Lecture 6

Thermal Wind (continued)

1 handout on heat low

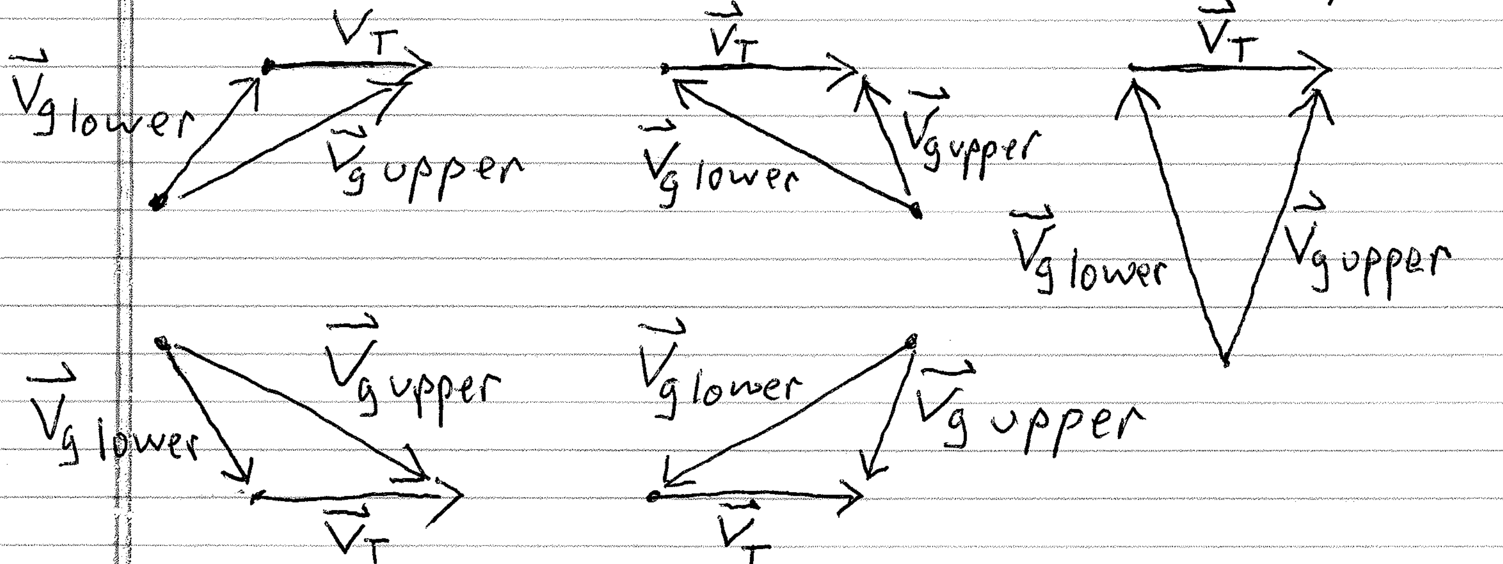
$\vec{V}_T \equiv \vec{V}_{g\,upper} - \vec{V}_{g\,lower}$

$\therefore \quad \vec{V}_{g\,upper} = \vec{V}_{g\,lower} + \vec{V}_T$

So $\vec{V}_T$ is the thing you add to $\vec{V}_{g\,lower}$ to get $\vec{V}_{g\,upper}$.

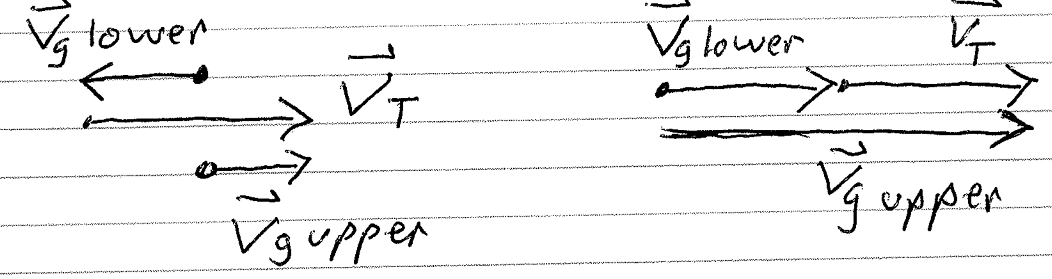
In general, if you know 2 of $\vec{V}_{g\,lower}$, $\vec{V}_{g\,upper}$ and $\vec{V}_T$ then you can calculate the third one.

Some possible geostrophic winds consistent with a westerly $\vec{V}_T$ vector $\longrightarrow \vec{V}_T$ are:



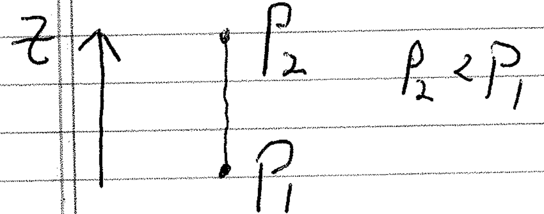
Top three pictures shows veering of geostrophic wind with height (clockwise turning as $z\uparrow$).
Bottom two pictures depict backing of geos wind with height (counter-clockwise turning as $z\uparrow$).

More examples with same $\vec{V}_T$ ⟶ :



Neither backing nor veering in the 2 pictures above.

Recall that $\vec{V}_T$ is related to the horiz temp gradient in the layer btw lower and upper isobaric surfaces as:

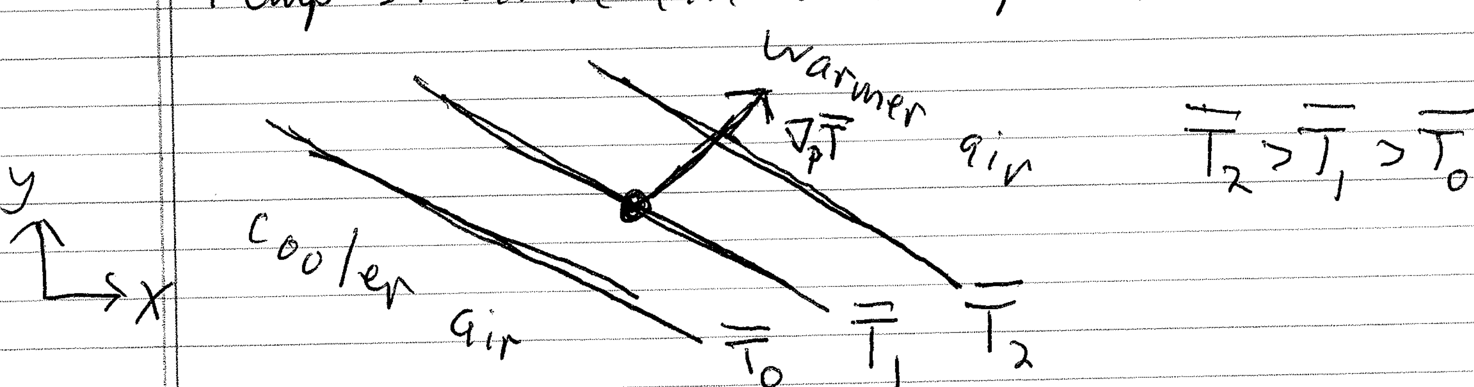


$$\vec{V}_T = \frac{R}{f} \ln\left(\frac{P_1}{P_2}\right) \hat{k} \times \nabla_p \overline{T}$$

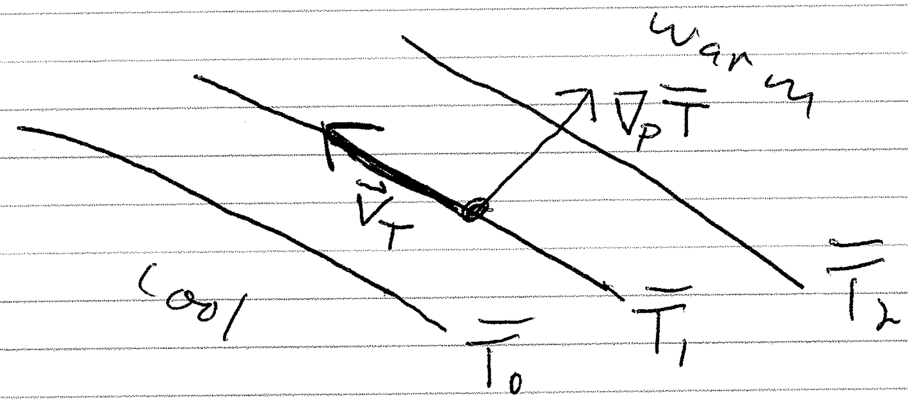
In the N. hemisphere $f > 0$ (and R is always > 0, and since $P_1 > P_2$, $\ln(P_1/P_2) > 0$). So $\frac{R}{f}\ln\left(\frac{P_1}{P_2}\right) > 0$ in the N. hemisphere.

So, in N. hemisphere: $\vec{V}_T = (\text{positive})\, \hat{k} \times \nabla_p \overline{T}$

Suppose we observe the following layer-mean temp structure (in N. hemisphere):



Then $\vec{V}_T$ looks like this:



So $\vec{V}_T$ is parallel to the layer-mean isotherms, with cold air to the left of $\vec{V}_T$ (in N. hemisphere).

Thermal Buys-Ballot's law: "With your back to the thermal wind, cold air is to your left (in N. hemisphere)"

Go through handout on heat low.

If we know the Temp field on an isobaric surface then we can calculate $\nabla_p T$ on that surface and then we can calculate $-\frac{\partial \vec{V}_g}{\partial p}$ on that surface.

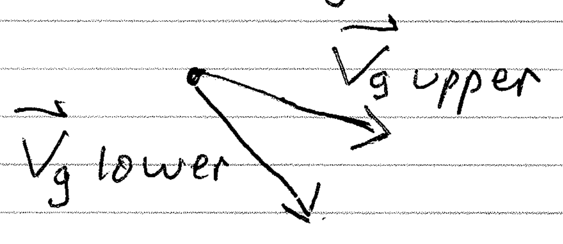
If we know the Temp field within the layer btw a lower and upper isobaric sfc then we can calculate $\nabla_p \overline{T}$ and then calculate $\vec{V}_T$. If we also know $\vec{V}_g$ lower then we can calculate $\vec{V}_g$upper.

If we know $\vec{V}_g$ at 2 levels then we can calculate $\vec{V}_T$ for that layer and then calculate the <u>layer-mean temp gradient</u> $\nabla_p \overline{T}$.

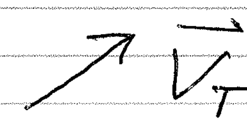
In this case we can also estimate the <u>mean temperature advection</u> by the geostrophic wind.

[So you can infer cold/warm air advection in the layer btw 2 cloud decks if you can estimate $\vec{V}_g$ from the motion of the clouds at the two levels (provided the decks are above ~1 km, the boundary layer)].

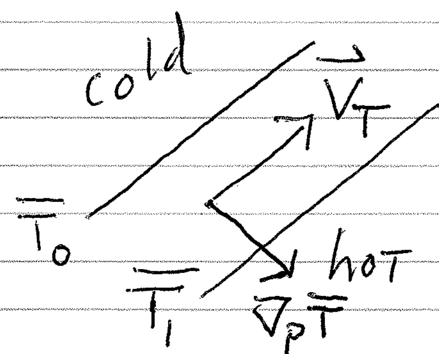
e.g. Suppose the geostrophic wind <u>backs</u> with height as follows:



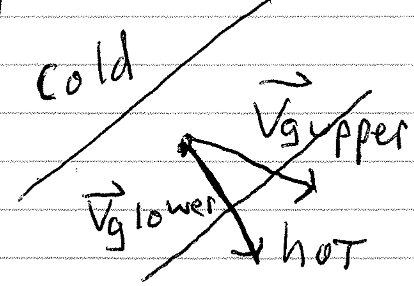
∴ Thermal wind vector is:



∴ horiz temp structure (in layer-mean sense) is:



Superimposing the geostrophic wind vectors, we can infer that there's <u>cold advection</u> going on:



Use thermodynamic energy eq^n to confirm that it's cold air advection:

If there's no vertical motion (so no adiabatic heating/cooling) the thermo energy eq^n is:

$$\frac{DT}{Dt} = \dot{Q}$$ ← diabatic forcings (e.g. radiative heating/cooling or latent heat release).

$$\therefore \frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T = \dot{Q}$$

$$\therefore \frac{\partial T}{\partial t} = \underbrace{\boxed{-\vec{V} \cdot \nabla T}}_{\text{Temp advection}} + \dot{Q}$$

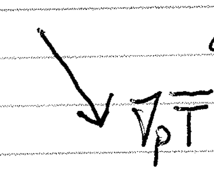
Approximate $\vec{V}$ by $\vec{V}_g$

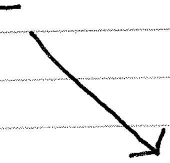
$$\therefore \frac{\partial T}{\partial t} = -\vec{V}_g \cdot \nabla T + \dot{Q}$$

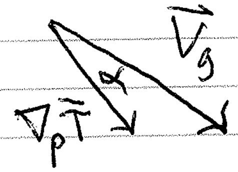
Average this eq^n btw lower and upper isobaric surfaces, get:

$$\frac{\partial \overline{T}}{\partial t} = -\overline{\vec{V}_g} \cdot \nabla_p \overline{T} + \overline{\dot{Q}}$$

[well, used an approx like $\overline{ab} \approx \overline{a}\,\overline{b}$]

For our backing example 

and $\overline{\vec{V}_g}$ 

So 

angle α btw them is less than 90°

So Temp advection by geos wind in layer is:

$$-\overline{\vec{V}_g}\cdot\nabla_p\overline{T} = \underset{-}{-}\underset{+}{\left|\overline{\vec{V}_g}\right|}\,\underset{+}{\left|\nabla_p\overline{T}\right|}\,\underbrace{\cos\alpha}_{+\text{ since }\alpha<90^\circ} < 0$$

i.e. This advection term is trying to make $\frac{\partial\overline{T}}{\partial t} < 0$. Cold air advection.

In general, a geostrophic wind that backs with height indicates cold advection

Similarly, a geos wind that veers with height is associated with warm advection.