[redacted]

#376

PIONEER VENUS 1

ALTIMETRIC AND RADIOMETRIC, LFD

78-051A-02D

78-051A-02E

REQ. AGENT	RAND NO.	ACQ. AGENT
SAR DHG	V0293	HKH

PIONEER VENUS 1
RADAR MAPPER

ALTIMETRIC AND RADIOMETRIC, LFD
78-051A-02D

SIDE-LOOKING BACKSCATTER DATA
78-051A-02E

This data set catalog consists of two magnetic tapes, one from each data set. The tapes are 9-track, ASCII, 6250 bpi. D-66234 is VAX Labelled and has 6 files (2 "user files"). The Volume name is PVORAD. D-79142 is IBM Standard Labelled, has 844 files (282 "user files"), and the Volume name is PVSAR. The first "user file" of each tape is a documentation file. The ´D´ and ´C´ numbers and time spans follow:

	D#	C#	Time Span
78-051A-02D	D-66234	C-24788	12/08/78 - 03/19/81
78-051A-02E	D-79142	C-26914	12/08/78 - 03/19/81

REQ. AGENT	RAND NO.	ACQ. AGENT
SAR DHG	V0293	HKH

PIONEER VENUS 1
RADAR MAPPER

ALTIMETRIC AND RADIOMETRIC, LFD
78-051A-02D

SIDE-LOOKING BACKSCATTER DATA
78-051A-02E

This data set catalog consists of two magnetic tapes, one from each data set. The tapes are 9-track, ASCII, IBM Standard Labelled. D-66234 is 1600 bpi and has 6 files (2 "user files"). The Volume name is PVORAD. D-79142 is 6250 bpi, has 844 files (282 "user files"), and the Volume name is PVSAR. The first "user file" of each tape is a documentation file. The ´D´ and ´C´ numbers and time spans follow:

	D#	C#	Time Span
78-051A-02D	D-66234	C-24788	12/08/78 - 03/19/81
78-051A-02E	D-79142	C-26914	12/08/78 - 03/19/81

Massachusetts Institute of Technology
Center for Space Research
Cambridge, Massachusetts 02139

Room 37-601 617-253-6485

December 6, 1988

National Space Science Data Center
Code 633.4
NASA Goddard Space Flight Center
Greenbelt, MD 20771

attn: Liz Kennedy

Dear Ms. Kennedy,

On behalf of the Principal Investigator, Dr. Gordon Pettengill, I'm enclosing two new data sets from the Pioneer Venus Radar Mapper Experiment. The first, **MIT–PV–A&R**, is an updated version of a data set (ID 78–051A–02D) that I submitted to NSSDC in January 1985. The second, **MIT–PV–SAR**, is a completely new submission. I'm enclosing two data abstracts in the format used in Volume 1B of the NSSDC Data Catalog Series for Space Science and Applications Flight Missions, April 1987 (NSSDC/WDC-A-R&S 87–03) to assist in cataloging these submissions.

The data sets are documented twice over—in the accompanying memoranda, and also in the first file on each tape, which contains a machine readable version of the memoranda. We can also make this documentation available in other formats, *e.g.* PostScript , so please let me know if you want it in some special form.

I look forward to hearing from you (email: *pgf@space.mit.edu* or *mitccd::pgf*) that the tapes have arrived safely and that your computers can read them. Please also let me know the NSSDC ID codes that you assign to them so that I can include the numbers in our future documentation.

Sincerely,

Peter G. Ford
Pioneer Venus Radar Team

cc: L. Colin, ARC
R. Fimmel, ARC
J. Head, Brown U.
H. Masursky, USGS
G. Pettengill, MIT

encl: Magnetic tapes (2)
Documentation (2)
Data abstract

ref: ~/NSSDC/pva&r.88.1

78-051A-02A

MIT–PV–A&R V.2

M.I.T. Center for Space Research
70 Vassar Street, Cambridge, MA 02139

December 1, 1988

From: Peter G. Ford, MIT <pgf@space.mit.edu>

Subject: Pioneer Venus Radar Altimeter/Radiometer Data Set Format

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This memo describes the format and contents of the altimeter/radiometer database generated from the Pioneer Venus radar mapper experiment. The database consists of a pair of files. On magnetic tape, they are written using Level 3 ANSI standards, each user file preceded and followed by an ANSI label file.

The first user file contains an ASCII version of this memorandum. On magnetic tape, it is written as 80-byte logical records, blocked into a series of 800-byte physical blocks. There are no separators between logical records, and each physical block therefore contains 10 lines of text. The file name recorded in the ANSI label is **PVORAD.DOC**.

The second user file contains the altimeter/radiometer data itself, in the form of 144132 logical records, each of 160 ASCII bytes. Its ANSI file name is **PVORAD.DATA**. It begins with three header records, containing the following "self-defining" information:

[1] The number of data fields,[1] followed by 4-byte-long field names. The Fortran format is **(I3,n(1X,A4))**. These names are listed in the second column of table 1.

[2] A Fortran "FORMAT" specification that may be used to read the remaining records. The individual format codes are listed in the third column of table 1.

[3] A record containing "undefined" values for all record variables. It may be read according to the format string in record 2. If a data field in a subsequent data record has the same value as the corresponding value in *this* record, that data item is undefined, and should be ignored. The undefined values are listed in the fourth column of tables 1.

[4] The remaining 144129 records contain the ORAD radar data itself. Appendix C contains an example of a Fortran 77 program that can list the data in this file.

As supplied to NSSDC on ½″ magnetic tape, the logical records are packed 200 per 32000 byte physical tape blocks, with no embedded end-of-record indicators such as carriage-return or line-feed characters. The tape is recorded on 9 tracks with odd parity at 1600 bytes per inch. Each file ends with a single tape mark, and an extra tape mark is written after the last EOF2 label.

The following examples assume that the program listed in Appendix C has been compiled into an executable named *listorad.* On IBM's OS/370, the data file would be read as follows:

```
//      EXEC PGM=LISTORAD
//FT05F001 DD UNIT=T1600,VOL=(2,SL),DISP=(OLD,KEEP),DCB=OPTCD=Q
```

---

[1] The first 4 fields, the Pioneer Project-supplied S/C Date, UT, Orbit, and Time-from-Periapsis fields are not included either in the field count or names in the first header record. They **are** included in the format specification and *undefined* definitions in the second and third header records.

and on IBM's VM/CMS as

```
FILEDEF 5 TAP1 SL 1 ( OPTCD Q
LISTORAD
```

A UNIX system might read it with the following commands:

```
mt -f /dev/rmt0 fsf 4
dd if=/dev/rmt0 ibs=32000 cbs=160 conv=unblock | listorad
```

On VMS, it would be read as follows:

```
ASSIGN FOR005 MSA0:PVORAD.DATA
RUN LISTORAD
```

Description of Data Fields

Date:	The year and day-of-year of the observation, as supplied by the Pioneer project. The year occupies the first 5 bytes, the day the remaining 3. This field may be used to correlate this radar observation record with data from other Pioneer Venus instruments, but the *RDAT* field should be used for radar mapping purposes.
Time:	The time of the observation, in milliseconds from midnight UT, as supplied by the Pioneer project. As with the *Date* field, this should only be used for comparison purposes. The accurate radar observation time is contained in the *RAUT* field, described below.
Orbit:	The Pioneer Venus orbit number. The spacecraft maintained a nearly 24–hour orbit. Radar data was taken from orbit 3 on December 7th, 1978 through orbit 834 on March 19th, 1981.
Roll:	The time from periapsis, in seconds, supplied by the Pioneer project. Negative values represent pre-periapsis measurements. These time fields are specified in precisely 12 second intervals from the periapsis time derived from S/C doppler tracking. The 12–second interval was chosen to closely approximate the S/C spin period. Radar data was taken once per S/C rotation, and therefore **not** at exactly 12–second intervals. In addition, the radar altimeter was able to refine the measurement of UT of periapsis. Each radar observation was therefore assigned to a particular 12–second interval by counting S/C revolutions before or after the *true* periapsis, assigning the last radar measurement before periapsis to the *Roll* field with value 0.
RDAT:	The year and day-of-year of the observation. The year occupies the first 5 bytes, the day the remaining 3.
RAUT:	The UT of the first *main bang* of the radar altimeter, i.e. the time that the first altimeter pulse left the transmitter, measured in milliseconds from midnight UT.
BLAT:	The latitude[2] of the center of the antenna beam projected on the planet during the radiometric mode. This is the latitude of the radiometric brightness measurement reported in the *PCAL, SCAL*, and *RBRT* fields.

---

[2] All latitudes and longitudes are expressed in degrees. Latitudes are positive in the northern hemisphere, negative in the southern. Longitudes are always positive, in the range 0 through 360. Longitudes increase eastward of the prime meridian, and the (retrograde) planetary rotation is from east to west. The body-fixed 1985 IAU coordinate system (VBF85) is used. See appendix B and the bibliography for more details.

Table 1: Format of Altimeter/Radiometer Data Record

	Field Name	*Fortran Format*	*Undefined Value*	*Data Units*	*Field Description*
1	Date	I8	0		Year and day of observation
2	Time	I9	0	msec	UT from midnight
3	Orbit	I5	0		Orbit number
4	Roll	I6	0	sec	Time ± periapsis UT
5	RDAT	I8	99999999		Year and day of radar measurement
6	RAUT	I9	999999999	msec	UT of radar measurement
7	BLAT	F7.3	999.999	°N	Radiometer footprint latitude
8	BLON	F7.3	999.999	°E	Radiometer footprint longitude
9	PCAL	F6.1	9999.9	V	Radiometer voltage reading
10	SCAL	F6.1	9999.9	V	Radiometer background reading
11	RBRT	F6.1	9999.9	K	Planet Brightness temperature
12	RLAT	F7.3	999.999	°N	Altimeter footprint latitude
13	RLON	F7.3	999.999	°E	Altimeter footprint longitude
14	XLIM	F5.0	9999.	km	Cross-track altimeter footprint size
15	YLIM	F5.0	9999.	km	Along-track altimeter footprint size
16	RRAD	F8.3	9999.999	km	Measured planetary radius
17	DRAD	F7.3	999.999	km	Formal error in DRAD
18	SLOP	F7.3	999.999	°	RMS slope at meter scale
19	DSLO	F7.3	999.999	°	Formal error in SLOP
20	RRHO	F5.2	99.99		Fresnel reflectivity
21	DRHO	F5.2	99.99		Formal error in RRHO
22	RCOR	F5.2	99.99		Correction to RRHO
23	RASL	F5.2	99.99		RRAD – SLOP correlation
24	RARH	F5.2	99.99		RRAD – RRHO correlation
25	SLRH	F5.2	99.99		SLOP – RRHO correlation

BLON:	The longitude of the radiometric brightness measurement reported in the *PCAL*, *SCAL*, and *RBRT* fields.
PCAL:	The voltage reading from the radar receiver during the radiometry period, when the transmitter was turned off and the antenna pointed within about 5° of the plane defined by the spacecraft spin-axis and the nadir.

SCAL: The voltage reading from the radar receiver during the radiometry–background period, when the transmitter was turned off and the antenna pointed within about 5° of the plane defined by the spacecraft spin-axis and the zenith.

RBRT: The microwave brightness temperature of the planet, in degrees Kelvin, derived from *PCAL* and *SCAL*. The data set was divided into 1° latitude intervals. For each interval, the average *SCAL* reading $\overline{SCAL}$ was taken to represent a measurement of the 3K cold sky.[3] The average *PCAL* values $\overline{PCAL}$ from lowland regions were interpreted as measuring an average temperature of 735K with an emissivity of 88%. *RBRT* is therefore obtained from $\overline{SCAL}$ and $\overline{PCAL}$ by the linear relationship

$$RBRT = \frac{735 \cdot 0.88 \cdot (PCAL - \overline{SCAL}) + 3 \cdot (\overline{PCAL} - PCAL)}{\overline{PCAL} - \overline{SCAL}}$$

RLAT: The latitude of the average radar altimeter *footprint* for this observation. Because of the delay and doppler filtering applied by the on-board data processing electronics, the footprint is not necessarily centered about the sub-orbital point (S/C nadir), nor is it symmetric with respect to the antenna axis. In addition, some observations are, in fact, averaged over up to 4 measurements taken at varying doppler frequency offsets, corresponding to 4 separated footprints spaced along the S/C ground track.

RLON: The longitude of the average radar altimeter footprint.

XLIM: The average cross-track dimension of the altimeter footprint, in km. This is determined by the delay-resolution of the radar receiver.

YLIM: The average along-track dimension of the altimeter footprint, in km. Above about 500 km S/C altitude, this is also determined by the delay-resolution of the radar receiver. Below this altitude, it is determined by the frequency resolution. The high altitude footprints are therefore circular, the low altitude ones are approximately elliptical, with $YLIM \leq XLIM$.

RRAD: The planetary radius in kilometers, measured by the radar altimeter. A correction has been made for atmospheric delay (see Kliore *et al.*, 1985).

DRAD: The formal error in *RRAD*, in km, derived from the statistics of the time-sampled altimetry echo-power profile. All other fields that are described here as *averages* are weighted by this formal error when averaging over multi-doppler-offset measurements.

SLOP: The r.m.s. average surface slope at meter scale, in degrees, from the altimeter measurement, derived by analyzing the time-sampled profile according to Hagfors' Law of near-normal-incidence scattering from a quasi-specular surface, where the specific radar cross-section, $\sigma_0(\theta)$ varies with the scattering angle θ according to

$$\sigma_0(\theta) = \rho_0 \frac{C}{2} \left\{ \cos^4\theta + C \sin^2\theta \right\}^{-\frac{3}{2}}$$

where ρ_0 is the Fresnel reflectivity (the *RRHO* variable, see below), and the Hagfors constant C is interpreted as $SLOP^{-2}$.

DSLO: The formal error in *SLOP*, in degrees, derived during the process of fitting the returned time-sampled radar echo to a set of Hagfors Law templates.

RRHO: The Fresnel reflectivity of the surface. Represented as ρ_0 in the Hagfors equation, above. This is related to the (complex) surface bulk dielectric constant ε via the expression

---

[3] A number of measurements were made in which the Sun appeared in the antenna beam during the *SCAL* readings, and these were therefore discarded.

$$\rho_f = \left| \frac{\sqrt{\varepsilon}-1}{\sqrt{\varepsilon}+1} \right|^2$$

where the difference between ρ_f and ρ_0 is explained in the *RCOR* entry, below.

DRHO: The formal error in *RRHO*, derived during the process of fitting the returned time-sampled radar echo to a set of theoretical templates derived from Hagfors Law.

RCOR: A correction to *RRHO* to account for that fraction of the incident radar beam that is reflected by sub-wavelength-sized scatterers. This component was estimated, where possible, from the ORAD side-looking radar imaging mode, and modeled by the phenomenological formula:

$$\sigma_D(\theta) = g\alpha\rho_f\cos^{\frac{3}{2}}\theta$$

where $g \approx 2.69$ is a fitted geometrical factor, and $\rho_0 = (1-\alpha)\rho_f$. α is the fraction of the surface covered by diffusely-scattering material, and ρ_f represents the "true" Fresnel reflectivity. *RCOR* is equal to $\rho_f - \rho_0$, i.e. it must be added to *RRHO* to obtain the true Fresnel reflectivity. This correction is only available for that portion of the altimetric dataset this is also covered by side-looking imaging data, i.e. from about 15°S to 45°N latitude.

RASL: The formal correlation coefficient between *RRAD* and *SLOP*, derived while fitting the observed echo-power profile to Hagfors Law derived templates.

RARH: The formal correlation coefficient between *RRAD* and *RRHO*.

SLRH: The formal correlation coefficient between *SLOP* and *RRHO*.

A. References

- T. Hagfors, *Radio Sci.*, **5**, 189 (1970).
- G.H. Pettengill, D.F. Horwood, C.H. Keller, "Pioneer Venus Orbiter Radar Mapper: Design and Operation", *IEEE Trans. Geosci. Remote Sensing*, **GE–18**, No. 1, January 1980.
- G.H. Pettengill, E. Eliason, P.G. Ford, G.B. Loriot, H. Masursky, G.E. McGill, "Pioneer Venus Radar Results: Altimetry and Surface Properties", *J. Geophys. Res.*, **85**, 8261 (1980).
- H. Masursky, E. Eliason, P.G. Ford, G.E. McGill, G.H. Pettengill, G.G. Schaber, G. Schubert, "Pioneer Venus Radar Results: Geology from Images and Altimetry", *J. Geophys. Res.*, **85**, A13, 8232 (1980).
- G.H. Pettengill, P.G. Ford, S. Nozette, "Venus: Global Surface Radar Reflectivity", *Science*, **217**, 640 (1982).
- P.G. Ford, G.H. Pettengill, "Venus: Global Surface Radio Emissivity", *Science*, **220**, 1379 (1983).
- A.J. Kliore, V.I. Moroz, G.M. Kesting, "The Venus International Reference Atmosphere", *Advances in Space Research*, **5**, 11 (1985), Pergamon Press. COSPAR Report JPL–D–2216.
- G.H. Pettengill, P.G. Ford, B.D. Chapman, "Venus: Surface Electromagnetic Properties", *J. Geophys. Res.*, **93**, B12, 14881 (1988).

B. Venus Coordinate Systems

The latitudes and longitudes in this data set are expressed in the Venus body fixed system adopted by the IAU in 1985 and used by the Magellan Project. It is related to other coordinate systems via a series of time-dependent rotation matrices. These coordinate systems are as follows:

PVO80	Venus body fixed (Pioneer Venus)
VME50	Venus equator of 1950
EMO50	Earth ecliptic of 1950
EME50	Earth equator of 1950
EME00	Earth equator of J2000
EMO00	Earth ecliptic of J2000
VME00	Venus equator of J2000 *(JPL/IAU)*
VBF85	Venus body fixed (Magellan) *(IAU of 1985)*

1. The Pioneer Venus Coordinate System (PVO80)

Latitude of Venus pole	88.50737°
Longitude of Venus pole	31.48165°
Rotation period	243.0 days
Latitude of Venus ascending node	–1.39873°
Longitude of Venus ascending node	51.91788°
Longitude of prime meridian in 1964.0	164.6089°

The angles and ascending node are defined in the EMO50 coordinate system. The following transformation matrices operate on right-handed cartesian 3-vectors.

2. PVO80 → VME50 Rotation

$$V_{VME50} = \mathbf{E}\, V_{PVO80} = \begin{bmatrix} \cos\delta & -\sin\delta & 0 \\ \sin\delta & \cos\delta & 0 \\ 0 & 0 & 1 \end{bmatrix} V_{PVO80}$$

$$\delta = 164.6089 - (JD - 1950) * 360/243.0$$

3. VME50 → EMO50 Rotation

$$V_{EMO50} = \mathbf{F}\, V_{VME50}$$

$$= \begin{bmatrix} 0.616606488128 & -0.786958046198 & 0.0222142369303 \\ 0.78689300063 & 0.616939511419 & 0.0136031176373 \\ -0.0244099233564 & 0.00909245696085 & 0.999660683866 \end{bmatrix} V_{VME50}$$

4. EMO50 → EME50 Rotation

$$V_{EME50} = \mathbf{B}^{-1}\, V_{EMO50} = \begin{bmatrix} 1.0 & 0.0 & 0.0 \\ 0.0 & 0.9174369451139180 & -0.3978812030494049 \\ 0.0 & 0.3978812030494049 & 0.9174369451139180 \end{bmatrix} V_{EMO50}$$

5. EME50 → EME00 Rotation

$$V_{EME00} = \mathbf{A}\, V_{EME50}$$

$$= \begin{bmatrix} 0.9999256794956877 & -0.0111814832204662 & -0.0048590038153592 \\ 0.0111814832391717 & 0.9999374848933135 & -0.0000271625947142 \\ 0.0048590037723143 & -0.0000271702937440 & 0.9999881946023742 \end{bmatrix} V_{EME50}$$

6. EME00 → VME00 Rotation

$$V_{VME00} = \mathbf{C}^{-1}\, V_{EME00} = \begin{bmatrix} 0.99889808 & 0.04693211 & 0.0 \\ -0.04325546 & 0.92064453 & 0.38799822 \\ 0.01820958 & -0.38757068 & 0.92166012 \end{bmatrix} V_{EME00}$$

7. VME00 → VBF85 Rotation

$$V_{VBF85} = \mathbf{D}^{-1}\, V_{VME00}$$

$$= \begin{bmatrix} \cos\omega & \sin\omega & 0 \\ -\sin\omega & \cos\omega & 0 \\ 0 & 0 & 1 \end{bmatrix} V_{VME00}, \quad \omega = 160.39-1.4813291*(JD-2000)$$

8. Resulting PVO80 → VBF85 Rotation

Cartesian 3-vectors are transformed by the product of the individual rotation matrices, i.e. $\mathbf{D}^{-1}(\omega)\mathbf{C}^{-1}\mathbf{A}\mathbf{B}^{-1}\mathbf{F}\mathbf{E}(\delta)$ which depends on time through ω and δ. At the epoch of 1980.0, *i.e.* approximately in the middle of the Pioneer Venus data taking period, 1980.0,

$$V_{VBF85} = \begin{bmatrix} 0.999990805 & 0.001520115 & -0.004009573 \\ -0.001530001 & 0.999995801 & -0.002462105 \\ 0.004005809 & 0.002468222 & 0.999988929 \end{bmatrix} V_{PVO80}$$

C. Fortran 77 Program to read Altimeter/Radiometer Data File

```
c           LENGTH = maximum record length in bytes
c           MAXVAR = maximum number of variables per record

            integer             LENGTH, MAXVAR
            parameter           ( LENGTH=160, MAXVAR=50 )

            real*4              rbuf(MAXVAR), dbuf(MAXVAR)
            integer*4           ibuf(MAXVAR), idbuf(MAXVAR)
            character*4         name(MAXVAR)
            character*1         frmt(LENGTH)

            data     name(1)    / "Date" /
            data     name(2)    / "ScUT" /
            data     name(3)    / "Norb" /
            data     name(4)    / "Roll" /
            data     nint       / 0 /
```

```
c           read field names
            read (5,"(I3,100(1X,A4))",iostat=ios,end=40,err=40)
    x               nitem, (name(i+4),i=1,nitem)

c           read field format
            read (5,"(1000A1)",iostat=ios,end=40,err=40)
    x               (frmt(i),i=1,LENGTH)

c           Compute nint = number of integer variables in each record.
c           It is assumed that all integers precede all floats.
            do 10 i=1,LENGTH
10                  if (frmt(i) .eq. "i" .or. frmt(i) .eq. "I") nint = nint + 1

c           read undefined field values
            read (5,frmt,iostat=ios,end=40,err=40)
    x               (idbuf(i),i=1,nint), (dbuf(i),i=nint+1,nitem+4)

            do 20 nrec = 1, 100000

c           read a data record
            read (5,frmt,iostat=ios,end=30,err=40)
    x               (ibuf(i),i=1,nint), (rbuf(i),i=nint+1,nitem+4)
            if (nrec .gt. 1) write (6,"(1x)")

c           transform seconds +- periapsis into roll number
            ibuf(4) = ibuf(4)/12

c           display field values
            do 20 n = 1,nitem+4

                    if ((n .gt. 4 .and. n .le. nint .and. ibuf(n) .eq. idbuf(n))
    x                       .or. (n .gt. nint .and. rbuf(n) .eq. dbuf(n))) then
                            write (6,"(1X,I6,'.',I2,'..  ',A4,' = ?')")
    x                               nrec, n, name(n)
                    else if (n .le. nint) then
                            write (6,"(1X,I6,'.',I2,'..  ',A4,' = ',I9)")
    x                               nrec, n, name(n), ibuf(n)
                    else
                            write (6,"(1X,I6,'.',I2,'..  ',A4,' = ',F12.5)")
    x                               nrec, n, name(n), rbuf(n)
                    end if

20          continue
30          stop

c           error return
40          write (0,"('read error ',i3)") ios
            stop 1
            end
```

MIT-PV-SAR V.2

M.I.T. Center for Space Research
70 Vassar Street, Cambridge, MA 02139

December 1, 1988

From: Peter G. Ford, MIT <pgf@space.mit.edu>
M.I.T. Room 37-601, tel: (617) 253-6485

Subject: Pioneer Venus Radar Side-Looking Backscatter Data Set Format

---

This memo describes the format and contents of the side-looking radar backscatter database generated from the Pioneer Venus radar mapper experiment. This database consists of a set of 281 files. On magnetic tape, they are written using Level 3 ANSI standards, each user file preceded and followed by an ANSI label file.

The first user file contains an ASCII version of this memorandum. On magnetic tape, it is written as 80-byte logical records, blocked into a series of 800-byte blocks. There are no separators between logical records, and each physical block therefore contains 10 lines of text. The file name recorded in the ANSI label is PVSAR.DOC.

The remaining 280 user files contain the data set itself-the backscatter measurements are sorted by increasing latitude value into 280 quarter-degree strips. File 2 contains data from latitude 19.75'S to 19.50'S, and file 281 contains data from 50.00'N to 50.25'N. In addition, within each data file, the records have been sorted into increasing value of longitude.

Each data file contains a set of fixed-length ASCII records, each 53 bytes long. The ANSI names are PVSAR001.RASTER through PVSAR281.RASTER. Each file begins with three header records, containing the following "self-defining" information:

[1] The number of data fields, followed by 4-byte-long field names. The Fortran format is (I3,n(1X,A4)). These names are listed in the second column of table 1.

[2] A Fortran "FORMAT" specification that may be used to read the remaining records. The individual format codes are listed in the third column of table 1.

[3] A record containing "undefined" values for all record variables. It may be read according to the format string in record 2. If a data field in a subsequent data record has the same value as the corresponding value in this record, that data item is undefined, and should be ignored. The undefined values are listed in the fourth column of tables 1.

[4] The remaining records contain the backscatter data itself. Appendix C contains an example of a Fortran 77 program that can list the data in this file.

As supplied to NSSDC on 1/2'' magnetic tape, the data records are packed 600 per 31800 byte physical tape blocks, with no embedded length fields or end-of-record indicators such as carriage-return or line-feed characters. The tape is recorded on 9 tracks with odd parity at 6250 bytes per inch. Each file ends with a single tape mark, and an extra tape mark is written after the last EOF2 label.

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The following examples assume that the program listed in Appendix C has been compiled into an executable named listsar. On IBM's OS/370, data file number "n" (user file "n+1") would be read as follows:

```
//       EXEC PGM=LISTSAR
//FT05F001 DD UNIT=T6250,VOL=(n+1,SL),DISP=(OLD,KEEP),DCB=OPTCD=Q
```

and on IBM's VM/CMS as

```
FILEDEF 5 TAP1 SL "n+1" ( OPTCD Q DSNAME PVSARn.RASTER
LISTSAR
```

A UNIX system might read it with the following commands

```
mt -f /dev/rmt0 fsf "3*n+1"
dd if=/dev/rmt0 ibs=31800 cbs=53 conv=unblock | listsar
```

On VMS, it would be read as follows:

```
ASSIGN FOR005 MSA0:PVSARn.RASTER
RUN LISTSAR
```

where "n" runs from "001" through "280".

Table 1: Format of Side-Looking Backscatter Data Record

	Field Name	Fortran Format	Undefined Value	Data Units	Field Description
1	NORB	I5	0		Orbit number
2	SECS	I6	0	sec	Time after periapsis (UT)
3	SMAP	I2	0		Early/Late mapping flag
4	SDEL	I2	0		Delay cell index
5	SDOP	I2	0		Doppler cell index
6	SLAT	F7.3	999.999	degN	Footprint latitude
7	SLON	F8.3	9999.999	degE	Footprint longitude
8	SIG0	F7.5	9.99999		Specific radar cross section
9	SARE	F7.1	99999.9	sqkm	Footprint area
10	SANG	F7.2	99999.9	deg	Scattering angle

DESCRIPTION OF DATA FIELDS

NORB: The Pioneer Venus orbit number. The spacecraft maintained a nearly 24-hour orbit. Radar data was taken from orbit 3 on December 7th, 1978 through orbit 834 on March 19th, 1981.

SECS: The time from periapsis, in seconds. Negative values represent pre-periapsis measurements. These time fields are specified in precisely 12 second intervals from the periapsis time derived from S/C doppler tracking. The 12-second interval was chosen to closely approximate the S/C spin period.

Radar imaging data was taken once or twice per S/C rotation, and therefore not at exactly 12-second intervals. In addition, the radar altimeter was able to refine the measurement of UT of periapsis. Each radar observation was therefore assigned to a particular 12-second interval by counting S/C revolutions before or after the true periapsis, assigning the last radar measurement before periapsis to the SECS field with value 0.

SMAP: A single decimal digit, set equal to 1 if the measurement was made during the early imaging mode, or to 2 if during the late imaging mode.

SDEL: A single decimal digit in the range 1-8 representing the range-window that corresponded to this measurement. Each side-looking radar map was processed on-board the spacecraft into 8 range intervals and 8 doppler intervals. Range 1 represents the shortest echo delay, and therefore the footprint nearest to the subradar point.

SDOP: A single decimal digit in the range 1-8 representing the doppler-window that corresponds to this measurement. A low doppler index normally represents negative doppler shifts, and therefore footprints behind the spacecraft, while a high index represents positive doppler shifts and footprints ahead of the spacecraft. However, the doppler filtering was performed on board by a fourier transform-spacecraft timing errors sometimes caused the antenna beam to point ahead of, or behind its intended target (between doppler cells 4 and 5). In this case, the subsequent doppler aliasing will cause doppler cell 1 (or 8) to lie ahead of cell 8 (or behind cell 1).

SLAT: The latitude of the center of the backscatter footprint in degrees, calculated by projecting the delay and doppler values onto a sphere of radius 6052 km. Within a given data file, the values of the SLAT field will be confined to a given 1/4 degree interval.

All latitudes and longitudes are expressed in degrees. Latitudes are positive in the northern hemisphere, negative in the southern. Longitudes are always positive, in the range 0 through 360. Longitudes increase eastward of the prime meridian, and the (retrograde) planetary rotation is from east to west. The Body fixed 1985 IAU coordinate system (VBF85) is used. See appendix B and the bibliography for more details.

SLON: The longitude of the center of the backscatter footprint, in degrees. The entries in each data file have been sorted into increasing SLON value.

SIG0: The specific radar cross-section sigma-zero, measured by the radar mapper, corrected for atmospheric absorption.

SARE: The area of surface interacting with this measurement, in square kilometers assuming a planetary radius of 6052 km.

SANG: The scattering angle for this measurement, in degrees, i.e. the angle between the incident (and reflected) ray and the surface normal.

A. REFERENCES

- G.H. Pettengill, D.F. Horwood, C.H. Keller, "Pioneer Venus Orbiter Radar Mapper: Design and Operation", IEEE Trans. Geosci. Remote Sensing, GE-18, No. 1, January 1980.
- H. Masursky, E. Eliason, P.G. Ford, G.E. McGill, G.H. Pettengill, G.G. Schaber, G. Schubert, "Pioneer Venus Radar Results: Geology from Images and Altimetry", J. Geophys. Res., 85, A13, 8232 (1980).
- G.H. Pettengill, P.G. Ford, B.D. Chapman, "Venus: Surface Electromagnetic Properties", J. Geophys. Res., 93, B12, 14881 (1988).

B. VENUS COORDINATE SYSTEMS

The latitudes and longitudes in this data set are expressed in the Venus body fixed system adopted by the IAU in 1985 and used by the Magellan Project. It is related to other coordinate systems via a series of time-dependent rotation matrices. These coordinate systems are as follows:

PV080	Venus body fixed (Pioneer Venus)
VME50	Venus equator of 1950
EM050	Earth ecliptic of 1950
EME50	Earth equator of 1950
EME00	Earth equator of J2000
EM000	Earth ecliptic of J2000
VME00	Venus equator of J2000 (JPL/IAU)
VBF85	Venus body fixed (Magellan) (IAU of 1985)

[1] The Pioneer Venus Coordinate System (PV080)

Latitude of Venus pole	88.50737 deg
Longitude of Venus pole	31.48165 deg
Rotation period	243.0 days
Latitude of Venus ascending node.	-1.39873 deg
Longitude of Venus ascending node	51.91788 deg
Longitude of prime meridian in 1964.0 . .	164.6089 deg

The angles and ascending node are defined in the EM050 coordinate system. The following transformation matrices operate on right-handed cartesian 3-vectors.

[2] PV080 -> VME50 Rotation

```
                              | cos(d) -sin(d)  0 |
V(VME50) = E * V(PV080) =     | sin(d)  cos(d)  0 | * V(PV080)
                              |   0       0     1 |

d = 164.6089 - (JD-1950)*360/243.0
```

[3] VME50 -> EM050 Rotation

```
V(EM050) = F * V(VME50)

     |  0.616606488128  -0.786958046198    0.0222142369303 |
F =  |  0.78689300063    0.616939511419    0.0136031176373 |
     | -0.0244099233564  0.00909245696085  0.999660683866  |
```

[4] EMO50 -> EME50 Rotation

V(EME50) = B**-1 * V(EMO50)

$$\text{B**-1} = \left|\begin{matrix} 1.0 & 0.0 & 0.0 \\ 0.0 & 0.9174369451139180 & -0.3978812030494049 \\ 0.0 & 0.3978812030494049 & 0.9174369451139180 \end{matrix}\right|$$

[5] EME50 -> EME00 Rotation

V(EME00) = A * V(EME50)

$$A = \left|\begin{matrix} 0.9999256794956877 & -0.0111814832204662 & -0.0048590038153592 \\ 0.0111814832391717 & 0.9999374848933135 & -0.0000271625947142 \\ 0.0048590037723143 & -0.0000271702937440 & 0.9999881946023742 \end{matrix}\right|$$

[6] EME00 -> VME00 Rotation

V(VME00) = C**-1 * V(EME00)

$$\text{C**-1} = \left|\begin{matrix} 0.99889808 & 0.04693211 & 0.0 \\ -0.04325546 & 0.92064453 & 0.38799822 \\ 0.01820958 & -0.38757068 & 0.92166012 \end{matrix}\right|$$

[7] VME00 -> VBF85 Rotation

$$\text{V(VBF85)} = \text{D**-1} * \text{V(VME00)} = \left|\begin{matrix} \cos(w) & \sin(w) & 0 \\ -\sin(w) & \cos(w) & 0 \\ 0 & 0 & 1 \end{matrix}\right| * \text{V(VME00)}$$

w = 160.39-1.4813291*(JD-2000)

[8] Resulting PVO80 -> VBF85 Rotation

Cartesian 3-vectors are transformed by the product of the individual rotation matrices, i.e.

D**-1(w) * C**-1 * A * B**-1 * F * E(d)

which depends on time through (w) and (d). At the epoch of 1980.0, i.e. approximately in the middle of the Pioneer Venus data taking period,

$$\text{V(VBF85)} = \left|\begin{matrix} 0.999990805 & 0.001520115 & -0.004009573 \\ -0.001530001 & 0.999995801 & -0.002462105 \\ 0.004005809 & 0.002468222 & 0.999988929 \end{matrix}\right| * \text{V(PVO80)}$$

-02E 7

C. FORTRAN 77 PROGRAM TO READ THE RADAR BACKSCATTER DATA FILE

```
c     LENGTH = maximum record length in bytes
c     MAXVAR = maximum number of variables per record

      integer        LENGTH, MAXVAR
      parameter      ( LENGTH=50, MAXVAR=20 )

      real*4         rbuf(MAXVAR), dbuf(MAXVAR)
      integer*4      ibuf(MAXVAR), idbuf(MAXVAR)
      character*4    name(MAXVAR)
      character*1    frmt(LENGTH)

c     read field names

      read (5,"(I3,100(1X,A4))",iostat=ios,end=40,err=40)
           nitem, (name(i),i=1,nitem)

c     read field format

      read (5,"(1000A1)",iostat=ios,end=40,err=40)
     x     (frmt(i),i=1,LENGTH)

c     Compute nint = number of integer variables in each record.
c     It is assumed that all integers precede all floats.

      nint = 0
      do 10 i=1,LENGTH
         if (frmt(i) .eq. "i" .or. frmt(i) .eq. "I")
     x      nint = nint + 1
10    continue

c     read undefined field values

      read (5,frmt,iostat=ios,end=40,err=40)
          (idbuf(i),i=1,nint), (dbuf(i),i=nint+1,nitem)

      do 20 nrec = 1, 10000000

c        read a data record

         read (5,frmt,iostat=ios,end=30,err=40)
     x        (ibuf(i),i=1,nint), (rbuf(i),i=nint+1,nitem)
         if (nrec .gt. 1) write (6,"(1x)")

c        display field values

         do 20 n = 1,nitem

            if (n .gt. nint .and. rbuf(n) .eq. dbuf(n))
     x      then
               write (6,"(1X,I6,'.',I2,'..  ',A4,' = ?')")
     x               nrec, n, name(n)
            else if (n .le. nint) then
               write (6,"(1X,I6,'.',I2,'..  ',A4,' = ',I9)")
     x               nrec, n, name(n), ibuf(n)
            else
               write (6,"(1X,I6,'.',I2,'..  ',A4,' = ',F12.5)")
     x               nrec, n, name(n), rbuf(n)
            end if
```

```
20      continue

30      stop

c       error return

40      write (0,"('read error ',i3)") ios
        stop 1
        end
```

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78-051A-02C
78-051A-02D

Pioneer Venus Hypsometry

Peter G Ford
MIT Center for Space Research
December 22, 1986

In 1980, Pioneer Venus altimetry results were published, claiming a mean planetary radius of 6051.5 km. This value was used by USGS when preparing Venus contour maps. A smoothed version of this early data set also found its way to Project Magellan. At the same time, the raw data were re-processed at MIT and the results were delivered to NSSDC, from which center they have been distributed to the scientific community. It has recently been pointed out that the re-processed data have a quite different mean radius of 6051.92 km. A careful review of the data processing history, and of the data sets themselves, show that the NSSDC data set is accurate, and that the previously published radius values were in error. The early error arises from several sources, and cannot be described by a simple algorithm.

Historical Review

Raw Pioneer Venus radar data were delivered to MIT as a set of three data products, one set per S/C orbit:

- **Quick-look data**, received via high-speed RSCS data link. The data stream was split up at MIT into nine files, and written to tape (PVQLxx).
- **Experimental Data Record**, received on CCT (PVExxx). Each tape contained three files: header, uplink commands, and down-link sensor and engineering data.
- **Supplementary Experimental Data Record** (PVSxxx), received on CCT. Each tape contained six files: header, S/C pulse times, attitude, roll period, Sun/star reference, and ephemeris.

To conserve tapes, the nine data files that defined each orbit were merged and written to CCT as a single file. These tapes were originally written at 800 *bpi* (PVBxxx), and were later copied to 6250 *bpi* (PVMxxx).

The raw data contained a mixture of nadir-pointing *altimetry* measurements and side-looking backscatter *images*. In addition, a total of four distinct "levels" of data product were recognized:

0. Quick-look data processed without any spacecraft ephemeris information.
1. Quick-look data processed with a priori orbit elements.
2. EDR/SEDR data processed with a spacecraft ephemeris derived from tracking data.
3. A re-processing of Level 2 data using more accurate algorithms.

Each level of data passed through the following data processing programs:

CYTHERA: A PL/1 program that read an orbit from a "merge tape", reconstructed the 9 original Quick-look or EDR/SEDR files, and processed the ORAD data, roll-by-roll[1]. Three output files were written for each orbit:

- **Archive file** (PVAxxx) containing a full binary record of all intermediate quantities used in the calculations. The Level 0, 1, and 2 archive files were written to 800 *bpi* tapes. The Level 3 files were written to 6250 *bpi* tapes and the previous 800 *bpi* tapes were re-cycled.

- **Composite Data file** (PVCDxx) containing an abbreviated record of each altimetry and imaging measurement. Copies of these files were sent to USGS Flagstaff. The originals were retained for subsequent *cythp* editing (see below), but were later re-cycled.

- **Print file** (PVPxxx) was written to CCT and thence to microfiche. The tapes were then re-cycled.The fiche contains lists of pertinent engineering and ephemeris quantities, and condensed roll-by-roll plots of altimetry and imaging results.

Cythera went through two major revisions (see Appendix). The first was made in the spring of 1979 when it became clear that the Project-derived spacecraft pulse times were seriously in error. *Cythera* was reprogrammed to use the down-link radar data header fields to estimate the timing corrections. The second revision, in the summer of 1981, incorporated a correction associated with atmospheric signal delay and attenuation. It also used a more reliable profile fitting algorithm and an improved treatment of doppler-filter efficiency.

CYTHP: an IBM/BAL program that edited individual altimetric data points. *Cythp* read and wrote composite data files, displaying single- or multi-orbit results on an HP2648A graphics terminal. Each orbit was inspected by this program, often several times, and each apparently anomalous datum was inspected on the corresponding micro-fiche frame. Bad points were then removed or flagged.

CYTFIT: an IBM/BAL program that extracted radius fields from a set of composite data files, grouped them into *cells* according to their footprint altitudes and longitudes, and computed a set of corrections to the periapsis orbital elements of each orbit so as to minimize the variance of radius values within each cell. *Cytfit* was first used in the fall of 1979, at the end of the nominal mission, and then at several times until the end of radar processing. After each use, the set of input composite data files was archived.

GIPS: the **General Image Processing System**, a set of C-language functions written for the VAX UNIX operating system as part of MIT's SIR-B involvement, was not applied to ORAD data until the spring of 1982. It identified several bad radius values, necessitating further *cytfit* global fitting, and was used extensively in later corrections to Pioneer Venus reflectivity and imaging data.

---

[1] The ORAD radar was operated once per spacecraft revolution, when its antenna pointed toward the nadir. Hence the term *roll* to denote a discrete radar measurement period.

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Hypsometry

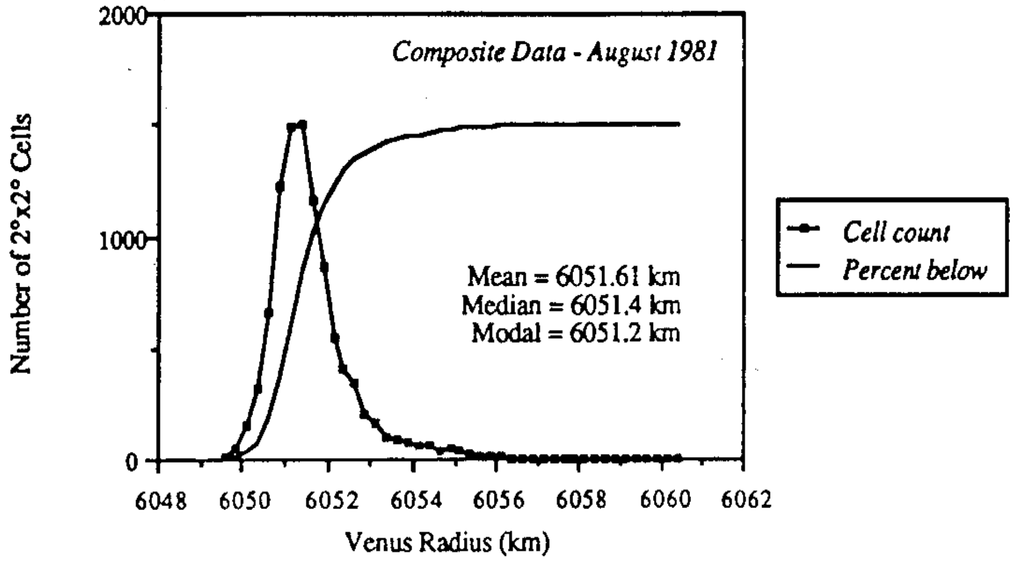
The global radius values reported[2] in 1980 were calculated in October 1979 when the nominal mission was completed. That data set contained two serious gaps: the first between orbits 15 and 47 was the result of an instrumental malfunction; the second, between orbits 249 and 284, was due to telemetry failure during superior conjunction. As we shall see, this led to sizable systematic errors in the values reported in this early paper:

Erroneous values reported in JGR 1980 article

Mean radius	6051.5 km
Median radius	6051.2 km
Modal radius	6051.1 km
Ellipsoid axis A.	6051.3 km
Ellipsoid axis B	6051.0 km
Ellipsoid axis C	6051.2 km

During the extended mission, EDRs were processed in weekly batches, and the resulting composite data were edited by *cythp* every few weeks. *Cytfit* was run on several occasions, and the resulting corrected composite data files were sent to USGS Flagstaff. Here a mistake was made—the *cytfit* input consisted of previously corrected composite data files along with freshly edited ones, thereby perpetuating the systematic radius errors inherited from the October 1979 fit. We *should* have used the un-fitted files, but these had already been re-cycled from the nominal mission and it would have been costly to re-create (and re-edit) them from the PVAxxx archive tapes. The last radar data were taken in March 1981, yielding the following global radius distribution:

Level 2 Hypsometric Distribution



---

[2] G.H. Pettengill, E. Eliason, P.G. Ford, G.B. Loriot, H. Masursky, G.E. McGill, "Pioneer Venus Radar Results: Altimetry and Surface Properties", *J. Geophys. Res.*, 85, 8261 (1980).

This reflects the "Level 2" data set that was used by USGS Flagstaff for all their published Pioneer Venus data products. MIT also distributed copies of this data to the Radar Team members and others:

Walter Brown	JPL
Don Campbell	Cornell/Arecibo
Bill Kaula	UCLA
George McGill	U. Mass, Amherst
Bob Reasenberg	MIT

In the spring of 1981, after the radar measurements were terminated,[3] we began working on improvements to the *cythera* reduction program. The following changes were made:

- A correction to the radar echo time, to account for atmospheric delay. Using Pioneer Venus data supplied to us by Kliore *et al.*, we derived the quadratic correction

  $$\Delta\tau = 0.8584 - 0.05227h + 0.000938h^2$$

  where $\Delta\tau$ is the excess one-way delay associated with the atmosphere (in µsec), and h is the measured altitude (in km) above a reference radius of 6051.2 km.

- A correction to the measured echo power, to account for atmospheric attenuation. This also came from data supplied by Kliore *et al.*

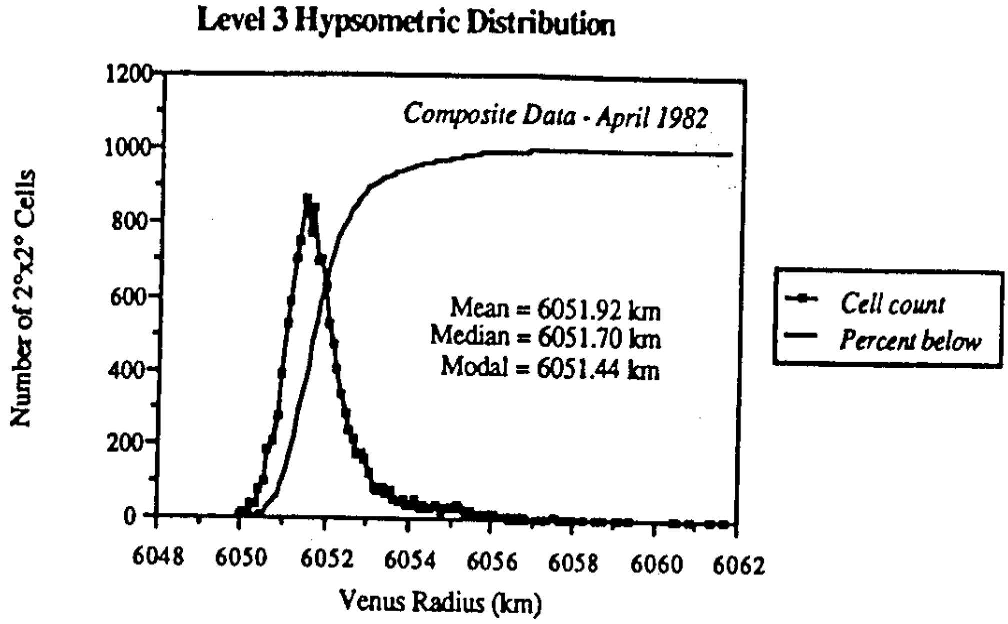
- An improved profile-fitting algorithm. The previous method was occasionally fooled by very rough terrain and by weak signals, when it confused noise with correlator side-lobes, particularly when the altimeter was "squinted" fore and aft.

- A correction to the receiver gain to better account for the effect of the approximations used in the on-board processing of the complex waveform.

In addition, by this time the Project had recalculated all spacecraft pulse times, which often differed from those reported on the original SEDRs by several tenths of a second. These developments argued for a complete re-processing of all data *ab initio*. For this purpose, the *cythera* and *cythp* software were ported to the Harvard computing center. Using a fast computer and high-density tapes, all orbits were re-processed and edited in October 1981. The resulting "Level 3" composite data files were sent to USGS Flagstaff and Eric Eliason and I edited them there in November, after the Palo Alto "Venus" conference. The resulting radius distribution was as follows:

---

[3] The instrument was still functioning flawlessly, but the spacecraft had run out of propellent with which to control periapsis altitude, which was increasing beyond range of the radar.



Two further major revisions of this Level 3 data set have proven necessary. Firstly, a total of some 70 orbits (out of a total of 726) still showed severe problems, either in radius, reflectivity, or side-looking back-scatter values. These problems were solved one at a time in the first half of 1982. The corrected data were merged with the previous Level 3 data files and the combination was run through *cytfit* for one last time. This was a similar operation to that performed several times with Level 2 data, but this time we did not permit *cytfit* to alter those orbits that had not been updated since the previous *cytfit* session. The updated composite data files were sent to USGS Flagstaff in April 1982 (see summary above), and the complete revised data set was sent to the following experimenters:

Don Campbell	Cornell/Arecibo
Jim Head	Brown U.
Bill Kaula	UCLA
George McGill	U. Mass, Amherst
Peter Mouginis-Mark	U. Hawaii
Irwin Shapiro	SAO

The second major revision came after much work at MIT to understand the side-looking radar back-scatter data. We estimated what fraction of the surface was acting as a large-angle diffuse scatterer, and did not therefore contribute to quasi-specular scattering. This caused us to increase our reported values of Fresnel reflectivity by an amount that depended on the side-looking back-scatter intensity in the vicinity of each altimeter footprint. The correction increased the average reflectivity by about 10%, but had no effect on the radius or Hagfors RMS slope values.

The corrected reflectivity values were not distributed as composite data files. Instead, they were merged with Pioneer Venus radiometry data[4] and submitted directly to the National Space Sciences Data Center (NSSDC) on January 1, 1985 in a format common to all Pioneer Venus "low frequency" data. We also submitted a tape containing our corrections to the Project's estimates of spacecraft orbital elements. I have also sent copies of the NSSDC submission to the following:

---

[4] P.G. Ford, G.H. Pettengill, "Venus: Global Surface Radio Emissivity", *Science*, 220, 1379 (1983).

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Copies of NSSDC data

A.T. Basilevsky	Vernadsky Institute
Don Campbell	Cornell/Arecibo
Eric Eliason	USGS Flagstaff
Jim Head	Brown U.
Steve Saunders	JPL
Sean Solomon	MIT

On the basis of the present analysis, I believe this to be the correct version of the Pioneer Venus radar data, although the composite data files distributed in April 1982 also contain accurate radius values.

↑ This final data set is NSSDC 78 051A-02D. The composite data files distributed in April, 1982 are NSSDC 78-051A-02C

Systematic Radius Errors

When Steve Wall recently asked me to characterize the accuracy of Pioneer Venus radius results for use by the Magellan project, our correspondence went as follows:

```
Date:       Wed, Jul 16 86 05:43:00 EDT
From:       SWALL <SWALL.TELEMAIL>
To:         Pford
CC:         ssdallas mkobrick
Subject:    the error bars on the topo data

We have an action item to answer from MGN Nav team that I would
like your help on.

They have been asked to determine if the "effective pointing
accuracy" of MGN is adequate to allow dead reckoning. They have
responded by requesting us to justify the current error bars on
the topo data we have furnished, saying that the topo uncertainty
is driving the whole "effective pointing" error.

As you know, we have beaten this issue before. The topo data is
limited in accuracy by (1) the actual variations in topography
within a topo "pixel" and (2) the accuracy with which the measur-
ement was made. As I understand it we have told the project that
the total uncertainty (1 + 2) is 1 km 3-sigma.

Could you comment on:

1) the accuracy of the PV measurement and the analysis which leads
you to believe your answer

2) the relative contributions of actual topography and measurement
uncertainty to your answer to 1)

3) the possibility of improving either

Thank you.
```

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Date: Thu, Jul 17 86 01:40:00 EDT
From: PFORD <PFORD.TELEMAIL>
To: swall
CC: ssdallas mkobrick pford
Subject: Error bars on PV topo data

To summarize an involved subject, the PV radar topo errors may be grouped into the following categories:

[1] Instrument error. This is the quantity we know best. We wrote software to simulate the radar geometry for a variety of surface scattering models, spacecraft altitudes, and instrumental parameters. We preserved these numbers through the data analysis, and quote these error bars and their correlations in the data set that we submitted to NSSDC. Typical range errors vary with latitude: approx 100m near 17N periapsis, rising to 300m at 74N or 65S.

[2] Scattering-Model Error. Throughout our analysis, we assumed that the surface that contributed to the altimetry echoes was composed of an ensemble of "quasi-specular" scattering regions, all at the same planetary radius. We computed a "suite" of theoretical echo profiles that we would expect to see from such a surface, and we matched each experimental echo to these profiles. We used a series of tests to determine whether the echo matched any of our theoretical profiles. If the match was too poor, we threw out the measurement. These tests eliminated about 20% of our data, particularly in areas of high surface relief, but also at high latitudes (when our SNR was poor). What does it mean if a surface does not scatter according to our quasi-specular (Hagfors law) assumption, but if the measurement still survives our template-recognition tests? The most probable answer is that the surface contains extremes of relief within the footprint area. In general, our analysis will break down if the relief (converted to 2-way light-time) is larger than the 4- or 6-microsec baud length of the PV altimeter. (The Hagfors model will break down before this, but, if we only want to measure range, it's good enough). So this analysis implies that some measurements may be in error by 600 to 900 meters. I doubt that further processing will help to identify more "anomalous" echoes, unless we have some other (a priori) criterion by which to determine the expected scattering behavior of each footprint.

[3] Side-Lobe Confusion. There is yet another, thankfully rarer, error in template fitting: the PV radar echoes contain "side-lobes" caused by the on-board time-compression correlator. When our SNR was particularly low (either at high S/C altitude, or because of intrinsically low-reflective surface material), our template fitting algorithms can confuse an instrumental side-lobe with the peak of a noisy signal! We resorted to hand editing to remove these disasters (the side-lobes are typically 3 or 4 baud away from the peak, i.e. 1.8-3.6km), but some may remain in highland areas.

[4] Sampling error. At periapsis, our radar measurements were made at approx 120km down-track intervals, and our orbits were spaced approx 150km apart. The corresponding footprint size was about 7x23km, so we were really sampling less than 1% of the surface.

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Moving away from periapsis, the figures improve: the sampling intervals become shorter and the footprints get larger. 100% sampling is achieved at ca. 55N and 20S. To estimate how much topography we "missed" by under-sampling, we looked at the variance in our results, i.e. we chose a sub-set of the data in which all other errors were relatively small and could be estimated: we attributed the excess variance in our measurements to actual variation in topography. We concluded that the surface could easily "hide" kilometer-deep grooves, provided they were less than about 20km wide and not fortuitously oriented along the S/C ground track.

[5] S/C Timing error. The most difficult part of the data analysis was forced on us by our lack of accurate knowledge of time of data taking. Someone (at HAC) forgot to give the radar an internal clock. Instead, we received readings from a count-down timer that was triggered from a S/C timing pulse that was itself synchronized from the sun or star sensor. Yes, a cheap mission! The sensors frequently became confused, the timing pulse wandered by hundreds of milliseconds (or worse), and we were forced to model this wandering. The bottom line is that our S/C timing errors became large when the S/C crossed the terminator (switch from sun to star sensor), and after telemetry frames had been dropped (insufficient data for pulse modeling). We tried to remove all data with suspected timing errors, but some probably remains. Chris Russell has a magnetometer on the PV spacecraft that is also sensitive to pulse timing. He and I have compared our timing corrections. We generally agree with an rms (1 sigma) of about 10msec (50m), but the distribution is far from gaussian, and there are some periods when we disagree by 100msec (i.e. up to 450m in radius).

[6] Ephemeris error. When footprints of successive orbits overlapped, we expected to measure the same planetary radius. When we didn't, we found that we could account for much of the discrepancy if we assumed that the JPL-supplied S/C ephemeris was in error, often by amounts that were much larger than estimated by the Nav team. We therefore fitted our entire data set to changes in s.m.a, eccentricity, and argument of periapsis of all orbits, minimizing the local variance of radar-derived planetary radii. We derived error estimates for these orbit elements. They are small, so a better estimate of the contribution of systematic S/C tracking errors to our radar radii is still that supplied by the Nav team: of about 300m, 1-sigma.

That's the picture in a fair amount of detail. To say that our topo measurements have a 3-sigma error of 1km is a vast oversimplification. Each error source varies with S/C altitude (latitude), some of the systematic errors also vary with longitude. I doubt that further analysis would reduce any of the remaining errors to any useful degree. Even if you could improve some of the systematics, the under-sampling problem is going to remain.

I would recommend that the PV contribution to the Magellan topo model be taken from our NSSDC data submission. It is ordered by time of data-taking (i.e. the counterpart to the MGN-ARCDR data set), and includes values of radius, Hagfors parameter, reflectivity, their statistical errors (item [1] above) and correlations, the footprint size and location, etc. I think that you should

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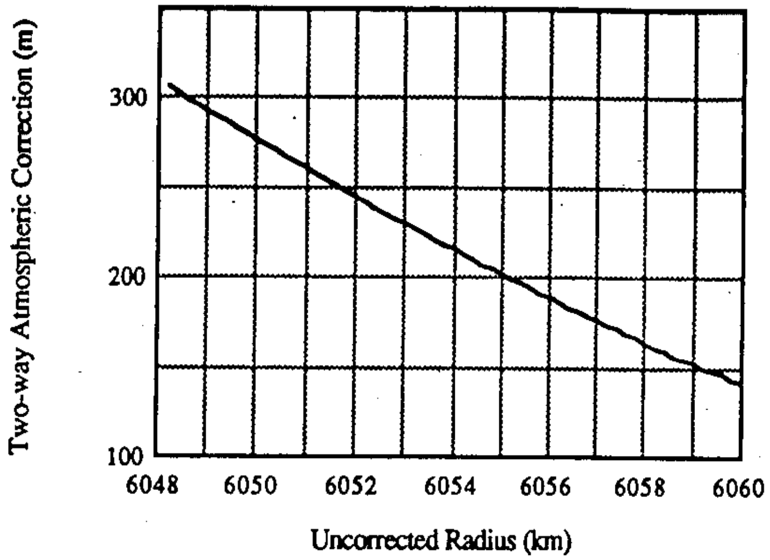
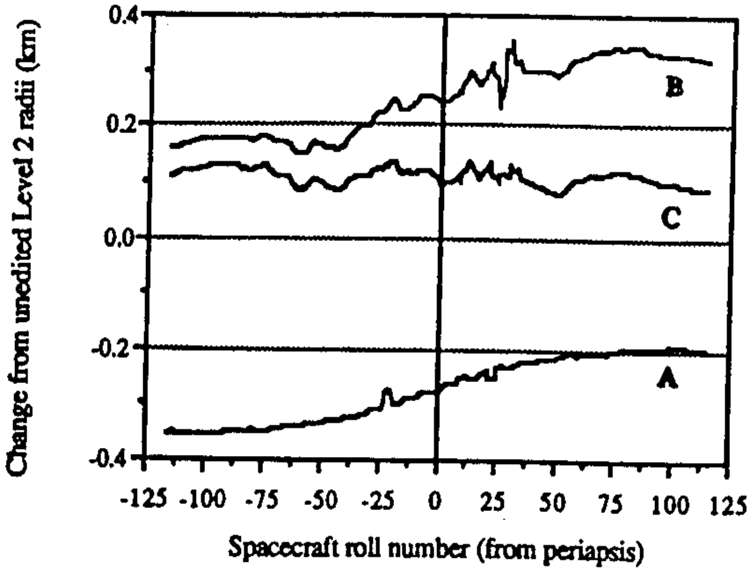
> directly fit a polynomial model to this data set, using the quoted radius errors to weight the variances. Optionally, you could first re-sample the data according to the tabulated footprint sizes.

During this correspondence, the Pioneer Venus data I was talking about was, of course, our NSSDC submission, not the Level 2 data that had been used by USGS to create the series of wall charts, culminating in the "VRM Planning Chart" of 1984. I knew that the NSSDC data would be substantially different, if only because of the atmospheric delay correction. The Level 2 data, further smoothed at Flagstaff, had been sent to Mike Kobrick, who has called it a "Pioneer Venus Topography Model". To correct this assumption, I sent him a copy of the NSSDC tape. It was clear that the average radius values had changed dramatically, and I was asked to investigate.

I began by cataloguing all existing Pioneer Venus data sets and by making a calendar of the processing history. As I have described above, some of the intermediate results are missing—the output tapes were re-cycled to save space and money—but the majority are still available. I verified the calculations of mean, median, and modal radii by re-executing the *cytfit* program for the particular sets of composite data input files. Although I was unable to reproduce the precise results that led to the published 1980 JGR figures, I obtained very similar results (mean radius = 6051.61 km) from the 1981 Level 2 files. Similarly, all Level 3 data sets produced mean radii ≈ 6051.92 km. The mean atmospheric delay correction is about 250 meters:



which left 100–200 meters unaccounted for. I found that this change came entirely from the *cytfit* program applied successively to the incomplete Level 2 data sets. Here for example are the cumulative changes that were made to the original Level 2 radius values of orbit 143, firstly as a result of global fitting (curve 𝔸, overleaf), then through Level 3 re-processing (curve 𝔹), and finally through Level 3 global fitting (curve ℂ).



The discrepancy that I have been asked to explain is that between curves **A** and **C**. Concentrating on the difference at periapsis (roll number 0), the (incorrect) Level 2 global corrections introduced a change of –280 meters to the published USGS data products (curve **A**), the atmospheric correction to level 3 data made a +250 meter change (curve **B**) which was subsequently reduced by about 140 meters by Level 3 global corrections (curve **C**). The differing slopes of the curves is due to the re-estimation of periapsis time at each processing stage. Curves **A** and **B** have nearly the same slopes because Level 3 *cythera* processing began by overriding the project-supplied periapsis times with the "best values" derived from Level 2 global fitting.

Conclusions

The data submitted to NSSDC in January 1985 (78-051A-02D) represent the most accurate Pioneer Venus radar altimetry data. All other data sets are known to be flawed to some degree. The systematic errors in the USGS topography maps are well understood—in fact, Level 3 *cythera* reprocessing was expressly designed to eliminate those errors.

The question remains whether it is necessary to re-generate the USGS contour maps merely for mission planning purposes. Magellan must use the accurate NSSDC data for its data-processing topography model, but if the zero contour level of the contour maps is re-interpreted relative to the new mean (or median, or modal) radius, the differential change in contours will be small, and the maps may be adequate for Magellan planning purposes. This matter will not be settled until we have more time to make a careful comparison between the existing contour maps and the NSSDC data set.

Appendix: PV Radar Processing Chronology

Date	*Data Processing Task Description*	*Archive Tape*	*Flagstaff Tape*
12/10/78	*Cythera* processing of quick-look data begins on IBM/370 CMS using project-supplied *a priori* orbit elements (Level 1).	PVCDAA	
03/01/79	Quick-look data reprocessed with new orbit elements when *a priori* elements missing or suspect (Level 0).	PVCDAB	
04/12/79	First *cythera* processing of EDR tapes on IBM/360-65 using measured spacecraft ephemeris (Level 2).	PVCDAC	
10/01/79	At end of 243-day nominal mission, global *cytfit* correction applied to all available orbits.	CYTFIT1	
11/01/79	First calculation of hypsometry (mean radius = 6051.5) and fit to tri-axial ellipse. Data were reported in the JGR article.		
01/80 to 01/81	Several *cytfit* global corrections followed by incremental data submissions to USGS.		PVCDxx
03/09/81	Global *cytfit* correction applied to all orbits. Mean radius was 6051.6 km.	CYTFIT2	
03/10/81	Last "complete" Level 2 data submission to USGS of orbits 3–567		PVCDBU PVCDBV
06/01/81	Last incremental Level 2 update sent to USGS, of all available orbits 3 to 834.		
07/01/81	All data processing moved to IBM/4341-II CMS at Harvard.		
08/01/81	Atmospheric refractive index data received from Kliore *et al.* Correction applied to *cythera* computation of radius and ρ.		
10/01/81	*Cythera* Level 3 reprocessing begins, using original EDRs but adjusting periapsis times according to Level 2 *cytfit* results.		
10/20/81	Level 3 *cythera* processing complete. Mean radius (including very many "bad" values) was 6052.02 km.	PVCD02	
10/30/81	Level 3 *cythp* editing complete. Mean radius 6051.89 km.	PVCD03	
10/31/81	Last global fitting of all orbits	CYTFIT7	
10/31/81	Last whole-planet composite data submission to USGS.	PVCD10	PVCDGA PVCDGB PVCDGC
04/26/82	Computation of mean reflectivity and radius (6051.92 km).		

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11/03/82	Level 3 data displayed by *GIPS* software, additional data points deleted by hand-editing.	PVA062	
11/04/82	Last global fitting, affecting only those orbits containing updated radius measurements.	CYTFIT8	
11/04/82	Last incremental composite data submission to Flagstaff, Brown, and Arecibo.	PVA070	PVCDGT
08/01/83	Beginning of *GIPS* image processing system on VAX/780 UNIX system at MIT Earth Resources Laboratory.		
07/24/84	Hagfors and reflectivity values edited via *GIPS* display.	PVCD10	
Fall 1984	*Cytim* and *cytim2* programs take average of PV imaging data in neighborhood of each altimetry point, generate updated reflectivity values.	PVCD05	
Fall 1984	*Cytpc* program reads archive tapes, transforms radiometry data to equivalent noise temperature.	CYTPC	
01/01/85	VAX software merges PVCD05 with CYTPC, writes the NSSDC data submission tape.	NSSDC1	

SAMPLE LISTING FROM PVDRAD.DATA
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FILE 839    RECORD      1       31600 BYTES

 10 NURB SECS SMAP SDEL SDUP SLAT SLON SIGO SARE SANG(I5,I6,I2,I2,I2,F7.3,F8.3,F7.5,F7.1,F7.2)                  0      0 0 0 0999.99999
99.9999.9999999999.999999.9  128  -396 2 2 5 49.776   2.717 0.2279 2515.0  24.45  130  -396 2 2 5 49.849   5.952 0.0776 2643.3  23.2
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46  164  -396 2 2 5 49.980  57.933 0.2735 3207.0  19.78  236  -408 1 1 4 49.807 169.634 0.2134 4467.9  23.22  124  -396 2 2 5 49.773
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