Sutcliffe Development Theory

Sutcliffe (1947) and Sutcliffe and Forsdyke (1950) used the vertical divergence profile between 1000 and 500 hPa to describe surface development. They developed a diagnostic expression for 1000 hPa divergence by subtracting the quasi-geostrophic vorticity equation (form that neglects friction, twisting, and vertical advection) at 1000 and 500 hPa, and assuming that 500 hPa is the level of nondivergence. This diagnostic expression for 1000 hPa divergence goes as [eq. 8.7 in Carlson (1998), p. 183]

$$-\vec{\nabla}_p \bullet \vec{V}_0 = \underbrace{-\frac{2}{f_0}\vec{V}_T \bullet \vec{\nabla}_p \zeta_0}_{A} \underbrace{-\frac{1}{f_0}\vec{V}_T \bullet \vec{\nabla}_p \zeta_T}_{B} \underbrace{-\frac{1}{f_0}\vec{V}_T \bullet \vec{\nabla}_p f}_{C} \quad .$$

Martin (2006, p. 160), his eq. 6.23, presents the complete form of the Sutcliffe Development equation without the 500 hPa level of nondivergence assumption. In both the Carlson (1998) and Martin (2006) forms, upward (downward) vertical motion is the result of greater convergence (divergence) near the surface compared to aloft, which is forced by (anti)cyclonic vorticity advection by the thermal wind. Computation of both the Carlson (1998; used here on this web page) and Martin (2006) forms for the 1000–500 hPa layer would look qualitatively similar.

Term A: Advection of 1000 hPa geostrophic relative vorticity by the 1000–500 hPa thermal wind. This term **controls the surface cyclone motion**.
Term B: Advection of 1000–500 hPa thermal vorticity by the 1000–500 hPa thermal wind. This term **controls the development of vorticity over the center of the surface cyclone**.
Term C: Advection of planetary vorticity by the 1000–500 hPa thermal wind. This term is relatively small compared to A and B, but can contribute to surface cyclone motion and the development of vorticity over the surface cyclone center.

Synoptic Application: Regions of 1000 hPa convergence (divergence) are associated with a positive (negative) contribution from the terms on the right-hand-side.

Further Reading: Carlson (1998), pp. 182–185; Martin (2006), pp. 157–160.

References:

Carlson, T. N., 1998: *Mid-Latitude Weather Systems.* Amer. Meteor. Soc., 507 pp.

Martin, J. E., 2006: *Mid-Latitude Atmospheric Dynamics: A First Course.* John Wiley & Sons, Ltd, 324 pp.

Sutcliffe, R. C., 1947: A contribution to the problem of development. *Quart. J. Roy. Meteor. Soc.,* **73,** 370–383.

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Key for symbols:

$\vec{\nabla}_p$	gradient on a pressure surface (m^{-1})
$\vec{V}_0$	geostrophic wind at 1000 hPa (m s^{-1})
$\vec{V}_T$	thermal wind in the 1000–500 hPa layer (m s^{-1})
ζ_0	geostrophic relative vorticity at 1000 hPa (s^{-1})
ζ_T	thermal vorticity in the 1000–500 hPa layer (s^{-1})
f	Coriolis parameter [s^{-1}; f_0=1.0×10^{-4} s^{-1} (negative in SH)]

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