

# John C. Wyngaard: His Career in Boundary-Layer Meteorology

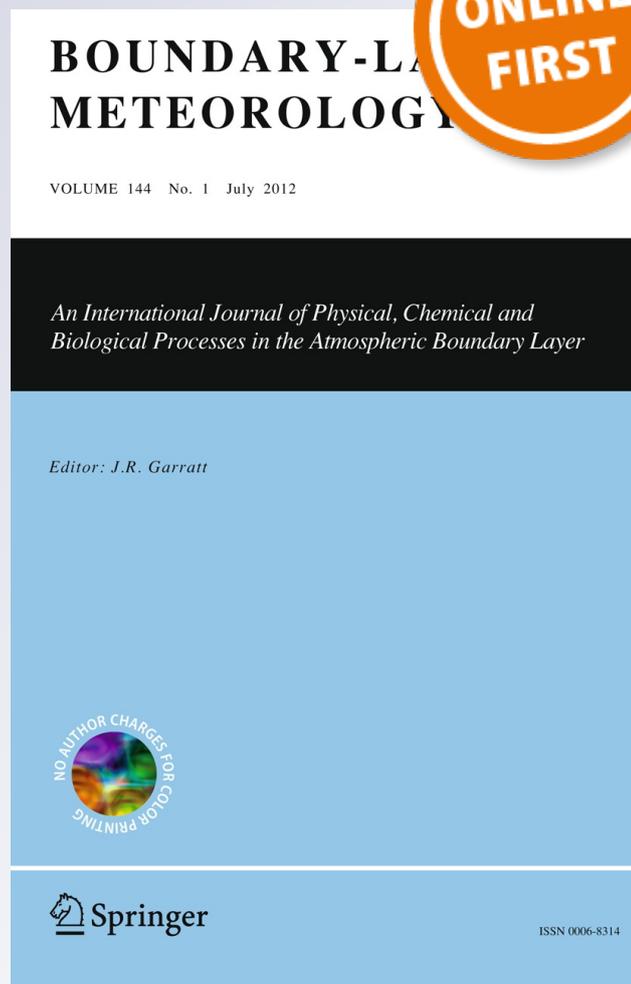
**Jose D. Fuentes & Dennis W. Thomson**

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To celebrate the distinguished scientific career of John C. Wyngaard, a symposium (<http://ploneprod.met.psu.edu/news-events/john-c.-wyngaard-symposium>) was held at the Pennsylvania State University, State College, during 24–25 June 2010. From the original 78 oral presentations, this special issue contains 13 articles on topics that are closely related to John's main interests in atmospheric turbulence and boundary-layer processes. Below we introduce the articles included in the Special Issue, followed by a brief description of John's professional career.

In the atmospheric surface layer, abrupt changes in the fluctuations of scalars in particular are ubiquitous. Such changes are evident as ramp structures occurring at frequencies that increase with wind shear. Shapland et al. (Parts I and II) report on a new approach to systematically identify ramp structures ordinarily observed as part of plant canopy-atmosphere scalar exchange. Since ramp structures meaningfully influence this exchange, the investigators propose approaches that identify the turbulence intermittency, duration, and their associated flux contribution using spectral analysis. The proposed method is ideally suited to investigate the surface-atmosphere scalar exchange over bare ground and short plant canopies.

Improved Monin-Obukhov similarity functions are still required to derive surface sensible heat and water vapour fluxes from scintillometer measurements. Since most existing similarity relationships fail during extreme unstable and stable conditions, Li et al. propose new similarity relationships to determine the turbulent transport of sensible and latent heat over homogeneous surfaces. The relationships do not require the use of the friction velocity and provide reliable flux estimates for moderate to strong unstable conditions. Then, Salesky and Chamecki outline and test a scale-similarity model to estimate the sub-filter scale energy in large-eddy simulations (LES) of the atmospheric boundary layer (ABL). The model is derived from a stability-dependent relationship of the energy spectrum in the ABL, and accounts for the effects of buoyancy and mean wind shear as a function of the Monin-Obukhov stability parameter.

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J. D. Fuentes (✉) · D. W. Thomson  
Department of Meteorology, The Pennsylvania State University, University Park, PA, USA  
e-mail: juf15@meteo.psu.edu

To make in situ observations of atmospheric thermodynamics in the ABL, Dias et al. describe an instrumented unmanned aerial vehicle to probe the atmosphere from the surface to 1,800 m above the ground. Airborne observations are combined with surface energy fluxes to derive estimates of energy entrainment into the convective boundary layer (CBL) based on top-down and bottom-up methods. In addition, based on upper air observations, DeLonge and Fuentes demonstrate that the depth of the CBL in the coastal region of Senegal exhibits too little diurnal variability during the rainy season due to onshore flows associated with the monsoonal circulation. Onshore flows, particularly during the nighttime, transport heat and moisture to the adjacent landscape, hence yielding a CBL up to 1 km in depth. Katzwinkel et al. provide high-resolution measurements of the dynamic, microphysical and turbulence attributes inside a turbulent inversion layer above a stratocumulus cloud, and conclude that large-scale eddies in the inversion layer are suppressed by buoyancy. Their study also reveals that mixing between the cloud top and free troposphere becomes inhibited due to the reduced entrainment velocity.

Momentum and energy transfers in the CBL drive many atmospheric processes, and McNaughton describes two frameworks to investigate such transfers. The first framework is based on the Reynolds-averaged Navier–Stokes equations while the second is provided by complex dynamical systems. The analyses presented by McNaughton provide an interpretation of local budgets of turbulence kinetic energy (TKE) in the CBL. In a complementary boundary-layer study, Wilson investigates the most appropriate forms of eddy viscosity formulations to estimate scalar transfer in the horizontally uniform ABL. He concludes that eddy viscosity models relying on the TKE provide the most reliable results. Using a Lagrangian particle dispersion model, Weil et al. estimate the dispersion of scalars in the CBL. Their model produces reliable estimates of vertical dispersion and the crosswind concentration of particles when the appropriate velocity fields are provided as input. For elevated sources, however, the model underestimates the dispersion of particles.

The transport of scalars during stable conditions over land still remains a topic of investigation as most numerical models fail to properly resolve the turbulent transfer in the stable boundary layer (SBL). Based on the prognostic equation for TKE, Acevedo et al. apply four different methods to determine the turbulent transport of scalars in the SBL. In general, formulations based on the TKE yield the most reliable estimates. Furthermore, applying a LES model, Lee et al. simulate the transport of carbon and oxygen isotopes in the ABL. Results indicate that variations in the oxygen isotopes associated with water vapour are an order of magnitude greater than changes in the carbon isotopes related to carbon dioxide. Differences in the oxygen and carbon isotopes are ascribed to the distribution of sources and sinks of water vapour and carbon dioxide. In general, within the CBL isotopic compositions remain well mixed. Finally, Shapiro et al. apply a two-dimensional Boussinesq model to investigate the katabatic flow patterns over a heterogeneous surface. The model is capable of representing key flow structures such as katabatic jets and rotor-like features.

Many of the studies reported in the Special Issue are largely based on work that John Wyngaard pioneered. He obtained his undergraduate degree from the University of Wisconsin in Mechanical Engineering, then pursued graduate studies at Penn State University under the direction of John Lumley and Henk Tennekes, obtaining his PhD in 1967. As a young scientist, then at the Air Force Cambridge Research Laboratories (1967–1975), his careful analysis of data and the use of fluid dynamics concepts provided a quantitative and detailed understanding of turbulence processes in the ABL and set new standards for flux measurements in the atmosphere. Much of his research at this time relied on the turbulence measurements from the Kansas (Businger et al., *Journal of the Atmospheric Sciences*, 28, 181–189, 1971) and Minnesota (Kaimal and Wyngaard, *Boundary-Layer Meteorology*, 50, 31–47, 1990)

experiments. Through this work, he gained recognition for his extraordinary attention to detail and critical inquiry of atmospheric turbulence. Throughout this early period of his career he encouraged a whole new approach to atmospheric surface-layer and boundary-layer experiments. If progress was to be made on the challenging problems of atmospheric turbulence, he recognized that it was essential to pursue a multi-pronged approach including theoretical work, laboratory modelling, and numerical simulations, the latter via application of the emerging LES.

In 1975 John moved to Boulder, working first at the National Oceanic and Atmospheric Administration (NOAA) Wave Propagation Laboratory. During that time he focused on problems relating to the behaviour of signals propagating through the turbulent atmosphere. In 1979 he moved to the National Center for Atmospheric Research (NCAR), initially as a senior scientist in the Atmospheric Analysis and Prediction Division. Later, he headed the Small-Scale Analysis and Prediction Program, and then became deputy director of the Mesoscale and Microscale Meteorology Division. During his years at NCAR, he continued not only to motivate and lead transformative boundary-layer turbulence research but also to mentor and collaborate with scientists from around the world. He influenced, directly and indirectly, many laboratory, numerical and field studies during this period, both within the USA and beyond.

In 1991, John moved back to his alma mater, and to his fourth main career appointment, this time as a full professor with faculty appointments in both meteorology and mechanical engineering. His impact on the academic program in meteorology at Penn State University was immediate. Many students were challenged in ways never before experienced—even in their graduate courses in atmospheric dynamics and physics. John did a truly exceptional job of communicating the intricacies and beauty of turbulence, and most notably and particularly to those students who were ready to rise to the intellectual and practical challenges he offered. We now know that for the best of those students, his teaching changed their lives and careers forever.

In matters of academic programs and classes, John also took the lead to completely rebuild the Penn State Meteorology Department's air quality program. For years this had been a matter of frustration for several of the faculty, often with professional opportunities for students going unexploited. At long last those students who were suitably inclined were able to refocus their career goals from being strictly weather-oriented to applying atmospheric science, with a strong boundary-layer focus, to problems in areas such as air quality, transportation, and environmental assessment. As a faculty member at Penn State, John extended the mentoring of students well beyond his own students and provided guidance to others. Such interactions enabled students, several of whom spoke at the Symposium, to apply the fundamentals of atmospheric turbulence to problems with which they would not otherwise have made connections. In a variety of departmental activities and meetings, John was often the quiet and reflective thinker who would force and guide the discussion to the core science problem and reject alternative methods that were inappropriate. These inclinations and habits also served his colleagues well in matters of departmental policy and administration.

John Wyngaard's wide-ranging knowledge has been encapsulated in his recently published textbook "Turbulence in the Atmosphere" published by Cambridge University Press (see the review by Evgeni Fedorovich: *Boundary-Layer Meteorology*, 139, 543–549, 2011). His book was long awaited by the boundary-layer community, and few will be disappointed. On the contrary, it is a thoroughly enjoyable and informative read to the expert, not only because it is so carefully written and mathematically lucid, but also because he conveys such deep appreciation of boundary-layer turbulence phenomena and the challenges that still exist in their understanding.

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