Validation and Performance Assessment of the Chinese First Multi-angle Polarimetric Satellite Sensor DPC/GF-5

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China National Space Administratives

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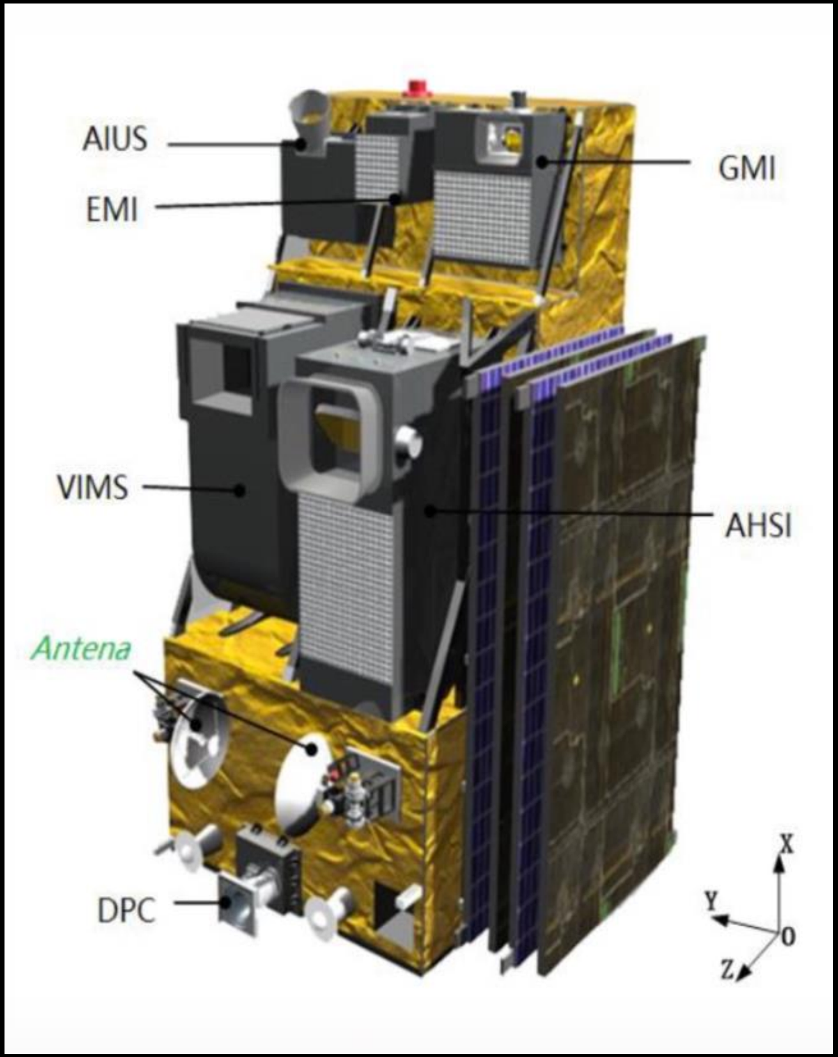
Contents

GF-5: Flagship Satellite of GaoFen Program



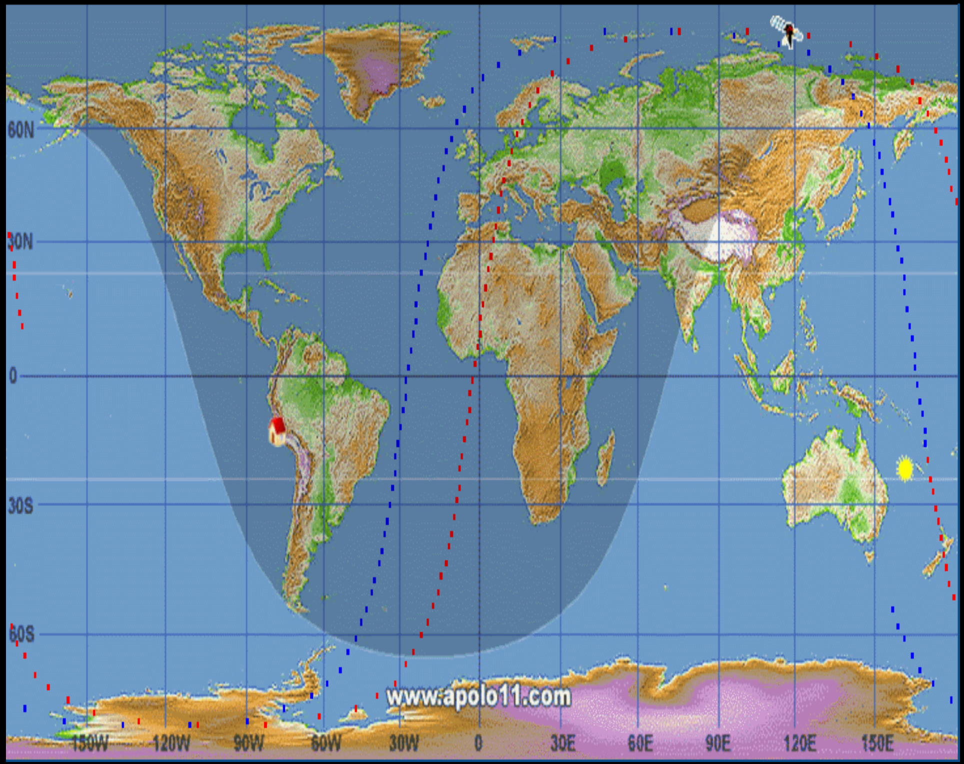
Six payloads onboard GF-5:

- ✓ Advanced Hyperspectral Imager (AHSI)
- ✓ Visual and Infrared Multispectral Sensor (VIMS)
- ✓ Greenhouse-gases Monitoring Instrument (GMI)
- ✓ Environment Monitoring Instrument (EMI)
- ✓ Directional Polarization Camera (DPC)
- ✓ Atmospheric Infrared Ultra- spectral Senor (AIUS)

https://doi.org/10.1016/j.jqsrt.2018.07.003

Launched successfully on 9th May, 2018

Overpass time: ~13:30 local time

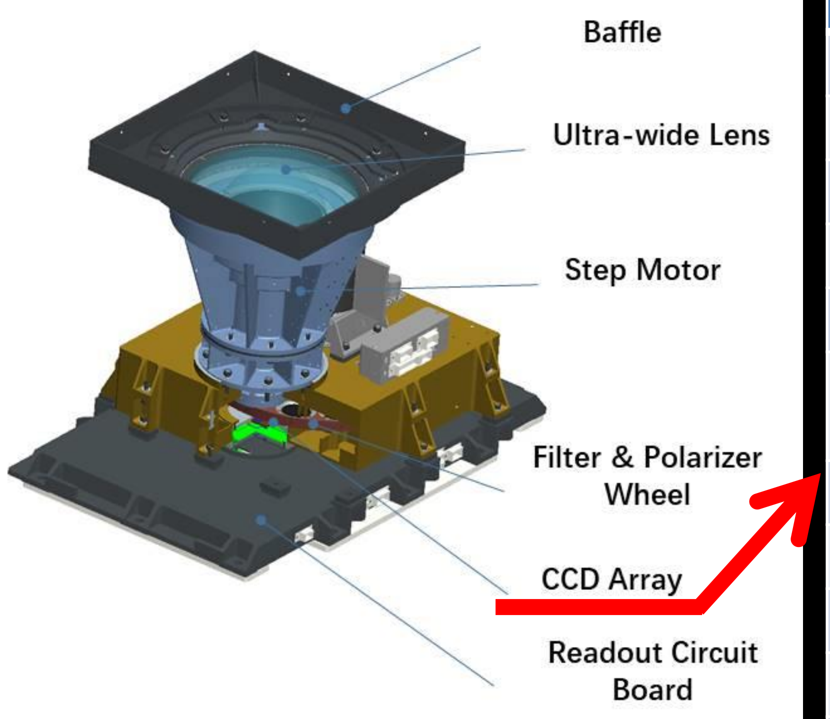


GF-5 satellite orbital map
(Revisit: 2 days)

Directional Polarization Camera (DPC)

DPC is designed to detect the properties of aerosol, cloud, water vapor as well as ocean and land properties.

Optical head of DPC/GF-5



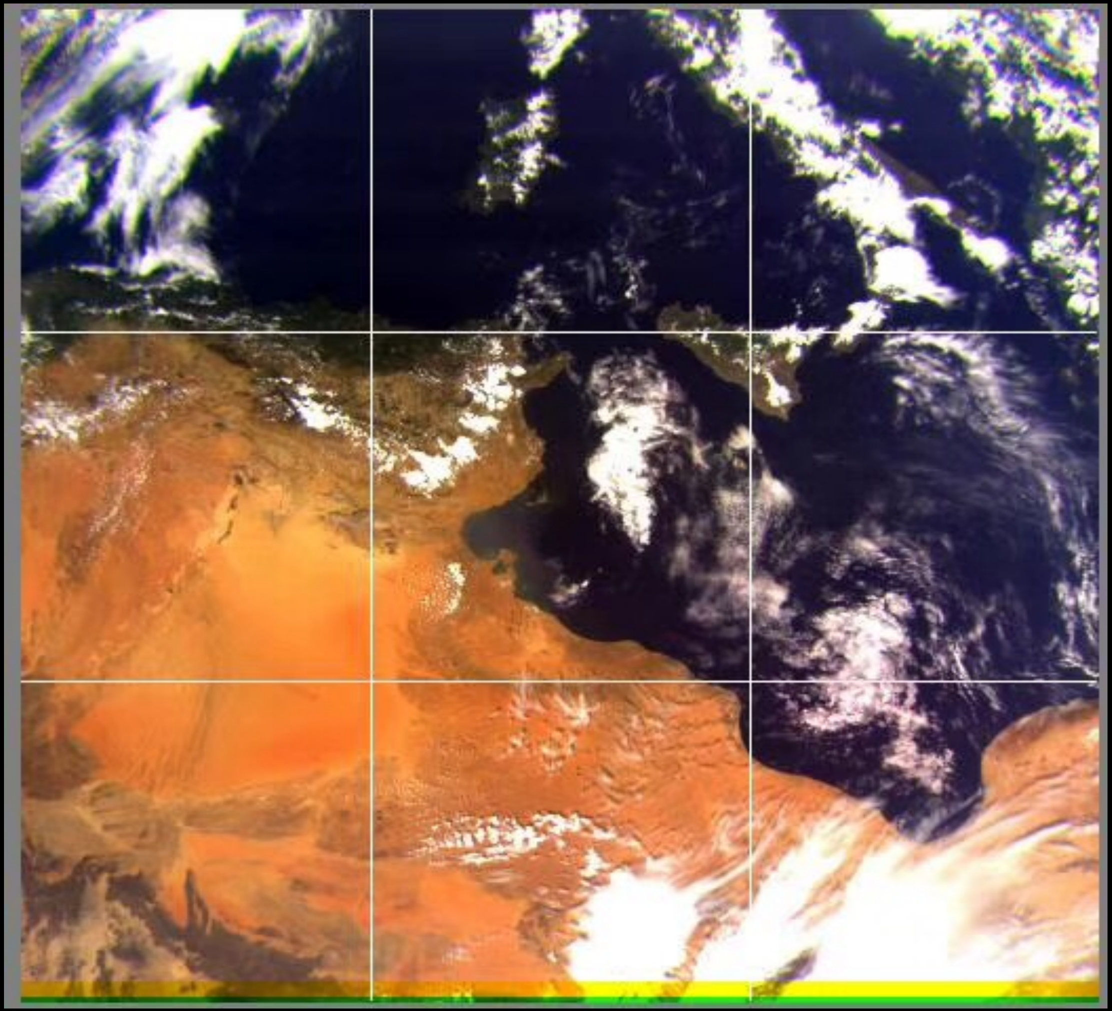
Band & polarization configuration

Parameter	Value
Instrument FOV	$\pm 50^\circ$ (across/along-track)
Spatial res. (km)	3.3
Swath width (km)	1850
Multi-angle	≥ 9
Image pixels	512×512
Spectral band (nm): P for polarization	443, 490 (P), 565, 670 (P), 763, 765, 865 (P), 910
Polarized angle	0°, 60°, 120°
Stokes parameters	I, Q, U
Rad. Cal. Error	$\leq 5\%$
Pol. Cal. Error	≤ 0.02
Band width (nm)	20, 20, 20, 20, 10, 40, 40, 20

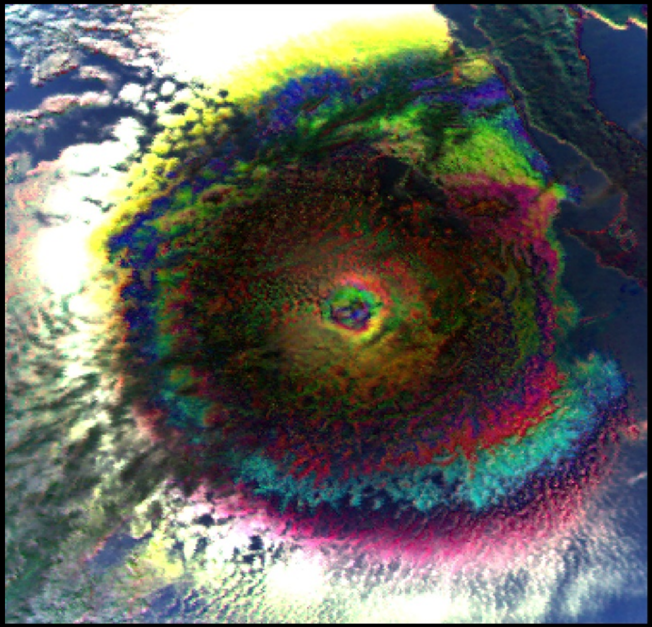
Li, Hou et al., JQSRT, 2018, doi: 10.1016/j.jqsrt.2018.07.003

First Image of DPC — 10th May, 2018

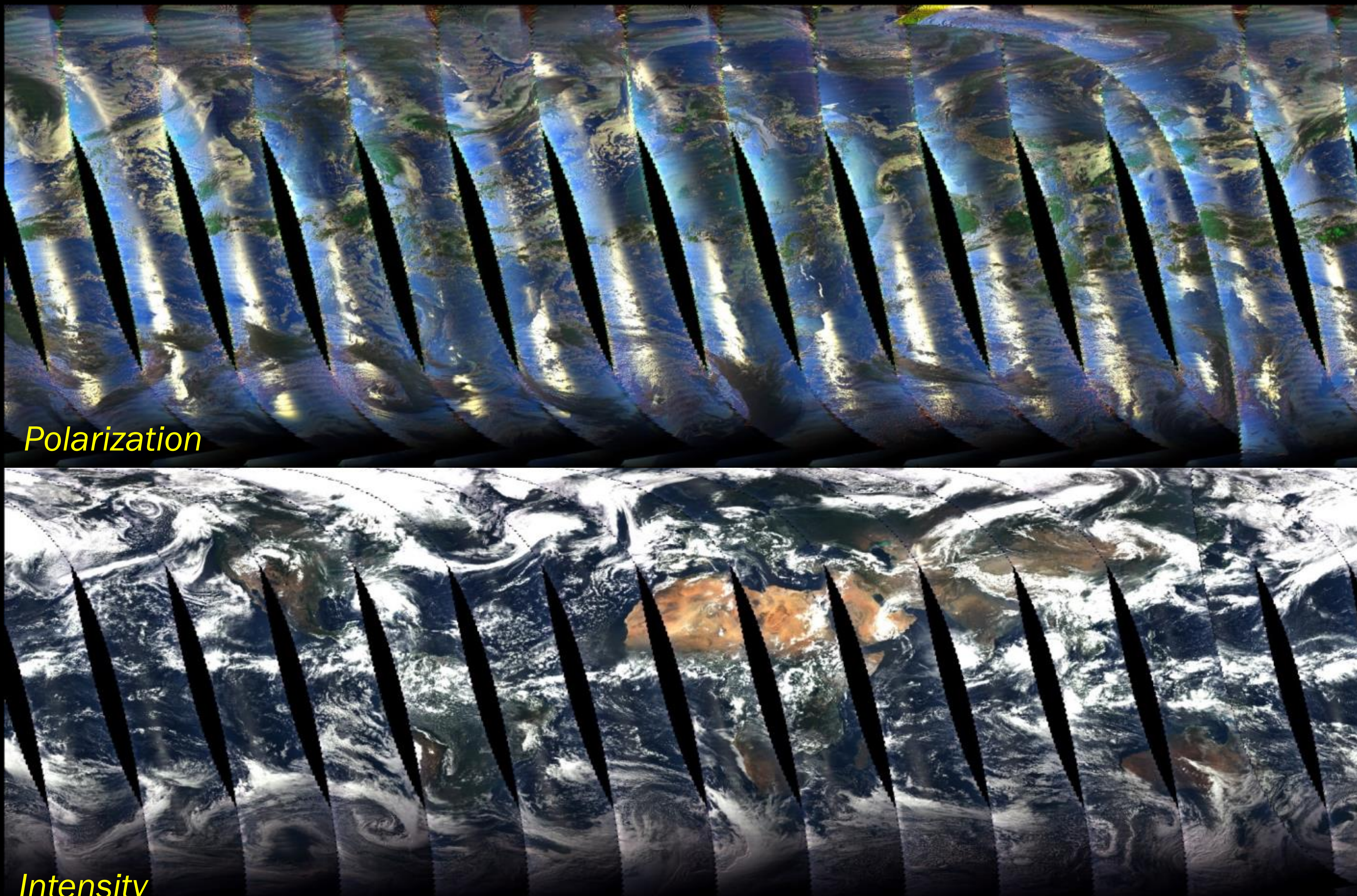
- True-color image of DPC (intensity) (North Africa - Mediterranean)



- Polarization image of the cloud rainbow (North America)



Global map on 27th May, 2018



Xie et al., Aerospace Shanghai, 2019, doi: 10.19328/j.cnki.1006-1630

Data products

Levels	Name	Description
Lev 0	Raw data	DN value
Lev 1	Radiance	Intensity reflectance (I) at TOA
Lev 1	Polarized Radiance	Stokes parameter (Q and U) at TOA
Lev 2	Cloud Mask	Cloud-cover index over land and ocean
Lev 2	AOD (Land)	Light extinction (optical depth) of total aerosol over cloud-free land
Lev 2	AOD_f (Land)	Light extinction (optical depth) of fine-mode aerosol over cloud-free land
Lev 2	AOD (Ocean)	Light extinction (optical depth) of total aerosol over cloud-free ocean
Lev 2	AOD_f (Ocean)	Light extinction (optical depth) of fine-mode aerosol over cloud-free ocean
Lev 2	Water vapor	Columnar mass concentration of water vapor (unit: g/cm^2)
Lev 2	Cloud Optical Depth	Light extinction (optical depth) of cloud
Lev 2	…	…

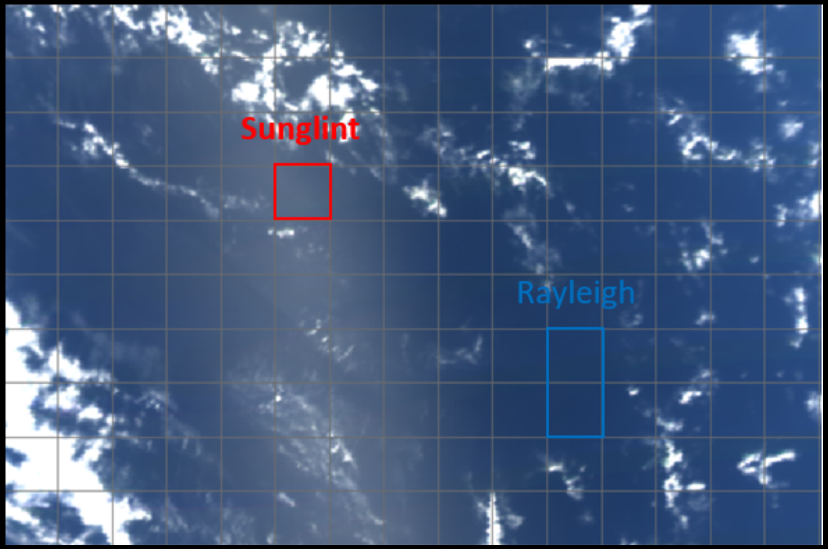
Contents

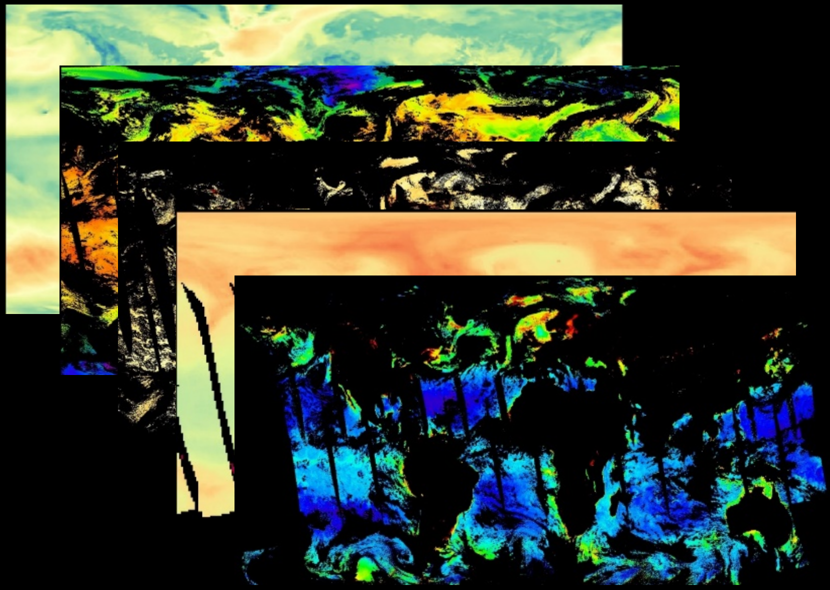
1. Introduction of the GF-5 mission
2. Validation of preliminary data products
3. Assessment of DPC scientific results
4. Future perspectives

2.1 Rayleigh Calibration over Ocean

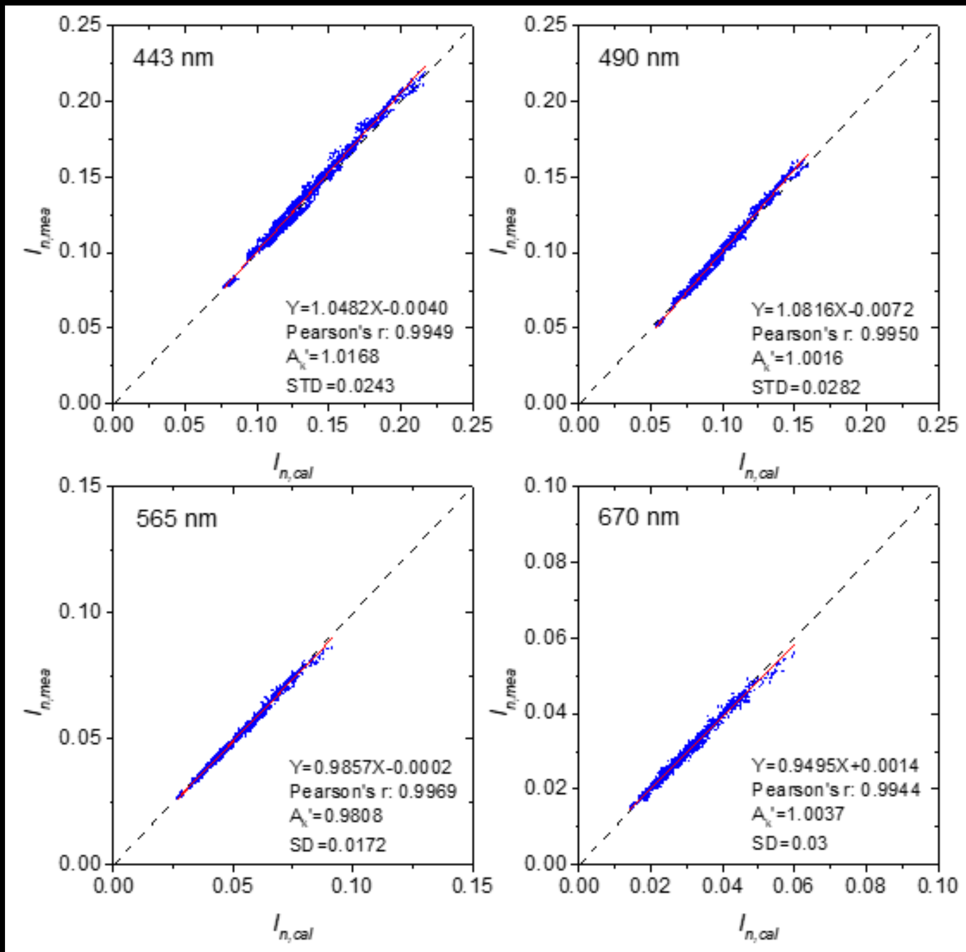
Method (In-orbit vicarious calibration):

- Selection of clean oceanic region
- Match of multiple data sources (AOD, O_3, chl, Wind, ...)
- Radiative transfer modeling of TOA radiance
- Calculation of calibration coefficients





Radiance Validation vs. Pre-launch



- Correlation coefficients of I_{meas} and I_{cal} at 4 short bands over 0.99
- Standard deviation (STD) less than 3%
- Calculated TOA radiances of Rayleigh scattering using 6S code have a great agreement with DPC measurements

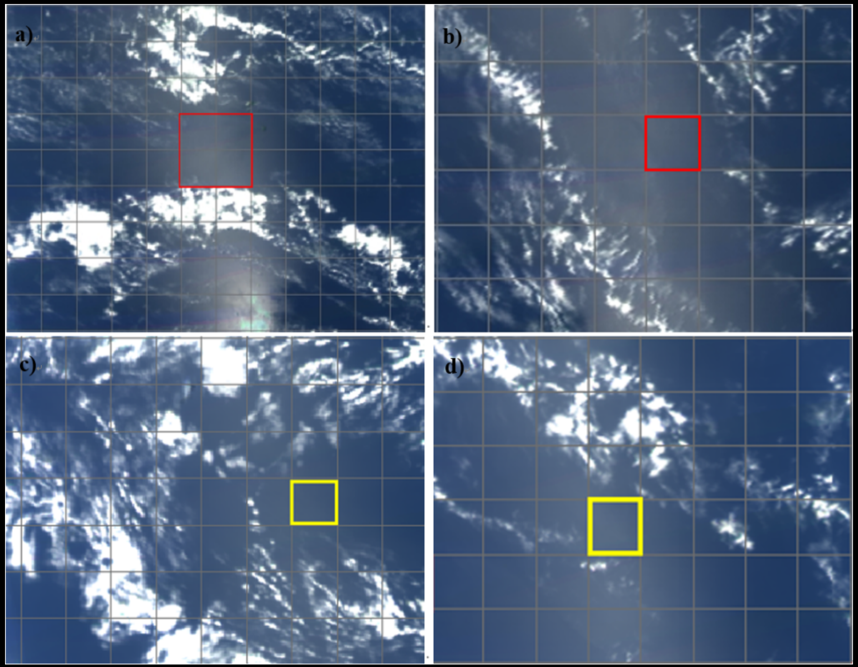
$$\mathrm{STD} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{I_{\mathrm{mea},i}}{I_{\mathrm{cal},i}} - A_k'\right)^2} \qquad A_k' = \frac{1}{N}\sum_{i=1}^{N}\frac{I_{mea,i}}{I_{cal,i}}$$

Qie et al., in preparation, 2019

2.2 Sunglint for Polarization Calibration

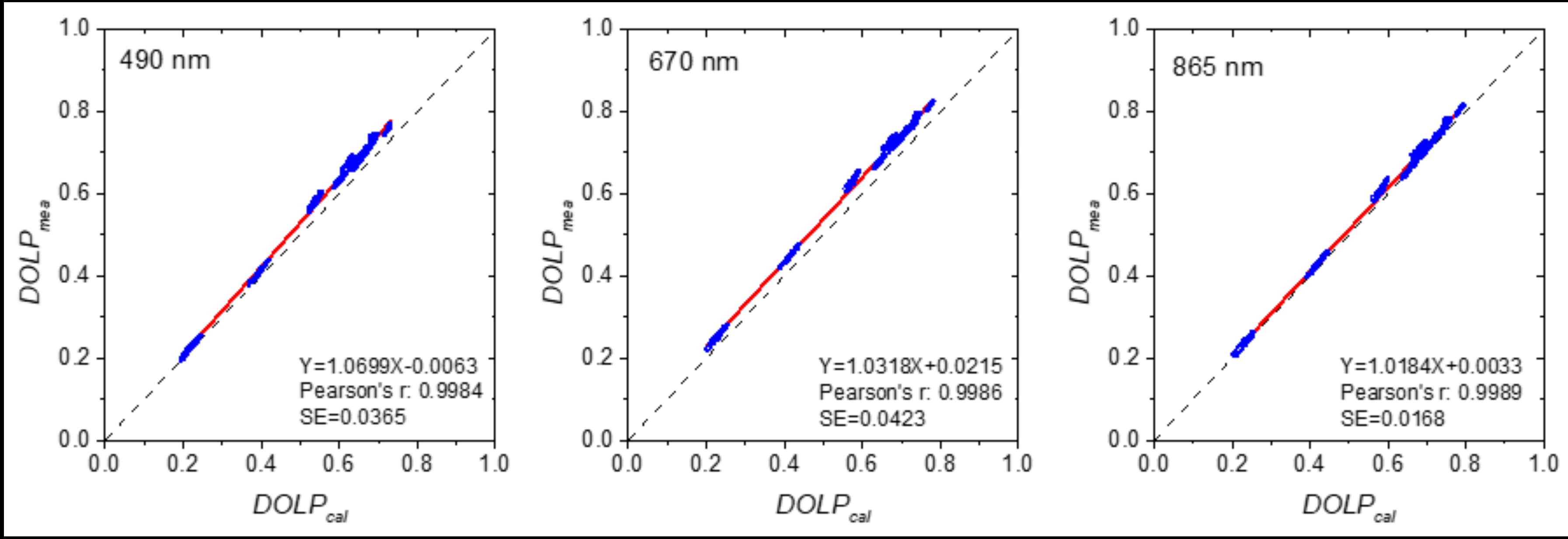
Method:

- Transfer coefficients of Rayleigh bands to longer bands (select a reference band, e.g. 565 nm)
- Selection of data (strict sunglint angle and WS condition)
- Radiative transfer calibration of sunglint region



Polarization Validation vs. Pre-launch

- Degree of Linear Polarization (DoLP) over sun-glint region changes from ~0.2 to ~0.8
- DoLP calculated at 3 bands (490, 670, 865) agrees with pre-launch calibration with linear slope varying from 1.02-1.07.

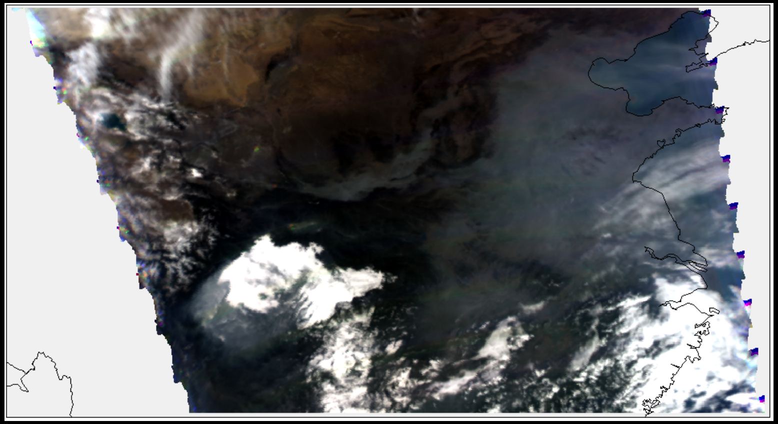


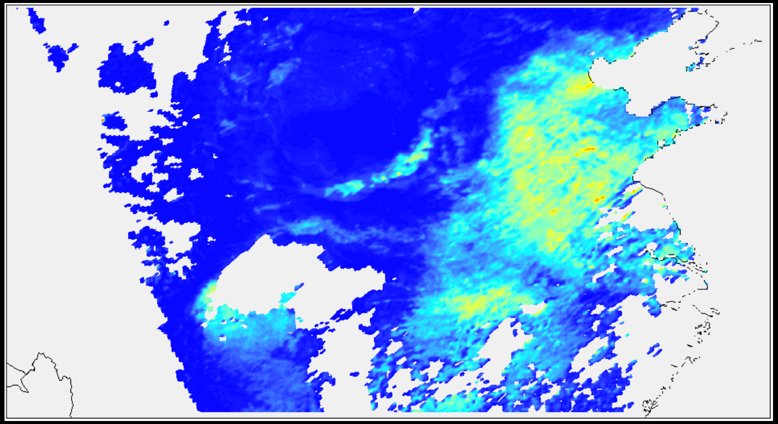
$$SE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(DOLP_{mea,i} - DOLP_{cal,i}\right)^2}$$

Qie et al., in preparation, 2019

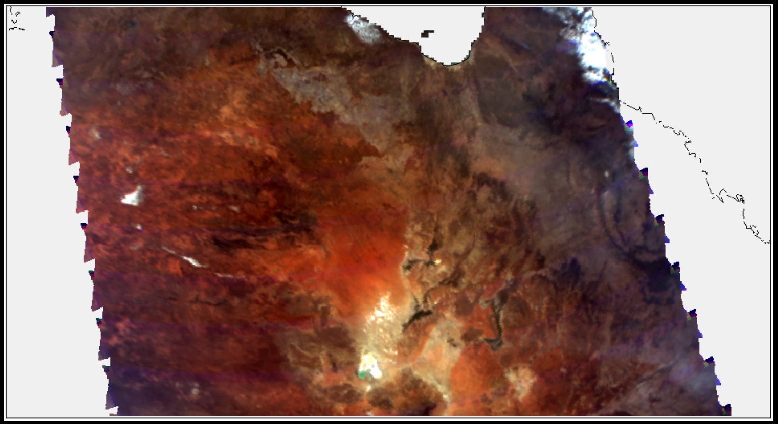
2.3 Retrieval of Fine Mode AOD (AODf)

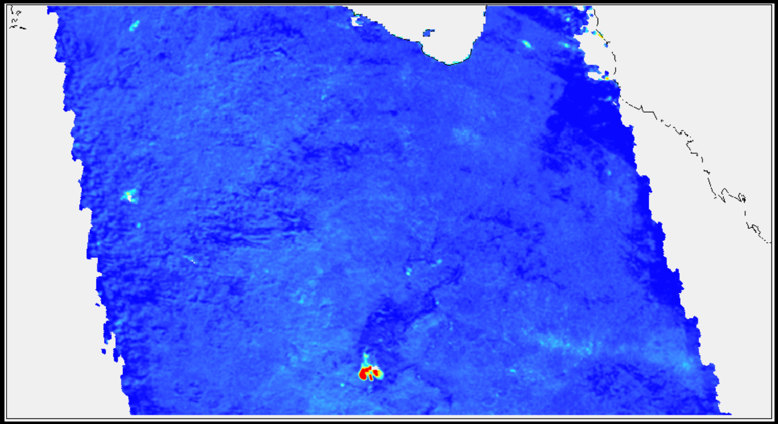
Polluted case over China

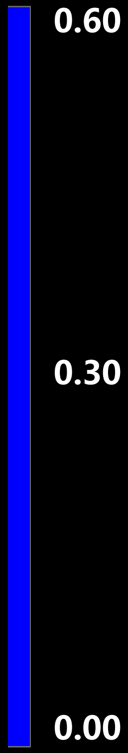




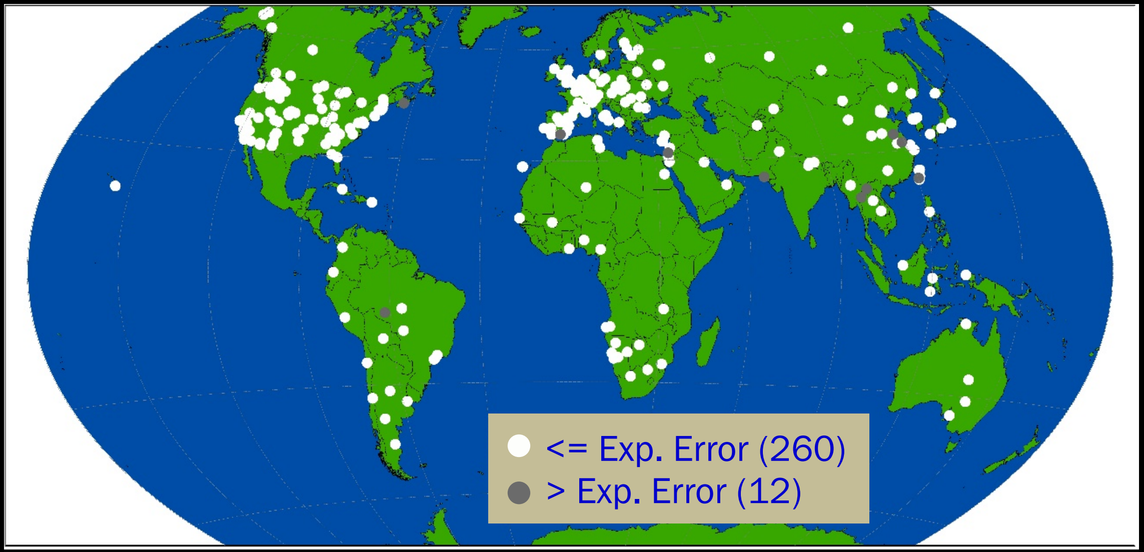
Clean case over Australia (Bright Surface)





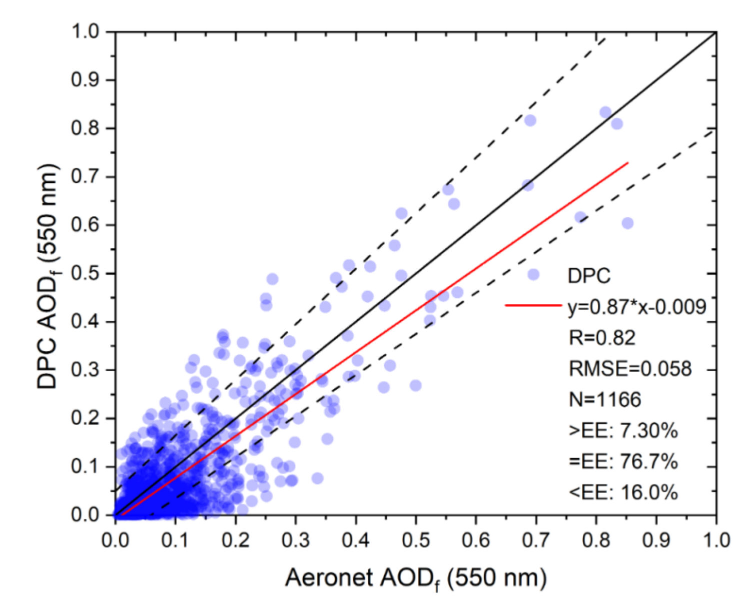


Validation of AOD_f vs. AERONET & SONET



Global AOD_f retrievals of DPC vs. AERONET/SONET data:

- within EE: 260/272 sites
- without EE: 12/272 sites



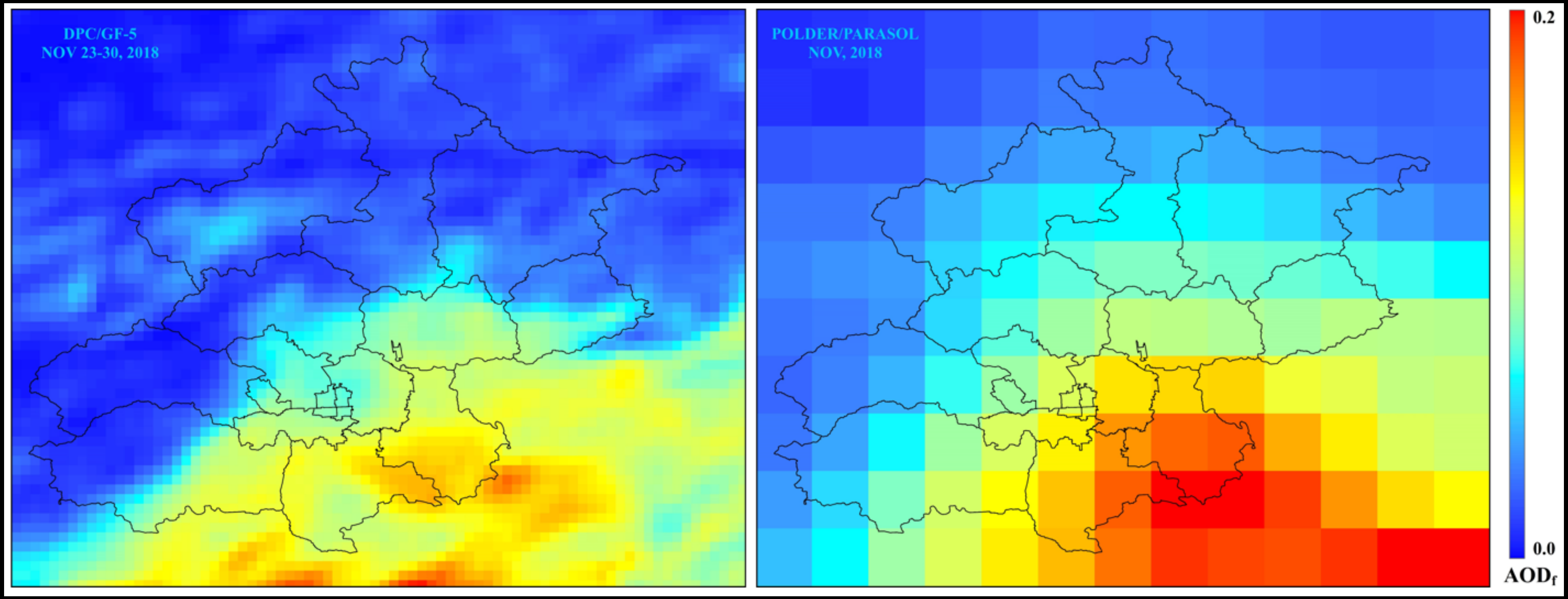
Correlation coefficient of satellite retrievals and ground-based data is 0.82, with about 77% data less than EE ($0.05+15\%AOD_f$)

Contents

3.1 City Pollution: Higher Resolution

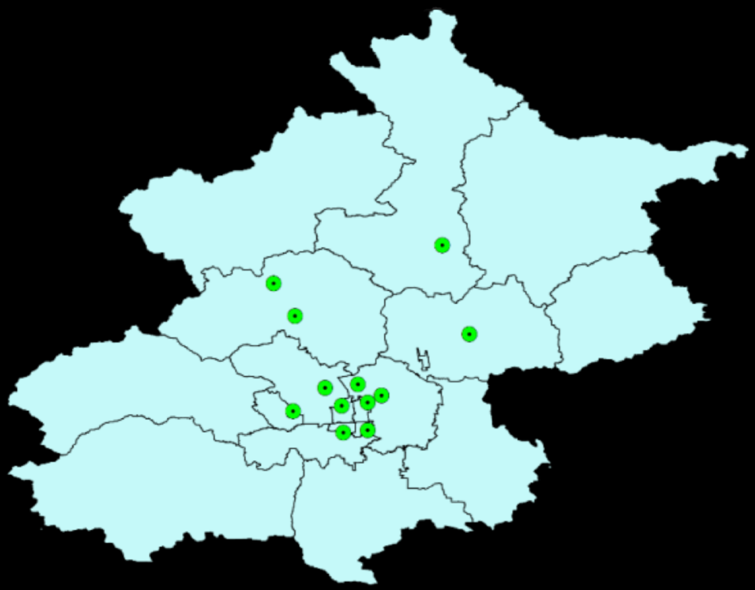
- AOD_f with 3.3km spatial resolution by DPC/GF-5, while right panel shows the official AOD_f with 18.5km spatial resolution by POLDER/PARASOL.
- The high spatial resolution AODf products can clearly show the local details of pollution distribution.

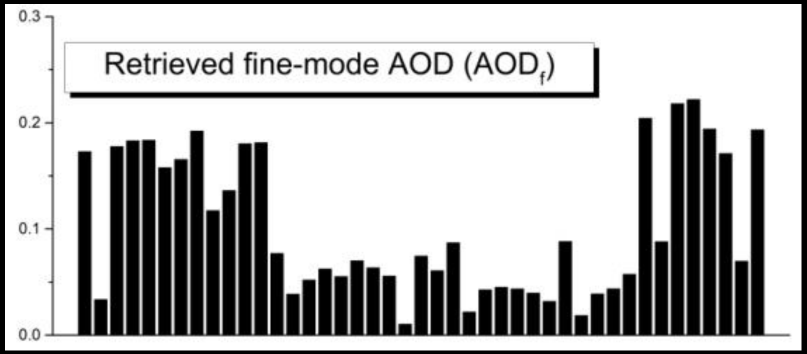
DPC/GF-5 （3.3 km） POLDER/PARASOL（18.5 km）



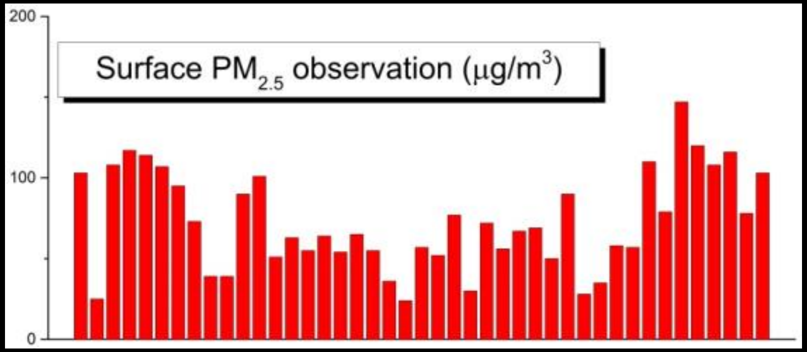
Spatial resolution is increased by about 6 times!

3.2 Correlation between AOD_f and $PM_{2.5}$





AOD_f



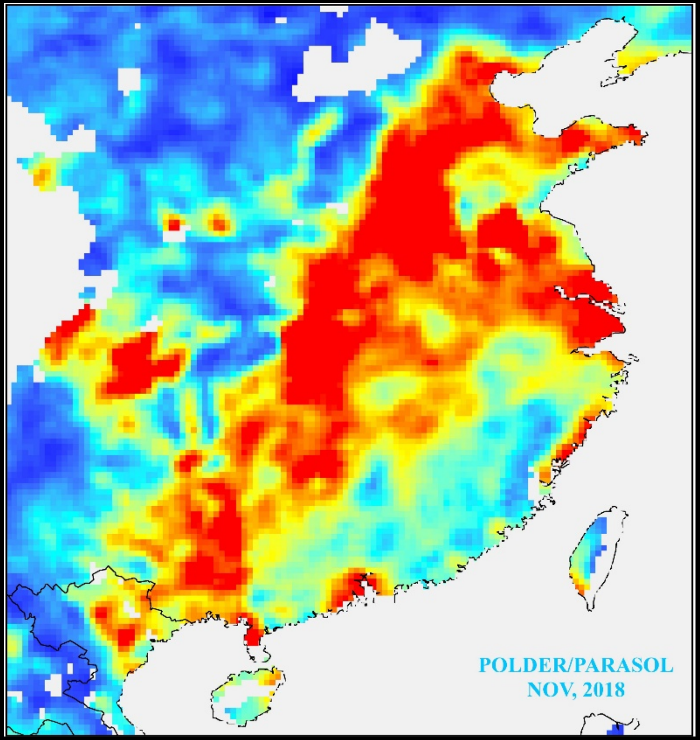
$PM_{2.5}$

- There is a good correlation between retrieved AOD_f and ground monitoring $PM_{2.5}$ in Beijing.
- Correlation results show good potential of DPC for quantitative estimation of air pollution fine particulate $PM_{2.5}$.

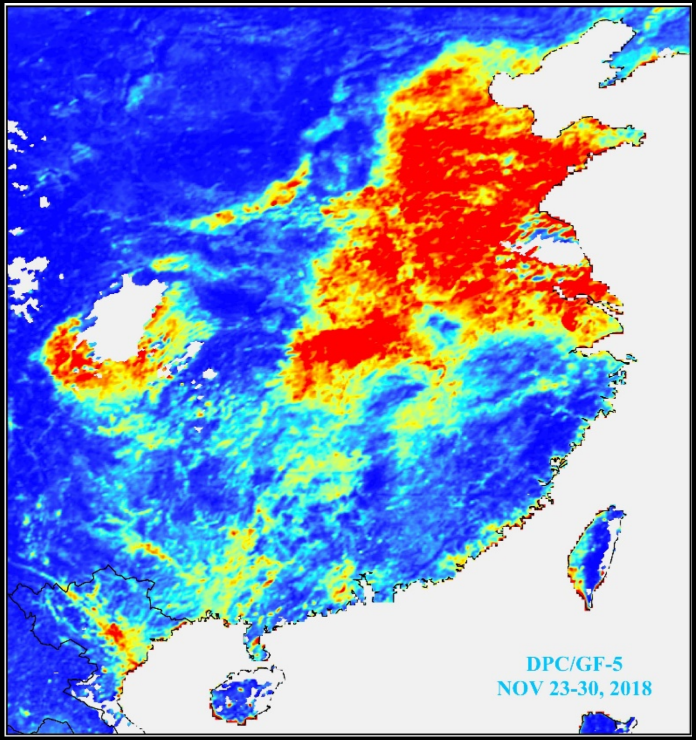
3.3 Significant pollution reduction in China

- The degree of pollution in eastern China has improved significantly from the peak of November 2011, especially in the southeastern coastal areas;
- The fine particle aerosol content in northern China is still high and needs further control and improvement.

POLDER/PARASOL (2011)



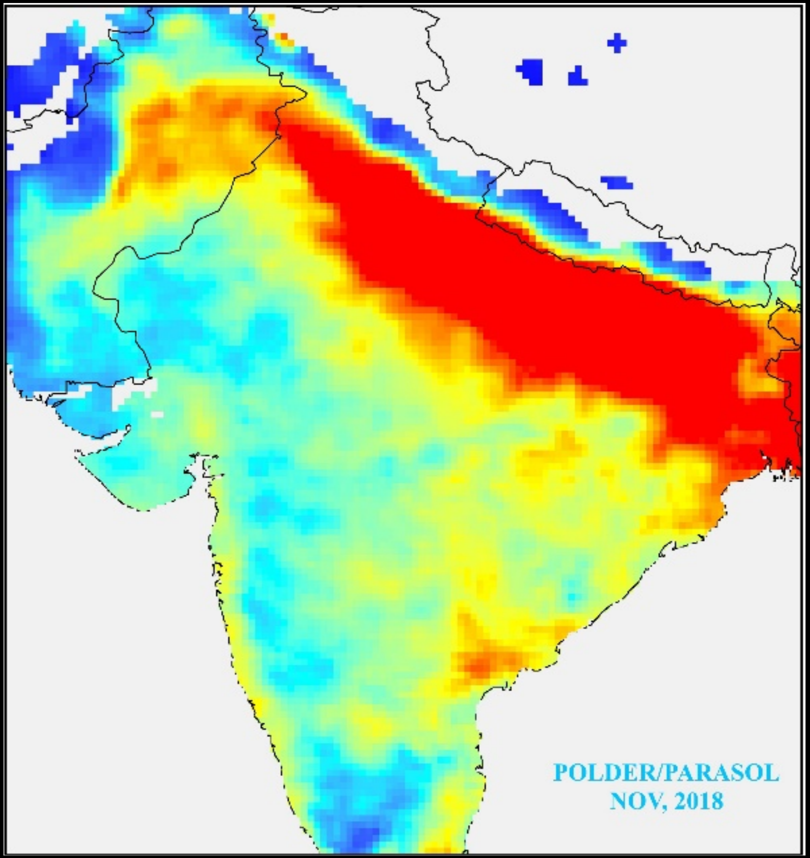
DPC/GF-5 (2018)



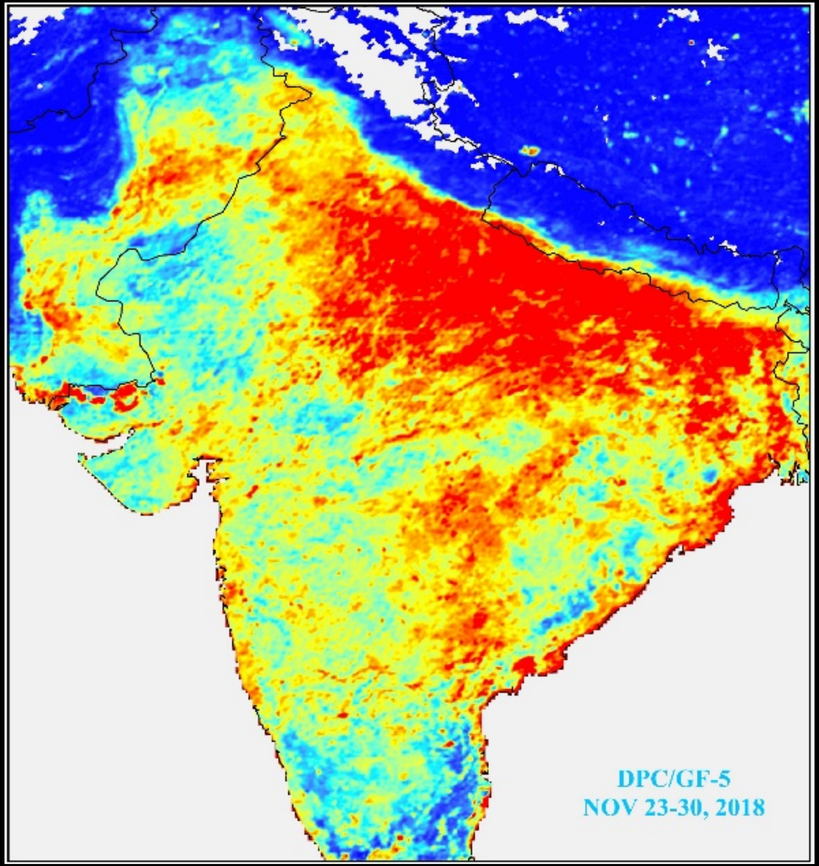
3.4 Rapidly increased pollution in India

- Compared with 2018 in 2011, India showed significant pollution growth, reflecting the increase in human activities such as increased industrial and agricultural emissions.

POLDER/PARASOL (2011)

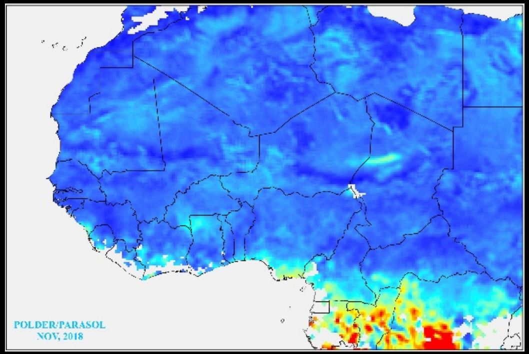


DPC/GF-5 (2018)

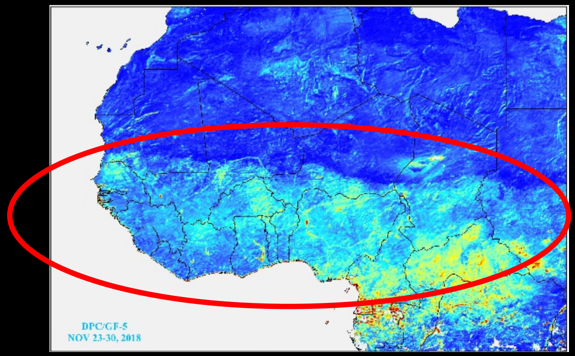


3.5 Dense Fire Activities in Center Africa

POLDER/PARASOL (2011)



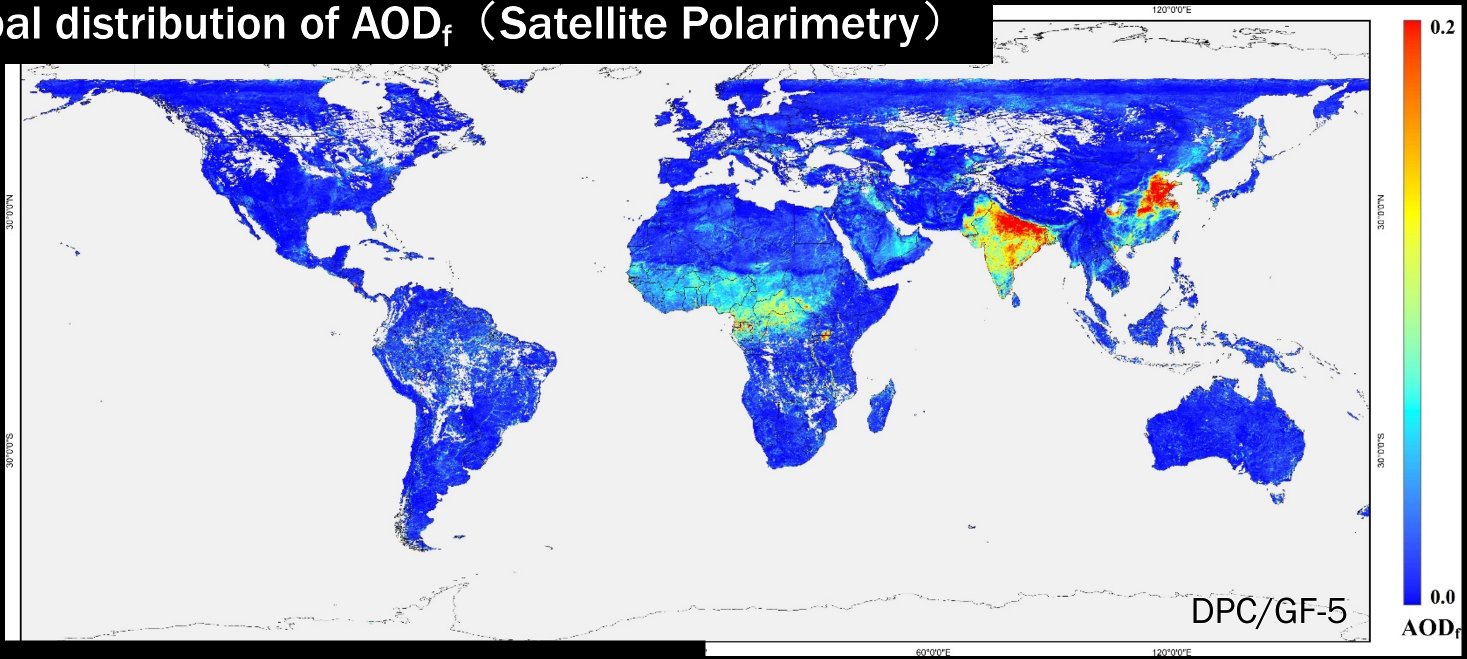
DPC/GF-5 (2018)



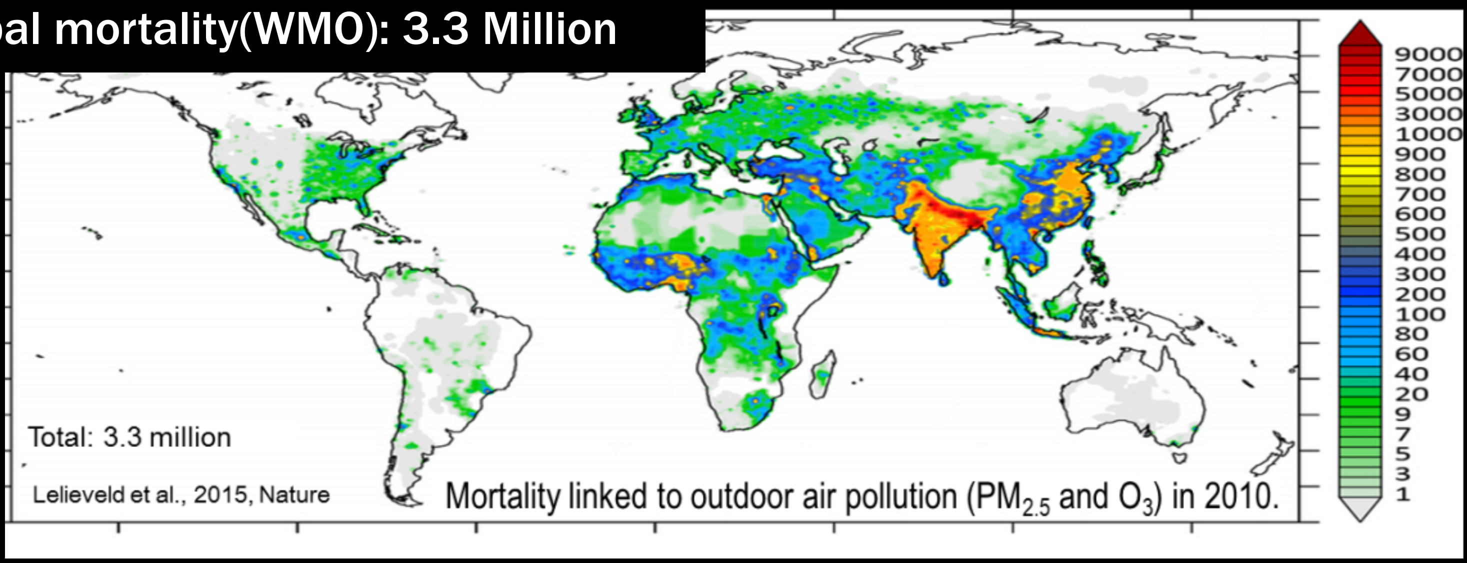
- The changes in AODf in central Africa are mainly affected by factors such as natural biomass burning and forest destruction.

3.6 Global AOD_f distribution vs. Mortality Map

1. Global distribution of AOD_f（Satellite Polarimetry）



2. Global mortality(WMO): 3.3 Million



Contents

1. Introduction of the GF-5 mission
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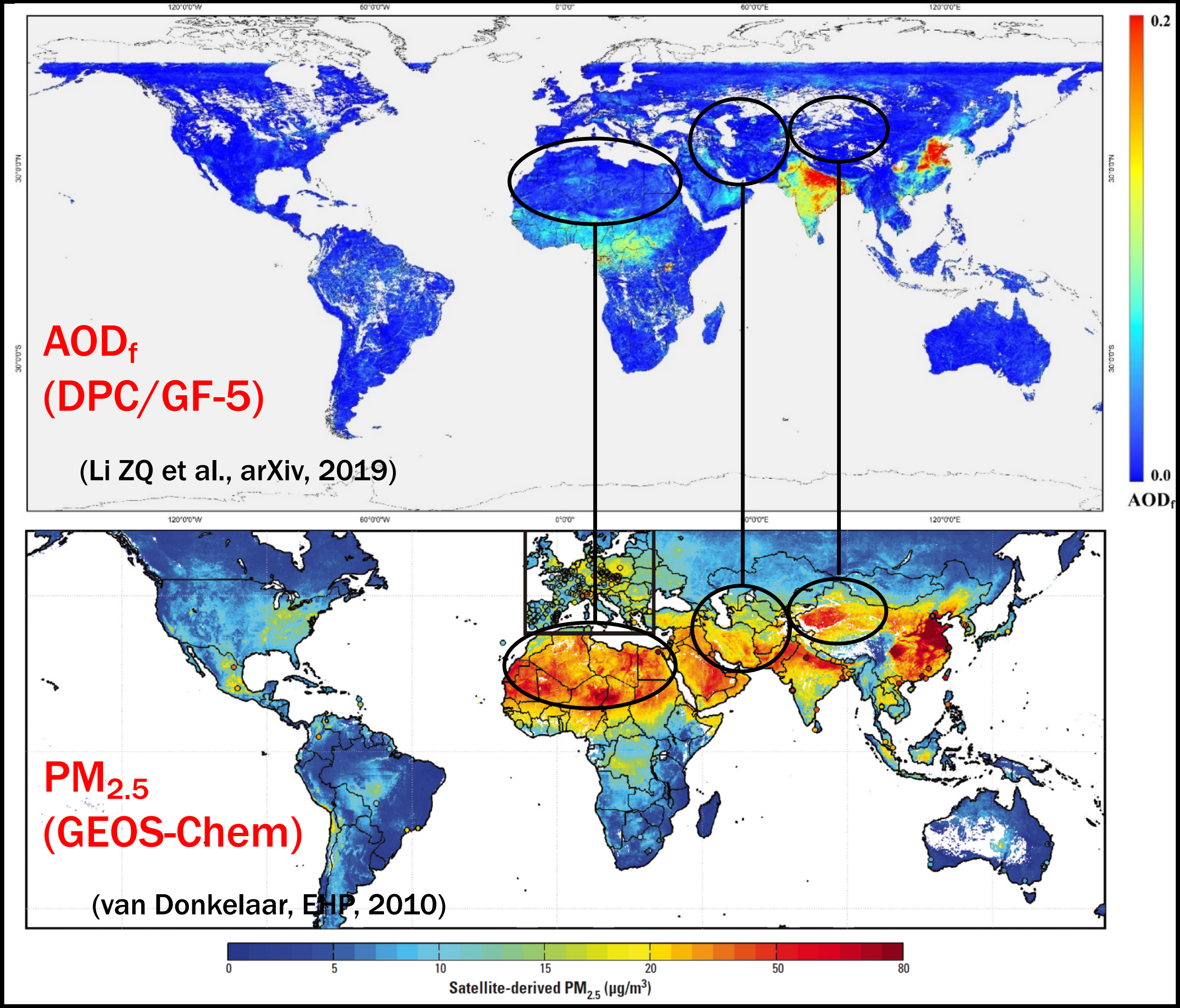
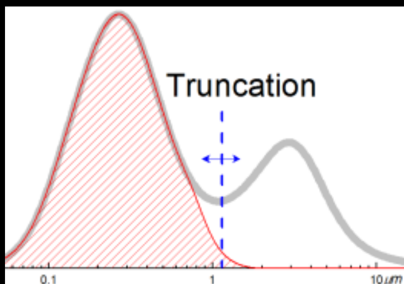
Challenge: Satellite-derived $PM_{2.5}$ map

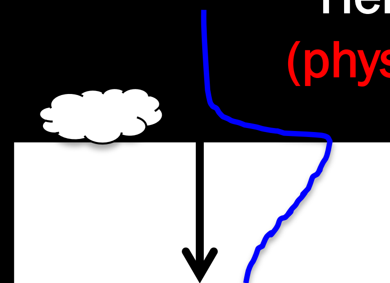
- Polarimetric sensor (DPC) results show interesting difference with previous $PM_{2.5}$ map
- But AOD_f itself is not the $PM_{2.5}$



New approach for $PM_{2.5}$ Rem. Sen.

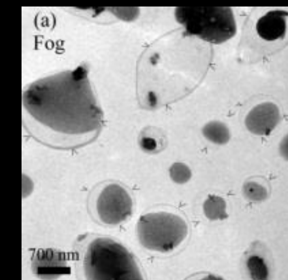


Size (optical)

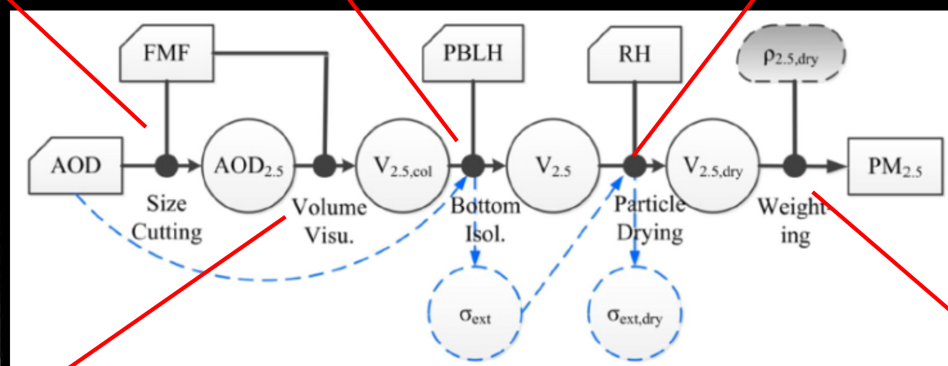


Height (physical)

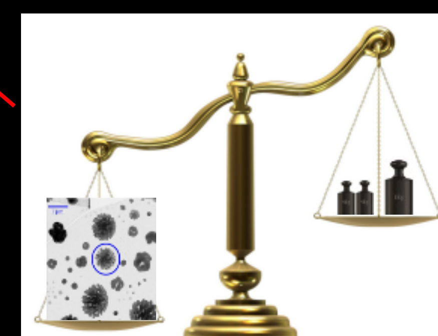
Humidity (physical)



Volume (optical)



Density (chemical composition)



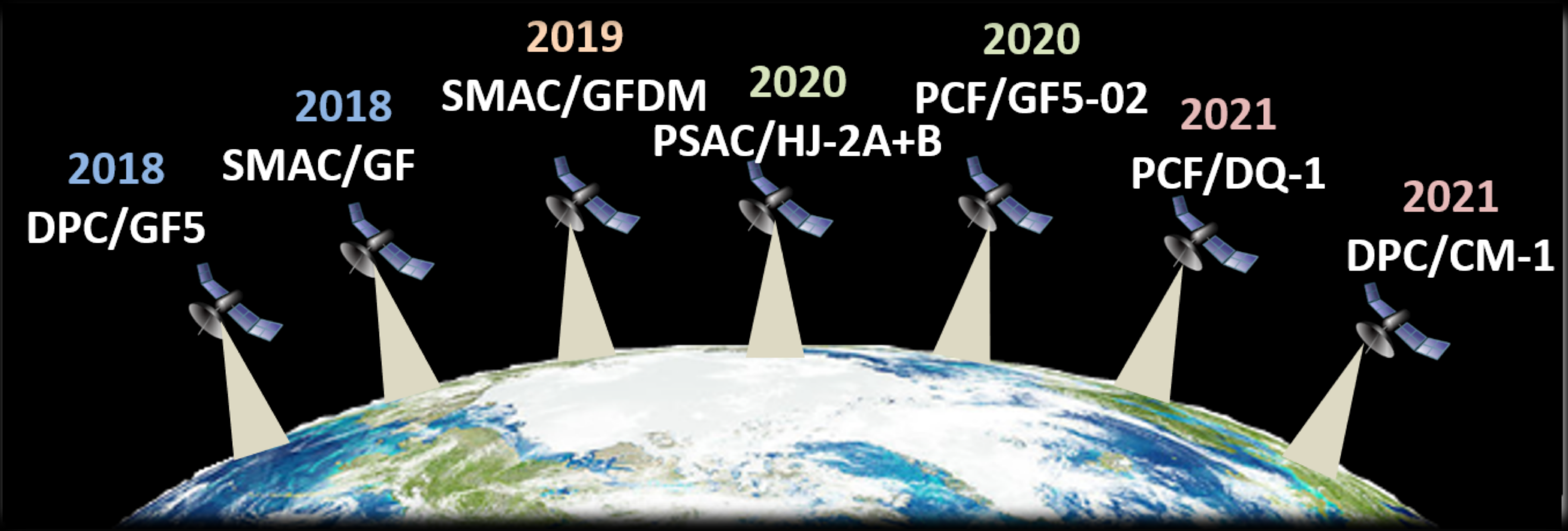
PMRS: instantaneous RS model

Zhang Y., and Li ZQ.*, 2015, Remote Sensing of Atmospheric Fine Particulate Matter (PM2.5) Mass Concentration near the Ground from Satellite Observation, ***Remote Sensing of Environment***, 160, 252-262.

Future: polarization constellation

- Series polarimetric satellites design and demonstration
- Polarization remote sensing of atmospheric, terrestrial and ocean parameters
- National civil space infrastructure common application support platform

Polarization CrossFire (PCF) Suite will focus direct measure $PM_{2.5}$ （2020）



Conclusion

1. The in-orbit calibration indicates that DPC works well with expected performance.
2. The aerosol data validation shows that key parameters can be retrieved from DPC.
3. Scientific highlights obtained over bright city surface, east China, India, Africa and over the world.
4. The DPC provide a test bad for a further polarization constellation.

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Thank you for your attention