

## TensorCS v3.20 Notes

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TensorCS is a utility program for processing combined scalar, vector and/or tensor CSAMT data. TensorCS replaces VectorCS, since it can do both vector and tensor processing, and it replaces AMT2VIP, since it estimates scalar and vector IP phase from low-frequency CSAMT electric-field data.

TensorCS reads AMTAVG \*.avg, \*.stn & .mde files and writes a series of Zonge and Surfer format output files. It creates vector CSAMT results for all stations with (Ex,Ey,Hx,Hy) data from at least one transmitter bipole. It creates tensor CSAMT results for all stations with (Ex,Ey,Hx,Hy) data from two to four Tx bipoles. By default, TensorCS assigns (Ey,Hx) data to nearby (Ex,Hy) soundings within  $\pm 0.6 * \text{Station\_Interval}$ . If two (Ey,Hx) soundings are the same distance from a (Ex,Hy) sounding, TensorCS uses the (Ey,Hx) sounding with the higher station number. To accommodate GDP setup configurations with multiple Ex, single Ey, v3.20 includes an option to distribute Ey and Hx between measured values, producing vector results at all stations.

A TensorCS option for saving IP phase data makes TensorCS a useful utility of CS IP processing. TensorCS's IP output option saves scalar IP values for all data and vector IP phase for all stations with vector (Ex,Ey) data. TensorCS applies three-point extrapolation to the lowest three frequencies for each sounding to reduce inductive coupling effects. However, 3-point extrapolation is only effect up to Tx-Rx separations of about 0.3 skin depths, after which a negative IP phase residual begins to grow in magnitude in proportion to increasing Tx-Rx separation. At a Tx-Rx separation of 0.5 skin depths, half-space modeling predicts an inductive coupling residual of 40 mrad after 3-point decoupling of 0.125, 0.375, 0.625 hertz E-field data. Using lower frequencies helps, 3-point on 0.125, 0.250, 0.375 leaves a residual of 25 mrad for half-space modeling with a Tx-Rx separation of 0.5 skin depths (at 0.125 hertz).

### Input Files

Typing "TensorCS tcsdemo" on the MS-DOS command line sets TensorCS to reading CSAMT survey configuration information and sounding data from tcsdemo.mde, tcsdemo.avg and tcsdemo.stn. Alternatively, if you type just "TensorCS", you will see an interactive dialog box showing \*.avg files in the current directory. You can then choose an \*.avg file holding vector or tensor CSAMT data and TensorCS will begin input.

TensorCS first looks at an optional \*.mde file to get survey annotation and configuration information. Data are then read from a required \*.avg file, which starting in 2006 will usually include survey annotation and configuration parameters. Finally station location (east, north, elevation) and optionally measured (x,y,z) EM component heading, pitch and roll are input from an optional \*.stn file.

After reading the \*.mde and \*.avg files, TensorCS shows a dialog box to verify survey annotation and configuration.

Project: TensorCS Documentation  
 Area:   
 for: Zonge Engineering and Research  
 by: Zonge Alaska  
 Job #: D2001 Date: Dec.99 Array: Vector Length Units: m  
 Line Name: 100NW Line Number: 100.0 Line Azimuth: 45.0 deg  
 Station Number Rescaling: Stn # Beginning: 0.00 Increment: 50.00 First Stn: 25.00 Stn Range: Last Stn: 1000.00 # Stations: 21  
 Rescaled: 0.00 50.00  
 Default EM Cmp Orientation => Rx Heading, Pitch, Roll  
 X Azimuth: 45.0 Z Positive: up Y azimuth: 315  
 Set all Rx HPR to default EM cmp orientation  
 Flip Hy: Median phase(Zxy) data = -3136 mrad  
 Flip Hx: Median phase(Zyx) data = 19 mrad  
 Read Stn File: tcsdemo.stn .stn  
 CS Transmitters

Tx Gdp Stn	Length (m)	Azimuth	Easting	Northing	Rx-Tx Dist	Rx-Tx Azm
3.0	1400.0	300.0	612500.0	9294250.0	10997.6	73.4

Continue Cancel

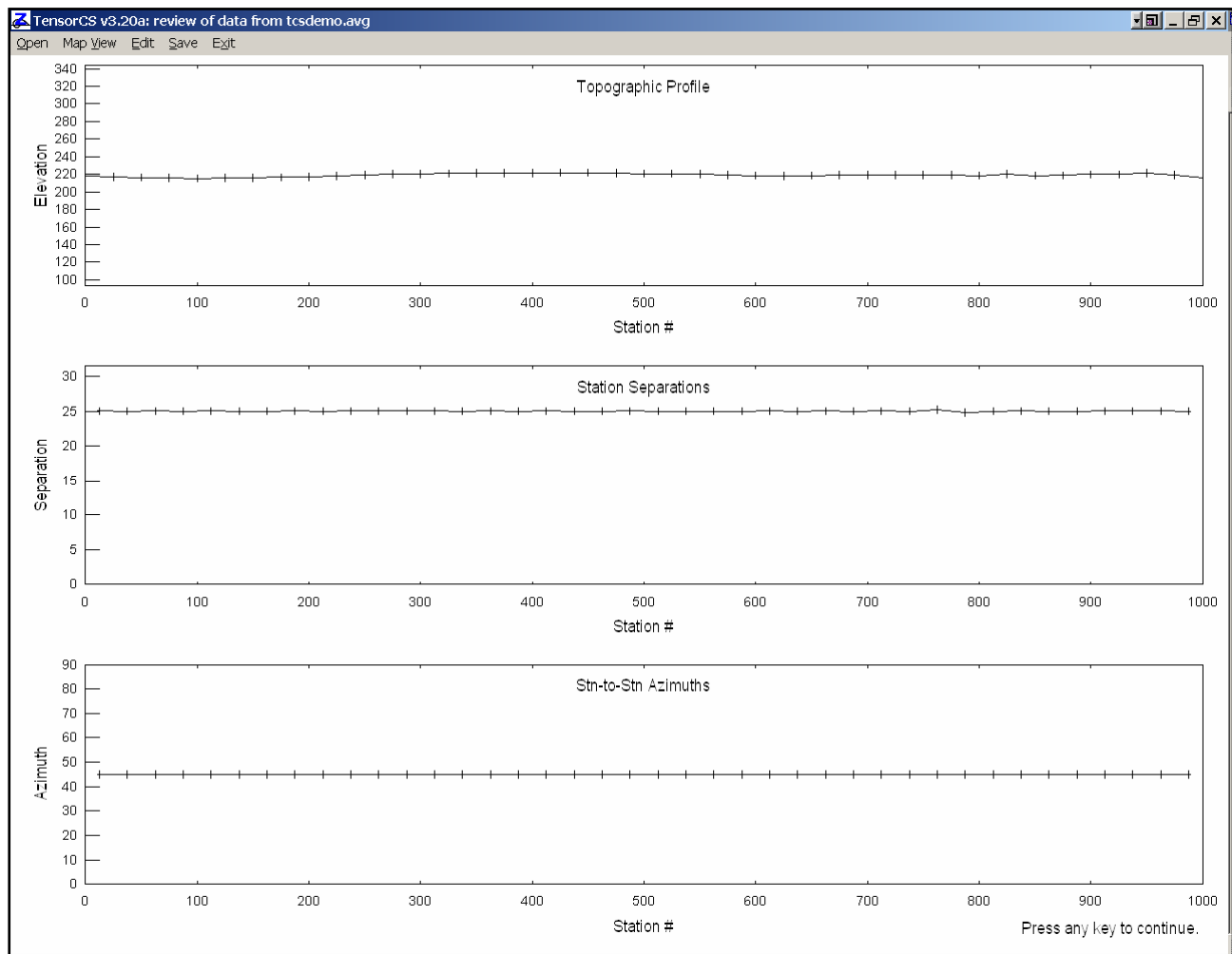
At the top of the CSAMT survey configuration dialog are fields for verifying and editing survey annotation text. The “Job Date” is usually taken to be the data acquisition date. Array types may be either Vector or Tensor. Vector surveys use one controlled-source transmitter but measure Ex, Ey, Hx and Hy components, while CSAMT tensor surveys require two or more transmitter bipole orientations in addition to measuring the four horizontal EM components.

The station number used by the field crew during data acquisition, “GDP station numbers”, may sometimes need to be rescaled to different values to suit customer preferences, i.e. “client station numbers”. A set of four dialog fields titled Station Number Rescaling facilitates that task. Station number offsets are controlled by the GDP and rescaled Stn # Beginning values. Station number increments between stations are controlled by the ratio of client and GDP Stn # Increments. Making one of the increment values negative has the effect of reversing the direction of increasing station number. **Station # Increment** is an important value to check, since it also controls the merging of Ex/Hy and Ey/Hx data. Station numbers within +/-0.6 station intervals are considered to be in the same sounding. Modify GDP and Rescaled Stn Increment values proportionally, as their values are used to determine GDP to client station number scaling as well as Ex/Hy + Ey/Hx data merging.

Electric and magnetic field components are usually measured with Ex and Hx along line (nominally across strike) and with Ey and Hy perpendicular to the line. The relative orientation of x and y EM components controls whether the z EM component direction is positive up or positive down in a right-handed coordinate system. TensorCS can handle either z positive up or down. If z is positive up, phase(Ex/Hy) should be in the 3rd quadrant and phase(Ey/Hx) in the first quadrant. If z is positive downward, then phase(Ex/Hy) should be in the first quadrant and phase(Ey/Hx) in the third quadrant. The choice between

using z+ up or z+ down should be made by the customer and can then be specified with the Z Positive dialog field. Internally, and in data files, TensorCS represents the orientation of the x,y,z EM components as heading, pitch and roll values. Heading is the direction of the positive x component axis. Pitch is the orientation of the positive x component relative to horizontal (0 for CSAMT surveys). Roll is the rotation of the positive z axis around x. Roll = 0 is z positive up, and roll = 180 is z positive down. To help make measured data consistent with a right handed coordinate system. TensorCS provides labels reporting the median values of phase(Zxy) and phase(Zyx) and shows a warning if phase values are in the wrong quadrant. Using the assumption that the field orientation of Ex and Ey are known, but that magnetic field polarities are often reversed, Flip Hy or Flip Hx buttons are provided to reverse magnetic field polarities to make the data self consistent with a right-handed coordinate system. TensorCS does assume that data for the entire line is measured with the same relative orientations of Ex, Ey, Hx and Hy. The CSAVGW program may be used to correct component polarities over rectangular pseudosection blocks if it is necessary to correct for changes in component polarity along line.

A Read Stn File button may be used to select a station file with a table of “station,east,north,elevation” or “station,east,north,elevation,heading,pitch,roll” (see stn file details in the file format appendix). After reading a \*.stn file, TensorCS shows a set of profile plots designed to highlight possible stn location errors.



A topographic profile is shown in the top panel, in the middle is a plot of station separation calculated from station-to-station easting and northing increments, while the bottom panel shows station to station azimuths. For reasonably straight lines with even station increments, the three profiles should be fairly

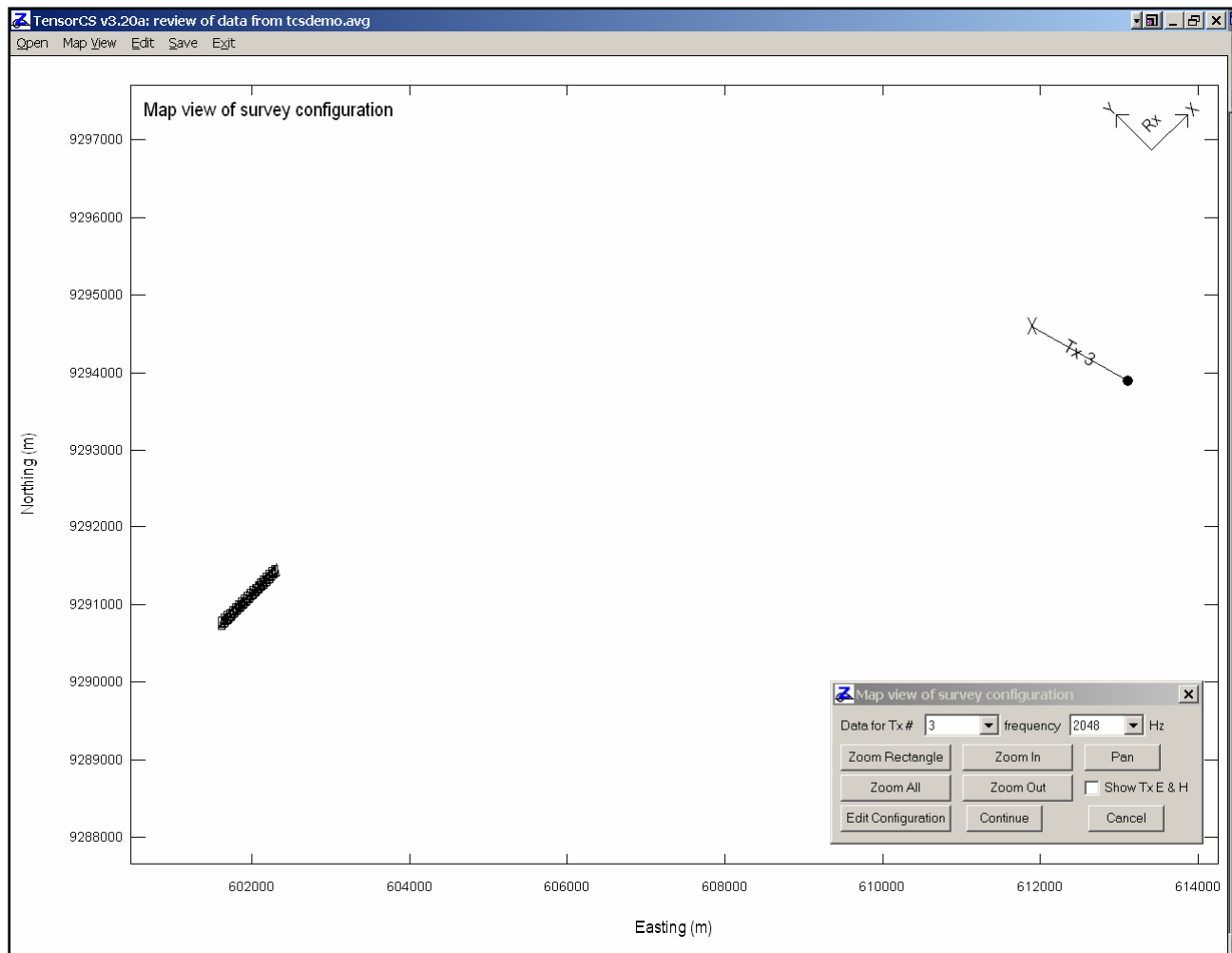
smooth. Any large \*.stn file errors, usually caused by typos, will show up as big excursions in the profile plots. The sample file tcsdemo.stn file includes the required columns of "station,east,north,elevation" along with three additional optional columns of "heading,pitch,roll". Heading, pitch and roll columns are not required, but may be included if it is necessary to specify different EM x,y,z component orientations for some stations.

The bottom of the CSAMT survey configuration dialog includes a field for the parameters of one to four controlled-source transmitters. Each transmitter is identified by its GDP Tx station number, and TensorCS prompts for the additional information specifying the transmitter's length, orientation and center coordinates. If receiver station coordinates have been imported from a \*.stn file by either CSAVGW, ASTATIC or by TensorCS, TensorCS will show the distance and azimuth between the average receiver station easting and northing and Tx center. The distance and azimuth provide a quick check on location coordinate values.

Clicking on the Continue button will finish data input, while selecting Cancel will abort TensorCS processing. Vector results are calculated for every station with both Ex/Hy and Ey/Hx data from the same Tx bipole. Tensor results are calculated for every station with vector data from two or more Tx bipoles.

### Map View of Survey Configuration

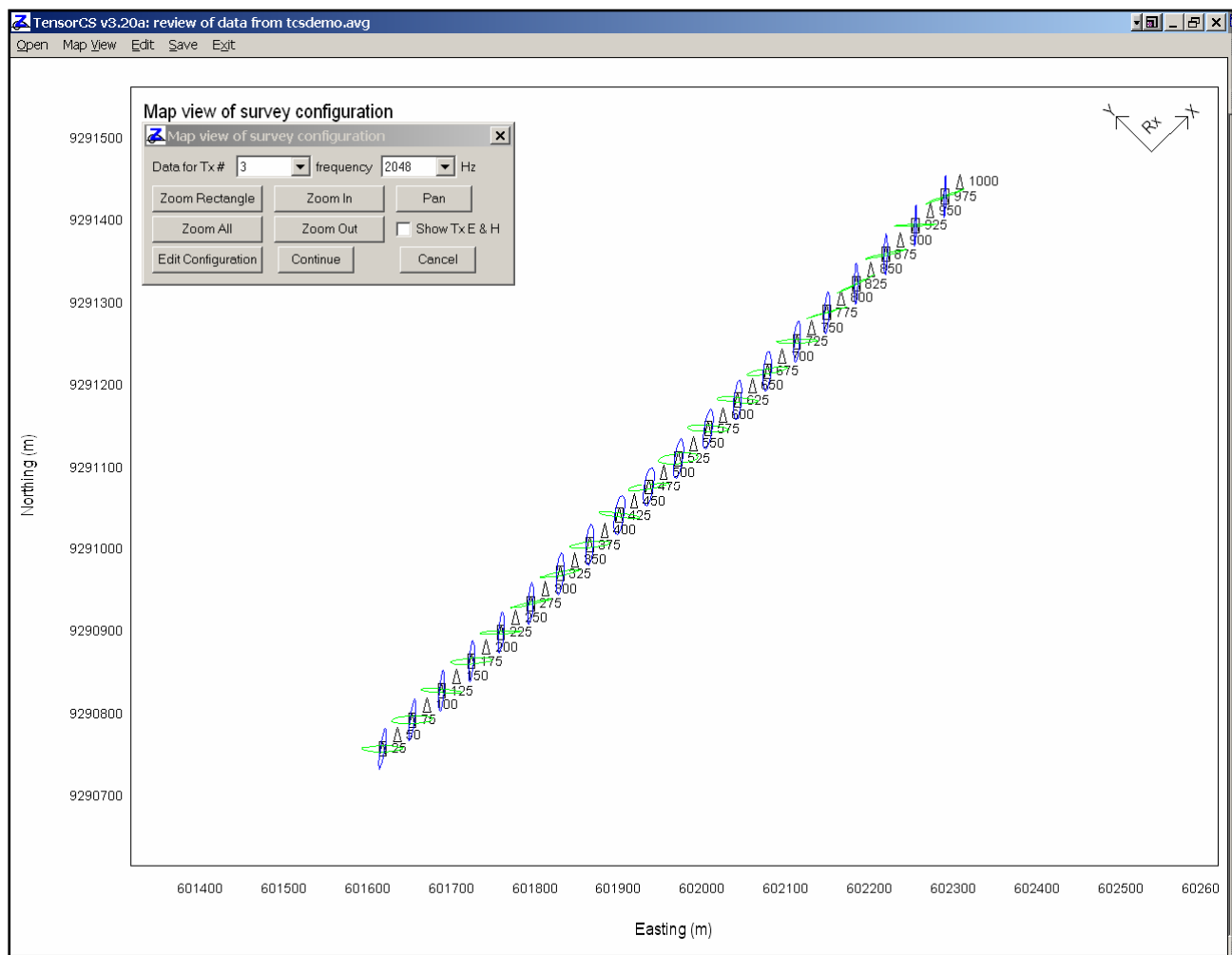
After reading \*.mde, \*.avg and \*.stn files, TensorCS v3.20 plots a plan-map view of Tx bipoles, Rx station locations and the polarity of individual E and H components for half-space Tx source fields.



The first map overview includes both Tx bipoles and station locations, to allow verification of Tx and Rx station coordinates. Tx bipole orientation, length and location may be modified by clicking on the Edit Configuration button, which brings up the same Edit Survey Configuration dialog box seen during data input. If station locations are incorrect, you can edit the \*.stn file, and then re-read it from the Survey Configuration menu with the Read Stn File button.

The Map View control dialog includes five buttons for adjusting the map view plot. **Zoom Rectangle** is useful for viewing a more detailed plot. Selecting **Zoom Rectangle** centers a cross-hair mouse cursor in the middle of the map-view plot. Move the mouse cursor to one corner of the new view area and click the left mouse button. TensorCS will then show a four-arrow cursor, which you can use to position the opposite corner of a new view area. Another click on the left mouse button will then generate a plot with the new view area. **Zoom In**, **Zoom Out** and **Pan** generate a cross-hair mouse cursor centered in the middle of the map-view plot, which you can move to position the center of the new view, followed by clicking the left mouse button to show the new view. Selecting **Zoom All** returns you to the original plot showing both Tx and Rx locations.

More detail for individual stations may be displayed by using **Zoom Rectangle** or multiple **Zoom In** button clicks to limit the plan map view to part of one line. Station details are plotted when the view has been zoomed in to show individual stations with sufficient separation (more than 0.2 plot cm).



In this view, we have zoomed in on part of the line, and clicked on the **Show Tx E and H** check box to turn off display of half-space E and H polarization ellipses. We have also selected a different frequency, 2048 instead of 16 hertz. Map view now shows E-field polarization ellipses in green and H-field polarization ellipses in blue. Green and blue ellipses should be roughly perpendicular to each other, particularly at high frequencies. They are often rotated relative to half-space fields due to channeling of Tx currents by large-scale geologic structure. Ellipticity is the ellipse minimum/maximum axis-length ratio and is sensitive to the ground's electrical properties.

TensorCS will post a black dot at stations with no data for the selected frequency and transmitter. It posts a square at locations with Ex/Hy data and a triangle at locations with Ey/Hx data for the selected frequency and transmitter. It posts red squares if phase(Ex/Hy) is not in the expected quadrant and red triangles if phase(Ey/Hx) is not in the expected quadrant (given the selection of z positive up or down in the Edit Survey Configuration dialog). If GDP Ex and Ey were set up with positive Ey 90 degrees counterclockwise from positive Ex in a map view, then z is positive up. If you see red squares over a range of high frequencies, then the polarity of Hy should be reversed with the Flip Hy button in the Edit Survey Configuration dialog. If you see red triangles over a range of high frequencies, you need to reverse the polarity of Hx with the Flip Hx dialog button.

Clicking on the **Continue** button finishes data input and enables TensorCS's main menu.

## Main Menu

After data input, TensorCS displays a menu across the top of the screen showing the choices **Open, Map View, Edit, Save** and **Exit**.

**Open** allows you to choose another \*.avg file name to read CSAMT survey configuration and sounding data.

**Map View** shows a plan-map view of the survey configuration with options to change the plot's view area.

**Edit | Edit Survey Configuration** is the interactive dialog box you see after TensorCS reads a \*.mde file and may be used to modify survey configuration parameters and update \*.mde files.

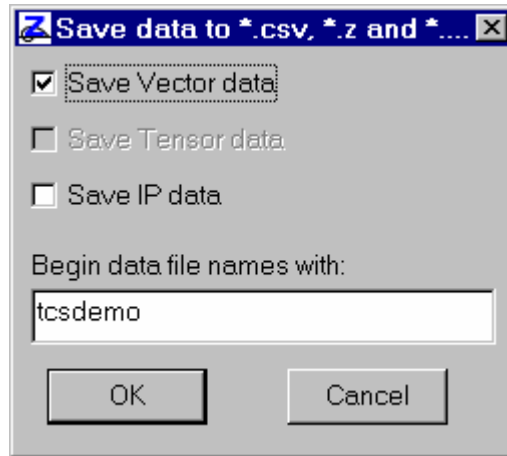
**Edit | Interpolate Ey and Hx** directs TensorCS to interpolate Ey and Hx data to all station locations, generating a full line of vector/tensor data from measurements made using multiple Ex and single Ey, Hx, Hy. TensorCS uses nearest-neighbor interpolation, assigning the nearest (Ey,Hx) values to each (Ex,Hy) sounding. If two (Ey,Hx) soundings are the same distance from a (Ey,Hx) sounding, TensorCS uses the (Ey,Hx) sounding with the higher station number.

**Save** writes current vector/tensor data to \*.z, \*.avg and \*.csv output files.

**Exit** stops TensorCS.

## Output Files

When you choose the **Save** option, TensorCS writes vector, tensor and/or IP data to output \*.z, \*.avg and \*.csv files. It first shows an interactive dialog box allowing you to control output-data categories.



You can left-mouse-click on check boxes to toggle output of vector, tensor and/or IP data. (The tensor check box is grayed out if there isn't any tensor data.) You are also given the option of changing output file names.

### Vector CSAMT output

Vector CSAMT results are generated for all stations with both (Ex/Hy,Ey/Hx) values. TensorCS writes:

1. Zplot-format, "z" files (\*.z) holding vector apparent resistivity, vector impedance phase, E-field ellipticity and H-field ellipticity.
2. Comma-separated-value (\*.csv) files with vector app. res. Z phase, E polarization direction and ellipticity, H polarization direction and ellipticity, and Tx E and H polarization direction. Tabular \*.csv files are suitable for use by Surfer or by spreadsheet programs.

### Tensor CSAMT output

Tensor CSAMT results are generated for all stations with vector data for two to four Tx bipoles. TensorCS writes:

1. Zplot-format files with apparent resistivity and impedance phase (\*tz.z with Zxx, Zxy, Zyx, Zyy and \*dt.z with Zdet).
2. "Average" files with apparent resistivity and impedance phase (\*tz.avg with Zxx, Zxy, Zyx, Zyy and \*dt.avg with Zdet).
3. Tabular Surfer-format files (\*.drp) with station coordinates, frequency, Zxy, Zyx, Ztm, Zte and Zdet apparent resistivity and impedance phase, principle direction and skew values. The principle direction equals the azimuth of  $x'$  when the rotated impedance parameter  $|Z_{xy}' + Z_{yx}'|$  is at its maximum.  $Z_{tm} = \max(Z_{xy}', Z_{yx}')$  and  $Z_{te} = \min(Z_{xy}', Z_{yx}')$  at the principle direction orientation. Note that the labels Ztm and Zte indicate the relative magnitude of  $Z_{xy}'$ ,  $Z_{yx}'$ , but are not indicators of strike direction. The relative magnitudes of  $Z_{xy}'$  and  $Z_{yx}'$  are reversed on either side of a vertical resistivity-contrast contact.
4. Tabular files (\*.tz) with station numbers and grid coordinates, frequency, and magnitude and phase of all four tensor impedance elements.

## IP phase output

TensorCS can generate IP phase from low-frequency electric-field data. It calculates 3-point, 0-hertz phase values by quadratic extrapolation of phase( $E_x$ ) and/or phase( $E_y$ ) at the lowest three frequencies present in the data set for each sounding. Getting useful IP data from a CSAMT setup does not require low-frequency H-field data, but does require measuring good-quality (IP quality), harmonic E-field data at a low frequency.

Large CSAMT Tx-Rx offsets (greater than 0.3 skin depths at the lowest Tx frequency) generate strong inductive coupling, so CS IP requires a moderate Tx-Rx separation and low Tx frequencies. TensorCS applies three-point extrapolation to the lowest three frequencies for each sounding to reduce inductive coupling effects. However, 3-point extrapolation is only effect up to Tx-Rx separations of about 0.3 skin depths, after which a negative IP phase residual begins to grow in proportion to increasing Tx-Rx separation. At a Tx-Rx separation of 0.5 skin depths, half-space modeling predicts an inductive coupling residual of 40 mrad after 3-point decoupling of 0.125, 0.375, 0.625 hertz E-field data. Using lower frequencies helps, 3-point on 0.125, 0.250, 0.375 leaves a residual of 25 mrad for half-space modeling with a Tx-Rx separation of 0.5 skin depths (at 0.125 hertz).

TensorCS returns scalar IP values from  $-1000 \cdot \text{atan}\{\text{Imag}(E_x)/\text{Real}(E_x)\}$  (and for any  $E_y$  values) at all stations. It also generates vector IP results for stations with ( $E_x, E_y$ ) vector data. Results are written to a Surfer/spreadsheet \*.csv file. (See the section on output file formats for details.) It is a good data-quality check to compare  $\{\text{Re}(E_x), \text{Re}(E_y)\}$  vector and Tx current orientations by using Surfer to post north-arrow symbols rotated by -azimuth column values. Columns for both parameters are included in TensorCS IP output files. Posting Tx current orientations in map view is also helpful in reviewing the validity of scalar CS IP data. If the Tx current vectors make an acute angle with the survey line, scalar CS IP data using the along-line  $E_x$  component is likely to be unrepresentative and noisy.



## Input File Formats

### MDE Files = plot annotation, survey configuration and data processing control

\*.Mde files hold plot annotation, survey configuration and Zonge data-processing-control information. A \*.mde file record has a \$program:keyword=value format. Each keyword record must begin with a "\$" character, optionally followed by a program name and colon ":". The name of the keyword is followed by an equal sign "=", then a value to assign to that variable. Spaces may be included between the special flag symbols and the program name or keyword. Some keywords, like Tx.Center have multiple comma-separated values.

#### Listing of tcsdemo.mde:

```
$ Job.Name      = TensorCS Documentation
$ Job.For       = Zonge Engineering and Research
$ Job.By        = Zonge Alaska
$ Job.Number    = D2001
$ Job.Date      = Dec/99
$ Line.Name     = 100NW
$ Line.Number   = 100
$ Rx.Azimuth    = 45
$ Unit.Length   = m
$ Tx.GdpStn     = 3
$ Tx.Length     = 1400 m
$ Tx.Azimuth    = 300
$ Tx.Center     =612500,9294250,0
$ Stn.GdpBeg    =0
$ Stn.GdpInc    =50
$ Stn.Beg       =0
$ Stn.Inc       =50
$ Stn.Left      =25
$ Stn.Right     =1000
```

#### \*.mde keyword descriptions:

##### Survey annotation

```
$Job.Name      project name (128 character string) (alias = Project)
$Job.Area       project area (128 character string)
$Job.For        client or customer name (128 character string) (alias = client)
$Job.By         contractor or data acquisition company (128 character string) (alias = company)
$Job.Number     job label (16 character string) (alias = JobNumb)
$Job.Date       data acquisition data (16 character string) (alias =JobDate)
```

##### Survey configuration

```
$Survey.Type    survey type (CSAMT, TEM, CR, TDIP)
$Survey.Array   array type (for CSAMT: Scalar, Vector, Tensor)
$Line.Name      line label (16 character string) (alias = JobLine)
$Line.Number    line number (float)
$Line.Azimuth   line azimuth (float, deg E of N) (alias = BrgLine)
$Stn.GdpBeg     first gdp station number (float) (alias = StnBeg)
$Stn.GdpInc     gdp station number increment (non-zero float) (alias = StnDelt)
$Stn.Beg        possibly rescaled first station number (float) (alias = LblFrst)
$Stn.Inc        possibly rescaled station number increment (float) (alias = LblDelt)
```

**\*.mde keyword descriptions (continued):**

Tx parameters

\$Tx.Type source type (for NSAMT /CSAMT: Natural, Bipole, Loop)  
\$Tx.Center transmitter center-point easting, northing, elevation (float, length units)  
(aliases = TxCX, TxCY)  
\$Tx.HPR transmitter orientation heading, pitch, roll (Tx heading alias = TxBrg)  
(heading = bipole azimuth, pitch=0, roll=0 for z+up or 180 for z positive down)  
\$Tx.Length transmitter bipole length or square loop width (positive float, length units)

Rx parameters

\$Rx.HPR EM component heading, pitch, roll (floats, Rx heading alias = RxBrg, Rx.Azm, ExAzm)  
(heading = x component azimuth in degrees east of north,  
pitch = x component orientation in degrees. up from horizontal,  
pitch = z cmp rotation about x cmp, 0=z+up, 180 = z+ down)  
\$Rx.Length E-field dipole length or loop widths (positive float(s), length units) (alias = aspace)  
\$Unit.Length length unit (m,ft) (alias = Units)  
\$Unit.Phase phase unit (mrad for Zonge EM data,deg in EMI files)

## AVG files = CSAVGW format (CSAMT/NSAMT geophysical data)

TensorCS reads \*.avg files with the format produced by the Zonge data-processing programs like CSAVGW and ASTATIC. \*.Avg files contain data averaged over repeated GDP readings, with measurement error estimated from variation between repeats. All \*.avg files have the same fundamental structure, but legacy \*.avg files generally include much less survey configuration information.

\*.Avg files hold blocks of geophysical data in a tabular spreadsheet format with space- or comma-separated values. Missing numeric values are flagged by a "\*" or a blank between separating commas. Column definitions may vary, so numeric data must be preceded by a column-label record to specify the meaning of subsequent numeric data. \*.Avg files may also include supplemental survey configuration data in \$keyword=value records. Comment lines may be included anywhere and are flagged with a leading "\", "/", "!" or "" character.

### Csavgw \*.avg keywords:

#### Survey annotation

\$Job.Name project name (128 character string)  
\$Job.Area project area (128 character string)  
\$Job.For customer company name (128 character string)  
\$Job.By contractor company name (128 character string)  
\$Job.Number job label or number (16 character string)  
\$Job.Date data acquisition date (16 character string)

#### Survey configuration

\$Survey.Type survey type (CSAMT, TEM, CR, TDIP)  
\$Survey.Array array type (for CSAMT: Scalar, Vector, Tensor)  
\$Line.Name line label (16 character string) (alias = JobLine)  
\$Line.Number line number (float)  
\$Line.Azimuth line azimuth (float, deg E of N) (alias = BrgLine)  
\$Stn.GdpBeg first GDP station number (float) (alias = StnBeg)  
\$Stn.GdpInc GDP station number increment (non-zero float) (alias = StnDelt)  
\$Stn.Beg possibly rescaled first station number (float) (alias = LblFrst)  
\$Stn.Inc possibly rescaled station number increment (float) (alias = LblDelt)  
\$Stn.Left rescaled station number on left edge of pseudosection plot (float) (alias=LblFrst)  
\$Stn.Right rescaled station number on right edge of pseudosection plot (float)  
\$Unit.Length length units (m,ft) (alias = Units)  
\$Unit.E electric field units (nV/m,nV/Am)  
\$Unit.B magnetic field units (pT,pT/A)  
\$Unit.Phase phase units (mrad,deg)

#### Transmitter properties

\$Tx.Type source type (for NSAMT /CSAMT: Natural, Bipole,Loop)  
\$Tx.GdpStn transmitter ID from GDP Tx field (GDP stn #) (alias = XMTR)  
\$Tx.Stn rescaled Tx ID (rescaled client stn #)  
\$Tx.Center transmitter center-point easting, northing, elevation (float, length units)  
(aliases = TxCX, TxCY)  
\$Tx.HPR transmitter orientation heading, pitch, roll (Tx heading alias = TxBrg)  
(heading = bipole azimuth, pitch=0, roll=0 for z+up or 180 for z positive down)  
\$Tx.Length transmitter bipole length or square loop width (positive float, length units)

#### Receiver properties

\$Rx.GdpStn	receiver gdp station number (alias = Station)
\$Rx.Stn	receiver client station number
\$Rx.HPR	EM component heading, pitch, roll (floats, Rx heading alias = RxBrg, ExAzm) (heading = x component azimuth in degrees east of north, pitch = x component orientation in degrees. up from horizontal, pitch = z cmp rotation about x cmp, 0=z+up, 180 = z+ down)
\$Rx.Length	E-field dipole length or loop widths (positive float(s), length units) (alias = aspace)
\$Rx.Cmp	EM component/impedance label (ExHx, ExHy, EyHx, EyHy, Zxx, Zxy, Zyx, Zyy, Zvec, Zdet)

#### Csavgw \*.avg file columns:

skp	skip flag (0=drop data, 1=skip data, 2=good data)
Freq	frequency (hertz)
Tx.Amp	Tx current (square-wave peak amps)
E.mag	electric field magnitude (Unit.E)
E.phz	electric field phase (mrad)
B.mag	magnetic field magnitude (Unit.B)
B.phz	magnetic field phase (mrad)
Z.mag	impedance magnitude (km/sec)
Z.phz	impedance phase (mrad)
Ares.mag	Cagniard apparent resistivity magnitude (ohm-m)
SRes	static-corrected apparent resistivity added by Astatic (ohm-m)
E.wgt	electric field weight, -1 indicates polarity flip
H.wgt	magnetic field weight, -1 indicates polarity flip
E.%err	relative  E  error (%)
E.perr	phase(E) error (mrad)
B.%err	relative  H  error (%)
B.perr	phase(H) error (mrad)
Z.%err	relative  Z  error (%)
Z.perr	phase(Z) error (mrad)
ARes.%err	relative apparent resistivity error (%)
Gdp.Blk	first GDP block number in average
Gdp.Chn	GDP chn1.chn2 analog channel #s
Gdp.Time	data acquisition time (hh:mm:ss)

## AVG files = AMTAVG or NSAVG format (CSAMT/NSAMT geophysical data)

Astatic will read or write \*.avg files with the “legacy” format produced by the Zonge data-processing programs Amtavg and Nsaveg. \*.Avg files contain data averaged over repeated GDP readings, with measurement error estimated from variation between repeats. All \*.avg files have the same fundamental structure, but legacy \*.avg files generally include much less survey configuration information.

\*.Avg files hold blocks of geophysical data in a tabular spreadsheet format with space- or comma-separated values. Missing numeric values are flagged by a “\*” or a blank between separating commas. Column definitions may vary, so numeric data must be preceded by a column-label record to specify the meaning of subsequent numeric data. \*.Avg files may also include supplemental survey configuration data in a \$keyword=value records. Comment lines may be included anywhere and are flagged with a leading “\”, “/”, “!” or “”” character.

### Amtavg/Nsaveg \*.avg keywords:

\$ ASPACE E-field dipole length (length units) (alias of Rx.Length)  
\$ XMTR Tx ID (alias of Tx.GdpStn)

### Amtavg/Nsaveg \*.avg file columns:

skp skip flag (0=drop data, 1=skip data, 2=good data)  
Station GDP station number  
Freq frequency (hertz)  
Comp impedance type (ExHx, ExHy, EyHx, EyHy, Zxx, Zxy, Zyx, Zyy, Zvec, Zdet)  
Amps Tx current (square-wave peak amps)  
Emag electric field magnitude  $((4/\pi)*\text{nanoVolt}/(\text{m}*amp))$   
Ephz electric field phase (mrad)  
Hmag magnetic field magnitude  $((4/\pi)*\text{picaTesla}/amp)$   
Hphz magnetic field phase (mrad)  
Resistivity Cagniard apparent resistivity (ohm-m)  
Phase impedance phase (mrad)  
%Emag relative |E| error (%)  
sEphz phase(E) error (mrad)  
%Hmag relative |H| error (%)  
sHphz phase(H) error (mrad)  
%Rho relative apparent resistivity error (%)  
sPhz impedance phase error (%)  
TMARES/SRES static-corrected apparent resistivity appended by Astatic (ohm-m)

## STN Files = station locations and EM component orientations

\*.Stn files most often used to import geographic easting, northing and elevation coordinates for each station, but may also include information about EM component orientation. A \*.stn file should have at least two entries, corresponding to the first and last stations. Additional entries may be necessary to trace out topographic changes or curved lines. Astatic assumes that station numbers represent distance along line and uses station numbers to interpolate between coordinate records, if necessary. **If station numbers have been rescaled, \*.stn station numbers should be in rescaled values, not the original GDP numbers.** Station number rescaling is controlled by the keywords Stn.GdpBeg, Stn.GdpInc, Stn.Beg, Stn.Inc equal to the legacy keywords StnBeg, StnDelt, LblFrst LblDelt.

\*.Stn files use a comma- or space-separated-value spreadsheet format. Comment lines with a leading !, ", \, or / character may occur anywhere in the file and are ignored. Column-label records begin with a letter and are applied to subsequent numeric data. \*.Stn files must always have the four columns station, easting, northing and elevation. A Line column may be included if the \*.stn file includes data for multiple survey lines. The optional columns heading, pitch and roll may also be included to specify EM component orientations for individual stations. Astatic looks for the case-insensitive sub-strings, line, station, east, north, elev, heading, pitch, roll, when parsing a column label line. Lines that do not begin with a comment line flag or a letter should hold numeric data.

### Partial \*.stn file listing:

```
! Sample *.stn file for astatic v3.30 using an extended format
! with column labels, comma-separated values and extra columns
! for EM cmp (x,y,z) heading, pitch and roll.
! Heading = x cmp azimuth in deg east of north.
! Pitch   = x cmp angle relative to horizontal (deg up from horizontal)
! Roll    = z cmp rotation around x axis
!         roll= 0 = z positive up
!         roll=180 = z positive down
station,easting,northing,elevation,heading,pitch,roll
-200,1472490,11773343,2475,100,0,180
0, 1472687,11773311,2490,100,0,180
200, 1472885,11773279,2495,100,0,180
400, 1473082,11773246,2505,100,0,180
600, 1473280,11773214,2505,100,0,180
800, 1473477,11773182,2510,100,0,180
1000,1473674,11773149,2520,100,0,180
.
.
.
7200,1479792,11772147,2718,100,0,180
7400,1479990,11772115,2730,100,0,180
7600,1480187,11772083,2760,100,0,180
```

## Z files = pseudosection plots with ZPLOT

\*.Z files are used for storing plot data in multiple blocks with *skp*, *x*, *y*, *z* columns. Numerical values are stored in a fixed format, so column widths are critical. Numerical field widths are indicated by the "lXyZ" record preceding numerical data. A "lXyZ" text string also flags the beginning of a block of numerical (*skp,x,y,z*) data and a 9999.0 value flags the end of the block. For each Tx with vector data, TENSORCS saves Cagniard apparent resistivity, impedance phase, E ellipticity and H ellipticity in a \*.z files with the file-name extension \*Vn.zcr, where n = Tx.GdpStn. For tensor data, Zxx, Zxy, Zyx and Zyy apparent resistivity and impedance phase are stored in \*tz.z and tensor determinant apparent resistivity and impedance phase are stored in \*dt.z.

### Partial listing of tcsdemoV3.z:

```
$ ZPLOT: DATA= FLOG
$ ZPLOT: PLTREV = No
$ ZPLOT: SizeX = 1.0
$ ZPLOT: SizeY = 1.0
$ ZPLOT: AXSTN = Vertical
$ PROJECT = TensorCS Documentation
$ CLIENT = Zonge Engineering and Research
$ COMPANY = Zonge Alaska
$ JOBNUMBER = D2001
$ JOBDATE = Dec.99
$ JOBLINE = 100NW
$ BRGLINE = 45
$ BRGBACK = 225
$ STNLOW = 25
$ STNHIGH = 1000
$ STNDELT = 50
$ LBLFRST = 25
$ LBLDELT = 50
$ UNITS = m
  Contour Plot Z-File
  Cl Cn Ce Ns Nd Yl  Plot file  1
    1  5  0  3  1  1
  VECTOR CSAMT DATA
  Tx 3 Vector APP. RES.
IIxxxxxxxxxYYYYYYYzzzzzzzzzzzz
  2      25    13.00  4.4567E+04
  2      25    14.00  2.6107E+04
  2      25    15.00  1.4284E+04
.      .      .      .
.      .      .      .
.      .      .      .
2      975    22.00  1.5233E+03
9999.00
  Cl Cn Ce Ns Nd Yl  Plot file  2
    0 10  3  3  0  1
  VECTOR CSAMT DATA
  Tx 3 Vector IMP. PHASE
IIxxxxxxxxxYYYYYYYzzzzzzzzzzzz
  2      25    13.00  1.0692E+02
.      .      .      .
.      .      .      .
.      .      .      .
2      975    22.00  8.2329E+02
9999.00
```

## Output CSV Files

### **\*Vn.csv = Vector CSAMT data for each Tx**

Tensor CS writes a comma-separated value file with vector data for each controlled-source transmitter. Surfer can be used to post rotated north arrows or line segments representing the direction of measured electric and magnetic field polarization. Since Surfer specifies posted symbol rotations in degrees counter-clockwise, the negative of polarization ellipse azimuths are also saved in \*Vn.csv files.

#### **\*Vn.csv columns**

Station	client station number
GridEast	station easting (length units)
GridNorth	station northing (length units)
Elevation	station elevation (length units)
Frequency	measurement frequency (hertz)
ARvec	vector apparent resistivity (ohm-m)
ZPvec	vector impedance phase (mrad)
E_Ellipticity	ratio maximum/minimum E-field polarization ellipse
B_Ellipticity	ratio maximum/minimum B-field polarization ellipse
-EazmRx	negative of measured E-field polarization ellipse azimuth
-BazmRx	negative of measured B-field polarization ellipse azimuth
-EazmTx	negative of Tx half-space E-field polarization azimuth
-BazmTx	negative of Tx half-space B-field polarization azimuth



## \*IPn.csv = scalar/vector CS IP data for each Tx

If the IP output option is selected, Tensor CS writes a comma-separated value file with low frequency Ex, Ey and vector E phase data for each controlled-source transmitter. TensorCS saves both phase values from the lowest measured frequency and 3-point phase values calculated by fitting a quadratic curve to data from the lowest three measured frequencies and then extrapolating the curve to 0 hertz. 3-point extrapolation of Real(E) and Imag(E) followed by a phase value calculation often does a better job of removing inductive propagation effects, but 3-point extrapolation of phase(E) values completely removes Tx-Rx time synchronization error. Values for both 3-point extrapolation methods are included in the output IPn.csv files and can be used as a check for any synchronization error

Scalar IP phase is calculated as

$$-1000 \cdot \arctan(\text{Imag}(E_x)/\text{Real}(E_x)) \text{ and } -1000 \cdot \arctan(\text{Imag}(E_y)/\text{Real}(E_y)) \text{ mrad.}$$

Maximum amplitude E-field component IP phase is calculated as

$-1000 \cdot \arctan(\text{Imag}(E_m)/\text{Real}(E_m))$  mrad, where  $E_m$  is the electric field component parallel to the in-phase electric field vector.

“Vector” IP phase = EvPhz0 & EvPhz1 is calculated as  $1000 \cdot \arctan(|\text{Imag}(\vec{E})|/|\text{Real}(\vec{E})|)$  mrad, a phase value based on the relative lengths of the out-of-phase,  $\text{Imag}(\vec{E})$ , and in-phase,  $\text{Real}(\vec{E})$ , electric field vectors.

## \*IPn.csv columns

Station	client station number
GridEast	station easting (length units)
GridNorth	station northing (length units)
Elevation	station elevation (length units)
TxAzm	azimuth of half-space Tx current (deg E of N)
"_-TxAzm"	negative of azimuth of half-space Tx current (deg W of N)
Re(Ex0)	in-phase 3-point Ex (nV/m)
Im(Ex0)	out-of-phase 3-point Ex (nV/m)
Ex0	magnitude of 3-point Ex (nV/m)
ExPhz0ri	3-point on Re(Ex) & Im(Ex), then phase calculation (mrad)
ExPhz0p	3-point on phase(Ex) (mrad)
ExPErr0	Ex 3-point phase error estimate (mrad)
Re(Ex1)	in-phase lowest-frequency Ex (nV/m)
Im(Ex1)	out-of-phase lowest-frequency Ex (nV/m)
Ex1	magnitude of lowest-frequency Ex (nV/m)
ExPhz1	phase lowest-frequency Ex (mrad)
ExPhzErr1	lowest-frequency Ex phase error (mrad)
ExAzm	azimuth of Ex component (deg E of N)

### \*IPn.csv columns (continued)

Re(Ey0)	in-phase 3-point Ey (nV/m)
Im(Ey0)	out-of-phase 3-point Ey (nV/m)
Ey0	magnitude of 3-point Ey (nV/m)
EyPhzOri	3-point on Re(Ey) & Im(Ey), then phase calculation (mrad)
EyPhzOp	3-point on phase(Ey) (mrad)
EyPErr0	Ey 3-point phase error estimate (mrad)
Re(Ey1)	in-phase lowest-frequency Ey (nV/m)
Im(Ey1)	out-of-phase lowest-frequency Ey (nV/m)
Ey1	magnitude of lowest-frequency Ey (nV/m)
EyPhz1	phase lowest-frequency Ey (mrad)
EyPhzErr1	lowest-frequency Ey phase error (mrad)
EyAzm	azimuth of Ey component (deg E of N)
Re(Em0)	in-phase maximum-amplitude E-field component (nV/m)
Im(Em0)	out-of-phase maximum-amplitude E-field component (nV/m)
Em0	magnitude maximum-amplitude E-field component (nV/m)
EmPhzOri	3-point on Re(Em) & Im(Em), then phase calculation (mrad)
EmPhzOp	3-point on phase(Em) (mrad)
EmPhzErr0	Em 3-point phase error estimate
EvPhz0	Vector E 3-point phase (mrad)
EvPhzErr0	Vector E 3-point phase error (mrad)
EvPhz1	Vector E low-frequency phase (mrad)
EvPhzErr1	Vector E low-frequency phase error (mrad)
EvRealAzm	azimuth of Real(vector E) (deg E of N)
EIazm	azimuth of Imag(vector E) (deg E of N)
"_-EvRealAzm"	negative of azimuth of Real(vector E) (deg W of N)
"_-EvImagAzm"	negative of azimuth of Imag(vector E) (deg W of N)