Changes in SLHD setup in ARPEGE/ALADIN cycle 35t1

1 Introduction

In ARPEGE/ALADIN cycle 35t1, new class of semi-Lagrangian interpolators with controlled damping was introduced. New interpolators were developed for SLHD (Semi-Lagrangian Horizontal Diffusion) scheme, but *they can be used also outside of SLHD framework*.

As a part of the exercise, semi-Lagrangian dataflow was changed, main reason being improved efficiency of SLHD code. Even though old SLHD interpolators were kept under key `LSLHD_OLD`, changed order of operations when constructing 2D/3D interpolators from basic 1D bricks causes *irreproducibility of SLHD results between cycles 35 and 35t1*. Fields computed under old and new dataflows (using same kind of interpolators) remain very close, but there is difference in spectral norms.

In order to prevent confusion, it is important to distinguish between old/new SLHD *interpolators* and *dataflow*. Difference is following:

- Old SLHD dataflow is available until cycle 35. In cycle 35t1 it was *replaced* by the new dataflow.
- Old SLHD interpolators are obtained as weighted combination of cubic Lagrange polynomial F_{lag} and linear interpolator F_{lin}. From cycle 35t1 they are kept under key `LSLHD_OLD`.
  New SLHD interpolators are obtained as weighted combination of cubic Lagrange polynomial F_{lag} and quadratic interpolator F_{quad}. They were introduced as default option in cy35t1. Their main advantages are scale selective damping equivalent to fourth order diffusion and second order accuracy.

This guide touches only gridpoint part of SLHD scheme. Associated spectral diffusions remain unchanged. Current tuning ensuring resolution independent SLHD user control was kept (variables `ZSLHDP1` and `ZSLHDP3` from namelist `NAMDYN`), but it may be revisited in the near future. Reason for retuning is different spectral response of the new SLHD interpolators.

2 Equivalent setup for old SLHD interpolators

Old SLHD scheme contained heuristic smoother ensuring certain amount of damping for cases when origin point of semi-Lagrangian trajectory lies in the vicinity of gridpoint. In cycle 35t1 heuristic smoother controlled via namelist variables `ALPHINT` and `GAMMAX0` was removed. New Laplacian smoother was introduced in its place, following the ideas of Pierre Bénard. It is controlled via namelist variables `SLHDEPSH` (horizontal part) and `SLHDEPSV` (vertical part). Under new dataflow, old SLHD interpolators with Laplacian smoother comparable to default setting of old heuristic smoother can be achieved by following namelist changes:

1. To be removed from namelist `NAMDYN` (cy35):

```
ALPHINT=0.15,       [removed]
GAMMAX0=0.15,       [removed]
SLHDKMAX=1.,        [moved to NAMDYNA]
```

2. To be put into namelist `NAMDYNA` (cy35t1):

```
* LSLHD_OLD=.T.,      [default .F.]
  LSLHD_STATIC=.F.,
* SLHDEPSH=0.0025,   [default 0.]
  SLHDEPSV=0.,
  SLHDKMIN=0.,
  SLHDKMAX=1.,
```

Only variables denoted by star need to be set explicitly in the namelist. Remaining variables have their default values.

Above mentioned setting is recommended for people who would like to keep old SLHD performance. However, it should be remembered that it does not profit from improved conservative properties and higher accuracy of the new SLHD interpolators.

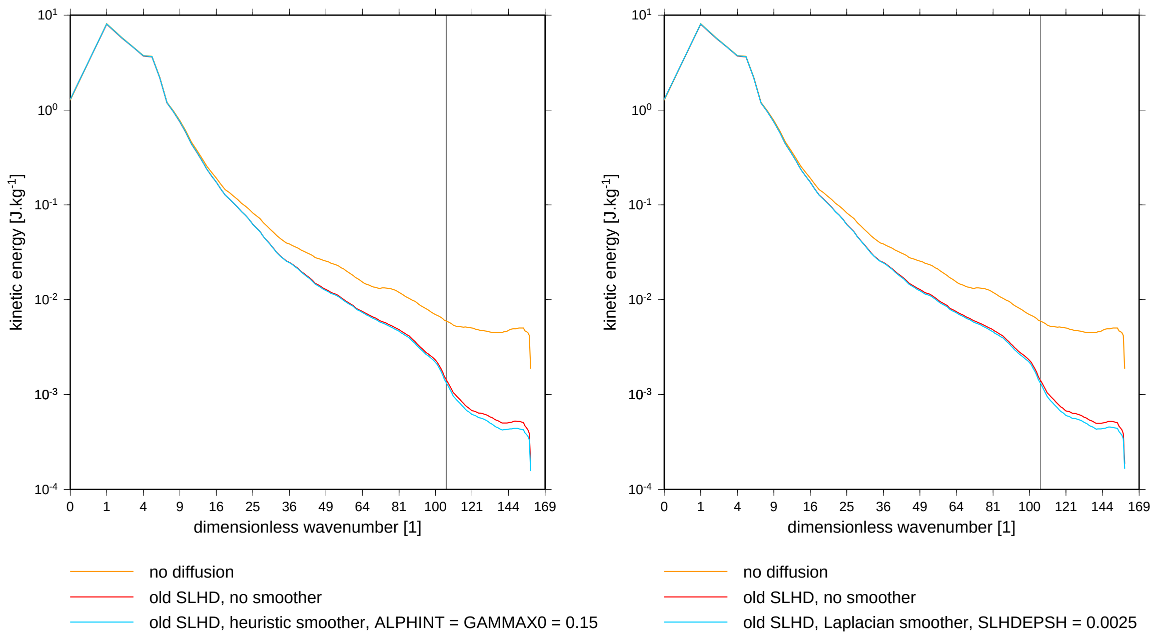

Figure 1: Impact of SLHD smoother on kinetic energy spectrum at model level 41. Results of 6 hour adiabatic integrations on ALADIN/CHMI domain ($\Delta x = 9\,\text{km}$, linear grid, 43 vertical levels). Left – old heuristic smoother with `ALPHINT=GAMMAX0=0.15`; right – new Laplacian smoother with `SLHDEPSH=0.0025`. Yellow – reference experiment without any diffusion; red – gridpoint part of SLHD without smoother; light blue – gridpoint part of SLHD with smoother. Plots have been smoothed using 9-point running average. Vertical line denotes quadratic truncation used for orography.

Figures 1 and 2 illustrate how the new Laplacian smoother was tuned. Tuning was done in adiabatic framework with deactivated spectral diffusions. The only source of damping was gridpoint part of SLHD. Value of parameter `SLHDEPSH` giving spectral response similar to the old smoother was sought.

As can be seen from figure 1, default setting of old heuristic smoother has only weak impact on kinetic energy spectrum, compared to damping caused by old SLHD interpolators. Figure 2 shows that equivalent tuning of the new Laplacian smoother gives slightly stronger damping for intermediate scales and weaker damping for short scales.

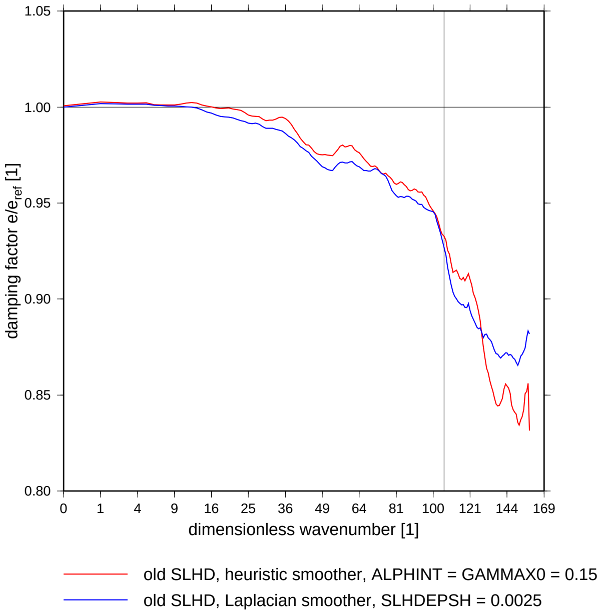

Figure 2: Impact of SLHD smoother on kinetic energy spectrum at model level 41, expressed as damping ratio with respect to reference experiment without smoother. Red – old heuristic smoother; blue – new Laplacian smoother. Experimental setup is the same as for figure 1.

Old heuristic smoother was acting only in horizontal direction (i.e. along model levels). New Laplacian smoother was implemented also in vertical. In the tests it was seen that while vertical smoother practically does not influence kinetic energy spectrum, it deteriorates mass conservation (seen as increased positive MSLP bias). That is why vertical smoother is off in recommended settings (`SLHDEPSV=0`). It may be useful in academic simulations where 3D viscosity is desired.

3 Setup for new SLHD interpolators

In cycle 35t1, new SLHD interpolators are activated by default (if not specified, `LSLHD_OLD` is set to false). This choice requires namelist adjustment, since the new interpolators have more scale selective damping than the old ones. Moreover, there is additional degree of freedom provided by Laplacian smoother, which can be used to control intermediate scales.

As an example, three SLHD configurations with damping of shortest resolved waves comparable to default configuration of old SLHD scheme can be given:

1. New SLHD interpolators without smoother, retaining second order accuracy. Namelist `NAMDYNA` should include settings:

```
  LSLHD_OLD=.F.,
  LSLHD_STATIC=.F.,
  SLHDEPSH=0.,
  SLHDEPSV=0.,
  SLHDKMIN=0.,
* SLHDKMAX=12.,     [default 1.]
```

2. New SLHD interpolators combined with Laplacian smoother. Namelist `NAMDYNA` should include settings:

```
  LSLHD_OLD=.F.,
  LSLHD_STATIC=.F.,
* SLHDEPSH=0.012,   [default 0.]
  SLHDEPSV=0.,
  SLHDKMIN=0.,
* SLHDKMAX=6.,      [default 1.]
```

3. Laplacian smoother only, semi-Lagrangian interpolators being fixed to cubic Lagrange polynomial. Namelist `NAMDYNA` should include settings:

```
  LSLHD_OLD=.F.,
  LSLHD_STATIC=.F.,
* SLHDEPSH=0.027,   [default 0.]
  SLHDEPSV=0.,
  SLHDKMIN=0.,
* SLHDKMAX=0.,      [default 1.]
```

For people who would like to switch to the new SLHD interpolators, second configuration can be recommended as a safe starting choice.

Figure 3 shows spectral damping of above mentioned SLHD configurations with respect to reference experiment without any diffusion. Default configuration of old SLHD scheme is included as well. It can be seen that configuration without Laplacian smoother (red curve) has weakest damping of intermediate scales. Including of Laplacian smoother (light blue curve) enhances damping of intermediate scales (at the same time `SLHDKMAX` must be reduced in order to preserve same amount of damping for shortest resolved waves), but even with pure Laplacian smoother (dark blue curve) action on these scales does not reach the strength of old SLHD scheme (magenta curve). It should be noted that improved accuracy and conservation properties of the new SLHD interpolators are due to their higher scale selectivity, seen as weaker damping of intermediate scales.

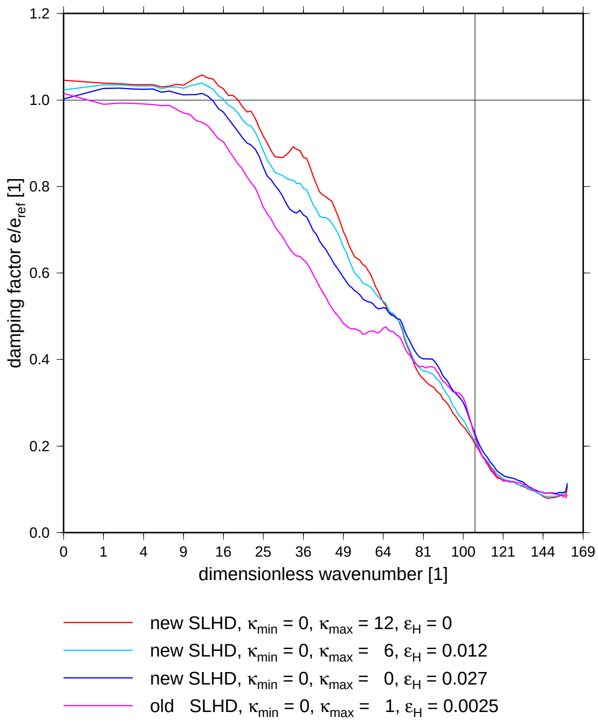

Figure 3: Impact of four SLHD configurations on kinetic energy spectrum at model level 41, expressed as damping ratio with respect to reference experiment without any diffusion. Red – new SLHD without smoother; light blue – new SLHD including smoother; dark blue – new SLHD using only smoother; magenta – old SLHD default configuration. Experimental setup is the same as for figure 1.

4 Redefining semi-Lagrangian interpolators outside of SLHD scheme

Under new dataflow, high order semi-Lagrangian interpolator can be redefined even when SLHD scheme is off. To achieve this, it is sufficient to put nonzero value of variable `SLHDKMIN` in namelist `NAMDYNA`. In such case, basic 1D interpolator F will be constructed as weighted combination of cubic Lagrange polynomial F_{lag} and quadratic interpolator F_{quad}:

$$F = (1 - \kappa_{\mathrm{min}})F_{\mathrm{lag}} + \kappa_{\mathrm{min}}F_{\mathrm{quad}}$$

Positive values of weight κ_{min} (= `SLHDKMIN`) increase diffusivity of default interpolator (cubic Lagrange polynomial) while negative values reduce it. Second order accuracy of interpolator F is retained. For safety reasons, values of namelist parameter `SLHDKMIN` outside of range $[-2, 12]$ are disabled in model setup. Interpolators beyond this range have either too weak diffusivity or considerably reduced precision for shorter waves (even if remaining second order accurate), so their use might lead to forecast deterioration and in worse case to model instability.

Effect of redefined high order semi-Lagrangian interpolator on kinetic energy spectrum is illustrated on figure 4. Before cycle 35t1, cubic Lagrange polynomial (yellow curve) was the only option for horizontal interpolations. (In the past also natural cubic spline was implemented, but later it was removed due to problems related to

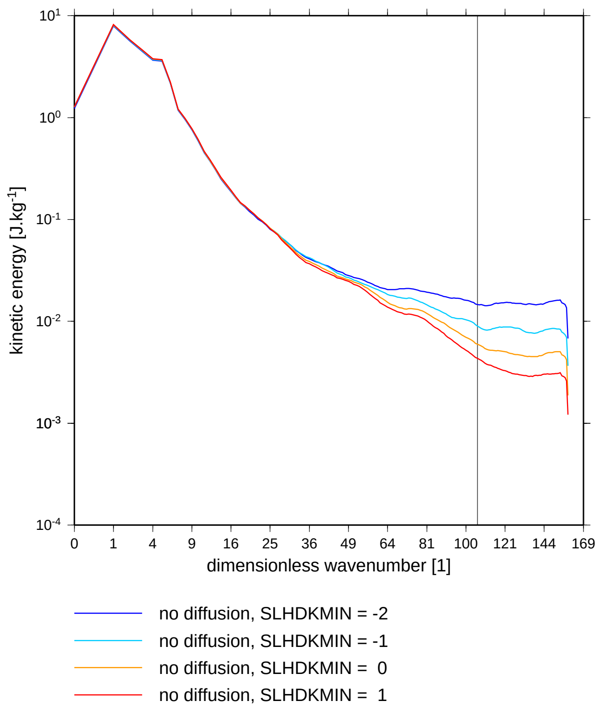

Figure 4: Impact of high order semi-Lagrangian interpolator on kinetic energy spectrum at model level 41. Dark blue – quasi-cubic spline ($\kappa_{\min} = -2$); light blue – interpolator with $\kappa_{\min} = -1$; yellow – cubic Lagrange polynomial ($\kappa_{\min} = 0$); red – quadratic interpolator ($\kappa_{\min} = 1$). Experimental setup is the same as for figure 1.

amplification of long waves.) From cycle 35t1, diffusivity of high order semi-Lagrangian interpolator can be adjusted in both directions. Figure 4 shows that it can be made weaker (blue curves) or stronger (red curve) than default option (yellow curve).

Remark:

State of SLHD scheme can be checked in output listing. It is indicated by internal key `LSLHD`. Scheme will be off when variables `LSLHD_T` and `LSLHD_W` from namelist `NAMDYNA` are false (in non-hydrostatic case also `LSLHD_SVD` and `LSLHD_SPD`; the latter should never be true), as well as `%LSLHD` attribute of all GFL fields.

Internal key `LSLHDQUAD` indicates whether quadratic interpolation weights are needed. It can be true even if SLHD scheme is off, but nonzero value of `SLHDKMIN` is set. In such case quadratic weights are used to construct redefined high order semi-Lagrangian interpolator.

5 Summary

Brief description of most important changes in SLHD setup related to developments introduced in ARPEGE/ALADIN cycle 35t1 was given. New SLHD scheme contains additional features which were not mentioned here, they will be described in a separate user guide. Most of them are related to SLHD triggering, e.g. general formula for horizontal flow deformation, diagnostics of flow deformation along truly horizontal surfaces or possibility of static SLHD. Their potential was not fully explored yet.