

PHASING TO CY45T1

PETRA SMOLÍKOVÁ, SEPTEMBER 2017

The branch `smolikovap_CY45_nhvfe` contains the work done in 2015-2016 on **finite elements used in vertical discretization of NH dynamics** by Jozef Vivoda (SHMI) and Petra Smolíková (CHMI). Its content may be summarized as follows:

- 1) **Two distinct definitions of finite element operators** for vertical derivative and integral differing in the choice of boundary conditions may be applied:
 - a) **Explicit definition:** the data vector is enlarged by (possibly several) boundary conditions which are built directly into the projection matrix from the grid point space to the finite element space. Hence stiff and mass matrices are overdimensioned with respect to the number of vertical levels.
 - b) **Implicit definition:** a special set of basis functions is chosen satisfying the given set of boundary conditions. These conditions have to be constant in horizontal direction and in time, we use only two kinds of them; all basis functions are 0 on the given boundary or the vertical derivative of all basis functions is 0 on the given boundary.

The choice of definition of vertical operator for integration is controlled through the namelist parameter `NVFE_INTBC`, while the choice of definition for the vertical derivative operator is controlled through `NVFE_DERBC` parameter respectively, both from `namcver/yomcver`.

Possible values are among 0,1,2,3:

`NVFE_DERBC/INTBC=0` corresponds to previous `LVFE_DERIB/INTB=F`

`NVFE_DERBC/INTBC=1` corresponds to previous `LVFE_DERIB/INTB=T`

`NVFE_DERBC/INTBC=2` implicit definitions

`NVFE_DERBC/INTBC=3` explicit definitions

- 1) **Revised definition of knots and explicit values of hybrid vertical coordinate η** on model half and full levels using minimization of a given cost function: The position of knots is based on the position of maxima of splines used for the definition of basis under the key `LVFE_MAXIMAS=.T.`, or on a Greville abscissa under the key `LVFE_MAXIMAS=.F.` The result of the new procedure is that B-spline basis of order $C-1$ has maxima of splines on the full model levels, while the B-spline basis of order C has the maxima of splines on the model half levels, where C is the namelist parameter `NVFE_ORDER` representing the order of B-splines. The minimization uses the standard `MINPACK` routine `LMDIM1`.
- 2) **The clean implementation of the key `LVFE_APPROX`** for the non-oscillatory approximation of functions based on Schoenberg VDA algorithm which provides more stable and less noisy solution than previously implemented interpolating polynomial while keeping still high order of accuracy.
- 3) **Revised definition of m^* , **A** and **B**** used for model levels definition which satisfies natural relations, see report of Jozef Vivoda, 2016. The new definition enables the whole vertical discretization to profit from properties which may lead to better accuracy and less noise production.

- 4) **Revised formulation of pressure gradient term** in horizontal and vertical momentum equation in a way that the real pressure depth is treated consistently.
- 5) With the use of revised definition of knots and model half and full levels, the choice of **invertible operators** with fixed sequence of knots has been designed under the key LVFE_FIX_ORDER=.F. which enables the usage of staggering of gw in the FE scheme, similarly as it is done for FD. The modification appears under the switch LVFE_GW_HALF.
- 6) **Design of an interface routine for the vertical integral and derivative** (VERDISINT) with the aim to choose only parameters of the desired operation when applying vertical operators and to keep details of the operator definition as the internal procedure to the interface routine: The application of vertical derivative and integral operators should become easy and without long decision trees inside. When going from cy45 to cy45_nhvfe one can not see the long decision trees and may ask why do this interface step, it is because we have introduced several variants of boundary condition definitions for vertical operators (point 1) and without this interface routine long decision trees would appear in any place where the vertical integral or derivative is applied. Routine VERDISINT is used only in routines needed to run nh vfe basic model, no ad/tl changes. Finite difference version of vertical integral/derivative could be added to the interface routine later to simplify even more vertical integral/derivative application.

DESCRIPTION OF THE BRANCH:

modules

- yomvert :
 - vector VFE_KNOT declared and allocated
 - 15 matrical operators declared and allocated (RINTBF00, RINTBFX IMPL, RDERBFX IMPL, RDDERBFX IMPL, RDERBHXX IMPL, RDERBFX, RDERBHXX, RDDERBFX, RINTGW, RDERGW)
- yomcver :
 - 1) several changes for consistency
 - we propose to remove NVSCH and use NVFE_TYPE instead; for the time being if NVSCH set in NAMCVER => NVFE_TYPE=NVSCH; safe choice for job reproducibility
 - NVFE_ORDER not read from namelist, but NVFE_ORDER=NVFE_TYPE+1
 - LVFE_ECMWF instead of LVFE_INT_ECMWF switches on old VFE (hydrostatic and old nh)
 - 2) several new keys for vfe in nh
 - NVFE_INTBC/DERBC = 0 - 4 boundary conditions choice for integral/derivative
 - NVFE_INTERNALS : number of internal knots
 - NVFE_BC = 0 or 1
 - LVFE_LAPL_TBC/BBC : separate choice of boundary conditions for vertical Laplacian
 - LVFE_LAPL2PI : simpler formula for vertical Laplacian in VFE
 - RLAPL2PI : parameter used for simpler Laplacian in VFE
 - LVFE_LAPL_HALF: Vertical Laplacian uses derivative operators full->half->full
 - LVFE_FIX_ORDER: T/F - VFE operators defined with fixed order splines/fixed knot sequence (BCs are included by changing order of splines)

- LVFE_GW_HALF : T - GW on HALF levels under key LGWADV
- LVFE_MAXIMAS : T/F - full levels at maximas of spline basis functions/full levels from Greville abscissa in variation diminishing approach
- LVFE_VERBOSE : print several diagnostics or not
- RMINDETA : minimum distance between knots; for smaller intervals knots are considered to be equal (multiple knots)
- yomgwdiag : interface routine verdisint used for vertical integral

utilities

- minvert : use minv with scaling
- verdisint : an interface routine for vertical derivative and integral

setup

- sunhbmatt : basic test of vertical laplacian
- sunhssi : remove abort for non real eigenvalues of B
- suvert : reshape centripetal definition
 - remove LVFE_VDA
 - add VFE_KNOT initialization
 - check consistency of half and full level layers
 - externalize set up of YRVAB in suvfe_adjust_ab + inside use verdisint
- suvertfeb : several changes, add implicit bc, add test of operator quality
- suvertfe : just interface to new routines
- suvfe_basis : minorities
 - suvfe_cpsplines : add PETAMAX - position of maxima of splines in eta coordinate and calculation under LVFE_MAXIMAS
- suvfe_knot : rewritten
- suvfe_matrix : add LDINT_FROM_SURF,KTYPE to header, rewritten
- suvfe_testoper : add CDEX,LDINT_FROM_SURF to header
 - remove PETA_TOP/BOT from header
 - reshape
- suv1 : add declarations and allocatios of new operators

new routines in setup

- sunh_vertfespline : after suvertfe, define old and new operators
- sunh_vertfespline_half : define new operators for half levels
- sunh_vertfespline_inv : define new invertible operators
- suvfe_implicitbc : change basis for implicit bc
- suvfe_oper_setup : set up several parameters for operators definition

adiab

- gnhdlr : use verdisint
- gnhgrdlr : use verdisint
- gnhgrgw : use verdisint
- gnhgw2svd : use verdisint

- gnhpreh : use verdisint
- gnh_tndlagadiab_gw : use verdisint
- gnh_tndlagadiab_svd : use verdisint
- gpcty : use verdisint
- gpge : use verdisint
- gpgrgeo : use verdisint
- gpgrp : use verdisint
- gpgw : use verdisint
- gppwcvfe : use verdisint
- gpxx : use verdisint
- lapineb : use verdisint
- lattes : use verdisint
- si_cccor : use verdisint
- sigma : use verdisint
- siseve : use verdisint
- situ : use verdisint

climate

- cormassdry : use verdisint

COMPATIBILITY WITH PREVIOUS CYCLE:

The CY45_main code may be run with the branch modification by using the following namelist parameters.

- **LVERTFE=F**: nothing special
- **LVERTFE=T and LNHDYN=F**:
 - set LVFE_ECMWF=T in namcver
 - set NVSCH=1 or 3, or NVFE_TYPE=1 or 3 (for the time being they do the same, but NVFE_TYPE may differ from 1 and 3) in namcver
- **LVERTFE=T and LNHDYN=T**:
 - set NVFE_TYPE = order of splines used -1 (3 for cubic)
 - Set NVFE_DERBC = 0 for previous LVFE_DERIB=F
 - Set NVFE_DERBC = 1 for previous LVFE_DERIB=T
 - set NVFE_INTBC = 0 for previous LVFE_INTB=F
 - set NVFE_INTBC = 1 for previous LVFE_INTB=T (NVFE_DERBC/INTBC = 2,3,4 allowed for research)
 - several new keys set to F (default)

TESTS DONE FOR THE PHASING:

- | | |
|--------------------------------------|----|
| 1) compare hydrostatic+novfe | OK |
| 2) compare hydrostatic+vfe+(nvsch=1) | OK |
| 3) compare hydrostatic+vfe+(nvsch=3) | OK |
| 4) compare nh+vfe+(lvfe_ ecmwf=true) | OK |

- 5) run nh+vfe+gw+(lvfe_int_ecmwf=false)+(nvsch=3)+(nvfe_derbc/intbc=0) OK
6) run nh+vfe+gw+(lvfe_int_ecmwf=false)+(nvsch=3)+(nvfe_derbc/intbc=1) OK

7) run nh+vfe+gw+(lvfe_int_ecmwf=false)+(nvsch=3)+(nvfe_derbc/intbc=2) OK2
8) run nh+vfe+gw+(lvfe_int_ecmwf=false)+(nvsch=3)+(nvfe_derbc/intbc=3) OK2
9) run nh+vfe+gw+(lvfe_int_ecmwf=false)+(nvsch=3)+(nvfe_derbc/intbc=4) OK2
10) repeat 7-10 with several choices in vfe: LVFE_DELNHPRE, LVFE_LAPL, LVFE_Z_TERM,
LVFE_GW etc. running

- OK = spectral norms are identical with corresponding choice in CY45_main for a 2D test case run for 300 steps
- OK2 = results of the experiment look reasonable, norms differ
- running = research choices checked only for running, no results compared, for time constraints