Lower Boundary Conditions and Large Scale Flow During Open Cell Convection Over the North Sea

by

Ernst Augstein
Max-Planck-Institut für Meteorologie

Abstract

The horizontal divergence of the large scale heat and water vapour transport in the lowest 500 m of the atmosphere has been calculated from the surface observations of the KonTur ships under the assumption of ideal mixing throughout this height regime. During conditions of open cell convection the following results are obtained: a) The horizontal air flow ist strongly convergent with values of convergence of up to $4 \cdot 10^{-5}$ s^{-1} on a 150 km grid scale. b) This kinematic situation causes a lateral heat and moisture inflow into the KonTur area within the subcloud layer which is twice as large as the heat flux and of the same amount as the water vapour input across the sea surface.

1. Introduction

The initialisation of close packed cellular convection between parallel plane surfaces can be described by Lord Rayleigh's (1916) stability criterion. Expansion of the linear theory to non-linear conditions has been suggested by several authors, among them Malkus and Veronis (1958), Schlüter et al. (1965), Krishnamurti (1975) and Shirer and Dutton (1979). The latter two as well as Moncrieff (1981) have made further attempts to treat atmospheric convection under more or less realistic flow conditions. Krishnamurti (1975) includes also the vertical motion within the cloud layer into her non-linear model calculations. She finds stable solutions for closed cells in a convergent and for open cells in a divergent horizontal flow below cloud base. In contrast to this result Sheu and Agee (1977) have observed during AMTEX that both open and closed cells may be present under large scale subsidence conditions. Thus, the reason for the development of the different convective flow structures in the atmosphere is still not known.

Furthermore some uncertainty exists whether earth surface or cloud base quantities must be chosen as lower boundary conditions in convection models. The subsequent estimates derived from KonTur observations suggest considerable differences between the heat and water vapour fluxes at the sea surface and at cloud base. The latter are strongly influenced by the large scale lateral transports in the subcloud layer.

2. KonTur Observations

During the convection and turbulence experiment KonTur 1981 open cloud cells were observed from 10 to 15 October 1981 in a north-westerly air flow over the North Sea. The mean horizontal wave length of the organized perturbations was about 50 km and the cloud layer thickness ranged from 2000 to 4000 m. Cloud base was observed between 500 m and 1000 m height.

From the daily averages of the hourly surface measurements of the 4 corner ships of the KonTur array - which are assumed to represent the large scale flow - the divergences of the horizontal velocity and of the transports of sensible and latent heat have been computed. Additionally the air-sea exchange of sensible and latent heat has been estimated with the aid of the aerodynamic bulk formulae, applying $C_H = 1.4 \cdot 10^{-3}$ and $C_E = 1.0 \cdot 10^{-3}$ for the transfer coefficients of heat and moisture, respectively.

The graphs displayed on the figure of the next page are obtained under the assumption that the layer between 10 m and 500 m height is well mixed. This prerequisite of height-independent wind velocity, potential temperature and specific humidity between 10 m height and cloud base is largely supported through the aerological soundings.

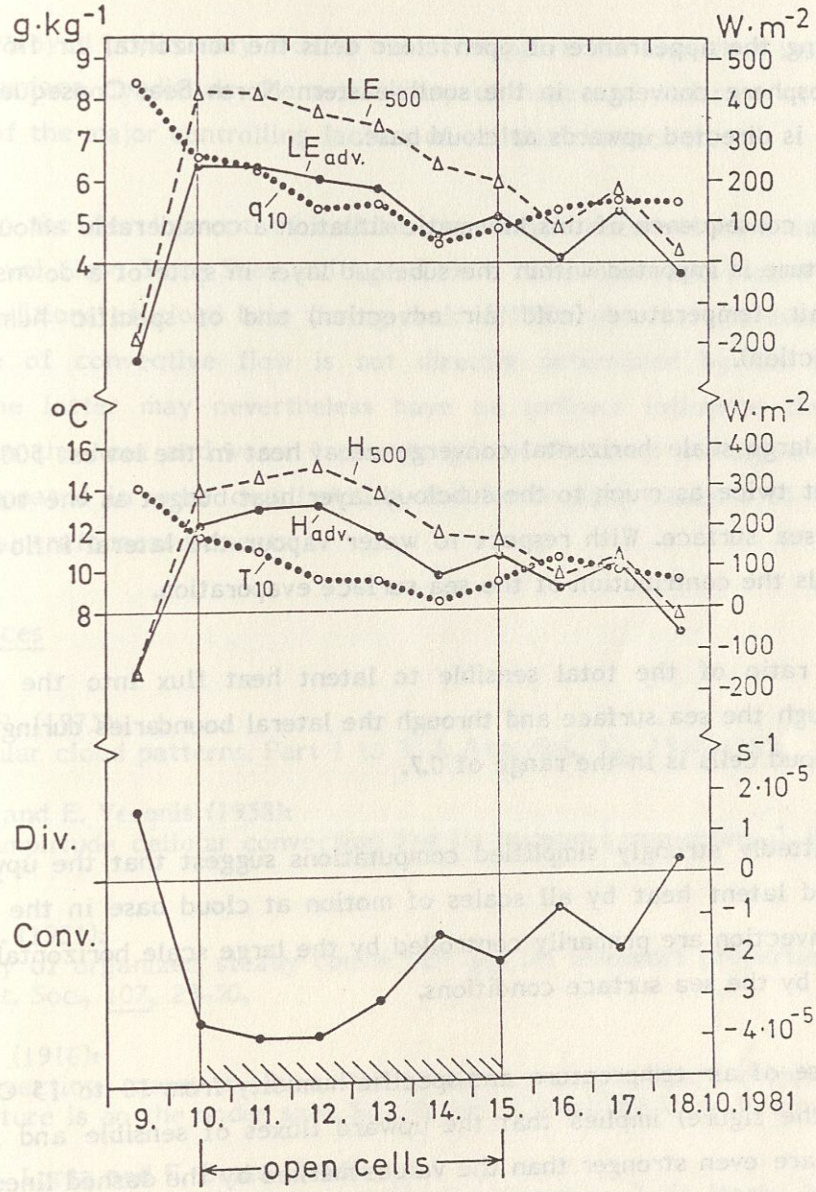

Figure: <u>Lower curve:</u> Daily averagesof the horizontal velocity divergence at the sea surface.

<u>Middle curves:</u> T_{10} = air temperature at 10 m height. H_{adv} = Heat inflow through the lateral boundaries below 500 m height. H_{500} = Vertical heat flux at 500 m height composed of the lateral input and the sea surface fluxes.

<u>Upper curves:</u> q_{10} = specific humidity at 10 m height. LE_{adv} = Latent heat inflow through the lateral boundaries below 500 m height. LE_{500} = Vertical heat flux at 500 m height composed of the lateral input and the sea surface evaporation.

The computations displayed on the figure manifest the following facts:

a. During the appearance of open cloud cells the horizontal air flow in the lower atmosphere converges in the south-eastern North Sea. Consequently, the mean flow is directed upwards at cloud base.

b. As a consequence of this kinematic situation a considerable amount of heat and moisture is imported within the subcloud layer in spite of a downstream increase of air temperature (cold air advection) and of specific humidity (dry air advection).

c. The large scale horizontal convergence of heat in the lowest 500 m contributes about twice as much to the subcloud layer heat budget as the turbulent flux at the sea surface. With respect to water vapour the lateral inflow more or less equals the contribution of the sea surface evaporation.

d. The ratio of the total sensible to latent heat flux into the subcloud layer through the sea surface and through the lateral boundaries during the occurance of cloud cells is in the range of 0.7.

These admittedly strongly simplified computations suggest that the upward fluxes of sensible and latent heat by all scales of motion at cloud base in the given case of cellular convection are primarily controlled by the large scale horizontal flow and only secondarily by the sea surface conditions.

The decrease of air temperature and specific humidity from 10 to 15 October (dotted curves of the figure) implies that the upward fluxes of sensible and latent heat at cloud base are even stronger than the values marked by the dashed lines of the figure if the radiational heat sink is neglected. This fact would in addition diminish the relative importance of the sea surface heat and water vapour fluxes for the moist convective process.

3. Conclusions

The above portrayed preliminary KonTur results support the idea that instead of the thermal sea surface conditions the availability of heat and moisture at cloud base might be one of the major controlling factors of cellular convection.

During KonTur the development of cellular convection occurred in a strongly convergent low level flow. Since Sheu and Agee (1977) found open and closed cells under subsidence conditions at cloud base during their AMTEX observations evidence grows that the type of convective flow is not directly determined by the large scale kinematics. The latter may nevertheless have an indirect influence through their contributions to the heat and water vapour budget of the lower atmosphere. This subject will be treated in more detail during the forthcoming analysis of the KonTur upper air and aircraft measurements.

4. References

Krishnamurti, R. (1975):
On cellular cloud patterns. Part 1 to 3. J. Atm. Sci., 32, 1354-1383.

Malkus, W.V.R. and E. Veronis (1958):
Finite amplitude cellular convection and its transport properties. J. Fl. Mech., 4, 225-260.

Moncrieff, W.W. (1981):
A theory of organized steady convection and its transport properties. Quart. J. Roy. Met. Soc., 107, 29-50.

Rayleigh, Lord (1916):
On convection currents in a horizontal layer of fluid when the higher temperature is on the under side. Sci. Papers, Cambridge Univ. Press, 6, 432-443.

Schlüter, A., D. Lortz and F. Busse (1965):
On the stability of steady finite amplitude convection. J. Fl. Mech., 23, 129-144.

Sheu, P.J. and E.M. Agee (1977):
Kinematic analysis and air-sea heat flux associated with mesoscale cellular convection during AMTEX 75. J. Atm. Sci., 34, 793-801.

Shirer, H.N. and J.A. Dutton (1979):
The branching hierarchy of multiple solutions in a model of moist convection. J. Atm. Sci., 36, 1705-1721.