Present-day Concepts of Atmospheric Frontogenesis.  
Part 2. Some Results of Computation from the Real Data  

N. P. Shakina, A. R. Ivanova, and N. I. Komas’ko  

Hydrometeorological Research Center of the Russian Federation,  
Bolshoi Predtechenskii per. 11–13, Moscow, 123242 Russia, e-mail: chakina@mecom.ru  

Received April 23, 2014  

Abstract—Reviewed are the recently published results of vector frontogenesis computation from the real and model data for a number of case studies. The results revealed that the development of troughs and ridges in upper-level frontal zones, jet stream meandering and intensification, cyclonic eddy generation and evolution are due to the specific distribution of frontogenesis. Main quantitative characteristics of vector frontogenesis are its components along and across the potential temperature contour and at the isobaric surface. The first component describes the frontogenetic effect of isotherm rotation and is called the rotational frontogenesis; the second component represents a measure of the change in the horizontal temperature gradient and is called the scalar frontogenesis. Frontogenesis characteristics are used not only as informative diagnostic parameters but also as the indicators of the future transformation of atmospheric fields. Presented are preliminary results of frontogenesis computation for a case of the high-amplitude wave in the upper-level frontal zone with the intense jet stream and deep stratospheric intrusion. It is demonstrated that the tropopause sinking on the cold side of the upper-level frontal zone is caused mainly by the scalar frontogenesis whereas the rotational frontogenesis plays a primary role in the area of the sharp rotation of isohypses causing the intensive rising of air on the warm side and the sinking on the cold side. The comparison of computations based on the objective analysis and global semi-Lagrangian atmospheric model output data, demonstrates that the jet streams, tropopause topography, and frontogenesis effect distribution are simulated correctly from the qualitative point of view while the forecasting fields are significantly smoothed in terms of numbers.

DOI: 10.3103/S1068373914110016

INTRODUCTION

The frontogenesis defined as the process of the change in the horizontal temperature gradient in the individual particle is one of the main mechanisms of the redistribution of properties among the motions of different scales. One more fundamental mechanism that causes the transformation of atmospheric fields and the evolution of weather-generating processes is the hydrodynamic instability resulting in the formation of waves and eddies in the zones of temperature and wind contrasts. The hydrodynamic instability was studied very intensively during almost the whole 20th century; this influenced greatly the development of numerical weather prediction methods. The investigation of frontogenesis causing the formation of these contrast zones has attracted the attention of scientists. The computations of frontogenesis characteristics as diagnostic parameters recently have become more widely used for studying the wide range of atmospheric processes from synoptic scales to mesoscales.

In the present paper consisting of two parts, the review is presented of frontogenesis study in a vector sense including both the approaching of isotherms and their rotation. In the first part of the paper [3], theoretical concepts are analyzed and the formulas used for diagnostic computations are presented. In the second part, the published physical conclusions are reviewed made as a result of frontogenesis computation from the real and model data and some authors’ calculations are presented.

The major property of frontogenesis is its role of the generator of vertical circulations which can be both thermally direct (upward motions on the side of the warmer air) and thermally opposite (upward motions on the side of the colder air). The zones of cloudiness and precipitation are developed at atmospheric fronts in upward branches of circulation cells. Downward motions in circulation cells caused by the frontogenesis in the tropospheric column and jet stream layer form stratospheric intrusions: the zones of the sinking of
stratospheric air to tropospheric levels. Besides, it is known that the frontogenesis in the free atmosphere creates the conditions for the surface cyclogenesis and is a predecessor of the latter. The visible evolution of cyclones in lower layers including the occluding stage is also associated with the upper-level frontogenesis. It is also known that the conditions for the convective instability are formed and the bands of convective clouds and shower precipitation are developed in ascending branches of circulation cells that accompany the frontogenesis. Other important effects of frontogenetic processes were also revealed; they have been actively studied by means of numerical modeling, diagnostic computations, and direct instrumental measurements.

**VERTICAL CIRCULATIONS INFRONTAL ZONES**

The first hydrodynamic model of two-dimensional frontal zone, frontogenesis, and vertical circulations in the limited layer in quasigeostrophic approximation was developed in the papers by J.S. Sawyer [29, 30] and A. Eliassen [10, 11]. The main result of these papers consisted in the revelation of the following regularity (known as the Sawyer–Eliassen theorem): vertical circulations being transversal to the frontal zone in quasigeostrophic approximation are compensatory with respect to the frontogenetic effect of horizontal wind. The compensatory nature of circulations means their striving for recovering the balance of the thermal wind disturbed by the frontogenetic advection.

After that this area of research has been developed in the series of papers dealing with the simulation of the evolution of linear deformation field or baroclinic unstable disturbances where, as known, the model front having the basic features of real atmospheric fronts are formed and developed.

In the papers by B.J. Hoskins [12, 13] and B.J. Hoskins and F.P. Bretherton [14] the classic models were developed of frontogenesis in the linear deformation field on the assumption of nonviscous adiabatic movement and in geostrophic moment approximation (see also [2] for the details). The solutions obtained in these papers mostly analytically demonstrate the development of upward motions on the warm side of the developing frontal zone and the sinking on the cold side. The tropopause fold is formed in the upper troposphere as well as the jet stream on its warm side. The zone of sharp temperature contrasts is formed near the underlying surface and the baroclinic zone sloping towards the cold air is formed in the tropospheric column.

In this model the tropopause sinking on the cold side of the jet stream was obtained; however, it was less intensive than indicated observations since [27] (these were the aircraft measurements of temperature and wind; they are considered in detail in [17]). More realistic conclusions were made in numerical models [9, 25, 26]. In particular, the important conclusion that many essential properties of the tropospheric frontal zone depend on the type of advection in the model with complete equations [16] taking account of the cold and warm advection along the front. For example, the downward branch of circulation in the case of cold advection turns out to be more intensive and is shifted towards the warm air so that the maximum sinking in agreement with observations takes place directly in the frontal zone. M.A. Shapiro [35] supposed using the analysis of the data of airborne measurements in the framework of the Sawyer–Eliassen model that the presence of cold advection at the cyclonic wind shear can strengthen the downward branch of the direct circulation cell in the zone of the flow convergence in the jet stream entrance and shift it toward the warm side of the upper-level frontal zone. Model computations corroborated this hypothesis which was called afterwards the Shapiro’s effect (in [28] for the first time) or Shapiro’s conceptual model.

The Shapiro’s conceptual model in the slightly more detailed form proceeds from the idea about the presence of the upper-level frontal zone with the converging northwestern flow where isentropes are almost parallel to isohypses at the initial moment. In about 24 hours, the frontal zone changes so that the thermal trough lags behind the baric trough that results in the cold advection along the frontal zone (cold advection stage). In one more day, the trough in the field of geopotential heights turns into the closed zone of low pressure (closed cyclone stage) with the warm advection in the front part and cold advection in the rear. Finally, in one more day, the closed cyclone opens and turns into the converging southwestern flow with the geostrophic warm advection in the frontal zone (warm advection stage). Actually, this scheme describes the process of the development of meandering of the upper-level frontal zone and associated jet stream.

The observations summarized in [31] demonstrate that such evolution is not always observed. However, the close relation between the advection type and jet stream evolution is always observed not only in the northwestern part of the jet stream but also in its southwestern part although the duration of evolution stages is often larger.

It should be stressed that the change in the structure of the circulation cell, the strengthening of the downward branch in the thermally direct cell, and the displacement of the intense narrow downward branch