Report from National Space Science Center, CAS

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CAS Key Laboratory of Microwave Remote Sensing
National Space Science Center
Chinese Academy of Sciences

(MiRS,NSSC,CAS)

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Outline

- Introduction to NSSC and MiRS
- EO satellite missions contributed
- CAL/VAL activities in NSSC
NSSC (National Space Science Center, CAS), Since 1958

Oct. 1958, set up by CAS, dedicated to the development of the first Chinese artificial satellite
The first Chinese artificial satellite DFH-1 was launched on April 24, 1970.
1980-90s, SJ series satellites, pioneered the space environment exploration in China
1990-2000, major player of China’s manned space flight program
In 2011, CSSAR ➔ NSSC

Center for Space Science and Applied research ➔ National Space Science Center

- Institute in CAS for planning, selection, management, development, launching and operations of China’s space science satellite missions;
- Taking leading role in China in space physics, space environment, microwave remote sensing.
- Also the Space Science Remote Sensing Department of NRSCC.
Institute in CAS for planning, selection, management, development, launching and operations of China’s space science satellite missions;

Taking leading role in China in space physics, space environment, microwave remote sensing.
Main research directions of NSSC

- Fundamental research in
  - space plasma physics,
  - space weather study and forecasting,
  - space-borne and ground-based space environment monitoring and detection,
  - special effects of the space environment,
  - and the related study of experimental technology.

- integrated electronics on complex spacecraft system and the related information technology,
- space mission simulation,
- microwave remote sensing and information technology.
Major Projects

- Strategic Pioneer Program on Space Science
- Double Star Program
- Meridian Project
- Manned Space Flight and Lunar Exploration Program
- Applied and Operational Satellites (FY, HY)
key labs and affiliated organizations

- State Key Laboratory of Space Weather
- CAS Key Laboratory of Microwave Remote Sensing (MiRS)
- CAS Key Laboratory of Complex Space Electronic Systems
- Hainan National Field Observation Station of Space Weather
- CAS Center for Space Environment Research and Forecast
- Chinese Society on Space Research (CSSR)
- Chinese National committee for Committee on Space Research (COSPAR)
MiRS, CAS

✧ Founded in 1958, as electronics group participated in the development of China’s 1st satellite (DFH-1) in early 1970s.

✧ NMRS developed the telemetry receiver for DFH-1.

✧ From 1973, focuses turned to microwave remote sensing technology.

✧ Research and development priorities:
  ➢ Theory and techniques of microwave sounding and imaging;
  ➢ Development of microwave remote sensing payloads
    • microwave radiometer,
    • radar altimeter,
    • radar scatterometer
  ➢ Calibration, and information techniques for microwave remote sensing.
EO Satellite Missions NSSC and MiRS Contributed

  - Ku-band scatterometer, altimeter
  - Multi-band microwave radiometer (C~Ka)

- FY-3 Polar Orbit Meteorological Satellite
  - Microwave Humidity Sounder (FY-3A 2008, FY-3B 2010): 150, 183GHz (5 channels)
  - Microwave Humidity Sounder-II (FY-3C 2013): 89, 118, 150, 183GHz (15 Channels)

- HY-2 Ocean Dynamic Environment Missions (A, 2011)
  - Radar altimeter (Ku, C)
  - Atmospheric Correction Microwave Radiometer
  - Radar Scatterometer (Ku, Rotation pencil beam, participated)

- CFOSAT (Chinese-French Oceanography Satellite, 2015)
  - Radar scatterometer (Ku, rotation fan-beam)
CAL/VAL activities in NSSC

- Calibration of radar altimeter with transponders
- Calibration of radar scatterometer with global oceans
- Calibration techniques for rotation fan-beam scatterometer
- Calibration of full-polarized microwave radiometer
- Calibration of spaceborne radiometers without rotation mechanism (SARad and Nadir looking radiometer)
Calibration of radar altimeter with transponders (W Guo and C Y Wang)

- Calibration of HY-2A radar scatterometer with transponders
- Estimation and correction of system offset
Active radar calibrator

- SUV-carried
- Mobility
- Automated
Accessories: **D-GPS for precise locationing**

- **GPS mobile receiver**
- **GPS base receiver**
- **Lifting-jack**
Principle of calibration by ARC

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Troposphere</td>
<td>$h_{\text{tropos}}$</td>
</tr>
<tr>
<td>Ionosphere</td>
<td>$h_{\text{ionos}}$</td>
</tr>
<tr>
<td>Solid tide</td>
<td>$h_{\text{solid}}$</td>
</tr>
<tr>
<td>Pole tide</td>
<td>$h_{\text{pole}}$</td>
</tr>
<tr>
<td>Clock difference</td>
<td>$h_{\text{clk}}$</td>
</tr>
<tr>
<td>ARC delay</td>
<td>$h_{\text{ARC}}$</td>
</tr>
</tbody>
</table>

$\text{InstrumDelay} = (R_n - T_n) \cdot C - \rho_{Tn} - \rho_{Rn} - h_{\text{tropos}} - h_{\text{iono}} - h_{\text{tide}} - h_{\text{clk}} - h_{\text{ARC}}$
Calibration sites

Beijing
E: 116.4392°
N: 39.8151°

Suizhong
E: 119.8798°
N: 40.0007°
ShangChuan Island, Guangdong Province, China

Calibration sites
Experiment procedure

Before the passing day:
✓ Charge the batteries and UPS;
✓ Predict the orbit height at the closest approach time;
✓ Power on GPS receiver;

On the passing day:
✓ Lift the jeep and antenna;
✓ Power on ARC and set parameters;
✓ Record the demodulated I/Q data.

After the passing day:
✓ Data analysing.....
### Calibration data available

<table>
<thead>
<tr>
<th>Date</th>
<th>Site</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-08-09</td>
<td>SuiZhong</td>
<td>OK</td>
</tr>
<tr>
<td>2012-08-19</td>
<td>BeiJing</td>
<td>OK</td>
</tr>
<tr>
<td>2012-09-02</td>
<td>BeiJing</td>
<td>OK</td>
</tr>
<tr>
<td>2012-09-06</td>
<td>SuiZhong</td>
<td>OK</td>
</tr>
<tr>
<td>2012-11-01</td>
<td>SuiZhong</td>
<td>OK</td>
</tr>
<tr>
<td>2012-11-15</td>
<td>SuiZhong</td>
<td>OK</td>
</tr>
<tr>
<td>2013-01-20</td>
<td>BeiJing</td>
<td>OK</td>
</tr>
<tr>
<td>2013-03-03</td>
<td>BeiJing</td>
<td>OK</td>
</tr>
<tr>
<td>2013-03-17</td>
<td>BeiJing</td>
<td>OK</td>
</tr>
<tr>
<td>2013-03-31</td>
<td>BeiJing</td>
<td>OK</td>
</tr>
</tbody>
</table>

- HY-2 altimeter transmits bursts at constant interval
- Unprocessed I/Q data, not averaged 20Hz power spectrum
- The ephemeris data and orbit data are obtained from DORIS
- The geophysical data are obtained from GPS & IGS
ARC response waveform

closest epoch

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Tropos and ionos correction

Tropos delay

Ionos delay

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Geophysical correction

Solid tide correction

Pole tide correction

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Doppler correction

\[ f = -\frac{v}{\lambda} \]

\[ f_d = -\frac{\Delta d}{T \lambda_c} \]

\[ d_f = f_d \frac{W_t - C}{W_f} \]

\( \Delta d : R_n - R_{n-1} \)

\( T : \text{Period} \)

\( \lambda_c : \text{Wavelength} \)

\( W_t : \text{Pulse Width} \)

\( W_f : \text{Bandwidth} \)

\( d_f : \text{Doppler Correction(m)} \)
Clock drift correction

\[
\begin{align*}
R_0 &= T_0 + \frac{\rho_0}{c} + \Delta t \\
R_1 &= T_1 + \frac{\rho_1}{c} + \Delta t \\
R_2 &= T_2 + \frac{\rho_2}{c} + \Delta t \\
R_3 &= T_3 + \frac{\rho_3}{c} + \Delta t \\
\end{align*}
\]

(2)-(1), (3)-(2), (4)-(3)……

\[
\begin{align*}
\Delta R_0 &= (T_1 - T_0) + \frac{\rho_1 - \rho_0}{c} \\
\Delta R_1 &= (T_2 - T_1) + \frac{\rho_2 - \rho_1}{c} \\
\Delta R_2 &= (T_3 - T_2) + \frac{\rho_3 - \rho_2}{c} \\
\end{align*}
\]

\[T_n - T_{n-1} = \text{constant}\]

\[
\begin{align*}
\Delta R_0' &= \frac{\rho_1 - \rho_0}{c} \\
\Delta R_1' &= \frac{\rho_2 - \rho_1}{c} \\
\Delta R_2' &= \frac{\rho_3 - \rho_2}{c} \\
\sum \Delta R_n' &= \text{theoretical transmit interval} \\
\end{align*}
\]

\[
\begin{align*}
s_0 &= \Delta R_0' + \Delta R_1' \\
s_1 &= \Delta R_1' + \Delta R_2' \\
s_2 &= \Delta R_2' + \Delta R_3' \\
\end{align*}
\]
Clock drift correction

- ARC tracking data
- ARC response data

Range

\[ \Delta t \]

\[ t \text{ (flight time)} \]
Clock drift correction

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### Summary

<table>
<thead>
<tr>
<th>Item\data</th>
<th>2012/09/02</th>
<th>2012/11/15</th>
<th>2012/11/25</th>
<th>2013/01/20</th>
<th>2013/03/03</th>
<th>2013/03/17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clock diff</td>
<td>0.7401</td>
<td>0.8163</td>
<td>0.8277</td>
<td>0.7986</td>
<td>0.8301</td>
<td>0.8295</td>
</tr>
<tr>
<td>Tropos</td>
<td>2.4147</td>
<td>2.3895</td>
<td>2.3355</td>
<td>2.3994</td>
<td>2.3399</td>
<td>2.3496</td>
</tr>
<tr>
<td>Ionos</td>
<td>0.063</td>
<td>0.034</td>
<td>0.024</td>
<td>0.026</td>
<td>0.034</td>
<td>0.065</td>
</tr>
<tr>
<td>Solid tide</td>
<td>-0.1013</td>
<td>-0.1607</td>
<td>-0.039</td>
<td>0.0816</td>
<td>0.1163</td>
<td>0.0722</td>
</tr>
<tr>
<td>Pole/ocean tide</td>
<td>0.008</td>
<td>0.001</td>
<td>-0.0001</td>
<td>0.0034</td>
<td>0.014</td>
<td>0.013</td>
</tr>
<tr>
<td>HY-2 Alitmeter instru corr</td>
<td>5.4515</td>
<td>5.4690</td>
<td>5.4543</td>
<td>5.4620</td>
<td>5.4732</td>
<td>5.4711</td>
</tr>
</tbody>
</table>

**Maximum difference:** 2.17cm  
**Standard:** 0.91cm
Calibration of Scatterometers with global ocean (R S Yun, X L Dong, and KNMI scatterometry team)

- **Scatterometer absolute calibration**
  - **Transponders**
    - Earth-based radar pulse stability limitation
    - Strong geographical and time limitations; few measurements
    - Weather influence
  - **sea ice/snow**
    - Geographical and time limitations; sparse measurements
    - Melt area backscatter instability
  - **rain forest**
    - Geographical and time limitations; sparse measurements
    - Small diurnal cycle
    - Other geographical features (e.g., rivers, forest reduction)
Scatterometer absolute calibration

- NWP Ocean Calibration (NOC)
  - The NOC may be applied over a large portion of the globe and consequently may provide accurate results over a relatively short period.
  - Drift of scatterometer backscatter can be inspected by NOC in time.
  - NOC has been applied successfully for the European Remote-Sensing Satellite (ERS) and Advanced SCATterometer (ASCAT) C-band fan-beam scatterometer wind products at KNMI.
Ku-band scatterometer NOC

- QuickSCAT/OSCAT/HY-2A is Ku band pen-beam conical scanning scatterometer; CFOSAT/SCAT is Ku band fan-beam rotating scanning scatterometer.
- WVCs experience the same set of incidence angle, but different azimuth; ASCAT WVCs have same azimuth and different inc.
- The atmosphere is not transparent at Ku band wavelengths and rain leads in particular to attenuation and volume scattering.
- Rain roughens the sea surface at low winds.
- KNMI QC flag, which is commonly used in the KNMI scatterometer wind products and shows excellent performance in screening rainy WVCs was used for QuickSCAT/OSCAT scatterometer NOC.
Ku-band NOC method per WVC

-The wind Geophysical Model Function (NSCAT2):

\[ \sigma^0(\theta, v, \phi) = B_0(\theta, v)(1 + B_1(\theta, v)\cos \phi + B_2(\theta, v)\cos(2\phi)) \]

Where, \( \theta \) is incidence angle, \( v \) is wind speed.

\( \phi \) is azimuth wind direction angle w.r.t. radar beam,

- In Fourier analysis and for fixed \( \theta \) (scanning beam):

\[ \sigma^0(v, \phi) = \frac{1}{2} a_0(v) + a_1(v)\cos \phi + a_2(v)\cos(2\phi) \]

-Integrating uniformly over the azimuth angle:

\[ a_n(v) = \frac{1}{\pi} \int_0^{2\pi} \sigma^0(v, \phi)\cos(n\phi)d\phi \quad n = 0,1,2. \]

\[ \langle \sigma^0 \rangle = \int_0^{\infty} 2a_0(v)\text{PDF}(v)dv \]
Ku-band NOC method per WVC

\[ \sigma_{SCAT}^0 \]

QC switch (rain)

Scatterometer product

NOC

Binning in NWP speed \( i \) and direction \( j \)

Integrate direction \( j \) uniformly

Integrate over speed PDF

\[ \sigma_{NWP}^0 \]

GMF

NWP winds

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QuikSCAT NOC and Validation

The average of the QuikSCAT ocean calibration residuals over January 2008.
(a) with QC-ed WVCs and (b) with QC-free WVCs.

- Rain QC provides VV & HH consistency
- Rain most affects inner
- Fore & aft looks are very close
The average of the QuikSCAT NOC residuals over January 6th, to 12th, 2008 after correction.

(a) QC-ed NOC correction on QC-ed WVCs;
(b) QC-ed NOC correction on QC-free WVCs;
(c) QC-free NOC correction on QC-ed WVCs;
(d) QC-free NOC correction on QC-free WVCs;
QuikSCAT NOC and Validation

- Rain causes a large inversion residual, MLE (dashed line)
- QC removes rain, gives more consistent $\sigma^0$ sets with GMF
- QC-ed NOC provided the lowest MLEs for all WVCs
QuikSCAT NOC NWP Validation

QuikSCAT versus ECMWF winds for the period January 6, to 12, 2008.

- NOC after QC provides lowest speed bias, as expected

- Also, lowest wind direction SD and lowest zonal wind component SD

- NOC has small detrimental effect on meridional wind component SD
QuikSCAT NOC buoy Validation

No correction

Statistics - speed

Average bias = -0.46, mean X val = 8.82, mean Y val = 8.37
average std dev = 1.24, correlation XY = 0.95

Statistics - direction

average bias = 3.40, mean X val = 169.77, mean Y val = 173.17
average std dev = 17.70, correlation XY = 0.98

NOC correction

Statistics - speed

average bias = -0.26, mean X val = 8.82, mean Y val = 8.55
average std dev = 1.24, correlation XY = 0.95

Statistics - direction

average bias = 3.14, mean X val = 169.77, mean Y val = 172.91
average std dev = 17.73, correlation XY = 0.98

➢ NOC correct the speed bias
➢ No other significant effects on direction and wind components
# QuikSCAT NOC and Validation

## Table 1: QuikSCAT collocated buoy validation (Jan.2008)

<table>
<thead>
<tr>
<th></th>
<th>Wind Speed (m/s): Average bias/Average stddev</th>
<th>Wind Direction (deg): Average bias/Average stddev</th>
<th>u component (m/s): Average bias/Average stddev</th>
<th>v component (m/s): Average bias/Average stddev</th>
</tr>
</thead>
<tbody>
<tr>
<td>No NOC correction (wind vector)</td>
<td>(3127) -0.46/1.24</td>
<td>(2860) 3.4/17.70</td>
<td>(3129) 0.35/1.85</td>
<td>(3130) 0.04/1.95</td>
</tr>
<tr>
<td>QC-ed NOC correction (wind vector)</td>
<td>(3125) -0.26/1.24</td>
<td>(2860) 3.14/17.73</td>
<td>(3129) 0.34/1.86</td>
<td>(3129) -0.03/1.98</td>
</tr>
</tbody>
</table>
RFSCAT NOC Brief Introduction

Unlike ASCAT or QSCAT/OSCAT/HY-2A, for 1 WVC with different across-track position:

- **view number** is different (fig. A)

Accordingly,

- **incidence angle** different for different view (fig. B)
- **azimuth angle** different for different view (fig. C)

<table>
<thead>
<tr>
<th>Scatterometer</th>
<th>View numver</th>
<th>Incidence angle</th>
<th>Azimuth angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCAT</td>
<td>3</td>
<td>Fixed</td>
<td>Fixed for 3 beams</td>
</tr>
<tr>
<td>QuikSCAT/OSCAT</td>
<td>4(inner WVCs)</td>
<td>Fixed for 2 beams</td>
<td>Fixed for 4 views</td>
</tr>
<tr>
<td>RFSCAT</td>
<td>3,4,5,6,7,8,9</td>
<td>Not fixed</td>
<td>Not fixed</td>
</tr>
</tbody>
</table>
Conclusions

- RFSCAT(CFOSAT/SCAT) is a rotating fan-beam scatterometer, there is a mix of incidence angles and azimuth angles for every WVC.
- NWP Ocean Calibration method can be applied on RFSCAT(CFOSAT /SCAT), definitely necessary.
- RFSCAT NOC should be more complicated, and it is should be a correction table of incidence angle, not of WVC number or across-swath position (need much more work on it...)

Future works

- Calibration with ocean and Amazon forest for azimuth variation
- Antenna pattern and satellite attitude calibration techniques
Thank You!