Wind field model Documentation

1. General Description

Input: storm track
Category, Centre pressure, Rmax, Longitude, Latitude, lsflg, Holland B, date & time for each of hourly fixes of the storm

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Wind field Model

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Output:
• Landfall or bypassing location (i.e. longitude/latitude) of storm   • Maximum OT wind speed/time/direction anywhere in the storm   • Maximum Marine Exposure anywhere in the storm   • Maximum wind speed/time/direction at each zip code affected by the storm

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 with the hurricane vortex moving at velocity **c**. The vortex translation is assumed to equal the geostrophic 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:

$$\frac{u\partial u}{\partial r} - \frac{v^2}{r} - fv + \frac{v}{r}\frac{\partial u}{\partial \phi} + \frac{\partial p}{\partial r} - K\,\nabla^2 u - \frac{u}{r^2} - \frac{2}{r^2}\frac{\partial u}{\partial \phi} + F\big(\overset{\ulcorner}{c},u\big) = 0 = \frac{\partial u}{\partial t}$$

(1)

$$u\,\frac{\partial v}{\partial r} + \frac{v}{r} + fu + \frac{v}{r}\frac{\partial v}{\partial \phi} - K\,\nabla^2 v - \frac{v}{r^2} + \frac{2}{r^2}\frac{\partial u}{\partial \phi} + F\big(\overset{\ulcorner}{c},v\big) = 0 = \frac{\partial v}{\partial t}$$

(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 windfield 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.
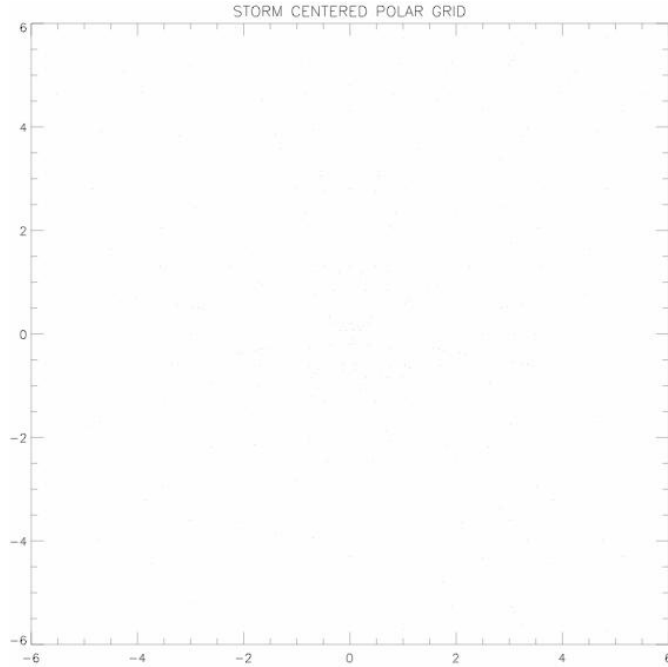
Figure 1. Polar coordinate system for solving equations of motion.

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 radially 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.
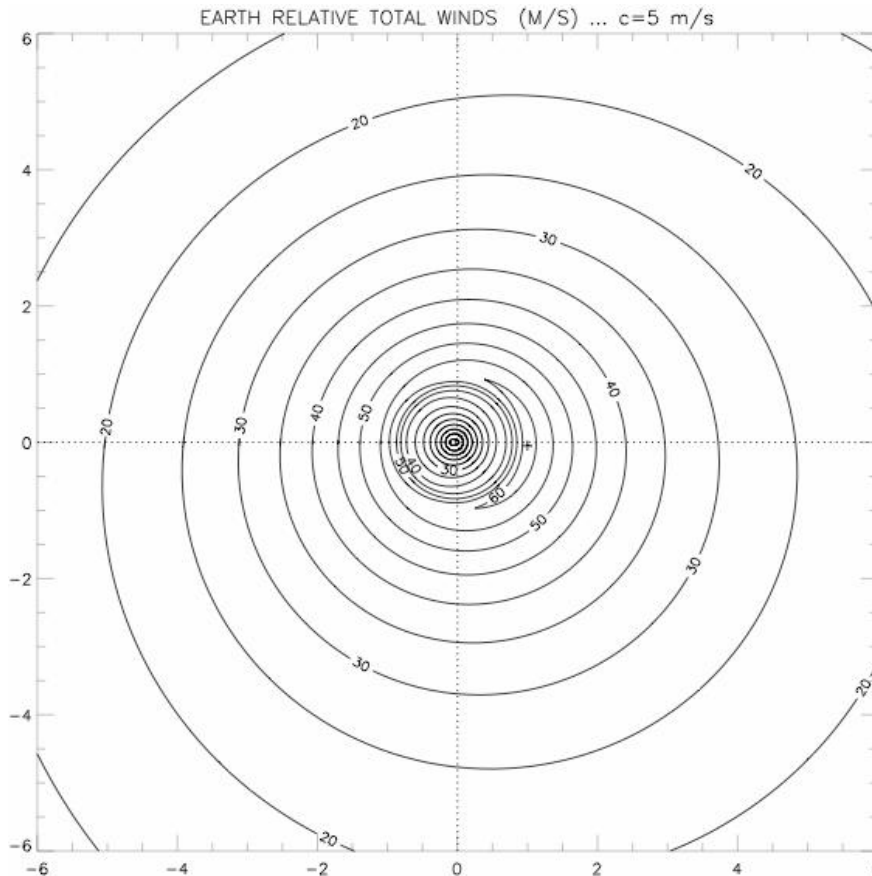
Figure 2. Horizontal distribution of mean boundary layer wind speed (m s^{-1}) relative to the earth for a Hurricane moving northward (top of page) at 5 m s^{-1}. Horizontal coordinates are scaled by the radius of maximum wind.

2. Input format

The input to the wind field model is a track file (usecase-3 output) for each of the storms containing the storm category, landfall date (month, day, year) and time (Hr Min), latitude-longitude, radius of the maximum wind, Holland B parameter and the Land or Sea flag. File format is explained below.

<number of fixes>
<storm Number><m/d/ yyyy > <hh: mm>
<storm category><year><mmdd><hh><minute><latitude><longitude><center pressure><R$_{max}$><Holand>
<lsflg>

```
Eg:
13
storm00001   8/24/ 1992   05:00
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
```

2.1 Wind Model Parameters.

Following are the input parameters to the wind field model

2.1.1 Delta P : Intensity parameter

This is the difference between the central minimum sea level pressure and an outer peripheral pressure. (assumed to be 1012 hPa). Intensity change is modeled by using the observed geographic probability distribution of six-hour changes of central pressure as related to the relative intensity. Potential intensity takes into account the concept of the hurricane as a heat engine constrained by the input (sea

surface) and outflow (upper troposphere) temperatures. Intensity change is limited so as to not exceed the maximum observed change for a particular geographic region. When a storm center crosses the coastline (landfall) the intensity change follows a pressure decay model (discussed below). If the storm moves back over the sea, the former intensity change model is reinstated.

2.1.2 R max : Radius of Maximum Wind

The radius of maximum wind is determined from a distribution of values as a function of p_o and latitude, where p_o is the central minimum sea level pressure. A log normal distribution is assumed for R with a mean value determined as a function of Δp and Latitude. The relationship between R and Δp and latitude shows much scatter but a generalized linear model for the natural log of R ($r^2 = 0.212$) provides a useful estimation:

$$\Delta p = 1013 - p_o$$
$$\ln R_{max} = 2.0633 + 0.0182\Delta p - 0.00019008\Delta p^2 + 0.0007336 Lat^2 + \varepsilon \tag{3}$$

Where ε is a normal random variable with a mean of zero and a variance of 0.169. Equation (3) describes the mean of the log normal distribution of R in nautical miles. When a simulated storm is close enough to land to become a threat, an R-value is randomly chosen given the Δp and Latitude. R is computed at each time step but the random error term is computed only once for each landfall.

Rmax in nautical miles is calculated as follows:

$$R_{max} = e^{\ln(R_{max})}$$

2.1.3 Pressure Profile & Holland B

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

$$p(r) = p_o + \Delta p e^{\frac{R_{max}}{r}^B} \tag{4}$$

where p_o 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 defined earlier. The central pressure is modeled according to the intensity modeling in concert with the storm track. The resulting expression for B is:

$$B = 1.38 + 0.00184\Delta p - 0.00309 R_{max} + \varepsilon \tag{5}$$

Where ε is a random term from a zero mean normal distribution with a standard deviation of 0.05.
Note: B has been calculated using equation (5) and saved in trackfile. Equation (5) used in the source code (TRACK.PRO) is to modify B when $B = 0$ (It rarely happens).

2.1.4 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
> 4 – Closest Approach of bypassing Storm

3. Definitions and Implementation of the wind model

3.1 Definitions and Equations

R = Radius of maximum surface wind speed, specified

c_t = storm translation speed, specified

cdir = storm translation direction compass heading , specified

Δp = Central pressure deficit, specified

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

$B = 1.38 + 0.00184\Delta p - 0.00309R$ = Holland profile parameter

ϕ = Azimuthal coordinate, measured counterclockwise from east

$s = \dfrac{r}{R} =$ 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

$v(s,\phi) = \dfrac{v}{V_{g\,max}} =$ Normalized storm-relative tangential wind component

$u(s,\phi) = \dfrac{u}{V_{g\,max}} =$ Normalized storm – relative radial wind component

α = Friction coefficient = $\dfrac{RC_d}{h}$

h= mean boundary layer height

C_d = Drag Coefficient

$c = \dfrac{c_t}{V_{g\,max}}$ = 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 $\bar{f}$.

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

3.2 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:

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

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

$$v = v_0 + \sigma$$

$$w^* = 0.8\sqrt{u^2 + v^2}$$

$$w = w^*(1 + \beta w^*) \qquad \beta = 0.132653 \tag{A8}$$

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:

$$u(s,\phi) = ffu(\phi)u(s) \tag{A9}$$
$$\sigma(s,\phi) = ff\sigma(\phi)\sigma(s) \tag{A10}$$

where the azimuthal dependence is introduced through the form factors:

$$ffu(\phi) = a_0 + a_1 \cos\phi + a_2 \sin\phi \tag{A11}$$
$$ff\sigma(\phi) = b_0 + b_1 \cos\phi + b_2 \sin\phi \tag{A12}$$

Now the six coefficients a_0, a_1, a_2 and b_0, b_1, b_2 can be variationally determined by substituting A9 and A10 into the left hand sides of A3 and A4, supplemented by A5 to form the "residuals" RA3 and RA4. We then form the functional:

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

$$|RA4| = |(A4)| = |u\partial_s \sigma + s^{-1}(v_o + \sigma)\partial_\phi \sigma + u(d + s^{-1}\sigma) + \alpha(v_o + \sigma + c\cos\phi)(w - c)|$$

$$J(a,b) = \frac{|RA3| + |RA4|}{NGRID} \tag{A13}$$

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 a_0, a_1, a_2 and b_0, b_1, b_2. 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:

$$\text{ur}(s,\phi) = u(s,\phi) \text{ and } \text{vt}(s,\phi) = v_g(s) + \sigma(s,\phi) \tag{A14}$$

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 :

$$\text{uer}(s,\phi) = \text{ur}(s,\phi) + c\sin\phi \tag{A15}$$
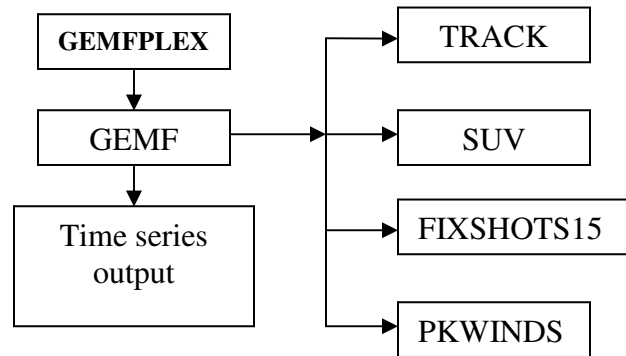$$\text{ver}(s,\phi) = \text{vt}(s,\phi) + c\cos\phi \tag{A16}$$

where c is the normalized translation speed $c = c_t/\text{Vgmax}$.

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.

4. Wind field model Implementation: IDL Code

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.

```
GEMFPLEX  ──────────┐        ┌──►  TRACK
    │                │        │
    ▼                └────────┼──►  SUV
  GEMF  ─────────────►        │
    │                         ├──►  FIXSHOTS15
    ▼                         │
Time series                   └──►  PKWINDS
 output
```

General structure or flow of the IDL Main Modules

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.
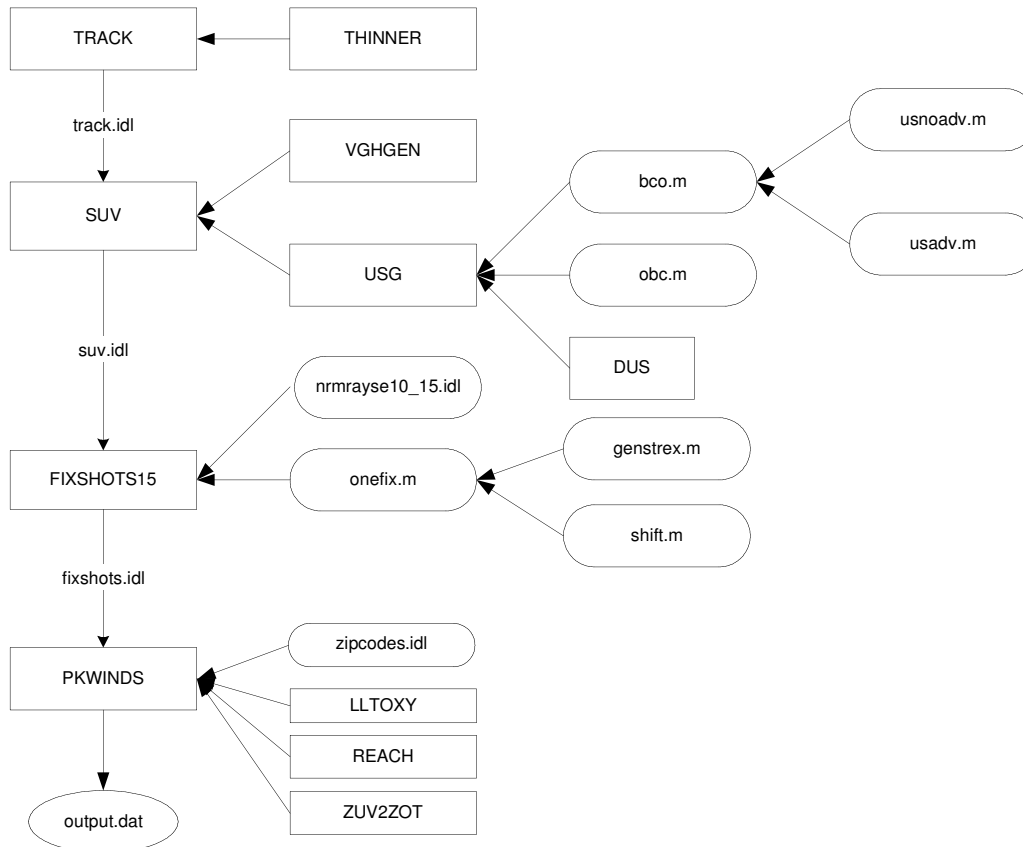
Wind model code (IDL code) flowchart

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. Smoothens 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 reduces the number of fixes depending upon the storm intensity.
1. Locate landfalls, sea falls and minimum pressure point.
2. Classify fixes by category
3. Thin out the fixes as below;
    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
4. Merge retained fixes and additional landfall and seafall fixes.

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. If Holland b is zero calculate it using $B = 1.38 + 0.00184\Delta p - 0.00309R$ (this step is rarely done)
3. 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)
4. Calculates the gradient wind profile for each fix using VGHGEN.PRO
5. Calculate g and d using equation (A1) and (A2).
6. Calculate initial estimate for alpha (alfi) neglecting first derivatives of u and σ.
7. Alpha is iteratively estimated until correct alpha is obtained (USG.PRO is used). To check the correctness of the estimate the boundary condition following boundary condition is used.
        Peak wind should be at s=1. (i.e. if iw is 10 answer of alpha is correct)
8. If a correct alpha value is not reached using the above method special matching is done.
9. Momentum equations are used to furnish tangential and radial profiles. USG.PRO
10. Collects radial and tangential profiles into a structure.
11. 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 using (BCO.M). Then the results are combined to get the complete profile.

1. Form the wind profile near the origin using bco.m (uout, sgout, 'sg' stands for Sigma)
2. Form the wind profile inward from s=20 using obc.m (uinw, sginw)
3. Numerically integrate momentum equations for stationary storm profiles.
4. Match solutions across the shock and obtain uz and sgz.

    For $0 \le s \le 1$;   uz = uout
                            sgz = sgout
    for $1 < s \le 20$;   uz = uinw
                            sgz = sginw

5. Sub-grid smoothing process simulates turbulent diffusion.
6. Subsample to recover original resolution.
7. Quasi-linear revision process.
    This is done in order to eliminate some possible dips in u and sg for s>15.

vi.   BCO.M
Form the solution for u and sg outward from the polar origin.

1. Recursively calls USNOADV.M to algebraically solve u and sigma. (Five recursions are enough to get accurate solution)
2. Recursively call USADV.M to improve the results.

vii.   USNOADV.M
Ignore radial advection and algebraically solve for u and sigma (equation (A6) (A7)) starting the numerical integration outwards from the origin.

viii.   USADV.M
This module iteratively improves the results of USNOADV.M by including radial advection terms (first derivatives) evaluated from the previous iteration.

ix.   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, A8).

x.   DUS.PRO
Calculates radial derivatives from momentum equations. (A6)(A7)(A8)

    $vz = v_0 + sg$ $dz = d + sg/s$ $gz = g + sg/s$
    du = first derivative of u
    dsg = first derivative of sigma

xi.   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)
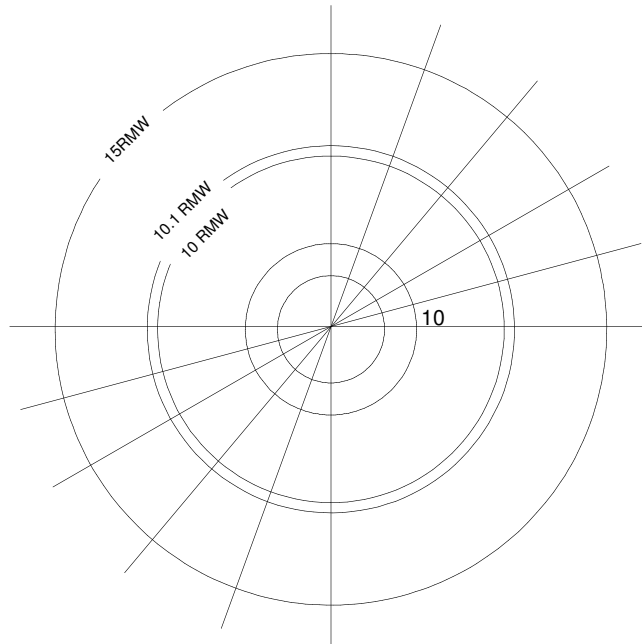
Figure: Polar grid

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 radial winds and vsnap contains the earth relative tangential 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.
9. Save field snap shots and time derivatives at each fix in fixshots.idl

xii. 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 ZMAR2ZOP 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. ZUV2ZOT.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 stamp and call the executable.
1. set the timestep 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…)

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

5.1 Land falling storms
```
ANDREW  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
```

5.2 Bypassing Storms
For a storm that does NOT make landfall but passes close enough to a zip code to do damage:

1. For each affected zip code, find the peak OT wind and the date/time of this peak wind speed

2. find the track positions closest to the time of the peak zip code wind speed and choose the fix with the lowest central pressure. Use the fix information to compute the maximum marine (MA) exposure wind speed in the storm.

3. Label this storm as "By-Passing" in the header and include the MA wind speed and date/time.

4. Include the zip code information identical to that done with the storms that make landfall.

This method will not include storms that bypass and then make landfall further along the track, or landfall and then bypass further along the track.

```
DAVID   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)
 OT       1      8      15      6.55432     -6.86560      9.49187      316
```