State Key Laboratory of Remote Sensing Science (SLRSS)

A Water Cycle Observation Mission （WCOM）

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Introduction of WCOM

- 2013, WCOM was selected as one of 8 candidate science driving missions to be launched before 2020; It is only one that for EO in China.
- 2014-2015：Phase-A to study key technologies;
- In Feb., 2015, 3 from 8 candidate missions were selected as the key support missions with full funding for 2014-2015. WCOM is one of them;
- WCOM has passed PDR and CDR. Now, it is under the engineering phase;
- Launch date around 2020.

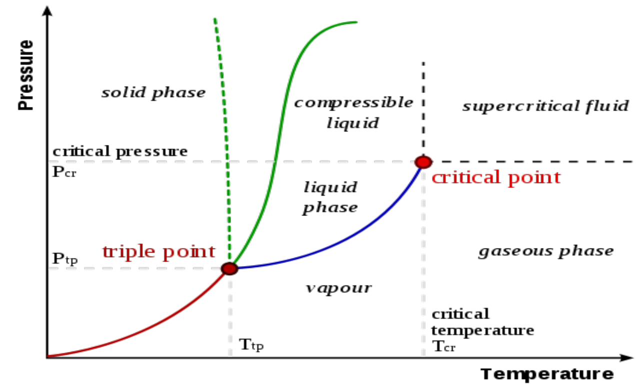
Water Cycle & Climate Change

Water Cycle /Climate Linkage

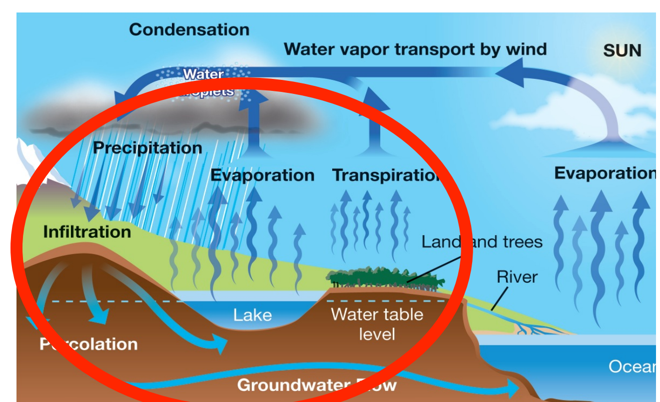
- One of the Earth system's major cycles
- The Clausius–Clapeyron equation governs the water-holding capacity of the atmosphere that increases by about 7% per degree Celsius.

Expectations: ⬇ drizzles, ⬆ storms, ET, speed of water cycle, therefore, hydrological extreme events

Clausius-Clapeyron_Equation



Water in the climate system functions on <u>all</u> time scales (from hours to centuries)



Application Linkage

Basic requirements for monitoring and prediction of water resource, flood, drought, agricultures …..

Key Science Questions

What are the spatial-temporal distribution characteristics of water cycle components and processes? Are the changing speeding up?

Available Sensors for Water Cycle

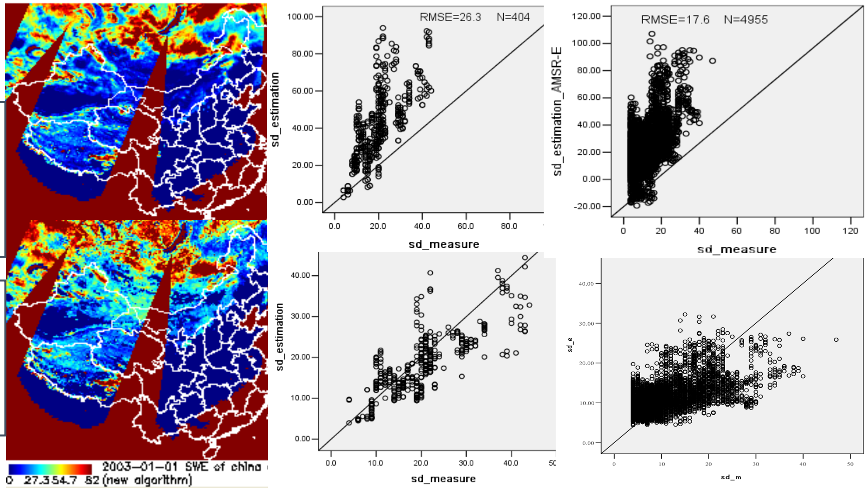
	Sensor	Frequency (GHz)	vapor	Preci.	Temp.	Soil Moisture	Freeze Thaw	SWE	Sea Salinity	Sea Surface wind
Multiple Frequency Sensor	AMSR-E	6.925;10.65;18.7;23.8;36.5;89	√	√	√	√	√	√		√
	GCOM/ AMSR2	6.9;7.3;10.65;18.7;23.8;36.5;89	√	√	√	√	√	√		√
	FY-3/ MWRI	10.65;18.7;23.8;36.5;89	√	√	√	√		√		
	SMMR	6.6;10.7;18;21;37	√		√		√	√		√
	SSM/I	19.35;22.235;37.0;85.5	√	√	√		√	√		√
	TRMM/TMI	10.65;19.35;21.3;37;85.5		√						√
	WindSat	6.8;10.7;18.7;23.8;37	√	√						√
	SSMIS	19.35;22.235;37;50-60;91.655;150;183.31	√	√	√			√		√
Single Frequency Sensor	ASCAT	5.255								√
	ERS	5.3								√
	QuikSCAT	13.4								√
	Aquarius	1.413							√	
	SMOS	1.41				√			√	
	SMAP	1.26; 1.41				√	√			

Problems in SWE inversion

- **Passive microwave（~25km):**
  - **SMMR**
  - **SSM/I**
  - **AMSR-E**
  - **AMSR2**
  - **FY-3**

AMSR-E B04 product (no pixel mixing decomposition)

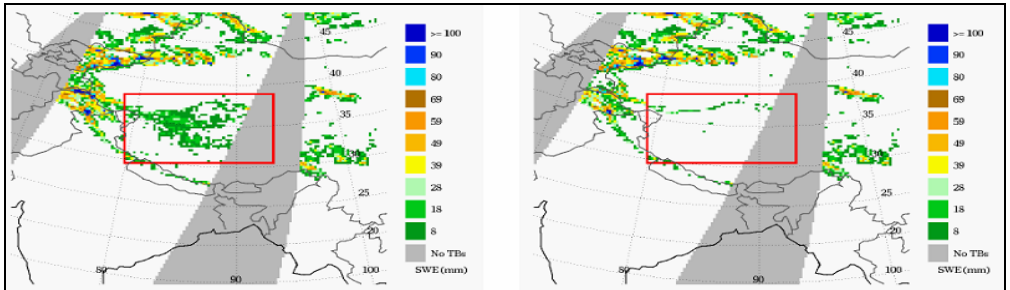
Our algorithm (with pixel mixing decomposition)



$$SD(SWE) = a + b \cdot \left(T_{Bp}(18) - T_{Bp}(37)\right)$$

1. Semi-empirical algorithm: Regional differences, inconsistent accuracy globally
2. Vertical inhomogeneous (layered snow), changes in snow characteristics
3. Atmospheres

4. Insufficient spatial resolution, horizontally in homogenous of snow (mixed pixel)



Result of atmospheric correction, November 29, 2003. SWE derived from uncorrected AMSR-E (left) and corrected AMSR-E (right).

Need: **Spatial observation capacity**

Problems of Current Techniques

1、**Single-Frequency:** Lack of synergistic observations on the other affecting factors

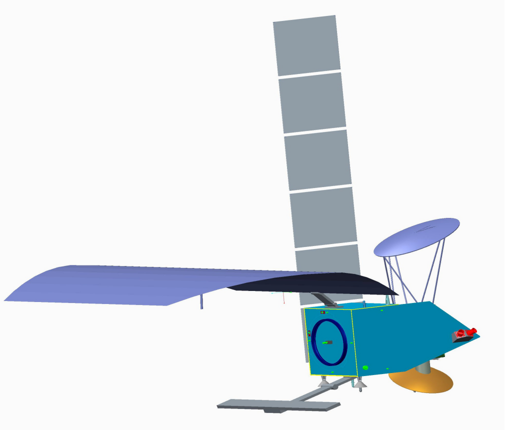
2、**Multi-Frequency:** Lack of optimal frequency on the surface water cycle components

3、**Both:** Lack of systematical observations on the characteristics the water cycle

Parameters	Disadvantages in Observations	Disadvantages in Inversion
Soil Moisture	Weak penetration for high freq.; lack of temperature for low freq. ; RFI	Lack of valid inversion technique on vegetation and surface roughness
SWE	Low spatial resolution of passive microwave	More considerations needed for snow process and atmosphere conditions
FT	Low spatial resolution for passive microwave	Limited validity for using fixed Threshold values
Sea Salinity	Lack of temperature and atmosphere observations	Lack of surface roughness correction
Sea Evaporation	lack of simultaneous observations on both sea surface and atmosphere	Uncertainties in the inversion of related parameters
Precip.	Cloud 3D properties	Need to Discern rain and snow

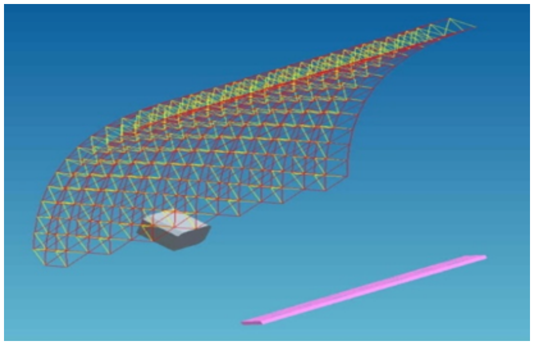
Payloads and Configurations

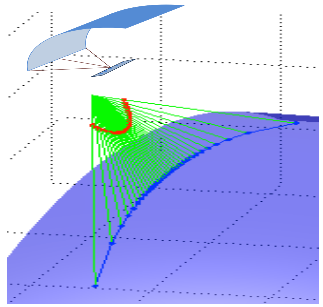
- **1. IMI，Full Polarized Interferometric Radiometer：Soil Moisture and Sea Salinity**
- **2. DPS, Dual Frequency Polarized Scatterometer：SWE and FT**
- **3. PMI, Polarimetric Microwave Imager，6.8～89GHz: Temperature, rain, water vapor , atmosphere correction, and bridge to historical data**



Payloads	IMI	PMI	DPS
Frequency（GHz）	L, S ,C (1.4,2.4,6.8)	C~W (7.2,10.65,18.7,23.8,37,89)	X, Ku (9.6,14/17)
Spatial Resolution（km）	L: 50, S: 30, C:15	4~50（frequencies）	2~5（processed）
Swath Width（km）	>1000	>1000	>1000
Polarization	Full-Pol	Full-Pol	Full-Pol
Sensitivity	0.1~0.2K	0.3～0.5K	0.5dB
Temporal Resolution（Day）	2～3	2～3	2～3

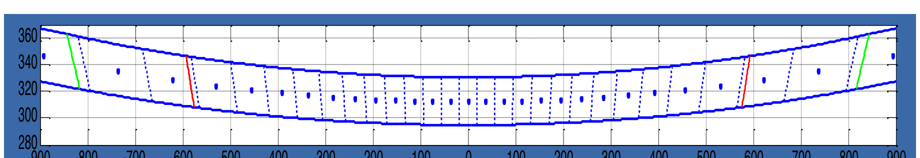
L/S/C Microwave Interferometric Radiometer





Instrument Concept：1D Microwave Interferometric Radiometer with parabolic cylinder reflector antenna

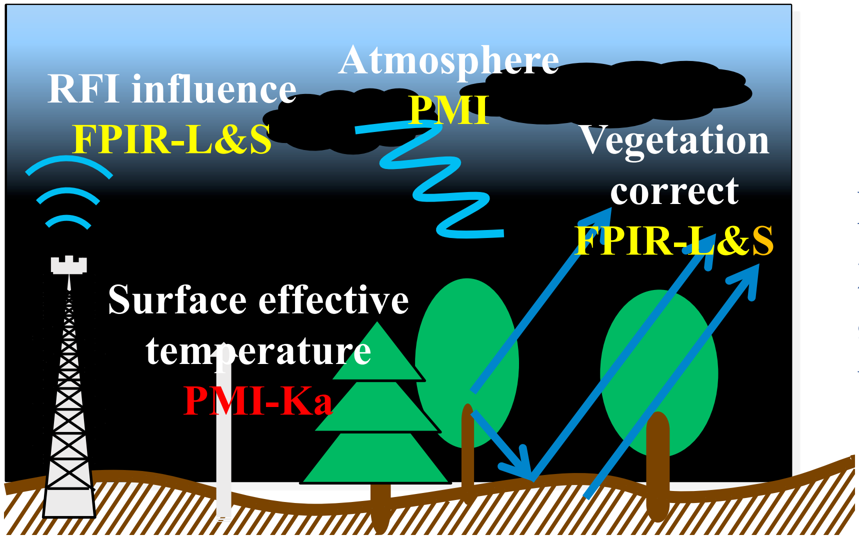
- Use parabolic cylinder reflector and interferometric technology to achieve High spatial resolution
- Patch feeds and shared reflector to achieve the multi-frequency ability
- Dual-size feeds to enhance the system sensitivity performance



Simulated footprints on the ground

system	1D Interferometry + parabolic cylinder reflector
frequency	L：1.4～1.427GHz，S：2.64~2.70GHz，C：6.6～6.9GHz
Sensitivity	L-band：0.1K；S-band：0.4K；C-band：0.4K
Polarization	Full pol（H,V,Q,R）
Antenna size	Reflector:6.0m×6.0m（after deployment） Feed array：4m×0.5m
FOV	>1000km
Incidence	30~55°
Spatial resolution	L-band：50km，S-band：30km，C-band：15km
revisit	2-3 days
weight	250kg
Data rate	< 1Mbps

Advantages in soil moisture retrieval



- **IMI**

1）Combination of L- and S-band can solve the polarization effects in vegetation correction.

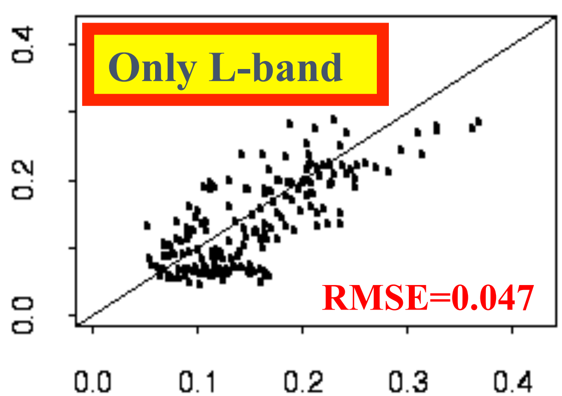
2）The probability of RFI occurrence at the same area and frequency is vary small. RFI can be avoid by switching L- and S-band .

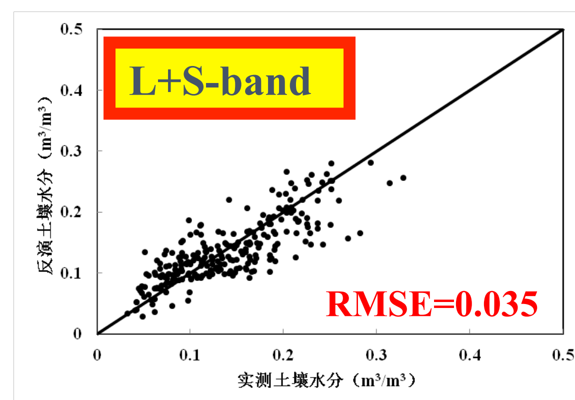
- **DPS**

Vegetation information of high resolution

- **PMI :** Surface effective temperature

Various vegetation types





Soil moisture Products

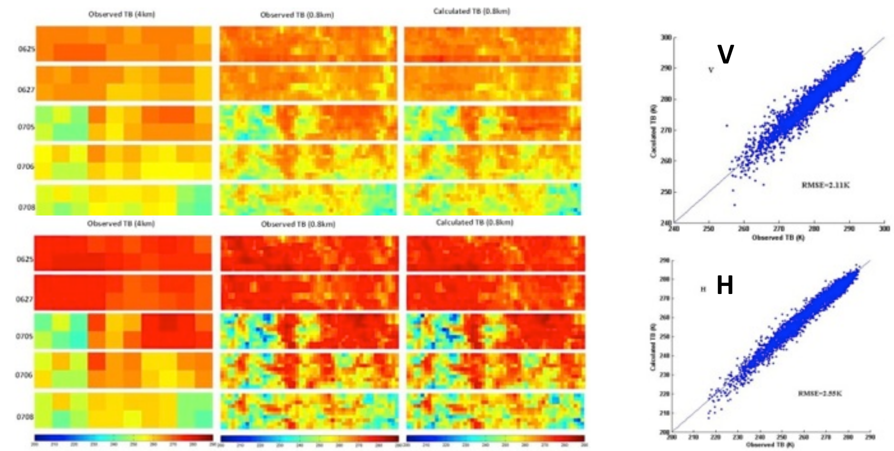
A） Passive microwave (IMI)

L/S/C-bands: 50/30/15 km

Experiment with Airborne data：

Downscale the L-band Tb (4km) at a scale of 800m using higher resolution Tb of S-band, and its validation with original L-band data

Spectral analysis downscaling method for passive microwave



Passive： Sensitive to soil moisture but low resolution

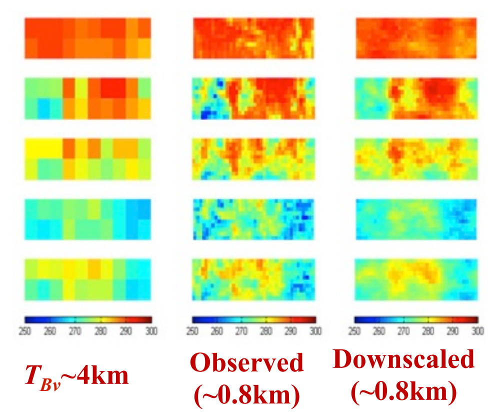
Active： High resolution but sensitive to vegetation and roughness

B） Active/passive microwave (IMI/PMI+DPS)

$$T_{Bp} = A + C\frac{\sigma^{t}_{vh}}{\bar{\sigma}^{t}_{vh}} + \left(B + D\frac{\sigma^{t}_{vh}}{\bar{\sigma}^{t}_{vh}}\right)\sigma^{t}_{pp}$$

Active /passive combination of C and X band：

Downscaling using both active and passive



Products： Soil moisture estimates at a scale of both 15km and 5km over nominal areas and 30km over forests.

Advantages of WCOM Payloads Design

	IMI	PMI	DPS
Soil Moisture	1 More sensitive to land surface 2 Minimizing vegetation effects 3 Mitigating RFI	1 Sensitive to temperature 2 Observing large-scale surface roughness	1 Surface Roughness and vegetation 2 high resolution soil moisture
Sea Salinity	1 More sensitive to sea surface 2 Faraday rotation correction	1 effective correction on atmosphere 2 ensitive to sea temperature	High resolution Wind Vector
Sea Evaporation	Corrections on sea surface roughness	Sensitive to temperature	High resolution Wind Vector
FT	Obtaining Soil Surface Parameters	Sensitive to temperature changes	1 Time series techniques for FT detection 2 Downscaling techniques for FT inversion
SWE	Obtaining Soil Surface Parameters	Obtaining SWE by scattering effects	1 Estimating SWE 2 Mitigating Mixed pixel effects
Vapor and Precip.	Helping determine land surface emissivity	1） obtaining Water Vapor 2） Precip. Rate 3） Discerning Rain and snow	High resolution observations on precip.

Vital major help

The Payloads Design： 1）Optimal channels for inversion，2）Effective corrections on affecting factors，3）Simultaneous observations

Objectives of WCOM

- Overall scientific objectives of WCOM
  - To significantly improve the accuracy and synchronization of measurements for spatial and temporal distribution of global water cycle key elements and system
  - To refine the long-term satellite observations over past decades, and to provide a new opportunity to improve water cycle related model.

2014-2016 Objectives

Science part

1）Further evaluation of science objectives; further optimization of payloads, to achieve higher precision water cycle parameters observation than any existing satellites;

2）Based on the simultaneously multi-sensor observation, to achieve joint key water cycle parameters and environmental parameters retrieval, and the preliminary algorithm validation;

3）The study of the method to calibration of historical observations of other satellites based on WCOM observations; Water cycle models parameter optimization;

Technology part

1）Design and evaluation of payloads: FPIR, PMI and DFPSCAT

2）To make breakthroughs in key technologies in payloads, and the experimental validation of the key technologies ;

3）WCOM satellite platform design and evaluation based on the requirement of payloads and their observation; Design and evaluation of interface between satellite system and other systems

Scientific Application System

1) Subsystem of Joint Retrieval and Validation

L1 data

Scientific objective 1:

Retrieved high accuracy scientific products of major water cycle components

L2/L3 data

spatial or temporal distributions of current water cycle system

Spatial and Temporal Patterns and Trends of the Water Cycle

Historical observations

2) Subsystem for historical data reprocessing

L4 data

spatial or temporal variations of water cycle in a long-term period

Long-term remote sensing data products of water cycle components

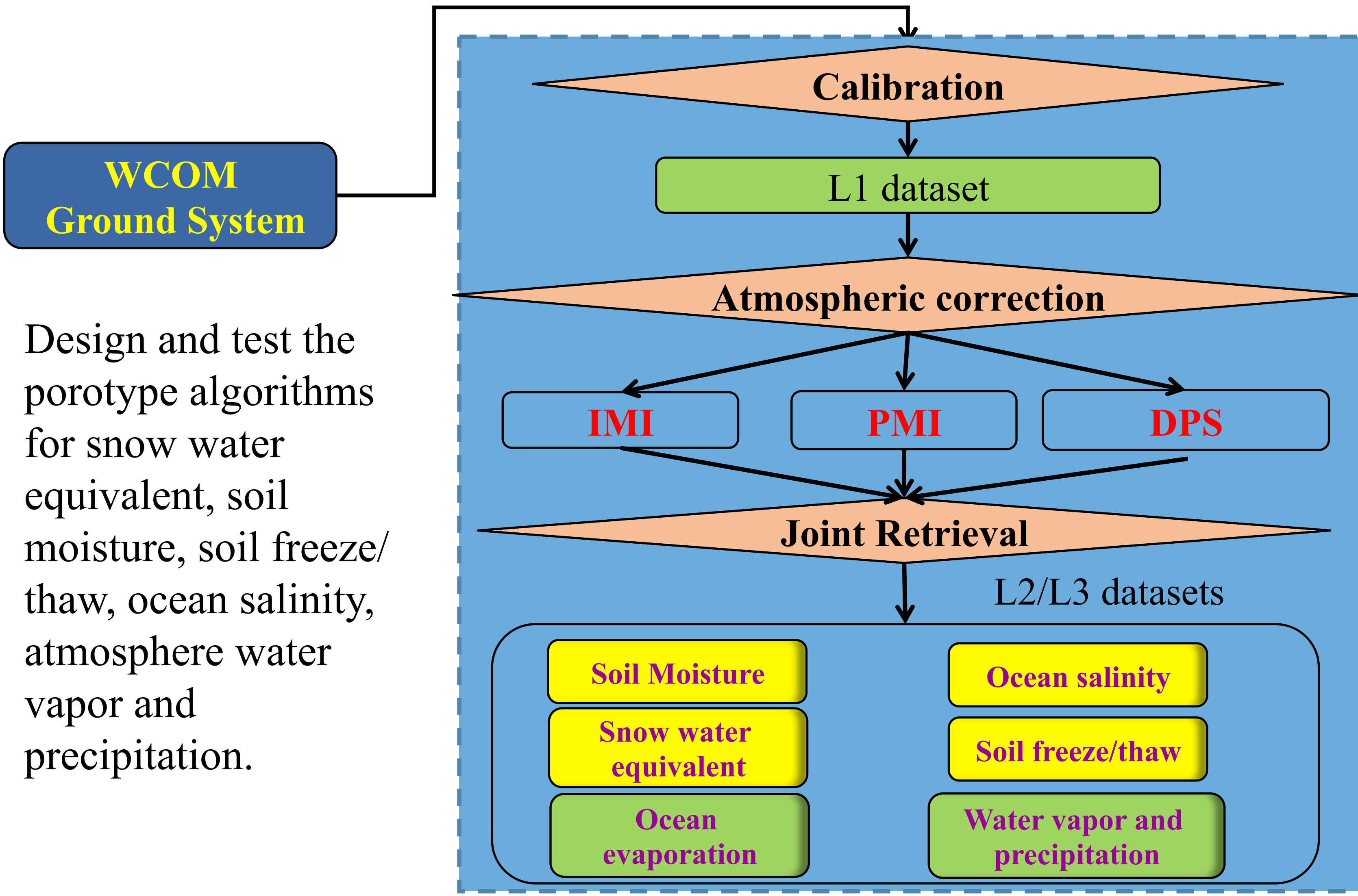
Scientific objective 2:

3) Subsystem for Modeling and Data Assimilation of Water Cycle

Parameter optimization and refinement of hydrological models

Responses of Water Cycle to Global Change and Its Feedback

WCOM data processing Structure

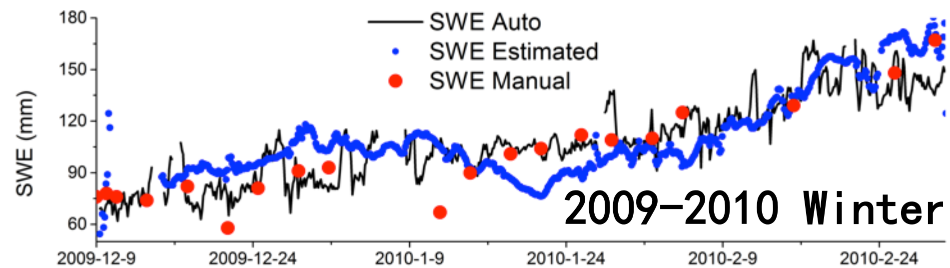


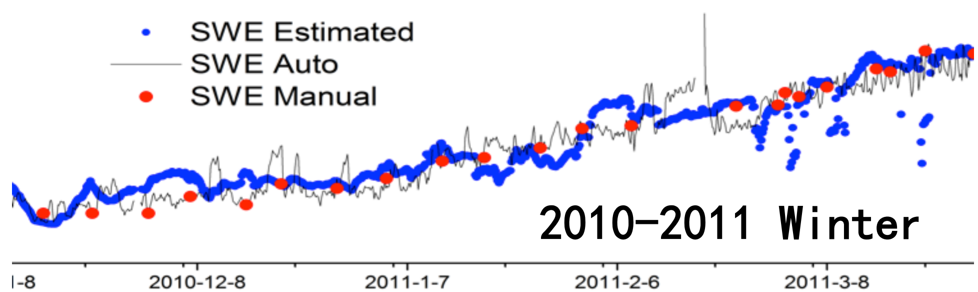
Design and test the porotype algorithms for snow water equivalent, soil moisture, soil freeze/thaw, ocean salinity, atmosphere water vapor and precipitation.

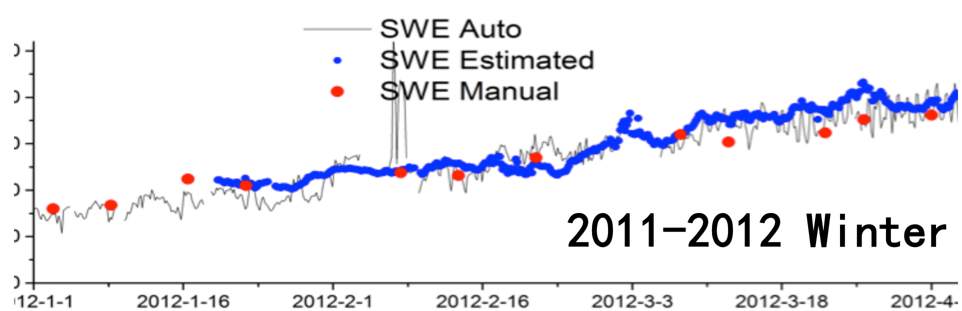
SWE retrieval and Validation

SWE inversion algorithm for DPS scatterometer is developed based on Bicontinuous+VRT model .

Three-year time series measurements at dual-polarization X and Ku bands in Finland Nosrex campaign.







WCOM data simulator

Dynamic forcing data module

WCOM payloads configuration

Land/Ocean/Atmosphere radiative transfer and backscatter modelling

1. FPIR/PMI Brightness temperature
2. DFPSCAT Backscatter coefficient

Satellite orbit, Sensor gain function, footprints and resampling

Initial WCOM data

Calibration with current satellites (SMOS/SMAP, AMSR2, etc)

Final WCOM data

2) Evaluate instrument error on science requirements

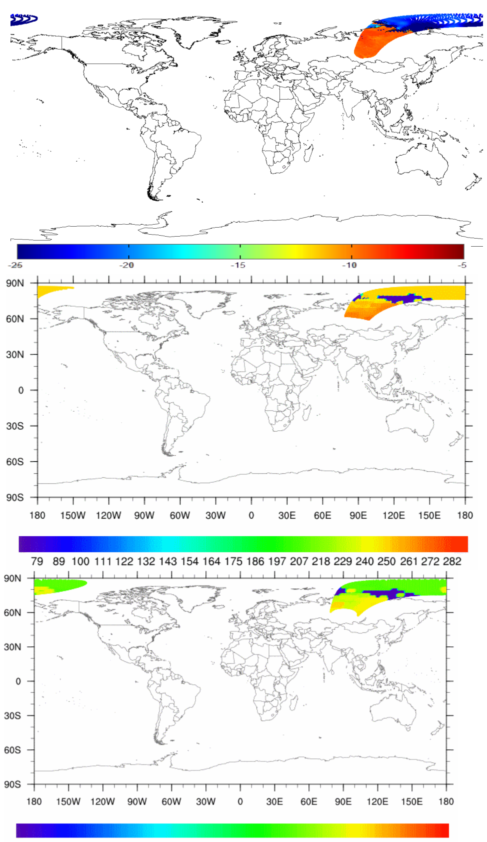
3) Parameter optimization of hydrologic model

1） Retrieval algorithm development and validation

DPS

IMI

PMI



Establishments of Historical Data

Improving the algorithms using the accurate WCOM measurements

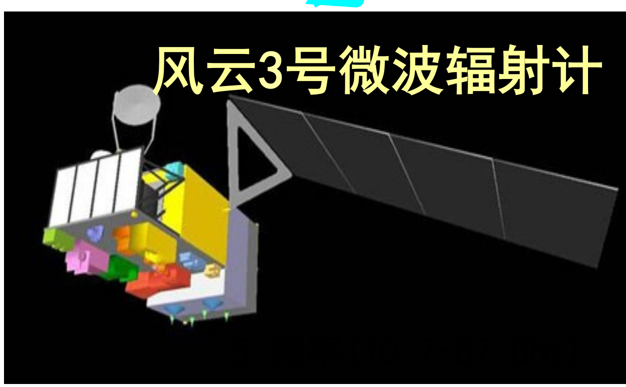
Form long time series measurements to analyze the change characteristics

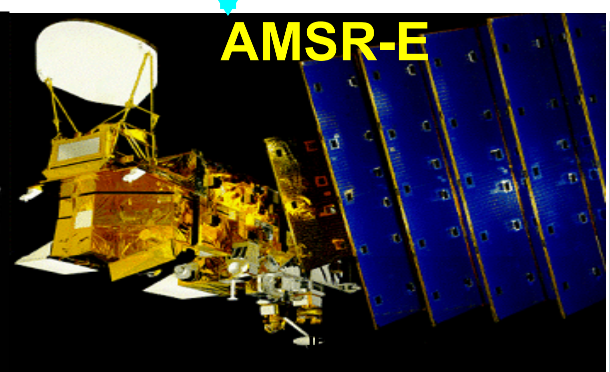
SWE

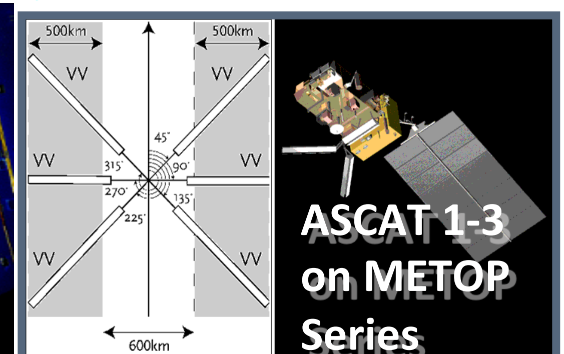
WCOM

F/T

Soil Moisture







TMI/TRMM 1998—GPM

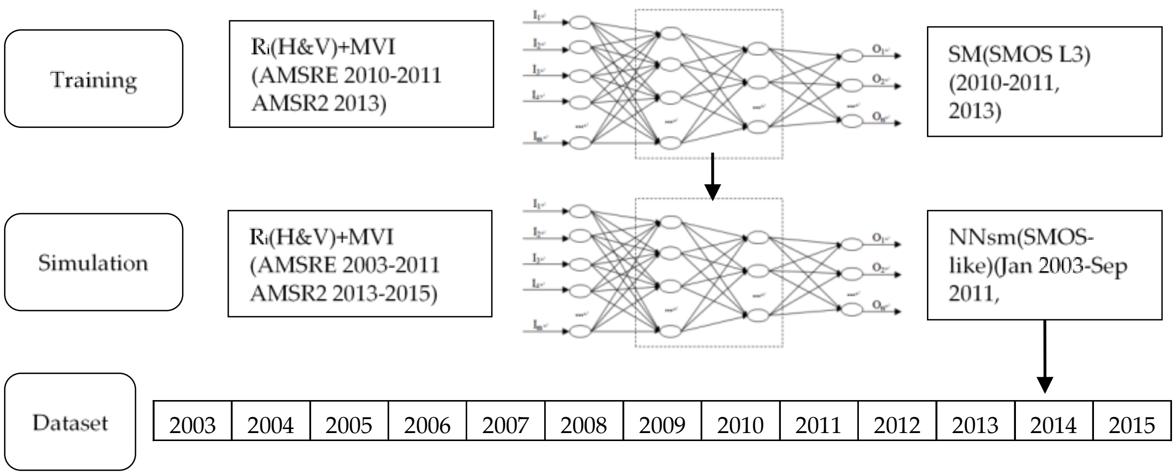
SSM/I(R): 1978 – Now

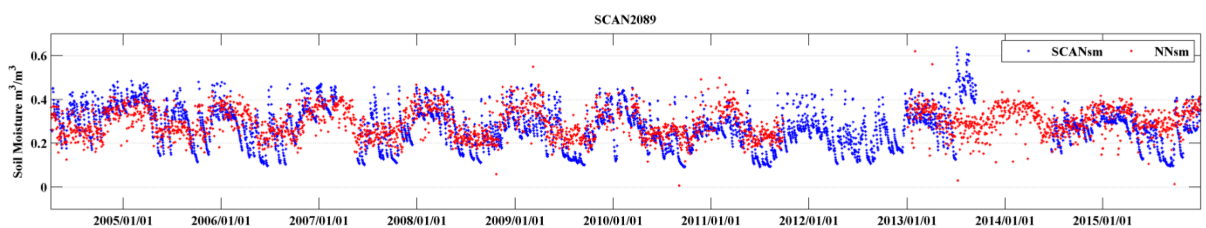
ERS + ASCAT 1991—Now

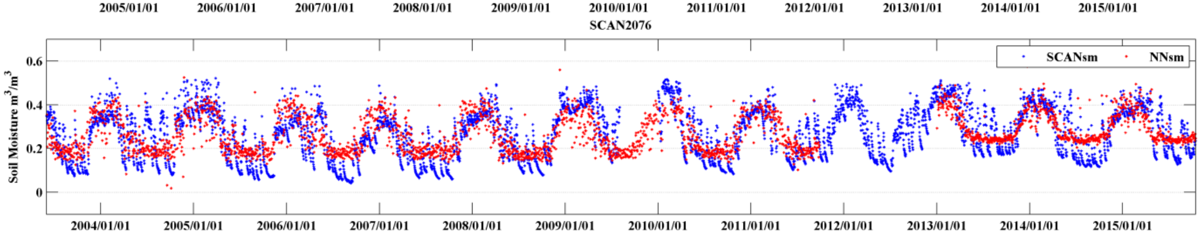
Combined Passive/Active

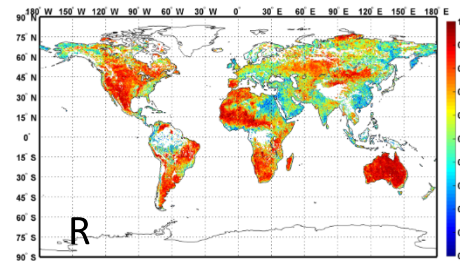
Test from SMOS-AMSR-E

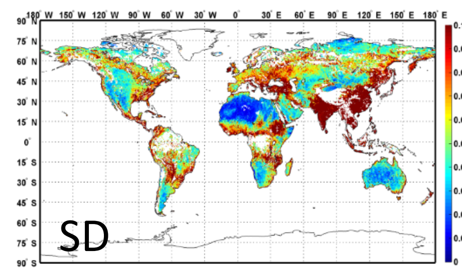
- input： SMOS soil moisture and AMSR-E observations；
- output： simulated SMOS soil moisture with AMSR-E.

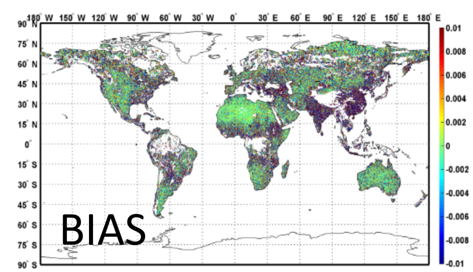












Model parameter optimization using systematic satellite observations

1、Parameter optimization using single-element observation

Case	Changes in model performances			
	Soil temperature	Soil moisture	Sensible heat flux	Latent heat flux
soil temperature observation	21.99%	−41.87%	11.13%	−46.08%
Soil moisture observation	−0.46%	10.85%	1.15%	1.29%

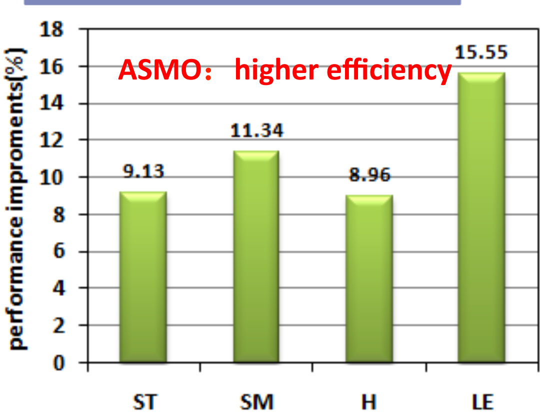
Test experiments by CoLM demonstrate that: the model error will transfer to another state variables when only one state is optimized by using single-element observation

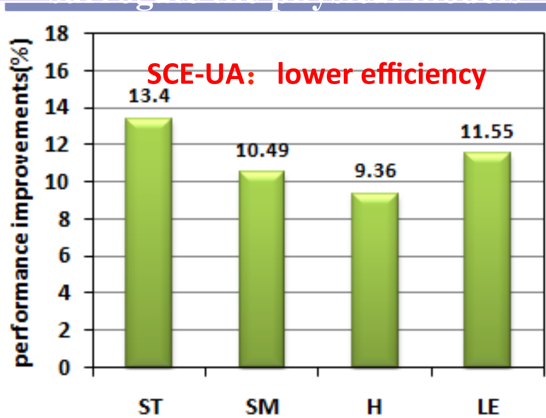
2、 Parameter optimization using multi-element observation

Parameter Selection
Select the most sensitive and controlling parameters

→ **Building Surrogate Models**
Building statistical models to surrogate the physical models

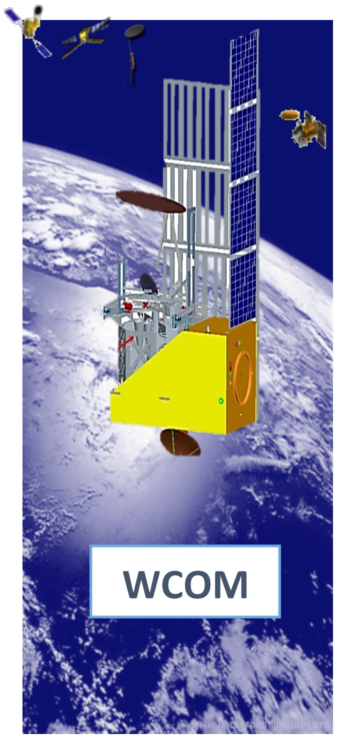
→ **Multi-Object Optimization**





Simultaneous multi-parameters optimization provide a much better chance for the model improvement

International Collaborations



WCOM,SMOS,SMAP

FY-3 Preci Sat

GPM

Global Water Cycle Observations

Ocean Salinity, Water Resource Sat(s)

SWOT, GRACE

Form a global water cycle consolidation

Water Cycle Observation Mission (WCOM) Summary