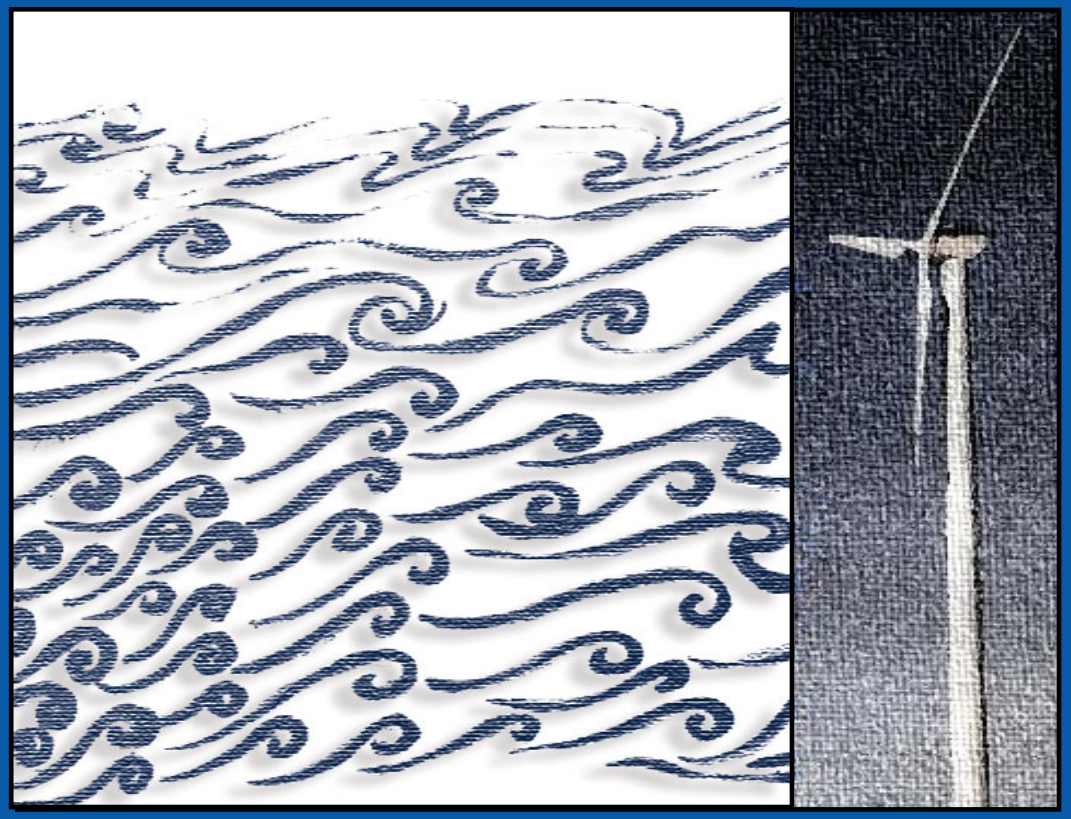
National Renewable Energy Laboratory
Innovation for Our Energy Future

Using TurbSim: The Meteorological Boundary Conditions



TurbSim Workshop
National Wind Technology Center

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September 23, 2008

Presentation Outline

- TurbSim Input File
- Meteorological Inputs
  - Meteorological Boundary Conditions Section
  - Non-IEC Meteorological Boundary Conditions Section
  - Input Parameters
    - Definitions
    - Default values
    - What they do
- Conclusions

The TurbSim Input File

- The TurbSim Input File for version 1.40: TurbSim.inp
  - All values needed to run TurbSim are contained in a single text file
  - Parameters are assumed to be on specific lines
  - Character strings are not case sensitive

Sample TurbSim Input File

```
TurbSim Input File. Valid for TurbSim v1.40, 12-Sep-2008

---------Runtime Options-----------------------------------
2318573             RandSeed1       - First random seed  (-2147483648 to 2147483647)
RANLUX              RandSeed2       - Second random seed (-2147483648 to 2147483647) for intrinsic pRNG, or a
False               WrBHHTP         - Output binary hub-height turbulence parameters?  (Generates RootName.bi
False               WrFHHTP         - Output formatted hub-height turbulence parameters?  (Generates RootName
False               WrADHH          - Output formatted AeroDyn hub-height time-series data?  (Generates RootN
False               WrADFF          - Output binary TurbSim/AeroDyn full-field time-series data? (Generates R
True                WrBLFF          - Output binary BLADED/AeroDyn full-field time-series data?  (Generates R
False               WrADTWR         - Output binary tower time-series data? (Generates RootName.twr)
False               WrFMTFF         - Output formatted full-field time-series data?  (Generates RootName.u, R
True                WrACT           - Output formatted AeroDyn coherent turbulence time steps? (Generates Roo
True                Clockwise       - Clockwise rotation looking downwind? (used only for full-field binary f
True                ScaleIEC        - Scale hub-height IEC turbulence to target TI?

--------Turbine/Model Specifications-----------------------
13                  NumGrid_Z       - Vertical grid-point matrix dimension
13                  NumGrid_Y       - Horizontal grid-point matrix dimension
0.05                TimeStep        - Time step [seconds]
600                 AnalysisTime    - Length of analysis time series [seconds] (program will add time if nece
40                  UsableTime      - Usable length of output time series [seconds] (program will add GridWid
84.2876             HubHt           - Hub height [m] (should be > 0.5*GridHeight)
80.00               GridHeight      - Grid height [m]
80.00               GridWidth       - Grid width [m] (should be >= 2*(RotorRadius+ShaftLength))
0                   VFlowAng        - Vertical mean flow (uptilt) angle [degrees]
0                   HFlowAng        - Horizontal mean flow (skew) angle [degrees]

--------Meteorological Boundary Conditions-------------------
"SMOOTH"            TurbModel       - Turbulence model ("IECKAI"=Kaimal, "IECVKM"=von Karman, "GP_LLJ", "NWTC
"1-ED3"             IECstandard     - Number of IEC 61400-x standard (x=1,2, or 3 with optional 61400-1 editi
"A"                 IECturbc        - IEC turbulence characteristic ("A", "B", "C" or the turbulence intensit
"NTM"               IEC_WindType    - IEC turbulence type ("NTM"=normal, "xETM"=extreme turbulence, "xEWM1"=e
default             ETMc            - IEC Extreme Turbulence Model "c" parameter [m/s]
default             WindProfileType - Wind profile type ("JET","LOG"=logarithmic,"PL"=power law,"IEC"=PL on r
84.2876             RefHt           - Height of the reference wind speed [m]
18.2                URef            - Mean (total) wind speed at the reference height [m/s] (or "default" for
default             ZJetMax         - Jet height [m] (used only for JET wind profile, valid 70-490 m)
default             PLExp           - Power law exponent [-] (or "default")
default             Z0              - Surface roughness length [m] (or "default")

--------Non-IEC Meteorological Boundary Conditions-----------
default             Latitude        - Site latitude [degrees] (or "default")
0.05                RICH_NO         - Gradient Richardson number
default             UStar           - Friction or shear velocity [m/s] (or "default")
default             ZI              - Mixing layer depth [m] (or "default")
default             PC_UW           - Hub mean u'w' Reynolds stress (or "default")
default             PC_UV           - Hub mean u'v' Reynolds stress (or "default")
default             PC_VW           - Hub mean v'w' Reynolds stress (or "default")
default             IncDec1         - u-component coherence parameters (e.g. "10.0  0.3e-3" in quotes) (or "d
default             IncDec2         - v-component coherence parameters (e.g. "10.0  0.3e-3" in quotes) (or "d
default             IncDec3         - w-component coherence parameters (e.g. "10.0  0.3e-3" in quotes) (or "d
default             CohExp          - Coherence exponent (or "default")

--------Coherent Turbulence Scaling Parameters-------------------
"M:\coh_events\eventdata"  CTEventPath     - Name of the path where event data files are located
"Random"            CTEventFile     - Type of event files ("LES", "DNS", or "RANDOM")
true                Randomize       - Randomize the disturbance scale and locations? (true/false)
 1.0                DistScl         - Disturbance scale (ratio of billow height to rotor disk). (Ignored when
 0.5                CTLy            - Fractional location of tower centerline from right (looking downwind) t
 0.5                CTLz            - Fractional location of hub height from the bottom of the dataset. (Igno
30.0                CTStartTime     - Minimum start time for coherent structures in RootName.cts [seconds]

===============================================
NOTE: Do not add or remove any lines in this file!
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```

The TurbSim Input File

- Overview of Sections in the Input File
  - Runtime Options
    - Sets random seed(s)
    - Determines type(s) of files to generate
  - Turbine/Model Specifications
    - Sets grid size and location
    - Determines time/frequency content
  - Meteorological Boundary Conditions
    - Sets spectral model
    - Determines wind speeds
    - Sets IEC-specific boundary conditions
  - Non-IEC Meteorological Boundary Conditions
    - Sets stability and friction velocity
    - Determines coherence
  - Coherent Turbulence Scaling Parameters
    - Locates LES and/or DNS files
    - Determines spatial scales for coherent structures

Meteorological Boundary Conditions

TurbSim's
Meteorological Input Parameters

```
--------Meteorological Boundary Conditions-------------------
"SMOOTH"    TurbModel       - Turbulence model (IECKAI,IECVKM,GP_LLJ,NWTCUP,SMOOTH,WF_UPW,WF_07D,WF_14D,NONE
"1-ED3"     IECstandard     - Number of IEC 61400-x standard (x=1,2,3 w/ 61400-1 Ed# option (i.e. "1-Ed2"))
"A"         IECturbc        - IEC turbulence characteristic (A,B,C or TI in %; KHTEST option w/ NWTCUP)
NTM         IEC_WindType    - IEC turbulence type (NTM,xETM,xEWM1,xEWM50; x=wind turbine class 1,2,3)
default     ETMc            - IEC Extreme Turbulence Model "c" parameter [m/s]
default     WindProfileType - Wind profile type (JET,LOG,PL,IEC, or "default")
84.2876     RefHt           - Height of the reference wind speed [m]
18.2        URef            - Mean (total) wind speed at the reference height [m/s] (or "default" for JET)
default     ZJetMax         - Jet height [m] (used only for JET wind profile, valid 70-490 m)
default     PLExp           - Power law exponent [-] (or "default")
default     Z0              - Surface roughness length [m] (or "default")

--------Non-IEC Meteorological Boundary Conditions------------
default     Latitude        - Site latitude [degrees] (or "default")
0.05        RICH_NO         - Gradient Richardson number
default     UStar           - Friction or shear velocity [m/s] (or "default")
default     ZI              - Mixing layer depth [m] (or "default")
default     PC_UW           - Hub mean u'w' Reynolds stress (or "default")
default     PC_UV           - Hub mean u'v' Reynolds stress (or "default")
default     PC_VW           - Hub mean v'w' Reynolds stress (or "default")
default     IncDec1         - u-component coherence parameters (e.g. "10.0  0.3e-3" in quotes or "default")
default     IncDec2         - v-component coherence parameters (e.g. "10.0  0.3e-3" in quotes or "default")
default     IncDec3         - w-component coherence parameters (e.g. "10.0  0.3e-3" in quotes or "default")
default     CohExp          - Coherence exponent (or "default")
```

Meteorological Boundary Conditions

11 input parameters:

```
---------Meteorological Boundary Conditions--------------
"SMOOTH"    TurbModel        - Turbulence model (IECKAI,
"1-ED3"     IECstandard      - Number of IEC 61400-x sta
"A"         IECturbc         - IEC turbulence characteri
NTM         IEC_WindType     - IEC turbulence type (NTM,
default     ETMc             - IEC Extreme Turbulence Mo
default     WindProfileType  - Wind profile type (JET,LO
84.2876     RefHt            - Height of the reference w
11.0        URef             - Mean (total) wind speed a
default     ZJetMax          - Jet height [m] (used only
default     PLExp            - Power law exponent [-] (o
default     Z0               - Surface roughness length
```

Meteorological Boundary Conditions: Spectral Model

Code	Spectral Model*	Reference & Notes
IECKAI	Kaimal	**IEC 61400-1, Ed. 2** **IEC 61400-1, Ed. 3** (a neutral-stability model)
IECVKM	von Karman	**IEC 61400-1, Ed. 2** (a neutral-stability model)
SMOOTH	Risø Smooth-Terrain Model	**Højstrup, J.**, October 1982, "Velocity Spectra in the Unstable Planetary Boundary Layer," Journal of the Atmospheric Sciences, Vol. 39. **Olesen, H.R., Larsen, S.E., and Højstrup, J.**, 1984, "Modeling Velocity Spectra in the Lower Part of the Planetary Boundary Layer," Boundary-Layer Meteorology, Vol. 29.
WF_UPW	Wind Farm, Upwind	**Kelley, N.D.**, November 1992, "Full Vector (3-D) Inflow Simulation in Natural and Wind Farm Environments Using an Expanded Version of the SNLWIND (VEERS) Turbulence Code," NREL/TP-442-5225, National Renewable Energy Laboratory, Golden, CO. Models are based on measurements in and around a wind farm in San Gorgonio Pass, California
WF_07D	Wind Farm, 7–D Spacing Downwind	
WF_14D	Wind Farm, 14-D Spacing Downwind	
NWTCUP	NWTC Upwind	Model based NWTC/LIST measurements (originally contained much WF_UPW scaling)
GP_LLJ	Great Plains Low-Level Jet	Model based on Lamar Low-Level Jet Project measurements

* Note that "Turbulence Model" and "Spectral Model" are used interchangeably in TurbSim.

Meteorological Boundary Conditions: IEC Standard

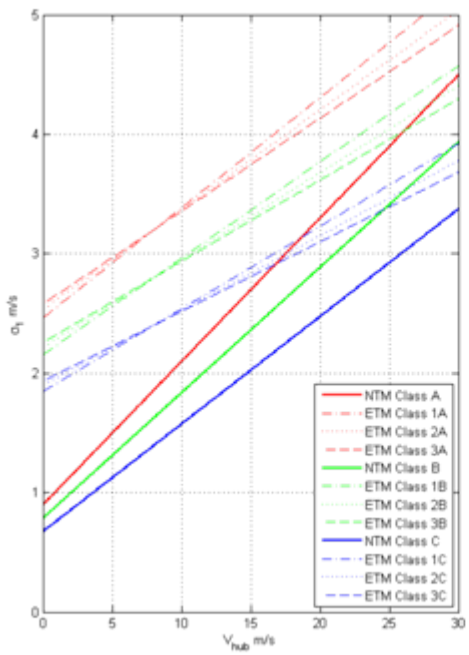
- Parameter 2, **`IECstandard`**: The IEC standard
  - Definition: The number, *x,* of the desired IEC 61400-*x* standard
    - Valid values are 1, 2, or 3
    - If *x*=1, edition number may be specified: “1-Ed2” or “1-Ed3”
    - If input is “1”, Ed. 2 is assumed for IECVKM model and Ed. 3 is assumed for IECKAI model
  - Used only for the two IEC models (ignored otherwise)
  - Determines the scaling parameters for the wind speed standard deviation, wind profiles, coherence, length scales, etc. as specified in the given standard

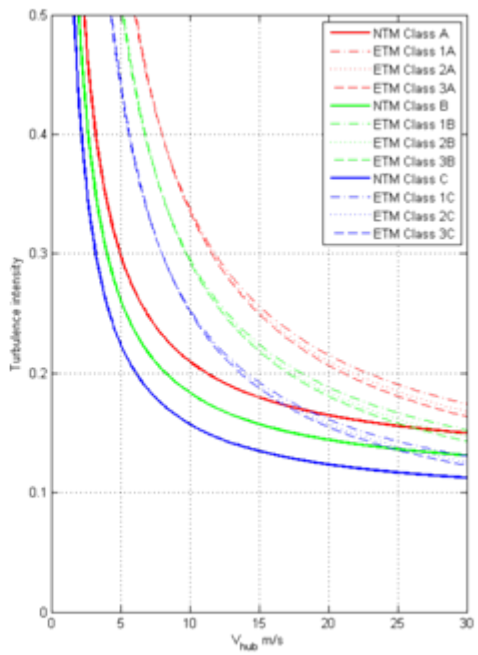
Meteorological Boundary Conditions: IEC Turbulence Characteristic

- Parameter 3, **`IECturbc`**: The turbulence characteristic
  - Definition: The turbulence characteristic
    - For IEC models, valid values are “A”, “B”, “C” or turbulence intensity (TI) in percent
    - For the NWTCUP model, the input can be “KHTEST” (other strings are ignored)
  - Used only for the two IEC models and NWTCUP model with the KHTEST option (ignored otherwise)

Meteorological Boundary Conditions: IEC Turbulence Characteristic

- Parameter 3, **`IECturbc`**: The turbulence characteristic (continued)
  - For IEC models it defines the standard deviation of the wind speed (and thus, TI)

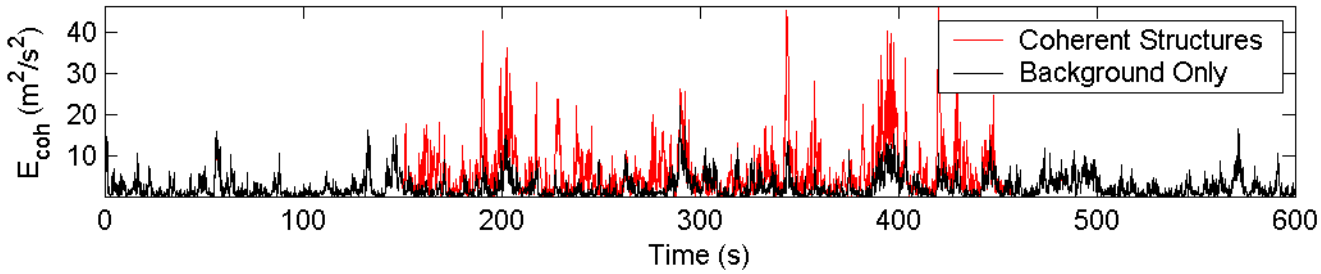




$$\sigma_1 = \frac{TI \cdot u_{hub}}{100}$$

Meteorological Boundary Conditions: IEC Turbulence Characteristic

- Parameter 3, **`IECturbc`**: The turbulence characteristic (continued)
  - For the NWTCUP model, the input "KHTEST"
    - Sets the Richardson number to 0.02
    - Sets the power-law exponent to 0.3
    - Increases the intensity of the coherent structures in the .cts file
    - Decreases the randomness in coherent structure scaling
      - Places one event in the middle of the time series with length about half the length of the background time series



Meteorological Boundary Conditions: IEC Wind Type

- Parameter 4, **`IEC_WindType`**: The IEC wind type
  - Definition: the type of IEC turbulence to be used
    - Valid values are NTM, *x*ETM, *x*EWM1, and *x*EWM50, where *x*=1, 2, or 3 is the wind turbine class
      - NTM: Normal turbulence model
      - 1ETM: Extreme turbulence model for a class I machine
      - 2EWM1: Extreme turbulent wind speed model for class II machine with 1-year extreme wind speed
      - 3EWM50: Extreme turbulent wind speed model for class III machine with 50-year extreme wind speed
    - If TI was specified instead of a turbulence characteristic for parameter 3, IEC_WindType must be “NTM”
  - Used only for the two IEC models (ignored otherwise)
  - Determines the wind profile and standard deviations, as specified in the IEC standard

Meteorological Boundary Conditions: ETM "c" parameter

- Parameter 5, **`ETMc`**: The "c" parameter for the IEC Extreme Turbulence Model
  - Definition: The parameter "c" in the equation for standard deviation of the IEC extreme turbulence model (ETM):

$$\sigma_1 = c\, I_{ref} \left(0.072 \left(\frac{V_{ave}}{c} + 3 \right) \left(\frac{V_{hub}}{c} - 4 \right) + 10 \right)$$

    - Valid values are positive velocities (m/s) or "default"
    - Default is *c*=2 m/s
  - Ignored if ETM is not specified

Meteorological Boundary Conditions: Wind Profile Type

- Parameter 6, **`WindProfileType`**: The wind profile type
  - Definition: The code for the type of wind profile to use
    - Valid values: PL, LOG, JET, IEC, or "default"
    - JET valid only for GP_LLJ model
  - Determines the mean wind speed for each height on the grid

Default Wind Profiles	
IECKAI	IEC
IECVKM	IEC
SMOOTH	IEC
GP_LLJ	JET
NWTCUP	IEC
WF_UPW	IEC
WF_14D	IEC
WF_07D	IEC

Meteorological Boundary Conditions: Wind Profile Type

- Parameter 6, **`WindProfileType`**: The wind profile type (continued)
  - JET: Jet wind speed and direction profiles, modeled with Chebyshev polynomials:

$$V(z) = \sum_{n=0}^{10} c_n \cdot T_n(z)$$

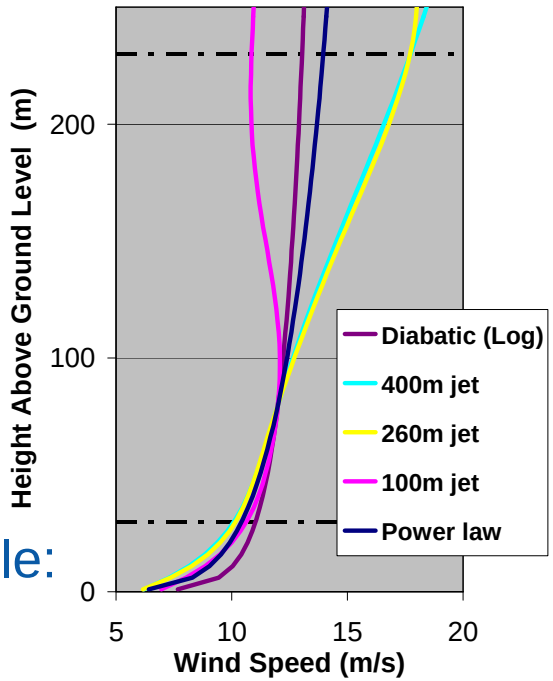
  - PL: Power-law wind profile:

$$V(z) = V(z_{ref}) \left(\frac{z}{z_{ref}} \right)^{\alpha}$$

  - LOG: The diabatic (logarithmic) wind profile:

$$V(z) = V(z_{ref}) \frac{\ln\left(z/z_0\right) - \psi_m}{\ln\left(z_{ref}/z_0\right) - \psi_m}$$

  - IEC: PL on the rotor disk, LOG elsewhere



Meteorological Boundary Conditions: Reference Wind

- Parameter 7, **`RefHt`**: The reference height
  - Definition: The height of the reference wind speed, in meters
    - Valid values: any height > 0.
- Parameter 8, **`URef`**: The reference wind speed
  - Definition: The mean wind speed for the simulation at the reference height, in m/s
    - Valid values: wind speed > 0; may be “default” with JET profile
    - Default speed based on jet height, stability, and friction velocity
- These two parameters (along with the wind profile type) are used to calculate the wind speed profile

Meteorological Boundary Conditions: Jet Height

- Parameter 9, **`ZJetMax`**: The jet height
  - Definition: The height of the maximum wind speed of the jet wind profile, in m
    - Valid values: height in the range 70 - 490 m or “default”
    - Default based on stability and friction velocity plus a random number from a distribution based on PDFs of LLLJP data
  - Used only with the JET wind profile type
  - Used to calculate the mean wind speed and direction profiles

Meteorological Boundary Conditions: Power Law Exponent

- Parameter 10, **PLExp**: Power-law exponent
  - Definition: The exponent, α, in the power-law wind profile

$$V(z) = V(z_{ref})\left(\frac{z}{z_{ref}}\right)^{\alpha}$$

    - Valid values: any number or "default"
  - Used only with the power-law (or IEC) wind profile

Default PL exponents		
IECKAI IECVKM	61400-1, -2 NTM	0.2
	61400-3 NTM	0.14
	EWM	0.11
SMOOTH GP_LLJ		0.143
NWTCUP WF_UPW	*f(Ri)*	0.08 – 0.15
WF_07D WF_14D	*f(Ri)*	0.13 – 0.18

Meteorological Boundary Conditions: Surface Roughness

- Parameter 11, **`Z0`**: The surface roughness length
  - Definition: A measure of the roughness of the surface terrain, in meters
    - Valid values: positive length or “default”
  - Used to calculate the following:
    - The LOG wind speed profile
    - The diabatic friction velocity, u_{*0}
    - The default mixing layer depth

Default Surface Roughness (m)	
IECKAI	0.03
IECVKM	0.03
SMOOTH	0.01
GP_LLJ	0.005
NWTCUP	0.018
WF_UPW	0.018
WF_14D	0.064
WF_07D	0.233

Non-IEC Meteorological Boundary Conditions

11 input parameters

- IEC models do not use any of these parameters
- All but Richardson number can be “default” values

```
--------Non-IEC Meteorological Boundary Conditions-----
default     Latitude        - Site latitude [degrees] o
0.05        RICH_NO         - Gradient Richardson numbe
default     UStar           - Friction or shear velocit
default     ZI              - Mixing layer depth [m] (
default     PC_UW           - Hub mean u'w' Reynolds st
default     PC_UV           - Hub mean u'v' Reynolds st
default     PC_VW           - Hub mean v'w' Reynolds st
default     IncDec1         - u-component coherence par
default     IncDec2         - v-component coherence par
default     IncDec3         - w-component coherence par
default     CohExp          - Coherence exponent (or "d
```

Non-IEC Meteorological Boundary Conditions: Latitude

- Parameter 1, **`Latitude`**: The latitude
  - Definition: Latitude (degrees from the equator) of the wind field modeled
    - Valid values: magnitude must be between 5 and 90 degrees or “default”, which uses 45˚
  - The latitude is used to calculate a Coriolis term in the default mixing layer depth

Non-IEC Meteorological Boundary Conditions: Richardson Number

- Parameter 2, **`Rich_No`**: The Richardson Number
  - Definition: The turbine layer vertical stability determined by the dimensionless gradient Richardson number

$$Ri = \frac{\frac{g}{\overline{T}}\left(\frac{\Delta T}{\Delta z}\right)}{\left(\frac{\Delta U}{\Delta z}\right)^2}$$

    - *g* is gravitational acceleration, *T* is absolute air temperature, *U* is wind speed, *z* is height above the ground
    - Valid values: any
      - NWTCUP and GP_LLJ limit input if necessary to $-1 \le Ri \le 1$

Non-IEC Meteorological Boundary Conditions: Richardson Number

- Parameter 2, **`Rich_No`**: The Richardson Number (continued)
  - A key parameter in determining
    - Default values for many other meteorological inputs
    - Monin-Obukuv *z/L* stability parameter
    - Shape of velocity spectra
    - Shape of JET profile
    - Scaling for superimposed coherent structures

Non-IEC Meteorological Boundary Conditions: Friction Velocity

- Parameter 3, **`UStar`**: The friction or shear velocity
  - Definition: The friction velocity over the rotor disk in m/s

$$u_* = \sqrt{\left|\overline{u'w'}\right|}$$

- Valid values: positive velocities or "default", based on u_{*0}, the diabatic u_* near the surface

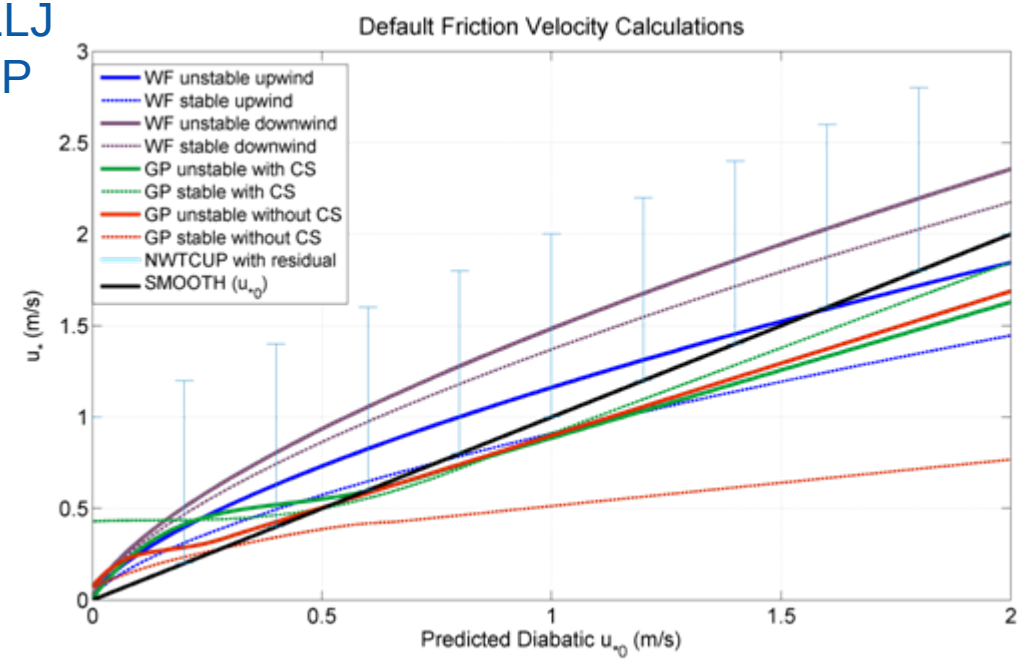
$$u_{*0} = \frac{0.4u_{ref}}{\ln\left(\frac{z_{ref}}{z_0}\right) - \Psi_M\left(z/L\right)}$$

Default Friction Velocity (m/s)	
SMOOTH	u_{*0}
GP_LLJ	$f(u_{*0}, z/L, CS)$
NWTCUP	u_{*0} + *RandNum*
WF_UPW	$f(u_{*0}, z/L)$
WF_14D **WF_07D**	$f(u_{*0}, z/L)$

Non-IEC Meteorological Boundary Conditions: Friction Velocity

- Parameter 3, **`UStar`**: The friction or shear velocity (continued)
  - A key parameter in determining
    - Default values for many other meteorological inputs
    - Amplitude of velocity spectra (compare to σ_u for IEC models)
    - Shape of stable GP_LLJ and unstable NWTCUP spectra
    - Shape of JET profile
  - For comparison, Kaimal model uses

$$\sigma_U \approx 2.17 u_*$$



Non-IEC Meteorological Boundary Conditions: Mixing Layer Depth

- Parameter 4, **`Zi`**: The mixing layer depth
  - Definition: The thickness of the mixing layer (mixed layer), in m; it's the location of a capping temperature inversion
    - Valid values: a positive number or "default", defined for all models (using the Earth's angular speed of rotation, ω) as

$$z_i = \begin{cases} \dfrac{400 u_{ref}}{\log_{10}\left(\frac{z_{ref}}{z_0}\right)}, & u_* < u_{*0} \\ \dfrac{u_*}{12.0\omega \sin\left(\frac{\pi}{180}\left|Latitude\right|\right)}, & u_* \geq u_{*0} \end{cases}$$

  - Used only in unstable flows
  - It scales the unstable velocity spectra

Non-IEC Meteorological Boundary Conditions: Mean Hub Reynolds Stresses

- Parameter 5, **PC_UW**: The mean *u'w'* hub Reynolds Stress
- Parameter 6, **PC_UV**: The mean *u'v'* hub Reynolds Stress
- Parameter 7, **PC_VW**: The mean *v'w'* hub Reynolds Stress
  - Definition: The desired mean Reynolds stresses at the hub grid point $\overline{u'w'}$ $\overline{u'v'}$ $\overline{v'w'}$
    - Valid values: any number, "default", or "none"
    - These are new parameters in v1.40

Default Reynolds Stresses (m/s)		
	u'w'	*u'v'* *v'w'*
SMOOTH	$-u_*^2$	*"none"*
GP_LLJ	$\pm f(u_*^2, u, Ri, du/dz, z)$	
NWTCUP	$\pm f(u_*^2, u, Ri, du/dz, z, Random\#)$	
WF_UPW	$-u_*^2$	$\pm f(u_*^2, du/dz)$
WF_14D	$\pm u_*^2$	$\pm f(u_*^2)$
WF_07D	$-u_*^2$	$\pm f(u_*^2)$

Non-IEC Meteorological Boundary Conditions: Mean Hub Reynolds Stresses

- Parameters 5-7: The mean hub Reynolds Stresses (continued)
  - These parameters define the cross-component correlation in the time domain
    - Independent, zero-mean, time series are correlated by changing *v* and *w* using linear combinations of the other components

$$u_{j,cor} = u_{j,indep}$$

$$v_{j,cor} = \alpha_{uv} u_{j,indep} + v_{j,indep} + \alpha_{vw} w_{j,indep}$$

$$w_{j,cor} = \alpha_{uw} u_{j,indep} + w_{j,indep}$$

Non-IEC Meteorological Boundary Conditions: Mean Hub Reynolds Stresses

- Parameters 5-7: The mean hub Reynolds Stresses (continued)
  - α coefficients are determined so that the input mean hub Reynolds stresses are achieved*

$$\overline{u_{hub,cor} w_{hub,cor}} = \overline{u'w'}$$

$$\overline{u_{hub,cor} v_{hub,cor}} = \overline{u'v'}$$

$$\overline{v_{hub,cor} w_{hub,cor}} = \overline{v'w'}$$

$$^{*}\left|\alpha_{ij}\right| \leq 1$$

  - Input value of "none" sets $\alpha_{ij} = 0$ for that cross-component term

Non-IEC Meteorological Boundary Conditions: Coherence Parameters

- Parameter 8, **`IncDec1`**: The *u*-component spatial coherence parameters, "a_u b/L_u"
- Parameter 9, **`IncDec2`**: The *v*-component spatial coherence parameters, "a_v b/L_v"
- Parameter 10, **`IncDec3`**: The *w*-component spatial coherence parameters , "a_w b/L_w"
  - Definition: The "*a*" (dimensionless) and "*b/L*" (m^{-1}) parameters in the equation for spatial coherence for each wind component:

$$Coh_{j,k} = \exp\left(-a \left(\frac{r}{z_m} \right)^{\beta} \sqrt{\left(\frac{f\,r}{u_m} \right)^2 + \left(\frac{b}{L} r \right)^2} \right)$$

Non-IEC Meteorological Boundary Conditions: Coherence Parameters

- Parameters 8-10, The spatial coherence parameters (continued)
  - Valid values: positive *a* parameters and non-negative *b/L* parameters or "default"
  - When specifying *a* and *b/L* they must be separated by white space and in quotes (otherwise *b/L*=0).
    - e.g. "12.1 3.5e-4" for a=12.1 and b/L=0.00035/m
  - *b/L* is a new input parameter in version 1.40

	Default Coherence parameters					
	a_u	b/L_u	a_v	b/L_v	a_w	b/L_w
SMOOTH	*u*	*0*	*0.75u*	*0*	*0.75u*	*0*
GP_LLJ NWTCUP	*f(u,Ri,z)*	*f(u,Ri)*	*f(u,Ri,z)*	*f(u,Ri)*	*f(u,Ri,z)*	*f(u,Ri)*
WF_UPW WF_14D WF_07D	*f(u,Ri,z)*	*f(u,Ri)*	*f(u,Ri,z)*	*f(u,Ri)*	$0.4a_u$	$10b/L_u$

Non-IEC Meteorological Boundary Conditions: Coherence Exponent

- Parameter 11, **CohExp**: The coherence exponent
  - Definition: The exponent, β , for all wind speed components in the coherence equation:

$$Coh_{j,k} = \exp\left(-a \left(\frac{r}{z_m} \right)^{\beta} \sqrt{\left(\frac{f\,r}{u_m} \right)^2 + \left(\frac{b}{L} r \right)^2} \right)$$

    - Valid values: any non-negative number or “default”
      - Default is $\beta = 0$

Conclusions

- What meteorological parameters must be specified (i.e. not “default”) for each model?
  - IECKAI and IECVKM
    - IEC standard (61400-1, -2, or -3)
    - Turbulence characteristic (A, B, C or % TI)
    - Turbulence type (NTM, ETM, etc.)
    - Reference height and wind speed
  - SMOOTH, GP_LLJ, NWTCUP, WF_UPW, WF_14D, WF_07D
    - Reference height and wind speed
    - Richardson number

Conclusions

- How do I compare turbulence in IEC models with the other models?
  - Friction velocity can be set to compare with IEC standard deviation: $\sigma_U / 2.17 \approx u_*$ (the 2.17 may be adjusted)
  - The coherence parameters may be adjusted*:

$$a_u = 12 \qquad b/L_u = \frac{0.021}{\min\left(z_{hub}, 60\ \mathrm{m}\right)}$$

$$a_v = \text{a large number} \qquad b/L_v = 0$$

$$a_w = \text{a large number} \qquad b/L_w = 0$$

  - The mean hub Reynolds stresses may be set to “none” to remove the cross-component correlation

*Values are for IEC 61400-1, Ed. 3. Ed. 2 scaling will differ.