TRMM Common Microphysics Product Definition Version 4 Document

[January-2002]

This document represents Version 4 of the TRMM Common Microphysical Product Definition (CMPD). The CMPD is not a substitute for the flight-level state parameter time series data provided by each aircraft to the TRMM DAAC. Neither is the CMPD the only microphysics data set that will be archived. Three basic types of microphysics products will reside in the DAAC: raw data as recorded onboard the aircraft, CMPD for defined flight legs, and specialized data products which contain detailed information not present in the CMPD.

A. Scientific Objectives

In situ measurements of the vertical profiles of hydrometeors were one of the primary objectives of recent TRMM Field Campaigns (FCs). These data will address key issues related to TRMM Microwave Imager (TMI) and TRMM Precipitation Radar (PR) algorithm designs, algorithm validation, cloud modeling, and generation of ground validation products. During the FCs, aircraft often flew in vertical stacks of up to three aircraft to simultaneously sample the hydrometer content of clouds at different temperatures.

The preliminary goal of microphysical data processing for TRMM Users is to produce a form of the data from the different aircraft and microphysical instruments that can be combined in a straightforward fashion to yield representative vertical profiles of hydrometeors. As much as possible, the data processing should remove the aircraft and instrument dependent aspects of the data to yield datasets from each aircraft that accurately portray the relative differences between the samples obtained at different temperatures. Additionally, the algorithms should be fully documented and available in the public domain so that other investigators will have a known starting point before applying additional corrections to the data.

These preliminary products will represent, by design, the lowest common denominator among the various aircraft instruments used in the FCs. Other more sophisticated and specialized products will be eventually produced by participants in this effort as well as by other TRMM PIs. Most importantly, the needs of the TRMM User community require a dataset that can be combined into vertical hydrometeor profiles by June-2001, and thus these common microphysical products must be given first priority. TRMM has funded Sky Tech Research, Inc to develop software (TRMM Microphysics Software) that will be used by TRMM PI’s to generate these products.

The Common Microphysical Product will serve as an input to computations of derived variables such as rain rate, brightness temperature, N_0 etc.

B. Schedule

A timetable of decisions and deliverables relevant to the TRMM CMPD is as follows:

Jan 2000: Complete Version 0.0 of CMPD document.

Feb 2000: Finalize Version 0.1 of CMPD document, algorithms and ASCII product format. Determine 2-3 *high priority* microphysics legs from each FC to be processed for May 2000-SLC meeting (no more than 30 min of data from each aircraft from each FC). Assign order for processing *high priority* microphysics legs for May-2000 SLC meeting.

May 2000: Examine *high priority* microphysics legs processed for SLC meeting. Revise to Version 1.0 CMPD document, algorithms and ASCII product format. Determine prioritization of aircraft missions within each FC.

Oct 2000: Complete definition of *priority* flight legs for product generation in priority order for each FC. Priority flight legs will include approximately 300 min of data from each aircraft from each FC. After interim assessment of User needs, refine to Version 1.1 CMPD document, algorithms and ASCII product format.

Mar 2001 Refine to Version 2 CMPD document and delivery of TRMM Microphysics Software (TMS) software to TRMM PIs.

May 2001 Refine to Version 3 CMPD document.

Sep 2001: Version 3 processing of all priority legs, approximately 300 minutes of data from each aircraft from each FC, due for delivery to TRMM DAAC.

Jan 2002: Alter bin widths at particle sizes greater than 1 mm to improve the quality of size and area spectra. Refine to Version 4 CMPD.

C. Lowest Common Denominator Product

The TRMM common microphysics product consists of a time series of variables derived over 1-km sections of flight tracks. For state variables such as temperature, and microphysical variables such as particle size spectra, these will represent 1-km track averages.

Aircraft and Instrumentation

Four different aircraft were used in the FC's:

UND Citation	TEFLUN B / CAMEX, LBA, KWAJEX
NASA DC8	TEFLUN B / CAMEX, KWAJEX
SPEC Lear	TEFLUN A
UW Convair	KWAJEX

Each aircraft was equipped with an array of microphysical instrumentation that included combinations of opto-electrical probes such as the FSSP (Forward Scattering Spectrometer Probe), CPI (Cloud Particle Imager), 2DC (Two-Dimensional Cloud Probe), HVPS (High Volume Particle Sampler), and 2DP (Two-Dimensional Precipitation Probe). The FSSP, CPI, 2DC, and HVPS are designed to sample increasingly larger sizes of hydrometeors with decreasing resolution. Each probe covers a relatively unique size range that can vary depending on the aircraft and FC in question. The 2DP has a slightly better resolution than the HVPS, but has a smaller dynamic sampling range. For the purposes of the CMPD, data from the HVPS will be used to characterize large particles unless that probe was not operating or not deployed on an aircraft; in this event, data from the 2DP will used unless that probe was not operating or not deployed on an aircraft.

In addition to the opto-electrical probes, the Citation, Lear, and Convair were equipped with King (hot-wire) and Rosemount (icing) probes to detect and quantify the presence of cloud liquid water. Finally, all four aircraft recorded navigation (e.g., location, altitude) and state parameter (e.g., temperature, pressure) data.

Flight Leg Definition

A coordinator from each field campaign (G. Heymsfield-TEFLUN A and B/CAMEX, W. Petersen- LBA, S. Yuter-KWAJEX) will specify the latitude-longitude coordinates of the start and end points of the microphysical legs to be processed so that the data from each aircraft can be associated in the vertical. Although the stacked aircraft tracks were usually within a few km in the horizontal, they often were not precisely overlaid. For purposes of the TRMM common microphysics product, the point at which an aircraft passes closest to the defined start point lat-lon is defined as the 0-km coordinate along a flight track. The point closest to the end point lat-lon is defined as within the N km coordinate along the flight track (N is determined as the scalar distance between the start and end points). This method of defining straight and spiral flight tracks will yield integer numbers of kilometers (N_i) for each ith leg.

An example of a proposed flight leg from KWAJEX (Fig. 1) is as follows: This leg is from the 11 Aug 1999 mission at ~2213-2225 UTC. The Citation and Convair are heading SW. The beginning point is 8.81 deg N/168.10 deg E while the end point is 8.23 deg N/167.85 deg E. The flight leg length is ~68 km.

Please note that the defined start and end times may not correspond to the actual start and end times for a specific aircraft, parameters that will be a function of exactly when the aircraft in question passes closest to the defined start and end locations. If an aircraft is executing a turn or another maneuver at the beginning or end of a defined, straight microphysical leg, and the microphysical data collected onboard are not considered to be usable for research purposes, the values of the product variables for the affected km coordinates will be set to missing. Another issue to address is when aircraft are flying in opposite directions along a flight track. In these cases the data file from an aircraft whose track starts with the end point (and ends with the start point) will need to be reversed in time order and then coordinate tagged accordingly. The proposed KWAJEX flight leg from ~2151-2159 UTC during the 19 Aug 1999 mission is an example of this scenario (Fig. 2). In this flight leg, the DC-8 is moving NE to SW whereas the Citation is on a reverse track heading SW to NE. The beginning point (i.e., the NE end of the leg) is at 8.45 deg N / 167.22 deg E while the end point (i.e., the SW end of the leg) is at 8.22 deg N / 166.83 deg E. The length of this flight leg is 50 km.

Data from each flight leg will be in a separate file consisting of header information followed by the actual time series data. The file naming convention is based on CMPD Version #, UTC date, experiment name, aircraft name, and total number of 1-km leg segments. The total number of 1 km segments may vary among aircraft for the same defined flight leg as aircraft did not usually fly on identical tracks. Leg start times and segment counts are determined by the field campaign flight leg coordinator and will be accessible from an online web master list. The filename format convention is to be given as:

cmp_vers#_yyyymmddhhmm_expname_acname_totseg#

For example, "cmp_vers4_199908112213_kwajex_cit_68" names a common microphysical product data file using the Version 4 CMPD (versions are now in whole rather than decimal numbers), for an August 11, 1999 KWAJEX flight leg from the Citation with defined leg start time of 2213 and with 68 1-km segments. Although dates alone would be adequate to differentiate between different field campaigns, the field campaign name is incorporated in the file definition to minimize file recognition mistakes by the various classes of Users. Note that “defined leg start time” is a label assigned by the field campaign flight leg coordinator and may or may not correspond to the exact start time of the leg for a particular aircraft.

D. Formats and Definitions

The common microphysical product variables will be given in ASCII format, with all lines ending in a carriage return. The format consists of several header lines followed by lines containing data for each 1-km leg segment.

Header

The 1st header line will contain an integer indicating the total number of header lines (which must NOT be less than 3). The 2nd header line will contain the filename. The 3rd header line will contain the bin center in μm of each size category in the spectra data. These bin centers are needed to properly plot the particle spectra. Additional header comment lines can be defined by a data provider as long as they are accounted for in the 1st header line. Data providers are STRONGLY encouraged to provide additional information in the comment lines regarding which probes were used to characterize certain sets of bins, the characteristics of probes used in the calculations (e.g., resolution, size range, response time), how size spectra were computed, specifications of mass-dimension relationships, and specifications for thresholds used in habit recognition calculations. The comment lines are also the place where specific "user beware" information regarding the uncertainties of various fields should be placed.

Time series

The time series data will be presented as columns delimited by a blank space, with a carriage return at the end of each line. A value of -999.99 must be used for missing values. Each 1-km segment along a flight track will be represented by 13 lines. The first line will contain fifteen parameter sectors in order, containing 92 fields as follows: time tag (6 fields), position coordinate (4 fields), ambient temperature (1 field), true air speed (1 field), ground speed (1 field) pressure (1 field), dewpoint (1 field), vertical air velocity (1 field), total counts and concentrations (8 fields), habit (45 fields), water/ice masses (13 fields), mass-weighted mean particle size (1 field), reflectivity (1 field), artifacts (2 fields) and spares (6 fields). The second and third lines will contain spectral representations of particle area (90 fields per line). Lines 4-13 will contain spectral representations of particle size (98 fields per line). If any spectra is missing, a value of -999.99 must be placed in all size bins. In this manner, the time tag information for each 1 km along the flight track will appear as the first 6 fields in every 13th line of the time series data.

<u>Line 1</u>

1. Time Tag: 6 fields containing UTC time at center of 1-km flight track segment (e.g., first time tag indicates time where aircraft is 500 m from start point) -- format is 4-digit year, 2-digit month, 2-digit day, hour, minute, seconds to 1-decimal place accuracy (note leading zeros must be present for 2-digit month, day, hour, and min values).

Example: 1999 08 05 22 15 2.3

2. Position Coordinate: 4 fields total, first two fields contain lat-lon coordinates at center of 1-km flight track segment (e.g., first position coordinate indicates position where aircraft is 500 m from start point) -- format in decimal degrees to 4-decimal place accuracy with north (south) latitudes given as positive (negative) and east (west) longitudes given as positive (negative). Third field contains best measurement of average altitude in meters MSL at center of 1-km flight track segment to nearest meter. Fourth field is a flag indicating source of lat-lon position data (I for INS, G for GPS).

Example: 8.8555 168.1000 5056 G

3. Ambient Temperature: 1 field containing best measurement of average temperature along 1-km flight track segment -- format in deg C to 1 decimal place accuracy.

Example: -2.1

4. True Air Speed: 1 field containing best measurement of average true air speed along 1-km flight track segment -- format in m/s to 1 decimal place accuracy.

Example: 150.3

5. Ground Speed: 1 field containing best measurement of average ground speed along 1-km flight track segment – format in m/s to 1 decimal place accuracy.

Example: 150.3

6. Pressure: 1 field containing best measurement of average pressure along 1-km flight track segment -- format in mb to nearest mb.

Example: 772

7. Dewpoint: 1 field containing best measurement of average dewpoint along 1-km flight track segment -- format in deg C to 1 decimal place accuracy. If data is considered unreliable set to missing.

Example: 5.3

8. Vertical air velocity: 1 field containing best measurement of average vertical air velocity along 1-km flight track segment -- format in m/s to 1 decimal place accuracy. If data is considered unreliable or is unavailable set to missing.

Example: 2.5

9. Total Counts and Concentrations: 2 fields computed for each of the FSSP, CPI, 2DC, and HVPS/2DP probes. Counts (non-dimensional) displayed in floating point notation with 1 decimal place accuracy and Concentrations (L^{-1}) displayed in exponential notation with 3 decimal place accuracy (e.g., 1.234e-56). All 2D/HVPS concentrations and counts based on the Heymsfield and Parrish (1978) reconstructed method. The description of the counts and concentrations will be in the following order:

a. Total Counts calculated from the FSSP over the size range specified for the FSSP in the size spectra below in (16).
b. Total Concentration calculated from the FSSP over the size range specified for the FSSP in the size spectra below in (16).
c. Total Counts calculated from the CPI over the size range specified for the CPI in the size spectra below in (16).
d. Total Concentration calculated from the CPI (scaled to 2DC observations) over the size range specified for the CPI in the size spectra below in (16).

e. Total Counts calculated from the 2DC over the size range specified for the 2DC in the size spectra below in (16).
f. Total Concentration calculated from the 2DC using a reconstructed sample volume over the size range specified for the 2DC in the size spectra below in (16).
g. Total Counts calculated from the HVPS/2DP over the size range specified for the HVPS/2DP in the size spectra below in (16).
h. Total Concentration calculated from the HVPS/2DP using a reconstructed sample volume over the size range specified for the HVPS/2DP in the size spectra below in (16).

10. Habit recognition for spheres (proxy for liquid), graupel, aggregates, needles/columns, and small, indeterminate particles: 45 fields (5 habits times 3 combinations of instruments times 3 different weighting functions) containing percentage of particles in each of the above habit classifications. Format in nearest integer percent from 0-100. The threshold for indeterminate particles will be images with less than 25 pixels of image area. Pixel area will be a function of probe type.

a. Number weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from CPI (5 fields).
b. Area weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from CPI (5 fields).
c. Mass weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from CPI (5 fields).
d. Number weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from 2DC using Heymsfield's area-sphere ratio (5 fields).
e. Area weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from 2DC using Heymsfield's area-sphere ratio (5 fields).
f. Mass weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from 2DC using Heymsfield's area-sphere ratio (5 fields).
g. Number weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from HVPS/2DP using Heymsfield's area-sphere ratio (5 fields).
h. Area weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from HVPS/2DP using Heymsfield's area-sphere ratio (5 fields).
i. Mass weighted percentage of spherical, graupel, aggregate, needle/column and indeterminate particles from HVPS/2DP using Heymsfield's area-sphere ratio (5 fields).

11. Water / Ice Masses: 13 fields containing (a) cloud liquid water existence (yes / no) as observed by either the King hot-wire, Rosemount icing, or FSSP probes, (b) cloud liquid water content (LWC) as observed by either the King hot-wire, Rosemount icing, or FSSP probes, (c) flag for probe used in determination of cloud LWC: K for King hot-wire, R for Rosemount icing or F for FSSP, (d) cloud / precipitation LWC from spheres as observed by the CPI, (e) cloud / precipitation ice water content (IWC) for all ice particles observed by the CPI, (f) cloud / precipitation (IWC) from graupel as observed by the CPI, (g) cloud / precipitation IWC from aggregates as observed by the CPI, (h) cloud / precipitation IWC from needles / columns as observed by the CPI, (i) precipitation LWC from spheres as observed by the 2DC and HVPS / 2DP, (j) precipitation IWC for all ice particles observed by the 2DC and HVPS / 2DP, (k) precipitation IWC from graupel as observed by the 2DC and HVPS / 2DP (l) precipitation IWC from aggregates as observed by the 2DC and HVPS / 2DP and (m) precipitation IWC from needles / columns as observed by the 2DC and HVPS / 2DP. Except for the first three fields, these parameters will be derived by integrating over the relevant size spectra using separate mass-dimension relationships for water, graupel, aggregates, and needles / columns as defined in the header. These LWC and IWC values will be reported in units of gram per cubic meter. If a mass field is unable to be calculated, a value of -999.99 will be set.

12. Mass-weighted mean particle size: 1 field containing mass-weighted mean particle size observed by the 2DC and HVPS / 2DP. Values will be reported in micrometers.

13. Reflectivity: 1 field containing reflectivity observed by the 2DC and HVPS / 2DP as calculated with the Heymsfield et al. (2000) technique. Values will be reported in dBZ_e. Missing values (-999.99) will be reported for air temperatures between –3º to +3º C.

14. Artifacts: 2 fields containing number weighted percentage of artifacts for the 2DC and HVPS / 2DP, respectively. Format in nearest integer percent from 0-100.

15. Spares: 6 fields set to missing –999.99 until used.

<u>Lines 2-3</u>

16. Area Spectra: Two types of area spectra for all particles will be provided. All 2D / HVPS images are to be processed by the Heymsfield and Parrish (1978) reconstructed technique. Data for each spectra is contained in 1 spectra type field and 89 area bin fields for a total of 90 fields per spectra.

The spectra type flag will be placed in 1 field prior to the 89 area bin fields. It will indicate the type of output: CT=counts and CN=concentrations. Line 2 will contain an area spectrum of counts (CT) and line 3 will contain an area spectrum of concentration (CN).

Each area spectra will consist of 89 fields corresponding to 89 area bins. Counts per bin (non-dimensional) will be displayed in floating point notation with 1 decimal place accuracy. Concentrations per bin per bin width (L^{-1} μm^{-2}) will be displayed in exponential notation with 3 decimal place accuracy (e.g., 1.234e-56). Area categories will be as follows: 1600-22500 μm^2 range with 1900 μm^2 bin width (11 bins), 22500-1000000 μm^2 range with 57500 μm^2 bin width (17 bins), 1-625 mm^2 range with 10.4 mm^2 bin width (60 bins) and greater than or equal to 625 mm^2 (1 bin). CPI data (scaled to 2DC observations) will be used for the 1600-22500 μm^2 area range, 2DC data for the 22500-1000000 μm^2 area range, and HVPS/2DP data (whichever is relevant) for areas greater than 1 mm^2. If the available instruments on an aircraft are not able to provide the desired information for a particle area bin, a value of –999.99 should be set. The 89 area bins are summarized below where A is the area of a particle:

1. $1.600 \times 10^3\ \mu m^2 <= A < 3.500 \times 10^3\ \mu m^2$
   …. CPI (scaled to 2DC)
11. $2.060 \times 10^4\ \mu m^2 <= A < 2.250 \times 10^4\ \mu m^2$
12. $2.250 \times 10^4\ \mu m^2 <= A < 8.000 \times 10^4\ \mu m^2$
   …. 2DC
28. $9.425 \times 10^5\ \mu m^2 <= A < 1.000 \times 10^6\ \mu m^2$
29. $1.000 \times 10^6\ \mu m^2 <= A < 1.140 \times 10^7\ \mu m^2$
   …. HVPS or 2DP
88. $6.146 \times 10^8\ \mu m^2 <= A < 6.250 \times 10^8\ \mu m^2$
89. $6.250 \times 10^8\ \mu m^2 <= A$

<u>Lines 4-13</u>

17. Size Spectra: Ten types of particle spectra will be provided. All 2D/HVPS images will be processed by the Heymsfield and Parrish (1978) reconstructed technique and sized by maximum dimension. Data for each spectra is contained in 2 spectra type fields and 96 size bin fields for a total of 98 fields per spectra.

The spectra type flags will be placed in 2 fields prior to the 90 size fields. The first flag indicates the subset of particles: AL=all, SP=spherical, GR=graupel, AG=aggegate, and NC=needle/column as determined from the Heymsfield area-sphere ratio. The second flag indicates the type of output: CT=counts and CN=concentration. Flags are separated by blank space.

The full list of spectra types to be included in CMPD is as follows:

a.	Line 4	(AL CT)	counts for all particles
b.	Line 5	(AL CN)	concentration for all particles
c.	Line 6	(SP CT)	counts for spherical particles

d. Line 7 (SP CN) concentration for spherical particles
e. Line 8 (GR CT) counts for graupel particles
f. Line 9 (GR CN) concentration for graupel particles
g. Line 10 (AG CT) counts for aggregate particles
h. Line 11 (AG CN) concentration for aggregate particles
i. Line 12 (NC CT) counts for needle/column particles
j. Line 13 (NC CN) concentration for needle/column particles

Each size spectra will consist of 96 fields corresponding to 96 size bins. Counts per bin (non-dimensional) will be displayed in floating point notation with 1 decimal place accuracy. Concentrations per bin per bin width (L^{-1} μm^{-1}) will be displayed in exponential notation with 3 decimal place accuracy (e.g., 1.234e-56). Size categories are as follows: 5-40 μm range with 5 μm bin width (7 bins), 40-150 μm range with 10 μm bin width (11 bins), 150-1000 μm range with 50 μm bin width (17 bins), 1-25 mm range with 400 μm bin width (60 bins) and greater than or equal to 25 mm (1 bin). FSSP data will be used for the 5-40 μm size range, CPI data (scaled to 2DC observations) for the 40-150 μm size range, 2DC data for the 150-1000 μm size range, and HVPS/2DP data (whichever is relevant) for sizes greater than 1 mm. If the available instruments on an aircraft are not able to provide the desired information for a particle size bin, a value of –999.99 should be set. The 96 size bins are summarized below where D is the maximum dimension of a particle:

1. 5 μm <= D < 10 μm
   …. FSSP
7. 35 μm <= D < 40 μm
8. 40 μm <= D < 50 μm
   …. CPI (scaled to 2DC)
18. 140 μm <= D < 150 μm
19. 150 μm <= D < 200 μm
   …. 2DC
35. 950 μm <= D < 1000 μm
36. 1000 μm <= D < 1400 μm
   …. HVPS or 2DP
95. 24600 μm <= D < 25000 μm
96. 25000 μm <= D

E. References

Heymsfield, A. J., and J. L. Parrish, 1978: A computational technique for increasing the effective sampling volume of the PMS two-dimensional particle size spectrometer. *J. Appl. Meteor.* 17, 1566-1572.

Heymsfield, A. J., P. R. Field, J. Stith, J. E. Dye, A. Grainger, 2000: Ice particle evolution in tropical stratiform ice clouds: Results from TRMM field programs. Preprints, *13th International Conference on Clouds and Precipitation*, Reno, 669-672.

F. Closing Remarks

The most current version of this document in PDF format can be found at:

http://www.atmos.washington.edu/gcg/MG/KWAJ/ops-web/intro_microphys.html

This site also contains links to web-accessible prioritized flight leg definitions for the field campaigns.

Please direct questions and comments to:

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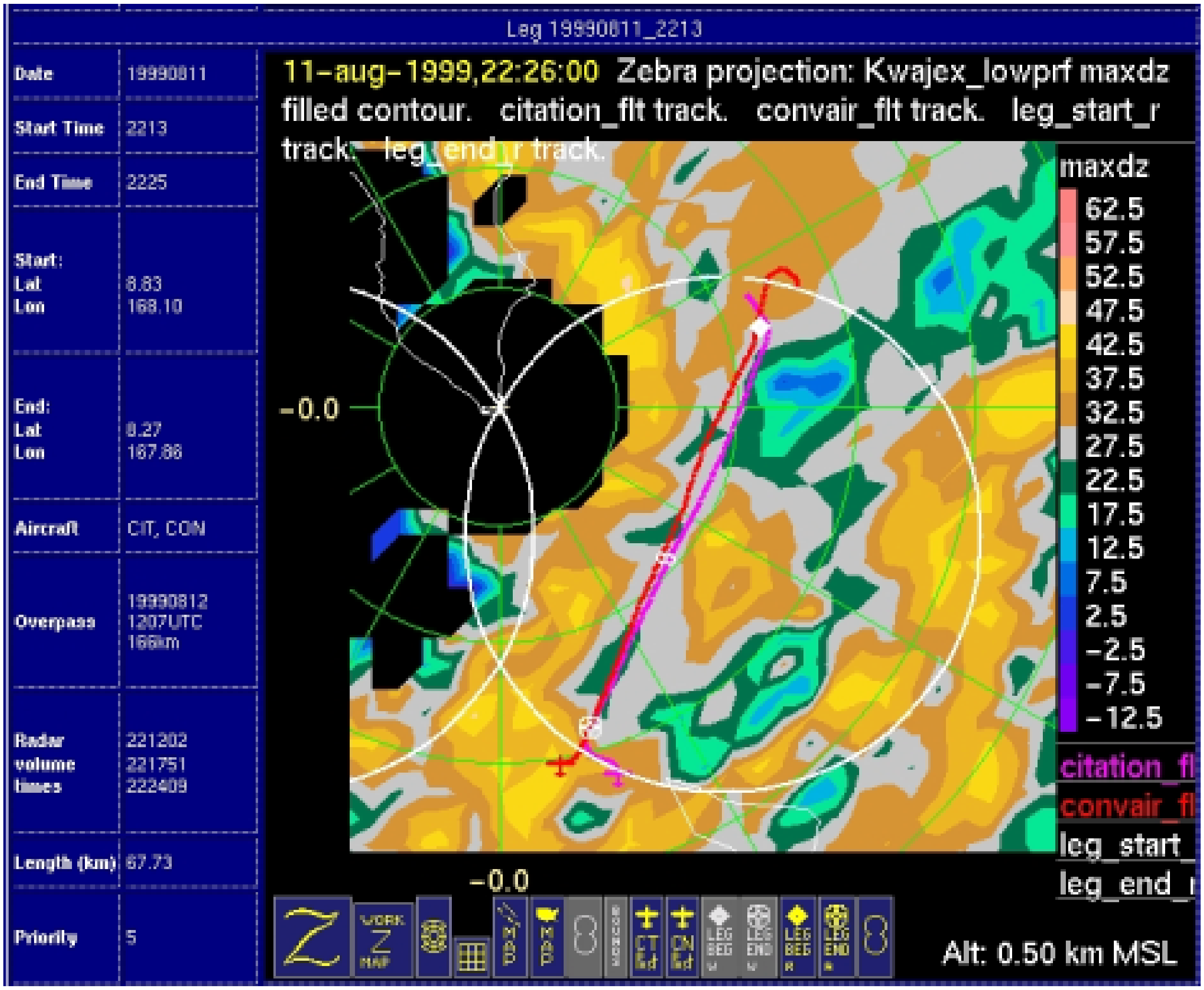

Fig. 1: KWAJEX aircraft flight legs from 11 August 1999 for the period 2213-2225 UTC overlaid on reflectivity from the Kwajalein radar. The Citation (purple) and Convair (red) are heading SW. The beginning point is indicated by the diamond and the end point by the circle enclosing a plus sign. The flight leg length is ~68 km.

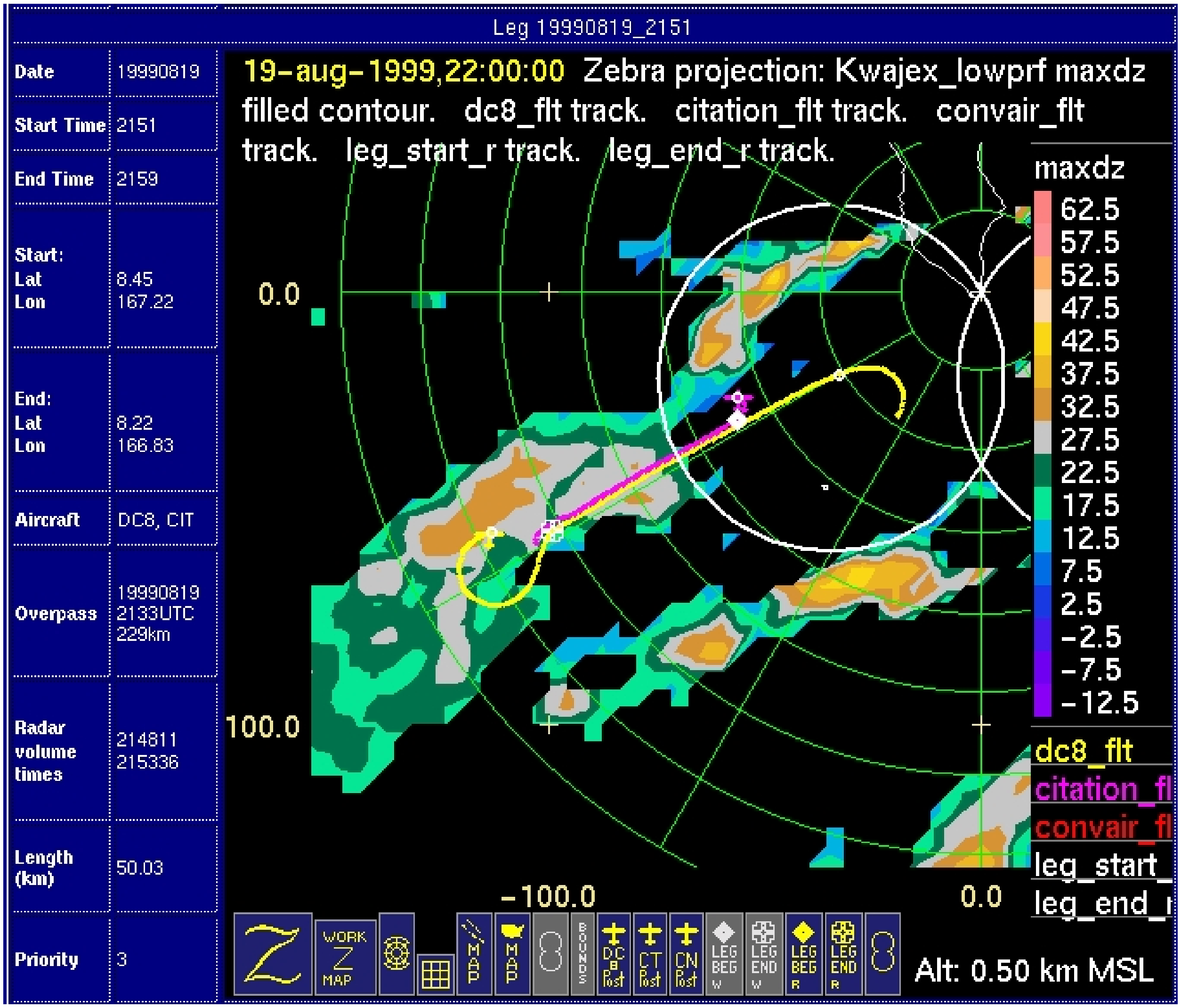

Fig. 2: KWAJEX aircraft flight legs from 19 August 1999 for the period 2251-2259 UTC overlaid on reflectivity from the Kwajalein radar. The DC8 (yellow) is moving NE to SW whereas the Citation (purple) is moving SW to NE. The beginning point (i.e., the NE end of the leg) is indicated by the diamond and the end point (i.e., the SW end of the leg) by the circle enclosing a plus sign. The flight leg length is ~50 km.