A GUIDE TO THE AZAM UTILITY

Table of Contents

I. Introduction

The AZAM utility is a software package for interactive "resolution" of the 180° ambiguity of the transverse component of the magnetic field vector.   In addition to this capability, AZAM also provides the user with a platform that performs many other useful tasks involving examination and display of the results of "inversion" of solar Stokes profile measurements. This utility was written by Paul Seagraves at HAO during the mid-1990s for use on data from the HAO/NSO Advanced Stokes Polarimeter. It is written entirely in the IDL language.

The software package has been stable and non-evolving until recently. The version of AZAM described herein has been extensively modified to work with data from the *Hinode* Spectro-Polarimeter (SP). With this modification, the package has been generalized and will be modified soon to work with data from other sources such as SDO/HMI. AZAM for *Hinode* SP data is available as a Hinode SolarSoft (SSW) package.

The interactive ambiguity resolution procedure of AZAM is based on attaining continuity of the field vector over the observed field of view. This is equivalent to minimizing locally the vertical current density. However, as the user becomes familiar with AZAM, he or she will impose other conditions often used in automatic ambiguity resolution procedures, such as the solenoidal condition $\nabla \cdot B=0$. An example of this is the field within a normal sunspot, a field that we expect to be diverging away from the center of the spot if it has positive polarity, or converging toward the center if it is negative polarity.

The observations often will present situations where discontinuities in the choice of the ambiguity resolution must occur somewhere within the observed map. The interactive visualization capability of AZAM allows one to select physically reasonable locations where this discontinuity resides. By way of an example of this situation, the occurrence of small intense flux concentrations may occur within regions surrounding large sunspots that are influenced by a magnetic canopy. AZAM helps to resolve this in ways that are not generally taken into account by automatic methods.

This guide presents an illustrated, step-by-step walk-through of most of the capabilities of AZAM. There are many permutations and combinations possible for use of this package, and the new user must expect to spend some time exploring the capabilities. This is not entirely onerous, because the use of AZAM is actually quite pleasurable! In normal use, AZAM shares some features with the very old children's toy Etch A Sketch™, but AZAM is in vibrant color, with simultaneous display of images in multiple windows. I hope you will agree in the end that it is rather easy and fun to use on real data. Many thanks go to Paul Seagraves for writing such a reliable, useful, and entertaining piece of software!

II. Quick Tutorial For Ambiguity Resolution

(A First Note: Many of the interactive windows have a blue "HELP" button. Clicking this button brings up another interactive window with help buttons for the interactive topics. To exit the HELP display, follow the instructions at the top of the HELP text window display – for example to exit HELP, right-click the mouse.)

A. Getting Started

AZAM for *Hinode* SP data is run on the command line using

IDL> AZAM_INIT_HINODE, {*path to the Hinode MERLIN inversion FITS file*}

Keywords for AZAM_INIT_HINODE allow one to specify a different directory for the output of AZAM results, and also allow one to specify a source directory for IDL code (for example, modified AZAM routines). For input of *Hinode* SP data, the data format is a FITS file as specified by the MERLIN Milne-Eddington inversions as run routinely on all applicable *Hinode* SP data. MERLIN inversions are available for download either from the LMSAL site (http://sot.lmsal.com/data/sot/level2d/) or the HAO CSAC site (http://www.csac.hao.ucar.edu/csac/archive.jsp).

Upon entrance to the program, the user is asked if processing a sub-area is desired[1]:

AZAM displays multiple screens simultaneously; they are necessary for efficient resolution of the ambiguity. It is often very convenient to process a sub-area, and for most computer display formats, sub-area processing is necessary for large *Hinode* maps (as large as 1024 X 2048) that will not fit on the screen. Below shows the interactive display when the Process Subarea is selected:

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[1] If the dataset is too large to fit within the available area of the display, selection of a sub-area is mandatory. In this case, the user will be prompted to either select a sub-area or exit the program.
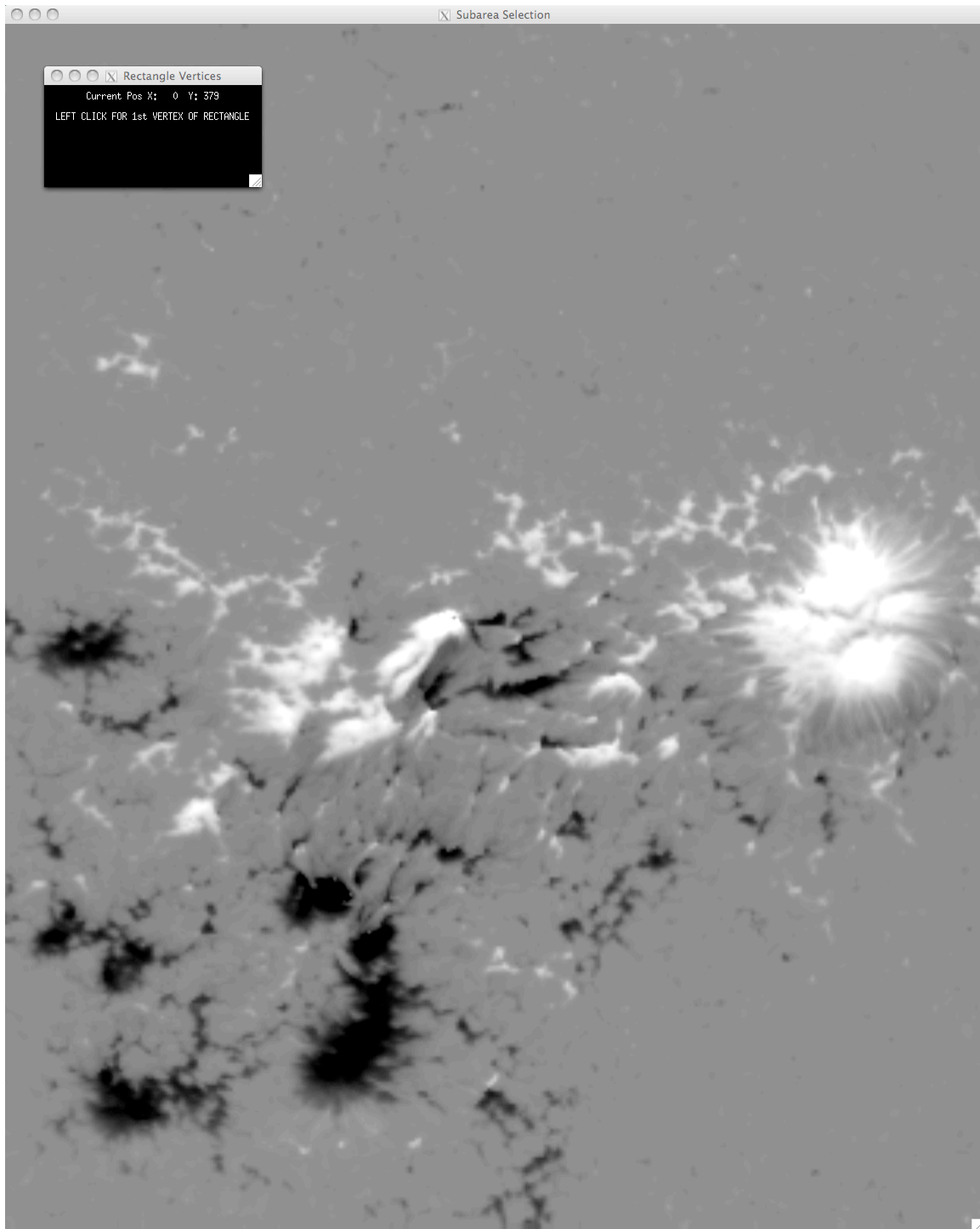
This display shows the longitudinal apparent flux density for the selected data set. It is scaled to fit within most of the available screen area to facilitate accurate sub-area identification. The interactive box at the top displays positions of the cursor. Within this window use the cursor to select one vertex of a sub-area rectangle, and click. Then select the diagonally opposite vertex of the sub-area. The following display results:
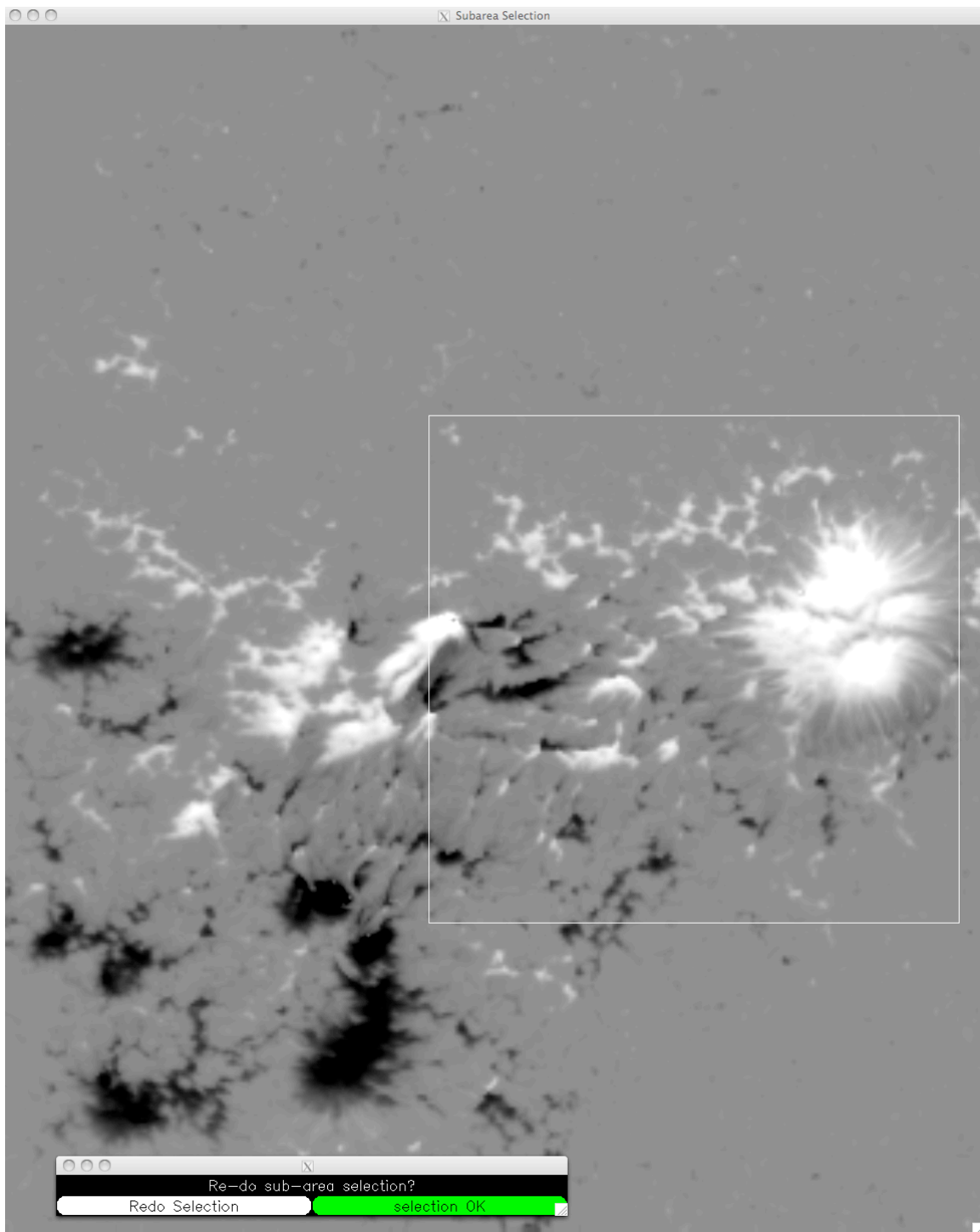
The user is asked if he or she wants to re-do the sub-area selection. Default (or normal) actions have green-colored buttons in AZAM. Presuming this area is OK, the next display is as follows:
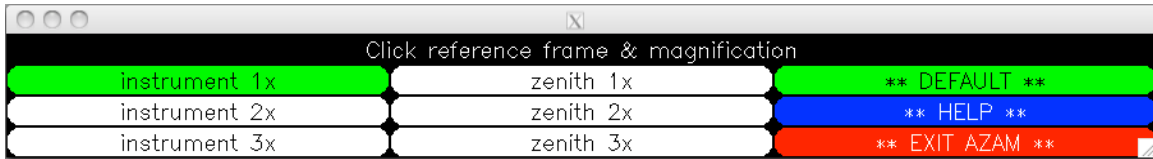
This interactive widget allows the user to work with the projection of the images in the "instrument" frame (as observed), or transformed onto a grid in the "zenith" frame (stretched in X and Y so as to present the data as if it were seen from directly above the center of the map). Below we will see that the vector field properties can be displayed on either of these choices, and the field parameters in either choice can be viewed either relative to the line-of-sight, or in the "local" frame (corresponding to field vectors as viewed from directly above). The 1x, 2x, or 3x options refer to magnification of the images by these factors in the ensuing displays. You will have to experiment with these magnifications to see what works for you, and that depends on sub-area selection, the chosen data set, and the particular target of interest.

Many of the AZAM pop-up widgets have a blue HELP button. This button brings up windows that allow one to select help instructions for each button in the corresponding panel.

The following screenshot shows the main working display for AZAM for the *instrument frame 2x* display of the sub-area selected above. The main widget panel at the top will be described in detail below. Five other display windows are opened. Left-to-right, and top-to-bottom they are:

1. The local frame field azimuth
2. The local frame field inclination
3. The continuum image
4. A magnified image near the center of the map, showing the continuum as a gray scale, the horizontal field as vectors *for each pixel*, and the vertical field as contours of various colors. Arrows are either black or white depending on the brightness of the background image
5. A display of numerical values of fit parameters at the location of the cursor

The cursor itself, shown on the three upper left images, is where the interactive disambiguation is performed. It has the appearance of an old-style metal thumbtack seen in perspective. In this case, the field under the cursor has positive polarity, and its horizontal component is directed slightly west of north (for *Hinode* data, solar north is up and west is to the right). For vertical fields the cursor becomes round, and for horizontal fields it becomes a line, as if the flat part of the thumbtack were seen edge-on. The cursor is orange for fields with positive vertical field (local incline < 90°), and gray for negative fields (local incline > 90°). Thus, the cursor itself is a valuable tool to visualize the orientation of the magnetic field at each pixel.
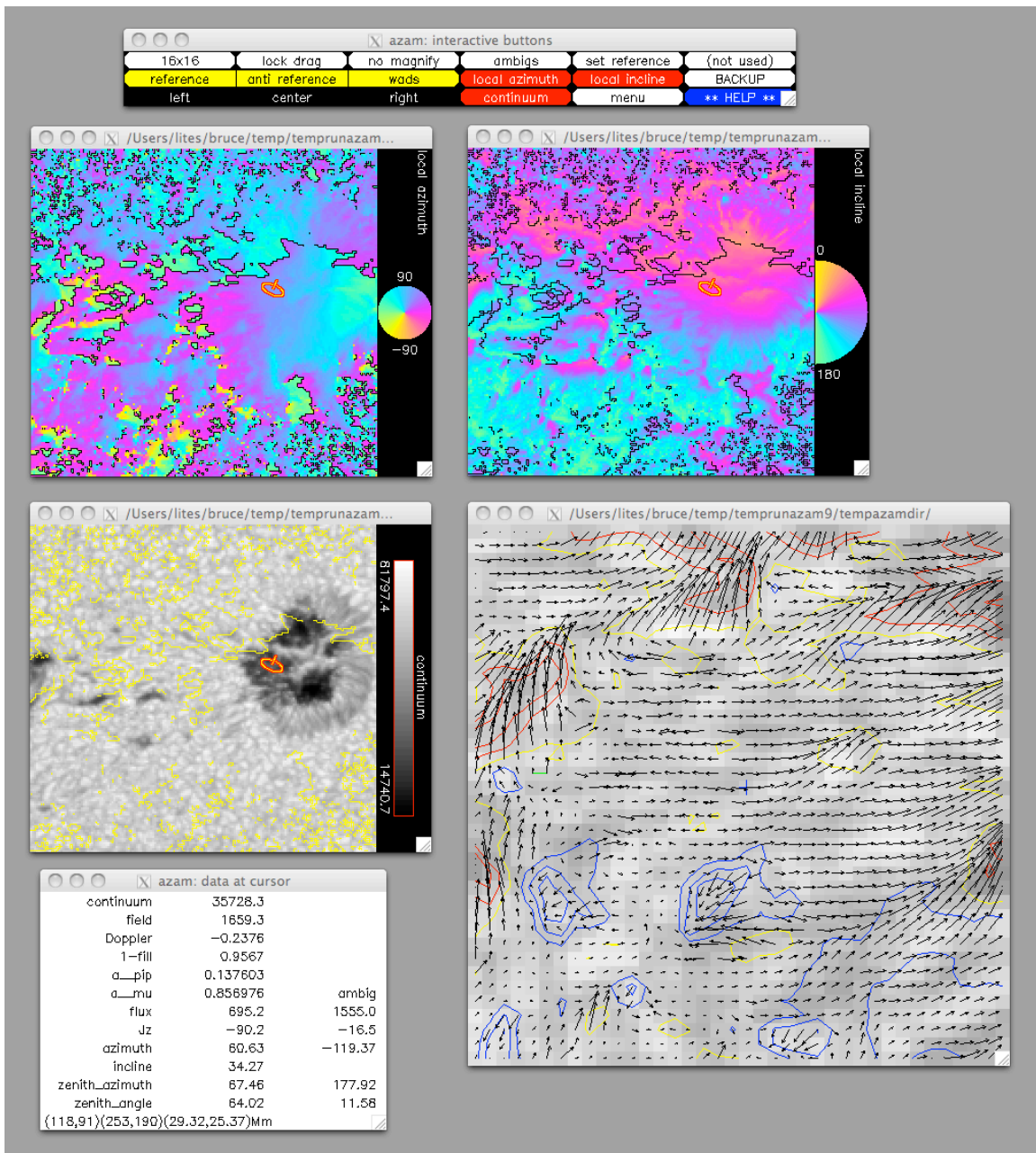
Note the color displays of the field azimuth and inclination in the top two images. Also note the many contour lines in the three images at upper left. These contours show the location of discontinuous azimuth selection. That is, the present condition for the choice of ambiguity resolution on one side of the contour is farther from the selected ambiguity resolution on the other side of the contour than is the opposite choice of azimuth ambiguity. Confused? Put another way, there are two choices for ambiguity resolution on each side of the contour. You can change the selection on either side of the contour, and the chosen field vectors across the contour line will be closer together in the vector sense. If you change the selected resolution (as will

be shown below), the contour lines will move accordingly. The object of the AZAM game is to minimize or eliminate these "*ambigs*" contour lines!

The window at the lower left displays interactively the inversion parameters and other parameters of the fit under the cursor. It also displays the angles of the field in the observer's frame (azimuth, incline), and in the local frame (zenith_azimuth, zenith_angle). Angles for both the selected ambiguity resolution are shown in the middle column, and for the other choice of ambiguity resolution (ambig) in the right column. Note that the magnetic flux [fill*field*cos(zenith_angle)] changes depending on the ambiguity resolution. Field strength is in Gauss, angles are in degrees, and flux is in Mx/cm^{-2}. The continuum is in data units and the Doppler shift is in spectral pixels (approximately 1.0 per km/s for *Hinode* ???????). Jz is the vertical current density. The data coordinates in the map under the cursor are shown at the bottom. The first pair is the (x,y) coordinates within the sub-area and the second pair are the coordinates within the original map. The third pair show the coordinates in the sub-area in megameters.

B. Basic DisAmbiguation

The data shown in this example is an operation starting at 2009 July 4 at 11:58:08 UT. What is displayed above is the raw azimuth ambiguity selection resulting from MERLIN; i.e., no ambiguity resolution whatsoever. In the future it is planned to run an automatic disambiguation procedure on all MERLIN inversions of Hinode data, but for now, we start from perhaps the worst possible case.

First, note from the local_incline image at upper right that the larger sunspot has positive polarity (represented by orange colors). This is our clue as to where to start. According to the solenoidal condition, we expect fields to diverge away from the center of the sunspot.   But note that where the cursor is located, the opposite is true. We therefore know that at the location of the cursor, the resolution of the ambiguity is incorrect. There is an "ambigs" contour running horizontally through the center of the sunspot, so we suspect that the resolution on the upper side of the sunspot is correct. Move the cursor to a position in the image above that contour, and click (but do not hold down) the **right** mouse button. That begins the "*wads*" action (what that stands for is a mystery to me). The three yellow buttons in the widget display panel indicate functions of the left, middle, and right mouse buttons (you need a functional 3-button mouse for proper operation of AZAM). A square will appear on the three upper left images, and will move with the movement of the mouse. This square is 16x16 pixels (see the upper left button in the widget display panel). As you move the position of the cursor downward past the contour line, the best continuous ambiguity resolution follows the mouse motion. Note that by this one action, the field at the center of the sunspot is more vertical (more yellow), and the center of the spot forms a pinwheel of color in the local_azimuth image resembling that of the azimuth color wheel. This is the correct azimuth selection for the sunspot!
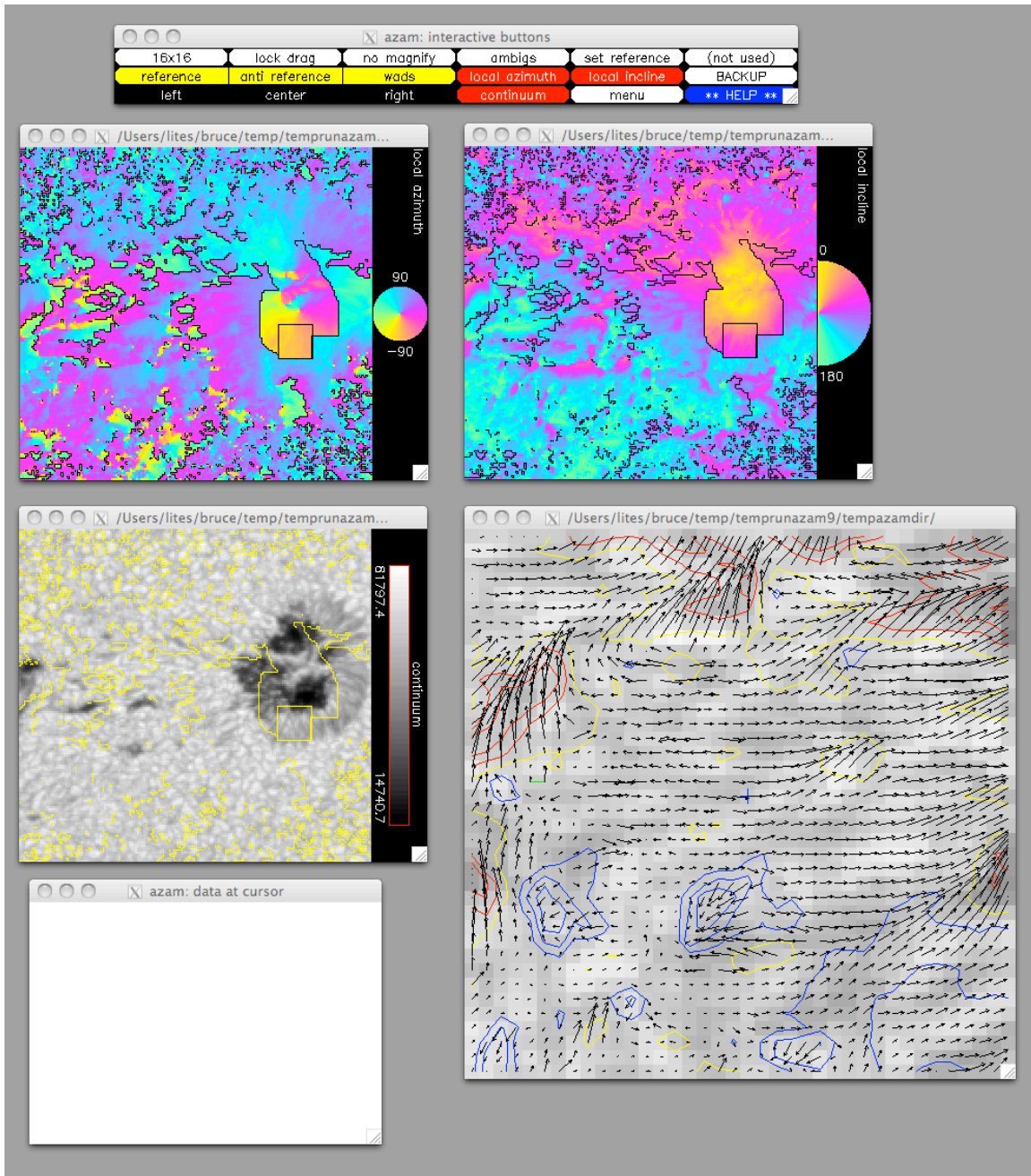
You can continue to paint across the image in this way. Do not move the mouse too fast or the computations cannot keep up with the motion. Clicking the right "wads" mouse button again will revert to the normal mode that does not change the ambiguity resolution. You will need to practice this until you get a feel for its operation.

Often you will want to work with a smaller area for azimuth continuity. Click on the white button at upper left of the widget panel (16x16) and the area of the continuity square decreases cyclically by factors of two. Often, 8x8 is a good choice, but sometimes it is necessary to go smaller where there are sharp discontinuities.

After progressing with the resolution for a bit, it is wise to pres the white button in the top row named "*set reference*". This temporarily saves your current ambiguity choice during your session, and if you do something that you don't like, you can paint over it using the yellow "reference" widget shown at the left end of the middle row. That is, click the **left** mouse button to recover your reference. Until set, the original solution you started with is the reference.

After painting for a while, and changing to the 8x8 continuity box size, the next image below shows the result of the progress. The cursor is located at a point where
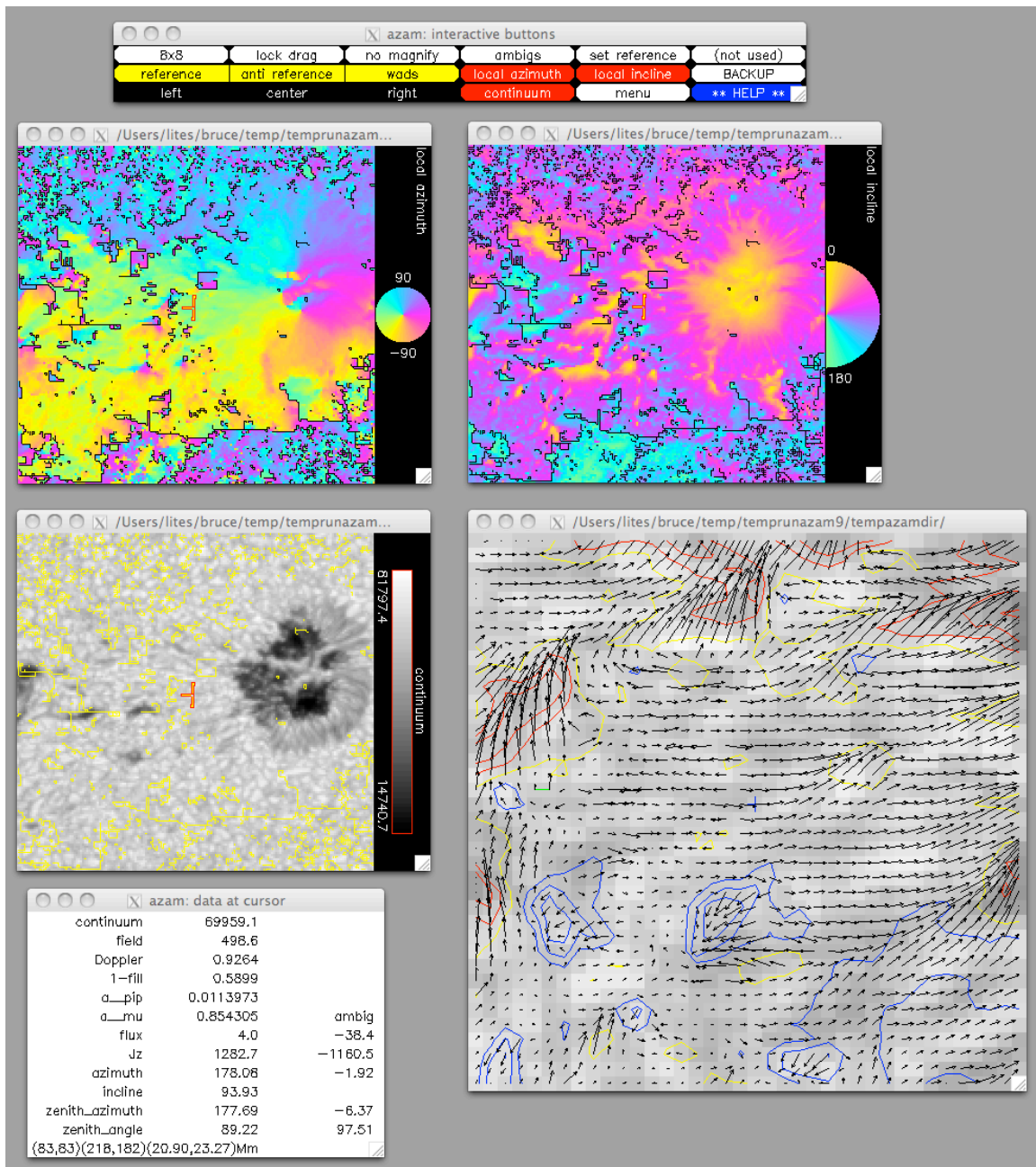
the field is horizontal (note the value for zenith_angle at lower left, and the shape of the cursor thumbtack). At this point it is desirable to "smooth" the image. Left-click the white menu button and a new, large pop-up selection widget will appear; see the next image below. Clicking the green *DISMISS* button will return you to the main widget interactive menu. To smooth the ambiguity solution, click the white "*smooth*" button in the *menu* widget display.
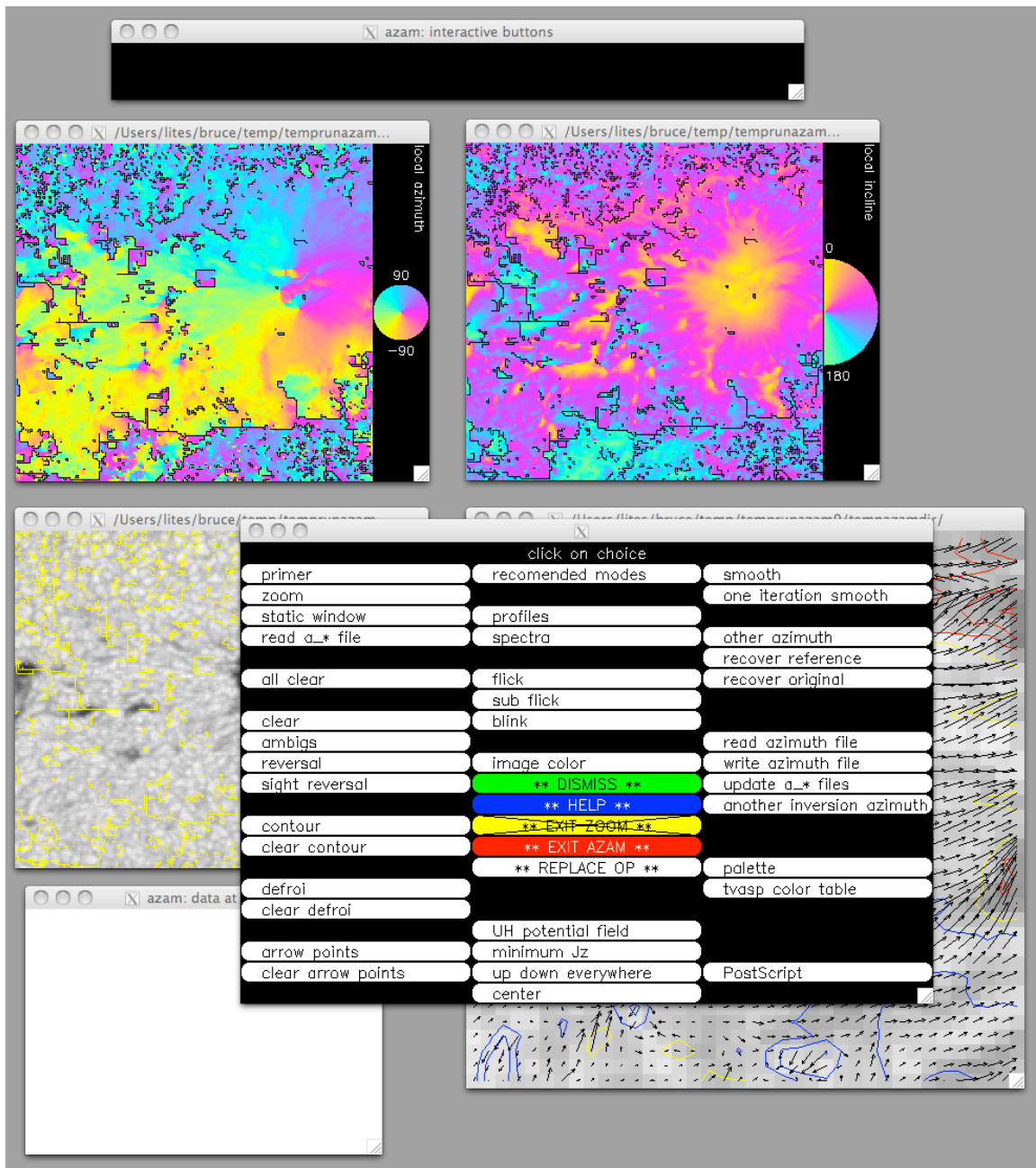
As you can see, there is a whole lot more you can do with AZAM as represented by the menu of choices here. We will get to that later, and here illustrate the use of only a few choices. After performing the "*smooth*" operation, the following display shows the results.
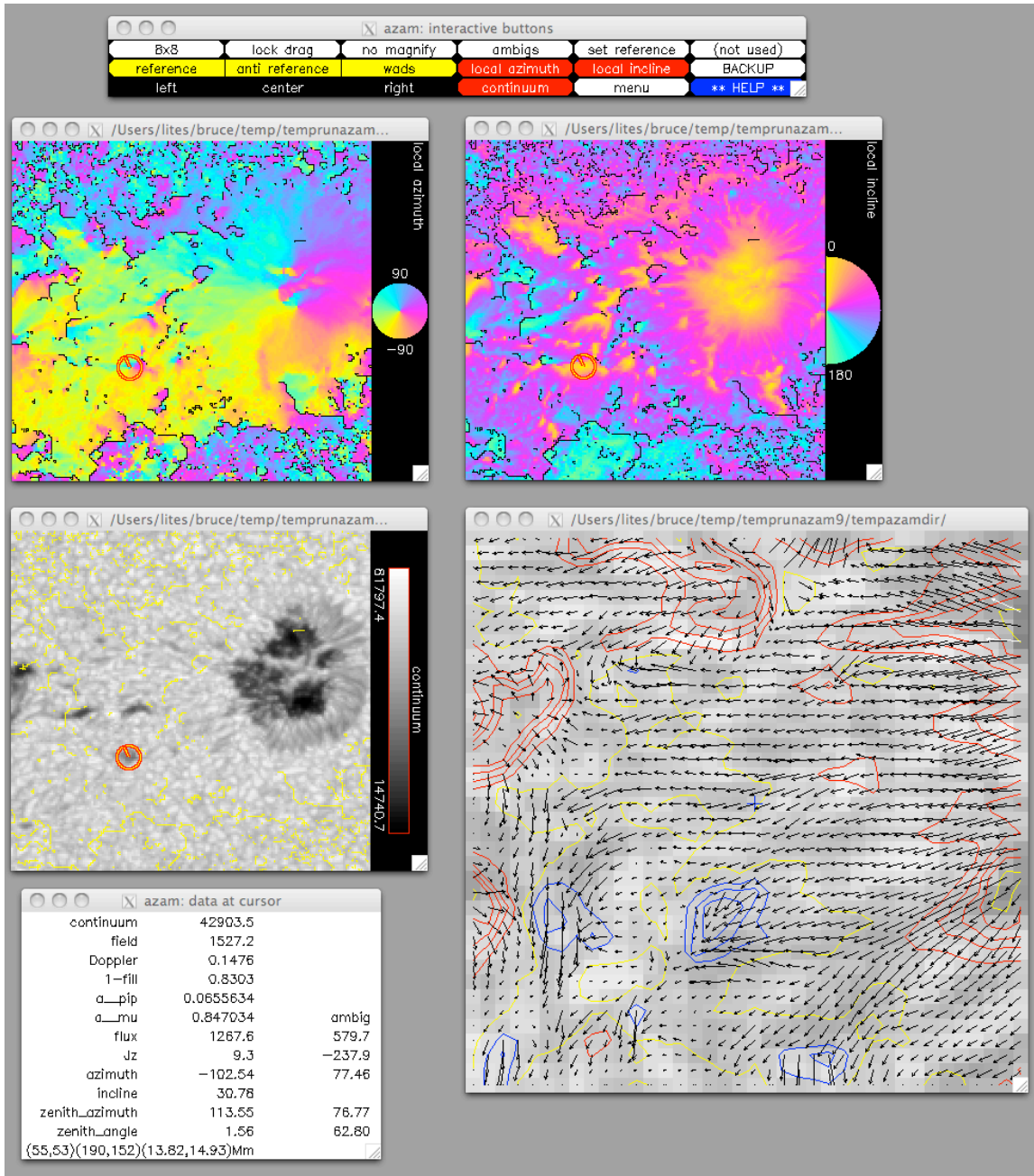

Note how the map is cleaned up in the sense that there are fewer and smoother "*ambigs*" contours. The cursor is positioned on a small pore of positive (yellow inclination) flux. Note that the thumbtack cursor is nearly a circle indicating nearly vertical fields (zenith_angle in the lower left display is only 1°.56), and the local_azimuth shows a small pinwheel of color around the center of this pore. This

is good: pores as well as sunspots usually have vertical fields that diverge (converge for negative polarity) about their centers. Many concentrations of plage often show a similar behavior (see "azimuth centers" as described by Martínez Pillet, Lites, and Skumanich 1997, *ApJ* **474**, p. 810).

We are clearly not finished with the ambiguity resolution. The next step is to see where the ambigs contours fall with respect to discontinuities in intrinsic field strength. We choose to overwrite the continuum image with the image of the intrinsic field strength. Click on the menu button in the main widget display. The upper left button in the large menu panel (see image of this panel above) is "*primer*". Once you click on "*primer*" the following panel is displayed:
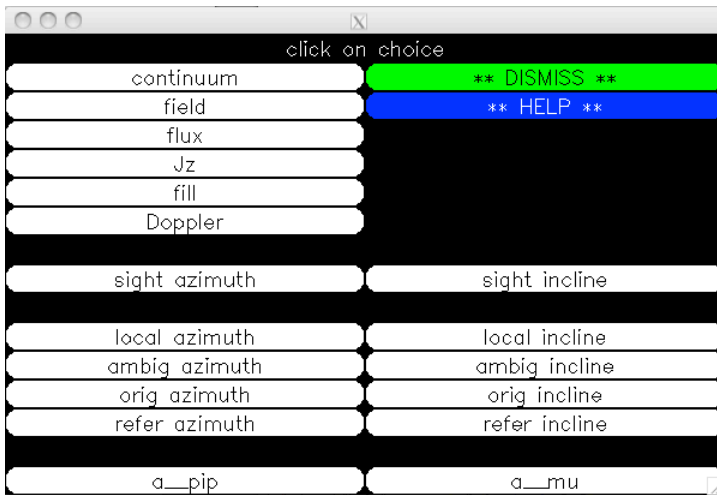

In this panel you select "*field*" to insert the field image. That brings up the following panel that allows you to overwrite the images that are currently displayed:
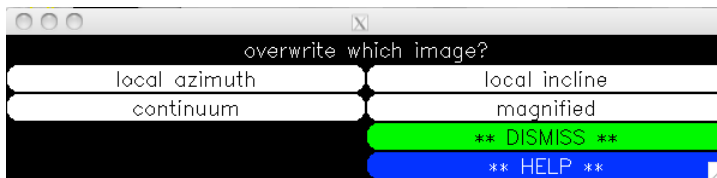
Now select "*continuum*". Below are the resulting images for the field strength and for the *local_incline*, in the process of using "*wads*" with a 4x4 pixel continuity window on two separate regions (near the center left in the *field* image, and near the bottom center for the *local_incline* image). The object here is to have the azimuth continuous in isolated regions of strong field (dark in the field strength image), and to push the *ambigs* contours to the discontinuous edge of strong field. The *ambigs* contours appear yellow in the field strength image, and black in the field angle images. Generally (but not always!) isolated strong field regions should be rather vertical, so the color of these regions in the *local_incline* image is preferably the blue-green color near 180° or the yellow color near 0°. Weaker field regions like

that in the emerging flux area to the left of the larger sunspot, or the canopy region surrounding the sunspot, will have more horizontal fields. Note again that small, isolated concentrations of strong field will also show the color pinwheel of diverging (converging) fields in the *local_azimuth* image.

After refining the ambiguity resolution using the "*wads*" action button with a 4x4 pixel continuity box, I have run the "*smooth*" operation again, and the screenshot below shows the final disambiguation result.
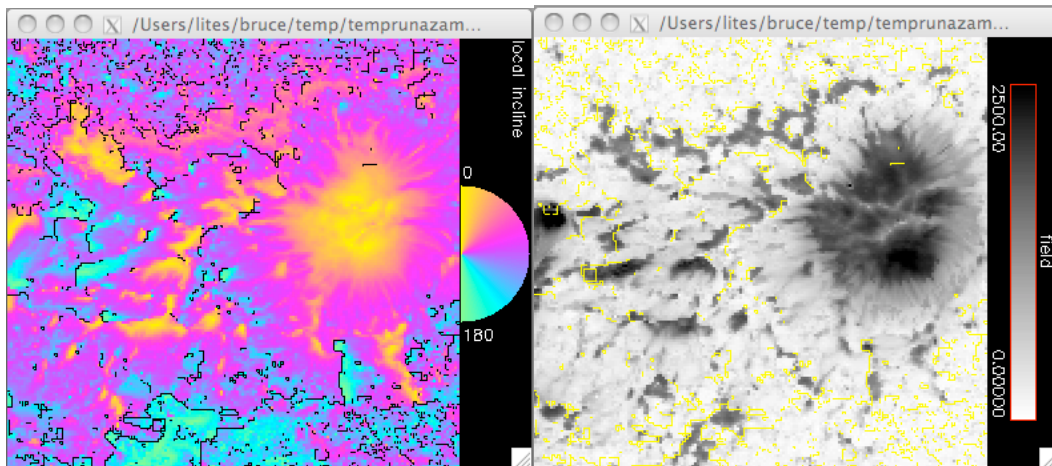

There are several items to note:

- The routine MERLIN *Hinode* inversions process every pixel of each map regardless of the strength of the polarization signal. Regions of quiet granulation have small polarization signals. This inversion, or any other inversion. will fail completely when the signals consist mainly of noise. The AZAM procedure is ineffective in these regions.   I generally run the "*wads*" process as far out away from the concentrations of activity as possible, then I ignore the ambiguity resolution beyond that point. Running "*smooth*" cleans up the appearance of these regions somewhat, but the result might well be unphysical.
- Automatic ambiguity resolution methods might well work better for quiet Sun regions. Those methods should give reasonably good results for small, isolated concentrations of strong fields in the quiet Sun, and relieve the user of the drudgery of finding all of these concentrations and manually using AZAM on the small patches. Thus, an automated but sophisticated method for resolution of the ambiguity, such as the simulated annealing method, would be an excellent choice for a starting point for AZAM, and hopefully AZAM would only be needed to "tweak" the solution.
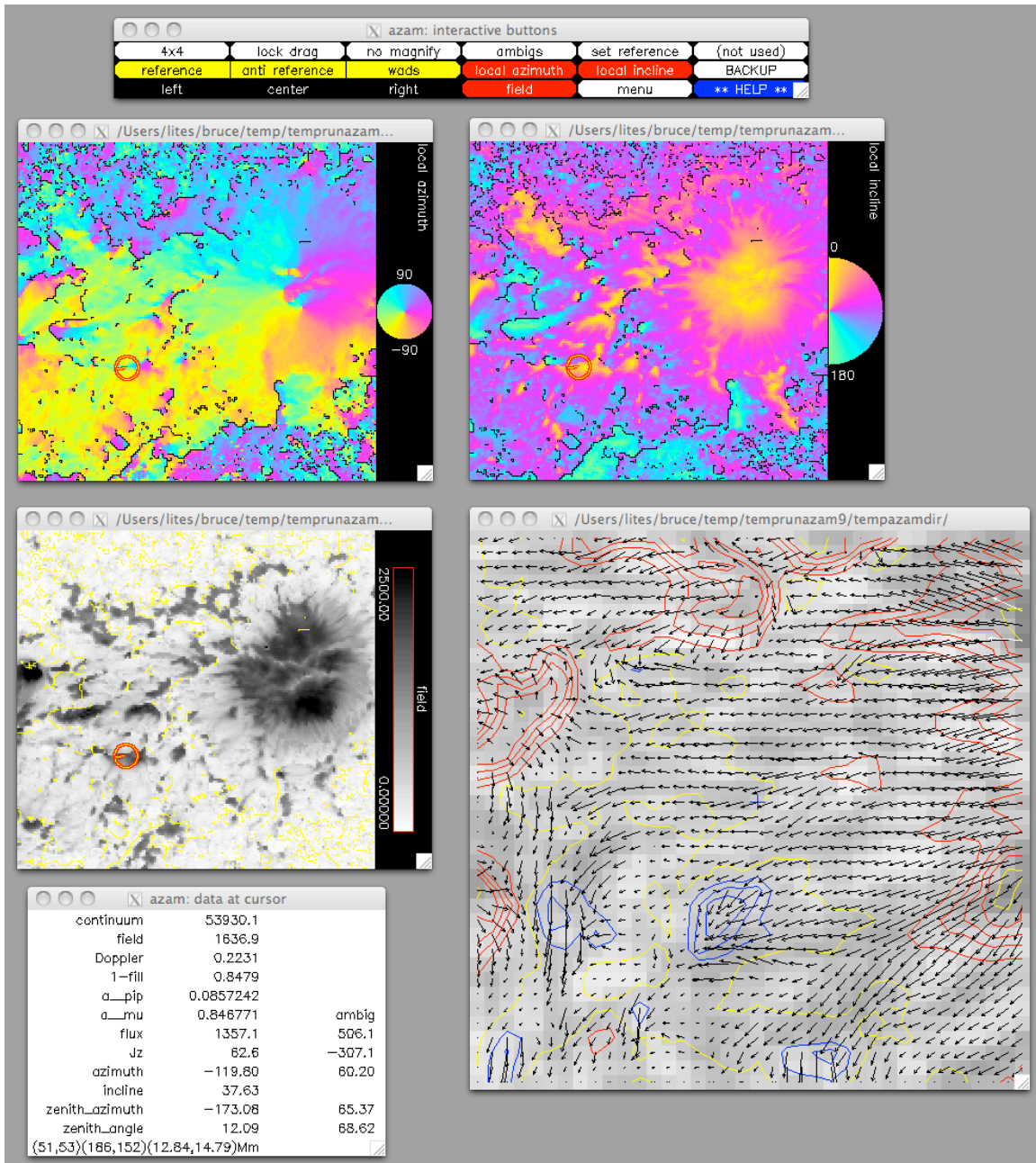
With this solution in had, we now wish to save the results. Return to the menu panel and click the button "*update a_* files*". The following verification panel will pop up:
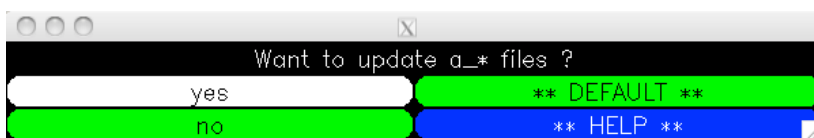
In this case click "*yes*". This updates the AZAM specific files in the working directory designated on start-up of AZAM (default is current directory), and hence saves your ambiguity solution.

Suppose you now want to return to the full area and process more of the map. Here, go to the main menu widget panel and click the red *"** EXIT AZAM **"* button. This will bring up the following choice:

Since we want to do more processing, click the red "*YES, Process Area*" button. Then you will again be asked to do another sub-area, or the entire region:


Next, I have chosen to do the green "*Entire Area*". The image display choice panel comes up:
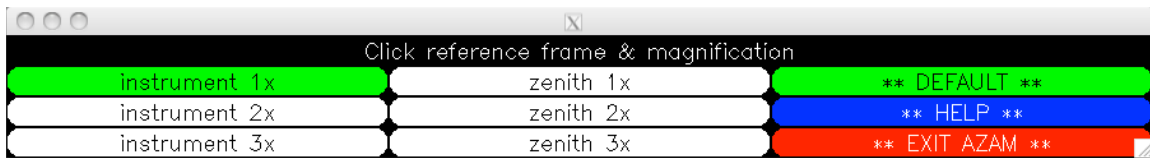
Now just for fun, I choose "*zenith 1x*". When the AZAM interactive display for the entire area returns, I decided to eliminate all the contour lines from the displayed images, so I brought up the menu widget panel again and clicked the white "*all clear*" button. The resulting display follows. You can clearly see where the ambiguity resolution was processed around the previously selected sub-area at the center-right of the *local_azimuth* and *local_incline* images. Note also the stretching of the displayed area because of the choice of zenith reference frame.

I can now continue with the disambiguation at will, choosing sub-areas to work intensively, or working with the entire area, and updating the a_* files regularly.
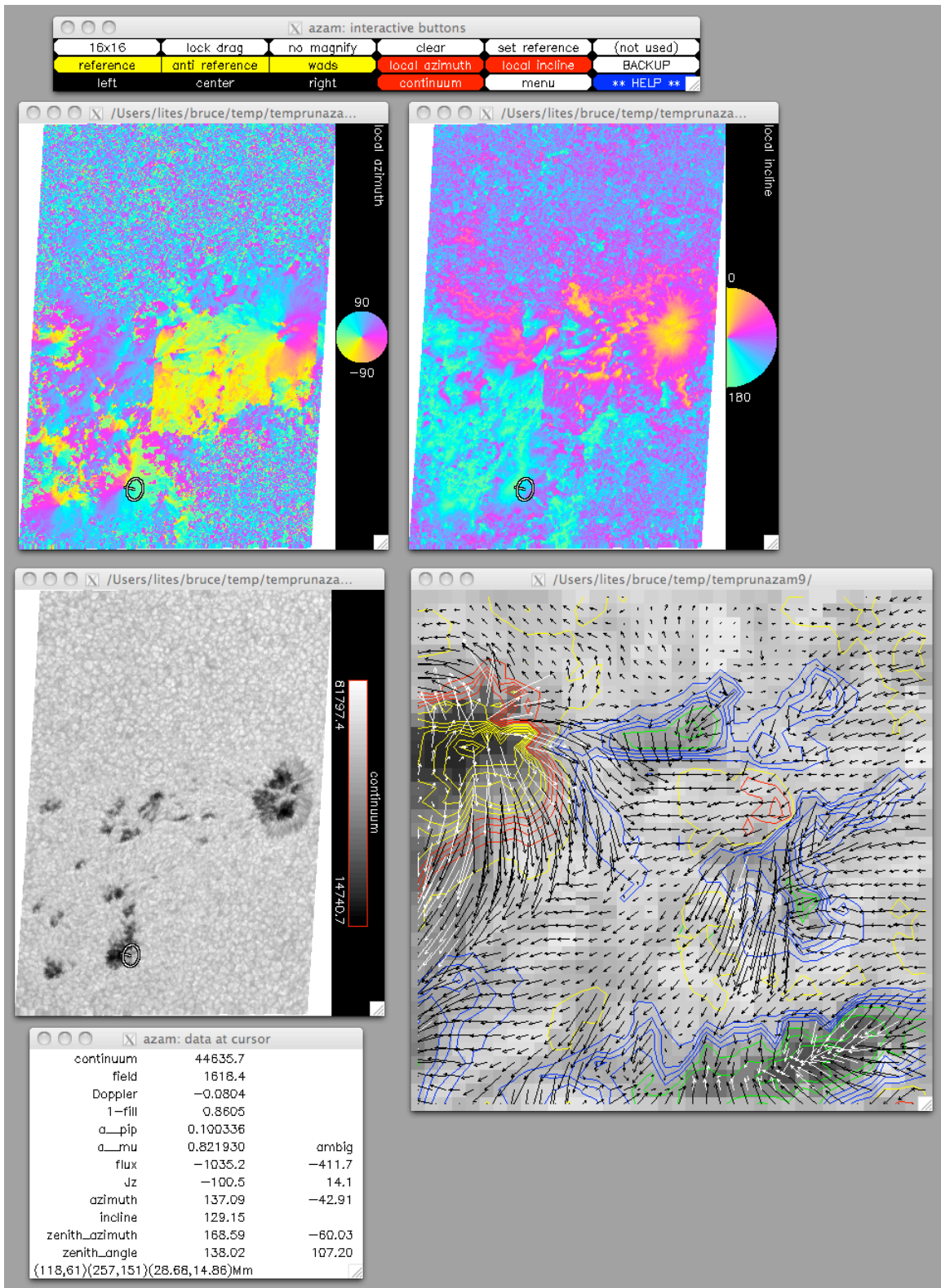
Once I have finished to my satisfaction, AZAM will output a FITS file indicating the choice of ambiguity resolution at each pixel. When exiting AZAM, do not process

another area, but instead choose the green "*NO, CONTINUE*" button. I am then asked if I want to write the FITS file:

This FITS file, "AZAM_ambig_resol.fits", is a single byte image array containing 0 where the resolution matches the original inversion output, and 1 where it differs from the original.

III. Functionality of the Main AZAM Panel
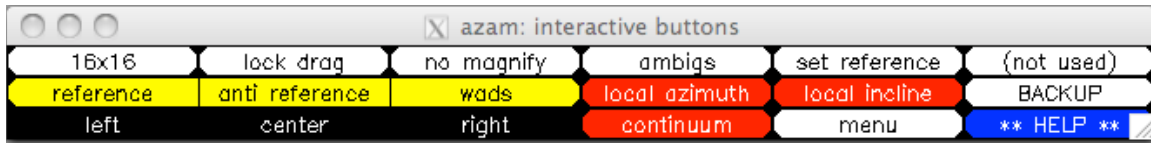
The AZAM Main Interactive panel shown above allows one to access the wide range of functions available to the user. The indicators in the black area below the yellow buttons in the above panel are inactive. They only associate the functions in the two rows above with the mouse button indicated in the bottom row.

The most important button on this panel is the *menu* button. It brings up a host of functionality in a pop-up menu panel. See Section VI for a description of these functions.

A. White Buttons of Top Row (from left to right):

1. **16x16/8x8/4x4/2x2/1x1**: Mouse-over square area, in original image pixels. Default initial value is the largest: **16x16**. Clicking on this button cycles downward through the possibilities; i.e. **8x8, 4x4, 2x2, 1x1, 16x16** ……

2. **lock drag/unlock drag**: The default, **lock-drag**, locks the function of the mouse-over when dragging it over the image. In other words, you do not need to hold the button down to have the effect of the button persist as you drag the cursor across the image. The opposite effect, **unlock drag**, initiated by clicking this button, sets the functionality of the buttons upon dragging the mouse such that you must hold down the particular mouse button.

3. **magnify/no magnify/short arrows**: The **magnify** function magnifies an image of the continuum (default) shown in the separate window around the point where the cursor is clicked. This image has superimposed contours of the locally vertical component of the field (red=toward observer, blue=away from the observer), the neutral line (yellow), and arrows indicating the strength of the horizontal component of the field. When the button indicates **magnify**, clicking on a region of interest displays a magnified area around the cursor in the magnify window. With **no magnify** displayed, clicking does not change the state of the magnify window. The short arrows option displays shorter length arrows for strong field regions within sunspots.

4. **ambigs/reversal/sight reversal/clear**: The default state of the display in the active AZAM windows displays contour lines where an ambiguity discontinuity occurs (**ambigs**). One may change the functionality of the contours using the mouse-over on the active images. An alternate set of contours

5. **set reference**: Clicking on this button sets the current values of the ambiguity resolution to the current reference. This button does not save the ambiguity resolution, it just stores temporarily the "reference" values. This enables one to make more changes to the ambiguity resolution, then return to the reference values.

6. **(not used)** (formerly was *** OTHER OP *** for ASP data): This button is a remnant from the ASP version of AZAM where two maps could be disambiguated simultaneously. It is de-activated in the current version.

B. Yellow Buttons, Second Row (left to right):

The left and center yellow buttons control the function of the left and center mouse buttons as acting on the interactive square area under the cursor on the active images. These buttons cycle their functions in synchrony with a left mouse click on either of the left or center yellow buttons. Below are the various functions assigned to the these two mouse buttons:

1. **[reference, anti reference]:** Changes the selection of azimuth ambiguity within the cursor box to the reference value, the opposite value.

2. **[reference, smooth]:** The middle mouse button invokes the *smooth* function for the region within the cursor box.

3. **[up down, anti up down]:** The right mouse button invokes the *up down* ambiguity resolution function locally within the cursor box (see Section IV.C. for applying this globally). As the title implies, the *anti up down* function applies the ambiguity solution opposite from *up down*.

4. **[minimum Jz, maximum Jz]:** Applies the functions for unambiguous vertical current density (see Section IV.B.).

5. **[azimuth, anti azimuth]:** The *azimuth, anti azimuth* functions apply locally the ambiguity resolution with respect to a chosen center position (see Section IV.D.).

6. **[original, anti original]:** This function allows the user to return to the original ambiguity resolution in effect at the time of starting the AZAM procedure (or is this the original output from MERLIN?????).

The third yellow button from the left allows the following functionality, as activated by a click on the right mouse button. Left-clicking on this button cycles through the functionality:

1. **wads:** This is the standard interactive ambiguity resolution using pixel-to-pixel continuity of the azimuth (see Section II.B.).

2. **smooth:** The right mouse button invokes the *smooth* function for the region within the cursor box.

3. **no change:** (self explanatory)

4. **average:** This function averages the quantities within the cursor box. The values of these averages are displayed interactively in the "data at cursor" display box instead of the value at the individual point under the cursor.

C. Functionality of the Red Buttons

The red buttons indicate the inversion quantity currently displayed in the three active AZAM image windows. Once a red button is clicked, AZAM disables the functionality of the right mouse button (see the "*no change*" indicator in the rightmost yellow button), and the inversion parameter displayed in the right mouse button is painted onto the respective active image by moving the cursor. Clicking on any of the red buttons allows one to cycle through the possible display parameters. It is possible to restore the functionality of all buttons using the "*recommended modes*" button in the AZAM *menu* display panel. It is also possible to cycle back to the desired functionality of the rightmost yellow button by clicking on it. The red buttons can be useful to see the behavior of some quantity (eg. field strength) locally at a location in another image (e.g. continuum). When using the red buttons, it is best to use small squares for the mouse area.

D. *Set Reference* and *BACKUP* buttons

Occasionally during an AZAM disambiguation one may wish to save your solution within your current session. Clicking the *set reference* button does this. Subsequently, any mouse-over *reference/anti reference* actions will use the current reference value, as will the *recover reference* action on the AZAM *menu* panel. This action only sets a reference within the current AZAM session. To save your solution prior to closing, use the *update a_* files* under the AZAM *menu* panel.

It is also possible to write a file named BACKUP of the current solution. This BACKUP file can be recovered internally using the *read azimuth file* function under the AZAM *menu* panel. The format of the BACKUP file is identical to that of the current solution saved by AZAM, appropriately named AZAM. If one wants to start from the BACKUP file, rename it AZAM.

CAUTION: the BACKUP function writes the file in the current working AZAM directory. This will be a temporary directory named "tempazamdir/" if one is

working on a sub-area of the map, and the BACKUP file will be deleted upon normal exit, but will be retained in the sub-directory tempazamdir/ upon abnormal exit. **For this reason, it is recommended to always use the *update a_* files* function under the AZAM *menu* panel to save your solution, and not to use the BACKUP function.**

IV. Other Disambiguation Tools in AZAM

Several other tools for disambiguation are implemented in AZAM. These tools are accessed via the *menu* widget panel, as shown again below by itself:
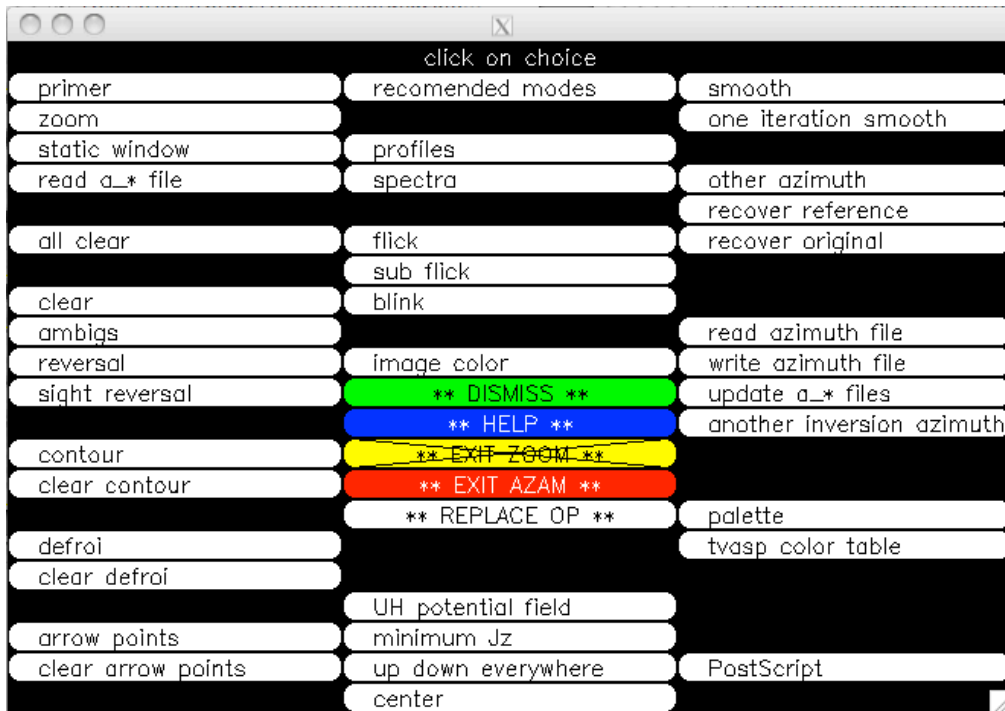

The four white buttons at the bottom of the middle column allow one to implement these disambiguation tools. I find these useful in some circumstances, as described in the following, but usually I rely heavily on the basic "*wads*" disambiguation tool described above in Section II. To illustrate these tools, they are applied to a sub-area of the sunspot to the left of center near the bottom of the map used in the previous section. The images below show the "*continuum*", "*local_azimuth*", and "*local_incline*" panels of the AZAM presentation only. They are displayed as "*instrument 3x*". Immediately below is the raw solution resulting from the MERLIN inversion of this small sub-area.
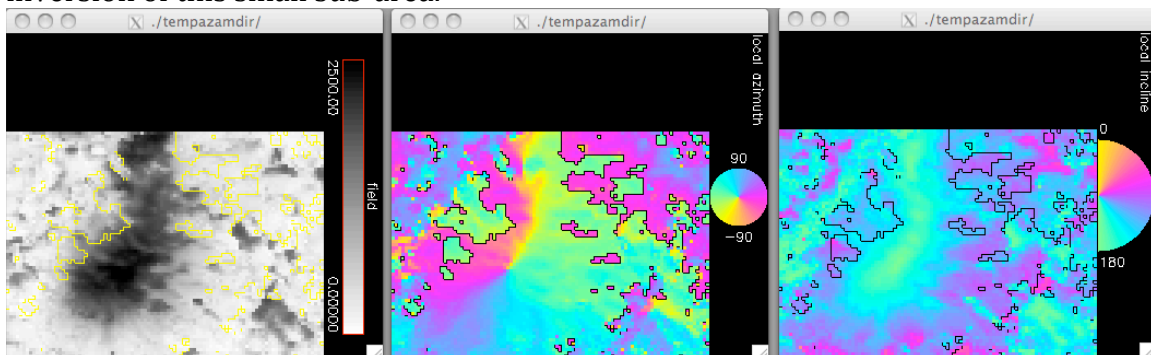
Some intermediate interactive panels offering exit and help information are not shown in the following.

A. The "*UH Potential Field*" Disambiguation

This tool applies a version of a potential field disambiguation that was implemented at the University of Hawaii in the 1990s. Newer potential field methods might be much more effective, but they are not implemented in AZAM yet. Often this disambiguation can be applied to an entire map of an active region as an initial guess. You will have to be the judge whether this, or any of these four tools, is useful or not on a particular data set. Below is the result of the "*UH potential field*" action:
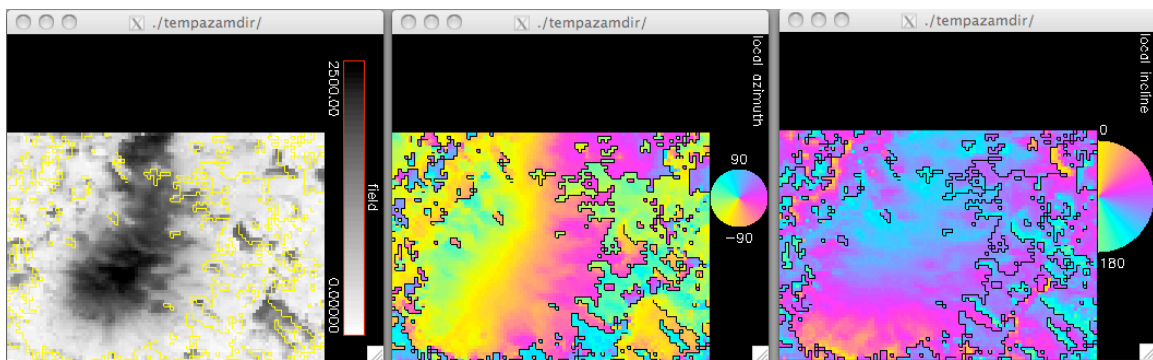

B. The "*Minimum Jz*" Disambiguation

This procedure is based on the method of Semel and Skumanich 1998 (*A&A* **331**, p. 383). It seems to show correct features of the large scale structure, but it produces a large amount of spurious small-scale structure with the high resolution *Hinode* data, as seen in the image below.
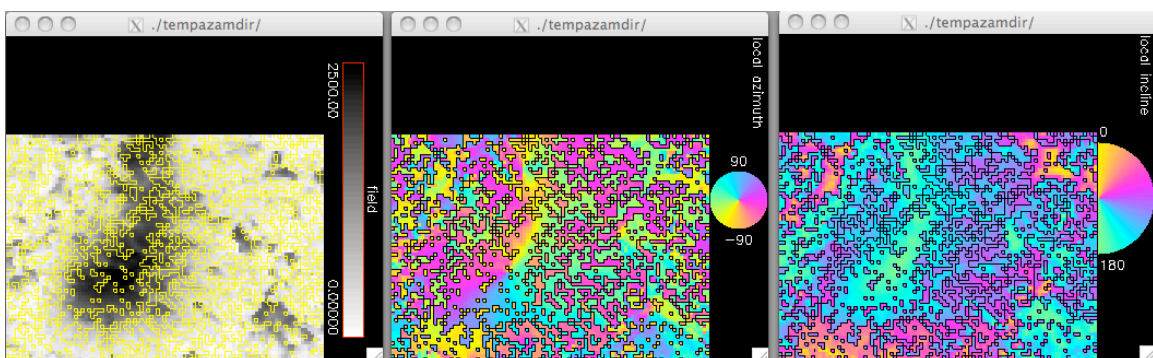
C. The "*Up Down Everywhere*" Disambiguation

This ambiguity resolution picks the solution that is closest to vertical (up or down). Obviously it does not work very well in sunspot penumbrae where the fields are dominantly horizontal (see image below), however it can be very useful for plage and quiet Sun network where the strong kilogauss flux elements are typically close to vertical because of their intrinsic magnetic buoyancy.
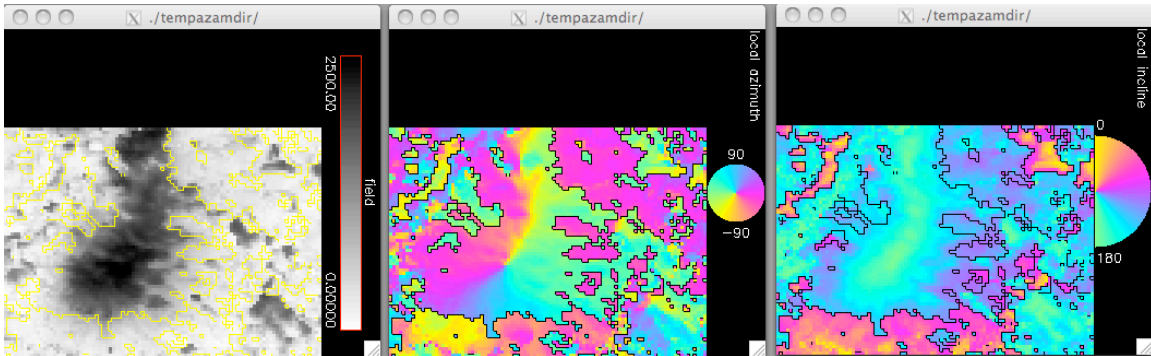

D. The "*Center*" Disambiguation

The "*center*" disambiguation selects the choice of azimuth that diverges (or converges) toward a user-selected central point (say the point of most vertical fields in an umbra). This works well for symmetric sunspots and pores, but it has its obvious disadvantages beyond that. The user is first presented with a panel that allows one to select the magnetic polarity of the point that will be chosen, then one is asked to click on a center point.
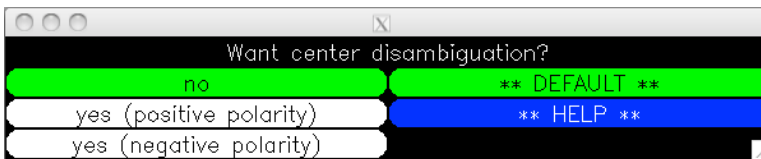
As is seen from the results shown below, the procedure works fairly well for isolated unipolar regions, but this method will normally require some manual intervention.
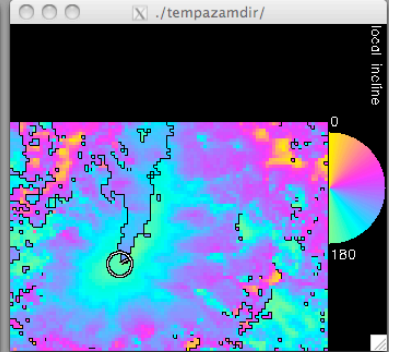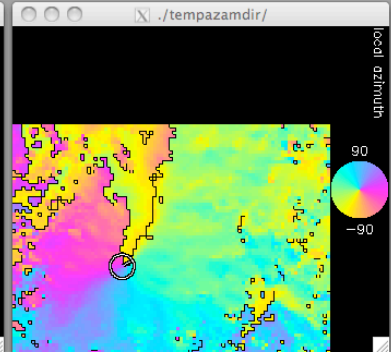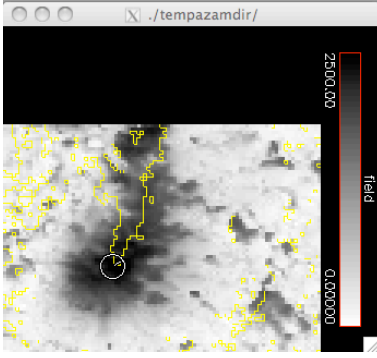
V. Interactive Spectra Display

The AZAM *menu* offers the possibility of interactive display of the observed profiles along with the synthetic profiles from the Unno-Rachkovsky solution of the radiative transfer equation for polarized light in a Milne-Eddington atmospheric model. This option is activated by clicking on the *spectra* button in the AZAM menu panel. In the *Hinode* implementation of AZAM, the display of the spectra profiles requires the user to direct AZAM to the location of the *Hinode*/SP Level1 calibrated profiles that were used to by the MERLIN inversion code.   An example of the widget text entry for input of this path is as follows:
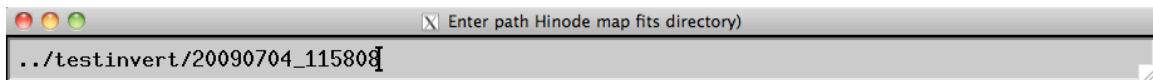
where the entry is the path to the directory containing the Level1 FITS files corresponding to this inversion.   This directory must contain identically the same data files that were used to produce the inversion; no more and no less.

Once entered, AZAM will require a few moments to read into memory all of the observed Stokes profiles. This may exceed the capacity of some machines. AZAM does not check the computer for this possibility. If memory is insufficient, then depending on the computer, the machine may use virtual memory in which case the AZAM interactive *spectra* function might be unacceptably slow.   One way to circumvent this problem is to perform the *spectra* function on a smaller sub-area for which the computer memory is sufficient.

Once in the *spectra* function, one may examine the observed and theoretical Stokes profiles interactively as the mouse is moved within any of the active AZAM images. The screenshot below shows the resulting display. The panel showing the Stokes profiles at the location of the cursor displays the observed profiles in black and the fit profiles in red. For Stokes *I*, the "magnetic" component of the fit *I*-profile, f I_{mag}, is plotted in blue (f is the magnetic fill fraction). The total Stokes *I* fit profile is the sum of f I_{mag} and the "scattered light" *I*-profile times (1-f). The fit profiles are computed on the fly[2].

Also shown by the *spectra* function is a gray-scale display (in the window titled "scan step") of the Stokes spectra along the slit corresponding to the horizontal location of the cursor over the active image.   This window is static, but performing a

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[2] The fit Stokes *I* may differ very slightly from the actual fit profiles computed by MERLIN. Those are typically not stored, and MERLIN is not used to compute them. In any case, comparison of the MERLIN fit profiles and those displayed by AZAM are not significant.

left-click of the mouse refreshes this display at the current cursor position over the image.
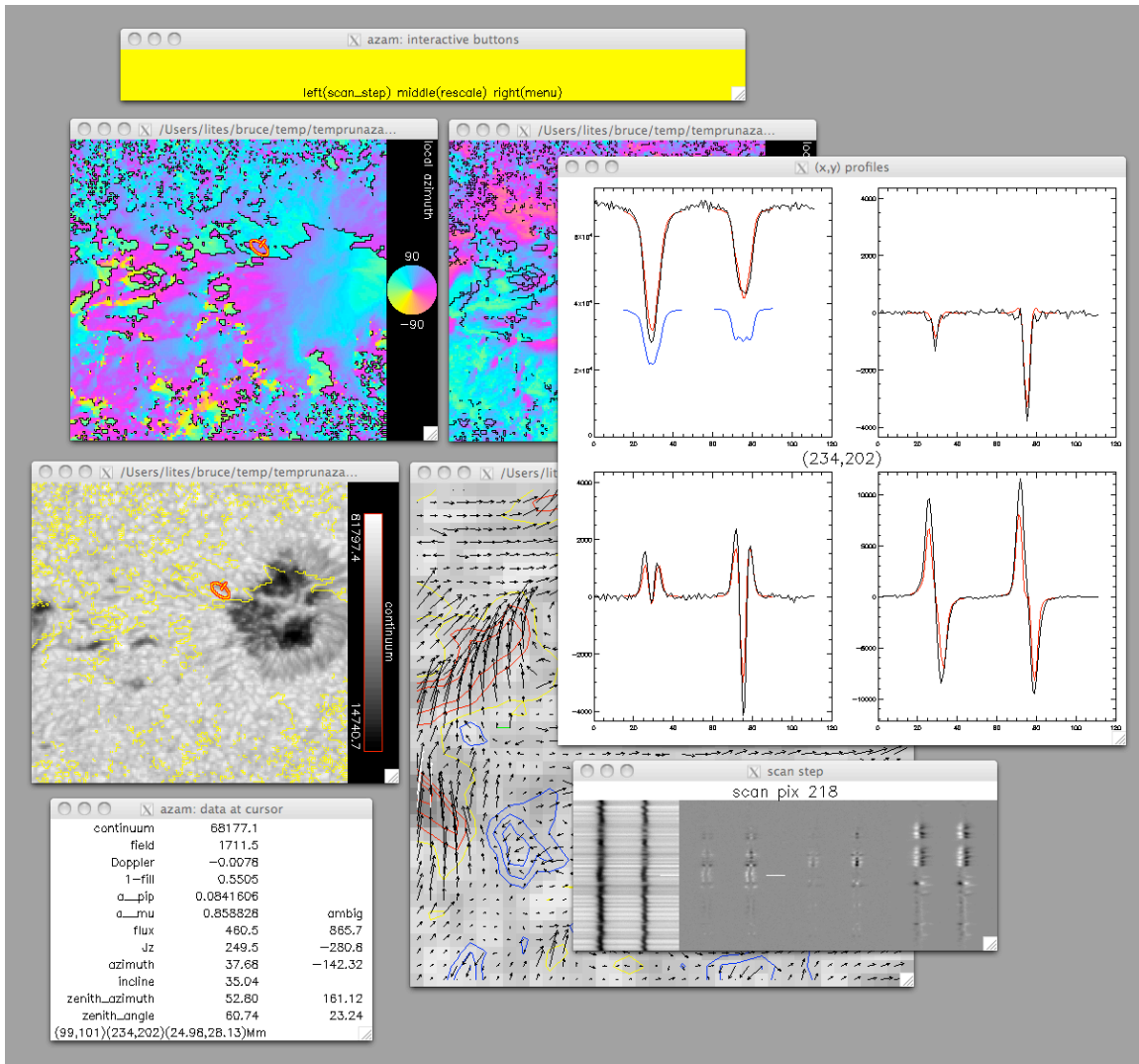
The middle mouse button scales the interactive profile display according to the minimum and maximum values at the location of the cursor. Then moving the mouse does not change this scaling. The default scaling of the profiles, *auto scaling*, can be recovered from the *spectra* menu panel, which may be opened by a right-click of the mouse. This right-click presents the user in the panel shown below with several other options for the *spectra* function:

The function *cross spectra* opens another gray scale display like the *scan step* window, but for which the spectra are displayed for a horizontal cut through the image (the window titled "along slit"). An expanded view of this display is given below:
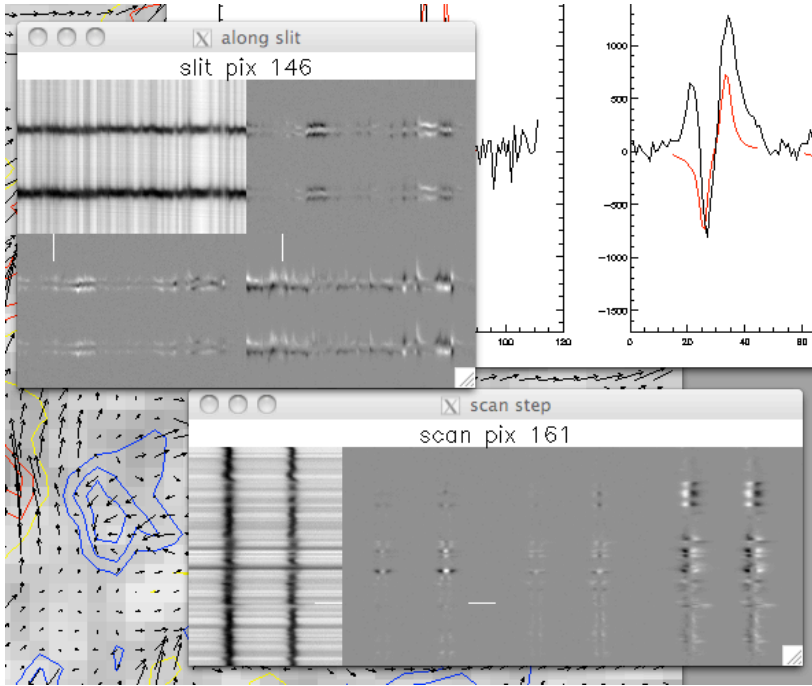
Other options in the *spectra* menu panel allow one to output PostScript (or encapsulated PostScript) images of the Stokes profiles and their respective fits. Profiles can be output in this manner with, or without, the blue I_{mag} profiles.

VI. AZAM Display Options

The AZAM *menu* widget panel offers the user many options for examination and manipulation of the inversion data. Below again is a display of the *menu* panel:
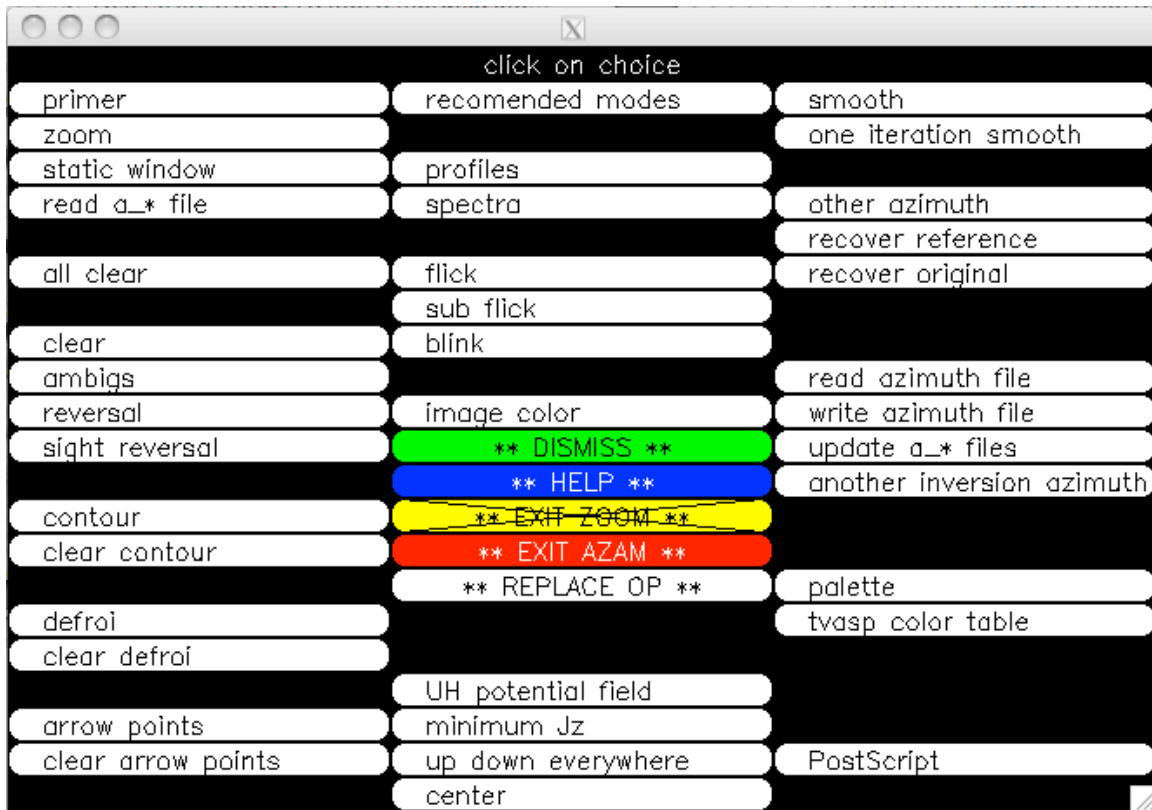
Note again that one may always click on the blue *** HELP ** button to see information on most options in this panel. When viewing a ** HELP ** screen, you may exit *** HELP ** by right-clicking your mouse.

Some hints and further discussion beyond the ** HELP ** pages are provided below. Items in the AZAM *menu* widget panel are treated top to bottom, then left to right.

A. ***primer** – This function allows one to switch the parameters that are displayed in the four AZAM image displays. The operation of this function has already been described above in Section II.

B. ***zoom** – This function brings up another set of image displays that zoom in on an area of interest. The AZAM disambiguation functions work in this zoomed view until the user dismisses *zoom* by the yellow *EXIT ZOOM ** button in the main widget display panel.

C. ***static window** – This function opens a new image display window that displays the current values for the selected parameter. AZAM disambiguation functions are not present in these windows.

D. **read a_* file** – This function will probably not be very useful to most users. The format that AZAM expects for data is that of the ASP data system. The data are stored as files having names beginning with "a_". So-named files will exist in the working directory after one has started the *Hinode* implementation of AZAM. Using this function, one may read into AZAM data corresponding to the name of the file. For example, suppose you wanted to read in the field strength from a previous data set of the same dimensions in another directory.

E. **all clear** – This function clears any overlay that exists on the images, including ambigs or other contours, arrow points, etc. This is useful, for example, if one wishes to output images of various parameters to PostScript files.

F. **clear** – The *clear* function allows the user to clear selected overlay contours

G. **ambigs** – Clicking this function draws the *ambigs* contours on the images. The *ambigs* contours are described in Section II.

H. **reversal** – The *reversal* contours are locations where the polarity of the field changes from positive to negative. In other words, they mark locations where the field vector is horizontal to the surface.

I. **sight reversal** – This function places contours of polarity reversal as seen in the observer's frame.

J. **contour/clear contour** – The contour function allows one to place contours on all the images representing the value of the parameter at the point where the user clicks on one of the images. For example, if one wants to see contours representing the umbral intensity, upon prompting click on a position near the outer edge of an umbra. The *clear contour* button clears the contours from the images.

K. **defroi/clear defroi** – This function implements the IDL DEFROI routine for the AZAM images. It is possible to define regions using contours or manually. See the HELP documentation that accompanies this function.

L. **arrow points/clear arrow points** – This function places arrow points on the active images indicating the orientation of the field vector. The arrow points may be thought of as the projection onto the horizontal plane of a 3-dimensional arrow point sticking into the horizontal plane at the point of observation with the same orientation as the magnetic field vector. The direction of the arrow point indicates the orientation of the horizontal field, and its length indicates the inclination to the horizontal.88

M. **recommended modes** – This function returns AZAM to the displays for *local_azimuth* and *local_incline*, with *ambigs* contours, and sets all button functionality in the main AZAM panel to their defaults.

N. **profiles** – This function prompts the user for a choice of parameter to display, then it provides an interactive plot of the profile either along a pixel row (default) or column (with left-click of the mouse) of that parameter.

O. **spectra** – The *spectra* function allows the user to interactively view the observed profiles along with the fitted profiles. This function is described in detail in Section V.

P. ***flick*** – The *flick* function blinks an inversion parameter (such as field strength) to blink alternatively in all three active AZAM windows.

Q. ***sub flick*** – The *sub flick* function is similar to that of the *flick* function, but the only a sub-area of the AZAM under the cursor is alternately blinked between the standard image and the chosen inversion parameter. The sub-area moves within the image with motion of the cursor.

R. ***blink*** – The *blink* function allows the user to select two inversion parameters to blink against one another. Once selected, a new window is opened for the comparison.

S. ***image color*** – the *image color* function first opens a new display window for a user-selected inversion parameter, then it allows some basic manipulation of the color/gray scale display, such as converting from color to gray or vice versa, setting maximum or minimum limits for the display, inverting the color table, and so forth.

T. ***** REPLACE OP ***** -- The *** REPLACE OP *** function cancels the current operations and allows the user to restart with a new operation. **This function is not recommended** to be used with the *Hinode* AZAM implementation. The user should exit AZAM normally and restart the AZAM session with the desired *Hinode* SP map.

(The alternative resolution procedures ambiguity *UH potential field, minimum Jz, up down everywhere,* and *center* are described in Section IV.)

U. ***smooth/one iteration smooth*** – The *smooth* function is extremely useful. This function applies an iterative smoothing function to the ambiguity resolution currently displayed in the active AZAM windows. The effect of applying the *smooth* function is illustrated in Section II.B.

V. ***other azimuth*** – The *other azimuth* function displays the alternate ambiguity resolution for the parameters displayed on all three active AZAM windows. One may recover the chosen ambiguity resolution by applying this function again.

W. ***recover reference*** – As the title implies, this function recovers the reference azimuth ambiguity solution on all three active AZAM windows. If one has not previously performed the *set reference* function, the values for the ambiguity resolution on startup of AZAM are recovered.

X. ***recover original*** – This function recovers the original azimuth ambiguity resolution encountered at start-up. This original azimuth is unaffected by saving the a_* files (see item VI.Z. below), or by the saving of a reference during the ambiguity resolution process.

Y. ***read/write azimuth file*** – Upon the command to update a_* files, AZAM writes the ambiguity solution to a file named AZAM. This command allows one to either read or write a file in this format. Writing the file requests the user to provide a file name (the default is AZAM).

Z. ***update a_* files*** – This function updates the files that contain the solution to the ambiguity solution: AZAM, a_1incl, a_2incl, a_1azm, a_2azm, a_azm. Use

of this command is the preferred method of saving the current solution prior to exit of the AZAM utility.

AA.　　　　*another inversion azimuth* – It is possible to adopt the ambiguity solution from another inversion. This function is only useful for processing a sequence of maps of the same region having identical dimensions. AZAM querries the user for the path to the directory containing the AZAM solution files (the a_* files).

BB.　　　　*Palette* – This function calls the IDL routine xpalette to show the current color table. Formerly it called a routine "palette" which apparently is depreciated and/or does not function correctly in the SSW environment. The interactive functions of xpalette are not active in this application, so it is not possible to alter the color table using this command. The xpalette window must be closed manually, and once closed, the *palette* function does not work in the current AZAM session.

CC.　　　　*tvasp color table* – The *tvasp color table* function restores the standard AZAM color table.

DD.　　　　*PostScript* – The *PostScript* function allows the user to write PostScript files of selected images. The following screenshots illustrate the progression of choices for output of PostScript images. First, the user is queried as to which directory is desired for output of the images:

Next, the choice is between regular or encapsulated PostScript:

Following that, one is asked to choose a suffix for the file names of the PostScript files. Perhaps the default file name indicates that Paul Seagraves intended the PostScript files to be promptly deleted ☺
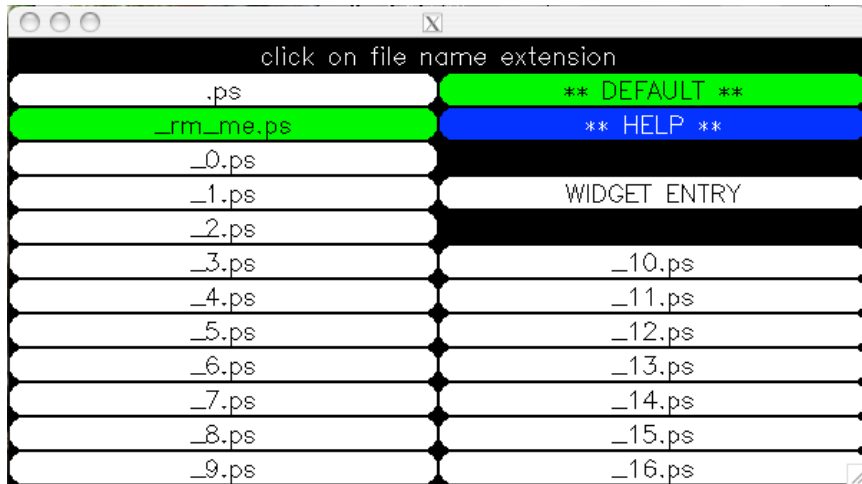
Next, the scale of the image displayed on the paper is requested. Usually it is prudent to select the "*just fits*" scale, which gives the largest possible display for 8.5 x 11 inch paper:

Next, the main panel for selection of images to be output is presented. Below is an example of the panel, where I have clicked on *cct* (continuum image), *fld* (field strength image), *flux*, *1azm* (the preferred azimuth in the local frame), *1incl* (the preferred inclination in the local frame), and *fill* (the fill fraction).
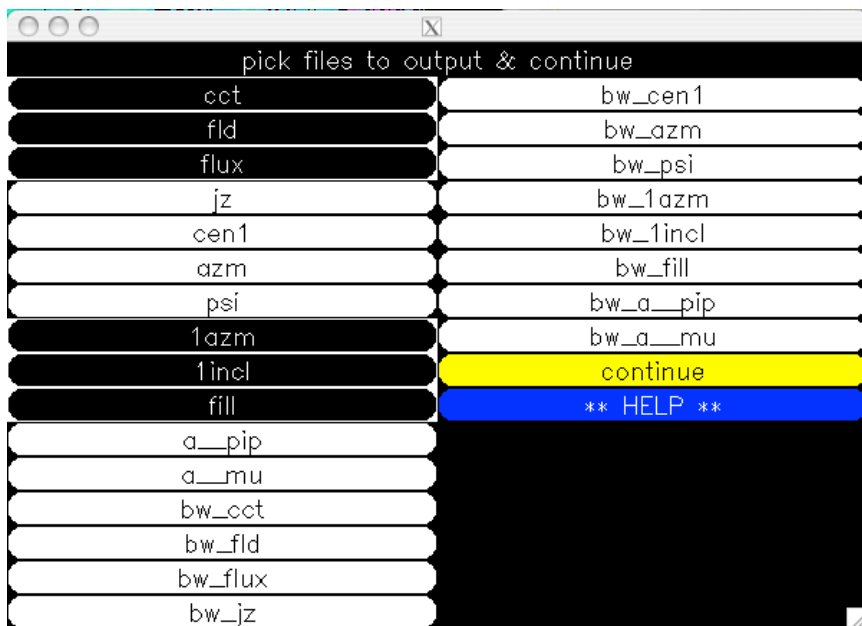
When finished with the selections, click the yellow "*continue*" button. That brings up the following sequence of panels where one may begin to select the tick intervals on the plots:


NOTE: when finished with this processing, the user is returned to the large "*pick files to output & continue*" panel, where you may either select more parameters for output to PostScript images, or simply click the yellow "*continue*" button to return to the main AZAM interactive panel.

An example of a PostScript output image for the field inclination in the local frame is given below:

Zenith Angle
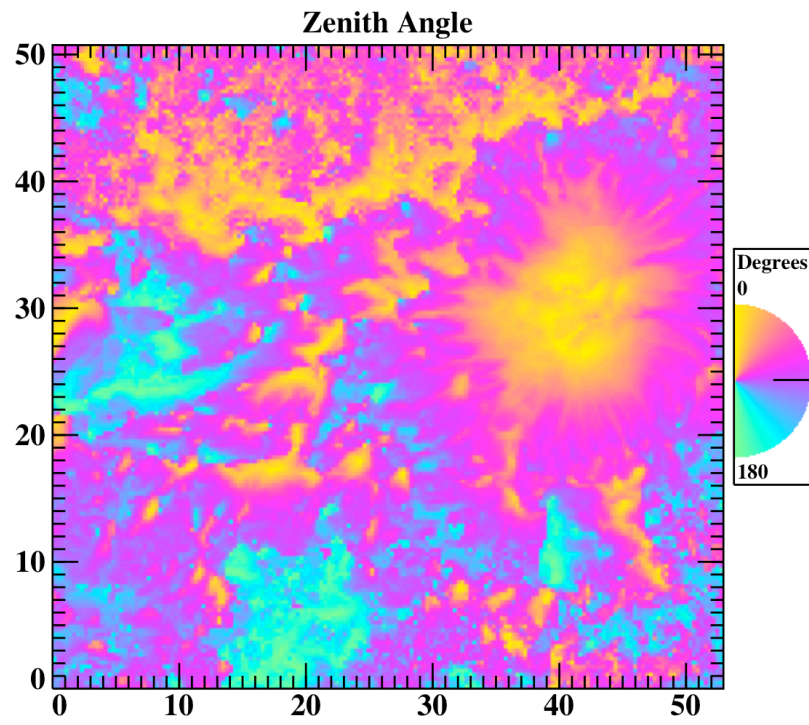
VII. AZAM for SDO/HMI

The AZAM utility has been built to work with data from the SDO/HMI instrument. At the time the modification for HMI was made, the SHARP active region cutouts were not available, only full-disk data were available. The utility has now yet been modified to work with SHARP subareas. However, AZAM is built for HMI so that the user may select his/her own subareas to disambiguate or display from the original full disk data.

Operation of AZAM for HMI data is nearly identical to that for Hinode SP data, as documented in the descriptions AZAM_documentation_v2. There are a few subtle differences from the Hinode SP AZAM, arising from the differences in the data and the inversions for HMI. These are diescribed briefly in the following.

In order to run AZAM on HMI data, one must first place all the relevant FITS files for the full-disk data into the appropriate directory. The routine HMI inversion yields the following parameters:

*alpha_mag.fits – the fill fraction (=1 for all standard HMI inversions)
*azimuth.fits – the field azimuth in the observers frame
*chisq.fits – the chi-squared of the least square fitting procedure
*damping.fits – the damping parameter
*dop_width.fits – the Doppler width
*eta_0.fits – the line-to-continuum opacity ratio
*field.fits – the strength of the magnetic field, Gauss
*inclination.fits – the inclination of the field to the line-of-sight
*src_continuum.fits – the surface value of the source function
*src_grad.fits – the slope of the source function with optical depth
*vlos_mag.fits – the line center wavelenth position
*alpha_err.fits – the formal error for the fill fraction
*azimuth_err.fits – the formal error for the azimuth
*field_err.fits – the formal error for the field strength
*inclination_err.fits – the formal error for the field inclination
*vlos_err.fits – the formal error for the line center position

One must obtain these parameters from the VFSIV inversion. In addition to these parameters, one must also obtain the continuum intensity that resides in the HMI data archive:

*continuum.fits – the continuum intensity image

All of these fits files for one HMI measurement should be placed into a single directory, for example called "hmi_data_dir".

To initiate AZAM, simply run the command under SSW IDL:
azam_init_hmi,'[hmi_data_dir]'

The AZAM code for HMI now works for both the SHARP data (spatial active region cutouts, disambiguated automatically) in addition to full-disk data. Note that the full-disk data have not been disambiguated, and the default azimuth falls in the

range of 0-180 degrees. There is an adjustment within AZAM of the azimuth orientation because AZAM expects the azimuth to be referenced to zero toward solar west, and increasing counter-clockwise. As a result of this, when one first enters AZAM for the full-disk data, the azimuths fall in the range 0 – 270 degrees.

A suggestion: starting AZAM from scratch with a custom area from the full-disk HMI data, it is often best to initialize the AZAM disambiguation with "up down everywhere" or "UH potential field". These selections may be found under the "menu" button on the main widget panel of AZAM. The "up down everywhere" selects the azimuth that selects the azimuth closest to vertical in the local reference frame. This is especially useful for plage where the fields are often close to vertical. The UH potential field selects the azimuth closest to a potential field solution (an adaptation of the procedure developed at University of Hawaii).

One should always bear in mind that the VFSIV procedure for inverting SDO/HMI data assumes unit fill fraction for the magnetic field. This assumption will lead to errors in the field inclination to the line-of-sight for fields that are spatially unresolved. Usually the sense of the error is such that the inclination of the field is more transverse to the line-of-sight than is actually the case. Of course, for observations away from the center of the solar disk, this error affects both the inclination and the azimuth in the local ("zenith" as it is called in AZAM) frame. Another consequence of this assumption is that the inferred field strengths are smaller than the intrinsic field strength for unresolved magnetic elements. One should bear this in mind especially when examining plage or network fields in HMI data.