PRELINMINARY CONSIDERATIONS ABOUT THE CALIBRATION OF A KU- BAND ROTATING FAN-BEAM SCATTEROMETER OF CFOSAT

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Outline

- Consideration about in orbit calibration of CFOSAT scatterometer
  - Missions of CFOSAT
  - Briefs of SCAT
  - Calibration requirements for CFOSAT SCAT
  - Internal calibration
  - External calibration
  - Summary
- Potential contribution of Microwave Sensors Subgroup (MSSG) of CEOS Working Group on Calibration and Validation
  - WGCV and MSSG
  - New work plan of WGCV and MSSG
  - Potential contribution to calibration/validation of scatterometer for OSVW
  - Forthcoming works to do

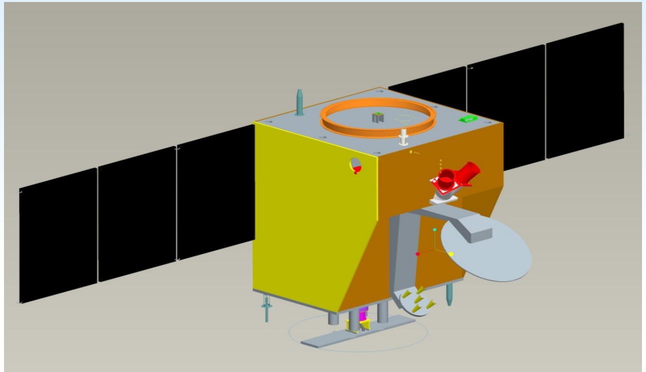
Missions -satellite

- CFOSAT: Chinese French Oceanography SATellite
- Mission Objectives:

monitoring the wind and waves at the ocean surface at the global scale in order to improve:

- The wind and wave forecast for marine meteorology (including severe events)
- the ocean dynamics modeling and prediction,
- our knowledge of climate variability
- fundamental knowledge on surface processes linked to wind and waves

- Two payloads:
  - SWIM (Sea Wave Investigation and Monitoring by satellite)
    - A Ku-band real aperture radar for measurement of directional ocean wave spectra ;
  - SCAT (SCATterometer)
    - A Ku-band rotating fan-beam radar scatterometer for measurement of ocean surface wind vector.



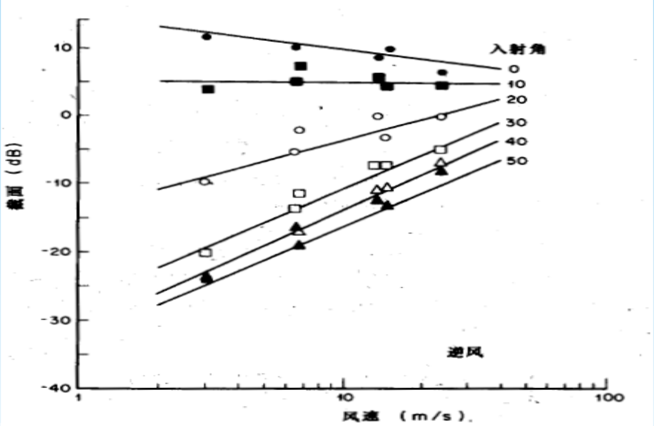
Mission –platform, orbit and schedule at satellite level

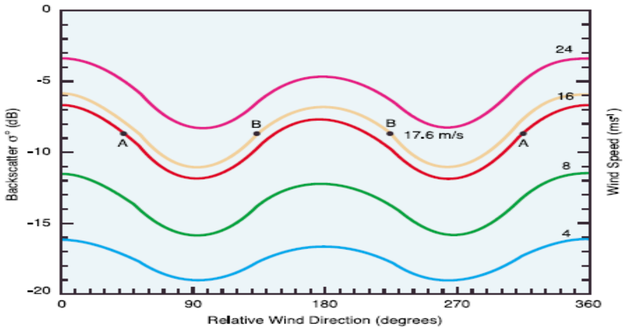
- Platform
  - CAST 2000 (<1000Kg)
- Orbit
  - ~500km
  - Sun synchronous polar orbit
  - Local descending time: 7:00am
- Ground station
  - 3 or 4 stations in China
  - 2 stations in arctic area

- Schedule
  - 2009.05 Mission definition
  - 2011.09 PDR
  - 2011.12 Engineering model delivery
  - 2013.06 Flight model delivery
  - 2014 Launch

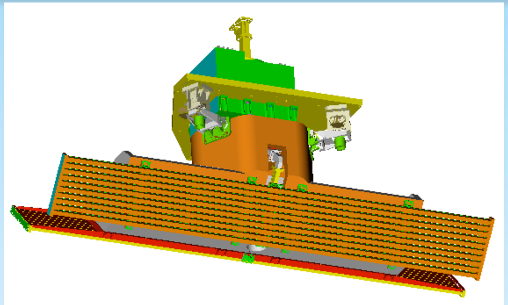
Briefs of CFOSAT/SCAT

- RFSCAT: rotating fan beam scatterometer
- Ocean wind vector measurement by radar scatterometry
  - Wind driven ocean surface roughness
  - Amplitude of NRCS/sigma 0 positively related to wind speed
  - Azimuth modulation of NRCS/sigma 0 by angle between look angle and wind direction
  - Requirements:
    - NRCS measurement (Bragg scattering) with multiple azimuth angles
    - Appropriate swath coverage (pencil beam/fan beam)

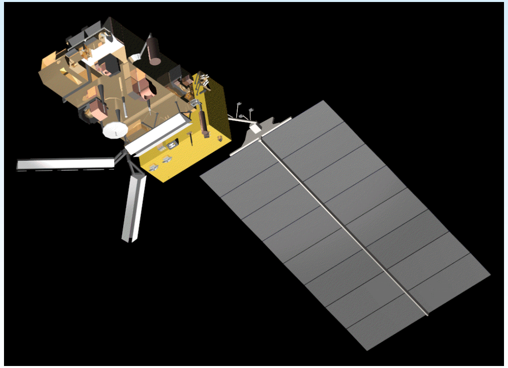




- Implementation of multiple azimuth observation measurements
  - Multiple fixed fan-beam (FFSCAT);
  - Rotating pencil-beam (RPSCAT);
  - Rotating fan-beam (RFSCAT).



(Courtesy from website of JPL/NASA)



(Courtesy from website of EUMETSAT)

	FFSCAT	RPSCAT	RFSCAT
Swath	Beamwidth of antenna	incident angle along elevation	Outer edge of the beam
Azimuth looks	Number of beam/ antennas	Scanning of beam	Scan of beam

Mission requirements for SCAT

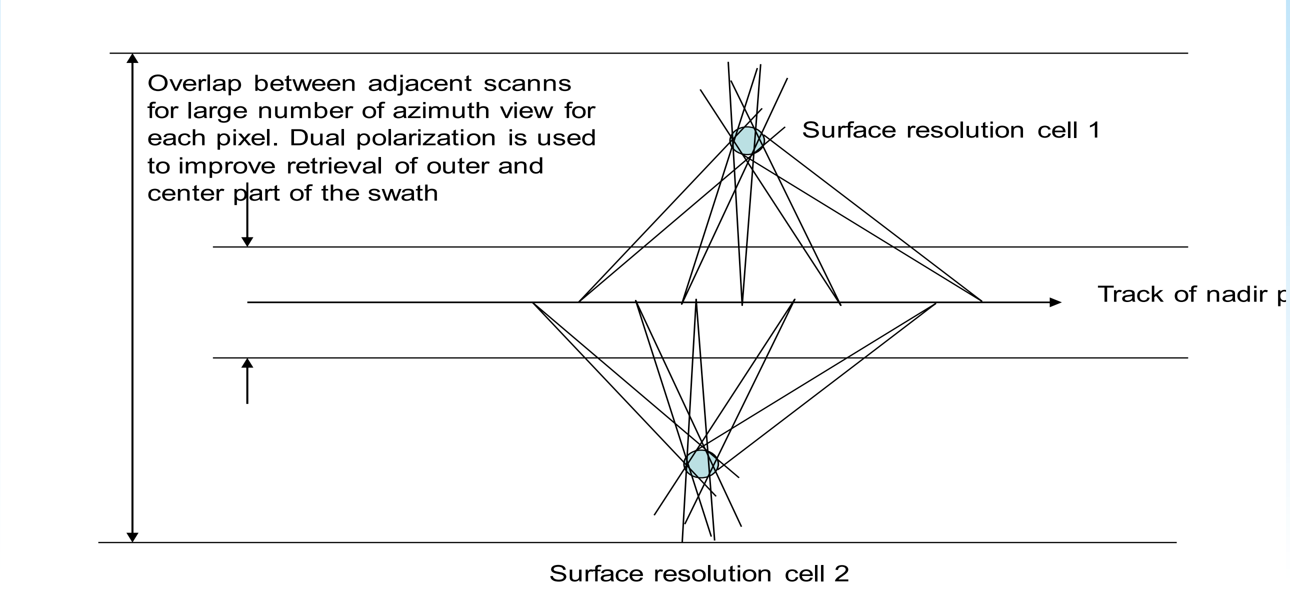
- Objectives:
  - Measurement of global sigma 0
  - Retrieval of global ocean surface wind vector
- Data requirements
  - Swath width: ≥ 1000km
  - Surface resolution for wind product: 50km (standard); 25km (goal)
  - Data quality (at 50km resolution)
  - Wind speed: 2m/s or 10% @ 4~24m/s
  - Wind direction: 20deg @ 360deg for most part of the swath
- Life time: 3yrs

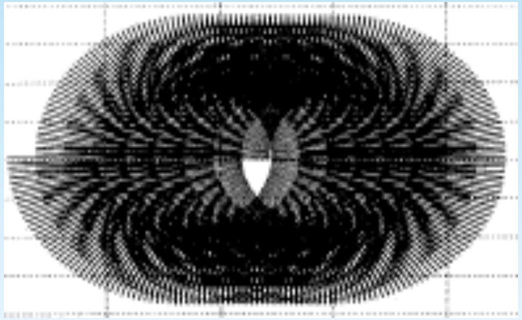
System overviews

- Ku-band rotating fan-beam scatterometer
  - Platform dimension
  - Technology heritage
  - Available GMFs
- Long LMF pulse with de-ramp pulse compression
  - TX: 1.35ms
  - RX: 2.72 ms
- Digital I-Q receiver with on-board pulse compression processing and resolution cell regrouping
- TX/RX channel except antenna and switch matrix identical primary/backup design to ensure liability

- Operation modes
  - Normal mode: dual polarization with rotation;
  - Test/cal mode:
    - raw waveform with lower PRF;
    - Including both rotating mode and fixed pointing mode;
  - Single polarization mode

Surface Coverage of RFSCAT

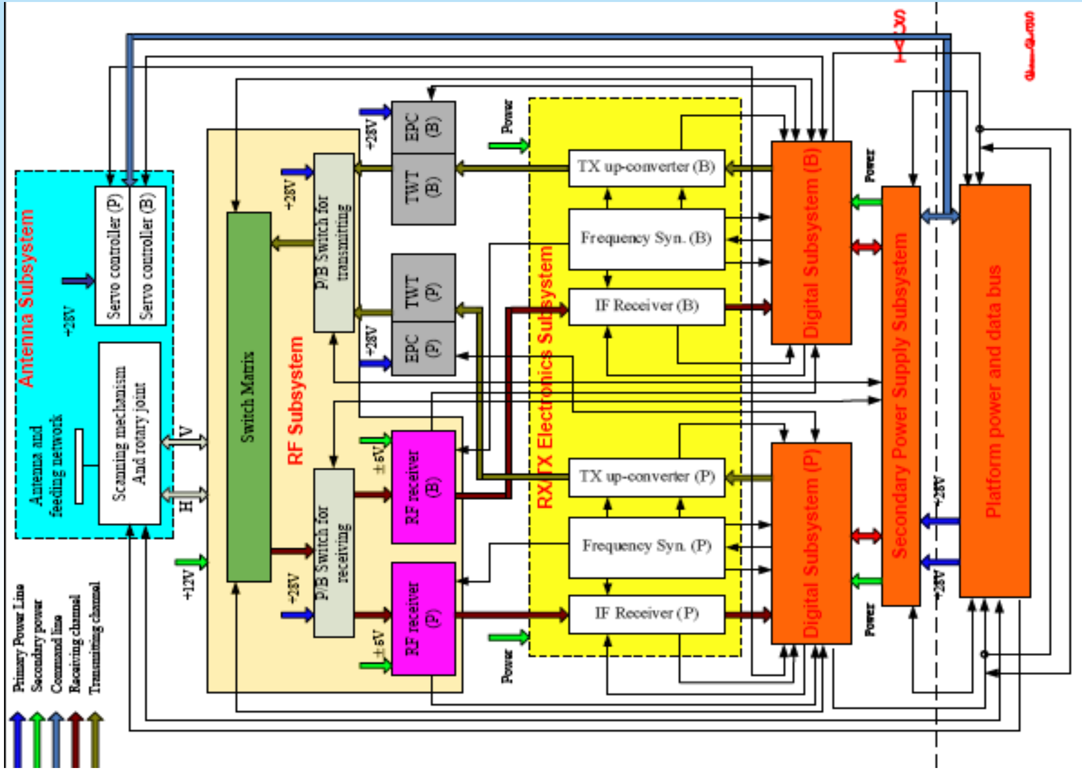


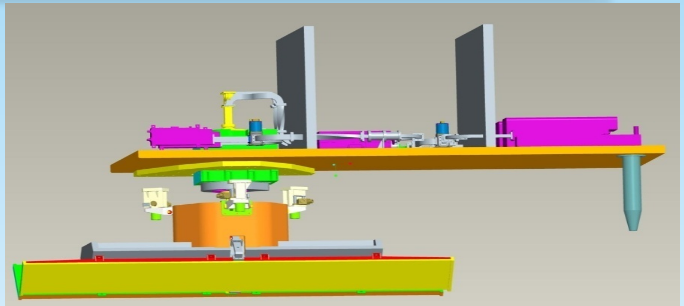


Choice of system type
-Why rotating fan beam?

- Why rotating beam?
  - Overlap of surface coverage with SWIM is requirement, nadir gap should be avoided.
  - Deployment of multiple fan-beam antenna is not allowed due to platform capability.
  - Large swath at a relatively low orbit (~500km) requires scanning.
- Why rotating fan beam?
  - Lower rotating speed to ensure life time of rotating mechanism;
  - Multiple incident angles for better wind direction retrieval;
  - Large incident angle ranges (20~46°) for investigation of ocean surface scattering characteristics, by compensating with SWIM (0~10°)
- Other constrains
  - Antenna dimension: <1.2m
  - Available Pulsed Ku-TWTA: <140W
  - Available TWTA PRF: >150Hz
  - Data rate: <220kpbs
  - Rotating speed and mechanism lifetime

System configuration





Parameter	Specifications
Frequency	13.256GHz
Signal bandwidth	0.5MHz
Internal calibration precision	Better than 0.15dB
Receiver NF	≤2.0dB
Insertion loss of TX channel	≤1.5dB
Insertion loss of RX channel	≤3.0dB
Transmitting power (peak)	120W
Pulse width	1.35ms
PRF	2×75=150Hz

Other radar parameters

Parameter	Specficiatiosn
Antenna Spinning rate :	3.4 rpm (nominal) ±10% (selectable)
Polarization:	VV, HH (alternatively pulse by pulse) 75 Hz/pol channel (150Hz total)
Pulse duration (τ_p):	1.3 ms
Analogue receiver bandwidth	3.0MHz
Receive gate length(T_g):	2.82 ms
Receive gate delay:	3.74 ms

Characteristics of RFSCAT

- Wide swath by rotating of beam;
  - Decided by outer edge of incident angle of beam
- More number of azimuth look angles by overlap of beam;
  - Decided by flying speed, rotating speed and beamwidth
- NRCS/sigma 0 dependent on antenna beam;
  - Decided by local antenna gain along elevation
- Single antenna for all azimuth directions;
  - No inter-beam balance required
  - But azimuth fluctuation may exist due to rotating mechanism

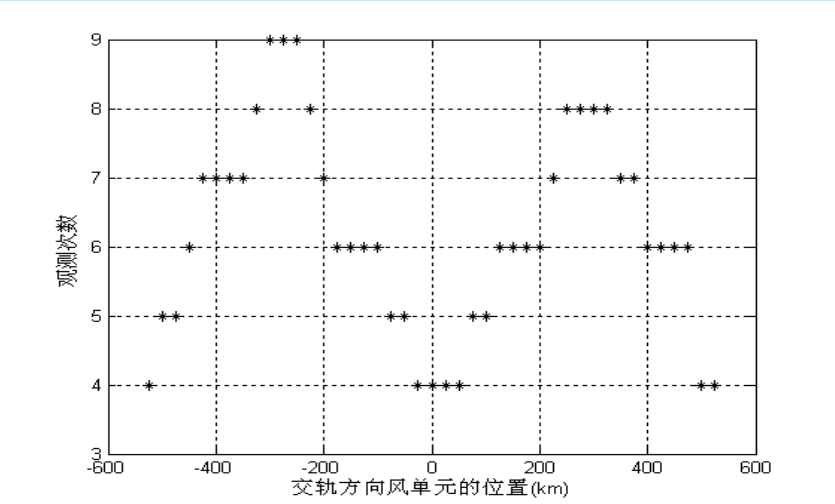
Calibration requirements for RFSCAT

- External/Internal calibration requirement
  - Calibration of in-orbit antenna gain patterns, especially the elevation antenna pattern for NRCS/sigma 0 estimation requirements;
  - Calibration and verification of possible antenna gain fluctuation during rotation due to insertion loss fluctuation of the rotary joint;
  - Calibrations of performance of transmitting/receiving channels and on-board processors.
- Internal calibration
  - Transform absolute power measurement to relative receiver output voltage ratio measurement (scattering measurement to internal calibration measurement)
  - Mitigation of effect of transmitting power and receiver gain fluctuation

Challenges for calibration (to determine sigma 0)

@each surface WVC ➔ variation of azimuth/elevation combination

➔antenna gain at each position required (prelaunch/post-launch)

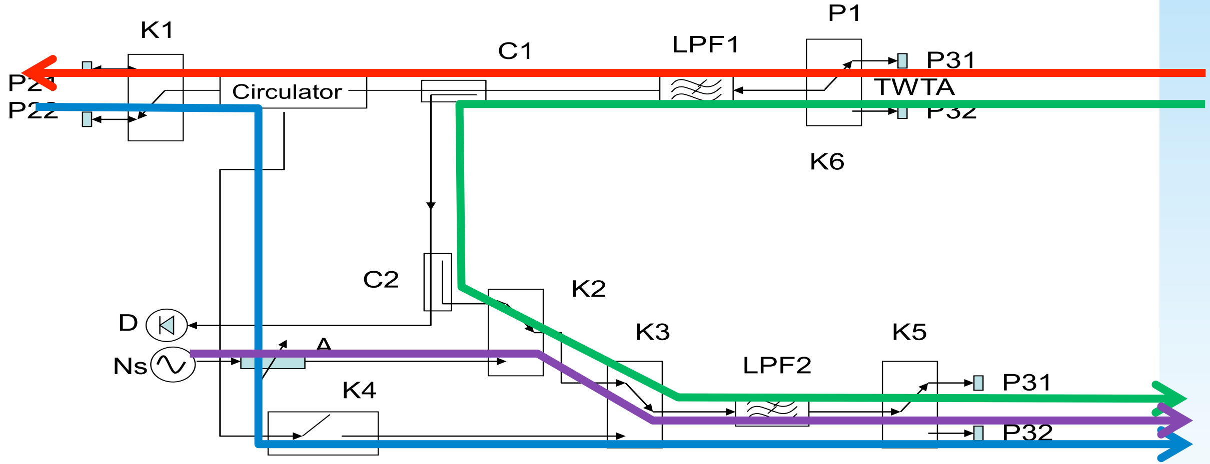


Number of looks with different azimuth and elevation look angles

Basic Considerations about Calibration of CFOSAT/SCAT

- Internal calibration
  - Fluctuations of Tx power and Rx gain;
  - Fluctuations of Rx noise level;
  - Fluctuations of Rx transfer characteristics.
- External calibration
  - In-orbit antenna gain pattern;
  - Tx signal characteristics;
  - Fluctuations of insertion loss during rotation

Internal calibration



Ports：
- P1： BJ-140 to TWTA
- P2： BJ-140 to antennas
- P3： BJ-140 to RF receiver

Compositions:
- C1， C2： directional couplers
- K1， K2， K3， K4： ferrite switches
- K5， K6： mechanical switches
- LPF1/2： EMC filters
- D: power monitoring detector
- Ns： internal noise source

Design considerations of internal cal

- No absolute power calibration is required

$$\sigma^0_{meas} \propto \frac{P_r}{P_t}$$

$$\frac{P_r}{P_t} = \left(\frac{P_{0r}}{P_{0c}}\right)\left(\frac{L_r L_t}{L_c L_{DC_t} L_{DCr}}\right) = \left(\frac{P_{0r}}{P_{0c}}\right)\left(\frac{L_r L_t}{L_f}\right)$$

- The clutter by coupling outside the internal calibration loop will be 20dB lower than the power coupled in the internal calibration loop, which lead to an uncertainty of about 0.1dB;
- The measurement precision for passive part of the transmitting/receiving channel outside the calibration loop will be about 0.1dB after thermal compensation;
- The programmable gain controller inside the receiver has a repetitive precision of 0.1dB;
- The fluctuation of the insertion loss of the rotary joint has a residual of about 0.1dB after external calibration;
- And the overall internal calibration error is better than 0.2dB.

External Calibration

- Purposes
  - Calibration of in-orbit antenna pattern;
  - Calibration of fluctuations of insertion loss of rotary joint during rotation;
  - Calibrations of performance of TX/RX channel and on-board processor.
- Possible Solutions
  - Natural area-extended target with uniform sigma 0
  - Point target with returned signal can be separated from background
  - Ground receiver can characterize Tx signal

External calibration with natural area-extended target

- Candidate area
  - Amazon forest
  - Ice shell (Antarctic, Greenland…)
  - Ocean
  - Desert
- What we had done?
  - Analysis of target stability and homogeneity (Amazon, Antarctic)
  - Simulation for antenna pattern and satellite attitude estimation

Some analysis and simulations

- Sigma 0 data for CFOSAT SCAT incident angle range
- Evaluation of the stability and homogeneity

Calibration simulations

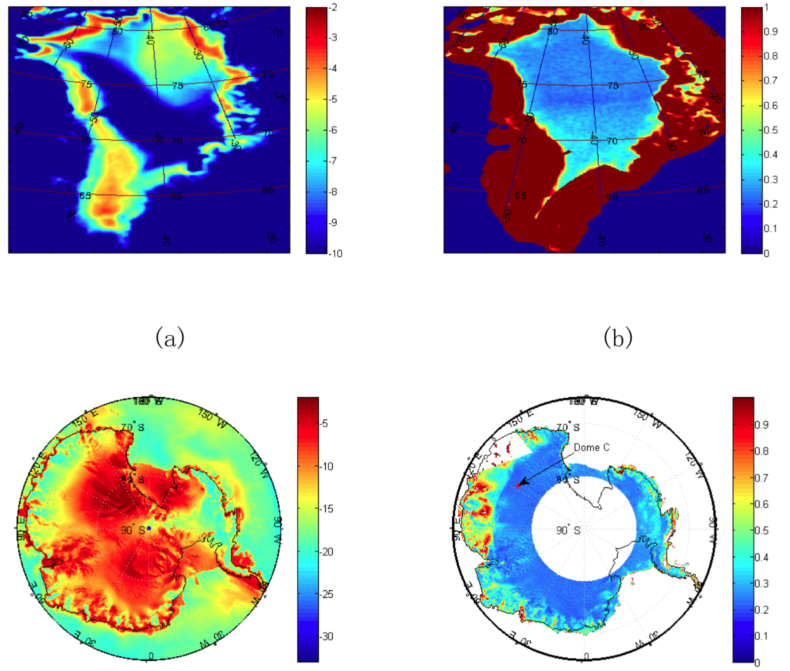
- Models: polynomial fitting (Skouson, Long)

$$\widehat{\sigma^0_{meas}}(k,\theta_n) = c(0,k) + c(1,k)\theta_n + c(2,k)\theta_n^2 + c(3,k)\theta_n^3 + c(4,k)\theta_n^4 + \Delta\sigma^0_{err}$$

- Data base for simulation:

$$\sigma^0(dB) = I_0 + \sum_{k=1}^{N}\left[I_k \cos k\phi_i + Q_k \sin k\phi_i\right]$$

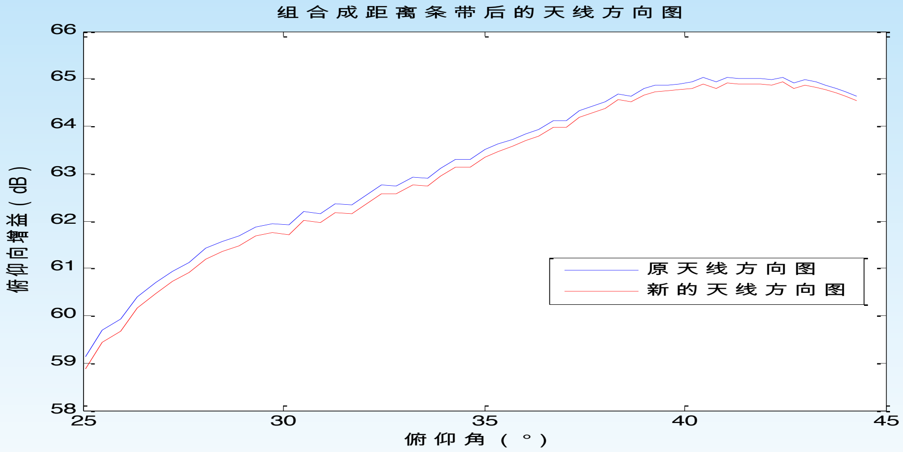
Simulation results

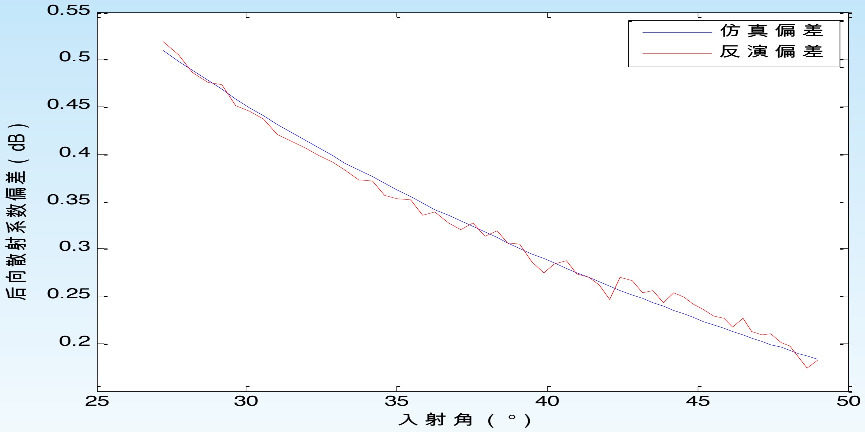


(a) (b)

	1	2	3	4	5
Greenland	（40W，75N）	（40W,78N）	(30W,75N)	(35W,78N)	(36W,76N)
Antarctic	(75S,123E)	(75S,120E)	(77S,37E)	(78S,30E)	(78S,5E)

Simulation of calibration of antenna pattern





Two-way antenna gain pattern :
Blue: before calibration
Red: after calibration

Antenna pattern calibration residual:
Blue: simulated antenna pattern error;
Red: retrieved antenna pattern error.

Further work:

- Investigation of model for elevation dependence of sigma 0 and verification;
- Investigation of azimuth anisotropy of sigma 0 of Antarctic ice shell and processing method for calibration applications.

Considerations of ground based station for calibration of RFSCAT

- Ground receiving station for characterization of azimuth antenna pattern and Tx signal properties;
- Characterization of on-board processing performances with ground based station by comparison between on-board processing data and ground processing;
- Coverage analysis and simulation of ground station applications;
- Investigation and assessment of necessity of transponder for calibration of RFSCAT.

More considerations

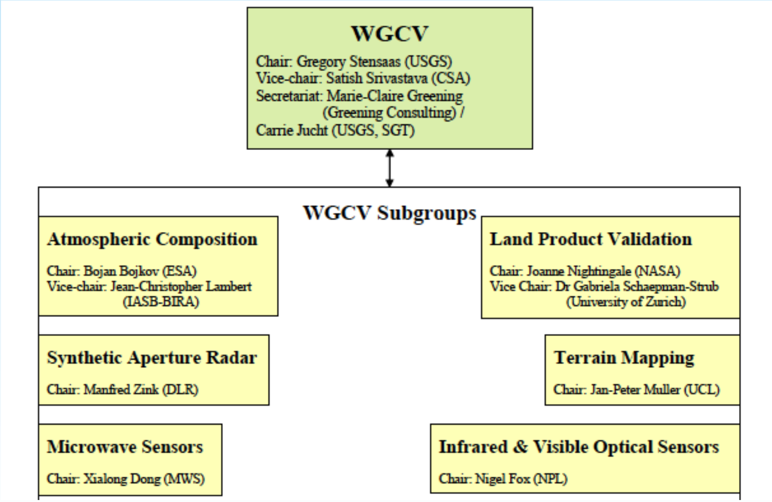
- Development and verification of sigma0 incidence-dependence for calibration sites candidates
  - Amazon forest
  - Antarctic ice shell
  - Oceans…
- Investigation of applications of calibration with oceans.
- Cross calibration with other sensors.

Summary

- Some basic considerations of in-orbit calibration of RFSCAT are presented ;
- Analyses show Amazon forest has good homogeneity and isotropy, which can be used for calibration;
- Analyses show Antarctic ice shell has good homogeneity, which can be a candidate for calibration, but azimuth isotropy needs to be addressed; processing method need to be investigated.
- Ground calibration station is necessary for antenna pattern calibration along azimuth direction and Tx signal characterization; necessity of transponders need to be investigated;
- Global Ocean Calibration can also be used to improve inter-sensor calibrations.

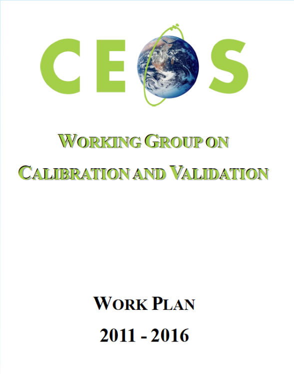
CEOS WGCV and MSSG

- WGCV, Working Group on Calibration and Validation
  - One of the working groups of CEOS
  - Dedicate to calibration and validation of earth observation
- MSSG, Microwave Sensors Subgroup
  - One of the subgroups of WGCV
  - Dedicate to calibration/validation of EO sensors operating in microwave frequency, except SAR.



New work plan for WGCV and MSSG

- Missions of WGCV
  - The mission of the WGCV is to ensure long-term confidence in the accuracy and quality of EO data and products, and to provide a forum for the exchange of information calibration and/or validation, coordination, and cooperative activities.
  - The WGCV promotes the international exchange of technical information and documentation, joint experiments and the sharing of facilities, expertise and resources.


CEOS

WORKING GROUP ON
CALIBRATION AND VALIDATION

WORK PLAN
2011 - 2016

Tasks of WGCV

- Support to CEOS and GEO
- Calibration and Validation of Earth Observation Systems
- Quality Assurance Framework for Earth Observation
- Calibration / Validation Test Sites
- Instrument / Field / Intercomparison Campaigns

Missions and objectives of MSSG

- Missions:
  - To foster high quality calibration and validation of microwave sensors for remote sensing purposes. These include both active and passive types, airborne and spaceborne sensors.
- Objectives
  - Facilitate international cooperation and co-ordination in microwave sensor Cal/val activities by sharing information on sensor development and field campaigns
  - Promote accurate calibration and validation of microwave sensors, through standardization of terminology and measurement practices
  - Provide a forum for discussion of current issues and for exchange of technical information on evolving technologies related to microwave sensor cal/val

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- Promote accurate calibration and validation of microwave sensors, through standardization of terminology and measurement practices.
- Provide a forum for discussion of current issues and for exchange of technical information on evolving technologies related to microwave sensor calibration / validation.
- Provide calibration/validation support to CEOS virtual constellations and data application groups/communities by coordination of reference sites for both passive and active microwave sensors, and standardization of quality assurance of microwave remote sensing data.

Work plan of MSSG

- Identification and characterization of reference sites for passive and active sensor, especially for L1b data product, collecting data on these sites;
- Identification and standardization of calibration procedure and calibration data processing of microwave sensors, for both prelaunch and in-orbit, to ensure the consistency of data for different sensors on different satellites and developed by different agencies;
- Standards or recommended guidelines for cross-calibration of in-orbit microwave sensors;
- Standards or recommended guidelines for quality assurance of microwave data for climate and global change applications;
- Standardization of radiometric references for passive sensors.

What MSSG will do for OSVW…

- Standards/guidelines for data quality assurance with OSVW community
  - Data quality
  - Criteria for reference sites
  - Sites and database survey
  - Portal for CAL/VAL of scatterometers

Forthcoming works…

- Tighter connection with OSVW VC.
- Team for CAL/VAL of scatterometer
- Survey and questionnaire for CAL/VAL references and standards/ guidelines for QA purpose
- CAL/VAL workshop for Microwave Sensors (November, 2012)
- POC in OSVW VC and IOVWST for WGCV