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Improving simulation predictions of wind around buildings using measurements through system identification techniques

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ABSTRACT

Wind behavior in urban areas is receiving increasing interest from city planners and architects. Computational fluid dynamics (CFD) simulations are often employed to assess wind behavior around buildings. However, the accuracy of CFD simulations is often unknown. Measurements can be used to help understand wind behavior around buildings more accurately.

In this paper, a model-based data interpretation framework is presented to integrate information obtained from measurements with simulation results. Multiple model instances are generated from a model class through assigning values to parameters that are not known precisely, including those for inlet wind conditions. The information provided by measurements is used to falsify model instances whose predictions do not match measurements and to estimate the parameter values of the simulation. The information content of measurement data depends on levels of measurement and modeling uncertainties at sensor locations. Modeling uncertainties are those associated with the model class such as effects associated with turbulent fluctuations or thermal processes.

The model-based data interpretation framework is applied to the study of the wind behavior around the buildings of the Treelodge@Punggol estate, located in Singapore. The framework incorporates modeling and measurement uncertainties and provides probability-based predictions at unmeasured locations. This paper illustrates the possibility to improve approximations of modeling uncertainties through avoiding falsification of the entire set of model instances. It is concluded that the framework has the potential to infer time-dependent sets of parameter values and to predict time-dependent responses at unmeasured locations.

1. Introduction

Understanding wind behavior in cities has received increasing interest by city planners and architects. The assessment of wind behavior around buildings is sought for a wide range of applications, such as pedestrian wind comfort [1–3], pollutant dispersion [4–6], convective heat transfer at exterior building surfaces [7–9], natural ventilation [10–13], wind loading on buildings [14,15], etc. Computational fluid dynamics (CFD) simulations are often employed to assess wind behavior around buildings. However, CFD simulations might not provide accurate predictions because of uncertainties in the values of parameters and the physical phenomena that are not modeled. Monitoring data can be used to enhance the knowledge of the wind behavior obtained with CFD simulations.

Two ways of using measurements in combination with CFD simulations are presented in Fig. 1. The first way is to use sensors to directly measure the inlet wind conditions used as input for the simulations. Then, simulations are executed to deduce the wind conditions in the area of interest (forward problem). One measured inlet wind speed and inlet wind direction (cause) correspond to one model response (effect). Therefore, there is no ambiguity other than the uncertainty associated with the model. However, values of inlet wind conditions are difficult to measure in urban areas [16]. Furthermore, other important CFD parameter values need to be estimated by engineering judgment, such as the roughness imposed on upstream building surfaces, which can significantly

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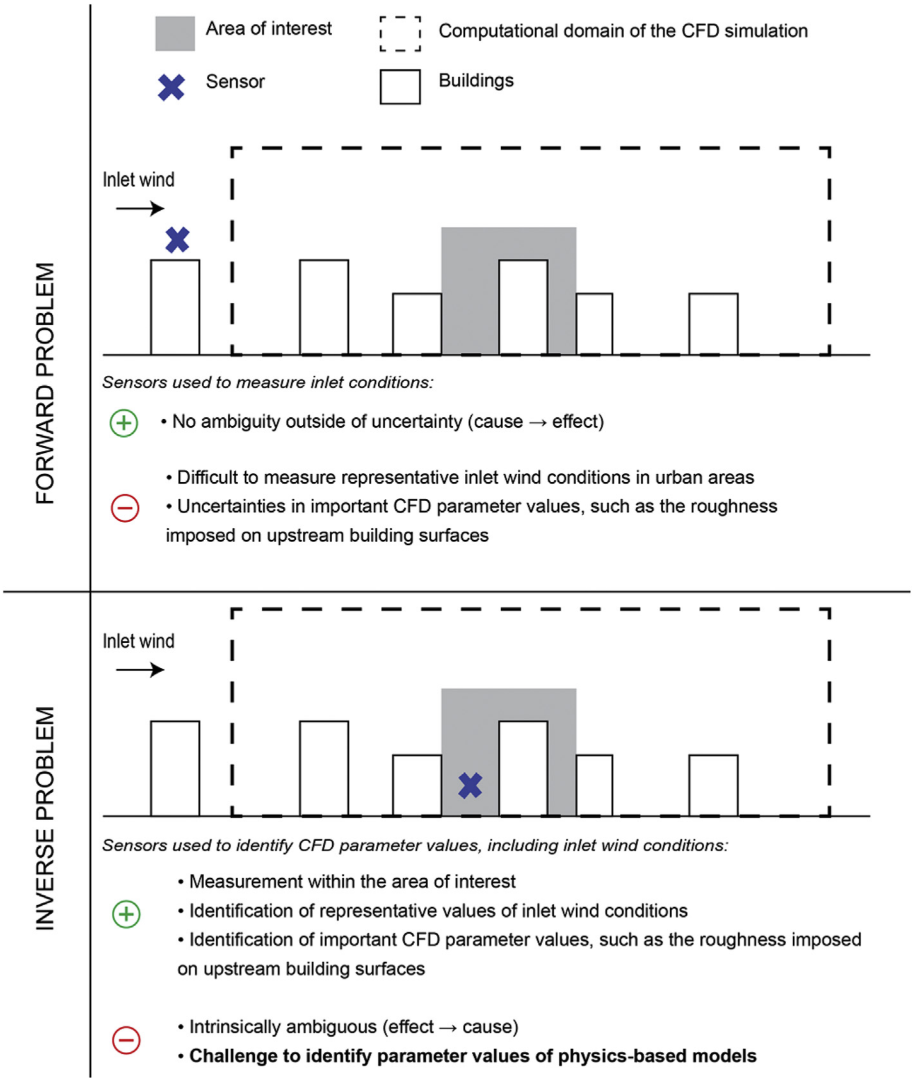

Fig. 1. Two ways to use sensors in combination with CFD simulations. This paper focuses on the inverse problem.

impact the wind conditions in the area of interest [2].

The second way is to use measurements to infer inlet wind conditions and other important CFD parameter values by solving an inverse problem. The inverse problem consists of estimating the set(s) of parameter values by comparing simulation predictions of multiple CFD simulations (generated through assigning different sets of parameter values to the model) with measurement data. This technique is generally known as system identification. Measurements are carried out within the area of interest. This allows inference of representative inlet wind conditions and other important CFD parameter values. This also allows estimations of uncertainties associated with thermal processes using data measured at different times of day. This aspect is explained in Section 5.2.

The inverse problem is the focus of this paper. This way of using measurements to estimate parameter values is intrinsically ambiguous because there might not be a single answer to the inverse problem [17]. Many sets of parameter values might give the same responses at measurement locations in complex systems [18,19]. Such ambiguities are amplified by modeling and measurement uncertainties, which reduce the information content of measurement data. Modeling uncertainties are uncertainties associated with the model that cannot be accounted for when sets of parameter values are varied. Thus residual minimization approaches, which provide a single set of parameter values, are not appropriate for the inference of parameter values of the CFD simulation.

It is a challenge to infer the set(s) of parameter values of physics-based models (such as CFD models) using measurement data because of measurement and modeling uncertainties. Several approaches can be used to infer the set(s) of parameter values of physics-based models from measurement data. Their potential depends on the knowledge of uncertainties (measurement and modeling uncertainties) at measurement locations and correlations between uncertainties at different measurement locations.

Bayesian inference is a statistical method that updates the prior probability of a hypothesis (e.g. a set of parameter values) using evidence (e.g. measurement data). Bayesian inference has been developed in the fields of statistics, signal processing and control engineering. Bayesian inference has also been used in environmental applications such as groundwater modeling [20,21], rainfall-runoff modeling [22,23], climate change predictions