

SATELLITE REMOTE SENSING FOR GEOLOGIC CARBON SEQUESTRATION FIELD MONITORING

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Abstract - Carbon dioxide is one of the major greenhouse gases generated by human activities which, by virtue of its impact on global climate through “Greenhouse Warming”, are implicated in extreme environmental impacts such as more prevalent and more intense storms, bushfires, floods, droughts and heat waves. In order to constrain the growth of atmospheric CO₂, Geologic Carbon Sequestration (GCS) has been proposed as a “clean coal” technology for mitigating the more extreme impacts of global warming. However, more understanding of CO₂ storage processes and a confirmation of its effectiveness, so as to minimize environmental, safety, and health impacts in the event of a leak to the atmosphere, is certainly required. In addition, long term GCS must be properly managed. This consists of planning and geologic analysis for the storage site, safe operating practices, careful monitoring of the underground CO₂ during injection period including continuous monitoring subsequent to its injection. GCS monitoring is therefore critical, and is expected to serve multiple purpose - from providing information about safety and environmental concerns, optimizing storage capacity, dealing with unintended leakage and addressing regulatory, legal and social issues. In particular, satellite remote sensing can provide indirect methods to monitor GCS site over short and long periods. Besides, it is a cost effective monitoring technique for large areas associated with sequestration site. This paper discusses the potential of satellite remote sensing for use in GCS, by reference to a variety of tests scenarios.

Keywords: Environmental, Climate change, GCS, CO₂ monitoring, Satellite remote sensing

1. INTRODUCTION

Climate change is one of the most serious problems which dramatically occur around the world. Climate change also represents a change in long-term weather patterns. It could become warmer or colder. Besides, annual amounts of rainfall or snowfall could rapidly increase or decrease. In scientist’s point of view, the most concern issue about climate change is global warming caused

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by human activities including burning fossil fuels and deforestation (Canada global warming, 2009). Geologic Carbon Sequestration is an essential instrument to remove massive amounts of CO₂ before it is released into the atmosphere. It is very important that

Geologic Carbon Sequestration is supplementary to the continued effort of increasing use of renewable energy as well as energy efficiency measures. In addition, these technologies are capable of deploying widely across the globe in many different economic sectors and in many different locations. Moreover, GCS has the potential to be an essential technology to significantly reduce greenhouse gas emissions and allow the continued use of fossil fuels for energy security, without damaging climate security. In addition, monitoring system is one of the answers enabling solution for CO₂ storage. It is expected to support multiple purposes from providing information about safety and environmental concerns such as used to optimize storage projects, deal with unintended leakage and address regulatory, legal and social issues. Particularly, satellite remote sensing such as DInSAR, PSInSAR, and Hyperspectral techniques will be a useful and cost effective tool to monitor ground deformation and assess environmental impact after injecting CO₂ underground. This study will aim at using remote sensing techniques to detect movement of ground elevation and change in environment at storage area.

2. METHODOLOGY

2.1 Radar remote sensing

Radar interferometry provides the solution for monitoring the ground surface displacement over a great area. The coverage is varies from 50km x 50km to 100km x 100km. It measures the amplitude and phase of the microwave signals that are emitted by a radar antenna and reflected off a target on the ground. The amplitude indicates the target reflectivity, and the phase is related to the distance between the radar antenna and the target. In radar interferometry case, only the phase measurement is interested.

DInSAR and PSInSAR

For CO₂ sequestration, there are several of key technologies to monitor the injection and the subsurface movement and storage of CO₂. To illustration, DInSAR and PSInSAR can contribute to an evaluation of the storage stability, since millimetric surface uplift could be one of the indicators for a potential storage leak by calculating the phase differences for a signal received from the same location for different calendar times.

Differential Interferometry for Synthetic Aperture Radar (DInSAR) technology is a space borne measurement method or in other words; a satellite based remote sensing technique which is able to detect ground motion with millimetric resolution using radar satellite images (Ge et al, 2004, 2007). The goal of using DInSAR is to separate phase contributions due to topography from displacement in order to get the deformation field. A digital elevation model or another SAR-image pair is needed to get the topographic phase, which will be subtracted from the deformation interferogram (Ferretti et al, 2007). The distance to a specific location on the Earth's surface can be measured with impressive accuracy by exploiting a sequence of satellite images. It is possible to monitor height changes versus time. The phase of the differential interferogram $\delta\phi$ is referred as

$$\Phi \approx \Phi_{disp} + \Phi_{topo} + \Phi_{atmo} + \Phi_{noise} \quad [1]$$

Where: disp = surface displacement
topo = topographic information
atmo = atmospheric delay
noise = phase noise

However, there are still four main problems which limited the conventional InSAR technique from achieving its full operational capability. The four main problems are (1) atmospheric disturbances and orbital errors (2) linear and non-linear decorrelation (3) temporal decorrelation (4) ambiguity as this technique has limited to achieve its full operational capability (Ng, 2007). Therefore, the Permanent Scatterers (PS) technique has been developed to detect isolated coherent pixels and tackle the problem of atmospheric delay errors at the expense of a large number of required images and a sparse, pixel-by-pixel based evaluation (Ferretti et al, 2007). Clearly, PSInSAR technique makes a systematic analysis of D-InSAR data taking advantage of the massive available data set (ERS1/2, ENVISAT ASAR), processing only the information of the coherent targets, which are slightly affected by temporal and geometrical decorrelation. The key processing steps of the PS technique are the following: (1) SLC data: images calibration; (2) persistent scatterer point selection; (3) differential interferogram stack generation; (4) initial phase model and DEM error estimation for PS candidate; (5) PS-selection (remove unreliable points); (6) phase unwrapping; (7) atmospheric and phase model correction; and (8) final product: generation PS velocity

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2.2 Optical remote sensing

In addition to the uplifting of the subsurface around CO₂ injection site, there is also the possibility of unintentional releases through geological faults/ cracks and fractures or even from abandoned wells. Accessing environmental impact around sequestration site can also assure that the safety has not been compromised. In fact, seepage of CO₂ from underground storage might affect vegetation above the site. Then the vegetation stress will be detected by analyzing Vegetation Indices and reflectance spectra of plant signatures in both multispectral and hyperspectral imagery.

Hyperspectral

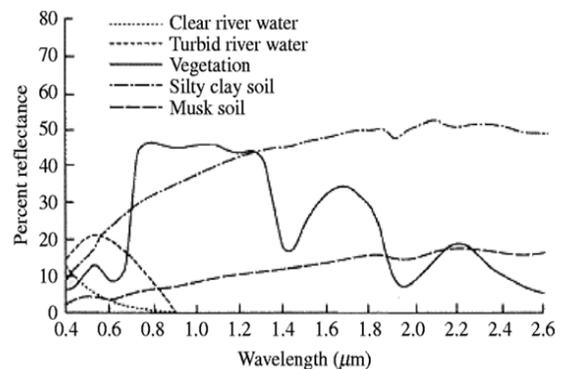


Figure 1 Reflectance spectra of different object (vegetation, soil water)

Figure 1 shows that hyperspectral imaging can be used to measure the absorption in specific wavelengths typically in the visible to the short-wave infrared region, 400–2500 nm. It has the ability to provide a high-resolution reflectance spectrum for each picture element in the image due to the absorption features in the spectra are determined by the chemical composition and physical structure of surface materials, which can be used to identify these materials (Jensen, 2005). Hyperspectral data also have been used in a wide range of studies such as establishing environmental status, mineral exploration, vegetation or identifying plant species, ecosystem tracking, agricultural problems and surface-water quality monitoring. In addition, one significant potential application of hyperspectral imaging to monitoring for CO₂ leakage is the detection of changes in plant health and communities related to elevated soil CO₂ concentration (Martini et al., 2000). Hyperspectral remote sensing is a useful technique for monitoring spectral change in vegetation or plant stress. In fact, plant stress can be explained when environmental conditions are non-favorable for suitable plant growth which could be caused by many factors such as drought, extreme heat or cold, insect infestation, water logging, bacterial diseases, oxygen depletion, nutrient deficiencies, or acidic soil (Male, 2010). The most likely case which happens for CO₂ storage is the CO₂ gas displaces oxygen to the roots of the plant, which occurs in natural gas leaks. Moreover, other possibilities are that large amounts of CO₂ could change the pH and redox potential of soil or alter natural microbial environments (Noomen et al., 2008). Due to the stress over long periods,

vegetation can be stunted growth, reduced water content, or a decrease in leaf chlorophyll concentrations. Moreover, carbon dioxide gas at higher concentrations is known to kill vegetation and can also lead to asphyxiation in humans and animals.

3. RESULT

3.1 Radar remote sensing

SAR data acquired by the Japanese ALOS satellite were used to monitor the Otway GCS sequestration site. The available SAR image products of Otway were limited for analysis due to orbit cycle. The targeting pairs were chosen from ALOS PALSAR radar images in order to maximize amount of CO₂ injection and keep the balance of both temporal and perpendicular baselines. In DInSAR case, the master image used was acquired on 1 January 2008 and for slave image was acquired on 3 March 2009.

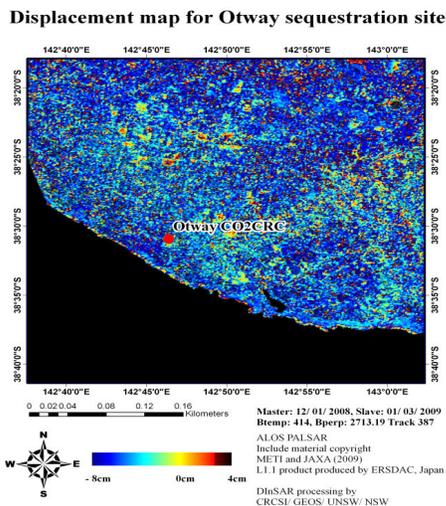


Figure 2: Displacement map of Otway CO₂ sequestration site, Australia process by DInSAR technique

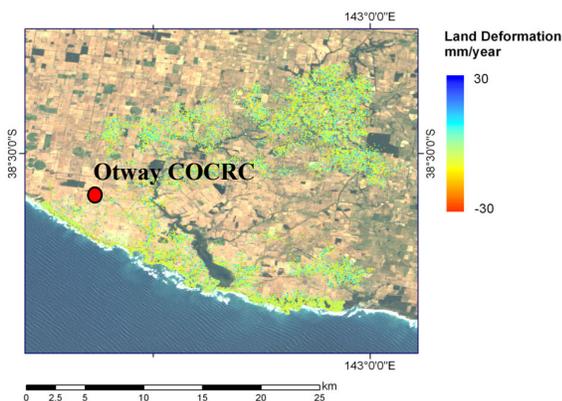


Figure 3: Displacement map of Otway CO₂ sequestration site, Australia process by PSInSAR technique

For PSInSAR result, images from January 2007 to April 2010 were used to generate the result of storage site to detect the deformation phenomena. A total of 16 ALOS PALSAR images have been selected to perform interferogram generation and stacking, and retrieve the ground elevation in the research area. In the data stack, each SAR image is labeled by the observation date and the image 20070109 is selected as master image, which also optimize the distribution of the baselines.

The result of DInSAR and PSInSAR (figure2 and 3) represent that the surface deformation pattern related to CO₂ injection at Otway, Australia did not show anticipated uplift because of several possible reasons. Firstly, it has shown that there is careful site selection in geological characteristic such as the stability of the underground storage reservoir. Another aspect could be that the amount of CO₂ injection is not large enough to effect storage formation and appear as ground elevation change. Due to Otway CO₂ storage site is only a demonstration project and injected rate is about 100,000 ton through a deplete gas field at a depth of 2 kilometers for the two year period (Cook, 2000). Thirdly, if there are more available numbers of interferometry pairs available, the deformation time series can be detected which could be one of the supplemental data to build up the underground geological sequestration model.

3.2 Optical remote sensing

The general shape of reflectance spectra for green vegetation is similar to green plants exhibit a sharp intensity change over a short spectral distance that is formed by strong chlorophyll energy absorption near the red wavelength (600 nm) and high reflectivity at the near-IR wavelength (760 nm) as shown in Figure 4. Changes in the health status of plants are often expressed as a shift of this red-edge toward longer or shorter wavelengths (Evans et al. 2002).

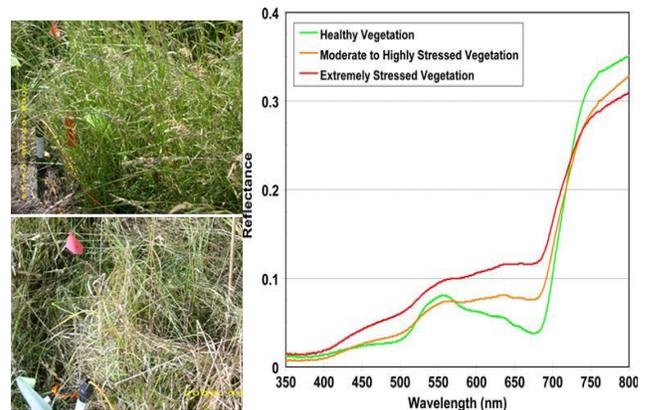


Figure 4: Reflectance spectra of healthy vegetation, moderate to highly stressed vegetation and extremely stressed vegetation (Male et al, 2010)

According to Male et al (2010), the result shows that stress could be recognized in some of the plants near to the injection well within after 4–5 days of CO₂ injection. After 14 days, the signature of plant stress increase to the maximum within two of identifiable

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zones of plant stress. In addition, a massive decrease in chlorophyll can cause more yellow or brown in vegetation appearance. Besides, the amount of stress measured during the test show there are different responses from the plants, or in other words, it is species dependent. The tall grasses and alfalfa in the field reacted quickly, whereas dandelion and some naturally short grasses appeared to be more resistant to stress (Male et al, 2010).

4. CONCLUSION AND FUTHER RESARCH

This paper presents the use of remote sensing technology which could be one of the monitoring tools for Geologic Carbon Sequestration (GCS) projects. The amount of injection and geological characteristic in sequestration storage area is a big challenge to the successfully application of DInSAR technique. And the limited number of SAR images is one of the reasons for the imperfection of the experiment results at this stage. Besides, on previous study CO₂ leaks through the soil could successfully be identified by hyperspectral signatures which could determine the vegetation stress above the field. Importantly, this monitoring technique can be utilized long term, even on 100-year timescales, as it would require little to no maintenance of the sequestration field. The only requirement is simply the presence of vegetation. To verify that CO₂ is successful be trapped, analyzing hyperspectral signatures for vegetation stress is a proficient method which could advantages sequestration fields.

Further research, firstly may attempt satellite data with shorter wavelength such as X and C band which is needed in order to achieve better sensitivity to ground deformation for radar prospective. It is also expected that the results will be improved combining with the other monitoring data such as GPS, artificial reflectors and the meteorological satellite images. Secondly, the most important task for monitoring CO₂ storage is to verify and ensure the safety and effectiveness of geologic carbon sequestration filed. Therefore, buildup of modeling in the near-surface environment is a challenge.

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