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Topography in NWP models: cut-cell Eta large scale skill vs. ECMWF—where does it come from?

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Invention of the sigma coordinate by Norman Phillips (1957) may have looked as a problem-free method for the representation of topography in atmospheric models. Yet, once the design of atmospheric general circulation models began, "difficulties resulting from the steepness of the mountain slopes at some places" were encountered (Kurihara, MWR 1968). They were addressed by the vertical interpolation of geopotential in calculation of the pressure-gradient force (PGF).

Many more methods were proposed in 50 years since, including a reinvention of the vertical interpolation, as summarized by Mesinger and Veljovic (Met. Atmos. Phys. 2017, MV2017 further on) and in papers cited in MV2017. Yet, except for the vertical interpolation, none of these methods remove the sigma system problem that, for sufficiently high topography slopes, PGF scheme begins to use prognostic values it should not for physical reasons, and fails to use those it should.

Radically new approaches were advanced in 1984 by Mesinger's eta coordinate, and in 2002 by Steppeler et al. cut-cell z-coordinate schemes, both moving away from the terrain-following systems. Refinement of the eta coordinate discretization, documented in MV2017, made it also a cut-cell discretization.

The cut-cell eta discretization removes the step-topography problems discovered by Gallus and Klemp of step-corner disturbances and flow separation, as the Witch of Agnesi step-corners are not admitted in the cut-cell eta formulation.

Both of these returns to quasi-horizontal, or horizontal, coordinate surfaces led in real data tests to considerable improvements in skill. Note in Steppeler et al. (GMD 2013) words of the removal of "major numerical errors near mountains," and precipitation results in Fig. 4 of MV2017. We are not aware of tests if vertical interpolation of PGF can result in comparable benefits. Note that there are features of terrain-following systems additional to PGF problems that seem likely to be detrimental to the results.

We shall review our experiments of cut-cell Eta members driven by ECMWF ensemble members, in which repeatedly, according to each of three verification scores, all 21 Eta ensemble members achieved better 250 hPa wind speed scores than the corresponding ECMWF driver members. Two of these scores verify accuracy of the placement of strongest winds, chosen as >45 m/s, and the third one is the standard RMS difference. We shall show results of our more recent test, distribution of contours of 250 hPa wind speeds >45 m/s, for all 21 ensemble members for three models, the driver ECMWF, cut-cell Eta, and the Eta switched to use sigma (Eta/sigma), at 4.5 day lead time. While the driver ECMWF contours perhaps reasonably well agree with the verification contours, they also show considerable spread so as to include areas not verifying. The cut-cell Eta contours show little spread, agreeing much better with verification.

Contours of the Eta/sigma are also considerably more accurate than those of ECMWF, but do recover some of the ECMWF errors. We have several candidate reasons for this advantage of the Eta/sigma over ECMWF, and plan to discuss those at our presentation.