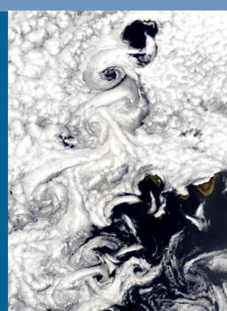
SMHI

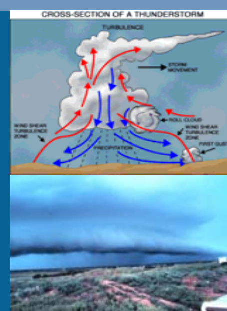
Turbulence and Icing

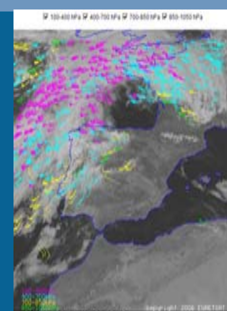
Nomek

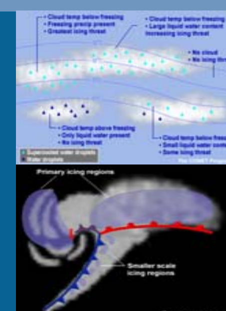
Helsinki Mar-Apr 2006

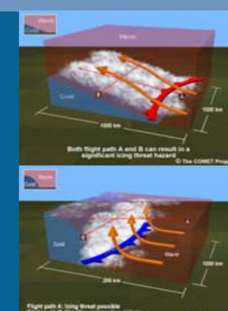
Sheldon Johnston











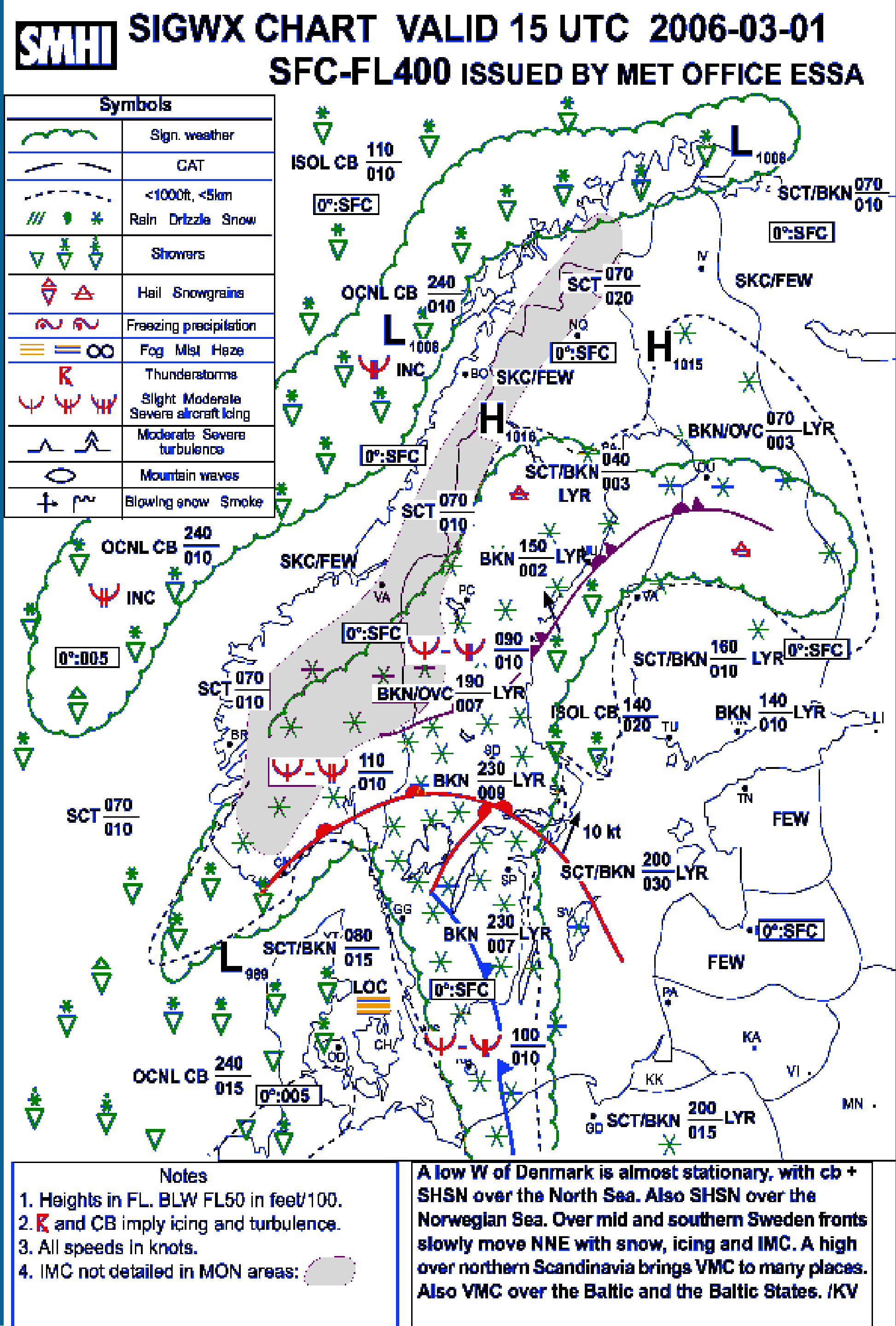
Contributing Organizations

Nowcasting and Forecasting

Significant weather charts

Created using a number of sources to anticipate when and where turbulence and icing will most likely arise

Presentation will look at some of the sources available to the forecaster



Forecast tools

Radiosondes

pilot reports (PIREPs)

Mesoscale Meteorology link

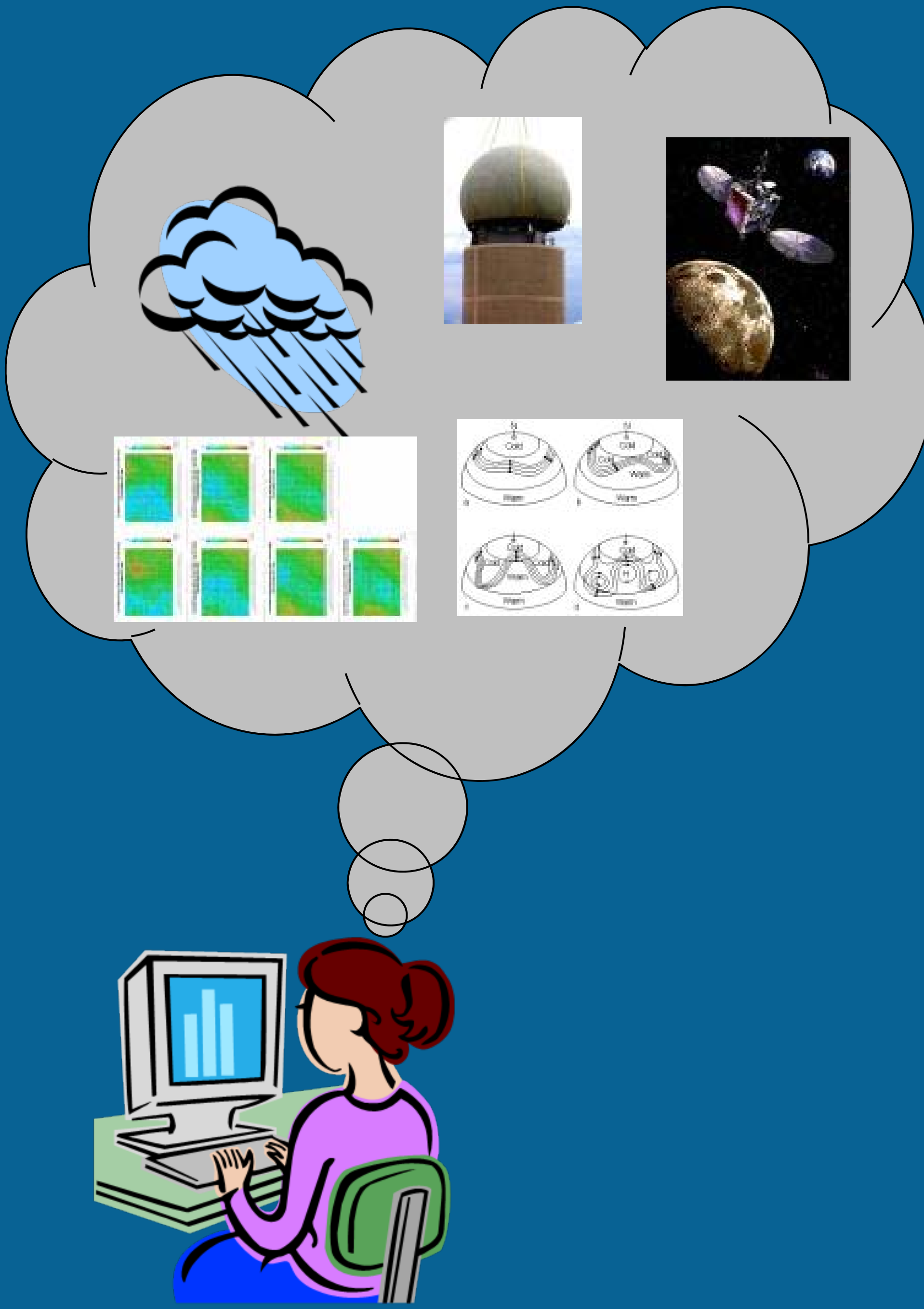
RADAR

Satellite images and SAF products

NWP

Rules of Thumb

Mastering Mesoscale Meteorology



Turbulence

Non-laminar flow

Semi-random stochastic property changes

Low momentum diffusion

High momentum convection

Rapid variation of pressure and velocity in space and time

Reynolds decomposition allows for simplification of Navier-Stokes equations

Reynold Stress component gives rise to turbulence

Non-hydrostatic phenomena

Navier-Stokes Equation

Acceleration of fluid particle = relationship between pressure and velocity changes

Reynolds decomposition is a mathematical technique to separate the average and fluctuating parts of a quantity.
Turbulent flow = [steady] + [perturbation (time average = 0)]

Major types of atmospheric turbulence

Convective turbulence (thermals)

differential surface heating, producing updrafts and downdrafts

Mechanical turbulence

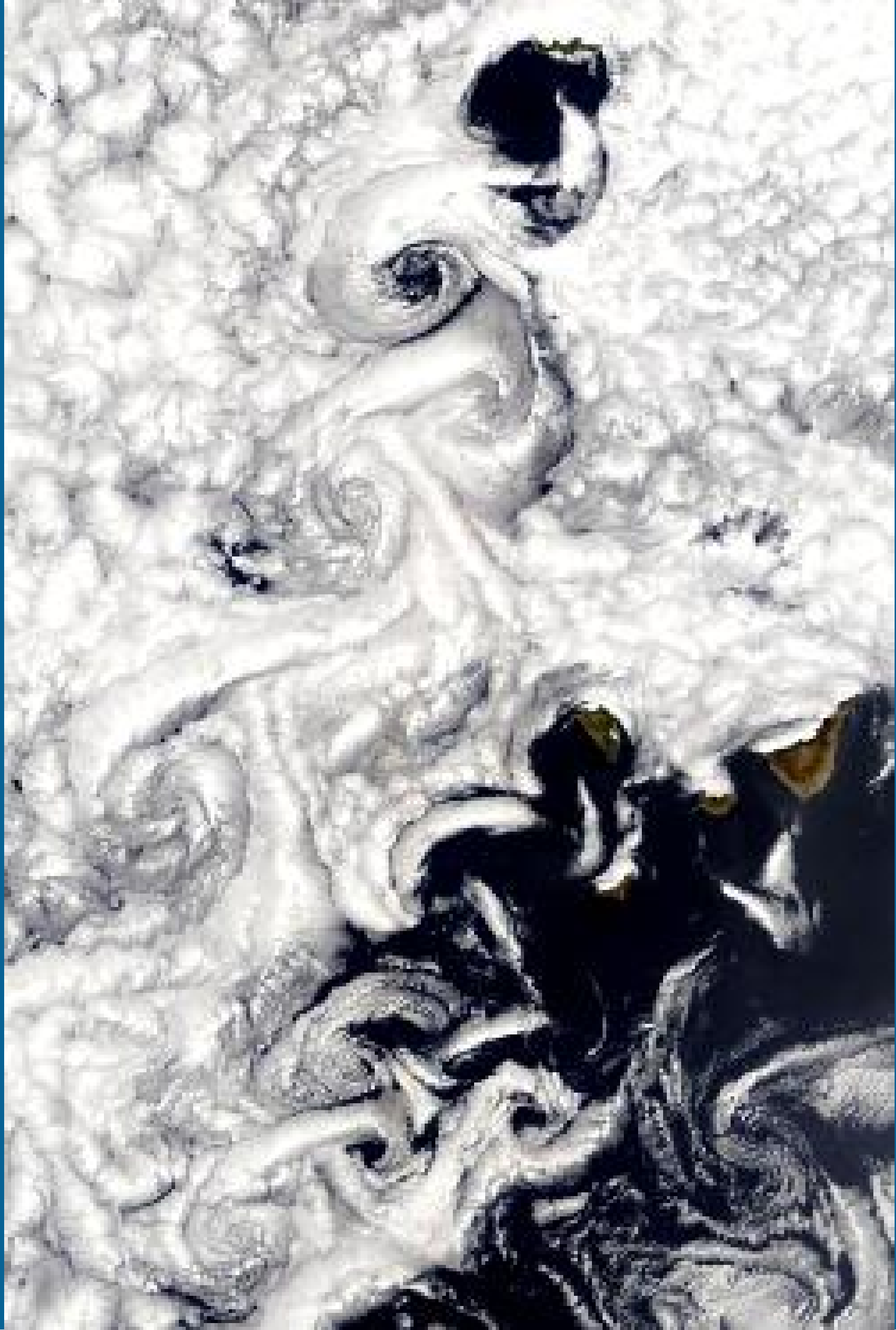
eddy currents on the leeward side of an obstacle

Wind shear

frontal zones, sea breeze fronts, thunderstorms and downburst

Clear air turbulence

can occur at any altitude due to convective currents, obstruction to wind flow, wind shear or any combination of these



Turbulence-Generating Mechanisms

Shear instability along jet and upper fronts

Flow over obstacles:

Mountains

Thunderstorms

Convection:

(thunderstorms, dry thermals)

Low level "mechanical":

(strong winds over rough terrain)

Wake turbulence from other aircraft

Mountain Waves
(Forecasting)

Generation of Lee Waves (Mountain Waves)

periodic changes of pressure in air flow as it moves over mountains

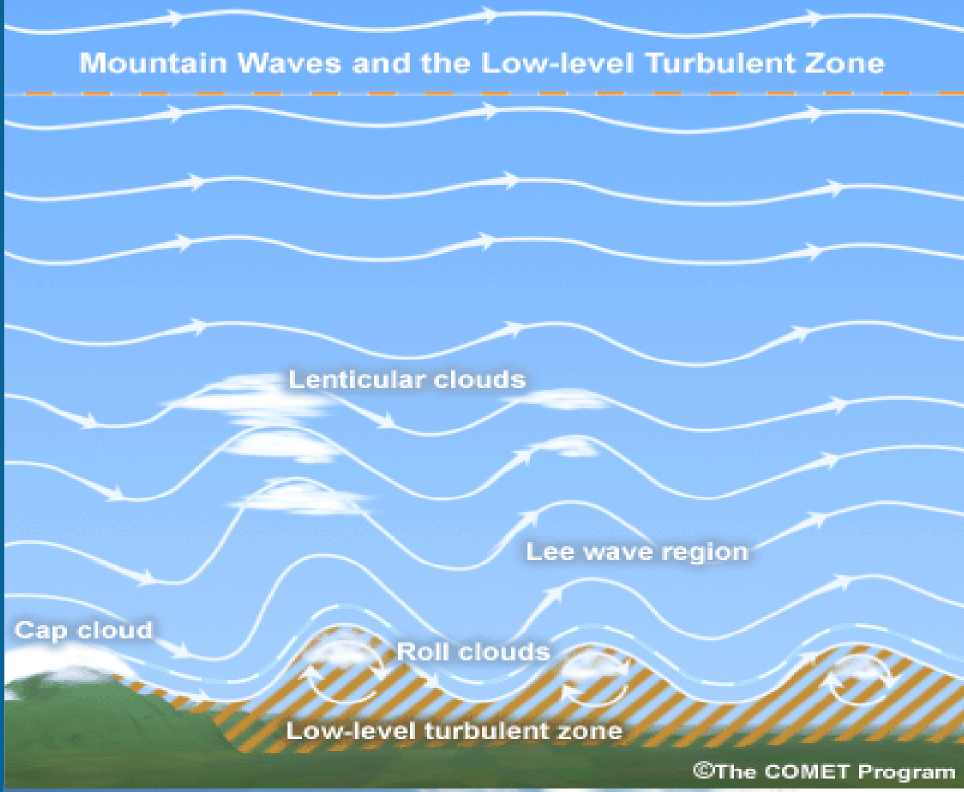
Causes periodic changes in speed and direction of the air within this air stream

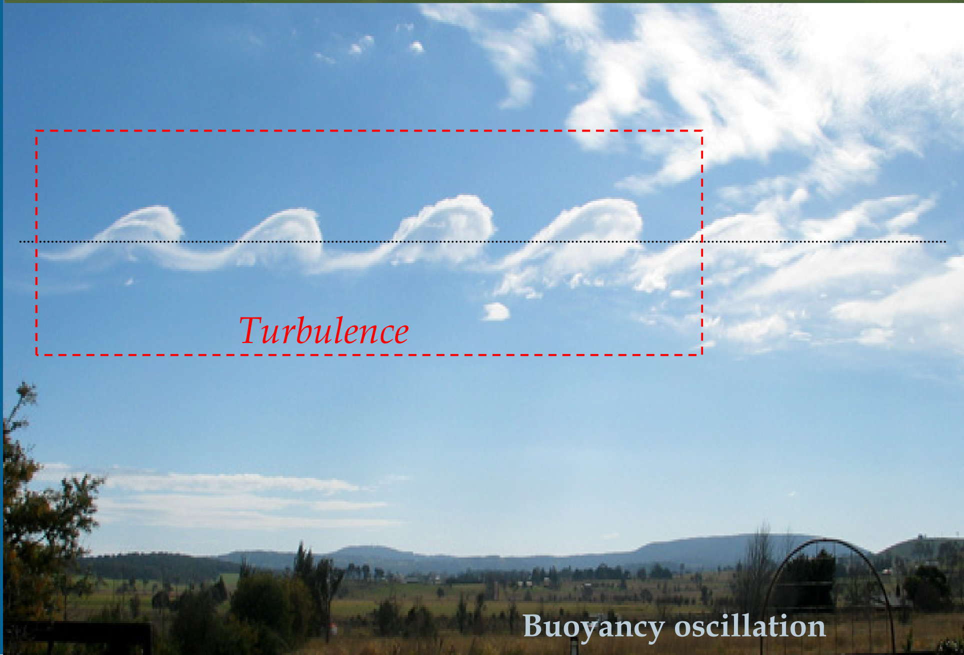
Usually horizontal turbulence is generated

Indicated by typical clouds which do not move with the wind

Frequently, a foehn wall cloud exists

May be harmful for small air crafts such as balloons, hang gliders and para gliders





Mechanical Turbulence

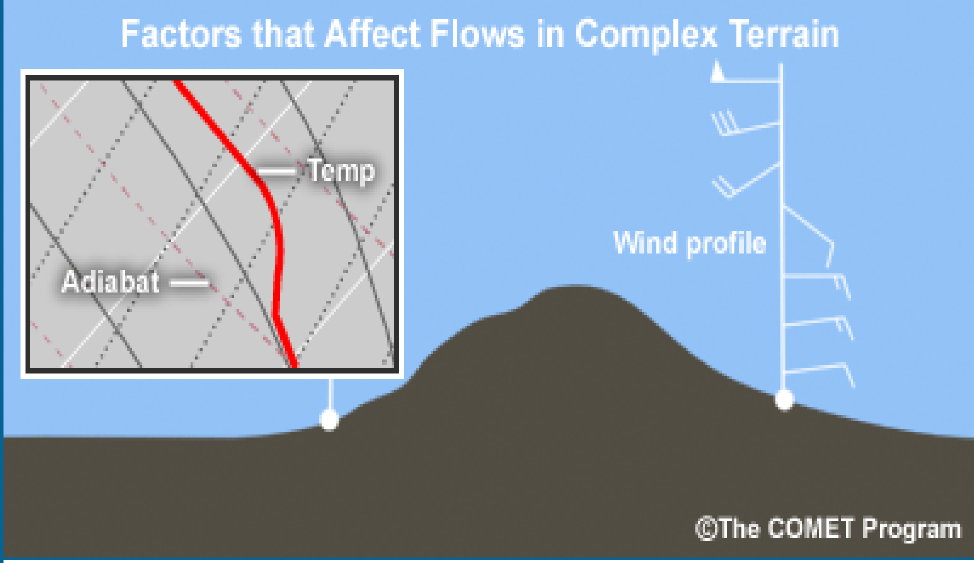
What determines the generation of waves and their characteristics?

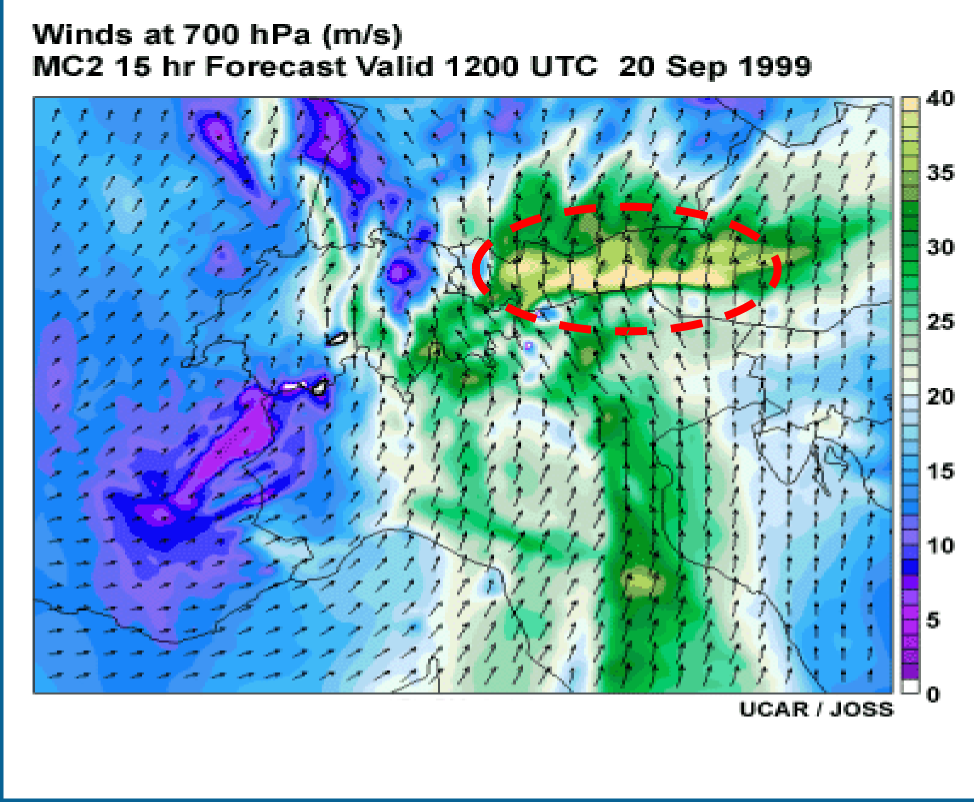
Generation of waves are determined by:

Speed and direction of air flow in relation to the barrier (right angle)

The characteristics of the barrier

Atmospheric stability (stable air)





Thermal

Turbulence

Thunderstorms

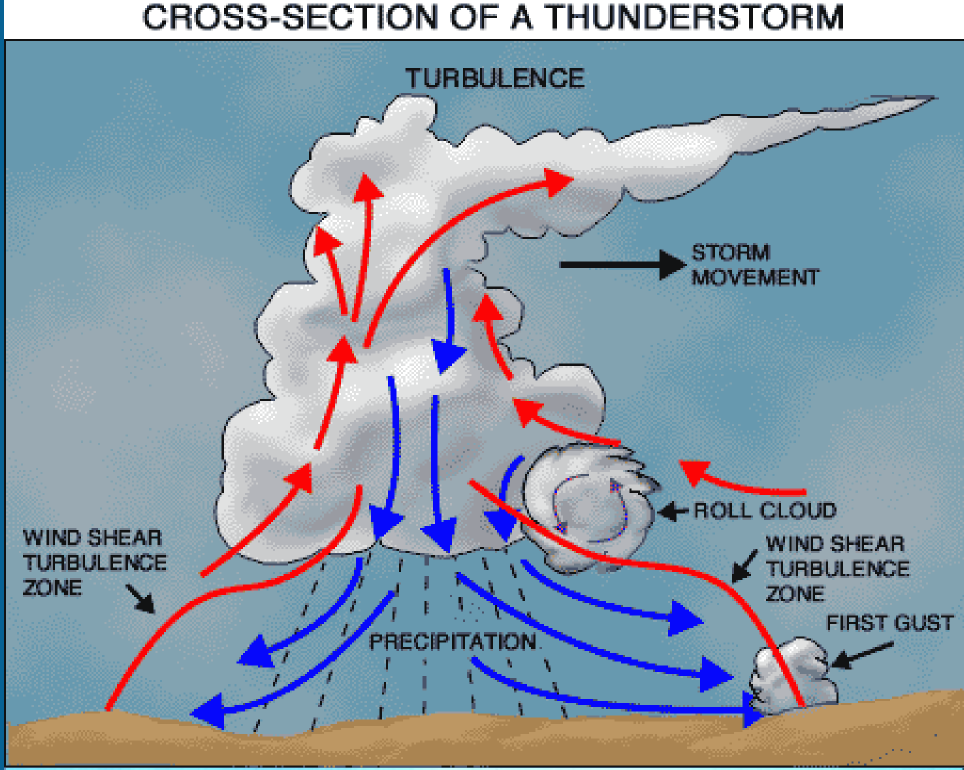
Turbulence may occur at any level within and around the CB

Generally most severe at intermediate levels than beneath the cloud, around the base, or near the top

Most severe during the early and mature stage

Airborne and ground RADAR are used to detect turbulent regions

Observations are relayed to NWP models to increase the forecast



Shear

Turbulence

Detection of Turbulence Using Satellite Imagery

Clear Air Turbulence (CAT)

Water vapour imagery (8~4 km)

Subsidence warming with time along fronts

Also gravity waves

Infrared (4 km)

Transverse cirrus cloud bands

Deformation zone cloud boundaries

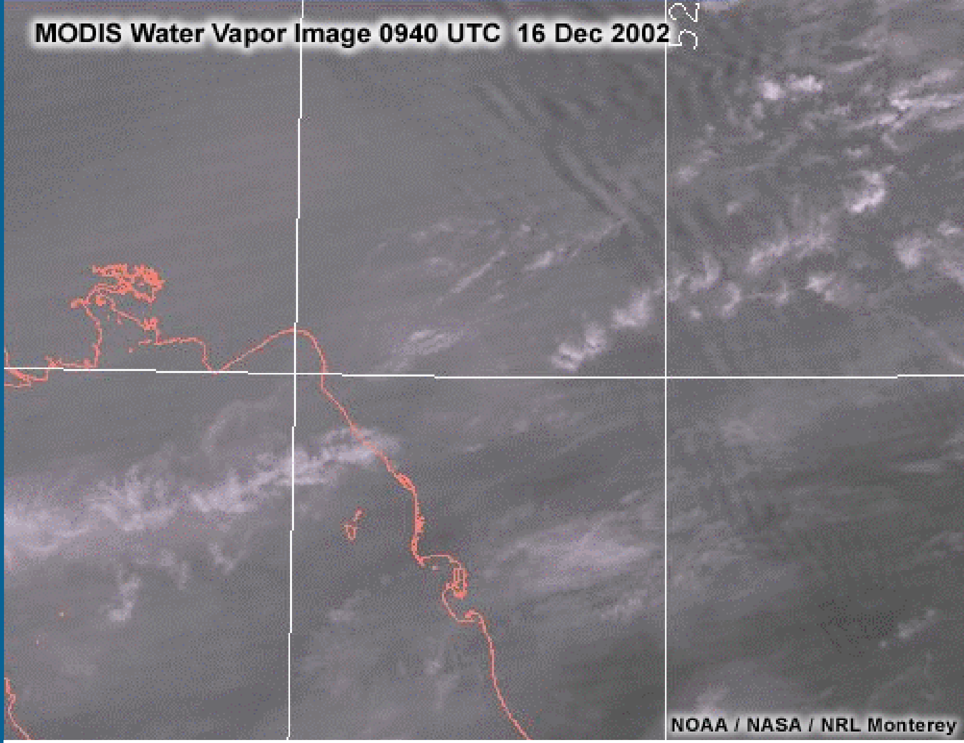
Visible (1 km)

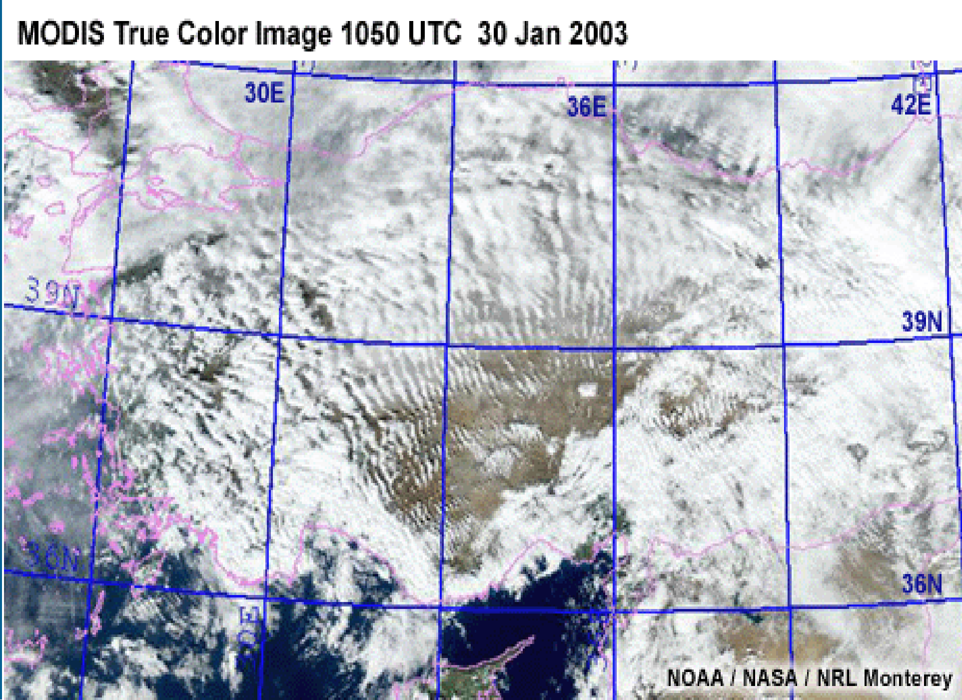
Billow wave clouds (K-H instability)

Mountain waves

Transverse cloud bands (IR/Vis)

Lee-of-mountain cirrus with lee gap (IR/WV)





Wind shear turbulence (CAT)

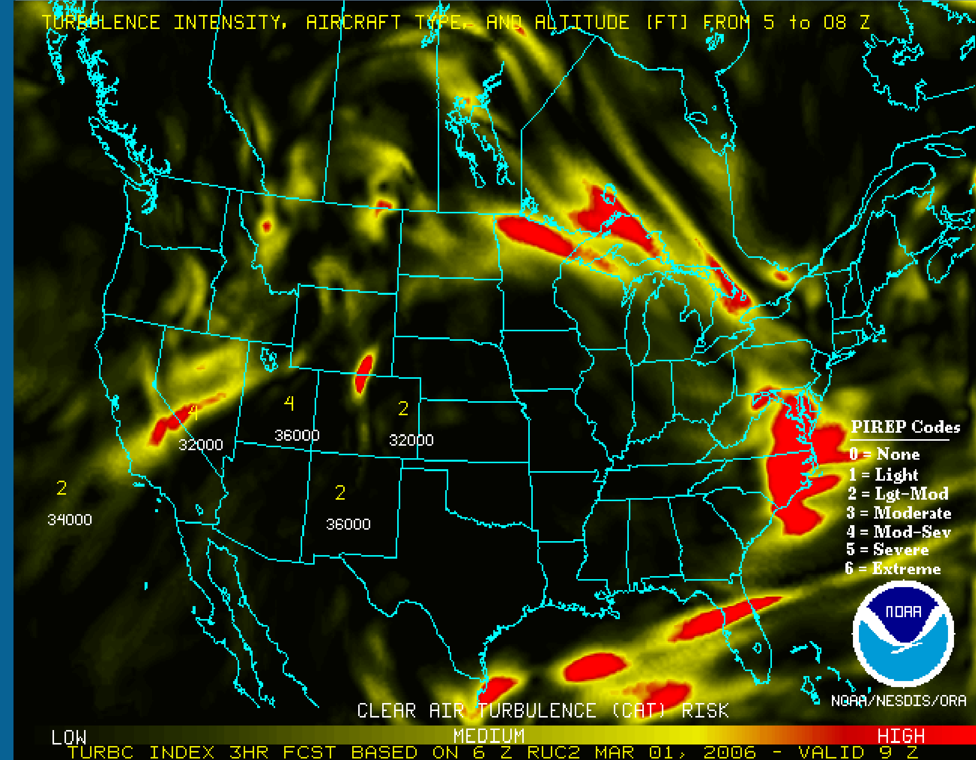
CAT usually occurs at relatively high altitudes of 20,000 feet (around 6 kilometres) or above

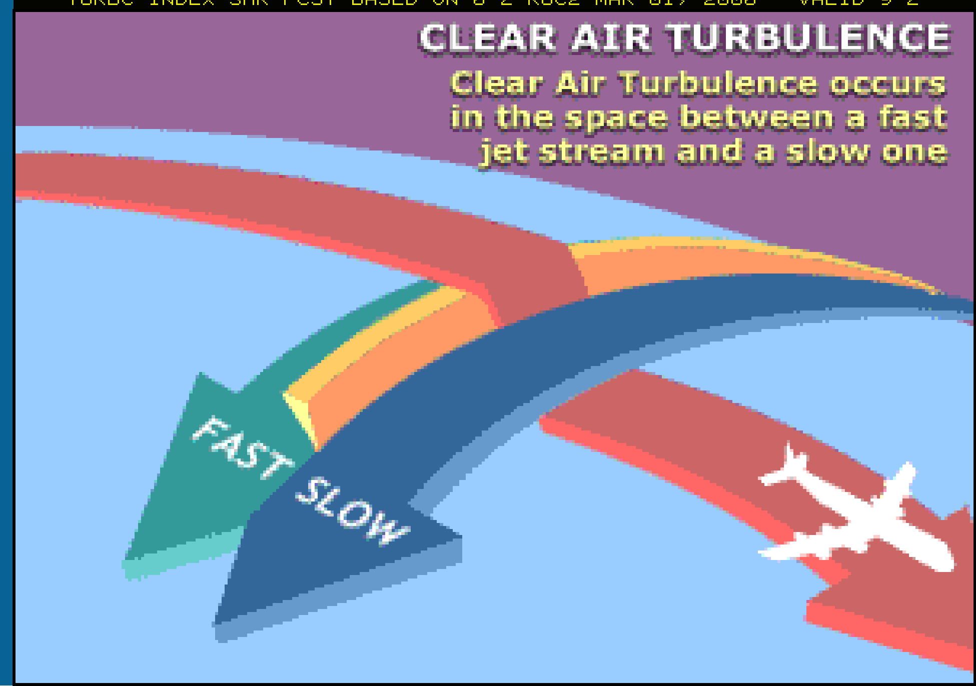
It typically occurs near jet streams and other regions of significant wind changes in the vertical direction

It can also occur when strong winds blow across mountain ranges

Observations show that CAT is common in anticyclonic flow

Can persist in the same area for several days

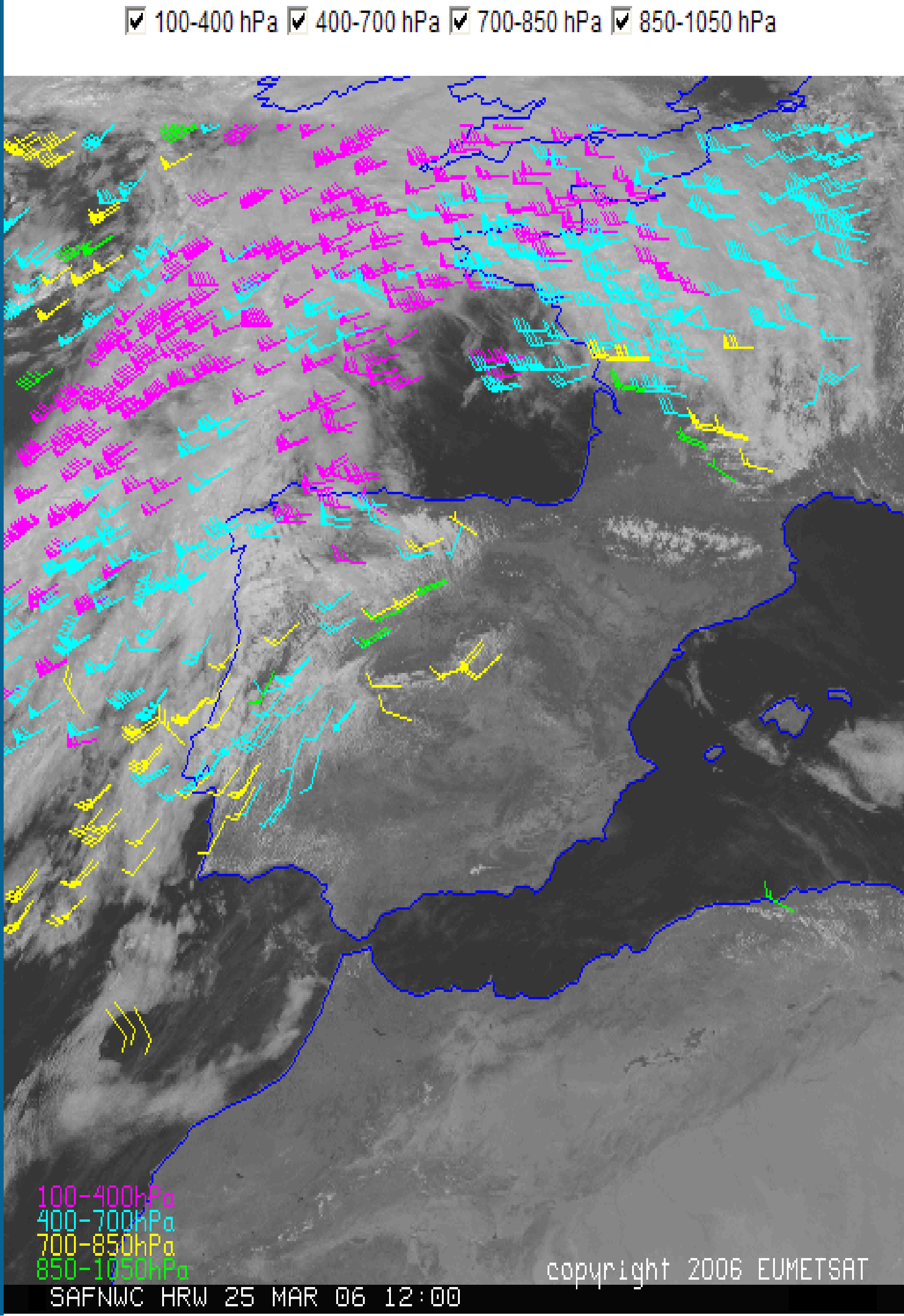




SAFNWC products High Resolution Winds

Depending on the cloud cover at particular altitudes, the High Resolution Wind product can give the forecaster the current wind field over a region at various levels

The ability to monitor hourly changes is also possible



RADAR

Density differences and airborne particles make areas of turbulence visible to radar (K-H waves)

Turbulence Prediction and Warning Systems (TPAWS)

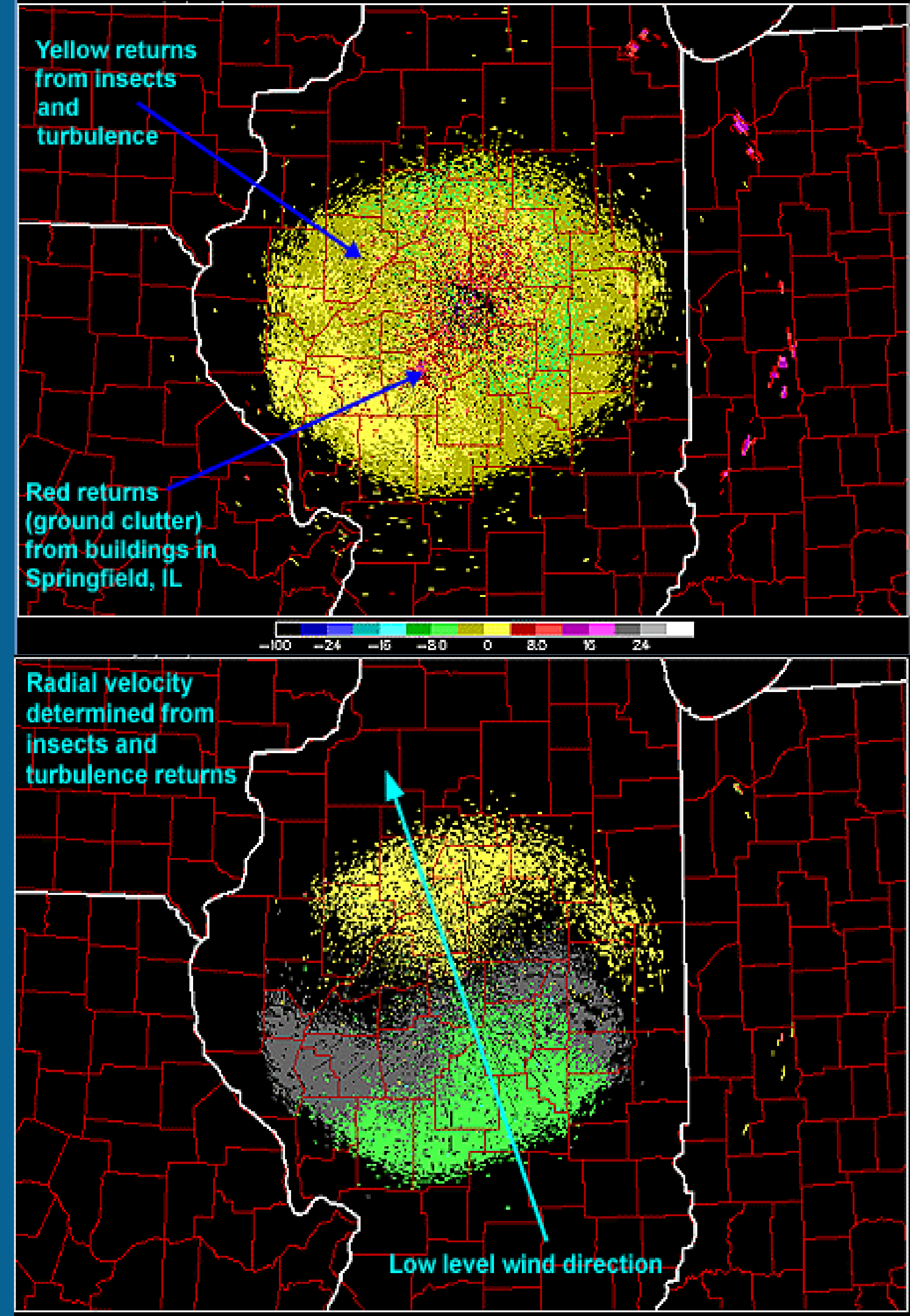
NASA's Aviation Safety program has investigated technologies to detect and warn of hazardous in-flight turbulence

As a result, a radar-based airborne turbulence-detection system (ATDS) has been developed

TAMDAR data

TAMDAR = Tropospheric Airborne Meteorological Data Reporting

Reports winds, humidity, turbulence…..



SMHI

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Coastal Jet

NWP Turbulent Kinetic Energy (TKE)

High NWP model resolution (<=10 km) is required to accurately depict mountain waves

A model's vertical coordinate system affects its ability to forecast mountain waves

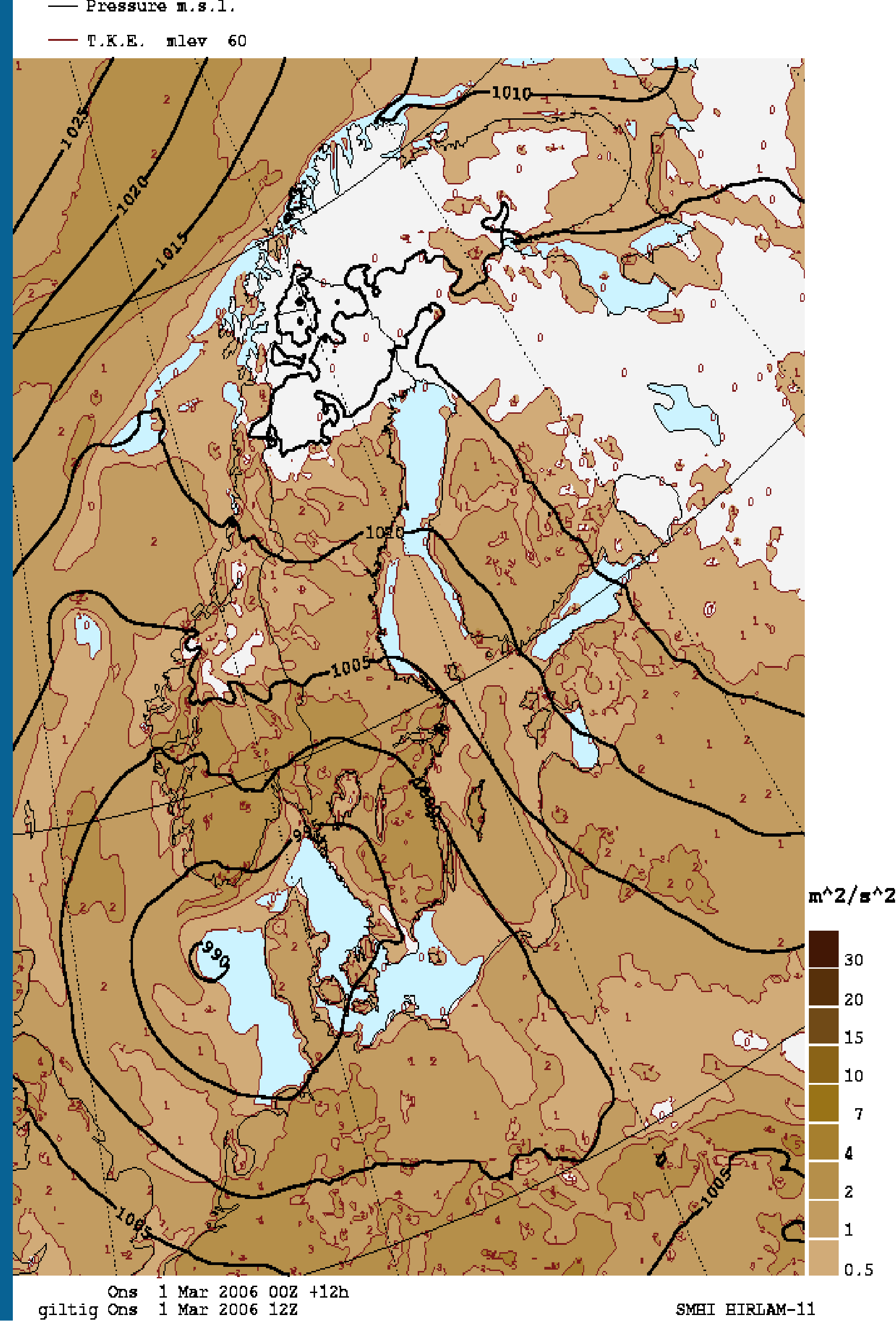
The Richardson number is the key to diagnosing and forecasting turbulence sources of TKE

Mechanical production of TKE through vertical shear

Buoyant production of TKE through thermals

Sinks of TKE through dissipation

Advection of TKE if the horizontal grid spacing is less than 10 km



3-D Gridded Forecasts of Turbulence

Model generated turbulence chart

GTG (Graphical Turbulence Guidance)

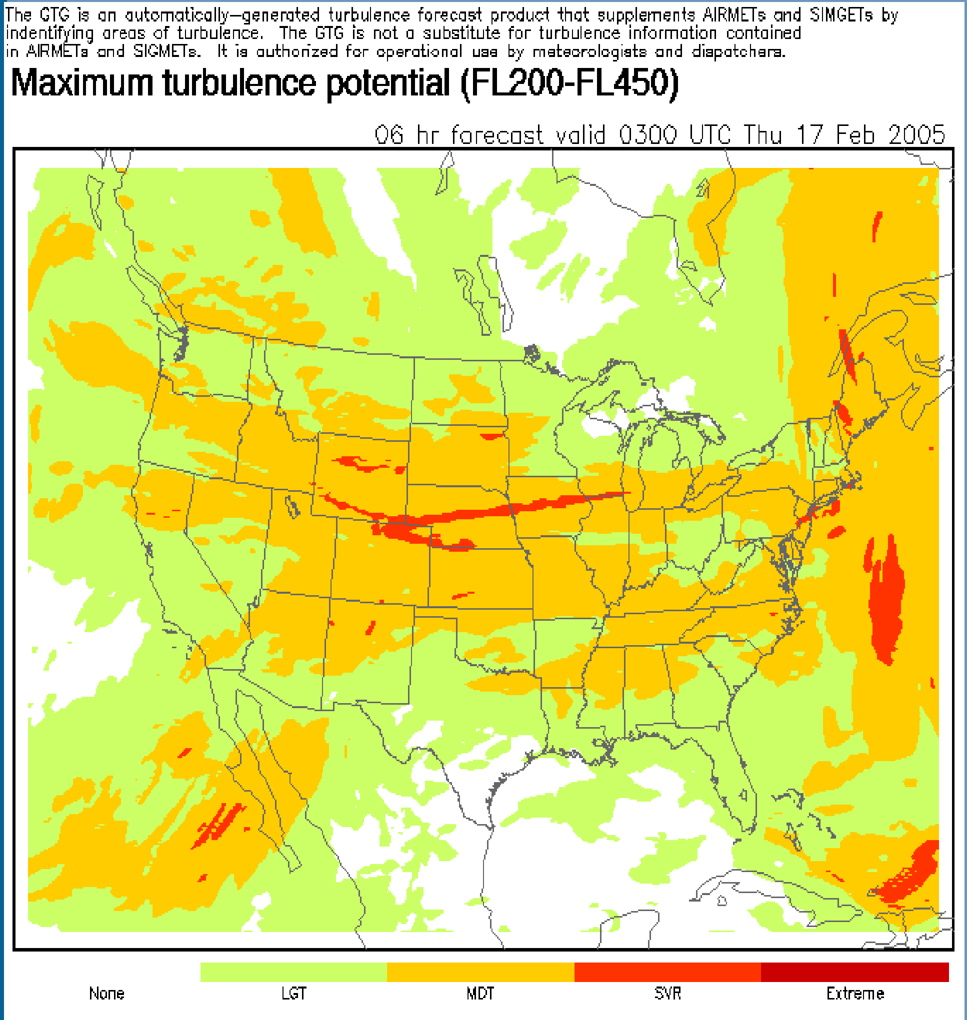
The GTG is an automatically generated turbulence product

Developed by National Center for Atmospheric Research (NCAR)

Run operationally at the AWC

Predicts the location and intensity of turbulence over the continental United States (CONUS)

RTVS has evaluated GTG since 2003.



6-h Turbulence forecast (GTG)

Pilot Reports

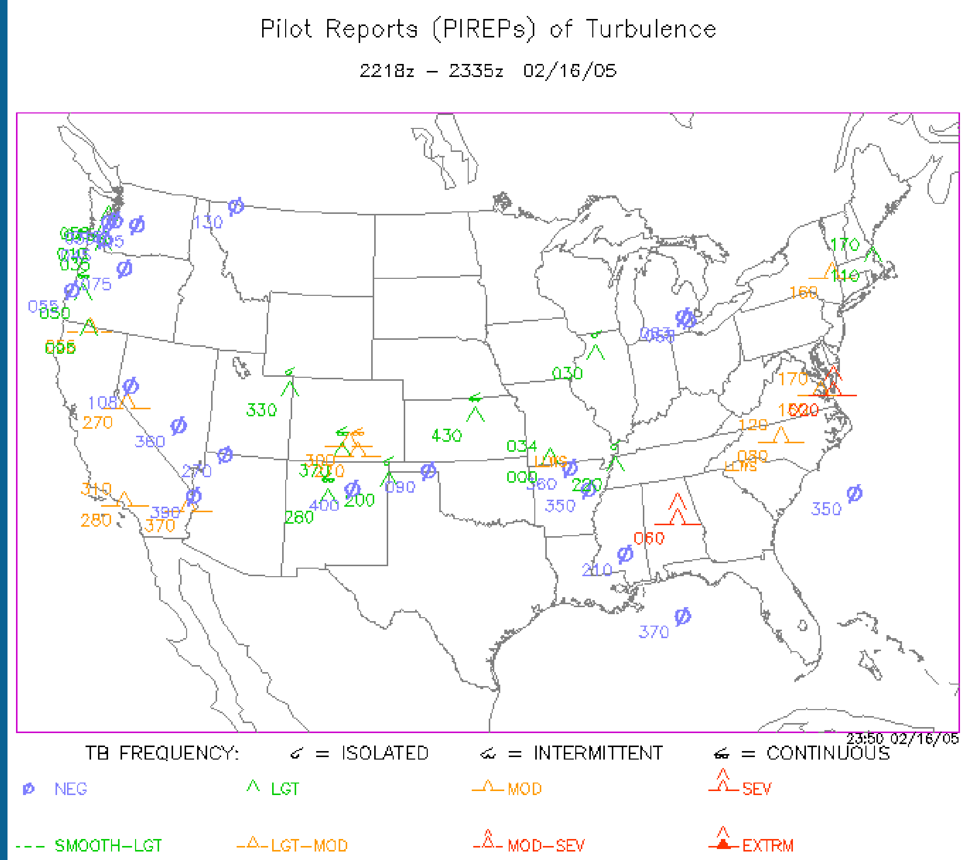
PIREPS

Highly useful for establishing where hazardous aviation weather conditions are occurring

Care must be used when interpreting the information

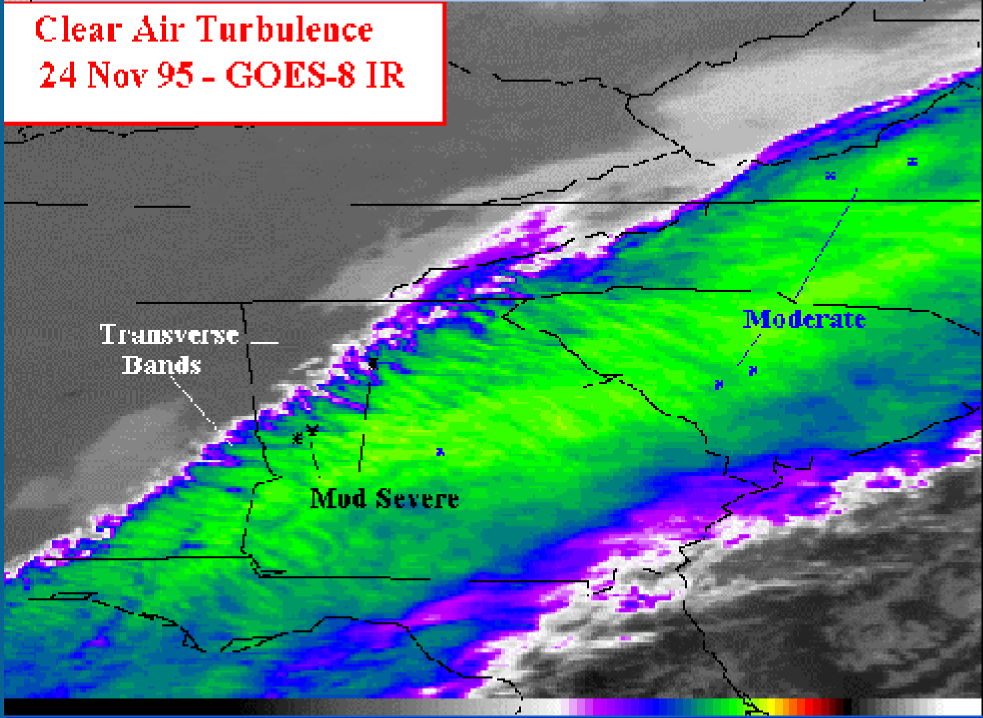
PIREP data quality can vary based on the aircraft and pilot experience

PIREP locations are not always completely accurate due to the lag time that often occurs between the observation and making the report



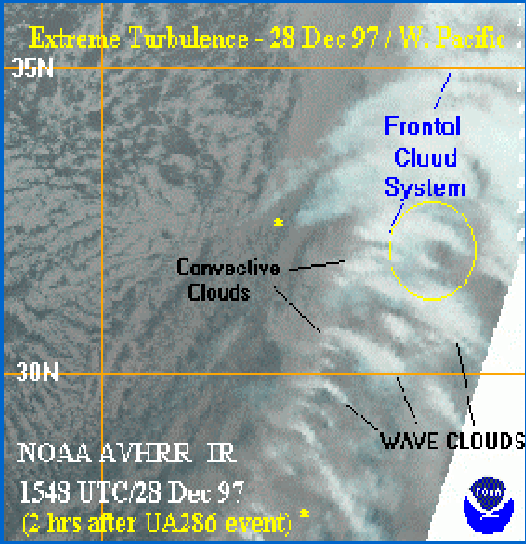
Turbulence ~ 1 hour

Severe Turbulence Scenario



Extreme Turbulence Scenario

- Environmental conditions:
  - Strong jet intersects:
  - Cold front with:
  - Low top convection
- Extreme turbulence possible downwind from convection



Rules of Thumb:

In areas in and around a CB (straight line winds or microbursts)

In areas where there is a cold front and / or squall line (inactive fronts)

Where the surface winds are over 30-35 knots (mechanical turbulence)

In mountainous areas under 2000 feet

Where there is strong wind shear

Where there is strong inversion during winter (>10 deg/1000 ft) and the forming of a low-level jet

In areas of inactive and fast moving fronts/troughs (speeds > 30kt)

In areas of lee waves on the leeward or luv side of mountains

Forms in stable atmosphere and when the wind across the obstacle at or near right angle

Wind speeds over 25 knots within a layer up to 500 hPa and increasing with height

When the Jet Stream has winds speeds of over 110 knots

On the north side of the Jet Stream (Inertial Instability and gravity waves)

In areas of sharp troughs or ridges (Curvature shear)

In areas where there is a rapidly developing ridge or trough

Near the leading edge of a jet max (super-geostrophic winds)

Icing

Refers to the synoptic, mesoscale, and local-scale setting in which aircraft icing occurs

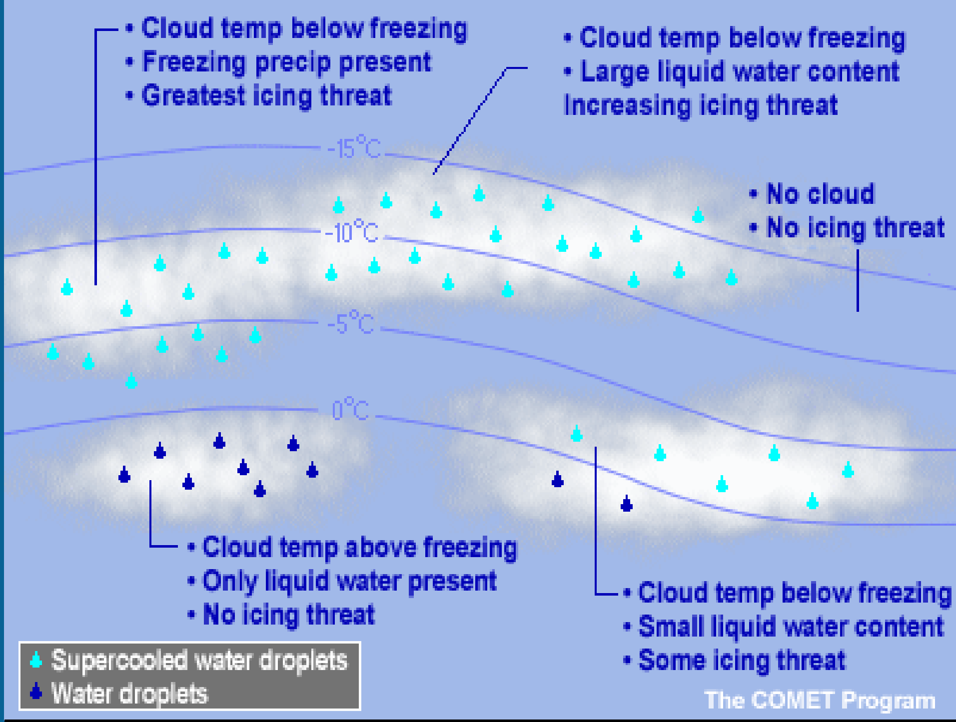
Occurs in but convective and non-convective processes

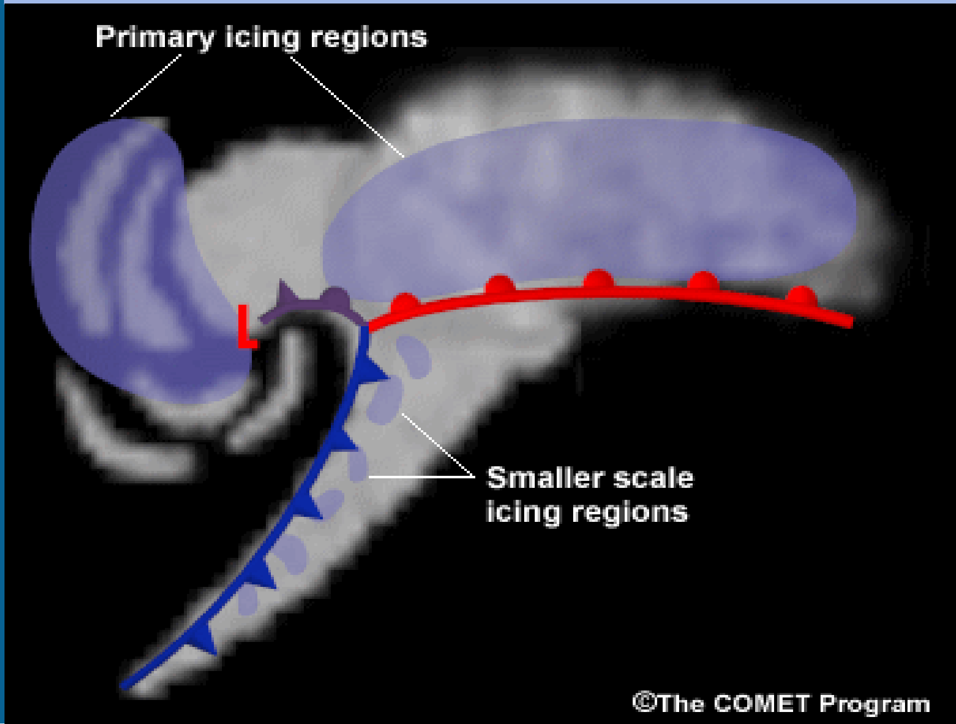
Most icing events occur within clouds and is enhances during the following processes that affects cloud formation:

Terrain

Fronts

Cyclones





Prerequisites for icing

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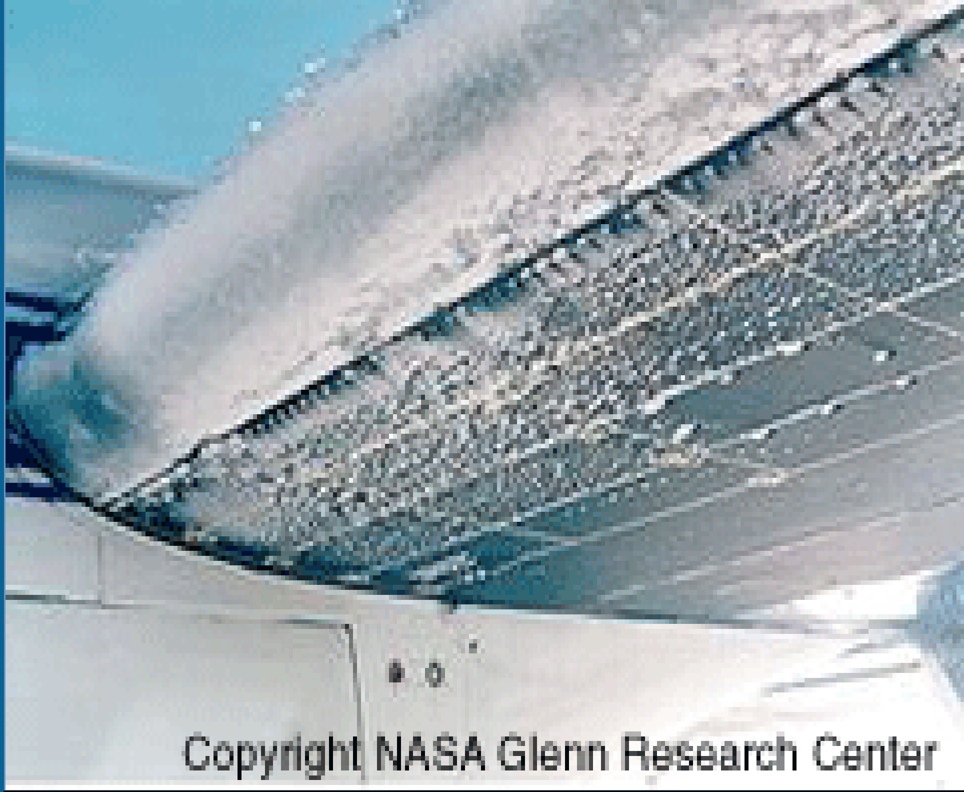
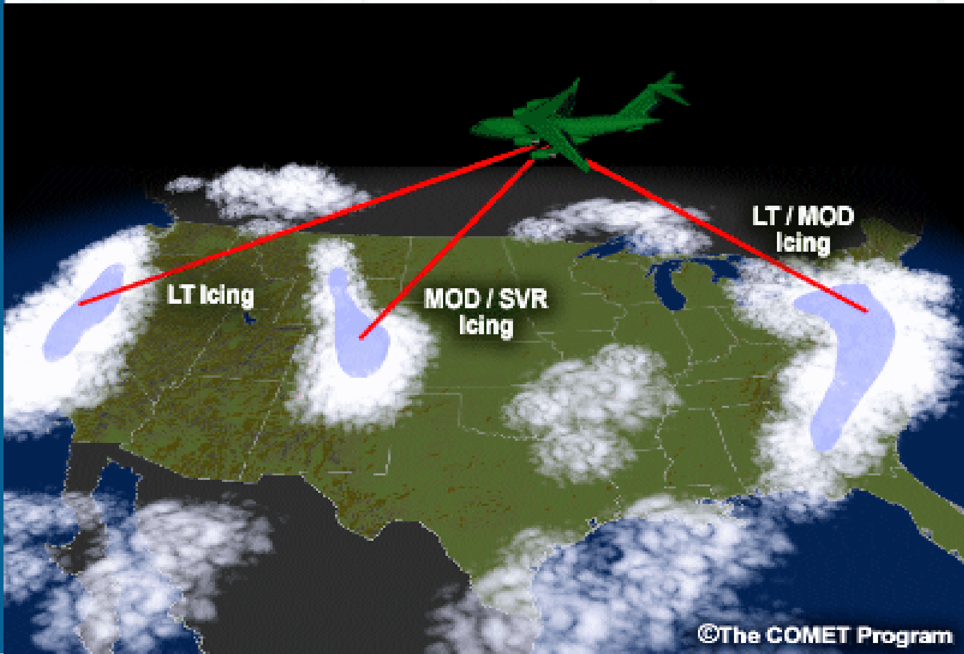
The meteorological quantities most closely related to icing severity and type are, in order of importance:

Liquid water content (LWC)

Temperature (Altitude)

Droplet size

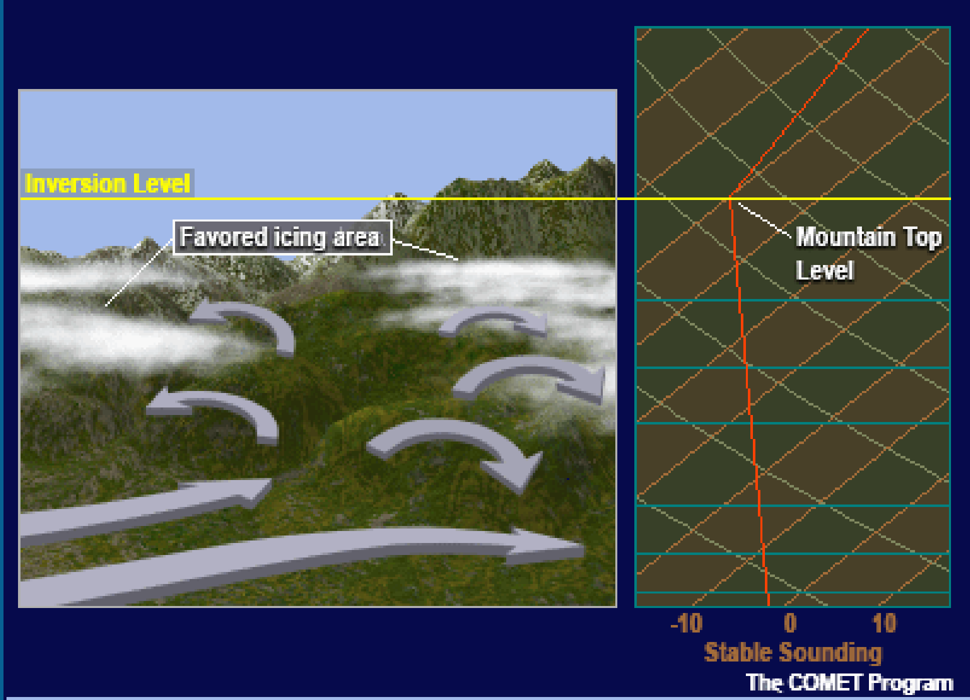


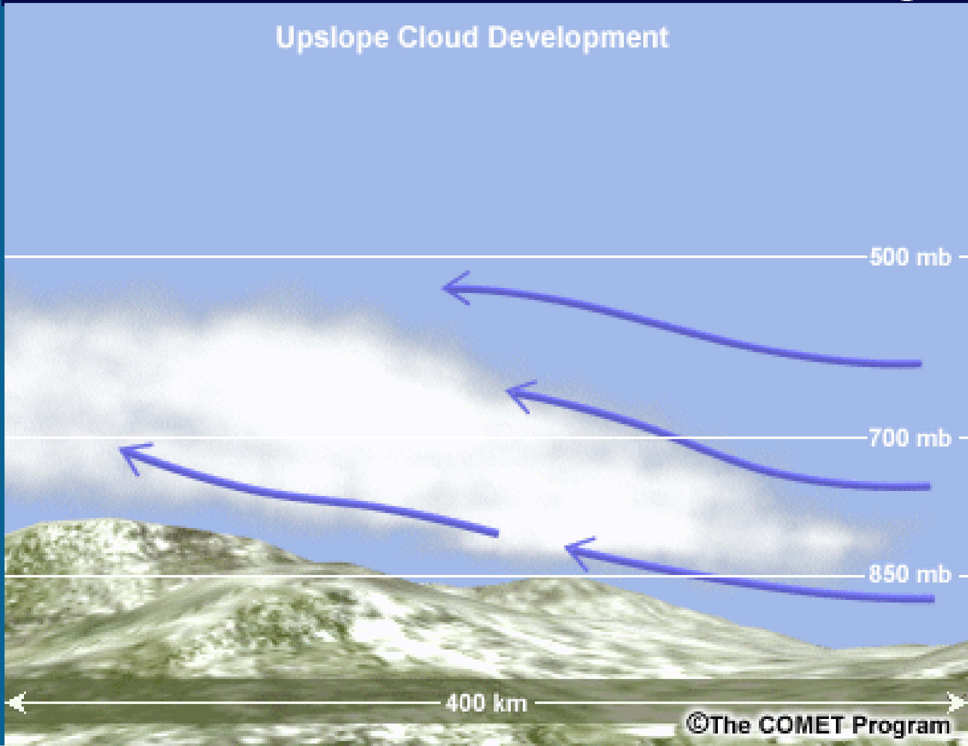


Icing over rough terrain

Icing hazards can also develop in orographic clouds, which tend to develop along mountaintops and ridges and can persist for days if the winds and moisture are consistent

Winds blowing perpendicular to ridgelines provide the most favorable conditions for orographic cloud development





Icing associated with fronts

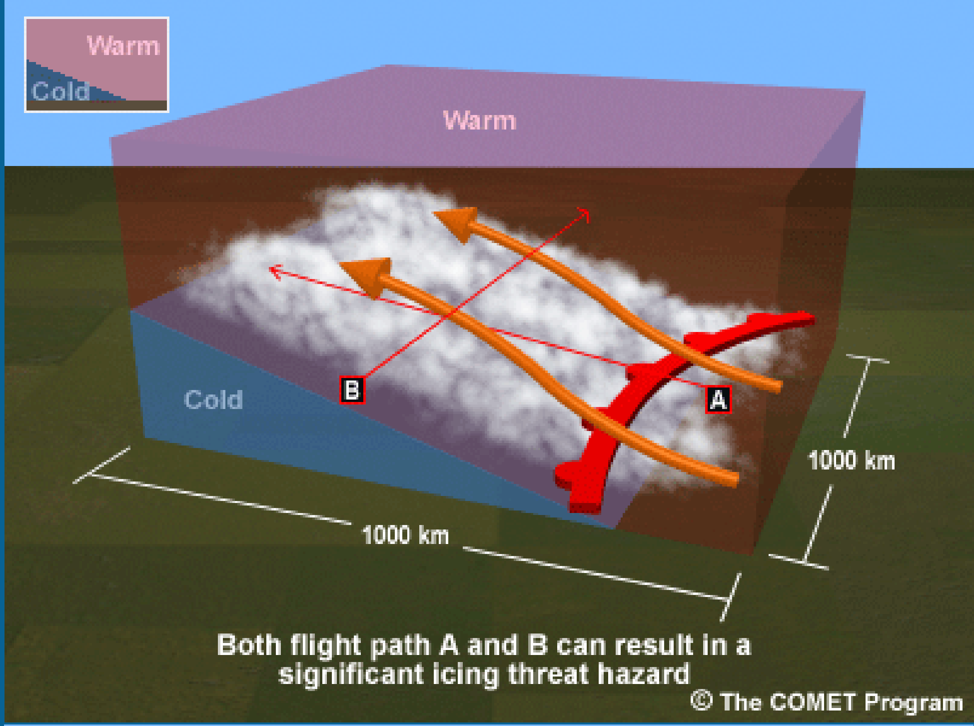
Fronts creates lift along a moving cold

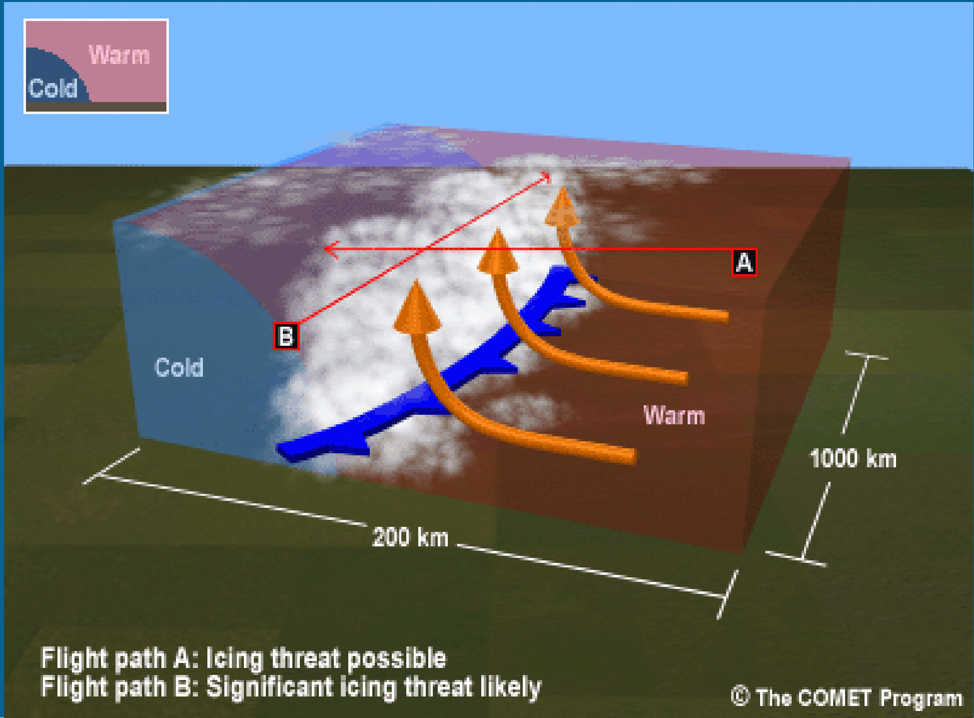
Can be areas of enhanced icing due to the presence of convection and ample moisture

The icing threat posed varies based on the strength and extent of the associated lift and ultimately, the aircraft's flight altitude and trajectory through the frontal cloud

Perpendicular path to the cloud band can reduce the icing threat (Path A)

While a path parallel to the cloud band can be particularly hazardous due to the prolonged time within the cloud





Phase transition

Condensation

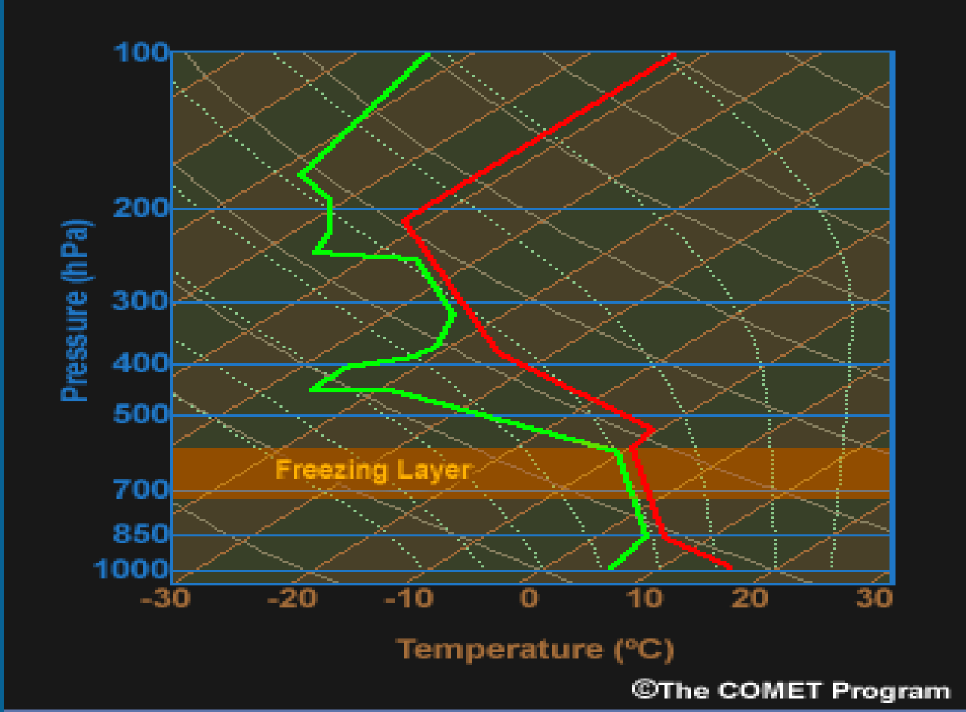
Evaporation

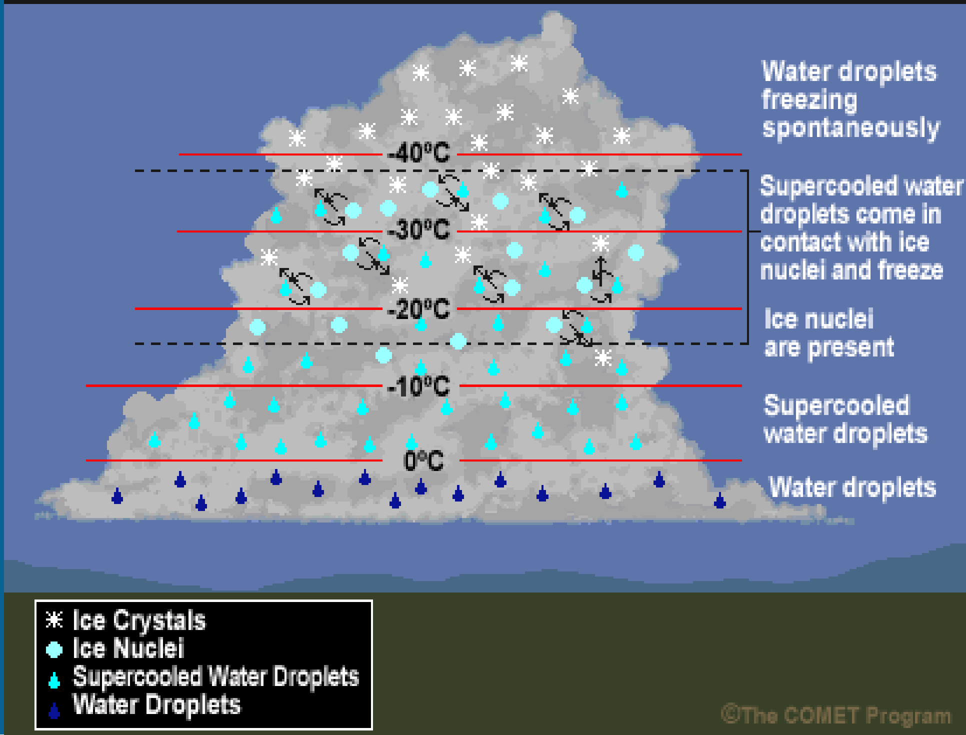
Freezing

Melting

Deposition

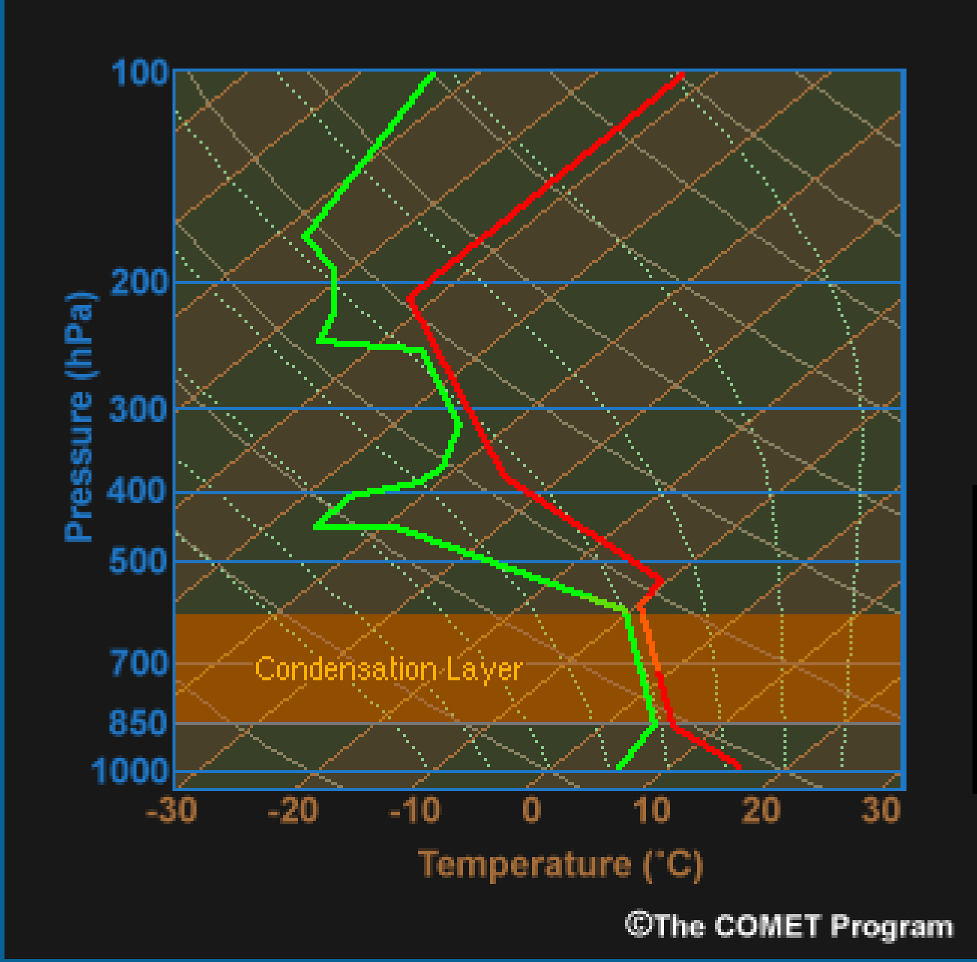
Sublimation





Condensation

The importance of condensation to the icing forecast problem is its role in increasing cloud liquid water content



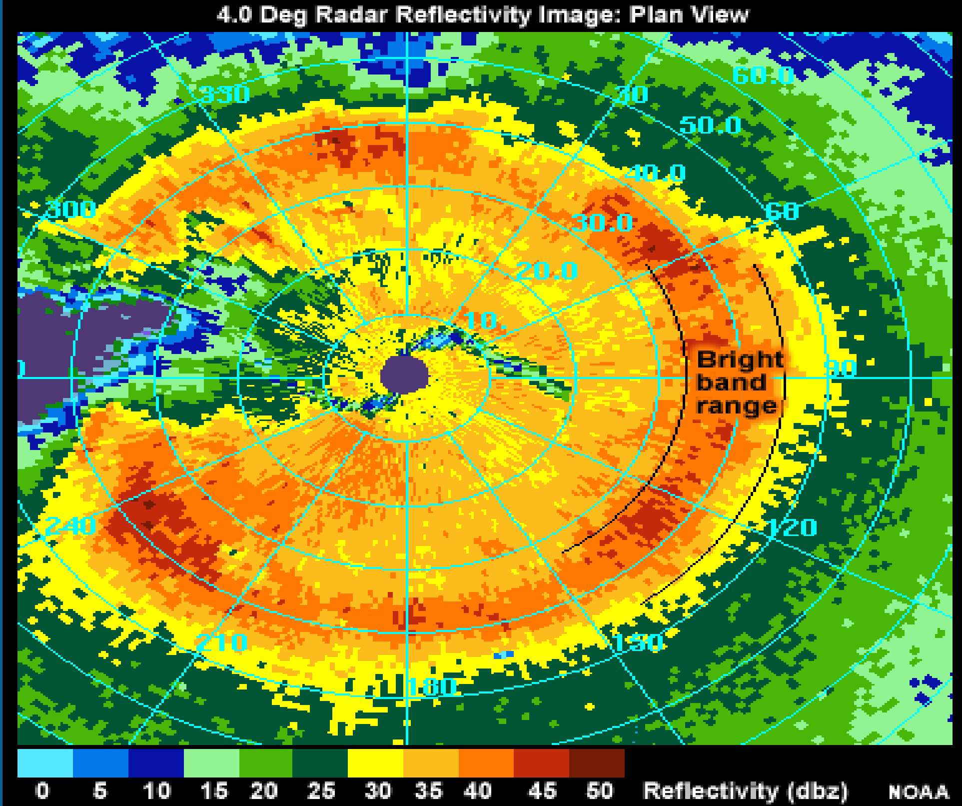
An environment favorable for condensation is likely to become more favorable for icing if other factors such as temperature are favorable (i.e., T < 0ºC)

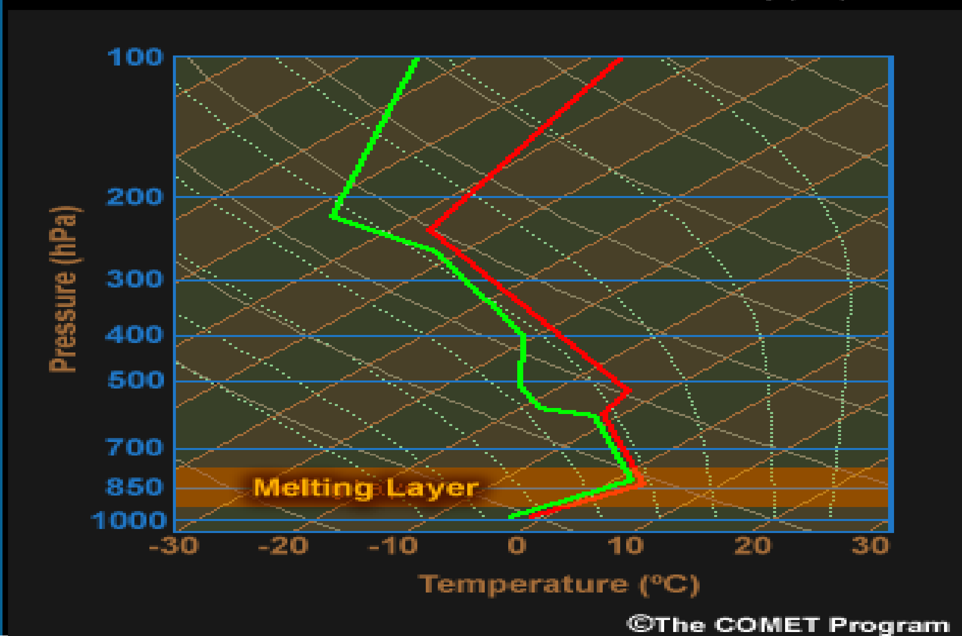
Melting

The melting process typically reduces the icing threat since temperatures are above freezing

The exception to this is the development of freezing precipitation

In such situations, the melting process acts to indirectly intensify the icing threat in the lower subfreezing layer





Impact on icing

- Deposition process generally mitigates the icing threat because it reduces cloud liquid water droplet concentration through the growth of ice crystals

- Entrainment of dry air into a cloud results in evaporation, which lowers the cloud liquid water content and consequently reduces the risk of icing

- Freezing of cloud droplets generally decreases the icing threat. The decrease in liquid water content and increase in ice particles lessens the icing threat since ice particles do not easily adhere to an airframe

- Sublimation has the potential to remove ice from an airframe while in flight. When an airplane exits cloud but remains within a cold environment (T< 0º C), ice can sublimate from the airframe

Using satellite

SAF Cloud Phase products along with cloud top height and cloud top temperature can be helpful in icing forecasts

Channels Useful in Icing Detection

Visible (0.6 mm)

Thickness, coverage, phase, convection

IR2 (3.9 mm)

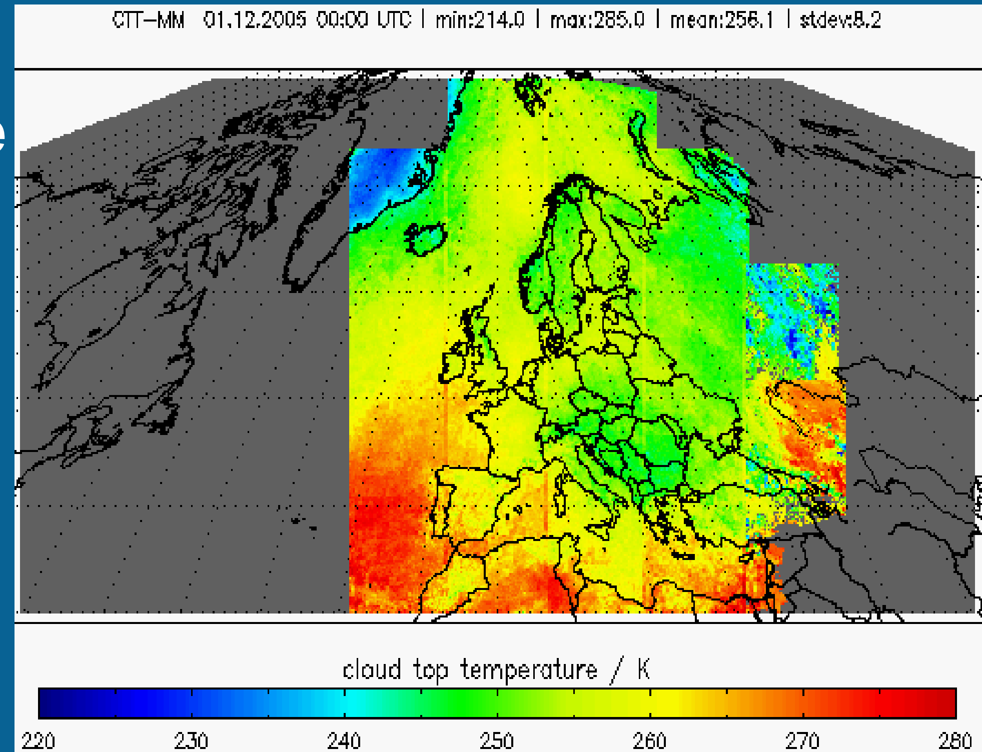
Cloud phase, drop size

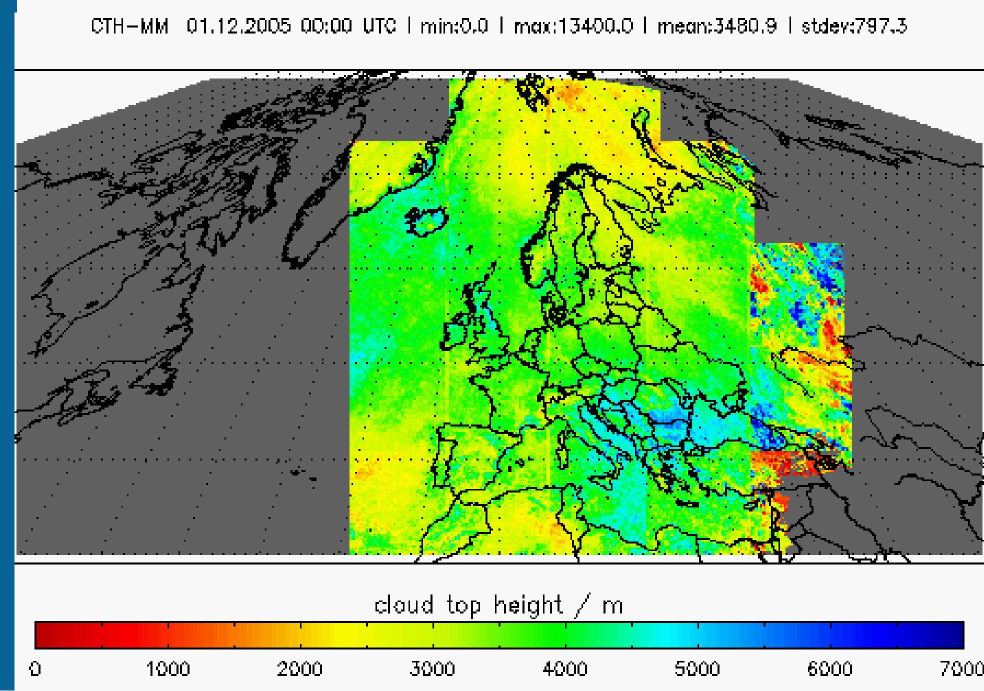
IR4 (10.7 mm)

Cloud top temperatures, thickness, coverage

IR5 (12.0 mm)

Thin cirrus detection





Meteorological Factors Conducive to Icing

Temperature (0 to -20C)

Liquid Phase (supercooled droplets)

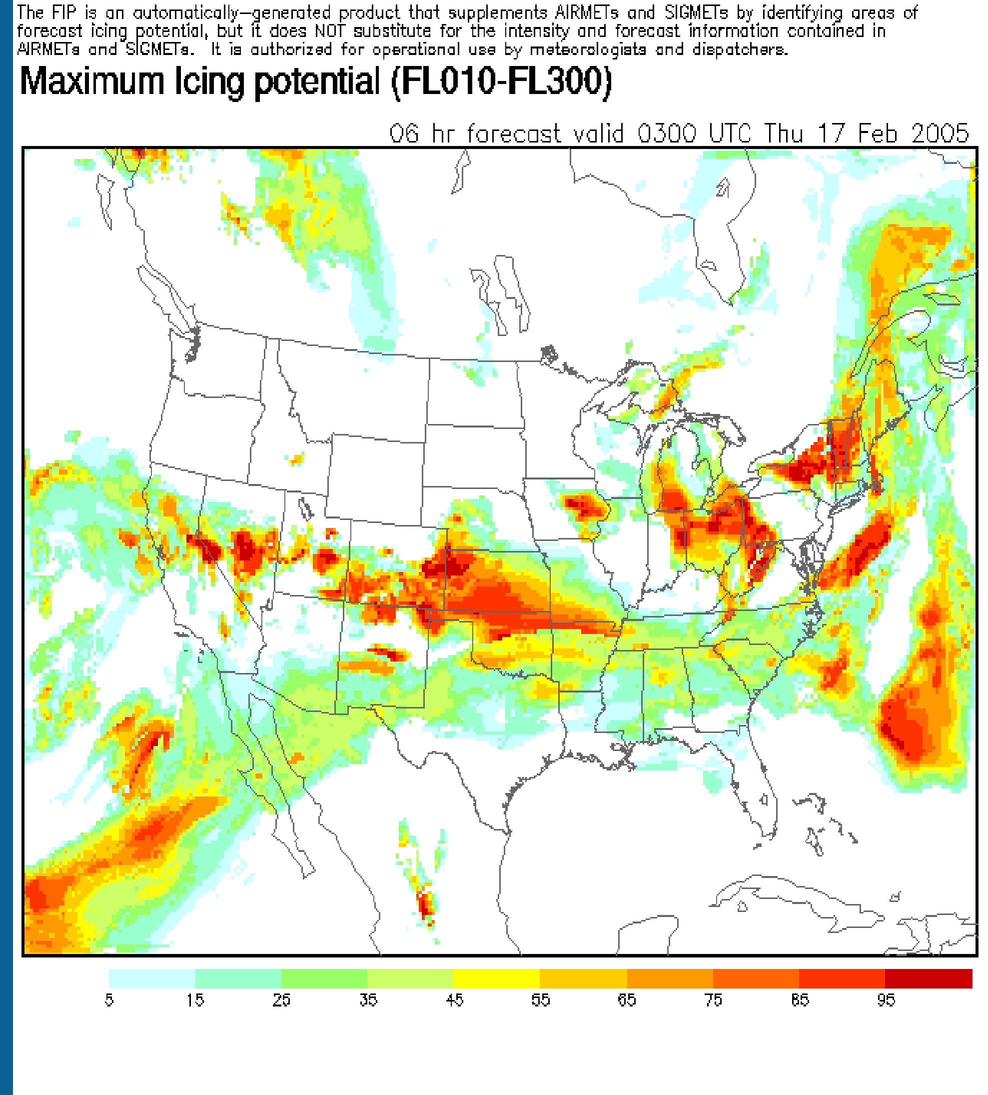
Large drop sizes (>50 µm)

High Liquid Water Content (0.25 gm-3)

Weak vertical motion (~1 µ bar s-1)

Embedded convection

Large areal extent



Rules of Thumb

- In CBs
  - during the developing stage
  - In layers from 0 to -25 oC (lokalt -40)
- Active fronts and developing lows
  - In layers from 0 to -15 oC
- In clouds above an inversion (ST/SC) with temperature 0-15 degrees below freezing
- Freezing rain
- In connection with lee waves