

Local Helioseismology with GONG and MDI as a Pathfinder for SDO/HMI

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Introduction

The Global Oscillation Network Group (GONG) Program will soon routinely be producing local helioseismic maps of the solar interior. Currently, the techniques being implemented are time-distance, ring diagrams, and both far- and near-side acoustic holography. The scientific planning and data processing strategy for the HMI instrument on SDO will benefit from the experience gained by GONG, particularly when frequent high-quality vector magnetograms are available from SOLIS. Here we present examples of the scientific products of the GONG pipelines and discuss the lessons learned from their implementation.

Ring Diagram Analysis

We have installed a pipeline to apply ring diagram analysis to patches of 15 degrees diameter over the solar surface as they cross the solar central meridian. The patches are distributed in the dense-pack arrangement: 189 patches centered at 7.5° intervals covering $\pm 52.5^\circ$ both in longitude from the central meridian, and in latitude from the solar equator. These sub-arrays are tracked for 1664 minutes and coordinated to the reduction used by the Stanford and U. Colorado MDI analysis group.

Figure 1 shows an example of localized changes in the mode frequency, amplitude, and line width for two selected modes. There is a clear difference above and below the acoustic cut-off frequency of the relationship between the mode amplitude and line width as a function of the magnetic field strength. This suggests that active regions may act as acoustic valves regulating the transfer of energy between trapped and escaping acoustic waves.

Figure 2 shows examples of some of the fluid dynamic quantities that can be derived from maps of the horizontal flows as a function of heliographic position and depth. The quantities shown are horizontal divergence, vertical vorticity, and the meridional flow field. The divergence and meridional flow patterns show the presence of two convective rolls in each hemisphere. These rolls meet at the latitude of the activity bands. These features are seen in both the MDI and GONG data, but the northern hemisphere counter cell is only present in the MDI observations. The vertical vorticity pattern shows a boundary in its direction at the active latitude, and the expected flip of the sense of the pattern between north and south.

Time-Distance Analysis

We are also developing a time-distance analysis pipeline to provide continual high spatial resolution flow maps. Figure 3 shows some examples of time-distance products using GONG data. One of these products is a time-distance diagram showing waves that have undergone multiple bounces before reappearing at the surface. The other product is a set of three maps of the solar disk center. The first map is an acoustic power map that shows the sunspot p-mode absorption. The second map shows the amplitude of the correlation for modes that have a lower turning point at 7 Mm. The correlation amplitude is reduced for the stronger active regions. The final map is the outward travel time differences measured from the phase of the correlation function. This map shows that the sound speed is lower at a depth of 7 Mm for the sunspot in the upper left corner of the region.

Discussion

Unlike the current MDI/SOI mission on SoHO, the GONG program returns full-resolution full-disk helioseismic data nearly all of the time. The HMI experiment on SDO will also return a constant full data stream instead of the episodic one MDI must return due to the limited bandwidth of the telemetry system on SoHO. Thus, the GONG data set provides a valuable scientific data set that will indicate fruitful research paths with HMI observations. GONG can provide continual uninterrupted maps of the flows in the solar interior which can be used for solar subsurface weather and associated space weather studies. Comparisons of GONG, MDI, and HMI results will allow the assessment of the reliability of specific features in the solar interior.

In addition, the advent of SOLIS at NSO will provide constant cadence vector magnetograms for the first time. With GONG, these images will allow the first investigation of the relationship between conditions in the outer solar convection zone and the vector nature of the surface field. This class of studies will be a major part of the scientific output of SDO/HMI.

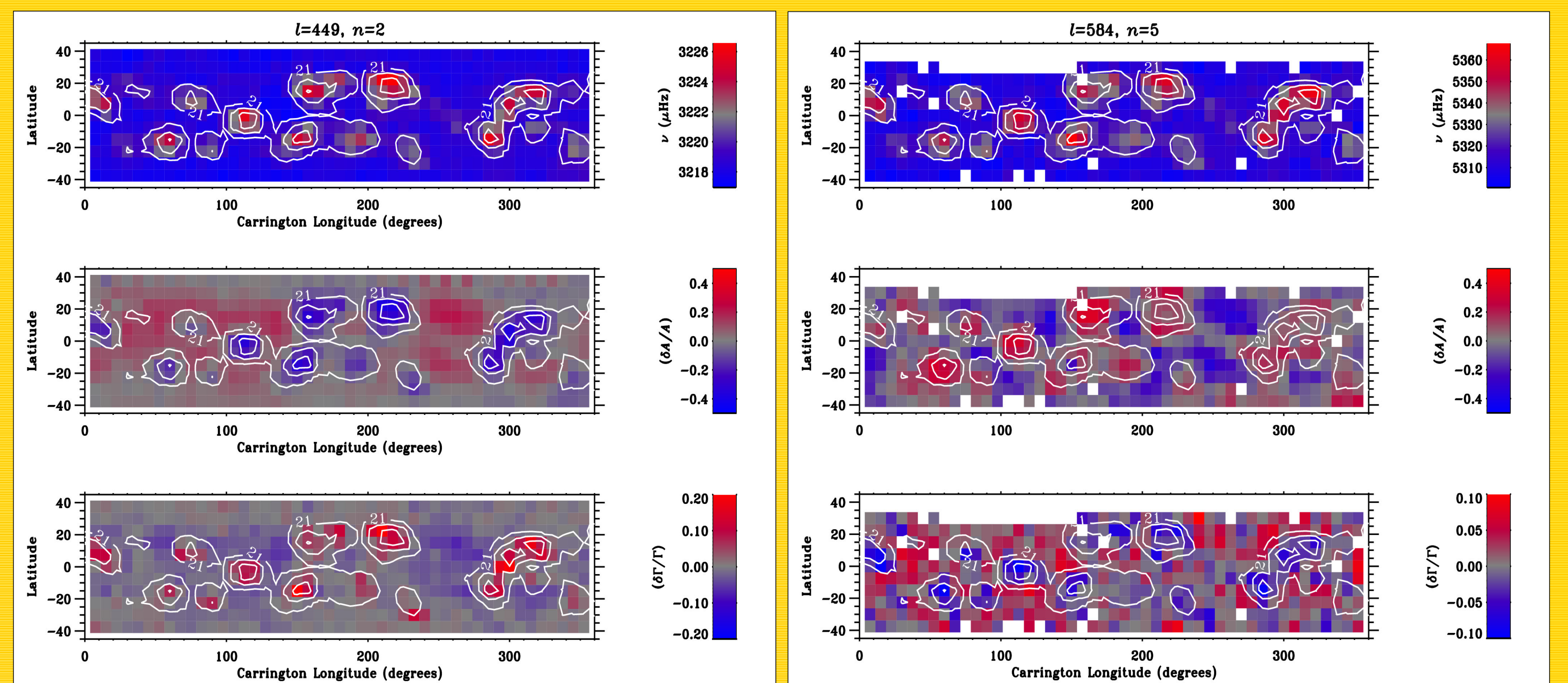


Fig 1: Localized measurements of frequency (ν), relative amplitude changes ($\Delta A/A$) and relative line width changes ($\Delta \Gamma/\Gamma$) derived from ring diagram analysis. The images are for Carrington Rotation 1988, with contours of magnetic field superimposed on maps of the localized oscillation parameters. For the 5-min mode in the left column, the frequency is generally higher, amplitude lower, and line width larger in regions of high magnetic field. The right column shows the results at higher frequencies around the acoustic cut-off in the solar atmosphere. Here, the amplitude increases and the line width decreases in regions of high magnetic field strength, while the frequency is again generally higher.

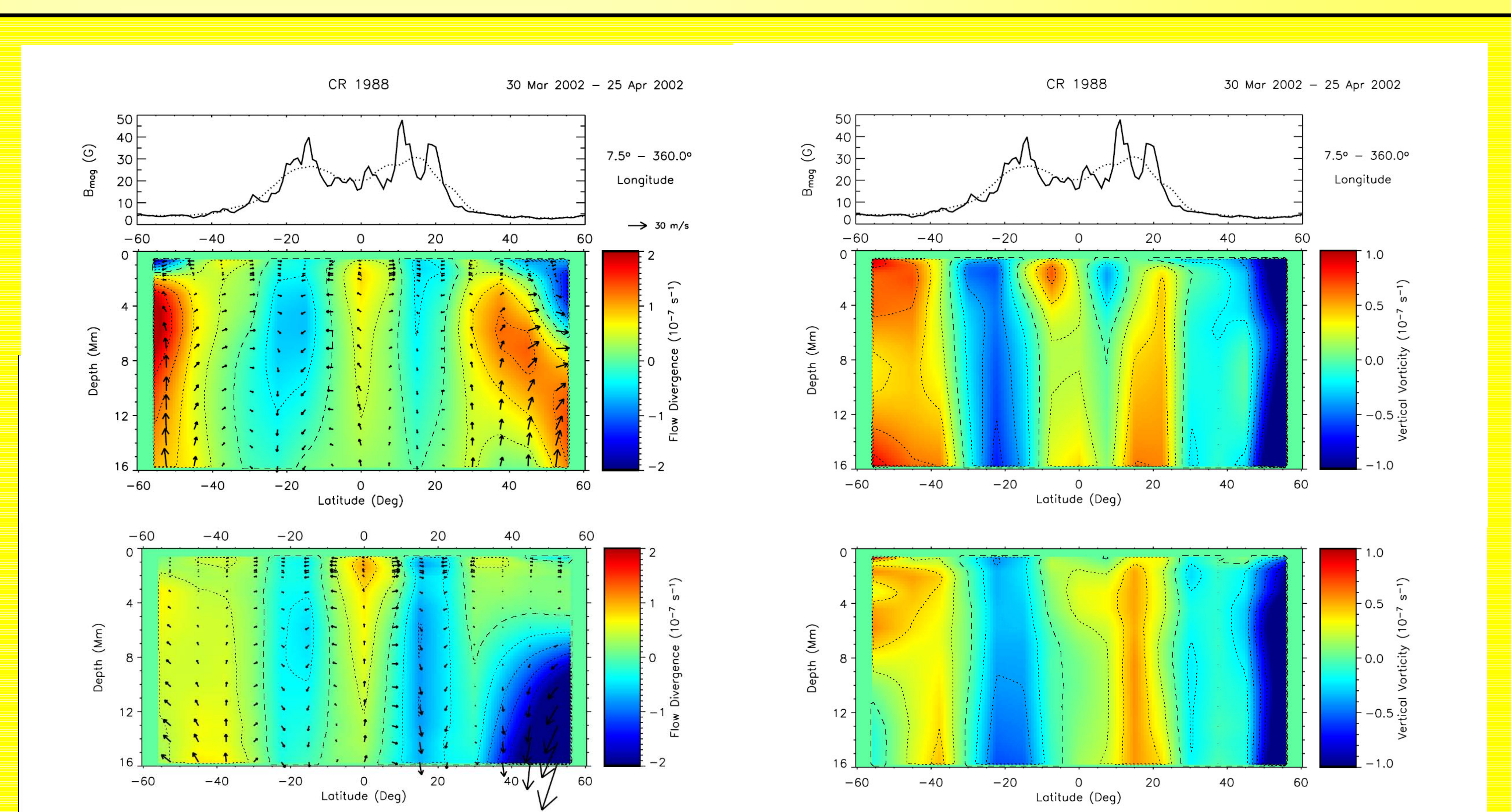


Fig 2: Fluid dynamics of Carrington rotation 1988 averaged over longitude and shown as a function of latitude and depth. Left column: The divergence (color) of the horizontal flow components after removing the large-scale flows. The arrows indicate the average meridional and vertical velocity with the vertical component being enlarged by a factor of 10 for visibility. The dashed line indicates the zero contour; the dotted lines indicate 20%, 40%, 60%, and 80% of the minimum and the maximum of the color scale. Right column: vertical vorticity. Top row: Surface magnetic flux as a function of latitude (solid line) and averaged over 15° (dotted curve). Middle row: results from GONG data. Bottom row: results from MDI data.

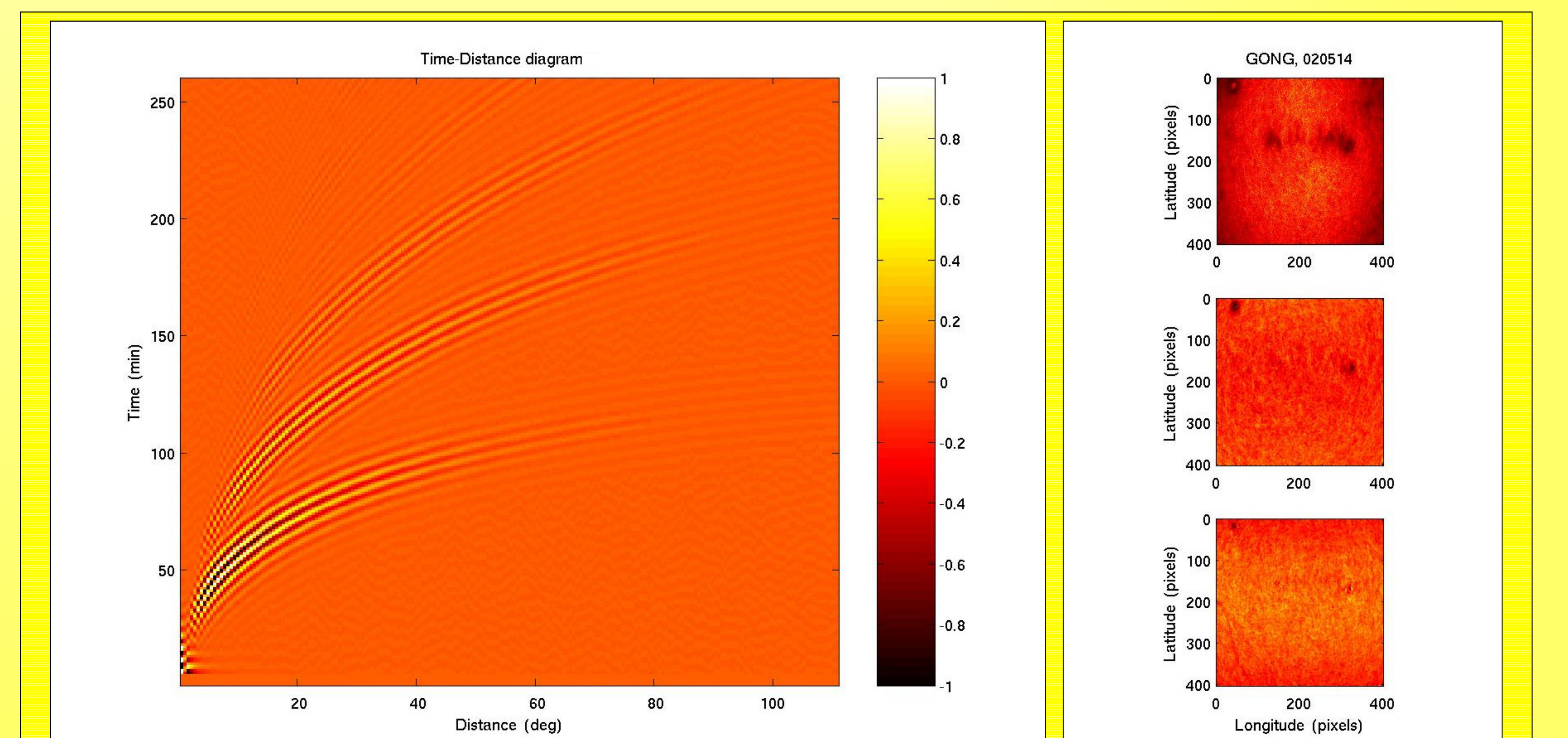


Fig. 3 Left: Time distance diagram computed from 10 days of GONG network data. The first ridge corresponds to single-bounce waves, the second ridge corresponds to waves arriving back at the surface after one reflection, etc. The correlation signal for waves with $t=20$ is visible for angular distances $> 90^\circ$. Right: observations of disk center on May 14, 2002. Top: acoustic power map Middle: correlation amplitude of acoustic waves propagated to about 7 Mm below the surface. Bottom: outward phase travel times