THE UNKNOWN

As we know,
There are known knowns.
There are things we know we know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown unknowns,
The ones we don't know
We don't know.

From *The Poetry of D. H. Rumsfeld: Recent Works by the Secretary of Defense*

http://slate.msn.com/id/2081042/

“As we know, there are *known knowns*.
There are things we know we know.

We also know there are *known unknowns*.
That is to say, we know there are some things we do not know.

But there are also *unknown unknowns*: the ones we don't know we don't know.”

What about *unknown knowns*?
Things we don’t know we know.

Cold Fronts: The Unknown Knowns

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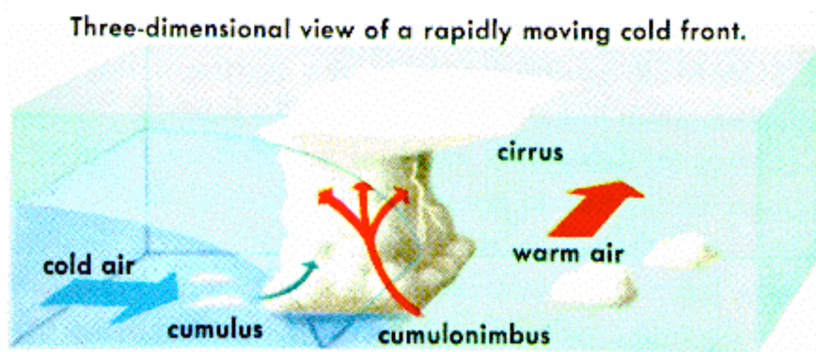


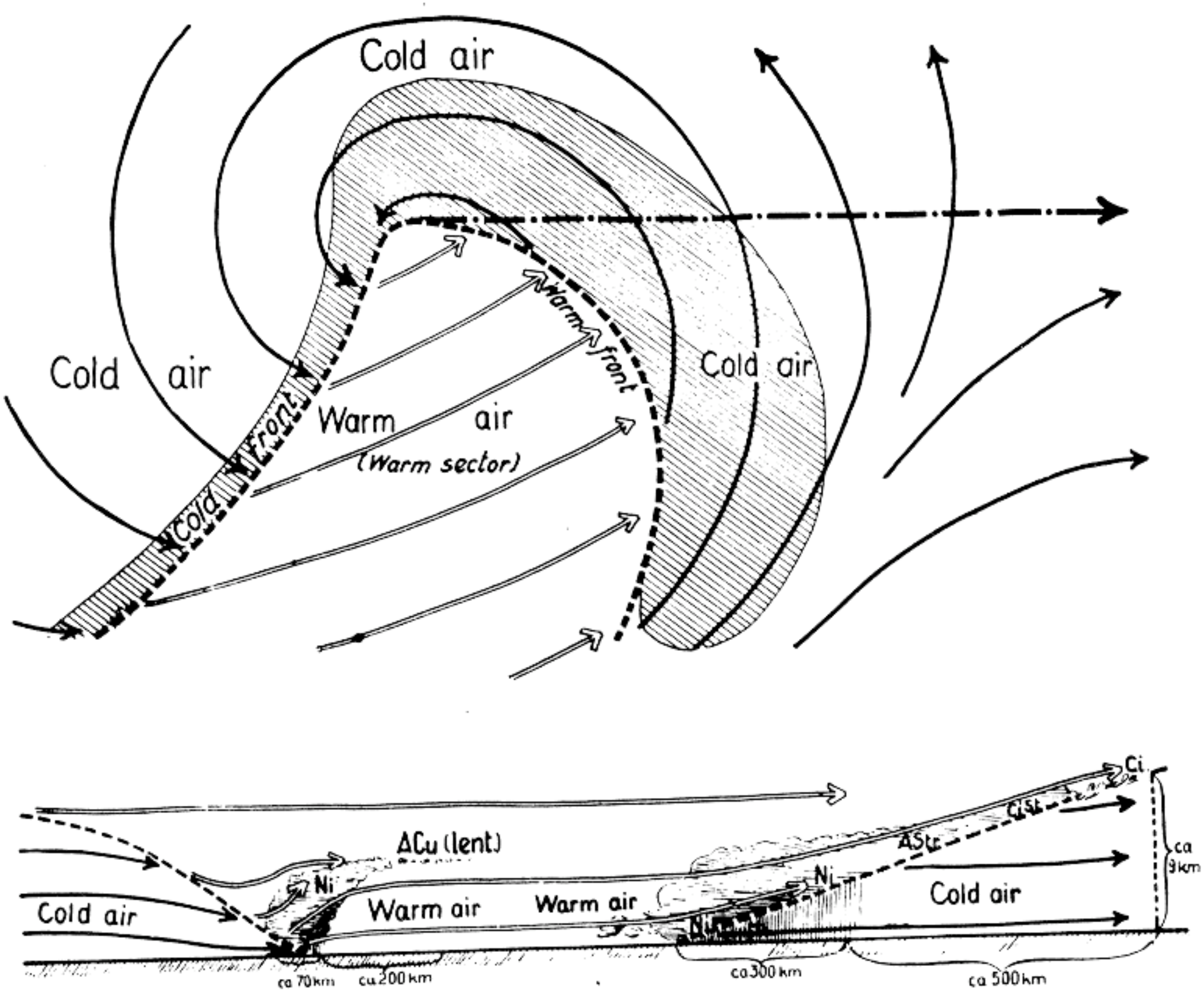
Motivation

- Outgrowth of some long-standing interests of mine coupled with preparation for my talk at the Fred Sanders Symposium (January 2004).
- Excellent research has been done over the years on fronts.
- Realization that there were many instances where we were “stuck in the past” with regard to frontal structures and dynamics.
- Nevertheless, we still have a lot to learn about fronts.
- Purpose of this talk: To put some of these issues to rest and to raise others that require further research.

But first, a little historical perspective:

“How did we end up here?”

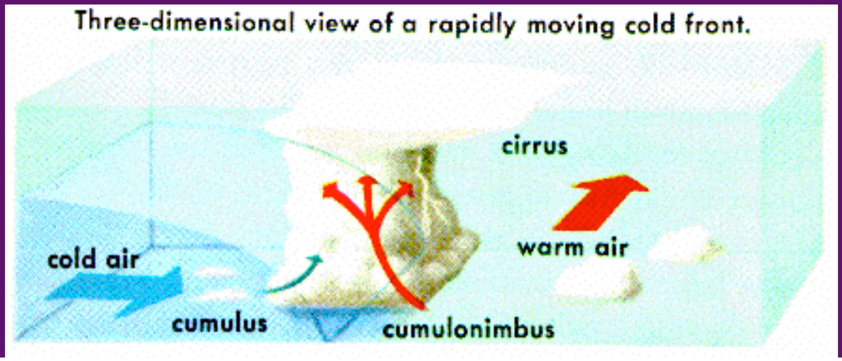
1920s: Norwegian Frontal Model



(Bjerknes and Solberg 1922)

Characteristics of Cold Fronts from Norwegian Conceptual Model

- Cold air replaces warm air
- Temperature drops coincident with wind shift
- Cold front tilts rearward over cold air.
- Clouds and precipitation occur along front (e.g., rope cloud, narrow cold-frontal rainband)



1920s: Norwegian Frontal Model

- Compact modern theory for frontogenesis and cyclogenesis
  - Cyclones arose from disturbances on the polar front
  - Observational analysis from a dense network of surface observing stations over Norway
  - Applied the principles of math and physics to the atmosphere
- Provided a common language for scientists, forecasters, and the public (consumers).
- Worldwide acceptance of Norwegian frontal model (1920s–1950s)

1950s: Interest Wanes

- Charney (1947) and Eady (1949) models of baroclinic instability: fronts were a *result* of cyclogenesis rather than the *cause.*

- Researchers: uniform definition of a front could not be agreed upon (as reviewed by Vincent and Borenstein 1980; Mass 1991; Uccellini et al. 1992; Sanders and Doswell 1995; Sanders 1999).

1950s: Interest Wanes

"A perusal of the titles of the more than 100 articles in the Compendium *would leave the uninitiated reader with the impression that there are no such things as fronts and air masses."*

– Taljaard et al. (1961),
writing about the *Compendium of Meteorology* (1951)

"Sometimes I wonder whatever happened to fronts? . . . Fronts have passed through a sort of Dark Age of neglect in which only a loyal few worried very much about them."

– Sanders (1967)

Theoretical Advances: 1966–2002

- Importance of ageostrophic circulation (e.g., Stone 1966; Williams 1968, 1972; Hoskins and Bretherton 1972)

- Role of fronts in cyclonic systems (e.g., Simmons and Hoskins 1978; Hoskins and West 1979; Davies et al. 1991; Thorncroft et al. 1993)

- Importance of surface processes (e.g., Blumen 1980; Keyser and Anthes 1982; Xu and Gu 2002)

1980s: Interest in "Mesoscale"

mid 1970s: NWS implements AFOS

1978: NOAA establishes CIMMS at OU

1979: NWS commits to NEXRAD program

1981: AMS forms an Ad Hoc Committee on Mesoscale Meteorology

1983: First AMS Mesoscale Processes Conference

1984: Intensive Course on Mesoscale Meteorology and Forecasting

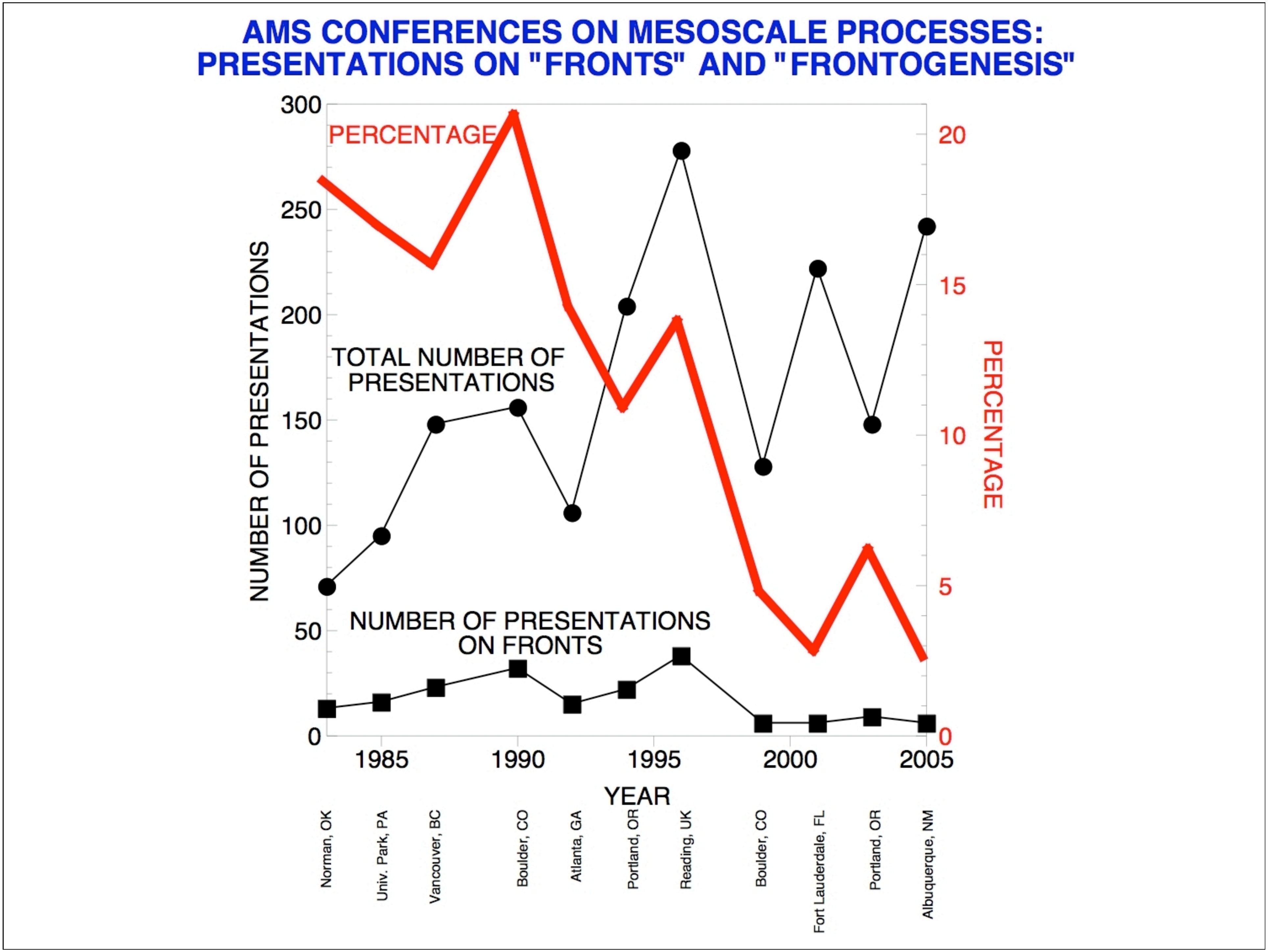
1986: Notes from Intensive Course published by AMS

1987: Keyser and Uccellini publish "Regional models: Emerging research tools for synoptic meteorologists."

1980s: Interest in "Mesoscale"

"One can say that surface fronts are presently considered one of the better understood and predictable of mesoscale atmospheric phenomena."

Shapiro et al. (1985, p. 1168)



AMS CONFERENCES ON MESOSCALE PROCESSES:
PRESENTATIONS ON "FRONTS" AND "FRONTOGENESIS"
PERCENTAGE
TOTAL NUMBER OF PRESENTATIONS
NUMBER OF PRESENTATIONS ON FRONTS
NUMBER OF PRESENTATIONS
PERCENTAGE
YEAR
0
50
100
150
200
250
300
0
5
10
15
20
1985
1990
1995
2000
2005
Norman, OK
Univ. Park, PA
Vancouver, BC
Boulder, CO
Atlanta, GA
Portland, OR
Reading, UK
Boulder, CO
Fort Lauderdale, FL
Portland, OR
Albuquerque, NM

Operational Disillusionment

- Before 1941, surface maps used to be contour charts of surface temperature and sea-level pressure.
- In 1941, the Weather Bureau introduced the station model and frontal analysis.
- More compact description of the atmosphere, but greater subjective interpretation of surface data.
- Evolution of operational surface analysis, given new advances, was slow.

1970s–1990s: Operational Disillusionment

- Increasing automation has led to an atrophying of map analysis skills and data interpretation.

FORECASTER'S FORUM

Whither the Weather Analysis and Forecasting Process?

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5 December 2002 and 19 December 2002

ABSTRACT

An argument is made that if human forecasters are to continue to maintain a skill advantage over steadily improving model and guidance forecasts, then ways have to be found to prevent the deterioration of forecaster skills through disuse. The argument is extended to suggest that the absence of real-time, high quality mesoscale surface analyses is a significant roadblock to forecaster ability to detect, track, diagnose, and predict important mesoscale circulation features associated with a rich variety of weather of interest to the general public.

The Result

- The atmospheric science community has been left clinging to a caricature of what fronts are.
- Some have argued that the Norwegian model has hindered progress (e.g., Sutcliffe 1952; Williams 1972; Schwerdtfeger 1981; Hoskins 1983; Mass 1991; Kocin et al. 1991; Schultz and Trapp 2003).
- The scientific literature and operational experience indicate that fronts are more complicated than we typically believe.

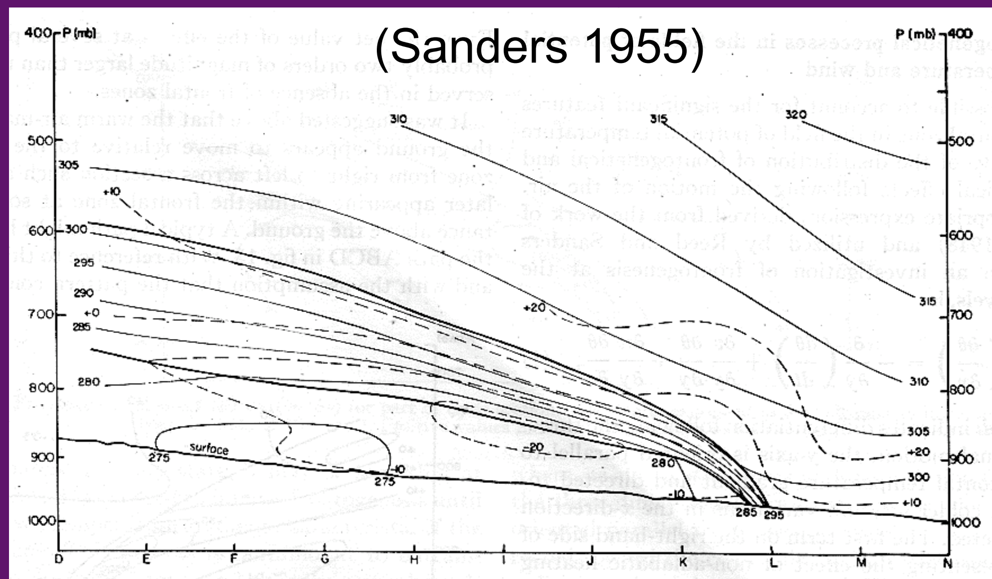
Going Beyond the Norwegian Frontal Model: The Unknown Knowns

There are reasons these misconceptions exist.

They often represent generalities.
Exceptions do exist.
Some are incorrect.

#1

- Cold fronts tilt rearward with height.



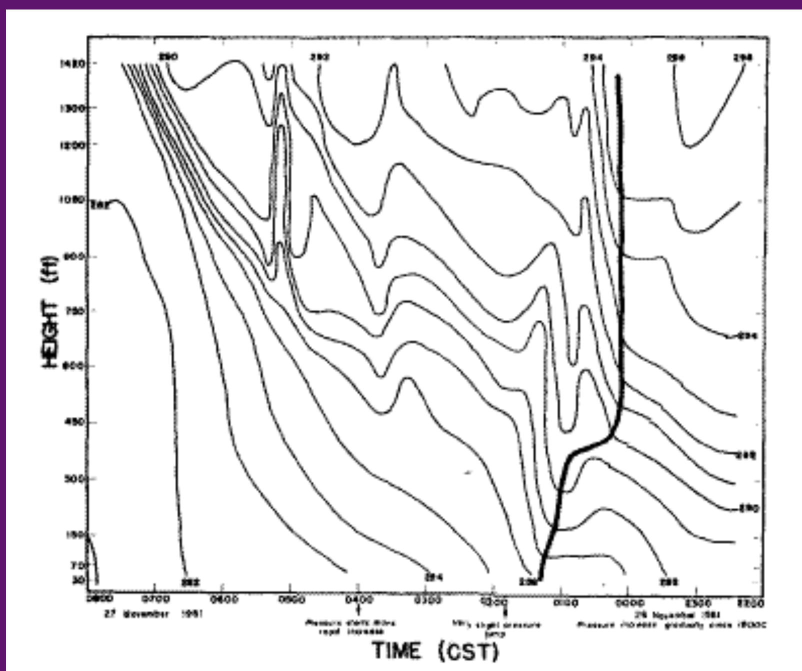
(Sanders 1955)

- Margules (1906): geostrophic balance, *w*=0, *c*=0
- Semigeostrophic theory: The ageostrophic circulation tilts the front rearward over the cold air.

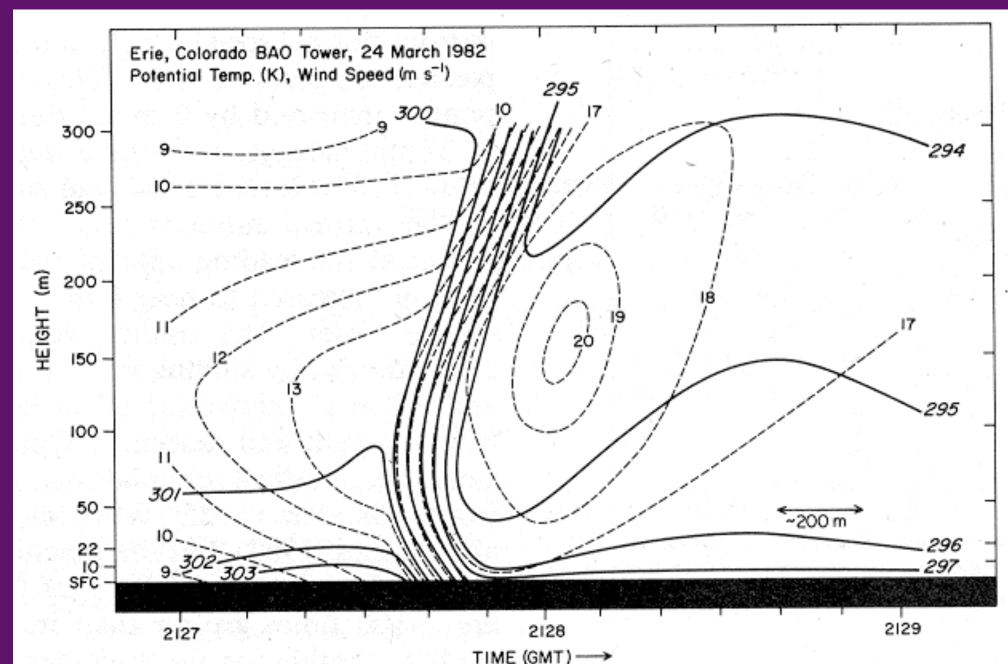
#1 Evaluated

Forward tilting fronts exist and have a variety of causes.

1. Surface friction



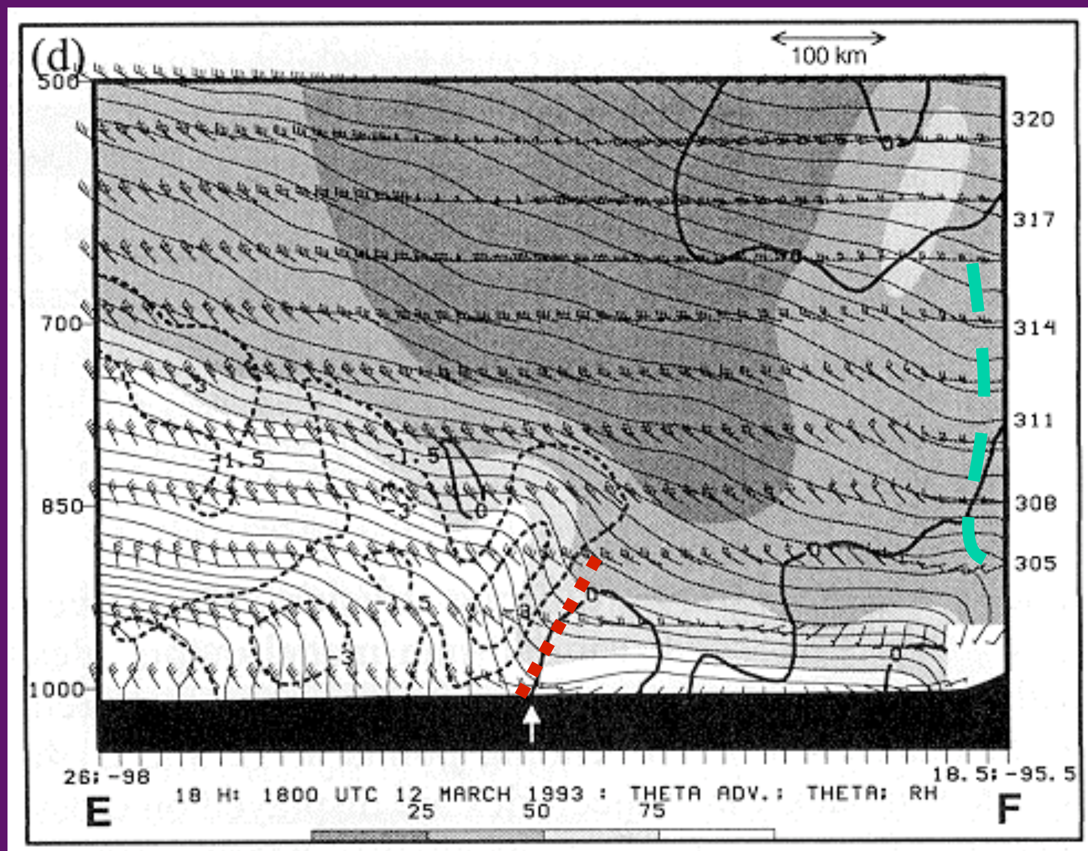
(Brundidge 1965)



(Shapiro 1985)

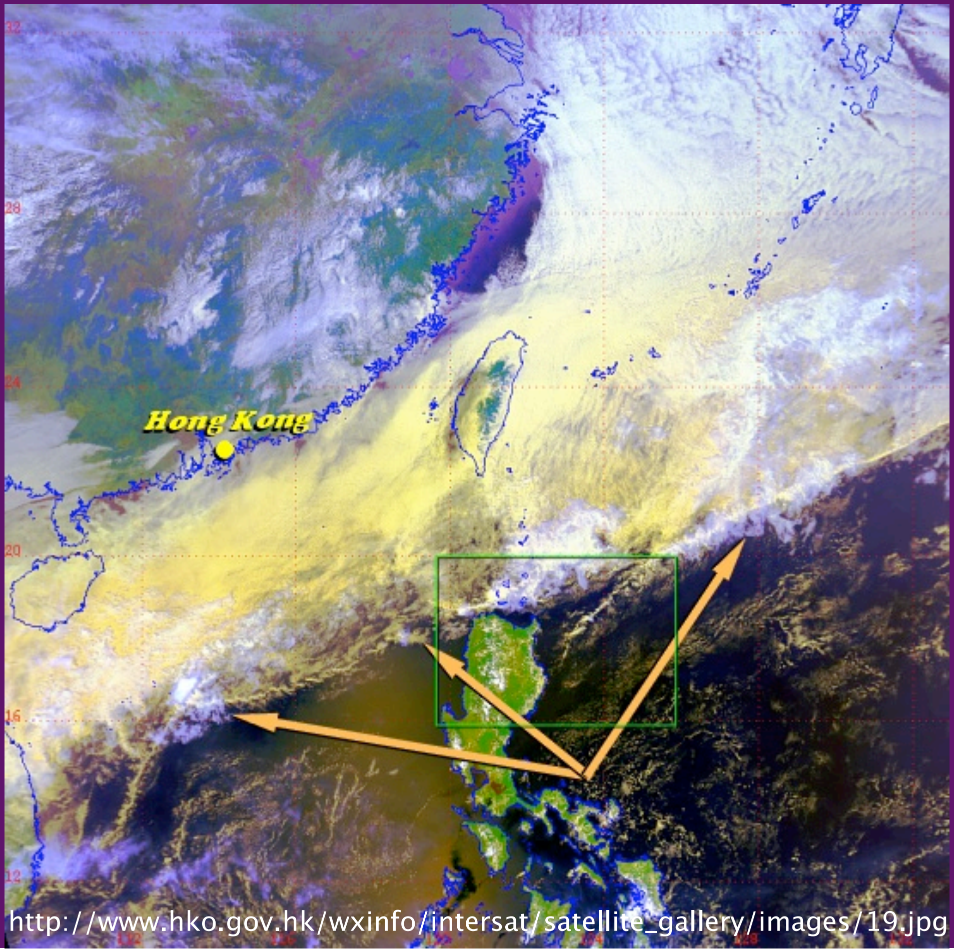
#1 Evaluated

2. Interaction of a surface cold front and a midtropospheric front (e.g., Schultz and Steenburgh 1999)

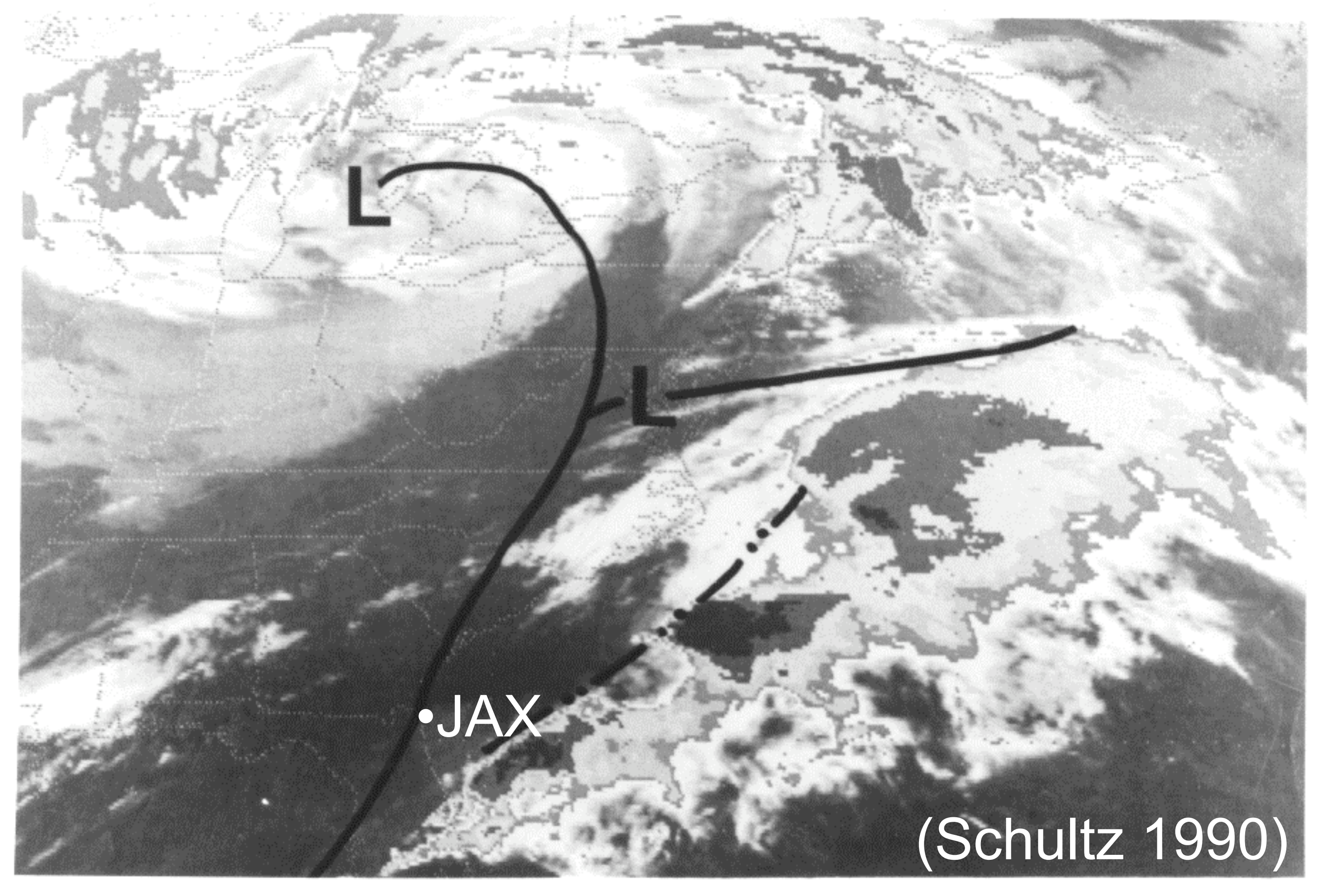


#2

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



#2 Evaluated

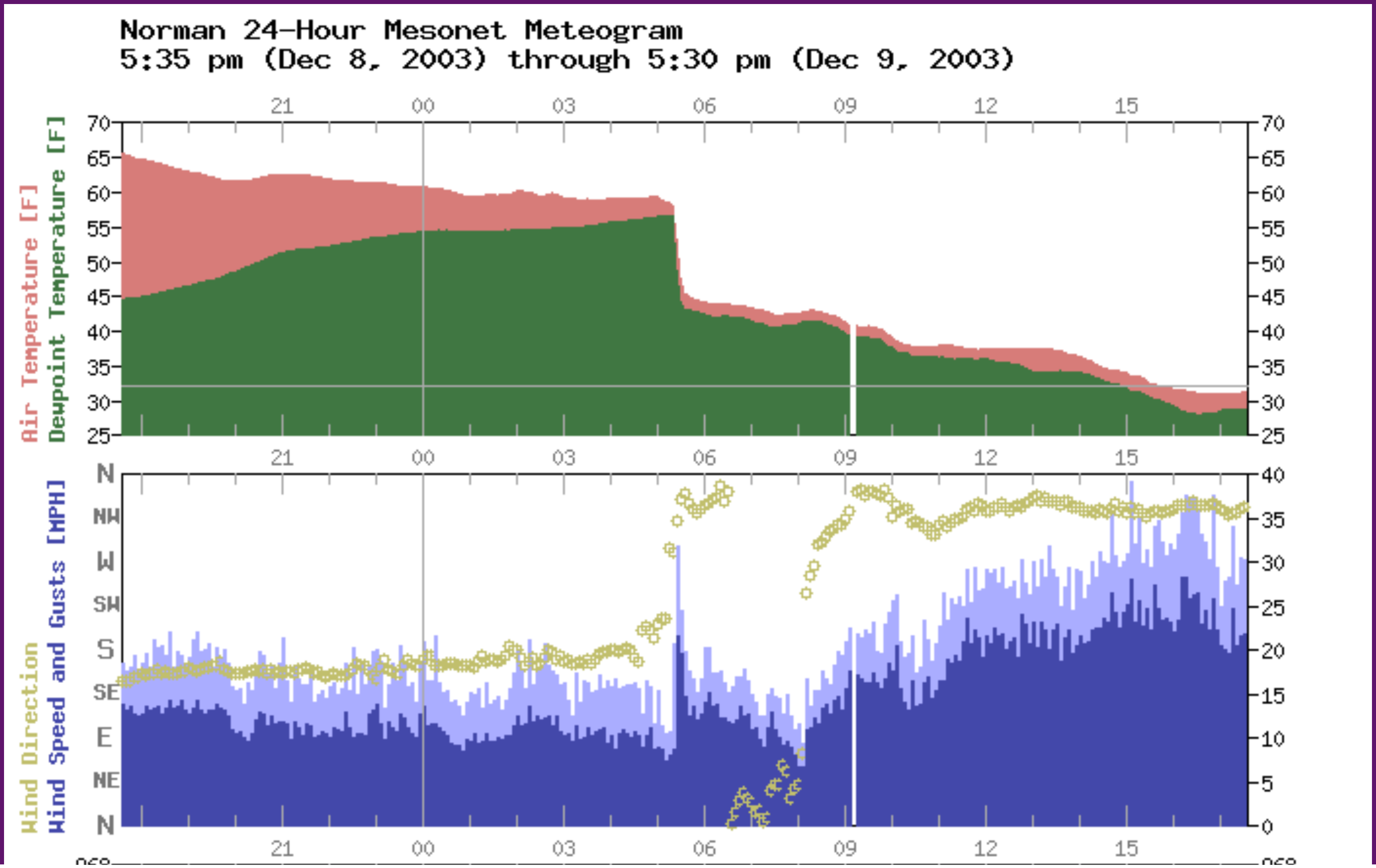


2301 UTC 15 December 1987

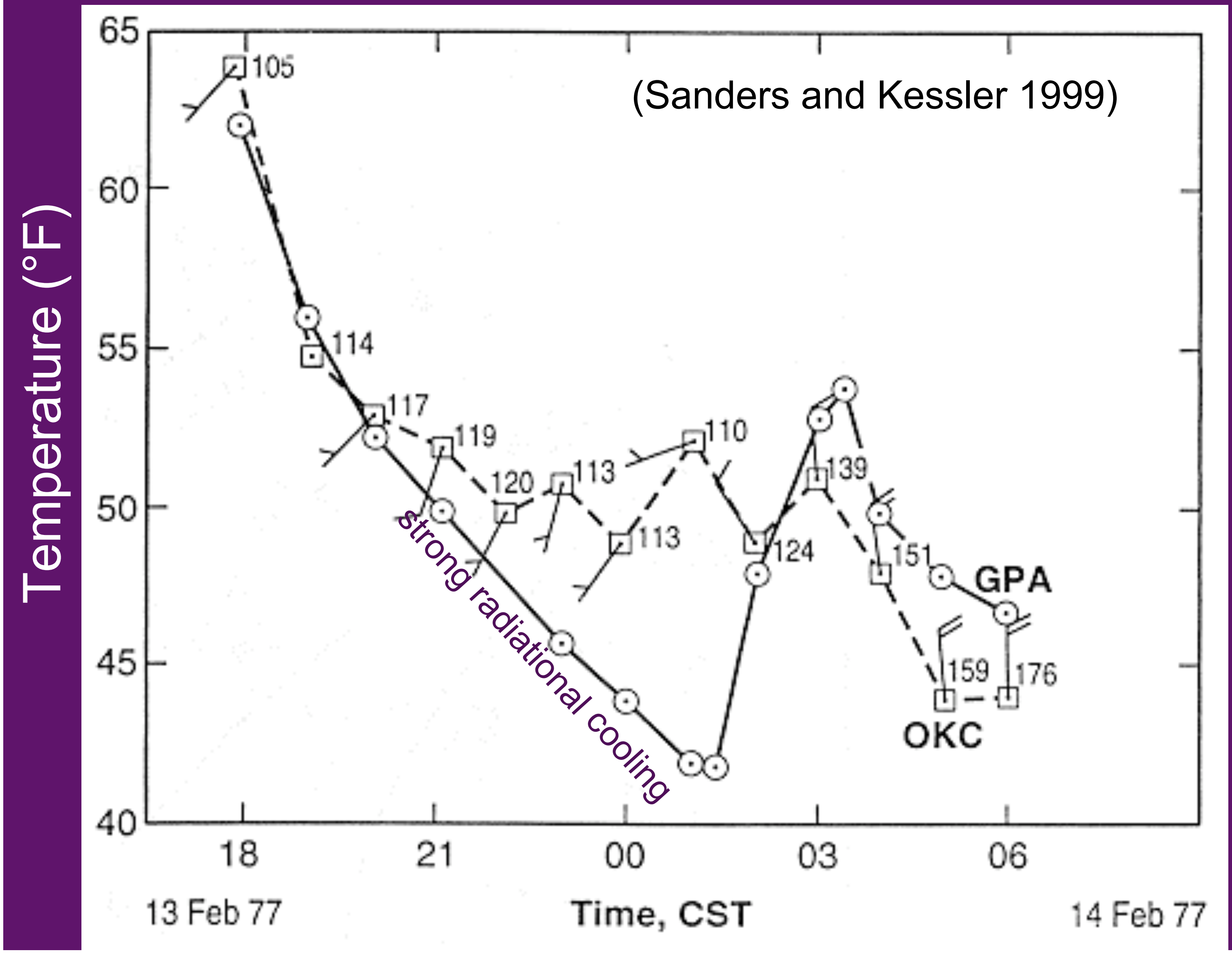
JAX fropa after 0000 UTC

#3

- Cold fronts are characterized by temperature decreasing after frontal passage.



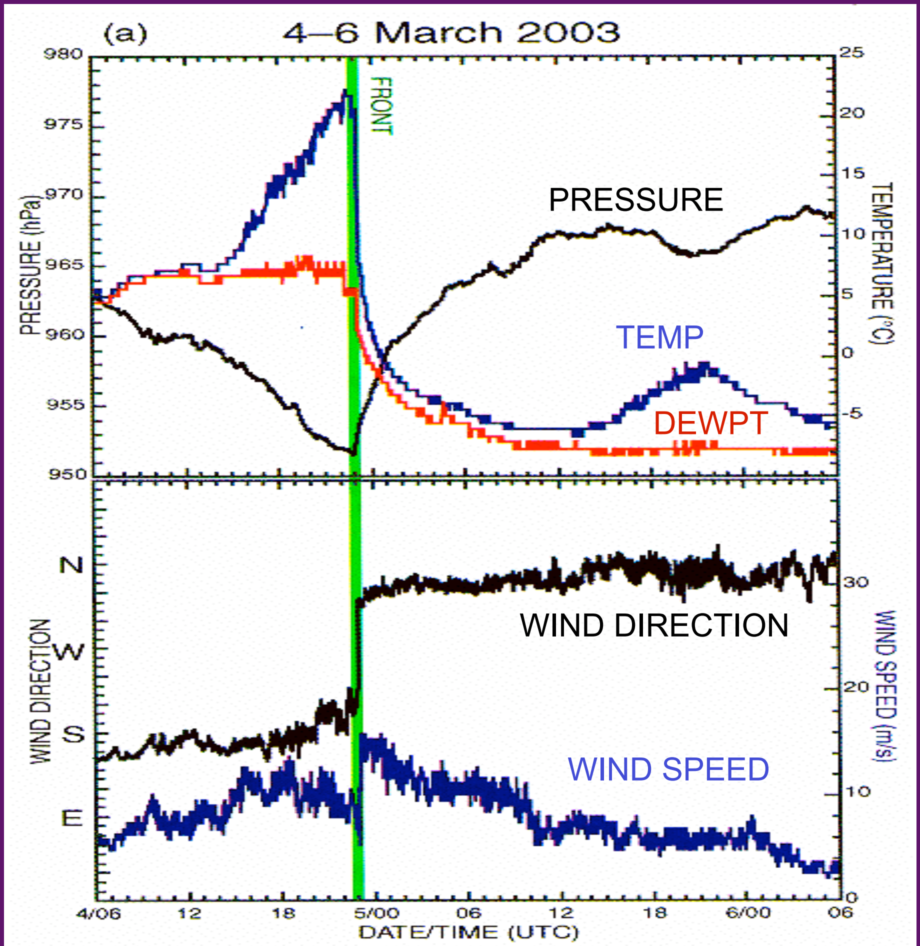
#3 Evaluated



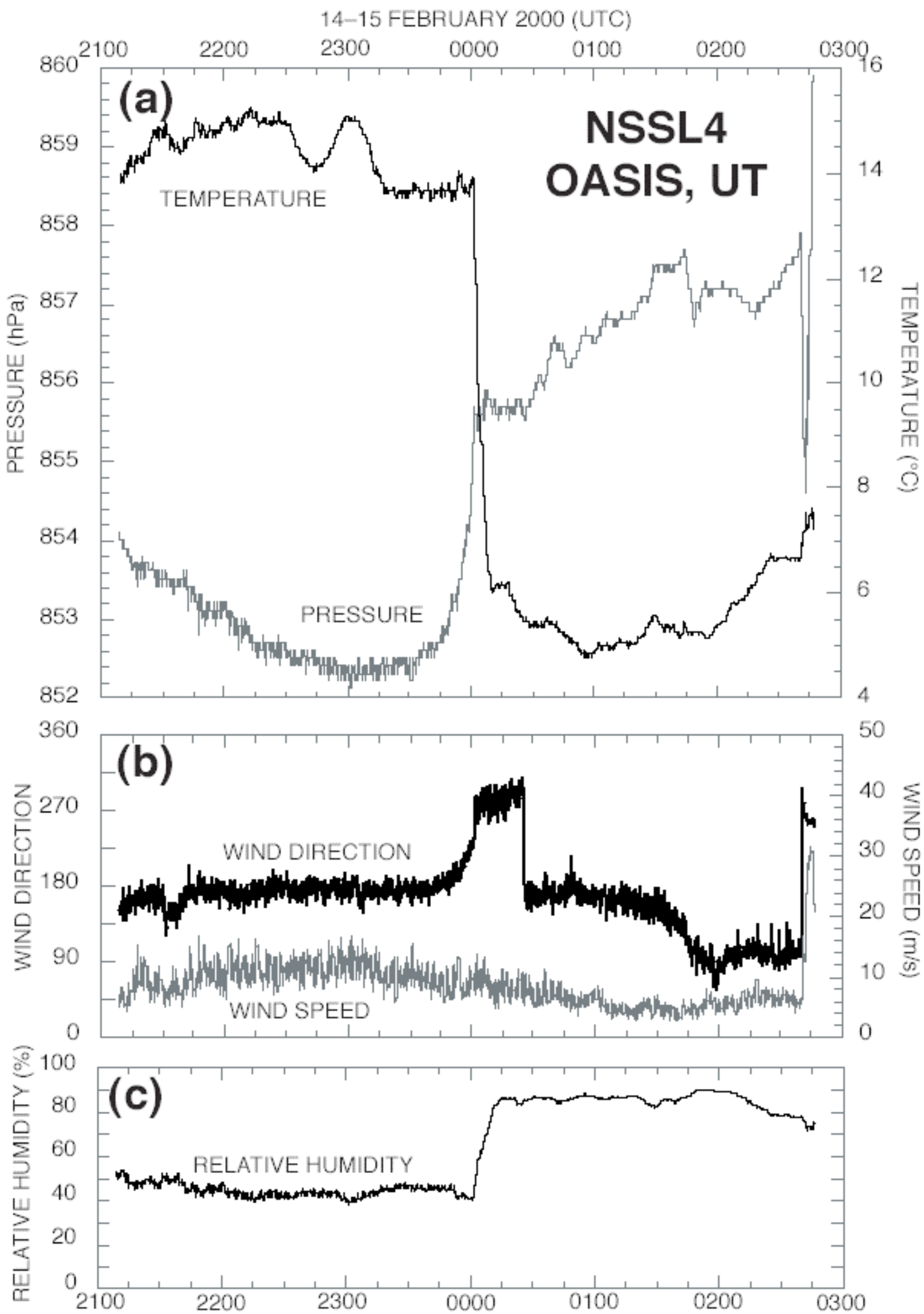
GPA is 43 km SSE of OKC

#4

- Cold fronts are collocated with the wind shift and pressure trough.

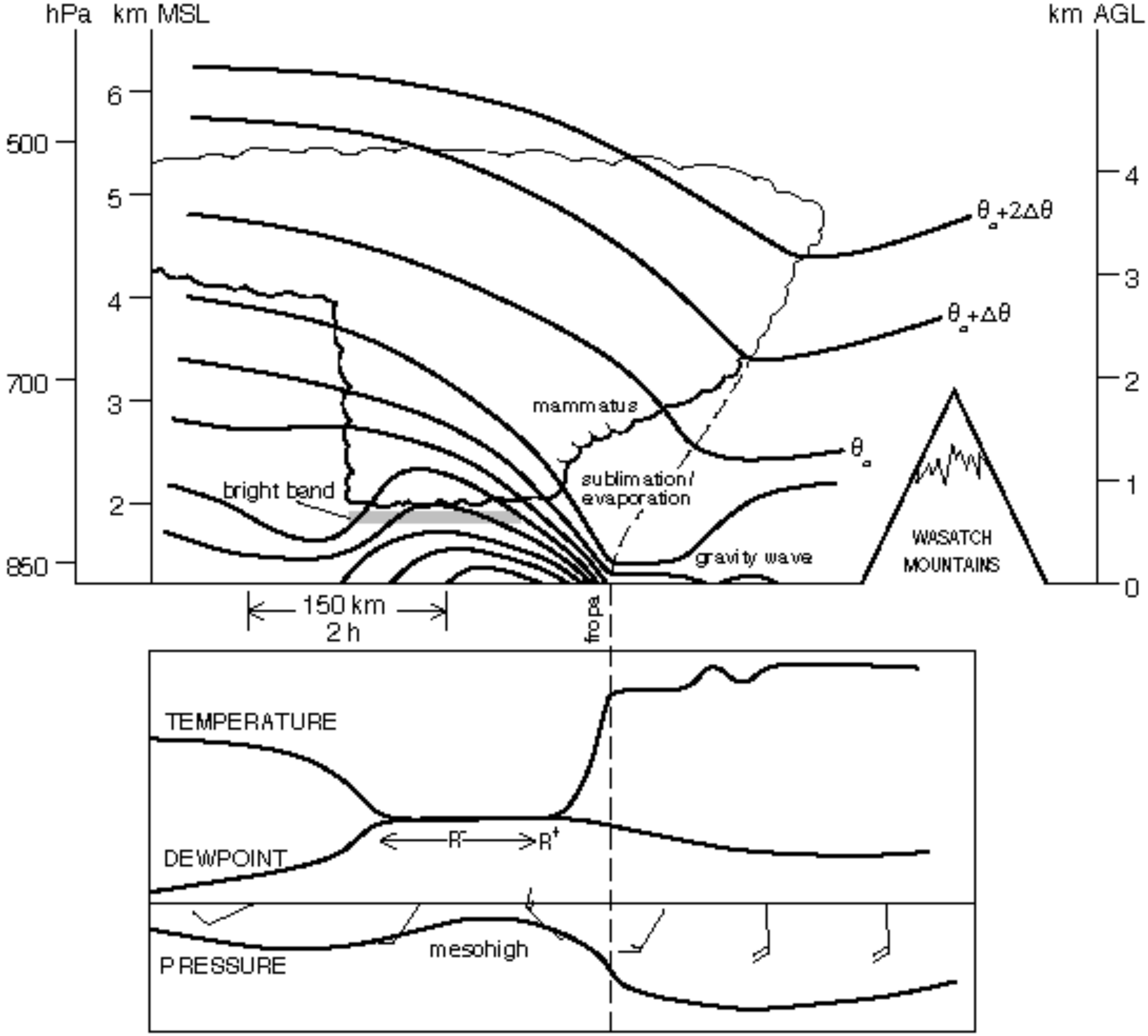


(Schultz 2004)

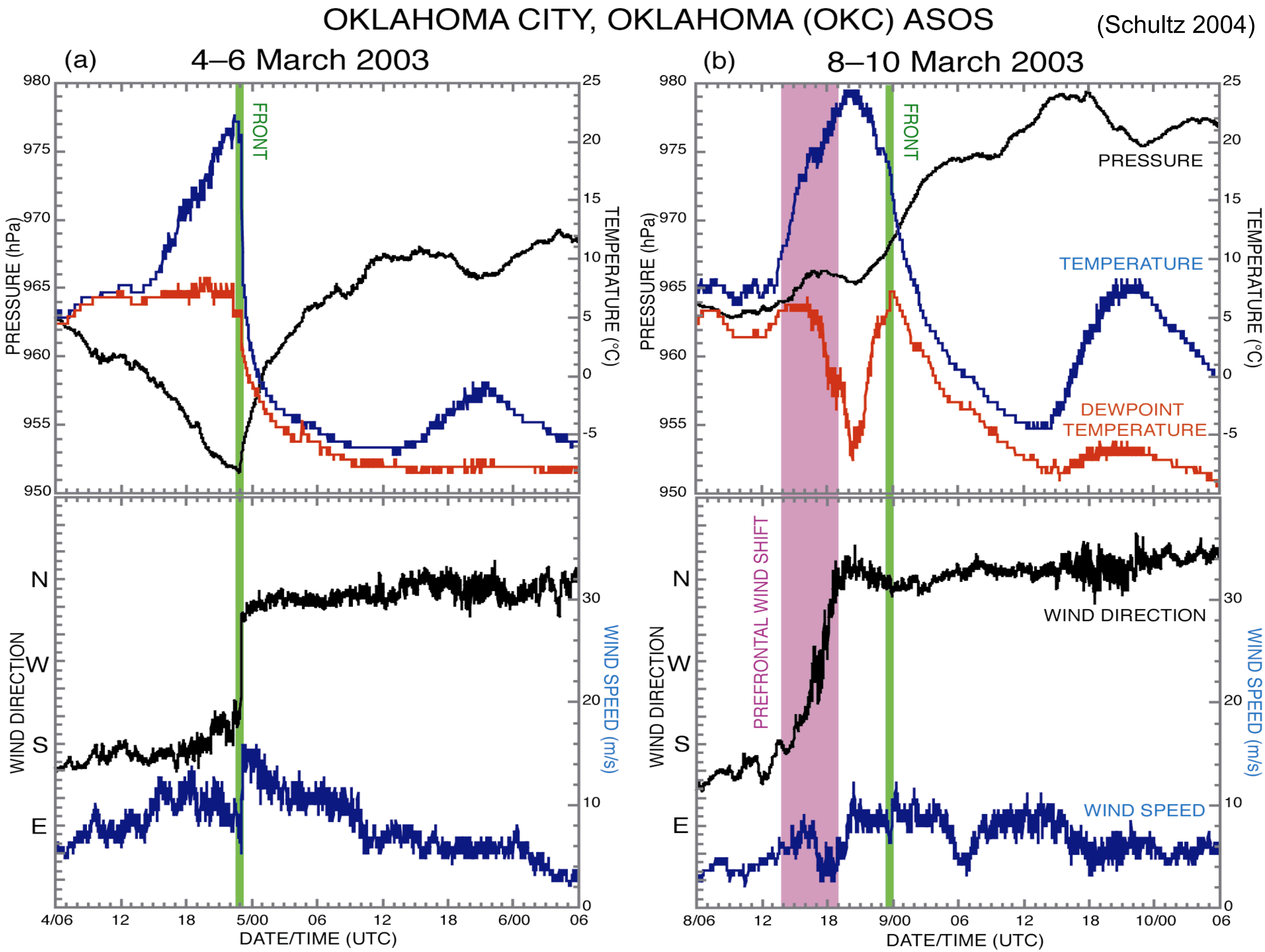


- temperature drops nearly 8°C in 8 minutes
- pressure rises 20 minutes before temperature drops
- wind changes direction in concert with pressure rise

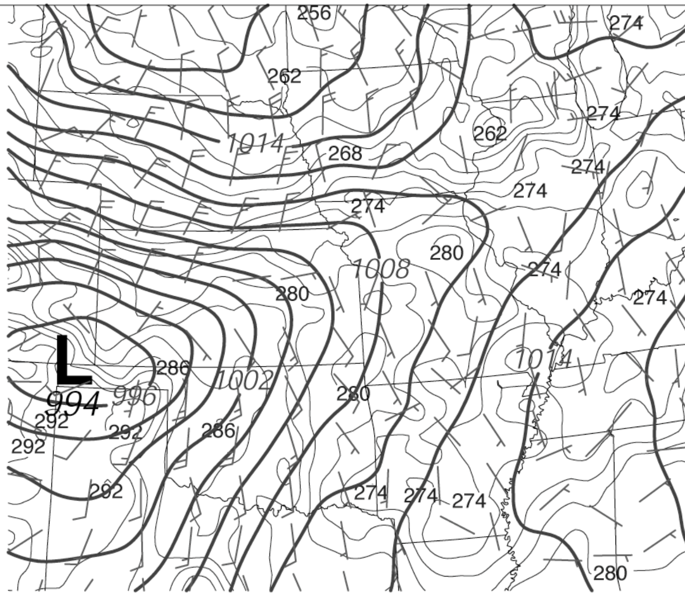
(Schultz and Trapp 2003)



(Schultz and Trapp 2003)

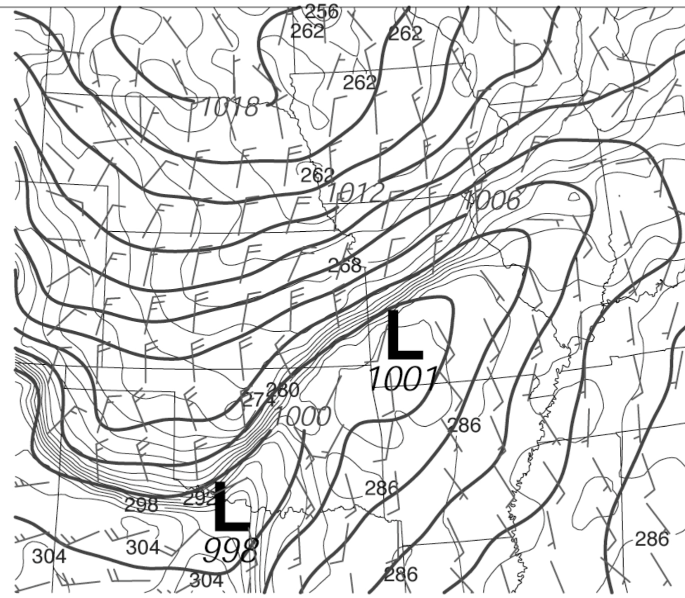

OKLAHOMA CITY, OKLAHOMA (OKC) ASOS
(Schultz 2004)
(a) 4–6 March 2003
(b) 8–10 March 2003
FRONT
PRESSURE
TEMPERATURE
DEWPOINT TEMPERATURE
PREFRONTAL WIND SHIFT
WIND DIRECTION
WIND SPEED
PRESSURE (hPa)
TEMPERATURE (°C)
WIND DIRECTION
WIND SPEED (m/s)
DATE/TIME (UTC)

1200 UTC 4 March



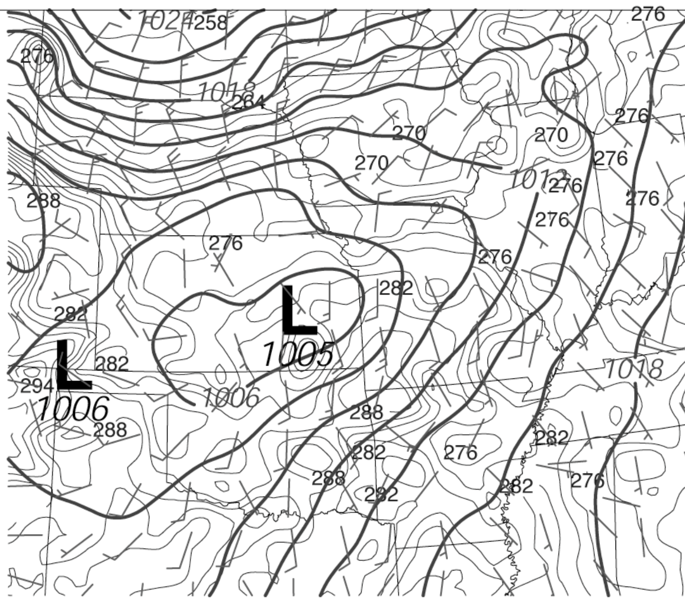
(a) 1200 UTC 4 March 2003: 2-m THETA, 10-m WIND, PRESSURE

0000 UTC 5 March



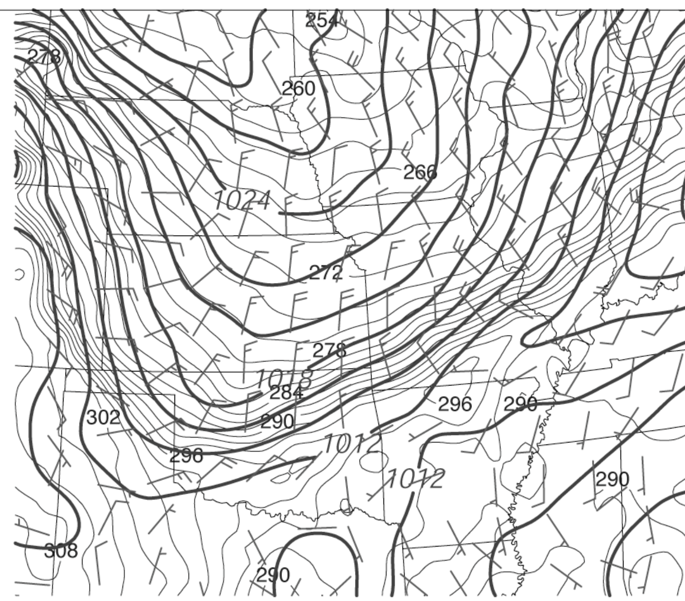
(b) 0000 UTC 5 March 2003: 2-m THETA, 10-m WIND, PRESSURE

1200 UTC 8 March

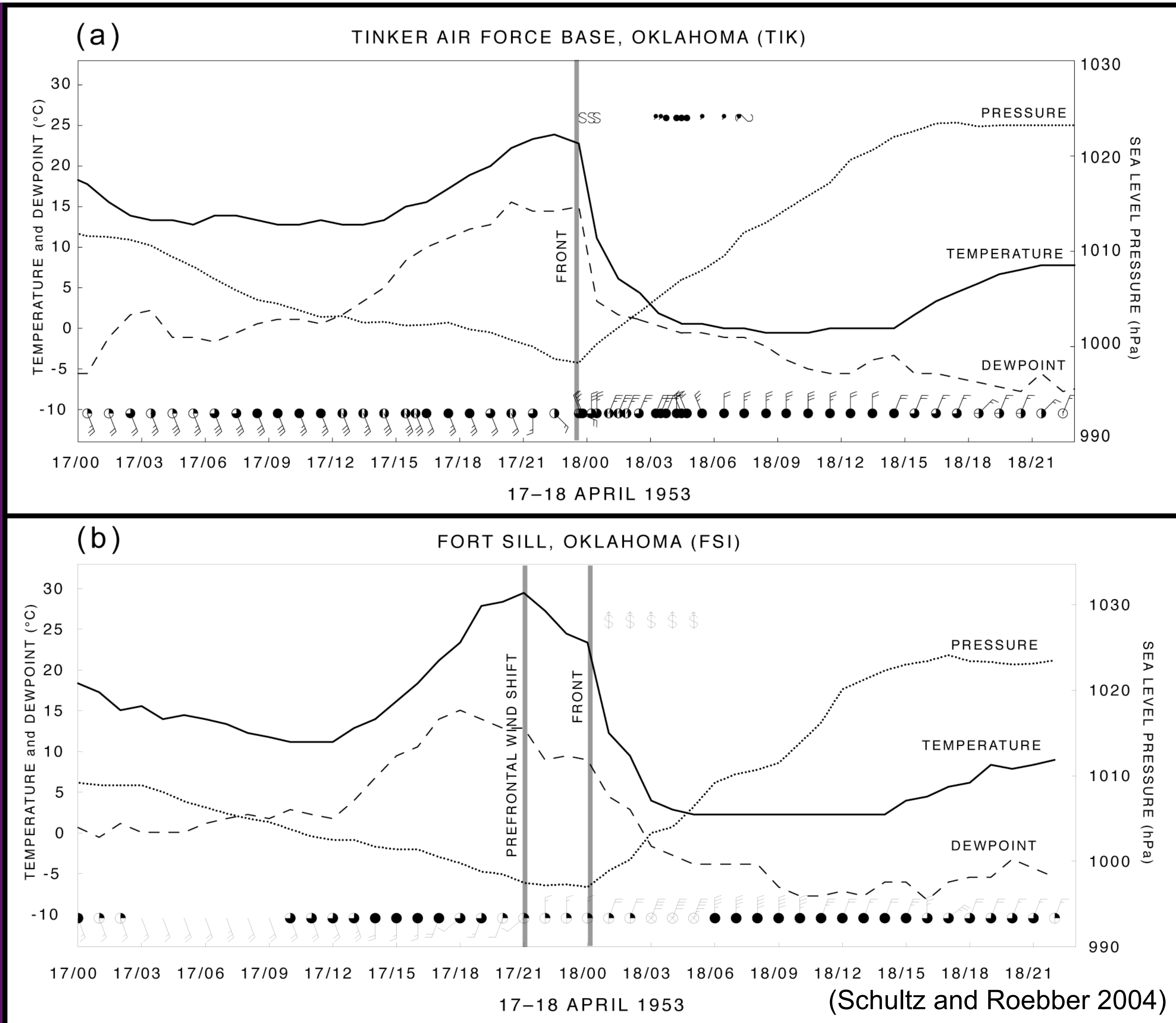


(c) 1200 UTC 8 March 2003: 2-m THETA, 10-m WIND, PRESSURE

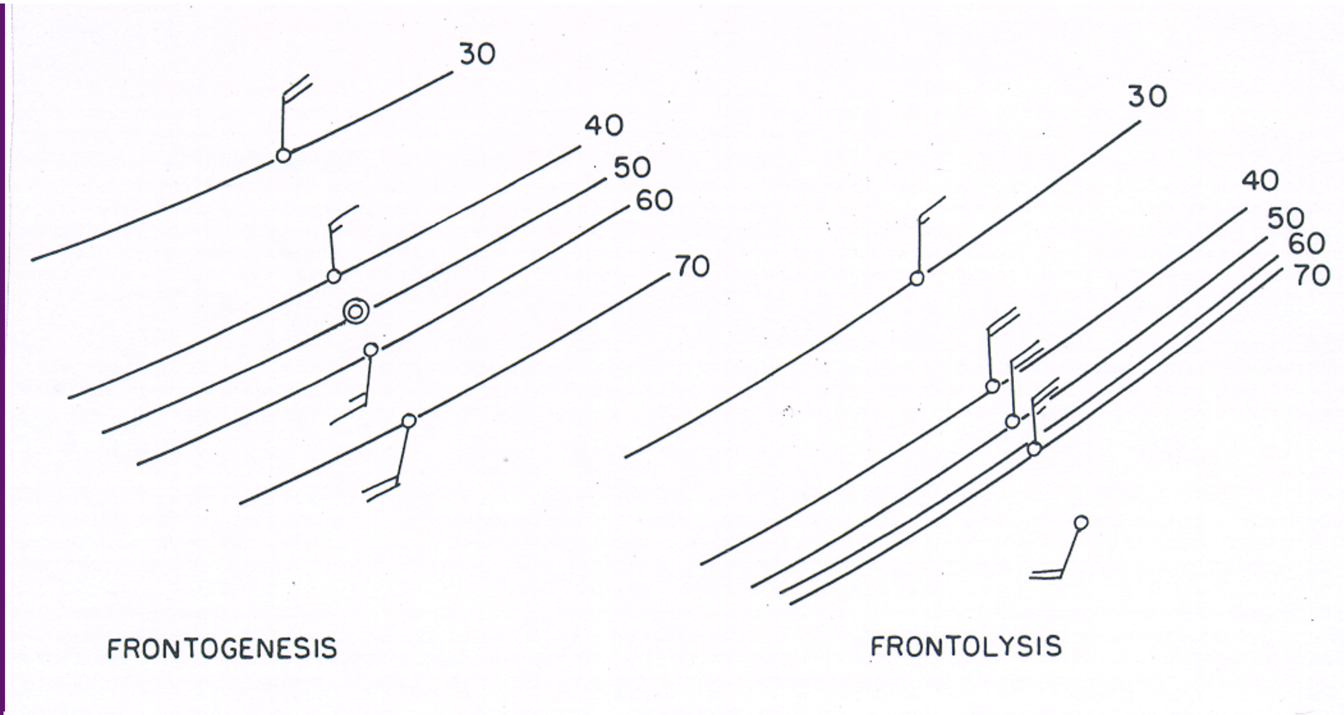
0000 UTC 9 March



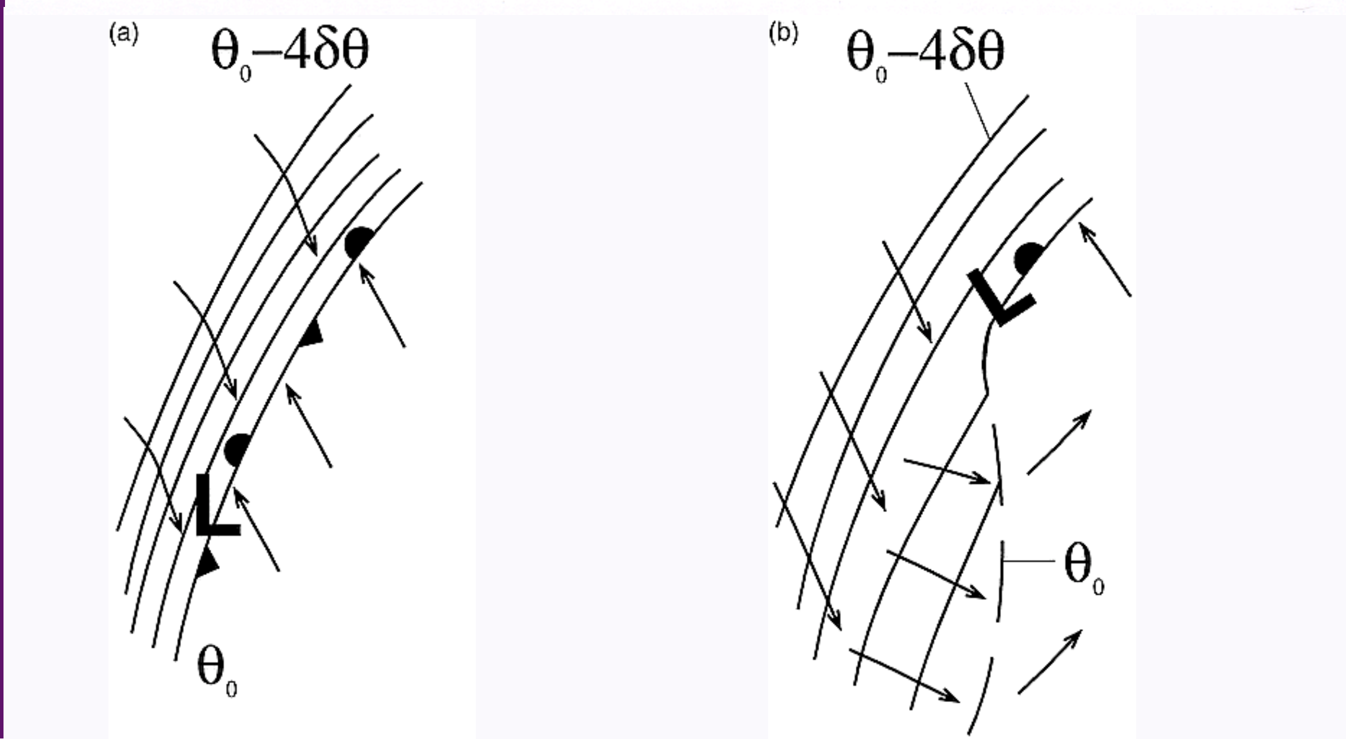
(d) 0000 UTC 9 March 2003: 2-m THETA, 10-m WIND, PRESSURE



(Schultz and Roebber 2004)



(Sanders 1967)



(Sanders 1999a)

#5

- The axis of dilatation is aligned parallel to the front.

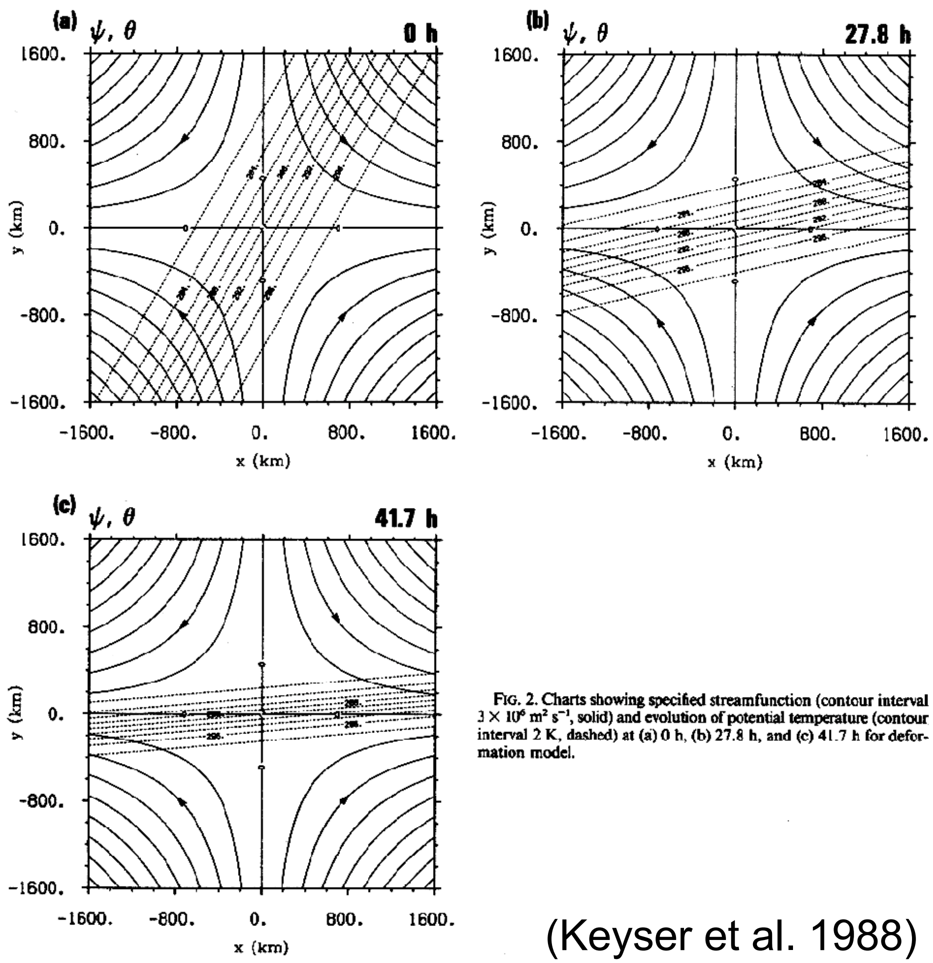


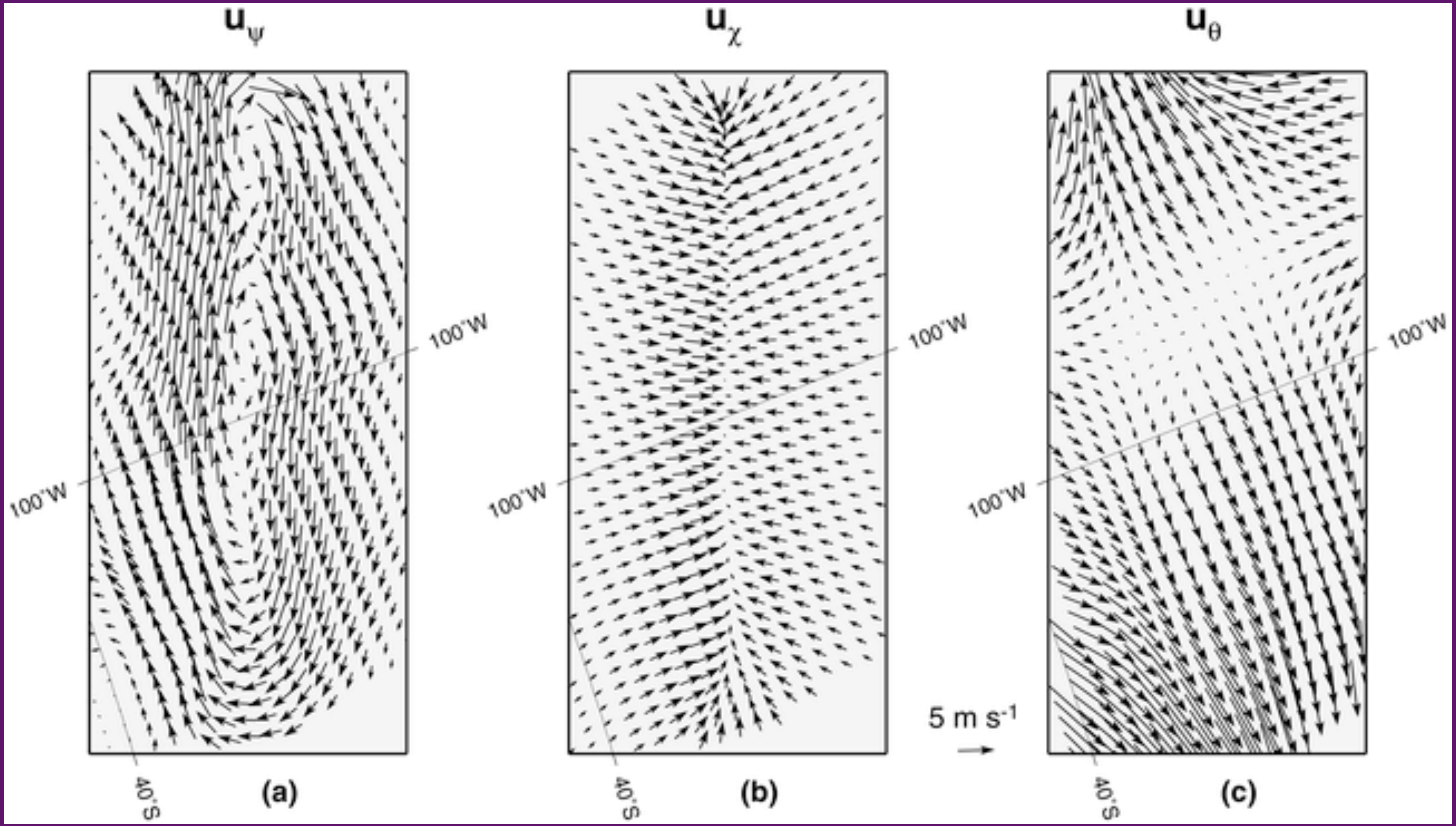
FIG. 2. Charts showing specified streamfunction (contour interval 3×10^6 m^2 s^{-1}, solid) and evolution of potential temperature (contour interval 2 K, dashed) at (a) 0 h, (b) 27.8 h, and (c) 41.7 h for deformation model.

(Keyser et al. 1988)

Bergeron (1928) deformation zone

#5 Evaluated

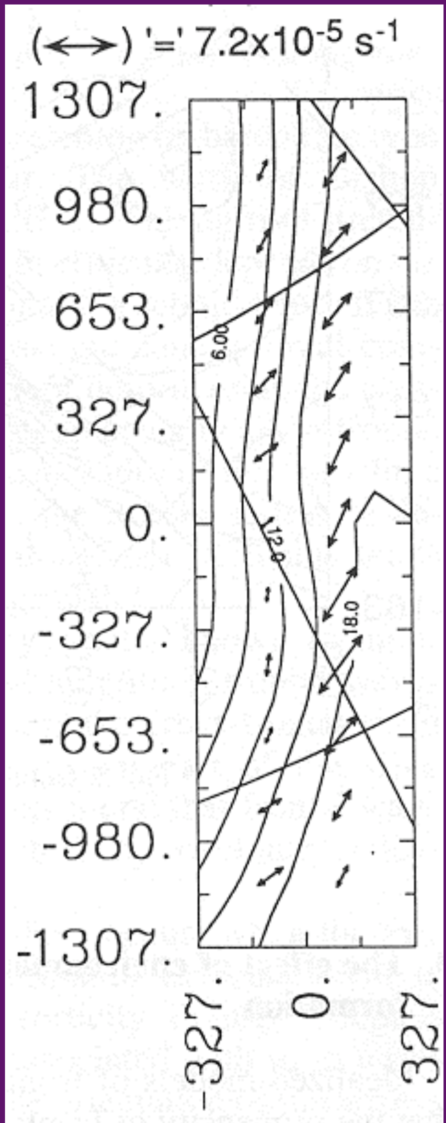
- In a nonrotating front, the vorticity along the front acting to rotate the front cyclonically offsets the deformation along the front acting to rotate the front anticyclonically (Keyser et al. 1988; Bishop 1996).



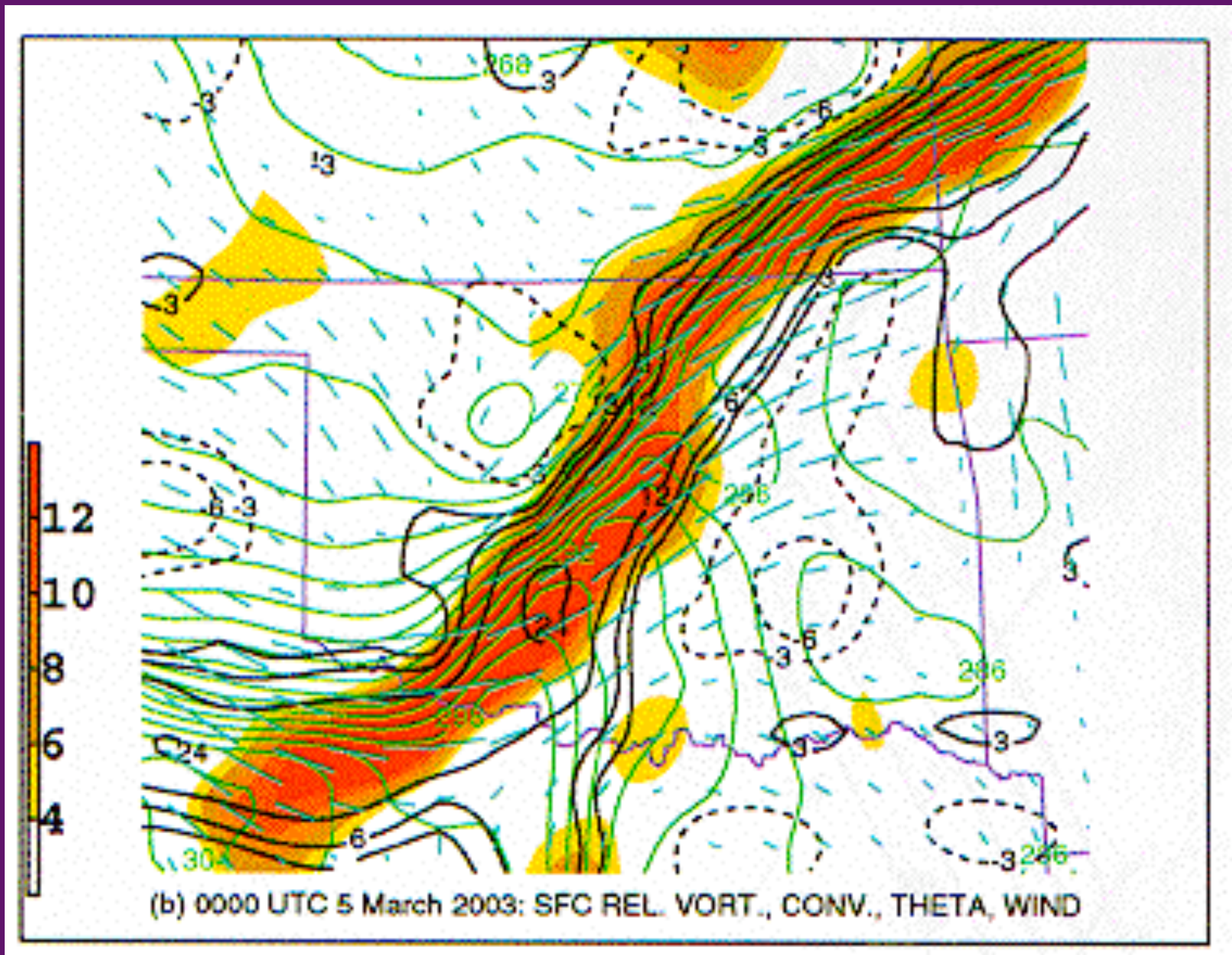
Nondivergent winds Irrotational winds Environmental winds

Partitioning of the winds associated with a front over the Southern Ocean at 25 Jul 1999 at 1300 UTC (Patoux et al. 2005)

#5 Evaluated



(Bishop 1996)



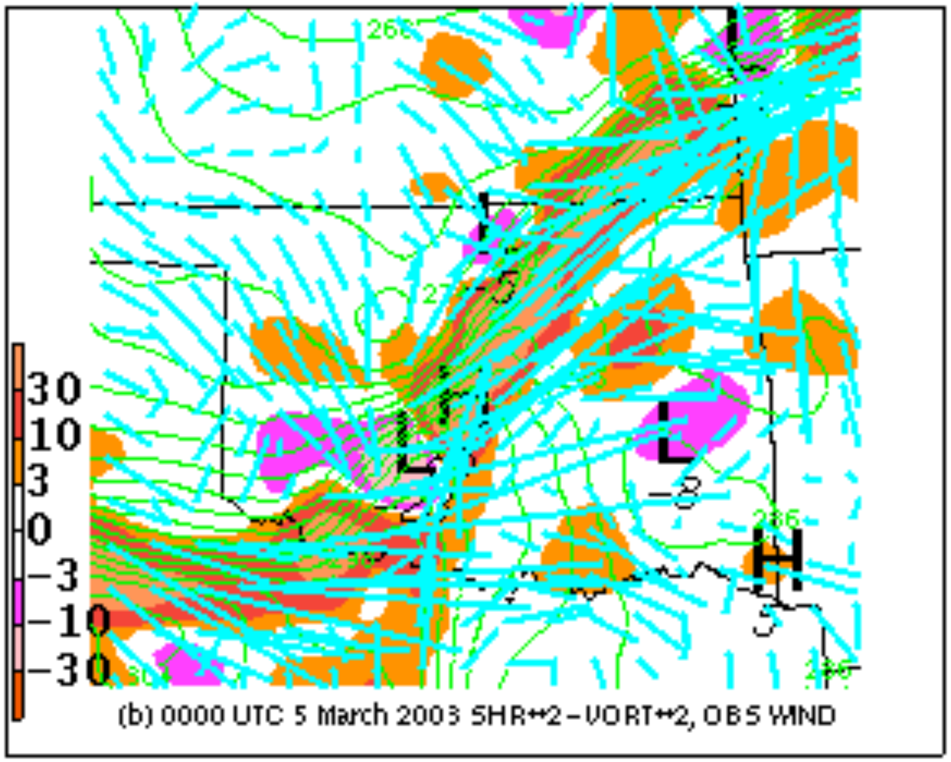
(Schultz 2004)

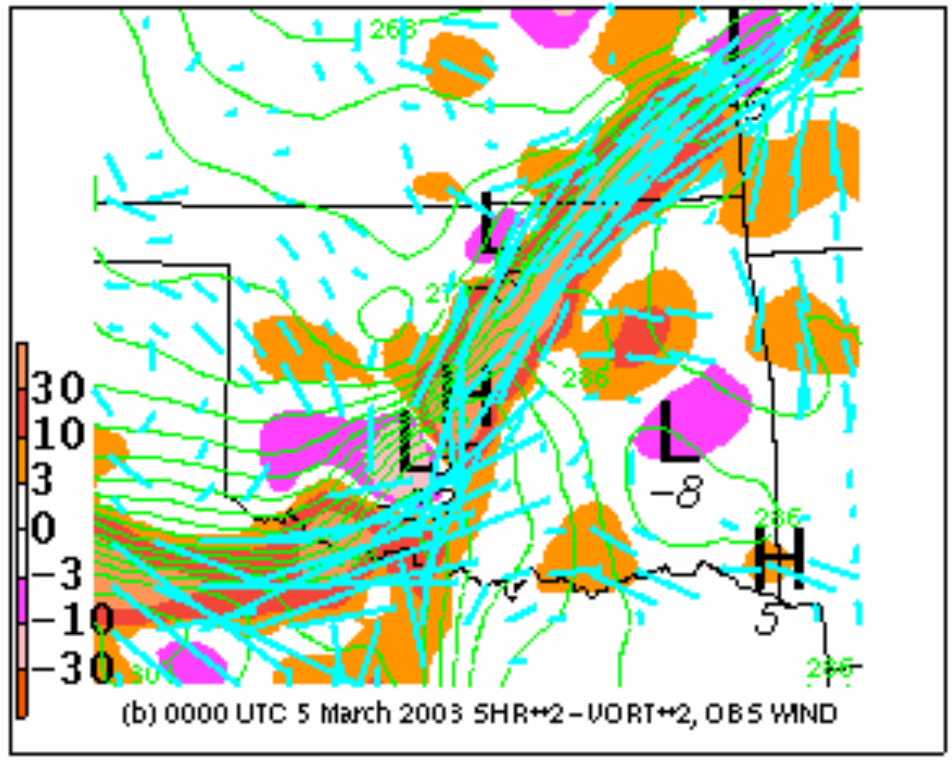
Cohen and Schultz (2005) Diagnostics

$E^2 - \zeta^2$ (purple: negative values)

Axes of Dilatation ψ_d proportional to E

Asymptotic Dilatation Axes χ_d proportional to $\mathcal{C}$





$$\mathcal{C} = -\sigma|_{\phi=\chi_c} = \frac{1}{2}[-D + (E^2 - \zeta^2)^{1/2}].$$

$$\chi_d = \psi_d + \frac{1}{2}\sin^{-1}\left(\frac{\zeta}{E}\right),$$

#6

- Fronts are material surfaces.

- “To a rather close approximation, fronts behave as *material surfaces* in the atmosphere; that is to say, if one could somehow tag or label the air parcels that lie along a frontal surface at some instant in time and follow them as they move along their respective three-dimensional trajectories through space, these very same air parcels would continue to define the frontal surface at future times. Thus it is almost correct to say air does not move through a frontal surface.”

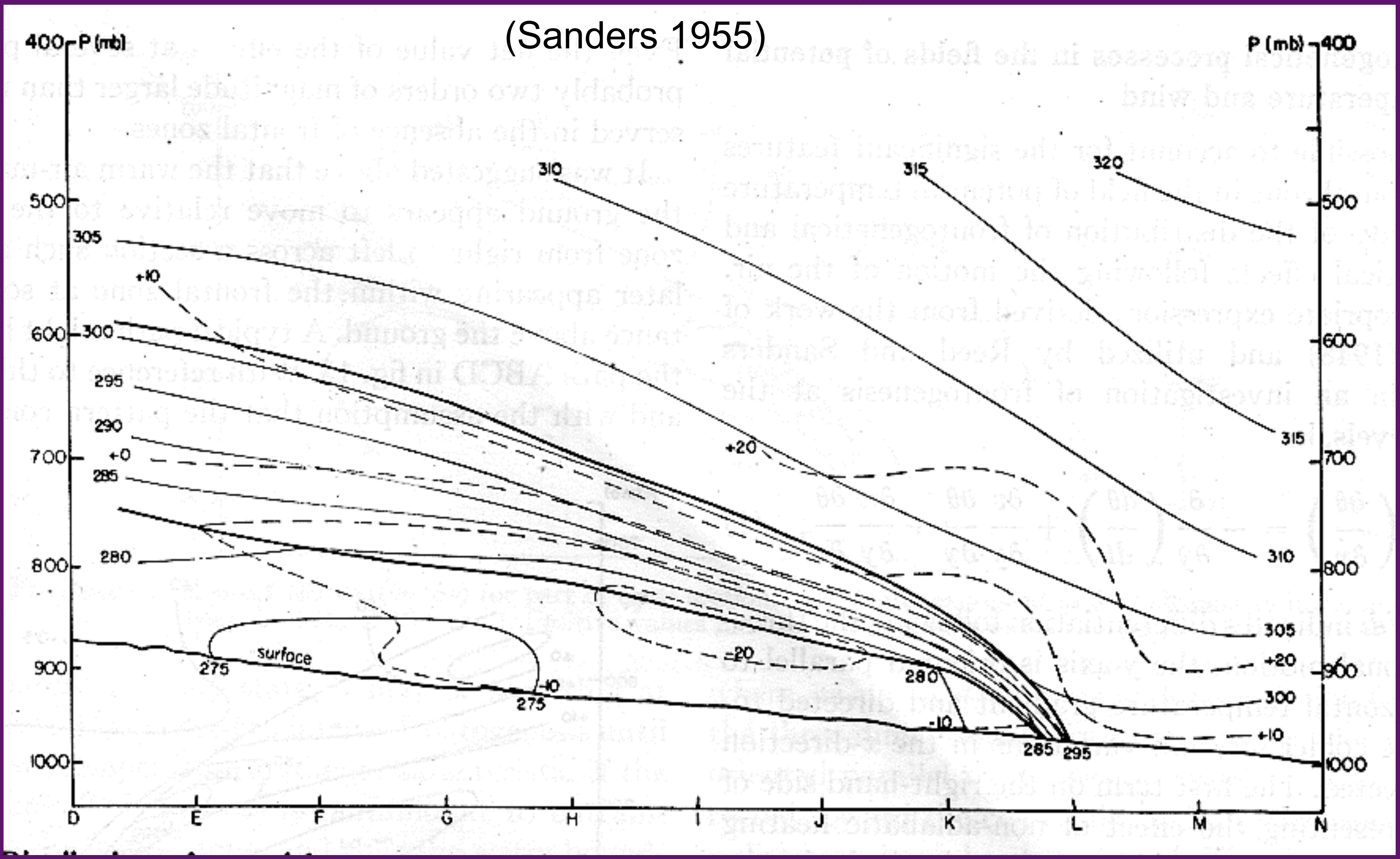
Wallace and Hobbs (1977, 116–117)

#6 Evaluated

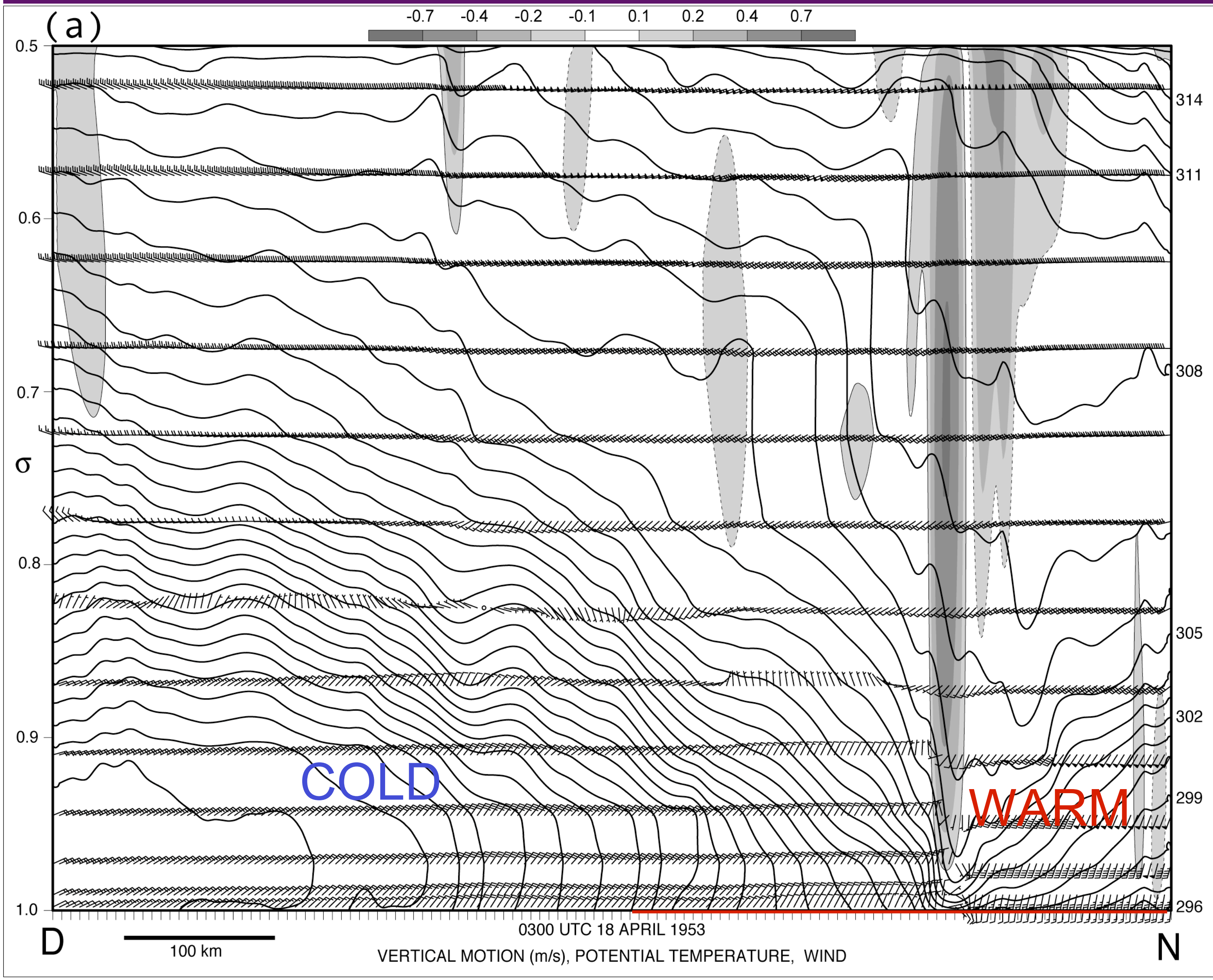
1) Because of the no-slip lower boundary, warm prefrontal air leaks through the front (Keyser and Anthes 1982; Xu and Gu 2002).

Evidence: The postfrontal air of nearly all the cold fronts in the literature is either well-mixed or absolutely unstable near the surface of the earth.

#6 Evaluated

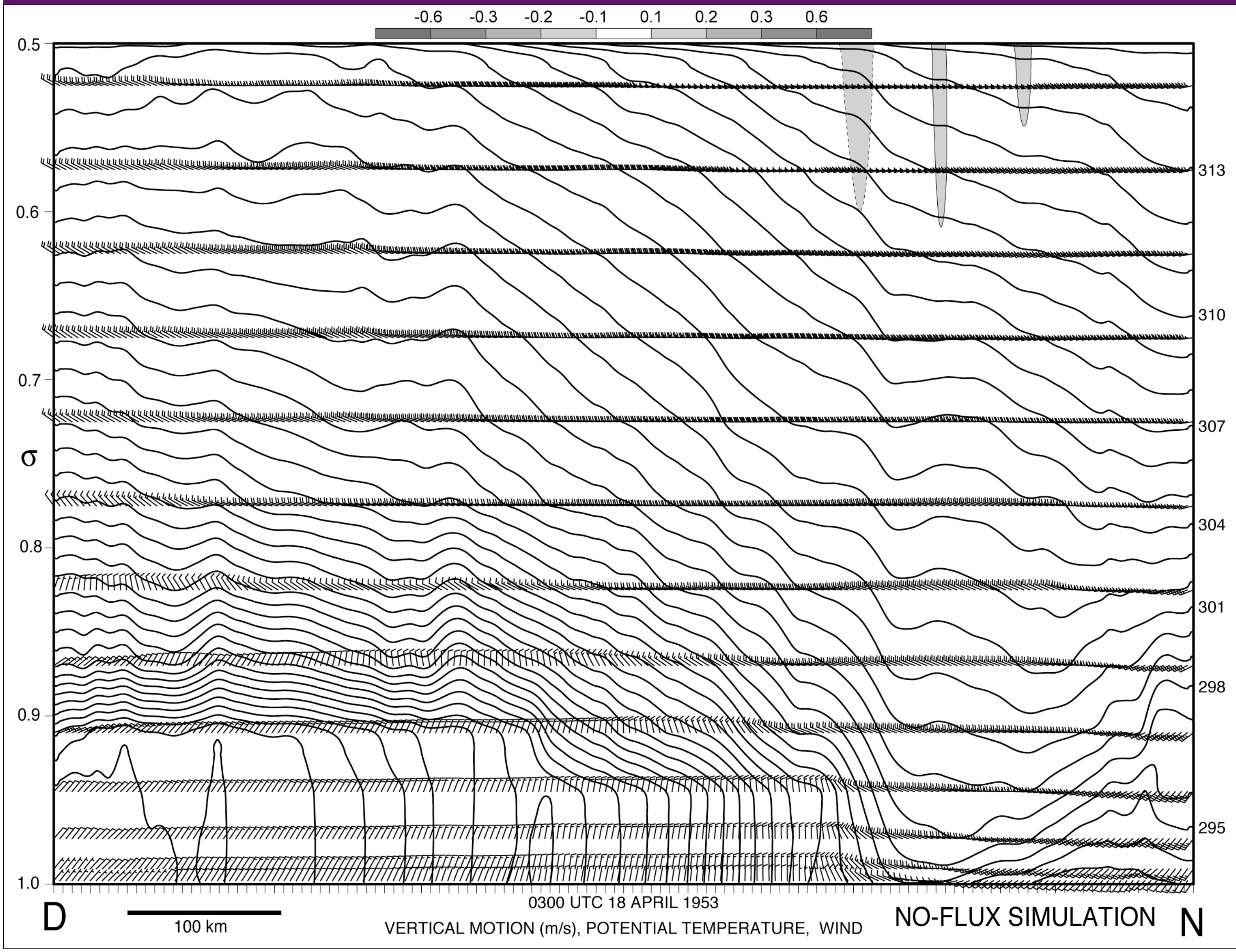

(Sanders 1955)
P (mb)
400
500
600
700
800
900
1000
310
315
320
305
+10
300
295
290
+0
285
280
+20
315
310
305
+20
300
+10
275
surface
275
-10
-20
280
-10
285
295
D
E
F
G
H
I
J
K
L
M
N

#6 Evaluated



(Schultz and Roebber 2004)

#6 Evaluated

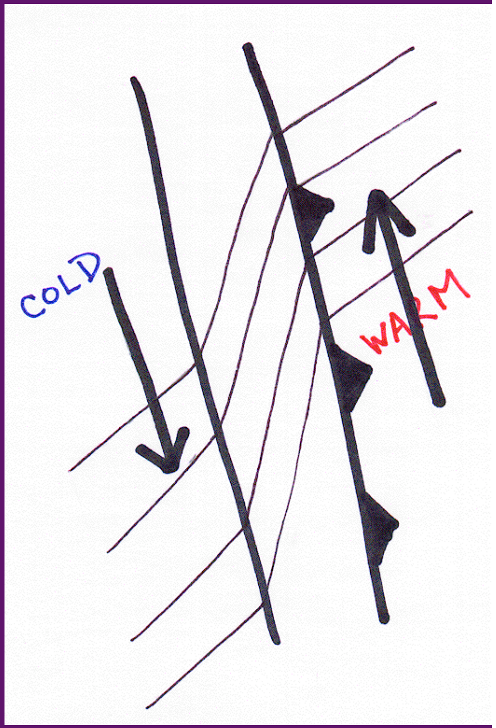


NO-FLUX SIMULATION

(Schultz and Roebber 2004)

#6 Evaluated

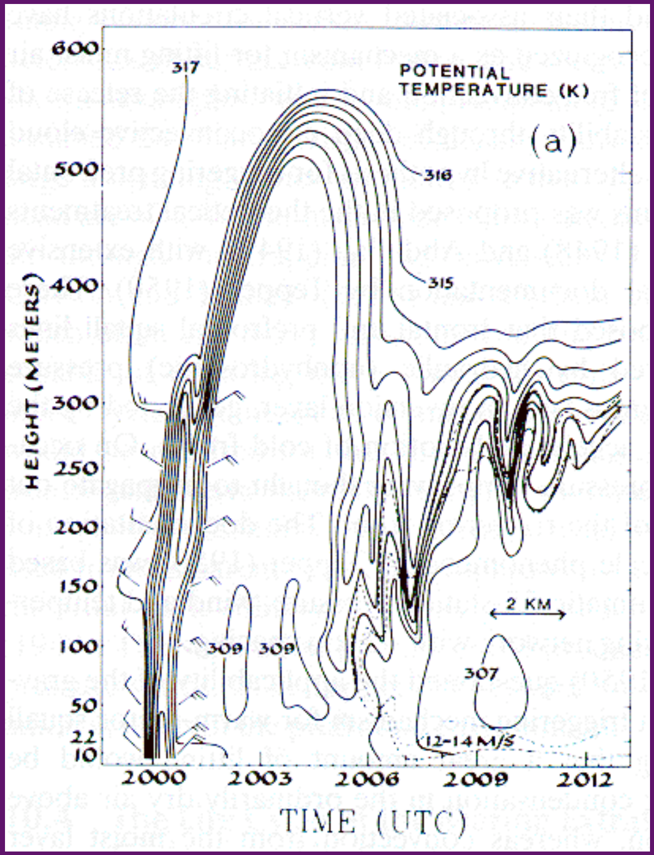
2) Frontal propagation due to alongfront temperature gradients

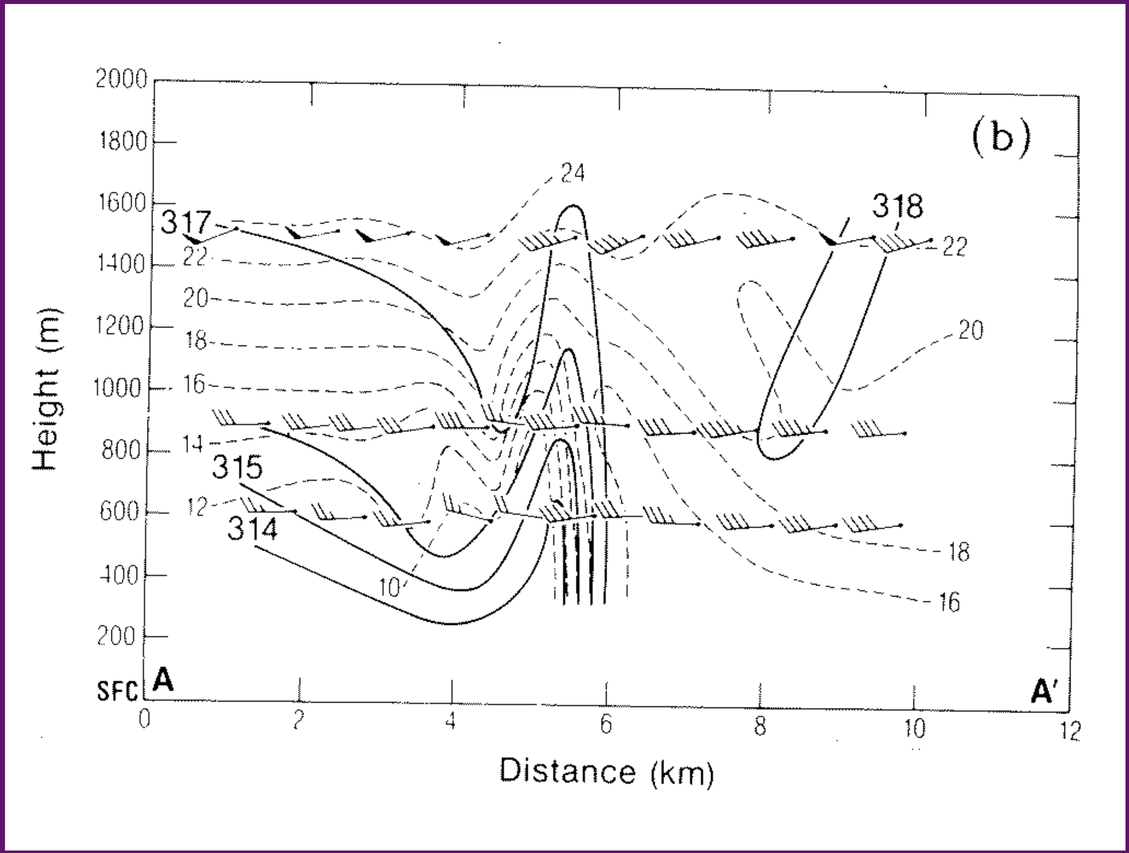


"When horizontal shear frontogenesis is operative, the surface front can move faster than the normal wind component behind the front. In essence, the frontal zone . . . advances principally because of the differential alongfront temperature advection in the presence of an alongfront temperature gradient." – *Smith and Reeder (1988, p. 1940)*

#6 ½

- Can cold fronts be considered density currents?





(Shapiro and Keyser 1990)

#6 1/2 Discussion

- Consider **nonprecipitating** fronts **not influenced by orography**.
- Both of these effects have been shown to produce structures that look like density currents.

#6 1/2 Discussion

1)

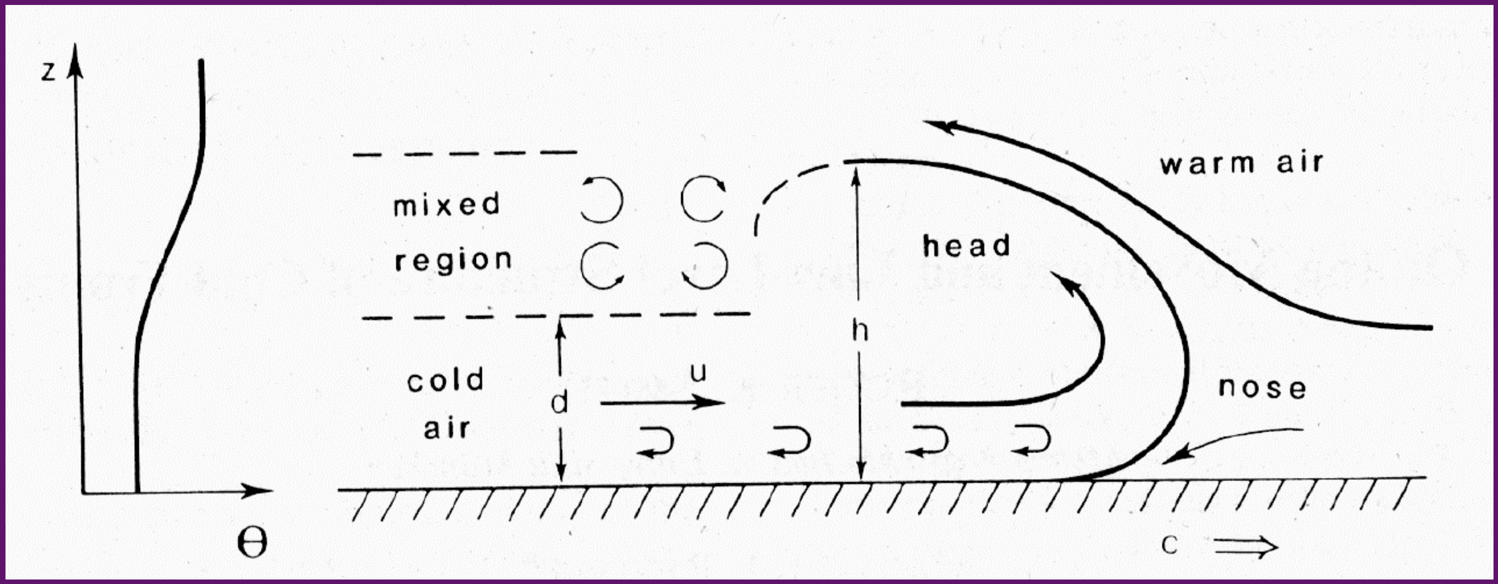
$$c = k\left[gh\left(\frac{\Delta\overline{\theta}}{\theta_0}\right)\right]^{1/2}$$

- how to determine *h* and temperature difference
- uncertainty in *k* (0.7–1.08)
- weak dependence of *c* on right-hand side
- error bars are so large as to make quantitative evaluation not worth much

“Comparisons of observed frontal speeds with speeds calculated from [the density-current equation (Benjamin 1968)] do not alone provide a very severe test of the *applicability* of the gravity current models to atmospheric fronts.” (Smith and Reeder 1988)

#6 ½ Discussion

2) "An additional test is to determine whether or not there is a region of low-level feeder flow toward the front. . . . This is not an exclusive test, however, since certain types of large amplitude solitary waves may have a similar structure." (Smith and Reeder 1988)



#6 ½ Discussion

3) Most idealized density current simulations designed to represent fronts do not possess synoptic-scale forcing to maintain frontogenesis (e.g., Parsons 1992).

Therefore, density currents experience frontolysis (Reeder and Smith 1992).

#6 $^{1}/_{2}$ Discussion

"There is little evidence to date to suggest that frontal speed is controlled by gravity current dynamics rather than processes that operate on the frontal scale itself, where the ageostrophic crossfront circulation plays a central role. . . . the front may appear to have the local character of a gravity current, but there is little reason to expect the speed formula for a *steady* gravity current to apply to the front." (Smith and Reeder 1988, 1941–1942)

". . . the applicability of gravity current theory to cold fronts remains uncertain; in some cases the evidence for this is clear, in some cases it is conflicting, and in other cases the theory seems clearly to be irrelevant" (Smith and Reeder 1988, p. 1932).

#6 ½ Discussion

Frontal collapse studies show density-current-like features at very high resolution (50–400 m) (Snyder and Keyser 1996).

Balance at small cross-front scales is between the cross-front acceleration and the pressure gradient.

“A density current exhibits the same balance, and thus a narrow surface front is likely to have similarities to density currents. . . . The degree to which the dynamics [of a front] . . . are similar to those of a density current, however, is not clear.” (Snyder and Keyser 1996)

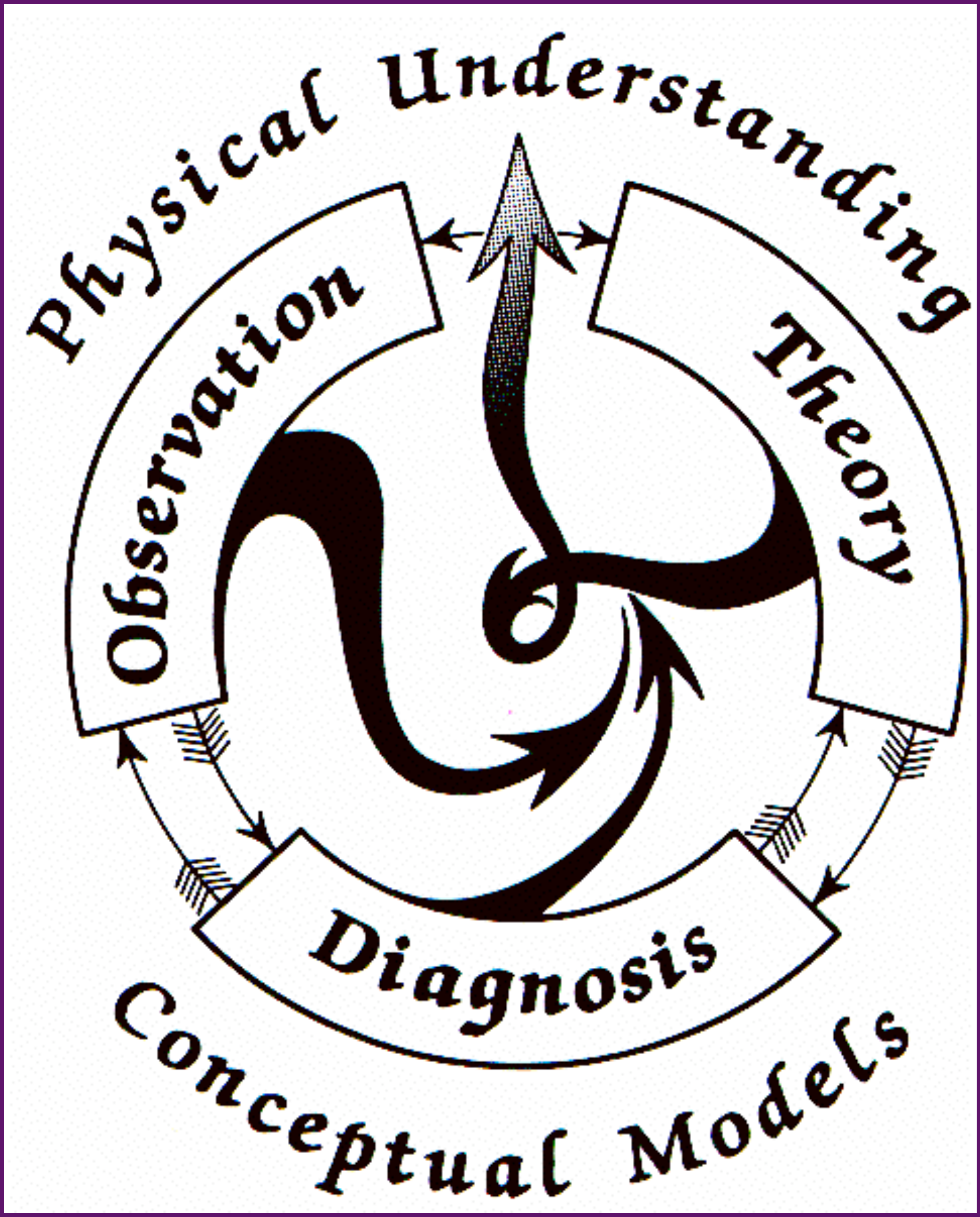
How Can We Fix This Situation?

It’s not the fault of the Norwegian frontal model for the present state of affairs.

The fault lies partially with those that overuse, misinterpret, and still rely on that conceptual model.

“Comparing [our] results. . . with observations is rendered impracticable by the apparent absence of observational studies of the structure and development of surface frontal zones based on modern dynamical perspectives provided by quasi- and semigeostrophic frontogenesis theories.”

Keyser and Pecnick (1987, p. 603)



(Shapiro et al. 1999)

The Unknown Knowns

1. Some cold fronts are vertical or tilt forward over the warm air with height.

2. Sometimes the cloud band does not represent the surface position of the cold front.

3. Cold fronts are not necessarily signified by decreasing temperature after frontal passage.

4. Sometimes prefrontal troughs and wind shifts exist.

5. For a steady front, the axis of dilatation is oriented anticyclonically to the cold front.

6. Cold fronts are not material surfaces.

6 $^{1}/_{2}$. The relationship between cold fronts and density currents is unresolved.

Lessons

Lessons

1. Challenge yourself to raise your competency in your diagnosis and theory.

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2. Know the history of your discipline. Become comfortable reading the scientific literature. Keep updated on your scientific interests.

Lessons

1. Challenge yourself to raise your competency in your diagnosis and theory.
2. Know the history of your discipline. Become comfortable reading the scientific literature. Keep updated on your scientific interests.
3. Hand analysis of observed data is required! Model data and forecasts are not reliable.

Lessons

1. Challenge yourself to raise your competency in your diagnosis and theory.
2. Know the history of your discipline. Become comfortable reading the scientific literature. Keep updated on your scientific interests.
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