MICROWAVE INTEGRATED RETRIEVAL SYSTEM (MIRS): RECENT ACTIVITIES AND SCIENCE IMPROVEMENTS

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Outline

• Algorithm Overview

• S-NPP Product(s) Overview
  – Standard validation: global performance for T, WV Sounding
  – Targeted validation:
    o in situ reference data (SURFRAD) for LST
    o ARM ground-based radiometers for CLW

• Applications/Example
  – Blended Layer Water Vapor
  – Hurricane Harvey example

• New Activities/Science Improvements
  – Air mass-dependent radiometric bias correction
  – Tropical Cyclone Adaptation (MiRS-TC)

• Summary and Path Forward
Algorithm Overview

Satellite Microwave (TB) Measurements (INPUTS)
- ~ 20 channels (multispectral)
- TB (Channel 1)
- TB (Channel 2)
- TB (Channel 3)
- TB (Channel Ntot)

MiRS Components
- Forward RT Model (CRTM):
  1. TB = F(Geophysical State Vector)
  2. Jacobians (dTB/dX)
- A Priori Background:
  Mean and Covariance of Geophysical State
- Basis Functions for State Vector:
  Reduce degrees of freedom in geophysical profile (~20 EOFs)
- Uncertainty of satellite radiances:
  Instrument NEDT + Fwd Model uncertainty

Geophysical State Vector (OUTPUTS)
- Temp. Profile (100 layers)
- Water Vapor Profile (100)
- Cloud Water Profile (100)
- Graupel Water Profile (100)
- Skin Temperature (1)

MiRS 1D Variational Retrieval

Derived Products (OUTPUTS)
- TPW
- CLW
- RWP
- GWP
- RR
- SFR
- SIC/SIA
- SWE/GS

MiRS Postprocessing

MiRS Components

A priori BG mean: obtained from dynamic climatology, not NWP

• MW Only, Variational Approach: Find the “most likely” atm/sfc state that: (1) best matches the satellite measurements, and (2) is still close to an a priori estimate of the atm/sfc conditions.
• “Enterprise” Algorithm: Same core software runs on all satellites/sensors; facilitates science improvements and extension to new sensors.
• Initial capability delivered in 2007. Running v11.2 since Jan 2017 on SNPP/ATMS, N18, N19, MetopA, MetopB, F17, F18, GPM/GMI, Megha-Tropiques/SAPHIR. (eventually MetopC...)
• Delivery of J1/ATMS (v11.3) capability in early 2018, assuming 10 Nov launch.
• External Users/Applications: TC Analysis/Forecasting at NHC, Blended Total/Layer PW at NHC and WPC, MIMIC TPW Animations (U. Wisconsin), CSPP Direct Broadcast (U. Wisconsin), NFLUX model (NRL, Stennis), Global blended precipitation analysis at NOAA/CPC (CMPORPH),...
MiRS SNPP/ATMS Temperature and WV Bias vs. Raobs (NPROVS): Sept 2015 – August 2017

- T profile reduction in stratospheric cold bias
- WV reduction in lower tropospheric dry bias, especially over land
- WV apparent increase in moist bias above 600 hPa may be artifact of known dry bias of radiosondes in upper troposphere

- MiRS radiometric bias corrections for T sounding channels (5-12): Block 1 (Static) and Block 2, OBS-SIMULATED
  - These corrections are subtracted from observed TBs prior to retrieval (i.e. negative means correction increases TB)
  - Block 2 corrections generally ~0.5 to 1 K lower than Block 1
Validation of Land Sfc Temperature

- Daily Comparisons:
  - Automated global comparisons with both ECMWF and GDAS; results posted daily
  - Advantage: Global coverage, all sfc and weather conditions, large sample sizes
  - Disadvantage: LST from NWP analyses may have large errors depending on obs available and land surface assimilation model.

- Targeted collocations with in situ data:
  - Collocations with SURFRAD LST (IR Flux Based): May 2016-May 2017, 6 stations over the CONUS
  - Advantage: in situ, direct measurement (need to convert from flux to LST using Stefan-Boltzmann law), IR emissivity assumed=0.97
  - Disadvantage: IR LST, not same as MW LST (vertical penetration/emission depth), representativeness error (point vs. IFOV average)
  - SURFRAD stations used:

<table>
<thead>
<tr>
<th>Station name</th>
<th>Surface</th>
<th>Latitude (N)/longitude (W)</th>
<th>Elevation (m)</th>
<th>U.S. state</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert Rock</td>
<td>Open shrub land</td>
<td>36.63°/116.02°</td>
<td>1007</td>
<td>NV</td>
<td>DRA</td>
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<tr>
<td>Bondville</td>
<td>Cropland</td>
<td>40.06°/88.37°</td>
<td>230</td>
<td>IL</td>
<td>BON</td>
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<tr>
<td>Fort Peck</td>
<td>Grassland</td>
<td>48.31°/105.10°</td>
<td>634</td>
<td>MT</td>
<td>FPK</td>
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<tr>
<td>Goodwin Creek</td>
<td>Deciduous forest</td>
<td>34.25°/89.87°</td>
<td>98</td>
<td>MS</td>
<td>GWN</td>
</tr>
<tr>
<td>Penn State</td>
<td>Mixed forest</td>
<td>40.72°/77.93°</td>
<td>376</td>
<td>PA</td>
<td>PSU</td>
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<tr>
<td>Sioux Falls</td>
<td>Grassland</td>
<td>43.73°/96.62°</td>
<td>473</td>
<td>SD</td>
<td>SXF</td>
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</tbody>
</table>
Validation of Land Sfc Temperature: Collocation with SURFRAD, May 2016-May 2017

Collocation with GDAS at SURFRAD sites

Validation Parameter

<table>
<thead>
<tr>
<th>All SURFRAD stations and overpasses</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>13 months</th>
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<tbody>
<tr>
<td>R</td>
<td>0.91</td>
<td>0.90</td>
<td>0.90</td>
<td>0.81</td>
<td>0.92</td>
</tr>
<tr>
<td>Bias (K)</td>
<td>-2.21</td>
<td>-2.55</td>
<td>-0.58</td>
<td>-2.05</td>
<td>-1.84</td>
</tr>
<tr>
<td>Std. dev. (K)</td>
<td>5.21</td>
<td>4.66</td>
<td>5.25</td>
<td>5.98</td>
<td>5.26</td>
</tr>
<tr>
<td>RMSE (K)</td>
<td>5.65</td>
<td>5.31</td>
<td>5.28</td>
<td>6.32</td>
<td>5.58</td>
</tr>
<tr>
<td>Slope</td>
<td>0.96</td>
<td>0.74</td>
<td>0.92</td>
<td>0.89</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Corr: 0.92
StdDev: 4.92
Bias: 0.43
Slope: 1.01
Npts: 5280

Manuscript submitted to GRL

Courtesy of Carlos Perez-Diaz (CUNY/CREST)
Validation of Oceanic Cloud Liquid Water:
Collocation with ARM Ground-based Measurements

Eastern N. Atlantic (Azores) ARM site:
- 3 channel radiometer (23, 30, 89 GHz)
- Period: 2014-03-01 to 2017-07-24
- Collocation window: +/- 1 hour

Global ocean collocation with GPROF GPM CLW

October 2016
- Corr: 0.71
- StdDev: 0.07 (0.08)
- Bias: 0.005 (0.03)
- Npts: 408

Spring
- Corr: 0.63
- StdDev: 0.20
- Bias: -0.07
- Npts: 565

Fall
- Corr: 0.66
- StdDev: 0.16
- Bias: -0.05
- Npts: 394
Application: Blended Layer Precipitable Water Combines MiRS WV from up to 7 Polar Satellites for Rapid Refresh and Advection (NWP-based winds)

To be implemented at NHC and WPC in next 1-2 months

Courtesy to J. Forsythe (CSU/CIRA)
Case Study: Hurricane Harvey
27 August, Day of Extreme Flooding

- MRMS: Operational Blended Radar-Gauge Analysis, 1 km resolution
- Both satellite and MRMS detected rainfall rates > 25 mm/h
Development of an Air Mass-Based Radiometric Bias Correction

• Motivation:
  – Current operational MiRS uses Histogram Adjustment Method. Derived over oceanic/clear scenes. Bias specified as function of channel and scan position.
  – Advantages: Stable, reduces impact of outliers/cloud/rain contamination, good at characterizing the average global differences between measurements and model.
  – Disadvantages: Systematic errors in forward model due to over/underestimation of absorber effects (e.g. water vapor, non-precip cloud) not accounted for. (also assumes atmospheric and ocean emissivity models are accurate).

• Testing air mass dependent bias correction (ocean only)
  – Regression-based, 2-steps
    o Step 1: CLW and TPW using uncorrected TBs
    o Step 2: $dTB(iChan, iscanpos)=f(CLW, TPW, Tskin, TB(iChan))$; Tskin from operational “Dynamic Background” ($f(lat,lon,time,month)$). Scan position dependent.
  – Applied to all channels except T sounding channels 4-15 (static bias correction used)
  – Applied over ocean only, using ATMS Block 2 SDRs (operational switch in March 2017)
    o Quantify impact on retrieved parameters (e.g. T, WV, ocean emissivity, CLW, TPW, chi-square, iterations)
  – Analogous to variational bias correction used in direct radiance assimilation for NWP
Testing an Air Mass-Based Radiometric Bias Correction

Static Correction (operational)

Air-mass Correction

Ch 1 (23 GHz)

Ch 18 (183+/− 7 GHz)

Courtesy of K. Garrett (RTI) and P. Liang (AER)
Testing an Air Mass-Based Radiometric Bias Correction: Ocean TPW vs. ECMWF

**TPW (Static Correction)**

### Clear Asc TPW (mm) Over Sea 2015–10–15 (r3783)
- Corr: 0.990
- Bias: 1.97
- StDv: 2.30

### Cloudy Asc TPW (mm) Over Sea 2015–10–15 (r3783)
- Corr: 0.988
- Bias: 1.49
- StDv: 2.51

**TPW (Air-mass Correction)**

### Clear Asc TPW (mm) Over Sea 2015–10–15 (r3783)
- Corr: 0.995
- Bias: 1.54
- StDv: 1.92

### Cloudy Asc TPW (mm) Over Sea 2015–10–15 (r3783)
- Corr: 0.991
- Bias: 1.05
- StDv: 2.34
Testing an Air Mass-Based Radiometric Bias Correction: Ocean Cloud Liquid Water

Cloudy NPP/ATMS CLW (mm) >0.05 20150715 Aec (r3783)

- CLW > 0.05 mm

Cloudy NPP/ATMS CLW (mm) >0.10 20150715 Aec (r3783)

- CLW > 0.10 mm

MiRS Static

MiRS Air Mass/Hybrid

ECMWF
Developing a TC-Specific Version of MiRS

• Motivation:
  – MiRS data currently used in the operational TC Intensity Algorithm (developed at CIRA). Utilizes T and WV sounding to estimate warm core structure combined with statistical/dynamic model to estimate TC intensity.
  – Challenge: (1) retrieval of warm core structure complicated due to presence of hydrometeors; scattering signal in TBs can interfere with retrievals (2) hurricane warm core structure is anomalous relative to “global climatology” currently used as a priori constraint in MiRS.

• Experiments with SNPP/ATMS (3 control parameters)
  – Modify use of higher frequency channels in scenes likely to have large amounts of scattering
    o (A) Oper: Use all 22 channels, (B) Turn off WV channels (18-22) when rain detected, (C) Turn off all high-frequency channels when rain detected (16-22).
  – Test varying sources of First Guess/Background constraints:
    o (A) Oper: Climatology f(lat,lon,time,month), (B) TC-Climatology based on COSMIC RO data (from CIRA)
  – Vary number of EOF basis functions for T and WV profiles:
    o (A) Oper: nEOFT=7, nEOFWV=5, (B) nEOFT=9, nEOFWV=4 when rain detected
Case Study: Hurricane Edouard, Sept 2014

- 11-19 Sept 2014
- Maximum strength: 105 knots, 955 mb (16 Sept)
- Retrievals performed:
  - 12 Sept
  - 13 Sept
  - 16 Sept

<table>
<thead>
<tr>
<th>Experiment</th>
<th>2nd att BG T</th>
<th>2nd att BG WV</th>
<th>WV Chans 18-22 On/Off</th>
<th>Chans 16-17 On/Off</th>
<th>2nd att nEOF T and WV</th>
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</thead>
<tbody>
<tr>
<td>OPER</td>
<td>Oper</td>
<td>Oper</td>
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<td>Exp 10</td>
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<td>Exp 70</td>
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<td>TC</td>
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<td>ON</td>
<td>nEOF=9,nEOFWV=4</td>
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<td>Exp 76</td>
<td>Oper</td>
<td>TC</td>
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<td>nEOF=9,nEOFWV=4</td>
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</table>
Temperature Anomaly Along -58 deg Lon: 2014-09-16

Exp70 and Exp76 closest to ECMWF anomaly

Hurricane Bonnie, 1998
Kidder at al. (2000)
Temperature Bias Statistics in Rainy Conditions (wrt ECMWF)

**Best result mid, upper-trop**: TC climatology for WV BG + chans 16-22 off (cold bias below 800-850 hPa); but ECMWF may also have errors

- Use of TC-specific WV BG critical when all WV sounding channels turned off

- **Future**: FG/BG from forecast, TC-specific covariance/EOFs, additional TCs (Joaquin 2015, Matthew 2016), validation w/dropsondes, continue collaboration with CIRA

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<td>TC</td>
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<td>nEOF T=9, nEOF WV=4</td>
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</table>
• MiRS is relatively mature algorithm; evolution and improvement since SNPP launch (v9.2 -> v11.2); additional improvements in progress.
• Next version (v11.3): Will include extension to J01/N20 ATMS processing
• Path Forward
  – FY18 Milestones: (1) preDAP delivery in Feb/Mar 2018 (initial cal/val), (2) official DAP ~L+12 months.
  – Future Improvements:
    • Snowfall Rate, included in v11.3
    • Snow (vegetation correction to emissivity), included in v11.3
    • CLW over land to improve light rain detection, included in v11.3
    • Air mass-dependent bias corrections
    • TC-specific applications (FG/BG a priori based on TC climo or 6-h fcst)
    • Rainy condition sounding (update a priori constraints)
    • Stakeholders/user needs…

Summary
Testing an Air Mass-Based Radiometric Bias Correction: Ocean Emissivity

MIRS-FASTEM (Static Correction)

31 GHz

Corr: 0.665
Bias: 0.009
StDv: 0.031

88 GHz

Corr: 0.805
Bias: 0.010
StDv: 0.026

MiRS-FASTEM (Air-mass Correction)

31 GHz

Corr: 0.834
Bias: 0.005
StDv: 0.021

88 GHz

Corr: 0.882
Bias: 0.007
StDv: 0.021
Validation of Land Sfc Temperature: Scan Dependence wrt SURFRAD and ECMWF

Scan Dependence wrt SURFRAD

- Relative scan dependence seen wrt both SURFRAD and ECMWF
- Absolute biases different
- Likely due to radiometric bias correction (trained over ocean)

Block1 and Block 2 Bias corrections