WW3 Tutorial 4.3: Garden Sprinkler Effect

Purpose

In this tutorial exercise we will reproduce and alleviate the Garden Sprinkle Effect (GSE), as first addressed by Booij and Holthuijsen (1987). We will focus on first and third order propagation schemes, and on removing the effects by grid rotation (first order scheme), or with adding diffusion terms (Booij and Holthuijsen, 1987) or averaging (Tolman, 2002).

Input files

The test case used here is a version of a standard WW3 test case (formerly `ww3_tp2.3`). Files needed to be able to run these tests are found in the directory `day_4/tutorial_GSE`.

```
switch              (switch file)
clean.sh            (auxiliary scripts)
run_it.sh
ww3_grid.inp        (input files)
ww3_strt.inp
ww3_shel.inp
ww3_outf.inp
gx_outf.inp
cbarn.gs            (GrADS scripts)
colorset.gs
map2_3.gs
figs                (directory with example graphics)
```

The test case; GSE and exact solutions

The case we will use here is the old test `ww3_tp2.3`, representing deep-water propagation in a simple two-dimensional grid without any source terms. For this test, the model is compiled without source terms, and with a propagation scheme of choice. The corresponding `switch` file is in the data directory, and needs to be copied to the WW3 work directory, after which the model needs to be re-compiled.

```
cd ~/day_4/tutorial_GSE
cp switch ~/wwatch3/work
w3_make
```

We will start off with the third order propagation scheme, identified in the switch file with the PR2 switch

```
F90 NOGRB LRB4 SHRD NOPA PR2 FLX0 LN0 ST0 NL0 BT0 DB0 TR0 BS0 XX0
WNX1 WNT1 CRX1 CRT1 O0 O1 O2 O3 O4 O5 O6 O7 O11 O14
```

Common wave models have relatively course spectral resolutions, typically 10% in frequency, and 15° (24 directions) in directions. In the model setup used here initially, this can be seen in the input file `ww3_grid.inp`:

```
$ WAVEWATCH III Grid preprocessor input file
$ ----------------------------------------
  'GARDEN SPRINKLER EFFECT TESTS '
$
$  1.0488088  0.04665  29 144  0.
   1.1  0.04665  15  24  0.
$  1.1  0.04665  15  24  0.5
$
   F T T F F F
  3600.  3600.  3600.  3600.
. . .
```

With these settings, and an accurate propagation scheme like the ULTMATE QUICKEST (Leonard, 1979, 1991), the Garden Sprinkler effect occurs, and will be reproduced here first. We will consider a rectangular basin with swell with a mean period of 10s with directional and frequency spreading propagating for 6 days. The grid is defined in `ww3_grid.inp` and the initial conditions are set in `ww3_strt.inp`.

```
$ WAVEWATCH III Initial conditions input file
$ -----------------------------------------
  1
   0.1  0.010 240.   2  0.E3  150.E3     0.E3  150.E3  2.5
```

The peak swell period as defined above is 0.1, with a spread of 0.01, the mean direction of 240° with a cos^2 type directional distribution, and spatial distributions have a spread of 150km around the location (0,0), with a maximum swell height of H_s = 2.5m (see manual or example input file for full explanation of input file). The model is set up and run by executing

```
ww3_grid
ww3_strt
ww3_shel
```

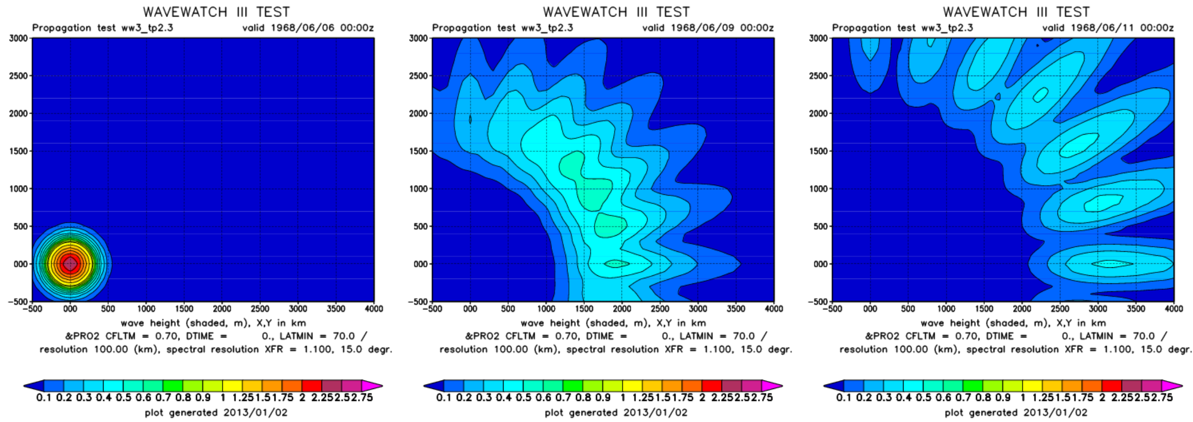
Output for this case can then be generated by

```
ww3_outf                          (test output only)
gx_outf                           (graphics ouput)
grads -pc "run map2_3"
```

As before, the entire test has been captured in a run time script, and a clean up script has been provided.

```
run_it.sh
clean.sh
```

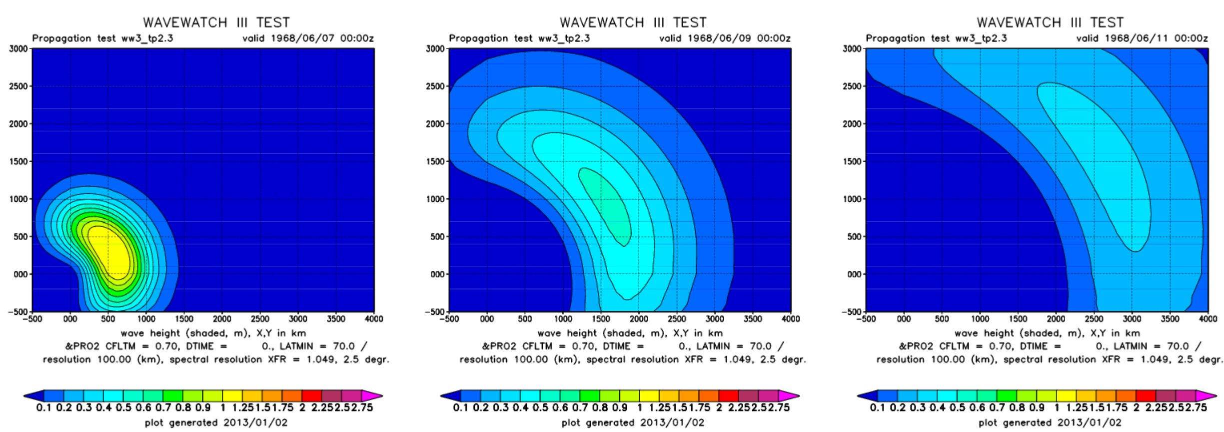
The resulting wave heights are presented below, for initial conditions, and after 2 and 4 days



As the waves propagate, they disintegrate in discrete swell fields, particularly with respect to wave propagation directions: the seven discrete wave fields on the right line up with discrete spectral directions originating at the swell location in the initial conditions at the left. As the GSE originates from a discrete spectral resolution that is too course, a more `exact' solution is easily obtained by increasing the spectral resolution. This can be achieved by editing the input file ww3_grid.inp as follows

```
$ WAVEWATCH III Grid preprocessor input file
$ ------------------------------------------
  'GARDEN SPRINKLER EFFECT TESTS '
$
   1.0488088  0.04665  29 144  0.
$  1.1  0.04665  15  24  0.
$  1.1  0.04665  15  24  0.5
$
   F  T  T  F  F  F
  3600.  3600.  3600.  3600.
. . .
```

which increases the directional resolution to 2.5° (144 directions), and halves the frequency increment (just under 5%). After this edit, the entire test can be re-run by executing `run_it.sh`, with the following results after 1, 3, and 5 days.



These results show a continuous dispersion of a swell field, which is obviously much more realistic than the discontinuous field obtained with the 'standard' spectral discretization.

GSE with a first order scheme

One way in which the GSE is "solved" is by using a highly diffusive propagation scheme, like a first order scheme. To test that concept, recompile the model with the PR1 switch (edit copy of switch file in `~/wwatch3/bin` or `~/wwatch3/work` directory)

```
F90 NOGRB LRB4 SHRD NOPA PR1 FLX0 LN0 ST0 NL0 BT0 DB0 TR0 BS0 XX0
WNX1 WNT1 CRX1 CRT1 O0 O1 O2 O3 O4 O5 O6 O7 O11 O14
```

Make sure you do *not* make this change in the tutorial directory, and then execute

```
w3_make
```

from virtually anywhere. Then go back to the tutorial directory

```
cd ~/day_4/tutorial_GSE
```

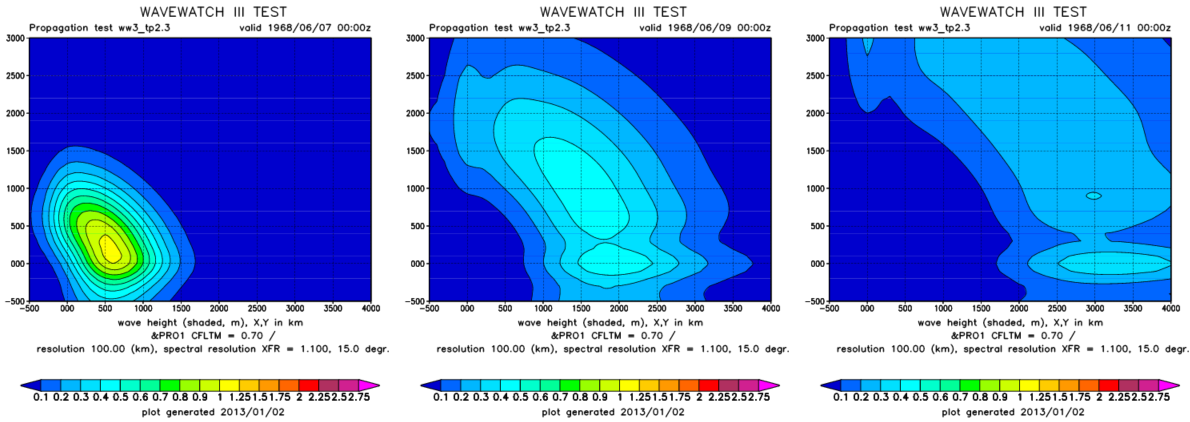
and reset the grid input file to its original state

```
$ WAVEWATCH III Grid preprocessor input file
$ ------------------------------------------
  'GARDEN SPRINKLER EFFECT TESTS '
$
$  1.0488088  0.04665  29 144  0.
   1.1  0.04665  15  24  0.
$  1.1  0.04665  15  24  0.5
$
   F T T F F F
  3600.  3600.  3600.  3600.
. . .
```

With this the test can be re-run by executing

```
clean.sh
run_it.sh
```

and the following results are obtained after 1, 3 and 5 days of model integration



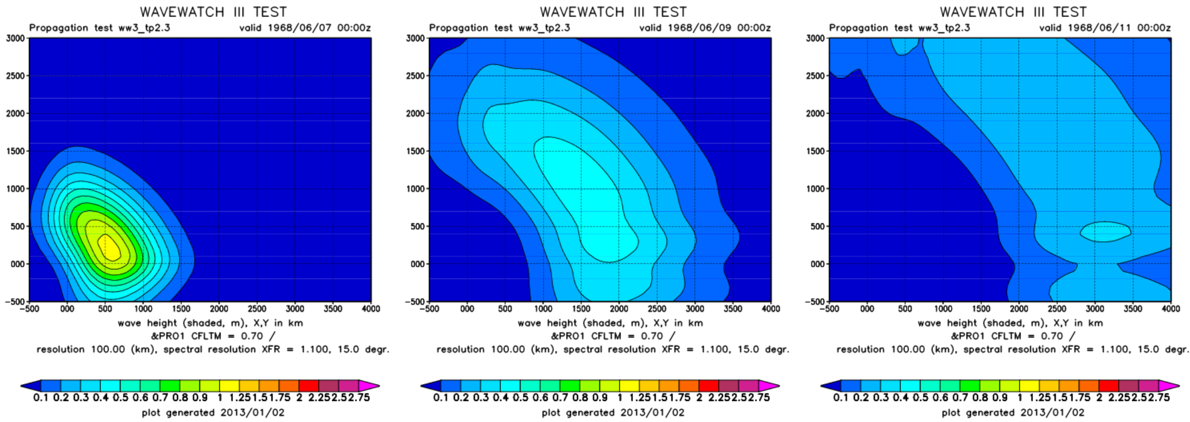
Clearly, the GSE is somewhat alleviated, but a spurious wave field still propagates along the horizontal grid lines from the origin of the swell field. Moreover, compared to the exact solution above, the wave field is clearly over-diffused by the first order scheme. The spurious concentration of wave energy traveling to the right can be suppressed by assuring that the spectral directions do not line up with the spatial grid directions. This is achieved by editing the grid input file as follows

```
$ WAVEWATCH III Grid preprocessor input file
$ ------------------------------------------
  'GARDEN SPRINKLER EFFECT TESTS '
$
$  1.0488088  0.04665  29 144  0.
$  1.1  0.04665  15  24  0.
   1.1  0.04665  15  24  0.5
$
   F T T F F F
  3600.  3600.  3600.  3600.
. . .
```

The last input variable on the activated line now rotates the first discrete direction by half the directional increment. With this the test can be re-run by executing

```
clean.sh
run_it.sh
```

and the following results are obtained after 1,3 and 5 days of model integration



The spurious wave field traveling directly to the right is now replaced by a smaller but still spurious gap in wave height in this direction, and, not surprisingly, the rotation does not influence the general diffusion characteristics of the solution.

GSE with the UQ scheme, adding diffusion

After this detour to the first order scheme, we will go back to the third order UQ scheme. This requires us to recompile the model with the PR2 switch

```
F90 NOGRB LRB4 SHRD NOPA PR2 FLX0 LN0 ST0 NL0 BT0 DB0 TR0 BS0 XX0
WNX1 WNT1 CRX1 CRT1 O0 O1 O2 O3 O4 O5 O6 O7 O11 O14
```

Make sure again that you make this change in the `work` or `bin` directory, and then execute

```
w3_make
```

Then go back to the tutorial directory

```
cd ~/day_4/tutorial_GSE
```

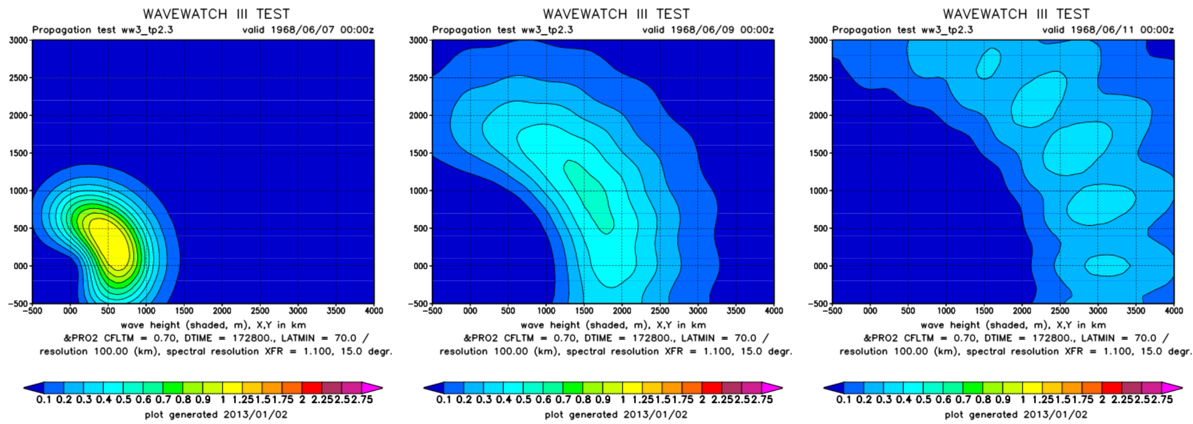
and reset the grid input file to its original state

```
$ WAVEWATCH III Grid preprocessor input file
$ ------------------------------------------
  'GARDEN SPRINKLER EFFECT TESTS '
$
$  1.0488088  0.04665  29 144  0.
   1.1  0.04665  15  24  0.
$  1.1  0.04665  15  24  0.5
$
   F T T F F F
  3600.  3600.  3600.  3600.
. . .
```

This will reproduce the original GSE results as produced at the start of this tutorial. The PR2 switch gives access to the additional diffusion terms introduced by Booij and Holthuijsen (1987, see their publication or the manual), which is controlled by a representative swell age. In the previous test runs, the swell age was set to 0, switching off the diffusion term. We will now run the model with a representative swell age of 2 days (172800s), which is done by editing the grid input file as follows

```
$
$ &PRO2 DTIME= 0. /
  &PRO2 DTIME=172800. /
$ &PRO2 DTIME=345600. /
  &PRO3 WDTHTH=0.00, WDTHCG=0.00 /
```

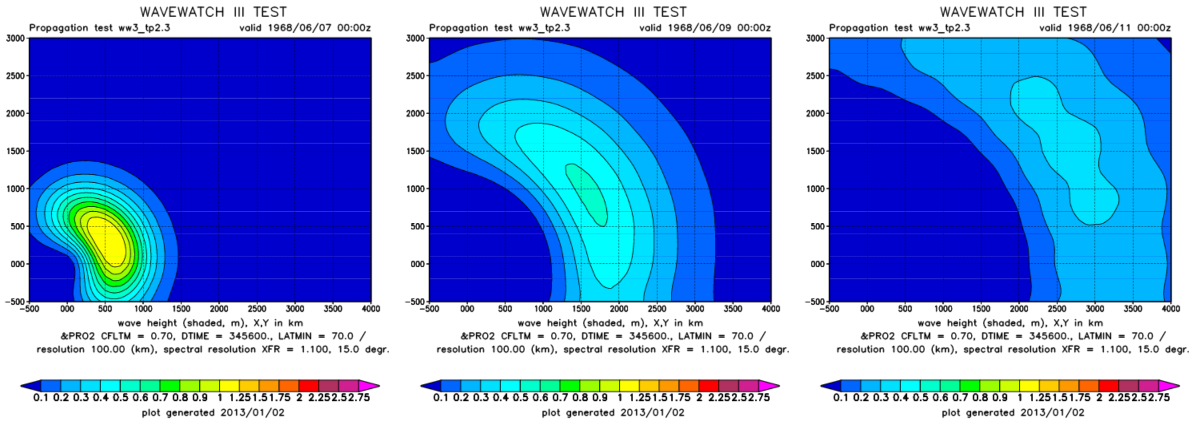
Re-running the test case by executing `run_it.sh` then gives the following results after 1,3 and 5 days of model integration



Compared to the original GSE results and the 'exact' solutions presented above, the wave field after 3 days is much improved. After 5 days, however, the GSE is somewhat alleviated, but still clearly recognizable. This is not surprising, as the representative swell age of 2 days is significantly smaller than the model run time of 5 days. Choosing a representative swell age of 4 days, by editing the grid file

```
$
$ &PRO2 DTIME= 0. /
$ &PRO2 DTIME=172800. /
  &PRO2 DTIME=345600. /
  &PRO3 WDTHTH=0.00, WDTHCG=0.00 /
```

Re-running the test case by executing `run_it.sh` gives the following results after 1,3 and 5 days of model integration, effectively removing the effects of the GSE, with no serious over-diffusion early in the model run.



Clearly, this approach is effective in alleviating the GSE, but requires a reasonable estimate of the representative swell age, representative for the actual wave conditions considered. Hence, this is at best an alleviation, and not a full solution.

GSE with the UQ scheme, adding averaging

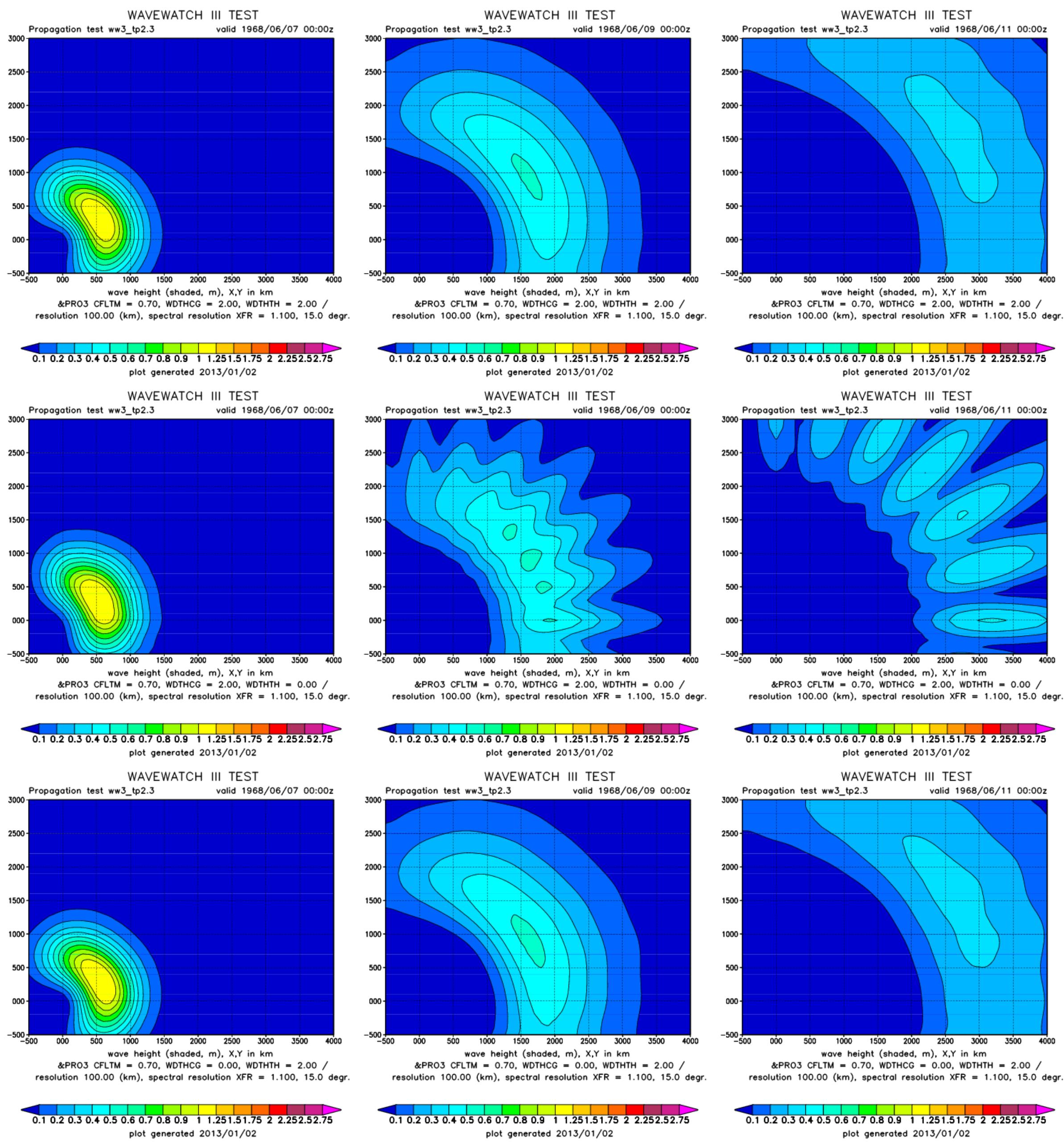
Finally, the diffusion term of Booij and Holthuijen can be replaced by the averaging of Tolman (2002), which is significantly cheaper, and has no propagation stability issues associated with it (see latter paper). This requires us to recompile the model with the PR3 switch

```
F90 NOGRB LRB4 SHRD NOPA PR3 FLX0 LN0 ST0 NL0 BT0 DB0 TR0 BS0 XX0
WNX1 WNT1 CRX1 CRT1 O0 O1 O2 O3 O4 O5 O6 O7 O11 O14
```

as outlined in several places above. With the original namelist setting of the `ww3_grid.inp` file

```
$ &PRO2 DTIME=172800. /
$ &PRO2 DTIME=345600. /
  &PRO3 WDTHTH=0.00, WDTHCG=0.00 /
$ &PRO3 WDTHTH=0.75, WDTHCG=0.75 /
$ &PRO3 WDTHTH=1.50, WDTHCG=1.50 /
$ &PRO3 WDTHTH=2.00, WDTHCG=2.00 /
$ &PRO3 WDTHTH=0.00, WDTHCG=2.00 /
$ &PRO3 WDTHTH=2.00, WDTHCG=0.00 /
$
```

this reproduces the full GSE (relative width of averaging areas set to 0), as can easily be verified by executing run_it.sh (graphs not reproduced here). Setting the averaging to strong, (activating blue line above), in propagation direction only (green line above), or in transfer direction only (activate red line above) results in wave fields after 1, 3 and 5 days for the three sets of three plots produced below.



The strong averaging in total (top figures) or in perpendicular to the propagation direction (bottom lines) reproduced mostly the results of Booij and Holthuijsen (1987). The methods are compatible and the swell age and averaging widths can be converted into each other as has been shown in Chawla and Tolman (2008). Thus the averaging has similar limitations as the diffusion term, and represents alleviation rather than a solution. The middle line of the graphs shows that the GSE is not affected by averaging in the propagation direction, and hence, is mostly a result of poor directional resolution in the spectrum. Moreover, it is sensitive to grid scales as was shown in the powerpoint presentation of this morning.

This tutorial is finished by trying the additional options for PR3 that are now commented out in `ww3_grid.inp`, by editing this file and subsequently running the test and producing the graphics (`run_it.sh`).

Additional suggestions and comments

Some additional experiments that can be done with this tutorial could be:

- Use the rotated spectral grid options as used for the first order scheme in conjunction with the third order scheme (PR2 and PR3 switches).
- Wave periods are typically more sensitive to the GSE than the wave heights, Modify the GrADS script to produce wave period plots.

GSE is also sensitive to how well the wind field is resolved by the spatial grid. This is obvious in the hurricane case presented in the presentation this morning. The hurricane regression test can also easily be expanded to do GSE alleviation experiments. See Tolman and Alves (2005) for GSE alleviation in connection with moving grids.

Additional GSE alleviation methods based on divergent propagation have been suggested in Tolman (2002), and were included in model version 2.22. They are intended for re-introduction in future versions of the model, if propagation divergence can be associate to the local spectral shape, or possibly to spectral partitioning and space-time tracking of wave fields.

References

Booij, N and L. H. Holthuijsen, 1987: Propagation of ocean waves in discrete spectral wave models. *J. Comput. Phys.*, **68**, 307-326.

Chawla, A, and H. L. Tolman, 2008: Obstruction grids for wave models. *Ocean Modelling*, **22**, 12-25.

Leonard, B. P., 1979: A stable and accurate convective modelling procedure based on quadratic upstream interpolation, *Comput. Methods Appl. Mech. Engng*. ,**18**, 59-98.

Leonard, B. P., 1991: The ULTIMATE conservative difference scheme applied to unsteady one-dimensional advection, *Comput. Methods Appl. Mech. Engng*. ,**88**, 17-74.

Tolman, H. L. 2002: Alleviating the Garden Sprinkler Effect in wind wave models, *Ocean Mod.*, **4**, 269-289.

Tolman, H. L. and J. H. G. M. Alves, 2005: Numerical modeling of wind waves generated by tropical cyclones using moving grids, *Ocean Modelling*, **9**, 305-323.

The manual

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