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Complex Terrain: A Valid Wind Option?

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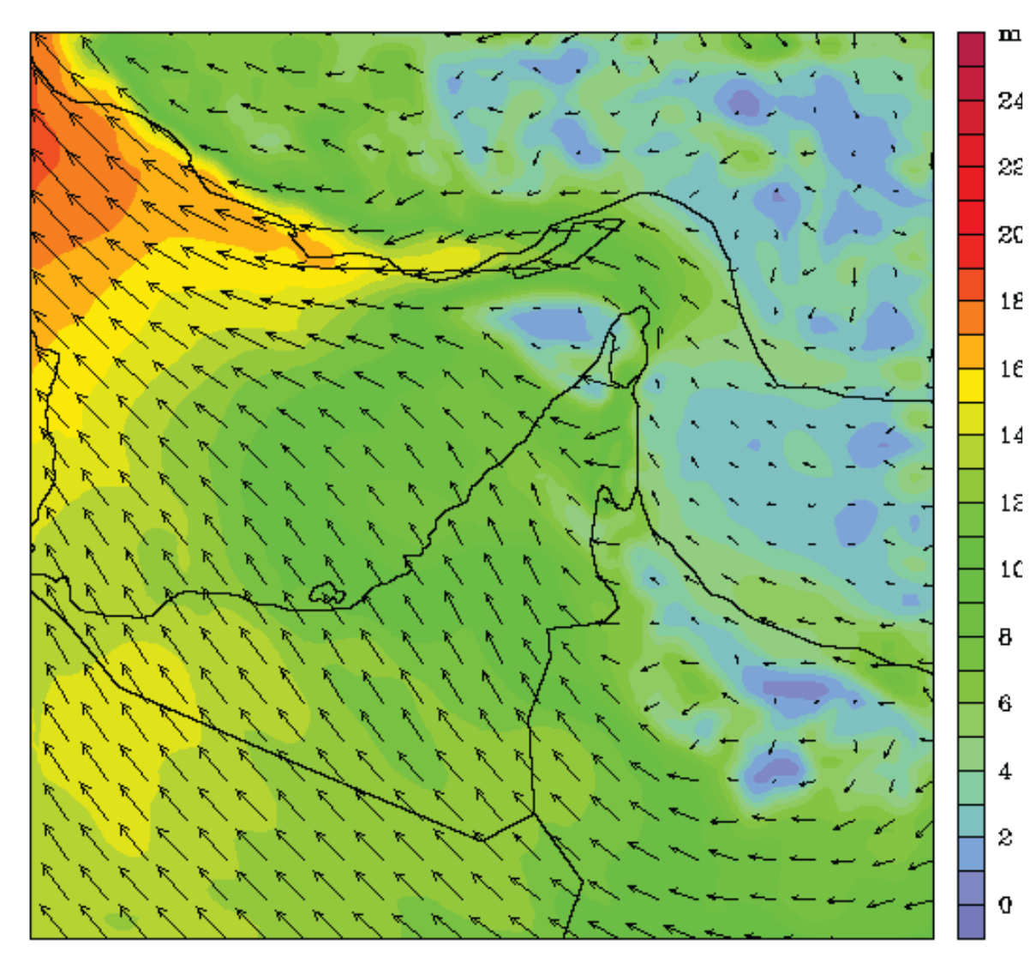
Abstract

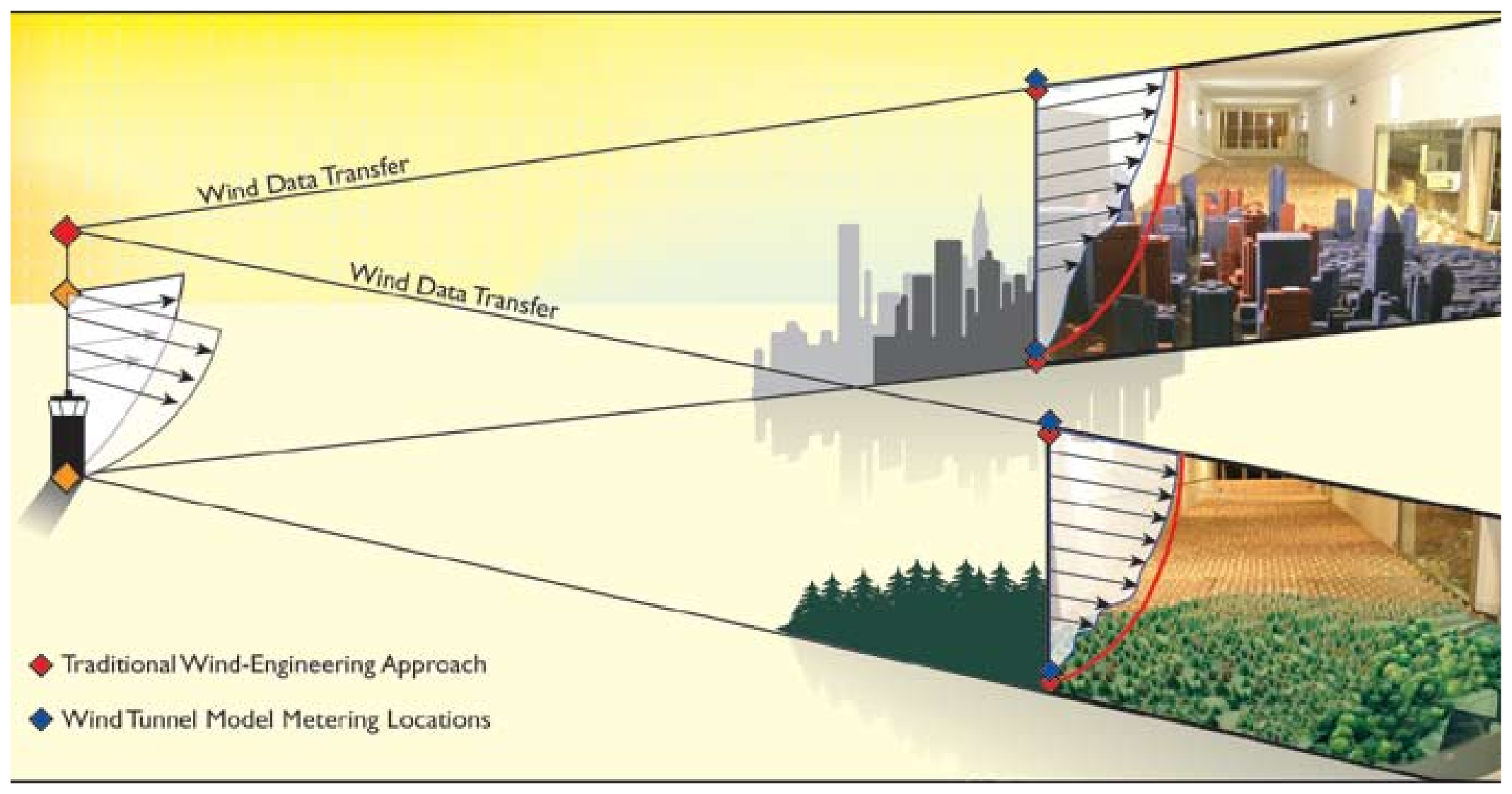
While potentially offering high wind speeds, complex orography presents a formidable challenge for the wind resource assessment as numerical models fail to capture the turbulent flow patterns affecting hub-height wind speeds. Erroneous evaluations of the wind field in complex terrain can lead to an economically flawed project and/or severe risk of curtailing a wind turbine's longevity.

In order to reduce the uncertainty in the wind resource assessment, CPP uses a "hybrid approach" including mesoscale modeling, analytical boundary-layer models, field data acquisition and correlation to long-term sources, and reduced-scale physical modeling.

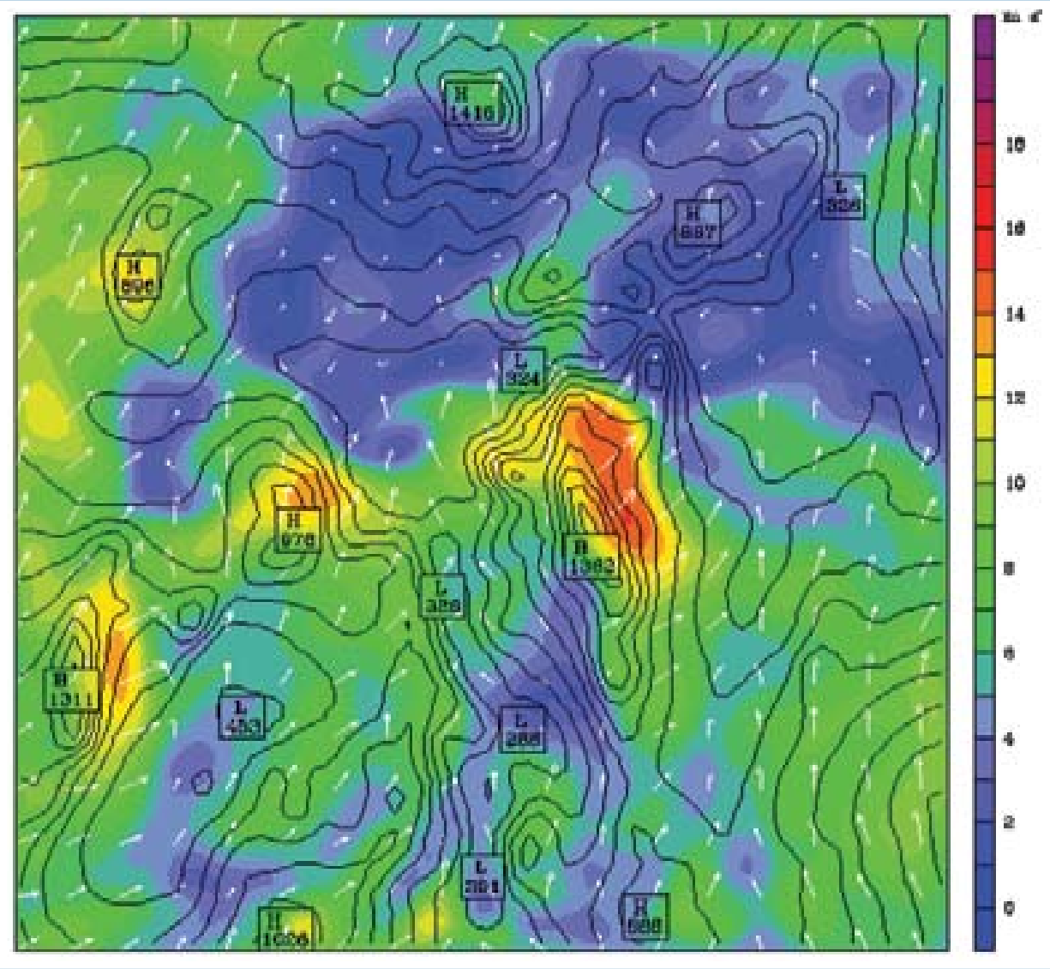
Mesoscale Modeling



Upper-level winds, largely unaffected by the topography, are generally well simulated by mesoscale models. CPP employs the state-of-the-art WRF (Weather Research and Forecasting model [http://www.wrfmodel.org/index.php]) to simulate atmospheric flow on a scale of a few hundred kilometers. The output of WRF is used for the initial **macro-siting** (~5 km).



For the actual **micro-siting** and resource assessment, analytical boundary-layer models can potentially be used to transfer data from long-term data sources to the atmospheric upper levels and back to the surface layer at the site of interest. Analytical models need to be validated, however, as they tend to break down if significant terrain is present.



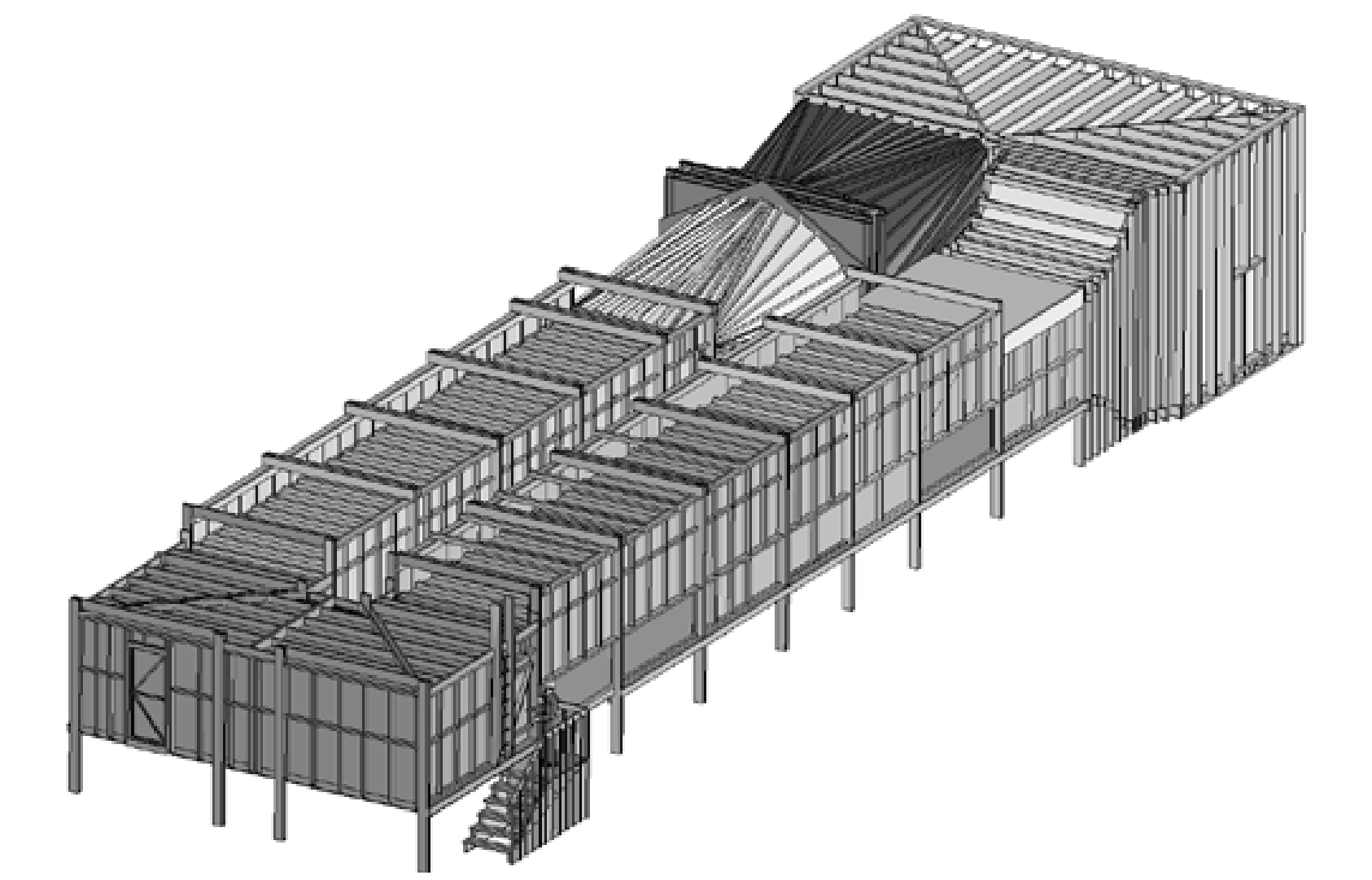
Alternatively, through high-resolution (~1 km) WRF simulations of a **typical wind meteorological year** (TWMY), CPP can calculate wind data from numerous locations across the site and at various heights above grade (10 m to 2000 m AGL).

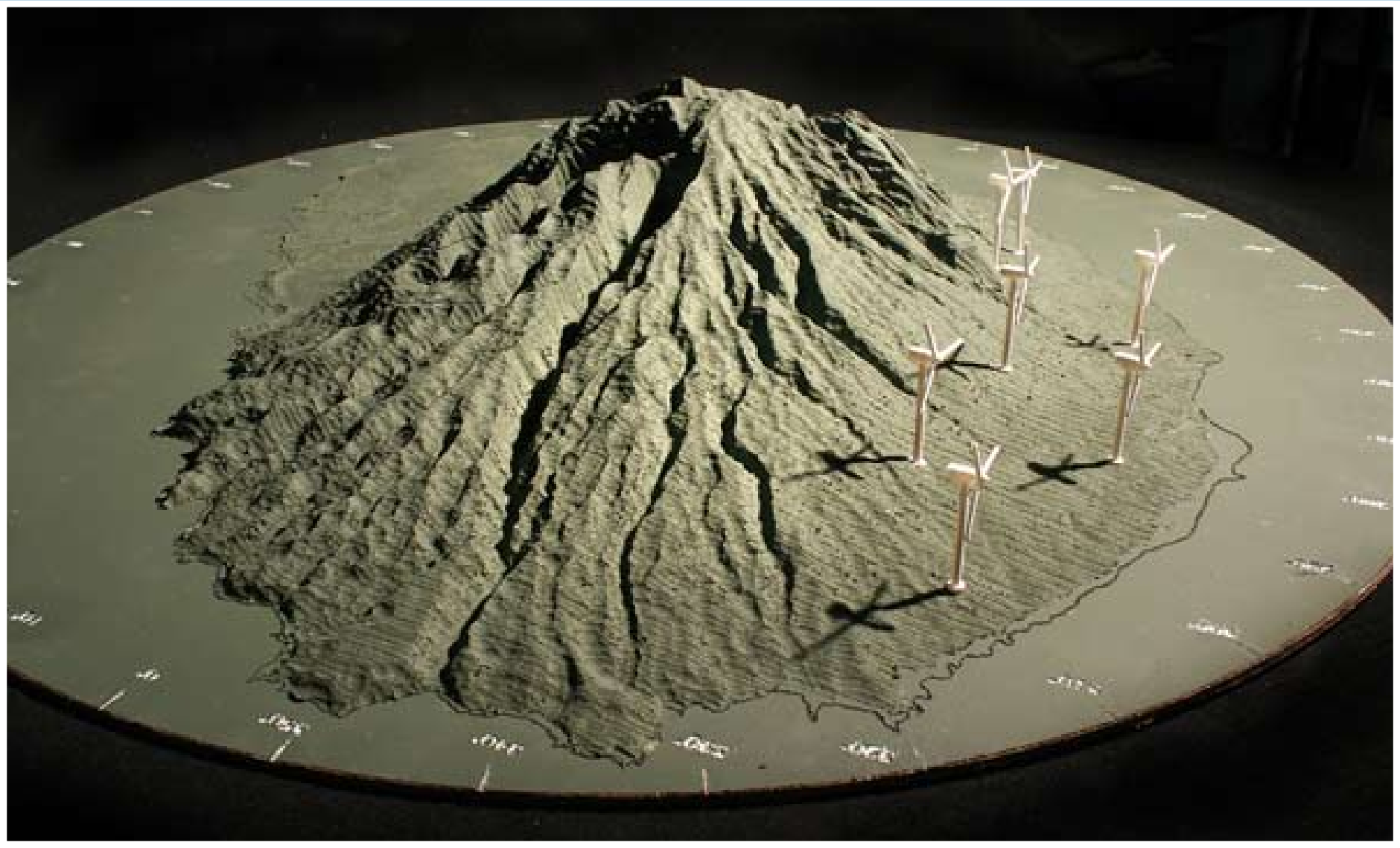
Physical Modeling:
Boundary-Layer Wind Tunnel

The best solution to transfer wind data from the upper to the lower levels is to use relationships developed through reduced-scale physical modeling in a boundary-layer wind tunnel, as they account for the effects of detailed topographical features.

Modeling requires that Reynolds numbers and vertical profiles of approach mean velocity and turbulence be kept similar between the modeled and the full-scale site, and that surfaces be aerodynamically rough [Cermak (1971, 1975); Meroney (1980)]. All tests are performed at a sufficiently high velocity and surface roughness to maintain Reynolds number independence.

The wind tunnel is designed specifically to model atmospheric winds. All data collection is performed in accordance with the American Society of Civil Engineers (ASCE) Standard 7-02 on wind loads (2003), and with the ASCE Manual of Practice Number 67 on wind tunnel testing (1999). Site-approach wind characteristics are specified using an accepted definition of wind speeds and turbulence, ESDU (1993).





5-hole Probe

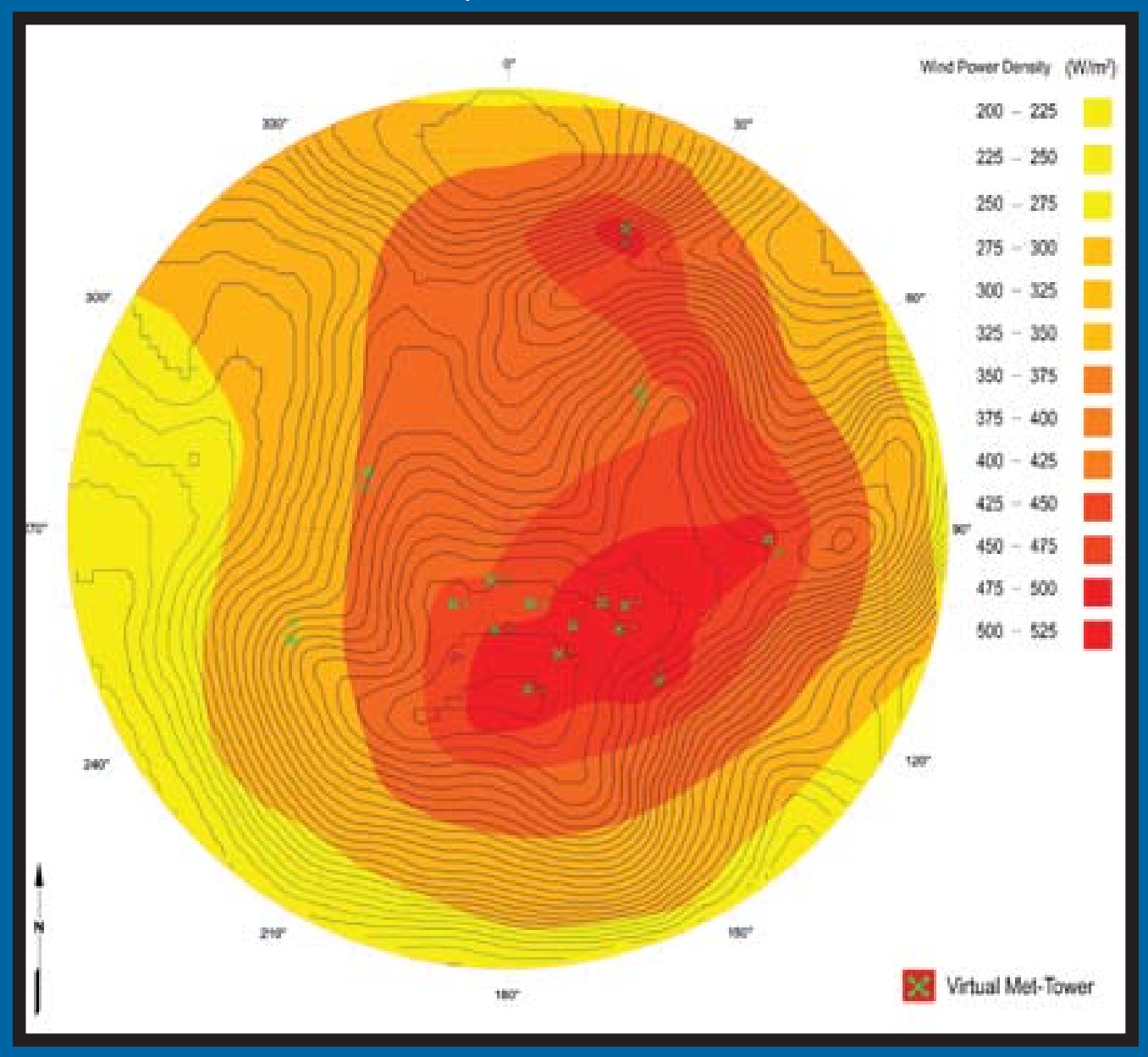
Virtual Met-towers

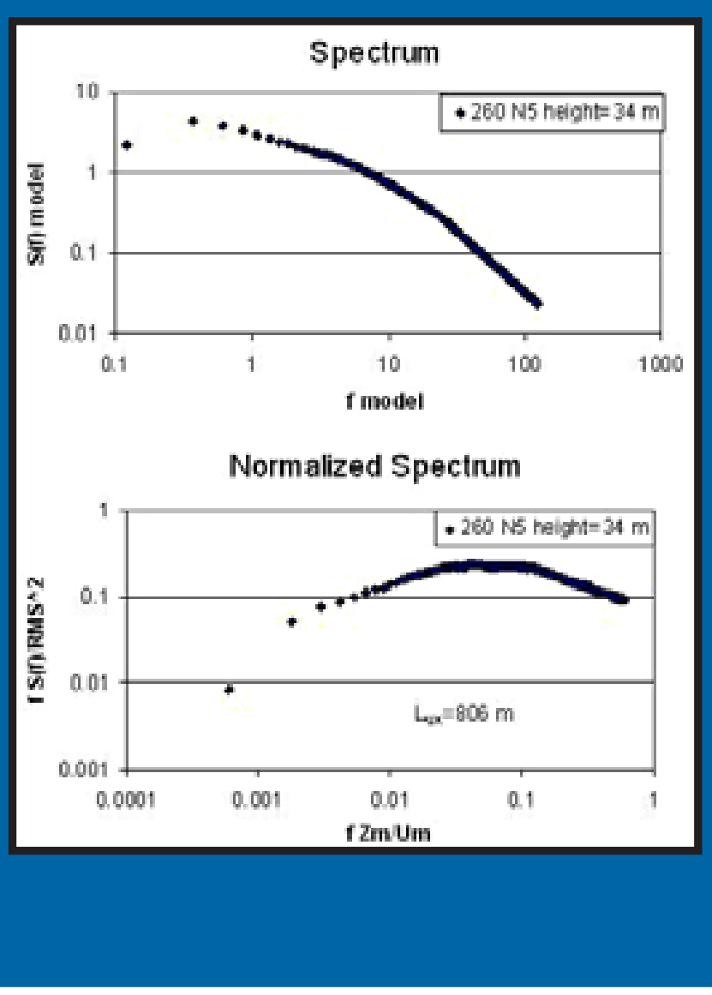
Measurements in the wind tunnel include wind velocity vectors and energy spectra at different levels above grade; virtually providing data from as many as needed met-towers, reaching and surpassing hub-heights. These measurements, correlated to long-term references and to on-site anemometer data, yield wind power densities and capacity factors. CPP uses a combination of **5-hole probe** and **hot-wire anemometry.**

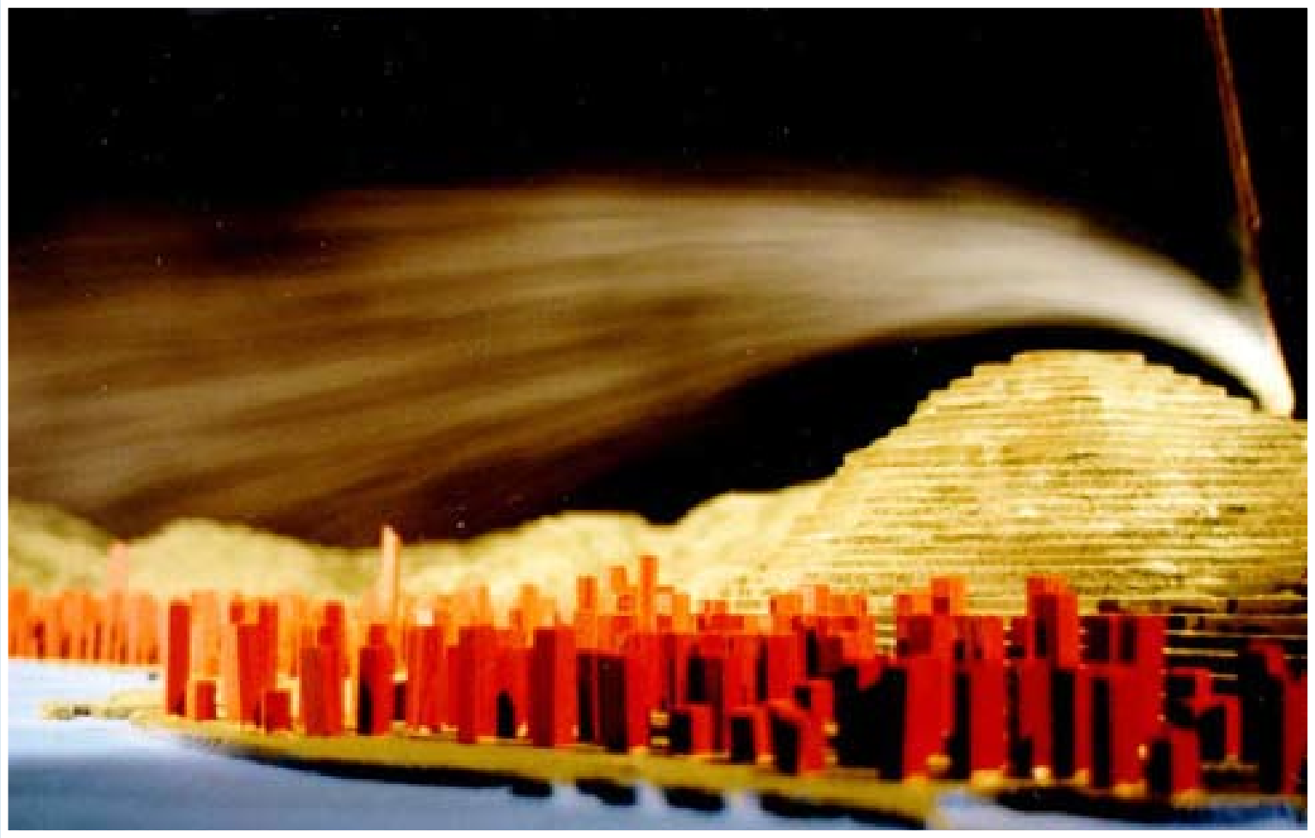
Measured turbulence intensities can mark certain regions as red flags for turbine installations and energy production, while indicating the best areas for turbine and met-mast siting.

Wind Tunnel data also supplement and/or validate WRF and other small-scale modeling data, (e.g., WASP (Wind Atlas Analysis and Application Program, www.wasp.dk)).

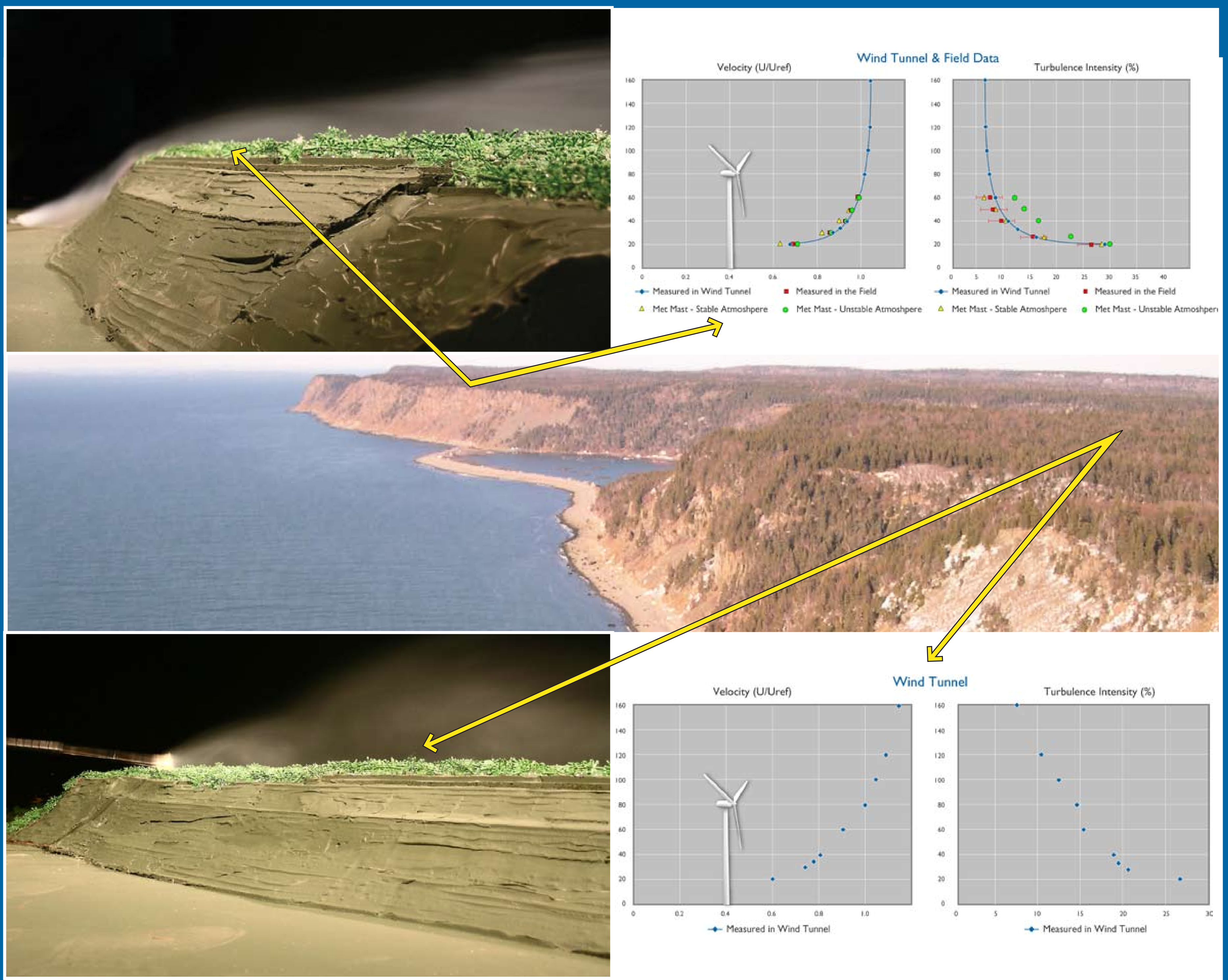
Wind Power Density Measured Across the Turntable







Visualization of Air Flow Over an Escarpment



Flow visualization is a valuable tool to quickly explore the nature of the flow in complex terrain:
In this example, the smoke reveals that no flow separation occurs near the lip of the escarpment, but that an internal boundary layer forms further inland. The consequence is that inland turbines would be exposed to greater wind shear.

This is also demonstrated by the wind profiles and shears derived from measurements at two locations representative of the two different flow conditions.

The wind tunnel performs the best under neutrally stratified conditions. Errors under different atmospheric conditions are comparable to the *rms* of the field measurements.

Conclusions

As most windy plains get claimed, more and more wind power sites are naturally sought in complex or extreme topography, where high wind speeds are expected. The wind resource assessment and micrositing in complex terrain, however, require a special set of tools not currently available under the form of numerical models. CPP's hybrid approach utilizes analytical and mesoscale models, field data, and boundary-layer wind-tunnel tests to provide answers for the developer as well as for the turbine manufacturer. Reduced scale physical modeling accounts for a large portion of the turbulent wind velocity spectrum, unmatched by current numerical models. As a consequence, wind tunnel data can identify turbulent regions detrimental to turbine reliability, map turbulence levels across the rotor, and indicate the most favorable areas for power production. Used in combination with field or mesoscale data, wind tunnel experiments allow the collection of data from virtual meteorological towers in number and in locations as needed, reaching and surpassing hub-heights, a considerable saving with respect to field masts. Further, wind-tunnel smoke visualization aids the wind engineer to interpret the flow patterns in complex topographical situations, guiding micrositing of wind turbines and meteorological masts.

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