Namelist dynamic parameters for high resolution experiments.

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Since in the recent past and in the future more and more people in the LACE community are interested in higher resolution experiments, we are forced to find a list of dynamical parameters which may ensure a robust and stable forecast for these resolutions. We focus on experiments with the ALARO physics for which we do not know about previous extensive testing of dynamical choices in high resolutions.

As the first choice one may use the operational choice of Météo France which is being run in 1.3km horizontal resolution with 90 vertical levels and AROME physics since March 2015. But we may as well try to find a set of parameters which will be more consistent with our current operational choice being used in 4.7km resolution (and hence being still run in hydrostatic adjustment). The main difference would be in the setting of horizontal diffusion realized through spectral diffusion or SLHD (semi-Lagrangian horizontal diffusion). Further parameters which will be discussed are connected to PC scheme and decentering parameter VESL.

We have been running a serie of experiments in the aim to find a set of dynamic parameters for robust and stable forecast in horizontal resolutions around 1km. We use 87 vertical levels of the current Czech operational setting and 1km horizontal rezolution over the domain covering the Czech Republic with small surroundings. The studied experiment is an orographic wave created over the western mountainous boundary of the Czech Republic on 27 January 2008. The simulation for 24 hours starts at 00UTC.

There are three sets of dynamic parameters we have been varying in the experiments:

1. spectral horizontal diffusion and SLHD
2. the time scheme (including SI reference state and X-term discretization)
3. the decentering through VESL

We do not mention the default choices if they are not considered as important. The namelist parameters values kept for all the experiments (unless mentioned otherwise) are the following:

DYNAMIC PARAMETERS USED IN ALL THE EXPERIMENTS

NH dynamics	**LNHDYN=.T.**
time scheme	LTWOTL=.T. SIPR=90000. SITR=350. SITRA=100.
miscelaneous	LADVF=.T. for Coriolis term treatment
vertical discretization	LREGETA=.F. LVERTFE=.F. LVFE_REGETA=.F. **NDLNPR=1**
SL scheme	averaging of RHS along the trajectory NXLAG=3 for all X
horizontal diffusion	LSLHD_OLD=.F. REXPDH=2. RRDXTAU=123. SDRED=1. SLEVDH=0.1 SLEVDHS=1. SLHDA0=0.25 SLHDB=4. SLHDD00=6.5E-05 ZSLHDP1=1.7 ZSLHDP3=0.6 SLHDKMAX=6.
choice of prognostic variables	LSPRT=.T. NPDVAR=2 **NVDVAR=4** **LGWADV=.T.** LRDBBC=.F.

SPECIAL PARAMETERS FOR SPDIF experiments

RDAMPX=20. for X=DIV,VOR,Q,T,VD,PD,
SLHDEPSH=0.080.

SPECIAL PARAMETERS FOR SLHD experiments

RDAMPQ=0.
RDAMPT=1.
RDAMPDIV=1.
RDAMPVOR=1.
RDAMPVD=1.
RDAMPDIVS=10.
RDAMPVORS=10.
RDAMPVDS=15.
SLHDEPSH=0.016
SLHDKMIN=-0.6

Time step

To see the difference in the stability and accuracy of distinct configurations, we have used an enhanced timestep of 50s. The apropriate choice would rather be 40s, but the differences are then less pronounced. As the control experiment we use the same setting with the timestep of 20s. When stable, both AROME and ALARO settings give a very good agreement in average spectral norms over the whole domain of all prognostic variables between the forecast made with $\Delta t = 50s$ and the one made with $\Delta t = 20s$ which is a basic condition to give a consistent forecast. Nevertheless, the precipitation fields after 12 hours of integration differ in both cases and we have to conclude that the forecast quality depends on the timestep chosen. (Compare precipitation charts on Fig. 1 and Fig. 2.) Almost all tested configurations are stable for $\Delta t = 20s$.

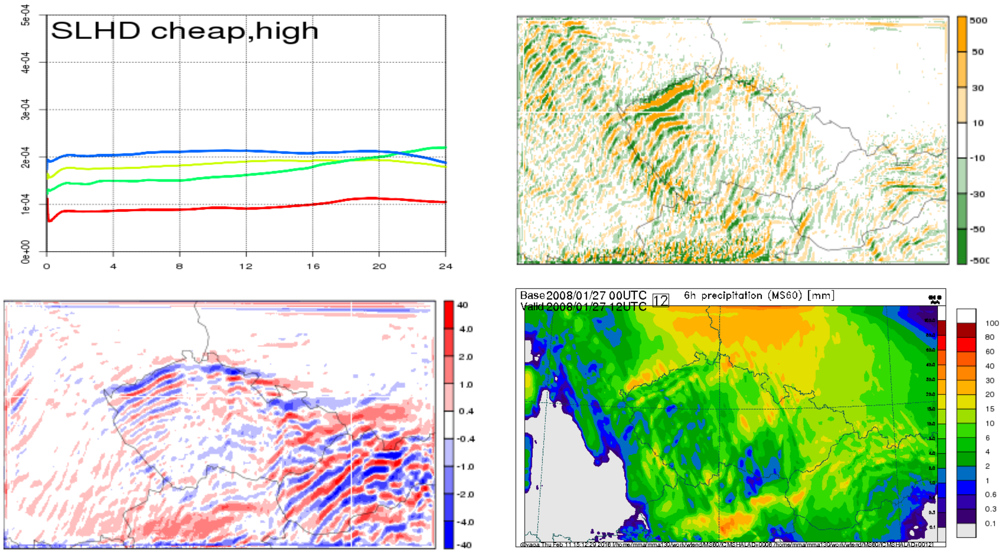

Figure 1: *Results for the experiment with SLHD setting and $\Delta t = 20s$ being considered as the control experiment. Top left: the time evolution of the average spectral norms for the whole domain; green: vorticity; blue: divergence; yellow: vertical divergence; red: pressure departure. Top right: pressure departure at the lowest (87th) vertical level at 12UTC. Bottom left: vertical velocity at 200hPa and 22UTC. Bottom right: cumulated precipitation from 06UTC to 12UTC.*

Horizontal diffusion

1) The application of SLHD instead of pure spectral diffusion on main prognostic variables (T,W,PD,VD) may be a more stable and noise-free choice - compare similar SLHD and SPDIF cases. (For example Fig. 2 left and Fig. 3 left.)

2) When applying SLHD, the recommended choice may follow the tuning found by Jan Mašek for Czech operational run at 4.7km. Main change with respect to the default SLHD settings is zero reduced spectral diffusion up to roughly 100hPa level (value SLEVDH=0.1) and second order reduced spectral diffusion above this level (value REXPDH=2.) acting with the same strength

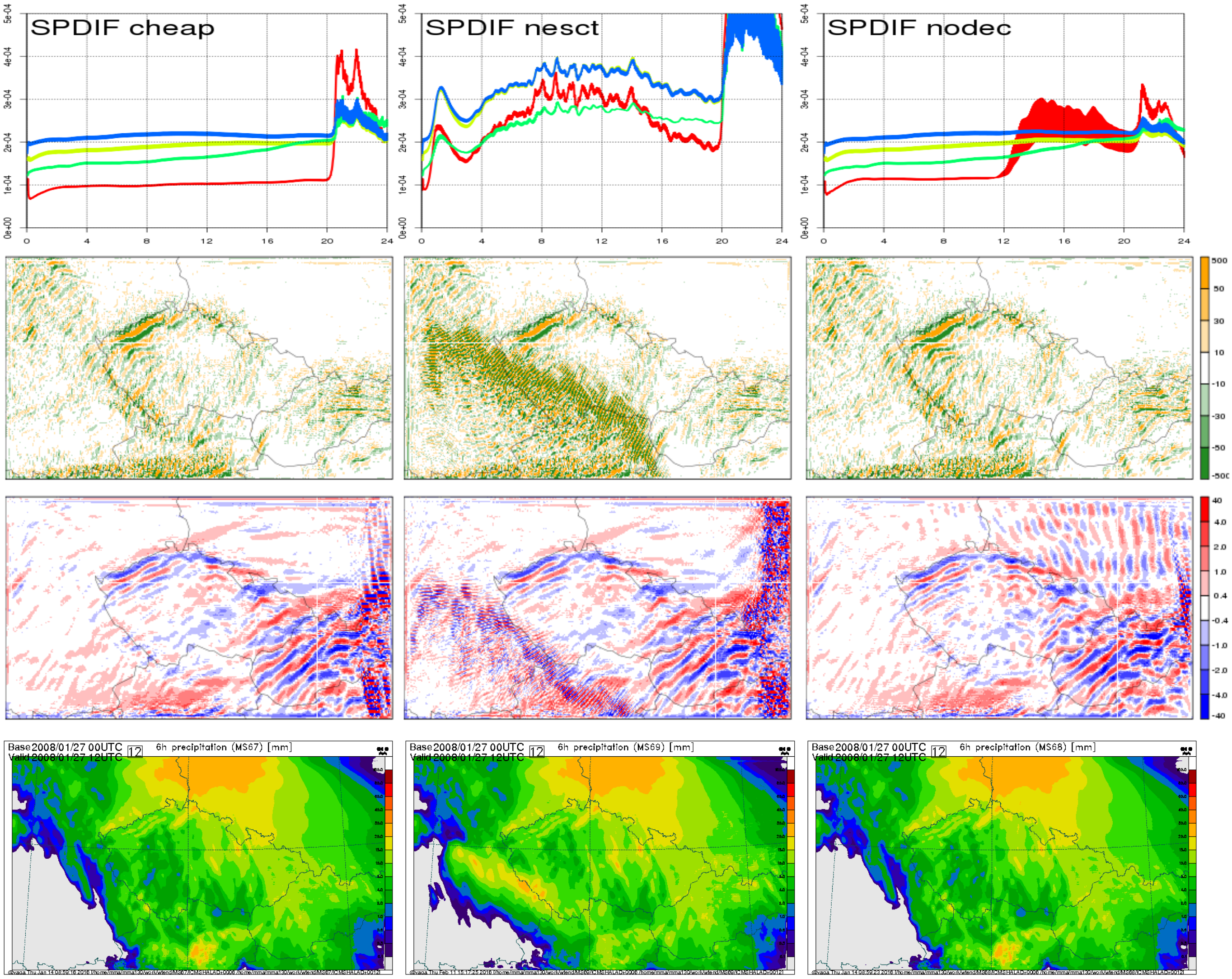

Figure 2: *The experiment with pure spectral diffusion and LPC_CHEAP=T,VESL=0.05 on the left; LPC_CHEAP=F,VESL=0.05 in the middle and LPC_CHEAP=T,VESL=0. on the right.*

on temperature, vorticity and divergence. At the same time supporting spectral diffusion acting on vorticity and divergence is weakened and equalized RDAMPDIVS=RDAMPVORS=10. It remains highly scale selective (6th order).

3) In the previous documentation of Karim Yessad to horizontal diffusion in ALADIN/AROME/ALARO [?] on page 9, it is recommended not to diffuse pressure departure variable. More recent recommendation following experiments in higher resolutions says that pressure departure should be diffused as strongly as the temperature variable. Météo France operational setting of AROME-France 1.3km follows this rule. The conclusion from our set of experiments is that not applying spectral diffusion on pressure departure may even force an integration crash or be a source of high frequency noise in the forecasted fields. Hence it is prefferable to apply spectral diffusion on pressure departure, eventually on top of SLHD applied. The application of SLHD

on pressure departure was not found to be crucial. See Fig. 3 for an illustration.

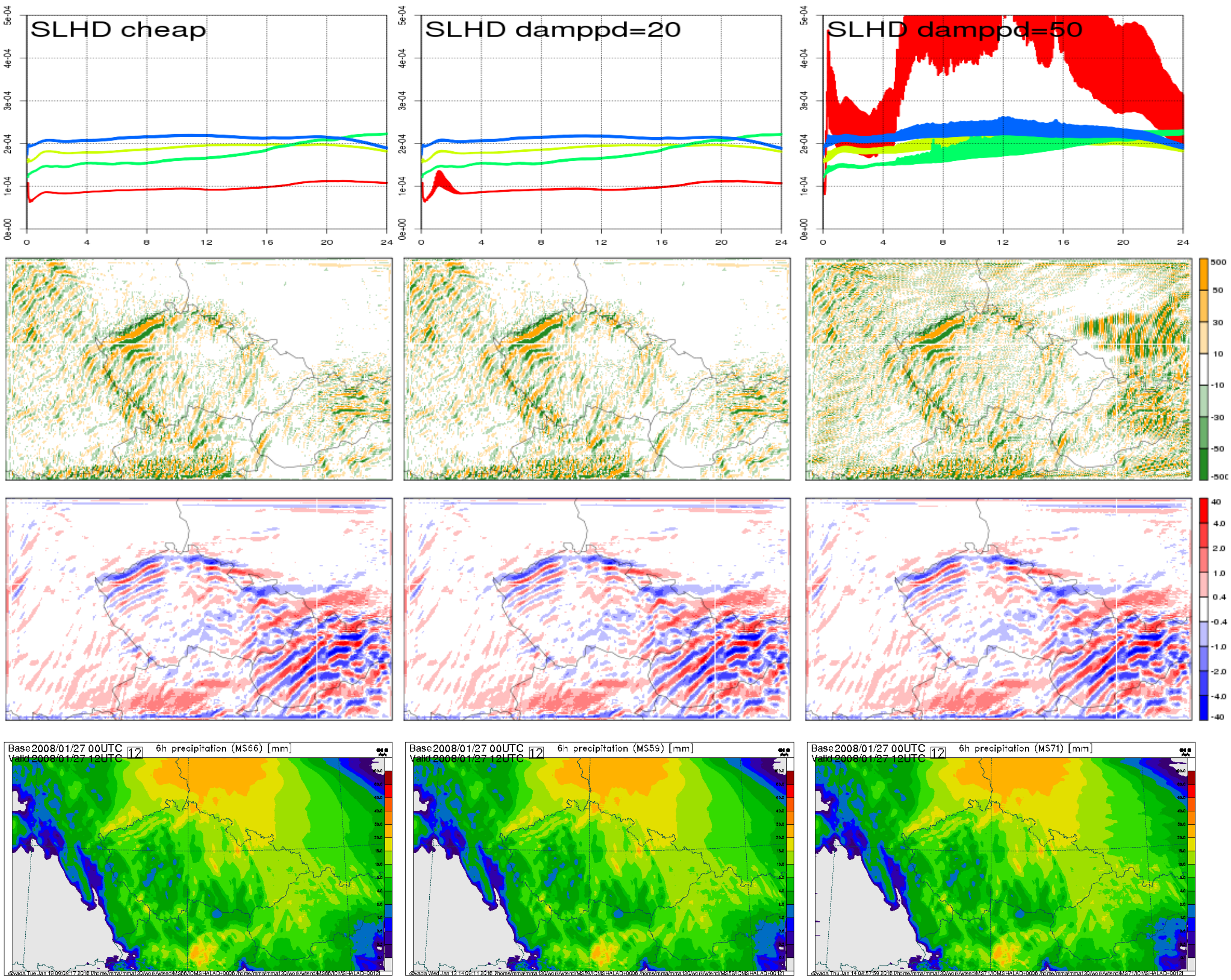

Figure 3: *The choice of RDAMPPD. SLHD experiment setting with RDAMPPD=5. on the left; RDAMPPD=20. in the middle and RDAMPPD=50. on the right.*

4) For iterative time schemes, there is a parameter LRHDI_LASTITERPC (namdyna) being set to true by default. If true, the horizontal diffusion is applied at the last corrector iteration only except if LPC_CHEAP=T when all horizontal diffusion is applied in predictor only since the whole advection is calculated in predictor only. If LRHDI_LASTITERPC=F and LPC_CHEAP=F, the horizontal diffusion is applied in all iterations (predictor and all correctors). We have found only a weak sensitivity to this inconsistency. Hence, one may stick on the default setting.

Decentering

- The decentering through VESL>0 may damp created noise but does not solve the problem. Moreover, some noise may be amplified when decentering applied (compare Fig. 2 left and right pictures, especially vertical velocity charts). On the other hand, a spurious periodical pattern may appear behind mountains when no decentering applied as on the right pictures of Fig. 2. It was not found to be needed with SLHD dynamics setting.
- Set always XIDT=0.

Time scheme

There are two basic time discretizations which appeared to be useful in ALADIN dynamics differing in the way the non-linear residual is treated, while linear terms are always processed in the semi-implicit manner by

$$Lin[X] = \frac{1}{2}\left(\mathcal{L}X_F^+ + \mathcal{L}X_O^0\right).$$

The first one, denoted NESC, is only first order accurate non-extrapolating average along SL trajectory which may be written as

$$Nonlin[X] = \frac{1}{2}\left(\mathcal{N}X_F^0 + \mathcal{N}X_O^0\right). \tag{1}$$

The second one is second order accurate extrapolation denoted SETTLS defined in [?] using

$$Nonlin[X] = \frac{1}{2}\left(\mathcal{N}X_F^0 + 2\mathcal{N}X_O^0 - \mathcal{N}X_O^-\right). \tag{2}$$

Then they are combinated in the two time level time scheme through

$$\frac{X_F^+ - X_O^0}{\Delta t} = Lin[X] + Nonlin[X].$$

Notice that when SETTLS applied the scheme ceases indeed to be two time level since X^- is involved in calculations as well.

Furthermore, an iterative process may be established by using either 2 or 1 in the predictor step and using 1 in the corrector steps. Moreover, the SL trajectory may again be recalculated to give new origin point position $O^{(i)}$ in the ith corrector step. And again, for the trajectory search, one may use either SETTLS or NESC scheme. It follows that the basic setting of the time scheme consists in the choice of seven parameters, not always independent: LPC_FULL, LPC_CHEAP, LPC_NESC, LPC_SETTLS, LPC_NESCT, LPC_SETTLST, NSITER.

Regarding computational price paid, the SETTLS scheme is the most cheap one and it is extensively used in operational installations of ALADIN/AROME/ALARO model among various services for horizontal resolutions above 3km. For higher resolutions, this simple and cheap solution may become unstable as referred to in many studies. We would like to evaluate the stability of pure SETTLS scheme in high resolution experiments. It was shown by Mariano Hortal that in some cases this instability originates in the reflection from the upper boundary. There was a proposal to apply the Davies'relaxation on the upper boundary similarly as it is applied in the

LAM model on the lateral boundaries via coupling. Hence the upper boundary levels are relaxed to LBC files being results of a run of a global model, ARPEGE in our case. The idea of upper boundary relaxation has been implemented by Mariano Hortal on the base of cycle cy38t1. We have slightly modified this implementation with the aim to introduce a new parameter NBZONZ as the width (or better "the height" in this case) of the relaxation zone in the vertical. The upper boundary relaxation is switched on by the key LUNBC=T. The relaxation coefficients have not yet been adjusted to the non-uniform spacing of the vertical levels and are calculated as for the regular spacing. Nevertheless, we have modified the relaxation coefficients and the sensitivity to this tuning was very weak.

Then we have been testing the SETTLS time scheme with distinct choices of NBZONZ parameter. Despite the fact that for the case of the orographic wave on the western Czech boundary the most unstable parts are in the higher atmosphere, to eliminate them we would have to use too big NBZONZ. It means to apply the relaxation on too wide part of the atmosphere. Moreover, for the elongated timestep of 50s, the relaxation on the upper boundary is not able to stabilize the scheme at all. For the short timestep of 20s and with the parameter NBZONZ=20 using the relaxation area of 20 levels extended aproximately above 200hPa, we got stable interpolation but still not noise free one. See Fig.4 for an illustration of the noise in the pressure departure field at the lowest vertical level. The noise appears troughout the whole vertical extent of the atmosphere and demonstrates itself in other prognosted fields as well. Nevertheless, on the kinetic energy spectra on Fig. 5 we may see that in upper levels (20th vertcal level on the left picture) there is a peak in all the experiments using the SETTLS scheme regardless of the upper boundary relaxation used, while results of the experiment with iterative time scheme (and SLHD applied) coincide with the results from the global model ARPEGE used as lateral boundary conditions. In central vertical levels (50th vertical level on the middle picture), all experiments coincide with LBC results, and near the ground (80th vertical level on the right picture), all experiments coincide but differ from LBC results.

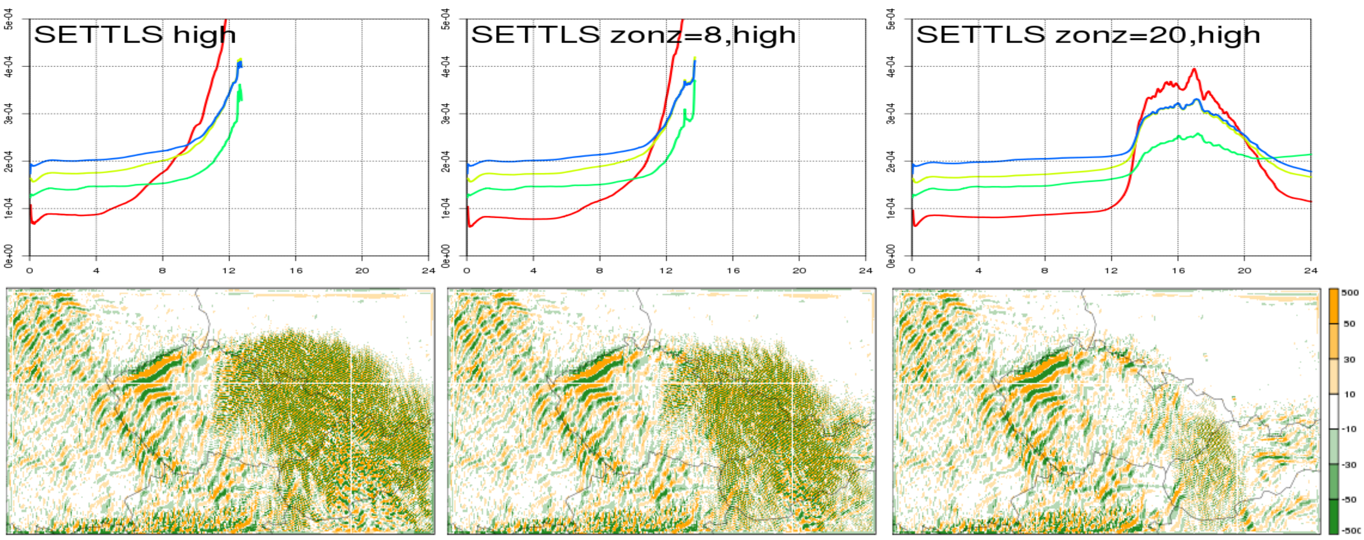

Figure 4: *The choices in SETTLS scheme with* $\Delta t = 20s$. *Left: LUNBC=F; middle: LUNBC=T, NBZONZ=8; right: LUNBC=T, NBZONZ=20.*

Hence it seems to be necessary for higher horizontal (and consequently vertical) resolutions to apply iterative time schemes (so called PC scheme). Iterative time schemes are switched on by

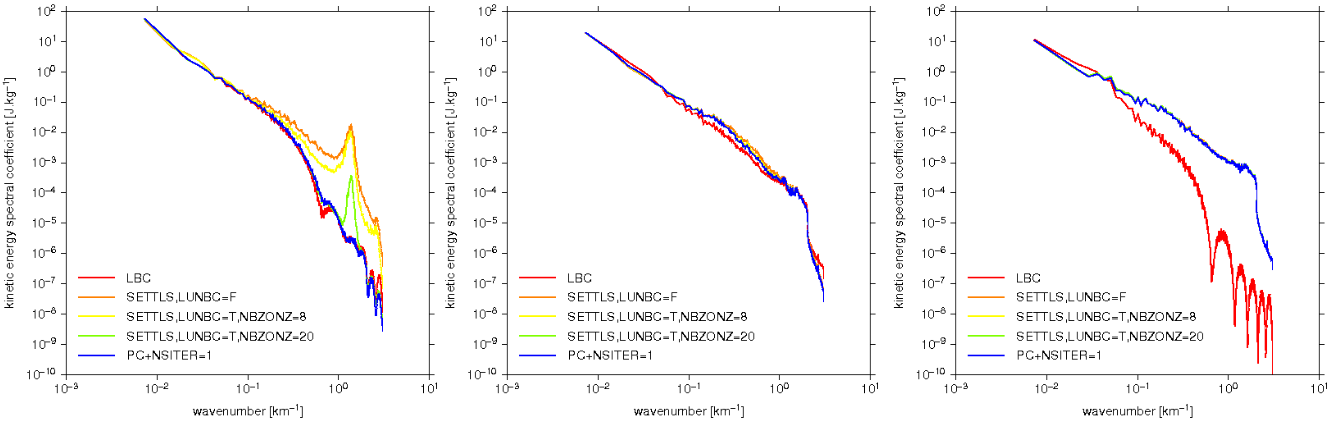

Figure 5: *The choices in SETTLS scheme with $\Delta t = 20s$ - spectrum of kinetic energy. Left: 20th vertical level (around 240hPa); middle: 50th vertical level (around 700hPa); right: 80th vertical level (around 990hPa).*

setting LPC_FULL=T and LPC_OLD=F. The number of iterations is set through NSITER>0.

For iterative time schemes, we have to chose the way of discretization in the predictor step, then in all corrector steps the NESC scheme (1) is used. Furthermore, we may decide if the SL trajectories will be recalculated in corrector steps or not, and in case of recalculation again the way in which the trajectories are recalculated may be chosed among SETTLS (2) and NESC (1). The trajectories are kept for corrector steps unchanged in case LPC_CHEAP=T.

We may conclude from the experiments serie that the SETTLS scheme may be beneficial in the trajectory calculations while the choice LPC_CHEAP=F with LPC_NESCT=T which enables to recalculate SL trajectories in the corrector steps through NESC formulae could be dangerous since serious oscillations in the prognosted fields may occur with significant influence on other prognosted fields. See left charts on Fig. 6 for the cumulated precipitation field between 6UTC and 12UTC where 40mm of spurious precipitation appear close to western boundary of the Czech Republic. These oscillations may be damped by additional iterations of the PC scheme. Moreover, these oscillations are sensitive to the choice of SITRA (higher values around 100K may help). In the presented case, NSITER=3 was needed to remove all the noise. See Fig. 6 for an illustration. Obviously, to reduce the timestep is as well going in right direction to get rid of these oscillations. Such solutions are unfortunatelly computationally expensive. For LPC_CHEAP=F and LSETTLST=T with trajectory recalculation using SETTLS and for LPC_CHEAP=T, where SL trajectories are calculated only in the predictor step by SETTLS and kept for all corrector steps, we got stable solutions. See Fig. 7 and left charts of Fig. 3 for an illustration. For trajectory calculations through SETTLS there is small noise in the pressure departure field while other results seem to be reasonable.

For the sake of completeness, we may explore the choice of iterative time schemes with SETTLS discretization used in the predictor step. The second order first guess is then iterated to get again a second order result which does not seem to be a well-designed procedure. Moreover, the inconsistency between predictor and corrector step (using NESC) is enourmous and the resulting fields are destroyed through the noise. See middle and right part of Fig. 7 differing in the way the SL trajectories are calculated. Nevertheless, even these extremely noisy calculations give results comparable to our reference (Fig. 1) for $\Delta t = 20s$.

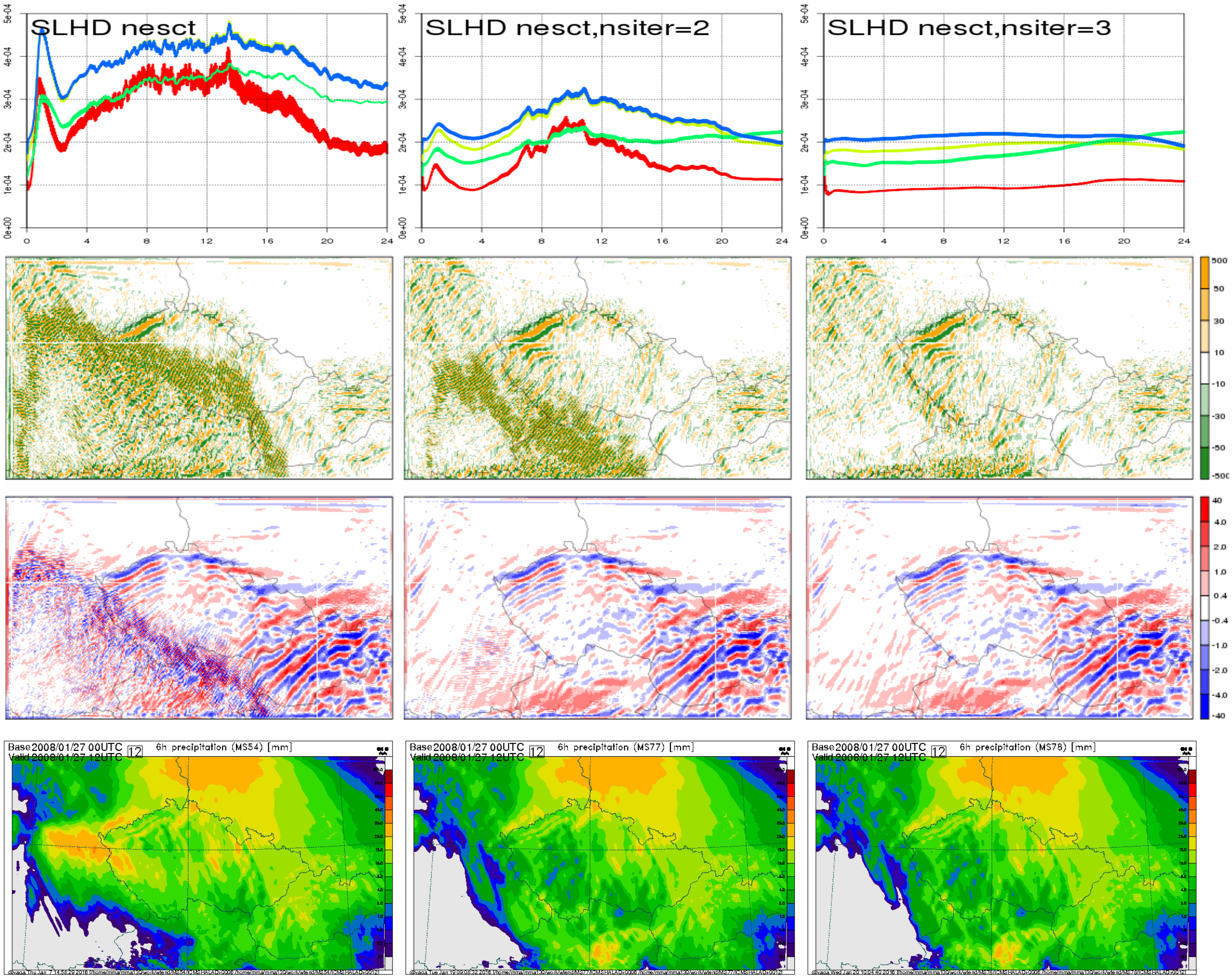

Figure 6: *The choices in iterative time scheme. SLHD experiment setting with LPC_CHEAP=F, LPC_NESCT=T and NSITER=1 on the left; NSITER=2. in the middle and NSITER=3 on the right.*

SI reference state

For the choice of the SI reference background state we have to set 3 values:

- "Warm" reference temperature SITR may be chosen as in the hydrostatic model.
- "Cold" reference temperature SITRA should range approximately between 50K and 100K. It is supposed to be lower than the real temperature in the atmosphere. Some oscillations may appear for very low values (50K).
- The reference surface pressure SIPR may be set to 90000. in most of the regions, SIPR=80000. may be needed for extremely high mountains (Himalayas).

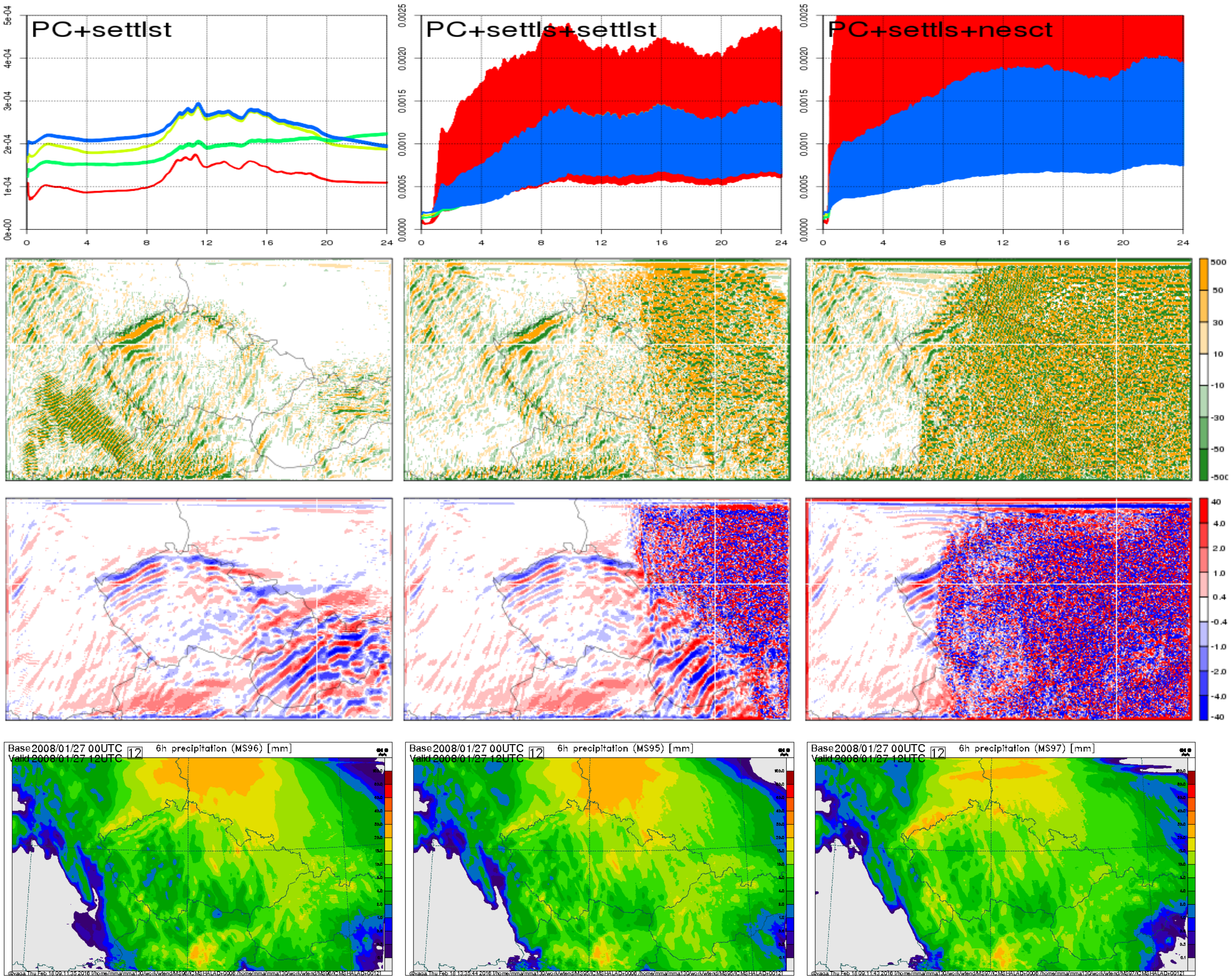

Figure 7: *The choices in iterative time scheme. SLHD experiment setting with PC scheme and NSITER=1. On the left: LPC_NESC=T, LSETTLST=T; in the middle: LSETTLS=T, LSETTLST=T; on the right: LSETTLS=T, LPC_NESCT=T. Notice 5 times enhanced scale for spectral norms of experiments with SETTLS.*

The choice of vertical velocity based prognostic variable and the X-term discretization

For experiments in higher horizontal resolutions (<2km) only vertical velocity may be used in the non-linear calculations. This choice could be done through LGWADV=T (and LRDBBC=F). The other choice of vertical divergence being used in non-linear model parts (LGWADV=F) is unstable. For linear parts, the vertical divergence including the X-term should be used through the choice of NVDVAR=4. Then for

$$d = g\frac{\partial w}{\partial \phi} + X, X = \frac{\partial \vec{V}}{\partial \phi} \cdot \nabla \phi$$

the parameter ND4SYS affects the discretization of $\frac{dX}{dt}$ which is always using only known past information and evaluated explicitely along SL trajectory. There are two possible choices of the parameter ND4SYS:

- ND4SYS=1: default choice which works well in all cycles. May become unstable for high resolutions (below 2km) as reported by Karim Yessad from Météo France.
- ND4SYS=2: more stable choice, but does not work properly in cy38t1 with LPC_CHEAP=T. It may be used in higher cycles. In our experiments, it does not perform better than ND4SYS=1 for noisy LPC_CHEAP=F,LPC_NESCT=T variant. See Fig. 8 for details.

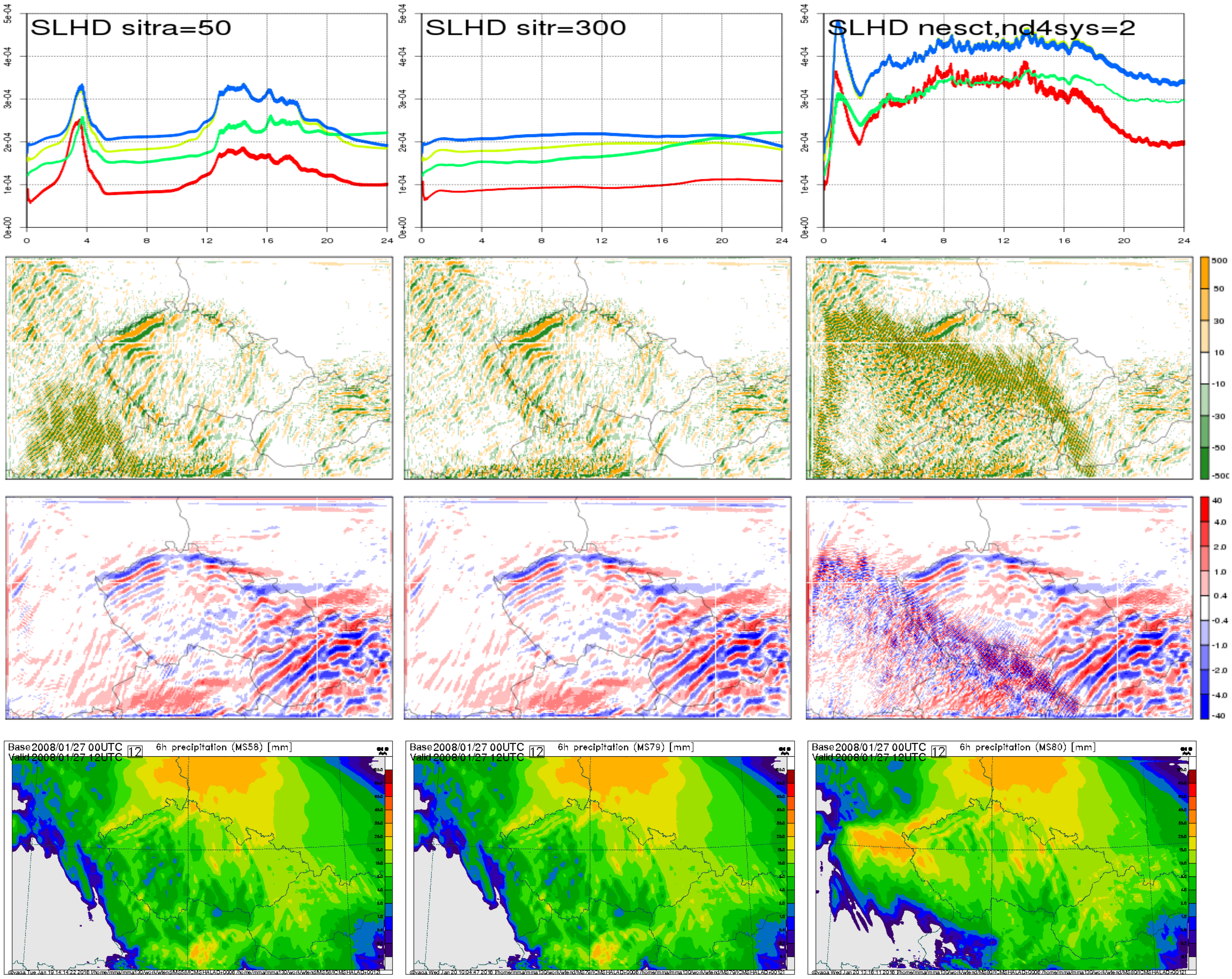

Figure 8: *SI reference state choices and X term discretization.*

Namelist setting

As the conclusion we give a dynamic part namelist for high resolution experiments with the ALARO physics which may be a good candidate for a robust and noise-free results. Unfortunatelly, the dynamic parameters are subject of a continuous shifting between particular namelists in order to finally have a more consistent namelists structure. Hence, the following holds up to cy38t1 only and several parameters appear elsewhere in more recent cycles.

```
&NAMCT0
LECMWF=.F.,
LELAM=.T.,
LRPLANE=.T.,
LNHDYN=.T.,
LSLAG=.T.,
LVERTFE=.F.,
LTWOTL=.T.,
LPC_FULL=T.,
LPC_NESC=T.,
LPC_NESCT=.F.,
LPC_CHEAP=.T.,
LREGETA=.F.,
LVFE_REGETA=.F.,
LSPRT=.T.,

&NAMDYN
LSETTLS=.F.,
LSETTLST=.T.,
NDLNPR=1,
NSITER=1,
REPS1=0.,
REPS2=0.,
REPSM1=0.,
REPSM2=0.,
REPSP1=0.,
LADVF=.T.,
LQMHT=.F.,
LQMHW=.F.,
LQMP=.F.,
NTLAG=3,
NVLAG=3,
NWLAG=3,
NSVDLAG=3,
NSPDLAG=3,
RDAMPDIV=1.,
RDAMPDIVS=10.,
RDAMPQ=0.,
RDAMPT=1.,
RDAMPVOR=1.,
RDAMPVORS=10.,
RDAMPPD=5.,
RDAMPVD=1.,
RDAMPVDS=15.,
REXPDH=2.,
RRDXTAU=123.,
SDRED=1.,
SIPR=90000.,
SITR=350.,
SITRA=100.,
SLEVDH=0.1,
SLEVDHS=1.,
SLHDA0=0.25,
SLHDB=4.,
SLHDD00=6.5E-05,
ZSLHDP1=1.7,
ZSLHDP3=0.6,
VESL=0.0,
XIDT=0.0,

&NAMDYNA
LGWADV=.T.,
LRDBBC=.F.,
NPDVAR=2,
NVDVAR=4,
LSLHD_OLD=.F.,
LSLHD_T=.T.,
LSLHD_W=.T.,
LSLHD_SPD=.T.,
LSLHD_SVD=.T.,
SLHDEPSH=0.016,
SLHDEPSV=0.,
SLHDKMAX=6.,
SLHDKMIN=-0.6,

&NAMGFL
YI_NL%LADV=.T.,
YI_NL%LQM=.F.,
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YI_NL%LQMH=.F.,
YI_NL%LSLHD=.T.,
YL_NL%LADV=.T.,
YL_NL%LGP=.T.,
YL_NL%LQM=.F.,
YL_NL%LQMH=.F.,
YL_NL%LSLHD=.T.,
YQ_NL%LADV=.T.,
YQ_NL%LQM=.F.,
YQ_NL%LQMH=.F.,
YQ_NL%LSLHD=.T.,
YR_NL%LADV=.T.,
YR_NL%LQM=.F.,
YR_NL%LQMH=.F.,
YR_NL%LSLHD=.F.,
YS_NL%LADV=.T.,
YS_NL%LQM=.F.,
YS_NL%LQMH=.F.,
YS_NL%LSLHD=.F.,
YTKE_NL%LADV=.T.,
YTKE_NL%LQM=.F.,
YTKE_NL%LQMH=.F.,
YTKE_NL%LSLHD=.T.,

Appendix

Experiments names and settings:

EXP	NAME	SLHD on GMV	SLHD on GFL	RDAMPPD	PC,PRED, CHEAP,TRAJ	VESL	TSTEP
MS61	SPDIF cheap,high	-	I,L,S,R	20.	T,NESC, T,SETTLST	0.05	20.
MS67	SPDIF cheap	-	I,L,S,R	20.	T,NESC, T,SETTLST	0.05	50.
MS69	SPDIF nesct	-	I,L,S,R	20.	T,NESC, F,NESCT	0.05	50.
MS68	SPDIF nodec	-	I,L,S,R	20.	T,NESC, T,SETTLST	0.	50.
SS26	SETTLS high	T,W,VD	I,L,Q,TKE	5.	F	0.	20.
TB26	SETTLS zonz=8, high	T,W,VD	I,L,Q,TKE	5.	F UPC NBZONZ=8	0.	20.
TB25	SETTLS zonz=20, high	T,W,VD	I,L,Q,TKE	5.	F UPC NBZONZ=20	0.	20.
TB24	SETTLS zonz=30, high	T,W,VD	I,L,Q,TKE	5.	F UPC NBZONZ=30	0.	20.
SS66	SETTLS	T,W,VD	I,L,Q,TKE	5.	F	0.	50. CRASH
TB76	SETTLS zonz=8	T,W,VD	I,L,Q,TKE	5.	F UPC NBZONZ=8	0.	50. CRASH
TB75	SETTLS zonz=20	T,W,VD	I,L,Q,TKE	5.	F UPC NBZONZ=20	0.	50. CRASH

EXP	NAME	SLHD on GMV	SLHD on GFL	RDAMPPD	PC,PRED, CHEAP,TRAJ	VESL	TSTEP
MS60	SLHD cheap,high	T,W,VD	I,L,Q,TKE	5.	T,NESC, T,SETTLST	0.	20.
MS64	SLHD nesct,high	T,W,VD	I,L,Q,TKE	5.	T,NESC, F,NESCT	0.	20.
MS66	SLHD cheap	T,W,PD,VD	I,L,Q,TKE	5.	T,NESC, T,SETTLST	0.	50.
MS53	SLHD nopd	T,W,VD	I,L,Q,TKE	5.	T,NESC, T,SETTLST	0.	50.
MS54	SLHD nesct	T,W,VD	I,L,Q,TKE	5.	T,NESC, F,NESCT	0.	50.
MS77	SLHD nesct, nsiter=2	T,W,VD	I,L,Q,TKE	5.	T,NESC, F,NESCT NSITER=2	0.	50.
MS78	SLHD nesct, nsiter=3	T,W,VD	I,L,Q,TKE	5.	T,NESC, F,NESCT NSITER=3	0.	50.
MS80	SLHD nesct, nd4sys=2	T,W,VD	I,L,Q,TKE	5.	T,NESC, F,NESCT	0.	50.
MS58	SLHD sitra=50	T,W,VD	I,L,Q,TKE	5.	T,NESC, T,SETTLST	0.	50.
MS79	SLHD sitr=300	T,W,VD	I,L,Q,TKE	5.	T,NESC, T,SETTLST	0.	50.
MS59	SLHD damppd=20	T,W,VD	I,L,Q,TKE	20.	T,NESC, T,SETTLST	0.	50.
MS71	SLHD damppd=50	T,W,VD	I,L,Q,TKE	50.	T,NESC, T,SETTLST	0.	50.
MS52	SLHD damppd=0	T,W,VD	I,L,Q,TKE	0.	T,NESC, T,SETTLST	0.	50. CRASH
MS96	PC+settlst	T,W,VD	I,L,Q,TKE	5.	T,NESC, F,SETTLST	0.	50.
MS95	PC+settls+settlst	T,W,VD	I,L,Q,TKE	5.	T,SETTLS, F,SETTLST	0.	50.
MS97	PC+settls+nesct	T,W,VD	I,L,Q,TKE	5.	T,SETTLS, F,NESCT	0.	50.
MS94	PC+settls+ settlst,high	T,W,VD	I,L,Q,TKE	5.	T,SETTLS, F,SETTLST	0.	20.