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Some Simple Improvements to an Emergency Response Model for Use in Complex Coastal Terrain

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Contents

Figures

Notation

D_j	measured wind direction
D_{comp}	computed average wind direction
g	gravitational constant
h	height of layer
L	horizontal distance between a tower and a location at sea
n	number of meteorological towers
P_k	pressure at sigma level k
P_s	pressure at surface
P_T	pressure at height of geostrophic flow
R	universal gas constant for dry air
R_i	radial distance from tower i to evaluated tower j
R_s	sweep radius (radius of influence)
$\overline{T}_j$	average temperature at jth tower
$\overline{T}_{sea}$	average temperature at sea
T_k	temperature at sigma level k
U_s	time-dependent sea breeze
VAFB	Vandenberg Air Force Base
w	weighting factor that linearly increases R_s with height
x_i, y_i	coordinates of meteorological towers other than tower j
x_j, y_j	coordinates of meteorological tower j
Z_k	geopotential height of sigma level k
Δt	time step
γ_{k+1}	grid-point-dependent lapse rate at sigma level k + 1
π	$P_s - P_T$
σ	vertical modeling surface

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1 Introduction

The MACHWIND model (Meyers 1989) is one of a group of models used to compute regional wind fields from tower wind data and/or vertical wind profiles. The wind fields are in turn used to calculate atmospheric diffusion, to guide emergency responses. MACHWIND has performed acceptably in uniform terrain under steady, well mixed conditions. However, extension of the model to more complex situations is problematic. In coastal, hilly terrain like that near Vandenberg Air Force Base (VAFB) in southern California, calculations of the wind field can be enhanced significantly by several modifications to the original code. This report highlights the structure of MACHWIND and details the enhancements that were implemented.

The MACHWIND model uses available meteorological data and information on surface topography to produce an extrapolated wind field for calculations over a 100-km by 100-km domain of atmospheric diffusion during an emergency response. The terrain is described with a fine grid spacing of 1 km by 1 km. A medium grid (2 km by 2 km) and a coarse grid (4 km by 4 km) are derived from the fine grid spacing. In the present use, wind speed and direction are assumed to be provided by 24 towers clustered mainly along the western portion of VAFB, between the Pacific coast and the coastal mountain range. Of these 24 towers, 12 provide measurements of wind speed and direction 3.7 m above the surface, 10 provide measurements at two levels (3.7 and 16.5 m), 1 has four measurement levels (3.7, 16.5, 31.1, and 62.1 m), and 1 has five measurement levels (3.7, 16.5, 31.1, 62.1, and 91.4 m).

To provide data for MACHWIND, wind speed and direction are extrapolated to fit a logarithmic profile asymptotic to geostrophic flow above each tower. Fixed heights (3.7, 16.5, 31.1, 62.2, and 91.4 m) are specified to match tower measurements. Missing data for wind speed and direction are extrapolated to each level for each tower. MACHWIND computes a wind field for each grid point at each level by using inverse-squared distance weighting of the tower wind data extrapolated to the grid point at each height. From this data set, wind fields for coarse, medium, and fine grids are calculated to achieve an iterative fit with data for the fixed heights.

2 Modification of MACHWIND

MACHWIND as it is currently designed computes the wind field with several significant restrictions. The improvements suggested here involve (1) definition of heights, (2) vertical extrapolation of winds, and (3) implementation of a very simple first approximation to a sea breeze. Although they are incomplete, these initial modifications to MACHWIND should improve extrapolation of wind fields in a mountainous coastal region so that an emergency response can be more properly implemented.

2.1 Sigma Heights

The original MACHWIND model describes the vertical grid spacing in terms of fixed height intervals above local terrain (Figure 1). Fixed heights may be acceptable over flat terrain, but the specified heights do not exceed 100 m, and the application here is over complex terrain. The height specification also presents problems because of (1) the nonconservation of mass in each layer and (2) diffusing plumes whose depth significantly exceeds 100 m.

These problems can be avoided if the vertical levels are defined with sigma surfaces (Phillips 1957) so that the top level coincides with the geostrophic flow. Each sigma level is described here as

$$\sigma_k = (P_k - P_T)/\pi\ , \tag{1}$$

where P_k is the pressure at the current height, P_T is the pressure at the height of geostrophic flow, and $\pi = P_s - P_T$ is the difference between the surface pressure, P_s, and P_T. The value of P_T for observed geostrophic flow will vary, but it can be determined from local rawinsonde measurements.

The surface pressure at each grid point is computed from a given local sea level pressure by assuming that dry adiabatic conditions prevail from sea level to the height of the local terrain. The geopotential heights of the sigma levels are computed as

$$Z_k = Z_{k+1} - RT_i/g(d \ln P_k)/[1 - (R/g)(\gamma_{k+1}/2)d \ln P_k]\ , \tag{2}$$

where

$$d \ln P_k = \pi(\sigma_k - \sigma_{k+1})/(P_T - \pi\sigma_{k+1})\ . \tag{3}$$

In Equation 2, R is the universal gas constant for dry air, T_k is the temperature at sigma level k, g is the gravitational constant, and γ_{k+1} is the grid-point-dependent lapse rate at level k + 1. The value of k ranges from 1 to 6, where the top level ($\sigma = 0.0$) is 1, the surface level ($\sigma = 1.0$) is 6, and k + 1 is the next level downward, toward the surface. When they are implemented, sigma levels at 0.92, 0.94, 0.96, and 0.98 will allow analysis in finer detail of the flow behavior near the surface. This modification is based on the hydrostatic approximation and is formulated as subroutine RELHT, called by subroutine TOPO from within the program MACHWIND (see Appendix).

Figures 1 and 2 show the wind field heights before and after the implementation of proper sigma levels. The surface contour represents a west-to-east cross section across VAFB and the adjacent regions. This change in heights is clearly necessary to conserve mass and is thus desirable for diffusion modeling.

2.2 Modification for Vertically Extrapolated Wind Fields

Low-level winds over VAFB are computed from 24 towers, which are mainly clustered about the western portion of the emergency response region (Figure 3). In this region, the Pacific Ocean lies to the immediate west and south; coastal ranges with surface heights over 300 m are oriented northwest to southeast. Approximately 30-40 km inland, the Pacific Crest range covers the eastern region, with surface elevations over 420 m.

Logarithmic profiles between the surface and the geopotential flow (assumed to be 1,000 m) are fitted to available tower data and then interpolated to each height level, but wind direction is initially held constant with height. The implemented modification searches for outliers at heights above the towers; uncharacteristic flow is then recalculated as shown below. This modification will tend to bring the winds into alignment with the geostrophic flow as the sigma surfaces approach the height of geostrophic flow. At each tower location, a weighted average velocity is computed. This height-dependent velocity is determined by computing a sweep radius as follows:

$$R_s = w/n \sum_{i=1;i\neq j}^{n} \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \tag{4}$$

Here w is a weighting factor that linearly increases the sweep radius with height, n is the number of meteorological towers, x_j and y_j are the coordinates of the tower being evaluated, and x_i and y_i are the coordinate locations of each of the remaining towers.

The sweep radius R_s represents a radius of influence and allows for analysis of the wind at the jth tower, exclusive of data from that tower (Figure 4). The distance between the ith tower and the evaluated tower j is denoted as R_i. Comparison of the measured wind direction and the computed wind direction at the jth tower determines whether any smoothing is required. If the absolute value of the difference between the measured wind direction (D_j) and the computed average wind direction (D_{comp}) is greater than $\varepsilon = D_j/3$, then the actual wind field at the jth tower is replaced by the computed average. The computed wind direction is defined as

$$D_{comp} = 1/n \sum_{i=1}^{n} D_i(R_i < R_s) \, . \tag{5}$$

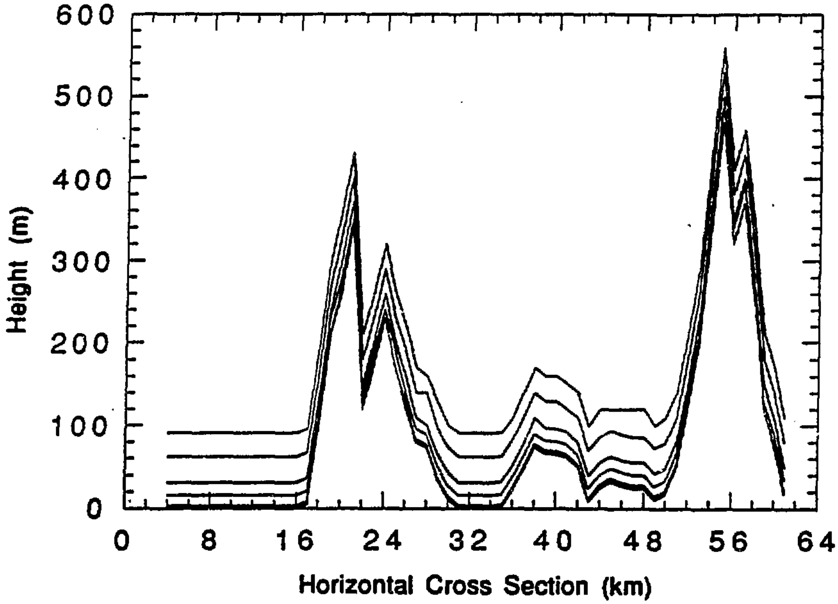


FIGURE 1 Original Fixed Sigma Heights, Specified as 0.0, 3.66, 16.46, 31.09, 62.18, and 91.44 m above Surface Contours

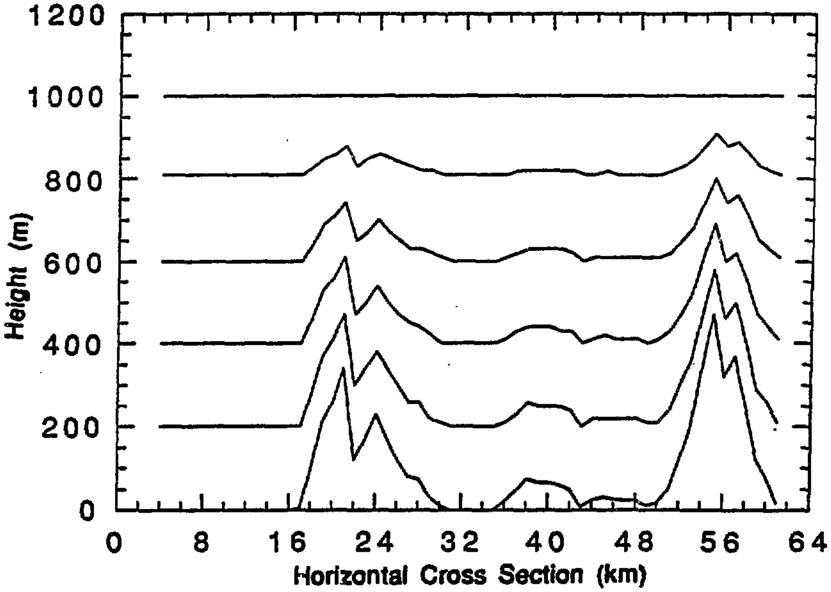


FIGURE 2 Computed Sigma Heights that Fit the Topography near the Surface and Approach Geostrophic Flow at $\sigma = 0$

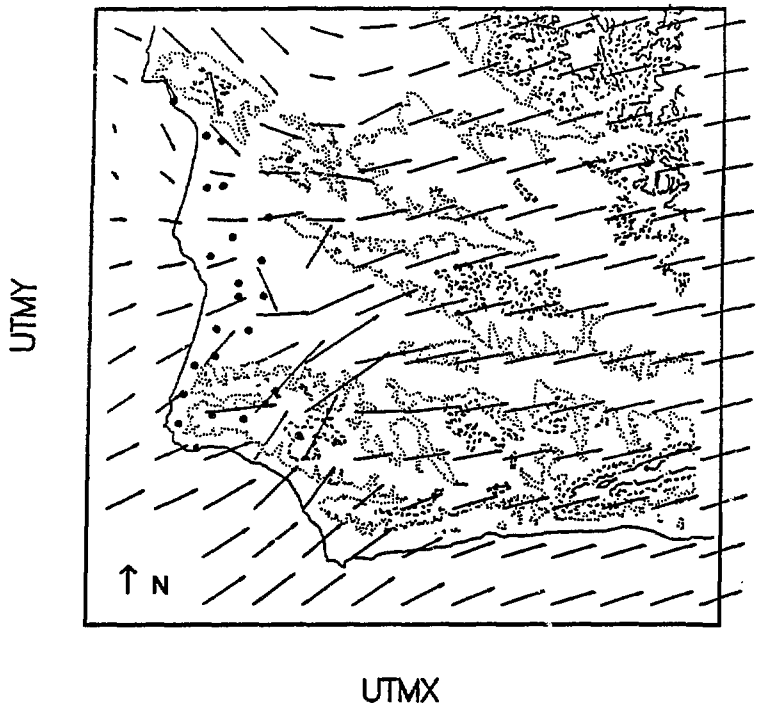


FIGURE 3 Tower Locations (closed circles) and Elevated Terrain (contours) in the Vicinity of Vandenberg Air Force Base (Vectors represent wind speeds at sigma level 0.4.)

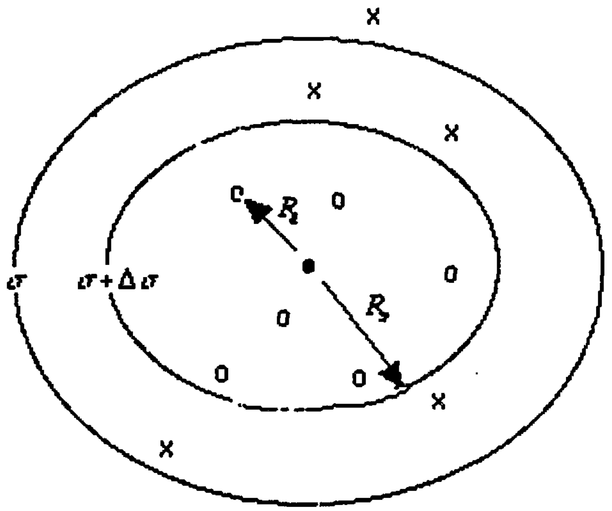
If

$$|(D_j - D_{comp})| > \varepsilon, \tag{6}$$

then D_j is set equal to D_{comp}. Figures 5 and 6 show flow fields before and after wind field modification for sigma levels 0.8, 0.6, 0.4, and 0.2. The anomalous velocities in Figure 5 (circled) have been reanalyzed and replaced in Figure 6. This modification is located in subroutine DOPSIG and is called subroutine WDTST (see Appendix).

2.3 Implementation of a Sea Breeze

Vandenberg Air Force Base is located along the California coast north of Los Angeles. The diurnal variations in the wind field due to the local sea breeze must be accounted for if MACHWIND is to adequately predict the wind field over the region. Because MACHWIND is designed to extrapolate the winds for a fixed time, no mechanism is available to compute the onset and magnitude of the sea breeze. This restriction limits MACHWIND's ability to realistically



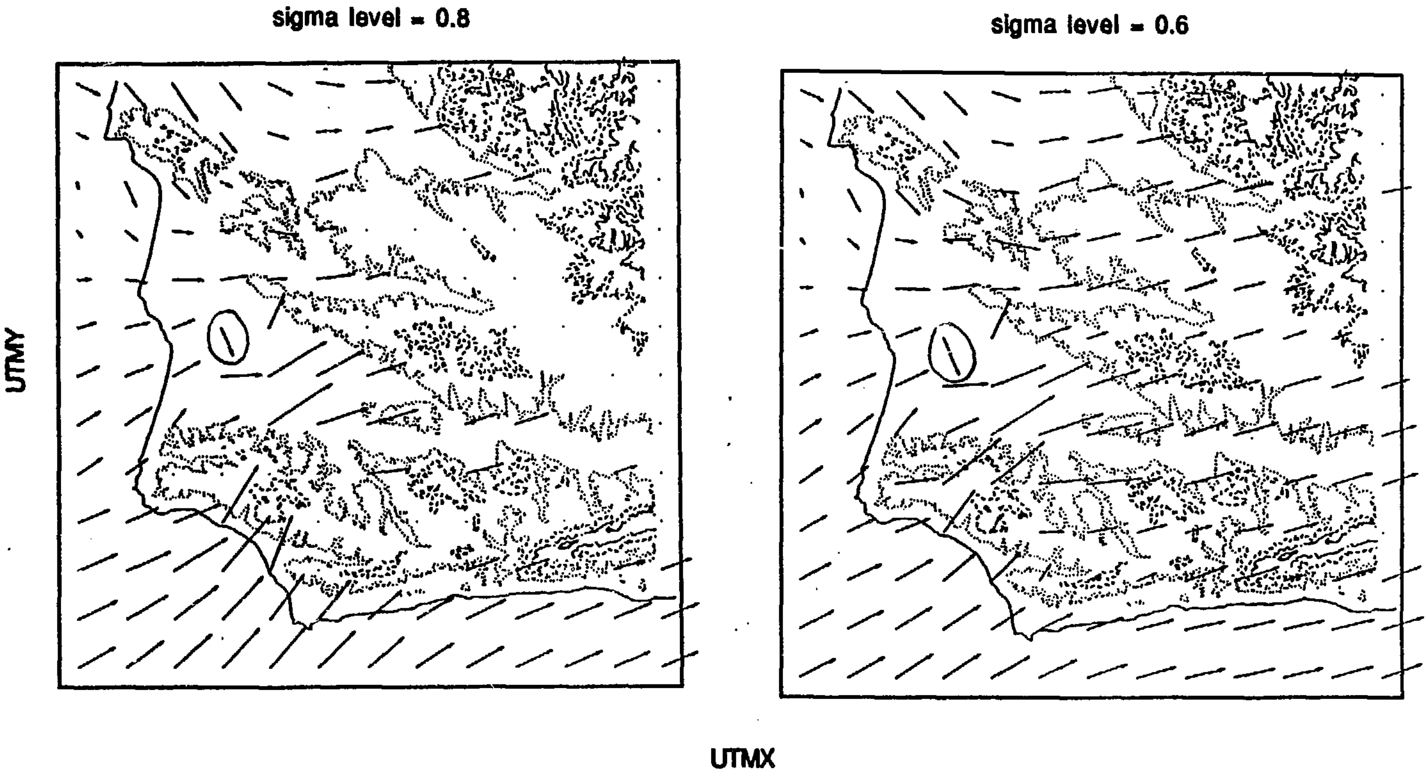
•	Tower being evaluated
°	Towers inside R_S, used in the computed average
x	Towers outside R_S, not used in the computed average
R_S	Computed radius of influence
R_i	Distance of tower i from evaluated tower j
$\sigma + \Delta\sigma$	Sigma level being evaluated
σ	Next sigma level above the $\sigma + \Delta\sigma$ level

FIGURE 4 Schematic Diagram for Computation of the Average Wind Direction, D_{comp} (The inner large circle represents the mean tower distance at level $\sigma + \Delta\sigma$. Towers inside R_S [small circles] were used to compute D_{comp}.)

simulate any time-dependent processes. Even with frequent updating, this wind field model is hampered by insufficient forcing.

To address this problem, a simple zonal sea breeze based on observed temperature has been incorporated into MACHWIND. This first approximation of the sea breeze is based on the vertical pressure difference ($P_s - P_k$) at each tower and the average horizontal temperature difference between a column at the observation tower and a column at a location at sea that is equidistant from the shoreline. Because most of the coastline near VAFB is oriented north-south, a gross assumption of a sea breeze from the west is made here. This time-dependent sea breeze (U_S) is defined as an add-on term to the west-to-east wind field and is defined as

$$U_s = R \ln (P_T/P_s)(\overline{T}_j - \overline{T}_{sea})/[2(h + L)]\Delta t \ . \qquad (7)$$



sigma level = 0.8

sigma level = 0.6

FIGURE 5 Wind Flow Fields over the Vandenberg Air Force Base Region before Modification of Unrepresentative Winds, for Sigma Levels of 0.8, 0.6, 0.4, and 0.2, with a Vector Spacing of 500 cm/s (Anomalous velocities are circled.)

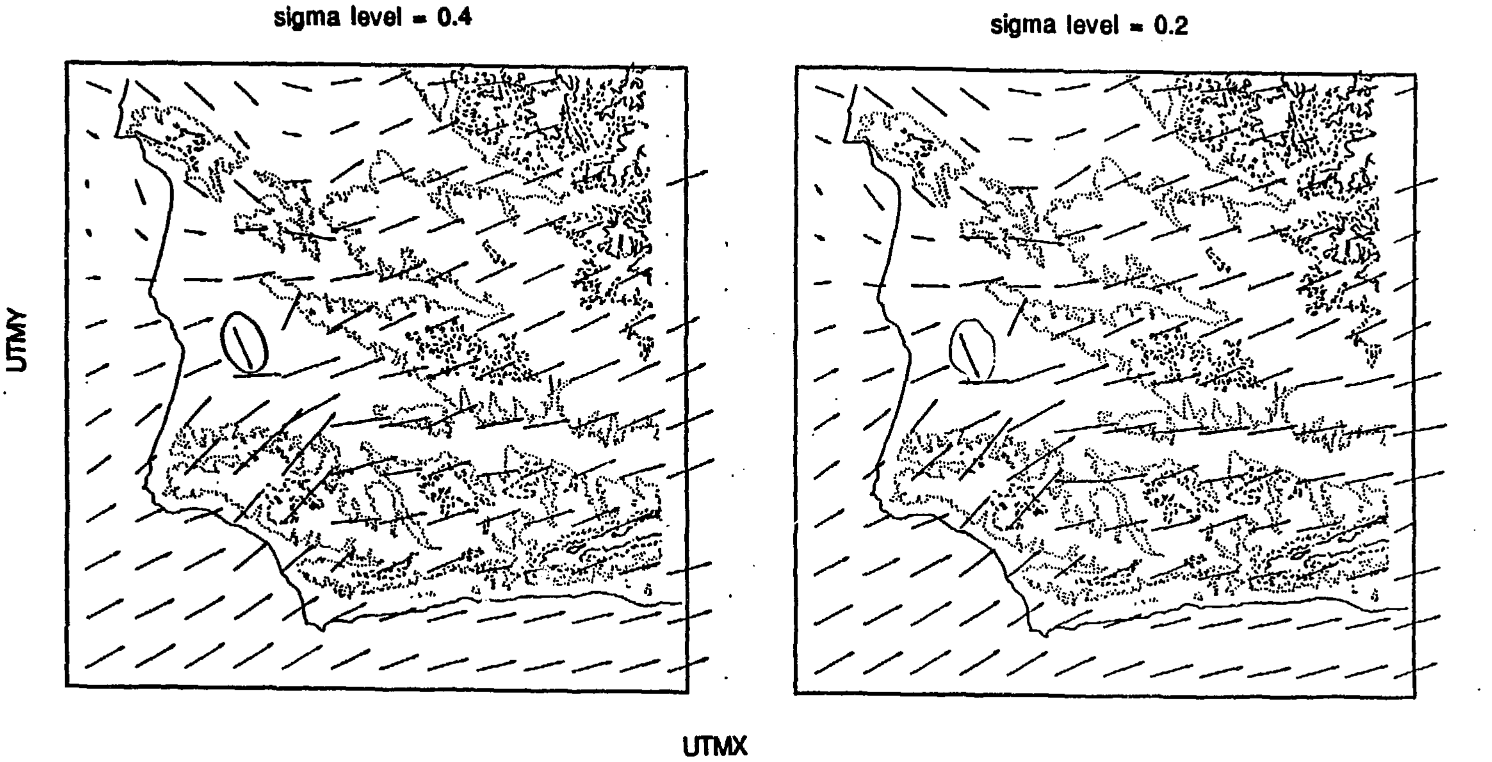


FIGURE 5 (Cont.)

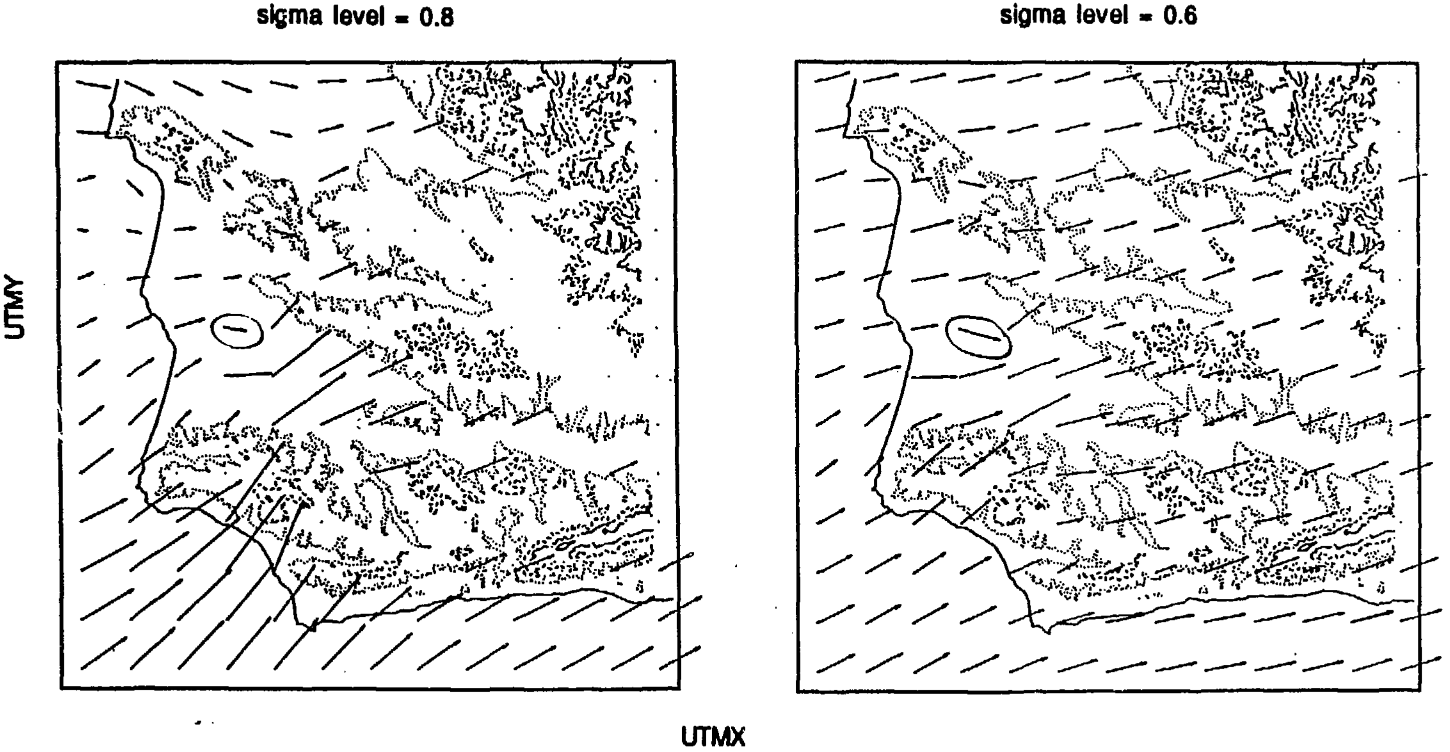


FIGURE 6 Wind Flow Fields over the Vandenberg Air Force Base Region after Wind Field Modification, for Sigma Levels of 0.8, 0.6, 0.4, and 0.2, with a Vector Spacing of 500 cm/s (Vectors replaced in the modification are circled.)

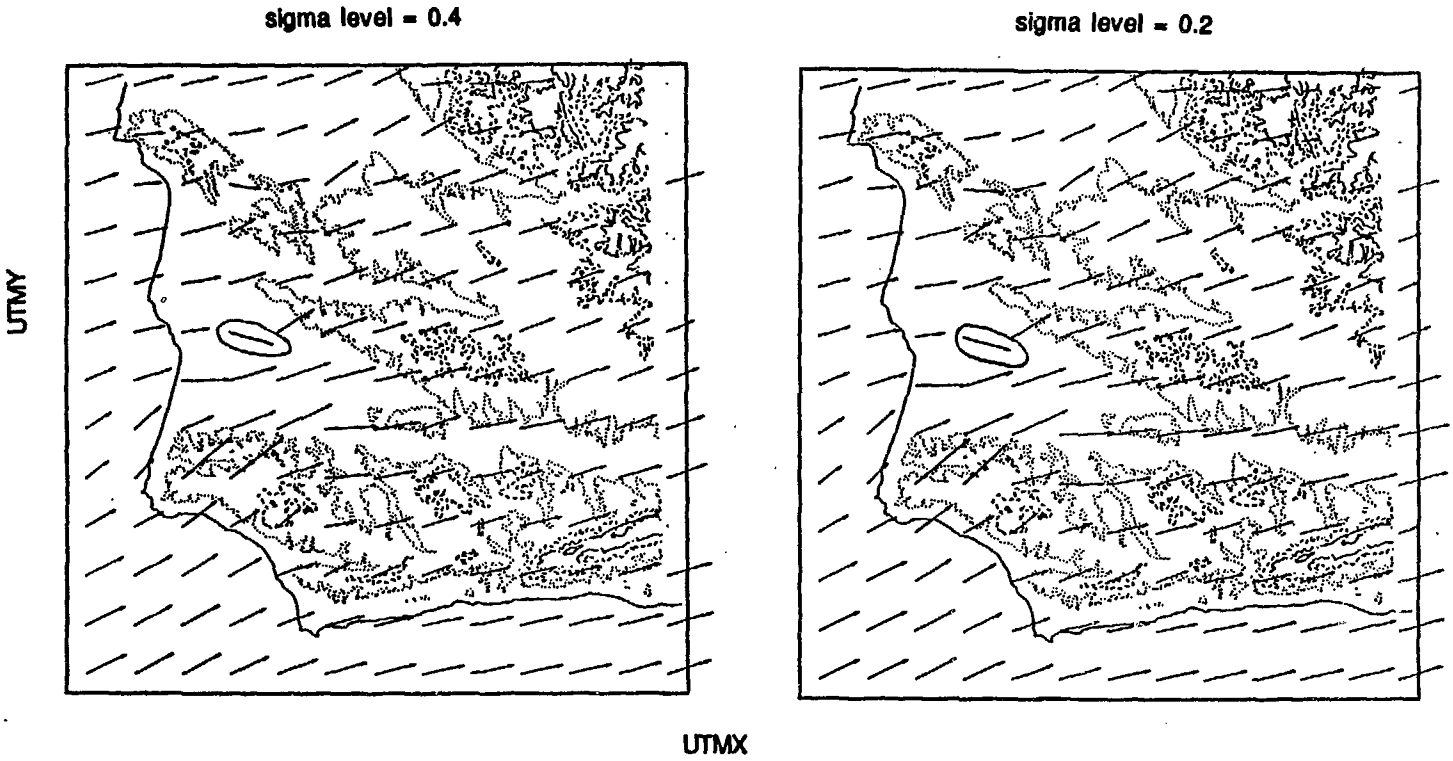


FIGURE 6 (Cont.)

In Equation 7, $\overline{T}_j$ and $\overline{T}_{sea}$ are the average temperatures at the jth tower and at an adjacent sea location in a vertical column between P_s and P_k (at the jth tower). In addition, L is the horizontal displacement between the jth tower and the sea location, h is the layer height, and Δt denotes the time step. A schematic diagram of the sea breeze is shown in Figure 7.

The intensity of the sea breeze is illustrated in Figures 8 and 9 for initial land-sea surface temperature differences of 5°C and 20°C, respectively. The tendency toward zonal flow in the presence of a sea breeze is most apparent as the land-sea temperature difference increases.

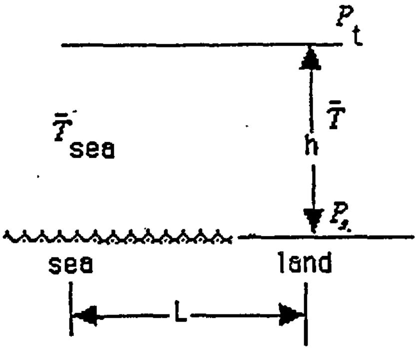


FIGURE 7 Schematic Diagram for Computing a Crude Sea Breeze for an Assumed North-South Coastline

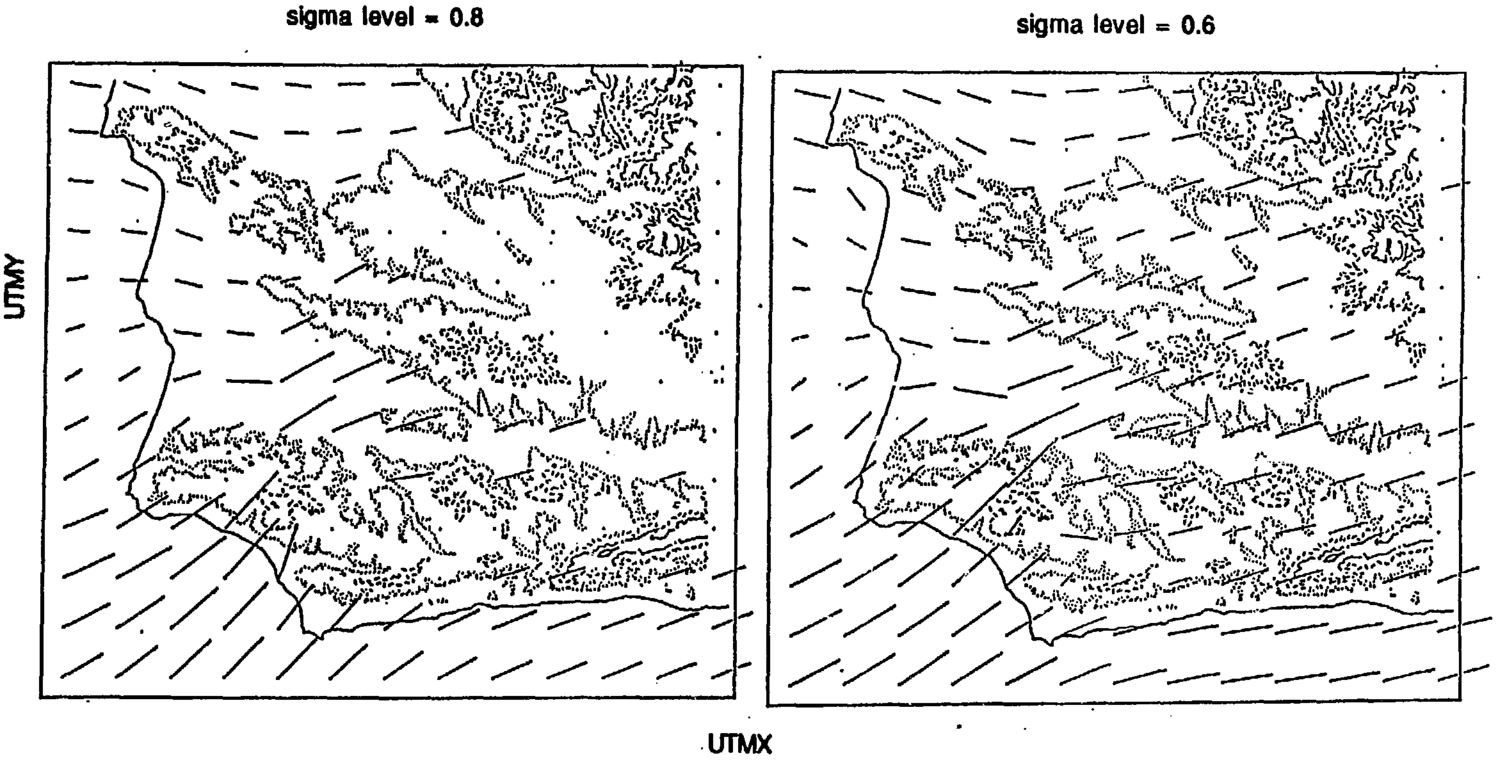


FIGURE 8 Zonally Approximated Sea Breeze at Sigma Levels of 0.8, 0.6, 0.4, and 0.2, for a Land-Sea Temperature Difference of 5°C, with a Vector Spacing of 500 cm/s

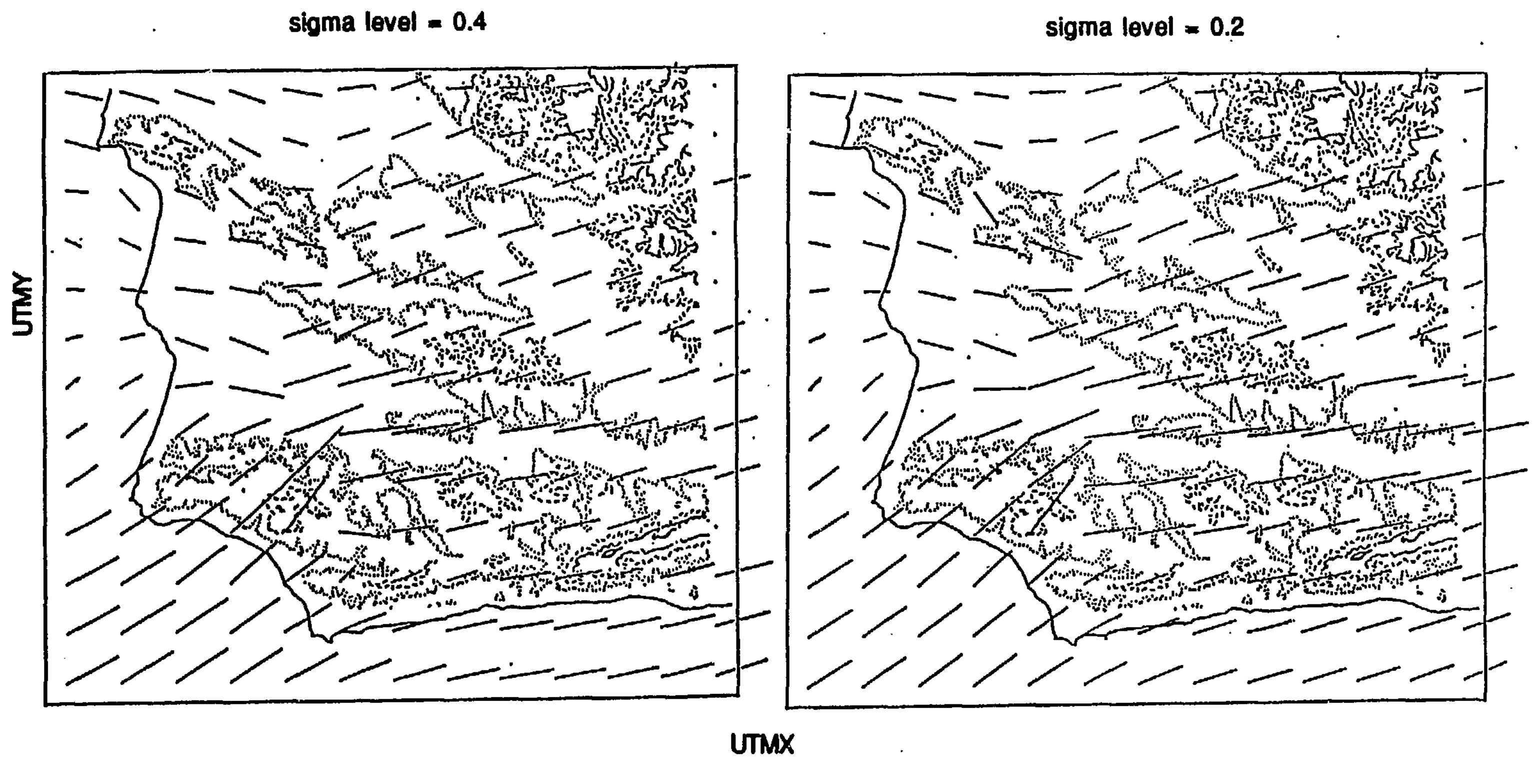


FIGURE 8 (Cont.)

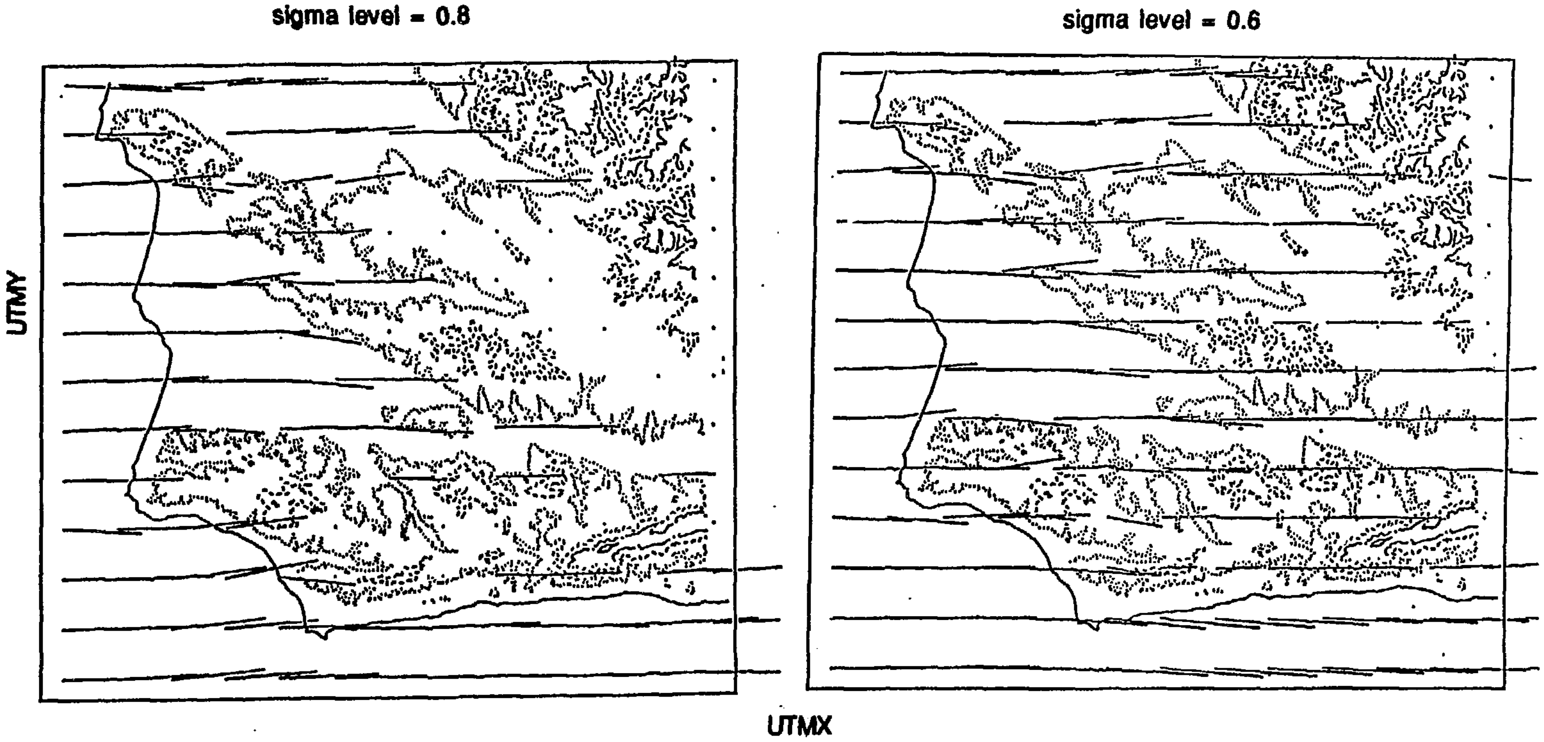


FIGURE 9 Zonally Approximated Sea Breeze at Sigma Levels of 0.8, 0.6, 0.4, and 0.2, for a Land-Sea Temperature Difference of 20°C, with a Vector Spacing of 500 cm/s

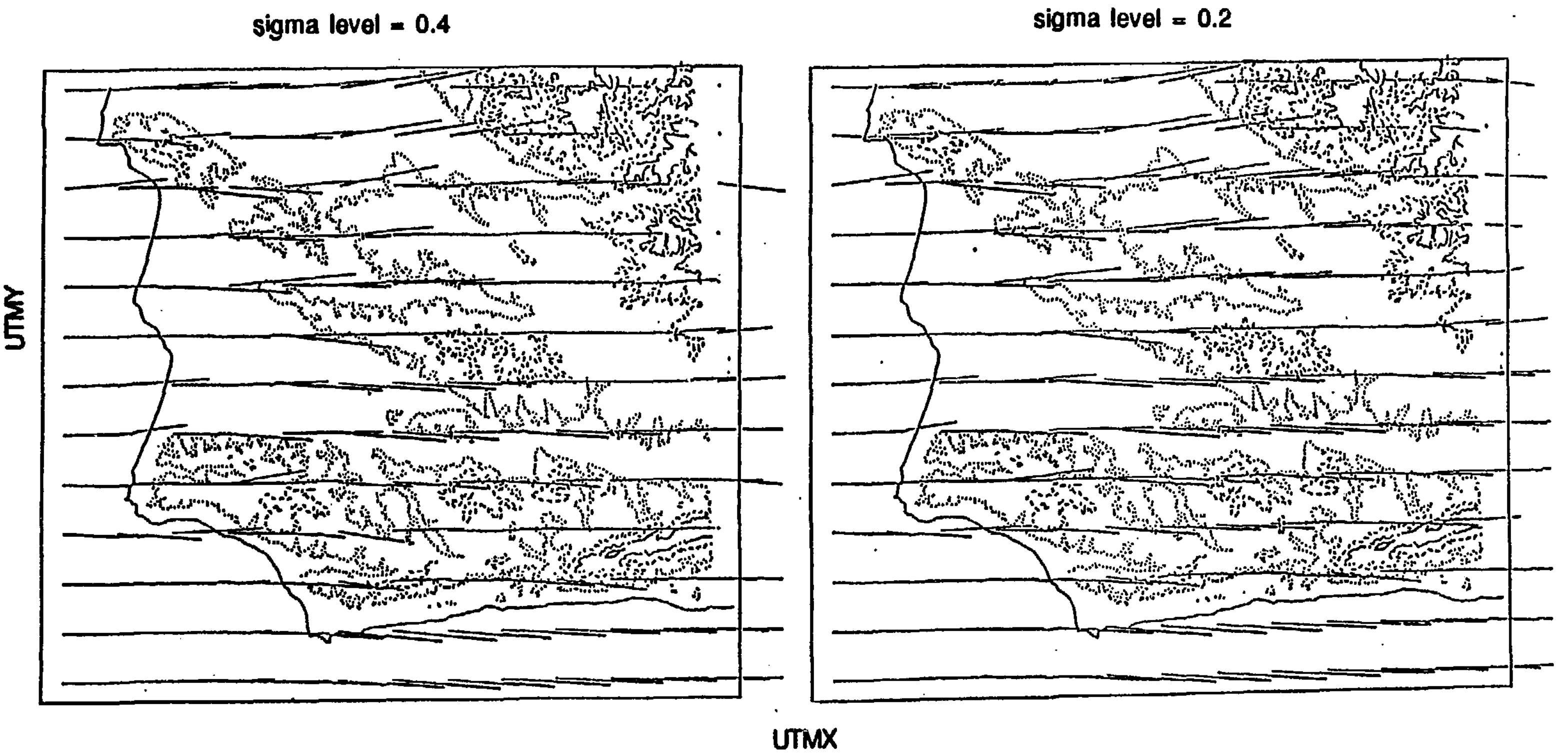


FIGURE 9 (Cont.)

3 Future Modifications of MACHWIND

Further modifications of MACHWIND should include a more elaborate scheme for adjusting the vertically extrapolated velocity fields. Development of a code to incorporate (1) wind field adjustments based on topographic features and (2) regional averaging at each surface grid point will enhance the accuracy. Implementation of finer sigma levels near the surface will improve calculations of low-level diffusion. Because MACHWIND is a snapshot calculation (in a single time step), nesting this model in a time-dependent mesoscale scheme will allow calculation of time-dependent forcing and of growth processes in the boundary layer. For application to VAFB, more towers or other wind data are desirable, especially in the central and eastern mountainous areas. Coupling to the National Meteorological Center data to obtain information about geostrophic flow will also enhance this model.

4 References

Meyers, R.E., 1989, *Preliminary Documentation of MACHWIND*, U.S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, N.M.

Phillips, N.A., 1957, "A Coordinate System Having Some Special Advantages for Numerical Forecasting," *Journal of Meteorology*, 14:184-185.

Appendix:

Modifications to MACHWIND Code

```
CNLM***  SEA BREEZE WEIGHT 1/DX
           WTS(J)=1./500.
           DO 300 IT=1,NUMT
             U(I,J,K)=U(I,J,K)+WT(IT)*USIG(IT,K)+WTS(I)*USEA(K)
             V(I,J,K)=V(I,J,K)+WT(IT)*VSIG(IT,K)
CCC             WRITE(6,401) USIG(IT,K),USEA(K),U(I,J,K),K
 401       FORMAT(1X,'USIG',F8.2,' USEA ',F8.2,' U ',F8.2,' K',I5)
 300       CONTINUE
 350     CONTINUE
 400   CONTINUE
       IF (DBUG(4)) THEN
          DO 430 K=2, NLVL
             WRITE(*,9035) K
             DO 420 JR=1, NROW
                JP=NROW+1-JR
 420         WRITE(*,9031) (U(IP,JP,K),IP=I1,I2)
             WRITE(*,9038) K
             DO 425 JR=1, NROW
                JP=NROW+1-JR
 425         WRITE(*,9031) (V(IP,JP,K),IP=I1,I2)
 430      CONTINUE
          WRITE(*,9002)
       END IF

9001  FORMAT (/ ' BEGIN SUBROUTINE GPAN  '/)
9002  FORMAT (//'  END OF SUBROUTINE GPAN '/)
9010  FORMAT (3X,8F6.1)
9030  FORMAT (/'   WTS FOR STATIONS FOR GRID POINT X,Y='2I3)
9031  FORMAT (1X,21F5.1)
9035  FORMAT (/'  U COMPONENT AT LEVEL ='I3/)
9038  FORMAT ('   V COMPONENT AT LEVEL ='I3/)

        RETURN
          END
C
```

```
CNLM################################################################
C
      SUBROUTINE SEABREEZ(USEA)
C
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C ****  NEW ADDITION TO ACCOUNT FOR SEA BREEZE EFFECTS *****
C       SEABREEZ IS SEEN AS AN ADDITIONAL COMPUTATION WHICH COMPUTES
C       THE VARIABLE SEA BREEZE AND ADDS ITS VALUE ON TO U COMPONENT
C ****  *** ******** ** ******* *** *** ****** ******* *****
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C     SUBROUTINE SEABREEZ ACCOUNTS FOR COASTAL SEABREEZ EFFECTS AT
C     VANDENBURG AIR FORCE BASE, CURRENTLY THERE ARE MANY GROSS
C     ASSUMPTIONS.
C
C             SURFACE TEMPERATURES AND PRESSURES ARE BROUGHT IN FROM
C             COMMON/ATMOS.  THESE VALUES ARE SPECIFIED IN RELHT AS
C             TSR=15. , PSR=1013, TTOP=8.5, PTOP=900.  THROUGOUT THE
C             GRID DOMAIN.  INDIVIDUAL SURFACE VALUES ARE CORRECTED AS
C             A FUNCTION OF THEIR LOCAL HEIGHT ABOVE SEA LEVEL USING
C             THE HYDROSTATIC EQUATION.  LOCAL HEATING VARIATIONS ARE
C             NEGLECTED.
C             VALUES: TSR,PSR,TSEAR,PSEAR WILL BE INPUTTED FOR EACH
C             SPECIFIC RUN
C             SEA BREEZE INLAND STRENGTH IS BASED ON DISTANCE FROM
C             COASTAL PERPENDICULAR (X), PRESSURE RATIO AND TEMPERATURE
C             DIFFERENCE.  SEA BREEZE IS ASSUMED ZONAL.
C
      INCLUDE 'WNDINPV2.INC'
      REAL USEA(6),TR(6),PR(6),TSEA(6),PSEA,DVSEADT(6)
      REAL TSR,PSR,TSSEA,PSSEA,HTSEA(6),HTREF(6)
      COMMON/SEA/TSR,PSR,TSSEA,PSSEA,
     $            PTOP,GRG,HTSEA,HTREF,PR,IR,JR
C       COMMON/GRDLOC/XGRID(61),YGRID(61)
C
            GRAV=9.8
            PIE=3.141592
            RAIR=287.
            RGR=1./GRG
            DTDV=0
            DTDZ0=6.5E-3
            TR(6)=TSR
            PR(6)=PSR
            TSEA(6)=TSSEA
C X VALUE IS 0?                 DX=XGRID(IR)
C                               WRITE(6,600) IR,XGRID(IR)
 600                            FORMAT(10X,'IR ',I5,' XGRID ',F12.4)
              DX=500.
              DO 100 K=5,1,-1
               KP=K+1
               TR(K)=TSR+DTDZ0*HTREF(K)
               DZ=HTREF(K)
               TRB=(TR(K)+TSR)/2.
               TSEA(K)=TSSEA+DTDZ0*HTSEA(K)
               TSEAB=(TSEA(K)+TSSEA)/2.
               DT=TRB-TSEAB
               DXZ=DX+DZ
C        WRITE(6,601) DXZ,PR(K),K,DZ,DX
 601     FORMAT(2X,'DZ+DX',F8.2,' PR(K)',F8.2,' K',I5,' DZ',F8.2,
     $          ' DX',F8.2)
C
        DVSEADT(K)=RAIR*LOG(PSR/PR(K))/(2.*(DZ+DX))*DT
        TIME=3600.*ABS(SIN(2.*PIE*DT))
        USEA(K)=DVSEADT(K)*TIME
        WRITE(6,120) USEA(K),TIME,DX,DZ,DT,K
  100          CONTINUE
C
         ITEST=ITEST+1
C         WRITE(6,130)ITEST
  130    FORMAT(5X,'SEABREEZE COUNTS:',I5)
  120    FORMAT(1X,'USEA ',F12.3,' TIME',F8.2,' DX ',F8.2,/,
     $          '  DZ ',F8.2,' DT ',F8.2,' K',I5)
        RETURN
        END
```

```
C
        IF(DEBUG(2)) WRITE(*,9020) IT
        IF(DEBUG(2)) WRITE(*,9010) (USIG(IT,K), VSIG(IT,K), K=1,NLVL)
  450  CONTINUE
CNLM*************MILLER CHANGE******************************************
C****************INITIAL AVERAGING SCHEME*******************************
C****************FORWARD-BACKWARD AVERAGING*****************************
C****************REPLACED BY R-SWEEP AVERAGING**************************
C
C USING VANDENBURG VALUES USIG,VSIG COMPUTE WIND DIRECTION AND
C COMPARE TO NEIGHBORS, IF GREATER THAN 33% THEN USE AVE VALUE

C FOR WIND DIRECTION, DECOMPOSE NEW USIG,VSIG FROM WDIR.
C
        ISKIP=1
        IF(ISKIP.EQ.1)GO TO 1177
        DO 1455 K=2,NLVL
         DO 1456 IT=1,24
              IF(IT.EQ.1)THEN
                  ITM=2
                  ITP=IT+1
                  ENDIF
              IF(IT.EQ.NUMDOP)THEN
                  ITM=IT-1
                  ITP=NUMDOP-1
                  ENDIF
              IF((IT.GT.1).AND.(IT.LT.NUMDOP))THEN
                  ITM=IT-1
                  ITP=IT+1
                  ENDIF
C         WRITE(6,888)USIG(ITM,K),USIG(ITP,K),IT
C 888     FORMAT(2X,'U(ITM)',F8.2,' U(ITP)',F8.2,' IT',I4)
              WDIR(ITM,K)=ATAN(VSIG(ITM,K)/USIG(ITM,K))
              WDIR(ITP,K)=ATAN(VSIG(ITP,K)/USIG(ITP,K))
              WDIR(IT,K)=ATAN(VSIG(IT,K)/USIG(IT,K))
                WDAVE=(WDIR(ITM,K)+WDIR(ITP,K))/2.
                UAVE=(USIG(ITM,K)+USIG(ITP,K))/2.
                VAVE=(VSIG(ITM,K)+VSIG(ITP,K))/2.
             WDTST=ABS((WDIR(IT,K)-WDAVE)/WDAVE)
              IF(WDTST.GT.0.33)THEN
                 USIG(IT,K)=UAVE
                 VSIG(IT,K)=VAVE
                 ENDIF
C              WRITE(6,1779)USIG(IT,K),VSIG(IT,K),IT,K
 1779          FORMAT('INI','U ',F12.3,' V ',F12.3,' IT ',I4,' K ',I4)
 1456     CONTINUE
 1455     CONTINUE
 1177     CONTINUE
CNLM*************MILLER CHANGE******************************************
C****************R-SWEEP AVERAGING**************************************
C  RADIUS OF INFLUENCE RI IS DEFINED SUCH THAT ANY STATION INSIDE OF
C  A CIRCLE MADE BY RI IS NOW INCORPORPORATED INTO AN AVERAGING SCHEME
C
C       WNDIR = WNDIR(I) + SUM[WNDIR(J)/R(J)**2
C
C USING VANDENBURG VALUES USIG,VSIG COMPUTE WIND DIRECTION AND
C COMPARE TO NEIGHBORS, IF GREATER THAN 33% THEN USE AVE VALUE
C FOR WIND DIRECTION, DECOMPOSE NEW USIG,VSIG FROM WDIR.
```

```
C
C   SELECT TOWER AND DETERMINE REFERENCE RADIUS
       DO 333 ITW=1,24
         SUM=0
         IC=0
         DO 444 I=1,24
         IC=IC+1
         IM=I-1
         IP=I+1
         IF(I.EQ.ITW)GO TO 444
         REF=SQRT((XS(ITW)-XS(I))**2+(YS(ITW)-YS(I))**2)
         SUM=SUM+REF
C        WRITE(6,454)XS(IP),XS(IM),YS(IP),YS(IM),REF,SUM,IC
 454    FORMAT('****************************',/,
     #    5X,'X:',2E12.2,' Y:',2E12.2,' REF:',E12.2,/,' SUM',E15.5,
     #    '    IC: ',I5)
 444     CONTINUE

          REF=SUM/FLOAT(IC)
c          REF=4.
        DO 455 K=2,NLVL
          REF=REF*FLOAT(K)/4.
CCC          DO 456 JJ=1,24
          PI2=1.570796
          RTOT=0.
          DO 447 IT=1,24
               RLOC=SQRT((XS(IT)-XS(ITW))**2+(YS(IT)-YS(ITW))**2)
C        WRITE(6,556) RLOC,REF,K
 556    FORMAT(10X,'RLOC',E12.2,' REF',E12.2,' LEVEL',I5)
               IF((RLOC.GT.REF).OR.(IT.EQ.ITW))GO TO 447
               RTOT=RTOT+RLOC**-2
447           CONTINUE
         UAVE=0.
         VAVE=0.
         WDAVE=0.
         RN=0.
         TEST=0.
         DO 457 IT=1,24
              RLOC=SQRT((XS(IT)-XS(ITW))**2+(YS(IT)-YS(ITW))**2)
              IF((RLOC.GT.REF).OR.(IT.EQ.ITW))GO TO 457
              RN=RN+1
              RFUNC=RLOC**(-2)/RTOT
              RFUNC=1.
              UAVE=UAVE+USIG(IT,K)*RFUNC
              VAVE=VAVE+VSIG(IT,K)*RFUNC
              TEST=TEST+RFUNC
C             WRITE(6,349)RFUNC,RTOT,TEST
 349         FORMAT(5X,'FUNC',E15.5,' TOT',F12.4,'TEST',F12.4)
 457     CONTINUE
               IF(RN.EQ.0.)GO TO 456
              UAVE=UAVE/RN
              VAVE=VAVE/RN
              WUTST=ABS((USIG(ITW,K)-UAVE)/UAVE)
              WVTST=ABS((VSIG(ITW,K)-VAVE)/VAVE)
            EPSW=0.3
            IF(WUTST.GE.EPSW)USIG(ITW,K)=UAVE
            IF(WVTST.GE.EPSW)VSIG(ITW,K)=VAVE
            WDIR(ITW,K)=ATAN(VSIG(ITW,K)/USIG(ITW,K))
C              WRITE(6,779)USIG(ITW,K),UAVE,VSIG(ITW,K),VAVE,ITW,K,
C     #                     WUTST,WDIR(ITW,K),WVTST
 779          FORMAT(2X,'U ',F12.3,' UAVE',F12.3,' V ',F12.2,' VAVE ',
     #                 F12.2,' ITW ',I4,' K ',I4,
     #                 /,5X,'WUTST',F12.4,' WDIR',F12.6,' WVTST',F12.5)
 456     CONTINUE
 455     CONTINUE
 333    CONTINUE
```

```
CXXXXXXORIGINALXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C  DENOTE GEOMETRIC HEIGHT ABOVE TERRAIN BY RHS
      DO 671 J=1,NROW
      DO 671 I=1,NCOL
         ZVAR=ELT(I,J)-SFCHT(I,J)
         DO 671 K=1,NLVL
            RHS(I,J,K,INDX)=SIGMA(K)*ZVAR
  671 CONTINUE
C       WRITE(6,9900)(K,RHS(10,10,K,INDX),K=1,NLVL)
CXXXXXVANDENBERG CHANGEXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX AA
      DO 670 J=1,NROW
      DO 670 I=1,NCOL
        RHS(I,J,1,INDX)=0.0
        RHS(I,J,2,INDX)=3.658
        RHS(I,J,3,INDX)=16.46
        RHS(I,J,4,INDX)=31.09
        RHS(I,J,5,INDX)=62.18
        RHS(I,J,6,INDX)=91.44
  670  CONTINUE
C       WRITE(6,9900)(K,RHS(10,10,K,INDX),K=1,NLVL)
CXXXXXXXXMILLER CHANGEXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX AA
C       WRITE(6,9011)
       CALL RELHT(NEWSIG)
       DO 67 J=1,NROW
       DO 67 I=1,NCOL
       DO 68 K=1,6
C          write(22,9009)
          RHS(I,J,K,INDX)=NEWSIG(I,J,K)
   68  CONTINUE
   67  CONTINUE
C       WRITE(6,9900)(K,RHS(10,10,K,INDX),K=1,NLVL)
C          WRITE(6,9910)(J,(NEWSIG(10,J,K),k=1,6),J=1,61)
 9900      FORMAT(2X,'K ',I3,'RHS ',F12.3)
 9910      format(1X,I5,'NSIG',6F8.2)
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX AA
  150 IF(DBUG(9)) WRITE(X,9002)
    2 FORMAT(8F10.2)
    4 FORMAT(/,5X,21F5.0)
 9001 FORMAT (/' BEGIN SUBROUTINE TOPO, NUM='I3)
 9002 FORMAT (/' END OF SUBROUTINE TOPO'/)
 9003 FORMAT (1H1,' TERRAIN HTS, METERS'/)
 9006 FORMAT (/'   PRINTOUT IS REVERSE OF INPUT - HAS NORTH ROW 1ST'/)
 9009 FORMAT (/'   CALL RELHT')
 9010 FORMAT (/'   NEWSIG ',E15.3)
 9011 FORMAT (/' TEST TEST TEST ')
      CLOSE (11)
      RETURN
      END
C
```

```
C***********MILLER ADDITION****************************************
C
       SUBROUTINE RELHT(NEWSIG)
       INCLUDE 'WNDINPV2.INC'
       REAL NEWSIG(61,61,6),TS(61,61),T(61,61,6),PI(61,61),STS(61,61,6),
     $      DUMSIG(61,61,6),OLSIG(61,61,6)
        REAL TSR,PSR,TSSEA,PSSEA,HTSEA(6),HTREF(6),PR(6)
        COMMON/SEA/TSR,PSR,TSSEA,PSSEA,
     $              PTOP,GRG,HTSEA,HTREF,PR,IR,JR
       COMMON /LIMITS/NCOL,NROW,NLVL,NCOLM1,NROWM1,
     $                  LOWIX(5),LOWIY(5),SFCMAX
       OPEN(UNIT=89,FILE='SFCHTS.DAT',FORM='FORMATTED',STATUS='NEW')
       OPEN(UNIT=90,FILE='NEWSIG.DAT',FORM='FORMATTED',STATUS='NEW')
       OPEN(UNIT=91,FILE='OLDSIG.DAT',FORM='FORMATTED',STATUS='NEW')
       OPEN(UNIT=92,FILE='SIG2.DAT',FORM='FORMATTED',STATUS='NEW')
       OPEN(UNIT=94,FILE='SIG4.DAT',FORM='FORMATTED',STATUS='NEW')
       OPEN(UNIT=96,FILE='SIG6.DAT',FORM='FORMATTED',STATUS='NEW')
       OPEN(UNIT=98,FILE='SIG8.DAT',FORM='FORMATTED',STATUS='NEW')
       OPEN(UNIT=99,FILE='SIG0.DAT',FORM='FORMATTED',STATUS='NEW')
C
C       OPEN(UNIT=192,FILE='OSIG2.DAT',FORM='FORMATTED',STATUS='NEW')
C       OPEN(UNIT=194,FILE='OSIG4.DAT',FORM='FORMATTED',STATUS='NEW')
C       OPEN(UNIT=196,FILE='OSIG6.DAT',FORM='FORMATTED',STATUS='NEW')
C       OPEN(UNIT=198,FILE='OSIG8.DAT',FORM='FORMATTED',STATUS='NEW')
C       OPEN(UNIT=199,FILE='OSIG0.DAT',FORM='FORMATTED',STATUS='NEW')
C     SPECIFY  CONSTANTS
       TEST=0.0
       GRAV=9.8
       RAIR=287.
       DTDZO=6.5E-3
       GRG=GRAV/(RAIR*DTDZO)
       RGR=1./GRG
C
C INITIAL SET OF REFERENCE TSR, ZSR
C**** FOLLOWING VALUES ARE TO BE READ IN FOR EACH RUN *****
C
C   *** REFERENCE LOCATION IR,JR ***
         IR=15
         JR=35
C   *** SPECIFY REFERENCE VALUES AT SURFACE
        TSR=25.
        ZSR=0.0
        PSR=1013
C   *** SPECIFY SEA SURFACE TEMPERATURE, PRESSURE.
        TSSEA=5.
        PSSEA=1000.
C   *** SPECIFY TOP TEMP., PRESSURE, HEIGHT
        PTOP=900.
        ZTOP=800.
        TTOP=8.5
C    ***         ***
        SIGMAS=SIGMA(6)
C
c       TYPE 100
c 100  .FORMAT(' ENTER TSR, ZSR: '$)
c       ACCEPT *, TSR, ZSR
C
      DO 10 J=1,NROW
      DO 10 I=1,NCOL
         DZ=SFCHT(I,J)-ZSR
         TSM=-DTDZO*DZ
         TS(I,J)=TSR+TSM
         T(I,J,6)=TS(I,J)
C  COMPUTE SURFACE PRESSUE AND PI(I,J)
       TAVE=(TSR+TS(I,J))/2.
       PS=PSR*((TS(I,J)+273.)/(TSR+273.))**GRG
       PI(I,J)=PS-PTOP
       C11=RAIR/GRAV
C        IF((I.EQ.10).AND.(J.GT.50))
C      1 WRITE(6,9002)I,J,DZ,TS(I,J),PS,C11
 9002  FORMAT(/,' I ',I3,' J ',I3,' DZ ',F8.2,' TS ',F8.1,
     1             ' PS ',F8.1,' R/G ',F8.2)
```

```
C          COMPUTE GEOMETRIC SIGMA HEIGHTS
      NEWSIG(I,J,6)=SFCHT(I,J)
      DO 11 K=5,1,-1
          KP=K+1
          DZT=ZTOP-DZ
          DTDZ=-(TTOP-TS(I,J))/DZT
C   TEMP CHANGE
          DTDZ=DTDZO
          PIS=(PTOP+PI(I,J)*SIGMA(K))/(PTOP+PI(I,J)*SIGMA(KP))
          ZSTEP=(T(I,J,KP)+273)*(1.0-(PIS)**RGR)/DTDZO
          STS(I,J,K)=ZSTEP
          NEWSIG(I,J,K)=NEWSIG(I,J,KP)+ZSTEP
          T(I,J,K)=T(I,J,KP)-(NEWSIG(I,J,K)-NEWSIG(I,J,KP))*DTDZ
C
          PK=SIGMA(K)*PI(I,J)+PTOP
          PKP=SIGMA(KP)*PI(I,J)+PTOP
          PI2=PK/PKP
C          IF((I.EQ.10).AND.(J.GT.50))
C     1    WRITE(6,120)J,K,NEWSIG(I,J,K),ZSTEP,T(I,J,KP),PI(I,J),PIS,
C     2                   SIGMA(K),PK,PKP,PI2
 120      FORMAT(2X,' J ',I2,' K ',I2,' Z',F8.2,' DZ',F8.2,
     1                ' T',F6.2,' PI',F8.2,'PIS',F10.2,/,10X,
     2                ' SIG ',F5.2,'PK ',F6.1,' PKP ',F6.1,'PK/PKP ',
     3                  F8.3)
C   OLD GEOMETRIC SIGMA HTS
            IF(K.EQ.6)OLD=0.0
            IF(K.EQ.5)OLD=3.658
            IF(K.EQ.4)OLD=16.46
            IF(K.EQ.3)OLD=31.09
            IF(K.EQ.2)OLD=62.18
            IF(K.EQ.1)OLD=91.44
            OLD=OLD+SFCHT(I,J)
            OLSIG(I,J,K) = OLD
C
        PS=PI(I,J)+PTOP
C        IF(I.EQ.99)WRITE(6,30),I,J,K,PIS,ZSTEP,PS
 30     FORMAT(1X,'I ',I3,' J ',I3,' K ',I3,
     1              'PI2 ',F6.2,' DZ ',F8.2,' PS ',F6.1)
        IF(TEST.EQ.1.0)GO TO 1199
C        IF((I.EQ.10).AND.(K.EQ.2))WRITE(92,95)NEWSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.3))WRITE(94,95)NEWSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.4))WRITE(96,95)NEWSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.5))WRITE(98,95)NEWSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.1))WRITE(99,95)NEWSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.3))WRITE(89,95)SFCHT(I,J),J
C
C

        IF(TEST.EQ.1.0)GO TO 1199

C
C        IF((I.EQ.10).AND.(K.EQ.2))WRITE(192,95)OLSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.3))WRITE(194,95)OLSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.4))WRITE(196,95)OLSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.5))WRITE(198,95)OLSIG(I,J,K),J
C        IF((I.EQ.10).AND.(K.EQ.1))WRITE(199,95)OLSIG(I,J,K),J
1199     CONTINUE
  95     FORMAT(2X,F15.2,I4)
         DUMSIG(I,J,K)=NEWSIG(I,J,K)
  11    CONTINUE
        IF(I.EQ.10)WRITE(90,96) J,SFCHT(10,J),(NEWSIG(10,J,KK),KK=1,5)
        IF(I.EQ.10)WRITE(91,96) J,SFCHT(10,J),(OLSIG(10,J,KK),KK=1,5)
  96     FORMAT(2X,I5,2X,6E12.2)
  10    CONTINUE
        DO 100 J=1,NROW
```

```
      DO 100 I=1,NCOL
      DO 111 K=1,6
      KR=7-K
      NEWSIG(I,J,K)=DUMSIG(I,J,KR)
 111  CONTINUE
 100  CONTINUE
C
       DO 112 K=6,1,-1
        HTSEA(K)=DUMSIG(1,1,K)
        HTREF(K)=DUMSIG(IR,JR,K)
        PR(K)=SIGMA(K)*PI(IR,JR)+PTOP
        WRITE(6,113)HTREF(K),PR(K),K
 113    FORMAT(2X,'RELHT:  HTREF',F8.2,' PR',F8.2,' K',I5)
 112   CONTINUE
C       WRITE(6,9910)(J,(STS(10,J,K),k=1,6),J=1,61)
 9910  FORMAT(2X,I4,' DZ:  ',6F8.2)
      IF(TEST.EQ.0.0)STOP
C
      RETURN
      END
```