UPPER WIND COMPONENTS AND FORECASTING

By

I. Gringorten

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California Institute of Technology

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WIND COMPONENTS AND THEIR RELATION TO FORECASTING

Plan

1. Purpose of paper.

   (A) Departure of Actual Winds from Geostrophic Winds.

   (B) Use of this departure in forecasting movements of highs, lows, and fronts.

   (C) Relative Magnitude of wind components.

2. Theory.

   (A) Development of Eqn of Horizontal motion.

   (B) The approximations

   (C) Relative magnitude of the wind components.

3. The numerical determination of each term in the wind equation.

4. Determination of the vertical wind component.

5. Changes in wind caused by each of these components.

6. How to make use of this theory.

7. Example.

8. Rapid Qualitative rules.

Upper Wind Components and Forecasting

Purpose.

It is generally assumed that upper winds may be taken as geostrophic winds to a close approximation. (See References 1,2). However all too frequently upper winds at a height, say, of 5000 ft, show serious departures from gradient winds, especially in direction. So great is this departure that at once the suggestion arises to make use of it.

The isallobaric component of the wind gives the direction of rising or falling pressure, also the magnitude of the gradient of the pressure tendency. By finding the isallobaric fields it is possible to determine the movement of pressure centres and fronts. Finding such fields aloft has its advantages over using the isallobaric fields on the surface of the earth. First, such fields at the surface appear very irregular. The terrain changes elevation, and such fields at the surface do not give a true picture of the horizontal isallobaric gradient. Further the surface pressure changes are affected by daily variations due to the sun's heating. They are also radically ~~radically~~ affected by turbulent conditions such as in thunderstorms. Again, upper frontal systems are not easily found by surface pressure tendencies. Further, frontal systems and low pressure centres frequently exist in the lower layers of the atmosphere while the upper layers are subject to prevailing winds only and therefore the daily weather chart will not be in any way useful for the forecasting of upper winds. Yet this latter type of forecasting is of utmost importance in aeronautical meterorology.

~~As for the relative magnitude of the wind components, other than the geostrophic component, it is partly the~~

Examples of the usefulnass of this departure from gradient wind are given in Showalter's paper (3), and in Bjerknes and Palmen's "Serial Ascents".(4).

As for the relative magnitude of the wind components other than the geostrophin component, it is partly the purpose of this paper to determine them numerically.

Theory

The Equations of Motion.

The following follows closely Sutcliffe(5). Begin with the equations of motion as developed in Brunt (6) for axes oriented in any diretion:

$$\frac{du}{dt} + 2\omega(w\cos\phi\cos\beta - v\sin\phi) = -\frac{1}{\rho}\frac{\partial p}{\partial x} + X \quad \text{------ (1.)}$$

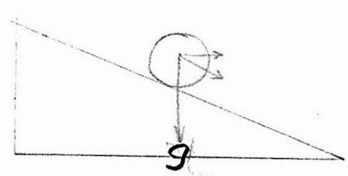
$$\frac{dv}{dt} + 2\omega(w\cos\phi\sin\beta + u\sin\phi) = -\frac{1}{\rho}\frac{\partial p}{\partial y} + Y \quad \text{---- (2.)}$$

$$\frac{dw}{dt} - 2\omega\cos\phi(u\cos\beta - v\sin\beta) = -g - \frac{1}{\rho}\frac{\partial p}{\partial z} + Z \quad \text{---- (3.)}$$

where u, v, w, are actual velocities including vertical velocity.

β =angle with east-west direction.

X,Y,Z are exterior forces like surface friction. Although the gravitational force is a vertical force, and is given by g in the 3rd equation, yet it may produce a horizontal acceleration like its effect on a ball on a hill. This force will also be included in the X,Y terms.



The vertical velocity , by comparison with the horizontal velocity is small. The terms $2\omega\cos\phi\cos\beta\, w$ and $2\omega\cos\phi\sin\beta\, w$ in the first two equations are to be neglected. Later the order of magnitude so neglected will be determined.

After this approximation equations (1) and (2) become:

$$\frac{du}{dt} - 2\omega v\sin\phi = -\frac{1}{\rho}\frac{\partial p}{\partial x} + X \text{ - - - - - } (4.)$$

$$\frac{dv}{dt} + 2\omega u\sin\phi = -\frac{1}{\rho}\frac{\partial p}{\partial y} + Y \text{ - - - - } (5.)$$

These combine to give:

$$\frac{d\bar{V}}{dt} + 2i\omega\sin\phi\,\bar{V} = -\frac{1}{\rho}\nabla p + \bar{F} \text{ - - - - - } (6.)$$

where $\bar{V}$ is the horizontal wind, a vector quantity. (complex

$\bar{F}$ is the horizontal acceleration caused by turbulence and gravity.

From (6.), $\frac{\partial}{\partial t}\left(\frac{d\bar{V}}{dt}\right) + 2i\omega\sin\phi\frac{\partial\bar{V}}{\partial t} = -\frac{1}{\rho}\nabla\dot{p} + \dot{\bar{F}}.$

Assume that $\frac{\partial}{\partial t}\left(\frac{d\bar{V}}{dt}\right)$ and $\dot{\bar{F}}$ are small by comparison with the other two terms in the equation. Then

$$\frac{\partial\bar{V}}{\partial t} = \frac{i}{2\omega\sin\phi}\cdot\frac{1}{\rho}\nabla\dot{p} \text{ - - - - } (7.)$$

From (6) $\frac{\partial\bar{V}}{\partial t} + u\frac{\partial\bar{V}}{\partial x} + v\frac{\partial\bar{V}}{\partial y} + w\frac{\partial\bar{V}}{\partial z} + i.2\omega\sin\phi(\bar{V}) = -\frac{1}{\rho}\nabla p + \bar{F}.$

Put $2\omega\sin\phi = l.$

From (7) $\frac{i}{l\rho}\nabla\dot{p} + \left(u\frac{\partial\bar{V}}{\partial x} + v\frac{\partial\bar{V}}{\partial y}\right) + w\frac{\partial\bar{V}}{\partial z} + il\bar{V} = -\frac{1}{\rho}\nabla p + \bar{F}.$

For gradient wind $\bar{V}_g$, $l\bar{V}_g = \frac{i}{\rho}\nabla p.$

$$\text{or } \bar{V}_g = \frac{i}{l\rho}\nabla p$$

$$\text{or } -\frac{\nabla p}{\rho} = il\bar{V}_g$$

Therefore, $i l \bar V = i l \bar V_g - \frac{i}{l\rho}\nabla p - \left(u\frac{\partial \bar V}{\partial x} + v\frac{\partial \bar V}{\partial y}\right) - w\frac{\partial \bar V}{\partial z} + F.$

that is $\bar V = \bar V_g - \frac{1}{l^2\rho}\nabla p + \frac{i}{l}\left(u\frac{\partial \bar V}{\partial x} + v\frac{\partial \bar V}{\partial y}\right) + \frac{iw}{l}\frac{\partial \bar V}{\partial z} - \frac{i}{l}F.$ . . . (8)

Deal for the moment with the term $u\frac{\partial \bar V}{\partial x} + v\frac{\partial \bar V}{\partial y}$.

$$u = V\cos\theta.$$
$$v = V\sin\theta.$$

$\ldots + v\frac{\partial \bar V}{\partial y}$ has components $u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}$, $u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}$.

that is $V\cos\theta\,\frac{\partial(V\cos\theta)}{\partial x} + V\sin\theta\,\frac{\partial(V\cos\theta)}{\partial y}$; $V\cos\theta\,\frac{\partial(V\sin\theta)}{\partial x} + V\sin\theta\,\frac{\partial(V\sin\theta)}{\partial y}$.

Take $\theta = 0$

Then these components become $V\frac{\partial V}{\partial x}$, $V^2\frac{\partial \theta}{\partial x}$.

The first component will be in the same direction as $\bar V$, the second perpendicular to $\bar V$.
Put r, the radius of curvature of the stream-line $\left(=\frac{\partial x}{\partial \theta}\right)$, s the distance along the stream-line. Then the components are $V\frac{\partial V}{\partial s}$, $\frac{V^2}{r}$.

Not clear.

The wind equation may now be written

$$\boxed{\bar V = \bar V_g - \frac{1}{l^2\rho}\nabla p + \frac{i}{l}V\frac{\partial V}{\partial s}\left(\frac{\bar V}{V}\right) - \frac{V^2}{lr}\left(\frac{\bar V}{V}\right) + \frac{iw}{l}\frac{\partial \bar V}{\partial z} - \frac{i}{l}F.}$$

Now ~~it may~~ if it be decided to neglect all components of the wind except the geostrophic component, then there will be no change in the pressure fields , and the atmosphere will be in equilibrium with no changes occurring. Here, then, appears a limit to forecasting! The relative importance of all terms must be found.

Offhand it would be convenient if the most important term were the isallobaric term, and that the other terms were of smaller order of magnitude.

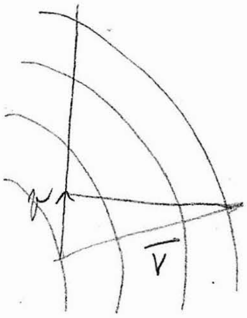
Considerations near the equator are going to be different. There the geostrophic term is negligible, and the isallobaric term must play a very important role. There must also be, by comparison, large vertical velocities.

<u>The determinations of the relative magnitudes of the Terms.</u>
To work with the original equations (1) and (2) seems hopeless. It will be necessary to use the simplified equation (8). To find what order of magnitude was neglected in the simplification, the terms $2\omega w \cos\phi \cos\beta$, $2\omega w \cos\phi \sin\beta$ must be compared with the other terms of the equations (1) and (2). It will be sufficient to compare them with the terms $2\omega v \sin\phi$ and $2\omega u \sin\phi$.

Take the axes E-W, N-S, the ratios of the terms to be compared are: $\frac{w\cos\phi}{v\sin\phi}$ and 0.

At latitude 45°, the first term is $\frac{w}{v}$.
In any case $\frac{\cos\phi}{\sin\phi}$ does not materially change the order of magnitude of $\frac{w}{v}\cdot\frac{\cos\phi}{\sin\phi}$, so the order of magnitude of $\frac{w}{v}$ alone will be found. It will naturally be of the same order of magnitude ~~of~~ as the slopes of fronts or less.

How should the vertical component of the wind velocity be determined? In making isentropic charts it is assumed that, as long as the air remains unsaturated, it moves up or down isentropic surfaces, that is, surfaces of equal potential temperature. Therefore, $\frac{w}{v}$ is the slope of the isentropic surface in the N-S direction.



$$w = V \tan\alpha$$
$$v = V \cos\gamma$$
$$\frac{w}{v} = \frac{\tan\alpha}{\cos\gamma} = (\tan\alpha)(\sec\gamma)$$

where $\tan\alpha$ is the slope in direction of the wind.

γ is the angle of wind with N-S direction.

In spaces like the south-western U.S. the lapse-rate in the atmosphere may be adiabatic, or nearly so, and then the vertical motions may be appreciable. Yet the winds will not have corr-spondingly large horizontal components. The lines of equal height may be ~~drawn~~ far apart, or ~~~~ at least drawn so. Then the vertical motion is indeterminate by isentropic chart. Use of such a chart should, therefore, be restricted to the cases where the lapse-rate is reasonably stable.

Working with the isentropic surfaces for for May 10-18 (incl), stations OL. WKS. ZN, orKF, the following results were obtained:

	OL			WKS	ZN
DATE:	TAN α:	γ, $\cos\gamma$	$\frac{\tan\gamma}{\cos\gamma} = \frac{w}{v}$		
MAY					
10	$\frac{10}{300}$	80	1.1×10^{-4}		
11	—	—	—		
12	$\frac{100}{220}$	- 50	420×10^{-4}		
13	—	—	—		
14					
15					
16					
17					
18					

1953 DATE	OL TAN α	OL γ	OL $\frac{\tan\gamma}{\cos\gamma}=\frac{w}{v}$	WKS TAN α	WKS γ	WKS $\frac{\tan\alpha}{\cos\gamma}=\frac{w}{v}$	ZN TAN α	ZN γ	ZN $\frac{\tan\alpha}{\cos\gamma}=\frac{w}{v}$
May 10	$\frac{10}{300}$	80°	1.1×10^{-4}	—	—	—	$\frac{50}{600}$	60°	1.0×10^{-4}
11	—	—	—	$\frac{50}{400}$	60°	1.55×10^{-4}	$\frac{50}{570}$	10	5.5×10^{-4}
12	$\frac{100}{220}$	50	42.0×10^{-4}	$\frac{50}{210}$	0	14.8×10^{-4}	$\frac{50}{520}$	10	5.5×10^{-4}
13	—	—	—	—	—	—	—	—	—
14	100/[illegible]0	30	44.8×10^{-4}	$\frac{50}{130}$	20	254×10^{-4}	—	—	—
15	—	—	—	—	—	—	—	—	—
16	—	—	—	$\frac{50}{400}$	20	8.3×10^{-4}	—	—	—
17	$\frac{50}{440}$	20	7.5×10^{-4}	—	—	—	—	—	—
18	$\frac{50}{220}$	0	14.1×10^{-4}	—	—	—	—	—	—

Average ~~ratio of the~~ value of the ratio $\frac{w}{v}$ is of the order 10^{-3} or less, comparable with the slope of frontal surfaces. This, then, is the order of magnitude that is being neglected in obtaining equation (8).

<u>The order of magnitude of the terms for the horizontal wind components</u>

(1) <u>Gradient wind.</u> (Vg): This will always be comparable with the actual wind velocity, sometimes smaller, sometimes larger.

(2). Term $\frac{i\,w}{l}\frac{\partial \bar{V}}{\partial z} = V_1$

"$\frac{\partial \bar{V}}{\partial z}$" mean the change in the horizontal velocity per unit increase in height above station. This can conveniently be found from balloon run observations as $\Delta \bar{V}$, both in magnitude and direction per 1000 ft, at some ~~specia~~ specified height.

It may be argued that balloon-run observations are not sufficiently accurate to give a reliable figure for This can only be decided by studying the observations for any one day and seeing if they show systematic changes both in direction and magnitude.

Studying changes in direction first, the following are the changes , every 1000 ft in the 11AM (EST) observations of Feb. 16, 1939:

HR.: Between 4 and 14 thsd ft direction changes gradually from 350 to 280.

VC.: Direction constantly after 5000 ft, 270 .

CV.: After 3000 ft: Direction changes per 1000 ft are -20, 0, -10, 0, 0, 0, 0, 0, 0, -10,

KY.: Direction 310 to 320.

WA.: Direction changes: 0, 0 ,-20, -20, 0 ,0 ,-30, 0.

Ignoring changes in direction for the moment the changes in wind magnitude, with average per 1000 ft are given below: Only the ~~direction~~ winds above the height where the direction becomes steady or steadily increases are taken.

Feb. 16, 1 PM

Station	Initial height	Increases	Ave
HR	2000	3, -8, 2, 1, 2, 0, 4, -3, 4, -1, 5, 4	
VC	5000	6, 2, 2, 2, 0	2
CG	6000	4, 2, 4, 0, -7, 10, 7, 4	3
EV	8000	12, 9, 4, 6, 4, -2	6
CV	3000	4, 5, 3, 5, 3, 6, 2, 2, 0, 7, 5	4
KY	0	3, -5, 0, 18, 11, 0, 5, 3, -2	4
WA	0	18, -6, -6, 14, 26, -22, -13, 5	2
CO	4000	8, 7, 1, 5, 1, -1, 1, 4	3
CC	5000	12, 6, 3, 3, 4, -4, 5, 1, 1	3
HX	0	10, 9, -2, -9, -4, 30, 13, 1	6

Station	ht Initial	Increases per 1000 ft	Ave
PK	6000	7, 8, 8, -7, -2, 7, 0, -10	1
NU	5000	-1, -1, 5, 7, 1, -3	1
ID	5000	6, 1, -2, 5, 5, 7, -2, 0, 5	3
KW		TOO LIGHT	
CS	4000	4, 9, 7, 6, 5, 4, -1, 3, 2, 2	4
LY	0	6, -2, 3, -1, 0, 5, -1, 1, -8, 8, 7, 4	2
NC	~~2~~0	7, 4, -4, -15, -5, 7, 2	-2
RW	0	2, 0, 4, 5, -3, 6, 13, -5, -4, 6, 6, -1, -4, 19	3
GW	3000	8, 10, -8, -2, -6, 5, 6, 13, 10, 4, 10	5
SU	8000	6, 8, 8, 6, 5, 11	7
XW	9000	14, 10, -3	4

Another observation to be made is that when the winds are easterly, the velocity decreases generally with height (once past the turbulence layer). The results ~~xxxpage~~ above were taken from observations of westerly winds, in general. The one case of decrease of wind velocity is actually a case of easterly winds.

Ther is a physical explanation for this. Air-masses moving eastward lose apparent weight, while air-masses moving westward increases in apparent weight. Therefore, a mass moving eastward will have its main mass movement close to the surface of the earth, this mass simply forcing the older airmass aloft. On the other hand, a mass moving eastward will move mostly aloft.

The above results establish the existence of the term $\frac{\partial \bar{V}}{\partial z}$, the increase (or decrease) of wind velocity with height. It is a very real term, which for west winds is of the order of 3 to 4 miles per hour. per 1000 ft increase in height.

To find ω, it will be necessary to find the slope of the isentropic surface, $\frac{\Delta h}{\Delta S}$, where ΔS is the horizontal distance, taken in the direction $\Delta \bar{V}$, for a rise Δh in the surface.

$$\omega = 0.00621 \frac{\Delta h}{\Delta S} (\Delta \bar{V})$$

where ω is measured in m.p,h.

Δh is measured in dekameters

ΔS is measured in miles.

$$l = 2\omega \sin \phi = 0.37/\text{per hr}.$$

$$\frac{\omega}{l} \frac{\partial \bar{V}}{\partial z} = 1.424 \times 10^{4} \omega \frac{\Delta \bar{V}}{\Delta z}$$ in miles per hour

The isentropic charts used were those for May10- 19, 1938.

~~Forxxthexverticalxvelocityx~~

DATE	STATION	$\frac{\Delta h}{\Delta S}$ (dkm/miles)	VELO (miles/hr)	ω (miles/hr) $0.0062 \frac{\Delta h}{\Delta S} V$	$\frac{\partial V}{\partial z}$ (miles/hr / ft)	$\frac{\omega}{l}\left(\frac{\partial V}{\partial z}\right) = V_1$	$\frac{\partial V_1}{V}$ (%)
May 10	FO	0	15	0	0	0	0%
	BI	50/250	6	.0075	3/1000	0.75	12%
	SM	100/170 ~~xx~~	11 ~~x0402~~	.0402	2/1000 ~~xxxx~~	1.14	10%
	CG	50/310	23	.023	6/1000	1.96	9%
	OH	0	31	0	8/1000	0	0
	CX	100/220	14	.0394	8 x10	4.49	3%
	SL	40/200	16	.0198	6x10	1.69	11%
	EO	50/230	7	.0152	—	—	—
	KF	50/700	26	.0115	4x10	0.66	0%

DATE	STATION	$\frac{\Delta h}{\Delta s}\left(\frac{dkms}{miles}\right)$	$V_{EL}\left(\frac{miles}{h}\right)$	$w\left(\frac{miles}{h}\right)$ $0.0062\frac{\Delta h}{\Delta s}V$	$\frac{\partial v}{\partial z}\left(\frac{miles/h}{ft}\right)$	$\frac{w}{l}\left(\frac{\partial v}{\partial z}\right)=V_1$	$\frac{V_1}{V}$ (%)
May 11	CX	$\frac{50}{180}$	32	0.0300	18×10^{-3}	7.69	24%
	SL	$\frac{50}{130}$	2	0.0048	2×10^{-3}	0.14	7%
	OA	$\frac{50}{210}$	2	0.0118	8×10^{-3}	1.34	67%
	EO	--	--	--	--	--	--
	FO	$\frac{50}{280}$	12	0.0111	10×10^{-3}	1.57	13%
	BI	$\frac{100}{310}$	28	0.008	4×10^{-3}	0.46	2%
	KF	--	--	--	--	---	--
12	WKS	$\frac{50}{230}$	22	0.0296	12	5.05	23%
	KF	$\frac{50}{900}$	32	0.011	6	0.94	3%
	OL	$\frac{100}{230}$	40	0.108	3	4.63	12%
	CX	0	4	0	2	0	0%
	BU		not	to be used		indefinite	
	OA	0	19	0	0-4	0	0%
	BI	0	13	0	0	0	
13	OH	$\frac{50}{150}$	10	0.0206	3	0.882	9%
	SL	$\frac{50}{150}$	9	0.0185	12	3.16	35%
	BU	--	--	--	--	--	--
	OA		indeterminate				
	FO	$\frac{50}{330}$	40	0.0376	2	1.07	3%
14	CX	$\frac{100}{250}$	18	0.0447	24	15.3	85%
	SL	$\frac{100}{300}$	4	0.00827	$\frac{15}{2}=7$	0.83	21%
	WKS	$\frac{50}{350}$	20	0.0177	$\frac{27}{2}=14$	3.52	18%
	BI	$\frac{50}{340}$	45	0.0410	$\frac{21}{2}=10$	5.84	13%
15	BI	$\frac{100}{780}$	4	0.0138	15	2.95	74%
16	BI	0	2	0	0	0	0%
	OH	50/170	12	0.0219	2	0,625	5%
	CX	$\frac{50}{130}$	28	0.067	5	4.77	17%

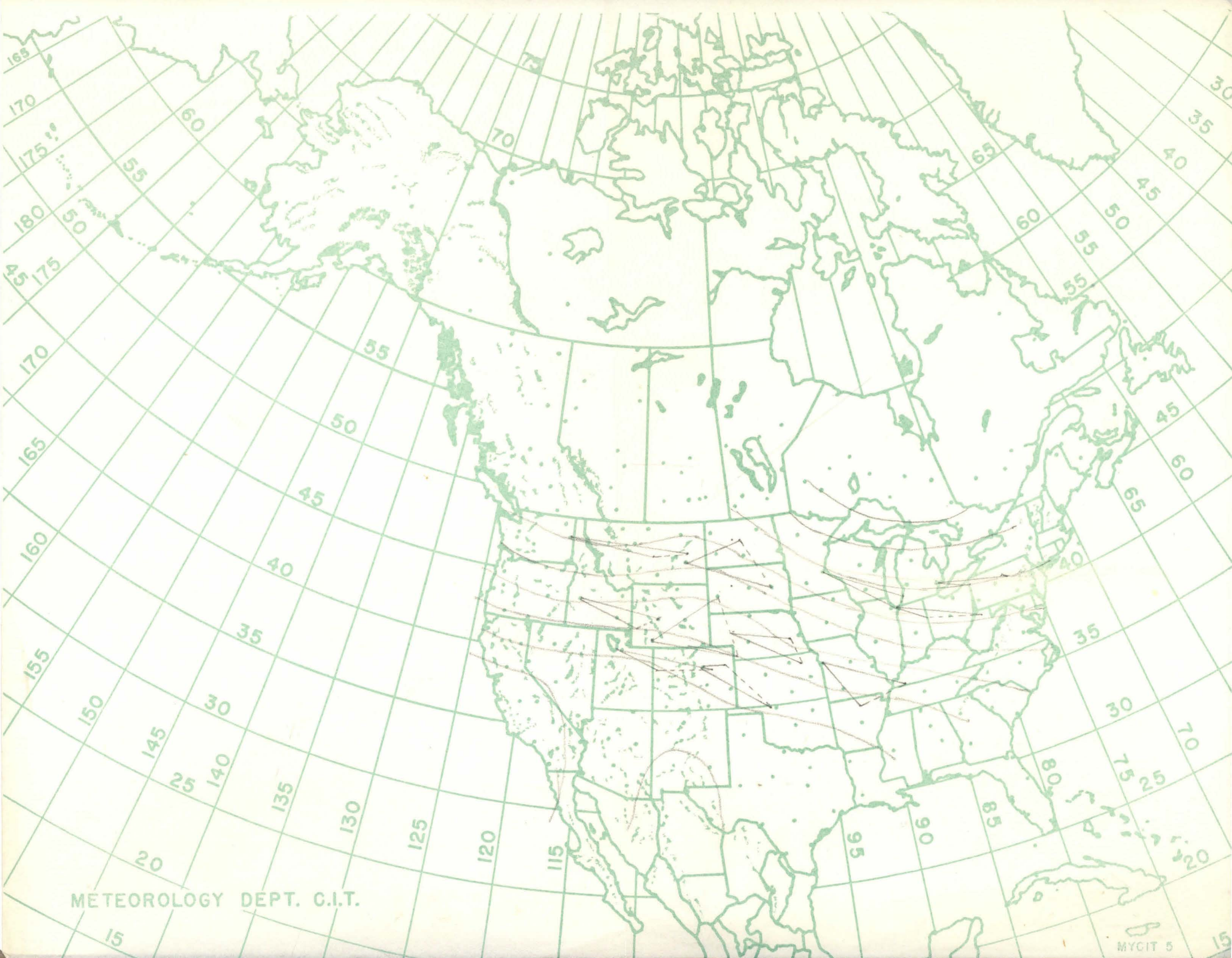
DATE	STATION	$\frac{\Delta h}{\Delta S}\left(\frac{dkm}{miles}\right)$	VEL $\left(\frac{miles}{hr}\right)$	$w\left(\frac{miles}{hr}\right)$ $0.0062\frac{\Delta h}{\Delta S}V$	$\frac{\partial V}{\partial z}\left(\frac{miles/h}{ft}\right)$	$\frac{w}{l}\left(\frac{\partial V}{\partial z}\right)=V_1$	$\frac{V_1}{V}$ (%)
May 17	SL	50/50	14	0.0289	.5	2.06	14%
X8	NA	50/140	26	0.0575	6	4.9	19%
18	SL	50/270	35	0.0402	5	2.86	8%
	OA	50/150	7	0.0145	-3	0.62	9%
19	CX	50/500	9	0.0056	11	0.877	10%
	EO	50/130	26	0.0620	0	0	0%
	NA	0	33	0	5	0	0%
AVERAGES			18	0.020	6.7	2.43	16%

The term $\frac{\partial V}{\partial z}$ is generally of the order of 3 to 4 m,p,h per 1000 ft increase in ht, which makes the term $\frac{w}{l}\frac{\partial V}{\partial z}$ in the eqn for the horizontal wind an important one, as the percentage values on the last page show.

(3) Term $\frac{V^2}{lr} = V_2$

"r" is the radius of curvature of the instantaneous stream line. It will have to be found by drawing the stream-line picture from the upper winds.

The procedure should be to draw stream-line pictures for 5000ft, 10,000 ft., 14,000 ft and at the same time draw isobars at these levels as a possible guide for the shape of the stream-lines. However, the first case drawn, that for Jan.31, 1939, 8 AM, showed the stream-lines far from conforming with the isobars at 5 000 ft. But it is quite easy to draw a stream-line picture just from the 50 odd balloon onservations, remembering to crowd them together where the wind velocity is greater.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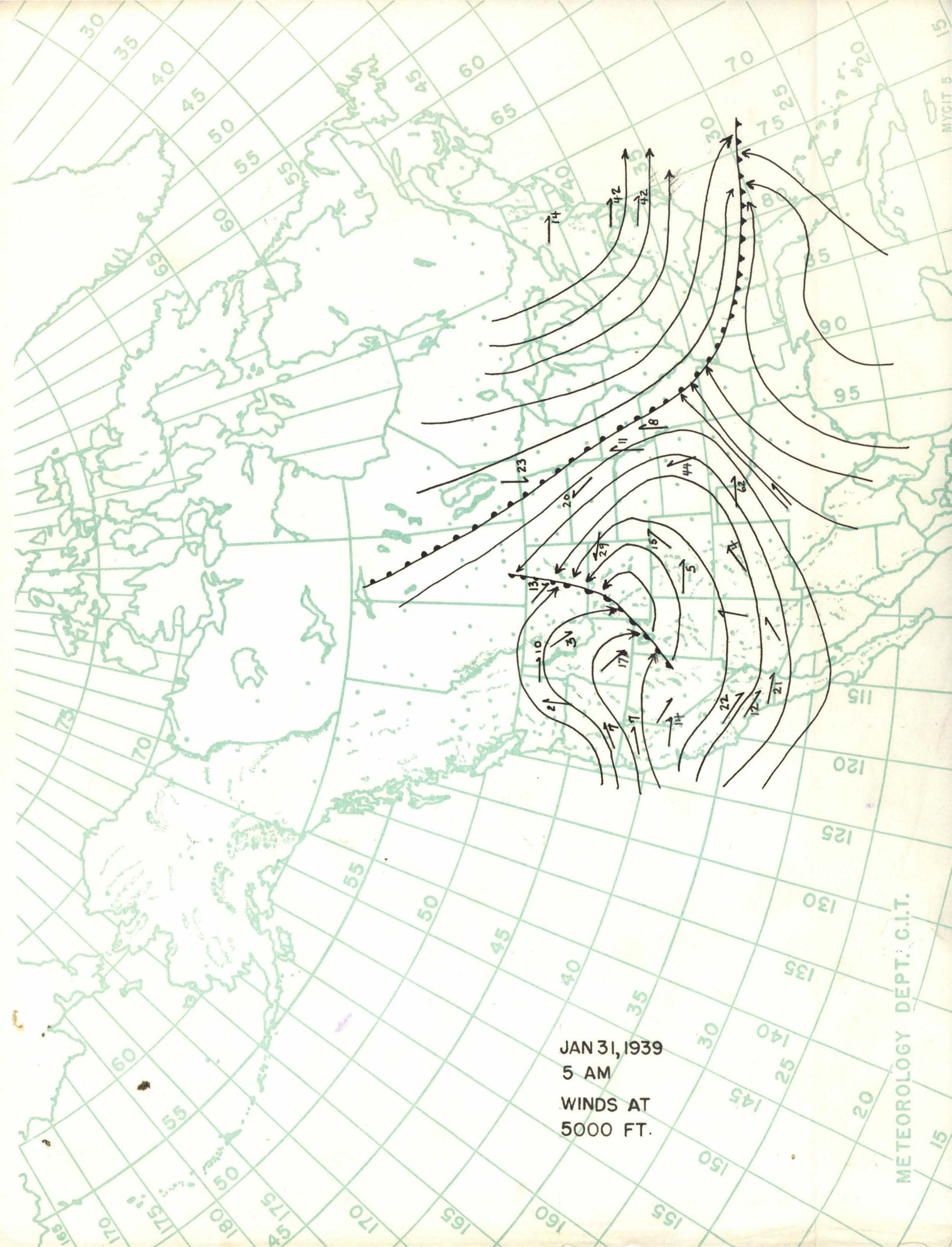
JAN 31, 1939
5 AM
WINDS AT
5000 FT.
METEOROLOGY DEPT. C.I.T.
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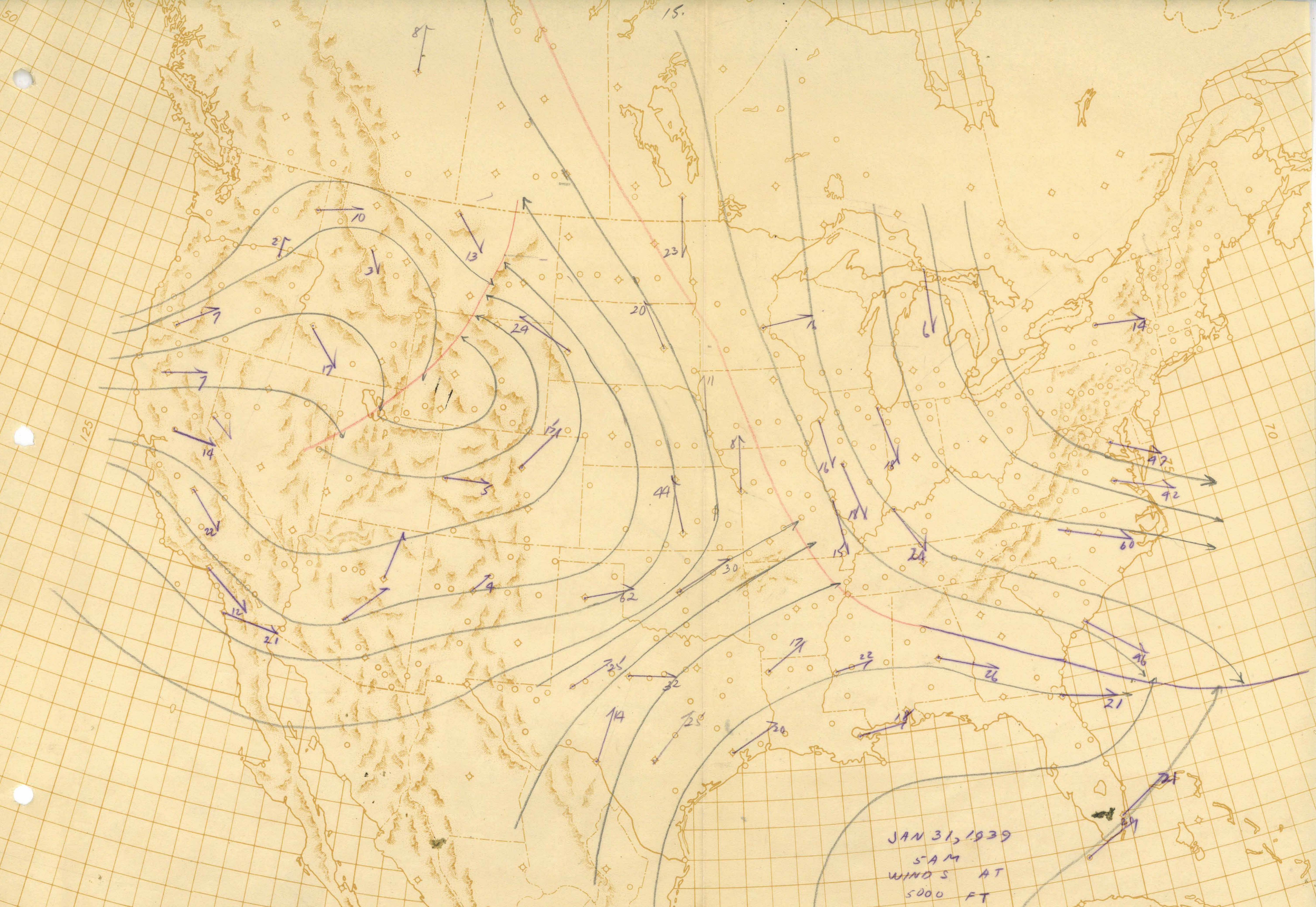
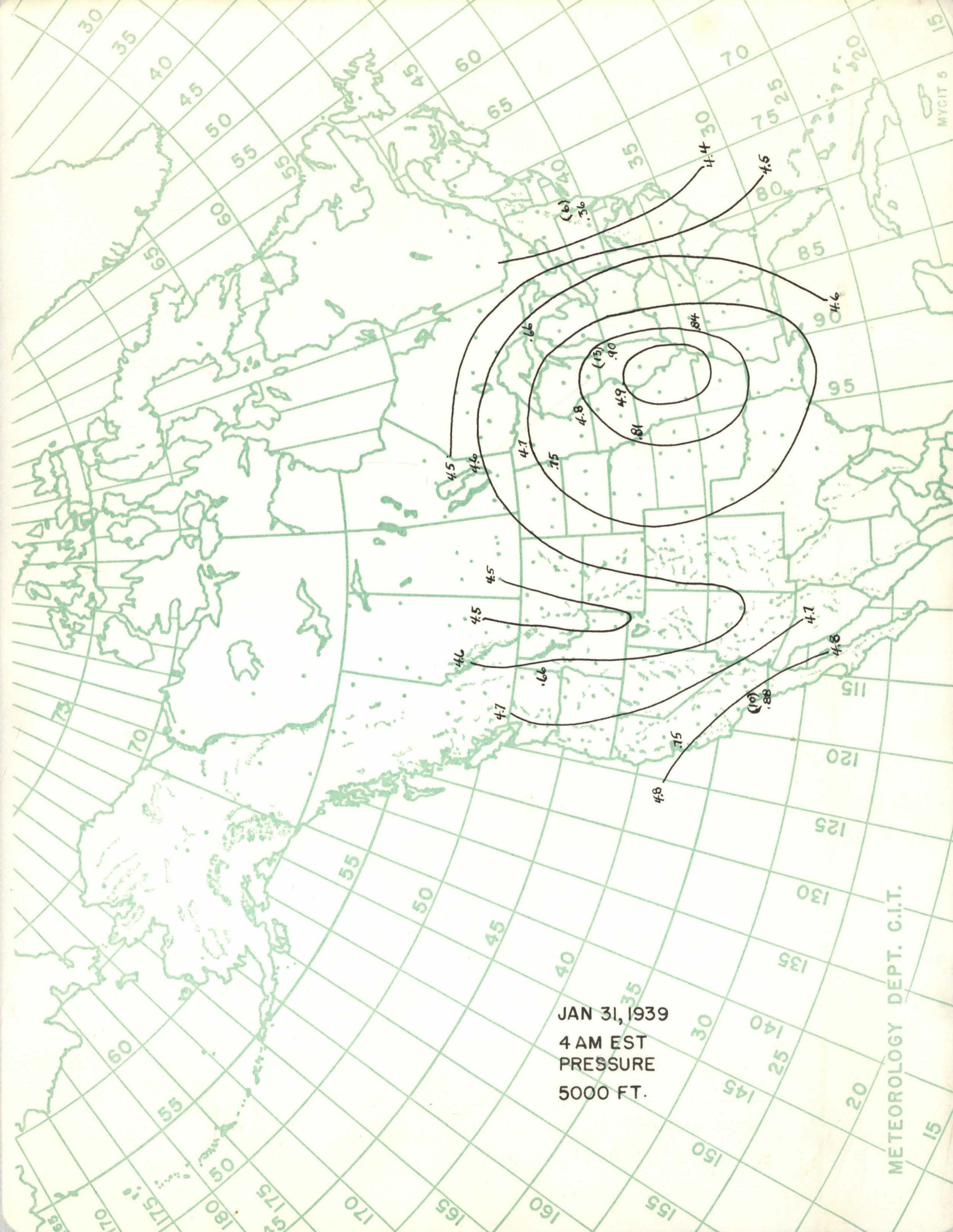
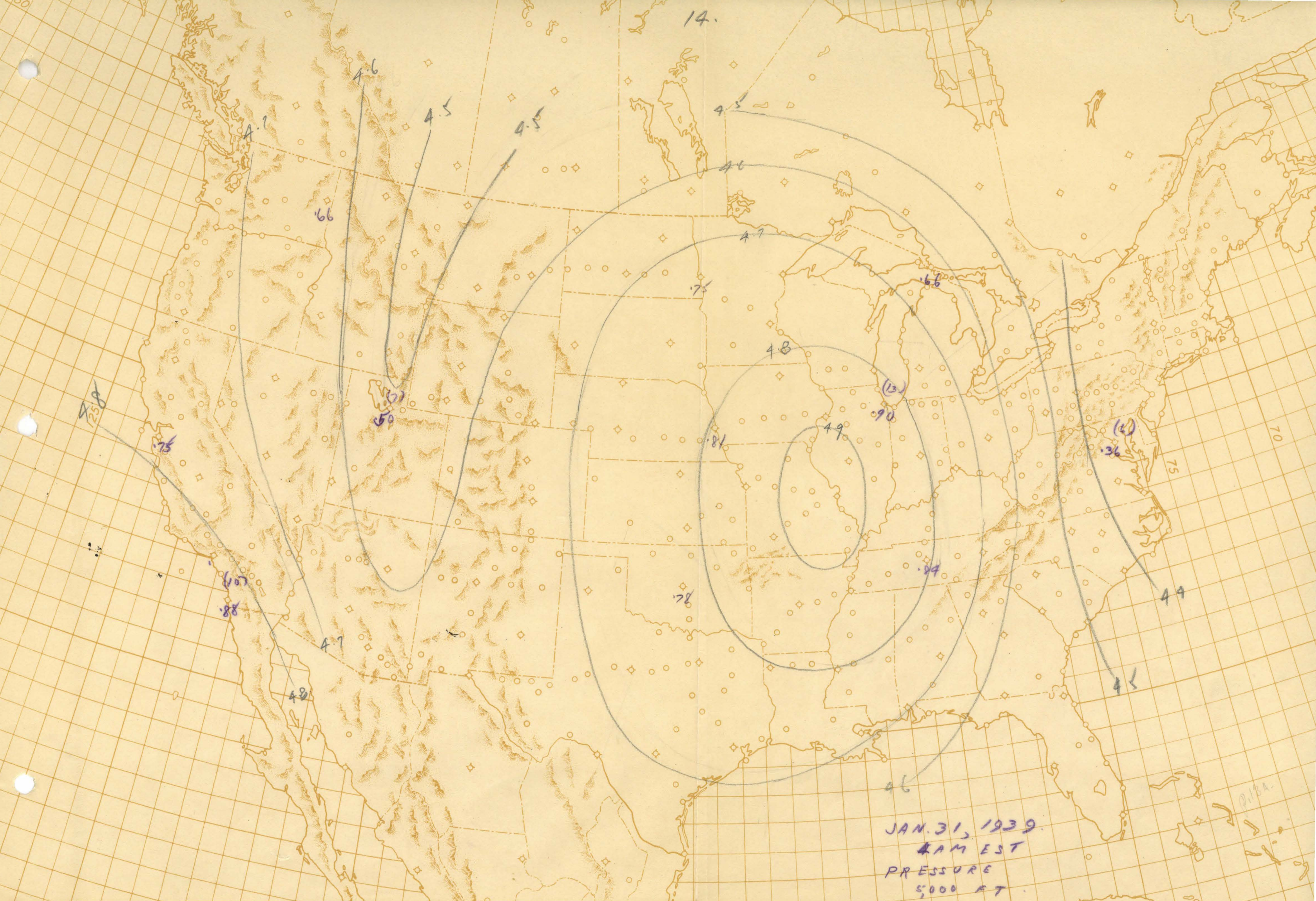

JAN 31, 1939
5 AM
WINDS AT
5000 FT


JAN 31, 1939
4 AM EST
PRESSURE
5000 FT.
METEOROLOGY DEPT. C.I.T.
MYCIT 5

14.



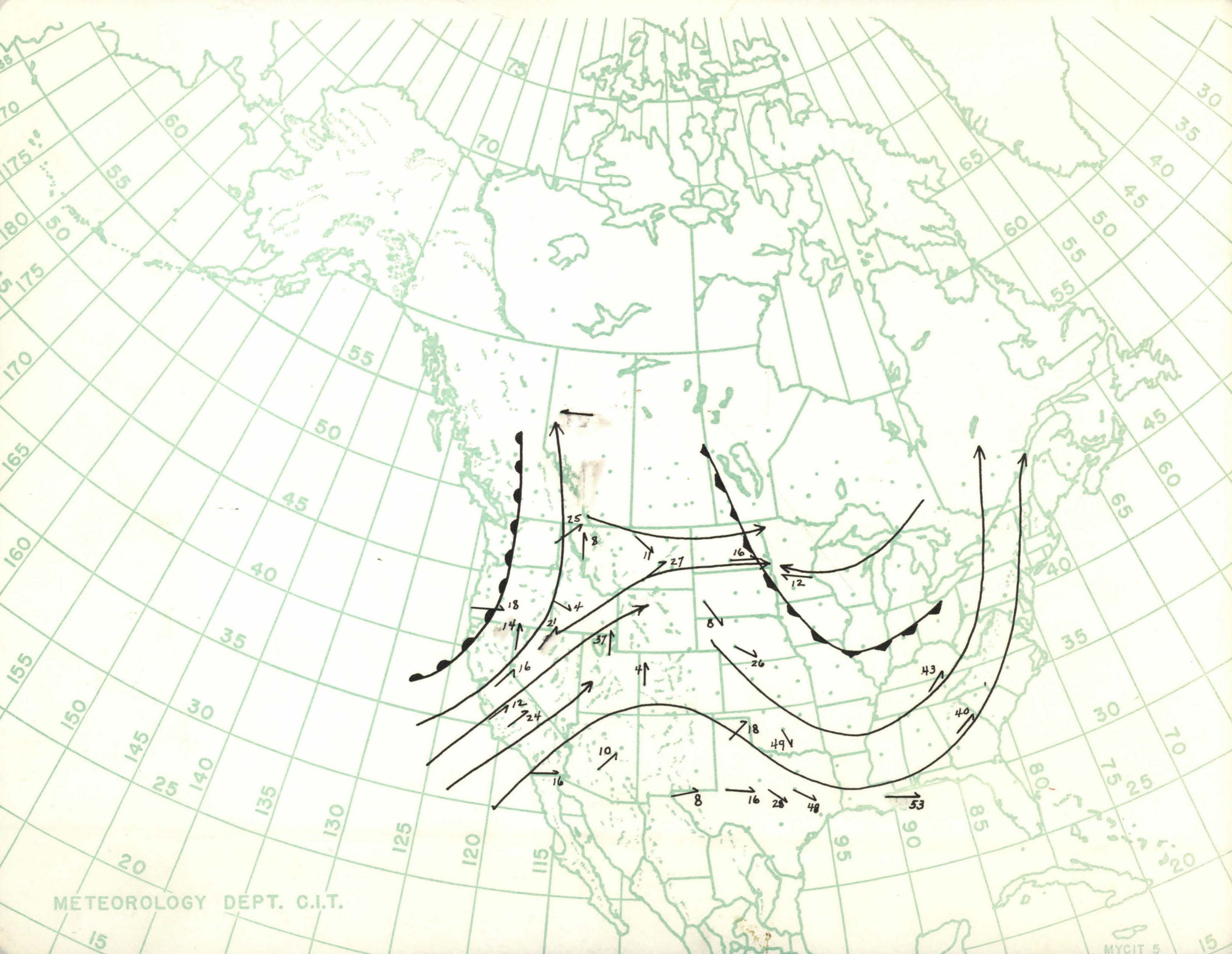
JAN. 31, 1939
4AM EST
PRESSURE
5000 FT

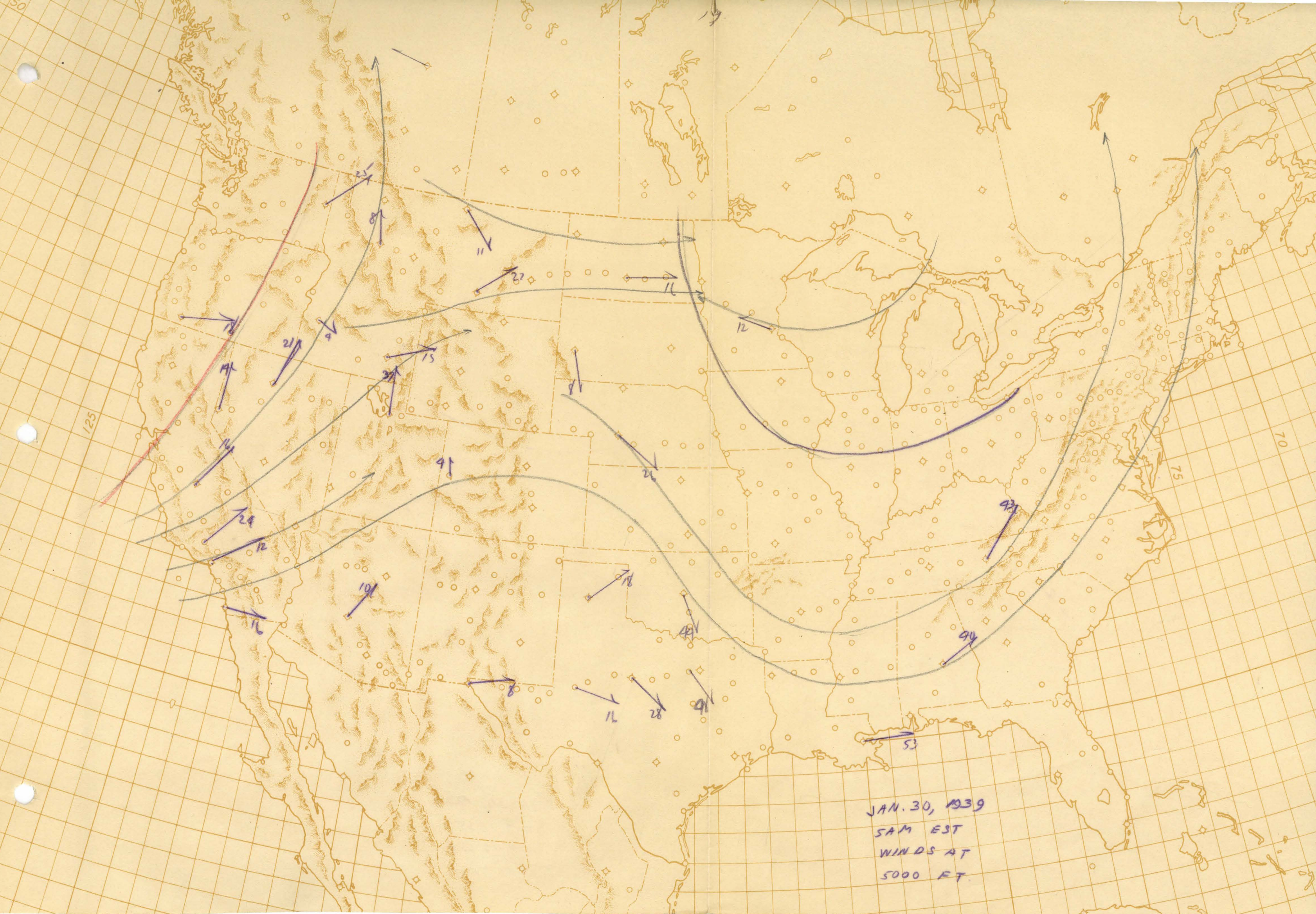
It is also obvious that many streamlines will have to be originated in areas where the wind velocities show marked increase, in such cases where horizontal convergence will not account for the increases , but rather convergence from layers above or below must be considered. Where the velocity decreases without horizontal divergence, then the streamlines are brought to an end, indicating vertical motion out of the horizontal surface that had been chosen.

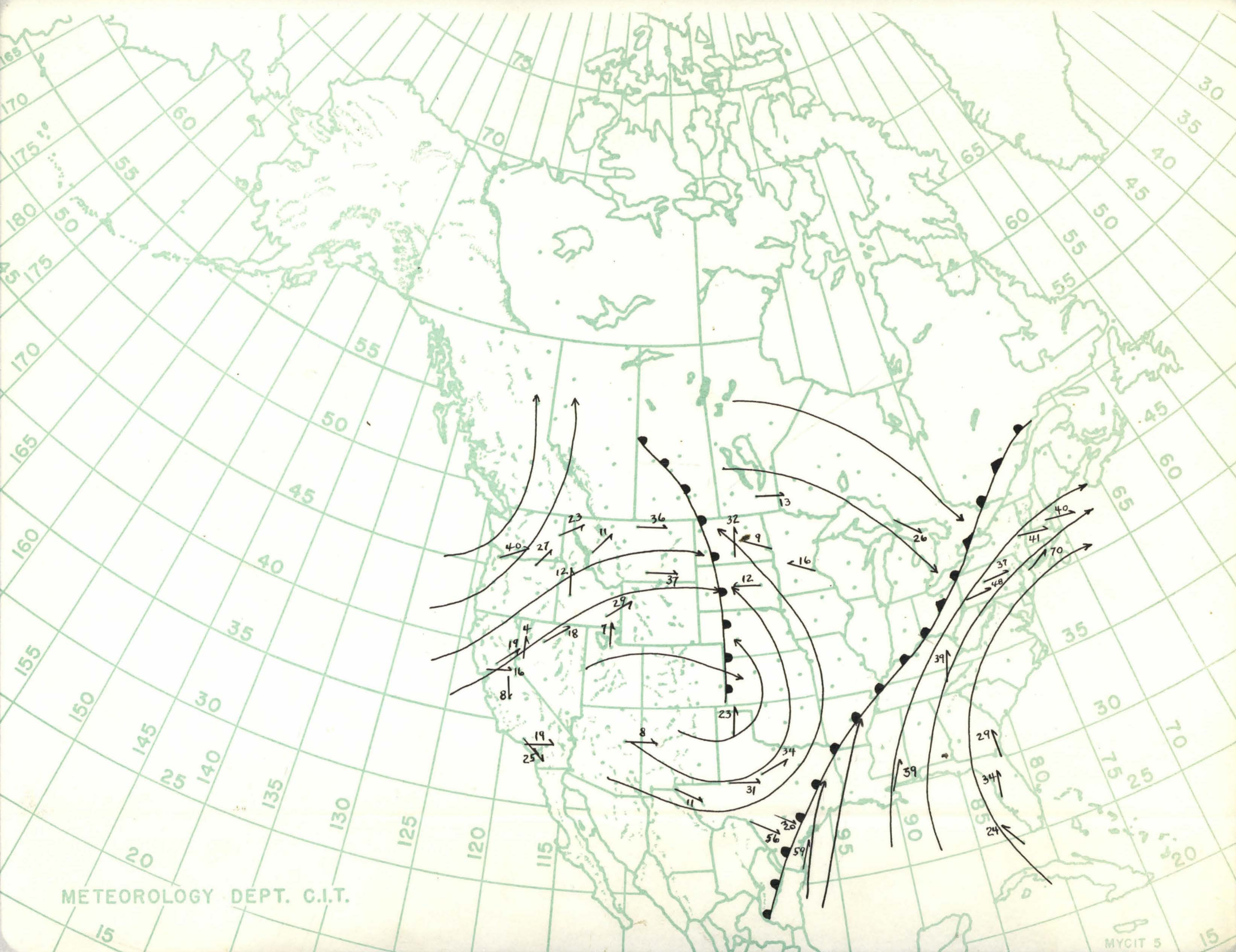
For the 5,000 ft surfaces:

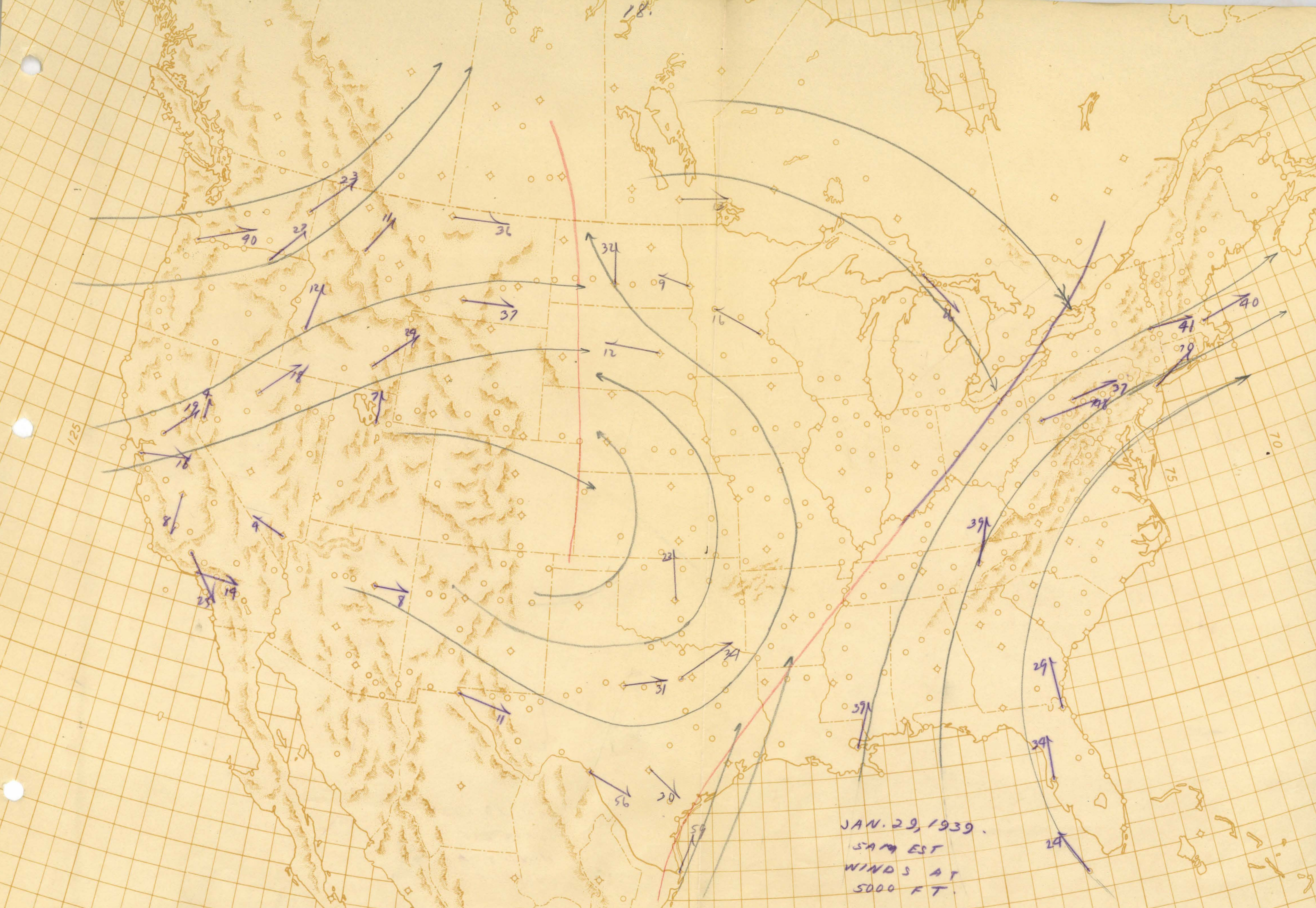
DATE	STATION	$\bar{V}$ (miles/hr)	V^2 (miles/hr)^2	r (miles)	$\frac{v^2}{lr} = 2.69\frac{V^2}{r}$	$\frac{V'}{V}$ x00 %.
JAN. 28	NA	33	1009	8000	3.7	11%
	CG	27		∞	0	0
	EO	23		∞	0	0
	LQ	13	169	340	1	8%
	OA			∞	0	
	ID	51	2630	900	8	16%
G	GW	12	144	330	1	8%
JAN 29	SM	23	∞		0	
	OA		∞		0	
	PQ	24	576	1150	1	4%
	FV	34	1150	450	7	21%
	KY	37	1370	1050	3.5	9.5%
JAN 30	ON	16	256	530	1.4	9%
	KX	43	1850	500	10	23%
	BH	40	1600	470	9	22%
JAN 31	DV	15	225	270	2.3	15%
	CG	18	324	∞		0%
	EV	24	576	400	4	17%
	VS	22	484	520	2.5	11%

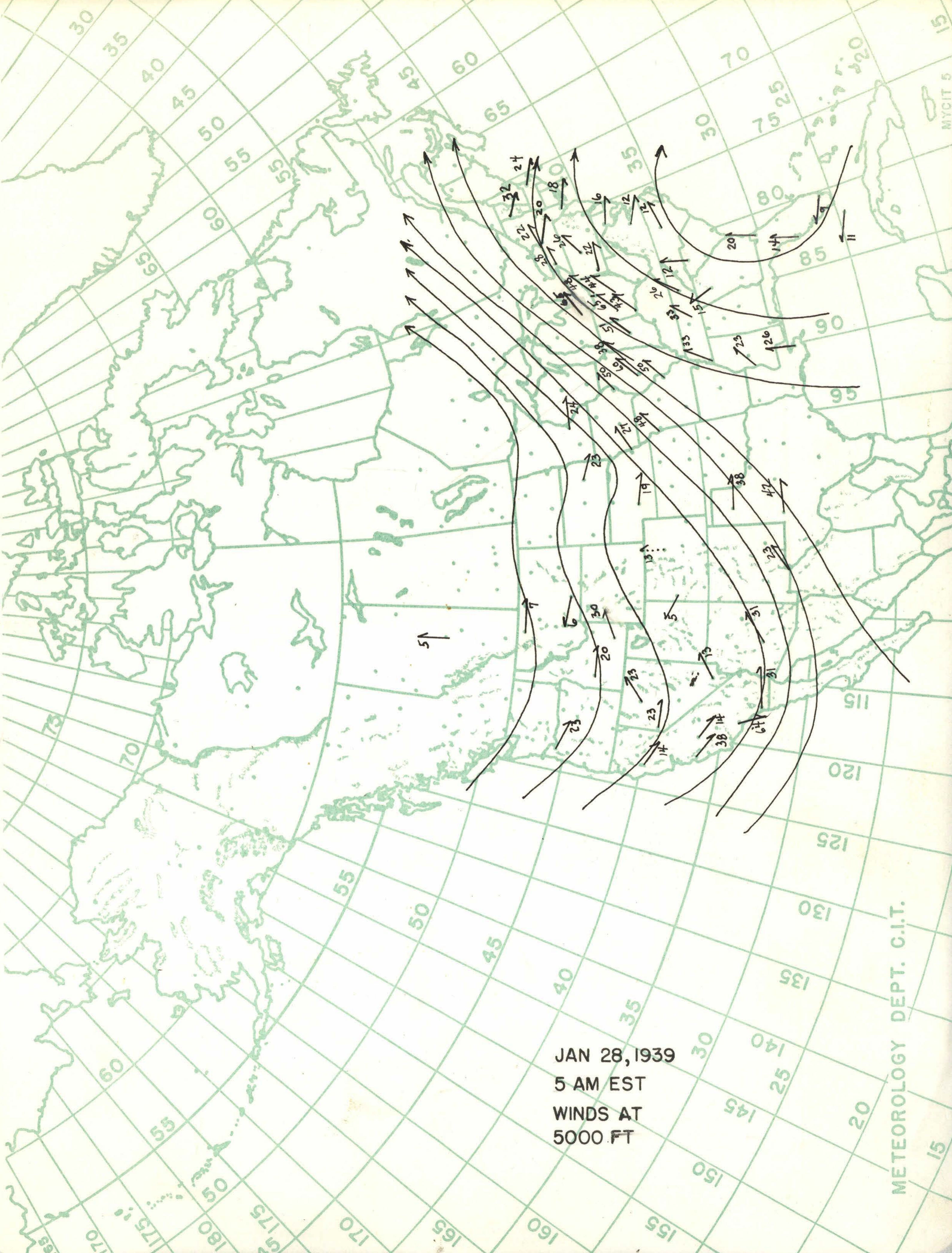
AVE 11%

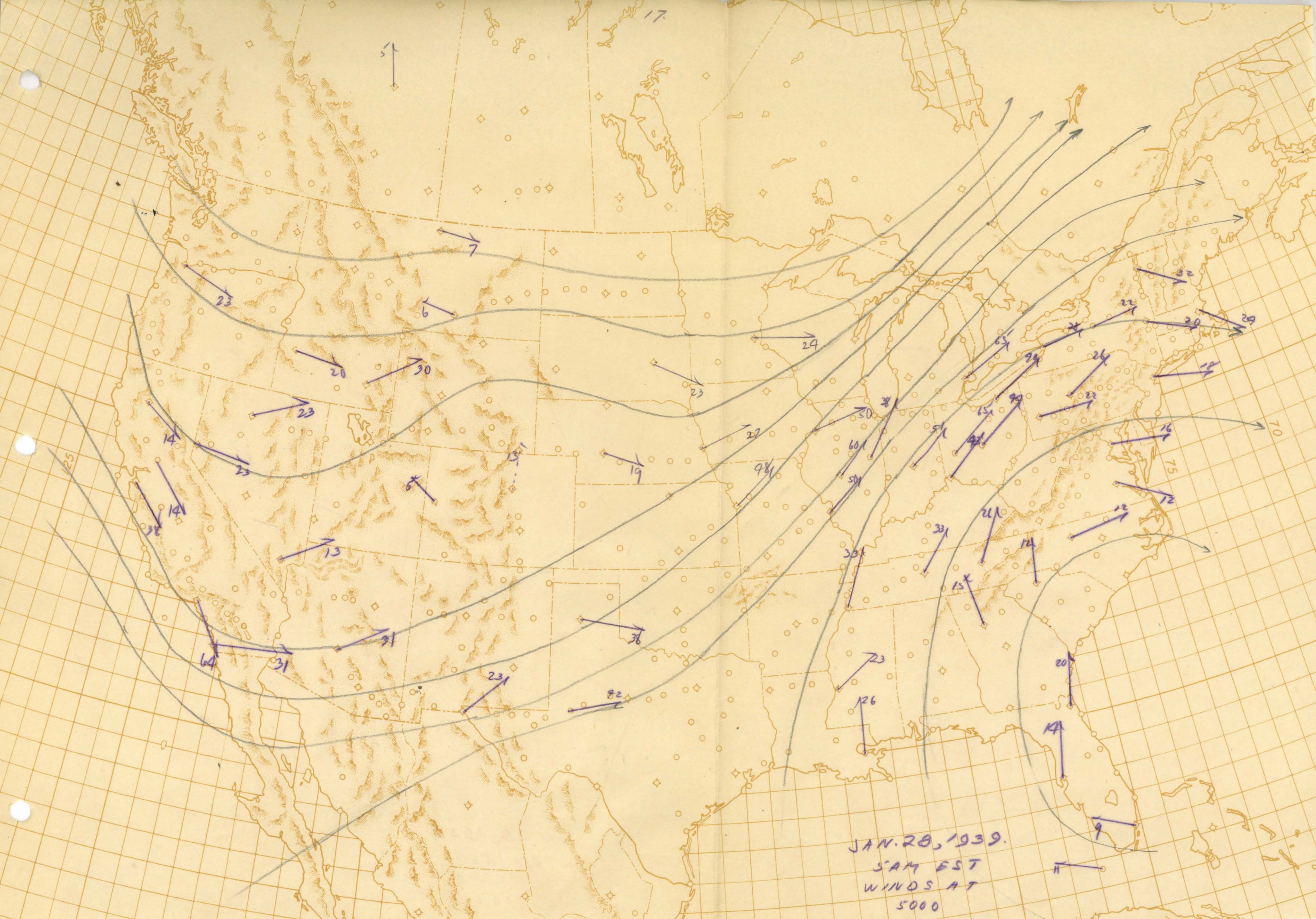

METEOROLOGY DEPT. C.I.T.
MYCIT 5


JAN. 30, 1939
5AM EST
WINDS AT
5000 FT
125
75
70


METEOROLOGY DEPT. C.I.T.
MYCIT 5


18.
JAN. 29, 1939.
5AM EST
WINDS AT
5000 FT.


JAN 28, 1939
5 AM EST
WINDS AT
5000 FT
METEOROLOGY DEPT. C.I.T.


JAN. 28, 1939.
8 AM EST
WINDS AT
5000

These calculations indicate that the wind compt $\frac{v^2}{\ell r}$ is generally not as important as the compt $\frac{w}{\ell}\frac{\partial \bar{V}}{\partial z}$. Moreover, it has the same direction as the wind itself, and so ~~xx~~ alters the <u>magnitude</u> of the wind, on an average 11%, but not the direction.

(4) Term $\frac{i}{2\ell}\frac{\partial V^2}{\partial s} = \frac{i}{\ell}\bar{V}\frac{\partial \bar{V}}{\partial s} = V_3$

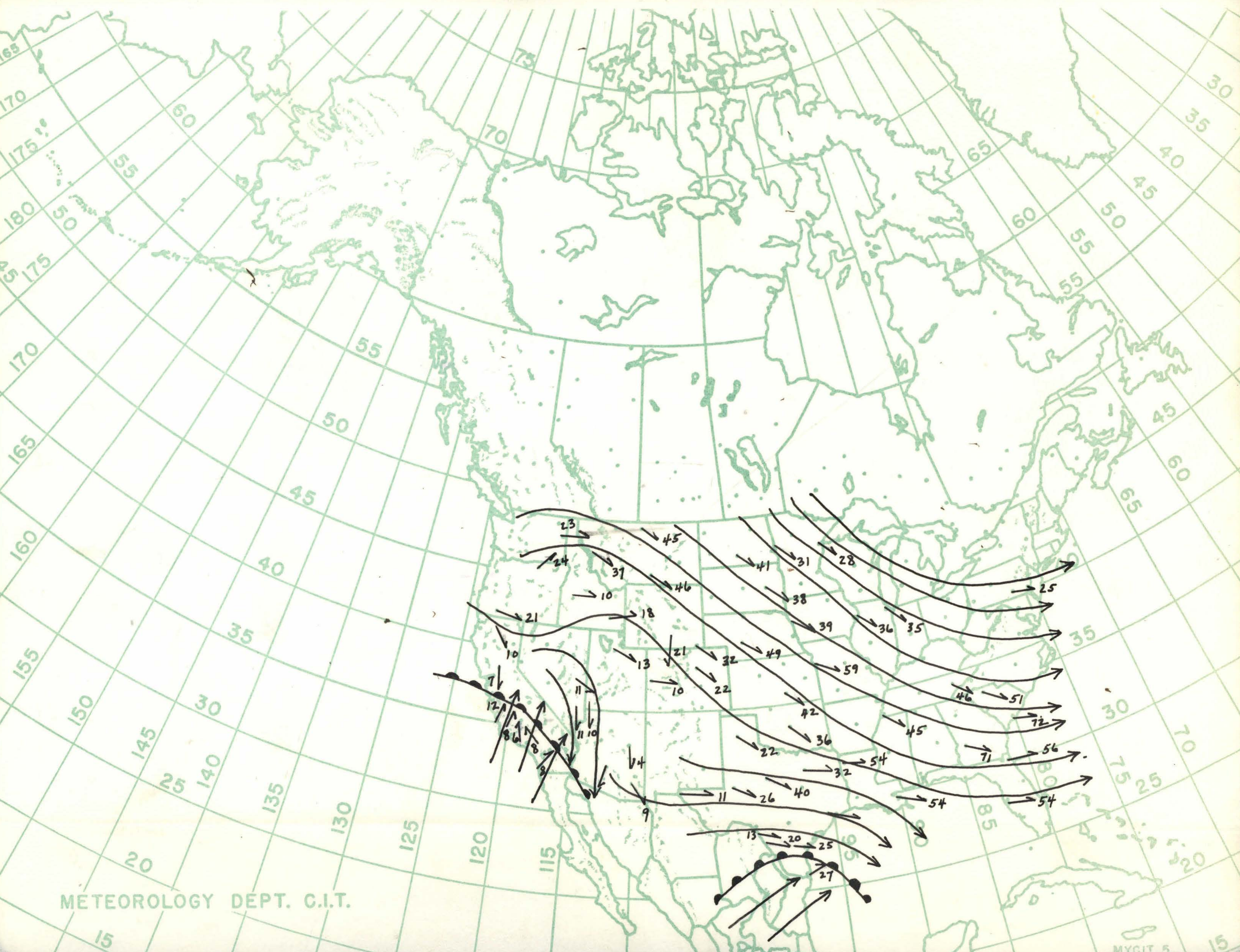
It is going to be more difficult to determine this term, The reason is that the ballon runs indicate greatly varying wind-speeds from one station to the next. Yet the streamlines do not necessarily converge and diverge to the same extent. As a typical example of this, note the winds at 10,000 ft for 2pm, PST, Feb.22, 1939. In ~~this~~ The Mississippi River area, or the middle West the wind velocities show a great dispersion. Yet the wind directions do not vary greatly, so the streamlines must be drawn parallel to each other. (see p.21)

In spite of the difficult-y in determining this quantity it must at least be considered qualitatively. It is a term which changes the direction of the wind, and therein will lie its importance.

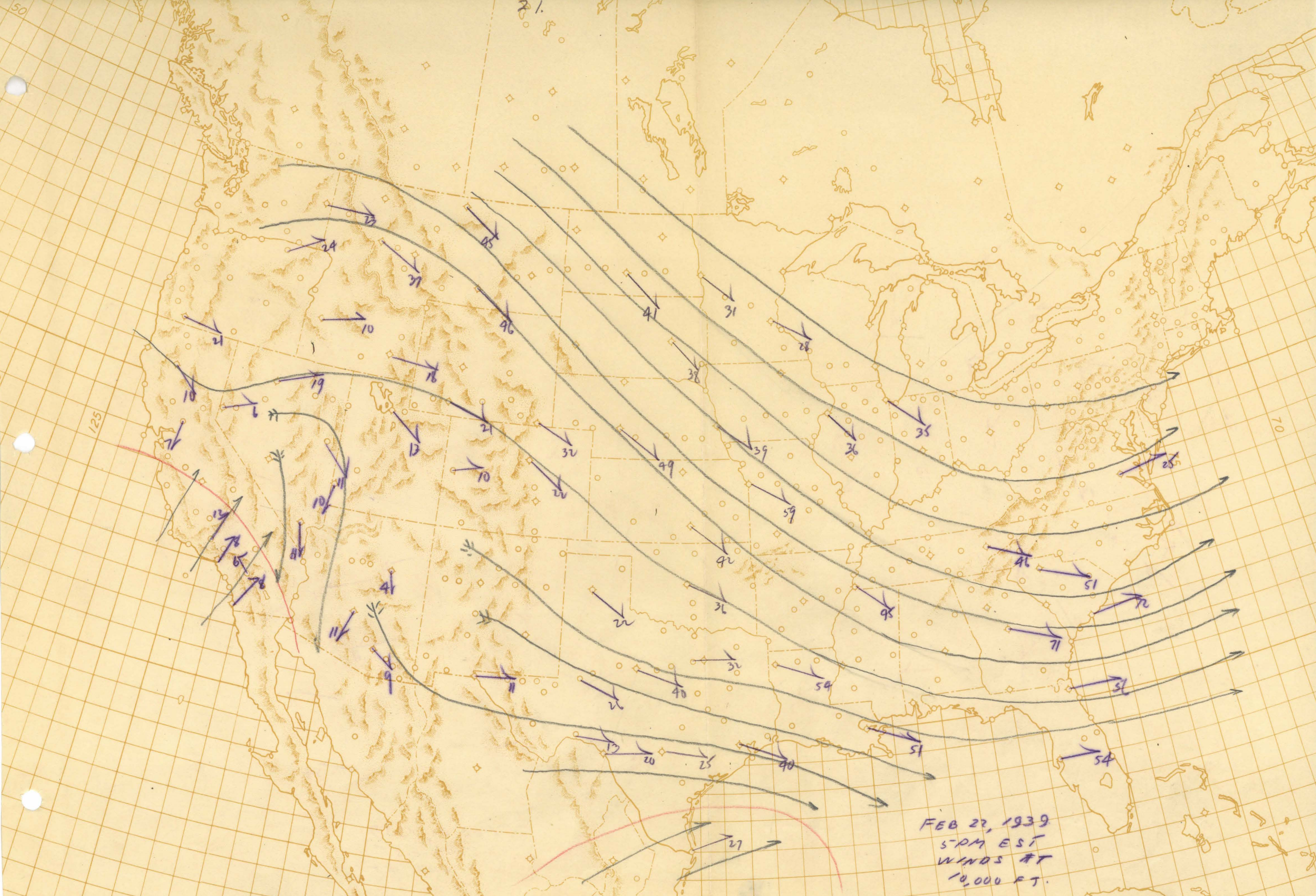
$$V_3 = 1.35\, V \frac{\Delta V}{\Delta S}$$ where V_3, V, ΔV are in milesper hr

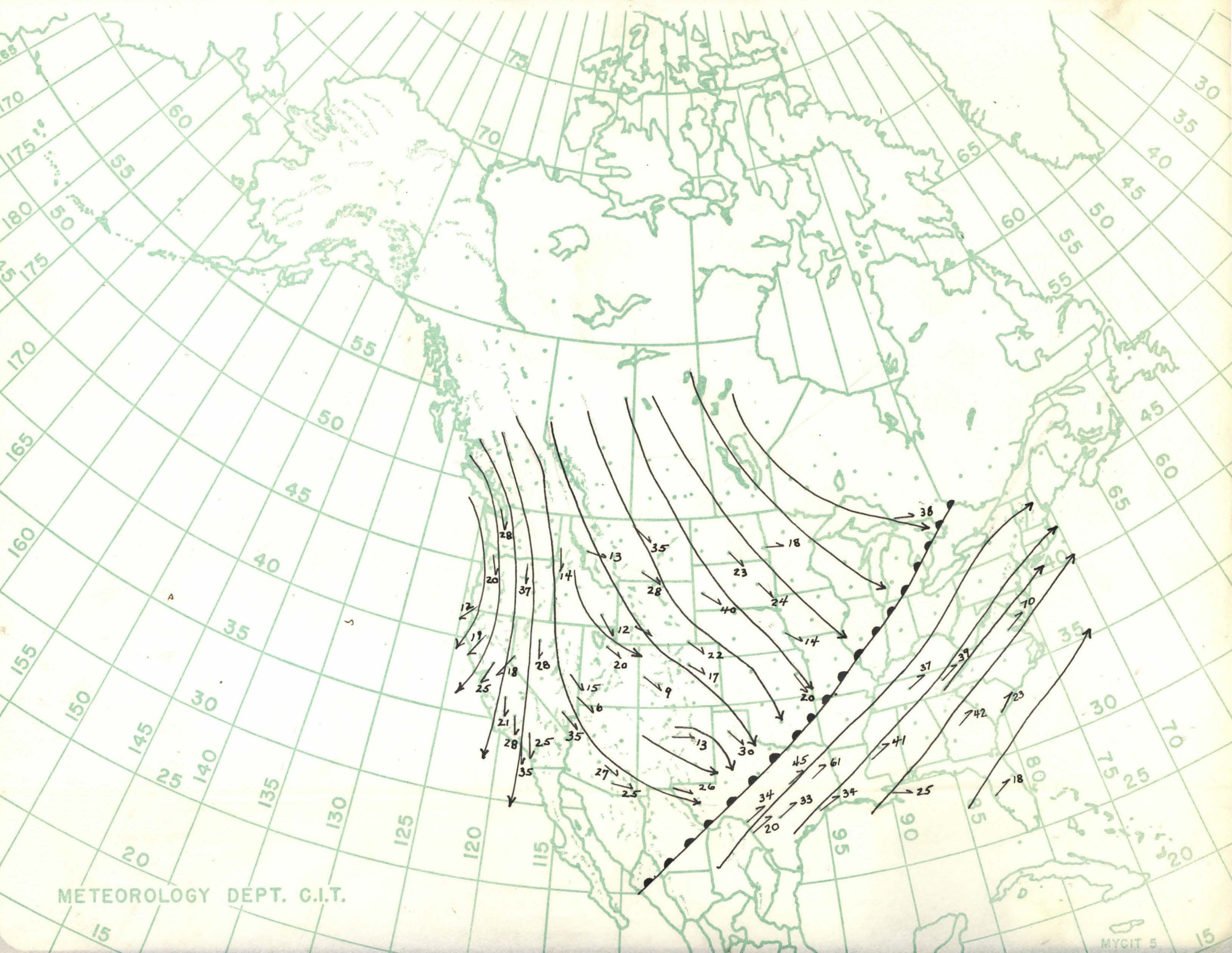
ΔS is in miles.

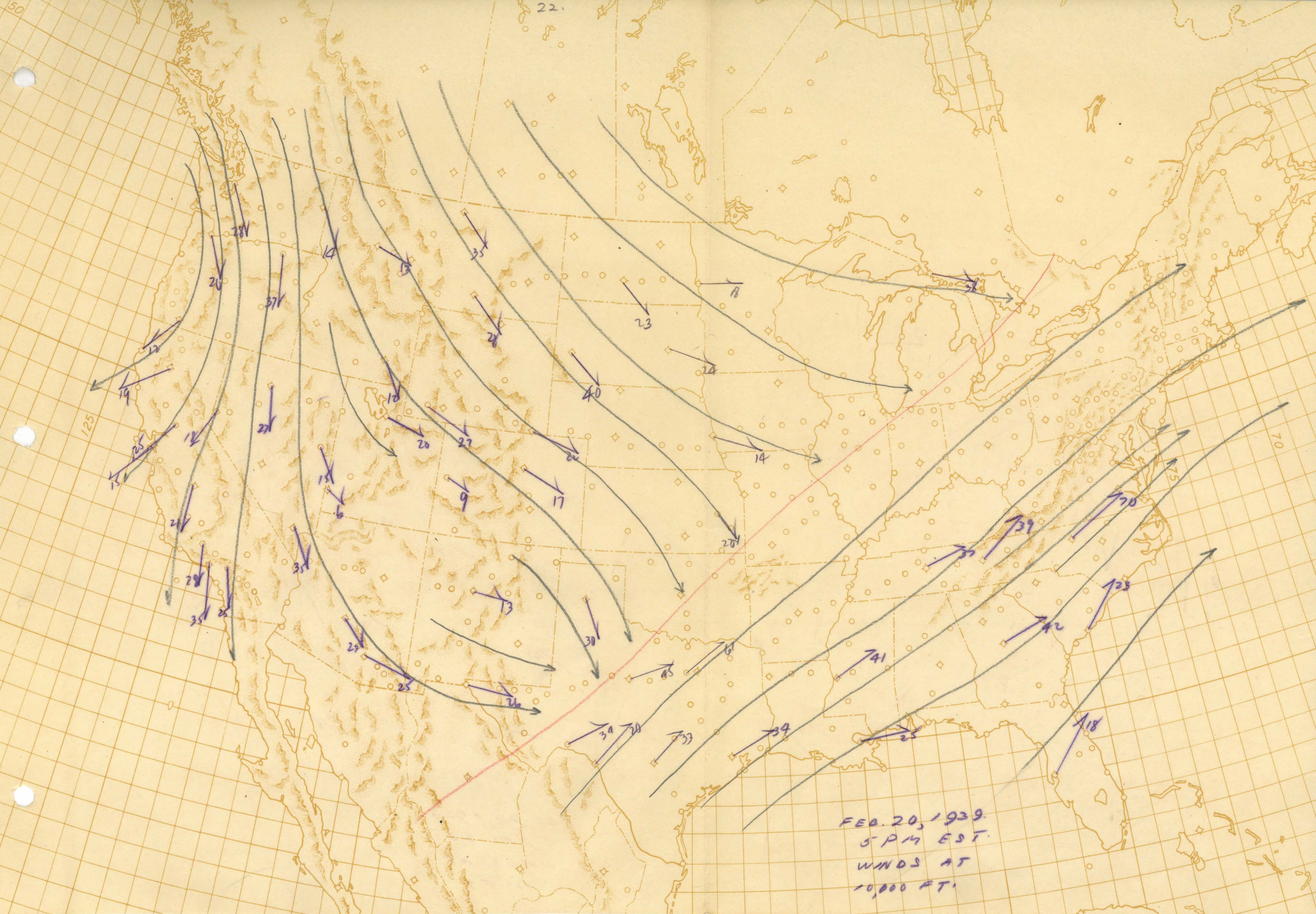
An attempt will be made to determine the magnitude of $\bar{V}_3$. $\Delta\bar{V}$ is always the increase or decrease in the direction of the stream-lines , over a distance ΔS.

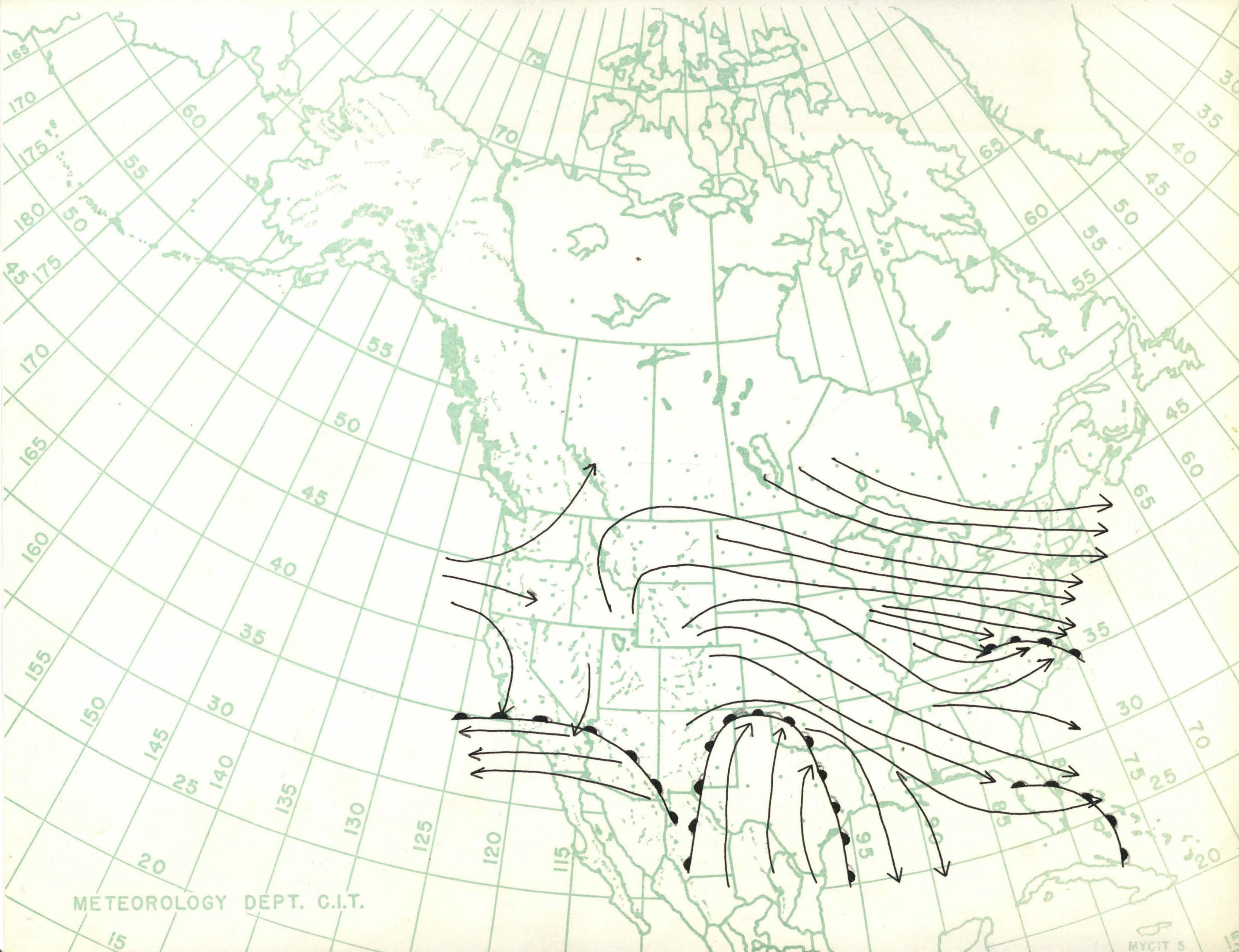

METEOROLOGY DEPT. C.I.T.

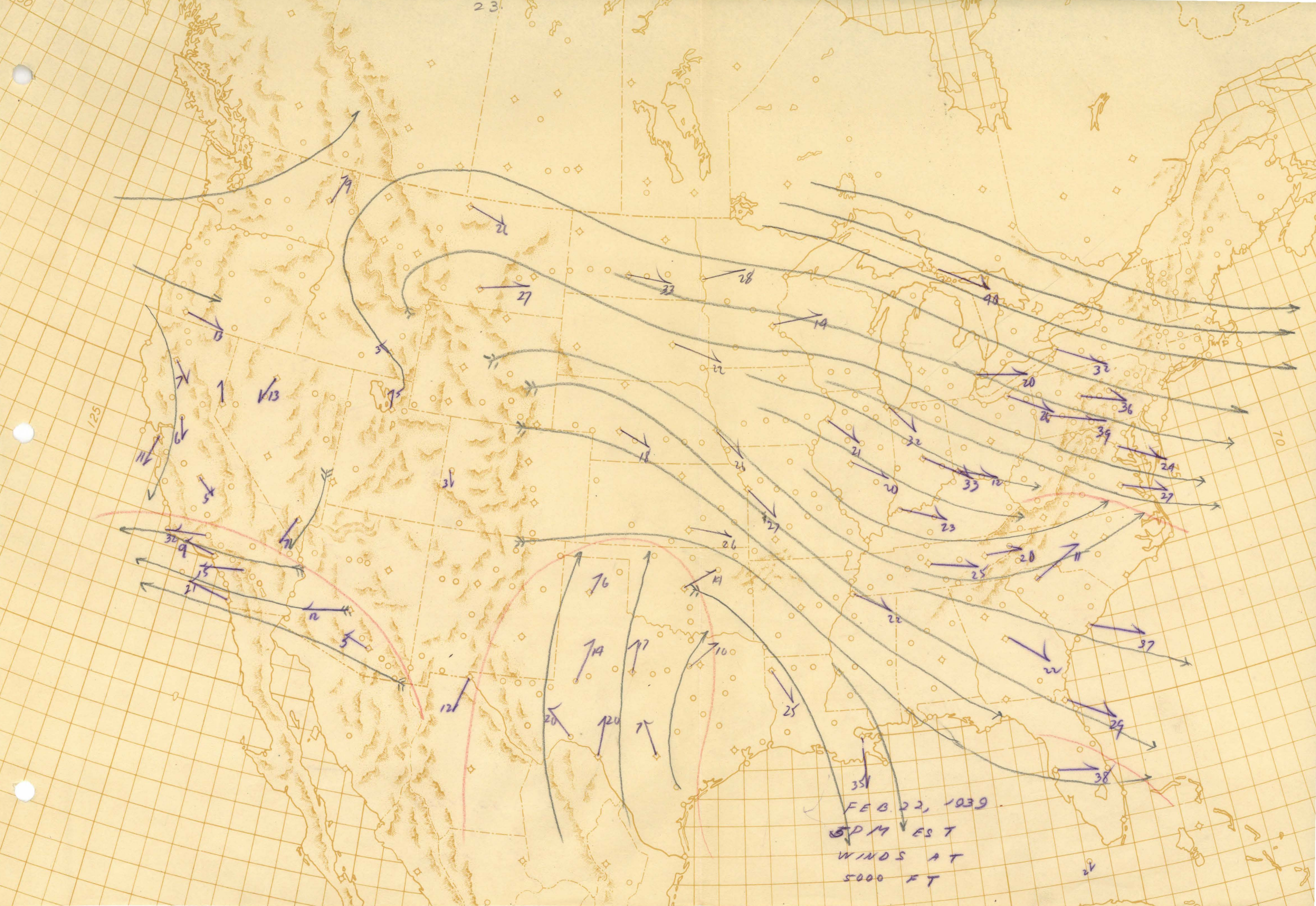
21.

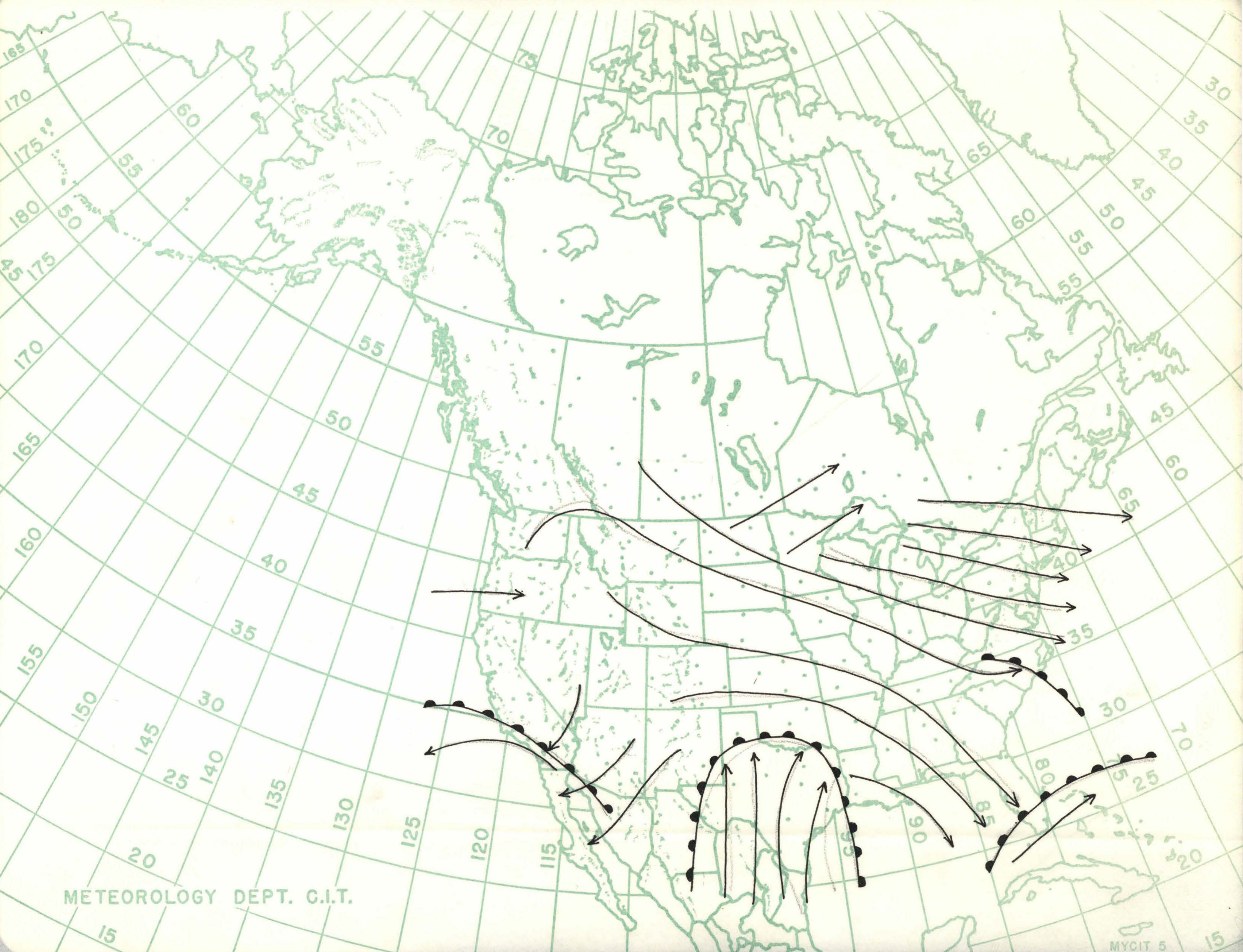


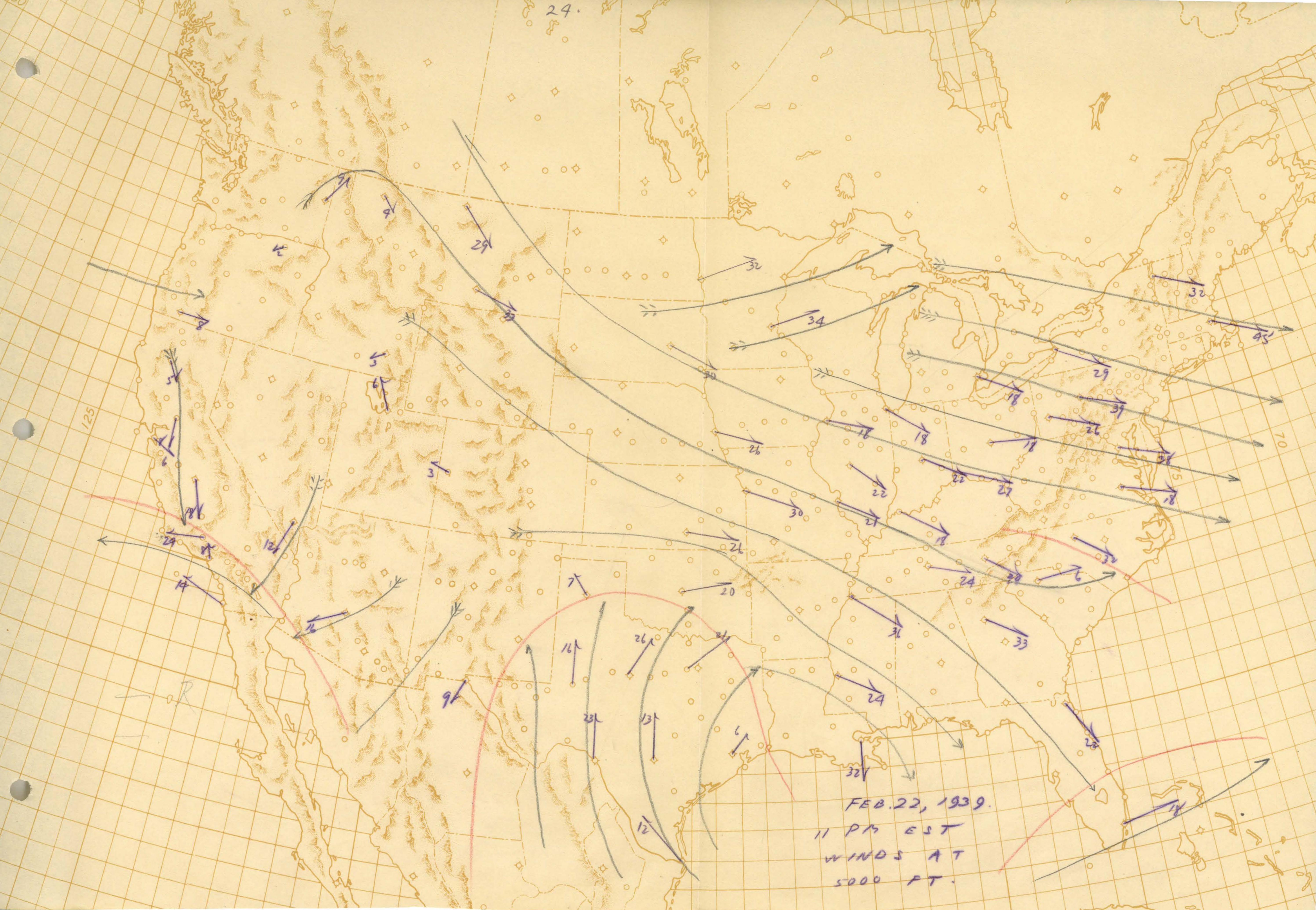

METEOROLOGY DEPT. C.I.T.
MYCIT 5


FEB. 20, 1939.
5 PM EST.
WINDS AT
10,000 FT.


METEOROLOGY DEPT. C.I.T.


23
FEB. 22, 1939
5 PM EST
WINDS AT
5000 FT


METEOROLOGY DEPT. C.I.T.
MYCIT 5


FEB. 22, 1939.
11 PM EST
WINDS AT
5000 FT.

DATE	STATIONS	v (miles/hr) (av.)	Δv (miles/hr)	Δs (miles)	$V_3 = 1.35 V \frac{\Delta v}{\Delta s}$	$\frac{V_s}{V}$ (%)
JAN28 8AM 5000	CC-PT	35	15	350	2.0	6%
Feb20 5pm 10000	HU- VS	38	7	330	1.1	3%
	UN- GW	55	28	300	7	13%
	PDR- FV	40	40	350	6	15%
Feb22 5pm 5000	RK- MP	20	20	380	1.5	7%
	DO- KY	27	16	270	2.2	9%
Feb22 5pm 10000	FV- ZH	43	22	210	6	14%
	PS- UN	58	26	410	5	9%
Feb22 11pm 5000	DO- KY	29	21	270	3.3	11%
	KC- PS	53	17	370	3.3	6%

The above examples were chosen for cases where neighbouring observations indicated a, more or less, systematic increase or decrease in wind velocity, without much change in direction. Only such cases where a significant increase was indicated were chosen. Therefore, the results give maximum values of the terms .

Nowhere was a velocity greater then 7 m.p.h. found, or percentage ratio of actual wind greater than 15%. Therfore, this term is essentially a small one, ~~xmdx~~ If there be reason to believe that its value will exceed 10% of the actual wind value, then it can be computed by the above formula.

(5) Term $\frac{1}{\ell^2 \rho} \nabla \dot{p} = V'$

An attempt at the magnitude of this term can be made by taking the pressure changes at altitudes for 24 hours periods. These will be obtained from the meteorograph observations.

As an example take the stations SL, CX, BI, and find $\nabla \dot{p}$ for these stations. The distances SL-CX, SL-BI are both 370 miles. This simplifies the problem.
Knowing two components of the vector quantity $\nabla \dot{p}$, the vector itself can be found by an easy geometrical contruction.

For our case,

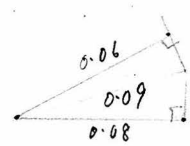
$$\nabla \dot{p} = \frac{\mathcal{R}}{(24)(370)} \quad \text{in inches of Hg per hr per mile.}$$

where $\mathcal{R}$ is the vector result of the isallobaric differences between the stations.

e.g, if $\left(\frac{\partial p}{\partial t}\right)_{SL} - \left(\frac{\partial p}{\partial t}\right)_{CX} = 0.08$

and $\left(\frac{\partial p}{\partial t}\right)_{SL} - \left(\frac{\partial p}{\partial t}\right)_{BI} = 0.06$

result for $\mathcal{R} = 0.09$



$$V' = \frac{1}{\ell^2 \rho} \nabla \dot{p} = \frac{(2.70)^2}{0.565} \times \frac{\mathcal{R}}{(24)(370)}$$

$$V' = 9.12\,\mathcal{R} \quad \text{mile/hr.}$$

Since $\mathcal{R}$ is generally of the order 0.1 this is a dicouraging result. It was this term that was to account for most pressure changes, and changes in air-mass movements. Howevere, it must be remembered that the pressure changes, especially those due to frontal movements and isallobaric fields, will be noted only over the shorter periods, and not over such long periods as 24 hours.

As an example of the magnitude that can be reached by the isallobaric term, the case of Dec.25, 1938 at 10,000 ft will be taken where the surface barometric tendencies indicated strong isallobaric gradients.

Page 29 shows the "isallobaric" winds, uncorrected for V_1, V_2, V_3 . They show a distinct convergence ~~for~~ and discontinuity inside the shaded area.

Again, to find the magnitude of the isallobaric wind at the surface we can take the isallobaric gradient at the surface and see what the corresponding wind component should be. The relation is $V' = 3/7 \dfrac{\Delta(\dot{p})}{\Delta S}$

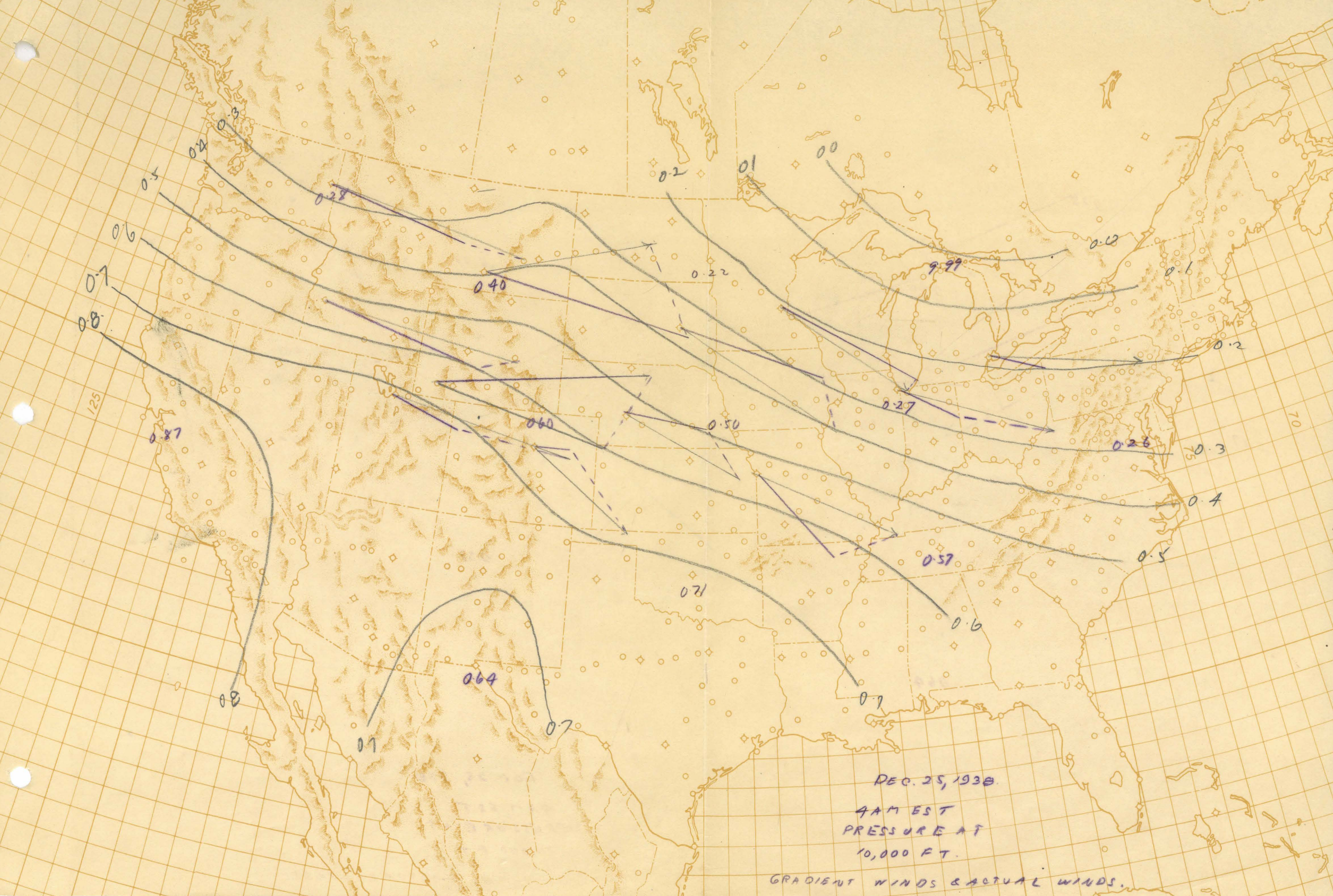
where $\Delta \dot{p}$ is measured in $(\frac{1}{100})''$ inches of Hg per 3 hrs.

ΔS is measured in miles.

Taking, arbitrarily, the maps for Dec. 1938, the above formula can be applied to isallobaric fields as follows:

DATE	STATIONS	$\Delta(\dot{p})$ $(\frac{1}{100})''$ in Hg / 3 hrs	ΔS	$3/7 \dfrac{\Delta(\dot{p})}{\Delta S}$	
AM Dec2	CH-YA	7	200	11 mph	
Dec3 AM	FR-PLA	16	430	12	
Dec4 PM	OH-SD	11	350	10	
Dec7 AM	DH-FO	9	200	14	
Dec8 PM	PTZ-PBE	16	300	17	
Dec13 AM	QT-VC	13	280	15	
Dec17 AM	NORTH DAKOTA	10	250	13	
Dec23 AM	LAKE ONTARIO	16	300	17	

28.



DEC. 25, 1938
4 AM EST
PRESSURE AT
10,000 FT.
GRADIENT WINDS & ACTUAL WINDS.
0.3
0.4
0.5
0.6
0.7
0.8
0.28
0.40
0.2
01
00
0.22
9.99
0.1
0.2
0.27
0.50
0.60
0.87
0.26
0.3
0.4
0.5
0.57
0.71
0.6
0.7
0.64
0.7
0.8
125
70

Areas of large pressure tendencies were taken in the above examples but they do ~~not~~ illustrate what magnitude can be reached by the isallobaric wind at the surface of the earth.

Aloft, the reverse procedure will be used. That is, finding the isallobaric wind, after correcting for all other wind components, the isallobaric gradient will be determined or else qualitatively determined.

The relation on page 27 will be more useful written in the form: $\Delta S = \frac{(317).10}{V'_*} = \frac{3170}{V'_*}$

where ΔS is distance in miles between isallobars differing by 10 units.

(6) Term $-\frac{i}{\ell}\overline{F}$.

This was introduced in the equation, simply to complete the theory. Such wind component is caused by friction, gravity, or possibly some other way, like heating by radiation. It cannot be measured and discussed as were the other terms, and for higher altitudes will be considered negligible. However, it will be considered as of importance in the case of sloping isentropic surfaces, and qualitatively used. Thus, an airmass blowing up-hill will be retarded, blowing down-hill it will be accelerated.

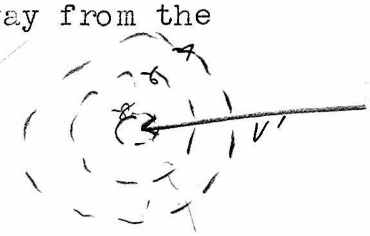
<u>The changes in wind caused by each component</u>

Having dealt with the ~~(discouraging)~~ magnitude of the wind components, it is now necessary to see <u>how</u> the wind changes with each of these components:

$$\bar{V} = \bar{V}_g - \frac{1}{\ell^2 \rho}\nabla \dot{p} + \frac{i}{2\ell}\frac{\partial \bar{V}^2}{\partial s}\left(\frac{\bar{V}}{V}\right) - \frac{V^2}{\ell r}\left(\frac{\bar{V}}{V}\right) + \frac{i\omega}{\ell}\frac{\partial \bar{V}}{\partial z}$$

$$= \bar{V}_g + \bar{V}' + \bar{V}_3 + \bar{V}_2 + \bar{V}_1$$

In the case of the term $-\frac{1}{\ell^2\rho}\nabla\dot{p}$ the wind component is directed into the isallobaric low, or away from the isallobaric high.



Term $\frac{i\omega}{\ell}\frac{\partial \bar{V}}{\partial z} = \frac{i\omega}{\ell}\frac{\Delta \bar{V}}{\Delta z} = \bar{V}_1$;

(a) For $\left.\begin{matrix}\omega > 0 \\ \frac{\partial \bar{V}}{\partial z} > 0\end{matrix}\right\}$ wind component $(\bar{V}_1)$ crosses to left of change $\Delta \bar{V}$.

(b) & (c) For $\left.\begin{matrix}\omega < 0 \\ \frac{\partial \bar{V}}{\partial z} > 0\end{matrix}\right\}$, $\left.\begin{matrix}\omega > 0 \\ \frac{\partial \bar{V}}{\partial z} < 0\end{matrix}\right\}$ Wind component $(\bar{V}_1)$ crosses to right of change $\Delta \bar{V}$.

(d) For $\left.\begin{matrix}\omega < 0 \\ \frac{\partial V}{\partial z} < 0\end{matrix}\right\}$ Wind component $(\bar{V}_1)$ crosses to left of change $\Delta \bar{V}$.

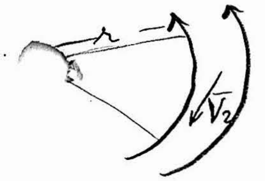
~~Term~~

~~Remembering how this term was obtained, the rule is as follows~~

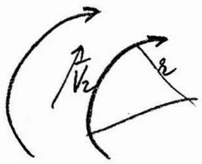
Usually, the change $\Delta \bar{V}$, with height is a change in magnitude only. That is the direction of the upper wind will not change appreciably with height. Hence the above rules could be used if instead of the term "change $\Delta \bar{V}$", the term "$\bar{V}$" were used instead.

Term $-\frac{V^2}{\ell r}\left(\frac{\bar{V}}{V}\right) = V_2$;

Remebering how this term was obtained, the rule is as follows:

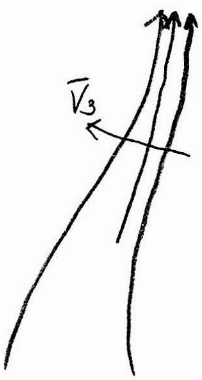


(a) For cyclonic curvature of the stream-lines, this component is opposite to the actual wind $\bar V$, being still in the same direction. That is, it ~~shows~~ slows the wind up.



(b) For anticyclonic curvature, the wind is assisted by this compt.

Term $\frac{i}{2l}\frac{\partial \bar V^2}{\partial s}\left(\frac{\bar V}{V}\right) = \frac{i}{2l}\,\bar V\cdot\frac{\Delta \bar V}{\Delta s}\left(\frac{\bar V}{V}\right) = \bar V_3$



(A) For an increase in velocity in the direction of the wind this component cresses to the left of the wind.

(b) For a decrease in velocity in the direction of the wind this component crosses to the right of the wind.

For rapid calculation of each of these components:

(1) Geostrophic: Draw isobaric chart, at 5000, 10000 or 14000 or at two of these hts.

Use Haynes' wind scale(Ref.1) or any other scale to find geostrophic wind, in direction of isobars.

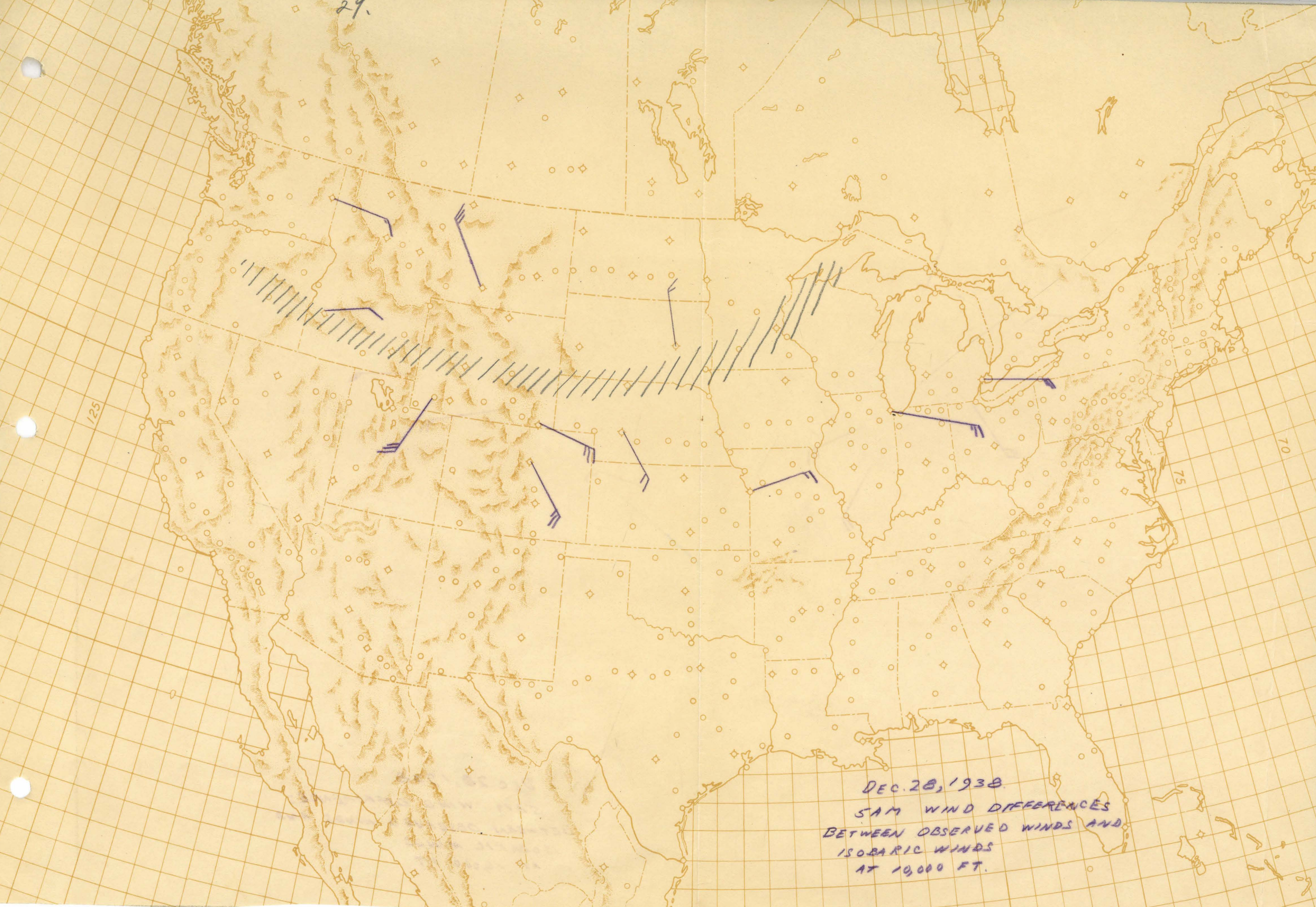
(2) $\bar V_1 = \frac{i\omega}{l}\cdot\frac{\partial \bar V}{\partial z}$ Draw isentropic chart, given ht ofisentropic surface.

Find $\frac{\Delta \bar V}{\Delta z}$ graphically (between 5 and 6 thsd of 4 and 5 thsd)

(between 10 and 11 thsd or 9 and 10 thsd)

$\omega = \frac{\Delta h}{\Delta s}\,\bar V$. Find $\frac{\Delta h}{\Delta s}$ from isentropic chart.

29.



DEC. 28, 1938
5AM WIND DIFFERENCES
BETWEEN OBSERVED WINDS AND
ISOBARIC WINDS
AT 10,000 FT.

With Δh in dkms,

Δs in miles

$\bar{V}$ in miles per hr

$$\omega = 0{\cdot}0062\ \frac{\Delta h}{\Delta s}\ \bar{V}.$$

$$|\bar{V}_1| = 19{\cdot}25 \times 10^3\ \omega\ \frac{\Delta V}{\Delta z}\ .$$

Then $V_1 = 8{\cdot}85\left(\frac{1}{s}\right)\bar{V}\Delta\bar{V}$ where s is distance between

~~where~~ contours with height difference of 100 dkms.

$\bar{V}$ is velocity

$\Delta\bar{V}$ is increase per 1000 ft.

(3) $V_2 = -\frac{V^2}{lr}\left(\frac{V}{V}\right)$: Find r graphically in miles: $\bar{V}$ in miles per hr

$$V_2 = 2{\cdot}69\ \frac{V^2}{r}$$

(4) $V_3 = \frac{i}{2l}\ \frac{\partial V^2}{\partial s}$ Find s in miles: ΔV in miles per hr

$= \frac{i}{2l}\ V\frac{\Delta V}{\Delta s}$ V in miles per hr

$$V_3 = 1{\cdot}35\ V\frac{\Delta V}{\Delta s}\ .$$

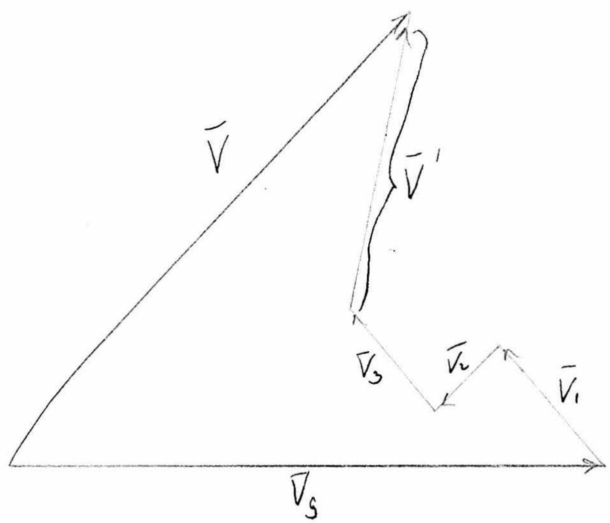
s must always be measured in direction of $\bar{V}$.

$$\bar{V} = \bar{V}_g + \frac{i\,\omega}{l}\frac{\partial \bar{V}}{\partial z} - \frac{V^2}{l r}\left(\frac{\bar{V}}{V}\right) + \frac{i}{2l}\frac{\partial V^2}{\partial s}\left(\frac{\bar{V}}{V}\right) - \frac{1}{l^2 \rho}\nabla \dot{p}.$$

$$\bar{V} = \bar{V}_g + \bar{V}_1 + \bar{V}_2 + \bar{V}_3 + \bar{V}'.$$

$$\bar{V} = \bar{V}_g + \begin{cases} 14.25\times 10^{-3}\left(0.0062\,\frac{\Delta\lambda}{\Delta S}\,V\right)\frac{\Delta V}{\Delta z} \\ (8.85)\left(\frac{1}{\Delta S}\right)(V)\,(\Delta V) \end{cases} + 2.69\,\frac{V^2}{r} + 1.35\,V\,\frac{\Delta V}{\Delta S} + \left(-\frac{1}{l^2\rho}\nabla \dot{p}\right)$$

GRADIENT WIND BY WIND SCALE	$\omega>0$, $\Delta V>0$ & $\omega<0$, $\Delta V<0$ CROSSES V TO LEFT	IN OPPOSITE SENSE TO $\bar{V}$	$\Delta V>0$ CROSSES $\bar{V}$ TO LEFT	ISALLOBARIC GRADIENT WIND
	$\omega<0$, $\Delta V>0$ & $\omega>0$, $\Delta V<0$ CROSSES $\bar{V}$ TO RIGHT	IN SAME SENSE AS $\bar{V}$	$\Delta V<0$ CROSSE $\bar{V}$ TO RIGHT	



MAPS

(1.) REGULAR SYNOPTIC CHART.

(2.) ISOBARIC CHART AT 5000.

(3.) ISENTROPIC SURFACE.

(4.) WIND CHART AT 5000

(2)′ (4)′ } DITTO FOR 10,000.

(2)″ (4)″ } DITTO FOR 14,000.

Example:

The first example of the application of this method was a forecast for Mar.1, 1939, using morning chart and signals, and forecasting for periods 24 hrs, 36 hrs, and 48 hrs ahead.

First an ordinary weather chart was drawn, no more time being spent on it than necessary, then main fronts located, and the rain areas located. It so happened that there were no rain areas for the American forecaster to be concerned with.

Secondly, the isentropic surface was drawn for $\theta = 295$ F. Then the pressure field at 5000 ft and the wind chart at 5000 ft. This latter chart gave good indication of an upper frontal system over New Mexico, Texas and Eastern southern States.

Three stations were singled out for forecasting, MP, PS, CX. Since Cheyenne is at high altitude, the pressure map and wind chart for 10,000 ft were also drawn.

Beginning with Minneapolis (MP) at 5000 ft:

MP $\bar{V} = 330^\circ$ 31 mph
$\bar{V}_g = 310$ 30 mph

$\bar{V}_1 =$ 5 mph
to right of $\bar{V}$

$V_2 = 0$

$V_3 = 0$

$\therefore V' = 3$ m.p.h. or practically 0.

Therefore , no change in pressure field, and so no change in airmass movement indicated for MP.

FO: $V = 310^\circ\ 24$ m.p.h.

$V_g = 300\ 32$

$V_1 = \frac{8.85}{\infty} = 0$

$V_2 = \frac{(2.69)(24)^2}{550} = 3$

$V_3 = \frac{(1.35)(24)5}{180} = 1$

$V' = 0$

HR: $V = 290\ 17$

$V_g = 310\ 25$

$V_1 = (8.85)0 = 0$

$V_2 = 0$ practically

$V_3 = \frac{(1.35)(17)8}{300} < 1$

$V' = 330\ 12$

~~RZ~~
RZ: $V = 290\ 15$

$V_g = 300\ 20$

$V_1 =$ small

$V_2 = 0$ practiaally

$V_3 = 0$

$V' = 100\ 5$

BI: $V = 260\ 14$

$V_g = 290\ 22$

$V_1 = \frac{(8.85)(14)4}{240} = 2$ miles

$V_2 = 0$

$V_3 = 0$

$V' = 160\ 13$

Summing these results they indicate that the wedge of high over the Dakotas is building up slightly. The air-mass that will be over MP should follow pretty closely the wind trajectories as they are seen on the present map. Possibly by the 3rd period MP will be affected by the low that is indicated as approaching BI. But not enough moisture to give precipitation. Hnece the forecast on page 37.

Now to arrange a forecast for Memphis(~~MK~~ (PS)

2. Developments expected during the forecast interval.

II. FORECAST

Station	Hour	Wthr.	Spcl. Phenohena	Ceiling	Vsby.	Pption.	Surface Winds		8000′ Winds		Temp.	D. P.
		○ ◑ ● R S	foggy smoky dusty hail thdrshwr. tornado sleet frost	< 1000 1000-5000 > 5000	< 2 2-4 > 2	none lgt. T-.10 mod. .11-.50 hvy. > .50	0 0 1 1 2 2 3 3	Calm < 6 Lite 0-10 Mod. 12-22 Str. 24-38 Gale > 38	Same as Surf.		0-5 5° or fraction thereof, one error	Same as Temp.
MP	5A	○		> 5	> 4	none	NE	light	300	S	13	9
	5P	◑		> 5	> 4	none	E	light	270	S	24	15
	5A	●		> 5	> 4	none	SE	light	220	S	24	20
PS	5A	○		> 5	> 4	none	NW	mod	280	S	24	19
	5P	○		> 5	> 4	none	NE	light	250	S	39	25
	5A	●		> 5	> 4	none	SE	light	220	G	39	31
CX	5A	○		> 5	> 4	none	W	light	280	M	15	13
	5P	○		> 5	> 4	none	W	light	280	S	25	13
	5A	●		> 5	> 4	none	W	light	270	S	25	13

III. 6-HOUR AIRLINE FORECAST (—)

1. Conditions over route
2. Ceiling
3. Visibility
4. Winds at flying levels
5. Special phenomena (icing, thundershowers, etc.)
6. Terminal conditions

PS: $V \equiv 300\ 12$

$V_g = 0 \qquad V_2 = \frac{(2.69)(12)^2}{900} = \frac{1}{2}\ m.p.h.$

$V_1 \approx \frac{8.85(12)(6)}{300} = 1\frac{1}{2}\ \frac{\text{mile}}{\text{hr}}$

$V_3 = \frac{(1.35)(12)(12)}{350} < 1\ \frac{\text{mile}}{\text{hr}}$

$V' \equiv 280\ 14$

VS: $V : 230\ 10$

$V_g = 0$

$V_1 = 0$

$V_2 = 0$

$V_3 = 0$

$V' : 230\ 10$

AG: $V : 250\ 32$

$V_g = 0$

V_1 : deflects V to right

$V_2 = 0$

$V_3 = 0$

$V' \equiv 270\ 32$

These results indicate that the centre of activity must be closer to Georgia than to Memphis or Vicksburg. A low pressure centre must be active aloft and must be moving to the north west from the ocean. (Compare this analysis with that which would be obtained from the synoptic map alone) The centre of the disturbance must be too far away to affect Memphis, but nevertheless it should affect the wind making it a northerly wind and moderate.

OL: $V : 100\ 12$

$V_g = 0$

$V_1 = \frac{(8.85)(12)(-4)}{200} = 2$ mph

$V_2 = \frac{(2.69)(144)}{130} = 3$ mph

$V_3 = \frac{(1.35)(12)(12)}{150} = 1\frac{1}{2}$ mph

AP: $V = 150\ 24$

$V_g = 80\ 15$

$V_1 = \frac{(8.85)(24)4}{300} = 3$

$V_2 = \frac{(2.69)(24)^2}{700} = 2$

$V_3 = ?$

$V' \approx 170\ 18$

The isallobaric winds at MP, VS, OL, AB would indicate a high pressure build-up between these stations. This will mean good weather for PS, and that no low pressure from Texas will invade this area at least for the next two days. Hence the forecast.

Forecast for Cheyenne:

V: 280 22 for 10,000ft.

V_g: 280 25

$V_1 = 0$

$V_2 = 0$

$V_3 = 0$

$V' = 0$ good enough.

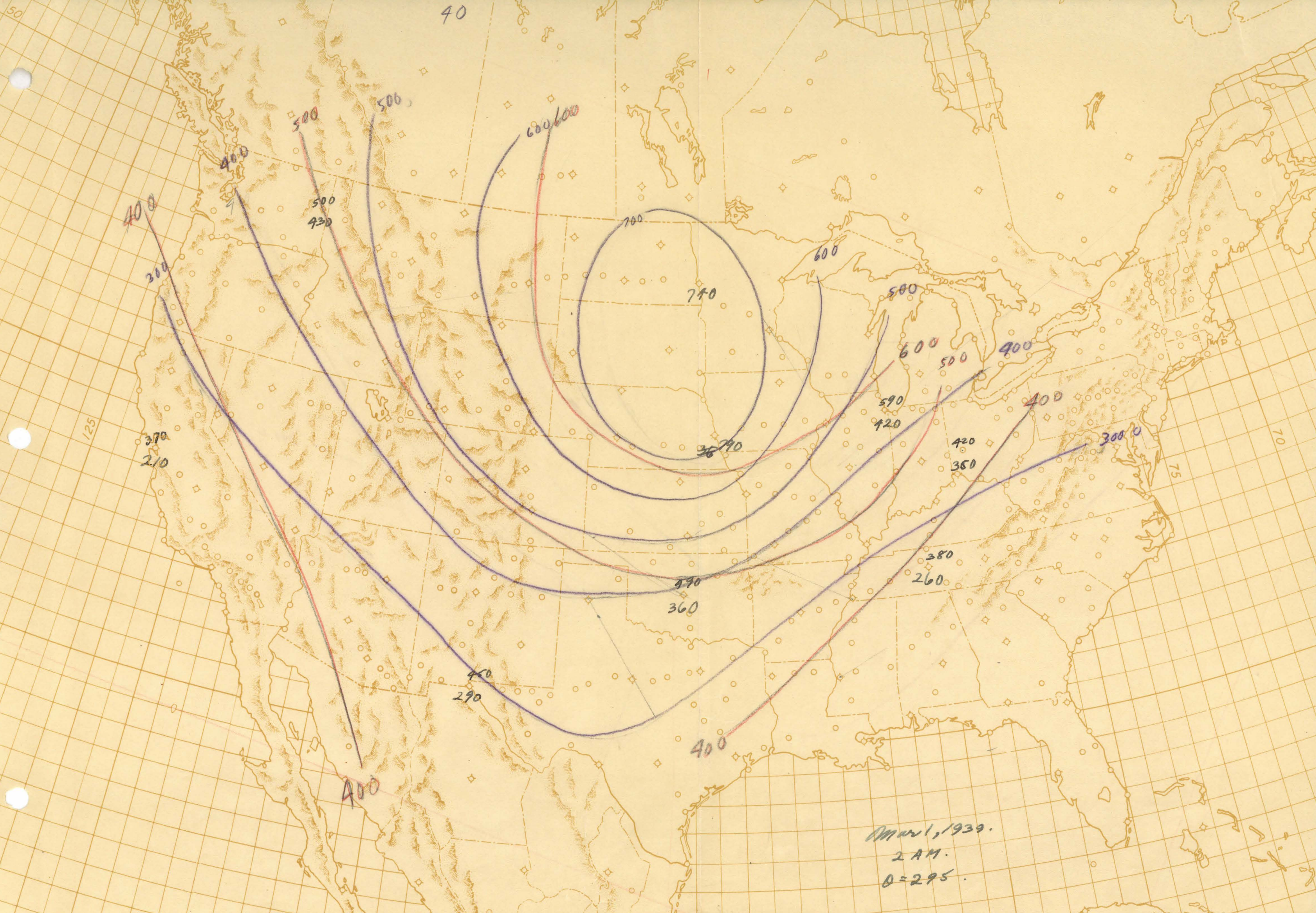
The winds for Cheyenne should continue as before. And observing what the weather is back of Cheyenne, the forecast is made accordingly, in this case clear weather.

The purpose of the above ahalysis is to give a picture of what movements will take place when it is not obvious otherwise.

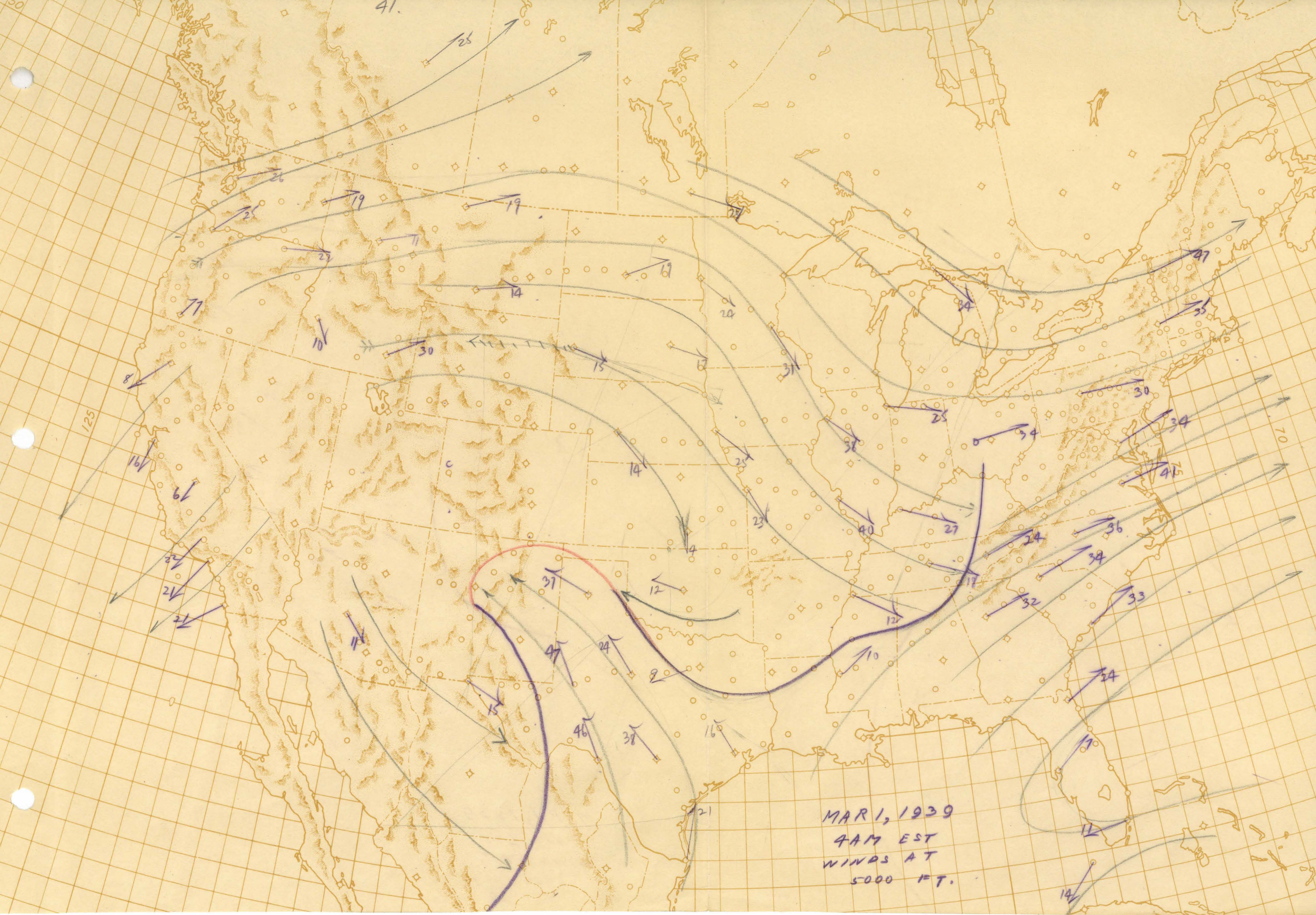
Rapid Qualitative Rules

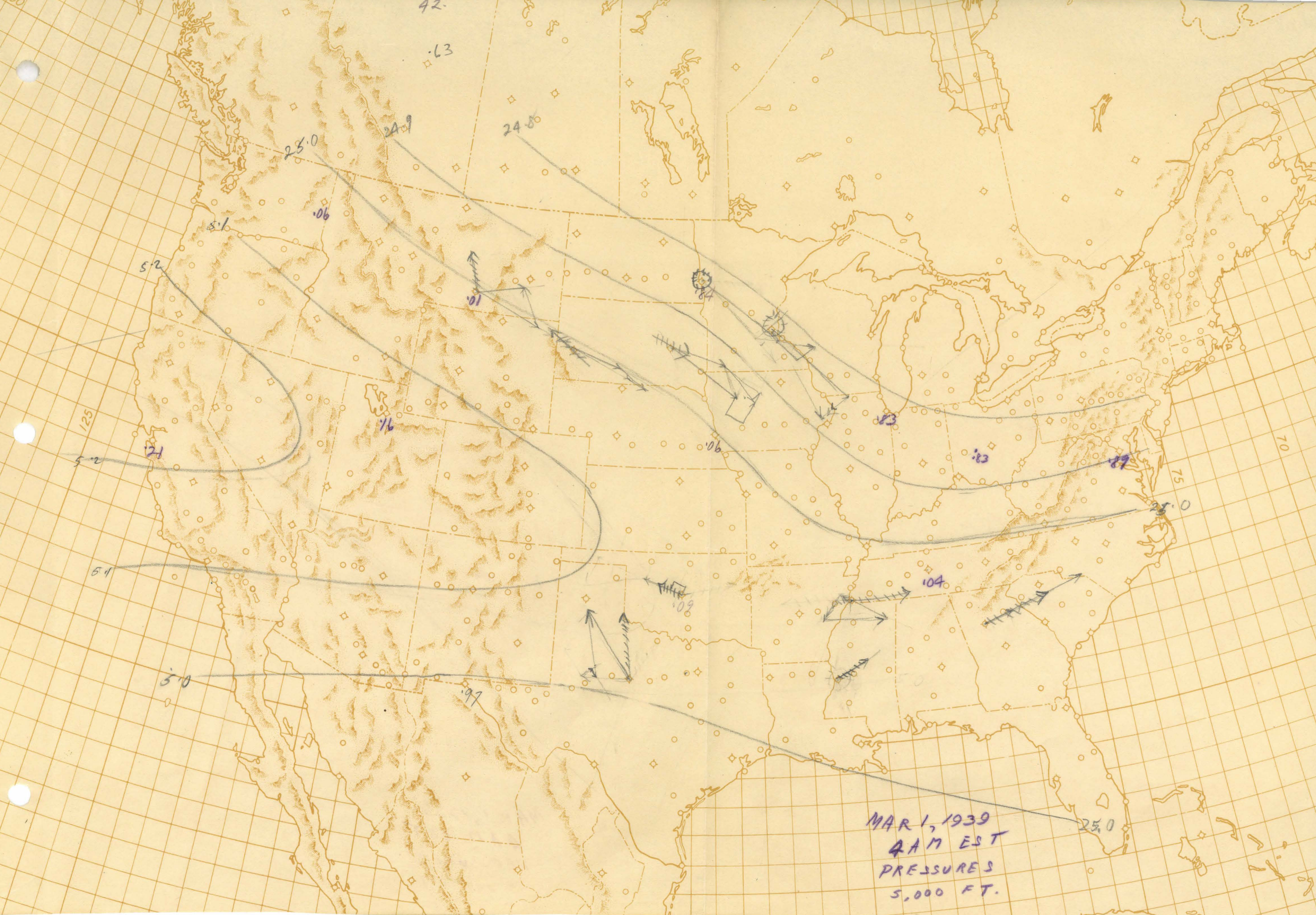
In the above case chosen for analysis the components V_1, V_2, V_3 have generally been too small to be considered. Unless some special conditions exist, likelarge wind velocities, rapid increase in wind velocities with height, or sharp curvatures of the stream-lines, these components may be neglected. In the previous part of the paper an attempt was made to select the extreme cases.

Page 34 is the all-important summary of rules, quantitative and qualitative. It should be kept

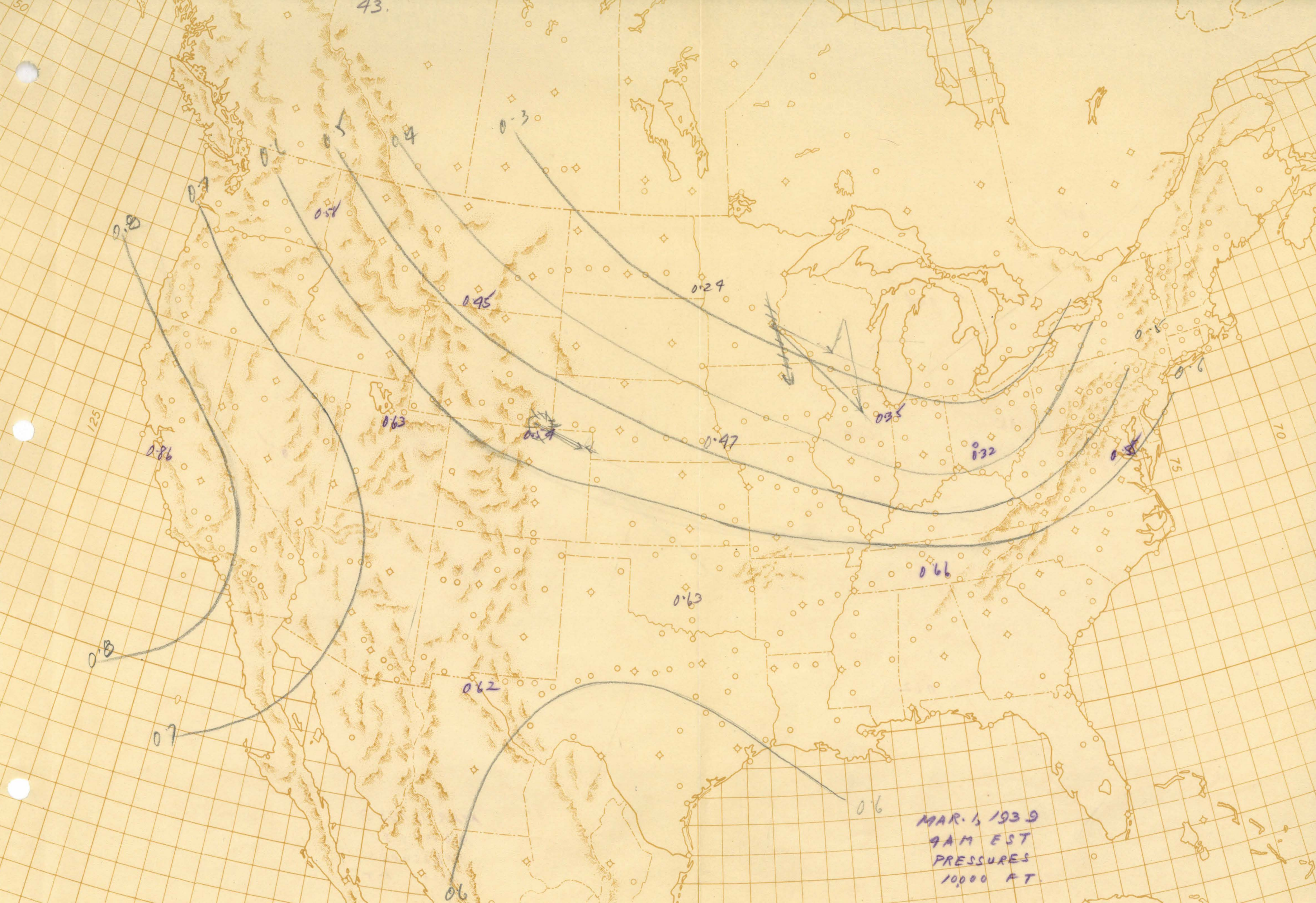


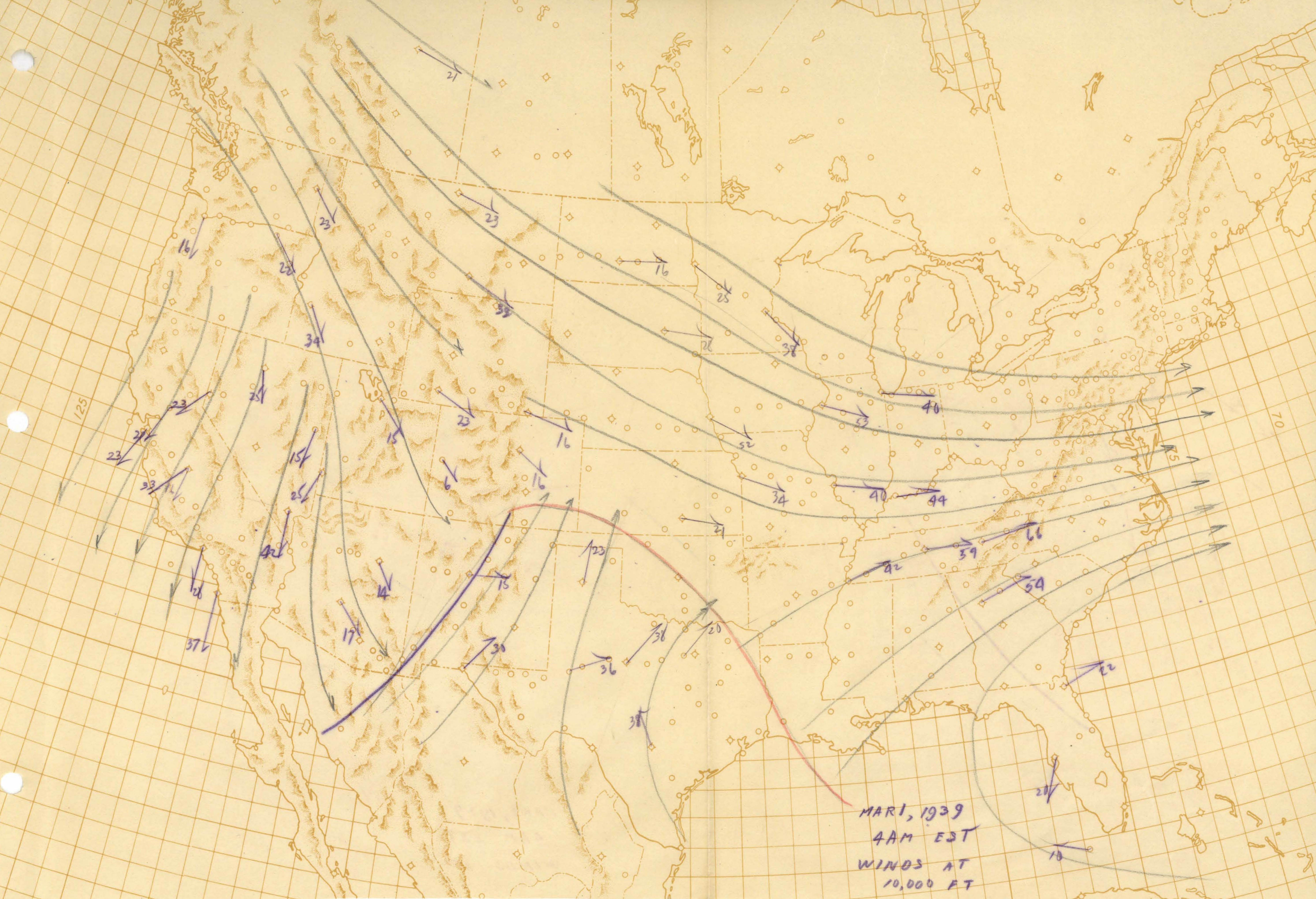
Mar 1, 1939.
2 AM.
θ = 295.
740
700
600
500
400
300
500
430
590
420
420
350
380
260
490
360
460
290
370
210


41.
MAR 1, 1939
4AM EST
WINDS AT
5000 FT.



MAR 1, 1939
4 AM EST
PRESSURES
5,000 FT.
24.9
24.8
25.0
25.0
25.0
5.1
5.2
5.2
5.1
5.0
.63
.06
.01
.64
.16
.21
.06
.83
.83
.89
.04
.09
.97
125
75
70


43.
0·3
0·4
0·5
0·6
0·7
0·8
0·58
0·45
0·24
0·63
0·54
0·47
0·35
0·32
0·86
0·66
0·63
0·62
0·8
0·7
0·6
0·6
MAR. 1, 1939
4 AM EST
PRESSURES
10,000 FT.


MAR 1, 1939
4 AM EST
WINDS AT
10,000 FT

in a conspicuous ~~xxxxxxxxx~~ position during the forecast.

The tools for this forecasting are a protractor, a convenient linear scale,(a cm. scale appears best) and wind scales for finding geostrophic winds. These may well be made separately, and designated as scales for 5000 ft, 10,000 ft, and 14,000 ft respectively. There will also be needed a scale for measuring distances on the map.

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