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An extreme dust storm over the Arabian Peninsula in Spring 2015: the role of convective mixing and vortex stretching

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The Arabian Peninsula is one of the World's largest dust sources. Severe dust storms occur throughout the year dominated by synoptic-scale driven frontal systems in winter and spring and convective systems during summer and autumn. Dust storm frequency peaks in spring, when extra-tropical upper-level troughs associated with near-surface cold fronts regularly penetrate into the peninsula.

In this study we investigate the dynamics of an extreme springtime dust event, which covered the entire Arabian Peninsula and the adjacent Indian Ocean in early April 2015. In addition to the more common trough/frontal characteristics, EUMETSAT's false-colour dust product shows a striking vortex-like structure during the initial state of the storm. Several SYNOP stations on the Arabian Peninsula report severe dust storms, rapid temperature drop, strong increase in wind speed up to 40 kn and zero visibility for several hours on 01 and 02 April. Remarkably also, 61 mm of rainfall are observed on 01 April at the station Arar in northern Saudi Arabia (annual average 52 mm), clearly indicating a convective contribution to this event. Some evidence for significant precipitation is also found in satellite products.

Operational analyses of the European Centre for Medium-Range Weather Forecasts (ECMWF) show a distinct short-wave upper-level trough swiftly propagating across the region during this period, accompanied by high relative vorticity values of up to 10 times the planetary vorticity. This vorticity is associated with the trough's curvature, but also with the large cyclonic shear at the northern side of the subtropical jet. The passage of the upper-level disturbance is well timed to overpass the region of the Arabian Peninsula heat low around midday, where vorticity is thermally generated. Most likely the deep boundary layer facilitated the triggering of convection by the upper-level forcing. Ultimately, downward mixing of the high vorticity by convection plus vortex stretching cause exceptionally high vorticity near the surface, which initiated this extreme and unusual dust storm.

Short-range ECMWF forecasts produce precipitation but not as extreme as measured at Arar. The model also generates strong near-surface winds, which are generally in good agreement with the SYNOP observations. Interestingly, however, the 10 m wind direction falls short to reflect the extreme cyclonic curvature evident in station observations, pointing to an underestimation of the vortex in the model. We hypothesise that the ECMWF model with its parameterised convection is unable to realistically represent the vertical mixing and vortex stretching. Numerical simulations on the convection permitting scale might improve forecasts of such events, but this is yet to be tested.