RFI 2022

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RFI Detection in Sentinel-1 SLC Image using Semantic Cognition Enhancement Network

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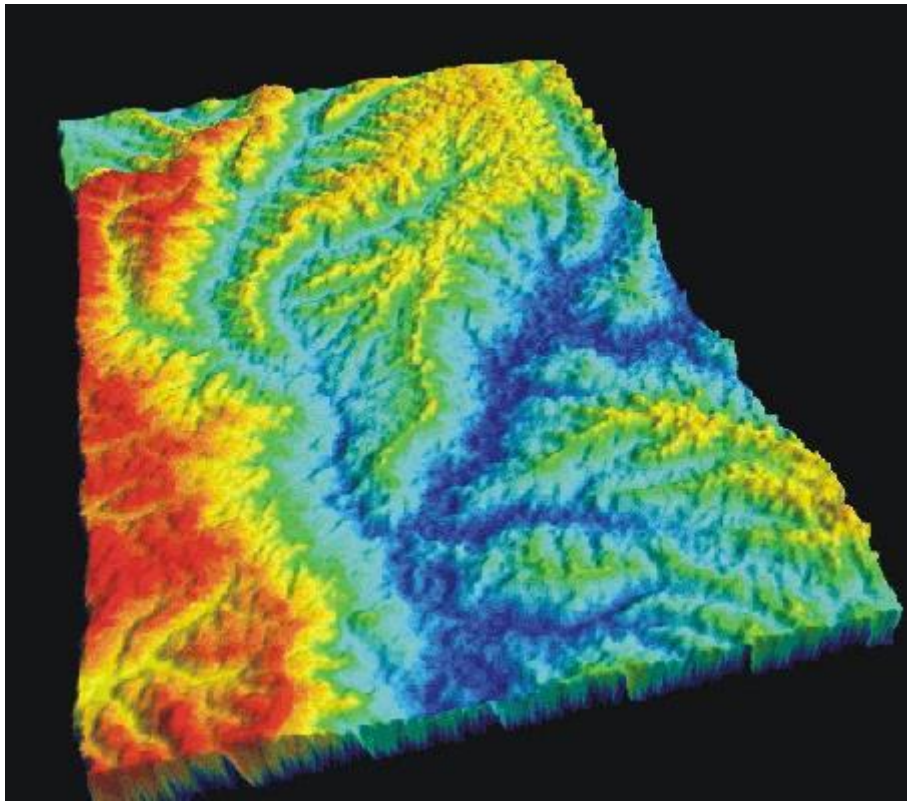
RFI 2022

Outline

1. Motivation – Congested and Contested Electromagnetic Environment

Synthetic Aperture Radar (SAR)

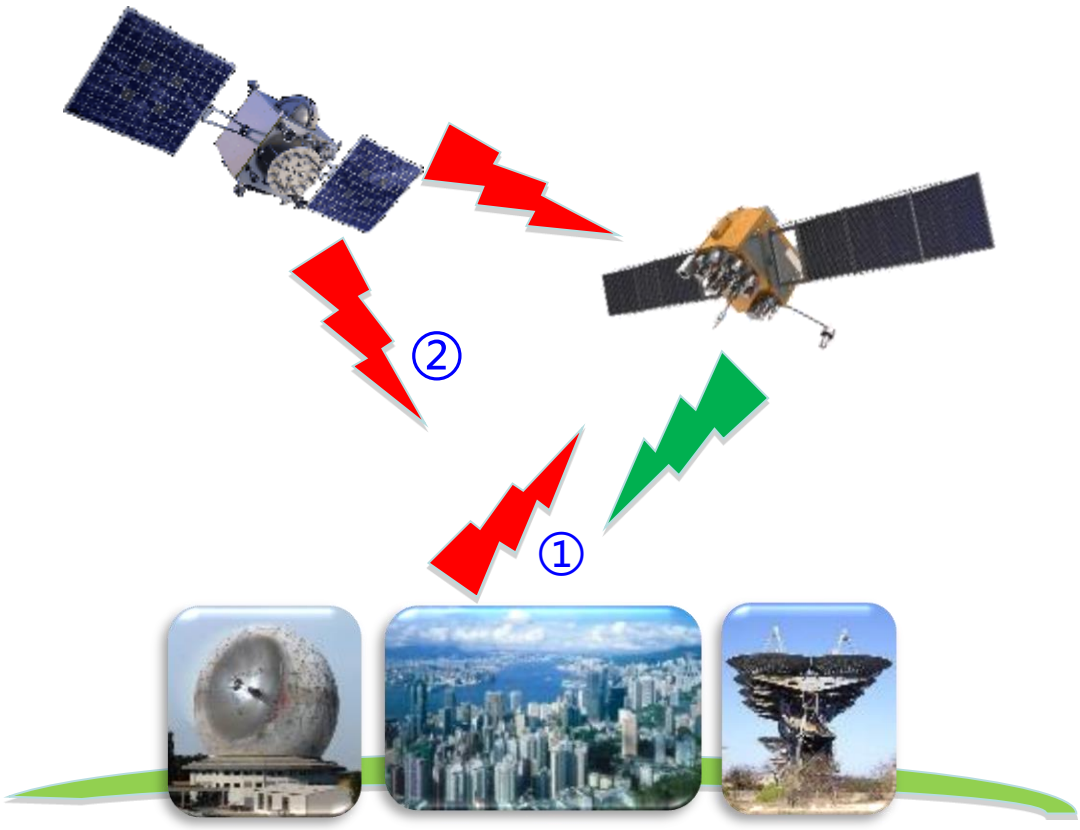
- Important active microwave remote sensing instrument, critical for earth monitoring and understanding
- Quantitative remote sensing requires low distortion level to radiometric measurements.



1. Motivation – Radio Frequency Interference (RFI)

Radio Frequency Interference

-- Unavoidable spectrum sharing for high-resolution SAR systems with large bandwidth



RFI Sources

① *Terrestrial Radiation Sources*

- Mostly associated with human activity over land and widely reported (*Radiolocation Radars, wind profilers, Telecommunication, Television Networks, etc*)
- *Wide variety of signals & modulations*

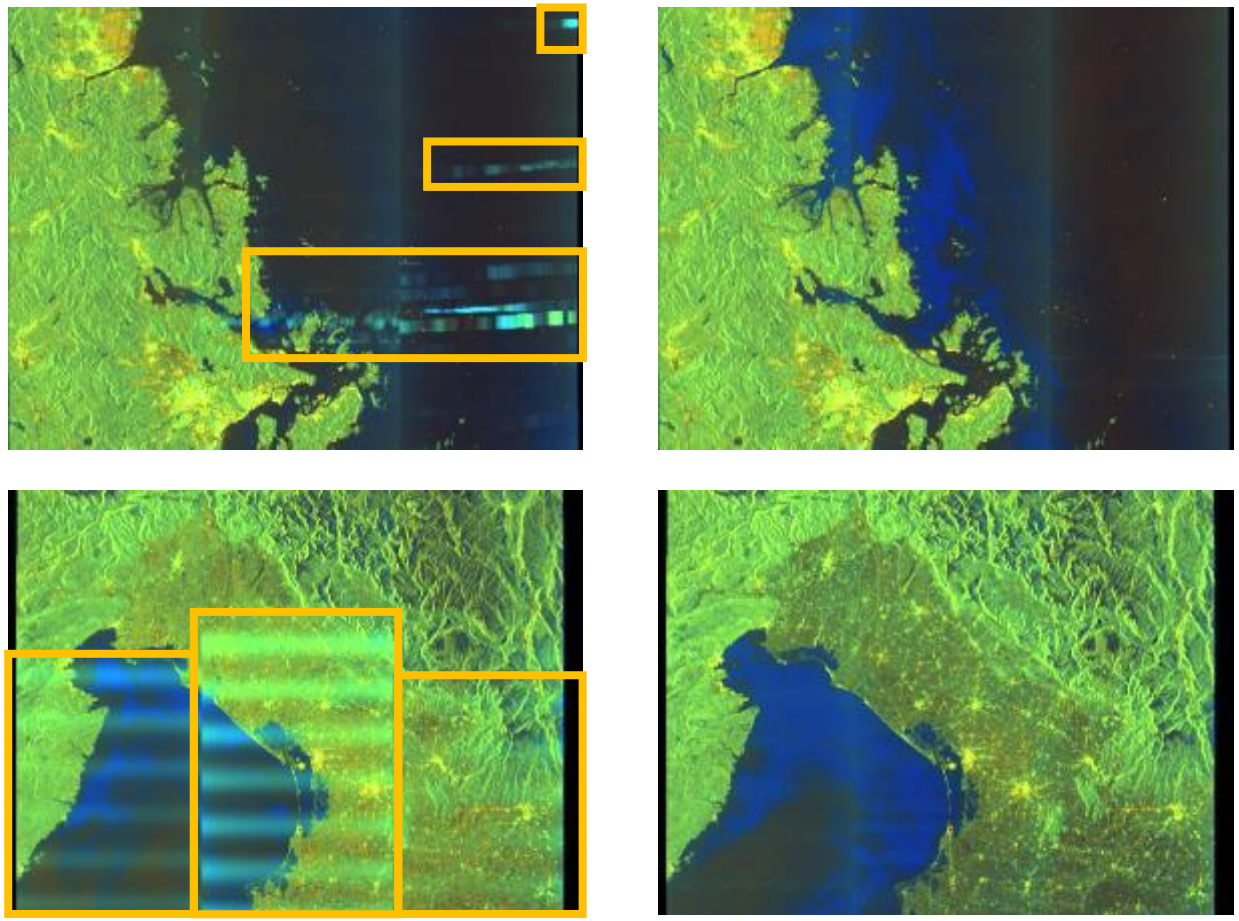
② *Spaceborne Mutual Interference*

- Mutual interference from other SAR satellites become common (*Sentinel vs RadarSat, Gaofen-3, etc.*)
- *Might be worse with the forthcoming SAR constellations and GeoSAR*

1. Motivation – Radio Frequency Interference (RFI)

Potential RFI Sources

- Authorized services sharing spectrum
- Non-authorized services sharing spectrum
- Unexpected emissions from adjacent spectrum



- **Amplitude & Phase distortion**
  - **Affect image interpretation (Target detection, land cover classification, etc)**
  - **Quantitative remote sensing application (Polarimety, Inteferometry, etc.)**

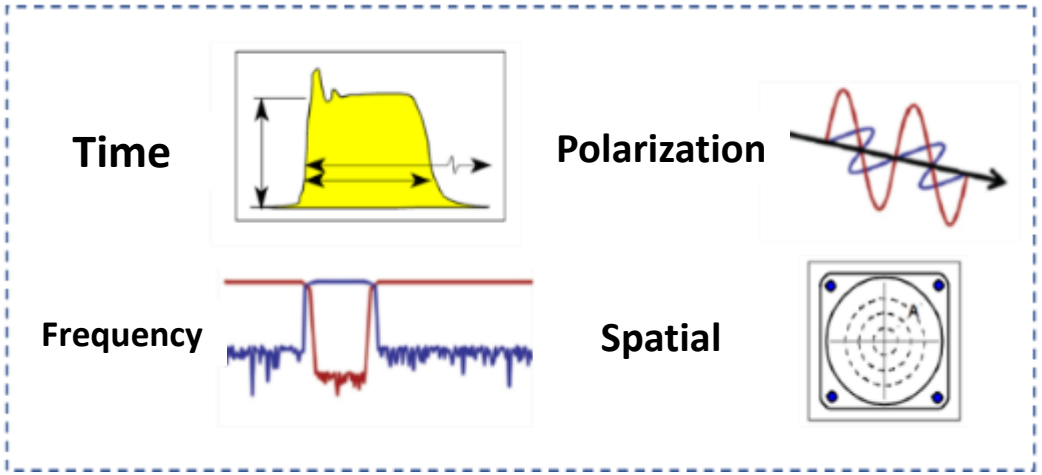
Detrimental to global and regional scientific research for space-borne SAR system

2. RFI Detection

- ***Detection Vs Signature Extraction***
  - ***Level 1:*** Whether RFI exists in echoes or images?
  - ***Level 2:*** Which part corresponding to RFI?

Binary Test Problem

$$\begin{cases} H_0 : X = S + N \\ H_1 : X = S + I + N \end{cases}$$

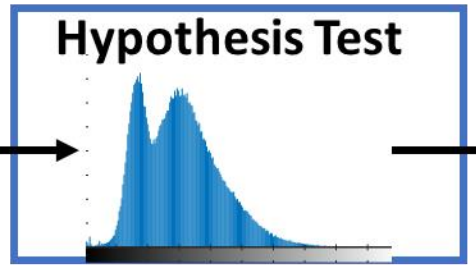


- ***Challenges***
  - Complex nature of interfering signals in both the time and frequency domain manifest themselves unpredictably, together with non-stationary property
  - **How to choose a suitable statistics to produce detection results with high confidence?**

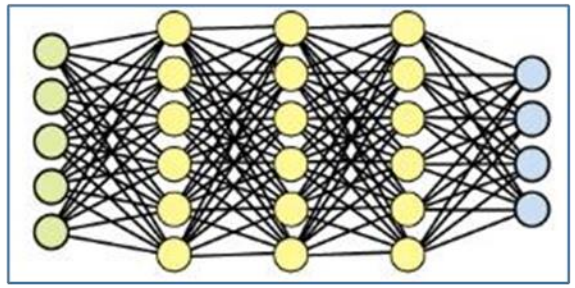
2. RFI Detection

Domain Knowledge

Power
Region
Clustering
Graph theory



Output
$y \in Y$



Classification
FCN
Segnet
Mask-RCNN

Model-based Method

Data-Driven Method

- ✓ *Simple calculation and high efficiency*
- × *Detection statistics relies on prior knowledge, may not be the optimal choice*

- ✓ *Deep level feature learning*
- × *The quality and quantity of training sets and the generalization of models*

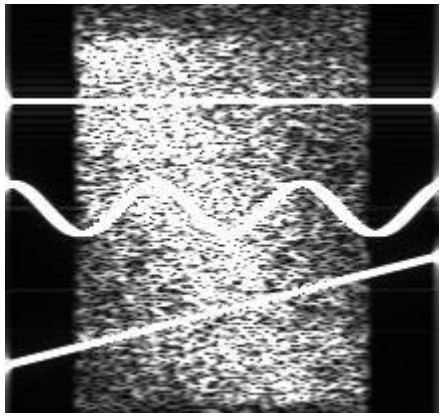
Data Knowledge

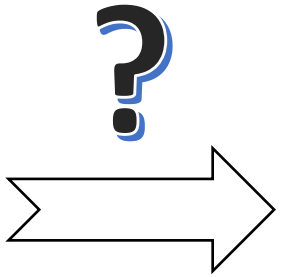
With the accumulation and publicity of "Big Data" for remote Sensing, more intelligent way could be exploited !

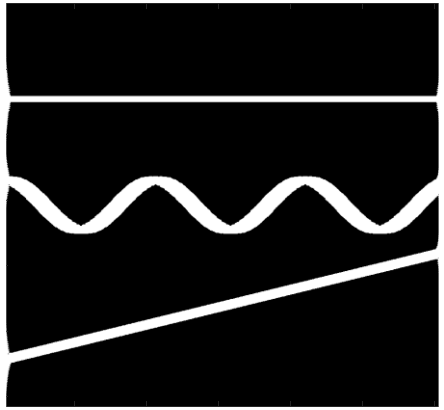
2. RFI Detection – Proposed scheme

- *Problem Description*
  - **Original Binary detection problem** could be formulated as a pixel-wise **segmentation** problem, i.e., produce a mask that will separate an image into different classes
  - Using Semantic Network to characterize deep-level intrinsic and contextual feature ?

Raw Data Domain





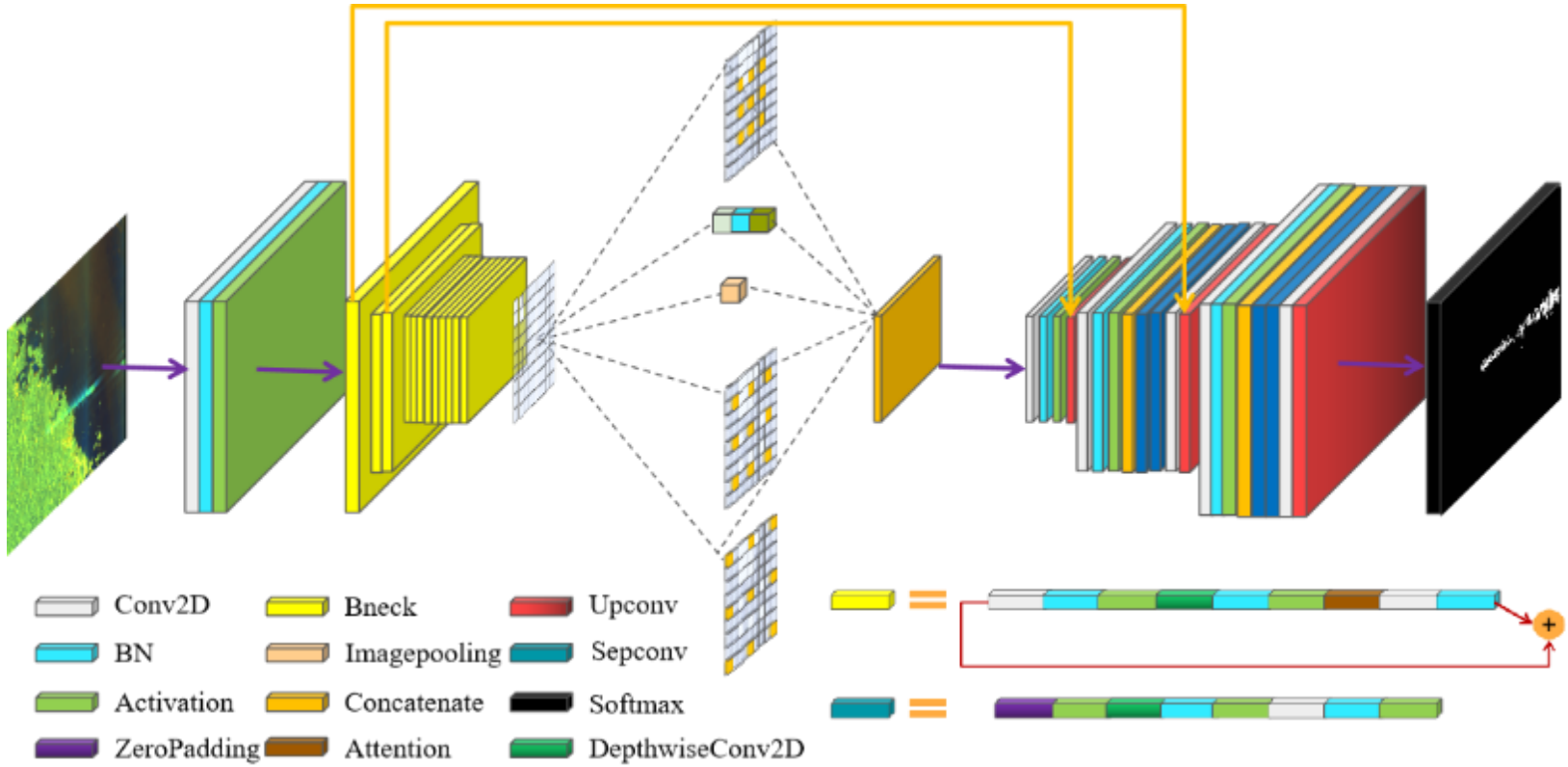


labeled segmentation mask

Image Domain

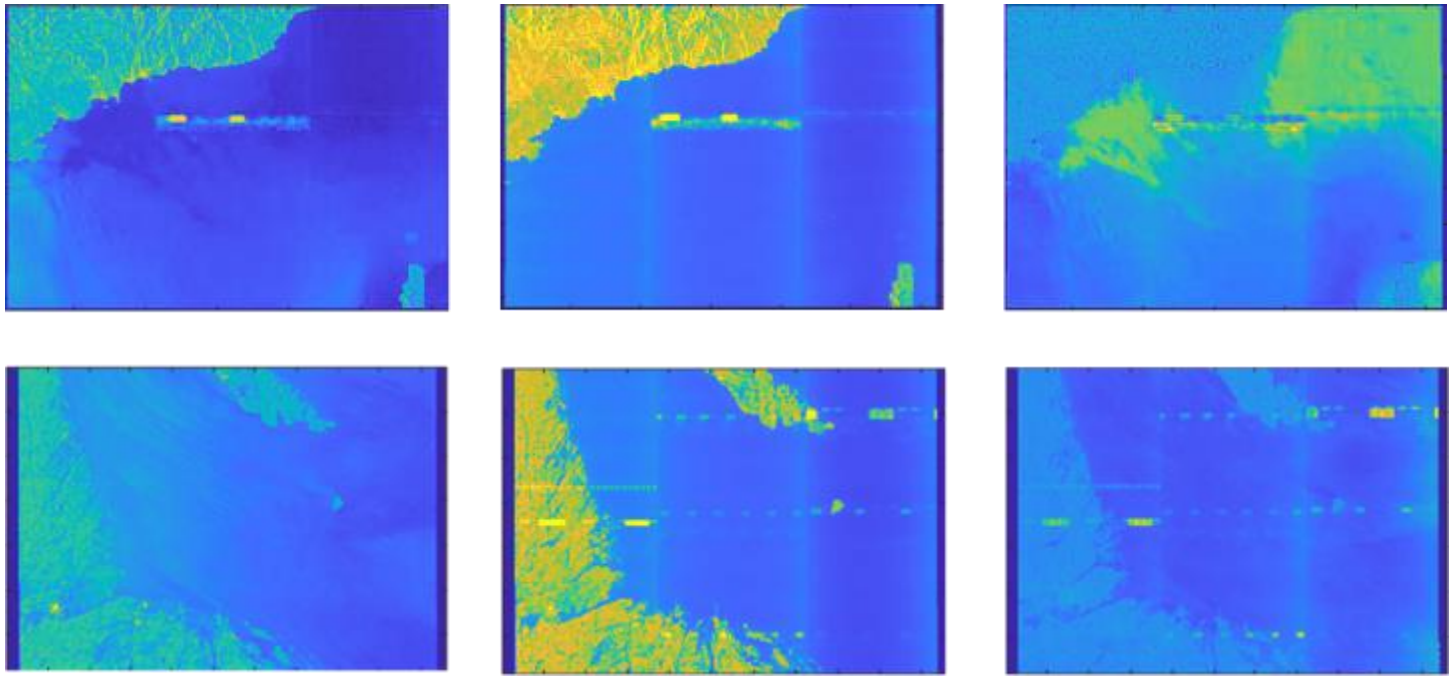
2. RFI Detection – Proposed scheme

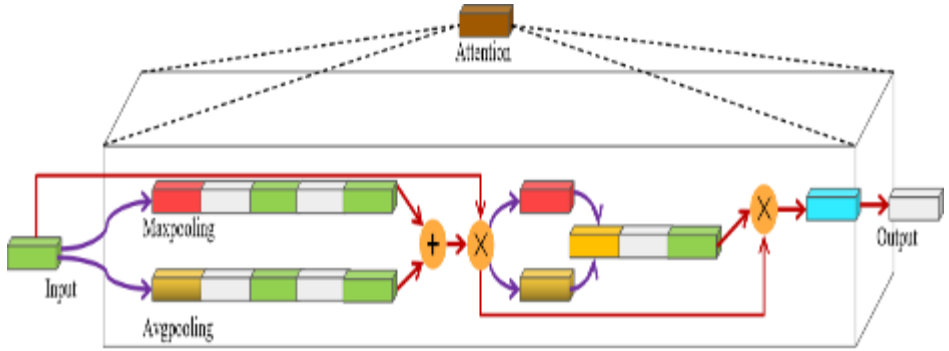
- *Network Architecture*
  - ***Encoder***: a contracting path consist of convolutional layers to capture context feature
  - ***Decoder***: symmetric expanding path that enables precise localization and High dimensional features
  - ***Residual Connection***: preserving information for better recovery using feature concatenation



2. RFI Detection – Proposed scheme

- *Slef-attentional Module*
  - ***Assign different weights to all pixels on each specific and spatial channel***
  - ***Channel Attention:* Patterns of interference signatures in different polarimetric channels are different**
  - ***Spatial Attention*: Artifacts appeared in limited spatial locations with unique patterns**

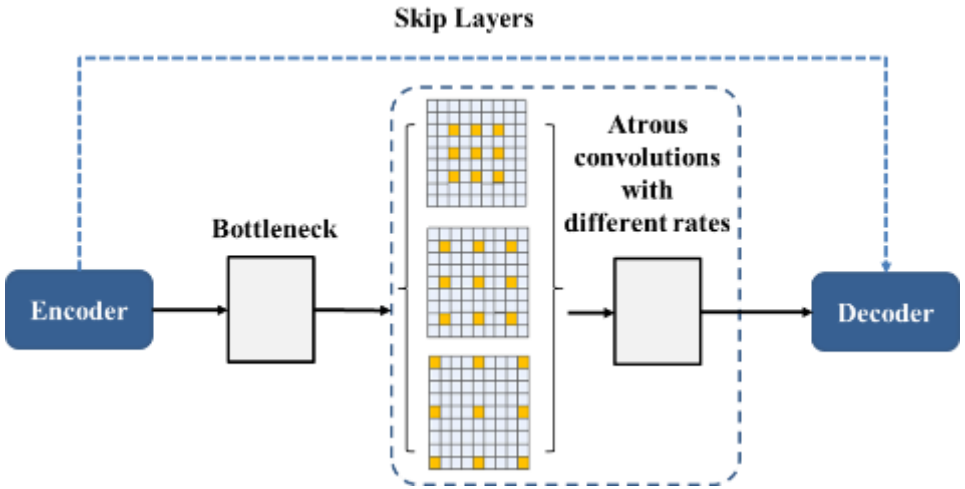


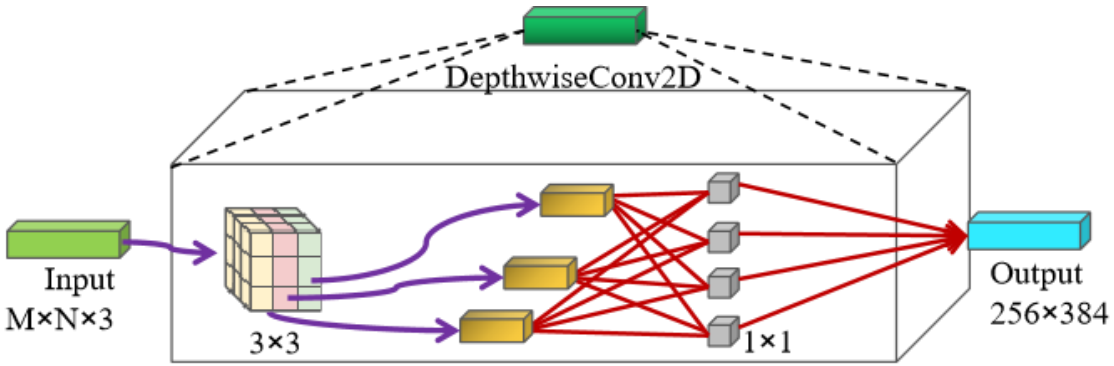


Architecture of the self-attention module

2. RFI Detection – Proposed scheme

- *Astrous Spatial Pyramid Pooling*
  - ***Convolutional layer contains a set of filters, which slide over the height and width of the image***
  - ***serves as a module to resample a specific feature layer before convolution at multiple scales***
  - ***It can yield more context information to capture the various RFI signatures in images while without increasing the number of network hyperparameters***
- *Depthwise convolution*
  - ***A special kind of convolution designed for mobile and embedded applications to alleviate the requirement on number of training samples***

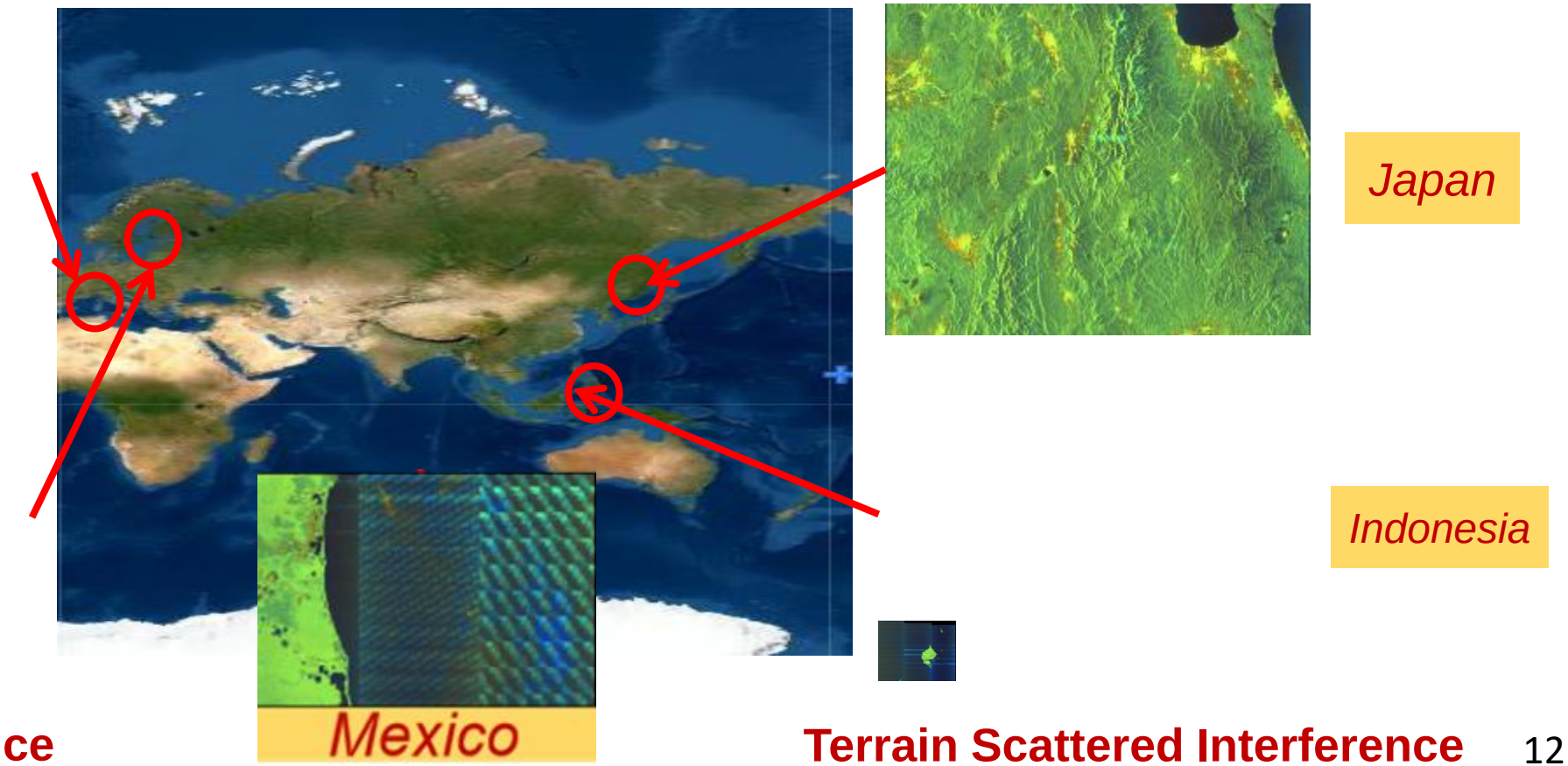




2. RFI Detection – Experimental Results

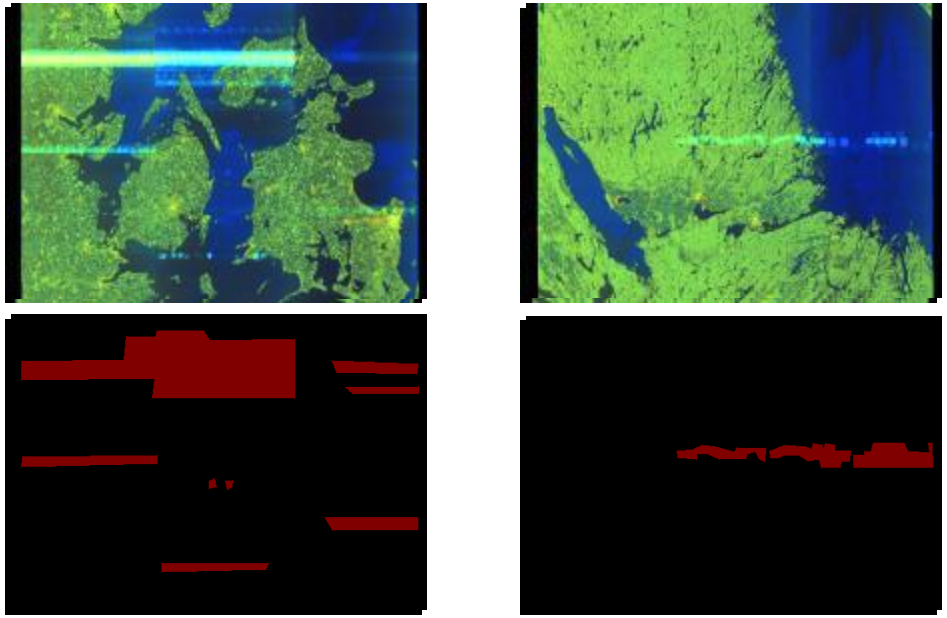
Case Study for Sentinel-1 Image Data

- Raw echoes is not always accessible for remote sensing end users
- In comparison with other STOA technique, the proposed network is also applicable for dealing with image data



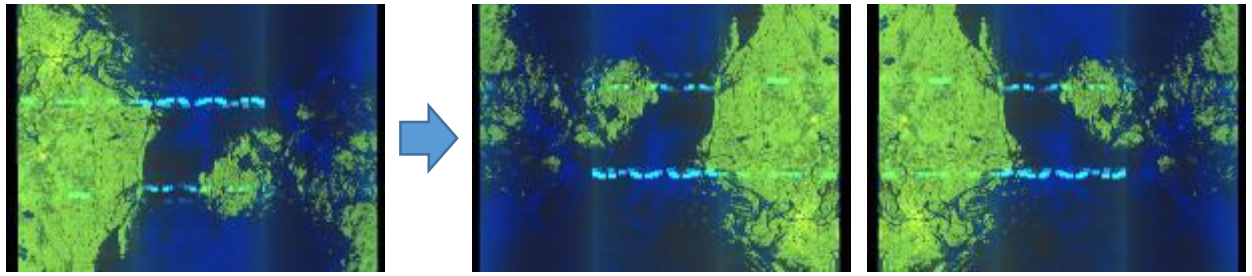
2. RFI Detection – Experimental Results

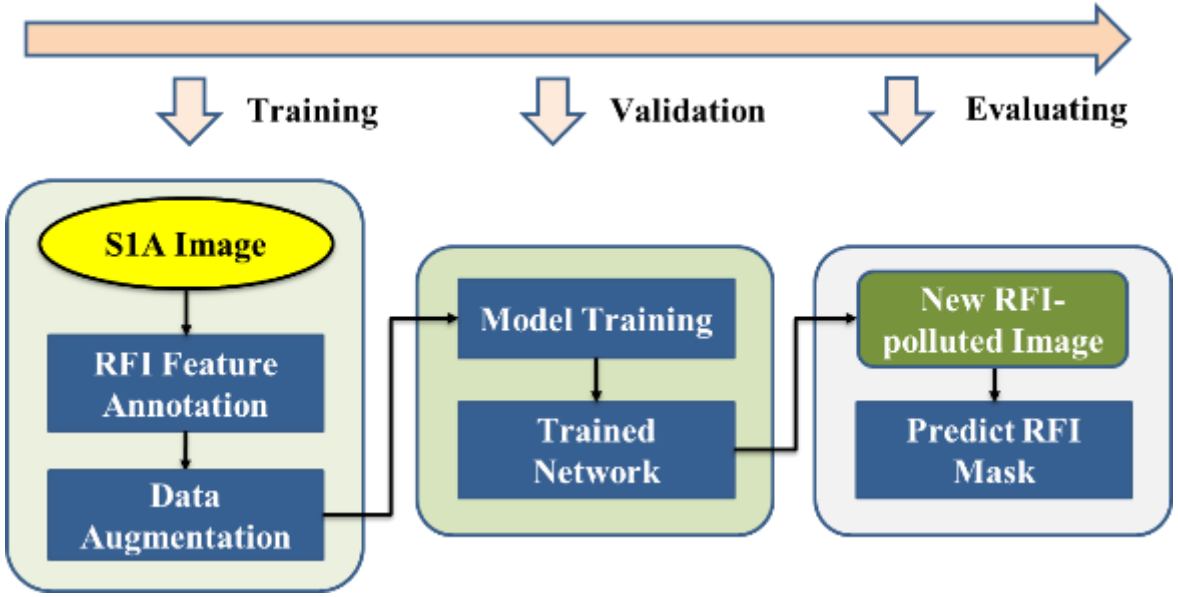
- *Dataset production* ***(Coarse Labeling)****:*



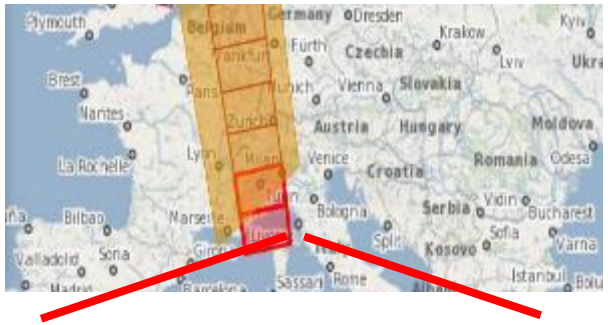
- *Data Augmentation:*

Original Image *Image flipping* *Image rotation*





2. RFI Detection – Experimental Results

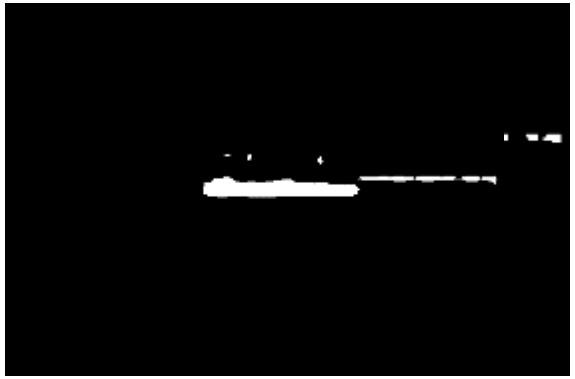


Scenario A: France

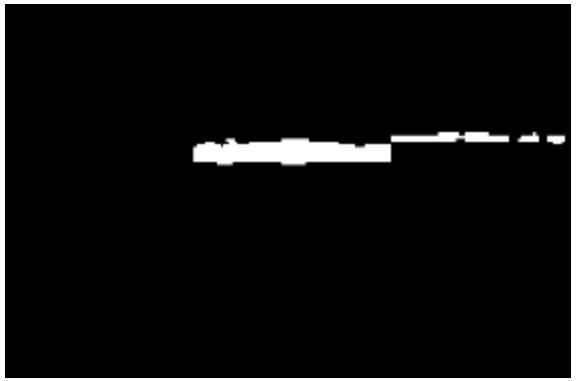
Original picture

Reference ground-truth

PCA-Kmeans

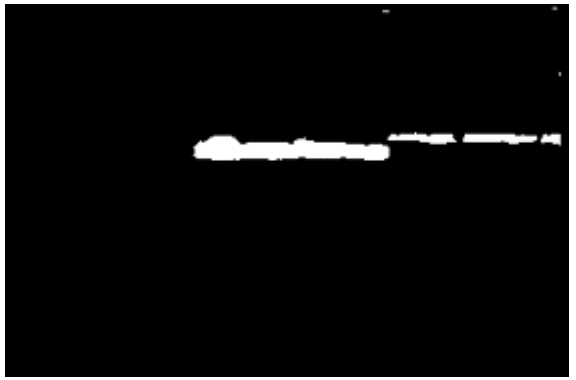


Unet



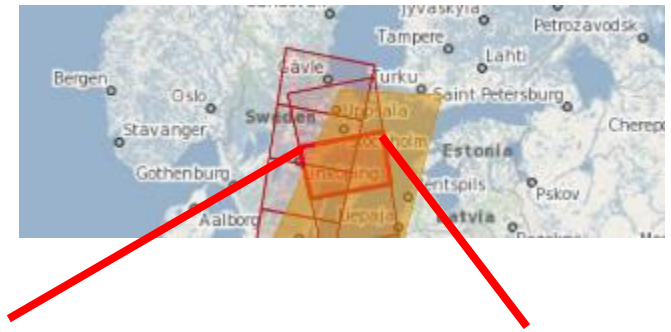
AC-Unet

MobileNetV2-DeepLabV3+



Proposed

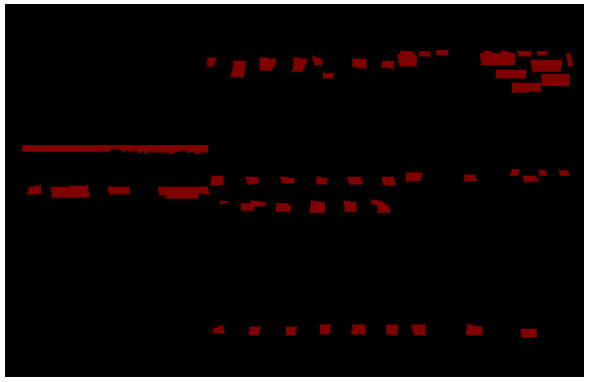
2. RFI Detection – Experimental Results



Scenario B: The Baltic Sea

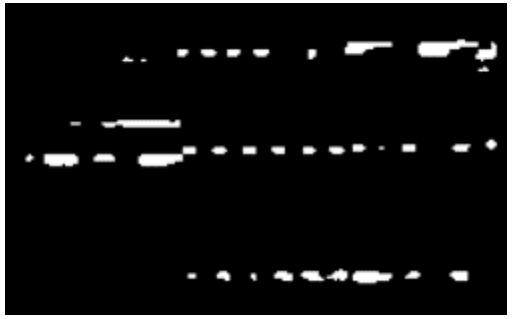
When the interference and background pixels are similar, the traditional model-based method is prone to miss detection

Original picture

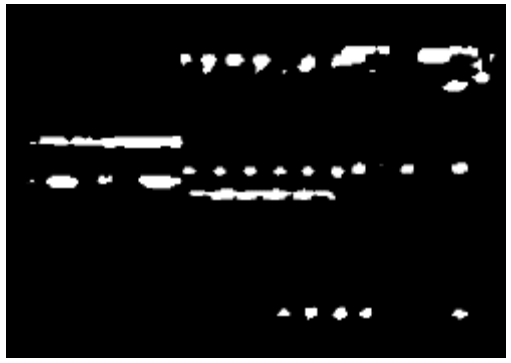


PCA-Kmeans

Unet



AC-Unet



MobileNetV2-DeepLabV3+

Proposed

2. RFI Detection – Experimental Results

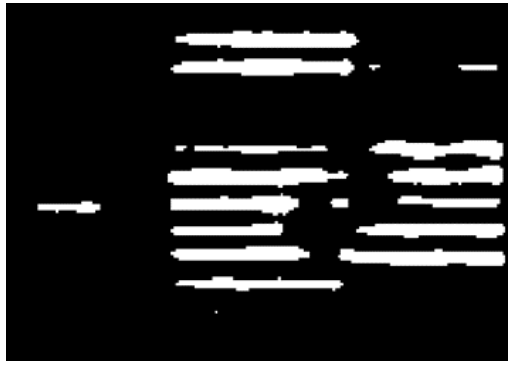
Scenario C: Indonesia

If the interference is very weak but regular, the data-driven method can learn more features and get better results than the traditional method

Original picture

Reference label

PCA-Kmeans



Unet

AC-Unet

MobileNetV2-DeepLabV3+

Proposed

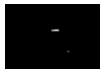
2. RFI Detection – Experimental Results

Scenario D: Japan

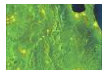
The test set also selects almost all scenes with land background, and the interference of such scenes is almost difficult to detect manually

Reference label

Unet



AC-Unet



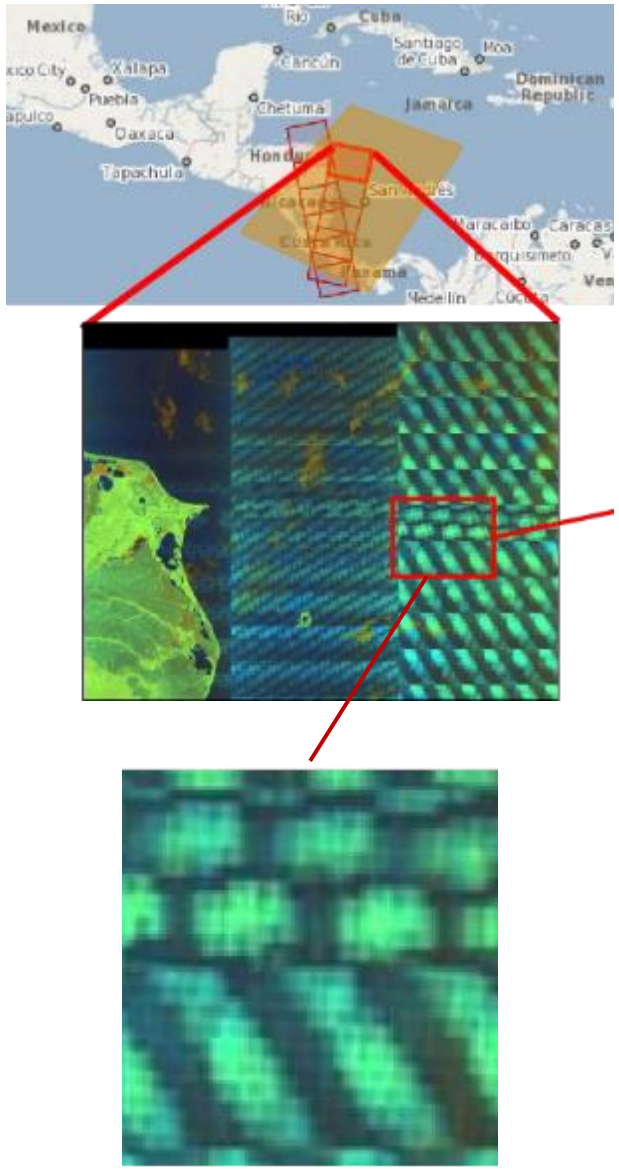
Original picture

PCA+K-means

MobileNetV2-DeepLabV3+

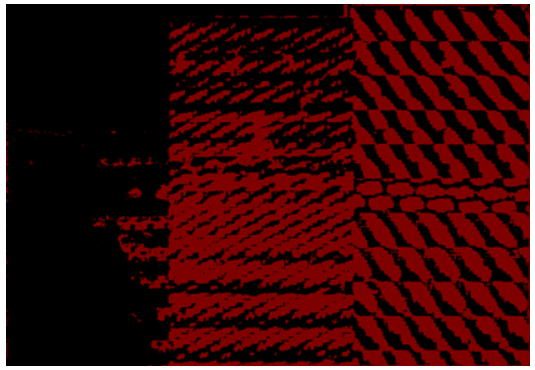
Ours

2. RFI Detection – Experimental Results

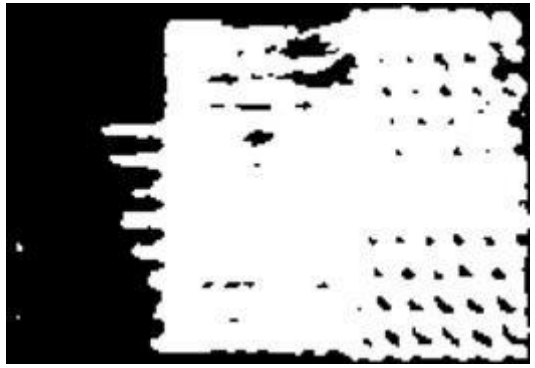


Scenario E: Japan

The neural networks could segment the complex disturbance from the background to some extent, but the texture is not segmented as well as the proposed method

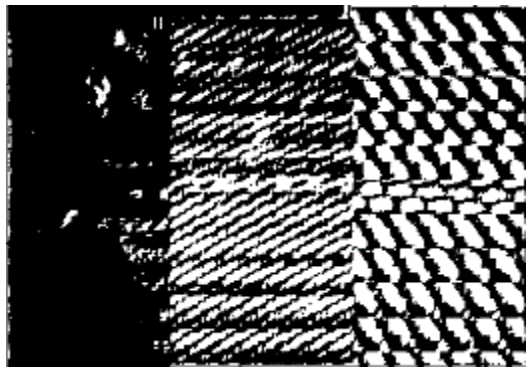


Reference label



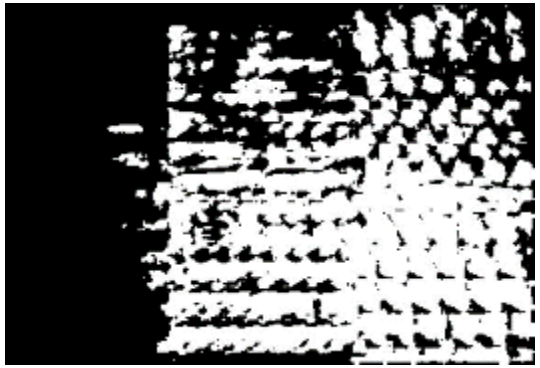
Unet

AC-Unet



PCA+K-means

MobileNetV2-DeepLabV3+



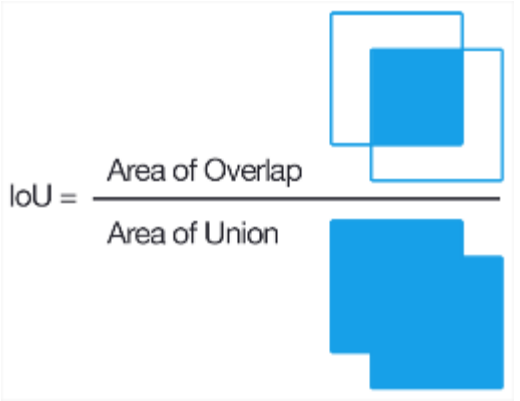
Ours

2. RFI Detection – Experimental Results

- *Performance Evaluation:*

MIoU is the standard measure of semantic segmentation. It calculates the average of the ratio of intersection and union of all categories

$$MIoU = \frac{1}{k+1}\sum_{i=0}^{k}\frac{p_{ii}}{\sum_{j=0}^{k}p_{ij}+\sum_{j=0}^{k}p_{ji}-p_{ii}}$$



Network Name	MIOU				
	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
U-Net [23]	76.89%	31.12%	48.22%	49.19%	56.64%
AC-Unet [25]	78.57%	27.78%	42.74%	34.16%	53.71%
MobileNetV2-DeepLabV3+ [27]	**78.93%**	36.79%	46.17%	41.87%	51.67%
Proposed Semantic Cognitive Enhancement Net	75.47%	**38.40%**	**50.37%**	**54.44%**	**59.63%**

3. Conclusion Remarks

- Attempt to incorporate data-driven learning techniques for RFI detection
- The proposed networks adopts an unique down-sampling to up-sampling structure, which enables identification of RFI in a sample-wise manner.
- It is capable of dealing with various RFI types, ranging from the typical single terrestrial RFI, complex mutual terrain-scattered interference.
  - The proposed method has lower requirement on the training data size.
  - Good performance on the small and weak interference detection
- **Worth Noting:**
  - Only training on the GRD, and no attempt has been made on **SLC data** carrying phase information and ground scattering amplitude information.
  - **Lacking paired images for training** is always an hindrance for performance improvement, traning dataset production requires **a lot time and effort.**

Thank You for Your Attention !

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