POES and MetOp AMSU/MHS and SNPP ATMS take passive microwave (MW) measurements at certain high frequencies (88.2~190.31 GHz) that are sensitive to the scattering effect of snow particles and can be utilized to retrieve snowfall properties. An AMSU/MHS snowfall rate (SFR) and an ATMS SFR algorithms have been developed at NOAA/NESDIS (Meng et al., 2012), where the AMSU/MHS product has been in operation since October 2012. The combined SFR products are generated from five satellites (NOAA-18/19, MetOp-A/-B, and SNPP), and can provide up to ten snowfall estimates at any location over global land at mid-latitudes. There are more estimates from overlapping orbits from ATMS and at higher latitudes from ATMS and AMSU/MHS.

### Methodology

1. Detect snowfall using principal component analysis (PCA) and logistic regression model (Kongoli et al., 2014). Input includes temperature and water vapor sounding channels. Output is the probability of snowfall. In addition, a set of filters based on NWP model temperature and water vapor profiles are used for further screening. A cold snowfall extension was also developed which is a major advancement compared to the previous version of AMSU/MHS SFR.

2. Cloud properties are retrieved using an inversion method with an iteration algorithm and a two-stream Radiative Transfer Model (Yan et. al, 2008).

\[
\frac{\Delta W_{\text{PP}}}{\Delta I_{25}} = \begin{bmatrix}
\Delta T_{223} \\
\Delta T_{301} \\
\Delta T_{388/39} \\
\Delta T_{389/39} \\
\Delta T_{216/157} \\
\Delta T_{215/137} \\
\end{bmatrix}
\]

- \( W_{\text{PP}} \): ice water path
- \( I_{25} \): ice particle effective diameter
- \( e \): emissivity
- \( A \): Jacobian matrix
- \( E \): error matrix
- \( T_{223}: \) brightness temperature

3. Compute snow particle terminal velocity (Heymsfield and Westbrook, 2010) and determine snowfall rate by numerically solving a complex integral.

### Cold Climate Extension

#### Statistics of ATMS Snowfall Detection

<table>
<thead>
<tr>
<th>Probability of Detection (%)</th>
<th>False Alarm Rate (%)</th>
<th>Heidke Skill Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm Regime</td>
<td>73</td>
<td>9</td>
</tr>
<tr>
<td>Cold Regime</td>
<td>56</td>
<td>13</td>
</tr>
</tbody>
</table>

### Product Applications

The SFR product can impact users mainly in two communities:
- Global blended precipitation products traditionally do not include snowfall derived from satellites because such products were not available operationally in the past. The ATMS and AMSU/MHS SFR can provide the winter precipitation information for these blended precipitation products. NCEP/CPC CMORPH is the first such data set to include the SFR products.
- The SFR products can fill in gaps where traditional snowfall data are not available to weather forecasters. The products can also be used to confirm radar and gauge snowfall data. NASA SPoRT led a project to evaluate the AMSU/MHS SFR at NWS Weather Forecast Offices and NESDIS/SAB in the past winter with very valuable feedback. The major concerns have been addressed since then. The SFR product will be evaluated again in the next winter in collaboration with SPoRT.

### Validation

Validation sources included StageV radar and gauge combined hourly precipitation data, NMQ radar instantaneous precipitation data, and station hourly accumulated precipitation data. Validation of snowfall product is especially challenging because of the spatial and temporal differences between satellite retrieval and validation data, and uncertainties in the validation data etc.

#### Limited Validation of ATMS SFR

<table>
<thead>
<tr>
<th>Stage IV 02/21/2013</th>
<th>Correlation Coefficient</th>
<th>Bias (mm/hr)</th>
<th>RMSE (mm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.80</td>
<td>0.05</td>
<td>0.83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage IV 3/5/2013</th>
<th>Correlation Coefficient</th>
<th>Bias (mm/hr)</th>
<th>RMSE (mm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td>0.65</td>
<td>0.02</td>
<td>0.26</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Stage IV 3/5/2013</th>
<th>Correlation Coefficient</th>
<th>Bias (mm/hr)</th>
<th>RMSE (mm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td>0.80</td>
<td>0.04</td>
<td>0.73</td>
</tr>
</tbody>
</table>

### SFR Application in Weather Forecasting

Time sequence of a snowstorm in the Northern Plains: (a) and (b) the AMSU/MHS SFR product at around 17:05Z and 19:40Z, respectively; (c)-(e) GOES-15 IR images at 17:00Z, 17:30Z, 18:30Z, and 19:30Z, respectively. The yellow arrow points to the most intense snow in the IR images. The IR sequence indicates that the snow max rotated counter-clockwise and moved north between the two SFR observations. This is confirmed by the second satellite pass at 19:40Z. The arrow max is in white color in the SFR images.

### SFR Application in Hydrology

NCEP/CPC CMORPH blended precipitation products used both ATMS and AMSU/MHS SFR for its winter precipitation analysis. In this snowfall event, the correlation coefficient between the CMORPH 3-hour precipitation and Stage IV reaches 0.62.

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