NOAA Technical Memorandum ERL ARL-100

FORTY-EIGHT HOUR ATMOSPHERIC DISPERSION FORECASTS AT SELECTED LOCATIONS IN THE UNITED STATES

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April 1981

UNITED STATES DEPARTMENT OF COMMERCE
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Abstract. Routine forecasts of atmospheric dispersion up to 48 hours after observation times (00 and 12 GMT) are calculated by combining the techniques of estimating dispersion suggested by Turner (1969) with NOAA numerical weather forecasts of wind direction, wind speed, cloud cover, and ceiling. The variables used to estimate dispersion are part of the routine forecast from the Techniques Development Laboratory's Model Output Statistics available at over 250 stations in the United States twice a day. Concentrations (sec/m^3) are calculated for selected sources at eight downwind distances of 0.5 to 100 km.

1. INTRODUCTION

The need to forecast dispersion of pollutants in the atmosphere requires the integration of specialized knowledge of dispersion meteorology with objective weather forecasts. In this paper a computer program to obtain an objective atmospheric dispersion forecast is described. The forecast is obtained by applying the calculation methods in Turner's Workbook (1969) to the routine forecasts of wind direction, wind speed, cloud cover, and ceiling produced by the procedure called Model Output Statistics (MOS) developed by NOAA's Techniques Development Laboratory (TDL).

2. MOS FORECAST

The MOS variables used in the dispersion forecast are generated twice a day from the 00 Greenwich Mean Time (GMT) and 12 GMT observations (see Glahn, 1974). The forecasts are produced from multi-linear regression equations previously developed at each station. The regression equations result from a screening procedure in which the predictands are related to selected variables forecast by the NOAA National Meteorological Center's (NMC) numerical models.

The forecast parameters required for dispersion calculations (wind direction, wind speed, cloud cover, and ceiling) are forecast at 6-hour intervals for up to 48 hours after each observation time. These forecasts are available for 255 stations in the United States, including Alaska and Hawaii.

The MOS forecasts were modified slightly to conform with the requirements of the dispersion calculations. The cloud cover is forecast by four categories which are modified as shown in Table 1. The ceiling forecast is made for six categories which are modified as shown in Table 2. The wind direction and wind speed are for the anemometer height at each station (assumed to be 10 m). For dispersion calculations, the wind speed (but not wind direction) is adjusted to the pollutant source height by the relation:

$$u = u_{10} \ (z/z_{10})^p$$

where u_{10} is the wind speed at height z_{10} (10 m) and u is the wind speed at emission height z. The exponent p is a function of stability as shown in Table 3 (from Draxler, 1980).

3. DISPERSION CALCULATION

The six-hour MOS forecasts are used to develop estimates of stability and mixing height. These values and the adjusted wind speed are the only parameters needed to compute a dispersion factor. The dispersion calculation assumes each six-hour forecast period to be independent. That is, a continuous six-hour emission is assumed to occur every six hours. Straight line flow, as given by the wind direction is assumed at each forecast time.

The stability as defined by Pasquill (1961) shown in Table 4, is computed by the method given by Turner (1964). A daytime mixing depth is calculated with the nomogram shown in Figure 1 provided by Smith and Hunt (1978). At night an optional constant maximum mixing depth of 400 m is assumed. The constant nighttime value of 400 m will only affect ground-level concentrations during "D" stability at distances greater than 20 km downwind. Hence, the assumption of a constant nighttime maximum mixing depth is not considered to be a serious limitation. Other values may be selected by the user.

The concentrations, assuming a unit emission rate, are computed for eight downwind distances (0.5, 1, 2, 5, 10, 20, 50, and 100 km) by the following equations after Turner (1969):

when the downwind distance is $\leq x_L$

$$(C/Q)_a = \frac{2.03}{2\sigma_z\, u\, x}\ \mathrm{EXP}\ (z,H,\sigma_z)$$

$$(C/Q)_p = \frac{1.0}{2\pi\ \sigma_y\ \sigma_z\ u}\ \mathrm{EXP}\ (z,H,\sigma_z)$$

and when the distance is $\geq 2x_L$

$$(C/Q)_a = \frac{2.55}{L\ u\ x}$$

$$(C/Q)_p = \frac{1.0}{\sqrt{2\pi}\ \sigma_y\ L\ u}$$

where the subscripts 'p' and 'a' refer to the centerline Peak and sector Average (22.5°) concentrations, respectively. The other variables are:

Q - emission rate (per second),

x - downwind distance,

u - emission height wind speed,

σ_y,σ_z - horizontal and vertical dispersion parameter, a function of distance and stability, as given by Turner (1969),

L - maximum mixing depth,

x_L - distance at which σ_z is equal to 0.47 L,

EXP (z,H,σ_z) - exponential term for source or receptor heights not at ground level, EXP $[-\frac{1}{2}(\frac{z-H}{\sigma_z})^2]$ + EXP $[-\frac{1}{2}(\frac{z+H}{\sigma_z})^2]$, where z is the receptor height and H is the source height.

Concentrations between x_L and $2x_L$ are interpolated as a function of logarithmic distance.

4. EXAMPLE DISPERSION FORECAST

The dispersion forecast can only be generated on the same computer system that the MOS forecasts are prepared. However, the forecast can be prepared manually from similar information available at any NOAA National Weather Service office.

On the NOAA computer system (IBM 360/195) access is obtained from remote sites by terminal (half duplex, 300 baud) by entering:

```
LOGON ACCOUNT/PASSWORD SIZE(250)
```

and the dispersion forecast is obtained by entering:

```
EXEC 'W.ERL.R32.RRD.MOS.SOURCE(RUNCLIST)'
```

and followed by a space on the same line the optional parameters

```
'WBAN(93738) TME(00) SHT(000) RHT(000) MXN(0400) MXD(5000) DMP(0) HRD (00)'
```

where:

WBAN - is a five digit code identifying the station,

TME - is a two digit number identifying the initial time upon which the forecast is based, where (00) is for 00 GMT and (12) is for 12 GMT,

SHT - is a three digit number giving the source height in meters,

RHT - is a three digit number giving the receptor height in meters,

MXN - is a four digit number giving the maximum nighttime mixing depth,

MXD - is a four digit number giving the maximum daytime mixing depth,

DMP - is a one digit number which prints all forecast variables when (1) or omits printing when (0) and,

HRD - is a two digit number (positive or negative) giving, in hours, the displacement of the dispersion forecast time from the meteorological forecast time.

WBAN, TME, SHT, RHT, MXN, MXD, DMP, and HRD are all optional and need not be entered. SHT and RHT default to '0' meters when not specified. MXN defaults to 400 m. DMP defaults to (0) and WBAN defaults to (93738), Washington, DC. A list of stations and WBAN numbers is given in Table 5. The TME, either 00 or 12, defaults to (00) when none is specified. The new forecasts are not usually available until about five hours after the observation time. The MXD parameter defaults to 5000 m, and it permits the user to override the internally calculated maximum daytime mixing depth with a lower value. The HRD parameter defaults to 0. It may be specified from -6 to +6 from the forecast times. The normal forecast times are 0, 6, 12, and 18 hours GMT. For example, when HRD equals 2 the dispersion forecast would be computed for 2, 8, 14, and 20 hours GMT. The same numerical forecast parameters as during the standard times are used but the solar elevation angle would differ hence, the computed stability might change. This parameter would be used when the local times corresponding to 0, 6, 12, and 18 hours GMT do not correspond to the most desirable forecast periods.

A sample of the dispersion forecast with the data dump is shown in Table 6. The forecast is for Washington, DC based on the 00 GMT observations on March 30, 1981. The calculations are performed for eight forecast times beginning at 06 GMT on the 30th to 00 GMT on April 1. The downwind sector is given below each date. The sector average and peak concentrations are given for eight distances with the travel time in minutes above each concentration pair. Concentrations normalized by a unit emission rate (sec/m^3) are given by two digits, so that the 4-5 in the upper left corner would be interpreted as 4×10^{-5} sec/m^3. Concentrations are only printed for travel times of less than 6 hours.

The listing of variables used in the calculations is shown in the lower half of Table 6. Here the forecast times are given in hours after the initial observations. Below each forecast time are the variables used in that calculation. Year, month, Julian day and hour are in GMT. The local hour is determined from the station longitude (daylight saving time and local variations in time zones are not considered). The cloud cover is given in tenths, wind speed (unadjusted) in m/sec. The ceiling is in feet. The solar elevation angle is determined from the station position and date and is given in degrees above (+) or below (-) the horizon. The downwind sector is given in degrees. Stability is by category from 1 (A) to 7 (G), mixing depth is given in meters, and sunrise time is in hours local time. This output is obtained by specifying the DMP parameter as (1).

Acknowledgments

This work was supported by the U.S. Department of Energy, Office of Health and Environmental Research.

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Table 1. Cloud Cover Forecast

Forecast Category	MOS Cloud Cover	Dispersion Modification to cloud cover
1	0/10 to 1/10	1/20
2	2/10 to 5/10	7/20
3	6/10 to 9/10	15/20
4	10/10	20/20

Table 2. Ceiling Forecast

Forecast Category	MOS Ceiling (ft.)	Dispersion Modification to ceiling (ft.)
1	< 200	200
2	200 - 400	400
3	500 - 900	900
4	1000 - 2900	2900
5	3000 - 7500	7500
6	>7500	22,000

Table 3. Power Law Wind Profile Exponents

Stability	A	B	C	D	E	F	G
Exponent	0.19	0.21	0.23	0.30	0.36	0.46	0.69

Table 4. Key to Stability Categories (Pasquill,1961).

Surface Wind Speed (at 10 m), m sec^{-1}	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or	
	Strong	Moderate	Slight	≥4/8 Low Cloud	≤3/8 Cloud
< 2	A	A–B	B		
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
> 6	C	D	D	D	D

The neutral class, D, should be assumed for overcast conditions during day or night.

Table 5. Available MOS stations and identifying WBAN number.

WBAN	STATION NAME	WBAN	STATION NAME
03103	Flagstaff, AZ	13881	Charlotte, NC
03812	Asheville, NC	13882	Chattanooga, TN
03813	Macon, GA	13883	Columbia, SC
03820	Augusta, GA	13889	Jacksonville, FL
03822	Savannah, GA	13891	Knoxville, TN
03856	Huntsville, AL	13893	Memphis, TN
03860	Huntington, WV	13894	Mobile, AL
03870	Greenville, SC	13895	Montgomery, AL
03872	Beckley, WV	13897	Nashville, TN
03927	Ft. Worth, TX	13899	Pensacola, FL
03928	Wichita, KS	13935	Alexandria, LA
03937	Lake Charles, LA	13957	Shreveport, LA
03940	Jackson, MS	13958	Austin, TX
03945	Columbia, MO	13959	Waco, TX
03947	Kansas City, MO	13960	Dallas, TX
04725	Binghamton, NY	13962	Abilene, TX
04751	Bradford, PA	13963	Little Rock, AR
11641	San Juan, PR	13964	Ft. Smith, AR
12834	Daytona Beach, FL	13966	Wichita Falls, TX
12835	Ft. Myers, FL	13967	Oklahoma City, OK
12836	Key West, FL	13968	Tulsa, OK
12839	Miami, FL	13970	Baton Rouge, LA
12841	Orlando, FL	13984	Concordia, KS
12842	Tampa, FL	13985	Dodge City, KS
12844	West Palm Beach, FL	13993	St. Joseph, MO
12884	Boothville, LA	13994	St. Louis, MO
12912	Victoria, TX	13995	Springfield, MO
12916	New Orleans, LA	13996	Topeka, KS
12919	Brownsville, TX	14606	Bangor, ME
12921	San Antonio, TX	14607	Caribou, ME
12924	Corpus Christi, TX	14732	New York-Laguardia, NY
12960	Houston, TX	14733	Buffalo, NY
13722	Raleigh-Durham, NC	14734	Newark, NJ
13723	Greensboro, NC	14735	Albany, NY
13729	Elkins, WV	14737	Allentown, PA
13733	Lynchburg, VA	14739	Boston, MA
13737	Norfolk, VA	14740	Hartford, CT
13739	Philadelphia, PA	14742	Burlington, VT
13740	Richmond, VA	14745	Concord, NH
13741	Roanoke, VA	14751	Harrisburg, PA
13743	Washington, DC	14764	Portland, ME
13748	Wilmington, NC	14765	Providence, RI
13781	Wilmington, DE	14768	Rochester, NY
13865	Meridian, MS	14771	Syracuse, NY
13866	Charleston, WV	14777	Scranton, PA
13873	Athens, GA	14778	Williamsport, PA
13874	Atlanta, GA	14819	Chicago-Midway, IL
13876	Birmingham, AL	14820	Cleveland, OH
13877	Bristol, TN	14821	Columbus, OH
13880	Charleston, SC	14826	Flint, MI

Table 5. Available MOS stations and identifying WBAN number (con't).

WBAN	STATION NAME	WBAN	STATION NAME
14827	Fort Wayne, IN	23159	Bryce Canyon, UT
14836	Lansing, MI	23160	Tucson, AZ
14837	Madison, WI	23161	Daggett, CA
14839	Milwaukee, WI	23169	Las Vegas, NV
14840	Muskegon, MI	23174	Los Angeles, CA
14842	Peoria, IL	23183	Phoenix, AZ
14847	Sault Ste. Marie, MI	23185	Reno, NV
14848	South Bend, IN	23188	San Diego, CA
14850	Traverse City, MI	23194	Winslow, AZ
14852	Youngstown, OH	23195	Yuma, AZ
14860	Erie, PA	23230	Oakland, CA
14895	Akron-Canton, OH	23232	Sacramento, CA
14898	Green Bay, WI	23234	San Francisco, CA
14913	Duluth, MN	23237	Stockton, CA
14914	Fargo, ND	23273	Santa Maria, CA
14918	International Falls, MN	24011	Bismarck, ND
14920	Lacrosse, WI	24013	Minot, ND
14922	Minneapolis, MN	24018	Cheyenne, WY
14923	Moline, IL	24021	Lander, WY
14925	Rochester, MN	24023	North Platte, NE
14929	Aberdeen, SD	24025	Pierre, SD
14931	Burlington, IA	24027	Rock Springs, WY
14933	Des Moines, IA	24028	Scottsbluff, NE
14935	Grand Island, NE	24029	Sheridan, WY
14936	Huron, SD	24033	Billings, MT
14940	Mason City, IA	24089	Casper, WY
14942	Omaha, NE	24090	Rapid City, SD
14943	Sioux City, IA	24121	Elko, NV
14944	Sioux Falls, SD	24127	Salt Lake City, UT
14991	Eau Claire, WI	24128	Winnemucca, NV
21504	Hilo, HI	24131	Boise, ID
22010	Del Rio, TX	24134	Burns, OR
22516	Kahului, HI	24143	Great Falls, MT
22521	Honolulu, HI	24144	Helena, MT
22536	Lihue, HI	24146	Kalispell, MT
23023	Midland, TX	24153	Missoula, MT
23034	San Angelo, TX	24155	Pendleton, OR
23042	Lubbock, TX	24156	Pocatello, ID
23044	El Paso, TX	24157	Spokane, WA
23047	Amarillo, TX	24172	Lovelock, NV
23048	Tucumcari, NM	24193	Wendover, UT
23050	Albuquerque, NM	24216	Red Bluff, CA
23062	Denver, CO	24221	Eugene, OR
23065	Goodland, KS	24225	Medford, OR
23066	Grand Junction, CO	24227	Olympia, WA
23090	Farmington, NM	24229	Portland, OR
23129	Long Beach, CA	24230	Redmond, OR
23153	Tonopah, NV	24232	Salem, OR
23154	Ely, NV	24233	Seattle-Tacoma, WA
23155	Bakersfield, CA	24243	Yakima, WA

Table 5. Available MOS stations and identifying WBAN number (con't).

WBAN	STATION NAME	WBAN	STATION NAME
24283	Arcata, CA	93814	Cincinnati, OH
24284	North Bend, OR	93815	Dayton, OH
25308	Annette, AK	93817	Evansville, IN
25309	Juneau, AK	93819	Indianapolis, IN
25339	Yakutat, AK	93820	Lexington, KY
25503	King Salmon, AK	93821	Louisville, KY
25624	Cold Bay, AK	93822	Springfield, IL
25713	St. Paul Island, AK	93987	Lufkin, TX
26411	Fairbanks, AK	93997	Russell, KS
26451	Anchorage, AK	94008	Glasgow, MT
26510	Mcgrath, AK	94012	Havre, MT
26615	Bethel, AK	94014	Williston, ND
26616	Kotzebue, AK	94224	Astoria, OR
26617	Nome, AK	94240	Quillayute, WA
27401	Barter Island, AK	94702	Bridgeport, CT
27502	Barrow, AK	94725	Massena, NY
93037	Colorado Springs, CO	94789	New York-Kennedy, NY
93044	Zuni, NM	94814	Houghton Lake, MI
93045	Truth or Cons., NM	94822	Rockford, IL
93058	Pueblo, CO	94823	Pittsburg, PA
93129	Cedar City, UT	94830	Toledo, OH
93193	Fresno, CA	94846	Chicago-Ohare, IL
93721	Baltimore, MD	94847	Detroit, MI
93729	Cape Hatteras, NC	94849	Alpena, MI
93730	Atlantic City, NJ	94860	Grand Rapids, MI
93738	Wash-Dulles, VA	94908	Dubuque, IA
93739	Wallops Island, VA	94910	Waterloo, IA
93805	Tallahassee, FL		

Table 6. Sample output from the dispersion forecast.

DISPERSION FORECAST FOR WASH-DULLES, VA
BASED ON 0Z 3/30/81 OBSERVATIONS

DAY-HOUR DIRECTION					DISTANCES (KM)				
		0.5	1.0	2.0	5.0	10.0	20.0	50.0	100.0
30- 6Z	TRAVEL	1	3	6	14	28	56	140	280
N	AVERAGE	4 -5	1 -5	3 -6	7 -7	2 -7	8 -8	2 -8	1 -8
	PEAK	7 -5	2 -5	7 -6	2 -6	7 -7	3 -7	8 -8	4 -8
30-12Z	TRAVEL	2	3	7	17	34	69	172	345
NNW	AVERAGE	4 -5	1 -5	4 -6	9 -7	3 -7	1 -7	3 -8	1 -8
	PEAK	9 -5	3 -5	9 -6	2 -6	8 -7	3 -7	9 -8	4 -8
30-18Z	TRAVEL	1	3	6	14	28	56	139	278
NNE	AVERAGE	4 -5	1 -5	3 -6	7 -7	2 -7	8 -8	2 -8	8 -9
	PEAK	7 -5	2 -5	7 -6	2 -6	7 -7	3 -7	8 -8	3 -8
31- 0Z	TRAVEL	2	4	7	18	35	71	177	355
ENE	AVERAGE	5 -5	1 -5	4 -6	9 -7	3 -7	1 -7	3 -8	1 -8
	PEAK	9 -5	3 -5	9 -6	2 -6	9 -7	3 -7	1 -7	5 -8
31- 6Z	TRAVEL	2	5	9	23	46	92	229	
NE	AVERAGE	8 -5	2 -5	8 -6	2 -6	7 -7	3 -7	7 -8	
	PEAK	2 -4	7 -5	2 -5	7 -6	3 -6	1 -6	4 -7	
31-12Z	TRAVEL	4	7	14	36	72	143	358	
NNE	AVERAGE	9 -5	3 -5	8 -6	2 -6	6 -7	2 -7	5 -8	
	PEAK	2 -4	6 -5	2 -5	5 -6	2 -6	7 -7	2 -7	
31-18Z	TRAVEL	2	3	7	17	35	69	174	347
NNE	AVERAGE	2 -5	6 -6	2 -6	3 -7	1 -7	3 -8	8 -9	4 -9
	PEAK	3 -5	9 -6	3 -6	6 -7	2 -7	6 -8	2 -8	1 -8
1- 0Z	TRAVEL	2	5	9	24	47	95	237	
NNW	AVERAGE	8 -5	3 -5	8 -6	2 -6	7 -7	3 -7	8 -8	
	PEAK	2 -4	7 -5	3 -5	7 -6	3 -6	1 -6	4 -7	

FORECAST	6	12	18	24	30	36	42	48
YEAR	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0
MONTH	3.0	3.0	3.0	3.0	3.0	3.0	3.0	4.0
JUL-DAY	89.0	89.0	89.0	90.0	90.0	90.0	90.0	91.0
JUL-HOUR	6.0	12.0	18.0	0.0	6.0	12.0	18.0	0.0
LOCAL-HR	1.0	7.0	13.0	19.0	1.0	7.0	13.0	19.0
STA-LAT	38.9	38.9	38.9	38.9	38.9	38.9	38.9	38.9
STA-LONG	77.4	77.4	77.4	77.4	77.4	77.4	77.4	77.4
CLOUD	7.5	10.0	10.0	7.5	0.5	0.5	0.5	3.5
SPEED	5.9	4.8	6.0	4.7	3.6	2.3	4.8	3.5
CEILING	20000.0	2900.0	900.0	20000.0	20000.0	20000.0	20000.0	20000.0
SOLAR EL	-46.4	10.9	53.0	-6.3	-46.0	11.2	53.4	-6.0
DOWNWIND	7.0	347.0	17.0	68.0	47.0	13.0	20.0	341.0
STABLITY	4.0	4.0	4.0	4.0	5.0	4.0	3.0	5.0
MIXING D	400.0	1097.0	1392.0	400.0	400.0	504.0	1313.0	400.0
SUNRISE	6.1	6.1	6.1	6.0	6.0	6.0	6.0	6.0

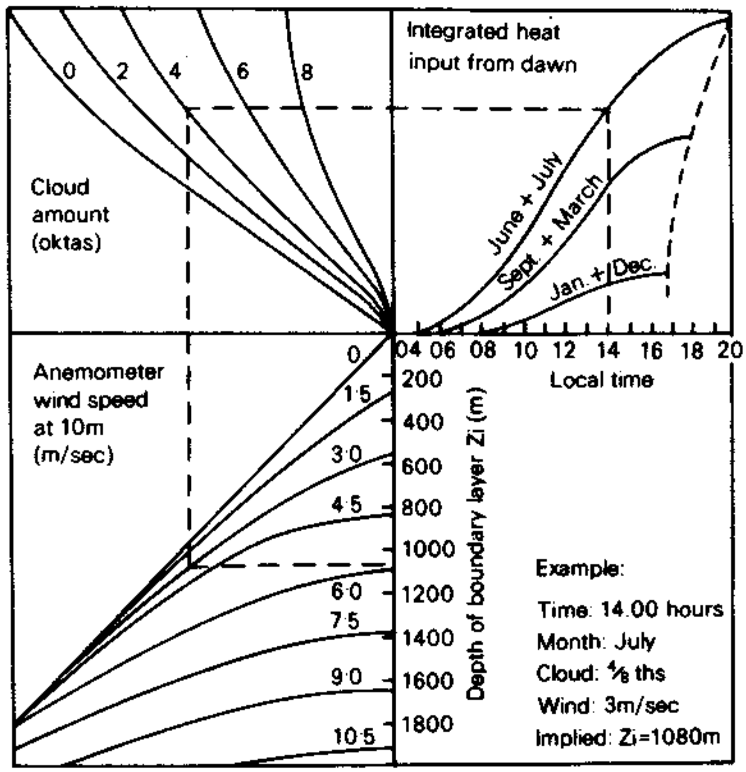

Figure 1. A nomogram for estimating the depth of the boundary layer in the absence of marked advective effects or basic changes in weather conditions (from Smith and Hunt, 1978).