FINAL REPORT TO THE BOEING COMPANY for PURCHASE CONTRACT NO. HV1881

by

Alan P. Waggoner and Peter V. Hobbs
Cloud and Aerosol Research Group
Atmospheric Sciences Department
University of Washington
Seattle

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Final Report from the University of Washington

Department of Atmospheric Sciences, Cloud and Aerosol Research Group,

to the Boeing Company, Defense Space Group, on Purchase Contract No. HV1881

Period: 19 April 1993 through January 1994.

Report Prepared by Dr. Alan Waggoner and Professor Peter V. Hobbs

Purpose of Flight Test Series

A new instrument, the Boeing Enhanced Mode Lidar, measures true air speed by detecting the doppler shift of light scattered from single particles in air near the aircraft. The major purpose of this test flight series was to determine the Enhanced Mode Lidar single particle detection rate in cloud free air, especially in air with low particle concentration. At the time of this test, the range of concentration of particles of sufficient size to be detected was unknown. The performance of the enhanced mode lidar was also tested in droplet and ice crystal clouds.

To achieve the goals of this project, three flights were conducted with the University of Washington's Convair C-131A research aircraft. The flights were mostly in cloud free air over the Pacific Ocean, near the Washington coast, and over rural Eastern Washington. Flight altitudes extended up to about 13,500 ft (4100 m) and included clear air (particle scattering coefficient below 10^{-6} m^{-1}) and clouds with up to 150 cloud droplets per cm^3 and up to 1.2 ice crystals per liter. The University of Washington flight numbers for these tests were:

1593, on 4/14/93, 12:09 - 15:40
1594, on 4/20/93, 14:34 - 17:54
1595, on 4/30/93, 10:15 - 14:16

Description of Enhanced Mode Lidar

The enhanced mode lidar used in these flights included a ~100 mW, 1.06 μm, CW laser. Lenses of 1 and 2 meter focal-lengths were used to define the measurement range at different times during the flights. A single objective lens was used for both the transmitter and receiver. A 1/4 wave plate and polarization-dependent beam-splitter were used to separate the transmitted and received optical signals. Coherent signal processing was used to detect the Doppler frequency shift in the received signal. The detected coherent signal

was recorded on both a Boeing designed system, based on a high-speed digital oscilloscope, and on a commercial signal processing system developed by TSI for laser doppler velocimeter applications.

Aircraft Data Base

Aircraft instrument data is recorded on Exabyte format, 8 mm video tape with most analog data channels recorded at a 13 Hz rate, particle probe size data is recorded at a 1 Hz rate. The data is recorded in a compressed format that is not directly readable. The Cloud and Aerosol Research Group has developed a series of programs that can read these tapes and present the data in either numerical or graphical format. The tapes are archived and can be loaded onto a hard disk on request for access by ourselves or outside users. Because the data is in a custom format and requires custom readout programs, neither a back up copy of the data nor the readout programs is provided to outside users. Users can obtain access to the data by creating outside accounts that can access our computer and data base and use the readout programs.

Software is available to make the plots of aircraft flight tracks and strip charts included in this report. In addition, software is available to make X - Y plots of the relationship of two variables, numeric dumps of continuous data values versus time, plots of particle size distributions and numerical dumps of particle size distributions. The numerical output can be in a form compatible with spread sheets. In general, questions regarding the instruments should be directed to Jack Russell and questions regarding software directed to Hap Terry, both available at (206) 543-7684.

Particle size distributions from 0.1 to 20 μm in diameter are measured on the aircraft using two optical scattering instruments made by Particle Measuring Systems (PMS) of Boulder, Colorado. In both of these instruments, single particles are illuminated as they pass through the measurement volume and the light scattered during the passage of each individual particle is directed onto a solid-state photodetector. The resulting current pulses from the detector are classified into one of a series of amplitude bins corresponding to specific particle sizes. These bins are calibrated in particle diameter by passing standard diameter particles through the measurement particle detection volume. Tables 1 and 2 list the bin channel edges in terms of particle diameter.

asas channel diameter limits (μm)

ch	
1	0.114 - 0.120
2	0.120 - 0.125
3	0.125 - 0.130
4	0.130 - 0.135
5	0.135 - 0.141
6	0.141 - 0.146
7	0.146 - 0.151
8	0.151 - 0.157
9	0.157 - 0.162
10	0.162 - 0.167
11	0.167 - 0.173
12	0.173 - 0.178
13	0.178 - 0.183
14	0.183 - 0.188
15	0.188 - 0.194
16	0.150 - 0.160
17	0.160 - 0.170
18	0.170 - 0.180
19	0.180 - 0.190
20	0.190 - 0.200
21	0.200 - 0.210
22	0.210 - 0.220
23	0.220 - 0.230
24	0.230 - 0.240
25	0.240 - 0.250
26	0.250 - 0.260
27	0.260 - 0.270
28	0.270 - 0.280
29	0.280 - 0.290
30	0.290 - 0.300
31	0.240 - 0.280
32	0.280 - 0.320
33	0.320 - 0.360
34	0.360 - 0.400
35	0.400 - 0.440
36	0.440 - 0.480
37	0.480 - 0.520
38	0.520 - 0.560
39	0.560 - 0.600
40	0.600 - 0.640
41	0.640 - 0.680
42	0.680 - 0.720
43	0.720 - 0.760
44	0.760 - 0.800
45	0.800 - 0.840
46	0.600 - 0.760
47	0.760 - 0.920
48	0.920 - 1.080
49	1.080 - 1.240
50	1.240 - 1.400
51	1.400 - 1.560
52	1.560 - 1.720
53	1.720 - 1.880
54	1.880 - 2.040
55	2.040 - 2.200
56	2.200 - 2.360
57	2.360 - 2.520
58	2.520 - 2.680
59	2.680 - 2.840
60	2.840 - 3.000

FSSP-300

Size Range - 0.3 - 20.0 μm

Channel	Size (microns)
1	0.30 - 0.35
2	0.35 - 0.40
3	0.40 - 0.45
4	0.45 - 0.50
5	0.50 - 0.55
6	0.55 - 0.60
7	0.60 - 0.65
8	0.65 - 0.70
9	0.70 - 0.80
10	0.80 - 0.90
11	0.90 - 1.00
12	1.00 - 1.20
13	1.20 - 1.40
14	1.40 - 1.70
15	1.70 - 2.00
16	2.00 - 2.50
17	2.50 - 3.00
18	3.00 - 3.50
19	3.50 - 4.00
20	4.00 - 4.50
21	4.50 - 5.00
22	5.00 - 6.00
23	6.00 - 7.00
24	7.00 - 8.00
25	8.00 - 9.00
26	9.00 - 10.00
27	10.00 - 12.00
28	12.00 - 14.00
29	14.00 - 16.00
30	16.00 - 18.00
31	18.00 - 20.00

Table 1. Listing of channel edges for the ASAS and FSSP-300 particle spectrometers

Table 2. Fill times for the ASAS sample cylinder on flights 1593, 1594 and 1595.

```
flt1593.nobag        Thu Jan  6 10:06:24 1994        1

        The times shown are when the switch was moved to FILL.
        Each character following the time represents either time
        spent in one of 5 states, or an event.

          f  FILL
          s  SAMPLE
          .  STANDBY
          e  EMPTY
          b  BAD or missing data
          E  EEA record
          L  Aerosol record (LAS, Roycol,Royco2)
          A  ASASP record
          D  difbat record
          M  mass monitor record
          T  keyboard text

        One character is 1 second except for s (SAMPLE), it's
        3 seconds and for b (BAD), it's 10 seconds. The event
        markers don't represent any time.  A + at the
        end of a line means that some characters didn't fit.

  flt1593  no-bag samples

 1 121307.2 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssseeeeeeeeeeeeef......................................+
            ALM                   ALM        E       ALM              ALM T                                            ALM
 2 121809.7 fffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseeeeeeeees
                    ALM  ALM              ALME               ALM        T     ALM
 3 122133.9 fffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseeeeeeee+
                         ALM              ALME               ALM               ALM              ALM               ALM
 4 122707.8 fffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseeef..................+
                    ALM  ALM    T          ALME               ALM              ALM    T          ALM
 5 123913.0 fffffffsssssssssssseeeeeeeeeeeees
                         ALM
 6 124011.3 fffffffssssssssssssssssssssssssssssssssssssssssssssssseesf..........................
                       ALMALM             ALME              ALM
 7 124305.9 fffffffsssssssssssssssssssssssssssssssssssssssssssssseeeeeeeees...................................................+
                    ALM  ALM               ALME              ALM                                           ALM
 8 125619.4 fffffffffssssssssssssssssssssssssssssseeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeesf...........................+
                          ALM           T  ALME                   T                   ALM
 9 130029.5 ffffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                           ALMT             ALME               ALM               ALM               ALM               ALM
10 131031.6 ffffffffffsssssssssssssssssssssssssssssssssssssssseeeeeeeeeees....................................................+
                      ALM  ALM              ALME                ALM                                                  ALM
11 131851.7 ffffffffffsssssssssssssssssssssssssssssssssssssssssseeeeeeeeees
                  ALM      ALM               ALME               ALM
12 132114.5 fffffffffsssssssssssssssssssssssssssseeeeeeeeeeeef..................
                          ALM              ALME
13 132321.0 ffffffffffsssssssssssssssssssssssssssssssss
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                   ALM     ALM              ALME
14 132604.3 ffffffffffssssssssssssssssssssssssssssssssssseeeeeeeeeeeeeeeeesf..................................................+
                         ALMALM              ALME                            ALM
15 133129.5 fffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssseeeeees.
                        ALMALM             ALME          T   ALM
16 133426.6 ffffffffffsssssssssssssssssssssssssssssssssseeeeeeeeeeeeeeeesf..................................................+
                   ALM    ALM               ALME                              ALM
17 134308.9 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
                         ALM           T   ALME             ALM               ALM
18 134617.1 ffffffffssssssssssssssssssssssssssssssssssssssssssssseeeeeeeeees................................................+
                        ALM T             ALME             ALM                                             ALM
19 140124.5 fffffffffsssssssssssssssssssssssssssssssssssseeeeeeeeeeeeees
                      ALM ALMT             ALME
20 140332.1 ffffffffssssssssssssssssssssssssssssssssssssseeeeeeeeef.........................................................+
                ALM      ALMT             ALME                        ALM                                                   AL
21 141407.9 ffffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssesf.
                    ALM   ALM               ALME   T          ALM              ALM
22 141824.9 ffffffffsssssssssssssssssssssssssssseeeeeeeef...................................................................+
                         ALM              ALME                            ALM
23 142932.9 ffffffffsssssssssssssssssssssssssssssssssssseeeeeeeeeeeeeeeees
                      ALM T            ALM E                  ALM    T
24 143211.7 ffffffffssssssssssssssssssssssssssssssseeeeeeeeeeeeeeeeeef......................................................+
                      ALMALMT             ALME                            ALM
25 144341.2 fffffffffssssssssssssssssssssssssssssseeeeeeeees
                  ALM    ALM       T       ALME
26 144528.3 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                        ALMALMT           ALME                       ALM              ALM                ALM              ALM
27 145906.6 fffffffffffsssssssssssssssssssssssssssssssseeeeeeees
                           ALMT        T      ALME
28 150104.4 ffffffffssssssssssssssssssssssssssssssssssssssssssssseeeeeef.....................
                      ALMTALM             ALME             ALM
29 150357.7 ffffffffsssssssssssssssssssssssssssssssssssssssseeeeeeeeesf.......
                    ALM  ALM              ALME               ALM
30 150646.0 fffffffsssssssssssssssssssssssssssssssssseeeeeeeeef.............................................................+
                     ALMALM               ALME                               ALM
31 152412.6 ffffffffsssssssssssssssssssssssssssssseeeeeeees
                         ALM              ALME
32 152555.0 ffffffffsssssssssssssssssssssssssssssseeeeeeeeees
                         ALM              ALME
33 152742.0 ffffffffssssssssssssssssssssssssssssssssssssseeeeeeeeeeeees
                        ALM               ALME
34 153018.2 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssss
                         ALM              ALME              ALM
35 153543.5 ffffffffsssssssssssssssssssssssssssssssssssssssssssseeesf........................................................+
                      ALMALM              ALME             ALM                                               ALM
```

Table 2. (Continued)

```
The times shown are when the switch was moved to FILL.
Each character following the time represents either time
spent in one of 5 states, or an event.

  f  FILL
  s  SAMPLE
  .  STANDBY
  e  EMPTY
  b  BAD or missing data
  E  EEA record
  L  Aerosol record (LAS, Roycol,Royco2)
  A  ASASP record
  D  difbat record
  M  mass monitor record
  T  keyboard text

One character is 1 second except for s (SAMPLE), it's
3 seconds and for b (BAD), it's 10 seconds. The event
markers don't represent any time.  A + at the
end of a line means that some characters didn't fit.
```

```
flt1594  no-bag samples


 1 144304.3 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssees.
                                 ALM          E    ALMT     T        ALM            T ALM    T           ALM
 2 144808.4 ffffffffffsssssssssssssssssssssssssssssssssssssssssssssssssseeeeeeeeeeeees
                   ALM     ALM                ALME             ALM
 3 145123.3 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                        ALM                ALME     T        ALM              ALM               ALM               ALM
 4 145843.8 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                  ALM    ALM                ALME              ALM               ALM              ALM               ALM
 5 150454.0 ffffffffsssssssssssssssssssssssssssssssssssssssssssseeeeeeeeesf..................................................+
                        ALMALM             ALME    T          ALM                                                    ALM
 6 151630.4 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssseeesf...........................................+
                     ALMALM                ALM                LM                         ALM
 7 152106.9 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseeeef......................................+
                    ALMALM             E ALM              ALM               ALM                                           ALM
 8 152709.8 ffffffffsssssssssssssssssssssssssssssssssssssssssss
                        ALM                ALME              ALM
 9 152924.4 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseeees
                                ALM         E      ALM               ALM              ALM
10 153503.4 ffffffffsssssssssssssssssssssssssseeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeef..............................................+
                        ALM               ALME                                        ALM
11 153942.6 ffffffffffssssssssssssssssssssssssssssssssseeeeef...
                   ALM    ALM                 ALME
12 154137.5 fffffffsssssssssssssssssssssssssssssseeees
                      ALMALMT             ALME
```

Table 2. (Continued)

```
13 154313.5 ffffffffsssssssssssssssssssssssssssssssssseees
                         ALM              ALME
14 154507.7 ffffffffsssssssssssssssssssssssssssssssssssssees.................................................................+
                      ALMALM              ALME   T                 ALM                                                   ALM
15 154833.8 ffffffffsssssssssssssssssssssssssssssssssseeeees
                        ALM               LME
16 155033.8 ffffffffsssssssssssssssssssssssssssseeeeeeeeses...................................................................+
                    ALM ALM               ALME                                           ALM
17 155718.6 ffffffffssssssssssssssssssssssssssssssssssssssssssssses
                         ALM              ALME          T    ALM
18 155940.8 fffffffffsssssssssssssssssssssssssssseeeeeeeeees.
                         ALM               ALME
19 160125.9 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssf.fseeeef................................................+
                          ALM              ALME               ALM                                       ALM
20 160626.8 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssses
                         ALM              ALMET              ALM               ALM
21 160938.0 fffffffffsssssssssssssssssssssssssssssssssssssssssssssseeeeesf....................................................+
                         LM      T         ALME              ALM                                          ALM
22 161449.8 fffffffffsssssssssssssssssssssssssssssssssssssssssssssssses
                         ALM          T   ALME               ALM
23 161723.0 fffffffffssssssssssssssssssssssssssssssssssssssssssssseeef.........................................................+
                         LM T              ALME              ALM                                             ALM
24 162530.5 ffffffffsssssssssssssssssssssssssssssssssssssssseees
                     ALMALMT              ALME
25 162741.7 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssf.............................................+
            ALM         TALM              ALME              ALM               ALM
26 163700.4 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssef..........................................+
                        ALM               ALME              ALM               ALMT
27 164518.4 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssss
             ALM         ALM               ALME              ALM
28 164824.5 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssees
                         ALM               ALME              ALM          T    ALMT              ALM
29 165302.8 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
                    ALM ALM                ALME             ALM               ALM               ALM
30 165700.5 fffffffssssssssssssssssssssssssssssssssssssssssssssssssssssef......................................................+
                       ALM              ALME               ALM                             ALM
31 170259.9 fffffffsssssssssssssssssssssssssssssssss
                       ALM               ALME
32 170620.3 fffffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
                           ALM               ALME              ALM               ALM
33 171009.9 ffffffffsssssssssssssssssssssssssssseeeeeeees
                    ALM ALM                ALME
34 171143.1 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseesf.....................................+
                        ALM                ALME              ALM               ALM                                         ALM
35 171625.0 ffffffffsssssssssssssssssssssssssssssssssssssssseeeeeeeeeeeees
                    ALM ALM               ALME             ALM
36 171918.6 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssse
                 ALM                     ALME               ALM
```

Table 2. (Continued)

```
37 173224.5 ffffffffffsssssssssssssssssssssssssssssssssssssssssssssseeeeees
                   ALM     ALM                  ALME                ALM
38 173456.6 fffffffffsssssssssssssssssssssssssssseeeeeeeeeeeeeeeees
                         ALM                    ALME
39 173647.3 fffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseeeeeesf.......
                        ALMALM                  ALME                ALM                 ALM                ALM
40 174115.7 fffffffssssssssssssssssssssssssssssssssssssssssssseeeeees
                       ALM                  ALME                ALM
41 174403.4 fffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssf
                    ALM ALM                  ALME                ALM                 ALM                ALM
42 174759.4 fffffffssssssssssssssssssssssssssssssssssseeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee+
                        ALM                  ALME                                   ALM
```

Table 2. (Continued)

```
The times shown are when the switch was moved to FILL.
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spent in one of 5 states, or an event.

  f  FILL
  s  SAMPLE
  .  STANDBY
  e  EMPTY
  b  BAD or missing data
  E  EEA record
  L  Aerosol record (LAS, Roycol,Royco2)
  A  ASASP record
  D  difbat record
  M  mass monitor record
  T  keyboard text

One character is 1 second except for s (SAMPLE), it's
3 seconds and for b (BAD), it's 10 seconds. The event
markers don't represent any time.  A + at the
end of a line means that some characters didn't fit.

flt1595  no-bag samples


 1 101818.3 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                              ALM           E   ALM                 ALM                ALM            ALM              ALM
 2 102510.1 ffffffffffffssssssssssssssssssssssssssssssssssssssssssssssssssseeeeeeeeeeeeeeeeeeeeeees
                             ALM           ALM E             ALM                 T
 3 102808.5 ffffffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssfsssssssssssee..........................
            LM              ALM               ALMET             ALM         T       ALM                           T
 4 103229.4 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssee.............................+
                        ALM                EALM              ALM           T    ALM                       ALM
 5 103825.9 ffffffffssssssssssssssssssssssssssssssseeeeeeeeeeeef.................................................................+
                        ALM               EALM                             T                 ALM
 6 104226.5 fffffffffffsssssssssssssssssssssssssssseeeeeeeeees
                  ALM       ALM               EALM
 7 104407.5 fffffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseee+
                            ALMT               EALM              ALM                 ALM               ALM                ALM
 8 104950.9 ffffffffsssssssssssssssssssssssssssssssssseeeeeeeeeees
                    ALMALM                ALME
 9 105143.9 ffffffffssssssssssssssssssssssssssssssssssssseeeeeeeeeesf..........................
                     ALMALM               ALME                            ALM
10 105411.3 ffffffffsssssssssssssssssssssssssssssssssssssssssssseeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee+
                        ALM               ALME              ALM                                           T ALM
11 110317.8 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                     ALMALM               ALME              ALM              ALM                ALM        T      ALM
12 110905.7 ffffffffsssssssssssssssssssssssssssseeeeeeeeees
                       ALM               ALME
```

Table 2. (Continued)

```
13 111042.0 fffffffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssseeees
                              ALM                ALME             ALM
14 111324.9 fffffffffsssssssssssssssssssssssssssssssssseeeeeeeeeeees
                          ALM                ALME
15 111541.0 ffffffffsssssssssssssssssssssssssssssssss
                         ALM                ALME
16 111741.7 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssseeees
                      ALM ALM                ALME               ALM                 ALM
17 112050.1 fffffffffsssssssssssssssssssssssssssssssssssssssssssssssssseeees
                          ALM                ALME               ALM
18 112327.2 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssef.......................................+
                         ALM    T          ALME               ALM                ALM                                        ALM
19 112913.6 ffffffffsssssssssssssssssssssssssssssssssssssssssssssseeeeeees
            ALM           ALM              ALME               ALM
20 113137.5 ffffffffssssssssssssssssssssssssssssssssssssssseeeeeeeeeees
                         ALM                 ALME
21 113345.8 fffffffffsssssssssssssssssssssssssssssssssssssssssseeeeees............................................................+
              ALM         ALM                 ALME                    ALM                                                     ALM
22 113718.4 ffffffffsssssssssssssssssssssssssssssseeeeeeeeees
                         ALM                ALME
23 113905.8 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssseeeeeeeees
                         ALMALM              ALME               ALM
24 114142.3 ffffffffsssssssssssssssssssssssssssssssssssssssseeeeeeeeesf..
                         ALM                ALME                ALM
25 114402.2 ffffffffsssssssssssssssssssssssssssssssssssssssseeeeeeeeeesf........................................................+
                         ALM                 ALME                 ALM                                                      ALM
26 114907.3 fffffffffsssssssssssssssssssssssssssssssssssssssssseeeeees
                         TALM                 ALME
27 115118.0 ffffffffsssssssssssssssssssssssssssssssssssssssseeeees
             ALM         ALMT                ALME
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              ALM        ALM               ALME               ALM
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                          ALM                ALME
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                          ALM
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32 120121.0 ffffffffsssssssssssssssssssssssssssseeeeeeees
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33 120254.7 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
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35 121547.6 ffffffffsssssssssssssssssssssssssssssssseeeeeeeeeees
                       ALMALM               ALME
36 121736.3 fffffffffsssssssssssssssssssssssssssssseeeeeeeeesf...................................................................+
                         ALMALM              ALME                                           ALM
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Table 2. (Continued)

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37 122156.3 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssf...............................................................
                         ALM                 ALME                ALM                                                ALM
38 122519.5 fffffffffssssssssssssssssssssssssssssssssssssssssssssf.....................
                          ALM                 ALME                ALM
39 122751.2 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssses
                         ALM                 ALME                ALM                 ALM
40 123134.6 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssss
                     ALM ALM                 ALME                ALM
41 123411.1 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                         ALM                 ALME                ALM                 ALM                 ALM                 ALM
42 124109.5 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssseeeees
                         ALM       T         ALME                ALM
43 124356.5 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
                       ALMALM                LME  T              ALM                 ALM                 ALM                 ALM
44 125114.8 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss+
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45 125721.8 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
                         ALM                 ALME                LM
46 130126.1 ffffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssf......................................+
                     T        ALM        E         ALM           T    ALM                   ALM
47 130651.6 fffffffsssssssssssssssssssssssssssssssssssssssseesf.
                        ALM                  ALME
48 130919.1 fffffffsssssssssssssssssssssssssssssssssssssssssssssssseeeees.
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                        ALM                  ALME
53 132101.9 fffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
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                        ALM                  ALME               ALM                 ALM                 ALM
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                        ALM        T        ALME
56 133333.4 ffffffffsssssssssssssssssssssssssssssssssssssssssssssseef................................................................+
                         ALM      T          ALME                ALM                                                     ALM
57 133920.2 ffffffffsssssssssssssssssssssssssssseeeeeeeeeeeeeeeeeeeeeees
                         ALMT                ALME                T
58 134101.4 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssseees
                         ALM                  ALME
59 134306.2 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssseef.................................................................+
                 ALM     ALM                 ALME                ALM                                                           ALM
60 134701.0 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssss
            ALM         TALM                 ALME T              ALM
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Table 2. (Continued)

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61 134933.9 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
                          ALM               ALME                ALM                ALM
62 135303.2 ffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssf......................................................+
                          ALM               ALME                ALM                          LM
63 135945.4 ffffffffsssssssssssssssssssssssssseeeeeeeeees
                          ALM               ALME
64 140120.2 ffffffffsssssssssssssssssssssssssssssssssssssssssssssss
                          ALM               ALME                ALM
65 140340.9 ffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssf...............................
                         TALM               ALME   T            ALM
66 140640.7 fffffffffssssssssssssssssssssssssssssssssssssssssssssseees
               ALM         ALM               ALME                ALM
67 140855.7 ffffffffffsssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
                            ALM               ALME                ALM               ALM
68 141246.2 fffffffffssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss
                   ALM     ALM                ALME                ALM                ALM
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Table 2. (Continued)

The two PMS instruments, the ASAS and the FSSP-300, differ greatly in their modes of sampling ambient particles. The ASAS samples air from a cylindrically shaped sample reservoir that is filled in about 10 seconds at discrete times. This reservoir is filled, sampled and then emptied under control of an operator. Table 3 lists the fill times and the durations of fill, sample and empty intervals. Aerosol from this sampling cylinder is at substantially lower relative humidity than ambient air because of ram-heating of the air. Hydrated particles will lose associated water and shrink in diameter. The FSSP-300 is a probe mounted under one wing of the aircraft; it samples particles in the air at ambient temperature and relative humidity.

Standard Aircraft Instrumentation

Standard measurements aboard the Convair C-131A are as follows.

Aircraft Position	Calculated from Global Positioning Satellite or Omega instruments. The aircraft position versus time can be used to produce an aircraft flight track.
Aircraft Altitude	Determined from Pressure or from the radar altimeter.
Aircraft Heading	From Omega or from a magnetic compass.
True air speed	Calculated from pitot tube pressure.
Turbulence	A measure of the energy dissipation rate. Determined from the RMS air speed fluctuations
Static Temperature	Determined from a reverse air-flow Rosemont temperature transducer.
Ice Particle Number per liter of air	Determined from single particle depolarized light scattering of 0.63 μm laser light. Data is the concentration of ice particles larger than ~50 μm.
Liquid Water, gm cm^{-3}	Determined from the loss of thermal energy from a heated wire exposed to impaction by cloud droplets.
Drop Rate Number per cubic cm of air	Determined from an *in situ* particle sizing probe, the FSSP300. Data is the concentration of particles larger than 3 μm in diameter as number per cm^3.
Relative Humidity	Determined from the ~3 μm optical absorption in a water vapor band. Data is constrained to values not greater than 100%.
Nephelometer	Measured value of particle scattering extinction at 0.53 μm. Periodic manually implemented zero checks detect zero drift in the instrument.

Particle Size	Particle concentration as a function of size was measured using *in situ* probes on the wing covering the particle diameter range, 0.3 - 3000 μm. Particles larger than ~100 μm are recorded as shadow-graph images. Particle concentration in the size range 0.01 - 3 μm diameter was also measured from bag samples collected in a 5 - 10 second interval at times selected by the science crew.
Forward Video	The image from a color video camera, looking forward through the aircraft windshield, is recorded on VHS tape during the flight.

Data in this report

The remainder of this report contains descriptions of each of the three flights. For each of the flights, the following are presented: a weather summary, a flight track for the entire flight and for each 1/2 hour, and a strip chart of the aircraft flight and meteorological variables at 1/2 hour per page.

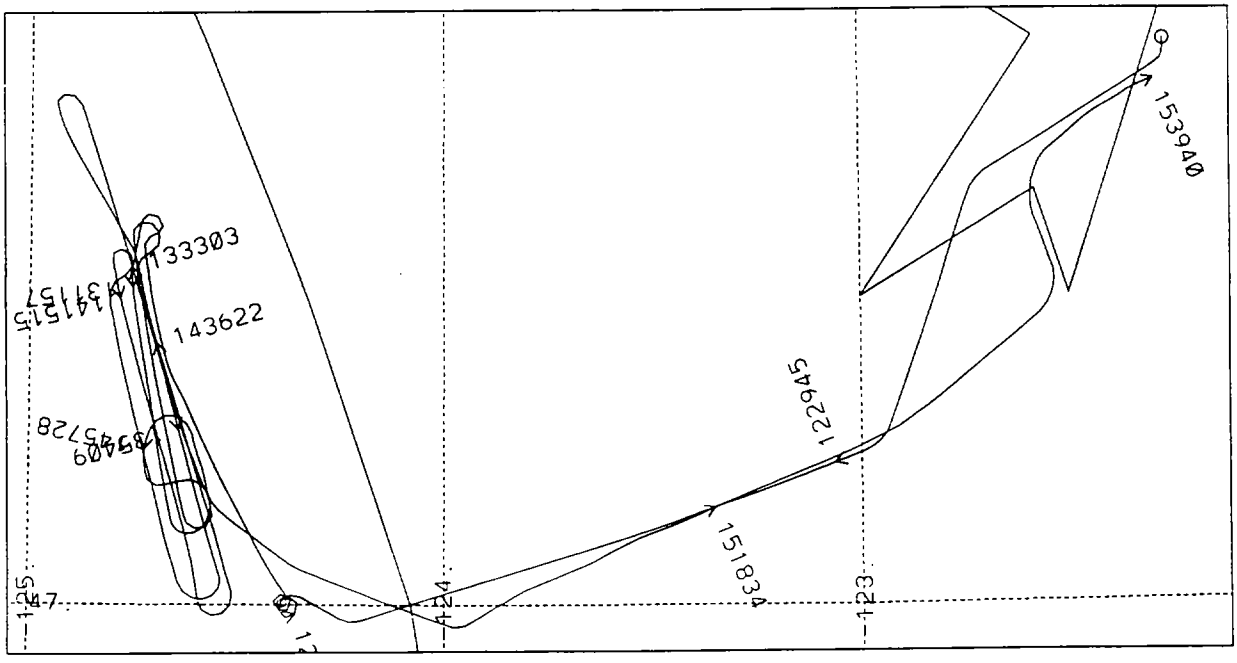
Flight 1593 on 14 April 1993

Flight Description

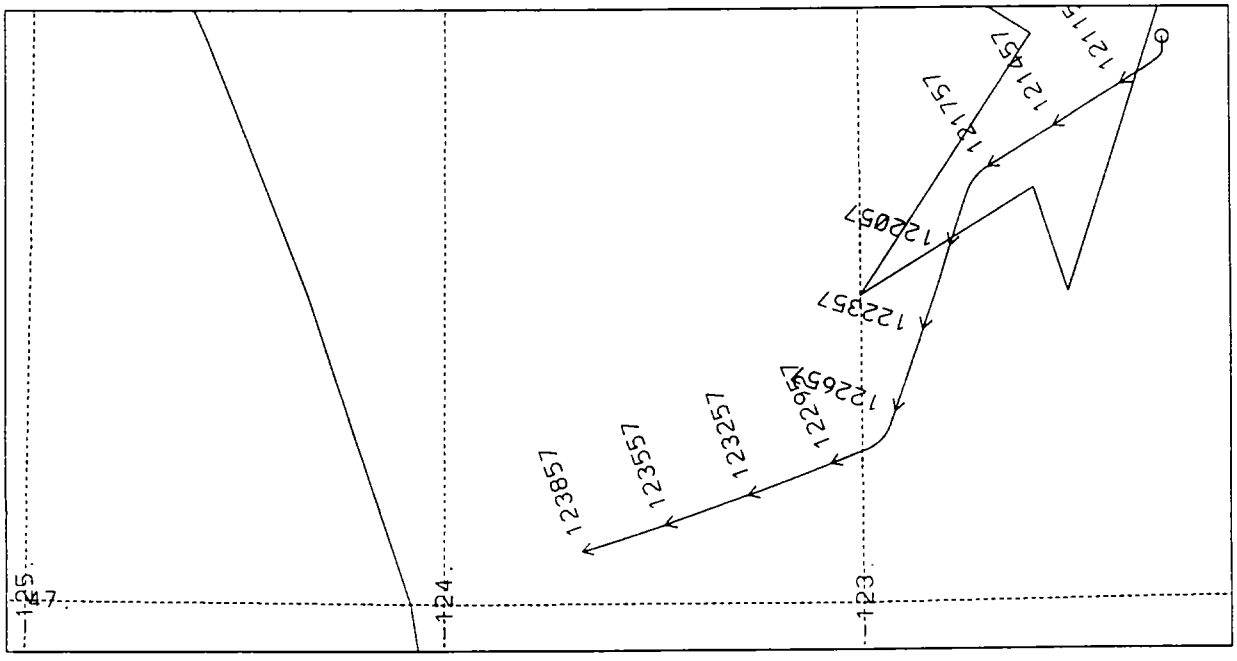
The flight began at Paine Field and headed WSW to the Pacific Coast. The major portion of this flight was conducted in a race-track pattern extending from about Aberdeen at the south to La Push at the north and about 30 miles off-shore. Segments were flown at altitudes from 300 to 9,000 feet. Most of the flight was in clear air with in-cloud intervals in the time period 1420 - 1525 during which both droplets and ice crystals were detected. The peak concentrations were ~6 drops per cm^3 and ~0.3 ice crystals per liter. Particle scattering extinction @ 530 nm was about 1.5×10^{-5} m^{-1} at 500 feet and decreased to about 0.3×10^{-5} m^{-1} at 8000, 0.1×10^{-5} m^{-1} at 9000 feet, and increasing to 0.3×10^{-5} m^{-1} at 10,000 feet.

Weather

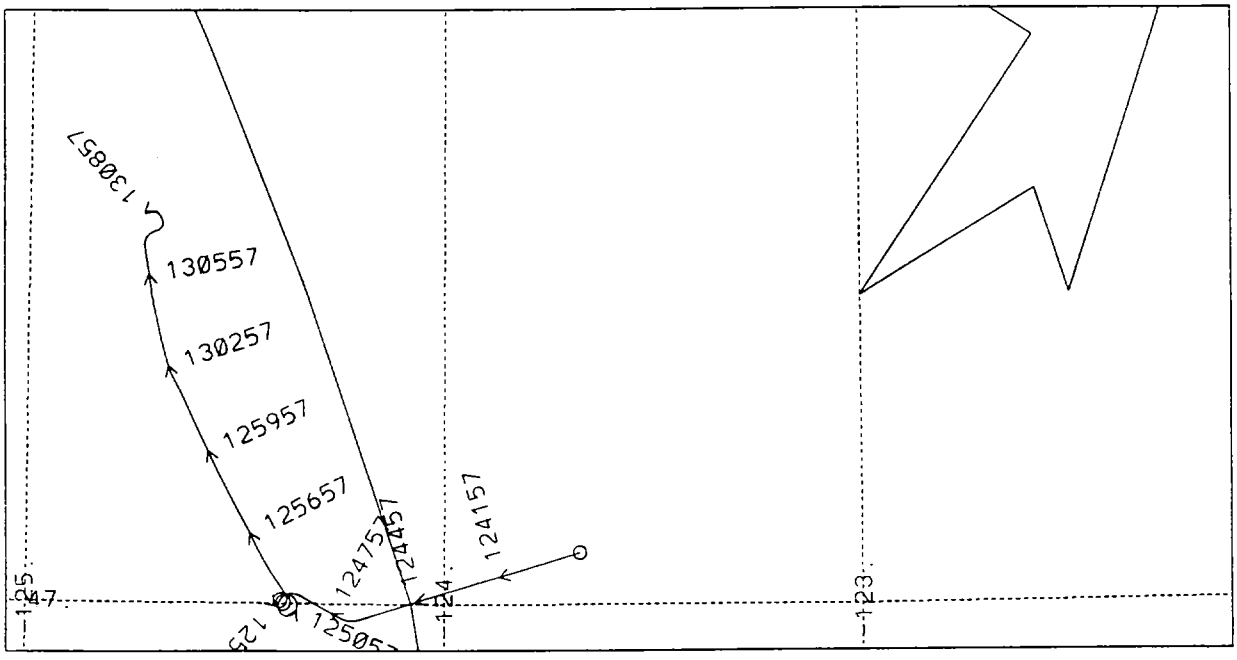
A large low-pressure center slowly approached the coast, pushing a cold front and spreading high and middle clouds in advance over the flight region. Offshore flow at mid-day at the coast became onshore flow as the coastal sea-breeze circulation temporarily dominated the synoptic gradients. A sharp upper-level ridge lay just west of the Pacific Coast at 0500 PDT and by 1700 PDT had passed inland as southwesterly flow developed aloft during the day.



GPS track of flight 1593, 04/14/93 12:09:00 - 15:40:00



GPS track of flight 1593, 04/14/93 12:09:00 - 12:39:00



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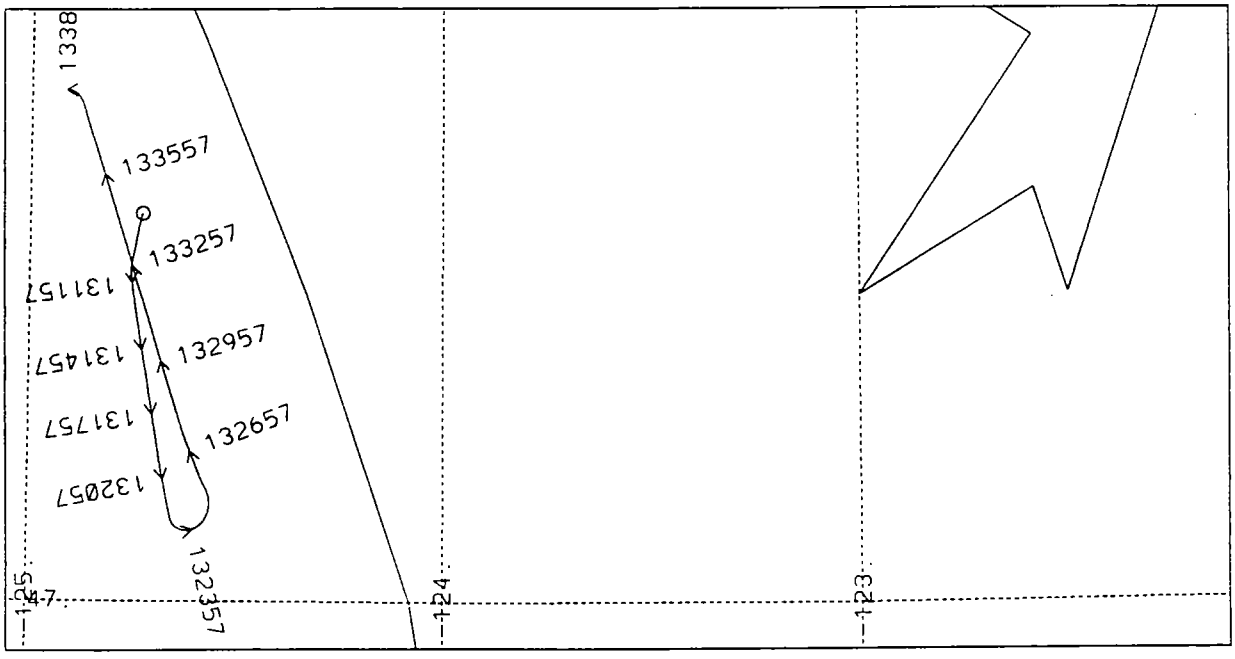

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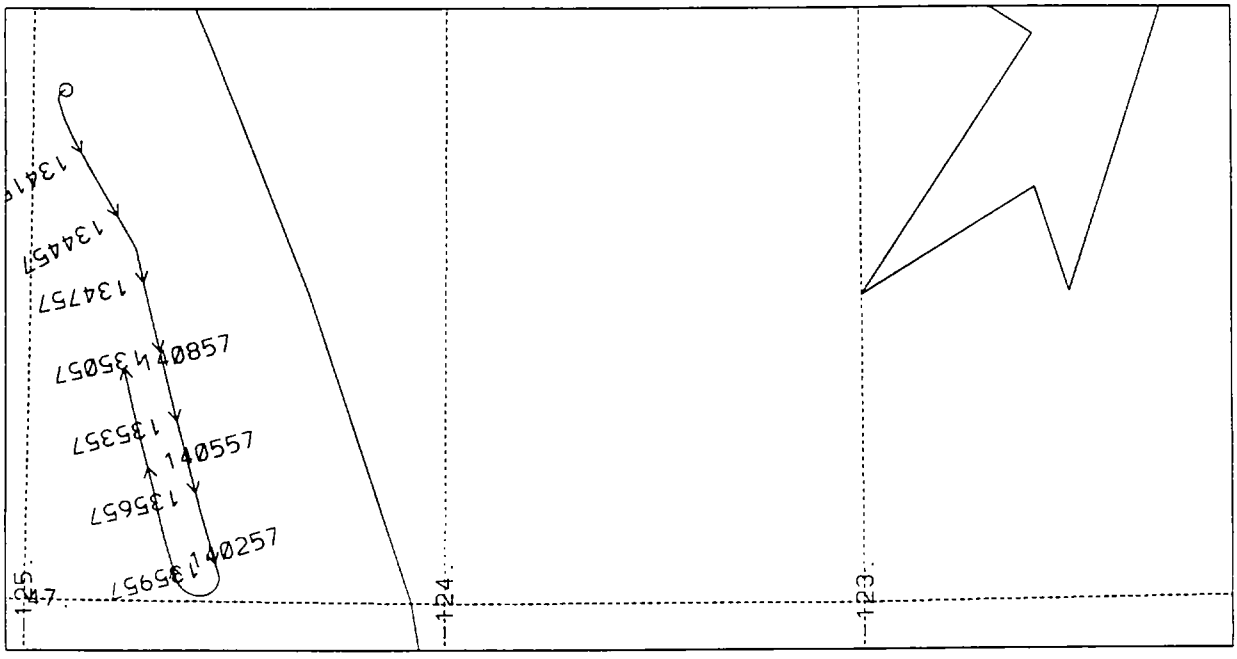

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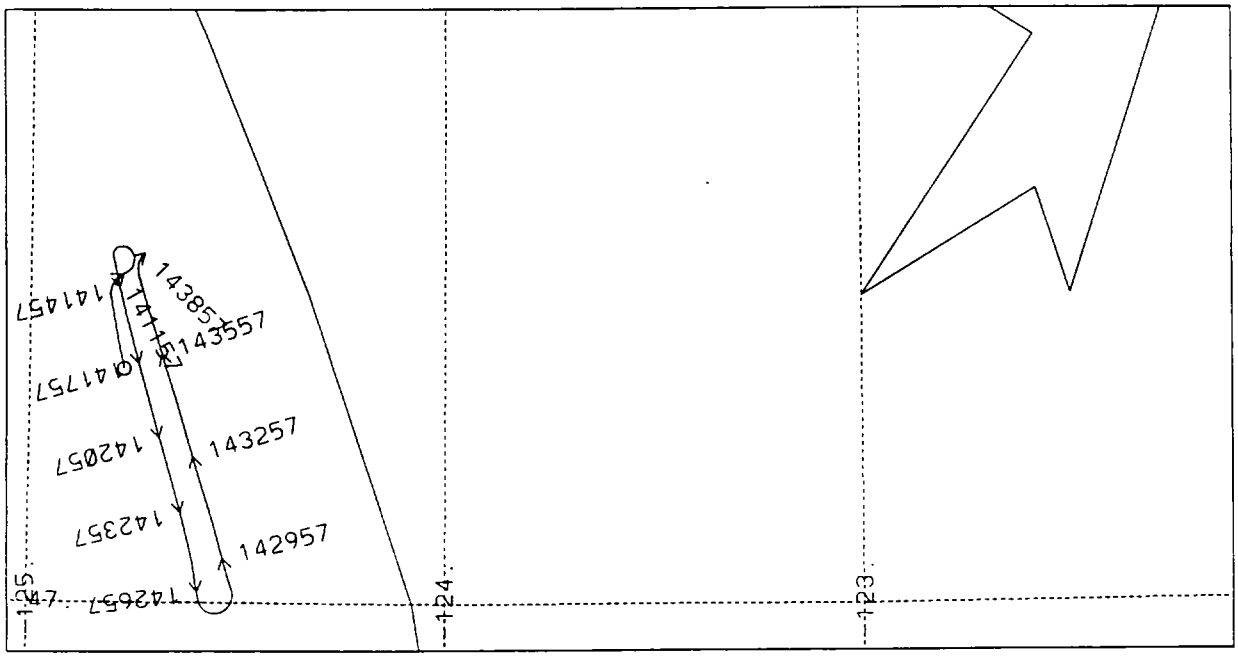
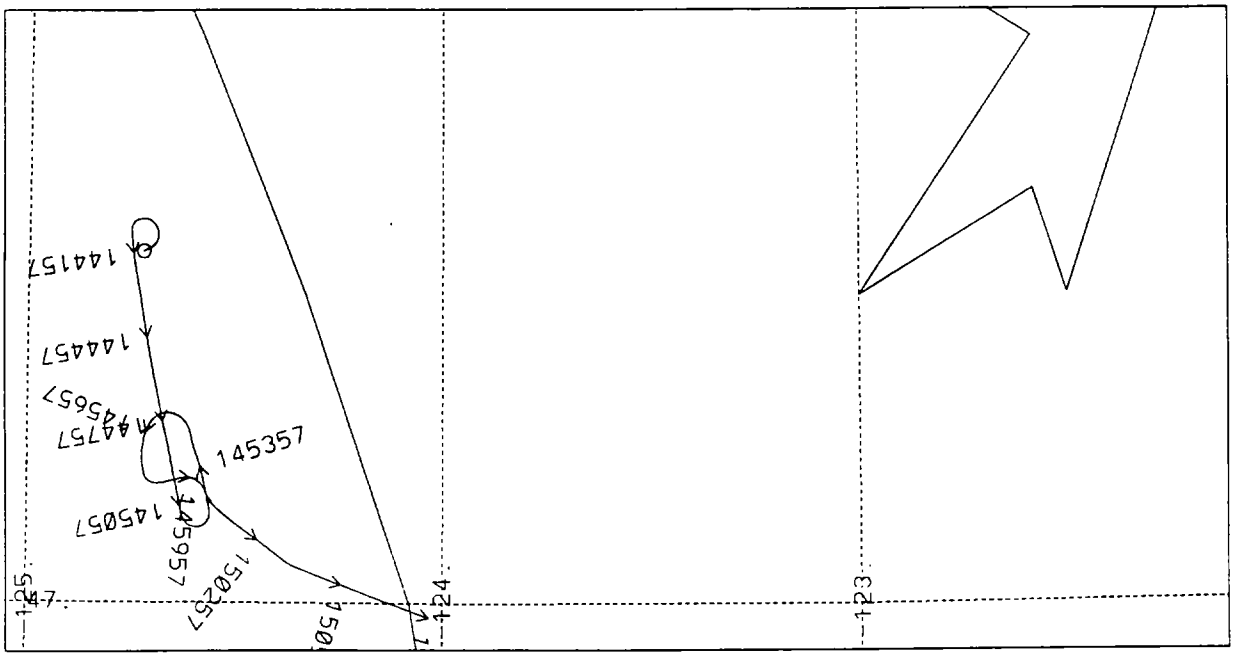
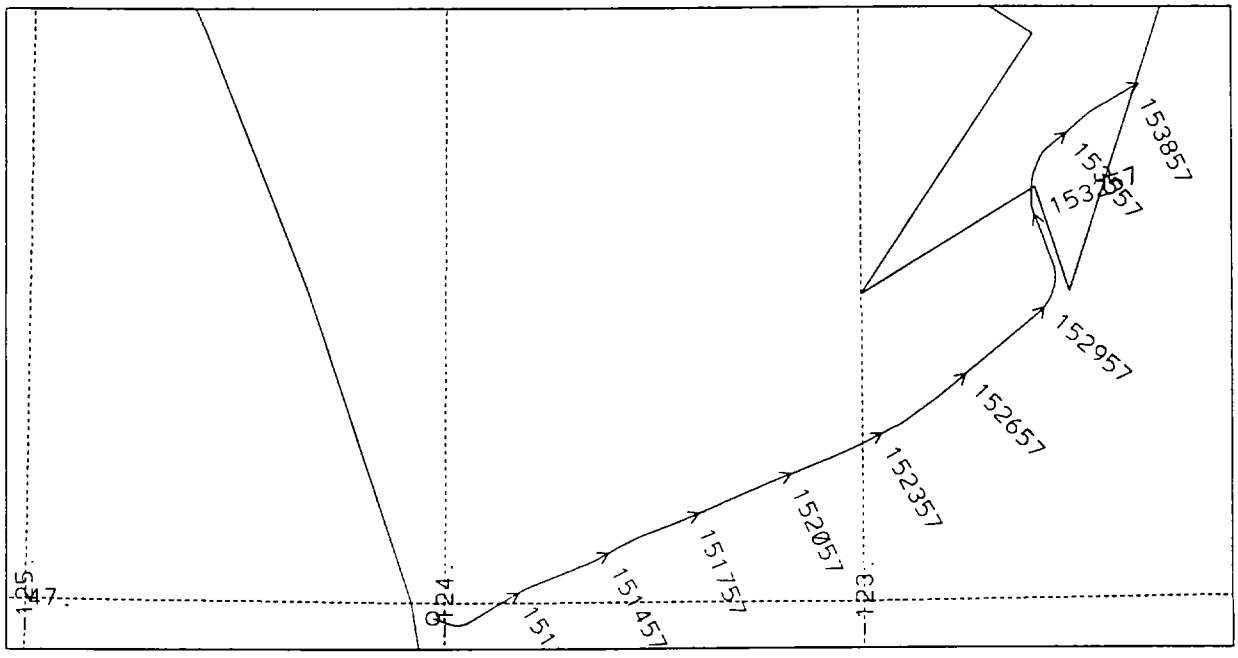


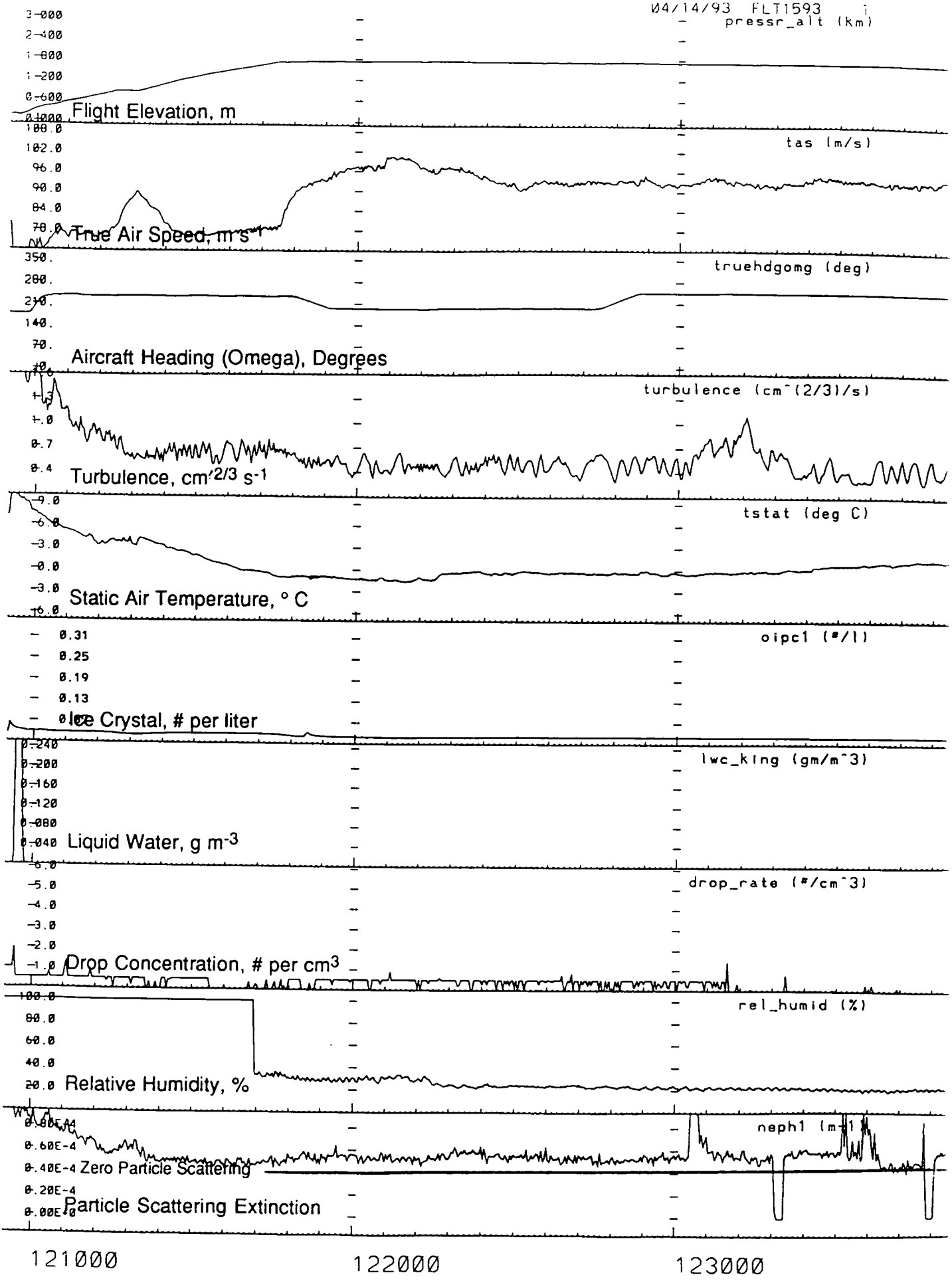
GPS track of flight 1593, 04/14/93 14:09:00 - 14:39:00



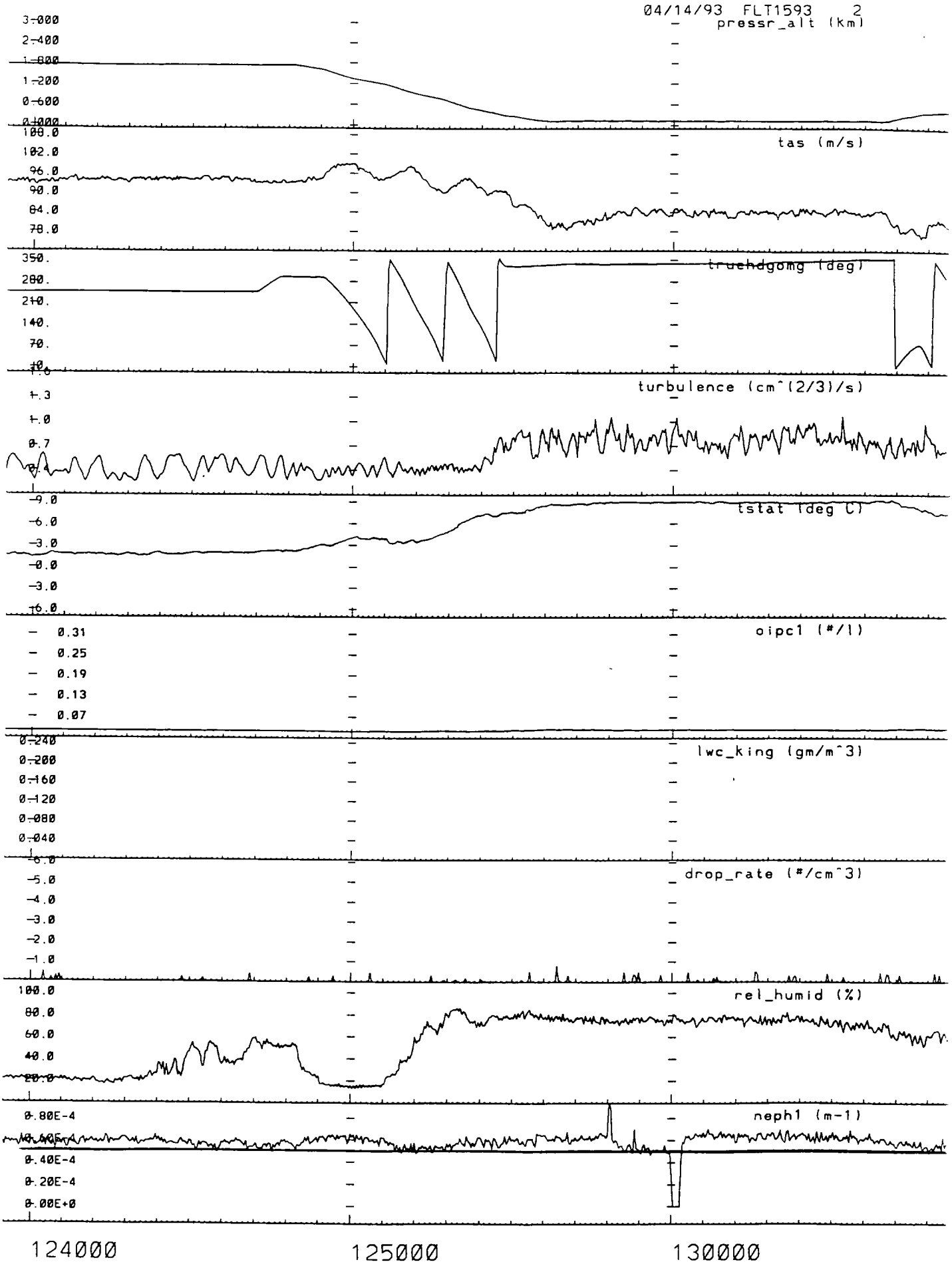
GPS track of flight 1593, 04/14/93 14:39:00 - 15:09:00



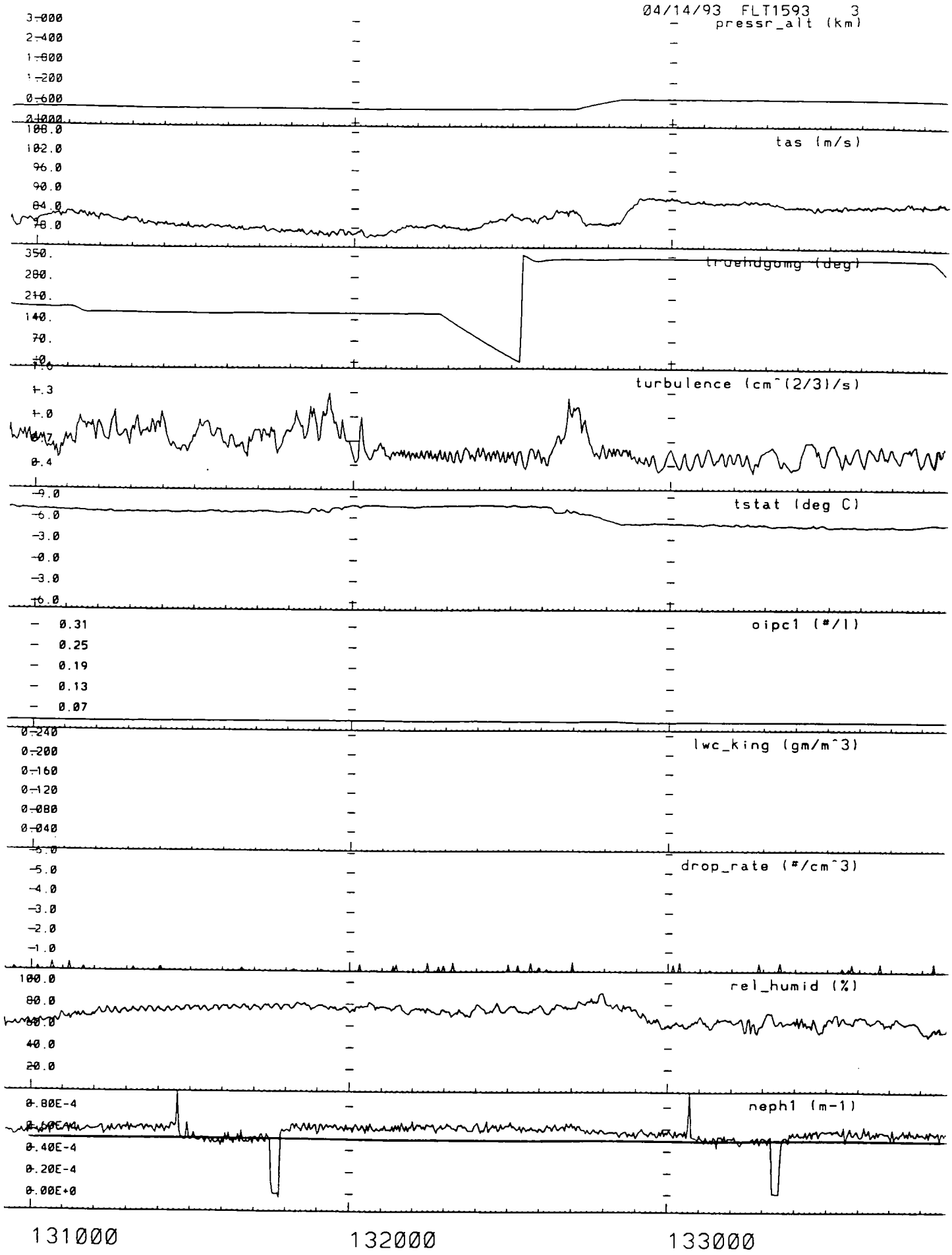
GPS track of flight 1593, 04/14/93 15:09:00 - 15:39:00



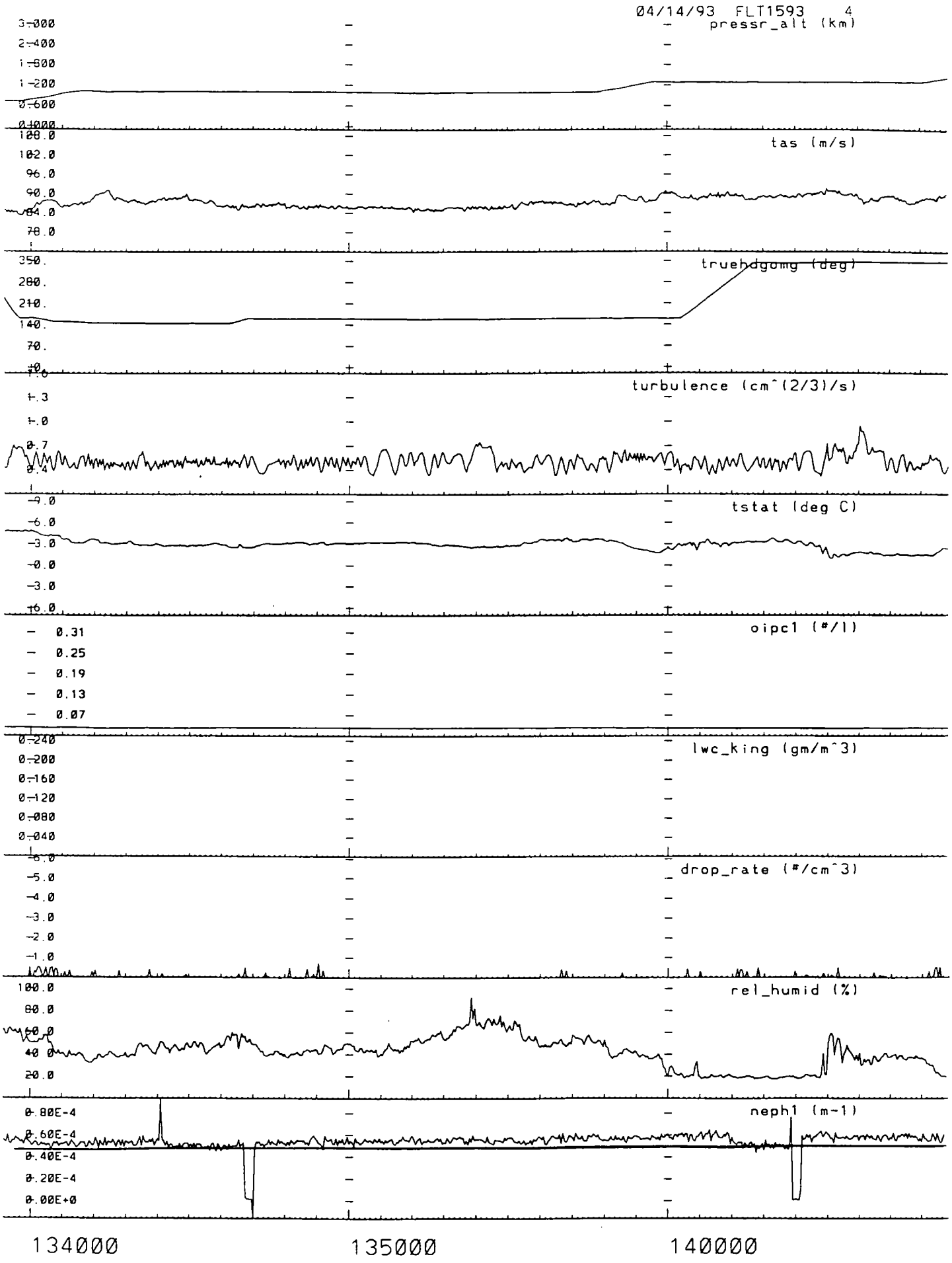
Flight-Level Data for UW Flight 1593, 04/14/93 from 1210–1230 hours



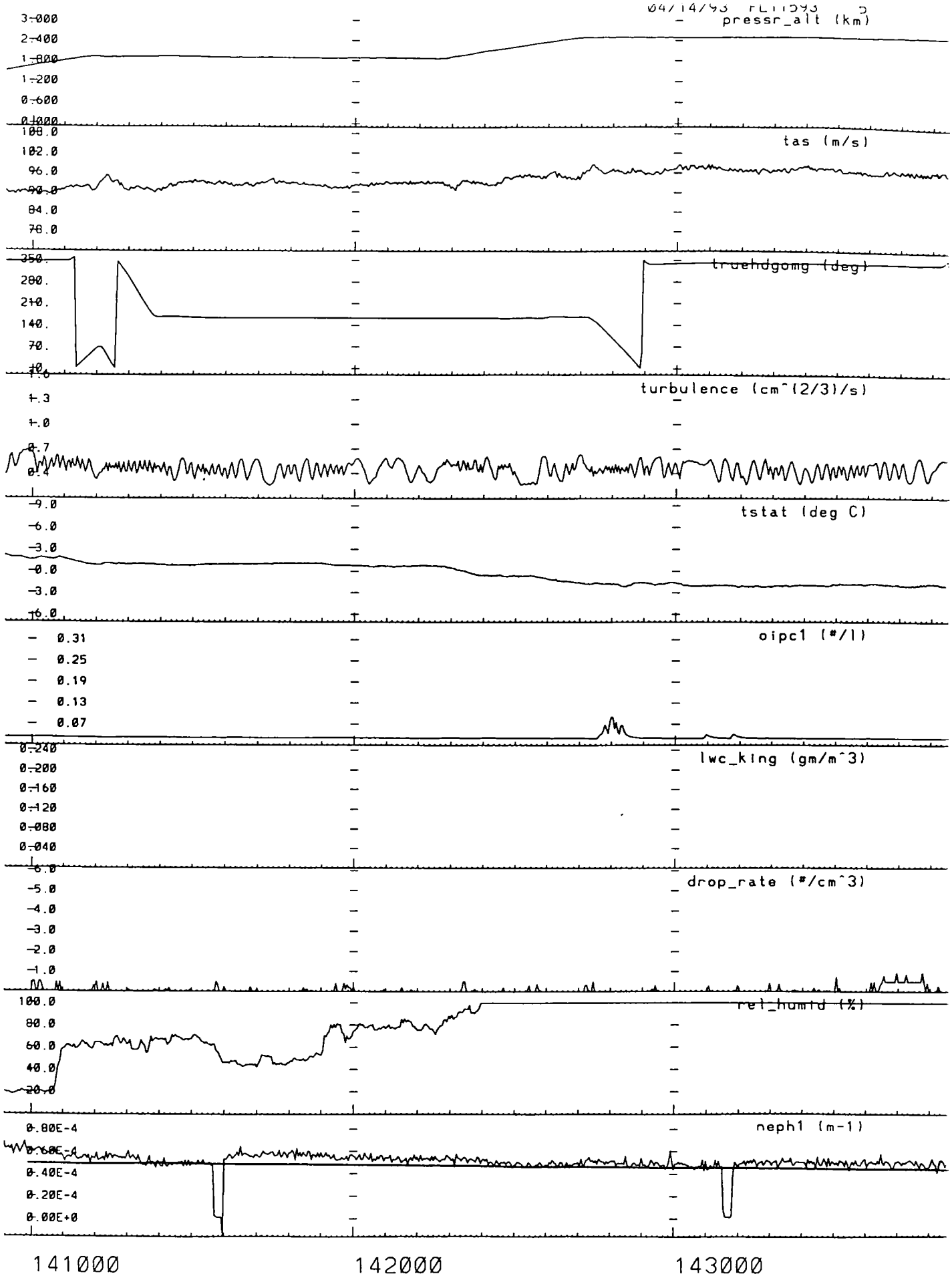
Flight-Level Data for UW Flight 1593, 04/14/93 from 1240–1300 hours



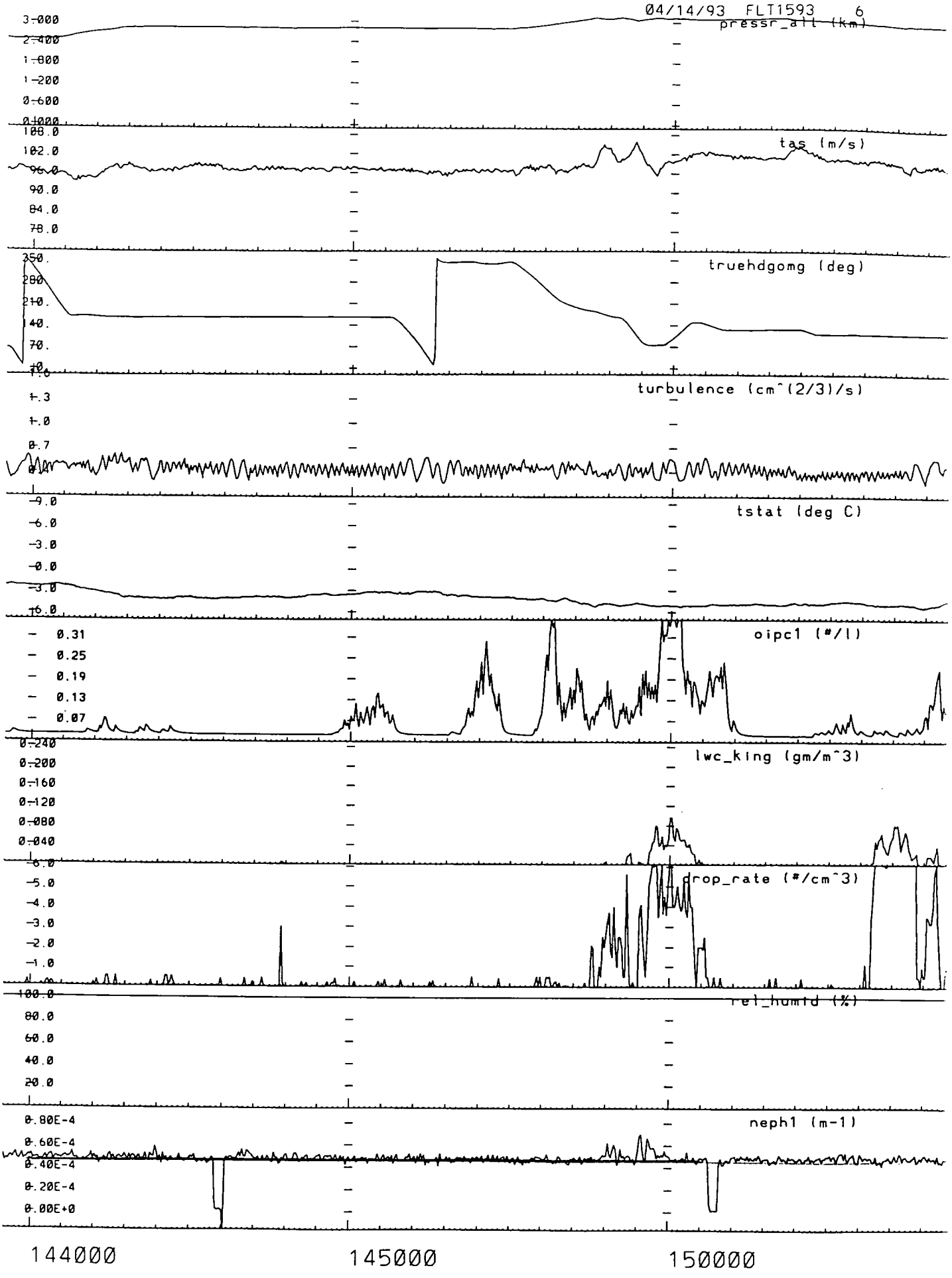
Flight-Level Data for UW Flight 1593, 04/14/93 from 1310–1330 hours



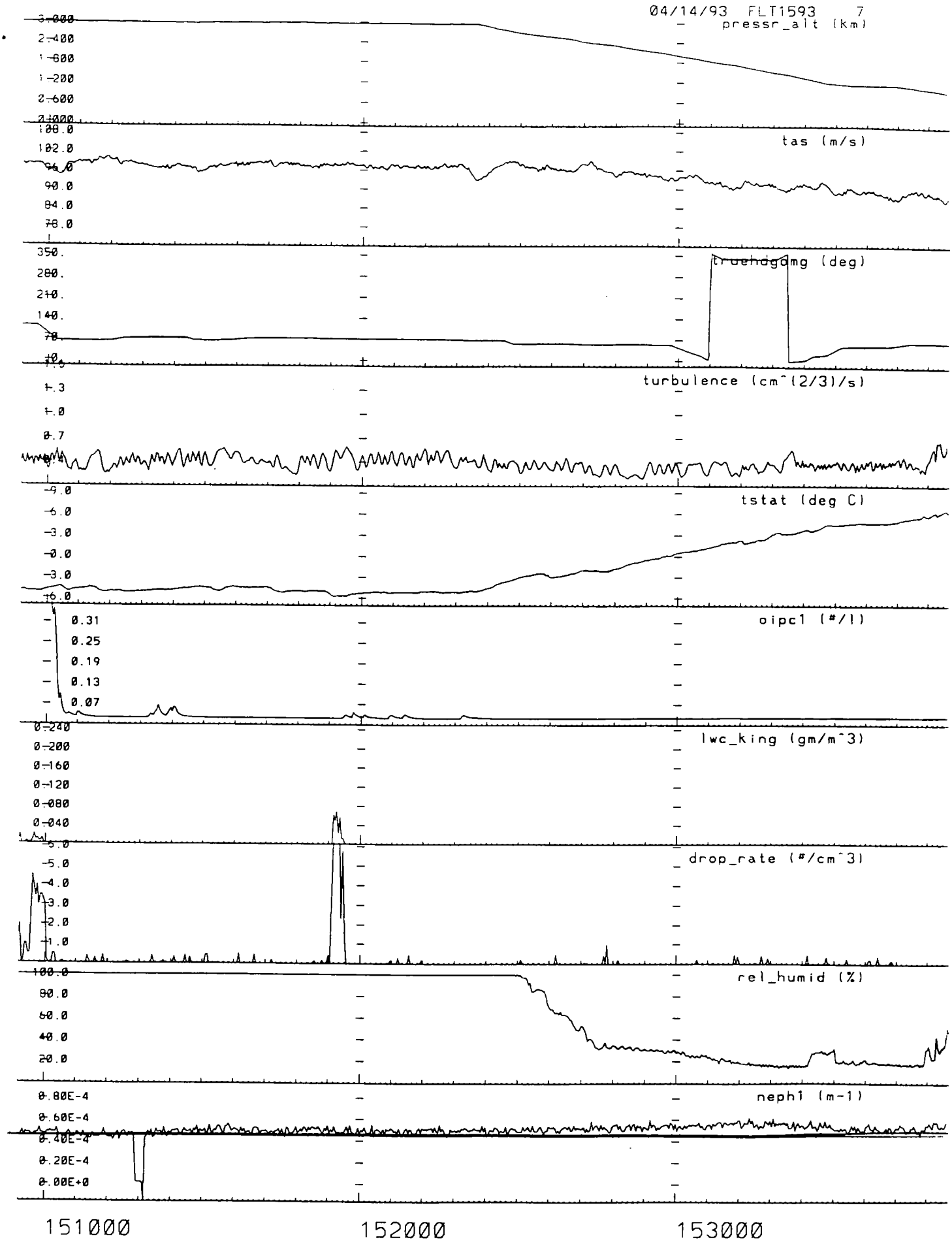
Flight-Level Data for UW Flight 1593, 04/14/93 from 1340–1400 hours



Flight-Level Data for UW Flight 1593, 04/14/93 from 1410–1430 hours



Flight-Level Data for UW Flight 1593, 04/14/93 from 1440–1500 hours



Flight-Level Data for UW Flight 1593, 04/14/93 from 1510–1530 hours

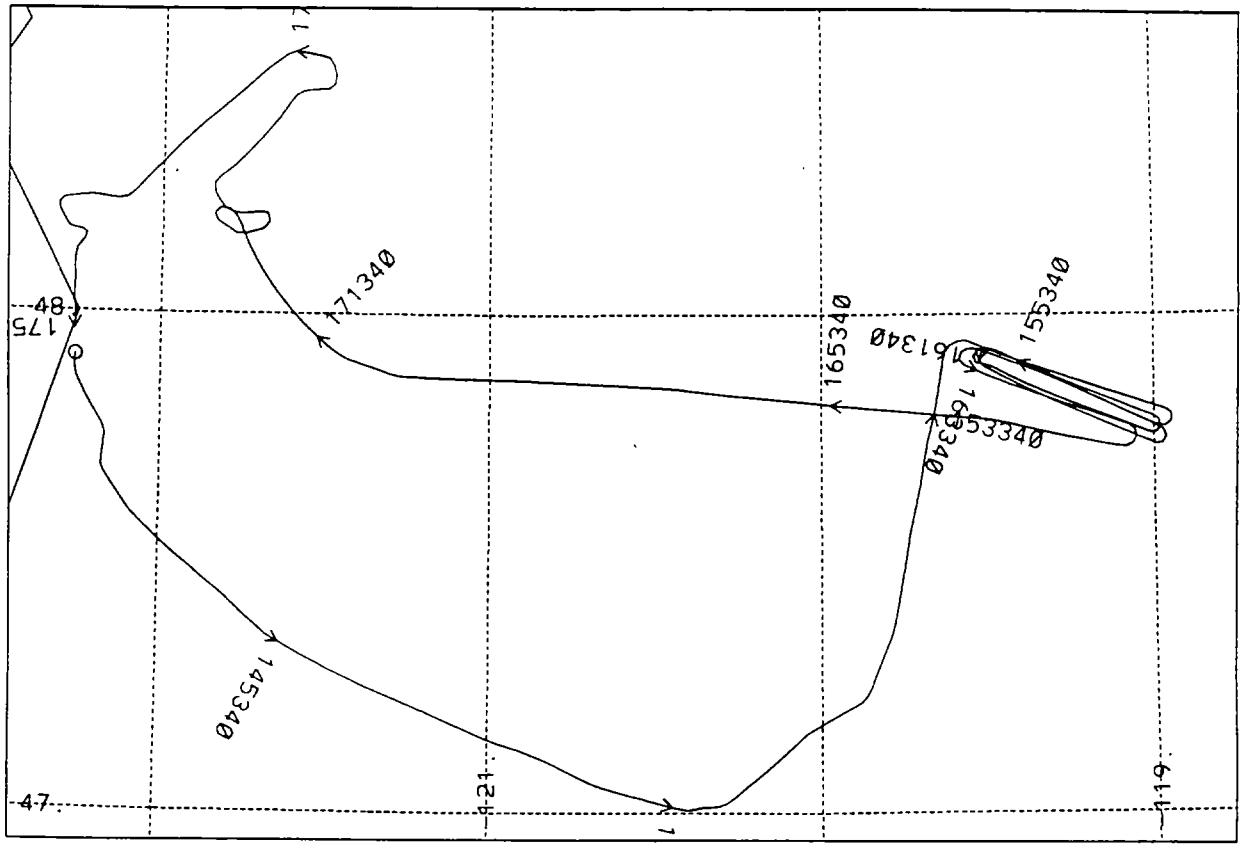
Flight 1594 on 20 April 1993

Flight Description

The flight began at Paine Field and headed ESE into Eastern Washington, crossing the Cascades at 8,000 feet. A race-track pattern was flown NE of Wenatchee, with the long axis of the pattern turned slightly clockwise from E-W. Flight segments were flown at various elevations from 2,500 feet to 12,000 feet. Droplet clouds were found during the time interval 1704 - 1720 at concentrations up to ~150 per cm^3; ice crystals were found during the time interval 1704 - 1735 at concentrations up to ~0.1 per liter. East of the Cascades at 8,000 feet above sea level, the particle scattering coefficient @ 530 nm was about 3×10^{-5} m^{-1}, increased to 1.5×10^{-5} m^{-1} in the layer from 2,500 to 6,000 feet above sea level.

Weather

This day was virtually identical to 14 April except that the sharp, upper-level ridge moved from the coast to Idaho during the day. A shield of high and middle clouds spread over Eastern Washington during the daylight hours, while cool, dry, easterly flow, circulating out of a large, high-pressure region centered in Montana, dominated flow in the boundary layer.



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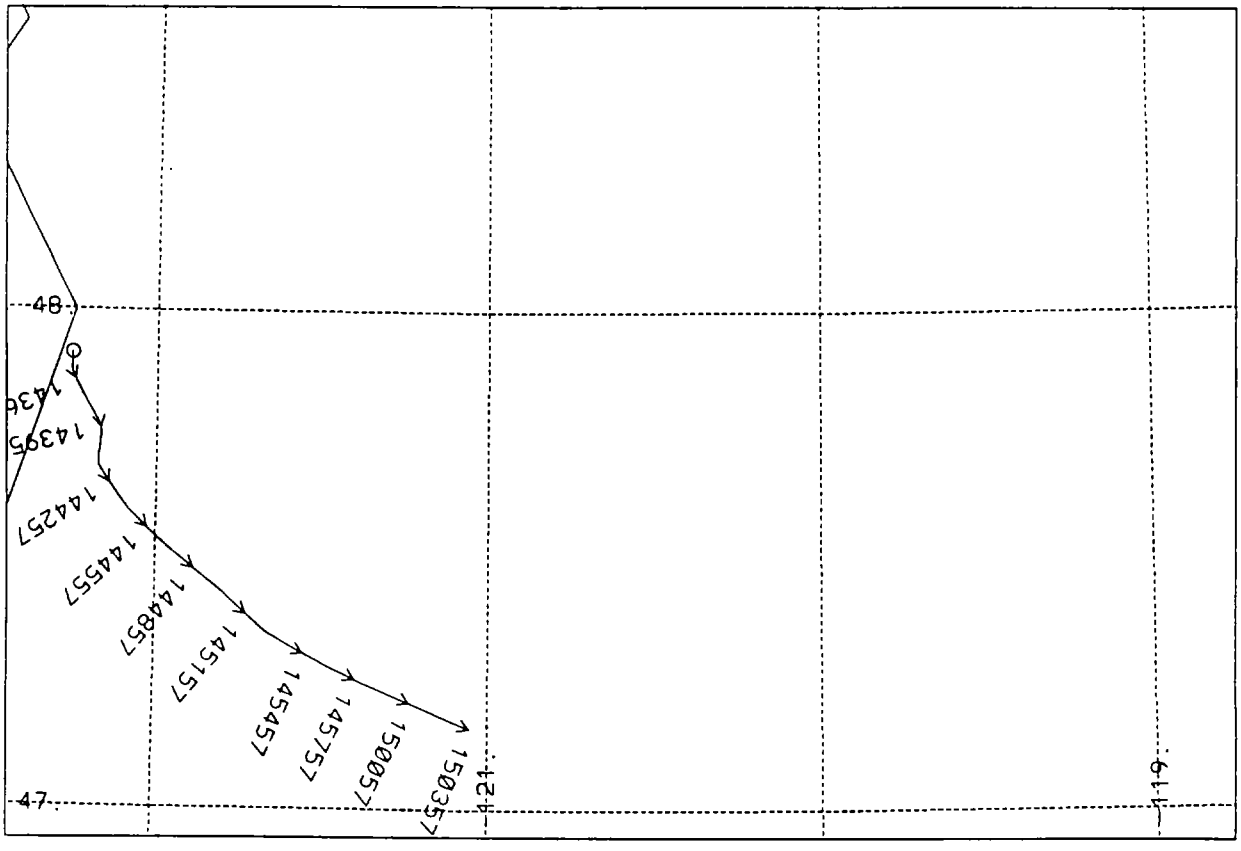

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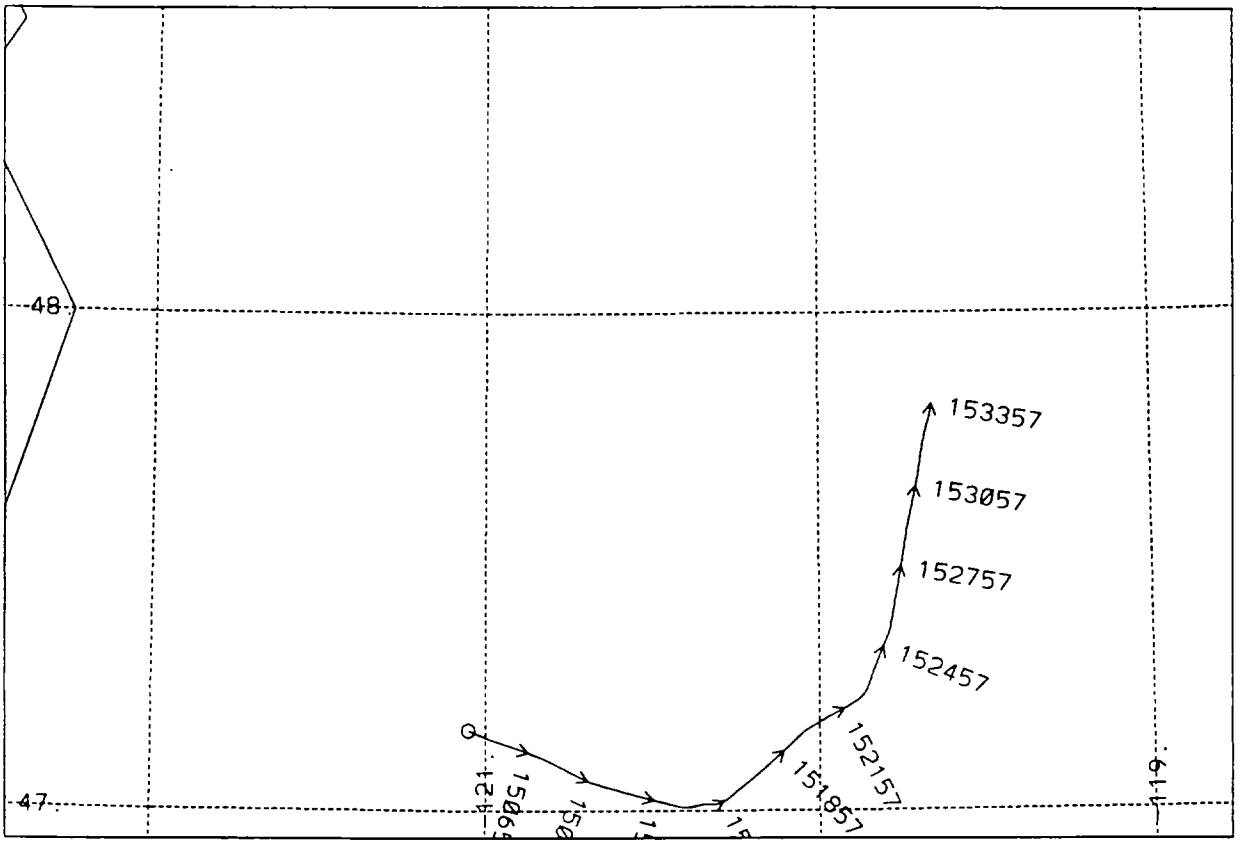

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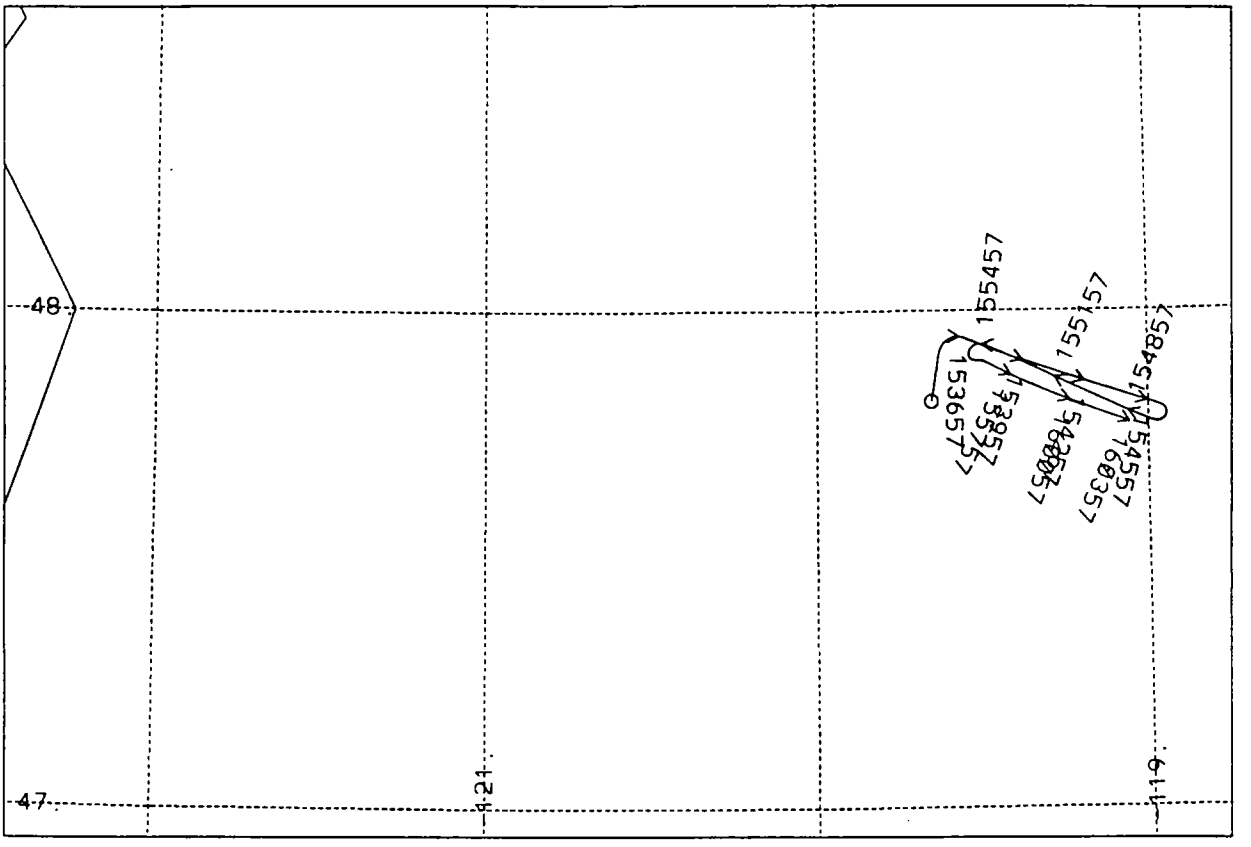

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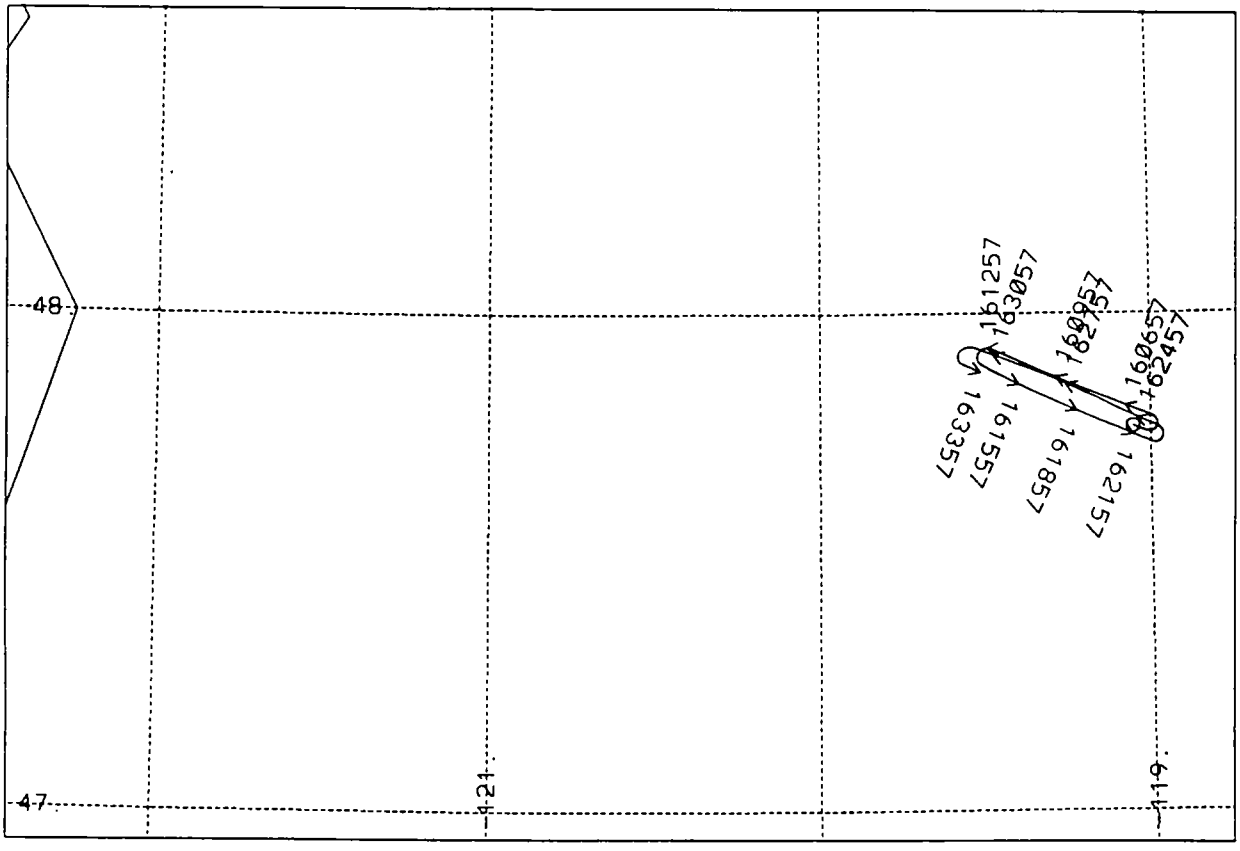

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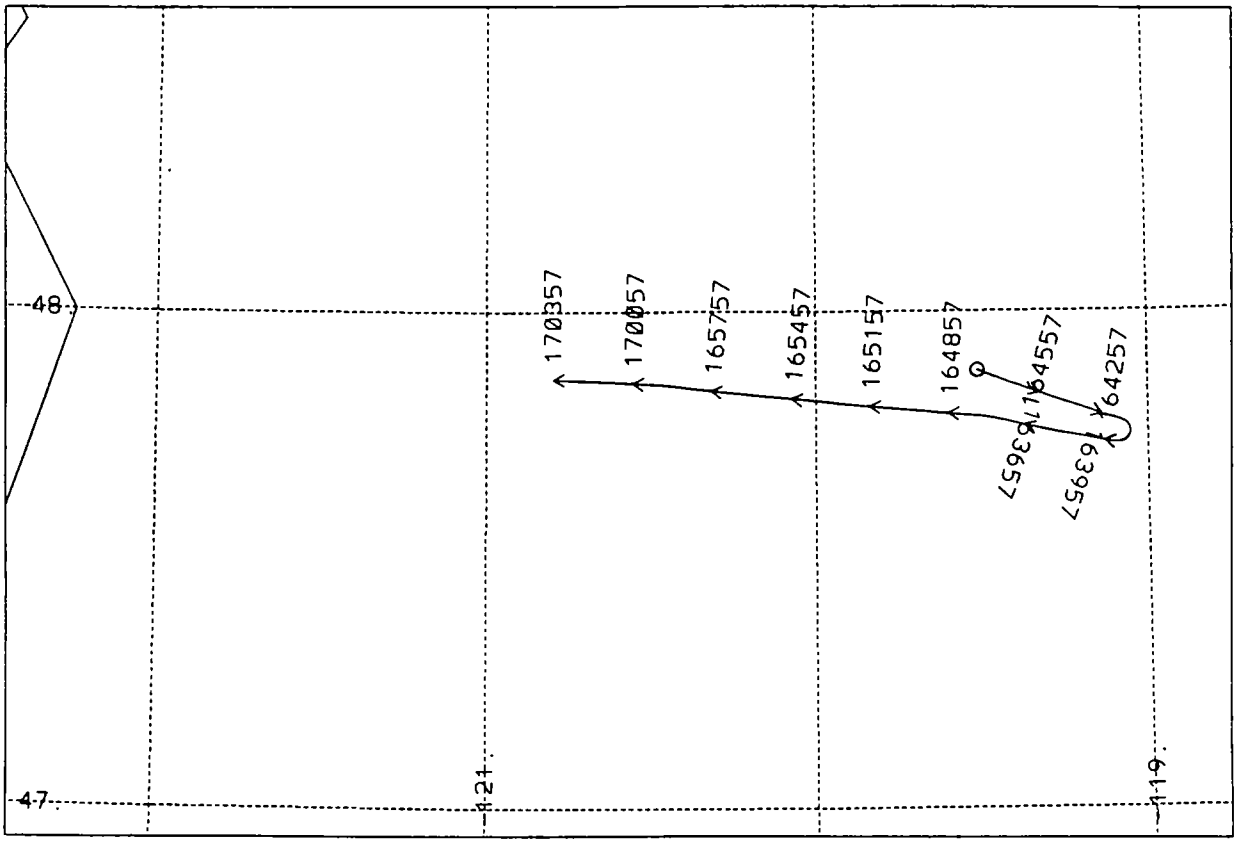
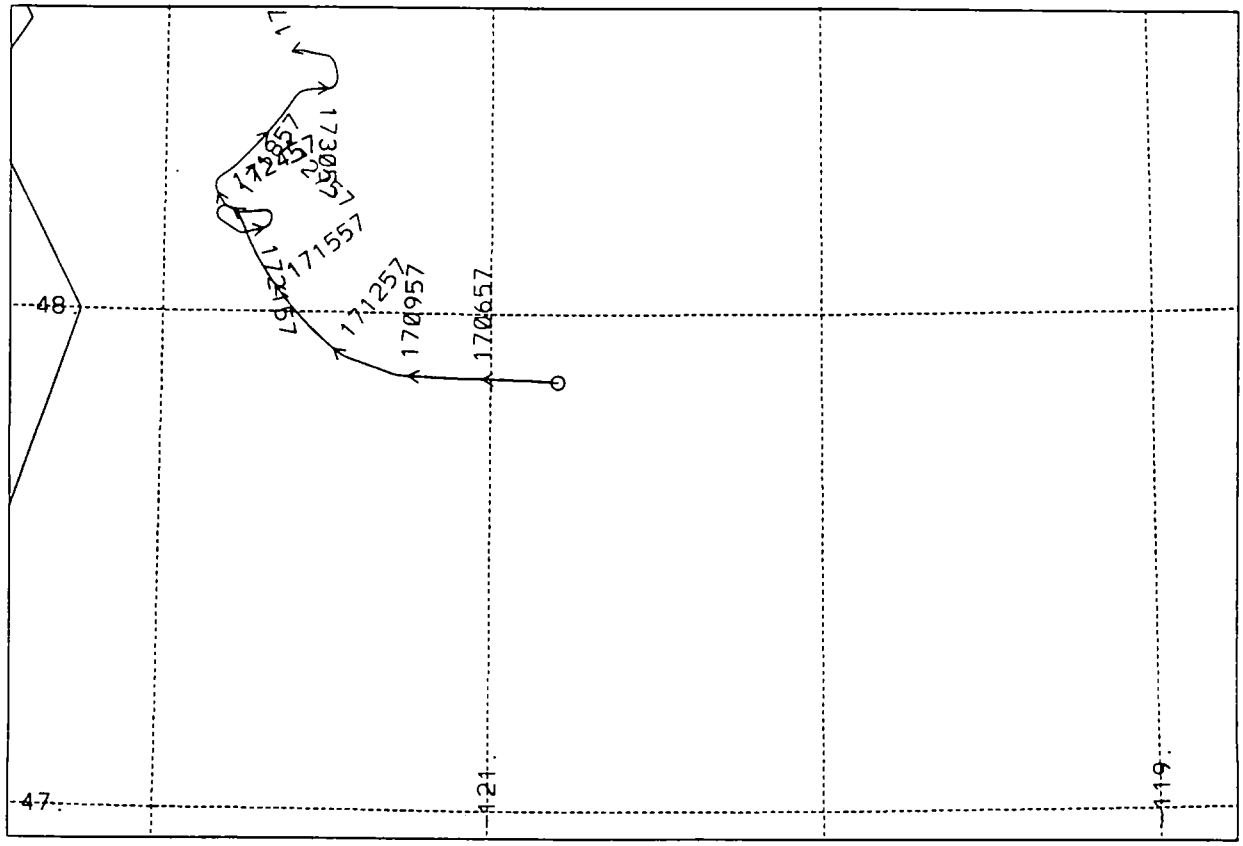


GPS track of flight 1594, 04/20/93 16:34:00 - 17:04:00



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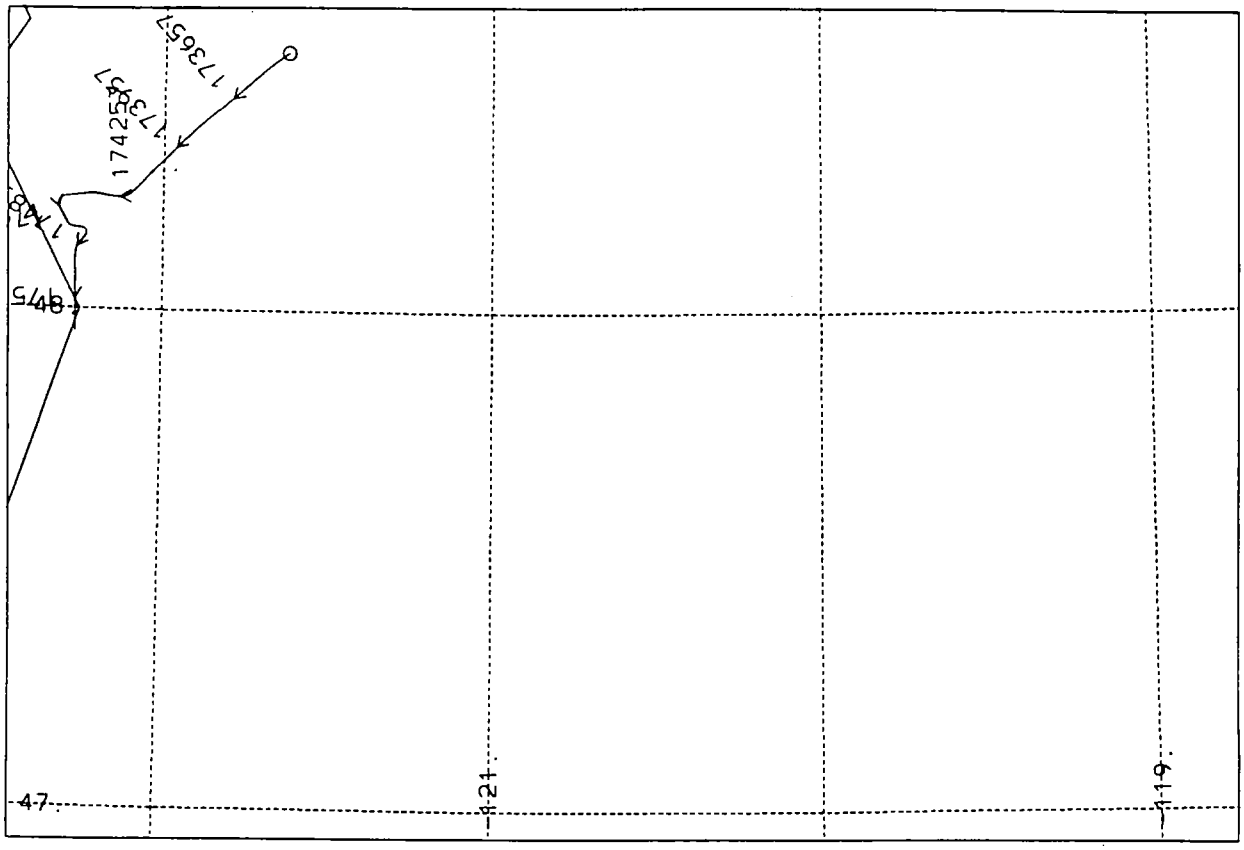

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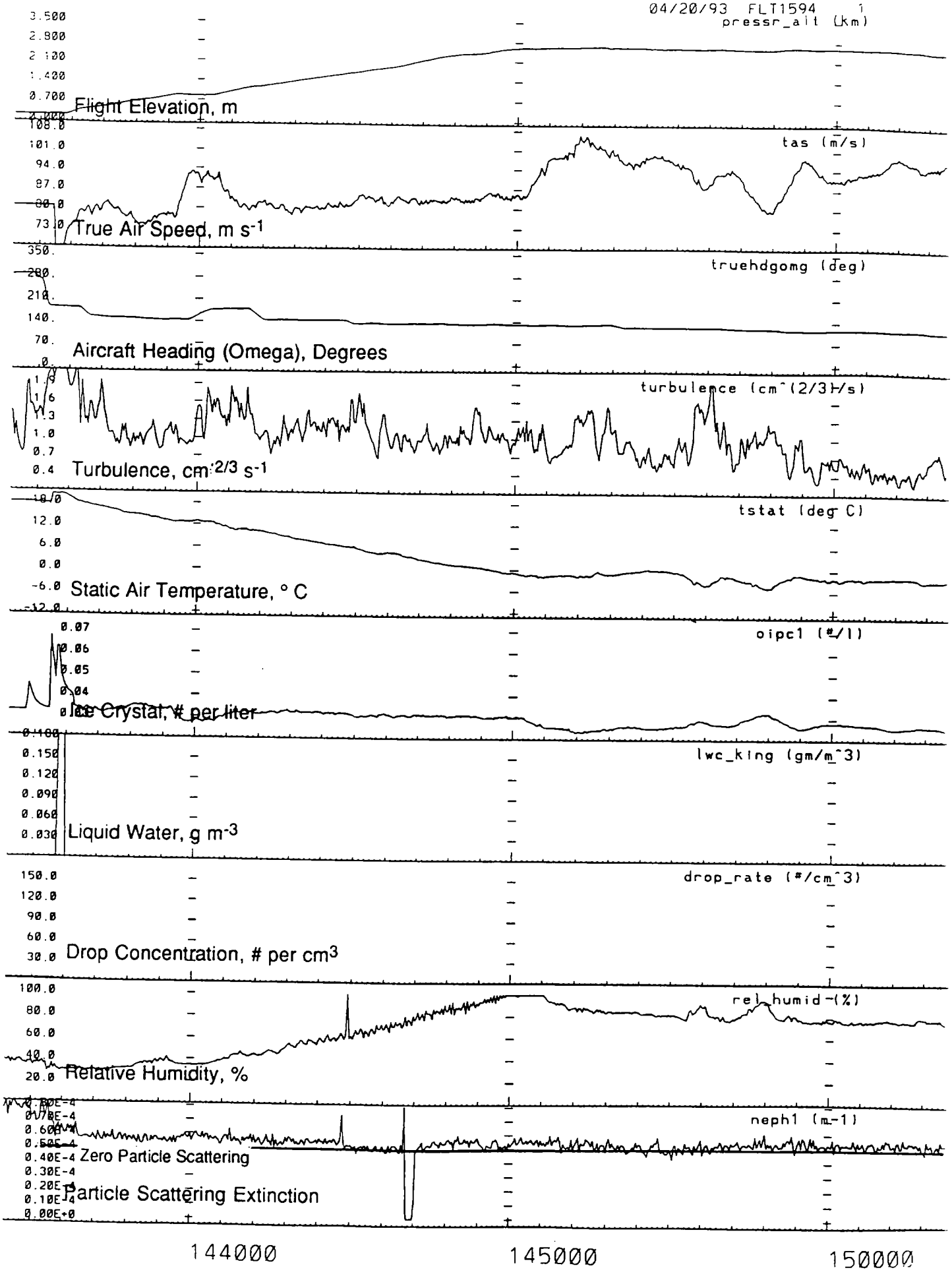
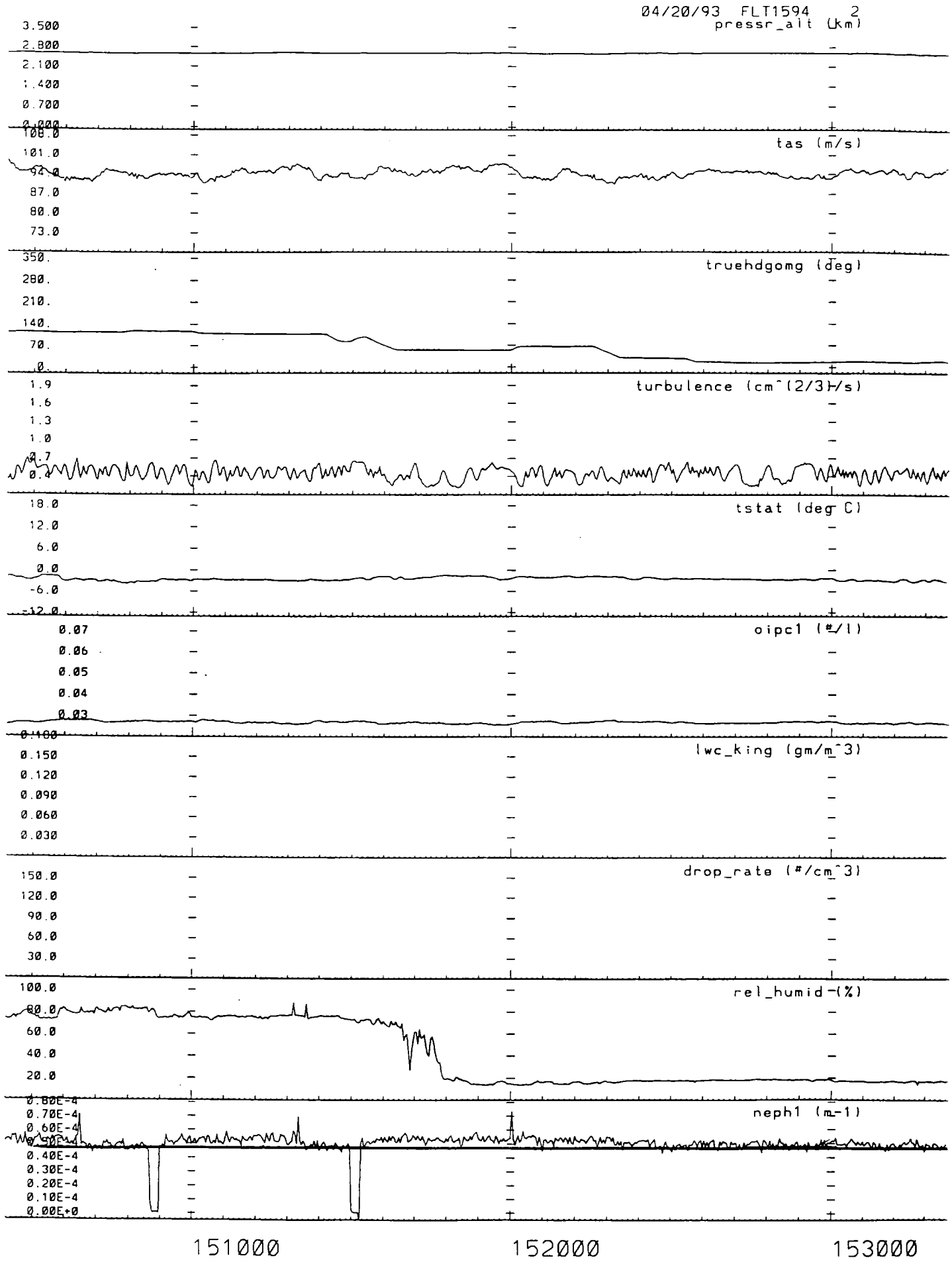
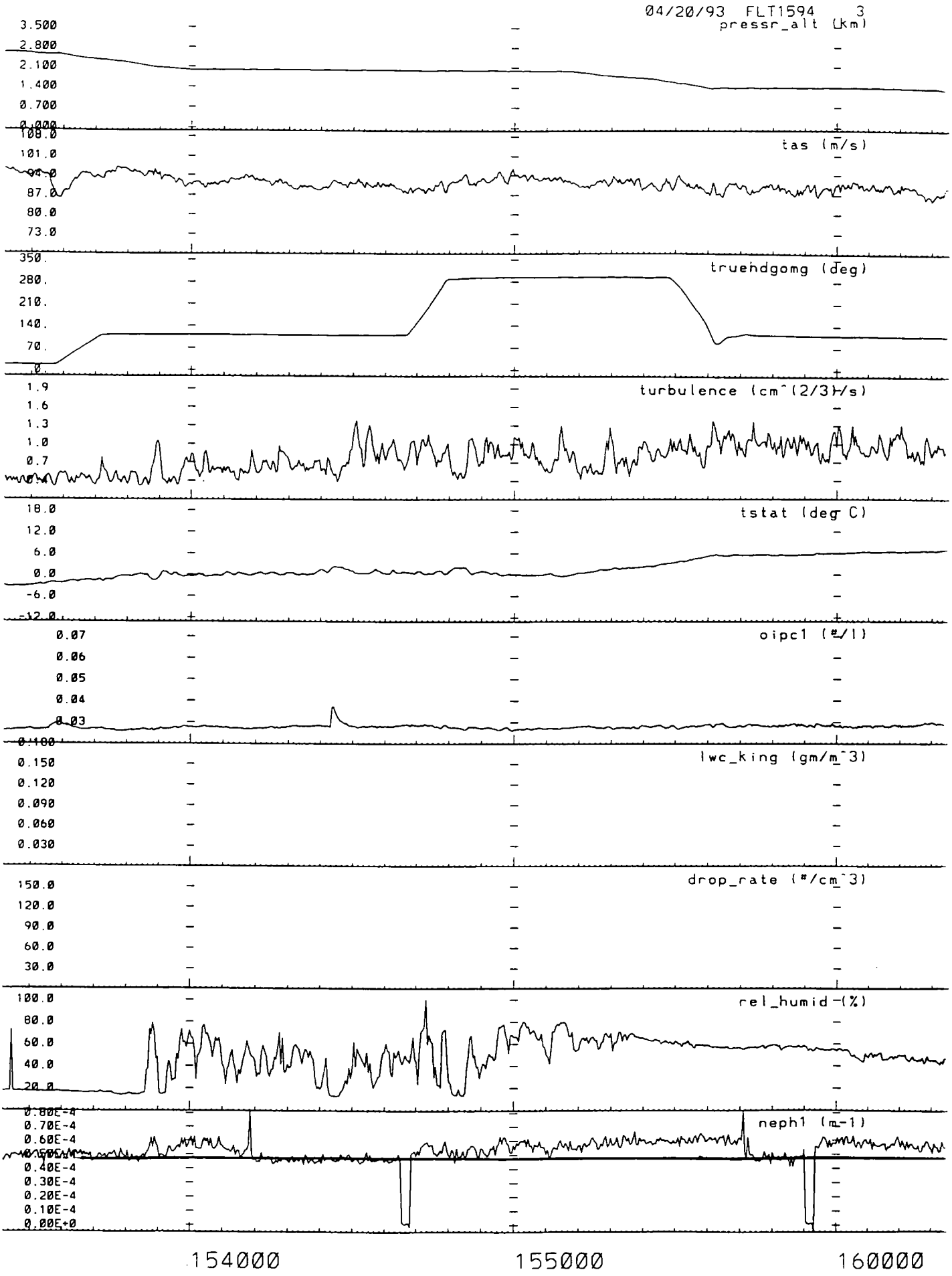


Flight-Level Data for UW Flight 1594, 04/20/93 from 1440–1500 hours



Flight-Level Data for UW Flight 1594, 04/20/93 from 1510–1530 hours



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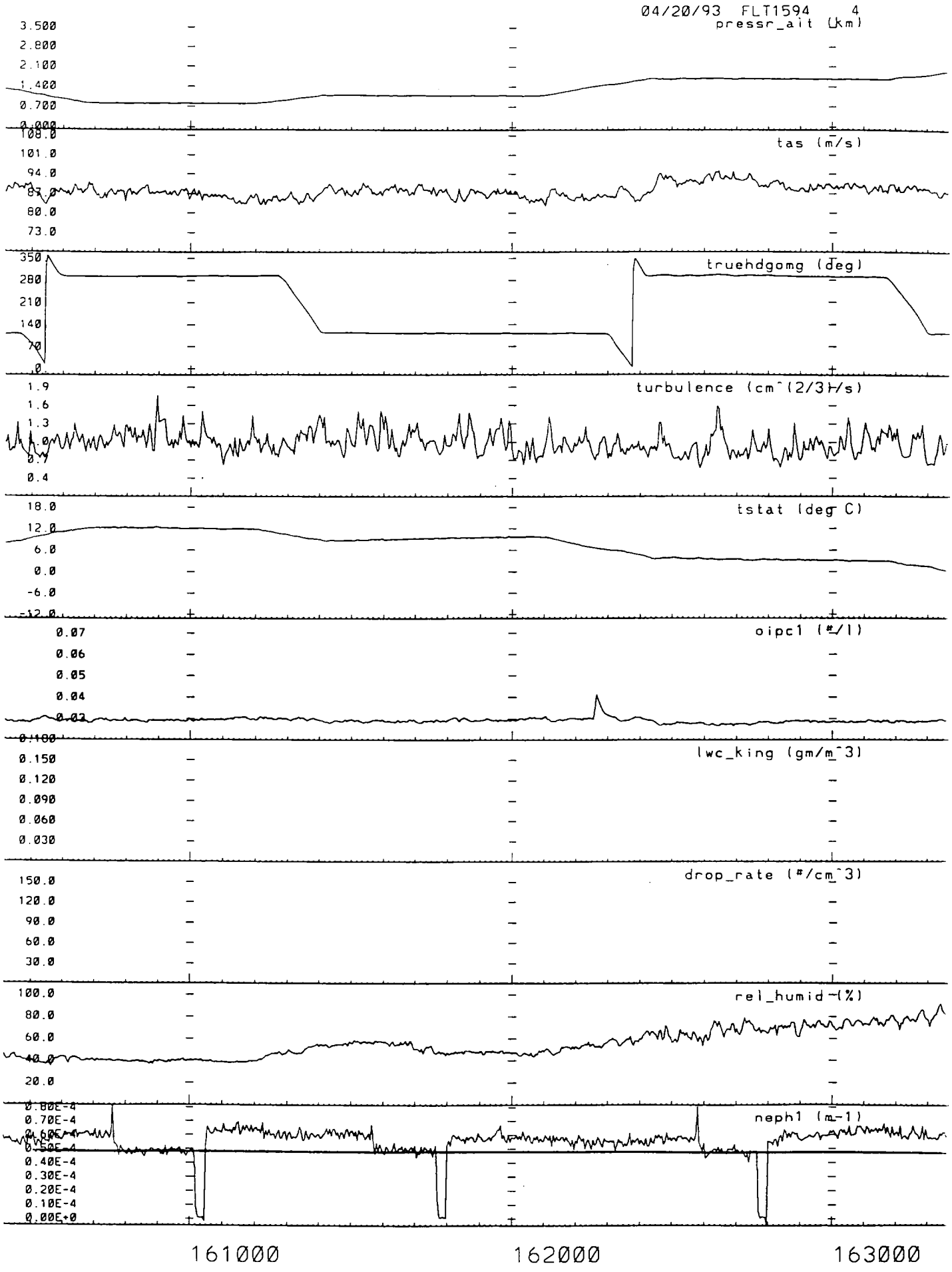
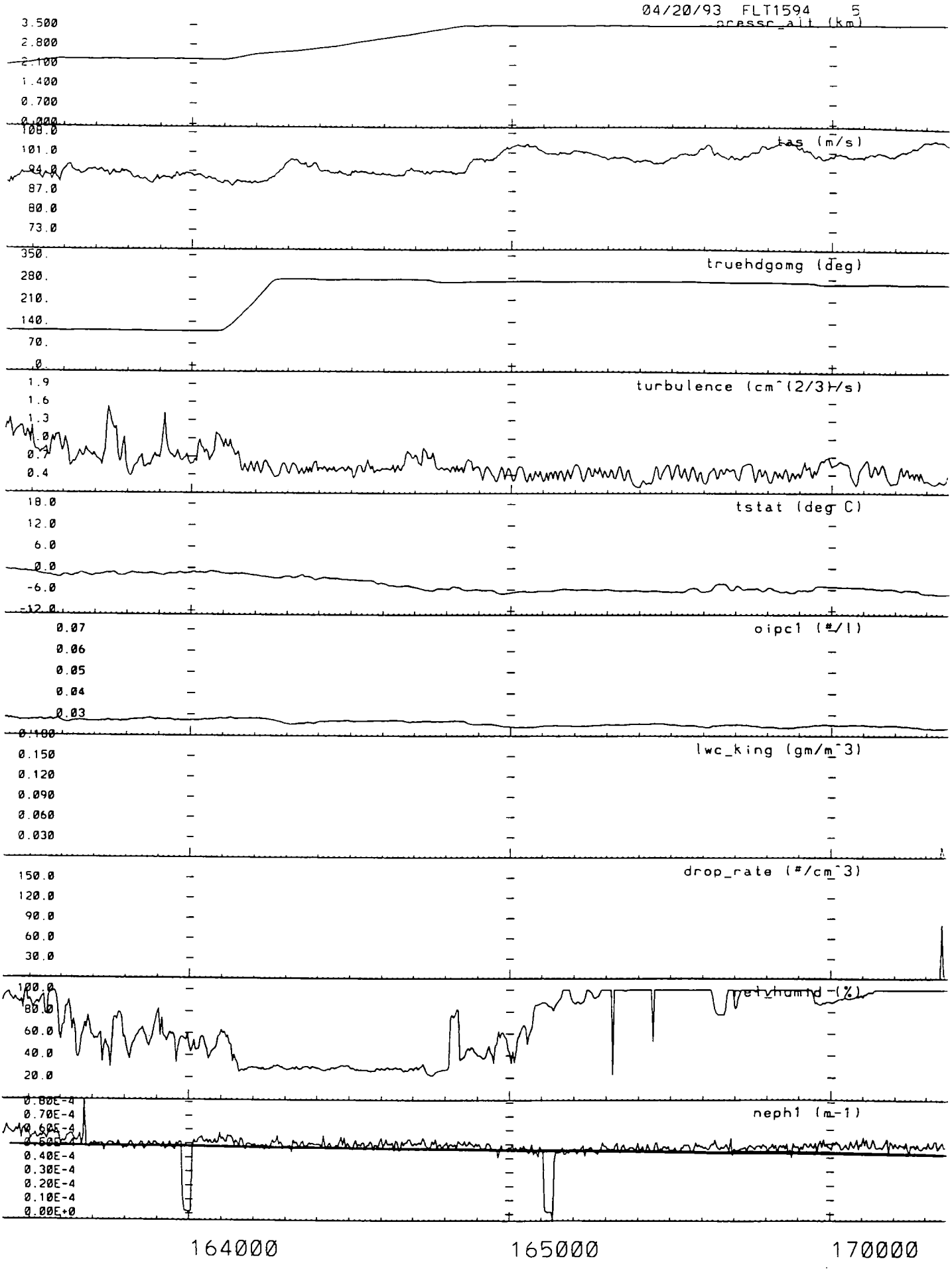
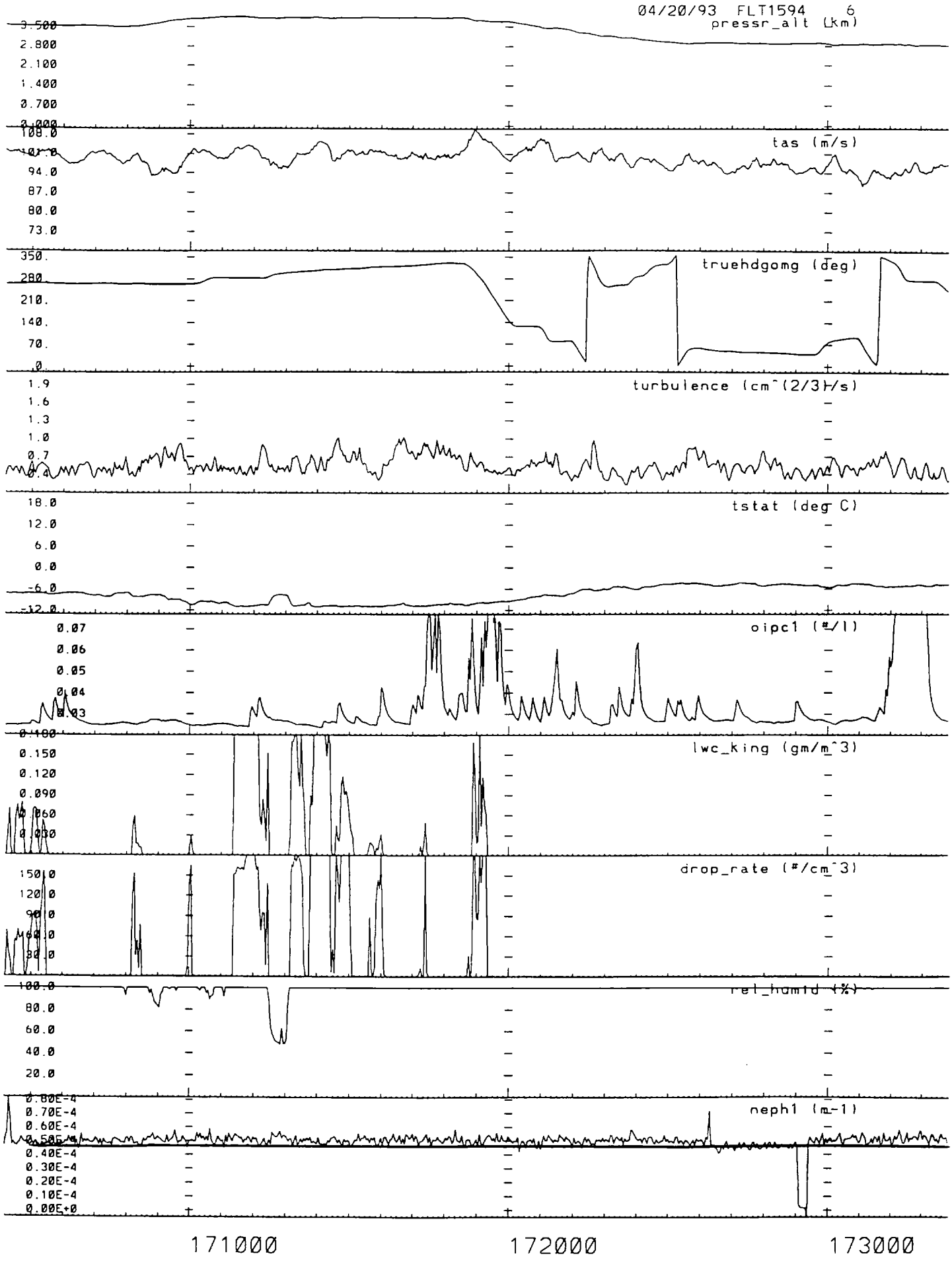


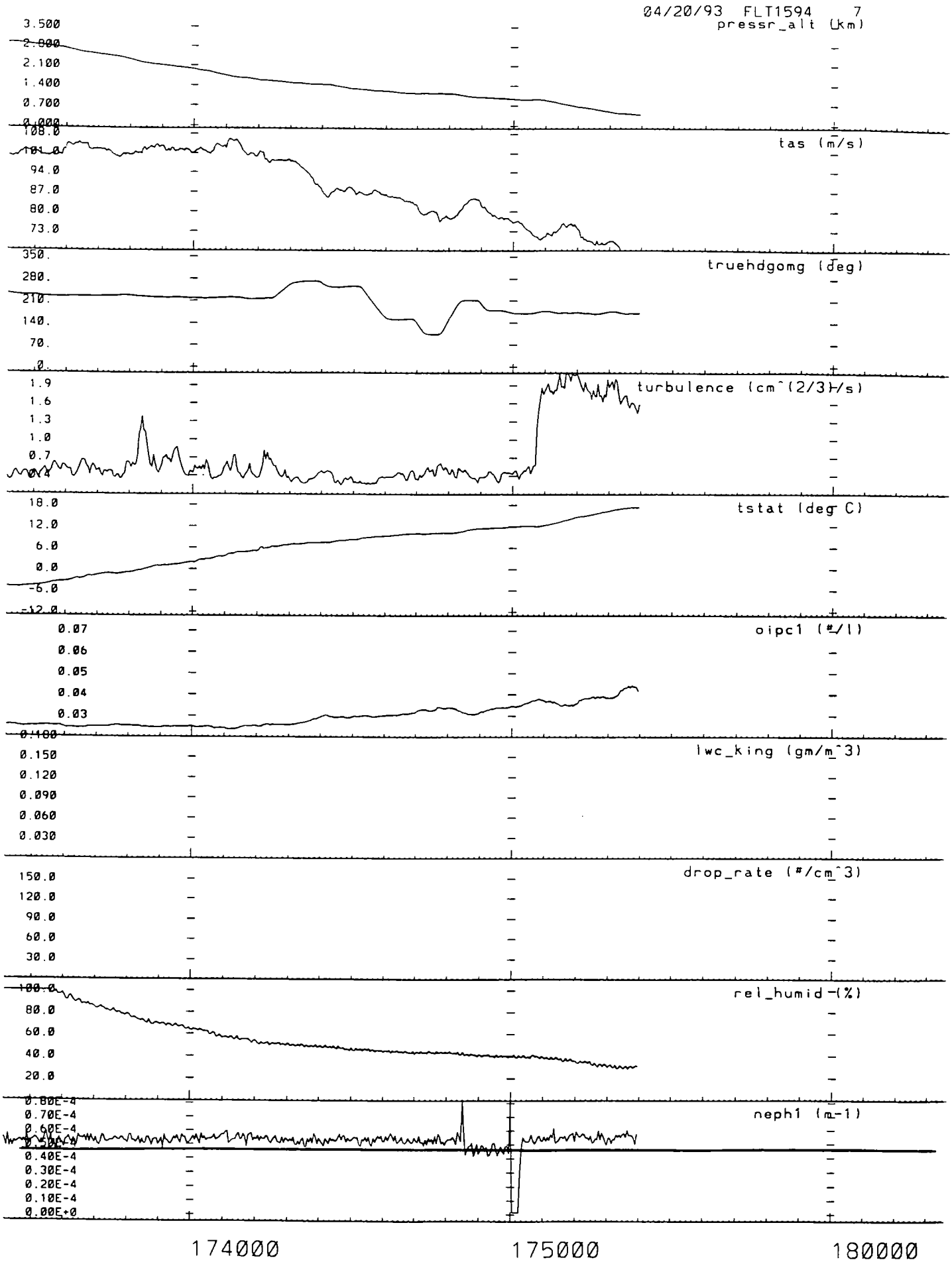
Flight-Level Data for UW Flight 1594, 04/20/93 from 1610–1630 hours



Flight-Level Data for UW Flight 1594, 04/20/93 from 1640–1700 hours



Flight-Level Data for UW Flight 1594, 04/20/93 from 1710–1730 hours



Flight-Level Data for UW Flight 1594, 04/20/93 from 1740–1800 hours

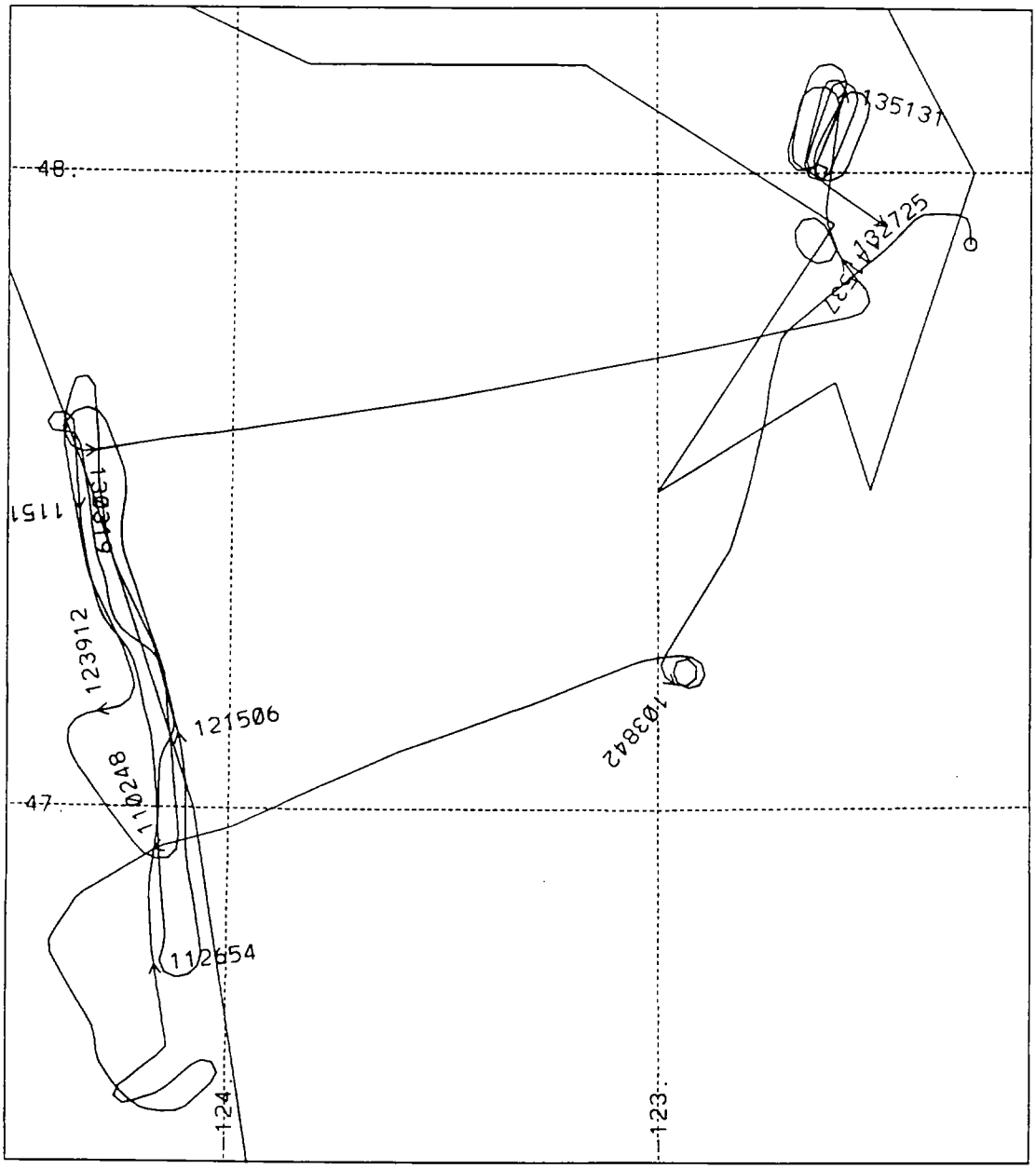
Flight 1595 on 30 April 1993

Flight Description

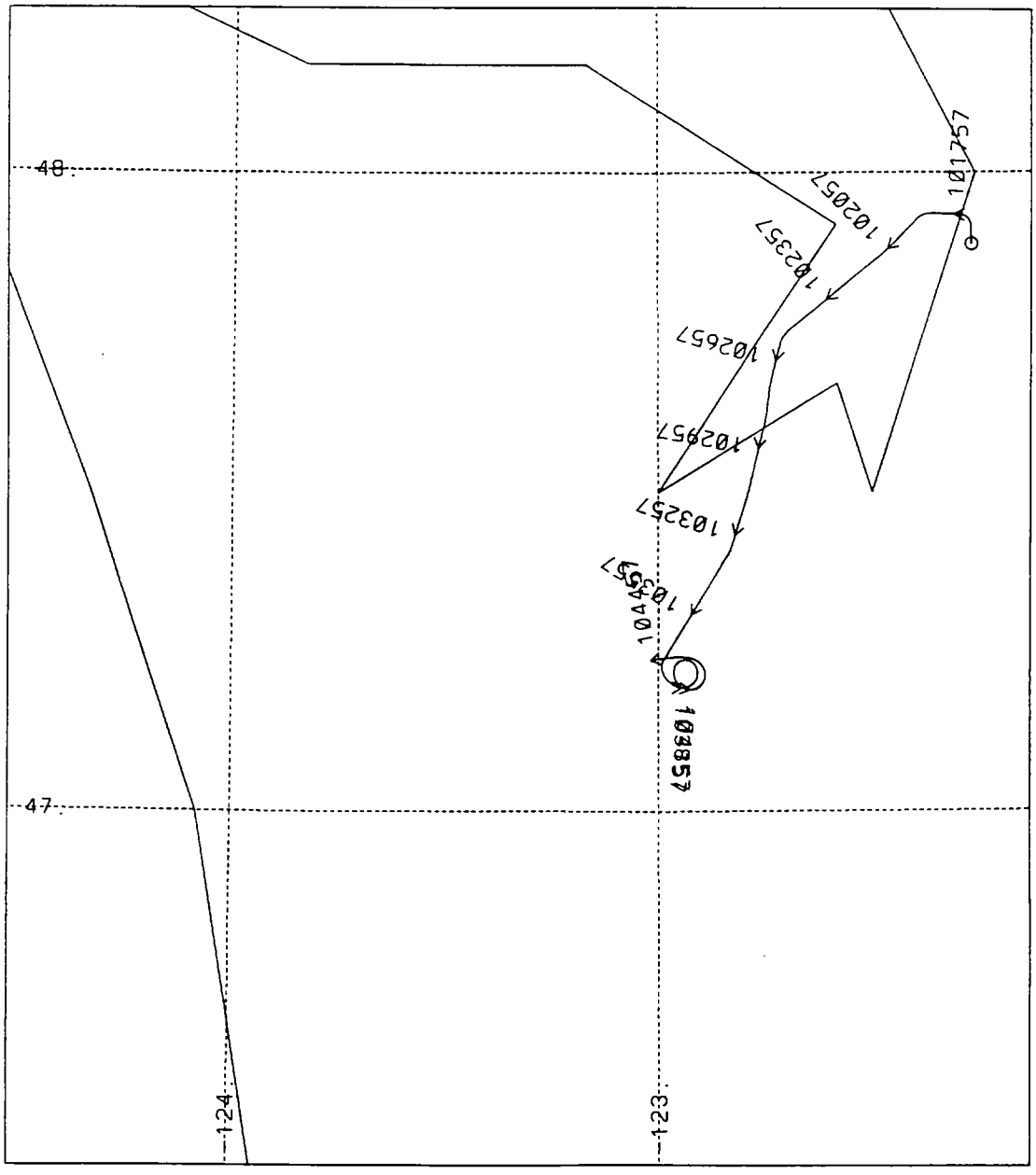
The flight began at Paine Field and headed SW. An orbit was conducted near Shelton, Washington, and then the flight continued WSW, passing over the Pacific Coast near Aberdeen and then turning south. The flight continued south to approximately Willapa Bay and then turned north. The remainder of the flight was a race-track pattern over the Pacific Ocean, within 5 miles or less of the coast between Willapa Bay on the south and Queets on the North. Flight segments were conducted at elevations of 5,000 - 13,000 feet. Droplet clouds at about 5,000 feet were detected during the time interval 1020 - 1100 and ice crystals between 1027 - 1036. The peak concentrations were ~120 drops per cm^3 and ~1.2 ice crystals per liter. The particle scattering extinction @ 530 nm was about 2×10^{-5} m^{-1} between 2,000 and 5,000 feet and increased to about 5×10^{-5} m^{-1} at 8,000 feet.

Weather

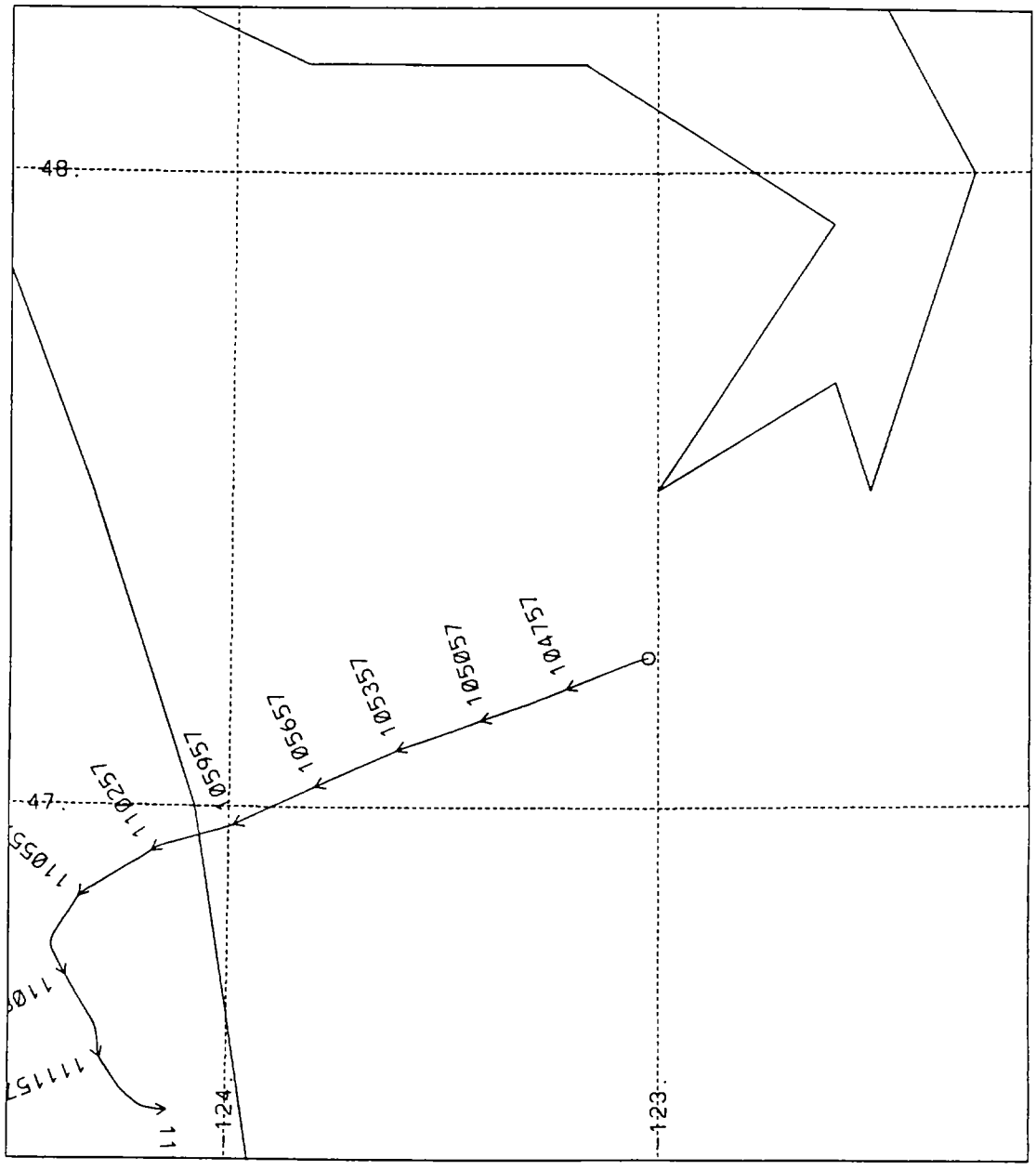
A surface, high-pressure ridge extended to the coast from the southwest of Washington. Light (5-10 kt) onshore winds prevailed during the day. Aloft, a moderate amplitude short-wave ridge embedded in the 500 mb jet stream moved to the coast by 1700. Widely scattered, small (<1 km thick) cumulus clouds were present in the boundary layer with high, scattered to thin, broken cirriform clouds above.



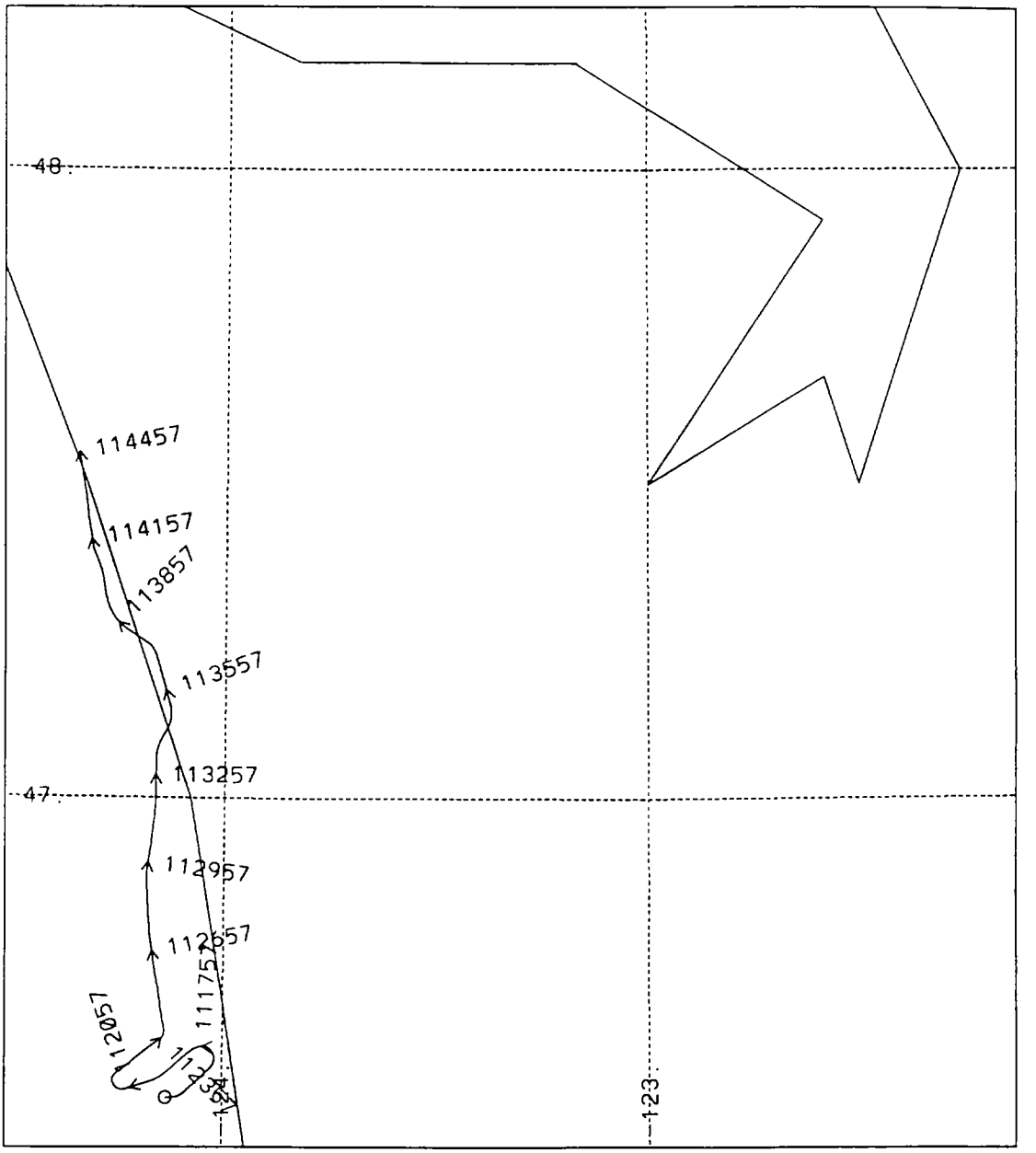
GPS track of flight 1595, 04/30/93 10:15:00 - 14:16:00



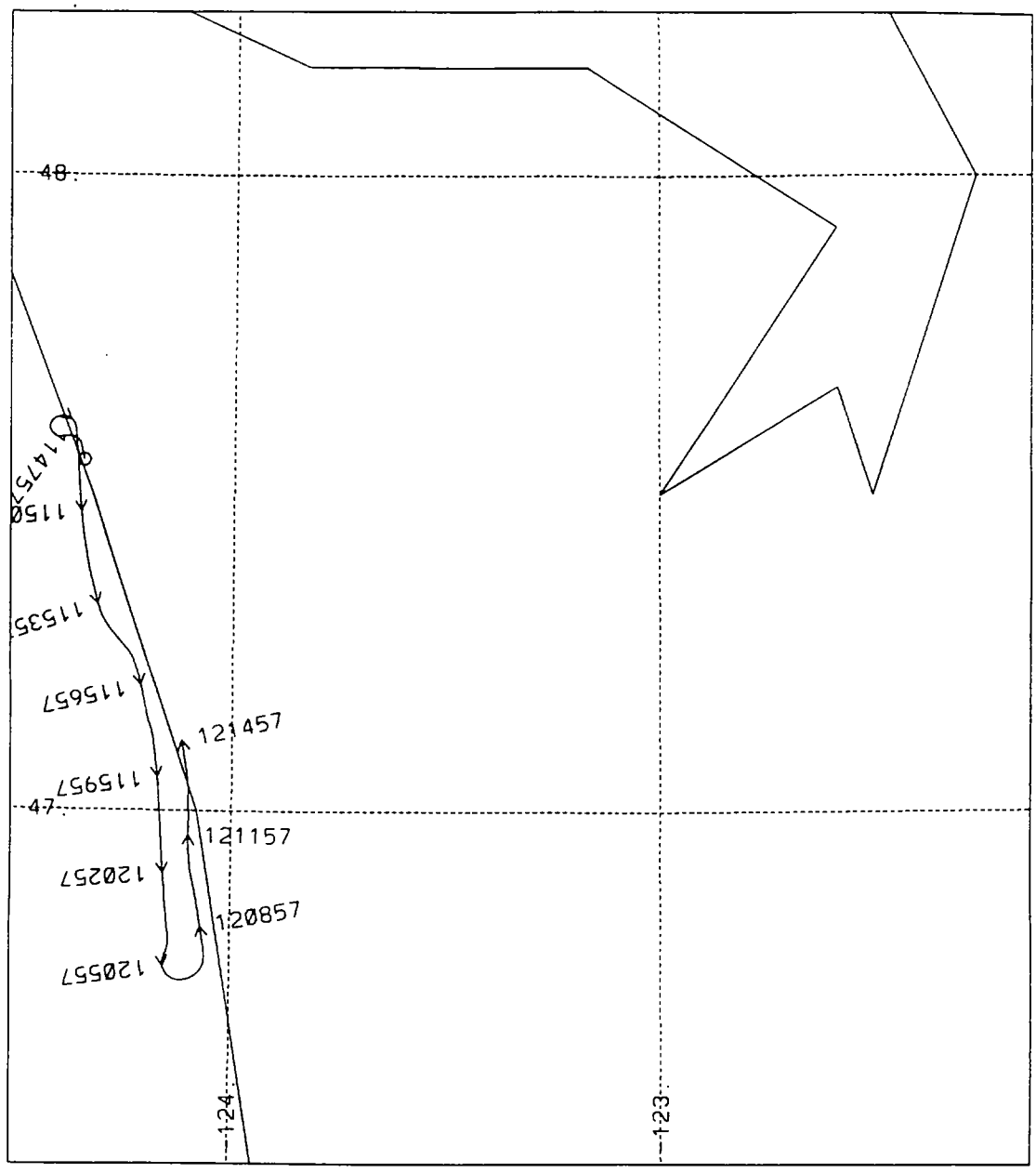
GPS track of flight 1595, 04/30/93 10:15:00 - 10:45:00



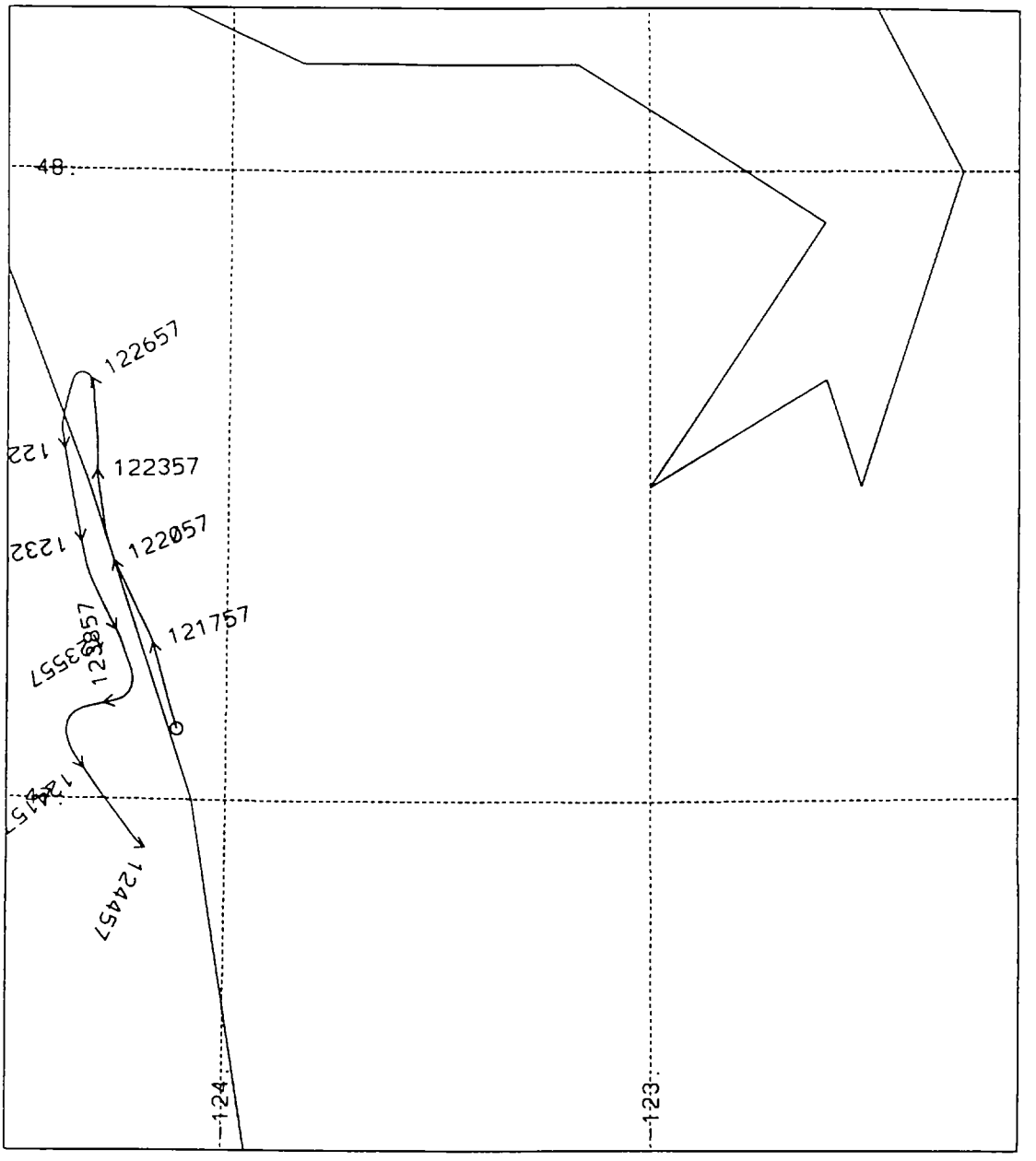
GPS track of flight 1595, 04/30/93 10:45:00 - 11:15:00



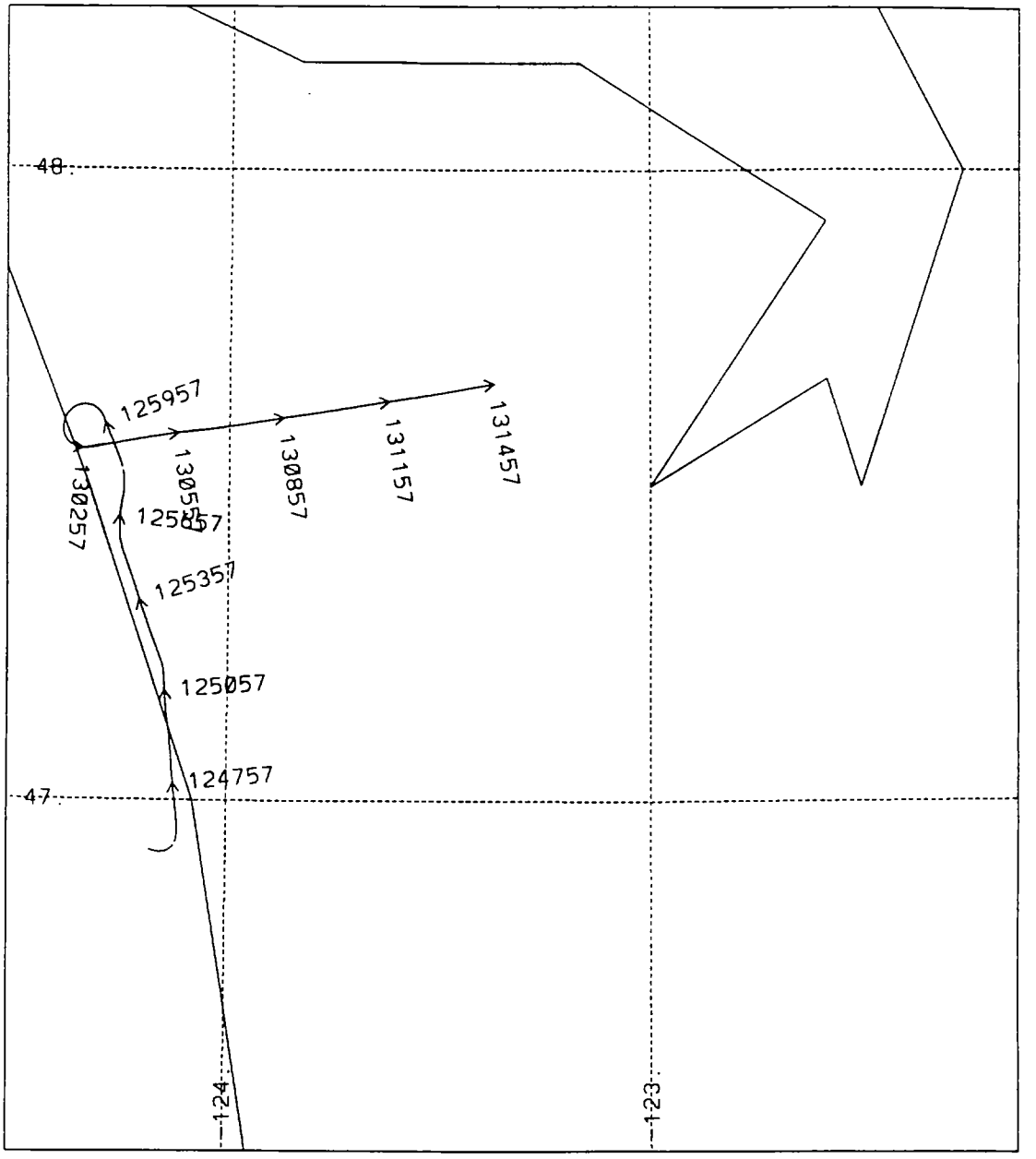
GPS track of flight 1595, 04/30/93 11:15:00 - 11:45:00



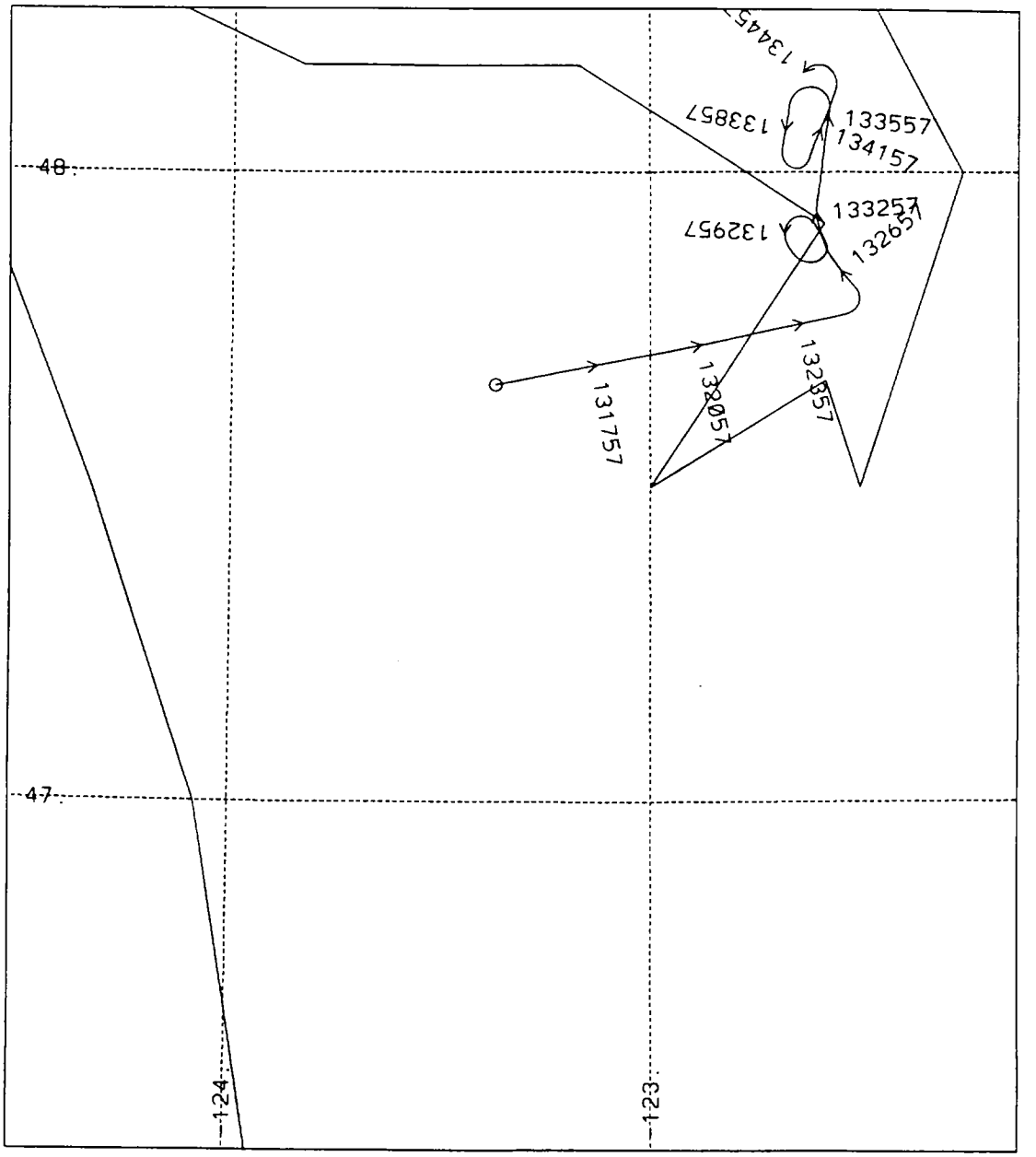
GPS track of flight 1595, 04/30/93 11:45:00 - 12:15:00



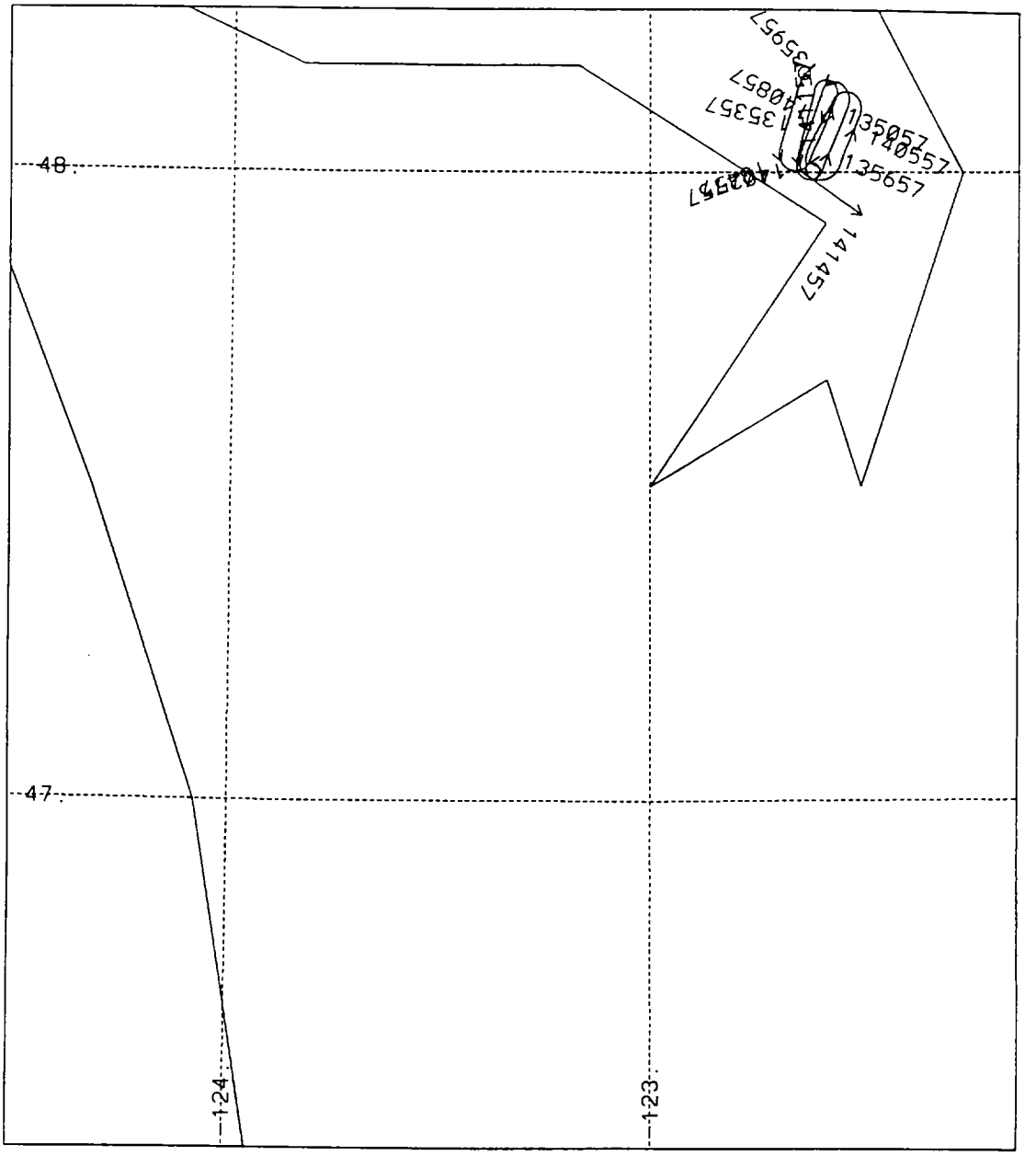
GPS track of flight 1595, 04/30/93 12:15:00 - 12:45:00



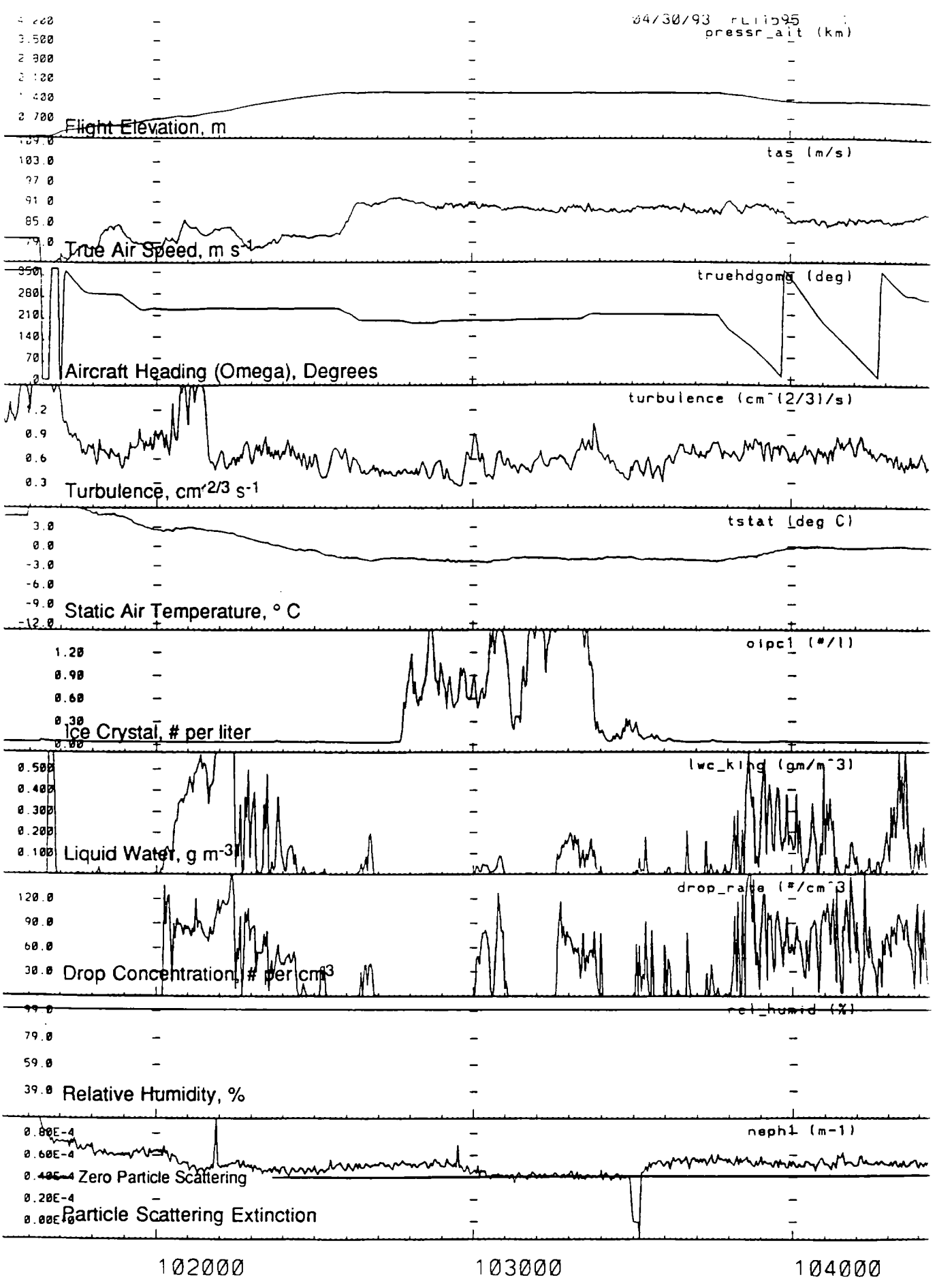
GPS track of flight 1595, 04/30/93 12:45:00 - 13:15:00



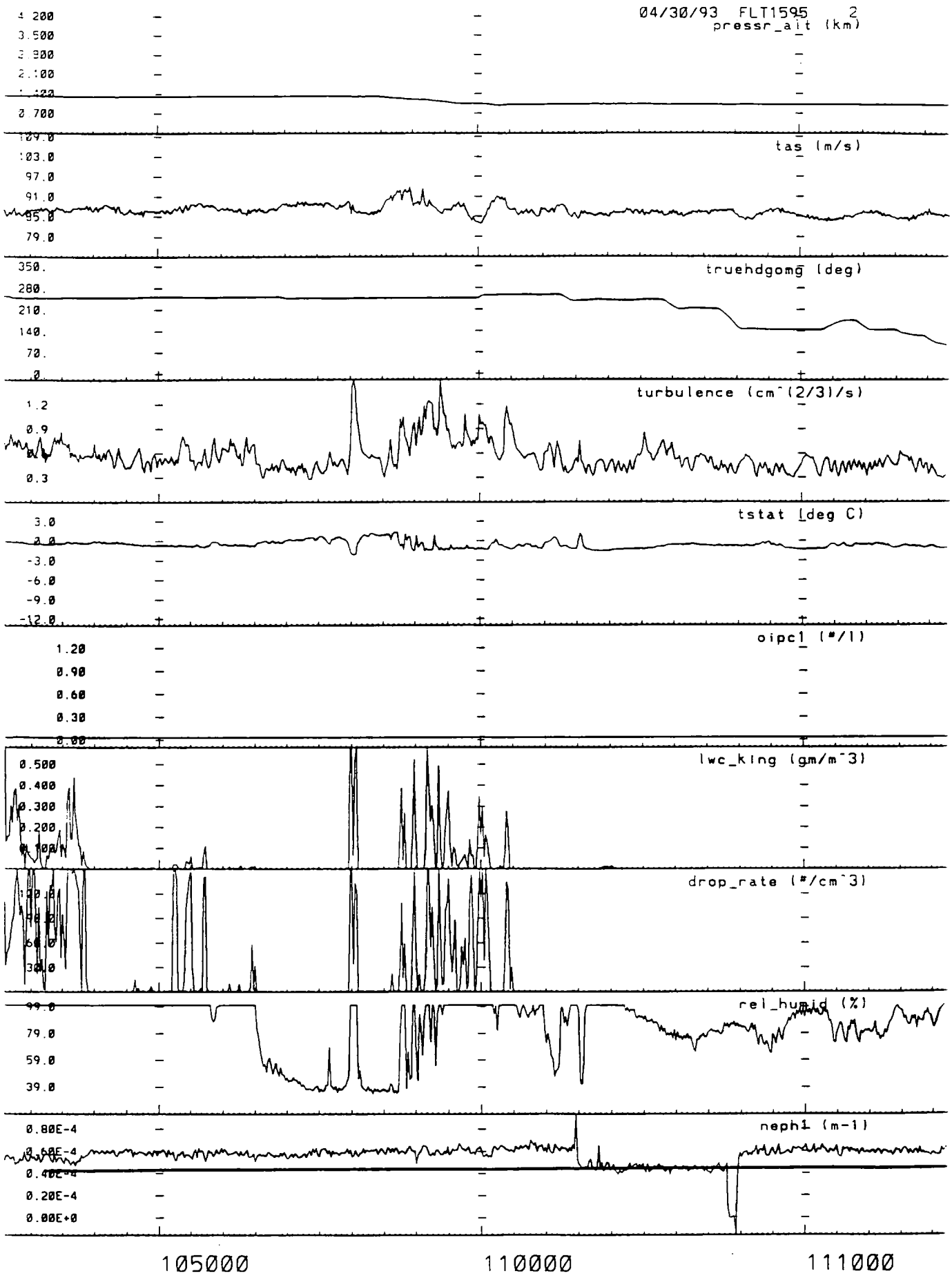
GPS track of flight 1595, 04/30/93 13:15:00 - 13:45:00



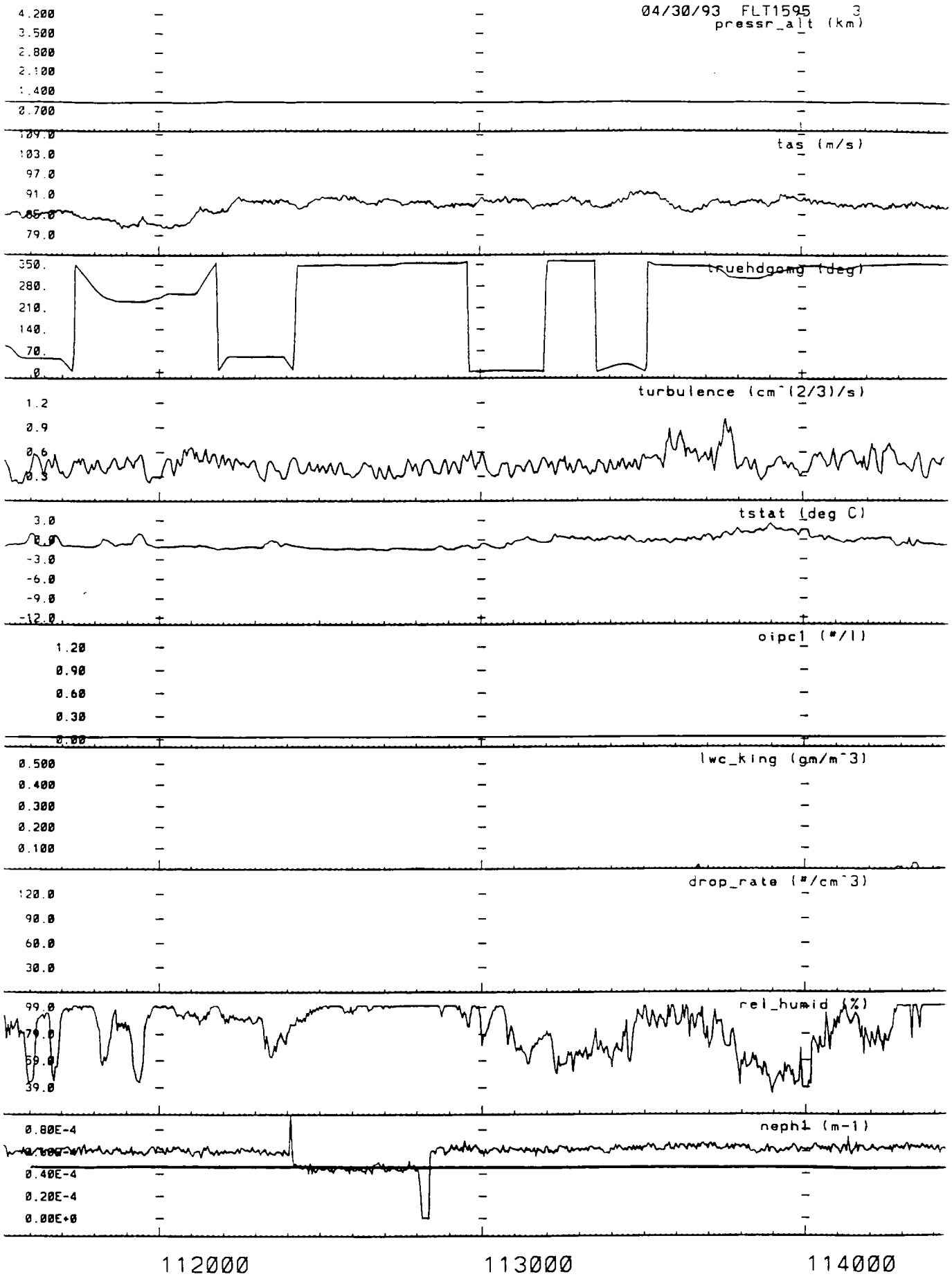
GPS track of flight 1595, 04/30/93 13:45:00 - 14:15:00



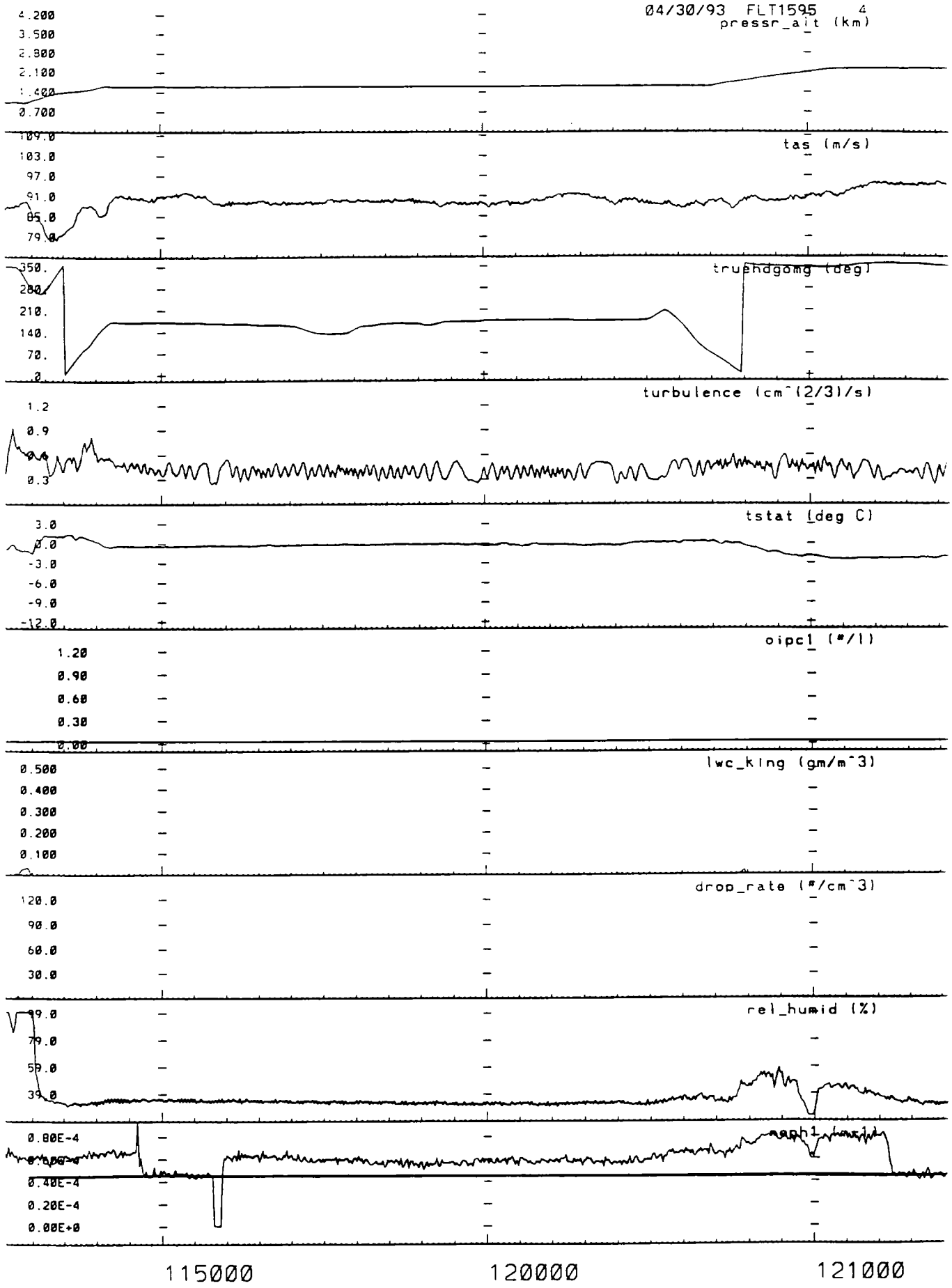
Flight-Level Data for UW Flight 1595, 04/30/93 from 1020–1040 hours



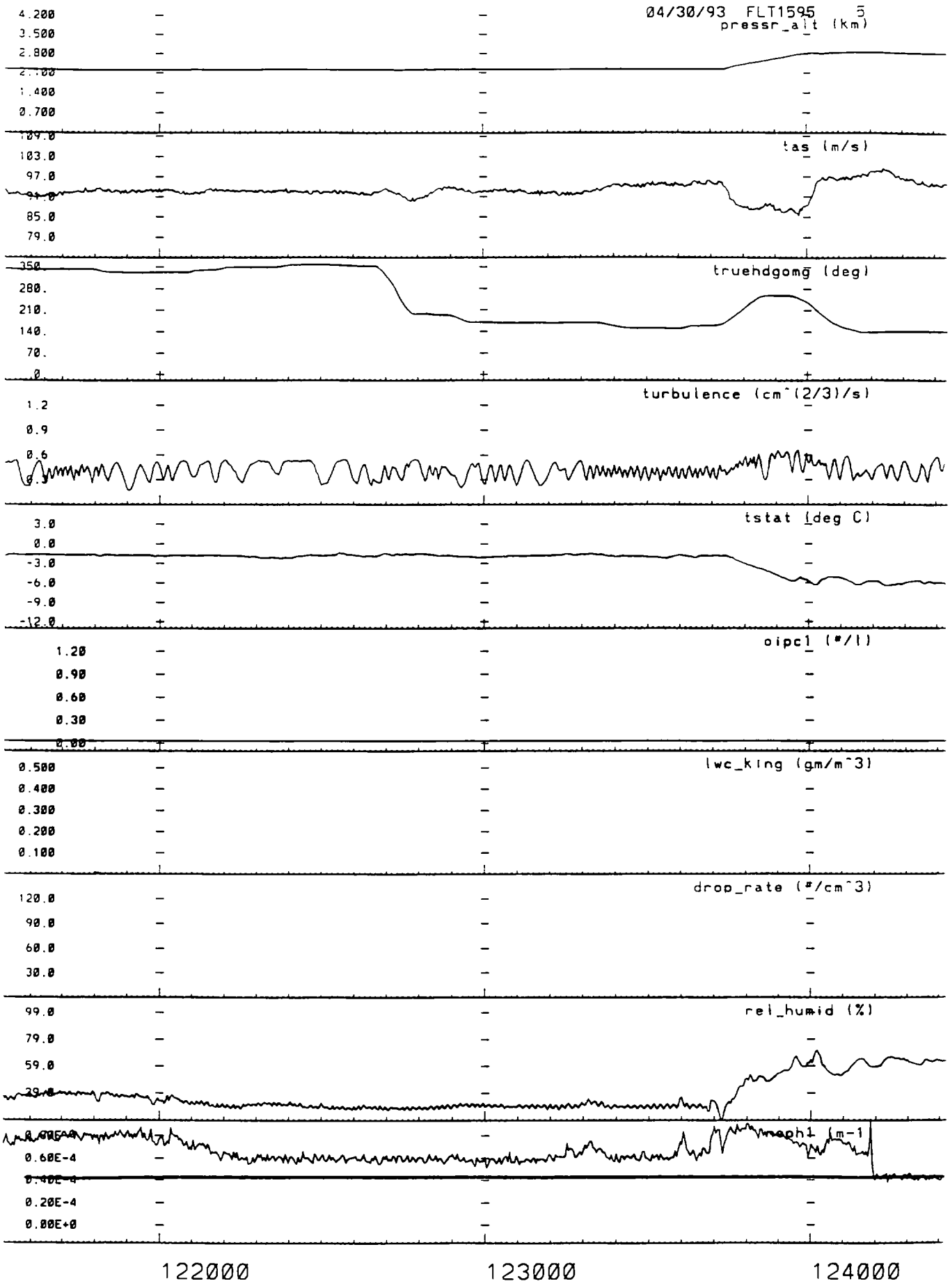
Flight-Level Data for UW Flight 1595, 04/30/93 from 1050–1110 hours



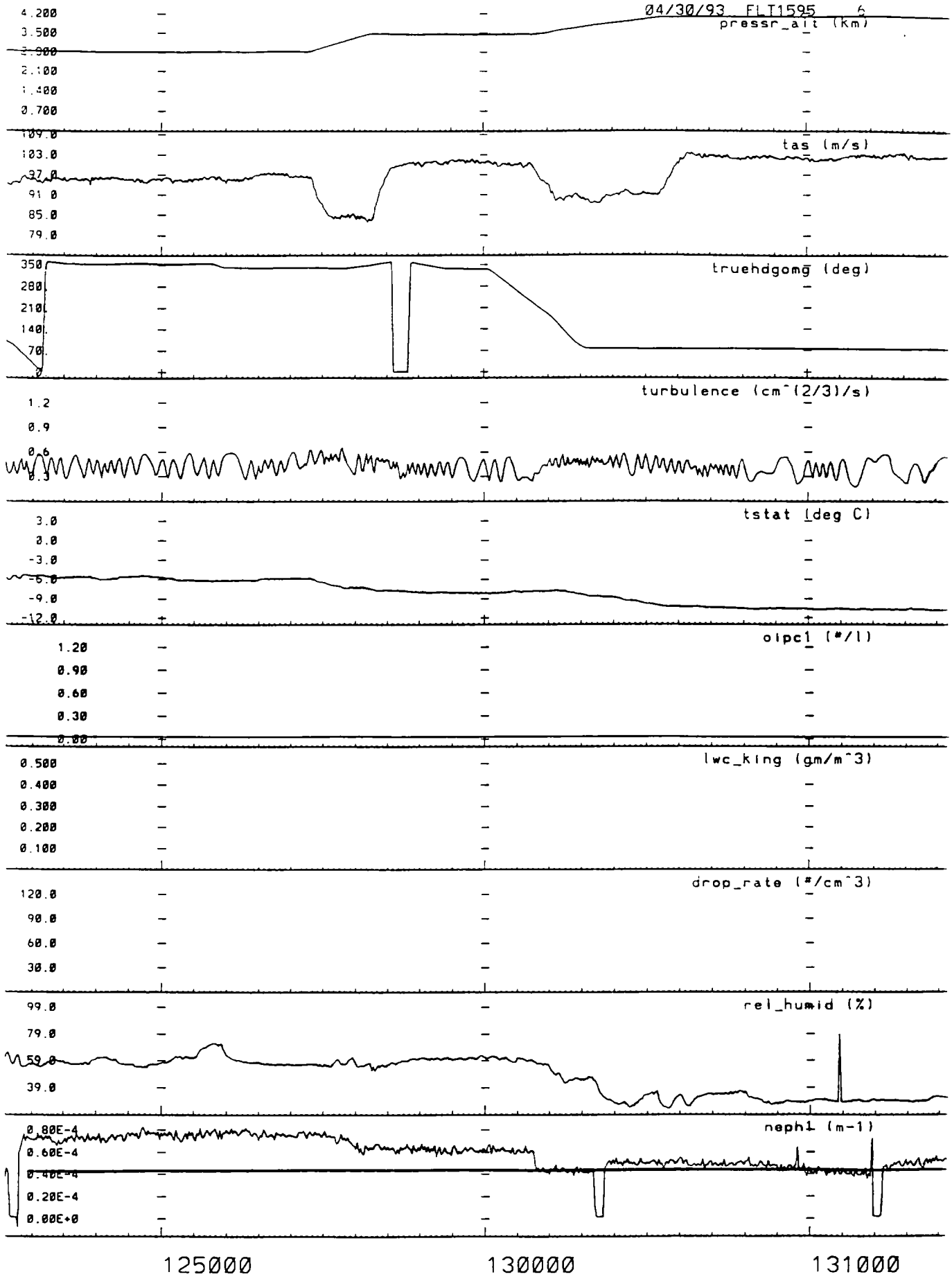
Flight-Level Data for UW Flight 1595, 04/30/93 from 1120–1140 hours



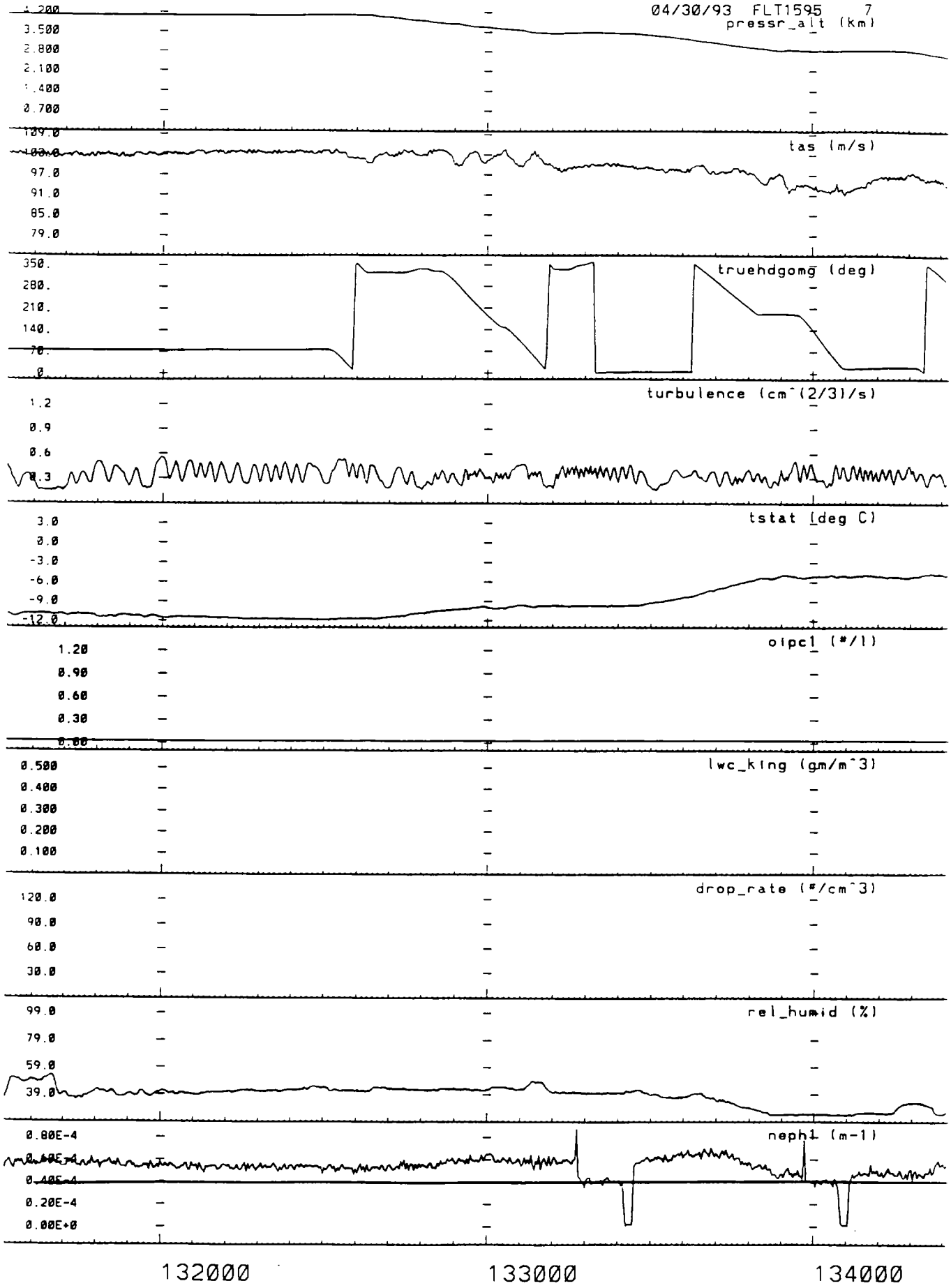
Flight-Level Data for UW Flight 1595, 04/30/93 from 1150–1210 hours



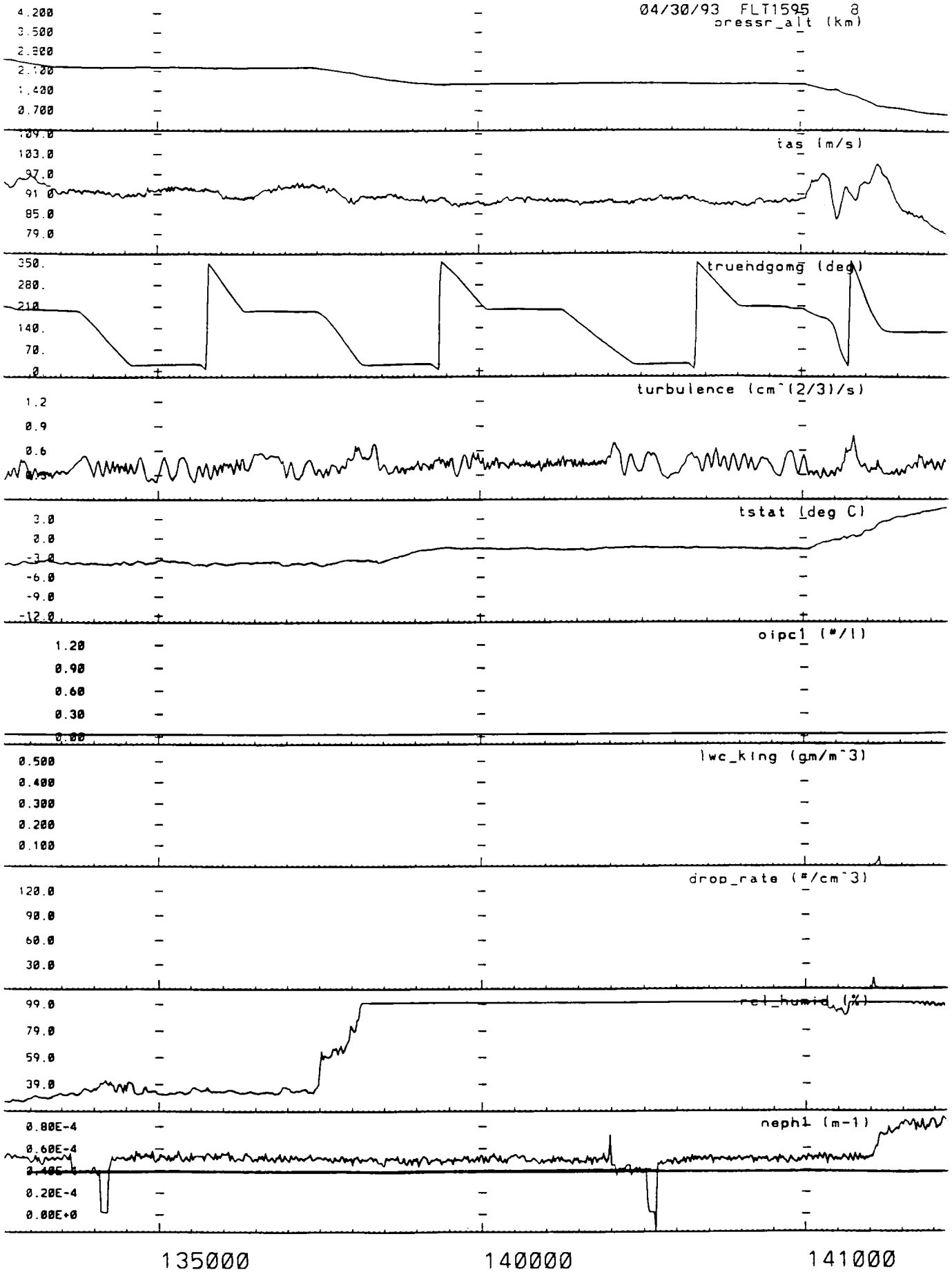
Flight-Level Data for UW Flight 1595, 04/30/93 from 1220–1240 hours



Flight-Level Data for UW Flight 1595, 04/30/93 from 1250–1310 hours



Flight-Level Data for UW Flight 1595, 04/30/93 from 1320–1340 hours



Flight-Level Data for UW Flight 1595, 04/30/93 from 1350–1410 hours