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A new method for quantifying and modeling large scale surface water inundation dynamics and key drivers using multiple time series of Earth observation and river flow data. A case study for Australia's Murray-Darling Basin

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Periodically inundated surface water (SW) areas such as floodplains are hotspots of biodiversity and provide a broad range of ecosystem services but have suffered alarming declines in recent history. Large scale flooding events govern the dynamics of these areas and are a critical component of the terrestrial water cycle, but their propagation through river systems and the corresponding long term SW dynamics remain poorly quantified on continental or global scales. In this research, we used an unprecedented Landsat-based time series of SW maps (1986-2011), to develop statistical inundation models and quantify the role of driver variables across the Murray-Darling Basin (MDB) (1 million square-km), which is Australia's bread basket and subject to competing demands over limited water resources. We fitted generalized additive models (GAM) between SW extent as the dependent variable and river flow data from 68 gauges, spatial time series of rainfall (P; interpolated gauge data), evapotranspiration (ET; AWRA-L land surface model) and soil moisture (SM; active passive microwave satellite remote sensing) as predictor variables. We used a fully directed and connected river network (Australian Geofabric) in combination with ancillary data, to develop a spatial modeling framework consisting of 18,521 individual modeling units. We then fitted individual models for all modeling units, which were made up of 10x10 km grid cells split into floodplain, floodplain-lake and non-floodplain areas, depending on the type of water body and its hydrologic connectivity to a gauged river. We applied the framework to quantify flood propagation times for all major river and floodplain systems across the MDB, which were in good accordance with observed travel times. After incorporating these flow lag times into the models, average goodness of fit was high across floodplains and floodplain-lake modeling units (r-squared > 0.65), which were primarily driven by river flow, and lower for non-floodplain areas (r-squared > 0.24), which were primarily driven by local rainfall. Our results indicate that local climate conditions (i.e. P, ET, SM) had more influence on SW dynamics in the northern compared to the southern MDB and were the most influential in the least regulated and most extended floodplains in the north-west. We also applied the statistical models of two floodplain areas with contrasting flooding regimes to predict SW extents of cloud-affected time steps in the Landsat time series during the large 2010 floods with high validated accuracy (r-squared > 0.97). Our findings illustrate that integrating multi-decadal time series of Earth observation data and in situ measurements with statistical modeling techniques can provide cost-effective tools for improving the management of limited SW resources and floods. The data-driven method is applicable to other large river basins and provides statistical models that can predict SW extent for cloud-affected Landsat observations or during the peak of floods and hence, allows a more detailed quantification of the dynamics of large floods compared to existing approaches. Future research will investigate the potential of image fusion techniques (i.e. ESTARFM) for improving the quantification of rapid changes in SW distribution by combining MODIS and Landsat imagery.