Mann Turbulence box - read in wrong direction

Since the very beginning of HAWC2, the mann turbulence boxes has been read backward.

In the turbulence files, the turbulence is saved as shown in Figure 2 from [1]

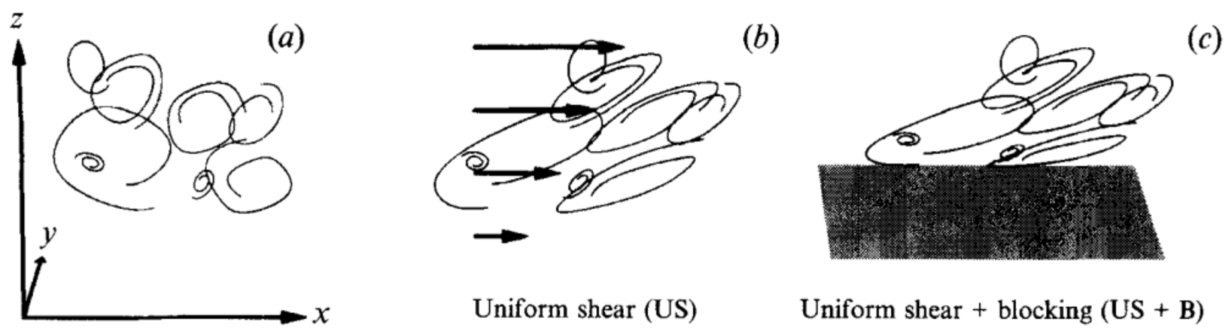
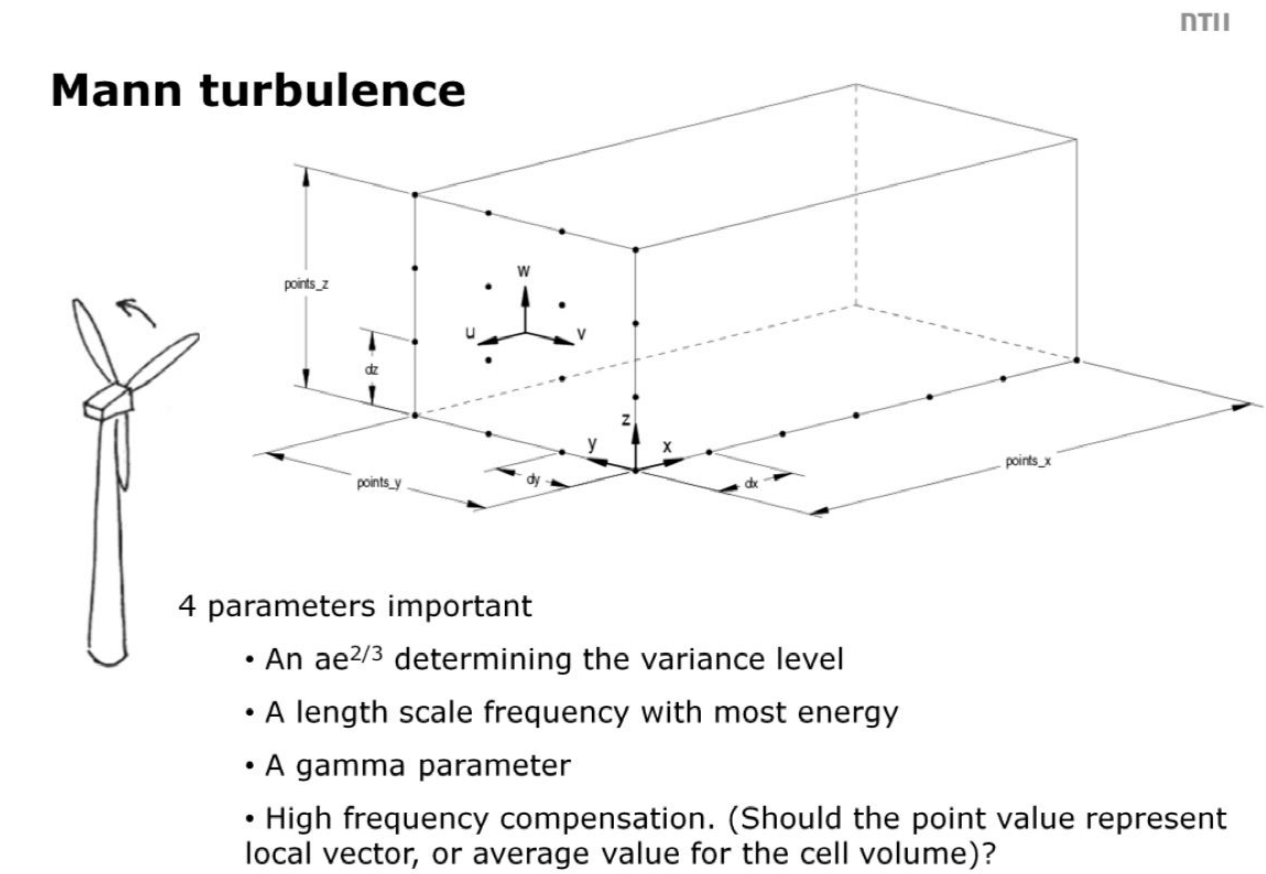


FIGURE 2. Sketch of the investigated models. (*a*) Both models are based on isotropic turbulence with the von Kármán energy spectrum (§ 2.4). (*b*) The effect of shear is modelled by rapid distortion theory in § 3.2. (*c*): In addition blocking by the surface is modelled by 'inhomogeneous rapid distortion theory' (Lee & Hunt 1989, see § 3.3).

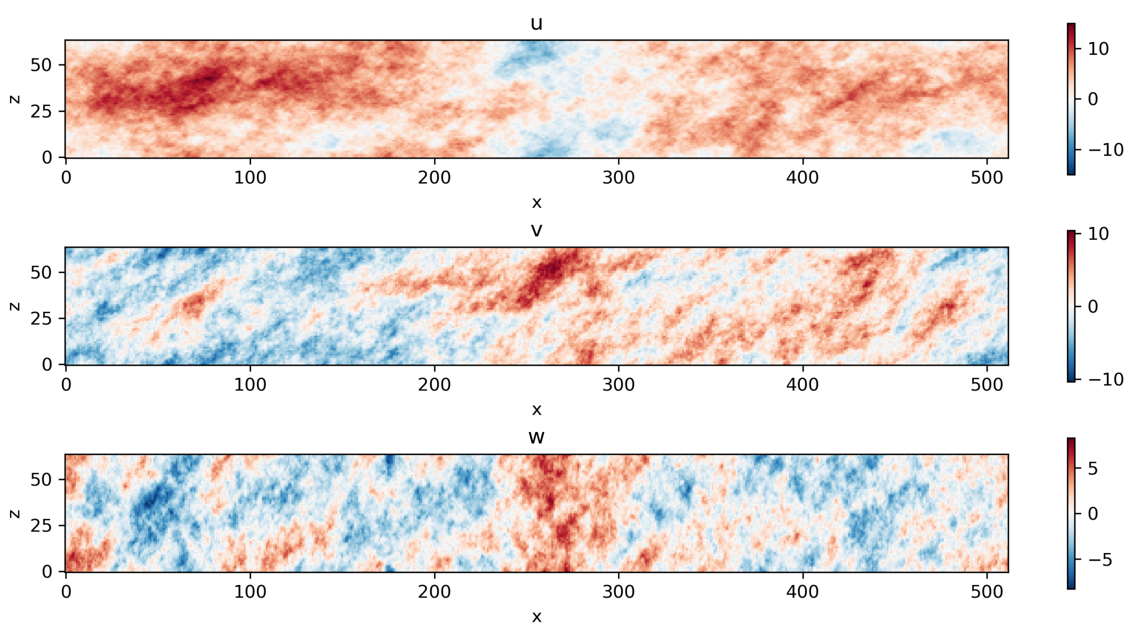
From this definition it is seen that the turbulence at the first plane (x=0, i.e. the first value in the files) will be the last to hit a wind turbine in the domain as the turbulence box is moved in the x direction.

In HAWC2, on the other hand, the turbulence has been read such that the first plane (x=0, i.e. the first value in the files) is the first to hit a wind turbine, as seen in a slide from the HAWC2 course:



This discrepancy corresponds to a 180 degree rotation of the turbulence box abound the vertical z axis.

The shear structures are clearly seen in a (x,z)-plane of the turbulence, especially in the v-component:

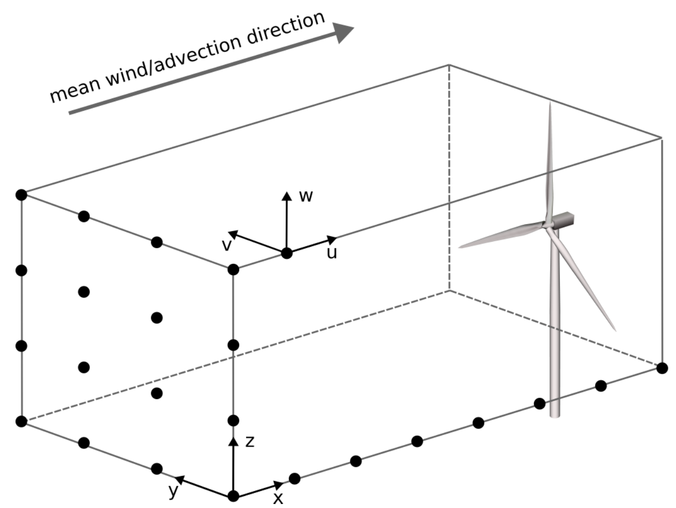


Mann Turbulence format

The mann turbulence binary format consist of one file per turbulence component, u,v,w. Each file contains turbulence values stored as 32-bit floats (little endian). It can be read from python using:

```
u = np.fromfile(u_filename, dtype=np.float32).reshape(Nx,Ny,Nz)
```

Location in file	Box (x,y,z)
0	(0,0,0)
1	(0,0,1)
Nz-1	(0,0,-1)
Nz	(0,1,0)
Nz+1	(0,1,1)
Ny*Nz-1	(0,-1,-1)
Ny*Nz	(1,0,0)



Direction

- Wrong direction (default in HAWC2 $\leq$ 13.0): First plane in file, `u[0,:,:]` , is box front.
- Correct direction (default in HAWC2>13.0): Last plane, `u[-1,:,:]` is box front.

HAWC2

A command has now been implemented in HAWC2 to specify if the turbulence should be read in the old wrong direction or in the correct way. The command is called `box_front` and should have one of the two key words:

- `first_plane` (default in HAWC2 $\leq$ 13.0)
- `last_plane` (default in HAWC2>13.0)

```
begin wind;
   density 1.225;
```

```
    wsp 4.0;
    tint    0.344;
    turb_format 1;  0=none, 1=mann,2=flex
    ...
    begin mann;
      create_turb_parameters    29.4 1 3.7 1001 1;
      filename_u    ./turb/mann_u.turb;
      filename_v    ./turb/mann_v.turb;
      filename_w    ./turb/mann_w.turb;
      box_dim_u 8192 0.293;
      box_dim_v 32 5.7516;
      box_dim_w 32 5.7516;
      ;-------------------
      box_front last_plane;
      ;-------------------
    end mann;
  end wind;
```

Impacts on loads

The impact on loads on the DTU 10MW reference turbine [2] version 9.1 which can be downloaded from the HAWC2 website: https://www.hawc2.dk/models/dtu-10-mw, has been investigated by analysing fatigue loads of simulation of DLC1.2:

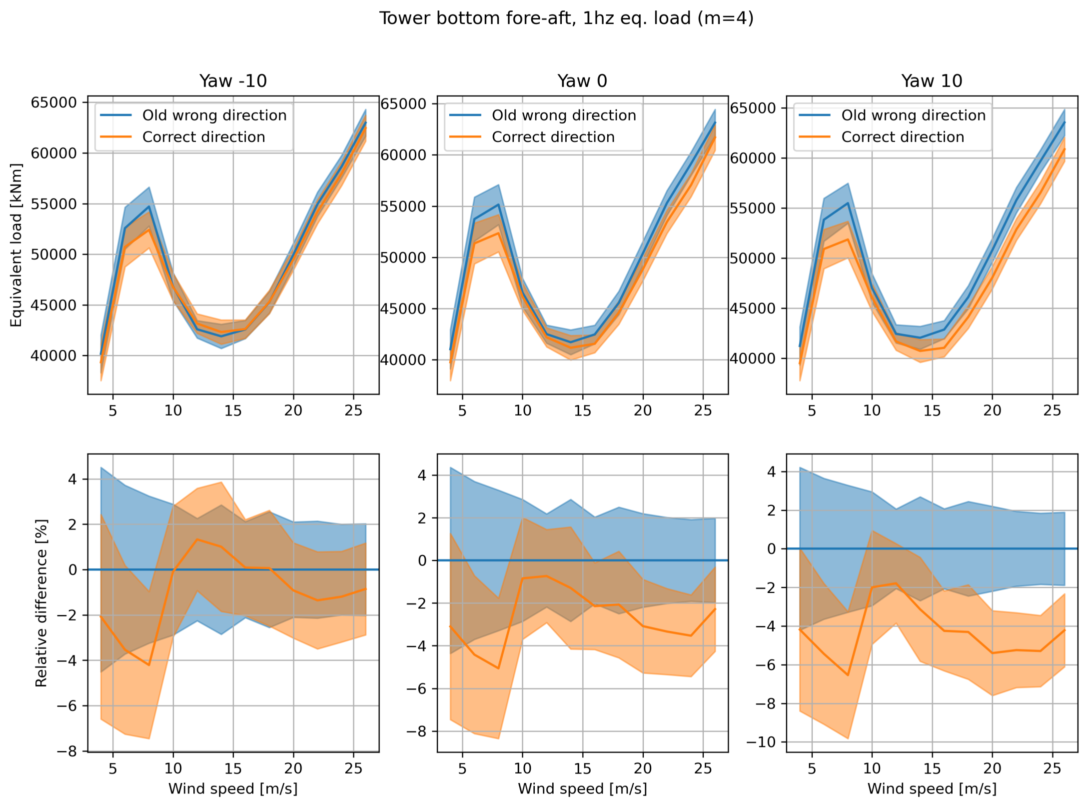
Wind speeds	[4, 6, .., 26]
Yaw misalignment	[-10, 0, 10]
Turbulence	NTM (Normal turbulence model)
Shear	NWP (Normal wind profile)
Seeds	100

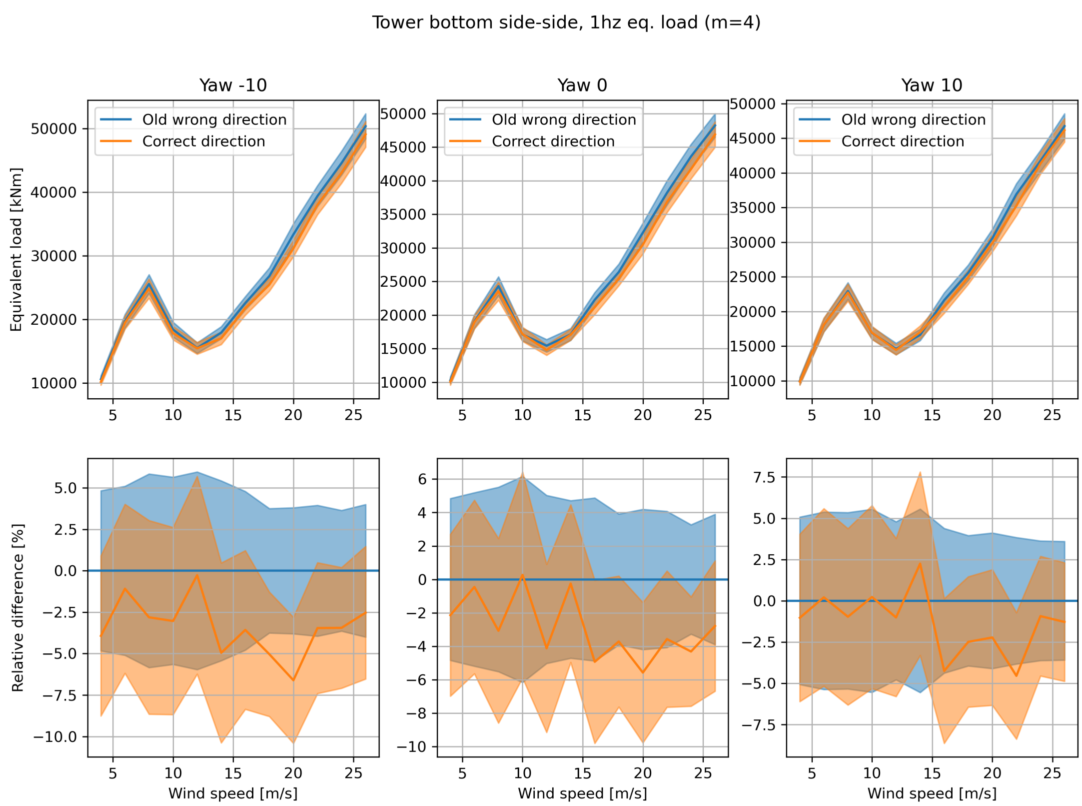
Results

The following plots shows:

- Top row: Mean fatigue loads for the three values of yaw misalignment plotted as a function of wind speed. Blue is the old wrong reading, while orange shows the correct reading behaviour. The bandwidths show the 99% confidence intervals.
- Bottom row: The blue line shows the relative fatigue load difference in percent, when

going from the old wrong behaviour to the new correct behaviour. The bandwidth shows the 99% confidence interval of the old wrong behaviour.





Conclusions

The 99% confident intervals show significant changes in loads for some combination of wind speeds and yaw misalignment for most of the presented load sensors. The changes are in general below 5%. In most cases the loads decrease when using the turbulence in the correct way.

References

1. Mann J. The spatial structure of neutral atmospheric surface-layer turbulence. Journal of Fluid Mechanics. 1994;273:141-168. doi:10.1017/S0022112094001886

2. Christian Bak, Frederik Zahle, Robert Bitsche, Taeseong Kim, Anders Yde, Lars Christian Henriksen, Anand Natarajan, Morten Hartvig Hansen.“Description of the DTU 10 MW Reference Wind Turbine” DTU Wind Energy Report-I-0092, July 2013.