Microwave Imager Data in Climate Observation and Numerical Weather Prediction

Karen St.Germain
NOAA NPOESS/JPSS

William Bell
ECMWF
Overview

• Introduction: Microwave Imager Data
• Aims of the Session
• Links with other initiatives:
  – GSICS
  – CEOS-WG Cal/Val MSSG
• Overview of presentations
• Questions to consider
Microwave Imager & Imager/Sounder Measurements

MW Imagers & Imager/Sounders provide measurements of many ‘Essential Climate Variables’ including:
• Upper atmospheric temperature
• Water vapour
• Cloud liquid water
• Precipitation
• Surface wind (over ocean)
The proliferation of imaging missions post-2010 requires international co-operation to ensure consistency of measurements.

‘Research’ platforms not shown, eg: Windsat, AMSR, TMI, GMI, Megha-Tropiques ...
Planned Operational Microwave Sounding Missions

- US
  - TIROS-N
  - NOAA-6
  - NOAA-7
  - NOAA-8
  - NOAA-9
  - NOAA-10
  - NOAA-11
  - NOAA-12
  - NOAA-13 (Power system failure)
  - NOAA-14
  - NOAA-15
  - NOAA-16
  - NOAA-17
  - NOAA-18
  - NOAA-19
  - NPOESS-NPP
  - NPOESS-C1
  - NPOESS-C2
  - NPOESS-C3
  - NPOESS-C4

- Europe
  - METOP (AM)
  - 2nd METOP
  - 3rd METOP

- China
  - FY3A
  - FY3B
  - FY3AM1
  - FY3PM1
  - FY3RM (TEST)
  - FY3PM2
  - FY3RM1
  - FY3RM
Research Microwave Imagers

- TMI (1997 -)
- AMSR-E (2002 -)
- Windsat (2003 -)

Operational Microwave Imagers

- F13 & F15 SSMI (1995 – present)
- F16 & F17 SSMIS (2003 – present)
Aims of Session F

- Review the current use of the data in NWP and Climate research and to review the measurement uncertainty requirements associated with these applications.

- Review instrument calibration issues uncovered to date and on-orbit radiometric performance of current imaging missions.

- Review current practise in pre-launch characterisation and in microwave metrology.

- Establish best practise for future missions.

- Specify requirements for improved underpinning metrology in order to provide a focus for national and international metrology programmes.

- Foster improved international collaboration between users, agencies, instrument teams and the metrology community, in order to reduce risk for future missions.
# Invited Participants

<table>
<thead>
<tr>
<th>Users</th>
<th>US</th>
<th>Europe</th>
<th>Russia</th>
<th>China</th>
<th>Japan</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>F. Weng</td>
<td>R. Saunders</td>
<td>A. Uspensky</td>
<td>J. Yang</td>
<td>H. Shimoda</td>
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<td></td>
<td>C. Zou</td>
<td>D. Dee</td>
<td>I. V. Cherny</td>
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<td>T. Mo</td>
<td>W. Bell</td>
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<td>B. Yan</td>
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<td>S. Gutman</td>
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<td>C. Mears</td>
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<td></td>
<td>G. Stephens</td>
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<tr>
<td>Agencies/Instrument teams</td>
<td>W. Blackwell</td>
<td>P. Schlüssel</td>
<td>J. Jiang</td>
<td>K. Imaoka</td>
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<tr>
<td></td>
<td>S. Brown</td>
<td>V. Kangas</td>
<td>H. Liu</td>
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<td></td>
<td></td>
<td></td>
<td>X. Dong</td>
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<tr>
<td>Metrologists</td>
<td>D. Walker</td>
<td>D. Jarvis</td>
<td>N. Feng</td>
<td>C. Chunyue</td>
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<tr>
<td></td>
<td></td>
<td>R. Dudley</td>
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Organisers aimed to fill the ‘space’ spanned by ‘agencies’ and ‘expertise’, given the limit of 15 people per session (= 30 over MWS and MWI Sessions).
Complementarity to other initiatives:
The Global Space Based Inter-Calibration System (GSICS)

Calibration Support Segment:
- Performing highly-accurate, SI standards traceable tests on satellite instruments and their on-board calibration references;
- Developing calibration “best-practices” procedures.

see:
Plenary talk by F. Weng
Session F talk by F. Weng
Complementarity to other initiatives: 
CEOS WG Cal/Val: 
Microwave Sensors Sub Group (MSSG)

Mission

• To foster high quality calibration and validation of microwave sensors for remote sensing purposes. These include both active and passive types, airborne and space-borne 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

WGCV-31 held March 2010
See Session A talk by X. Dong

http://calvalportal.ceos.org/cvp/web/guest
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>16:00</td>
<td>Trends in total precipitable water from microwave imagery data</td>
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<tr>
<td></td>
<td><em>Graeme L. Stephens, Colorado State University {US}</em></td>
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<td>16:30</td>
<td>Microwave imagery data in NWP</td>
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<td><em>William Bell, ECMWF {UK}</em></td>
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<td>17:00</td>
<td>NPOESS Microwave Imager/Sounder (MIS) sensor development</td>
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<td></td>
<td><em>David B. Kunkee, The Aerospace Corporation {US}</em></td>
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<td>17:30</td>
<td>Lessons learned from AMSR and plans for GCOM-W</td>
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<td></td>
<td><em>Haruhsia Shimoda, EORC, JAXA {JP}</em></td>
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<td>18:00</td>
<td>Closure, second day</td>
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<tr>
<td>8:30</td>
<td>Pre-launch testing, calibration and on-orbit performance of the METEOR-M N 1 microwave imager/sounder</td>
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<td></td>
<td>*A. B. Uspensky &amp; I. V. Cherny, State Research Center on Space Hydrometeorology “Planeta” {RF}</td>
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<tr>
<td>9:00</td>
<td>Calibration issues of microwave imagers</td>
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<td><em>Shannon Brown, JPL {US}</em></td>
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<tr>
<td>9:30</td>
<td>A plan for developments of climate data records from special sensor microwave imager (SSM/I) and sounder (SSMIS)</td>
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<td><em>Fuzhong Weng, NOAA, NESDIS</em></td>
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<td>10:00</td>
<td>Topic Discussion</td>
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Session F talk by G. Stephens
Randomly selected control Model 19 year column water vapor

Santer et al. conclude:

Data from the satellite-based Special Sensor Microwave Imager (SSM/I) show that the total atmospheric moisture content over oceans has increased by 0.41 kg/m² per decade since 1988. Results from current climate models indicate that water vapor increases of this magnitude cannot be explained by climate noise alone.

Anthropogenically forced climate change trends in water vapor compared to SSMI trends

Session F talk by G. Stephens
## Assimilation of MWI data at NWP Centres

<table>
<thead>
<tr>
<th>Model/DA</th>
<th>SSMI</th>
<th>SSMIS</th>
<th>AMSR-E</th>
<th>TMI</th>
<th>Windsat</th>
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<tbody>
<tr>
<td><strong>ECMWF (Europe)</strong></td>
<td></td>
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<tr>
<td>T1279/L90 4D-Var</td>
<td>F15 only</td>
<td>F16</td>
<td>F17/F18</td>
<td></td>
<td>radiances</td>
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<td><strong>Met Office (UK)</strong></td>
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<tr>
<td>N512/L70 4D-Var</td>
<td>F16 (LAS)</td>
<td>F16/F17 ENV</td>
<td>F17/F18</td>
<td></td>
<td>(u,v)</td>
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<td><strong>JMA (Japan)</strong></td>
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<tr>
<td>T959/L60 4D-Var</td>
<td>F16/F17 ENV</td>
<td>F16 LAS</td>
<td>F18</td>
<td></td>
<td>radiances</td>
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<td><strong>NRL (US)</strong></td>
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<tr>
<td>T239/L42 4D-Var</td>
<td>WS/TCWV</td>
<td>WS/TCWV</td>
<td>F16/F17/F18 radiances</td>
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<td>(u,v)</td>
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<tr>
<td><strong>Canada</strong></td>
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<tr>
<td>35km/L80 4D-Var</td>
<td>sea ice</td>
<td>F16/F17/F18</td>
<td>sea ice</td>
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<tr>
<td><strong>NOAA/NCEP (US)</strong></td>
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<tr>
<td>T382L64 3D-Var</td>
<td>sea ice</td>
<td>F16/F17</td>
<td>sea ice</td>
<td>precipitation</td>
<td>(u,v)</td>
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<td>T574L64 Planned 2010</td>
<td>sea ice</td>
<td>F16/F17</td>
<td>Radiance &amp; SST</td>
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<td><strong>Meteo-France</strong></td>
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<tr>
<td>T798/L70 4D-Var</td>
<td>F16/F17/F18</td>
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**Assimilated** | **Monitored** | **Planned in 2010**  
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Session F talk by W. Bell
Special Sensor Microwave Imager / Sounder (SSMIS)

F16 launched October 2003
F17 launched November 2006
F18 launched October 2009

Session F talk by W. Bell
NPOESS Satellites: Microwave Imager Sounder

- MIS planned for NPOESS C2, C3, C4
- Conical scanning at ~29 rpm
- Swath Width: ~1,700 km
- 1.8 m main reflector and deployable structure
- 41 Channels; 13 feedhorns (6.2 – 183 GHz)
- Upper Air Sounding: 60 – 63 GHz [FM2 on C3]
- 17 Environmental Data Products
- Major EDRS:
  - Soil Moisture
  - Sea Surface Wind Speed
  - Atmospheric Vertical Temperature and Moisture Profiles
  - Sea Surface Wind Direction
  - Sea Surface Temperature

Session F talk by D. Kunkee
Uncertainties and Errors in Cal/Val

Observation Vector

Ground “Truth”
- Raobs/Lidar/dropsondes
- Surface Obs.
- Space/Time Coincidence
- Accuracy
- Research Field Campaigns
- Magnetic Storms

Antenna
- spillover
- xpol
- emission
- pol rotation
- FOV intrusion
- beam pointing

Receiver
- Freq set/stab
- Passband set/stab
- Sq. Law
- NEDT
- ΔG/G
- Quantization
- RFI

Cal Targets
- warm-load
- unif/stab
- Sun-intrusion
- emissivity
- cold-space FOV
  (moon, S/C)

NWP
- Background Fields
- Coincidence
- Interpolations
- Data Bases

CAL/VAL
- Match-ups
- Stratifications
- Performance/QC
- Anomalies

Ground Data Processing

TDRP
- Geo-location
- EIA/Az

ECTBP
- slope/offset

SDRP
- APC
- RFI Detection
- Resampling
- Foot print Match

EDRP
- Inversion Problem
- Uniqueness/stability
- Foot print Match
- RFI Detection
- Mapping

Session F talk by D. Kunkee
GCOM satellites - AMSR2

• GCOM-W1
  – AMSR2 (Advanced Microwave Scanning Radiometer 2)
  – Planned to be launched on Nov., 2011
• GCOM-C1
  – SGLI (Second generation Global Imager)
  – Planned to be launched in fiscal 2013
• Plan for the 2\textsuperscript{nd} and 3\textsuperscript{rd} generations
  – GCOM-W2 (in 2015),
    GCOM-W3 (in 2019)
  – GCOM-C1 (in 2017),
    GCOM-C3 (in 2021)
Improvement of HTS (Hot Load)

1. Temperature inside HTS is kept constant (= 20 degrees C) using heaters on 5 walls of HTS and TCP.
2. Sunshields attached to HTS and TCP minimize the sun light reflection into HTS.
3. TCP thermally isolates HTS from SU structure (much colder than HTS).

HTS: High Temperature noise Source, TCP: Thermal Control Panel, SU: Sensor Unit

- Maximum temperature difference inside HTS: less than 2K
- Estimated brightness temperature accuracy:
  - 0.2 K (Variable bias during orbit, season, design life)
  - 0.1 K (Random due to quantization)

Session F talk by H. Shimoda
Microwave Radiometer Calibration

• Pre-launch calibration of microwave radiometers involves careful characterization of both the antenna and receiver sub-systems
  – The radiometer output is referenced to high quality microwave blackbody calibration targets
  – But often, the plane of calibration is not the same as the plane of the measurement, requiring several additional corrections prior to obtaining the calibrated main beam brightness temperature

• Antenna system
  – Introduces cross-polarization
  – Sidelobe and spill-over contributions
  – Surface imperfections

• Receiver system
  – Non-linearity
  – Short-term gain instability
  – NEDT

• Calibration system
  – Often observed through different path than scene
  – Non-ideal target performance (blackbody load thermal variations and finite reflectivity, pattern artifacts from secondary reflector)

Session F talk by W. Blackwell
Microwave Radiometer Calibration

• The demand for high quality calibrated microwave radiances has increased
  – direct assimilation of the radiances into numerical weather prediction models
  – climate change studies

• These studies have revealed many previously unknown or undetected calibration issues
  – Caused by either inadequate pre-launch characterization, instrument design or processing algorithm limitations
  – Examples include receiver linearity errors, calibration target instability, reflector surface emission and scan dependent errors

• In response to these issues, new pre-launch calibration and characterization techniques have been developed in an attempt to mitigate these errors

• What is needed for future systems?

Session F talk by W. Blackwell
SSM/I Intersensor Calibration

• Develop unique technique for matching SSM/I obs from two DMSP satellites
  – Simultaneous conical over-passing
  – Characterize biases according to surface type

• Work with CSU (Kummerow) and RSS (Wentz)
  – Independent calibration approach
  – Intercomparison

• Work with NASA GPM Cross-Calibration team
  – TMI and SSM/I
  – Windsat and SSM/I

Simultaneous observations from DMSP F10 and F11 satellites over Antarctic continent

Session F talk by F. Weng
Preliminary Results: SSM/I TDR Trend

Comparison of SSM/I Monthly Oceanic Rain-free TDR Trend using F13 satellite as a reference.

Session F talk by F. Weng
Questions to Consider:

- What are the radiometric accuracy, precision, and characterization requirements for numerical weather prediction and climate observation?
- What is the role, or potential role of metrology in large, open aperture microwave imager/sounders?
- Are standard error analyses and propagation approaches needed?
  - Pre-launch
  - Post launch
- By what mechanisms can the lessons learned in the US be most effectively shared with emerging national programs elsewhere?