Idealized Hurricanes:

Hurricane characteristics:
Two Category-1 and two Category-2 hurricanes develop in the high-resolution LES domain (d05: $\Delta x = 55.55$ m) with different surface forcing (Figure 1). Warmer surface temperatures result in faster 1-min sustained winds.
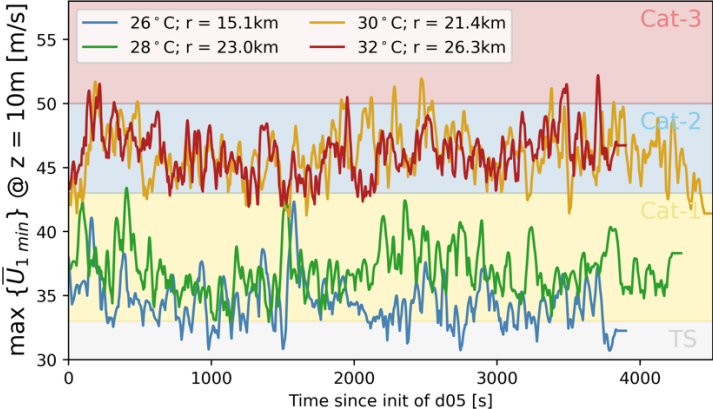

Figure 1: Maximum 1-min averaged wind speed at 10 m above the surface for each hurricane simulation. The simulations are labeled based on surface temperature and radius of the eyewall. The horizontal, colored regions represent the lower and upper bound for a Tropical Storm (TS), Cateogry-1 (Cat-1), Category-2 (Cat-2), and Category-3 (Cat-3) hurricane in the Saffir-Simpson scale.

Warmer surface temperatures result in bigger hurricanes, as defined by the hurricane eyewall (Figure 2). The average hurricane eyewall for each simulation is as follows:

- $26^o C \rightarrow r_{eye} = 15 \; km$
- $28^o C \rightarrow r_{eye} = 23 \; km$
- $30^o C \rightarrow r_{eye} = 21 \; km$
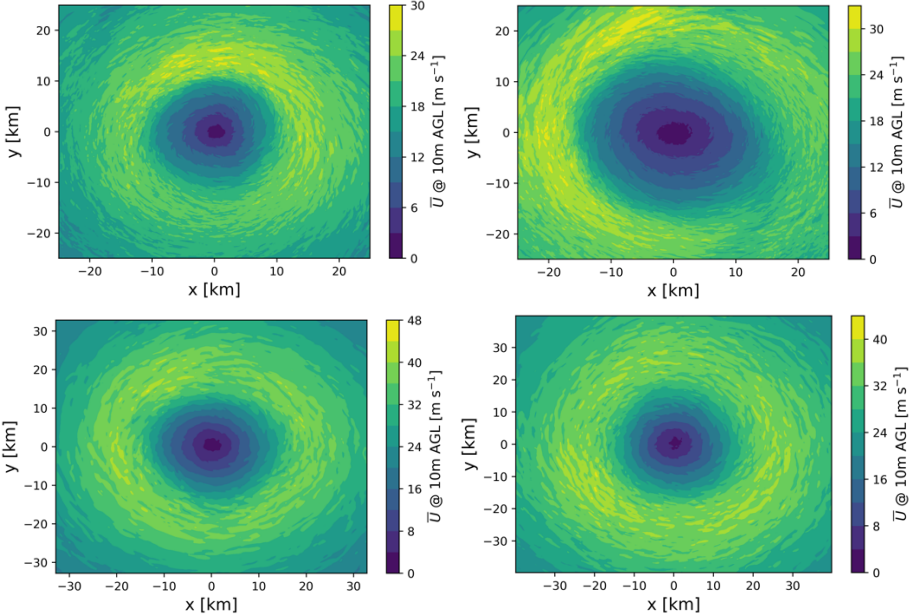- $32^o C \rightarrow r_{eye} = 26 \; km$

Figure 2: Time-averaged velocity field at 10 m above the surface for the 26 ℃ (top left), 28 ℃ (top right), 30 ℃ (bottom left), and 32 ℃ (bottom right) hurricane simulations. Note the different domain size and colorbar for each hurricane simulation.

Turbulence spins up rapidly throughout the high-resolution LES domain (Figure 3). Small-scale turbulence develops rapidly after initialization close and far away from the center of the hurricane. Five minutes after initialization, turbulence spectra become self-similar thought the domain.
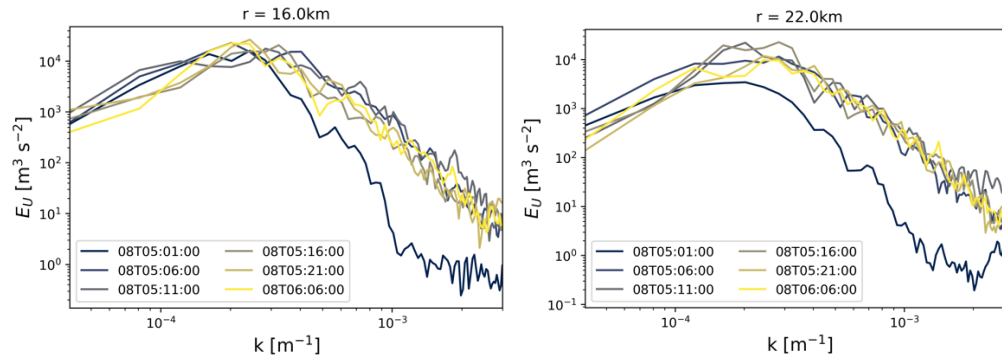

Figure 3. Temporal evolution of turbulence spectra of the horizontal velocity at 10 m for r = 16km (left) and r = 22km (right) of the 26 °C hurricane simulation.

Time series output in WRF:
The time-series output in WRF records atmospheric quantities at a given location for every time step of the simulation. For the hurricane simulations, the time series output records the three wind speed components and height at every time step.
-   UU: u-wind/zonal component [m s^{-1}].
-   VV: v-wind/meridional component [m s^{-1}].
-   WW: w-wind/vertical component [m s^{-1}].
-   PH: height above the surface [m].

The naming convention for a time series output file is as follows:
`name.d##.XX`
-   `name`: name for each time series location (specified by the user)
-   `d##`: domain for time series output
-   `XX`: variable in time series ouput

For example, the file `hi118.d05.UU` contains the time series output for the u-velocity component in domain 05 of the simulation at location `hi118` specified by the user.

The time series output files have a specific format. The first line in each file has the following convention:

`name  domain_ID  timeSeries_ID (lat,lon) grid_indices:(index_x,index_y)  actual_lat_lon:(lat,lon)`

The `name` of each time series location is specified by the user and should match the name of the file. The `domain_ID` is the domain number for the time series output. The `timeSeries_ID` is the time series location within the `tslist` file (i.e., irrelevant for end user). Given that our simulations are idealized, the values for `(lat,lon)` are zero. The `grid_indices` represent the grid cell for the time series output within the domain.

The rest of the lines in each file follow this convention:

`time  var_z1  var_z2  var_z3  var_z4  var_z5  var_z6  …`

The first column (`time`) represents the time since initialization in hours. Initialization time for the high-resolution domain (i.e., d05) varies for each hurricane simulation as follows:

- 26^oC → d05 initializes after 7 days and 5 hours of simulation (~173 hr).
- 28^oC → d05 initializes after 6 days and 5 hours of simulation (~149 hr).
- 30^oC → d05 initializes after 6 days and 11 hours of simulation (~155 hr).
- 32^oC → d05 initializes after 6 days and 4.5 hours of simulation (~148 hr).

The remaining columns (`var_zi`) provide the output for each variable at increasing vertical levels in the domain. The staggered vertical levels for each output are provided in the `name.d##.PH` files. For this hurricane simulation, data are output for the following non-staggered vertical levels: z = [10 33 56 81 107 134 162 192 223 256] m above the surface. Note that the height coordinate changes slightly with every time step given that the vertical coordinate in WRF is a function of hydrostatic pressure.

The file `tslist_d04_d05.txt` provides the names and locations ((i, j) grid point in d05) for each time series output file.

Location of time-series output in LES domains:
The time series output for the highest resolution domain (d05: $\Delta x = 55.55$ m) are distributed at different radial and azimuthal locations from the center of the hurricane (Figure 1). Also, as shown in Figure 1, time-series output for each radial location for an azimuth angle $\theta = 90$ deg includes data for each grid cell surrounding the desired radial location (3x3 grid).
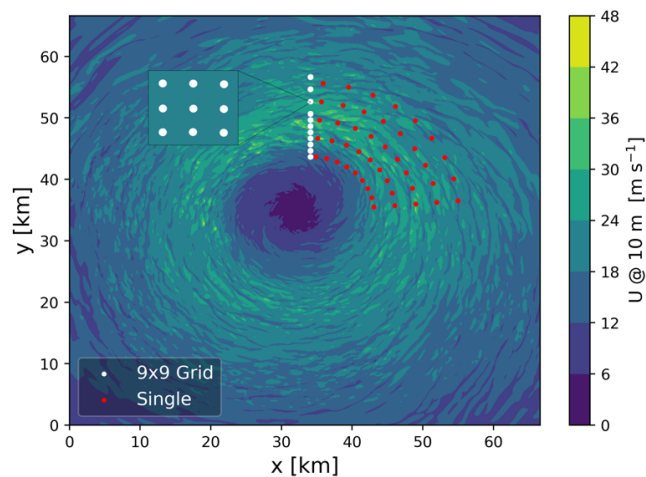

Figure 4. Plan view of the instantaneous horizontal velocity at 10 m above the surface for d05 of the 26 ℃ hurricane simulation. The white dots represent 3x3 grids of time-series output. The red dots represent single time-series output locations.

<u>3x3 grid:</u>
Because the hurricane eyewall and domain size changes with each simulation, the location of the time series output for the 3x3 grids also varies. For each simulation, the radial location of each 3x3 grid is at the following radial distances from the center of the hurricane:

- $26^oC \rightarrow r =$ [9 10 11 12 13 14 15 16 18 20 22] km
- $28^oC \rightarrow r =$ [17 18 19 20 21 22 23 24 25 26] km
- $30^oC \rightarrow r =$ [13.9 14.9 15.9 16.8 17.8 18.8 19.8 20.8 21.8 22.8 23.8 24.8] km
- $32^oC \rightarrow r =$ [14.3 17 19.7 22.4 23.7 25.1 26.4 27.8 29.2 30.4 33.2 35.8 38.6] km

Time-series output for the 3x3 grids corresponds to the files: `hi[000-n_3x3].d05.*` where n_3x3 corresponds to the number of radial locations multiplied by 9.
The files are named in ascending order as a function of their radial location relative to the center of the hurricane. In this way, files `hi[000-008].d05.*` correspond to the 3x3 grid centered at a radial location of 9 km from the center of the hurricane that is forced with 26^oC surface temperature.

Single locations:
The location of the single time series output also varies with hurricane simulation to accommodate different hurricane sizes.
- $26^oC \rightarrow r =$ [9 12 15 18 21] km
- $28^oC \rightarrow r =$ [13.5 18 22.5 27 31.5] km
- $30^oC \rightarrow r =$ [10.5 14 17.5 21 24.5] km
- $32^oC \rightarrow r =$ [16.5 22 27.5 32] km

The time series output is at different azimuthal locations in the domain. For each radial location, time series output is specified at azimuthal θ = [5 15 25 35 45 55 65 75 85] deg locations as shown in Figure 4.
The files are named such that all azimuthal angles for a given radial location are grouped together. For example, files `hi[099-107].d05.*` contain output for all azimuthal locations at r = 9km from the center of the hurricane that is forced with 26^oC surface temperature.

Additional files:
The hurricanes in d05 drift over time (Figure 5), therefore the relative radial location between each time-series output and the center of the hurricane varies throughout the simulation. For the 26^oC hurricane, the center is displaced 3.3km to the south-east of the domain throughout the simulation. As a result, two additional files named `center_x.txt` and `center_y.txt` provide the (x,y) location for the center of the hurricane at every time step within d05.
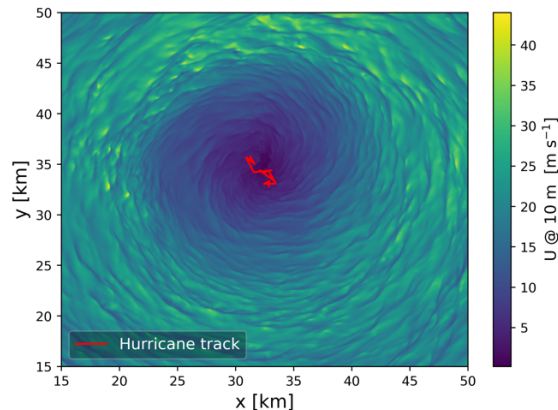

Figure 5. Plan view of horizontal wind speed at 10 m. The red, solid line shows the hurricane track in 5-minute time increments throughout the simulation.