The texture of atmospheric humidity: Near-surface turbulence in precipitating cumulus convection

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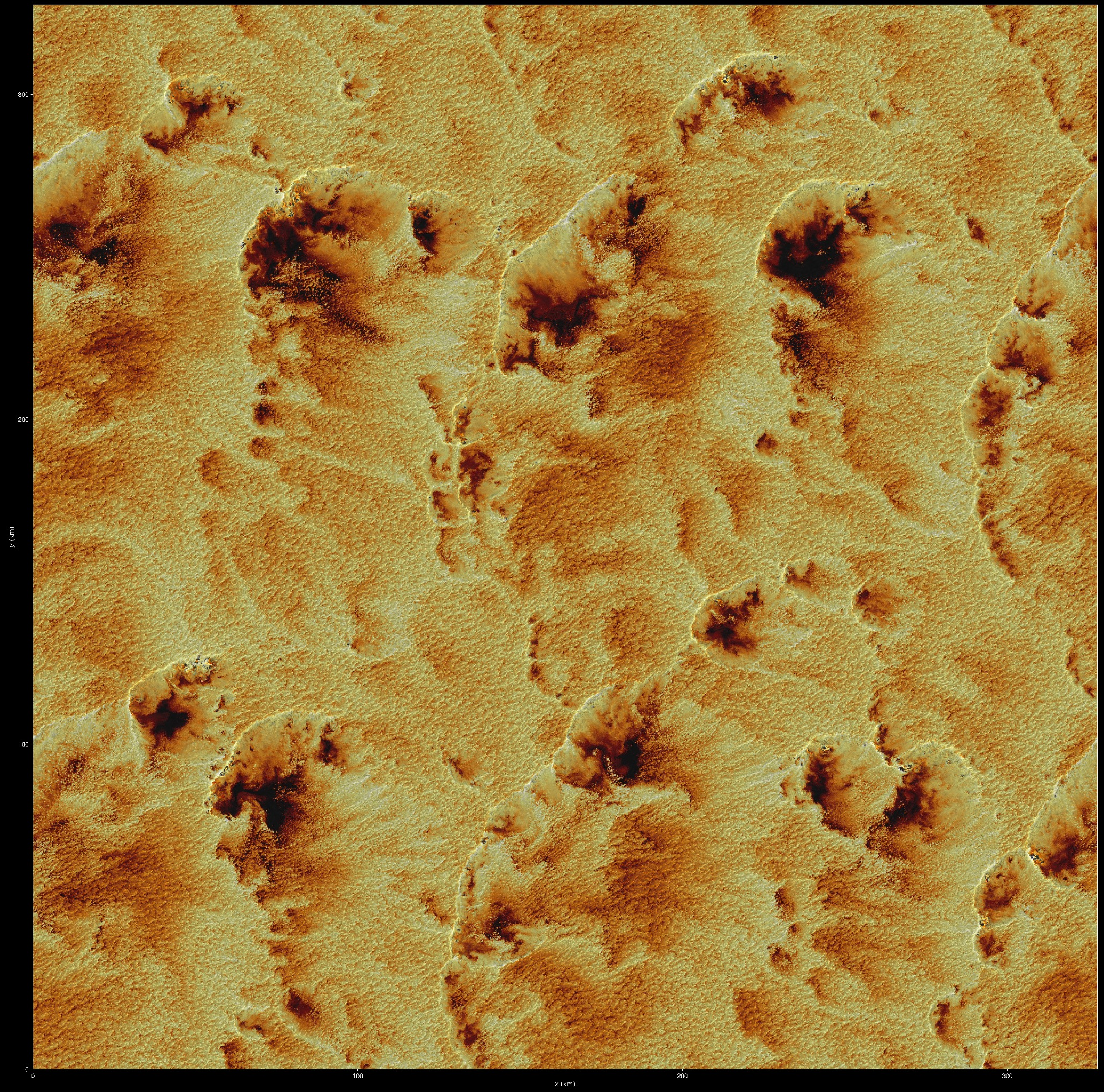
The atmosphere is in a perpetual motion. Near the surface, in the atmospheric boundary layer, the atmosphere is often turbulent. The character of boundary layer turbulence influences the formation of clouds, storms, and air quality. The image was created from a large-eddy simulation of precipitating trade-wind cumulus clouds corresponding to the conditions observed during the RICO campaign (van Zanten et al. 2011). The computational domain is $330^2 \times 5$ km^3 in the horizontal and vertical directions, the grid resolution is 40 m with $8192^2 \times 125$ grid points.

The image shows a combination of specific humidity and vertical velocity on a horizontal plane 300 m above the ocean surface. Specific humidity is plotted with color contours (lighter colors is moister atmosphere) and vertical velocity is overlayed as a varying transparent shading (more transparent/lighter shading is larger vertical velocity). The shading "texturizes" the humidity field and creates an appearance of depth. Vertical velocity and humidity are well-correlated because vertical motions lift moist air near the ocean surface aloft.

Near the surface, the combination of buoyant convection and shear generate streak-line structures. Higher in the atmosphere (between 0.6 and 3 km) cumulus clouds form. Many of the deeper cumulus develop precipitation. As precipitation falls below cloud base, rain drops evaporate and cool the surrounding atmosphere. These regions of colder (and less buoyant) atmosphere generate gravity currents, also referred to as "cold pools" in the meteorological literature. At the gravity current leading edges, convection fronts form, which propagate and expand to large coherent structures in the boundary layer. In the cold pools, the suppression of turbulence production by buoyancy results in less vigorous turbulence. On the downwind side of the fronts (towards the North–East in the image) humidity and vertical velocity occasionally become decorrelated resulting in sudden color variations in the image.

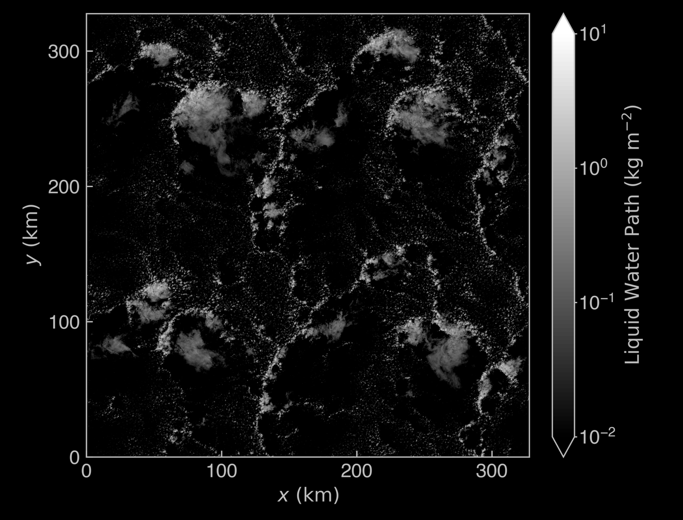
In the atmosphere, turbulence is not merely multi-scale but its nature can vary within short distances. In the image, convection fronts sweep through convection- and shear-induced streaks to form regions of reduced vertical transport. Eventually, convection breaks through and regenerates in the cold pools. Regenerating convection in cold pools can be seen as bright-color blobs in the darker regions of the image, for instance, at $x = 80$ and $y = 250$ km.

The present large-eddy simulation was carried out to understand the variable nature of turbulence in the boundary layer and the development of large horizontal coherent structures. The simulation results are used to develop and evaluate convection parameterizations in weather and climate models, helping improve the accuracy of weather forecasts and climate projections.



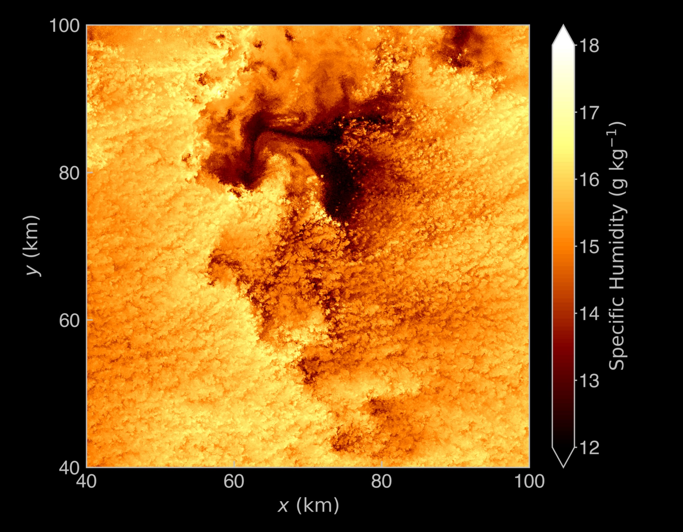
Cloud field

The cloud field is visualized by plotting contours of liquid water path, the vertical integral of the cloud liquid water mixing ratio. The cloud field shows the mesoscale organization of convection. Many of the smaller cumulus are not visible in the image.



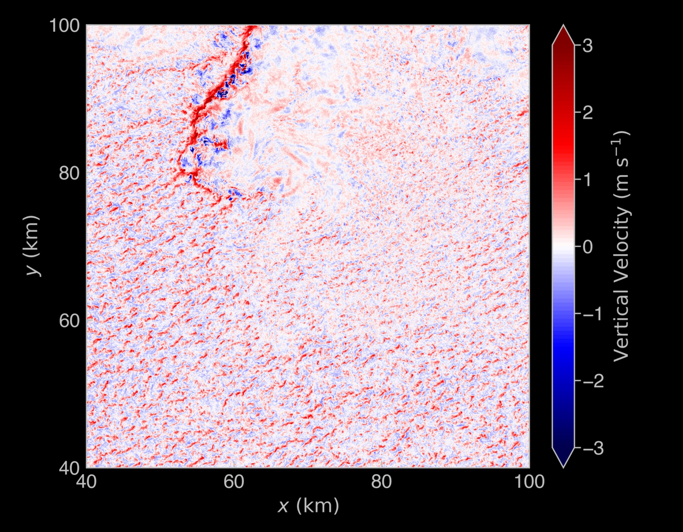
Specific humidity

Specific humidity is plotted in a small subsection of the computational domain to show the variations in the humidity field without the vertical velocity overlay.



Vertical velocity

Vertical velocity is plotted in a small subsection of the computational domain. The vertical velocity field is converted to a layer of varying transparency and overlayed on the humidity contour field in the main image. Larger values correspond to more transparent regions, whereas negative (downwards motion) values are converted to darker opaque regions.



References

Lamaakel, O. and G. Matheou, 2022: Growth rates of turbulence length scales in precipitating shallow cumulus convection. *75th Annual Meeting of the APS Division of Fluid Dynamics*, Abstract L33.00004

Matheou, G. and O. Lamaakel, 2022: Turbulence structure in shallow precipitating cumulus convection. *75th Annual Meeting of the APS Division of Fluid Dynamics*, Abstract L33.00005

van Zanten, M. C. et al. 2011, Controls on precipitation and cloudiness in simulations of trade-wind cumulus as observed during RICO, *J. Adv. Model. Earth Syst.* 3, M06001

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