HIGH RESOLUTION MULTI-TRACER STUDY OF WATER FLOW AND SOLUTE TRANSPORT IN THE GLACIAL TILL

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The aim of this study was to explore water flow and solute transport mechanisms in the unsaturated and saturated zone (aquitards) and how the mechanisms differ between uplands and lowlands in the Canadian Prairie glacial till. Past and recent studies on surface water-groundwater interaction involving physical measurements and stable isotope tracers show that prairie wetland ponds have distinctive isotope signatures from till aquitards and aquifers and that they may not play significant roles in groundwater recharge. Tritium data from aquitards and aquifers also suggest that aquifers are recharged with modern water. The observations suggests that uplands may play an important role in prairies groundwater recharge and possibly contribute more recharge water to aquitards and aquifers. We studied three soil profiles depths (0.2- 8 m, 0.2-10 m, and 0.2 -14 m) obtained from uplands and lowlands to identify the extent of deep percolation in the uplands and the lowlands and to test the established hypothesis of depression focused recharge, and critique it. We employed sets of tracers ($\delta^{18}O$, $\delta^{2}H$, Cl^- & SO_4^{2-}), line condition (lc)-excess, complemented by soil analysis and physical measurements from piezometers. The depth profiles show a steady increase in both $\delta^{18}O$, $\delta^{2}H$ tracers and lc -excess below depth, from the ground surface to >2m in lowlands and >5m in both uplands and piezometers. The Cl^- and SO_4^{2-} also showed leaching to similar depths. The change in $\delta^{18}O$, $\delta^{2}H$ and lc-excess values below 7 m depth is muted and no significant evaporated water signals was found in the aquitards. It is suggested that the major process responsible for enhancing deep water flow and solutetransport into aquitards and intertill aquifers is not soil infiltrability beneath permanent recharge wetlands (i.e., depression focused) but rather preferential flow; since the former will lead to greater degree of evaporation before recharge.

Keywords: Glacial till, stable isotopes, lc-excess, chemical ions, water flow and solte transport, mechanisms

立山地獄谷の温泉水の同位体比
The isotopic ratios of the hot springs in the Jigokudani Valley, Tateyama Volcano

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立山地獄谷は飛騨山脈に位置する活火山で、現在は地獄谷と呼ばれる場所で活発な噴気・温泉活動が行われている。地獄谷は４万年前以降に繰り返し発生した水蒸気爆発によって形成され、地獄谷の直下には水蒸気爆発の発生場である熱水系が発達していることが期待される。近年、火山ガス組成の変化や硫黄溶岩の流出が観測されるなど、地獄谷の火山活動は高まっている。そこで、地獄谷の熱水系を明らかにすることを目的として、比抵抗構造調査や温泉水の化学分析を行ってきた。本講演では、温泉水の化学分析に焦点をあてて報告する。

温泉水の採取は、2014年から2016年にかけて行い、陰イオン濃度の他、同位体比($\delta^{18}O_{water}$, δD_{water}, $\delta^{34}S_{sulfate}$, $\delta^{33}S_{sulfate}$)を測定した。水の同位体比($\delta^{18}O_{water}$, δD_{water})は、マグマ水と地獄谷周辺の天水を結ぶ混合線上に、全ての温泉水がプロットされた。水の同位体比と陰イオン濃度の特徴から、立山地獄谷の温泉水を、次の３つに分類した。①陰イオン濃度が大きく、その水の同位体比はマグマ水に近い値をとる温泉水。Cl^-/SO_4^{2-}濃度比は１に近い値を示す。②Cl^-濃度の減少のためCl^-/SO_4^{2-}濃度比の時間的変動が大きく、水の同位体比はマグマ水と天水の間の値をとる温泉水。③Cl^-を欠くSO_4^{2-}が主体の温泉水で、陰イオン濃度も小さい。水の同位体比は地獄谷周辺の天水と変わらない値を示す。

地獄谷の温泉水の硫酸中の硫黄の同位体比($\delta^{34}S_{sulfate}$, $\delta^{33}S_{sulfate}$)を2015年と2016年の温泉水で測定した。一般的に、$\delta^{34}S_{sulfate}$の高い温泉水は、初生的な硫酸で、SO_2の不均化反応により形成される。一方で$\delta^{34}S_{sulfate}$の低い温泉水は、二次的な硫酸でH_2Sの酸化によるものだと考えられている。地獄谷の温泉水の$\delta^{34}S$は、-0.81‰から19.93‰の値をとった。③の温泉水の$\delta^{34}S$は低いため、この温泉水中に含まれる硫酸はH_2S起源である。一方で、①と②の温泉水の$\delta^{34}S$値は、温泉水の陰イオン濃度や水の同位体比と相関が見られなかった。また、同位体分別は質量に依存するため、平衡状態において$\delta^{34}S$と$\delta^{33}S$の間に線形関係があることが知られている。立山地獄谷の温泉水は、この質量同位体分別からのずれ($\Delta^{33}S_{sulfate}$)が-0.016‰から0.058‰に及んだ。更に$\Delta^{33}S_{sulfate}$と$\delta^{34}S_{sulfate}$には負の相関が認められ、$\Delta^{33}S_{sulfate}$=0（質量同位体分別の期待値）と、$\Delta^{33}S_{sulfate}$-$\delta^{34}S_{sulfate}$プロットの回帰直線とが交わる、$\delta^{34}S_{sulfate}$ ≒+9‰ が、地獄谷の温泉水を作る深部マグマの硫黄同位体比を表していると考えられる。

以上より、３タイプの温泉水の成因を考えると次のようになる。①熱水流体が地下浅部で気液二相にわかれ、その液相が天水とほぼ混じること無く湧出した温泉水。②気液二相の気相が、天水と様々な度合いで混合し湧出した温泉水。③地表水にH_2Sガスが溶けた温泉水。

温泉水の化学分析と、地獄谷の地下比抵抗構造(Seki et al., 2016)を比較した結果、地獄谷の温泉水は500mより浅い場所で作られていることがわかった。特に、②の温泉水は、比抵抗構造でイメージングされた水蒸気爆発の誘発を促すキャップ構造の直下で作られていることが明らかになった。水蒸気爆発の発生は、地下浅部の温度や圧力状態が重要であるため、その変化を受ける浅部で形成された温泉水のモニタリングは、地獄谷の火山活動の推移を知る上で重要だと考える。

キーワード：熱水系、温泉水、水同位体比、硫黄同位体比

Keywords: Hydrothermal system, Hot spring, Water isotopic ratio, Sulfur isotopic ratio

同位体比と化学組成からみる、過去１５年間の片貝川扇状地地下水の水質及び涵養状況

A study of water quality and groundwater recharge in Katakai River alluvial fan over the past 15 years based on isotopic composition and chemical concentration

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In the Katakai River alluvial fan located in Uozu City, Toyama Prefecture, groundwater is used extensively for tap water, agricultural and industrial purposes, etc. However, the quality of the groundwater has been, as it were, taken for granted, and monitored only partially and irregularly in the recent past. The aim of this study was to reanalyze the data from two previous studies in order to evaluate the groundwater quality in the area, based on the stable isotopes of hydrogen and oxygen and chemical composition.

Suzuki, who studied the groundwater from wells throughout the area and its relation to water from Katakai River, suggested that there are at least two layers of aquifers in the Katakai River alluvial fan –one shallower than 70 m from the ground surface and the other deeper than 80 m. By measuring tritium concentration, he also found that the residence time of groundwater is 10 to 20 years (Suzuki, 2002). Also in 2002, Uozu City conducted a groundwater research throughout the area, and has been conducting an annual monitoring of groundwater quality in the northern part of the river fan since 2004.

The $\delta^{18}O$ value of the groundwater in the Katakai River fan in 2002 was similar to the $\delta^{18}O$ value of the river water from the Katakai River along the coast. Furthermore, the contribution ratio of river water to groundwater was about 80 %. The similar isotopic composition of river water and groundwater, indicates that the Katakai River discharged to groundwater through the ancient river course without being affected by precipitation.

Both the hexa-diagram of unconfined groundwater described in Suzuki (2002) and that obtained in my own study in 2016 were the type of Ca-HCO_3. Therefore, it seems that water quality has not changed over these years. In addition, from the annual monitoring data of self-discharge quantity of confined groundwater in 2004-2016, it was found that the volume of water increased in summer and decreased in winter. The exploitation of groundwater for the snow melting on the roads may be causing the decrease of confined groundwater flux in winter. At one well with the depth of 100 m, a decrease was observed in the volume of confined water. Since this groundwater is the type of Na・Ca-Cl, it may take a long time for water recharging from Katakai River. This seems to suggest t the vulnerability of deep confined groundwater. Consequently, the reasonable utilization and conservation of deep groundwater should be considered for sustainable groundwater management in the future.

キーワード：地下水、片貝川扇状地、魚津市
Keywords: ground water, Katakai River alluvial fan, Uoze city

水安定同位体を用いた樹冠遮断蒸発推定の新たな手法
A new approach to estimate evaporation of canopy interception using stable isotope of water

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Evaporation of canopy interception CI, accounts for around 20% of gross rainfall PG. However, it is strange that CI is proportional to PG on an hourly basis during rainfall (e.g. Murakami, 2006, J. Hydrol.; Saito et al., 2013, J. Hydrol.). To understand the mechanism of canopy interception we estimated evaporation of wet canopy surface EW using stable isotope of water.
Murakami and Toba (2013, Hydrol. Res. Lett.) measured CI in a plastic Christmas tree stand placed on a 180-cm square tray that was set outside under natural rainfall. We used the same system to measure PG and net rainfall PN to calculate CI (= PG - PN) using water balance. Manual sampling of gross and net rainwater was also conducted on an hourly basis. EW was estimated based on the difference of d18O (or d2H) values in gross and net rainwater using fractionation factor, and the results were compared with CI. In a rain event we focused on, PG and PN (runoff from the tray) were 28.0 mm and 22.7 mm, respectively, with CI of 5.3 mm (18.9% of PG). The d18O (or d2H) value in net rainfall was higher than that in gross rainfall because of fractionation by EW. Calculated EW by the values of d18O was 5.2% of PG on average. We tried to reproduce the results using a tank model (Yoshida et al., 1993, J. Japan Soc. Hydrol & Water Resour.). Firstly, evaporation rate is assumed to be constant, 20% of PG and the calculated PN was 23.1 mm, i.e. CI was 4.9 mm (17.5% of PG). Secondly, retaining the parameter of the model, we calculated PN based on hourly surface evaporation derived from the d18O values. The simulated PN was 25.6 mm that means CI was only 2.4 mm (8.6% of PG).
The difference between the two methods can be explained by rapid evaporation of micro-droplets produced by splash after rain impacts the canopy (Murakami, 2006). We will present the results using d2H data at the session.
This work was supported by JSPS KAKENHI Grant Number JP15H40250.

キーワード：樹冠遮断、飛沫、水安定同位体
Keywords: Canopy interception, Splash, Stable isotope of water

NICAM-isotopeでシミュレートされた梅雨前線に関連する水安定同位体の挙動

Stable water isotope behavior associated with the Baiu front simulated by NICAM-isotope

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Stable water isotopes (SWI) are an observable water tracer that reflects integrated history of phase change and mixing. SWI are exploit not only for climate proxy (e.g. Dansgaard, 1993) but for studying precipitation systems.

The Baiu Front (BF) is stationary front during the late spring and early summer near Japan, which is the “boundary” between tropical and extratropical airmass. BF is characterized by large gradient of SWI as well as equivalent potential temperature. To study BF from the viewpoint of SWI, it is expected to improve our understanding about water cycle associated the front.

From observational study by Kurita et al. (2015), highest isotope ratio in water vapor near surface correspond to the warm airmass advection by southerly flow, while abrupt isotopic depleting corresponds to cold air advection associated with southward migration of BF. Rainfall results in isotopic depletion of water vapor since heavy isotopologues (HDO) preferentially condensate and are taken away from water vapor by rainout. In this study, we attempt to quantify the effect of water vapor (airmass) advection and depletion by rainout on isotopic variability associated with the BF.

We developed isotope-incorporated microphysics scheme based on NSW6 (Tomita, 2008), which is a version of microphysics scheme by Lin et al. (1983). We simulate the isotopic behavior associated with BF using this scheme on global cloud-resolving model NICAM (Satoh et al. 2008; 2014).

To check validity of our isotope-incorporated model, simulated values in our model are compered with observation at paddy field in Tsukuba, Japan (Wei et al. 2015; 2016). Although there is some discrepancy between the observation and our simulation, our model successfully reproduced ascending/descending timing of dD.

From composite analysis against to precipitation intensity by BF, dD contrast between north and south of BF reflects airmass difference in the case with weak precipitation, which consistent with Kurita et al. (2015). On the other hand, heavy precipitation case is almost same with weak precipitation case except for “V-shape” depletion near BF region. this result is consistent with temporal V-shape change in isotope ratio of precipitation associated with front passing (e.g. Celle-Jeanton et al. 2004).

キーワード：梅雨前線、水安定同位体、雲解像モデル
Keywords: Baiu front, stable water isotopes, cloud resolving model

トゥファ年輪$\delta^{13}C$に基づく火山活動の評価
A possibility of annually-laminated tufa $\delta^{13}C$ record as a reflection of volcanic activity

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浅間火山は日本列島で最も活動的な火山のひとつであり、山体とその周辺には多くの湧水が存在する。山体南麓に位置する濁川源泉は高濃度の鉄質炭酸泉からなり、1180年の大噴火の際に生じた追分火砕流堆積層を侵食しながら流れ下っており、その河床には方解石を主体とする縞状堆積物（トゥファ）が沈積している。また、濁川の段丘涯中にも、過去に河床で生成された古トゥファが埋没する。トゥファは一般に、石灰岩地帯の沢や湖沼などの淡水環境で生成されており、その縞状組織は水の化学成分、水温や降水量などの季節変動を反映することが知られている（Ihelnfeld et al. 2003; Kano et al., 2003）。我々は、活火山の湧水から湧出した沢で初めて確認されたトゥファの形成過程とそこに記録される情報を解明するために、水文調査と同位体及び化学組成の分析を行っており、本発表ではこれまでの研究結果を報告する。

調査地域は、濁川の鉄質炭酸源泉群から下流約4 kmの範囲である。その河床には、源泉群付近から下流約1 kmで水酸化鉄、そこから下流約3 kmでトゥファがそれぞれ堆積している。我々は、源泉群（2地点）、水酸化鉄の沈殿場（1地点）、トゥファ堆積場（3地点）、非堆積場（1地点）の定点観測点を7地点設け、2011年12月～現在にかけて2ヶ月ごとの観測を行っている。現地では、採水及び水質測定（pH, ORP, DO, EC, 水温、アルカリ度）を行い、水の陽イオン濃度と陰イオン濃度の分析結果をもとに方解石の飽和度指数と*PWP-rate*（方解石沈殿速度）が求められた。また、河川水と天水の安定同位体比（δD_w, $\delta^{13}C_w$, $\delta^{18}O_w$）、トゥファ試料の安定同位体比（$\delta^{13}C_c$, $\delta^{18}O_c$）、水とトゥファの放射性炭素同位体比（$\Delta^{14}C$）分析、EPMAを用いたトゥファの化学組成分析が行われた。

濁川の水の$\delta^{18}O_w$とδD_wは源泉からトゥファ堆積場にかけて季節によらず誤差範囲内で一定に推移する（$\delta^{18}O_w$=-12.9~-12.2‰, δD_w=-90.0~-86.1‰）。その$\delta^{18}O_w$-δD_w関係は天水線上に分布し、天水に比べて狭い範囲（$\delta^{18}O_w$=-12.9~-12.2‰, δD_w=-90.0~-86.1‰）に分布することから、山体内部でよく混合された水が源泉から湧出しているとみなすことができる。

トゥファ年輪方解石$\delta^{13}C_c$・$\delta^{18}O_c$は共に、Mgに富む夏季の縞では相対的に低い値（$\delta^{18}O_c$=-10.1‰, $\delta^{13}C_c$=-6.5‰）、Mnに富む冬季の縞では高い値（$\delta^{18}O_c$=-9.2‰, $\delta^{13}C_c$=-7.0‰）を示す。トゥファ$\delta^{18}O_c$で見られる季節変動は、$\delta^{18}O_w$が時間的空間的にほぼ一定であることから、水温効果で生じているとみなされる（$\delta^{18}O_C$ - $\delta^{18}O_W$ = -0.0051T + 3.2509; R = 0.75）。Zheng (1999)に基づく$\delta^{18}O_c$から推定される年平均水温は、エルニーニョ発生年の2003年と2010年で増加が認められた。

トゥファ堆積場における$\delta^{13}C_w$起源を求めるために、河川水$\delta^{13}C_w$、DIC濃度、$\Delta^{14}C$をもとに炭素収支計算を行った。結果、トゥファ堆積場では夏季に有機物由来の炭素付加の増加が見られ、有機物付加がトゥファ$\delta^{13}C_c$増減を決めていると推察される。さらに、そうした$\delta^{13}C_c$の季節変動幅（年間の最大と最小値幅）は0.57‰（平均5.6‰）であるとのに対し、2004年晩夏に顕著な低値（$\delta^{13}C$=4.8‰）と$\delta^{18}O_c$増加（水温低下）が認められた。浅間火山では2004年9月に中規模噴火が生じており、トゥファ$\delta^{13}C_c$で見られた低値は山体内部の活動度の上昇で火山性起源の水の供給が一時的に増加したものと見なされる。

キーワード：トゥファ、安定炭素同位体、安定酸素同位体

Keywords: Tufa, δ13C, δ18O

鍾乳石中に流体包有物として保存された過去の水の同位体比分析

Isotope analysis of past drip water preserved as fluid-inclusions in stalagmites

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過去の気候復元の研究では、ウラン-トリウム法によって絶対年代が測定できる鍾乳石は重要な記録媒体である。気候変動のプロキシとしては、$CaCO_3$の酸素同位体比（$\delta^{18}O_c$）が広く用いられている。しかし、$\delta^{18}O_c$は、二つの変数（滴下水の酸素同位体比（$\delta^{18}O_w$）と生成時の気温）に支配されており、定量的解釈が困難なことが多い。

鍾乳石の流体包有物は、この点を解決する有望なプロキシとして注目されている。流体包有物とは、滴下水が結晶中の微小な空隙に保存されているものであり、過去の洞窟内の滴下水は、過去の地下水といえる。高湿度の洞窟内においては包有された時点での酸素同位体比（$\delta^{18}O_w$）は、元の滴下水の同位体比を保存していると考えられる。

鍾乳石の流体包有物は、分析手法上の困難さからあまり研究が進まなかったが、近年開発された分光式の同位体比分析計によって研究開発が活発化している(e.g., Affolter et al., 2014; Arienzo et al., 2013)。我々のグループも、流体包有物中の水の水素・酸素安定同位体比を測定する手法を開発した(Uemura et al., 2016)。必要試料量は20-300ナノリットルであり、高感度かつ高精度である。発表では、沖縄県の鍾乳石に適用した結果を中心に最近の研究成果を紹介する。

Affolter et al., (2014) *Clim. Past*, 10, 1291–1304.
Arienzo et al., (2013) *Rapid Commun. Mass, Spectrom.* 27, 2616–2624.
Uemura et al., (2016) *Geochim. Cosmochim. Acta*, 172, 159-176, doi:10.1016/j.gca.2015.09.017

キーワード：安定同位体、鍾乳石、流体包有物
Keywords: stable isotope, speleothem, fluid inclusioon

Controls on the isotopic composition of surface water and groundwater and hydrologic implications in the mid Merced River basin, Sierra Nevada, California, USA

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Isotopic composition in stream water, springs, groundwater, and precipitation was examined to understand the controls on the spatiotemporal variability from 2006 to 2008 in the mid Merced River basin (1,873 km^2), Sierra Nevada, California. Mean isotopic values in small tributaries (basin area < 122 km^2), rock glacier outflows and groundwater were correlated with mean basin elevation ($n = 16$, $p < 0.001$), suggesting an isotopic lapse rate of -1.9‰/100 m for δ^2H and -0.22‰/100 m for $\delta^{18}O$ in meteoric water. Evaporation had little effect on the isotopic signature of precipitation, springs, and groundwater, but affected stream water during low flows in summer and fall. The isotopic composition in stream water in the Merced River was most depleted during snowmelt. However, the isotopic composition-elevation relationship in tributaries and the Merced River did not vary much over seasons. A basin-characteristic isotopic value was established for each basin based on the relation between isotopic composition and the mean basin elevation to elucidate hydrometeorologic processes over seasons. It is suggested that flow and flow duration of Yosemite Creek are most sensitive to temperature increase due to its strong evaporation. Based on the isotope-elevation relation, groundwater in Yosemite Valley was recharge from the upper snow-rain transition zone (2,000-2,500 m), suggesting its strong vulnerability to temperature increase, shift in snow-rain ratio and the earlier onset of snowmelt. The information helps advance our understanding of hydrologic responses to climate change in snowmelt-fed river systems in the U.S. West.

Keywords: Stable isotopes, Isotopic lapse rate, Snow-rain transition, Merced River

Reanalysis, Stable Isotopes and the Age of Water: Improving Constraints for Model Identification at a Critical Zone Observatory

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This paper presents a hydrologic model for an upland catchment constrained by climate observations and stable isotopes of oxygen and hydrogen at the Susquehanna/Shale Hills Critical Zone Observatory (SSH_CZO).

Model forcing uses NLDAS-2 reanalysis time series for daily weather forcing and IsoRSM regional atmospheric model (isotope-incorporated regional spectrum model) for simulating stable isotopes in precipitation and water vapor at 10 km x 10 km spatial resolution. The regional model is developed through a dynamical downscaling technique that applies the results of the global simulation and a spectral nudging technique to produce the higher resolution data (Kei Yoshimura & Kanamitsu, 2008). The regional model results were compared to 4 years of daily sampled stable isotope data in precipitation at the SSH/CZO and good agreement is found, extending the precipitation isotope data to the full reanalysis period (1979-2014).

The paper next develops the theoretical basis for simulation of flow, isotope ratios and “age” as water moves through the canopy, to the unsaturated and saturated zones and finally to an intermittent stream. The model formulation demonstrates that the residence time and age of environmental tracers can be directly simulated without knowledge of the form of the underlying residence time distribution function and without the addition of any new physical parameters.

The model is then used to explore the rapid attenuation of event and seasonal isotopic ratios in precipitation over the depth of the soil, and the impact on streamflow and stream isotope ratios. The results suggest the importance of mobile macropore flow on recharge to groundwater during the non-growing cold-wet season. The soil matrix is also recharged during this season with a cold-season isotope signature on recharge and baseflow. During the growing (dry) season, root uptake and evaporation from the soil matrix along with a declining water table determines the growing season isotope signature.

The paper concludes by illustrating how system memory, age and residence time estimation can be used to constrain the model through sensitivity analysis of parameters as a function of mean isotopic age.

Keywords: catchment hydrology, stable isotopes , dynamical model, isotopic age of water

An improved analytical method for determining radioactive ^{35}S in water/snow samples and its applications to snow and glacier hydrology

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Cosmogenic ^{35}S is useful in understanding a wide variety of chemical and physical processes in the atmosphere, the hydrosphere and the cryosphere. The 87.4-day half-life and the ubiquity of sulfur in natural environments renders it an ideal tracer of many phenomena. For example, recent ^{35}S measurements in aerosol samples provided new insights into the vertical and horizontal transport processes in the atmosphere [1-2]. However, measurements of ^{35}S in snow and water samples remained scarce as existing analytical methods required a large volume of sample (>20 L) due to their high analytical activity background and low counting efficiency [3-4]. Here, we present a new set of snow/water sample collecting and handling procedures for high-sensitivity determination of cosmogenic ^{35}S using an optimized low-level liquid scintillation spectrometer technique [5]. The counting background and efficiency of this technique were ~0.9 counts per minute and ~78%, respectively, and therefore we can easily analyze water samples as small as ~2 L, ~10 times smaller than previous methods. Laboratory experiments using diluted ^{35}S standards (with activities of <5 disintegrations per minute) showed a ^{35}S recovery percentage of ~95%, demonstrating a relatively small deviation from the true value. This new method will provide a powerful tool in studying ^{35}S in small volumes of snow and water samples, especially those from remote but climatically important regions such as the polar regions and the Tibetan Plateau and Himalayas (also known as the Third Pole). The measurements are particularly important as the radioactive sulfur provides an actual clock of glacial melting processes. With the growing rate of glacial loss, the need for measurements from remote locations becomes all the more important. Using this method, we successfully measured ^{35}S in ~1 L of fresh snow sample collected from a glacier on the Tibetan Plateau (Laohugou Glacier No.12; 39˚05’-40’ N, 96˚07’-97˚04’ E; 4260–5481 m above sea level) to be 47±7 mBq/L. We point out that the precision can be easily improved by collecting relatively larger amounts of samples (e.g. ~3 L) and measuring samples as soon as possible. Based on ^{35}S activities in 9 natural samples (fresh and aged snow, ice, runoff) made in this pilot study, a first proof-of-concept approximation for age determinations and source attributions will be presented. Along with water stable isotope measurements (dD and $d^{18}O$), our ^{35}S measurements may assist in quantifying snow melting rates. More samples (n>100) collected from Laohugou Glacier No.12 and other three glaciers across the Tibetan Plateau and Himalayas (East Rongbuk Glacier at Mount Everest, Xiao Dongkemadi Glacier at Tanggula Range and Baishui Glacier No.1 at Mount Yulong) during 2015-2016 are being measured and will be reported. We anticipate that these results will provide deeper insight into snow/glacier melting processes over the Tibetan Plateau and Himalayas.

References:
[1] Lin, M., et al. (2016). PNAS, 113(40), 11131–11136.
[2] Priyadashi, A., et al. (2011). PNAS, 108(35), 14422–14425.
[3] Hong, Y. and G. Kim (2005). Anal. Chem., 77, 3390-3393.
[4] Uriostegui, S., et al. (2015). Anal. Chem., 87, 6064-6070.
[5] Brothers, L., et al. (2010). PNAS, 107(12), 5311-5316.

Keywords: Sulfur isotopes, Cosmogenic nuclides, Snow melt, Glacier retreat, Cryosphere, Tibetan Plateau and Himalayas