TUGOm Tidal ToolBox

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Contents

Acronyms

IHO International Hydrographic Organization
TTB Tidal ToolBox
SSH Sea Surface Height

1 Tidal waves

1.1 Naming conventions

The Tidal ToolBox (TTB) follows the Darwin convention, described in Schureman (1940, §74-79). It takes its list of waves from Schureman (1940, Tab. 2). The Darwin spectrum needs a 1 year analysis to be complete.

There is also the Doodson convention. A list of waves with their Doodson number is available from the International Hydrographic Organization (IHO) at `http://www.iho.int/mtg_docs/com_wg/IHOTC/IHOTC_Misc/TWLWG_Constituent_list.pdf`. The Doodson spectrum needs an 18 year analysis to be complete.

[More on Doodson numbers]

1.2 Types of waves

One would say there are 3 types of waves.

Astronomic waves are generated by the gravitational attraction of the Moon and the Sun. They have a non-zero astronomic potential. [More on astronomic potential] The biggest ones are : M2 K1 S2 O1 P1 N2 Mf K2 Mm Q1 Ssa, but there are 38 registered by the TTB. See the waves with a non-zero astronomic potential in listing 2.

Radiational waves are generated by a cyclic geophysic phenomenom other than gravitational. For example, the Sun heats the ocean and the atmosphere, in particular the mesosphere, causing pressure variations at the sea level. This generates a strong S1, but also a lot of S2! One would consider the main radiational wave to be ... the mean level Z0, which is not really a wave, but is registered by the TTB.

Non-linear waves are generated by the non-linear interaction of a couple of waves when they propagate together over small depths or high friction areas. A couple generates two other waves, whose frequencies are the sum and the subtraction of the originating waves. This mean a wave can have some regenerated components from the waves it has non-linearly produced, meaning **all waves have a non-linear component!** The stronger the product of the amplitude of the originating waves, the stronger the amplitude of the generated waves, although the generated part of the waves will be weaker than originating waves.

See the following horrifying examples. **A wave belonging to all three types is S2, which is strongly astronomic, quite strongly radiational, and is the non-linear combination of, of course, S1+S1 and S3-S1, but also K1+P1 ! The other horrifying combinations of astronomic waves contributing to a third astronomic frequency are K1+O1=M2 and M1+O1=N2. The subtractions are also of course true : K1=S2-P1, etc... This means, for example, that both K1 and P1 have a component from the non-linear interaction of the Solar-heat-generated S2 and one another!**

1.3 The admittance method

The oceans and seas have a fairly smooth response so can be approximated as linear. This means the ratio of the amplitude over the astronomic potential of astronomic waves can be interpolated from their neighbours. This is useful when going from the Darwin convention to the Doodson convention. For example, taking Π the astronomic potential and η the tidal elevation at a certain location, we have the P1 component from the nearest neighbour interpolation:

$$\eta_{\mathrm{P1}} \approx \Pi_{\mathrm{P1}} \frac{\eta_{\mathrm{K1}}}{\Pi_{\mathrm{K1}}}$$

or from the linear interpolation:

$$\eta_{\mathrm{P1}} \simeq \Pi_{\mathrm{P1}} \frac{\frac{\eta_{\mathrm{O1}}}{\Pi_{\mathrm{O1}}}\left(\omega_{\mathrm{K1}} - \omega_{\mathrm{P1}}\right) + \frac{\eta_{\mathrm{P1}}}{\Pi_{\mathrm{P1}}}\left(\omega_{\mathrm{P1}} - \omega_{\mathrm{O1}}\right)}{\omega_{\mathrm{K1}} - \omega_{\mathrm{O1}}}$$

A spline interpolation can also be done when there are 3 known components.

This only works for astronomic waves. So it will of course fail if the astronomic waves are contaminated by strong non-linear components. So the input waves must be strongest in their category: only M2, K2, N2, K1, O1, Q1, Mf, Mm and Mtm should be allowed as input! Do see the end of 1.2 for the horrifying examples! THE MORE NON-LINEAR AND MIXED SEMIDIURNAL THE ZONE IS, THE LESS RELIABLE THE ADMITTANCE METHOD IS. S2 has got a strong radiative component, so DO NOT PUT S2 IN THE LIST OF WAVES UNLESS YOU ARE AWARE OF WHAT RISKS YOU ARE TAKING.

1.4 Wave list

You can have almost all the information you need about waves with the `showarg` command. Its help is shown on listing 1.

Listing 1: output of `showarg --help`

```
NAME AND VERSION
```

```
 showarg version 2.5 Mercurial revision 2060:0fdb2a3fb74f of 2014-08-28 19:08 +0200

USE
  showarg [OPTIONS] [ wave1 ... ]

DESCRIPTION
  Shows informations about a list of waves : Astronomic potential, pulsation, period, critical latitude,
Doodson number and separation.
  If no list of waves is given, show informations about all coded waves, sorted by increasing pulsation,
but do not show waves separation.
  The wave names are taken from Schureman (1940, Tab2)
http://www.archive.org/details/manualofharmonic00schu
whose convention is followed throughout this software.
  It shows the Doodson number. A list of waves with their doodson number is available from the IHO at
http://www.iho.int/mtg_docs/com_wg/IHOTC/IHOTC_Misc/TWLWG_Constituent_list.pdf

OPTIONS :
  -h,--help  show this help
  -s  followed by the start date in dd/mm/yyyy format
  -f  followed by the end date in dd/mm/yyyy format
  -a  show arguments periodically, by default every day
  -i  followed by the daily frequency at which the arguments are shown. Enforced minimum is daily. Implies
-a.
```

Without arguments, it shows the list of waves known by the TTB, with their name, astronomic potential, pulsation and period in various units, critical latitude and Doodson number as shown on listing 2.

Listing 2: output of showarg

```
# nbre d'ondes: 123
--------astronomic potential amplitude in cm, pulsation in degrees/h and in /h, period in hours and in days
, critical latitude in degrees, Doodson number
     wave      Ap          deg/h             /h                h              days          deg   Doodson
       Sa   0.0000     0.041068639     0.000114080  8765.812771979   365.242198832     0.0782   0565555
      Ssa   1.9416     0.082137278     0.000228159  4382.906385989   182.621099416     0.1564   0575555
```

MSm	0.3094	0.471521089	0.001309781	763.486530333	31.811938764	0.8981	0636555
Mm	2.2056	0.544374697	0.001512152	661.309207939	27.554550331	1.0369	0654555
MSf	0.2240	1.015895786	0.002821933	354.367057034	14.765294043	1.9353	0735555
Mf	4.1765	1.098033064	0.003050092	327.858979630	13.660790818	2.0918	0755555
MStm	0.1147	1.569554153	0.004359873	229.364497779	9.556854074	2.9908	0836555
Mtm	0.8081	1.642407762	0.004562244	219.190391341	9.132932973	3.1298	0854555
MSqm	0.0667	2.113928850	0.005872025	170.299014535	7.095792272	4.0296	0935555
Mqm	0.0000	2.186782459	0.006074396	164.625428795	6.859392866	4.1687	0953555
3OK1	0.0000	11.746969447	0.032630471	30.646202123	1.276925088	22.9854	1055550
2Q1	0.2587	12.854286180	0.035706350	28.006222591	1.166925941	25.2967	1257554
Sig1	0.1627	12.927139789	0.035908722	27.848387647	1.160349485	25.4503	1275554
Q1	1.9469	13.398660877	0.037218502	26.868356718	1.119514863	26.4491	1356554
Ro1	0.3787	13.471514486	0.037420874	26.723053326	1.113460555	26.6042	1374554
O1	10.0573	13.943035575	0.038730654	25.819341711	1.075805905	27.6131	1455554
MS1	0.0000	13.984104214	0.038844734	25.743515244	1.072646468	27.7014	1465555
MP1	0.0800	14.025172853	0.038958813	25.668132848	1.069505535	27.7898	1475556
M1	0.9788	14.496693942	0.040268594	24.833248288	1.034718679	28.8098	1556556
Ki1	0.1120	14.569547550	0.040470965	24.709072039	1.029544668	28.9683	1574556
Pi1	0.2747	14.917864683	0.041438513	24.132140065	1.005505836	29.7294	1625564
P1	4.6806	14.958931361	0.041552587	24.065890224	1.002745426	29.8195	1635554
S1	0.0000	15.000000000	0.041666667	24.000000000	1.000000000	29.9097	1645555
K1	14.1484	15.041068639	0.041780746	23.934469594	0.997269566	30.0000	1655556
Psi1	0.1120	15.082135317	0.041894820	23.869299170	0.994554132	30.0904	1665546
Phi1	0.2027	15.123205917	0.042008905	23.804476510	0.991853188	30.1808	1675556
Tta1	0.1120	15.512589728	0.043090527	23.206956822	0.966956534	31.0425	1736556
J1	0.7921	15.585443336	0.043292898	23.098476715	0.962436530	31.2046	1754556
SO1	0.0000	16.056964425	0.044602679	22.420177966	0.934174082	32.2606	1835556
OO1	0.4347	16.139101703	0.044830838	22.306074193	0.929419758	32.4458	1855556
KQ1	0.0085	16.683476401	0.046342990	21.578236535	0.899093189	33.6830	1954556
2MN2S2	0.0000	26.407937944	0.073355383	13.632264691	0.568011029	61.3854	2096555
2NS2	0.0000	26.879459033	0.074665164	13.393126683	0.558046945	63.3209	2177555
3M2S2	0.0000	26.952312641	0.074867535	13.356924313	0.556538513	63.6317	2195555
ST1	0.0000	26.961596311	0.074893323	13.352325131	0.556346880	63.6715	2197555
OQ2	0.0000	27.341696452	0.075949157	13.166703121	0.548612630	65.3540	2256553
E2	0.1789	27.423833730	0.076177316	13.127267454	0.546969477	65.7318	2276555

MNS2	0.0000	27.423833730	0.076177316	13.127267454	0.546969477	65.7318	2276555
MNuS2	0.0000	27.496687339	0.076379687	13.092486217	0.545520259	66.0717	2294555
ST2	0.0000	27.505971008	0.076405475	13.088067311	0.545336138	66.1153	2296555
ST3	0.0000	27.803933872	0.077233150	12.947808093	0.539492004	67.5581	2335555
2MK2	0.0000	27.886071150	0.077461309	12.909670856	0.537902952	67.9715	2355555
2N2	0.6267	27.895354819	0.077487097	12.905374473	0.537723936	68.0187	2357555
Mu2	0.5841	27.968208428	0.077689468	12.871757622	0.536323234	68.3925	2375555
SNK2	0.0000	28.357592238	0.078771090	12.695012925	0.528958872	70.5053	2436555
N2	4.6313	28.439729516	0.078999249	12.658348238	0.527431177	70.9796	2456555
Nu2	0.9094	28.512583125	0.079201620	12.626004400	0.526083517	71.4101	2474555
MSK2	0.0000	28.901966936	0.080283241	12.455899655	0.518995819	73.8978	2535555
OP2	0.0000	28.901966936	0.080283241	12.455899655	0.518995819	73.8978	2535553
M(SK)2	0.0000	28.943035575	0.080397321	12.438225392	0.518259391	74.1823	2545554
M2	24.2297	28.984104214	0.080511401	12.420601215	0.517525051	74.4718	2555555
M(KS)2	0.0000	29.025172853	0.080625480	12.403026911	0.516792788	74.7667	2565556
MKS2	0.0000	29.066241492	0.080739560	12.385502271	0.516062595	75.0673	2575555
La2	0.1760	29.455625303	0.081821181	12.221774154	0.509240590	78.2860	2636553
L2	0.6694	29.528478911	0.082023553	12.191620201	0.507984175	78.9904	2654553
NKM2	0.0000	29.537762580	0.082049341	12.187788395	0.507824516	79.0834	2656555
T2	0.6614	29.958933322	0.083219259	12.016449188	0.500685383	84.8127	2725565
S2	11.2734	30.000000000	0.083333333	12.000000000	0.500000000	85.7650	2735555
R2	0.0933	30.041066678	0.083447407	11.983595784	0.499316491	87.0057	2745543
K2	3.0697	30.082137278	0.083561492	11.967234797	0.498634783	nan	2755555
MSN2	0.0000	30.544374697	0.084845485	11.786130951	0.491088790	nan	2834555
KJ2	0.1707	30.626511975	0.085073644	11.754521713	0.489771738	nan	2854555
2SM2	0.0000	31.015895786	0.086155266	11.606951561	0.483622982	nan	2915555
SKM2	0.0000	31.098033064	0.086383425	11.576294850	0.482345619	nan	2935555
2SN2	0.0000	31.560270484	0.087667418	11.406746345	0.475281098	nan	3014555
2SMu2	0.0000	32.031791572	0.088977199	11.238834368	0.468284765	nan	3095555
MQ3	0.0000	42.382765091	0.117729903	8.494018718	0.353917447	nan	3356554
2MK3	0.0000	42.927139789	0.119242055	8.386302972	0.349429291	nan	3455554
MO3	0.0000	42.927139789	0.119242055	8.386302972	0.349429291	nan	3455554
M3	0.0000	43.476156321	0.120767101	8.280400810	0.345016700	nan	3555555
SO3	0.0000	43.943035575	0.122063988	8.192424472	0.341351020	nan	3635554
MS3	0.0000	43.984104214	0.122178067	8.184775078	0.341032295	nan	3645555

MK3	0.0000	44.025172853	0.122292147	8.177139956	0.340714165	nan	3655556
SP3	0.0000	44.958931361	0.124885920	8.007307761	0.333637823	nan	3815554
S3	0.0000	45.000000000	0.125000000	8.000000000	0.333333333	nan	3825555
SK3	0.0000	45.041068639	0.125114080	7.992705566	0.333029399	nan	3835556
K3	0.0000	45.123205917	0.125342239	7.978156531	0.332423189	nan	3855558
2MNS4	0.0000	56.407937944	0.156688717	6.382080486	0.265920020	nan	4276555
N4	0.0000	56.879459033	0.157998497	6.329174119	0.263715588	nan	4357555
3MS4	0.0000	56.952312641	0.158200868	6.321077816	0.263378242	nan	4375555
MN4	0.0000	57.423833730	0.159510649	6.269173906	0.261215579	nan	4456555
MNu4	0.0000	57.496687339	0.159713020	6.261230284	0.260884595	nan	4474555
M4	0.0000	57.968208428	0.161022801	6.210300607	0.258762525	nan	4555555
SN4	0.0000	58.439729516	0.162332582	6.160192783	0.256674699	nan	4636555
ML4	0.0000	58.512583125	0.162534953	6.152522770	0.256355115	nan	4654553
NK4	0.0000	58.521866794	0.162560741	6.151546759	0.256314448	nan	4656555
MS4	0.0000	58.984104214	0.163844734	6.103339278	0.254305803	nan	4735555
MK4	0.0000	59.066241492	0.164072893	6.094851999	0.253952167	nan	4755555
2MSN4	0.0000	59.528478911	0.165356886	6.047525598	0.251980233	nan	4834555
S4	0.0000	60.000000000	0.166666667	6.000000000	0.250000000	nan	4915555
SK4	0.0000	60.082137278	0.166894826	5.991797501	0.249658229	nan	4935555
3MNK6	0.0000	85.309904880	0.236971958	4.219908585	0.175829524	nan	6256555
3MNS6	0.0000	85.392042158	0.237200117	4.215849521	0.175660397	nan	6276555
4MK6	0.0000	85.854279577	0.238484110	4.193151486	0.174714645	nan	6355555
3MNL6	0.0000	85.863563247	0.238509898	4.192698118	0.174695755	nan	6357557
4MS6	0.0000	85.936416855	0.238712269	4.189143708	0.174547655	nan	6375555
2MN6	0.0000	86.407937944	0.240022050	4.166283892	0.173595162	nan	6456555
2MNu6	0.0000	86.480791553	0.240224421	4.162774109	0.173448921	nan	6474555
3MSK6	0.0000	86.870175364	0.241306043	4.144115037	0.172671460	nan	6535555
M6	0.0000	86.952312641	0.241534202	4.140200405	0.172508350	nan	6555555
3MKS6	0.0000	87.034449919	0.241762361	4.136293161	0.172345548	nan	6575555
MSN6	0.0000	87.423833730	0.242843983	4.117870204	0.171577925	nan	6636555
2ML6	0.0000	87.496687339	0.243046354	4.114441483	0.171435062	nan	6654553
MSNu6	0.0000	87.496687339	0.243046354	4.114441483	0.171435062	nan	6654555
MNK6	0.0000	87.505971008	0.243072142	4.114004974	0.171416874	nan	6656555
2MS6	0.0000	87.968208428	0.244356135	4.092387539	0.170516147	nan	6735555
3MLN6	0.0000	88.041062036	0.244558506	4.089001106	0.170375046	nan	6753553

```
      2MK6   0.0000     88.050345706      0.244584294      4.088569978      0.170357082        nan   6755555
      MSL6   0.0000     88.512583125      0.245868286      4.067218324      0.169467430        nan   6834553
     3MSN6   0.0000     88.512583125      0.245868286      4.067218324      0.169467430        nan   6834555
     3MKN6   0.0000     88.594720403      0.246096446      4.063447555      0.169310315        nan   6854555
      2SM6   0.0000     88.984104214      0.247178067      4.045666394      0.168569433        nan   6915555
      MSK6   0.0000     89.066241492      0.247406226      4.041935463      0.168413978        nan   6935555
     2M2N8   0.0000    114.847667460      0.319021299      3.134586953      0.130607790        nan   8357555
      3MN8   0.0000    115.392042158      0.320533450      3.119799193      0.129991633        nan   8456555
        M8   0.0000    115.936416855      0.322045602      3.105150304      0.129381263        nan   8555555
     2MSN8   0.0000    116.407937944      0.323355383      3.092572606      0.128857192        nan   8636555
      3ML8   0.0000    116.480791553      0.323557754      3.090638338      0.128776597        nan   8654553
      3MS8   0.0000    116.952312641      0.324867535      3.078177694      0.128257404        nan   8735555
      3MK8   0.0000    117.034449919      0.325095694      3.076017363      0.128167390        nan   8755555
     2M2S8   0.0000    117.968208428      0.327689468      3.051669639      0.127152902        nan   8915555
     2MSK8   0.0000    118.050345706      0.327917627      3.049546343      0.127064431        nan   8935555
     2M2K8   0.0000    118.132482984      0.328145786      3.047425999      0.126976083        nan   8955555
 ^^^^^^^^^^^^^ end of computation ^^^^^^^^^^^^^
```

It otherwise shows information about wave separation, which is important when doing harmonic analysis. An example is shown in 2.1.

2 Detiding

Tides induce mixing in the ocean layers on high continental shelves or on continental margins. So most models of the ocean take into account the tides. However, when you are interested in, for example, Sea Surface Height (SSH) variations ($< 0.1m$) induced by the weather or the circulation, the tides ($> 1m$) will just drown what you want to observe. [Show one example of drowned SSH] Thankfully, as the tidal spectrum has very sharp components, it is fairly easy to filter the tides out.

This is done with the `comodo-detidor` command. Its help is shown on listing 3.

Listing 3: output of `comodo-detidor --help`

```
NAME AND VERSION
  comodo-detidor version 2.5 Mercurial revision 2060:0fdb2a3fb74f of 2014-08-28 19:08 +0200

USE
  comodo-detidor file1 [ file2 ... ] [OPTIONS] -d wave1 [ wave2 ... ]

DESCRIPTION
```

```
  Detides comodo-compliant NetCDF outputs and produces tidal atlases.
  It takes a file or a list of files as input, carries out a spectral analysis on the given list of wave
and produces the atlases and the detided output.

OPTIONS
  --nodal=no  do not do nodal corrections
  -c,--control  followed by the path of the list of control points: it is an ascii file with the number of
control points followed by their coordinates (longitude latitude [layer]).
  --only-atlases  produce only atlases : no detiding. It of course implies -a
  --variable-mask  take into account that the mask may vary at each frame. This takes a tiny bit of CPU,
without taking any extra time when the speed is limited by the hard drive.
  --take-first  (*)if some time frames are simultaneous, take the first one
  --take-last  (*)if some time frames are simultaneous, take the last one
  -a  produce atlas
  -1  put all atlases in one file. YOU WILL NOT BE ABLE TO USE comodo-admittance ON THIS FILE.
  -t  show separation tables of all harmonics and list of files within time boundaries
  -l  followed by the path of the list of files to analyse. This list will override the list given as
arguments.
  -g  followed by the path of the grid file. This is only necessary when the coordinates are not available
in the files to analyse and you want to produce atlases or use control points.
  -p  followed by an output folder path. IT IS STRONGLY ADVISED TO OUTPUT ON A DIFFERENT HARD DRIVE WHEN
DOING DETIDING.
  -s  followed by the start date in dd/mm/yyyy format
  -f  followed by the end date in dd/mm/yyyy format
  -o  followed by the default date origin in dd/mm/yyyy format
  -v  followed by the name of the variable to detide
  -d  followed by the list of waves to analyse. A good start is Q1 O1 P1 K1 N2 M2 S2 K2 M4 MS4

(*) BUGS
  Options marked with a (*) are not properly implemented yet.

ENVIRONEMENT
  This uses OpenMP version 201107. Check the relevant API for more environment variables.
  For information, OpenMP version 200505 and above are sensitive to the following variables :
    OMP_SCHEDULE for the runtime schedule type and chunk size.
```

```
    OMP_NUM_THREADS for the number of threads to use.
    OMP_DYNAMIC for the dynamic adjustment of threads to use.
    OMP_NESTED to enable or disable nested parallelism.
  For example, in bash :
    OMP_NUM_THREADS=6 comodo-detidor ...

  If you are running on a machine with already loaded CPUs, you SHOULD take only a number of CPUs
equivalent to the number that will remain free, otherwise the program will grind to an equivalent halt as
soon as it parallelises.
```

It always carries out a harmonic analysis. Unless requested not to do so by the `--only-atlases` option, it calculates a prediction from the amplitudes and phases of the analysed waves and subtracts it from the input to obtain a detided output.

2.1 Harmonic analysis

It is possible to get amplitudes and phases of waves from a signal $[h_t]$ from:

$$\left[\nu_n e^{j(\omega_n t+\phi_n)}\right][x_n] = [h_t] \qquad (1)$$

$$\left[\nu_n e^{j(\omega_n t+\phi_n)}\right]^* \left[\nu_n e^{j(\omega_n t+\phi_n)}\right][x_n] = \left[\nu_n e^{j(\omega_n t+\phi_n)}\right]^* [h_t] \qquad (2)$$

with:

- t the time since the reference
- ν_n a complex number giving the nodal correction (in amplitude and in phase)
- w_n the pulsation of the wave
- ϕ_n the astronomic angle of the wave
- $\mathbf{A} \equiv \left[\nu_n e^{j(\omega_n t+\phi_n)}\right]^* \left[\nu_n e^{j(\omega_n t+\phi_n)}\right]$ the harmonic matrix
- $\mathbf{b} \equiv \left[\nu_n e^{j(\omega_n t+\phi_n)}\right]^* [h_t]$ the right-hand side vector
- $\mathbf{x} \equiv [x_n]$ the harmonic coefficients

The modulus and argument of x_n are respectively the amplitudes and phases of the analysed waves.

$\mathbf{x}$ is obtained with a simple invertion of (2).

2.1.1 Issues

Two waves are poorly separated when they are so close in frequency f that they have numbers of periods Tf over the period T of the time series that differ by less than 1:

$$T\,|f_1 - f_2| < 1$$

This makes $\mathbf{A}$ singular. These waves are then unresolved. The `showarg` command can be used to check if waves are separated over an analysis period. The separation period of two waves is

$$|f_1 - f_2|^{-1}$$

and can be calculated by `showarg` followed by the list of waves. When you specify the period of your analysis, `showarg` will only show you the couples of unresolved waves whose separation period is more than half of the analysis period. For example, listing 4 shows you that **an analysis period of 10 days is way too short for just about anything**.

Listing 4: extract of the output of
`showarg -s 01/01/2012 -f 11/01/2012 K1 O1 M2 S2`

```
----------------------separations above 5 days
wave:        K1        O1, separation:    13.661 days
wave:        M2        S2, separation:    14.765 days
```

As a general rule, an analysis over a long period and with as few waves as possible gives good atlases, and an analysis over a short period and with as many waves as possible gives a properly detided output, but short periods are not very compatible with high number of close waves. **Also, with periods so short that important waves have a small and non-integer number of periods, these important waves will pollute the estimation of the other waves if they are not given in the list of waves to analyse.**

If an unresolved wave is not astronomic, it can not be analysed with the admittance method and its column in **A** is replaced with 0s but for its row, replaced with a 1, which takes this wave out of the equation. If an unresolved wave is astronomic, it can be analysed with the admittance method and its column in **A** is replaced with weights calculated from the astronomic potential of the waves. **There are issues with the admittance method, see 1.3 and 1.2! It is still better to use the admittance method during the analysis than doing so later with `comodo-admittance`!**

2.2 Examples

The following command:

```
comodo-detidor champs_Meteo.nc --only-atlases -v XE
 -d Q1 O1 P1 K1 N2 M2 S2 K2 L2 M4 MS4
```

- carries out a harmonic analysis on the data of the variable `XE` (option `-v`)
- takes into account the following waves: Q1 O1 P1 K1 N2 M2 S2 K2 L2 M4 MS4 (option `-d`)
- saves an atlas for each wave, whose name is the name of the wave followed by `-XE-atlas.nc` (option `-a` implied by option `--only-atlases`)

That's all (option `--only-atlases`). [Show at least one atlas]

The following command:

```
comodo-detidor champs_Meteo.nc -a -c control.dat -v
 XE -d Q1 O1 P1 K1 N2 M2 S2 K2 L2 M4 MS4
```

does the same as the previous command. It additionally:

- saves the detided `XE` in `detided-XE-champs_Meteo.nc` as variable `XE_detided`
- reads the coordinates of the control points from `control.dat` (option `-c`) and saves harmonic constants, time series, signal spectrum and residual spectrum to, respectively, `constants-XE-*.txt`, `series-XE-*.txt`, `signal-fft-XE-*.txt` and `residuals-fft-XE-*.txt`, with `*` the index of the control point in the grid.

The detiding requires reading the input twice, so this command takes almost twice as long as the previous one. [Show one example of cleaned-up SSH]

3 Completing atlases with the admittance method

You may end up with atlases that lack a certain number of weak but important astronomic waves, most often for two reasons: the model was not forced with these waves or they were forgotten when making the list for the harmonic analysis (see the end of 2.1). You may then redo your analysis, which can take some time, or your model, which will take a lot of time, or rather interpolate the missing waves with the admittance method, described in 1.3, which will take a very small amount of time. **There are issues with the admittance method, see 1.3 and 1.2!**

This is done with `comodo-admittance`. Its help is shown on listing 5.

Listing 5: output of `comodo-admittance --help`

```
NAME AND VERSION
  comodo-admittance version 2.5 Mercurial revision 2060:0fdb2a3fb74f of 2014-08-28 19:08 +0200

USE
  comodo-admittance [OPTIONS] wave1 wave2 wave3 [wave4 ...]

DESCRIPTION
  Expands the spectrum of a set of atlases using the admittance method.
  The list of waves (at LEAST 3) are the waves you have and the waves you want.
  Missing atlases will be created with their constants interpolated or extrapolated with the admittance
method.

TIP
  You will have better atlases if you use comodo-detidor with a complete list of waves instead.

IMPORTANT WARNINGS
  When adding frequencies, we have among other : K1+O1=M2 , K1+P1=S2 and M1+O1=N2 , so
THE MORE NON-LINEAR AND MIXED SEMIDIURNAL THE ZONE IS, THE LESS RELIABLE THE ADMITTANCE METHOD IS. USE AT
YOUR OWN RISK.
  S2 has got a strong radiative component, so
DO NOT PUT S2 IN THE LIST OF WAVES UNLESS YOU ARE AWARE OF WHAT RISKS YOU ARE TAKING.

OPTIONS
  -h,--help  Show this help and exit.
  -a  followed by atlas file name convention. See below.
  -v  followed by 2 variable names, repectively for amplitude and phase
  -d  followed by the discretisation, e.g. LGP2. If unspecified, a structured grid will be assumed
  -p  prefix for forcing admittance of last wave. BUG: NOT AVAILABLE FOR UNSTRUCTURED GRIDS YET!

CONVENTION
  "WAVE" is replaced by the name of the wave (which is all upper-case).
  "wave" is replaced by the lower-cased name of the wave.
  "Wave" is replaced by the all-but-first-letter-lower-cased name of the wave.
  If the file exists without any replacements made, do not do any replacement.
```

Say for example L2 was forgotten when forcing the model. Its atlas (see 2.2) would show ridiculously small amplitudes and dubious phases only due to bad separation with the non-linear NKM2. The following command would give you better values from the atlases of N2, M2 and K2:

```
comodo-admittance -a WAVE-XE-atlas.nc -v XE_a XE_G
N2 M2 L2 K2
```

The order with which the waves are given is irrelevant: only the waves for which the atlases are missing will be interpolated. [Show both analysed and interpolated atlases]

4 Interpolation and prediction

This is done with `predictor`. Its help is shown on listing 6.

Listing 6: output of `predictor --help`

```
NAME AND VERSION
  predictor version 2.5 Mercurial revision 2060:0fdb2a3fb74f of 2014-08-28 19:08 +0200

USE
  predictor -p lon_lat_list -a atlas_convention [-s start -f end] -w wave1 [wave2 ... ] [OPTIONS]

DESCRIPTION
  Interpolates constants and predicts tides at given points with given atlases.
  If start and end dates are provided, predicts tides and spring/neap times.

OPTIONS :
  -h,--help  show this help
  --nodal=no do not do nodal corrections
  -p  followed by the path of the list of control points: it is an ascii file with the number of control
points followed by their coordinates (longitude latitude).
  -a  followed by the atlas file name convention. See below.
  -s  followed by the start date in dd/mm/yyyy format
  -f  followed by the end date in dd/mm/yyyy format
  -i  followed by the date increment concatenated with the unit: s (default), m, h or d. Default increment:
 3600s=60m=1h.
  -v  followed by the variables names for the amplitude and the phase. Default: Ha Hg
  -w  followed by the list of waves to predict for
  -o  followed by the path of the ascii output. Default: predictions.dat

TIP
  To get all available atlases :
```

```
f=(*.spectral.nc);predictor -p control.dat -a WAVE.spectral.nc -v a_eta_LGP2 G_eta_LGP2 -w ${f[@]/.spectral
.nc}

CONVENTION
  "WAVE" is replaced by the name of the wave (which is all upper-case).
  "wave" is replaced by the lower-cased name of the wave.
  "Wave" is replaced by the all-but-first-letter-lower-cased name of the wave.
  If the file exists without any replacements made, do not do any replacement.
```

Say for example you want to predict the tides at 2 points, one in the Mont St Michel Bay at 49N 2W, and one in the middle of the Bay of Biscay at 45N 5W, during Jan 2000. You then need to put the number of points to predict for and their latitude and longitude in a file, for example `control.dat`, as shown by listing 7.

Listing 7: example list of control points

```
2
49 -2
45 -5
```

and run the following command:

```
predictor -p control.dat -a WAVE-XE-atlas.nc -v
XE_a XE_G -s 01/01/2000 -f 01/02/2000 -w Q1 O1 P1
K1 N2 M2 S2 K2 L2 M4 MS4
```

This will show you the constants for all waves on the screen and produce `predictions.dat` (listing 8).

Listing 8: first few line of `predictions.dat`

```
#file produced with : predictor -p control.dat -a
WAVE-XE-atlas.nc -v XE_a XE_G -s 01/01/2000 -f
01/02/2000 -w Z0 Q1 O1 P1 K1 N2 M2 S2 K2 L2 M4 MS4
#time(days since 2000/01/01 00:00:00) time(human-
readable) point0 point1
0.00000 2000/01/01_00:00:00 1.02995 0.918104
0.04167 2000/01/01_01:00:00 1.84631 0.657546
0.08333 2000/01/01_02:00:00 2.20802 0.227027
0.12500 2000/01/01_03:00:00 2.06563 -0.262829
0.16667 2000/01/01_04:00:00 1.45274 -0.689614
0.20833 2000/01/01_05:00:00 0.486658 -0.948384
0.25000 2000/01/01_06:00:00 -0.627089 -0.975137
```

As the output is in ascii, you can then easily plot the results, for example with `gnuplot` (listing 9).

Listing 9: `gnuplot` commands for `predictions.dat`

```
set xlabel 'days since 2000/01/01 00:00'
plot 'predictions.dat' u 1:3 w l t 'Mt St Michel',\
  '' u 1:4 w l t 'Bay of Biscay'
```

5 Energy budget

This is a diagnosis tool for modellers. The energy budget is calculated with the `comodo-energy` command from tidal atlases. The help of this command is shown on listing 10

Listing 10: output of `comodo-energy --help`

```
NAME AND VERSION
  comodo-energy version 2.5 Mercurial revision 2060:0fdb2a3fb74f of 2014-08-28 19:08 +0200

USE
  comodo-energy bathymetry bathymetry_varname atlas_convention elevation_varname lon_speed_varname
lat_speed_varname wave1 [wave2 ...]

DESCRIPTION
  Calculates the spectral energy budget from structured-grid tidal atlases.
  The first argument is the bathymetry.
  The following argument is the bathymetry variable name.
  The 3rd argument is the atlas file name convention. See below.
  The following 3 arguments are the variable names for the elevation and the longitudinal and and
latitudinal speed components.
  The following arguments are the waves you want to analyse.
  For each wave, it will calculate Stokes'transport, energy flux and dissipation rate. The elevations and
speed components will be interpolated at bathymetry points.

CONVENTION
  "WAVE" is replaced by the name of the wave (which is all upper-case).
  "VAR" is replaced by the name of the variable.
  "wave" is replaced by the lower-cased name of the wave.
  "Wave" is replaced by the all-but-first-letter-lower-cased name of the wave.
  If the file exists without any replacements made, do not do any replacement.

OPTION :
  -h,--help  Show this help and exit.

ENVIRONEMENT
  This uses OpenMP version 201107. Check the relevant API for more environment variables.
  For information, OpenMP version 200505 and above are sensitive to the following variables :
    OMP_SCHEDULE for the runtime schedule type and chunk size.
    OMP_NUM_THREADS for the number of threads to use.
    OMP_DYNAMIC for the dynamic adjustment of threads to use.
    OMP_NESTED to enable or disable nested parallelism.
```

```
  For example, in bash :
    OMP_NUM_THREADS=6 comodo-energy ...

  If you are running on a machine with already loaded CPUs, you SHOULD take only a number of CPUs
equivalent to the number that will remain free, otherwise the program will grind to an equivalent halt as
soon as it parallelises.
```

[review this, especially the symbols]
The scalar product of 2 complex vector is :

$$\text{with} \quad z = x + jy = ae^{j\phi} \tag{3a}$$

$$\overline{\overline{a_1 \left[e^{j(\omega t+\phi_1)} + e^{-j(\omega t+\phi_1)}\right] a_2 \left[e^{j(\omega t+\phi_2)} + e^{-j(\omega t+\phi_2)}\right]}} \tag{3b}$$

$$= a_1 a_2 \left[e^{j(\phi_1-\phi_2)} + e^{-j(\phi_1-\phi_2)}\right] = a_1 a_2 \cos(\phi_1 - \phi_2) \tag{3c}$$

$$= \Re(z_1 \overline{z_2}) = x_1 x_2 + y_1 y_2 \tag{3d}$$

$$\equiv z_1 \cdot z_2 \tag{3e}$$

It calculates Stokes transport S with:

$$\overrightarrow{S} = \eta \cdot \overrightarrow{u} \tag{4}$$

As (4) needs elevation and both speed components at the same location, and as (4) also needs the depths at that location, the elevation and both speed components are interpolated at depth locations. It calculates energy flux E with:

$$\overrightarrow{E} = \rho g h \overrightarrow{S} \tag{5}$$

and dissipation rate with:

$$W = -\nabla \cdot \overrightarrow{E} \tag{6}$$

Because it is obtained from a spatial derivation, it is not calculated for values at the boundary of the domain. [It should take into account astronomic forcing.] This shows why it is so unstable:

$$W = -\rho g \left[(\nabla h) \cdot \overrightarrow{S} + h \nabla \cdot \overrightarrow{S}\right]$$

Also, it is taken for each wave separately, when all main waves should be taken simultaneously. Because of wave-to-wave non-linear energy transfers, it will be positive and negative, when it should only be negative.

But thankfully, we have the 2D wave equation:

$$\frac{\partial \eta}{\partial t} + \nabla \cdot (H \overrightarrow{u}) = 0 \tag{7}$$

which gives the dissipation from the pressure work:

$$W_p = \rho g h (\nabla \eta) \cdot \overrightarrow{u} \tag{8}$$

6 Current ellipses

The direction and strength of the current when the phase of the force is 0 is simply the same as

$$\Re \mathbf{u} \tag{9}$$

We have the modulus of the current $|\mathbf{u}|$ from:

$$\begin{aligned}
2\,|\mathbf{u}|^2 &= U^2 \left[1 - \cos\left(2\omega t + 2\phi_u\right)\right] + V^2 \left[1 - \cos\left(2\omega t + 2\phi_v\right)\right] \\
&= U^2 \left[1 - \cos 2\omega t \cos 2\phi_u + \sin 2\omega t \sin 2\phi_u\right] \\
&\quad + V^2 \left[1 - \cos 2\omega t \cos 2\phi_v + \sin 2\omega t \sin 2\phi_v\right] \\
&= U^2 + V^2 - \left[U^2 \cos 2\phi_u + V^2 \cos 2\phi_v\right] \cos 2\omega t \\
&\quad + \left[U^2 \sin 2\phi_u + V^2 \sin 2\phi_v\right] \sin 2\omega t
\end{aligned}$$

Taking

$$u^2 = U^2 \cos 2\phi_u + jU^2 \sin 2\phi_u$$
$$v^2 = V^2 \cos 2\phi_v + jV^2 \sin 2\phi_v$$
$$d = u^2 + v^2 = U^2 \cos 2\phi_u + V^2 \cos 2\phi_v + j\left[U^2 \sin 2\phi_u + V^2 \sin 2\phi_v\right]$$

gives

$$\begin{aligned} 2\left|\mathbf{u}\right|^2 &= U^2 + V^2 - \Re\left(de^{2j\omega t}\right) \\ &= U^2 + V^2 - |d| \cos\left(2\omega t + \arg d\right) \end{aligned}$$

which gives the maximum current:

$$\left|\mathbf{u}\right|_{max} = \sqrt{\frac{U^2 + V^2 + |d|}{2}} \quad (10a)$$

$$\text{at} \quad 2\omega t = -\arg d \Leftrightarrow \omega t = \phi_M = -\frac{\arg d}{2} \quad (10b)$$

and the minimum current:

$$\sqrt{\frac{U^2 + V^2 - |d|}{2}}$$

(10b) gives the direction of the maximum current:

$$\arg\left[\Re\left(ue^{-j\phi_M}\right) + j\Re\left(ve^{-j\phi_M}\right)\right] \quad (11a)$$
$$= \arg\left[U \cos\left(\phi_u - \phi_M\right) + jV \cos\left(\phi_v - \phi_M\right)\right] \quad (11b)$$

The polarisation is given with the sign of the vectorial product of the speed components:

$$\Re\left(u\right) \Im\left(v\right) - \Im\left(u\right) \Re\left(v\right) \quad (12a)$$

with positive relating to anti-clockwise.

This is done with the `ellipse` command. Its help is shown on listing 11.

Listing 11: output of `ellipse --help`

```
NAME AND VERSION
  ellipse version 2.5 Mercurial revision 2060:0fdb2a3fb74f of 2014-08-28 19:08 +0200

USE
  ellipse grid_file gridded_varname atlas_convention lon_speed_varname lat_speed_varname wave1 [wave2 ...]

DESCRIPTION
  Calculates current ellipses.
  The first argument is the grid file.
  The following argument is a variable name at whose points the speed components will be interpolated. So
that can be anything (bathymetry, temperature, ...).
  The 3rd argument is the atlas file name convention. See below.
  The following 2 arguments are the variable names for the longitudinal and and latitudinal speed
components.
  The following arguments are the waves you want to analyse.
  For each wave, it will calculate current ellipses.
```

```
CONVENTION
  "WAVE" is replaced by the name of the wave (which is all upper-case).
  "VAR" is replaced by the name of the variable.
  "wave" is replaced by the lower-cased name of the wave.
  "Wave" is replaced by the all-but-first-letter-lower-cased name of the wave.
  If the file exists without any replacements made, do not do any replacement.

OPTION :
  -h,--help  Show this help and exit.
  -t  for testing
```

Bibliography

Paul Schureman. *Manual of harmonic analysis and prediction of tides*, 1940. URL `http://www.archive.org/details/manualofharmonic00schu`. Downloaded BW version on 7 Oct 2011 because all the book is in BW ... but the yellowed paper! 1.1