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近 50 年我国极端降水时空变化特征综述

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摘要： 全球变暖背景下，我国极端降水事件频发，引发严重水土流失事件，并造成重大损失；因此，开展极端降水及其时空变化特征研究对明晰极端降水变化规律、指导水土保持规划和治理等工作具有重要现实意义。目前，我国基于不同时空尺度的极端降水及其变化趋势的研究已取得丰富的成果，但对这些成果的总结和提炼不足，不利于正确认识我国极端降水规律。笔者通过搜集大量相关文献，对我国极端降水的时空变化特征进行分析，认为整体上我国极端降水事件呈增加趋势，但华北、东北和西北东部等地区呈减小趋势。研究表明，我国目前极端降水研究具有以下薄弱环节：1）气象站点密度普遍偏小；2）地形因素对极端降水的影响考虑不足；3）点状和面状降水数据结合不够紧密——从而造成不同学者在同一区域的研究结论往往不尽相同，一定程度上降低了研究结论的可靠性和可比性，也使得研究成果对实践工作的指导能力不足。建议后续研究应加密气象站点、充分考虑复杂地形条件对极端降水的影响以及加强点状和面状降雨数据的结合，以期获得更为准确的极端降水时空变化规律，增强对水土保持、防汛抗旱和水利工程防护等实践工作的指导作用。

关键词： 极端降水事件；极端降水指标；时空变化特征；地形；气象站点密度
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Review on spatio-temporal variation of extreme precipitation events in China in the past 50 years

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Abstract: **[Background]** Extreme precipitation events occurred frequently in China due to the climate change and global warming, resulting in severe soil erosion events and huge property and personnel losses, such as the torrential rains in Wudinghe Basin in 2017. Thus, studies on the extreme precipitation events and their spatial-temporal variations are of great importance for soil and water conservation planning and management. Currently, there are abundant researches on this issue across China, however, the results of these studies have not been fully and comprehensively analyzed, which limited us for better understanding the extreme precipitation events in China. **[Methods]** In this study, s researches on extreme precipitation in China have been collected, important information such as the extreme precipitation indices, diagnostic methods for trend analysis, interpolation methods for spatial

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interpolation, and the results on spatial-temporal variations were extracted from literatures according to different regions of China and then, summarized and compared with each other with carefulness. [Results] After the comprehensively review of published literature, it is found that the spatial-temporal trends were mainly analyzed based on daily precipitation from meteorological stations and a nonsignificant increasing trend for extreme precipitation was reported on the national scale, of which, the increasing trends were mainly in South China and Southwest China, while the decreasing trends in North China, Northwest China and Northwest China. However, there are still some deficiencies which may limit the further researches: first, currently the densities of rain gauges in many studies are usually sparse; second, the effects of topographical factors on extreme precipitation are usually not taken consideration, probably due to the rain gauges are sited preferably in the flatland; third, the spatial-temporal trends may be greatly affected by the inter-decadal quasi-periodic oscillations in rainfall since the study period in many studies are relatively short. These deficiencies may have lower down the reliability of current studies and then make different studies less comparable. Under this circumstance, some advices aiming to improve the further studies have been proposed in this study: first, more meteorological station should be established quickly to get more available precipitation data; second, studies on the effects of topographic factors on extreme precipitation should be strengthened, which can be initiated from small scale watershed with plenty rainfall and hydrological data and then extend to wider regions; third, the precipitation data from meteorological stations should be used combinedly with spatial coverage data, such as TRMM to improve the station based data. [Conclusions] The researches on extreme precipitation events in China have been reviewed from published literature in this study, it can bee seen that many valuable results have been reported while there are still some deficiencies. Some advices were proposed in this study for future researches and it is expected more valuable results can be acquired in the future, which are also important for practical works, such as flood control, soil conservation, etc..

Keywords: extreme precipitation event; extreme precipitation indices; spatial and temporal variation; landforms; density of meteorological stations

全球变暖背景下,全球及区域尺度极端降水事件普遍呈增加趋势[1-2],我国极端降水事件也频频发生,据统计,2004—2015 年间达到或超过历史极值记录的极端降水事件就有 79 次(表 1)[3]。极端降水事件增多往往对经济发展、粮食生产、生态环境及生命安全等造成重大风险,因而极端降水时空变化及其影响因素已成为全球范围内的研究热点之一[1,4-5]。特别值得注意的是,在我国,由于山丘面积较大,且人为活动较为强烈,极端降水事件往往会造成严重的水土流失事件:我国大部分地区水土流失一般主要由少数几次大雨或暴雨造成[6],如 2017 年无定河特大暴雨事件等。因此,从防灾减灾以及水土保持科学的现实应用角度考虑,应加强极端降水变化规律的研究,以增强其对实际工作的指导作用。

目前,我国学者基于不同时空尺度开展了大量有关极端降水变化趋势和规律的研究,取得丰富的研究成果。一些学者对此进行总结和梳理,例如:

表 1 中国 2004—2015 年极端降水事件汇总表

Tab. 1 Summary of extreme precipitation events in China during 2004—2015

年份 Year	经济损失 Economic losses/ 10^8 Yuan	死亡人数 Deaths	达到或超历史极值记录次数 Number of extreme events exceeding the historical records
2004	127.91	239	11
2005	164.50	260	3
2006	89.50	29	2
2007	237.30	189	6
2008	31.65	110	8
2009	116.00	88	6
2010	338.70	122	8
2011	385.90	169	5
2012	409.52	181	2
2013	1 424.70	783	10
2014	78.10	31	8
2015	249.00	129	10

孔锋等[5]梳理了极端降水阈值界定和诊断方法;高涛等[7]探讨了极端降水趋势及其物理成因;王苗

等[8]对不同气候模式下的极端降水预估进行了综述。总体上,现有综述多集中于大尺度下极端降水的预报和物理成因分析,对基于实测数据的极端降水变化趋势和规律综述不足;因此,笔者广泛搜集基于实测站点的极端降水研究文献,对相关研究结论进行分析综述,以期明确我国极端降水的研究现状及不足之处,为未来开展更具针对性的研究和指导实际工作服务。

1 极端降水指标及研究方法

1.1 极端降水事件

目前我国极端降水事件主要综合2方面的因素进行判断:一是基于简单的气候统计学确定的发生频率较低的降水事件;二是造成严重经济损失或人员伤亡的事件[4-5]。

1.2 极端降水指标

目前学术界通常运用与极端降水事件相关的气候指数作为极端降水指标,一般分为相对指标(通常通过百分位阈值确定)、绝对指标(通过绝对阈值确定)和持续指标等[9],相对指标多用于气候差异大的区域,绝对指标多用于气候特征一致的地区[5]。基于大量文献,笔者整理了目前国内研究中常用的极端降水指标,其中相对指标包括极端降水阈值(R95、R99)[10-15]、极端降水量(R95P、R99P)[16]、极端降水时间(R95D、R99D)[12-13,15-20]、极端降水强度(R95I、R99I)[12,15-17]等,绝对指标包括日降水量大于固定降雨量的时间(如R10、R20等)[11,20],持续指标包括日降水强度(SDII)[10-11,14]、最大1 d降水量和最大5 d降水量(RX1day、RX5day)[10-12,14,19]、持续降水时间(CWD)[10,14]以及持续干旱时间(CDD)[14]。这些指标在全国应用较为广泛,一定程度上有利于不同研究之间的对比。

1.3 研究方法

多数文献通常先按照时间序列对各站点降水进行趋势诊断,再运用空间插值法得到极端降水的空间分布情况。常见的趋势诊断方法有线性倾向估计法、滑动平均法、累计距平法、Mann-Kendall法和滑动T检验等,周期性分析常用小波分析法。其中:线性倾向估计法较为简便,但参数确定具有一定主观性[21];累积距平和滑动平均法的统计均值易受少数异常值干扰[22];Mann-Kendall法不需要样本遵从一定的分布,但对异常值不敏感,易出现假突变点[23];小波分析能较准确地检验信号突变时间点,但小波基函数的选取过于复杂[22,24]。空间分析多采用克里金插值和反距离权重插值等方法,但这些方法均未考虑地形因素对极端降水空间分布的影响,在地形复杂区域可能有较大误差[25]。

2 我国极端降水时空变化特征

绝大部分研究认为我国极端降水事件趋强[15,26-27],这与全球变暖背景下极端降水事件增加的趋势一致;然而,不同学者的研究结论有一定差异,如Zhai等[27]认为我国极端降水雨日减少,但孔锋等[28]认为部分地区暴雨雨量和暴雨雨日明显增加。区域上,我国极端降水时空变化特征如表2所示。

总体而言,我国南方极端降水呈现增加趋势,华北、东北和西北东部呈现下降趋势,这可能是由于自1970年以来东亚夏季风减弱,雨带北上动力不足,导致我国南方地区强降水增加,而北方地区降水减少[26];而西南地区极端降水增加可能由来自孟加拉湾的印度洋水汽充足造成的[35]。上述研究结论总体上较为一致,有助于提高对我国极端降水变化趋势和规律的认识;但不同学者的结论仍有一定的差异性,这与极端降水指标、降水资料类型、时间序列长度、分布密度以及趋势检验方法的选取有关[7-8]。研究结论的不一致性可能对认识极端降水规律和指导生产实践活动造成一定的影响,因此相关研究还应进一步深入和加强。

3 极端降水研究的不足之处与展望

3.1 气象站点密度小

极端降水事件时空变化研究多以气象站实测降雨资料为基础,但我国气象站点的分布具有稀疏性和不均匀性[36]。笔者整理文献的过程中发现文献中气象站点密度在4 841 ~ 4万8 306 km^2/站[11-13,15,18-20,32-33]之间,远低于世界气象组织建议的最稀薄的站网密度(300 ~ 1 000 km^2/站)[37],且这些站点多分布在平原地区,高山区站点密度更少且多集中在山间盆地或山谷[10],无法满足对极端降水雨区的有效覆盖,也无法实现对极端降水的准确观测,如黄土高原主要暴雨的中心雨区往往只有几十平方公里[38],目前该地气象站密度并无法有效覆盖[16]。因此,我国当前气象站点存在密度小、对区域降水特别是极端降水代表性不足的问题。

3.2 与地形地貌结合较为薄弱

地形是局地气候形成的一个主要因子[39],对降水有着巨大影响,如我国横断山区地形复杂,降雨受

表 2 我国区域极端降水时空变化特征

Tab. 2 Spatial and temporal variations of extreme precipitation events in China

区域 Region	主要研究结论 Main conclusions	不一致性结论 Inconsistent conclusions
东北 Northeast China	极端降水事件及强度均下降[27,29] The number of extreme events and their intensities both decreased[27,29].	1. 北部强度上升，南部下降[30] 2. 20 世纪 80 年代后极端降水明显增加[17] 1. The intensity in north increased and decreased in south[30]. 2. Extreme precipitation increased significantly after 1980s[17].
华北 North China	极端降水事件及强度均下降[15,29] The number of extreme events and their intensities both decreased[15,29].	华北中部[18]和河北省[19]极端降水事件正在增强 Extreme precipitation increased in central North China[18] and Hebei[19]
西北东部(黄河流域) Eastof Northwest China (Yellow River Basin)	极端降水呈下降趋势[14,16,30] Extreme precipitation tended decreasing[14,16,30].	主体区域黄土高原极端降水事件未发生变化[31] The extreme precipitation on the Loess Plateau remained unchanged[31].
西北西部(新疆、甘肃等) West of Northwest China (Xinjiang, Gansu, etc.)	极端降水呈增加趋势[27,29,32-33] Extreme precipitation tended increasing[27,29,32-33].	—
南方 South China	极端降水增加[10,27,30]，特别是长江流域[11,15,29] Extreme precipitation increased[10, 27, 30], especially in the Yangtze River Basin[11, 15, 29].	—
西南 Southwest China	大部分研究认为极端降水增加[12-13,29] Most studies indicated that extreme precipitation increased[12-13, 29].	同一区域指标变化不同，如 RX5day[12,34]和极端降水日数[12-13,30]的变化 The same indices changed differently in the same region, such as RX5day[12,34] and extreme precipitation days[12-13,30].

海拔、坡向等地形影响显著，在垂直方向上的分布极不均匀[40]；但目前的极端降水研究多未考虑地形因素，一定程度上影响了研究结果的准确性及其对实际工作的指导价值[10,12,16]。

3.3 点数据和面数据结合较为薄弱

目前，国际上已有较多基于台站观测和卫星反演的高分辨率融合降水产品，如 TRMM 和 GPCP 等面状空间降水数据应用较为广泛[41]，可实现空间全覆盖，弥补地面站点空间估计能力不足的缺点[42]。当前运用面状数据进行极端降水研究的报道较为少见，点面结合的研究更为缺乏；因此可考虑通过融合地面站点观测降水数据和卫星反演降水数据，更加准确地刻画极端降水的空间分布。

上述研究的薄弱之处造成不同学者在同一区域的研究结论往往不尽相同，一定程度上降低了研究结论的可靠性和可比性，也使得研究成果对实践工作的指导能力不足：一些学者[43-45]已经注意到极端降水雨洪资料可以为水利和水保工程的规划设计和应急管理提供技术支持，但相关研究案例仍少见报道。建议后续研究应加密气象站点、充分考虑复杂地形条件对极端降水的影响，以期获得更为准确的极端降水时空变化规律，增强对水土保持、防汛抗旱和水利工程防护等实践工作的指导作用。

4 结束语

1) 我国极端降水事件总体上呈增多趋势，但不同研究的结论不尽一致。

2) 目前我国极端降水研究面临气象站点密度小的问题，未充分考虑地形因素对极端降水的影响，且点、面数据结合较为薄弱。

3) 应进一步加强极端降水研究对水土保持、防汛抗旱和水利工程防护等实际工作的指导作用。

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