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Variability of the "glaciological regime" and its consequences for interpretation and modelling of glacier length changes - a case study from maritime South Norway

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Mountain glaciers are acknowledged as high-resolution indicators of short-, medium-, and long-term climate changes. Variations in glacier mass, area, length, and frontal position have important effects upon various aspects of sustainable development in mountain regions. Maritime mountain glaciers can react very sensitive to changes of the 'glaciological regime', i.e. the relationship between mass-balance or length changes and predominant weather or climate conditions.

The steep sensitive-reacting outlet glaciers of Jostedalsbreen, western South Norway, underwent two fairly contrasting periods during the past 20 years. Interpretation of this 'extreme' behaviour deserved special attention. A considerable increase in ice mass and related frontal advance during the AD 1990s was caused by increased winter precipitation. Relative contributions of the winter balance to the annual net balance variations were high during the last decades of the 20th century AD. By contrast, glacier tongues experiences a sharp retreat in the most recent years since c. AD 2000. Above-average summer air temperatures unambiguously caused the most recent retreat. This retreat was, however, not clearly linked to mass-balance data as its proportion significantly exceeded the slight contemporary mass loss. The virtual absence of any time lag of frontal response indicates a regime change towards a 'disturbed' dynamic response of the glacier tongue occurring around c. AD 2000.

Detailed analysis of mass-balance, length variation, and climate data from maritime Southern Norway reveals their variations are not entirely determined by air temperature changes, as implicated by most existing models. Substantial changes occurred after AD 2000 with the correlation of different mass-balance parameters to length variations. The correlation of net balance to length variation dropped significant during to the most recent retreat. Comparable changes between long-term means and the most recent retreat phase take place between selected meteorological parameters and length variation. This analysis reveals substantial changes in the relationships and interrelation within the 'glaciological regime' during the most recent years. It gives a clear warning to the common procedure of averaging long-term data series of glaciological and meteorological parameters as input for existing models. These inputs must not automatically be considered as constant. Temporal and spatial differentiated, high-resolution data and multiple-phase regression seem to be appropriate strategies in the context of significant weather regime changes. However, this refers merely to length variation data as no comparable significant regime change was detected in the mass-balance data.

In a number of studies, annual air temperatures are still related to length changes. Two major concerns arise with those attempts. In general, annual air temperatures related to calendar years are applied although both, mass-balance and length variation are calculated for budget years (i.e. October – September). Empirical data analysis from the study area reveals that differences of up to 1.0 °C exist between air temperatures calculated on an annual base for calendar years and budget years. Furthermore, fluctuations of mass-balance and length variations during the past decades cannot empirically be explained by variations of the annual air temperature. For example, the considerable mass increase and related frontal advance during the AD 1990s corresponds with an

increase in annual air temperatures primarily caused by a series of mild and wet accumulation seasons. Because mid-latitudinal maritime glaciers own a marked seasonal differentiation in their mass budget, the differentiation between winter and summer balance is regarded as useful for the analysis of individual climate factors driving the mass-balance. Due to missing causal links, annual air temperature data have additionally been detected in theory as unsuitable to explain length variations. Merely statistical 'parallels' between annual air temperatures and glaciers retreat are, therefore, misleading for the interpretation of length variations at the glaciers studied here.