



武汉大学

WUHAN UNIVERSITY



# Cloud Removal for Sentinel-2 By Progressively Spatio-Temporal Patch Group Learning

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IGARSS  
2019

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Remote Sensing Symposium  
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# Outline



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## Background

2

## Methodology

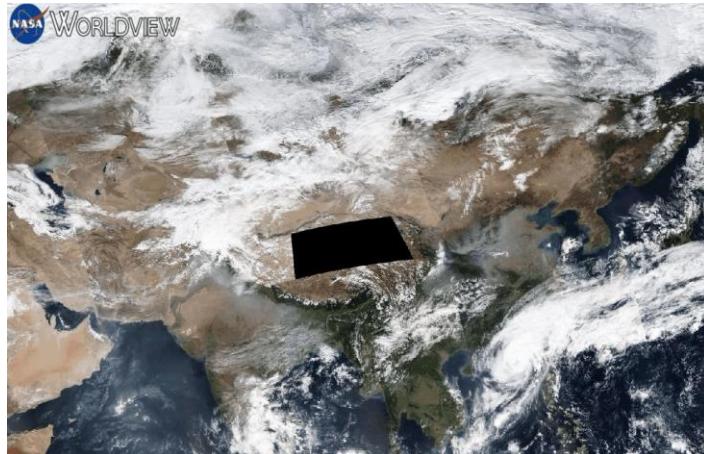
3

## Experiments

4

## Summary

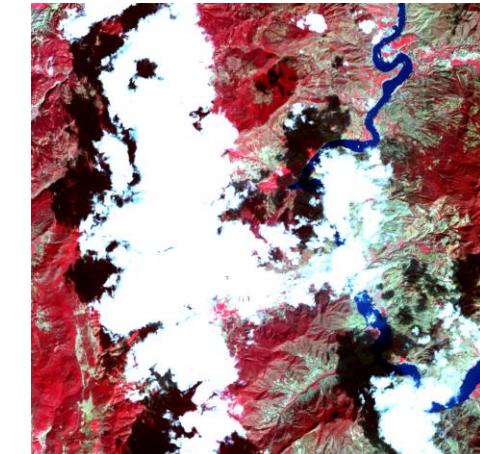
# Background



Large-scale Cloud Covering



Sentinel-2 MSI



Landsat-8 OLI

Data Selecting/  
Omitting

Incontinuity

Week/Month  
Averaging

Inaccuracy

Temporal  
Replacement

Inconformity

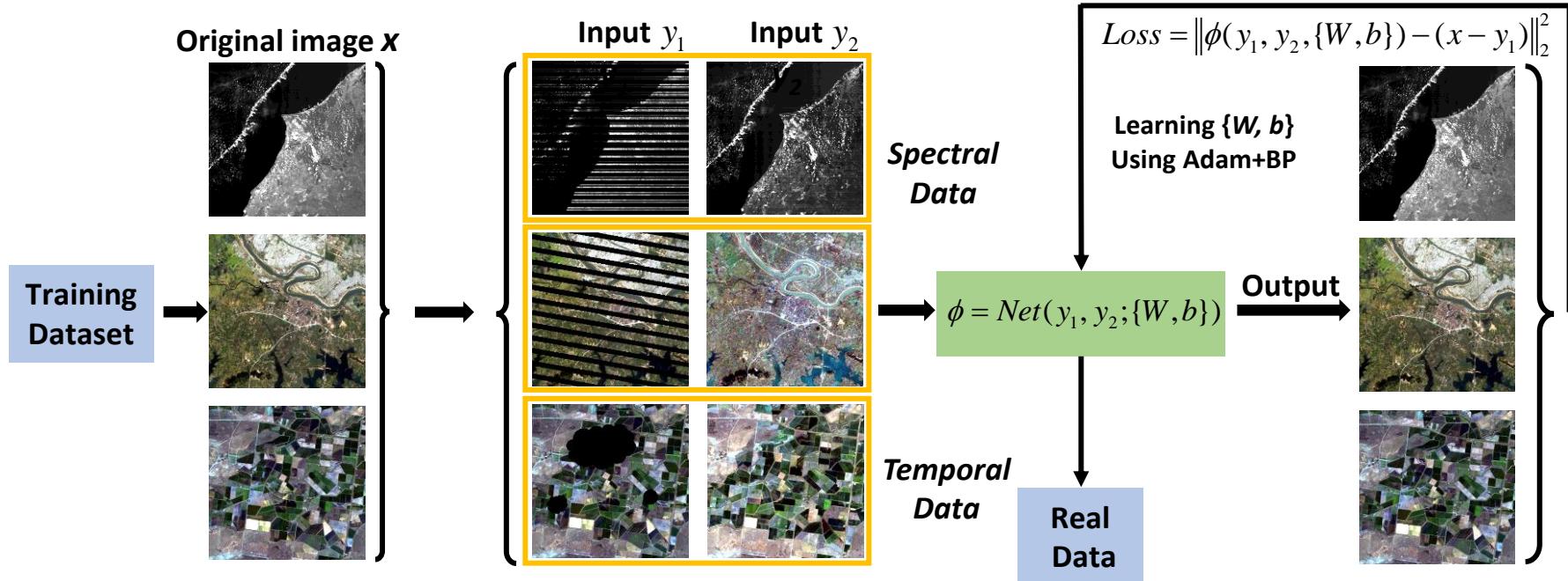
Cloud/shadow greatly  
reduce the data usability!



Spatio-Temporal  
Cloud/Shadow Removal

# Background

## Our Pre-existing Work (**STS-CNN**) for Cloud Removal



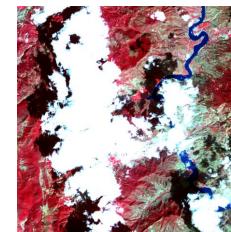
- Joint Spatial-Temporal-Spectral Information
- End-to-end Learning Model through DCNN
- Unified Framework for Inpainting Missing Data

Zhang et al., IEEE TGRS, 2018.  
**Code has been released!**  
[github.com/WHUQZhang](https://github.com/WHUQZhang)

## Deficiencies Analyzing of Pre-existing Works

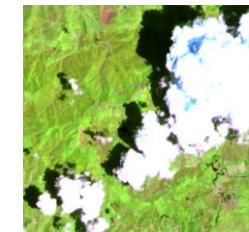
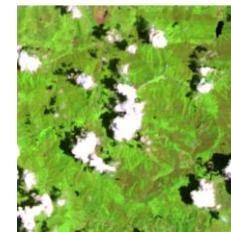
### 1) Large-scale Cloud/Shadow Covering

- Marginal Differences
- Vague Texture



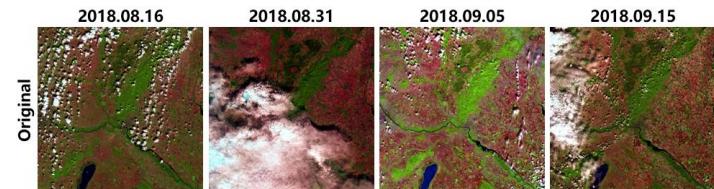
### 2) Need Ensure Integrity of Temporal Data

- Most Temporal Imageries are Fragmentary
- Limited in Actual Scenarios



### 3) Multiple Sequence Temporal data

- Redundancy Complementary Information
- Complicated/Changeable Scenarios



V1.0: STS

Upgrade a new framework!

For Cloud/Shadow Removal

V2.0: ?

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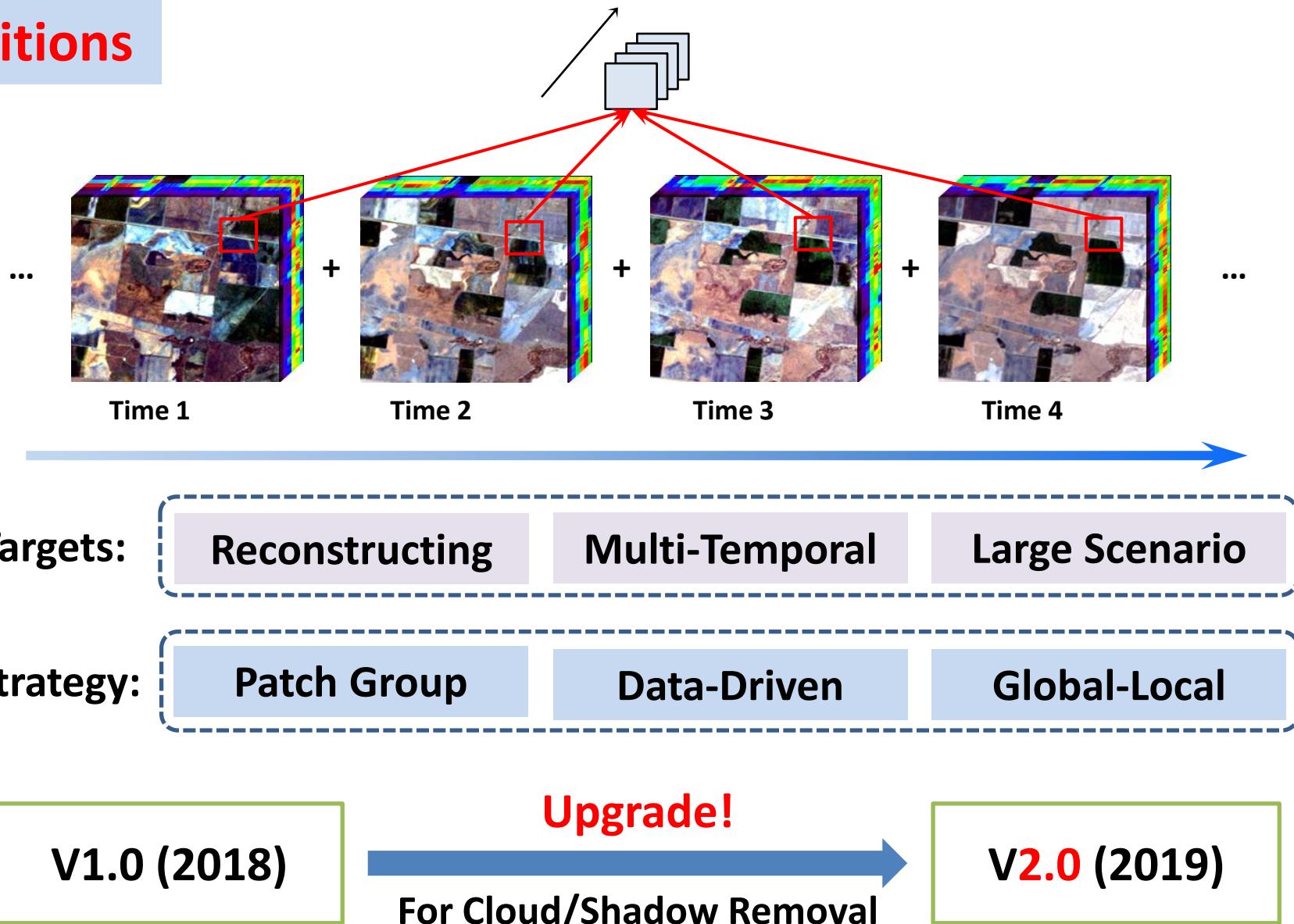
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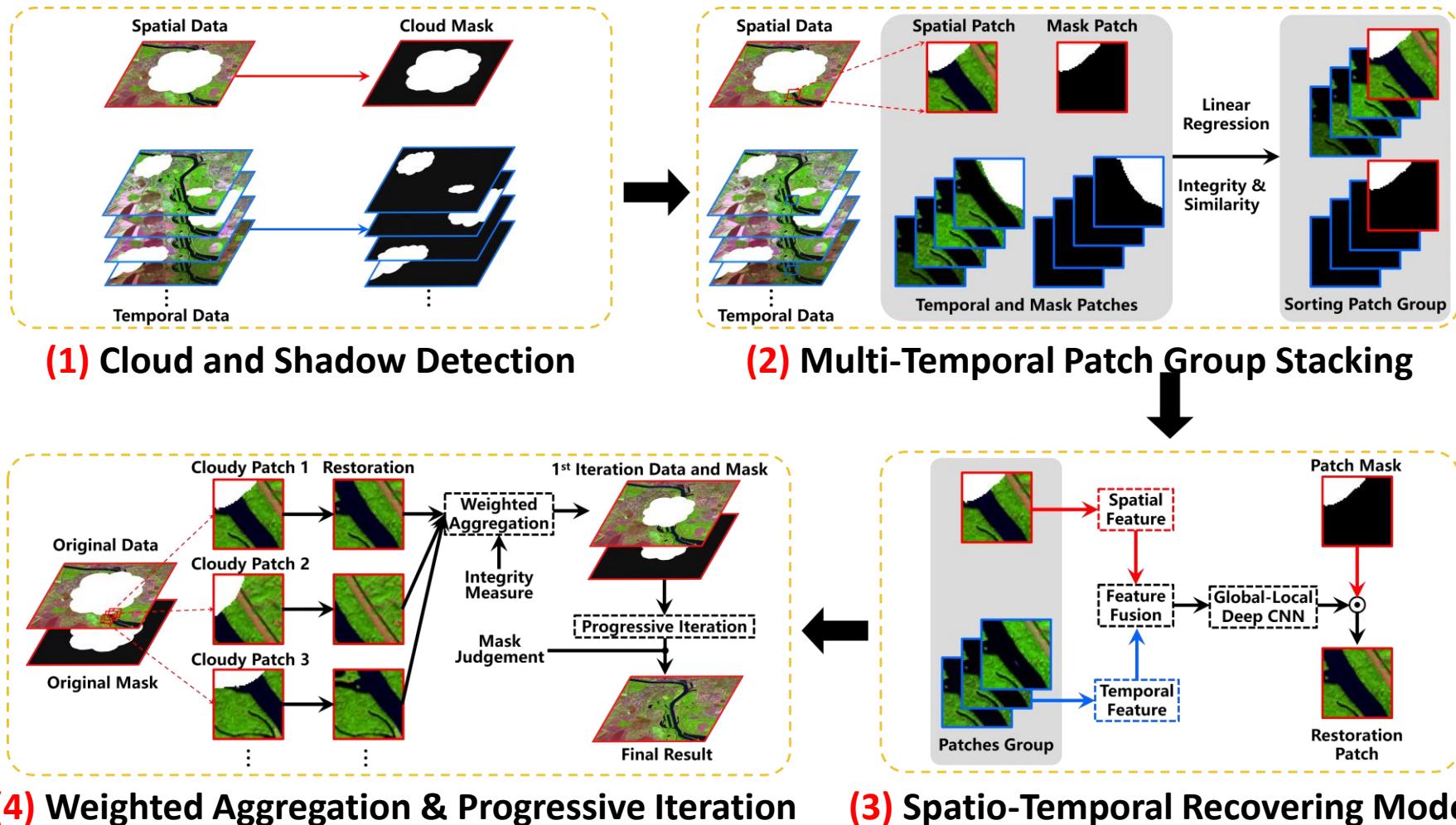
# Methodology

## Intuitions

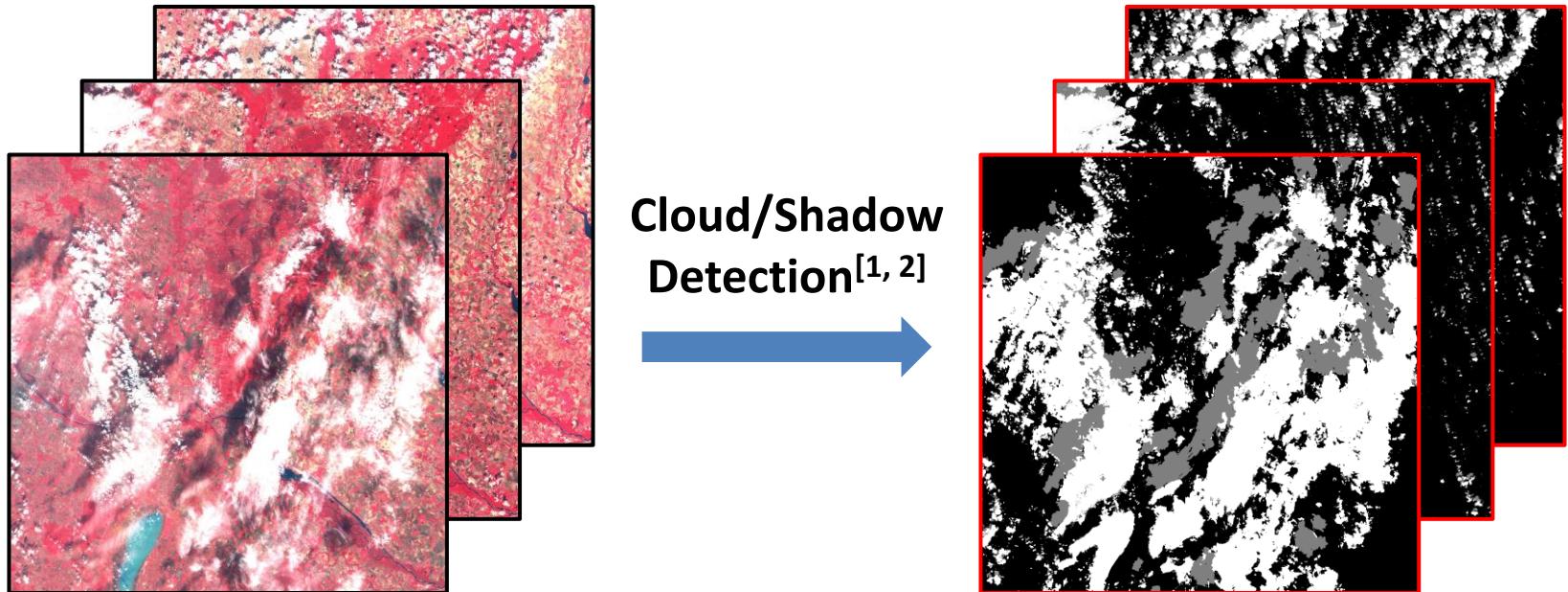


# Methodology

## Flowchart of the Proposed Method



## (1) Multi-Temporal Imagery Cloud/Shadow Detection

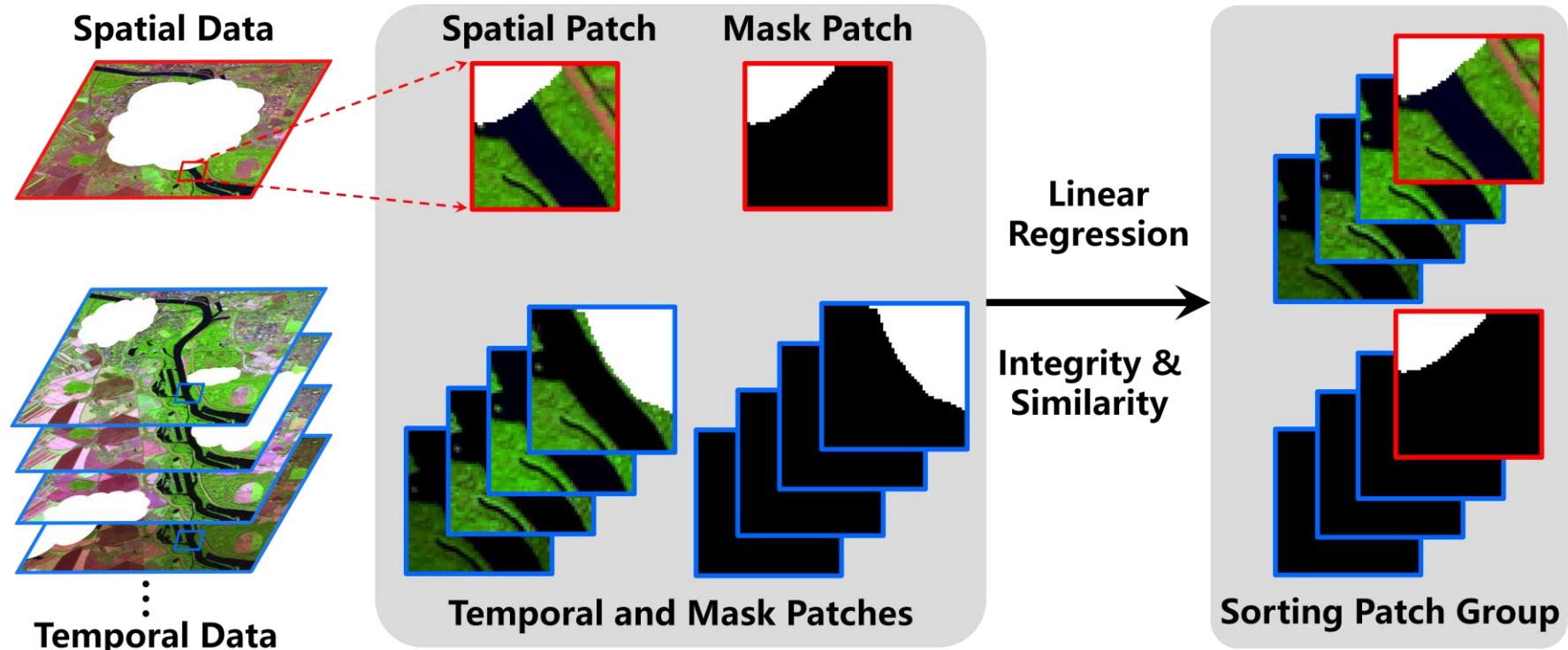


Obtaining Accurate **Location** of Cloud/Shadow for Reconstructing

[1] **Fmask 4.0**: S. Qiu *et al.*, RSE, 2019.

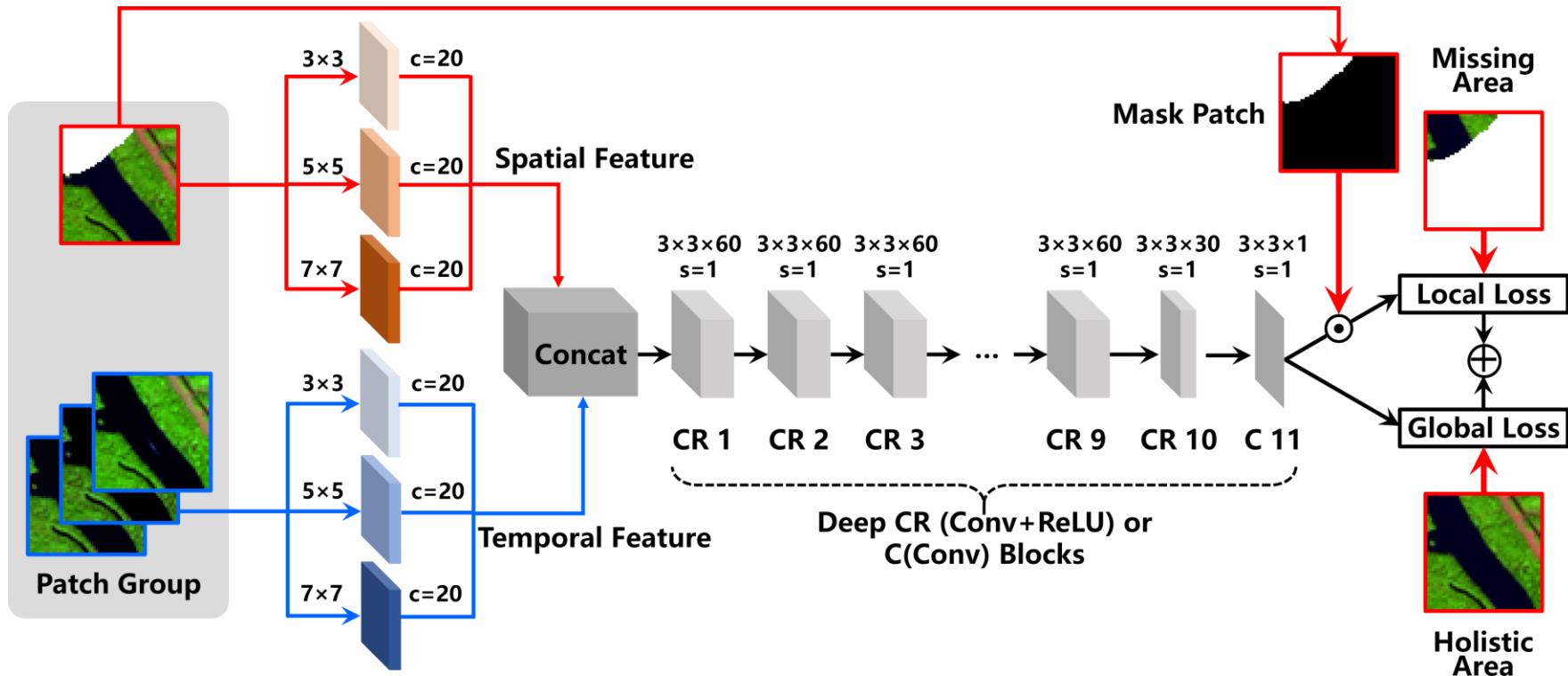
[2] **MSCFF**: Z. Li *et al.*, ISPRS, 2019.

## (2) Multi-Temporal Patch Group Stacking and Sorting



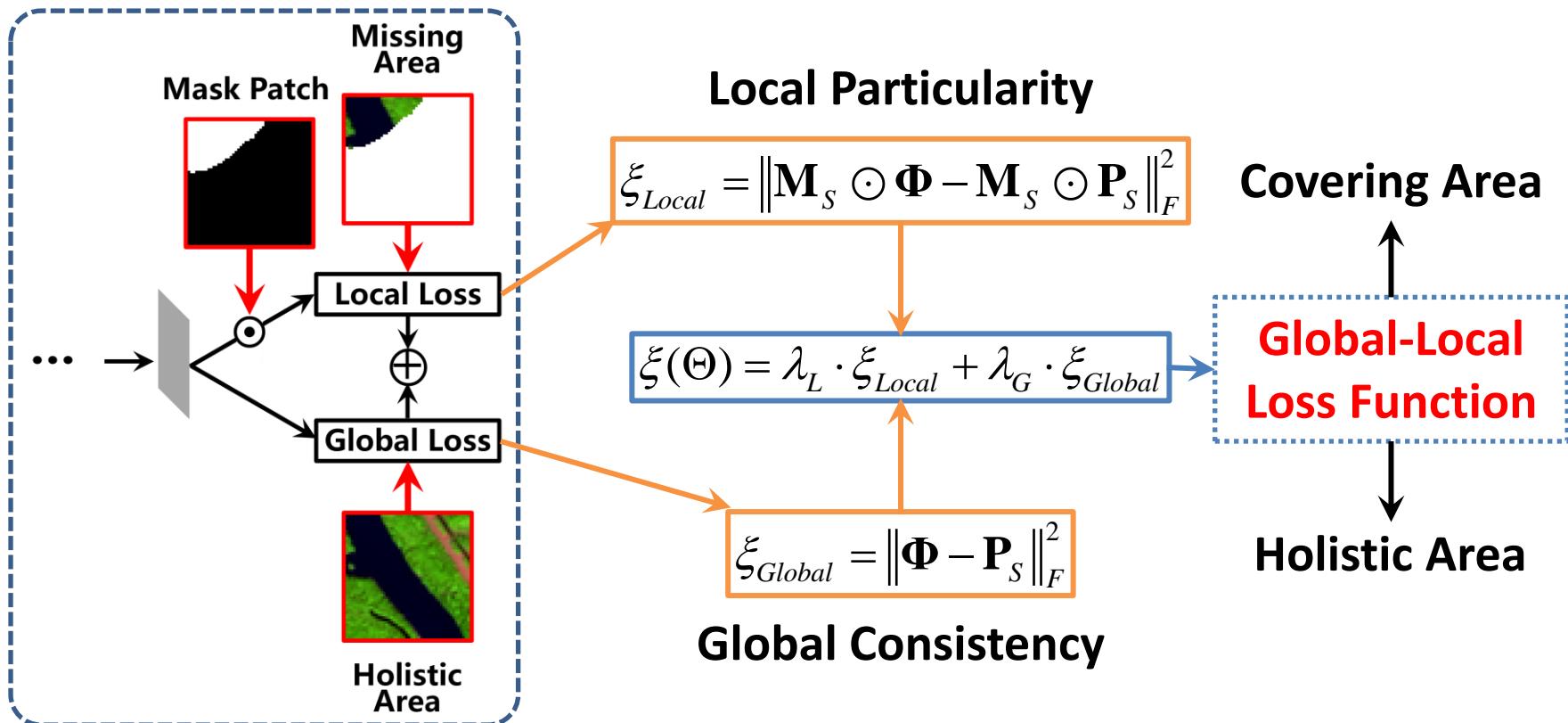
**Building Spatio-Temporal Patch Group With High Correlation**

## (3) Spatio-Temporal Patch Group Recovering Model



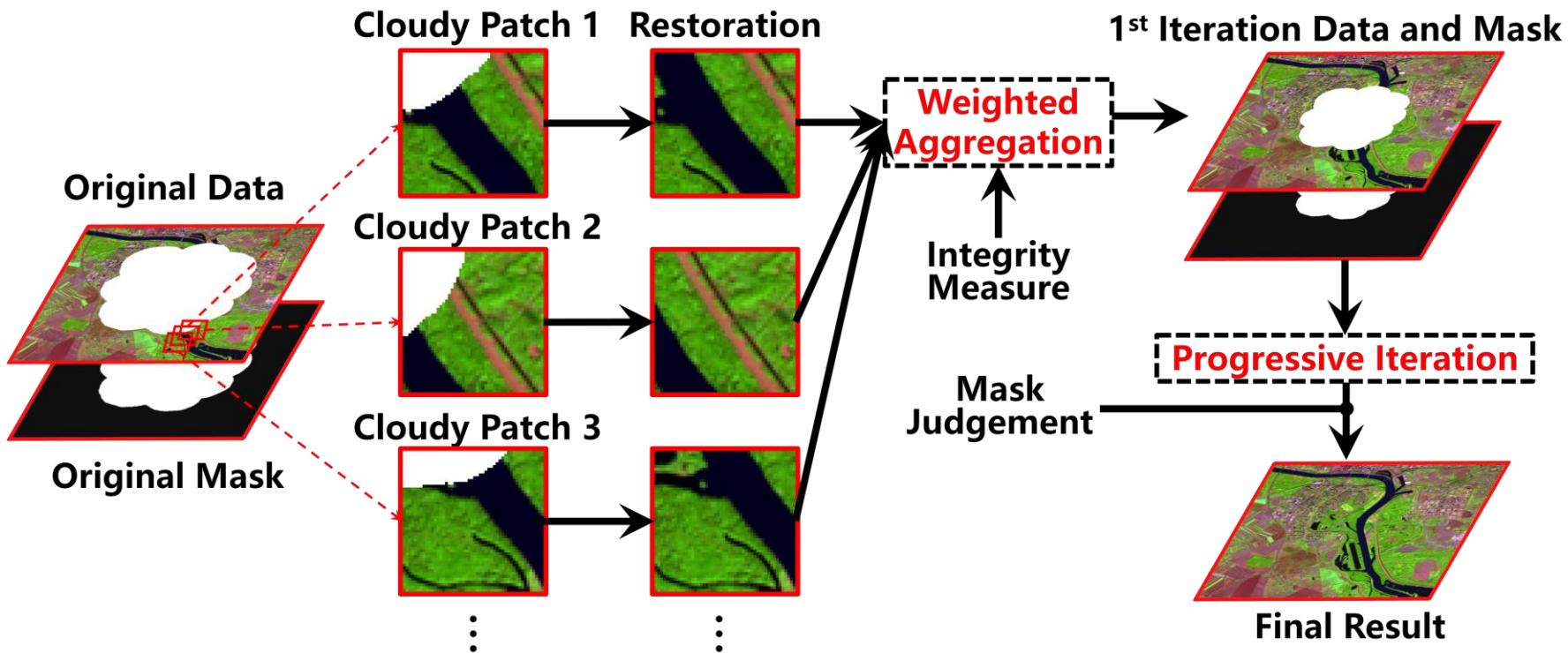
Reconstructing Spatial Patch Covered by Cloud/Shadow

## (3) Spatio-Temporal Patch Group Recovering Model



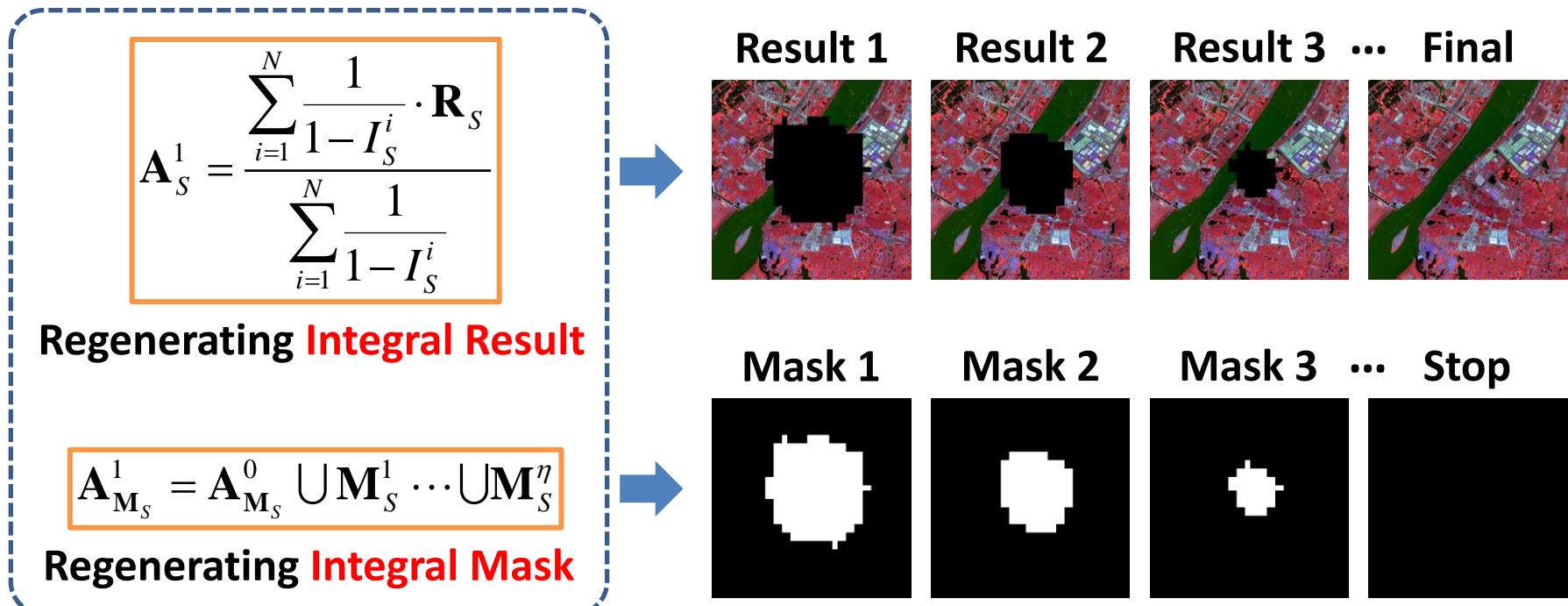
Considering **Global-Local Constraint** for Recovering Spatial Patch

## (4) Weighted Aggregation and Progressive Iteration



Reconstructing Final Integral Result Through Multiple Restored Patches

## (4) Weighted Aggregation and Progressive Iteration



Weighted Aggregation

Progressive Iteration

Larger Integrity  $I_S$  → More Believable Spatial information

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# Experiments

## Simulated Experiments: Case 1 (Sentinel-2, Single Temporal)



(a) B05, B8A, B12



(b) Simulated Cloudy



(c) Temporal data



(d) STS

By Zhang et al., TGRS, 2018



(e) WLR

By Zeng et al., RSE, 2013

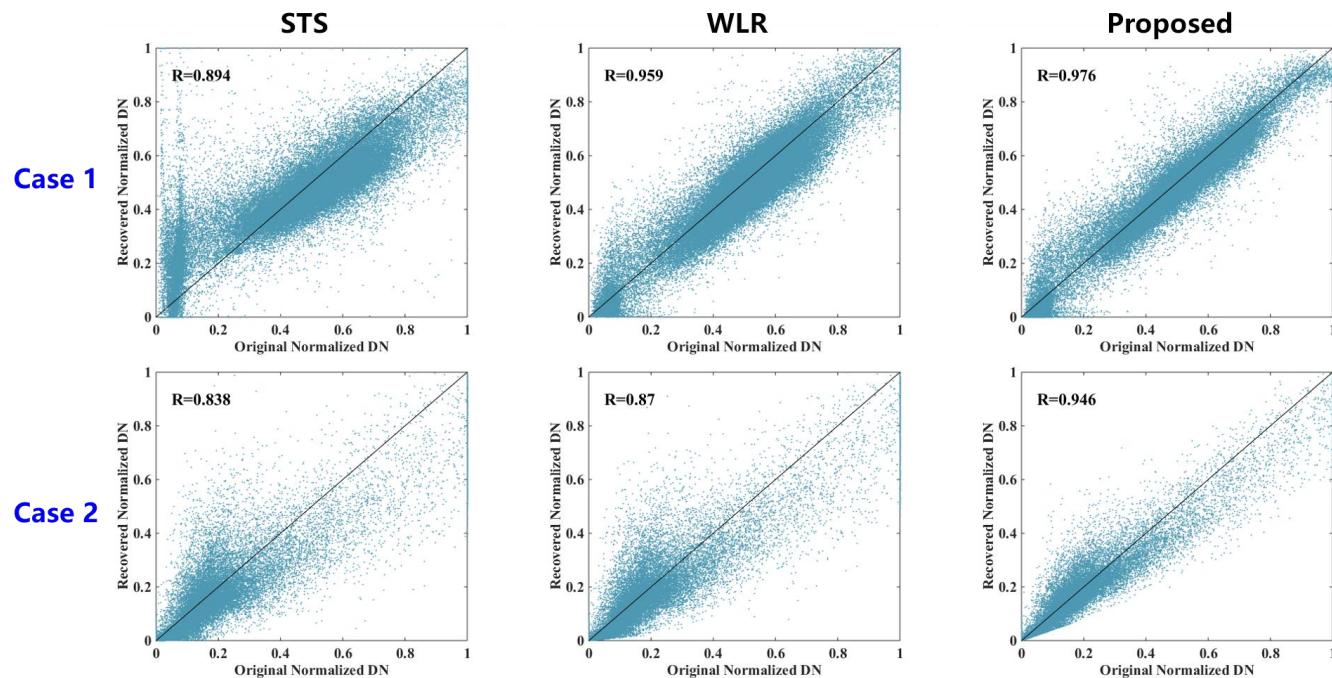


(f) Proposed

# Experiments

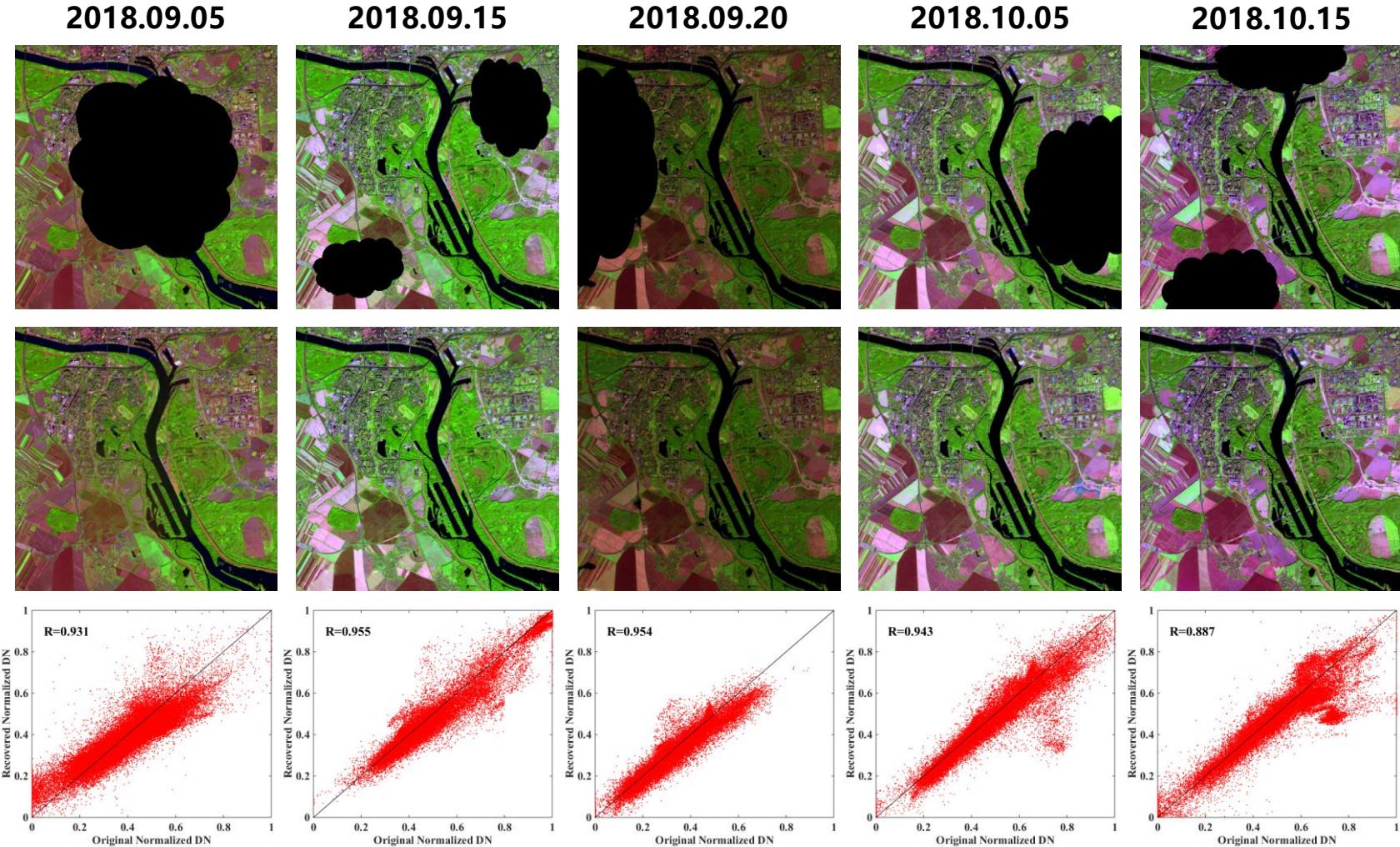
## Simulated Experiments: Index Evaluation

Index	Ideal	Case 1				Case 2			
		Linear	WLR	STS	Proposed	Linear	WLR	STS	Proposed
CC	1	0.9270	0.9617	0.9395	<b>0.9881</b>	0.9689	0.9859	0.9772	<b>0.9937</b>
SSIM	1	0.7834	0.9083	0.8498	<b>0.9414</b>	0.9262	0.9623	0.9486	<b>0.9814</b>
RMSE	0	0.0843	0.0510	0.0722	<b>0.0298</b>	0.0486	0.0317	0.0403	<b>0.0213</b>



# Experiments

## Simulated Experiments: Case 3 (Sentinel-2, Multi-Temporal)

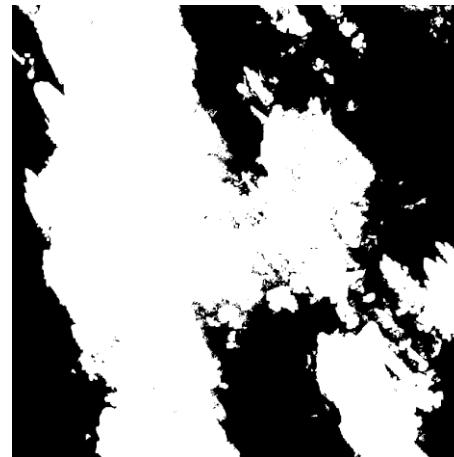


# Experiments

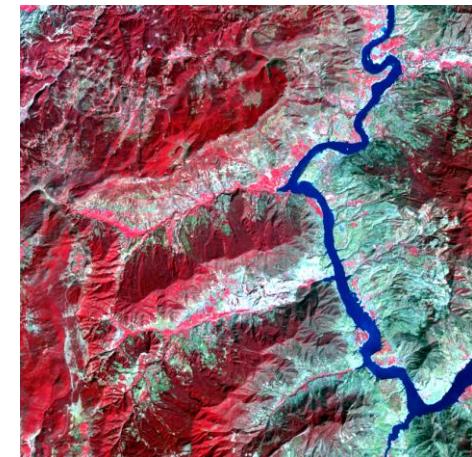
Real Experiments: (Sentinel-2 MSI, Single Temporal Data)



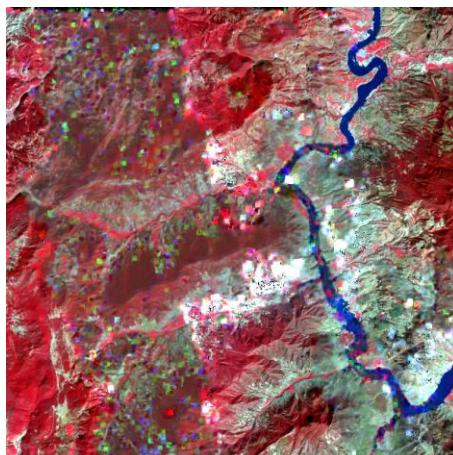
(a) B05, B8A, B12



(b) Cloud Mask



(c) Temporal



(d) STS



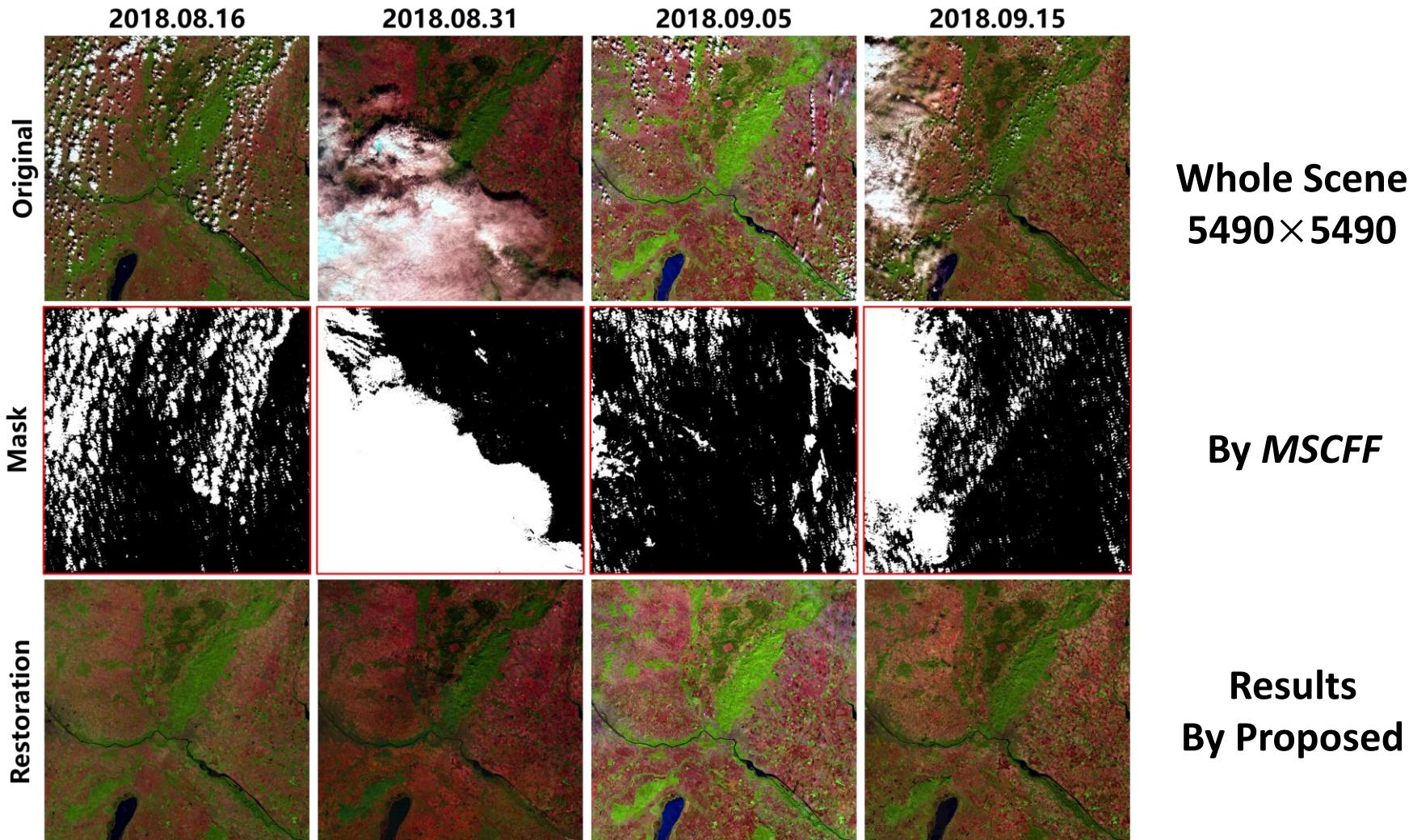
(e) WLR



(f) Proposed

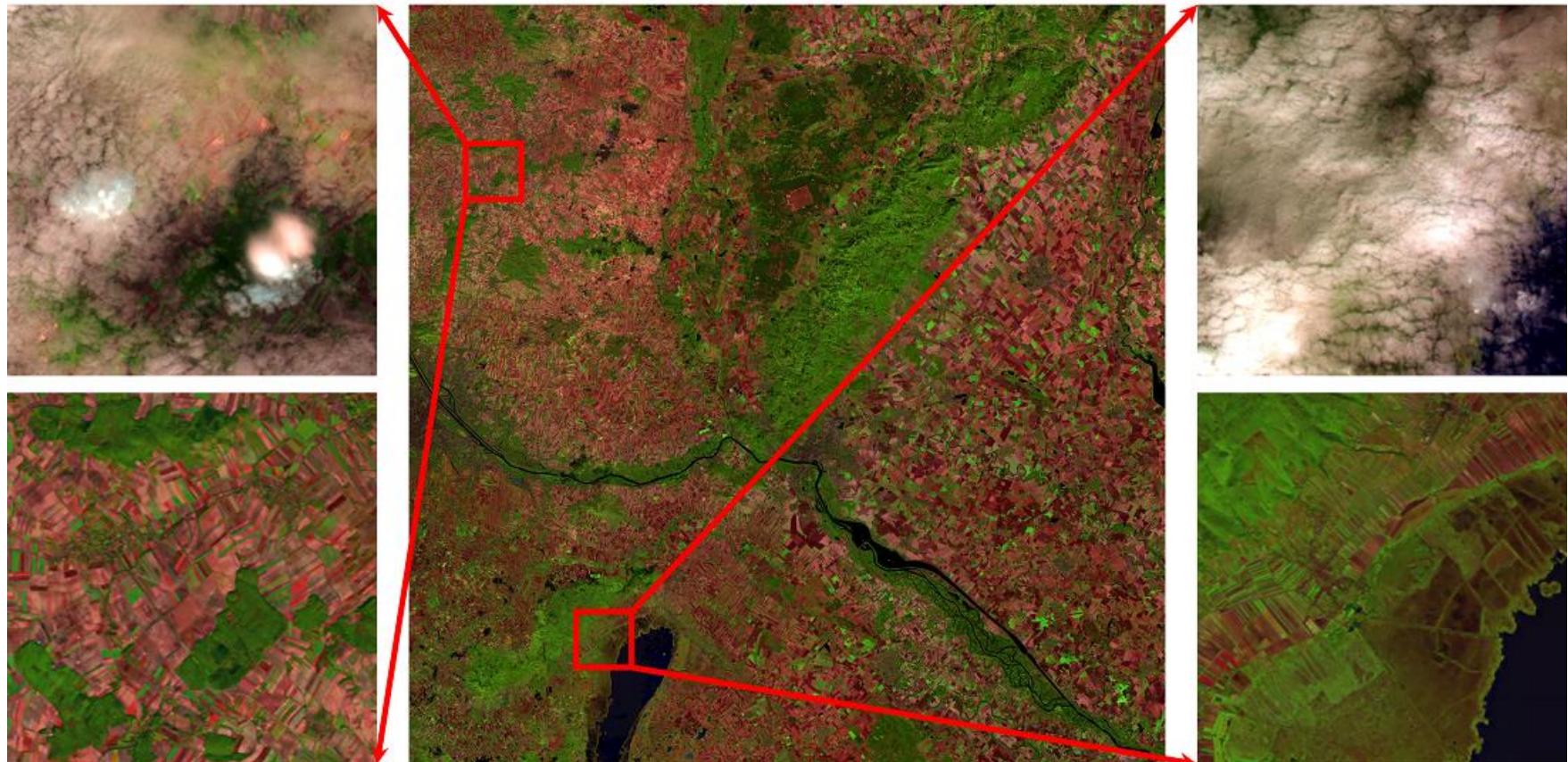
# Experiments

Real Experiments: (**Sentinel-2 MSI, Multi-Temporal Data**)



# Experiments

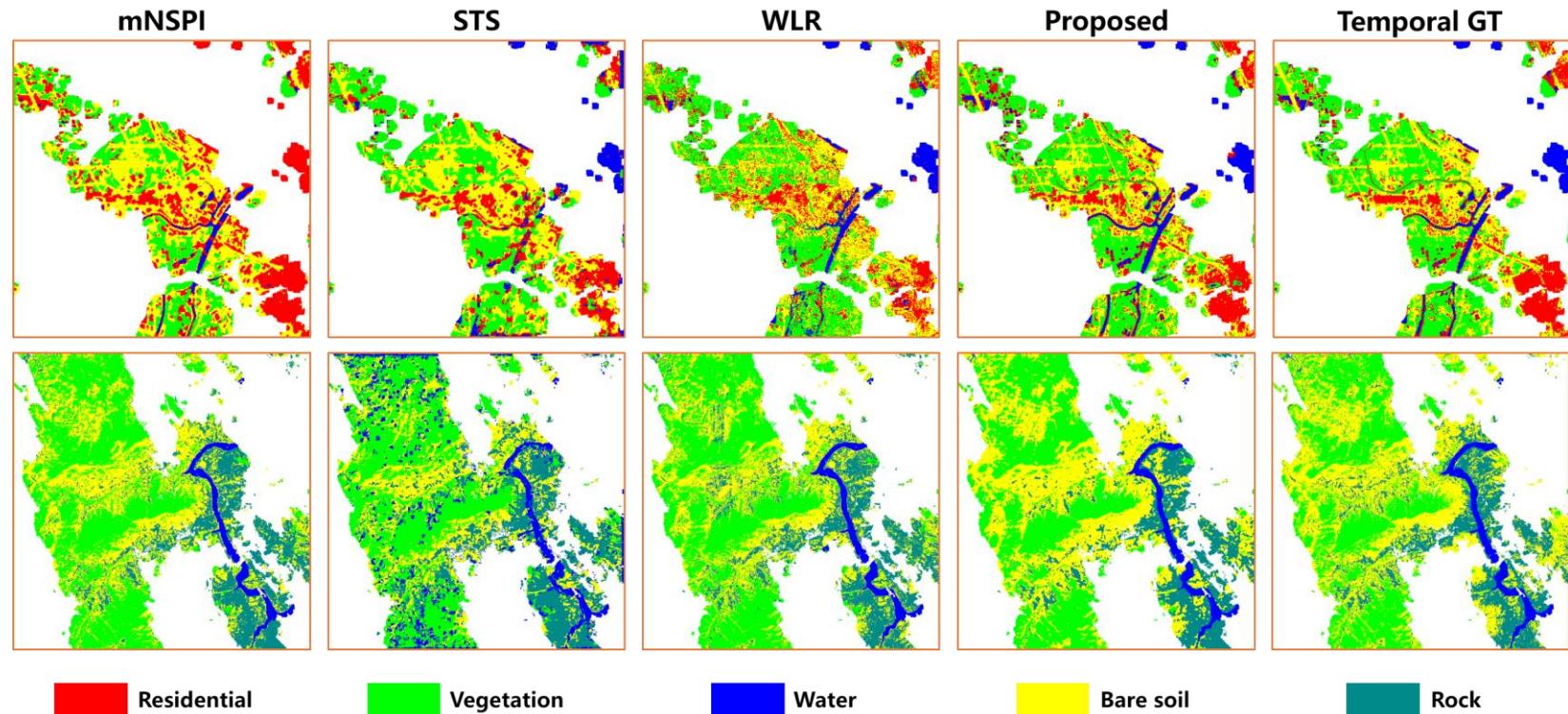
Real Experiments: (Multi-temporal, Large-Scale Scenarios)



Global and Two Local Amplification Results In 2018.09.15

# Experiments

## Discussion: Validation of the Restoring Results



	Linear	STS	WLR	Proposed
Data 1	74.4%/0.628	69.5%/0.587	76.8%/0.646	81.3%/0.695
Data 2	76.8%/0.647	64.5%/0.549	77.3%/0.652	79.4%/0.683

**Supervised Land Cover Evaluation Index (OA/Kappa)**

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## Conclusions

### Spatio-Temporal Patch Group Cloud Removal Framework

- Cloud and Shadow Detection
- Multi-Temporal Patch Group Stacking
- Spatio-Temporal Recovering Model
- Weighted Aggregation and Progressive Iteration

### Deficiencies and Future Works

- Mask Type (Thick Cloud, Thin Cloud, and Shadow)
- Patch Group (Patch Size, Aggregating Weights, Global-Local...)
- Spatial Self-Reconstructing under no Temporal Information
- For Other Satellite Products Recovering (AOD, LST, NDVI... )



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Released Codes

*Thanks!*

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[www.escience.cn/people/qz/index.html](http://www.escience.cn/people/qz/index.html)