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The troposphere-to-stratosphere transition in kinetic energy spectra and nonlinear spectral fluxes as seen in ECMWF analyses

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We present spectra, nonlinear interaction terms, and fluxes computed for horizontal wind fields from high-resolution meteorological analyses made available by ECMWF for the International Polar Year. Total kinetic energy spectra clearly show two spectral regimes: a steep spectrum at large scales and a shallow spectrum in the mesoscale. The spectral shallowing appears at ∼200 hPa, and is due to decreasing rotational power with height, which results in the shallower divergent spectrum dominating in the mesoscale. The spectra we find are steeper than those observed in aircraft data and GCM simulations. Though the analyses resolve total spherical harmonic wavenumbers up to n = 721, effects of dissipation on the fluxes and spectra are visible starting at about n = 200. We find a weak forward energy cascade and a downscale enstrophy cascade in the mesoscale. Eddy-eddy nonlinear kinetic energy transfers reach maximum amplitudes at the tropopause, and decrease with height thereafter; zonal mean-eddy transfers dominate in the stratosphere. In addition, zonal anisotropy reaches a minimum at the tropopause. Combined with strong eddy-eddy interactions, this suggests flow in the tropopause region is very active and bears the greatest resemblance to isotropic turbulence. We find constant enstrophy flux over a broad range of wavenumbers around the tropopause and in the upper stratosphere. A relatively constant spectral enstrophy flux at the tropopause suggests a turbulent inertial range, and that the enstrophy flux is resolved. A main result of our work is its implications for explaining the shallow mesoscale spectrum observed in aircraft wind measurements, GCM studies, and now meteorological analyses. The strong divergent component in the shallow mesoscale spectrum indicates unbalanced flow, and nonlinear transfers decreasing quickly with height are characteristic of waves, not turbulence. Together with the downscale flux of energ y through the shallow spectral range, these findings add further evidence that the shallow mesoscale spectrum is not generated by balanced two-dimensional turbulence.