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NOAA Technical Memorandum ERL ARL-157

PROGRAM FOR OPERATIONAL TRAJECTORIES (POT)

Jerome L. Heffter
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Air Resources Laboratory
Silver Spring, Maryland
August 1987

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CONTENTS

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ABSTRACT. POT was developed at the NOAA Air Resources Laboratory to be used for emergency response or field operations. The program can be used to determine diagnostic (analyzed), prognostic (forecast), or linked diagnostic-prognostic long-range trajectories anywhere in the Northern Hemisphere from wind fields stored on disk files at the National Meteorological Center in Suitland, MD. Various models that constitute POT are discussed, and a complete set of operating instructions is presented along with examples of input and output.

1. INTRODUCTION

A Program for Operational Trajectories (POT) was developed at the NOAA Air Resources Laboratory (ARL) to be used for emergency response (e.g., accidental radioactive or pollutant releases, volcanic eruptions) or field operations (e.g., tracer studies, balloon flights). ARL, as a participant in the Federal Emergency Response Program, is responsible for providing information to various government agencies on the atmospheric movement of potentially harmful pollutant transport and dispersion following an accidental or natural pollutant release into the atmosphere, such as the recent Chernobyl nuclear accident or the Mt. St. Helens volcanic eruption. The program was used for those events and it was also used operationally by ARL scientists during the Cross Appalachian Tracer Experiment (Ferber et al., 1986) and the Across North America Tracer Experiment (Draxler et al., 1987). It proved invaluable for determining tracer release times and for vectoring sampling aircraft.

POT can be used to determine diagnostic (analyzed), prognostic (forecast), or linked diagnostic-prognostic long-range trajectories anywhere in the Northern Hemisphere from wind fields stored on disk files at the National Meteorological Center (NMC) in Suitland, MD. The program is run using an interactive terminal linked with the NAS 9000 computer system at NMC.

2. MODELS

Several models are used in POT. The models, with their descriptions and sources, are given in Table 1. All models use input data generated from the NMC Production Suite.* The NGMA model uses data from the NMC "regional" Nested-Grid Model run stored on NMC 36-day archive rotating files; the MRFA uses data from the NMC "final" Medium-Range Forecast run also stored on 36-day archive rotating files. The NGM and MRF models obtain forecast fields directly from the NMC twice-daily Production Suite "regional" and "aviation" runs, where the fields are available about 4 h and 6 h, respectively, after observation time.

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*National Meteorological Center (NMC) Handbook, Section 2.2.1 (Revision 1), July 1, 1987.

Table 1. Models in POT

Model	Description	Source
Diagnostic		
NGMA	Nested Grid	NMC 36-day archive
MRFA	Medium Range	
Prognostic		
NGM	Nested Grid	NMC Twice-daily Production Suite
MRF	Medium Range	

Model characteristics (Table 2) determine which ones to consider for operational trajectory calculations:

Time
For diagnostic trajectories, both models use analyzed wind fields (00Z and 12Z) paired with 6-h forecast fields (06Z and 18Z). For prognostic trajectories, both models use forecast fields every 6 h. The exception is the 66-h fields, which are not available for the MRF model run.

Level
Models use wind fields at various levels. They are grouped in three categories as given in Table 3.

Grid
Two grids are available: a North American (NA) grid with a grid point separation of 190 km at 60°N latitude, and a Northern Hemisphere (NH) grid with a separation of 381 km at 60°N.

3. TRAJECTORY CALCULATIONS

Trajectory calculations use a 1-h advection step with spatial bilinear interpolation of the horizontal and vertical wind components and a modified Euler approximation to the acceleration term (Carnahan et al., 1969). The wind fields are time centered for advection (i.e., a 6-h field is assumed to persist from 3 h before to 3 h after its designated time).

Table 2. Model characteristics

Model	Time	Level*	Grid (km)
Diagnostic			
NGMA	00Z, 00Z +6 h, 12Z, 12Z +6 h	Mandatory, sigma	190 NA**
MRFA	00Z, 00Z +6 h, 12Z, 12Z +6 h	Mandatory	381 NH
Prognostic			
NGM	every 6 h: 0 h - 48 h	Mandatory, significant, sigma	190 NA
MRF	every 6 h: 0 h - 60 h, and 72 h	Mandatory	381 NH

*See Table 3.
**NA = North American; NH = Northern Hemisphere.

Table 3. Level categories for wind fields

Mandatory (mb)	Significant (mb)	Sigma* (non-dimensional)
100	350	.78
150	450	.84
200	550	.90
250	600	.94
300	650	.98
450	750	
500	800	
700	900	
850		
1000		

*Sigma = P/π, where P = pressure at a level and π = surface pressure (Haltiner, 1971).

4. OPERATIONS

POT has been organized to be simple for the user. A standardized execution procedure, input prompting, and well-documented output make it possible to run and interpret POT results with ease. Operational trajectories are obtained as follows.

4.1 Pre Execution (MFRA model only)

To provide wind fields for an MFRA run, the following should be entered:

```
EX 'ERL.R32.JH.MFRA.CRE8.CLIST'
```

With input prompting, fields for 2 days at a time are created. (For 4 days, 2 executions are required, etc.)

4.2 Execution

The execution step to run a model is entered as follows:

```
EX 'ERL.R32.JH._ _ _ _.CLIST'
```

where _ _ _ _ is the desired model, as given in Table 1.

4.3 Input

After the execution step has been entered, input requests with the required format are prompted on the screen. (Critical input values are rewritten on the screen after entry to check for input error.) The list of input requests and a brief description of each follows. Each model will require some (but not all) entries from the list, and a request may be repeated.

TRAJECTORY START LAT LON:
latitude (°N) and longitude (°W, negative for °E) of a trajectory starting position.

OBSERVATION DATE/TIME:
observation date and time [00 or 12 UTC (Z)] of the operational run whose forecast fields are used to compute a prognostic trajectory.

OBSERVATION TIME:
observation time of the operational run.

TRAJECTORY START DELAY FROM OBSERVATION TIME:
the number of hours for the prognostic trajectory start time to be delayed from the observation time. This allows for flexibility; for example, a trajectory starting at 21Z using an observation time of 12Z would have a start delay of 9 h.

TRAJECTORY START DATE:
date for the start of a diagnostic trajectory.

TRAJECTORY START TIME:
time (Z) for the start of a diagnostic trajectory.

TRAJECTORY DURATION:
duration, in days, for a diagnostic trajectory.

PLOT DIAGNOSTIC TRAJECTORY?:
NO = 0 or YES = 1 for plotting a combined diagnostic/prognostic trajectory on an output map. A diagnostic trajectory must have been previously calculated. The prognostic trajectory start latitude and longitude should then be taken from the earlier execution output. For example, a diagnostic trajectory is run from July 19/12Z to 20/09Z. A prognostic trajectory can then be linked to it with an observation date/time of 20/00Z, a trajectory start delay of 9 h, and a trajectory start latitude, longitude at 20/09Z taken from the output of the diagnostic run (this example is illustrated in Section 4.4).

2-DIMENSIONAL ADVECTION = 2
3-DIMENSIONAL ADVECTION = 3:
the MRF model is to be run: a 2 designates a constant pressure (mb) level; a 3 designates that the pressure (mb) level may vary with time based on the vertical wind component.

MANDATORY OR 950 MB LEVELS = 1
SIGNIFICANT OR SIGMA LEVELS = 2
3-DIMENSIONAL ADVECTION = 3:
the NGM model is to be run: a 1 designates a constant mandatory pressure (mb) level; a 2 designates a constant significant pressure (mb) or constant sigma level; a 3 designates the pressure (mb) level may vary with time.

MANDATORY AND/OR 950 MB LEVEL[S]:

SIGNIFICANT LEVEL[S]:

ANY MB LEVEL (1000 to 100 mb):

SIGMA*100 LEVEL[S]:

trajectories can be run simultaneously on up to three levels from one of the above categories or a combination of the above categories as prompted (see Table 3). Pressure levels are in mb; sigma levels are multiplied by 100 (e.g., the .94 sigma level would be entered as 94). Individual output tables of latitude and longitude positions (see Section 4.4) will be printed for each trajectory, and superimposed positions will be plotted on an output map (see Section 4.4) for visual trajectory comparison.

Three examples of input are given in Fig. 1. In Fig. 1a the NGMA (diagnostic) model was executed (EX statement at top). Trajectory input, in order of occurrence, is explained as follows:

- Start latitude of 40.0°N and longitude of 105.0°W

- Duration of 2 days

- Start date of 87-7-19

- Start time of 12Z

- Mandatory level of 400 mb

In Fig. 1b the NGM (prognostic) model was executed. Input is explained as follows:

- Mandatory level (code 1)

- Observation time of 00Z

- A diagnostic trajectory was previously executed (Fig. 1a) so a link to the diagnostic trajectory for the plotted output is requested (code 1)

- Start latitude of 47.6°N and longitude of 91.5°W taken from the output of the previously executed diagnostic trajectory (see Fig. 2a)

- Observation date/time of 87-7-20/00Z

- Start delay from observation time of 9 hours

- Mandatory level of 400 mb

In Fig. 1c the NGM model input is similar to that in Fig. 1b except that three-dimensional advection was requested (code 3) and no diagnostic trajectory was considered (code 0).

4.4 Output

Output from a model run is given in two forms--tables and maps. The tabular output (Fig. 2) is headed by the year (YR), month (MO), start day (DY), start hour (HR), and the indication ANALYSIS for a disgnostic run (Fig. 2a) or the observation time (OBS) and the start delay from observation time (DLY) for a prognostic run (Figs. 2b and c). The table that follows the head gives the day (DY), time (HR), latitude (LAT), longitude (LON), and level (LVL) for the trajectory start and each subsequent 3-h segment endpoint. Note that the examples shown in Fig. 2 correspond to the input given in Fig. 1, and that the starting position on the linked prognostic trajectory (Fig. 2b) has been taken from the last position of the diagnostic trajectory (Fig. 2a).

The output map (Fig. 3) requires map boundaries in order to be displayed. Request for boundaries are prompted and include the top latitude, bottom latitude, and left longitude. The map is headed by a description of the run (same as for the tabular heading) and includes the trajectory start level. Latitude and longitude are plotted on the map axis.

The trajectories shown in Fig. 3 correspond to the output tables of Fig. 2. The trajectory start position on the map is indicated by #, above which is printed the day/time(Z) and below the first two digits of the pressure or sigma level. Subsequent 3-h trajectory positions are indicated by *, the time and pressure level are indicated at the 00Z, 06Z, 12Z, and 18Z positions, and the date is included only at the 00Z position. The 3-h positions are connected by

alphanumerics for identification: low (L), middle (M), and high (H). This is especially desirable when multiple trajectories are displayed. The diagnostic (analysis) section of a linked trajectory uses A to distinguish it from the prognostic section (Fig. 3b). A + or - is used for upward or downward advection on three-dimensional trajectories (Fig. 3c).

Finally, operation messages are also displayed, if applicable, during output. They include the following:

LEVEL _ _ _ NEVER AVAILABLE:
the input level is never available for the model run requested; check Table 2.

SOME OR ALL FIELD NOT AVAILABLE:
a requested field is missing from the 36-day archive, or a requested field is not, at the time of request, available from the twice-daily Production Suite.

TRAJECTORY RAN OFF GRID:
the trajectory calculation was terminated at the grid boundary (North American grid only; NGM or NGMA model runs).

TRAJECTORY RAN OFF TOP OR BOTTOM LEVEL:
a three-dimensional trajectory calculation was terminated at the upper or lower level limits indicated by the input prompt ANY MB LEVEL (1000 to 100 mb).

5. ACKNOWLEDGMENTS

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Ferber, G.J., J.L. Heffter, R.R. Draxler, R.J. Lagomarsino, F.L. Thomas, R.N. Dietz, and C.M. Benkovitz, 1986. Cross-Appalachian Tracer Experiment (CAPTEX '83) Final Report. NOAA Tech. Memo. ERL ARL-142, Air Resources Laboratory, Silver Spring, MD, 60 pp.

Haltiner, G.J., 1971. Numerical Weather Prediction. John Wiley and Sons, New York, p. 193.

(a)

```
EX 'ERL.R32.JH.NGMA.CLIST'

TRAJECTORY START LAT LON
(RETURN TO STOP)
LL.L LLLL.L
40.0  105.0
40.0  105.0
TRAJECTORY DURATION
(1 TO 5 DAYS)
D
2
2
TRAJECTORY START DATE
(YEAR MONTH DAY)
YR MO DY
87 07 19
87  7 19
TRAJECTORY START TIME
(00 03 ... 21 GMT)
ZZ
12
12
ANY MB (1000 TO 100 MB) AND/OR SIGMA*100 LEVEL[S]
(LOW [MID] [HIGH], [ ] BLANK IF NOT USED)
LLLL MMMM HHHH
 400
 400     0     0
```

(b)

```
EX 'ERL.R32.JH.NGM.CLIST'
MANDATORY OR 950 MB LEVELS = 1
SIGNIFICANT OR SIGMA LEVELS = 2
3-DIMENSIONAL ADVECTION = 3
L
1
OBSERVATION TIME
(00 OR 12)
ZZ
00
PLOT DIAGNOSTIC TRAJECTORY?
(NO=0 YES=1)
X
1


TRAJECTORY START LAT LON
(RETURN TO STOP)
LL.L LLLL.L
47.6   91.5
47.6   91.5
OBSERVATION DATE/TIME
(YEAR MONTH DAY HOUR(SAME AS ABOVE))
YR MO DY ZZ
87 07 20 00
87  7 20  0
TRAJECTORY START DELAY FROM OBSERVATION TIME
(0 OR MULTIPLE OF 3)
HH
09
 9
MANDATORY AND/OR 950 MB LEVEL[S]
OR
SIGNIFICANT AND/OR SIGMA*100 LEVEL[S] (.98 NOT AVAILABLE)
(LOW [MID] [HIGH], [ ] BLANK IF NOT USED)
LLLL MMMM HHHH
 400
 400     0     0
```

(c)

```
EX 'ERL.R32.JH.NGM.CLIST'
MANDATORY OR 950 MB LEVELS = 1
SIGNIFICANT OR SIGMA LEVELS = 2
3-DIMENSIONAL ADVECTION = 3
L
3
OBSERVATION TIME
(00 OR 12)
ZZ
00
PLOT DIAGNOSTIC TRAJECTORY?
(NO=0 YES=1)
X
0


TRAJECTORY START LAT LON
(RETURN TO STOP)
LL.L LLLL.L
47.6   91.5
47.6   91.5
OBSERVATION DATE/TIME
(YEAR MONTH DAY HOUR(SAME AS ABOVE))
YR MO DY ZZ
87 07 20 00
87  7 20  0
TRAJECTORY START DELAY FROM OBSERVATION TIME
(0 OR MULTIPLE OF 3)
HH
09
 9
ANY MB LEVEL (1000 TO 100 MB)
LLLL
 400
 400
```

Fig. 1. Examples of input. The following models were executed: (a) NGMA diagnostic model, (b) NGM prognostic model with a link to the diagnostic trajectory, (c) NGM prognostic model with no link to the diagnostic trajectory but with three-dimensional advection.

```
*****************************
 YR=87     DY=19/    ANALYSIS
 MO= 7     HR=12Z
*****************************
  DY HR     LAT     LON   LVL
  19/12Z   40.0   105.0   400
  19/15Z   41.2   103.6   400
  19/18Z   42.5   102.3   400
  19/21Z   43.9   100.7   400
  20/ 0Z   45.2    98.7   400
  20/ 3Z   46.3    96.4   400
  20/ 6Z   47.1    93.8   400
  20/ 9Z   47.6    91.5   400
*****************************
```

(a)

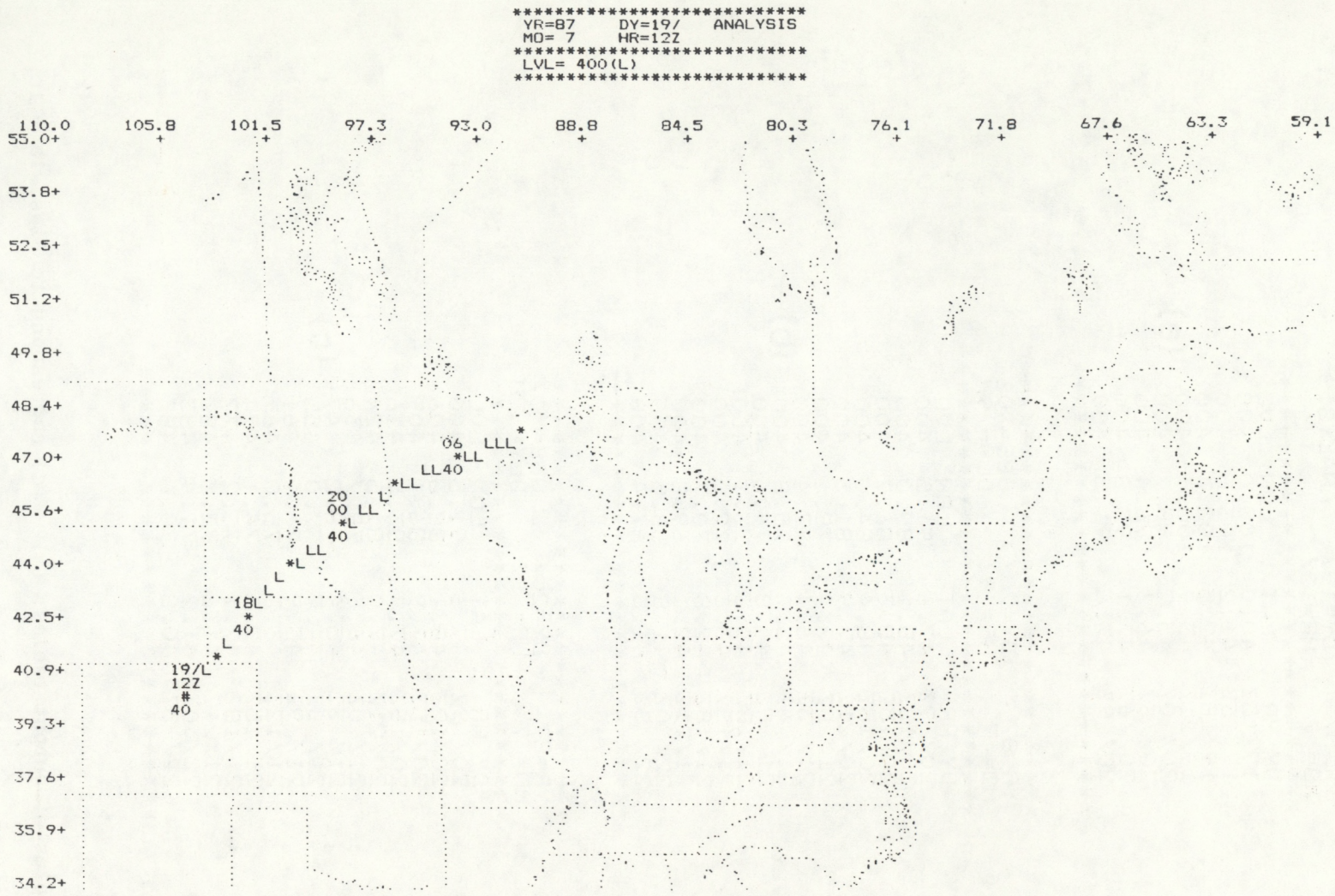
```
*****************************
 YR=87     DY=20/     OBS= 0Z
 MO= 7     HR= 9Z     DLY= 9H
*****************************
  DY HR     LAT     LON   LVL
  20/ 9Z   47.6    91.5   400
  20/12Z   48.1    89.0   400
  20/15Z   48.3    86.7   400
  20/18Z   48.4    84.0   400
  20/21Z   47.9    81.5   400
  21/ 0Z   47.4    79.1   400
  21/ 3Z   46.4    77.4   400
  21/ 6Z   45.7    75.8   400
  21/ 9Z   44.8    74.6   400
  21/12Z   44.2    73.1   400
  21/15Z   43.3    72.0   400
  21/18Z   42.8    70.7   400
  21/21Z   42.1    69.8   400
  22/ 0Z   41.8    68.5   400
  22/ 3Z   41.3    67.4   400
*****************************
```

(b)

```
*****************************
 YR=87     DY=20/     OBS= 0Z
 MO= 7     HR= 9Z     DLY= 9H
*****************************
  DY HR     LAT     LON   LVL
  20/ 9Z   47.6    91.5   400
  20/12Z   48.1    88.6   406
  20/15Z   47.9    86.1   409
  20/18Z   47.7    83.5   416
  20/21Z   47.0    81.5   424
  21/ 0Z   46.3    79.7   436
  21/ 3Z   45.4    78.2   447
  21/ 6Z   44.7    77.0   455
  21/ 9Z   43.9    76.1   461
  21/12Z   43.3    75.0   467
  21/15Z   42.5    74.1   474
  21/18Z   42.1    73.2   477
  21/21Z   41.6    72.5   483
  22/ 0Z   41.2    71.4   483
  22/ 3Z   40.8    70.6   483
*****************************
```

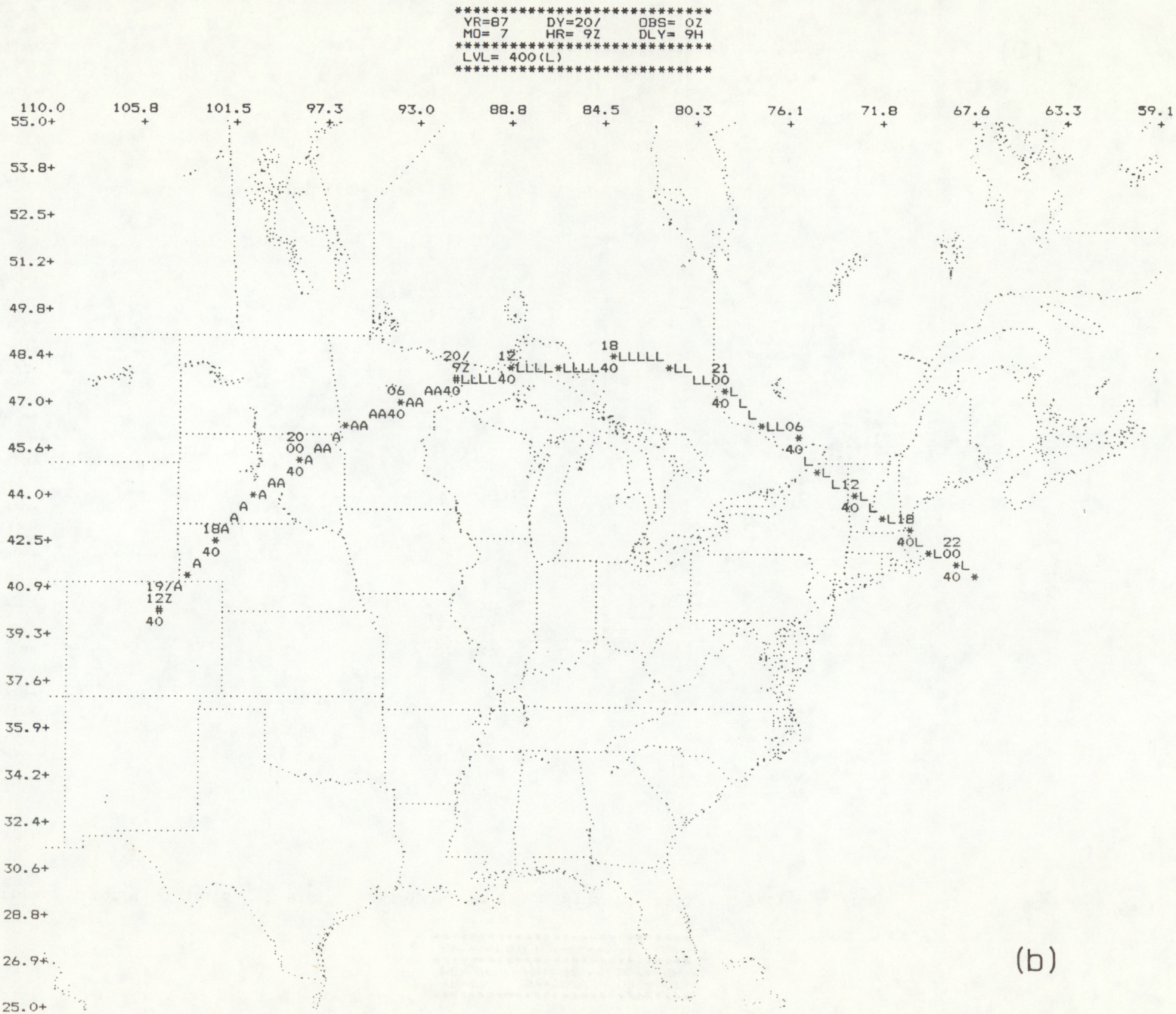
(c)

Fig. 2. Examples of output tables: (a) - (c) correspond to Figs. 1a - 1c.

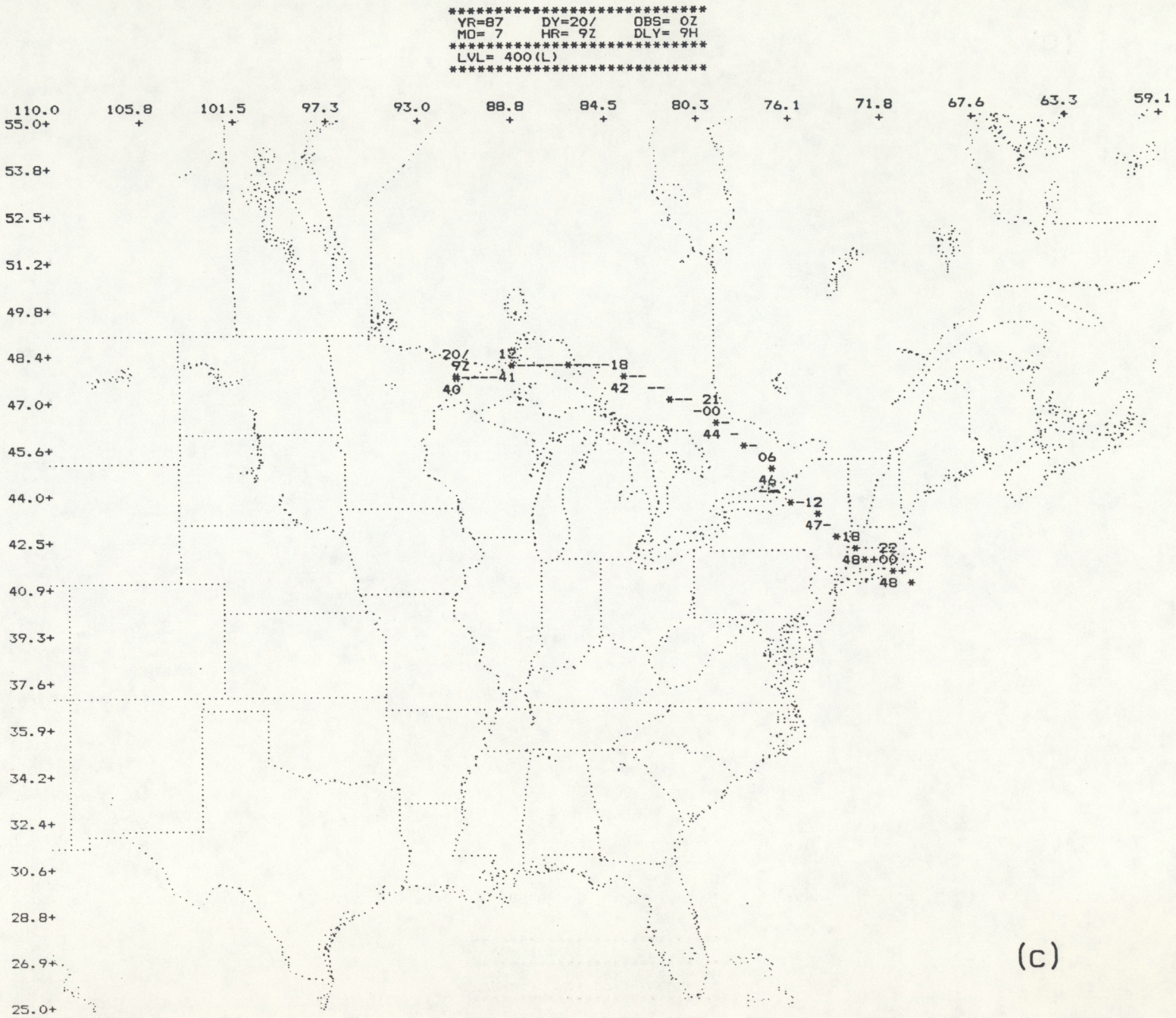


(a)

Fig. 3. Examples of output trajectory maps: (a) - (c) correspond to Figs. 2a - 2c. The trajectory start position is indicated by #. Above the # are the day/time (Z) and below are the first two digits of the pressure or sigma level. Subsequent 3-h trajectory positions are indicated by *; the time and pressure level are noted at the 00Z, 06Z, 12Z, and 18Z positions, and the date at only the 00Z position. Trajectories are identified as L (low), M (middle), or H (high). The diagnostic (analysis) section of a linked trajectory is identified by A (Fig. 3b). Upward advection is identified by + and downward by - (Fig. 3c).


YR=87 DY=20/ OBS= 0Z
MO= 7 HR= 9Z DLY= 9H
LVL= 400(L)
110.0 105.8 101.5 97.3 93.0 88.8 84.5 80.3 76.1 71.8 67.6 63.3 59.1
55.0+
53.8+
52.5+
51.2+
49.8+
48.4+
47.0+
45.6+
44.0+
42.5+
40.9+
39.3+
37.6+
35.9+
34.2+
32.4+
30.6+
28.8+
26.9+
25.0+

(b)


YR=87 DY=20/ OBS= 0Z
MO= 7 HR= 9Z DLY= 9H
LVL= 400(L)
110.0
105.8
101.5
97.3
93.0
88.8
84.5
80.3
76.1
71.8
67.6
63.3
59.1
55.0+
53.8+
52.5+
51.2+
49.8+
48.4+
47.0+
45.6+
44.0+
42.5+
40.9+
39.3+
37.6+
35.9+
34.2+
32.4+
30.6+
28.8+
26.9+
25.0+
20/ 12
9Z
18
41
40
42
21
00
44
06
46
12
47
18
22
48
00
48

(c)