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Vilhelm Bjerknes's "First task of theoretical meteorology": Assimilation of observational data for atmospheric monitoring and forecasting (Vilhelm Bjerknes Medal Lecture)

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In 1904, Vilhelm Bjerknes set out the approach to weather prediction that in essence is followed in today's numerical forecasting systems. Towards the end of his article, he concluded: "Based on the observations made, the first task of theoretical meteorology will then be to derive the clearest possible picture of the physical and dynamical state of the atmosphere at the time of the observations. [...] From the directly observable quantities we must calculate as comprehensively as possible all accessible data on the non-observable ones. For that purpose one has to utilize the relationships between the different quantities. Thus, even for constructing a coherent picture of the state of the atmosphere from scattered observations, one must extensively use dynamical-physical methods[1]."

Systematic measurement of surface weather parameters was becoming established by the beginning of the 20th Century, and Bjerknes was able to foresee the later use of data from balloon-borne instruments. More difficult to foresee were the advent in the 1950s of electronic computers that could run the models needed to project atmospheric states forward in time, and the advent in the 1970s of routine temperature and humidity sounding from satellites. Refinement of computing, modelling and observation has continued apace since then. Observations today are far less scattered than envisaged by Bjerknes, but accurate estimation of the atmospheric state remains a challenge in view of the diversity of the measurements that are made, often of quantities that depend in complex ways on the geophysical variables that are modelled, monitored and forecast.

The key to addressing Bjerknes's "first task" has been the development of data assimilation. Data assimilation provides a sequence of analyses of atmospheric and related oceanic and land-surface conditions. It uses information from the latest observations to adjust a "background" model forecast initiated from the preceding analysis in the sequence. The model carries information from earlier observations forward in time, and information is spread in space and from one variable to another by the model forecast and through the background-error structures used in the adjustment process. The set of observations may comprise many different types of measurement, each with its own accuracy and spatial distribution.

The talk will outline the development of atmospheric observation, modelling and data assimilation, and the improvements brought to global weather forecasts. It will illustrate how data assimilation is used also for reanalysis of the changing observational record extending back to the beginning of the 20th Century. Attention will be focused on some aspects of climate variability and change over recent decades, showing how inconsistencies in the raw records from different types of measurement can be reconciled by estimating and correcting biases. A brief account will also be given of the assimilation of data on trace chemical and aerosol constituents important for air quality and climate forcing, including estimation of net surface sources and sinks of key species.

[1] Translated from the original German language by Esther Volken and Stefan Brönnimann