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Support Geoscience Research, Environmental Management, and Engineering Construction with Investigation and Monitoring on Permafrost in the Qinghai-Tibet Plateau, China

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Support Geoscience Research, Environmental Management, and Engineering Construction with Investigation and Monitoring on Permafrost in the Qinghai-Tibet Plateau, China

Abstract

Due to the climate warming and the implementation of China's western development strategy, the variation in permafrost has increasingly and significantly influenced the ecology, hydrology, climate, and engineering construction on the Qinghai-Tibet Plateau (QTP) during the past decades. Long-term *in-situ* monitoring and large-scale field investigation on permafrost have become a major demand for addressing key scientific and engineering issues in the cryosphere, ecology, hydrology, climate, and engineering construction in cold regions. Since the Cryosphere Research Station on Qinghai-Xizang Plateau of Chinese Academy of Sciences was established in 1987, we have conducted long-term continuous monitoring and large-scale field investigations on permafrost of the QTP, and thus synthetically studied the mechanisms of the change in hydrothermal conditions of permafrost and their simulations and ecological effects. Under the support of major programs funded by the Ministry of Science and Technology, the National Natural Science Foundation of China, and Chinese Academy of Sciences, we carried out many international cooperations actively and standardized the approaches of *in-situ* monitoring and field investigation on permafrost, and thus established the monitoring network of permafrost which is in the leading position around the world. We also quantitatively studied the spatial distribution, ground temperatures, thickness, and ground ice of permafrost on the QTP. By comparing the multi-source dataset and multi-models, we released the spatial grid dataset of ground temperatures, thickness, and ground ice of permafrost on the QTP with a spatial resolution of 1 km×1 km. Furthermore, based on the long-term monitoring dataset, we developed and improved the one-dimensional model of heat conduction and land-surface-process model for applying to the Tibetan permafrost, and thereby quantitatively estimated the variation of permafrost and its physical mechanisms on the QTP during the last three decades. Those results not only provide a basic-data support for the construction of the Qinghai-Tibet Railway, the environmental protection of the Three-River Source national park, and the regional simulation of climate but also promote decision-making services for national demands and major scientific programs. Moreover, the spatial distributions of vegetation types, soil types, and soil organic carbon and nitrogen in the permafrost regions of the QTP also fill the gaps in those aspects and provide the basic-data support for the global research programs of the future Earth and the development of the Earth system models.

Keywords

Qinghai-Tibet Plateau (QTP); permafrost; investigation; monitoring; ground ice; carbon cycle

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Geocryology, the Chinese Society of Cryosphere Science, the China Society on Tibet Plateau, and the Chinese Association for Quaternary Research. He has more than 130 scientific publications, including approximate 60 journal papers indexed by the *SCI* and 7 monographs or book chapters. He was a contributor author of the Working Group I of the Intergovernmental Panel on Climate Change (IPCC) Fourth and Fifth Assessment Reports, and was awarded the national outstanding field-scientific and technological workers, the Ministry of Science and Technology. His major contributions include: establishing the monitoring network of permafrost on the Qinghai-Tibet Plateau (QTP), ascertaining the spatial distributions of permafrost, ground ice, soil types, vegetation types, soil organic carbon, and soil total nitrogen on the QTP, building the spatial database of permafrost on the QTP, revealing the spatial variation of permafrost in the high-altitude regions of the central Asia, elucidating the hydrothermal coupling and biogeochemical processes of the active layer thickness during the freezing and thawing processes and their physical mechanisms, and predicting the variation of the QTP permafrost and its potential feedback to climate change based on the land-surface-process models and permafrost models. These key findings were founded by the State Key Programs and General Projects of the National Natural Science Foundation of China, the Special Program for Key Basic Research of the Ministry of Science and Technology, China, the National Key Basic Research of the Ministry of Science and Technology, China, the Key Program of CAS, and the National R&D Infrastructure and Facility Development Program of China. E-mail: linzhao@lzb.ac.cn

多年冻土调查和监测为青藏高原 地球科学研究、环境保护和 工程建设提供科学支撑



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摘要 随着我国西部大开发战略的实施和气候变暖对青藏高原影响的日益显著，多年冻土变化对生态、水文、气候和工程建设的影响日渐突出，多年冻土的长期定位监测和大范围野外调查已经成为冰冻圈、生态、水文、气候和寒区工程建设等方面深化研究和解决重大科学和工程问题的重大需求。中科院青藏高原冰冻圈观测研究站（简称“高原冰冻圈站”）自建站以来对青藏高原多年冻土进行了长期连续的监测和大范围的野外调查，开展了多年冻土水热状况的变化机理、模型模拟和生态效应综合研究。特别是近年来在科技部、国家自然科学基金委和中科院等重大项目支持下，高原冰冻圈站积极开展国内外科研合作，规范了多年冻土野外考察和定位监测的方法，建成了在国际上处于领先地位的多年冻土综合监测网络；系统地开展了高原多年冻土分布、温度、厚度和地下冰空间分异规律的定量研究，基于多源数据和多模式比对，发布了空间分辨率为1 km的高原多年冻土温度、厚度和地下冰的空间格网数据。基于长期监测数据，构建和改进了适合于青藏高原多年冻土的一维热传导模式和陆面过程模式，定量评价了过去30年来高原尺度多年冻土的变化及物理机制。这些科研成果不仅为青藏铁路建设、三江源国家公园生态保护、区域气候模拟等问题的解决提供了强有力的基础数据支撑，同时也面向国家需求和国家重大项目研究，推动决策咨询服务。有关青藏高原多年冻土区植被、生态和土壤有机碳氮空间分布的研究成果，填补了该领域的国际空白，为未来地球国际科学研究计划和地球系统模式发展提供了最为基础的本底数据支撑。

关键词 青藏高原，多年冻土，调查，监测，地下冰，碳循环

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经过2亿多年间数次构造运动的作用，青藏高原从平均海拔低于海平面的“特提斯海”

逐渐隆升,成为全球中低纬度地区海拔最高的高原,气候也由温暖湿润逐渐转变为整体严寒干旱,多年冻土也随着海拔的升高和气候的变冷而逐渐形成。人类现有的认识水平还没能确切地给出青藏高原的多年冻土到底是在什么时候和什么地点开始发育,但距今2万多年前的末次冰盛期时,高原的85%地表下发育着多年冻土,多年冻土面积至少可达220万平方公里^[1]。之后,随着气候波动转暖,到全新世最适宜期时,高原多年冻土的分布面积退缩到最小范围。总体而言,自晚更新世以来,青藏高原多年冻土呈现总体萎缩状态。现有多年冻土的发育是以高原主体为主,呈现大片连续状分布,向周边山体逐渐转变为辐射状不连续的“镶边”模式。高原主体的大片连续多年冻土的东部从阿尼玛卿山脉开始,一直向西延伸到喜马拉雅山脉西部和喀喇昆仑山脉西坡;南部从唐古拉山脉南坡开始,向北到昆仑山北坡结束。而“镶边”的多年冻土以“帽状”覆盖于高原周边的高山顶部,主要发育于北部的祁连山脉,东部的阿尼玛卿山脉和横断山脉,南部和西部的念青唐古拉、冈底斯和喜马拉雅山脉,平面上呈现不连续和岛状的环带状围绕在高原主体周边。

青藏高原以其海拔高、面积大而被称为世界“第三极”,通过其热力和机械强迫作用,对区域气候和全球环境产生重大影响,是我国气候变化的“敏感区”和“启动区”,以及全球变化的“驱动机”和“放大器”。目前,青藏高原多年冻土面积达106万平方公里^[2],是全球中低纬度地区海拔最高、面积最大的多年冻土分布区,在世界冻土分布中占有重要的位置^[1]。过去50余年来,青藏高原变暖的趋势明显,升温趋势可能还会继续。青藏高原多年冻土出现温度升高、活动层厚度增厚、范围萎缩,厚度减薄的趋势^[3]。这些变化无疑会对多年冻土区地下冰和有机碳的形成、存储环境,对多年冻土区地表的水、土、气、生等要素间的相互作用关系产生影响,进而影响到区域水文、生态乃至全球气候系统。同时,这些变化也会影响到人类工程活动及区域

可持续发展。中科院青藏高原冰冻圈观测研究站(简称“高原冰冻圈站”)的建立主要是着眼于对多年冻土的独特特征、过程、变化及其影响的长期监测和研究,为青藏高原的地球科学研究和生产实践积累基础数据资料 and 提供理论支撑。建站30年来,构建了迄今为止世界上最完善的多年冻土监测网络,取得了大量宝贵的监测和第一手调查资料,开展了多年冻土及与多年冻土相关的地球系统科学研究。

1 构建了青藏高原多年冻土监测网络,为高原地球系统研究、环境保护和重大工程建设奠定了坚实的数据基础

受高寒、缺氧、交通不便等诸多因素的影响,青藏高原成为全球地球科学类数据最为贫乏的地区之一,而平均海拔高度4500米以上的多年冻土区的数据稀缺程度尤甚,突出表现为各类地球系统模式所需要高精度的强迫和验证数据的短缺,这极大地限制了有关青藏高原地球系统科学的研究水平。

从1987年建站到1997年的10年间,高原冰冻圈站主要通过横向生产性项目的支持,在解决当地交通部门和部队建设的生产实践问题的同时,艰难地维护了沿青藏公路西大滩至五道梁段建立的4个浅层多年冻土温度监测孔(最大监测深度30米)和一个人工观测的边界层梯度气象塔^[4],首次取得青藏高原腹面连续的多年冻土地温资料。

1990年到21世纪初,通过国际合作项目外方经费的支持,高原冰冻圈站完成了对青藏公路沿线5个活动层水热监测场和3个自动梯度气象站的建设,形成了最初集气象、活动层水热和多年冻土温度为一体的多年冻土监测系统,由此所获得的观测资料不仅为青藏公路的维护和正常使用提供了科学支撑,也成为后来青藏铁路建设多年冻土路基稳定性划分、基础设计和施工的主要依据;同时也基本满足了陆面过程模式单点模拟数据要求,促进了高原多年冻土区地表能水过程的模拟。

2009年开始,重点依托科技部基础性工作专项“青藏高原多年冻土本底调查”项目,同时集成中科院和国家自然科学基金委各类科研和建设经费的支持,在完成编纂野外调查、定位监测方法和规范^[5]的同时,先后建立了西至喀喇昆仑山,东至阿尼玛卿山,北自祁连山和阿尔金山北坡,南至冈底斯山南坡范围内,基本覆盖青藏高原主体的多年冻土监测网络;更新和完善了20世纪80—90年代在新疆乌鲁木齐河源和甘肃榆中县马街山建立的多年冻土监测系统。观测区跨越甘肃、青海、西藏和新疆4省份,平均海拔高度4500米以上,观测场点达130多个(图1),包括10个3—4层梯度综合气象站、5套涡动相关观测系统、20个活动层水热观测点和100个多年冻土温度观测钻孔。除多年冻土温度观测孔没能完全实现全自动观测之外,其他观测均实现了全自动记录。观测内容包括气象要素、地表能水平衡过程、活动层水热特征、多年冻土地温、多年冻土区温室

气体排放、土壤碳氮循环过程以及在地表生态、水文环境相关的其他要素等,形成了天-地-空一体化的观测体系。观测站点大多位于之前无任何观测资料的地区,弥补了高原各类监测站点稀少的不足,极大地提高了观测资料对青藏高原高海拔地区的覆盖水平。

高原冰冻圈站的观测站点先后成为国际环北极活动层监测网络(CALM)、国际多年冻土地温观测网络(GTN-P)和全球冰冻圈观测网络(GCW)的重要组成部分。高原冰冻圈站的观测方法、规范和观测场点被GCW作为多年冻土观测的标准向世界推荐。高原冰冻圈站的观测资料一年一度在中国气象局主编的《中国气候变化公报》以及由美国 and 英国气象主管部门主编的《全球气候公报》(State of the Climate)上发布,为青藏高原气候、水文和生态系统科学研究以及重大工程建设提供了数据支撑。

长期监测资料和典型区调查表明,青藏高原地区的

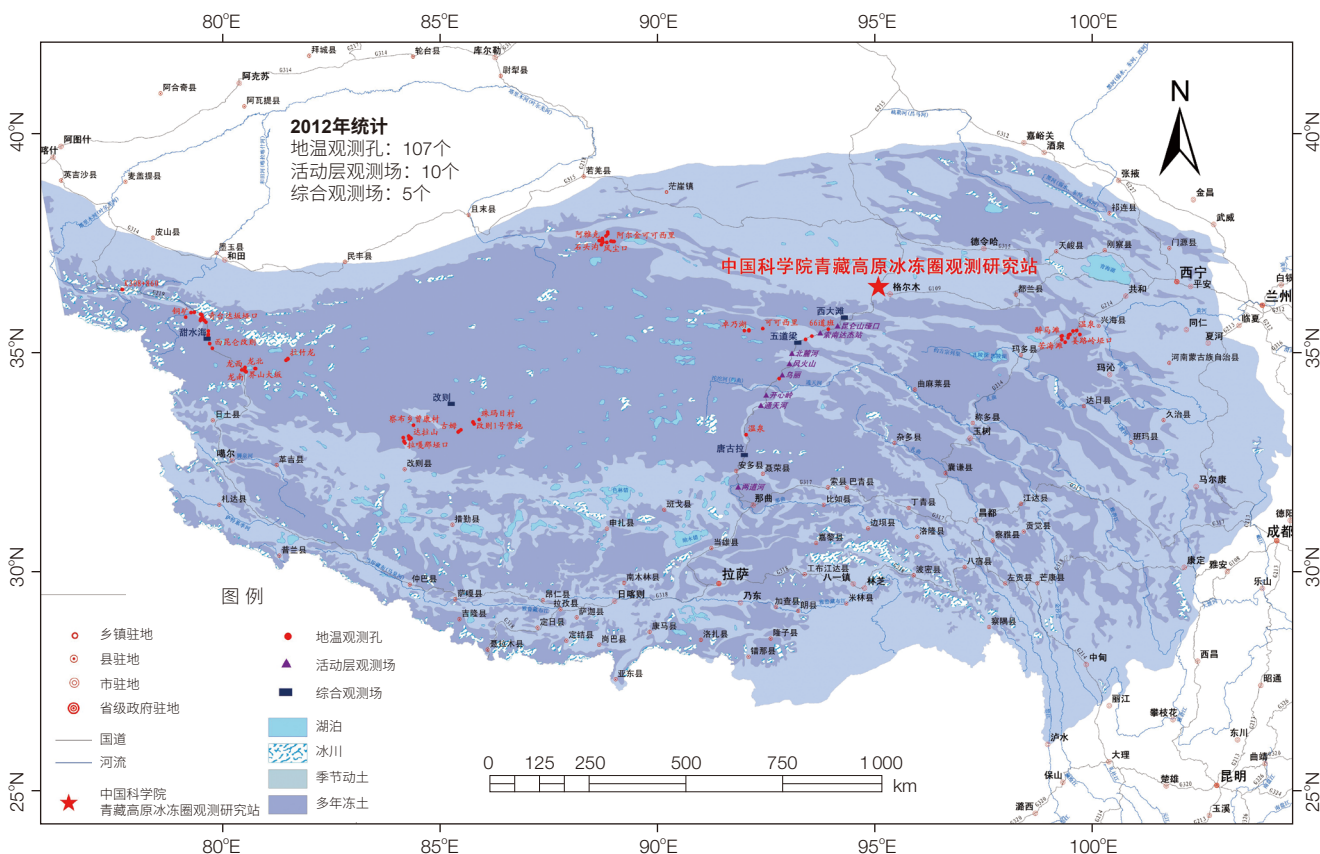


图1 中科院青藏高原冰冻圈观测研究站观测站点分布图

多年冻土大部分属于年平均地温高于 -1.0°C 的高温冻土,平均地温低于 -2.0°C 的多年冻土仅分布在部分高山区^[3,6]。相对于低温冻土,高温冻土以其升温变化过程复杂,对区域环境和工程建设影响显著而受到广泛关注。高原冰冻圈站利用连续的高精度监测资料对活动层和多年冻土本身的水热动态变化过程进行了深入分析,首次将活动层季节冻融循环过程区分为4个阶段,并对不同阶段的水热耦合过程进行了全面阐述,深化了对冻融循环过程的理解^[7]。大量的地温监测结果表明,多年冻土内部热物理参数、地温在垂直方向的分布格局以及地表输入的能量在不同深度的分配比率均发生着连续的变化。冻土的升温将导致地温年变化深度和土壤热扩散率的减小,促进多年冻土的自上而下退化(活动层厚度增大)^[6]。这些监测研究成果合理地解释了青藏高原地区多年冻土活动层增厚明显而地温上升缓慢的原因。观测数据和研究结果为青藏铁路/公路等重大工程建设提供了强有力的科技支持。

2 完成了对青藏高原多年冻土的本底特征及其主要影响因子的系统调查,查明了青藏高原多年冻土及主要环境背景本底

占据青藏高原陆面面积一半以上的多年冻土,在高原的气候、水文和生态系统中发挥着重要作用。长期以来,我国对于青藏高原多年冻土的研究和认识主要来源于青藏公路/铁路沿线、青康公路共和至玉树段,而高原其他地区的调查和研究基本上处于空白状态,极大地限制了有关高原地球系统科学的集成研究,也是制约青藏高原生态屏障建设方案设计、自然资源可持续利用规划和寒区工程建设规划设计的主要因素之一。自2009年开始,在科技部基础性工作专项“青藏高原多年冻土本底调查”项目的资助下,高原冰冻圈站开始了连续5年的大规模多年冻土现状调查工作,先后以青海兴海县温泉地区、曲麻莱县可可西里无人区、杂多县,西藏改则县、安多县,以及新疆阿尔金地区、西昆仑甜水海地区等为典型区,通过雷达、电磁、钻探、土壤剖面和植被

样方乃至无人机航拍等手段,对这些地区的多年冻土分布边界、厚度以及地下冰、活动层厚度、土壤、植被、气候、地质地貌和多年冻土温度等方面开展了综合调查。形成了以7个典型调查区为主、2横3纵调查线路为辅(图2),基本覆盖青藏高原腹地不同气候、地质和地貌区域的多年冻土调查网络,首次在高原腹地无人区获取了大量实地调查资料;在此基础上,综合利用多源遥感数据反演和多模式模拟比对的方法,编制了空间分辨率为1 km的典型调查区和高原尺度的多年冻土区土壤、植被图^[8-11],极大深化了对青藏高原腹地土壤、植被等本底资源信息的认识水平。

基于野外调查资料和站点监测数据,高原冰冻圈站深入研究了多年冻土温度、地下冰、厚度等多年冻土主要特征指标与气候、土壤、植被以及地质地貌背景等的关系,构建了多年冻土和活动层温度、厚度的空间分布模型。利用经过基于高原冰冻圈站实测资料纠正过的遥感地表温度数据和新编制的土壤和植被空间数据,并且采用5个典型区、3个调查剖面的多年冻土分布数据进行验证,编制了最新的、分辨率最高的“青藏高原多年冻土图”(图3)^[12]。此图不仅给出了高原多年冻土的空间分布特征,也详细刻画了多年冻土温度的空间分布信息^[12],认为青藏高原多年冻土的实际分布面积为106万平方公里,多年冻土温度主要在 -2°C — -0.5°C 。基于大量实测多年冻土厚度资料和多模式比对研究,高原冰冻圈站完成了青藏高原多年冻土厚度空间分布图的编制,结果显示,青藏高原多年冻土的平均厚度约39米,其中高山、丘陵带为60—130米,而宽广的高平原及河谷地带为数米至60米;利用遥感地表温度、土壤调查数据更新了Stefan方程的参数,对青藏高原多年冻土活动层厚度进行了模拟,结果表明,高原尺度活动层的平均值为1.9米,其中90%集中于0.9—2.7米。同时,在充分挖掘历史钻孔资料的基础上,高原冰冻圈站开展了冻土条件和地质、地貌等因素对地下冰发育规律的研究,重新评估了高原多年冻土层中的地下冰储量约为 12.7×10^{12} 立方

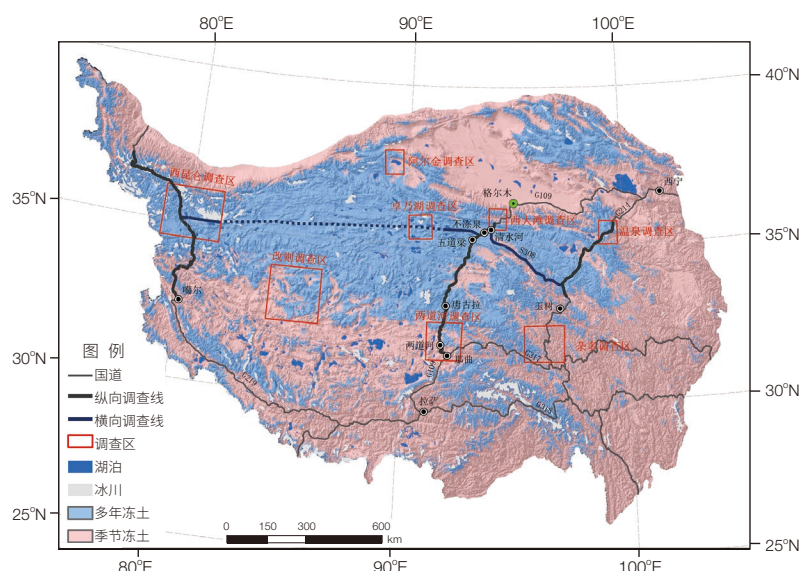
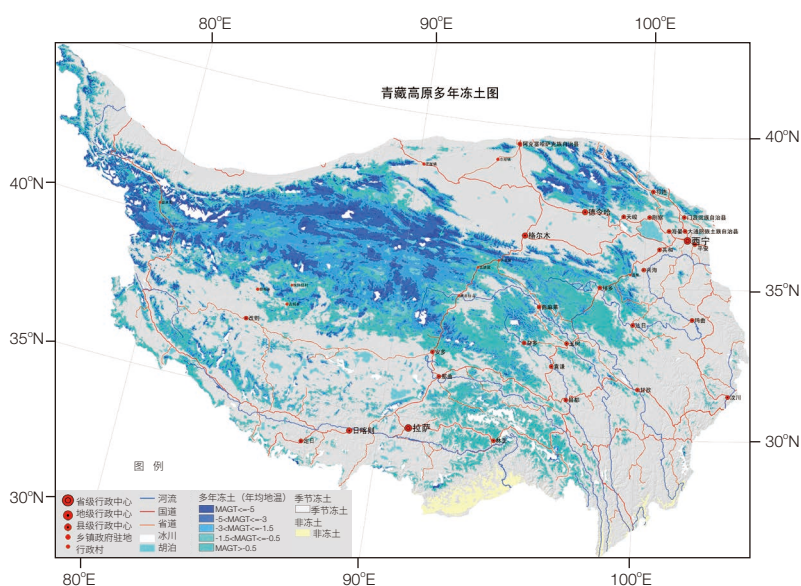


图2 青藏高原多年冻土典型调查区位置和调查线路图

图3 基于调查资料重新绘制的青藏高原多年冻土分布图^[14]

米,其中深度在10米以上的多年冻土中的地下冰储量,其值约为 2.2×10^{12} 立方米^①。

3 发展和改进了陆面过程模型,提出了冻融参数化方案,模拟了多年冻土分布和变化

高原冰冻圈站多年来的监测和研究结果表明,青藏高原多年冻土区地表能量平衡过程表现为夏季和秋季潜热占主导地位,而冬季和春季感热占主导地位的特征。多年冻土区

活动层的冻融过程和季风降水是导致地表蒸发潜热较非多年冻土区大的主要原因^[13],主要表现为每年4月中下旬开始,活动层表层开始发生日冻融循环;到5月中下旬,表层土壤完全融化,融化锋面之下的冻结层阻滞了液态水向下渗透;5月份之后随着高原印度季风和西风的增强,降水增多,表层土壤的含水量较大,增加了地表潜热的输出;到9月活动层达到最大融化深度,印度季风和西风也基本退出高原,通过降水补给的地表水分迅速减小,潜热开始减小。

通过现场监测和研究表明,青藏公路沿线可可西里、北麓河、开心岭、通天河等地区,冻结状态下浅表层土壤导热率均表现出较融化状态下小的特点^[14-17]——高原腹地五道梁干寒草原区浅层土壤非冻结条件下的导热率是冻结条件下的1.81倍^[18]。非冻结条件下导热率与冻结条件下导热率比值的大小与下垫面类型密切相关,该比值在荒漠草原最大,退化草甸次之,草甸较小^[17]。基于上述研究结果,高原冰冻圈站的科研团队开创性地获得了青藏高原土壤饱和度和孔隙度、含冰量等重要而难以测定的动态参数,并研究了诸热力特征参数变化的物理机制,初步建立高原地区典型地段的土壤热参数统计模型,为较准确的预报青藏高原气候与冻土变化趋势及速度提供了热力学参数。

为深入探讨气候变化对青藏高原多年冻土的影响,高原冰冻圈站依托大气-植被-多年冻土综合监测系统,根据实地观测结果对SHAW、CoLM、NOAH、SIB2和CoupModel等陆面过程模式中土壤未冻水含量、热物理特性、地表粗糙度、反照率等参数化方案进行了系列改进,并针对多年冻土的特点,把模拟深度由2—4米扩展到15—17米,改进后的模型能够较好地模拟青藏高原多年冻土活动层水热过程及地气能水交换过程^[16,19-21];随后,利用改进后的模式模拟了过去30年来整个青藏高原冻土空间分布变化的时间序列。结果表明,青藏高原多年冻土面积缩减速度滞后于气候变暖的速率,这与沿青藏公路沿线的实测结果一致(图4)^[11]。

① 赵林,盛煜,等,编著. 青藏高原多年冻土及变化. 北京: 科学出版社,待出版

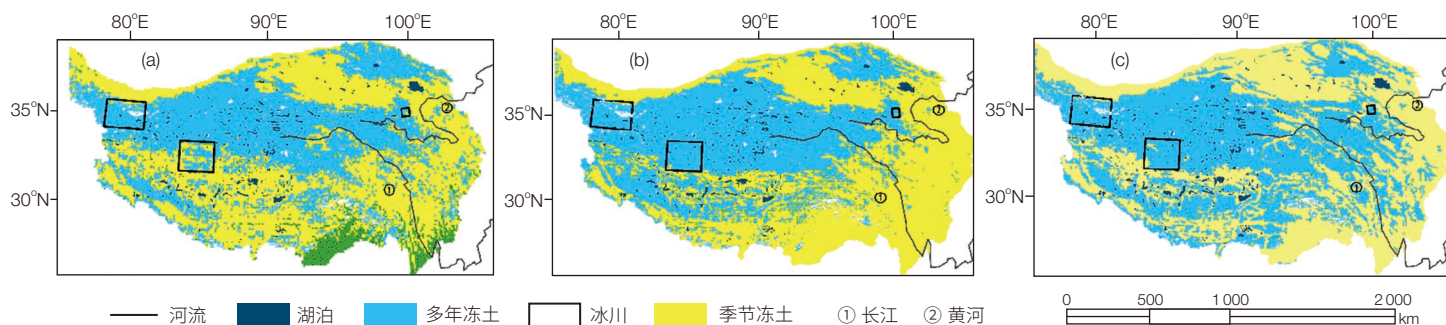


图4 模拟的青藏高原多年冻土分布图^[11]

(a) 基于改进的 Noah 模型模拟的多年冻土分布图；(b) CHINA2005 多年冻土分布图；(c) QTP1996 多年冻土分布图

4 定量评估了青藏高原多年冻土区碳的源汇效应

为查明青藏高原多年冻土区土壤有机碳库的储量和源汇效应，自 2003 年开始，高原冰冻圈站在青藏高原多年冻土区展开了较大范围的土壤有机碳分布和组成调查及研究，系统分析了土壤有机碳、氮与土壤质地、土壤理化性质以及相关气候、植被、地质、地貌等因素间的关系，发表了系列研究成果^[22-29]。通过数理统计、数值模拟等手段第一次给出了土壤剖面中不同深度（0.5 米、1 米和 2 米）的有机碳密度的空间分布网格数据（图 5）^②，结果显示，青藏高原多年冻土区表层 2 米

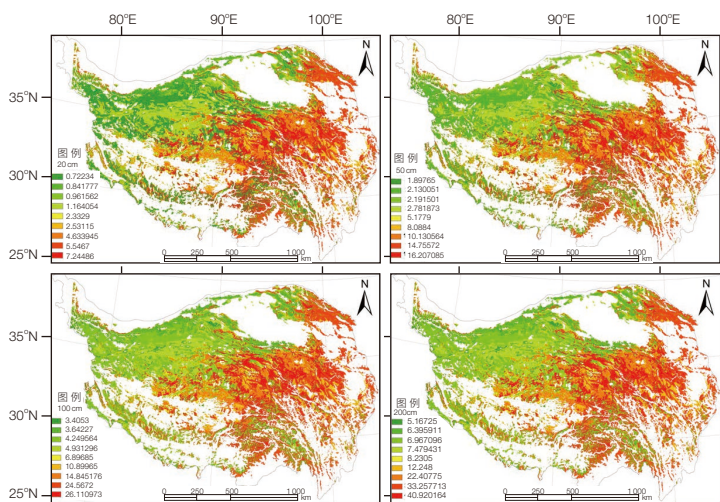


图5 基于调查资料绘制的青藏高原多年冻土区土壤有机碳分层密度分布图

② 赵林, 盛煜, 等, 编著. 青藏高原多年冻土及变化. 北京: 科学出版社, 待出版

深度内土壤有机碳储量约为 25.37 Pg (1 Pg=10¹⁵ g)，总氮储量为 2.40 Pg。在青藏高原西部干旱地区，多年冻土和非多年冻土区土壤碳、氮的含量差异不显著^[24]，但是多年冻土区的土壤碳氮比高于非多年冻土区^[25]。在青藏高原东部，沼泽草甸的土壤碳、氮和养分含量最高^[26,27]。整体上，降雨的差异是导致青藏高原东西部土壤中有机碳含量和总氮差异的主要原因；而在局地范围内，土壤碳、氮含量的决定因素是土壤质地和活动层厚度^[28]。

研究表明，土壤有机碳中活性碳组分的含量随土壤水热条件变化而发生着明显的季节变化，非多年冻土区表层土壤中酶的活性要较多年冻土区强，有机质的循环强度也比多年冻土区大；土壤微生物群落组成也与有机碳含量和土壤的酸性密切相关。这说明在气候变暖背景下，伴随着土壤升温，活动层增厚和表层土壤水分含量的减少，有机碳的分解和温室气体排放的潜力较大^[30-35]，非多年冻土区的酶活性较强，表明有机质的循环强度比多年冻土区大^[34]。

多年冻土区碳通量和循环过程的监测结果表明，青藏高原多年冻土区目前主要表现为弱的碳汇，土壤呼吸与活动层厚度密切相关，活动层较厚地区植被的生物量较小，但土壤呼吸仍然很高^[36]，即使是在非多年冻土区，土壤呼吸速率同样较高，这表明多年冻土退化后可能加速土壤有机碳的分解^[37]。热融滑塌是多年冻土退化的典型冰缘现象。监测结果表明，热融滑塌可以促进表层土壤由碳汇向碳源转变，而土壤甲烷的排放量却表现出减小趋势^[38]。

5 结语

中科院青藏高原冰冻圈综合观测研究站建站30年来,围绕青藏高原冰冻圈系统各要素的变化、机理及影响等方面开展了长期、系统的监测和试验研究,承担了大量的国家级项目,通过一系列项目的实施,构建了迄今为止国际上最完善的多年冻土监测网络,取得了丰富的监测和第一手调查资料。高原冰冻圈站的大部分观测站点位于自然条件恶劣的无人区,定位监测获取的气象数据和环境数据,填补了这些地区气候环境资料空白,成为高原上开展相关研究的第一手资料。基于实测资料,首次给出了包含以往数据空白区的青藏高原地区多年冻土的分布格局,首次绘制了基于美国土壤分类标准的青藏高原地区土壤分类图,给出了青藏高原地区植被分布图,并估算了青藏高原多年冻土区地下冰储量及多年冻土区土壤有机碳含量。系统研究了多年冻土区冻融循环过程的不同阶段活动层土壤的水热动态变化机制;并在此基础上,改进了经典的冻土模式,量化了冻融过程中非相变热,确定了青藏高原陆面 Bowen 比出现负值时积雪厚度的阈值,发现了活动层冻结条件下导热率较小的反常现象。相关的研究结果为三江源自然环境保护、青藏高速公路、部队建设提供服务,为青藏高原的地球科学研究和生产实践积累基础数据资料 and 提供理论支撑。

高原冰冻圈站的研究结果得到了国际同行的认可。自2011年开始,青藏高原多年冻土变化研究成果连续7次在《全球气候公报》(*State of the Climate*)上发布;并于每年7/8月,在《美国气象学会通报》(*Bulletin of the American Meteorological Society*)以特辑形式发表。改进的冻土模式作为子模块被加拿大的寒区水文模型 CRHM 使用,同时研究结果被政府间气候变化专门委员会(IPCC)多次引用。监测网络也被纳入了全球多年冻土地温监测网络(GTN-P)、环北极活动层监测网络(CALM)和世界气象组织的全球冰冻圈监测网络(WMO-GCW)重要组成部分和标准野外站。另外,高原冰冻圈站有机碳氮调查结果和冻土区碳排放的研究结果,为深入分析多年冻土变化

对全球气候变化的反馈作用提供了证据。

毫无疑问,高原冰冻圈站已经成为青藏高原多年冻土和冰冻圈环境相关基础数据的主要生产基地、全球多年冻土研究的野外基地以及冰冻圈科学人才的培养基地,已在国际上产生了广泛的影响。目前,高原冰冻圈站正在完善冰冻圈研究体系和观测体系,补充无人区的监测,加强无人机的区域实时监测;同时注重人才的培养和人员的培训工作,严格规范管理,以期更进一步提高站上科研人员的科研能力、协作能力、创新能力,以及野外科研平台的管理能力,努力建成国际一流的多年冻土观测及研究平台。

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Support Geoscience Research, Environmental Management, and Engineering Construction with Investigation and Monitoring on Permafrost in the Qinghai-Tibet Plateau, China

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Abstract Due to the climate warming and the implementation of China's western development strategy, the variation in permafrost has increasingly and significantly influenced the ecology, hydrology, climate, and engineering construction on the Qinghai-Tibet Plateau (QTP) during the past decades. Long-term *in-situ* monitoring and large-scale field investigation on permafrost have become a major demand for addressing key scientific and engineering issues in the cryosphere, ecology, hydrology, climate, and engineering construction in cold regions. Since the Cryosphere Research Station on Qinghai-Xizang Plateau of Chinese Academy of Sciences was established in 1987, we have conducted long-term continuous monitoring and large-scale field investigations on permafrost of the QTP, and thus synthetically studied the mechanisms of the change in hydrothermal conditions of permafrost and their simulations and ecological effects. Under the support of major programs funded by the Ministry of Science and Technology, the National Natural Science Foundation of China, and Chinese Academy of Sciences, we carried out many international cooperations actively and standardized the approaches of *in-situ* monitoring and field investigation on permafrost, and thus established the monitoring network of permafrost which is in the leading position around the world. We also quantitatively studied the spatial distribution, ground temperatures, thickness, and ground

ice of permafrost on the QTP. By comparing the multi-source dataset and multi-models, we released the spatial grid dataset of ground temperatures, thickness, and ground ice of permafrost on the QTP with a spatial resolution of 1 km×1 km. Furthermore, based on the long-term monitoring dataset, we developed and improved the one-dimensional model of heat conduction and land-surface-process model for applying to the Tibetan permafrost, and thereby quantitatively estimated the variation of permafrost and its physical mechanisms on the QTP during the last three decades. Those results not only provide a basic-data support for the construction of the Qinghai-Tibet Railway, the environmental protection of the Three-River Source national park, and the regional simulation of climate but also promote decision-making services for national demands and major scientific programs. Moreover, the spatial distributions of vegetation types, soil types, and soil organic carbon and nitrogen in the permafrost regions of the QTP also fill the gaps in those aspects and provide the basic-data support for the global research programs of the future Earth and the development of the Earth system models.

Keywords Qinghai-Tibet Plateau (QTP), permafrost, investigation, monitoring, ground ice, carbon cycle

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