Sutcliffe-Petterssen Development Theory

Following the work of Sutcliffe (1947) and Sutcliffe and Forsdyke (1950), Petterssen (1956) derived a similar expression to describe surface development. Assuming that divergence at 500 hPa is negligible compared to that at the surface, and vorticity advection at the surface is negligible compared to that at 500 hPa, the following 1000 hPa geostrophic relative vorticity tendency equation results [eq. 8.10[1] in Carlson (1998), p. 185]

$$\frac{\partial \zeta_0}{\partial t} = \underbrace{-\vec{V}_5 \bullet \vec{\nabla}_p \left(\zeta_5 + f\right)}_{A} - \frac{R}{f_0}\nabla^2\left[\underbrace{-\vec{V}_7 \bullet \vec{\nabla}_p T_7}_{B} + \underbrace{\omega\sigma\frac{p}{R}}_{C} + \underbrace{\frac{1}{C_p}\frac{dQ}{dt}}_{D}\right].$$

Term A[2]: Advection of 500 hPa geostrophic absolute vorticity by the 500 hPa geostrophic wind. This term **controls the development of vorticity over the center of the surface cyclone**.
Term B: Horizontal Laplacian of the advection of 700 hPa temperature by the 700 hPa geostrophic wind (assumes 700 hPa is representative of the 1000–500 hPa layer). This term **controls the surface cyclone motion**.
Term C: Horizontal Laplacian of adiabatic heating and cooling based upon 700 hPa vertical motion (assumes 700 hPa is representative of the 1000–500 hPa layer).
Term D: Horizontal Laplacian of diabatic heating and cooling (neglected here).

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

Further Reading: Carlson (1998), pp. 185–186.

References:
Carlson, T. N., 1998: *Mid-Latitude Weather Systems.* Amer. Meteor. Soc., 507 pp.
Petterssen, S., 1956: *Motion and Motion Systems.* Vol. I. *Weather Analysis and Forecasting.* McGraw-Hill, 428 pp.
Sutcliffe, R. C., 1947: A contribution to the problem of development. *Quart. J. Roy. Meteor. Soc.,* **73,** 370–383.
-----, and A. G. Forsdyke, 1950: The theory and use of upper air thickness patterns in

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[1] The form of the equation presented here is slightly modified from eq. 8.10 in Carlson (1998). Here, terms B and C are evaluated at 700 hPa under the assumption that 700 hPa is representative of the 1000–500 hPa layer.
[2] Carlson (1998) has a notation error that evaluates term A at 1000 hPa. This error is corrected here.

forecasting. *Quart. J. Roy. Meteor. Soc.,* **76,** 189–217.

Key for symbols:

$\vec{\nabla}_p$	gradient on a pressure surface (m^{-1})
∇^2	Laplacian operator (m^{-2})
$\vec{V}_5$	geostrophic wind at 500 hPa (m s^{-1})
$\vec{V}_7$	geostrophic wind at 700 hPa (m s^{-1})
ζ_5	geostrophic relative vorticity at 500 hPa (s^{-1})
f	Coriolis parameter (s^{-1}; f_0=1.0×10^{-4} s^{-1} (negative in SH))
R	gas constant for dry air (R=287 J K^{-1} kg^{-1})
T_7	temperature at 700 hPa (K)
ω	vertical motion at 700 hPa (Pa s^{-1})
σ	static stability (assumed constant σ =2.0×10^{-6} m^2 Pa^{-2} s^{-2})
p	pressure (70000 Pa)
C_p	specific heat of dry air at constant pressure (1004 J K^{-1} kg^{-1})
Q	diabatic heating (neglected here)

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Last modified: 7/24/12

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