Nobeyama Radioheliograph (NoRH) Analysis Manual ver. 2.3

Nobeyama Solar Radio Observatory, NAOJ

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Contents

1 Introduction

This is a manual for analyzing the data of Nobeyama Radioheliograph [NoRH] that is an imaging radio telescope (17/34GHz) for the Sun in Nobeyama Solar Radio Observatory [NSRO] of the National Astronomical Observatory of Japan [NAOJ] (Nakajima et al. 1994; Nishio et al. 1994; Hanaoka et al. 1994). The contents are as follows: Section 2 describes how to install this package, Section 3 describes how to analyze the data using IDL. Section 4 describes how to analyze *without* IDL. The detailed description of synthesis programs are given in Section 5. Appendix A and B give the detailed information on NoRH data and on the FITS header used, respectively. A brief introduction of the NSRO data archive is given in the last section Appendix C.

For any questions and requests, please send an e-mail to
`nsro-service@solar.nro.nao.ac.jp`

The latest information on NoRH is updated on NSRO Web site. The URL is
`http://solar.nro.nao.ac.jp/norh/`

1.1 What's New

Change from ver 2.2
• Significant update of spectrum analysis procedure `norh_polariz` (section 3.5.7), `norh_alpha` (section 3.5.9). New procedures `ramaty_gysy`, `dulk_gysy` (section 3.5.11), `dulk_frfr` (section 3.5.12).
• Easy plot procedure `norh_plot` (section 3.6.4, 3.6.5) and `norh_plot_alpha` (section 3.6.6).
• New procedure for reading raw data directly `norh_rd_rdt` (section 3.7.1)
• New procedure for obtaining the position (azimuth and elevation) of the Sun in Nobeyama `norh_t2azel` (section 3.7.3).
• New procedure for obtaining the correspondance between antenna number and name (section 3.7.2).
• How to make original SZ file (section 3.7.4)
• Remove `norh_dat`
• Add new database for Sun tracking

2 How to set up the Analysis Softwares

To use the softwares that are introduced in this manual, the following set-up is necessary.

2.1 For analysis with IDL

(1) Installation of the *SolarSoftware*.

Install the SolarSoftware (SSW) with the subpackage 'Radio/NoRH'. We strongly recommend to install the SolarSoftware with the sub-package for Yohkoh/SXT. If these softwares were not installed, please contact your system manager. The primary distribution site for SolarSoftware is: `http://www.lmsal.com/solarsoft/` We define the top directory of SSW as `${SSW}` and that of NoRH subpackage as `${NORH}` (usually `${SSW}/radio/norh`) in this manual. The original version of the NoRH software is included in the distribution CD-ROM.

(2) Installation of *NoRH data base*

Copy the NoRH data base after getting them from the NoRH distribution CD-ROMs or from the NSRO archive at `ftp://nsro-archive.nro.nao.ac.jp/pub/norh/data`. The recommended destination is `${NORH}/data`.

Note 1 ! Due to the limited network capability in Nobeyama, we strongly recommend you to use CD-ROMs for the initial setup and then to update through the network.

Note 2 ! The 'tsx' data (see Appendix A.8) in NoRH data base is quite huge although it is still possible to analyze the NoRH data *without* this. So you do not have to install it.

(3) Setup of your personal environment

Include the followings in your environment setup file (`~/.cshrc`).

```
setenv SSW SSW-directory[1]
setenv SSW_INSTR ''norh''
setenv NORH ${SSW}/radio/norh
source ${SSW}/gen/setup/setup.ssw
source ${NORH}/setup/setup.norh
```

Note that the enviroment variable `${SSW}` can be different (Ask your system manager)[2]. In case you analyze many kinds of data at the same time, define SSW_INSTR as follows, e.g.

```
setenv SSW_INSTR ''sxt hxt norh''
```

In some sites, to save the disk space, the NoRH data base could be installed somewhere that is not the default place (`${NORH}/data`) [3]. In this case, include following

```
setenv NORHDB data-base-directory
```

2.2 For analysis without IDL

(1) Installation of *NoRH software* package

Install the NoRH software package. The destination directory is basically arbitrary. We define this top directory as `${NORH}` in this manual.

(2) Installation of *NoRH data base*

Copy the NoRH data base after getting them from the NoRH distribution CD-ROMs or from the NSRO archive at `ftp://nsro-archive.nro.nao.ac.jp/pub/norh/data`. The recommended destination is `${NORH}/data`.

Note 1 ! Due to the limited network capability in Nobeyama, we strongly recommend you to use CD-ROMs for the initial setup and then to update through the network.

Note 2 ! The 'tsx' data (see Appendix A.8) in NoRH data base is quite huge although it is still possible to analyze the NoRH data *without* this. So you do not have to install it.

(3) Setup of your personal environment

Include the followings in your environment setup file (`~/.cshrc`).

```
setenv NORH NoRH-directory
source ${NORH}/setup/setup.norh
```

Note that the enviroment variable `${NORH}` can be different (Ask your system manager)[4]. In some sites, to save the disk space, the NoRH data base could be installed somewhere that is not the default place (`${NORH}/data`) [5]. In this case, include following

```
setenv NORHDB NoRH-data-base-directory
```

[1] `/sgi1/ssw` in NSRO
[2] In NSRO, it is `/sgi1/ssw`
[3] In NSRO, it's in default place.
[4] In NSRO, it is `/archive/pub/norh`
[5] In NSRO, it's in default place.

3 Analysis with IDL

3.1 Start up SSW/IDL

The NoRH IDL procedures described in this section all depend on the SolarSoftware (SSW). When you start the analysis, start up the SSW/IDL as follows:

`unix%` **sswidl <CR>**

3.2 Data Base

3.2.1 Observation Time and Logs

There is a data base for the observation time ('info' data: Appendix A.6). For example, to see the observation time of the schedules on 1998-7-25 UT of 17GHz steady-mode (1sec integration) data,

`IDL>` **norh_pr_info,'1998-07-25' <CR>**

or for data from 1998-7-25 to 1998-7-28,

`IDL>` **st_time='1998-07-25' <CR>**
`IDL>` **ed_time='1998-07-28' <CR>**
`IDL>` **norh_pr_info,st_time,ed_time <CR>**

For 17GHz event-mode (50/100 msec integration) data,

`IDL>` **norh_pr_info,st_time,ed_time,/event <CR>**

For 34GHz event-mode data,

`IDL>` **norh_pr_info,st_time,ed_time,/event,freq=34 <CR>**

Then you will get

```
                 Start      End   Schedule   StFr   EdFr
                  (UT)      (UT)
 1998-06-30 22:45:22  06:44:56   980701       1  28775
 1998-07-01 22:45:24  06:44:57   980702       1  28774
```

One line is for one NoRH schedule (Appendix A.2). From left, start time,end time, schedule ID, start frame number, end frame number. If you see the observation logs ('lob' data: Appendix A.11),

`IDL>` **norh_pr_info,st_time,ed_time,/log <CR>**

You will get

```
### 92/07/24
Data between 08:03 and 08:35 were lost.

### 92/07/31
*Phase tracking software bug was fixed. Phase jumps which were found every
250 sec. will disappear.
```

3.2.2 Event List

There is a data base for the events ('evx' data: Appendix A.10). In order to list them, e.g. on 1998-4-23 UT,

`IDL>` **norh_pr_evx,'1998-04-23' <CR>**

or for data from 1998-4-23 UT to 4-27 UT,

`IDL>` **st_time='1998-04-23' <CR>**
`IDL>` **ed_time='1998-04-27' <CR>**
`IDL>` **norh_pr_evx,st_time,ed_time <CR>**

For 34 GHz event list,

`IDL>` **norh_pr_evx,st_time,ed_time,freq=34 <CR>**

For the events that are beyond some averaged correlation value (say, 1.5 %),

`IDL>` **norh_pr_evx,st_time,ed_time,criterion=0.015 <CR>**

To see GOES class and NOAA ID of the active regions of the events[6],

`IDL>` **norh_pr_evx,st_time,ed_time,/goes <CR>**

Moreover you can display even with Yohkoh/HXT counts[7],

`IDL>` **norh_pr_evx,st_time,ed_time,/goes,/hxt <CR>**

[6] It is necessary to have the Yohkoh software and data base installed.
[7] It is necessary to have the Yohkoh software and data base installed.

Then

```
                Start       Peak       End     Dur    Max Cor. / GOES NOAA  Loca- /  HXT
                (UT)        (UT)       (UT)   (sec)  (x 10^-4) /             tion /   Low  Med1  Med2  High
   1992-11-02 02:40:31  02:49:18  03:40:30   3599       1769 / X9.0              /  5278  1500   210    30
   1992-11-05 06:06:44  06:20:41  06:39:59   1995        171 / M2.0              /    68    36    22    15
   1992-11-23 03:33:42  04:31:07  06:37:18  11016        555 / C9.1 7347 S09W13 /    12     7     5    10
```

3.2.3 Tohban Report

After 1998 17th week, data-tohban (duty observer) reports are available ('rep' data: Appendix A.12). The report of 1998 Week 20 is

`IDL>` **norh_pr_rep,1998,20 <CR>**

3.3 Time-series data

After the daily observation, files that contain the averaged correlation value are automatically created from the raw data. This data is convenient for quick-look of the data. Definition of 'correlation' is "averaged values of correlation of antenna pairs (after removing short base-line pairs) of NoRH". Correlation increases as a strong microwave signal comes due to e.g. a flare. So it is used instead of the *real* light curve (plot of flux density). For 17 GHz plot, 1 % of correlation corresponds to 30 SFU flux density. It is used because much computation resource is necessary for image synthesis that is the only method to obtain flux density at each time (see section 3.5.6). And correlation has an advantage that it is almost not affected by the weather condition. However, it does not increase when the flux is so strong because it has an upper limit of unity.

3.3.1 Correlation tcx data

The 'tcx' data is relatively small that uses less memory space (Appendix A.9). But it has no information on circular polarization, and time accuracy is about 1 sec. To read this data, e.g. 1998-4-20 JST 17GHz,

`IDL>` **norh_rd_tcx,'1998-4-20',index,data <CR>**

e.g., from 1998-4-23 JST to 4-27

`IDL>` **norh_rd_tcx,'1998-04-23','1998-04-27',index,data <CR>**

for 34GHz,

`IDL>` **norh_rd_tcx,'1998-4-20',index,data,freq=34 <CR>**

You can directly give the file name as an argument

`IDL>` **norh_rd_tcx,file,index,data <CR>**

To plot the data use the Solar Software standard routine `utplot`

`IDL>` **utplot,index,data <CR>**

3.3.2 Correlation tsx data

The 'tsx' data is relatively huge but including the circular polarization information (for 17GHz only), and the time accuracy is 1 msec (Appendix A.8). To read this data, e.g. 1998-4-20 JST 17GHz,

`IDL>` **norh_rd_tsx,'1998-4-20',index,data <CR>**

e.g., from 1998-4-23 JST to 4-27

`IDL>` **norh_rd_tsx,'1998-04-23','1998-04-27',index,data <CR>**

for 34GHz,

`IDL>` **norh_rd_tsx,'1998-4-20',index,data,freq=34 <CR>**

You can directly give the file name as an argument

`IDL>` **norh_rd_tsx,file,index,data <CR>**

to plot the data use the Solar Software standard routine

`IDL>` **utplot,index,data(0,*) <CR>** ; 17GHz RCP component

`IDL>` **utplot,index,data(1,*) <CR>** ; 17GHz LCP component

`IDL>` **utplot,index,data <CR>** ; 34GHz

3.4 Image Synthesis

3.4.1 Image Files at NSRO Archive

Some synthesized images (Table 1) are put in the NSRO archive (Table C). You can obtain them by anonymous FTP. Before synthesizing by yourself, try them first.

Table 1: Image Files at NSRO Archive

Data	Frequency	Synth. Prog.	Covered duration	Directory
10 min. interval	17GHz	koshix	since 1999	`images/10min`
@3:00 UT (noon in Japan)	17/34GHz	koshix/hanaoka	since Jul 1992	`images/daily`
Event*	17/34GHz	hanaoka/fujiki	since Jun 1992	`images/event`
Weak Event*	17/34GHz	hanaoka	since Jun 1992	`images/eventw`
GOES M,X Event	17/34GHz	hanaoka	since Jun 1992	`images/goes_event`

*: The 'Event's here have peak correlation more than 1.5 %, the 'Weak Event's have more than 0.5 % and less than 1.5 %.

3.4.2 Pre-Processing for Image Synthesis — Transfer of Raw Data

You have to transfer the raw-data and 'SZ' files (Appendix A.3 and A.4) from NSRO archive (Appendix C) to your computer through the network before synthesis of the NoRH images.

Note ! The size of one raw-data file is about 16 Mbytes (that includes 10 minutes of data, i.e. 600 image frames). We strongly recommend the users who are far away (in the sence of the network) to request us to send the data to you by ordinary mail as a form of CD-ROM (Appendix C).

(1) Basics

For example, to transfer the raw data that is necessary to synthesize one frame (image) every 600 seconds between 1997-4-20 1:30 UT and 3:30 UT,

`IDL>` **st_time='1997-04-20 1:30:00'** <**CR**>
`IDL>` **ed_time='1997-04-20 3:30:00'** <**CR**>
`IDL>` **interval=600** <**CR**>
`IDL>` **norh_trans,st_time,ed_time,interval** <**CR**>

(2) Images at specific times

To transfer the raw data that is necessary for synthesis of images at specific times,

`IDL>` **time=['1997-04-20 1:30:00','1997-04-20 1:40:00' ,' 1997-4-21 2:00:00']** <**CR**>
`IDL>` **norh_trans,time** <**CR**>

(3) 34GHz

To transfer 34GHz data,

`IDL>` **norh_trans,time,freq=34** <**CR**>

(4) Event-mode

To transfer event-mode data,

`IDL>` **norh_trans,time,/event** <**CR**>

3.4.3 Image Synthesis

This package has three programs for synthesis, See table 2 for supporting data. Detailed description for each program is given in Section 5.

Note ! All the synthesis programs are written in Fortran 77 (partially 90). The IDL procedures described in this section call externally the executive binaries of these programs. We prepared the binaries for Sun/Sparc, NEC/SX, NEC/EWS architectures in this package. So it is possible to synthesize the NoRH package on machines with these architecture. To run on others, it is necessary to compile them by yourself (You have to purchase commercial numerical library in this case. See Section 5 for detail.).

(1) Basics

For example, to synthesize one frame (image) every 600 seconds between 1997-4-20 1:30 UT and 3:30 UT,

IDL> **st_time='1997-04-20 1:30:00' <CR>**
IDL> **ed_time='1997-04-20 3:30:00' <CR>**
IDL> **interval=600 <CR>**
IDL> **norh_synth,st_time,ed_time,interval <CR>**

Note that in this case, the synthesis program runs on the local workstation that you are working on. To synthesize on some remote machine,

IDL> **norh_synth,st_time,ed_time,interval,host='sx' <CR>**

Then, the program will run on remote machine 'sx' as a foreground job.
To submit the job to the system running under NQS (Network Queing System; standard queing system for super-computers),

IDL> **norh_synth,st_time,ed_time,interval,host='sx',queue='B' <CR>**

(2) Non-uniformly spaced

You may synthesize the images non-uniformly in time. For example, for images at 1997-4-20 1:30, 1:40 and 1997-4-21 2:00 UT,

IDL> **time=['1997-04-20 1:30:00','1997-04-20 1:40:00' ,'1997-4-21 2:00:00'] <CR>**
IDL> **norh_synth,time <CR>**

(3) 34GHz

For synthesis of 34GHz images[8],

IDL> **norh_synth,time,freq=34 <CR>**

(4) Event mode

To synthesize the data of the event mode:

IDL> **norh_synth,time,/event <CR>**

(5) Koshix, Fujiki

The default synthesis program is Hanaoka. To use Koshix or Fujiki, [9]:

IDL> **norh_synth,time,prog='koshix' <CR>**

(6) Partial Sun image

For partial Sun images, the spatial shift from the Sun center to the image center and the size of the field of view have to be given. The spatial shift could be given by unit of [1] arc-seconds or [2] pixel. See table 2 for size of pixel in unit of arcsec. The size of FOV is given as number of pixels. See table 2 for size of field of view in unit of pixels for each synthesis program. For example, for an image that has (-431,54) arc-seconds shift from the Sun center to the image center and with FOV (256× 256) pixels,

IDL> **norh_synth,time,cenunit=1,cenfnl=[-431,54],size=256 <CR>**

For (100,-20) pixel shifted image,

IDL> **norh_synth,time,cenunit=2,cenfnl=[100,-20],size=128 <CR>**

(7) Syntesize an image at the designated time

In default, the frame to be synthesized is chosen by using 'info' data (Appendix A.6). But in this case it sometimes chooses the frame a little bit (1-sec at maximum) away from the designated time. If you need to synthesize image with more accurate timing, use 'tsx' data (Appendix A.8) as follows[10]

IDL> **norh_synth,st_time,ed_time,interval,/usetsx <CR>**

3.5 Data Analysis

3.5.1 Read and display images

You can directly give the file names as an argument.

IDL> **norh_rd_img, file, index, data <CR>**

Then, the images of brightness temperature (unit K) is stored in array 'data' and structure 'index'. To

[8] 34GHz synthesis is only available by program Hanaoka

[9] Fujiki can synthesize only partial images. So it is necessary to give the center of the field-of-view.

[10] This is because 'info' data only contains the start and end times of a schedule but 'tsx' data contains one by one correspondence of frame number and observation time.

display

IDL> **stepper, data, norh_get_info(index)** <**CR**>

3.5.2 Beam Pattern

To obtain a beam pattern

IDL> **beam=norh_beam(index)** <**CR**>

This is a 21×21 pixels array. To display this pattern (contour of half power beam width [HPBW])

IDL> **ocontour,beam,levels=[0.5]** <**CR**>

3.5.3 Coordinate grid

To overlay the coordinate gird on the image,

IDL> **stepper, data(*,*,0), norh_get_info(index(0))** <**CR**>

IDL> **norh_grid, index(0)** <**CR**>

To get the heliographic coordinate of the pointer

IDL> **norh_grid, index(0), /read_out** <**CR**>

3.5.4 Getting Information about Images

To get the observation time

IDL> **print,fmt_tim(index)** <**CR**>

To get the image frequency

IDL> **print,norh_gt_freq(index)** <**CR**>

To get the circular polarization information

IDL> **print,norh_gt_polariz(index)** <**CR**>

To get the position of the image center in the coordinate in which the origin is the solar disk center and the unit is arcsec

IDL> **print,norh_gt_imgcen(index)** <**CR**>

To get the roll of the image (usually zero)

IDL> **print,norh_cen(index,roll=roll)** <**CR**>

To get the exposure duration of the image

IDL> **print,norh_gt_expdur(index)** <**CR**>

3.5.5 Using map procedure of the SolarSoftware

In order to coalign the NoRH image with those obtained by the other instruments, it is convinient to use the map procedures made by Dr. D. Zarro (for detailed information, see `http://orpheus.nascom.nasa.gov/~zarro/idl/maps.html` . The map of the NoRH image can be made as follows:

IDL> **norh_index2map,index,data,map** <**CR**>

IDL> **plot_map,map** <**CR**>

3.5.6 Derivation of Flux Density (F_ν) from Brightness Temperature (T_b)

An NoRH image indicate distribution of brightness temperature (unit K). To know the intensity (unit SFU/sterad) from each pixel,

IDL> **fi=norh_tb2flux(data,index,/intensity)** <**CR**>

The flux density (unit SFU) of the whole image, the procedure is as follows.

IDL> **fi=norh_tb2flux(data,index)** <**CR**>

The flux density from the partial area of an image, $i0 < i < i1$ $j0 < j < j1$ is

IDL> **box=[i0, i1, j0, j1]** <**CR**>

IDL> **fi=norh_tb2flux(data,index,box=box)** <**CR**>

or by giving the (x, y) coordinate (origin solar disk center; unit arcsec), for the area $x0 \leq x \leq x1$ and $y0 \leq y \leq y1$,

IDL> **abox=[x0, x1, y0, y1]** <**CR**>

IDL> **fi=norh_tb2flux(data,index,abox=abox)** <**CR**>

3.5.7 Circular Polarization Degree

From a pair of (R+L) and (R–L) images of 17 GHz, distribution of circluar polarization degree can be obtained. It is used for judging the emission mechanism and/or deriving the magnetic field strength. The definition is;

$$r_c \equiv \frac{F_\nu^{(R-L)}}{F_\nu^{(R+L)}} = \frac{T_b^{(R-L)}}{T_b^{(R+L)}}$$

Minimum is –1 (perfectly left-handed circular polarized), and maximum is +1 (perfectly right-handed circular polarized). The procedure is :

```
IDL> file='./ipa990828_005642' <CR>
IDL> norh_rd_img,file,indexa,dataa <CR>
IDL> file='./ips990828_005642' <CR>
IDL> norh_rd_img,file,indexs,datas <CR>
IDL> fi17=norh_tb2flux(dataa,indexa,/intensity) <CR>
IDL> fv17=norh_tb2flux(datas,indexs,/intensity) <CR>
IDL> norh_polariz,indexa,fi17,indexs,fv17,indexp,pol,mvdp <CR>
```

`pol` is an array of r_c. `mvdp` is an array including the values of unity (1) for valid data or zero (0) for non-valid data. `indexp` is an index correspoinding to data `pol`.

3.5.8 Make the Size of Beams Same between Two Images

In order to analyze data of dual frequency observation, the size of the beams have to be made same before taking ratio. The method is as follows,

```
IDL> norh_rd_img,file0,index0,data0 <CR>
IDL> norh_rd_img,file1,index1,data1 <CR>
IDL> norh_convol,index1,index0,data0,index0c,data0c <CR>
```

By `norh_convol`, data `data0` is convolved by a beam associated with `index1`. The pixel size of the result array `data0c` will become the coarser one between the beam and the image. Similarly,

```
IDL> norh_convol,index0,index1,data1,index1c,data1c <CR>
```

then `data0c` and `data1c` have the same beam and the same pixel size.

3.5.9 Spectrum Distribution

From a pair of 17GHz and 34GHz images, spectrum distribution can be obtained. It is used for judging the emission mechanism and/or deriving the power-law index of non-thermal elecrons. The derived variable is α whose definition is

$$F_\nu \propto \nu^\alpha$$

Since available frequencies for NoRH are only two, the actual derivation is

$$\alpha = \frac{\log\left(F_\nu^{34\mathrm{GHz}}/F_\nu^{17\mathrm{GHz}}\right)}{\log\left(34\mathrm{GHz}/17\mathrm{GHz}\right)}$$

By using a pair of images of 17 GHz and 34 GHz with the same field of view

```
IDL> file='./ipa990828_005642' <CR>
IDL> norh_rd_img,file,indexa,dataa <CR>
IDL> file='./ipz990828_005642' <CR>
IDL> norh_rd_img,file,indexz,dataz <CR>
IDL> fi17=norh_tb2flux(dataa,indexa,/intensity) <CR>
IDL> fi34=norh_tb2flux(dataz,indexz,/intensity) <CR>
IDL> norh_convol,indexz,indexa,fi17,indexa_c,fi17_c <CR>
IDL> norh_convol,indexa,indexz,fi34,indexz_c,fi34_c <CR>
IDL> norh_alpha,indexa_c,fi17_c,indexz_c,fi34_c ,indexal,alpha,mvda <CR>
```

`alpha` is the power law index of spectrum α. `mvda` is an array including the values of unity (1) for valid data or zero (0) for non-valid data. `indexal` is an index correspoinding to data `alpha`.

3.5.10 Curves of Flux, Circular Polarization, and Spectrum Index from a Partial Area

In order to obtain curves of flux, circular polarization degree, and spectrum index from a partial area of a series of images,

`IDL>` **abox=[23,35,33,41]** <CR>
`IDL>` **fi17=norh_tb2flux(dataa,indexa,abox=abox)** <CR>
`IDL>` **fv17=norh_tb2flux(datas,indexs,abox=abox)** <CR>
`IDL>` **fi34=norh_tb2flux(dataz,indexz,abox=abox)** <CR>
`IDL>` **norh_polariz,indexa,fi17,indexs,fv17,indexp,polariz,mvdp** <CR>
`IDL>` **norh_alpha,indexa,fi17,indexz,fi34,indexal,alpha,mvda** <CR>

Plot as, say,

`IDL>` **utplot,indexp,polariz** <CR>
`IDL>` **utplot,indexal,alpha** <CR>

3.5.11 Optically-Thin Non-Thermal Gyrosynchrotron Emission (Preliminary)

Note: The procedures described in this subsection are under testing. Comments are welcome for improvement.

Based on approximation models, the relation between the physical variables of emitting region and the emission can be derived. The electron distribution function is assumed to be the power law.

$$\frac{dNV(E)}{dE} = K\left(\frac{E}{E_0}\right)^{-\delta}$$

where E is electron energy (keV), $NV(E)$ is number of electrons (particles) that has larger energy than E. This distribution is described with parameters δ, E_0, and K. But it is usual to use $NV(E_0) = K/(\delta-1)/E_0^{\delta-1}$ instead of K. And we fix $E_0 = 10$ keV after Dulk (1985).

(a) From Physical Variables to Emission

Inputs; power-law index δ, magnetic field strength (G), angle between magnetic field and line of sight (degree), and NV — total number (particles) of non-thermal electron (of $E > 10$ keV): Outputs; flux density (SFU), circular polarization degree:

By Dulk's (1985) method:

`IDL>` **dulk_gysy,delta,bb,theta,nv,freq,fi,rc** <CR>

If the size of emitting source (by solid angle in unit of sterad) is given additionally, optical depth is also obtained

`IDL>` **dulk_gysy,delta,bb,theta,nv,freq,fi,rc,omega,tau** <CR>

By Ramaty's (1969) method:

`IDL>` **ramaty_gysy,delta,bb,theta,nv,freq,fi,rc** <CR>
`IDL>` **ramaty_gysy,delta,bb,theta,nv,freq,fi,rc,omega,tau** <CR>

(b) From Emission to Physical Variables

Based on Dulk's (1985) model we may derive the physical variables from emission. After deriving α (see 3.5.9), power law index of non-thermal electron distribution function is

`IDL>` **norh_alpha,indexa,fi17,indexz,fi34 ,indexal,alpha,mvda** <CR>
`IDL>` **norh_alpha2delta,alpha,delta** <CR>

If V-component (R−L) of 17 GHz is given adding to this, physical variables can be derived to some extent. For this, we have to assume one of three variables to be obtained — magnetic field strength (G), angle between magnetic field and line of sight (degree), and total number of non-thermal electron of $E > 10$ keV (particles).

`IDL>` **norh_gysy_inv,fi17,fi34,delta,fv17,thetain,bb,nv,/assumetheta** <CR>
`IDL>` **norh_gysy_inv,fi17,fi34,delta,fv17,bbin,nv,theta,/assumebb** <CR>
`IDL>` **norh_gysy_inv,fi17,fi34,delta,fv17,nvin,theta,bb,/assumenv** <CR>

Adding to this, if the size of emission source is given (as solid angle. Unit is sterad), optical thickness is derived

`IDL>` **norh_gysy_inv,fi17,fi34,delta,fv17,thetain,bb,nv,/assumetheta ,omega,tau** <CR>
`IDL>` **norh_gysy_inv,fi17,fi34,delta,fv17,bbin,nv,theta,/assumebb ,omega,tau** <CR>
`IDL>` **norh_gysy_inv,fi17,fi34,delta,fv17,nvin,theta,bb,/assumenv ,omega,tau** <CR>

Note: In case of images, make the size of beams same between two images (see section 3.5.8).

3.5.12 Optically-Thin Thermal Free-Free Emission (Preliminary)

Note: The procedures described in this subsection are under testing. Comments are welcome for improvement.

Based on Dulk (1985)'s approximation model, the relation between the physical variables of emitting region and the emission can be derived.

(a) From Physical Variables to Emission

Inputs; electron temperature (K), line-of-site component of magnetic field (G), and volume emission measure (cm^{-3}) Outputs; flux density (SFU), circular polarization degree:

`IDL>` **dulk_frfr,te,b_loc,vem,freq,fi,rc <CR>**

If the size of emitting source (by solid angle in unit of sterad) is given additionally, optical depth is also obtained

`IDL>` **dulk_frfr,te,b_loc,vem,freq,fi,rc,omega,tau <CR>**

(b) From Emission to Physical Variables

Inputs; I-component (R+L) and V-component (R−L) of flux density (SFU): Outputs; line-of-sight component of magnetic field (G), $VEM/\sqrt{T_e}$ where VEM is volume emission measure, T_e is electron temperature:

`IDL>` **norh_frfr_inv,fi,fv,b_los,vem_over_sqrtte <CR>**

If one of VEM or T_e is assumed, the other is derived:

`IDL>` **norh_frfr_inv,fi,fv,b_los,tein,vem,/assumete <CR>**

`IDL>` **norh_frfr_inv,fi,fv,b_los,vemin,te,/assumevem <CR>**

Adding to this, if the size of emission source is given (as surface angle. Unit is sterad), optical thickness is derived

`IDL>` **norh_frfr_inv,fi,fv,b_los,tein,vem,/assumete,omega,tau <CR>**

`IDL>` **norh_frfr_inv,fi,fv,b_los,vemin,te,/assumevem,omega,tau <CR>**

3.6 Example of Analysis Session

3.6.1 Choose an Event

Many interesting events are introduced in NoRP web site. It is recommended to access first to these pages. The URL is

`http://solar.nro.nao.ac.jp/norh/`

3.6.2 Light Curves

After choosing an event for analysis, see the light curves. It is useful to plot the correlation instead of the flux density. The method is as follows (Fig 1).

`IDL>` **norh_rd_tcx,'1999-8-28',index,data <CR>**

`IDL>` **utplot,index,data,/ylog <CR>**

Definition of 'correlation' is "averaged values of correlation of antenna pairs (after removing short baseline pairs) of NoRH". Correlation increases as a strong microwave signal comes due to e.g. a flare. So it is used instead of the *real* light curve (plot of flux density). For 17 GHz plot, 1 % of correlation corresponds to 30 SFU flux density. It is used because much computation resource is necessary for image synthesis that is the only method to obtain flux density at each time (see section 3.5.6). And correlation has an advantage that it is almost not affected by the weather condition. However, it does not increase when the flux is so strong because it has an upper limit of unity.

3.6.3 Image Synthesis

For the choosen event, synthesize images. Before this, search for the already synthesized images in our FTP server since we prepare images for most of the important events. The URL is `ftp://nsro-archive.nro.nao.ac.jp/norh` It can be reached by following the link in our web page[11].

For the one who wants to synthesize by her/himself, do the following two sets of commands. `IDL>` **norh_trans,['1999-8-28 0:56:42']<CR>**

[11] They are under `/archive/pub/norh/images` in NSRO.

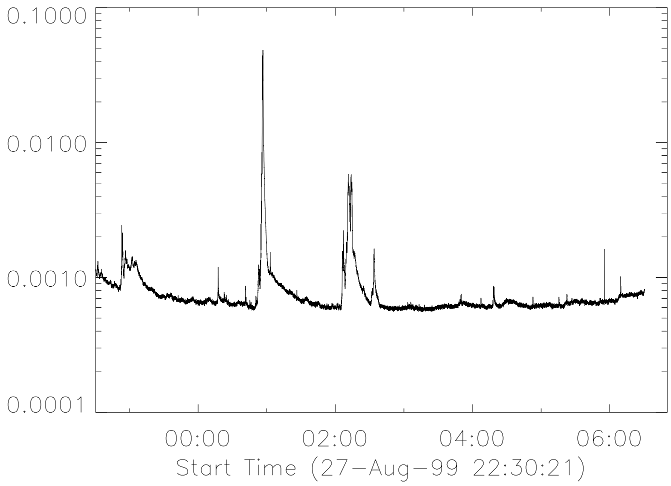

Figure 1: Light curves (Correlation plot)

IDL> **norh_synth,['1999-8-28 0:56:42']<CR>** [12]

The former is for transfering the raw data file (`ss17990828...` including Fourier components and `sz00990828...` including ephemeris parameters) from NSRO archive to the current directory. It takes several minutes depending on the network condition. Please ignore the warning message "`No such file or directory`". If the trasfer is successful, you have files named `ss17990828027` (≈ 16 Mbyte) and `sz00990828001` (≈ 200 byte). The second command is the actual synthesis procedure and it takes tens of seconds to a few minutes per an image. If it is successful, you will obtain `ifa990828_005642` and `ifs990828_005642` in the current directory. These are the FITS files whose contents are NoRH (R+L) and (R–L) images, respectively. For spectrum analysis, make also 34 GHz image,

IDL> **norh_trans,['1999-8-28 0:56:42'],freq=34<CR>**

IDL> **norh_synth,['1999-8-28 0:56:42'],freq=34<CR>** [13]

Similarly, the raw data files (`ss17990828...` and `sz00990828...` are transformed and image FITS file `ifz990828_005642` is made. Note only (R+L) component for 34 GHz image.

3.6.4 Image Plot

Next, plot the images. We use a FITS file `ipa990828_005642`. This file contains "an image of partial Sun of 17 GHz (R+L) component at 00:56:42 UT on Aug 28, 1999". To read

IDL> **file='./ipa990828_005642' <CR>**

IDL> **norh_rd_img,file,indexa,dataa <CR>**

IDL> **stepper,dataa,norh_get_info(indexa) <CR>**

IDL> **norh_grid,indexa <CR>**

Easy plot is (Fig 2)

IDL> **norh_plot,indexa,dataa <CR>**

The unit of data is brightness temperature (K). Solar north is up.

For preparing to overplot with other instrumental data, change the data format to SolarSoftware map.

IDL> **norh_index2map,indexa,dataa,mapa <CR>**

IDL> **plot_map,mapa,/cont,/grid <CR>**

IDL> **beam=norh_beam(indexa,xbeam=xbeam) <CR>**

IDL> **contour,beam,!x.crange(0)+xbeam,!y.crange(0)+xbeam,/over,levels=[0.5] <CR>**

[12]Add option "host='sx'" in NSRO for faster synthesis.

[13]Add option "host='sx'" in NSRO for faster synthesis.

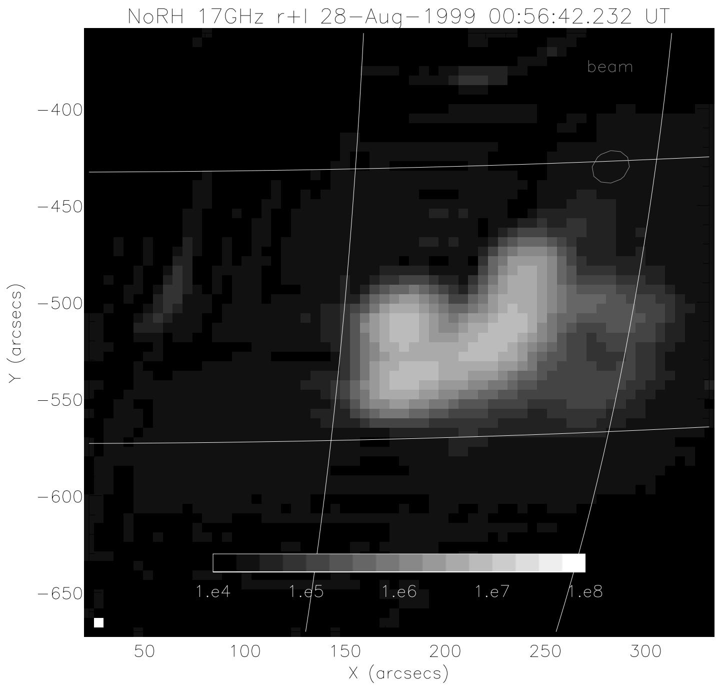

Figure 2: 17GHz (R+L) image

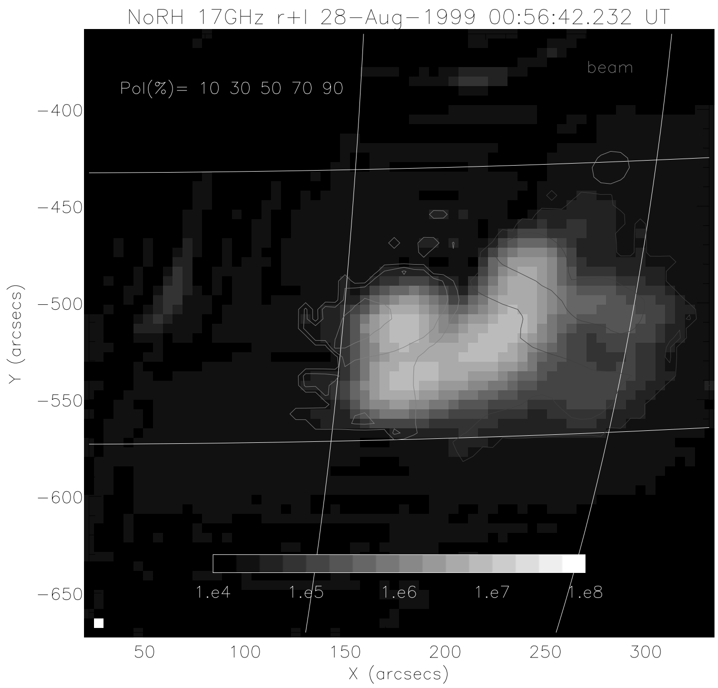

Figure 3: distribution of 17GHz circular polarization degree

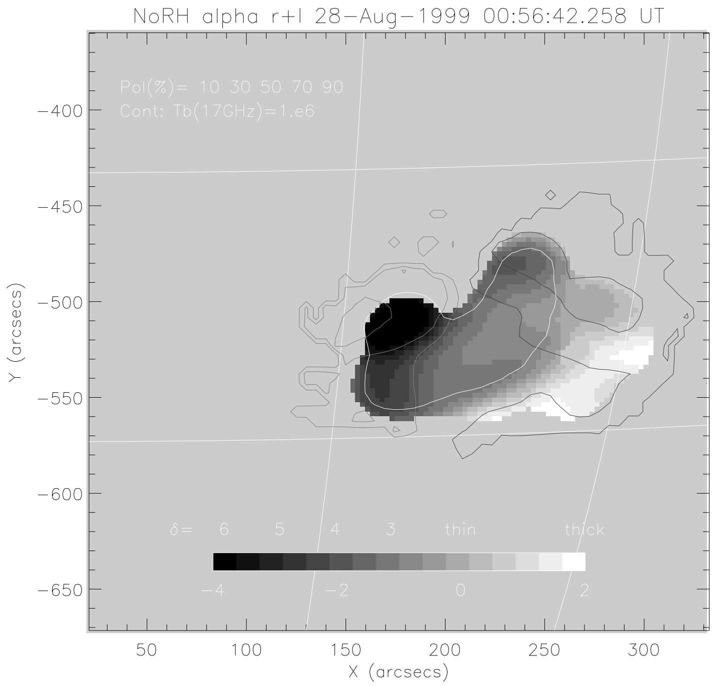

Figure 4: Spectrum Distribution (gray scale), $T_b^{17\mathrm{GHz}} = 1\mathrm{MK}$ (contour of thick line), and circular polarization degree (contour of thin line)

3.6.5 Polarization Plot

From a pair of 17GHz and 34GHz images, spectrum distribution can be obtained. It is used for judging the emission mechanism and/or deriving the power-law index of non-thermal elecrons. The derived variable is α whose definition is

$$F_\nu \propto \nu^\alpha$$

Since available frequencies for NoRH are only two, the actual derivation is

$$\alpha = \frac{\log{(F_\nu^{34\mathrm{GHz}}/F_\nu^{17\mathrm{GHz}})}}{\log{(34\mathrm{GHz}/17\mathrm{GHz})}}$$

By using a pair of images of 17 GHz and 34 GHz with the same field of view

```
IDL> file='./ips990828_005642' <CR>
IDL> norh_rd_img,file,indexs,datas <CR>
IDL> fi17=norh_tb2flux(dataa,indexa,/intensity) <CR>
IDL> fv17=norh_tb2flux(datas,indexs,/intensity) <CR>
IDL> norh_polariz,indexa,fi17,indexs,fv17,indexp,pol,mvdp <CR>
```

`pol` is an array of r_c. `mvdp` is an array including the values of unity (1) for valid data or zero (0) for non-valid data. `indexp` is an index correspoinding to data `pol`. For easy plot (Fig 3)

```
IDL> norh_plot,indexa,dataa,indexp,pol,mvdp <CR>
```

For preparing to overplot with other instrumental data, change the data format to SolarSoftware map.

```
IDL> norh_index2map,indexp,pol*mvdp,mappol <CR>
IDL> plot_map,mappol,/cont,levels=[-0.8,-0.4,-0.2,0.2,0.4,0.8] <CR>
```

3.6.6 Spectrum Distribution

From a pair of 17GHz and 34GHz images, spectrum distribution can be obtained. It is used for judging the emission mechanism and/or deriving the power-law index of non-thermal elecrons. The derived variable is α whose definition is

$$F_\nu \propto \nu^\alpha$$

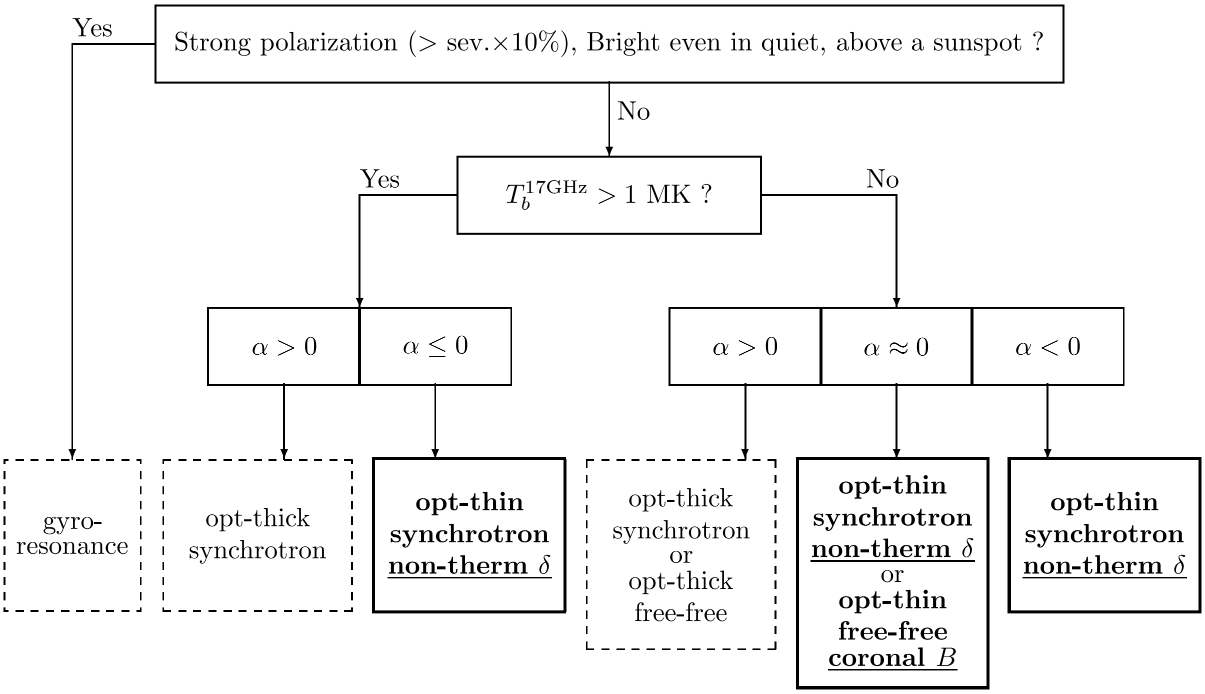

Figure 5: Chart for interpretation of emission mechanism from the spectrum distribution

Since available frequencies for NoRH are only two, the actual derivation is

$$\alpha = \frac{\log\left(F_\nu^{34\mathrm{GHz}}/F_\nu^{17\mathrm{GHz}}\right)}{\log\left(34\mathrm{GHz}/17\mathrm{GHz}\right)}$$

By using a pair of images of 17 GHz and 34 GHz with the same field of view

```
IDL> file='./ipa990828_005642' <CR>
IDL> norh_rd_img,file,indexa,dataa <CR>
IDL> file='./ipz990828_005642' <CR>
IDL> norh_rd_img,file,indexz,dataz <CR>
IDL> fi17=norh_tb2flux(dataa,indexa,/intensity) <CR>
IDL> fi34=norh_tb2flux(dataz,indexz,/intensity) <CR>
IDL> norh_convol,indexz,indexa,fi17,indexa_c,fi17_c <CR>
IDL> norh_convol,indexa,indexz,fi34,indexz_c,fi34_c <CR>
IDL> norh_alpha,indexa_c,fi17_c,indexz_c,fi34_c ,indexal,alpha,mvda <CR>
```

`alpha` is the power law index of spectrum α. `mvda` is an array including the values of unity (1) for valid data or zero (0) for non-valid data. `indexal` is an index correspoinding to data `alpha`. For easy plot (Fig 4)

```
IDL> norh_plot_alpha,indexal,alpha,mvda,indexp,pol,mvdp,indexa,dataa <CR>
```

For preparing to overplot with other instrumental data, change the data format to SolarSoftware map.

```
IDL> norh_index2map,indexal,alpha*mvda,mapalpha <CR>
IDL> plot_map,mapalpha,dmin=-4,dmax=2 <CR>
```

3.6.7 Interpretation of Data

The interpretation is done by using the chart in Figure 5. Physical information can be obtained when the emission is by "optically-thin gyrosynchrotron" or by "optically-thin free-free". We can derive the variable using the Dulk's (1985) models.

In case "optically-thin gyrosynchrotron" emission, we obtain power-law index of the non-thermal electrons. Here we assume the distribution function of electrons to be

$$\frac{dNV(E)}{dE} = K\left(\frac{E}{E_0}\right)^{-\delta}.$$

where E is electron energy (keV), $NV(E)$ is number of electrons (particles) that has larger energy than E. This distribution is described with parameters δ, E_0, and K. But it is usual to use $NV(E_0) = K/(\delta-1)/E_0^{\delta-1}$ instead of K. And we fix $E_0 = 10$ keV after Dulk (1985). If we find the emission to be "optically-thin gyrosynchrotron", we will obtain δ from α by

$$\delta = -1.1(\alpha - 1.2).$$

In case "optically-thin free-free" emission, we obtain line-of-sight component of coronal magnetic field. From the circular polarization degree r_c,

$$B \approx 30\mathrm{G}\left(\frac{r_c}{1\%}\right).$$

For example, figure 4 can be interpreted as follows: First, the strong polarized source at $(x, y) = (180, -520)$ is by gyroresonance. It may be confirmed by comparing the image with optical magnetogram to see if there is a sunspot. Next, the area inside the contour line of $T_b^{17\mathrm{GHz}} = 1\mathrm{MK}$ is emitting by optically-thin gyrosynchrotron. Non-thermal power-law index δ is obtained from α immediately and we see that the emission from two-sides of the loop structure is 'softer' than that of the top. Next is for the area where $T_b^{17\mathrm{GHz}} < 1\mathrm{MK}$. Around $(x, y) = (270, -500)$, it is hard to judge if it is 'optically-thin gyrosynchrotron' or "optically-thin free-free" because $\alpha \approx 0$. If it is bright in soft X-ray it may be free-free emission. In this case, line-of-sight component of coronal magnetic field is obtained. Since the other area has $\alpha > 0$, it is optically thick and no information can be obtained.

3.7 Others

3.7.1 Read Raw Data Directly

In order to read raw data directly,

`IDL>` **norh_rd_rdt,st_time,ed_time,rdata,header <CR>**

for 34 GHz

`IDL>` **norh_rd_rdt,st_time,ed_time,rdata,header,freq=34 <CR>**

These are in case the raw data is installed under directory `${NORH}/rawd`. To read the raw data after copying to the current directory,

`IDL>` **norh_rd_rdt,st_time,ed_time,rdata,header,dir_raw='.' <CR>**

To read by giving file name

`IDL>` **norh_rd_rdt17,file,rdata,header <CR>**

`IDL>` **norh_rd_rdt34,file,rdata,header <CR>**

For obtaining observing time (JST)

`IDL>` **timej=norh_rdt2timej(rdata) <CR>**

3.7.2 Antenna/Antenna-Pair ID and Name

Each NoRH antenna has its own ID number and name. The correspondance is

`IDL>` **antname=norh_antnum2name(indgen(84)) <CR>**

The inverse is

`IDL>` **antnum=norh_antname2num(['n15','w01']) <CR>**

Each NoRH anttena-pair pair has its own ID number. The correspondance of this number and the names of anttennas of this pair is given by

`IDL>` **ant=norh_pair2ant(indgen(84*83/2)) <CR>**

The inverse is

`IDL>` **pair=norh_ant2pair([0,28]) <CR>**

3.7.3 Sun Position at Nobeyama

The azimuth and elevation of the Sun at Nobeyama is obtained by

`IDL>` **norh_t2azel,time,az,el <CR>**

Unit is degree.

3.7.4 Make original SZ file

For making original SZ file by some reason,
`IDL>` **norh_mksz,date <CR>**
For unusing some data obtained by some paticular antenna from synthesis procedure, make a new SZ file
`IDL>` **norh_mksz,date,['n1','e10'] <CR>**
In this example, data of antenna N01 and E10 are unused.

4 Analysis without IDL

It is described in this section how to analyse the NoRH data *without* IDL. This is based on the UNIX commands, C-shell scripts and free astronomy softwares such as AIPS, IRAF etc.

4.1 Data Base

The observation time (info), logs (lob), event lists (evx) are recorded in ASCII text files. you can read them directly by using any editor softwares. The detailed explanation of each file is given in Appendix A.

4.2 Time-series data and Images

Time-series averaged correlation (tcx, tsx) and images (ifx, ipx) are both recorded as FITS format files. You can read them by using popular free astronomy softwares such as AIPS, IRAF etc.

4.3 Image data

4.3.1 Image Files at NSRO Archive

Some synthesized images (Table 1) are put in the NSRO archive (See Section C). You can obtain them by anonymous FTP. Before synthesizing by yourself, try them first.

4.3.2 Transfer of raw data

You have to transfer the raw-data and 'SZ' files (Appendix A.3 and A.4) from NSRO archive (Appendix C) to your computer through the network before synthesis of the NoRH images. It is convenient to use the `norh_trans` command for this purpose. This is a C-shell script that can be run on any UNIX machine. Or you can directly log in the NSRO anonymous FTP server.

Note ! The size of one raw-data file is about 16 Mbytes (that includes 10 min. of data, i.e. 600 image frames). We strongly ask the users who are far away (in the sence of the network) to request us to send the data to you by ordinary mail as a form of CD-ROM (see Appendix C).

(1) By using norh_trans
After editing the input file (say `input`) adequately
`unix%` **norh_trans input <CR>**
The raw data files as well as corresponding 'SZ' files will be transfered. The format of the input file is as follows:

```
ss17980214006         # 17GHz
ss34980214006         # 34GHz
ss17920812002 b       # schedule b
se17990216085759      # event
```

One line corresponds to one raw-data file. For steady-mode data that has multiple schedules (Appendix A.2),
(file name) (schedule ID)
The explanation for schedule and names of files are given in Appendix A.

(2) By logging in to anonymous FTP server
You can get the data by logging in to the FTP server,
`unix%` **ftp nsro-archive.nro.nao.ac.jp <CR>**
The NoRH raw-data is put in the directory `/pub/norh/raw`. Do not forget to retrieve the 'SZ' file for corresponding day.

4.3.3 Image synthesis

This package has three programs for synthesis, See table 2 for supporting data. Detailed description for each program is given in Section 5.
Note ! All the synthesis programs are written in Fortran 77 (partially 90). The C-shell scripts described in this section call externally the executive binaries of these programs. We prepared the binaries for

Sun/Sparc, NEC/SX, NEC/EWS architectures in this package. So it is possible to synthesize the NoRH package on machines with these architecture. If you run on other, it is necessary to compile them by yourself (You have to purchase commercial numerical library in this case. See section 5 for detail.).

It is convenient to use the `norh_synth` command for synthesis. This is a C-shell script that can be run on any UNIX machine. After editing the input file (say `input`)

`unix%` **norh_synth input <CR>**

The format of input file is dependent on what synthesis program is used. See section 5 for detailed information.

The default program is Hanaoka for 17GHz data. For 34GHz data,

`unix%` **norh_synth -p hanaoka34 input <CR>**

For using Fujiki,

`unix%` **norh_synth -p fujiki17 input <CR>**

For using Koshix,

`unix%` **norh_synth -p koshix17 input <CR>**

4.4 Pre-processing for usage of AIPS

AIPS is a popular software among the radio astronomical society. You have to re-format the NoRH raw data to be readable by AIPS. The program `c2fits` is developed for this purpose.

For 17GHz data,

`unix%` **c2fits17 < input <CR>**

For 34GHz data,

`unix%` **c2fits34 < input <CR>**

The format of input file (a template is given in ${NORH}`/soft/c2fits`) is as follows,

```
Inputs file for C2FITS17
-----------------------------------------------------------------
Data file path and prefix     : ./ss17921008
Ephemeris file path and name  : ./sz00921008001
Frame info file path and name : ./info
Phase diff file path and name : ../../../data/rlphdif/sun0706_2rlphdif
Output file path and name     : 921008F
Start time                    : 110000
End time                      : 111000
UT or JST?                    : JST
Image Averging time           :  10
Image Increment               : 300
Smoothing Time (sec)          :   1
Bypass Amplitude Calibration? :  NO
Fixed Calibration Interval?   :  NO
Start time of interval        : 120001
End time of interval          : 120010
Dump calibration solutions?   :  NO
Skip output of FITS files?    :  NO
-----------------------------------------------------------------

Note 1: The meaning of bypassing the amplitude calibration is that
        instead of computing the amplitude of the complex gains
        explicitly, the value 1.0 is used for all antennas. If the
        amplitude calibration is bypassed the amplitude smoothing
        time is ignored.

Note 2: If a fixed calibration interval is used, the smoothing time
        is ignored. It is assumed that the time standard for the
        fixed calibration interval is the same as that of the data
        interval.
```

Table 2: Summary of synthesis programs

	Supported data [Yes/No]			Pixel Size [arcsec]		Field of View [pixel]	
	17/34GHz	Steady/Event	Full/Part	17GHz	34GHz	17GHz	34GHz
Hanaoka	Y/Y	Y/Y	Y/Y	4.9	2.45	≤ 512	≤ 1024
Koshix	Y/N	Y/Y	Y/Y	4.9	–	≤ 512	–
Fujiki	Y/N	Y/Y	–/Y	2.45	–	128	–

	Note
Hanaoka	good at flares, no-good at diffuse sources
Koshix	good at diffuse faint sources, no-good at flares
Fujiki	high-spatial resolution synthesis of compact sources

5 Detailed Description of Synthesis Programs

The standard NoRH synthesis programs, Hanaoka, Koshix, Fujiki are explained in this section (table 2). The executable binary files are given for Sun/Sparc, NEC/EWS, NEC/SX architectures in this package. Compile procedure will be necessary if you run these programs on others. See section 5.4 (You may have to purchase commercial numerical libraries).

5.1 Hanaoka

This is the most basic program for synthesis. It applies the CLEAN algorithm to the point sources on the images and is good at analysis of flares. On the other hand, it is not good at diffuse sources.
Present version ver. 6.2
Supported computer architecture NEC/SX, NEC/EWS, Sun/Sparc
Supported data 17GHz/34GHz, Steady/Event, Full/Partial Sun
Pixel Size 4.9 arcsec/pixel (17GHz), 2.45 arcsec/pixel (34GHz)
Field of View Under 512 pixels for 17GHz. Under 1024 pixels for 34GHz.
How to use

(1) `unix%` **hanaoka17 < input**
(2) `unix%` **norh_synth -p hanaoka17 input**
(3) `IDL>` **norh_synth,time,prog='hanaoka',freq=17**
(4) `unix%` **hanaoka34 < input**
(5) `unix%` **norh_synth -p hanaoka34 input**
(6) `IDL>` **norh_synth,time,prog='hanaoka',freq=34**

Example of input file

The line numbers are given for convinience. The item with (`*`) usually do not have to be changed. A template is given in `${NORH}/soft/synthesis/hanaoka`.

17GHz

```
 1:  .               ; output directory
 2:  ss17980419      ; raw-data file name
 3:  sz00980419001   ; 'SZ' file name
 4:  512             ; FOV pixel size
 5:  1,0,0           ; image center offset from Sun center
 6:  1               ; start frame number
 7:  3600            ; end frame number
 8:  600             ; frame interval
 9:  1               ; *number of integration frames for calibration
10:  1               ; *number of integration frames for synthesis
11:  -0.5,-0.5       ; *CLEAN criterion 1 (R+L), (R-L)
12:  0.01            ; *CLEAN criterion 2
```

34GHz

```
 1:  .               ; output directory
 2:  ss34980419      ; raw-data file name
 3:  sz00980419001   ; 'SZ' file name
 4:  1024            ; FOV pixel size
 5:  1,0,0           ; image center offset from Sun center
 6:  1               ; start frame number
 7:  3600            ; end frame number
 8:  600             ; frame interval
 9:  1               ; *number of integration frames for calibration
10:  1               ; *number of integration frames for synthesis
11:  -1              ; *CLEAN criterion 1
12:  0.01            ; *CLEAN criterion 2
```

Explanation for each item

(line 1) output directory

(line 2) raw-data file name

In case of steady-mode data, give only `ss`*FFYYMMDD* where *FF* is frequency (17 or 34), *YYMMDD* is the date of observation. Do not give full file name like `ss`*FFYYMMDD###* where *###* is the file number. That is automatically calculated from the given frame. In case of event-mode data, give full file name.

(line 3) 'SZ' file name

'SZ' file name corresponding to the date of the raw-data file.

(line 4) pixel size of the field of view

A square region with pixel size given in this line will be the field of view of the syntehsized image. In case of 17GHz data, the full Sun image is 512-pixel square, and in case of 34GHz data, that is 1024-pixel square. Pixel size is 4.9 (2.45) arcsec for 17GHz (34GHz).

(line 5) image center offset from Sun center

Give non-zero values if you synthesize an image with the center that has an offset from the Sun center. The first element indicates the unit of shift, arcsec if 1, pixel if 2. If you do *not* want to get a shifted image, just give '`1,0,0`'.

(line 6) first frame to synthesize

Give zero in case of non-uniform interval.

(line 7) last frame to synthesize

Give number of frames in case of non-uniform interval.

(line 8) frame interval

Give frame numbers in case of non-uniform interval. If it's too long, give in multiple lines.

(line 9) number of intergration frames for calibration

(line 10) number of intergration frames for synthesis

(line 11) CLEAN criterion 1
Continue CLEAN until the maximum of the dirty map will become this value. The unit is brightness temperature (steady solar disk is 10000 K). The criterion that is given in the next item (line 12) will be adopted if it is larger than this value. If given values are negative, the absolute value of them times the disk brightness would be adopted as the criterion. For 17GHz data, give values for (R+L) and (R-L), the recommended values are -0.5 and -0.5, respectively. For 34GHz data, give value only for (R+L), the recommended value is -1.

(line 12) CLEAN criterion 2
This given value times the maximum of the dirty map will become the other criterion for CLEAN algorithm. The criterion given in the previous item (line 11) will be adopted if it is larger than this value. The recommended value is 0.01. It is safer to give larger value for poor S/N data.

5.2 Koshix

This program is based on the Steer algorithm. It applies the CLEAN method to the diffuse sources on the images and is good at analysis of the quiet Sun and filaments. On the other hand, it is not good at flares.

Present version ver. 6.2
Supported computer architecture NEC/SX, NEC/EWS, Sun/Sparc
Supported data 17GHz (non-support for 34GHz), Steady/Event, Full/Partial Sun
Pixel Size 4.9 arcsec/pixel
Field of View Under 512 pixels.
How to use

(1) `unix%` **koshix17 < input**
(2) `unix%` **norh_synth -p koshix17 input**
(3) `IDL>` **norh_synth,time,prog='koshix',freq=17**

Example of input file

The line numbers are given for convinience. The item with (`*`) usually do not have to be changed. A template is given in `${NORH}/soft/synthesis/koshix`.

1:	`.`	; output directory
2:	`ss17980419`	; raw-data file name
3:	`sz00980419001`	; 'SZ' file name
4:	`512`	; FOV pixel size
5:	`1,0,0`	; image center offset from Sun center
6:	`1`	; start frame number
7:	`3600`	; end frame number
8:	`600`	; frame interval
9:	`1`	; *number of integration frames for calibration
10:	`1`	; *number of integration frames for synthesis
11:	`3000,3000`	; *CLEAN criterion (R+L), (R-L)

Explanation for each item

(line 1) output directory

(line 2) raw-data file name

In case of steady-mode data, give only `ss`*FFYYMMDD* where *FF* is frequency (17 or 34), *YYMMDD* is the date of observation. Do not give full file name like `ss`*FFYYMMDD###* where *###* is the file number. That is automatically calculated from the given frame. In case of event-mode data, give full file name.

(line 3) 'SZ' file name

'SZ' file name corresponding to the raw-data file.

(line 4) pixel size of the field of view

A square region with pixel size given in this line will be the field of view of the syntehsized image. In case of 17GHz data, the full Sun image is 512-pixel square, and in case of 34GHz data, that is 1024-pixel square. Pixel size is 4.9 (2.45) arcsec for 17GHz (34GHz).

(line 5) image center offset from Sun center

Give non-zero values if you synthesize an image with the center that has an offset from the Sun center. The first element indicates the unit of shift, arcsec if 1, pixel if 2. If you do *not* want to get a shifted image, just give '`1,0,0`'.

(line 6) first frame to synthesize

Give zero in case of non-uniform interval.

(line 7) last frame to synthesize

Give number of frames in case of non-uniform interval.

(line 8) frame interval

Give frame numbers in case of non-uniform interval. If it's too long, give in multiple lines.

(line 9) number of intergration frames for calibration

(line 10) number of intergration frames for synthesis

(line 11) CLEAN criterion 1
Continue CLEAN until the maximum of the dirty map will become this value. The unit is brightness temperature (steady solar disk is 10000 K). For 17GHz data, give values for (R+L) and (R-L), the recommended values are 3000 and 3000, respectively.

5.3 Fujiki

It is possible to analyze the flare images in detail with this program because it synthesizes the compact sources with a narrow beam by emphasizing the power of the higher wavenumber components. This program always outputs the partial Sun images.

Present version ver. 6.2
Supported computer architecture NEC/SX, NEC/EWS, Sun/Sparc
Supported data 17GHz (non-support for 34GHz), Steady/Event, Partial Sun
Pixel Size 2.45 arcsec/pixel
Field of View 128 pixels fixed.
How to use

(1) `unix%` **fujiki17 < input**
(2) `unix%` **norh_synth -p fujiki17 input**
(3) `IDL>` **norh_synth,time,prog='fujiki',freq=17**

Example of input file

The line numbers are given for convinience. The item with (`*`) usually do not have to be changed. A template is given in `${NORH}/soft/synthesis/fujiki`.

```
 1:  .              ; output directory
 2:  ss17980419     ; raw-data file name
 3:  sz00980419001  ; 'SZ' file name
 4:  1,0,0          ; image center offset from Sun center
 5:  1              ; start frame number
 6:  3600           ; end frame number
 7:  600            ; frame interval
 8:  1              ; *number of integration frames for calibration
 9:  1              ; *number of integration frames for synthesis
10:  10             ; reference frame number
11:  1              ; *num. of integ. frames for calibration of reference
12:  1              ; *num. of integ. frames for synthesis of reference
13:  10000,10000    ; *CLEAN criterion 1 (R+L), (R-L)
14:  10000,10000    ; *CLEAN criterion 2 (R+L), (R-L)
15:  0.01           ; *CLEAN criterion 3
```

Explanation for each item

(line 1) output directory

(line 2) raw-data file name
In case of steady-mode data, give only `ssFFYYMMDD` where `FF` is frequency (17 or 34), `YYMMDD` is the date of observation. Do not give full file name like `ssFFYYMMDD###` where ### is the file number. That is automatically calculated from the given frame. In case of event-mode data, give full file name.

(line 3) 'SZ' file name
'SZ' file name corresponding to the raw-data file.

(line 4) image center offset from Sun center
Give non-zero values if you synthesize an image with the center that has an offset from the Sun center. The first element indicates the unit of shift, arcsec if 1, pixel if 2. If you do *not* want to get a shifted image, just give '`1,0,0`'.

(line 5) first frame to synthesize
Give zero in case of non-uniform interval.

(line 6) last frame to synthesize
Give number of frames in case of non-uniform interval.

(line 7) frame interval
Give frame numbers in case of non-uniform interval. If it's too long, give in multiple lines.

(line 8) number of intergration frames for calibration

(line 9) number of intergration frames for synthesis

(line 10) frame number of reference frame

(line 11) number of intergration frames for calibration of reference frame

(line 12) number of intergration frames for synthesis of reference frame

(line 13) CLEAN criterion 1
Continue 1st CLEAN until the maximum of the dirty map will become this value. The unit is brightness temperature (steady solar disk is 10000 K). For 17GHz data, give values for (R+L) and (R-L), the recommended values are 10000 and 10000, respectively. The criterion that is given in the next item (line 15) will be adopted if it is larger than this value.

(line 14) CLEAN criterion 1
Continue 2nd CLEAN until the maximum of the dirty map will become this value. The unit is brightness temperature (steady solar disk is 10000 K). For 17GHz data, give values for (R+L) and (R-L), the recommended values are 10000 and 10000, respectively. The criterion that is given in the next item (line 15) will be adopted if it is larger than this value.

(line 15) CLEAN criterion 2
This given value times the maximum on the dirty map will become the other criterion for CLEAN algorithm. The criterion given in the previous item (line 13) will be adopted if it is larger than this value. The recommended value is 0.01.

5.4 Compilation of synthesis programs

All the synthesis programs are written in Fortran 77 (partially 90). The executable binary files are given for Sun/Sparc, NEC/EWS, NEC/SX architectures in this package. Compile procedure that is explained in this section will be necessary if you run these programs on other architectures. You may have to purchase commercial numerical libraries.

(1) install numerical libraries
Get and install the following numerical libraries.

Fujitsu/SSLII	Commercial	`http://www.fujitsu.co.jp/`
NEC/ASL	Commercial	`http://www.nec.co.jp/`

Note ! NEC/ASL is necessary only to compile on NEC/SX or NEC/EWS.

(2) install the FITSIO library
Get and install the I/O library for FITS format data from
`http://legacy.gsfc.nasa.gov/docs/software/fitsio/`

(3) compile HeliogLib
Compile and create library under `${NORH}/soft/helioglib`.

(4) compile the synthesis programs
Compile the programs under `${NORH}/soft/synthesis`.

Table 3: NoRH data

pre-fix	contents	directory
ss17,ss34	raw data (steady mode)	anywhere [`raw/steady`]
se17,se34	raw data (event mode)	anywhere [`raw/event`]
sz00	'SZ' data	anywhere [`raw/steady`,`data/sz_update`]
ifa,ifs,ifr,ifl,ifz	Full Sun Image	anywhere [`images`]
ipa,ips,ipr,ipl,ipz	Partial Sun Image	anywhere [`images`]
info	observation time	`data/info`
rlphdif	R/L phase difference	`data/rlphdif`
tsa,tsz	averaged correlation	`data/tsx`
tca,tcz	averaged correlation (only R+L)	`data/tcx`
eva,evz	event list	`data/evx`
lob	observation log (antenna conditions etc.)	`data/lob`
rep	tohban report	`data/rep`

[ ] : at the NSRO archive (nsrl-archive)

Table 4: abreviation marks used for file names

YY	last two digits of year
MM	month
DD	day
HH	hour
MN	minute
SS	second
LLL	milli-second
###	sequential number
S	schedule ID

A NoRH data

In this section, the NoRH data is explained in detail (Table 3). We use marks that are explained in Table 4.

A.1 Observation mode of NoRH

Basically there are two modes of NoRH data recording. In the *steady* mode, the raw data is recorded as a *frame* after 1-sec integration. One raw-data *file* has 600 frames (i.e. 600 sec) each and is named with a sequential number. In the *event* mode, the raw data is recorded as a *frame* after 50 milli-seconds (before September 1995) or 100 milli-seconds (after October 1995) integration. The event data is recorded when a flare-event occurs on the Sun. One event-mode *file* corresponds to one flare-event and has almost no limitation on number of frames.

A.2 What is *Schedule* for NoRH ?

The unit of NoRH observation is called *schedule*. In principle, one day has one schedule. But when some trouble happens to the observing system, there may be multiple schedules. The *schedule ID* is given to identify each schedule. They are "date + an alphabet letter". That may be only "date" if there is only one single schedule per day. For example, the schedule ID on July 10, 1992 is "920710" because there was only one schedule on that day. On the other hand, there were two schedules "920712a" and "920712b" on July 12.

A.3 Raw data (ss17,ss34,se17,se34)

File name

`ss17`*YYMMDD###*	steady mode, 17GHz
`ss34`*YYMMDD###*	steady mode, 34GHz
`se17`*YYMMDDHHMNSS*	event mode, 17GHz
`se34`*YYMMDDHHMNSS*	event mode, 34GHz

The *HHMNSS* part in the event data file name is the start time of the event.

Unit of storage

Steady-mode raw data is processed one file per 600 frames (600 seconds), and event-mode is one file per one event.

Directory

Anywhere. In NoRH archive, they are put under `raw`.

A.4 'SZ' data (sz00)

The files that contains information on ephemeris and valid antennas. (1) Ephemeris data: solar declination δ (in arc-degree), hour angle (in time-sec), apparent solar radius (in arc-sec), solar p-angle (in arc-degree), solar b-angle (in arc-degree) at JST noon for previous, present, next days. (2) Valid antenna: In the order of N01 – N28, E28 – E01, and W01 – W28. 0: use when synthesis, 1: unuse.

File name

`sz00`*YYMMDD*`001`

Unit of storage

One file per one day

Directory

Anywhere. In NoRH archive, they are put under `raw/steady`. This file may be updated if some trouble on antennas is found later. In this case, the file will be put in `data/sz_update`.

A.5 Images (ifa,ifs,ifz,ipa,ips,ipz)

FITS format files that contain the NoRH images. See Appendix B for the detailed description for the FITS headers, The unit of intensity in the image is brightness temperature in Kelvin.

File name

Steady mode

`ifa`*YYMMDD_HHMNSS*	Full Sun	17GHz	(R+L)
`ifs`*YYMMDD_HHMNSS*			(R−L)
`ifz`*YYMMDD_HHMNSS*		34GHz	(R+L)
`ipa`*YYMMDD_HHMNSS*	Partial	17GHz	(R+L)
`ips`*YYMMDD_HHMNSS*			(R−L)
`ipz`*YYMMDD_HHMNSS*		34GHz	(R+L)

Event mode

`ifa`*YYMMDD_HHMNSS.LLL*	Full Sun	17GHz	(R+L)
`ifs`*YYMMDD_HHMNSS.LLL*			(R−L)
`ifz`*YYMMDD_HHMNSS.LLL*		34GHz	(R+L)
`ipa`*YYMMDD_HHMNSS.LLL*	Partial	17GHz	(R+L)
`ips`*YYMMDD_HHMNSS.LLL*			(R−L)
`ipz`*YYMMDD_HHMNSS.LLL*		34GHz	(R+L)

Example

`ifa981123_020533`	Full-Sun, 17GHz, R+L, Steady 1998-11-23 2:5:33 UT
`ipz981123_020533.824`	Partial, 34GHz, R+L, Event 1998-11-23 2:5:33.824 UT

Directory

Anywhere. We have daily images, 10min-interval images, event images (maximum averaged correlation > 1.5%) under `images` in NoRH archive. The synthesis of a raw data file (e.g., ss17...) results in these image files (e.g. ifa... and ifs...).

A.6 Observation Time (info)

This is an ASCII-text file that contains the observation time, and its corresponding frame number.

File name

`info`*YYMM*`s`	steady
`info`*YYMM*`e`	event

Unit of storage

One file per one month

Directory

`data/info`

Example of Contents

```
s99030108001 ss17990301001 990301 080023 140022 000001 021600 TRACK
s99030108001 sz00990301001
s99030108002 ss17990301037 990301 140023 151458 021601 026076 TRACK
s99030108002 ss34990301001 990301 080023 151458 000001 026076 TRACK
s99030108002 sl00990301001
s99030108002 sz00990301001
```

The 1st, 3rd, and 4th lines are the records for raw-data files and the 2nd and 6th lines are for 'SZ' files. From the left: The volume ID of the master CD-ROM for this data, the first file name of the sequence of raw-data files, observing date, the time (JST) of the first frame in the corresponding data file, that of the last frame, ID number of the first frame, that of the last frame, and the recording mode (TRACK means the ordinary observation sequence). In this example, it means that the data of 1999-3-1 is contained in the CD-ROM `s99030108001` and `s99030108002`. From the 1st to the 36th file are in CD-ROM `s99030108001`. These files include frame 1 to 21600 that correspond to the data from 8:00:23 JST to 14:00:22 JST. The CD-ROM `s99030108002` has the data from 14:00:23 JST to 15:14:58 JST. Each of these CD-ROMS has its own `sz00990301001` file.

A.7 R/L phase difference (rlphdif)

There are 3 files. Each file is valid for the following term(s). These files are used in the older version of synthesis programs. In the newest version of synthesis programs, these are no longer necessary. But for C2FITS program, still necessary.

file	valid term
`sun0628rlphdif`	– 1992-6-28
`s971101rlphdif`	1997-10-30 – 1997-11-06
	1998-01-21 – 1998-01-26
`sun0706_2rlphdif`	all days other than above

File name

`s`*YYMMDD*`rlphdif`

Unit of storage

non-periodically

Directory

`data/rlphdif`

A.8 Averaged correlation (tsa,tsz)

This FITS file contains: 1) exact time of observation, 2) correlation averaged over the antenna pairs (max is 100%), (R+L) & (R−) components for 17GHz, (R+L) for 34GHz. 3) observation status, 4) intensity. See Appendix B for the detailed description for the FITS header,

File name

`tsa`*YYMMDDS*	17GHz	Steady
`tsz`*YYMMDDS*	34GHz	Steady
`tsa`*YYMMDD_HHMNSS*	17GHz	Event
`tsz`*YYMMDD_HHMNSS*	34GHz	Event

The *HHMNSS* part of event data is the start time of the event.

Unit of precess

One file per one schedule/event

Directory

data/tsx

A.9 Averaged correlation Digest (tca,tcz)

This FITS file contains: correlation averaged over the antenna pairs (max is unity). Only (R+L) components. See Appendix B for the detailed description for the FITS header,

File name

tca*YYMMDDS*	17GHz	Steady
tcz*YYMMDDS*	34GHz	Steady
tca*YYMMDD_HHMNSS*	17GHz	Event
tcz*YYMMDD_HHMNSS*	34GHz	Event

The *HHMNSS* part of event data is the start time of the event.

Unit of storage

One file per schedule/event

Directory

data/tcx

A.10 Event list (eva,evz)

ASCII-text files that contains the lists of events (flares).

File name

eva*YYMM*	17GHz
evz*YYMM*	34GHz

Unit of storage

One file per one month

Directory

data/evx

Example

```
1  1999-04-01  23:00:47    23:11:24  23:02:42    637     23    17.7     0.6 22/ 19
```

From the left: Sequential number, date, start (UT), end (UT), peak (UT), duration (sec), max. averaged correlation $\times$ 32768 and so on. In this example, there was an event with peak correlation of $23/32768 \approx 0.007 = 0.7\%$ at 23:02:42 UT with duration of 637 seconds.

A.11 Observation log (lob)

ASCII-text files that contain useful information for data analysis, e.g., antenna conditions, weather, etc.

File name

lob*YYMM*

Unit of storage

One file per a month

Directory

data/lob

Example

```
### 99/03/10
   Due to an ice sticked to 84 antenna dishes, data quality is
   not good during the following times (before the sun shined
   and melt the ice):
       Mar. 10, 00:00 UT - Mar.10, 02:30 UT.
```

A.12 Tohban report (rep)

Observing tohban's (duty observer) weekly reports that has brief description on Solar activity, significant events on that week.

File name

rep*YYWW*

Unit of storage
  one file per one week
Directory
  `data/rep`

A.13 Sun tracking table (track_table)

Information for tracking the Sun at Nobeyama. They are obtained by using the ephemeris data and the latitude/longitude of Nobeyama. The contents are solar declination δ (in arc-degree), hour angle (in time-sec), apparent solar radius (in arc-sec), solar p-angle (in arc-degree), solar b-angle (in arc-degree) at JST noon.
File name
  `track_table`YY`.dat`
Unit of storage
  one file per one year
Directory
  `data/ephe`

B NoRH FITS header

In this section, the regulation of the FITS header that is adopted by NoRH data is given. This is used in the files of image (ifx, ipx), and averaged correlation (tcx, tsx).

B.1 Header Regulation

(1) Needed Part

- The keywords for standard FITS
  The keywords below must appear in all FITS files and have a fixed format.
  - `SIMPLE` : 'T' if the file subjects to the FITS regulation
  - `BITPIX` : number of bits and type of the data
  - `NAXIS` : number of dimensions of the data
  - `NAXIS1` : number of pixels in x-axis
  - `NAXIS2` : number of pixels in y-axis
- Basic information for NoRH data
  The keywords bellow should appear in all FITS files related to NoRH data.
  - ◦ Information on observation time
    - `STARTFRM` : the first IDs of used frames
    - `ENDFRM` : the last IDs of used frames
    - `JST-STRT` : the start time (JST) of integration for `STARTFRM`
    - `JST-END` : the end time (JST) of integration for `ENDFRM`
    - `JST-TIME` : exact middle time (JST) between the `JST-STRT` and `JST-END`
    - `JST-DATE` : the date (JST) for `JST-STRT`. The format is yyyy-mm-dd
    - `STRT-OBS` : UT for `JST-STRT`
    - `END-OBS` : UT for `JST-END`
    - `TIME-OBS` : UT for `JST-TIME`
    - `DATE-OBS` : UT for `JST-DATE`
  - ◦ Information of data contents
    - `OBJECT` : fixed to `sun`
    - `TELESCOP` : fixed to `radioheliograph`
    - `ORIGIN` : fixed to `nobeyama radio obs`
    - `POLARIZ` : choose from `rcp`, `lcp`, `r+l`, `r-l`, `l-r`, `r|l`, `(r-l)/(r+l)`, `unknown`
    - `ATT-10DB` : choose from `00dB`, `10dB`
    - `OBS-MODE` : choose from `fix`, `alt`
    - `OBS-FREQ` : choose from `17GHz`, `34GHz`
    - `FRM-STAT` : choose from `1-sec obs`, `event`, `calib`
    - `DATA-TYP` : brief description of data type, e.g. `cleaned_map`

○ Information of FITS header version

FITS header version. Now the newest is ver 2.0

`HDRIDENT  : 'HeliogFITS 2.0'`

(2) Ephemeris

The keywords bellow should appear in NoRH image files. These are necessary for obtaining the heliographic coordinates or the beam patterns. They are not only the parameters determined from the date and time, but also those local to the Nobeyama site.

`SOLR`	: apparent radius of the solar disk
`SOLP`	: polar angle of the sun
`SOLB`	: the heliographic latitude of the solar disk center
`DEC`	: declination of the Sun at Nobeyama
`HOURA`	: hour angle of the Sun at Nobeyama
`AZIMUTH`	: azimuthal angle of the Sun at Nobeyama
`ALTITUDE`	: altitude of the Sun at Nobeyama
`ZANGLE`	: zenith angle of the Sun at Nobeyama
`PMAT1/2/3/4`	: transformation matrics between the antenna coordinates (on the geosphere: antenna north is up) and the solar-disk coordinates (on the celestial sphere: solar-north is up)

(3) Image coordinates

The keywords bellow should appear in NoRH image files in order to co-align them with images obtained at other frequencies. They are basically regulated by the FITS standard.

`CTYPE1` / `CTYPE2`:
type of coordinate axis. Usually '`solar-west`' and '`solar-north`', respectively. The origin is at the solar disk center.
`CDELT1` / `CDELT2`: size of pixel in arcsec
`CRVAL1/CRVAL2/CRPIX1/CRPIX2`:
The coordinate value of center of the `CPIX1`th pixel equals to the `CRVAL1` in coordinate `CTYPE1`. That's same for '...2'. The NoRH standard is
`CRVAL1` = 0.00 (fixed)
`CRVAL2` = 0.00 (fixed)
`CRPIX1` = 'x' of the pixel for the solar disk center in the image
`CRPIX1` = 'y' of the pixel for the solar disk center in the image

In case of partial images (ipx), CRVAL1 and CRVAL2 may be larger than the size of the image or may have negative values.

Note that, in the FITS regulation, the *center of the pixel* is the origin of the position. Be careful when you try to coalign with the image described with a coordinate which has its origin at the *edge of the pixel.* The distance (in arcsec) of the image center from the Solar disk center is given as

x-offset = (`NAXIS1`/2+0.5-`CRPIX1`)*`CDELT1`+`CRVAL1`
y-offset = (`NAXIS2`/2+0.5-`CRPIX2`)*`CDELT2`+`CRVAL2`

(4) Parameters for each synthesis program

Parameters for synthesis should be given in order to make it possible to re-synthesize with these. Although they may be diffferent from one program to another, some keywords are common. They may be input parameters for synthesis

- ○ what program is used for synthesis,
- ○ parameters for calibration (e.g. used frame ID),
- ○ parameters for synthesis itself, (CLEAN parameters etc.)

and output on synthesis

- ○ value of an indicator variable for CLEAN results.

The following keywords are recommended to be included at least.

`PROGNAME`	: The format is arbitrary
`NFRCAL`	: number of frames used for calibration
`CRITER`	: CLEAN criterion
`SOLR-FAC`	: ratio of the radio to optical solar disk radius
`MBEAMC`	: main beam correction
`NCOMPO`	: number of CLEAN conponents
`DDOFF1`	: x-offset of the center of the dirty solar disk
`DDOFF2`	: y-offset of the center of the dirty solar disk
`DSKBR`	: brightness of the dirty solar disk
`BUNIT`	: unit of the intensity of the image, usually brightness temperature in Kelvin (K).

(5) Others

Other keywords could be added.

B.2 Example of Header

(1) Needed Part

- The keywords for standard FITS

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                  -32 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                  512 / length of data axis   1
NAXIS2  =                  512 / length of data axis   2
```

• Basic information for NoRH data

◦ Information on observation time

```
DATE-OBS= '1998-05-09'          /
TIME-OBS= '03:20:23.754'        /
STRT-OBS= '03:20:21.254'        /
END-OBS = '03:20:26.254'        /
JSTDATE = '1998-05-09'          /
JSTTIME = '12:20:23.754'        /
JST-STRT= '12:20:21.254'        /
JST-END = '12:20:26.254'        /
STARTFRM=                16499 /
ENDFRM  =                16503 /
```

◦ Information of data contents

```
POLARIZ = 'r+l     '           /
ATT-10DB= '00dB    '           /
OBS-MODE= 'alt     '           /
OBS-FREQ= '17GHz   '           /
FRM-STAT= '1-sec obs'          /
DATA-TYP= 'cleaned_map'        /
OBJECT  = 'sun     '           /
TELESCOP= 'radioheliograph'    /
ORIGIN  = 'nobeyama radio obs' /
```

◦ Information of FITS header version

```
HDRIDENT= 'HeliogFITS 2.0'     /
```

(2) Ephemeris

```
SOLR    =               952.22 / optical solar radius (arcsecond)
SOLP    =             -22.5235 / solar polar angle (degree)
SOLB    =              -3.3307 / solar b0 (degree)
DEC     =              17.2807 / declination (degree)
HOURA   =              2270.83 / hour angle (second)
AZIMUTH =              27.7610 / azimuth (degree)
ALTITUDE=              70.3056 / altitude (degree)
ZANGLE  =              23.5280 / zenithangle (degree)
PMAT1   =              0.98640 / projection matrix
PMAT2   =              0.09448 / projection matrix
PMAT3   =             -0.04883 / projection matrix
PMAT4   =              0.94981 / projection matrix
```

(3) Image coordinates

```
CRVAL1  =                 0.00 / arcsec
CRVAL2  =                 0.00 / arcsec
CRPIX1  =               257.00 /
CRPIX2  =               257.00 /
CDELT1  =              4.91106 / arcsec
CDELT2  =              4.91106 / arcsec
CTYPE1  = 'solar-west'         /
CTYPE2  = 'solar-north'        /
```

(4) Parameters for each synthesis program

• example for Hanaoka

```
PROGNAME= 'snap2d17 v5.1  Y. Hanaoka' /
BUNIT   = 'K       '           / disk = 10000 K
SOLR-FAC=              1.01250 / radius correction factor
NFRCAL  =                    1 / number of calibration frames
CRINPUT =                -0.50 / clean criterion input
MBEAMC  = 'yes     '           / main beam correction
DISKRSTR= 'yes     '           / disk restoration
DDOFF1  =               -12.77 / x-offset of the dirty disk
DDOFF2  =                10.68 / y-offset of the dirty disk
DDCORR  =               0.9631 / correlation between dirty disk and model
DSKBR   =             37145.51 / brightness of the dirty disk
CRITER  =             24384.39 / clean criterion
NCOMPO  =                 1050 / number of clean components
```

• example for Koshix

```
PROGNAME= 'snap2d51_koshix_vfast' /
FRAME   =                16501 /
ICAL    =                    3 / integration for calibration
ITGR    =                    3 / integration for restoration
ICLN    =                    3 / integration after restoration
BUNIT   = 'k       '           / disk = 10000 K
CRITER  =               3000.0 / CLEAN criterion
SOLR-FAC=              1.01250 / radius correction factor
GAINP   =                0.020 / CLEAN loop gain for estimation of sky and disk
GAINE   =                0.200 / CLEAN loop gain
TRIM    =                0.800 / CLEAN trim level
NCOMPO  =                66143 / number of CLEAN components
DDOFF1  =                  0.5 / x-offset of the dirty disk
DDOFF2  =                  0.9 / y-offset of the dirty disk
NCLNYN  = 'yes     '           / negative CLEAN
JCIMYN  =                    1 / jitter - add/sub - integration
PJIMYN  =                    1 / projection - integration
MBEAMC  = 'yes     '           / main beam correction
```

B.3 Implimentation to subroutines

Subroutines are given in `soft/helioglib` in order to write the above header to NoRH FITS files.

1. For *Needed* part, use subroutine `puthdr`.
2. For *Ephemeris* part, use subroutine `putoep`.
3. For *Coordinate* part, use subroutine `putcor`.
4. For parameters of each synthesis program, make an adequate subroutine for its own.

C NoRH data archive: anonymous FTP

The Nobeyama Solar Radio Observatory (NSRO/NAOJ) has prepared the anonymous FTP server for the NoRH data archive. The URL is

`ftp://nsro-archive.nro.nao.ac.jp/pub/norh`

If you need to transfer a large amount of data , please contact

`nsro-service@solar.nro.nao.ac.jp`
We will make and mail a CD-ROM for you. The network capability in Nobeyama is limited.

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