CORHEL 1.0 user guide

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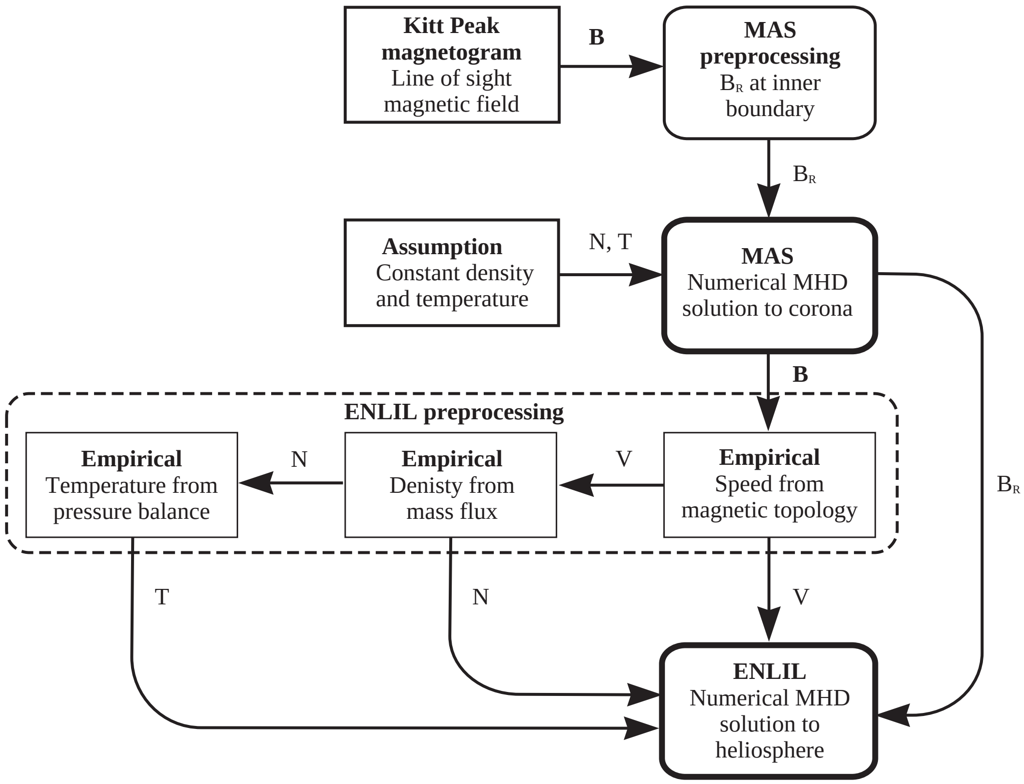

Figure 1: A flowchart showing the linkage and variables passed between the separate components of CORHEL.

1 Introduction

The aim of this document is to describe the installation, running and output of the CORHEL 1.0 model.

2 Background

2.1 Overview of CORHEL

CORHEL is a collection of numerical codes and data processing routines coupled together by a **cshell** script. Photospheric magnetograms are obtained from the Kitt Peak observatory, processed, and used to drive the MAS numerical MHD simulation the solar corona. The MAS output is then processed and used to drive the ENLIL numerical MHD simulation of the Heliosphere. The interconnections between the various components of CORHEL are shown in Figure 1. See [4] for more detail.

2.2 MAS preprocessing

The **corhel** script automatically obtains the required magnetogram from the Kitt Peak ftp site (support for other observatories will added in future versions of CORHEL). However, before this magnetogram can be used by MAS, a number of prepocessing steps are required.

The **kpsyn** command carries out a number of stages of processing. First the magnetogram is interpolated to the required mesh size. The line of sight magnetic field of the Kipp Peak magnetogram is then converted to a radial component via a simple geometric correction. Next the polar regions of the magnetogram are filled in by fitting a Taylor expansion to a given latitudinal band. Any magnetic monopole is then subtracted uniformly from the magnetogram. Finally, the magnetogram is filtered by removing longitudinal Fourier modes greater than some threshold value.

The **filter** command handles the final stage of the MAS preprocessing by applying a digital low pass filter to latitudinal magnetic field modes.

2.3 MAS

A steady state magnetohydrodynamic solution to the photospheric boundary conditions (i.e. the processed magnetogram) is performed by the MAS code. See [2], [1] and [3] for more detail.

2.4 ENLIL preprocessing

The topology of the MAS solution to the coronal magnetic field is used by the **mapfl** function to make an empirical calculation of the solar wind speed (see [3]). This radial solar wind speed, along with the MAS-computed radial magnetic field at the MAS/ENLIL interface are interpolated to the ENLIL resolution. The density is then computed from mass flux and temperature from pressure balance. These parameters are used to drive the ENLIL code.

2.5 ENLIL

A steady state MHD solution to the heliospheric boundary conditions is calculated by the ENLIL code, from $+60°$ to $-60°$ heliographic latitude. See [4] for more detail.

3 Requirements and installation

This section describes the basic hardware and software requirements to compile and run the CORHEL model.

3.1 Recommended platform

CORHEL is designed and tested to run on a 32-bit PC running RedHat Linux (release 2). While it is possible that CORHEL will run on other hardware/software configurations, only the recommended platform is presently supported by the CORHEL team.

3.2 Additional software

The CORHEL script makes calls to both **c-shell** and **wget**, and hence they must installed (these are normally part of a standard Linux installation). KPSYN converts the Kitt Peak magnetograms from **fits** to **hdf** format using the precompiled exectuable **fits2hdf**, which requires the **cfitsio** library. If this standard library is not installed, it be obtained from:
http://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html

MAS uses the **hdf** data format (tested with version 4.1r5. Previous and subsequent versions may not be compatable). The libraries can be obtained from:
http://hdf.ncsa.uiuc.edu/

MAS assumes a default installation path of **/usr/lib**. If a different installation path is used, the **LIBDF** flag must point to the alternate location in the MAS compile script:
CORHEL/source/corona/cism_mas/source/compile

ENLIL uses the **netCDF** (tested with version 3.5.0) format to store data, which can be obtained from:
http://my.unidata.ucar.edu/content/software/netcdf/

The default installation path is **/opt/netcdf-3.5.0**, other locations require the appropriate changes to the **netcdf** flag in the ENLIL makefile:
CORHEL/source/helio/param/Makefile

3.3 Compiling CORHEL

The MAS and ENLIL source codes must be compiled on the system on which they are to run. They have been verified to compile under the commercial Lahey-Fujitsu compiler. Future versions of CORHEL will support the Intel Fortran Compiler (IFC), which is freely avaible for non-commercial purposes.

The MAS and ENLIL components of CORHEL must be compiled individually. To compile MAS, the current working directory must be:
CORHEL/source/corona/cism_mas/source

Both the low and medium resolution versions of MAS can then be compiled with the command:
compile mas47d_cism_v01

Compilation of ENLIL requires the current working directory to be:
CORHEL/source/helio

The scripts **make-helio-low** and **make-helio-med** will compile the low and medium resoltuions versions of ENLIL respectively.

4 Running CORHEL

Once all the required software is in place the CORHEL model is ready to be run via the execution of a user-friendly script which sets robust default values for all the various model parameters (see Section 6). This section describes the use of this script, along with some guidelines for checking the validity of the model output.

4.1 The CORHEL script

The **corhel** script that runs the individual pieces of the CORHEL model is located in root directory. Two arguments must be given to the script: The number of the Carrington rotation to be modelled, and the required resolution of the model run (either **low** or **medium**):
corhel <*CRNumber*> <Res>

e.g. A low resolution run of Carrongton rotation 1912 would be intialised by **corhel 1912 low**. This will attempt to set up an appropriate run directory is step up (see also Section 5). If this directory already exists, the user will be notified, and the script will exist, so as not to overwrite existing data. If no such directory exists, the script will autonomously run a number of sequential processes (see also Figure 1). First, the relavent synoptic map is obtained from the Kitt Peak ftp site using the **wget** command. If successful, the file filtered by the KPSYN module. The processed magnetogram is then used to initialise the MAS model. Once the MAS code has completed its run, the output is converted to the appropriate format, and used to intialise the ENLIL model. Progess is continually output to the screen throughout the CORHEL run to enable the user to identify the source of any problems encountered (see Section 8).

4.2 Checking the output

It is vital the output of any CORHEL run be thoroughly checked before the results are utilised. The MAS and ENLIL history files (**hmas** and **helio.out<*SeqNum*>** respectively. See Section 5) are extremely useful for this purpose, as they contain the values of key-parameters at regular intervals throughout the CORHEL run.

The time-step (**dt**) of the model can be useful in identifying numerical problems, as frequently

```
CORHEL
├─bin    Compiled CORHEL executables
├─run    CORHEL run data
│ └─cr<CRnumber>-<Res>    Unique run directory
│     ├─corona_bc    MAS preprocessing files
│     ├─corona       MAS input and output data
│     ├─helio_bc     ENLIL preprocessing files
│     └─helio        ENLIL input and output data
└─source    CORHEL source files
  ├─corona    MAS and MAS preprocessing source files
  │   └─cism_mas
  │       └─source  CORHEL specific MAS source files
  └─helio    ENLIL source files
      └─param    The ENLIL Makefile
```

Figure 2: The CORHEL directory structure. Only directories containing files vital to the standard installation and operation of CORHEL are shown.

these are associated with sudden drops in **dt**. Additionally, the time-series contained in the **hmas** file are also useful diagnostic tools: The magnetic energy (**W**) should normally be seen to increase rapidly as the solution moves away from potential, asymptotically settling toward a constant value as the solution reaches equilibrium. Conversely, the kinetically energy (**K**) should normally decrease rapidilly initially, before levelling off. Any major deviations from this behaviour should be treated with suspicion. It is also advisable to check these parameters intermittently at run-time, to prevent a corrupt run from wasting large amounts of computing time.

If a run encounters problems it may be necessary to increase the run resolution and/or further filter the synoptic maps (see Section 6 for more information).

4.3 Computing time

On a single Pentium 4 processor, a low resolution run of a single Carrington rotation is expected to around 6 hours. Future versions of CORHEL will include benchmarking facilities to give the user a more accurate estimate of the computing time required on their individual system.

5 Data Organisation

The CORHEL model uses an organised directory structure to keep track of the input and output data for each model run. This section outlines the basic directory structure and the filename conventions used by the various CORHEL components.

File Name	Decription
m<*CRnumber*>f.fits	The Kitt Peak magnetogram in its original **fits** format
kp<*CRnumber*>.hdf	The KP magnetogram converted to **hdf** format
br_raw.hdf	The KP magnetogram transformed to radial field
br_polefit.hdf	The radial field magnetogram with the polar correction
br.mmax<*MMax*>.hdf	The processed magnetogram, with all meridional modes greater than <MMax> removed
br.mmax<*MMax*>.filt<*FNum*>.hdf	The magnetogram after both meridional mode removal and azimuthal filtering
br_rms_before_filt.dat	The intensity contained in the longitudinal modes pre-filter
br_rms_after_filt.dat	The intensity contained in the longitudinal modes post-filter
br.m<*MMax*>.filt<*FNum*>.dat	The final, processed magnetogram in **ascii** format
brc.hdf	The final processed magnetogram in **hdf** format, ready for input to MAS
brs.hdf	The final processed magnetogram in **hdf** format, ready for input to MAS

Table 1: The files used and created by the MAS preprocessing module, KPSYN. These files are located in the **corona_bc** sub-directory of the current run directory.

5.1 The run directory

A valid call to the CORHEL script (requiring a valid Carrington rotation number, ***CRnumber***, and resolution, ***Res***, either **low** or **med**) will attempt to create a unique directory to store all the input and output data of the CORHEL run:
CORHEL/run/cr<*CRnumber*>-<*Res*>

e.g. **CORHEL/run/cr1912-low** for a low resolution run of Carrington rotation 1912. If this directory already exists, the script will abort so as to avoid overwriting any existing data. The user will be prompted to remove or rename the exisitng directory for the run to proceed.

Within the unique run directory, the files created by the individual processes of CORHEL are standarised for all runs, and are described in the remainder of this section. See also Figure 2.

5.2 Coronal boundary conditions

All data obtained and created prior to the MAS run is stored in the **corona_bc** directory. See Table 1.

The Kitt Peak synoptic map is obtained by the CORHEL script from the Kitt Peak ftp site and

File Name	Decription
<***VarName***><***Comp***><***StepNum***>**.hdf**	The values at each grid-cell of the <***Comp***> component of variable <***VarName***> at time-step <***StepNum***>
hmas<***SeqNum***>	The MAS history file: A log of key parameters of the MAS code created at set intervals
vmas<***SeqNum***>	A log of velocity at a set position in the MAS code created at set intervals
qmas<***SeqNum***>	A log of viscosity at a set position in the MAS code created at set intervals
br.m<***MMax***>**.filt**<***FNum***>**.dat**	The coronal boundary conditions used to initialise MAS
br_photo.hdf	The input radial field at the inner radial boundary
parker1.8.pw	The Parker solution to the solar wind speed used to initialise MAS
imas	The MAS input file (A FORTRAN namelist file conatining the run parameters)
omas	The MAS output file summarising the run
rsmas<***SeqNum***>**.hdf**	The MAS restart files (not used in the current version of CORHEL)

Table 2: The files used and created by the MAS code. These files are located in the **corona** sub-directory of the current run directory.

saved as **m**<***CRnumber***>**f.fits** (**m** signifies magnetogram, **f**, final). This file is converted to **HDF** format and saved as **kp**<***CRnumber***>**.hdf**.

The KPSYN module then removes all meridional modes higher than ***MMax*** (CORHEL default: ***MMax* = 9**) and is filtered azithmuthally ***FNum*** times (CORHEL default: ***FNum* = 3**). These processed magnetograms are saved at each stage as **hdf** files. See Table 1.

The final input files for the MAS code are the **brc.hdf** and **brs.hdf** files.

5.3 Corona

Input and output files generated by the MAS code are stored in the **corona** directory. The input file, **imas**, is a FORTRAN namelist file generated by the CORHEL script. It contains the MAS run parameters (set to default values. See Section 6 for more information).

During the running of the MAS model, files are created for diagnostic purposes to enable the user to check the integrity of the run. History files (**hmas**<***SeqNum***>, where ***SeqNum*** is the sequential number of the history file, beginning at ***SeqNum***= 01) are created at set intervals throughout the MAS run and store key variables of the MAS code in **ascii** format. Similarly, **vmas**<***SeqNum***> and **qmas**<***SeqNum***> store logs of the velocity and viscosity at set points within the MAS grid (see also Section 4).

Symbol	Physical variable
a	Vector potential
b	Magnetic field
j	Current density
p	Thermal pressure
rho	Mass density
t	Temperature
v	Velocity

Table 3: The MAS varible naming conventions.

Variable	Conversion factor
Length (cm)	6.96e10
Time (s)	1445.87
Velocity (km/s)	481.3711
Density (cm^{-3})	1e8
Mass density (g cm^{-3})	1.6726e-16
Pressure (dyn cm^{-2})	0.3875717
Temperature (K)	2.807067e7
Magnetic field (Gauss)	2.2068908

Table 4: The MAS units and conversion factors to recognised units. 1 MAS unit = Conversion factor × Variable.

The CORHEL version of MAS outputs the current state of the code at two timesteps during its run: The inital state (***StepNum*** = **001**) and the final state (***StepNum*** = **002**). Each variable is saved in a separate **.hdf** file, with vector quantites first separated into their components (***Comp*** = **r**, **p** or **t** for radial, poloidal or tangential components respectively. ***Comp*** is omitted for scalars):
<***VarName***><***Comp***><***StepNum***>**.hdf**

e.g. the final tangential magnetic field is saved as **bt002.hdf**. See also Tables 2 and 3. All variables are stored in MAS units (see Table 4) in heliographic coordinates.

The output file, **omas**, is created upon successful completion of a run. It summarises all the information pertaining to a MAS run.

5.4 Heliospheric boundary conditions

The MAS ouput must be converted into a format usable by the ENLIL code. Table 5 lists the files created during this process, all of which are stored in the **helio_bc** sub-directory of the current run directory.

File name	Description
br_helio.hdf	The radial magnetic field output from MAS
br_helio_scaled.hdf	The radial magnetic field, scaled for use in ENLIL. Stored in **hdf** format
br_helio_scaled.dat	The radial magnetic field, scaled for use in ENLIL. Stored in **ascii** format
ch_dist.hdf	
mapfl.dat	The output of the **mapfl** function
v_smooth_0.05_0.025.hdf	The radial velocity, scaled for use in ENLIL. Stored in **hdf** format
v_smooth_0.05_0.025.dat	The radial velocity, scaled for use in ENLIL. Stored in **text** format
<***VarName***><***StepNum***>**.hdf**	

Table 5: The files used and created during the preprocessing of MAS output for use in ENLIL. These files are located in the **helio_bc** sub-directory of the current run directory.

5.5 Heliosphere

Input and output files generated by the ENLIL code are stored in the **helio** sub-directory of the current run directory. See Table 6.

ENLIL requires two forms of input file: The parameter list (**helio.in**), set to default values by the CORHEL script (see Section 6), and the MAS processed data (**bnd.nc**) that will drive the heliospheric simulation.

Two distinct types of output data are generated by an ENLIL run: Snapshots of all variables at all grid cells at a single timestep, and temporal evolution of all variables at a single position (though not necessarily confined to a single grid cell). The snapshot files are termed **tim** files, and have the naming convention **tim.**<***StepNum***>**.nc**, where ***StepNum*** is a 4 digit number denoting the simulation timestep. The temporal evolution data is stored in **ev** files which have the form **ev**<***Pos***>**.nc**, where ***Pos*** indicates the position at which the data was taken (see Table 6). All ENLIL data uses SI units, and is the model coordinate system (heliographic, but with zero longitude set at the Sun-Earth line).

Output files (**helio.out**<***SeqNum***>) store the details of the ENLIL run.

6 Advanced: Customising the run

This section describes how to customise the CORHEL run parameters. However, any changes are made at the discretion of the user: Only the CORHEL 1.0 defaults are currently supported by the CORHEL team.

File Name	Decription
helio.in	The ENLIL input file (A FORTRAN namelist file conatining the run parameters)
bnd.nc	The boundary conditions used to drive ENLIL in **netCDF** format
grd.nc	The details of the grid cell positions in **netCDF** format
evg.nc	Temporal evolution of variables at geospace locations in **netCDF** format
evl.nc	Temporal evolution of variables at locations along Sun-Earth line in **netCDF** format
tim.<*StepNum*>.nc	A snapshot of the entire computational domain at time step ***StepNum*** in **netCDF** format
helio.out<*SeqNum*>	The ENLIL output files. They contain messages produced during computation

Table 6: The files used and created by the ENLIL code. These files are located in the **helio** sub-directory of the current run directory.

6.1 Filtering the magnetograms

It may be necessary to alter the level of filtering applied to a magnetogram prior to the MAS run. This can be achieved (somewhat messily) by altering the relavent section of the **corhel** script:

```
brc.hdf
9
br_rms_after_filt.dat
br.mmax9.hdf
EOF
../../../bin/filter -n 3 -periodic y br.mmax9.hdf br.mmax9.filt3.hdf
../../../bin/hdf2txt br.mmax9.filt3.hdf br.m9.filt3.dat
cp br.m9.filt3.dat ../corona/
```

The ***9*** is the maximum meridional mode number (***MMax***) that is not removed by KPSYN, the ***3*** is the level of azimuthal filtering (***FNum***). These numbers may be changed by the user. The **bnfile** flag in the MAS input file must also be changed accordingly (see Table 7).

Over-aggressive filtering will remove too much information from the synoptic maps, whereas too passive filtering could result in problems with the running of the MAS code. It is recommended that the user examine how the power contained in the meridional and azithmuthal modes are modified by the chosen level of filtering. Inspection of the pre- and post-processed magnetograms is also advisable.

Parameter Name	Decription	CORHEL default
fldtype	The starting solution to the magnetogram	**potential**
bnfile	The pointer to the fully processed magnetogram	**br.m9.filt3.dat**
eqtype	The starting solar wind solution type	**parker**
onedfile	The file containing the inital solar wind speed solution	**parker1.8.pw**
tmax	The maximum number of cycles MAS will run (i.e. for a CORHEL run, the time for the MAS code to relax to a constant solution)	**100**
dtmax	The maximum value the timestep is allowed to take (in model units)	**0.05**
dtmin	The minimum value the timestep is allowed to take (in model units)	**0.005**
isideal	A flag for an ideal Faraday equation (i.e. no resistivity)	**0**
visc	The viscosity of the MAS code	**0.01**
rsifile	The pointer to the restart file	**N/A**
rl	The length of the simulation box (in solar radii)	**29**
slund	The Lundquist number	**1000**
rfrac	Settings for the radial mesh	**.4,1**
tfrac	Settings for the theat mesh	**.5,1**
tpltxint	The number of cycles between data file saves	**100**
ihistint	The number of cycles between history file saves	**1**
trsdump	The number of cycles between restart file saves	**20**
dformat	The required format of data files	**hdf**
plotlist	The variables that are saved as data files	**ar, at, ap, vr, vt, vp, br, bt, bp, jr, jt, jp, p, rho, t**
ihst, jhst, khst	The grid cell coordinates for the **vmas** and **qmas** output files	**23, 33, 1**

Table 7: The key MAS input file parameters and the default values set by the **corhel** script.

6.2 MAS parameters

A MAS input file is generated by the **corhel** script, setting the run parameters to the CORHEL default settings. Table 7 details the key parameters of the MAS input file and their CORHEL default settings.

If **dt** drops too low, there is probabaly a problem with the code (see Section 4.2). Hence **dtmin** should not be set to zero.

6.3 ENLIL parameters

An ENLIL input file is generated by the **corhel** script, setting the run parameters to the CORHEL default settings. Table 7 details the key parameters of the ENLIL input file and their

Parameter Name	Decription	CORHEL default
gamma	The ratio of specific heats	**1.5**
vrot	The period of the inner boundary rotation (days)	**27**
cfl	The maximum value of the CFL stability number	**0.4**
tstart	The simulation start time (in days) relative to the reference time	**-6**
tstop	The simulation end time (in days) relative to the reference time	**30**
vux1	The simulation length unit (in metres)	**1.496e11**
vutime	The simulation time unit (in seconds)	**3600**
ttfrom	The time (in days) at which **tim.<*StepNum*>.nc** file output begins	**0**
ttto	The time (in days) at which **tim.<*StepNum*>.nc** file output ends	**30**
ttstep	The time (in days) between **tim.<*StepNum*>.nc** file output	**27.2753**
nestep	The frequency (in model cycles) of **ev<*Pos*>.nc** file output	**1**
nsel	The number of observation points along the Sun-Earth line	**9**
ngeo	The number of geospace observation points	**5**

Table 8: The key ENLIL input file parameters and the default values set by the **corhel** script.

CORHEL default settings.

6.4 Restarting CORHEL runs

CORHEL does not currently support run reinitialisation.

7 Visualisation

The latest distribution of CISM_DX contains **.net** routines to load, process and visualise the MAS and ENLIL data produced during a CORHEL run.

8 Trouble shooting

This section attempts to provide solutions to commonly encountered problems.

8.1 General issues

"Command not found" or "Unknown file" type errors
First check the command or file name. Depending on the method used to obtain and install the CORHEL files, it is possible that the capitalisation of file names may be lost. This can frequently cause problems with **Makefile** and <***FileName***>**.F** files.

If the required command is in the current working directory but the system returns an error, use **./**<***CommandName***> rather than just <***CommandName***>.

"Permission denied" type errors
Alter the permission of the target file using: **chmod ugo+rwx** <***FileName***>

8.2 Compilation

"condim.128x60x90.F: File not found" and "condim.256x120x180.F: File not found" errors when compiling ENLIL
The actual files are called **condim128x60x90.F** and **condim256x120x180.F** (note the additional period before the resolution). Either correct the typos in the **make-helio-low** and **make-helio-med** scripts or rename the files, located in:
CORHEL/source/helio/param/

Attempting to use the Intel Fortran Compiler
Set the **F90_COMPILER** (**fortran**) flag in the MAS **compile** script (ENLIL **Makefile**) to **"ifort"**.

Use the latest version of IFC (8.1 at time fo writing), as older versions do not have full support for FORTRAN 95 (as required by ENLIL).

The ENLIL **Makefile** sets up the free-form flag used by the Lahey Fijitsu compiler (**"–nfix"** in the **comp** flag). This should be changed to the equivalent IFC flag (**"–FR"**).

8.3 Running CORHEL

"parker1.8.pw: File not found" error when running MAS
The file is named **parker18.pw**. Correct the **onedfile** flag in the **corhel** script generated MAS input file (see Table 7).

"libfj9i6" related errors when running CORHEL
This is a library used by the Lahey-Fijitsu compiler used that was used to compile the binary files that come with as part of the CORHEL distribution. Recompile MAS and ENLIL with the FORTRAN compiler on the system that will be used to run CORHEL, and ensure that the newly created binaries are copied to **CORHEL/bin**, overwriting existing files if necessary.

References

[1] Linker, J.A., Mikic, Z., Bisecker, D.A., Forsyth, R.J., Gibson, S.E., Lazarus, A.J., Lecinsji, A., Riley, P., Szabo, A. and Thompson, B.J. (1999), Magnetohydrodynamic modeling of the solar corona during Whole Sun Month, *J. Geophys. Res., 104*, 9809.

[2] Mikic, Z., Linker, J.A., Schnack, D.D., Lionello, R. and Tarditi, A. (1999), Magnetohydrodynamic modeling of the global solar corona, *Phys. Plasmas, 6*, 2217.

[3] Riley, P., Linker, J.A. and Mikic, Z. (2001), An empirically-driven global MHD model of the solar corona and inner heliosphere, *J. Geophys. Res., 106*, 15,889-15,901.

[4] Odstrcil, D., Linker, J.A., Lionello, R., Mikic, Z., Riley, P., Pizzo, V.J. and Luhmann, J.G. (2002), Merging of coronal and heliospheric numerical two-dimensional MHD models, *J. Geophys. Res., 107*, 1493.