A Climate Record of Enhanced Spatial Resolution Microwave Radiometer Data

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Earth-observing Passive Microwave (PM) sensors (radiometers)

Availability of SMMR, AMSR-E, SSM/I and SSMIS sensors (dates are approximate);
DMSP-F19 launched 3 Apr 2014 and F20 is not yet launched.
The State of Gridded Passive Microwave (PM) Data

Current state of gridded PM data

- Various gridding techniques (Ditb, ID2, BG, rSIR image reconstruction)
- Various temporal sampling (daily avg, daily asc/des, daily ltod)
- Mix of Level 2 source data versions (whatever was available at the time it was gridded)
- Mix of resolutions, 25, 12.5 km, some finer to 2.25 km
- Not all data from all sensors has been processed completely any given consistent way
NASA MEaSUREs CETB Project Goals

The *Calibrated, Enhanced-Resolution EASE-Grid 2.0 Brightness Temperature (CETB)* project will:

- Leverage recent work to recalibrate Level 2 PM data record from SSM/I-SSMIS as FCDRs
- Use improved *EASE-Grid 2.0* projection definition
- Use developments in image reconstruction to enhance spatial resolution in addition to conventional gridded
- Process all data (instead of only 1 month sensor overlaps) from SMMR, all SSM/I-SSMIS and AMSR-E
- Data distribution will be from NSIDC DAAC
- Software to be turned over to the DAAC for ongoing processing
CETB: Calibrated, Enhanced-Resolution EASE-Grid 2.0 TBs

Time series of current (left) set of gridded passive microwave data sets, compared to planned (right) CETB ESDR. The various processing methods are indicated by colors; lengths of colored bars approximate respective periods of record. Note the consistency of the processing of the proposed products.
**Input swath data**

CETB product uses the latest available reprocessing/recalibration available by sensor:

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Years</th>
<th>Swath Data</th>
<th>Source</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSM/I-SSMIS*</td>
<td>1987-present</td>
<td>CSU FCDR, V1</td>
<td>CSU</td>
<td>Berg et al., 2013; Sapiano et al, 2013</td>
</tr>
<tr>
<td>SSM/I-SSMIS*</td>
<td>1987-present</td>
<td>RSS FCDR, V7</td>
<td>RSS</td>
<td>Hilburn and Wentz, 2008</td>
</tr>
<tr>
<td>AMSR-E</td>
<td>2002-2011</td>
<td>AMSR-E/Aqua L2A Global Swath Spatially-Resampled TBs, V3</td>
<td>NSIDC</td>
<td>Ashcroft and Wentz, 2013</td>
</tr>
</tbody>
</table>

*CETB will choose between CSU and RSS, depending on feedback from Early Adopters.
The trouble with EASE-Grid (1.0)

EASE-Grid defined a spherical projection ellipsoid with data referenced to WGS84 datum, but this makes reprojection tricky, because most software assumes the ellipsoid and datum are the same.

EASE-Grid 2.0 improvement details

Defines the equator barely outside the grid extent, to ensure corner pixels are well-defined.

Changes higher-resolution grid definitions from bore-centered to nested.
# EASE-Grid (1.0) vs. EASE-Grid 2.0

<table>
<thead>
<tr>
<th></th>
<th>EASE-Grid (1.0)</th>
<th>EASE-Grid 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Projection spheroid</strong></td>
<td>International 1924 Authalic Sphere</td>
<td>WGS84*</td>
</tr>
<tr>
<td><strong>Pole location</strong></td>
<td>Center of center cell</td>
<td>Intersection of center cells</td>
</tr>
<tr>
<td><strong>Scale (data-set specific)</strong></td>
<td>Azimuthal/Cylindrical coupled, e.g. N1/S1/M1 25.067525 km</td>
<td>Azimuthal: exact, e.g. 25.0 km or 36.0 km, etc.; Cylindrical: integer-multiples across latitude of true scale</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>Odd-numbered</td>
<td>Even-numbered</td>
</tr>
<tr>
<td><strong>Nested Grids</strong></td>
<td>Force choices between total coverage and nested cells</td>
<td>Coverage can stay the same, only number of cells changes</td>
</tr>
<tr>
<td><strong>Corner Points</strong></td>
<td>Undefined: azimuthal grids “wrapped beyond” opposite pole</td>
<td>No undefined corner cells</td>
</tr>
<tr>
<td><strong>GeoTIFF</strong></td>
<td>Requires reprojection</td>
<td>Supported w/o reprojection*</td>
</tr>
<tr>
<td><strong>Software Issues</strong></td>
<td>Usually requires user to understand “custom projection” settings</td>
<td>Most software will “do the right thing”*</td>
</tr>
</tbody>
</table>

*Key to success for geoTIFF is setting projection ellipsoid to the reference datum.*
Special Sensor Microwave/Imager (SSM/I)

- Microwave radiometer operated on a series of DMSP weather satellites
  - Almost continuously since 1987
- Seven channels at ~51 deg incidence angle
  - Variable resolution/channel
  - Three dual-polarized channels (19.35, 37, 85.5 GHz)
  - One single polarization channel (22.2 GHz)
- 1400 km wide swath
- Cross-calibration issues
Comparison of footprints between channels

In addition to conventional processing, the CETB Product uses oversampled measurements to enhance gridded spatial resolution.
Apparent antenna temperature distribution

\[
T_{AP}(\theta, \phi) = [T_b(\theta, \phi) + T_{sc}(\theta, \phi)]e^{-\tau(\theta)\sec \theta} + T_{up}(\theta) + T_{sky}(\theta, \phi)
\]

- \(T_b = \varepsilon T_p\)  
  Surface brightness temperature
- \(T_{sc}\)  
  Surface scattering temperature
- \(e^{-\tau(\theta)\sec \theta}\)  
  Atmospheric attenuation
- \(T_{up}(\theta)\)  
  Upwelling signal
- \(T_{sky}\)  
  Sky temperature

Antenna temperature

\[
T_A = \frac{\int \int G(\theta, \phi) T_{AP}(\theta, \phi) \, d\theta \, d\phi}{\int \int G(\theta, \phi) \, d\theta \, d\phi}
\]
**Image Reconstruction**

Typical SSM/I measurement density improvement with multiple passes. Image reconstruction techniques take advantage of irregular sampling locations.
**Image Reconstruction**

Typical SSM/I measurement density improvement with multiple passes. Image reconstruction techniques take advantage of resulting irregular sampling locations.
**Backus Gilbert and rSIR**

*Backus Gilbert (BG) and radiometer version of Scatterometer Image Reconstruction (rSIR)* both can be tuned for either enhanced spatial resolution or low noise—but not both.

Both techniques require a reasonable knowledge of the instrument antenna pattern, which determines the Measurement Response Function (MRF) to weight the contribution of overlapping measurements to a given gridded pixel TB.

<table>
<thead>
<tr>
<th></th>
<th><strong>BG</strong></th>
<th><strong>rSIR</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>Matrix Inversion (slow)</td>
<td>Iterative (at least 10x faster)</td>
</tr>
<tr>
<td>Tuning Parameter</td>
<td>“gamma” (dimensionless)</td>
<td>N=number of iterations</td>
</tr>
</tbody>
</table>
**MRFs**

Exact knowledge of the antenna pattern is not required: a reasonable approximation is a 2-D Gaussian.

(Good: we don’t know all of them!)

Backus Gilbert and rSIR

We determined (subjective) “best” BG/rSIR tuning parameters using a synthetic truth image.


**Backus Gilbert and rSIR**

Qualitative comparison of “truth” vs. BG and rSIR result
(Quantitative statistics in white paper)


rSIR produced in a fraction of the computational time of BG

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Figure 26. Comparison of true, Non (Grd), Ave, SIR, and BGI images with $\gamma=0.45$ and BGI with median filter for the 37 GHz channel with $N_f=3$. Note the reduction in RMS error in BGI after median filtering.

Conventional versus rSIR results

SIR results for N=20 iterations, at various frequencies.

Figure 21. Comparison of (left column) NON, (center column) AVE, and (right column) SIR images for the (top full row) 19, (center full row) 37 and (bottom row) 85 GHz channels for N_{it}=3, 20 SIR iterations, and two passes. The top row image shows the true synthetic image.

Backus Gilbert and rSIR

Tuning parameters for prototype data, (details in Enhancement Tradeoffs white paper)

Figure 24. RMS error versus $\gamma'$ for the 37 GHz channel with $N_s=3$.

Figure 16. 37 GHz, dual-pass, $N_s=3$ SIR image error versus iteration number. (left) mean error. (right) RMS error. The red line is the noisy measurement case, while the blue line is the noise-free case.

Sample Images

GRD (Low-noise, 25 km) vs. SIR (3.125 km), 1997 day 061 morning passes

Ditb (non) Conventional  
25 km pixels

rSIR Enhanced resolution  
3.125 km pixels
GRD (Low-noise, 25 km) vs. SIR (3.125 km), 1997 day 061 morning passes

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rSIR Enhanced resolution
3.125 km pixels
**Ltod (Gunn and Long, 2008)**

Due to sun-synchronous orbit, a given location is observed at a set of discrete times over the 2-4 day orbit cycle.

At the equator, this is two measurements 12 hours apart.
- Separate by ascending or descending orbit passes.

At the poles, the orbits overlap, resulting in multiple times per day.
- Ascending/Descending does not work well.
- Use local time of day (ltod) division instead.
Asc/Dsc Division

Ascending/Descending

Ascending passes

Descending passes

Pass time in minutes from start of UTC day
LTOD Division

LTOD

“Morning” LTOD passes

“Afternoon” LTOD passes

Pass time in minutes from start of UTC day
**Ltod (Gunn and Long, 2008)**

Histogram of LTOD of measurements

Two LTOD groupings:
- Morning, Afternoon within < 8 hours

Combine measurements within same LTOD
- At equator, LTOD and Asc/Dec same

Two images per day
LTOD Image Examples

Image examples (Dib)

NHe

SHe

Global
**AMSR-E Images**

- Enhanced resolution image examples
  - Radiometer Scatterometer Image Reconstruction (sSIR) ($T_b$)
  - Sample applications
    - Sea ice extent
    - Sea ice age
    - Snow coverage

www.scp.byu.edu

- JD 002, 2007
CETB Project Status – Aug 2015

Available now:

- ATBD available for comment now
- Prototype data (SSM/I and AMSR-E for 2003) available for Early Adopter feedback and evaluation
  - SSM/I data from both CSU and RSS for comparison
  - “GRD” (ditb) (25, 12.5 km) low-noise grids
  - BGI, SIR (6.25, 3.125 km) enhanced-resolution grids
- Early adopters welcome! (contact brodzik@nsidc.org)

Coming:

- SMMR and SSMIS, eventually AMSR
- Data content/format finalized
- Complete historical record available at NSIDC DAAC

http://nsidc.org/pmesdr
A Climate Record of Enhanced Spatial Resolution Radiometer Data

David G. Long (long@byu.edu), Aaron Paget, Mary J. Brodzik

Operational satellite radiometers, such as SMMR, SSM/I, SSMIS, and AMSR-E, provide a multi-decadal time series of observations of the globe that can support studies of climate change. Unfortunately, spatial resolution and sampling characteristics differ between sensors, which complicate compiling a single climate record. Resolution concerns can be ameliorated by reconstructing radiometer brightness temperature measurement (Tb) data onto daily-averaged compatible grids. We consider and contrast two widely used methods for image reconstruction: a radiometer version of the scatterometer image reconstruction (SIR) algorithm and Backus-Gilbert (BG). Both require the spatial response function (antenna gain pattern) and the sampling geometry. We discuss considerations for an optimum gridding scheme based on the EASE-Grid 2.0 map projection. The EASE-Grid 2.0 simplifies the application of the Tb images in derived products since the reconstruction for each radiometer channel is implement on the same grid. This has the effect of optimally interpolating low-resolution measurements to locations of the highest resolution measurements. By employing reconstruction techniques rather than traditional “drop in the bucket” (dib) gridding, the effective resolution of the images is spatially enhanced compared to dib images, at the expense of additional computation required for the reconstruction processing. We evaluate the sensitivity of the radiometric accuracy of the resulting Tb images to uncertainties in the antenna gain pattern as well as variations in local-time-of-day. We briefly consider a number of applications of reconstructed Tb images. As part of the NASA-MEASUREs project “An improved, enhanced-resolution, gridded passive microwave ESDR for monitoring cryospheric and hydrologic time series” we are processing all available satellite radiometer data to generate a consistently calibrated and processed time series of gridded images spanning from the 1970’s to the present that will be available from the National Snow and Ice Data Center starting later this year.