PIESAT

Preparation for the assimilation in NWP of new satellite observations on board Chinese meteorological satellite

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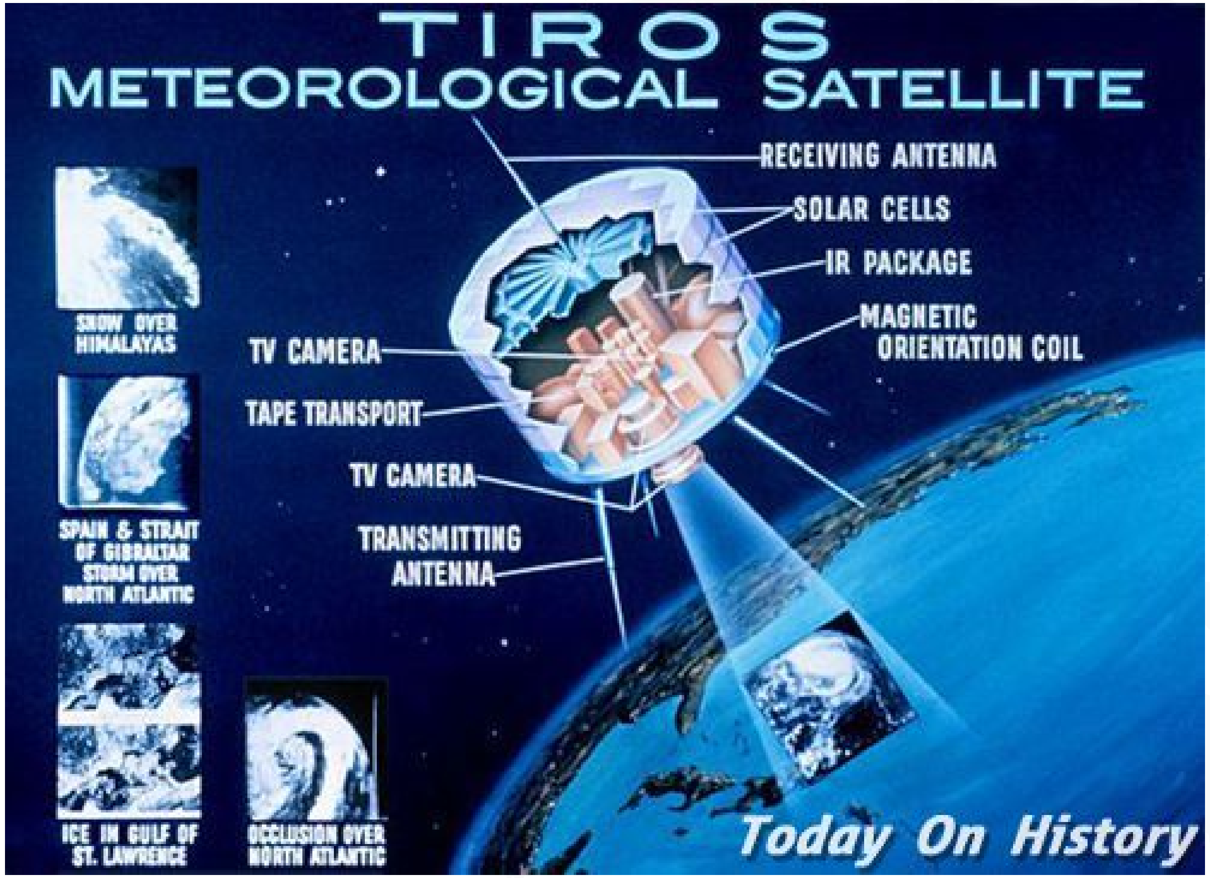
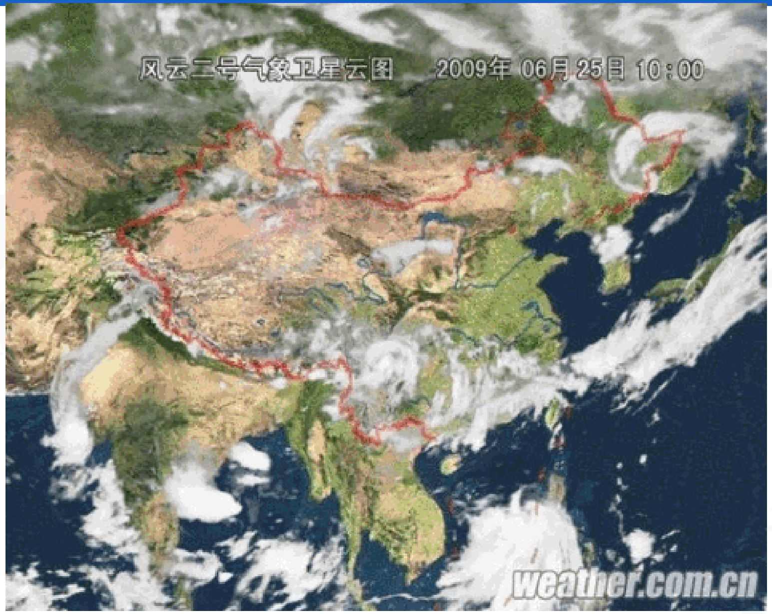
Contents

Contents

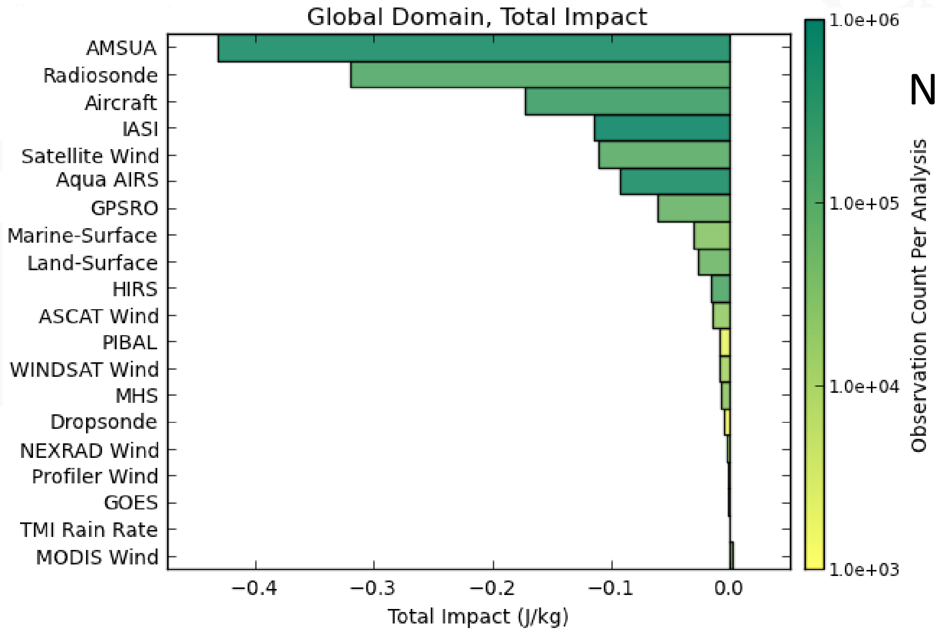
Meteorological satellite plays an important role in the development of meteorological science.



The first meteorological satellite TIROS—1 (1st Apr 1960)



Weather monitor & short-term forecast



Numerical Prediction

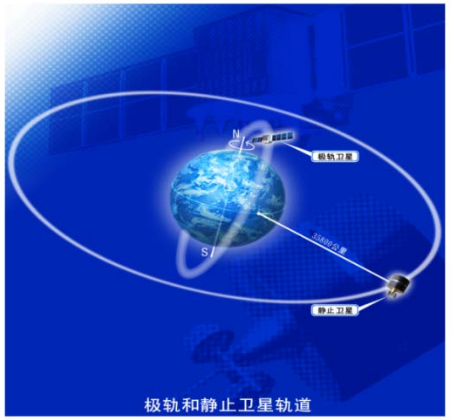
Climate

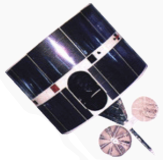
Environment…….

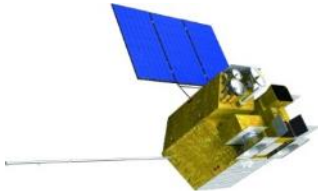
Chinese meteorological satellite have been developing rapidly, especially in recent years.

FengYun Meteorological Satellites

Polar System	Geostationary System
First Generation FY-1 A, B, C, D	**First Generation** FY-2 A, B, C, D, E, F, G, H
Second Generation FY-3 A, B, C, D, E, F, G	**Second Generation** FY-4 A, B, C, D, E
Expected until 2025	Expected until 2030

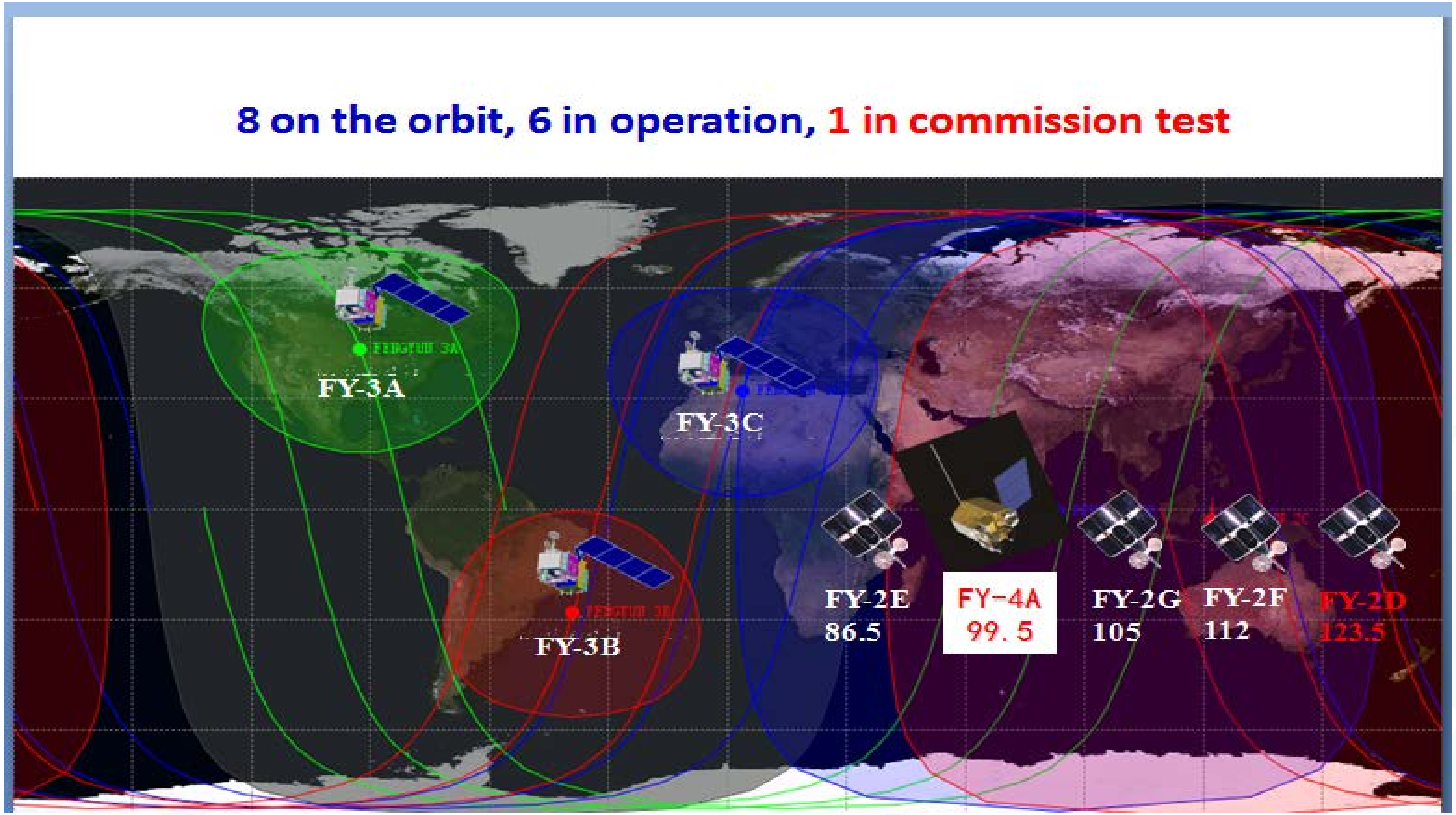






Jun Li, 2017

These satellites provide rich information resource to atmospheric, land and ocean.



Before 2000s : emphasizing to develop the satellite

2000 – 2010 : emphasizing the transition from the R&D to the operational satellite

After 2010s : emphasizing the calibration and validation for the operational satellite

Jun Li, 2017

The sensor on broad the satellite are also developing quickly with many new sensors.

Table 1 Channel number and center frequency for microwave atmospheric sounders

FY-3A/B MWTS/MWHS Channel No.	FY-3C MWTS/MWHTS Channel No.	NOAA MSU Channel No.	NOAA&MetOp AMSUA/AMSUB(MHS) Channel No.	NPP ATMS Channel No.	Centre Frequency (GHz)
				16	88.2
	1		1		89.0
	2				118.75±0.08
	3				118.75±0.2
	4				118.75±0.3
	5				118.75±0.8
	6				118.75±1.1
	7				118.75±2.5
	8				118.75±3.0
	9				118.75±5.0
1(H) 2(V)	10		2		150.0/157.0(MHS)
				17	165.5
3	11		3	22	183.31±1
	12			21	183.31±1.8
4	13		4	20	183.31±3
	14			19	183.31±4.5
5	15		5	18	183.31±7/190.311(MHS)

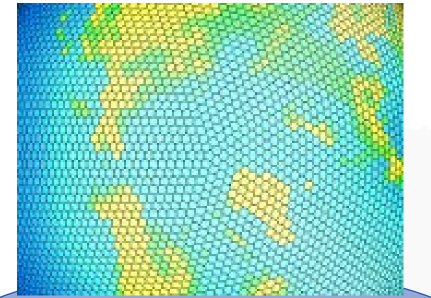
GIIRS: The First Geo. Interferometric Infrared Sounder

	FY-4A (R&D)	FY-4B (Operational)
Spectral Parameters (Normal mode)	Channels Range Resolution LWIR: 700-1130 Cm -1 0.625 689 S/MIR: 1650-2250Cm -1 0.625 961 VIS : 0.55-0.75 μm 1	Range Resolution Channels LWIR: 700-1130 0.625 689 S/MIR: 1650-2250 0.625 961 VIS : 0.55-0.75 μm 1
Spatial Resolution	LWIR/S/MIR : 16Km SSP VIS : 2Km SSP	LWIR/S/MIR : 8Km SSP
Operational Mode	China area 5000 × 5000 Km² Mesoscale area 1000 × 1000 Km²	China area 5000 × 5000 Km² Mesoscale area 1000 × 1000 Km²
Temporal Resolution	China area <1 hr Mesoscale area <½ hr	China area <1 hr Mesoscale area <½ hr
Sensitivity (mW/m2sr cm-1)	LWIR: 0.5 -1.1 S/MIR: 0.1-0.14 VIS: S/N>200(ρ=100%)	LWIR: 0.3 S/MIR: 0.06
Calibration accuracy	1.5k (3σ) radiation	1.0k (3σ)
Calibration accuracy	10 ppm (3σ) spectrum	5 ppm (3σ)
Quantization Bits	13 bits	13 bits

Jun Li, 2017

It present great opportunity, together with challenge for the application of these observation.

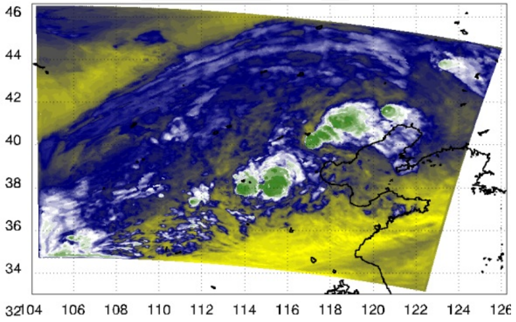
Radiance Transfer Model



Model variables

Observation operator

Simulated observation



Cloud examination

Bias correction

$$BC_{total} = BC_{scan} + BC_{air\ mass}$$

$$BC_{air\ mass} = \sum_{i=1}^{N} \beta_i P_i(x)$$

Window channel is used to do cloud examination and satellite observation based CLW estimation is utilized as one of the predictors of bias correction. While,

Table 1 Channel number and center frequency for microwave atmospheric sounders

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			1	1	23.8
			2	2	31.4
1	1	1	3	3	50.3
	2			4	51.76
	3		4	5	52.8

Contents

02 PIE Package

Development Course

2016 ~ ——PIE 4.0

Underlying architecture optimizing

Concentrated code carding

RS-GIS platform integration

Multi-source data fusion and interpretation

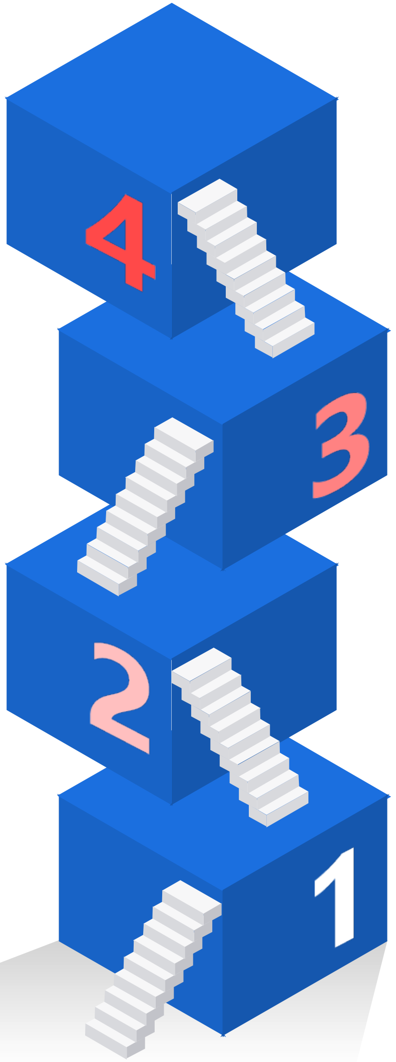
Cross-platform , support domestic soft-hardware platform

2010~2012——PIE 2.0

Interface reconstruction

Enrich remote sensing function

Industry tool package



2013~2015——PIE 3.0

Framework restructuring Algorithm cross-platform

Secondary development Multi-languages

Integration project application

2008~2009——PIE 1.0

Software prototype development

Basic function development

PIE4.0 Product Capabilities

2.1 Full flow operation chain capability

2.2 High efficiency and accuracy in optical mapping & reprocessing

2.3 Strong ability in information extraction & interpretation

2.4 Hyperspectral data processing

2.5 Microware data processing

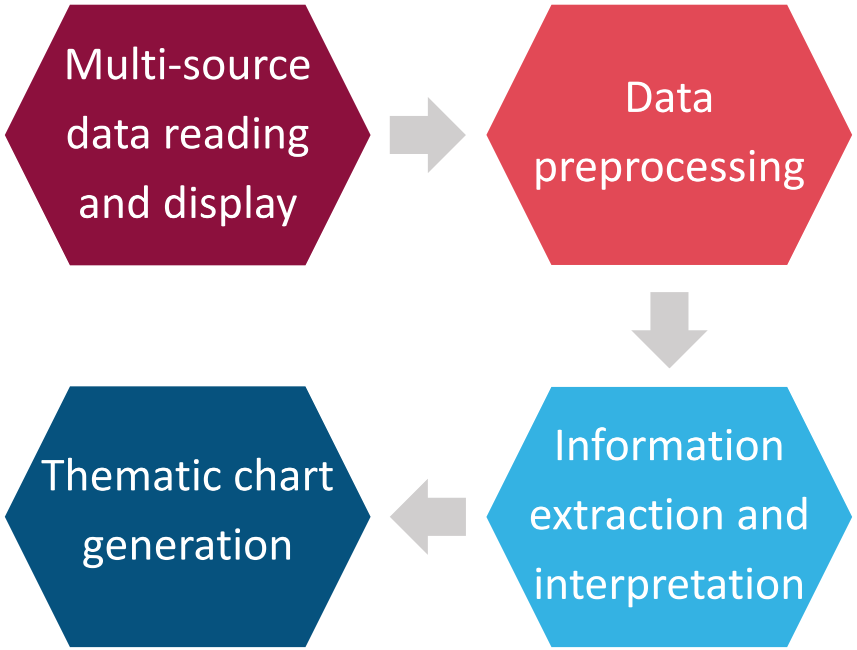
2.6 LiDAR data processing

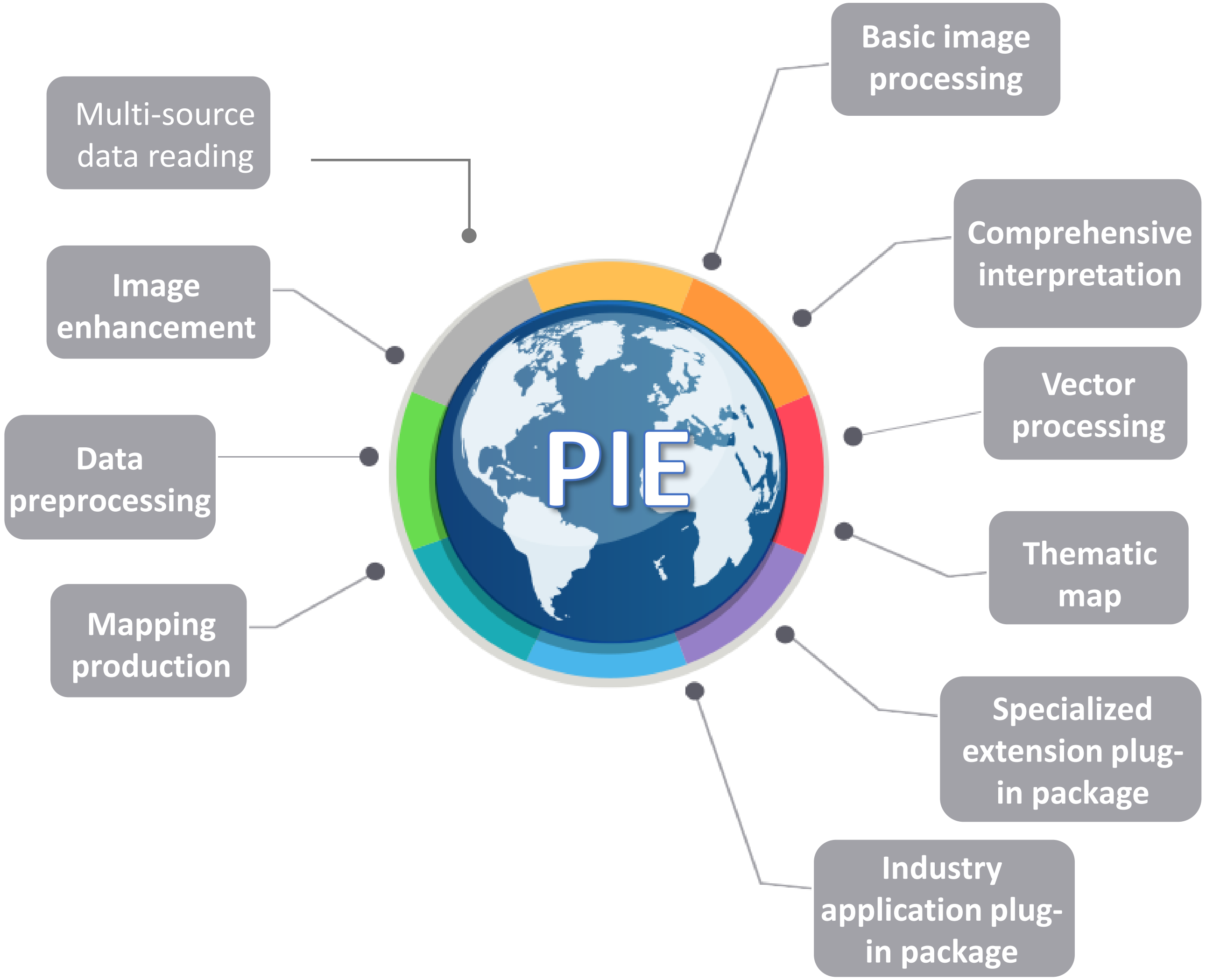
2.7 UAV data processing

2.8 Convenient secondary development wizard

2.1 Full Flow Operation Chain Capability

Integration solution





2.2 High Efficiency and Accuracy in Optical Mapping & Preprocessing

Optical mapping & Preprocessing

★ Easy to use, high efficiency and accuracy

★ Various adjustment methods

★ DSM\DEM production

★ Multi-model color balance

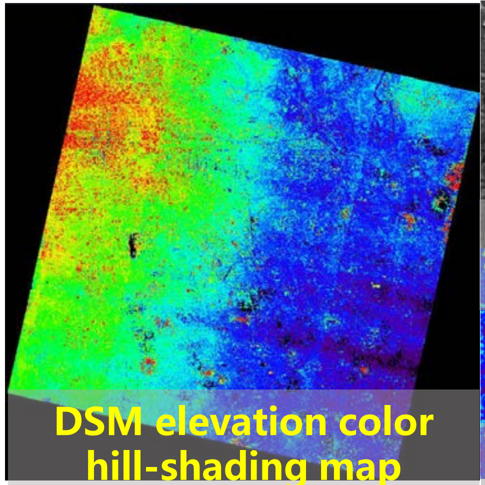
★ Intelligent image mosaic

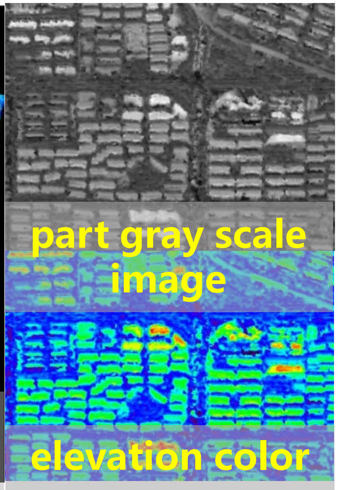
★ Fast sensor extension

Radiometric Correction → Image matching → Region adjustm

Ortho-rectification → DEM production

Image fusion → Color balance → Image mosaic





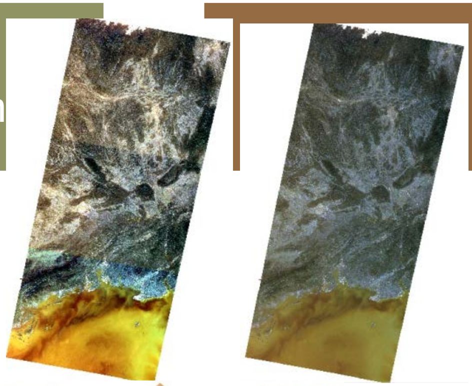
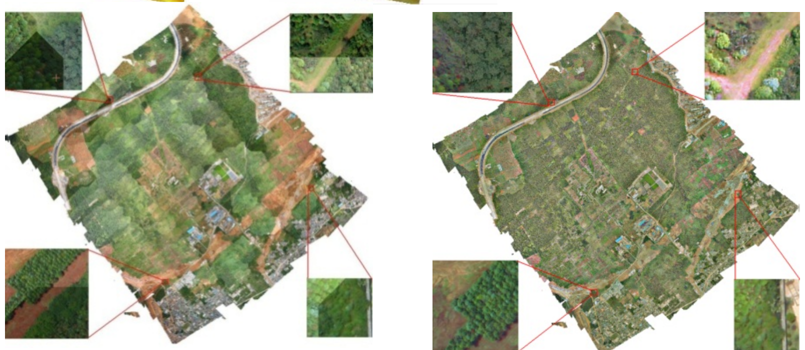


Image color balancing

(left: before color balancing ; right : after color balancing)

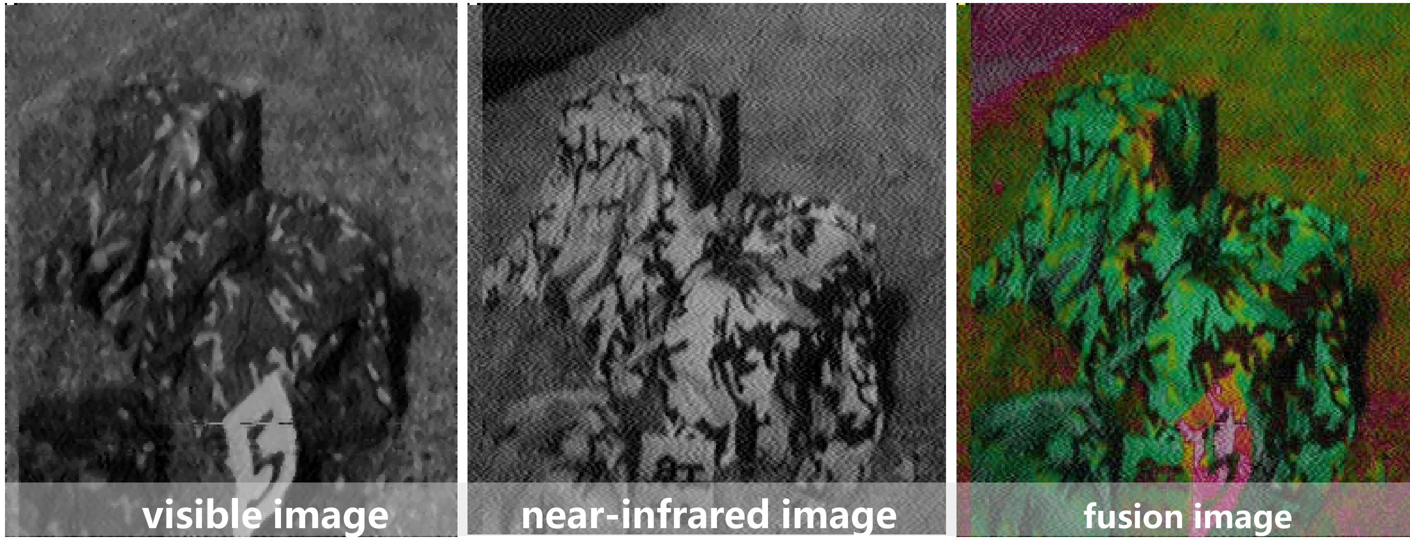


2.3 Strong Ability in Information Extraction & Interpretation

Multi-type/source data fusion and interpretation

★multi-source data spatial fusion: multi-source combined adjustment, multi-source registration

★multi-source data information fusion：pixel-level fusion, feature-level fusion, decision-level fusion



2.4 Hyperspectral Data Processing Capabilities

Hyperspectral data basic processing

★ spectrum browser

★hyperspectral data preprocessing

radiometric calibration

atmospheric correction

geometric correction

★ data noise reduce

bad line repairing

destriping

SMIL effect wiping-off

MNF noise reduction

★ spectral analysis

spectral unmixing

spectral filtering

endmember extraction

……

★ hyperspectral classification

binary coding

spectral angle mapper

……

★ image spectral cube

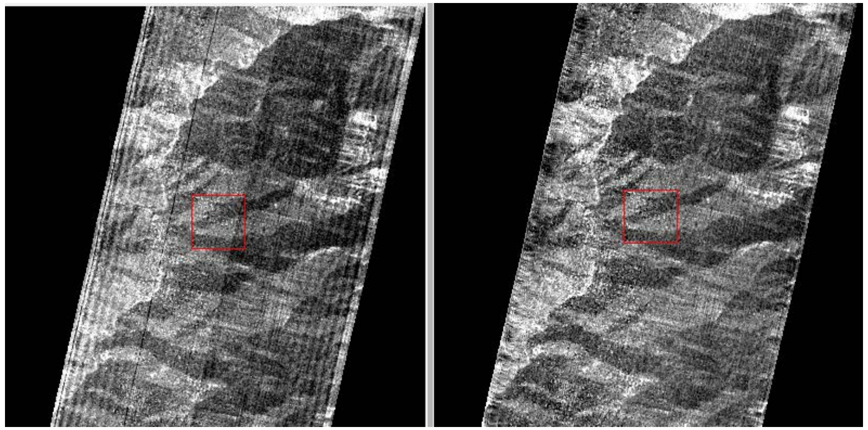
★ spectral resampling

★ continuum removal

★ RXD anomaly detection

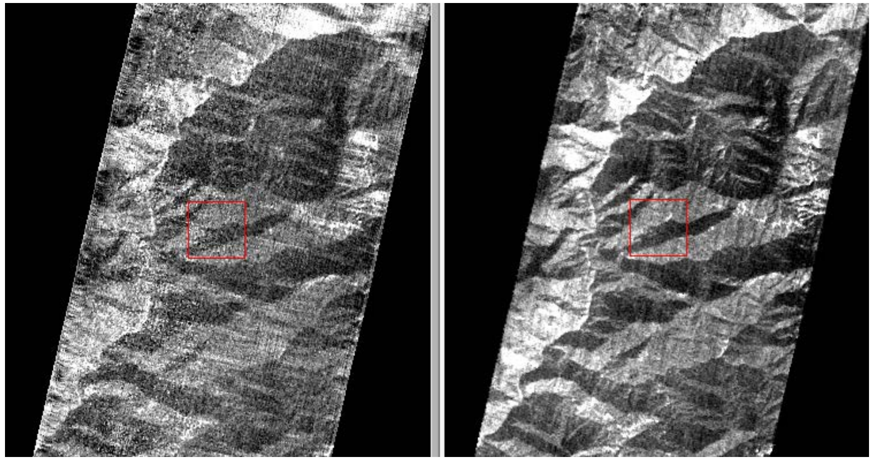
★ data compression/data decompression

……



bad line and stripe wiping

(left: before , right: after)



MNF noise reduction

(left: before , right: after)

2.4 Hyperspectral Data Processing Capabilities

Advanced processing of hyperspectral data

★ **spectral feature analysis**

band order histogram

★ **spectral feature selection**

multi-band spectral line analysis

multi-band spectrum rearrangement

multi-parameter analysis of spectrum

related matrix analysis

regression skewness analysis

divergence-deviation analysis

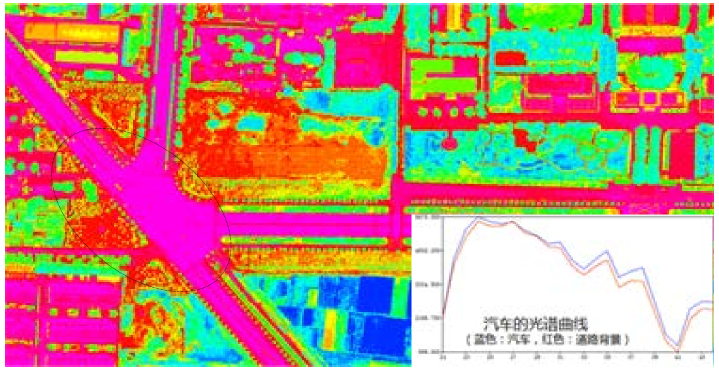
characteristic matrix analysis

★ **spectral feature extraction**

2-D related color coding

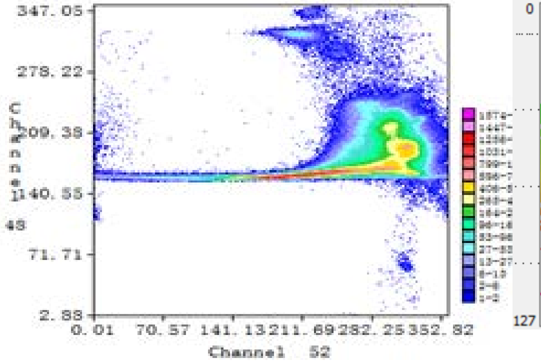
PCA

primitive hyperspectral data

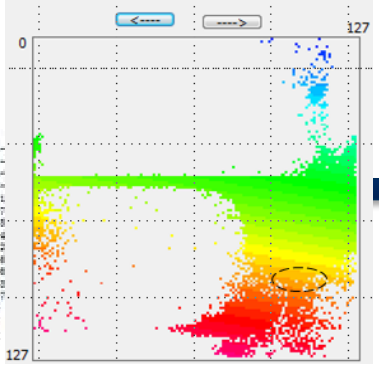


normal extraction result

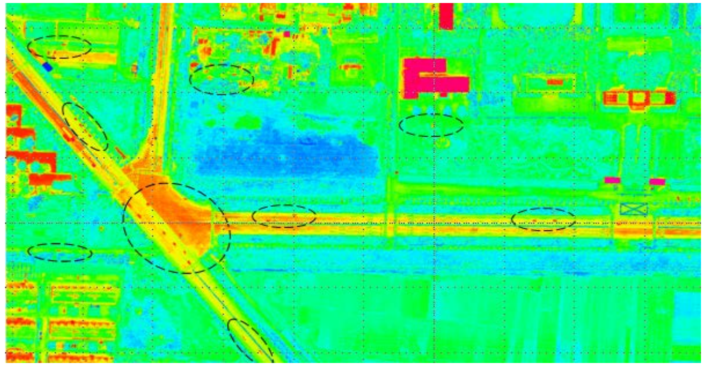
Fourier analysis



2-D point array analysis



2-D color coding extraction



vehicle extraction result

2.5 Microwave Data Processing Capabilities

General processing of SAR data

data I/O
- space-borne SAR data input
- air-borne SAR data input
- binary data input
- data output

basic processing
- band extraction
- multi-look processing
- plural format converting
- image clipping
- image rotation and mirror

radiometric processing
- image enhancement
- radiometric calibration
- terrain radiometric correction
- image filtering
- texture analysis

geometric processing
- image registration
- slant range to ground range
- geometric correction
- projection conversion
- image mosaic

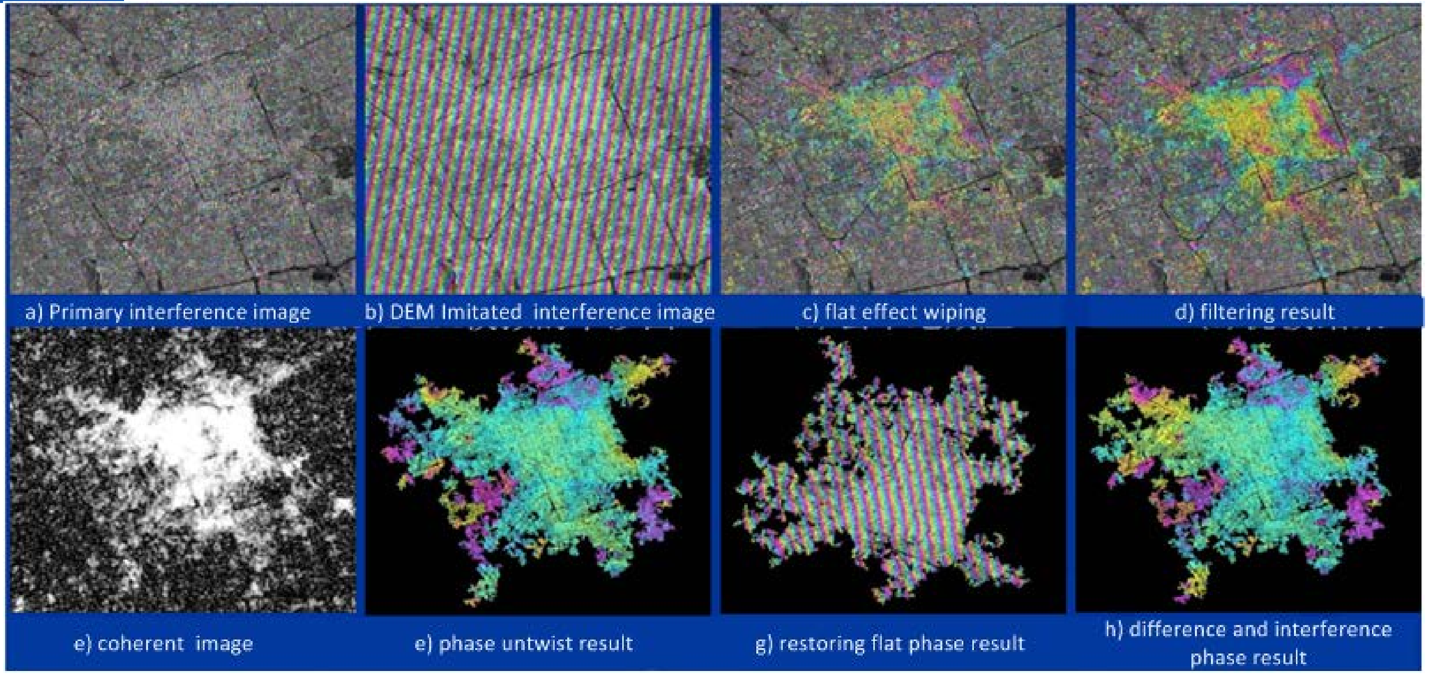
polarization processing
- polarimetric matrices generation
- polarimetric matrices transformation
- change of polarimetric basis
- polarization synthesis
- polarimetric filtering
- polarimetric decomposition
- PolSAR classification

2.5 Microwave Data Processing Capabilities

Advanced processing of SAR data

InSAR&D-InSAR

- base line estimation
- interference image generation and flat effect wiping
- interference image filtering and coherent computing
- phase unwrapping
- phase editing
- track refinement and flat effect re-wiping
- phase to elevation and geocoding
- phase to deformation and geocoding
- ……



- DEM（InSAR）
- surface deformation monitoring（D-InSAR）

2.5 Microwave Data Processing Capabilities

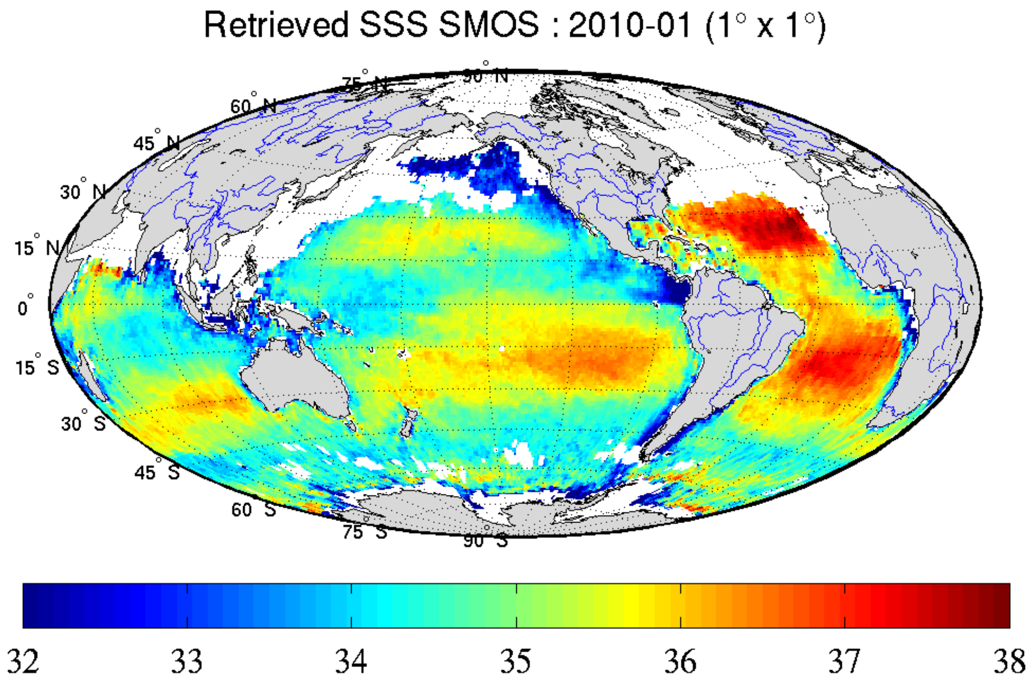
Sea parameters inversion using space-borne microwave scatterometer

★ AMSR-E/AMSR2/Windsat/HY2A sea parameters inversion

- sea surface temperature
- wind speed
- atmosphere moisture content
- atmosphere route delay
- liquid water content of cloud, precipitation

★ salinity remote sensing

- brightness temperature simulation research
- multi-angle inversion of salinity
- calibration and data analysis technology



2.6 LiDAR Data Processing Capabilities

Basic processing of LiDAR data

★ **LiDAR data browsing**

support ASCII, Las etc. common point cloud file,image,3D model

symbolic rendering of point cloud by the category and elevation

★ **LiDAR data processing**

point cloud denoising

automatic filtering, classification and manual edit of point cloud

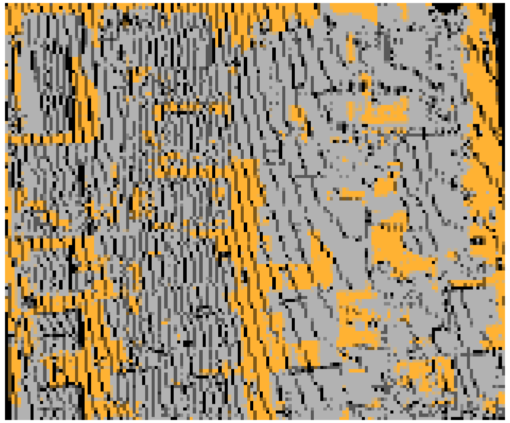
DEM, DSM, nDSM production

point cloud clipping

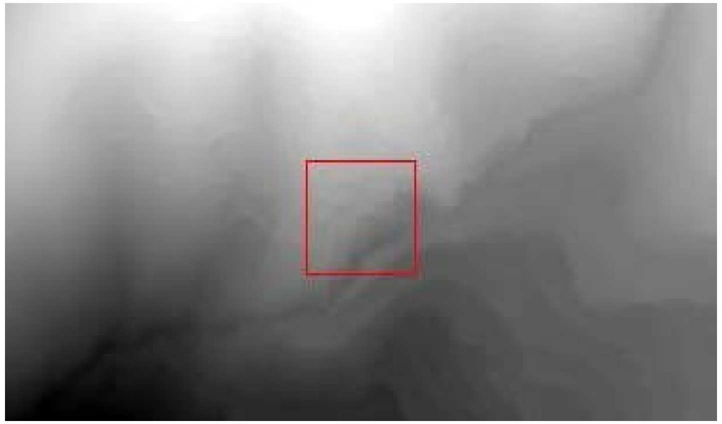
point cloud data analysis

section analysis

3D measurement

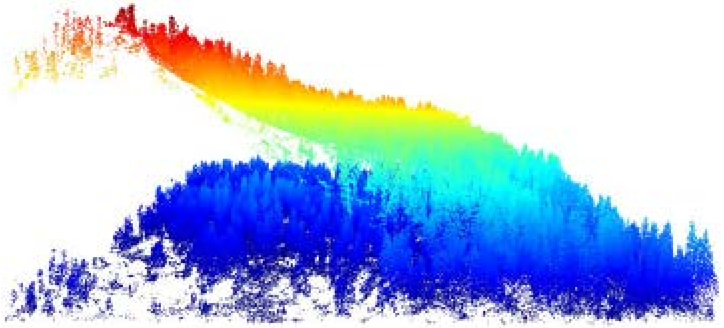


filtering



DEM

red points represent noise



nDSM point cloud

2.6 LiDAR Data Processing Capabilities

Advanced processing of LiDAR data

★ building extraction and 3D modeling

building point cloud extraction

roof plane slice division

building model

automatic modeling

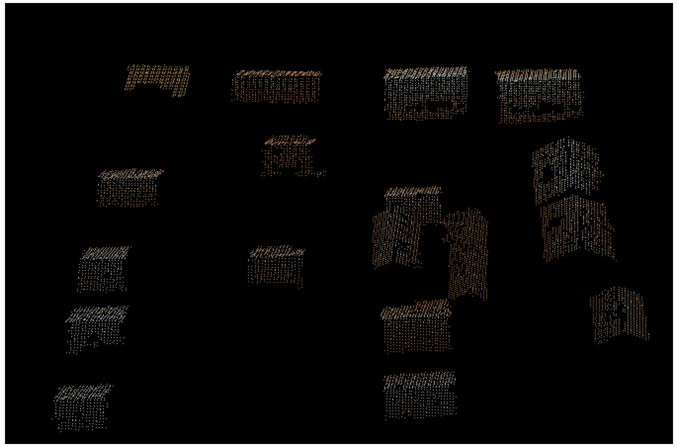
★ electricity

safety distance analysis

work condition simulation

cross-astride point extraction

electricity line vectorization



building point cloud extraction

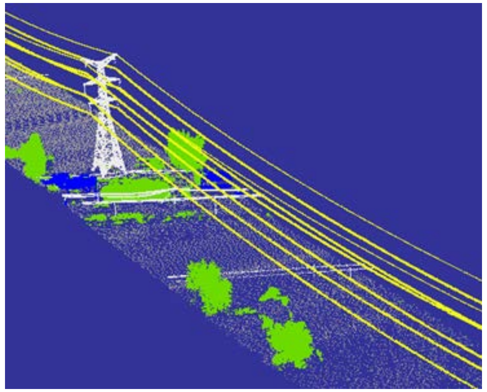
modeling

★ vegetation structure parameter and extraction

statistics parameter extraction

regression model

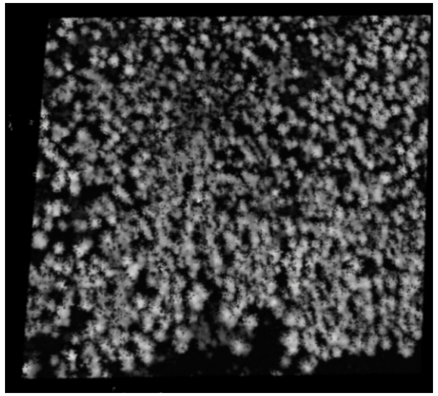
single tree segmentation



electricity line

X	Y	tree height	crown diameter	crown area
608946.4	4265902	14.89870644	4.145931721	13.5
608957.4	4265904	11.91897678	3.090194941	7.5
608949.9	4265905	15.33765697	4.370195389	15
608969.9	4265906	12.03290558	4.333624363	14.75
608938.4	4265906	16.16638374	4.548643589	16.25
608970.4	4265908	10.45675373	2.111005068	3.5
608975.9	4265909	13.63699532	2.646284819	5.5
608962.4	4265910	15.27049923	4.222010136	14
608988.4	4265912	14.41033936	4.820439816	18.25
608970.4	4265912	10.1274929	3.090194941	7.5
608955.4	4265913	2.382050514	0.564189851	0.25
608985.9	4265913	12.29161167	2.185097694	3.75
608943.9	4265918	10.64956284	3.33779192	8.75
608951.9	4265915	2.471440554	0.564189851	0.25

single tree parameter



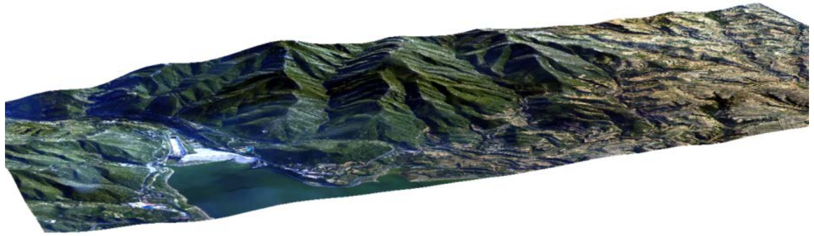
CHM

2.7 UAV Data Processing Capabilities

UAV image processing

★ fast processing UAV image by one-click image stitching,

capable to generate DOM,DEM,3D landscape products



UAV video processing

★ process UAV video in real time

video stitching

mobile target tracking

video auto stability

video location

2.8 Convenient Secondary Development Wizard

Highly mature SDK

★ PIE micro-kernel compiled by C++ which follows cross-platform standard, can deploy on Windows, UNIX/Linux, Mac OS.

★ support multiple API form, can be developed by C++, C#, Python, Lua, etc.

★ provide guide for secondary development, can create remote sensing application solution quickly.

support multiple operation system
- Windows
- UNIX
- Linux
- Mac OS

support multiple developing language
- C/C++、C#
- Java
- VB、Delphi
- Python、JavaScript、Lua

support multiple developing platform
- Visual Studio 2005/2008/2010/2013
- Borland Delphi Stduio、Borland C++ Builder
- Eclipse、CodeBlocks、QT Creator
- ......

support multiple hardware platform
- 32bit、64bit CPU
- Multi-core CPU/GPU

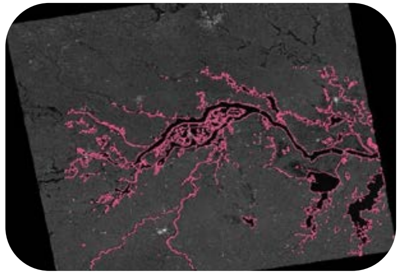
multiple developing language algorithm integration
- ENVI IDL
- Matlab
- Fortran

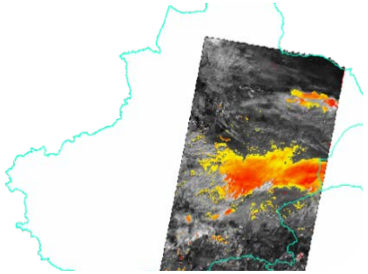
multiple secondary developing mode
- guided development by existed formwork
- function calling by self-set formwork
- third part module and procedure integration(parallel)

Disaster Reduction Application

Disaster monitoring and assessment

- ★ flood monitoring
- ★ landslide and debris flow monitoring
- ★ fire monitoring
- ★ snow monitoring
- ★ sand and dust monitoring
- ★ major road damage monitoring
- ★ house monitoring
- ★ victims settled point monitoring


flood information extraction

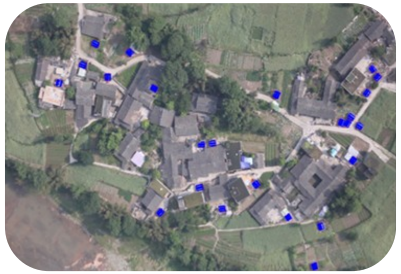

sand storm strength distribution


fire point extraction


debris flow automatic extraction


major road damage

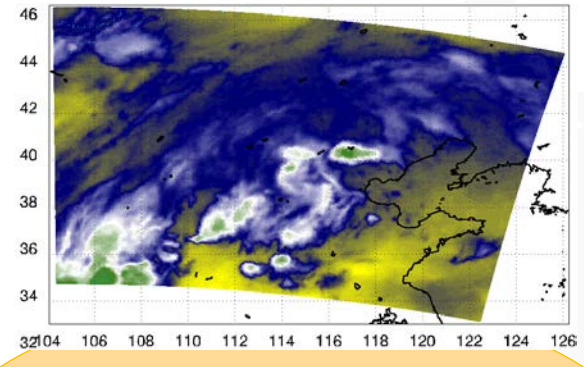

house extraction


victims settled point monitoring

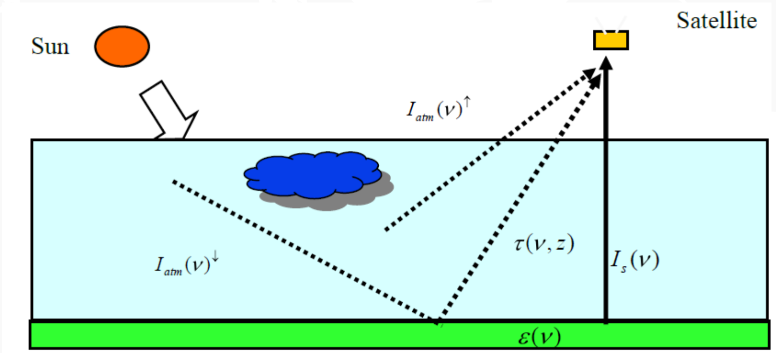
Content

03 Rapid radiative transfer model with support to new sensor

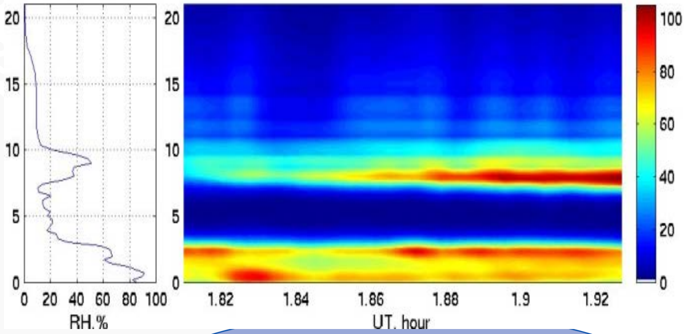
Radiative Transfer Mdel (RTM)– Link of satellite observation and model variables



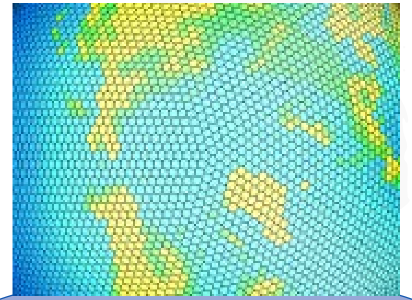
Satellite observation
R^0



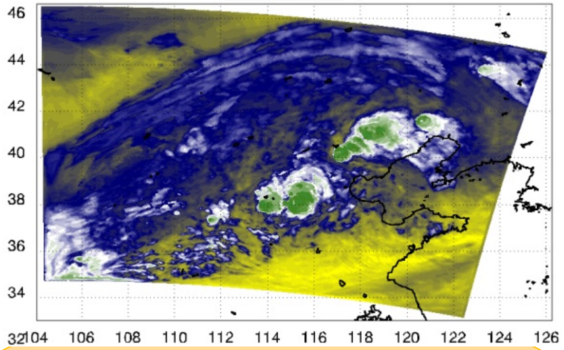
Radiative Transfer Model
R=H(X)
Taking account of spectral characteristic of satellite sensor and atmospheric radiation, absorption and scattering etc.



Retrieval variables
$Xr=H^{-1}(R)$



Model variables
X



Simulated observation
R^S

(https://en.wikipedia.org/wiki/Atmospheric_radiative_transfer_codes)

Name	Website	References	UV	Visible	Near IR	Thermal IR	mm/sub-mm	Microwave	line-by-line/band	Scattering	Polarised	Geometry	License	Notes
MODTRAN	[21]	Berk et al. (1998) [22]	$\tilde{\nu}<50,000\ cm^{-1}$	Yes	Yes	Yes	Yes	Yes	band or line-by-line	Yes	?		proprietary commercial	solar and lunar source, uses DISORT
MOSART	[22]	Cornette (2006) [23]	$\lambda>0.2\ \mu m$	Yes	Yes	Yes	Yes	Yes	band	Yes	No		freely available	
PUMAS	[23]		Yes	Yes	Yes	Yes	Yes	Yes	Line-by-line and correlated-k	Yes	Yes	plane-parallel and pseudo-spherical	Free/online tool	
RFM	[24]		No	No	No	Yes	No	No	line-by-line	?	?		available on request	MIPAS reference model based on GENLN2
RRTM/RRTMG	[25]	Mlawer, et al. (1997) [24]	$\tilde{\nu}<50,000\ cm^{-1}$	Yes	Yes	Yes	Yes	$\tilde{\nu}>10\ cm^{-1}$		?	?		free of charge	uses DISORT
RTMOM	[26][dead link]		$\lambda>0.25\ \mu m$	Yes	Yes	$\lambda<15\ \mu m$	No	No	line-by-line	Yes	?	plane-parallel	freeware	
RTTOV	[27]	Saunders *et al.* (1999) [25]	$\lambda>0.4\ \mu m$	Yes	Yes	Yes	Yes	Yes	band	Yes	?		available on request	
SBDART	[28][dead link]	Ricchiazzi *et al.* (1998)	Yes	Yes	Yes	?	No	No		Yes	?	plane-parallel		uses DISORT

The list of atmospheric radiative transfer codes

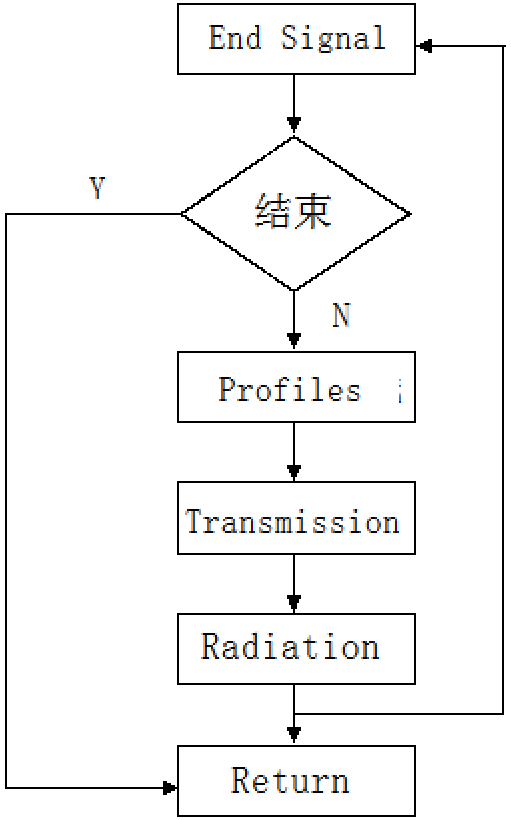
This table is incomplete. *(August 2016)*

Name	Website	References	UV	Visible	Near IR	Thermal IR	mm/sub-mm	Microwave	line-by-line/band	Scattering	Polarised	Geometry	License	Notes
4A/OP	[1]	Scott and Chédin (1981) [3]	No	No	Yes	Yes	No	No	line-by-line	?	?		freeware	
6S/6SV1	[2]	Kotchenova et al. (1997) [4]	No	Yes	No	No	No	No	band	?	Yes			non-Lambertian surface
ARTS	[3]	Buehler et al. (2005) [5]	No	No	No	Yes	Yes	Yes	line-by-line	Yes	Yes	spherical 1D, 2D, 3D	GPL	
BTRAM	[4]	Chapman et al. (2009) [6]	No	Yes	Yes	Yes	Yes	Yes	line-by-line	No	No	1D, plane-parallel	proprietary commercial	
COART	[5]	Jin et al. (2006) [7]	Yes	Yes	Yes	Yes	No	No		Yes	No	plane-parallel	free	
CRM	[6]		No	Yes	Yes	Yes	No	No	band	Yes	No		freely available	Part of NCAR Community Climate Model
CRTM	[7]		No	Yes	Yes	Yes	No	Yes	band	Yes	?			

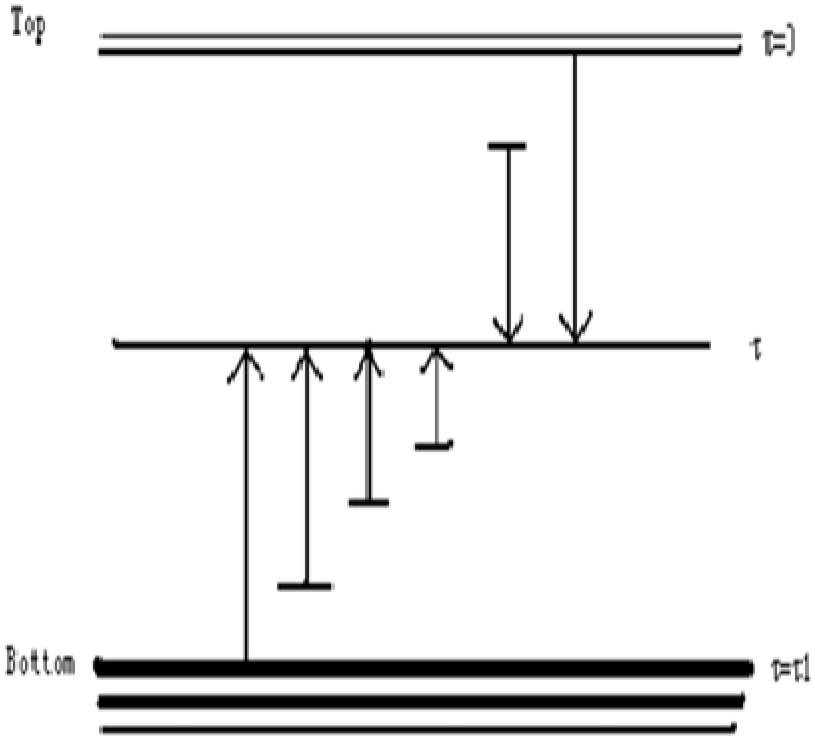
The calculation of transmission is the core of radiative transfer equation

Radiative transfer equation

$$L^{Clr}(\nu,\theta)=\tau_s(\nu,\theta)\varepsilon_s(\nu,\theta)B(\nu,T_s)+\int_{\tau_s}^{1}B(\nu,T)d\tau+(1-\varepsilon_s(\nu,\theta))\tau_s^2(\nu,\theta)\int_{\tau_s}^{1}\frac{B(\nu,T)}{\tau^2}d\tau$$



Flowchart of radiative transfer model



Absorption coefficient and transmission

- Transmission $T_v = \exp(-\tau_v)$
- Optical depth $\tau = \int_u^{u_1} k_v du$
- Absorption coefficient $k_v = Sf(v - v_0)$
- optical path (optical mas) $u = \int_{z_1}^{z_2} \rho(z) dz$

LINE-BY-LINE Radiative transfer model

The absorption coefficient is associated with different gaseous molecules, that has different absorption lines. So there is the need to calculate the absorption coefficient of different gaseous molecules LINE-BY-LINE. (accurate but slow)

Then combining

$$k_{v,j,n} = \sum_{l=1}^{L} k_{v,j,n,l}$$

$$= \sum_{l=1}^{L} S_{n,l}(T_j) f_{v,n,l}(T_j, p_j)$$

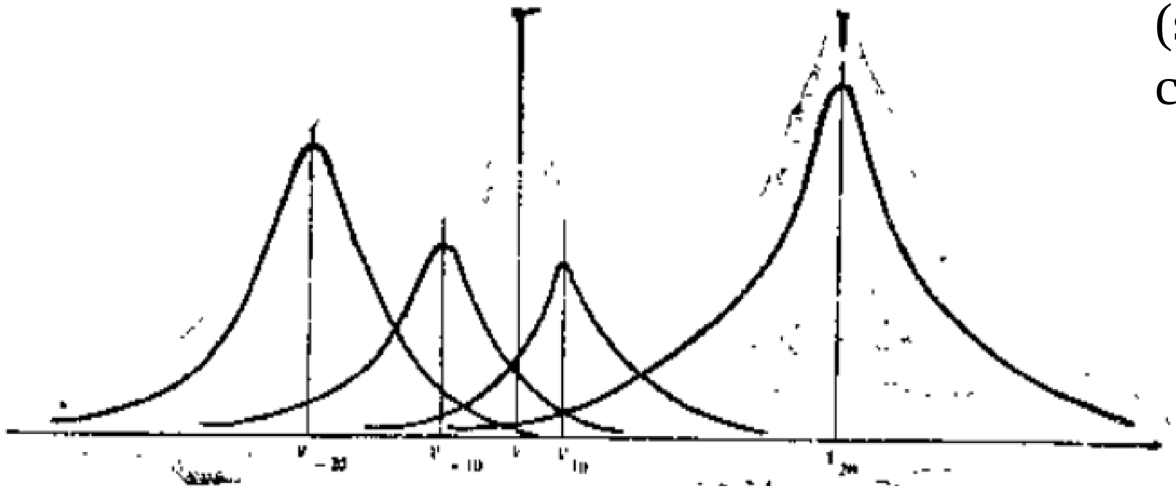
n: the different gaseous molecule

l : the different absorption line

j : the different atmospheric layer

Integration in spectral band

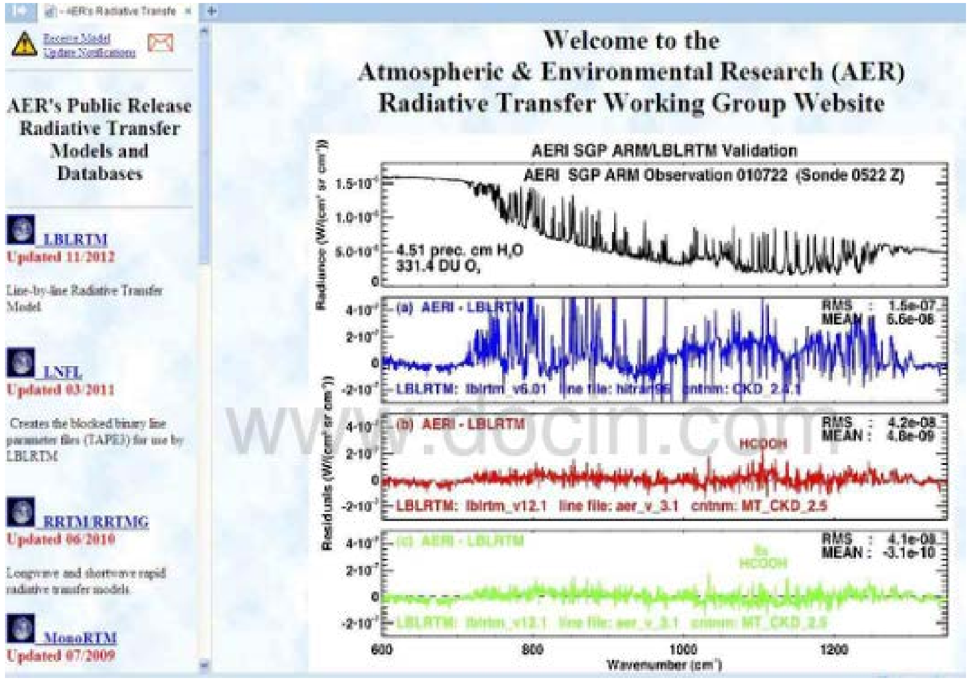
BAND (satellite channel)



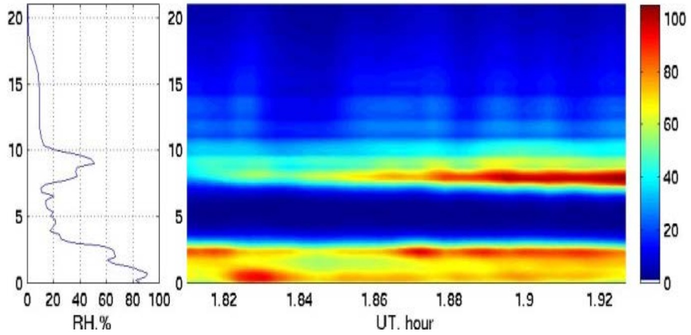
Spectral response function

The extension of rapid transfer model RTTOV to support the new sensor

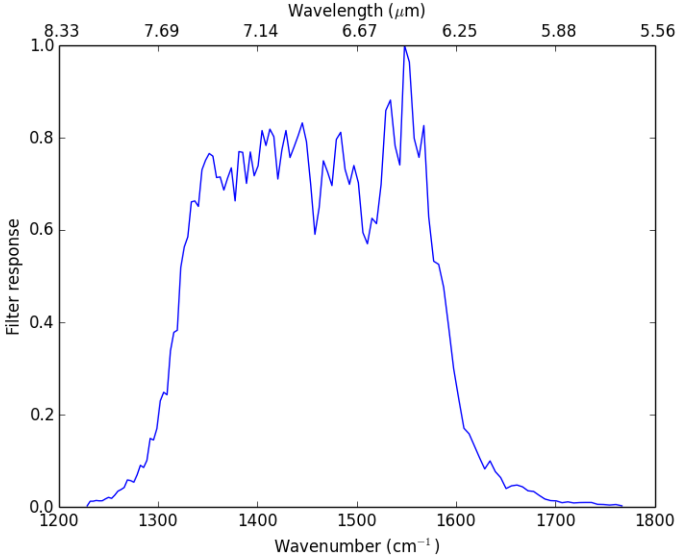
LBLRTM-IR/FY4A-GIIRS
MPM-MW/FY3-MWTS/MWHS



Typical profiles



Applying convolution with satellite channel
Spectral response function



Satellite sensor
Channel transmission

The extension of rapid transfer model RTTOV to support the new sensor (continued)

The transmission is extended by the multivariate linear combination of the predictors of uniformly mixed gases, water vapor and ozone:

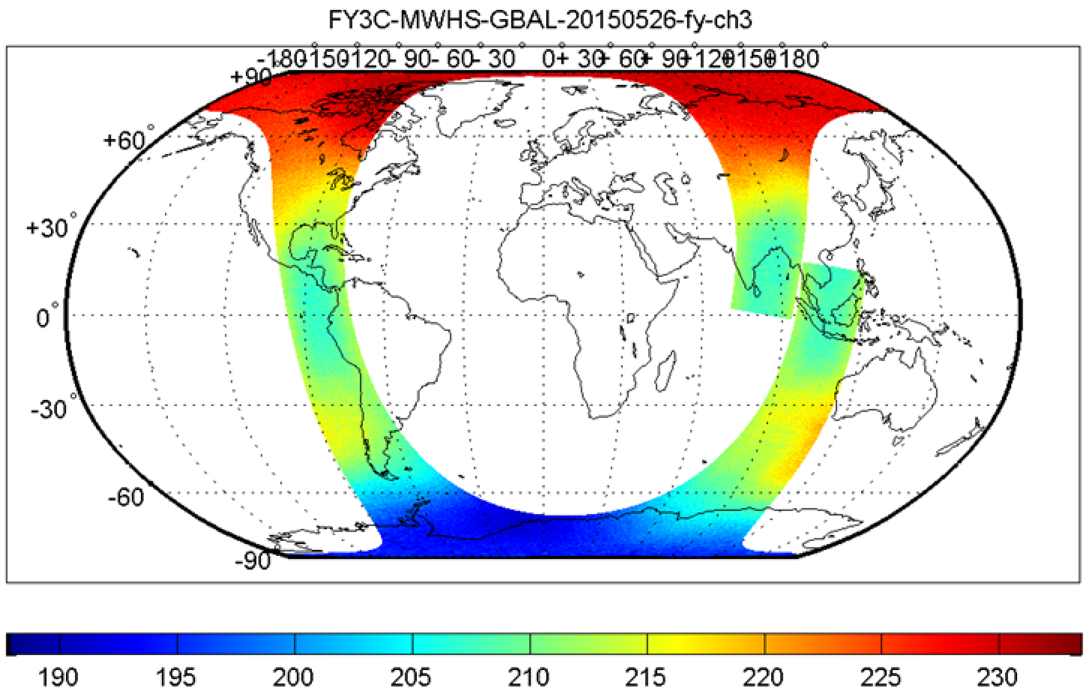
$$\tau_{i,j} = \tau_{i,j-1} + \sum_{k=1}^{K} a_{i,j,k} X_{k,j}$$

The coefficients $a_{i,j,k}$ are obtained by regression.

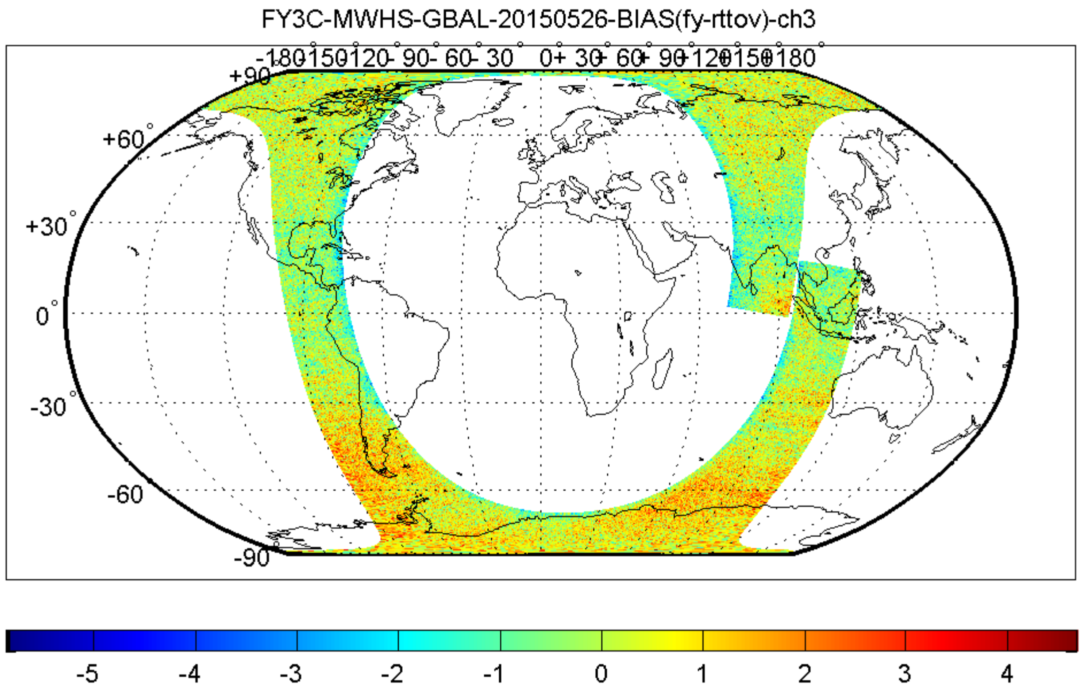
Then, the calculation of transmission in the application using the regression coefficients is rapid and has adequate accuracy.

Predictors	uniformly mixed gases	HIRS water vapour/ ozone	AMSU water vapour/ozone
X_{1j}	$\delta T_j \sec\theta$	δT_j	δT_j
X_{2j}	$\delta T_j^2 \sec\theta$	$\overline{p\delta T_j}$	$\overline{p\delta T_j}$
X_{3j}	$\overline{\delta T_j} \sec\theta$	δq_j	δq_j
X_{4j}	$\overline{p\delta T_j} \sec\theta$	$\overline{p\delta q_j}$	$\overline{p\delta q_j}$
X_{5j}	$(\sec\theta - 1)$	$\delta T_j (\sec\theta\, u_j)^{1/2}$	$\delta T_j (u_j)^{1/2}$
X_{6j}	$(\sec\theta - 1)^2$	$\delta T_j^2 (\sec\theta\, u_j)^{1/2}$	$\delta T_j^2 (u_j)^{1/2}$
X_{7j}	$\overline{\delta T_j}(\sec\theta - 1)$	$\delta q_j (\sec\theta\, u_j)^{1/2}$	$\delta q_j (u_j)^{1/2}$
X_{8j}	$\overline{p\delta T_j}(\sec\theta - 1)$	$(\sec\theta - 1)(\sec\theta\, u_j)^{1/2}$	0
X_{9j}	$\overline{\delta T_j}(\sec\theta - 1)$	$(\sec\theta - 1)^2 (\sec\theta\, u_j)^{1/2}$	0
Y_j	*1*	$(\sec\theta\, u_j)^{1/2}$	$(\sec\theta\, u_j)^{1/2}$

The FY-3C MWHS simulation using RTTOV with the new coefficients

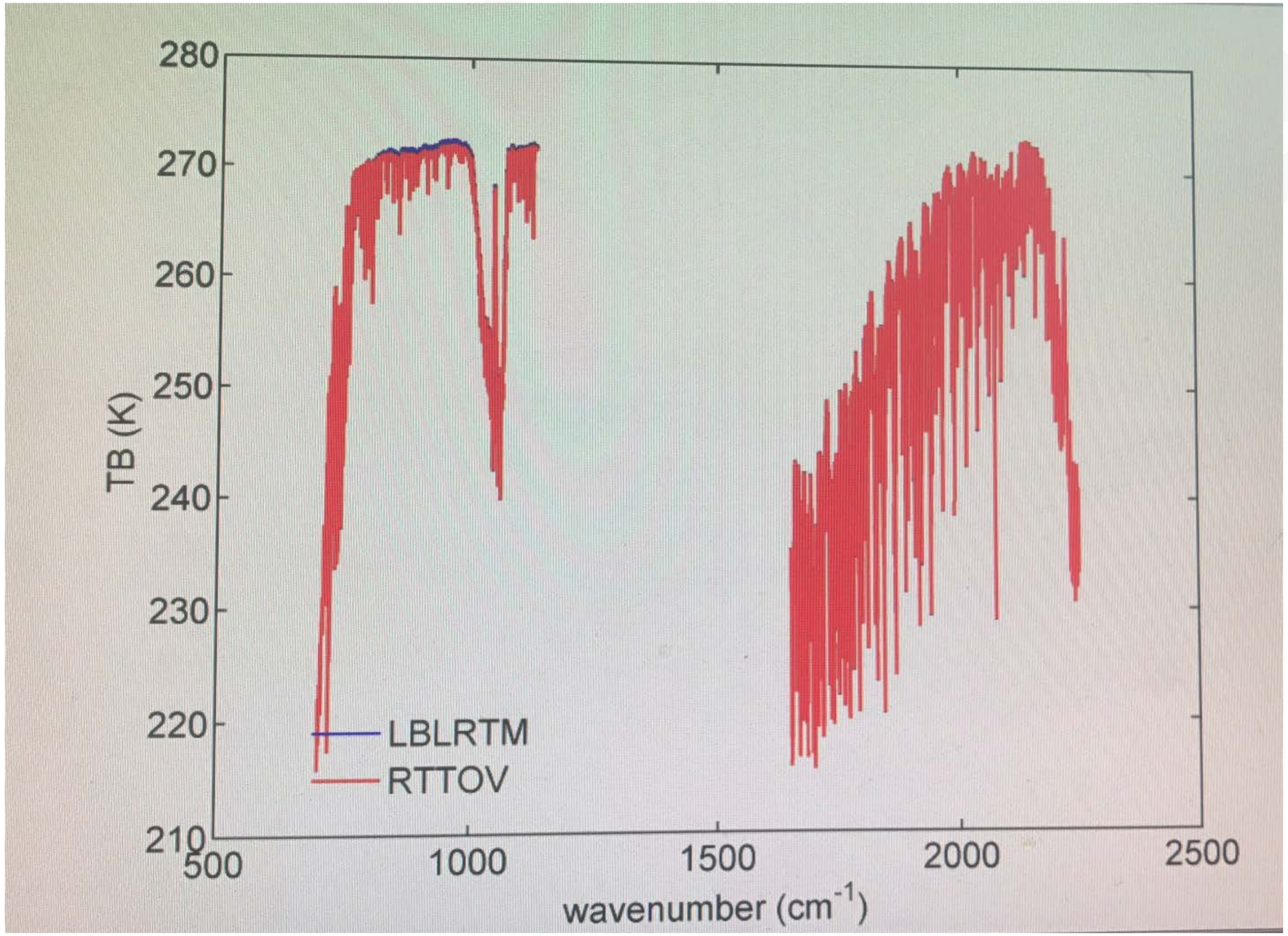


Simulated observation

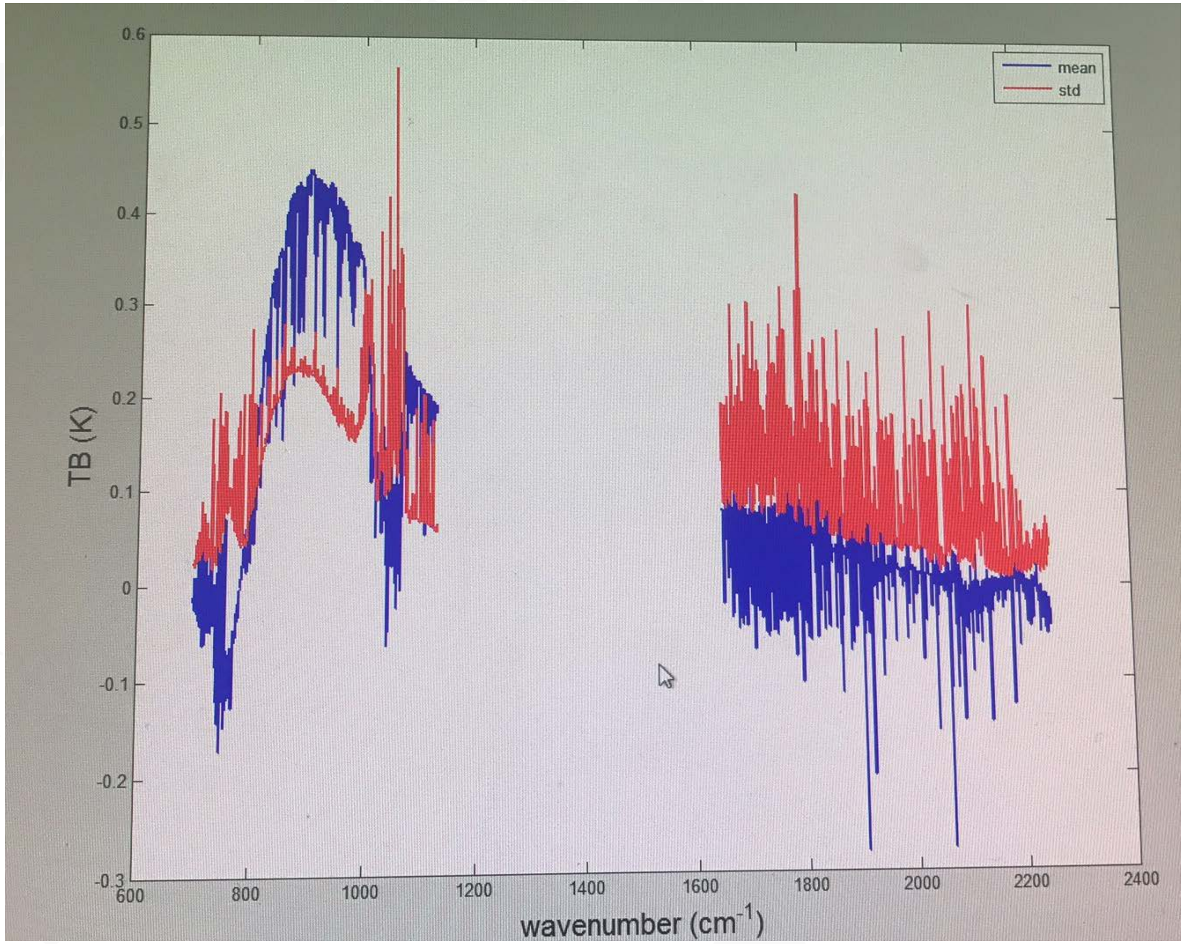


Difference between simulated and observation

The GIIRS simulated brightness temperature and difference between LBLRTM and RTTOV



Brightness temperature



Mean and standard deviation

Didi, 2017

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04 Use of FY-3 118.75GHz

Background

FY-3 microwave vertical sounding has 118.75GHz, but with the absence of window channels at 23.8, 31.4 GHz.

Generally, the Window channel is used to do cloud examination and satellite observation based CLW estimation. The latter is one of the predictors of bias correction.

It is proposed to use double oxygen absorption band microwave sounding observation.

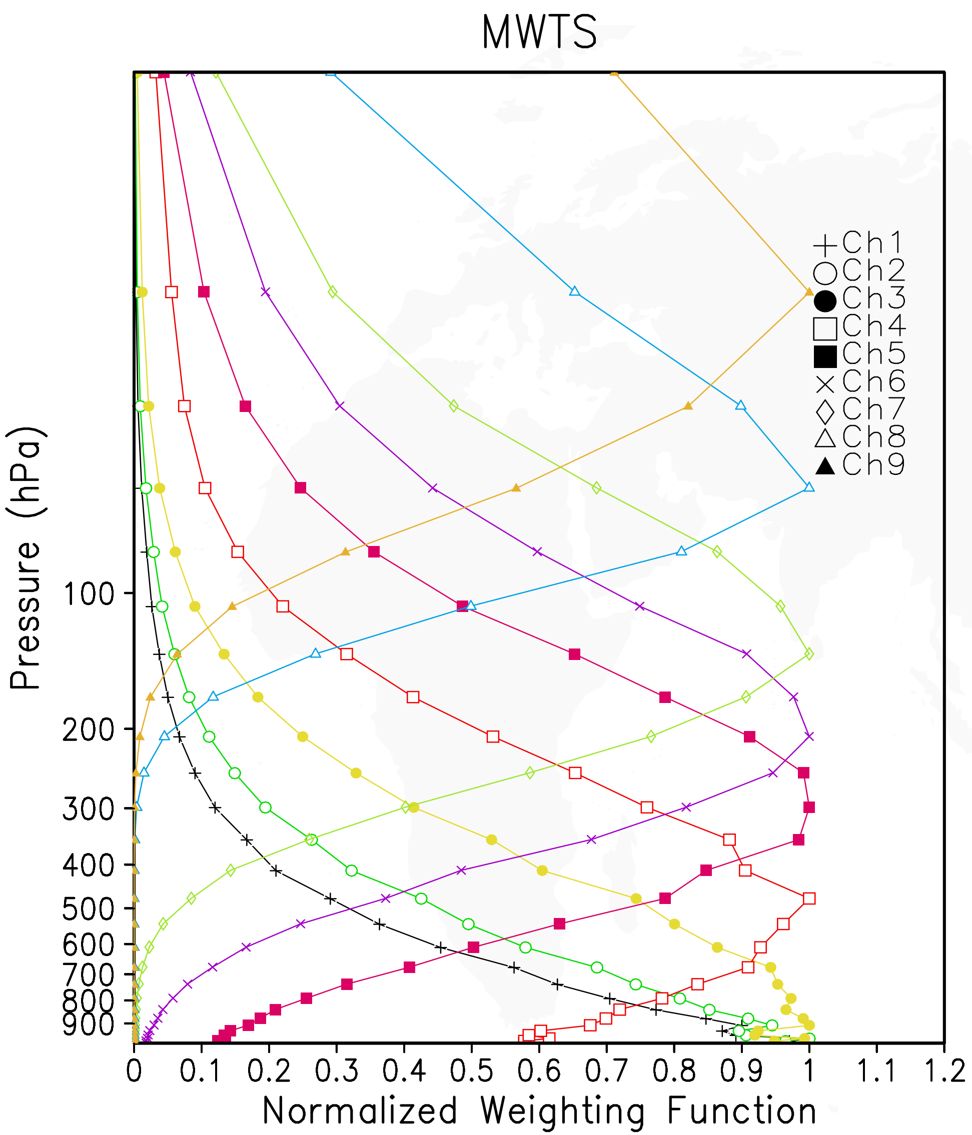
Table 1 Channel number and center frequency for microwave atmospheric sounders

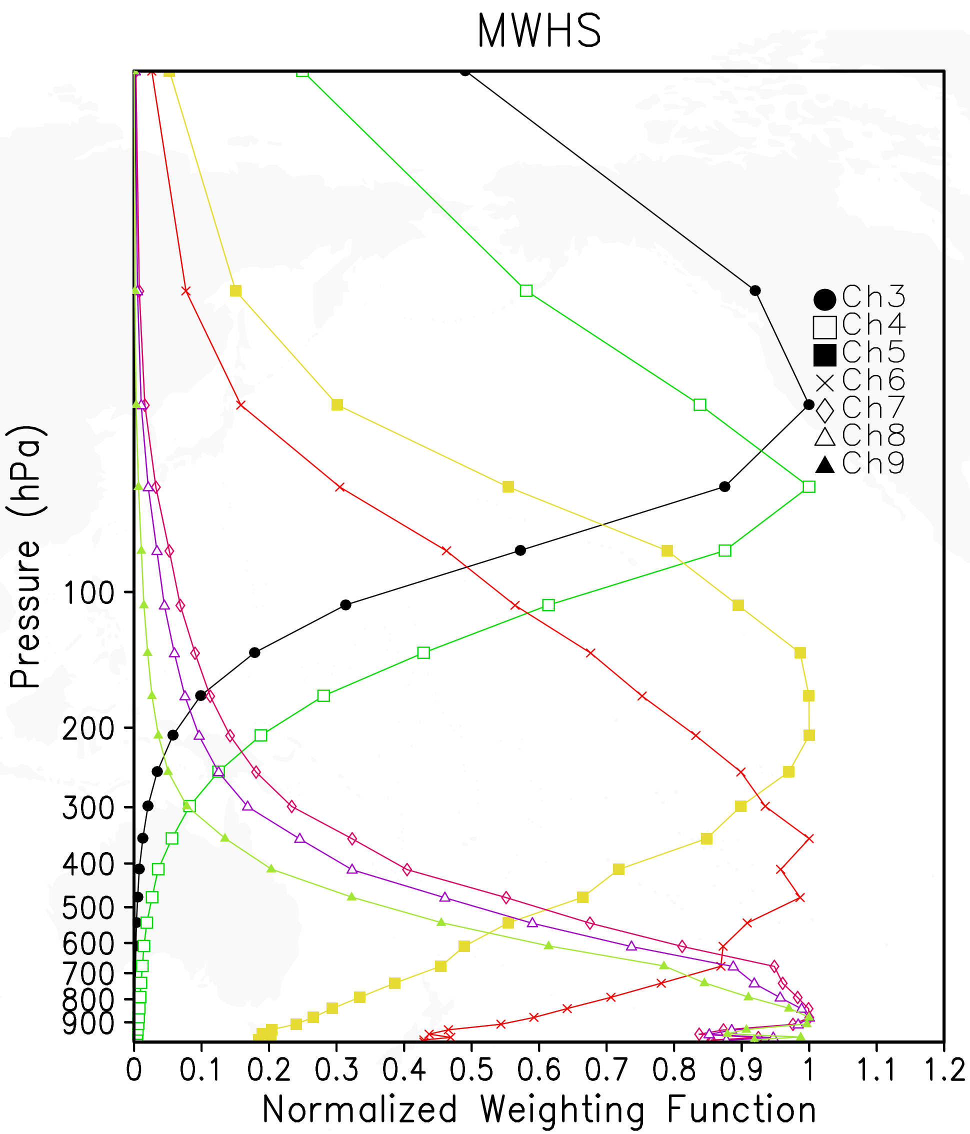
FY-3A/B MWTS/MWHS Channel No.	FY-3C MWTS/MWHTS Channel No.	NOAA MSU Channel No.	NOAA&MetOp AMSUA/AMSUB(MHS) Channel No.	NPP ATMS Channel No.	Centre Frequency (GHz)
			1	1	23.8
			2	2	31.4
1	1	1	3	3	50.3
	2			4	51.76
	3		4	5	52.8

				16	88.2
	1		1		89.0
					118.75±0.08
					118.75±0.2
					118.75±0.3
					118.75±0.8
					118.75±1.1
					118.75±2.5
					118.75±3.0
					118.75±5.0
			2		150.0/157.0(MHS)
				17	165.5
			3	22	183.31±1
	12			21	183.31±1.8

Dong P. et al., Estimation of cloud liquid water over oceans from dual oxygen absorption band to support the assimilation of second generation of microwave observation on board the Chinese FY-3 satellite, International Journal of Remote Sensing, 2017.

The paired MWHS and MWTS channels with the similar peak-weighting function altitude.



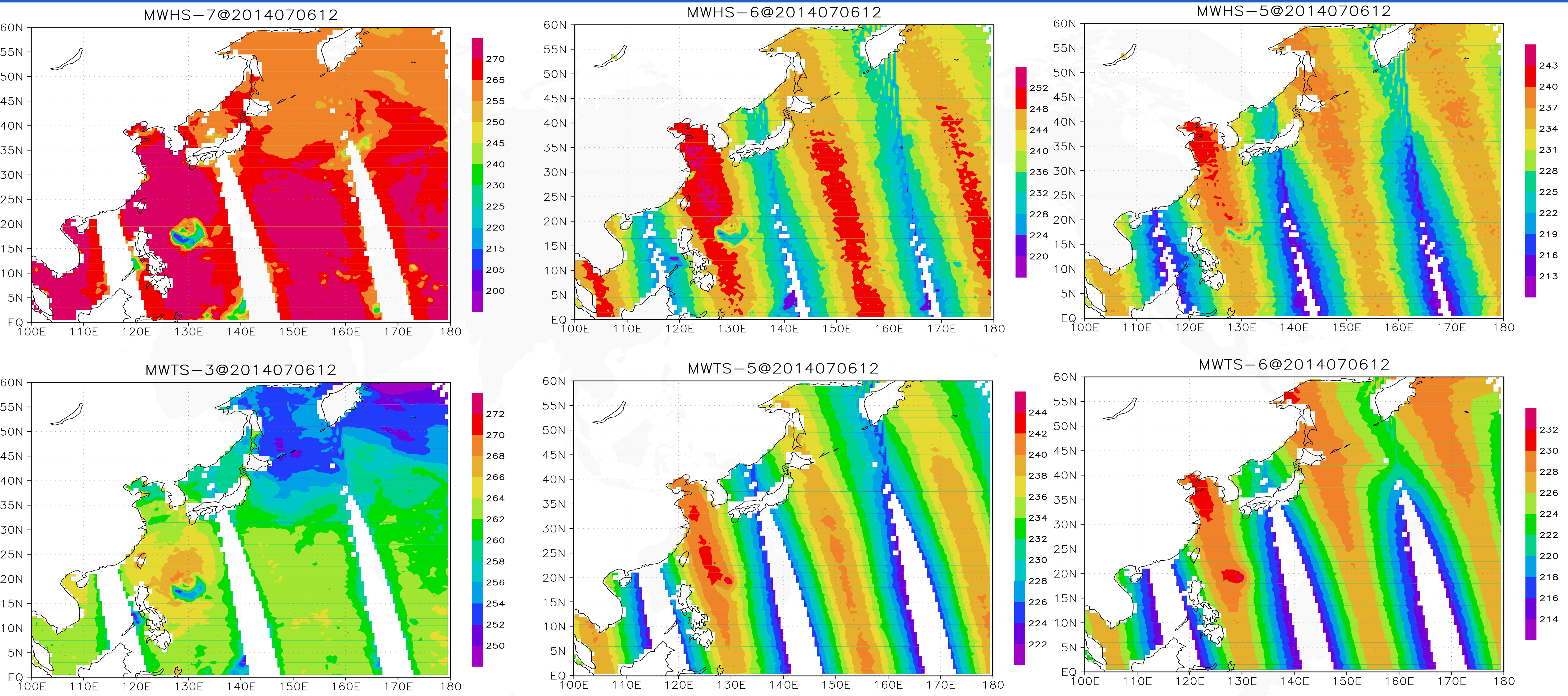


MWHS7(118.75±2.5 GHz)
MWTS3(52.80 GHz)

MWHS6(118.75±1.1 GHz)
MWTS5 (53.596 GHz)

MWHS5(118.75±1.1 GHz)
MWTS6(54.40 GHz)

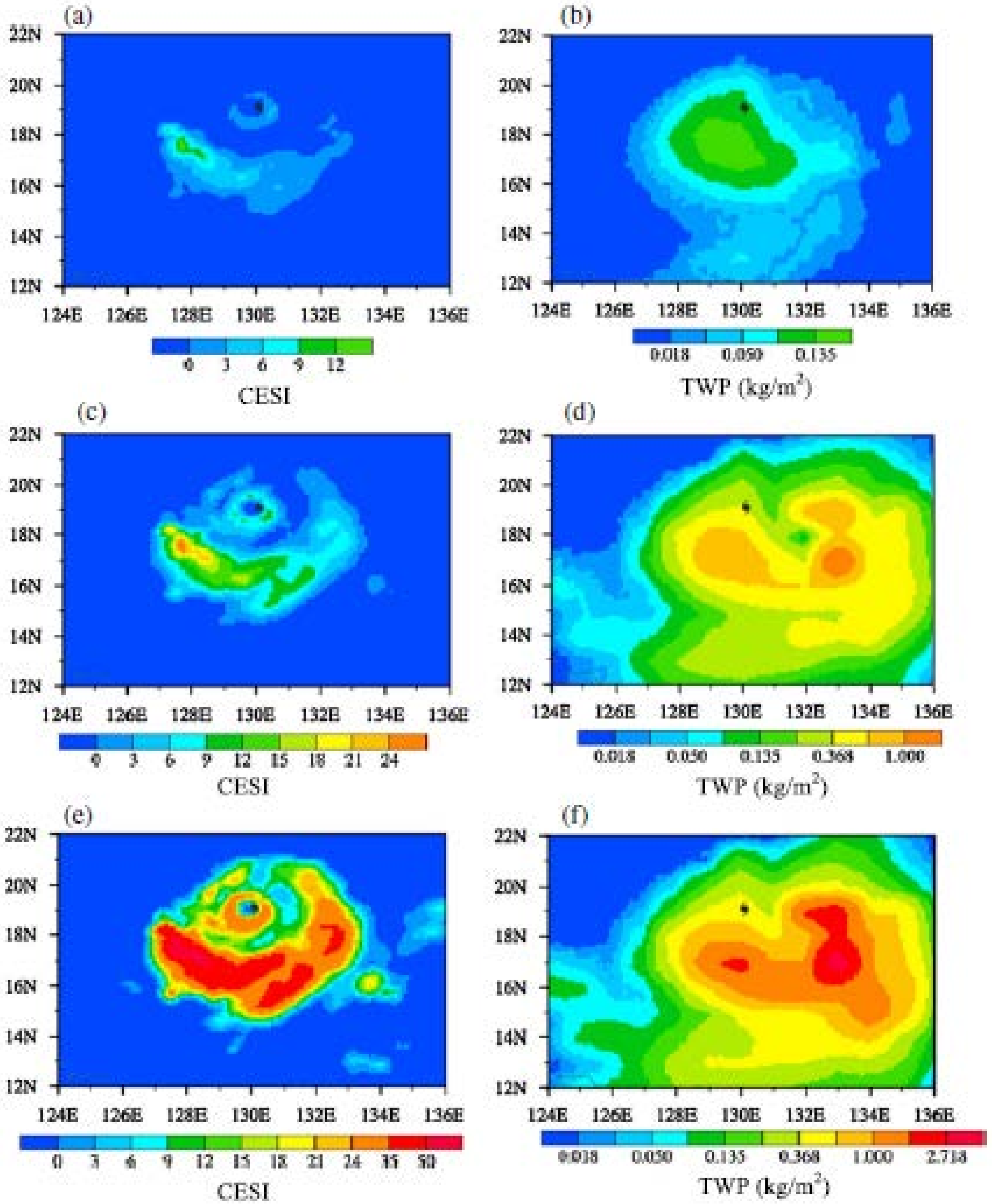
The spatial distribution of brightness temperature for the paired channels.



Spatial distributions of brightness temperature for the three paired channels observed from dual oxygen absorption band microwave sounding instruments.

The cloud emission and scattering index (CESI) corresponds with the water very well.

$$T_{CESI} = T_{B,H}^{reg} - T_{B,H}^{obs}$$



(Han, Zou and Weng 2015)

The estimation of CLW using the paired channels and CESI index derived.

Algorithm 1 (Grody et al., 2001)

$$V_{\mathrm{TPW}} = \cos\theta\left\{C_0 + C_1 \ln\left[T_s - T_B(\upsilon_1)\right] + C_2 \ln\left[T_s - T_B(\upsilon_2)\right]\right\}$$

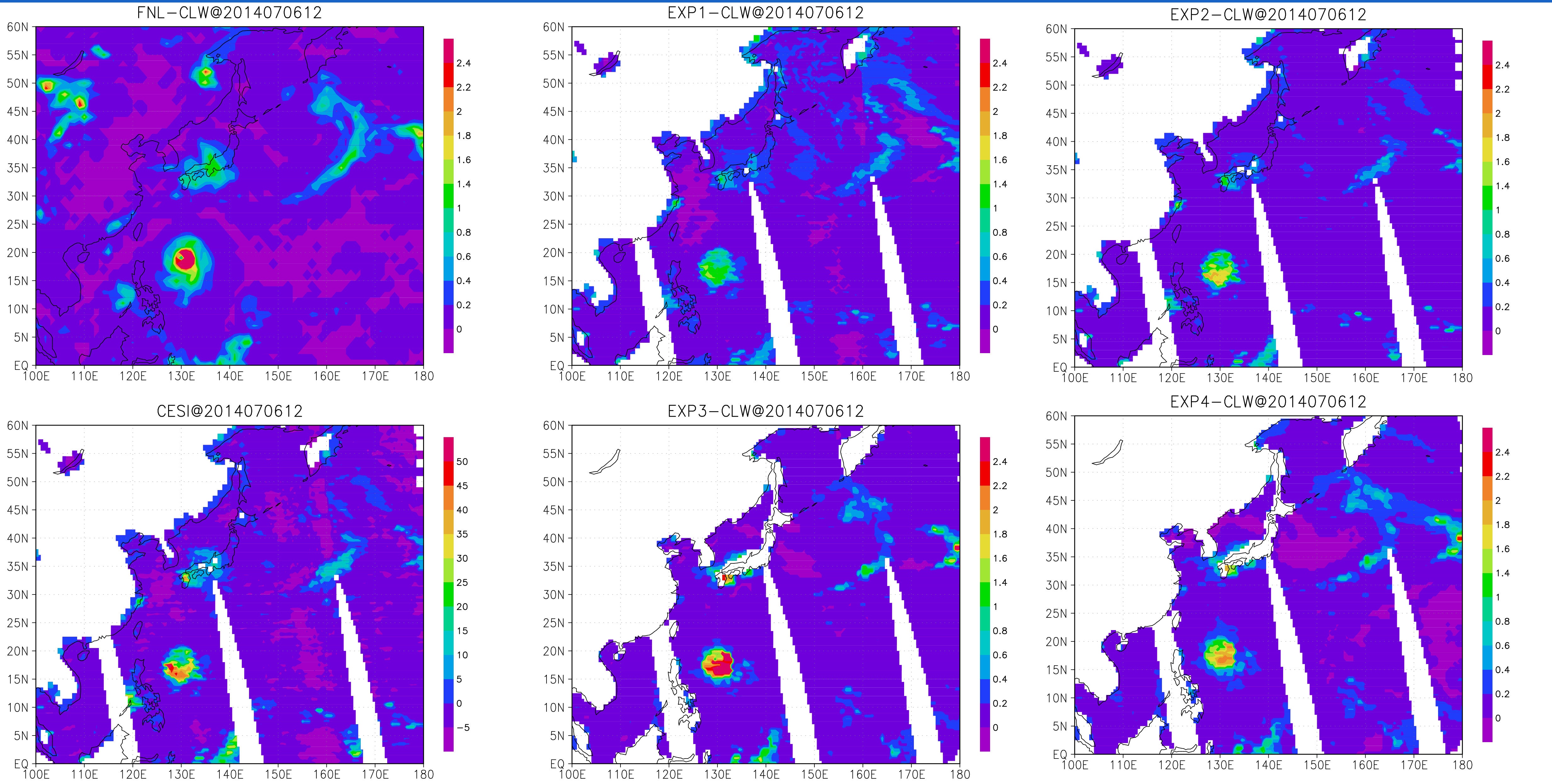
$$V_{\mathrm{CLW}} = \cos\theta\left\{D_0 + D_1 \ln\left[T_s - T_B(\upsilon_1)\right] + D_2 \ln\left[T_s - T_B(\upsilon_2)\right]\right\}$$

Algorithm 2

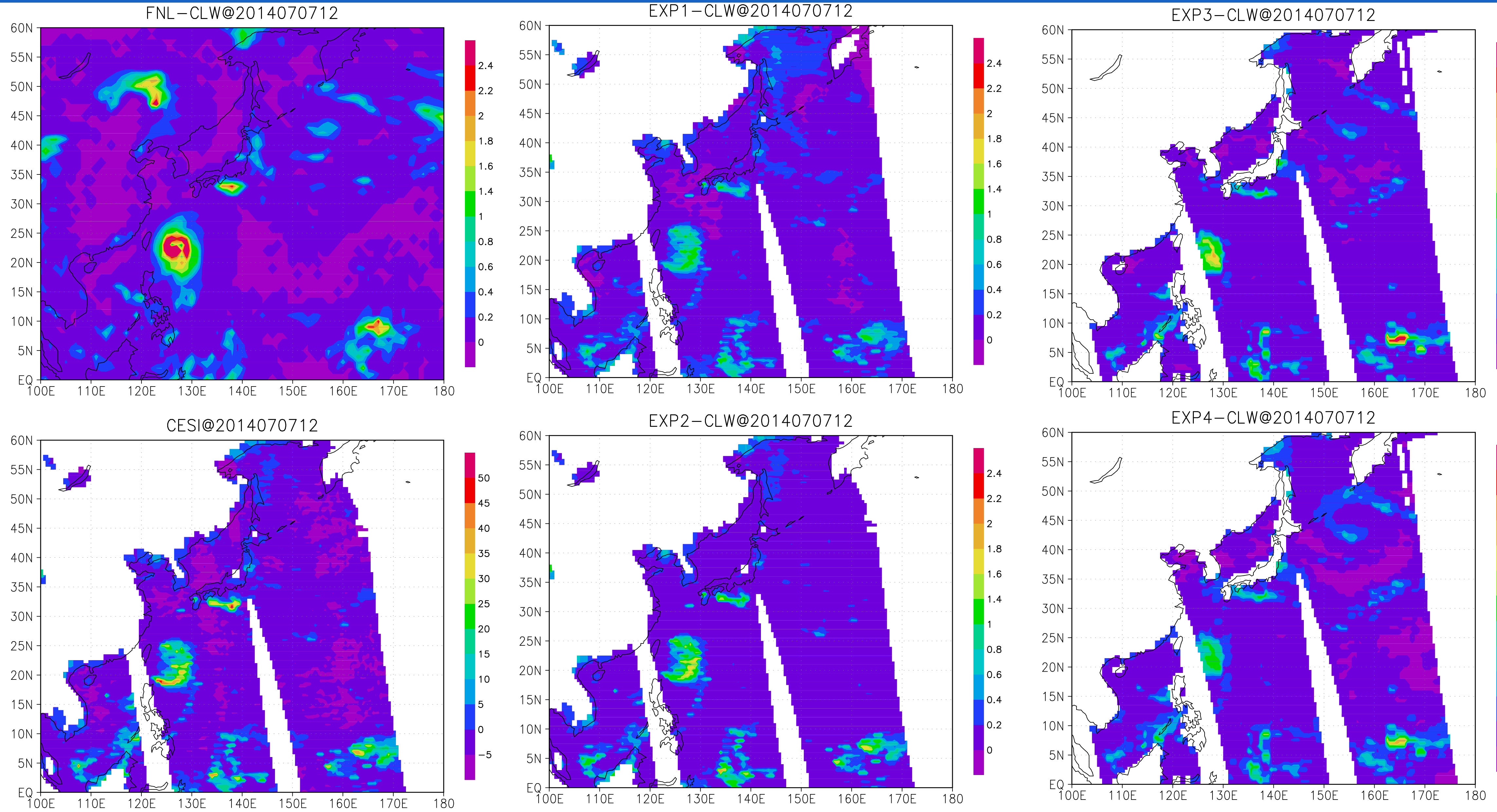
$$V_{\mathrm{CLW}} = \cos\theta\left(a_0 + a_1 V_{\mathrm{CESI}} + a_2 V_{\mathrm{CESI}}^{2} + a_3 V_{\mathrm{CESI}}^{3}\right)$$

Number	Experiment name	Detail description
1	Algorithm 1	Retrieval using Algorithm 1 from FY measurements at 52.80 and 118.75±2.5 GHz. Regression conducted on the actual brightness temperature and FNL reanalysis data.
2	Algorithm 2	Retrieval using Algorithm 2 from CESI defined by FY measurements at 52.80 and 118.75±2.5 GHz. Regression conducted on the CESI and FNL reanalysis data.
3	Grody scheme	Retrieval using the Grody scheme from MetOp-B measurements at 23.8 and 31.4 GHz. Existing coefficients used whose regression was conducted on a simulated data set.
4	Grody scheme-FNL	Retrieval using Algorithm 1 from MetOp-B measurements at 23.8 and 31.4 GHz. Regression conducted on the actual brightness temperature and FNL reanalysis data.

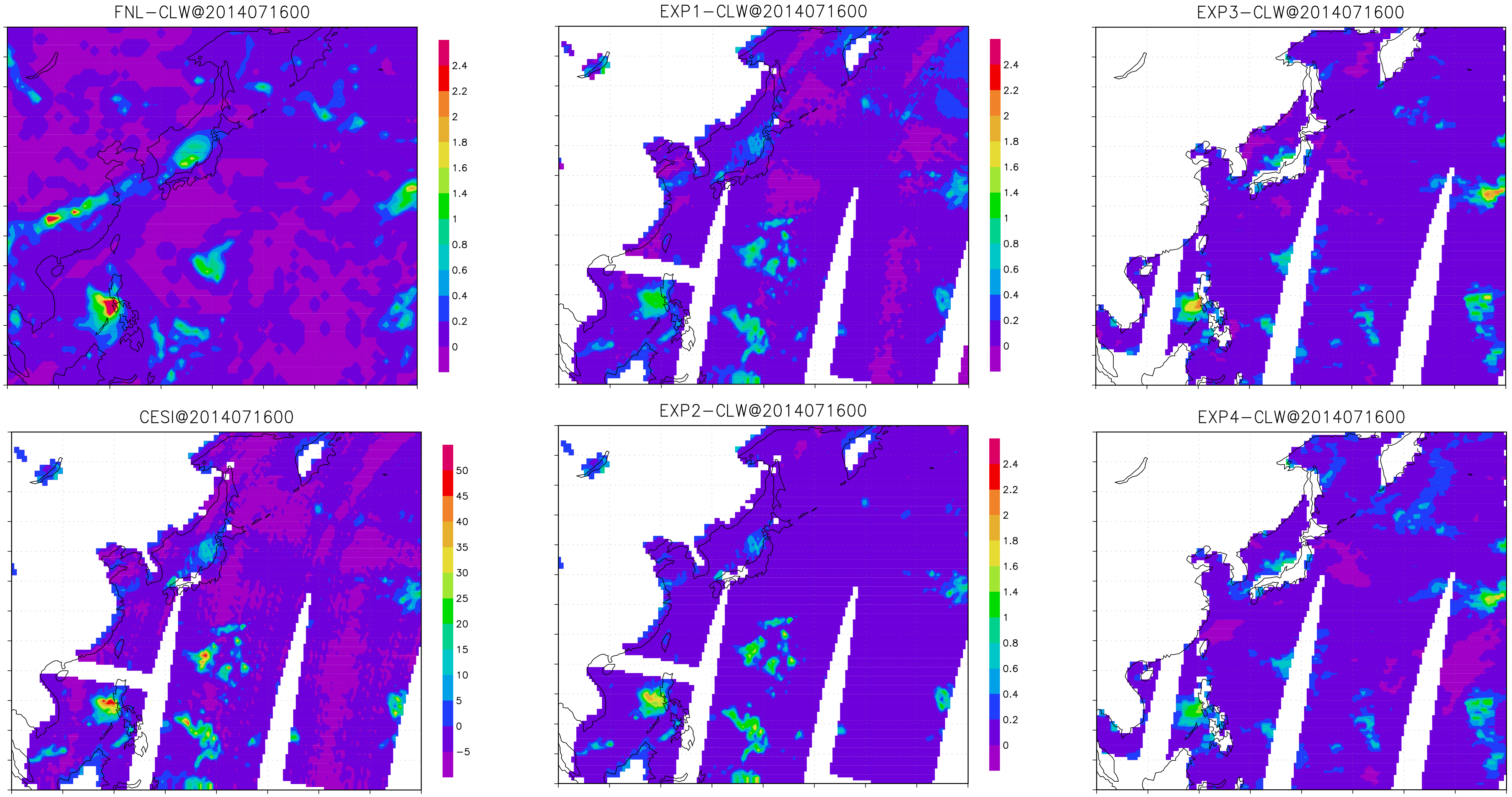
The verification of CLW estimation for case 1.



The verification of CLW estimation for case 2.



The verification of CLW estimation for case 3.



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05 Conclusion and discussion

Conclusion

1. With the rapid development of Chinese meteorological satellite, together with the new sensors flew on, its role in promoting meteorological sciences is promising. While it also presents challenge to handle the issues in the application properly.
2. The extension of rapid radiance transfer model with support to these new satellite sensors is fundamental and crucial to the application in not only data assimilation, but also satellite retrieval product and so on.
3. A method is proposed to estimate the cloud liquid water by using double oxygen absorption band microwave sounding observation. It could be utilized in bias correction and cloud examination to make up the absence of window channels at 23.8, 31.4 GHz in FY-3 Microwave temperature sounding observation.

Discussion

1. Including the process of new satellite sensors such as FY3/MWTS/MWHS and FY4/GIIRS etc to prompt the application.
2. Matching the MWTS and MWHS observations to the same location as AMSUA/MHS. The consistence between temperature and humidity sounding in ATMS displays great convenience in the application. The same considerations applied to GIIRS visible and IR observation is highly recommended.
3. Enriching the package with the derived information as CLW and cloud emission and scattering index to support the assimilation of satellite data in NWP.

THANK YOU

谢　谢