Global Precipitation Measurement (GPM) Mission and Falling Snow Retrievals

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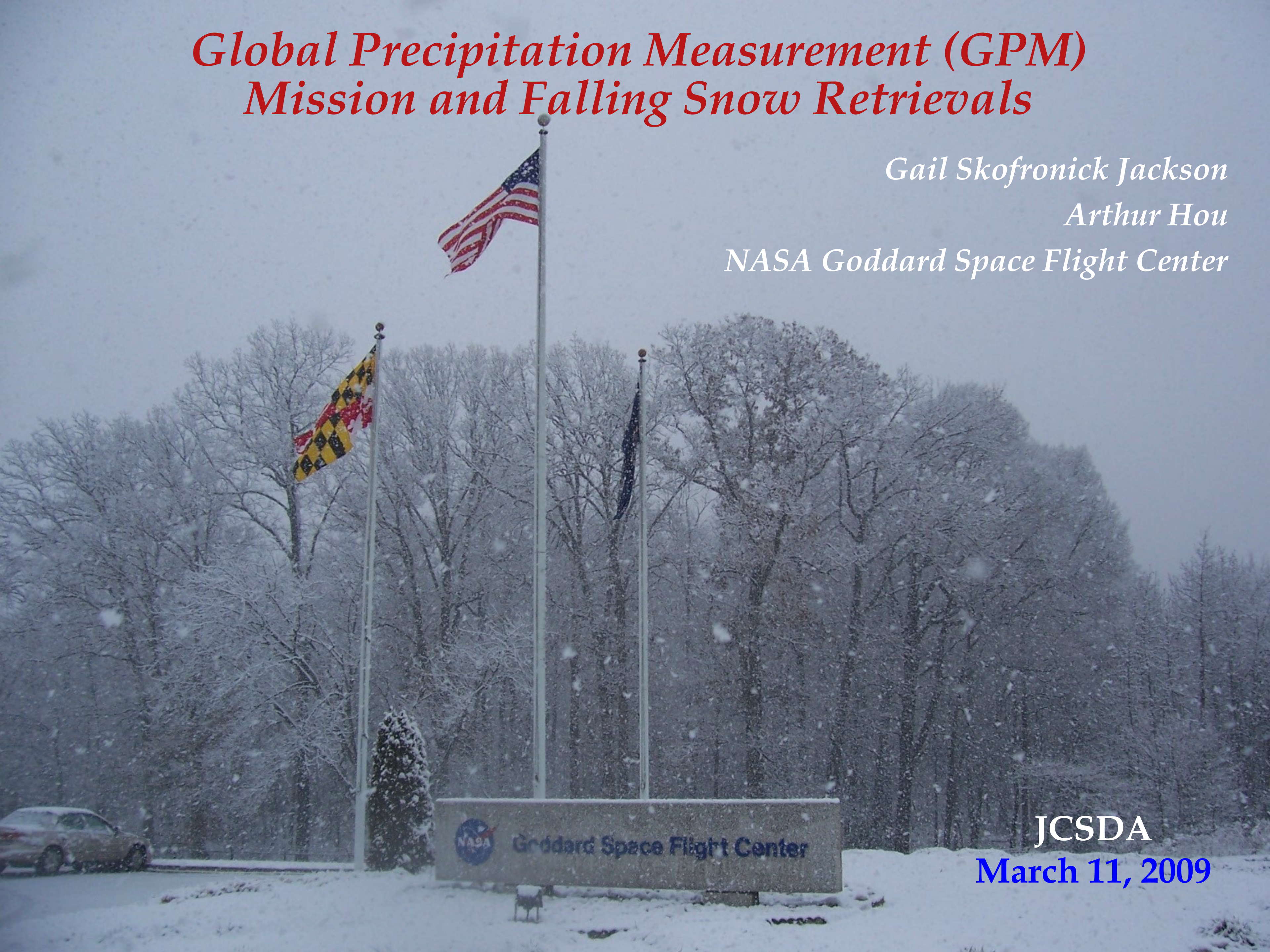
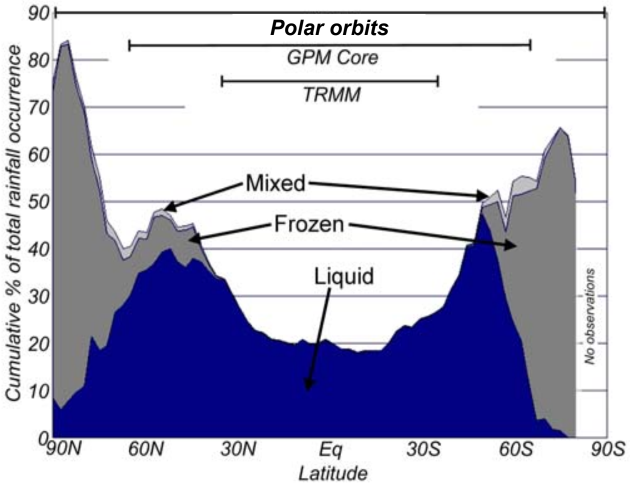
JCSDA
March 11, 2009

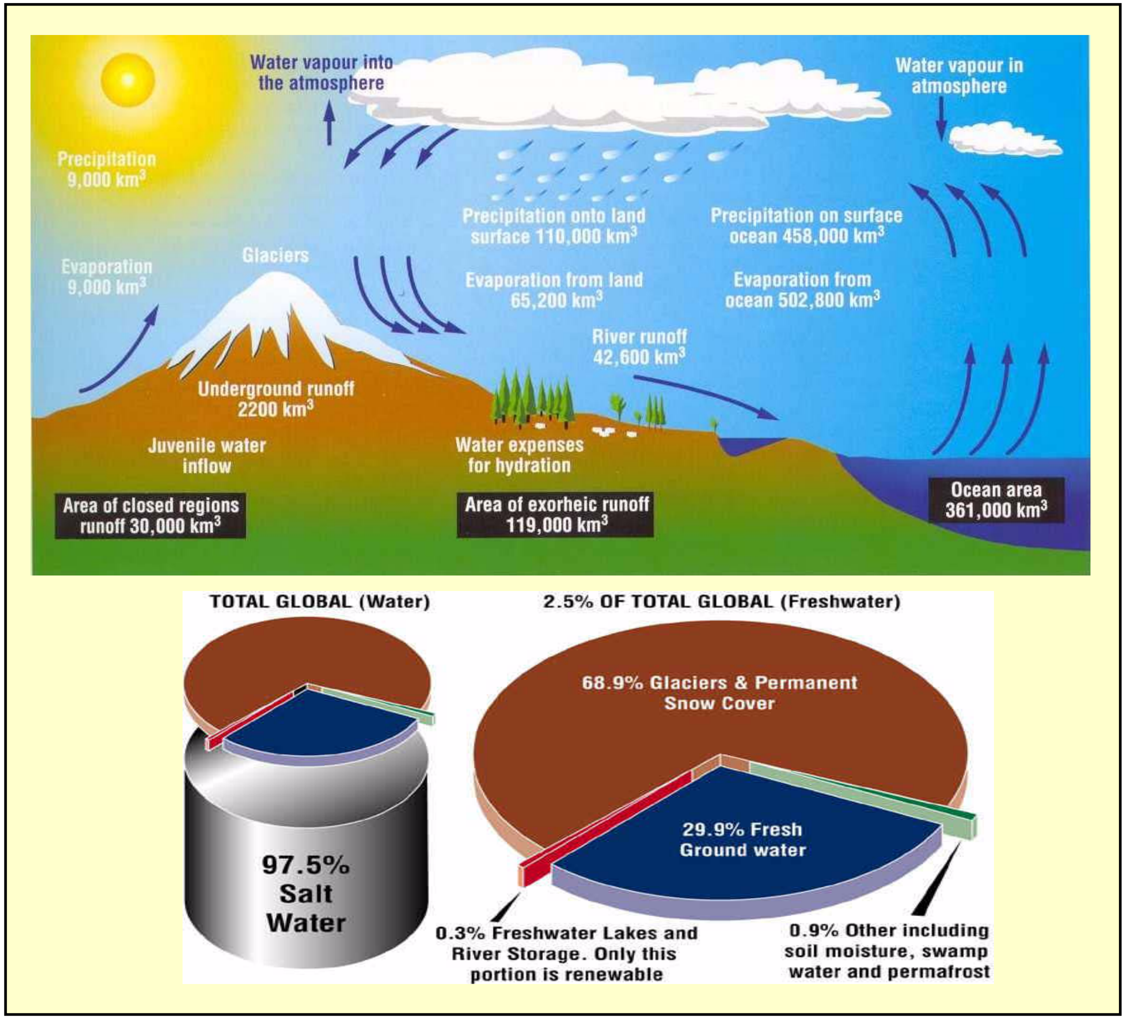


Presentation Outline

- ***Motivation***
  - *Global Water and Energy Cycles*
- ***GPM Mission***
  - *GPM Science and Mission Concept*
  - *Core Instrument Capabilities*
  - *Constellation Sampling and Performance*
  - *GPM Algorithms and Products*
- ***Snow Retrievals***
  - *Falling Snow Field Campaign*
  - *Falling Snow Detection Process*
  - *Detection Results*
- ***Future Work***
  - *Surface emission studies*
- ***Summary***



Motivation: Precipitation



Accurate global precipitation measurement is required for better prediction of freshwater resources, <u>climate change</u>, <u>weather</u>, and the <u>water cycle</u> because *precipitation* is a key process that links them all….

Falling snow and ice that melts into rain are important components of precipitation

GPM: A Science Mission with Integrated Application Goals

Science Objectives

- New reference standards for precipitation measurements from space
- Better understanding of precipitation physics, water cycle variability, and freshwater availability
- Improved numerical weather prediction skills
- Improved hydrological prediction capabilities for floods, landslides, and freshwater resources
- Improved climate modeling and prediction capabilities

GPM will make data accessible to stakeholders beyond the traditional scientific community to support societal applications, policy planning, and outreach:

- *Freshwater Utilization and Resource Management*
- *Natural Hazard Monitoring/Prediction*
- *Operational Weather Forecasting*
- *Climate Change Assessment*
- *Agriculture Policy and Planning*
- *Education and Outreach*

Global Precipitation Measurement (GPM) Reference Concept

An international satellite mission specifically designed to unify and advance global precipitation measurements from dedicated and operational satellites for research & applications

GPM Low-Inclination Observatory (40^{o})

GMI (10-183 GHz)
LRD: Nov. 2014

- *Enhanced "asynoptic" (non-Sun-synchronous) observations*
- *Improved sampling for near realtime monitoring of hurricanes and midlatitude storms*

GPM CORE Observatory (65^{o})

DPR (Ku-Ka band)
GMI (10-183 GHz)
LRD: July 2013

- *Precipitation physics observatory*
- *Reference standard for inter-calibration of constellation precipitation measurements*

Partner Satellites: GCOM-W, DMSP, Megha-Tropiques, MetOp-B, NOAA-N', NPP, NPOESS

Next-generation global precipitation products through

advanced active & passive microwave sensor measurements
a consistent framework for inter-satellite calibration (radiance & rain rates)
international collaboration in algorithm development and ground validation

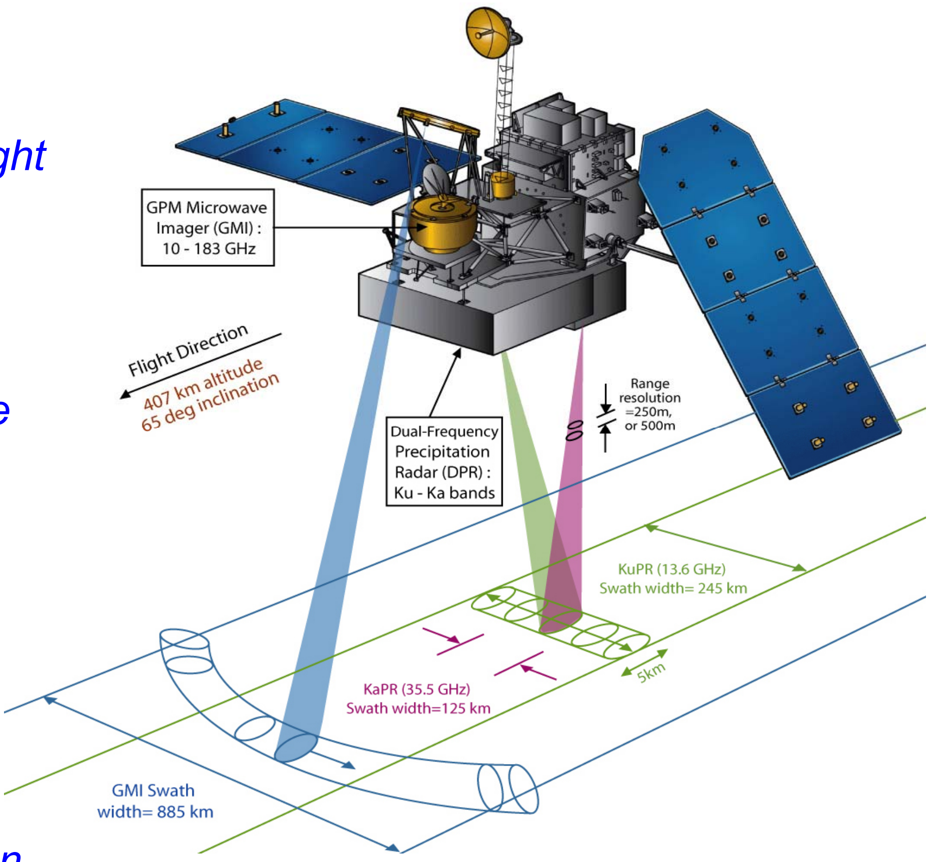
Core Observatory Measurement Capabilities

Dual-Frequency (Ku-Ka band) Precipitation Radar (DPR):

- *Increased sensitivity (~11 dBZ) for light rain and snow detection*
- *Better measurement accuracy with differential attenuation correction*
- *Detailed microphysical information (DSD mean mass diameter & particle no. density) & identification of liquid, ice, and mixed-phase regions*

Wide-Band (10-183 GHz) Microwave Imager (GMI):

- *High spatial resolution*
- *Improved light rain & snow detection*
- *Improved signals of solid precipitation over land (especially over snow-covered surfaces)*
- *4-point calibration to serve as a radiometeric reference for constellation radiometers*



Combined Radar-Radiometer Cloud Database

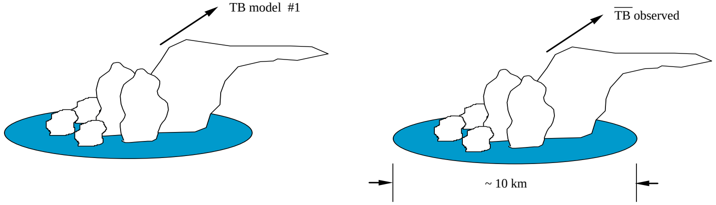
- *DPR & GMI together provide greater constraints on possible solutions to improve retrieval accuracy*
- *Improved a-priori cloud database for constellation radiometer retrievals*

GPM: A consistent framework to unify a heterogeneous constellation of radiometers using GMI and DPR measurements

- *Calibration of Level-1 constellation radiometric data using GMI as reference:*
  GMI is designed to ensure greater accuracy and stability by employing
  - *Encased hot load design to minimize solar intrusion*
  - *4-point calibration for nonlinearity removal under nominal conditions and backup calibration during hot-load anomalies*
- *Calibration of Level-2 rainfall data using DPR+GMI measurements:*
  Making combined use of GMI and DPR measurements to provide a common cloud/hydrometeor database for precipitation retrievals from the GPM Core and Constellation radiometers.

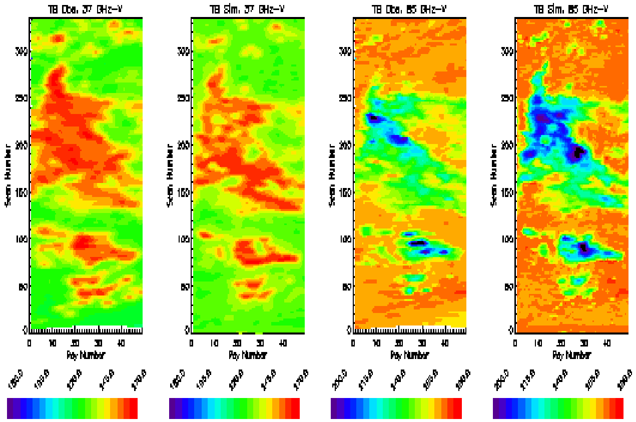
Physical precipitation retrieval: Matching observed T_b with those simulated from a prior cloud database within a statistical framework

Simulated T_b *Observed T_b*



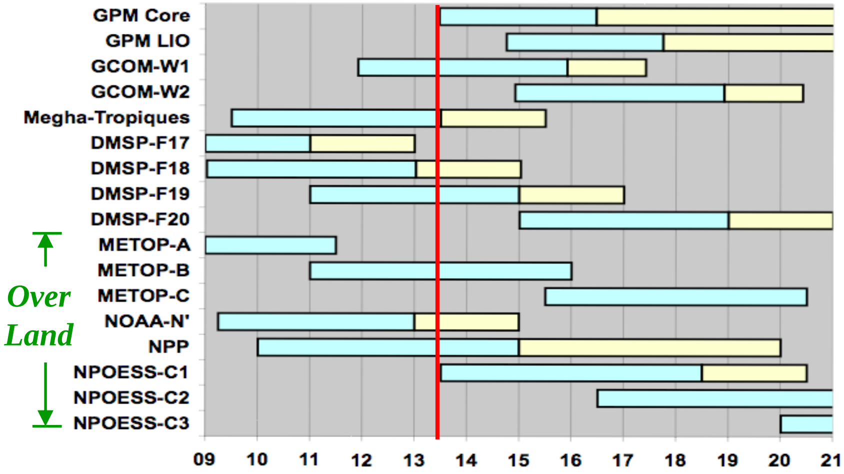
TRMM uses a model-generated database
GPM uses a combined DPR+GMI database

Simulated vs. observed TMI T_b



Baseline GPM Constellation Performance

GPM Core Launch



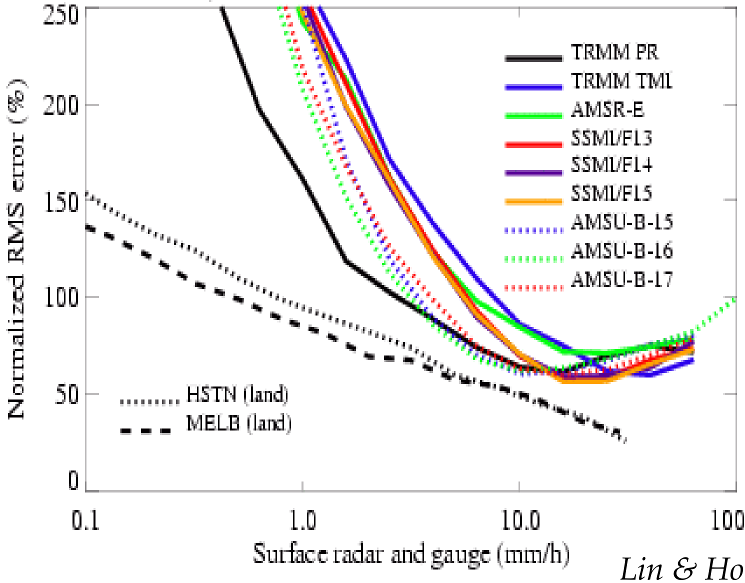
🟦 Prime Life 🟨 Extended Life

Additional partners possible: Brazil, Russia, China

	Average Revisit Time (hr)				
Year	2013	2014	2015	2016	2017
	Land				
Tropics	1.6	1.5	1.6	1.8	2.3
Extratropics	1.1	1.0	1.0	1.0	1.4
Globe	1.4	1.2	1.3	1.4	1.8
	Ocean				
Tropics	3.1	2.5	3.2	3.9	4.9
Extratropics	3.2	2.6	2.1	2.6	3.3
Globe	3.1	2.5	2.7	3.3	4.2
	Land and Ocean				
Tropics	2.6	2.2	2.7	3.1	4.0
Extratropics	2.3	1.9	1.6	1.9	2.5
Globe	2.4	2.0	2.1	2.5	3.3

1-2 hr revisit time over land

Performance of Sensors over Land (US)

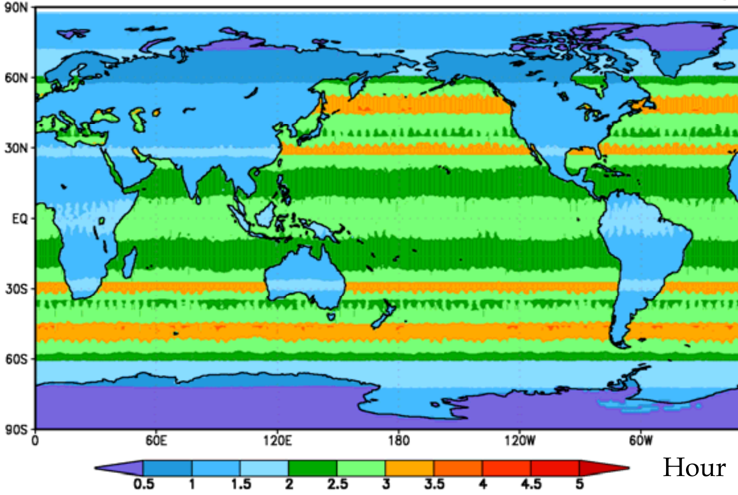


Lin & Hou (2008)

GPM (2015)

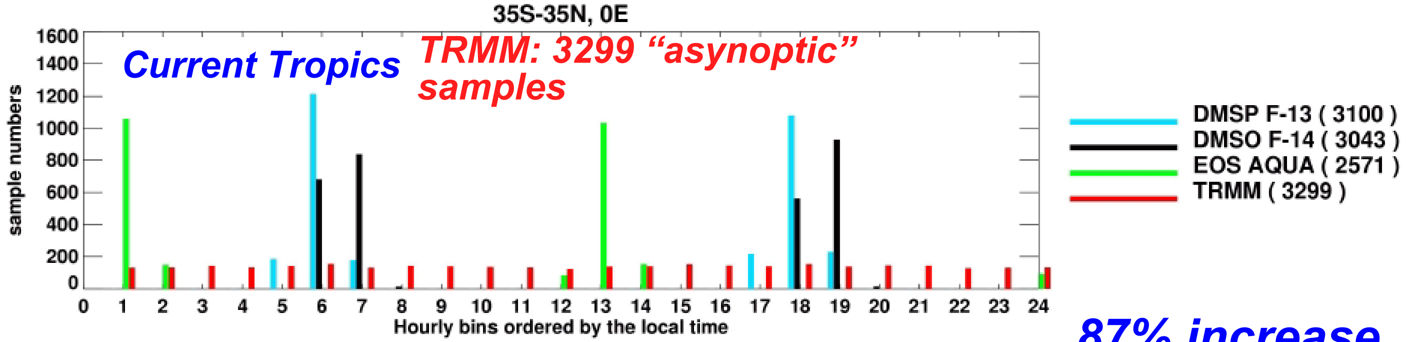
(≤ 3h over 92% of globe)

Radiometers+METOP−1+NPP+NOAA19+NPOESS−C1 (land)



Improved Temporal Sampling with observations from non-Sun-synchronous orbits

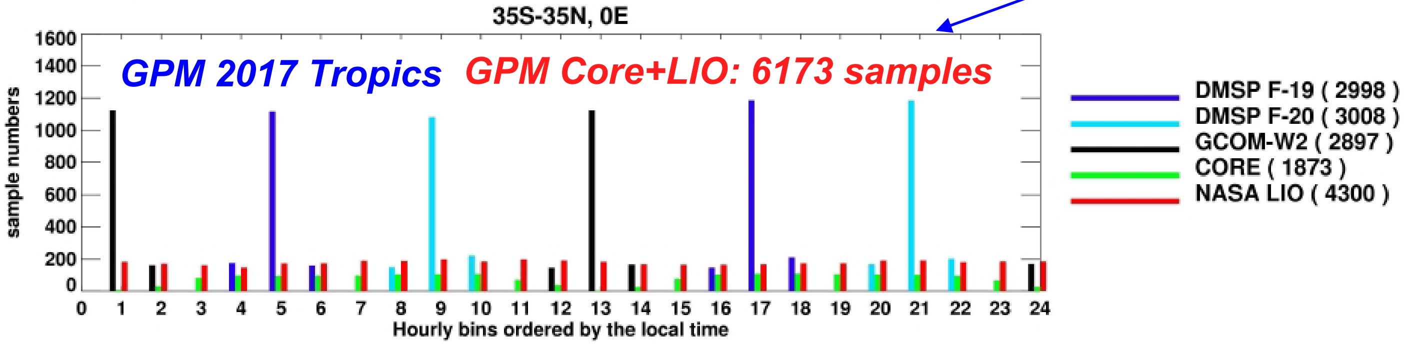
Monthly Samples as a Function of the Time of the Day (1^o x 1^o Resolution)



Current Tropics

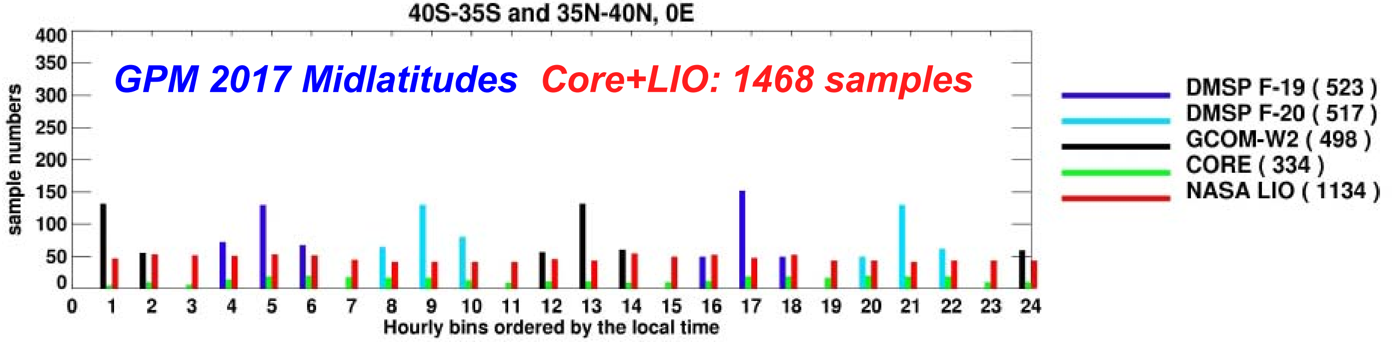
TRMM: 3299 “asynoptic” samples

87% increase



GPM 2017 Tropics

GPM Core+LIO: 6173 samples



GPM 2017 Midlatitudes

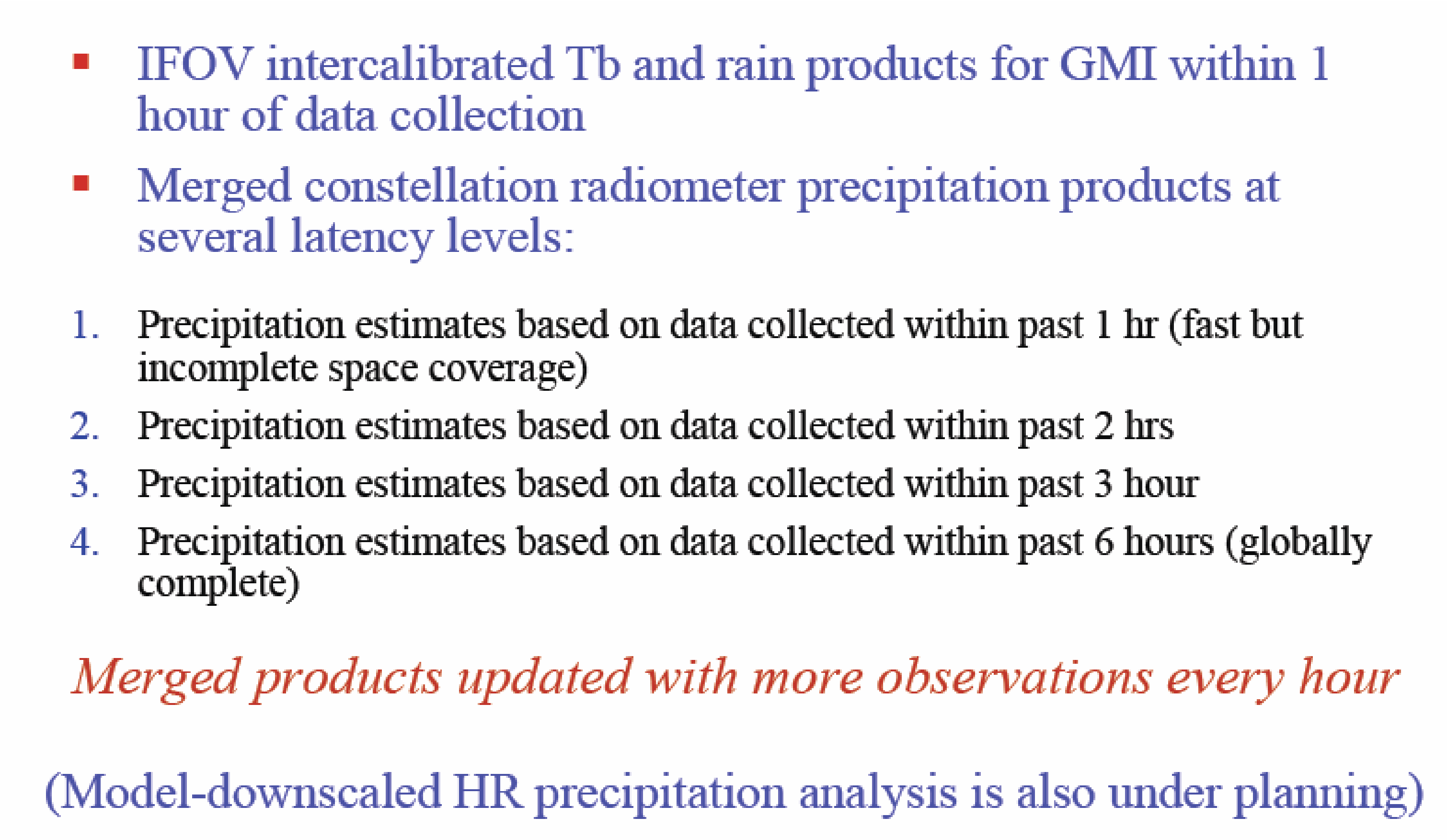
Core+LIO: 1468 samples

Provisional GPM Products

- ***Level-1 DPR reflectivity products***
- ***Level-1 Inter-calibrated Core and constellation radiometric products***
- ***Level-2 DPR precipitation products***
- ***Level-2 DPR+GMI combined precipitation products***
- ***Level-2 Radar-enhanced constellation radiometer products***
  - *Constellation radiometer retrievals using the DPR+GMI combined cloud database*
- ***Level-3 Multi-satellite MW global precipitation products***
- ***Level-3 Multi-satellite MW+IR global precipitation products***
- ***Level-4 Model+observation assimilated global precipitation products***
  - *NWP global precipitation forecasts*
  - *4D global "dynamic precipitation analyses"*
  - *High-resolution (1-2 km) model-downscaled regional precipitation products*

Levels-1 & 2 are instantaneous orbital products
Levels-3 & 4 are grid-averaged products

Provisional GPM precipitation products for nowcasting



- IFOV intercalibrated Tb and rain products for GMI within 1 hour of data collection
- Merged constellation radiometer precipitation products at several latency levels:

1. Precipitation estimates based on data collected within past 1 hr (fast but incomplete space coverage)
2. Precipitation estimates based on data collected within past 2 hrs
3. Precipitation estimates based on data collected within past 3 hour
4. Precipitation estimates based on data collected within past 6 hours (globally complete)

Merged products updated with more observations every hour

(Model-downscaled HR precipitation analysis is also under planning)

Provisional Algorithm Management & Organization

NASA/JAXA Joint Algorithm Team
Co-Leads: A. Hou, K. Nakamura

Radar Only Algorithm
JAXA Lead: T. Iguchi

JAXA WG team:
- *S. Seto (U. Tokyo)*
- *H. Hanado (NICT)*
- *N. Yoshida (JAXA)*

NASA WG team:
- *R. Meneghini (NASA)*
- *J. Kwiatkowski (NASA)*
- *L. Liao (UMD)*
- *S. Durden (JPL)*
- *S. Tanelli (JPL)*
- *L. Tian (UMD)*
- *Chandra (CSU)*

Combined Algorithm
JAXA Co-Lead: H. Masunaga
NASA Co-Lead: W. Olson

JAXA WG team:
- *M. Hirose (Meijo U.)*
- *F. Furuzawa (Nagoya U.)*

NASA WG team:
- *Z. Haddad (JPL)*
- *M. Grecu (UMD)*
- *G. Liu (FSU)*
- *B. Johnson (UMD)*
- *L. Tian (UMD)*

PMR-RE Algorithm
NASA Leads: C. Kummerow
& G. Jackson

JAXA WG team:
- *K. Aonashi (JMA/MRI)*
- *S. Shige (Osaka Pref. U.)*
- *N. Takahashi (NICT)*
- *S. Satoh (NICT)*
- *Eito (JMA/MRI)*
- *T. Kubota (JAXA)*

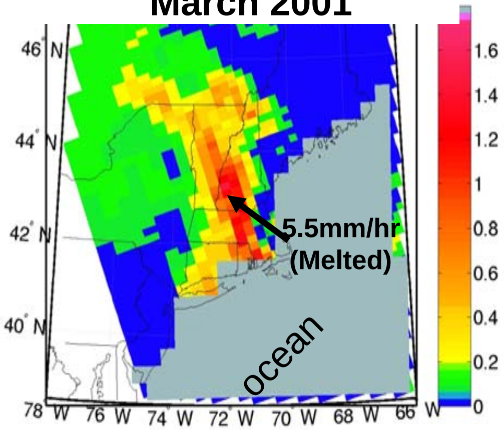
NASA WG team:
- *G. Petty (U. Wisconsin)*
- *G. Liu (FSU)*
- *R. Ferraro (NOAA)*
- *D. Staelin (MIT)*
- *N.-Y. Wang (UMD)*
- *K. Hilburn (RSS)*

Currently 8 GPM working groups supporting pre-launch algorithm development (e.g., land surface emissivity, mixed phase, ground validation, etc.)

US-Based GPM Falling Snow Radiometer *Algorithm Retrieval Methodologies*

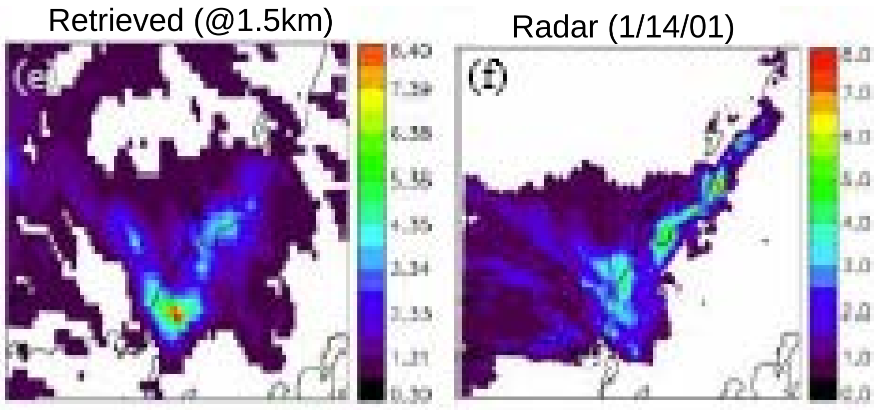
Physically-Based

March 2001



NASA Goddard/U. Wash.
Skofronick-Jackson, et al TGRS 2004,
Kim JGR 2008

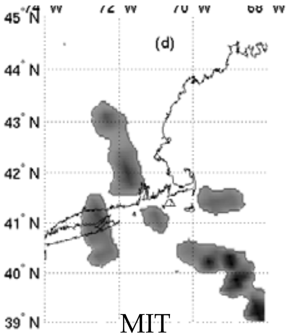
Physically-Based


Retrieved (@1.5km)
Radar (1/14/01)

FSU, Liu & Noh, 2004, 2005
Wakasa Bay, Japan data

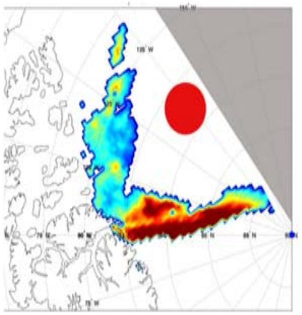
Neural Networks

March 2001



MIT
Chen and Staelin
Trans Geosci Remote Sens 2003

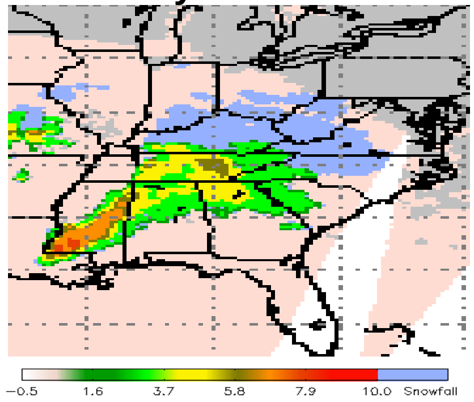
Polar Retrievals



MIT, Staelin

Empirical Approach

25 January 2004

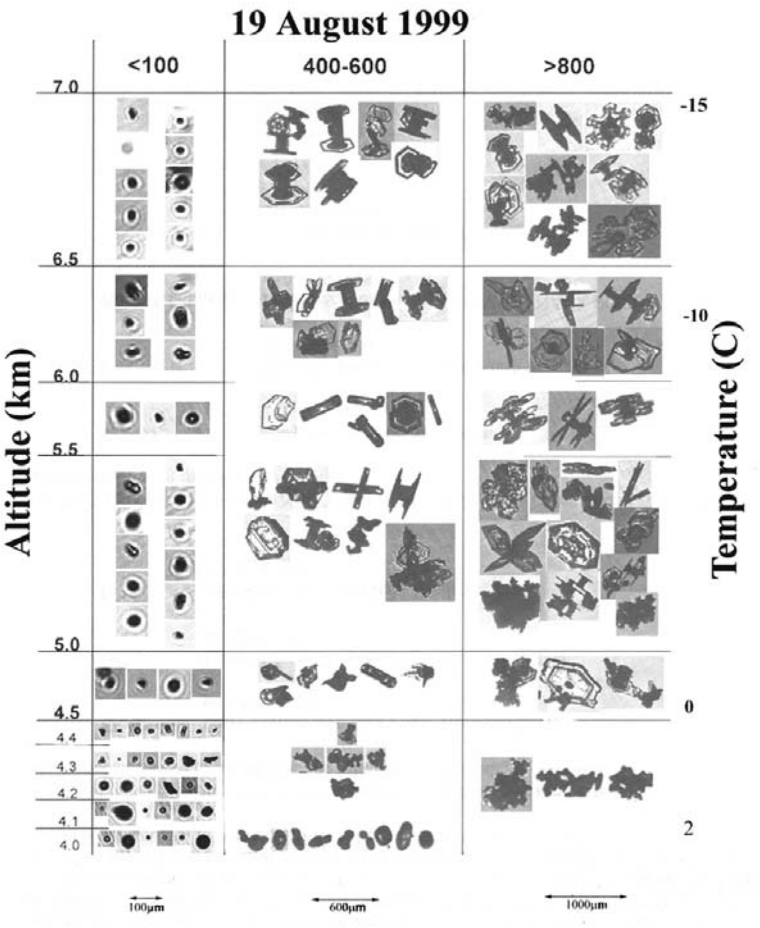


Snow Detection

NOAA, Kongoli, et al
Geophys Res. Letters 2003
& Ferraro et al TGARS 2005

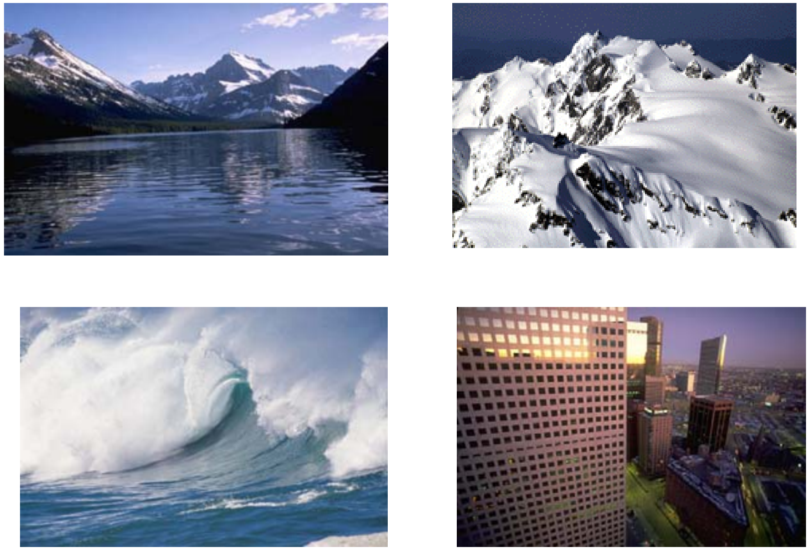
Challenges in Estimating Snow over Land

Frozen Particle Variability



CPI *in situ* images, Andy Heymsfield

Surface Variability

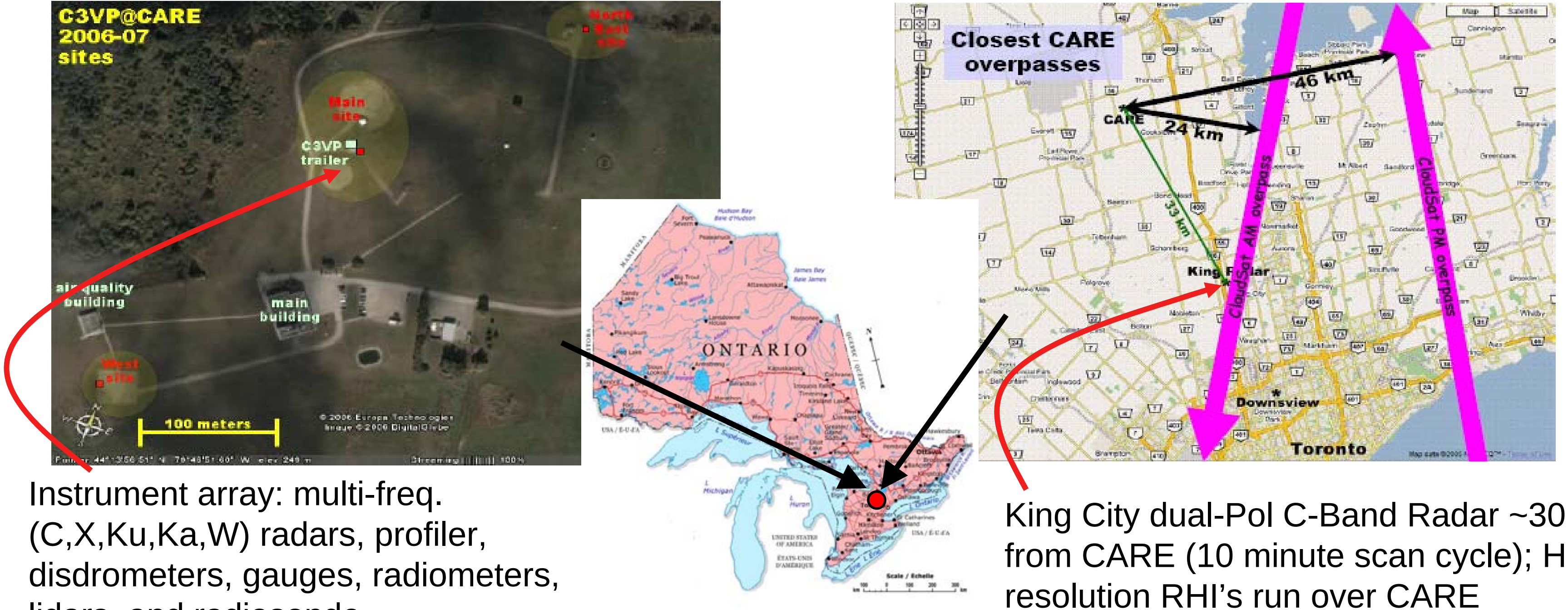


Non-Linear and Under-Constrained Relationships between physical characteristics of ice particles and microwave observations

Canadian CloudSat/Calipso Validation Project (C3VP)

Collaboration: Canadian MSC/EC, NASA-JPL CloudSat, NASA-Glenn, McGill U., PSU, and CSU-CIRA DoD Geosciences Center (CLEX-10)

EC Centre for Atmospheric Research Experiments (CARE) site located ~70km north of Toronto



Instrument array: multi-freq. (C,X,Ku,Ka,W) radars, profiler, disdrometers, gauges, radiometers, lidars, and radiosonde

King City dual-Pol C-Band Radar ~30km from CARE (10 minute scan cycle); High resolution RHI's run over CARE

Four aircraft IOPs:

IOP-1: Oct. 31 – Nov. 9; IOP-2: Nov. 30 – Dec. 11;
IOP-3: Jan. 17 – Jan. 28 NASA PMM/GPM; IOP-4: Feb. 18 - March 1

IOPs include C580 aircraft carrying extensive microphysical instrumentation. Regional Modeling System output (EC and WRF) during entire field campaign.

Satellites: A-Train (AMSR-E, CloudSat/CALIPSO), NOAA (AMSU-A, AMSU-B)

Estimating Surface Emissivity & Detecting Falling Snow

1) **Use forest cover in each AMSU-B/MHS footprint to obtain average forest fraction, *f*.**
2) **For forest fraction, use emissivity: $\varepsilon 1$**
3) **For (1- *f*) use emissivities for different snow depths**
   - a) *If snow depth at Egbert ground station = 0 cm;* $\varepsilon_{avg} = f * \varepsilon 1 + (1 - f) * \varepsilon 2$
   - b) *When snow depth < 30cm;* $\varepsilon_{avg} = f * \varepsilon 1 + 0.5 * (1 - f) * (\varepsilon 2 + \varepsilon 3)$
   - c) *When snow depth > 5cm;* $\varepsilon_{avg} = f * \varepsilon 4 + (1 - f) * \varepsilon 3$

$\varepsilon 1$ = emissivity of winter open forest

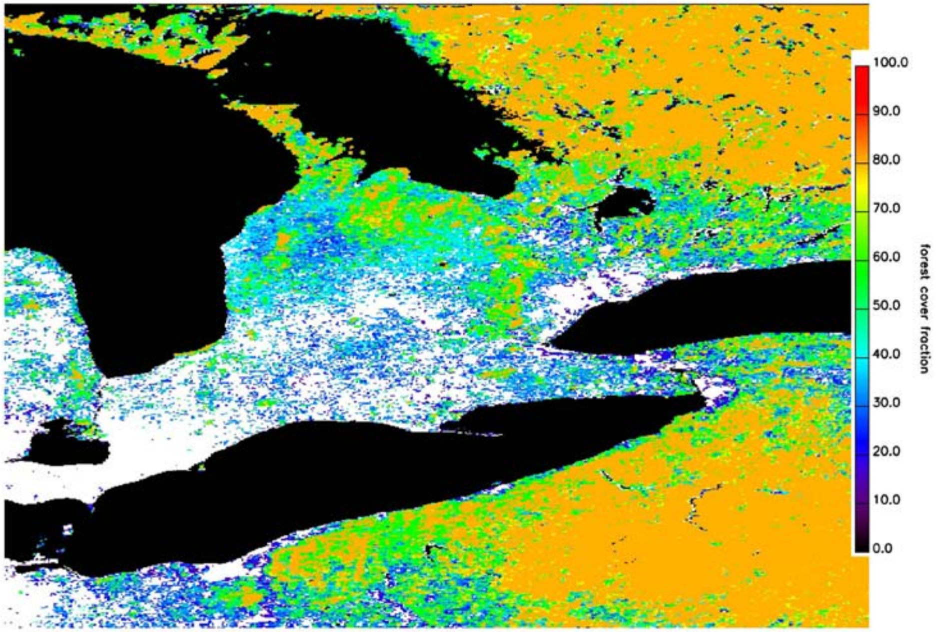
$\varepsilon 2$ = emissivity of grass

$\varepsilon 3$ = emissivity of deep dry snow

$\varepsilon 4$ = emissivity of snow in close forest

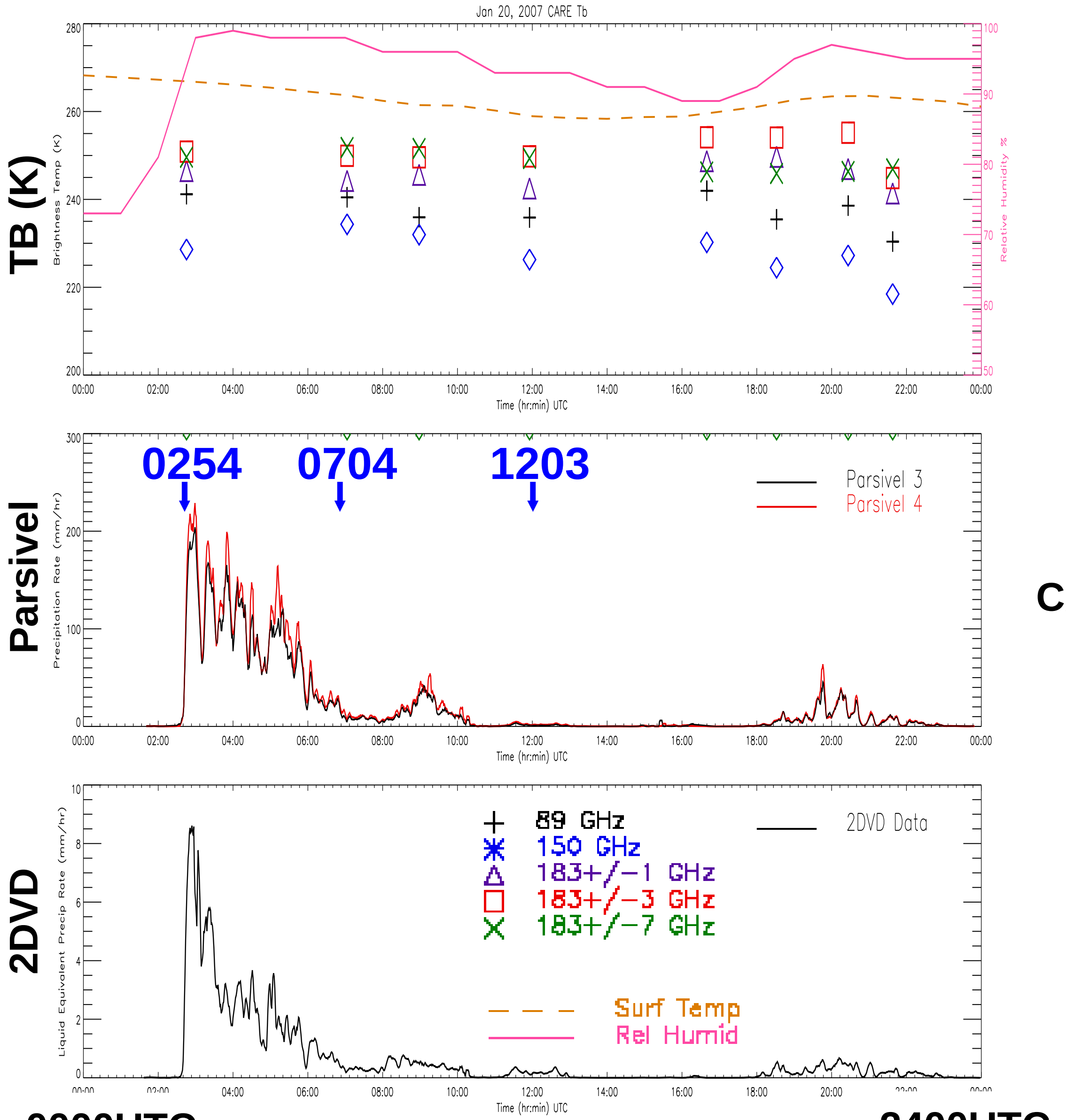
ε from Hewison and English 1999,
& Hewison 2001

4) ***Compute TB using surface emissivity and radiosonde profiles and assuming clear air***
5) ***Take the Difference:***
   $TB_{AMSU\text{-}B} - TB_{computedClearAir}$
6) **Multiple channel differences less than zero = snow detection**



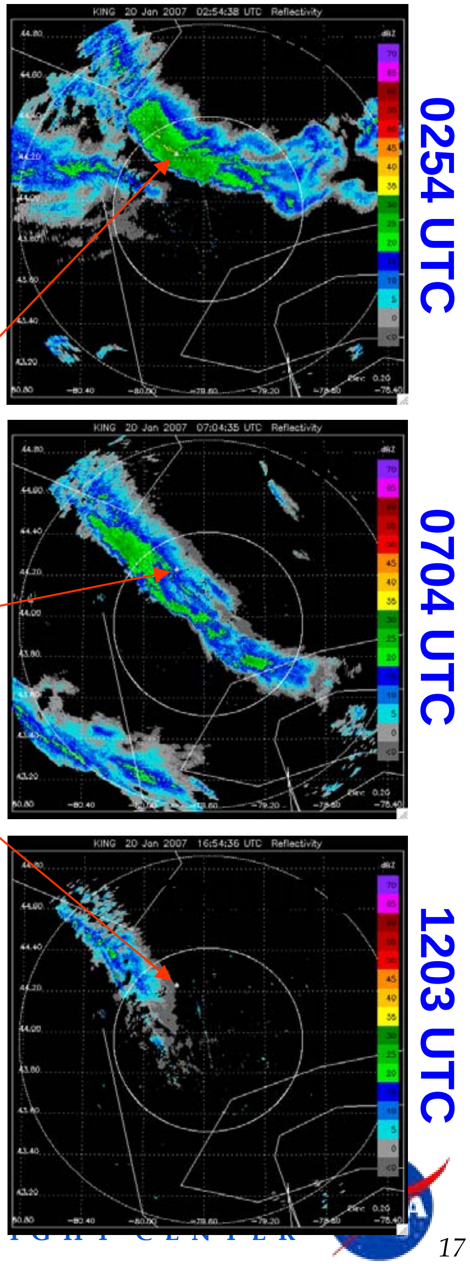
Forest Fraction Map/UM GLCF

20 Jan 2007/Lake Effect Snow/Ground Obs



0000UTC **2400UTC**

CARE Site

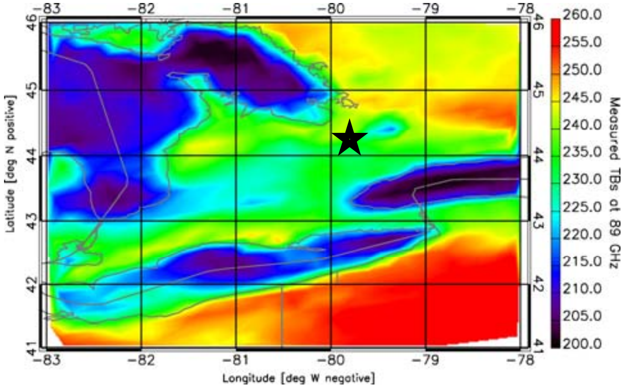


5°x5° Detection: 20 Jan 2007: Lake Effect Snow

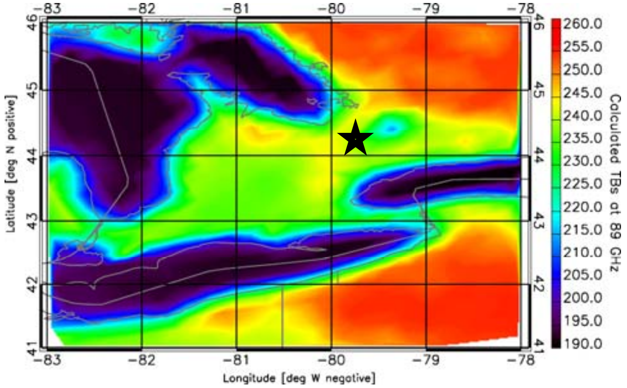
NOAA-17 AMSU-B Overpass at 02:45 UTC (150 GHz)

20 – 30 cm snow accumulation from 0300 to 1000 UTC at C3VP site

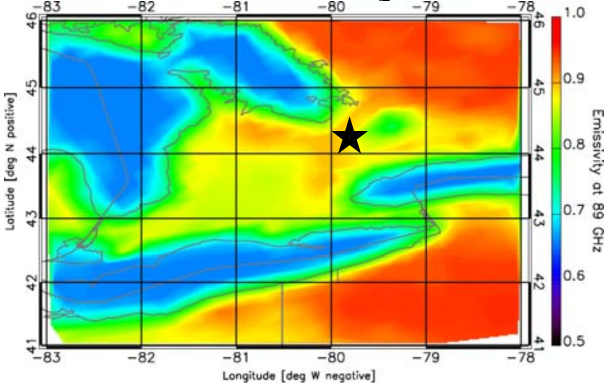
AMSU-B TB



Calculated TB



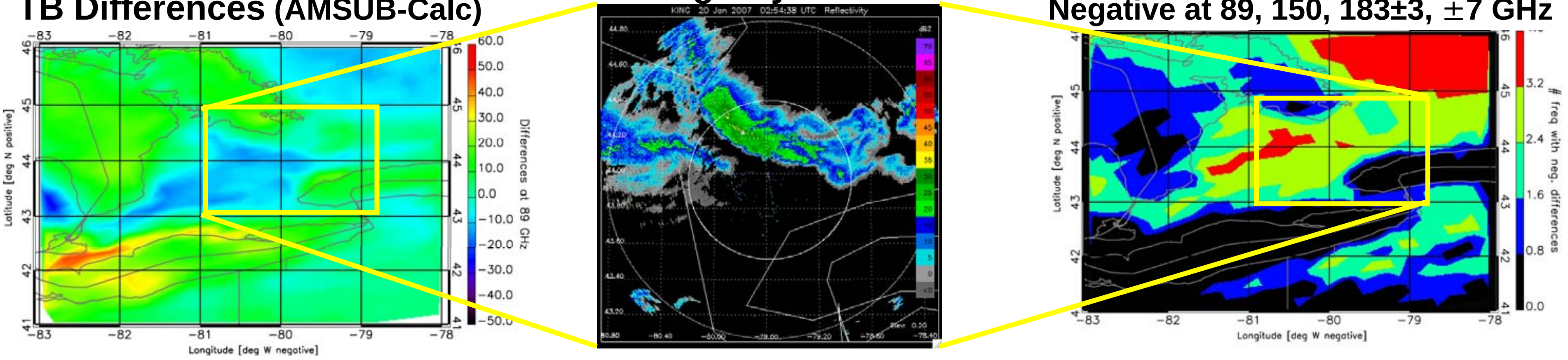
Emissivity



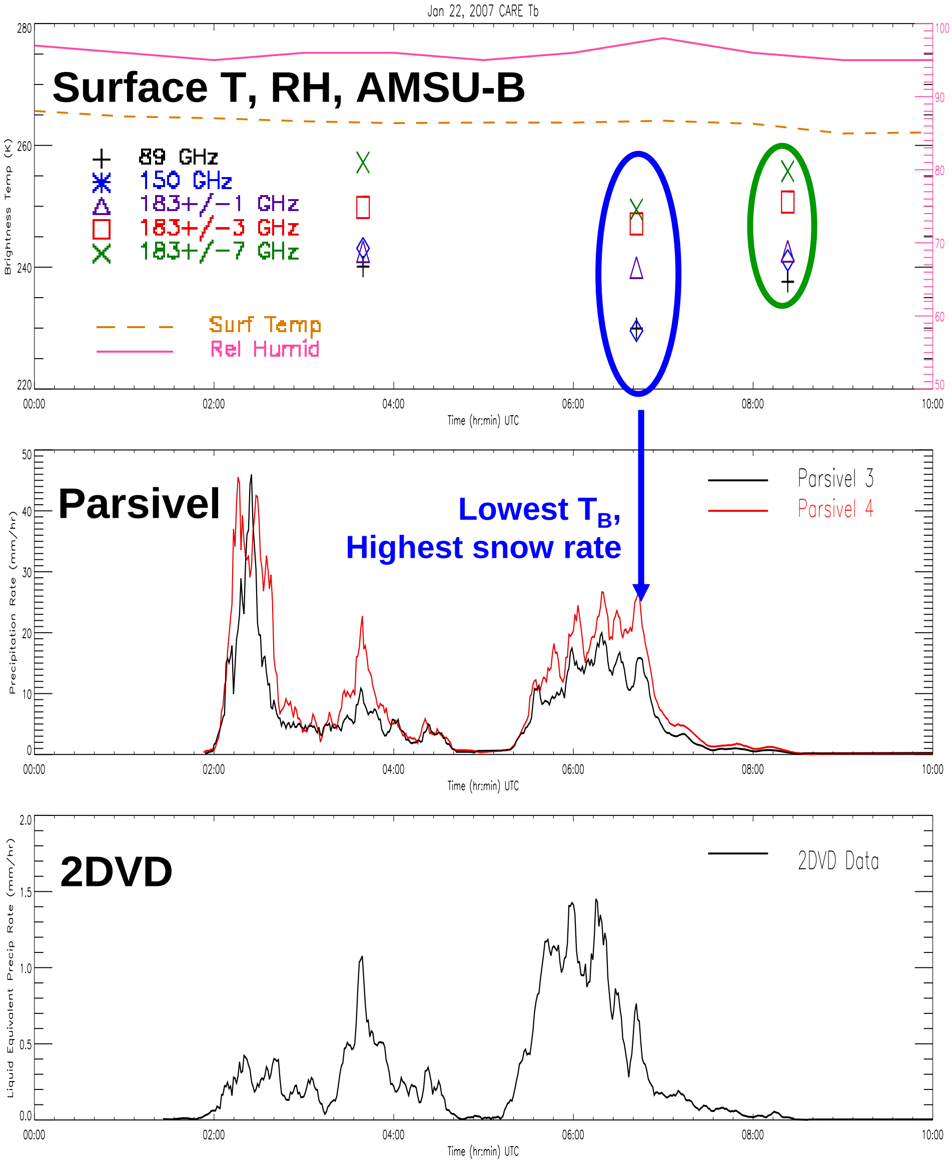
TB Differences (AMSUB-Calc)

King City Radar

Dark Red = TB Differences are Negative at 89, 150, 183±3, ±7 GHz

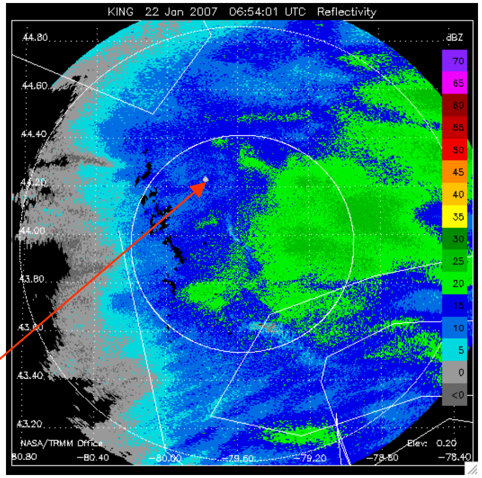


22 Jan 2007/Synoptic Snow/Ground Obs



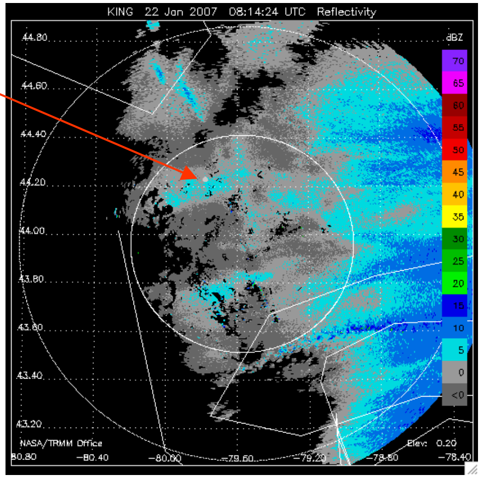
Lowest T_B, Highest snow rate

King City C-Band 0653 UTC



CARE Site

King City C-Band 0814 UTC



0000UTC

1000UTC

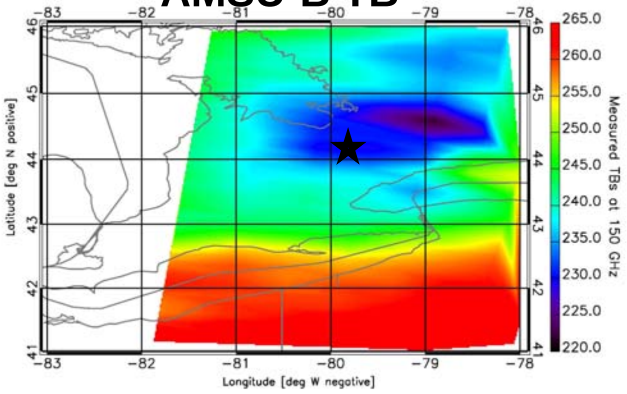
Skofronick-Jackson, JCSDA, 11 March 2009

5°x5° Detection: 0642UTC 22 Jan 2007: Synoptic Snow

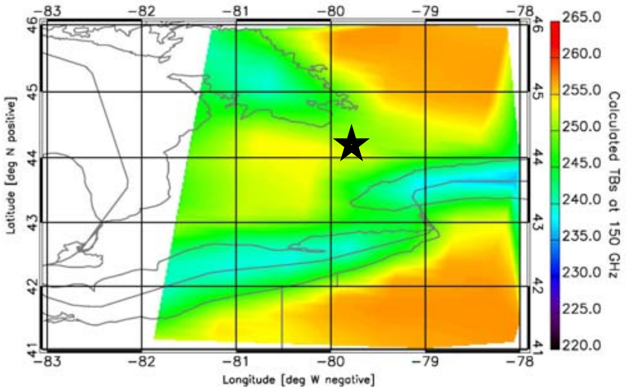
AMSU-B Overpass at 06:42 UTC (150 GHz)

4-6 cm snow accumulation at C3VP site

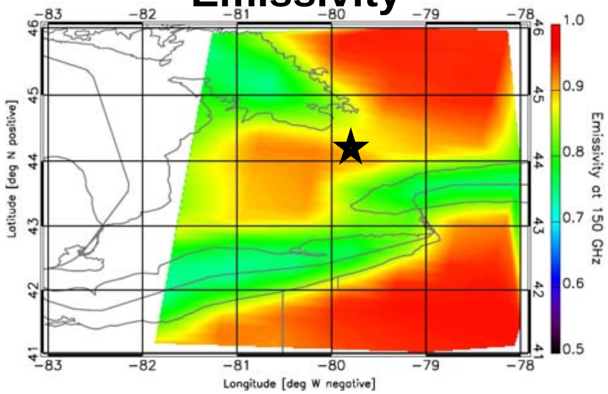
AMSU-B TB



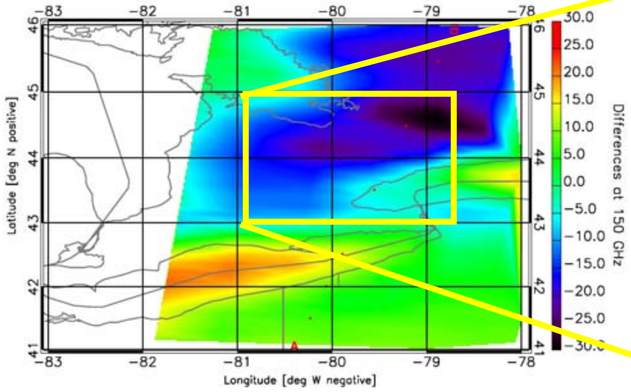
Calculated TB



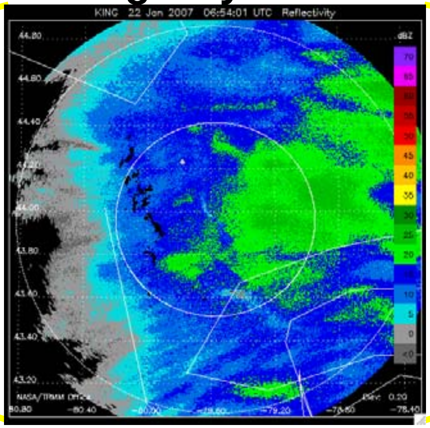
Emissivity



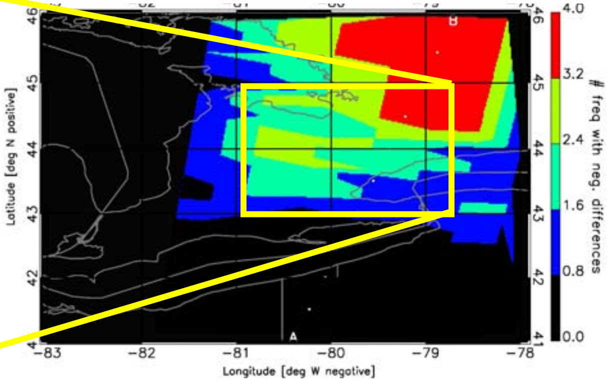
TB Differences (AMSUB-Calc)



King City Radar



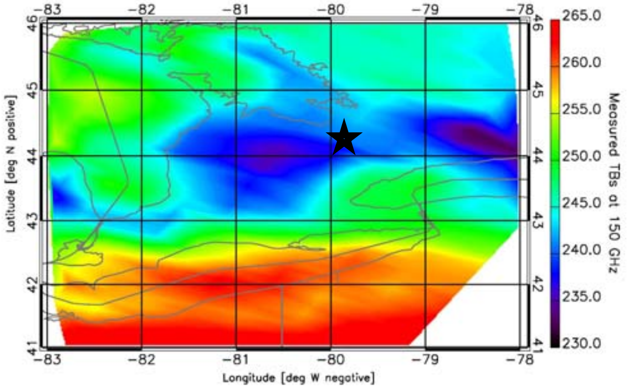
Dark Red = TB Differences are Negative at 89, 150, 183±3, ±7 GHz



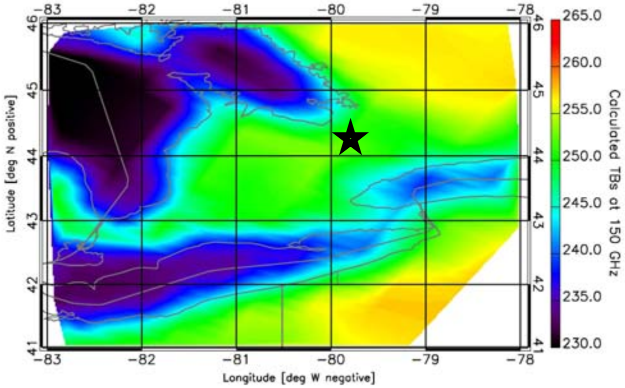
5°x5° Detection: 0823UTC 22 Jan 2007: Synoptic Snow

AMSU-B Overpass at 08:23 UTC (150 GHz)

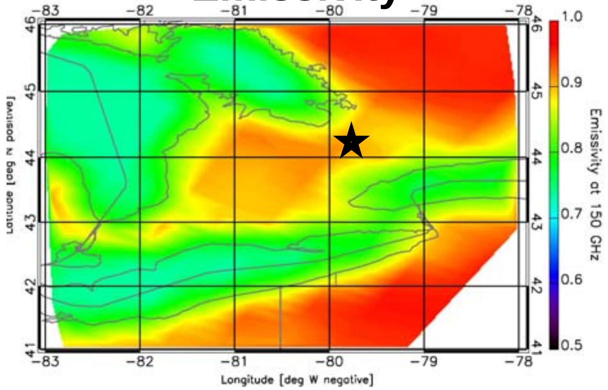
AMSU-B TB



Calculated TB



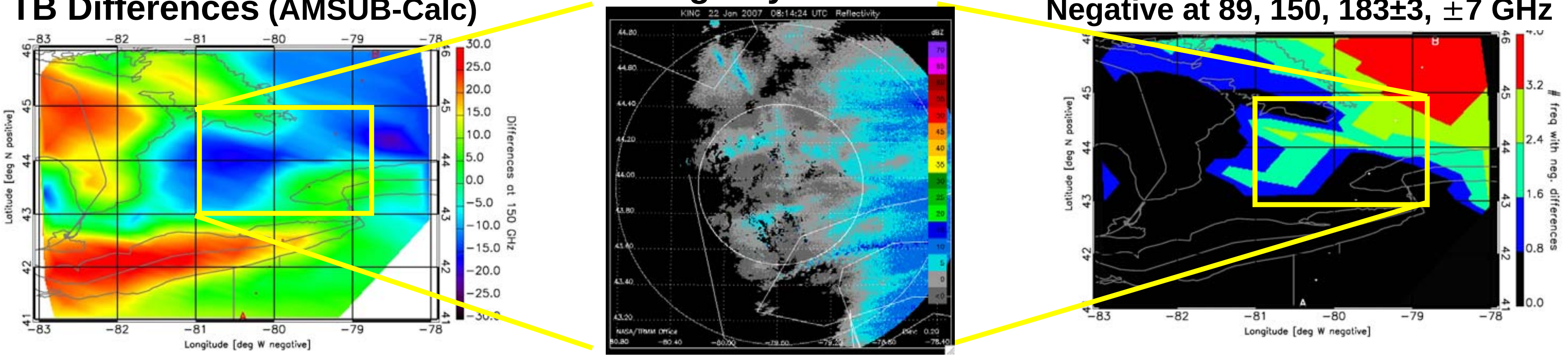
Emissivity



TB Differences (AMSUB-Calc)

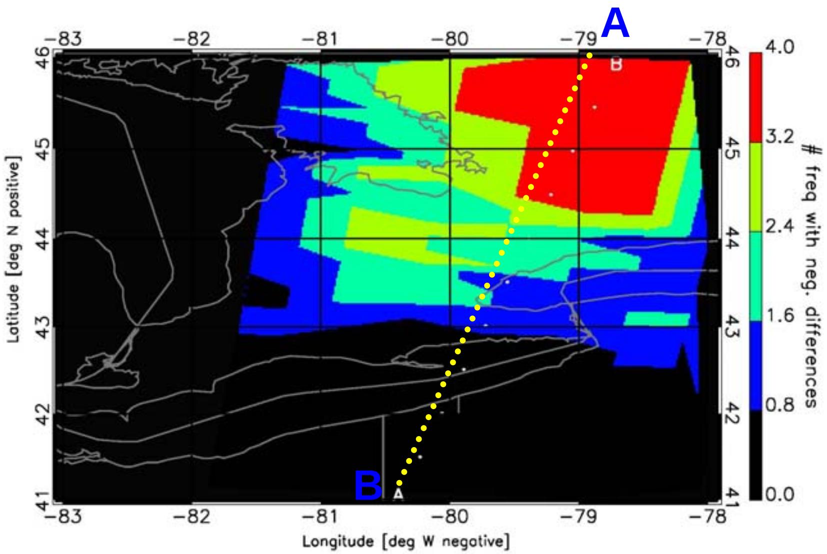
King City Radar

Dark Red = TB Differences are Negative at 89, 150, 183±3, ±7 GHz

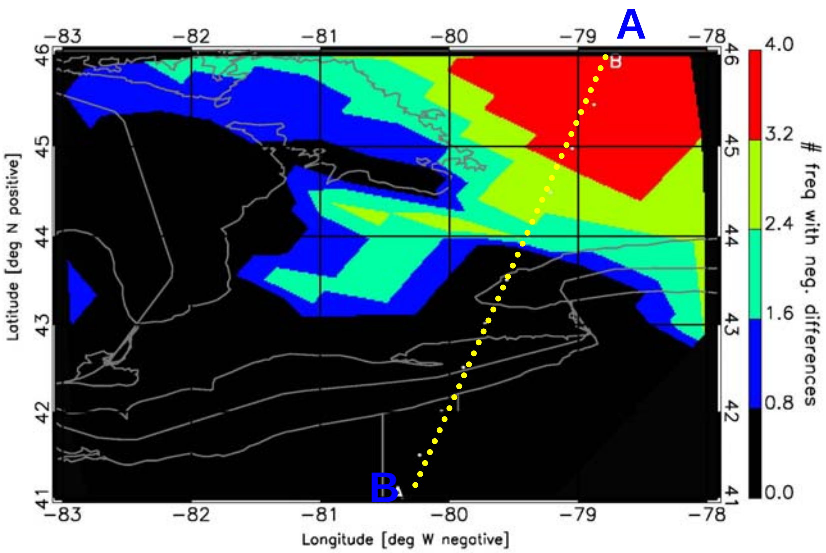


Passive versus Active Snow Detection: 22 Jan 2007

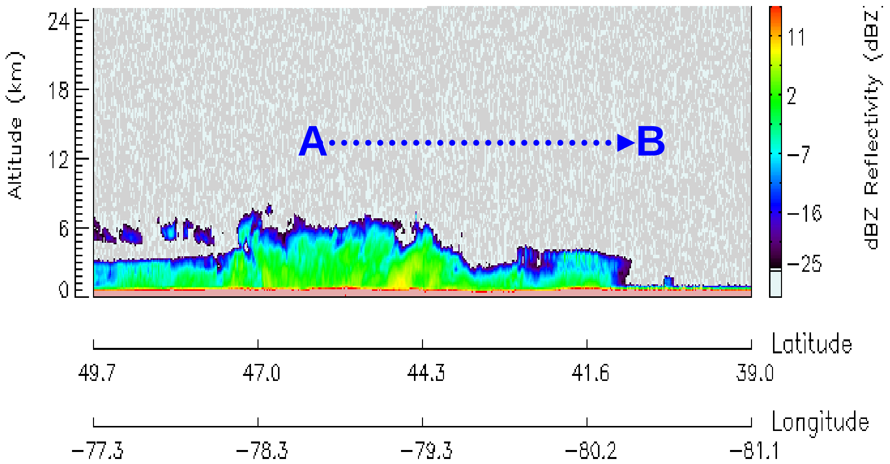
0642 UTC, Passive Detection



0823 UTC, Passive Detection



CloudSat,
0733 UTC,
Active Detection

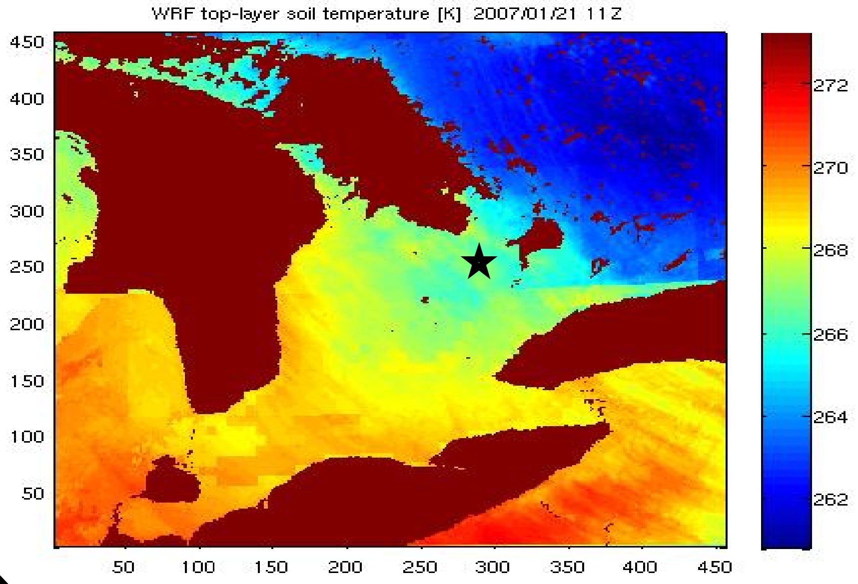


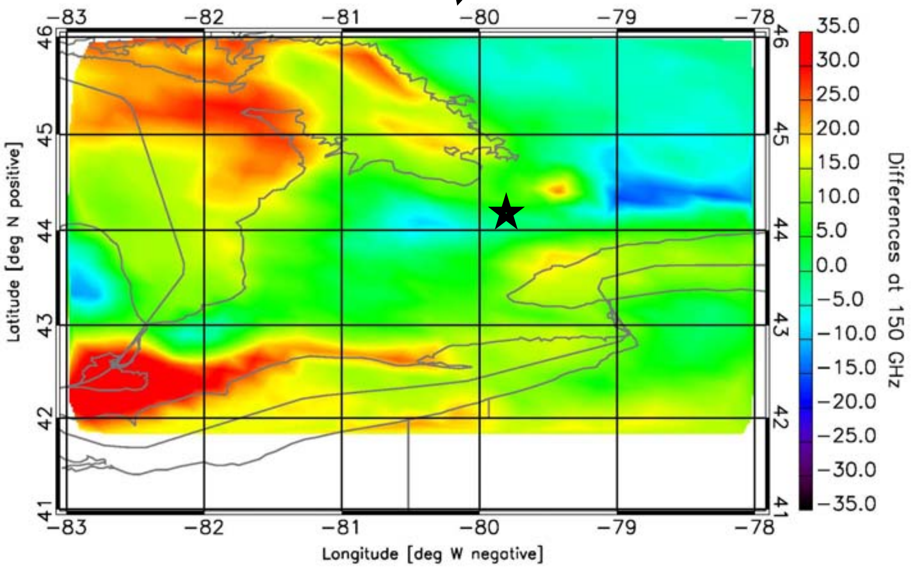
Sensitivity to Surface Temperature: 21 Jan 2007 (Clear Air)

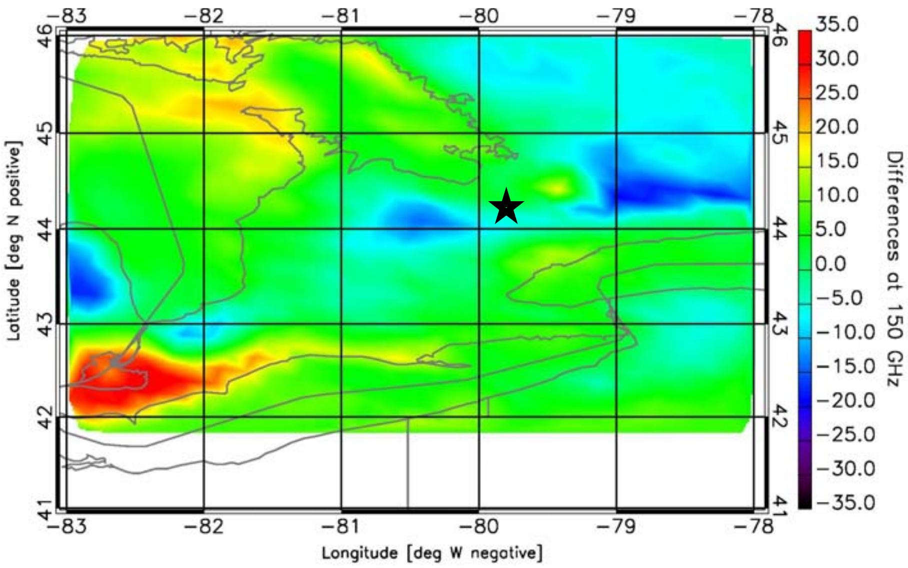
NOAA-15 AMSU-B Overpass at 11:31 UTC (150 GHz)

TB Differences when surface emission (temperature) changes.

WRF modeled temperature
Differences using WRF T
Differences using fixed T







Sensitivity to Surface Emissivity: 21 Jan 2007 (Clear Air)

NOAA-15 AMSU-B Overpass at 11:31 UTC (150 GHz)

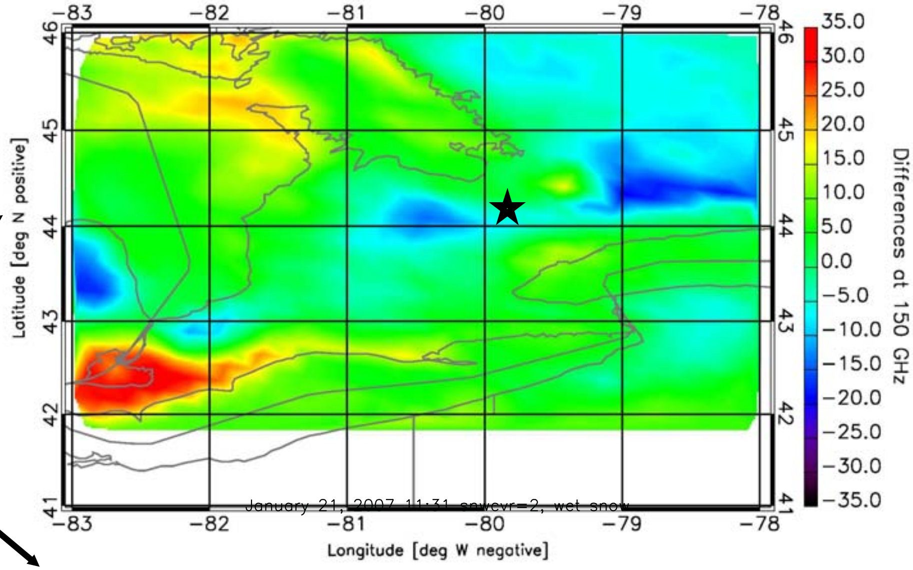
Differences when surface emission (emissivity) assumptions change.

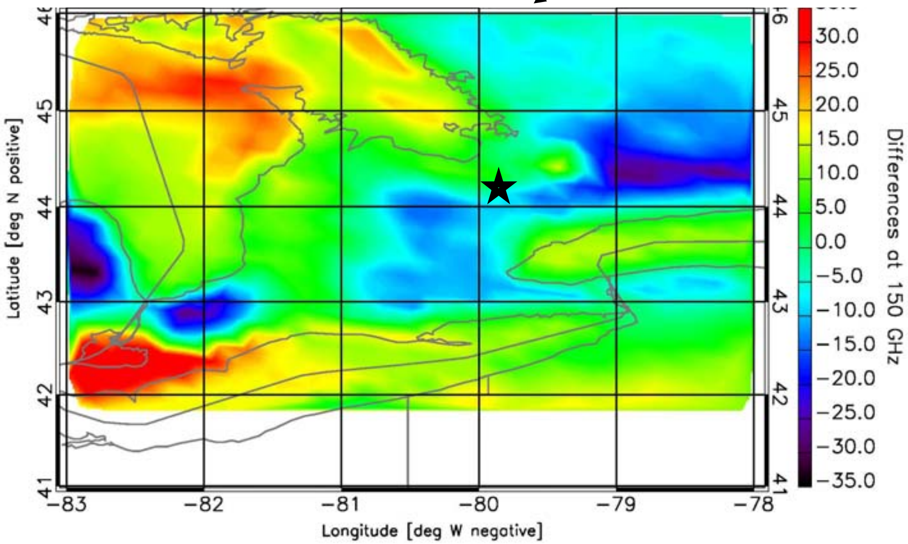
Non-forested areas=

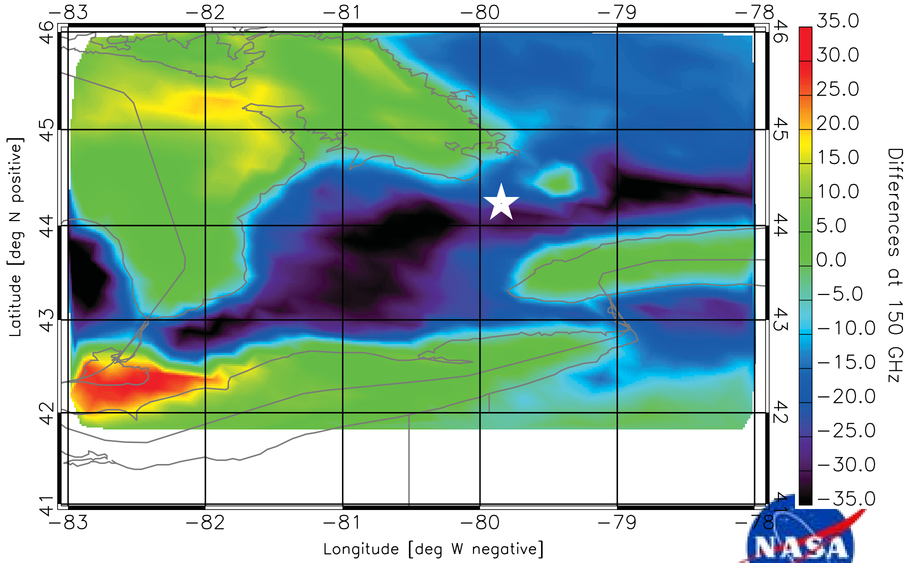
Deep Dry Snow ε (fixed depth)

Wet Snow ε (fixed depth)

Deep Dry ε (WRF variable depth)







Future Work: Explore Surface Emissivity

- ***Investigate sensitivity of brightness temperature (10-183 GHz) to changes in surface emission***
  - *Theoretical analysis*
  - *C3VP analysis for clear air days before and after rain and snow events*
- ***Evaluate methodologies for obtaining surface emission***
  - *Comparison study underway for GPM Land Surface Characterization working group*
  - *Estimation from satellite observations (Slide to follow)*
  - *Derived from land surface models (Slide to follow)*
    - *Using measured emissivities (e.g., Hewison & English)*
    - *Using numerical models (e.g., F. Weng)*
  - *Other methods (climatology, empirical relationships, etc.)*
- ***Test GPM snow detection and estimation algorithms under common global emission (or emissivity and temperature) database***
  - *Static global database*
  - *Dynamic database*

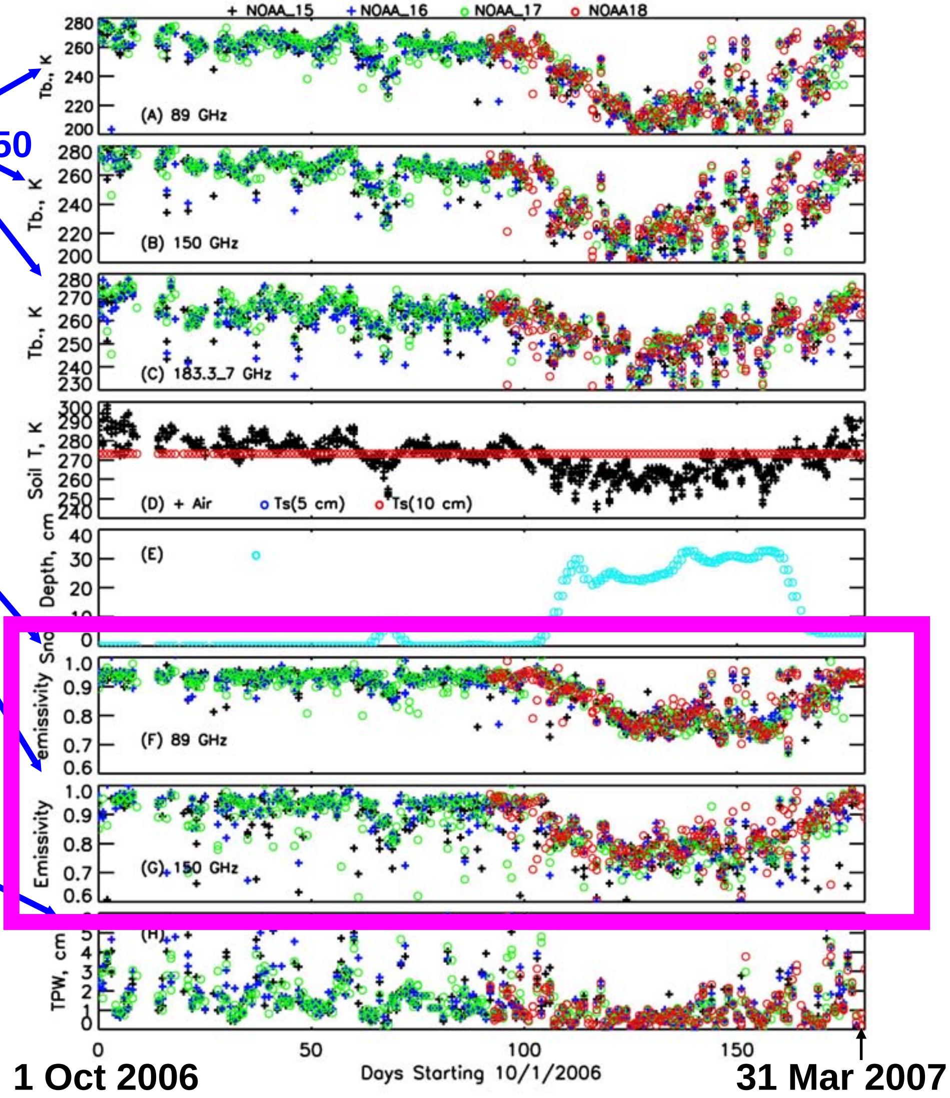
Emissivity Estimated from AMSU-B Observations

Preliminary results courtesy of James R. Wang

- Retrieved from multiple AMSU-B overpasses per day
- Retrieved emissivity directly over the C3VP site

Future work:

1) Use clear-air overpasses only
2) Improve TP3000 TPW retrievals
3) Use a multi-layer cloud model to obtain 183 GHz emissivities



1 Oct 2006

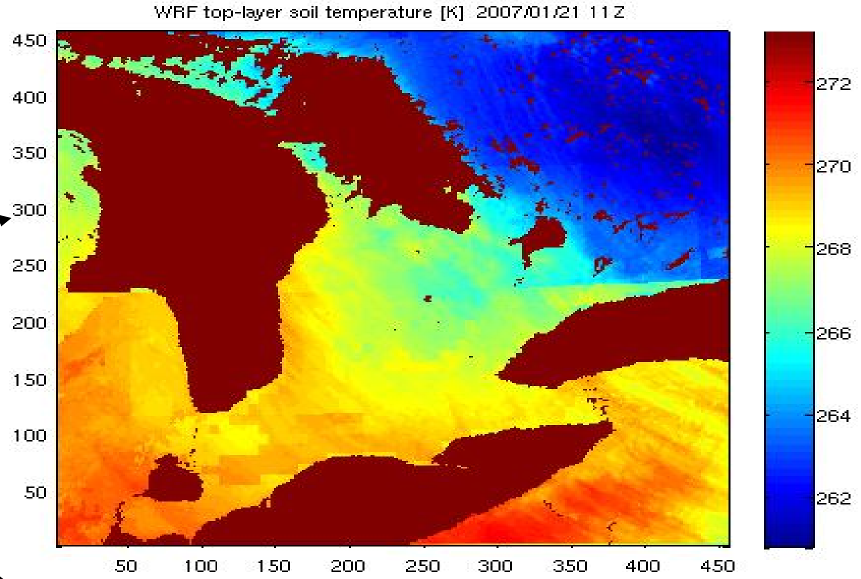
31 Mar 2007

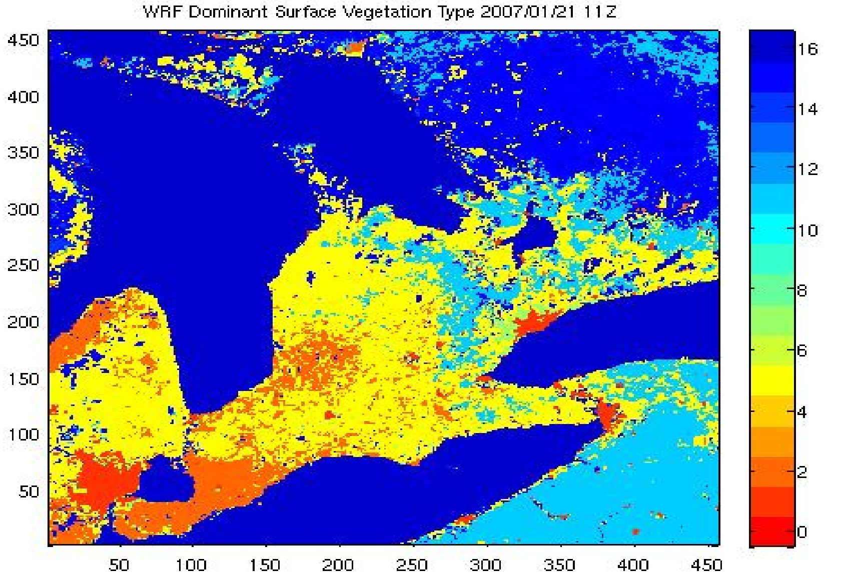
Emissivity Derived from Land Surface Models

WRF Modeled Fields

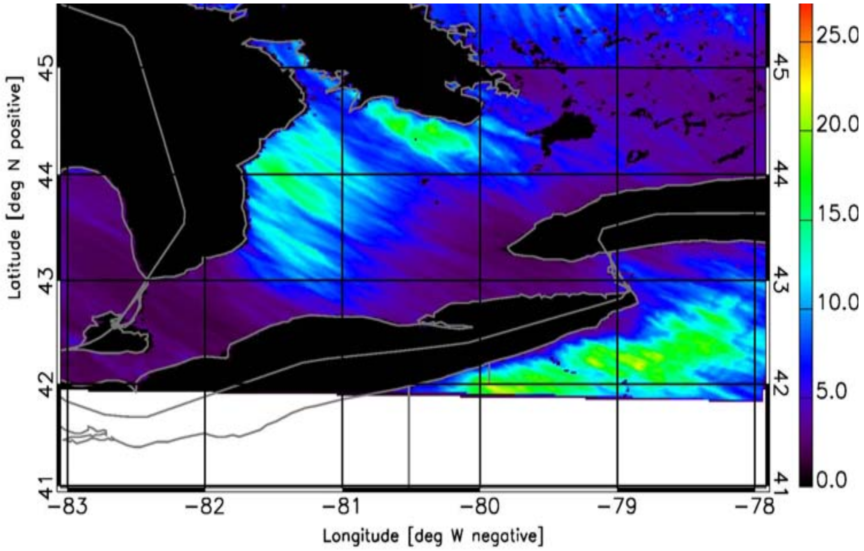
Need to adjust surface emission for variability in surface state.

Surface Temperature (K)
Vegetation Type
Surface Snow Depth (cm)


WRF top-layer soil temperature [K] 2007/01/21 11Z


WRF Dominant Surface Vegetation Type 2007/01/21 11Z

Urban cropland deciduous evergreen/mixed water



Summary

- *GPM Mission Discussion*
- *Snow Detection*
- *Surface Emissivity*

QUESTIONS?