Semi-Lagrangian horizontal diffusion in ALADIN/ARPEGE

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1 Preface

This paper aims to be an user's handbook for the SLHD scheme implemented into the ALADIN/ARPEGE system. It should give a brief description of the scheme and its tuning possibilities by namelist parameters. It should fully supersede the previous approach for the SLHD tuning given in Glavač-Šah (2003).[1] Few model results with different SLHD settings will be also presented here to illustrate the scheme performance.

Note that this paper is not supposed to be neither the code documentation nor the scientific description of the SLHD aspects. The relevant code documentation is well described in continuously updated documentations of semi-Lagrangian scheme Yessad (2004) and horizontal diffusion Yessad (2004). The scientific aspects are discussed in Vana (2003) and hopefully soon as well in Vana et al (2005).

The part of the main importance for the model users is the section 4. Here the namelist parameters are explained. Same basic guidelines for the scheme tuning are also given there. In case a reader is not really interested about details, it is recommended to skip all the other text and read directly that section.

2 Things to know about SLHD

Semi-Lagrangian horizontal diffusion (hereafter referred as SLHD) is an alternative scheme for horizontal diffusion implemented in the ALADIN/ARPEGE. Contrary to the linear spectral diffusion which is purely a numerical tool (having some similarity with the physical reality), SLHD is constructed in a way to reflect physical processes of a (horizontal) damping character. Seen from this point of view, SLHD can be considered as a sort of parameterization for horizontal (or even 3D) physical processes.

However since the exact parameterization of such processes would be very expensive and technically difficult, a compromise solution had to be found. The SLHD tends to perform in agreement with a physical reality while being numerically very efficient scheme. To reach both previous principles the scheme was designed and implemented in a way to fit the existing model constraints. The one of main importance is that damping properties of semi-Lagrangian interpolatores are used for representation of the diffusive processes. This novel idea significantly reduces the overall computational cost for the scheme. It also gives the convenience to be applied in the 3D stencil during the semi-Lagrangian interpolation. On the other hand it imposes certain limitations for such diffusive scheme. Here are listed the most important ones:

- Due to the model discretization, the SLHD is not able to directly control the small scale noise originated from the model orography forcing.
- Due to a random distribution of the origin points of the Lagrangian trajectories with respect to the model grid and local character of diffusive impact of interpolatores, the scheme needs some time to act.
- Due to given properties of the damping interpolator, the scheme has just limited possibility for tuning. Namely: the selectivity of the SLHD and the diffusion activity (impact) are not independent characteristics.

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[1] This work is however still valuable for interested reader, since it presents unique results from the two diffusion schemes simulations performed by the ALPIA pseudo-academic framework.

- For simplicity, diffusion of all variables is controlled by the same diagnostics field (deformation of the horizontal flow).
- The diffused quantities have to be advected by semi-Lagrangian advection scheme.

With all those limitations the SLHD still offers beneficial features. Those are especially:

- Being function of the flow field it offers realistic non-linear diffusion
- Its local and three-dimensional character prevents model from an erroneous advection along sloped surfaces.

Moreover with respect to the spectral horizontal diffusion it offers other beneficial features like:

- It gives a freedom to act not only strictly along model levels (like spectral diffusion does) but as a full 3D feature. (This quality has been proven as very profitable and it is currently the default setting for the SLHD.)
- The scheme can be tuned according to scales it affects. This effectively makes it independent to the domain size and resolution.
- Thanks to the non-linearity and local character it acts exactly upon targeted areas. Contrary to the quasi-horizontal spectral diffusion there is no danger for a diffused feature to be masked by the model orography.
- It can affect any model field being advected by semi-Lagrangian scheme. It doesn't require the obligation for a field to be transformed into the spectral space. The SLHD also doesn't imply any additional restriction to the existing model timestep.

With all its limitations and benefits the intention of gridpoint diffusion is surely not to replace completely the numerical spectral diffusion. It rather aims to represent the physical part of horizontal diffusion while leaving the spectral diffusion to acts like pure numerical filter. The following model tasks hardly can be treated by gridpoint diffusion. As it is evident they are mainly of a technical (numeric) character:

- To compensate decreasing vertical resolution toward the top of the model atmosphere by increased filtering.
- To act as a kind of sponge near the upper bound of model atmosphere.
- To remove a spectral energy accumulated at the end of the model spectra trapped by a finite resolution.

When the SLHD is activated in the model the first two points are represented by the so-called *reduced spectral diffusion* directly derived from the standard spectral diffusion setting. The third point is jointly realized by the gridpoint (physical) diffusion and the additional weak and very selective spectral diffusion. The latter one is called *supporting spectral diffusion* and it is specific model feature when the SLHD is activated.

To sum up the previous. When the SLHD is activated in the ALADIN/ARPEGE model, other (at least) two spectral diffusions are still present in the model.

3 SLHD description and tuning rules

Knowing that together with the gridpoint part of the SLHD other two diffusions exist in the model one can have an impression that to tune whole SLHD must be very complicated. Fortunately it is not exactly the case. As mentioned, the gridpoint part of the SLHD offers fairly more physical framework for tuning. It is believed to be almost domain and size independent. The other diffusions are similar to the classical spectral diffusion, so their tuning is quite about the same.

Let's first define some terminology used hereafter. SLHD is used for the whole set of the model diffusions jointly activated with the gridpoint non-linear diffusion. The members of this group used to be named as: *reduced spectral diffusion*, *supporting spectral diffusion* and the *gridpoint part of the SLHD*. The first two diffusion schemes are spectral linear diffusions used mainly to cover numerical aspects, the latter is the key part of the SLHD - the non-linear diffusion using semi-Lagrangian interpolatores.

When the SLHD is activated by the model switch, it automatically activates all three its components. Of course still each from this set can be controlled independently. In following sections basic tuning possibilities are going to be discussed for each from the SLHD components.

3.1 Reduced spectral diffusion

Reduced spectral diffusion is obtained by reducing the classical spectral diffusion by constant factor. As explained before the purpose of this diffusion is to produce enhanced damping high in the model atmosphere. The standard spectral diffusion is supposed to be well tuned for this purposes. The reduced spectral diffusion is then using exactly the same vertical profile. In the model this is reached by following construction: When $\mathcal{D}(l)$ is the standard spectral diffusion at a given model level l, the reduced spectral diffusion for the same level is defined as $\mathcal{D}(l) - SDRED * \mathcal{D}_0$. Here $\mathcal{D}_0$ is the spectral diffusion at the model surface (without the vertical component) and $SDRED$ is tunable parameter (default value is $SDRED = 1.$). From previous is evident that when $SDRED$ is set to $0.$, the reduced spectral diffusion becomes identical with the standard spectral diffusion.

The reduced spectral diffusion is automatically activated for all the model prognostic variables being transformed into the spectral space with one exception: The moisture is purely a tropospheric feature. Logically there is no need to treat specifically neither the upper boundary condition or the decreased vertical resolution of model in the high atmosphere for this parameter. Therefore the reduced spectral diffusion is useless for moisture field. When the SLHD is activated the model automatically switch off the reduced spectral diffusion of this variable (by setting $RDAMPQ = 0$).

For any other specific tuning feature for the reduced spectral diffusion see the model documentation of the spectral diffusion scheme (Yessad, 2004), the design description of the scheme (Bénard, 2002) or the mini-documentation about the new features in the spectral diffusion setup (Váňa, 2004).

3.2 Supporting spectral diffusion

As said the purpose of the supporting spectral diffusion is to control the small scale impact of the model orography to model prognostic fields. This specific part of the SLHD is applied just to the variables with a forcing term containing orography in their prognostic equation. They are namely horizontal wind components u and v with the vertical divergence related variable d (d_3, d_4,...) in case of the non-hydrostatic dynamics. Since this complementary diffusion to the gridpoint part aims to control the end of a field spectra, it is represented by week and very selective (high order) spectral diffusion. Similarly to the tuning for the gridpoint part the supporting spectral diffusion is set constant with height along the whole troposphere.

The supporting diffusion can be technically seen as an additional spectral diffusion in the model. Logically the tuning for it is very similar to the one for the standard spectral diffusion. Typically namelist parameters for the supporting diffusion keep the same name appended by letter "S" denoting the supporting diffusion. The setup for this diffusion is computed according the parameter $RRDXTAU$ which is the main tuning parameter for all model spectral diffusions. When $RRDXTAU = 0.$ all spectral diffusions are deactivated including the supporting diffusion.[2] The relation of the supporting spectral diffusion to the reduced spectral diffusion is

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[2] Note that before CY30T1, the supporting diffusion rely as well to the parameter $RDAMPDIV$. This conceptual inconvenience however doesn't impact the standard SLHD usage.

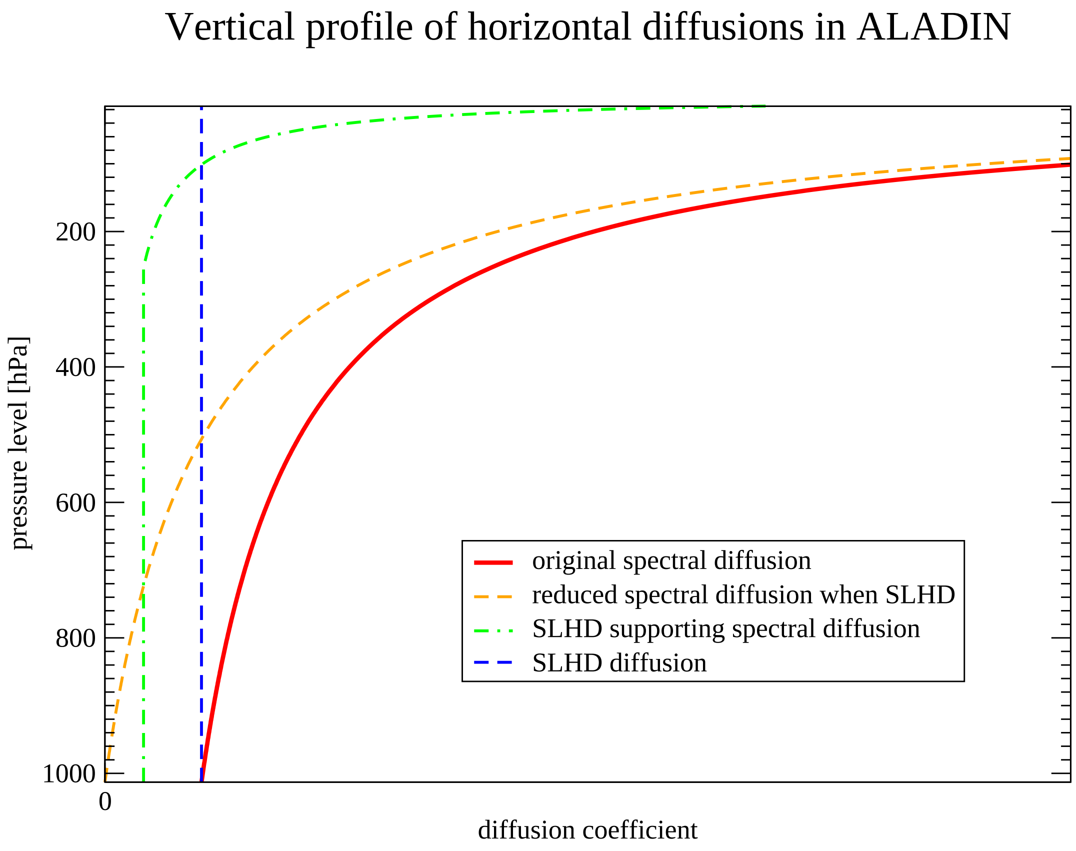

Figure 1: *Schematic diagram showing the activities of the horizontal diffusions (symbolized by the diffusion coefficient) in the ALADIN model as a function of the atmospheric pressure. The red full line represents the standard spectral diffusion (reference), the reduced spectral diffusion in symbolized by the orange dashed line, the supporting diffusion is represented by the dashed-dotted green line and the dashed blue line represents the gridpoint diffusion.*

computed internally by the model. Individual variables can be however accessed through the $RDAMPxS$ parameters. In the previous x stands for VOR, DIV and VD in case of vorticity, divergence and vertical divergence respectively.

The contribution of the two previous diffusions illustrates the figure 1. There the red full line symbolizes an activity of the standard spectral diffusion. When the SLHD is activated, this one diffusion is replaced by the reduced spectral diffusion (orange dashed line), higher order supporting spectral diffusion (green dashed line) and the gridpoint diffusion which is for simplicity visualized as straight blue dashed line. Here the gridpoint diffusion is represented by its tuning which is kept constant for all altitudes. In reality this flow dependent diffusion reflects the activity in the atmosphere. The experiments with the real atmosphere shows that the gridpoint diffusion is the strongest near the surface and around the tropopause while almost vanishes in the levels above 50 hPa. Anyway it is evident from the figure that the gridpoint diffusion dominates near the surface. The reduced diffusion simulates the increasing difference between the reference spectral diffusion and the constantly tuned gridpoint diffusion with the heights. Finally the supporting spectral diffusion is acting as a weak and selective diffusion applied to the end of a field spectra. This component is again constant with height along most dynamically active areas.

Two remarks related to the spectral part of the SLHD:

Since a spectral diffusion is generally function of the model domain, the supporting diffusion and the reduced diffusion also depend to the size and the number of spectral waves of the computational domain. This is accepted weakness of the spectral diffusion. Just one should not be surprised by a fact that changing domain

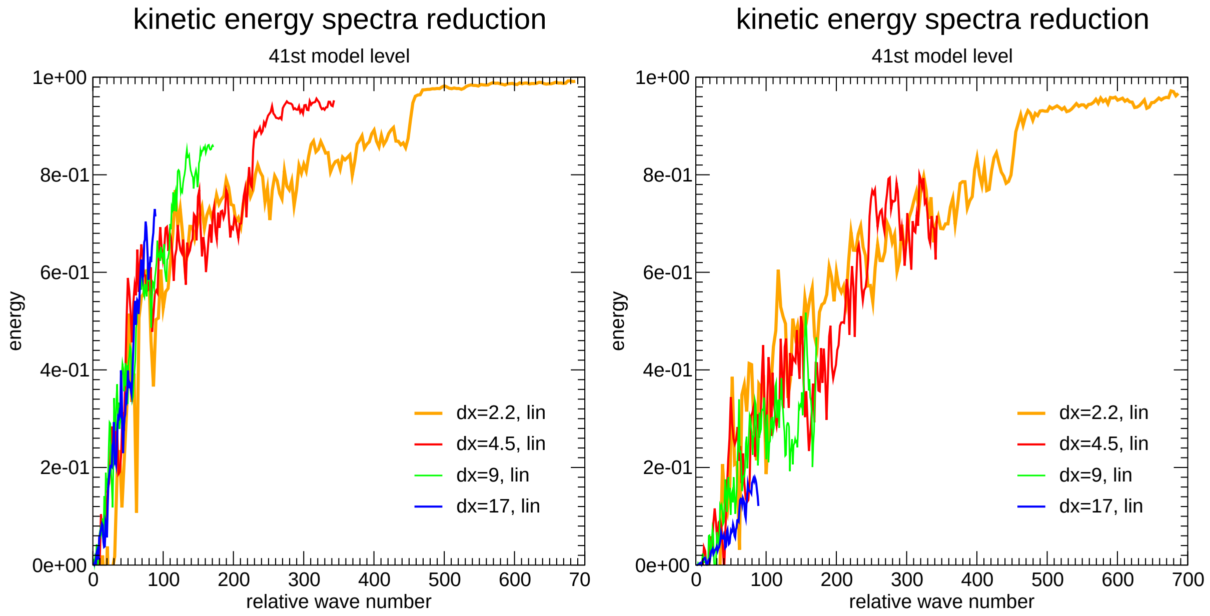

Figure 2: *The relative amplification factor caused by the gridpoint diffusion as a function of the relative wavenumber obtained from a 6 hours diabatic simulation. (The amplification equal to 0 means no impact of diffusion while amplification close to 1 means very significant impact.) The left figure presents rather strong diffusion case ($SLHDA0 = 1.$), the right figure a weak one ($SLHDA0 = 0.1$). Both cases shows the results from four runs with different resolution and size. The grid resolutions and kind of truncation (linear in all cases) are given by the legend box of each graph.*

size (even when keeping the same resolution) the model spectral diffusion is changed. (As it will be shown, the physical gridpoint diffusion with the ability to be domain independent should be tuned with respect of the computational domain as well.)

It is known fact that diffusion for the divergence field use to be intentionally set stronger than the one for the other prognostic variable. It is believed that this arrangement helps to prevent the spurious accumulation of inertia-gravity wave energy near the cut-off wavenumber. The current empirical factor used for the increased diffusion for divergence in ALADIN/ARPEGE is 5. When measured this factor for the remaining gridpoint part of the SLHD, it has been found that it damps divergence just 3-times stronger than the other field. However this different behavior of the gridpoint scheme compared to the spectral diffusion tuning can be still easily ignored. To keep the consistency between all the spectral diffusion in the model, the damping factor equal to 5. is kept (by default) for the two spectral diffusions being part of the SLHD.

3.3 Gridpoint part of the SLHD

3.3.1 Physical diffusion tuning for a general model area

The essential part of the SLHD tends to represent physical processes in the atmosphere. It is known that role of such horizontal processes is becoming increasingly important when going to represent finer scales. Following this logic an ideal tuning for a physical diffusion should be based on scales of diffused features rather than on the model domain. This is really possible with the gridpoint part of the SLHD as it is illustrated by figure 2. There the amplification for the two different gridpoint diffusion settings are presented for a kinetic energy spectra as a function of scales. The x-axis represents scales by the relative wave number i' (wave number rescaled to the reference model domain). The wavelength λ of the corresponding waves (in meters) can be obtained from the simple formula: $\lambda = 3106198.46/i'$. The impact of the diffusion is then shown on four model runs with different domains and mesh sizes. Since this figure shows the impact of the gridpoint diffusion only, the end of each spectra is not correctly handled and thus it is not aim of the interest here. (This is the task for the supporting diffusion.) The y-axis shows the amplification of the corresponding scale by the gridpoint diffusion (0 means no impact caused by diffusion, 1 means 100% of damping at a given scale). As it can be seen the two different settings (rather strong one and quite weak one) are presented. The agreement of the four experiments for both presented settings is quite good. This supports the conclusion that there is a chance to tune the gridpoint diffusion in such physical way.

Unfortunately this way of tuning is not always sufficient for a general model domain. The role of a horizontal diffusion in the model should be among many others the capability to remove the accumulated energy trapped by the finite truncation of a model. Here the downward cascading energy (toward smaller scales) is accumulated. In case it is not effectively controlled it can start erroneously propagate back toward the large scales. Like that a model information would be corrupted. As mentioned, the conditional task for horizontal diffusion is to effectively prevent accumulation of such energy. Consequently to be able to act in this sense, diffusion has to be reasonably strong near the end of the model spectra. As it can be seen from the figure 2 the maximum diffusion in the model with low resolution is quite weak. For sure such diffusion is not able to fulfill the task preventing the energy accumulation. Even in case that another special and selective spectral diffusion will be applied to treat this problem, the transition zone between the exclusive activity of the gridpoint diffusion and the one controlled mainly by such special diffusion would be quite steep if not even of a discontinuity character. Once we would like to replace a major part of the spectral diffusion by the gridpoint diffusion, this numerical role of the spectral diffusion has to be also supplied by the new scheme. Hence the gridpoint diffusion must be tuned with respect to the model domain (as it is the case for the spectral diffusion).

3.3.2 Tuning parameters of gridpoint diffusion

The gridpoint diffusion for a prognostic model variable ψ is implemented (for example in two-time-level scheme) in the following way:

$$\mathcal{D}_{\psi}^{+} = \kappa(I_D - I_A) - \frac{\Delta t}{2}\mathcal{R}^{\frac{1}{2}} \tag{1}$$

Here the second term represents the part of right hand side evaluated at the arrival point of the semi-Lagrangian trajectory which is not directly controlled by the diffusion operator. In the further this residual term will be omitted. The main term for the diffusion is the first term on the right hand side.

The difference in brackets represents the diffusion contribution of the diffusive semi-Lagrangian interpolation I_D to the accurate one I_A. Both interpolations are evaluated for the origin point of the semi-Lagrangian trajectory. The diffusive interpolator I_D is the (tri)linear interpolator with additional smoothing near the gridpoints. This additional smoothing makes the damping more independent to the distance of the origin point of the semi-Lagrangian trajectory from the closest model gridpoint. This damping enhancement is especially useful for the situations where there is nearly no wind at some areas with high deformation value (centers of cyclones) or large areas with quasi steady flow. The maximum distance from the closest gridpoint in x or y directions where this additional smoothing is applied (i.e. has nonzero mask) is controlled by the namelist parameter $ALPHINT$. This parameter varies between 0. (no smoothing interval) and 0.5 which then applies smoothing at $< -0.5\Delta x, 0.5\Delta x >$ around each gridpoint. As it can be easily seen, $ALPHINT = 0.5$ means that the additional smoothing is applied everywhere. The default value is $ALPHINT = 0.15$. The resulting value of the diffusive interpolator I_D is then obtained as the $I_D = (1. - \Gamma)I_L + \Gamma S$. Here I_L stands for the (tri)linear interpolator, S for the smoother and Γ is the mask decreasing with the distance from gridpoint to $ALPHINT \cdot \Delta x$ by power of 3. The smoother S for the interval $< x_i - ALPHINT\Delta x, x_i + ALPHINT\Delta x >$ is evaluated as $S_i = \left(f(x_{i-1}) + f(x_{i+1})\right)/2$, where $f(x_i)$ represents the grid point x_i value of the quantity to be interpolated. Outside this interval (i.e. inside $< ALPHINT\Delta x, (1. - ALPHINT)\Delta x >$) the Γ is equal to zero. To keep consistency of the smoother with varying model timestep the Γ is scaled by the model timestep Δt and the namelist parameter $GAMMAX0$:

$$\Gamma = GAMMAX0\frac{\Delta t}{\Delta t_{ref}}$$

The meaning of $GAMMAX0$ then would be the maximum weight of the Γ for optimal time-step Δt_{ref}. The parameter Δt_{ref} is computed internally by the model as a function of the used advection scheme and model (horizontal and vertical) resolutions. Setting $GAMMAX0 = 0.$ effectively deactivates the smoother. Default value is $GAMMAX0 = 0.15$.

The key variable for the gridpoint diffusion is the κ varying roughly between 0 and 1 (in some special cases it can be even more than 1). It can be considered as a sort of coefficient of diffusion. It is defined in the following way:

$$\kappa = SLHDKMAX \frac{\Delta t F(d)}{1 + \Delta t F(d)} \tag{2}$$

Here the $SLHDKMAX$ is tunable parameter limiting the κ. It can vary from 0 up to 5. Default value is $SLHDKMAX = 1.$ $F(d)$ represents monotonic function of the horizontal flow total deformation d. It is defined in the following way:

$$F(d) \equiv a \quad 2d \left(\max \left[1., \frac{d}{d_0} \right] \right)^{SLHDB} \tag{3}$$

In the previous a is the main scaling factor for the gridpoint diffusion, d_0 is the threshold of d above which the enhanced diffusion is activated and $SLHDB$ is tunable parameter for the enhancement. To make previous formula independent to a model resolution a and d_0 can be rewritten in the following way:

$$\begin{aligned} a &= SLHDA0 \left(\frac{c[\Delta x]_{3,ref}}{[\Delta x]_3} \right)^{ZSLHDP1} && (4) \\ 2d_0 &= SLHDD00 \left(\frac{c[\Delta x]_{3,ref}}{[\Delta x]_3} \right)^{ZSLHDP3} && (5) \end{aligned}$$

Here c is the stretching factor (for the plane geometry $c = 1$), $[\Delta x]_3$ is the "CFL-spectral" mesh-size and $[\Delta x]_{3,ref}$ is a reference value of the previous (it is relevant to the old ALADIN/LACE domain: $\pi[\Delta x]_{3,ref} = 52349.828$ m). The others are tunable parameters. The purpose of the empirical constants $ZSLHDP1$ and $ZSLHDP3$ is to make definition of $F(d)$ general with respect to the actual model mesh and domain size.[3] (Their values have been found as $ZSLHDP1 = 1.7$ and $ZSLHDP3 = 0.6$.) Hence the only three tunable parameters for the gridpoint part of the SLHD remains $SLHDA0$, $SLHDB$ and $SLHDD00$.

Still three tunable parameters for the scheme where is just one degree of freedom seems to be a bit too many.

Let us first consider that there is just one tuning parameter $SLHDA0$ scaled by the empirical constant $ZSLHDP1 = 1.7$ in order to make a independent to a model domain following the (4). (The influence of the rest of the formula (3) can be easily suppressed by setting $SLHDB = 0.$) With such arrangement the gridpoint part of the SLHD acts selectively for each scale proportionally to the value of the $SLHDA0$ as it is illustrated by 2. There the left one displays the situation with $SLHDA0 = 1.$ (rather strong diffusion) while the one on right corresponds with the $SLHDA0 = 0.1$ (very weak diffusion). Note also that the amplification curve differs in both examples. Its shape is purely given by properties of used interpolatores. Thus a chance to change its shape is very limited.

As it has been explained, such arrangement presented by figure 2 is fine from the physical point of view but not really practical for model running above various model domains and resolutions. From this reason (but not only for it) the enhancement of the function $F(d)$ has been introduced into the formula (3). Using the enhancement, it is possible to easily access the actual domain small scale information by increased gridpoint diffusion. If the amount of enhanced point is sufficiently small, this can even increase the selectivity of gridpoint diffusion. Once the portion of points to be enhanced becomes significant with respect of the whole amount (when it is more than few percents), it behaves similarly as when just $SLHDA$ would be increased. Anyway the enhancement threshold d_0 can be easily scaled according (5) to affect always the same portion of points independently to the actual model resolution. Therefore the diffusion enhancement can be easily used to strengthen gridpoint diffusion specifically to each domain. Like that the amplification function starts to be model dependent so is not any longer function of just a given scale. Especially near the end of a model spectra the damping strongly relies to the actual resolution. On the other side this allows the gridpoint part of the SLHD to sufficiently replace the spectral diffusion.

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[3] As it will be further presented the $ZSLHDP3$ parameter is slightly dependent to the value of the $SLHDD00$. However the simple approach considering that $ZSLHDP3$ is a constant sufficiently fits almost all useful ranges of the enhancement.

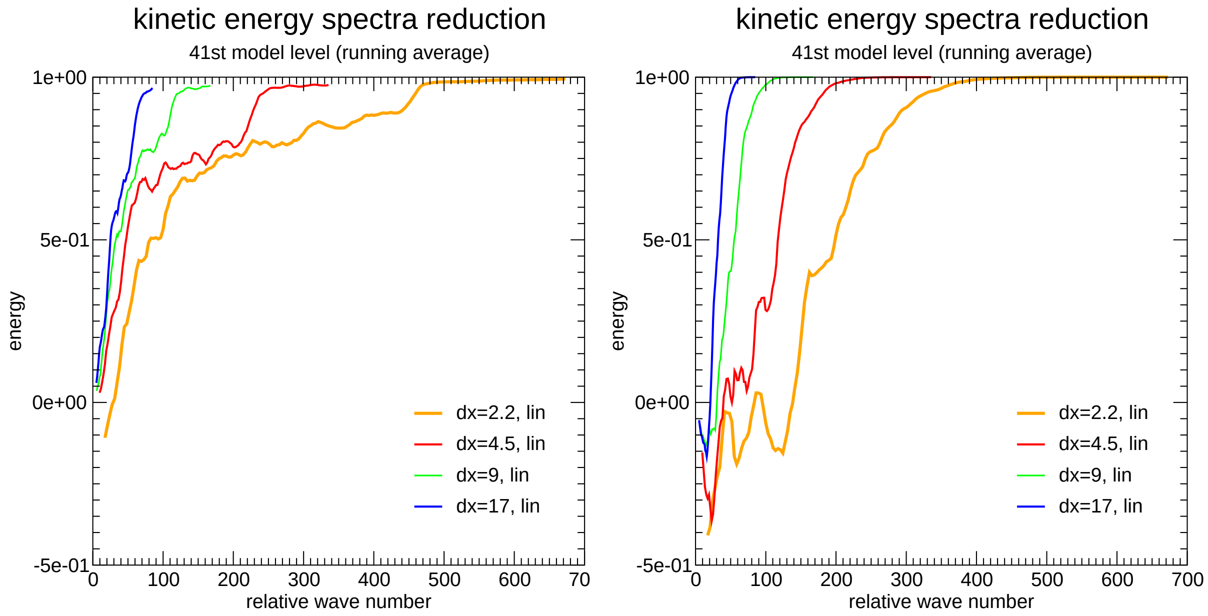

Figure 3: *The relative amplification factor of kinetic energy spectra as a function of the scale (relative wave number defined in the same way as before) obtained from 6 hours adiabatic simulation. Left figure shows the results obtained from the gridpoint part of the SLHD, right figure the same obtained by standard spectral diffusion. As in previous figure 2 the four used gridpoint resolutions are explained by legend box. All curves are regularized by 9-points running averages.*

The proposed tuning than sets $SLHDA0 = 0.25$ with $ZSLHDP1 = 1.7$ making the points diffused without enhancement to be affected by physical scale independent diffusion. The threshold for enhancement is then set equal to the 75% quantile by scale independent d_0 ($SLHDD00 = 0.000065$, $ZSLHDP3 = 0.6$) Like that roughly 25% of points (in active levels of the atmosphere) are affected by increased diffusion controlled by exponent $SLHDB = 4$. This settings for the gridpoint part of the SLHD with all the defaults for reduced spectral diffusion and supporting diffusion gives roughly same kinetic energy spectra slopes as resulted from the spectral diffusion only.

There is also other reason for which the enhancement is beneficial for the overall scheme performance. The total diffusion caused by the gridpoint diffusion is related to an average value of κ. With the enhancement we can achieve the same value of this average affecting less points by the diffusive interpolation. Only very few portion of points be affected by quite strong diffusion. This trick reduces the side effect of the gridpoint diffusion coming from the less accurate vertical interpolation: the positive BIAS of the surface pressure reflecting a mass lost of the simulated atmosphere.

Figure 3 illustrates the proposed default situation on kinetic energy amplification curves for the gridpoint part of the SLHD and the reference spectral diffusion. Contrary to the previous raw curves those are filtered from the random noise by applying of the running average filter. It is evident there that the amplification of the gridpoint diffusion is no longer uniform for a given scale. It becomes also a function of the model domain now. The numerical spectral diffusion behaves in the same way due to its definition relying directly to the model domain. The figure 3 also nicely illustrates the weakness of the gridpoint diffusion to access the part of the spectra influenced by the model orography. As it can be seen, quite significant portion of the model spectra is proportional to the slope and structure of the model orography. This is especially evident by the stair near the small scale end related to the missing small scale forcing of the quadratically truncated orography to the linear spectra of the model prognostic fields. The spectral diffusion applied like an independent filter doesn't show such feature.

Surprisingly the long wave part of the spectra (corresponding to the most important model information) seems to be less sensitive to the gridpoint diffusion than to the spectral diffusion. Knowing that spectral diffusion preserves long waves almost unaffected while acting in middle and mostly at the small scales of the model, this result is quite unexpected. The amplification values bellow zero mean that waves are positively amplified instead of damped in the figure 3. It is then evident that even very long waves are significantly (and indirectly) affected by presence of the spectral diffusion. This means that without spectral horizontal diffusion the mode large scale information would be quite different. This trend is not that strong with the gridpoint diffusion. Keeping in mind that during the 6 hours simulation spurious small scale energy would hardly be able to affect the large scales in the total absence of the horizontal diffusion, last result clearly shows that the gridpoint (non-linear) diffusion is more in agreement with the physical reality.

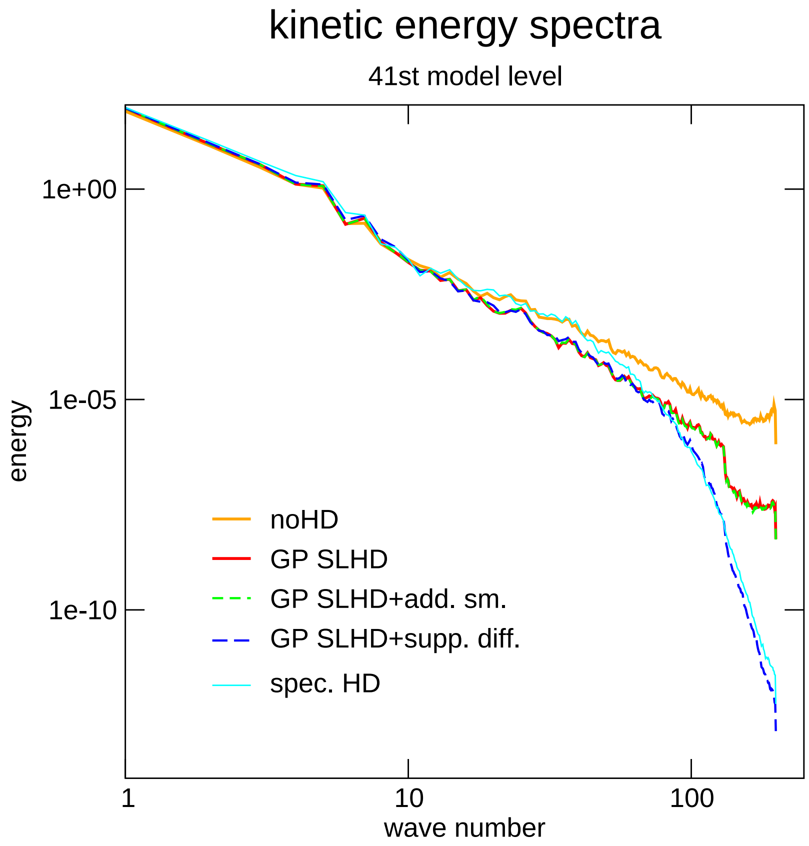

Figure 4: *Kinetic energy spectra of the 41^{st} model level (out of total 43) from a 6 hours adiabatic model ($\Delta x = 2.2$ km, linear grid) simulation with no horizontal diffusion* `noHD`*, gridpoint part of the SLHD with the diffusive interpolator I_D without additional smoother S* `GP SLHD`*, the same with the I_D containing the additional smoother S* `GP SLHD+add. sm.`*, the gridpoint part of the SLHD (without additional smoother S in I_D) and supporting spectral diffusion* `GP SLHD+supp. diff.` *and the standard spectral diffusion of 4^{th} order* `spec. HD`

At the end of this descriptive section of the SLHD, the impact of the scheme components will be demonstrated. At the figure 4 kinetic energy spectra at the 41^{st} model layer are presented for several model 6 hours adiabatic simulations with different horizontal diffusion settings. All of them are relevant to the domain with horizontal grid mesh $\Delta x = 2.2$ km and linear truncation. The line labeled as `noHD` reflects a kinetic energy spectra for the simulation without any horizontal diffusion. The results of the situation with default gridpoint part of SLHD (without smoothing enhancement) is labeled as `GP SLHD`. The same just with the smoothing enhancement (in their default values) is labeled as `GP SLHD+add. sm.` It is quite evident that the influence of the gridpoint diffusion to the model spectra is mainly at the middle scales. The fine scales are then evidently influenced to the spectra of the model orography. The impact of the smoothing enhancement for the lows and quasi-steady flow is in term of global average quite week. The spectra labeled as `GP SLHD+supp. diff.` is then result of the gridpoint and supporting spectral diffusions. As said the supporting diffusion impacts mainly the small scale end. Finally as the reference the result of the simulation with the classical spectral diffusion is presented as `spec. HD`. One can see, that the main differences of the last two are in middle scales and large scales. Since the reduced spectral diffusion is not important for the presented model level (which is close to the model surface), the last two curves corresponds with the default tunings for the SLHD and the spectral diffusion.

4 Namelist parameters for SLHD

This section tends to be something like crash course for those not really interested about details. It gives basic impression what to do, when asking model to activate the SLHD. At the end of this section some guidelines for any further scheme tuning (different from defaults) are given.

Hopefully one will find the SLHD scheme very simple to activate and to play with. It was at least coded with this intention. However some limited knowledge about the model is still required for the interested user. The one of the main importance is the knowledge of the actual model cycle for which the scheme intends to be activated. The major part of the SLHD entered source code during CY27 phasing.[4] However the minimal cycle recommended for this scheme is CY29T1 (or version based on CY28T3 distributed from Prague). Since this cycle SLHD is efficient and safe (at least for LAM). Some minor changes appeared in CY29T2 (as will be presented later). Finally there is a hope that from the CY30T1 the proper defaults will be committed to the code.

Here it is automatically supposed that the minimal cycle requirement is satisfied. The specifications of the older cycles are not taken into account hereafter.

Another very important point to keep in mind is the fact that the SLHD is intrinsically linked to the semi-Lagrangian advection scheme. Hence it can be activated just for such variables for which this kind of advection is requested.

Up to now, default horizontal diffusion is the spectral one. To replace it by the SLHD one has to explicitly define switch $LSLHD =$.TRUE. in NAMDYNA namelist block. Starting from CY29T2, this global switch has been split into independent switches for separate or group of variables (again belonging to the namelist block NAMDYNA) which are:

$LSLHD\_W$	activating SLHD for the horizontal flow components,
$LSLHD\_T$	activating SLHD for the temperature,
$LSLHD\_SPD$	activating SLHD for the (NH) pressure departure,
$LSLHD\_SVD$	activating SLHD for the (NH) vertical divergence,
$LSLHD\_Q$	activating SLHD for the moisture field,
$LSLHD\_O3$	activating SLHD for the prognostic ozone filed,
$LSLHD\_PREC$	activating SLHD for the prognostic precipitating, species: rain, snow and graupel,
$LSLHD\_CIW$	activating SLHD for the prognostic cloud ice and water,
$LSLHD\_TKE$	activating SLHD for the prognostic TKE,
$LSLHD\_V$	activating SLHD for the other GFL variables,

If the one of those switches is set to .TRUE. the gridpoint diffusion is activated for the appropriate variable. In such case the original spectral diffusion is reduced (if exists) or reset (in case of moisture). For the flow components and the NH vertical divergence the supporting spectral diffusion of 6^th order is activated.

All the other tuning variables for the SLHD belong to the namelist block NAMDYN. Here is the list of all of them with their preferable defaults:

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[4] It in fact appeared as the ClerCase branch already under CY26T1. The CY25T1 version is also locally available in Prague.

Variable name	Default value	Description
$SLHDA0$	0.25^*	Scaling parameter for the deformation d in F(d) function
$SLHDB$	$4.$	Enhancing factor (exponent) for F(d) funct.
$SLHDD00$	$6.5E-5^*$	Threshold for deformation d enhancement
$ZSLHDP1$	1.7^*	Factor defining independence of a to the model resolution
$ZSLHDP3$	0.6^*	Factor defining independence of d_0 to the model resolution
$ALPHINT$	0.15	Interval of the influence of the additional smoother for homogeneous diffusive interpolator
$GAMMAX0$	0.15	The maximum weight for the additional smoother for homogeneous diffusive interpolator
$SLHDKMAX$	$1.$	The maximum value for the κ coefficient
$RDAMPVORS$	$5.$	Local enhancing factor for the supporting spectral diffusion of vorticity (corresponds with RDAMPVOR of spectral diffusion)
$RDAMPDIVS$	$1.$	Local enhancing factor for the supporting spectral diffusion of divergence (corresponds with RDAMPDIV of spectral diffusion)
$RDAMPVDS$	$15.^{**}$	Local enhancing factor for the supporting spectral diffusion of vertical divergence (corresponds with RDAMPVD of spectral diffusion)
$REXPDHS$	$6.$	Order of the supporting spectral diffusion (corresponds with REXPDH of spectral diffusion)
$SLEVDHS$	0.25	First threshold for the supporting diffusion pressure dependency scaled by VP00 (corresponds with SLEVDH of spectral diffusion)
$SLEVDHS2$	0.01	Second threshold for the supporting diffusion pressure dependency scaled by VP00 (corresponds with SLEVDH2 of spectral diffusion)
$SDRED$	$1.$	The reduction of the spectral diffusion when SLHD (0. no reduction, 1. maximum reduction)

*) default since CY30T1 **) recommended to get rid of diffusive chimney; default value is $RDAMPVDS$=1.

As said in the previous sections the scheme with the proposed defaults can be used for any scale and a general truncation (linear, quadratic and even something intermediate). Validation tests for the ALADIN between resolutions from 2.2 Km to 19 km proved that the proposed settings is sufficient. **Please be aware that till CY30T1 some tuning constant have to be specified by the namelist!** Their default values corresponds to the old SLHD settings.

In case one would like to further tune the proposed defaults here are some guidelines for the gridpoint diffusion tuning. As mentioned, the key role for the gridpoint diffusion is the value of the κ average (hereafter as $\bar{\kappa}$). Using the equations (2) and (3) it is evident that the value of $\bar{\kappa}$ is related to a $2d$ distribution through the tuning parameters $SLHDA0$, $SLHDB$ and $SLHDD00$. Figure 5 illustrates a typical distribution of the $2d$ from the active model level. Easiest way to increase $\bar{\kappa}$ is to increase parameter $SLHDA0$. This would result in enhancement of the diffusion for the whole points (the portion of diffusive interpolator would increase for all interpolatores). Other way is to play with the enhancement threshold. This second possibility allows to keep quasi-same performance as the first method affecting less points by (more significant) diffusive interpolation.

The two methods can be demonstrated by following spreads of the κ. They are related to 6 hours model simulation with $\Delta x = 2.2$km and linear truncation. Both of them perform quite the same gridpoint diffusion. When using no diffusion enhancement ($SLHDA0 = 0.083, SLHDB = 0$) the kappa has following characteristics:

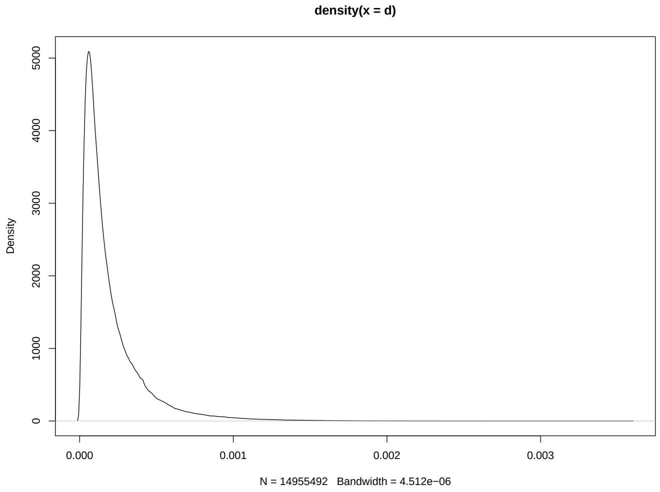

Figure 5: *Frequency distribution of the $2d$ values diagnosed during a 6 hours integration at 41st model level (out from 43) with liner grid and $\Delta x = 2.2$ km.*

```
     Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
5.066e-06 1.774e-02 3.309e-02 4.814e-02 6.268e-02 4.892e-01
```

With the enhancement ($SLHDA0 = 0.0070, SLHDB = 4, SLHDD0 = 0.000065$) the spread becomes:

```
     Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
4.271e-07 1.521e-03 2.877e-03 4.816e-02 5.606e-03 9.997e-01
```

It is evident that second example affects less points by more diffusive interpolation. This is definitely preferable solution for the model due to a more precise (less corrupted by the linear interpolation) overall semi-Lagrangian interpolation.

To conclude previous. One way to make gridpoint diffusion stronger is to increase $SLHDA0$ parameter. Other way for the same is to lower the enhancement threshold $SLHDD00$. The default value $SLHDD00 = 0.000065$ (and $ZSLHDP3 = 0.6$) affects something like 25% points from active zones. To affect 50% of points, this value should be set to $SLHDD00 = 0.000039$.[5] Typically something like compromise is the best solution. It can be reached by slight increase of the $SLHDA0$ parameter and lowering of the $SLHDD00$ when gridpoint diffusion is required to be set stronger. When enhancement affects significant amount of points (like 15% and more), the power of enhancement $SLHDB$ may also be an option to play with. From the (3) is evident that higher value of $SLHDB$ means stronger diffusion.

5 Conclusion

As an alternative to the spectral horizontal diffusion scheme the SLHD is available in the ALADIN/ARPEGE model. Contrary to the spectral diffusion this scheme tends to be physically realistic. The price one has to pay for it is the increase of the computational time (around 5% of the whole model performance) and less straight forward possibility for the model damping control. However the SLHD scheme is coded in the way to be user friendly. It is believed that the proposed default tuning fits most of the operational application. The numerous tuning parameters further extends the SLHD scheme skills to be able to fit even very specific model applications.

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[5] Note that in this case the tuning for the resolution should be reduced to $ZSLHDP3 = 0.5$. This is valid in the opposite way as well: For example at the maximum meaningful value for $SLHDD00 = 0.00052$ affecting just few points, the resolution tuning should be increased to $ZSLHDP3 = 0.9$.

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