# Strong Winds in Extratropical Cyclones: Sting Jets and Cold Conveyor Belts

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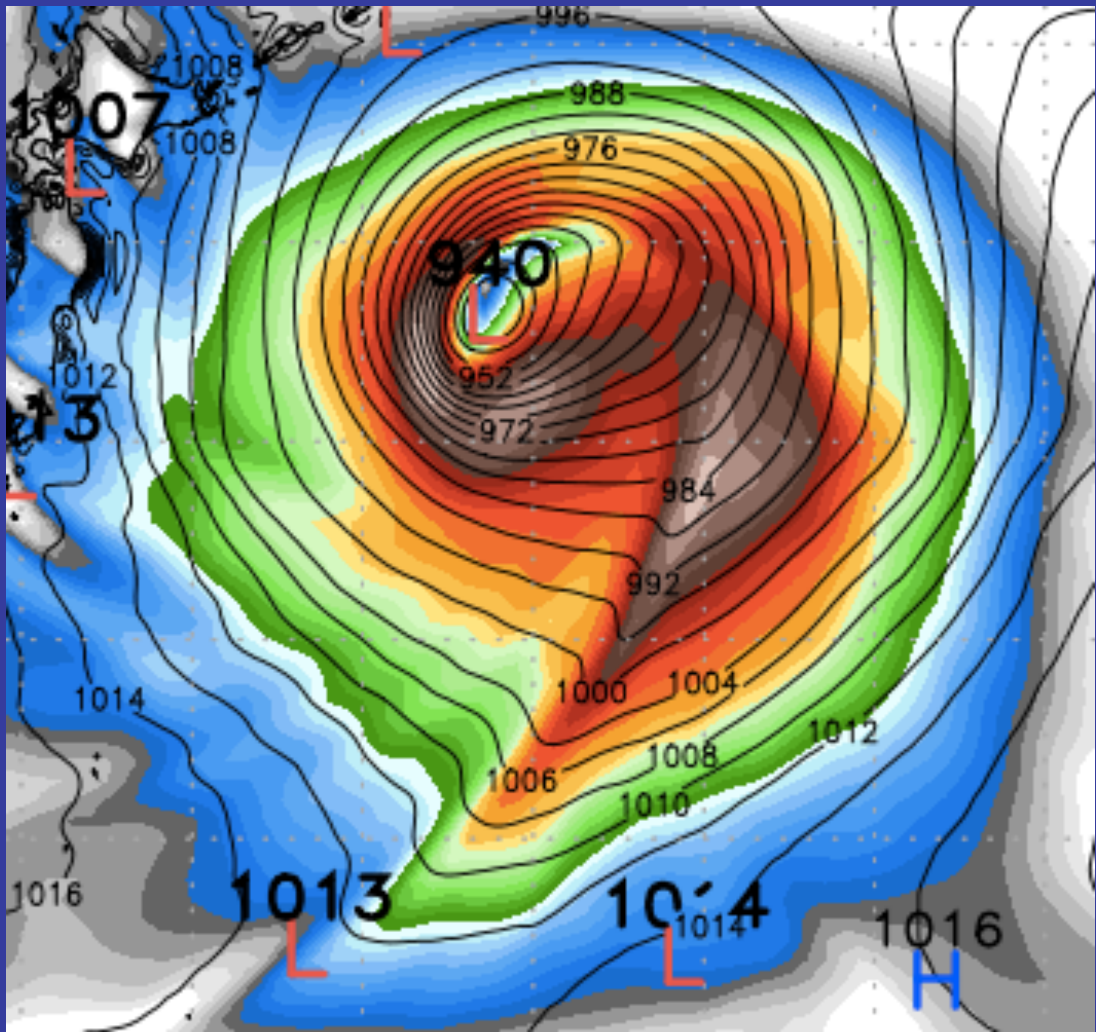
with J. Sienkiewicz, G. Vaughan, T. Slater

# Three locations where strong winds occur in extratropical cyclones.



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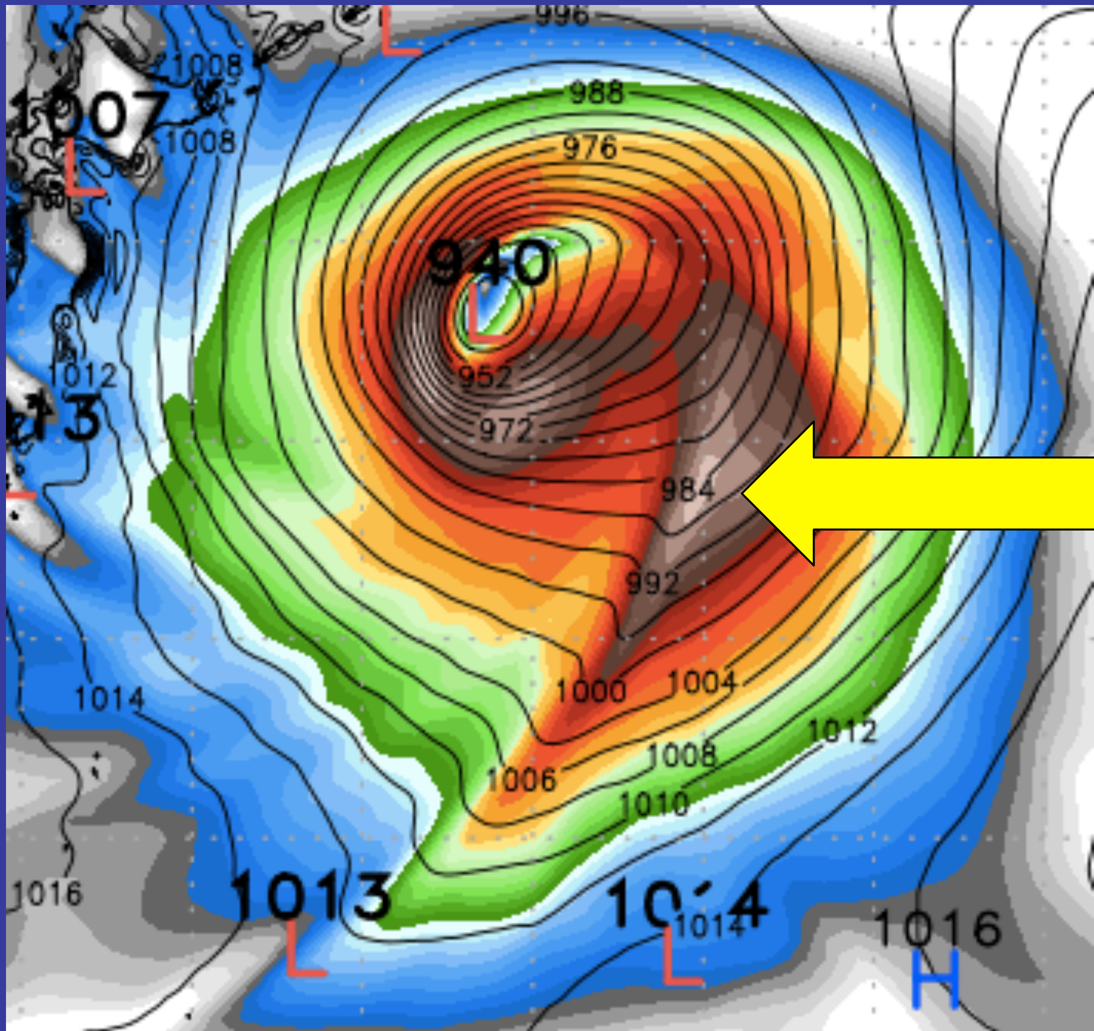
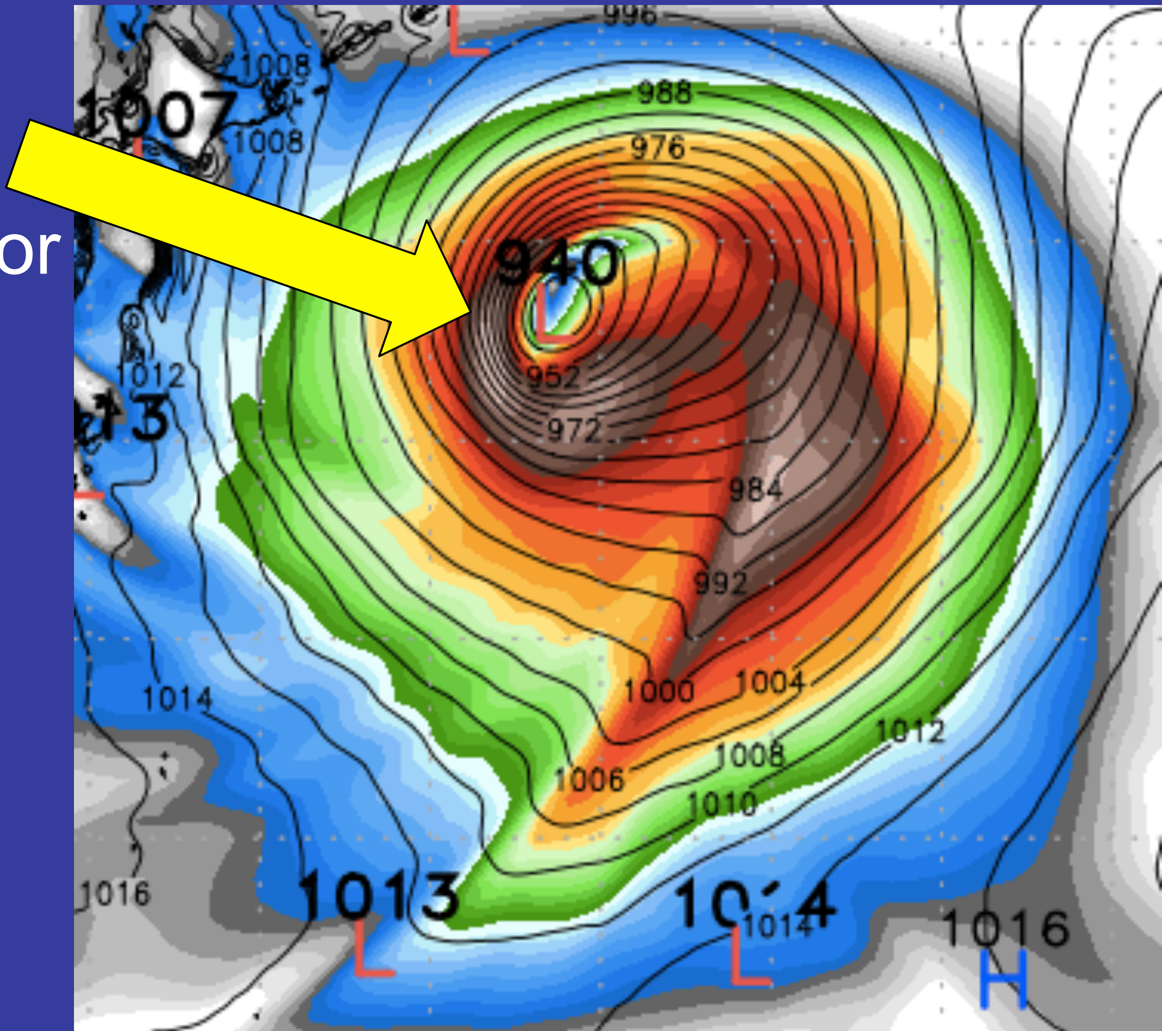



warm sector

# Three locations where strong winds occur in extratropical cyclones.

cold
conveyor
belt



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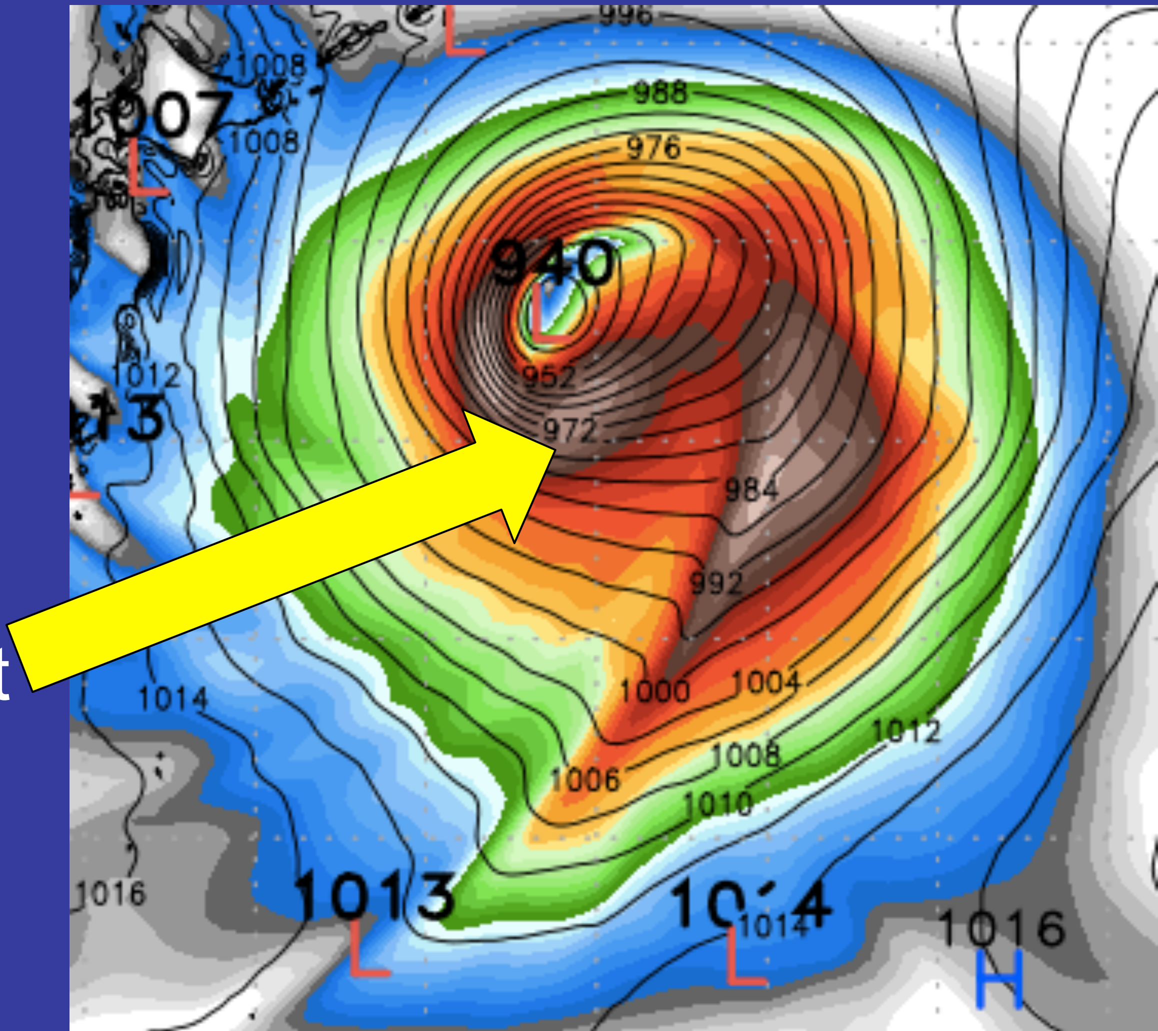
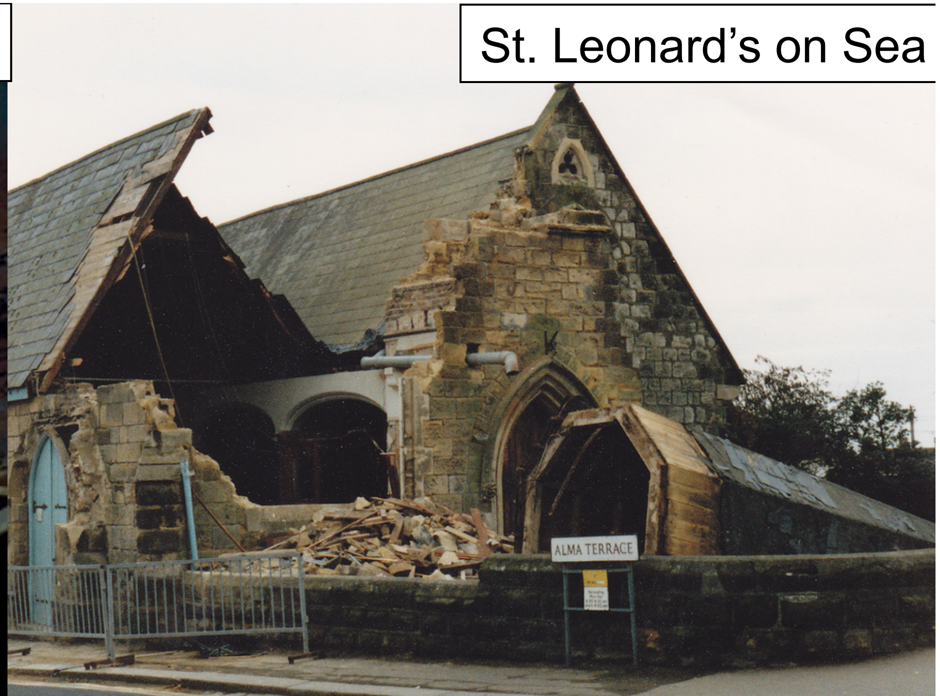



sting jet


Folkestone




St. Leonard's on Sea

Peacehaven

16 October 1987


BBC
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# Sting jet technology means no more hurricane mishaps for Michael Fish

theguardian

**BBC Weather** @bbcweather

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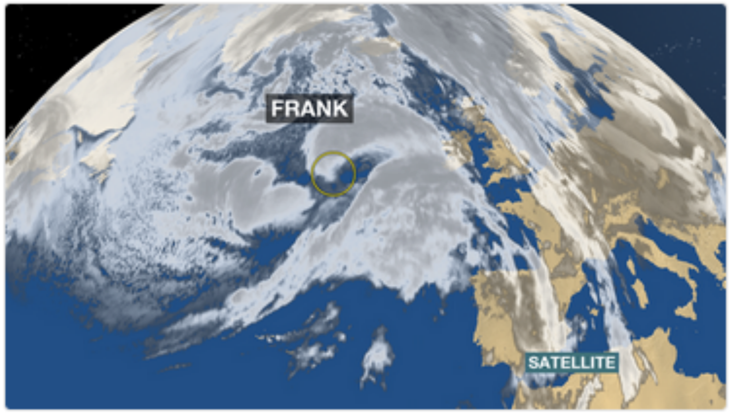
Storm #Frank is developing a sting jet (think 1987 storm), this thankfully staying well out to sea. Chris F



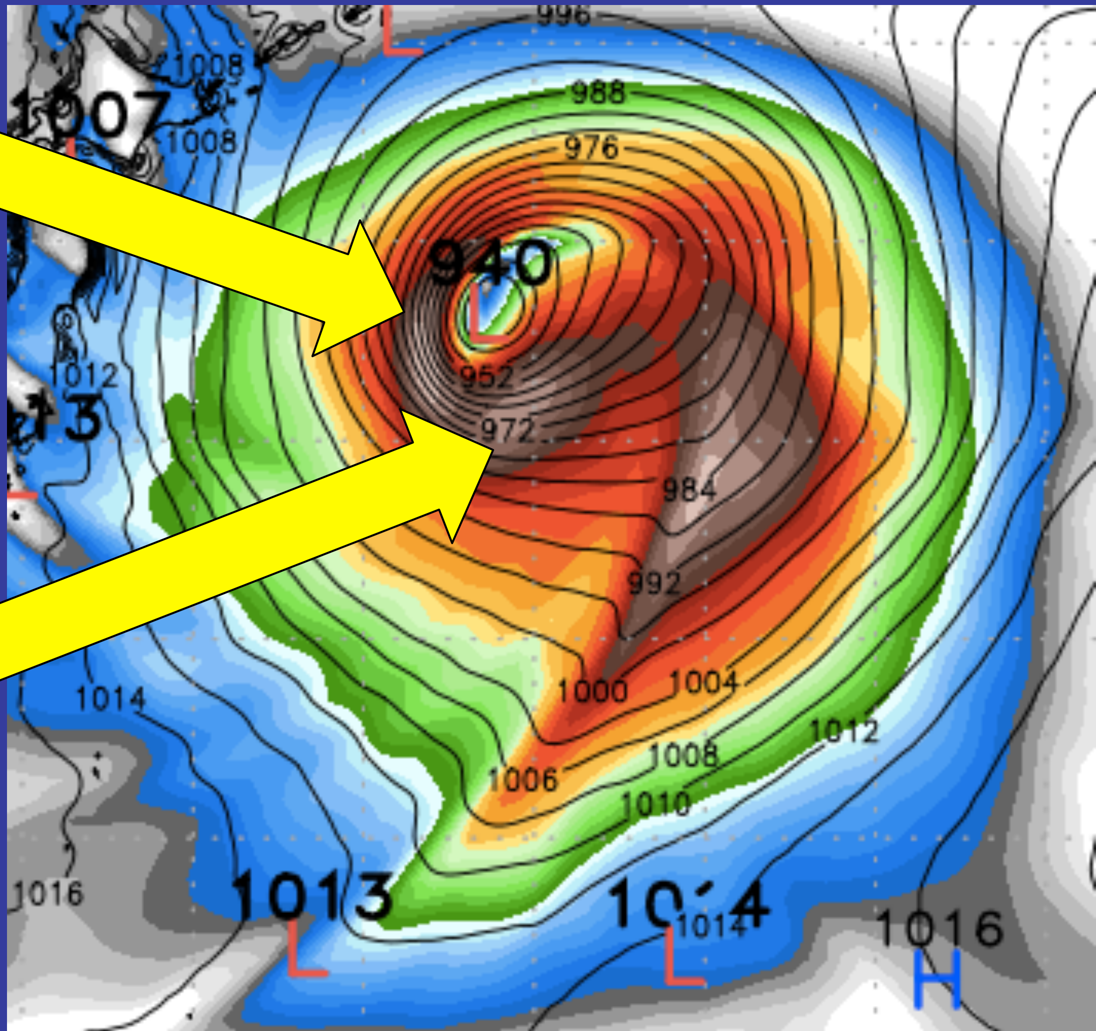

risk for power outages early tomorrow morning. The part of the storm we have to pay particular close attention to houses the highest pressure gradients—or the back-bent occlusion/ trough that wraps itself around the low pressure system. In rare cases, this can form the 'poisonous tail of the back-bent occlusion,' or also simply referred to as a sting jet.

The Weather Network

# Clear spatial distinction, but not always.

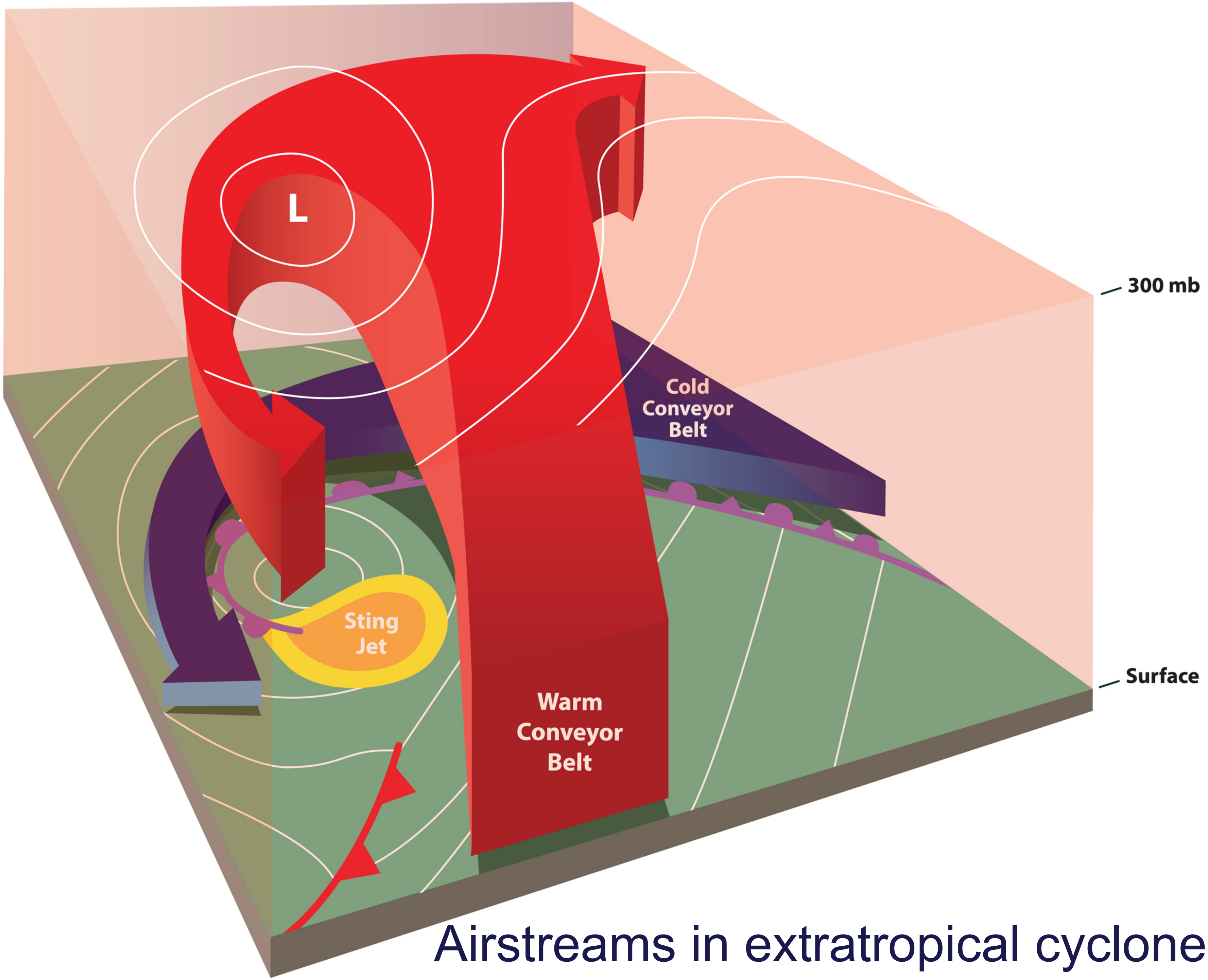
cold
conveyor
belt

sting jet

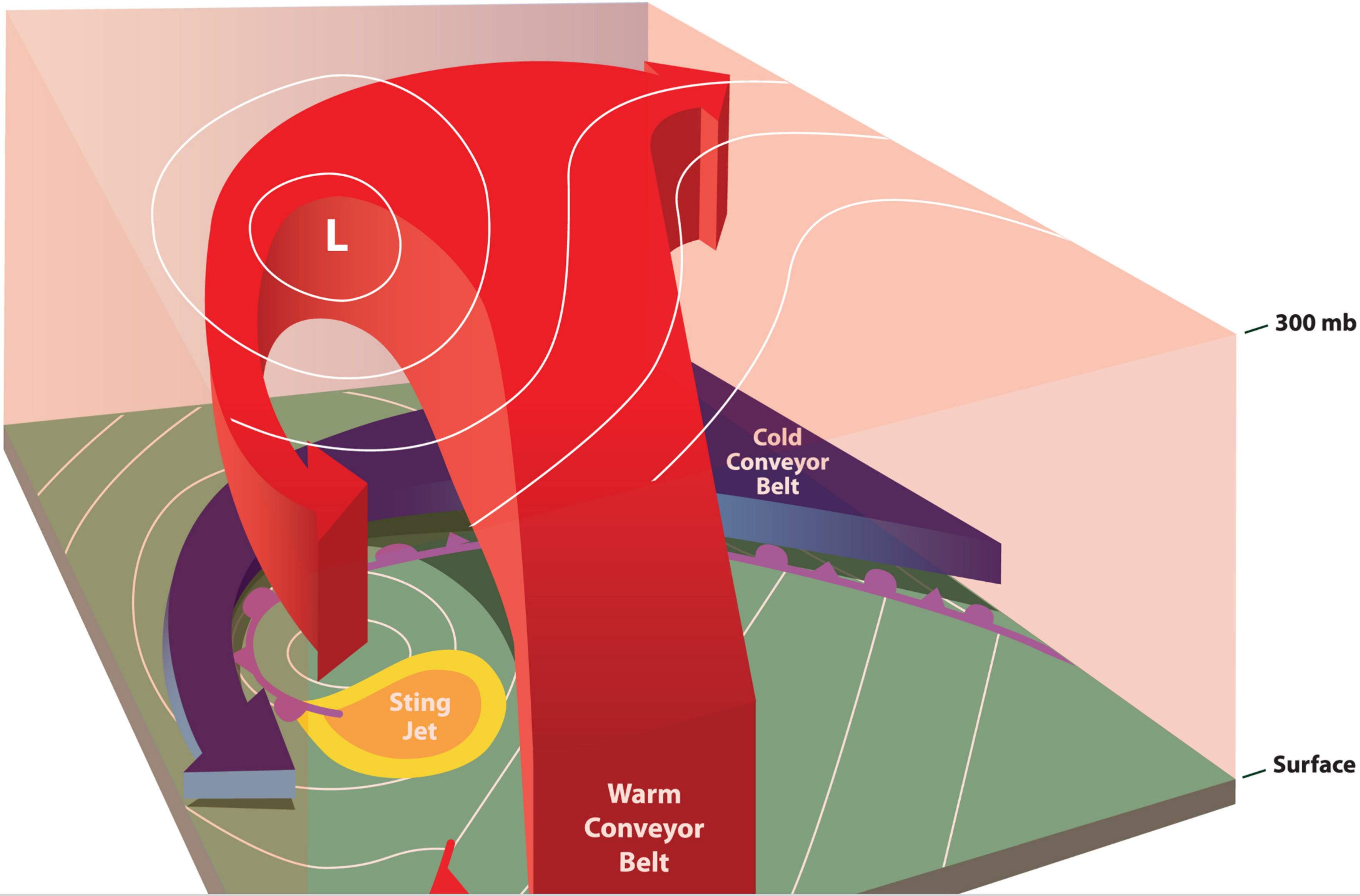


*What distinguishes the sting jet from the cold conveyor belt?*

(Schultz and Browning 2017, *Weather*)

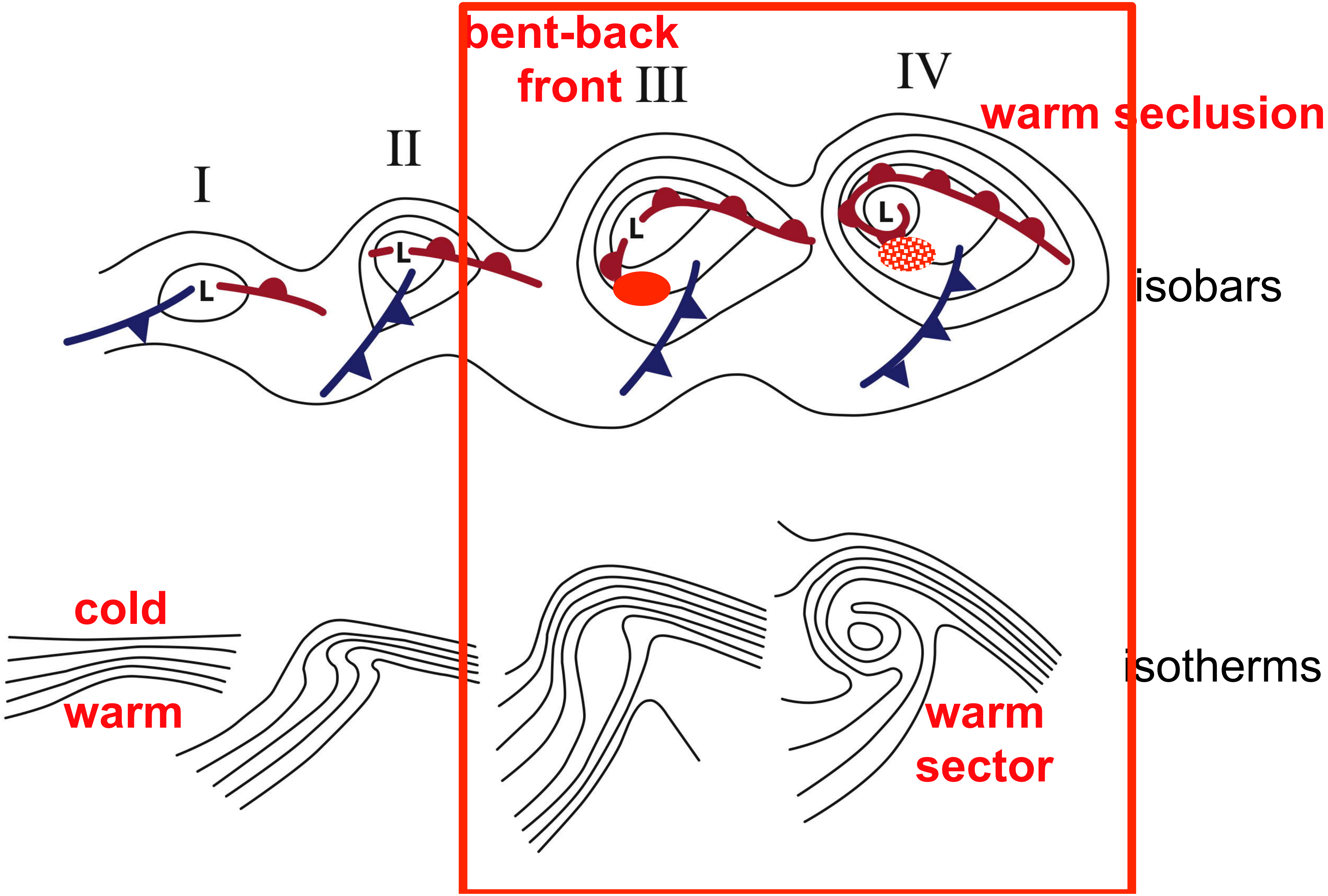


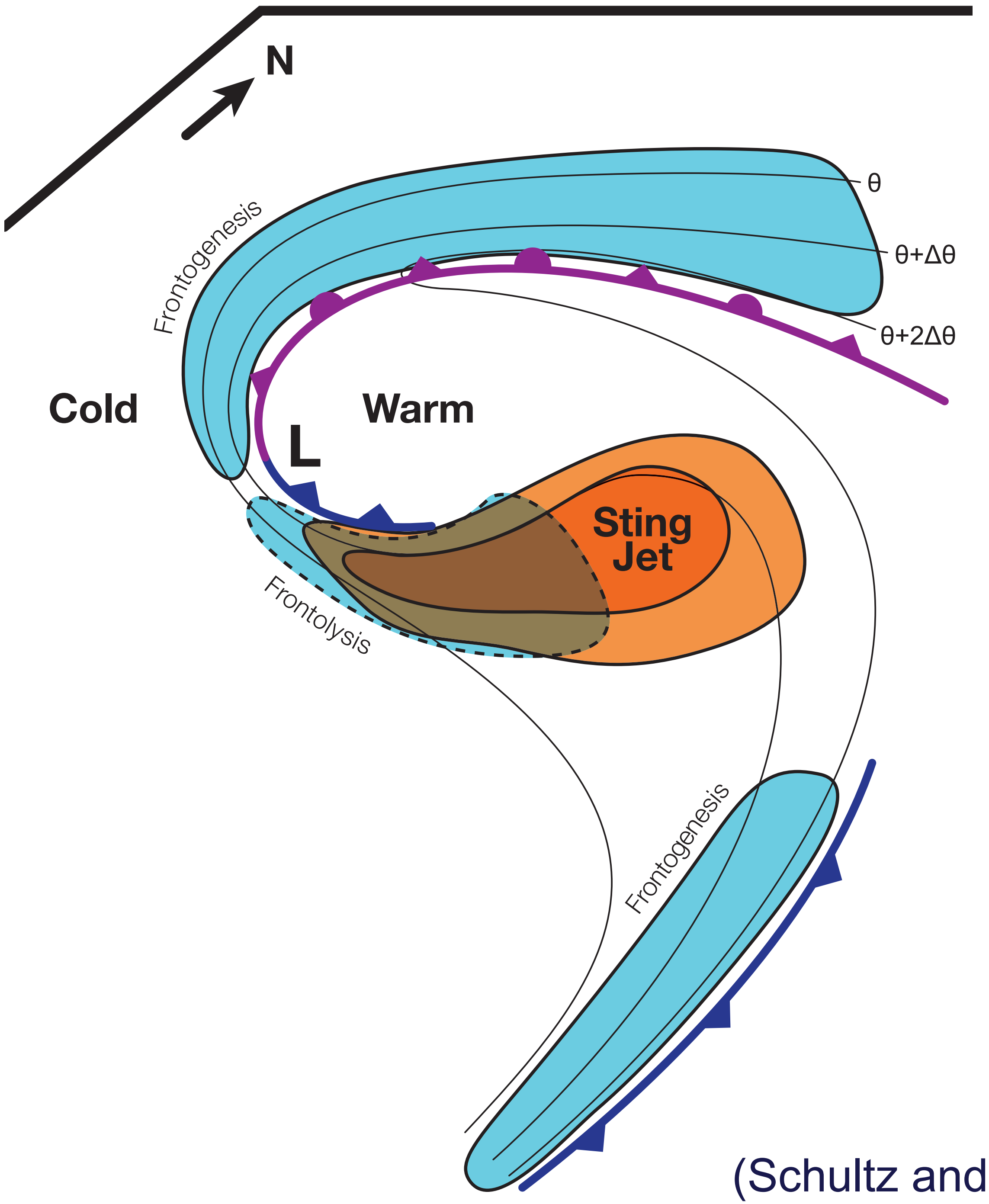

Airstreams in extratropical cyclones



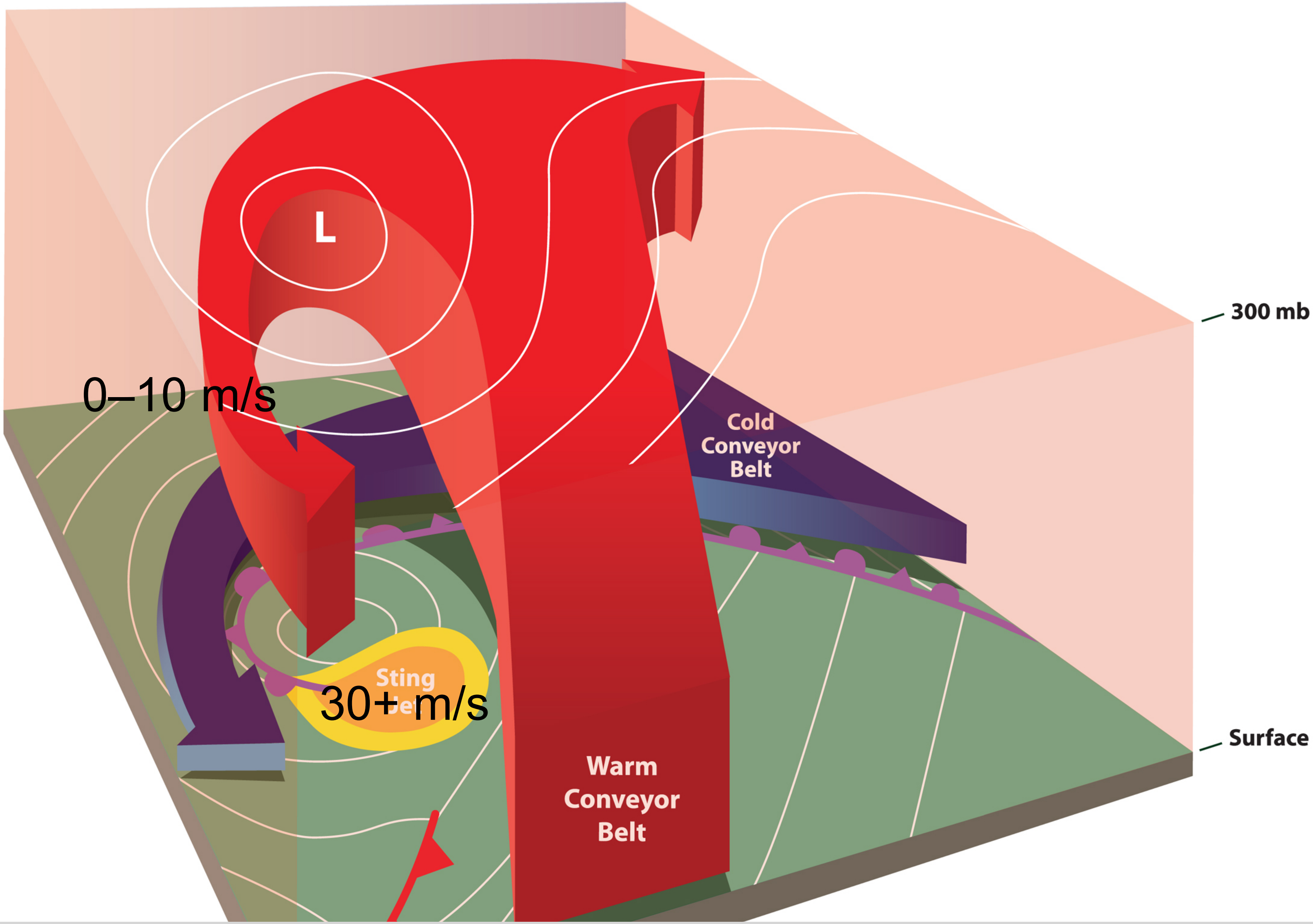

The sting jet descends and occurs at the tail of the bent-back front.

# Sting jet in context of Shapiro–Keyser (1990) cyclones






(Schultz and Sienkiewicz 2013)




# Why does the air accelerate during descent?

# The momentum equation tells us how winds accelerate.

$$\frac{\partial \boldsymbol{u_h}}{\partial t} = \underbrace{-(\boldsymbol{u_h}.\boldsymbol{\nabla}_h)\boldsymbol{u_h}}_{\boldsymbol{F}^{HADV}} \underbrace{-w.\frac{\partial \boldsymbol{u_h}}{\partial z}}_{\boldsymbol{F}^{VADV}} \underbrace{-f\boldsymbol{k} \times \boldsymbol{u_h}}_{\boldsymbol{F}^{COR}} \underbrace{-\frac{1}{\rho}\boldsymbol{\nabla}_h p}_{\boldsymbol{F}^{PGF}} + \boldsymbol{F}^{PBL}$$

Slater et al. (2015)

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just moves momentum around:
can't explain acceleration

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acts perpendicular to winds:
can't explain acceleration

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$$\frac{\partial \boldsymbol{u_h}}{\partial t} = \underbrace{-(\boldsymbol{u_h}.\boldsymbol{\nabla}_h)\boldsymbol{u_h}}_{\boldsymbol{F}^{HADV}} \underbrace{-w.\frac{\partial \boldsymbol{u_h}}{\partial z}}_{\boldsymbol{F}^{VADV}} \underbrace{-f\boldsymbol{k} \times \boldsymbol{u_h}}_{\boldsymbol{F}^{COR}} \underbrace{-\frac{1}{\rho}\boldsymbol{\nabla}_h p}_{\boldsymbol{F}^{PGF}} + \boldsymbol{F}^{PBL}$$

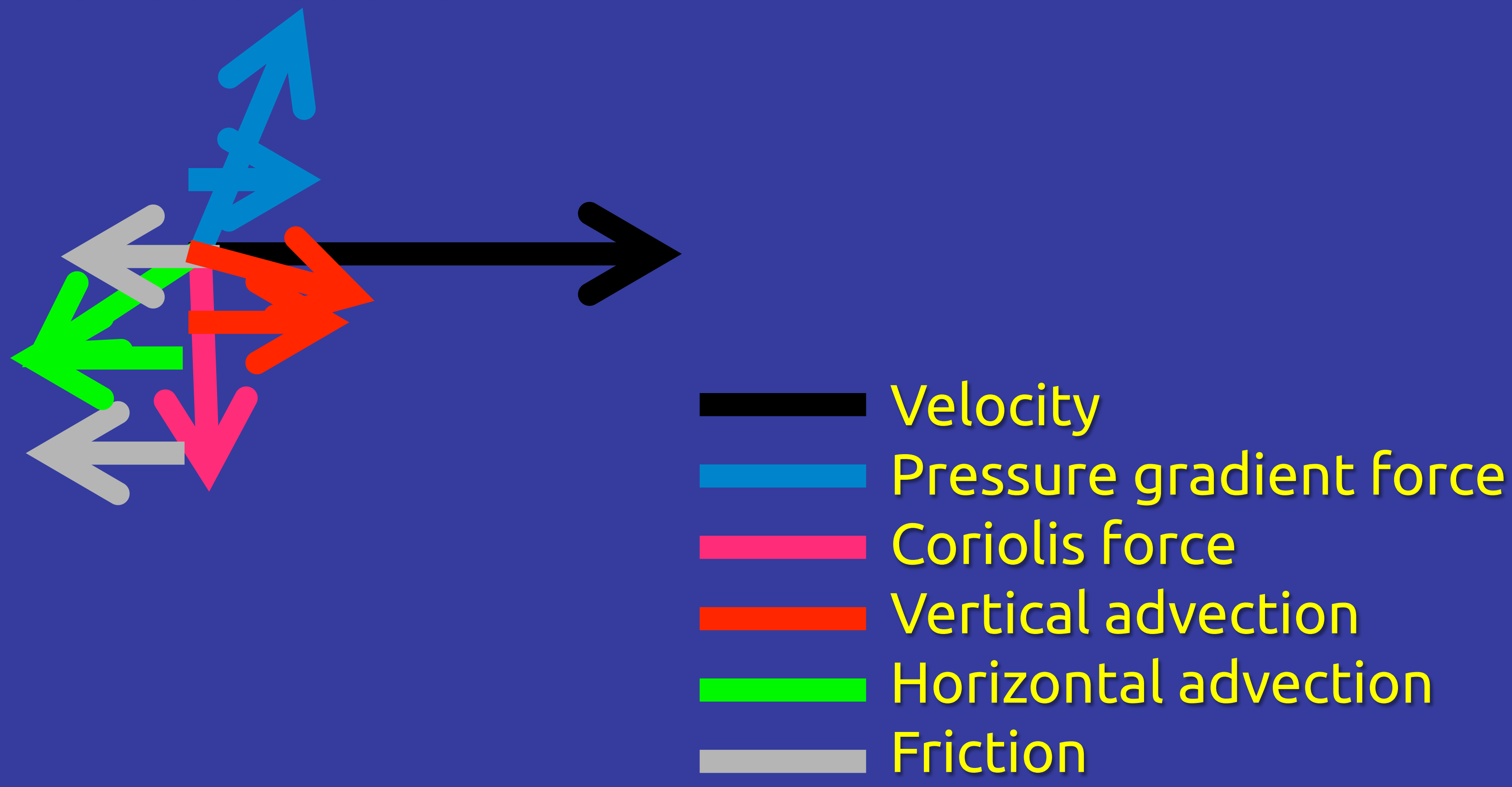
slows wind down:
can't explain acceleration

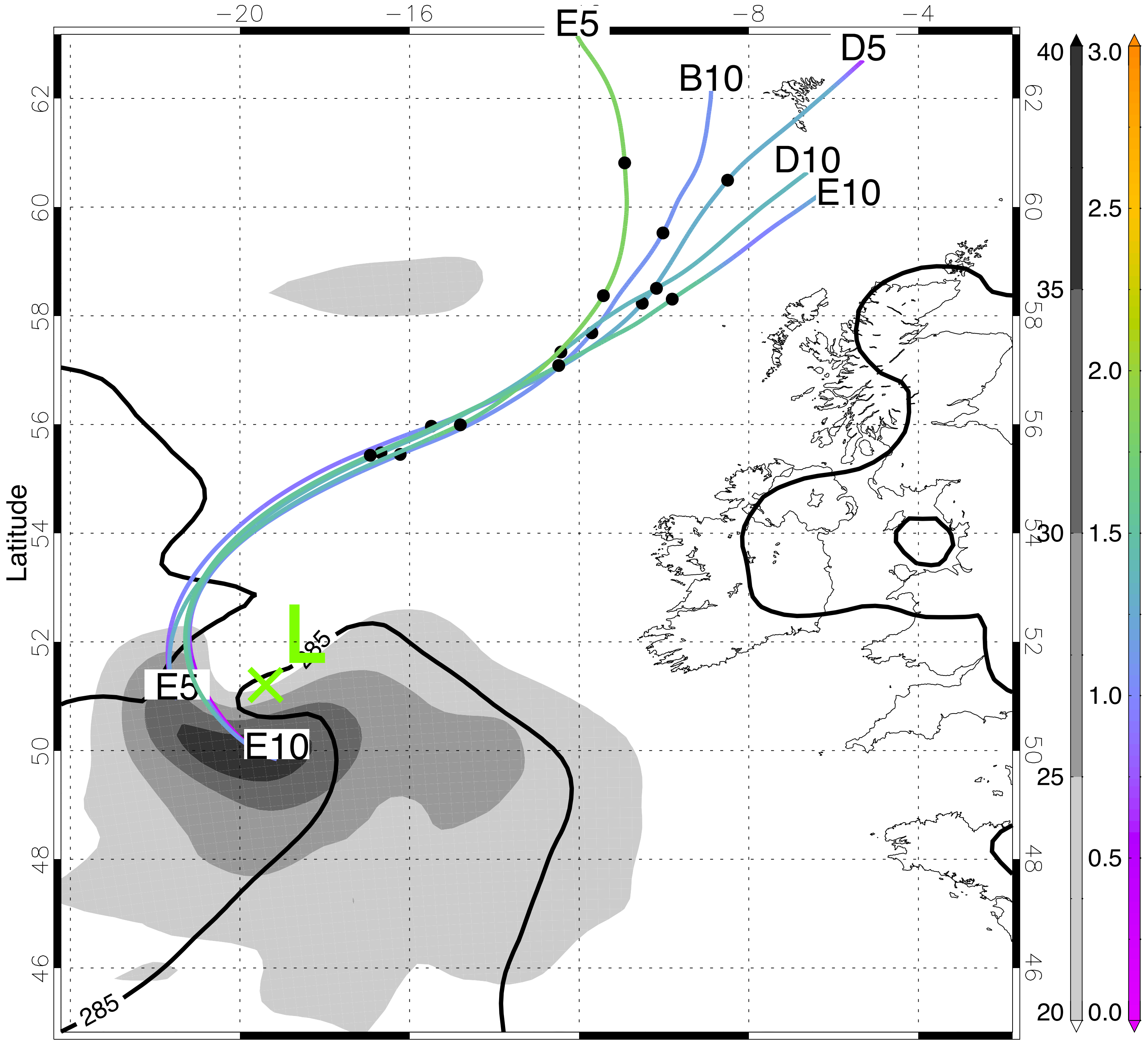
# The momentum equation tells us how winds accelerate.

$$\frac{\partial \boldsymbol{u_h}}{\partial t} = \underbrace{-(\boldsymbol{u_h}.\boldsymbol{\nabla_h})\boldsymbol{u_h}}_{\boldsymbol{F^{HADV}}} \underbrace{-w.\frac{\partial \boldsymbol{u_h}}{\partial z}}_{\boldsymbol{F^{VADV}}} \underbrace{-f\boldsymbol{k} \times \boldsymbol{u_h}}_{\boldsymbol{F^{COR}}} \underbrace{-\frac{1}{\rho}\boldsymbol{\nabla_h} p}_{\boldsymbol{F^{PGF}}} + \boldsymbol{F^{PBL}}$$

Can create acceleration/force vectors from model output.

To understand increases in wind speed look at along-flow accelerations.





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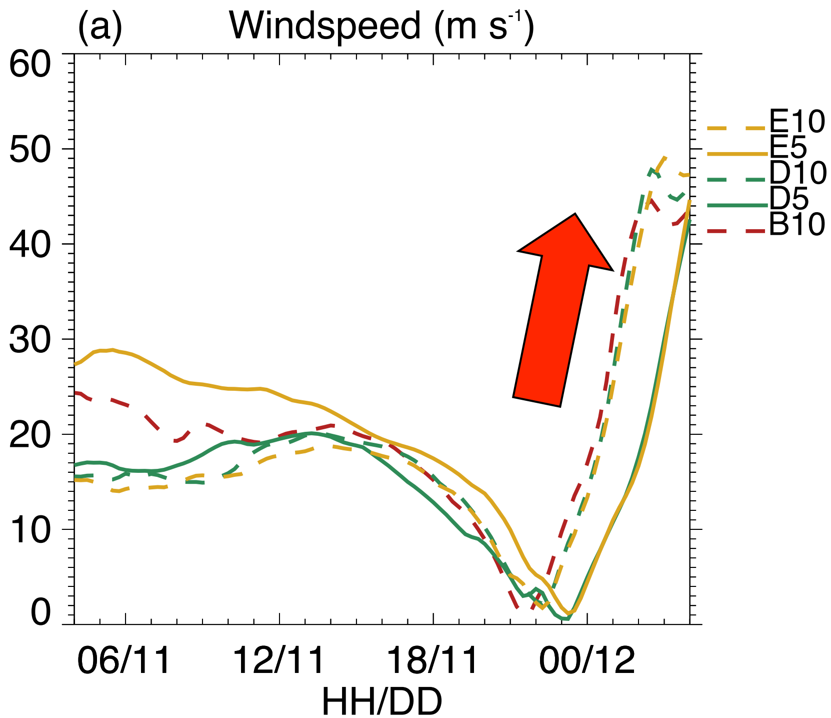
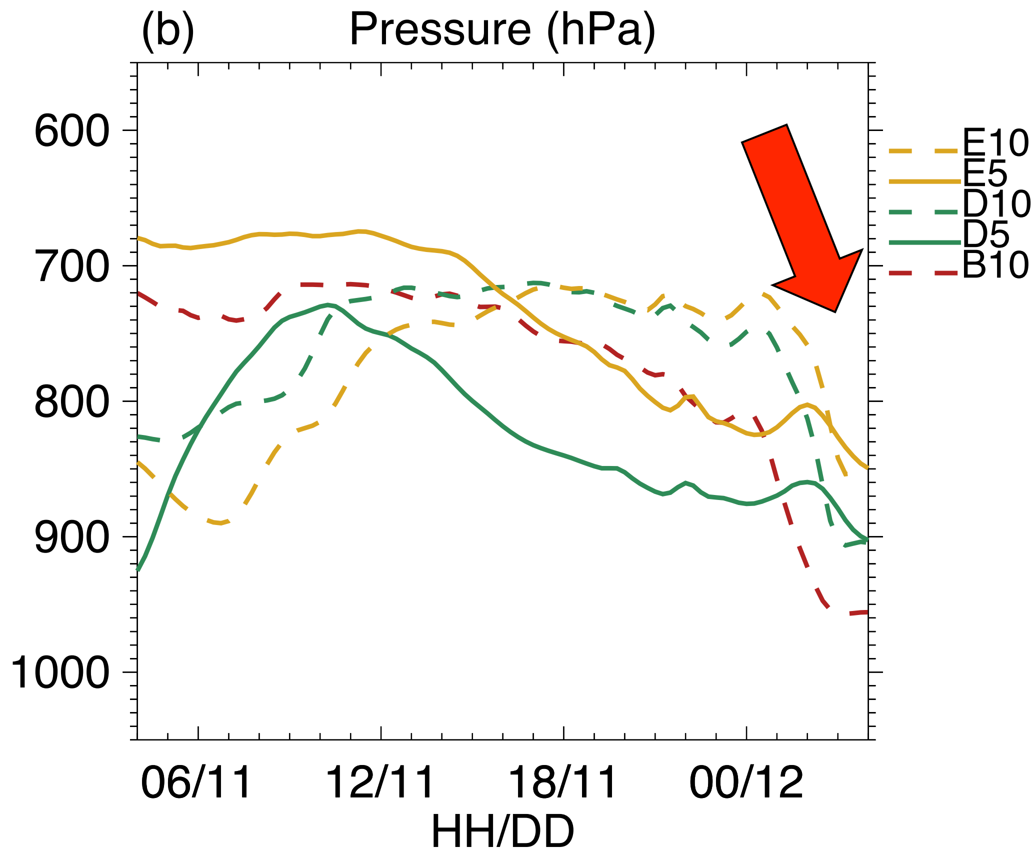
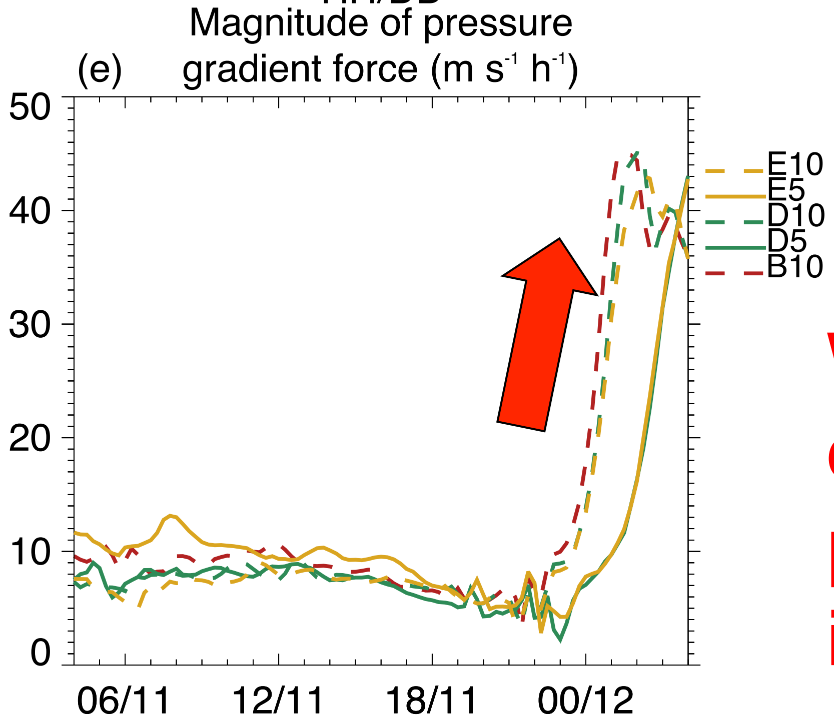
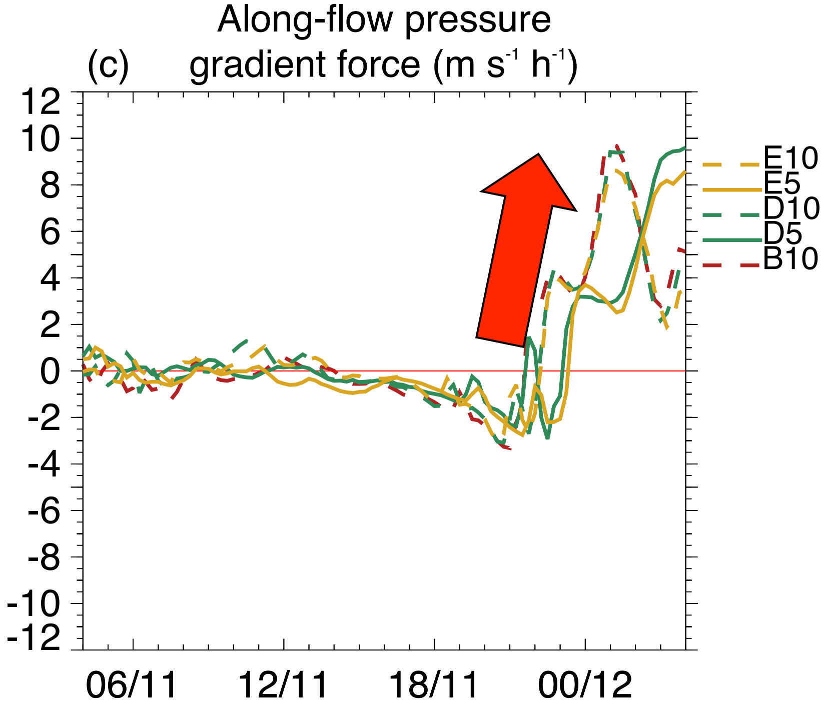
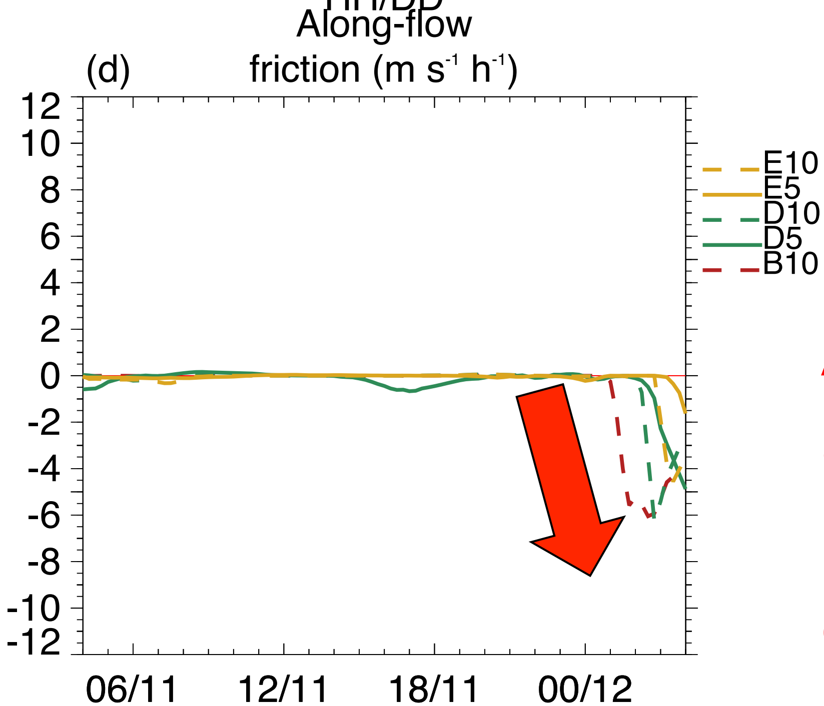


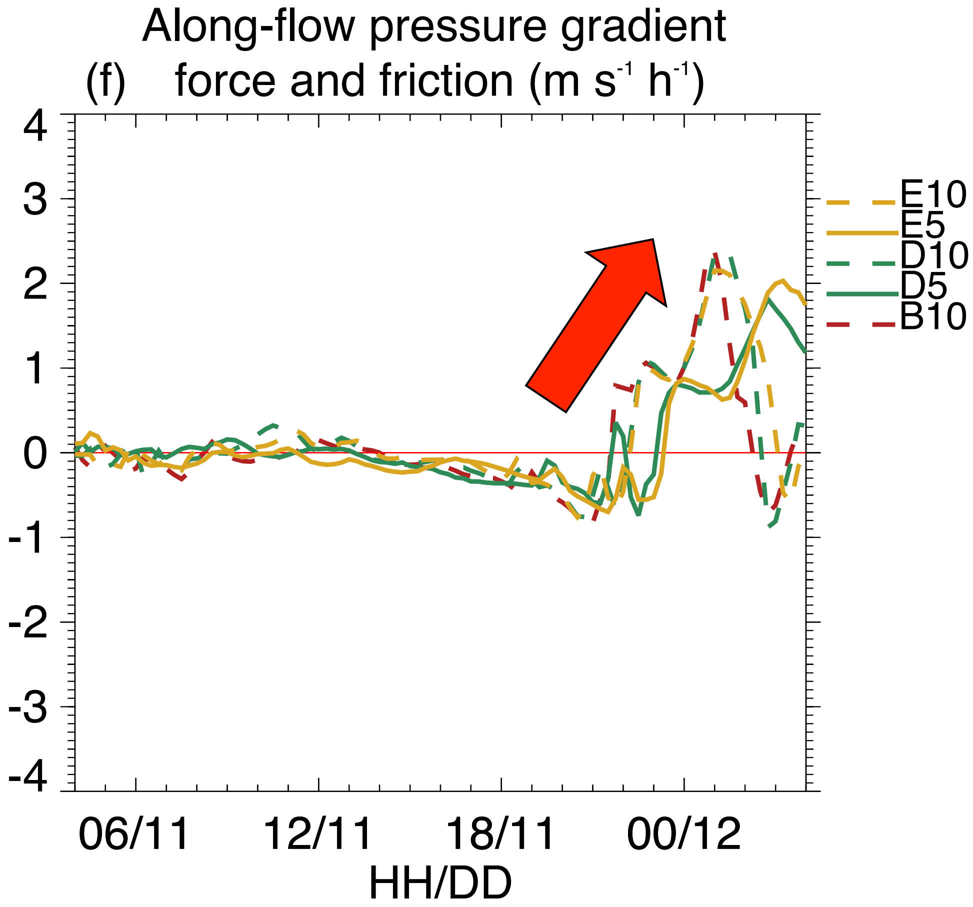




Wind speed increases during descent as the horizontal pressure gradient force increases substantially.




Acceleration largely happens aloft, but near-surface friction is not enough to decelerate descending air.

# Strong winds in cyclones

Frontolysis associated with descent of the sting jet.

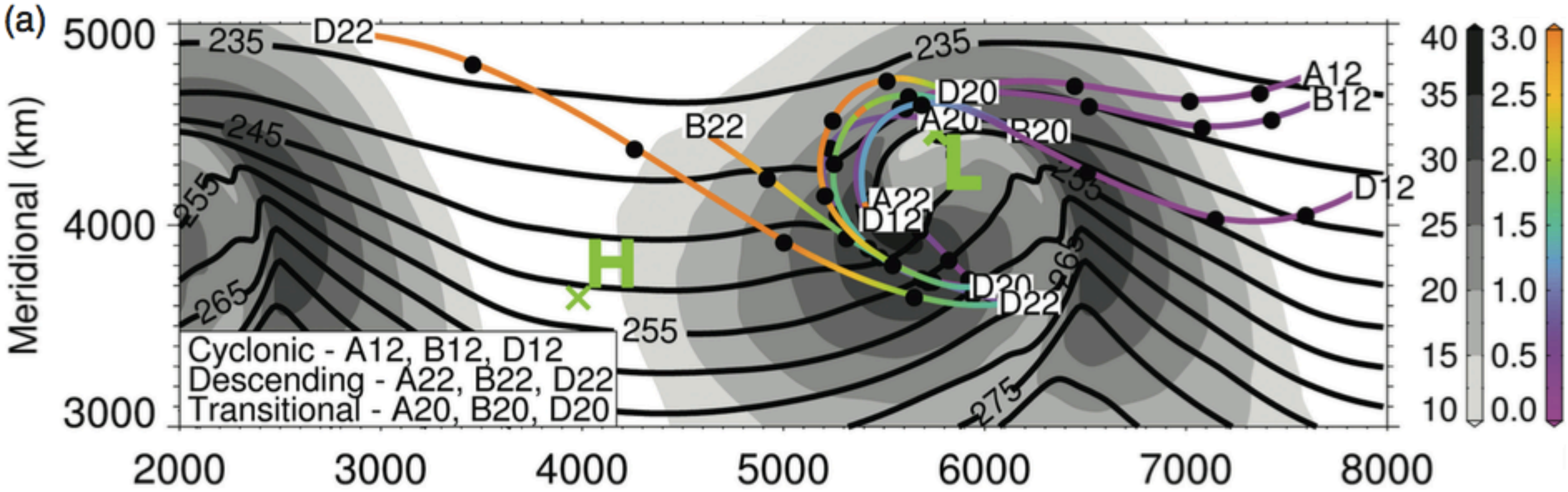
- End of bent-back front
- Lasts for a finite time just before maturity of cyclone

Southwest wind maximum accelerated by both:

- Horizontal pressure-gradient force
- Downward advection of momentum.

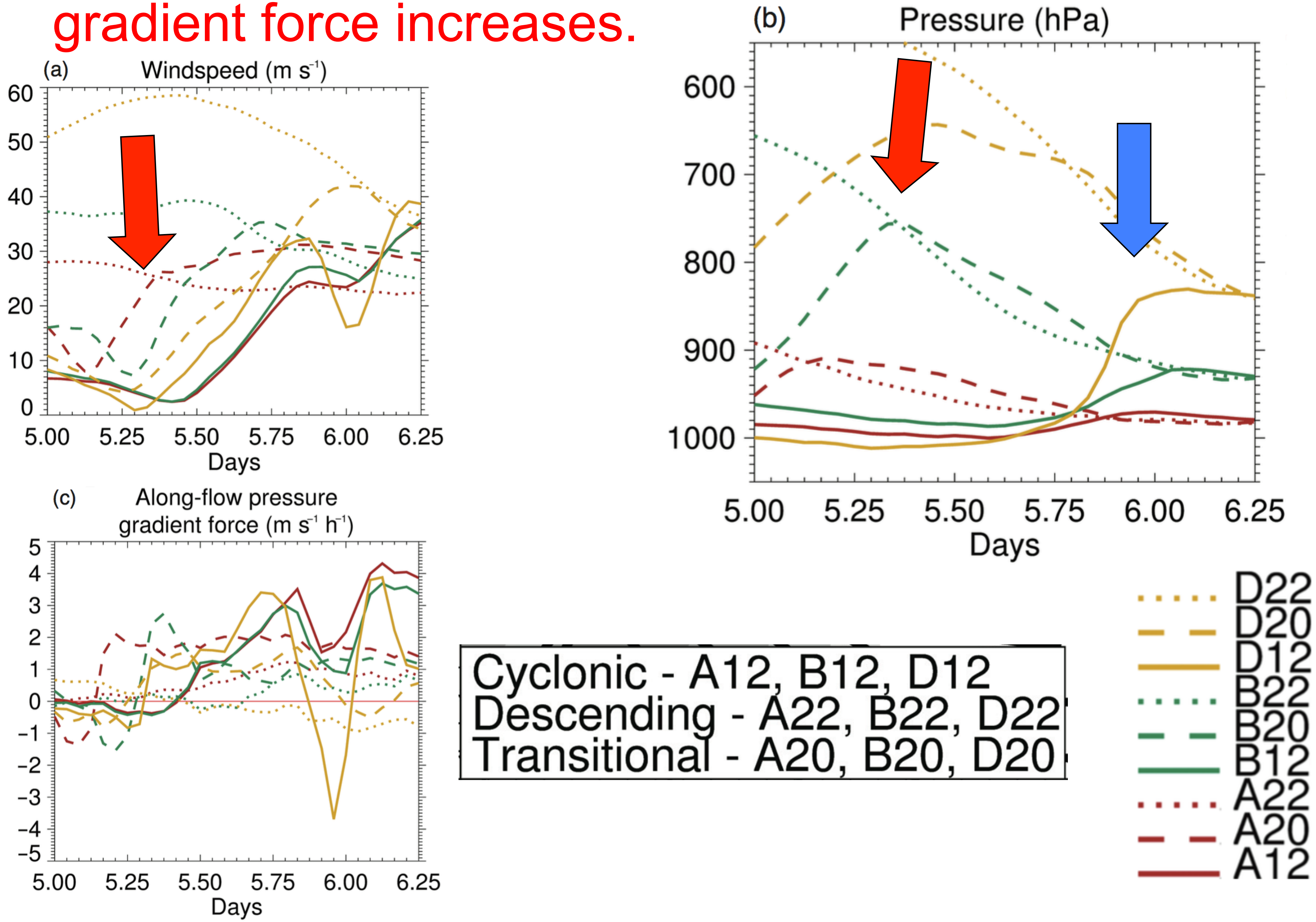
Complicates identifying “sting jet” in real time operations.

# Wind speed and trajectory height from idealized dry baroclinic wave




(Slater et al. 2015, *QJRMS*)

# Wind speed increases as the horizontal pressure gradient force increases.



# Frontogenesis (Petterssen 1936)

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

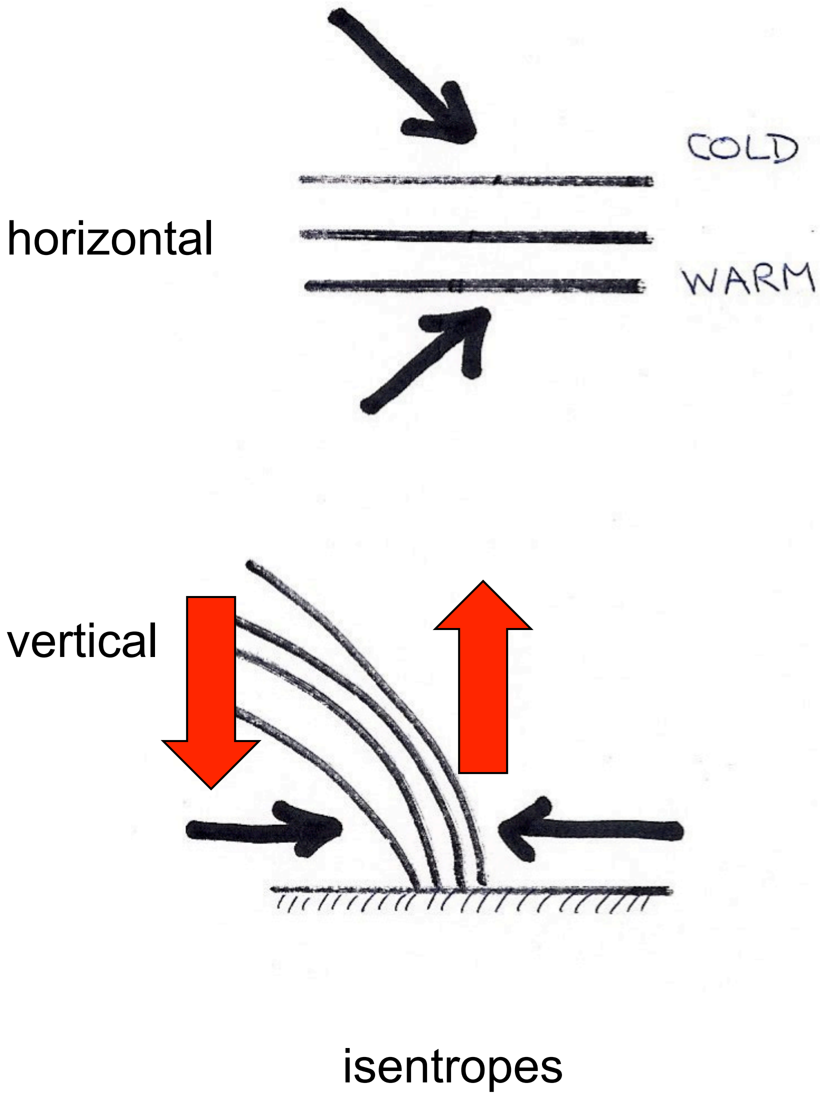
$$\frac{d}{dt} = \frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y},$$

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

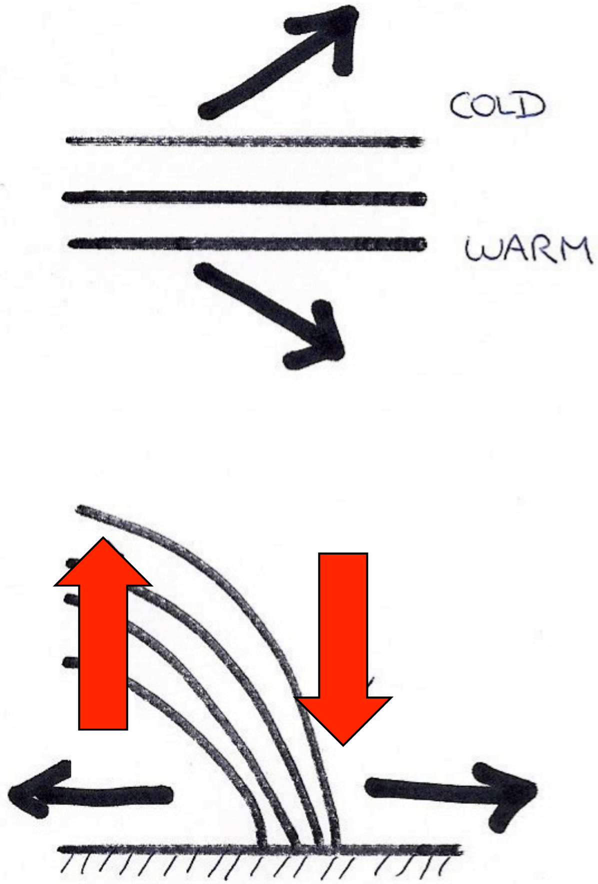
$$\nabla_H = \mathbf{i}\frac{\partial}{\partial x} + \mathbf{j}\frac{\partial}{\partial y}.$$

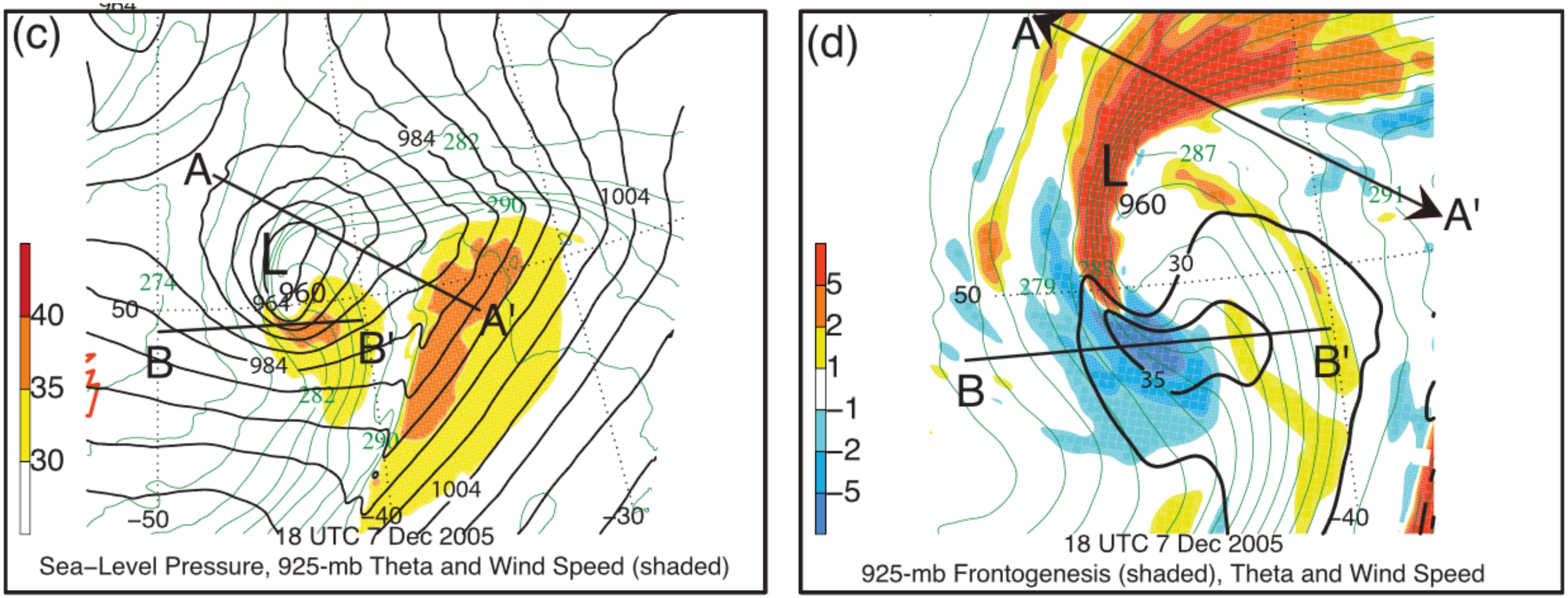
$$F = \frac{1}{2}|\nabla_H \theta| \, (\underbrace{E \cos 2\beta}_{\text{deformation}} - \underbrace{\nabla_H \cdot \mathbf{V}_H}_{\text{divergence}}),$$

# Frontogenesis

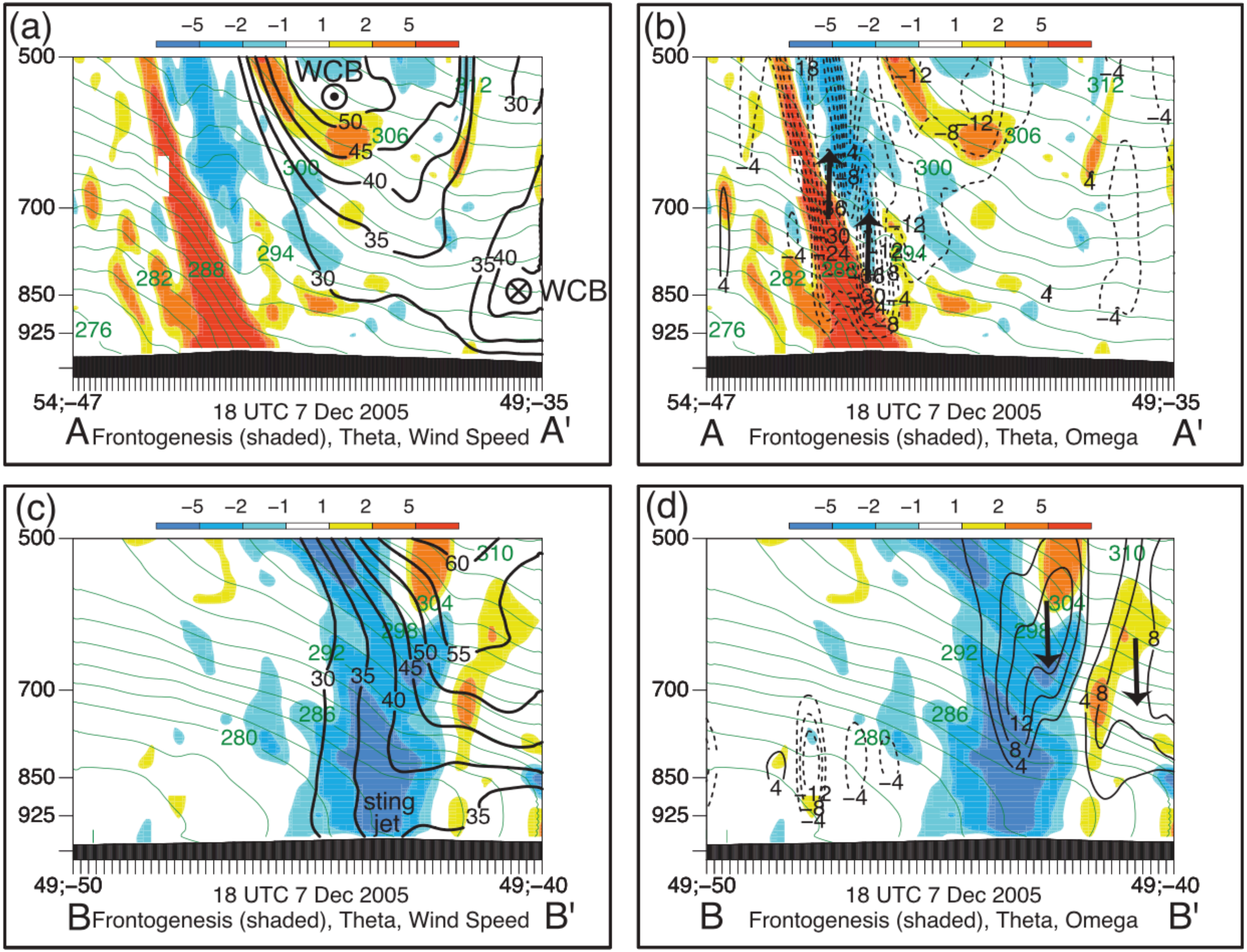



# Frontolysis






(Schultz and Sienkiewicz 2013)

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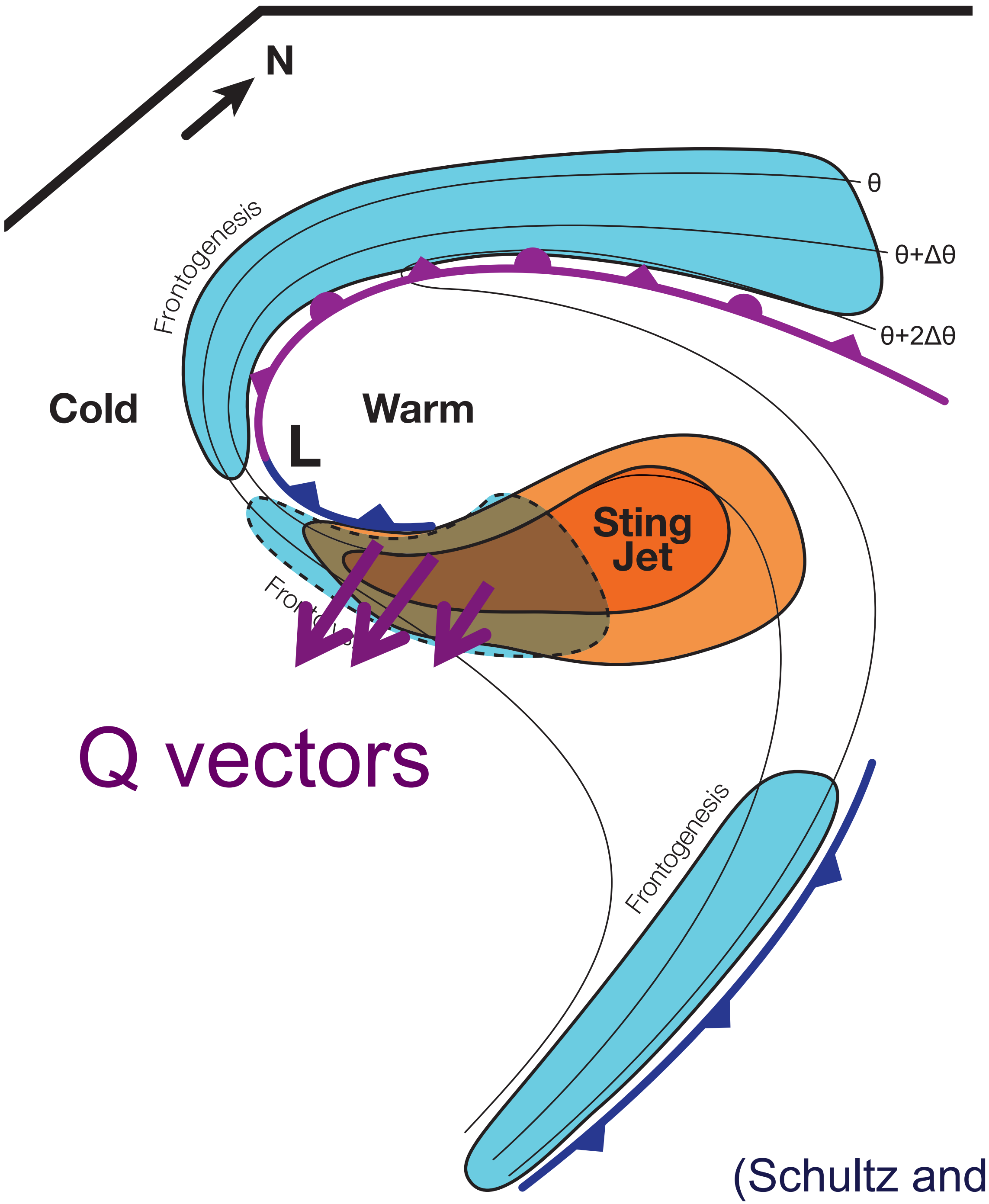


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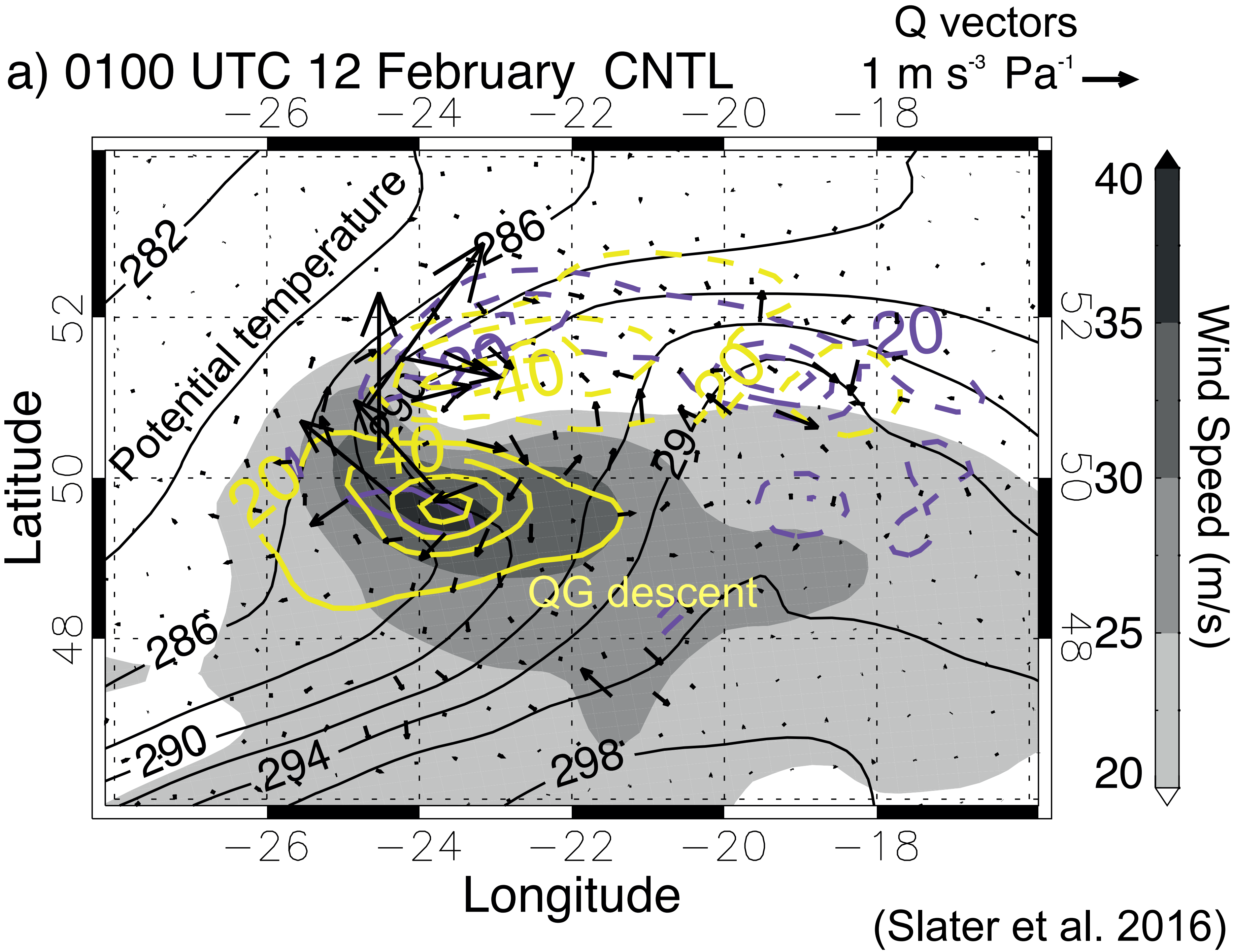
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QG descent
Wind Speed (m/s)
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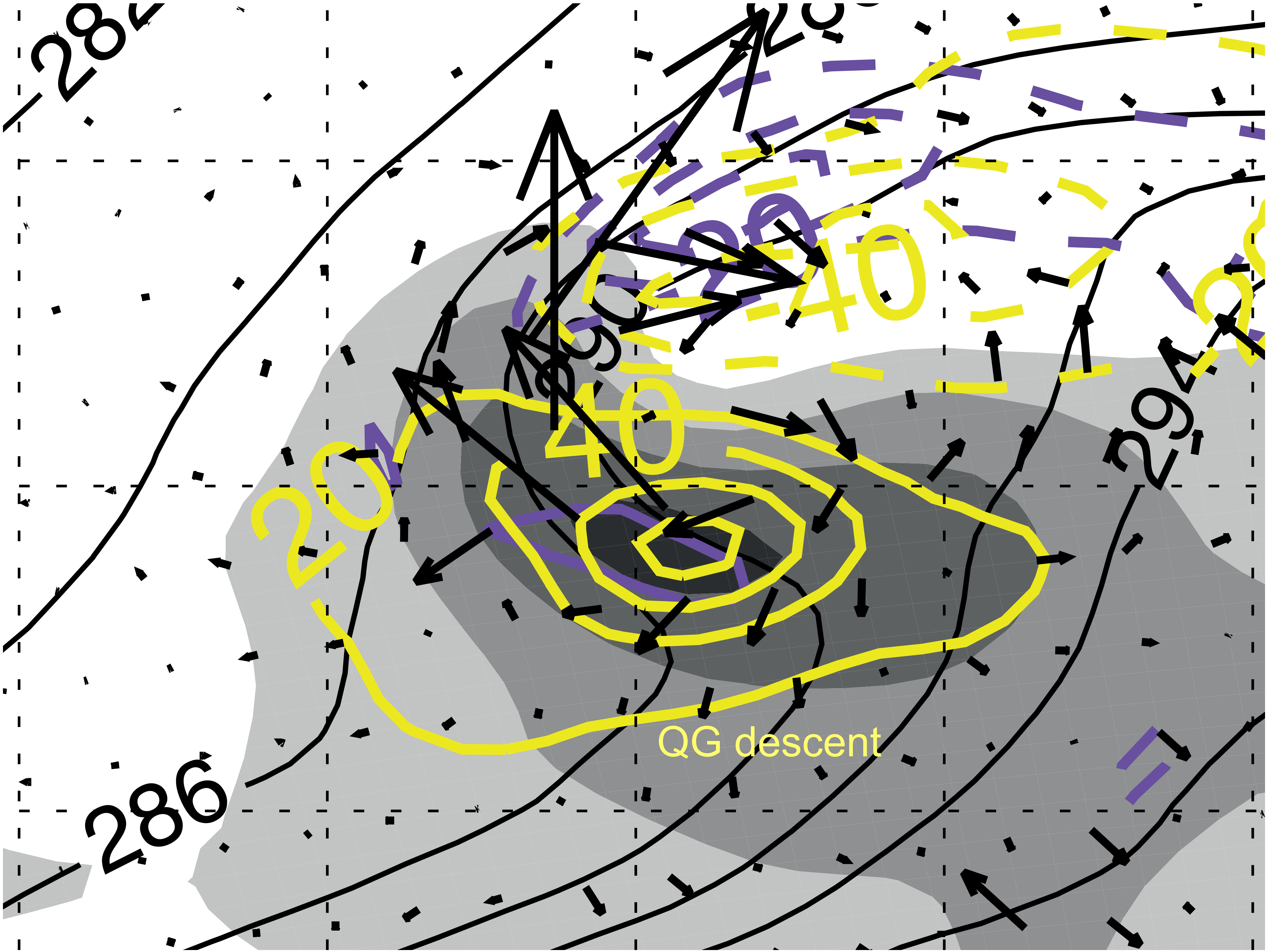
(Slater et al. 2016)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QG descent

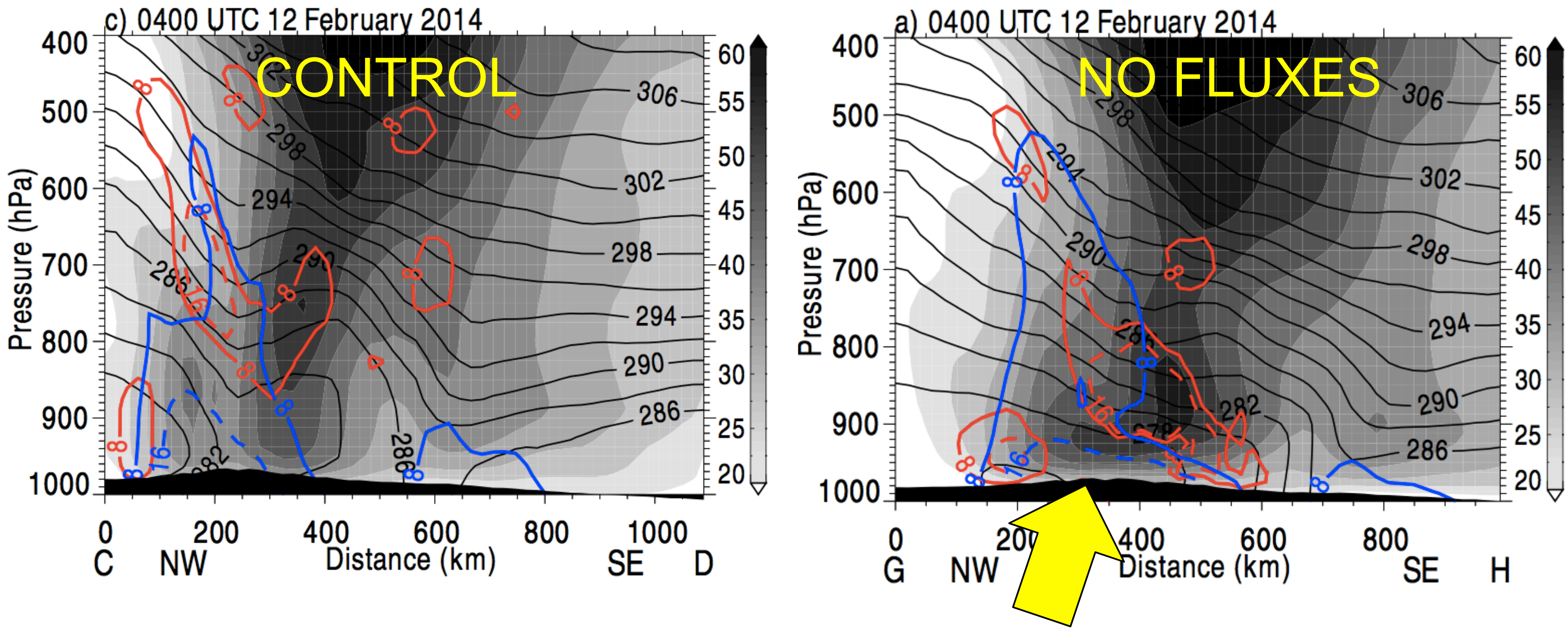
# Frontogenesis/frontolysis explains sting jets on the mesoscale.

Why sting jets occur at the end of bent-back front.

Why sting jets occur in Shapiro–Keyser cyclones, but not Norwegian cyclones.

Why trajectories in sting jet descend.

# Fluxes from ocean may be critical.




Simulations with no fluxes did not produce strong surface winds.

Slater, Schultz and Vaughan, 2015: Near-surface strong winds in a marine extratropical cyclone: Acceleration of the winds and the importance of surface fluxes. *QJRMS,* in revision.