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Review Article

A tribute to Michael R. Raupach for contributions to aeolian fluid dynamics

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ABSTRACT

Since the pioneering work of Bagnold in the 1940s, aeolian research has grown to become an integral part of earth-system science. Many individuals have contributed to this development, and Dr. Michael R. Raupach (1950–2015) has played a pivotal role. Raupach worked intensively on wind erosion problems for about a decade (1985–1995), during which time he applied his deep knowledge of turbulence to aeolian research problems and made profound contributions with far-reaching impact. The beauty of Raupach's work lies in his clear conceptual thinking and his ability to reduce complex problems to their bare essentials. The results of his work are fundamentally important and have many practical applications. In this review we reflect on Raupach's contribution to a number of important aspects of aeolian research, summarise developments since his inspirational work and place Raupach's efforts in the context of aeolian science. We also demonstrate how Raupach's work provided a foundation for new developments in aeolian research. In this tribute, we concentrate on five areas of research: (1) drag partition theory; (2) saltation roughness length; (3) saltation bombardment; (4) threshold friction velocity and (5) the carbon cycle.

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Contents

1. Introduction

Aeolian research is multi-disciplinary, but its core lies arguably in the fluid dynamic interactions between soil particles, the atmosphere, and the soil surface. Since the early work of Bagnold (1941), it has advanced to become an integral part of earth-system studies. Aeolian processes are highly relevant topics in the earth sciences because of the need to: (1) better quantify the dust cycle for climate projections; (2) assess the anthropogenic impact on natural and human environments; (3) prevent soil loss from wind erosion in land-conservation practice; and (4) understand aeolian processes and landform development on other planets in particular, Mars and Venus, as well as moons such as Titan. Many individuals have contributed to this development, and Dr. Michael R. Raupach (1950–2015) was one of the most outstanding (Steffen, 2015).

For colleagues in aeolian research, and in climate research at large, Michael R. Raupach is Mike, but he used to abbreviate his name MR^2. This abbreviation was related to his university training in Applied Mathematics. Raupach received his BSc degree, with honours in mathematical physics, from the University of Adelaide in 1971, and a PhD in micrometeorology (under the supervision of Prof. Peter Schwerdtfeger) from the Flinders University of South Australia in 1976. After a postdoctoral position at the University of Edinburgh, he joined the Centre for Environmental Mechanics (CEM, also referred to as the Pye Lab) of the CSIRO (Commonwealth Scientific and Industrial Research Organisation) in Canberra in 1979, where he worked for much of his 35-year career. From 2000 to 2008, he was inaugural co-chair of the Global Carbon Project, an international program bridging the research effort between the natural and human dimensions of the carbon cycle. In February 2014, he took up the role of Director at the Climate Change Institute of the Australian National University and remained an Honorary Fellow with the CSIRO. Based on his research foci, his career can be divided into two stages. In the first he worked on atmospheric boundary-layer turbulence and atmosphere-land-surface exchanges, including aeolian processes, and in the second on climate change, in particular the carbon cycle.

Raupach's scientific drive originated from his passion for protecting the environment, and his interest in aeolian processes following from his concerns with land conservation. The period of 1977–1988 saw three successive El Niño events, including the intense phase of 1982–1983, which brought record drought to eastern Australia, turning the farmlands in the wheat-sheep belt into a hot spot of wind erosion. On 8 February 1983, a "cool change" (a dry cold front) preceded by hot (43.2 °C) gusty northerly winds blew large quantities of red-brown dust over Melbourne. This event inspired Raupach to write one of his first essays on wind erosion (Raupach et al., 1994), which was pioneering in its attention to three fundamental goals of dust research: identification of dust sources; estimating dust loads; and quantifying the nutrient loss of topsoil by wind erosion. Their estimate of the dust loading (2 ± 1 Mt) in the 1983 Melbourne dust storm was one of the earliest attempts to quantify event-based dust loading. This value was based upon a few back-of-the-envelope calculations; reducing a complex problem to its fundamental components, for which Raupach became famous. Raupach's estimate of topsoil nutrient loss was highly innovative, and 20 years later, wind-erosion related soil nutrient and soil carbon transport has become one of the most fundamental aspects of studies on the dust cycle.

In 1985, John Leys, then with the New South Wales Soil Conservation Service, had just started his PhD at Griffith University in Brisbane under the supervision of Professor Grant McTainsh, and was developing a portable wind tunnel for wind-erosion field experiments. At the time, Raupach was among a group of world-class micro-meteorologists gathered in the Pye Lab, conducting wind-tunnel experiments on flow over complex terrains. Raupach and Leys went on to modify the design of Marsh and Carter (1983) and develop Australia's aeolian-research wind tunnel (Leys and Raupach, 1990). The excellent fluid dynamic features of this tunnel made it a valuable research tool not only for land-conservation studies (McTainsh and Leys, 1993), but also for the studies of basic wind-erosion processes (Shao and Raupach, 1992; Shao et al., 1993). In 1991, a group of Australian wind-erosion researchers gathered at the Murdoch University in Perth and staged the 1st Australian workshop on wind erosion (Fig. 1). In this workshop, William Nickling gave a keynote presentation "Shear Stress: What Drives Wind Erosion Processes". Following the meeting, with a cool sea breeze and bright stars in the sky in the port of Freemantle, Raupach treated everyone with beer. In 1993, the group met again in the Mallee country town of Mildura and formed the Wind Erosion Research Community of Australia (WERCA, a name that Raupach and Grant McTainsh conceived over drinks at the meeting). Dale Gillette gave a philosophical talk on the paradigms of wind erosion. It is unfortunate that Raupach will not be with us for the ninth International Conference on Aeolian Research (ICAR IX) to be held in Mildura in 2016. However, the influences of his work will be evident at the conference and will provide a legacy for a considerable time.

Raupach worked for about a decade (1985–1995) intensively on wind erosion problems, but he did so brilliantly by relating aeolian problems to his deep knowledge of turbulence, and made profound