Super Resolution with GF-4 for Finer Scale Earth Observing

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1 Backgrounds

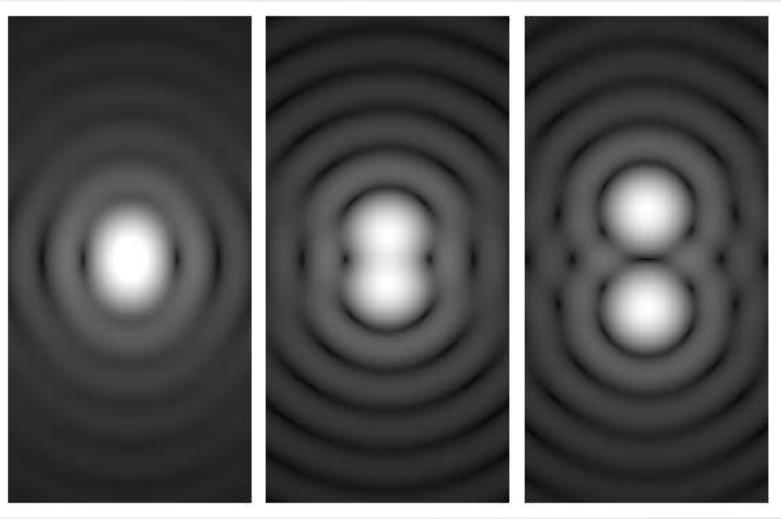
Gaofen 4 (GF 4) is a geostationary disaster relief satellite in the Gaofen series of Chinese civilian remote sensing satellites, which was launched on December 28, 2015.

Each snapshot covers around 400 x 400 Square kilometres. A ground resolution of 50 meters is achieved in the visible wavelengths while the mid-wavelength infrared with 400 meters.

	Channel	Wavelength (um)	Spatial resolution (m)	Field of view (km)	Revisit cycle (seconds)
Visible and near-infrared	1	0.45~0.90	50	400	20
	2	0.45~0.52			
	3	0.52~0.60			
	4	0.63~0.69			
	5	0.76~0.90			
Mid-wavelength infrared	6	3.5~4.1	400		

Resolution:

Definition: the ability to detect two closely spaced objects
Twofold meaning: optical resolution and sensor resolution

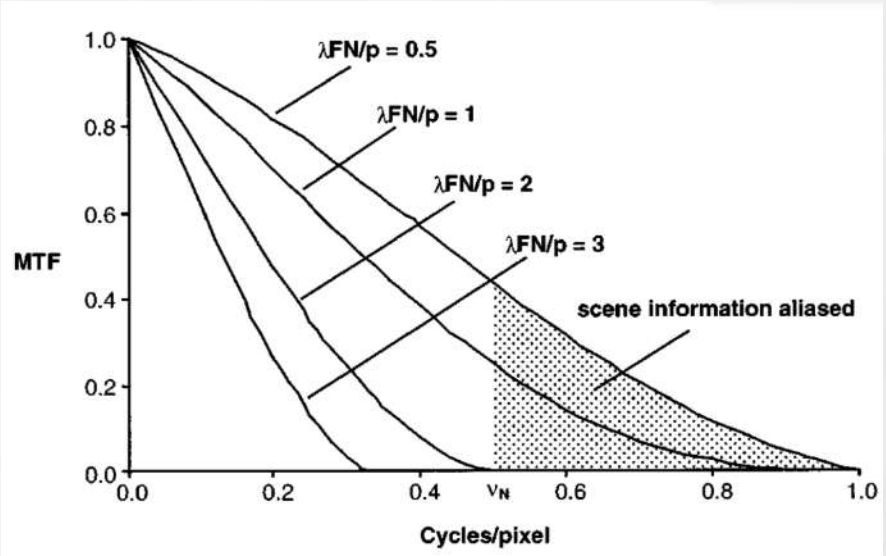


The optical cutoff frequency for an imaging system is $1/\lambda F_{\#}$ （lp/mm）， where $F_{\#}$ is the f- number; It limits the spatial resolution that can be imaged with sensors;
The Nyquist frequency for a sensor is defined as Nyquist = 1/2p （lp/mm）, where p is the pixel size;

Bear in mind: $\lambda F_{\#} /p=2$ is perfect, but nothing is perfect
Most of earth observing systems follows:

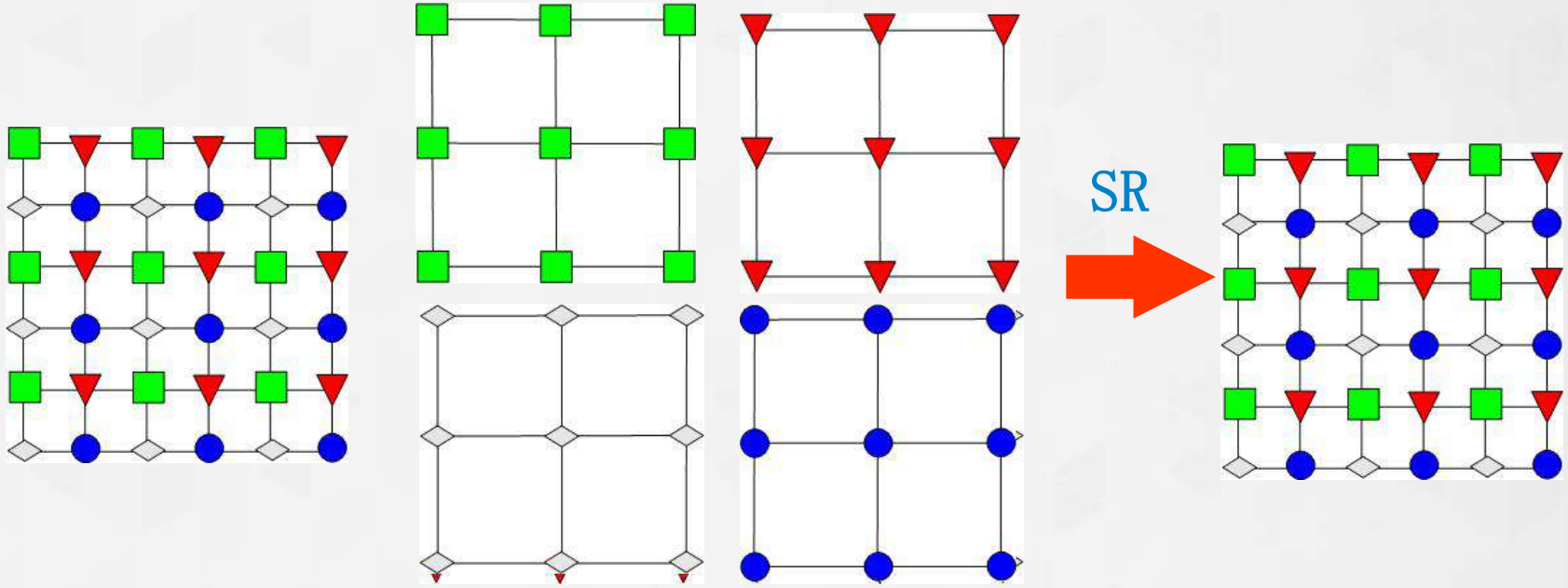
$$\lambda F_{\#} /p<2$$

卫星	$F_{\#}$	像元尺寸p （μm）	$\lambda F_{\#} /p$
GF-4	10	9	0.67



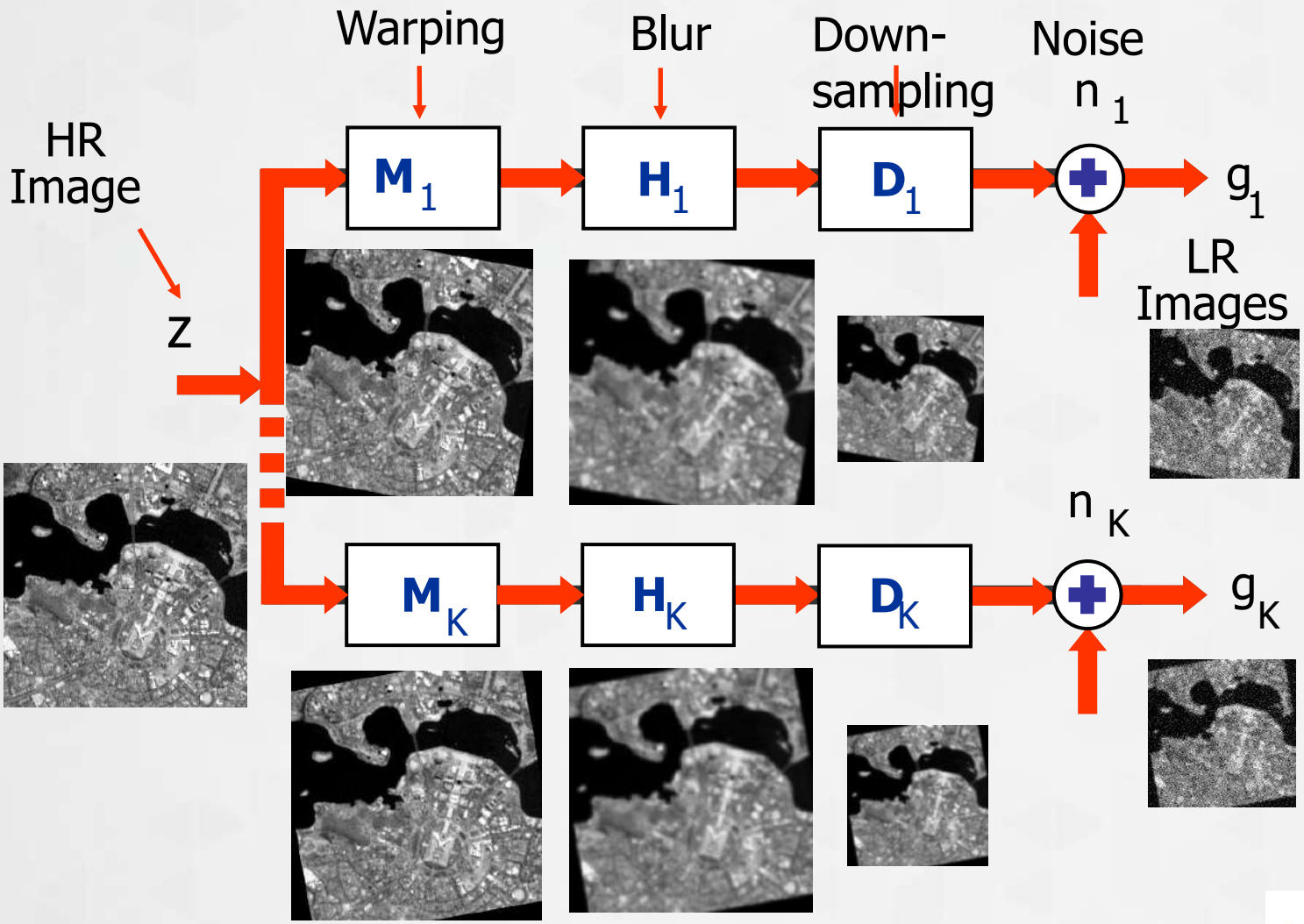
2 Super Resolution(SR)

SR: restoring a high spatial resolution image from a series of low resolution images of the same scene



- Make full use of remote sensing resources in orbit or in disk;
- Lower the cost for the future optical remote sensing satellites;

3 Group Sparse Representations based SR



Imaging Procedure

$$\left\{ g_i = D_i H_i M_i z + n_i \right\}_{i=1}^{K}$$

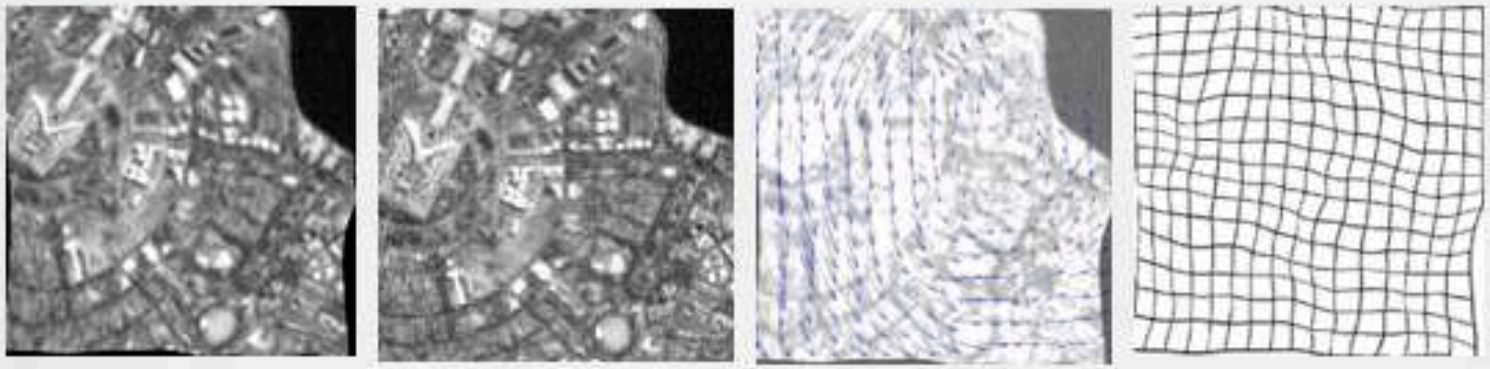
$$\left\{ g_i \right\}_{i=1}^{K} \rightarrow z \quad ?$$

ill-posed problem

Group Sparse Representations (GSR) is proposed for solving ill-conditioned problem SR, GSR is regarded as a prior for Maximum a Posterior

$$\min \{\lambda_1 \|\mathrm{W}\mathbf{z}_w\|_1 + \lambda_2 \|\mathrm{C}(\mathbf{z}_c)\|_1 + \lambda_3 \|(\mathbf{z}_s)\|_1\}$$
$$s.t.\ \|\mathbf{g}_i - \mathrm{D}\mathrm{H}_i\mathrm{M}_i\mathbf{z}\|_2 \leq \delta_i,\ \ i = 1, \cdots, K$$

Registration is an important step in SR, an elastic registration is proposed;



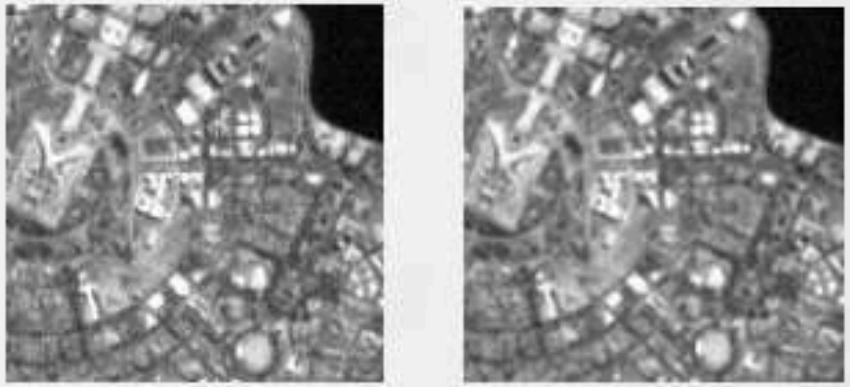
Local warps inevitable caused by air turbulence and platform vibrations;

Before

After

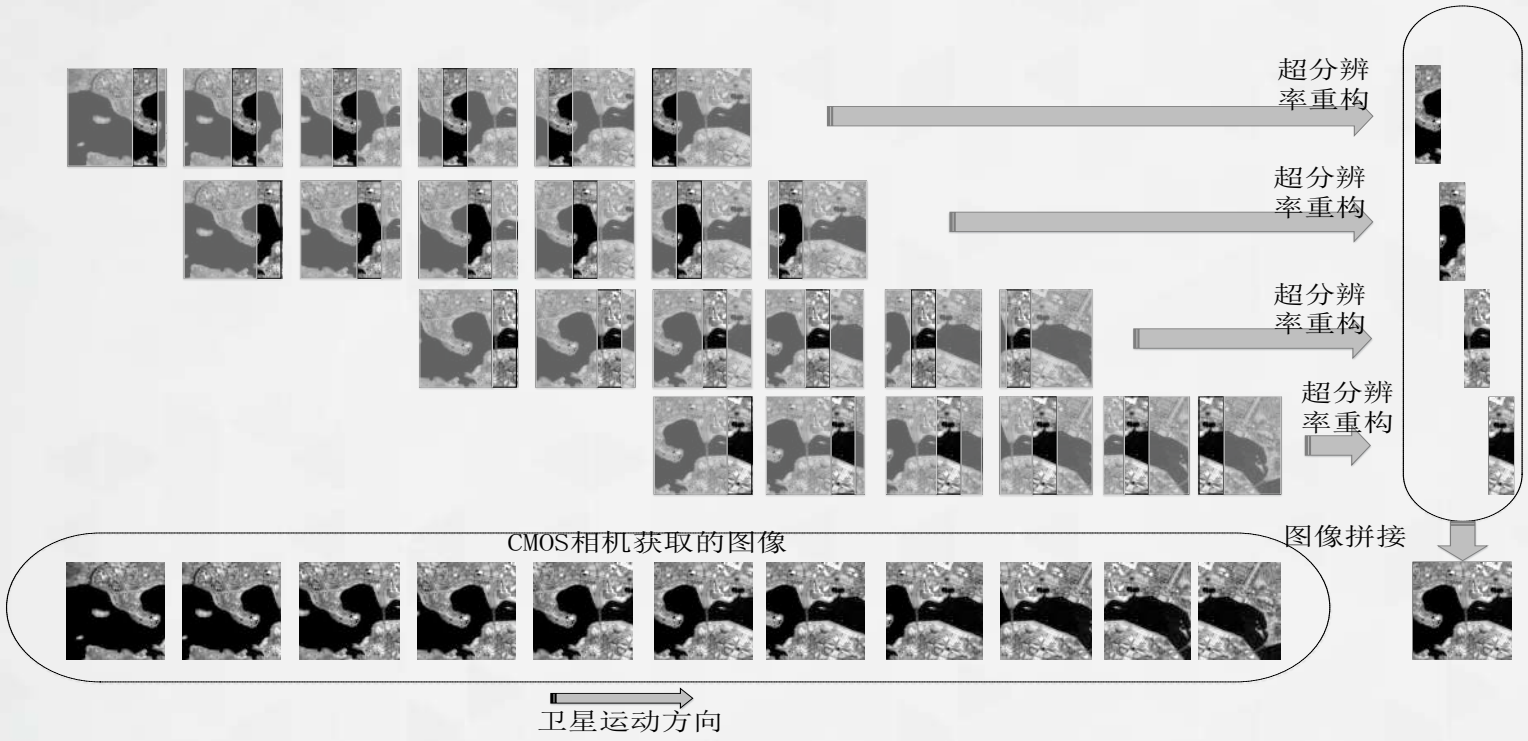
Before

After

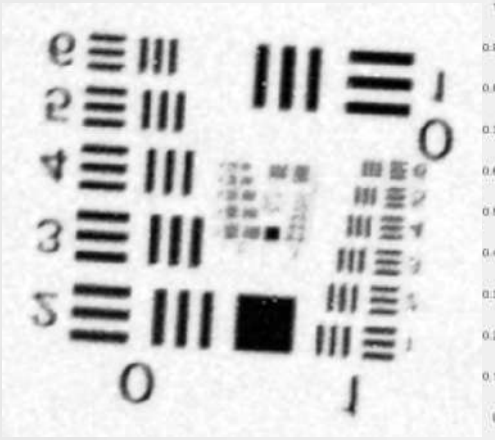


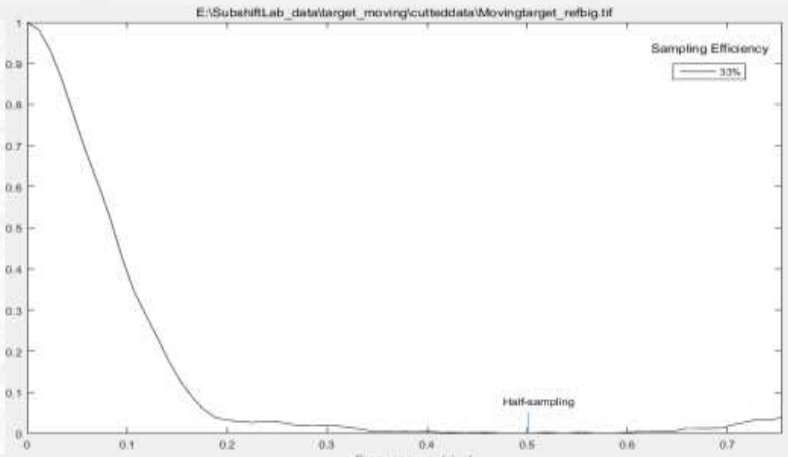
Before

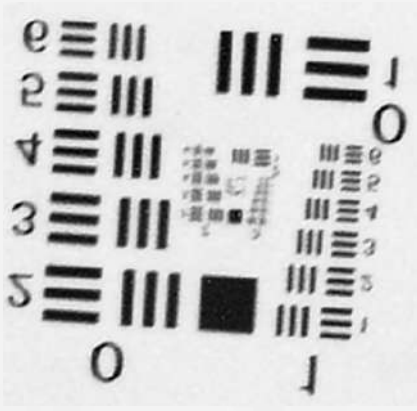
After

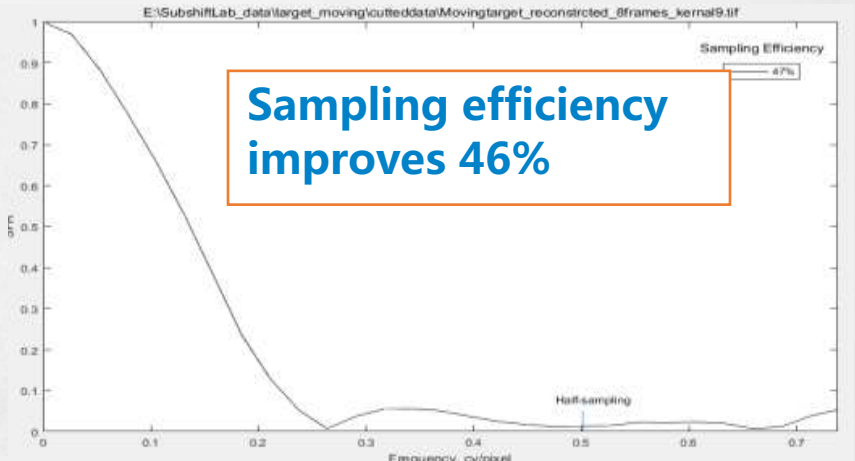


Moving target









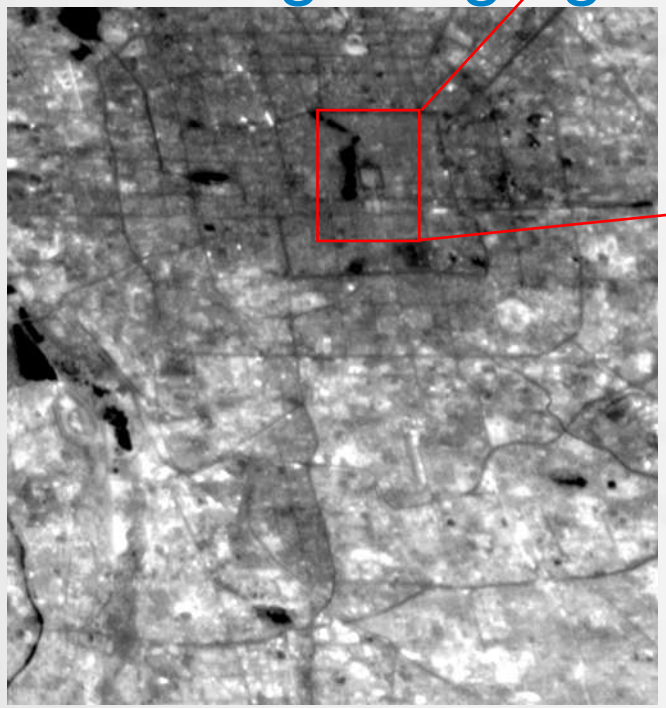
Sampling efficiency improves 46%

4 Experiments with GaoFen-4

Advantages：

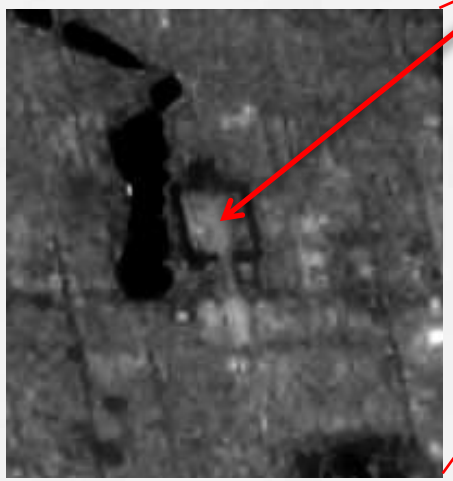
- High tempal resolution
- CMOS array
- Geo-stationary
- Staring imaging

Panchromatic band test

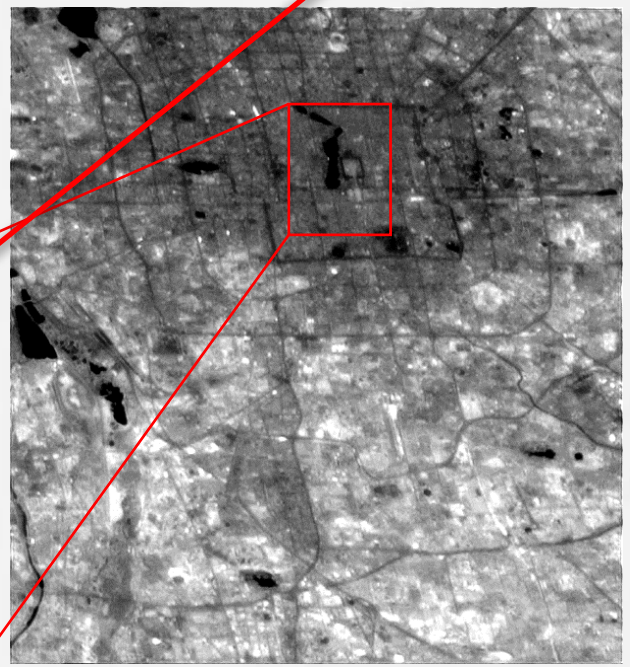


Original

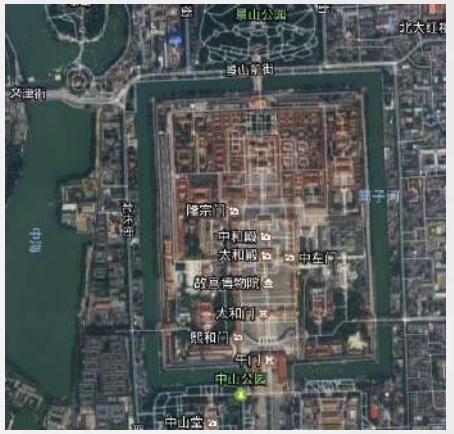
Forbidden city



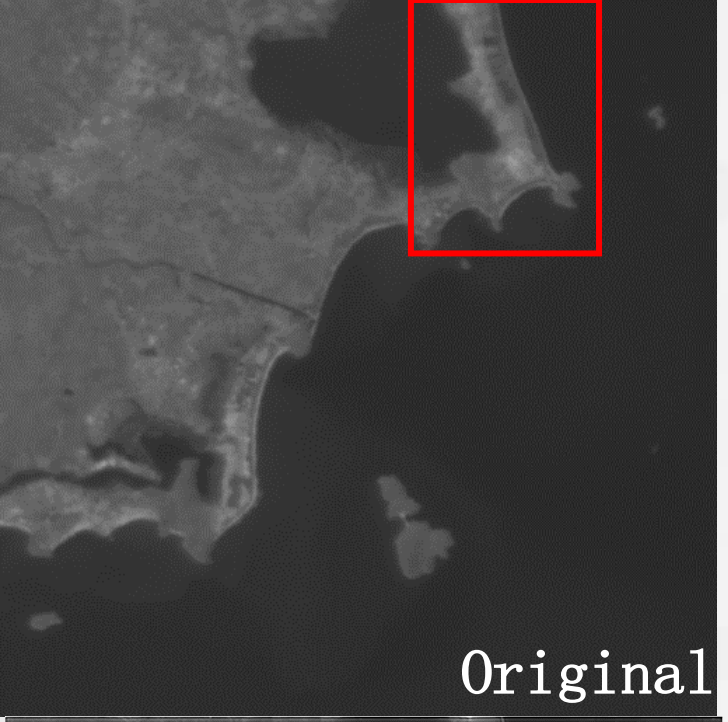
Beijing, 3 frames within 2days



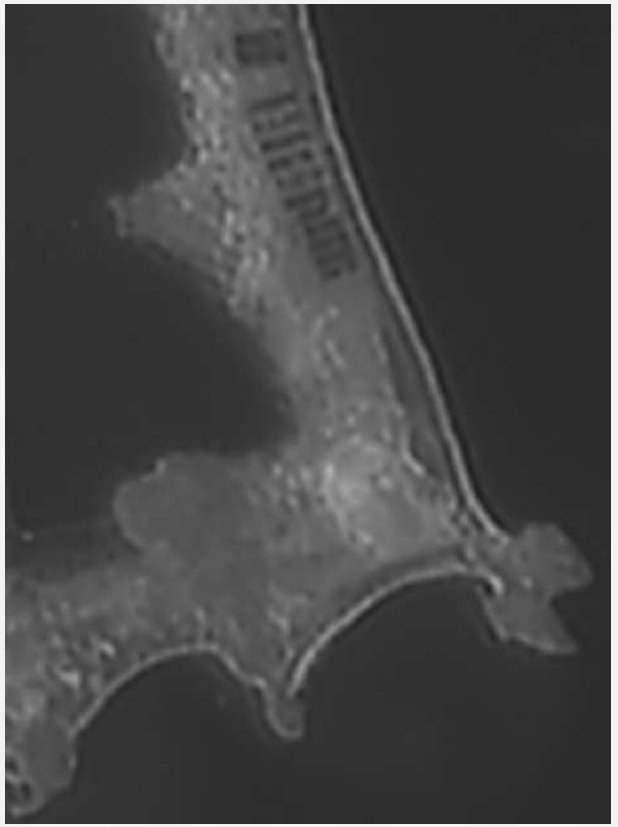
SR (2X GSD)



Panchromatic band test



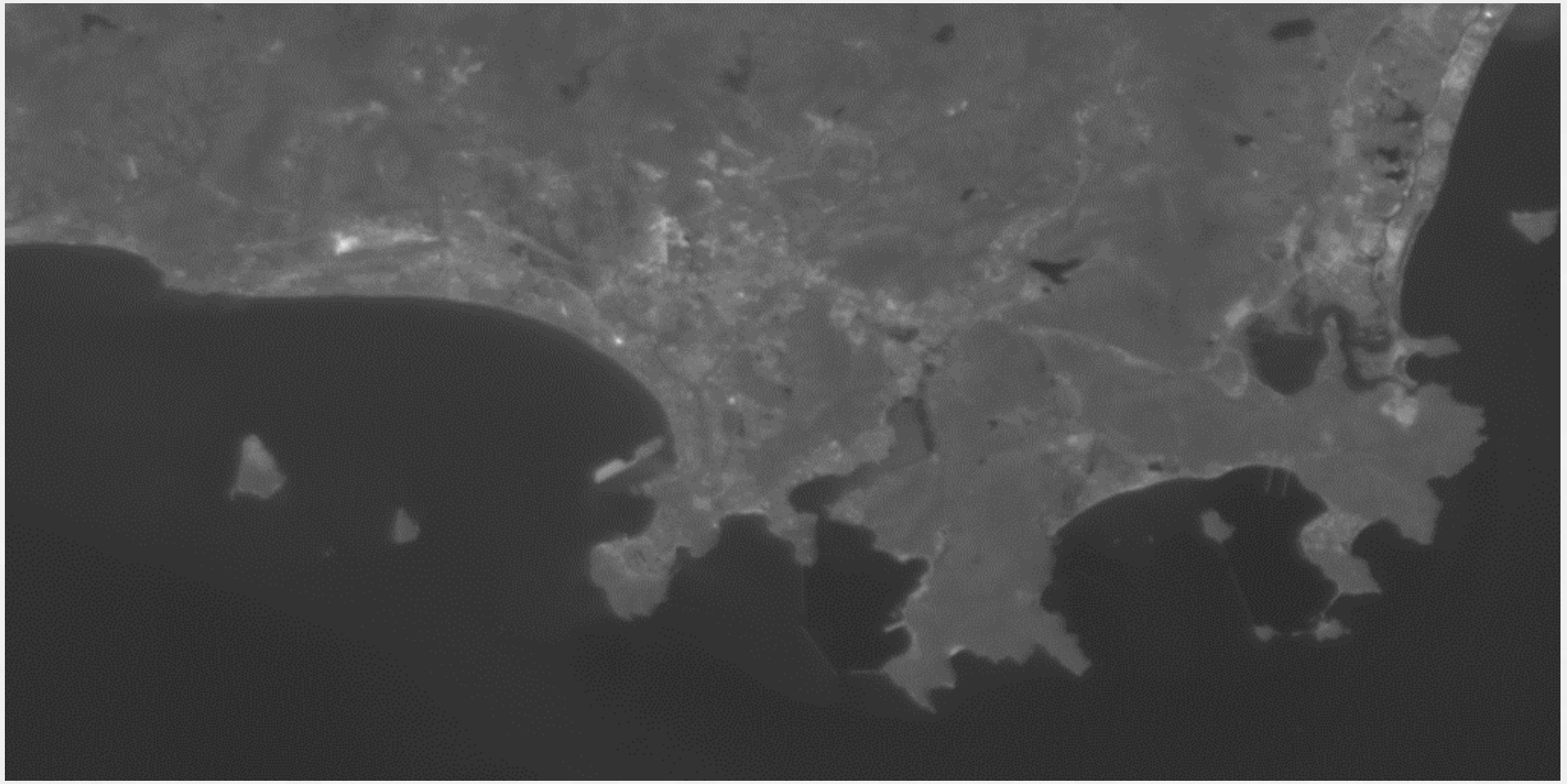
Original



SR

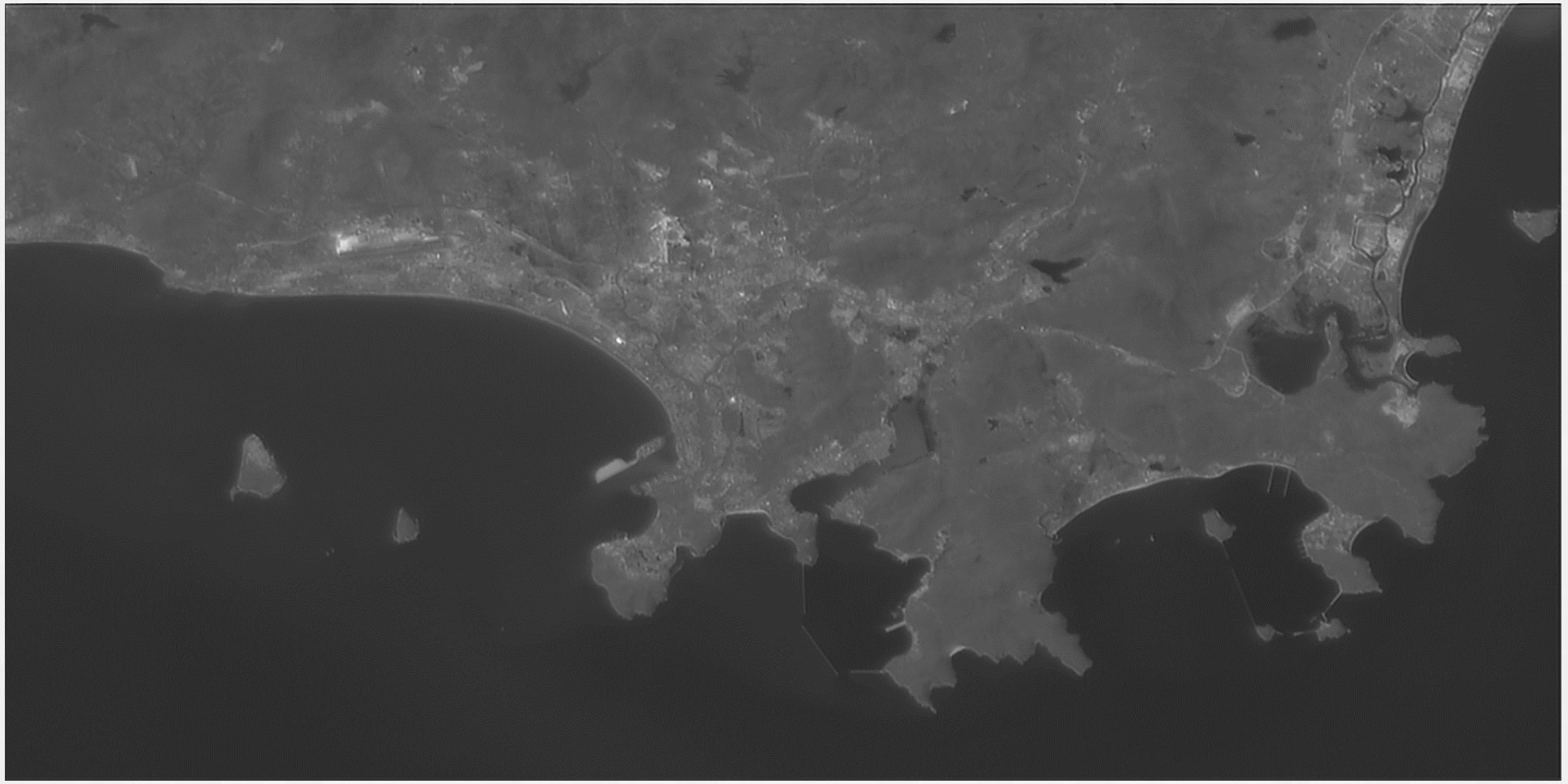
Google Earth

Wanning, Hainan Provience, 7frames on 26 Aug, 2016



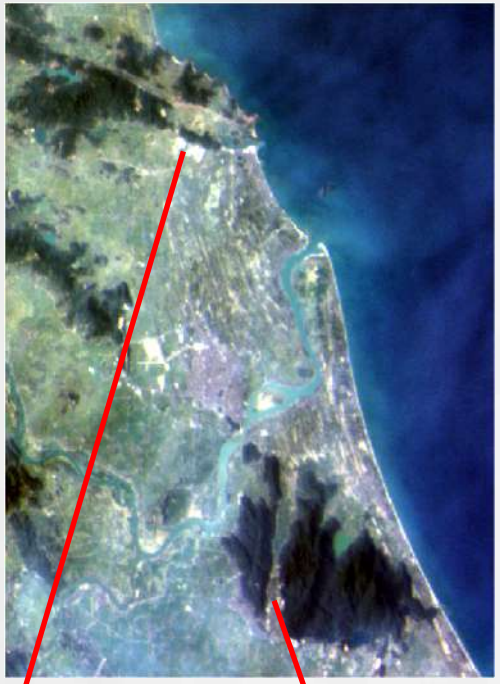
South of Hainan

Original

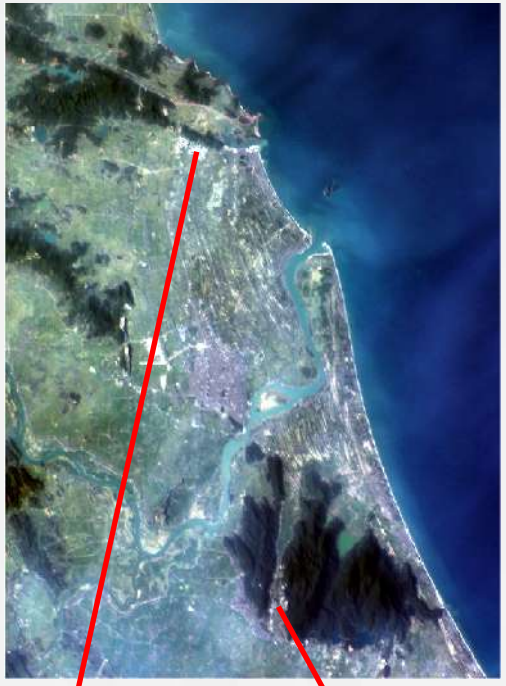


South of Hainan

SR

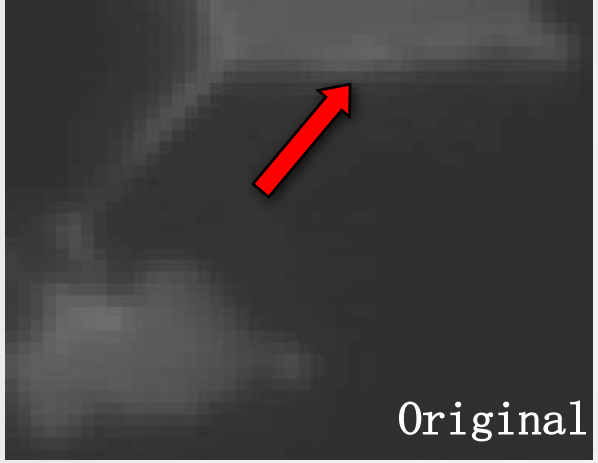


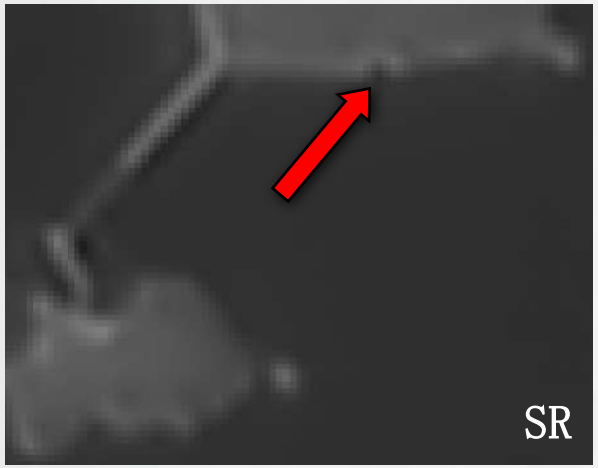
GF-4， Source Image

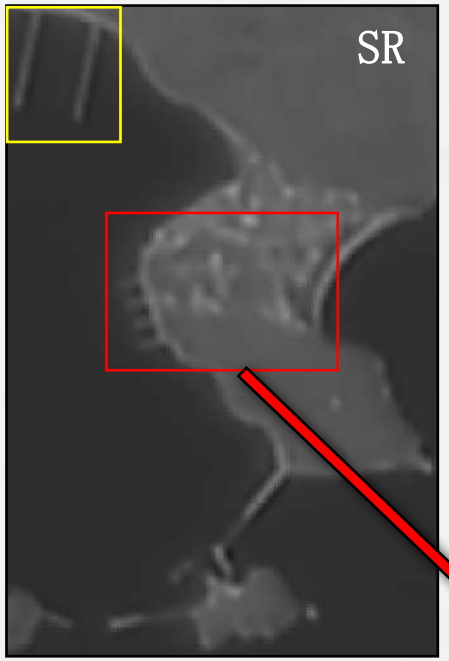


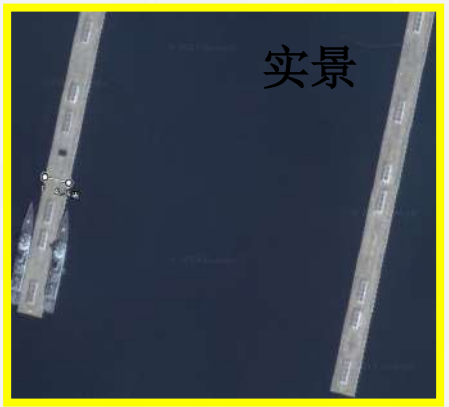
GF-4， super-resolution

Vietnam, 2018-03-04
12 images within minutes

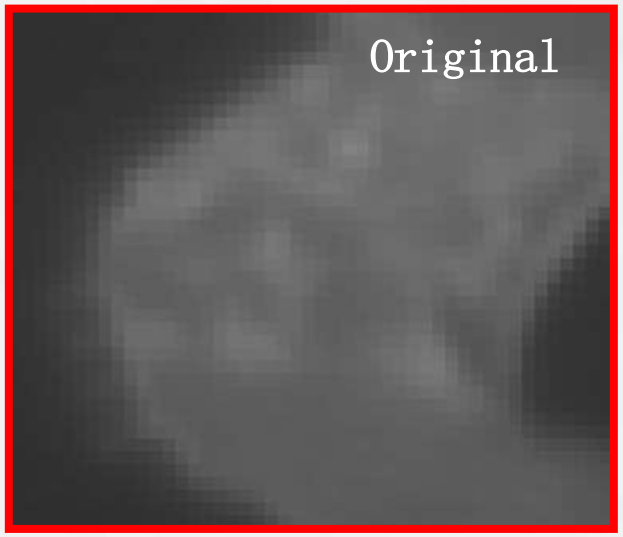


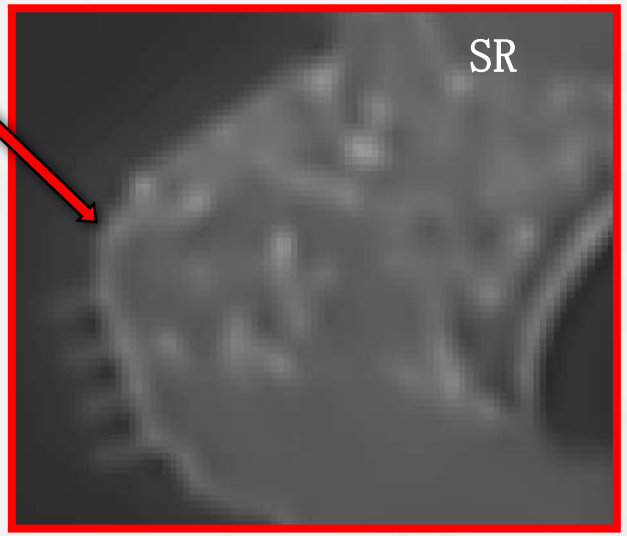






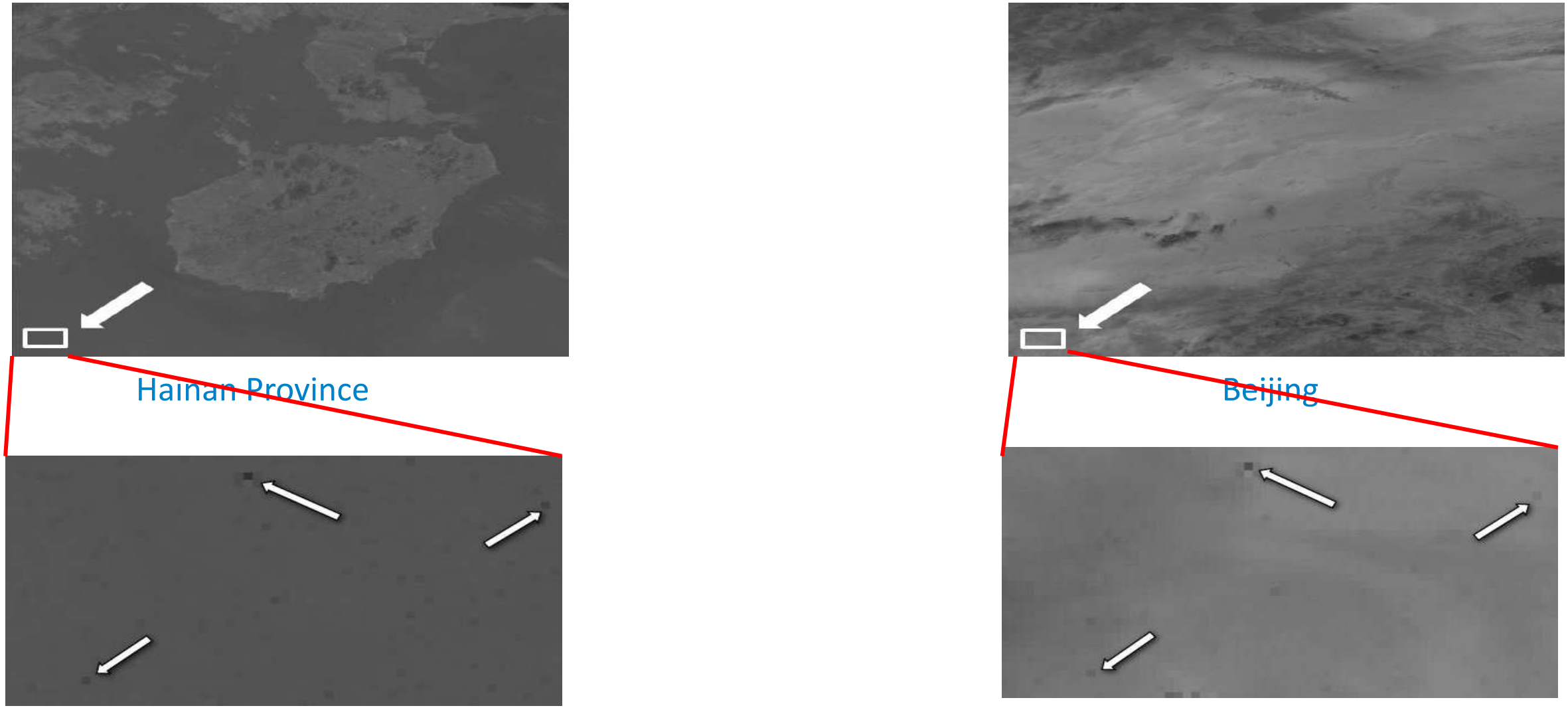
SanYa, Hainan





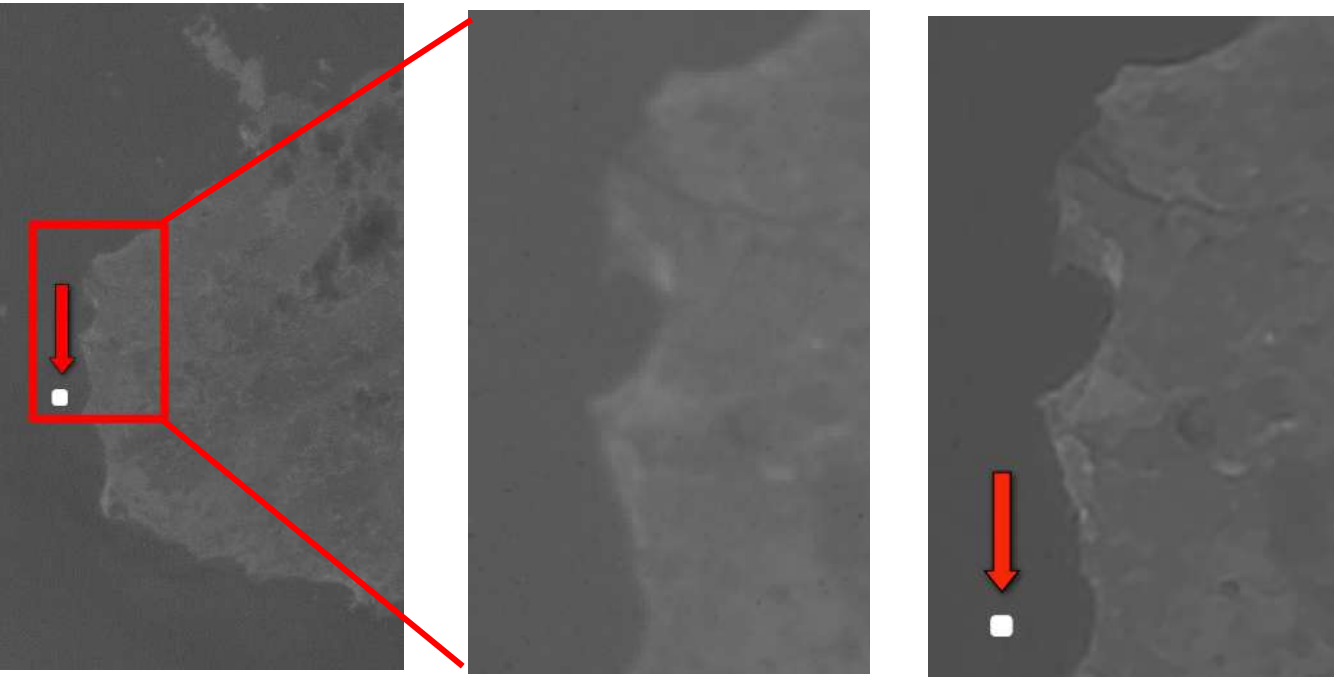
Google Earth

Mid-wavelength infrared test



Different scenes contain similar noise pattern

Mid-wavelength infrared test(1)



One LR from Datacube

Interpolated the red box

The super resolved red box

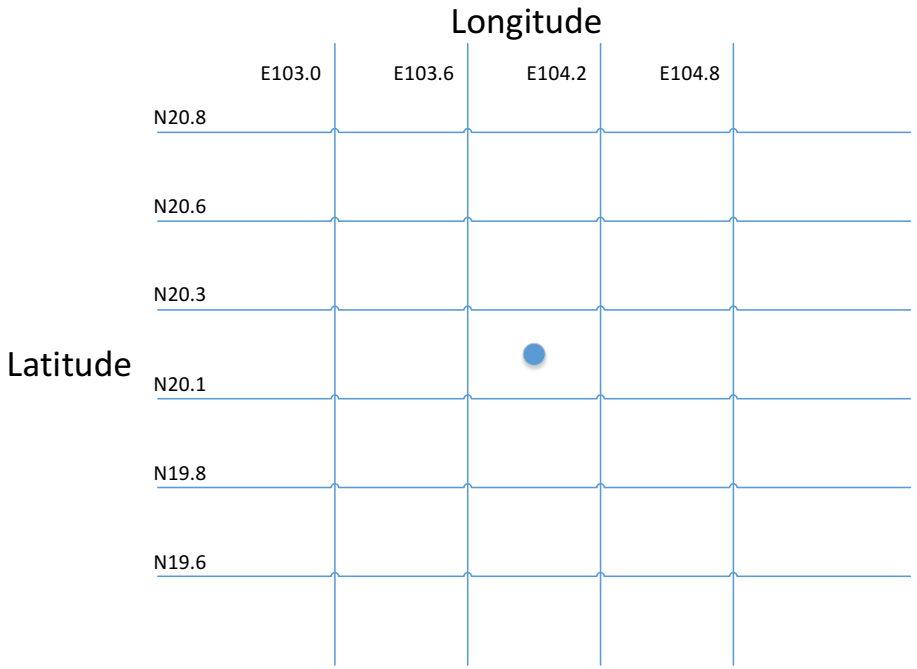
Temperature retrieved from the SR image is more reliable.

27.7	27.5	27.4	27.3	27.3	27.3	27.4	27.4	27.6	27.6
27.6	27.5	27.4	27.4	27.4	27.4	27.4	27.5	27.5	27.6
27.6	27.5	27.5	27.5	27.4	27.5	27.4	27.4	27.5	27.5
27.5	27.5	27.5	27.5	27.5	27.4	27.4	27.3	27.3	27.4
27.5	27.5	27.5	27.5	27.5	27.4	27.3	27.3	27.2	27.2
27.5	27.5	27.5	27.5	27.5	27.4	27.3	27.2	27.1	27.1
27.6	27.5	27.5	27.5	27.4	27.4	27.2	27.1	27.0	27.0
27.6	27.6	27.5	27.5	27.4	27.3	27.2	27.1	27.0	27.0
27.7	27.6	27.5	27.4	27.3	27.2	27.1	27.0	27.1	27.1
27.6	27.5	27.4	27.3	27.2	27.1	27.0	27.0	27.2	27.3

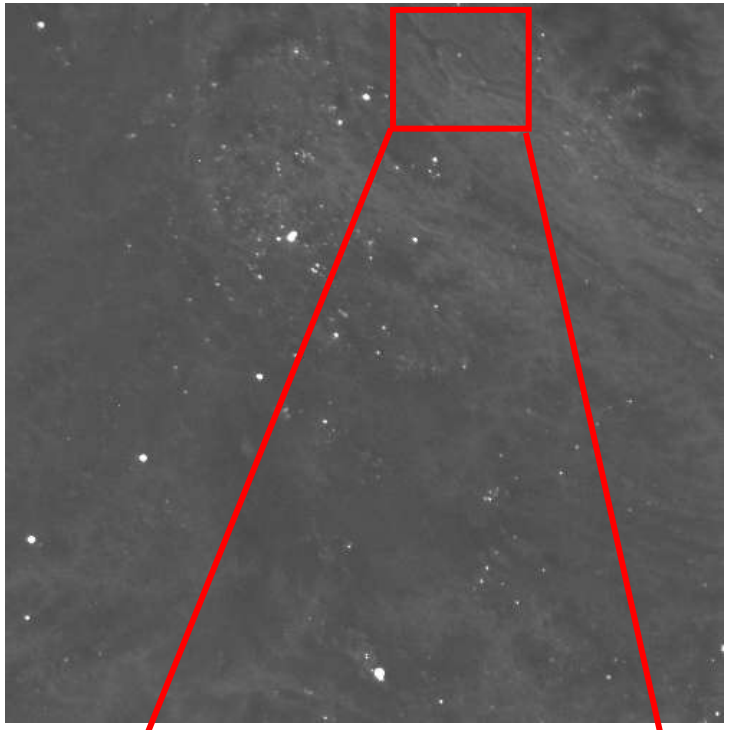
Two neighbor pixels' sea temperature (within 800 meters) are not suppose to have over 4℃ difference.

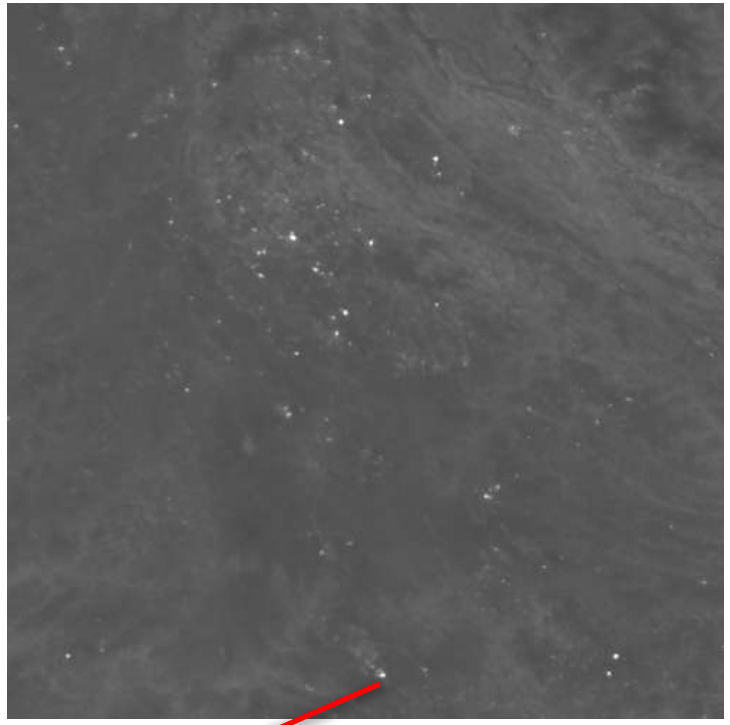
28.2	28.3	25.7	28.0	27.3
[illegible]	28.1	26.9	27.5	27.8
28.0	23.9	26.5	27.8	27.3
28.0	27.7	28.1	28.0	27.7
27.8	27.6	27.6	27.1	27.3

Mid-wavelength infred test(2)



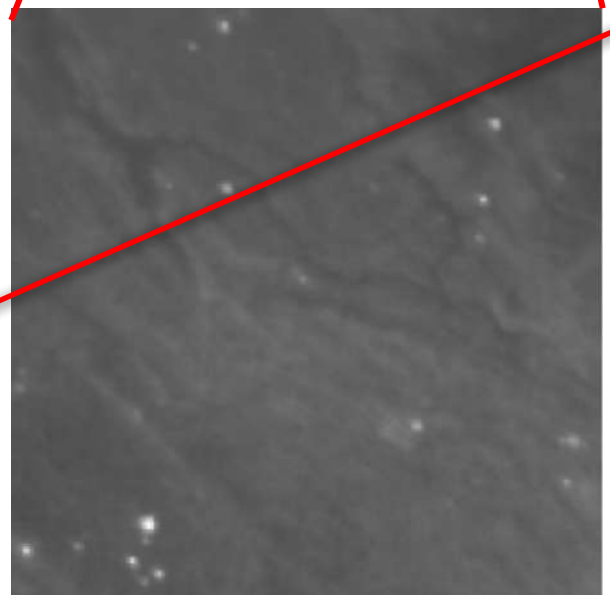
Central area locates the border of Vietnam and Laos

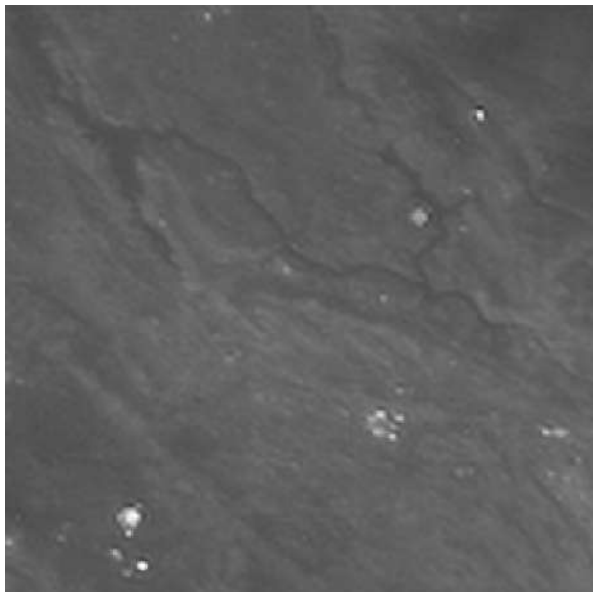




37 frames within about 1 hour
2018-03-04 14:30:01~15:25:21

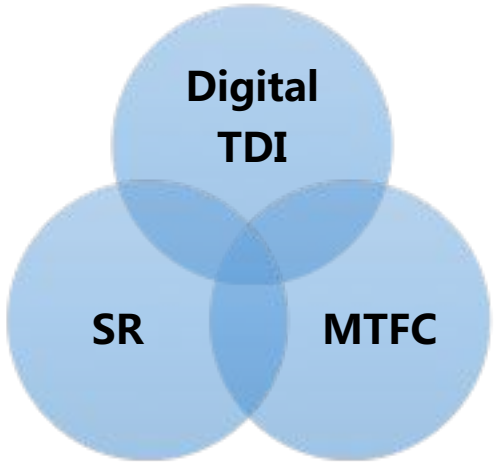
Data fusion along time series





5 Conclusions

- SR benifits：Detection，Measure，Sub-pixel classification……
- SR reconstruction is possible, but … not always! (needs aliasing, accurate image registration, enough frames, …).
- Make full use of remote sensing resources in orbit or in disk; decrease the cost for the future optical remote sensing satellites
- Airborn based CMOS cameras bring hopes……
  - ➢Digital Time Delay Integration(TDI)
  - ➢Super Resolution
  - ➢Modulation Transfer Function Compensation (MTF)



5 Relevant publications

Journal Papers:

[1] **F. Li**, L. Xin, Y. Guo, D Gao, X. Kong, X. Jia, Super Resolution for GaoFen-4 Remote Sensing Images, IEEE Geoscience and Remote Sensing Letters, Volume: 15 Issue: 1, 2018

[2] **F. Li**, L. Xin, Y. Guo, J. Gao, and X. Jia, A Framework of Mixed Sparse Representations for Remote Sensing Images, IEEE Transactions on Geoscience and Remote Sensing, Volume: 55, Issue: 2, Pages: 1210 - 1221, 2017

[3]Y. Guo, J.B. Gao, **F. Li** , Random Spatial Subspace Clustering, Knowledge-Based Systems, Vol 74, pp 106-118, 2015

[4] **F. Li**, C. Li, L Tang, Y.Guo, Elastic registration for airborne multispectral line scanners, J. Appl. Remote Sens., 8(1), 083614 (2014)

[5] Y. Guo, J.B. Gao, **F. Li** , Spatial subspace clustering for drill hole spectral data. J.Appl. Remote Sens. 8 (1), 083644 (April 28, 2014); doi: 10.1117/1.JRS.8.083644

[6] **F. Li**, S.Brown, T.Cornwell, and F. De Hoog. The Application of Compressive Sampling to Radio Astronomy II: Faraday Rotation Measure Synthesis, Astronomy & Astrophysics, Vol 531, 2011

[7] **F. Li**, T.Cornwell, and F. De Hoog. The Application of Compressive Sampling to Radio Astronomy I: Deconvolution, Astronomy & Astrophysics, Vol 528, 2011

[8] **F. Li**, X. Jia, D. Fraser and A. Lambert. Super resolution for remote sensing images based on a universal hidden Markov tree model. IEEE Transactions on Geoscience and Remote Sensing, Vol 48, Issue: 3, Pages: 1270-1278, 2010.

[9]**F. Li**, X. Jia, and D. Fraser. Super resolution reconstruction of multi-spectral data for improved image Classification. IEEE Geoscience and Remote Sensing Letters, Vol 6, Issue: 4, Pages: 689-693, 2009.

[10]**F. Li,** D. Fraser and X. Jia. Improved IBP for Super-resolving Remote Sensing Images. CPGIS, Vol.12, No.2, Pages 106-111 , 2006

Books：

[1]《Introduction of Compressive Sensing》 **Feng Li**、Yi Guo， ISBN：978-7-03-045748-6，Science China Press, 2015

[2]**Feng Li**，Xiuping Jia, Donald Fraser, Andrew Lambert, ” Super resolution for multispectral image classification” , in the book “Image Restoration: Fundamentals and Advances”, ISBN-13: 978-1439869550, Taylor and Francis, 2012

Patents：

[1]Group **Group Sparse Representations based super resolution** ，201610032463.5, **Feng Li**，Lei Xin，Kun Zhan，Granted