Volume III. Wind Field Module (Module II)

3.1.   Storm Track Model Use Case III

3.1.1. General Description of Storm Track Model

Strom track model is aimed at generating the storm tracks for simulated storms based on data obtained from Use Case II and stochastic algorithms.

The storm track model consists of two main components: the empirical probability distribution generator (GENPDF), and the storm track generator (STORMGEN). Descriptions of these components are given below.

3.1.2. Technical Description of the Storm Track Model

3.1.2.1. *The empirical probability distribution generator (GENPDF)*

This component derives the probability distribution functions (PDFs) from the historical record (HURDAT) that are subsequently used by the STORMGEN track generator. The PDFs are conditional probabilities, as they depend on location, time of season and other parameters. The PDFs are empirical in that they are obtained by discrete binning. The following PDFs are derived:

- Initial storm speed
- Initial storm direction
- Initial storm intensity (pressure)
- Change in storm speed
- Change in storm angle
- Change in storm intensity (relative intensity)

The bin size and location of these PDFs are defined in a header file "genpdf.h" which is used by both GENPDF and STORMGEN. The bins may be linearly on nonlinearly spaced. A mapping function is available which allows nonlinear mapping so that higher resolution (of a particular parameter) may be obtained.

Storm genesis is defined to occur when a storm first enters or appears within the threat area and has a minimum wind speed of 64 kt. The threat area is described in Section 2.1. The HURDAT database contains a variety of storm report types:

- "E" – extra tropical
- "L" - low
- "D" - depression
- "S" - subtropical
- "W" - wave
- tropical – pressure reports
- tropical – wind reports

All non-tropical storm reports ("E","L","D","W","S") are excluded in the intensity PDFs. Pressure reports are used whenever available. If a pressure report is not available, then an attempt is made to interpolate from reports that are within a 24 hour period including the target report. Otherwise, pressure is obtained using an empirical wind-pressure relation (see Appendix A). Intensity changes are only computed for similar report types – observed pressure or wind-derived pressures. Mixing observed and wind-derived pressures was found to create spurious pressure changes. Pressures over land were excluded.

Due to the sparsity of data in some regions or parameter space, the PDFs may be coarsened (bins widened) so that a sufficient number of observations are available to create a robust PDF. This is done in the RESIZE function in GENPDF.

Pressure changes are converted to relative intensity changes. The relative intensity calculation is described in Appendix B. PDFs for pressure and relative intensity are created, though only one is used in STORMGEN. By default, the relative intensity PDF is used by STORMGEN.

♦ **Input Data**

GENPDF requires the following input files:

- The HURDAT database
- Land Mask file – the land mask is based on USGS land use data.
- Outflow temperature for the relative intensity calculation (see Appendix B)
- Sea surface temperatures for the relative intensity calculation (see Appendix B)

♦ **Output Data**

- Initial storm location, motion and intensity of all selected storms
- Initial storm location, motion and intensity PDFs
- Storm motion and intensity change PDFs
- Diagnostic output file

3.1.2.2. *The storm track generator (STORMGEN)*

STORMGEN generates the stochastic tracks based on the PDFs derived by GENPDF. The initial conditions may either be sampled from the initial storm location, motion and intensity PDFs or taken from observed initial conditions. The default configuration is to use random initial conditions. Both these input data are created by GENPDF.

The model uses a 1-hour time step, which requires interpolation of the 6-hour report changes used in the storm motion change and intensity PDFs.

The basic flow of the model is as follows:

1   If using specified initial conditions, read in initial storm location, date, motion and intensity. If using random initial conditions, read in storm genesis time (see Use Case for Hurricane Genesis, SGT) and sample initial storm location, motion and intensity PDFs. Add a uniform random term equal to the width of the location PDF bin size, so that the storm may form anywhere within the bin.
2   Sample storm parameters Rmax and Beta.
3   Update storm position using current motion

4 If at 6-hour interval, sample new motion and intensity change. Pressure tendency, obtained from sampled relative intensity tendency, is interpolated to one-hour tendency.
5 Determine if landfall or currently over land. If yes, decay the storm using the decay model described in Vickery (2005). Otherwise, update pressure.
6 Check if maximum relative intensity is exceeded, cap if necessary. If the pressure is greater than 1011 mb, dissipate storm.
7 Calculate new Rmax, Beta.
8 If storm outside threat area, terminate. Otherwise go to step 3.
9 After storm track is generated, it is trimmed based on the distance criteria described in the Use Case for Zip Code Criterion.

♦ **Input Data**

- Initial storm location, motion and intensity (if using specified initial conditions)
- Initial storm location, motion and intensity PDFs from GENPDF
- Storm motion and intensity change PDFs from GENPDF
- Hurricane genesis time (output from Use Case for Hurricane Genesis, SGT)
- Zip code locations (used for distance criteria described in Use Case for Zip Code Criterion)
- Land Mask file
- Outflow temperature file (see Appendix B)
- Sea surface temperature file (see Appendix B)

♦ **Output Data**

- Track positions in special format for use in wind model.
- Landfall data for diagnostic purposes
- Diagnostic output file

3.1.2.3.   *Appendix A – Wind-Pressure Relation*

An empirical wind-pressure relation is used to convert HURDAT wind reports to pressure. The relation is dependent on region.

The relation is
If longitude is > 81.5W and latitude > 20N,
$$P = 1013 - (W/10.627)^{1.7730}$$
Else if latitude < 25 N,
$$P = 1013 - (W/12.016)^{1.8737}$$
Else if latitude < 35N,
$$P = 1013 - (W/14.172)^{2.0929}$$
Else,

$$P = 1013 - (W/16.086)^{2.3079}$$

Where P is central pressure in mb and W is wind speed in kt.

This relationship is described in the report: "The Atlantic Hurricane Database Re-analysis Project - Documentation for 1850-1910 Alterations and Additions to the HURDAT Database" by Christopher W. Landsea et al. (contributed as a Chapter for the RPI book (24 January 2002))

3.1.2.4. *Appendix B – Relative Intensity Calculation*

The relative intensity calculation is based on Darling (1991). The calculation is as follows:

$$rv = 461$$
$$rh = 0.80$$
$$e = (ts - to)/ts$$
$$es = 6.112 * \exp(17.67(ts - 273.)/(ts - 29.5))$$
$$Pda = 1013 - (rh * es)$$
$$Lv = 2.5 * 10^6 - 2320.(ts - 273)$$
$$a = e * Lv * es/((1 - e) * rv * ts * Pda)$$
$$b = rh * (1 + es * \log(rh)/(Pda * a))$$

Then solve for x in
$$x = \exp(-a(1/x - b))$$
and then finally the relative intensity is given by
$$RI = (1013 - Pmsl + (1 - rh) * es)/((1 - x)(1013 - (rh * es)))$$

3.1.2.5. *Data Sources*

This calculation requires the mean sea level pressure (Pmsl) as input, which in our case is the storm central pressure, the outflow (to) and sea surface temperatures (ts). The outflow temperature is taken to be the monthly mean 100 millibar temperature derived by the Climate Diagnostics Center (CDC) using National Center for Environmental Prediction Center (NCEP) Reanalysis II data. This data is available online at http://www.cdc.noaa.gov/ncep_reanalysis. The sea surface temperature data is monthly mean Reynolds Optimal Interpolation Version 2 (OIv2) data (Reynolds et al., 2002).

3.1.3.   Computer Model Design & Implementation

3.1.3.1.   *Use Case View of Storm Track Model*

A.   Actors:

There is one actor, scientist.

B.   Use Case:

Strom track model is aimed at generating the storm tracks for simulated storms based on data obtained from Use Case II and stochastic algorithms.
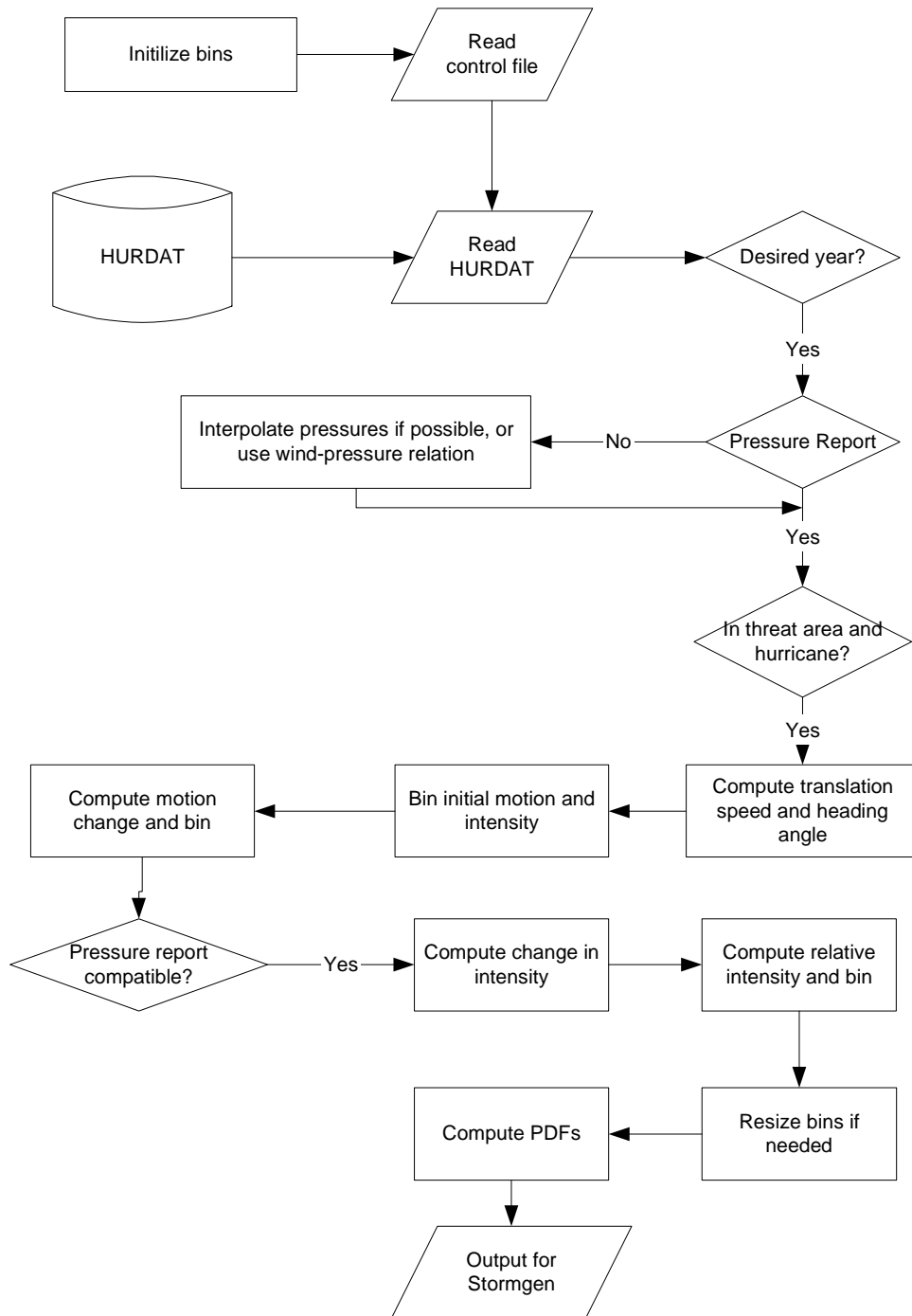
C.   Use Case Diagram:

Scientist   StormTrackUseCase

Figure 3.1.1: Use Case Diagram
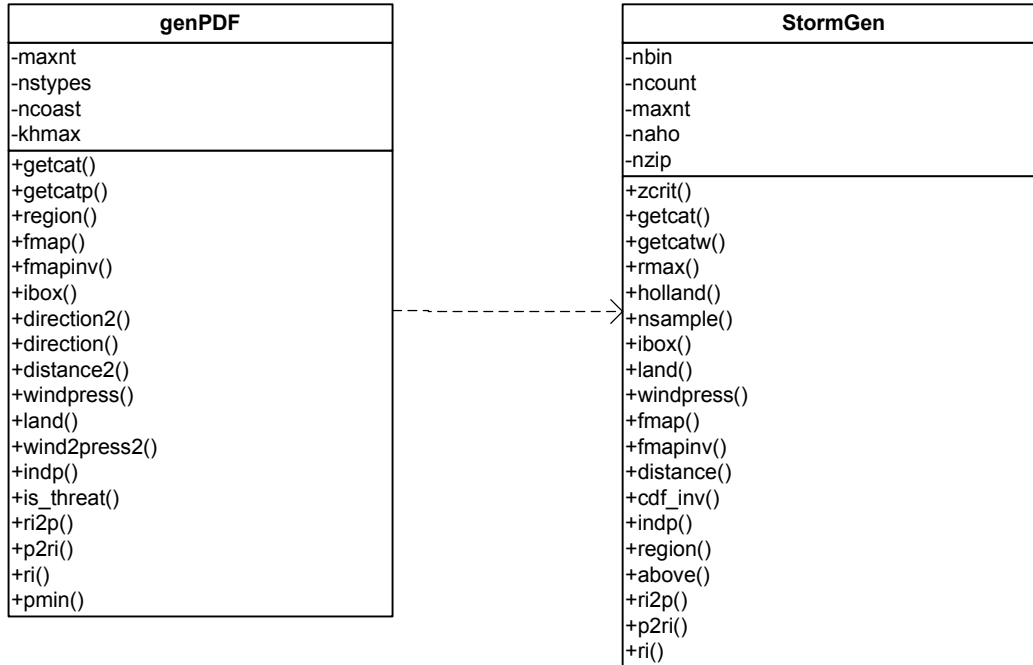
3.1.3.2. Storm Track Model Implementation

This model is implemented using FORTRAN language in Unix console-based environment. This section includes the overall flow chart of Storm Track Model Implementation.

3.1.3.3 Program Flow Chart of Storm Track

```
┌──────────────┐        ╱────────────╲
│ Initilize bins│─────→ │    Read      │
└──────────────┘        │ control file │
                         ╲────────────╱
                               │
                               ↓
  ⎛────────⎞          ╱────────────╲          ╱──────────╲
  │        │          │     Read     │         ╱            ╲
  │ HURDAT │ ───────→ │   HURDAT     │──────→ ╱ Desired year?  ╲
  │        │          ╲────────────╱          ╲            ╱
  ⎝────────⎠                                    ╲──────────╱
                                                      │ Yes
                                                      ↓
┌───────────────────────────┐              ╱──────────╲
│ Interpolate pressures if   │    No        ╱            ╲
│ possible, or               │ ←────────── ╱ Pressure Report ╲
│ use wind-pressure relation │             ╲            ╱
└───────────────────────────┘              ╲──────────╱
              │                                   │ Yes
              └──────────────────────────────────→│
                                                   ↓
                                          ╱──────────╲
                                          ╱ In threat area and╲
                                         ╱    hurricane?       ╲
                                          ╲            ╱
                                          ╲──────────╱
                                                │ Yes
                                                ↓
┌──────────────┐   ┌──────────────┐   ┌──────────────────┐
│Compute motion │ ← │Bin initial motion│ ← │Compute translation│
│change and bin │   │ and intensity    │   │ speed and heading │
└──────────────┘   └──────────────┘   │      angle        │
      │                                 └──────────────────┘
      ↓
 ╱──────────╲        ┌──────────────┐   ┌──────────────┐
 ╱Pressure report╲  Yes│Compute change in│   │Compute relative│
 ╲ compatible?   ╱ ──→ │  intensity     │──→│intensity and bin│
 ╲──────────╱        └──────────────┘   └──────────────┘
                                                 │
                                                 ↓
          ┌──────────────┐          ┌──────────────┐
          │ Compute PDFs  │ ←────── │ Resize bins if │
          └──────────────┘          │    needed      │
                 │                   └──────────────┘
                 ↓
          ╱────────────╲
          │  Output for  │
          │  Stormgen    │
          ╲────────────╱
```

3.1.3.4   *Class Diagram and Description*

A.   Class Diagram

genPDF
-maxnt
-nstypes
-ncoast
-khmax
+getcat()
+getcatp()
+region()
+fmap()
+fmapinv()
+ibox()
+direction2()
+direction()
+distance2()
+windpress()
+land()
+wind2press2()
+indp()
+is_threat()
+ri2p()
+p2ri()
+ri()
+pmin()

StormGen
-nbin
-ncount
-maxnt
-naho
-nzip
+zcrit()
+getcat()
+getcatw()
+rmax()
+holland()
+nsample()
+ibox()
+land()
+windpress()
+fmap()
+fmapinv()
+distance()
+cdf_inv()
+indp()
+region()
+above()
+ri2p()
+p2ri()
+ri()

B.   Class Description

- genPDF: generates PDFs for storm track model.
- StormGen: generates the stochastic tracks based on the PDFs derived by genPDF.

3.1.3.5 Data Flow Diagram

```
┌─────────────────┐          ┌─────────────────┐
│ Annual          │          │ Storm           │
│ Hurricane       │          │ Genesis Time    │
│ Occurrence      │          │ Outputs         │
│ Outputs         │          │                 │
└─────────────────┘          └─────────────────┘
         │ AHO                    │ SGT
         │ results                │ results
         ↓                        ↓
```

┌─────────────────┐   ┌─────────────────┐
│ Historical   │   Hurricane Data   ┌────────┐   Outflow   │ Outflow   │
│ Hurricane   │ ─────────────────────▶│ genPDF │◀──Temperature──────│ Temperature   │
│ Data   │   └────────┘   │   │
│ (HURDAT)   │   └─────────────────┘
└─────────────────┘

┌─────────────────┐   Land Mask   Sea Surface   ┌─────────────────┐
│ Land Mask   │   Data   Temperature   │ Sea Surface   │
│ File   │ ─────────────────────▶ ◀───────────────────────── │ Temperature   │
│   │   └─────────────────┘
└─────────────────┘

                                            ┌─────────────────┐
                         Initial Storm Location,   │ Diagnostic   │
                         motion, and intensity PDFs; │ Output File   │
                         Storm motion and   └─────────────────┘
                         intensity change PDFs
                         Hurricane Genesis Time

   Land Mask Data   Sea Surface   Outflow
                                                    Temperature   Temperature

┌─────────────────┐   ┌──────────┐
│ Zip Code   │   Zip Code   │ StormGen │◀──────────────
│ Data   │ ──Location───────────▶└──────────┘
│   │   ┌─────────────────┐
└─────────────────┘   │ Diagnostic   │
                                                       │ Output File   │
                         Simulated   └─────────────────┘
                         Storm Track Data;
                         Landfall Data; etc.

                         ┌─────────────────┐
                         │ Storm Track   │
                         │ Outputs   │
                         └─────────────────┘

3.1.3.4.　　　Storm Track Output

12
storm00004 8/24/ 1992 01:00

```
4  1992  0824  05 00    25.4    79.3   937   19   1.4772400  0
4  1992  0824  06 00    25.4    79.3   937   19   1.4772400  0
4  1992  0824  07 00    25.4    79.6   939   18   1.4727061  0
4  1992  0824  08 00    25.4    80.0   942   18   1.4681721  0
4  1992  0824  09 00    25.5    80.4   945   18   1.4636379  0
4  1992  0824  09 05    25.5    80.3   922   19   1.5048399  1
4  1992  0824  10 00    25.5    80.8   948   18   1.4591039  3
4  1992  0824  11 00    25.6    81.2   951   17   1.4545699  3
4  1992  0824  12 00    25.6    81.2   951   17   1.4545699  2
4  1992  0824  13 00    25.6    81.5   950   18   1.4541880  0
4  1992  0824  14 00    25.6    81.9   949   19   1.4538059  0
4  1992  0824  15 00    25.7    82.3   948   20   1.4534241  0
```

3.1.4.　　References

Reynolds, R.W., N.A. Rayner, T.M. Smith, D.C. Stokes, and W. Wang, 2002: An Improved In Situ and Satellite SST Analysis for Climate. J. Climate, 15, 1609-1625.

3.2.   Wind Field Model Use Case IV

3.2.1.   General Description of Wind Field Model

The wind field model estimates the peak wind speed, associated time and direction for all zip codes within a certain distance from the storm circulation center.

3.2.2.　　General Requirements of Wind Field Model

Name:　　　Wind Field Model

Description: The user enters *Category* (based on pressure-based Saffir-Simpson scale), *Year, Date, Time, Latitude, Longitude, Centre pressure, Rmax, Holland B and lsflg for each of hourly fixes of the storm*. The system generates the following:

1. Landfall or bypassing location (i.e. longitude/latitude) of storm
2. Maximum OT wind speed/time/direction anywhere in the storm
3. Maximum Marine Exposure at landfall or bypassing position
4. Maximum wind speed/time/direction at each zip code affected by the storm

The end user enters the input file as the following format:

```
<number of fixes>
<storm Number><m/d/ yyyy > <hh: mm>
<storm category><year><mmdd><hh><minute><latitude><longitude><center pressure><Rmax><Holand> <lsflg>
```

Example:
```
4
storm1   8/24/ 1992 05:00
4  1992  0824  07 00    25.43    79.62    932.14    19.31  1.40  0
4  1992  0824  08 00    25.46    79.95    927.27    19.31  1.40  0
4  1992  0824  09 05    25.50    80.30    922.00    19.31  1.40  1
```

Based on the input data from step 1, the model generates the output as follows:

　　Given below a partial output file showing the wind field for some of the zip codes affected by Storm1 while the original file contains wind fields for all zip codes in the threat area, which were affected by this storm.

A. Land falling storms

```
Storm1  8/24/92  5:00 UTC
landfall: longitude:     -80.3000 deg   latitude:      25.5000 deg
ter      day    hour     min     zonal     meridional    total m/s dir(deg)
 MA       1      9        5     -52.1610    -16.7574      54.7866      72
 OT       1      9        5     -41.1068    -26.5020      48.9094      57

zipcode:          31  longitude:    -80.1000 deg   latitude:      25.5900 deg
ter      day    hour     min     zonal     meridional    total m/s dir(deg)
 OT       1      9        0     -42.9686     13.8472      45.1448     107

zipcode:          32  longitude:    -80.2700 deg   latitude:      25.3400 deg
ter      day    hour     min     zonal     meridional    total m/s dir(deg)
 OT       1      9        0      30.4650     21.1683      37.0973     235
```

B. Bypassing Storms

For a storm that does NOT make landfall but bypasses the state then the peak marine and open terrain winds are listed
For the fix exhibiting the lowest central pressure. See the bypass line for the example below.

```
Storm2  9/03/79  06:00 UTC
bypass:  longitude:     -80.5000 deg   latitude:      28.8000 deg
ter      day    hour     min      zonal     meridional    total m/s dir(deg)
 MA       2      4        0     -23.6102     34.6558      41.9340      145
 OT       2      4        0     -26.7334     23.0222      35.2802      130

zipcode:          31  longitude:     -80.1000 deg   latitude:      25.5900 deg
ter      day    hour     min      zonal     meridional    total m/s dir(deg)
 OT       1      8        0      8.13654    -10.2191      13.0626      321

zipcode:          32  longitude:     -80.2700 deg   latitude:      25.3400 deg
ter      day    hour     min      zonal     meridional    total m/s dir(deg)
OT        1      8        0      8.26174     -4.41157      9.36580      298

zipcode:          33  longitude:     -80.1310 deg   latitude:      25.7100 deg
ter      day    hour     min      zonal     meridional    total m/s dir(deg)
OT        1      8       15      7.02892    -10.4825      12.6210      326

zipcode:          34  longitude:     -80.3200 deg   latitude:      25.6100 deg
ter      day    hour     min      zonal     meridional    total m/s dir(deg)
T         1      8       15      6.55432     -6.86560      9.49187      316
```

Note: That the pressure-based Saffir-Simpson scale follows;

cat =0 for press > 990.0
cat =5 for press <= 920.0
cat =4 for press <= 944.0 and p >920
cat =3 for press <= 964.0 and p > 944
cat =2 for press <= 979.0 and p >964
cat =1 for press >979 and p <990.0

3.2.3. Technical Description of Wind Field Model
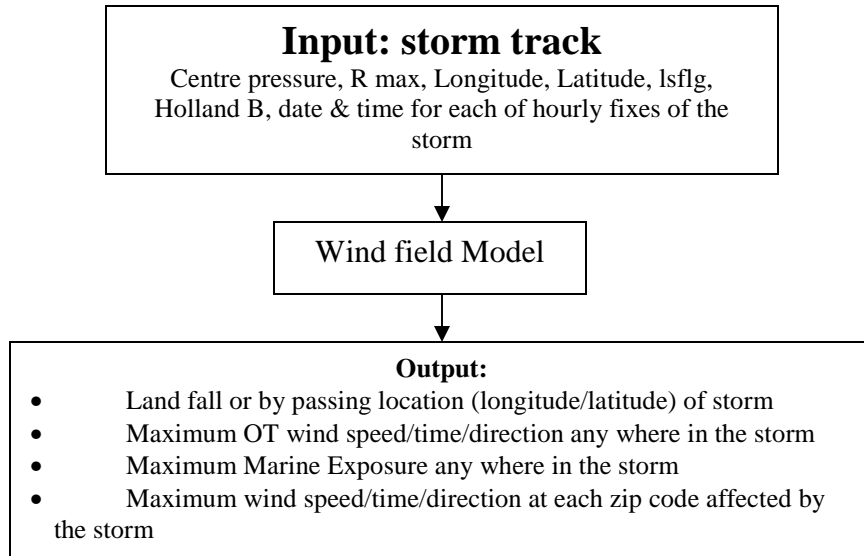
Figure 3.2.1 Input Output of Wind Field Model

Once a simulated hurricane moves to within a distance threshold of Florida communities, the wind field model is turned on. Gradient balance represents a circular flow caused by the balance of forces on the flow whereby the inward directed pressure gradient force is balanced by outward Coriolis and centripetal accelerations. The coordinate system translates the hurricane vortex moving at velocity **c**. The vortex translation is assumed to equal the geotropic flow associated with the large-scale pressure gradient. In cylindrical coordinates that translate with the moving vortex, equations for a slab hurricane boundary layer under a prescribed pressure gradient are:

$$\frac{u\partial u}{\partial r} - \frac{v^2}{r} - fv + \frac{v}{r}\frac{\partial u}{\partial \phi} + \frac{\partial p}{\partial r} - K\left(\nabla^2 u - \frac{u}{r^2} - \frac{2}{r^2}\frac{\partial u}{\partial \phi}\right) + F(\vec{c},u) = 0 = \frac{\partial u}{\partial t} \tag{1}$$

$$u\left(\frac{\partial v}{\partial r} + \frac{v}{r}\right) + fu + \frac{v}{r}\frac{\partial v}{\partial \phi} - K\left(\nabla^2 v - \frac{v}{r^2} + \frac{2}{r^2}\frac{\partial u}{\partial \phi}\right) + F(\vec{c},v) = 0 = \frac{\partial v}{\partial t} \tag{2}$$

where u and v are the respective radial and tangential wind components relative to the moving storm, p is the sea-level pressure which varies with radius (r), f is the Coriolis parameter which varies with latitude, ϕ is the azimuthal coordinate, K is the eddy diffusion coefficient, and F(c,u), F(c,v) are frictional drag terms. All terms are assumed to be representative of means through the boundary layer. The motion of the vortex is determined by the modeled storm track.

The hurricane wind field model is based on a fully two dimensional, time-independent, scaled version of the tangential and radial momentum equations (1 and 2) for the mean boundary layer wind components. The model makes use of a polar coordinate representation grid (Fig. 1) centered on the moving cyclone. The nested

circles are separated from their inscribed and circumscribed neighbors by a radial separation of 0.1 in units of Rmax (Radius of maximum winds); the azimuthal interval is 10 degrees.
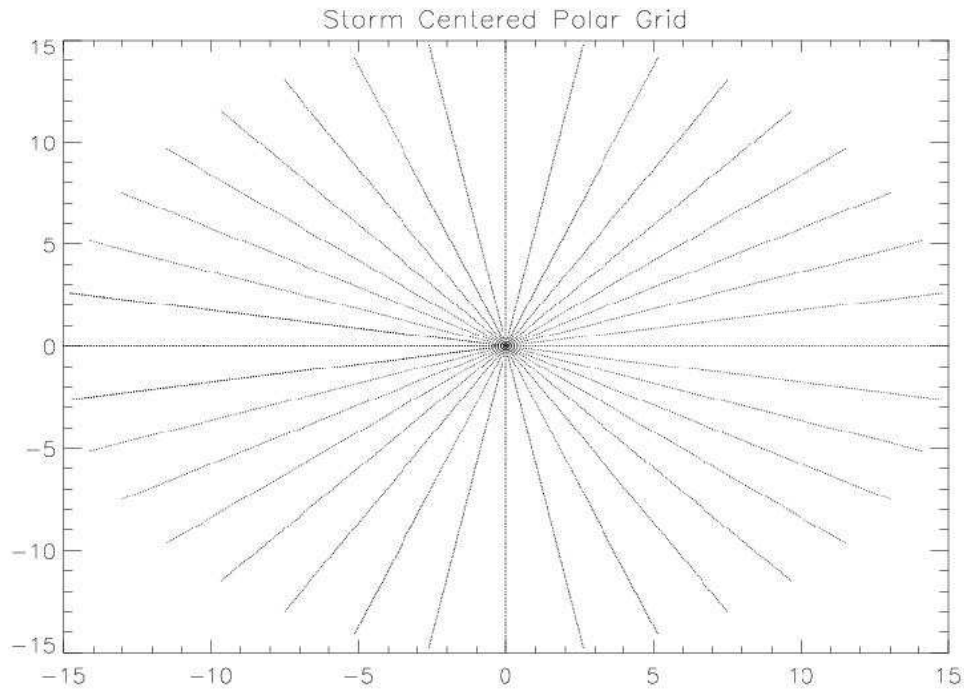
Figure 3.2.2: Polar coordinate system for solving equations of motion.

Implementation proceeds according to the following steps: First, based on the input parameters, namely the radius of maximum winds, the central pressure and the Holland B parameter, radial profiles of the radial and tangential winds are calculated based on a stationary cyclone over open water to provide an "envelope" with which to set the size of the cyclone vortex. The wind field produced by these profiles is radically symmetric.

Azimuthal variation is introduced thru the use of two form factors. The form factors multiply the radial and tangential profiles described above and provide a "factorized" ansatz for both the radial and tangential storm–relative wind components. Each form factor contains three constant coefficients which are variationally determined in such a way that the ansatz constructed satisfies (as far as its numerical degrees of freedom permit) the scaled momentum equations for the storm-relative polar wind components. The azimuthal variable (ϕ) has its usual mathematical meaning such that ϕ increases from left to right with the rectangular X axis aligned (ϕ =180, 0) and the Y axis aligned (ϕ =270, 90) with Y increasing in the direction of storm translation.

The translational motion of the storm is vectorially added to the storm-relative wind components in order to obtain the earth-relative wind field. The translational motion of the storm is incorporated in the surface friction terms in the momentum equations which depend on the ϕ and are specific for the direction of storm translation which is aligned with the Y axis. The wind field grid is then rotated so that the computational y axis coincides with the actual direction of motion of the cyclone center. The wind field thus far constructed (Fig. 2) usually shows the location of peak winds to be to the right or forward edge of the right-rear quadrant of the cyclone.

EARTH RELATIVE TOTAL WINDS (M/S) ... c=5 m/s
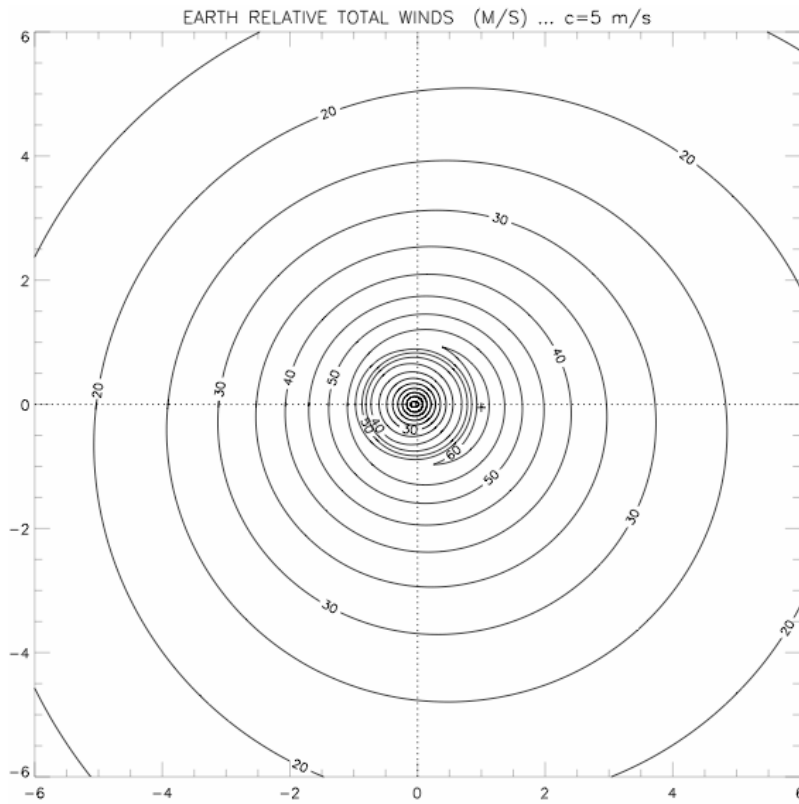
Figure 3.2.3. Horizontal distribution of mean boundary layer wind speed (m s^{-1}) relative to the earth for a Hurricane moving northward (top of page) at 5 m s^{-1}. Horizontal coordinates are scaled by the radius of maximum wind.

3.2.3.1.   *Wind Model Parameters*

Following are the input parameters to the wind field model

Central Pressure

When a storm is over open ocean and/or approaching land, the central pressure is modeled based on historical information in the same region, using geographic PDFs. Once a storm makes landfall, the subsequent pressures over land decay due to lack of an oceanic heat source. (See Pressure decay USE CASE).

R max: Radius of Maximum Wind

The radius of maximum wind is determined from a distribution of values as a function of po and latitude. A log normal distribution is assumed for Rmax with a mean value determined as a function of Delta p (in mb) and Latitude (in decimal degrees). In developing the models for Rmax, we used the data from Ho et al., 1987 for storms from 1900-1983; NOAA-HRD archives of realtime surface wind analyses from 1995-2005; an archive of the National Hurricane Center that was maintained by Dr. Mark DeMaria (now with NOAA~Rs NESDIS at Colorado State University) for the years 1988-1999; and an HRD archive of aircraft observations for the years 1984-1987. To create a model to describe Rmax we considered U. S. Atlantic and Gulf of Mexico basin hurricane landfalls with latitudes as high as 34 degrees north in order to help fill a dearth of information on storms affecting the Northeast Florida coastline. The relationship between Rmax, Delta p, and latitude shows much scatter but a stepwise screening linear regression model for the natural log of Rmax ($r2 = 0.15$) provides a useful estimation:

lnRmax= 1.9433951 + 0.0193654*delp - 0.000196*delp**2 + 0.0008291 * lat**2 + epsilon   (3)

where epsilon is a normal random variable with a mean of zero and a variance of 0.048. This equation is for the natural log of Rmax in Nautical miles.

Pressure Profile & Holland B

The symmetric pressure field p(r) is specified as follows:

$$p(r) = p_o + \Delta p e^{\left(\frac{R_{max}}{r}\right)^B}$$

(4)

where po is the central minimum sea level pressure, B is the Holland pressure profile shape parameter, R is the radius of maximum wind speed (in nautical miles), and Δp is the pressure deficit.

The Holland parameter computed uses the following formula;
        B = 1.74425 -0.007915 Lat + 0.0000084 DelP^2 -0.005024 Rmax + Epsilon

Where Lat is the latitude, DelP and e is a random term from a zero mean normal distribution with a standard deviation of 0.286.

Land See Flag: lsfg

Gives the position of the wind at the storm fix.

        0 – Over Ocean

        1 – Land Fall

        2 – Sea Fall

        3 – Over Land

3.2.3.2. Definitions and Equations of the wind model

R = Radius of maximum surface wind speed, specified

ct = storm translation speed, specified

cdir = storm translation direction compass heading , specified

Δp = Central pressure deficit, specified

$$p(r) = p_o + \Delta p\, e^{\left(\frac{R_{max}}{r}\right)^B} = \text{sea level pressure}$$

B = 1.74425 -0.007915 Lat + 0.0000084 DelP^2 -0.005024 R, Holland parameter

ϕ = Azimuthal coordinate, measured counterclockwise from east

$$s = \frac{r}{R} = \text{normalized radial coordinate}$$

$v_g(s)$ = Gradient wind: $\dfrac{v_g^{\,2}}{s} + Rfv_g = \dfrac{1}{\rho}\dfrac{\partial p}{\partial s}$

$f = 2\Omega \sin \vartheta$ =Coriolis parameter

ϑ = latitude of storm center

$v_0(s)$ = normalized gradient wind (symmetric) $= \dfrac{v_g(s)}{V_{g\,max}}$ where $V_{g\,max}$ is the maximum gradient wind in the radial profile

$\bar{f} = \dfrac{Rf}{V_{g\,max}}$ = Normalized Coriolis parameter

$$v(s,\phi) = \frac{v}{v_g} = \quad \text{Normalized storm-relative tangential wind component}$$

$$u(s,\phi) = \frac{u}{v_g} = \quad \text{Normalized storm – relative radial wind component}$$

Alpha=Cd *(Sigma/h)
h= mean boundary layer height
On water h=450m
On land (ie lsflg=3) h=1000m

Cd = Drag Coefficient
Cd on water is defined by (large and Pond 1981):
Cd=(0.49+0.065*(0.8*Vg)*0.001 for winds greater than hurricane force
We cap Cd at 2*10^-3 based on Powell et al 2003.
Cd on land (ie lsflg=3) is specified according to a mean value of roughness equivalent to 0.2m
Cd=0.01

SigmaIs the percentage of the planetary boundary layer height to apply:
On water: Sigma=0.3
On land (ie lsflg=3):   Sigma=0.9

$$c = \frac{c_t}{V_{g\,max}} = \text{normalized translation speed}$$

$$g(s) = 2v_o(s)s^{-1} + \bar{f} \tag{A1}$$

$$d(s) = \dot{v}_0 + v_0 s^{-1} + \bar{f} \tag{A2}$$

where a "dot" represents a derivative with respect to s, $g(s)$ and $d(s)$ depend only on V_0 and $\bar{f}$

$$\sigma(s,\phi) = v(s,\phi) - v_o(s) = \text{Normalized departure from gradient balance}$$

♦ **Scaling of the governing equations prior to implementation.**

Substituting the terms from the above definitions and changing the radial coordinate from r to s, the steady-state form of the governing equations (1) and (2) become:

$$u\partial_s u + s^{-1}(v_o + \sigma)\partial_\phi u - \sigma(g + s^{-1}\sigma) + \alpha(u + c\sin\phi)(w - c) = 0 \tag{A3}$$

$$u\partial_s\sigma + s^{-1}(v_o + \sigma)\partial_\phi\sigma + u(d + s^{-1}\sigma) + \alpha(v_o + \sigma + c\cos\phi)(w - c) = 0 \tag{A4}$$

$$w = \sqrt{(u + c\sin\phi)^2 + (v_o + \sigma + c\cos\phi)^2} \tag{A5}$$

Where, w is the total normalized earth-relative wind.

In the event that c vanishes, so that the cyclone is stationary, these equations reduce to the ordinary differential equations:

$$u\dot{u} - \sigma(g + s^{-1}\sigma) + \alpha uw = 0 \tag{A6}$$

$$u(\dot{\sigma} + s^{-1}\sigma + d) + \alpha(v_0 + \sigma)w = 0 \tag{A7}$$

$$v = v_0 + \sigma$$

for the radial profiles $u(s)$ and $\sigma(s)$, Here, "." indicates differentiation with respect to s.

Equations A3 and A4 supplemented by A5, constitute two, coupled, time independent partial differential equations for the storm relative radial velocity u and the storm relative departure from gradient balance σ. The storm relative tangential wind is then given by $v = v_g + \sigma$.

Unfortunately, the direct numerical solution of A3 and A4 is time-consuming even though the equations are time-independent because the non-linear coupling of the terms necessitates an iterative numerical approach.

However, equations A6 and A7, can readily be numerically integrated to furnish a completely symmetric windfield fully described by the radial profiles u(s) and $v(s) = v_g(s) + \sigma(s)$.

The functions u(s) and $\sigma(s)$ so obtained can serve as radial profiles for the construction of basis functions for a more realistic attack on A3 and A4.

Namely, we put forth the ansatz:

$$u(s,\phi) = ffu(\phi)u(s) \tag{A8}$$

$$\sigma(s,\phi) = ff\sigma(\phi)\sigma(s) \tag{A9}$$

Where the azimuthal dependence is introduced through the form factors:

$$ffu(\phi) = a_0 + a_1 \cos\phi + a_2 \sin\phi \tag{A10}$$

$$ff\sigma(\phi) = b_0 + b_1 \cos\phi + b_2 \sin\phi \tag{A11}$$

Now the six coefficients a0, a1, a2 and b0, b1, b2 can be variationally determined by substituting A8 and A9 into the left hand sides of A3 and A4, supplemented by A5 to form the "residuals" RA3 and RA4. We then form the functional:

$$|RA3| = \sum |(A3)| = \sum |u\partial_s u + s^{-1}(v_o + \sigma)\partial_\phi u - \sigma(g + s^{-1}\sigma) + \alpha(u + c\sin\phi)(w - c)|$$

$$|RA4| = \sum |(A4)|$$

$$J(a,b) = \frac{\sum |RA3| + |RA4|}{NGRID} \tag{A12}$$

Where the sum is taken over every spatial point for which the profiles and trigonometric functions are known (polar grid) and NGRID is the total number of such grid points.

J then depends solely on the unknown coefficients a0, a1, a2 and b0, b1, b2. These coefficients are chosen to minimize J and so furnish us with an approximate solution for $u(s,\phi)$ and $\sigma(s,\phi)$, from which we form the storm relative radial and tangential wind components ur and vt, namely:

$$ur(s,\phi) = u(s,\phi) \text{ and } vt(s,\phi) = vg(s) + \sigma(s,\phi) \tag{A13}$$

By adding the translational velocity c (in polar coordinates) to ur and vt we obtain the earth-relative components of the windfield uer and ver :

$$uer(s,\phi) = ur(s,\phi) + c\sin\phi \tag{A14}$$
$$ver(s,\phi) = vt(s,\phi) + c\cos\phi \tag{A15}$$

where c is the normalized translation speed $c = c_t/Vgmax$.

Finally, since A3, A4 and A5 refer to a cyclone moving along the y-axis, the entire generated windfield grid must be rotated so that the y-axis of the calculation coincides with the actual compass direction of motion of the translating cyclone.

3.2.4. Computer Model Design

3.2.4.1. *Use Case View of Wind Speed Model*

A.   Actors:

There is one actor, scientist.

B.   Use Case:

Wind Speed model is used to estimate terrain wind speed.

C.   Use Case Diagram:

Scientist

WindSpeedCalUseCase

Figure 3.2.4: Use Case Diagram

3.2.4.2.   Detailed Flowchart

```
                                    ┌──────────────┐
                                    │    Start     │
                                    └──────┬───────┘
                                           │ g_trackfile
                                    ┌──────▼───────────┐
                                    │ Reads g_trackfile and │
                                    │ separates it into individual │
                                    │ track files │
                                    └──────┬───────────┘
                                           │
                                    ┌──────▼───────────┐
                                    │ Process individual │
                                    │ track │
                                    └──────┬───────────┘
```

1. Read trackfiles into arrays.
2. Mark the fix of lowest central pressure.
3. Thin out storm fixes based on the adjusted fix frequency.
4. Calculate time in minutes for each fix.
5. Samples data and calculate fbarx.
6. Subsample the smoothed input data to recover original resolution.
7. Get landfall location and time.
8. Calculate storm translation speed.
9. Smoothen translation speed.
10. Evaluate smoothed translation speed, track position and save track related quantities.

In trackfile, locate fixes corresponding to landfall and sea fall and location of min. pressure

Check category

Selects fix interval depending upon the category

If holland B ==0   — yes →

Calculate it with formula B=1.881093–0.010917Lat–0.005567 Rmax.

1. Calculate radial and tangential wind profiles for each storm.
2. Calculate gradient wind profile for each fix.
3. Collects radial and tangential profiles.
4. Saves the variables calculated.

No

Track related info

Radial and Tangential profile

1. For each retained fix, construct polar grid of earth relative marine surface winds.
2. Process the matrix provided by onefix.m.
3. Compute second order derivatives of fields for time interpolation.

Field snapshots

1. Calculates the time series.
2. Determine the zipcodes affected by the storm.

Has zipcode affected by the storm?

yes

1. Generate relevant portion of gridded field fo current time.
2. Evaluate marine windfield components at admissible zip code centroids.
3. Convert marine windspeed to Open Terrain windspeeds
4. Obtain marine and OT peak winds at landfall or lowest pressure for bypassing storms.

Wind Speed

Damage Estimation Module

3.2.4.3.   Class Diagram

Wind Field Model
+ctg
+zhour
+zmin
+nlat
+elon
+cpr
+rmx
+hdb
+lsflg
+TRACK.PRO()
+THINNER.PRO()
+SUV.PRO()
+VGHGEN.PRO()
+USG.PRO()
+OBC.M()
+DUS.PRO()
+FIXSHOTS15.PRO()
+ONEFIX.M()
+GENSTREX.M()
+SHIFT.M()
+PKWINDS.PRO()
+REACH.PRO()
+LLTOXY.PRO()
+ZMAR2ZOT.PRO()
+GEMF.M()
+UDVS.PRO()
+SGDVS.PRO()
+RSDU.PRO()
+RSDSG.PRO()
+MNRDU.PRO()
+MNRDSG.PRO()
+GEMFPLEX.PRO()
+GEMF.PRO()

Figure 3.2.5: Cass Diagram

Please change this image to reflect the correct number of files (as below)
CLASS DESCRIPTION

➢ Wind Field Model aims at estimating the terrain wind speed with respect to the actual terrain. It calculates the maximum wind speed and direction for each of the zip code affected by the storm. The following methods perform the required functions of the Wind Field Model.

- TRACK.PRO: This method reads the trackfiles into arrays and performs a number of operations on them like calculating storm translation speed, evaluating smoothed track positions etc.
- THINNER.PRO: This method reduces the number of fixes depending upon the storm intensity.
- SUV.PRO: This method computes the radial and tangential wind profiles u and v as well as the gradient wind profile and the functions g and d and their second derivatives.

- VGHGEN.PRO: This method calculates the gradient wind profile and its second derivative.
- USG.PRO: This method computes the radial and tangential wind profiles for a stationary storm with surface friction for exactly one fix.
- OBC.M: This method computes the outer boundary values for u and sg to start the inward numerical integration of u and sg.
- DUS.PRO: This method calculates the radial derivatives from momentum equations.
- FIXSHOTS15.PRO: This method calculates the field snapshots and their second time derivatives at each retained fix time on a polar grid.
- ONEFIX.PRO: This method constructs zonal and meridional windfield components for exactly one fix.
- GENSTREX.M: This method places the profile functions and the auxiliary functions g and d.
- SHIFT.M: This method simply shifts the polar coordinate system so that the origin of the coordinate system lies on the center of the storm.
- PKWINDS.PRO: This method produces an output file, which lists peak marine and open terrain wind components experienced at each zip code for the current storm.
- REACH.pro: This function determines the influence radius.
- LLTOXY.PRO: This method converts east longitude and north longitude into zonal distance and meridional distance.
- ZMAR2ZOT.PRO: This module converts marine wind speeds into open terrain windspeeds.
- GEMF.M: This module is used to set the time step and the entire executable.
- UDVS.PRO: This module computes the radial and azimuthal derivatives of u.
- SGDVS.PRO: This module computes the radial and azimuthal derivatives of sigma.
- RSDU.PRO: This module estimates the u residual to be minimized.
- RSDSG.PRO: This module estimates the sigma residual to be minimized.
- MNRDU.PRO: This function evaluates the residual for u and is used in AMOEBA to minimize this residual.
- MNRDSG.PRO: This function evaluates the residual for sigma and is used in AMOEBA to minimize this residual.
- GEMFPLEX.PRO: This module reads g_trackfile and separates it into individual track files for processing.
- GEMF.PRO: This module processes each single track.

3.2.4.4.   Data Flow Diagram
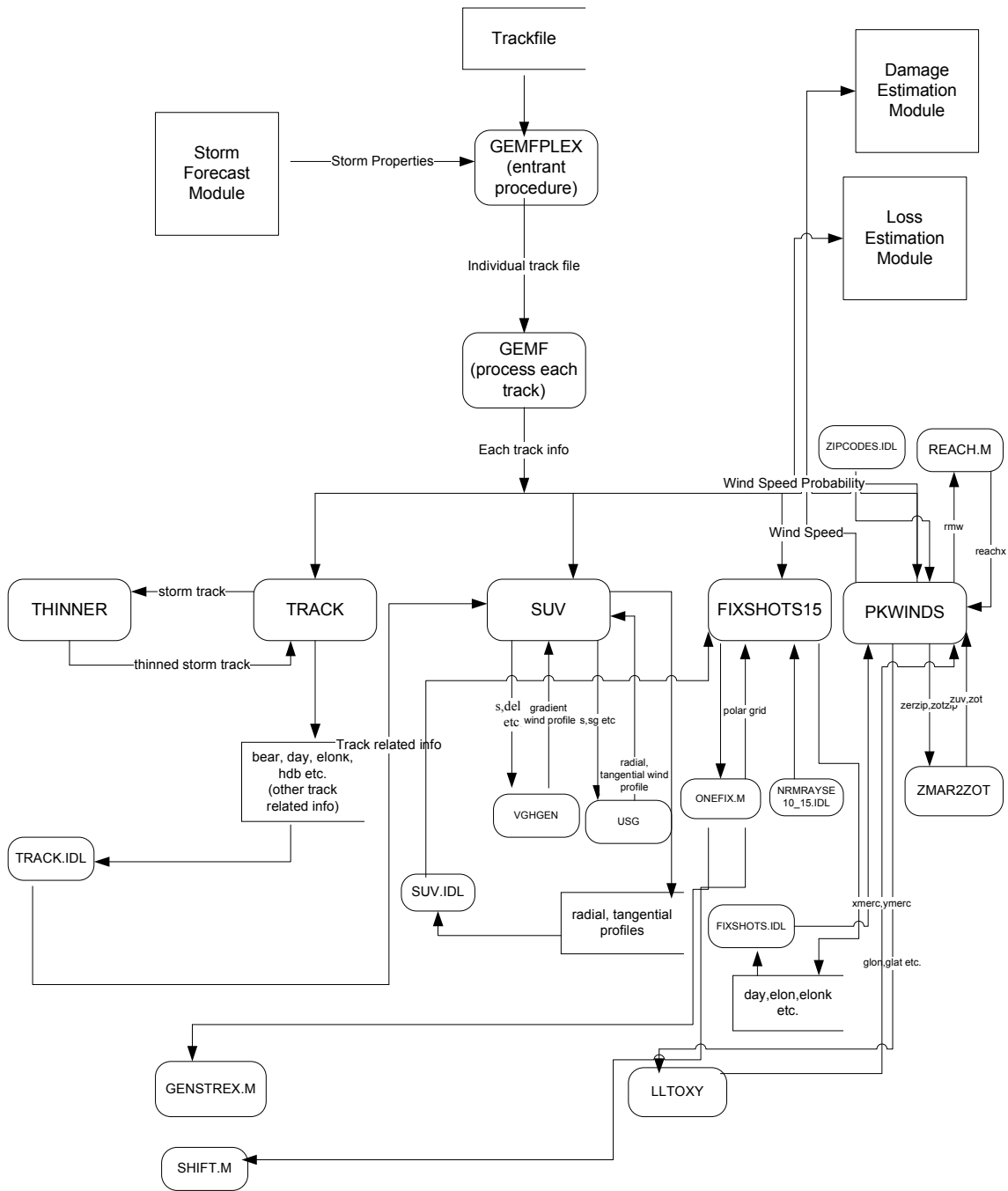
Figure 3.2.6: Data Flow Diagram

➤ Implementation of Wind Field Model

This model is implemented using Interactive Data Language (IDL) language in Unix console-based environment. This section includes appropriate diagrams and the overall flow chart of Wind Speed Model Implementation.

3.2.4.5.   Program Flow Chart of Wind Speed Model

Wind field model has been implemented using Interactive Data Language (IDL). To be precise it calculates wind speed time series for each of the zip code affected by the storm. The time series includes the date, landfall time of the storm. It also includes the zonal wind speed (m/s), surface wind speed (m/s), and the wind direction in degrees at regular time intervals.

General structure of the main IDL modules is given below.
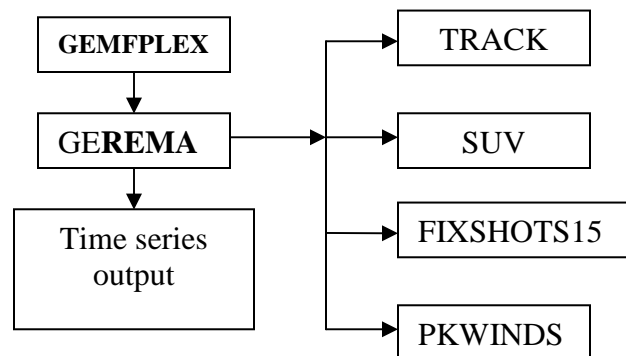
Figure 3.2.5. General structure or flow of the IDL

- GEMFPLEX is analogous to a main or the entrant procedure in C/C++. It reads g_trackfile and separates it into individual track files for processing.
- GEMF processes each single track.
- Each of the procedures TRACK, SUV, FIXSHOTS15 and PKWINDS call other procedures.
- TRACK reads the necessary input parameters from the storm track and thins out the fixes based on the storm category and saves track related quantities for future use.
- SUV generates radial profiles from stationary cyclone equations.
- FIXSHOTS15 generate field snapshots with azimuthal variation for each fix.
- PKWINDS is responsible for picking the maximum wind for each zip code. If the storm happens to encompass or run through the entire state of the FL then this step would end up consuming a lot of resources.

Note: All the equations referenced in the following are from Wind field Model Technical description. Please see the document for the detailed information.

Wind model code (IDL code) flowchart

Coded by: Dr George A. Soukup	Frozen Model
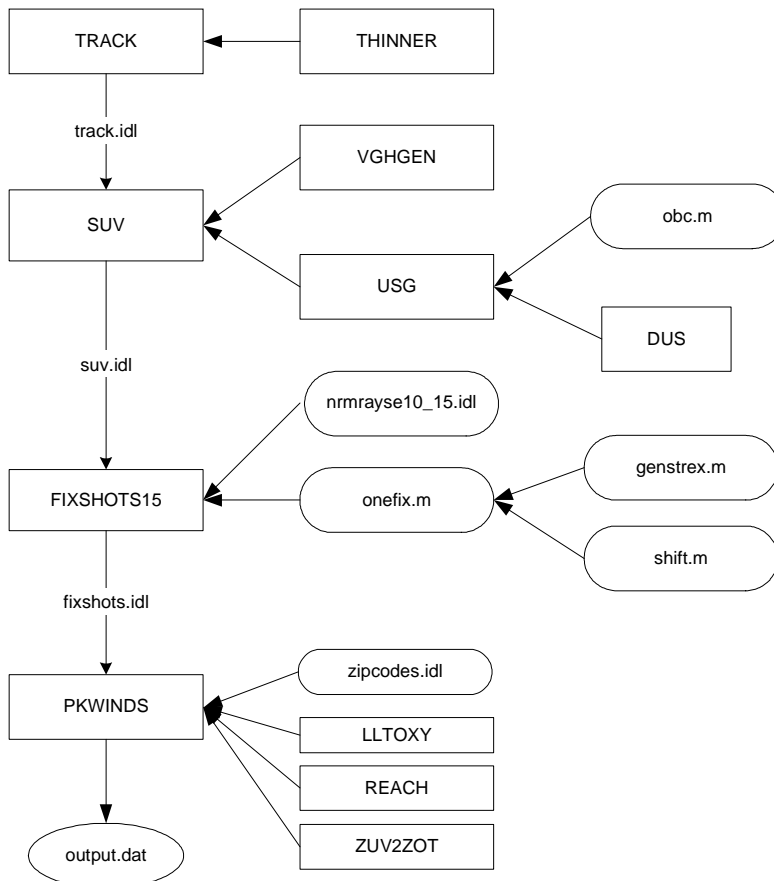
i. TRACK.PRO
1. Reads in the trackfile to arrays
   ctg = storm category, zhour = fix hour, zmin=fix min, nlat=latitude, elon=longitude, cpr=centre pressure, rmx=Rmax, hdb=Holland B, lsflg=land sea flag.
2. Mark the fix of lowest central pressure unless it coincides with landfall. (lsflg is set to 4)
3. Thins out the storm fixes based on the adjusted fix frequency. THINNER.PRO is used to accomplish this task.
4. Calculate the time in minutes for each fix from the start of the storm rack. (ktime)

5. Samples the data at regular (1 hrs) intervals prior to the smoothing using cubic spline interpolation.
6. Calculate fbarx=Rmax . f   where f= 0.14544* sin(nlat)
7. Sub-samples the smoothed input data to recover the original resolution (unequal intervals based on the storm category).
8. For the landfall fix get the landfall location and time.
9. Calculates the storm translation speed in m/s (spdmsx) and bearing (bearx) based on the fix data.
10. Smoothes translation speed and bearing (clock wise angle from north) on hourly grid.
11. Evaluates smoothed translation speed (spdms) and bearing (bear) at fix times using Cubic spline interpolation.
12. Evaluates smoothed track positions (elonk,nlatk) and Rmax (rmwk) minute by minute.
13. Finally, saves track related quantities for use by other procedures as trackc.idl.

bear=Bearing at each fix,	cpr=center pressure at each fix,
day=day of each fix,	elon=longitude of each fix,
elonk=longitude of storm at each minute,	fbr=f bar at each fix,
hdb=Holland B at each fix,	ktime=array from 0 to last minute of storm track (step=1),
lsflg=land sea flag of each fix,	minz=min of each fix,
nlat=latitude of each fix,	nlatk=latitude of storm at each minute,
pdf=delta p of each fix,	rmwk=R max at each minute,
rmx=Rmax of each fix,	spdms=translation speed of the storm at each fix

ii.   THINNER.PRO

This module selects fix resolution according to pressure based Saffir-Simpson intensity rating. The most intense storms are simulated at the highest storm motion resolution, the track of weaker storms are sampled at more coarse resolution equivalent to HURDAT in order to improve the computation performance of the model.

1. In trackfile locate fixes corresponding to landfall (-1hr, +1hr) and sea fall (-1hr,+1hr) and location of minimum pressure.
2. Select intermediate fixes at the following resolutions;
      i.   Category 0:Select fixes in 8 hour separations
     ii.   Category 1:Select fixes in 6 hour separations
    iii.   Category 2:Select fixes in 4 hour separations
     iv.   Category 3:Select fixes in 3 hour separations
      v.   Category 4:Select fixes in 2 hour separations
     vi.   Category 5:Select fixes in 1 hour separations

iii.   SUV.PRO
This module computes the radial and tangential wind profiles u and v, as well as the gradient wind profile and the functions g and d and their second derivatives.

1. Restores variables saved in track.idl
2. Calculates radial(ur) and tangential(vt) wind profiles for each storm fix. Wind profiles are calculated at 201 points starting from 0(the storm center) to 20 in steps of 0.1 (in units of RMW)
3. Calculates the gradient wind profile for each fix using VGHGEN.PRO
4. Calculate g and d using equation (A1) and (A2).
   Peak wind should be at s=1. (i.e. if iw is 10 answer of alpha is correct)
5. Momentum equations are used to furnish tangential and radial profiles. USG.PRO
6. Collects radial and tangential profiles into a structure.
7. Saves the variables for use by the other procedures as suv.idl.
   uvstr= holds the wind profiles calculated for each fix.

iv. VGHGEN.PRO
   This module calculates the gradient wind profile and its second derivative.

v. USG.PRO
   This module computes the radial and tangential wind profiles for a stationary storm with surface friction for exactly one fix. Wind profiles are calculated from two directions, inward and outward from center. Then the results are combined to get the complete profile.
   1. Form the inward boundary value at s=20 using obc.m
   2. Numerically integrate momentum equations for stationary storm profiles LSODE.
   3. Match solutions across the shock and obtain uz and sgz.
      For 0≤ s≤1;   uz = uout
                     sgz = sgout
      for 1<s≤20;   uz = uinw
                     sgz = sginw
   4. Sub-grid smoothing process simulates turbulent diffusion.
   5. Sub sample to recover original resolution.

   .

vi. OBC.M
   This module computes the outer boundary values for u and sg to start the inward numerical integration of u and sg using LSODE. (Refer to IDL manual for LSODE). Procedure DUS is used to calculate the derivatives of u and σ from (A6, A7).

vii. DUS.PRO
   Calculates radial derivatives from momentum equations. (A6)(A7)
       vz = v_0+sg   dz=d+sg/s   gz=g+sg/s
       du =first derivative of u
       dsg=first derivative of sigma

viii.   FIXSHOTS15.PRO
This module calculates the field snapshots and their second time derivatives at each retained fix time on a polar grid extending outward from the storm center to 15 RMW in steps of 0.1RMW and 10^0 angle. (This would give a matrix of 151 x 36 points. But three extra lines are added for the convenience of future calculations making the matrix dimension 151 x 39)
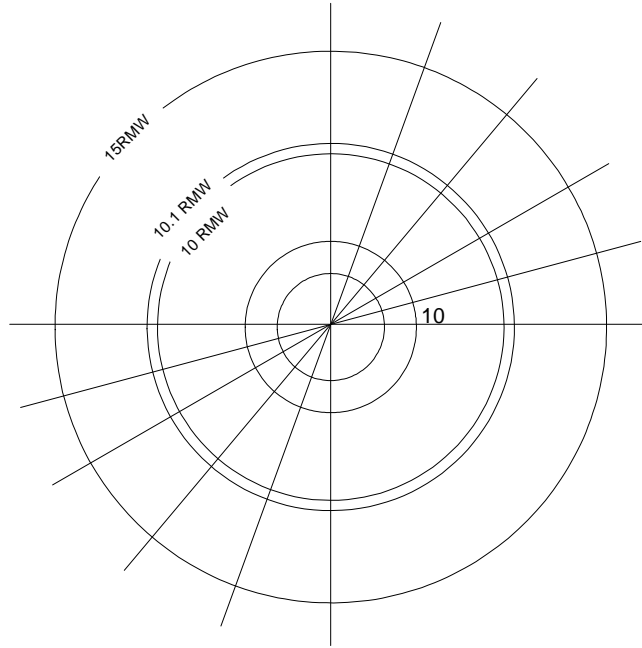
Figure 3.2.6: Polar grid

1. Restore suv.idl
2. Restore nrmrayse10_15.idl, which contain some trigonometric values corresponding to each of the grid point.
3. For each retained fix, construct the polar grid of earth relative marine surface winds. (onefix.m)
4.   onefix.m gives the polar grid of earth relative marine surface winds for exactly one fix.
5. 'reform' converts this 151x39 matrix in to a raw matrix of 1x 5889.
6. zsnapi is a complex matrix which contains the snap shots of the retained fixes. [#retained fixes X 5889]
7. usnap contains the earth relative zonal winds and vsnap contains the earth relative meridional winds.
8. Compute second time derivative of fields for time interpolation. Time interpolation is done in order to find the details of the storm every minute.

ix. ONEFIX.M
This module constructs zonal and meridional windfield components for exactly one fix.
1. Load single fix profiles and corresponding data.
2. Calculate purely radial (no azimuthal dependence) functions on a polar grid. (GENSTREX.M)
3. Then introduce azimuthal dependencies and calculate storm relative-wind field. Equation (A11) through (A13)
4. Calculate the form factors (a_0, a_1, a_2, b_0, b_1, b_2 of equation A11 & A12)
   cfu=coefficients of u (a_0, a_1, a_2)   cfsg=Coefficients of Sigma (b_0, b_1, b_2)
   initial estimate=1,0,0   initial estimate=1,0,0
5. Keep changing the estimate to minimize J (equation A13) using AMOEBA, MNRDU and MNRDSG. (AMOEBA is a built in function in IDL)
   MNRDU= Calculate a's keeping b's fixed.
   MNRDSG=Calculate b's keeping a's fixed.
6. Form the earth relative wind field assuming that the storm moves northwards.
7. Calculate u, σ, uer and ver using equations (A14) through (A16)
8. Storm rotates counter clockwise. Once the northward storm translation speed is induced storm center tend to move towards west. Shift.m takes this into account and shifts the polar origin to the storm center.
9. Advance phase
10. Orient the wind field to track direction. - Initially we assumed that the storm is moving northwards. In this step some interpolation is required since the actual direction of the storm unlikely to lie exactly on a radial of the grid.
11. Convert the radial and tangential wind fields to zonal and meridional components. vystre=holds the meridional component of the wind at each grid point.
    uxstre=holds the zonal component of the wind at each grid point.
    zxystre=Complex array containing the zonal and meridional wind components at each grid point.

xiii. GENSTREX.M
This module places the profile functions and the auxiliary functions g and d (which we calculated earlier) on the polar grid yielding fields with no azimuthal dependence for exactly one fix. sstre=array containing radial distance to each of the grid point from the centre.

xiv. SHIFT.M
This module simply shifts the polar coordinate system, so that the origin of the coordinate system lies on the center of the storm. (Center of the storm is the point where wind speed is zero.)

xv. PKWINDS.PRO

This module produces an output file, which lists the peak marine and open terrain wind components experienced at each zip code for the current storm. If the storm makes landfall, then the peak marine and open terrain winds are listed at the tie and the site of the landfall. If the storm only bypasses the state then the peak marine and open terrain winds are listed for the fix exhibiting the lowest central pressure.

1. Restore zipcodes.idl. This contains the longitude and latitude of all zip codes.
2. Restore fixshots.idl. (We generated this in previous step)
3. Initialization of other variables.
   elonk=east longitude of the track every minute
   nlatk=north latitude of the track every minute
   kmax=maximum time(life time) of the storm in Minutes. Since the storm is moving it will affect one zip code for a variable time. But we initialize zuvzip for the worst case.
   nzip=Number of zip codes
   werzipx=holds the maximum wind per each zip
4. Calculate all time series. (time k is incremented in steps of 'kinc' from zero to kmax)
   elc=longitude of the storm center at each time step.
   nlc=latitude of the storm center at each time step.
   rmw=radius of maximum wind at each time step.
5. Determine which zip codes will be affected by the storm.
   At time k the storm can affect several zip codes in its vicinity and the affected area depends on Rmax. MAP_2POINTS is used calculate the distance from the center of the storm to each of the zip codes. (This is done at each time step). Then REACH is used to calculate the reach of the storm at that particular time step. Storm 'reach' is calculated in terms of RMW. If the calculated 'reach' is less than 12.5 that calculated value is taken as the reach. Other wise 12.5 is considered as the storm reach.
6. If at least one of the zip codes is affected by the storm; generate relevant portion of gridded field for current time k.
   unow=value of u at this time at each grid point.
   vnow=value of v at this time at each grid point.
7. Evaluate marine windfield components at admissible zip code centroids. First use LLTOXY, latitude & longitude information of the storm center and zip code centroid to calculate the (x,y) distance between storm center and the zip code centroid. Then using interpolation calculates the marine wind speed at the zip code centroid.
8. Use ZMAR2ZOT to convert above calculated marine windspeeds into Open Terrain windspeeds.
9. After the construction of the time series record maximum total OT windspeed at each zip code.
10. Obtain marine and OT peak winds at landfall or lowest pressure for bypassing storms. At the same time record the time and location of landfall or lowest pressure fix.
11. Write the output file if at least one zip code is affected by the storm.

xvi. REACH.M

This function determines the influence radius.

Influence radius = 12.3246 – 0.162*rmw

If the calculated value is less than 4, then set it to 4

xvii. LLTOXY. PRO

This module converts east longitude and north latitude into zonal distance (xmerc) and meridional distance (ymerc) in meters from the cyclone center (elo,gglo)

ymerc= mercator y coordinates from latitudes

xmerc= mercator x coordinates from longitudes

xviii. ZMAR2ZOT.PRO

This module converts marine wind speeds (m/s) into Open Terrain windspeeds (m/s).

xix. GEMF.M

This module is used to set the time step and call the executable.

1. set the time step for storm series calculations and load gemplex.exe

kinc=15 : time step is set to 15 minutes

flcnt= 0: start the output file numbering from 1. (output1.dat, output2.dat…)

UDVS.PRO:

This module computes the radial and azimuthal derivatives of u.

cfu: coefficients of u (a0,a1,a2)

udotstre: partial derivative of u with respect to s

uprstre : partial derivative of u with respect to azimuth

SGDVS.PRO:

This module computes the radial and azimuthal derivatives of sigma.

Csfg: coefficients of sigma (b0,b1,b2)

Sgdotstre: partial derivative of sigma with respect to s

Sgpstre: partial derivative of sigma with respect to azimuth

RSDU.PRO:

This module estimates the u residual to be minimized.

Ufnl: functional for u.

RSDSG.PRO:

 This module estimates the sigma residual to be minimized.

Sgfnl: sigma functional.

MNRDU.PRO:

This function evaluates the residual for u and is used in AMOEBA to minimize this residual.

MNRDSG.PRO:

This function evaluates the residual for sigma and is used in AMOEBA to minimize this residual.

GEMFPLEX.PRO:

 This module reads g_trackfile and separates it into individual track files for processing.

It outputs a file called 'trackfile'.

GEMF.PRO:
  This module processes each single track. It reads the input file called trackfile.

3.2.5.   References

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3.3. Wind Speed Correction (WSC) Use Case V

3.3.1. General Description Of WSC

WSC, shorts for Wind Speed Correction, is the fifth use case of the Florida Hurricane Loss Model. It aims at refining open terrain wind speed produced by the hurricane wind model with respect to the actual terrain (based on land use – land cover).

3.3.2.   WSC General Requirements

Name: Wind Speed Correction

Description: The inputs are zip code, surface wind speed for open terrain produced by the wind model, surface wind direction, and roughness length for open terrain. The system generates the following:

> **(1) Surface wind speed for actual terrain (m/s).**
> **(2) 10-minute sustained wind speed for actual terrain (mph).**
> **(3) 3-Second gust wind speed for actual terrain (mph).**

1. Following are the input data:
   - *Zip*: Zip Code
   - *Vo*:   Surface Wind Speed for open terrain produced by the wind model (m/s)
   - *WD*: Surface Wind Direction (Deg from North)
   - *Zoo*: Roughness Length (m) for open terrain = 0.03m
   - *Zoa*: Roughness length based on upstream terrain
   - Lat: Latitude

2. Based on the input data from step 1, the system queries the database and returns Zoa parameter, which corresponds to the actual roughness length based on FEMA HAZUS conversion table relating land use-land cover (LULC) to aerodynamic roughness (m). Roughness represents a weighted average of all roughness pixels within a 45-degree sector with origin at the population-weighted centroid of the zip code and extending outward to 20 km from the centroid. The weighting function for averaging the roughness values is a Gaussian filter with a half power point at 3 km. The format of the lookup table is as following:

Zip	Lon	Lat	Zo1	Zo2	Zo3	Zo4	Zo5	Zo6	Zo7	Zo8

Where:

> Zo1 = Actual Roughness for wind directions inclusive of 46-90
> Zo2 = Actual Roughness for wind directions inclusive of 1-45
> Zo3 = Actual Roughness for wind directions inclusive of 316-0, 360
> Z04 = Actual Roughness for wind directions inclusive of 271-315
> Z05 = Actual Roughness for wind directions inclusive of 226-270
> Zo6 = Actual Roughness for wind directions inclusive of 181-225
> Zo7 = Actual Roughness for wind directions inclusive of 136-180
> Zo8 = Actual Roughness for wind directions inclusive of 91-135

Table 3.3.1 shows a sample record from the lookup table.

Zip	33172
Lon	80.358246
Lat	25.775768
Zo1	.254
Zo2	.277
Zo3	.333
Zo4	.253
Zo5	.297
Zo6	.274
Zo7	.287
Zo8	.281

Table 3.3.1: A sample record for the lookup table

3. Given the wind direction for each zip code centroid, the appropriate value for actual terrain roughness is extracted from the lookup table. The system then computes the output values as below:

Compute open terrain friction velocity *Uo* (Unit: m/s):
$$Uo = Vo * 0.4 / [Ln (10.0 / 0.03)]$$

Compute actual terrain friction velocity *Ua* (Unit: m/s, using equation 3 of Powell et al., 1996)
$$Ua = Uo / ([Zoo / Zoa] \wedge 0.0706)$$

Compute actual terrain wind speed at 10 m *Va*:
$$Va = (Ua / 0.4) (Ln (10 / Zoa))$$

Convert wind speed to the unit of MPH:
$$Vamph = Va * 2.24$$

Compute gust factors for peak 1 min wind over 10 min $G_{10min,60}$ and peak 3s wind over 10 min $G_{10min,3}$ based on the actual roughness. [See gust factor calculations below]

Compute max 1 min wind (m/s) occurring within 10 min period
$$V1 = Va * G_{10min,60}$$
$$ZipOTWS1 = Va * 1.142$$

Compute max 1 min sustained wind speed in mph
$$V1mph = V1 * 2.24$$

Compute peak 3s gust in mph
$$V3mph = Va * G_{10min,3} * 2.24$$

4. Gust factor calculations

12. Compute friction velocity (u)

$$u = \frac{0.4Va}{Ln\left(\dfrac{10}{Zoa}\right)}$$

4.1. Compute Height scaling parameter based on a height of 10 m

$$\eta = 1 - 6f\left(\frac{10}{u}\right)$$

where $f = 2\left(7.292 * 10^{-5} \sin(Lat)\right)$ is the Coriolis parameter

4.2. Compute the standard deviation of the wind speed

$$\sigma_u(z) = \frac{7.5\eta u\left[0.09Ln\left(\dfrac{10}{Zoa}\right) + 0.538\right]^{\eta^{16}}}{\left(1 + 0.156Ln\left(\dfrac{u}{f.Zoa}\right)\right)}$$

4.3. Compute the standard deviation of the low-pass filtered wind speed considering a filter with a cut-off frequency of 1 cycle per 3 seconds (for the peak 3s gust) and 1 cycle per 60 seconds (for the maximum 1 min sustained wind speed calculation:

$$\sigma_u(z,60) = \sigma_u(z)\left(1 - 0.193\left(\frac{I_t}{60} + 0.1\right)^{-0.68}\right)$$

$$\sigma_u(z,60) = 0.386762\,\sigma_u(z)$$

where 60 represents 1 min or 60 seconds and the integral scale time parameter I_t is,

$$I_t = 3.13Z^{0.2}$$

$$I_t = 4.96$$

In which Z = 10 meters is used.

$$\sigma_u(z,3) = \sigma_u(z)\left(1 - 0.193\left(\frac{I_t}{3} + 0.1\right)^{-0.68}\right)$$

$$\sigma_u(z,3) = 0.868256421\sigma_u(z)$$

Where 3 represents 3 seconds

4.4. Compute the wind fluctuation cycling rates:

$$C_r(60) = \frac{\left(0.007 + 0.213\left(\frac{I_t}{60}\right)^{0.654}\right)}{I_t}$$

$$C_r(60) = 0.00982$$

$$C_r(3) = \frac{\left(0.007 + 0.213\left(\frac{I_t}{3}\right)^{0.654}\right)}{I_t}$$

$$C_r(3) = 0.061$$

4.5. Compute the Peak factors for the max 1 min (60 sec) and max 3 second winds

$$P_f(3) = \left[\sqrt{2Ln(600C_r)} + \frac{0.557}{\sqrt{2Ln(600C_r)}}\right]\frac{\sigma_u(z,3)}{\sigma_u(z)}$$

$$P_f(60) = \left[\sqrt{2Ln(600C_r)} + \frac{0.557}{\sqrt{2Ln(600C_r)}}\right]\frac{\sigma_u(z,60)}{\sigma_u(z)}$$

4.6. Compute the longitudinal turbulent intensity

$$T_{il} = \frac{\sigma_u(z)}{U_h}$$

4.7. Compute the gust factors:

$$G_{10\min,60} = 1 + T_{il}P_f(60)$$
$$G_{10\min,3} = 1 + T_{il}P_f(3)$$

A sample calculation is as follows:

Input	Lookup value	Output
Zip = 33133 Vo = 50 m/s WD = 60 Zoo = 0.03 Lat = 25.73	Zoa = 0.431 m	Uo = 3.44 m/s Ua = 4.16 m/s Va = 32.66 m/s V1mph = 90.08 mph V3mph = 123.55 mph

3.3.3. WSC Interface Design Requirements

This section presents the Graphic User Interface design for the Wind Speed Correction (WSC).

1. The first step: the user logs in the system

Figure 3.3.1 shows the Login Interface. User needs to enter the user id and password to enter the system. The system verifies the user's information with the login data extracted from the database. If it matches, the user logs into the system successfully. Otherwise, system displays the "wrong user name/password" error and requests the user to login again.

UserID: FDOIUSER

PassWD: ********

LOGIN

Figure 3.3.1: Login Interface

2. The second step: select the use case from the service selection page

Figure 3.3.2 is the service selection page interface. System presents a list of available use cases to the user. User selects "Wind Speed Correction Model" use case and clicks "Go" to submit.

Please choose an online service: ------------------------------------ ▼

Go

Figure 3.3.2: Service Selection Interface

3. The third step: The user provides the input from the wind model

In this step, system provides the interface for the user to input data generated by the wind model. The following inputs are required and are illustrated by Figure 3.3.3:

- *Zip code*:

- *Wind Speed*: Surface wind speed (m/s) for open terrain produced by the wind model.
- *Wind Direction*: Surface wind direction (Degree(s) from the North).
- *Roughness Length*: Roughness length (m) for open terrain = 0.03 m.
- *Latitude*:

Num	Zip Code	Wind Speed (m/s)	Wind Direction	Roughness length (m)	Latitude (deg)
1					

Figure 3.3.3: Input from Wind Model Interface

4.   The forth step: The system displays the result in the interface

In this step, system calculates the result and displays both the input and the output to the user as shown in Figure 3.3.4. The output includes:
- *Zoa*: Actual roughness length based on FEMA HAZUS conversion table relating land use land cover (LULC) to aerodynamic roughness (m).
- *Uo*: Open terrain friction velocity (m/s).
- *Ua*: Actual terrain friction velocity (m/s).
- *Va*: Surface wind speed for actual terrain (m/s).
- *Vamph*: Above with English units of statute miles per hour.

Input				Output						
Zip	Vo (m/s)	Wd	Zoo	Zoa (m)	Uo (m/s)	Ua (m/s)	Va (m/s)	Vamph (mph)	V1mph (mph)	V3mph (mph)
33133	50.0	60	0.03	0.431	3.44	4.16	32.66	73.17	90.08	123.55

Figure 3.3.4: Wind Speed Correction Calculation Result Interface

3.3.4.   Computer Model Design

3.3.4.1.   *Use Case View of WSC*

A.   Actors:

There is one actor, scientist in WSC.

C.   Use Case:

WSC is used to convert open terrain winds produced by the hurricane wind model to winds more representative of the actual terrain (based on land use- land cover).

C.   Use Case Diagram:

Scientist   WindSpeedCalUseCase

Figure 3.3.5: Use Case Diagram for WSC

3.3.4.2.   System Design

This section includes the appropriate diagrams to describe the system classes, components, activities and the overall flow chart of WSC.

3.3.4.3.   Program Flow Chart of WSC

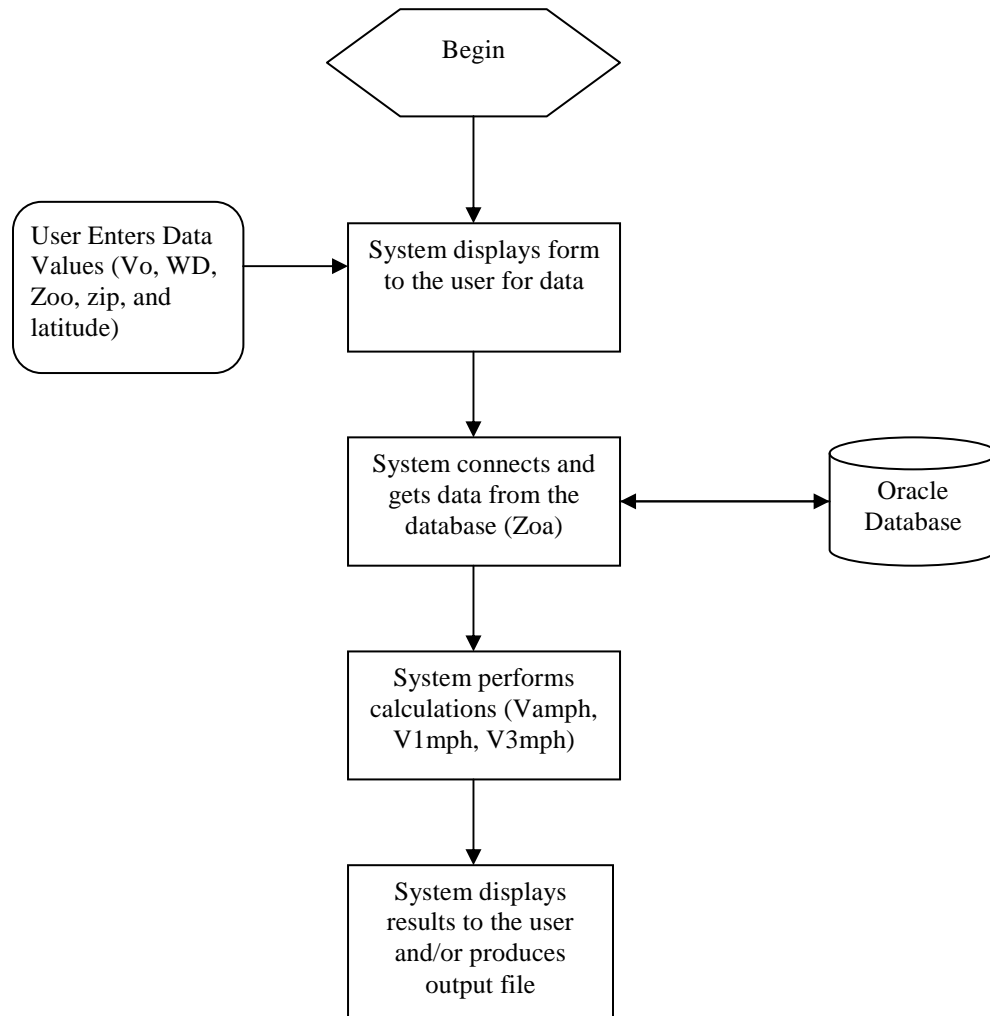The flow chart of WSC is depicted in Figure 3.3.6.

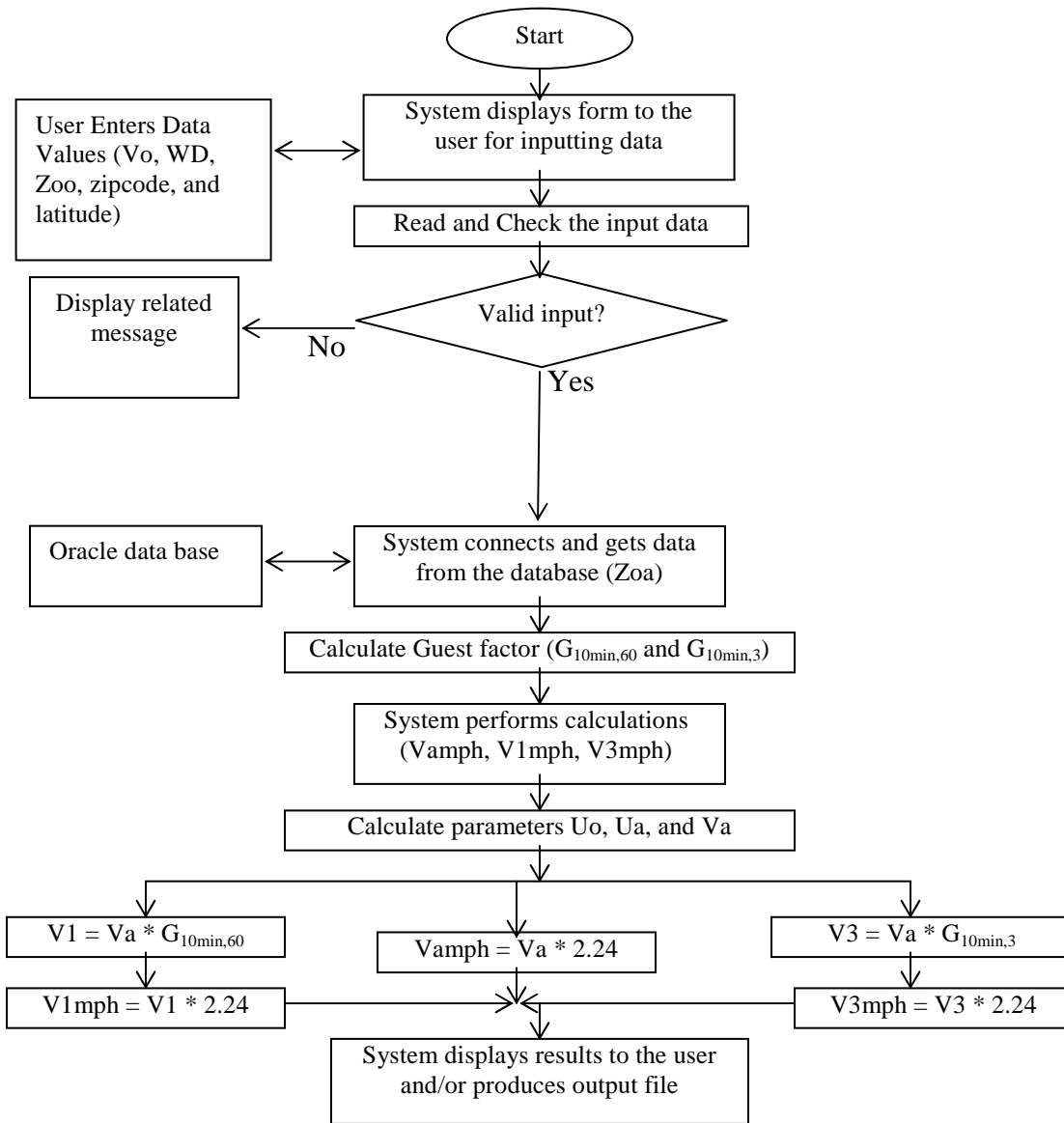**Figure 3.3.6: Flow chart of WSC**

3.3.4.4. Detailed Flowchart

Figure 3.3.7: Detailed Flow chart of WSC

3.3.4.5. Class Diagram and Description
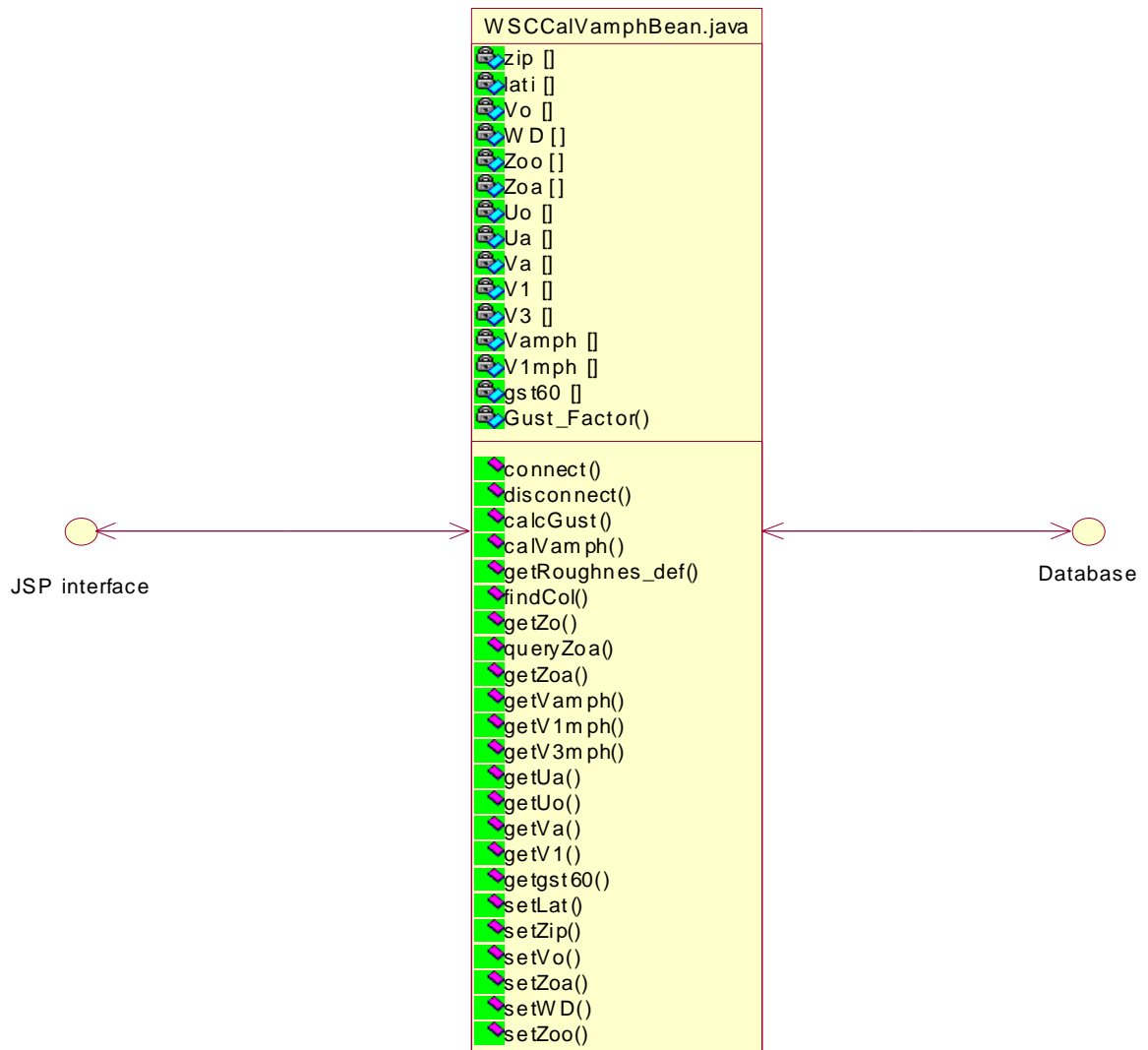
A. Class Diagram

Figure 3.3.8: Class Diagram for WSC

B.   Classes Descriptions

Here is a brief introduction of the functions in the class we used.

➢ WCSCalVamphBean
This class performance all the functionalities needed for the wind speed correction calculation. It includes the following main methods:
  • connect()
  Method is used to establish a connection to the database
  • setLat (double [] l)
  Method takes an array of doubles and sets the latitude array to the passed array

- setZip(int [] z)

Method takes an array of integers and sets the zip array to the passed array

- setVo(double [] z)

Method takes an array of doubles and sets the Vo array to the passed array

- setWD(int [] w)

Method takes an array of integers and sets the WD array to the passed array

- setZoo(double [] z)

Method takes an array of doubles and sets the Zoo array to the passed array

- queryZoa()

Uses the connection to the database to send a query and retrieve the value for Zoa based on the zip and the returned string value from a call to the findCol method.

- calVamph()

Method is used to calculate the Vamph, Va, Uo and Ua using the following input values from the user Vo, Zoo and Zoa

- calcGust()

Method is used to calculate the gust factors $G_{10min,60}$ and $G_{10min,3}$ using the following input values Lat, WD, Zoa and Va

- GetRoughness_def()

Method uses the established connection to the database to find and return the column names and starting and ending degrees corresponding to each column of the roughness_def table.

- findCol(int wd)

Method takes a wind direction (WD) as a parameter. It uses the established connection to the database to find and return the correct string, using the WD, which represents the column in the lookup table for Zoa.

- get Zoa()

Return the value of Zoa

- getVamph()

Return the value of Vamph

- getV1mph()

Return the value of V1mph

- getV3mph()

Return the value of V3mph

- getUa()
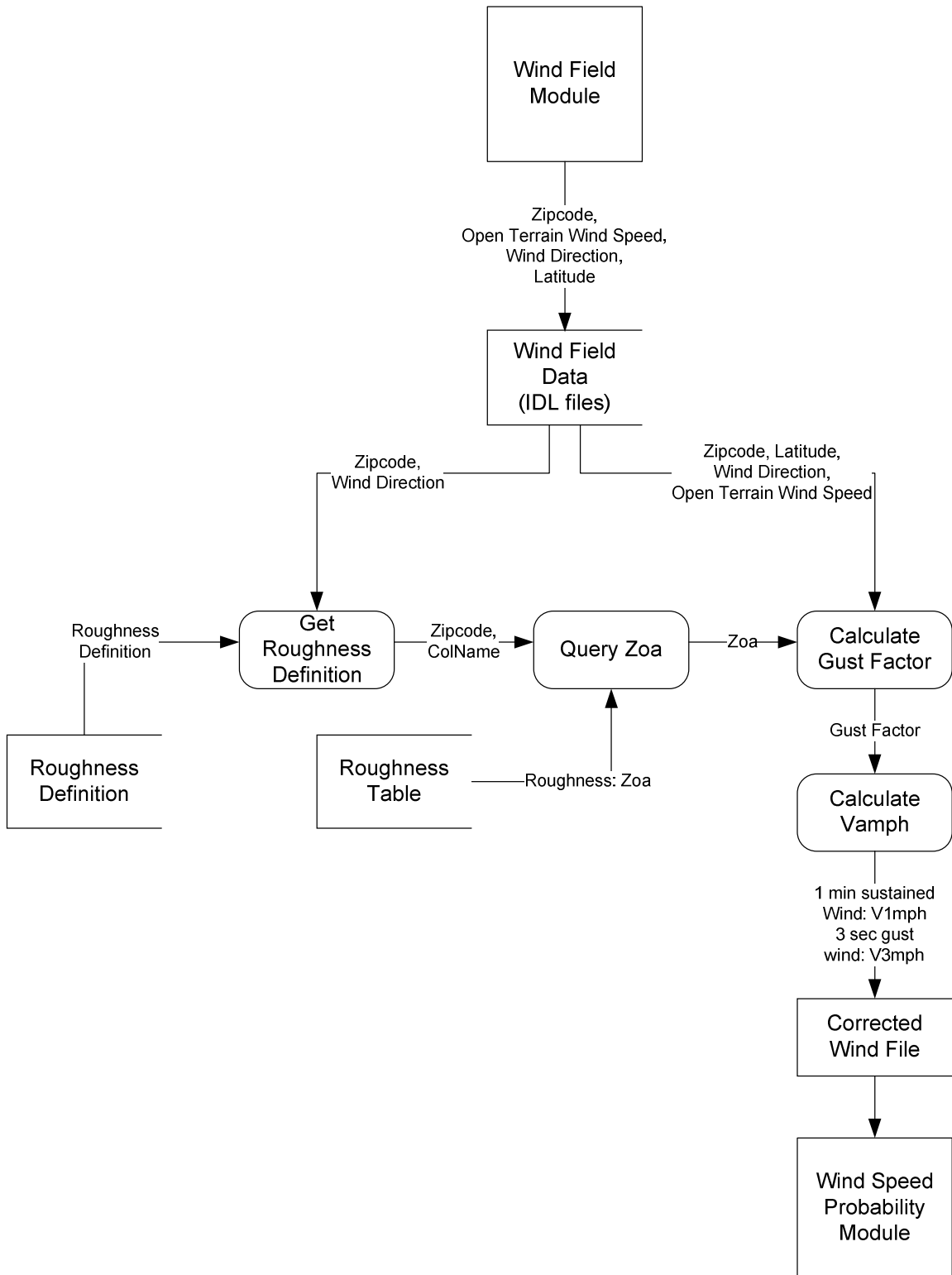
Return the value of Ua

- getUo()

Return the value of Uo

- getVa()

Return the value of Va

- disconnect()

Method is used to disconnect from the database

3.3.4.6. Data Flow Diagram

```
                          ┌─────────────────┐
                          │   Wind Field    │
                          │    Module       │
                          └────────┬────────┘
                                   │
                              Zipcode,
                     Open Terrain Wind Speed,
                          Wind Direction,
                              Latitude
                                   │
                                   ▼
                          ┌─────────────────┐
                          │   Wind Field    │
                          │     Data        │
                          │   (IDL files)   │
                          └────────┬────────┘
```

Zipcode,   Zipcode, Latitude,
Wind Direction   Wind Direction,
                                         Open Terrain Wind Speed

Roughness
Definition

```
    ┌──────────────┐   Zipcode,   ┌───────────┐   Zoa   ┌──────────────┐
    │     Get      │   ColName    │           │         │  Calculate   │
    │  Roughness   │────────────▶ │ Query Zoa │────────▶│ Gust Factor  │
    │  Definition  │              │           │         │              │
    └──────────────┘              └───────────┘         └──────┬───────┘
                                                               │
                                                          Gust Factor
                                                               │
                                                               ▼
    ┌──────────────┐              ┌───────────┐         ┌──────────────┐
    │  Roughness   │              │ Roughness │         │  Calculate   │
    │  Definition  │              │   Table   │         │    Vamph     │
    └──────────────┘              └───────────┘         └──────┬───────┘
                                   Roughness: Zoa               │
```

1 min sustained
Wind: V1mph
3 sec gust
wind: V3mph

```
                                                    ┌──────────────┐
                                                    │  Corrected   │
                                                    │  Wind File   │
                                                    └──────┬───────┘
                                                           │
                                                           ▼
                                                    ┌──────────────┐
                                                    │ Wind Speed   │
                                                    │ Probability  │
                                                    │   Module     │
                                                    └──────────────┘
```

3.3.4.7.   *State Chart Diagram*

Figure 3.3.8 depicts the state chart diagram for Use Case Five. This diagram illustrates states that the use case goes through from beginning to end.
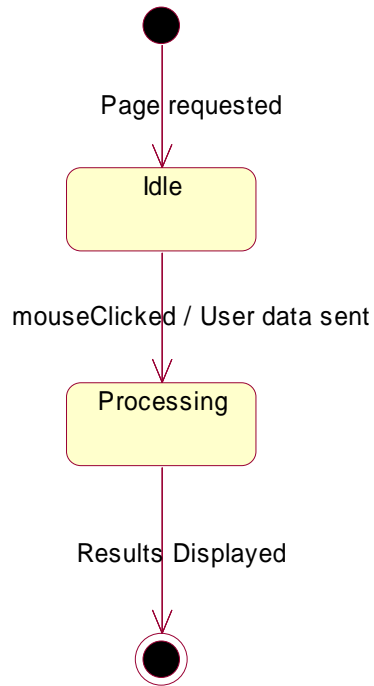

Figure 3.3.9: State Chart for WSC

3.3.4.8.   *Sequence Diagram*

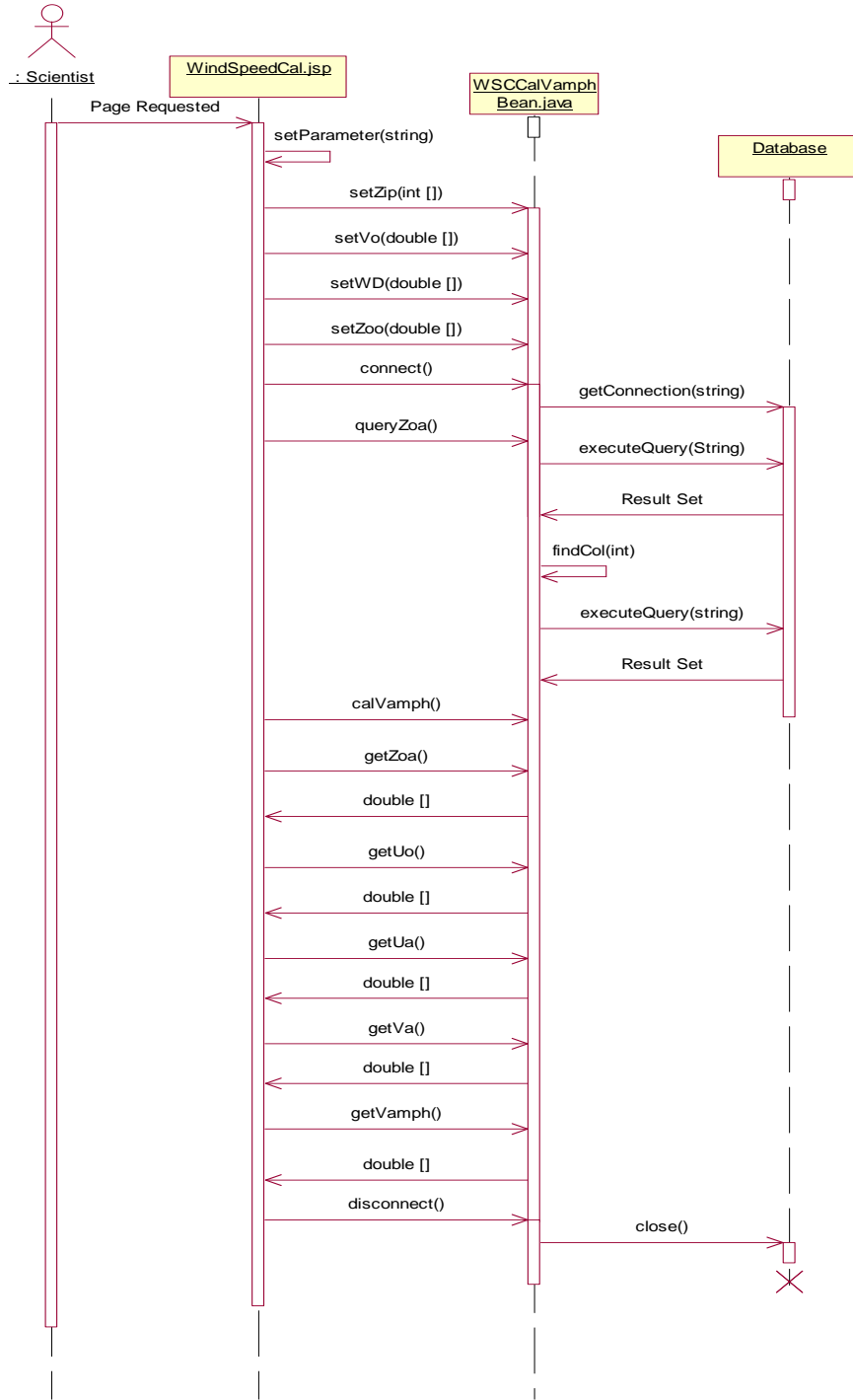## A.   Sequence Diagram for the Vamph Calculation Process

Figure 3.3.10: Sequence diagram for Vamph calculation process

B. **Sequence Diagram Steps for the Vamph Calculation Process**

- **Step 1**: The user requests the html page

- **Step 2**: The user enters the number of data sets to be calculated

- **Step 3**: The user inputs data for zip code, Vo, WD and Zoo and they are passed to the WSCCalVamphBean object

- **Step 4**: WindSpeedCalc.jsp requests WSCCalVamphBean object to establish a connection to the database

- **Step 5**: WSCCalVamphBean establishes a connection to the database

- **Step 6**: WindSpeedCalc.jsp requests WSCCalVamphBean to query the database based on data passed from JSP

- **Step 7**: WSCCalVamphBean queries the database which returns a ResultSet to the BEAN

- **Step 8**: WSCCalVamphBean calls its findCol method.

- **Step 9**: WSCCalVamphBean queries the database which returns a ResultSet to the BEAN

- **Step 10**: WindSpeedCalc.jsp requests to perform Vamph calculations.

- **Step 11**: WindSpeedCalc.jsp requests the results for Zoo, Uo, Ua, Va and Vamph and WSCCalVamphBean returns the required data.

- **Step 12**: WindSpeedCalc.jsp notifies that it is okay to close the database connection

- **Step 13**: WSCCalVamphBean closes the database connection

3.3.5.   Implementation of WSC

Currently, the implementation for Use Case five (WSC) has been finished. The demo is reachable at http://www.cs.fiu.edu/PHRLM.

3.3.5.1.   *Login page:*

Users need username/password to access the *Florida Hurricane Loss Model*. Following is a snapshot of the login web page.
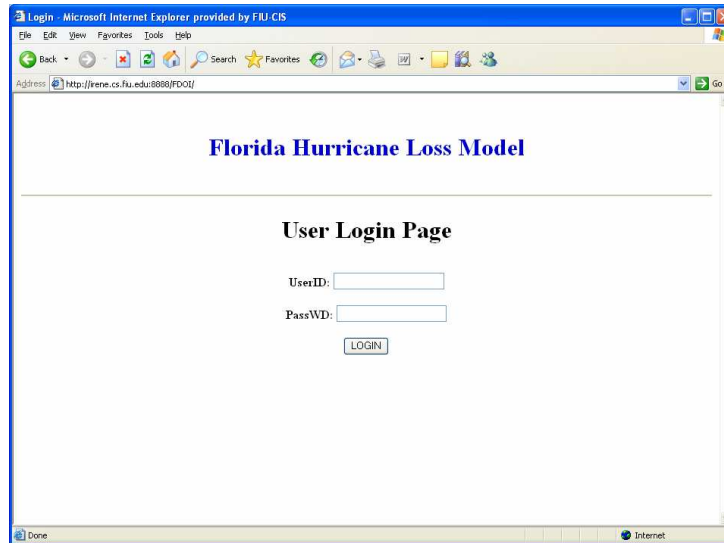
Figure 3.3.11. Login webpage for FHLM

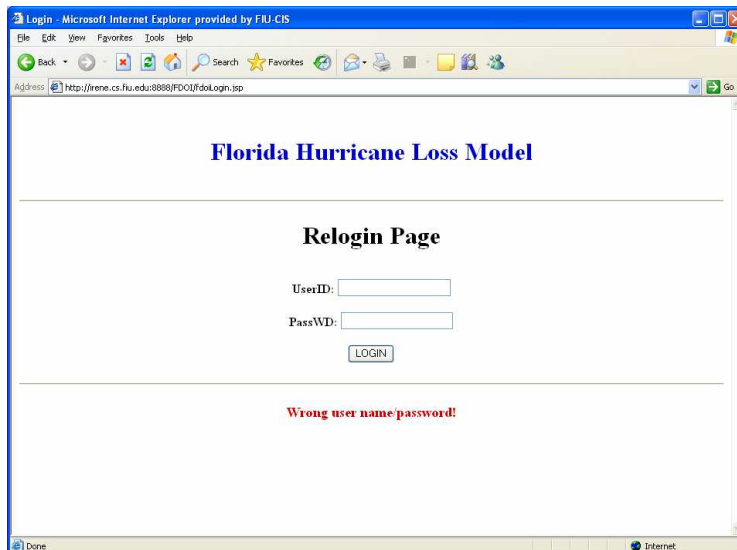If the username/password is wrong, an error message will be displayed. User will be required to input the username and password again to enter.

Figure 3.3.12. Login webpage shows the inputted user ID or password is wrong

3.3.5.2.   WSC Page:

If the login is successful, the user can see the web page named "Service Selection Page" (as shown in Figure 3.3.13). To view the WSC use case page, from the drop-down list, select "Wind Speed Correction" and click "Go" button.

Figure 3.3.13. Service selection page for WSC

Several steps need to be followed to accomplish the task of Wind Speed Correction,
User can select two input methods.
    a. Input from file (this is the use case four output)
    b. Manual Input
If user want to take the input from file
    1. Click on 'From File' radio button
    2. Select the input data set from an available data set
    3. Click on 'submit'
If the user wants to enter the input manually, first click on 'Manual Input' radio button.
Step 1:
Then, the users need to input the wind field data fields. Input data sets from the wind model include the following fields:
- ***Zip*:** Zip code
- ***Vo*:** Surface wind speed for open terrain produced by the wind model (m/s)
- ***Wd*:** Surface wind direction (Deg from North). The data range for this field is from 0 to 360.
- ***Zoo*:** Roughness length (m) for open terrain = 0.03 m
- ***Latitude:*** Latitude of the corresponding zip code. (a value between 20 and 40)

A data input page is provided to facilitate users to input the corresponding data easily. Users are allowed to input a variety of collections of input data and submit this data for wind speed correction calculation.

By default, the number of input data sets is one. So initially, there is only one set of blank control for the user to input his/her data. Figure 3.3.14 illustrates the snapshot of the dataset input page for wind speed calculation.
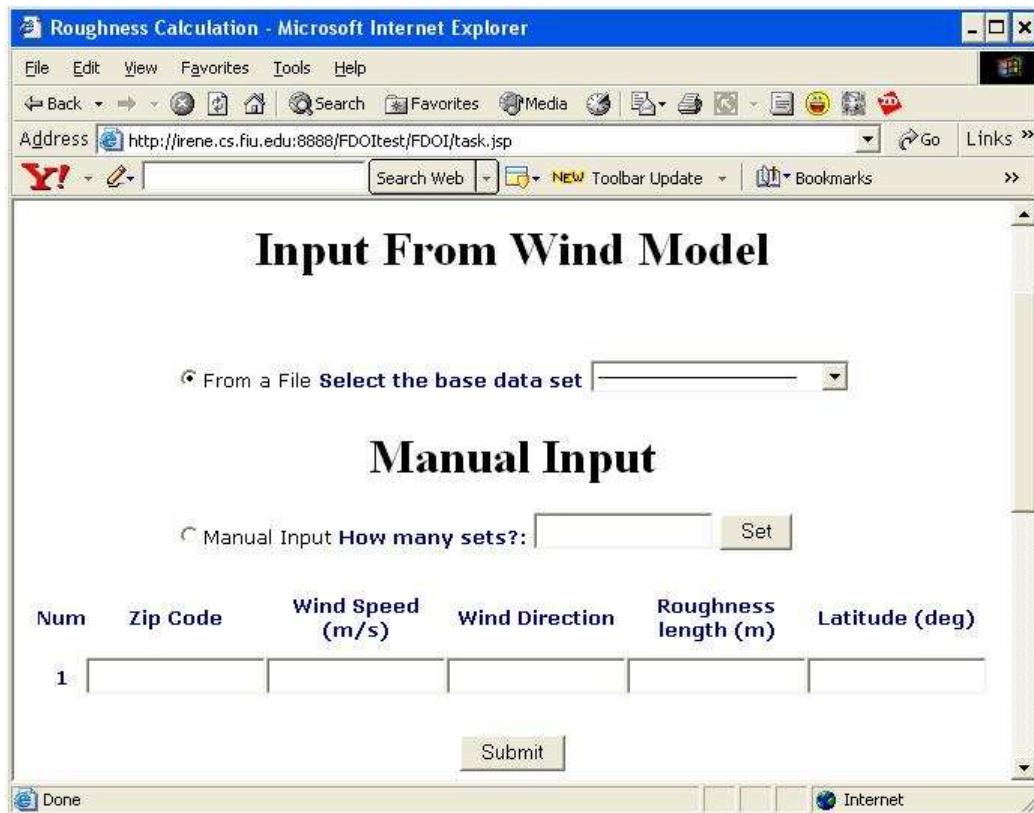

Figure 3.3.14. Snapshot of the first web page for WSC

To input more than one set of input data, the user can change the number of input data sets by using the "number of sets change" option provided at the top of the dataset input page. The user inputs the desired number of data sets in the blank after "How many sets?", and then clicks "Set" button. Figure 3.3.15 shows an example dataset input web page after the user requests three sets of input data.
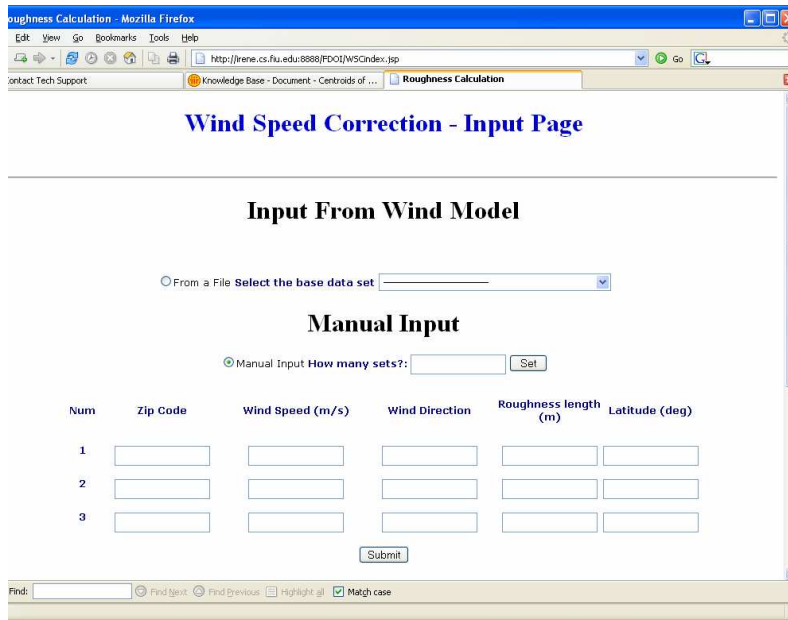
Figure 3.3.15. Snapshot of the web page after user specify the sets number to 3

<u>*Step 2:*</u>

Secondly, the system constructs a query using the user's data to obtain desired data from the underlying Oracle database. This desired data along with the user data is used to carry out the correction computation.

Once the correction computation is done, the system displays the whole data set: the input data set, retrieved data, and the computation results, back to the user. Figure 3.3.16 shows a result page as an example.
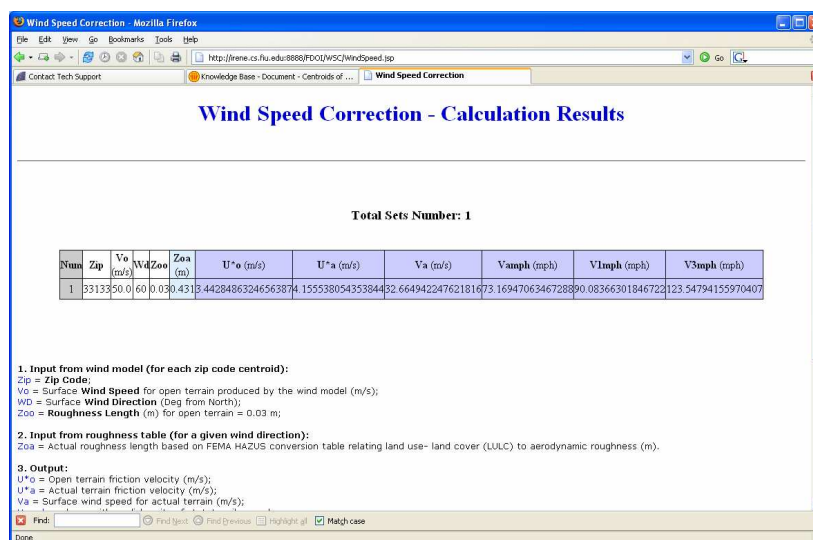
Figure 3.3.16: Snapshot of the result web page for WSC

3.3.5.3.   Exception Handling:

Users may make some error inputs. The JSP webpage can catch the exceptions and show the error messages. Here we show some examples:

After user fills in the set number blank and clicks the "Set" button, the system will check if the inputted value is an integer. If no, the corresponding error message will be generated and shown under this blank (as shown in Figure 3.3.17).
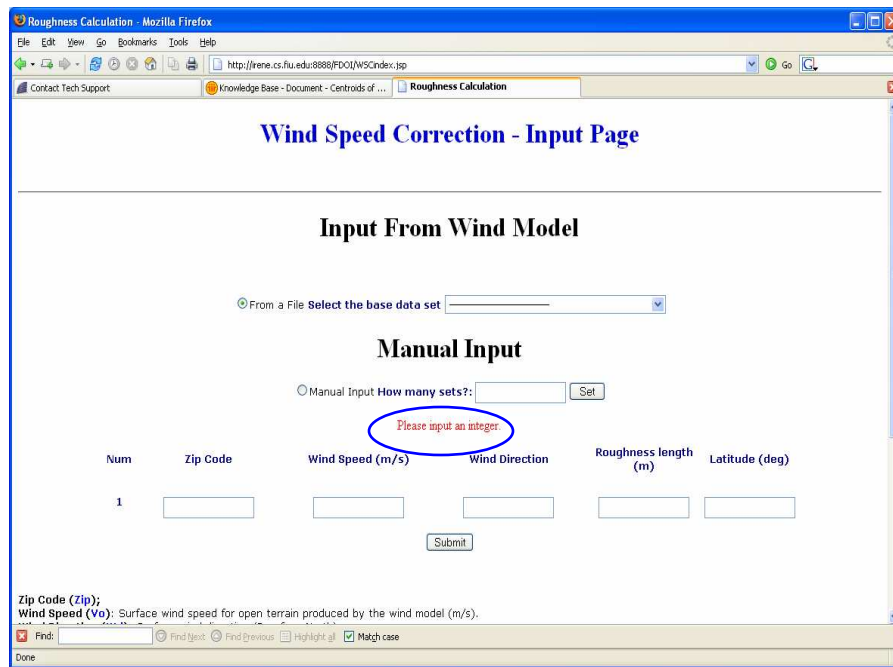

Figure 3.3.17. The input webpage shows the exception that the inputted set number is not an integer.

User needs to follow the instructions, fill in all the blanks and input the data sets in the correct format. Figure 3.3.18 shows some error inputs. For example: some blanks are not filled; the zip code field is filled by words; the wind direction is not in the interval [0, 360]; etc. Figure 3.3.19 displays the webpage which caught these exceptions and displays several error messages.
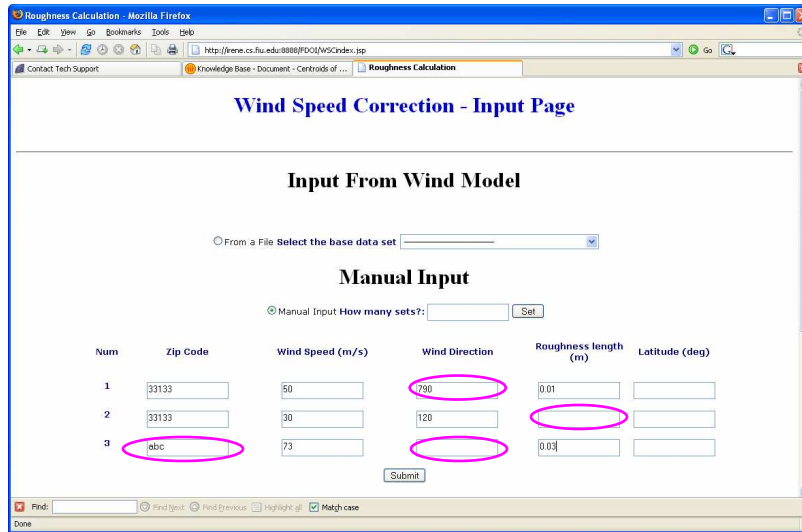
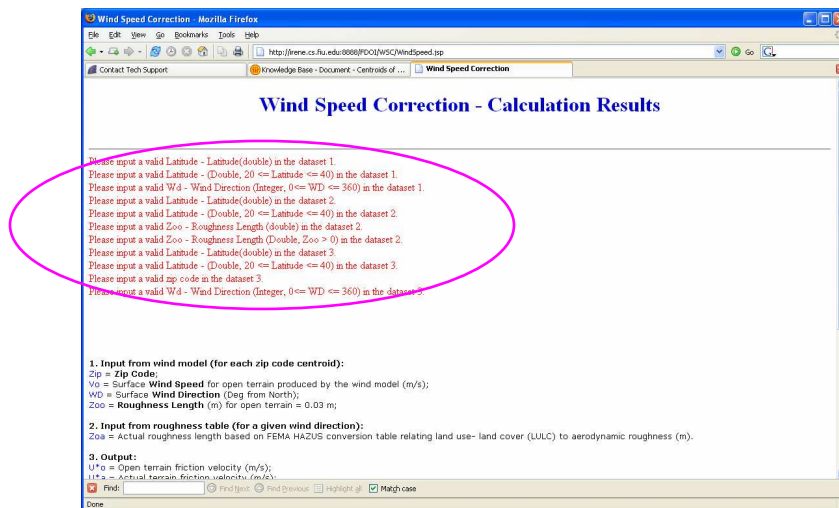**Figure 3.3.18: The input webpage contains a set of error inputs**

Figure 3.3.19: The result webpage catches all the available exceptions

Another possible exception is caused by the invalid zip code. Sometimes the user inputs the zip code within the correct format, but this zip code cannot be found in the specific lookup table. As shown in the Figure 3.3.20, user inputted a zip code as "12345", which is not in the lookup table. In Figure 3.3.21, the webpage shows this message so that the user can identify this error.
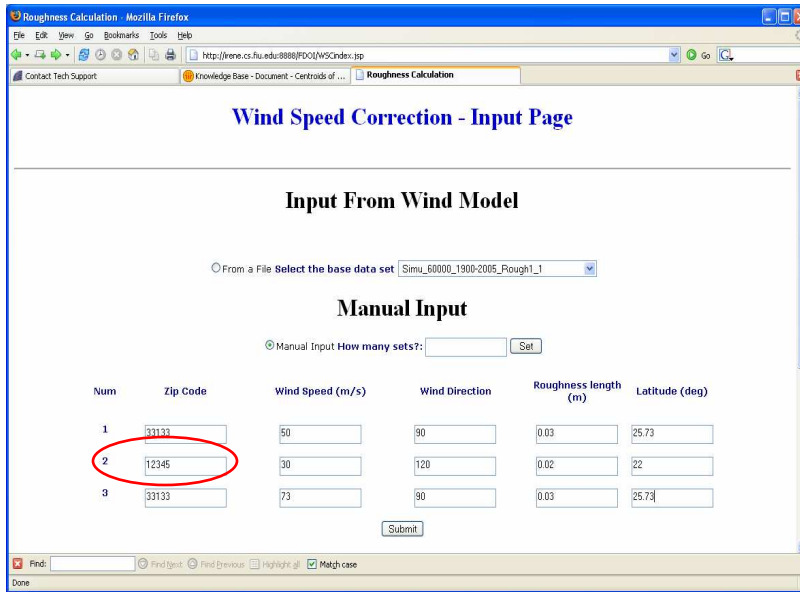
Figure 3.3.19: The input webpage contains a Zip code value which is not included in the lookup table
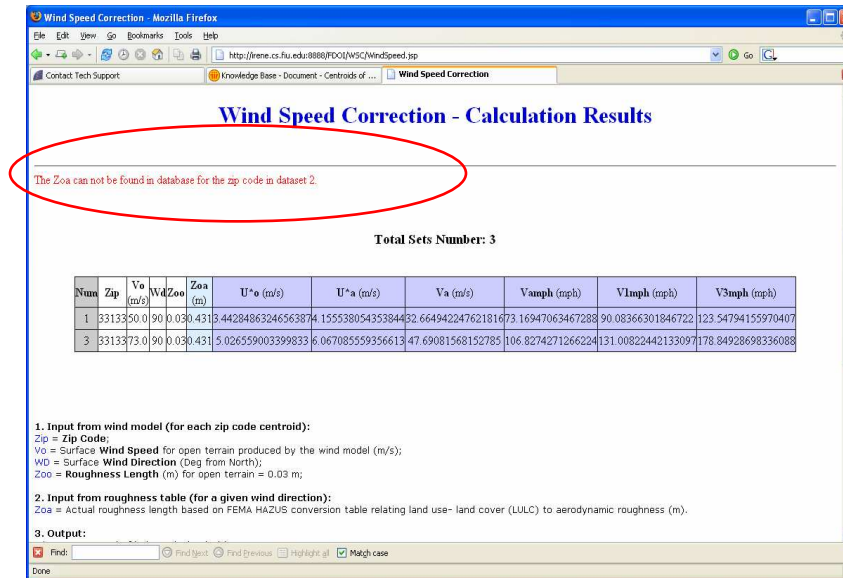
Figure 3.3.21: The result webpage which caught the exception when the Zoa value can not be fetched for some specific Zip code

3.4. Wind Speed Probability (WSP) Use Case VI

3.4.1.   General Description Of WSP

WSP, short for Wind Speed Probability, is the sixth use case of the Florida Hurricane Loss Model. It aims at calculating the probabilities of the 3s gust wind speeds affecting each of the zip codes in the threat area.

3.4.2.   WSP General Requirements

Name: Wind Speed Probability
Description: The user provides the system with the surface corrected wind
speed time series for each of the storm. The wind speeds are
in units of miles per hour (mph).
The system computes the following:
   **(1) For each zip code the annual probability of the maximum
   wind speeds being within the 5 mph interval for all storms
   starting at 22.5 mph and ending at 302.5 mph.**
   **(2) For each zip code the annual probability of the wind speeds
   exceeding the mid-point m for each of the 5 mph interval for
   all storms starting at 22.5 mph and ending at 302.5 mph.**

1. The end user enters the following input data:
    Y: Number of years in simulation
    T: Wind speed time series for each of the storms (one file for each storm)
    Z: All the target zip codes

    Each of the *T* consists of following pertinent information
    Storm_name: Storm name
    Storm_date_time: Storm landfall date and time
    Zip: Zip Code
    V3mph: Surface corrected 3Sec gust wind speed in mph obtained from the WSC
    use case

    A sample input is as follows:
storm0000002 8/19/   1 15:00

Num	Zip	Vo	Wd	Zoo	Zoa	U*o	U*a	Va	V1mph	V3mph
1	32008	21.6816	150	0.03	0.664	1.492	1.857	12.596	38.203	55.113
2	32009	14.6592	163	0.03	0.818	1.009	1.274	7.978	24.786	36.494
3	32011	14.2175	162	0.03	0.699	0.978	1.222	8.132	24.949	36.345
…	…	…	…	…	…	…	…	…	…	…

2. For each of the zip code:
    a. From each storm wind speed time series we select the maximum 3S gust
    wind speed (V3mph).
    b. Wind speeds (V3mph) affecting each of the zip codes for N number of
    storms in the simulation (affecting each zip code) are then sorted in an
    ascending order.
    c. The sorted vector of wind speeds is then distributed into bands of 5 mph
    starting at 22.5 mph and ending at 302.5 mph. Wind speeds over the
    midpoint of each band are assigned to the corresponding bin.

d. Count the number of instances of maximum wind speeds within each of the wind speed bands and below the midpoint of each band.
e. Compute the annual probability of the maximum wind speed being within each band defined by wind speed x (on low side) and z (on high side) as:

$$PVxz = \frac{(\text{Number of Instances of } V3mph \geq x \quad \text{and} < z)}{N}$$

f. Compute the probability of the wind speed exceeding the mid point v of the band as:

$$Pv<v = \frac{(\text{Number of Instances of } V3 \, mph < v)}{N}$$

   N= number of storms affecting that zip code
g. Estimate
   λ = (total #of storms affecting that zip code)/ (# simulation Years)

h. Estimate the probabilities:

$$P(V>v) \qquad = 1 - e^{-\lambda} e^{\lambda Pv}$$

$$\text{Also } P(V < v) = 1 - e^{-\lambda} e^{\lambda(1-Pv)}$$

$$P(z < V < x) = \sum_{n=1}^{\infty} \left(\sum_{j=1}^{n} \frac{n!}{j!(n-j)!} P_{xz}^{j} (1 - P_{xz})^{n-j} \right) \frac{(\lambda)^{n} e^{-\lambda}}{n!}$$

3. Plot histogram and cumulative frequency diagram of maximum wind speeds for each zip code, use x axis with wind speeds at 5 mph resolution starting at 22.5 mph and ending at 302.5 mph.

A sample calculation result is as follows:

```
PVxz = annual probability of a wind(Gust) speed within the band
indicated at left, greater than the first number and less than or equal
to the second number
PV>y = annual probability of the wind(Gust) speed exceeding the mid
point of the band

ZipCode = 41
Gust Band(mph)    Mid-Point    PVxz    Pv
> - =<
22.5- 27.5           25.0           0.017 0.262
27.5- 32.5           30.0           0.022 0.247
32.5- 37.5           35.0           0.022 0.229
37.5- 42.5           40.0           0.023 0.211
42.5- 47.5           45.0           0.022 0.192
47.5- 52.5           50.0           0.019 0.176
52.5- 57.5           55.0           0.017 0.160
57.5- 62.5           60.0           0.017 0.146
62.5- 67.5           65.0           0.017 0.131
```

```
67.5-  72.5          70.0          0.017 0.116
72.5-  77.5          75.0          0.017 0.102
77.5-  82.5          80.0          0.014 0.088
82.5-  87.5          85.0          0.014 0.075
87.5-  92.5          90.0          0.011 0.064
92.5-  97.5          95.0          0.010 0.054
97.5- 102.5         100.0          0.008 0.045
102.5- 107.5        105.0          0.008 0.037
107.5- 112.5        110.0          0.006 0.031
112.5- 117.5        115.0          0.005 0.025
117.5- 122.5        120.0          0.004 0.020
122.5- 127.5        125.0          0.004 0.016
127.5- 132.5        130.0          0.003 0.013
132.5- 137.5        135.0          0.002 0.010
137.5- 142.5        140.0          0.002 0.008
142.5- 147.5        145.0          0.002 0.006
147.5- 152.5        150.0          0.001 0.005
152.5- 157.5        155.0          0.001 0.003
157.5- 162.5        160.0          0.001 0.002
162.5- 167.5        165.0          0.000 0.002
167.5- 172.5        170.0          0.000 0.001
172.5- 177.5        175.0          0.000 0.001
177.5- 182.5        180.0          0.000 0.001
182.5- 187.5        185.0          0.000 0.000
187.5- 192.5        190.0          0.000 0.000
192.5- 197.5        195.0          0.000 0.000
197.5- 202.5        200.0          0.000 0.000
202.5- 207.5        205.0          0.000 0.000
207.5- 212.5        210.0          0.000 0.000
212.5- 217.5        215.0          0.000 0.000
217.5- 222.5        220.0          0.000 0.000
222.5- 227.5        225.0          0.000 0.000
227.5- 232.5        230.0          0.000 0.000
232.5- 237.5        235.0          0.000 0.000
237.5- 242.5        240.0          0.000 0.000
242.5- 247.5        245.0          0.000 0.000
247.5- 252.5        250.0          0.000 0.000
252.5- 257.5        255.0          0.000 0.000
257.5- 262.5        260.0          0.000 0.000
262.5- 267.5        265.0          0.000 0.000
267.5- 272.5        270.0          0.000 0.000
272.5- 277.5        275.0          0.000 0.000
277.5- 282.5        280.0          0.000 0.000
282.5- 287.5        285.0          0.000 0.000
287.5- 292.5        290.0          0.000 0.000
292.5- 297.5        295.0          0.000 0.000
297.5- 302.5        300.0          0.000 0.000
```

3.4.3. Computer Model Design

3.4.3.1. *Use Case View of WSP*

A. Actors:

There is one actor, scientist in WSP.

B. Use Case:

WSP is used to calculate the annual probabilities of the wind speeds lying in a wind speed interval and lying over the mid point the interval.

C. Use Case Diagram:

Scientist

WindSpeedProbabilityUsecase

Figure 3.4.1: Use Case Diagram for WSP

3.4.3.2.   System Design

This section includes the appropriate diagrams to describe the system classes, components, activities and the overall flow chart of WSP.

General Flow Chart of WSP

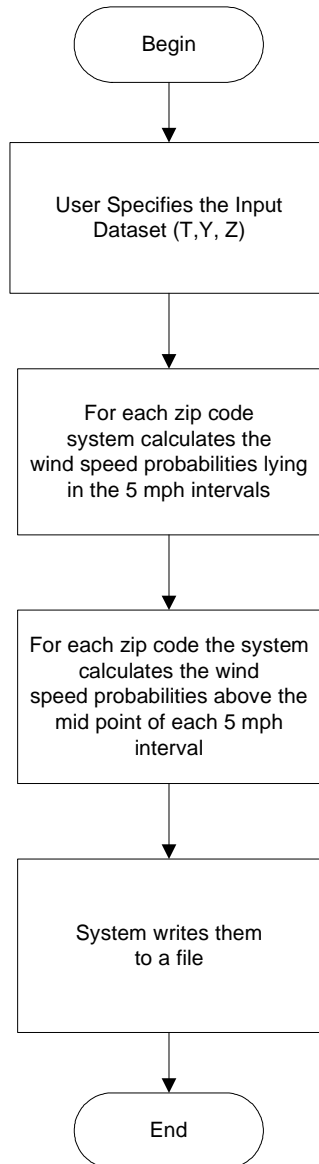The general flow chart of WSP is depicted in Figure 3.4.2.

```
        ┌──────────┐
        │  Begin   │
        └────┬─────┘
             │
             ▼
   ┌────────────────────┐
   │ User Specifies the │
   │  Input Dataset     │
   │    (T,Y, Z)        │
   └─────────┬──────────┘
             │
             ▼
   ┌────────────────────┐
   │  For each zip code │
   │  system calculates │
   │  the wind speed    │
   │  probabilities     │
   │  lying in the      │
   │  5 mph intervals   │
   └─────────┬──────────┘
             │
             ▼
   ┌────────────────────┐
   │ For each zip code  │
   │ the system         │
   │ calculates the     │
   │ wind speed         │
   │ probabilities      │
   │ above the mid      │
   │ point of each      │
   │ 5 mph interval     │
   └─────────┬──────────┘
             │
             ▼
   ┌────────────────────┐
   │  System writes     │
   │  them to a file    │
   └─────────┬──────────┘
             │
             ▼
        ┌──────────┐
        │   End    │
        └──────────┘
```

Figure 3.4.2: Flow chart of WSP

The detailed flow chart of WSP is depicted in Figure 3.4.3.

Start

Count Number of Zip Codes
& Build Zip Codes Array

Loop for Zip Codes

Loop
Y

Max Wind Speed
At One Zip Code (V)

Order Max Wind Speed & Count
# of storms affecting the Zip Code (N)

Sort Max Wind Speed into bands of 5 mph,
Low side (x), high side (z), and middle (v).

Count # of instances of Max Wind Speed
Within x and z (Nxz) and above
Mid point of each band (Nv)

Calculate Probability of Max Wind Speed

Lying In Band
Pxz = Nxz / N

Above the Mid
Pv = Nv / N

Estimate
λ = N / (total # of years in simulation)

Estimate the Probability

$$P(z < V < x) = \sum_{n=1}^{\infty} \left(\sum_{j=1}^{n} \frac{n!}{j!(n-j)!} P_{xz}^{j} (1-P_{xz})^{n-j} \right) \frac{(\lambda)^{n} e^{-\lambda}}{n!}$$

$$P(V>v) = 1 - e^{-\lambda} e^{\lambda P_v}$$

Yes

Finish
Zip Code?

End

No

Y

Figure 3.4.3: Detailed Flow chart of WSP

3.4.3.3.   Calculation of WSP

The implementation for Use Case six (WSP) has been completed and meets the requirements specification. The back end for the implementation of WSP use case has been coded in C++.

Input:
1. Zip codes in threat area
2. For each storm passing within the threat area:
   - Peak max sustained wind speed and associated peak gust wind speed already corrected for the upstream terrain of the zip code
   - Storm name, date, and time for each peak wind

Implementation:
(1)   For each zip code:
(2)   For each storm, select the maximum 3s Gust wind speed (V3mph)

   Note: These wind speeds are in units of miles per hour and should already have been corrected for roughness.

(3)   Order according to the peak maximum sustained wind speeds of all storms affecting the zip code from low to high
(4)   Count the number of instances of maximum wind speeds within each wind speed band and above the mid point of each band.
(5)   Estimate P_v, probability of the maximum wind speed being less than mid point v as:

   $P_v = (\text{Count } V < v) / N$
   Where N = Number of Storms affecting that Zip code

   Estimate:
   $P(z < V < x) = P_{xz} = \text{Count } (z < V < x)/N$

(6)   Estimate:
   $\lambda = (\text{total \# of storms affecting that zip code})/(\text{total \# of years in simulation})$
   $\lambda = N / (\text{total \# of years in simulation})$

(7)   Compute the probabilities:
   $P(V > v) = 1 - e^{-\lambda} e^{\lambda P v}$
   Also:
   $P(V < v) = 1 - e^{-\lambda} e^{\lambda(1 - Pv)}$

(8) $P(z < V < x) = \sum_{n=1}^{\infty} \left(\sum_{j=1}^{n} \frac{n!}{j!(n-j)!} P_{xz}^{j} (1 - P_{xz})^{n-j} \right) \frac{(\lambda)^{n} e^{-\lambda}}{n!}$

This above equation is going to require a program – however, as n gets large, the Poisson probabilities should start to go to 0 and therefore, the sum might not be too formidable. So the maximum limit of n is taken as 13.
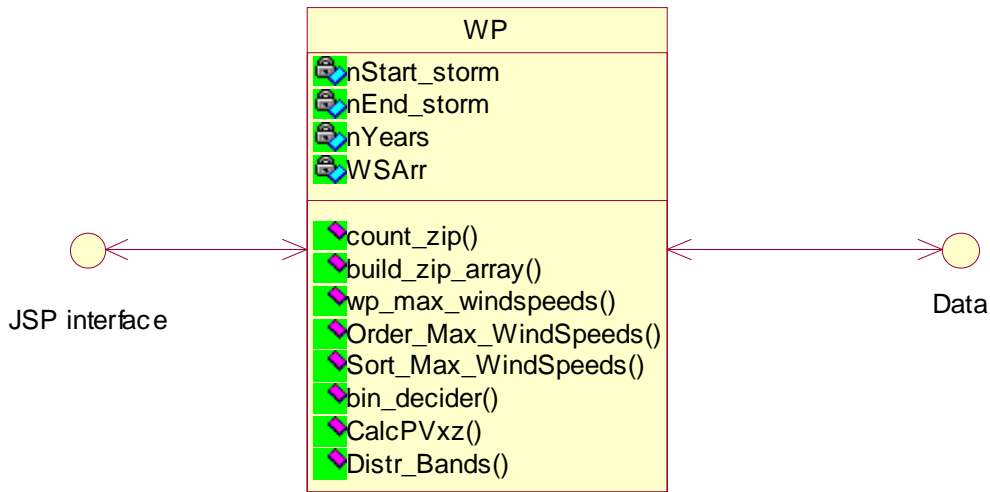
3.4.3.4.   Class Diagram

Figure 3.4.4: Class Diagram for WSP

3.4.3.5.   Class Description

WP class performs all the calculations needed for WSP use case. It includes following methods.

- **count_zip()**

Read the zipcodes.txt file to count and return the number of lines in the file.

- **build_zip_array()**

Read the zipcodes.txt file and store the zip codes in to an array

- **wp_max_windspeeds()**

Search through one storm to find the maximum 3s Gust wind speeds at each zip code and record it as intermediate output. Iterate this process through all storms.

- **Order_Max_WindSpeeds()**

Search through all the storms and record (in an array) the maximum wind speed for specified zip for each storm.

- **Sort_Max_WindSpeeds()**

Sort the wind speed array in descending order

- **bin_decider()**

maps the specified wind speed to a bin

- **Distr_Bands()**

Estimates the wind speed probabilities of the wind speeds lying in the band (PVxz) and above the midpoint of the band (Pv>y)

- **CalcPVxz()**

Calculate the wind probabilities Pv and PVxz and produces the CalcP__.txt output file.
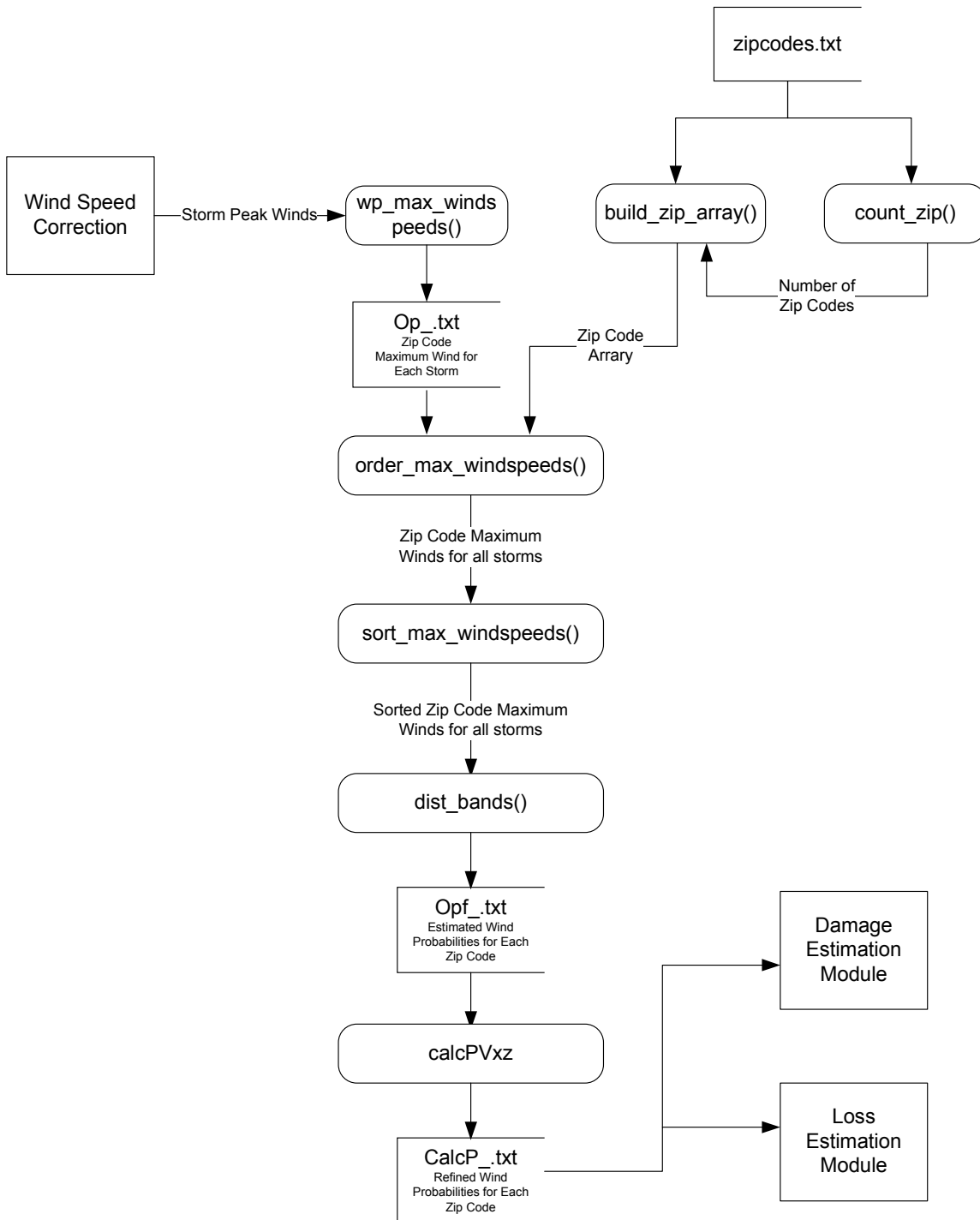
3.4.3.6. *Data Flow Diagram*

Figure 3.4.5: Data Flow Diagram for WSP

3.4.3.7.   State Chart Diagram

Figure 3.4.6 depicts the state chart diagram for WSP use case. This diagram illustrates that the use case goes through from beginning to end.
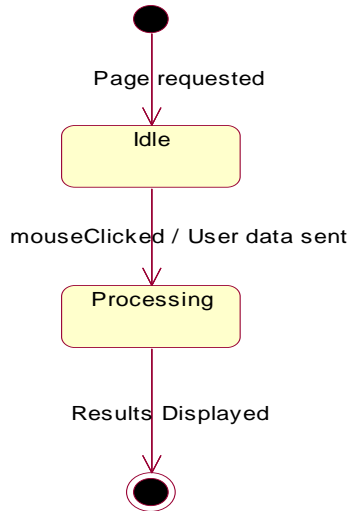

Figure 3.4.6: State Chart for WSP
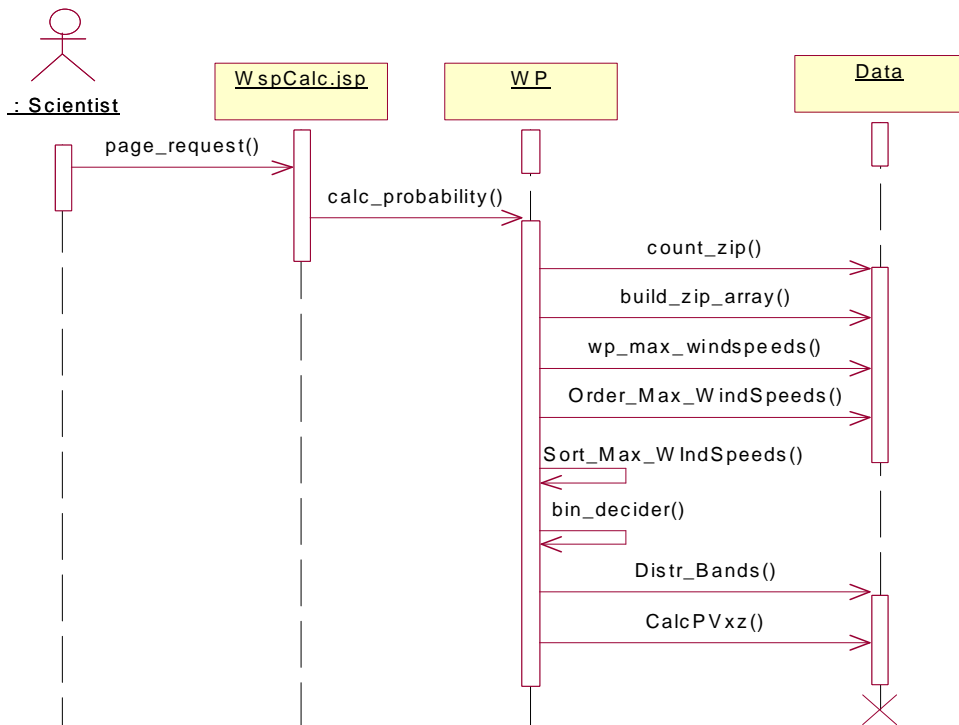
3.4.3.8.   Sequence Diagram

Figure 3.4.7: State Chart for Wind Probability Calculation Process
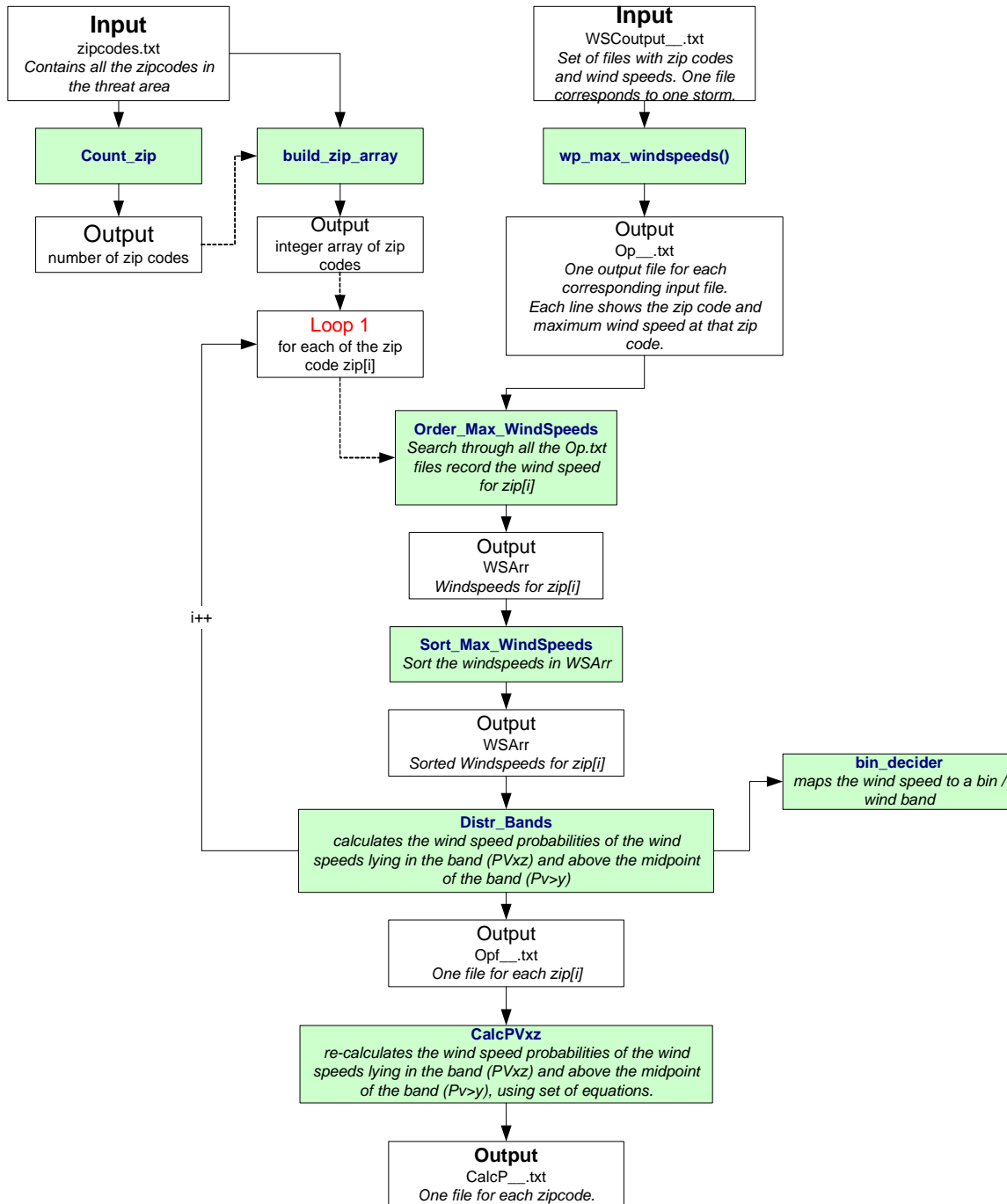
3.4.3.9. Program Flow Chart

Input
zipcodes.txt
Contains all the zipcodes in the threat area

Input
WSCoutput__.txt
Set of files with zip codes and wind speeds. One file corresponds to one storm.

Count_zip

build_zip_array

wp_max_windspeeds()

Output
number of zip codes

Output
integer array of zip codes

Output
Op__.txt
One output file for each corresponding input file. Each line shows the zip code and maximum wind speed at that zip code.

Loop 1
for each of the zip code zip[i]

Order_Max_WindSpeeds
Search through all the Op.txt files record the wind speed for zip[i]

Output
WSArr
Windspeeds for zip[i]

Sort_Max_WindSpeeds
Sort the windspeeds in WSArr

Output
WSArr
Sorted Windspeeds for zip[i]

bin_decider
maps the wind speed to a bin / wind band

i++

Distr_Bands
calculates the wind speed probabilities of the wind speeds lying in the band (PVxz) and above the midpoint of the band (Pv>y)

Output
Opf__.txt
One file for each zip[i]

CalcPVxz
re-calculates the wind speed probabilities of the wind speeds lying in the band (PVxz) and above the midpoint of the band (Pv>y), using set of equations.

Output
CalcP__.txt
One file for each zipcode.

Figure 3.4.8: Unit flow diagram

3.4.4.   Implementation of WSP

WSP is online at http://www.cs.fiu.edu/PHRLM.

3.4.4.1.   Login page:

Users need username/password to access the *Florida Hurricane Loss Model*. Following is a snapshot of the login web page.
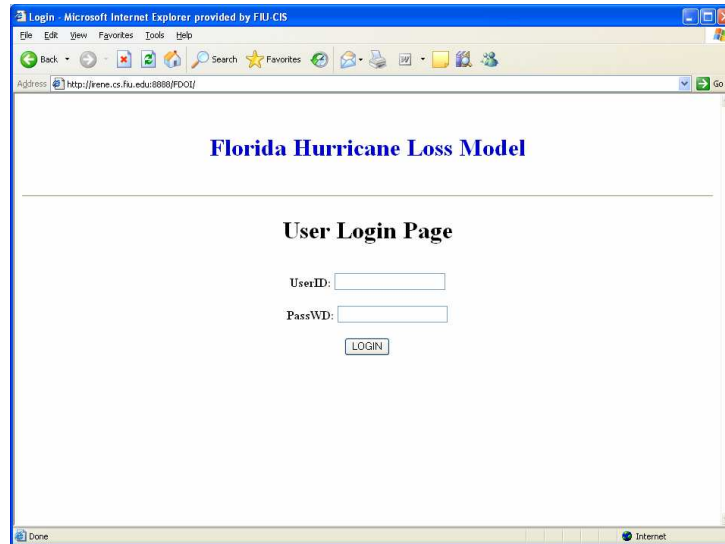

Figure 3.4.9. Login webpage for FHLM

If the username/password is wrong, an error message will be displayed. User will be required to input the username and password again to enter.
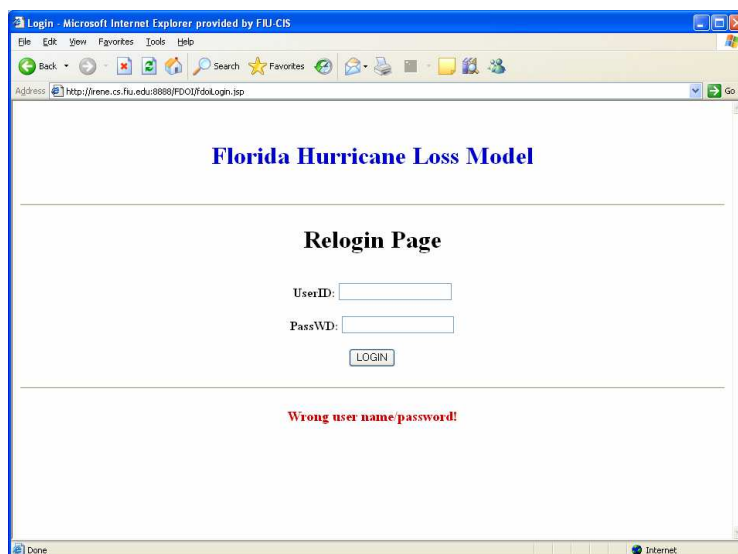
Figure 3.4.10. Login webpage shows the inputted user ID or password is wrong

3.4.4.2.   WSP page:

If the login is successful, the user can see the web page named "Service Selection Page" (as shown in Figure 3.4.11). To view the WSP use case page, from the drop-down list, select "Wind Speed Probability" and click "Go" button.
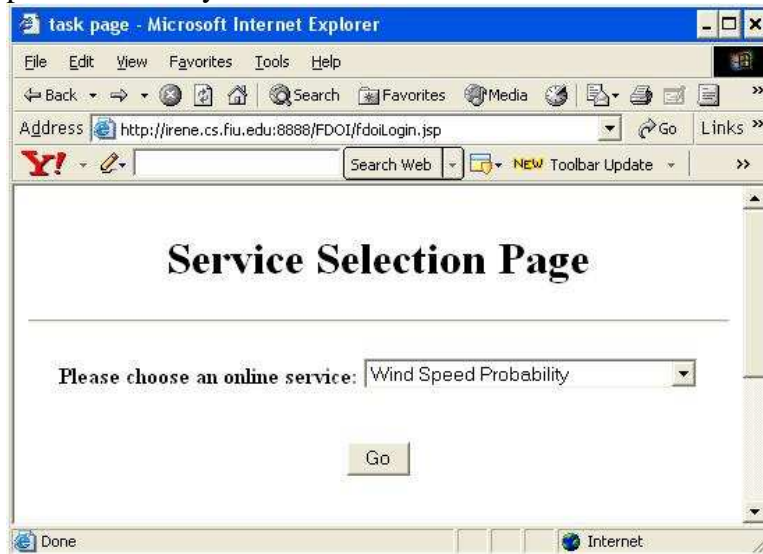

Figure 3.4.11: Service Selection Page
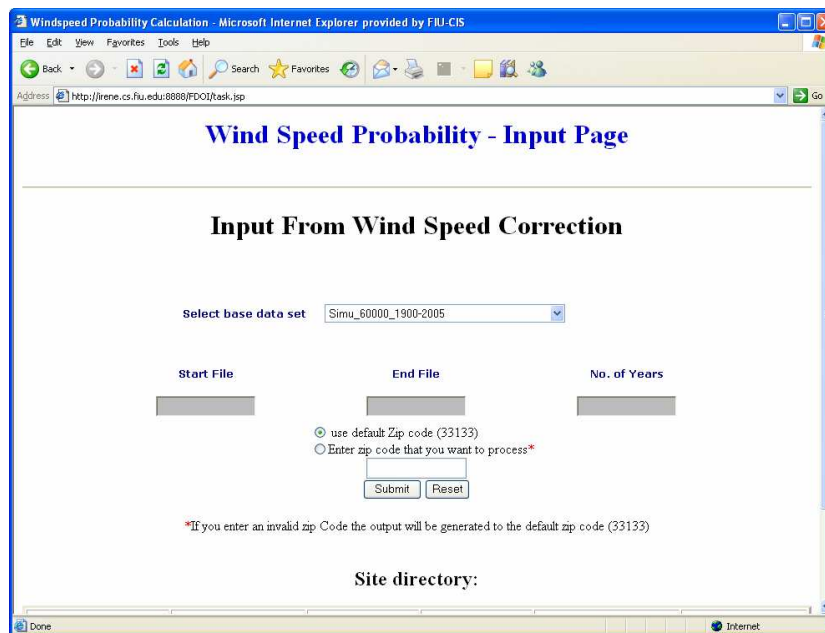
3.4.4.3.   WSP input selection

Figure 3.4.12: Input Selection page

User should select the input from the available list of simulations. Then the user has the option of entering a zip code in order to view a summery of results for that zip code. In order to do this, user has to click on the "Enter zip code that you want to process" radio button and then type the required zip code in the input box provided below. If the user doesn't want to enter any specific zip code just press "Submit" button.

3.4.4.4.   WSP results page

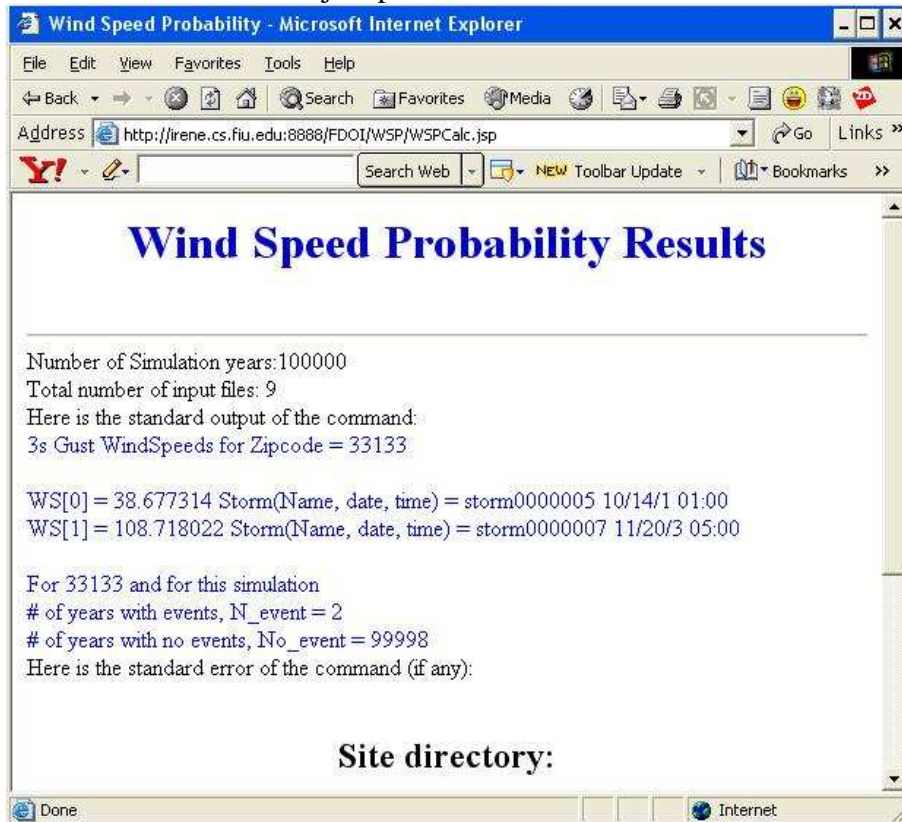Note: The results listed below are just placeholders. Actual values will be different.

Figure 3.4.13: WSP results page

3.4.4.5. Results of WSP

Results for zip code: 41

```
ZipCode = 41
Gust Band(mph)    Mid-Point    PVxz    Pv
 >  -  =<
22.5- 27.5          25.0        0.017 0.262
27.5- 32.5          30.0        0.022 0.247
32.5- 37.5          35.0        0.022 0.229
37.5- 42.5          40.0        0.023 0.211
42.5- 47.5          45.0        0.022 0.192
47.5- 52.5          50.0        0.019 0.176
52.5- 57.5          55.0        0.017 0.160
57.5- 62.5          60.0        0.017 0.146
62.5- 67.5          65.0        0.017 0.131
67.5- 72.5          70.0        0.017 0.116
72.5- 77.5          75.0        0.017 0.102
77.5- 82.5          80.0        0.014 0.088
82.5- 87.5          85.0        0.014 0.075
87.5- 92.5          90.0        0.011 0.064
92.5- 97.5          95.0        0.010 0.054
97.5- 102.5        100.0        0.008 0.045
102.5- 107.5       105.0        0.008 0.037
107.5- 112.5       110.0        0.006 0.031
112.5- 117.5       115.0        0.005 0.025
117.5- 122.5       120.0        0.004 0.020
122.5- 127.5       125.0        0.004 0.016
127.5- 132.5       130.0        0.003 0.013
132.5- 137.5       135.0        0.002 0.010
137.5- 142.5       140.0        0.002 0.008
142.5- 147.5       145.0        0.002 0.006
147.5- 152.5       150.0        0.001 0.005
152.5- 157.5       155.0        0.001 0.003
157.5- 162.5       160.0        0.001 0.002
162.5- 167.5       165.0        0.000 0.002
167.5- 172.5       170.0        0.000 0.001
172.5- 177.5       175.0        0.000 0.001
177.5- 182.5       180.0        0.000 0.001
182.5- 187.5       185.0        0.000 0.000
187.5- 192.5       190.0        0.000 0.000
192.5- 197.5       195.0        0.000 0.000
197.5- 202.5       200.0        0.000 0.000
202.5- 207.5       205.0        0.000 0.000
207.5- 212.5       210.0        0.000 0.000
212.5- 217.5       215.0        0.000 0.000
217.5- 222.5       220.0        0.000 0.000
222.5- 227.5       225.0        0.000 0.000
227.5- 232.5       230.0        0.000 0.000
232.5- 237.5       235.0        0.000 0.000
237.5- 242.5       240.0        0.000 0.000
242.5- 247.5       245.0        0.000 0.000
247.5- 252.5       250.0        0.000 0.000
252.5- 257.5       255.0        0.000 0.000
257.5- 262.5       260.0        0.000 0.000
262.5- 267.5       265.0        0.000 0.000
```

```
267.5- 272.5        270.0           0.000  0.000
272.5- 277.5        275.0           0.000  0.000
277.5- 282.5        280.0           0.000  0.000
282.5- 287.5        285.0           0.000  0.000
287.5- 292.5        290.0           0.000  0.000
292.5- 297.5        295.0           0.000  0.000
297.5- 302.5        300.0           0.000  0.000
```
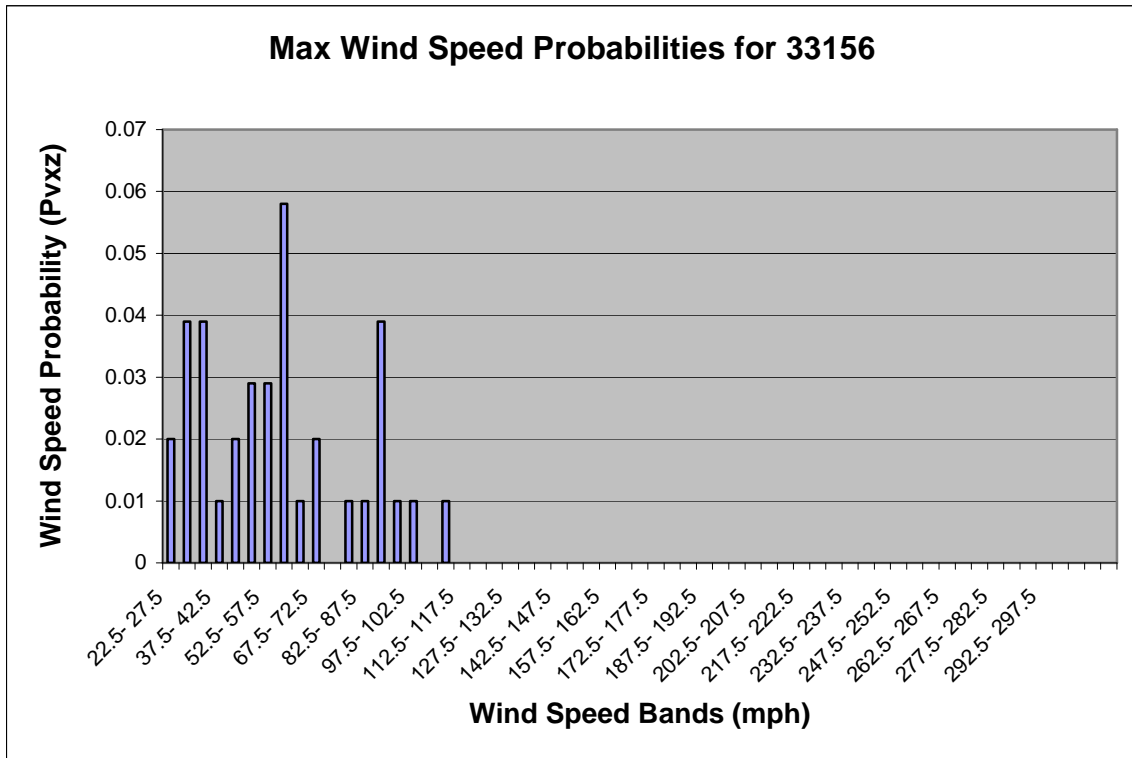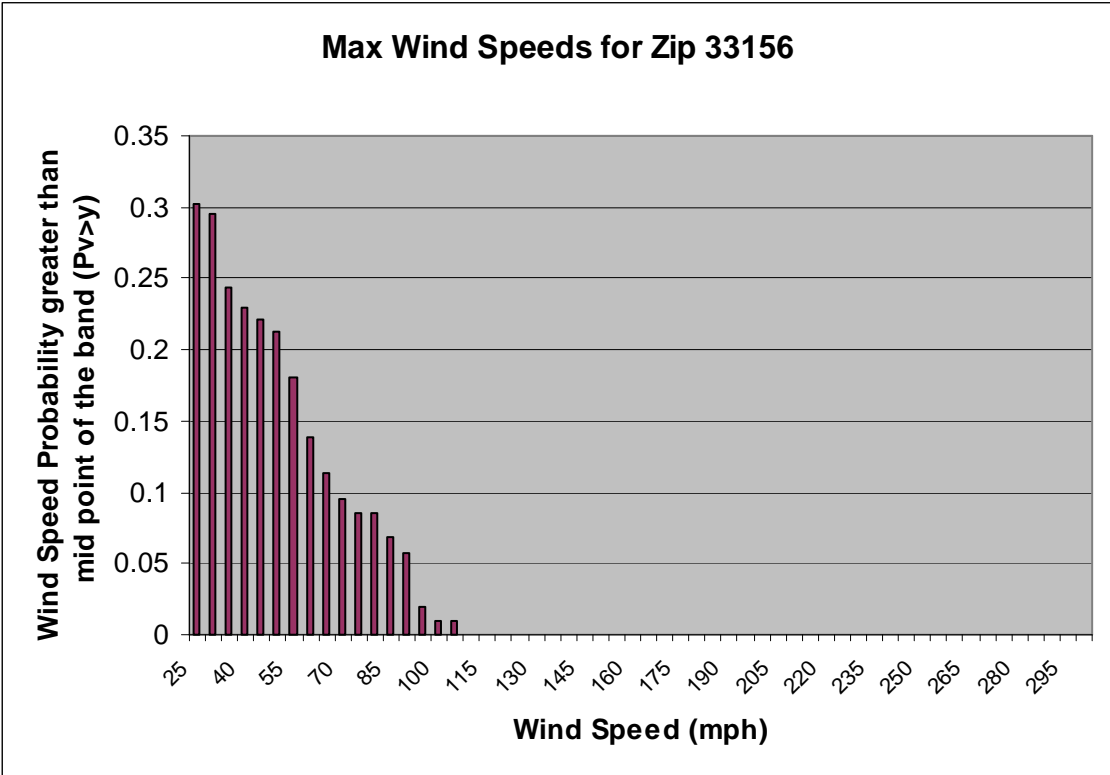

Figure 3.4.14: Histogram for PVxz

Figure 3.4.15: Histogram for PV>y

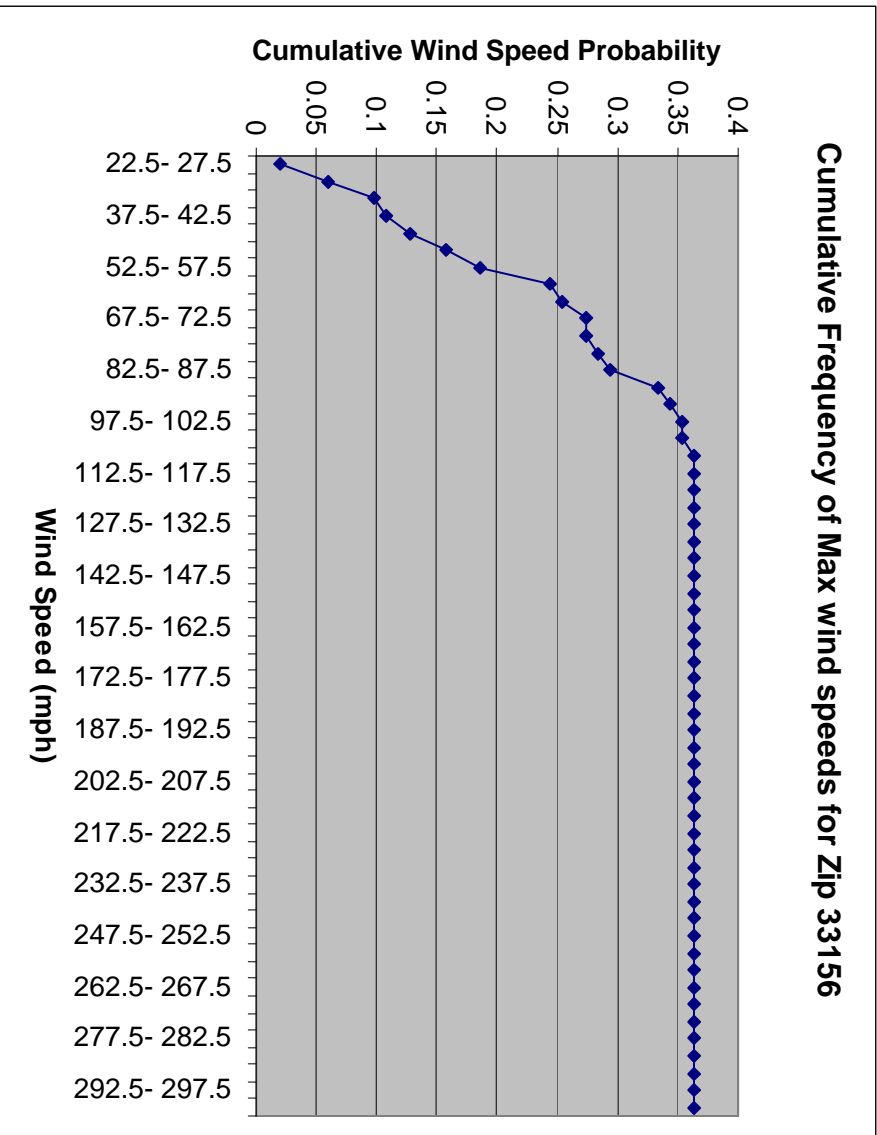**Cumulative Frequency of Max wind speeds for Zip 33156**

Figure 3.4.16: Cumulative frequency diagram for maximum wind speed probabilities for zip code 33156.