LBWG memo 23

A LOFAR wide-field imaging pipeline

Frits Sweijen

Here I summarize an *imaging pipeline* designed to run after what is currently the long baseline pipeline. This has sort of spun off of memo 17, exploring further the creation of widefield high-resolution LOFAR maps. The most complete functionality is only possible if the calibration process was done starting from the `DATA_DI_CORRECTED` state of the ddf-pipeline.

This pipeline is built around DDFacet and in a style aiming to be similar to the ddf-pipeline. It is not implemented in the genericpipeline framework for this reason. It can be found here: `https://github.com/tikk3r/lofar-highres-widefield` (still much W.I.P.)

Ideally the long baseline pipeline would have as an output the blocks of 10 SB averaged to 4ch/4s/SB containing DATA_DI_CORRECTED calibrated data.

What does it need?

The pipeline needs access to the following input:

1. Prefactor or ddf-pipeline direction independent calibrated data, averaged to 4 seconds and 4 channels per subband, served in blocks of 10 SB (i.e. identical to how the dutch data is reduced).
2. The output of the standard ddf-pipeline run (for source subtraction).
3. The SOLSDIR containing the direction independent solutions found by the ddf-pipeline.
4. A DS9 box region, centered on the pointing center (for source subtraction).
5. One or two H5Parms with solutions from an infield calibrator: one with phase solutions and one with phase+amplitude solutions. They need to have all C, R and I stations.

What does it do?

After being given the required input, it will run for some days to produce a direction independent calibrated $1''$ map of the field. During this process it will:

1. Apply DI solutions to arrive at DATA_DI_CORRECTED (can be skipped if already done).
2. Subtract all sources outside the given box using the direction dependent LoTSS solutions (can be skipped if e.g. a custom subtract was done, or no subtract is necessary).
3. Apply solutions from the infield calibrator.
4. Image the field at $1''$.
5. Run PyBDSF with standard SKSP settings and output some catalogs.

Applying DI solutions

The ddf-pipeline does an additional direction-independent (DI) solve on top of the prefactor corrected data. To properly subtract sources later on, we need to arrive at the right DI corrected data first. This is achieved by first converting the DIS2 solutions from the pipeline to H5Parms using LoSoTo, and then applying those to the prefactor-corrected data. It is important to have the exact same 10SB blocks that prefactor outputs (and the ddf-pipeline ran on), as the solutions have varying solutions intervals and so need to be matched correctly. The source subtraction is then executed using the standard `sub-sources-outside-region.py` provided by the ddf-pipeline.

Source subtraction using LoTSS

Many sources reside outside the field of view of the international stations, but are still within the field of view of the Dutch stations. Because these sources are not deconvolved or accounted for otherwise, they will introduce unwanted noise in the image. Figures 1a to 1c show the difference that subtracting bright sources can make.

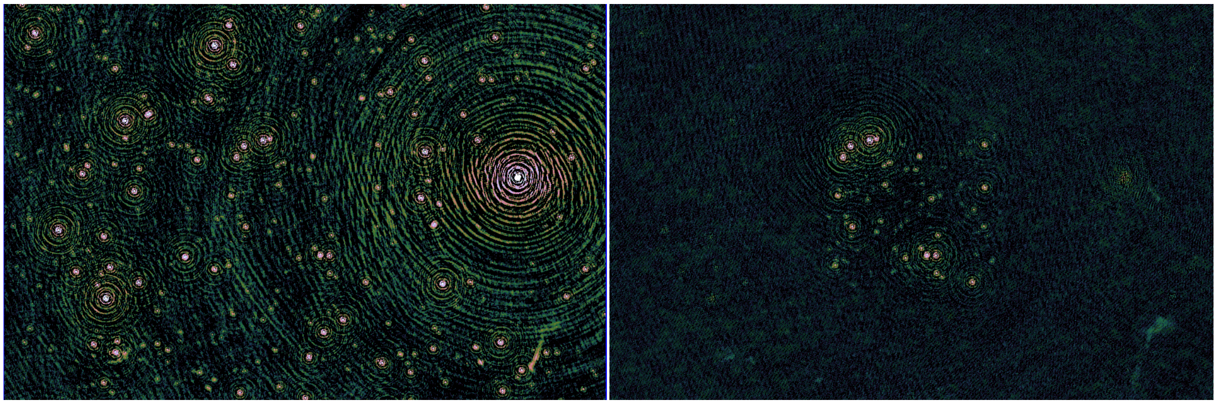
Using the `sub-sources-outside-region.py` script, all sources outside a box, provided by the user, are subtracted from the field, using the DDS3 direction dependent solutions. This gives excellent source subtraction on the $6''$ scales. With these sources gone, the noise level in the $1''$ map drops significantly. Improvements of 20%-30% in terms of RMS noise level can be seen throughout the image. A 230 SB map, after subtraction, measures an RMS noise level of around 230 μJy/beam.

$1''$ imaging of the field

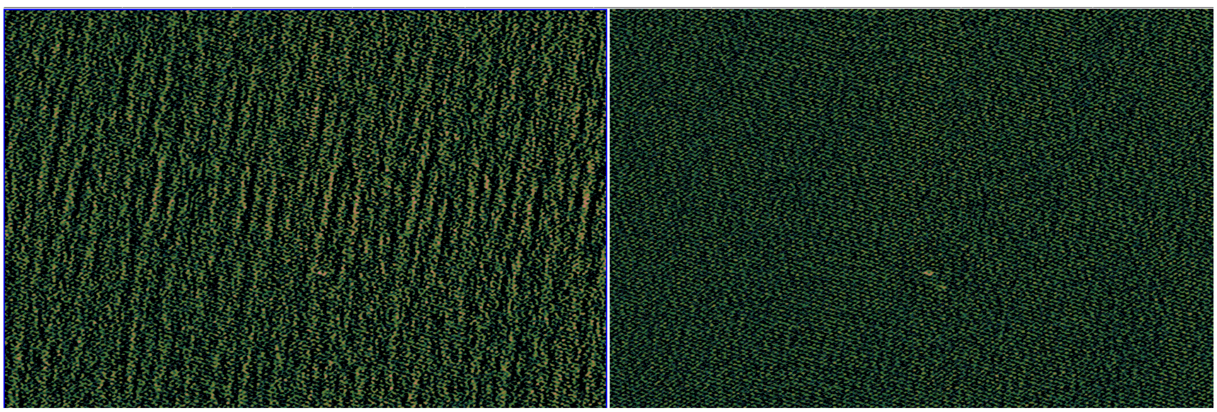
Most important during for imaging the field is the correct weighting, to arrive at the desired resolution. WSClean is used to compute weights, using a combination of weighting and tapering, to arrive a PSF of approximately $1''$. We settled on Briggs weighting with robust set to -1 and a Gaussian taper of $1''$, together with an inner uv cut of 5 km. The weights are stored in the `IMAGING_WEIGHT_SPECTRUM` column by WSClean, and then transferred to `IMAGING_WEIGHT`, dropping the polarization axis. Then DDFacet is used, with Natural weighting (i.e. no additional weighting is applied), passing the `IMAGING_WEIGHT` column as the weights to be used.

In hindsight, the 5 km inner cut is not necessary to produce a good taper. This means we can in principle use the LoTSS inner cut of 100 m, to have matched inner uv coverage. The fitted beam can produce various results depending on uv cuts and/or tapers applied, but it seems to be that the central part will always approach a $1''$ size. Thus the restoring beam can just be forced to be $1''$.

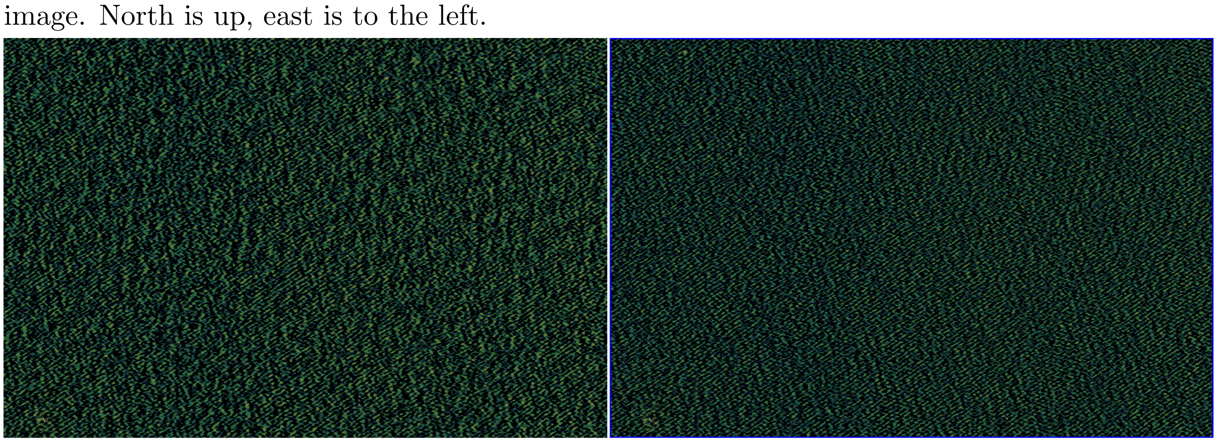
Once the final image is ready, PyBDSF is run and two catalogues are written out: a CSV catalogue containing all columns (most notably the peak flux density) and a BBS format catalogue which can be fed to e.g. DPPP. This catalogue can then be used to identify suitable DDE calibrators.



(a) A 30 SB dirty image of a portion of the Lockman Hole field with all sources present (*left*) and the same portion with sources outside a $1.4^\circ \times 1.4^\circ$ box subtracted (*right*), using the direction dependent solutions. The key point is that bright sources are subtracted well, removing strong ripples that are visible through the entire image. North is up, east is to the left.



(b) A 10 SB dirty image at $1''$ angular resolution, zoomed in on a portion that is adjacent to the brightest source seen in the west of Fig. 1a. Shown is the same region with no sources subtracted (*left*) and with all sources outside a $2.5^\circ \times 2.5^\circ$ box subtracted (*right*). The subtraction has a significant effect on increasing image quality. The RMS noise level on the ripples is approximately 4.2 mJy/beam in the unsubtracted image and 2.8 mJy/beam in the same region in the subtracted image. North is up, east is to the left.



(c) Similar to Fig. 1b, but in a lesser affected region of the map. The RMS noise level drops from 2.1 mJy/beam before source subtraction to 1.6 mJy/beam after source subtraction. North is up, east is to the left.