Mesoscale Precipitation Bands within Extratropical Cyclones

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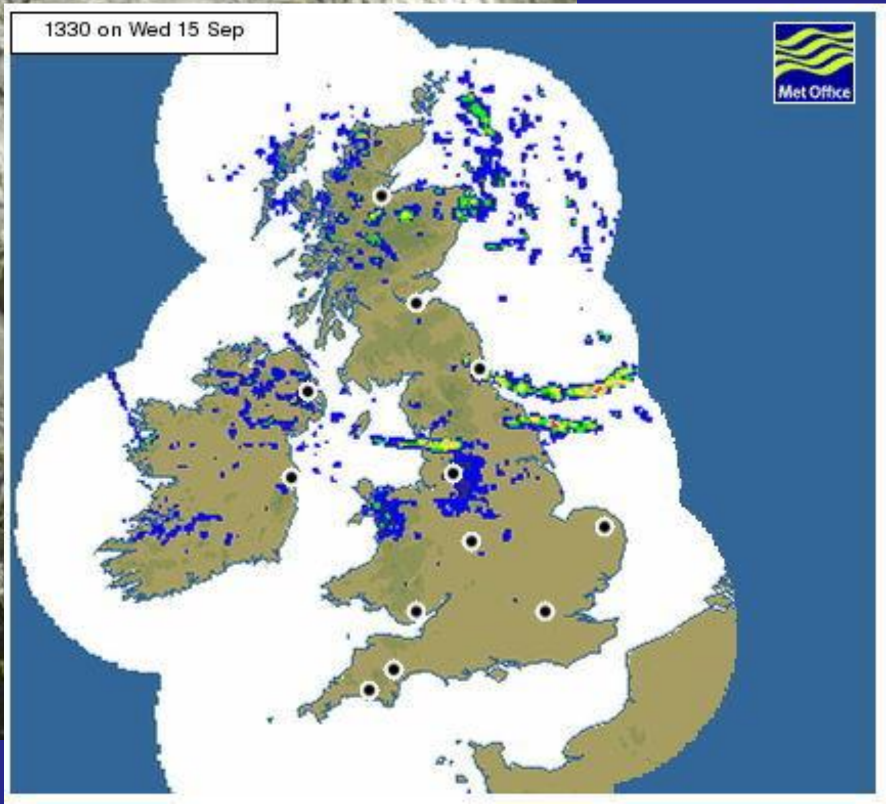
Why is there cloud/rain?



My Philosophy of Diagnosis

1. QG thinking: advection of vorticity by thermal wind (e.g., vorticity advection, warm advection)

2. If not QG, then try frontogenesis at different levels.

3. If not frontogenesis, then something else:

    topographic circulations

    boundary-layer circulations

    gravity waves

    etc.

My Philosophy of Diagnosis

1. QG thinking: advection of vorticity by thermal wind (e.g., vorticity advection, warm advection)

2. …is at different levels.

3. If not frontogenesis, the…

    topographic circulations

    boundary-layer circulations

    gravity waves

    etc.

Also need to consider instability, which ***modulates*** the response to the forcing.

The more unstable the air is, the greater the response.

Frontogenesis

a diagnostic tool for locating circulations associated with fronts

Frontogenesis (Petterssen 1936)

$$F = \frac{d}{dt}|\nabla_H \theta|,$$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y},$$

$$\mathbf{V}_H = u\mathbf{i} + v\mathbf{j},$$

$$\nabla_H = \mathbf{i}\frac{\partial}{\partial x} + \mathbf{j}\frac{\partial}{\partial y}.$$

$$F = \frac{1}{2}|\nabla_H \theta|(E\cos 2\beta - \nabla_H \cdot \mathbf{V}_H),$$

deformation divergence

Petterssen (1936) Frontogenesis

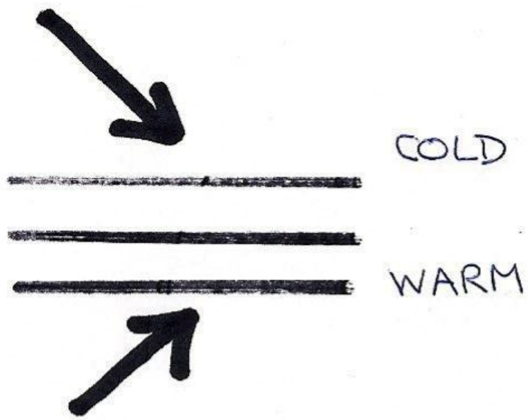
$$F = {}^{d}/_{dt}\ |\nabla\theta|$$

$$F = {}^{1}/_{2}\ |\nabla\theta|\ (E\cos 2\beta - D)$$

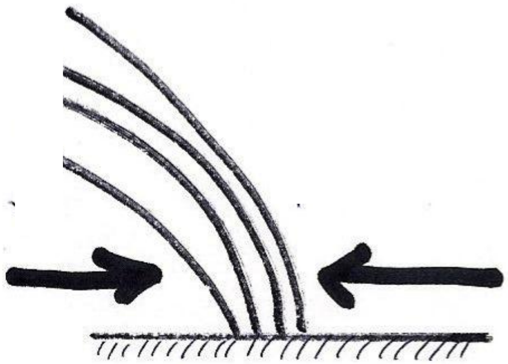
θ = potential temperature
E = resultant deformation
β = angle between the isentrope and the axis of dilatation
D = divergence

Frontogenesis (F>0)

horizontal



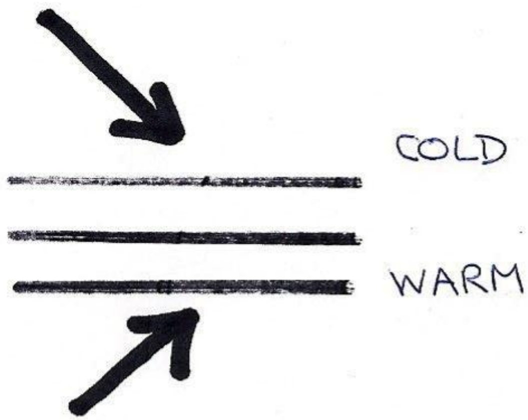
vertical



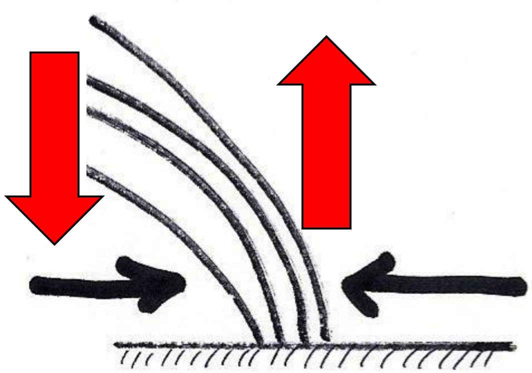
isentropes

Frontogenesis (*F*>0)

horizontal



vertical

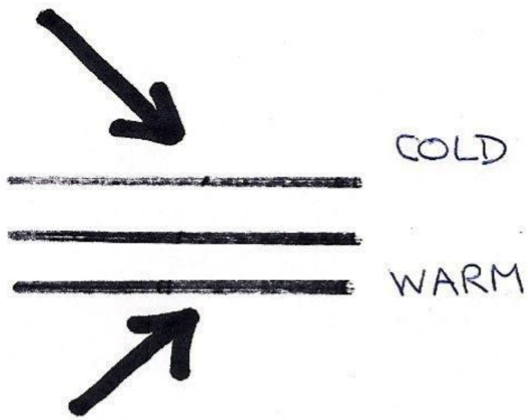


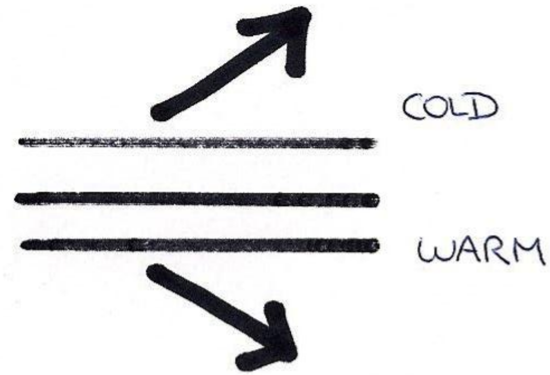
isentropes

Frontogenesis (*F*>0)

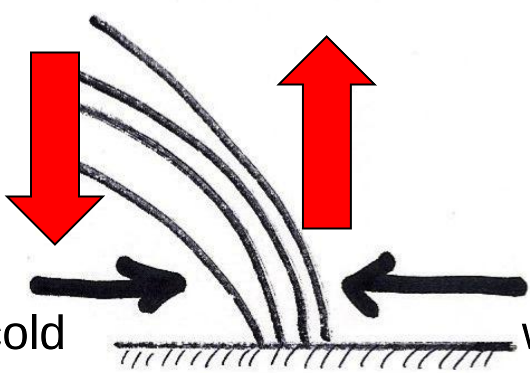
Frontolysis (*F*<0)

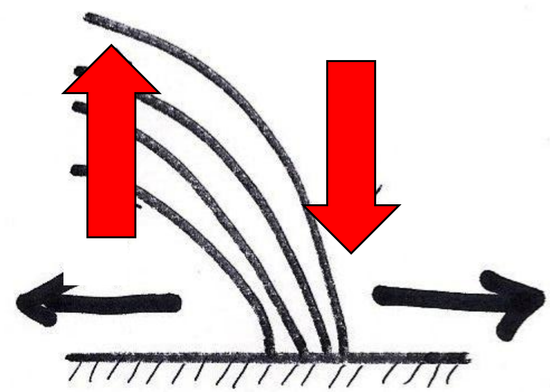
horizontal





vertical





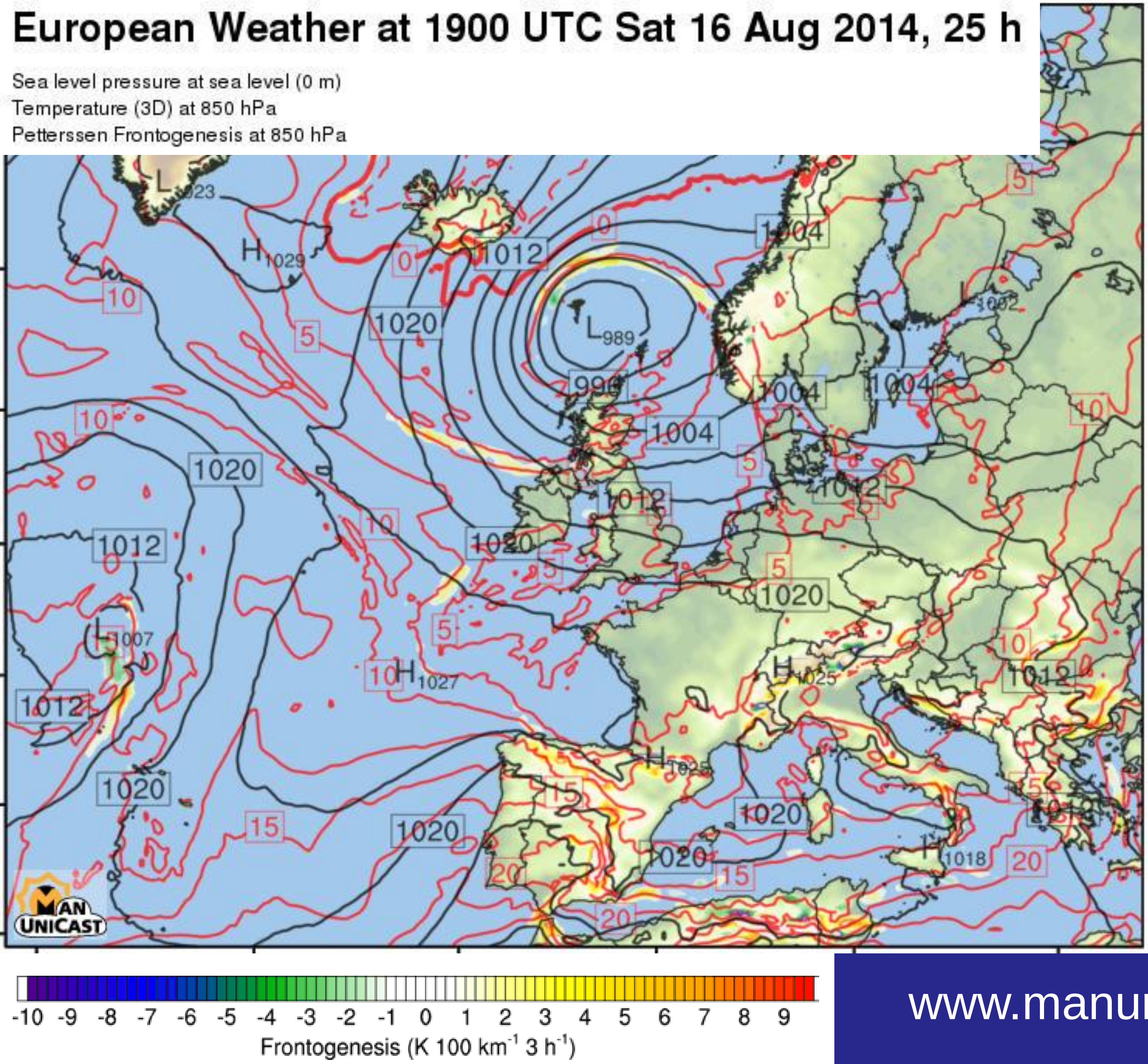
cold

warm

isentropes (lines of constant potential temperature)

European Weather at 1900 UTC Sat 16 Aug 2014, 25 h

Sea level pressure at sea level (0 m)
Temperature (3D) at 850 hPa
Petterssen Frontogenesis at 850 hPa



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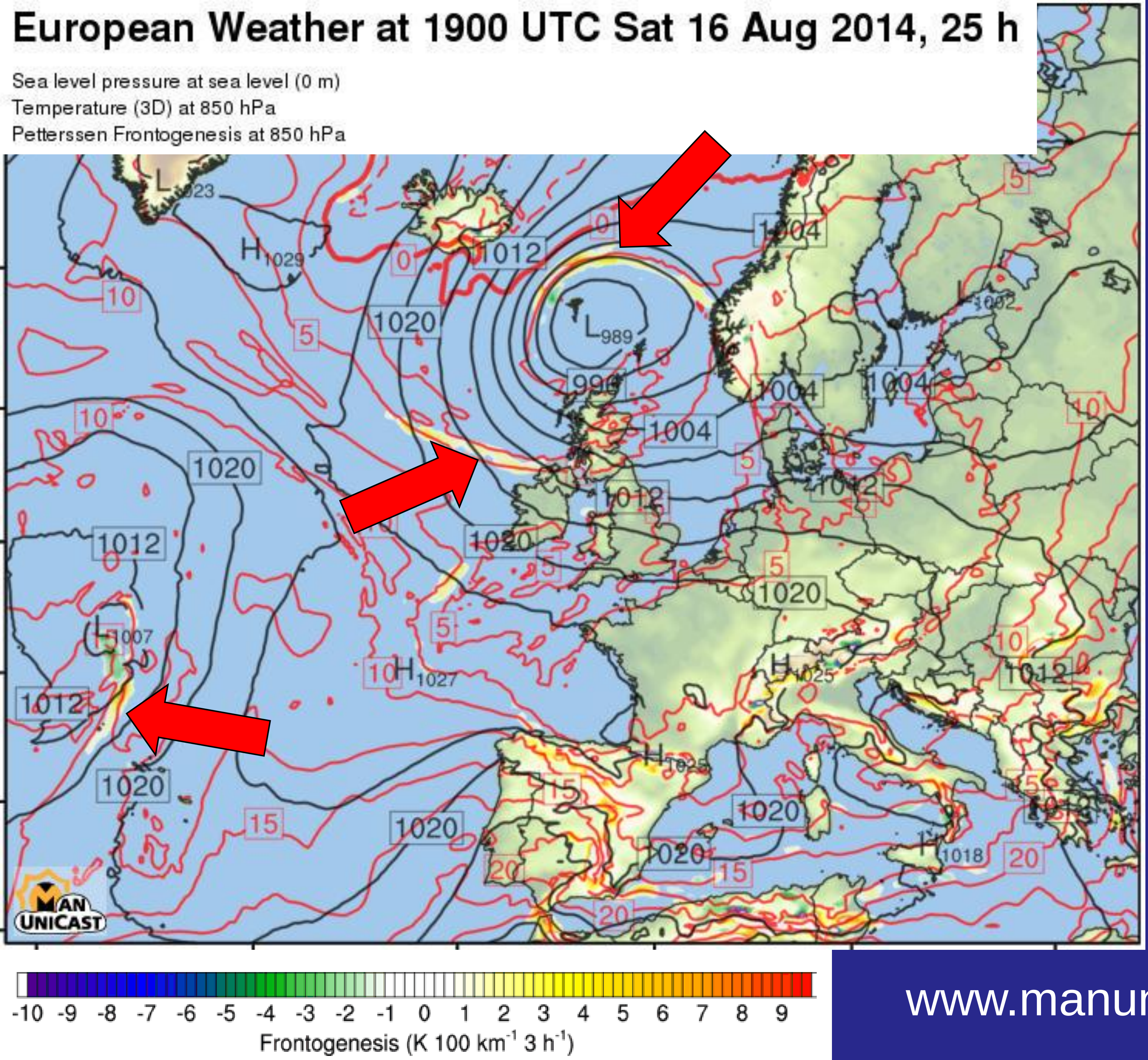

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Frontogenesis Facts

Frontogenesis is superior to the thermal front parameter (TFP) because it indicates “kinematically active” fronts (i.e., where the flow is acting to bring isentropes together).

Frontogenesis is “following the flow” (Lagrangian).

Fronts that are weakening can still possess frontogenesis.

Note that tilting effects are not included in Petterssen’s (1936) form of frontogenesis.

Note that frontogenesis should be used with potential temperature, not equivalent potential temperature.

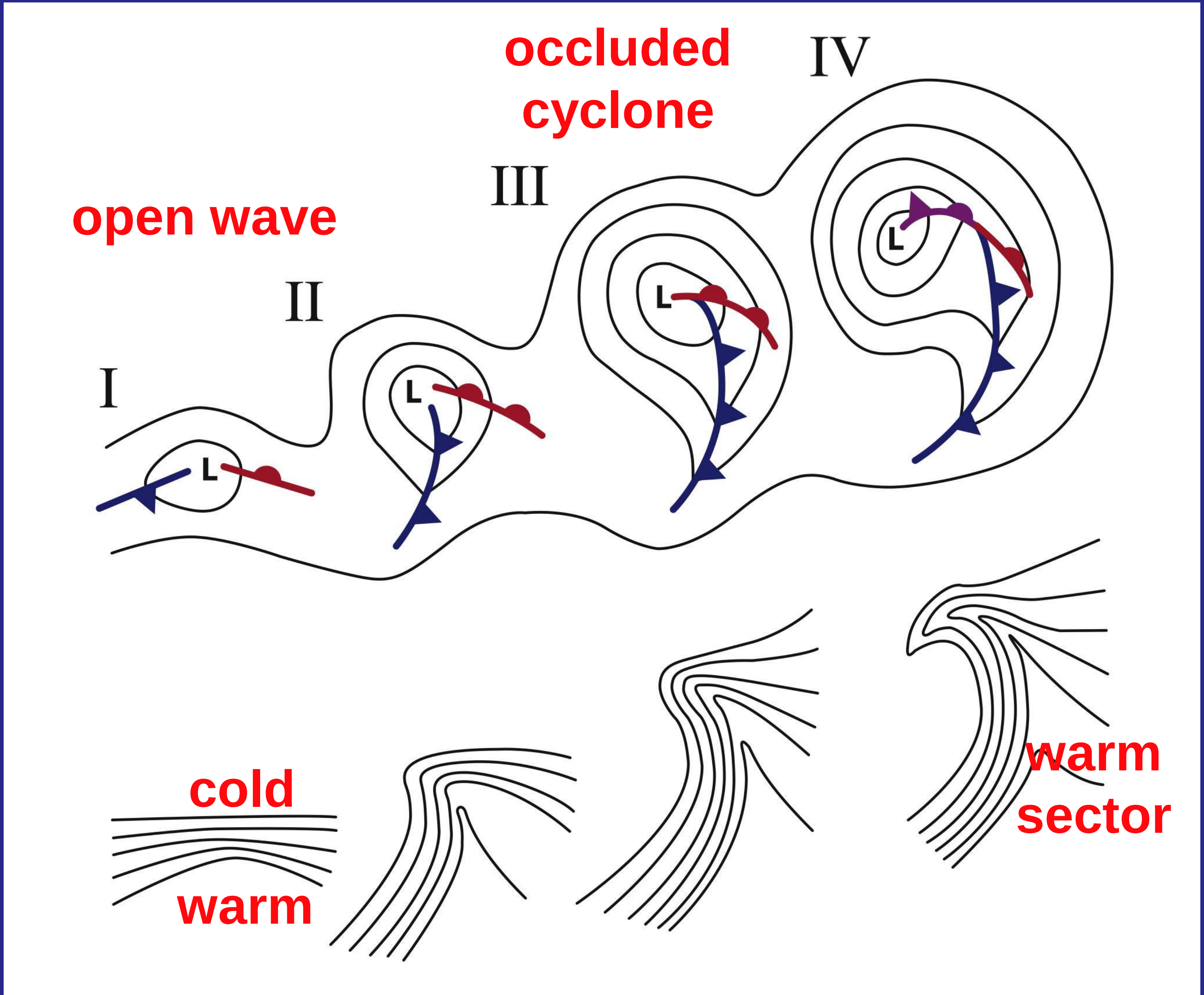
Frontogenesis Facts

Diagnosis of frontogenesis results in a diagnosis of the forcing for vertical motion on the frontal scale.

Ascent occurs on the warm side of a maximum of frontogenesis and on the cold side of a region of frontolysis.

Two conceptual models of frontal structure and evolution in extratropical cyclones

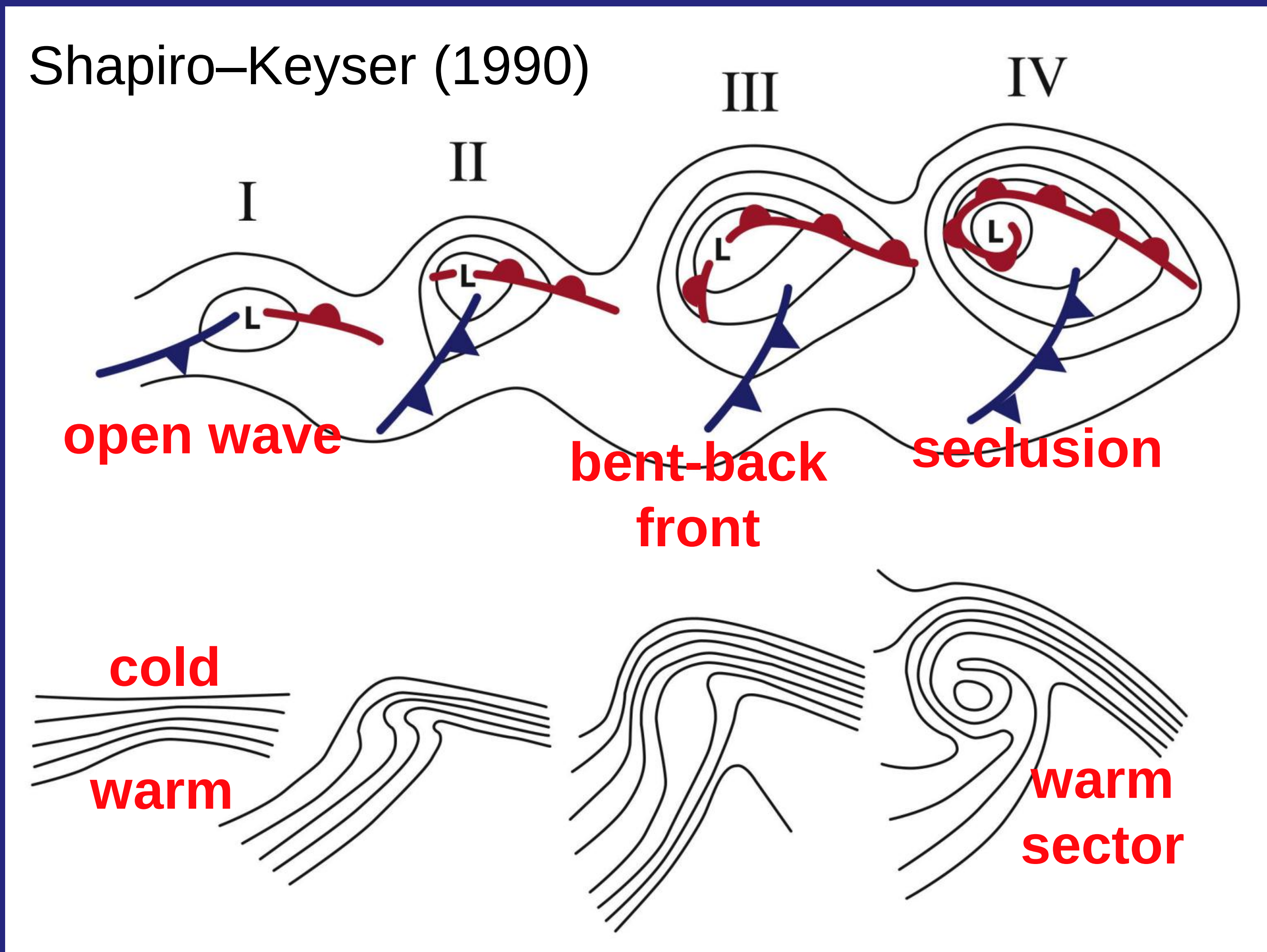
Norwegian cyclone model



isobars

isotherms

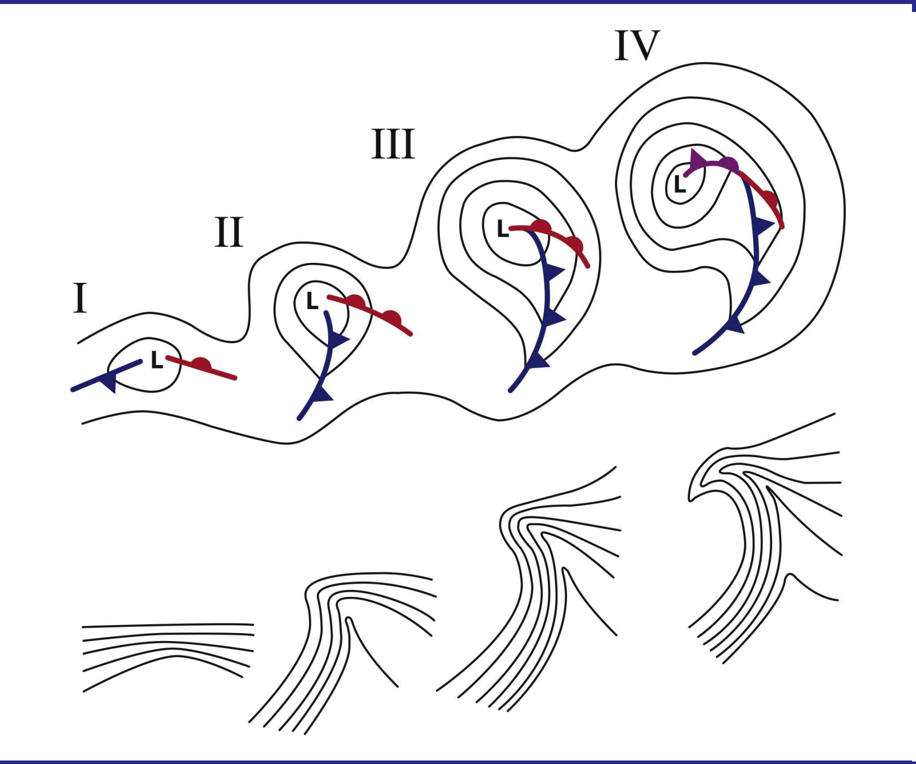
Shapiro–Keyser cyclone model

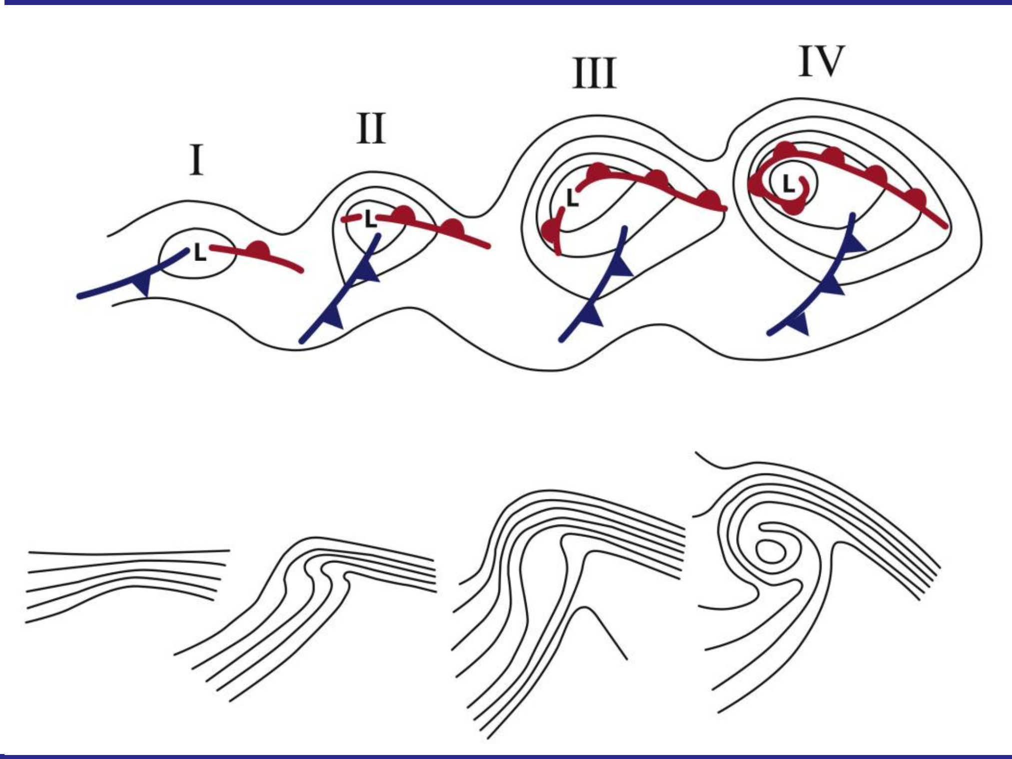


isobars

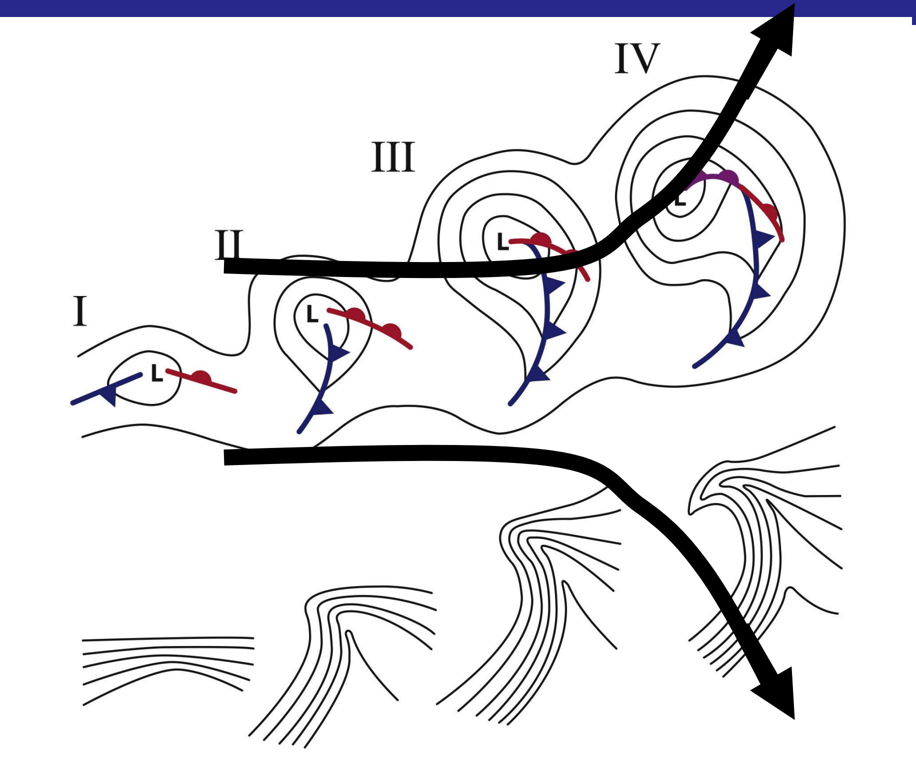
isotherms

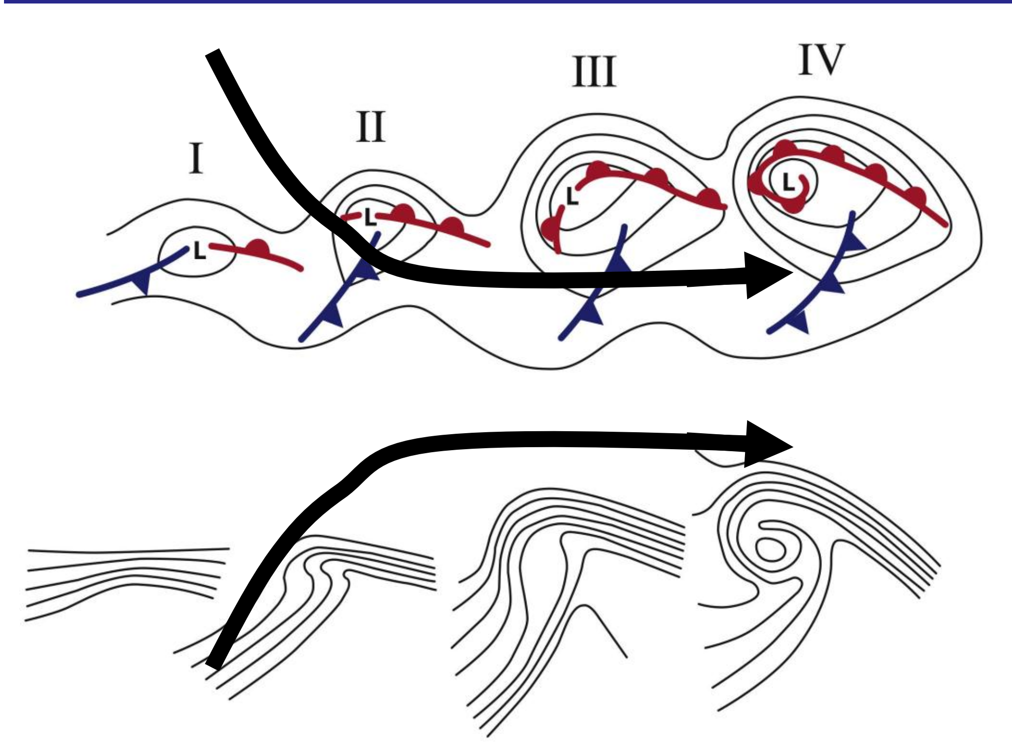
What causes the differences in structure and evolution?





The large-scale flow that the cyclone is embedded in.





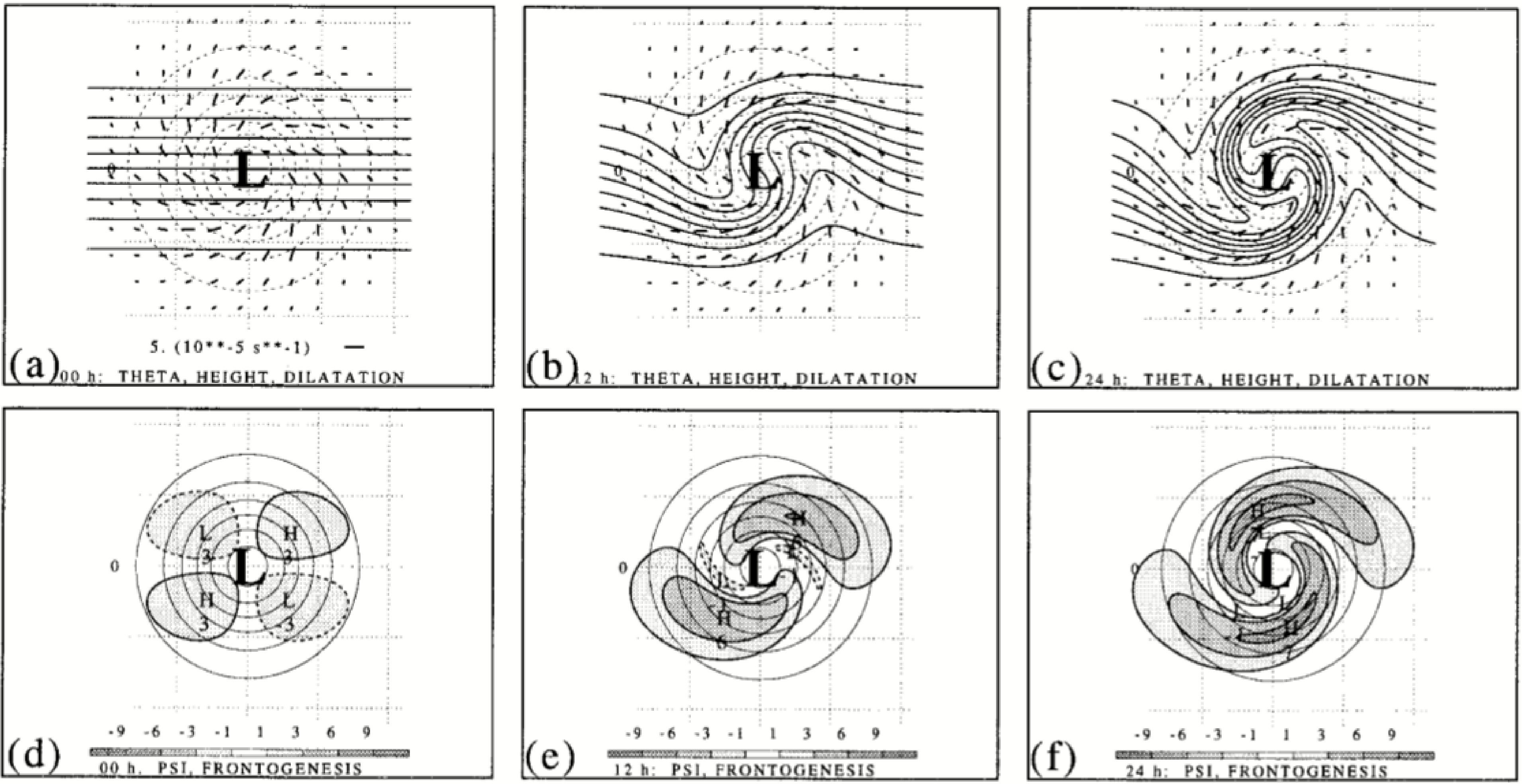
diffluence

confluence

(Schultz et al. 1998; Schultz and Zhang 2007)

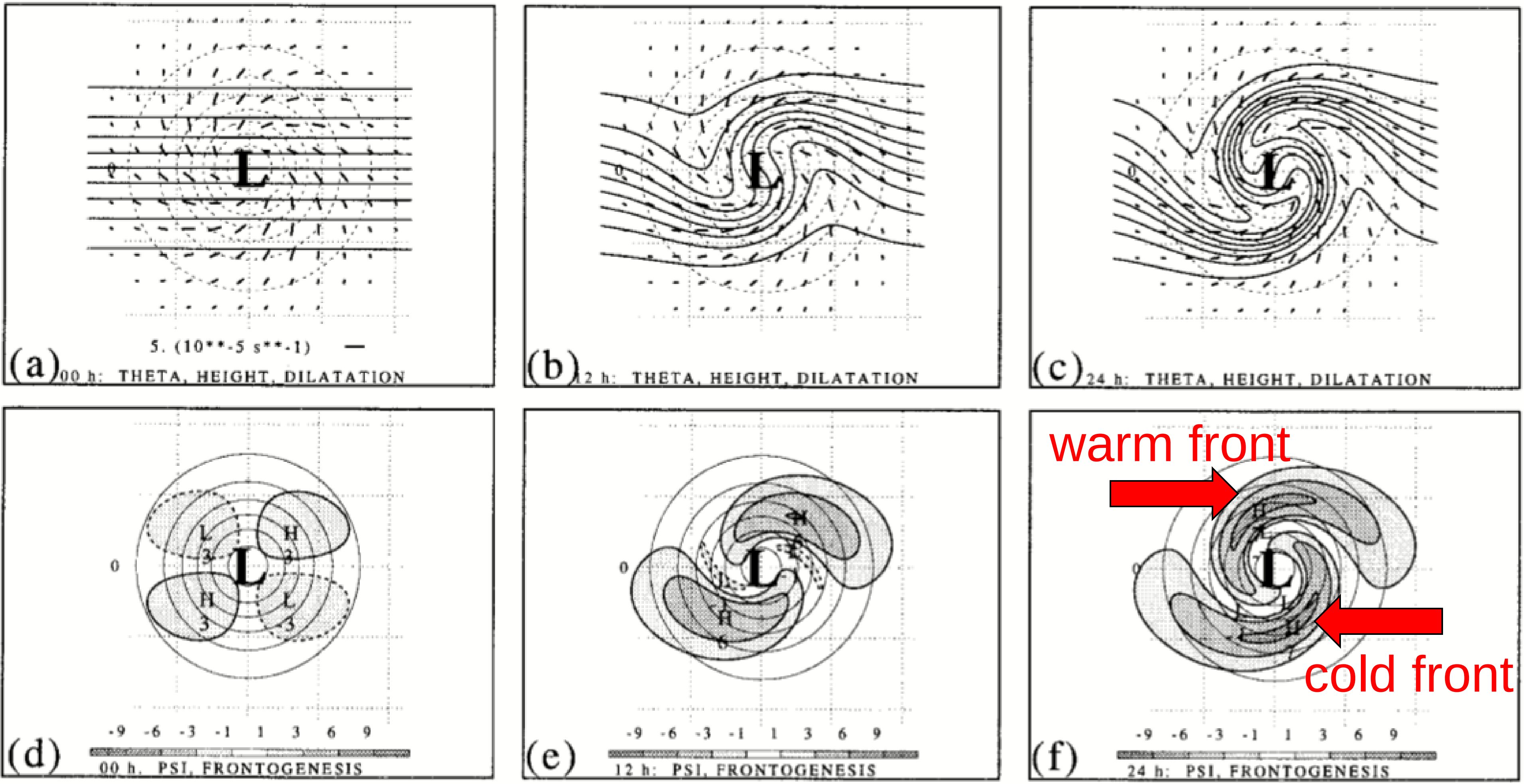
What does this mean for where clouds and precipitation form?

potential temperature



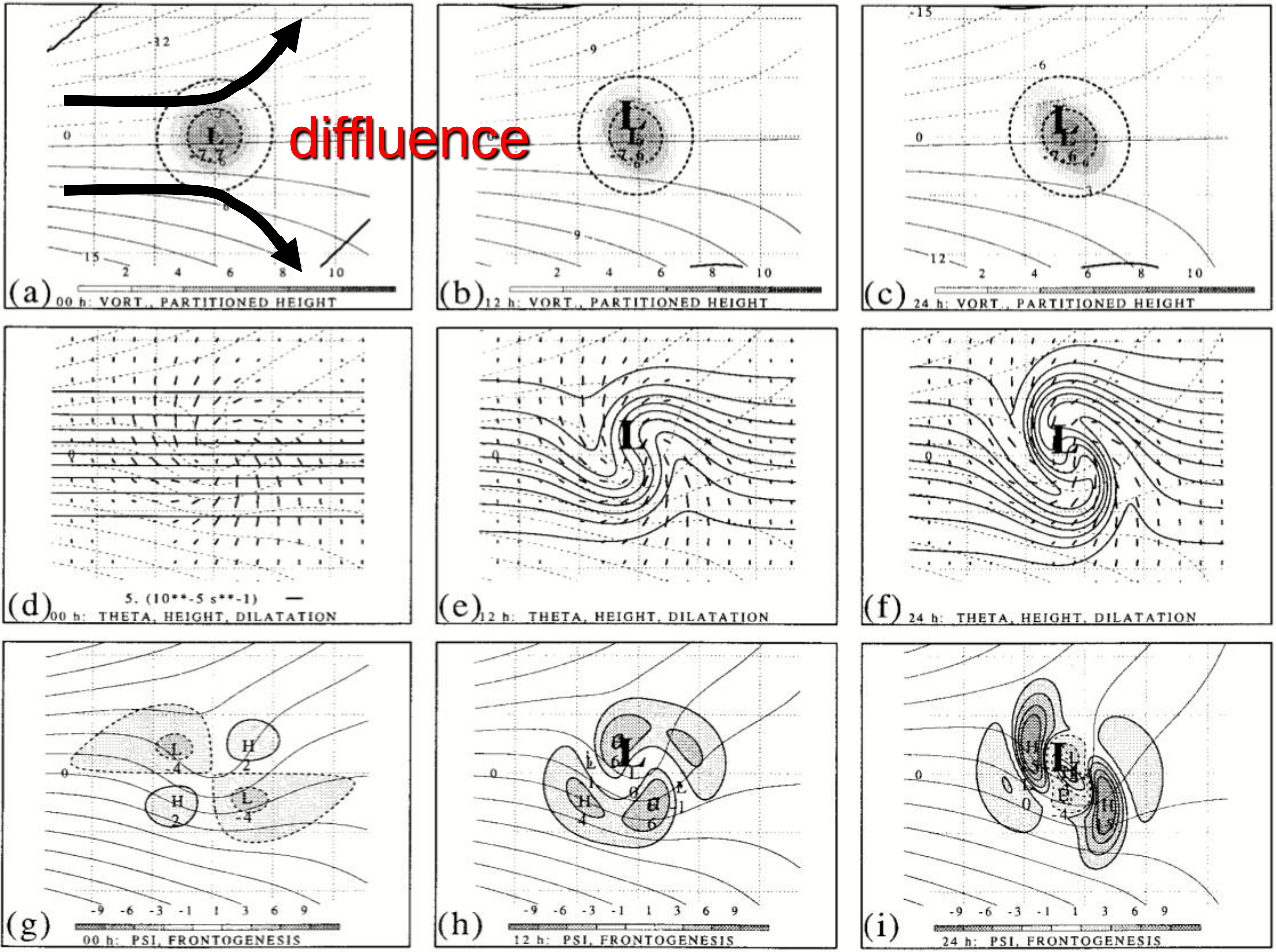
frontogenesis

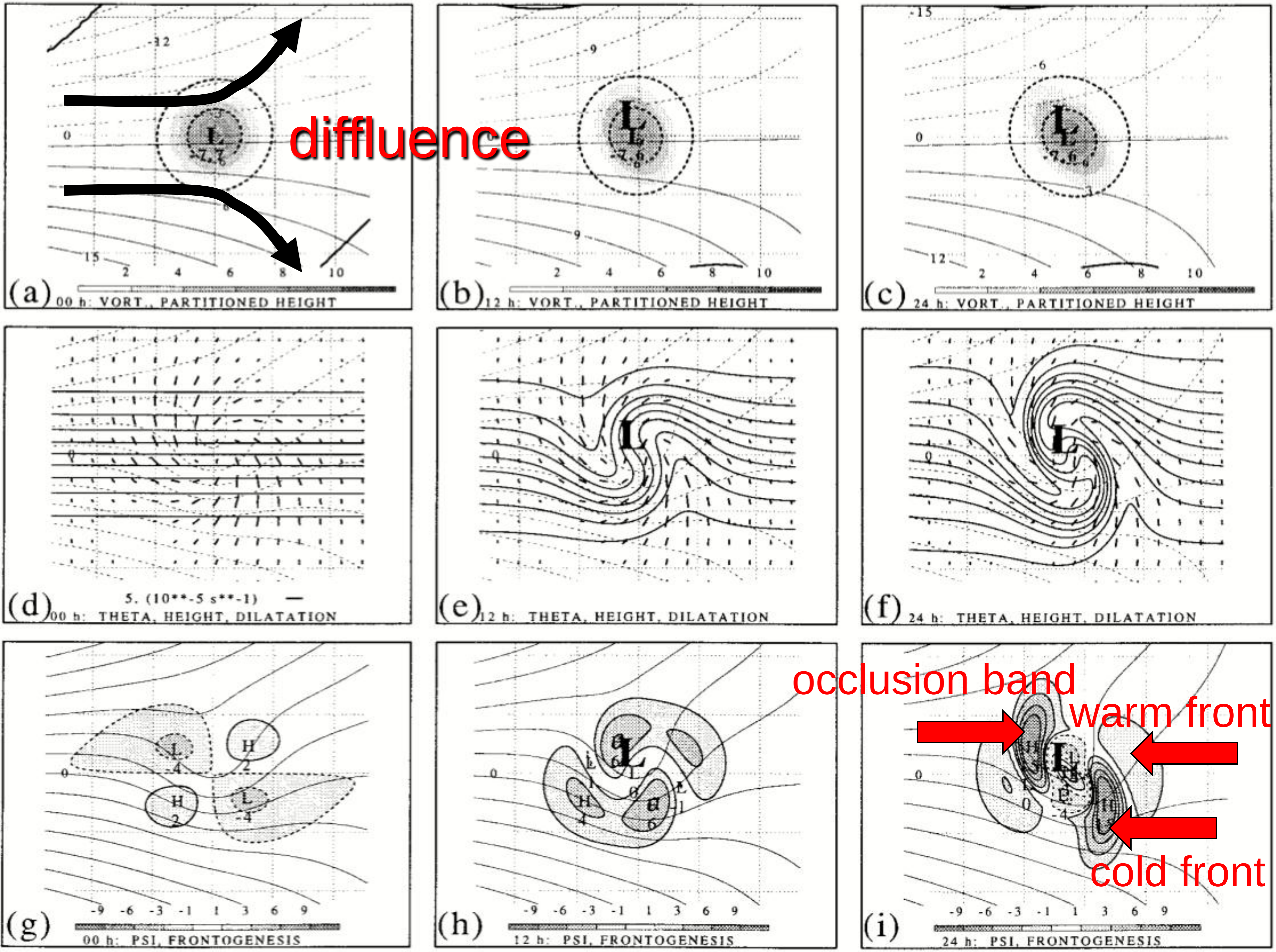
potential temperature



frontogenesis

wrap up of isentropes, cold and warm front equal magnitude


diffluence
(a) 00 h: VORT., PARTITIONED HEIGHT
(b) 12 h: VORT., PARTITIONED HEIGHT
(c) 24 h: VORT., PARTITIONED HEIGHT
(d) 00 h: THETA, HEIGHT, DILATATION
5. (10**-5 s**-1)
(e) 12 h: THETA, HEIGHT, DILATATION
(f) 24 h: THETA, HEIGHT, DILATATION
(g) 00 h: PSI, FRONTOGENESIS
(h) 12 h: PSI, FRONTOGENESIS
(i) 24 h: PSI, FRONTOGENESIS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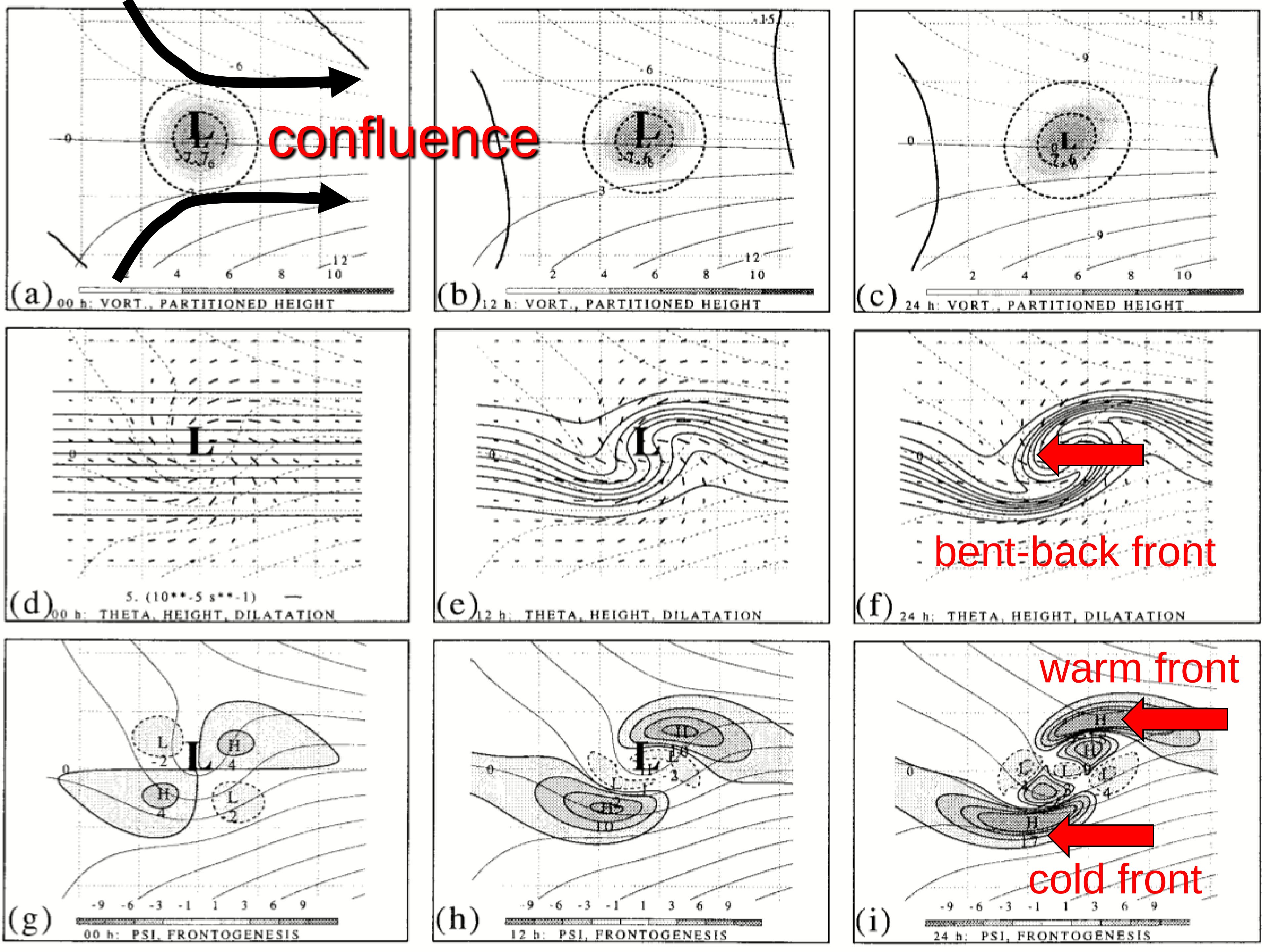
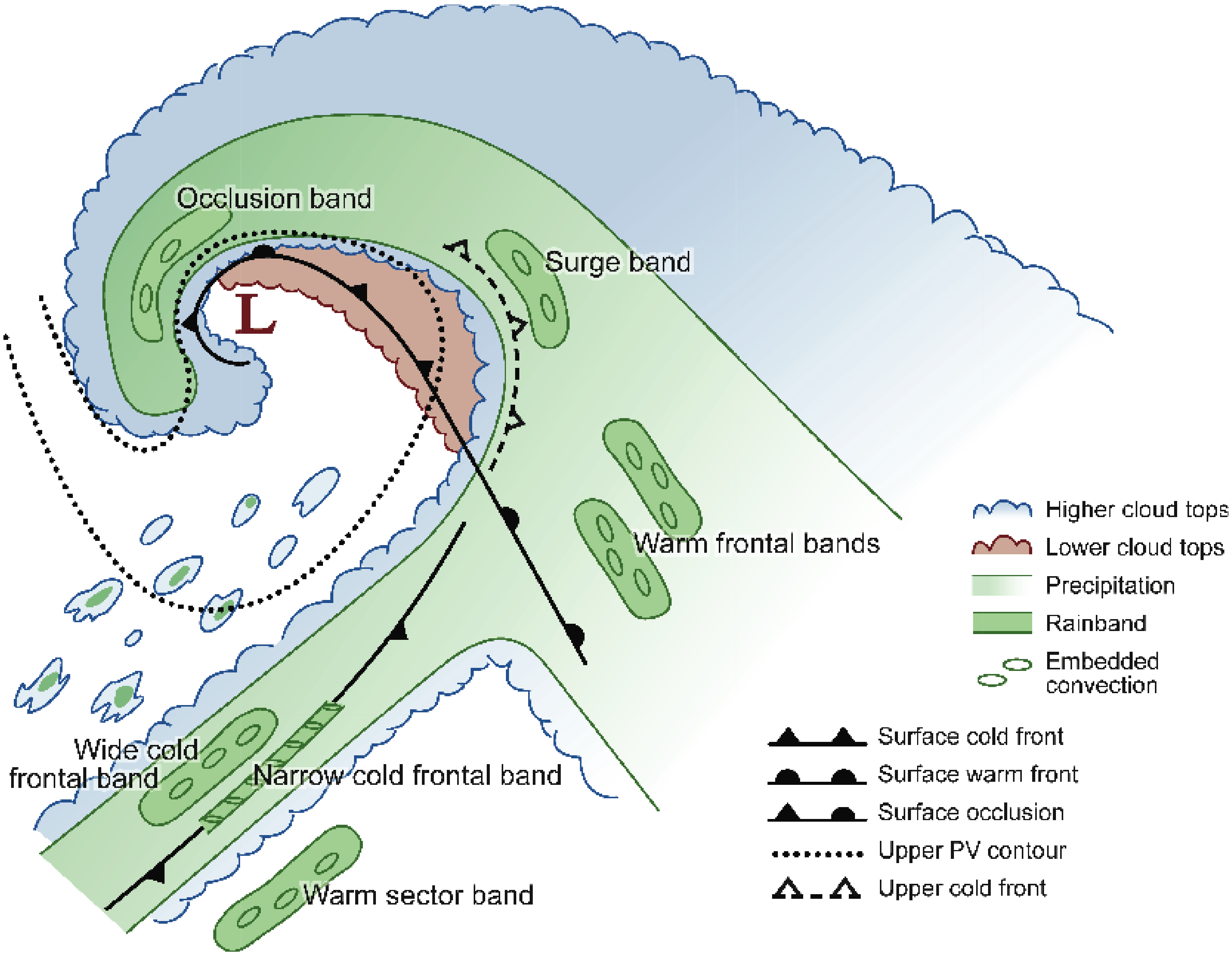
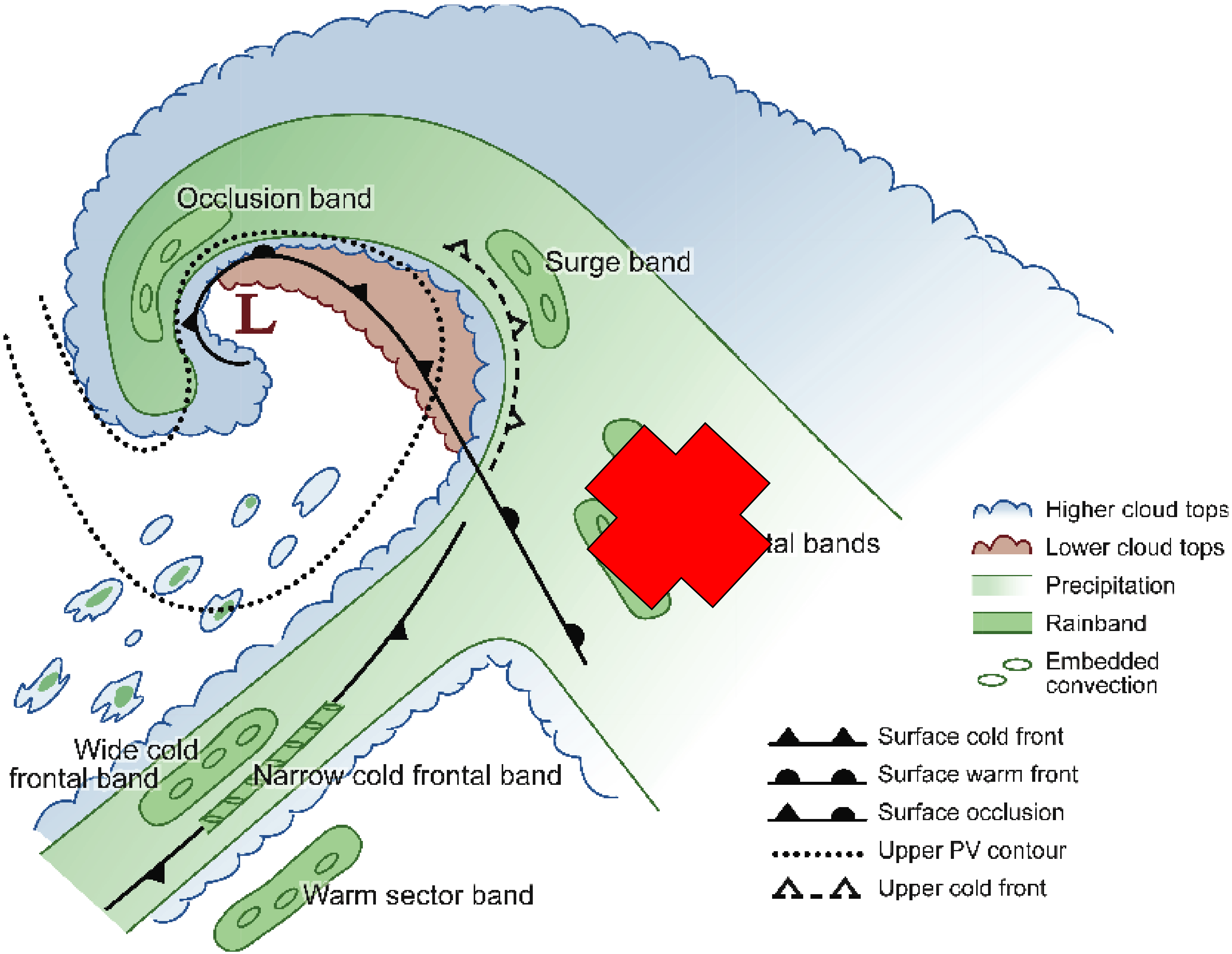
(g) 00 h: PSI, FRONTOGENESIS
(h) 12 h: PSI, FRONTOGENESIS
(i) 24 h: PSI, FRONTOGENESIS
occlusion band
warm front
cold front

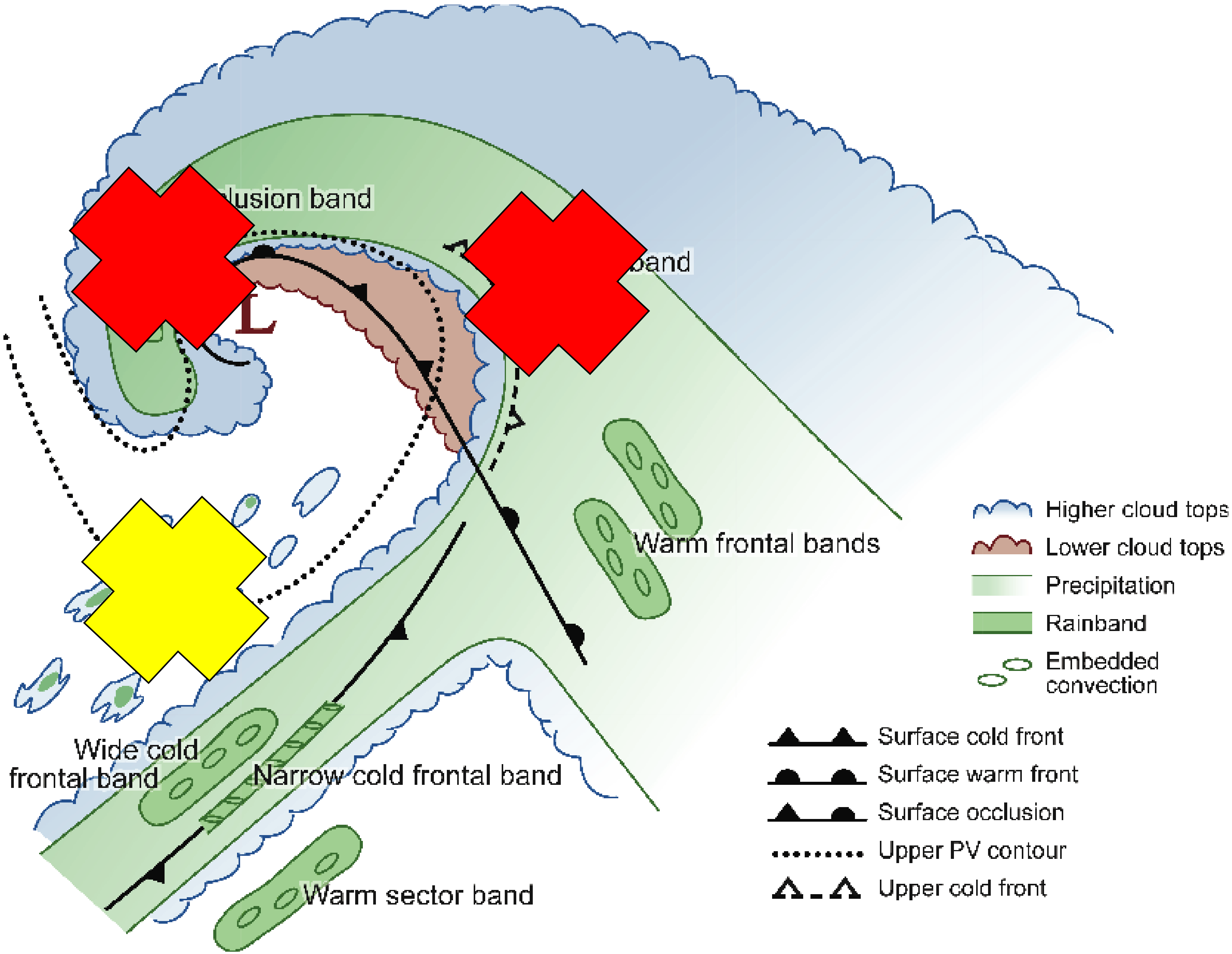

confluence
(a) 00 h: VORT., PARTITIONED HEIGHT
(b) 12 h: VORT., PARTITIONED HEIGHT
(c) 24 h: VORT., PARTITIONED HEIGHT
(d) 00 h: THETA, HEIGHT, DILATATION
5. (10**-5 s**-1)
(e) 12 h: THETA, HEIGHT, DILATATION
bent-back front
(f) 24 h: THETA, HEIGHT, DILATATION
(g) 00 h: PSI, FRONTOGENESIS
(h) 12 h: PSI, FRONTOGENESIS
warm front
cold front
(i) 24 h: PSI, FRONTOGENESIS



Cloud Dynamics, Second Edition – Robert Houze



Norwegian cyclone in large-scale diffluence



Shapiro–Keyser cyclone in large-scale confluence

Shapiro–Keyser cyclones can become more Norwegian as the trough deepens and downstream ridge strengthens.

New ideas in conceptual models:

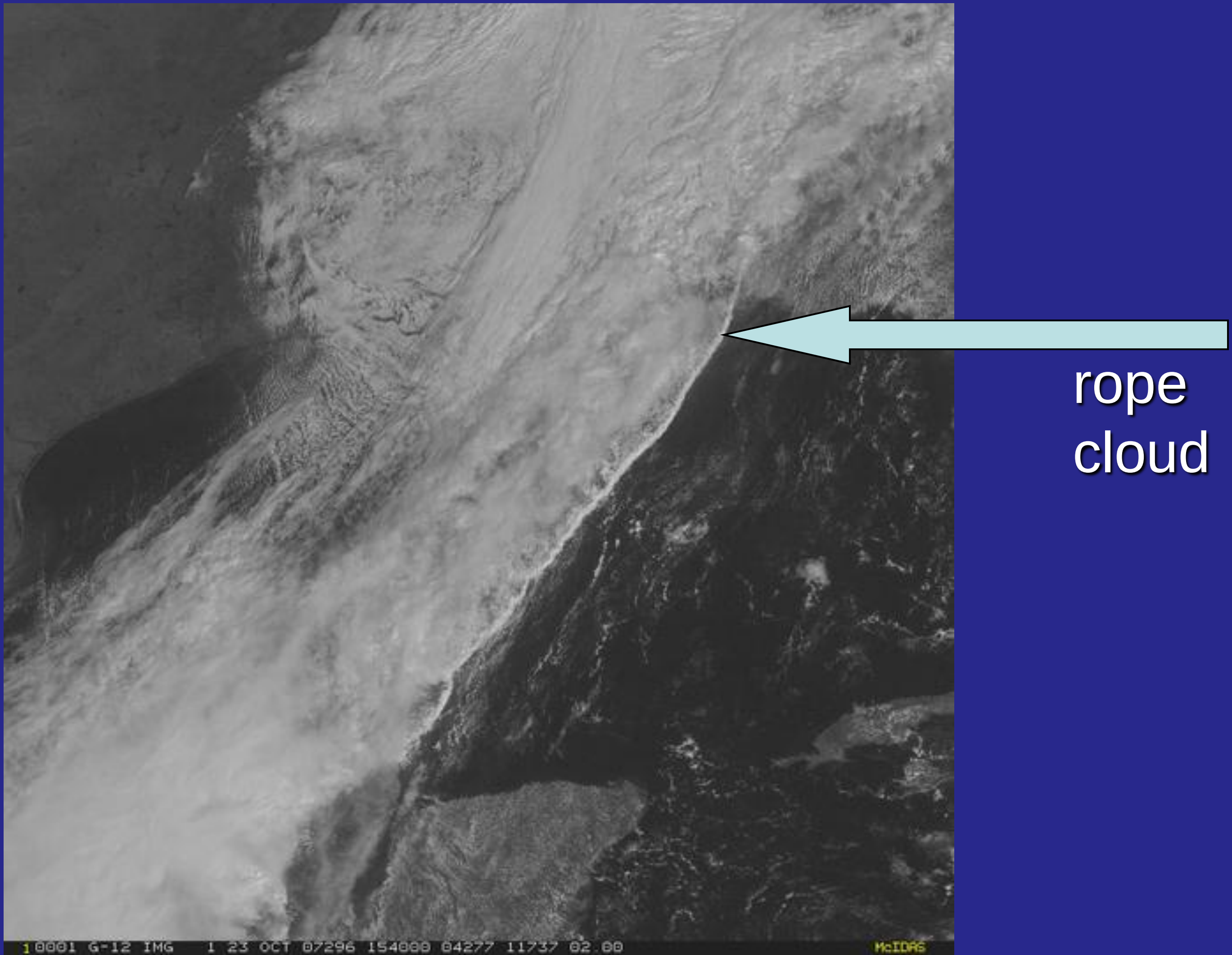
Cold fronts

Sting jets

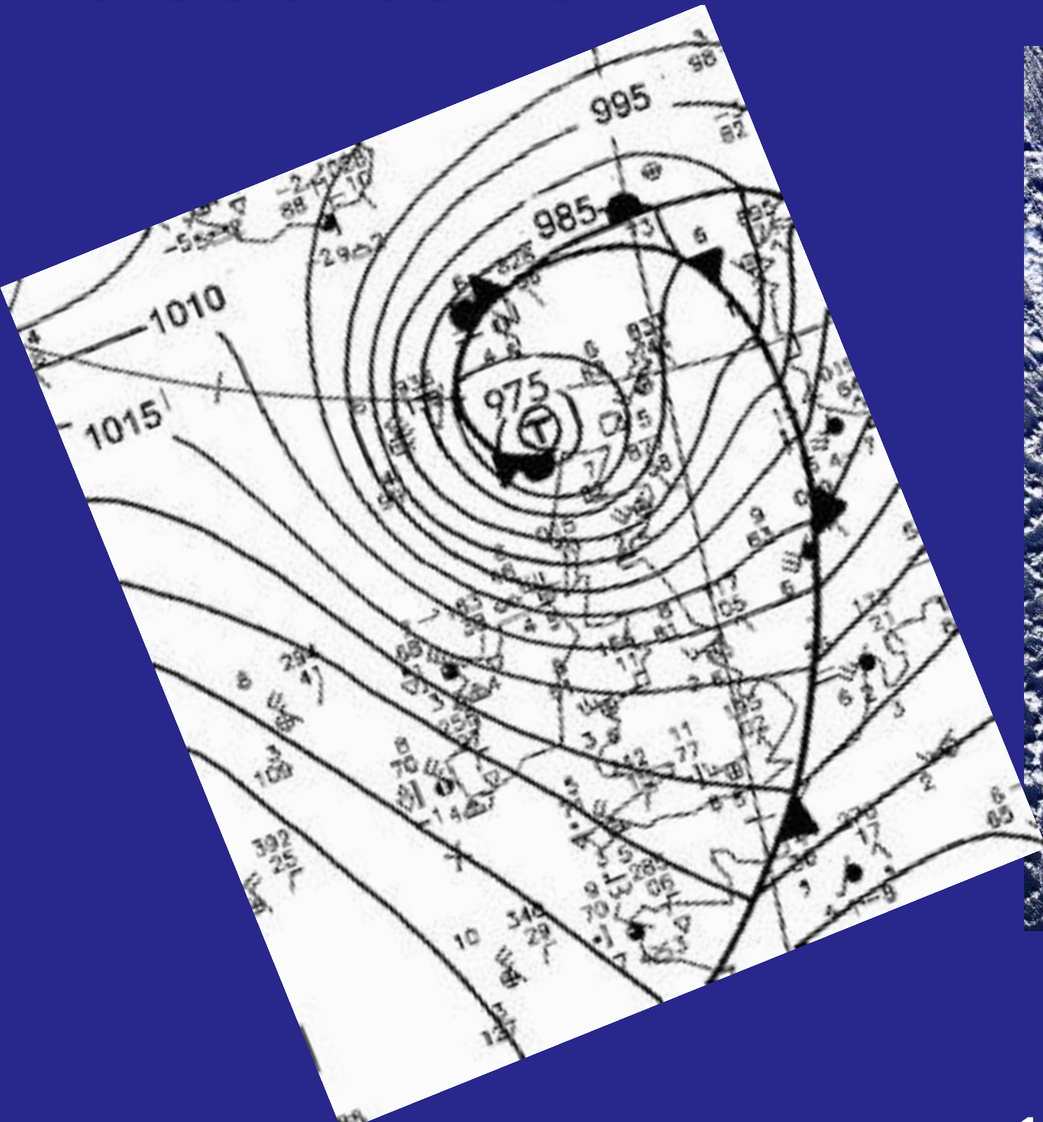
Occluded fronts

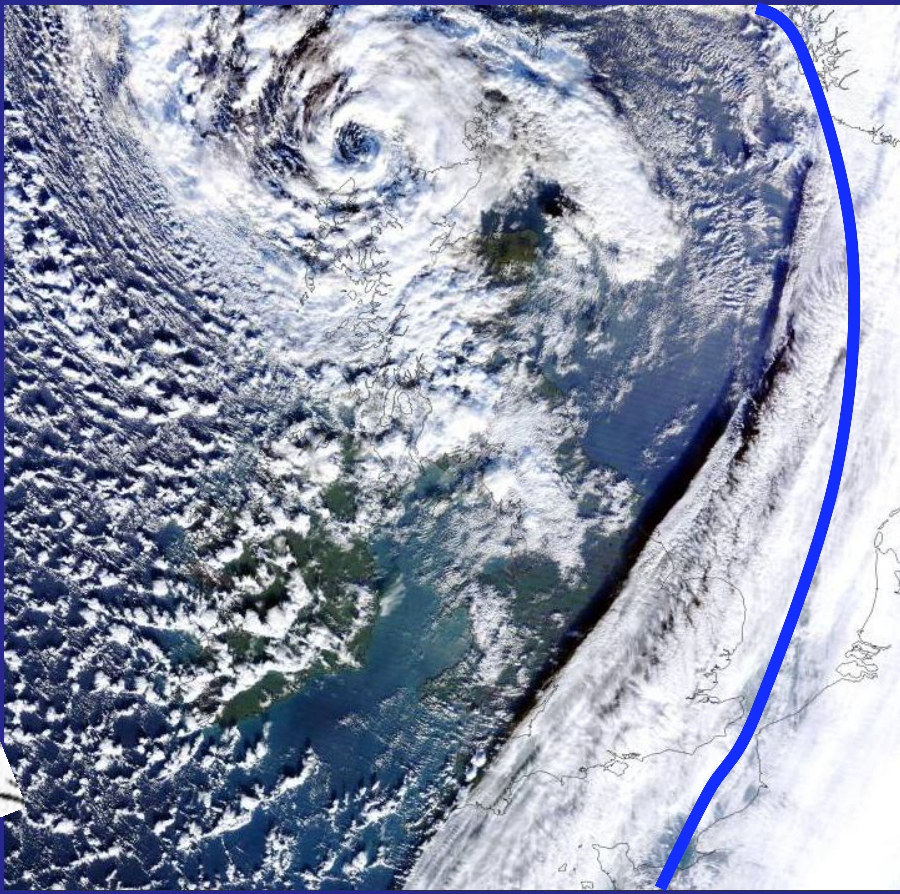
Conventional Wisdom:

The cloud band depicts the location of the surface cold front.



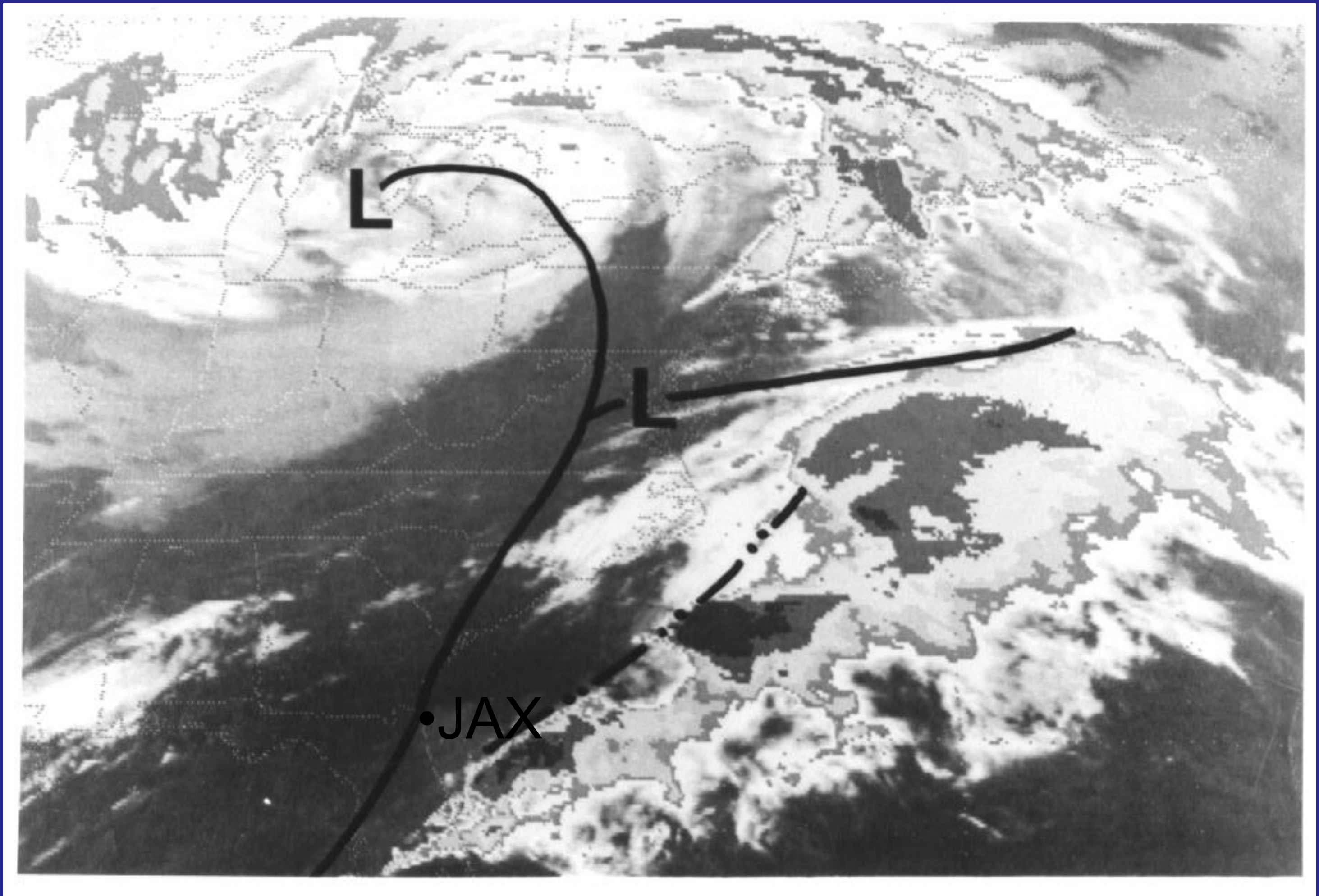
This cold front is not associated with a cloud band.





1200 UTC 28 December 2011

This cold front is not associated with any cloud band.



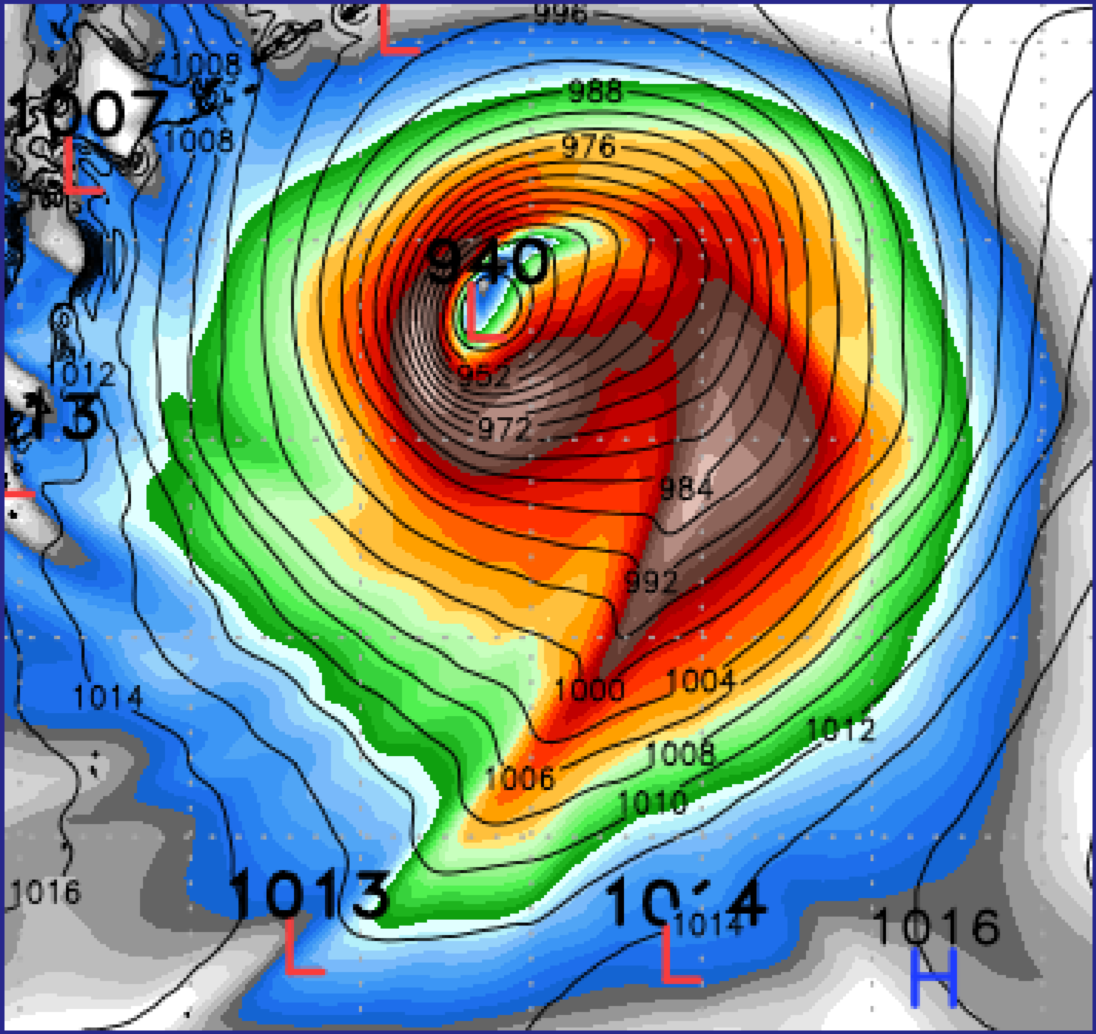
2301 UTC 15 December 1987

JAX frontal passage after 0000 UTC

(Schultz and Vaughan 2011)

sting jets

Sting jets are regions of strong winds south/southeast of the low center.



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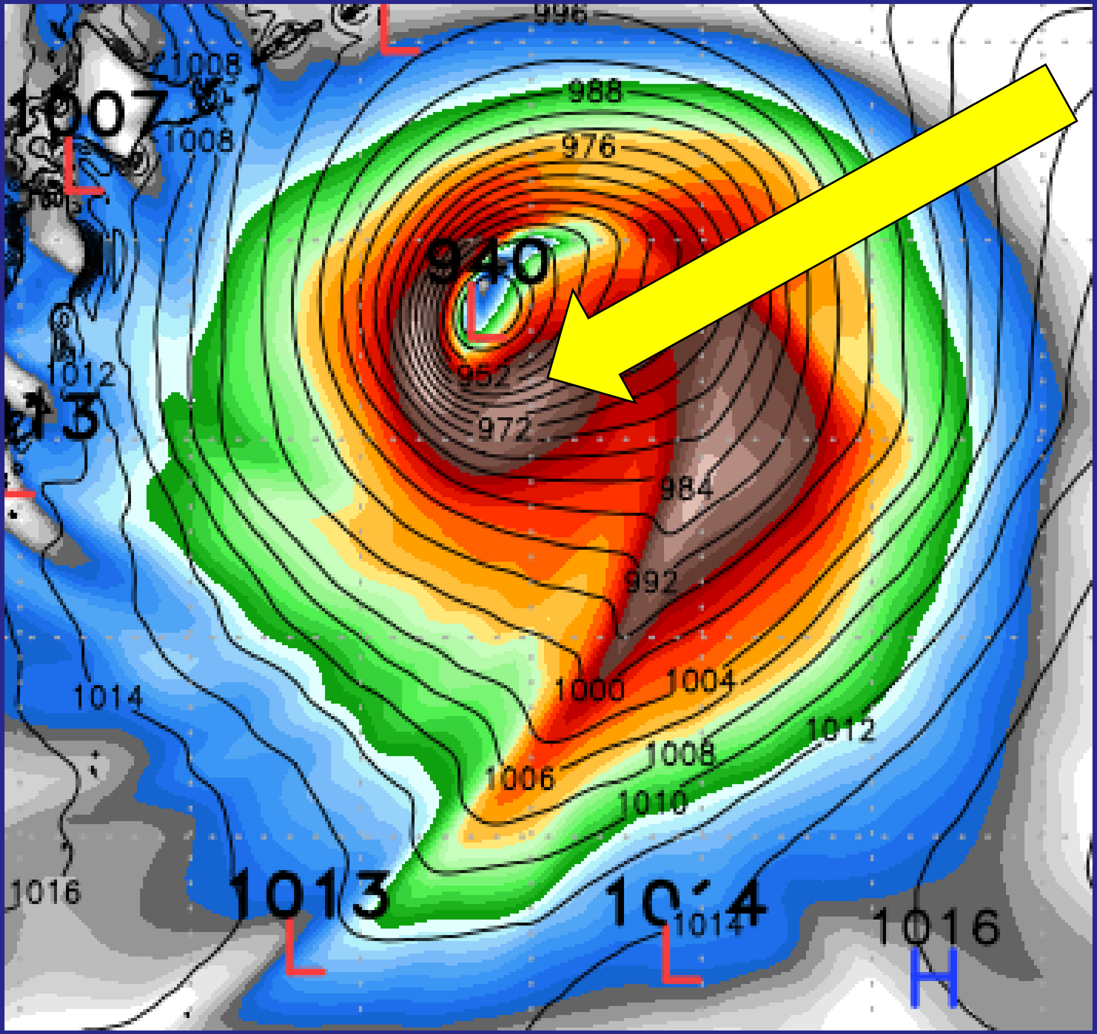
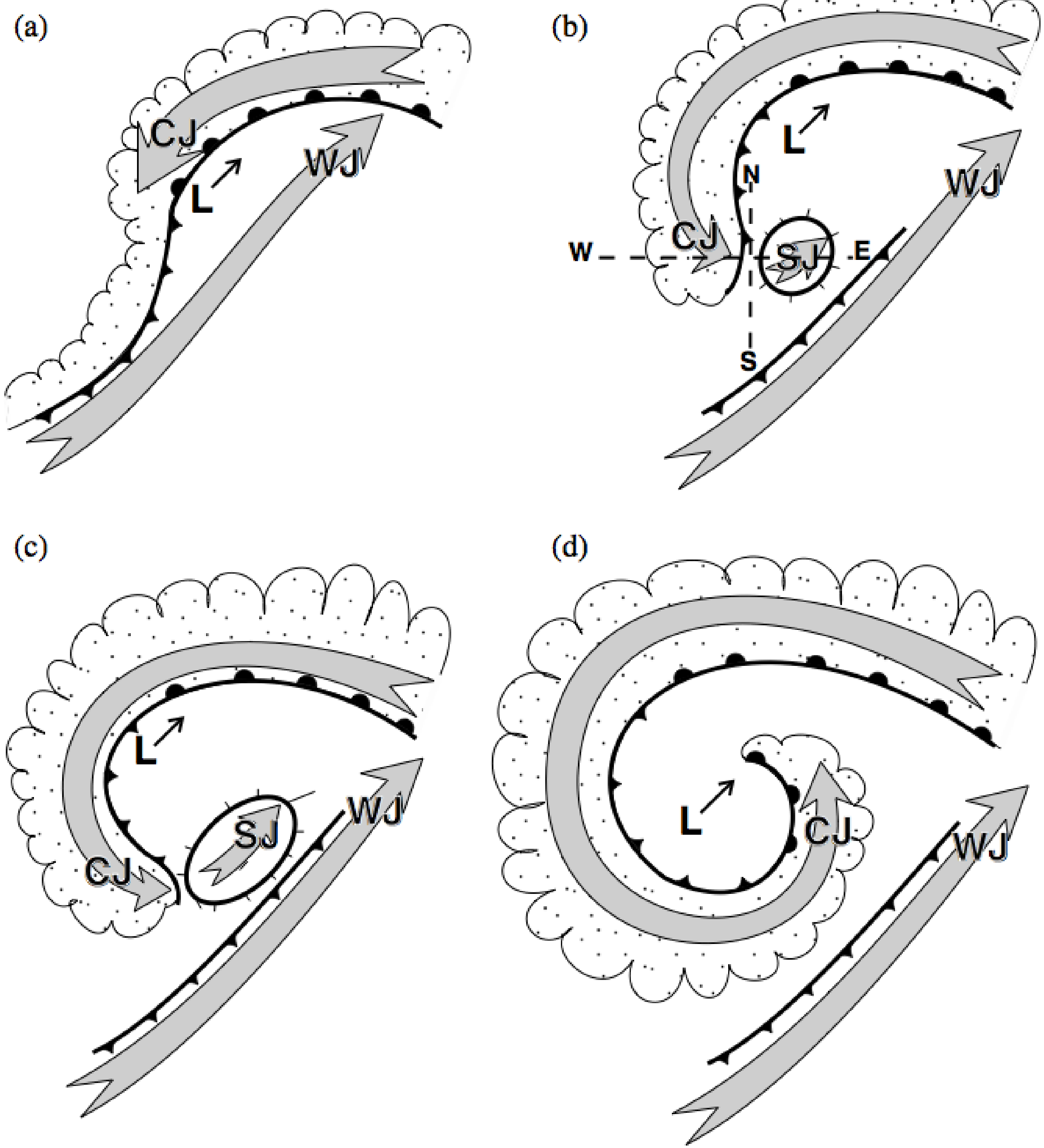
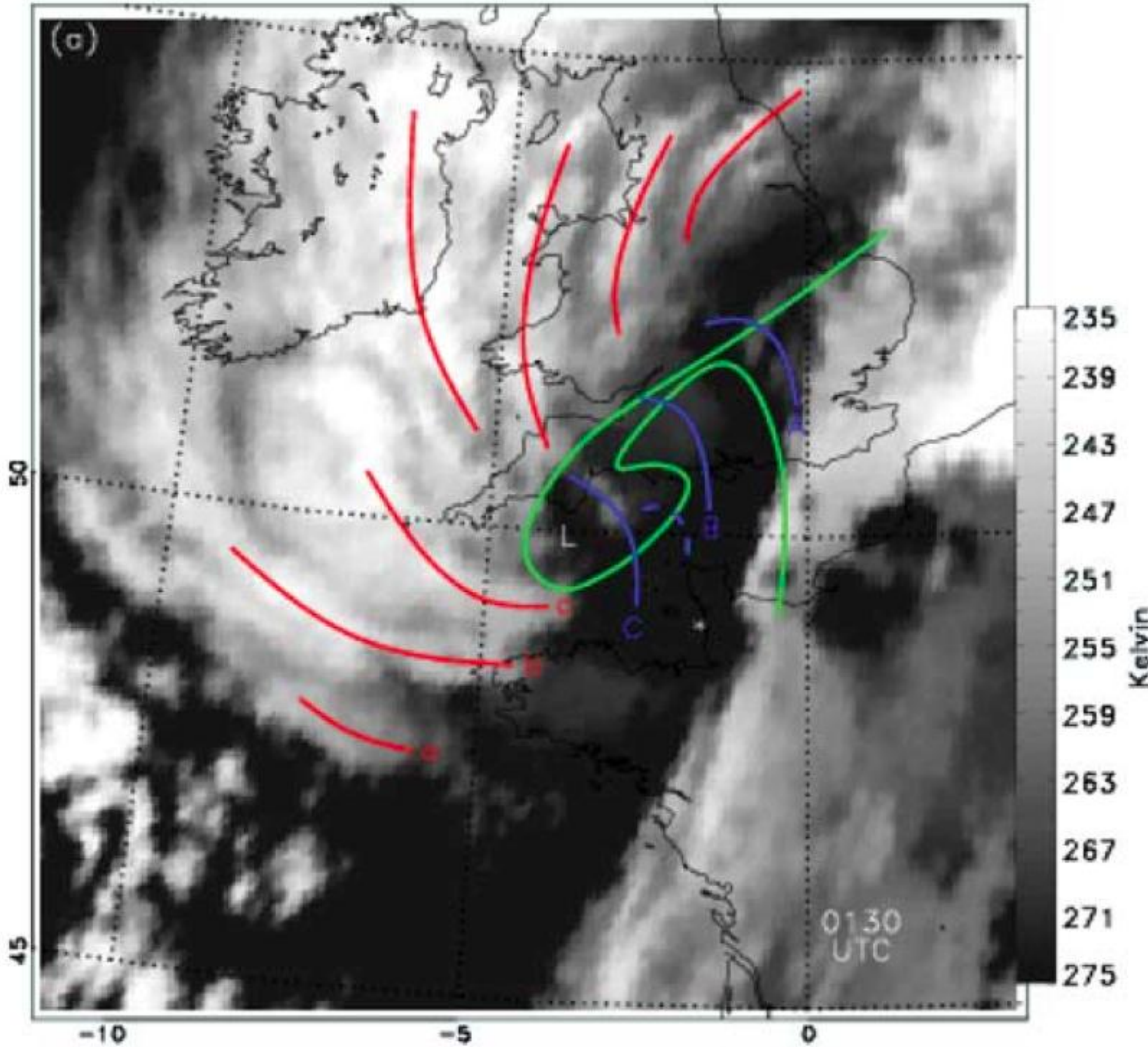


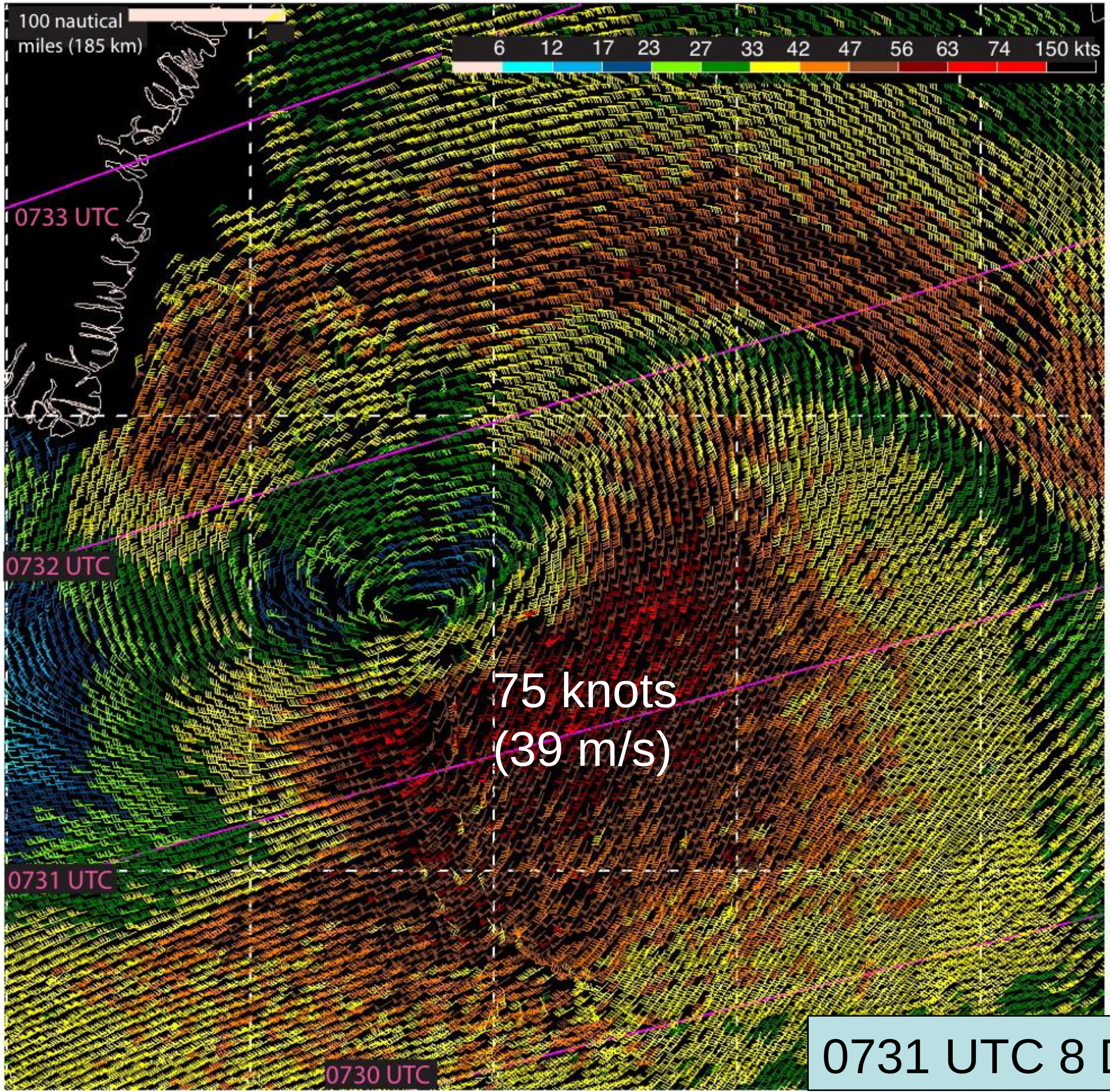


surface airstreams and fronts

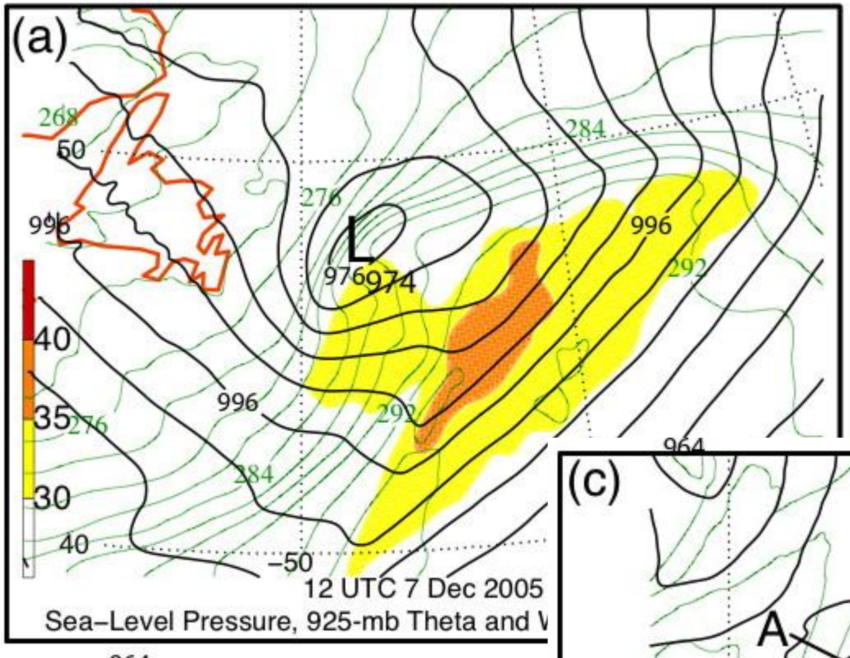
Clark et al. (2005)



Browning and Field (2004)

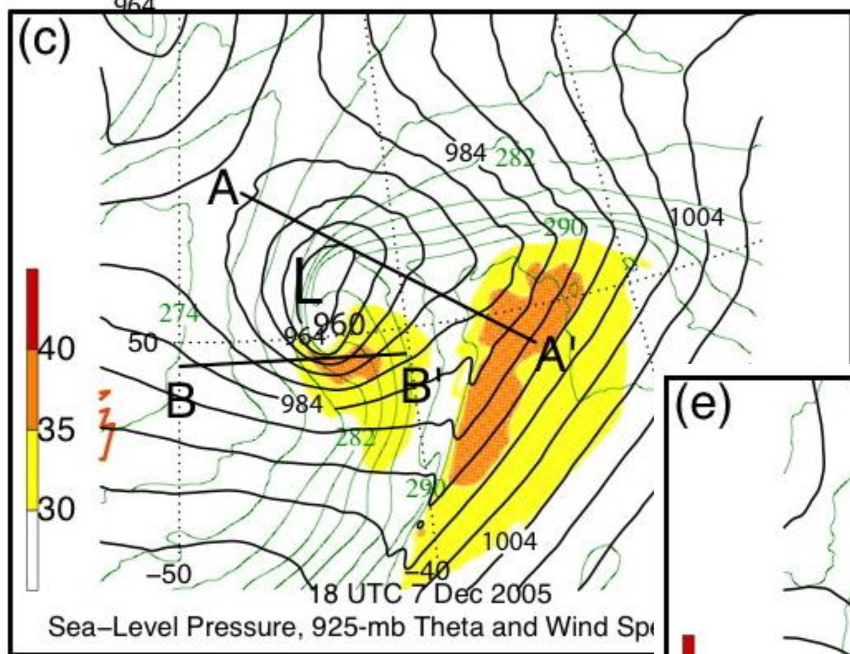


0731 UTC 8 December 2005

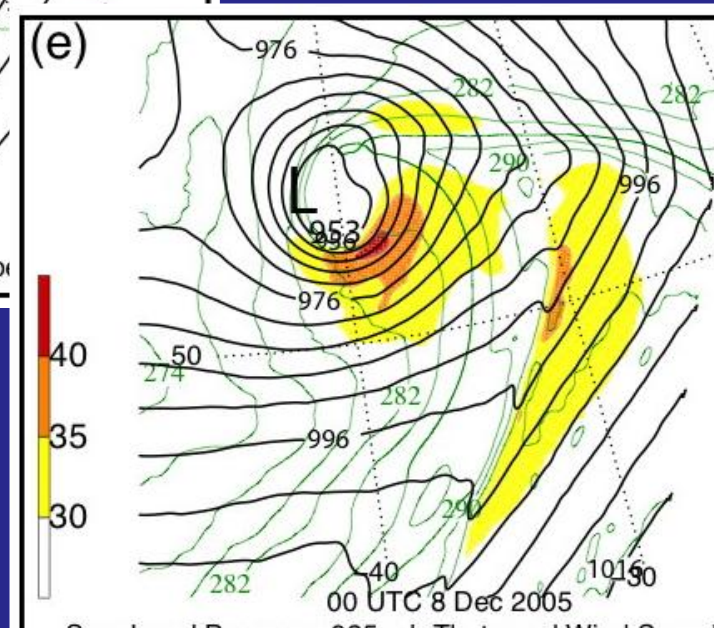


12 UTC 7 Dec

18 UTC 7 Dec

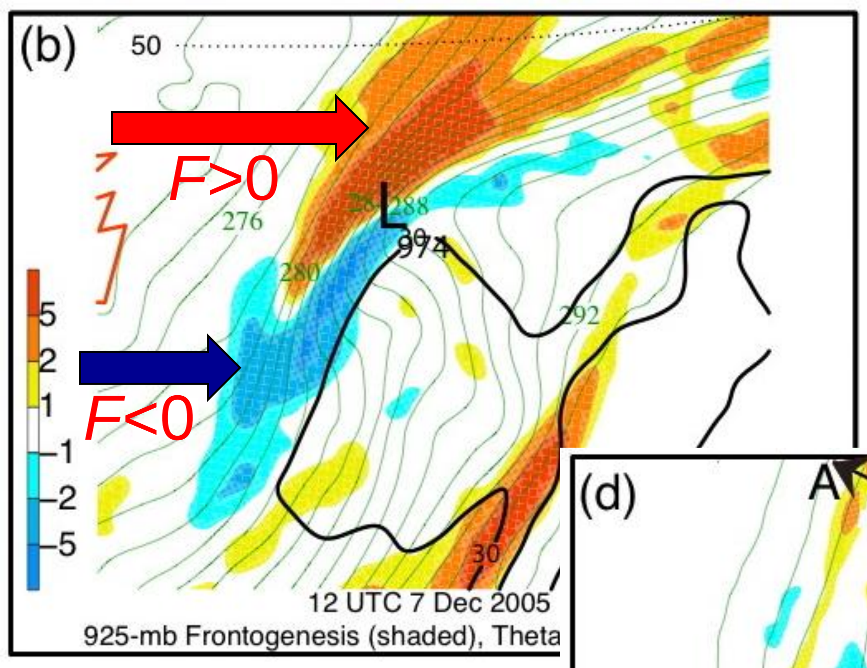


00 UTC 8 Dec

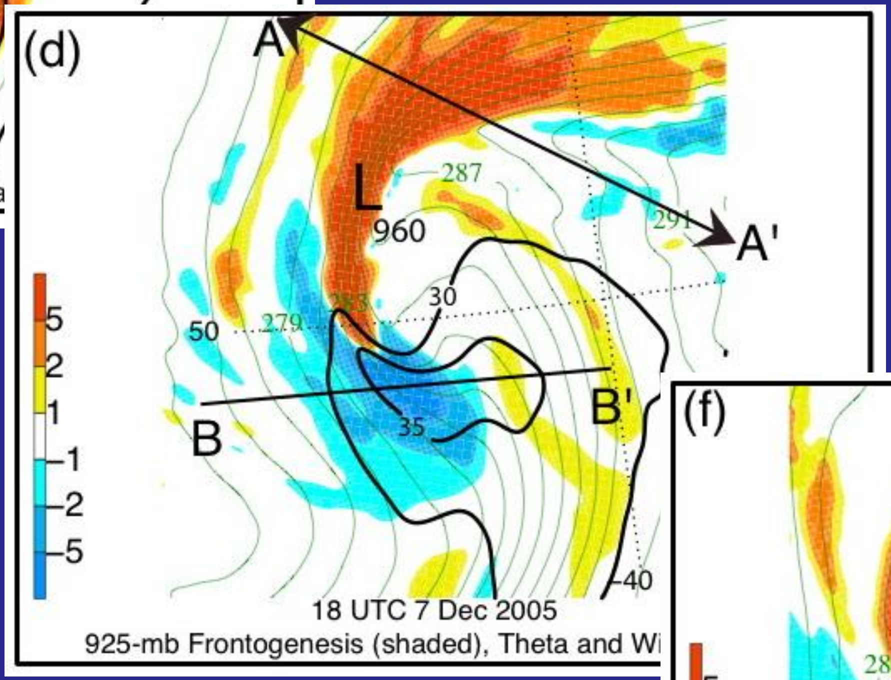


Sea-level pressure
925-mb theta
wind speed (shaded)

12 UTC 7 Dec



18 UTC 7 Dec



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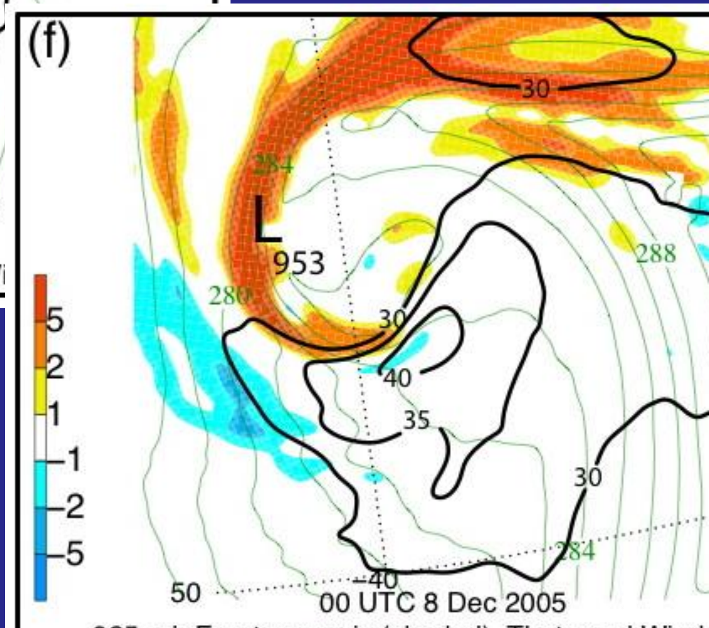
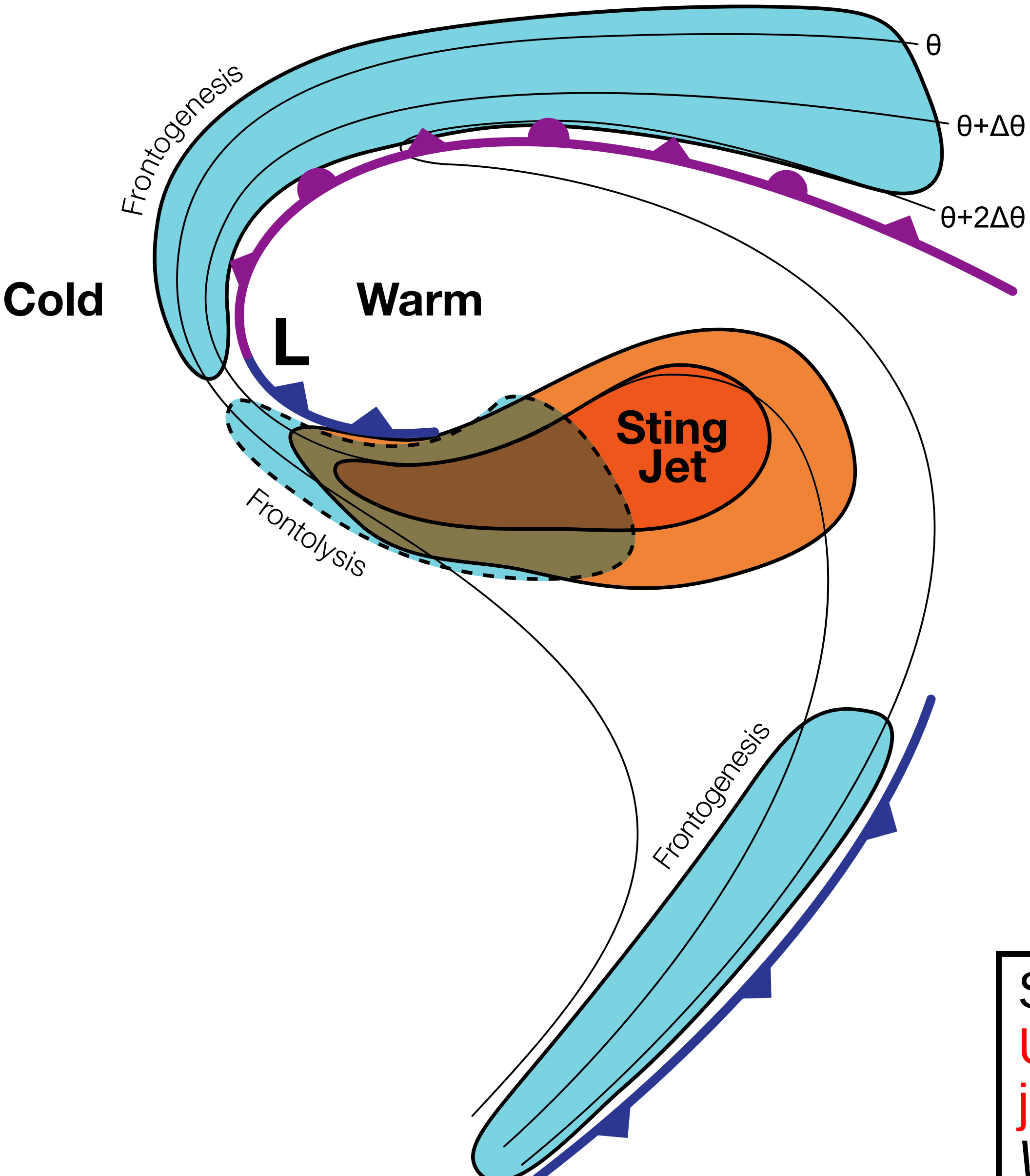


925-mb theta
wind speed
frontogenesis (shaded)

Ingredients for a Sting Jet



1. Frontogenesis and ascent of warm air along bent-back front.

2. Frontolysis at end of back-bent front and descent of warm air.

3. Cold advection over warm water creates low static stability, which favors mixing downward of high momentum air.

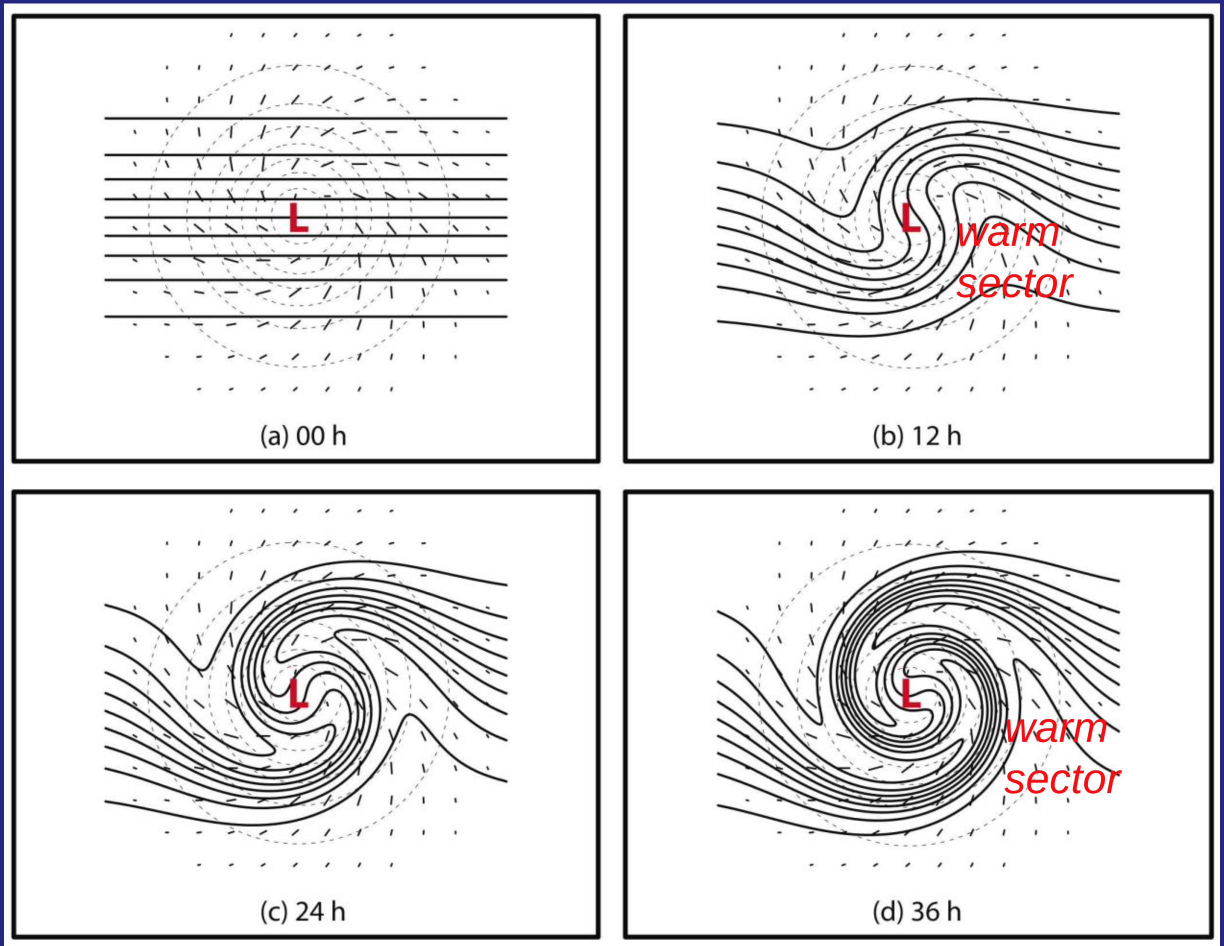
Schultz and Sienkiewicz, 2013: Using frontogenesis to identify sting jets in extratropical cyclones. *Wea. Forecasting*, **28,** 603–613.

What about occluded fronts?

Conventional Wisdom

Occluded fronts form when cold fronts ***catch up*** to warm fronts.

Rotation and deformation around a nondivergent vortex will produce a narrowing warm sector.



isentropes

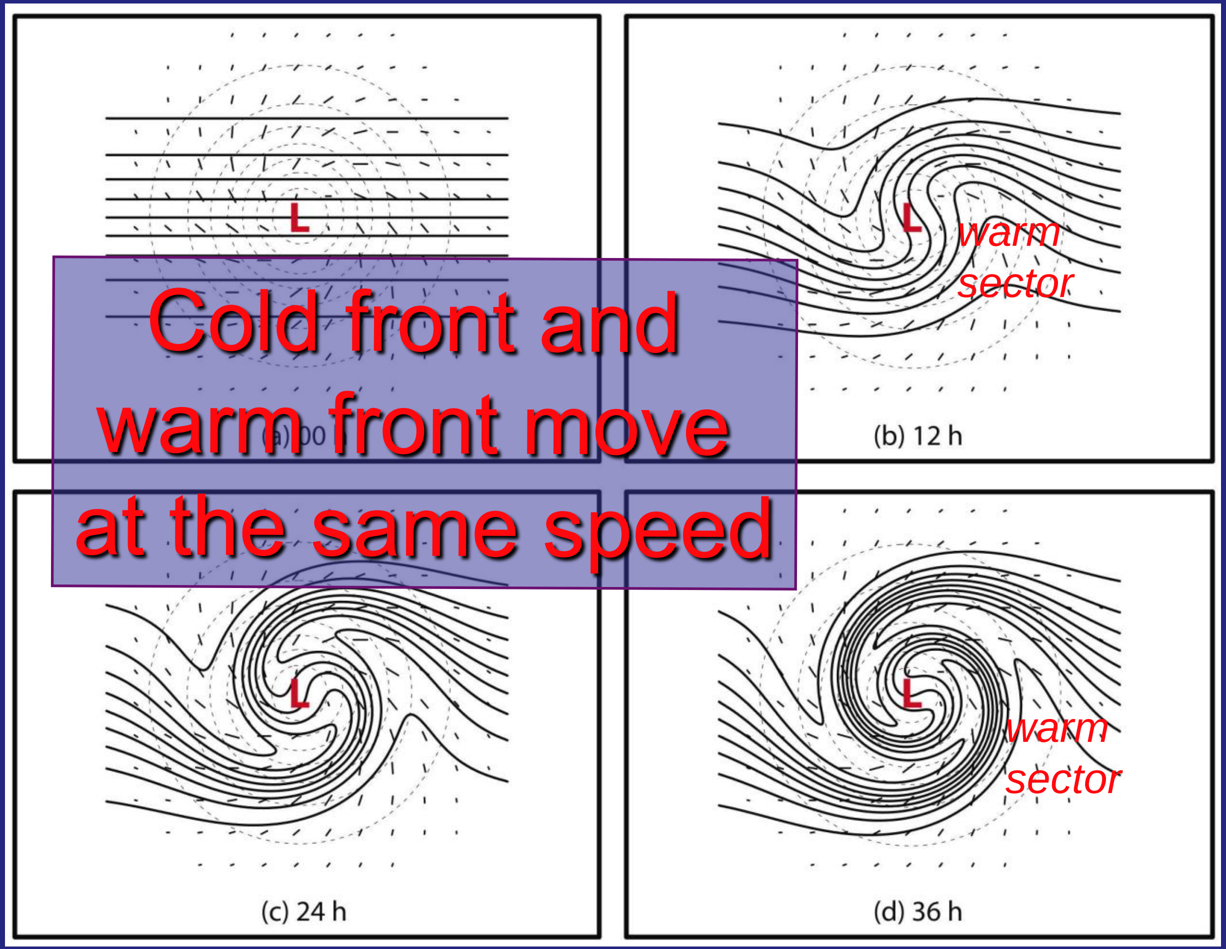
streamlines

axes of dilatation

barotropic model with passively advected isentropes

(Doswell 1984, 1985; Davies-Jones 1985; Schultz et al. 1998)

Rotation and deformation around a nondivergent vortex will produce a narrowing warm sector.



isentropes

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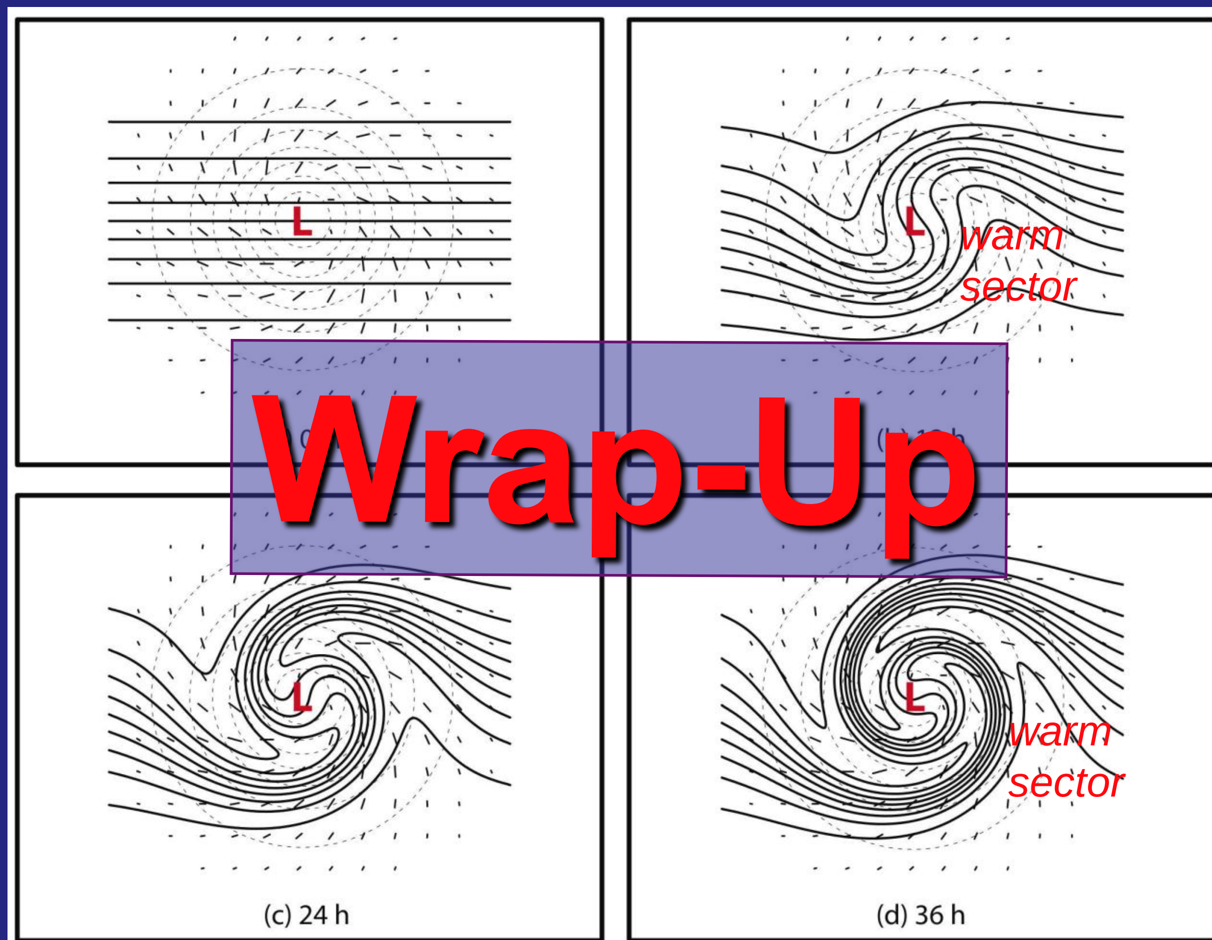


isentropes

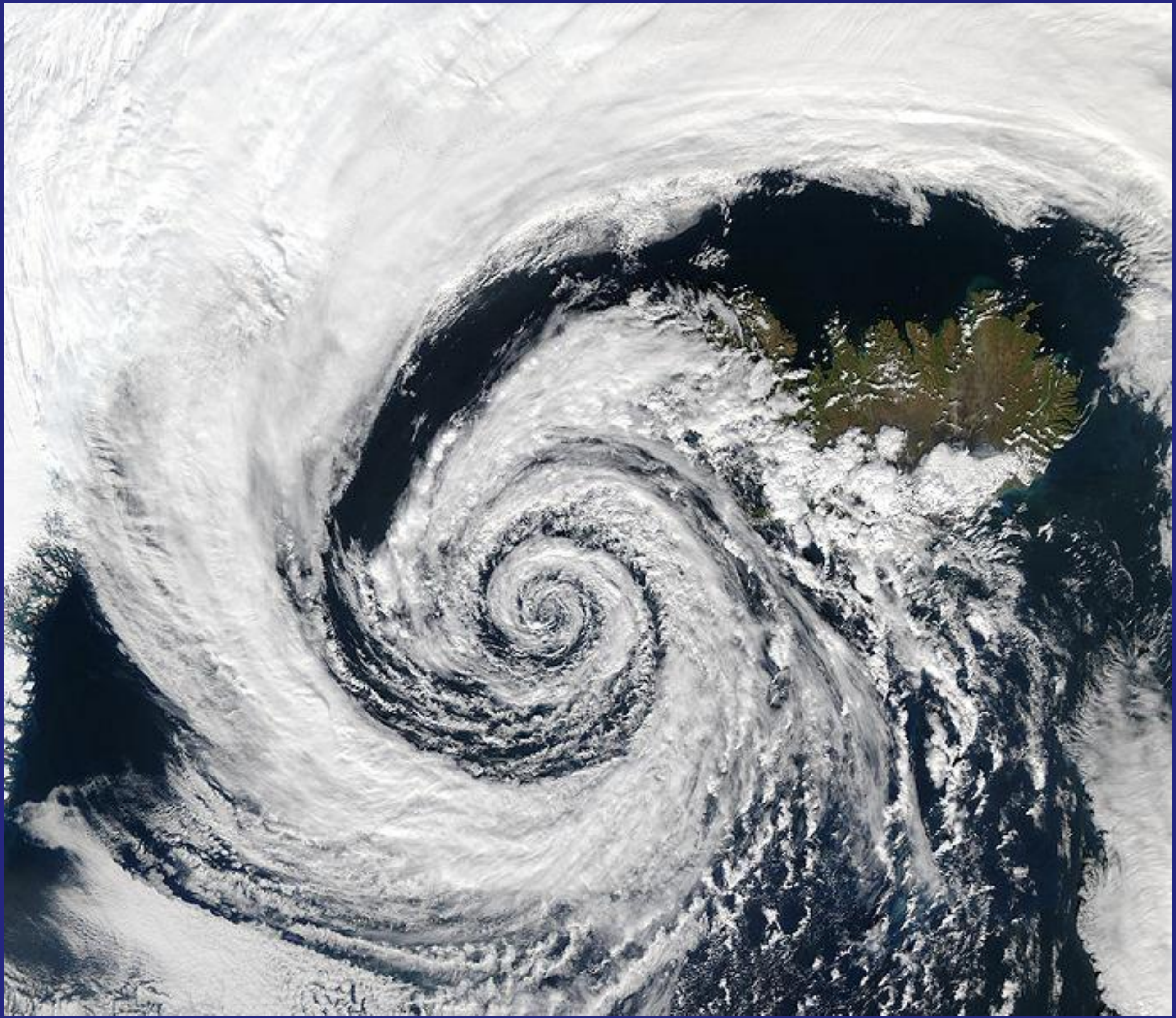
streamlines

axes of dilatation

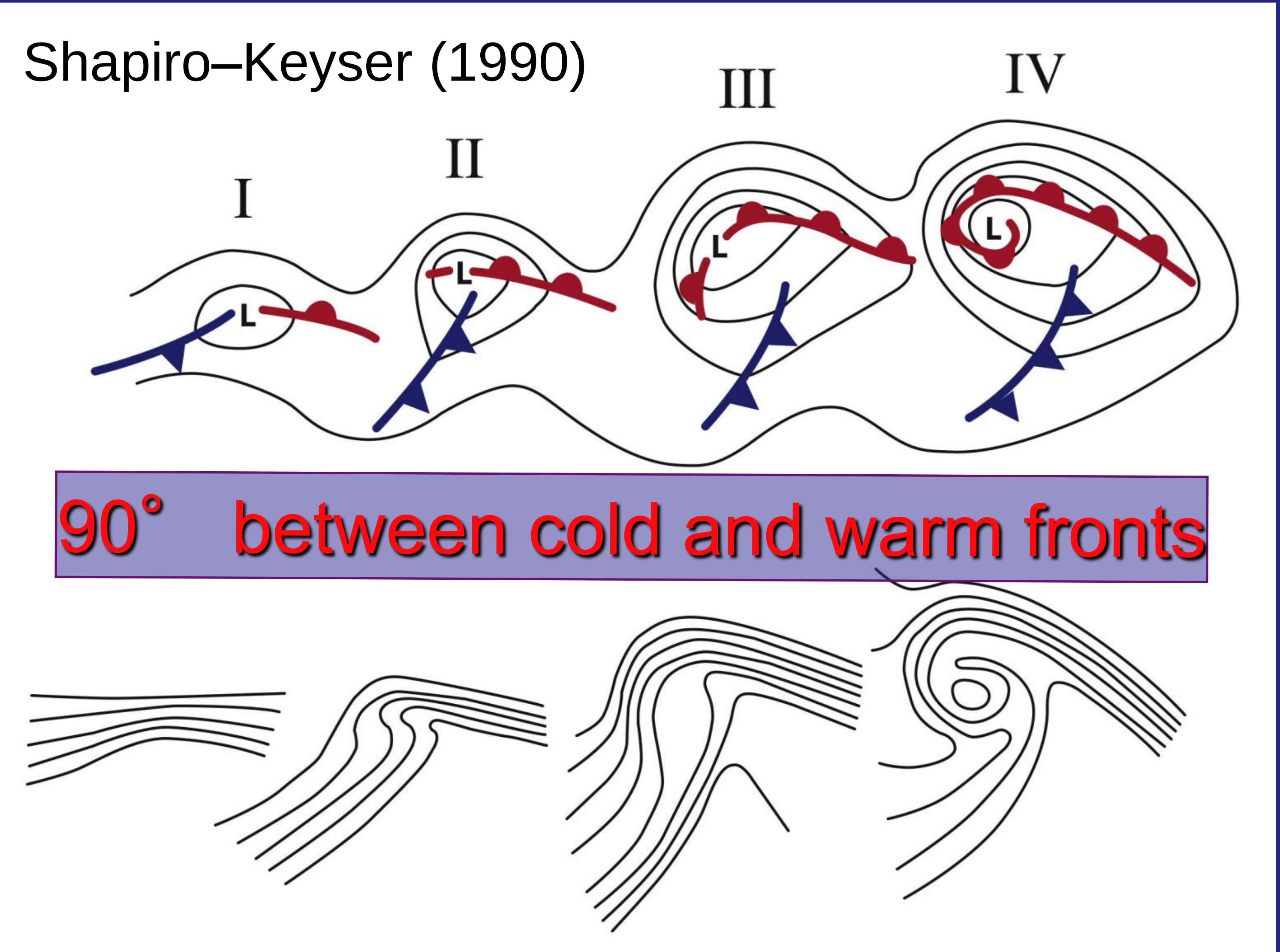
barotropic model with passively advected isentropes

(Doswell 1984, 1985; Davies-Jones 1985; Schultz et al. 1998)

Wrap-up explains long spiral occluded fronts.



Wrap-up allows the occlusion process to be incorporated in other cyclone models.



90˚ between cold and warm fronts

isobars

isotherms

Wrap-up is a better description of the occlusion process than catch-up.

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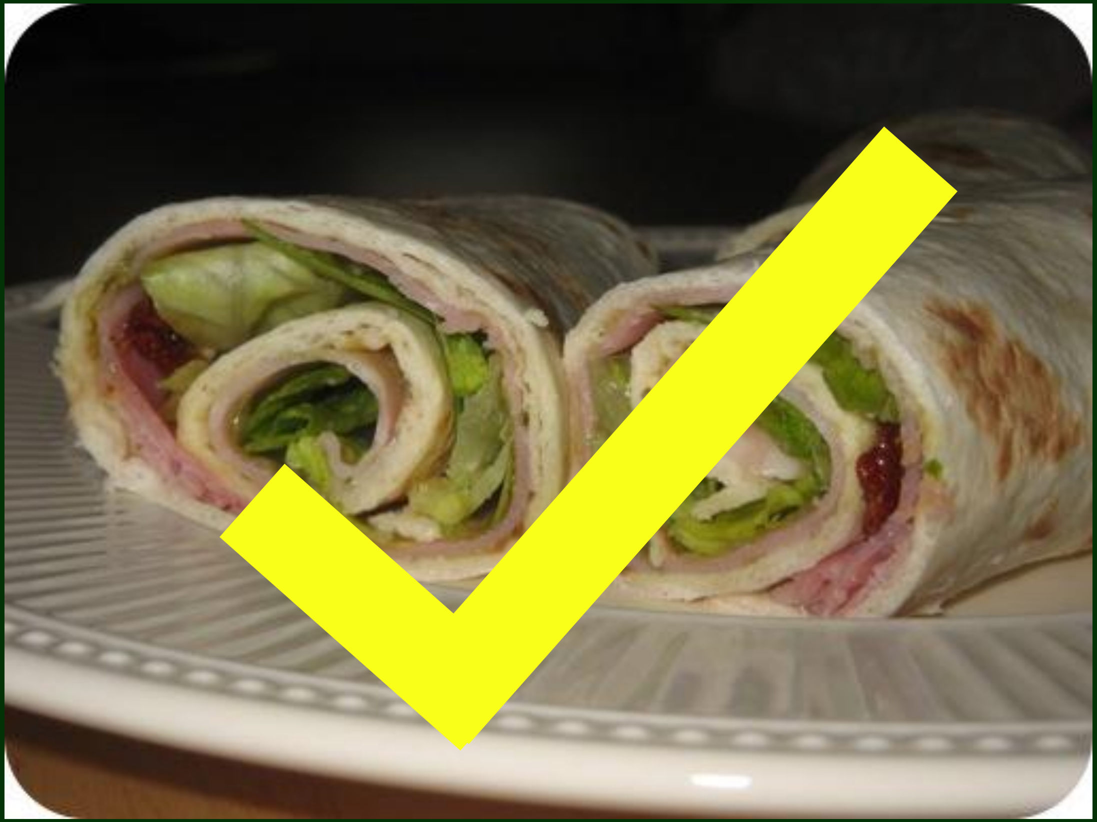

Summary

- Philosophy of diagnosis
- The value of frontogenesis
- Norwegian cyclones => form within diffluence
- Shapiro–Keyser cyclones => form within confluence
- Precipitation bands are favored in confluence/diffluence
- Comma tail is not always coincident with cold fronts
- Sting jets and cloud bands are associated with frontolysis at the end of the back-bent front.
- Wrap up, not catch up.