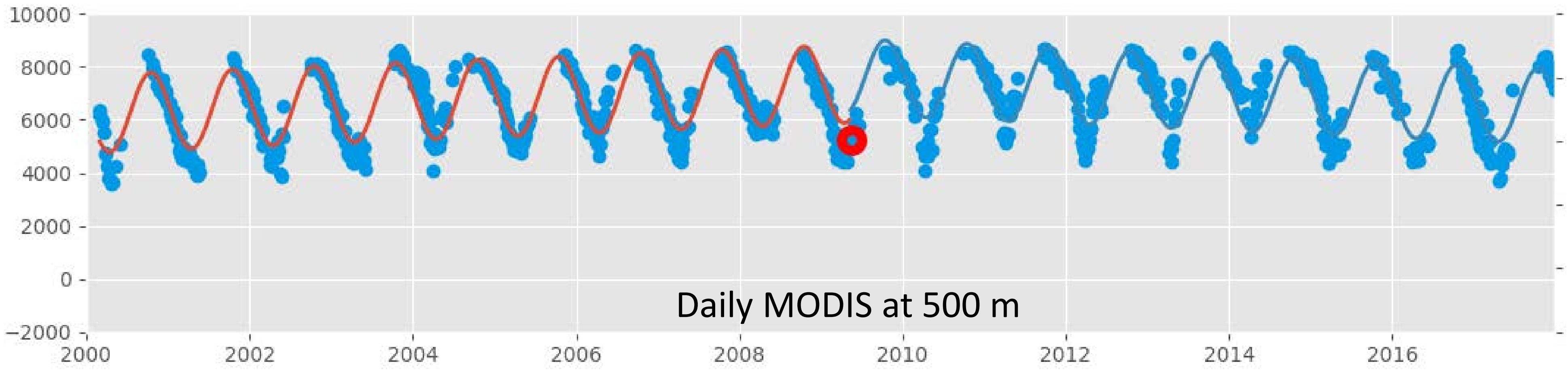


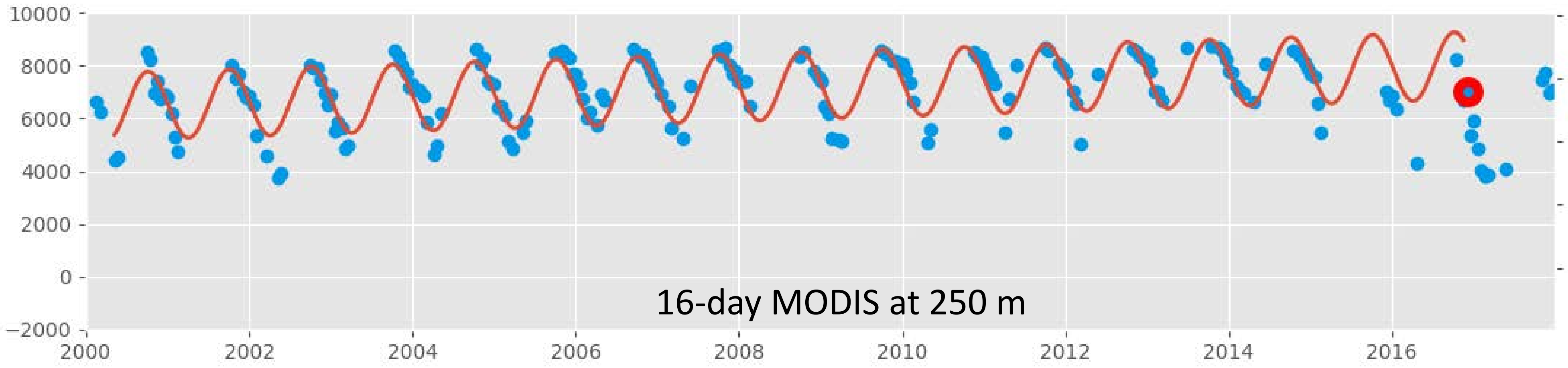
Example 2: Agriculture

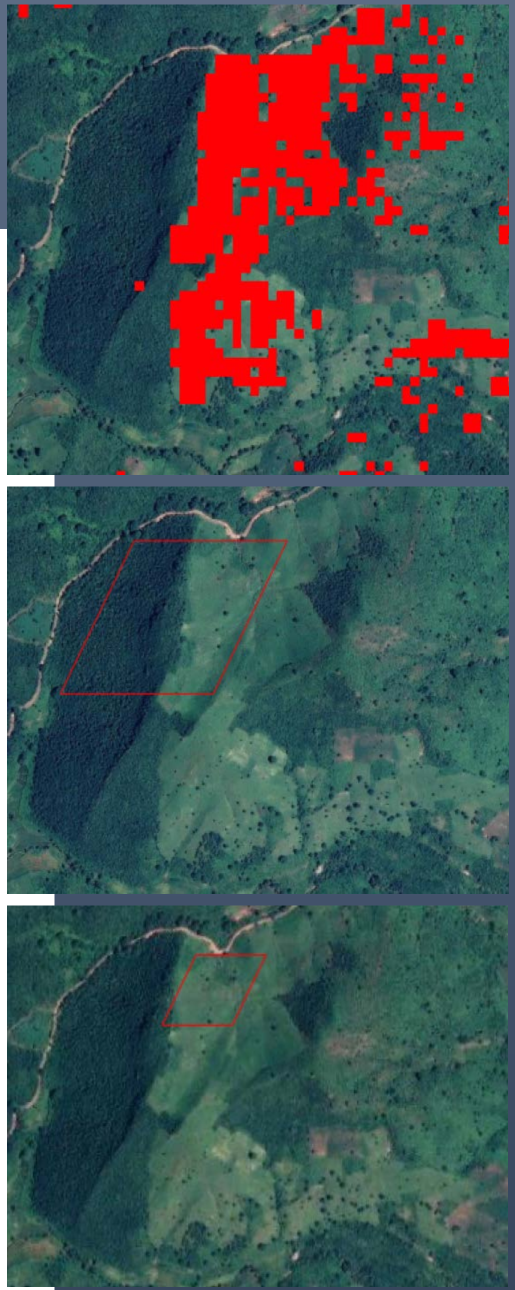




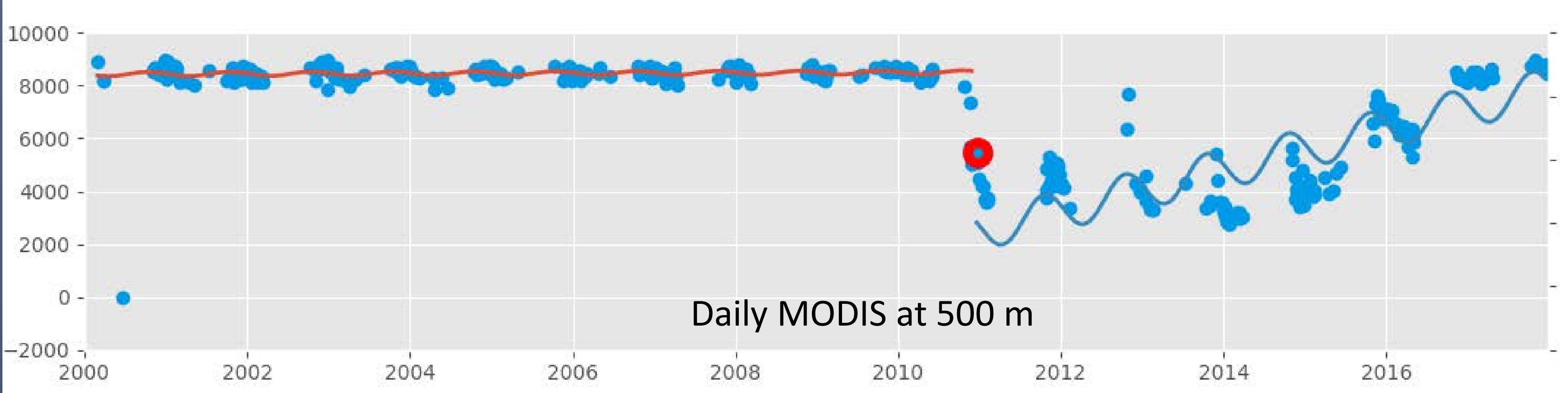
Example 3: Forest to Pasture

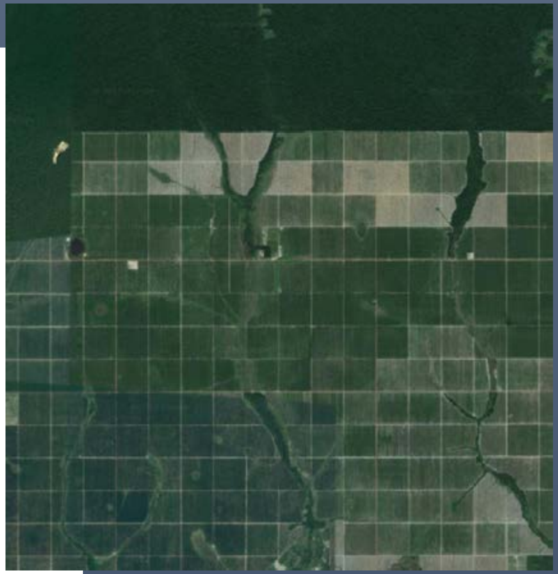


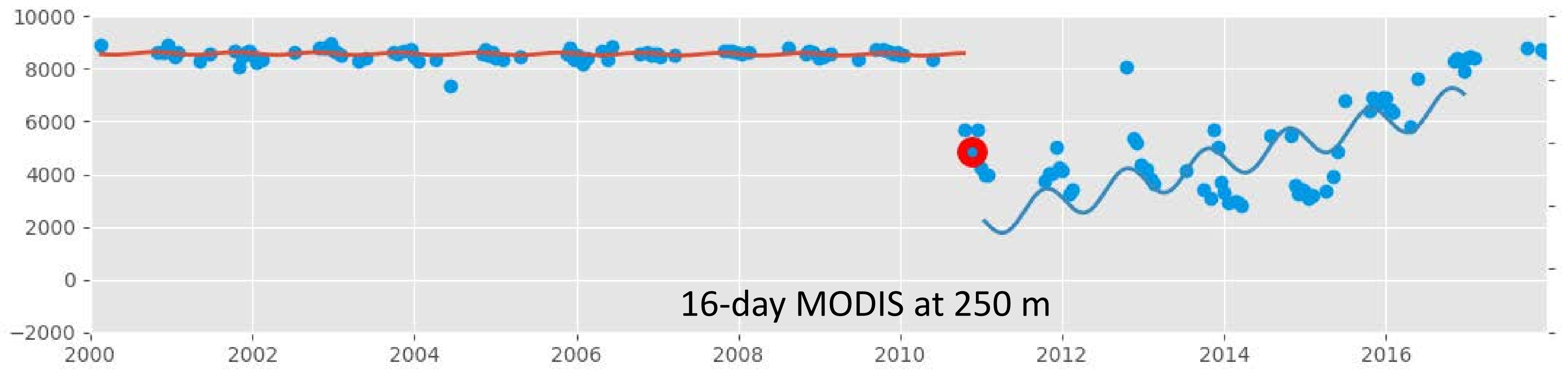


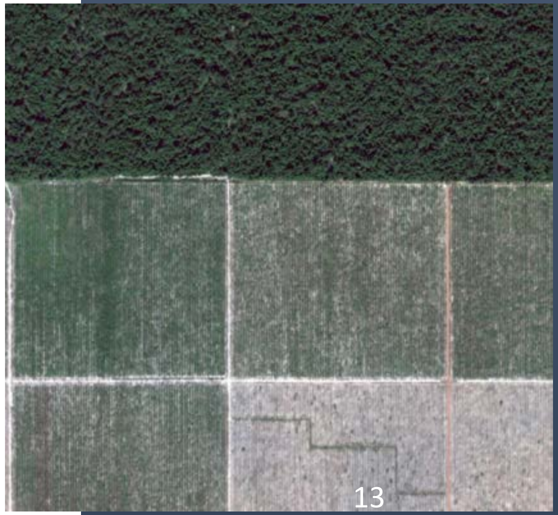


Example 4: Forest to Plantation

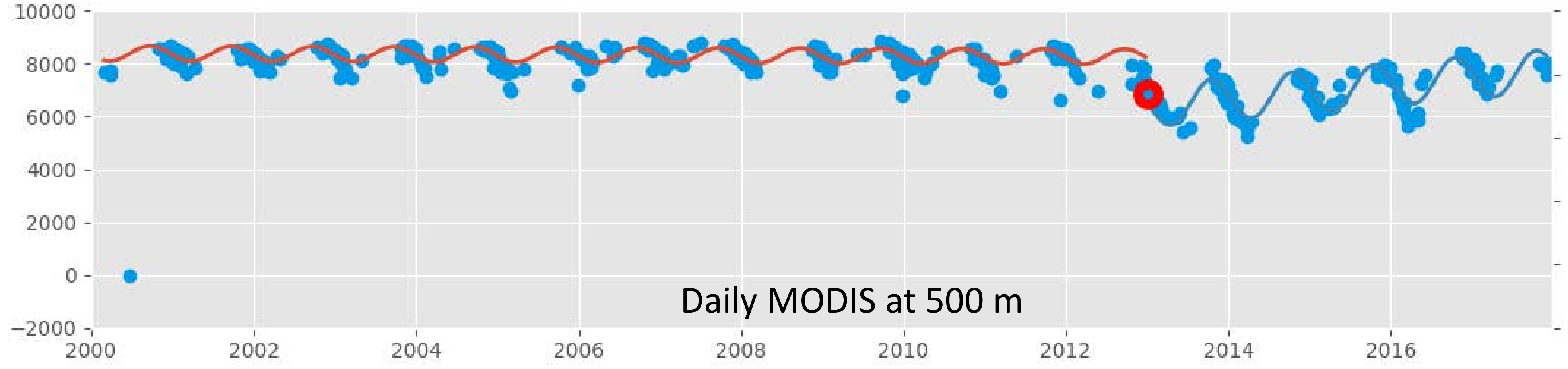


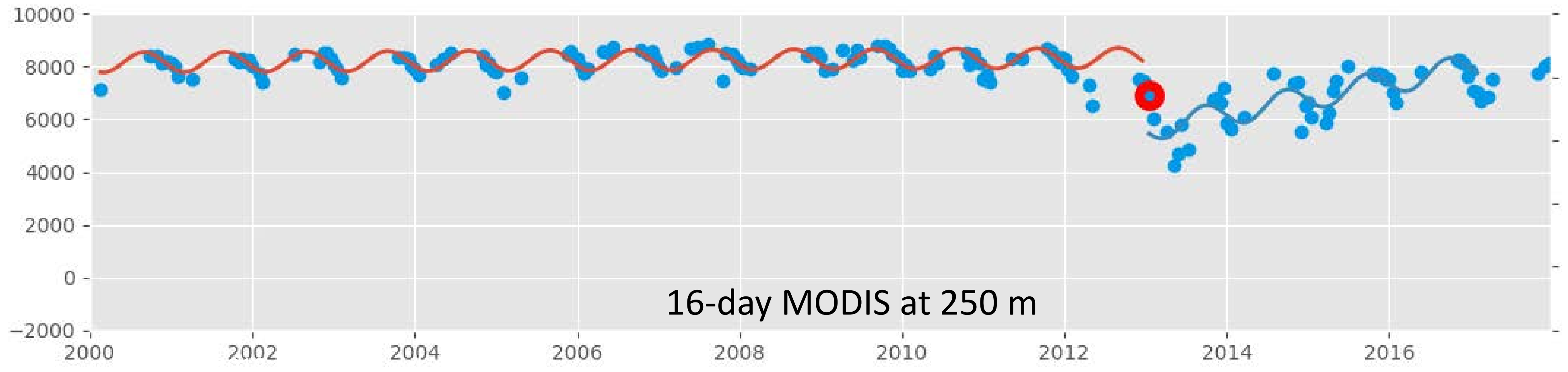






Example 5: Forest to Agriculture





Objective 1: Land-to-Ocean flux change detection system

- Hydrological model (WBM) incorporates land cover information through its runoff model
- Multiple runoff sub-models: simple approach only uses rooting depth, which correlates well with canopy height. Intend to test more complex models that utilize canopy height, LAI, other variables (which would need to be parameterized from land cover)

Objective 1: Land-to-Ocean flux change detection system

- Utilizing radar remote sensing for land surface inundation mapping and assessment of coastal wetland dynamics
- Less data available than optical over this time period
- Sentinel-1 is used to map contemporary wetland area, inundation variability
- Compared with pixel- and local-area trends using PALSAR and PALSAR-2, where available

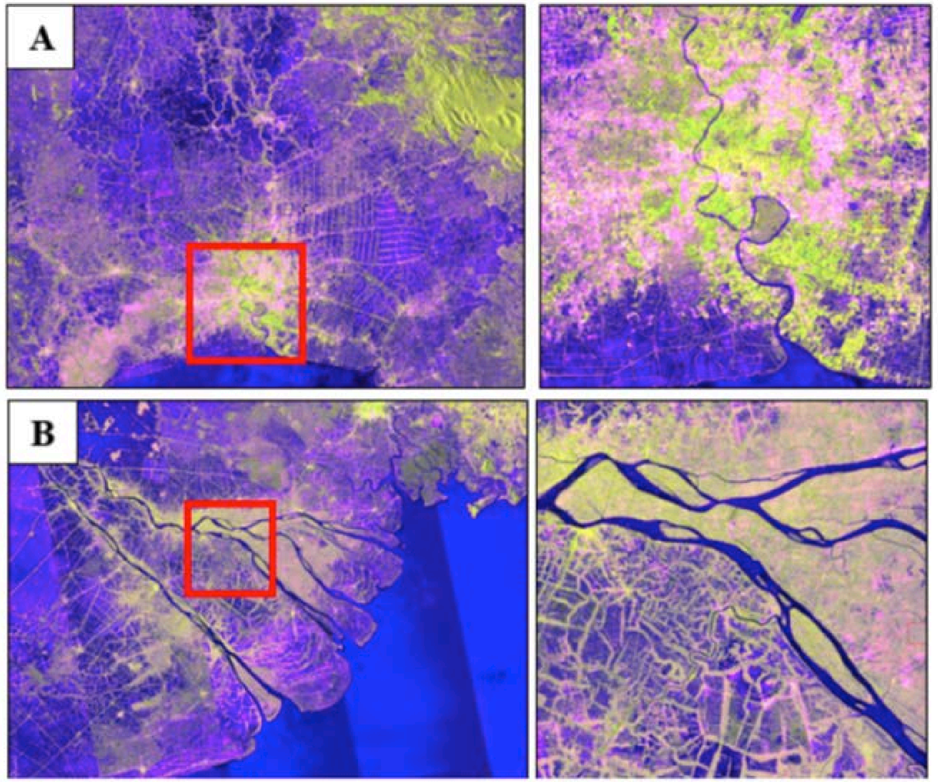
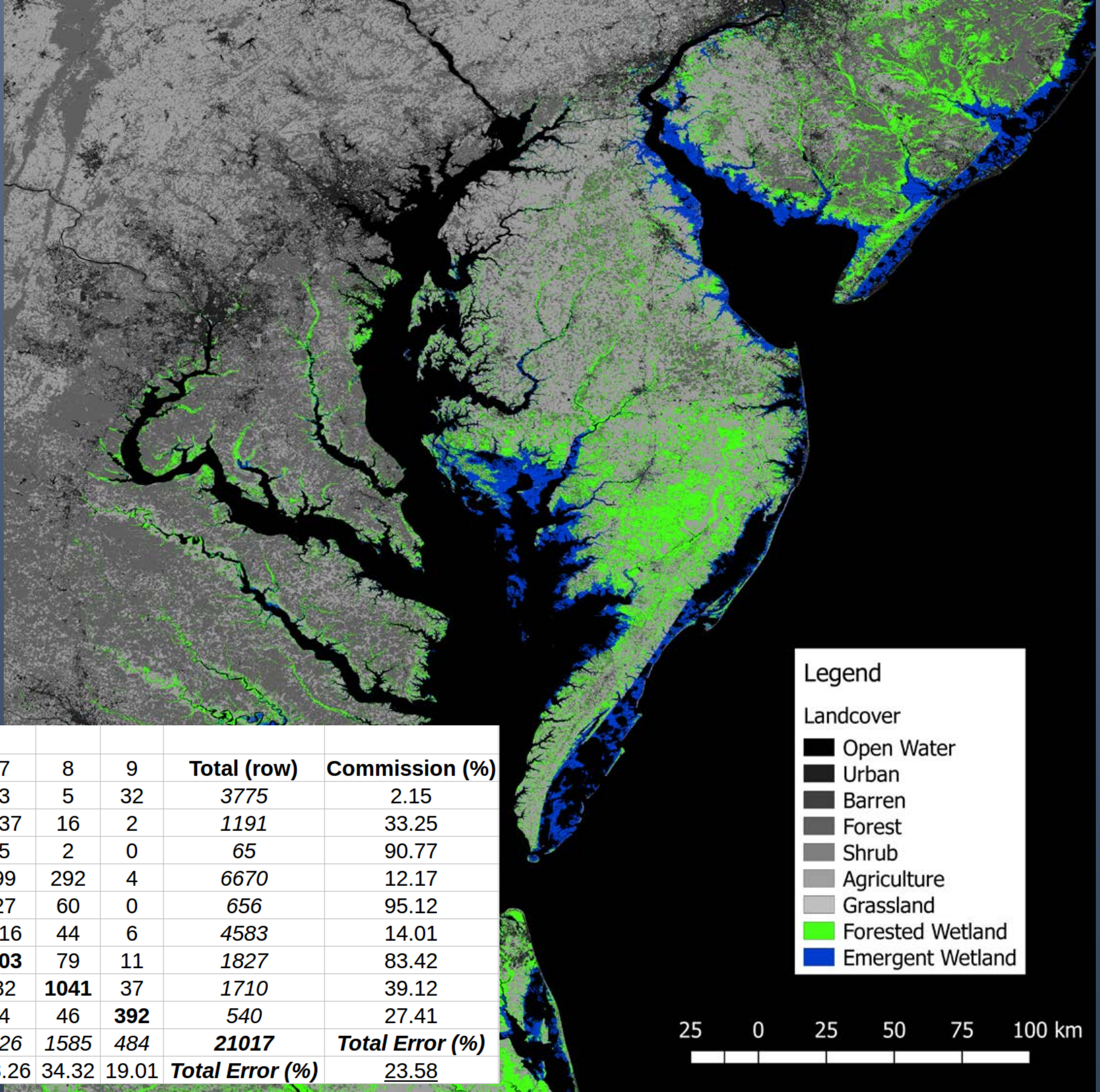


Figure 3: Land surface inundation state (purple: inundated, green: dry) observed by ALOS PALSAR fine beam mosaic, RGB: HH, HV, HH/HV observed over (A) Chao Phraya Delta, (B) Mekong Delta, Summer 2009, at 90m Resolution.

Chesapeake Bay Wetlands Classified Map

Random Forest Classification with multi-temporal Sentinel-1 SAR, Landsat 8 optical, and DEM.

Emergent wetlands were classified with omission error of 19.1%, and commission error of 27.4%

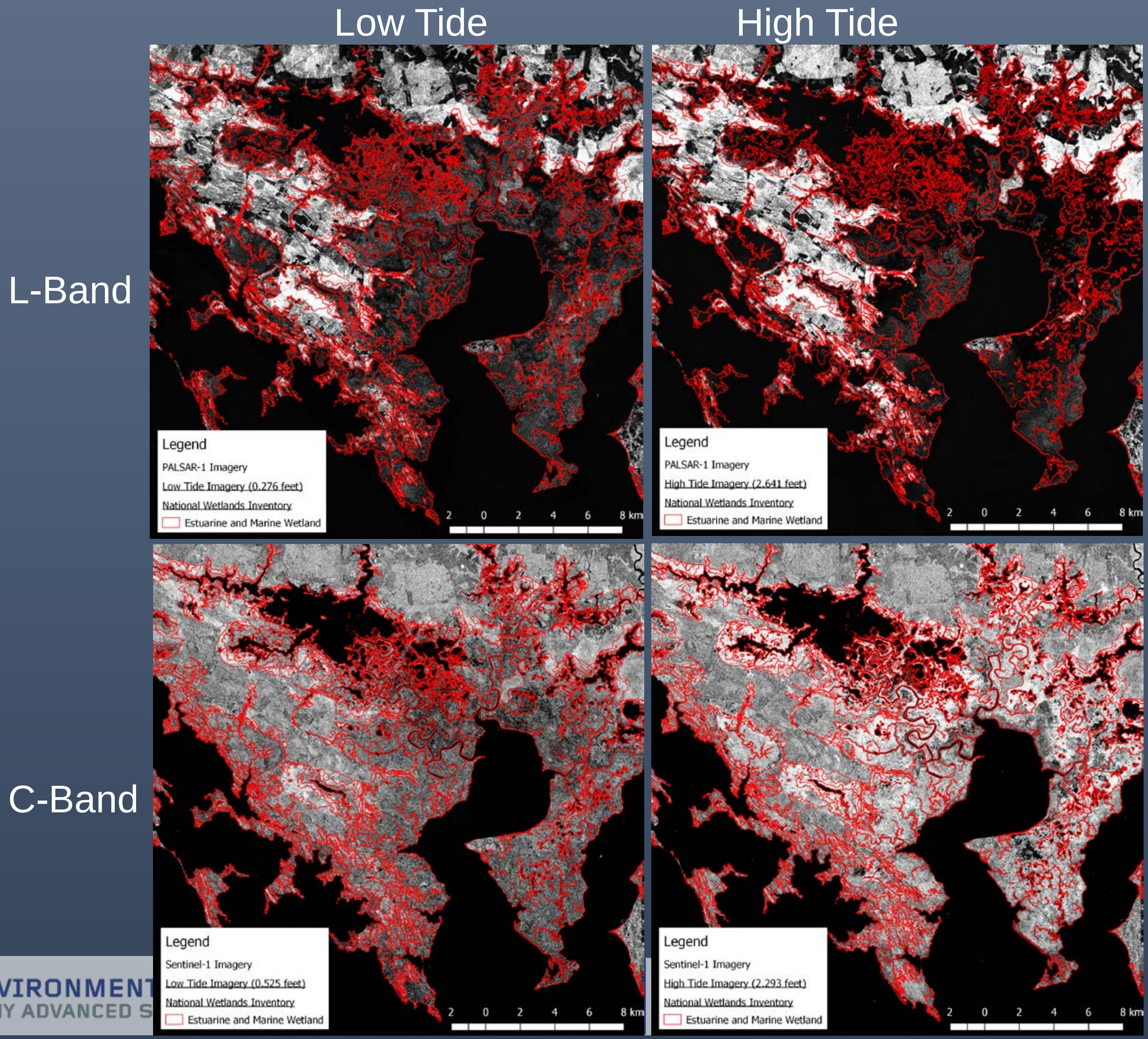


Confusion Matrix											
Class	1	2	3	4	5	6	7	8	9	**Total (row)**	**Commission (%)**
1) Open Water	**3694**	6	0	23	0	12	3	5	32	*3775*	2.15
2) Urban	4	**795**	5	86	0	146	137	16	2	*1191*	33.25
3) Barren	13	9	**6**	12	1	17	5	2	0	*65*	90.77
4) Forest	5	36	0	**5858**	28	348	99	292	4	*6670*	12.17
5) Shrub	1	11	0	416	**32**	109	27	60	0	*656*	95.12
6) Agriculture	1	75	0	394	6	**3941**	116	44	6	*4583*	14.01
7) Grassland	3	151	1	566	12	701	**303**	79	11	*1827*	83.42
8) Forested Wetland	13	8	0	509	11	59	32	**1041**	37	*1710*	39.12
9) Emergent Wetland	42	6	0	21	2	27	4	46	**392**	*540*	27.41
Total (column)	*3776*	*1097*	*12*	*7885*	*92*	*5360*	*726*	*1585*	*484*	***21017***	***Total Error (%)***
Omission (%)	2.17	27.53	50.00	25.71	65.22	26.47	58.26	34.32	19.01	***Total Error (%)***	23.58

PALSAR-1 L-Band and Sentinel-1 C-band show different responses to inundation state

L-Band HH polarization backscatter decreases in responses to increases in tidal stage

C-Band VV polarization backscatter increases in response to increases in tidal stage



ENVIRONMENT
CUNY ADVANCED S

Objective 2: Variability and trends of coastal phytoplankton and river plume structure

DOC (left) and Chlorophyll (right) derived from MERIS data (2004)

Use of high- and mid-spatial resolution satellite ocean color imagery (MERIS, OLCI/Sentinel-3, Landsat, MCI/Sentinel-2) to study changes in habitat and exchanges of nutrients and organic matter at land-ocean interfaces and to identify potential links with human and environmental pressures.

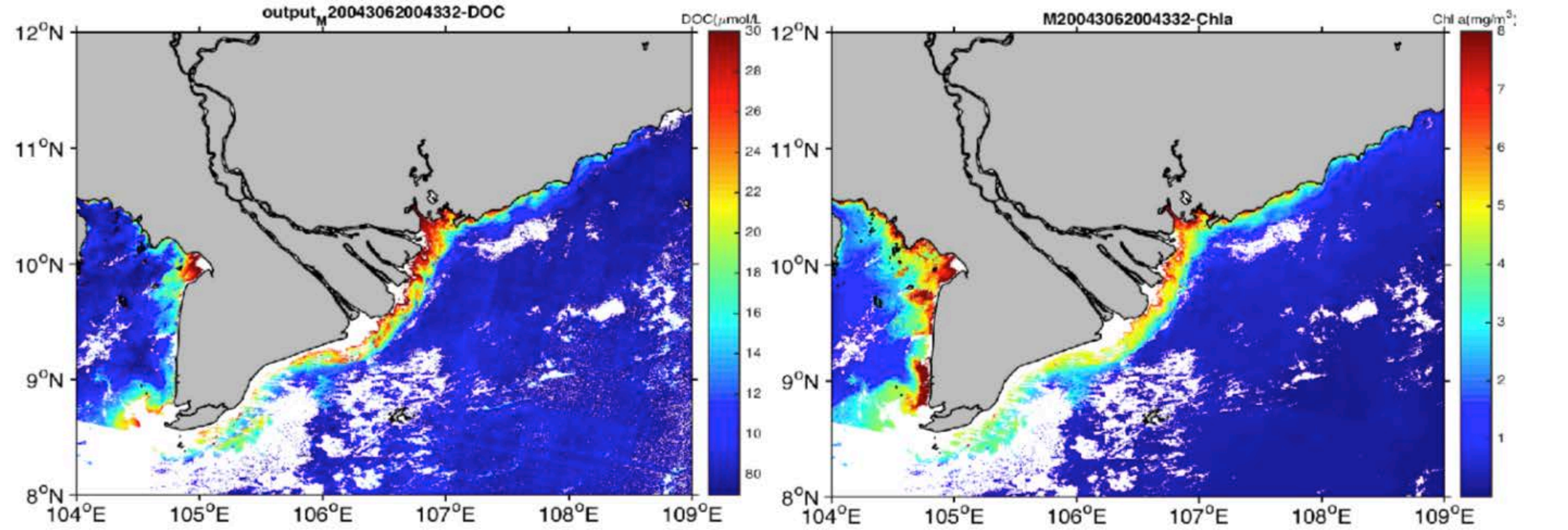
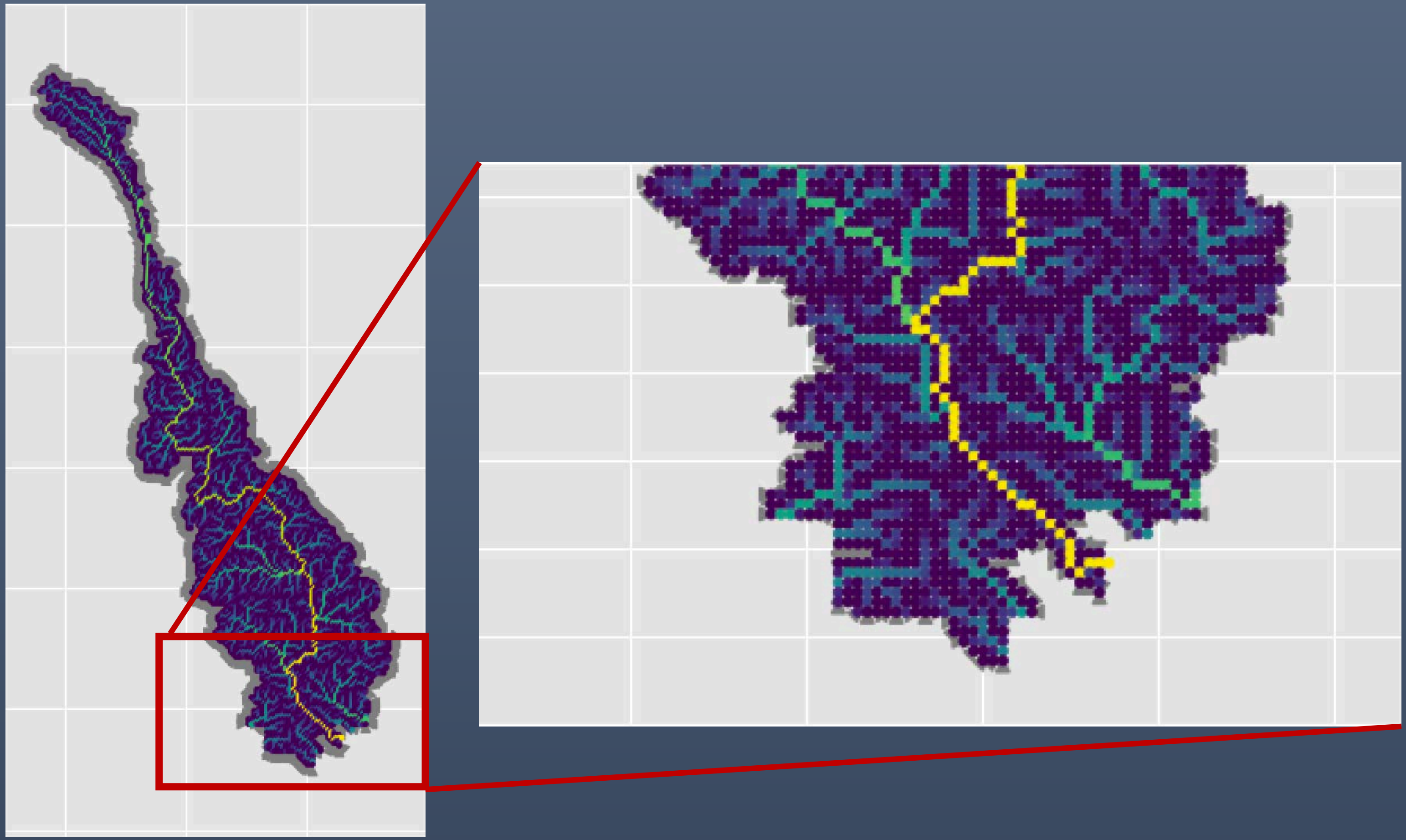


Figure 9: Satellite imagery from MERIS at 300 m resolution captures the influence of freshwater inputs and tidal marsh-estuarine exchanges on coastal water biogeochemistry across the Vietnamese coastline. Here shown are DOC dynamics (left panel) and Chlorophyll patterns (right panel, monthly composites for November 2004). DOC is based on new algorithms that our group is developing for nearshore waters.

Objective 3: Process-modeling of land-to-ocean linkages between watershed change and coastal ocean dynamics

- Mekong River Delta
    - Previously documented eutrophic conditions at river mouth
    - Existing network of water quality monitoring stations throughout the river system and delta, maintained by the Mekong River Commission
- Krishna/Godavari Deltas
    - Opportunity to compare coastal responses to similar climatological and meteorological forcings, but different human impacts. Godavari is more populated, with more extensive flood controls and other water management. Krishna has more extensive upstream river damming.

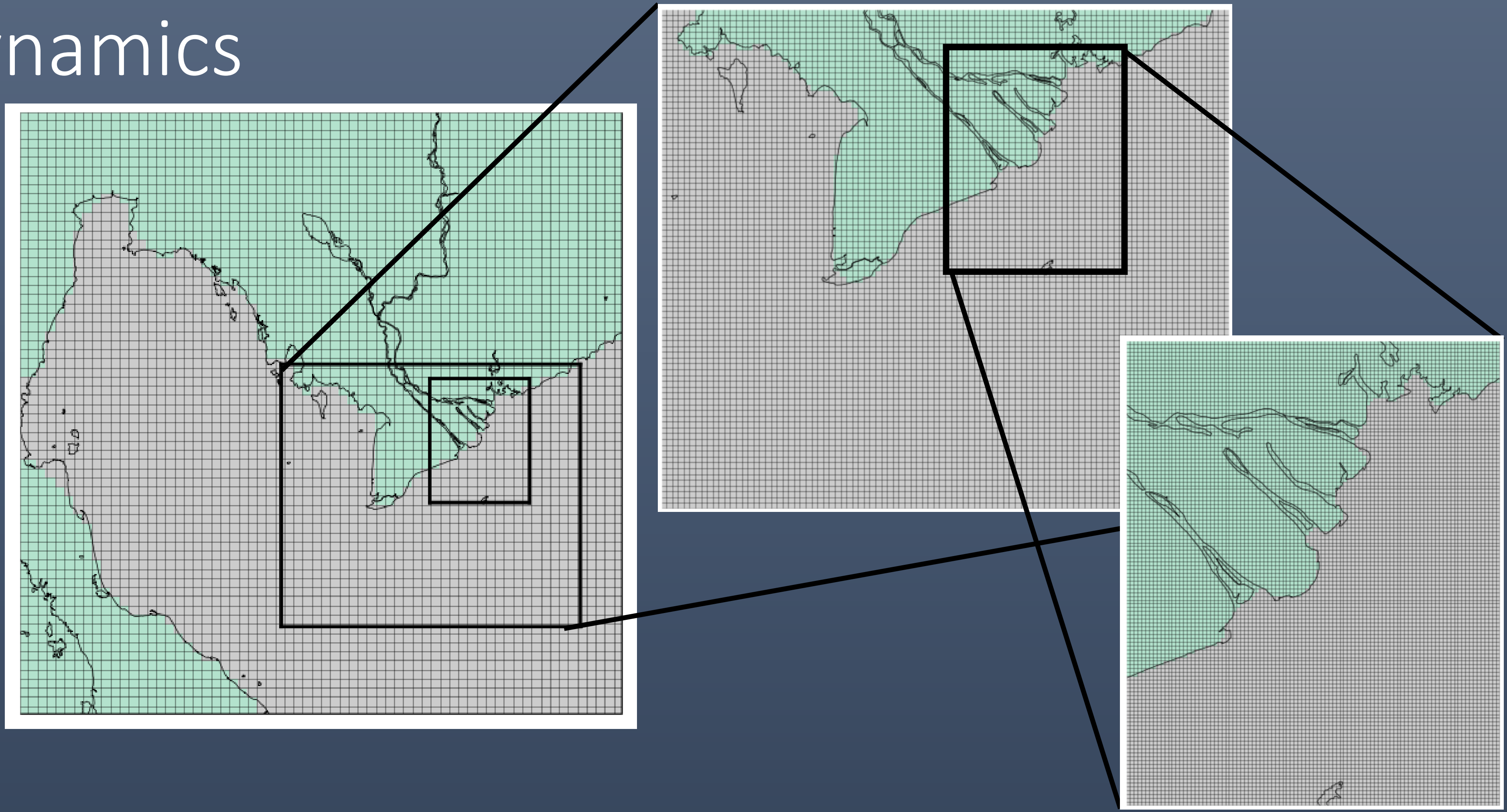
Objective 3: Process-modeling of land-to-ocean linkages between watershed change and coastal ocean dynamics



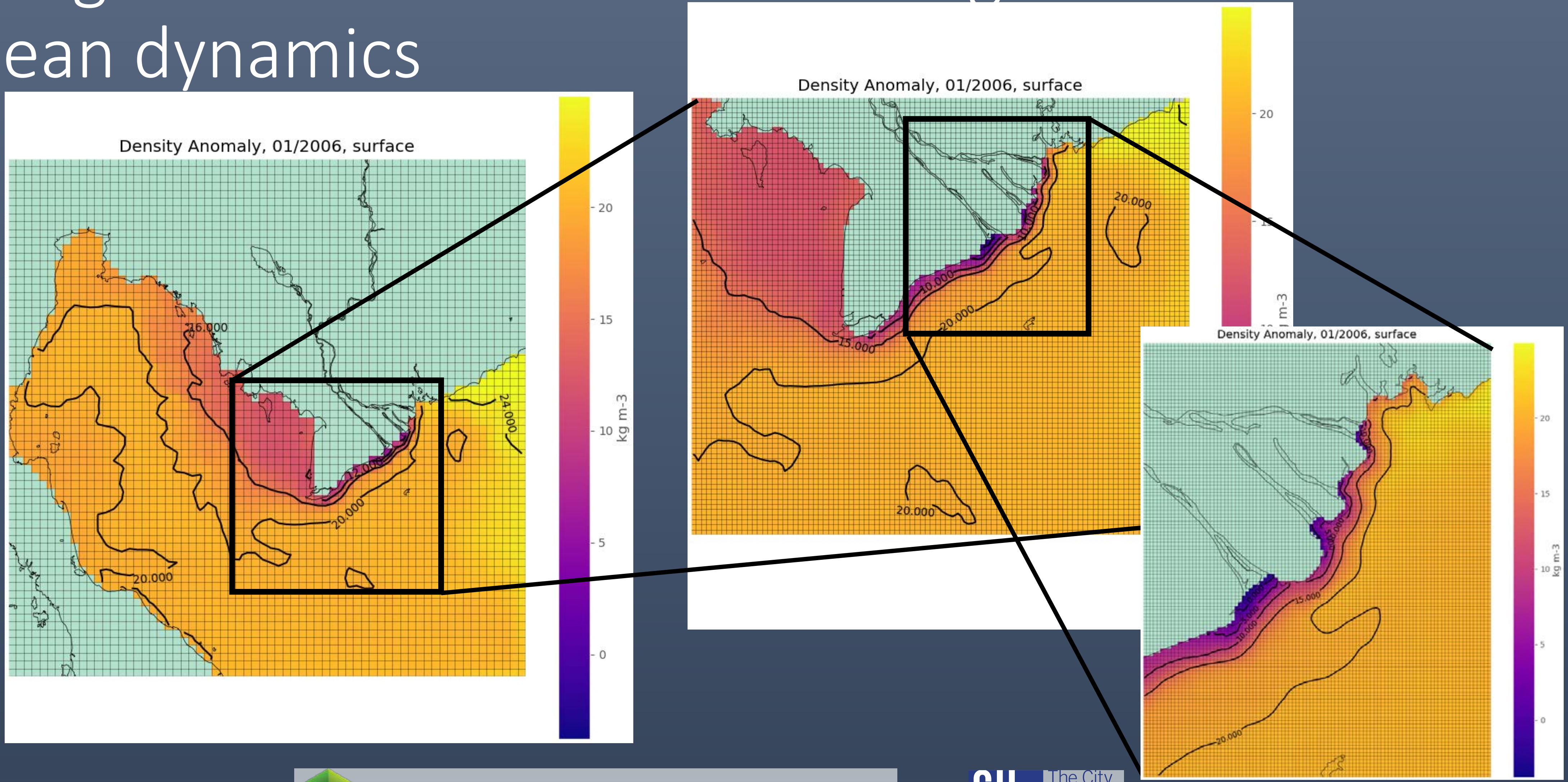
Most hydrological river network routing models are derived from DEMs based on flow direction. This is not effective in low-relief deltas, resulting in incorrect delta river networks and incorrect offshore distribution of freshwater and nutrient fluxes

Objective 3: Process-modeling of land-to-ocean linkages between watershed change and coastal ocean dynamics

Initial ROMS computational domain. Nested structure allows for efficient implementation of boundary conditions far from the region of interest, and higher resolution of river plume structure



Objective 3: Process-modeling of land-to-ocean linkages between watershed change and coastal ocean dynamics

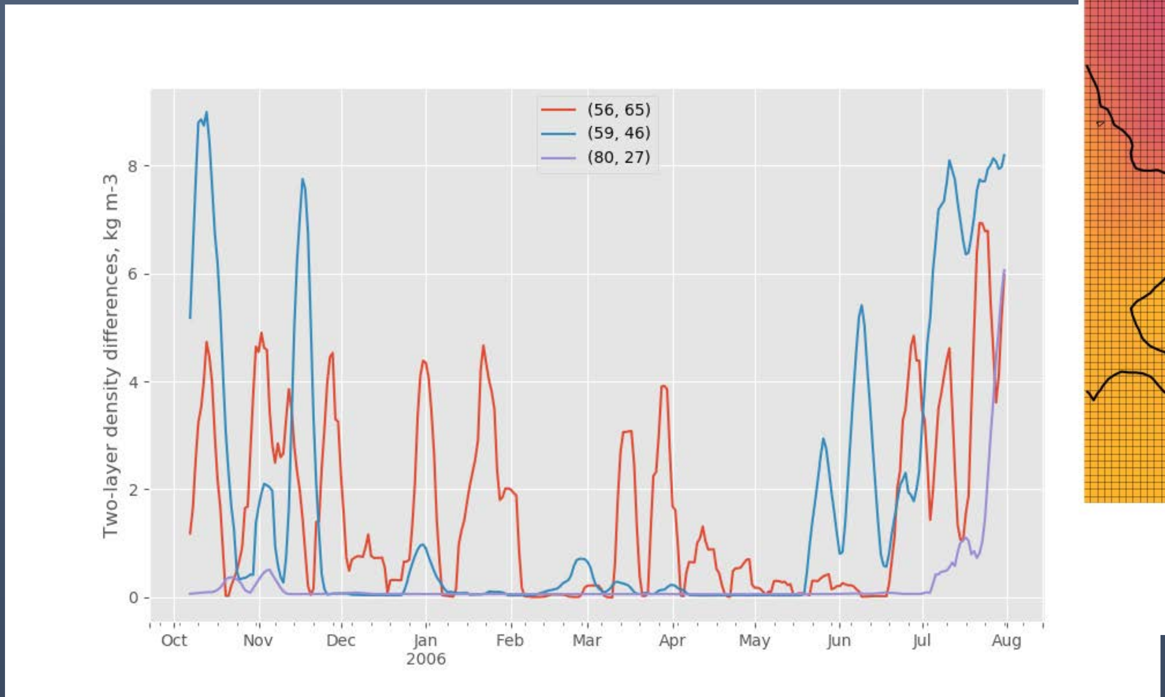


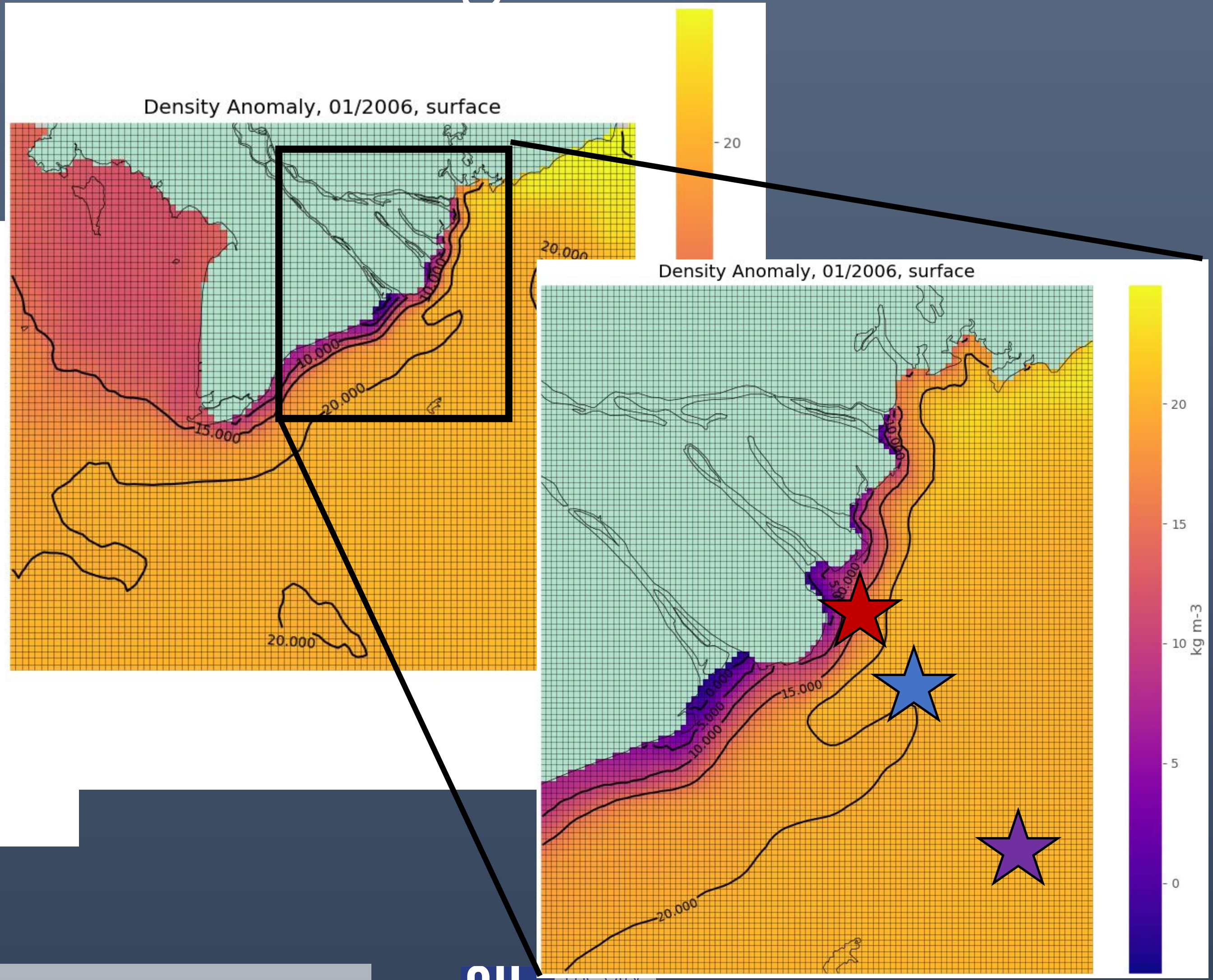
ENVIRONMENTAL SCIENCES INITIATIVE
CUNY ADVANCED SCIENCE RESEARCH CENTER

CUNY The City University of New York

Objective 3: Process-modeling of land-to-ocean linkages between watershed change and coastal ocean dynamics

Stratification - seasonal and spatial dynamics



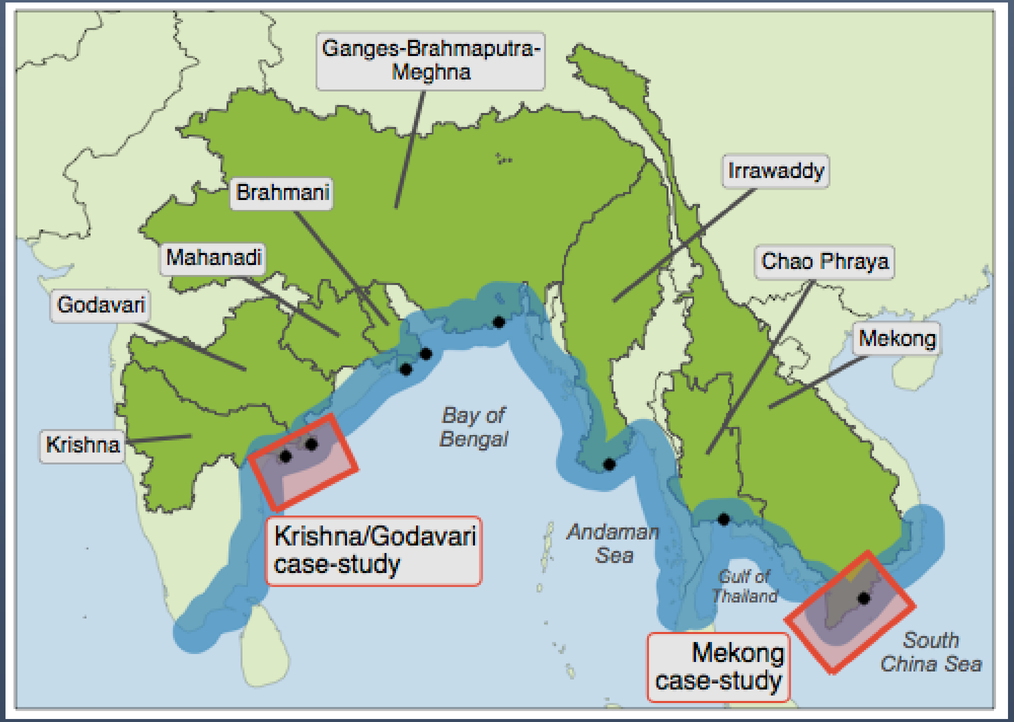


ENVIRONMENTAL SCIENCES INITIATIVE
CUNY ADVANCED SCIENCE RESEARCH CENTER

CUNY The City University of New York

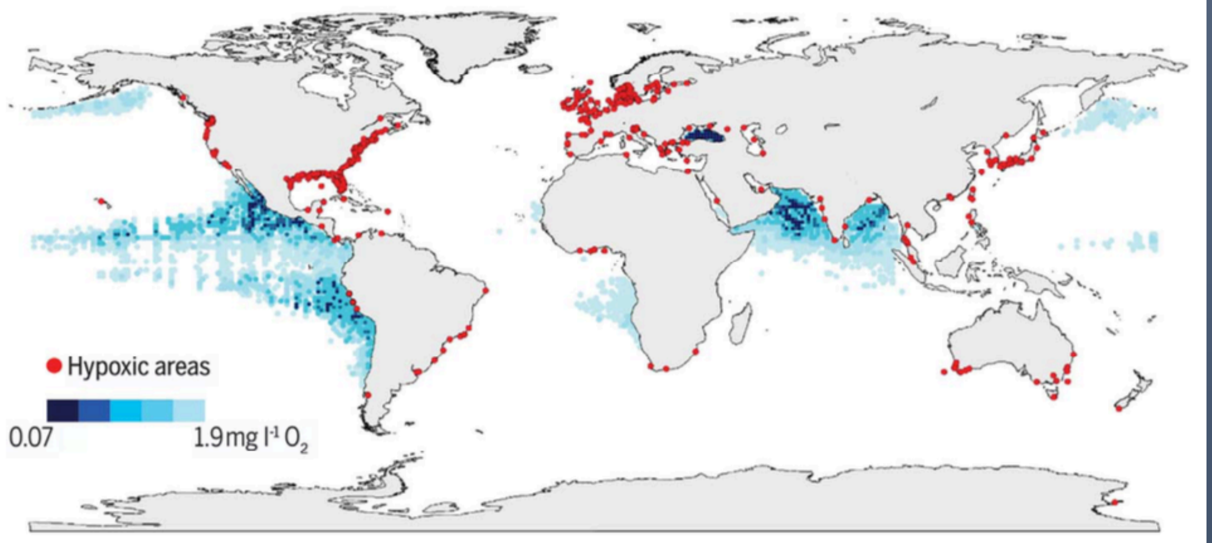
Objective 4: Map contemporary coastal "hotlines" of risk across all river mouths in the South and Southeast Asia

- Scaling up from high-resolution case study domains to broader region using remote sensing and hydrological modeling tools
- 2-5 year risk forecasts from contemporary remote sensing trends and risk model



Bigger picture

- Concentration of coastal hypoxia in N. America and Europe a sampling bias?
- Or related to real differences in local/regional dynamics and development patterns?
- What does this mean for future land and coastal change in South and Southeast Asia, and other regions?



Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security. The global map indicates coastal sites where anthropogenic nutrients have exacerbated or caused O_2 declines to <2 mg liter^{-1} (<63 µmol liter^{-1}) (red dots), as well as ocean oxygen-minimum zones at 300 m of depth (blue shaded regions). [Map created from data provided by R. Diaz, updated by members of the GO_2NE network, and downloaded from the World Ocean Atlas 2009].

Breitburg *et al.*, *Science* **359**, 46 (2018) 5 January 2018