Comment on "Detection of Emerging Sunspot Regions in the Solar Interior"

Douglas C. Braun

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Ilonidis *et al*. (Reports, 19 August 2011, p. 993) report acoustic travel-time decreases associated with emerging sunspot regions before their appearance on the solar surface. An independent analysis using helioseismic holography does not confirm these travel-time anomalies for the four regions illustrated by Ilonidis *et al*. This negative finding is consistent with expectations based on current emerging flux models.

Ilonidis *et al.* (*1*) claim the detection of acoustic travel-time decreases of 12 to 16 s, between 1 and 2 days before the maximum surface flux emergence rate, using a time-distance analysis of acoustic waves penetrating between 42 and 75 Mm below the solar surface. This result is contrary to recent numerical simulations of emerging magnetic flux tubes (*2*) that predict travel-time shifts due to flows of about 1 s and shifts on the order of 10^{-1} to 10^{-2} s due to magnetic field or temperature fluctuations. Ilonidis *et al*. (*1*) note this discrepancy and acknowledge that the physical origin of the observed travel-time shifts is unknown. The results, if confirmed, may offer hope for enabling the prediction of emerging magnetic flux 1 to 2 days in advance of its appearance at the surface, but would also challenge current understanding.

NorthWest Research Associates, 3380 Mitchell Lane, Boulder, CO 80301, USA. E-mail: dbraun@cora.nwra.com

The goal of the present work is to ascertain whether the claimed travel-time anomalies are detectable with an independent analysis. This goal is distinct from an independent replication of the exact time-distance methodology of Ilonidis *et al*. (*1*). A variety of methods in local helioseismology (*3*) exist that are capable of detecting travel-time (or phase) shifts due to perturbations in subsurface conditions affecting wave propagation. Among these is helioseismic holography applied in the "lateral-vantage" or "deep-focus" scheme (*4*–*6*). To test for the presence of the signatures reported, I applied helioseismic holography (*7*) to 6-hour time segments of full-disk Doppler observations from the Michelson Doppler Imager (MDI) (*8*) on board the Solar and Heliospheric Observatory (SOHO) to compute travel-time maps of the four emerging flux regions presented by Ilonidis *et al.* (*1*).

The resulting maps (Fig. 1 and fig. S2) and statistics (fig. S3) of the travel-time shifts near the target regions do not support the existence of decreases in acoustic travel times on the order of 12 to 16 s at any of the expected depths and positions, although such signatures would be at least 5 times the background noise. Instead, the observed fluctuations in the depth-averaged travel-time maps appear to be consistent with realization noise (*9*), which for these measurements is ~2 s. The use of multiple arc configurations by Ilonidis *et al*. (*1*) implies that the signal-to-noise ratio of their maps may vary with the number of arc configurations employed. Figures S3 and S4 demonstrate that the signal in this holography analysis is not enhanced, nor is the noise reduced, by the cumulative addition of egression-ingression correlations using multiple arc configurations, particularly with the smaller arc configurations advocated by Ilonidis *et al*. (*1*).

The findings here are consistent with the expectations (*2*) that acoustic travel-time signatures of magnetic flux, at depths of ~50 Mm, are less than a second, and thus below the typical helioseismic noise for observations spanning less than a day (*6*). It is worth noting that both time-distance and holography methods are demonstrably capable

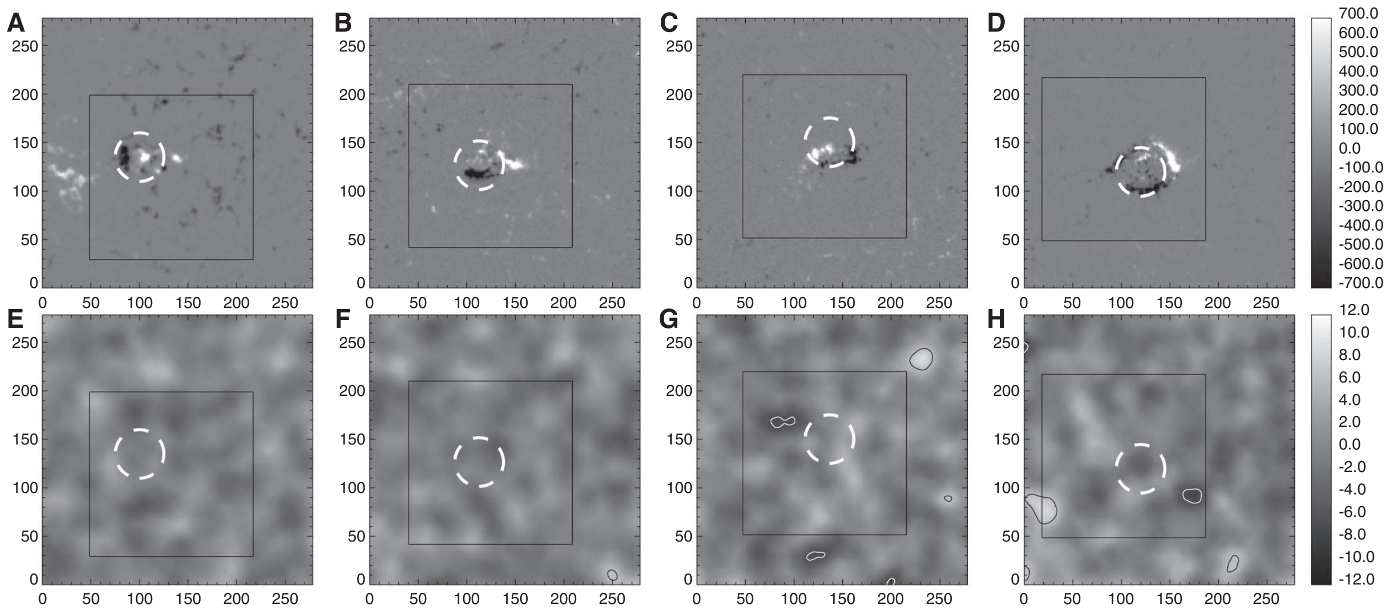

Fig. 1. (**A** to **D**) Line-of-sight MDI magnetograms (in units of Mx/cm^2) and (**E** to **H**) travel-time shift maps (in units of seconds) for the four active regions studied. From left to right, the active regions shown are AR 07978, AR 08164, AR 08171, and AR 10488, respectively. (A) to (D) show the photospheric magnetic field at post-emergence (at identical times as those shown by Ilonidis *et al*. in figures 4C, 3C, S2C, and 2C, respectively), and the boxes show the field of view as employed by them (with dimensions in Mm). The dashed white circles (50 Mm in diameter) approximately mark the size and location of the reported signatures. The black (white) contours in (E) to (H) indicate travel-time shifts of +6 (–6) s. The travel-time shift maps were made from 6-hour time series centered on the following times (from left to right): 6 July 1996 12:00 UT, 23 February 1998 00:00 UT, 27 February 1998 03:00 UT, and 26 October 2003 03:00 UT, all of which are near the times of the maximum travel-time shifts reported by Ilonidis *et al*. The computed maps extend beyond the region shown and represent averages over the four target depths (maps for the individual depths are shown in fig. S2).

(as a prominent example) of detecting ~10-s travel-time shifts caused by strong magnetic flux concentrations on the far surface of the Sun (*10–12*). The discrepancy between the results presented here and those of Ilonidis *et* al. (*1*) is difficult to reconcile in terms of the properties of known acoustic travel-time anomalies such as compact perturbations of sound speed. Ascertaining the potential consequences for the results of (perhaps subtle) changes in methodology may be important. For example, the holography analysis includes acoustic waves propagating through the target depths at impact angles up to ±45 degrees from the horizontal, as opposed to the selection of predominantly horizontally impacting waves by Ilonidis *et al*. (*1*). Quantitative measurements of variations of travel-time shifts with impact angle and other parameters may be critical in understanding the physical nature of the anomalies. The holography method used here is applied to fairly large regions of the Sun surrounding the targets, which allows the assessment of realization noise for each separate target region. Applying the time-distance procedure of Ilonidis *et al*. (*1*) over comparably large areas would be useful for future comparisons. Due to differences in methodology, I draw no conclusions regarding the replicability of the reported anomalies using the time-distance methods described by Ilonidis *et al*. (*1*). However, given the disparity of results and the lack of physical basis for such signatures, I consider the 12- to 16-s travel-time decreases reported by Ilonidis *et al*. to be controversial and suggest that a resolution of the issue might be achieved using blind tests with simulated and real data.

References and Notes

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Supplementary Materials

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Materials and Methods
Figs. S1 to S4
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