澳大利亚“黛比”热带气旋登陆前后附近海岸线变化的卫星观测

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摘要 2017年3月28日, 热带气旋“黛比”从澳大利亚昆士兰州登陆, 给当地民众的生命安全和公共财产带来了巨大威胁. 热带气旋在短时间内改变了局部海岸地形, 并使海岸线位置迅速发生变化. 针对海波因特附近的海岸进行研究, 收集了热带气旋登陆前后的两景陆地卫星图像, 结合水体指数和人工检查进行海陆分类制图, 并得到海岸线变化空间分布图. 计算表明, “黛比”登陆前后, 海波因特附近海岸区域陆地面积净增加 54.50 km², 98.2%的海岸线表现为淤积, 仅 1.8%的海岸线表现为侵蚀. 准确及时的海岸线变化信息可以帮助港口恢复运营, 还可以用于发展风暴潮-波浪-泥沙数值模式.

关键词 热带气旋, 黛比, 卫星观测, 海岸线变化, Landsat-8 OLI

2017年3月28日, 热带气旋“黛比”从澳大利亚昆士兰州登陆, 是近6年来登陆澳大利亚最强的热带气旋. 该热带气旋已造成5人死亡, 并摧毁铁路、中断电力和引发洪水, 使得昆士兰州所有的煤炭出口码头关闭. 带来煤炭市场运输问题, 造成不可估量的经济损失. 热带气旋引起的风暴潮可引发强烈的水动力作用, 在短时间内对近海岸地形产生巨大影响. 及时准确地获取热带气旋之后的海岸线位置变化信息对于解决港口和航道的骤淤问题, 帮助码头顺利恢复运营和发展风暴潮-波浪-泥沙数值模式都具有重要意义. 卫星数据在灾害监测中已经获得了应用^[1,2], 但用作监测热带气旋登陆后海岸线短期变化还较为少见.

海岸线的位置由潮位和海岸地形共同控制. 因此需要排除卫星成像时刻的潮位偏差对海岸线实际位置的影响. 我们依据研究区附近的Rosslyn海湾验潮站的潮位数据筛选得到“黛比”热带气旋登陆前后澳大利亚海波因特(Hay Point)附近的两期陆地卫星(Landsat-8 OLI)图像(轨道编号为92~25). 数据获取时间分别为2017年3月10日和4月11日, 对应的卫星成像时刻潮位相差15 cm(图1). 该验潮站位于23.16°S, 150.79°E, 位于研究区域南方约70 km. 研究区域以沙滩型海岸线和植被海岸线为主, 因此15 cm的潮位差基本不会导致海岸线水平位置偏移. 我们将这两景遥感图像作为本研究的数据源. 使用的数据均已通过LPGS2.7.0软

件处理为Level 1TP级别的产品, 并投影至WGS84坐标系. 两景图像均已通过地面控制点进行几何校正, 均方根误差分别为8.1和7.8 m. 本研究所使用的两景遥感图像的云覆盖比例为6.49%和7.29%, 大部分海岸地区无云覆盖. 为避免云对制图结果的影响, 本文将研究限定在海岸无云的区域.

本文利用近红外和绿波段计算两景图像的归一化水体指数(NDWI), 通过频率直方图确定最优阈值进行水体和陆地的分类制图^[3]. 填充内陆水体, 并在ArcGIS10.2软件中进行人工检查和编辑, 得到两期海陆分类图, 确保提取得到的海岸线(海陆分界线)的几何误差在一个像元(30 m)以内. 将两期海陆分类图叠加在一起得到“黛比”登

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图1 获取于“黛比”热带气旋登陆前后的两期 Landsat-8 OLI 图像

Figure 1 Two Landsat-8 OLI scenes acquired before and after tropical cyclone “Debbie”

陆前后的海岸线变化信息。结果表明，“黛比”登陆前后，该海岸区域陆地面积净增加54.50 km²。为进一步定量地度量海岸线变化和展示海岸线变化空间格局，我们统计了海岸线1 km×1 km 格网中的陆地面积变化百分比。热带气旋登陆前后，各格网中陆地面积增大定义为淤积，反之定义为侵蚀。海岸线格网通过如下方法得到：首先，利用两期海陆分类图得到海岸线堆积

区域和海岸线侵蚀区域；然后，将两者的并集作为海岸线变化区域；最后，这些变化区域所在的格网被定义为海岸线格网。结果表明，“黛比”登陆之后，98.2%的海岸线表现为淤积，1.8%的海岸线表现为侵蚀(图2)。卫星观测结果显示，该区域的陆地面积大幅增加，海岸线向海洋大幅推进。此外，我们发现海岸线堆积比较剧烈的区域集中在河口和凹向陆地的沙滩海岸，这可

能和当地较弱的水动力条件有关系。

我们沿着海岸线选取3个局部区域，以进一步展示该区域的海岸线变化。如图3(a)所示，展示了海波因特港口的变化，可看出热带气旋登陆之后，该港口表现出侵蚀特征，对照Google Earth高分辨率影像可以发现，该港口停泊的船只有所减少。海波因特港位于澳大利亚的昆士兰州，是澳大利亚第二大煤炭输出港，也是世界二十大

图2 “黛比”热带气旋登陆前后海波因特附近海岸线变化

Figure 2 Coastline change around the Hay Point before and after tropical cyclone “Debbie”

图3 海波因特附近海岸线变化局部示意图, 用 Landsat-8 OLI 的近红外、红、绿波段合成标准假彩色图像用于显示. (a) 研究区的港口; (b) 沙滩; (c) 树林. 红点表示两期图像中的相同位置, 用于展示热带气旋登陆前后的海岸线位置变化

Figure 3 Coastline change in some regions around Hay Point. False RGB color image composed with near-infrared, red and green bands of Landsat-8 OLI was used for the demonstration. (a) The port; (b) sandy beach; (c) forest. Red points represent the same locations in Landsat images acquired on different dates and they were used to characterize the coastline change before and after the cyclone

散货港之一,“黛比”使得该煤炭码头停止运营. 图3(b)展示了该区域的一段沙滩,可看到,热带气旋之后,该区域的沙滩范围显著增加,海岸线向海洋推进. 还能看出该沙滩附近的近海泥沙浓度明显增大. 图3(c)展示了一片滨海湿地,其外边界也增加了一些泥滩. 此外,在图3(b)中所观测到的近海泥沙浓度增大的现象在图1中展示的整片海岸区域都有所体现,这和该区域

的海岸线显著堆积或许有一定关联.

本文简要地说明了现有的卫星数据在突发自然灾害监测、应对和评估中表现出来的巨大潜力. 利用卫星影像,可以及时地获取热带气旋登陆前后的海岸线位置变化信息,这个信息具有工程应用和科学研究的双重价值. 此外,该研究也暴露出一些数据和技术上的不足,如Landsat-8 OLI作为多光谱影像无法应对海岸带地区多云多

雨的情况,今后需要结合可以避免云雨干扰的SAR数据共同用于海岸线的变化监测. 本文对热带气旋登陆前后各半个月左右的海岸线进行观测,还不足以详细描述海岸线在热带气旋登陆之后较短时间内发生的剧烈变化,未来需进一步考虑如何将中高空间分辨率的遥感数据和高时间频率的遥感数据结合起来用以监测热带气旋登陆之后的海岸线连续动态变化.

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Summary for “澳大利亚‘黛比’热带气旋登陆前后附近海岸线变化的卫星观测”

Satellite observation of coastline change around Hay Point, Australia before and after tropical cyclone “Debbie”

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On March 28, 2017, tropical cyclone “Debbie” made landfall on the coast of the state of Queensland in Australia. This was the most powerful tropical cyclone to hit Australia in the past 6 years. Debbie has resulted in at least five deaths and caused rail damage, power outages and flooding according to relevant reports. This cyclone halted railway transportation and several mines in Queensland had to be closed, including the coal exports terminals of Abbot Point, Dalrymple Bay and Hay Point. In a short period, Debbie resulted in a strong hydro-dynamical response. Subsequently, Debbie caused considerable coastline movement and significantly modified the coastal topography.

The position of a coastline is controlled by tide level and coastal topography. Hence, we should take tide level variation into consideration to avoid its impact on the determination of coastline position. To locate the position of coastline and assess its temporal change around Hay Point, we collected tide level data from Rosslyn Bay station near the study area. Based on the tide level data, two Landsat-8 Operational Land Imager (OLI) images showing similar tide levels before and after Debbie were obtained from the United States Geological Survey (USGS) Earth Explorer website. Landsat scenes used in this paper from Landsat Surface Reflectance Climate Data Records (CDR) had been pre-processed to L1TP level (Precision and Terrain Correction). The widely used Normalized Difference Water Index (NDWI) was used to enhance water information. This water index is able to enlarge the discrimination between surface water and other types of land cover. The optimal threshold was manually determined using the frequency histogram of the NDWI image. We applied the optimal threshold to produce a land-water map. Then, inland water was filled to remove its effect on the land-ocean map. Finally, manual checking and editing were implemented in ArcGIS10.2 to ensure the quality of land-ocean maps before and after Debbie. We used the produced land-ocean map to represent the position of the coastline. Two land-ocean maps were overlaid and subtracted to generate the coastline change map. The net change of land area per 1 km×1 km cell along the coastline was calculated to characterize the spatial pattern of coastline change after cyclone Debbie.

Our results suggest that the coastline significantly expanded to the ocean after the landfall of Debbie with a net land gain of 54.5 km² along the coast around Hay Point, Australia. In our study area, 98.2% of the coastline exhibited expansion to the ocean and only 1.8% of the coastline retreated to the land. Note that we may slightly underestimate the net land gain because some regions in the study area were covered by cloud/shadow during observations. We also observed a significant increase of suspended sediment concentration around some coasts using visual judgement, which is likely to be associated with the coastline expansion around the coastal area near Hay Point. Timely and accurate information on coastline position and its change is essential to the management of sudden siltation of ports and waterways, and the subsequent resumption of the operation of wharves. Such datasets can also be helpful to develop and validate storm surge-wave-sediment numerical models. This paper used a simple application to demonstrate the great potential of satellite technology for natural disaster monitoring and assessment. In the future, more attention should be paid to the use of multi-source remotely sensed data to conduct continuous monitoring of coastline dynamics with higher spatial resolution and temporal frequency.

tropical cyclone, Debbie, satellite observation, coastline change, Landsat-8 OLI

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