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Cyclic steps on ice and a sediment-covered bed: their analogies and differences

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A series of steps with a relatively long and regular wavelength are often observed to be formed on steep slopes. One of the most important features of these steps known as “cyclic steps”, is that, in each step, Froude subcritical flow makes a gradual transition to supercritical flow with increasing bed slope in the streamwise direction, and, further downstream, the supercritical flow shows, in turn, an abrupt transition to subcritical flow accompanied by a hydraulic jump where the bed slope suddenly drops. It has been found that cyclic steps are observed in a variety of environments such as the river bed, the ocean floor, and the surfaces of ice caps on Mars as well as on the Earth. In this study, analogies and differences between a variety of families of cyclic steps formed in different environments are studied from physical and mathematical points of view. Cyclic steps formed by free surface flow on a bed covered with non-cohesive fine sand and by a turbidity current on the ocean floor are both governed by the shallow flow equation, the diffusion/dispersion equation of suspended sediment, and the Exner equation describing the time variation of the bed elevation due to deposition and erosion of suspended sediment. A similar but slightly different diffusion/dispersion equation of temperature, and an equation describing the time variation of the ice surface elevation due to freezing and melting (Stefan condition) assume an important role in the process of the formation of cyclic steps on ice. In the case of ice steps, however, there is no mechanism for selecting wavelength because there is no threshold condition for freezing and melting. In addition, the cyclic steps on ice may migrate either upstream or downstream depending on a temperature condition. That is, cyclic steps migrate upstream when the atmospheric temperature is higher than the melting point and the whole ice surface is in degradation while steps travels downstream when the atmospheric temperature is lower than the freezing point and the whole ice surface is in aggradation.