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Taiwan Oscillation Network and Small-Telescope Research at Tsing Hua University

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Abstract. Two projects, the Taiwan Oscillation Network (TON) project and the earthshine project, at Tsing Hua University will be discussed. The TON is a ground-based network to measure solar intensity oscillations to study the solar interior. Four telescopes have been installed in Tenerife (Spain), Big Bear (USA), Huairou (PRC), and Tashkent (Uzbekistan). The recent scientific results from the TON data will be briefly discussed. The earthshine project is to measure the brightness of the dark portion of the lunar disk to obtain the Earth's global albedo. The dark portion of the Moon is lit by the sunlight reflected from the Earth. The global albedo is linked to the global temperature of the Earth. The long-term measurement of earthshine will provide information on the long-term variation of the global temperature. An automated earthshine telescope is being developed at Tsing Hua University. It will be installed at Lulin Mountain in central Taiwan. The ultimate goal is to build a ground-based global network to measure the long-term variation of earthshine to learn about the long-term variation of the global temperature.

1. The Taiwan Oscillation Network Project

The Taiwan Oscillation Network (TON) is a ground-based network measuring solar K-line intensity oscillation for the study of the internal structure of the Sun. The TON project has been funded by the National Research Council of ROC since July of 1991. The plan of the TON project is to install several telescopes at appropriate longitudes around the world to continuously measure the solar oscillations. So far four telescopes have been installed. The first telescope was installed at the Teide Observatory, Canary Islands, Spain in August of 1993. The second and third telescopes were installed at the Huairou Solar Observing Station near Beijing and the Big Bear Solar Observatory, California, USA in 1994. The fourth telescope was installed in Tashkent, Uzbekistan in July of 1996. The locations and pictures of four TON telescopes are shown in Figure 1. We are planning to install an automated TON telescope at Lulin Mountain.

The TON is designed to obtain informations on high-degree solar p-mode oscillations, along with intermediate-degree modes. A discussion of the TON project and its instrumentation has been given by Chou et al. (1995). Here we give a brief description. The TON telescope system uses a 3.5-inch Maksutov-type telescope mounted on a German-type equatorial mount. The annual average diameter of the Sun is set 1000 pixels. A K-line filter, centered at 3934Å,

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of FWHM = 10Å and a prefilter of FWHM = 100Å are placed near the focal plane. The measured amplitude of intensity oscillation is about 2.5%. A 16-bit water-cooled CCD is used to take images. The image size is 1080 by 1080 pixels. The exposure time is set to 800-1500 ms, depending on the solar brightness. The photon noise, about 0.2%, is greater than the thermal noise of the CCD and circuit. The TON telescope is a semi-automated system. At the beginning of day, observers have to open the cover, point the telescope to the Sun, and enter control commands on two computers. The telescope will guide itself and take images at a rate of one per minute. The image data are recorded by two 8-mm Exabyte tape drives.

The TON full-disk images have a spatial sampling window of 1.8 arcseconds per pixel, and they can provide information of modes up to $l \approx 1000$. The TON high-resolution data is specially suitable to study local properties of the solar interior.

Recently, we have developed a new method, acoustic imaging, to study local inhomogeneities in the solar interior (Chang, Chou, & LaBonte 1997; Chen et al. 1998; Chou et al. 1999; Chou 2000). A resonant p-mode is trapped and multiply reflected in a cavity between the surface and a layer in the solar interior. The acoustic signal emanating from a point at the surface propagates downward to the bottom of the cavity and back to the surface at a different horizontal distance from the original point. Different p-modes have different paths and arrive at the surface with different travel times and different distances from the original point. The modes with the same angular phase velocity ω/l have approximately the same ray path and form a wave packet, where ω is the mode angular frequency and l is the spherical harmonic degree. The relation between the travel time and the travel distance of the wave packet can be measured in the time-distance analysis (Duvall et al. 1993). Acoustic imaging uses the time-distance relation to construct the acoustic signals at the target point. For a target point on the surface, one can use the measured time-distance relation. For a target point located below the surface, one has to use the time-distance relation computed with a standard solar model and the ray approximation (D'Silva and Duvall, 1995; Chang et al. 1997).

The constructed signals in acoustic imaging contain information on intensity and phase. The first acoustic intensity maps of the solar interior were constructed with the high-resolution TON data (Chang et al. 1997). They show that the acoustic intensity is lower in magnetic regions. The phase-shift maps, first derived by Chen et al. (1998), show that the sound speed is smaller in magnetic regions. To correctly interpret the phase-shift maps, the inversion of measured phase shifts is necessary (Chou, Sun, & The TON Team 2001). We have developed a kernel for phase shifts which links the measured phase shifts with the phase-speed perturbation distribution (Chou & Sun 2001). An inversion method with regularized least-square-fit has been developed by Sun & Chou (2001). The preliminary inversion results show that the depth of the phase-speed perturbation distribution for a typical active region is about 20,000-30,000 km (Chou et al. 2001).

2. The Earthshine Project

Earthshine is sunlight reflected by the Earth which is visible as a dim image of dark portion of the lunar disk. The intensity of earthshine relates to the average of the Earth albedo, so it relates to the global temperature of the earth. A fraction (albedo, about 30%) of sunlight incident on the Earth is reflected by the earth atmosphere and surface back into space. The rest of solar energy is absorbed by the Earth (atmosphere and surface) and converted into heat. This energy is re-emitted into space in the infrared range as an approximate black-body radiation of 225°K (The spectrum of this re-emitted energy is well separated from the incident sunlight whose effect temperature is about 5780°K). Thus the albedo relates to the global temperature of the earth. A change in albedo relates to a change in the global temperature T.

More than seventy years ago, Danjon first tried to determine the average earth albedo from earthshine measurements (Danjon 1928, 1936, 1954). He used the ratio of the intensity of the dark portion to the intensity of the bright portion to reduce the effects of the atmosphere and solar intensity. However, the error bar of his measurements, about 5%, was too large to determine the variation of global temperature. Recently the earthshine measurements at the Big Bear Solar Observatory show that the error bar of A can be as small as 1%, which corresponds to about 0.25% change in global temperature (Goode et al. 2001). Thus earthshine measurements with modern technology becomes a promising method to measure the variation of the global temperature.

Since earthshine measurements at one site can yield the albedo averaged over only a part of the Earth. Our ultimate goal is to to build a ground-based global network to measure the long-term variation of earthshine to learn the long-term variation of the global temperature. To make long-term observations feasible with a low cost, we need to use automated telescopes. The goal of our design is to make the telescopes operate automatically without human care for a reasonable period, for example, a couple of weeks. The first step of the project is to build a prototype automated telescope at Lulin Mountain. Then we will build a few more telescopes to install at suitable sites around the world. The design of the prototype telescope is briefly described as follows.

2.1. Optical and Imaging System

A 3.5-inch ruggedized Questar telescope (Maksutov type) and a German-type equatorial mount are used. A 10^{-5} neutral density filter is used to reduce the intensity of the bright portion of the lunar disk so that the dark portion and the bright portion can be measured simultaneously. A heat-block filter will also be used to remove the near-infrared energy. A 16-bit 1024×1024 air-cooled CCD will be used to take images.

2.2. Tracking and Control System

Tracking the Moon is more difficult than tracking stars or the Sun because the shape of the dominant bright portion of the lunar disk changes with time. We will use both the passive tracking (using the pre-determined coordinates) and the active tracking (using the observed lunar images to adjust pointing).

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Pointing of the telescope will be measured with an optical decoder accurate to sub-arcseconds.

To make the telescope robust, we minimize electronic hardware by using a digital signal processor (DSP) to control the telescope. This allow us to improve or update the control system by modifying the software of the DSP. The DSP will be controlled by a Linux-based computer. A GPS will be used to provide accurate time.

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台灣全球日震觀測網

Taiwan Oscillation Network

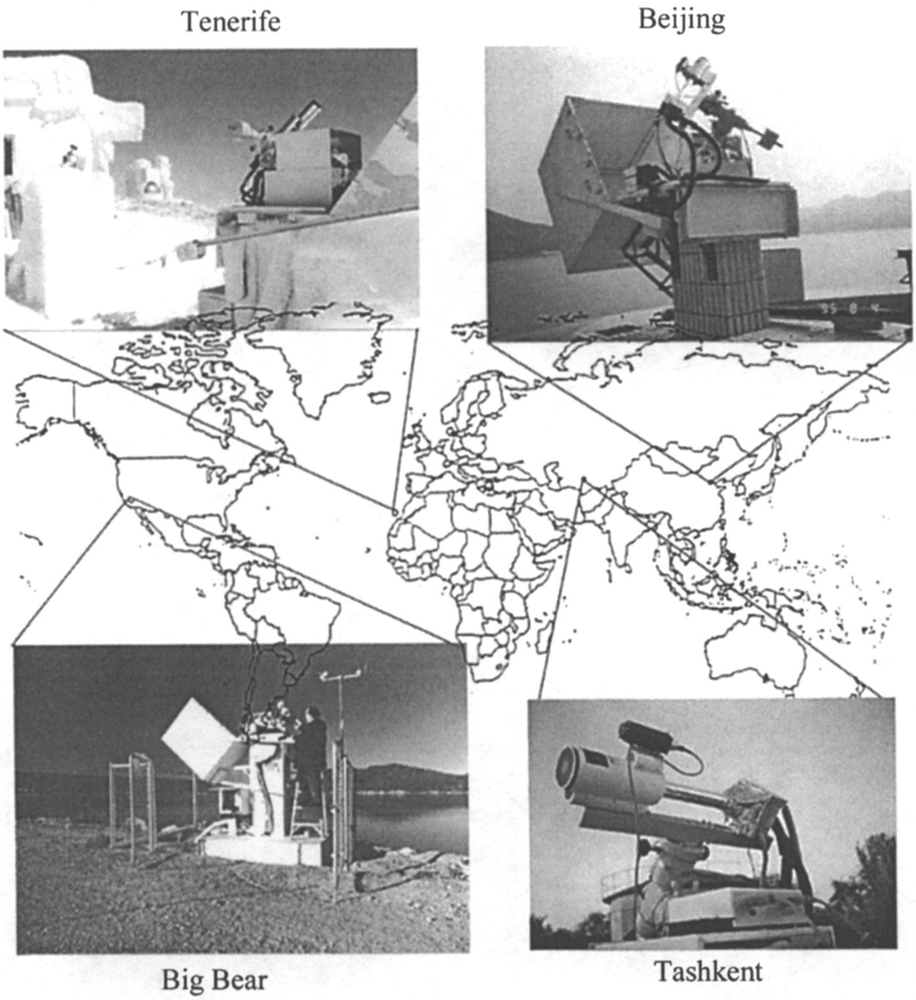

Figure 1. Locations and pictures of four TON telescopes.

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