Geophysical Research Abstracts
Vol. 13, EGU2011-10785, 2011
EGU General Assembly 2011

Water Divide Migration as a Bifurcating Dynamic System

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River basin self-organization and geometry are functions of the stability of the intervening water divides. Divides are stable or move in response to differences in erosion rate in each bounding basin. In the extreme case, divides migrate to the point that one river captures its neighbor, either through river piracy or simply by progressive area capture. This problem can be parameterized in terms of two channel heads with an intervening water divide, whose position and lateral velocity are a function of the channel head elevations and downcutting rates. The downcutting rates are, in turn, a function of the exiting channel slope and the contributing area to the channel head. The channel slope provides a negative feedback (higher slope leads to faster downcutting and thus lower slope), whereas the contributing area provides a positive feedback (larger area leads to faster downcutting and thus increasing area). Due to these competing feedbacks, this outwardly simple problem exhibits a remarkably complex dynamic response. A phase plane analysis demonstrates classic bifurcation behavior with extreme sensitivity to initial conditions. The key parameter is a form of the erosion number expressing the ratio between tectonic uplift and erosional efficiency. With high relative erosional efficiency (e.g. low tectonic uplift or high precipitation rates) the system has 3 singular points in phase space, one of which is a stable solution with a divide located midway between the channel heads; the other two are attractors with bifurcating divide migration leading to either the stable solution or to capture of one channel by the other. With low relative erosional efficiency (e.g. high tectonic uplift or low precipitation rates) the system has only one singular point, which is an attractor, but not a stable node. Thus all water divides are unstable and small perturbations from symmetry lead inevitably to capture of one basin by the other. These results are confirmed by numerical models using DAC, a surface process model implementing precise divide location tracking. In particular, under low erosional efficiency, unstable water divides lead to perpetual basin reorganization with no topographic steady-state, even with constant tectonic and climatic forcing.