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Renewable Energy Forecasting

From Models to Applications

Edited by George Kariniotakis

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Part One

Introduction to meteorology and measurement technologies

Principles of meteorology and numerical weather prediction

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1.1 Introduction to meteorology for renewable energy forecasting

Renewable resources are fast becoming the predominant energy source of the future, but to harvest them requires an understanding of the causes of their variability and the ability to predict numerous atmospheric processes over a range of scales. This understanding of the atmosphere is the key to harvesting renewable energy, specifically wind and solar power, in at least three ways. First, one must be able to characterize the resource availability to appropriately site plants and elements (such as wind turbines) within those plants. Second, it is imperative to forecast the resource on time periods of minutes to seasons to properly plan how to blend the renewable resources into the grid while continuing to meet the load obligation. Third, forecasts of expected energy generation and variability, including forecasts of extreme weather or sudden changes in the weather that may affect energy generation, are helpful in planning operation and maintenance of the sites. Thus, understanding the atmospheric physics and dynamics that ultimately cause the wind and solar resource to vary is key to modeling and forecasting for renewable energy. In this section, we briefly review the causes of atmospheric motion and the basics of forecasting before getting into more detail in subsequent sections.

1.1.1 Atmospheric motion

The atmospheric circulation arises because the Earth is spherical and the Sun's rays impact the Earth more directly near the equator than at the poles. The warmer tropical atmosphere is less dense than the polar atmosphere, forcing the predominant motion from the polar regions toward the tropics at the surface. Thus, the tropical air converges and rises at the Inter-Tropical Convergence Zone near the thermal equator, while the movement of surface air out of the polar regions causes a polar subsidence. This resulting circulation includes a return flow aloft from the tropics toward the polar region as the primary solar-forced circulation, known as the Hadley circulation (Anthes et al., 1981). Because the Earth rotates on its axis, it is actually a bit more complicated than that. This rotation creates an apparent Coriolis force that turns the flow toward the right in the northern hemisphere and toward the left in the southern hemisphere.

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In addition, this Coriolis force, due to the conservation of angular momentum, causes there to be not a single hemispheric-spanning Hadley cell, but rather three primary cells in each hemisphere (Fig. 1.1). The thermally indirect Ferrel cell encompasses the mid-latitudes and acts to mix the air through large-scale eddies and vertical instabilities. These instabilities generate waves that form the low- and high-pressure waves that continually pass over the mid-latitudes, transporting warm air poleward and cool air equatorward at the surface, with prevailing westerly winds at mid-latitudes and tropical easterlies in the regions near the equator. Finally, the polar cell is a thermally direct circulation, exhibiting high pressure from subsiding air at the poles.

The Earth's 23.5°-tilted axis generates the seasonality of the flow, the diurnal heating patterns cause the rise and fall of the atmospheric boundary layer (the lowest kilometer or so of well-mixed air), differential ocean and land heating rates cause further instabilities, and mountain ranges impede atmospheric flow, frequently leading to the generation of new low-pressure systems in the lee of the mountains. All these forcings work together to form the variability of the atmospheric flow (Fig. 1.1). Introductory meteorology texts (e.g., Holton, 2004; Wallace and Hobbs, 2006) provide more details of this general circulation theory and demonstrate how it can be codified into a series of

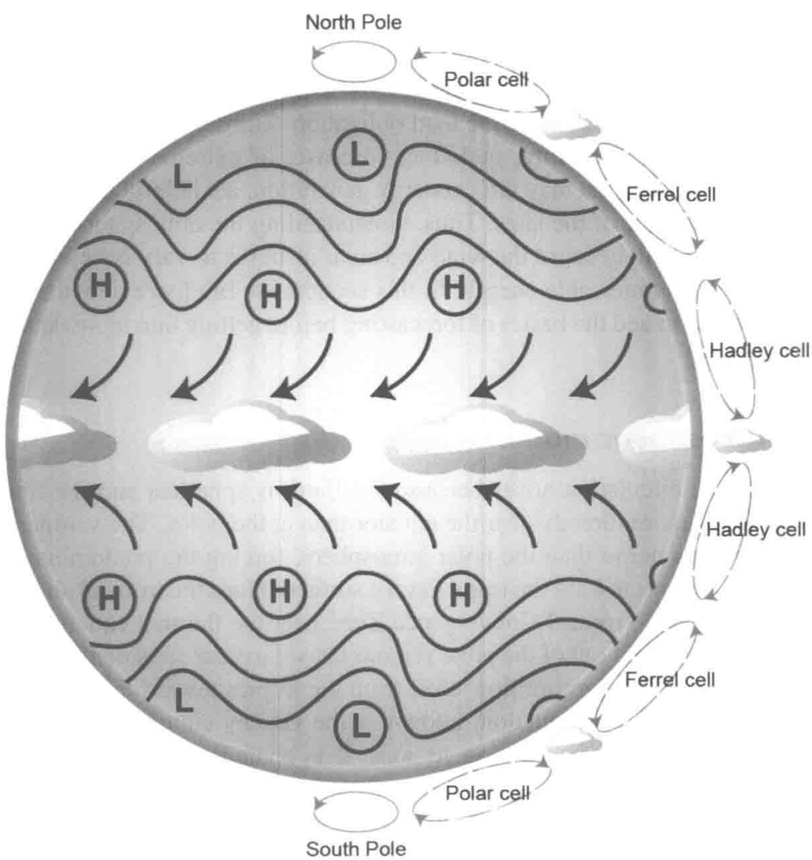

Figure 1.1 Depiction of the general circulation of the atmosphere.

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