

Reply

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Since Dr. Rossby is not available for consultation, the views expressed below are my own. First, with respect to specific details of Dr. Palmén's discussion, the following statements can be made.

a. The main point made in the discussion pertains to the function of mean meridional cells in the atmosphere in transporting angular momentum. It is impossible by means of present observations to detect the presence of such circulations directly in any undisputed fashion much less to estimate their magnitude, direction, or location. This circumstance results directly from the fact that if present they must be very slow, as has been pointed out by previous investigators. Palmén's mere reaffirmation that even slow circulations of this kind could accomplish a large momentum transport unfortunately does not add to our information concerning the fundamental problem involved, namely: do they exist in sufficient intensity to be of importance for this purpose? Any truly "critical analysis" would have to answer this question. Indeed the intensities which he quotes would, in my opinion, already be very considerable.

In the investigations carried out at M.I.T. the approach has been as follows. If meridional cells are of crucial importance for the angular-momentum balance, any approach to the subject which neglects them should lead to crucial difficulties. A study of the angular-momentum balance neglecting these circulations was made by Widger and reported in the preceding issue of this JOURNAL. It was found that no crucial difficulty presented itself; in fact, the momentum transport showed a very reasonable distribution *at all levels studied*. Actually, Widger's investigation may be looked upon as the *first systematic effort using appropriate and extensive data* to detect indirectly the presence of mean meridional cells.

b. According to Palmén's own admission, the term involving the earth's rotation in my equation cannot in the long run account for the *total* necessary transport across a given latitude circle. It therefore follows that if mean meridional circulations are important, their contribution to this total transport must result from the term involving the product of the wind components. In view of this circumstance, Palmén is mystified by the seeming lack of importance of the

earth's rotation in the process. Apparently he confuses the angular-momentum balance of the atmosphere with a rational theory for the general circulation. The angular-momentum balance merely states one integral requirement for the mechanism of the general circulation, just as continuity relationships (mass balance) furnish another such requirement, indeed not involving the earth's rotation. All that we can accomplish by considering the angular-momentum balance is to see how the atmosphere *as we find it from observation* achieves internal consistency in one necessary respect.

c. It has never been shown that the motions of the atmosphere as we know them, even in a vague way, resemble the motions that might result initially were the general circulation to start from rest. In all probability, there never was such an initial instant.

d. Apparently Palmén suspects me of highest heresy lest I suggest that the energy production process may also be accomplished without the aid of meridional circulations. This I have indeed proposed, and one outcome is reported by Dr. H. C. Willett in correspondence published in the preceding issue of this JOURNAL. Other results, in some ways more substantial, have been obtained since then, and will be published in due course. If to this we add Widger's result, the hypothesis that meridional cells are of small importance seems to be bearing fruit. Indeed if such are the fruits of heresy, then I say let us have more heresy.

In a broader sense, the fundamental issues which Dr. Palmén raises far transcend the specific point under consideration. A complete discussion of these issues deserves much more space than can be allowed here. Nevertheless a few statements at least to indicate the nature of these questions are much in order.

Dr. Palmén speaks of "the whole foundation of dynamic meteorology." What does he mean by it? Certainly he does not mean the collection of sundry differential equations such as the hydrostatic equation, the continuity principle, *etc.*, which is found in textbooks. Does he mean some rational solution of these equations which purports to give the essential mechanism of the general circulation? To the best of my information the problem is so difficult that we have no such solution and cannot hope for one in the directly foreseeable future. Any insistence that at the present time the fundamental facts concerning the mechanism of the general circulation have been established is unfounded and misleading. The history of science and all of our general experience in meteorological research points to the inherent danger of the premature acceptance of superficially plausible hypotheses as fact. I therefore maintain that under present circumstances we must encourage free experimentation with various hypotheses and proposals in order to see which ones lead to the *discovery of new observationally verifiable facts*, since definitive criteria for acceptance or rejection are lacking.