



Periodic Fields by Boyd's Window in ALADIN

TECHNICAL REPORT

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Summary

This report proposes a technical solution for the implementation of Boyd's suggestion to include periodic to implement the proposal of Boyd (2005) to have periodic fields in a spectral model by windowing large-scale fields, within the code structure of the IFS-ARPEGE-ALADIN-AROME-HARMONIE models.

1 The current structure of the ALADIN domain

First, let us recall the structure of the current ALADIN domain for the Davies scheme. It consists of three zones: C,I and E, schematically given as (only a 1D view) in Fig.1. The solid line represents the relaxation function. We shall call it here \mathcal{R} .

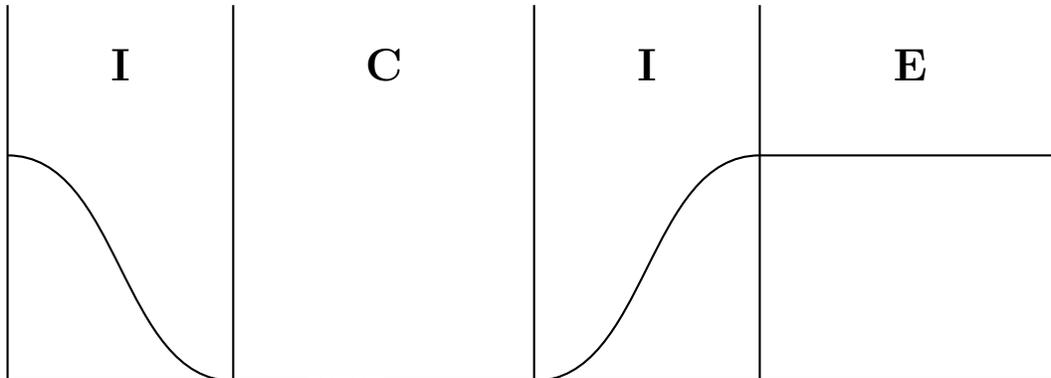


Figure 1: Zones for the Davies scheme and the relaxation function α (schematically). The solid line represents the relaxation function \mathcal{R} . The E-zone is entirely determined by the large-scale coupling fields that have to be first of all biperiodicized, before being transformed in a spectral space in fullpos.

2 The implementation of Boyd's window

The basic idea is to implement Boyd's windows in fullpos under the project `bip` by calling a new routine in `fpbipere`. That we avoid any problem with the parallelization, since in the part of the code we are on 1 CPU. The domain in fullpos is organised as shown in Fig.2.

In order to apply Boyd's window, we temporarily introduce a **P** (periodic) and **G** zone within the **C**∪**I** zone of the model, as illustrated in Fig.2, In the implementation, the width of both the **G** and the **P** zones should be equal, and given by the variable `NFPBWX` and by `NFPBWY`, for the x- and the y-directions respectively. Both are needed to make the fields periodic as in Boyd (2005), symbolically written as follows,

$$\begin{aligned}
 \mathbf{P}_L : & \quad \mathcal{B}(\mathbf{P}_L) \phi(\mathbf{P}_L) + [1 - \mathcal{B}(\mathbf{P}_L)] \phi(\mathbf{G}_R), \\
 \mathbf{P}_R : & \quad \mathcal{B}(\mathbf{P}_R) \phi(\mathbf{P}_R) + [1 - \mathcal{B}(\mathbf{P}_R)] \phi(\mathbf{G}_L),
 \end{aligned} \tag{1}$$

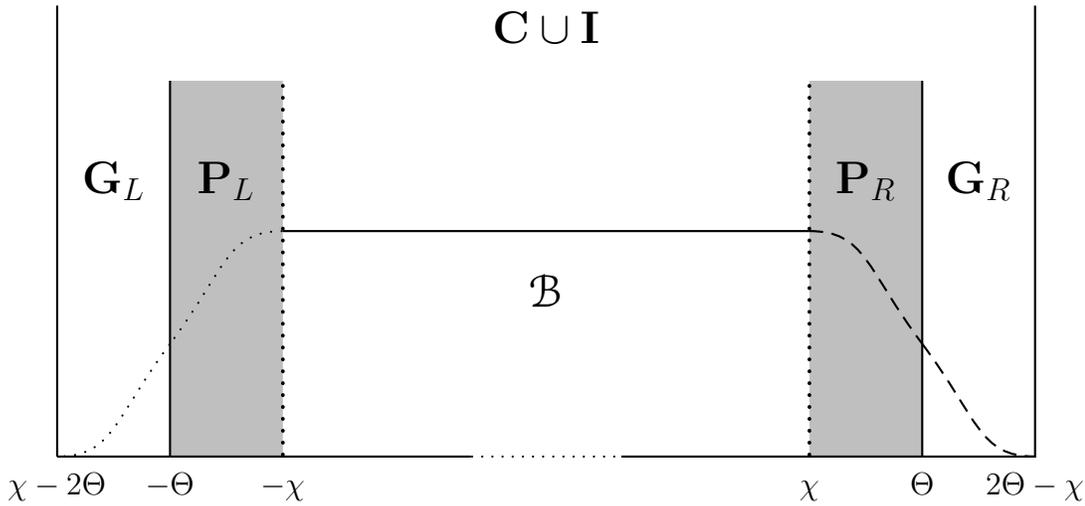


Figure 2: Location of the Boyd's window function \mathcal{B} with respect to the zone $\mathbf{C} \cup \mathbf{I}$ and the \mathbf{E} -zone within the ALADIN model. The function \mathcal{B} is indicated by three different types of lines (dots, solid, dashed) in order to make Fig.2 consistent with Fig.3 and Fig.4. The labels $-\chi - 2\theta$, $-\theta$, $-\chi$, ... are added to make a comparison with the Fig.1 in Boyd (2005).

where \mathcal{B} is given by

$$\mathcal{B}(x) = \begin{cases} \frac{1}{2} \left[1 + E \left(\frac{x+\theta}{\theta-\chi} \right) \right], & -2\theta + \chi \leq x < -\chi \\ 1, & -\chi \leq x \leq \chi, \\ \frac{1}{2} \left[1 + E \left(-\frac{x-\theta}{\theta-\chi} \right) \right], & \chi < x \leq 2\theta - \chi. \end{cases} \quad (2)$$

where E is an 'erf-like' function which is antisymmetric with respect to $x = 0$ and with the property that $E(x) \equiv \text{sign}(x)$ for $|x| \geq 1$. For this work, we have used the same E -function as in Boyd (2005), (see the paper for further details of the E -definition). The shape of the Boyd windowing function \mathcal{B} is roughly displayed in Fig.2.

The information in the right-hand side of the geographical zone \mathbf{G}_R is used with a factor $1 - \mathcal{B}$ in the \mathbf{P} zone at the left-hand side, i.e. \mathbf{P}_L . In this case both \mathbf{G} and \mathbf{P} are included within the original $\mathbf{C} \cup \mathbf{I}$ zone of fullpos. This is easy to code by calling a new routine `ewindow` from `fpbipere`, and as mentioned above the parallelization is no longer a problem.

After applying Boyd's window, the \mathbf{G} zone is not necessary anymore. It is important to note here that by discarding this zone of equal length at both sides, we retain a smaller domain which (a) has exactly the same centre¹ as the original domain and (b) is composed

¹The conformal Lambert projection of the domain is determined by the centre point of the $\mathbf{C} \cup \mathbf{I}$ domain.

of gridpoints that exactly coincide with the subset of grid points of the original domain. In other words, the projection does not change. The \mathcal{B} function is indicated with dotted and dashed line (same convention as in Fig.2).

To produce a coupling file with a Boyd window we then:

1. define a FA frame for the new domain in `sufpoph`, and
2. adapt the routine `WRHFP` that prepares the output of the fields in the file `PXE9270000+0000`.

The new frame is defined by the new dimensioning parameters and by correctly coupling the content of the periodic $\mathbf{C} \cup \mathbf{I} \cup \mathbf{P}$ zone in the output. In order to see how this works, it is useful to recall how fullpos performs. In fact, an ee927 performs a number of tasks by a series of calls to `STEPO`. This is shown in table 1.

nr.	CDCONF	inv. spectral transf.	spectral transf.	gridpoint comput.	IO pack
1	OAAOM0000	✓	-	vertical	-
2	0000A0000	-	-	horizontal	-
3	Z00000000	-	-	-	✓
4	OAAOSOPPP	✓	✓	vertical	-
5	Z00000000	-	-	-	✓

Table 1: The five calls to `STEPO` during full pos and the tasks they carry out.

Additionally, the fourth and fifth call to `STEPO` are carried out in the so-called second part of fullpos (`LFPART2=.TRUE.`). This second part is actually a call from `CPREP4` to `CNT0`, as can be seen from table 2. So basically at this stage, ee927 calls the model from scratch. The fields are passed from part 1 to part 2 by the `PXE9270000+0000`. This file contains fields on the η levels of the original model which are stored in the gridpoint representation. Then, the second part interpolates the fields on the η levels of the target domain, carries out the direct spectral transform and stores them in the output file.

The advantage of this implementation is that if we get part 1 right, then the implementation of Boyd’s window will automatically follow, provided the setup is properly modified to fit the new target domain and without applying anything else that is related to the Boyd’s windowing. A new logical `LFPBOYD` (in `YOMFPC`) is introduced and everything is placed under `LFPBOYD.AND.(LFPART2==.FALSE.)`.

In fact, Table 2 shows how the fields are made periodic. `FPBIPERE` box is the only relevant place. The other calls to `ETIBIHI(1)`, `FPBIPERE(1)` and `FPBIPERE(2)` are there to make the Coriolis, the map factor, the orography, and the clim files. These were not modified. The code currently works when these are still made periodic with splines. This is open as a `TODO` (see below).

The `PXE9270000+0000` file is created in a call to `IOpack` during the third `STEPO` with the configuration `Z000000000`.



Table 2: The part of the calling sequence that is relevant for the Boyd’s solution.

Regarding the dataflow, it is important to note that the Boyd window is computed in EWINDOW after copying the buffer HFPBUF into some local variable (this copy is done in the fpezzone routine). Since these local variable will be de-allocated at a later stage, it is very important that their content should be copied back into HFPBUF. In fact, in the code, the fields in the E-zone which are yielded by the mean of splines, are stored in a distinct buffer HEFPBUF. Further in the code, the routine EXBIP inserts HEFPBUF together with HFPBUF and this is then copied in a local variable ZREAL in WRHFP. This is then written into the file PXE9270000+0000. For Boyd’s window, the way these buffers are copied back into the local variable are modified.²

For the time being, 2 options are left open to debate:

- For option 1 we include the **P** zone in the **E** zone of the target file. Option 1 is illustrated in Fig.3.

We define the frame CADRE.BOYD.#01 by the following lines in SUFPOPH

```
JLONB(1)=NFPLUX-2*NFPBW
JLATB(1)=NFPGUX-2*NFPBW
JFPLUXB=JLONB(1)-2*NFPBW
JFPGUXB=JLATB(1)-2*NFPBW
```

The spectral truncation is then also computed from JLONB and JLATB for this domain and put in JFPMAXB(1) and in JMFPMAXB. The SE and NW corners are also computed anew by a call to EGGX_N. The new frame CADRE.BOYD.#01 is then computed by

²In this case we introduced in WRHFP, a new local variable ZFRAC. ZREAL can be used for the same purpose. This is a matter of cleaning.

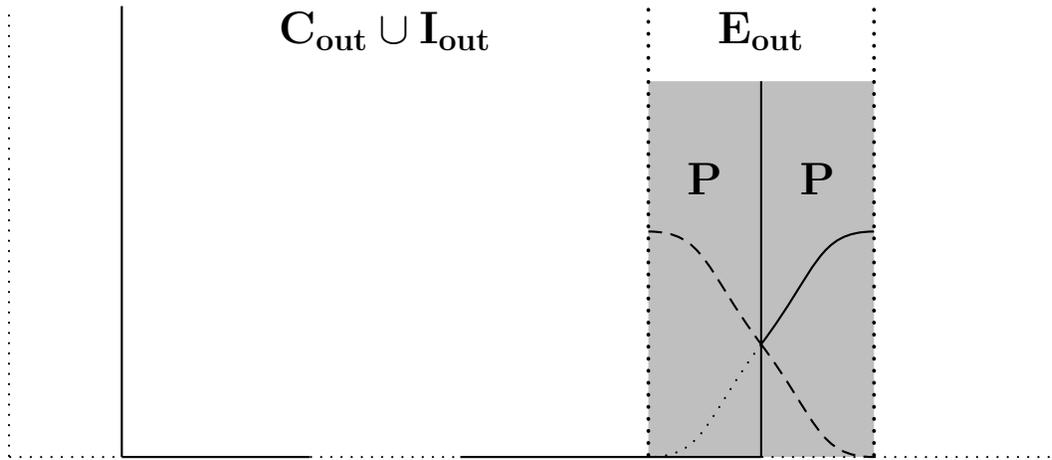


Figure 3: The E-zone option: the window is entirely included in the E-zone of the target frame.

a call to `SUEFRAME`. This frame can be used later in the code whenever needed to write data into a file. In this option, `HFPBUF` is copied in the order that translates the left **P** at the right side and in the extension zone of the target file, by a proper loop with proper dimensioning.

- For option 2, the output file will have an empty **E** zone, but with the **P** zone included in the target $C \cup I$ part of the domain. This option is illustrated in Fig.4.

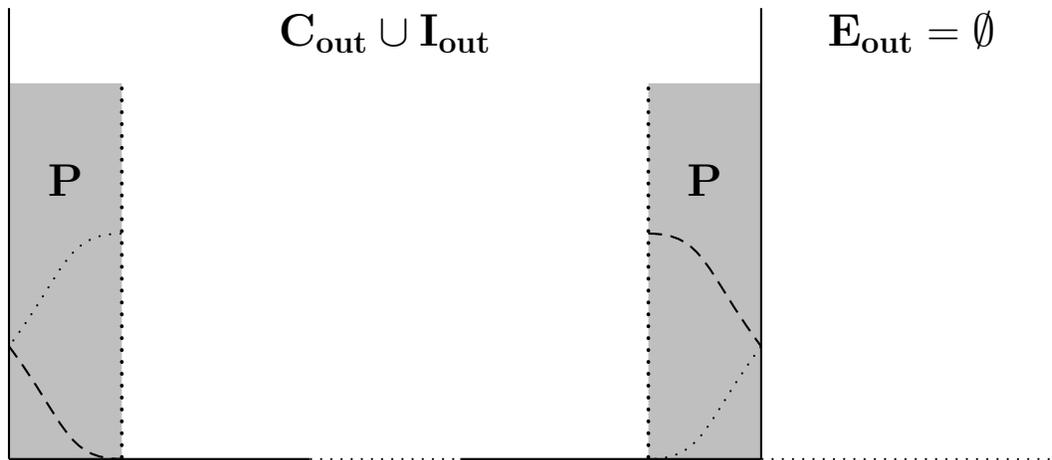


Figure 4: Option 2: there is no **E** zone in the target frame. The **B** function is indicated with dotted and dashed line (same convention as in Fig. 2).

This is done by defining the frame `CADRE.BOYD.#01` by

```
JLONB(1)=NFPLUX-4*NFPBWX
JLATB(1)=NFPGUX-4*NFPBWY
```

```
JFPLUXB=JLONB(1)
JFPGUXB=JLATB(1)
```

in `SUFPOPH`. The spectral truncation is then also adapted. For this option, nothing has to be translated, but only to change the frame and to copy `HFPBUF` in the correct form in `WRHFP`.

In fact, the translation of the left **P** zone in option 1 can be seen by comparing Fig.3 to Fig.4. In 2D, this corresponds to a translation of all the zones on the torus.

The second part now becomes straightforward: all modification are put under `LFPBOYD` && (`LFPART2==.FALSE`) and the Boyd dimensioning in `SUFPC` must be specified to ensure that the dimensions are not over written by the original input (in `SUFPG1`). In order to avoid an abort in `slcset` routine `MOD(NDLON,2)` is removed from the line `NDSUR1=3-MOD(NDLON,2)` in `SUDIM2` to make our tests run on a domain of uneven length.

In practice, it is expected that only option 1 will be needed, where the periodicity is hidden in the **E** zone. That way users can keep on using the code as before. The only thing that changes is that the splines are replaced by the Boyd window. However, if one takes into consideration the \mathcal{R} function in Boyd (2005), in the code this implies to choose an \mathcal{R} that is different from 1 in the **E** zone. In option 1, this involves a drastic change of the code (calling dynamics and physics in the **E** zone) whereas in option 2 the test of this new \mathcal{R} function is trivial. For the scientific tests, we expect that $\mathcal{R} = 1$ in the **E** zone will work best, but in order to carry them out we still keep option 2 present in the code, at least for the time being.

All the work is done in `fullpos`. In practice the preparation should be done for the initial file, the geographical file and all the coupling files.

Note that the spectral transforms require that the domains have widths that are decomposed in primes of the form $2^p 3^q 5^r$. In the case of an `ee927`, this can lead to difficulties. Indeed, as can be seen from Fig.1 the **E** zone is first removed (usually 11 points for existing clim files) and then the **G** zone is removed from both sides. Domains will shift from an even to an odd number and *vice versa*. Secondly, if we start from a domain that satisfies the decomposition requirement, finding a target domain that also satisfies this requirement may be difficult. This could be solved by allowing the $\mathbf{G} \cup \mathbf{P}$ zone not to entirely fit within the original $\mathbf{C} \cup \mathbf{I}$ zone. This has not been implemented yet.

For option 1, some preliminary tests were carried out, starting with a domain with `NDLON=320`, `NDLAT=288`. For the tests we chose `NFPBWX=42`, `NFPBWY=26`. This led to a target domain with `NLON=225` and `NLAT=225` (corresponding to a decomposition of $3^2 5^2$). This is an excessively large **E** zone but here it was used only to test the code.

A first run was carried out to test whether the model remained stable or not. Fig.6 shows the temperature at the lowest level of this run.

Extensive testing of the quality of the forecast remains to be carried out. The correspondence between the 9-km and the 15-km runs in Fig.6 seems acceptable.

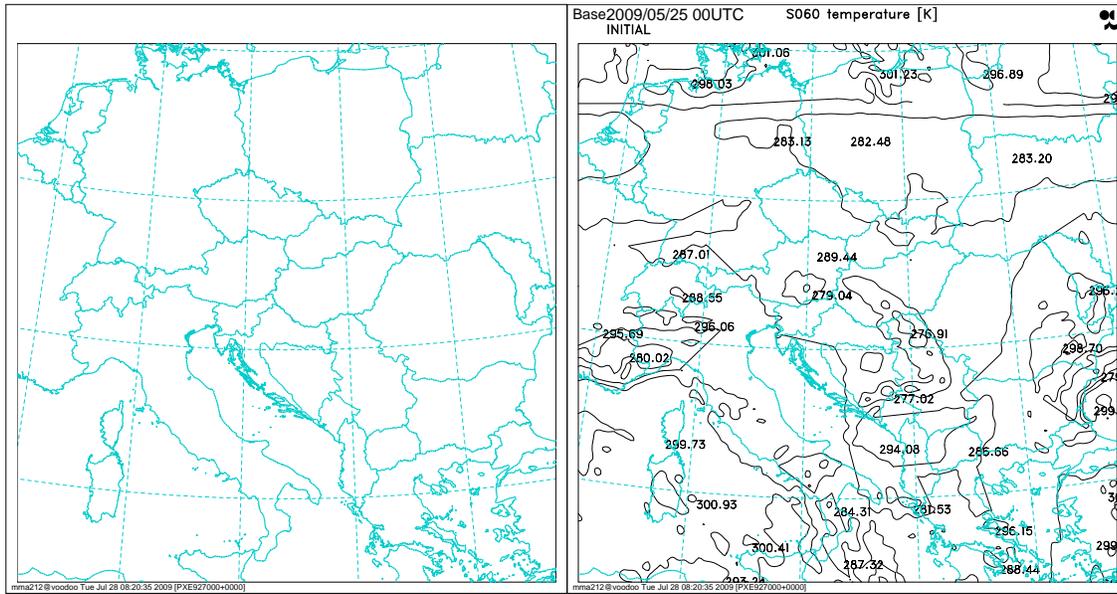


Figure 5: An example of the periodicity of the fields with the Boyd window: temperature at the lowest level as found in the PXE9270000+0000 file (9 km resolution). This map includes the **E** zone of 84 gridpoints at the right hand side.

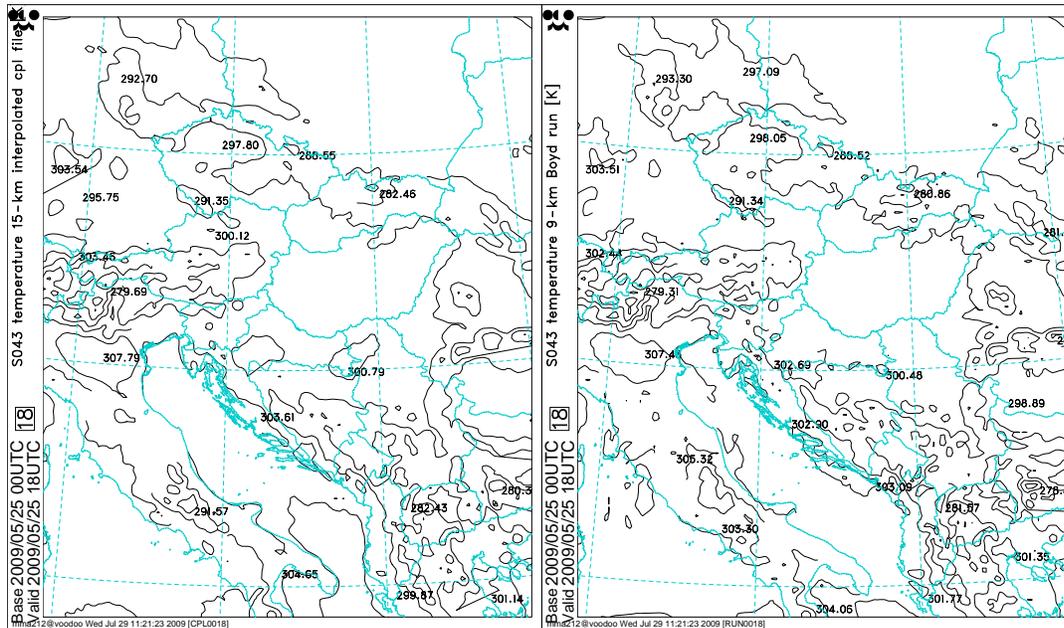


Figure 6: A preliminary run: the content of the original domain (resolution 15 km) after being interpolated to 9 km (left), and the run (resolution 9 km), at a 18-h forecast range (right).

3 Code

The code of our work has been implemented at CHMI. The code is in the branch

- `Ald_mma211_AL35t1_Boyd_Extension`,
- `Arp_mma211_CY35t1_Boyd_Extension` and
- `Bip_mma211_BI35t1_Boyd_Extension`.

The code has not been cleaned. Before being phased, some effort should be made to clean it.

3.1 Modified routines

This should be included in the `bip` project as much as possible.

- `yomfpc` : `LFPBOYD`, `NFPBWX`, `NFPBWY` have been added.
- `sufpc`: The choice of the domain is unfortunately still hard coded. This should be turned into a default value and the variables have to be included in the `namfpc` namelist.
- `sufpoph` : Note there is in this branch some code in `sufpoph` that checks whether the grid points of the target domain still coincide with the grid point of the domain of the clim files (given in the original $\mathbf{C} \cup \mathbf{I}$ part of the domain).
- `sufpg1`: The initial value of the parameters `NFPMAX` and `NMFPMAX` are forced to keep their set defaults values (under the logical key `LFPBOYD`). Possible modifications of these parameters from namelist `namfpg` is therefore avoided.
- `sufpg2` : only some comments.
- `sufpd`: fullpos Boyd horizontal sub domain is initialized after the reading of the namlist `namfpd` and under the key (`LFPART2.&&.LFPBOYD`).
- `wrhfp`: The local array `ZREAL` (extracted from post-processed buffer `HFPBUF`) is then copied in a new allocatable local array `ZFRAC` on the periodic $\mathbf{C} \cup \mathbf{I} \cup \mathbf{P}$ domain. Norms computations (`fpgpnorm` routine) and packing of data (`prepacka` routine) are performed on `ZFRAC`. `openfpfa` and `newfa` routines are called in order to define file 'PX E927000+0000' with the new frame `CADRE.BOYD.#01`. The file is written out by calling `faisan` routine. `ZFRAC` is de allocated. Everything has been done under the key (`LFPBOYD`) and only with `NPROC=1`. The unit and the name the file are still hard coded.
- `openfpfa`: The key `LFPBOYD` has been used to circumvent checking between defined geometry and frame in the ALADIN file made by `echien`. This latter routine should be modified to take the Boyd geometry into account.

- **ewindow**: This is a new routine in the project **bip**, where the Boyd 'window functions' are computed (via error function 'ERF'), and then the fields which need to be biperiodicized are multiplied by these 'window functions'. It is called from **fpbipere**.
- **fpbipere**: Calling to the new routine **ewindow** is added. The scale factor **RSCAL** used in definitions of the window function is unfortunately still hard coded here.
- **fpezzone**: To avoid any changes in the biperiodic treatment of the geographical fields, physical fields and the clim files, a new logical argument **LWIND** has been added to **fpezzone**. under (**LWIND**), The boyd **fpbiperiodicized** contents of the local array **ZREAL** is copied in the global array **HFPBUF**. This is done only with **NPROC=1**.
- **fpezo2h**: **fpezzone** is called with a different assignement for the logical **LWIND** in respect with the configuration (**CDCONF**).
- **sudim2**: the mystery **NDSUR1** is unrelated to the implementation of Boyd's windowing, but it is necessary to bear it in mind. For the time being an adhoc solution consists in forcing this **NDSUR1** integer to 3,(that avoids a 'call abort' in **slcset** routine)

3.2 Namelist variables

LFPBOYD, **NFPBWX**, **NFPBWY**, and **RSCAL**. This latter should be added beforehand in **yomfpc**.

4 TODO

The following items should still be carried out. They are not necessarily listed in order of priority.

4.1 Coding

- In this case the entire **CUI** was filled by **CUPUG**. In fact, we could allow the code to fill a subdomain of **CUI**, but keep symmetric so that we have still the center of the domain. This would generate more freedom to fit the $2^p 3^q 5^r$ constraint. But the routine **EWINDOW** should be modified and changed from **ZREAL** to **ZFRAC** in **WRHFP**.
- cleaning, cleaning, cleaning , ...
- add namelist choices of **LFPBOYD**, **NFPBWX** and **NFPBWY** (domain choice is hard coded now).
- check if there are enough keys everywhere, make sure the code both runs with and without Boyd.
- remove hard coding from **sufpg1**,**sufpg2**, **sufpoph**,

- parallelize. The 07/09 CHMI work was restricted to `NPROC=1` (not bad for practice) but it should better be extended to `NPROC>1` as it might not be remembered at a later stage. Check whether `NPROC == 1` is checked.
- Analyse the problem of `NDLSUR1 = 3 - MOD(NDLON,2)`. This problem is not a problem originating from this work, but should be removed and should be studied independently from this work in order to leave more freedom in matching the decomposition constraint for the FFT.
- In this setup, we used clim files with a spline structure. It would be good to have and use clim files with a Boyd-style extension zone. Although we are not sure there is some gain in this. So create Boyd-style clim files with 923.
- Test a Boyd e927 from ARPEGE to ALADIN
- The filename `PXE9270000+0000` is still hard coded.
- introduce the $L \equiv \text{RSCAL}$ scale factor of the paper of Boyd (2005) in `yomfpc` and in the namelist.
- Check the Mercator projection.
- Our coding also works for only one subdomain. This should be checked and adapted or put under the necessary switches in case the user wants more domains together with `LFPBOYD`.

4.2 Scientifically

This should enter the dynamics ALADIN workplan.

- Perfect model tests to prove amelioration with respect to splines.
- Tuning of the width of the zones and the relaxation function.
- There is still the problem that the map factor, the orography and the Coriolis parameters are still biperiodicised with the splines (in part 2 of fullpos). This may provide some extra gain in accuracy.
- SL trajectories: **if** we can make this run with a symmetric E zone (cfr. work of Benedikt in Brussels) we may benefit from almost physical information near the boundaries in the E zone (i.e. the **P** zone) for calculating the SL trajectories. for this we should
 1. phase the work of Benedikt,
 2. start research on this.

- Study the problem of D.A. With this approach there should be in principle no problem. LAM D.A. is done on the $\mathbf{C} \cup \mathbf{I}$ zone and extended into the \mathbf{E} zone by splines. This \mathbf{E} zone should have the same dimension as the target one of the Boyd-window construction. Then the forecast is done with the spline for a forecast range 0 and from the next coupling file onward with the Boyd-window in the \mathbf{E} zone. Later research could be carried out to see if doing Data Assimilation on an extended domain could allow to have a Boyd initial file to fill up the whole \mathbf{E} zone with assimilated data. However, the expected gain will most probably be small (unless in cases of fast large-scale flow). Scientifically, it should be investigated whether the gain is large enough compared to the extra cost in the D.A..
- Tackle the problem of the \mathbf{B} matrix in DA, and the correlation passing the \mathbf{E} zone.
- The runs were tested with $\text{NEINI}=0$. Test with DFI, in particular SSDFI in case of fast propagating storms.
- Test the system with the $\mathbf{C} \cup \mathbf{P}$ entirely in $\mathbf{C} \cup \mathbf{I}$ and run with \mathbf{E} empty. Then we can test $\mathcal{R} \neq 1$ in the \mathbf{P} zone, as it was proposed by Boyd (2005).

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References

- Boyd, J. P., 2005: Limited-Area Fourier Spectral Models and Data Analysis Schemes: Windows, Fourier Extensions, Devaies Relaxation, and All That. *Mon. Wea. Rev.*, **133**, 2030–2042.