Changes to domzgr.F90 routine

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To improve NEMO for use in shelf applications the vertical coordinates were adapted to replicate the Song and Haidvogel[1] system as applied in Holt et al[2]. To do this it was necessary to include a new stretching function, identical to that used in Song and Haidvogel, and to include the option for hybrid s-sigma vertical coordinates (the current NEMO code gave only the option for hybrid z-sigma).
A new function fssig1 was added which parallels the original NEMO function fssig, but using the Song and Haidvogel stretching function:

$$fssig1(pk, bb) = (1-bb)\frac{\sinh(\theta(-\frac{pk-0.5}{jpkm1}))}{\sinh(\theta)} + bb\frac{\tanh[\theta((-\frac{pk-0.5}{jpkm1}) + 0.5)] - \tanh(0.5\theta)}{2\tanh(0.5\theta)} \quad (1)$$

The new fssig1 also provides the option for the user to obtain uniform sigma levels by setting *theta* to 0, this is done using an if clause.

All other changes were done within the zgr_sco subroutine, and so ln_sco must be set to true for hybrid s-σ levels to be used. To allow the user to choose hybrid s-σ levels, a new namelist parameter, ln_s_sigma was added, this is a logical parameter with $ln\_s\_sigma = true$ giving the hybrid s-σ levels, and $ln\_s\_sigma = false$ giving the original NEMO hybrid z-s levels.

Two other namelist parameters were added, *hc* and *bb*. The parameter *hc* is used to specify the critical depth, s-levels are used where the depth is greater

[1] A Semi-implicit Ocean Circulation Model Using a Generalised Topography-Following Coordinate System, 1994

[2] An s coordinate density evolving model of the northwest European continental shelf - 1 and 2, 2001

than hc, and regularly spaced σ-levels are used when the depth becomes less than hc. The parameter bb is passed to the function fssig1, and is used in the equation to control how the levels are stretched (it is similar to the NEMO parameter $thetb$). A value of 1 gives high resolution at the sea surface and seabed, and a value of 0 gives high resolution at the surface only. The original NEMO parameter $theta$ (θ) is also used within the fssig1 function. As in the original NEMO context this affects how much the levels are stretched, with $\theta = 0$ giving no stretching and $\theta = 20$ giving maximum stretching.

New stretching parameters $gsigw3$, $gsigt3$, $gsi3w3$, $esigt3$, $esigw3$, have also been added. These parallel the original NEMO stretching parameters ($gsigw$, $gsigt$ etc), but are 3 dimensional with dimensions (jpi, jpj, jpk) (the number of model points in each direction), compared to the original 1 dimensional parameters, with dimension jpk (the number of vertical points/levels). In the original NEMO set up the stretching is identical everywhere and so the stretching parameters are the same at all model points and there is no need for the stretching parameters to be defined separately for the horizontal points. However in the new setup the stretching, and hence the values of the stretching parameters change depending on the depth and so the stretching parameters need to be defined at each grid point.
Parameters $esigtu3$, $esigtv3$, $esigtf3$, $esigwu3$, and $esigwv3$ have also been added, this is to ensure continuity across the critical depth. The values of esigt3 and esigw3 are averaged using suitable points, with weightings of the depth at each point, to obtain estimates of the values of esigt and esigw at the u, v, and f points. This was not necessary in the original NEMO as esigt and esigw were the same everywhere, but in the new ln_s_sigma setup the transition from one coordinate set to another means that in the transition region the values will be different. This may cause problems for u,v,f points if the averaging is not applied.

If $ln\_s\_sigma = true$ the code loops over all the horizontal points. For each horizontal point the depth is tested to see if it is less than or greater than hc and then gsigw3 and gsigt3 are defined at all vertical levels for that point accordingly. Then (as in the original NEMO code) esigt3, esigw3, and gsi3w3 are defined based on values of gsigw3 and gsigt3. Finally the depth levels (gdept, gdepw and gdep3w) are defined using the values of gsigt3, gsigw3 and gsig3w3 along with the appropriate critical depth and the depth at the specified point.

Then each horizontal point is looped over again. Values of esigtu3, esigtv3, esigtf3, esigwu3 and esigwv3 are defined based on the surrounding esigt3, or esigw3 values, and then e3t, e3u, e3v, e3f, e3w, e3uw, and e3vw are evaluated based on the previously calculated parameters.

If ln_s_sigma is set to false the original code is followed with no changes.