# Synoptic Meteorology I: Jets and Jet Streaks

## For Further Reading

Sections 2.7 and 2.8.2 of *Synoptic-Dynamic Meteorology in Midlatitudes, Vol. II* by H. Bluestein go into extensive detail regarding the structure of jets. Jets and their relationship with horizontal temperature gradients are discussed in Chapter 11 of *Weather Analysis* by D. Djurić.

## Introduction

A jet or jet streak is an intense, narrow, quasi-horizontal current of wind that is associated with large vertical wind shear. The qualifiers "intense" and "narrow" are slightly subjective, however. A jet can refer to one of two features:

- A climatological maximum in the zonal wind. The temporal duration of the climatology can vary from on the order of one week to on the order of one year.

- A localized corridor of high wind speed at one given analysis time. This manifestation of a jet is that which is typically analyzed on synoptic-scale weather maps and that which we will consider within this class.

In this course, we will focus upon upper-tropospheric manifestations of jets. We will only cursorily discuss the low-level jet, a lower-tropospheric jet. Likewise, we will focus upon jets located within the middle and higher latitudes. There exist jets within the tropics, such as the African easterly jet and tropical easterly jet, but the study of these features is beyond the scope of this course.

## The Polar Jet

The polar jet (or polar-front jet) is located along the tropopause, or approximately 200-300 hPa in the midlatitudes. Due to the thermal wind relationship, the polar jet is associated with large quasi-horizontal temperature gradients in the lower troposphere (usually with zonally oriented isotherms and thus also a meridionally oriented temperature gradient) and large vertical wind shear (usually westerly). These features are often associated with the polar front, the name given to cold fronts that trail cyclones in polar front theory.

As noted above, the polar jet and quasi-horizontal temperature gradients are linked through the thermal wind relationship. Winds along the polar jet typically have a westerly component to them; concordantly, given westerly vertical wind shear and thus a westerly thermal wind, relatively cold lower-tropospheric air is found poleward of the polar jet and relatively warm lower-tropospheric air is found equatorward of the polar jet. Meridional undulations of the jet are associated with poleward and equatorward displacements of warm and cold air, respectively.

Presuming that the polar jet is a westerly jet, the height of the tropopause is lower poleward and higher equatorward of the polar jet. This can be viewed in the context of thickness arguments, with greater (lesser) tropospheric depth where it is relatively warm (cold). Climatologically, the height of the tropopause gently slopes upward from the pole to the equator through the polar jet.

A vertical cross-section through the polar jet and associated polar front is depicted in Fig. 1. The polar front slopes northward with height, from south of Norman, OK (OUN) toward North Platte, NE (LBF), as indicated by the sloping corridor of tightly packed isentropes. Winds are northerly beneath the front and west-southwesterly ahead of and atop the front. The jet is centered at around 300 hPa at Dodge City, KS (DDC) and OUN and has maximum wind speeds of 140-150 kt at tropopause height. The tropopause itself is higher to the south, in the warm air, and lower to the north, in the cold air. The tropopause is locally depressed downward where it intersects the polar front. The polar jet is found atop the cold frontal zone, as expected from thermal wind balance.

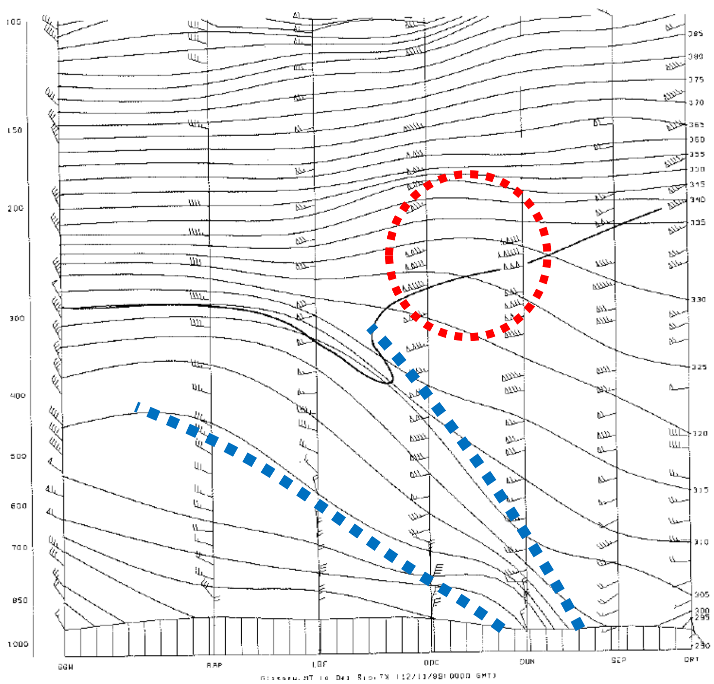

**Figure 1**. Vertical cross-section of potential temperature (contoured every 5 K) and wind (half-barb: 5 kt, full barb: 10 kt, pennant: 50 kt) through a strong polar front (blue annotation) and polar jet (red annotation). The thicker black line denotes the approximate location of the tropopause. The northern extent of the cross-section, at left, is at Glasgow, MT. The southern extent of the cross-section, at right, is at Del Rio, TX. Reproduced from *Synoptic-Dynamic Meteorology in Midlatitudes (Vol. II)* by H. Bluestein, their Fig. 2.86.

**The Subtropical Jet**

Like the polar jet, the subtropical jet is located along the tropopause, or approximately 200 hPa in the subtropics and midlatitudes. The subtropical jet is primarily a wintertime phenomenon found between 20-35°N/°S latitude. In the time-mean view, the subtropical jet can have the appearance of being a continuous jet around the globe within the subtropics. Consequently, the subtropical jet can be viewed as a quasi-steady or quasi-persistent feature of the cold-season climatology. On a day-to-day basis, however, the subtropical jet may merge with or become indistinct from the polar jet, particularly when the latter protrudes equatorward.

A vertical cross-section through the subtropical jet is depicted in Fig. 2. Unlike the polar jet, the associated frontal zone is primarily found in only the middle-to-upper troposphere. The subtropical jet itself is centered at around 200 hPa at Waycross, GA (AYS) and has maximum wind speeds of 120-125 kt at tropopause level. The tropopause itself, though not explicitly depicted on this figure, is higher to the south and lower to the north.

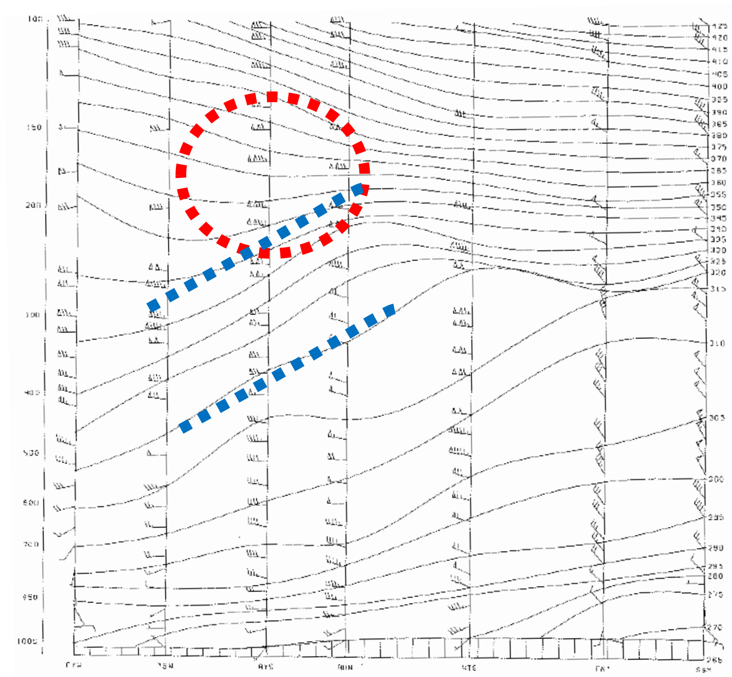

**Figure 2**. As in Fig. 1, except for a south-to-north (left-to-right) vertical cross-section through the subtropical jet. Here, the blue annotation reflects the region of largest horizontal temperature gradients rather than a true frontal zone. Reproduced from *Synoptic-Dynamic Meteorology in Midlatitudes (Vol. II)* by H. Bluestein, their Fig. 2.92.

The dependence of the thermal wind on the Coriolis parameter, which is lowest at low latitudes, means that a relatively weak horizontal temperature gradient (such as found at mid-levels with the subtropical jet) in the subtropics can be accompanied by relatively large vertical wind shear.

The subtropical jet can be viewed from two complementary perspectives. The first relates to the Hadley and Ferrell general circulation cells. The Hadley cell, the meridional vertical circulation that characterizes the tropics, is associated with poleward flow aloft and equatorward flow near the surface. The Ferrell cell, the meridional vertical circulation that characterizes the midlatitudes, is associated with equatorward flow aloft and poleward flow near the surface. Together, this results in convergence aloft and divergence at the surface at subtropical latitudes, acting to intensify the meridional temperature gradient aloft and weaken it at the surface. The latter explains why there is often little or no frontal structure at the surface beneath the subtropical jet. From thermal wind balance, the meridional temperature gradient aloft, with warmer air toward the equator and colder air toward the poles, gives rise to the westerly subtropical jet.

The second relates to the conservation of absolute angular momentum in the context of the Hadley cell. Absolute angular momentum is a function of the Earth's rotation and an air parcel's velocity; in the absence of friction, an air parcel generally strives to conserve absolute angular momentum as it follows the wind. Consider an air parcel that is initially at rest at the Equator within the upper troposphere. If this parcel is displaced poleward, such as within the poleward flow aloft found with the Hadley cell, it will accelerate to conserve absolute angular momentum. It will also deflect toward a westerly direction due to the Coriolis force, with rightward deflection in the northern hemisphere and leftward deflection in the southern hemisphere, giving rise to the subtropical jet.

**The Low-Level Jet**

There are two types of low-level jets (or LLJs) that are of interest: nocturnally driven LLJs and LLJs induced by upper tropospheric and/or synoptic-scale forcing. The two types of LLJs are not mutually exclusive of one another; in the presence of synoptic-scale forcing, a southerly LLJ over the Great Plains may have structural characteristics of both types of LLJs.

Nocturnally driven LLJs are at their maximum intensity at night; there may be little to no evidence of a nocturnal LLJ during the daytime hours. They owe their existence to sloping topography, such as is found across the Great Plains of the United States (with higher terrain to the west gradually sloping down toward the east), and to inertial oscillations associated with unbalanced ageostrophic flow. Nocturnal LLJs are typically found at or just above the surface. In the Great Plains, they are often associated with southerly winds of >15 m $s^{-1}$ and may influence thunderstorm development, maintenance, and upscale growth.

LLJs induced by upper-tropospheric and/or synoptic-scale forcing are often found in association with upper-level jets and synoptic-scale cyclones. The conveyor belts of midlatitude synoptic-scale cyclones that we will examine in a subsequent lecture can be viewed, to first approximation, as LLJs. The presence of such LLJs is not dependent upon the time of the day; rather, they can appear at all times of day. Likewise, these LLJs can be every bit as strong as their nocturnal counterparts. As compared to nocturnal LLJs, however, LLJs induced by other forcing are typically found at slightly higher altitudes (~850 hPa).