

Far-side helioseismic maps: the next generation

Irene González Hernández¹, Charles Lindsey², Douglas C. Braun²,
Richard S. Bogart³, Philip H. Scherrer³, and Frank Hill¹

¹National Solar Observatory, Tucson, Arizona, USA

²NorthWest Research Associates, Boulder, Colorado, USA

³Stanford University, Stanford, California, USA

E-mail: irenegh@nso.edu

Abstract.

For more than a decade, far-side seismic maps of medium-to-large active regions have proven their capability as a space weather forecasting tool. In the last few years, these maps have started to serve another purpose: complementing the front side observations that are input to different solar models. Photospheric flux transport as well as solar spectral irradiance models have been shown to produce improved results when incorporating the far-side seismic maps as well as providing better forecasting. The challenge for the future is twofold: Far-side seismic monitoring needs to be more sensitive, and it needs to offer more information. We present here initial steps towards fulfilling these goals using higher resolution input images, adding extra *skips* to the analysis and changing the presentation of the maps.

1. Introduction

Since 2000, when Lindsey and Braun [1] applied seismic holography to reconstruct large active regions at the non-visible hemisphere of the Sun, maps of the far hemisphere have been obtained from helioseismic analysis of Earth side observations of the solar surface velocity field. Currently far-side maps using data from both the Global Oscillation Network Group (GONG) and the Helioseismic and Magnetic Imager (HMI) are calculated daily and presented on-line for space weather forecasters (*farside.nso.edu* and *sdo.gsfc.nasa.gov/data/*). The location of the active regions is highlighted and the seismic signature is calibrated in terms of the magnetic field strength [2]. Figure 1 presents an example of a calibrated helioseismic far-side map for October 7, 2012 showing three active regions. The on-line maps include an associated file detailing the position, maximum seismic signature (phase shift), probability of eventual appearance on the front side [3], date of arrival at the East limb and the NOAA number if the active region was previously on the front side.

Fontenla et al. [4], in a case study, explored the possibility of using a combination of far-side maps from backscattered Ly- α observed by the SWAN instrument on board of SOHO and helioseismic far-side maps to complement the front-side observations used to model and forecast the solar spectral irradiance. The forecast of Ly- α was significantly improved by adding the far-side information. Very recently, Arge et al [5] used far-side helioseismic maps as input to the Air Force Data Assimilative Photospheric Flux Transport (ADAPT) model, finding that both the solar wind forecast and the F10.7 forecast from ADAPT maps improve with far-side information. This paper describes initial steps we are taking towards improving the look of



the maps to make them more usable for space weather forecasters as well as to provide more accurate values for the maps to be used as input to solar models.

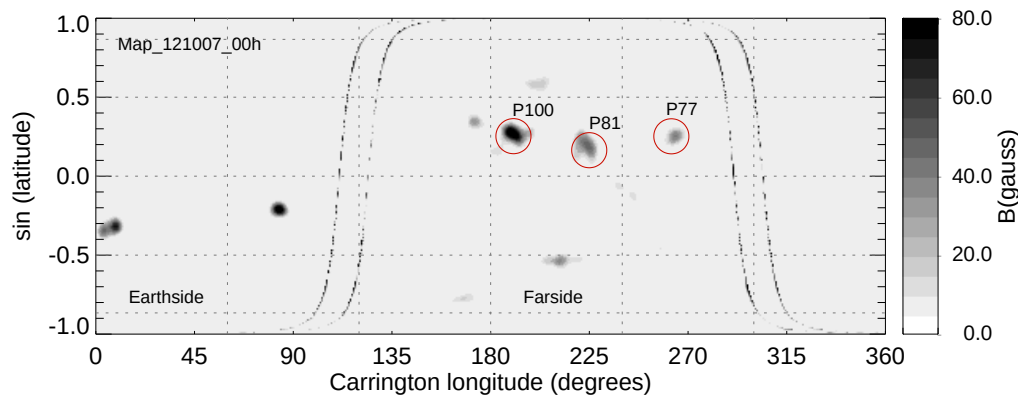


Figure 1. Calibrated GONG seismic far-side map for October 7, 2012 showing three active regions. Signatures with more than 70% probability of appearance upon arrival to the near hemisphere are highlighted in red.

2. Enhancing the seismic signature of active regions

Once the far-side seismic maps have been calibrated into magnetic field strength [2], they can complement front-side observations of the photospheric magnetic field for a full view of the Sun [5]. The information from the far side is particularly useful in case of emergence of new active regions or re-growth of decaying flux. Several lines of research are open to compute the maps more accurately. We have had successful results with two of them: the addition of extra *skips* to the computations and a higher spatial resolution in the input data.

2.1. Adding more skips to the calculations

The current far-side maps correlate helioseismic signatures from waves that skip twice beneath the solar surface (2×2 -skip holography) to cover the central far side of the Sun and signatures from waves that skip once with waves that skip three times (1×3 -skip holography) to cover the outer far side and limb. J. Zhao [6] developed 2×3 -skip time-distance correlations for far-side monitoring. This has optimum sensitivity in the intermediate region where the 2×2 -skip and the 1×3 -skip correlations are sub-optimum. Figure 2 shows a comparison between calibrated far-side maps using the standard 2×2 -skip and 1×3 -skip combination (left) and the new 2×3 -skip maps (right). Because the calibration is based on a relationship between the phase shift and the magnetic field found by González Hernández et al. [2] for the traditional maps, and the 2×3 -skip maps present a different phase shift distribution, the new maps were first divided by a factor of 2.5 before applying the calibration. These maps show a clear enhancement of the seismic signal of active region NOAA 11476 three days before it appears on the front side of the Sun. A preliminary analysis of three similar cases show improvements in two of them and no improvement in the other one. A statistical analysis of 4 years of 2×3 -skip maps to quantify the improvement and to calibrate the phase shift in terms of magnetic field strength is underway.

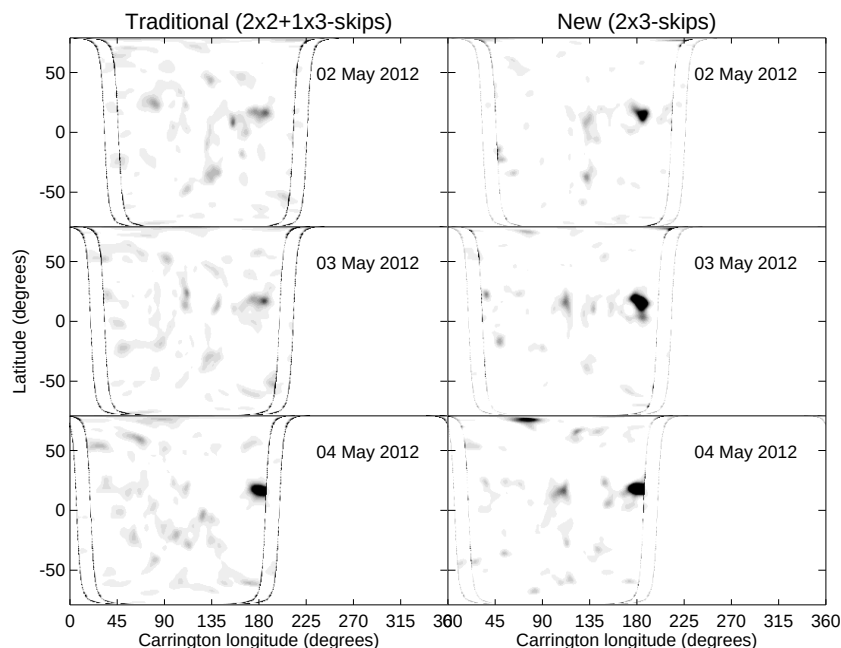


Figure 2. Far-side maps calculated with the traditional 2×2 and 1×3 -skip schema (left) compared to the simultaneous maps calculated using 2×3 -skip combinations. This series shows a particular example of far-side maps with an “ad-hoc” calibration where the 2×3 -skip combination clearly enhances the signature of active region NOAA 11476 three days before it appears on the front side of the Sun. These maps were calculated from GONG Doppler observations.

2.2. Higher resolution input data

Due to technical limitations of several types, the current far-side maps are calculated with binned-down $200\times 200\text{pixel}^2$ Dopplergrams. The near-real time availability of high resolution Dopplergrams enhances the quality of the far-side maps. Application of a Postel projection to the high-resolution image before it is binned down circumvents seismic signal lost approaching the limb due to foreshortening. Due to the heavy load of the computations, a faster algorithm for parallel processing of the data has been developed and tested, and is nearing implementation. Preliminary comparisons between far-side maps obtained from the low resolution (binned down) versus the high resolution HMI Dopplergrams show an increased signal-to-noise ratio in the far-side maps. A full statistical study is needed to properly quantify the improvement.

3. A new look for space weather forecasters

The higher resolution and inclusion of waves that have taken more skips offer the prospect of more sensitive maps with finer spatial resolution. Far-side seismic maps are a direct input for space weather forecasters, because they show the location and strength of active regions that will rotate to face the Earth. Currently, the synoptic maps present the far-side helioseismic signature along with the front side magnetograms. The front side represents the absolute value of the magnetic field smoothed to helioseismic resolution (see Figure 1 or Figure 3 left hand panels) to give a sense of continuity as the active region crosses from far side to near side. This has proven confusing for some users. The new look will present the front-side observations with a higher resolution and will preserve polarity, while the far-side calculations will use a color palette that will more intuitively represent helioseismic signatures, which cannot discriminate polarity. Preliminary new-look maps are shown in Figure 3. The same sequence of three consecutive days (May 22-24 2012) including active region NOAA 11476 on its second full passage across the farside is shown with GONG data and using the traditional wave combination and color palette (left) and calculated with HMI data, including the new 2×3 -skip signature with the new palette (right). The inclusion of the new 2×3 -skip signature seems to localize the active region better. However a full statistical evaluation of this is needed.

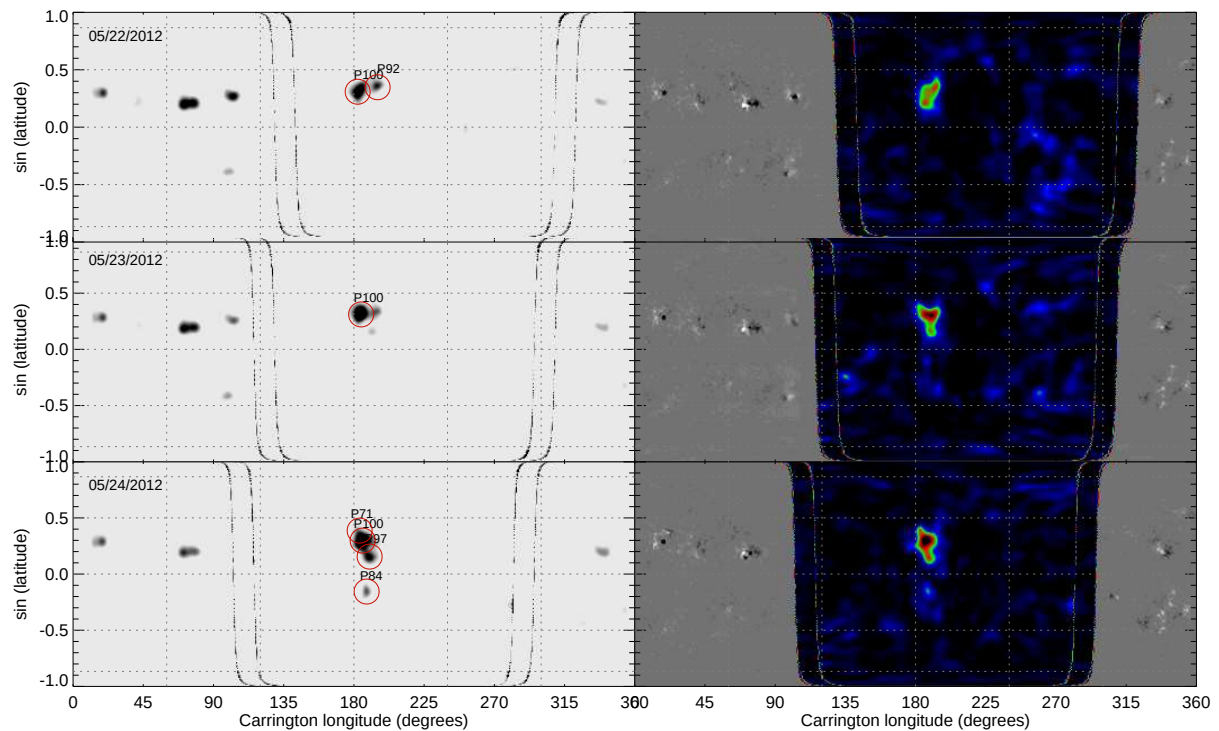


Figure 3. Comparison of far-side seismic maps for May 22-24 2012 calculated with GONG data and the traditional approach (left) and the new higher-resolution, more skips and new color palette calculated with HMI data (right).

4. Discussion

Far side helioseismic maps allow us to locate and track active regions over the whole solar surface. Preliminary case analysis has extended their usage for solar forecasting models. This paper presents initial steps towards improving the maps by including 2×3 -skip correlations and applying Postel projections to a high-resolution version of the helioseismic data before binning it down to a more compact datacube. A full statistical analysis of the 2×3 -skip maps is needed to quantify the improvement provided by incorporating this extra information, as well as an update in the calibration in terms of magnetic field strength. Future work includes a proper computation of intrinsic errors as well as an assessment of the effective area of the far-side active regions. The intended new look will make the maps more user-friendly for direct use by space weather forecasters.

Acknowledgments

This work utilizes data obtained by the GONG instrument of the NISP Program. NISP is managed by the National Solar Observatory, which is operated by AURA, Inc. under a cooperative agreement with the National Science Foundation. The data were acquired by instruments operated by the Big Bear Solar Observatory, High Altitude Observatory, Learmonth Solar Observatory, Udaipur Solar Observatory, Instituto de Astrofísica de Canarias, and Cerro Tololo Interamerican Observatory. This work has been supported by the NASA Living with a Star - Targeted Research and Technology program under grant NNH11AQ24I. Usage of the SDO/HMI data courtesy of NASA/SDO and the HMI science team.

References

- [1] Lindsey C and Braun D C 2000a *Science* **287** 1799
- [2] González Hernández I, Hill F and Lindsey C 2007 *Astrophys. J.* **669** 1382
- [3] González Hernández I, Hill F, Scherrer P, Lindsey C and Braun D C 2010 *Space Weather* **669** 806002G
- [4] Fontenla J M, Quémerais E, González Hernández I, Lindsey C and Haberreiter M 2009 *AdSpR* **44** 457
- [5] Arge C N, Henney C J, González Hernández I, Toussaint W A, Koller J and Godinez H C 2012 *Proceedings of the Thirteen International Solar Wind Conference, AIP, submitted*
- [6] Zhao J 2007 *Astrophys. J. Lett.* **664** 113