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MODELLED AND MEASURED ENERGY EXCHANGE AT A SNOW SURFACE

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ABSTRACT

Results of a model developed at JPL for the energy interchange between the atmosphere and the snow are compared with measurements made over a snowfield during a warm period in March, 1978. Both model and measurements show that turbulent fluxes are considerably smaller than the radiative fluxes, especially during the day. The computation of turbulent fluxes for both model and data is apparently lacking because of problems inherent in the stable atmosphere.

INTRODUCTION

Snow surfaces in GCMs are generally treated as most other surfaces with high albedos with the exception, perhaps, of constraining the surface temperature to remain always at or below 0°C. Hydrology models of the snowpack give detailed analyses of the physical processes present in the snow, but the related, complex atmospheric processes are usually parameterized in bulk fashion. Neither of these two approaches can suffciently portary the interchange of energy at the surface, especially when turbulent fluxes are involved. To fill this gap, an investigation of the air-snow interface was undertaken with detailed measuring and modelling of both the atmospheric boundary layer and the snowpack.

THE MODELLING EFFORT

The model initially developed is one-dimensional (columnar) divided into a free atmospheric layer, an upper boundary layer (the Ekman layer, or, simply the upper layer), and a lower, constant flux layer (the surface layer). The snowpack lies below the atmosphere at an initial depth of 60 cm, where calculations are performed on a logarithmic grid to give very high resolution near the surface. Below the snow rests the ground which has an assumed constant temperature at a 20 cm depth. The equations for the upper layer predict winds, temperature and humidity assuming a constant pressure gradient and employing variable eddy diffusivities calculated from the Hoffert and Sud (1976) parameterizations. The surface layer is then derived diagnostically from the Businger et al (1971) equations, given the calculated values of wind, temperature and humidity at the bottom of the upper layer and a derived surface temperature based on a flux balance equation. The fluxes present at the surface are net long-wave radiation, conduction to the snowpack, and sensible and latent heat convection. The turbulent convective processes are themselves dependent on the surface temperature, necessitating an iterative procedure for solution.

The snowpack equation involves the ordinary diffusivity equation with additional terms to account for internal heating due to short-wave (solar) radiation (the snow being translucent) and latent heat release due to melting and refreezing. The water that is produced by melting is assumed to leave the snowpack and enter the ground.

The modelling of the surface layer during stable conditions runs into a problem because the flux profile relationships are valid only for subcritical Richardson numbers (Ri < .21). When Ri approaches its critical value, the first-order turbulence is inhibited by strong buoyant forces. What happens in nature is that a laminar layer is created which effectively blocks momentum or heat transfer to the lower turbulent layer which continues to lose heat and momentum. When enough momentum has been lost to create sufficient shear between the laminar flow and the turbulent region, Ri decreases to subcritical values and a "burst" of heat and momentum, as described by Businger (1973), is delivered to the surface. These "burst" phenomena have been included in ad hoc fashion in the model.

DATA GATHERING IN A SNOW-COVERED FIELD

In support of the modelling effort, measurements were made over and in a snow-covered field in Lee Vining, CA. The area is about 8 km southwest of Mono Lake and is a fairly flat area until the Sierra Nevada range some 30 km west of the site. Measurements were made from 15-17 March 1978 during a period of high pressure and subsidence when daytime air temperature (at 2m) reached about 20° C while night-time readings dropped to near -9°C. The snowpack was some 0.75m deep initially with obvious melt taking place during the period.

Instruments were mounted with logarithmic spacing on an 8m mast connected to a recorder to obtain windspeed, temperature, and dew point at various heights averaged over 16 min. A net radiometer was used to measure surface temperature. Eight temperature probes were used in the snow to define the temperature profile. A field weather station was mounted 2m above the snow as a backup to the other instruments.

Once measurements were gathered, momentum and sensible and latent heat fluxes were computed for the period using a method described by Businger (1973). The method basically converts profile measurements, using a least-square fit, to flux data through the flux-profile relationships.

RESULTS

The model was run for 5 1/3 simulated days under conditions in qualitative agreement to the ones present at Lee Vining. The sky was assumed clear with the sun declination near 0°. Figs. 1 (a) - (b) show the bihourly averaged sensible and latent heat fluxes with the negative (positive) sign corresponding to negative (positive) stability. (Units are in cal cm^2 s^{-1} with 1 unit = 4.2×10^4 Wm^{-2}.) After an initial adjustment period, the heat flux is seen to be mostly directed toward the surface with but brief negative excursions right after solar noon (0 h corresponds to noon local time). The maximum positive flux is between 7 and 8 Wm^{-2} which is relatively small compared to radiative fluxes. The latent heat pattern is similar to the sensible heat record but achieves only about one half the magnitude. The noisy form of the record is probably due to the action of the parameterized bursts which occur intermittently.

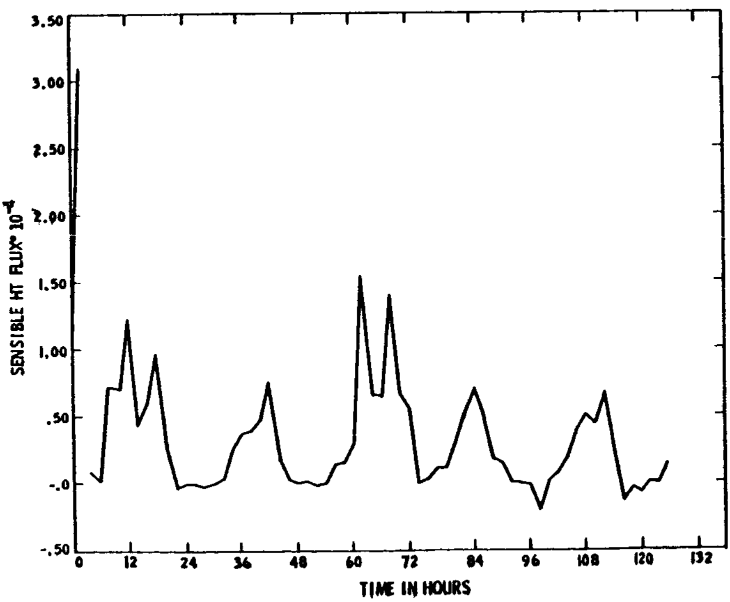

Fig. 1 (a) Computed sensible heat flux (in cal $cm^{-2}S^{-1}$) for 5 1/3 days beginning at noon.

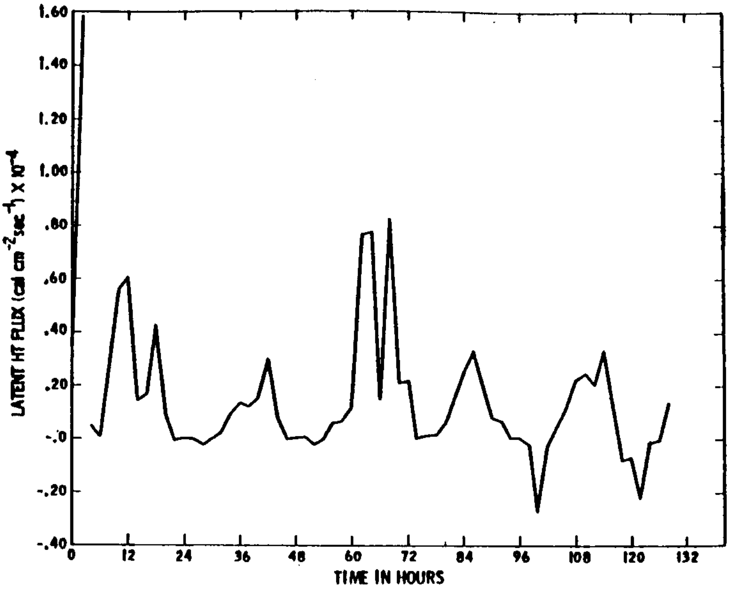

Fig. 1 (b) Computed latent heat flux for the same period.

Fig. 2 shows the sensible and latent heat fluxes calculated for the Lee Vining data. Here the fluxes were derived from 16 min averages of the heat and humidity profiles fitted by least squares to the similarity equations. The peak magnitudes are somewhat higher than the model values, but the noisy pattern, similar to the one produced by the model, is obvious throughout the night. The latent heat pattern, except for a brief departure around sunset, parallels the sensible heat record, again, in basic agreement with the model. A note of caution, however, must be inserted in the derivation of the heat fluxes from the profile data. A noontime profile measurement for the snow and atmosphere on 16 March, depicted in Fig. 3, shows an extremely large gradient (~ 16°C) between the snow surface and the atmosphere at 0.5m above the snow. The airflow is surprisingly laminar down to 0.5m (the wind data point at 6m should appear at 4m), with winds very light up to the top of the mast. With this kind of airflow, the surface layer is poorly defined, turbulent motion being suppressed to but a few centimeters above the snow. The matching of such profile data to well-developed turbulent structures becomes a highly dubious venture.

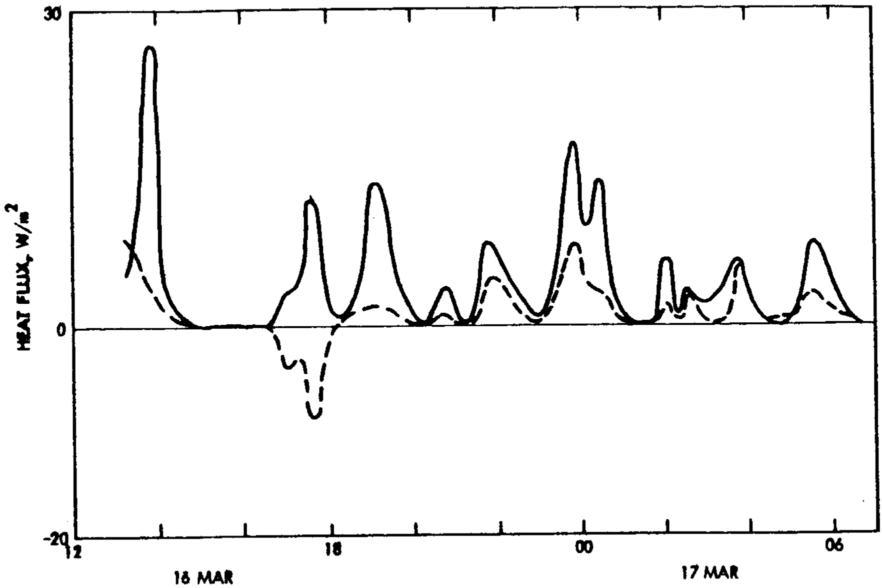

Fig. 2 Sensible (solid line) and latent heat (dashed line) fluxes at the surface based on measurements at Lee Vining from 1200 PST to 0600 PST, 16-17 March 1978.

CONCLUSIONS

The model apparently behaves well and predicts behavior which is at least in qualitative agreement with observed phenomena. A large gap remains in the understanding of the stable atmosphere, especially when Ri exceeds its critical value. Undertaking more measurements of this nature while continuing with the modelling effort will help in the re-evaluation of boundary layer theory for highly stable conditions.

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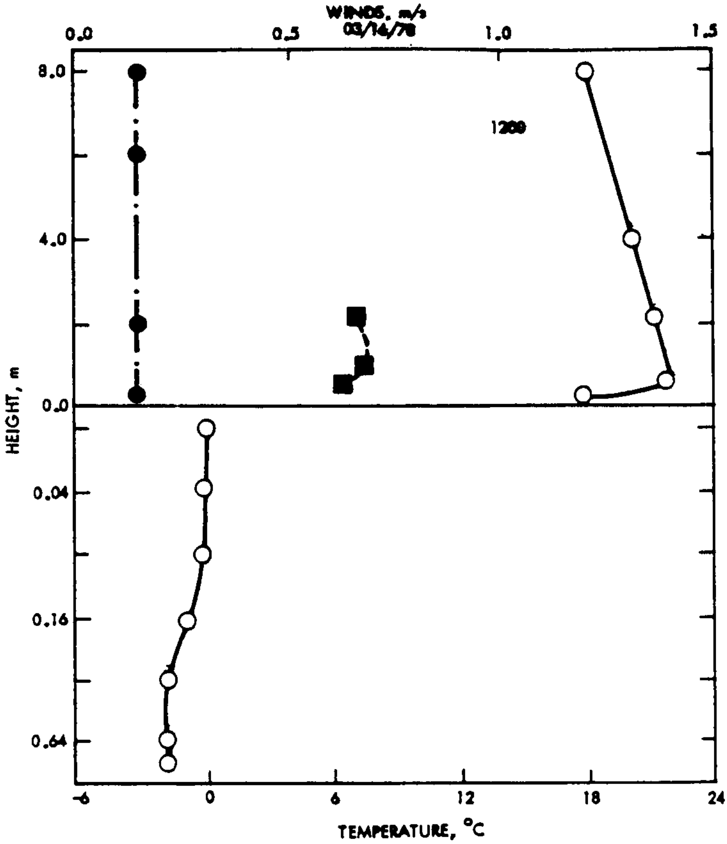

Fig. 3 Profiles of temperature (open circles, wind speed (black circles), and dewpoint (black squares) at 1200 PST on 16 March at Lee Vining. The solid line dividing upper and lower portions of the figure represents the snow surface, with logarithmically-spaced temperatures taken in the snow appearing below the line.