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对人观测的理论、技术与应用进展

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摘 要:对人观测是由来已久的基础应用需求,现代信息通讯技术发展所带来的大数据普及化,大大促进了对人观测理论、技术与应用的进步,也大幅深化了测绘、遥感、地理、城市科学等多学科交叉融合。在理论进展方面,主要体现在人群感知、特征度量、效应观测这3个层次上,特别地,以群体时空过程为视角的系统化表达、建模与演化等方面理论,具有基础性、多态性、系统性等特征,符合以人为本的理论发展趋势。在技术进展方面,主要体现在人群多源感知、时空特征智能计算、时空效应分析应对等层次上的技术进步,特别是以时空GIS和人工智能技术为代表的感知技术、平台技术、决策技术等,具有较好的通用性和适应性,符合地理空间人工智能的技术趋势与特点。在应用进展方面,对人观测技术显著应用在城市内和城市之间的多个行业领域,如公共安全、智能交通、社会治理、生命健康、城市群发展、乡村振兴等邻域平台和服务系统,从复杂社会系统角度,推动了各式各样社会问题的空间化感知、研判、预测、预警、决策、治理、协同与融合解决。对人观测已经发展成测绘遥感与其他学科深度交叉融合的前沿方向,具有广泛的理论研究与应用需求。

关键词:对人观测;群体过程;时空GIS;人工智能;观测平台系统

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Theory, Technology and Application Progress for Human Being-Oriented Observation

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Abstract: Human being-oriented observation has been a basic application requirement for a long time. The popularization of big data brought about by the development of modern information and communication technology has greatly promoted the progress of the theory, technology and application of human being-oriented observation, and also greatly deepened the interdisciplinary intersection of surveying and mapping, remote sensing, geography, urban science and so on. In terms of theory, it is mainly embodied in the development of the three levels of population perception, feature measurement, and effect observation, especially the theory of systematic expression, modeling and evolution from the perspective of spatio-temporal process of crowd, which has the characteristics of foundation, polymorphism, and systematization, and is in line with the development trend of people-oriented theory. In terms of technology, it is mainly reflected in the technological progress at the level of multi-source perception of crowds, intelligent calculation of spatio-temporal characteristics, and analysis and response of spatio-temporal effects, especially the perception technology, platform technology, and decision-making technology represented by spatio-temporal GIS and artificial intelligence technology, which have good versatility and adaptability, and are in line with the technical trends and characteristics of geospatial artificial intelligence. In terms of application, human being-oriented observation technology has been widely used in many industries within and between cities, such as

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public safety, intelligent transportation, social governance, life and health, urban agglomeration development, extreme and other neighborhood platforms and service systems, which have promoted the spatial perception, research and judgment, prediction, early warning, decision-making, governance, coordination and integrated solution of various social problems from the perspective of complex social systems. Human being-oriented observation has developed into a frontier direction of deep cross-integration of surveying, mapping and remote sensing with other disciplines, and has a wide range of theoretical research and application needs.

Key words: human being-oriented observation; crowd process; space-time GIS; artificial intelligence; observation platform and system

对人观测是指利用卫星遥感、移动/室内通信、物联网与泛在传感网等手段对人类在物理空间、社交空间、认知空间等多类型空间活动、行为动态特征、时空规律、群体效应等核心信息的观测理论与方法,包括面向人群的环境认知、活动感知与群组识别、多维度动态与交互效应揭示等核心观测任务,是“空、天、地、海、人”全球完整观测体系中的一个重要组成部分,对发展测绘科学与技术、遥感科学、地理学、信息科学等学科的基础理论,以及开展交叉融通的前沿理论研究与技术研发应用,具有不可替代的显著支撑作用。

对人观测中有关人群动态的部分,已被定义为人群动态观测,主要是指“探测与度量地理环境中人群活动的时空动态特征、模式、规律、影响作用等”[1-3],有助于回答“人群活动与环境的相互影响是什么”“如何调控人群活动对环境影响”等一系列的科学研究难题。对人观测与人群动态的观测有一些区别,除了关注人群动态,还更注重如下几个方面:数据的代表性[4]、感知的准确性与认知的全面性,人群的可观测性、行为不确定性、效应可预测性,时空的协调性、交互的扰动性、系统可调控性等诸多方面的科学内容。

本文将从理论研究进展、技术研发进展、创新应用进展这3个方面对对人观测进行综述与分析。

1 理论研究进展

对人观测理论可以归纳为3个层次(图1):人群感知、特征度量、效应观测。

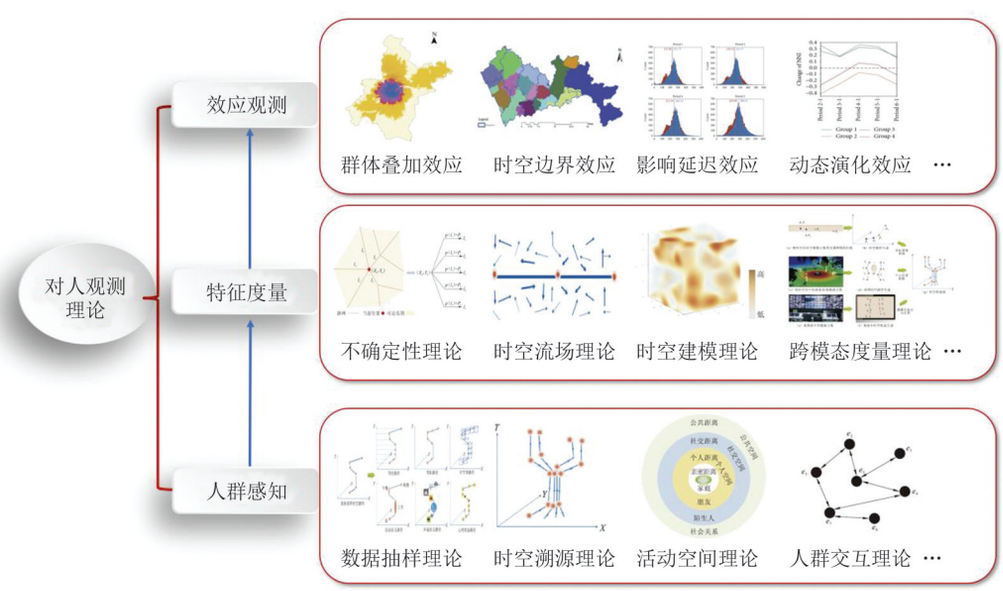


图1 对人观测的三层理论

Fig. 1 Three-Tier Theory of Human Being-Oriented Observation

在人群感知层次,主要包含大规模群体的数据抽样理论、群体过程的时空溯源理论、群体活动空间理论,以及多特征组别的人群交互理论等。(1)大规模群体的数据抽样理论涵盖了简单随机抽样、分层随机抽样、多阶段抽样、分层多阶段抽样、时间/空间抽样、滚雪球法、同伴推动抽样法等[5],特别针对手机位置、地铁/公交刷卡、社交媒体等大数据覆盖人群的差异性,需要采用恰

当的数据抽样方法来支撑人群的代表性,如社会群体民主倾向的代表性[6]、手机位置代表性对人群移动性结果的影响[7-8]等。(2)群体过程的时空溯源理论包括基于时间地理、因果图模型、区块链等理论,如时空轨迹与活动交互溯源[9]、交互群体的因果与或图模型溯源[10]、数据生命周期的区块链架构溯源模型[11]等。(3)群体活动空间理论包括虚实混合空间理论、位置理论、物理活动统一理论等,如虚实混合空间活动表达与建模理论[4,9],对位置的无地性、内在、外在、身份、地方感、本质等方面[12-13]的群体感知;冲动-特点-品质的3层物理活动理解[14]等。(4) 特征组别的人群交互理论包括空间交互理论[15-16]、社交交互理论[17]、虚实交互理论[9]等。其中,交互行为感知[9]、交互空间网络化和流式理解[18]、交互结果模型化(重力模型、辐射模型等)是空间交互的一些主要理论方向;交流、竞争、冲突、合作、共通等类型的社交类型感知[17];基于个体的和基于群体的通用移动性模型构建,如随机游走、莱维飞行、重力模型、干预机会模型、辐射模型等[19-20]。

在特征度量层次,主要包含不确定性理论、时空流场理论、时空建模理论、跨模态度量理论等。(1)不确定性理论主要包括手机/GPS定位位置、空间对象数据与分析的不确定性理论,如手机位置“乒乓效应”[21]影响到手机用户活动停留位置确定[22];GPS/手机/刷卡等感知数据的采样不确定性[23],以及点、线、面、体等空间对象的位置不确定性[24]等。(2)时空流场理论包括地理流、时空轨迹流场、时空场等,如地理流邻域体积以及地理流密度等测度下的随机、丛集、聚散、社区、并行与等长等常见模式分析[18];时空轨迹流场流动性、方向性、叠加性、吸附性,以及扇形、带状、网络、面体、孔洞等时空域的度量[3];针对以稀疏、维度非对称、结构异质为代表的典型非规则时空场数据的张量表达、非规则特征测度方法构建和特征分析[25]等。(3)时空建模理论包括人群动态的时空特征建模、时空过程建模、几何代数建模等,如人群过程的聚集性、集中度、散度、强度、混合性、时空利用率、拥挤度、稳定性、波动性、扩散性、分异性等时空特征的建模[3],时空过程的建模包括潜在特征探索与时空预测、时空过程仿真与决策[26],以及涵盖时空定位、几何结构、要素关系、物理属性、语义特征、演化过程整合描述的几何代数时空统一数据模型建模[27]等。(4)跨模态度量理论包括人群的多模态情感分析模型、红外与红绿蓝(red green blue,RGB)多模态图像人群统计模型、Wi-Fi与视频结合的人群分析模型等,如面向文本-视觉-语音联合表达多模态情感分析的跨模态语义时空动态交互网络及其机器学习模型[28];利用红外和RGB图像的跨模态Transformer机器学习模型统计场景的人数动态[29];利用Wi-Fi和视频多模态数据开展人群中个体位置、人群规模、人群密度分布与速度分析[30]等。

在效应观测层次,主要包含群体叠加效应、时空边界效应、影响延迟效应、动态演化效应等。(1) 群体叠加效应包括活动叠加、时空过程叠加、舆情叠加等产生的群体性叠加影响。如不同的对象、场景、空间(物理空间、网络空间、心理空间等)和约束条件下的活动叠加[3];出租车服务城市群体、重大活动场地群体疏散、城市管理复杂决策等时空过程叠加[31-34];微信舆情叠加效应下群体性事件的预警与阻断[35]等。(2)时空边界效应包括群体活动/移动性/社交活动边界、群体出行特征(如拥堵、拥挤)动态边界、群体针对城市空间的认知边界等扩散或收缩的效应。如行政区/社区居民的活动空间边界[36-37]、特殊群体(青少年等)自我定义活动空间边界[38]、社交媒体活动[39]和古代社交活动空间边界[40]等;基于群体轨迹的车辆交通拥堵边界[41]、人员疏散拥挤区域边界[42];城市居民认为的邻里边界[43-44]和实际扮演的空间功能边界[45]等。(3)影响延迟效应包括管理政策、群体行为特征等对不同组群对象的时空延迟影响。如打车补贴政策/绿色能源化等对城市出租车服务群体的延迟影响[31,46],动态/潮汐车道收费对城市道路交通流量的时空延迟影响[47],以及人类行为空间特性对种群传播动力学的延迟影响[48]等。(4)动态演化效应包括群体的爆发与重尾演化效应[49]以及群体模式与机制演化定量[50]、人类行为与疫情/自然灾害等动态融合演化[51-53]、邻避和群体行为对舆情演化效应[54-55]等,特别地,群体动态演化效应研究呈现了3个重要转向:从物理空间到虚拟空间、从历史空间到实时空间、从人到情境[56]。

总体来说,对人观测理论是聚焦以人为对象的观测理论体系,主要隶属于测绘科学与技术学科,同时与遥感、信息学、地理学、城市科学等多领域交叉融合的学科方向,其人群感知、特征度量、效应观测层次的理论体系具备基础性、多态性、系统性等特征,符合以人为本的理论发展

趋势。

2 技术研发进展

对人观测技术进展可以归纳为人群感知、特征计算、效应分析等技术层次(图2)。

在人群感知技术层次,主要包含大规模群体的主被动感知技术和大数据技术等。(1)在感知技术方面,通过Wi-Fi、图像/图片、视频、手机传感器、物联网和社交媒体与网络等被动方式的感知,涌现了一些多种数据融合感知技术,如跨模态融合[29]、Wi-Fi和视频融合[30]、遥感和社会感知融合[57]等;传统的问卷调查与人口普查方式,以及基于GPS/5G+超宽带[58]等室内外定位技术、公交/地铁刷卡、扫码出行/进出、手机蜂窝网络主动探测信令、激光雷达等主动方式的感知技术,出现了环境/位置上下文感知的群体感知实时计算技术[59]。(2)地理时空大数据平台方面,传统GIS商家都提供了实时大数据平台技术,如GeoEvent Server、SuperMap的大数据GIS技术体系、MapGIS信创大数据与云平台一体机技术、吉奥时空数治平台GeoPanel等时空信息云平台技术,以及开源的时空大数据管理组件GeoMesa等,在大数据应用、大数据生态对接和高效的数据管理等方面有较好的优势。一般地理时空大数据平台提供了空间相关的人群感知信息动态/实时接入技术,较好地提供对人观测的数据支撑。

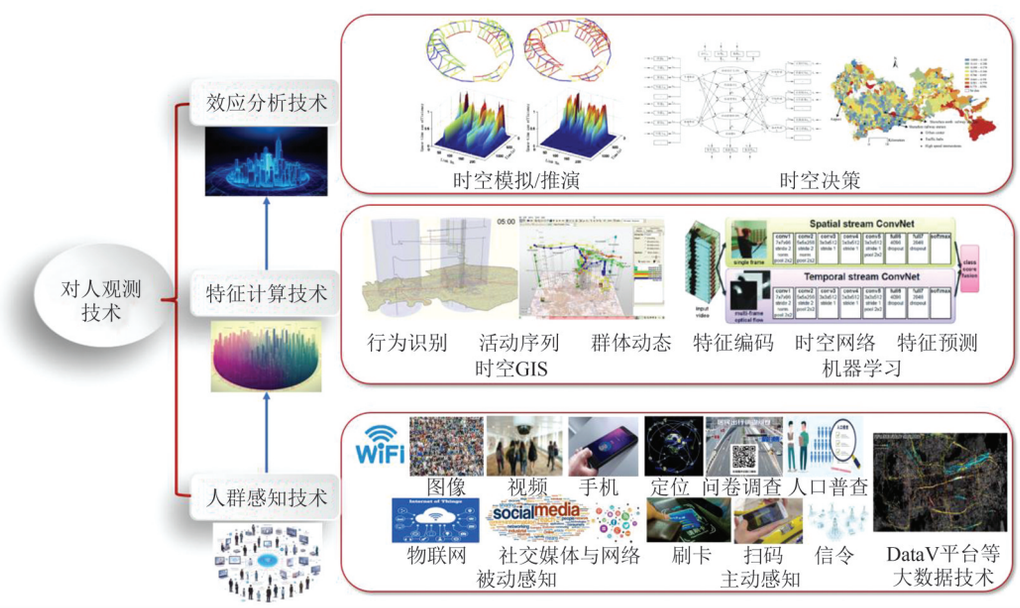


图2 对人观测技术研发进展

Fig. 2 Technique Progress of Human Being-Oriented Observation

在特征计算技术层次,可以笼统概括为时空GIS技术和机器学习技术等。(1)美国SHAW团队较早开发出ArcGIS的时空GIS插件技术[60],中国李响教授团队开发出时空轨迹大数据分析软件XSTAR等;商业化的有GeoTime可视化时空分析软件[61],支撑手机、GPS和社交轨迹的行为识别、活动序列分析、群体动态计算等可视化分析功能,这方面技术在空间、时间、交互和模式等语义[3]的时空关联方面还有一些改善空间,比如全空间组织与分析[62]、多空间行为因素、多领域的对接能力[63]以及突发事件下的模式解读应急能力[64]等。(2)机器学习的特征编码、时空网络与特征预测等技术结合地理信息,催生了地理空间人工智能(geospatial artificial intelligence,GeoAI)的空间显式和隐式的人工智能模型(如深度合成空间模型、空间生成对抗网络模型和长短期记忆网络-轨迹生成对抗网络模型等[65-68])和深度学习轨迹计算技术,有助于对轨迹、图像和视频等空间特征表征学习、时空预测等,但是在模型的迁移性和可解释性、空间推理等方面[68]还存在一些挑战。

在效应分析技术层次,主要包含时空模拟/推演技术、时空决策技术等。(1)在时空模拟/推演方面,从基于流、实体和智能体[69]的群体模拟技术发展到微观、介观和宏观模型,实现理论模型(动力学模型、速度障碍模型、元胞自动机等)和数据驱动模型[70],近期发展到知识和实时数据驱动的机器学习框架(如长短时记忆网络[71]、强

化学习[72]、生成对抗网络[73])模拟技术；在模拟的基础上，构建知识元网络模型、动态贝叶斯网络模型、证据理论等为基础的时空态势推演技术[74-76]，实现城市物质的映射、城市非物质要素的映射及其与人员物资要素的互动、城市发展规律的发掘、基于规则发掘的城市诊断与优化等，促进城市的科学迭代[77]。(2)在时空决策技术方面，为服务于复杂的信息-物理-人类系统[78]，构建了行为模式建模支持[79]、时空预测与情景驱动[80-82]的决策技术，特别针对高动态的人与环境交互时空系统过程，亟需面对不确定性环境或条件下的多目标与模糊优化[83-84]、共享式[85]、自适应动态[86]决策能力，来进行科学支撑。

3　创新应用进展

对人观测是由来已久的基础应用需求。现代信息与通信技术快速发展催生了海量的大数据，基于大数据的对人观测技术发展，显著促进了对人观测在城市内和城市之间的多个行业领域的广泛应用，如公共安全、智能交通、社会治理、生命健康、城市群发展、乡村振兴等(图3)，支撑了智慧城市、区域协调发展等战略目标的实施。具体为：



层次＼领域	公共安全	智能交通	社会治理	生命健康
感知	安全监测 警力巡逻 紧急救援	流量监测 换乘需求 运力需求	超前感知 优先排查 靠前处置	暴露监测 健康感知 智能看护
特征	态势趋势 时空异常 预测预警	拥堵拥塞 交通预测 承载预警	闭环处置 研判预警 动态调处	传播预警 环境关联 健康管理
效应	综合防控 联动调度 辅助决策	交通规划 应急预案 综合调度	综合维稳 立体防控 整体联动	健康环境 主动健康 康养融合

层次＼领域	城市群发展		乡村振兴	
感知	活动强度	交通网监测	贫富人口	人口承载
特征	扩张关联	空间演变	结构乡风	农文旅体
效应	功能布局	空间协同	精准衔接	传承融合

图3　对人观测的应用

Fig. 3　Application Progress of Human Being-Oriented Observation

1)在公共安全方面，主要聚焦在“社会和公民个人从事和进行正常的生活、工作、学习、娱乐和交往所需要的稳定的外部环境和秩序”[87]，目前构建的城市安全大数据中心包含了城市公共基础(市情)、部门业务、社情民意、物理环境与灾害监测、城市运行、人行为(活动)、突发事件应急处置等方面，实现灾害和人员的安全监测、人群分布与移动特征的动态推演[88]、人群异常检测[89-90]、符合犯罪时空分布特性的警力巡逻、突发事件(如城市大规模人员踩踏、特大暴雨洪水、危化品泄漏/厂区爆炸等)的应急救援，公共安全及其衍生事件的预测预警[91]，支撑综合风险评估与防控、科学辅助决策、应急联动和调度，形成多灾种综合、各部门协同、跨行业合作的防灾减灾防治和综合应用[87]。

2)在智能交通方面，主要加强车辆、道路、使用者三者之间的联系，形成保障安全、提高效率、改善环境、节约能源的综合运输系统。目前构建了人、车、路、环境等对象的感知，实现一些智能化的群体覆盖应用，包括混合交通流量和状态监测、交通出行行为规律建模、动态交通流时空特性提取、对交通态势的短期与长时序分析研判[92]、交通预测与区域性交通承载力预警、交通优化控制[93]与诱导，以及基于大数据的公共交通精细化服务(如定制化公交等)、交通需求精准化调控、道路交通的精明化管控、交通系统演化过程干预、综合交通一体化整合与管理决策[94]、交通应急资源配置与协同保障[95]等，特别针对无人交通系统时代(如无人车、无人机、无人船等)，信息不完全下的人车/机交通冲突[96]预判与安全可靠换道决策[97]化解显得非常重要。

3)在社会治理方面，聚焦在人、房、地、事、物、情、组织等要素的精细化社会综合治理。在大数据互联互通的支持下，实现一系列人群社会相关的智能化应用，包括特殊人群的生活网络全覆盖与快速关联应对[98]，群体社会性问题的超前感知[99]、优先排查和靠前处置[100]，群众问题的闭环处置[101]，人群管理形式(如住房、养老等)的宏

微观研判[102],预警体系(如社会事件与矛盾、社会心理、洪涝、生态、贫困)的分层分级构建[103-104],大型水利工程、水源污染、公共场站、通信保障、城市生命线、突发事件等)[105-106]应急中的人群方案设计,信息流支撑和周边资源联动调度(垂直-横向协同)的动态调节处理[107]。通过构建多方参与智慧化的决策引擎,实现跨地域、跨部门、跨行业[87]的综合维稳、立体防控、整体联动等。

4)在生命健康方面,主要聚焦在健康促进、预防、诊断、控制、治疗、康复等方面的应用发展,从群体层面,开展的立体化、多层次应用包括工作环境颗粒物[108]、水[109]和重金属[110]等职业暴露监测,以及PM2.5[111-112]、甲醛[113]、苯系物及多环芳烃等主要大气污染物、热环境[114]、膳食中的铬[115]等大众环境暴露监测,支撑人群暴露风险的评估;老人群体跌倒防护[116]、进藏人群的适应过程、群体心理(抑郁、焦虑等)等物理、生理和心理等方面的健康感知,以及基于移动终端或物联网的儿童与老人群体智能看护[117]以及智能楼宇居民服务[118];传染病的建模、推估预警、风险评估、防控[119-121]与非药物干预措施效果评估[122];癌症、生殖障碍、肾病等疾病[122]与大气、水质等环境[123-125]的关联建模与归因分析,指导群体性的健康环境构建与维护。此外,以主动健康为导向的数字赋能健康管理、康养融合等应用,提供了全球超过2亿用户、覆盖170个国家的数字运动健康服务[126]。

5)在城市群发展方面,在时空大数据支持下,主要开展了空间界定与发展监测、城市群交通网络监测、关联性分析与功能布局评价、产业协同分析和环境监测与评估等方面[127]的工作,如探究人类活动强度与城市群植被覆盖、景观系统、生态系统服务价值以及大气环境的时空关系与影响[128-129];建立建设用地扩张与人口-经济-社会城市化的关联关系[130],识别城市群外部形态紧凑扩张与内部功能发育空间错配[131];城市群交通网络及各类型交通线路的理论与实际载流能力[132],以及基于手机和联网收费数据的城市群人口时空分布与流动特征[133];城市群人类居住空间的空间演变[134],以及城市群人口布局与农业生态、旅游、康养、产业等[127,135-137]方面的空间协同等。

6)在乡村振兴方面,主要开展了脱贫攻坚、农文旅体、融合发展等方面的工作,如农村人口结构与低收入人口动态监测,支撑困难群众的协同比对、主动发现、快速预警[138-139];基于乡村环境的农村人口承载力分析[140],指导种植业、渔猎业、放牧畜牧业等发展,提升农产品安全保障;开展农文旅体融合的共同体发展,提升乡村的精准衔接、传承融合、资源整合、协同治理等能力[141-144]。

4 结 语

对人观测是研究人、分析人、服务人的核心任务,是认知、分析和调控人群动态的基础性工作,具备以人为中心的核心理论发展理念、以人为本的关键技术创新思路、以人的满意度为重要标准的智能化实用等特点,亟需测绘遥感、信息科学、社会科学、安全科学、经济学、健康医学等多领域的联合交叉攻关,开拓出对人观测的重要学科方向,支撑"空、天、地、海、人"全球观测体系的完整发展,满足智慧城市、公共安全、智能交通、社会治理、健康卫生等国家战略与重大社会工程的理论、方法与应用需求,具有重要的科学研究与社会应用价值。

未来对人观测的研究和应用仍需要突破如下一些关键问题:(1)以无感为关键目标的精细化对人观测设备集成与研制,解决不同应用场景的差异化对人观测需求。(2)以多重空间为核心的准确化对人观测理论与技术突破,解决不同社会现象与问题的自适应观测建模与时空分析能力问题。(3)以GeoAI为手段的泛化应用实时计算平台与框架,解决不同应用领域的对人观测核心需求支撑能力问题。

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