Characterizing Turbulent Events at a Tidal Energy Site using ADCP Data

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Abstract

In recent years, there has been increasing interest in using tides as a clean, renewable energy source, but in order to move from the design stage to production, a more comprehensive characterization of turbulence is needed to predict loads on a turbine in a tidal environment. The commonly used turbulence intensity metric does not describe turbulent length or time scales, nor does it give any directional information. Using acoustic Doppler current profiler (ADCP) data from Admiralty Inlet, WA, several additional statistics are calculated to more fully characterize the turbulence that a turbine would experience in a tidal flow. These metrics include coherent turbulent kinetic energy, time-frequency (wavelet) properties, measures of anisotropy, and structure functions. Coherent turbulent kinetic energy (CTKE) highlights intermittent turbulent events and wavelet analysis of the CTKE can be used to predict loading events on the turbine. Anisotropy invariant analysis allows the anisotropy to be quantified in terms of one, two, or three (isotropic) component turbulence. Structure functions are typically used to predict spectral slopes or dissipation rates that are then used as inputs to synthetic turbulence generators for simulations of tidal turbines, but a more in-depth analysis can differentiate between isotropic, low-turbulence events and their counterparts which cause unwanted loads on a turbine. Not only do these results provide useful information about large, anisotropic eddies that affect tidal energy production, but they exemplify the wide range of possible quantities available from the simple velocity component observations of an ADCP. These quantities can be used to generate realistic inflow and boundary conditions for simulations of tidal turbines, and can also be used to validate results from the simulations.

Observations

Latitude	N 48 09.088'
Longitude	W 122 41.129'
Dates	May 9 – Jun 8, 2011
Depth	56m
Sampling Frequency	1 Hz
Noise	0.112 m/s
Proposed Hub Height	8.1m
Hub Height Max. Velocity	3.2 m/s
z	1.1-25.1 m
dz	1m

The data used in this analysis were collected from an acoustic Doppler current profiler (ADCP) at Admiralty Head, on the western side of Whidbey Island in the Puget Sound (Thomson et al. 2012). Admiralty Head is the proposed location for two OpenHydro™ turbines. Velocity profiles were collected from May 9 to June 8, 2011 on an acoustic wave and current meter (AWAC) mounted on a SeaSpider. Three velocity components were collected every second for 32 days. For a more in-depth description of the sites and the data collection details, see Thomson et al. (2012).

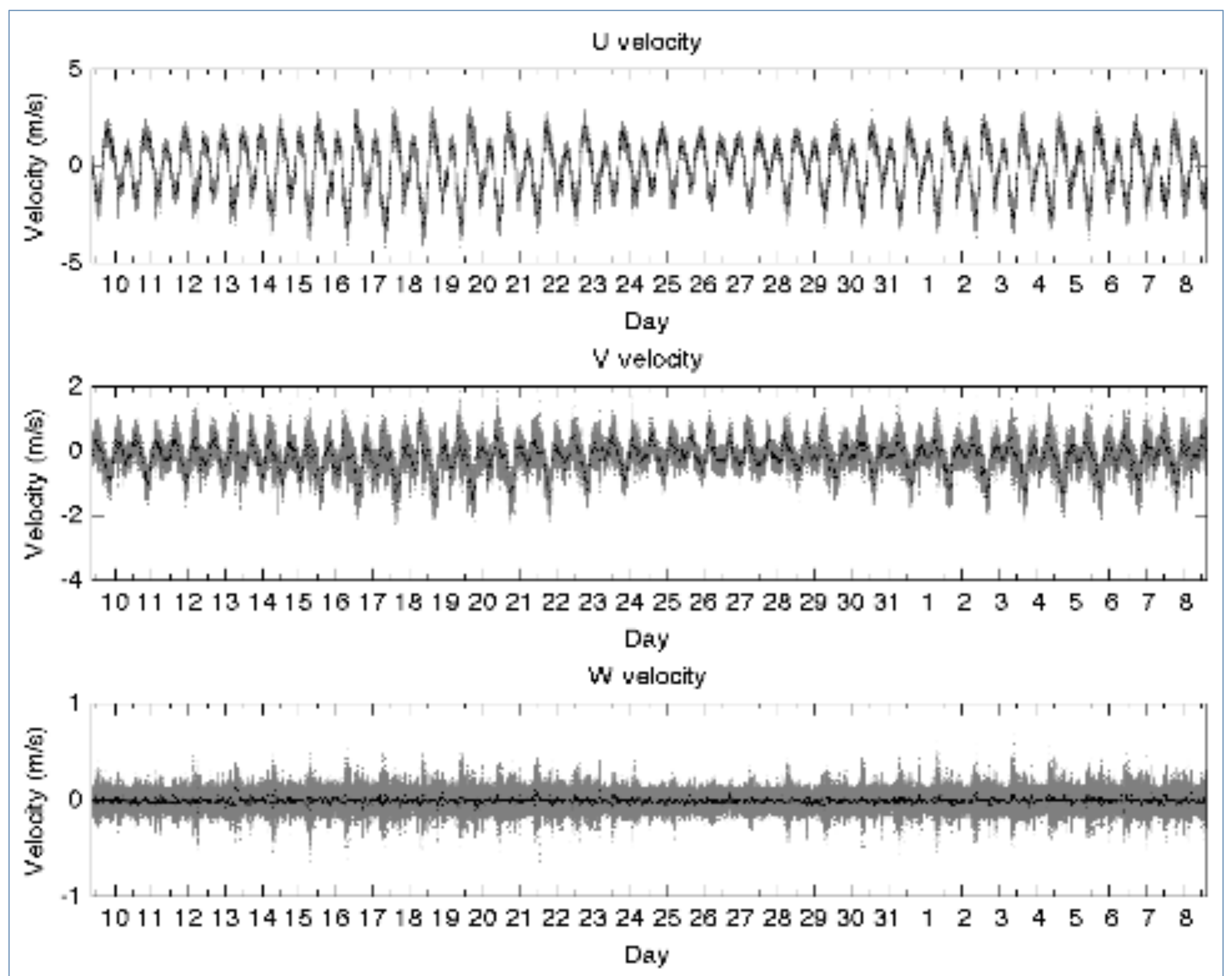

Figure 1: Three components of velocity for the 32 day observation campaign.

Turbulence and Scaling Metrics

Turbulence Intensity:

$$I_u = \frac{\sigma_u}{\langle u \rangle} = \frac{\sqrt{\langle u'^2 \rangle - n^2}}{\bar{u}}$$

Coherent Turbulent Kinetic Energy:

$$CTKE = \frac{1}{2}\sqrt{(u'v')^2 + (u'w')^2 + (v'w')^2}$$

Reynolds Stresses and Anisotropy Tensor:

$$a_{ij} = \frac{\overline{u'_i u'_j}}{2k},\ k = \frac{\overline{u'_i u'_i}}{2}$$

Temporal Autocorrelation:

$$R(\tau) = \frac{\overline{u'(t)u'(t+\tau)}}{\overline{u'^2}}$$

Integral Scale:

$$\Lambda_t = \int_0^\infty R(\tau)\,d\tau$$

Structure Function:

$$D(s) = \overline{[u'(z) - u'(z+s)]^2}$$

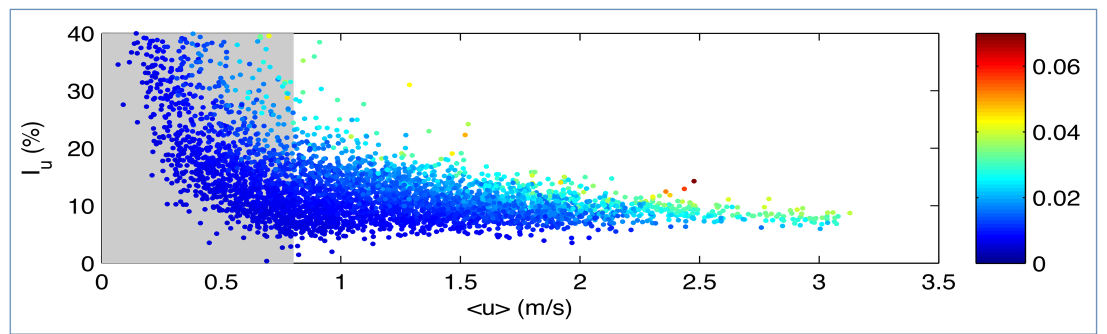

Figure 2: Turbulence intensity, I_u, versus mean velocity, colored by CTKE.

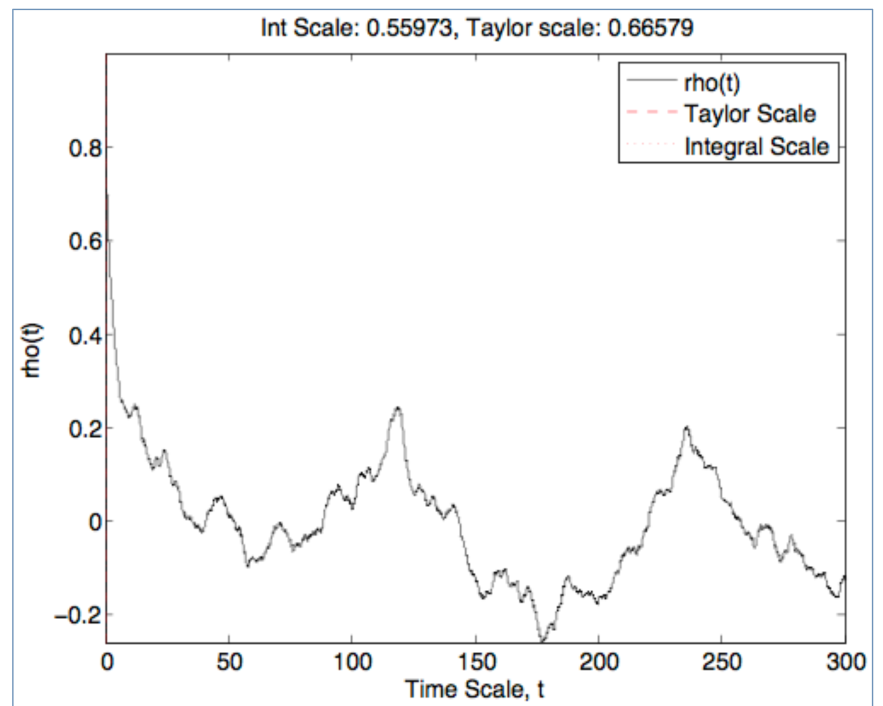

Figure 4: Autocorrelation, with integral and Taylor scales shown.

CTKE Wavelet Analysis

Kelley et al, 2000 showed a strong correlation between peaks in the wavelet decompositions of CTKE and loads that a wind turbine experiences. A continuous wavelet decomposition using the Morlet Wavelet was done on the Reynold's stresses and CTKE in order to infer the loads that could be expected on the tidal turbine.

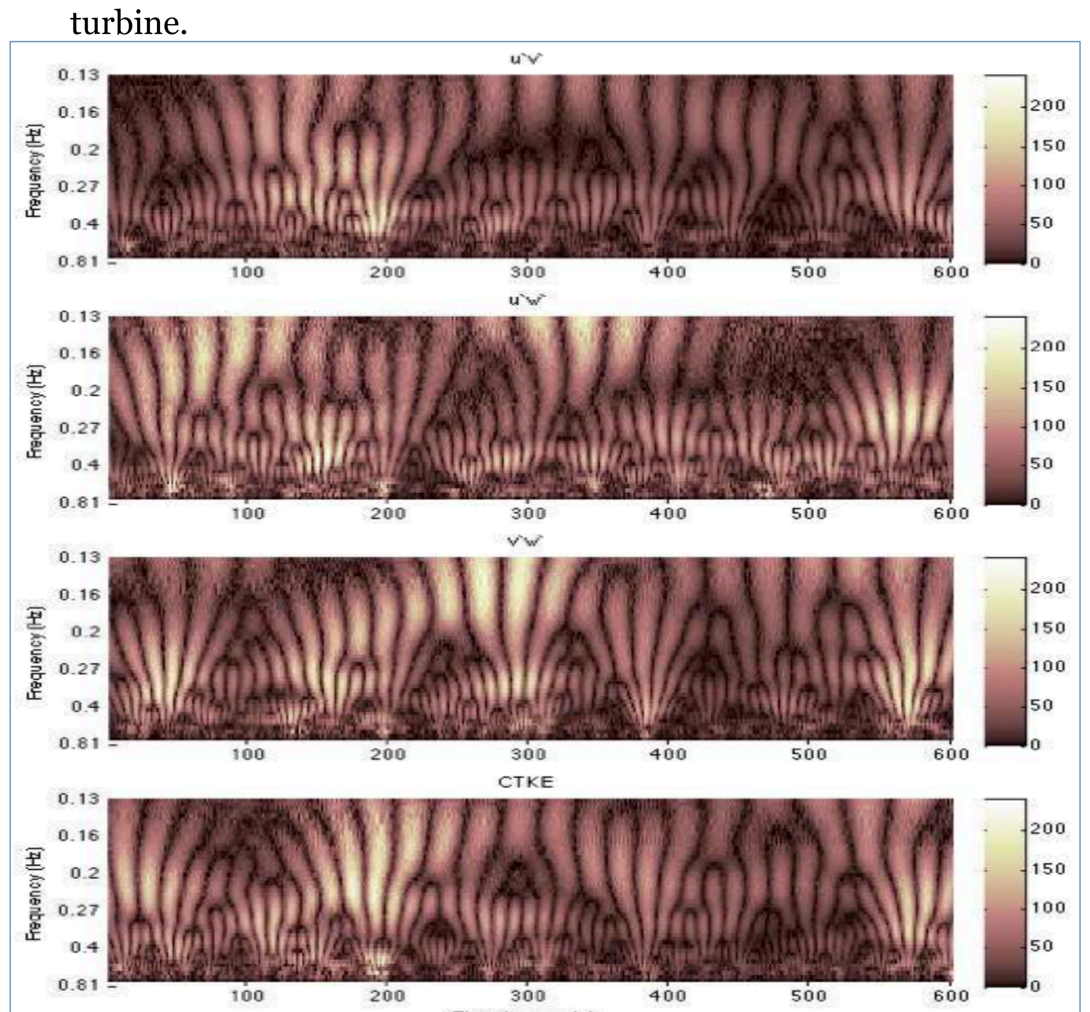

Figure 3: Wavelet decomposition of the three Reynold's stress components and the CTKE during one 10-minute interval.

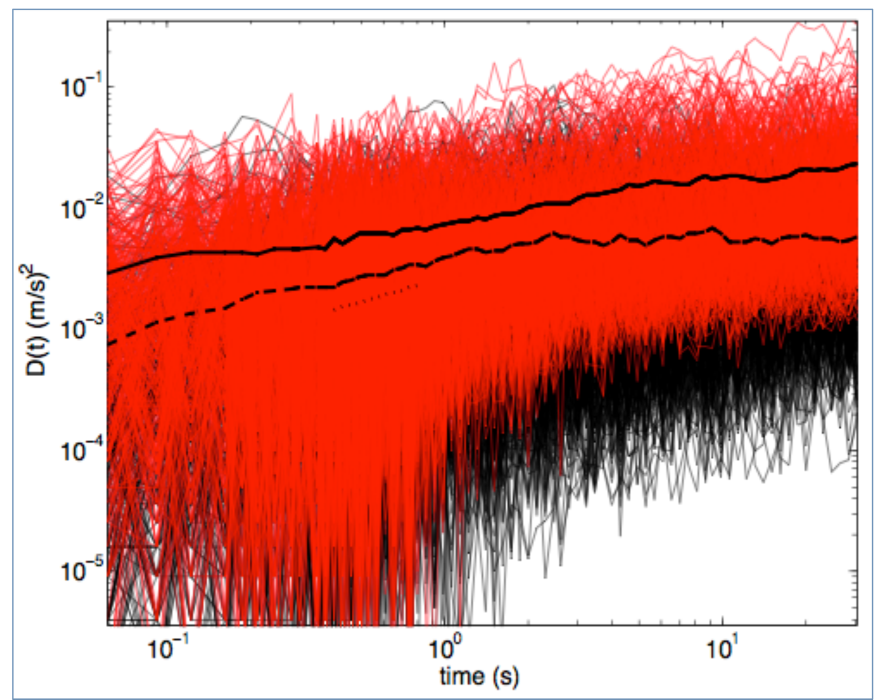

Figure 5: Temporal velocity structure function. Red: horizontal. Black: vertical

Taylor's hypothesis, which assumes that the length scales as the mean velocity multiplied by the time, can be used to get a horizontal structure function from the time series data.

Anisotropy Invariant Map

Anisotropy Invariants:

$$I = a_{ii}$$
$$II = a_{ij}a_{ji}$$
$$III = a_{ij}a_{in}a_{jn}$$

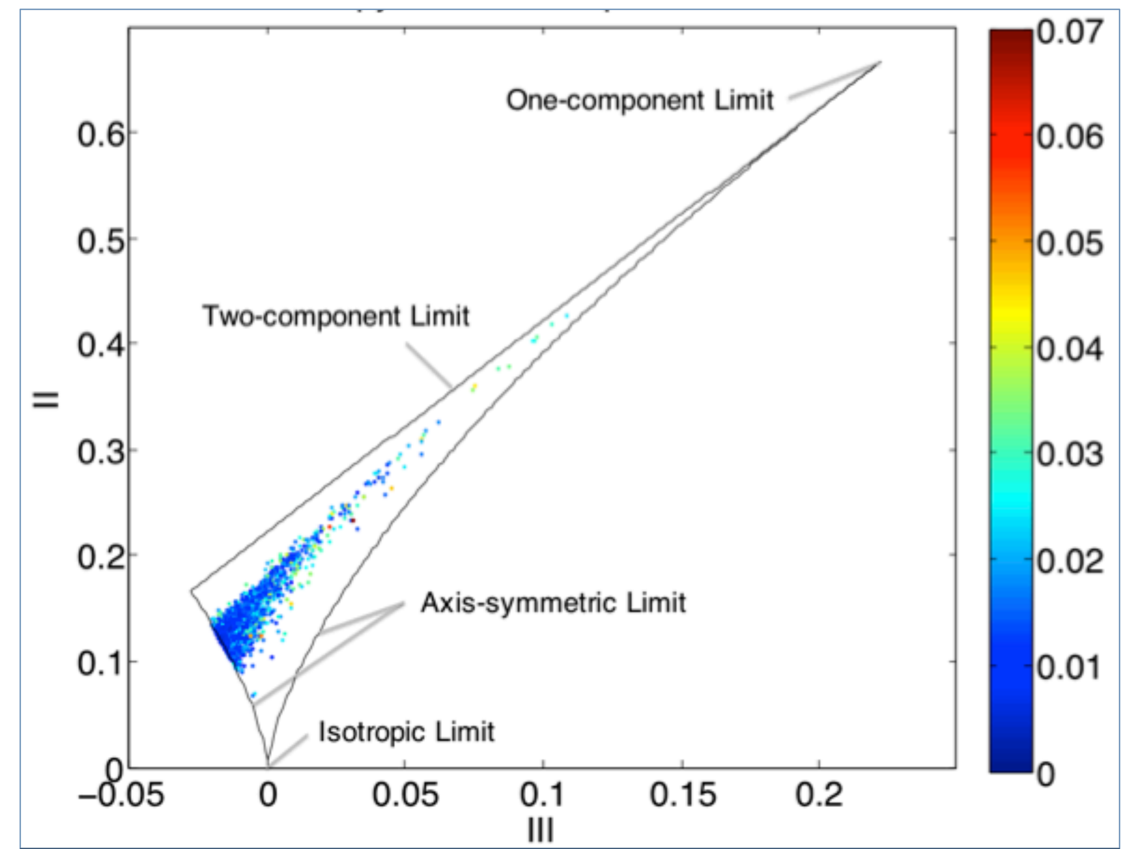

Figure 6: Anisotropy map based on II and III.

Barycentric Map

Using the eigenvalue approach of Banerjee et al 2007, a barycentric map was made to more completely describe the anisotropy in the flow. For eigenvalues, λ_i, of the anisotropy tensor, a_{ij}, ordered from greatest to least, the barycentric coordinates are defined by:

$$C_{1c} = \lambda_1 - \lambda_2$$
$$C_{2c} = 2(\lambda_2 - \lambda_3)$$
$$C_{3c} = 3\lambda_3 + 1$$

Normalized to guarantee to be in the triangle by:

$$C_{1c} + C_{2c} + C_{3c} = 1$$

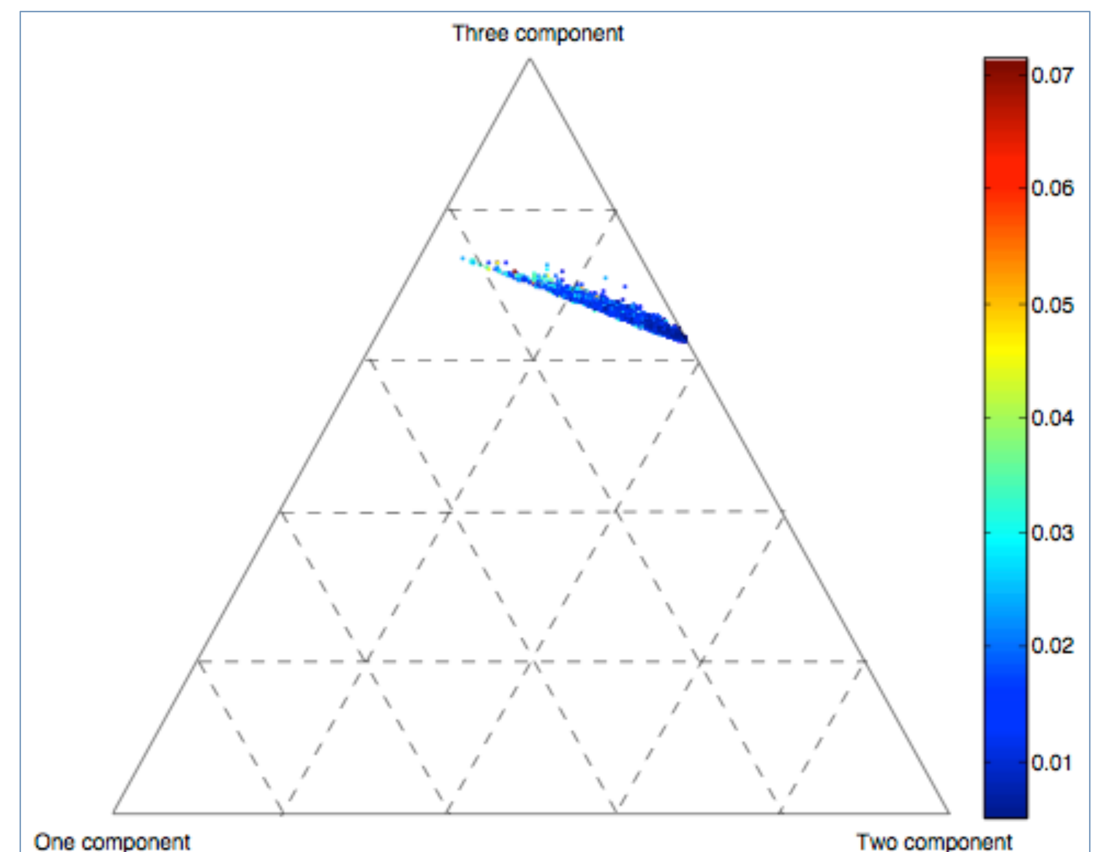

Figure 7: Barycentric map

Future Directions

The results of this analysis will be compared to a similar statistics computed from the output of turbulence-generating models, such as NREL's TurbSim, and NCAR's LES model, both of which are used to generate turbulence to be fed into turbine simulators. The results from the Puget Sound can also be the first in describing a method to classify locations around the world for tidal power.

Acknowledgements

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