



Occluded fronts

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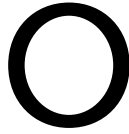
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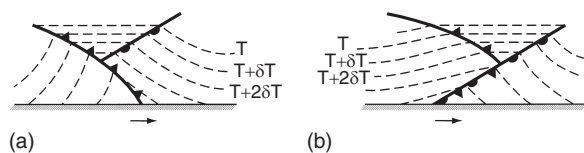
OCCLUDED FRONTS

An *occluded front* is generally believed to result from the merger of a cold front and a warm front during the life of a midlatitude cyclone. The occluded front can often be identified by a tongue of warm air connecting the low-pressure center to the pool of much warmer tropical air in the warm sector of the cyclone. At the surface, a wind shift and pressure minimum usually coincide with the front. More generally, the formation of an occluded front occurs during the *occlusion process*, a stage in the life cycle of an extratropical cyclone when the warm sector air is separated from the low center near the surface and the low center becomes wrapped in cold air. [See Cyclones, *subentry on* Midlatitude Cyclones.] Although controversy has surrounded the occlusion process ever since its discovery, a new paradigm for the occlusion process resolves many of these previous controversies.

The Polar Front Theory of Midlatitude Cyclones. The occluded front was first discovered by Tor Bergeron while investigating a cyclone on 18 November 1919 off the Norwegian coast. He noticed that the warm sector shrank and separated from the low center as the cyclone aged, implying that the static model of extratropical cyclones presented by Jacob Bjerknes needed revision. Bergeron noticed that the faster-moving cold front approached, and eventually appeared to

ride up over, a slower-moving warm front (in this case, impeded from coming inland by the coastal mountains of the Scandinavian peninsula). With the meeting of the two fronts, the warm air between them was forced aloft, leaving a boundary between two polar air masses that he called the occluded front. Bergeron later determined that the occluded front formed when the cold front caught up to the warm front, because the cold front was rotating around the cyclone center faster than the warm front did. Bergeron's occlusion process was incorporated into the landmark paper by Jacob Bjerknes and Halvor Solberg in 1922, "Life Cycle of Cyclones and the Polar Front Theory of Atmospheric Circulation." The polar front theory was the first to describe midlatitude cyclones undergoing an evolutionary life cycle rather than maintaining a static structure.

During the formation of an occluded front, the Bergen meteorologists believed that if the polar air behind the cold front was colder (and thus denser) than the polar air ahead of the warm front, then this less dense air and the associated warm front would ride up off the ground over the cold front as the occluded front formed. This type of structure is called a cold-type occlusion (Figure 1a). In contrast, if the polar air ahead of the warm front was colder than the polar air behind the cold front, then the cold front would be lifted



OCCLUDED FRONTS. Figure 1. *Idealized models of occluded fronts: (a) cold type and (b) warm type.* The sketches represent frontal surfaces (solid line) and isotherms (dashed line) in vertical cross sections normal to occluded fronts, which are moving from left to right. (From Wallace and Hobbs, 1977, p. 128. Copyright 1977 by Academic Press.)

off the ground by the warm front, thus forming a warm-type occlusion (Figure 1b).

Challenges to Polar Front Theory. After this theory was proposed, serious criticisms were leveled against the polar front theory of occlusion. These criticisms can be grouped into four categories.

The first category of criticisms encompasses objections that the structure of the ideal occluded front could be duplicated without the cold front ever joining the warm front. Indeed, questions arose about how representative the frontal catch-up model was for most midlatitude cyclones, and whether the occluded stage of a midlatitude cyclone could be arrived at by other means. In particular, the cyclones occurring in the lee of the Rocky Mountains sometimes possessed the structure of an occluded cyclone without undergoing the catch-up of the warm front by the cold front. In other examples, satellite investigations showed that occlusion-like features could form without catch up of the two fronts. In a process called instant occlusion, a polar cloud vortex approaches and merges with a polar front cloud band, forming a single comma-shaped cloud mass out of two distinct cloud masses. The resulting structure has similarities with the classical occluded cyclone without ever having undergone the catch up. A third example comes from rapidly developing cyclones over the oceans, which often undergo a different frontal evolution from the polar front model (the Shapiro–Keyser cyclone model). [See *Cyclones, subentry on Midlatitude Cyclones.*] In these oceanic cyclones, the cold front separates from and then moves perpendicularly to the warm front, and hence never catches up. The strong winds

ahead of the warm front carry the warm front around the low center, forming a so-called back-bent front. [See *Cyclones, subentry on Explosive Cyclones.*] By generalizing the occlusion process to one in which the warm sector air is separated from the low center and the low center becomes wrapped in cold air, these other cyclone evolutions can also be viewed as undergoing the occlusion process.

The second criticism is that observations of occluded fronts show that the temperature structure across the occluded front does not determine whether a warm-type or cold-type occlusion forms. In fact, few, if any, examples of cold-type occlusions exist, despite the temperature being colder behind the cold front than ahead of the warm front. Instead, recent research suggests that whether the resultant structure is a cold or warm occluded front is controlled by the difference in static stability across the occluded front, not the difference in temperature. Thus, because warm frontal zones are characterized by greater static stability than cold frontal zones, the resulting occluded front is more likely to be a warm-type occluded front with the cold frontal zone being lifted over the warm frontal zone.

The third criticism is that the occlusion process does not represent the end of development of a midlatitude cyclone. Indeed, many midlatitude cyclones, especially rapidly developing ones, continue to deepen after forming an occluded front. It is now recognized that the process of occlusion is distinct from the process of cyclone deepening. In fact, only cyclones that undergo deepening are likely to undergo occlusion.

The fourth criticism is that the cloud and precipitation structure of an occluded front is more complicated than the simple picture of the merger of a cold front and warm front suggests. For example, mesoscale observations of occlusions in the 1960s and 1970s by Carl Kreitzberg led to the discovery that the structure of occlusions was more complicated than originally believed. He identified a prefrontal surge of dry air above the warm front, warm tongues of air associated with locally heavy precipitation, and secondary cold fronts behind the primary surface occluded front. Kreitzberg also

found that younger occlusions often extended vertically throughout the lower troposphere (atmospheric region closest to Earth) and that they split to form features such as squall lines, secondary cold fronts, and rain bands. In contrast, the older occlusions often dissipated, never reaching the ground. Thus, the clouds and precipitation associated with occluded fronts are more complicated than the polar front theory.

Modern Perspective. Taking into account these criticisms, a modern view of the formation of an occluded front can be described as follows. If the cyclone becomes intense enough, its structure may begin to change. As the cyclone intensifies, it draws warm and cold air around its circulation. As the fronts rotate around the cyclone center, they lengthen and approach each other. As cold air encircles the low and the warm air is lifted from the surface over the warm front, the warm sector narrows. Eventually, the two cold air masses meet and lift all the intervening warm air aloft; the remaining boundary is the occluded front. The occluded front continues to be lengthened by rotation and deformation of the flow around the cyclone.

In some cases, the dry airstream from the upper troposphere (also called the dry slot) may descend over the occluded front. The dry airstream usually represents the westernmost limit to clouds and precipitation associated with the cyclone. [See Cyclones, *subentry on* Midlatitude Cyclones.]

Weather. Occluded fronts have been described as “back-to-back front,” with the weather ahead of the occluded front being similar to that in advance of a warm front, and the weather behind it being similar to that behind a cold front. Such an expression is not an accurate way to describe the weather associated with occluded fronts, however. A few hundred kilometers ahead of the occluded front, the highest cirrus clouds are first visible. As the occluded front approaches, the height of the cloud base lowers and the clouds thicken and become darker. Persistent rain, freezing rain, sleet, and/or snow may fall from *nimbostratus* clouds, and heavier rain and thunderstorms may be embedded along the elevated warm front and at the prefrontal

surge. After the passage of the prefrontal surge or the surface occluded front, rapid clearing usually ensues as the dry airstream aloft appears. Temperatures at the surface usually remain nearly constant or reach a slight maximum during the passage of the occluded front. Winds at the surface are usually from an easterly or southerly direction ahead of the occluded front and shift to westerly or northerly after its passage. The dew-point temperature (a direct measure of the amount of moisture in the air) usually decreases with the passage of an occluded front.

On the western coast of the United States, the polar air behind an occluded front comes from the ocean and is warmer and moister than the continental air ahead of the system, and so the temperature and dew point will often rise behind an occluded front coming in off the Pacific Ocean. This is one example of the ways local topography and geography can affect the kind of weather associated with occluded fronts.

[See also Fronts; and Occlusion.]

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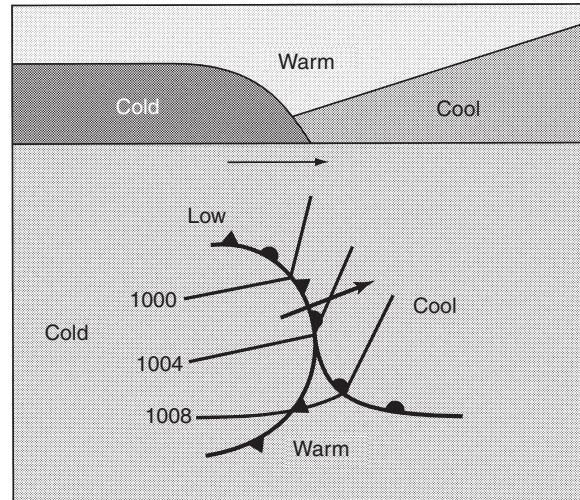
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David M. Schultz

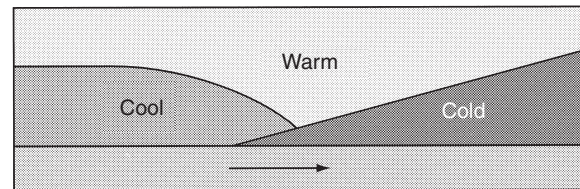
OCCLUSION

The Norwegian cyclone model was the first to describe the evolution of midlatitude cyclones. In this conceptual model, cyclones are disturbances that develop along fronts. In a developing storm there are two fronts: a warm front preceded by warm-air *advection*, and a cold front followed by cold-air advection. The warm front is ahead of the cold front; however, owing to stronger steering winds associated with the cold front, the cold front travels faster than the warm front. In mature cyclones, the part of the cold front nearest the storm catches up to the warm front, forming what is known as an occluded front; the process by which an occluded front forms is referred to as occlusion (see Figure 1). The intersection of the occluded front, cold front, and warm front is known as the triple point. This classical theory of how an occluded front forms has been controversial since it was first published in 1922, and alternative theories have since been proposed (e.g., Davies, 1997) [see Occluded Fronts].

It is believed that an occlusion usually signals that the storm has finished developing and is beginning to decay, though the data seem to show that storms continue to deepen even after the occlusion. Sometimes a secondary storm will form at the triple point. Occluded cyclones also tend to be vertically stacked or aligned (that is, the surface cyclone lies directly beneath the upper-troposphere storm),



(a)



(b)

OCCLUSION. Figure 1. (a) A cross-sectional illustration of an occluded front. First-order discontinuity in the pressure field is represented by the isobars in this cold-type occlusion. (b) A cross-sectional illustration of a warm-front type occlusion. (Adapted from Cole, 1980.)

reducing the storm's forward speed. When an occlusion occurs, the warm air near the surface storm center is forced aloft and is replaced by colder air. According to the Norwegian model, when the warm air is forced aloft this stabilizes the atmosphere, and steady precipitation is cut off and replaced by drizzle. Unlike the case around cold fronts and warm fronts, no strong thermal gradients exist adjacent to an occluded front. The air behind an occluded front can be either colder (referred to as a cold occlusion) or warmer (a warm occlusion) than the air ahead. However more recent studies question the assumptions of the Norwegian model. For example heavy precipitation bands do occur even after the occlusion process, occluded fronts can have strong thermal gradients (e.g., Shultz and Vaughn 2010) [see Cyclogenesis; Fronts; and Occluded Fronts].