ANALYSIS OF THE GLOBAL CLOUD DYNAMICS AND RADIATION DATABASE (CDRD)

P 12.6 CLOUD-SCALE PARAMETER AND RADIATION DISTRIBUTIONS

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1. INTRODUCTION

Passive microwave remote sensing of precipitation from platforms such as the Special Sensor Microwave Imager (SSM/I), the Advanced Microwave Scanning Radiometer (AMSR), and the Tropical Rainfall Measurement Mission (TRMM) has been a major focus in hydrological research for the past several years. Successful estimation of precipitation from these platforms relies on the accuracy of the particular retrieval algorithm being utilized. Retrieval algorithms are based on cloud radiation databases (CRDs) to relate in-situ measurements of brightness temperatures and radar reflectivity profiles to a-priori microphysical profiles found in the CRDs. One problem with CRD retrieval based systems is that profiles can be chosen that are unrepresentative of the dynamical and thermodynamical state of the atmosphere. We have recently introduced the concept of the Cloud Dynamics and Radiation Database (CDRD) for precipitation retrieval purposes. The CDRD concept is an improved version of the current CRDs. The CDRD contains the same information as the present CRDs, but in addition contains information about the dynamical and thermodynamical structure of the atmosphere.

The CDRD contains dynamical tags that are computed from a cloud-resolving model, the same simulations used to calculate brightness and microphysical profile information. The University of Wisconsin Non-hydrostatic Modeling System (UW-NMS) is used for CDRD cloud resolving simulations.

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The main goal of this new approach is to improve space-based measurement of precipitation, especially snowfall. The CDRD also provides the opportunity to investigate relationships between the microphysical structure of precipitation systems to large-scale dynamic and thermodynamic variables of the atmosphere. This is important because inaccurate understanding of microphysics, such as characterizing the properties of precipitation-sized hydrometeors incorrectly, can lead to rainfall retrieval error (Mugnai and Smith 1988; Kummerow and Giglio 1994).

The objective of this paper is to highlight the benefits of such a large database system. Currently, the CDRD is composed of over one million profile points. Figure 1 shows the location of the CDRD mesoscale simulations. In this paper the database is used to study relationships between certain dynamical/ thermodynamical tags and microwave frequency brightness temperatures. Distributions and correlations are presented and discussed. It is important to identify which tags are useful and will add value to any CDRD precipitation retrieval scheme.

Section 2 discusses the CDRD tags that are available. Section 3 of the paper focuses on several important distributions, such as surface snowfall and rainfall rates versus microwave brightness temperatures, and topography height versus rain rate and brightness temperatures. Also, the tags with the highest correlation coefficients, when compared to brightness temperatures, are presented. These are the tags that would be most useful for CDRD based retrieval. Section 4 focuses more closely on snowfall and rainfall distributions, mainly because the original purpose of the CDRD is to improve satellite measured precipitation. Finally, conclusions and future work are presented.

2. CDRD and CDRD TAGS

The fundamental core of the CDRD system is based around a cloud resolving model (CRM). The UW-NMS is used to produce simulations for the formulation of the CDRD version 1.0 system. The UW-NMS is described in detail by Tripoli (1992). The model used for radiative transfer calculations is the Successive Order of Interaction (SOI) Radiative Transfer Model. The SOI is a one-dimensional azimuthally averaged, plane-parallel radiative transfer model. This model includes the effects of scattering from all hydrometeors. Atmospheric polarization is ignored, but not surface polarization (Heiginger, O'Dell, Bennartz, and Greenwald 2005).

Every day a random global location is selected for a new CRM simulation. The random locations move between four global regions, based on the equator and international dateline. This technique is used for somewhat equal global simulation spacing. The UW-NMS is used to simulate a 12 hour prediction over the selected location. Microphysical profiles and dynamical/ thermodynamical tags are saved at the 12 hour forecast time. Vertical profiles, at all 36 levels, of microphysical variables are saved based on simulated surface precipitation rates. The criteria for saving a profile in the database occurs when surface rain rates are 0.50 mm hr^{-1} or greater and/or frozen (snow, graupel, aggregates, pristine crystals) surface rates are 0.25 mm hr^{-1}or greater. These criteria were selected based on the capability of current microwave remote precipitation sensors. These precipitation criteria are near the accepted lower limits of useful satellite data.

For purposes of the CDRD, dynamical and thermodynamical tags are paired with microphysical profiles at two different resolutions, 50km grid spacing (low resolution) and 2km grid spacing (high resolution). Microphysical profiles contain vertical estimates of hydrometeor properties, as shown in table 1. The majority of CDRD tags are saved at low resolution so that they are comparable to global model resolutions, such as the Global Forecasting System (GFS). New precipitation retrievals will use microwave brightness temperatures paired with the following CDRD dynamical tags, obtainable from global operational models, which are shown in tables 2 and 3. These tags should provide for more accurate microphysical profiles selected from the CRM database, thus improving precipitation estimation. The selection of CDRD profiles is based on a Bayesian approach.

These particular tags were selected on their ability to correctly identify particular meteorological regimes. For example, convective environments can be differentiated from stratiform based on tags such as vertical velocity, cloud fraction, convective available potential energy, and wind shear. Tropical and non-tropical environments can be differentiated from mean sea level pressure, theta-e, freezing level, thickness, and latitude. An area favorable for internal gravity waves can be detected by momentum flux, temperature, froude number, and brunt-vaisala frequency.

The following section focuses on database tags that have shown a statistically significant relationship when compared to microwave brightness temperatures.

3. CDRD DISTRIBUTIONS

The CDRD currently contains over one million microphysical profiles and accompanying tags. This large amount of data provides an opportunity to study relationships between variables and discover potentially new relationships.

The first type of distribution analyzed is created from surface snowfall rates and various microwave frequency brightness temperatures. The frequencies included in this paper are 10.65, 19.35, 89.0, and 150.0 GHz. Figure 2 shows snow rate distributions. Since snow detection can be strongly affected by land, these distributions have been divided into land points and ocean points.

Both land and ocean snow distributions develop a bi-modal structure, which becomes more evident as frequency decreases. This is most likely because land affects brightness temperatures more as frequency decreases. The parts of the distributions that do not move reflect the surface temperature. The satellite would be seeing the surface and missing the precipitation signatures. As can be seen in the distributions, the ocean has less of a surface effect due to decreased emissivity. The mean of these distributions reflect the highest measured snow rates. The mean of the 150.0 GHz snow distribution is 240K, which decreases with decreasing frequency: 225K, 178K, and 160K. These distributions can be useful for developing snow retrieval algorithms.

Figure 4 shows similar distributions, but for surface rainfall rates. These distributions have not been divided into ocean and land points only because the simulated rain rates are much higher intensity than snow and often block out much of the surface effects. The land effects only start to become evident for the 10.65 GHz brightness temperature as a bi-modal distribution begins to develop. The mean of the 150.0 GHz rain distribution is 250K, which decreases with decreasing frequency: 245K, 220K, and 180K. These distributions can be useful for developing rain retrieval algorithms.

One of the advantages of the CDRD is the ability to further define these distributions with the use of tags. One of the most useful tags is topography height. Figure 4 shows the 3D distribution of rainfall rate, 89.0 GHz brightness temperatures, and topography height. This distribution shows that as topography height increases rain rates can increase and brightness temperatures tend to shift towards higher temperatures.

The last section of this paper focuses on the correlations between every CDRD variable, low and high resolution, and the four mentioned brightness temperatures. Figure 5 shows the correlation coefficients between each tag and the brightness temperatures. After computing these correlations, it is evident that the 150.0 GHz temperature typically shows the highest correlations with the CDRD tags. Table 4 lists the tags with the highest correlations. The highest positive correlation tags include surface temperature, freezing level, surface theta, 500mb temperature, 850mb thickness, specific humidity, and latent heating. The lowest negative correlation tags include theta-e minimum, surface pressure, and froude number. All of these tags will be used to develop the CDRD precipitation retrieval scheme.

4. CONCULSIONS

This paper highlights some of the potential benefits from the CDRD approach. The CDRD can be used for precipitation retrieval, but also for understanding relationships between atmospheric parameters and microwave satellite measurements. This paper has focused on relating surface snowfall and rainfall rates to microwave brightness temperatures. As frequency decreases the mean of the precipitation distribution shifts towards lower temperatures. Correlations between each CDRD tag and microwave temperatures have been computed. The tags with the highest correlations will be used to design a new CDRD based retrieval scheme.

The CDRD is a robust system that can improve microwave precipitation retrieval techniques. This system can also be used for many other earth science applications. The CDRD is available online and can be used to investigate many possible relationships between microphysical quantities and atmospheric parameters.

5. REFERENCES

Heiginger A. K., C. O'Dell, R. Bennartz, T. Greenwald, 2005: The Successive Order of Interaction Radiative Transfer Model, Part I: Model Development, *J. Atmos. Sci.*, submitted.

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TABLE 1 – UW-NMS Microphysical Profile

Total Condensate Mixing Ratio
Rain Mixing Ratio
Cloud Mixing Ratio
Water Vapor Mixing Ratio
Graupel Mixing Ratio
Aggregate Mixing Ratio
Pristine Crystal Mixing Ratio
Surface Precipitation Rates (Rain, Snow, Aggregate, Pristine Crystal, Graupel)
Surface Skin Temperature
Q1, Q2
Temperature
Pressure
Height
Zonal Wind (U)
Meridional Wind (V)
Vertical Velocity (w)

Table 1: CDRD Microphysical profile variables

TABLE 2 – High-Resolution Dynamic Tags

73) Cloud Ceiling (m)	**80)-88)** ** Temperature (K)
74) Topography Height (m)	**89)-97)** ** Specific Humidity Vector
75) Largest Topography Neighbor Difference (m)	**98)-106)** ** Vertical Velocity (m/s)
76) Direction of Topography Direction (degrees)	Cloud Fraction
77) PBL Height	Convective Cloud Fraction
78) Mean Sea Level Pressure (hPA)	Stratiform Cloud Fraction
79) Surface Pressure (hPA)	

Table 2: High-resolution tags for the CDRD.
** Denotes vector variables (1000,925,850,700,500,250,200,150,100mb)

TABLE 3 – Large Scale Dynamic Tags

1) Mean Sea Level Pressure (hPa)	**14)** Freezing Level (m)	**34)** 0-6km Wind Shear	**60)** Theta-E minimum (K)
2) Surface Temperature (F)	**15)** Lifted Index	**35)** Surface Theta Gradient	**62)-63)** 500 and 850 mb thickness (m)
4) U Momentum Flux	**16)** Froude Number	**36)** 700mb Theta Gradient	**64)** LFC Height (m)
5) V Momentum Flux	**18)** Surface Theta-E (K)	**37)** Surface Theta-E Gradient	**65)** LCL Height (m)
9) CIN (J/kg)	**19)** Surface Brunt Vaisala Frequency	**38)** 700mb Theta-E Gradient	**66)** Topography Height (m)
10) Height of Maximum CAPE (m)	**20)-28)** **Temperature	**39)-47)** ** Q Vector Convergence	**67)** PBL Height (m)
11) Surface CAPE (J/kg)	**29)-30)** Potential Vorticity at 700 and 200 mb	**48)** Surface Divergence	**68)** Richardson Number in the PBL
12) Maximum CAPE (J/kg)	**31)** Surface Vertical Vorticity	**49)-50)** Divergence at 700 and 200 mb	**69)-70)** Potential Vorticity Advection at 700 and 250 mb
13) Kinetic Energy	**32)-33)** Vertical Vorticity at 700 and 200 mb	**51)-59)** ** Vertical Velocity Vector	**71)** Diabatic Moisture Term
			72) Latent Heat Term

Table 3: Large-scale tags for the CDRD.
** Denotes vector variables (1000,925,850,700,500,250,200,150,100mb)

TABLE 4 – Best Correlation Coefficients Between CDRD Tags and Brightness Temperatures

	10.65 GHz	**19.35 GHz**	**89.0 GHz**	**150.0 GHz**
Surface Temp.	0.120	0.259	0.559	0.645
Freezing Level	0.278	0.369	0.663	0.662
Surface Theta	0.237	0.365	0.608	0.662
500mb Temp.	0.299	0.414	0.648	0.677
850mb Thickness	0.278	0.399	0.636	0.673
Latent Heating	0.333	0.438	0.620	0.658
Sp Hum - 1000mb	0.135	0.274	0.558	0.623
Theta-E Min.	- 0.204	- 0.302	- 0.416	- 0.547
Surface Pres.	- 0.156	- 0.246	- 0.329	- 0.408
Froude Num.	- 0.562	- 0.526	- 0.353	- 0.245

Table 4: CDRD tags that have the highest correlations when compared to the four brightness temperatures at the frequencies listed.

FIGURE 1 – Current CDRD Simulation Locations

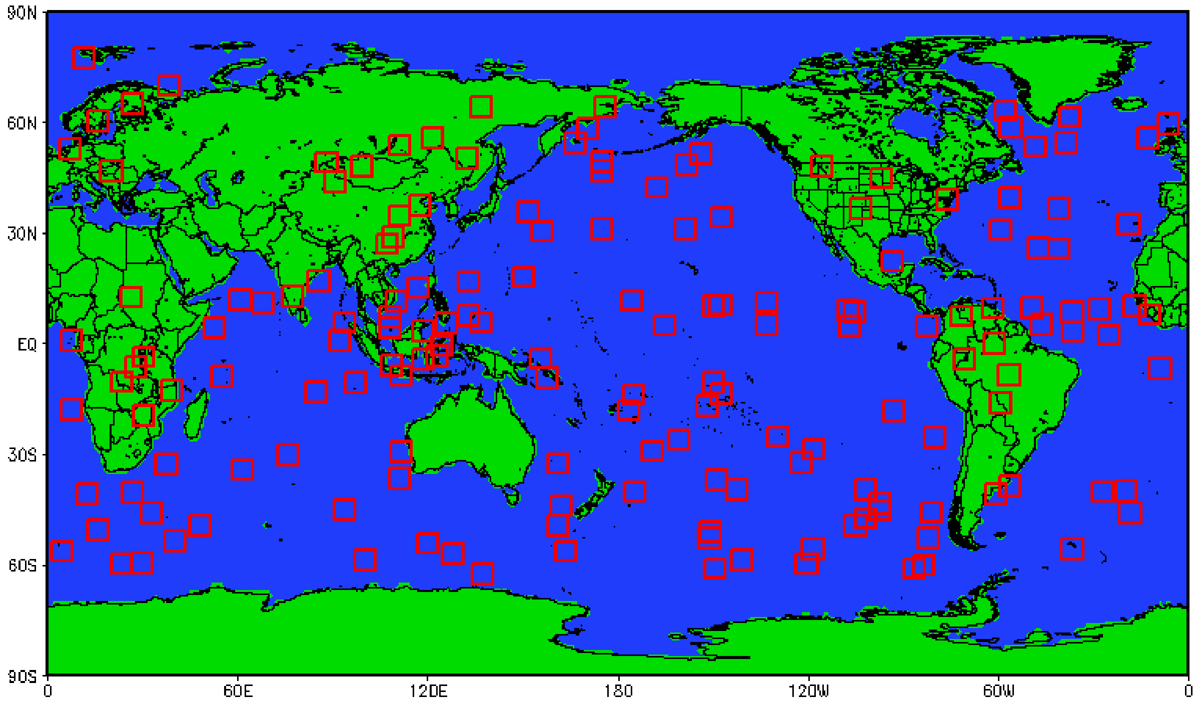

Figure 1: Current CDRD simulation locations – these simulations include over one million profile points.

FIGURE 2 – Surface Snowfall Rates vs. Microwave Brightness Temperatures

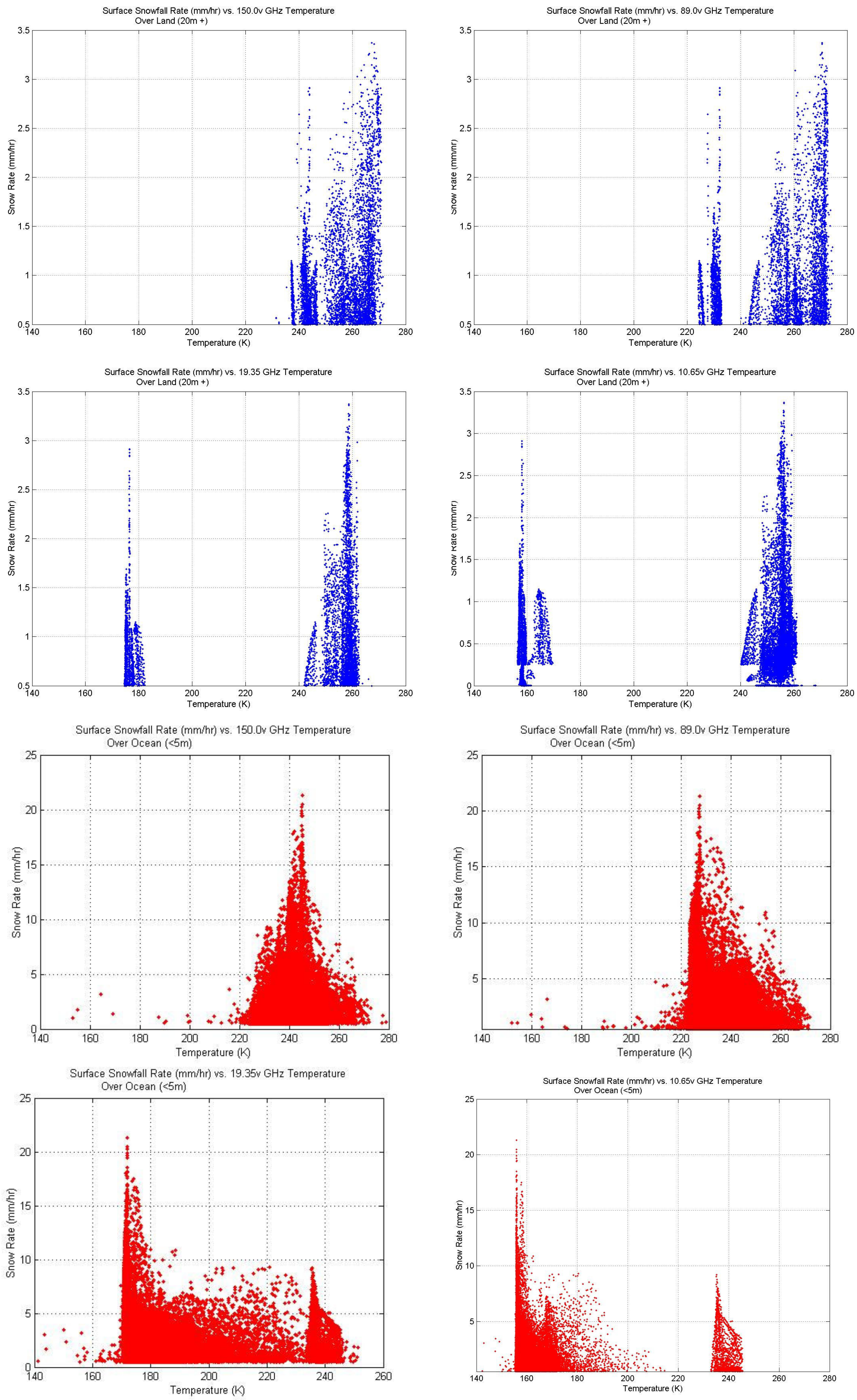

FIGURE 3 – Surface Rainfall Rates vs. Microwave Brightness Temperatures

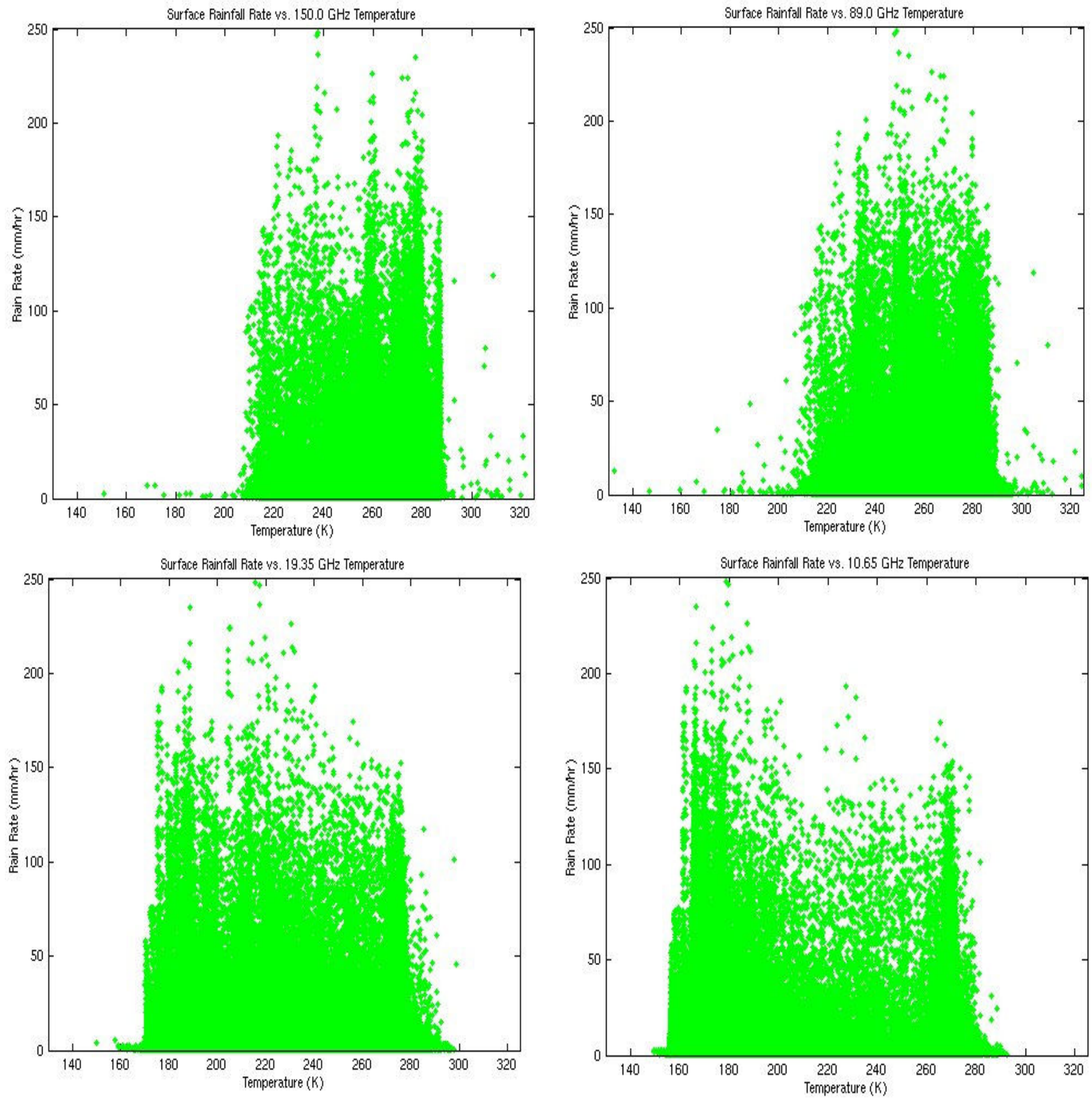

Figure 2: (previous page) Distributions between surface snowfall rates and microwave brightness temperatures. Blue points - only land points, Red points – only ocean points.

Figure 3: (above) Distributions between surface rainfall rates and microwave brightness temperatures.

FIGURE 4 – Distribution of Rainrates, Topography Height, and 89.0GHz Brightness Temperature

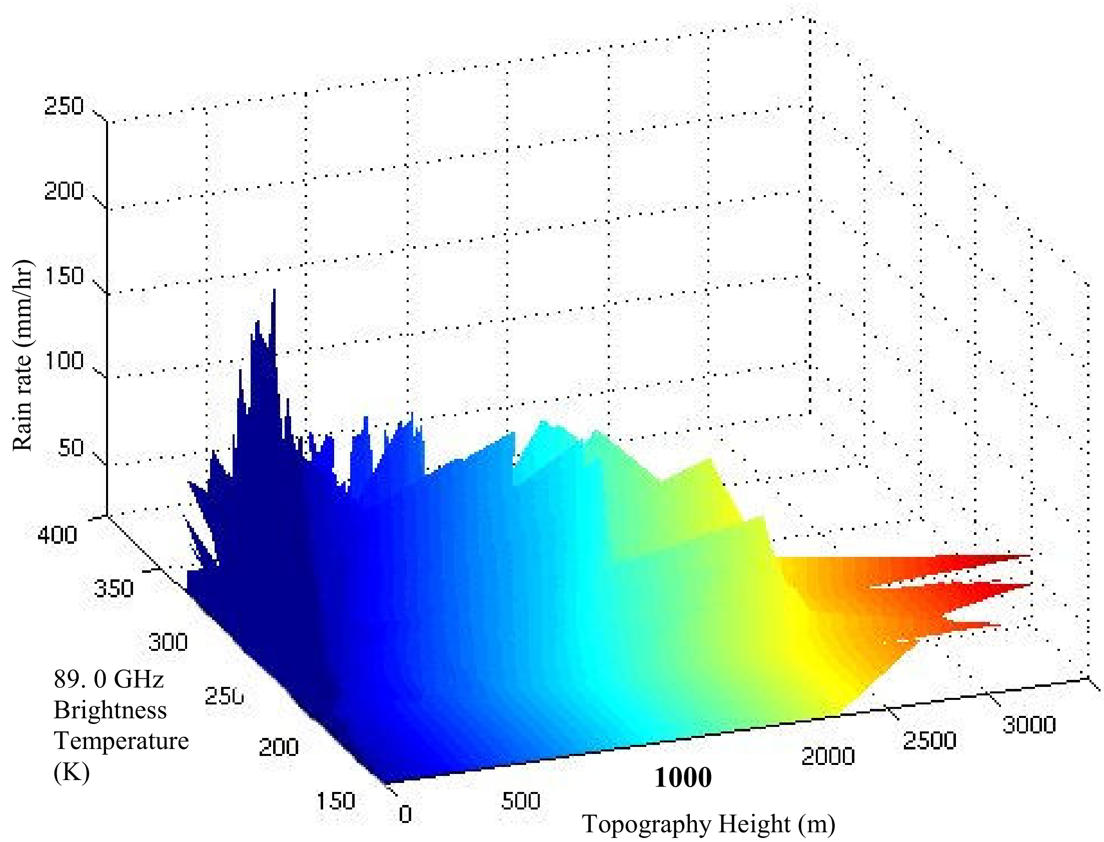

Figure 4: 3D distribution of topography height, rainfall rates, and 89.0 GHz brightness temperatures.

FIGURE 5 – Correlation Coefficients Between CDRD Tags and Brightness Temperatures

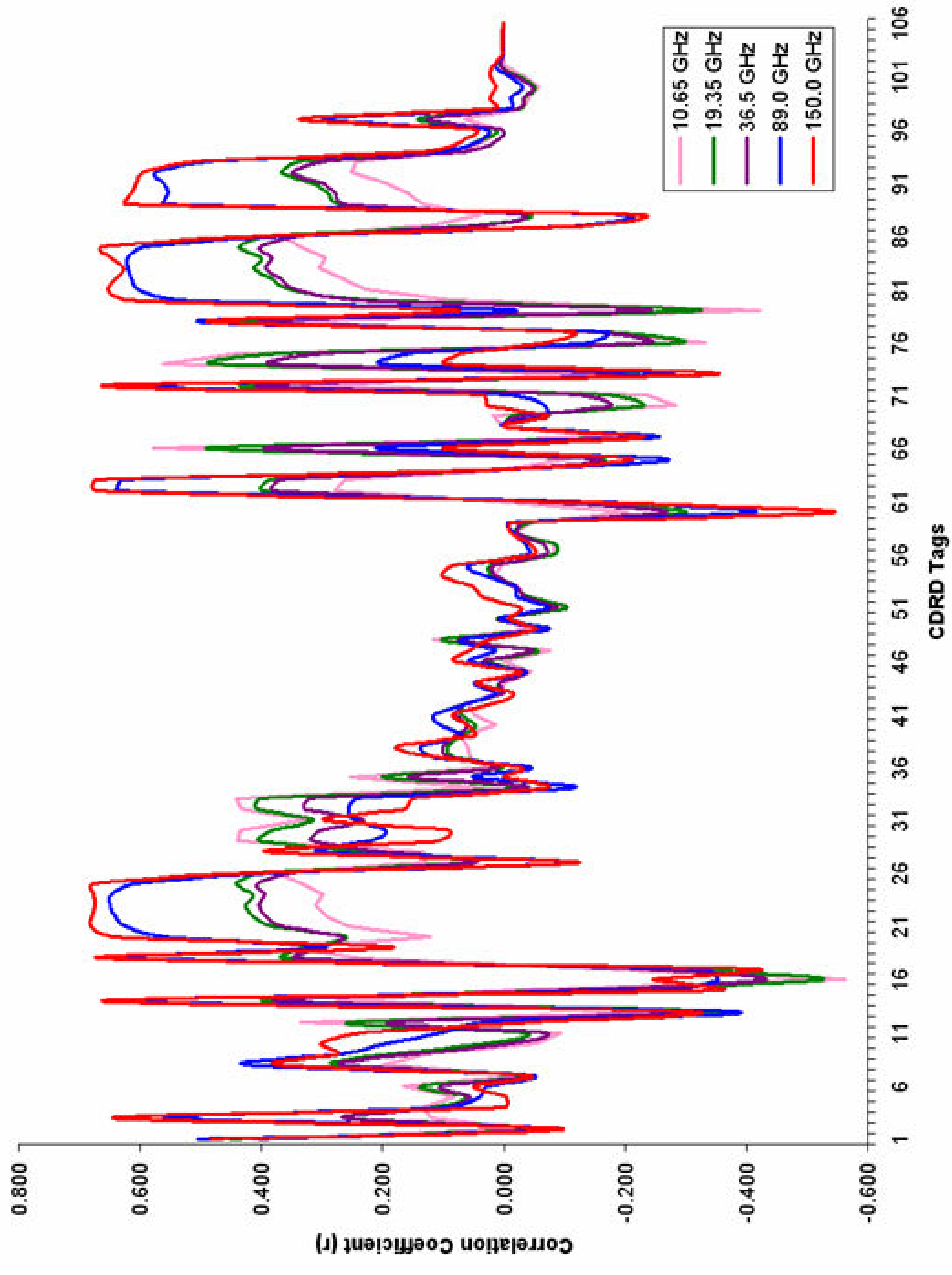

Figure 5: Correlation coefficients for every CDRD variable and four microwave brightness temperatures at the listed frequencies. Each tag corresponds to a certain number. These numbers can be found in tables 2 and 3.