The UNIVERSITY of NEWCASTLE AUSTRALIA

Critical Fire Weather Analysis

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Introduction

Part one:

- Essential concepts in meteorology.
  - Wind-Driven Fire
  - Fire Whirls
  - Plume-dominated fire
  - Horizontal vortices within a fire (This sequence shows that a "finger" of fire burst forward about 100 meters from the head of the fire at speeds exceeding 100 miles per hour, and then retreated back into the fire within three seconds, **("Finger Of Death“).**
  - Fire Weather in New South Wales

Part Two:

Comprehensive weather analysis checklist is developed to successfully assist fire weather investigators.

Part Three:

- Meso - Scale wind regime
- Mechanical Turbulence
- Relative humidity
- Influence of topography

Extreme Fire Behaviour

- Extreme fire behaviour results when several of the components of the fire environment interact to cause the rate of spread of the fire to increase by 60 times or greater.

- Situations in which abundant fuels with sufficiently low moisture values are located on a steep slope and combine with strong winds and unstable atmospheric conditions can lead to extreme fire behaviour.

- Each of the conditions can potentially increase fire behaviour, so when all of these conditions occur at the same time, the potential danger increases significantly.

Extreme Fire Behaviour

- Extreme fire behaviour is generally defined as fire behaviour that often precludes methods of direct fire suppression, and usually involves one or more of the following characteristics:
- High rate of spread and frontal fire intensity
  - Crowning
  - Prolific spotting
  - Presence of large fire whirls
  - Well-established convective column
- Fires exhibiting such phenomena often influence the surrounding environment and create dangerous conditions.

- Other terms used to describe extreme fire behaviour include “blow-up”, "fire storm", "flare-up" and "fire behaviour in the third dimension

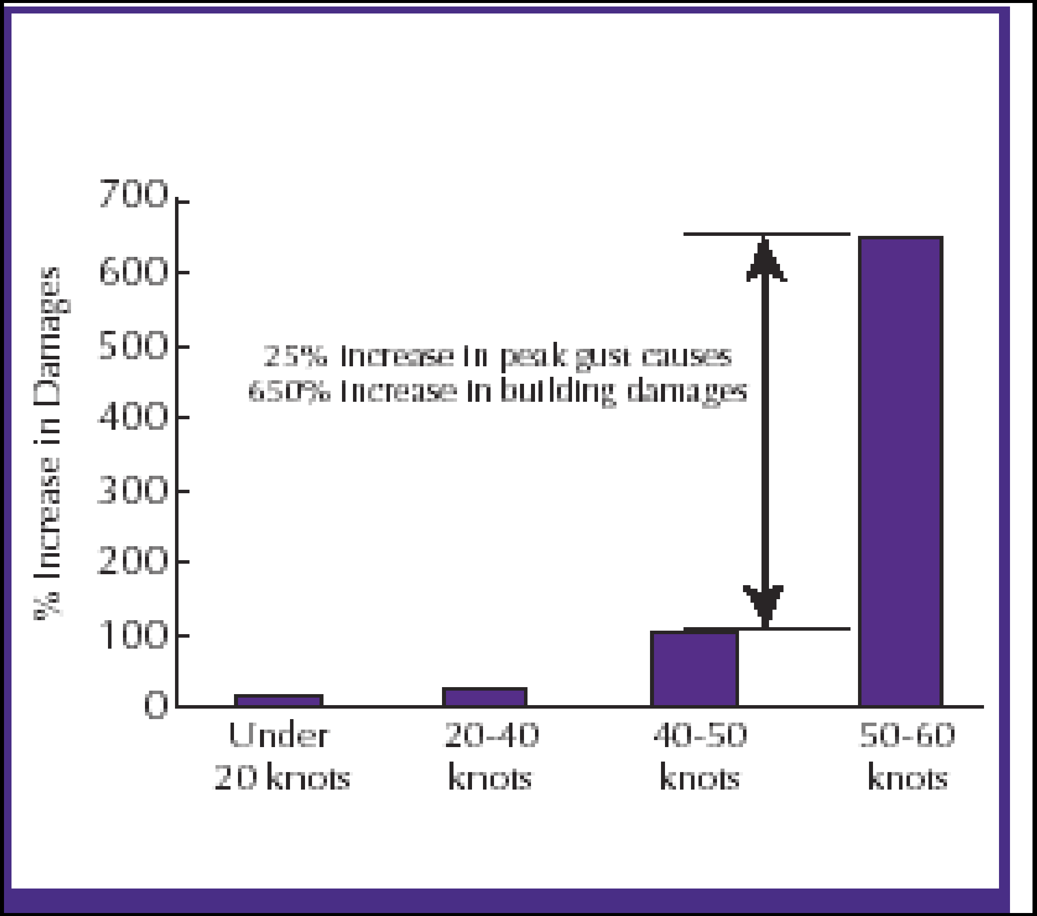
Changes to the Bureau's Fire Weather Warnings and Forecasts

- The Bureau of Meteorology is changing the way fire danger is rated within its weather forecasts and warnings.
- What's changing?
- The Extreme category is being divided into three levels - Severe, Extreme and Catastrophic (Code Red).
- These new levels are based on the Forest Fire Danger Index (FFDI) and the Grass Fire Danger Index (GFDI).

The new Fire Danger Ratings

- Severe fire danger will be indicated when FFDI/GFDI is between 50 and 74
- Extreme fire danger will be indicated when FFDI/GFDI is between 75 and 99
- Catastrophic (Code Red) fire danger will be indicated when FFDI/GFDI is 100 or above

Insurance claims Versus peak wind gust speeds



Insurance Group Australia building claims Versus peak wind gust speeds, Showing disproportionate increase in claims coast from small increases In peak gusts causing 650% increase in building damages (1 knot=0.5m/s)

Australian fire falls into broad classes

1. Type one: Fire behaviour can be predicated with reasonable accuracy, taking account of terrain and weather factors.
2. Type two: the behaviour is erratic.

- Majority of fires are type one, due to low intensity seldom exceeding 1000 BTU/sec/foot. (Note: BTU unit of heat equal to 1055 joules.
- By contrast, fire type two is of high intensity and usually large and very destructive, the term BLOW UP being applied to them.
- This type of fire sometimes appears suddenly on smaller fires.
- The intensity of BLOW UP fires can reach to 20,000 to 30,000 BTU/sec/foot of the fire front.

LOW- LEVEL WIND SHEAR DECISION TREE - ONE
Local effects are not addressed

Step #	Factor	Action Required
1	**Are thunderstorms forecast or observed within 10 NM ?**	**Yes, LLWS assumed** **No, go to step 2.**
2	**Is there a low-level jet below 2,000 ft ?**	**Yes, forecast LLWS.** **No, go to step 3.**
3	**Is the sustained surface wind speed 30 kt or greater?**	**Yes, forecast LLWS** **No, go to step 4.**
4	**Is the sustained surface wind speed 10 kt or greater?**	**yes, go to step 5,** **No, go to step 6.**
5	**Is the difference between the gradient wind speed and two times the surface wind speed 20 kt or greater ?**	**Yes, forecast LLWS** **No, go to step 9.**
6	**Is there an inversion or isothermal layer below 2,000 ft ?**	**Yes, go to step 7.** **No, go to step 8.**

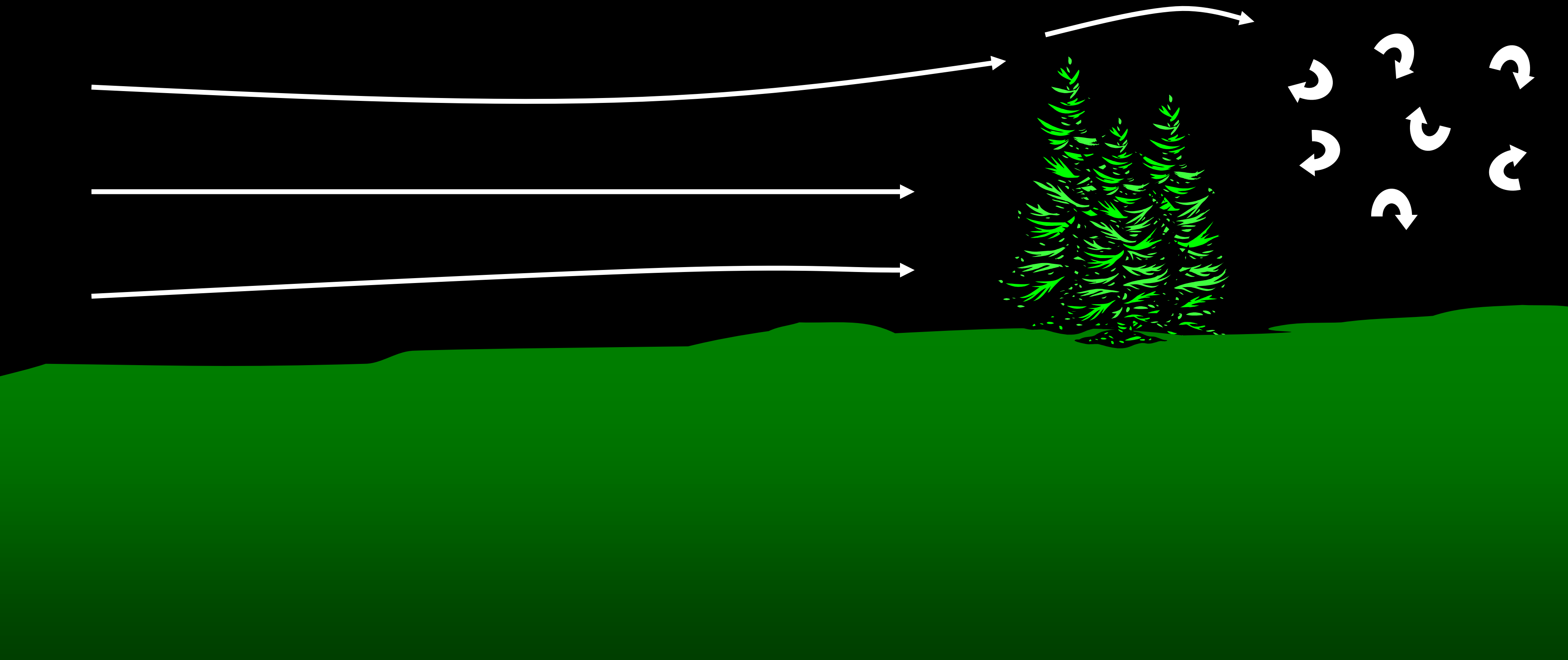
LOW- LEVEL WIND SHEAR DECISION TREE - TWO

Local effects are not addressed

Step #	Factor	Action Required
7	Is the value of the vector difference between the gradient wind and the surface wind 30 kt or greater ?	Yes, forecast LLWS. No, go to step 9.
8	Is the value of the vector difference between the gradient wind and the surface wind 35 kt ?	Yes, forecast LLWS. No, go to step 9.
9	Is a surface front present or forecast to be in the area ?	Yes, forecast LLWS. No, go to step 13.
10	Is the vector difference across the front equal to or greater than 20 kt over 50 NM ?	yes, forecast LLWS. No, go to step 11.
11	Is the temperature gradient across the front 5°C or more ?	Yes, forecast LLWS. No, go to step 12.
12	Is the speed of the movement of a front 30 kt or more ?	Yes, forecast LLWS. No, forecast no significant LLWS

Mechanical Turbulence

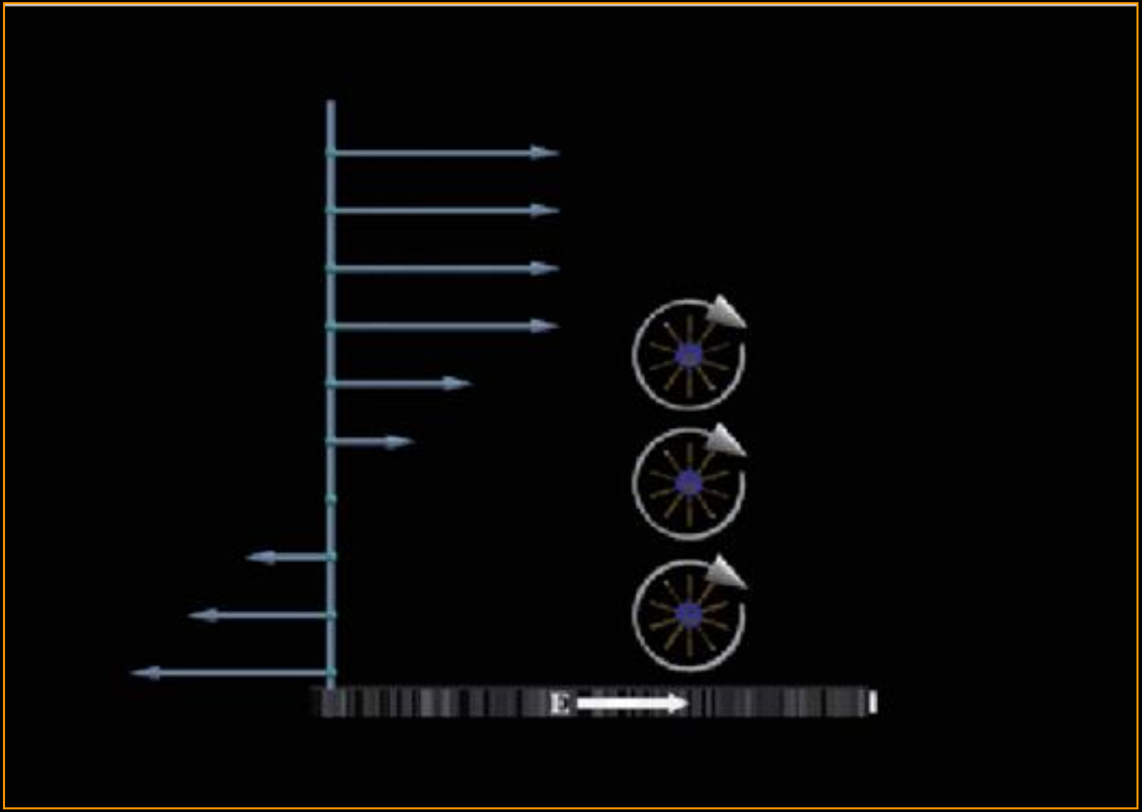
Friction between the air and surface features of the earth is responsible for the swirling vortices of air called "eddies".



Shear Creating Vorticity

When the vertical wind profile is sheared, horizontal vorticity is present in the environment.

We can visualize this vorticity if we imagine the rotation that would be imparted to paddle wheels placed in the environmen



Fire Whirls

- A fire whirl is a vertically oriented vortex.
- It is made up of a spinning, moving column of ascending air that lifts smoke, debris and fire.
- Fire whirls range in size from less than one foot to over 500 feet in diameter and belong to the same family as tornadoes and dust devils

Conditions: When and Where to Expect Fire Whirls

- Fire whirls are the result of local events or processes.
- These events involve heating of the lower atmospheric layers through the convective plume and the existence of rotation in the local airflow.
- The strong heating generated by the fire produces the vertical motion needed to tilt and stretch the existing rotation in the air and produce the elongated whirls.

Creating Vorticity

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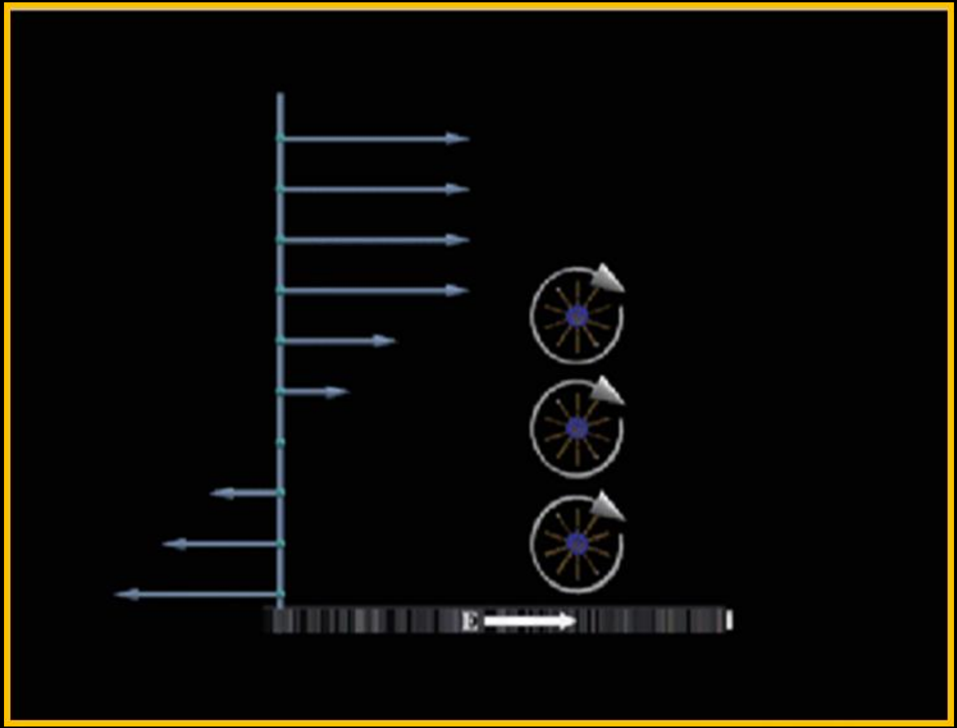
- We can visualize this vorticity if we imagine the rotation that would be imparted to paddle wheels placed in the environment.



Wind-Driven

- Most of the fires that escaped initial attack and those that became historically large fires could be described as being wind-driven fires.
- When the force of the wind dominates the fire spread, predicting probable fire behaviour, which is a function of the wind speed and direction, is somewhat simplified.
- The direction of spread and the anticipated fuel bed can be evaluated.
- Predicting changes in wind is critical since wind shifts can pose serious threats to safety.

Horizontal Vortices

Vortices are divided into two types, which are named based on the orientation of their axes of rotation to the ground.

*The vortices that rotate with their axes parallel to the ground are called **horizontal vortices** and those that rotate perpendicular to the ground are referred to as **vertical vortices.***

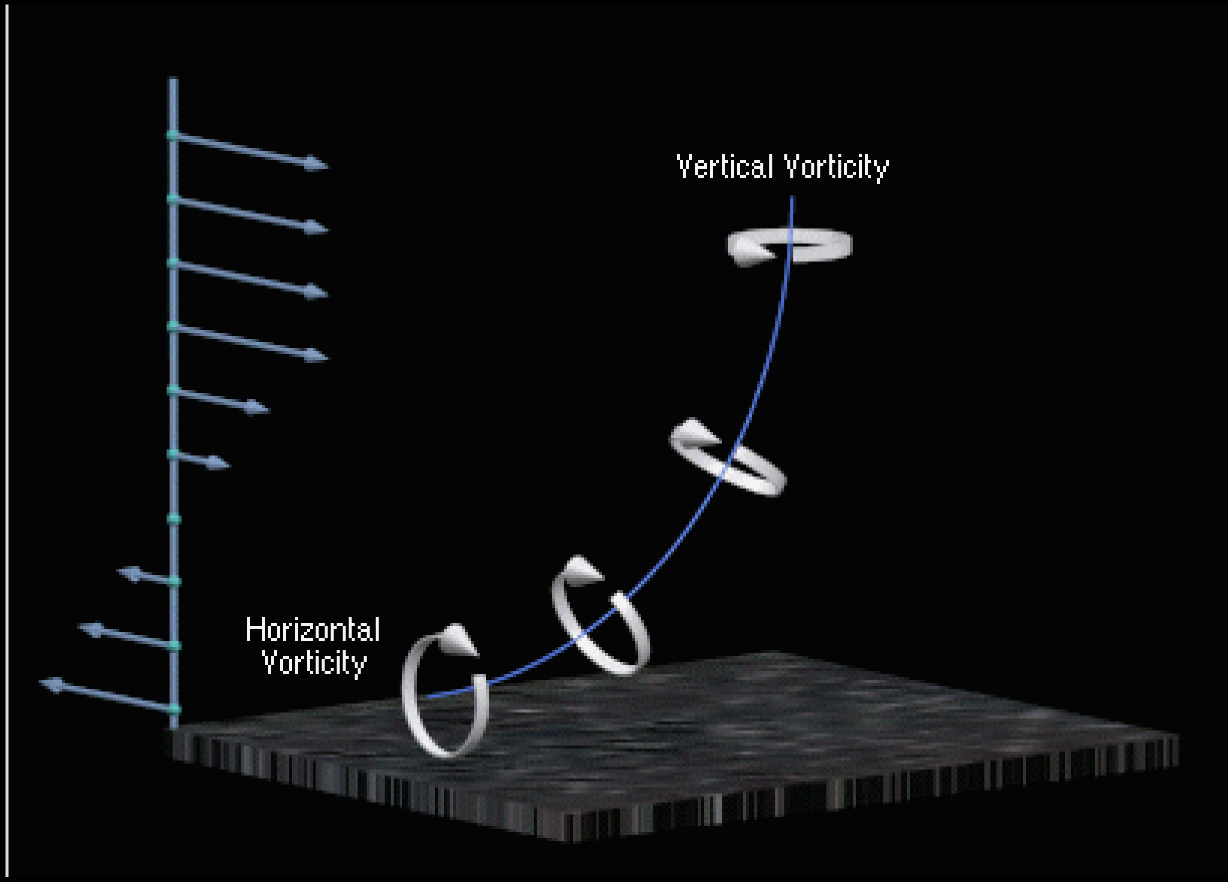
Horizontal Vortices

Horizontal vortices develop under extreme burning conditions. There are basically two types of horizontal vortices that develop relative to wildfires.

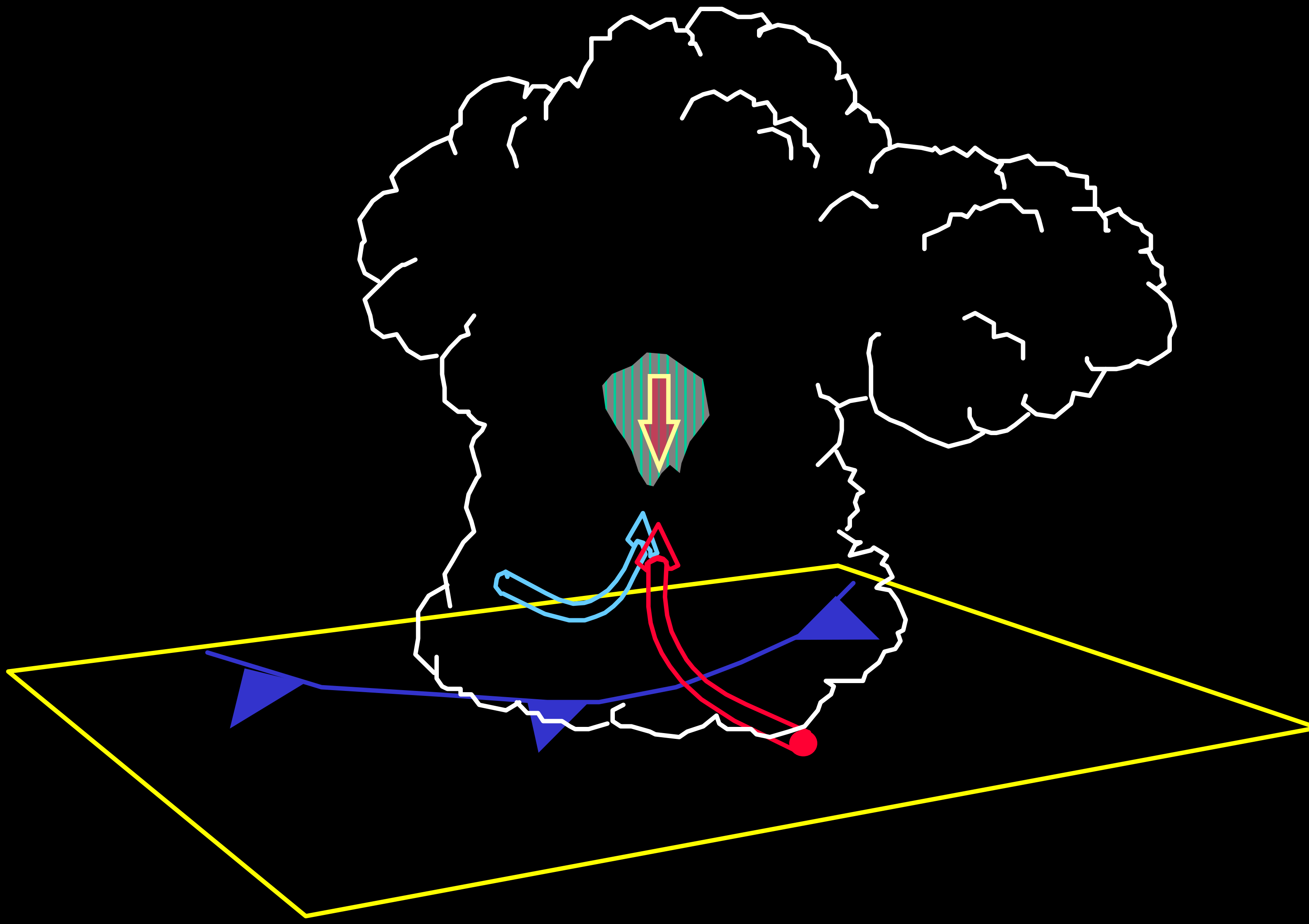
The first occurs along the ground on the flanks of wildfires and can directly impact the safety of fireline personnel

The second type occurs in the convective column over the fire and can affect air operations near the fire.

These vortices tend to form more readily with low to moderate wind speeds over flat or gentle terrain.



Vertical Vorticity
Horizontal Vorticity



Plume-Dominated

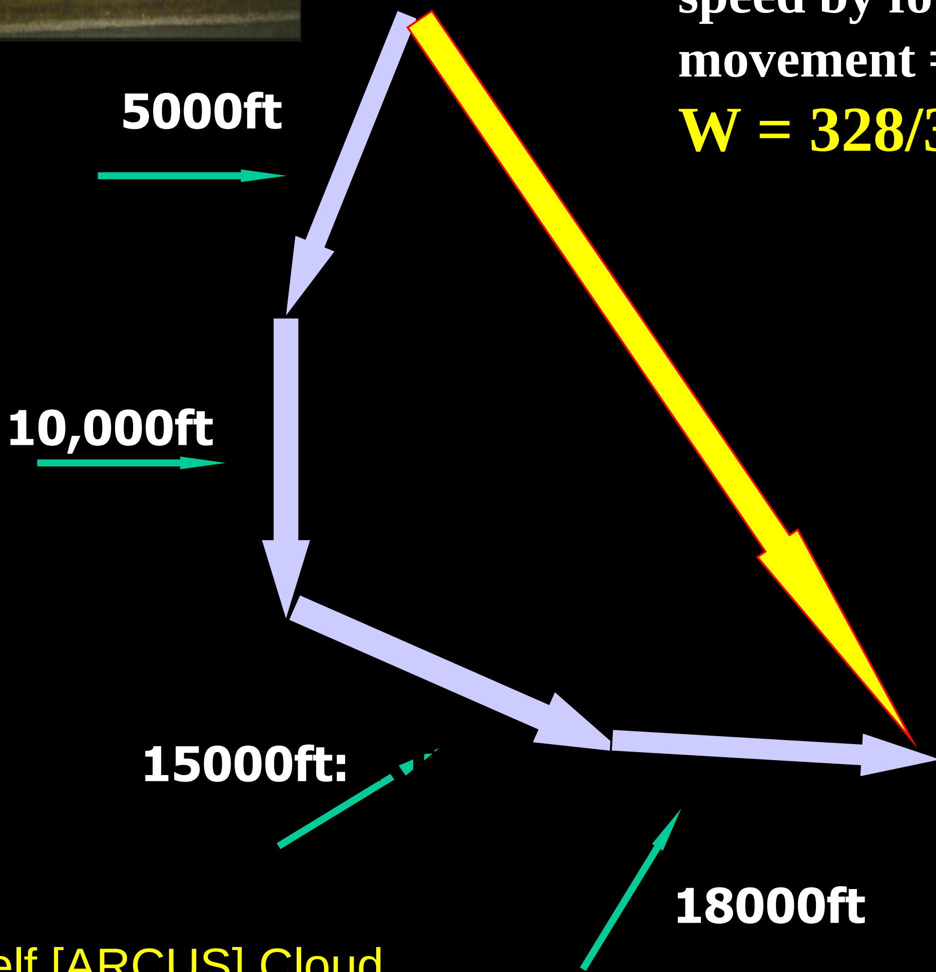
- A plume-dominated fire exhibits the increased role of the convective force generated by the heating of the fire.
- The fire itself begins to influence the wind field around it.
- This added vertical development has also been described as "fire in the third dimension" along with the length, width and atmosphere above and around the fire.
- Consequently, fire spread rate and direction become less predictable because the role of the general wind in fire spread becomes less pronounced.
- Spotting is normally short-ranged but occurs in all directions.
- All convective columns have updrafts and downdrafts.
- Associated with these are indrafts, which is the flow of air into the column, and downdrafts or downbursts of air out of the convective column.

Danger area near
Supercell thunderstorm

Estimation of Danger Area Near Thunderstorm

Add the movement vectors, divide the speed by four to give the mean wind movement = W

W = 328/38kt



Example: reported winds

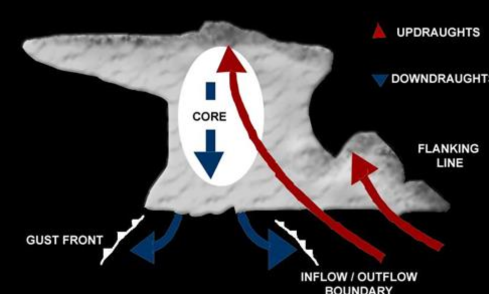
5000ft : 020/40kt

10000ft: 360/30kt

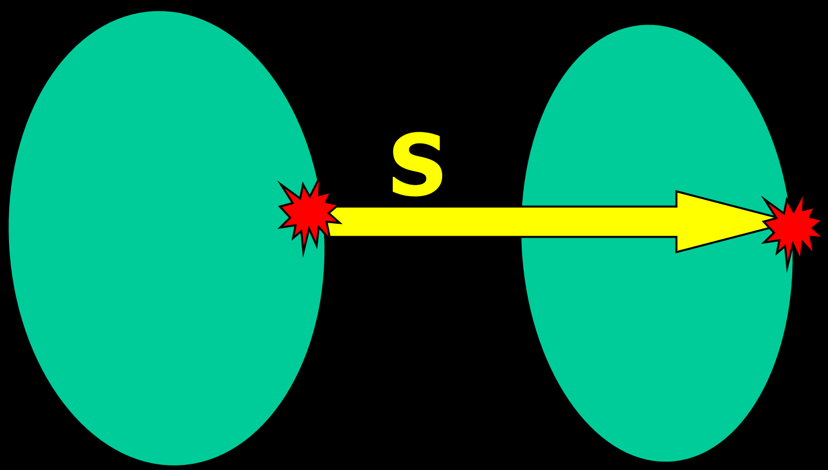
15000ft: 320/40kt

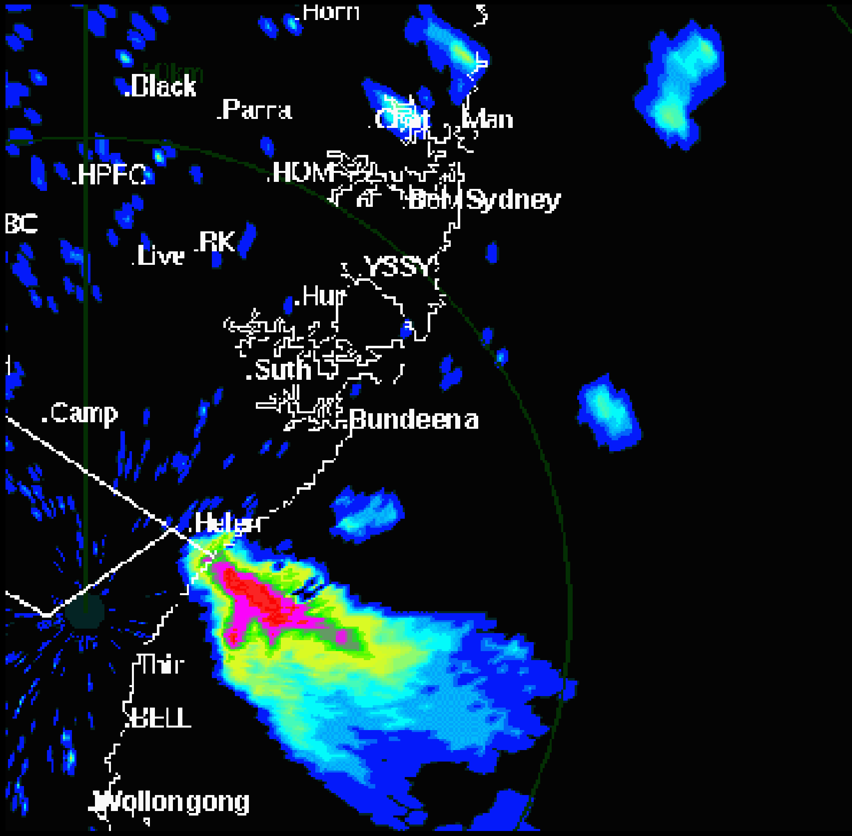
18000ft: 280/44kt

Shelf [ARCUS] Cloud

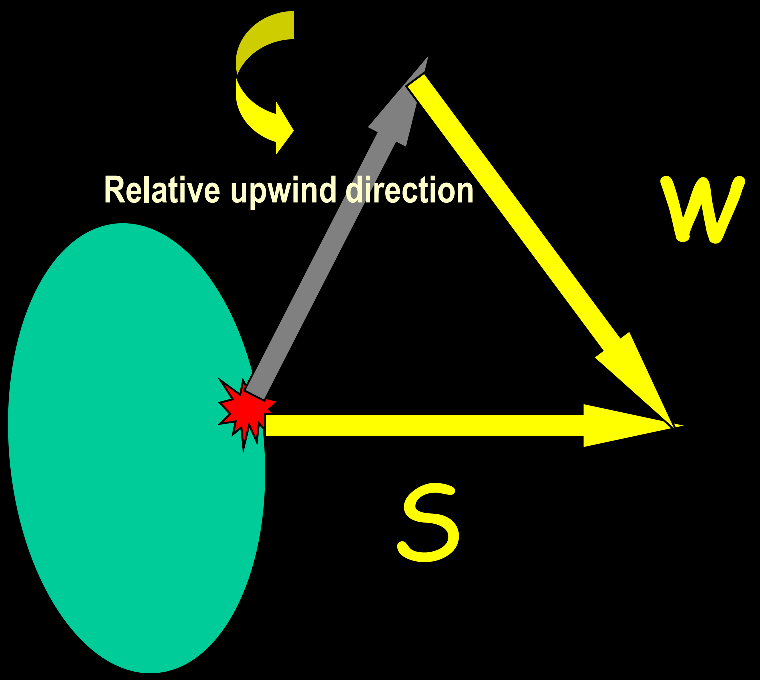


Storm movement = S





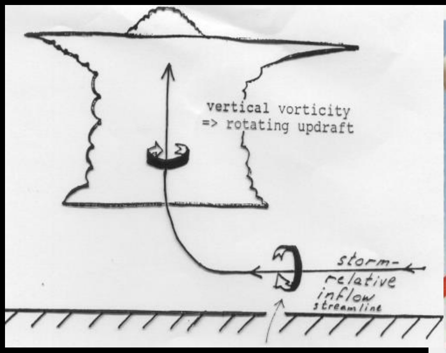
Relative upwind

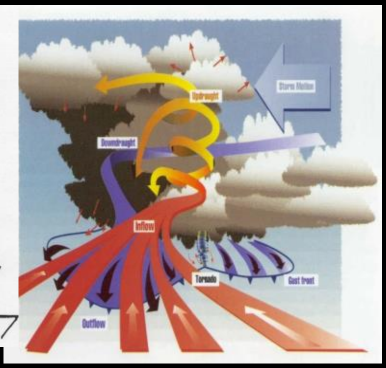


Put tips of W and S vectors together,

The relative upwind direction is from tail of S to tail of W

- NOTE: the reverse of this direction is the relative inflow.



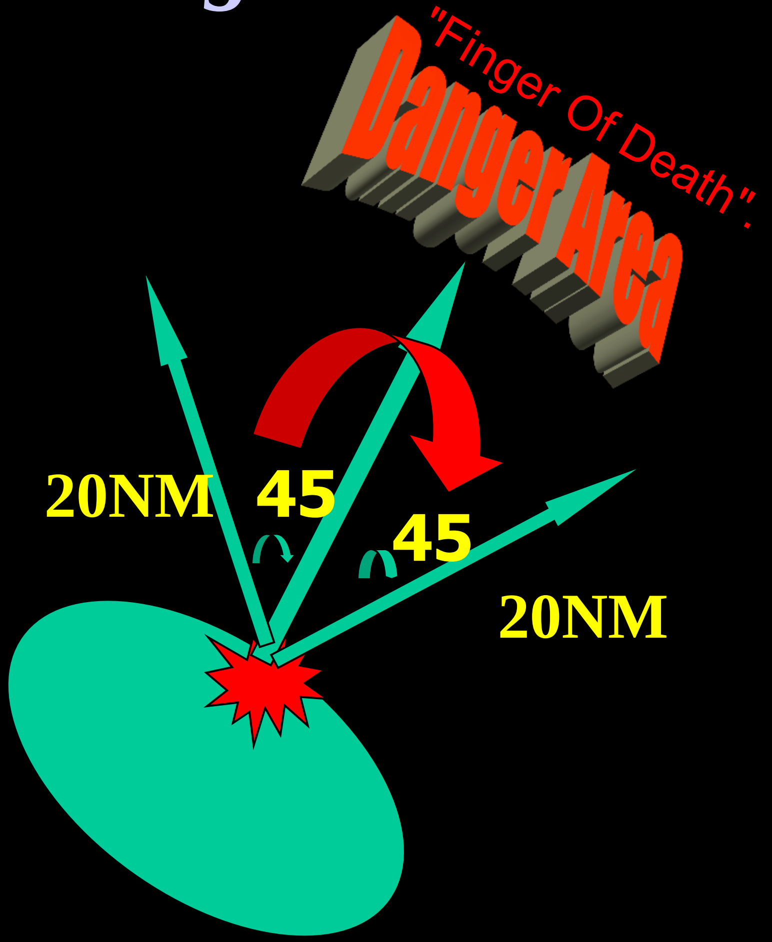


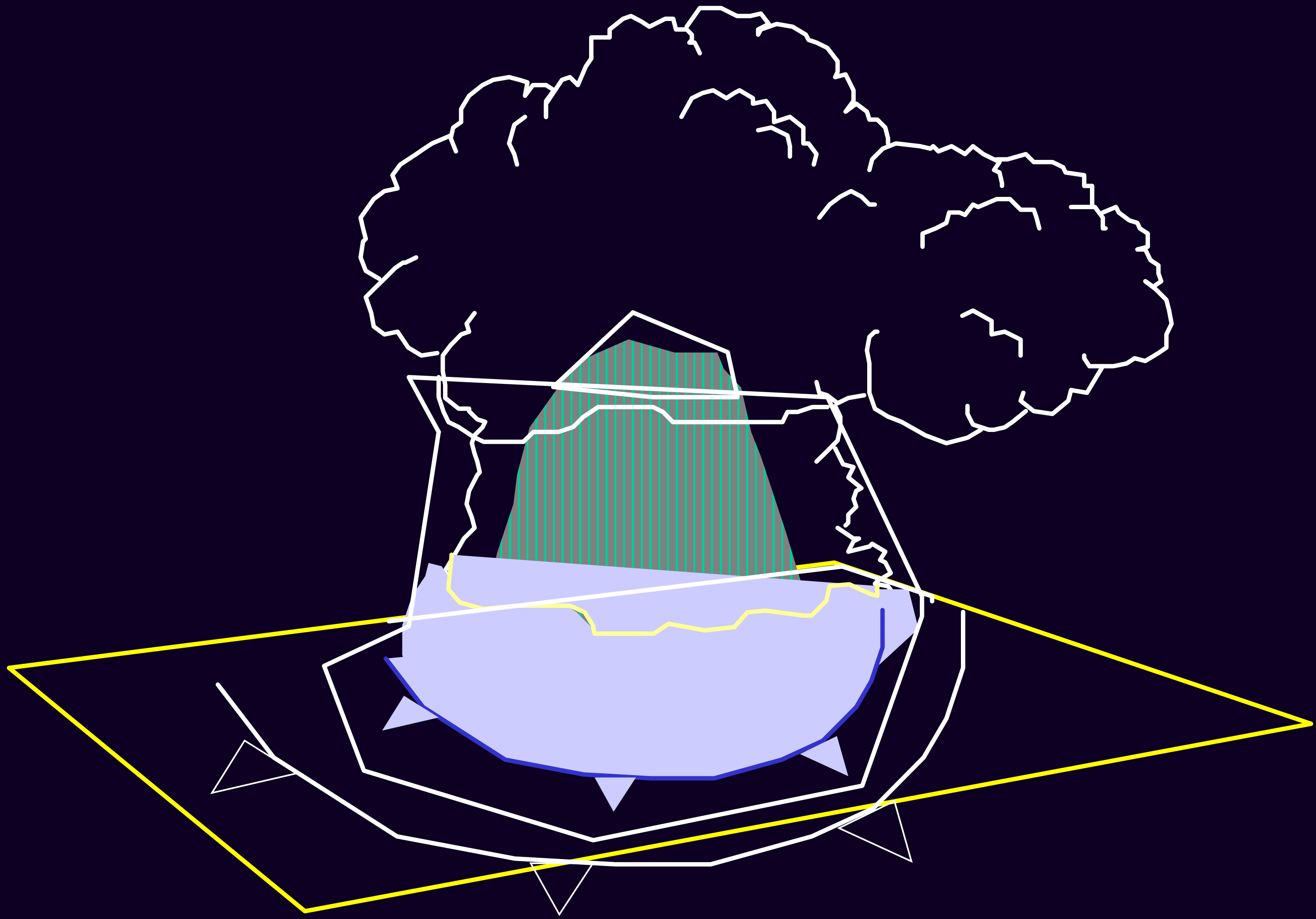
Delineate inflow danger area.

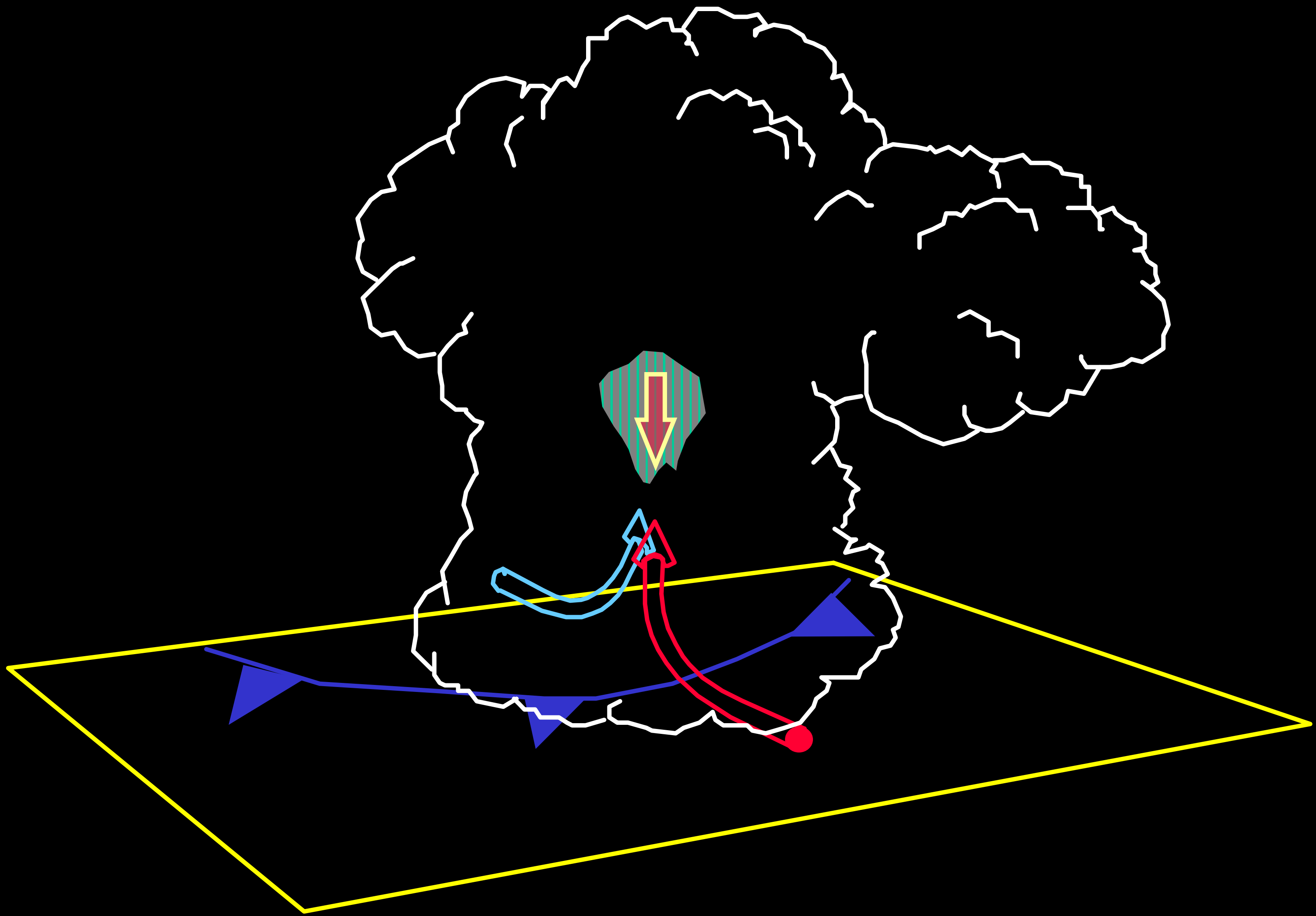
- The danger area is taken as within 20NM from the edge of the intense core and 45 deg about relative upwind

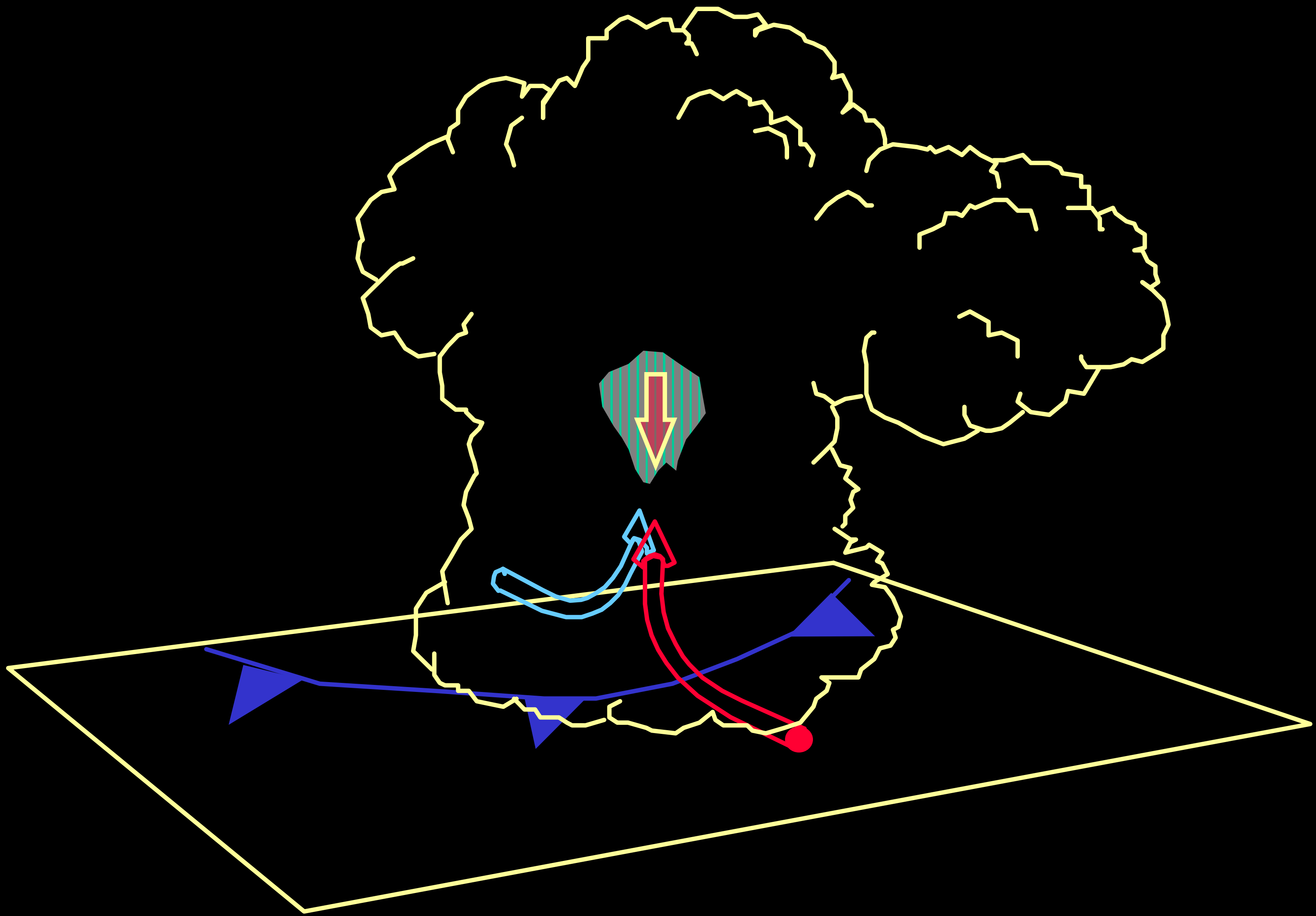
Note:

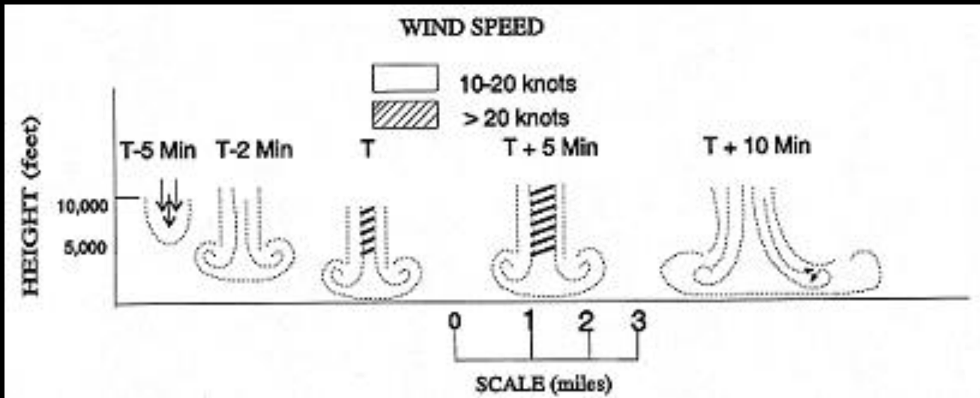
The intense core and its immediate vicinity is also potentially very dangerous



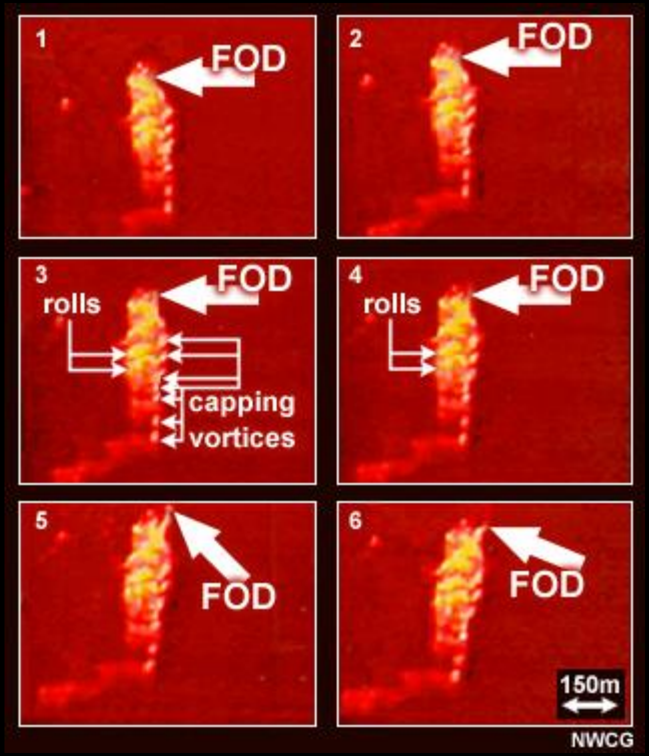







WIND SPEED
10-20 knots
> 20 knots
HEIGHT (feet)
10,000
5,000
T-5 Min
T-2 Min
T
T + 5 Min
T + 10 Min
0
1
2
3
SCALE (miles)

Horizontal Vortices

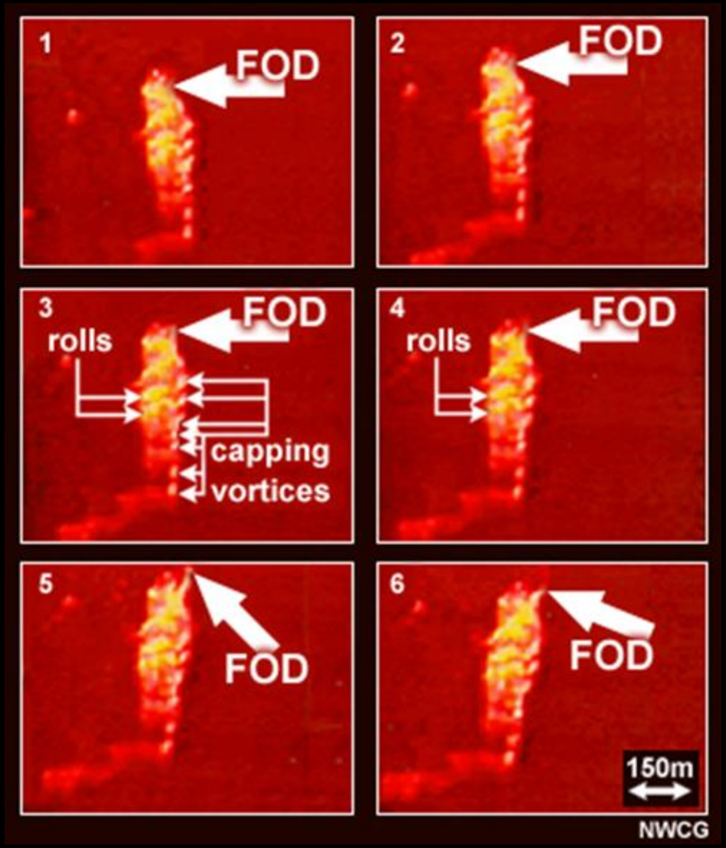


- This sequence of six images, taken 0.75 seconds apart, looking down on a horizontal vortices within a fire, comes from the University Corporation for Atmospheric Research (UCAR) Infra-metrics Therma-cam .
- The brightest yellow areas represent the hottest temperatures.

FOD in each image refers to the "Finger Of Death".

frame 1 the arrow points to the starting point of the FOD in the upper right shoulder of the fire at the beginning time of 0.00 seconds.
Frame 2 *has arrow pointing to the FOD, which is beginning to form and burst forward at 0.75 seconds.*
The next image,
frame 3 *has the arrow showing* that the FOD progresses further by 1.50 seconds.
Frame 4 shows further elongation of the FOD at 2.25 seconds.
By frame 5 the arrow shows that the FOD has extended to approximately 100 meters or 109 yards in just 3.00 seconds.
Frame 6 shows the regression of the FOD to the main fire by 3.75 seconds.

Horizontal vortices within a fire



This sequence shows that a "finger" of fire burst forward about 100 meters from the head of the fire at speeds exceeding 100 miles per hour, and then retreated back into the fire within three seconds.

Seven horizontal rolls and capping vortices are also identified in the third frame. Horizontal rolls within fires have been hypothesized as occurring with crown fires. However, actual documentation has been limited.

Vertical Vortices

- Commonly observed vertical vortices include dust devils and whirlwinds.
- When a vertical whirling mass of air includes the fire's flames, the vortex is called a fire whirl.
- We can further classify vertical vortices based on their triggering mechanisms.
- Thermally-driven vortices develop on hot days and in intense portions of the wild-land fire.
- Wake-type vortices occur on the lee sides of physical obstructions to wind movement such as ridge tops and trees, and can also be seen on the edges of convective columns.

Implications

- The presence of fire vortices in an area represent extreme fire behaviour.
- A vertical vortex or fire whirl is a concentrated localized wind.
- Wind speeds greater than 100 mph are not uncommon in the centre of the vortex.
- The vortex aids in the spread of fire through heat and mass transfer as it moves along the surface lofting firebrands into the ambient air flow.

- Horizontal vortex development, movement, and dissipation are even more difficult to predict, as is the vortex's effect on fire behaviour.
- Some general indicators for the formation of horizontal vortices include extreme burning conditions, low to moderate wind speeds over flat or gentle terrain.
- The critical concern about these phenomena is that they occur on the flanks of rapidly growing or large fires, and can occur over a large area, or be just large enough to trap a single engine or crew.
- Fire-fighters should be aware of the possibility of vortices in fires that exhibit rapid growth, crowning, and other extreme fire behaviour indicators.
- Also, remember that these vortices can occur along the flanks of the fire.

- Spotting almost always occurs downwind and is a major contributor to spread rates.
- As the fire grows and convective lift strengthens, spotting could become long-range, creating new fires miles ahead of the original fire.
- Crown fire can be sustained by strong winds at the canopy level when fuel moistures are low, regardless of topography.
- When observing a wind-driven fire, the convective column is typically fractured, or appears bent over by the wind.
- By bending the column toward the ground, the convective heat from the fire helps to preheat fuels ahead of the fire, which increases spread and intensity.
- Fires that are initially wind-driven, can transition into a more plume-dominated event as the convective column associated with the fire grows and begins to affect the surrounding environment.

Fire Environment - Weather

Weather is the most variable component of the fire environment.

- Weather elements can change rapidly due to changes in air masses, the diurnal cycle (night-times to daytime), and local influences such as topography.
- Also, conditions change unexpectedly , so you may not experience the same weather at different locations on a fire.

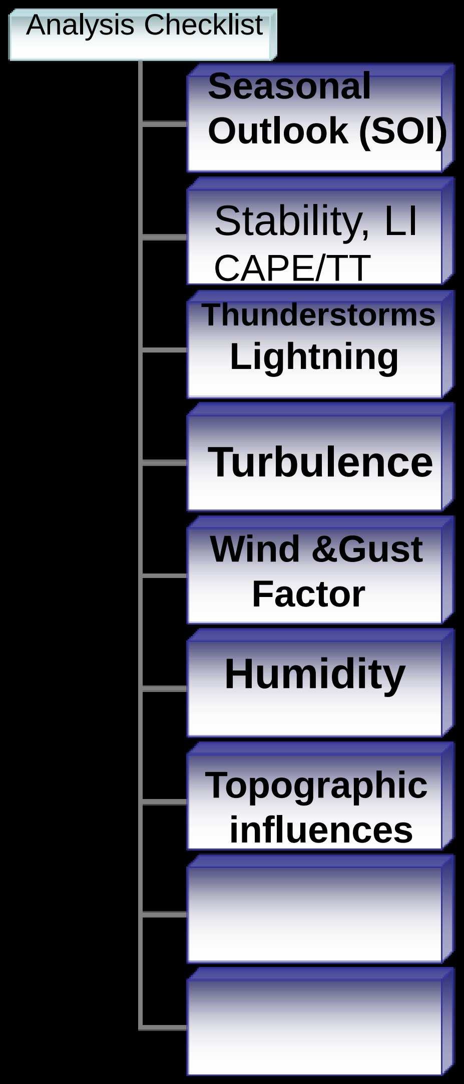
The weather elements that influence fire behaviour are:

- Atmospheric stability
- Temperature
- Relative humidity
- Wind speed and direction
- Precipitation

Weather Observation Decision Making

This Analysis Checklist is developed to allow for comprehensive weather analysis.

In addition, this framework successfully addresses every Fire weather related accidents.



Weather Decision Making

Understanding weather signs and recognising weather clues.

- **Stability**
  - **Stability Application And Stability Indices**
  - **LI - Lifted Index**
  - **Convective Available Potential Energy (CAPE)**

- **Cloud**
  - **Towering Cumulus cloud, Cumulonimbus.**
  - **Microburst, Mammatus cloud, Lens shaped cloud.**
  - **Funnel shaped cloud.**
  - **Virga.**
  - **Anvil cloud.**
  - **Castellatus cloud.**
  - **Super cells.**

- **Weather**

  Weather observations on fire line
  - **Looking for potentially hazardous Weather and extreme fire behavior conditions**
  - **inflow danger area near thunderstorm**

The weather forecasting problem areas can be divided to broad-scale (Synoptic) problems and local or meso-scale problems

- One major meso-scale problem area is fire weather forecasting.
- Conditions can change rapidly on "blow up days".
- Winds can freshen and temperatures soar in the space of an hour or two.
- Dry air mixing down from higher level can decrease the humidity suddenly so that the fire danger can increase alarmingly.

Atmospheric Stability

Stability

Applications

1. Can be a useful tool when applied correctly.
2. Can’t be applied to every weather situation.
3. Only indicate a potential for severe weather.
4. Track stability index changes over time.
5. Keep into consideration past and if available future stability trends.

LI - Lifted Index

$$LI = Te_{500} - Tp_{500}$$

Te= Environment

T p = Lifted parcel

> 0	Thunderstorms unlikely
0 to -2	Thunderstorms possible
-3 to -5	Thunderstorms probable
< -5	Severe **thunderstorm potential**

Convective Available Potential Energy (CAPE)

- Amount of energy available to a surface parcel that has reached its Level of Free Convection (LFC).
- A positive CAPE value indicates upward vertical motion.
- A negative CAPE value indicates downward vertical motion.
- CAPE values should be monitored daily when there is a potential for severe weather.
- Values >1000 but less than 2500 are associated with severe thunderstorms.
- Values >2500 are associated with tornadic activity.

Weather decision making understanding ten weather signs and recognising weather clues

Lightning

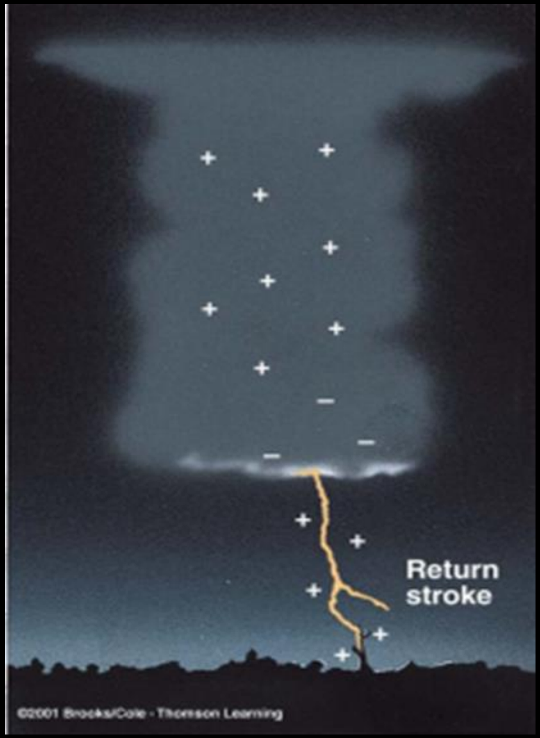
Looking for Stepped Leader cloud to ground stroke

Wind

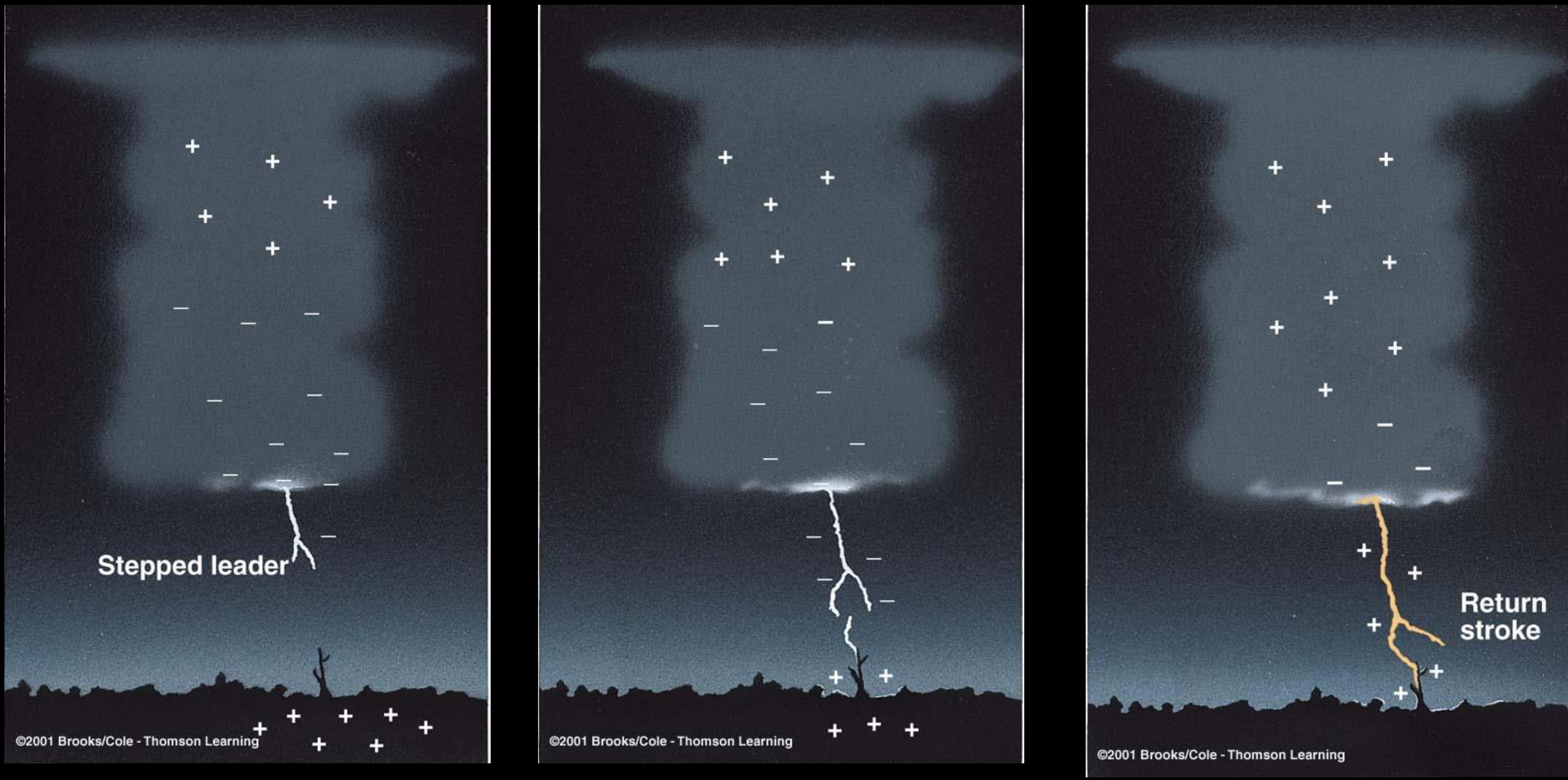
Gust Factor, this can be used to warn increased wildfire activity and lowering of near-surface humidity

Topographic influences

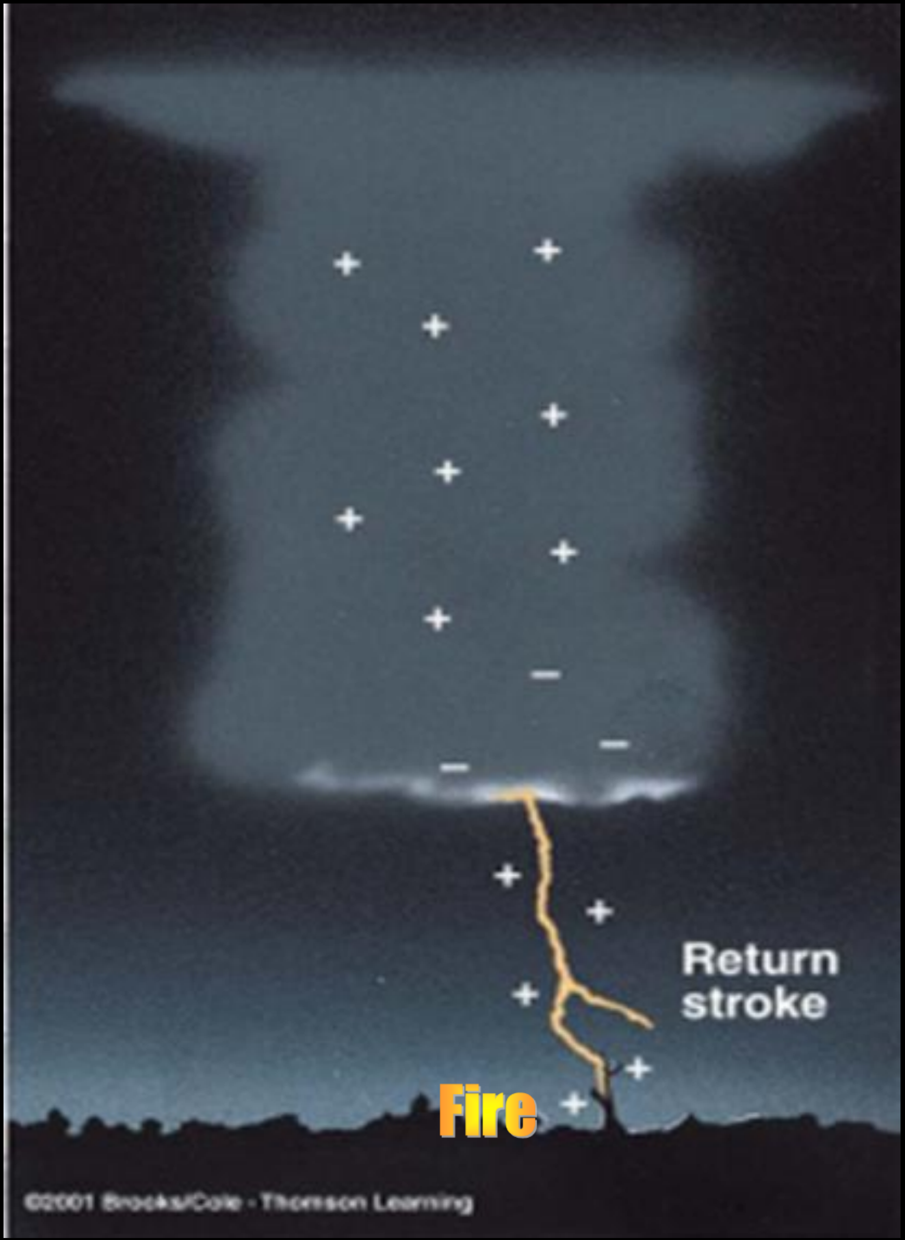
Low Level Wind shear (LLWS) and Turbulence



Cloud-to-Ground Lightning



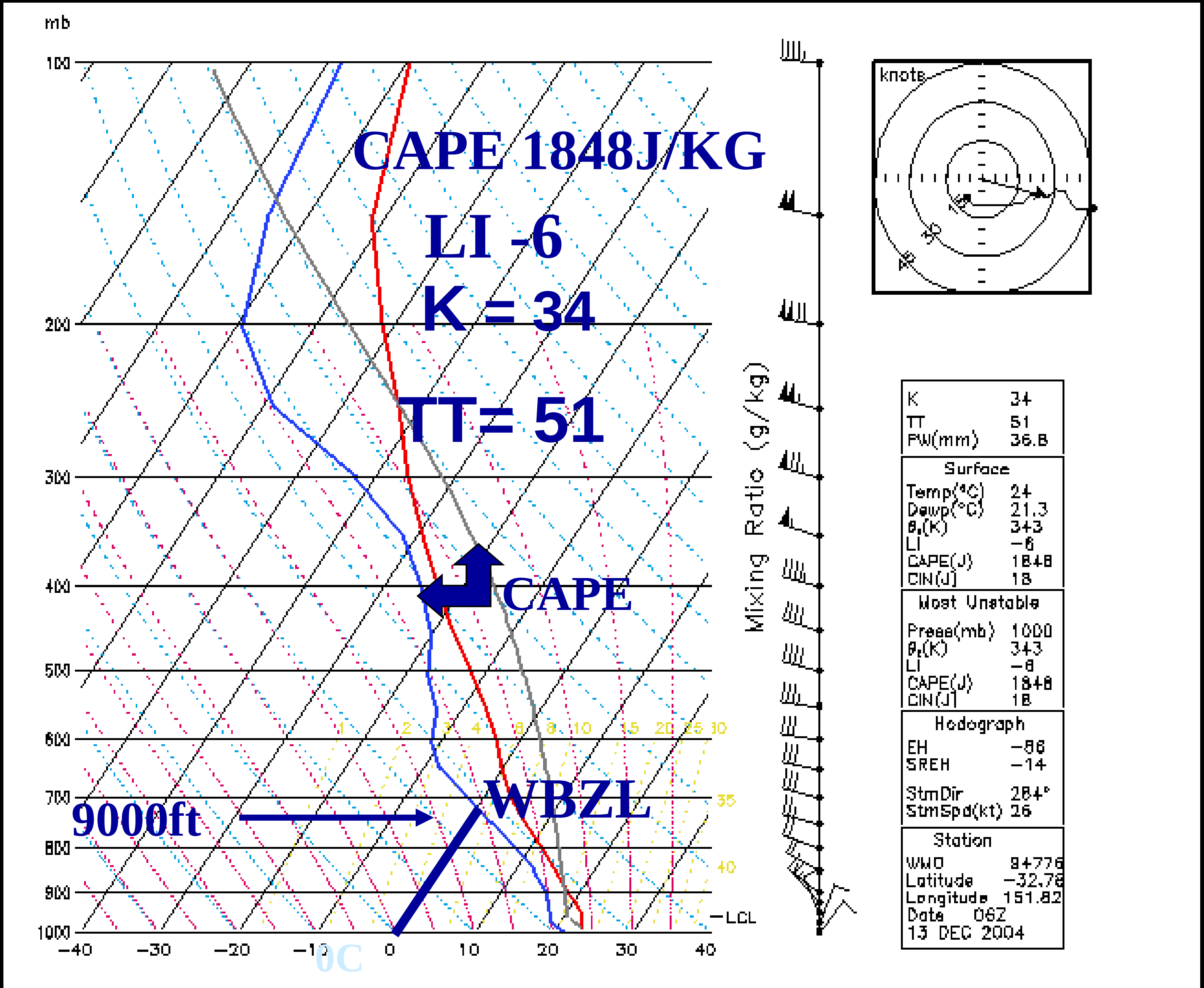
The Stepped Leader-Cloud to ground stroke



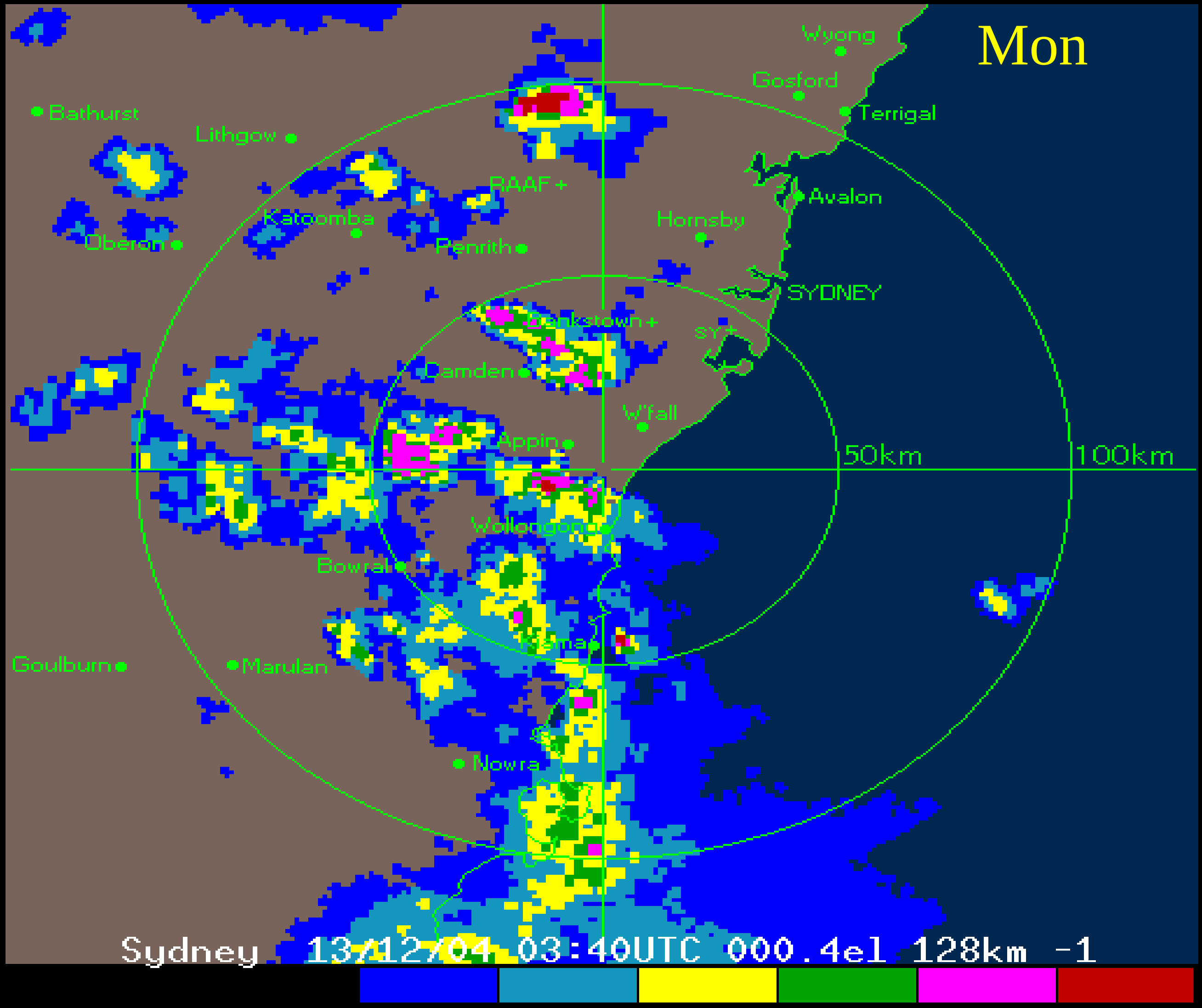
When the stepped leader gets near the ground (100 m or so):
Positive charge moves from the ground up toward the stepped leader -- these are called streamers.

The streamers may come from almost any pointed object on the ground: People, Trees, Flagpoles, Antennas, Telephone Poles, Boats etc.

Wet Bulb freezing level (WBZL) on 13 Dec 2004 (0600UTC)

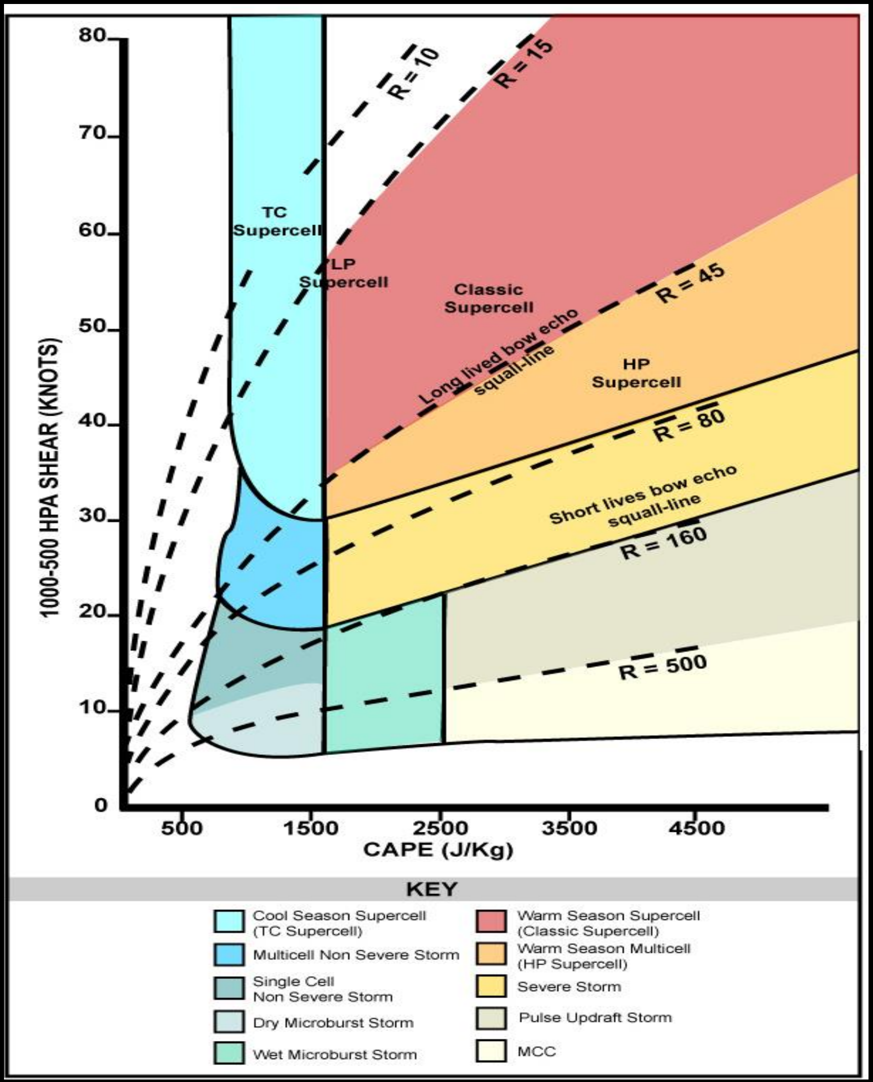


13 December 2004



13 December 2004

Various storm categories within a CAPE/Shear parameter space



Convective Available Potential Energy (CAPE

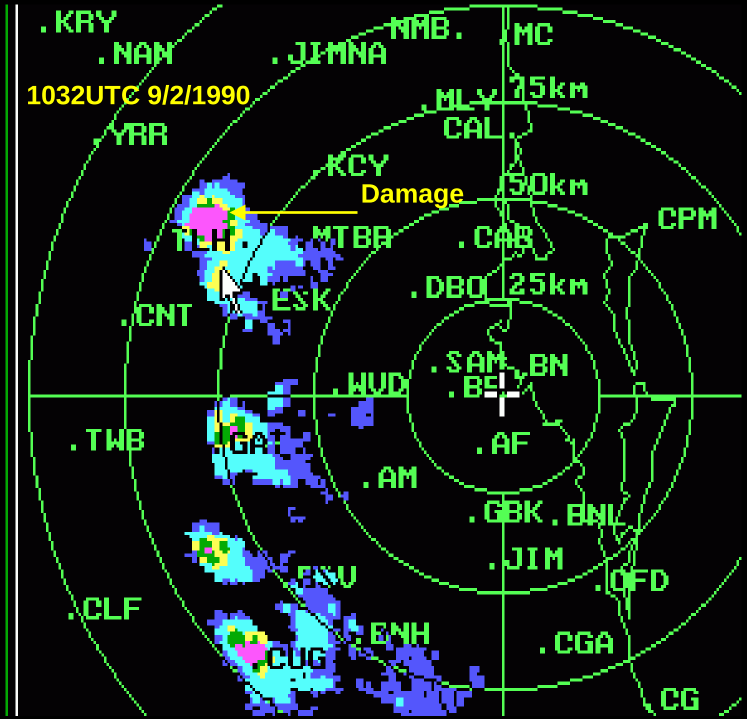
- Values >1000 but less than 2500 are associated with severe thunderstorms.
- Values >2500 are associated with tornadic activity.
- CAPE values should be monitored daily when there is a potential for severe weather.

•Labelling indicates approximate location of storm type in CAPE/Shear space
•A schematic depiction of the spectrum of storm and storm system types within a CAPE/shear parameter space.

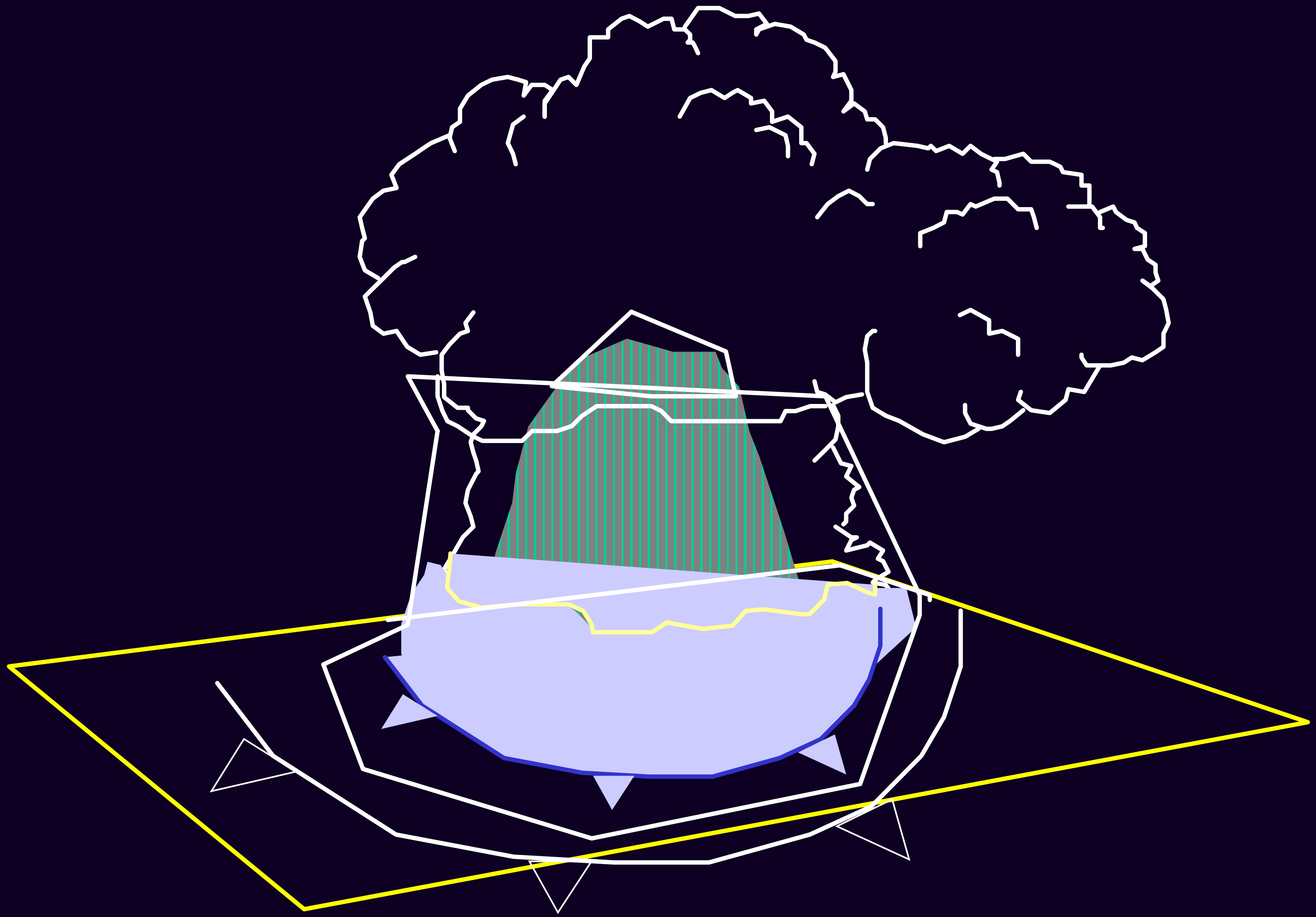
Severe thunderstorms in synoptic E'ly wind regimes - example.

Harlin storm – February 9th 1990.

Five high voltage electricity pylons (rated to 120 knots) blown down.

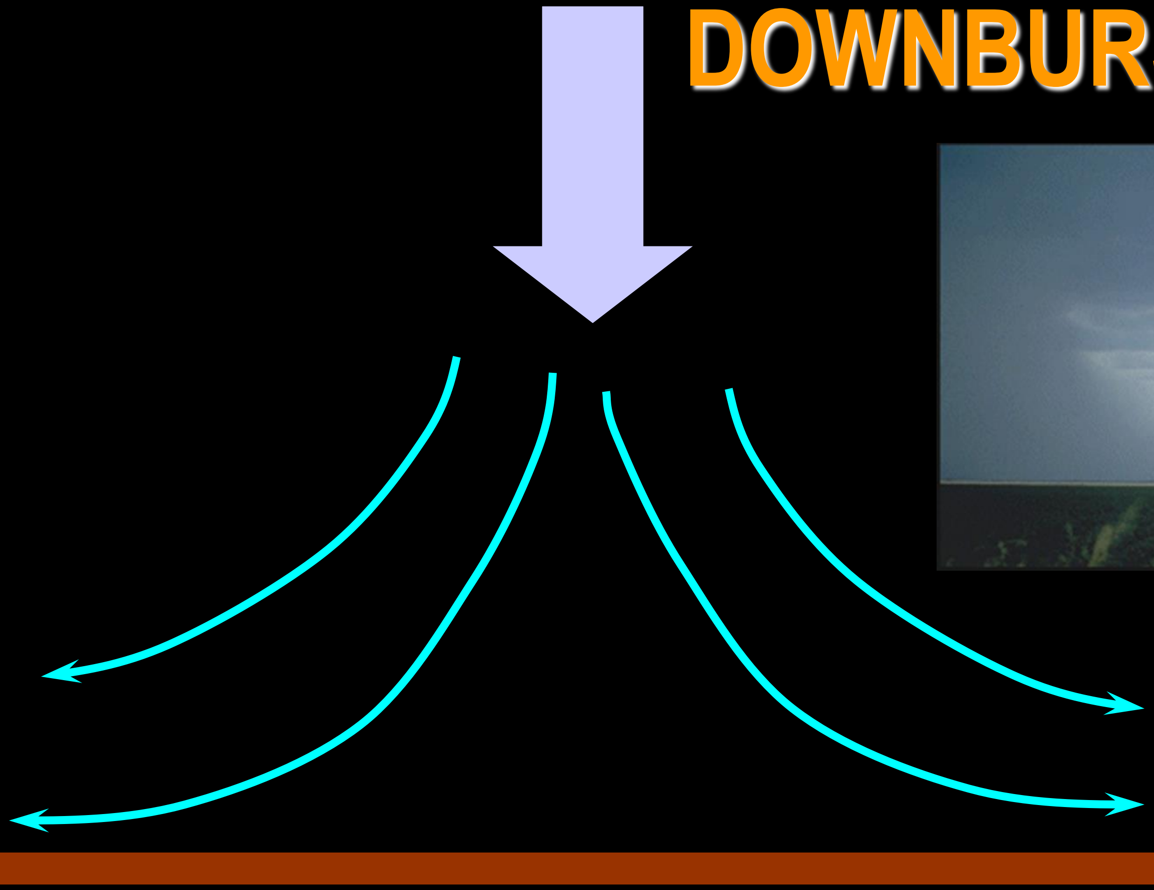


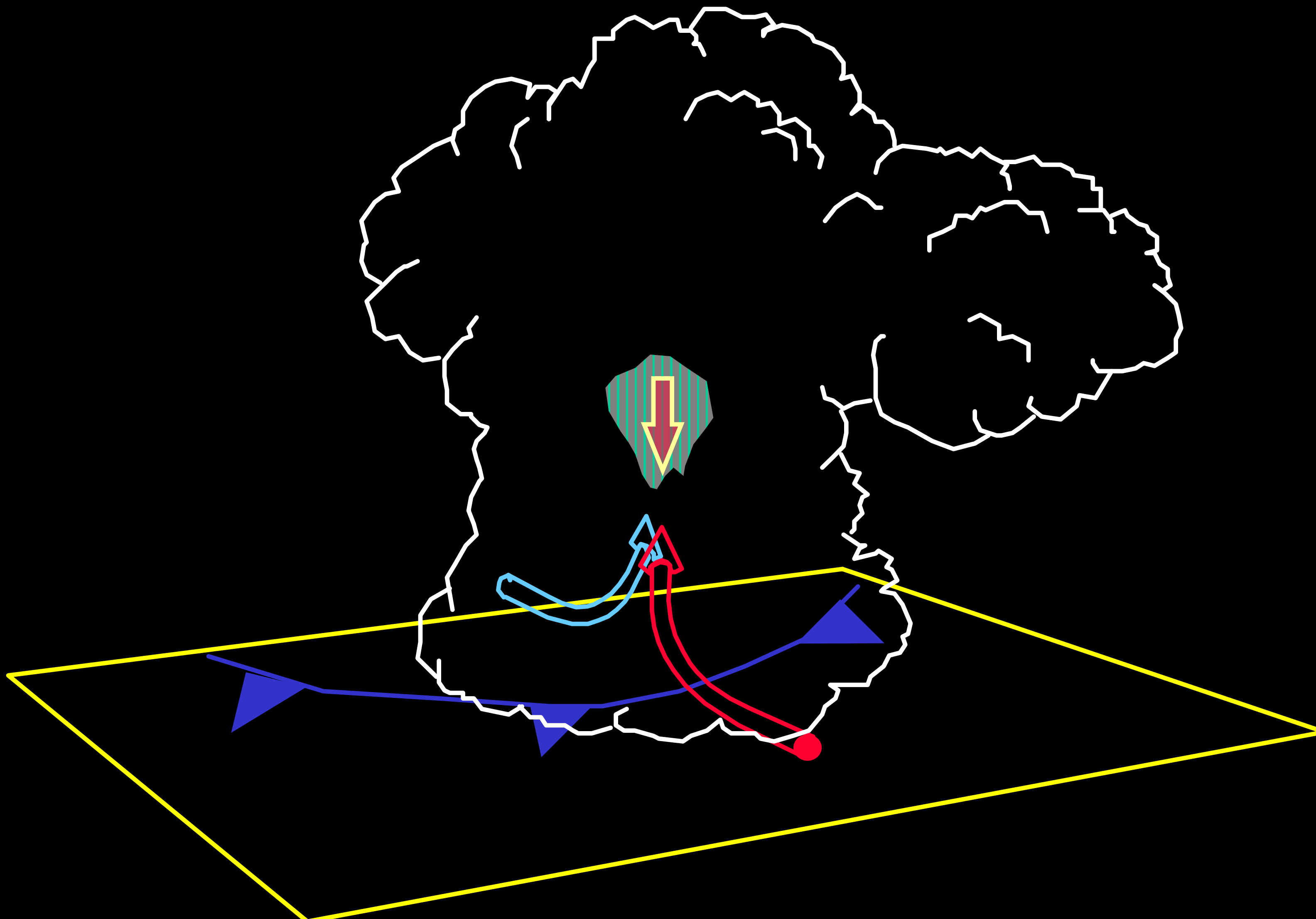
Damage - 1973 tornado

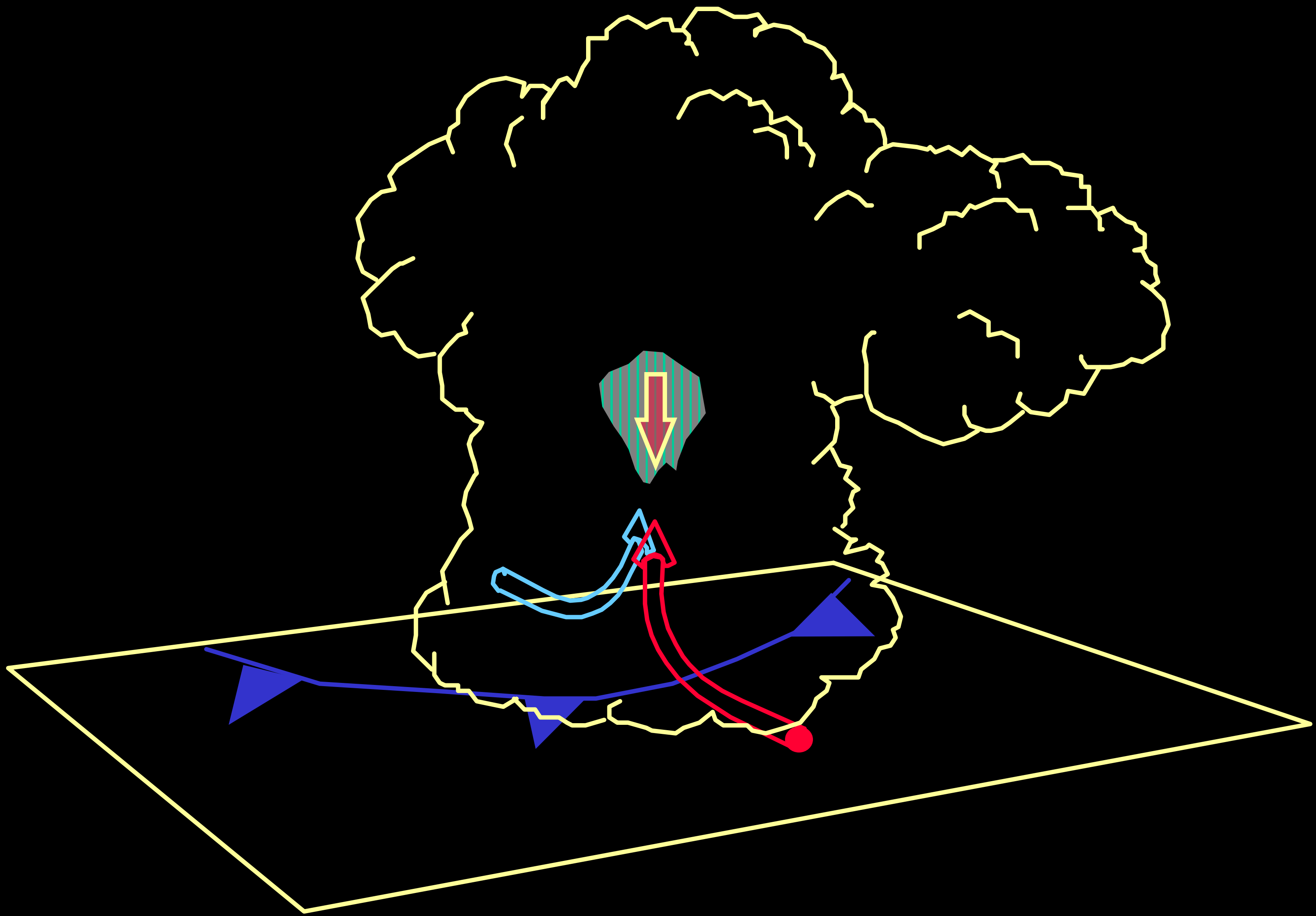


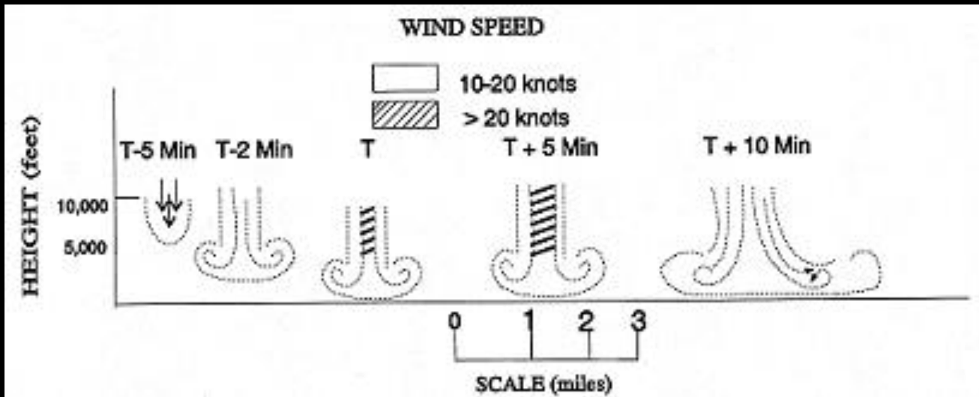
Downbursts/Microburst

DOWNBURST








WIND SPEED
10-20 knots
> 20 knots
HEIGHT (feet)
10,000
5,000
T-5 Min
T-2 Min
T
T + 5 Min
T + 10 Min
0
1
2
3
SCALE (miles)

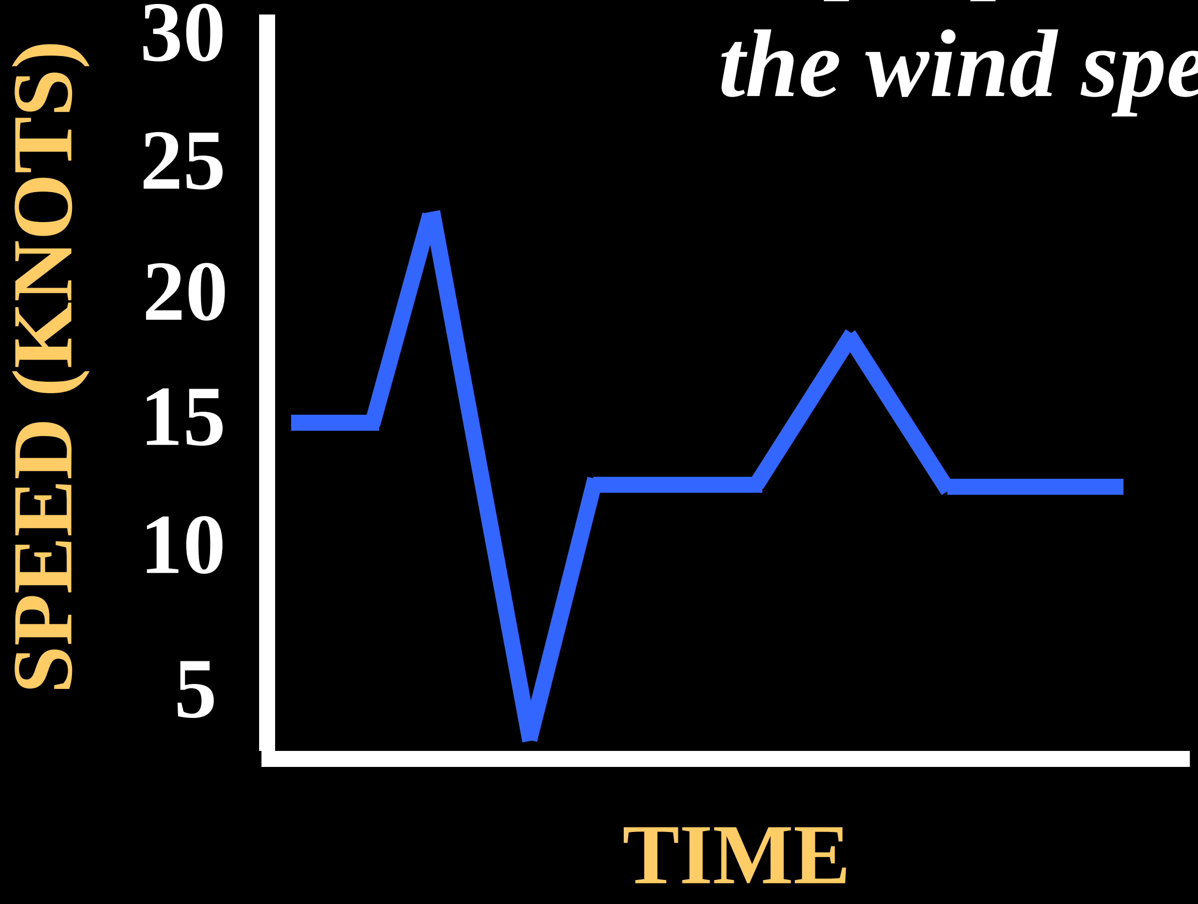
Meso - scale Wind Regimes

GUSTS

A rapid and brief increase in the wind speed. It is often associated with rapid fluctuations in the wind direction.

GUSTS

Rapid peaks and lulls in the wind speed



Gust Factor

This can be used to warn expected turbulence with gusting surface wind.

$$\text{GUST FACTOR} = \frac{\text{The range of fluctuation in gust and lulls} \times 100}{\text{The mean wind-speed}}$$

Example:
Surface observation showed Gusts 35 kts and Lulls 15 kts and the mean-speed would 25 kts.

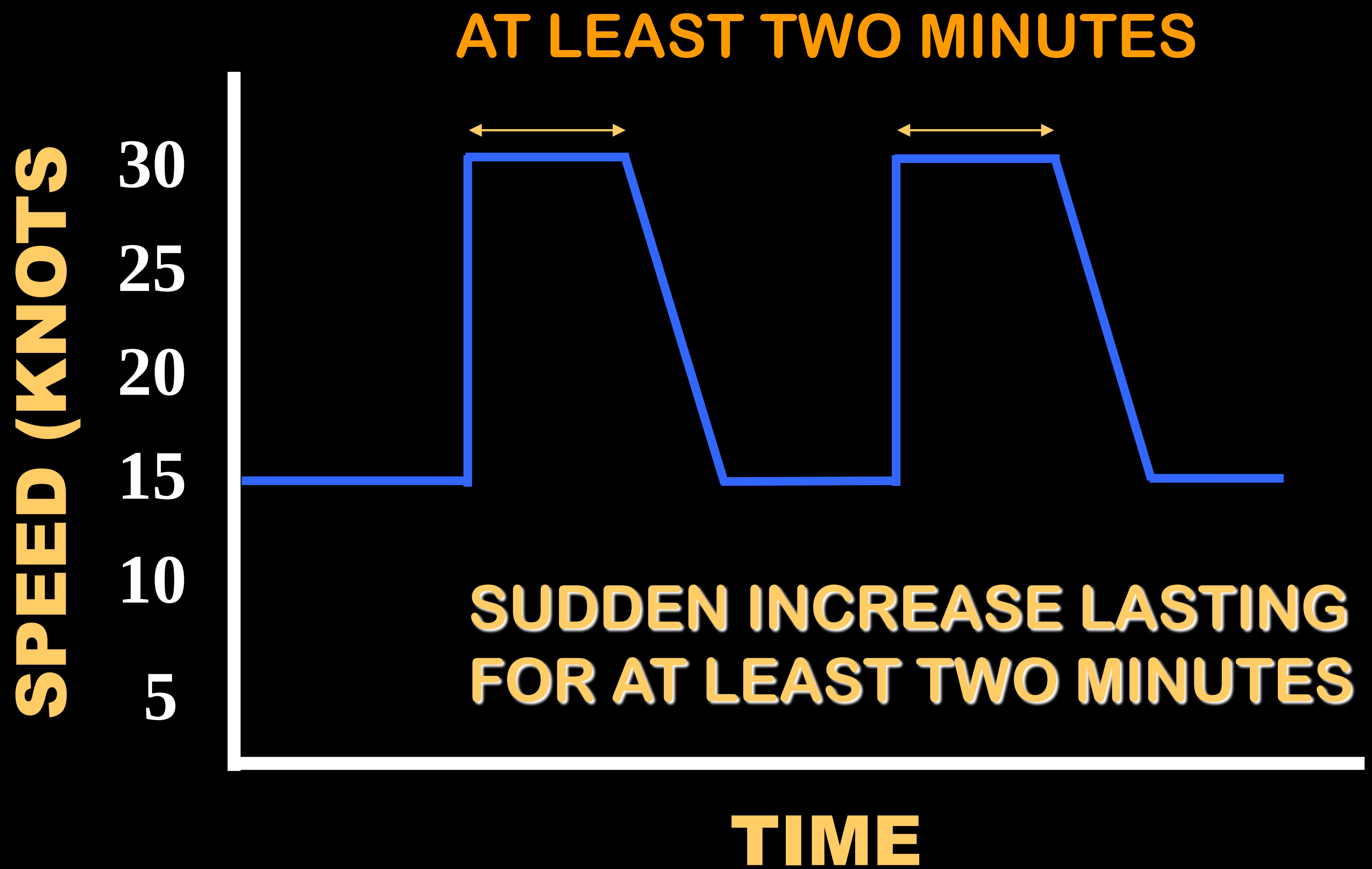
The range of fluctuations would be 20 kts

Answer: In this case, the gust factor would be 80%

SQUALLS

Similar to a gust but of longer duration. Caused by the passage of a fast moving cold front or a thunderstorm.

SQUALLS


AT LEAST TWO MINUTES
SPEED (KNOTS
30
25
20
15
10
5
SUDDEN INCREASE LASTING
FOR AT LEAST TWO MINUTES
TIME

Relative Humidity

- High fire hazard is always a result of low relative humidity.
- Strong winds and slope, intensity heat from burning materials increase the rate of fire spread, but regardless of these factors any fire will die down to the smoldering stage and remain so if the relativity humidity becomes high.

Relative Humidity

Relative Humidity %	Fire Behaviour
Over 60%	Fire will not spread
50 -60 %	Fire spread slowly
40 - 50%	Fire begin to pick-up
30 -40 %	Fire may spread rapidly
Below 30%	Fire may go beyond control
Below 25%	Crown fires develop

Summary

- As you can see there are many atmospheric parameters to examine and analyse to see if the potential for the development of severe fire and convective severe weather exists.

- Analysing the atmosphere correctly is the first step in developing a good forecast that can protect millions of dollars in resources and possibly save lives.

Thank you for listening