

Recent Advances in Remote Sensing Applications for Coastal Wetland Monitoring

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OUTLINE



Background

- **Mangroves**
- Salt marshes
- Tidal flats



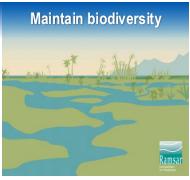


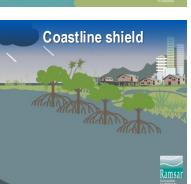
Background



- Coastal wetlands are dynamic ecosystems found along the margins where land meets the sea
- >> Shaped by the interaction of tides, freshwater inflows, sediment deposition, and vegetation

Coastal wetlands are highly biodiverse and productive, providing vital ecosystem services



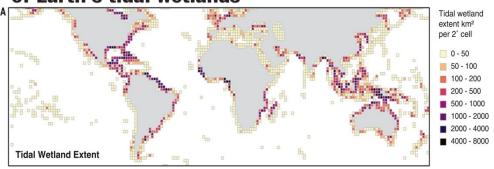








High-resolution mapping of losses and gains of Earth's tidal wetlands



Globally, coastal wetlands declined by 63% in the last 100 years (Murray et al., 2022, Science)









Background



Difficulty

Given the high heterogeneity and dynamic environment, how can satellite remote sensing accurately delineate boundaries and capture large-scale spatial distribution of coastal wetlands?





Spatial extent of tidal flats during high and low tides



Salt marshes exhibit significant spatiotemporal variability



Mangroves show apparent differences across regions

Tidal flats

Cross-site

High or low tide



Salt marshes

Multi-seasonal

Growth and withering



Mangroves

Large-scale

National and global



OUTLINE



1	Background
2	Mangroves
3	Salt marshes
4	Tidal flats





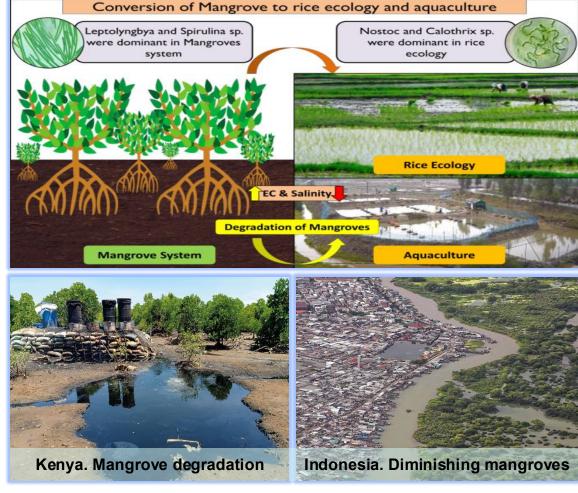
Mangrove degradation



Mangroves are among the most productive and biodiverse ecosystems worldwide, serving as a vital marine "Blue Carbon" ecosystem.

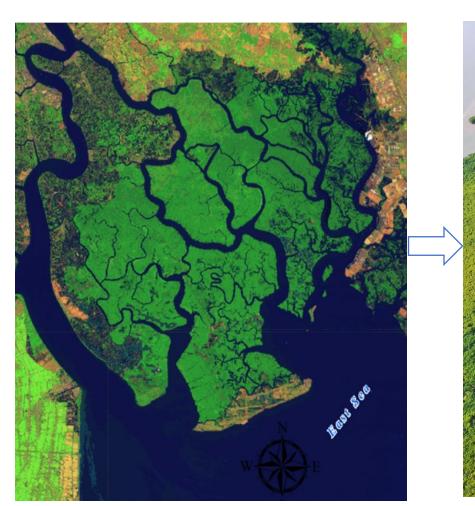


In the past century, one-third of global mangroves have been lost, mainly due to human activities.

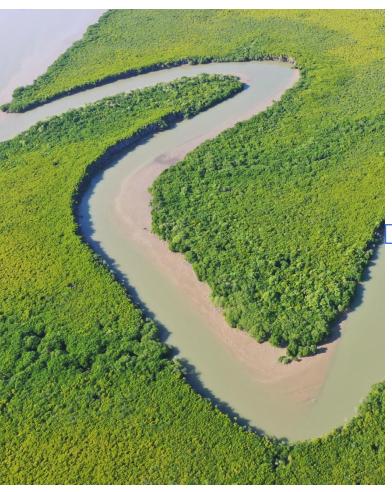




Mangrove remote sensing



Spatial distribution



Mangrove species delineation



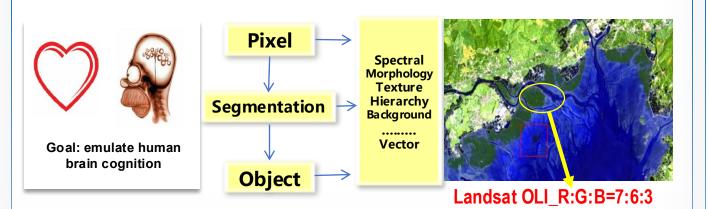
Functional traits inversion



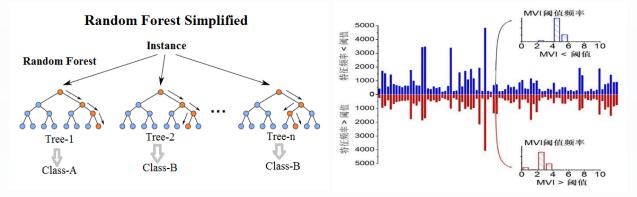
Spatial distribution—Methodologies



Object-based image analysis+Random Forest

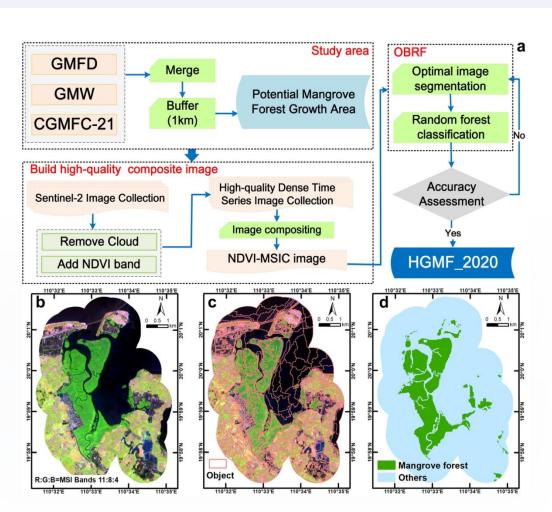


IMMA Explainable Artificial Intelligence method



The specific water content of mangroves is the key mechanism for identifying mangrove distribution using satellite remote sensing at a 10 m resolution

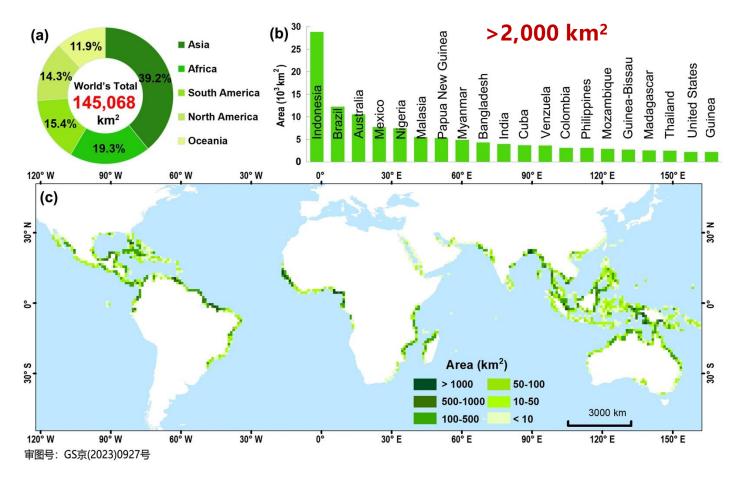
Workflow





Global Mangrove Distribution





- ➢ In 2020, the global mangrove area was 145,068 km².
- > 96% of mangroves are distributed in tropical regions.
- > Asia has the largest mangrove area (39.2%), followed by Africa (19.3%), South America (15.4%), North America (14.3%), and Oceania (11.9%).

Table 1. Area of mangrove forests with 95% confidence intervals for each UN statistics geographic regions.

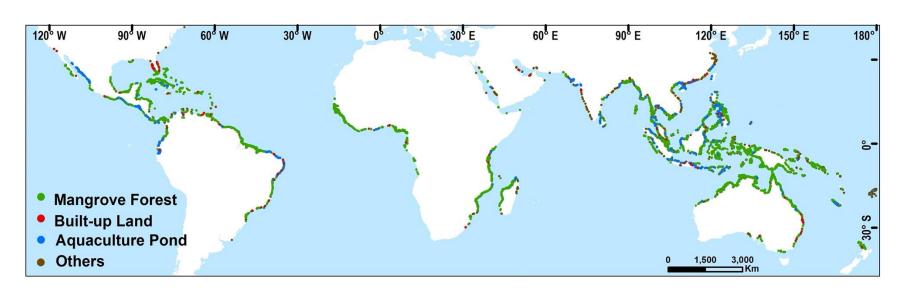
Geographic Region	Area (km²)	Percentage
Northern Africa	7.5	0.0%
Eastern Africa	7132.2	4.9%
Middle Africa	4137.2	2.9%
Southern Africa	22.4	0.0%
Western Africa	16657.1	11.5%
Caribbean	5518.9	3.8%
Central America	12715.7	8.8%
Northern America	2487.8	1.7%
South America	22288.0	15.4%
Eastern Asia	340.8	0.2%
South-eastern Asia	47008.2	32.4%
Southern Asia	9333.2	6.4%
Western Asia	197.8	0.1%
Australia and New Zealand	10994.0	7.6%
Melanesia	6091.4	4.2%
Micronesia	129.5	0.1%
Polynesia	6.0	0.0%

Jia et al., 2023, Science Bulletin, ESI, Hotspot



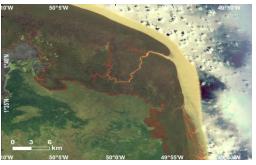
Accuracy assessment





- Collect Earth (https://openforis.org/tools/collect-earth).
- > Global Biodiversity Information Facility (https://www.gbif.org/).
- > Visually interpreted ground samples from sub-meter resolution imagery in Google Earth.

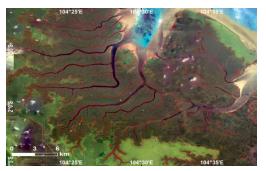
Class	Mangrove forest	Built-up land	Aquaculture pond	Others	User's acc.
Mangrove forest	19925	59	68	1652	92%±0.004
Built-up land	41	2617	54	256	$88\% \pm 0.012$
Aquaculture pond	235	42	2353	255	82%±0.014
Others	1862	201	198	57982	$96\% \pm 0.015$
Producer's acc.	$90\% \pm 0.0007$	$84\% \pm 0.0002$	$82\% \pm 0.0002$	$97\% \pm 0.0007$	
Overall Accuracy	$94\% \pm 0.0014$				



Estuary of the Amazon River, Brazil



Sundarbans along the Bay of Bengal



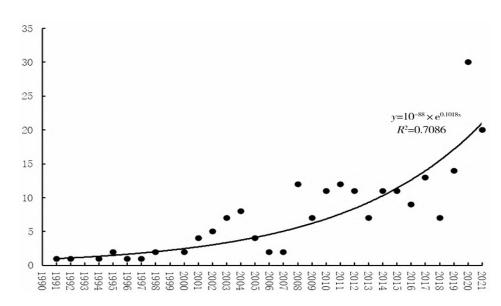
Sembilang National Park, Indonesia



Mangrove species delineation—Sonneratia apetala



- □ *Sonneratia apetala*, a superior mangrove species, has been widely introduced in China for afforestation and reforestation of mangroves.
- Sonneratia apetala grows rapidly and has higher resource acquisition ability than native mangrove species, raising widespread concern among Chinese researchers over its potential invasiveness



Number of publications on the ecological traits and conservation biology of **Sonneratia apetala** from 1990 to 2021



Sonneratia apetala is already showing a trend of invading native Kandelia obovata forests in Futian Mangrove Nature Reserve



Methodologies



Data source:



Balancing mangrove species classification accuracy and data cost

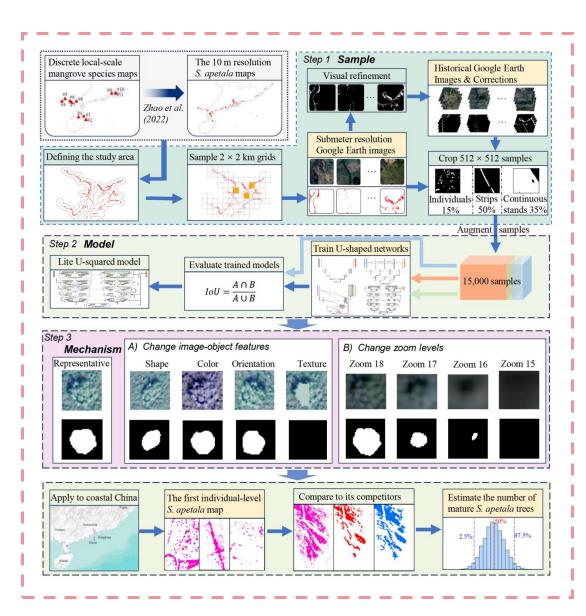
- ☐ Google Earth imagery is regularly updated, offering timely, high-resolution data over extensive areas;
- ☐ Google Earth provides abundant free imagery resources
- □ Google Earth imagery (zoom level 19, 0.6 m) was acquired via the open-source SASPlanet for this study

Workflow:

How to reduce sample acquisition costs

- 10 m resolution Sonneratia apetala data can efficiently generate sub-meter polygon samples
- ☐ Use deep learning to mitigate mis- and omission errors from varying data sources

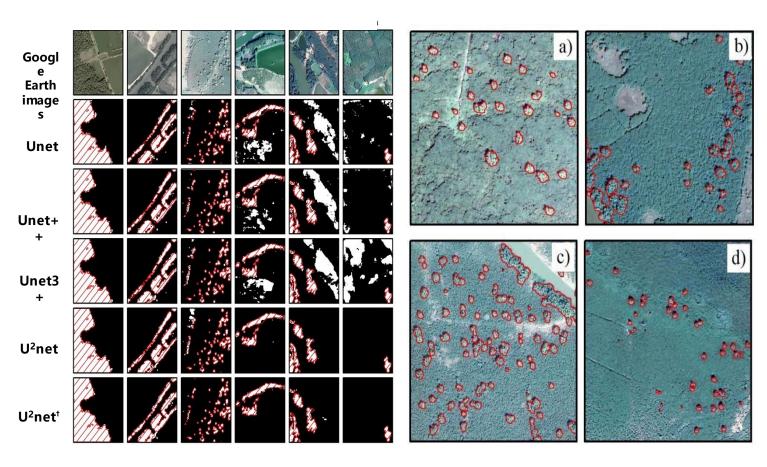
Omission of small Sonneratia apetala patches in classification





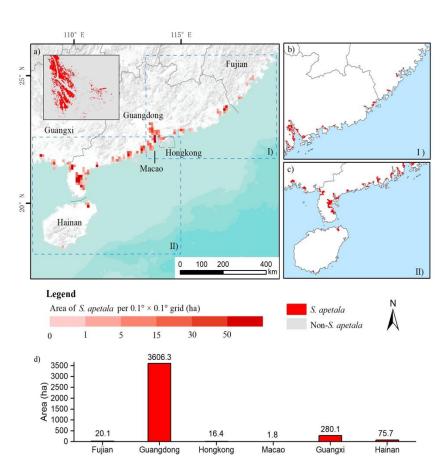
Sonneratia apetala distribution





National-scale sub-meter S. apetala prediction using U2Net[†]

S. apetala data validated with independent points:
98.2% overall accuracy; Field-plot accuracy: 91.0%



S. apetala distribution in China (2022)

4,000.4 ha (14.8% of mangroves);
About 2.38 million trees



Functional traits inversion—Canopy Height



Tree height is an important indicator of mangrove biomass and carbon sequestration capacity.

Challenges:

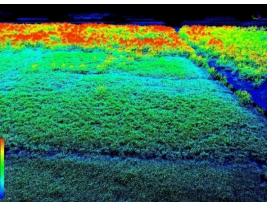
Mangrove canopies exhibit high density and interlocking structure.

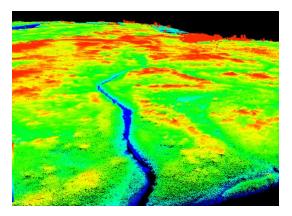
Height differences among different mangrove species are small.

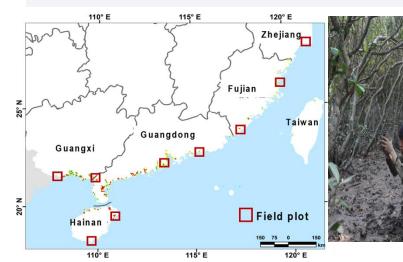
Field survey

Set up $10 \text{ m} \times 10 \text{ m}$ square plots and use RTK to record the coordinates of each plot center. Within each plot, measure every tree, recording species, diameter at breast height (DBH, at 1.3 m), and tree height, and measure functional traits both in the field and in the laboratory.

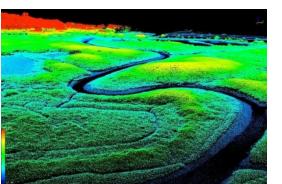


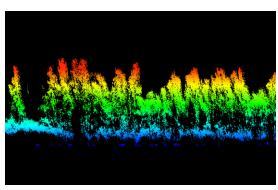








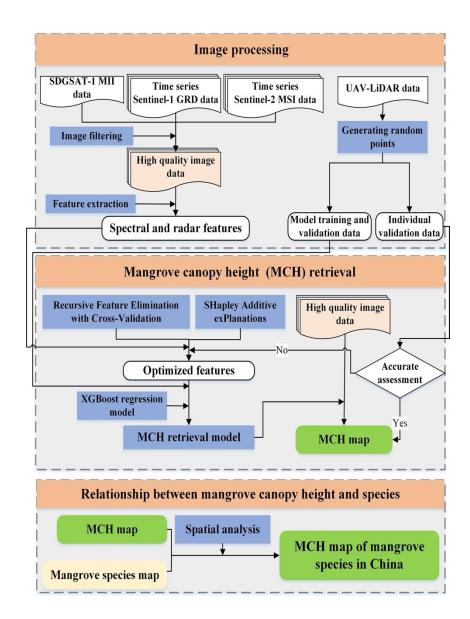






Canopy Height—Methodologies





Data processing: image filtering & multi-source feature fusion

Tidal dynamics correction Multi-feature extraction

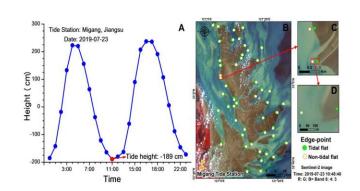
Data processing: image filtering & multi-source feature fusion

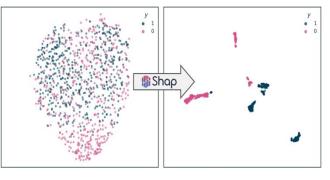
Recursive Feature Elimination with Cross-Validation (RFECV)

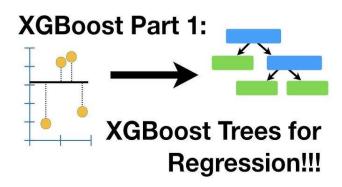
SHAP-based interpretable modeling

Model building: XGBoost hyperparameter optimization

Multi-scale validation



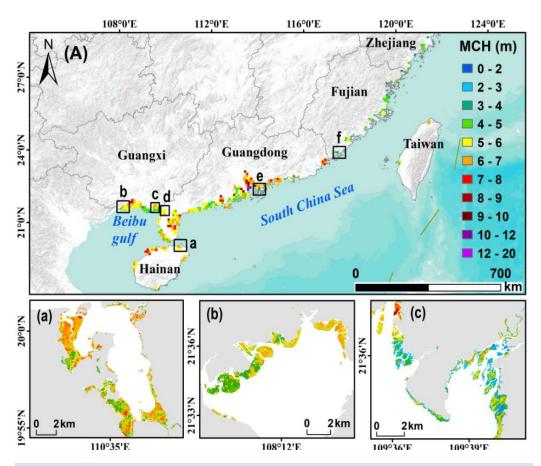




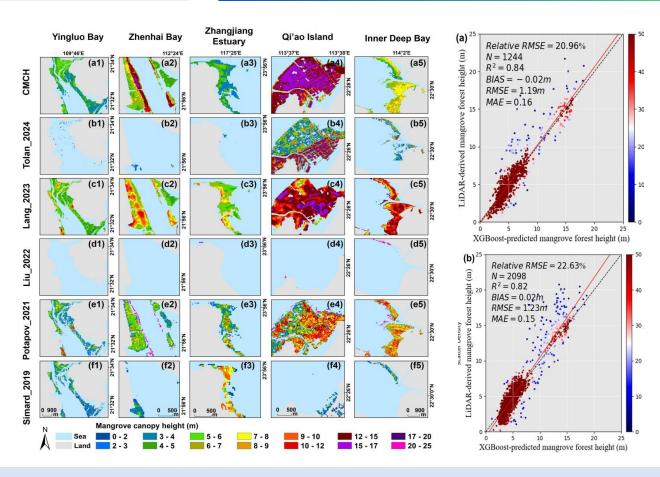


Mangrove Canopy Height in China





- ➤ The average canopy height of mangroves in China is 6 m, significantly lower than the global average of 12.7 m.
- > The non-native Sonneratia apetala has the tallest canopy, reaching 18.7 m.



- The constructed 10 m resolution CMCH map achieved $R^2 = 0.84$ (RMSE = 1.19 m), improving over existing global products.
- The inclusion of the SDGSAT-1 Red-edge band is the most sensitive variable for canopy height inversion.



OUTLINE





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- Tidal flats







□ Coastal salt marshes are transitional zones between marine and terrestrial ecosystems, dominated by herbaceous plants and low shrubs, providing ecosystem services such as shoreline protection, species conservation, and carbon sequestration.

In coastal salt marsh vegetation mapping, these communities are treated as a single class-> Large variability within the class



S. alterniflora

P. australis

Scirpus spp. 藨草属

Suaeda spp.

咸水草

C. malaccensis S. portulacastrum T. chinensis

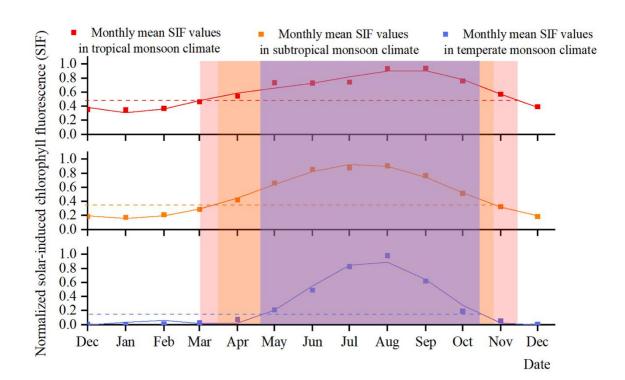
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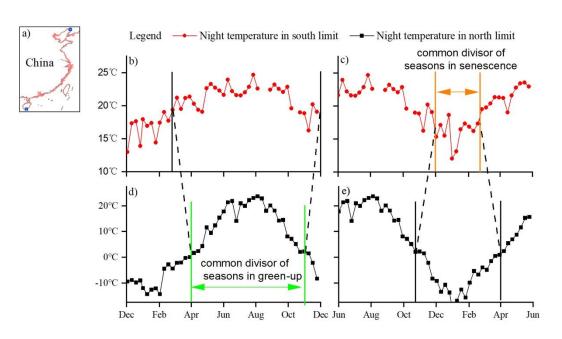


Methodology — Temporal Image Synthesis



- Across different climate zones, phenology of salt marshes shows regular patterns: the **growing season** in temperate monsoon zones is nested within the periods of the other two zones, and similarly, the **withering period** in tropical monsoon zones is nested within the others.
- Using nighttime temperature as a proxy, and based on the common growing and senescence periods between southern and northern regions along the latitudinal gradient, combined with existing phenology studies, the common start and end of the growth and senescence seasons can be determined.





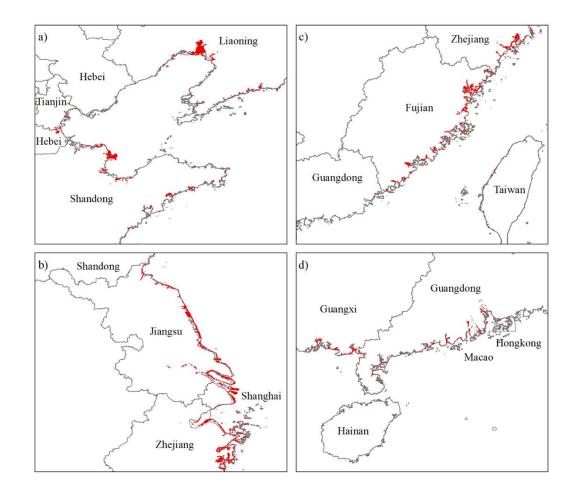
Zhao & Jia* et al., ISPRS JP&RS, 2023

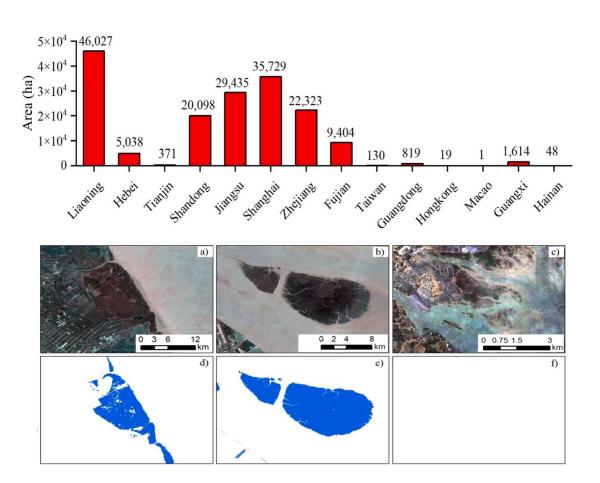


Results— Salt marsh distribution across China



☐ As a consequence, the estimated area of coastal salt marshes was 171,048 ha, larger than that from existing studies ranging from 109,851 ha to 127,477 ha.







OUTLINE



1	Backgroun	d
///		

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Coastal Tidal Flats

Intertidal mudflats, rocks, and sands, are transition zones between marine and terrestrial environments.

Threats

Noticeable industrialization, urbanization, and aquaculture expansion.

Challenges

- Remote sensing has long been used to map intertidal zones.
- > The greatest challenge of such attempts is the variation of tidal inundations.







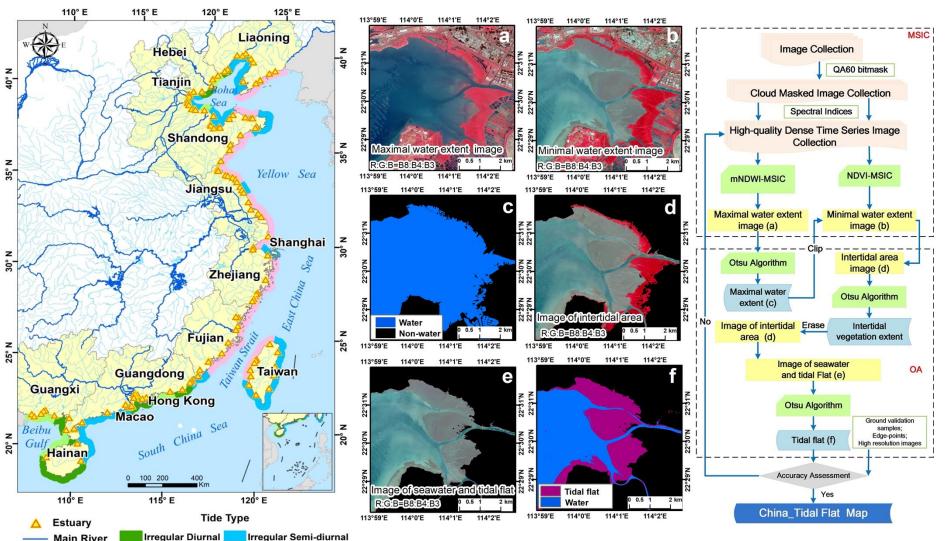


Regular Diurnal

Other River

Regular Semi-diurnal



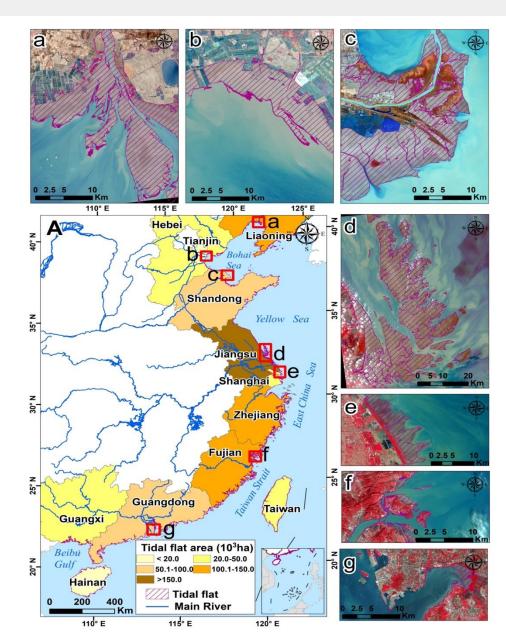


- Coastal tidal flats were defined as non-vegetated areas between the maximal and minimal tidal inundations, i.e., the highest and lowest tidal waterlines, along the shoreline.
- To map tidal flats, the key is to obtain spatial distributions of the maximal and minimal water extents between the highest and lowest tides, respectively.
- The MSIC, as we defined, sets each pixel in the composite based on which pixel in the time series Sentinel-2 image collection has the maximum value of a selected spectral index.



Results— Tidal flats distribution





National and provincial areas, percentages, and mean widths of tidal flat

Province	Tidal flat area (10 ⁴ m ²)	Percentage (%)	Coastline length (10³m)	Mean tidal flat width (m)
Liaoning	101,114	11.77	2803	361
Hebei	35,021	4.08	391	890
Tianjin	10,474	1.22	798	135
Shandong	104,612	12.18	3479	286
Jiangsu	204,135	23.77	1302	1577
Shanghai	35,590	4.14	302	1140
Zhejiang	113,192	13.18	2173	521
Fujian	106,670	12.42	2976	358
Taiwan	22,577	2.63	4056	56
Guangdong	62,078	7.23	1173	529
Guangxi	46,935	5.47	1912	245
Hainan	16,381	1.91	1589	103
Total	858,784	100.00	22,954	374



Thanks for your attention!

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