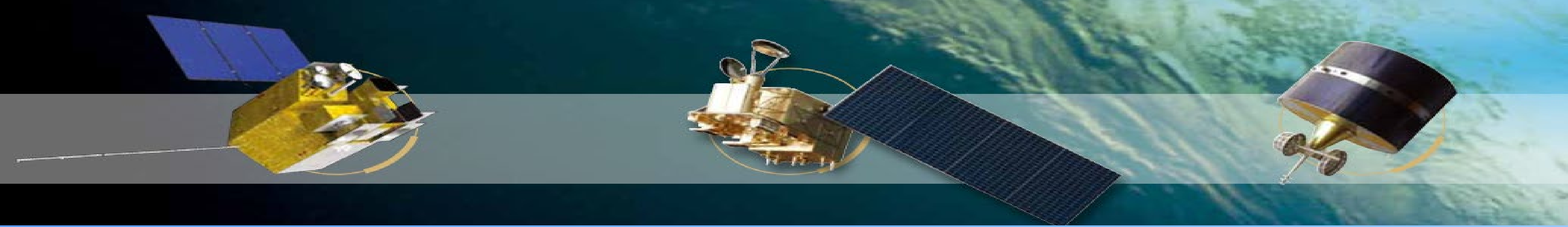


RetrospectIve Calibration of Historical Chinese FengYun Satellite Data (RICH-FY)

RICH-CEOS

P. Zhang, X.Q. Hu, S.Y. Gu., L. Sun, N. Xu, L. Chen, H. Qiu, L.Y. Zhang, C.L. Qi, S.L. Wu, Y. Guo, D.W. An, et al.

National Satellite Meteorological Center

Fund by National Key R&D Program of China，2018YFB0504900

NSMC

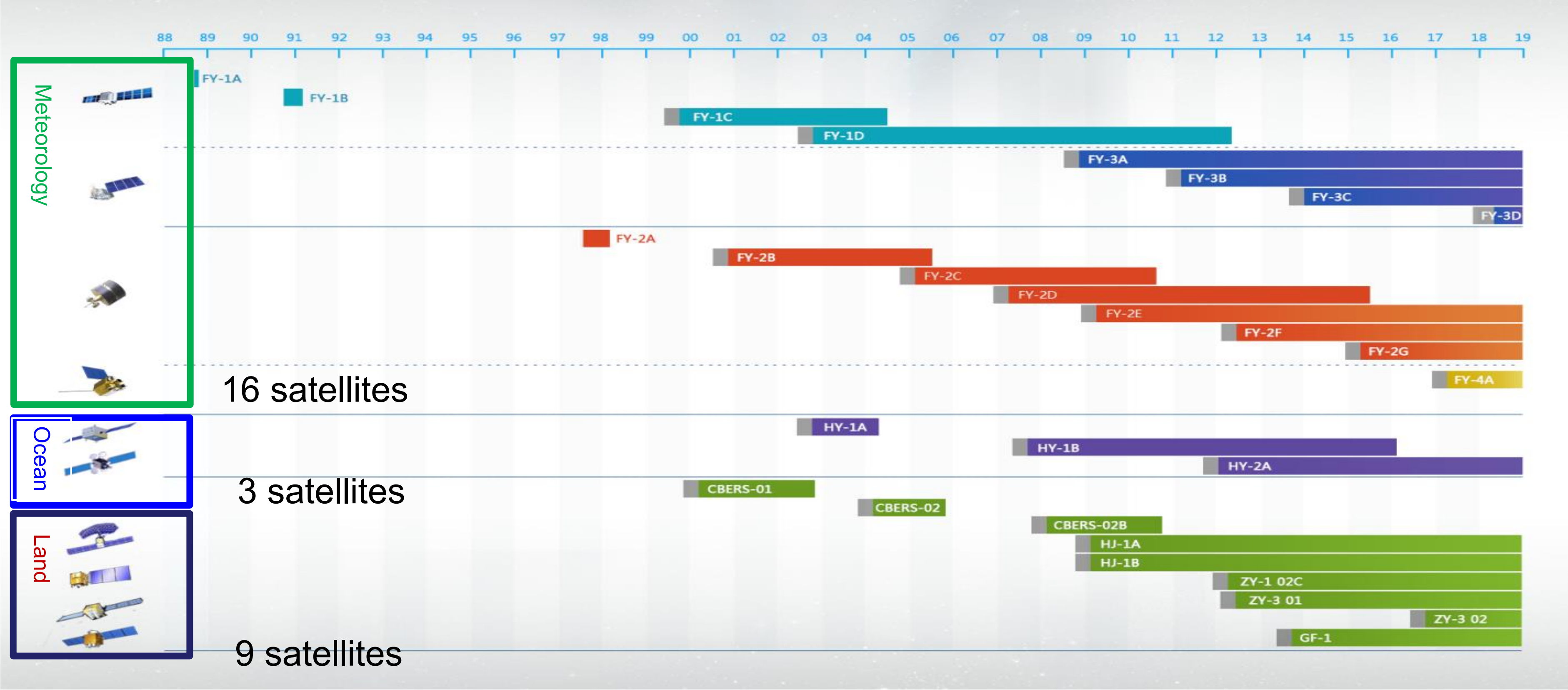
ITSC -22
Oct 31-6, 2019, Saint-Sauveur, Canada

Outline

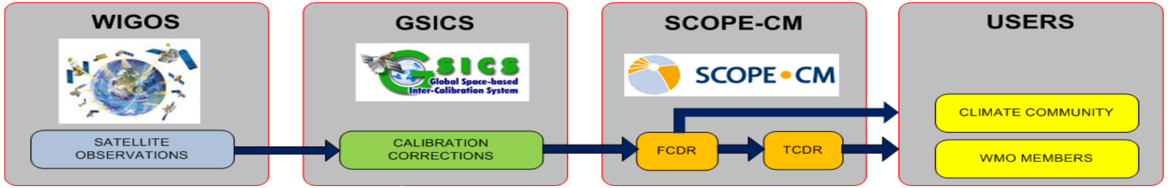
- Opportunity：project background
- Challenge：problem and solution
- Preliminary Progress
- Summarization

1. Opportunity: project background

30 years' Chinese historical Satellite data (2018-2022) **Amount √** **Quality ？**



- In 1998, Pathfinder project was proposed by NOAA and NASA for reprocessing AVHRR,TOVS,GEOS,SSM/I.
- In 2010, GCOS proposed satellite observed ECV concept, ESA started CCI(Climate Change Initiative), including 14 ECV products.
- CEOS WGCV proposed QA4ECV plan, aiming at an internationally recognized QA framework, providing understandable and traceable quality.
- C3S was proposed coordinating with Copernicus space program, FIDUCEO and GAIA-CLIM were funded.
- Satellite based climate dataset construction was supported by Chines 11th and 12th Five-Year plans, mainly using overseas satellites.



Calibration is the core of data reprocessing

Retrospectlve Calibration of Historical Chinese Eerth Observation Satellite Data (RICH-CEOS)

中华人民共和国科学技术部
Ministry of Science and Technology (MoST)

National Key R&D Program of China
Founded since 2018

18 Institutions Involved

- **RICH-FY：** Chinese Meteorological Satellites
- **RICH-ZY：** Chinese Land Resources Satellites
- **RICH-HY：** Chinese Marine Satellites

National Satellite Meteorological Centre (NSMC)

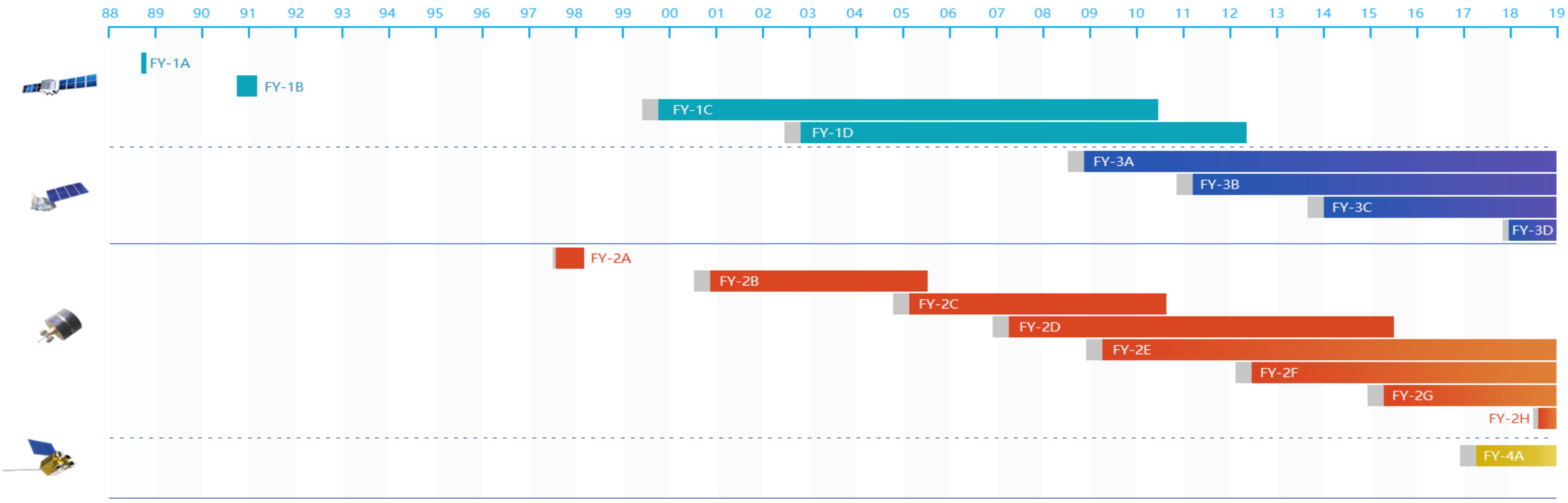
National Satellite Ocean Application Center (NSOAC)

China Center for Resources Satellite Date and Application (CRESDA)

FY：13 satellites and 7 instruments

Satellite	Instrument	Wavelength	Total Channel No.	Spatial Resolution	Lifetime
FY-1A	VIRR	0.48 – 12.5 μm	5	1.1 km	1988.9.8（1988.9.7） – 1988.10.17（1988.10.17）
FY-1B	VIRR	0.48 – 12.5 μm	5	1.1 km	1990.9.3 （1990.9.3） – 1991.2.15（1991.2.15）
FY-1C	VIRR	0.43 – 12.5 μm	10	1.1 km	1999.5.10（1999.5.10） – 2004.4.26（2004.4.26）
FY-1D	VIRR	0.43 – 12.5 μm	10	1.1 km	2002.5.15（2002.5.15） – 2012.4.1（2012.4.1）
FY-2A	VISSR	0.5 – 12.5 μm	3	1.25 km, 5 km	1997.6.10（1997.6.10） – 1998.2.12（1998.2.12）
FY-2B	VISSR	0.5 – 12.5 μm	3	1.25 km, 5 km	2000.7.19（2000.6.25） – 2005.6.2（2005.6.2）
FY-2C	VISSR	0.5 – 12.5 μm	5	1.25 km, 5 km	2004.10.27（2004.10.19） – 2010.8.2（2010.8.2）
FY-2D	VISSR	0.5 – 12.5 μm	5	1.25 km, 5 km	2006.12.19（2006.12.8） – 2015.6.30（2015.6.30）
FY-2E	VISSR	0.5 – 12.5 μm	5	1.25 km, 5 km	2009.2.17（2008.12.23） – 今
FY-2G	VISSR	0.5 – 12.5 μm	5	1.25 km, 5 km	2015.6.3（2014.12.31） – 今
FY-3A	VIRR 2	0.43 – 12.5 μm	10	1.1 km	2008.5.29（2008.5.27） – 2018.3.6（2018.3.6）
	MERSI 1	0.41 – 11.25 μm	20	250 m, 1 km	2008.6.2（2008.5.27） – 2018.2.11（2018.3.6）
	IRAS	0.69 – 1.64 μm & 3.76 – 14.95 μm	26	17 km	2008.6.26（2008.5.27） – 2016.8.13（2018.3.6）
	MWTS 1	50 – 57 GHz	4	50 – 60 km	2008.6.8（2008.5.27） – 2013.5.6（2018.3.6）
	MWHS 1	150 GHz, 183 GHz	5	15 km	2008.5.31（2008.5.27） – 2016.8.13（2018.3.6）
	MWRI	10 – 89 GHz	10	12 – 75 km	2008.6.6（2008.5.27） – 2010.5.18（2018.3.6）
FY-3B	VIRR 2	0.43 – 12.5 μm	10	1.1 km	2010.11.18（2010.11.5） – 今
	MERSI 1	0.41 – 11.25 μm	20	250 m, 1 km	2010.11.18（2010.11.5） – 今
	IRAS	0.69 – 1.64, 3.76 – 14.95 μm	26	17 km	2010.11.18（2010.11.5） – 今
	MWTS 1	50 – 57 GHz	4	50 – 60 km	2010.11.18（2010.11.5） –2014.2.21
	MWHS 1	150 GHz, 183 GHz	5	15 km	2010.11.18（2010.11.5） – 今
	MWRI	10 – 89 GHz	10	12 – 75 km	2010.11.18（2010.11.5） – 今
FY-3C	VIRR 2	0.43 – 12.5 μm	10	1.1 km	2013.9.25（2013.9.23） – 今
	MERSI 1	0.41 – 11.25 μm	20	250 m, 1 km	2013.9.30（2013.9.23） –2015.5.30
	IRAS	0.69 – 1.64, 3.76 – 14.95 μm	26	17 km	2013.9.29（2013.9.23） – 今
	MWTS 2	50 – 57 GHz	4	50 – 60 km	2013.9.30（2013.9.23） – 今
	MWHS 2	150 GHz, 183 GHz	5	15 km	2013.9.30（2013.9.23） – 今
	MWRI	10 – 89 GHz	10	12 – 75 km	2013.9.29（2013.9.23） – 今

Goal for FY series: FCDR



Instruments:

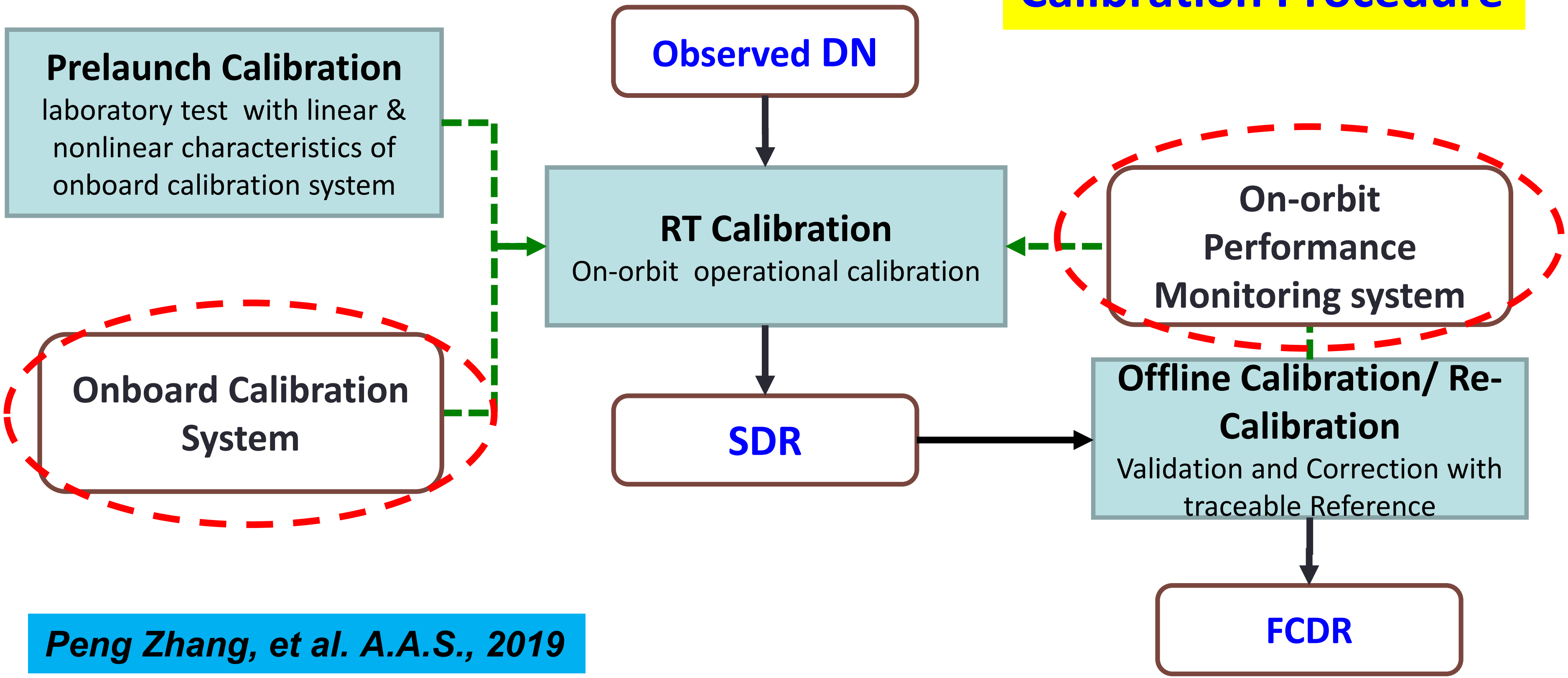
- **VIRR:** **FY-1A/B/C/D FY-3A/B/C**
- **MERSI/IRAS/MWTS/MWHS/MWRI:** **FY-3A/B/C**
- **VISSR:** **FY-2A/B/C/D/E/G**

Accuracy:

- **RSB: 8%(R&D), 5%(O)**
- **TIR: 1K(R&D), 0.5K(O)**
- **MW: 1K(Absorption),1.5K(Window)**

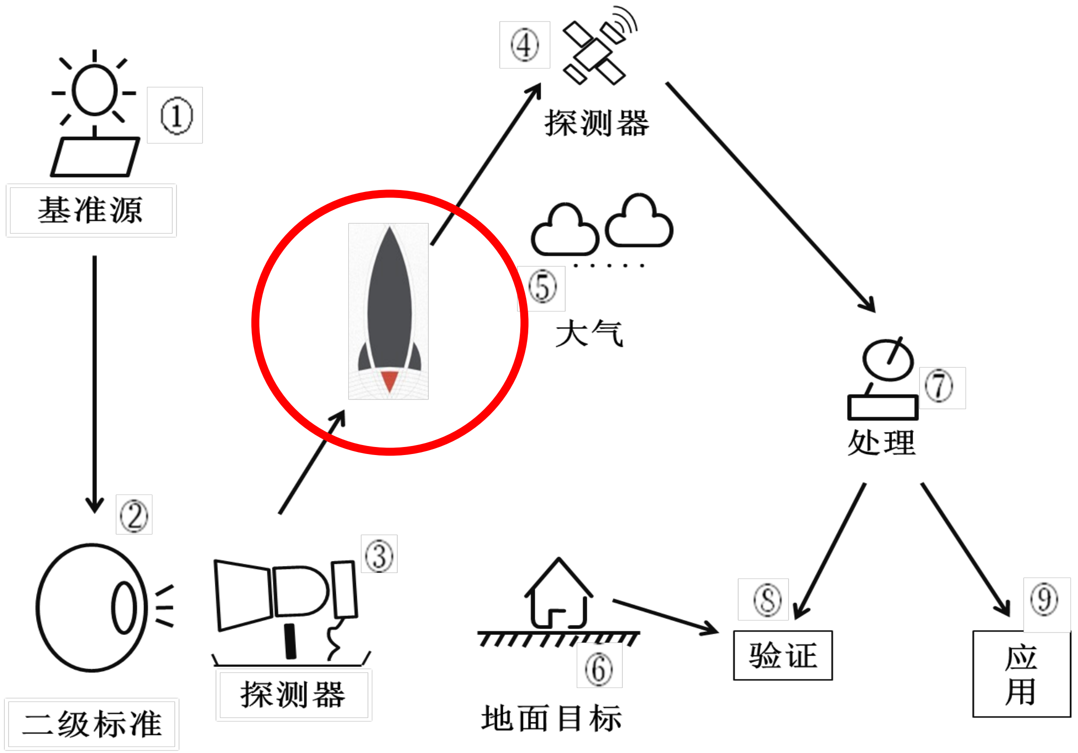
2. Challenges: problem and solution

Calibration Procedure



Peng Zhang, et al. A.A.S., 2019

Difficulties Faced: Radiometric Traceability of satellite sensors



- Uncertainty of calibration source
- Detector Response (SNO, nonlinearity)
- Variation of satellite operation environment status
- Degradation of instrument performance
- Contamination of Instrument

Onboard Calibration System

- **State of art:** International: visible 2%, infrared 0.2K, stability <1%
- **Fengyun:** visible 7-10%, infrared 1-1.5K, stability?
- **Fengyun:** Large change before and after launch, poor in-orbit stability

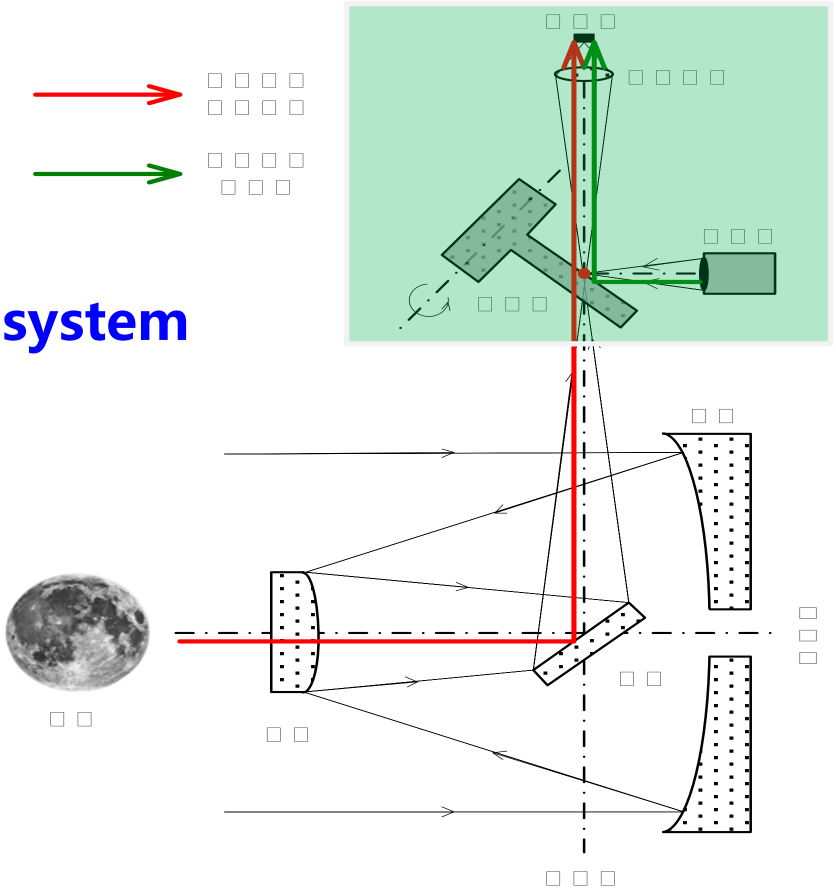
Onboard Calibration System on FY-2 and FY-3 satellites

Spectral band	On-board calibration	Instrument	uncertainties
UV bands	Sun + diffuse reflector Mercury lamp + solar continuous spectrum	TOU/FY-3 SBUS/FY-3	1) State change before and after launch 2) Attenuation of diffuse reflector
Visible and NIR bands	VOC: small integrating sphere with diameter of 6 cm, light beam expanding system, trap detector	MERSI/FY-3	1) State change before and after launch 2) Degradation
	Moon observation	MERSI/FY-3C	Moon model accuracy
	Tungsten halogen lamp	ERM/FY-3	1) State change before and after launch 2) Degradation
	Absolute radiometer	SIM/FY-3	1) State change before and after launch 2) Degradation
Infrared bands	Onboard blackbody + space view	VISSR/FY-2 VIRR/FY-3 MERSI/FY-3 IRAS/FY-3	1) State change before and after launch 2) Blackbody temperature control accuracy 3) Accuracy and changes in blackbody emissivity 4) Extent of the cold space contaminated by radiation
	Onboard blackbody (two temperature points)	ERM/FY-3	1) State change before and after launch 2) Blackbody temperature control accuracy 3) Accuracy and changes in blackbody emissivity
Microwave bands	Onboard blackbody + space view	MWTS/FY-3 MWHS/FY-3 MWRI/FY-3	1) State change before and after launch 2) Blackbody temperature control accuracy 3) Accuracy and changes in blackbody emissivity 4) Extent of the cold space contaminated by radiation

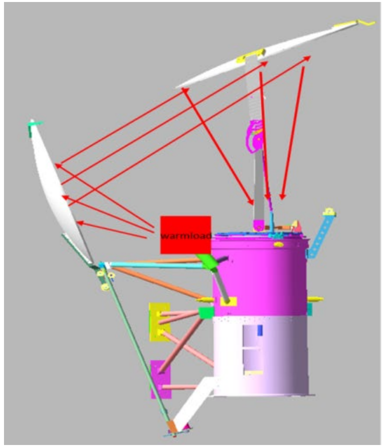
FY-2 VISSR onboard calibration system

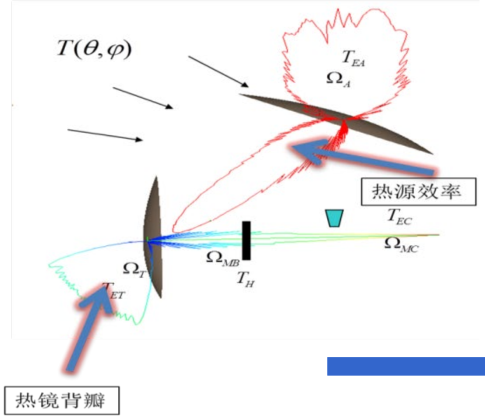
Semi-optical path calibration system

Calibration Uncertainty about 2~8K on TIR bands

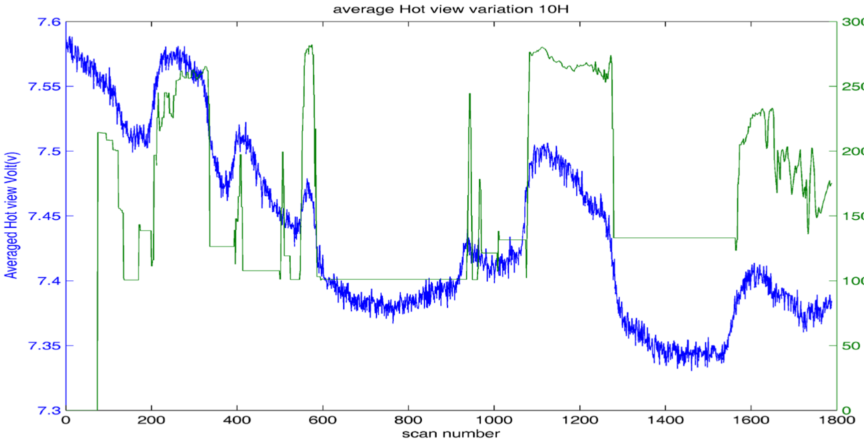


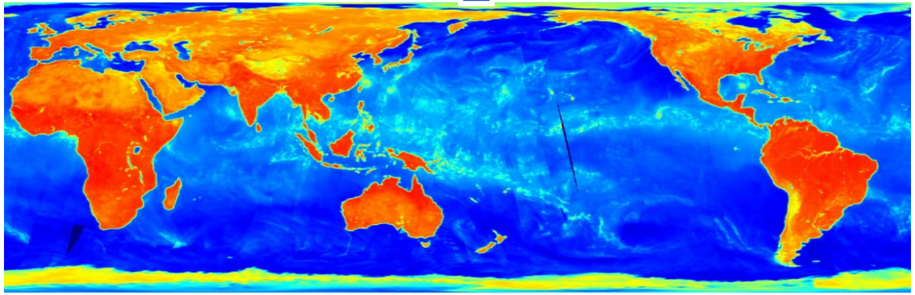
FY-3 MWRI onboard Calibration System





Hot mirror dorsal lobe effect





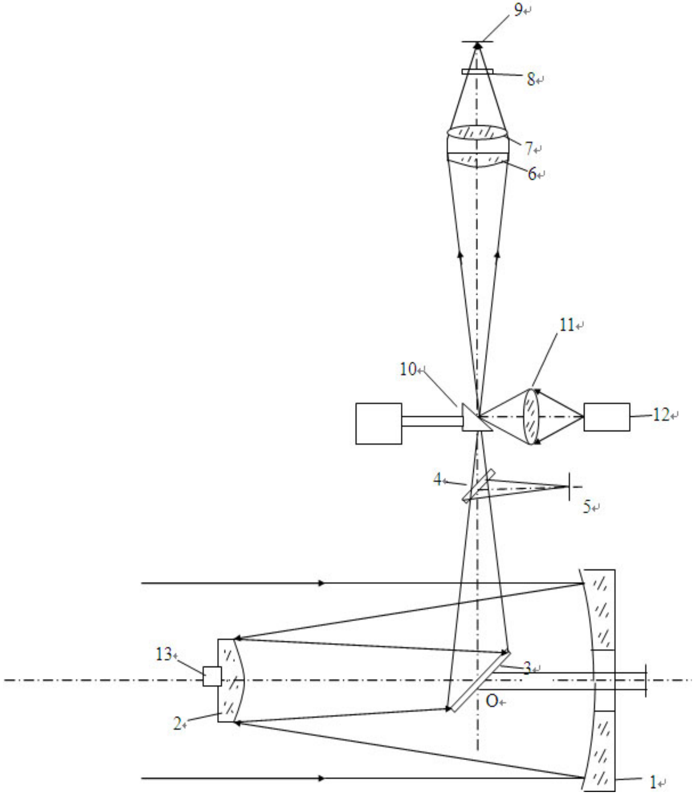
Calibration Uncertainty about 0.2~0.4K on MW bands

Nonlinearity comparison among Microwave sounding instruments (vacuum calibration test)

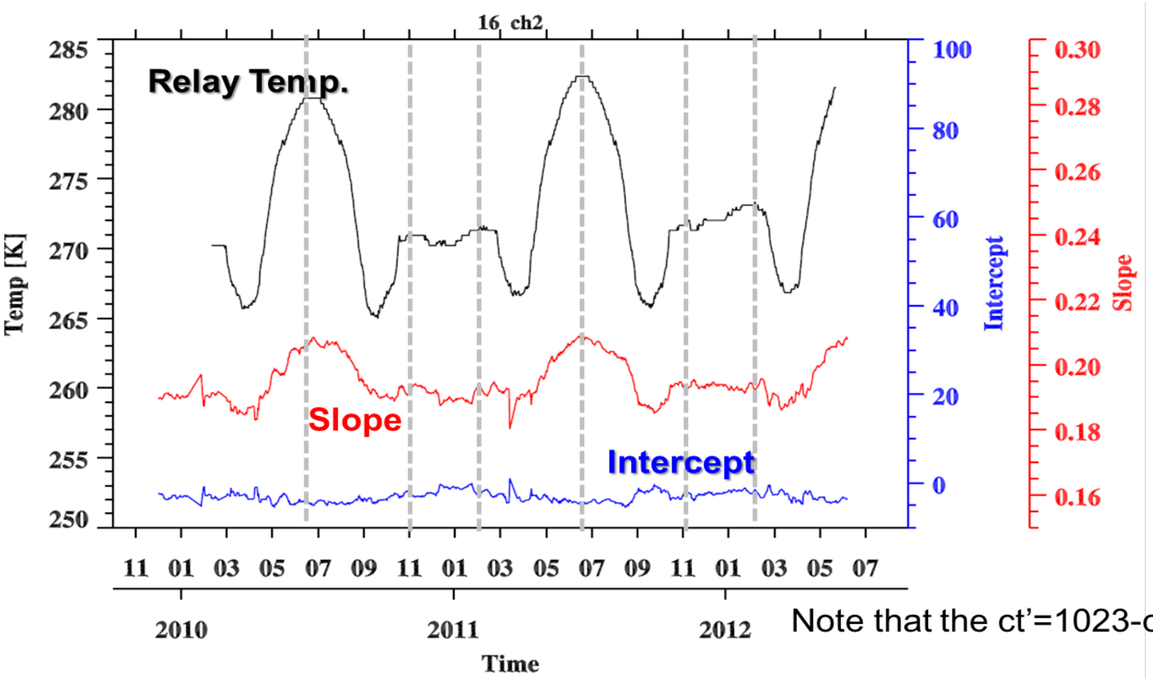
CH	1	2	3	4	5	6	7	8	9	10	11	12
Fre. (GHz)	23.8	31.4	50.3	51.76	52.8	53.596±0.115	54.4	54.94	55.5	f0±57.29	f0±0.3222±0.217	f0±0.3222±0.048
SNPPATMS (K)	0.3	0.4	0.1	-0.08	-0.05	-0.08	0.07	0.1	0.1	0.4	0.4	0.4
FY-3D MWTS MWHS (K)			-0.48	-0.99	-0.73	-0.59	-0.65	-0.64	-0.58	-0.80	-0.82	-0.80

CH	13	14	15	16	17	18	19	20	21	22
Fre. (GHz)	f0±0.3222±0.022	f0±0.3222±0.010	f0±0.3222±0.0045	88.2	165.5	183.31±7	183.31±4.5	183.31±3	183.31±1.8	183.31±1
SNPP ATMS (K)	0.5	0.4	0.5	0.2	0.4	0.2	0.2	0.2	0.3	0.3
FY-3D MWTS MWHS (K)	-0.96	-0.75	-0.58	2.7	0.9	3.4	1.9	0.9	0.2	0.5

Satellite Environment Status:



VISSR/FY-2 radiometric uncertainty affected by relay mirror temperature

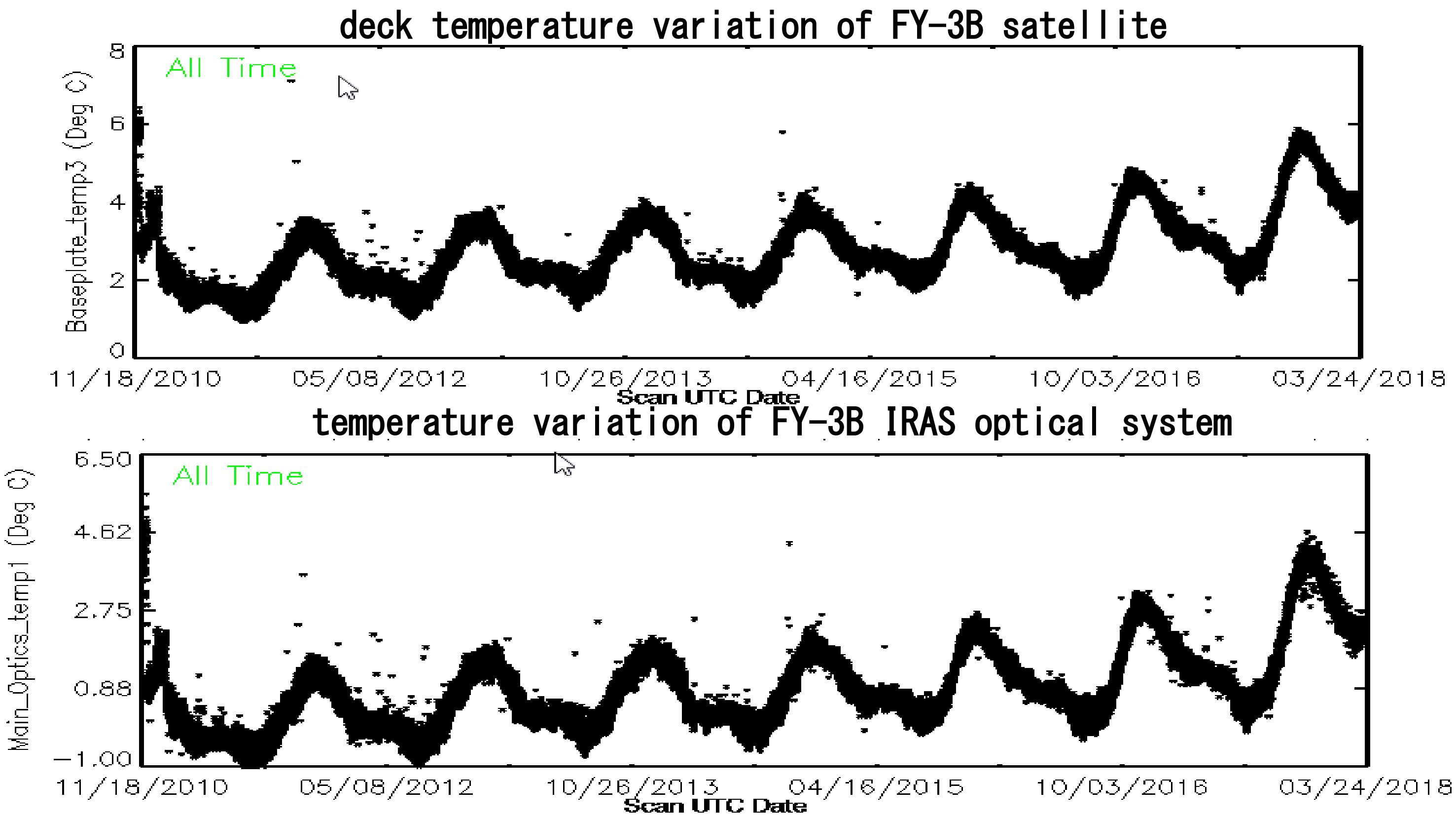


Note that the ct'=1023-ct

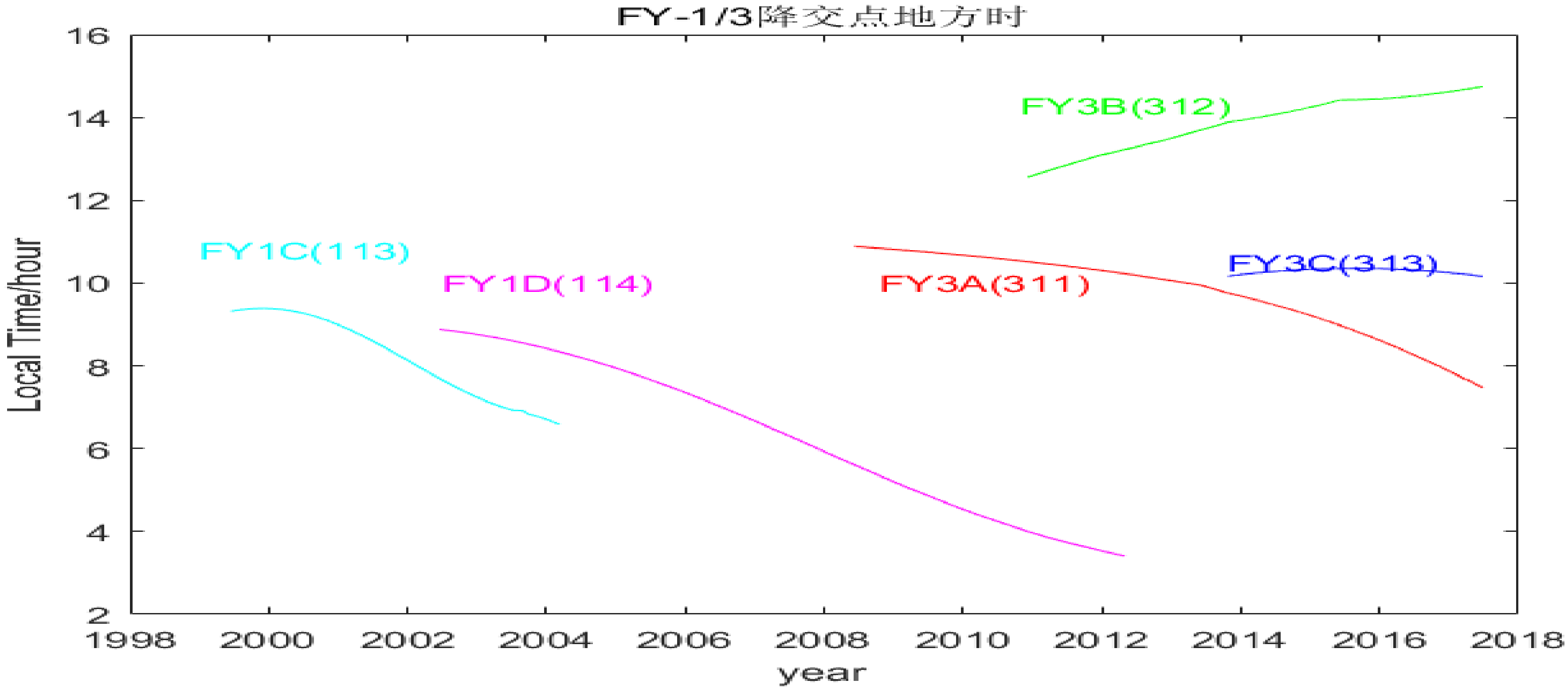
FY-2E VISSR Relay Miror Temp

Satellite Environment Status: all-life-time model

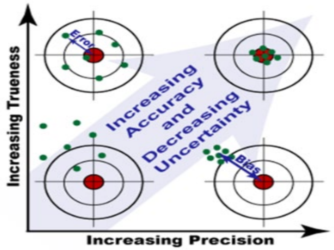
Temperature Status of IRAS/FY-3b



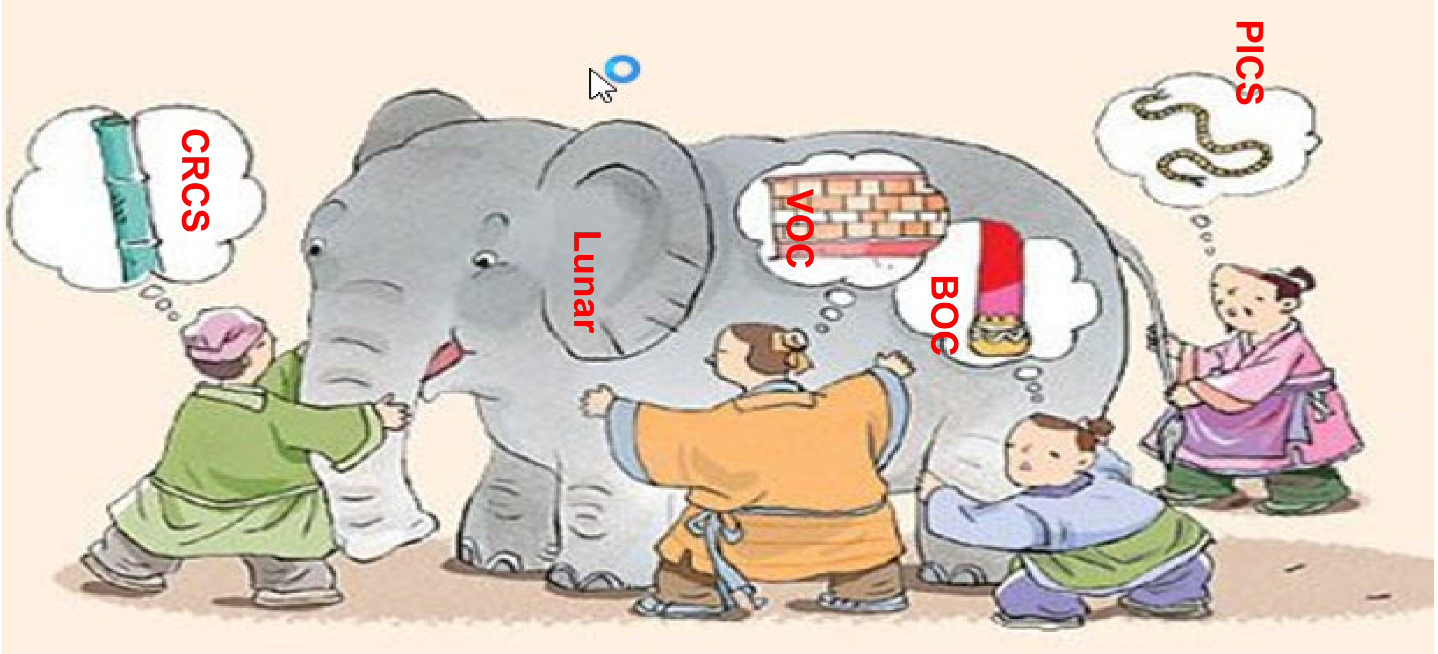
FY Polar orbit drift (Local time at descending node)



How to make the historic data traceable to the reference?

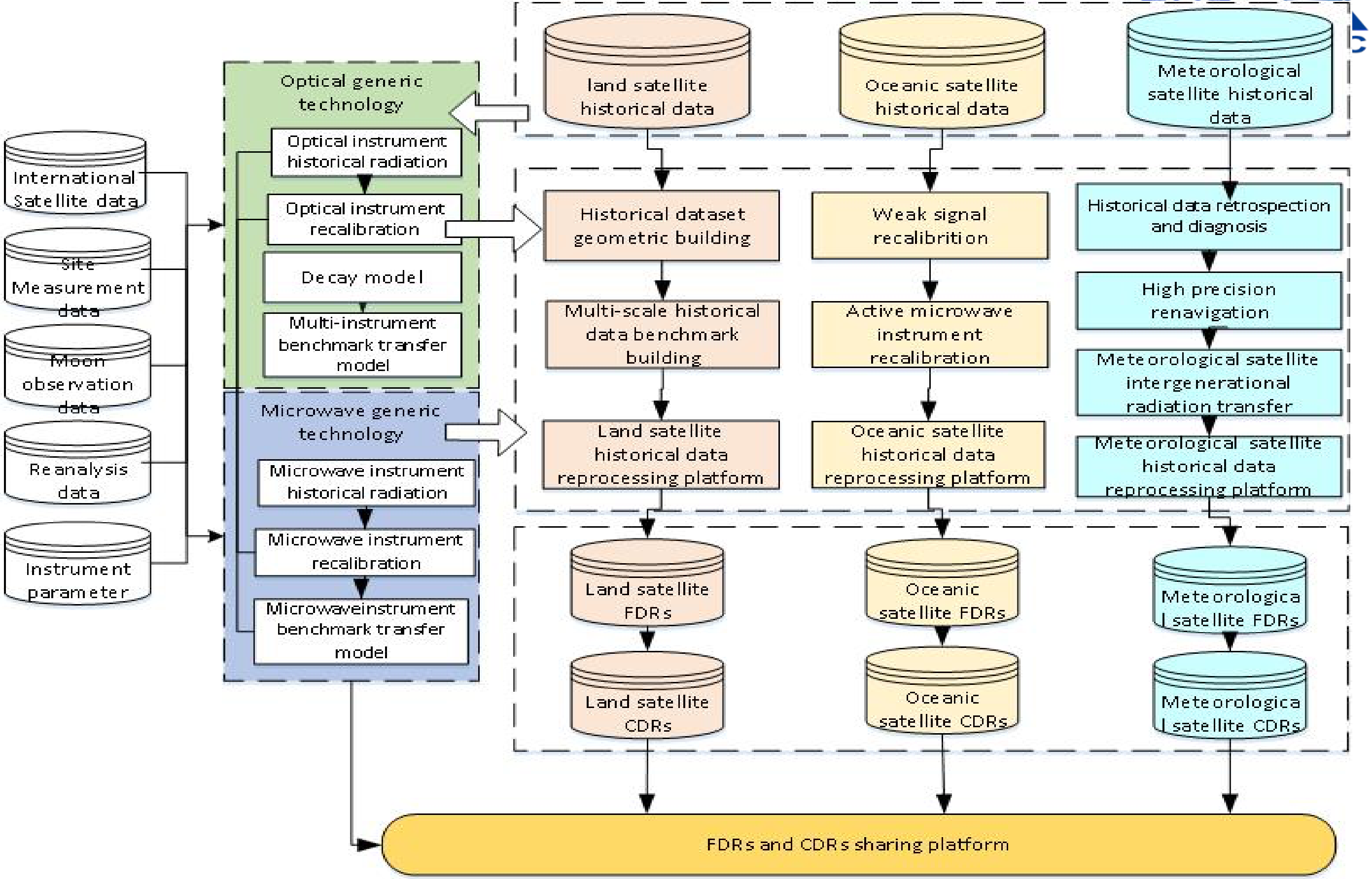


SI Traceability



Solution

- Historic Status Document Re-building
- Onboard Calibration Model Re-building
- Reference/Benchmark Collection (model reanalysis dataset, PICs, Lunar, DCC, reference instrument, Gruan, etc.)



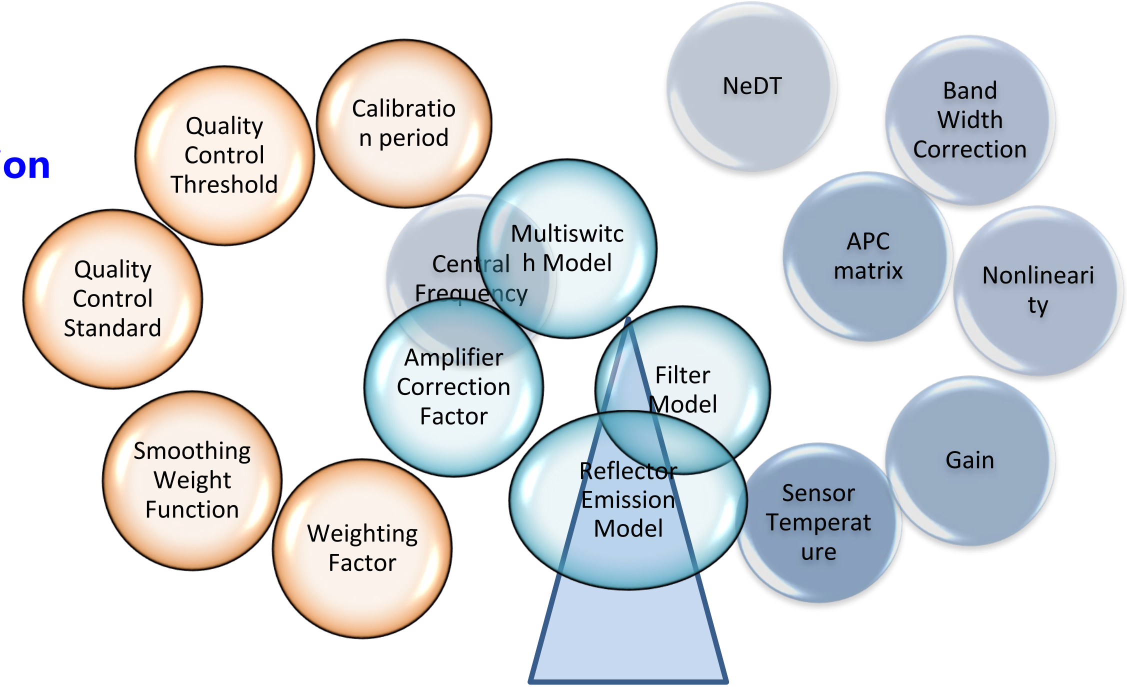
Re-building

Re-procedure

Onboard Calibration Model Re-building

Passive Microwave Sensor

- **Theoretical modeling**
- **Experiment testing**
- **Application testing and iteration improvement**



Passive optical instruments: radiometric reference (1/3)

Calibration Reference	Accuracy	Source
CRCS (China Remote Sensing Satellite Radiometric Calibration Site)	Reflectance: 15-30% Stability: 1-2% Directional effect: Yes Spectral: Smooth but not flat Accuracy: 3-5%	Hu et al, 2010 Chen et al, 2017
PICS (Pseudo Invariant Calibration Site)	Reflectance: 15~50% Stability: Directional effect: Yes Spectral: Accuracy: 3%±2%	H. Cosnefroy,1996 Y. M. Govaerts, 2004 G. Chander,2007； P. M. Teillet,2007 Sun et al., 2012 Mishra et al., 2014 Wang et al., 2018
DCC (Deep convective cloud)	Reflectance: 80-90% Stability: 1-2% Directional effect : Yes Spectral: flat Accuracy: 3-5%	B. Fougnie ,2009 B. J. Sohn, 2009
Liquid Water Cloud (LWC)	Reflectance: 20-70% Stability: 3% Directional effect: obvious Spectral: flat Accuracy: 5%	Ham & Sohn， 2010 B.J. Soh， 2013

Passive optical instruments: radiometric reference (2/3)

Calibration Reference	Accuracy	Source
Rayleigh Scattering	Reflectance: 5~10% Stability: 1~2% Directional effect: Yes Accuracy: 3~5%	E. Vermote, 1992 E. Dilligeard， 1997 O. Hagolle,1999
Sun glint	Reflectance: 5~50% Stability: 1% Directional effect : Yes Accuracy: 1~2% High degree of polarization; Fat spectrum; Reflectance depends on observation geometry and sea surface roughness	C. Cox and W. Munk， 1954； B. Toubbé, 1999； O. Hagolle, 2004；
Snow	Reflectance: >90%(300-700 nm) Stability: 1.5% Directional effect: Yes Spectral: flat (<700) Accuracy: 2%	Masonis et al., 2001 Wu et al., 2009 **Wang et al., 2019**
Moon	Reflectance: ~7% Stability: 10^{-8}/year Directional effect: Yes Spectral: flat Uncertainty: 5-10% (ROLO)	Kieffer and Stone, 2005 Miller and Turner, 2009 **Zhang, et al., 2017**

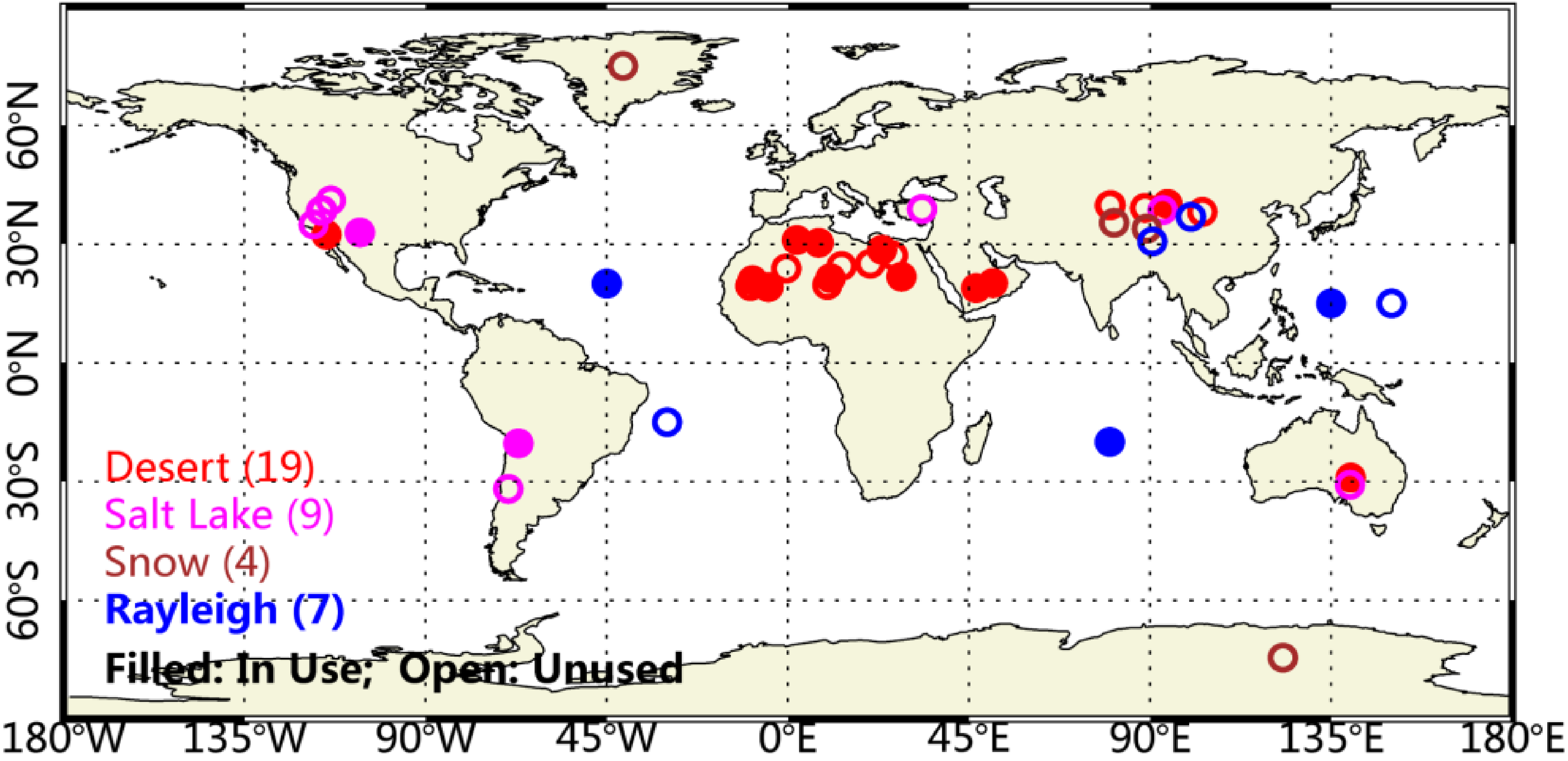
Passive optical instruments: radiometric reference (3/3)

Reference Instrument	Accuracy	Source
HIRS	Stability: 0.2K Number of channels：20 Accuracy: 0.5K；	L. Shi, 2013
IASI	Stability: 0.2K Spectral resolution: 0.25cm-1 Accuracy: 0.2K；	T. J. Hewison，2013
AIRS	Stability: 0.2K Spectral resolution: 0.625cm-1 Accuracy: 0.2K；	L. Wang，2011
CrIS	Stability: 0.2K Spectral resolution: 0.625cm-1 Accuracy: 0.2K；	Hui Xu, 2018 Likun Wang, 2017
MODIS	Stability: 0.1K/1% Number of channels：36 Accuracy: 0.2K (IR)；2% (RSB)	A. K. Heidinger，2002 X. J. Xiong，2010； C. Cao,2008
VIIRS	Stability: 0.1K/1% Number of channels：36 Accuracy: 0.2K (IR)；2% (RSB)	

Passive Microwave Sensor: Radiation Reference

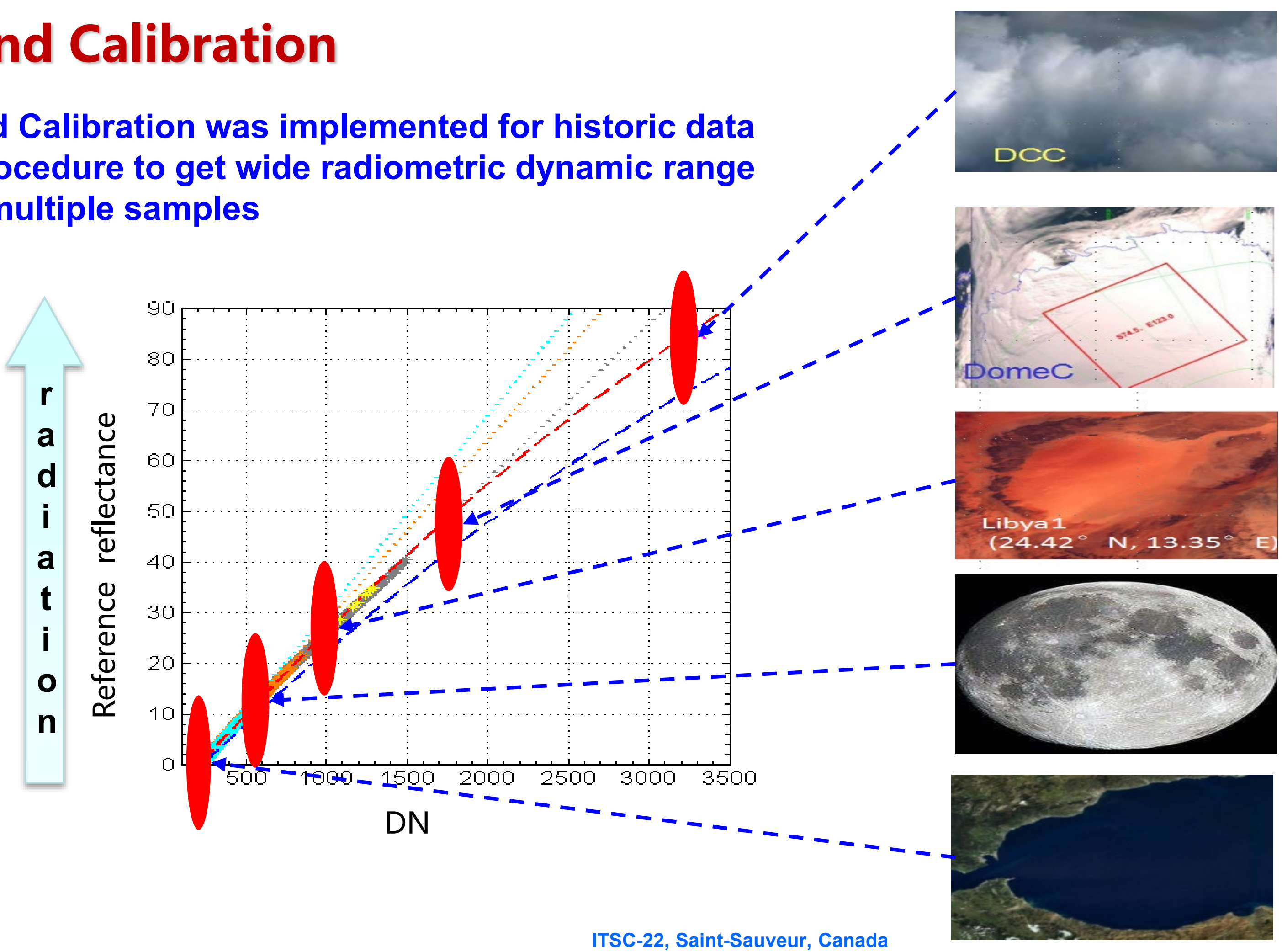
	Accuracy	Source
ERA5	<2.5K	http://www.ecmwf.int/publications
GRUAN	0.6K,6%	http://www.gruan.org
GNSS/OR	0.02%/5 yrs, 0.06 K/5 yrs	Ho, S., et al. 2012: J. Geophys. Res., 117
GMI	Accuracy<0.4K， Stability < 0.2K	Wentz,F.J.and D.Draper, J.Atmos.Oceanic Technol.,33
ATMS	Channel 3-15<0.75K Other Channel <1.0K	Weng, F., et. al. 2013: J. Geophys. Res. Atmos., 118
AMSU	0.5-1K	Cheng-Zhi, et al. 2016: CDR-ATBD
MHS	1K	EUMETSAT， MHS Lecel 1 PGS
SSM/I FCDR	0.5K	Wentz, F. J., 2013. SSM/I Version-7 Calibration Report
Cool Ocean Surface	0.27K/yr （18GHz）	Christopher S. Ruf， 2000. IEEE TGRS 38
Cold Space	2.72548±0.00057K， Peak wavelength 1.063mm， radiation intensity change <0.2%-0.3%	Baike of Baidu
Microwave Calibration Field (Simao)	Bt Change in 30d(Dry season)<0.4K； Horizontal heterogeneity<0.15K 。	“Research on Key Technologies of Microwave Calibration Field” Project closing report， 2009

Pseudo-invariant sites（PICs)



Blend Calibration

Blend Calibration was implemented for historic data re-procedure to get wide radiometric dynamic range and multiple samples



DCC
> 90%

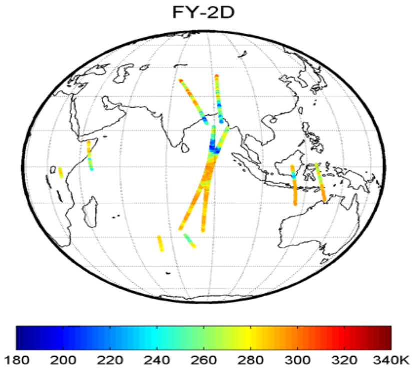
Glacier
50-80%

Desert
20-30%

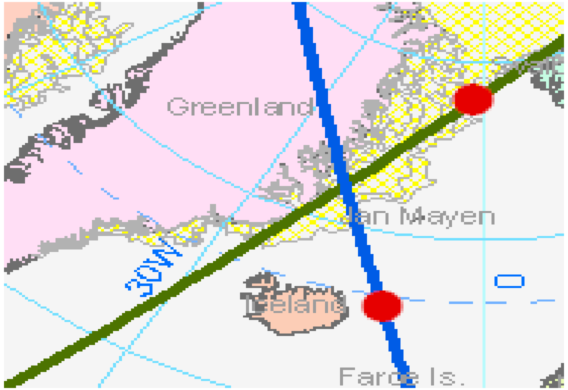
Moon
5-10%

ocean
< 5%

Inter-calibration with reference sensors



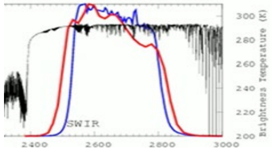
Geo-Leo

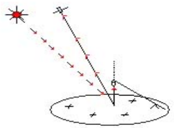


Leo-Leo

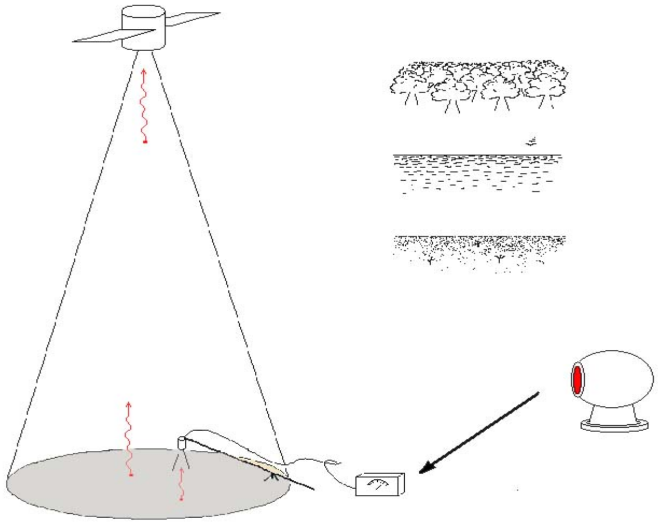
Direct Inter-calibration with global data matching

- Space
- Time
- Geometry
- Spectral

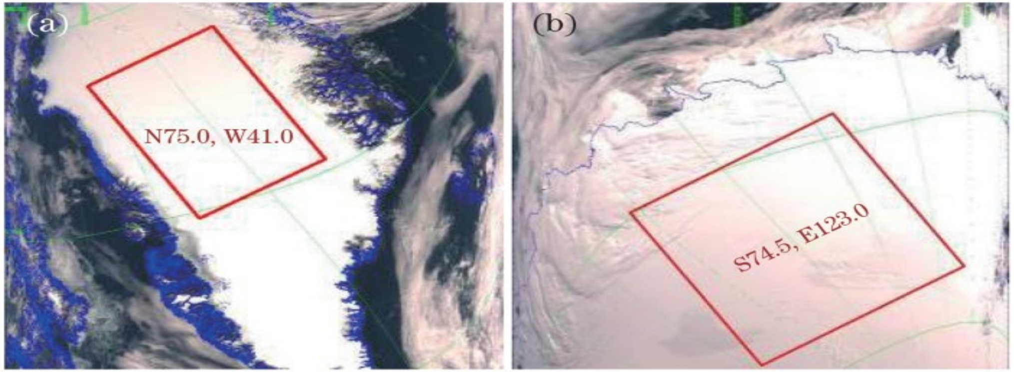




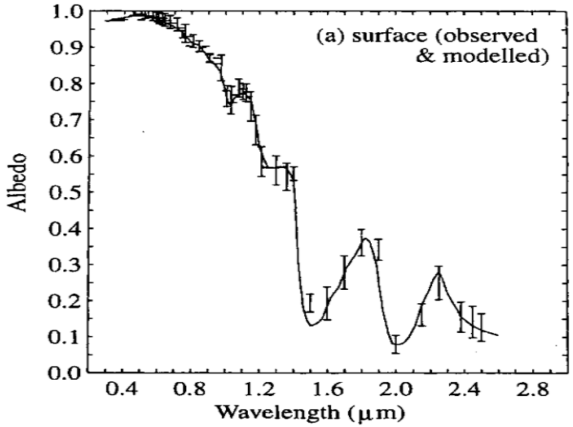
Indirect Inter-calibration with PICS



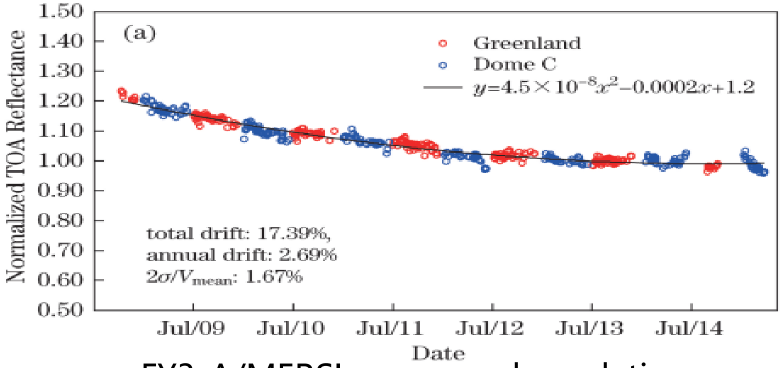
RSB Channels Degradation monitoring by polar glacier



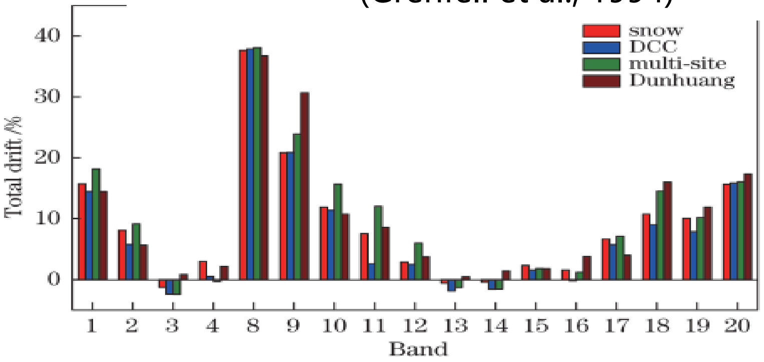
FY3-A/MERSI polar RGB images
(a) Greenland; (b) DomeC



Spectral reflectance of glacier at south pole
(Grenfell et al., 1994)



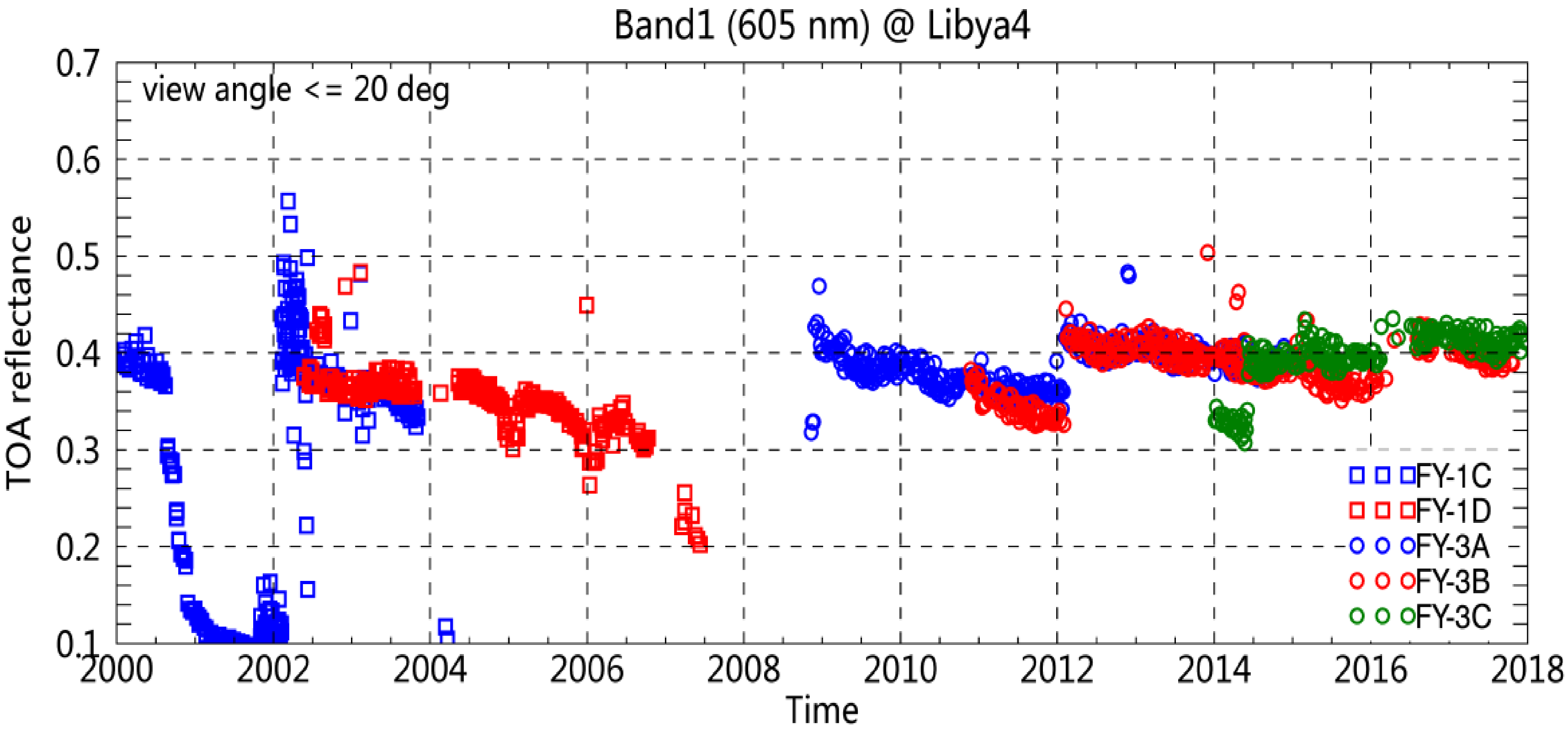
FY3-A/MERSI response degradation
(Polar glacier)



FY3-A/MERSI RSB total degradation rates

RSB channels Degradation monitoring by PICS

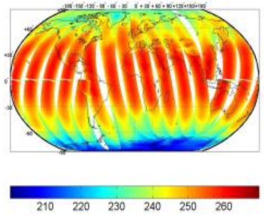
VIRR Harmonization Check with Libya 4



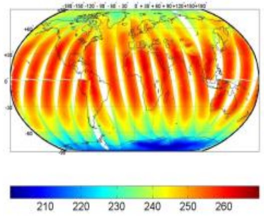
Sounding Channels Monitoring by O-B method

IRAS Data Quality Monitoring

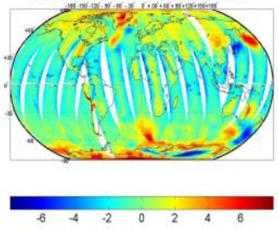
Simulated FY3A-MWTS Bright Temperature of Band 2 With BC

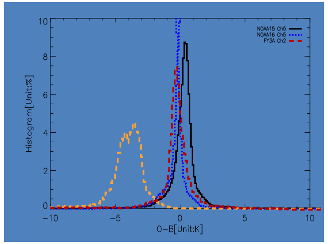


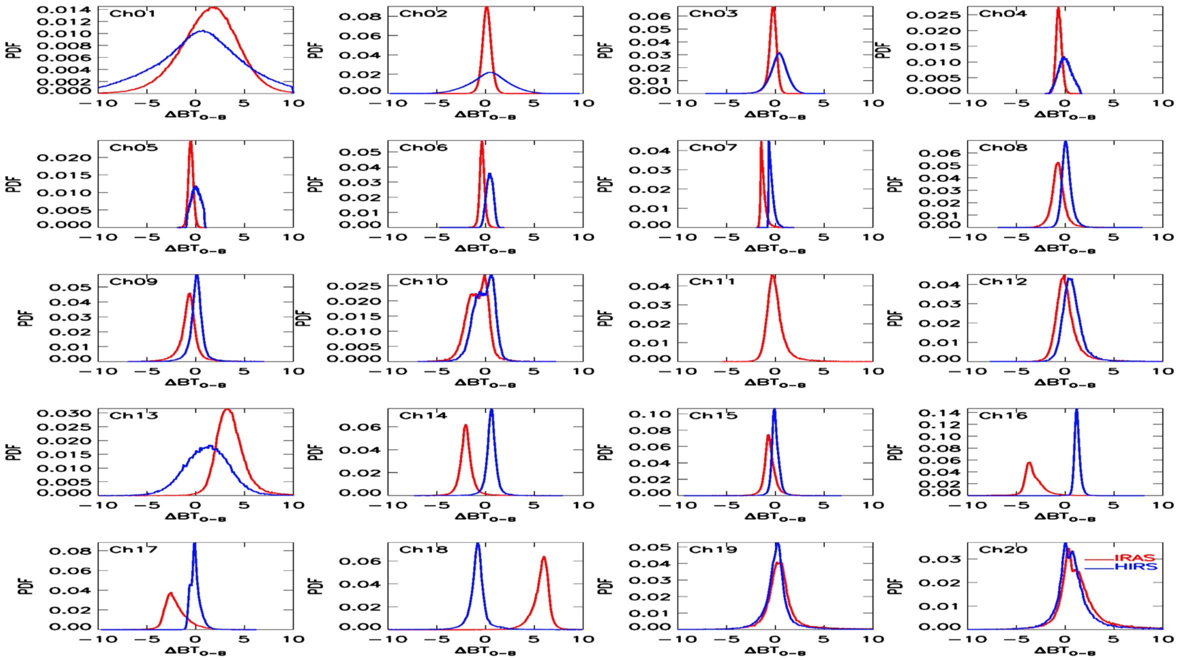
Observed FY3A-MWTS Bright Temperature of Band 2



Diff between OBS and SIMU With BC of Band 2

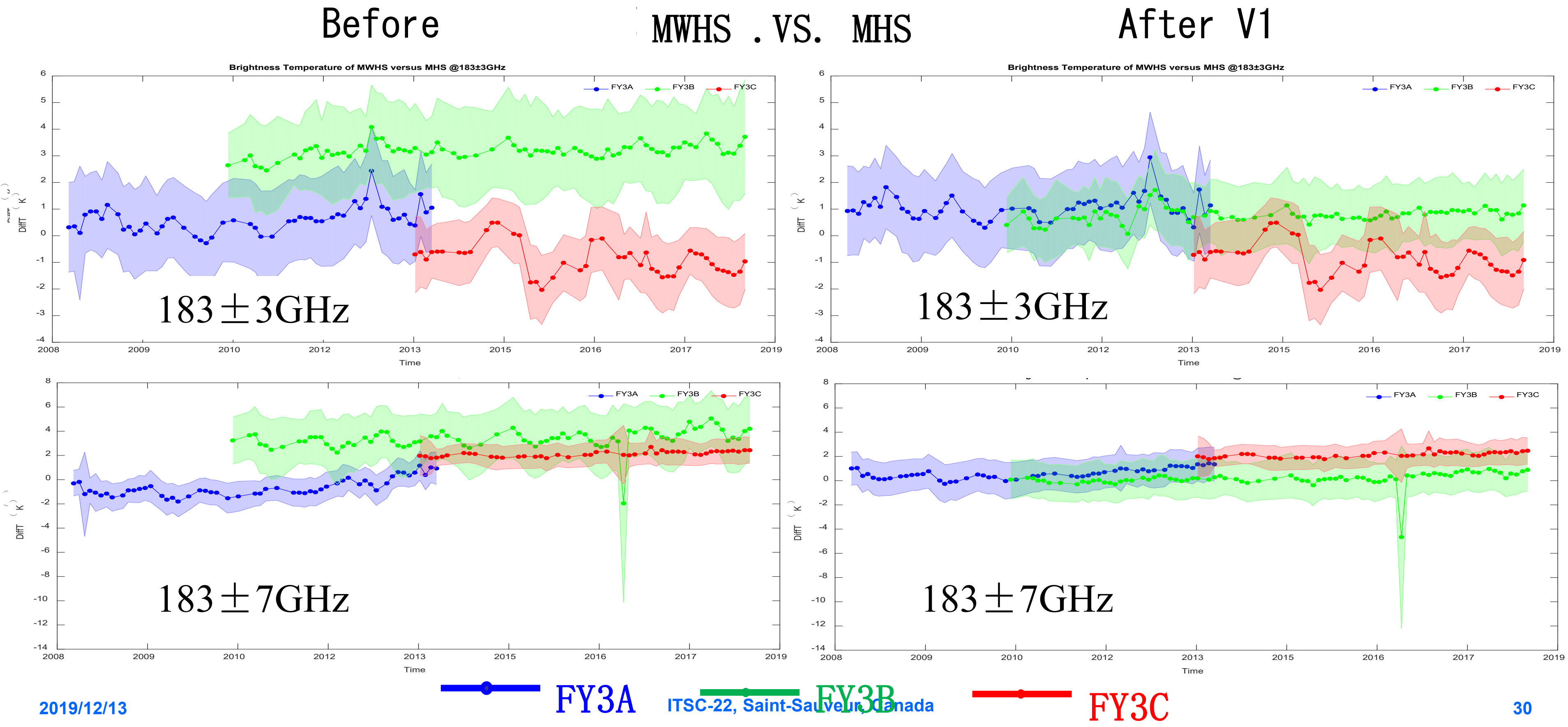






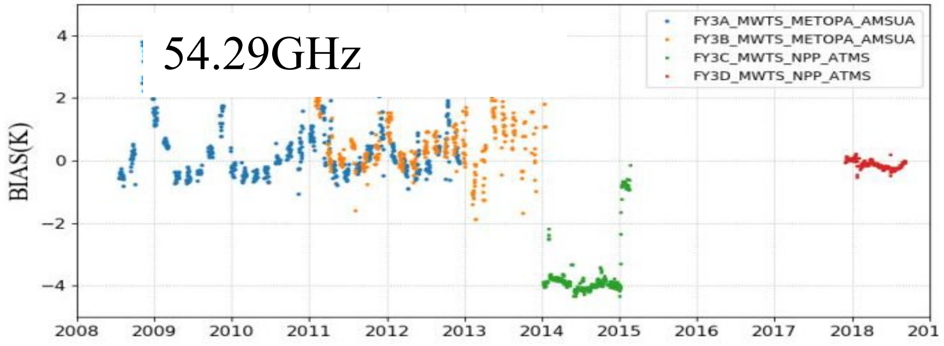
3. Preliminary Progress

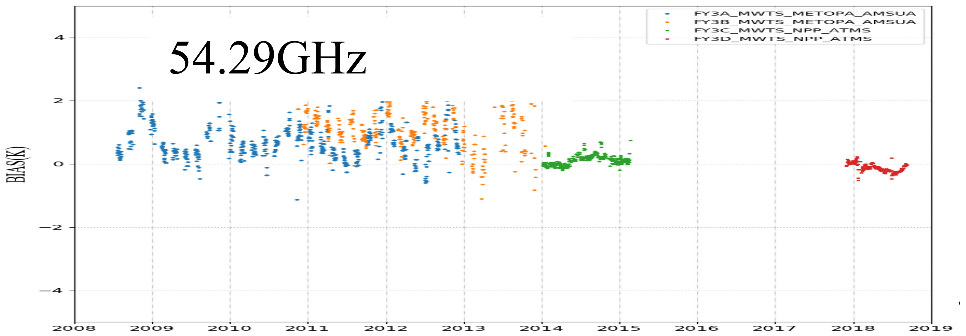
FY-3/MWHS Sounding Ch. Re-calibration by SNO

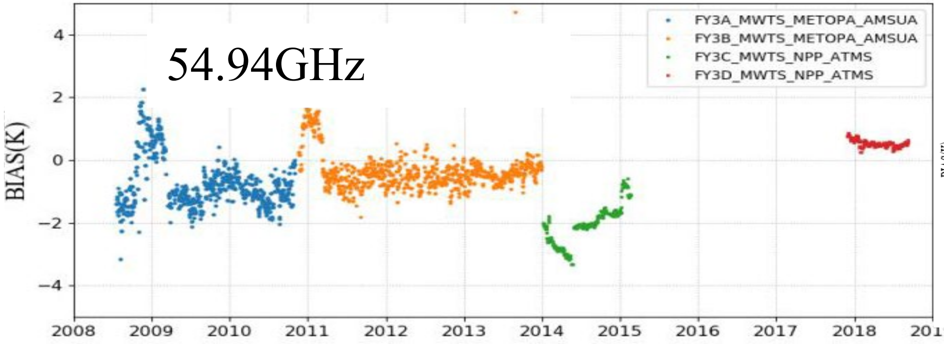


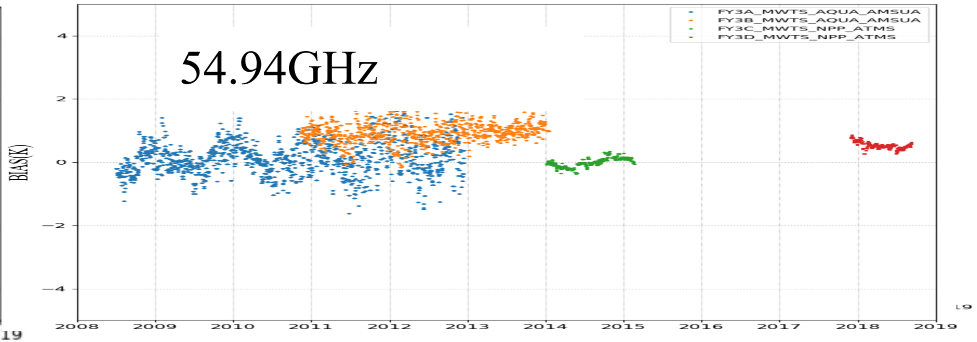
FY-3/MWTS Sounding Ch. by SNO

Before MWTS .VS. AMSUA ATMS After Re-calibration V1



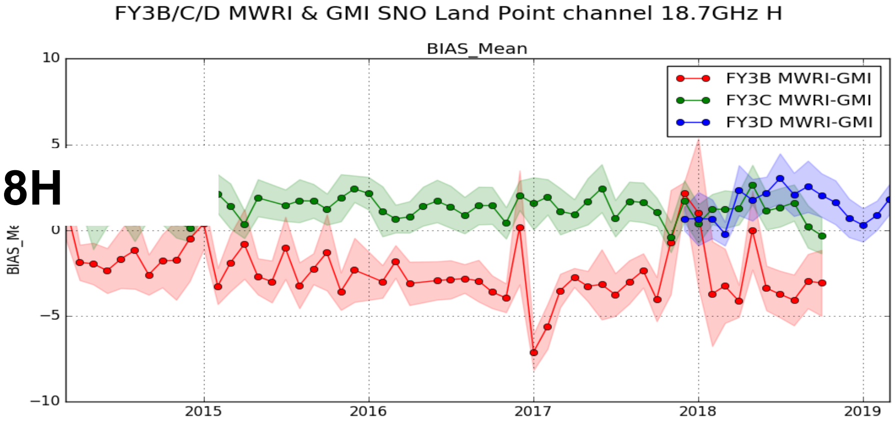


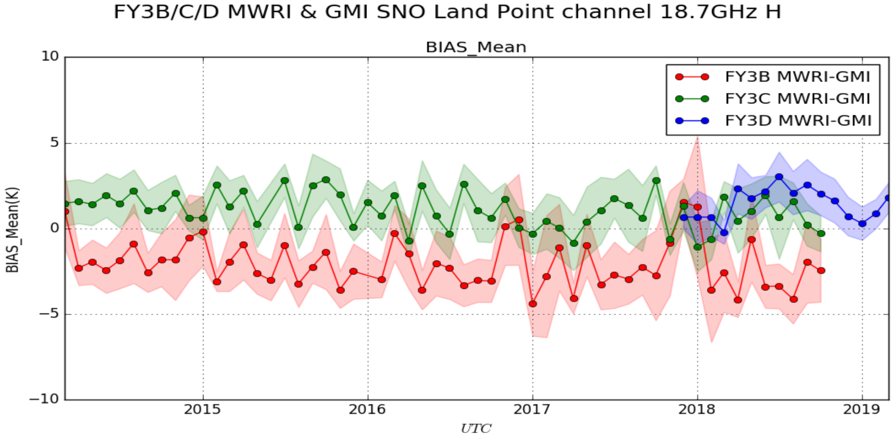




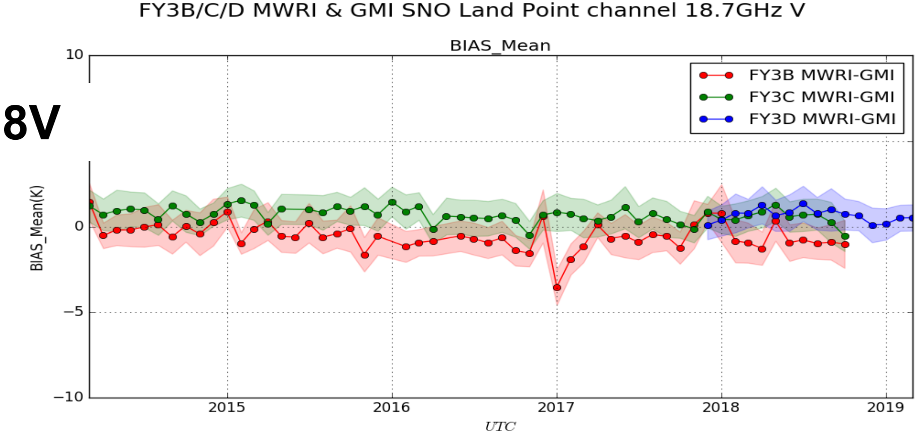
FY-3/MWRI Window Ch. By SNO

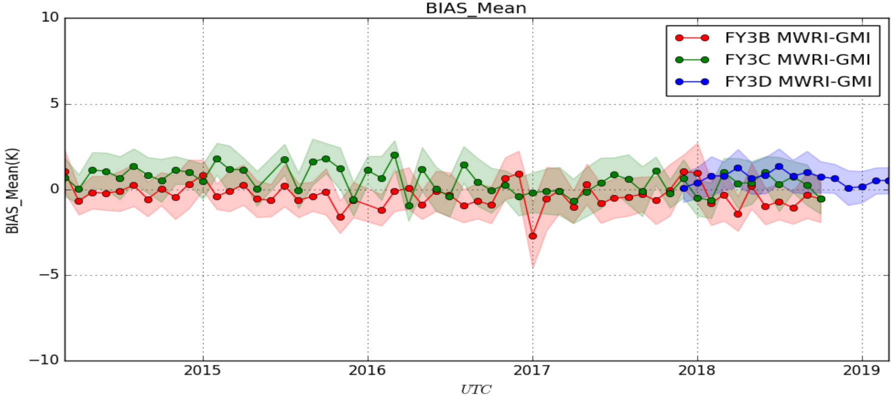
18H





18V





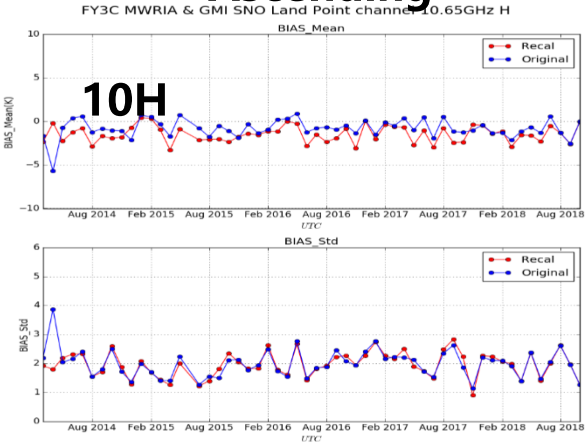
Before

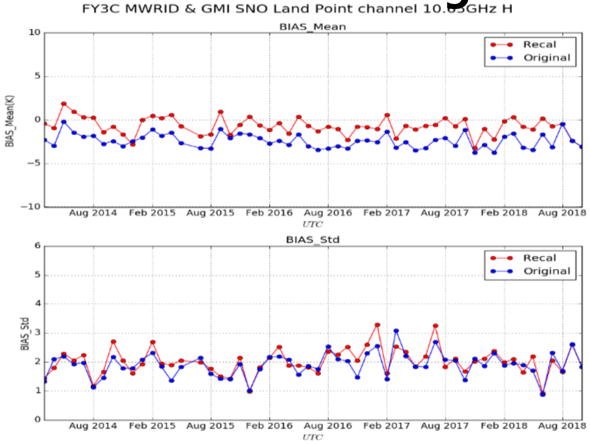
After Re-calibration V1

Ascending

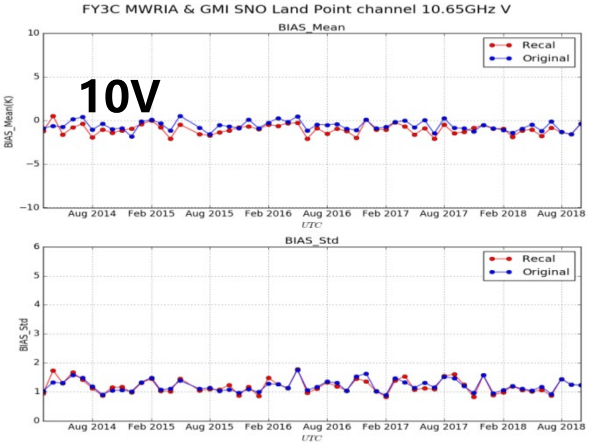
Descending

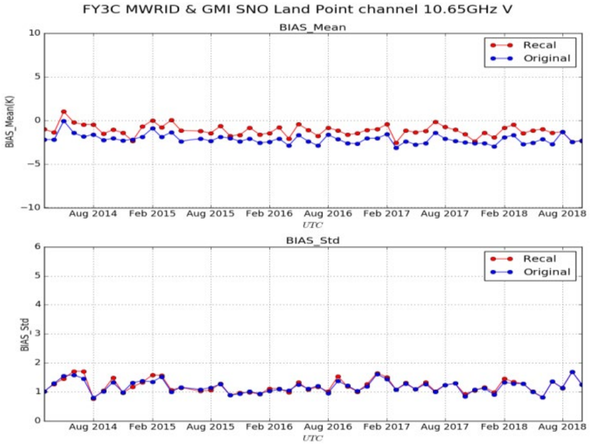
10H





10V

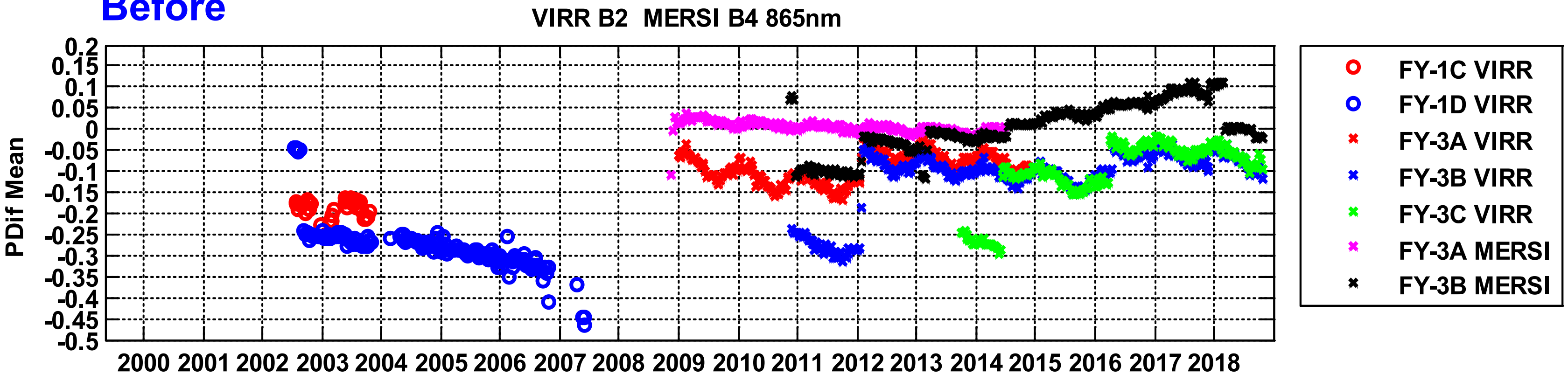




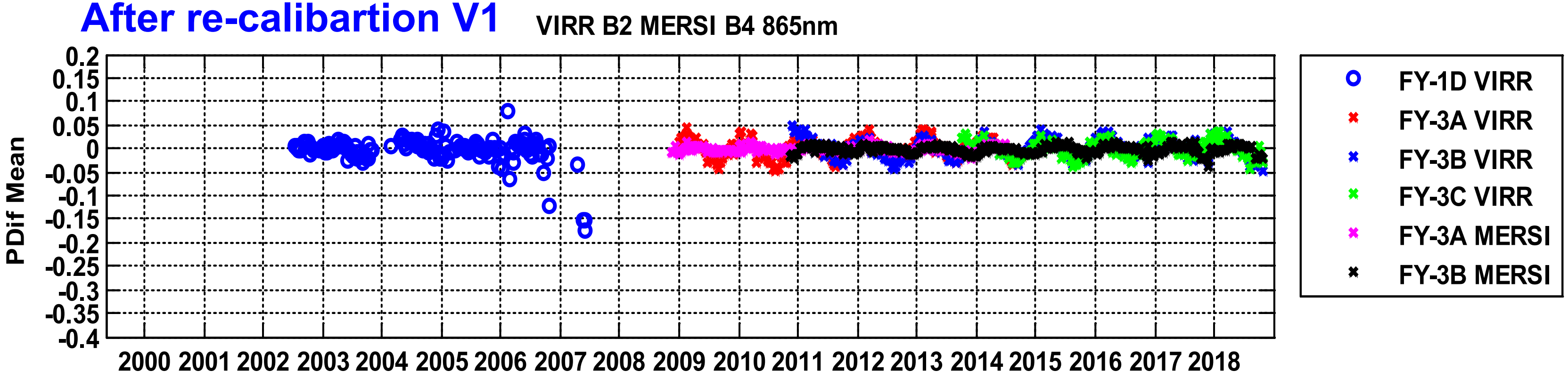
Obviously improved

FY-1C/D/3 VIRR & FY-3 MERSI

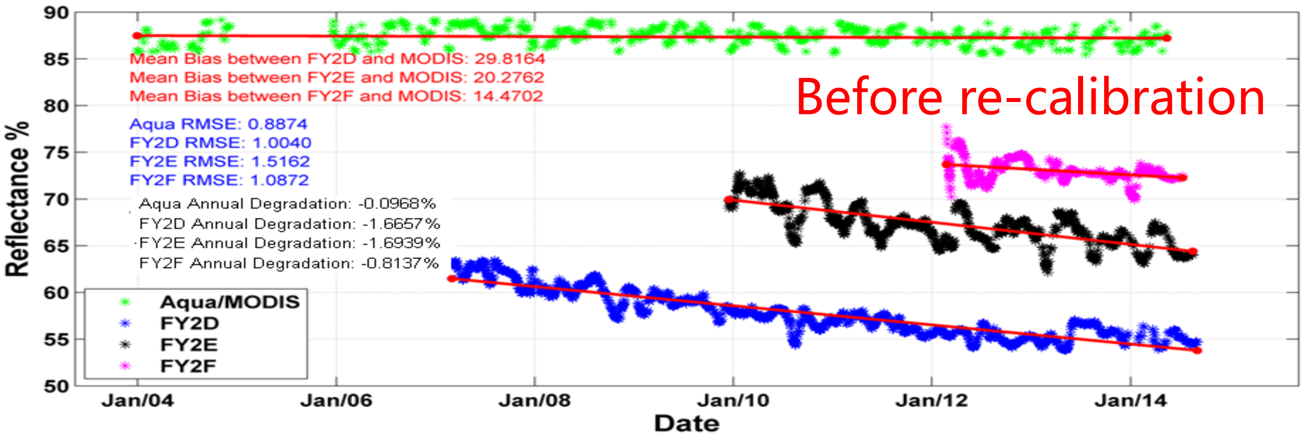
Before



After re-calibartion V1

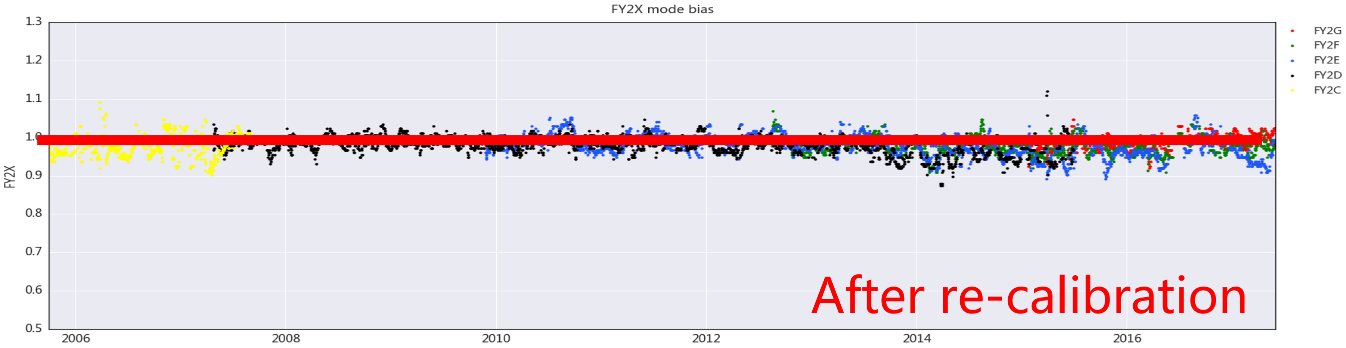


Re-calibration of FY2 VISSR RSB



- **Maximum Difference: 50% to 10%**

FY2C~G Re-processed V1 Normalized DCC Ref



Lin Chen, et al.2016

Project Plan

	任务内容	2018 Q3	2018 Q4	2019 Q1	2019 Q2	2019 Q3	2019 Q4	2020 Q1	2020 Q2	2020 Q3	2020 Q4	2021 Q1	2021 Q2	2021 Q3	2021 Q4	2022 Q1	2022 Q2
课题1	光学载荷历史数据再定标共性技术技术调研																
	地球稳定目标历史辐射基准的建立与关键特性验证			△					◆	△							
	月球源辐射基准的建立及长序列历史定标		◆	△			◆			△	◆		△				
	光学载荷星上定标物理模型的精细重构				□					◆	□						
	遥感仪器长序列衰变规律与机理复合分析				□						□						
	基于参考仪器和辐射基准的多载荷长周期历史数据一致性基准传递技术			△									△				
课题2	微波载荷历史数据再定标共性技术调研																
	微波长序列遥感数据辐射参考基准研究		◆		△		△				△						
	国产卫星微波辐射计辐射响应共性模型研究						□										
	国产卫星微波辐射计寿命期全链路辐射传递共性模型研究					□	◆										
	微波吸收通道基于月球观测的通道间辐射传递技术研究						□		□								
	微波载荷辐射基准交叉传递模型研究						□				◆	□			□		
	国产卫星微波长序列数据再定标结果验证模型研究						□					□			□		
	外场综合观测试验																
	微波共性技术研究课题成果优化凝练及结题准备																
	地球稳定目标微波辐射特征外场观测试验+辐射校正外场试验						◆				◆				□		
课题3	陆地卫星数据再定标重处理技术调研																
	陆地卫星历史数据回溯与评估诊断																
	陆地卫星多光谱数据几何/辐射基准统一技术研究					●测试		◆	□							凝练总结	
	多系列卫星辐射再定标技术研究					◆	●测试			◆							
	陆表典型专题产品生产技术研究						■测试		◆		◆						
	陆地卫星优化再定标处理系统构建																
	陆地卫星初级产品数据集生产、评估、发布										●试用			●正式			
	陆地卫星专题数据集生产、评估、发布										■试用			■正式			
课题4	海洋卫星数据再定标重处理技术调研																
	海洋卫星历史数据数据回溯及评估诊断																
	水色水温扫描仪数据恢复与再定标技术研究					●测试											
	雷达高度计测距延迟校正技术研究					●测试											
	微波散射计数据再定标技术研究					●测试											
	海洋卫星数据再定标与重处理系统构建																
	海洋卫星初级产品数据集生产、评估、发布										●试用			●正式			
	海洋卫星专题数据集生产、评估、发布										■试用			■正式			
课题5	气象卫星再定标与重处理技术调研																
	气象卫星历史数据数据回溯及评估诊断																
	长时间序列气象卫星历史数据地理精度定位技术研究					●测试											
	长时间序列历史数据一致性再定标技术研究					●测试											
	气象卫星长序列典型气候产品处理分析技术研究						■测试										
	PB级历史数据密集型快速重处理平台构建																
	气象卫星初级气候产品数据生产、评估、发布										●试用			●正式			
	气象卫星专题气候产品数据生产、评估、发布											■试用			■正式		
	国产卫星气候与专题数据集共享服务系统构建																

- ◆试验
- △基准
- □模型
- ●初级产品
- ■专题产品

4. Summarization

- There are 7 instruments of 13 Fengyun satellites archived data is under re-calibration.
- First version of FCDR of these 7 instruments is planning to be released in the middle of 2020.
- Refined onboard calibration model, multiple calibration reference or benchmark (PICS, Lunar, DCC, Reference instrument, GRUAN, NWP re-analysis, etc.) are the kernel of re-calibration procedure.
- The users are encouraged to contact us and feedback are appreciated.
- Inter-comparisons are expected with the similar in-dependent space-based FCDR.

Make the data better and easier to use！