NOAA

National Weather Service

An overview on Mesoscale Convective Systems and their forward motion

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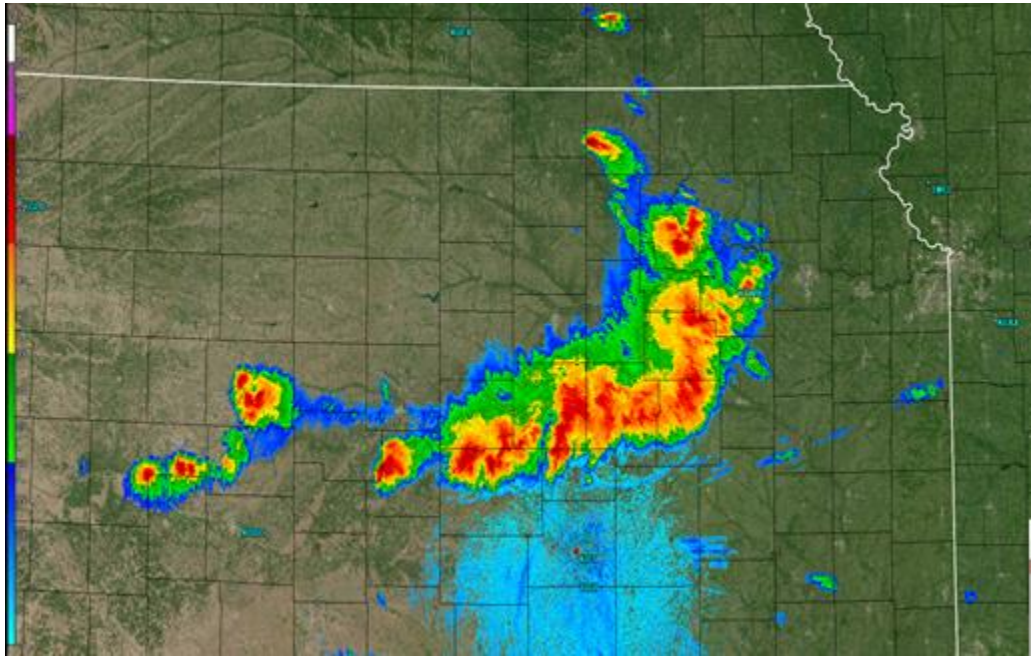
What is an MCS?

A **Mesoscale Convective System** (**MCS**) is “a cloud system that occurs in connection with an ensemble of thunderstorms and produces a contiguous precipitation area on the order of 100 km or more in horizontal scale in at least one direction” (AMS Glossary – 2025).

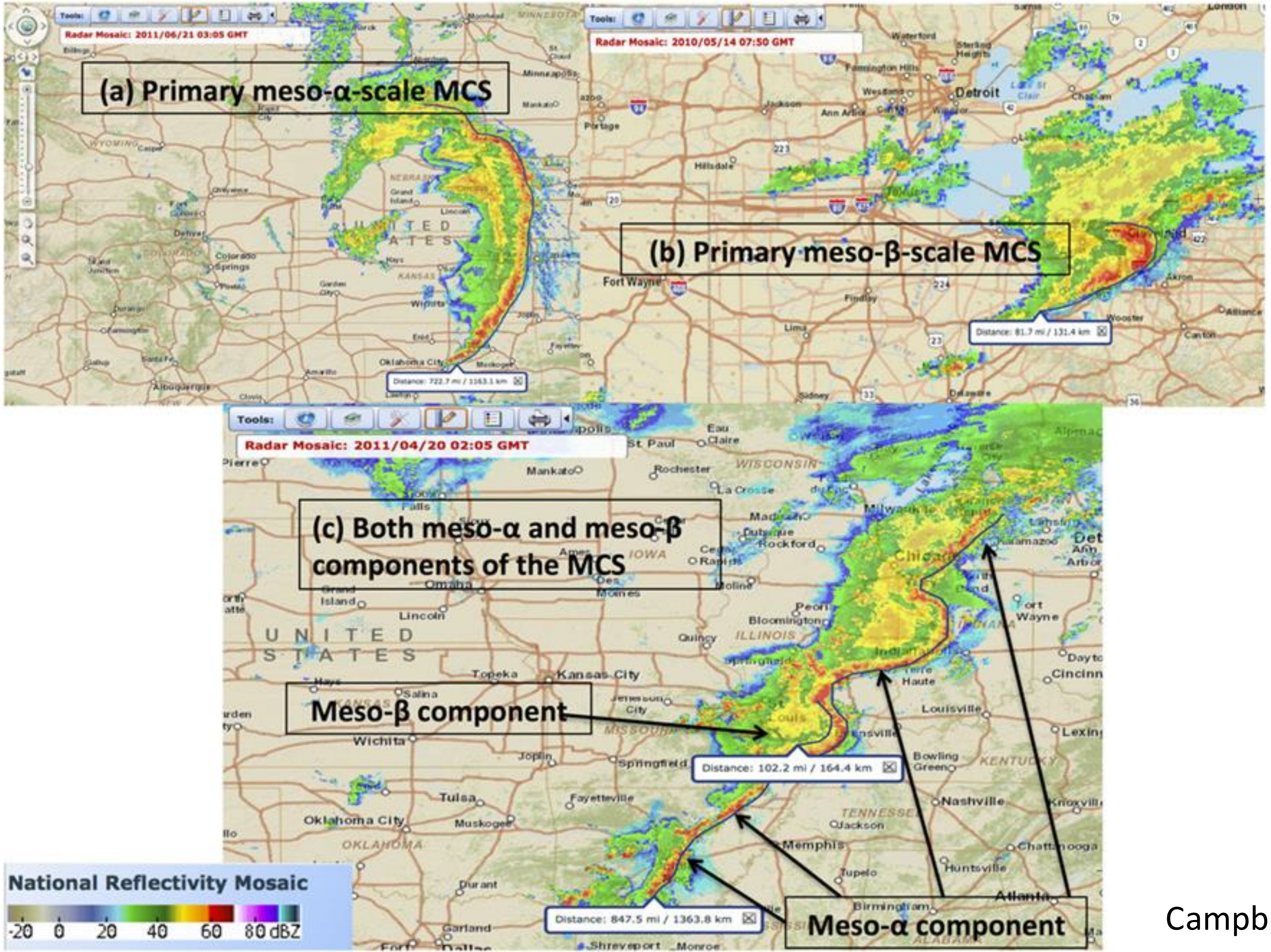
- This definition can be applied liberally to any organized thunderstorm clusters that:
  - Is at least 100 km long
  - Lasts for at least 3 hours
  - Shares a common feature, such as a trailing precipitation region or cold pool.

- MCSs may take on many forms, morphology and evolution

- MCSs may be accompanied by all thunderstorm hazards:
  - Heavy rain and potential flooding
  - Frequent Lightning
  - Strong, damaging winds/gusts
  - Tornadoes
  - Hail



MCS Types



Campbell et al. (2017)

MCSs on the spatial and temporal spectrum

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- In mid-latitudes: $-\frac{1}{\rho}\frac{\partial p}{\partial x} = \frac{1}{1\, kg\, m^{-3}}\frac{10\, mb}{1000\, km} \sim 10^{-3}m\, s^{-2}$, with F_u also 10^{-3} m s^{-2}

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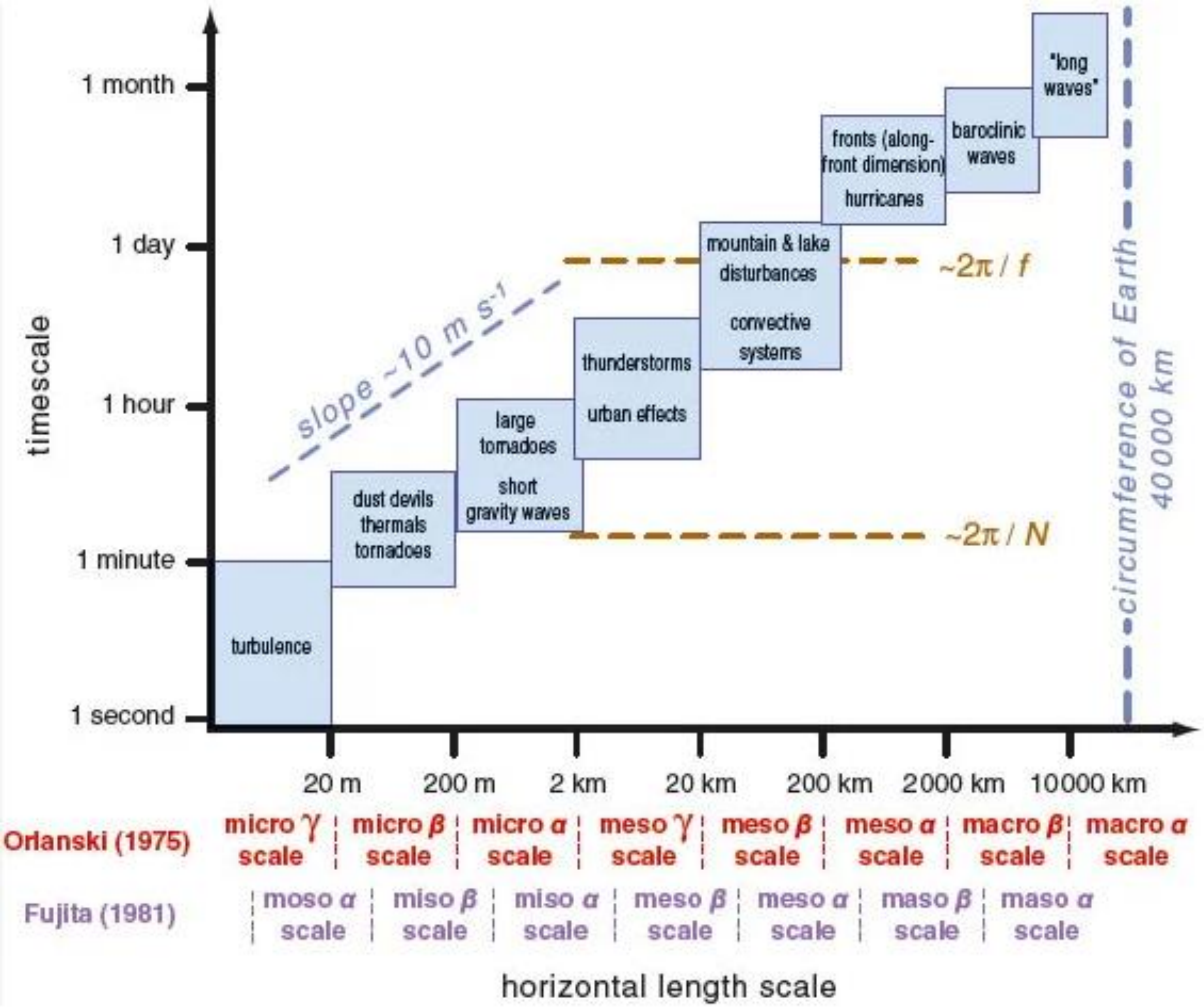
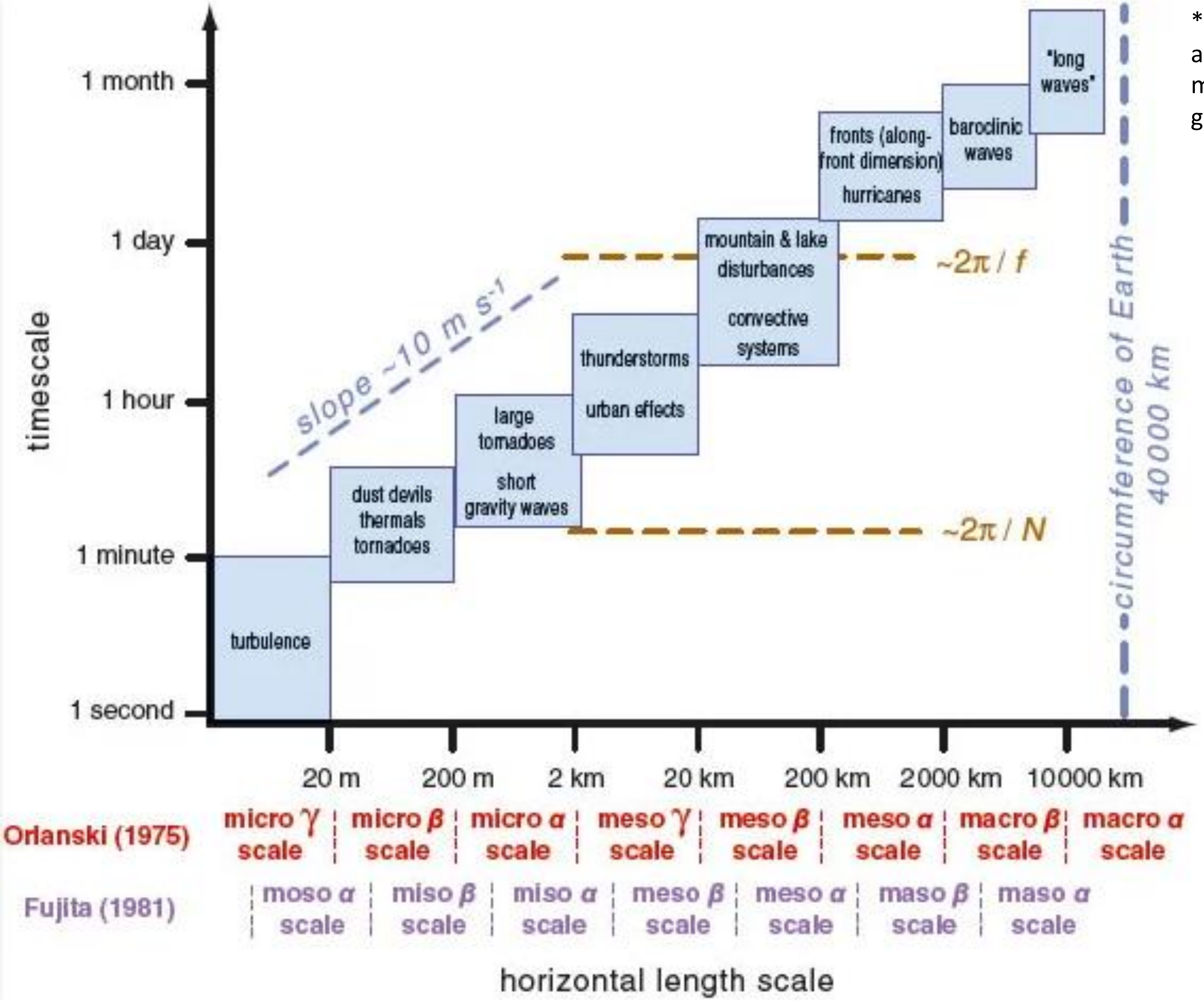
- Parker and Johnson (2000): Making an advective assumption, length scale is $L = U\tau = 10\ m\ s^{-1} * 10^4\ s = 10^5\ m$ or **100 km**.



timescale
1 month
1 day
1 hour
1 minute
1 second
turbulence
dust devils
thermals
tornadoes
large
tornadoes
short
gravity waves
thunderstorms
urban effects
mountain & lake
disturbances
convective
systems
fronts (along-
front dimension)
hurricanes
baroclinic
waves
"long
waves"
slope ~10 m s-1
~2π / f
~2π / N
circumference of Earth
40000 km
20 m
200 m
2 km
20 km
200 km
2000 km
10000 km
Orlanski (1975)
micro γ scale
micro β scale
micro α scale
meso γ scale
meso β scale
meso α scale
macro β scale
macro α scale
Fujita (1981)
moso α scale
miso β scale
miso α scale
meso β scale
meso α scale
maso β scale
maso α scale
horizontal length scale



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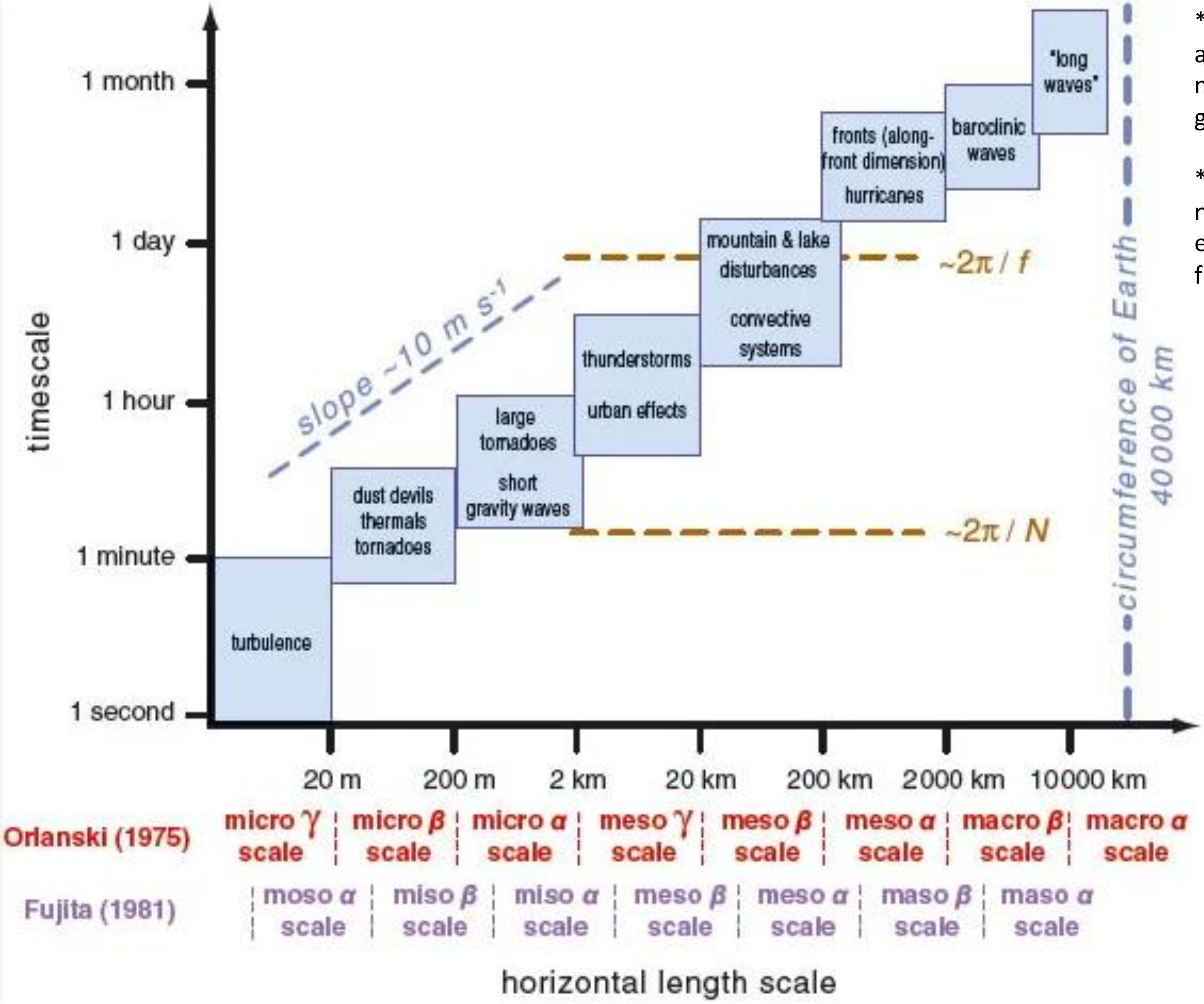

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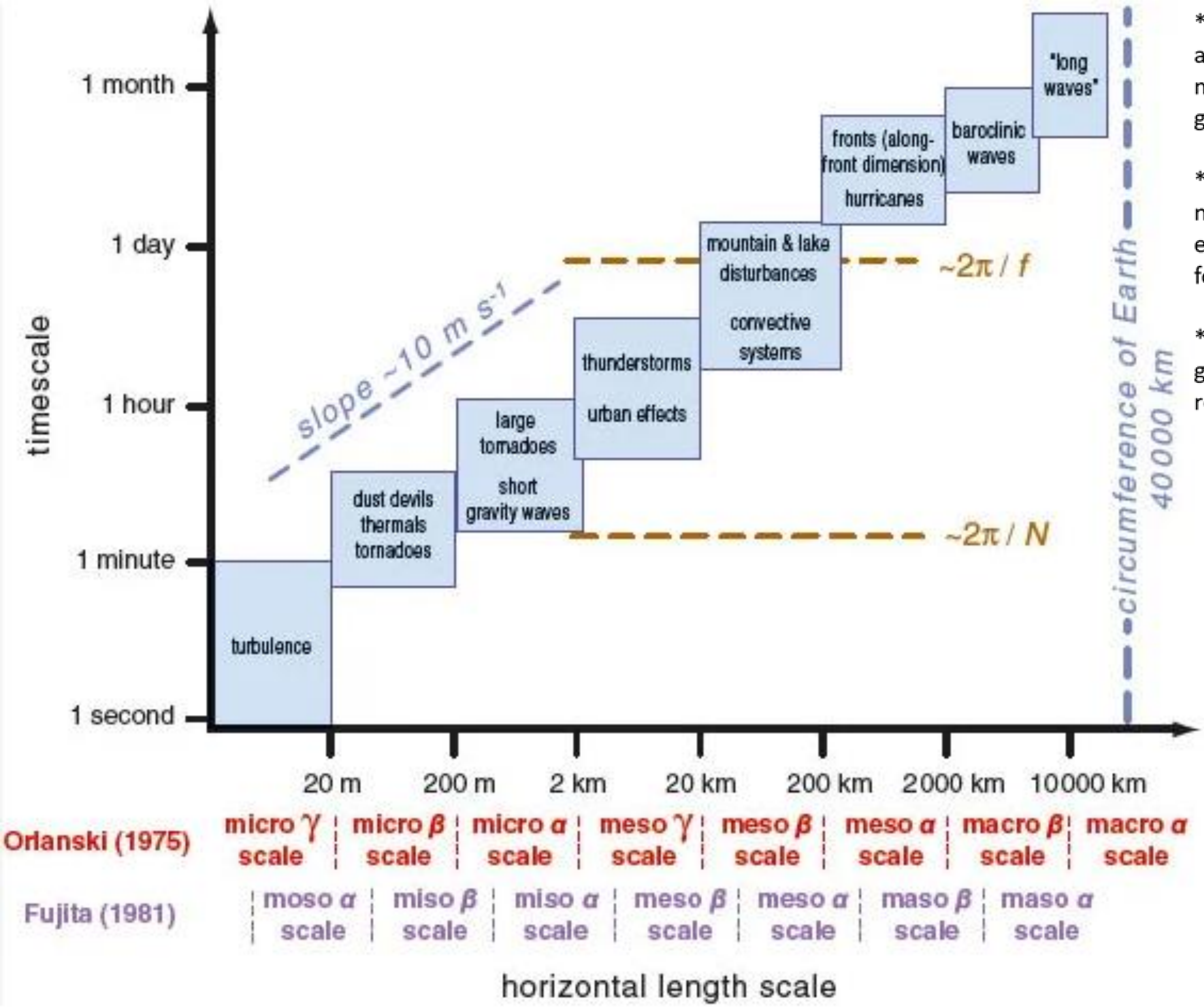

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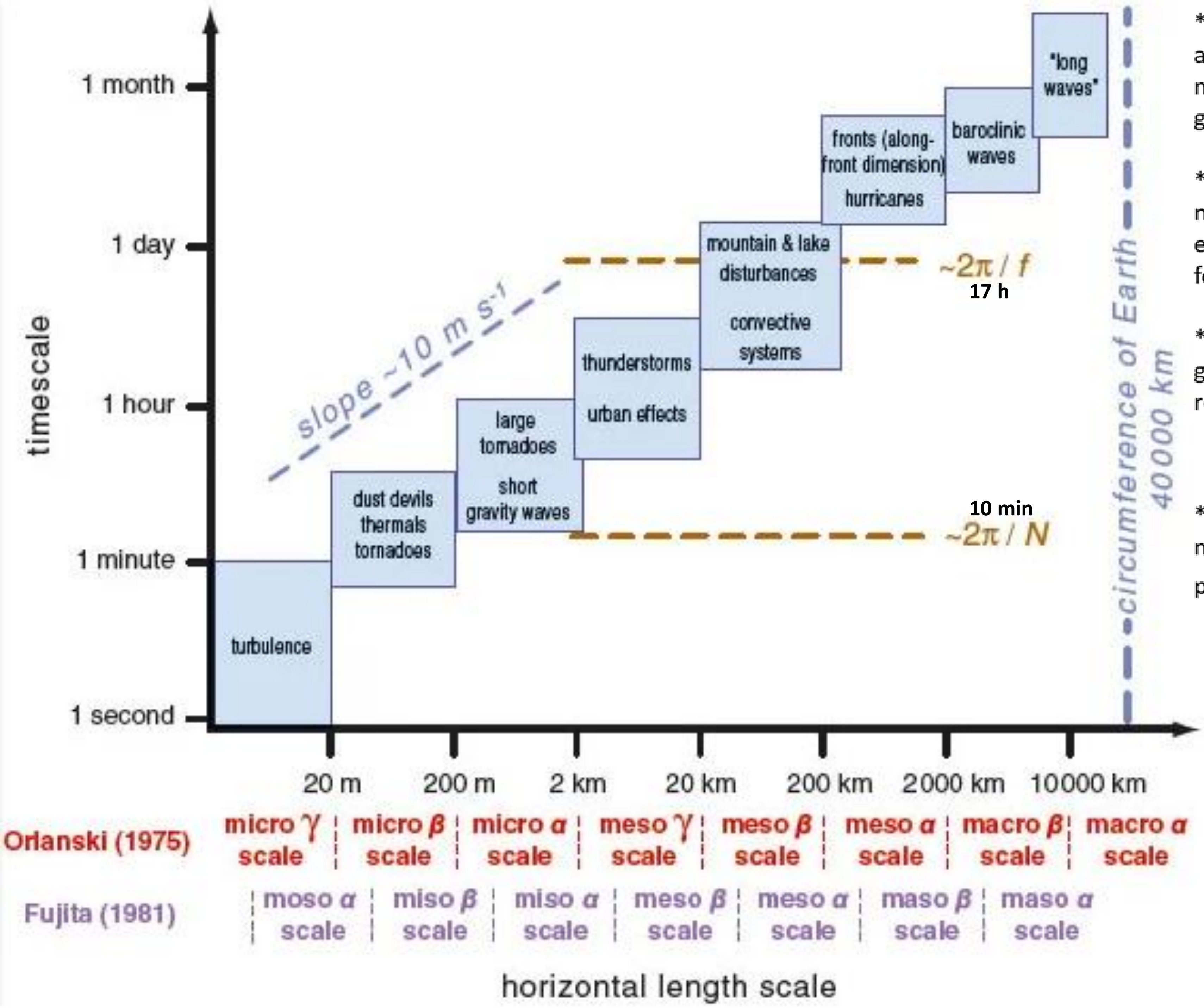

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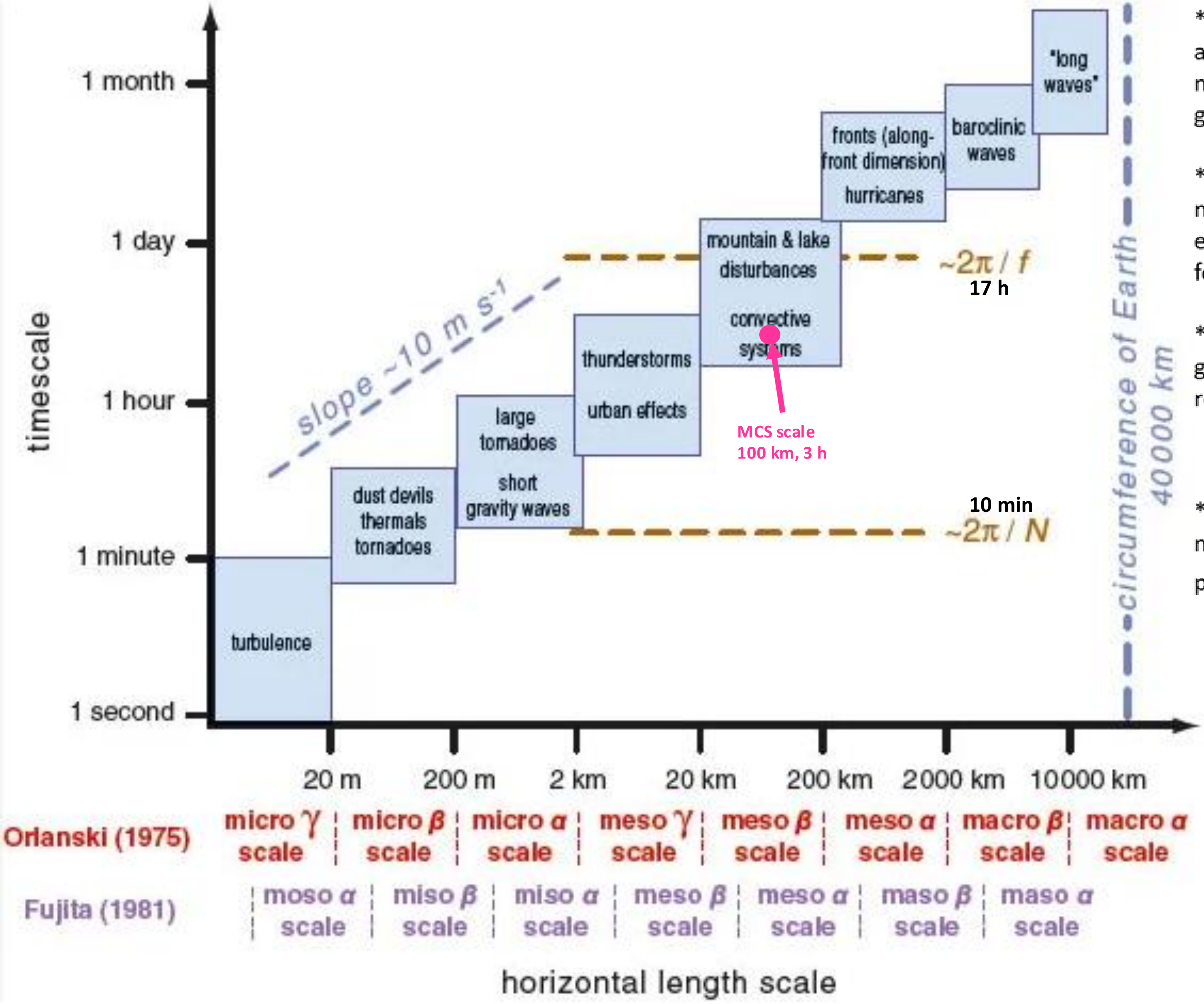

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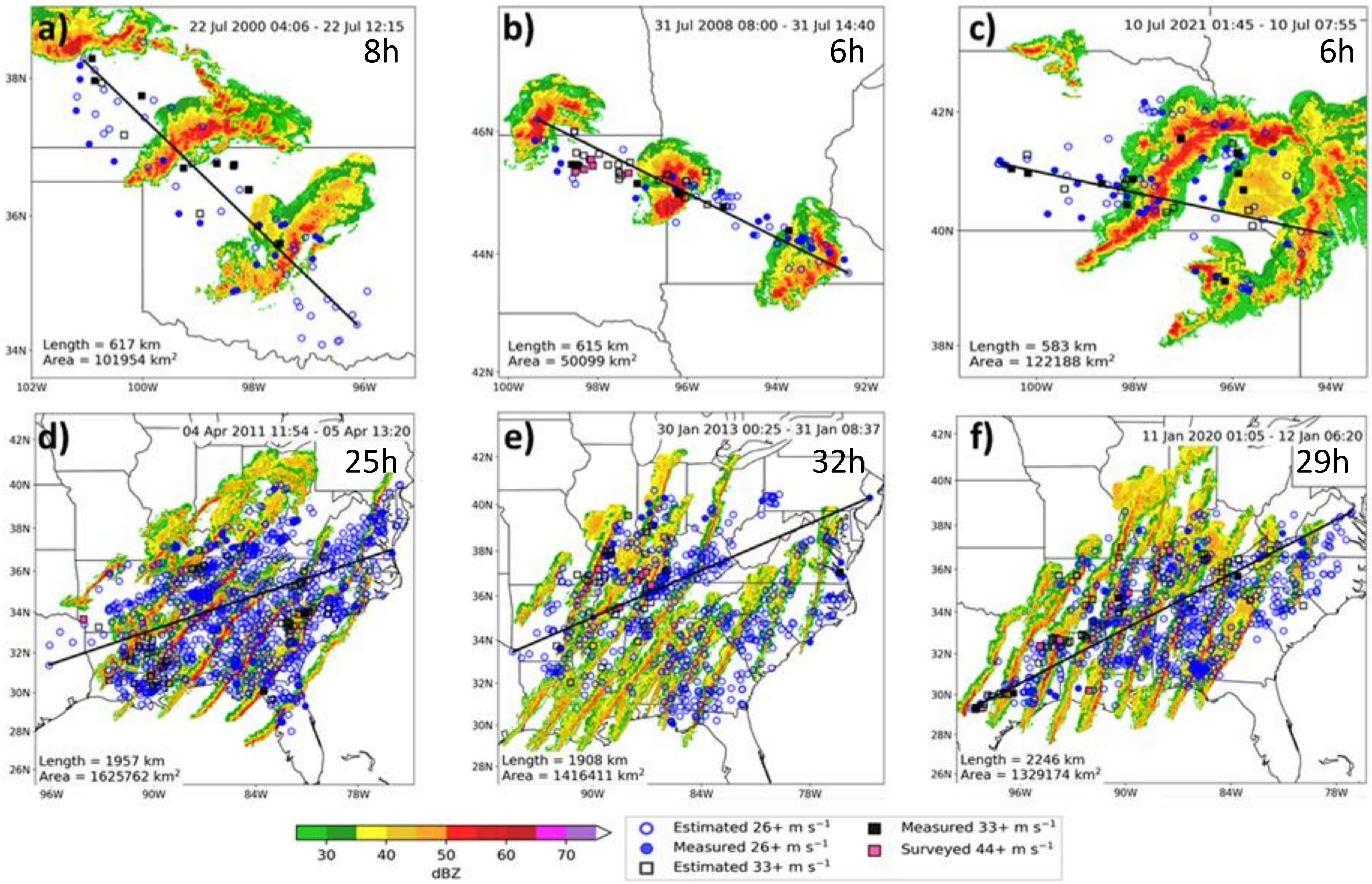
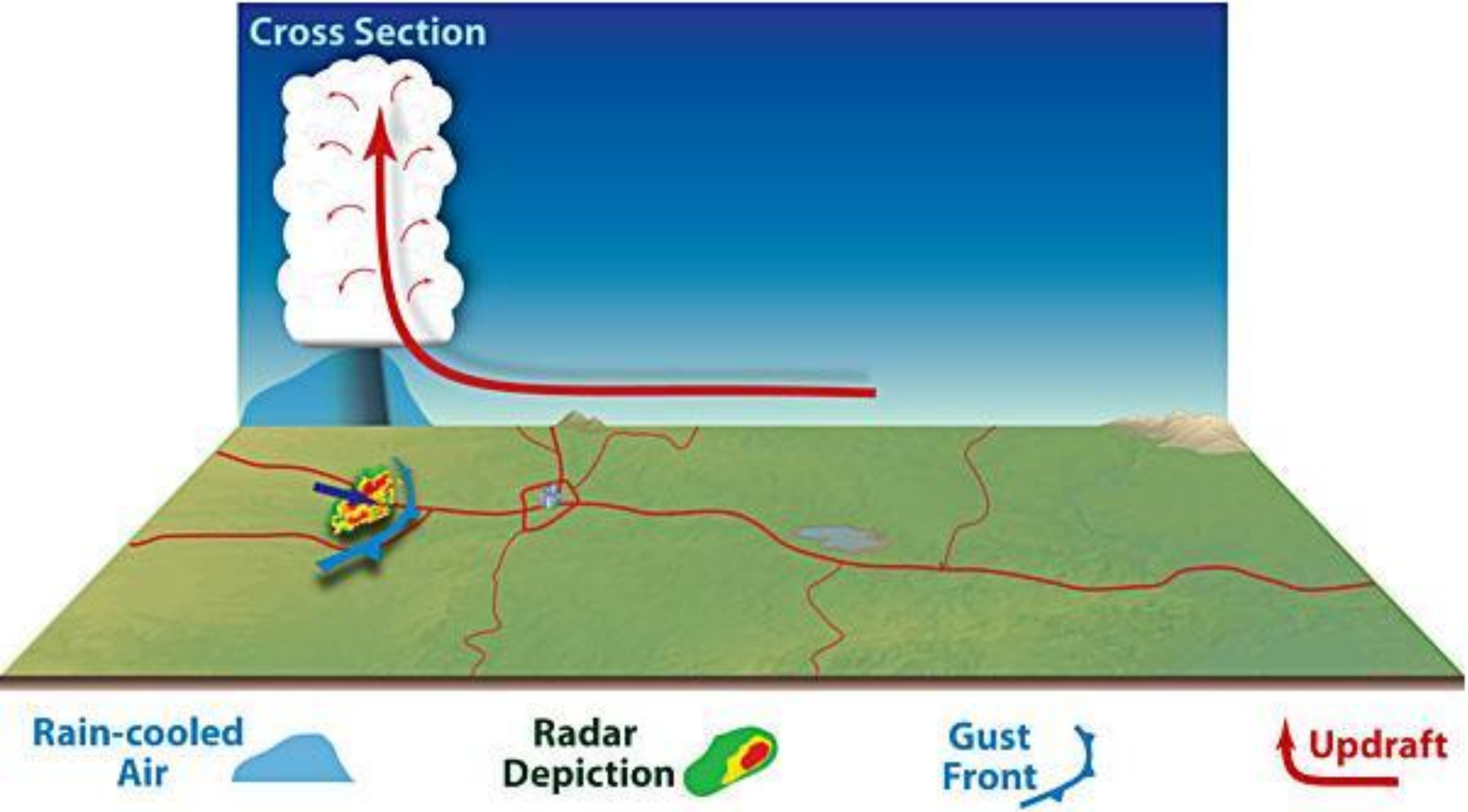
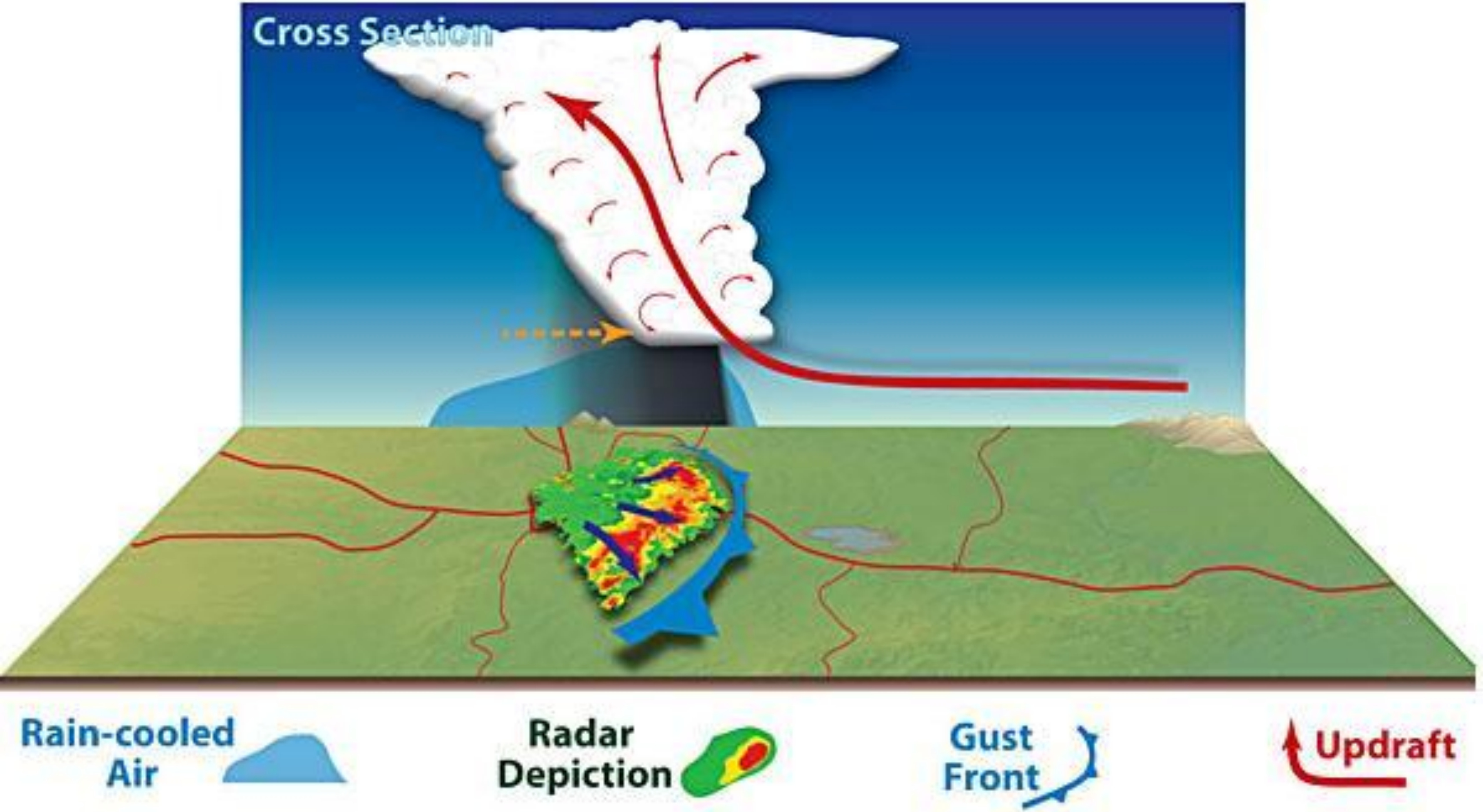
Cold-pool-driven MCSs tend to differ in structure from synoptically forced squall lines, with differences in wind swath attributes




Cross Section
Rain-cooled Air
Radar Depiction
Gust Front
Updraft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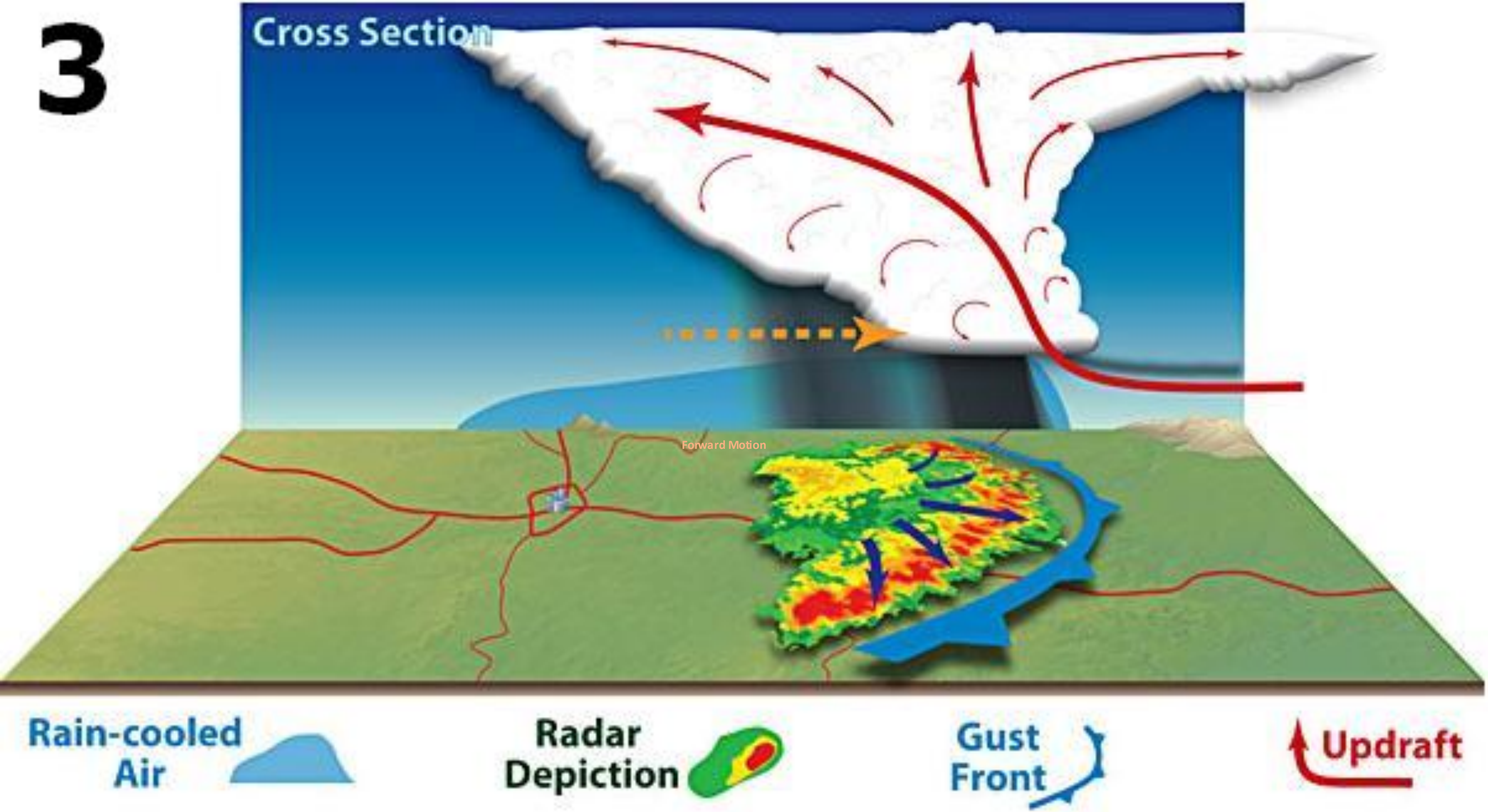
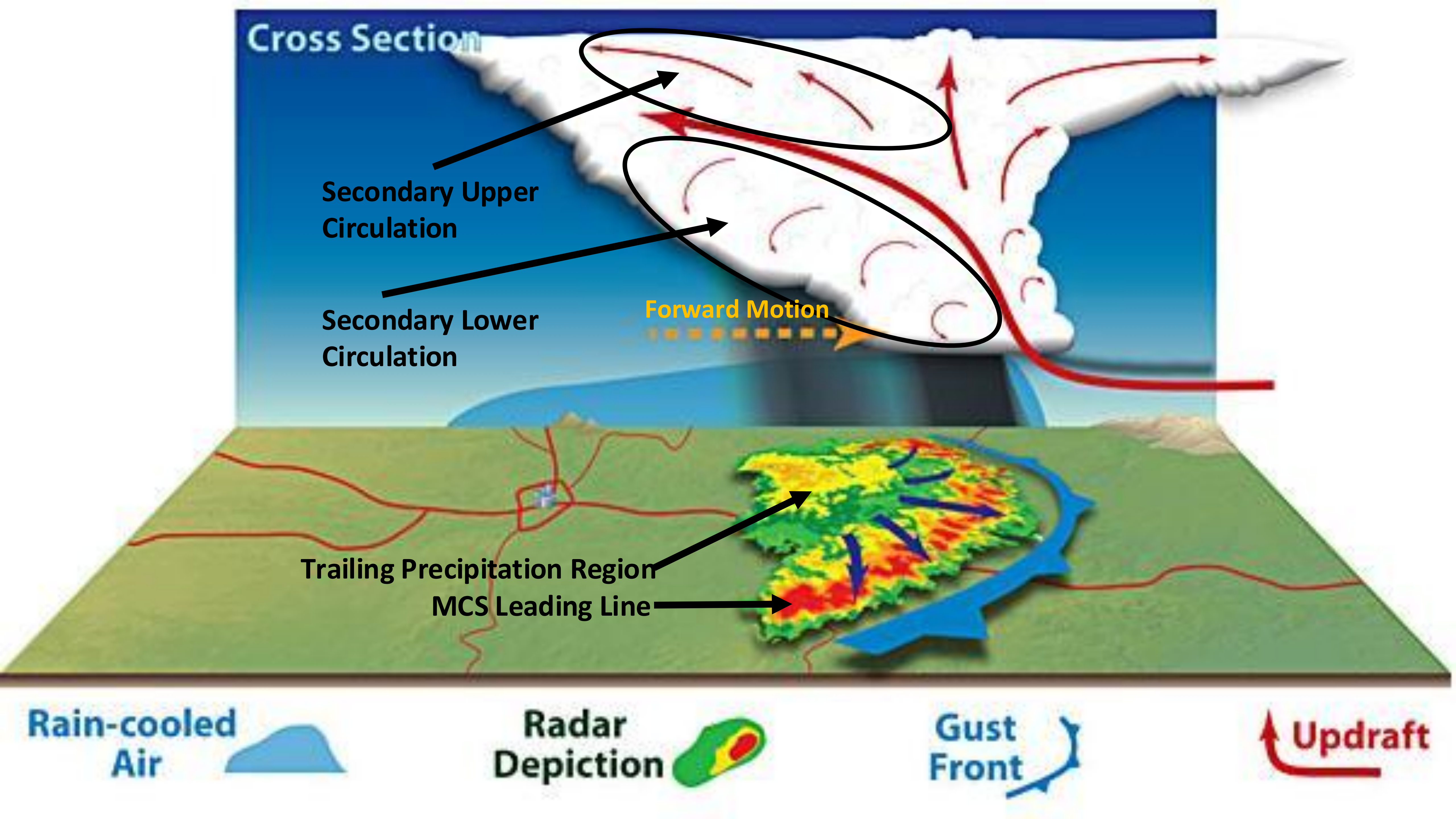
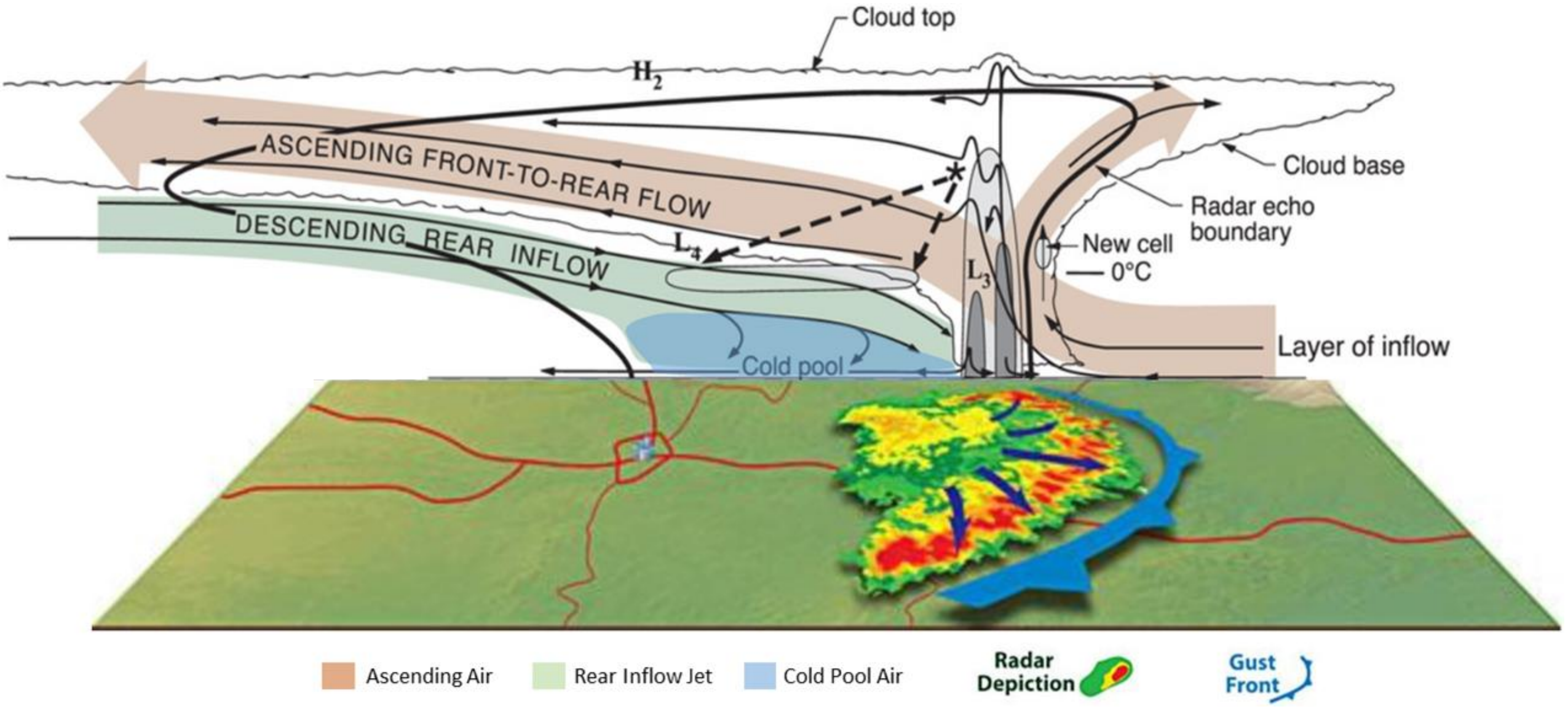
3

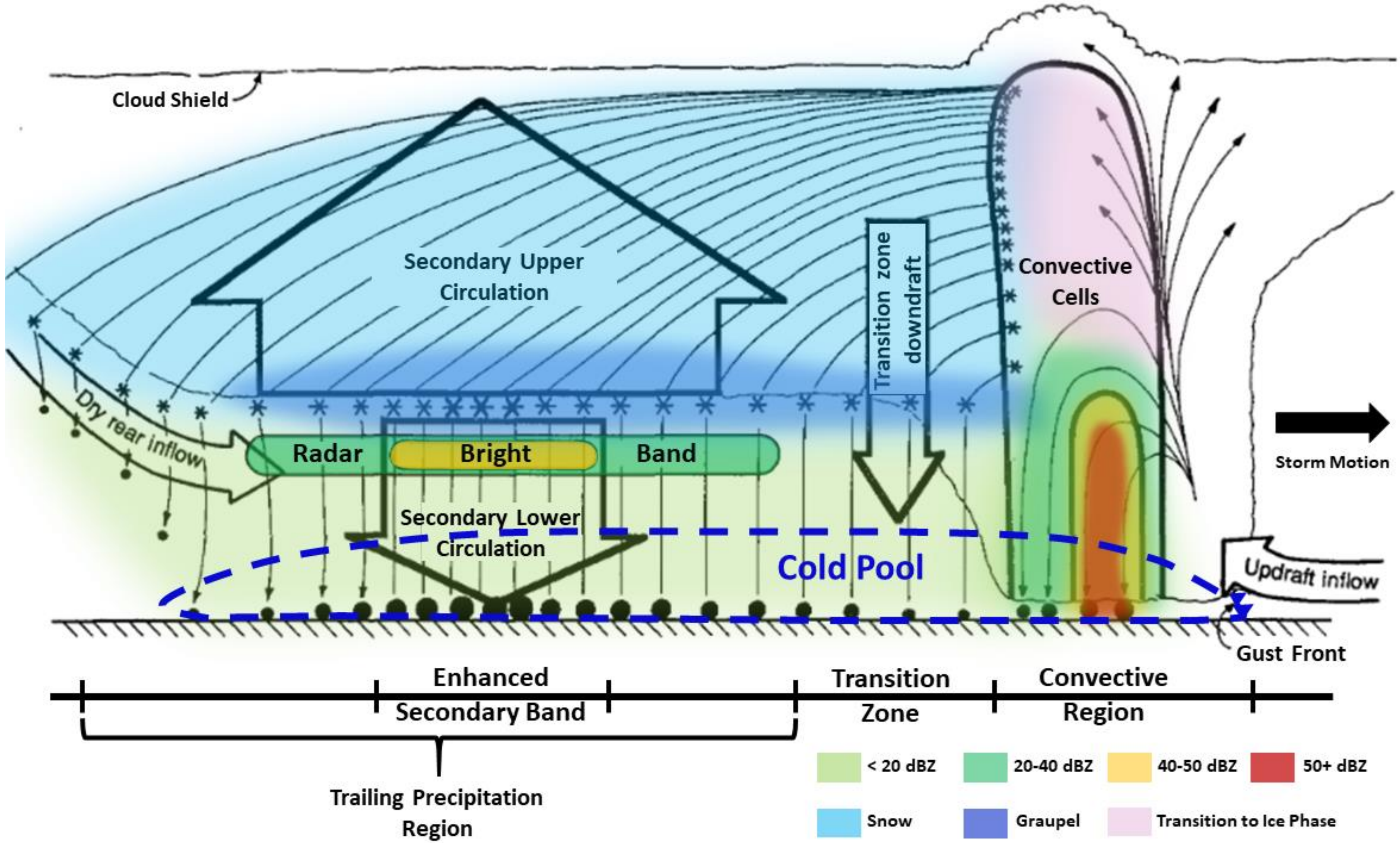

Cross Section
Forward Motion
Rain-cooled Air
Radar Depiction
Gust Front
Updraft



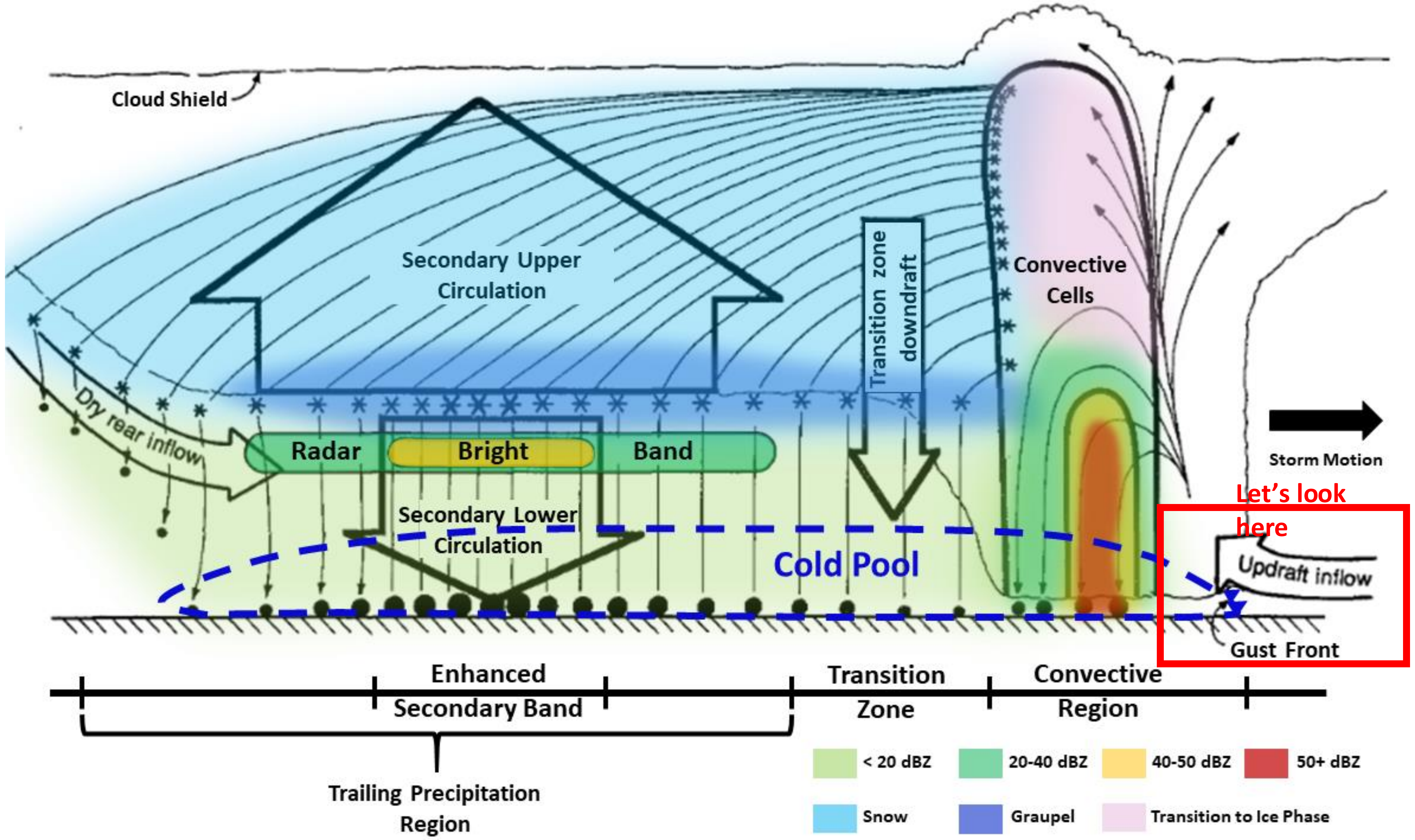
Cross Section
Secondary Upper Circulation
Secondary Lower Circulation
Forward Motion
Trailing Precipitation Region
MCS Leading Line
Rain-cooled Air
Radar Depiction
Gust Front
Updraft



Cloud top
H2
ASCENDING FRONT-TO-REAR FLOW
DESCENDING REAR INFLOW
L4
L3
Cloud base
Radar echo boundary
New cell
0°C
Layer of inflow
Cold pool
Ascending Air
Rear Inflow Jet
Cold Pool Air
Radar Depiction
Gust Front



Cloud Shield
Secondary Upper Circulation
Transition zone downdraft
Convective Cells
Dry rear inflow
Radar
Bright
Band
Storm Motion
Secondary Lower Circulation
Cold Pool
Updraft inflow
Gust Front
Enhanced Secondary Band
Transition Zone
Convective Region
Trailing Precipitation Region
< 20 dBZ
20-40 dBZ
40-50 dBZ
50+ dBZ
Snow
Graupel
Transition to Ice Phase



Cloud Shield
Secondary Upper Circulation
Transition zone downdraft
Convective Cells
Dry rear inflow
Radar Bright Band
Storm Motion
Let's look here
Secondary Lower Circulation
Cold Pool
Updraft inflow
Gust Front
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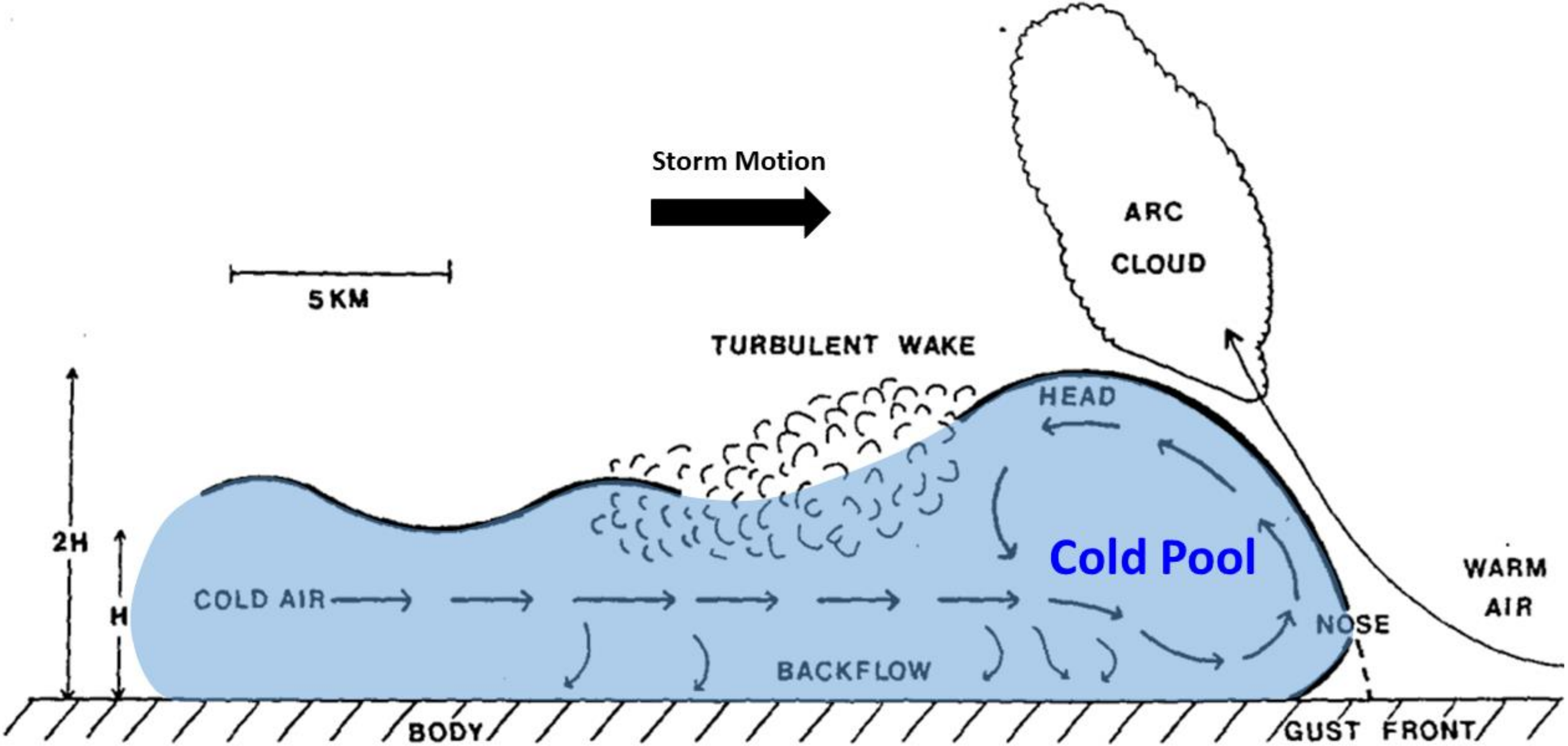

Storm Motion
5 KM
ARC
CLOUD
TURBULENT WAKE
HEAD
2H
H
Cold Pool
COLD AIR
WARM
AIR
NOSE
BACKFLOW
BODY
GUST FRONT

MCS Forward Motion

- Johns and Hirt (1987) and Corfidi et al. (2016) both found that derechos move faster (sometimes much faster) than the full mean wind speed.

- Derecho wind swaths are produced by thunderstorm clusters where either cold pool dynamics or other internal mechanisms dominate the processes that produce severe/destructive wind gusts.

- Corfidi et al. (1996) and Corfidi (2003) devised a routine that can determine MCS forward motion based on the interaction between the cold pool and ambient flow fields.

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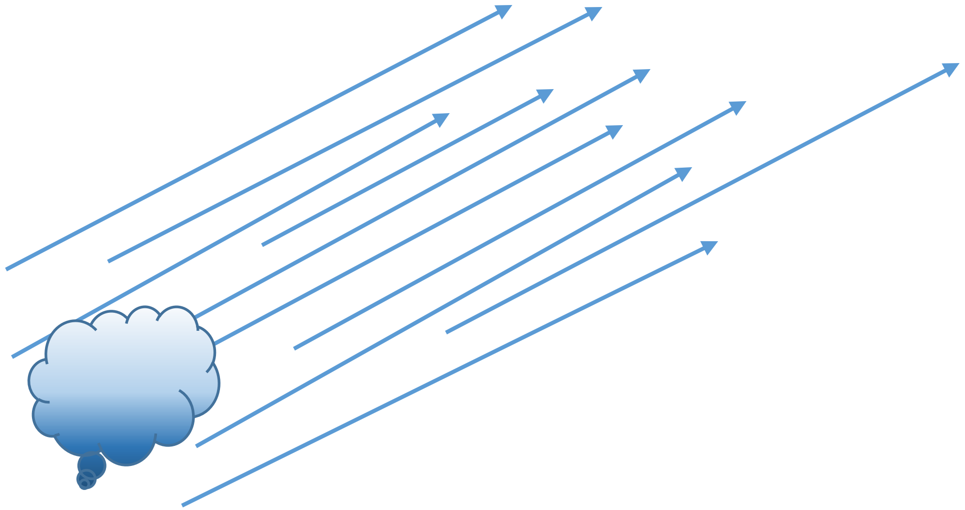

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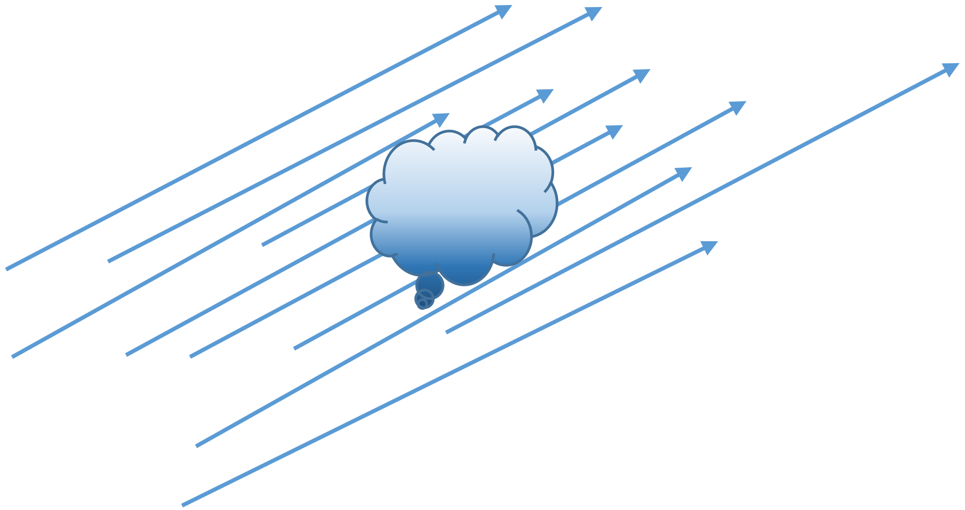

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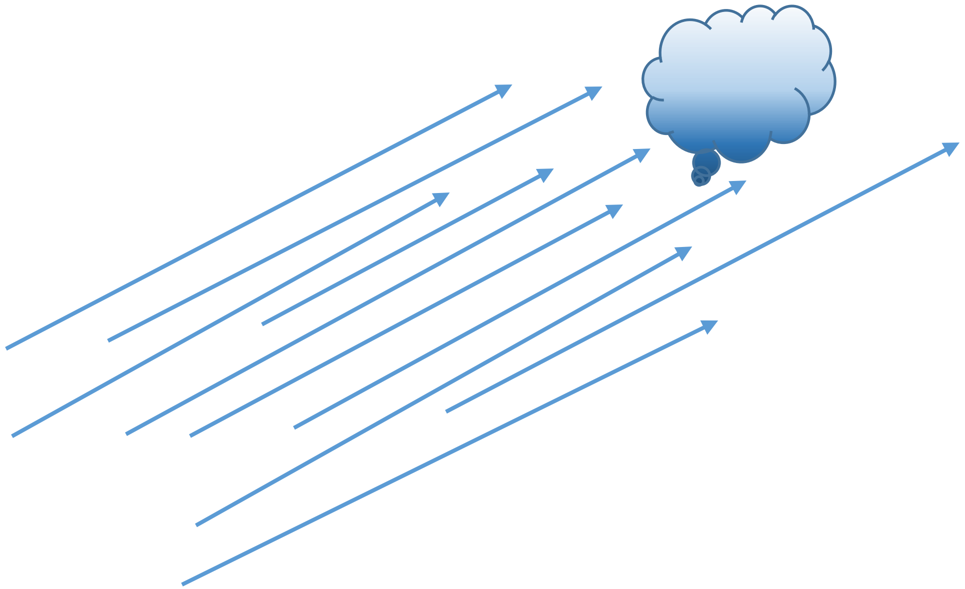

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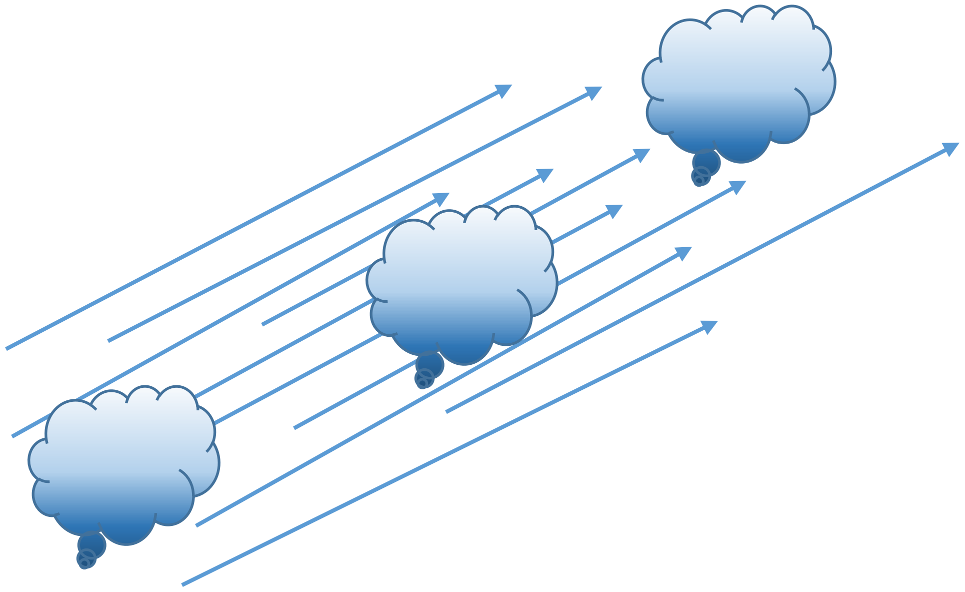

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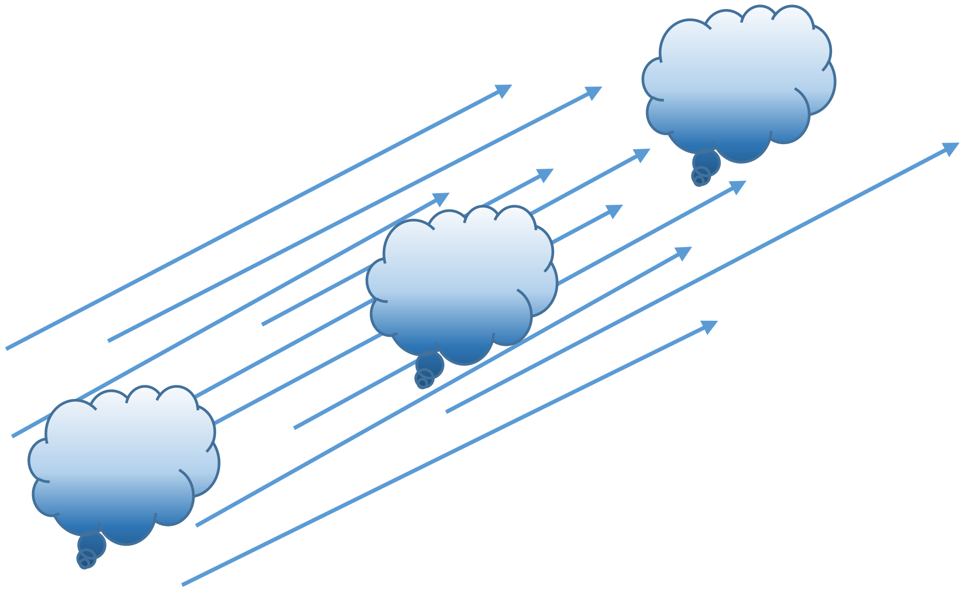

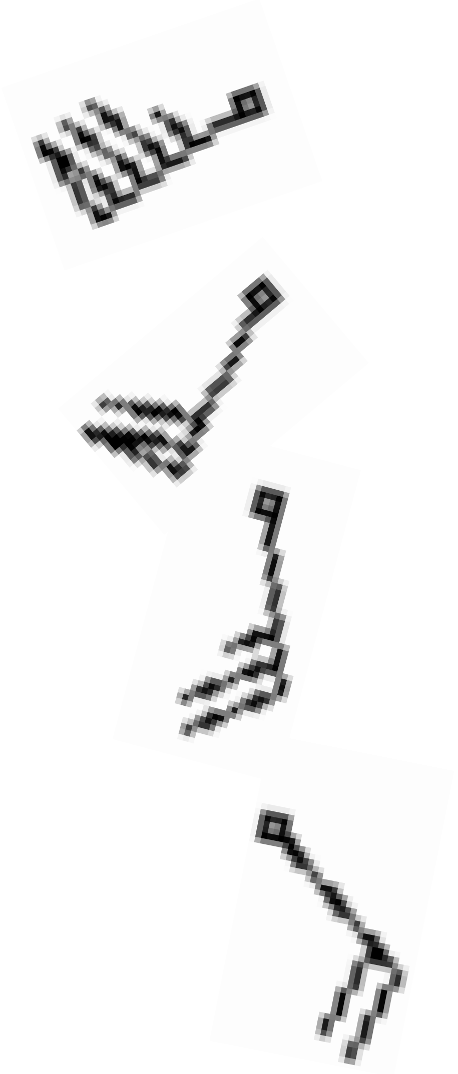

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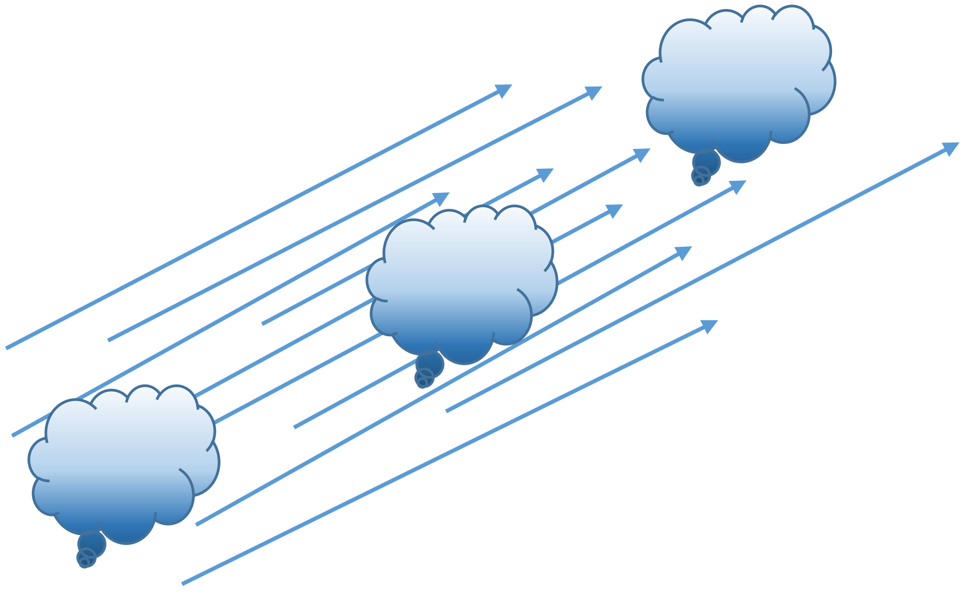

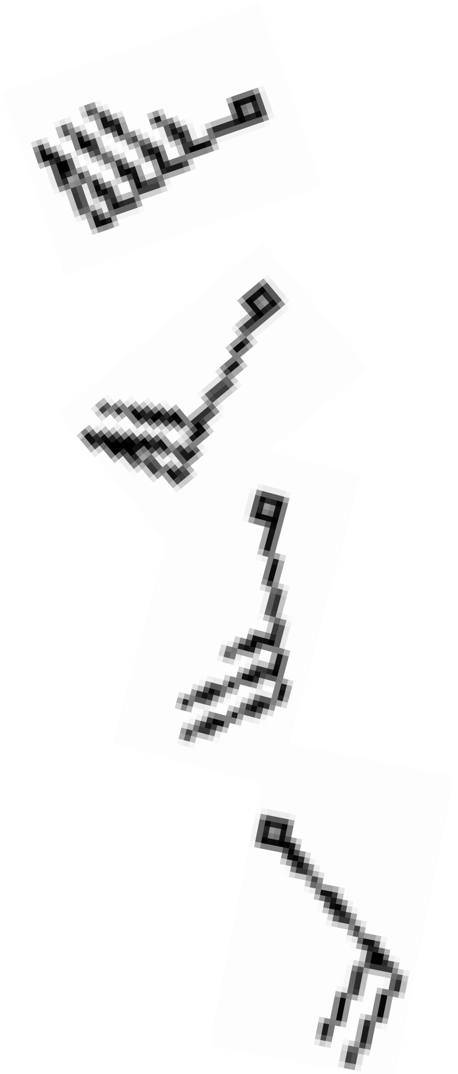

$$V_{CL} = \frac{\sum_{i=0}^{n} V_i}{n}$$

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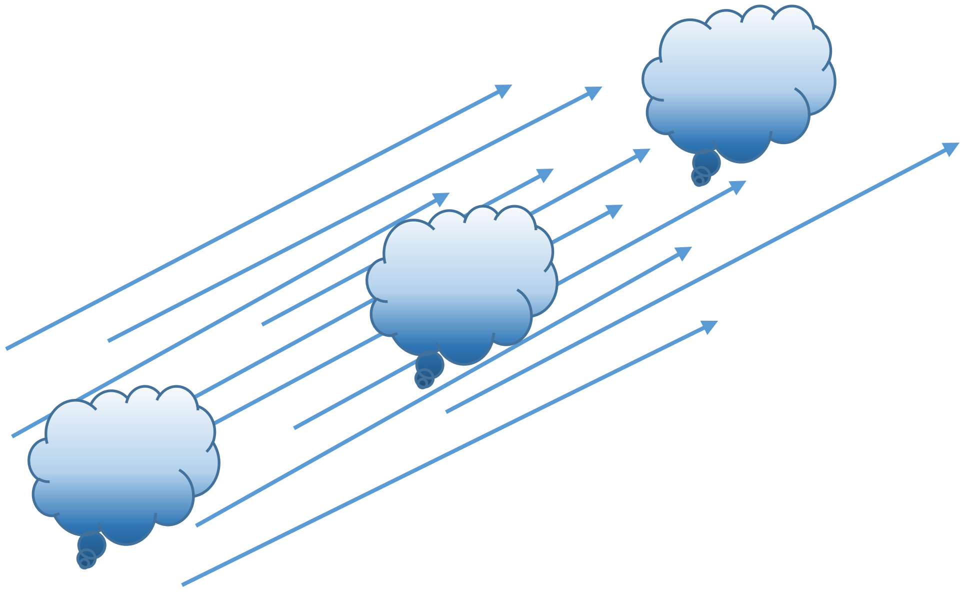

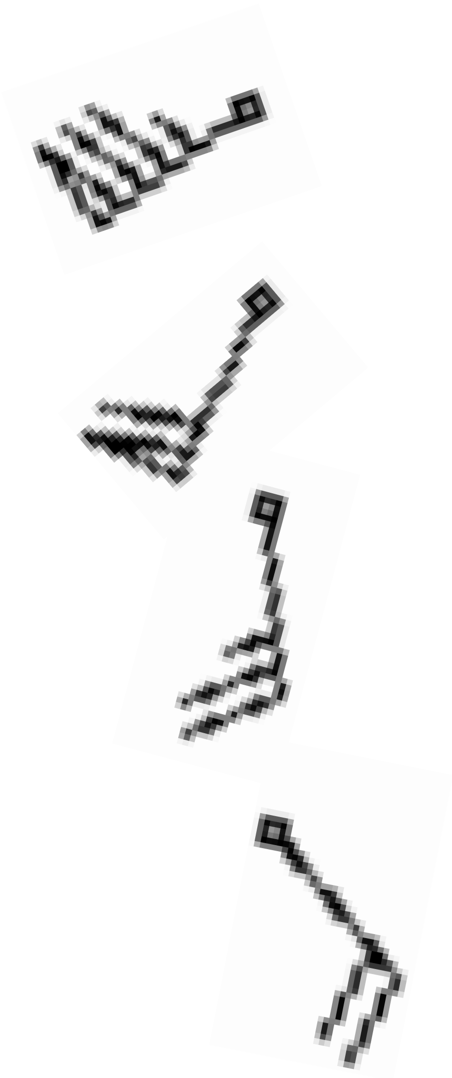

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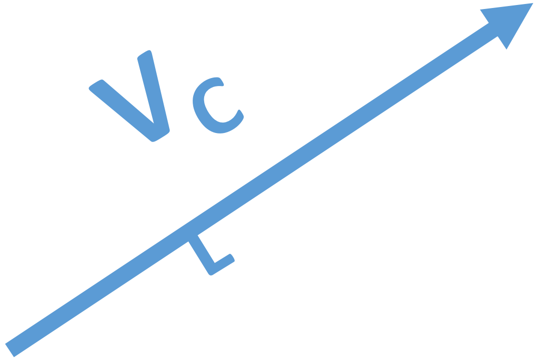

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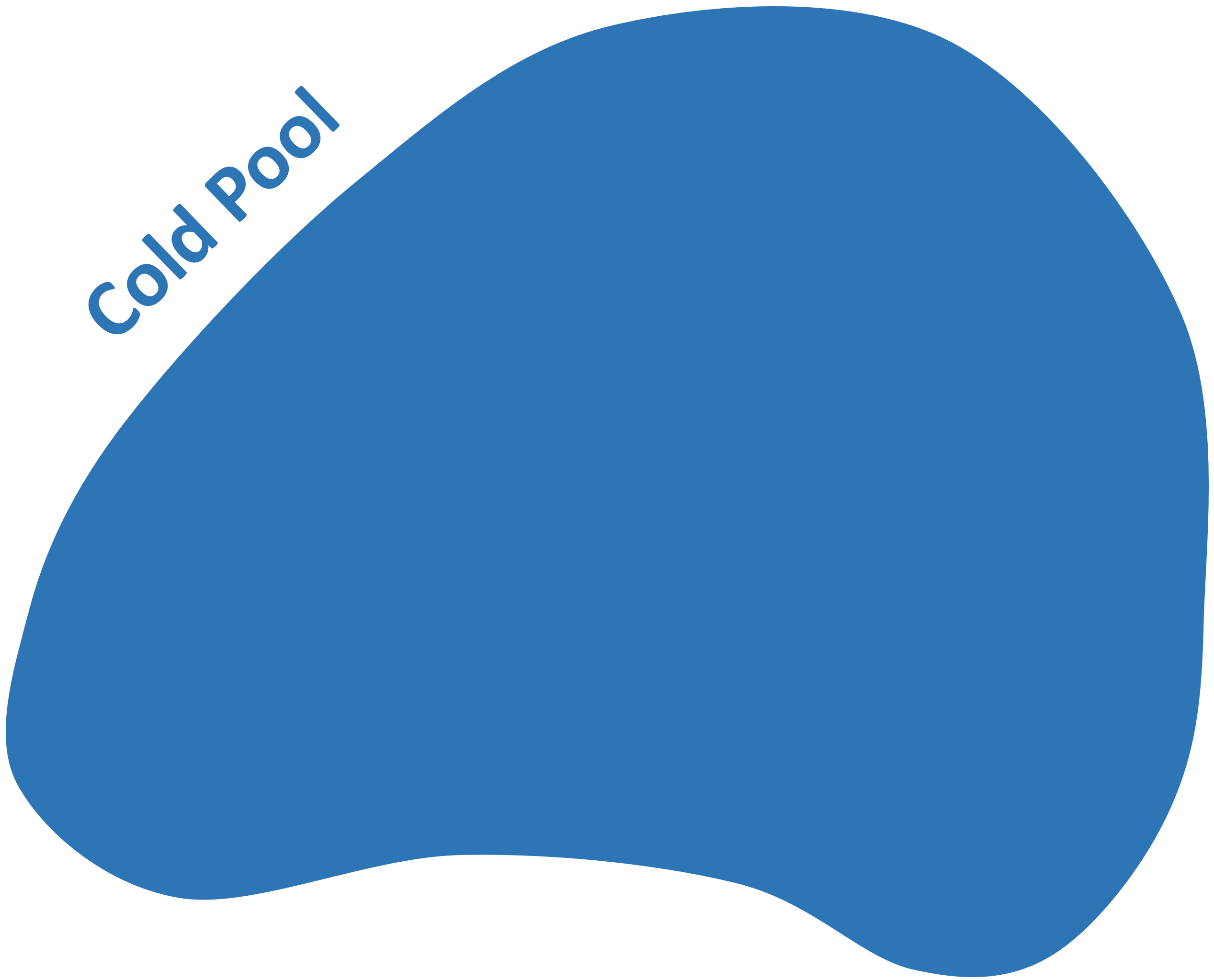

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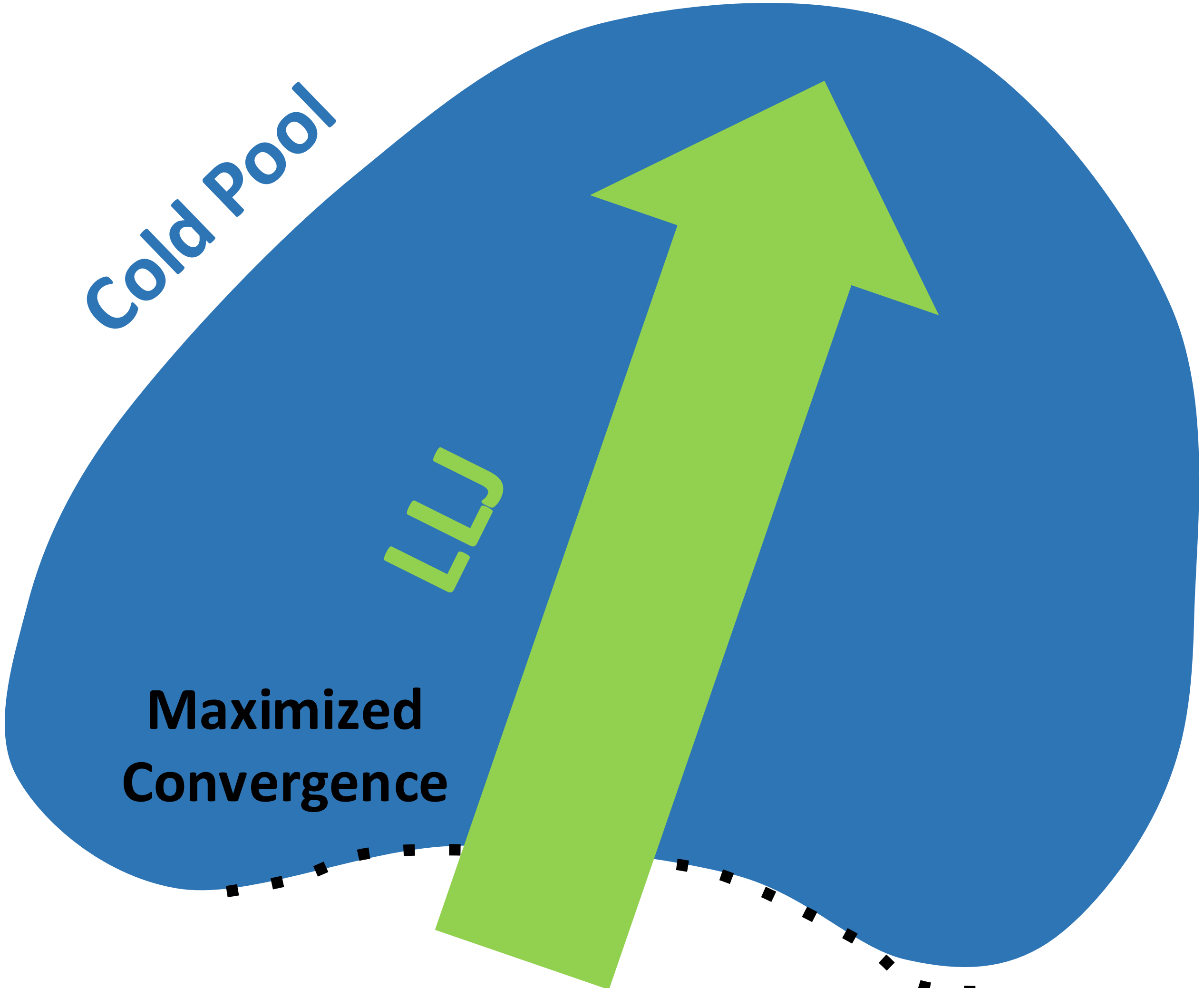

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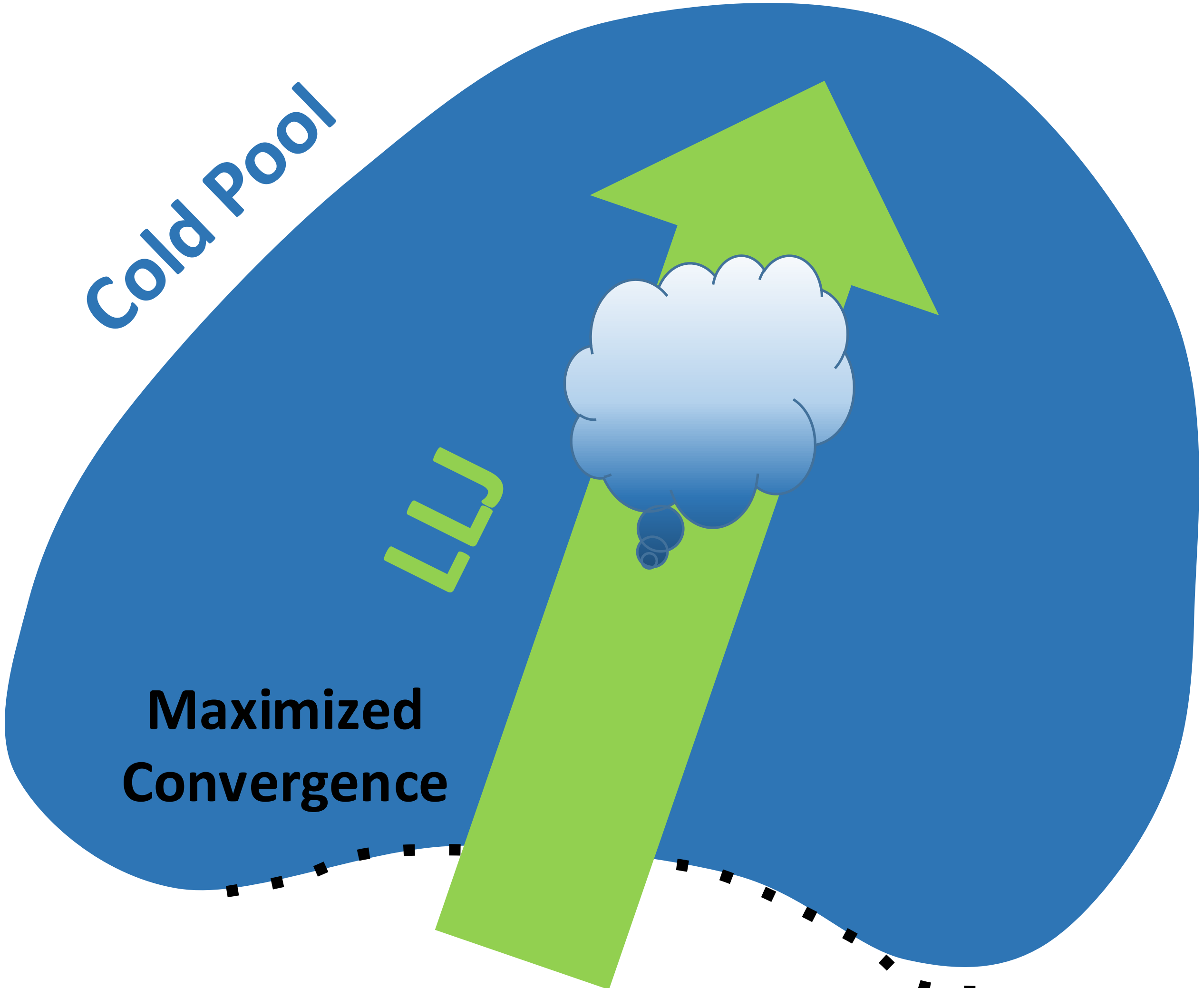

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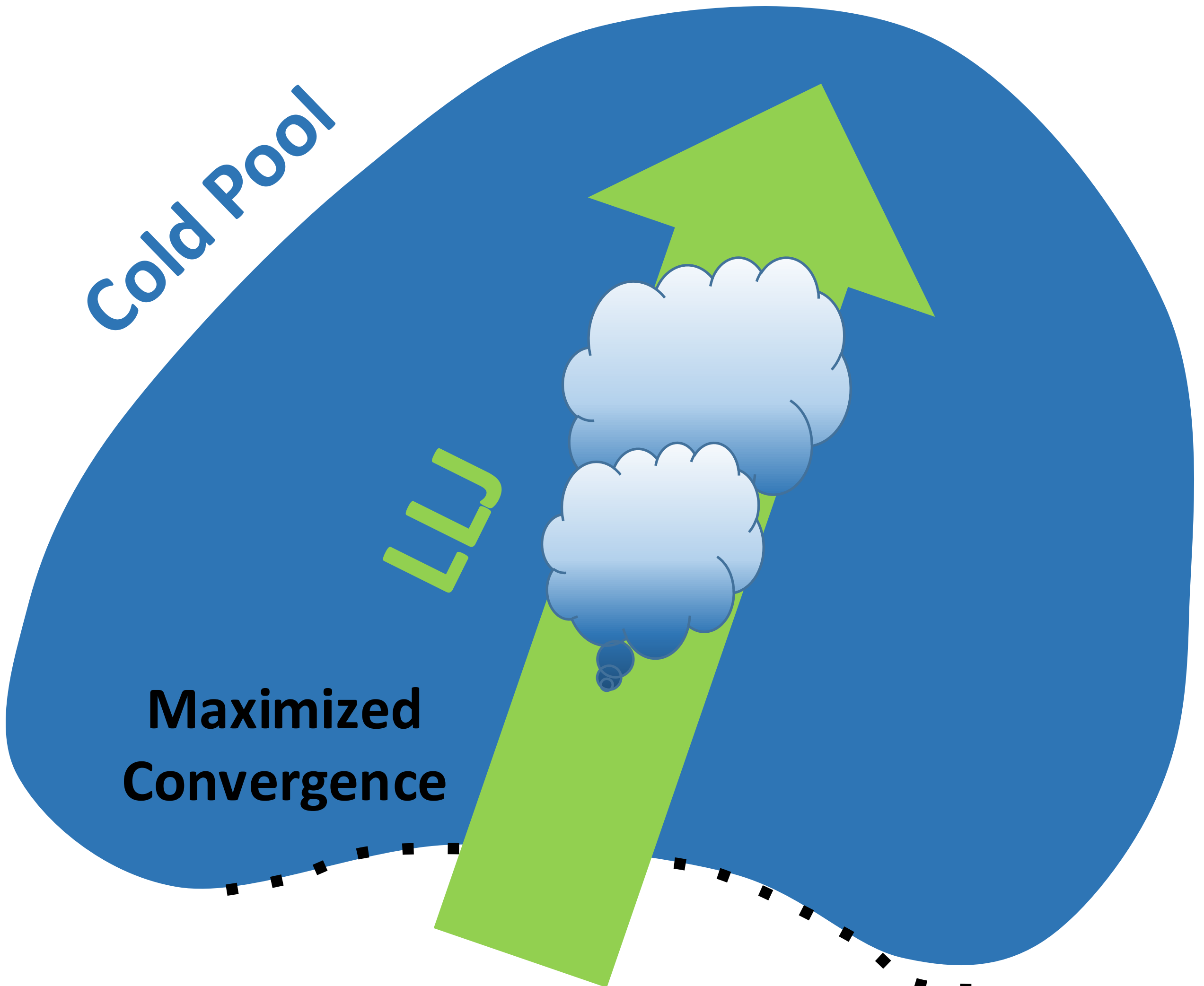

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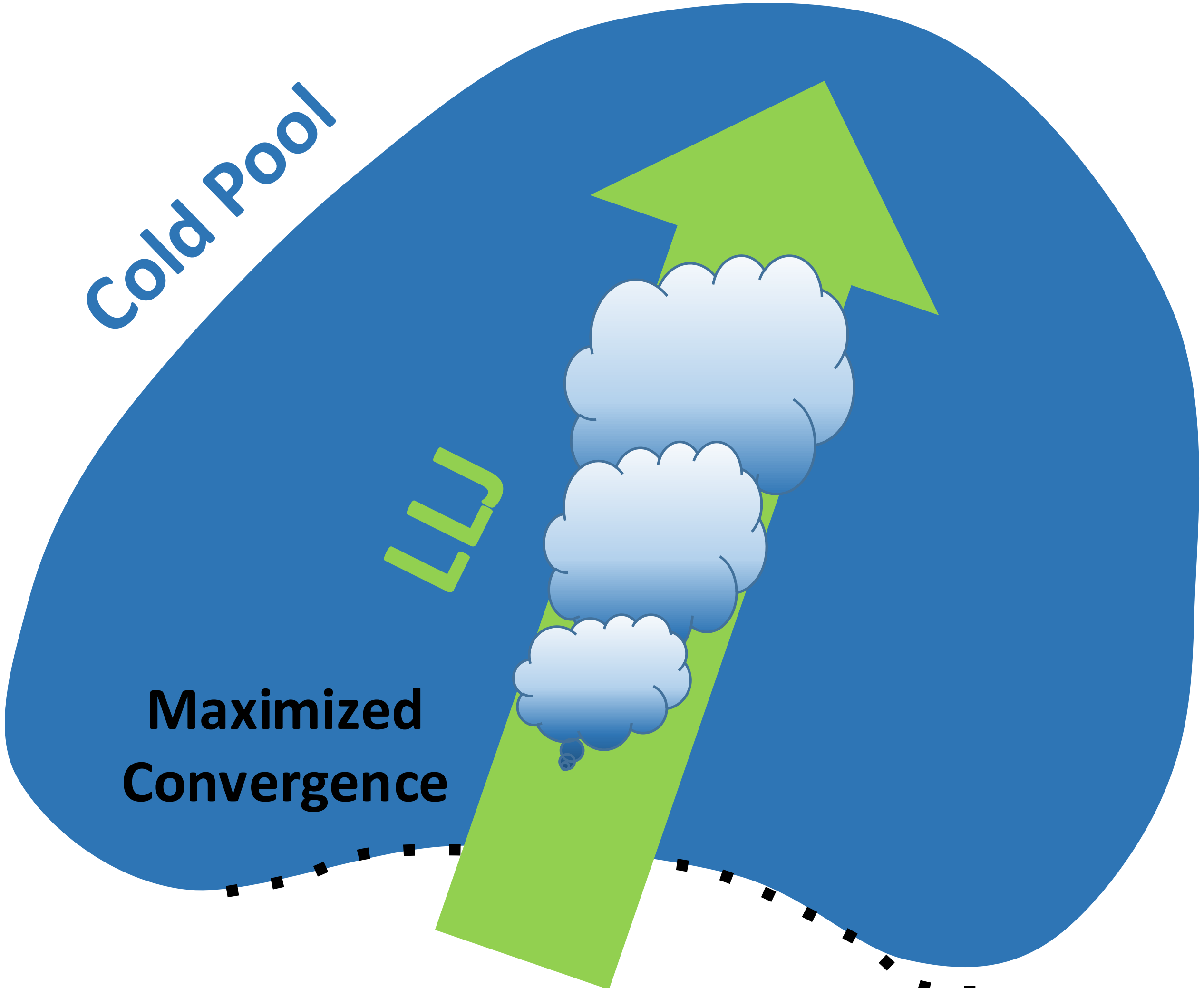

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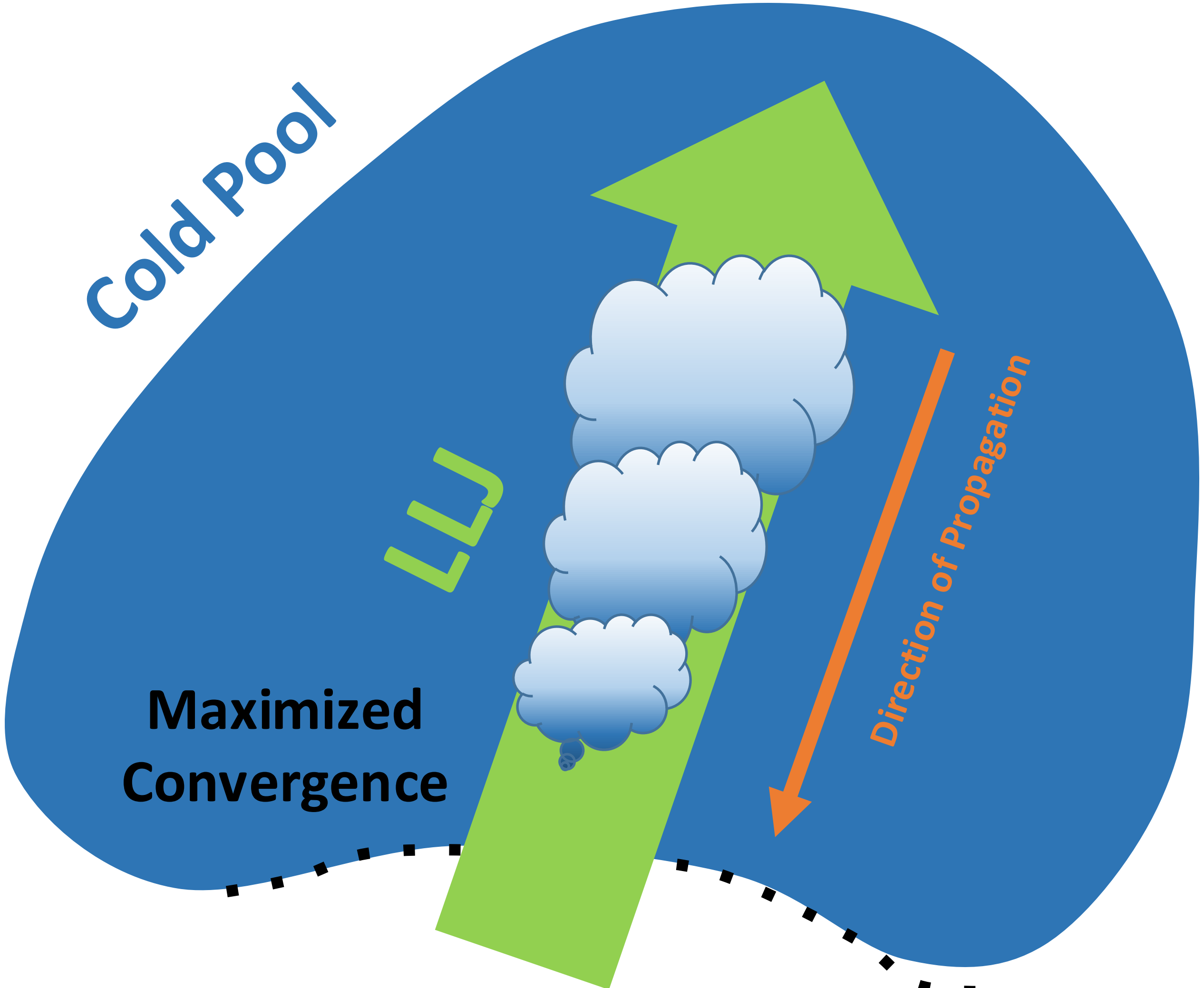

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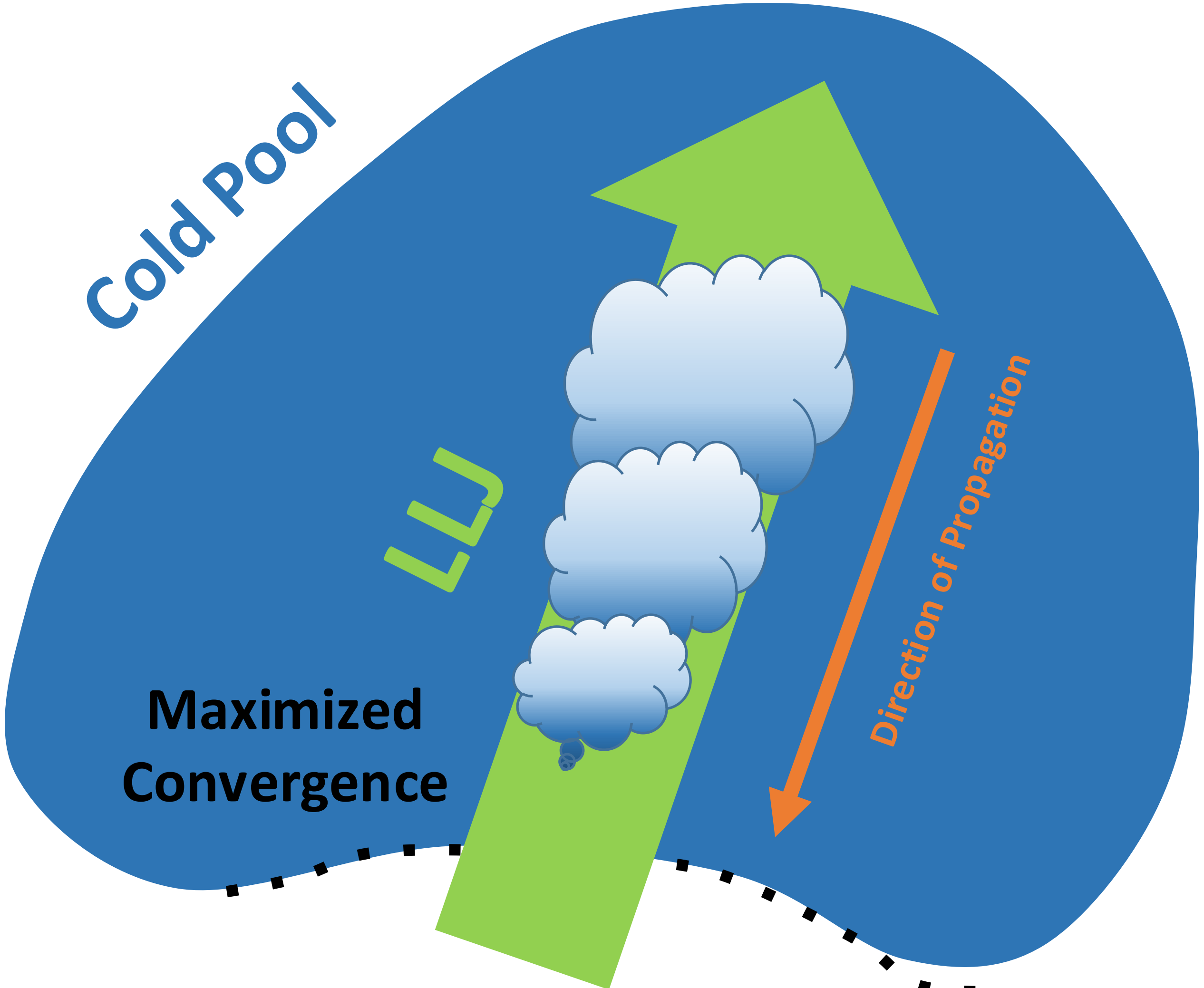

$V_{-LLJ} = V_{Prop}$

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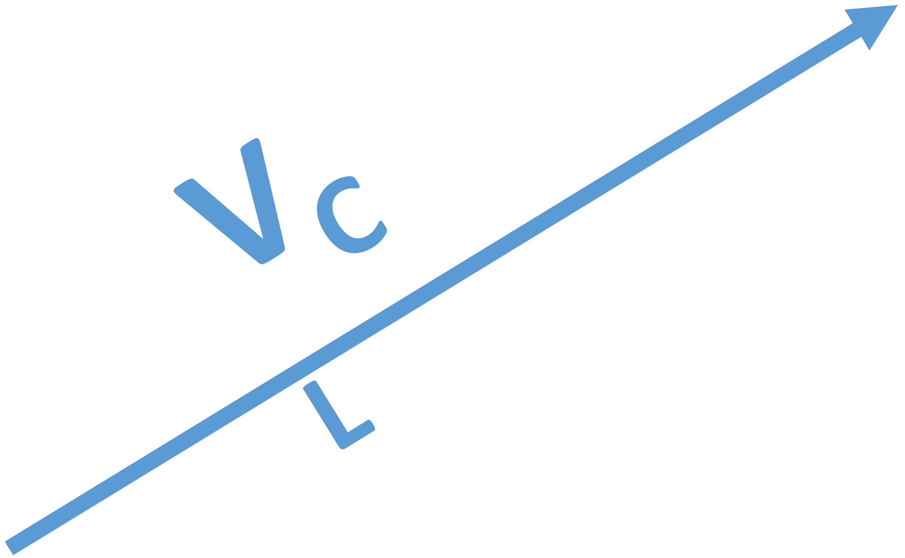

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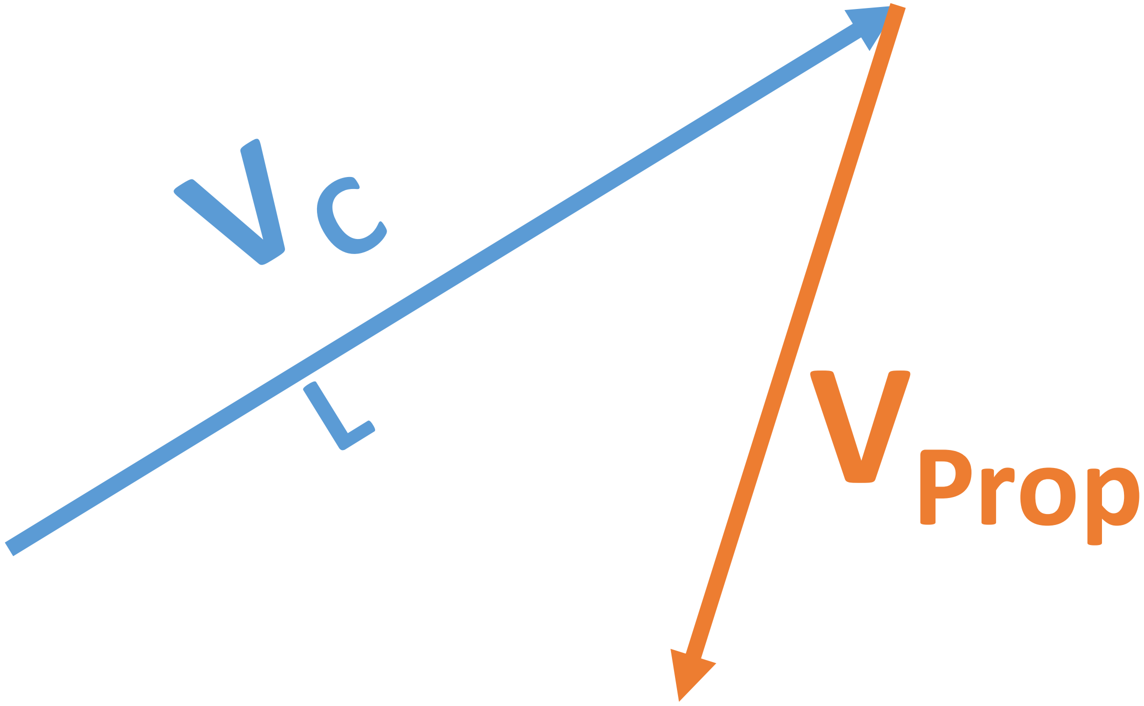

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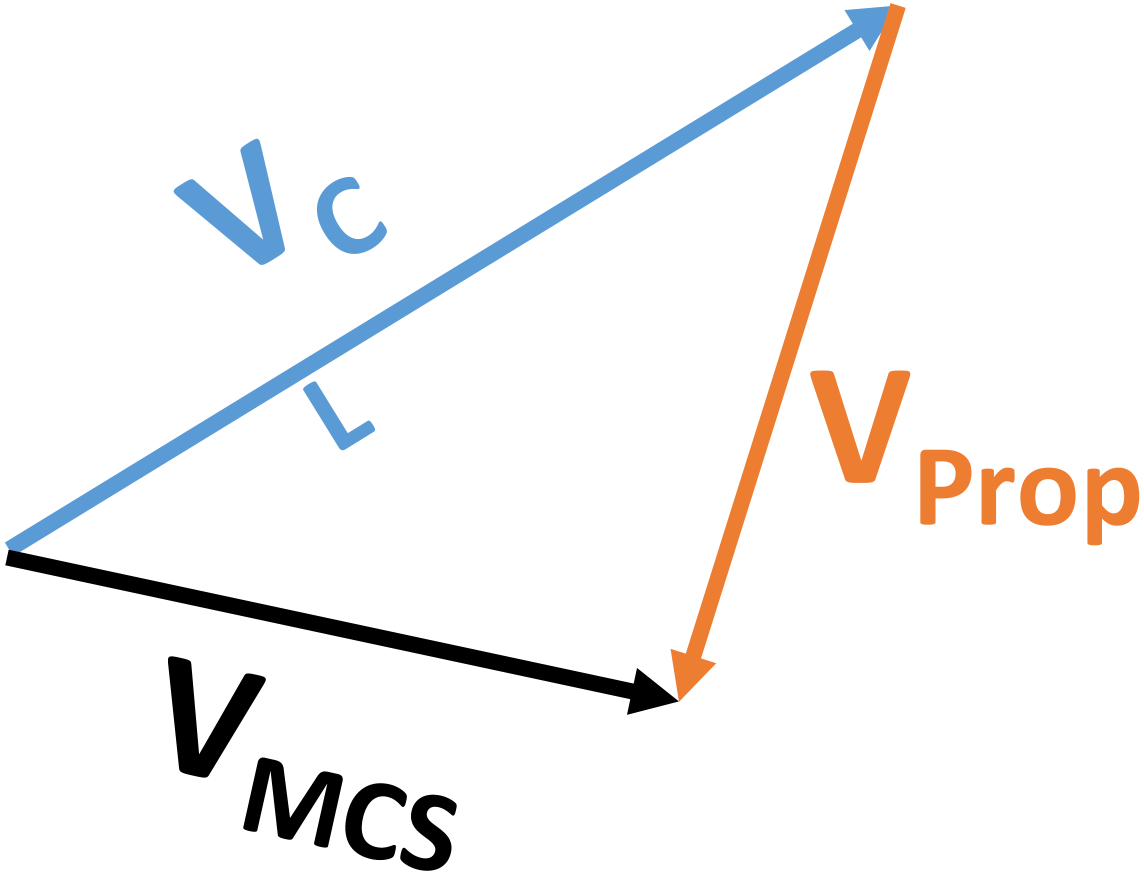

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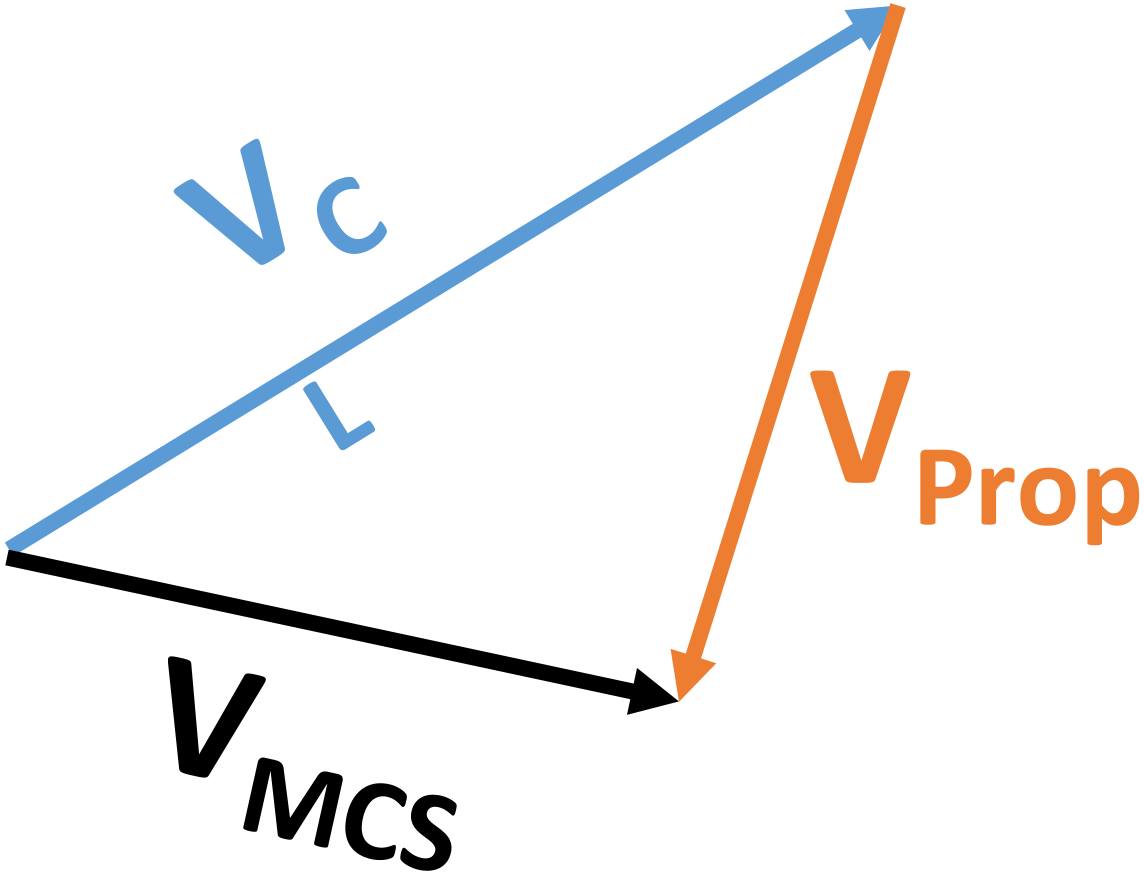

$$V_{MCS} = V_{CL} + V_{Prop}$$

OR

$$V_{MCS} = V_{CL} - V_{LLJ}$$

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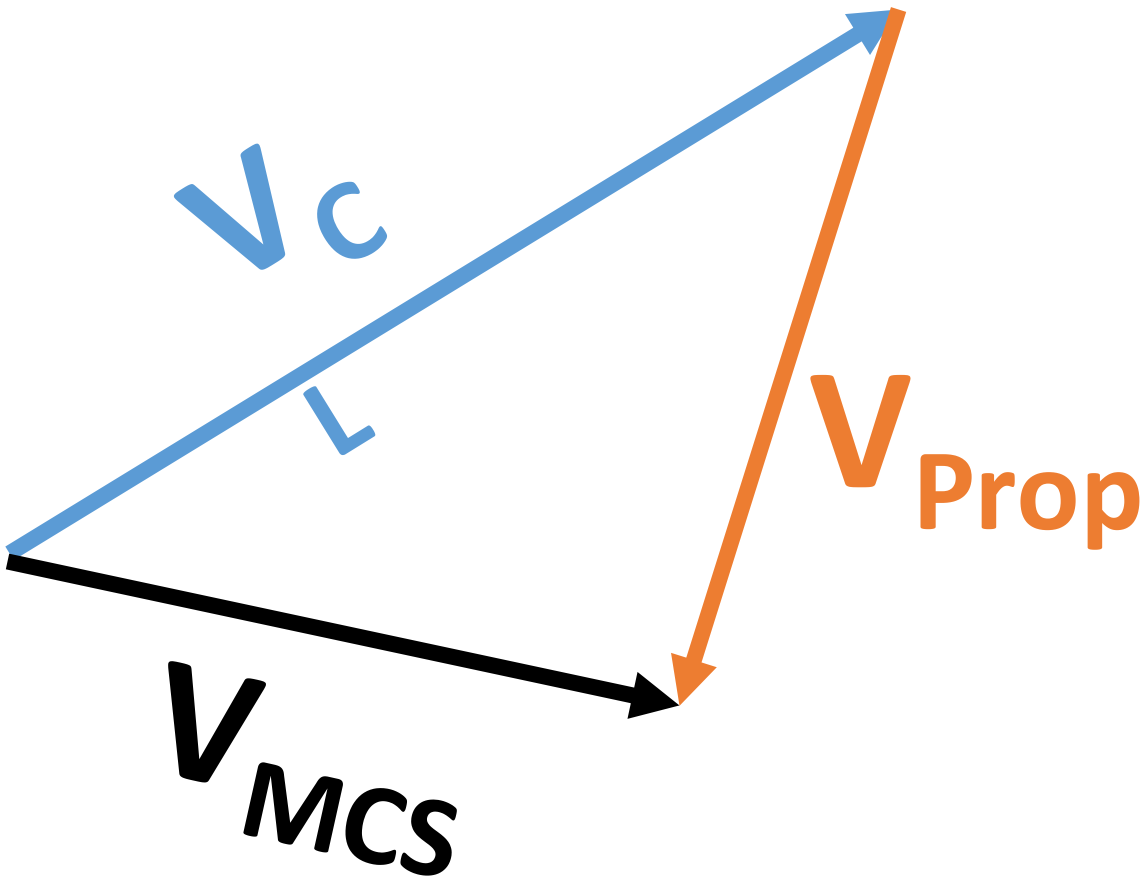

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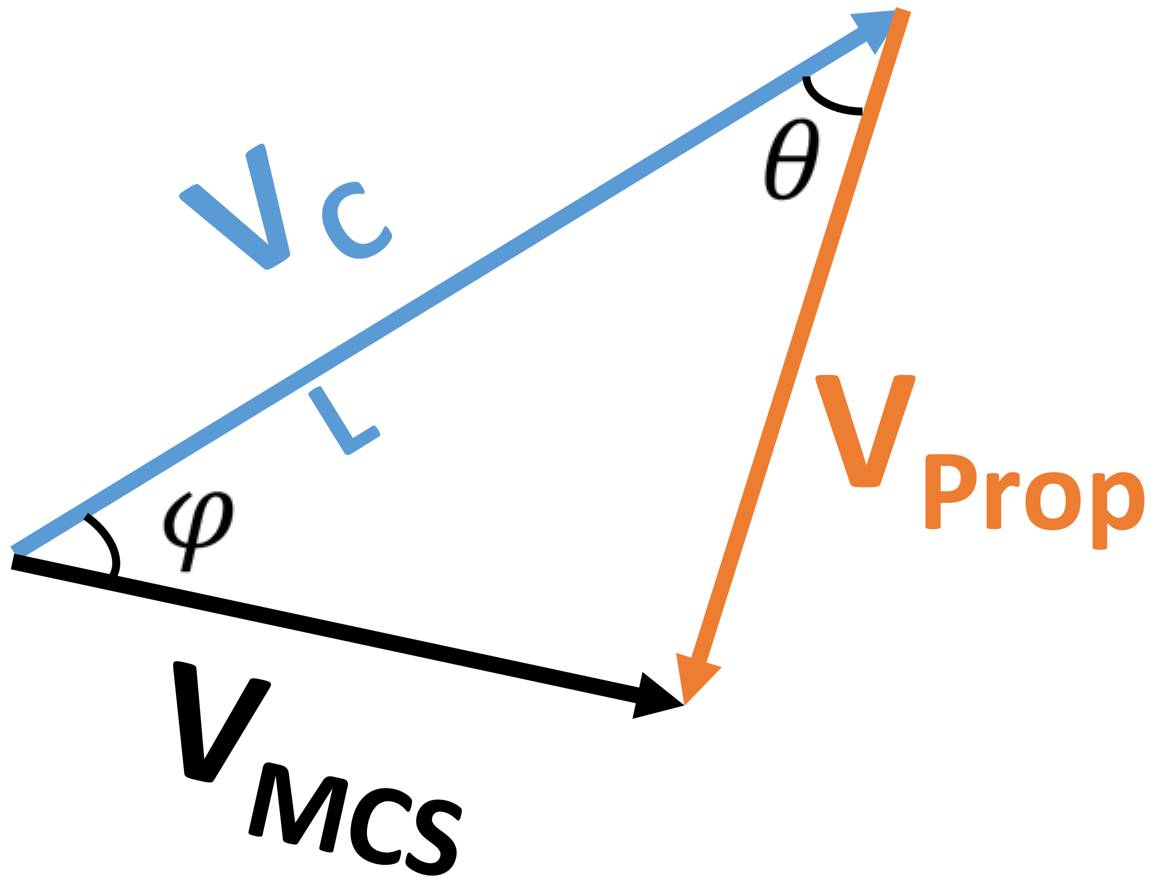

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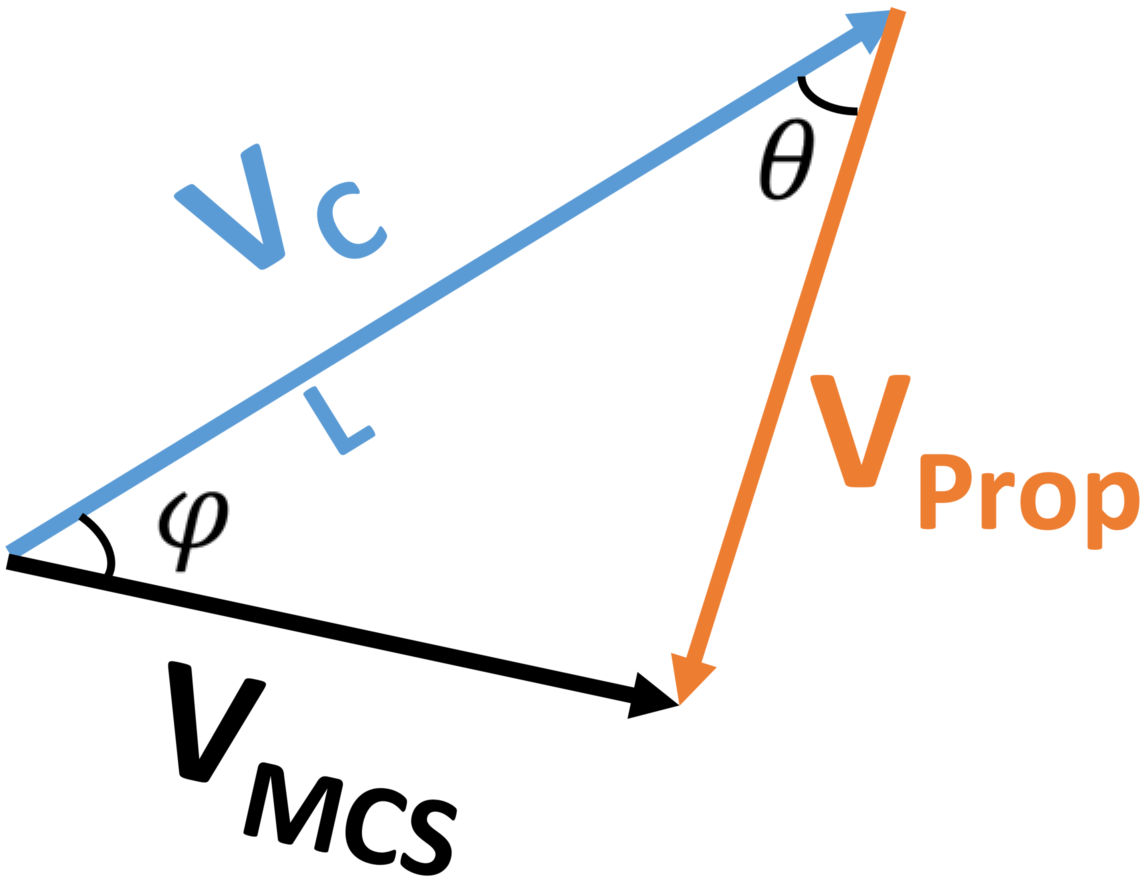

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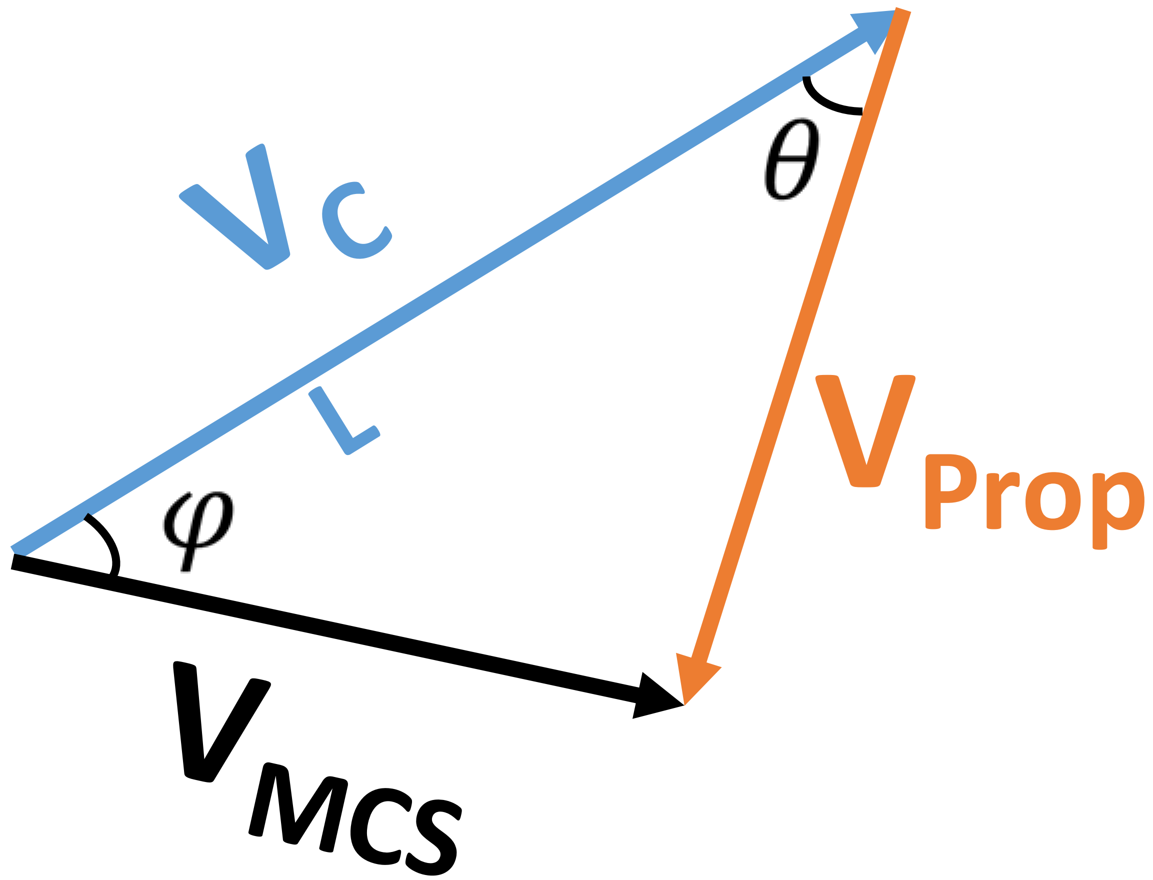

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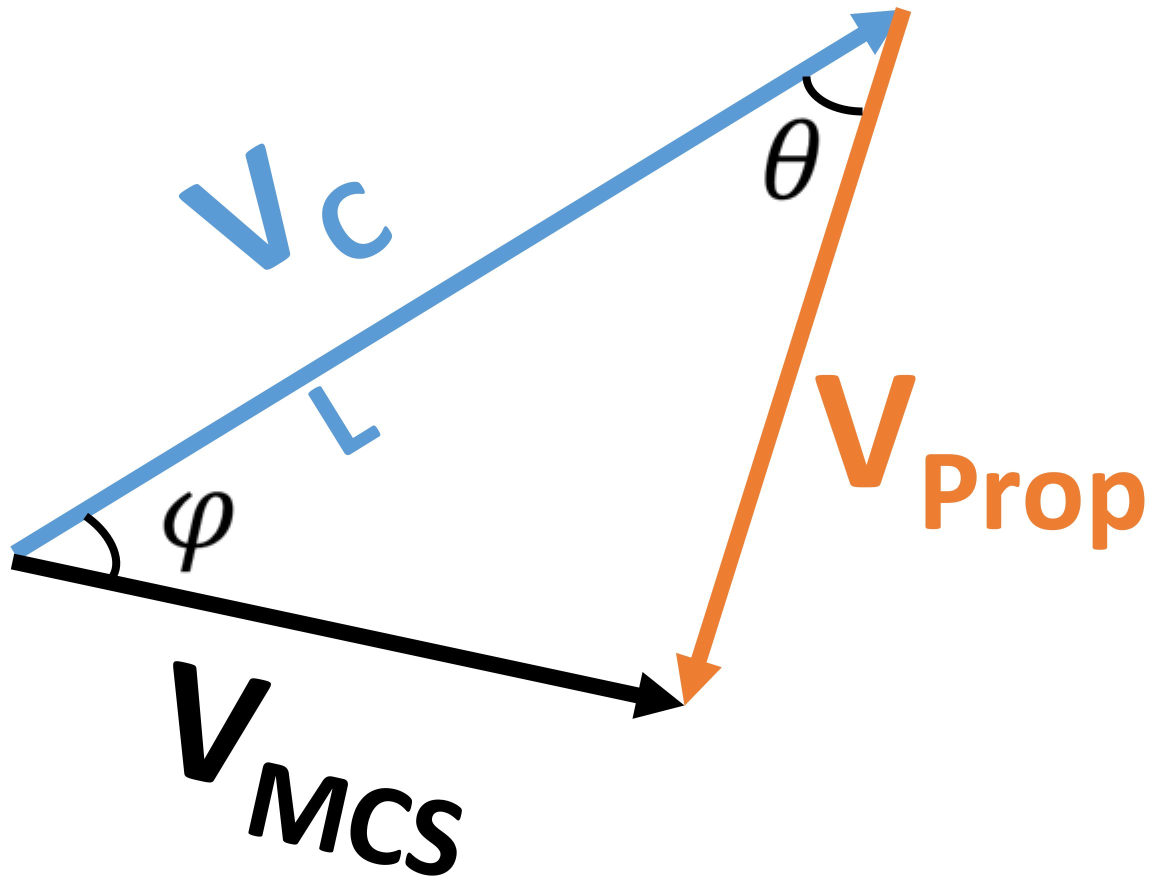

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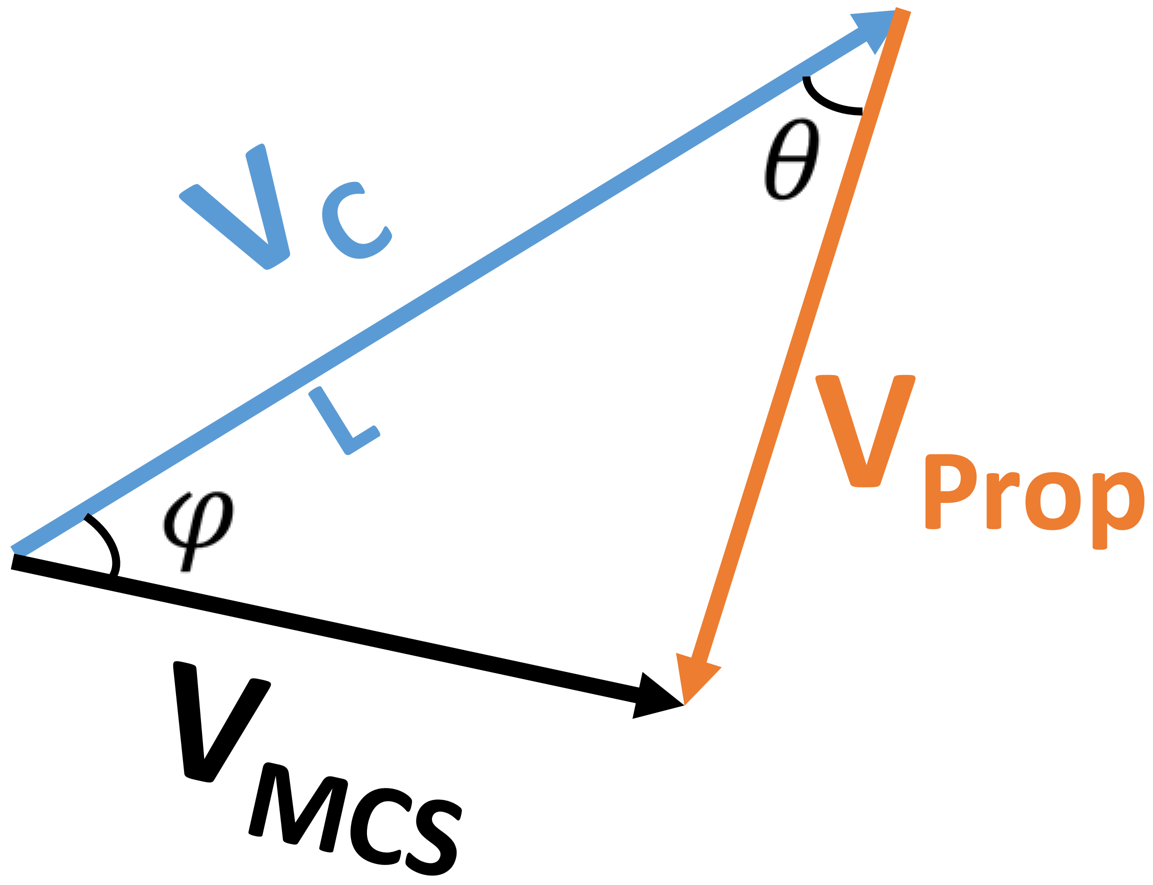

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$$\varphi = \arcsin\left(\frac{|V_{Prop}| * \sin(\theta)}{V_{MCS}}\right)$$

$$|V_{MCS}| = \sqrt{|V_{CL}|^2 + |V_{Prop}|^2 - 2\left(|V_{CL}| * |V_{Prop}|\right)cos\theta}$$

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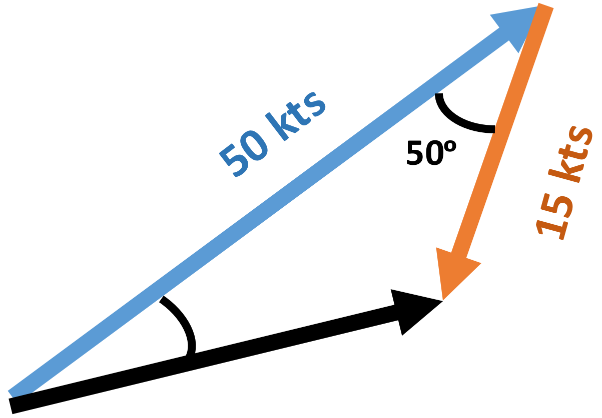

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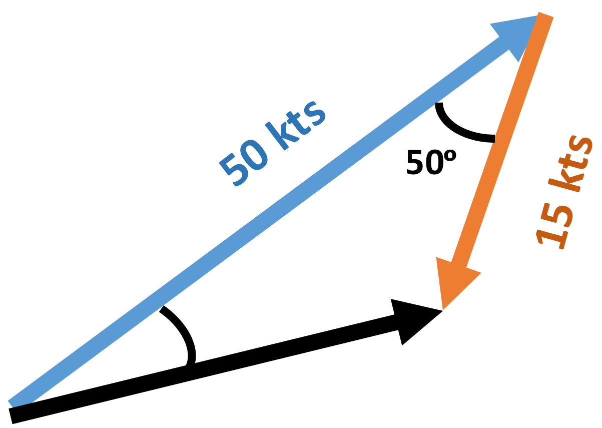

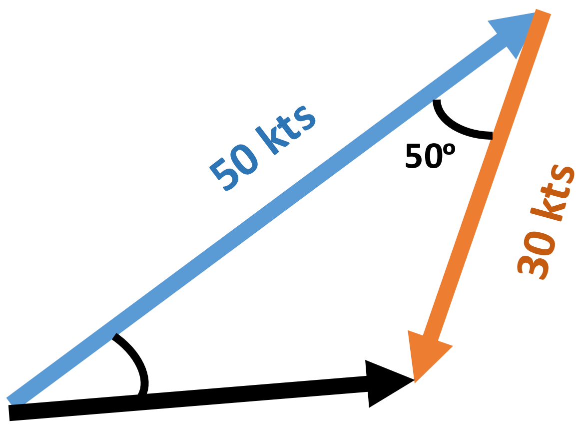

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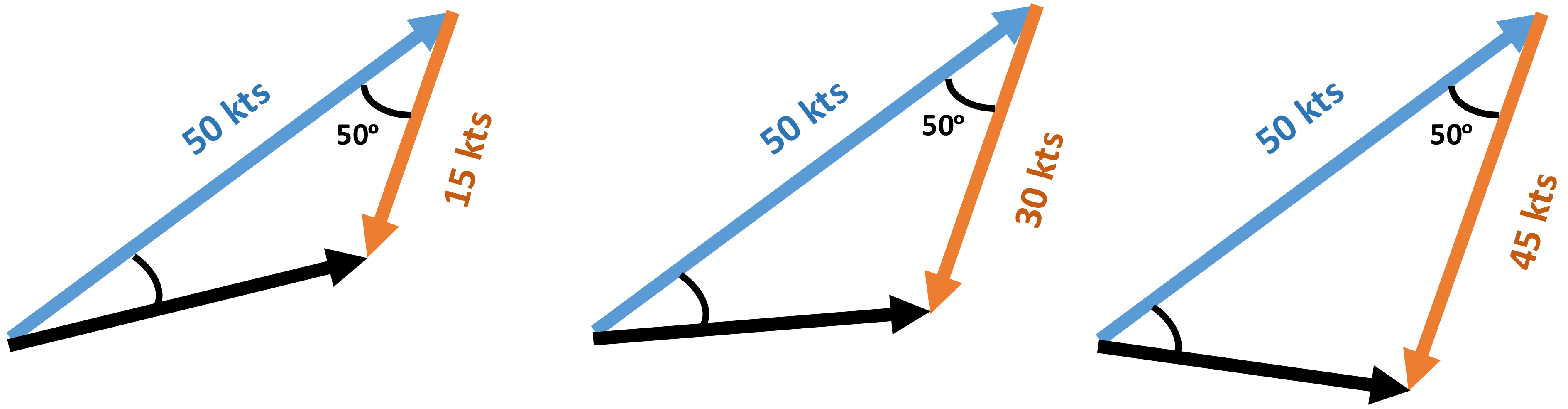

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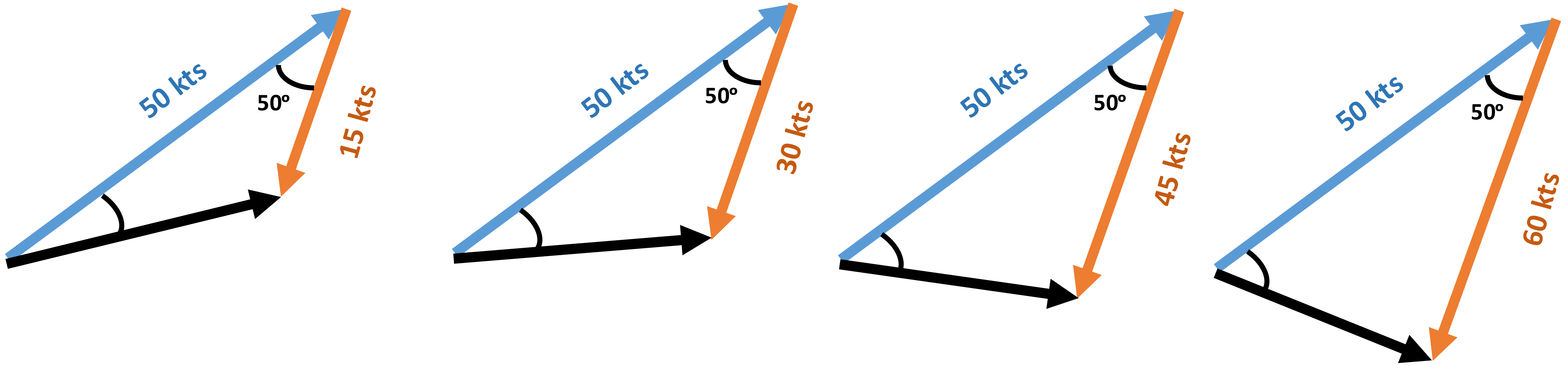

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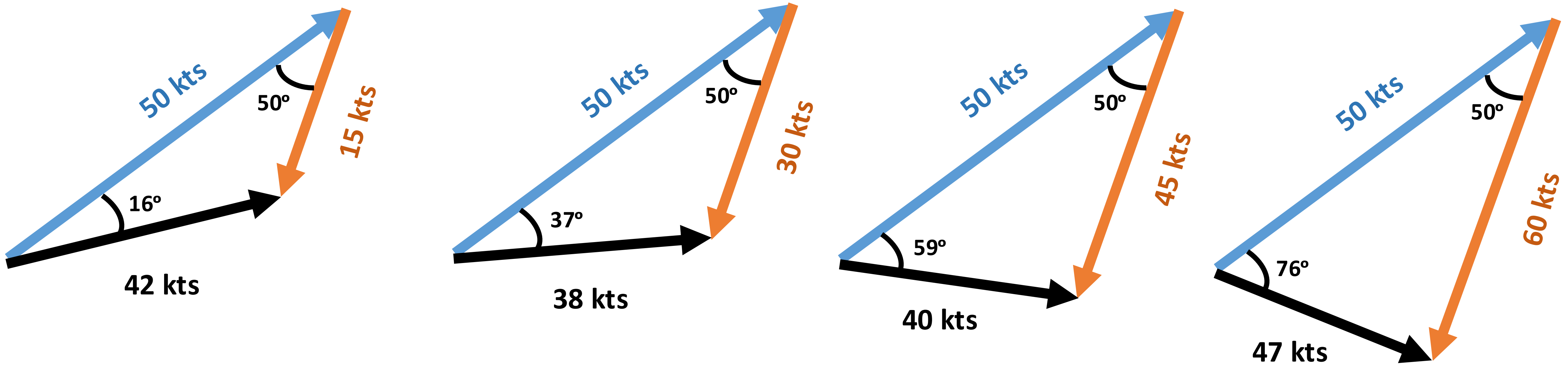

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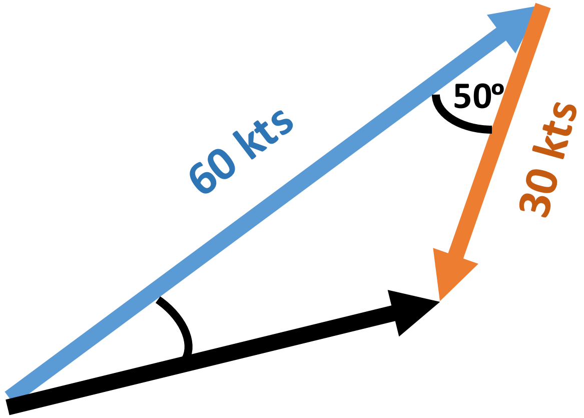

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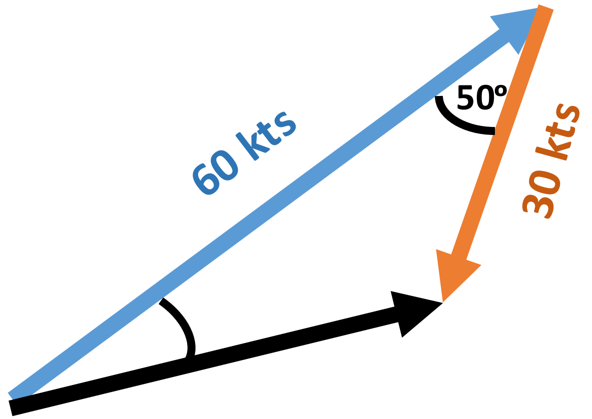

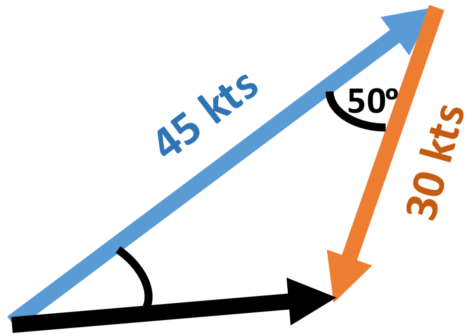

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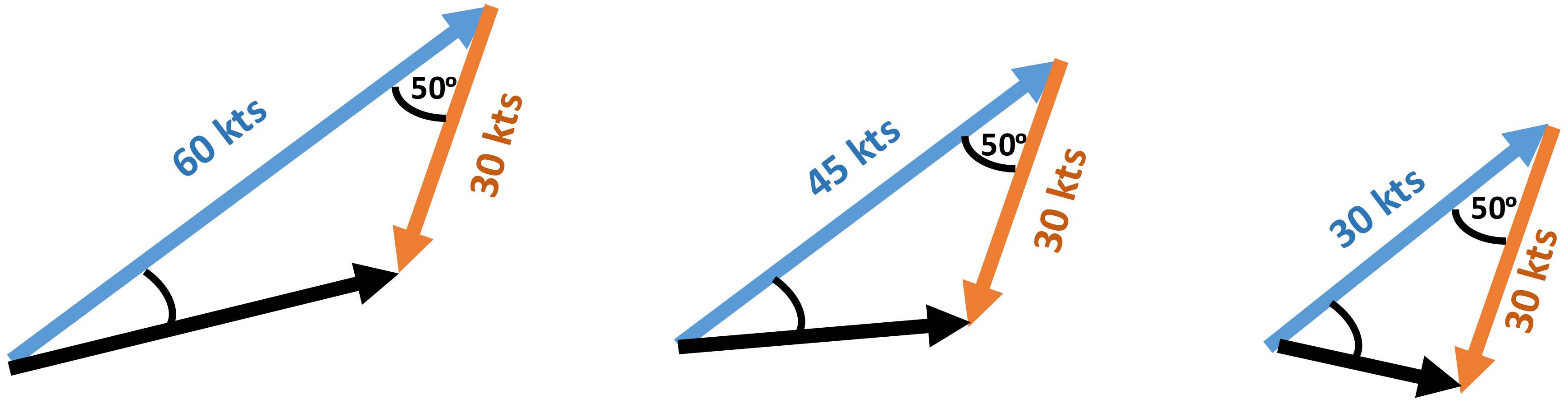

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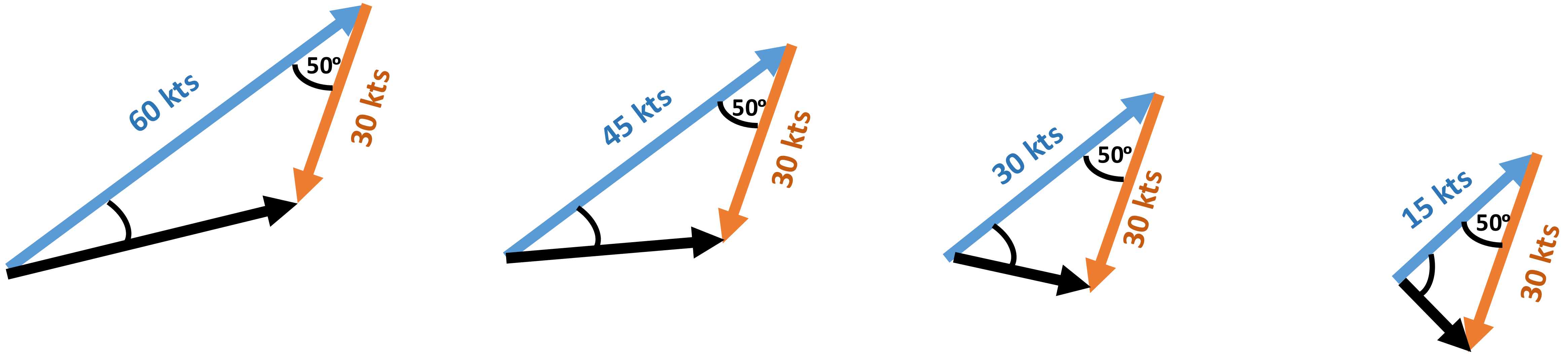

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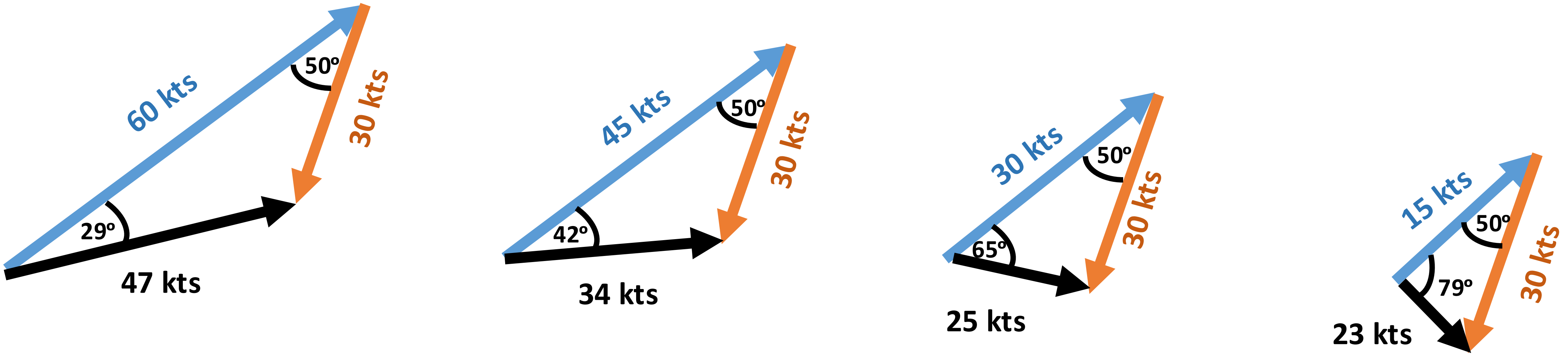

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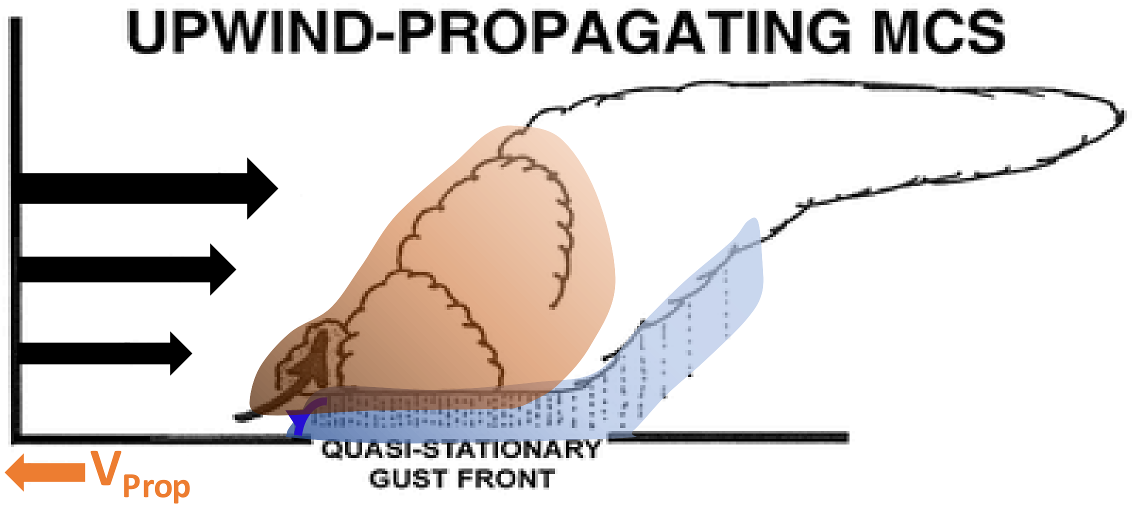

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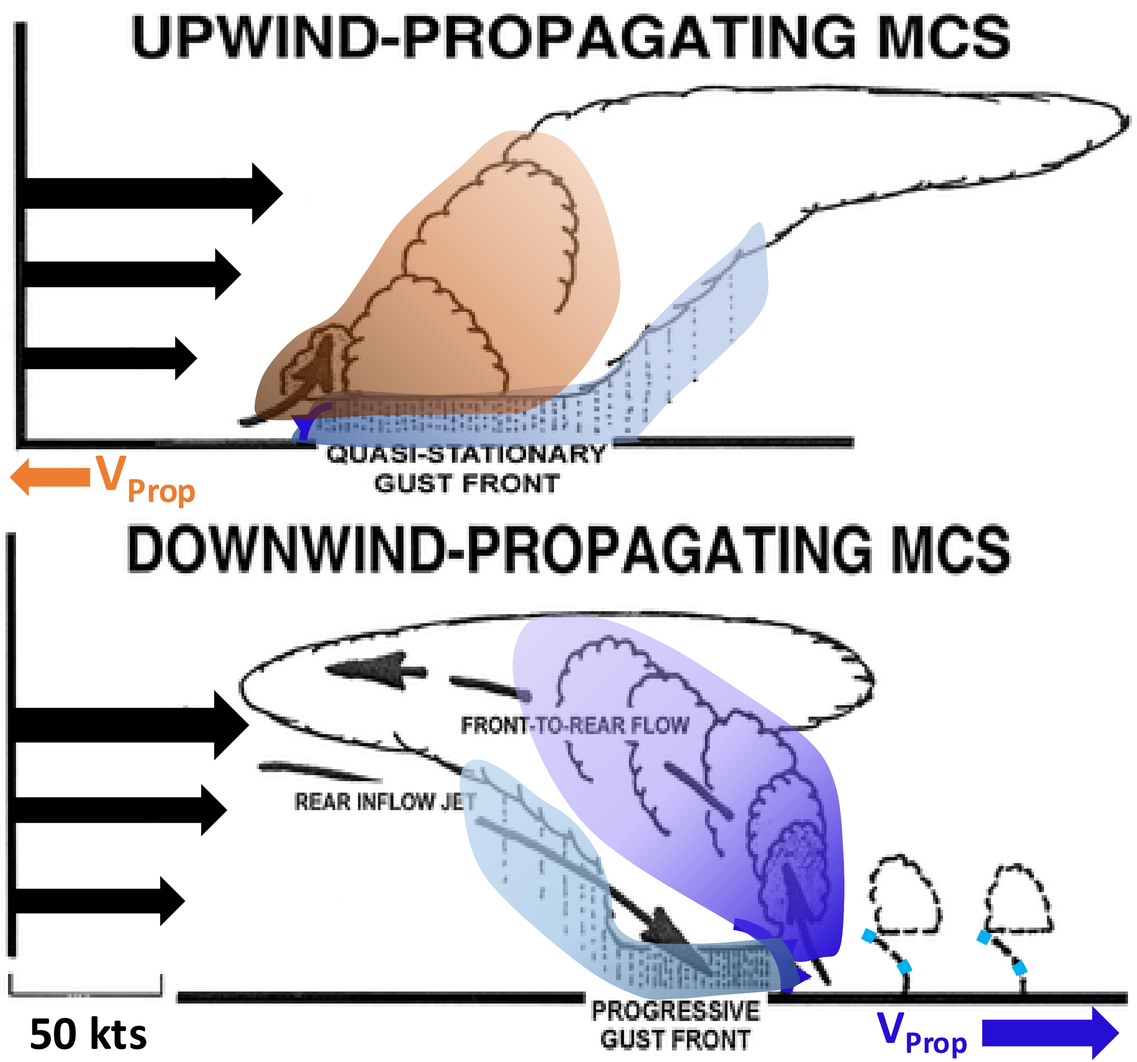

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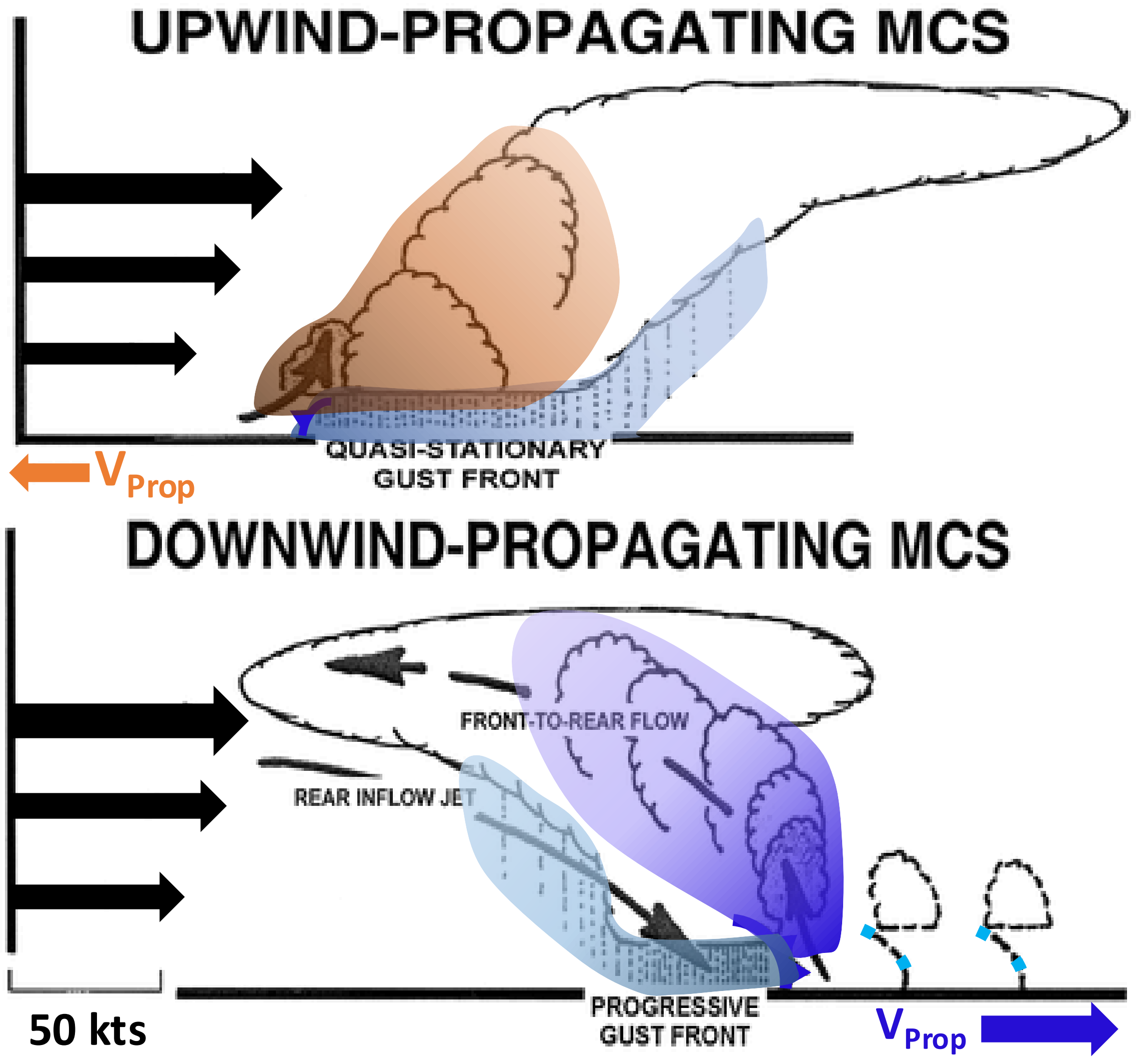

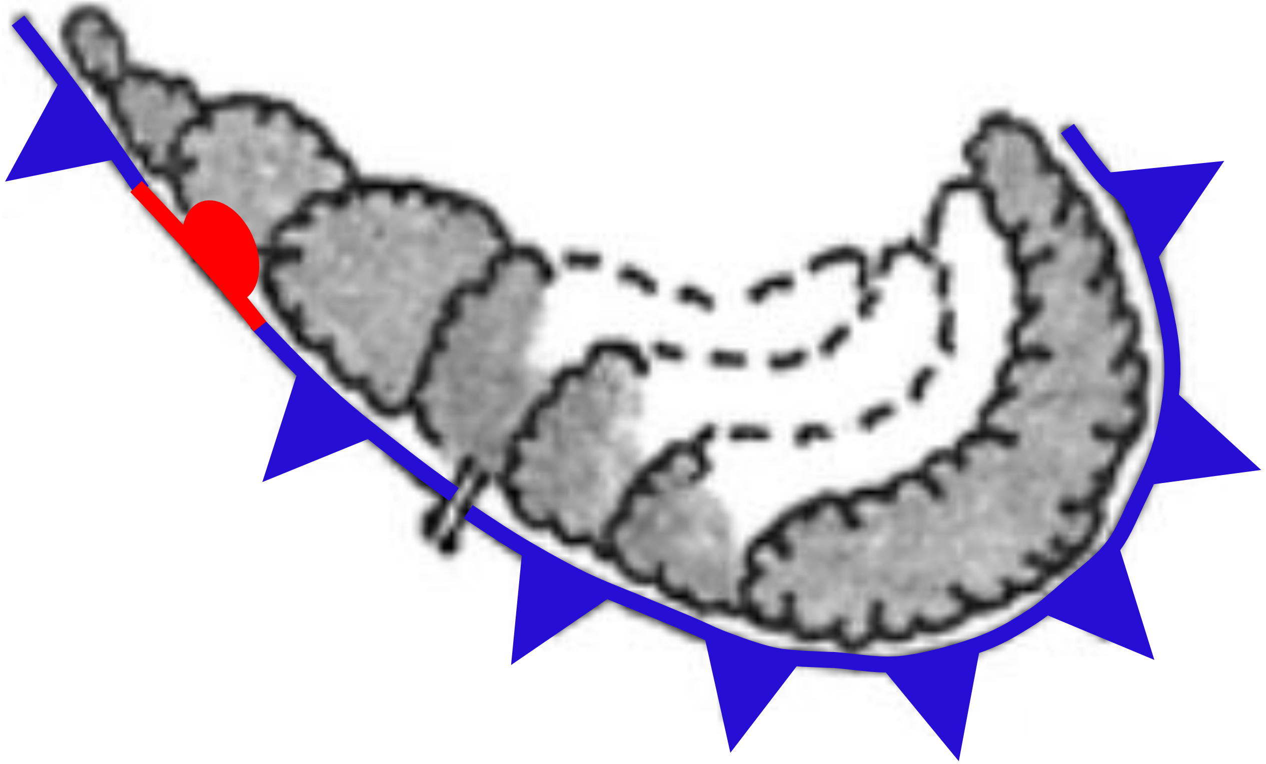

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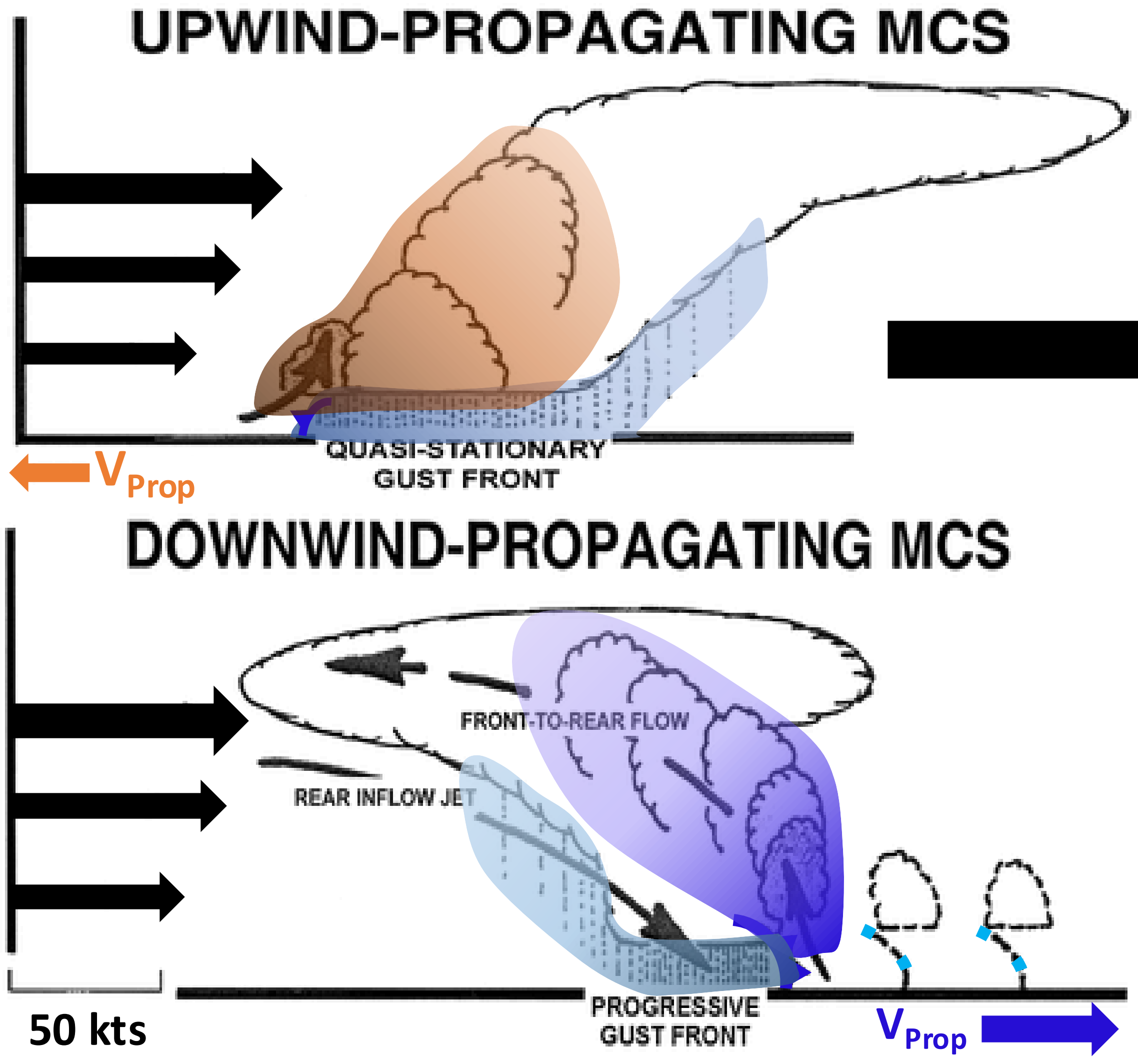

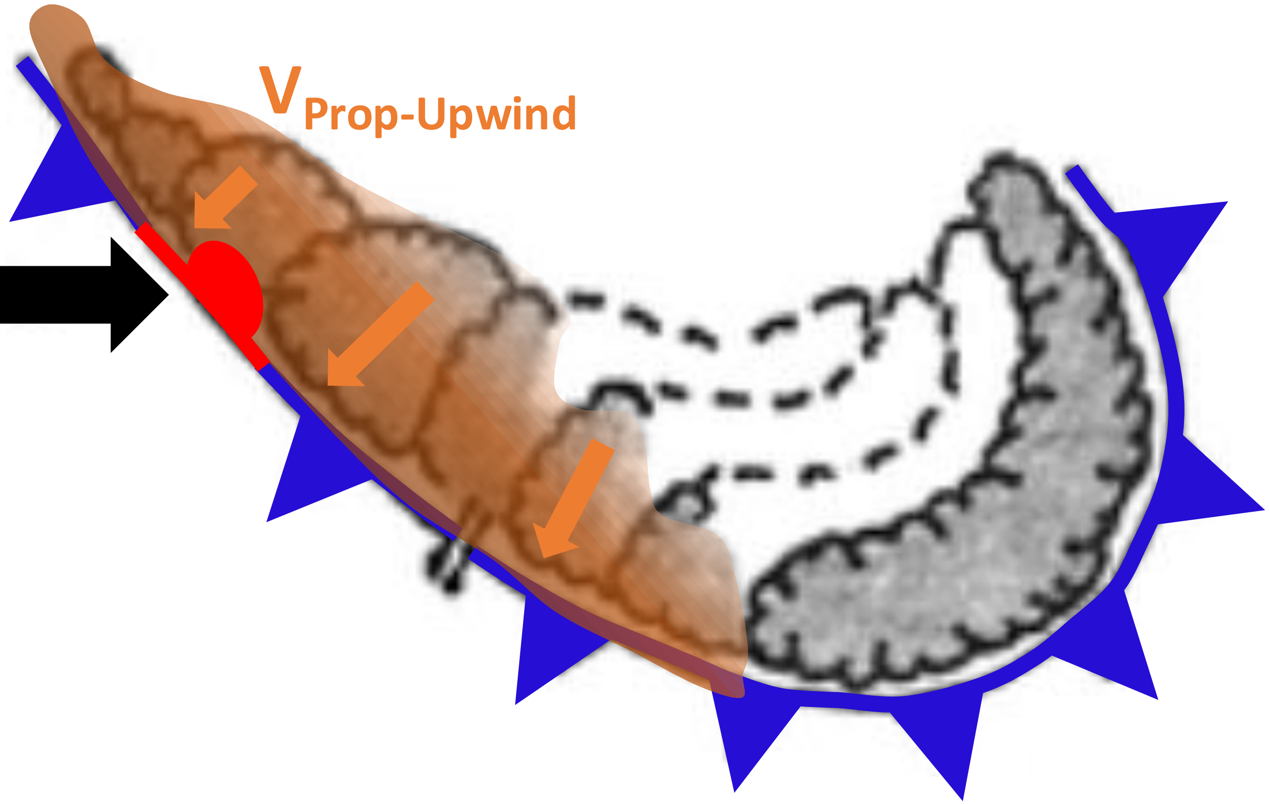

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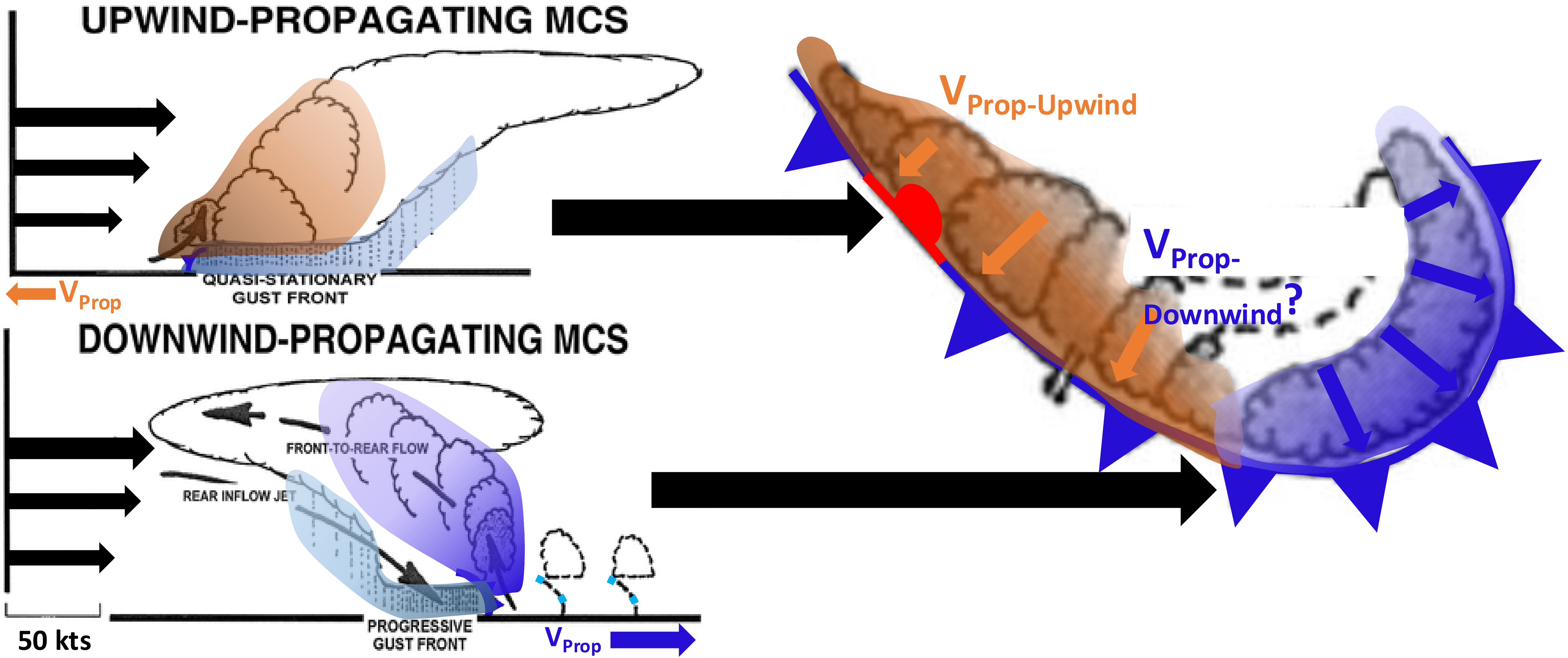
- Corfidi et al. (1996) demonstrated how to account for upwind propagation. What about downwind propagation?



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- What about the cold pool? Studies have shown that MCS forward speed is dependent on cold pool evolution (Charba 1974; Newton and Fankhauser 1975; Betts 1976; Miller and Betts 1977).

MCS Forward Motion Factors

- In reality, MCS forward motion is influenced by 3 factors: Mean Wind Speed - V_{CL}, Upwind (low-level-convergence-driven) propagation - $V_{Prop\text{-}Upwind}$, and Downwind (cold-pool-driven) propagation – $V_{Prop\text{-}Downwind}$ (Corfidi 2003).

- However, the Corfidi et al. (1996) $\mathbf{V_{MCS}}$ vector already takes into upwind propagation, so we can substitute this vector in as a component of MCS motion. Henceforth, we will call the '$\mathbf{V_{MCS}}$' vector '$\mathbf{V_{upwind}}$'.

MCS Forward Motion Factors

- Again, the components of MCS forward motion are additive, so we add V_{CL} and $\mathbf{V}_{\mathbf{upwind}}$ to get $\mathbf{V}_{\mathbf{downwind}}$. As such,

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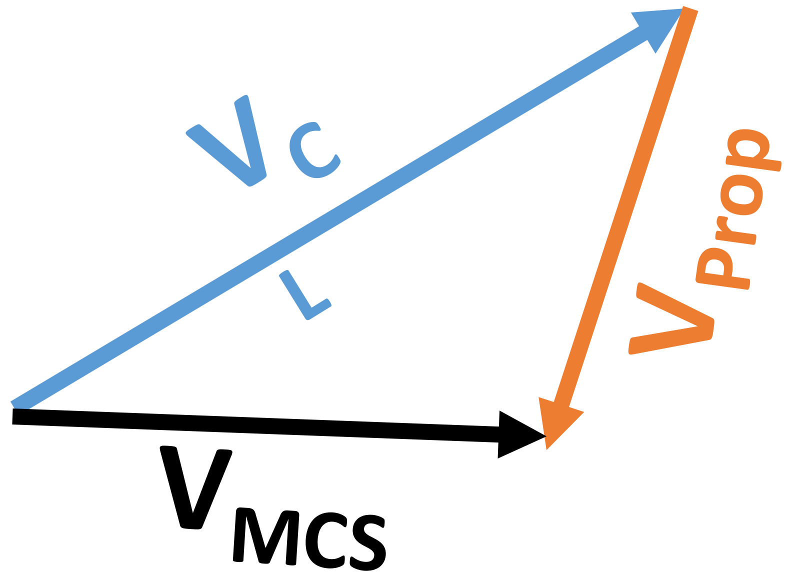

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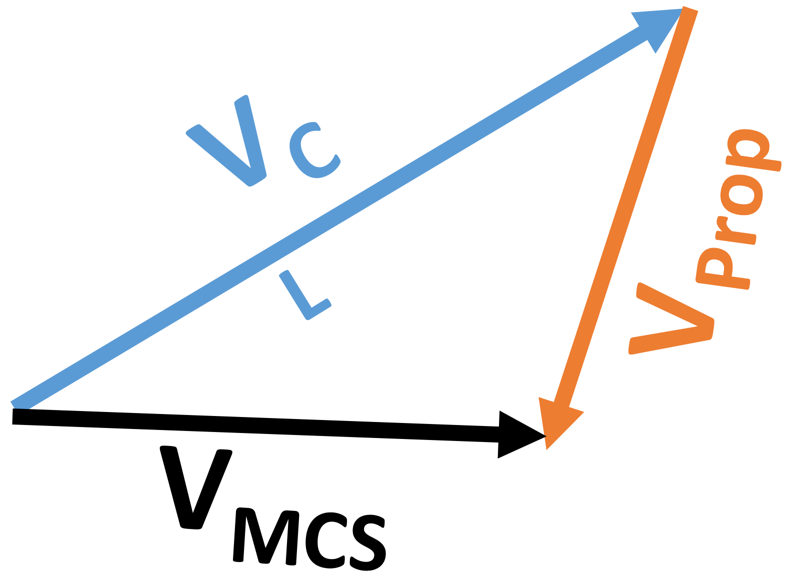

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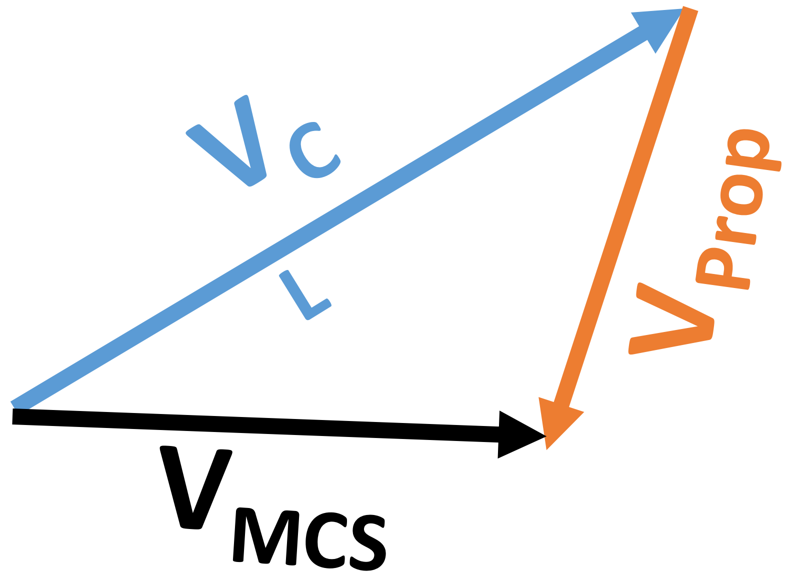

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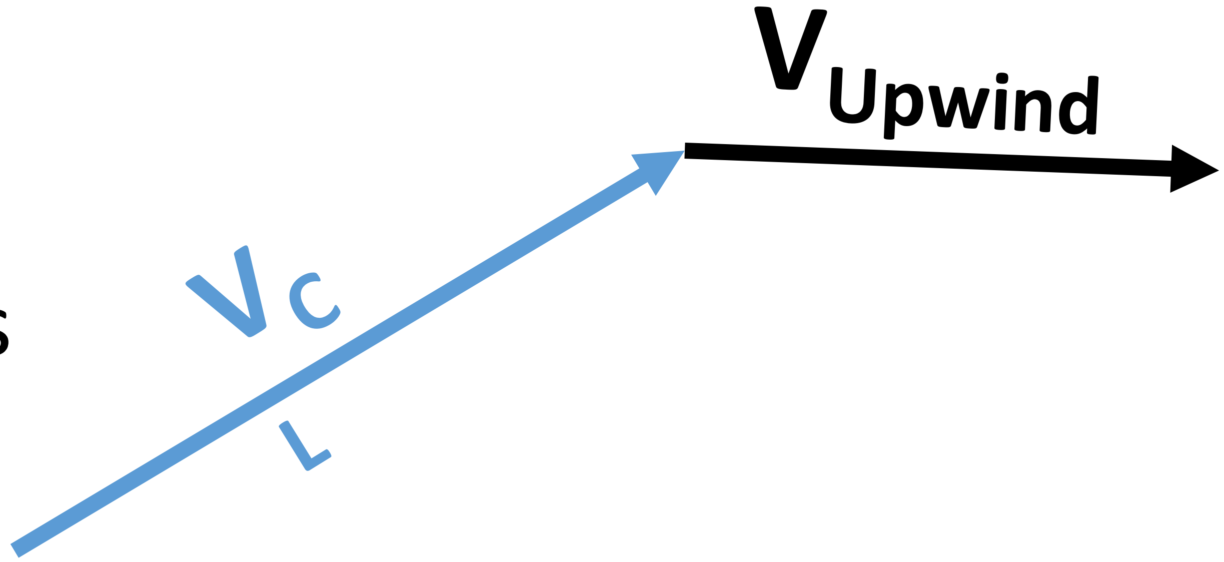

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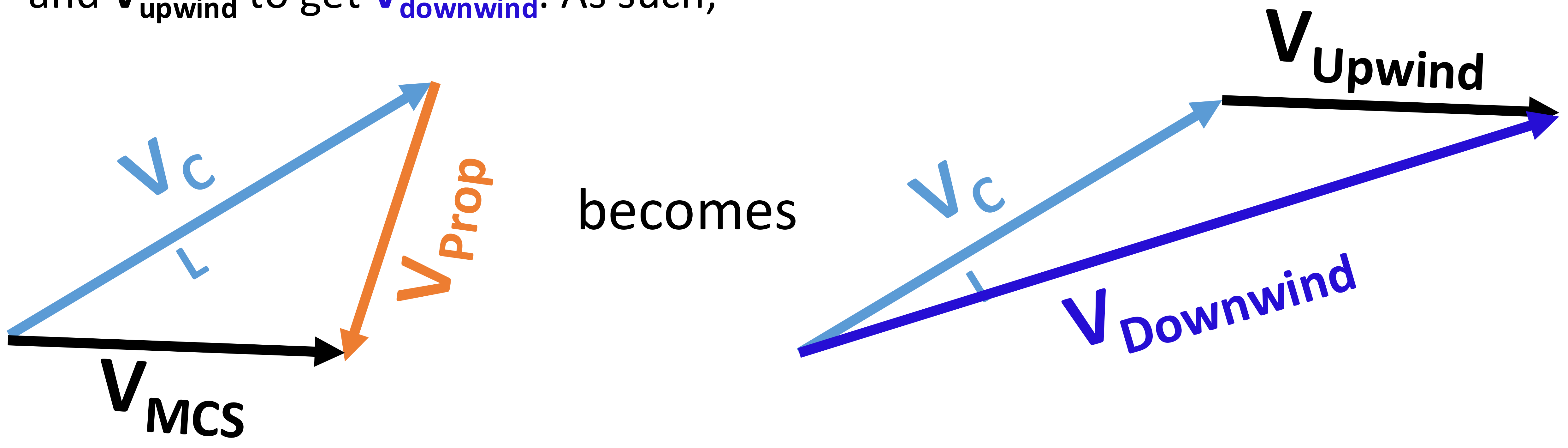
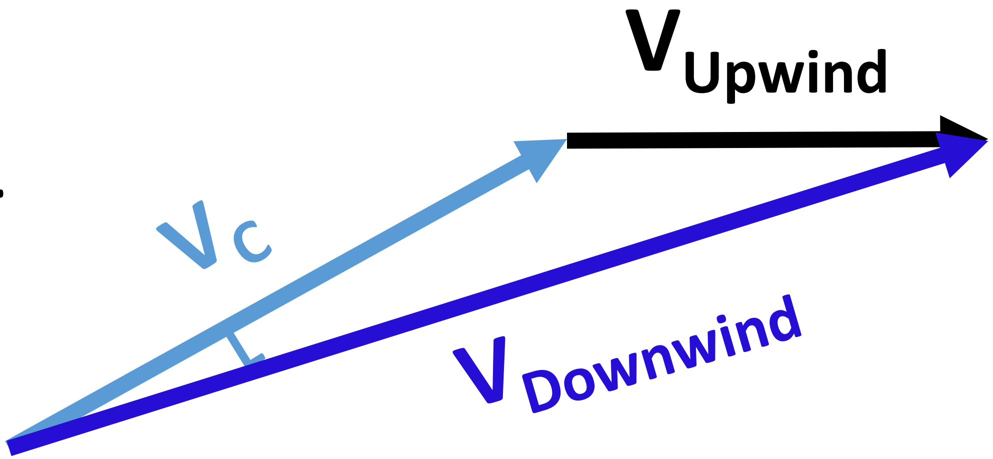


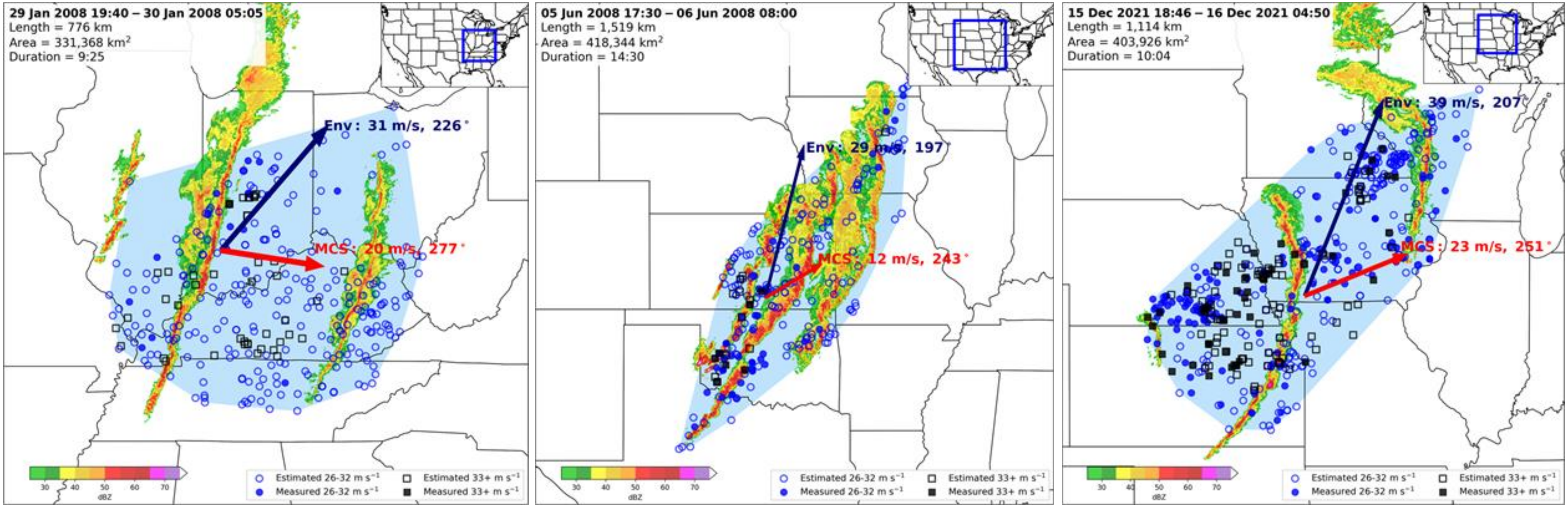
Where $\mathbf{V}_{\mathbf{MCS}} = \mathbf{V}_{\mathbf{Upwind}}$

MCS Forward Motion Factors

- Downwind-propagating MCSs are dominated by the cold pool, and derechos are also produced by cold-pool-driven MCSs, which are dominated by internal forcing mechanisms.
- As such, $\mathbf{V}_{\mathbf{downwind}}$ would be a useful vector for monitoring derecho progression.
- Note that $\mathbf{V}_{\mathbf{downwind}}$ is a longer vector than V_{CL}.



MCSs moving faster than the mean wind speed is an excellent discriminator between cold-pool-driven MCSs and their squall line counterparts.



Note: Cold-pool-driven MCSs and strongly forced squall lines both have degrees of internal and external forcing (i.e. a level of contribution from the cold pool

The argument is that to define derechos as a distinct phenomena, internal forcing mechanisms must dominate, which is defined by the MCS moving faster than the full mean wind speed.

References

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