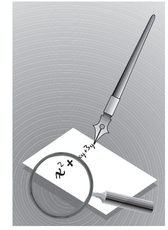
commentary and analysis



Carbon Sequestration—The Need for an Integrated Climate System Approach

The concern with respect to the anthropogenic input of carbon dioxide into the atmosphere (Houghton et al. 1995) has resulted in proposals for long-term removal programs of this gas based on forestation and agricultural procedures. Referred to as "carbon sequestration," the value of this effort is defined by the amount of CO_2 removal and the length of time before it would be reemitted into the atmosphere. The extraction of the CO_2 from the atmosphere reduces its contribution as a radiatively active greenhouse gas. Landscapes that would be modified for this purpose have been referred to as "biomass farms."

However, the alteration of the land surface is likely to result in other effects on the heat energy of the atmosphere. Any additional water vapor evaporated or transpired into the atmosphere, for instance, would increase the greenhouse gas warming effect and at least partially offset the benefit of carbon sequestration. Alternatively, a net reduction in water vapor input might enhance the benefit of carbon sequestration with respect to a reduction in greenhouse gas concentrations.

Since, in the atmosphere, however, a water vapor molecule has a much shorter lifetime than a carbon dioxide molecule, the evaluation of changes in transpiration or evaporation would have to consider its net effect over multiyear timescales. Changes in water vapor flux into the atmosphere can also alter cloud and precipitation, so that its net effect on the radiation budget is quite complex.

It is, therefore, somewhat more straightforward to evaluate the change in the long-term surface energy budget due to the landscape change associated with carbon sequestration. A darkening of the land surface, for example, would result in a lower albedo, which would contribute to atmospheric heating (Cotton and Pielke 1995)—an effort contrary to the goals of carbon sequestration. Elevating the albedo would add to the goal of carbon sequestration. Just changing the surface albedo from 0.2 to 0.15, for example, can reduce the annual averaged insolation reflected back into space by 5 W m^{-2} or more!

There has, unfortunately, been no attempt to evaluate the benefit of carbon sequestration as a means of reducing the concentrations of the radiatively active gas CO_2 in the atmosphere, while at the same time, assessing the influence of this sequestration on the radiatively active gas H_2O, and on the surface heat energy budget. Until these effects are factored in as part of an integrated climate assessment, a policy based on carbon sequestration as a means to reduce the radiative warming effect of increased atmospheric concentrations of CO_2 could actually enhance this warming.

References

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C.-G. Rossby's Experience and Interest in Weather Forecasting

There is some tendency to classify meteorologists into synoptic or theoretical types—as if a good theoretician is likely to be a poor synoptician, and a good forecaster is likely to be uninterested in theory. It is true that there are good theoreticians who cannot read a weather map, and skilled forecasters who know little of theory. But the roles of theoretician and forecaster become much easier if the former has practical experience and the latter a good general grasp of theory. C.-G. Rossby was an outstanding example of this. Since he was one of the great theoreticians in meteorology, it is interesting to see how he related to practical aspects of his subject. A look at his personal history reveals not only that he was interested in practical matters but also skilled and experienced as a routine weather forecaster in his younger days.

His career in meteorology started in 1919–20 when he was a 21-year old apprentice forecaster in Vilhelm Bjerknes' team in Bergen, Norway. His employment at the Swedish Meteorological and Hydrological Institute (SMHI) in 1922–26 (following a sojourn in Leipzig) is reflected in the surprisingly rich material found in the Swedish archives, which one of us (A. Persson) had a brief glimpse of in early 1999. Rossby's work included establishing a pilot balloon network. He served as bench forecaster together with four other meteorologists, analyzing maps for morning, midday, and evening, and issuing nationwide forecasts to be read over the newly established radio network. An example of a weather map analyzed by Rossby is reproduced in Fig. 1. The same archives contain the record of early radio weather forecasts in Sweden. On 24 September 1924 Rossby prepared the following forecast for broadcast (translated from the original Swedish):

> During the past several days a storm center has moved slowly from Iceland to the Shetland Islands. It is now slowly dying, and its influence in Sweden should therefore diminish to shortlived rain, primarily in western Sweden. Cloudy weather is expected for the Stockholm area with small amounts of rain likely in the afternoon. Improving and generally dry weather is expected later with moderate southerly winds changing to southwesterly, with some rise of temperature.

He also served two summers as forecaster on a sailing ship (Phillips 1998), gave lectures to the crew, and took pilot balloon observations.

Rossby's move to the United States in 1926 was sponsored by the Swedish–American Foundation and the SMHI for Rossby to make dynamical and aerological studies in the United States for two to three months. He would stay at the aerological stations established by the U.S. Department of Agriculture [then home of the U.S. Weather Bureau (USWB)], since these stations were "exceptionally well equipped and probably had no comparison in Europe." He was also to "inform himself of the methods of experimental hydrodynamics at Cornell University" (Swedish National Archives 1926). [For Rossby's start in the United States, see Phillips (1998) and Newton and Newton (1994).] After his arrival, Rossby added instruction in the Bergen forecasting method to these assignments (Rossby and Weightmann 1926). The appendix reproduces a letter from C. F. Marvin to the Scandinavian–American Foundation supporting Rossby's experimental work and his instruction of forecasters in the Norwegian methods. (Marvin's reference to Dr. Rossby is not strictly correct. At that time Rossby had a Swedish degree of *filosofie licentiat* in mechanics. This is equivalent to our Ph.D., but without the thesis requirement.)

His forecast in 1927 for Lindberg's flight to Mexico City was not Rossby's first attempt to make aviation forecasts, which the USWB did not provide at that time (Bates 1989; Byers 1959; Newton and Newton 1994). The Swedish newspaper *Svenska Dagbladet* reported on 6 July 1927 that Rossby had been engaged earlier during the year by the aviator Richard Byrd to organize the weather service for his (later failed) attempt to fly across the Atlantic. According to Byers (1959), these forecasts did not endear Rossby to the Weather Bureau hierarchy. After he left the bureau, the Guggenheim Fund for the Promotion of Aeronautics gave Rossby the job of organizing an airways weather system for the route between San Francisco and Los Angeles (Bates 1989; Byers 1959). The system was then successfully handed over to the Weather Bureau (Rossby 1928).

Fig. 1 (pages 2124–2125). A synoptic map drawn by Rossby for 0800 UTC 29 Sep 1924. On the right-hand side Rossby has written a comment (to the man coming after him, perhaps?) "Fara för nybildning i sydöstligaste England, C.G.R"). ("Watch out for new development over southeasternmost England, C.G.R."). This was verified the next day. Isallobars are shown in the region of northern Norway. ["S" = stigende ("rising") and "F" = fallende ("falling").]