# Satellite-based microwave remote sensing of snowfall at the surface

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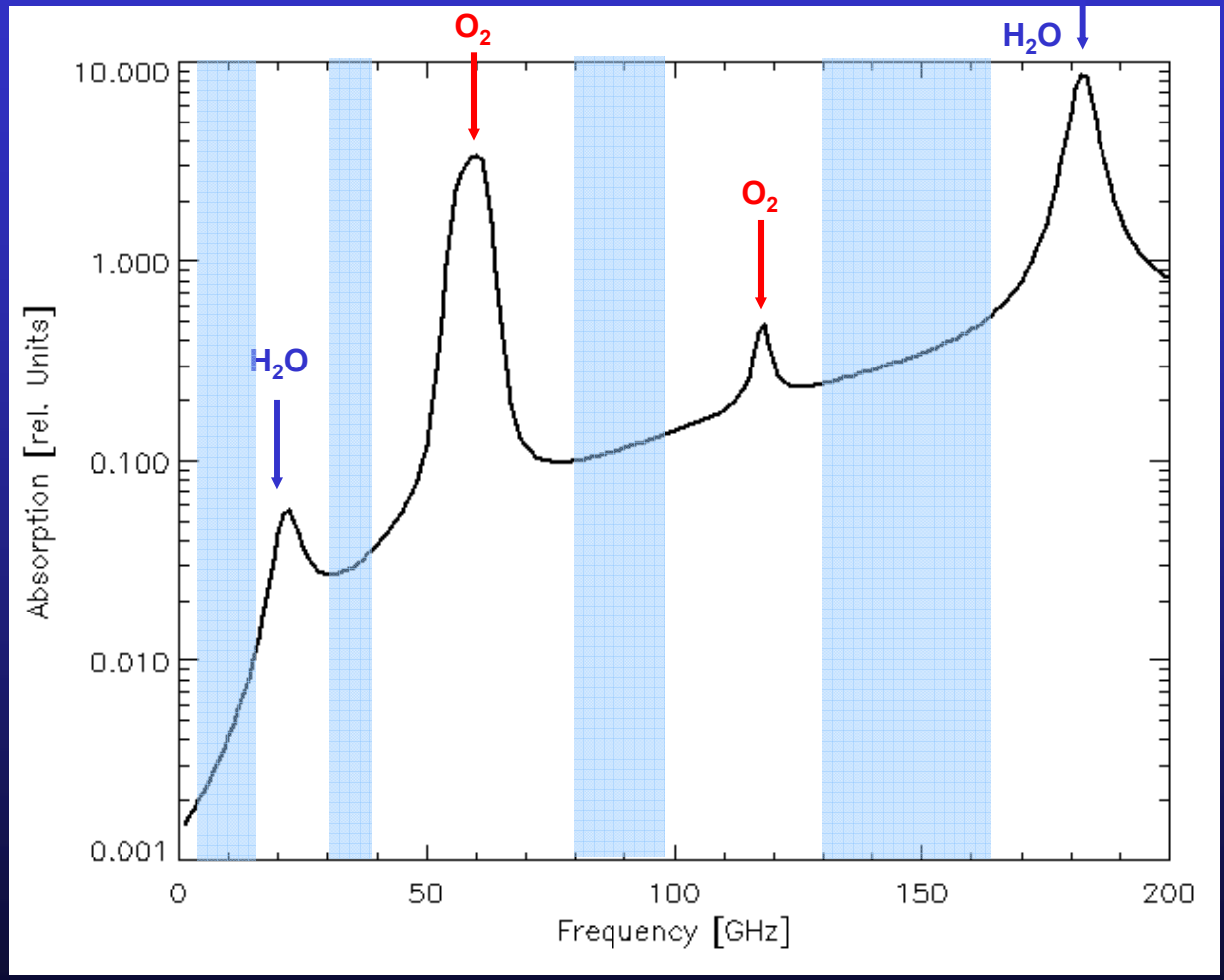
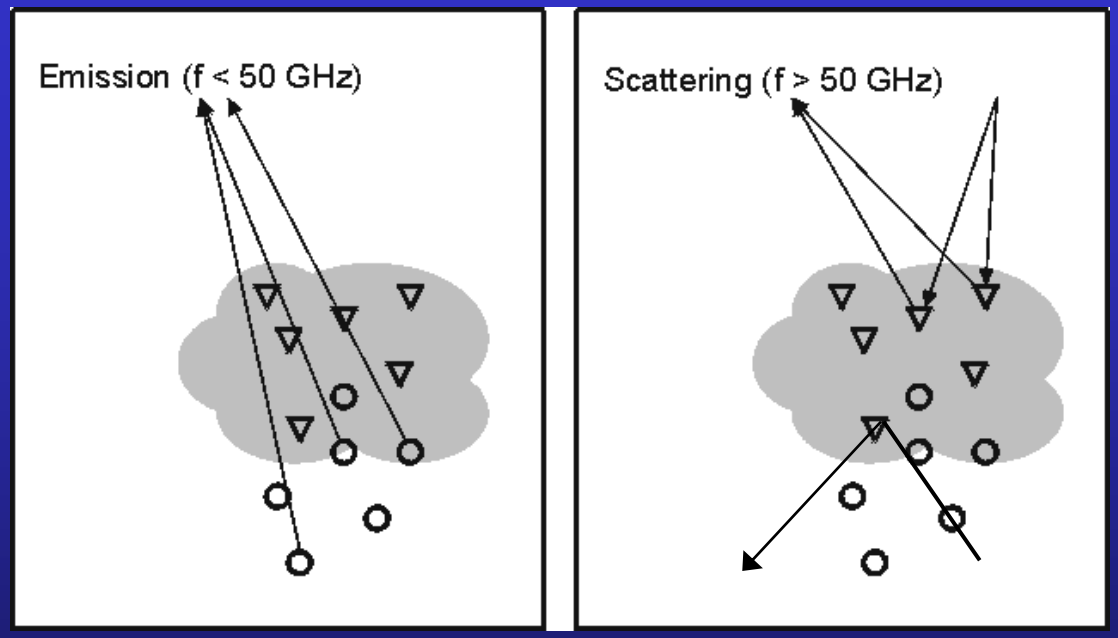
# Outline

- Observational issues
- IPWG/GPM/GRP Workshop on global microwave modeling and retrieval of snowfall
- High priority recommendations and status

# Microwave spectral range



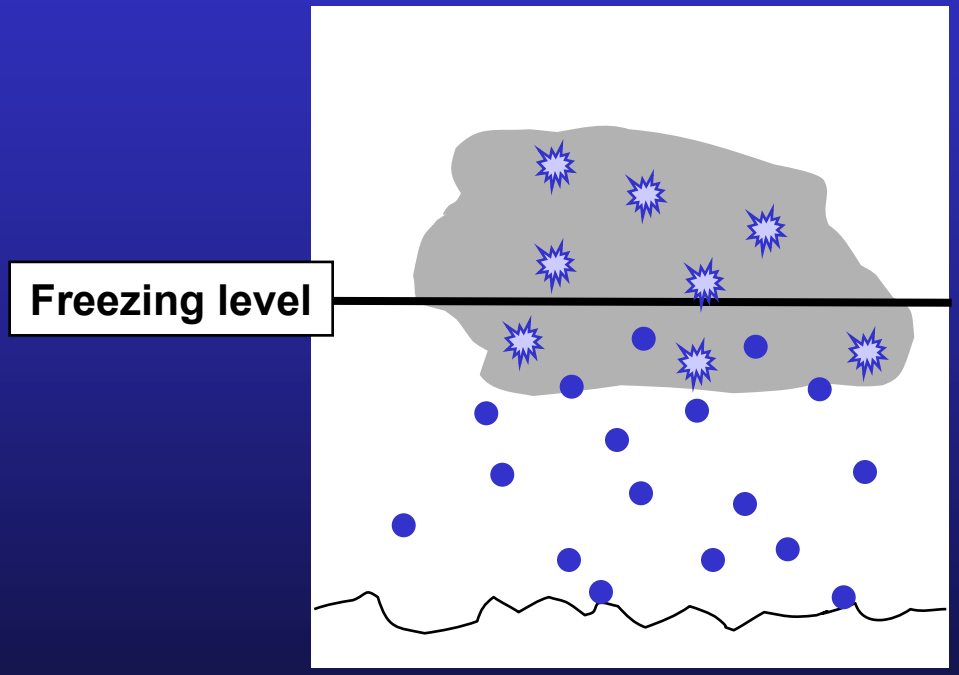
# Passive microwave precipitation signal




- Emission by liquid precipitation
- Dominant at low frequencies

- Scattering by precipitation sized ice particles
- Dominant at high frequencies

# Can the type of precipitation at the surface be directly detected from passive microwave observations?



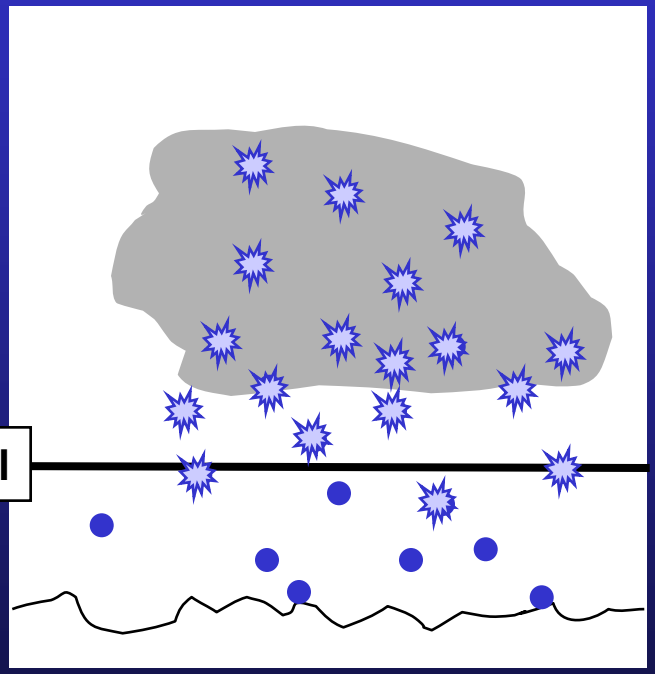

**Freezing level high:**

**Strong emission signal**

**Scattering signal**

**Rain**

# Can the type of precipitation at the surface be directly detected from passive microwave observations?




**Freezing level lower:**

**weak emission signal**

**Scattering signal**

**Still Rain**

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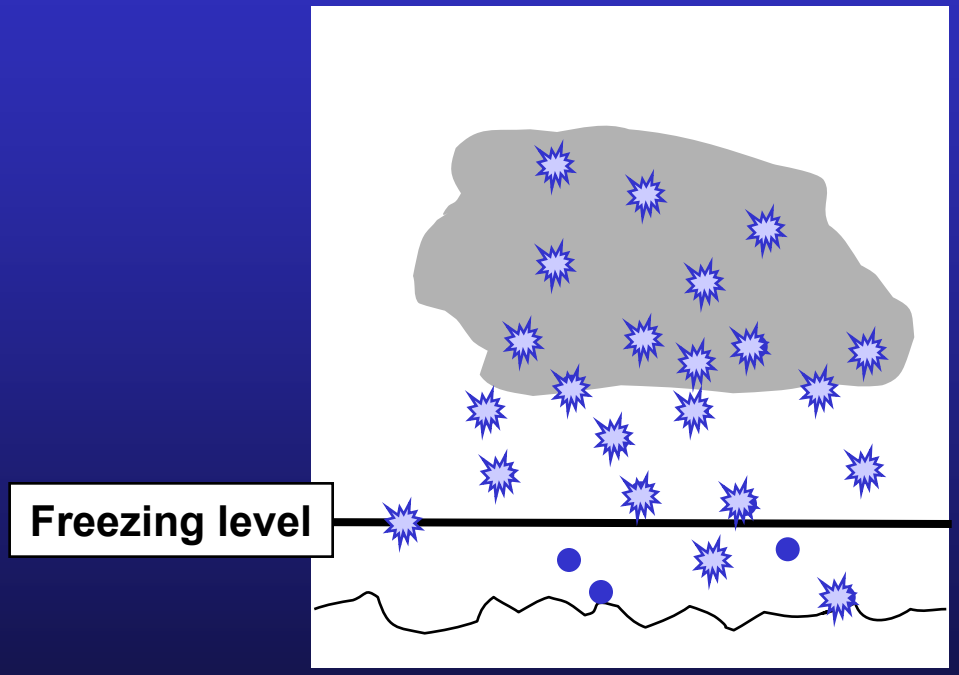


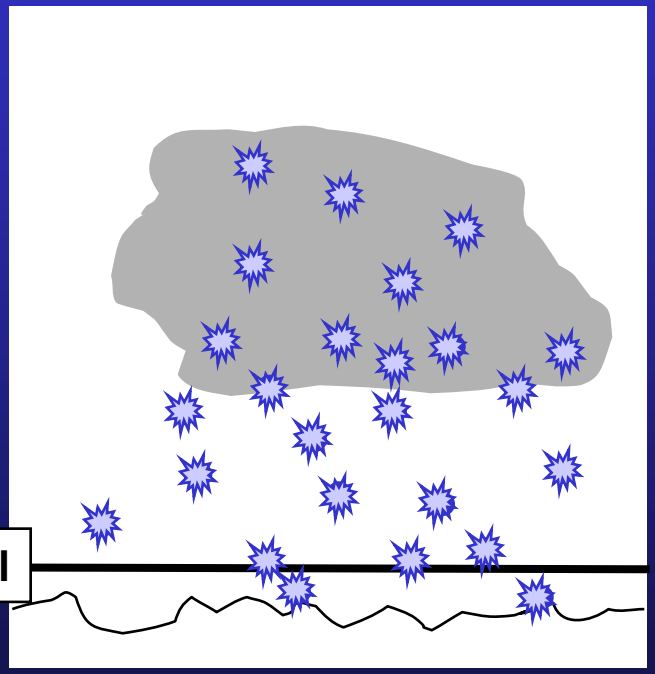

**Freezing level lower:**

**weak or no emission signal**

**Scattering signal**

**Mixture**

# Can the type of precipitation at the surface be directly detected from passive microwave observations?




**Freezing level lower:**

**weak or no emission signal**

**Scattering signal**

**Snow**

## Can the type of precipitation at the surface be directly detected from passive microwave observations?

- **No**. Because microwave sensors are only sensitive to column-integrated quantities and not to quantities at any particular level.

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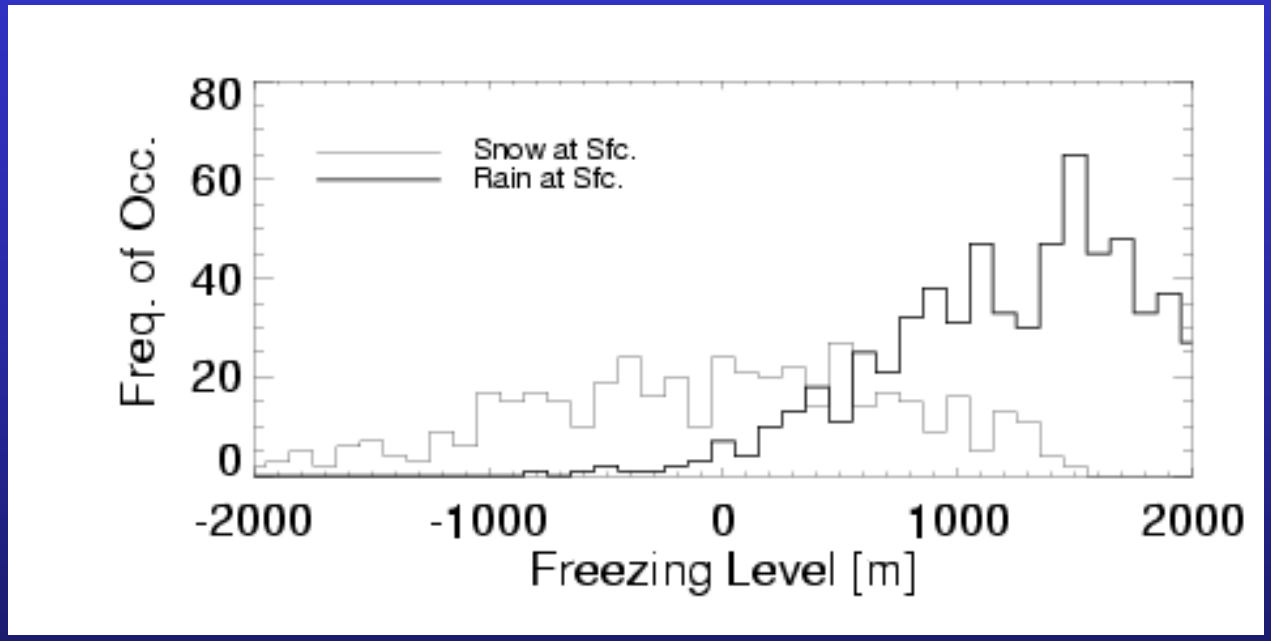
- **But**: If the freezing level height can be inferred, we might be able to estimate the type of precipitation at the surface.

- Note also, that in reality there are many instances where a mixture of rain and snow reaches the ground.

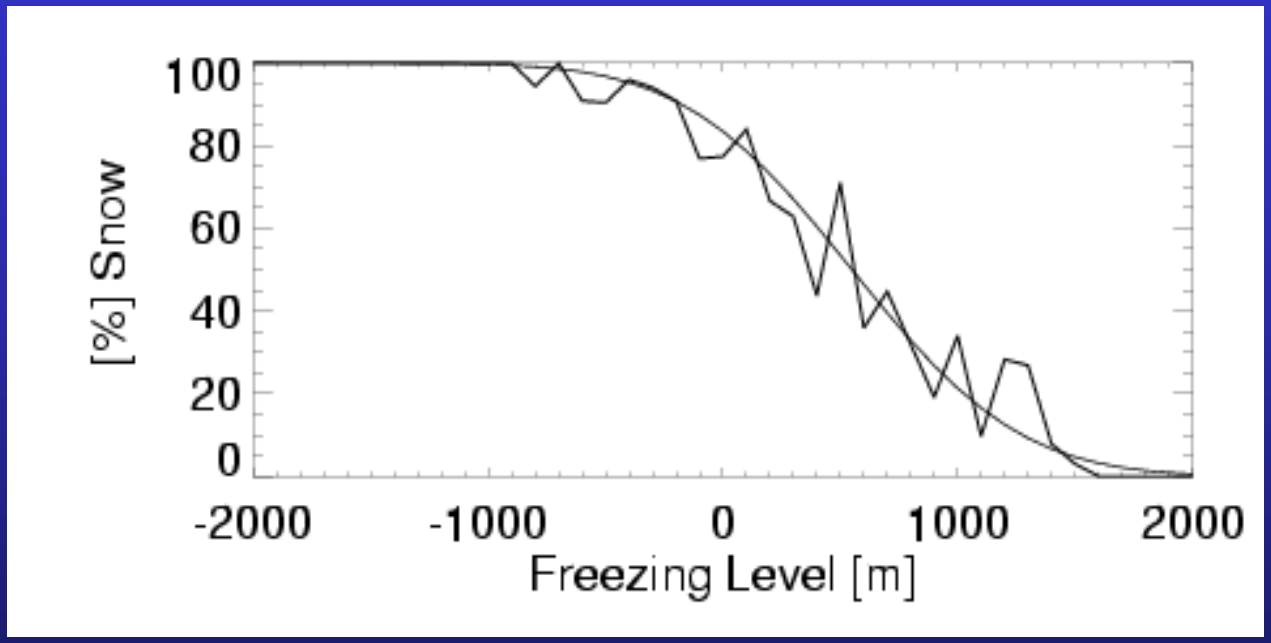
# Likelihood of snowfall versus rain at the surface derived from AMSR-E estimates of the freezing level




**Thick** lines: Surface observer reports liquid rain at the surface (741 cases)

Thin line: Surface observer reports snowfall at the surface (449 cases)

# Cumulative likelihood of snowfall at the surface as function of freezing level




**Zigzag** line:

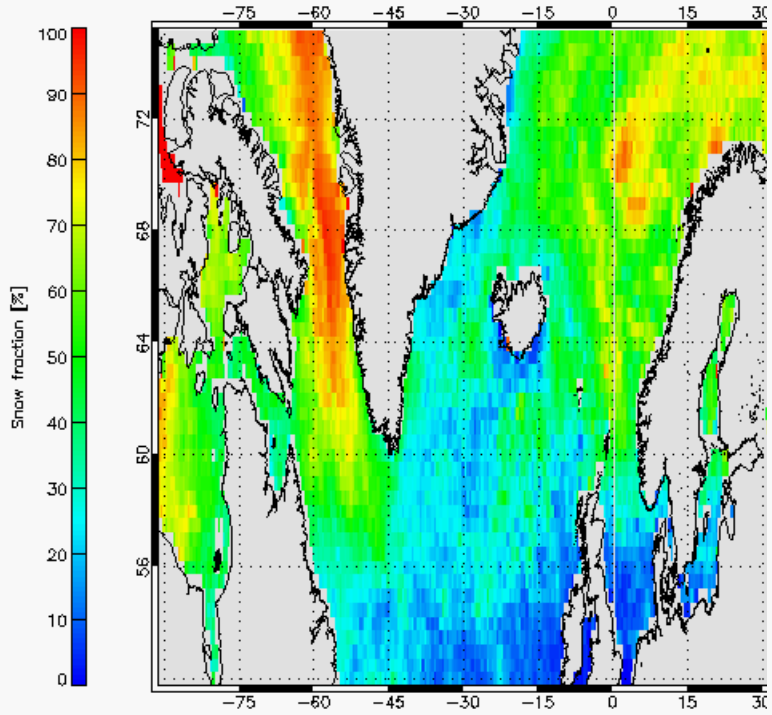
Data

Smooth line:

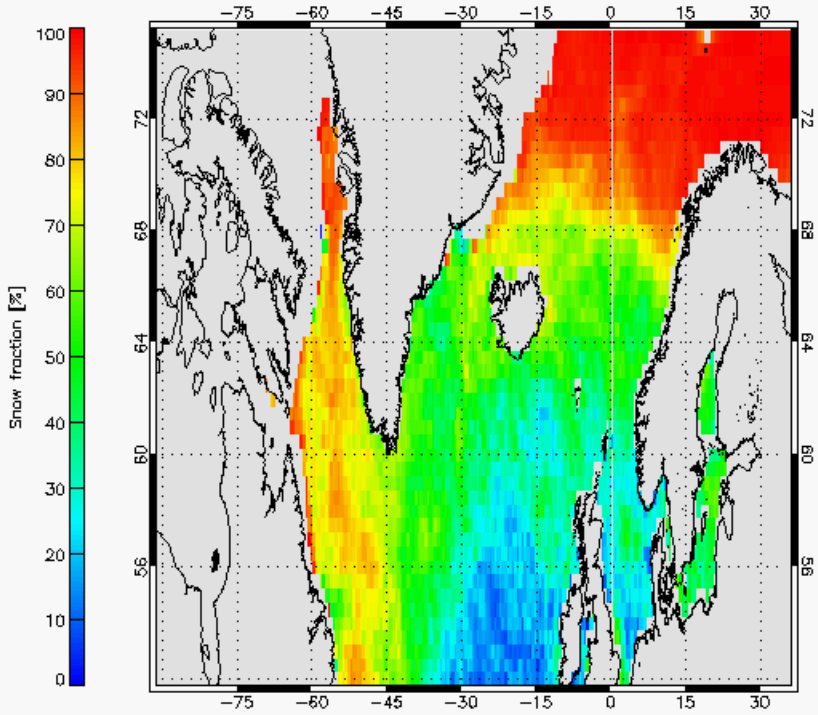
Cumulative gaussian fit

# AMSR-E derived frequency of frozen precipitation over the North Atlantic

October 2002

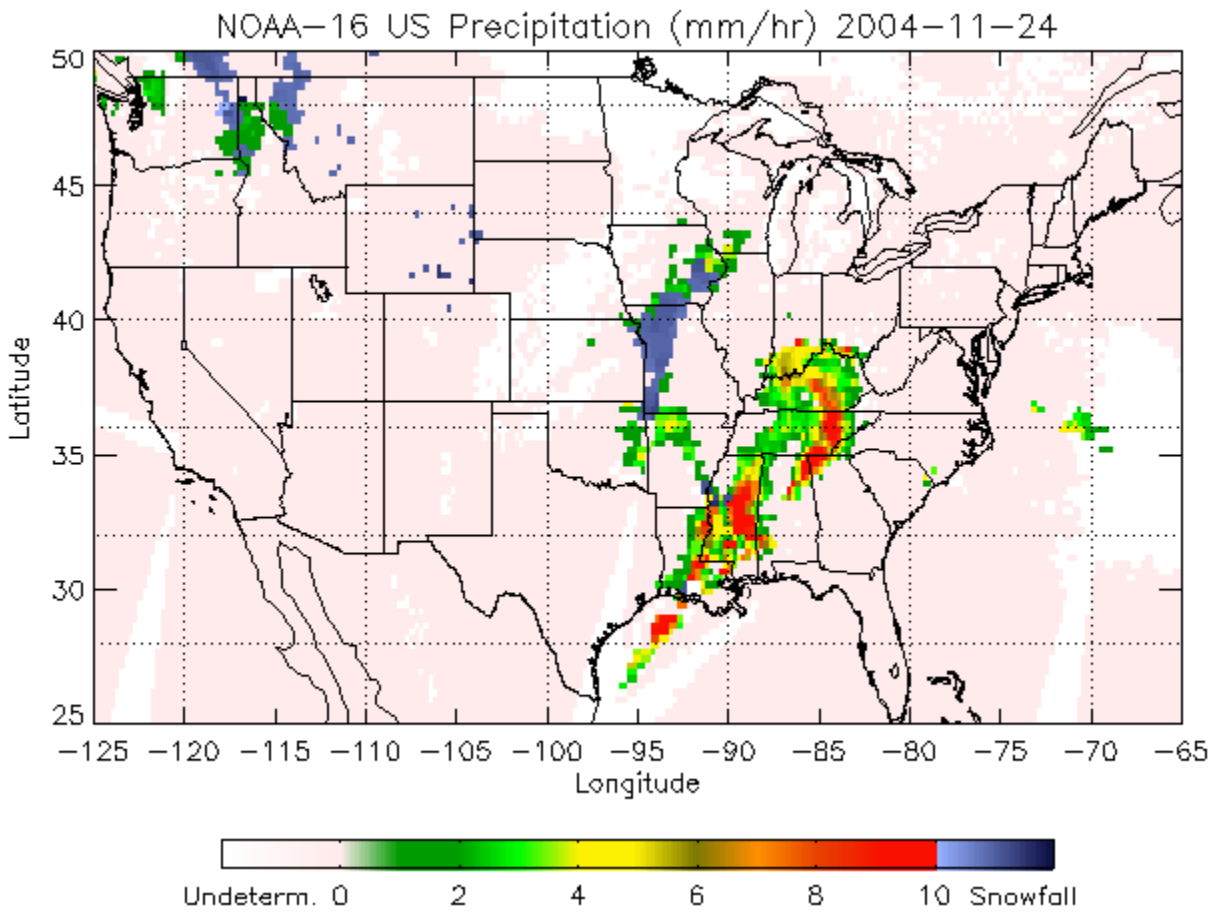



January 2003



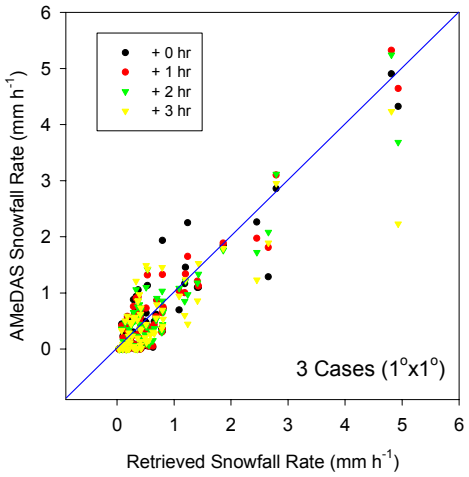
# Retrieval results using existing sensors

# Ferraro (NOAA/NESDIS AMSU-A/B)



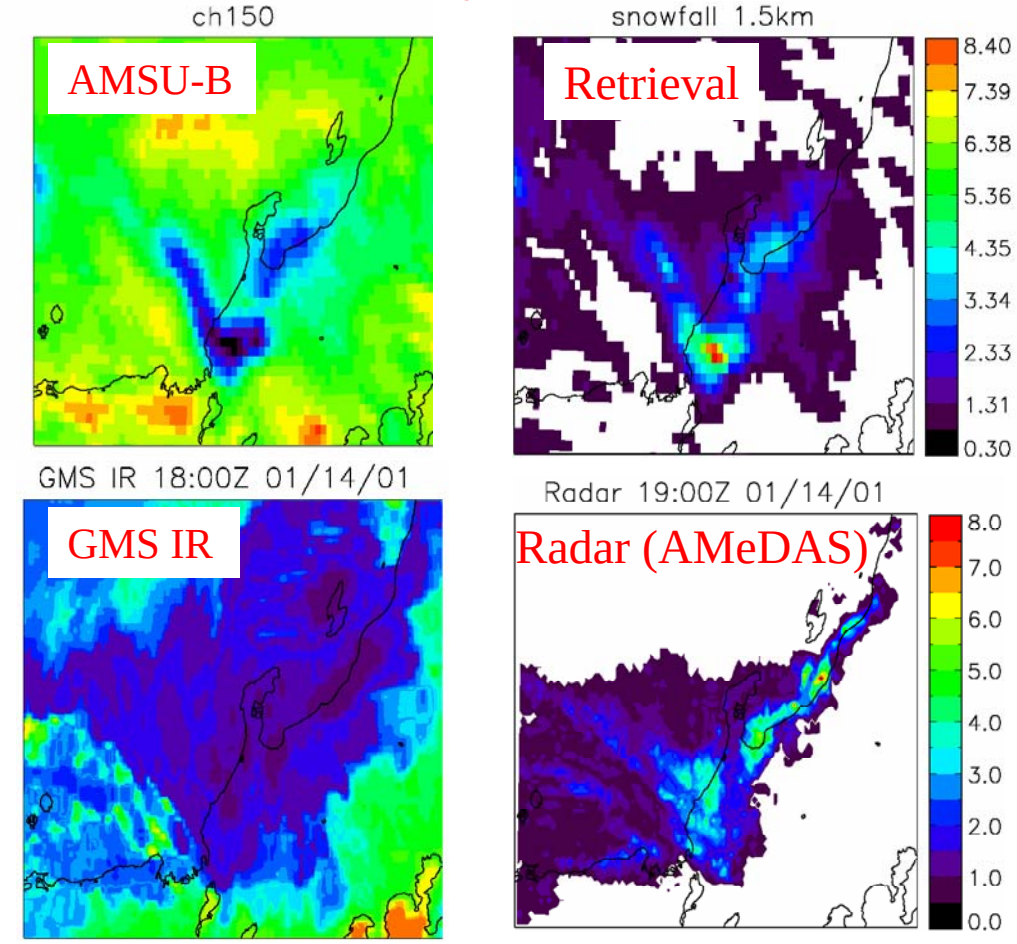
# G. Liu: Snowfall Retrieval From High – Frequency Microwave Satellite Observations

- Use surface and airborne radar snowfall observations as the basis to build the a-priori database – Bayesian Retrieval
- Radiative transfer model utilizes nonspherical snowflakes scattering calculations




Compare AMSU-B Retrieval with AMeDAS radar (3 cases, correlation coefficient: 0.79)

## A Case Study (Jan 14 2001)

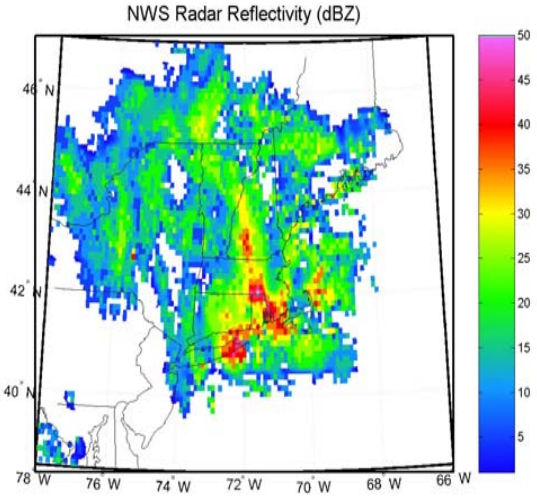


# Retrievals: Precipitating Snow

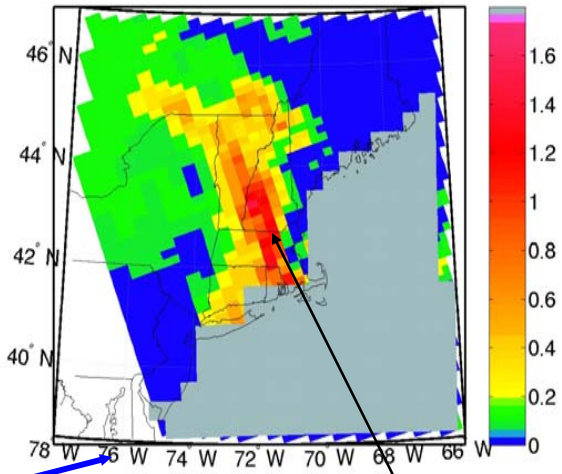
**First Ever Physically-Based Snow Rate Retrievals**

**Retrieval Algorithm estimates (1) Snow content profile, (2) Relative humidity profile, and (3) Surface snow cover fraction.**

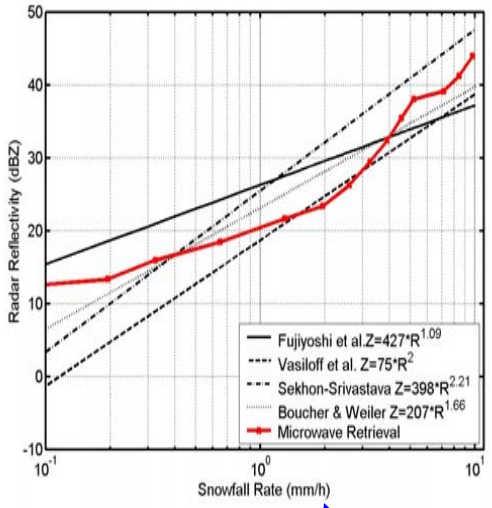
**Radar Reflectivity (Z)**




**Retrieved Snow**




**Z-R Relationship**




***Retrieved snow content spatial distribution matches observed radar reflectivity.***

***Retrieved Z-Rainfall relationship (red) matches those reported in literature.***

**G. Skofronick-Jackson et al. (GSFC) TGARS 2004 & Min-Jeong Kim, Ph.D. Dissertation, Univ. of Washington, 2004**

CGMS IPWG International Precipitation Working Group

# IPWG/GPM/GRP Workshop on global microwave modeling and retrieval of snowfall

**Date:** 11-13 October 2005
**Venue:** University of Wisconsin – Madison


**Workshop Co-Organizers**
Ralf Bennartz (University of Wisconsin)
Ralph Ferraro (NOAA/NESDIS)


**Objective :** The International Precipitation Working Group (IPWG), the GEWEX Radiation Panel (GRP) and NASA's Global Precipitation Measurement Program (GPM) co-sponsor a workshop on passive microwave modeling and retrieval of snowfall. The aim of this workshop is to review the state of the art in passive microwave modeling and retrieval of falling snow over both land and ocean and to develop future directions and requirements for algorithm development, implementation and validation of applications ranging from short-term weather forecasting to climate data set generation.

CGMS IPWG International Precipitation Working Group

# Working groups and high priority recommendations

- Modeling
- New Technology
- Validation

## Modeling

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- **Intensification of data assimilation studies** including systematic studies to evaluate *model error covariances* used for constructing retrieval databases; possibly error databases.

# Different cloud/precipitation overlap models (O'Dell, Bauer, Bennartz, JAS, 2006)

- Conventional approach uses cloud cover to subdivide NWP pixel in cloudy/precipitation
- New approach derives two/three optimal columns based on subscale distribution of precipitation columns with similar optical properties
- Numerically efficient (2-3 radiative transfer calculations per NWP grid point)
- Highly accurate against independent column/MR-overlap reference
- Optimal approach reduces errors due to cloud overlap from maximum values of 5-10 K to values < 1K

## Modeling

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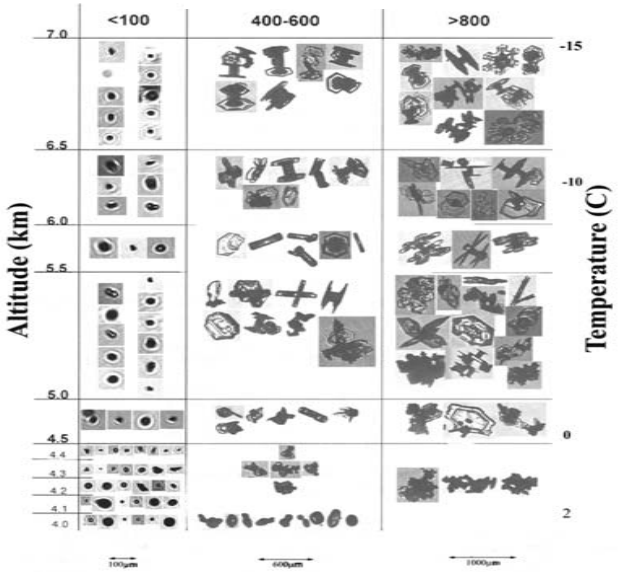
- **Intensification of data assimilation studies** including systematic studies to evaluate *model error covariances* used for constructing retrieval databases; possibly error databases.
- **Establishment of modeling chain:** Two-dimensional spectral cloud models with multiple ice particle and frozen precipitation categories -> non-spherical (inhomogeneous) particle optical property (permittivity, size, shape) modeling -> development of parameterizations for general use in cost-driven applications.

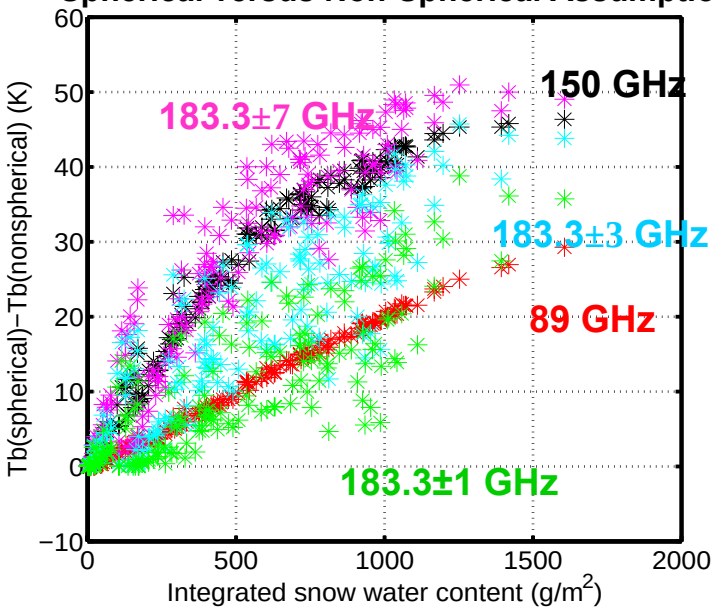
# Retrieval Challenges: Particle Models

**Complex Atmospheric Snow Particle Shapes**




*From A. Heymsfield et al. (2001)*

**Spherical versus Non-Spherical Assumptions**




*Courtesy of Min-Jeong Kim*

- For simplicity, spheres and dielectric mixing theories have been used.
- Methodologies such as the Discrete Dipole Approximation (DDA) allow the computation of radiative properties for various idealized shapes of snow crystals.
- These DDA calculations are in progress with results to be archived in a database open to scientific community for related remote sensing studies.

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- **Development of high-latitude surface emissivity products** (10-200 GHz) including error estimates.

- Surface emissivity workshop held in June 2006. (Prigent/ Ruston)
- Coordination with ITWG-radiative transfer and surface emissivity working group.

## New Technology

- **The development and further refinement of inexpensive ground-based remote sensing instruments**: 1. Vertically pointing micro radars such as (Precipitation Occurrence Sensing System) POSS or Micro-Rain-Radar (MRR). 2. Microwave transmission links that measure attenuation of a microwave beam.

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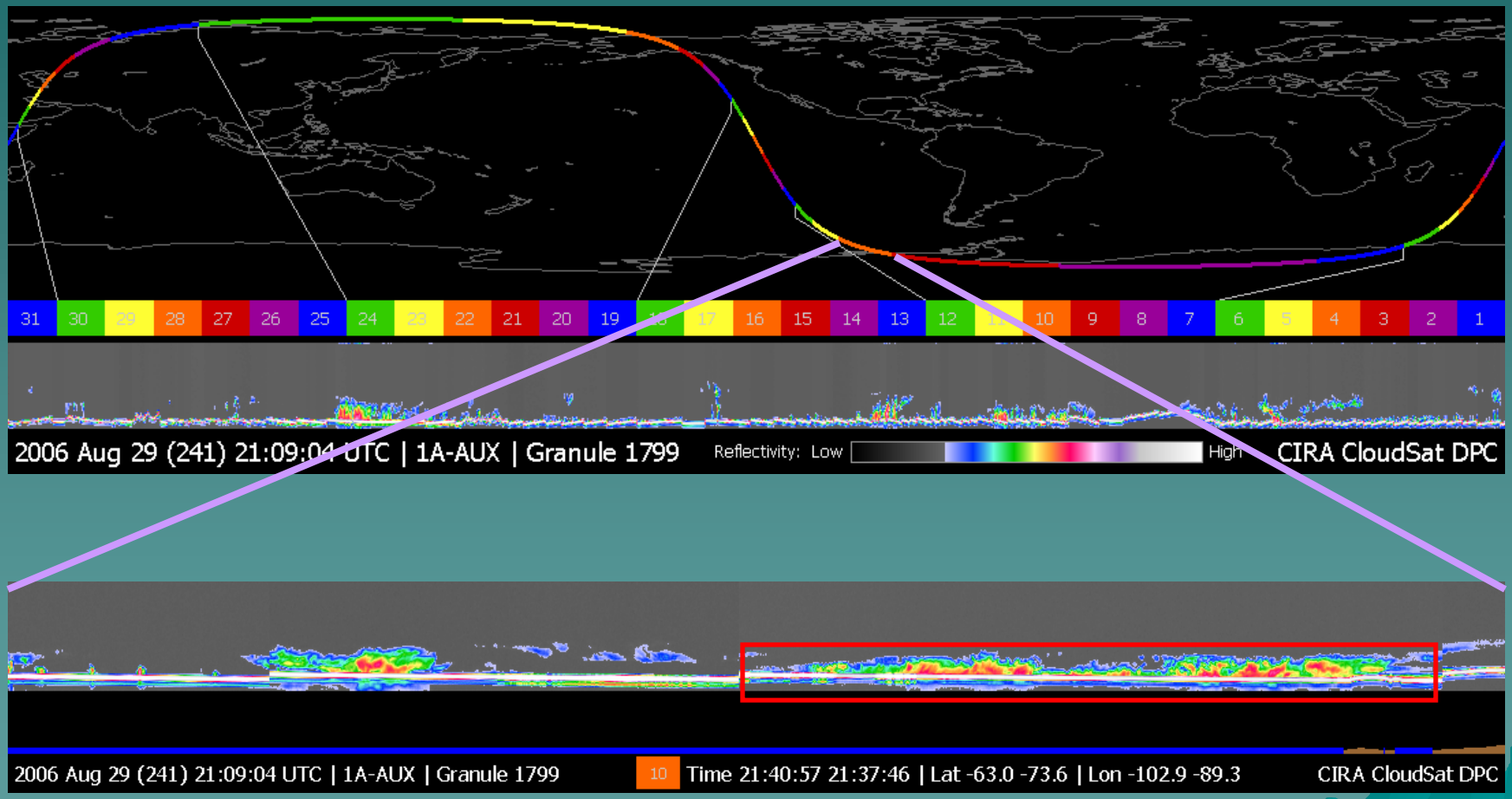
- The use of **combined active and passive satellite data** for snowfall detection/retrieval should be further encouraged. Low detectability threshold (smaller than roughly 5 dBZ) to detect light rainfall and snowfall. CloudSat+Aqua, EarthCare.

# Preliminary (Unvalidated) Snowfall Retrievals from CloudSat

Tristan S. L'Ecuyer and Richard Austin
Colorado State University

# A First Look at Snowfall from CloudSat's Perspective

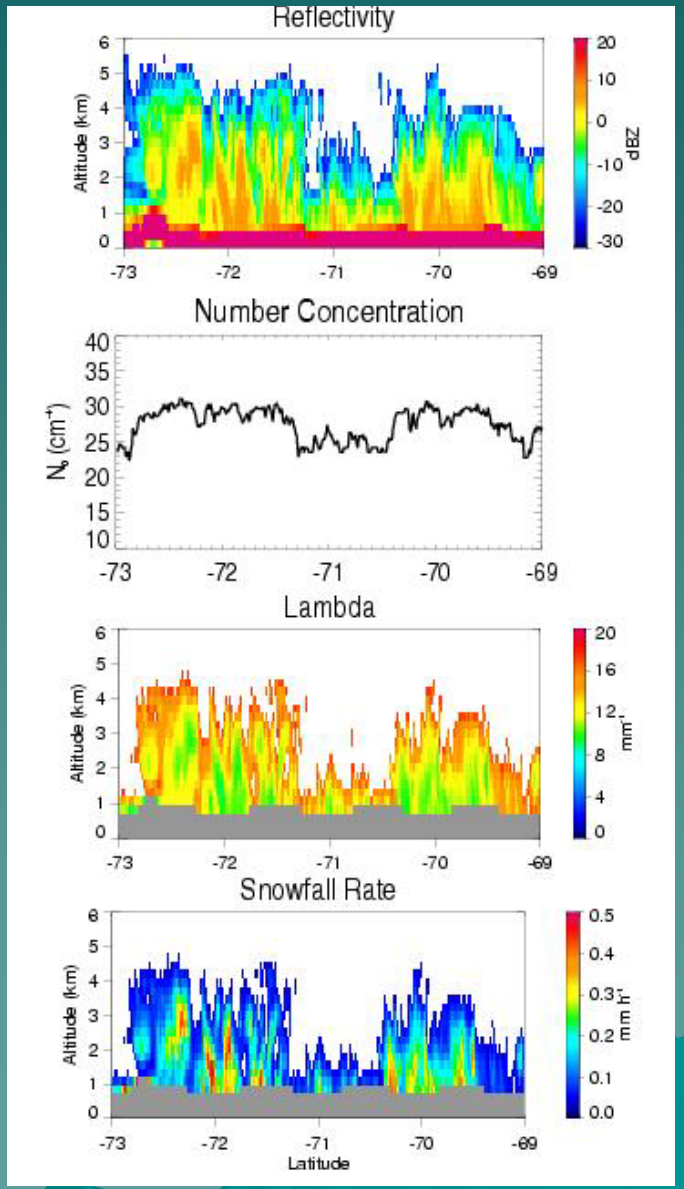


# Snowfall Product

- Very preliminary version of CloudSat snowfall retrieval (with no PMW constraint)
- Assumes exponential distribution of snow particles

$$N(D) = N_0 \exp(-\Lambda D)$$

- Retrieves vertical profile of Λ and a column-mean value of number concentration.
- From these, snowfall rate is derived.
- Applied to an orbit granule from Aug. 19, 2006



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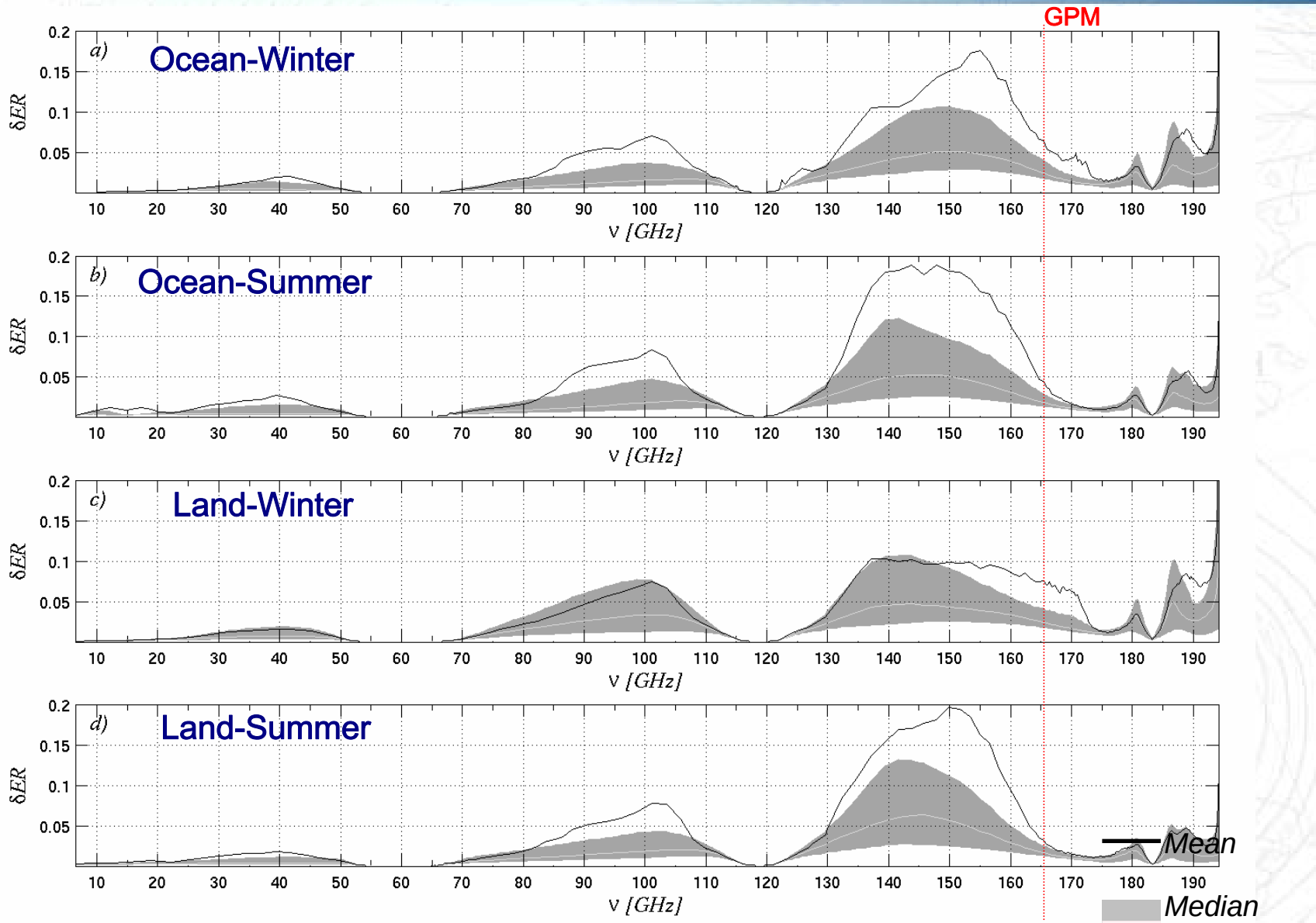
- **New passive microwave instruments and new channel combinations need to be studied.**

- Trade-off studies for future generation MW instruments currently being performed at ECMWF (Bauer, diMichele)
- 118 GHZ oxygen absorption line and high frequency window channels appear promising to better detect precip.

# Full Dataset Information Content Distribution: Snow




(DiMichele and Bauer 2005)

## Validation

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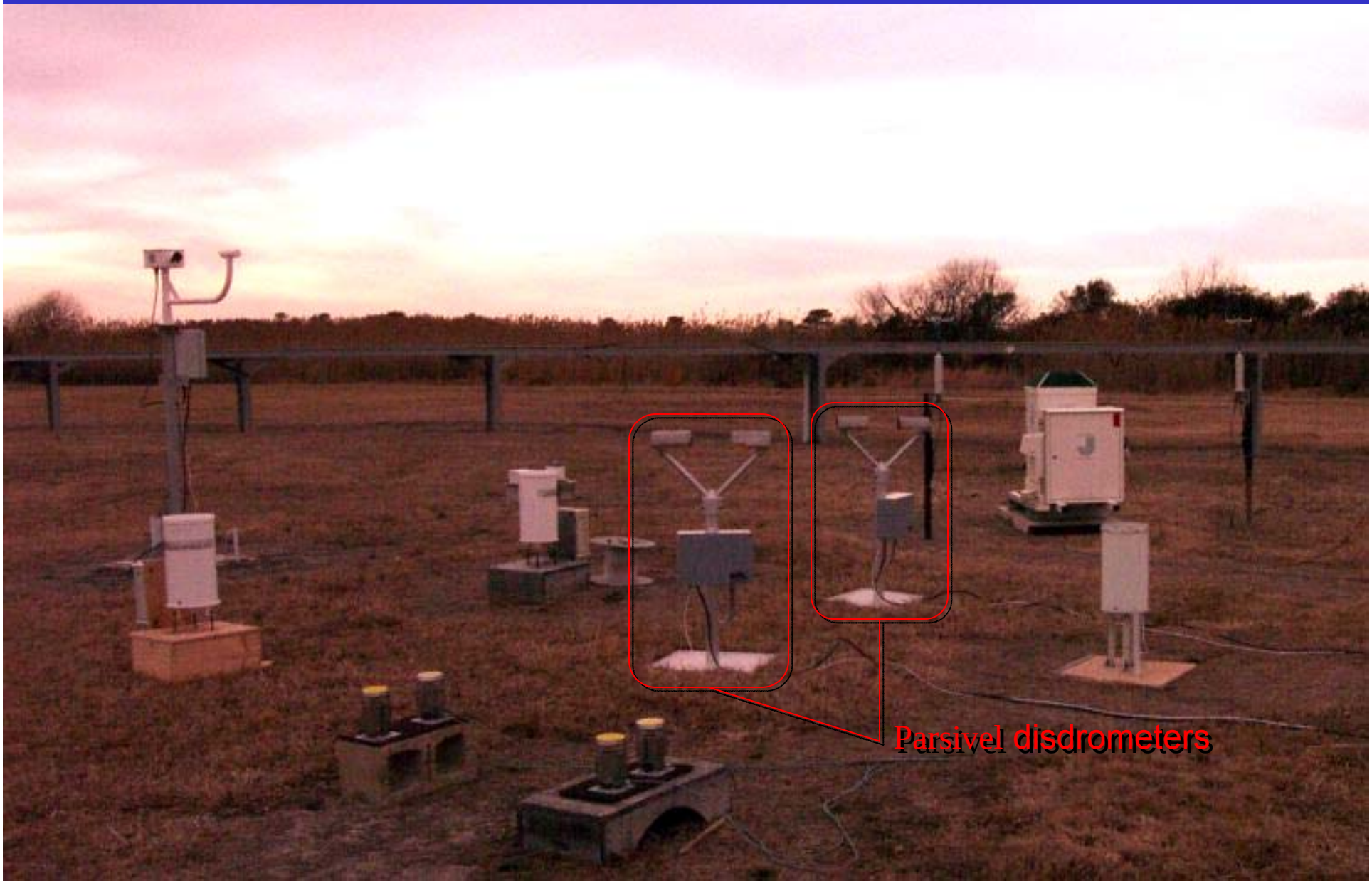
- **High level coordination of international GV programs for snowfall (e.g., through GPM, GEWEX, IPWG) is urgently needed.**
  - GPM-GV
  - Formed falling snow algorithm group meeting with Dr. G. Skofronick-Jackson (NASA/GSFC) as the coordinator. Email discussions continuing
  - C3VP (Canadian Cloud-Sat/Calipso Validation Program) is a field campaign conducted in and around Toronto Canada this winter to support Cloud-Sat/Calipso GV in addition to NASA PMM/GPM GV in snowfall.
  - IPWG meets in two weeks. Body of WMO/CGMS will take active part in global validation coordination.

## Validation

- **High level coordination of international GV programs for snowfall (e.g., through GPM, GEWEX, IPWG) is urgently needed.**
- **Dedicated validation:** MW transmission links with parallel particle probing, inter-sensor validation in radiance/reflectivity space, statistically robust datasets for (frozen) cloud processes. Microphysical parameters are lacking; Data should be made freely available to international research community.

# NASA Wallops Flight Facility
# Rainfall Observation Network



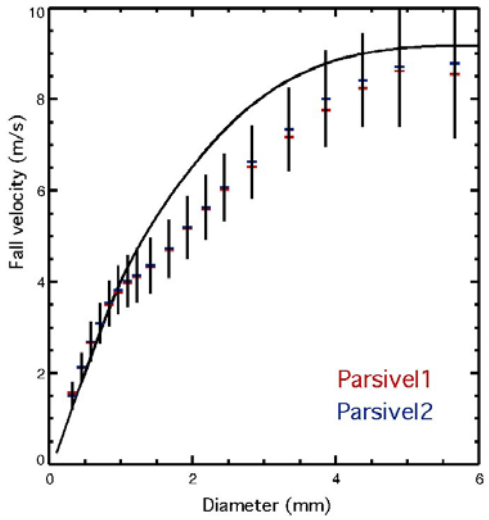
# Parsivel (Laser Optical) Disdrometer

## PI: Ali Tokay (JCET/UMBC, NASA/GSFC)

Measures size and fall velocity of hydrometeors
Present weather sensor
Sampling area: ~50 $cm^2$, varies with drop diameter
Number of size and velocity bins: 32 x 32 matrix
Drop size range: 0.06-24.5 mm
Velocity range: 0.05-20.8 m/sec
Operation period at Wallops Island: Spring 2002 - present
Manufacturer: OTT in Germany www.ott-hydrometry.de

### Shortcomings

- Measures maximum diameter of the 1-D projection of the particle.
- Spurious drops - rain drops falling at velocities that differ ±50% from terminal fall speed are rejected.
- Spurious drops - two particle in the light sheet at the same time (raindrops larger than 8 mm are rejected).
- Fall velocities are underestimated at mid-size drops.
- Underestimates the drop concentration at diameters < 1 mm.
- Quantization error due to binning the observed maximum diameter and velocity.

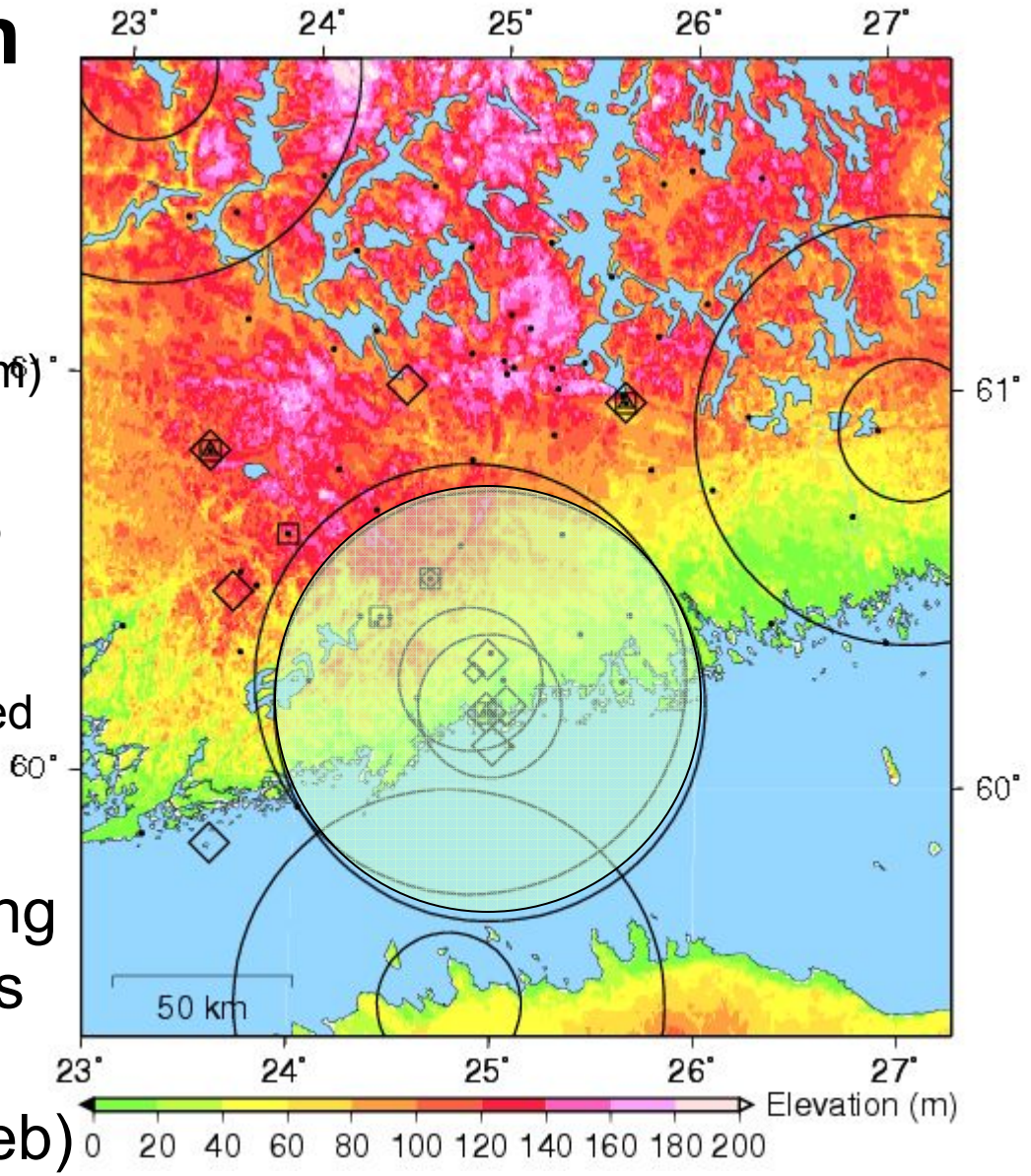



More Information: Loffler-Mang and Joss (2000), Loffler-Mang Blachak (2001)

# HTB Precipitation Measurements (Koistinen, FMI)

-circles: radar 20-60km (0-250 km)
-dot: manual obs
-big diamond: FD12P
-small diamond: potential FD12P
-triangle: autom snow depth
-square: weighing gauge
- plan: 2 POSS to be implemented

http://testbed.fmi.fi
public realtime data during the campaigns (6 months during Aug 2005 – Aug 2006, snow: Nov, Jan-Feb)

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## Validation

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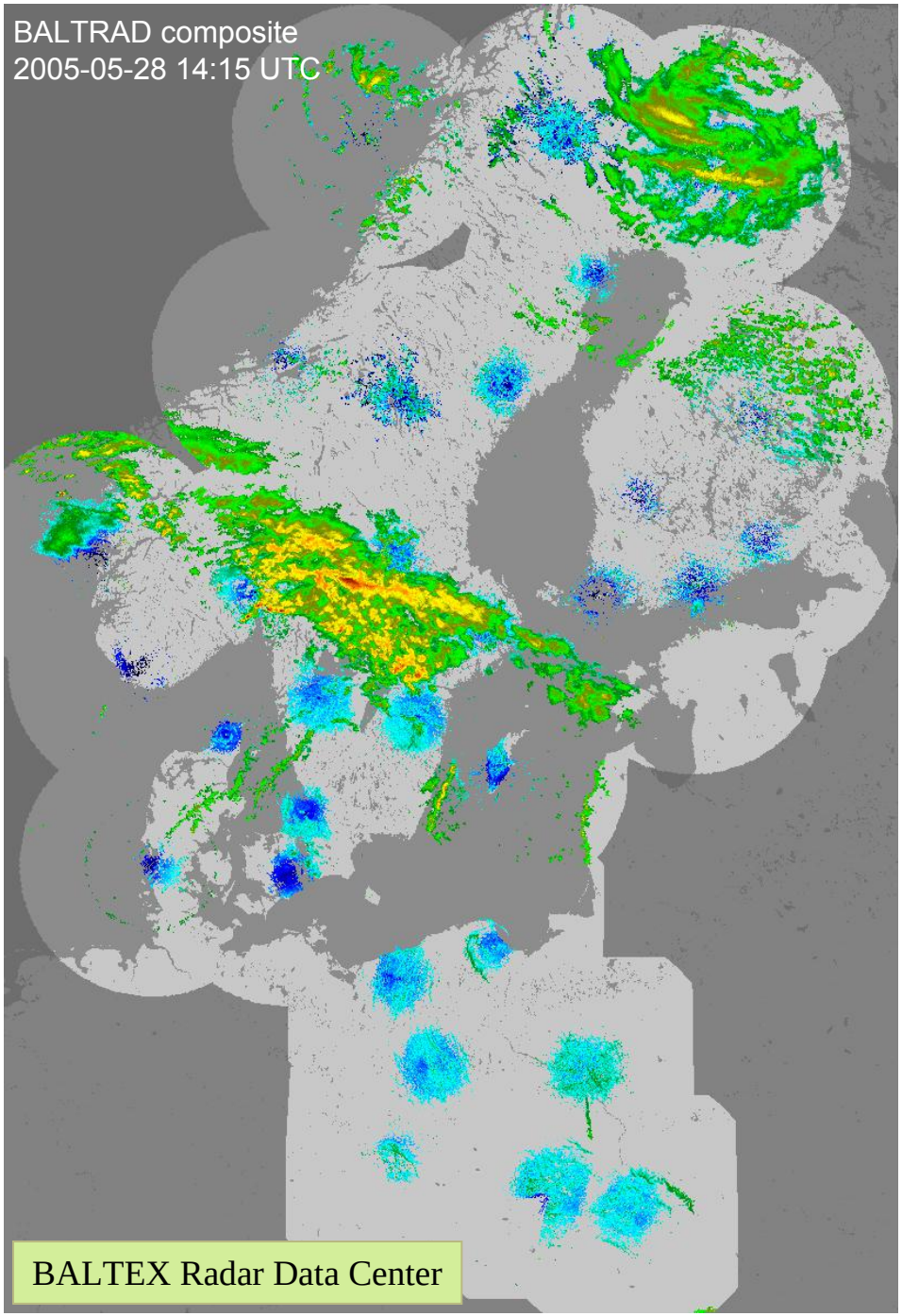
- **Dedicated validation:** MW transmission links with parallel particle probing, inter-sensor validation in radiance/reflectivity space, statistically robust datasets for (frozen) cloud processes. Microphysical parameters are lacking; Data should be made freely available to international research community.
- **Long term surface based measurements must continue to insure long term continuity for climate assessment and monitoring.**

# WCRP/GEWEX/BALTEX: DBZC - Composites of radar reflectivity

- More than 30 radars in 11 countries: **BALTRAD**
- Radar Data Centre at SMHI, Sweden (Daniel Michelson)
- Continuous operation since October 1, 1999
- Resolutions: 2×2 km, 15 minutes, 0.4 dBZ

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# Conclusions

- Snowfall retrievals from MW still in their infancy
- However, promising activities due to especially GPM and availability of new active and passive sensors
- High need for international coordination