• Physical and direct validation of Global Precipitation Measurement (GPM) Mission satellite remote sensing retrievals in orographic snow
• NuWRF short range forecasts in complex terrain
• Test/improve cloud model representation of snow microphysics and application to satellite remote sensing
• NASA Short Term Prediction and Operational Research Transition (SPoRT)- field product testing, utility
• Development of satellite-based ocean latent heat fluxes and potential impacts for nowcasting and NWP
GPM: “Flagship” Core Observatory

Carries **two instruments** that can view precipitation (rain, snow, ice) in new ways; serves as a standard to calibrate measurements made from partner satellites

**GPM Microwave Imager (GMI):**
10-183 GHz

13 channels that provides an integrated picture of energy emitted and scattered by precipitation

**Dual-frequency Precipitation Radar (DPR): Ku-Ka bands**

Two different radars with different frequencies that look at precipitation in 3-D throughout the atmospheric column
GPM Observations – Provide a Global View

(a) North Pacific frontal system 2016-04-25
(b) Severe storms Texas, US 2015-05-11
(c) Winter storm eastern US 2014-03-17
(d) N. Atlantic Winter storm 2016-04-07
(e) Typhoon Fantala 2016-04-16
(f) Typhoons Chan-Hom, Nangka 2015-07-11

(g) South Pacific frontal system 2015-06-19
(h) South Atlantic frontal system 2015-03-24
(i) Africa: Line of convection 2016-02-16
(j) Sumatra land/sea convection 2015-03-04 daytime
(k) Right: 2015-04-10 night
(l) Australian weather system 2015-12-25
GPM Detects and Estimates Falling Snow Rates

March 17, 2014

Jan 26, 2015

Feb 17, 2015

Feb 21, 2015

Liquid Precipitation Rate

Frozen Precipitation Rate

mm/hour

0.1 0.2 0.3 0.5 1.0 2.0 3.0 5.0 10 20 50

mm/hour

0.1 0.2 0.3 0.5 1.0 2.0 3.0 5.0 10 20 50
• Fundamentally, GPM must produce accurate precipitation estimates over a broad range of warm and cold season conditions—difficult proposition!

**Ground Validation**

*Direct, Physical, and Integrated Approaches*

**Goal:** Convergence between space and ground-based measurements
Winter storms with mix of liquid, freezing, frozen precipitation.

GPROF and D3R delineate snow and rain. So, we can detect it.

But not always uniformly -

Vision: Unambiguously capture physical variability and reliably estimate liquid equivalent rates over all terrain types.

GPM’s Level 1 Requirement: Detect snow!
GPM Ground Validation (ICE-POP Field Campaign - RDP)

- Direct/physical validation of satellite-based snowfall retrieval algorithms (radar, radiometer, merged satellite algorithms) over coastline and mountains; melting layer interaction with terrain also of interest.
- Physics of snow, coupling to SWER and satellite remote sensor retrieval algorithm assumptions
- Model + Observational analyses: Movement toward level IV products leverage intensive and multi-faceted NWP component.
- Support current PMM/GPM collaboration with KMA- leverage significant international observational science/data effort.
- Cloud/precipitation model processes (liquid, mixed phase and frozen) testing and improvement in orographic natural laboratory and under satellite coverage. Builds model testing database for further remote sensing algorithm development
Specific Measurement Interests

- Storm Type/Regime: Shallow, deep, synoptic, terrain-forced……
- Physical process and structure responsible for snow in the column
- Snow size distribution
- Snow habit, density, fall speeds, liquid eq. rate, and spatial variability
- Measurement quality and limitations (sensitivity, calibration, viewing angle…. other artifacts…..)
- Determining and developing a ground “reference” for liquid equivalent snow rate measurement
NASA Instruments for ICE-POP: D3R, PIP, Pluvio, MRR

Dual Frequency Dual Polarimetric Doppler Radar (D3R)

Precipitation Imaging Package (PIP) x 2

Pluvio₂ x 3

MRR x 2

Parsivel disdrometer (APU) x 3
PyeongChang Area: Instrument layout

NASA: 3 Pluvio 400 + APU (Fall 16), 2 PIP, 2 MRR (Fall 17)
Retrieving snowfall from DPR

Lookup tables of DFR to estimate $D_o$

Use with $Z_{Ku}$ to estimate $N_w$ with $\mu = \text{fixed}$ (ambiguities in assumed $\rho$ and $\mu$).

Integrate to get contents.

CMB additionally uses the GMI scattering to constrain total column IWP (at say, 166 GHz).

Dual-Frequency Approach tested with GV data

$D_{eff}$ vs. DFR...a bit of spread by type

Some separation of snow “type”

Courtesy, V. N. Bringi
### System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Ku- 13.91GHz ± 25MHz; Ka- 35.56GHz ± 25MHz</td>
</tr>
<tr>
<td>Minimum detectable signal (Ku, Ka)</td>
<td>-8 dBZ, -2 dBZ noise equivalent at 15 km, at 150m range resolution</td>
</tr>
<tr>
<td>Minimum operational range</td>
<td>450 m</td>
</tr>
<tr>
<td>Operational range resolution</td>
<td>150 m (nominal)</td>
</tr>
<tr>
<td>Maximum range</td>
<td>30 km</td>
</tr>
<tr>
<td>Angular coverage</td>
<td>0-360° Az, -0.5-90° El (full hemisphere)</td>
</tr>
</tbody>
</table>

### Antenna

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parabolic reflector Diameter</td>
<td>6 ft (72 in.) (Ku), 28 in. (Ka)</td>
</tr>
<tr>
<td>Gain</td>
<td>45.6 dBi (Ku), 44.3 dBi (Ka)</td>
</tr>
<tr>
<td>HPBW</td>
<td>0.89° (Ku), 0.90° (Ka)</td>
</tr>
<tr>
<td>Polarization (Ku, Ka)</td>
<td>Dual linear simultaneous and alternate (H and V)</td>
</tr>
<tr>
<td>Maximum side-lobe level (Ku, Ka)</td>
<td>~ -25 dB</td>
</tr>
<tr>
<td>Cross-polarization isolation (on axis)</td>
<td>&lt; -30 dB</td>
</tr>
<tr>
<td>Ka-Ku beam alignment</td>
<td>Within 0.1 degrees</td>
</tr>
<tr>
<td>Scan capability</td>
<td>0-24°/s Az, 0-12°/s El</td>
</tr>
<tr>
<td>Scan types</td>
<td>PPI sector, RHI, Surveillance, Vertical pointing</td>
</tr>
</tbody>
</table>

### Transmitter / Receiver

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Architecture</td>
<td>Solid State Power Amplifier Modules</td>
</tr>
<tr>
<td>Peak Power / Duty cycle</td>
<td>200 W (Ku), 40 W (Ka) per H and V channel, Max duty cycle 30%</td>
</tr>
<tr>
<td>Receiver Noise figure</td>
<td>4.8 (Ku), 6.3 (Ka)</td>
</tr>
<tr>
<td>Receiver dynamic range (Ku, Ka)</td>
<td>~ 90 dB</td>
</tr>
<tr>
<td>Clutter Suppression</td>
<td>GMAP</td>
</tr>
</tbody>
</table>

### Data Products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard products</td>
<td>- Equivalent reflectivity factor (Z₀) (Ku, Ka)</td>
</tr>
<tr>
<td></td>
<td>- Doppler velocity (unambiguous: 26 m/s)</td>
</tr>
<tr>
<td>Dual-polarization products</td>
<td>- Differential reflectivity (Z₁d) (Ku, Ka)</td>
</tr>
<tr>
<td></td>
<td>- Differential propagation phase (φ₁d) (Ku, Ka)</td>
</tr>
<tr>
<td></td>
<td>- Copolar correlation coefficient (ρ₁h) (Ku, Ka)</td>
</tr>
<tr>
<td></td>
<td>- Linear depolarization ratio (LDR₀, LDR₂) (Ku, Ka)</td>
</tr>
<tr>
<td></td>
<td>(Ku, Ka) (in alternate mode of operation)</td>
</tr>
<tr>
<td>Data format</td>
<td>NETCDF</td>
</tr>
</tbody>
</table>
DFR (X/Ka, Ka/W)

DFR (Ku/Ka, Ka,W)

Pol (CDR, ZDR)

Kniefel et al., 2015 JGR

Tynella and Chandrasekar (2014, JGR)
D3R February 26, 2015 Snow in Virginia

13:00 UTC RHIs

Growth of large aggregates and some mixed phase
**GPM Physical Validation of Retrievals (databases, forward models etc.)**

- Direct/physical validation of satellite-based snowfall retrieval algorithms over complex terrain; melting layer interaction with terrain also of interest.
- Physics of snow, retrieval algorithm assumptions and cloud model parameterizations of ice processes
- Model + Observational analyses: Movement toward level IV products leverage intensive and multi-faceted NWP component.
- Support current PMM/GPM collaboration with KMA- leverage significant international observational science/data effort.

**GPM GV Deployment**

- D3R Radar IOP 2018
- Supporting snow measurement instruments including PIP, MRR2, Parsivel, Pluvio (partial winter 2016, remainder IOP 2018)
EXTRA
Summary D3R Deployment Requirements (Current Configuration)

- Power: 208-240 V, 60 Hz, 50A (D3R does have a propane generator, requires LP gas for setup and backup operations during short power loss (2-4 hours))
- Cell communications for remote instrument monitoring, control, display (or wire/fiber hook-up), just one fixed IP address required
- On board servers/processing/storage (RAID), graphical user interface setup in remote operator location through internet connection to instrument
  - Antennas and transceiver + IF electronics boxes shipped separately from trailer
  - Towing vehicle required for transport and local set up
  - Forklift required to assemble antennas and transceiver + IF electronics boxes
  - Typically ready to operate within 1-2 days