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When and why does turbulence transport momentum, heat, and moisture differently?

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Understanding turbulent transport of momentum and scalars such as temperature, water vapor, and trace gases in the atmospheric boundary layer is important in many disciplines such as meteorology, hydrology, agriculture and air quality control. The assumption that momentum and all scalars are transported similarly (i.e. in the same "way" and with the same efficiency), also known as the Reynolds analogy, has been shown to be invalid under most conditions. Yet few studies have examined the physical basis for the failure of the Reynolds analogy and for the dissimilar transport of various scalars such as heat (active scalar) and humidity (passive scalar). Using data sets collected over water, snow, and vegetated surfaces, we revisit this problem with a focus on the ties between coherent structures, atmospheric stability, and turbulent transport.

The results confirm that the topology of the coherent structures is very sensitive to stability. Although three-dimensional visualizations are not possible with the data set; the findings point to a gradual transformation of the structures from hairpin vortices (or horizontal rolls) to thermals, as the upward buoyancy flux increases. More importantly, this change induces a decorrelation of the momentum and scalar fluxes in the surface layer and significant change in the relative efficiencies of momentum and scalar transport. Scalars are transported much more efficiently under unstable conditions.

On the other hand, the transports of active and passive scalars are found to be much more similar. We discuss the implications of this similarity for microwave scintillometry and evaporation measurements and its breakdown near neutral conditions due to entrainment at the top of the ABL.