

# On the changing design of ARPEGE/ALADIN spectral horizontal diffusion setup

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## 1 Preface

This paper aims to bring some light into the evolving setup of the horizontal diffusion scheme of ARPEGE / ALADIN models (with some brief remarks to IFS as well). All scientific aspects then have been suppressed to an absolute minimum necessary just to understand the following. Hence this should be considered more like some technical memo rather than a scientific or a code documentation of the horizontal diffusion scheme. Anyone with ambitions exceeding the range being presented in this paper is kindly recommended to study by its own the papers listed at the reference section.

## 2 Introduction

Since the joint ARPEGE/IFS cycle CY27 the setup of spectral horizontal diffusion (hereafter referred as HD) has been redesigned to a more flexible way.

Till that time the so-called "numerical" part of the HD at a given model level was controlled by the order of diffusion and for some historical reason by parameter HDIR[X] being proportional to e-folding time of the smallest wave represented by the model. This arrangement implies a dependency of the HDIR[X] namelist parameters to a given model resolution and truncation. Moreover since model uses the parameter  $1/\text{HDIR}[X]$  during the computation of the HD spectral response field some extra care has to be cared for the cases when  $\text{HDIR}[X] = 0$ .

New proposal (in addition to merging the "numerical" and "geographical" parts of the HD) tried to get rid of those inconveniences while preserving the same model performance. Instead of HDIR[X] parameters defining HD for each prognostic field X, the whole scheme was defined by just two parameters RRDXTAU and RDAMPDIV independent to a model geometry. The relation between HDIR[X] and RRDXTAU then becomes:

$$\text{HDIR}[X] = \frac{F(\Delta x, \text{truncation})}{\text{RRDXTAU}}$$

In this sense the  $\text{RRDXTAU}^{-1}$  is the ratio of the time-continuous local damping time of the shortest spectral wave divided by the local linear grid mesh size. The diversity of HD for each variable X then were controlled by the only parameter RDAMPDIV, knowing that typically just two different values of HDIR[X] were used to define whole set of model diffusion: HDIRDIV(divergence) = HDIRVD(vertical divergence) and HDIRVOR(vorticity) = HDIRT(temperature) = HDIRQ(moisture) = HDIRPD (pressure departure). The ratio between HDIRVOR and HDIRDIV then corresponded with the namelist parameter RDAMPDIV.

This arrangement was surely a step toward a good direction. Unfortunately due to following constraints its adaptation to the model was not fully challenging:

- The ECMWF didn't accept this new arrangement, so the old structure has to be preserved in the model parallel with the new one. This created some strange consequences, like that HDIR[X] parameters were still allowed in the namelist, without having any impact for the model setup. (New setup was optional for ECMWF but remained as the only possible option for ARPEGE/ALADIN).

- Roughly at the same time appeared the semi-Lagrangian horizontal diffusion scheme (SLHD) in the code as an alternative way to non-linear horizontal diffusion scheme. This implied to HD some additional requirements for different prognostic variables which couldn't have been controlled by just one ratio RDAMPDIV.
- Moreover since the HD spectral response function has been evaluated still in the same way using  $1/\text{HDIR}[X]$  the new arrangement was leading to the substitution of previous by  $1/[F(\Delta x, \text{truncation})/\text{RRDXTAU}]$ . This despite the fact that it is algorithmically a bit bizarre solution implied some extra care to avoid division by zero (which was even not implemented correctly at that time).

Since CY29T1 this situation is supposed to be further improved in order to maximise the profit from the new HD setup. To keep some track with history, the full profit is still activated just optionally. Anyway some radical and irreversible approach to new fashion of HD has been done (at least for ARPEGE/ALADIN code part).

### 3 Description of the changes in the CY29T1 setup of horizontal diffusion

The setup of horizontal diffusion being active between CY27 and CY29 (hereafter referred as NewHD1) computes the spectral response function of the horizontal diffusion in following steps:

1. Default or namelist parameters of RRDXTAU and RDAMPDIV are assigned.
2. Parameter HDIRDIV is computed as:

$$\text{HDIRDIV} = \frac{F(\Delta x, \text{truncation})}{\text{RRDXTAU}}$$

3. Parameter HDIRVOR is computed as:

$$\text{HDIRVOR} = \text{HDIRDIV} * \text{RDAMPDIV}$$

4. Both HDIRDIV and HDIRVOR are rounded to nearest lower integer.
5. Other parameters are set equal to either HDIRDIV, HDIRVOR or zero.
6. The spectral response field RDI[X] of HD is computed as:

$$\text{RDI}[X] = SP(n, m, \text{REXPDH})/\text{HDIR}[X]$$

Here the  $SP(n, m, \text{REXPDH})$  represents some function of spectral numbers  $n$  and  $m$  and order of diffusion REXPDH.

*The following is relevant just to ARPEGE/ALADIN. The new setup for IFS will be briefly discussed by the end of this section*

Since CY29T1, this way of computation has been replaced by two options. The first one (LREPHD=.TRUE.) preserves the old style of computation for HDIR[X]. As a consequence it modify slightly the namelist parameters. The other option (LREPHD=.FALSE.) keeps the exact namelist variables and simplifies the evaluation of the HD spectral response field. Both options anyway use a different way of computation of the HD spectral response field with respect to the previous cycles and hence both of them produce different spectral norms of the model. The two settings will be further referred as NewHD2 for LREPHD=.TRUE. and NewHD3 for the LREPHD=.FALSE. **Note that for ARPEGE/ALADIN the LREPHD=.TRUE. option reproduces just the HD setup parameters and not the model results.**

For a higher flexibility of the HD for each prognostic field X the separate namelist parameter RDAMP[X] has been introduced defining the ratio between the strongest diffusion and the actual diffusion of the variable X: **This means, that RDAMPDIV is typically equal to 1. now, while the value of old RDAMPDIV (which is 5. for ARPEGE/ALADIN) is preserved in RDAMPVOR, RDAMP T, RDAMP Q,...**

The model algorithm corresponding with the option NewHD2 is then:

1. Default or namelist parameters of RRDXTAU and RDAMP[X] are assigned.
2. Parameter ZHDIR is computed as:

$$\text{ZHDIR} = \frac{F(\Delta x, \text{truncation})}{\text{RRDXTAU}}$$

3. ZHDIR is rounded to the nearest lower integer
4. Parameter HDIR[X] is computed as:

$$\text{HDIR}[X] = \text{ZHDIR} * \text{RDAMP}[X]$$

5. HDIR[X] is again rounded to nearest lower integer.
6. Reverse of HDIR[X] is computed:

$$\text{HRDIR}[X] = 1./\text{HDIR}[X]$$

7. Finally the spectral response field RDI[X] of the horizontal diffusion is computed as:

$$\text{RDI}[X] = SP(n, m, \text{REXPDH}) * \text{HRDIR}[X]$$

Here the  $SP(n, m, \text{REXPDH})$  stands for the same as in previous.

The procedure of HD setup in NewHD3 is following:

1. Default or namelist parameters of RRDXTAU and RDAMP[X] are assigned.
2. Parameter ZRHDIR (reverse of ZHDIR) is computed as:

$$\text{ZRHDIR} = \frac{\text{RRDXTAU}}{F(\Delta x, \text{truncation})}$$

3. Parameter HRDIR[X] is computed:

$$\text{HRDIR}[X] = \text{ZHDIR}/\text{RDAMP}[X]$$

4. The spectral response field RDI[X] of the horizontal diffusion is computed as:

$$\text{RDI}[X] = SP(n, m, \text{REXPDH}) * \text{HRDIR}[X]$$

Again the  $SP(n, m, \text{REXPDH})$  stands for the same as in previous.

It is evident that the last alternative is far simpler than the other two. Moreover, there is no need to check whether some parameter is equal zero except for the namelist variables RDAMP[X]. The parameter RRDXTAU is also directly proportional to the model diffusion for the NewHD3 case: The zero value of RRDXTAU defines no diffusion while a great value of this variable is equivalent to a very strong diffusion. The NewHD2 case contrary to previous sets zero diffusion for cases when RRDXTAU is either zero or either some sufficiently big value. This irregularity originates in the rounding and double reversion of RRDXTAU which has to be secured from division by zero.

Since the procedure to set up HD differs for each case, it should not be surprising that the spectral norms vary with respect to a selected way of the HD setup. Following table summarises the average spectral norms obtained at the end of 6 hours forecast of the current operational configuration of ARPEGE (TL359L41c2.4) on Fujitsu VPP 5000 and the highest code optimization with respect to the setup of HD:

HD setup	SURF. PRESSURE	VORTICITY	DIVERGENCE	TEMPERATURE
NewHD1	0.114888050517821E+02	0.475332901567206E-04	0.149653194073912E-04	0.255471058327669E+03
NewHD2	0.114888050411038E+02	0.475341926795498E-04	0.149651598601510E-04	0.255471064744696E+03
NewHD3	0.114888050808361E+02	0.475355475520048E-04	0.149681245290171E-04	0.255471110545731E+03

Let us focus to the namelist variable controlling the HD new. All three setups are driven by RRDXTAU and in some sense RDAMP[x] (although it is arranged in a less convenient way in the NewHD1 case). The current ARPEGE operational configuration uses value RRDXTAU=123. and exactly 5 times stronger diffusion of divergence than for other prognostic variables. In the convention of the NewHD2 and NewHD3 setting this can be expressed as RDAMPDIV=1. and RDAMPVOR=5. (RDAMPT=RDAMPQ=5.). The NewHD3 setting then keeps those namelist values exactly, so the corresponding HDIR[X] parameters are: HDIRDIV=452.02814 and HDIRVOR=2260.1407. The other two settings (NewHD1 and NewHD2) are for a given model resolution rounding HDIR[X] so their corresponding values are HDIRDIV=452. and HDIRVOR=2260. This logically imply that either RRDXTAU or RDAMP[x] must be modified by model. If we decide to fix RRDXTAU to be constant, then in our case RDAMPDIV and RDAMPVOR (RDAMPT, RDAMPQ,...) will be modified by the model to RDAMPDIV=.99993774723847944510 and RDAMPVOR=4.9996887361923972255. Of course, this is not a dramatic change. Just it seems a bit strange, that the namelist parameters are not preserved exactly in the case NewHD1 and NewHD2. More over, their actual values vary with the model geometry.

The ECMWF setting is still computing the HD spectral response function through HDIR[X] parameters which can be either set by namelist or in case LNEWHD=.T. they are computed according the algorithms presented for NewHD2 and NewHD3. This means, that for LREPHD=.T. for their case the spectral norms are exactly preserved.

The new setup introduced since CY29T1 is as already mentioned also supposed to be general with respect to all the possible values of the namelist parameters. To switch off the spectral diffusion of one prognostic field X, one just needs to set RDAMP[X] = 0. in the namelist. To switch all spectral diffusion off then can be arranged by either setting all RDAMP[X] variable to zero, or to set RRDXTAU = 0. Additionally some security has been introduced into the model to warn the users not to use any longer HDIR[x] parameters in the namelist. (They have to be still recognised by namelist due to the ECMWF constraints, but they have no impact to the HD setting.) In case the namelist contains some of the parameters HDIR[X] the program will abort with the warning message now.

## 4 Facing the future of HD

As mentioned, the change has been done. Since the model cycle CY29T1 the results will slightly differ from the ones computed with older cycles. Optionally the HD parameters can be still "preserved" to be consistent with the old settings. Due to this such less radical change of HD (NewHD2) is preferably going to be the next operational fashion for Meteo-France. (At least from the current point of view.)

On the other hand, the NewHD2 is still just standing in the middle of the road between the historic HD setting and the full modernity represented by NewHD3. As proven, the results are not very different in any case, while the setup procedure is far more simpler for the NewHD3 case. So according author's mind, there is some good hope to expect, that sooner or later the full power of new HD setup will be used exclusively for the purpose of at least ARPEGE/ALADIN setting.

The ECMWF has actually several options. They can still keep the obsolete setting. With the key LNEWHD=.T. they can use the modern one up to the setup of the HDIR[X] parameters. In such a case, they can use both options LREPHD. For them the LREPHD=.T. is then fully consistent with the old settings. The LREPHD=.F. is on the other side loosing its power, since "modern" HDIR[X] are at the end converted to obsolete HDIR[X] parameters. Of course otherwise this modern style is fully consistent with the one of ARPEGE including the dependency to the model truncation and mesh size.

## 5 References

- Bénard P. - On the design and scaling of ARPEGE diffusions.  
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- Yessad K. - Horizontal diffusion computations in the cycle 28 of ARPEGE/IFS.  
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