APR-2 Dual-frequency Airborne Radar Observations, Wakasa Bay, Version 1

USER GUIDE

How to Cite These Data

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Im, E. 2004. *APR-2 Dual-frequency Airborne Radar Observations, Wakasa Bay, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/DE3KZ17QDAVJ. [Date Accessed].

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1 DATA DESCRIPTION

The Airborne Second Generation Precipitation Radar (APR-2) collected data in the Wakasa Bay AMSR-E validation campaign over the Sea of Japan on board a NASA P-3 aircraft. Data were collected on all P-3 flights that encountered precipitation.

1.1 Parameters

Parameters are reflectivity at 13.405 and 35.605 GHz and Doppler and LDR at 13.405 GHz.

1.1.1 Sample Data Record

The example browse image below is from the file "APR2.030119.043716.2.HDF.jpg." The browse images show the along-track section provided by ray #12. Vertical axis is altitude (km), and horizontal axis is time (minutes). Reflectivity values are expressed in dBZ, Doppler velocity in m/s, Linear Depolarization Ratio in dB. The value of the surface index is represented by colored dots at 0 m altitude (0 = black, 1=blue, 2=cyan, 3 = green, 4=yellow, 5=red). The four plots at the bottom visualize the navigation data. They should always be checked before interpreting the radar data.

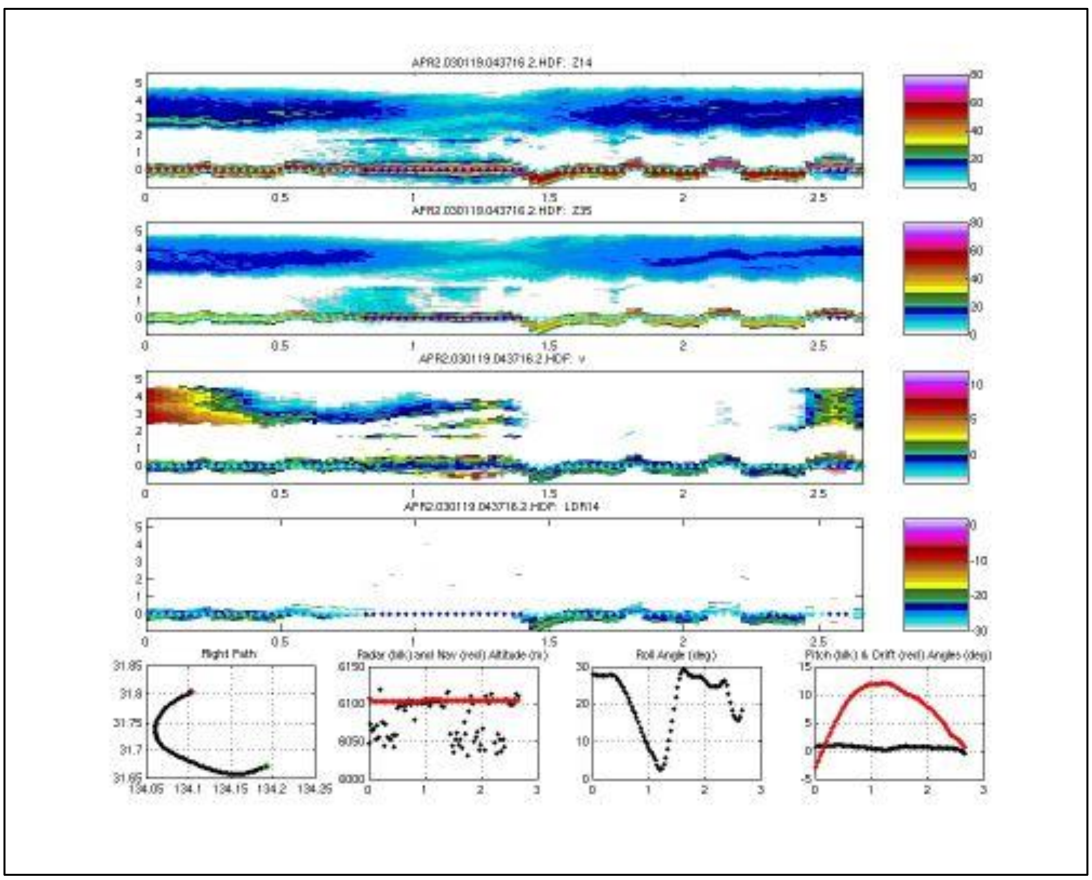

Figure 1. Example Browse Image

1.2 File Information

1.2.1 Format

Data are provided in Hierarchical Data Format (HDF) and browse images in JPEG format.

There are tar files containing data for each date and a "browse" directory for the browse images.

Binary files range from 307 KB to 68 MB. Browse image files range from 112 KB to 250 KB.

Total volume is 3.5 GB, but the tar files are between 7.7 and 195 MB. If the tar files are too large for you to download, please contact NSIDC's User Services to provide the data on CD- or DVD-ROM or on some other media.

The table below describes objects within the APR-2 HDF data files, which are described in more detail after the table. Three-dimensional objects such as "look_vector" and "zhh14" are interleaved by line.

Table 1. Description of Objects within APR-2 HDF data files.

Name	Format	Size	Notes
fileheader	int32	18	
scantime	int32	nscan x nray	Beginning of scan in seconds since 1 January 1970
scantimus	int32	nscan x nray	Beginning of scan; microseconds past scantime
lat	float	nscan x nray	From P-3 navigation files
lon	float	nscan x nray	From P-3 navigation files
roll	float	nscan x nray	From P-3 navigation files
pitch	float	nscan x nray	From P-3 navigation files
drift	float	nscan x nray	From P-3 navigation files
alt_nav	float	nscan x nray	From P-3 navigation files (meters)
alt_radar	float	nscan x nray	From APR-2 surface echo (meters)
look_vector	double	nscan x nray x 3	From P-3 navigation files

Name	Format	Size	Notes
look_vector_radar	double	nscan x nray x 3	From APR-2 surface echo
range0	float	nscan x nray	Distance of the first radar range bin from aircraft
isurf	int32	nscan x nray	Index of radar range bin intersecting surface (starting from 0).
sequence	int32	nscan x nray	Ray number within the file
v_surfdc8	float	nscan x nray	Apparent surface Doppler velocity as estimated from P-3 navigation
v_surf	float	nscan x nray	APR-2 measured surface Doppler velocity
beamnum	float	nscan x nray	Ray number within a scan
surface_index	float	nscan x nray	Preliminary surface classification index
zhh14	int16	nscan x nray x nbin	Radar Reflectivity at Ku band (scaled dBZ) (scaling factor is given in file header)
zhh35	int16	nscan x nray x nbin	Radar Reflectivity at Ka band (scaled dBZ) (scaling factor is given in fileheader)
ldr14	int16	nscan x nray x nbin	Linear Depolarization Ratio at Ku band (scaled dB) (scaling factor is given in fileheader)
vel14	int16	nscan x nray x nbin	Doppler Velocity at Ku band (scaled m/s) (scaling factor is given in fileheader)

Within the table:

- nscan - the number of scans in a file
- nray - the number of rays, or beams, within a scan
- nbin - the number of bins within a ray

The file header data are stored as Vdata. The remaining items are Scientific Data Sets (SDSs). Missing data are replaced by -9999.

Altitude and look vector (the 3 components of the antenna relative to a global coordinate system where x is the aircraft ground track and z is vertical) are provided in two estimates. The alt_nav and look_vector items are calculated based on the aircraft navigation information, but alt_radar and look_vector_radar are calculated based on the observed surface return in APR-2 data. The latter pair is reliable only when flying over the ocean, as it provides a more accurate geolocation than the navigation-based pair.

The predicted and observed surface Doppler velocities are also provided. The Doppler velocities were corrected for occasional aliasing and were used to correct the Doppler measurements of precipitation for the bias introduced by the aircraft motion.

The surface_index is estimated by analyzing APR-2 surface return (roughness, angle dependence of the surface normalized radar cross section, apparent surface inclination, and LDR at nadir). It assumes one of six values (this classification is preliminary, see Error Sources for known issues):

0 = Rough land
1 = Ocean (level flight)
2 = Ocean (roll maneuver)
3 = Flat land (level flight)
4 = Flat land (rolling maneuver)
5 = Antenna not scanning (unknown surface)

The file header contains information about the APR-2 data. These are parameters that are constant over the entire file. The next table describes the file header structure. All file header items are expressed as 4-byte integers.

Table 2. File Header Structure

1	PRF	Pulse repetition frequency in Hz
2	Pulse Length	Radar pulse length in 1 us units
3	Antenna Left	Antenna scan left-limit in degrees
4	Antenna Right	Antenna scan right-limit in degrees
5	Scan Duration	Scan time for antenna in second * 100
6	Return Duration	Antenna retrace time in second * 100
7	Ncycle	Number of pulse averaged by Wildstar board
8	AZ Average	Number of blocks averaged in a beam or ray
9	Range average	Number of 30 m range cells averaged in a bin
10	Scan average	Number of scans averaged
11	Number of Bins	Number of range bins in the ray
12	Number of Beams	Number of rays in each scan
13	Range Bin Size	The vertical resolution of range bin
14	Z scale factor	Factor multiplying reflectivity
15	V scale factor	Factor multiplying Doppler
16	Valid Ka scan begin	Scan number where the valid Ka data begin
17	Valid Ka scan end	Scan number where the valid Ka data end

<table>
<tr><td>18</td><td>CalVersion</td><td>Version number of the calibration table</td></tr>
<tr><td colspan="3">In the course of processing, browse images were also created. These are saved in JPEG format. They show the beam #12 (pointing downwards in the aircraft reference) of APR-2 data, versus along-track time (in minutes), providing a downward-looking slice of the 3-D data set.</td></tr>
</table>

1.2.2 File Contents

There are tar files containing data for each date and a "browse" directory for the browse images.

1.2.3 Naming Convention

Binary and browse image files share file names but have different extensions. The convention is:

APR2.YYMMDD.Time(UTC).version#

The binary file extension is .HDF and the browse image extension is .jpg.

For example, the following files contain data for the same flight pass:

APR2.030114.084057.2.HDF
APR2.030114.084057.2.HDF.jpg

1.3 Spatial Information

1.3.1 Coverage

Southernmost Latitude: 30° N
Northernmost Latitude: 45° N
Westernmost Longitude: 130° E
Easternmost Longitude: 150° E

1.4 Temporal Information

1.4.1 Coverage

Data were collected from 14 January to 03 February 2003.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

APR-2 data quality has been assessed by examining a number of engineering parameters related to the radar's stability and calibration. The observed minimum detectable reflectivity (Z) for APR-2 at both frequencies was derived from clear-air observations of the radar return signal and of the receiver noise floor. (In the Wakasa Bay experiment, no pulse was transmitted in ray #1 of each scan to measure receiver noise.) The values for both Ku-band and Ka-band are below 5 dBZ at 10 km range from the radar. Due to system non-linearities, the effective minimum detectable reflectivity was approximately 5 dBZ at 6 km range. The surface return, along with pulse compression sidelobes, can be seen at approximately 6 km range. The pulse compression sidelobes, rather than thermal noise, limit performance near the surface. Achieving such low pulse compression sidelobes required careful design of the transmit waveform and control of gain and phase errors.

Radar calibration can be verified using observations of the ocean surface. This technique has been used previously, since the ocean backscatter near nadir is well known, especially near 10 degrees incidence, where sensitivity to wind speed is a minimum. Ocean backscatter at Ka-band is not as well characterized, although models show similar behavior to the Ku-band. At Ka-band, the reflectivity in very light rain should be nearly identical to that at Ku-band, since Rayleigh scattering should apply at both frequencies.

Observations of the ocean surface with APR-2 show a cross section near 7 dB, which is close to previous measurements. Ocean backscatter comparisons with surface reflectivities calculated with Geophysical Model Function (GMF) or from TRMM/PR measurements indicate a bias of less ~0.5 dBZ, but strong winds and clouds undetected by APR-2 are possible contributors for this bias at Ku band. In-depth analysis is required to further refine calibration. The Ka-band data have reflectivities within about 1 dB of the Ku-band reflectivities in light rain. Surface Doppler measurements can be compared with Doppler calculated from the P-3 navigation parameters and the APR-2 antenna pointing. Such a comparison indicates the bias between the observed and calculated Doppler is very small.

2.2 Acquisition

APR-2 operated on eleven out of the twelve atmospheric science flights of the NASA P-3 aircraft during the Wakasa Bay Experiment (WBE). It did not operate on flight number 6, a clear-air flight, or on the sea-ice flights into Russian air space. Parameters under operator control were set to the same values throughout the experiment, with the exception of the receive window attenuation, which varies with surface brightness. The pulse length was always set to 10 microseconds and the PRF to 5000 Hz. The number of pulses averaged in real time was 250, equivalent to about 60 independent pulses. The elevation angle of the antenna (along-track angle) was set during flight to maintain a near-zero Doppler from the surface, minimizing platform motion contamination to the measured Doppler from precipitation. The platform motion was estimated from the surface and subtracted during ground processing. The azimuth scan limits were about +/- 25 degrees.

For the flights on January 14th and 30th and February 1st, different radar bit-processor configurations were tested, so only a limited amount of the data from these flights have been processed for this release of the data.

The following table is a brief summary of the data collected during the WBE.

Table 3. APR-2 Operation on Wakasa Bay P-3 Flights

Flt. #	Date	Comments
1	1/14/03	APR-2 in Engineering Operations (testing and optimization of configuration) - one file of science data available in this release
2	1/15/03	Mainly snow over land
3	1/19/03	Rainfall over ocean - APR-2 turned off during low altitude lags
4	1/21/03	Mainly rainfall over ocean, some snow
5	1/23/03	Widespread rain and squall line over ocean
6	1/26/03	Clear air flight for PSR calibration, but APR-2 not turned on
7	1/27/03	Widespread rain over land
8	1/28/03	Scattered snow showers over land and ocean
9	1/29/03	Widespread snow over land and ocean
10	1/30/03	Snow showers over ocean - APR-2 in Engineering Operations after 0500 UTC
11	2/1/03	No precipitation - APR-2 mainly in Engineering Operations, no files of science data available in this release
12	2/3/03	Rainfall with varying freezing level

2.3 Processing

The raw APR-2 data are saved in a unique APR-2 format. These data are run through a processor that calibrates the data to reflectivity Z, LDR, and velocity. A second processor uses these data and the aircraft navigation data to create a geolocated Level 1B product. This product is saved in a Hierarchical Data Format (HDF) format similar to the TRMM Precipitation Radar.

2.4 Quality, Errors, and Limitations

This section lists all known problems with the APR-2 version 2 data. Some of these problems are caused by problems in the raw data, while others are processing problems.

Ka-band TWTA had occasional faults. Missing data are replaced by -9999.

Occasional "locks" occurred in the antenna scanning. They are indicated by the value 5 in the surface index product.

On some occasions (1/14, 2/1, and 1/30 after 0500 UTC), APR-2 was operated in "engineering mode," meaning that different radar configurations were tested. Scientific data from these periods may be available upon request from the PI.

External calibration was used for all products. Reflectivity measurements should be considered reliable within ±1 dBZ. At this stage of the analysis, comparison with other PR measurements and modeled sea surface backscatter indicate that APR-2 reflectivities at both frequencies are slightly underestimated. However, further analysis of sea surface return is needed to refine calibration.

LDR requires inter-channel calibration and still has moderate uncertainty at this point; this is especially true for Ka-band LDR, so only Ku-band LDR is provided in this data set.

Artificially high LDR and biased Doppler were seen at rain boundaries due to a low signal-to-noise ratio in these areas. They were replaced by missing data flags (-9999).

Antenna sidelobes show up as artifacts in data in some cases (i.e., thin feature at constant range appearing at large scan angles a few hundred m above the surface).

Occasionally, high lateral winds caused the Doppler measurements to be aliased. Doppler measurements should already be corrected to account for a maximum unambiguous velocity of ±27.5 m/s. Also, correction for aircraft motion is less reliable when the aircraft was maneuvering or was affected by turbulence. Correction for aircraft motion over land is not reliable.

The surface_index is estimated on a scan-by-scan basis. The most frequent misclassification is ocean being classified as flat land.

Overflows and saturations in the receiver were occasionally generated by the surface return. They appear more frequently in off-nadir rays when the aircraft is in roll maneuver, and during flight #2 (1/15). They can affect all channels, but more often they affect only one.

The following data fields are present but are not used in the HDF version 2 files: ka_begin, ka_end, and vsurf (v_surf replaces it). Users should ignore them.

No data are available from the 24th ray of each scan (beamnum = 1). In the Wakasa Bay Experiment, this ray was used for noise measurements (no pulse transmitted). The 24th ray was included in this data set solely for compatibility with APR-2 data sets from previous experiments.

2.5 Instrumentation

2.5.1 Description

The Precipitation Radar (PR) aboard the Tropical Rainfall Measuring Mission (TRMM) satellite launched in 1997 was the first-ever spaceborne radar dedicated to three-dimensional, global precipitation measurements over the tropics and the subtropics.

A second generation, dual-frequency precipitation radar (PR-2) was designed to include digital, real-time pulse compression, extremely compact radio frequency (RF) electronics, and a large deployable dual-frequency cylindrical parabolic antenna subsystem. The antenna is fed by a linear active array for electronic beam scanning.

To demonstrate many of the key PR-2 technologies and designs, an airborne version called APR-2 was developed. The cylindrical reflector antenna and linear feed array for the spaceborne PR-2 have been replaced by traveling wave tube amplifiers (TWTAs), front-end electronics, and an offset parabolic reflector antenna with mechanical scanning. The APR-2 operational geometry is shown in the figure below; it looks downward and scans its beam across-track, with each scan beginning at 25 degrees to the left of nadir and ending at 25 degrees to the right.

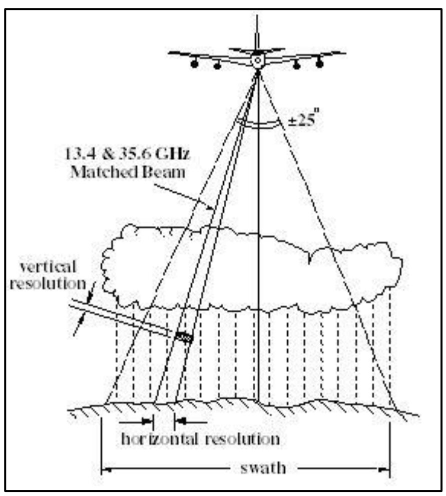

Figure 2. APR-2 Operational Geometry

APR-2 consists of a 0.4 m offset reflector antenna with a mechanically scanned flat plate. For PR-2 the 13.8-GHz antenna feed has been replaced by a dual-frequency feed (13.4 and 35.6 GHz) and the aperture at 35.6 GHz is under-illuminated to provide matched beams at the two frequencies. This choice results in poor Doppler accuracy at Ka-band, but is needed for rain retrieval.

The RF circuitry can be divided into two categories: circuits operating at frequencies of less than 1.5 GHz and circuits operating at frequencies above 1.5 GHz. The lower-frequency circuitry is contained in a single unit, the local oscillator/intermediate frequency (LO/IF) module. This unit converts transmitted chirp signals from 15 MHz up to 1405 MHz and down-converts received IF signals from 1405 MHz to 5 MHz. The unit contains both upconversion channels and all four receive channels and fits into the equivalent of a double-wide 6U-VME card.

The RF front-end electronics are unique to the APR-2 design and consist of five units: one local oscillator/up converter (LO/U) unit, two TWTAs and two waveguide front end (WGFE) units. In the NASA P-3 installation, the two TWTAs are stacked vertically in a standard rack with the LO/U in between. The two WGFEs are mounted on top of the antenna pressure box, near the antenna feed. A calibration loop is included for each channel. This feeds some of the transmit power to the receiver, allowing in-flight variations of the transmit power and receiver gain to be monitored and removed from the data.

The digital electronics consist of a control and timing unit (CTU), an arbitrary waveform generator (AWG), and a data processor. The CTU generates the pulse timing and all other timing signals. It also provides control signals to RF. The AWG is loaded with a digital version of the linear FM chirp to be transmitted. The data processor is based on Field-Programmable Gate Array (FPGA) technology. It performs pulse compression and averaging in real time. The pulse compression scheme in APR-2 is based on real-time filtering in the time domain. The 4 MHz bandwidth received signals are sampled at 20 MHz, then digitally downconverted to complex samples, resulting in I and Q samples at 5 MHz rate. The data processor also includes pulse-pair Doppler processing. The output of the processor is the lag-0 (power) and lag-1 (complex Doppler data) for the co- and cross-polarized channels at each frequency. A Virtual Machine Environment (VME) workstation runs the radar, including ingesting and saving the processed data. Following calibration on the ground, the APR-2 data are stored in a binary HDF format similar to that for the TRMM PR.

The horizontal resolution for the two channels depends on both the particular Antenna Beamwidth and the aircraft altitude, with the latter changing frequently. The horizontal resolution D can be calculated as follows:

$$D=2[h\cdot\tan^{-1}(\theta_{3dB}/2)]$$

where h is the aircraft altitude and θ_{3dB} is the 3dB antenna beamwidth.

Table 4. APR-2 Parameters

Frequency	13.4 GHz	35.6 GHz
Polarization	HH, HV	HH, HV
Antenna diameter	0.4 m	0.14 m
Beamwidth	3.8 deg	4.8 deg
Antenna gain	34 dBi	33 dBi

Antenna sidelobe	-30 dB	-30 dB
Polarization isolation	-25 dB	-25 dB
Peak power	200 W	100 W
Bandwidth	4 MHz	4 MHz
Pulse width	10-40 ms	10-40 ms
PRF	5 kHz	5 kHz
6 dB Pulse Width	60 m	60 m
Range Bin spacing	30 m	30 m
Horizontal Resolution at 6 km Altitude	400 m	500 m
Ground Swath at 6 km Altitude	4.5 km	4.5 km
Noise-equivalent Ze (10 km range)	5 dBZ	5 dBZ
Doppler precision	0.4 m/s	>1 m/s

3 SOFTWARE AND TOOLS

HDF is a multi-object file format developed at the National Center for Supercomputing Applications (NCSA) at the University of Illinois. HDF software and libraries may be accessed from NCSA.

For Matlab users, a sample Matlab routine ("PR2_HDFv2read.m") is available with the data for reading APR-2 HDF data.

4 RELATED DATA SETS

- AMSR-E Validation Data
- AMSR-E Data at NSIDC
- Wakasa Bay Weather Forecast Maps

5 RELATED WEBSITES

Text goes here

6 CONTACTS AND ACKNOWLEDGMENTS

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Next Generation Precipitation Radar

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8 DOCUMENT INFORMATION

8.1 Publication Date

February 2004

8.2 Date Last Updated

February 2021

APPENDIX A - SECOND-GENERATION PRECIPITATION RADAR (PR-2) DESCRIPTION

The Tropical Rainfall Measuring Mission (TRMM) payload includes a 14-GHz precipitation radar (PR), which can provide estimates of rainfall as a function of altitude within its 220-km swath. In response to TRMM's success, various potential improvements to the PR have been considered for the future include using Doppler 3 and dual-polarization, real-time pulse compression for improved rainfall retrieval, enhanced swath, and reduced mass.

As part of a recent study, a complete spaceborne second-generation precipitation radar (PR-2) has been designed. This sensor simulates space-borne rain-mapping radars at 13.4 and 35.6 GHz. This new system offers greatly enhanced capability with much smaller mass than the TRMM PR. The PR-2 operates at 13.4 GHz (Ku-band) and 35.6 GHz (Ka-band), and uses a deployable 5.3-m, electronically-scanned membrane antenna. The operating frequencies were chosen to be within the current allocation for spaceborne radar remote sensing.

Key features of the system include an extremely compact local oscillator and intermediate frequency (LO/IF) module which supports Ku-band and Ka-band transmission at one polarization and reception at two polarizations, allowing co-polarized and cross-polarized backscatter from rainfall to be measured simultaneously. Another innovation is the use of FPGAs for real-time digital filtering, pulse compression, and averaging. The measurements in precipitation will be used for retrieving rain rates to provide improved understanding of rainfall.

(Excerpts taken from Development of an Advanced Airborne Precipitation Radar. G.A. Sadowy, A.C. Berkun, W. Chun, E. Im, and S.L. Durden. technical feature. Jet Propulsion Laboratory)