Outcomes Report for Southern Sierra Critical Zone Observatory 2007-2013

The Southern Sierra Critical Zone Observatory (SSCZO) is investigating how mountain soils and weathered bedrock develop over geologic time, and interact with shorter-term climate variability and ecosystem behavior. This understanding provides the foundation for predicting how environmental change, including human disturbances, fire, pests and changes in climate, influence water resources, material flows and forest health. The SSCZO is pioneering accurate measurement systems for snow accumulation and melt, soil moisture, climate and evapotranspiration; and the use of the measurements to drive advanced models for forecasting future conditions. Through close partnerships with regional stakeholders SSCZO results help to assess options available to resource managers to enhance management of forests, water and other ecosystem services, given environmental change.

The SSCZO is also a community platform for research on critical-zone processes, both locally and as part of the broader CZO national network. Located in the Southern Sierra Nevada near Fresno (Figure 1), it lies along a steep elevation transect where precipitation grades from dominantly rain to dominantly snow and ecosystems range from oak savannah biomes to subalpine forests (Figure 2). Spatial gradients in critical-zone properties and processes permit substitution of space for time, making the SSCZO an excellent natural laboratory for studying how the critical zone responds to disturbance and how the water cycle drives critical-zone processes. The Providence catchments are the most heavily instrumented of the sites (Figure 3). There are 2 meteorological stations, a 50-m flux tower, a 60-node wireless embedded sensor network, 215 EC-TM sensors for volumetric water content, over 110 MPS sensors for matric potential, 60 snow-depth sensors, meadow piezometers and wells, sap-flow sensors, stream gauges and water-quality measurements. SSCZO research involves a core SSCZO team from 6 campuses, plus collaborators and cooperators from other institutions who use SSCZO data and other resources in their research.

The conceptual science model for the SSCZO is built around links between water/material fluxes and landscape/climate variability across the rain-snow transition (Figure 4). Investigations link drivers of change to impacts on the water cycle, ecosystems and biogeochemical cycles, and ultimately to impacts on ecosystem services. Ongoing research focuses on water balance, nutrient cycling and weathering across the rain-snow transition, with soil moisture as the integrating variable.

The distributed snow and soil-moisture measurements show a close coupling between snowmelt and soil drying in spring/summer, with systematic variability across elevation, aspect and canopy cover. Runoff increases with elevation, corresponding to decreasing temperature, more precipitation falling as snow, decreasing vegetation density and coarser soils. Evapotranspiration decreases proportionally as soils dry, going from about 1 to 0.1 mm d^{-1} over the summer. However, evapotranspiration is high in mid-elevation vegetation despite dry summers and freezing winter temperatures (Figure 5). That is, photosynthesis persists through the winter, and soils and regolith store enough water for photosynthesis to occur all summer. As soils dry out, trees apparently extract water from the deeper soils. Bedrock indicates weathering as deep as 40 m in some locations (Figure 6), providing a source of water for continued summer evapotranspiration. Higher elevations experience winter cold shutdown and lower elevations summer shutdown due to moisture stress; however, in between the broad mixed-conifer elevation zone of the Sierra Nevada experiences neither limit. Soil-mantle patterns at a larger scale indicate bedrock nutrients are more variable than previously thought, impacting vegetation. Annual runoff is about 15-30% of precipitation in dry years, increasing to 30-50% in wet years. The ground is snow covered for 4-5 months each year, and may experience multiple melt events during the winter and spring.

The SSCZO provides a platform for research in a landscape with vital importance to society, yet poorly understood in its potential response to climate warming. The twin threats of a changing climate and land-use practices raise fundamental questions about the sustainability of critical-zone services in the semi-arid U.S. West, which depends heavily on seasonally snow-covered mountains for many of these services. The Sierra Nevada provides ecosystem services, ranging from water to biodiversity, to a large fraction of California's and thus the nation's population. SSCZO partnerships with federal, state, and local resource-management agencies show the interest that decision makers have in using both research results and SSCZO technology to improve predictive capabilities. SSCZO data and lessons to enhance the science experience of thousands of middle- and high-school students, several undergraduate students and the public.

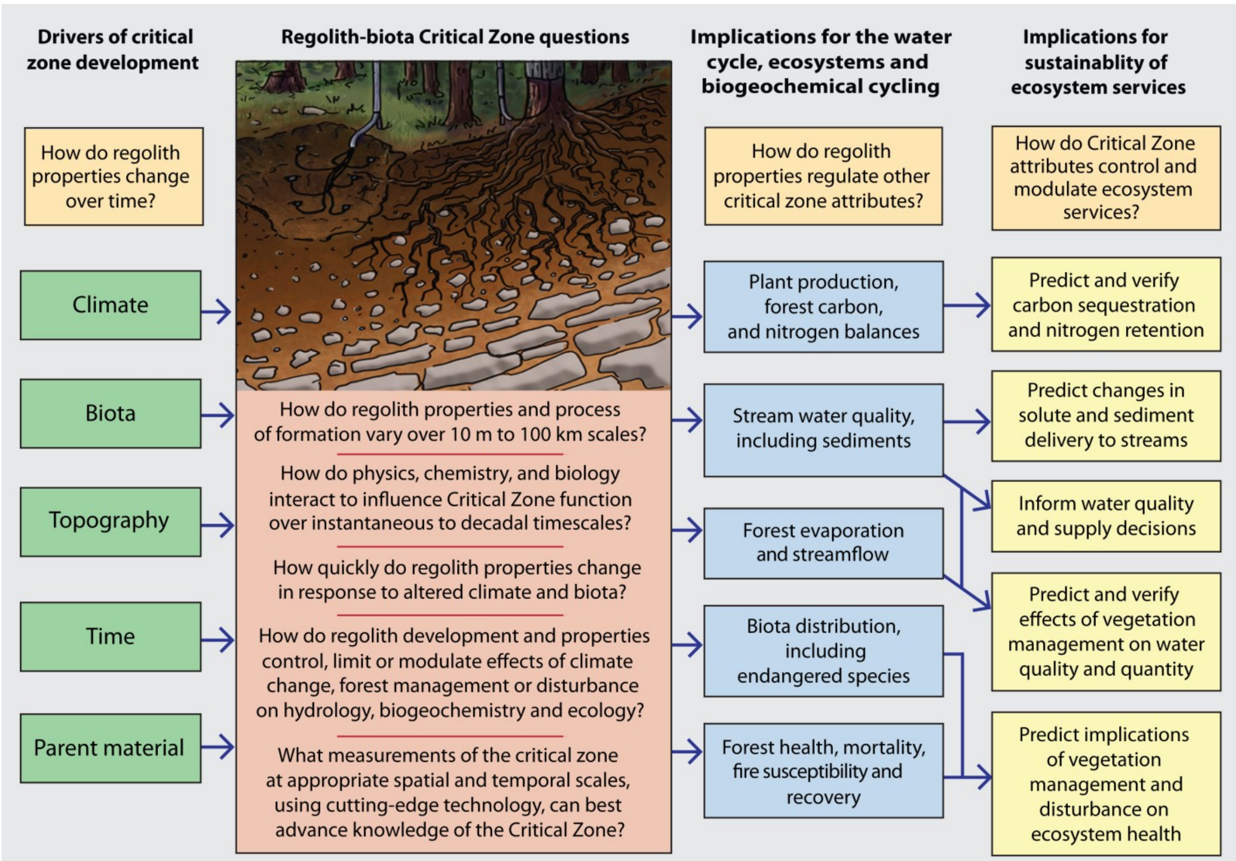

Figure 1. Schematic of relationships among drivers of critical-zone development, science questions that guide Southern Sierra Critical Zone Observatory research, implications for critical-zone attributes and implications for critical-zone services and sustainability.

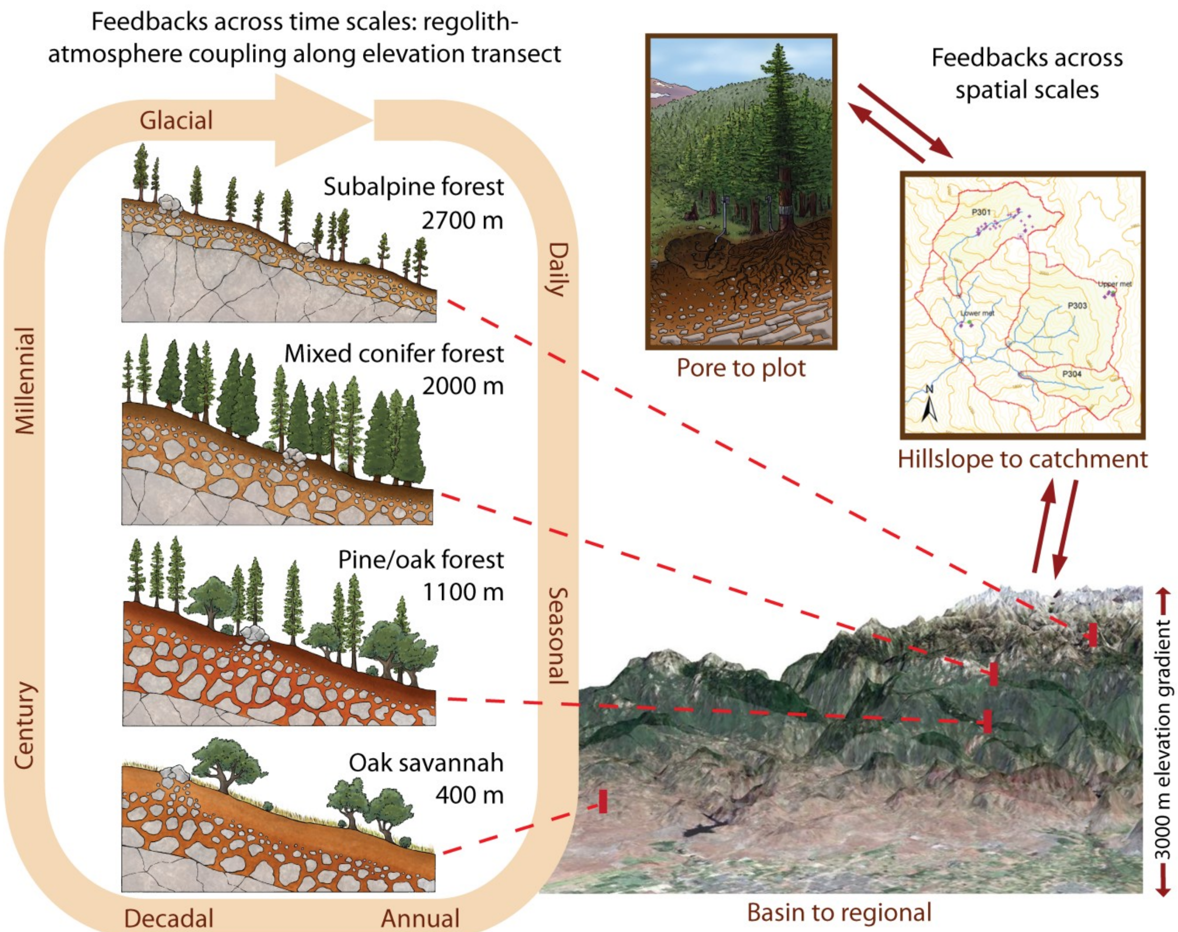

Figure 2. The Southern Sierra Critical Zone Observatory involves measurements and research across multiple scales of space and time. We have established four focus sites spanning a 2500-m elevation range, exploiting gradients in climate soil properties, vegetation, and material cycles. The subalpine forest (2700-3000 m) has thin patchy soil that may limit soil-moisture storage. The mixed-conifer forest (2000 m) is our most heavily instrumented research area, with three gauged headwater catchments nested in a fourth, 4.6 km2 gauged catchment (see inset map). Instrumentation around 2000 m includes a flux tower, two meteorological stations, soil lysimeters, groundwater wells, over 1000 continuous sensors for snow depth, soil moisture, streamflow, water quality, and sap flow. The local vegetation, soils, streams and other attributes have been well characterized. The pine/oak-forest (1100 m) has the most intense weathering; soil profiles display subsurface horizons with evidence of clay and iron accumulation and a deep regolith. The oak-savannah (400 m) has little woody vegetation but high belowground biomass (in grass roots), posing sharp contrasts in soil-water utilization and nutrient cycling relative to the upper sites. Image in lower right of figure indicates greenness (a measure of vegetation density).

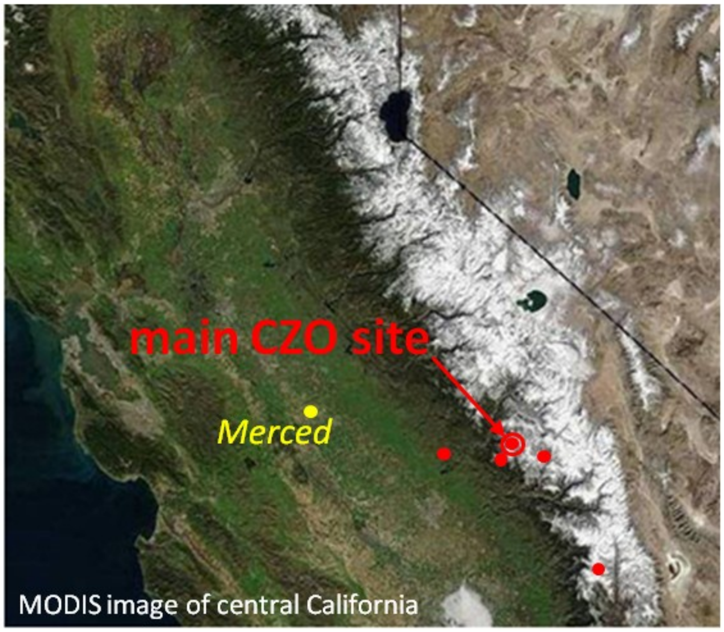

Figure 3. The Southern Sierra Critical Zone Observatory (CZO) sites are distributed in the southern Sierra Nevada. One site is located in the foothills, three are in Sierra National Forest, and a fifth is in Sequoia National Park.

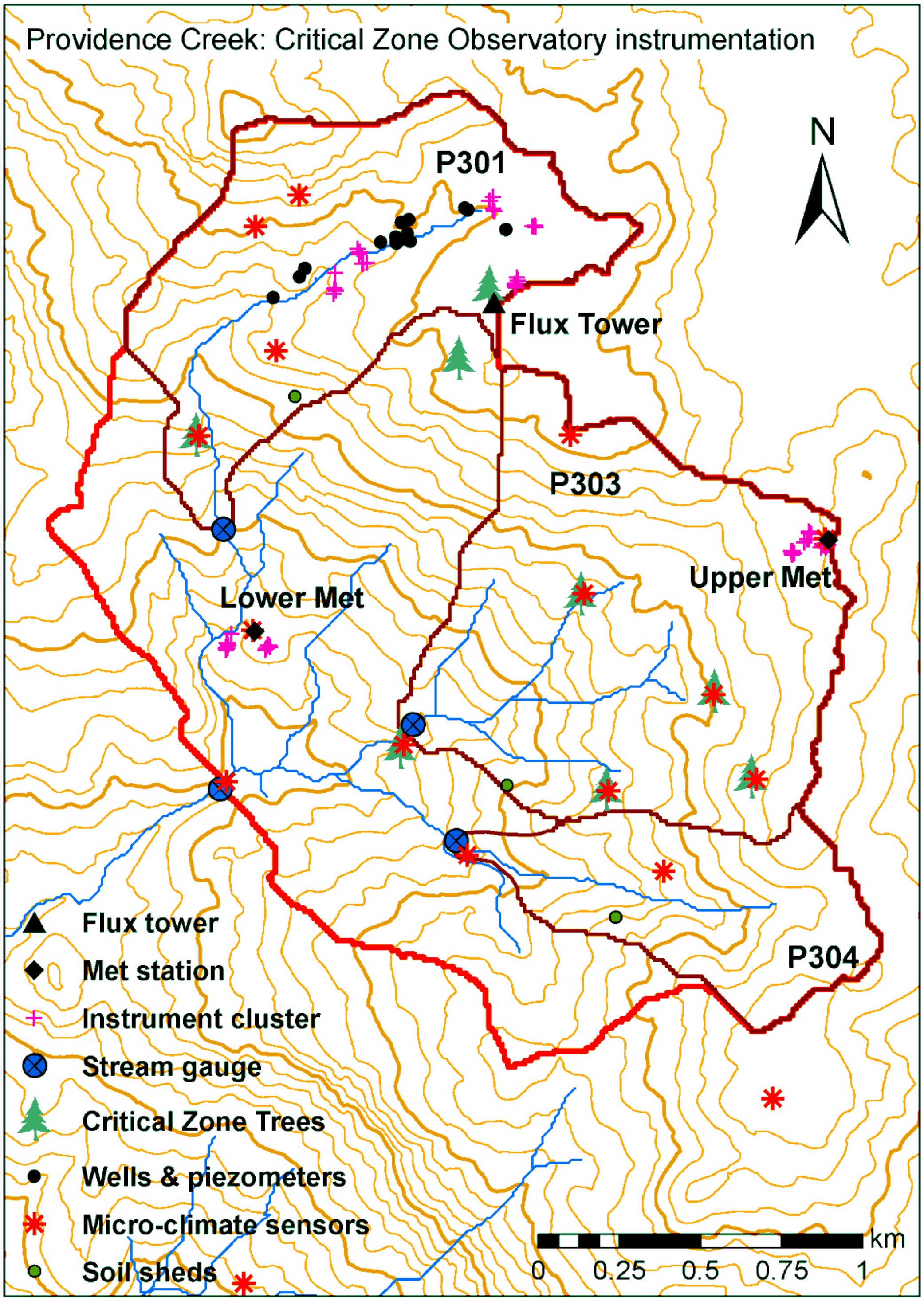

Figure 4. Instrument cluster design at the Critical Zone Observatory site that overlaps with the Kings River Experimental Watershed. Instrument node locations are strategically placed to capture variability in aspect, elevation, and vegetation properties.

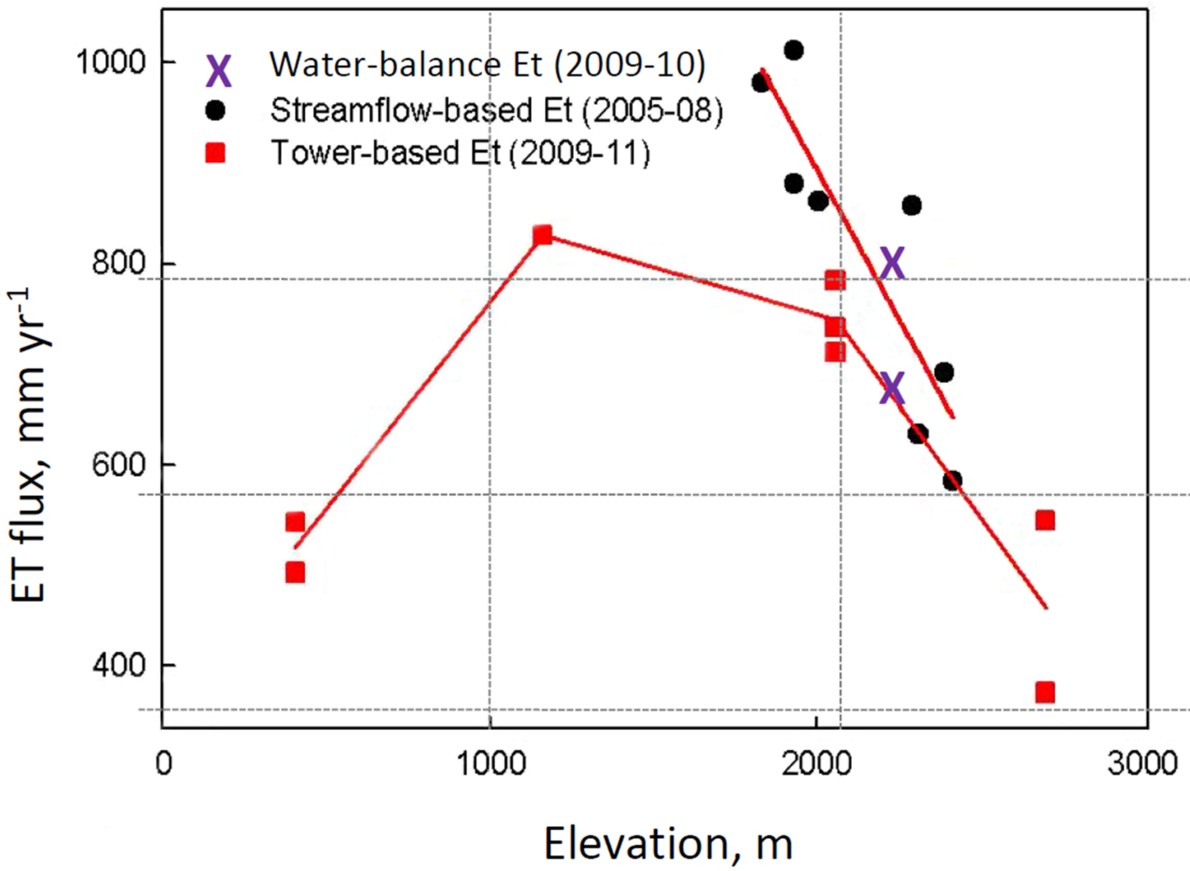

Figure 5. Annual evapotranspiration across the CZO elevation gradient (Goulden et al. 2012).

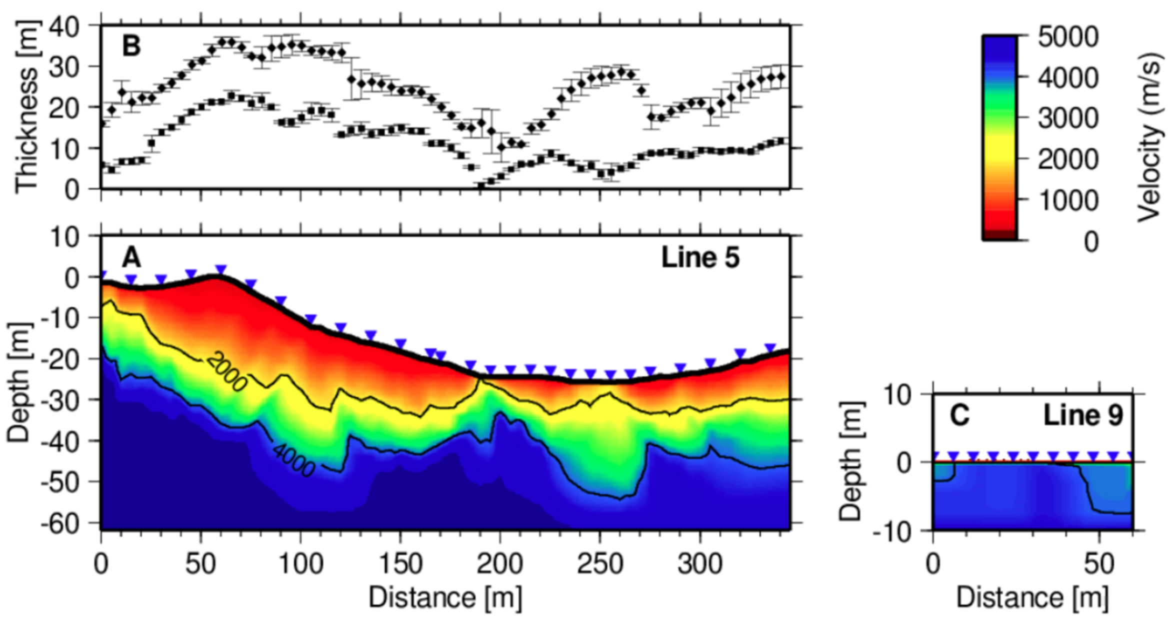

Figure 6. Regolith thickness from a seismic survey at the Southern Sierra CZO. Upper panel shows thickness to 2000 and 5000 m/s velocity profile (Holbrook et al., 2013).