



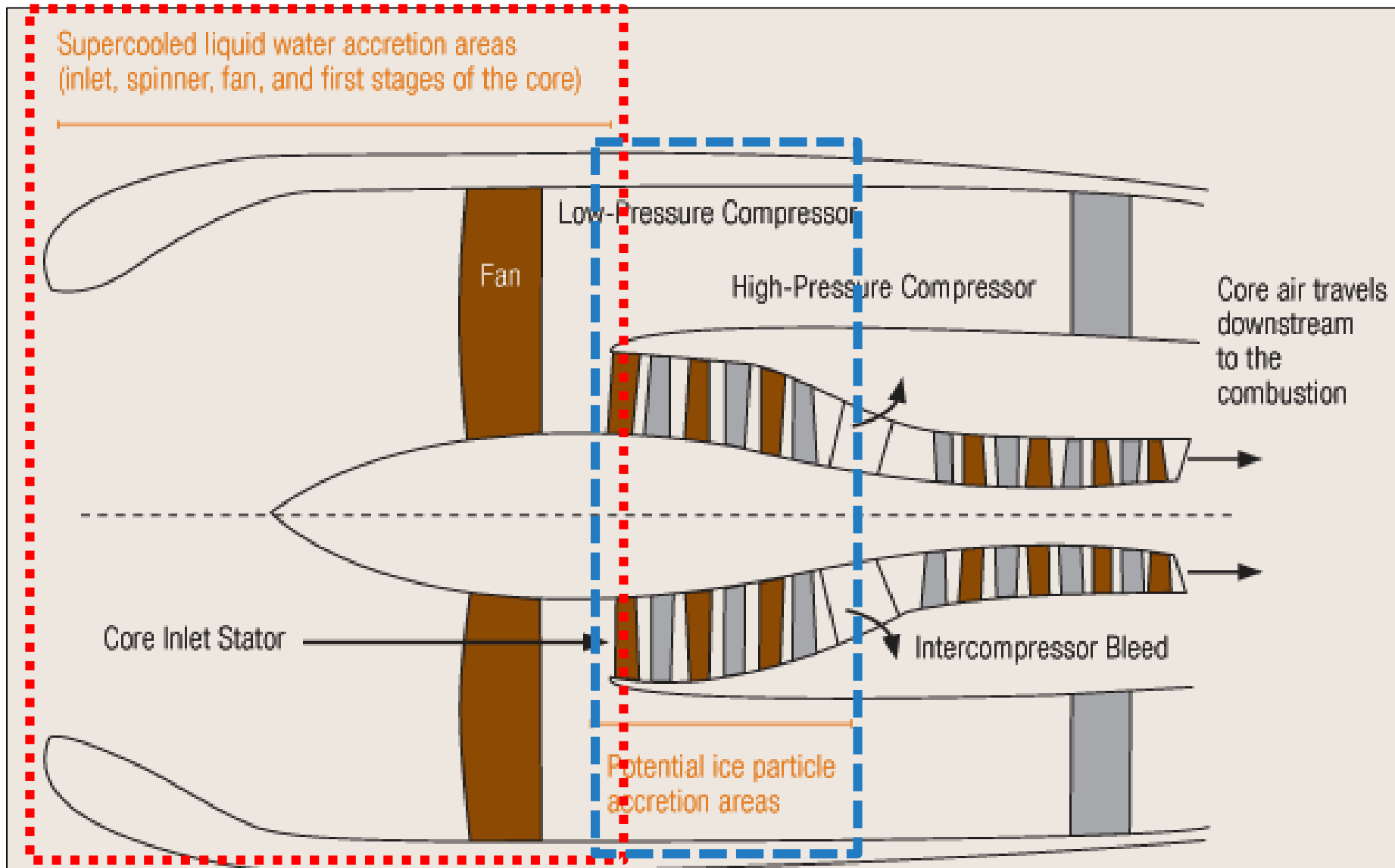
Ice Crystal Icing Briefing

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Agenda

- Differences between Ice Crystal Icing (ICI) and Conventional Icing
- Defining ICI
- The Effect of ICI on Boeing aircraft
- ICI Identification and Mitigation
- Radar Guidance
- ICI Environmental Envelope Regulation
- Summary

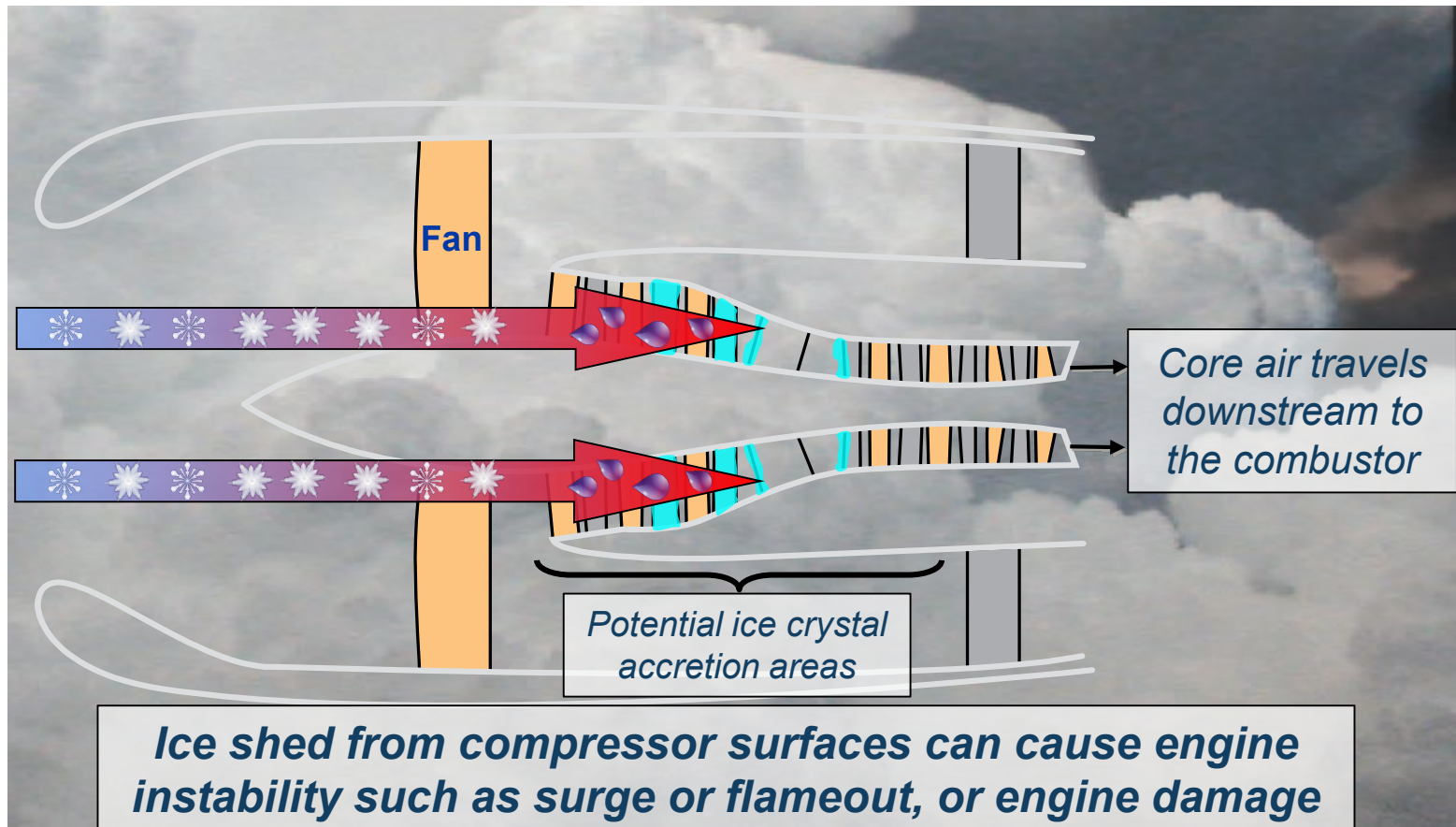
Differences Between “Regular” Icing & ICI



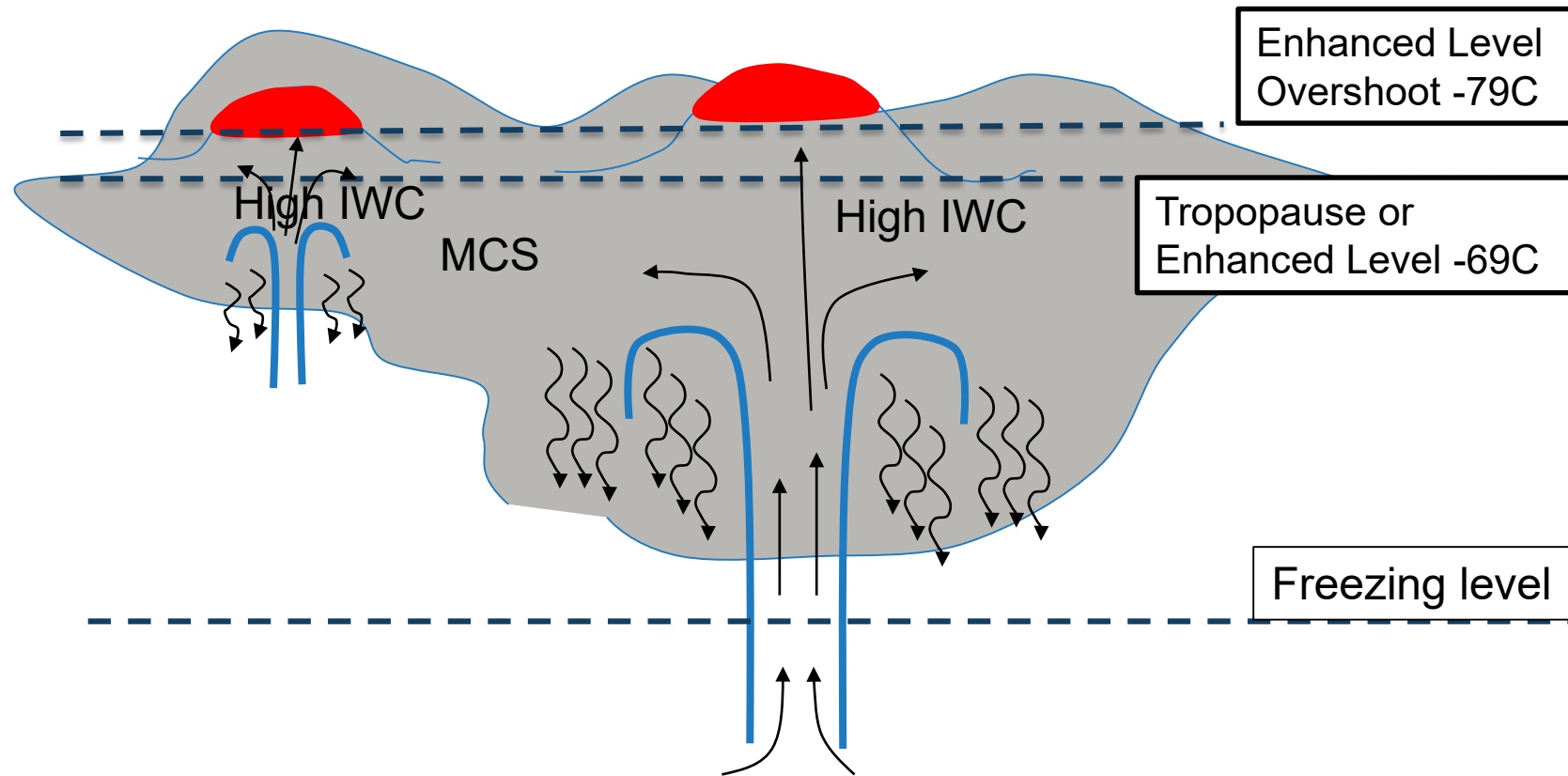
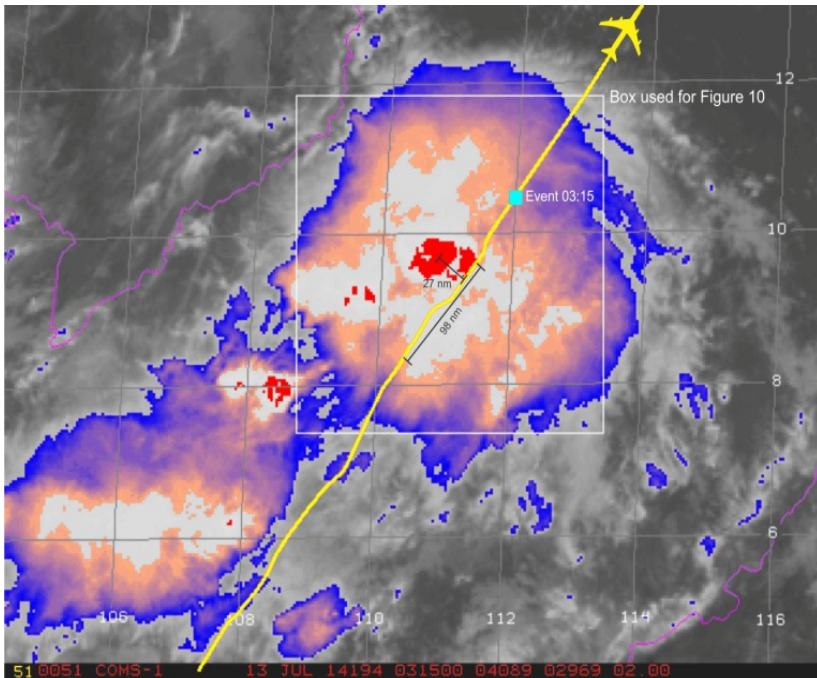
Ice Crystal Icing – Ice in the Engine Core Flowpath

Physics:

- Ice crystals can accrete on engine surfaces warmer than freezing
- These warm engine surfaces are in the compressor (aft of the fan)

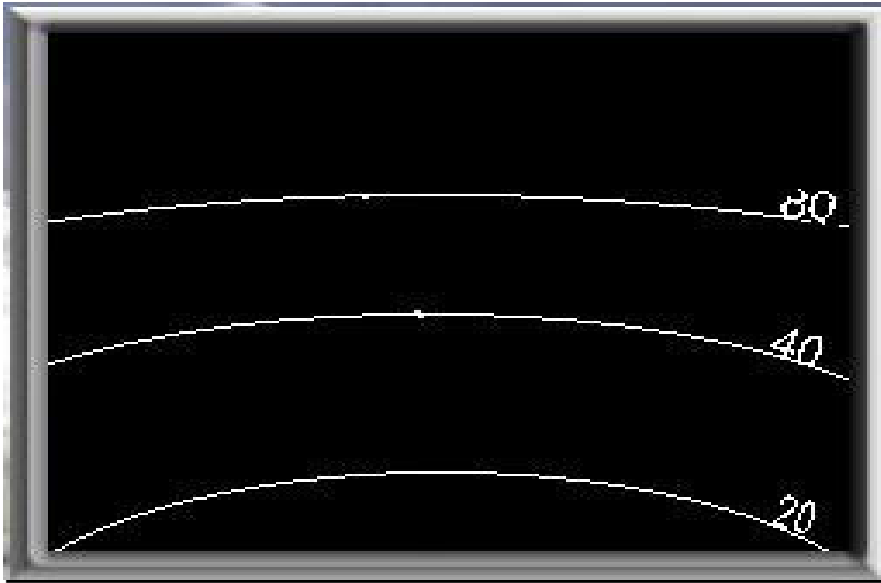


What is a Mesoscale Convective System?



The area of cloud reaching cold temperatures can be a surrogate for high altitude ice concentrations

Ice Crystals are Challenging to Recognize and Avoid

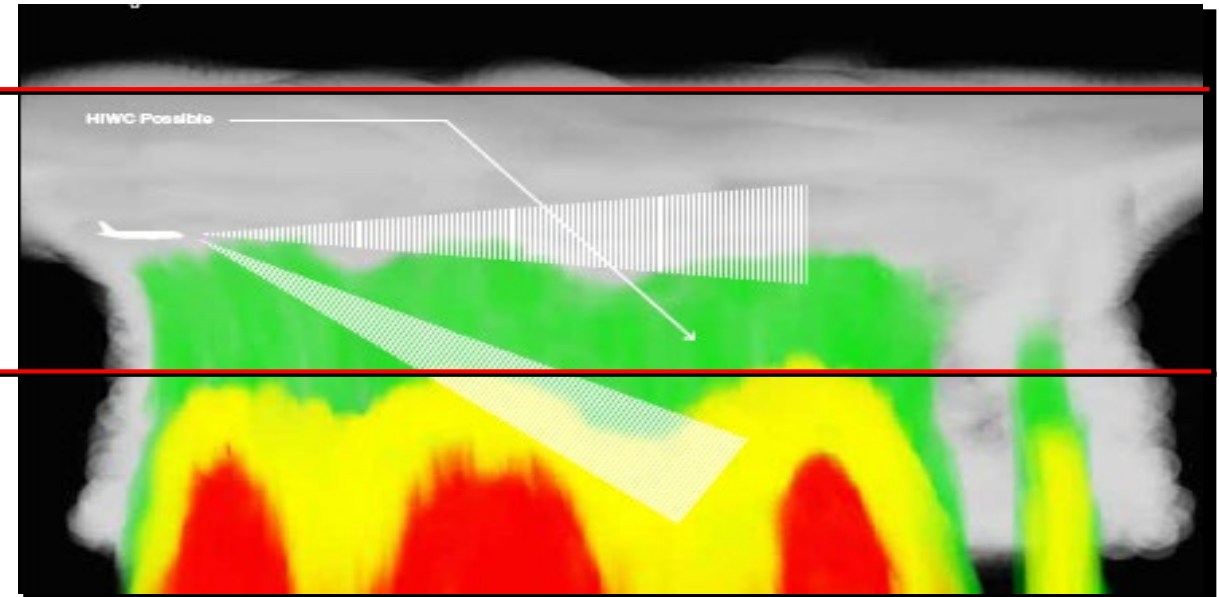


Flight Level Radar Returns

Cross-Section of Radar Returns

Tropopause

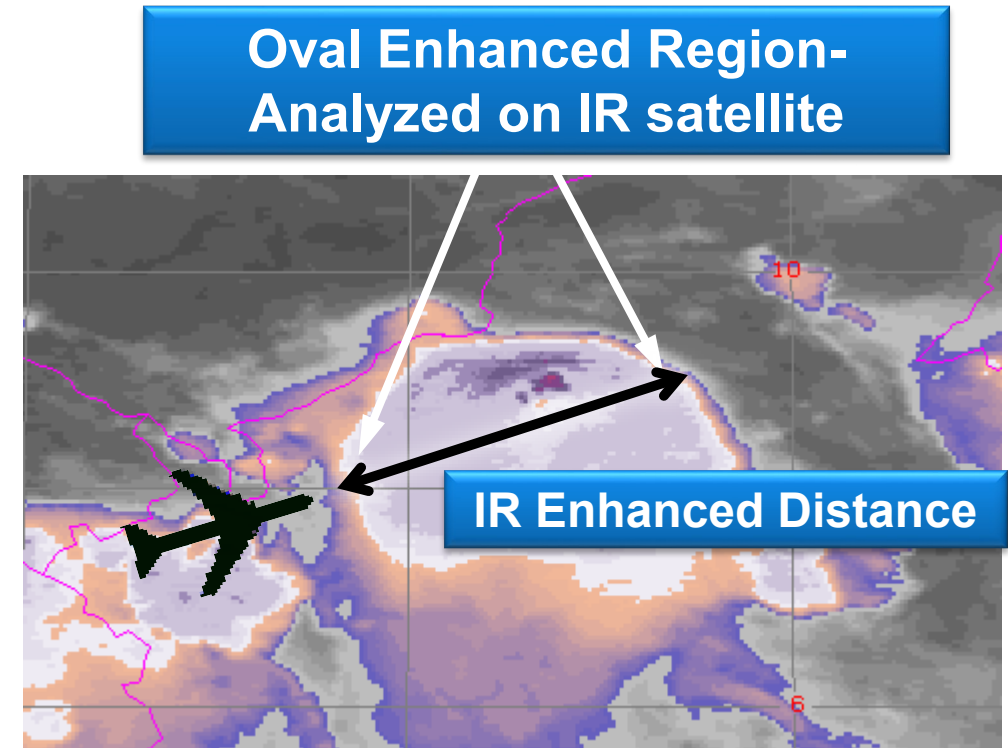
Freezing level



Dispatch/Avoidance/Recognition: HIWC Cloud Identification

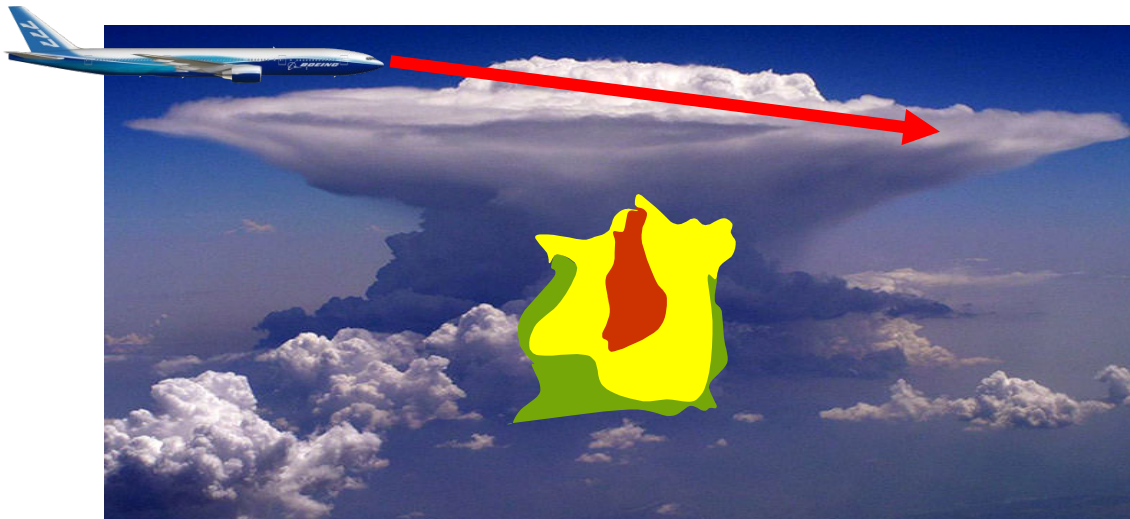
Engine events typically occur when the airplane traverses greater than 100 km of significant convective anvil cloud associated with a MCS.

- These systems have a large, often oval region of convective anvil cloud above cruise flight levels
- Within that region, there often are embedded convective core/updraft areas which push moisture up above the tropopause, resulting in overshooting cloud



In-flight ICI Identification

- In IMC, flying over amber and red below the aircraft is no longer recommended
- Regions of HIWC can not be avoided by flying over them – typically these storms reach the tropopause
 - Flying above the reflectivity is exactly where events are occurring



When flying through ICI, avoiding laterally is the best approach

Ice Crystal Icing Reports From the Flight Deck



Overall Approach to Successful Identification of ICI and Mitigation of Engine Events

- Awareness of the condition – crew training/communication
- Dispatch/avoidance/recognition
 - Use of HIWC maps & other weather resources
 - Communication / awareness
- Mitigation
 - Use of radar
 - Engine-specific actions

[Airplanes without ice detection]

Note: There is no significant airframe icing.

[Airplanes with ice detection system]

Note: There is no significant airframe icing. The icing conditions detection system does not detect ice crystal icing. It is designed to detect supercooled water only.

Avoid Ice Crystal Icing Weather

During flight in IMC, avoid flying directly over significant amber or red radar returns, even if there are no returns at airplane altitude

Use the weather radar controls to assess weather radar reflectivity below the airplane flight path. Refer to weather radar operating instructions for additional information.

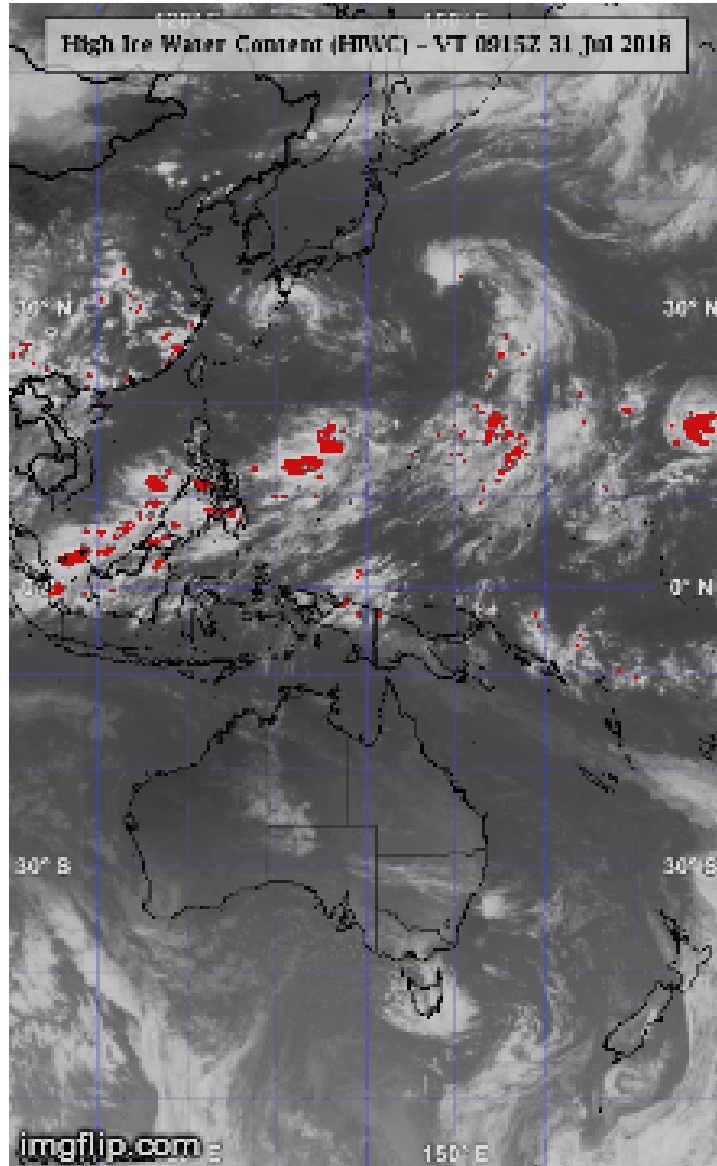
[Editors need to create B&W image. Need better picture with airplane scanning straight ahead into the dashed line area]



Flight Crew Training & Awareness Materials

- Operations Manual Bulletin (TBC-89), Subject: Additional Guidance On Ice Crystal Icing (released 4/20/2018)
- Flight Ops Tech Bulletin, Subject: Ice Crystal Icing (revised 8/25/2017)
- FCOM SP16 - Adverse Weather section
- QRH NNC 3 - Anti-Ice and Rain section
- High Ice Water Content Map (via Jeppesen JetPlan software)
- Boeing Aero Magazine Articles 2007 & 2010
- Air France Training Module via MyBoeingFleet website
- ICI Feedback Form available at MyBoeingFleet & ALPA website

Dispatch/Avoidance/Recognition: High Ice Water Content (HIWC) Maps – Near-Real-Time ICI Areas Identified



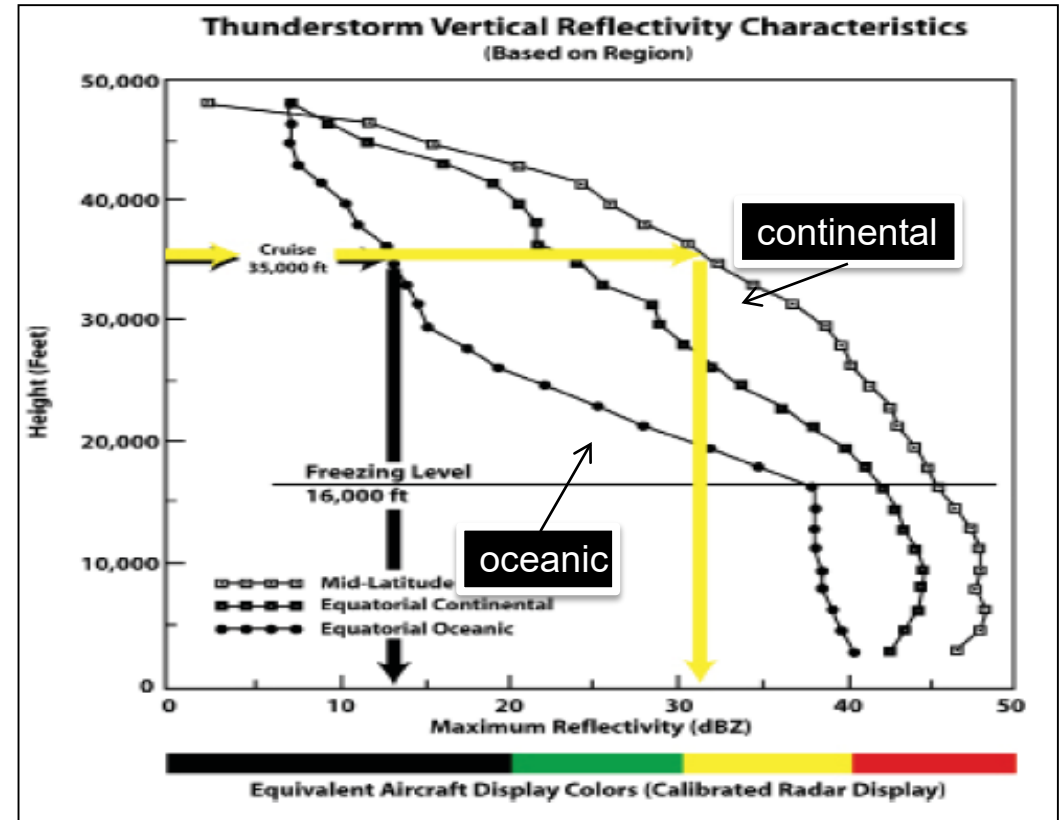
- Dispatchers at the airline review the map and the intended flight route/time
- Route revised as dispatch finds necessary
- En route, ACARS message sent to the flight crew with location of HIWC
- The crew can send an ACARS message to request weather/ice crystal condition updates from dispatch



RADAR GUIDANCE

Reflectivity in ICI

- Different clouds have different reflectivity profiles with altitude
- “Continental” have red/ amber returns to cruise flight level
- “Oceanic/tropical” have lower reflectivity at flight level
- ICI events are associated with oceanic/tropical-like convection with low updraft velocities and low reflectivities at flight level – average 15 dbz
- These clouds are highly reflective at the freezing level, as melting occurs



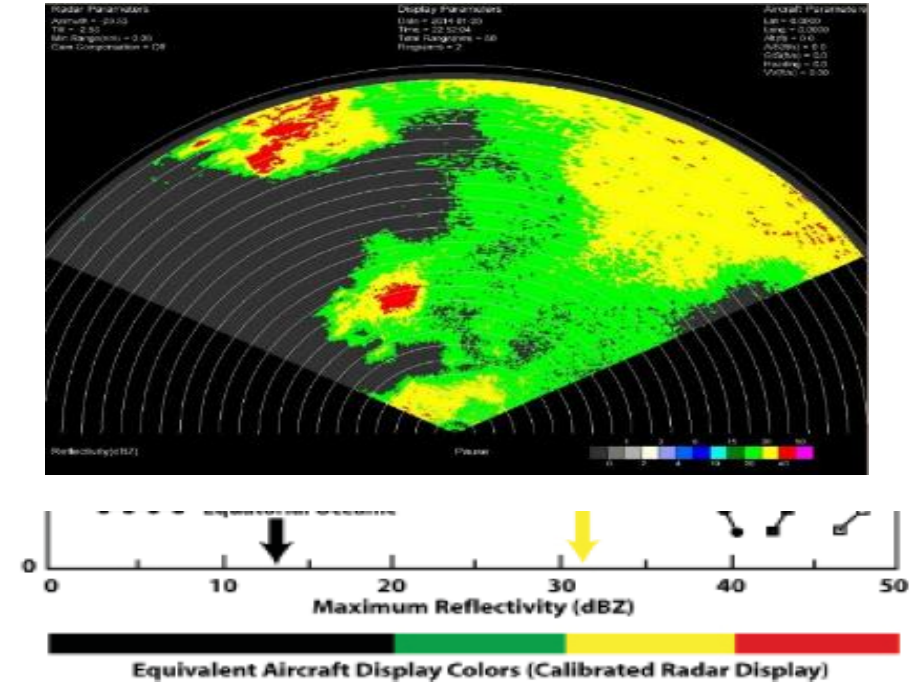
Zipser, E.J. and Lutz, K.R., “The vertical profile of radar reflectivity of convective cells: A strong indicator of storm intensity and lightning probability?,” *Mon. Wea. Rev.*, Vol. 122, 1994, pp. 1751–1759

Identifying The ICI Environment

- At cruise altitudes, tilt based WXR systems will typically be set to between 0 and -2 degrees tilt in order to view weather at or near flight level. Ice crystals are small particles and therefore poor reflectors of radar energy even in high concentrations.
- Manual WXR techniques described in the following slides may help reveal high concentrations of ICI at or near flight level. However, lower concentrations of HIWC and in certain types of ICI conditions, radar returns may not be sufficient for the WXR to directly detect ICI conditions.
- With this in mind, the following slides provide information on how different radar configurations may be used when one of the following cues suggests ICI:
 - HIWC map
 - Location on the globe and IMC at cruise flight level
 - Checklist condition statements (e.g. appearance of rain on the windscreen)

Manual Tilt WXR Systems

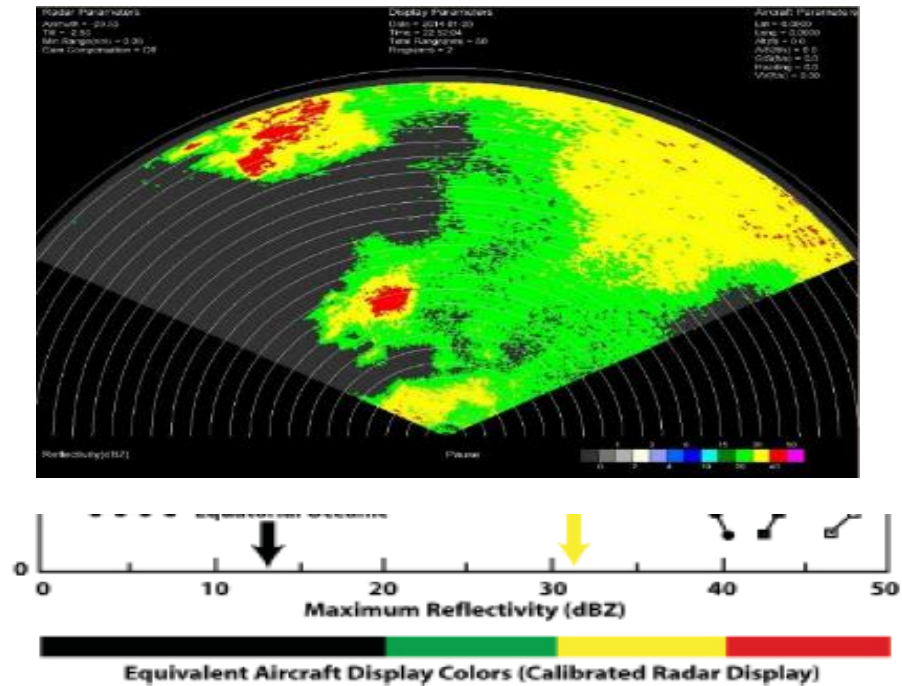
- The gain may be increased to display returns from higher concentrations of ICI conditions which may otherwise be displayed as 'black' on the Nav Display. Flight through any weather displayed using this method should be avoided or minimized.
- Evaluation of the cell(s) below expected ICI conditions using lower tilt settings may be necessary for lower concentrations of ICI.



Any weather displayed as green, amber or red using this method should be evaluated further

Rockwell Collins MultiScan and Honeywell AutoTilt WXR

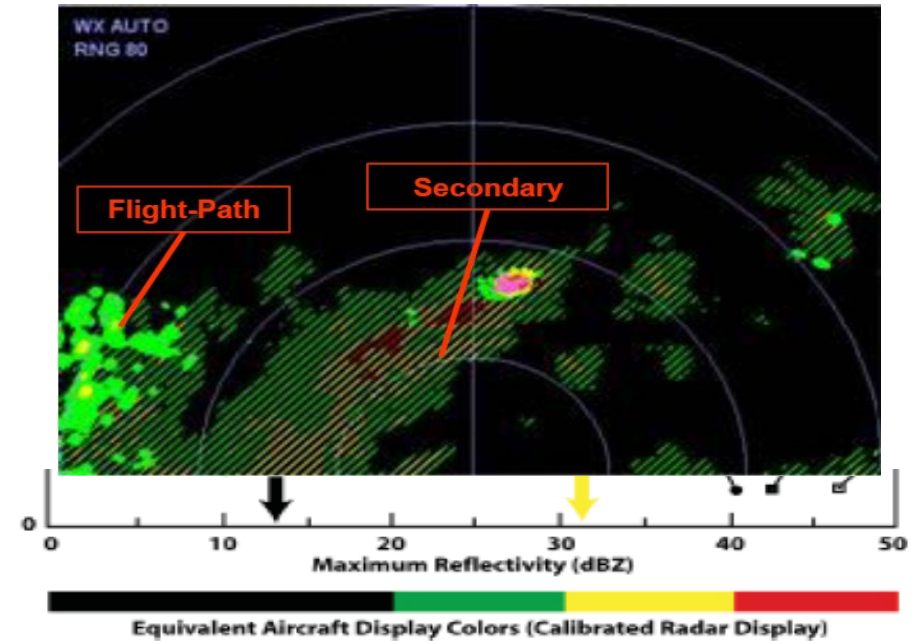
- In WXR AUTO mode, the gain is automatically adjusted based on temperature and may display weather associated with ICI engine events. ICI conditions that may have been below the threshold for display, may appear green or amber. Gain may be further increased beyond the automatic gain adjustments for temporary weather analysis, such as at low temperatures where ice crystal icing is encountered or expected.
- Note: Some radar systems also make gain adjustments based on global location while in AUTO mode.
- In WXR MANUAL mode: The gain may be increased to display returns otherwise displayed as 'black' on the ND. Evaluation of the cell below expected ICI conditions using lower tilt settings may be necessary for lower concentrations of ICI.



Any weather displayed as green, amber or red using this method should be evaluated further

Honeywell RDR-4000 IntuVue WXR

- In WXR AUTO mode, weather below the flight path will be shown with black diagonal lines (shaded). Any weather displayed in solid green/yellow/red is within +/- 4000 feet of your current flight path. MAX gain should only be used above the freezing level temporarily to help see less reflective frozen storm tops.
- In WXR Manual mode, MAX gain may be used when looking at altitude slices above the freezing level where particles are less reflective.



Any weather displayed as green, amber or red using this method, should be evaluated further

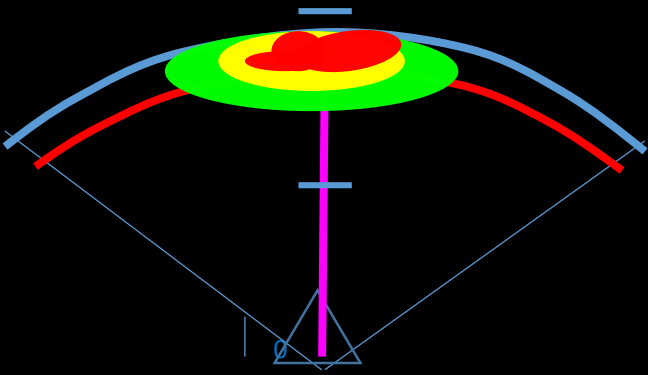
When ICI is Identified, Assess the Weather Below

- The next three slides illustrate operation of the weather radar with typical settings for cruise:

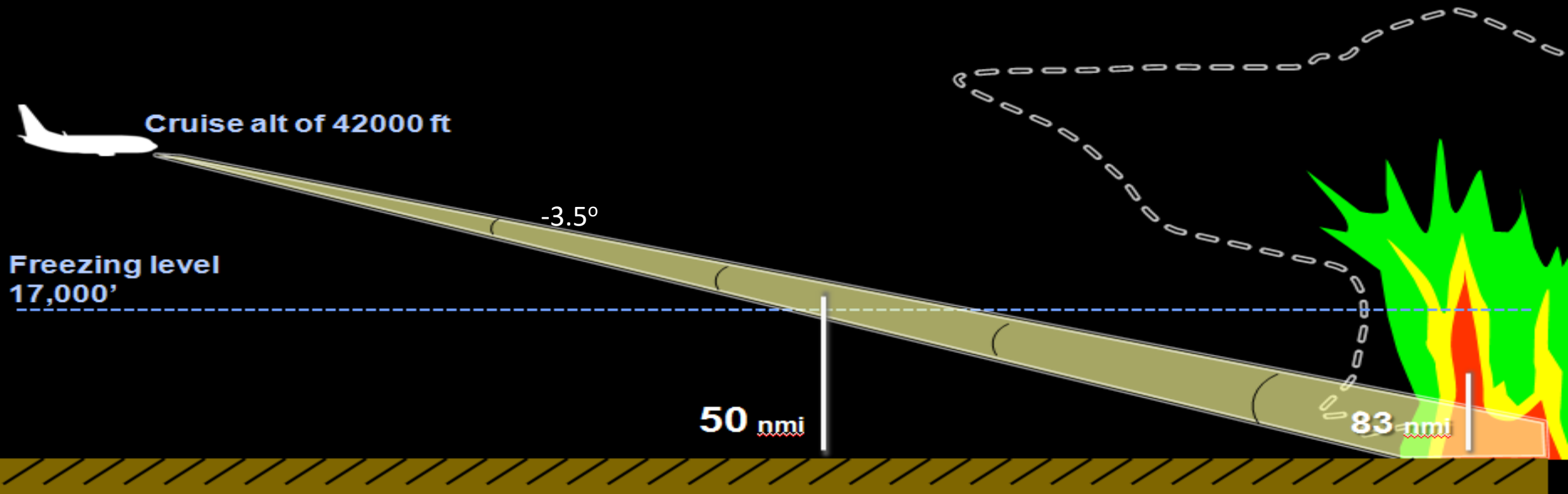
Rockwell Collins MultiScan WXR

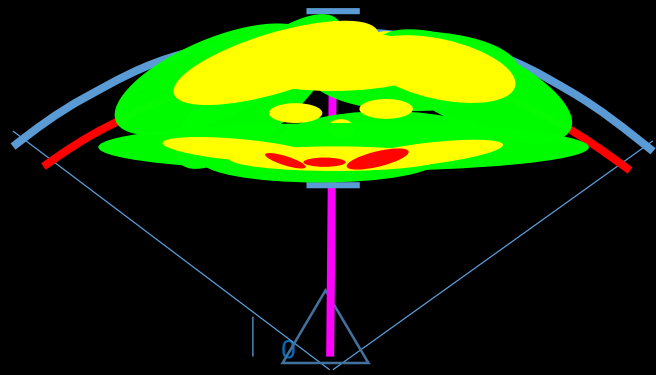
- Select a range (80 nmi on one display and 160 nmi on the other)
In Manual Mode, adjust the tilt to put the ground return ring on the edge of the 80 nmi display (typical results - @ FL420, 80 nmi display, tilt at ~ -3.5 degrees)

NOTE: no additional gain applied for this step

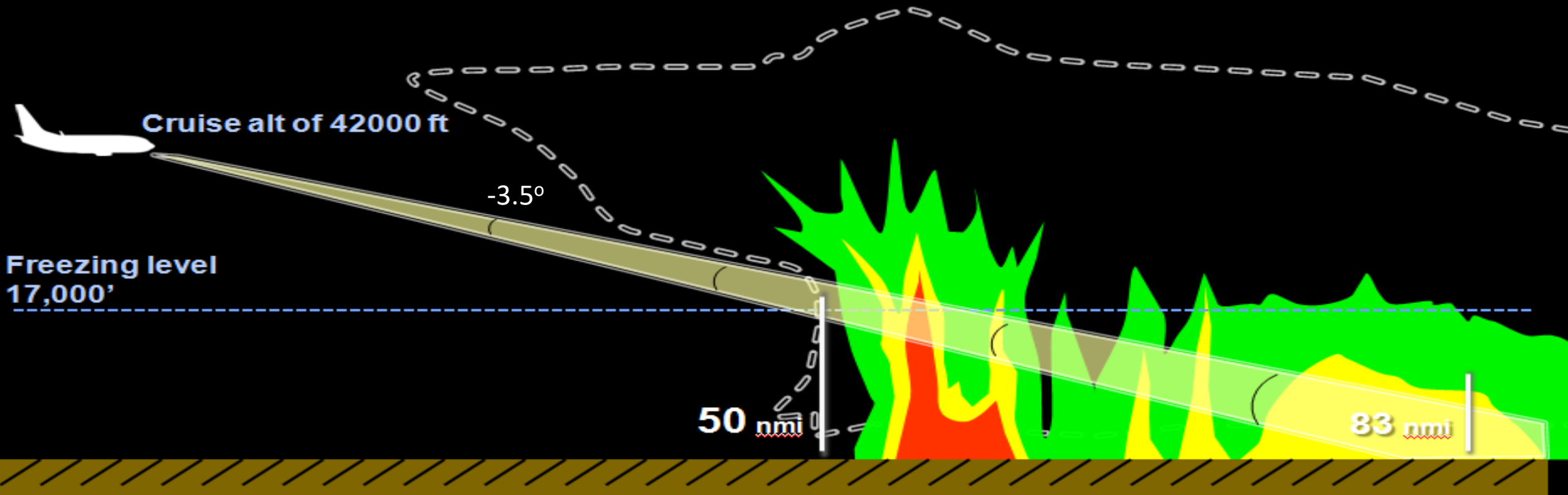


This slide illustrates an MCS just coming into view at 80 nm

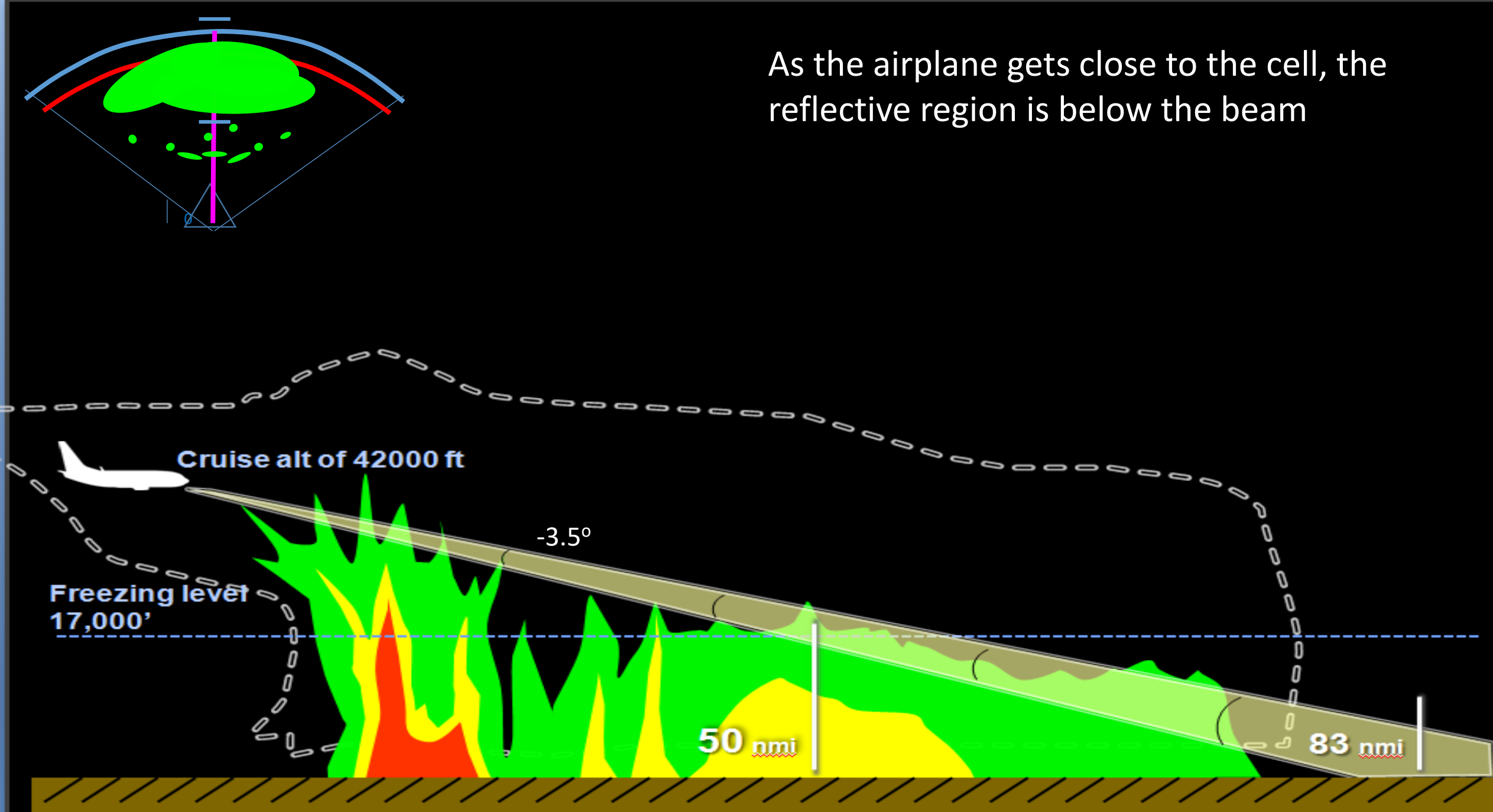




At 50 nmi, the top of the reflective region is coming into view

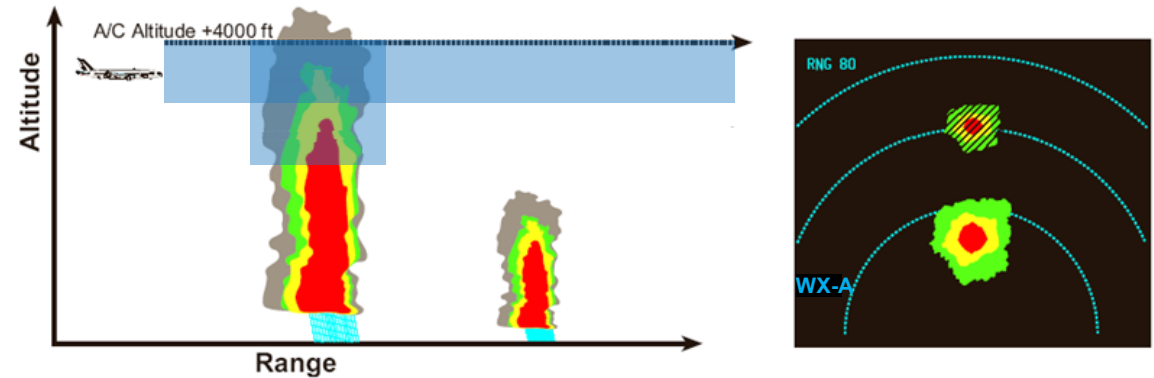
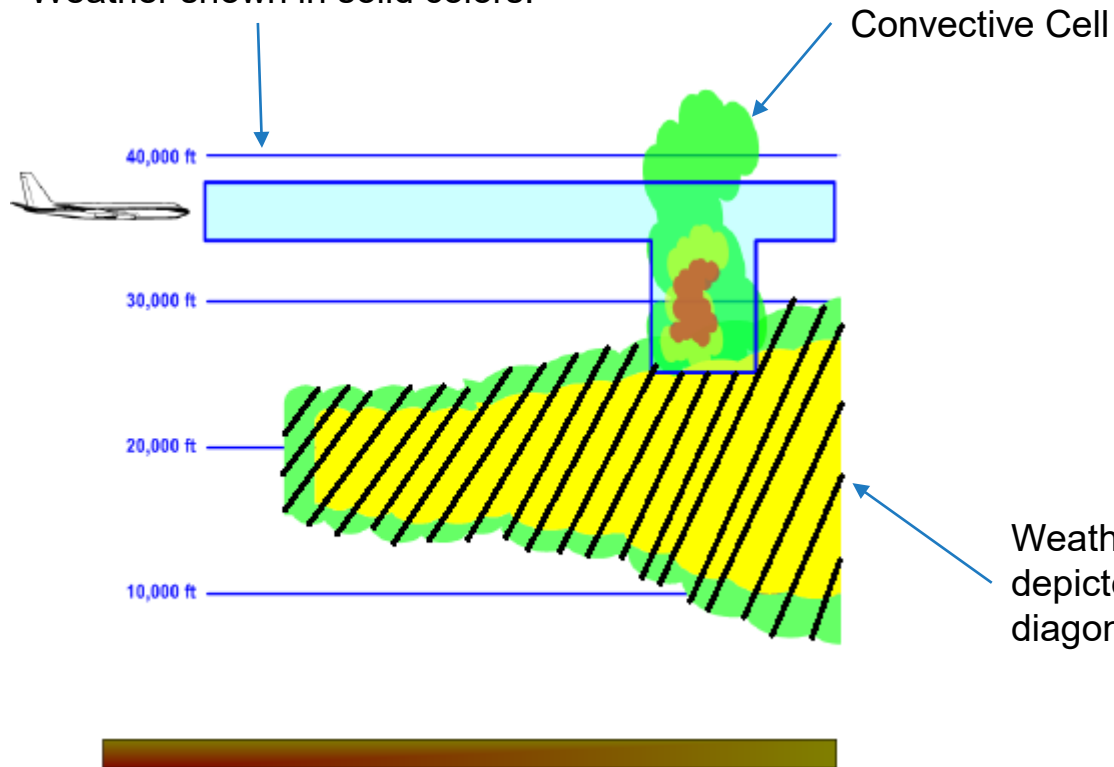


As the airplane gets close to the cell, the reflective region is below the beam



Honeywell RDR-4000 IntuVue WXR (Auto Mode)

Shaded blue Area is +/-4000 ft of current altitude or a cell with vertically integrated reflectivity below the flight path (typically convective systems). Weather shown in solid colors.

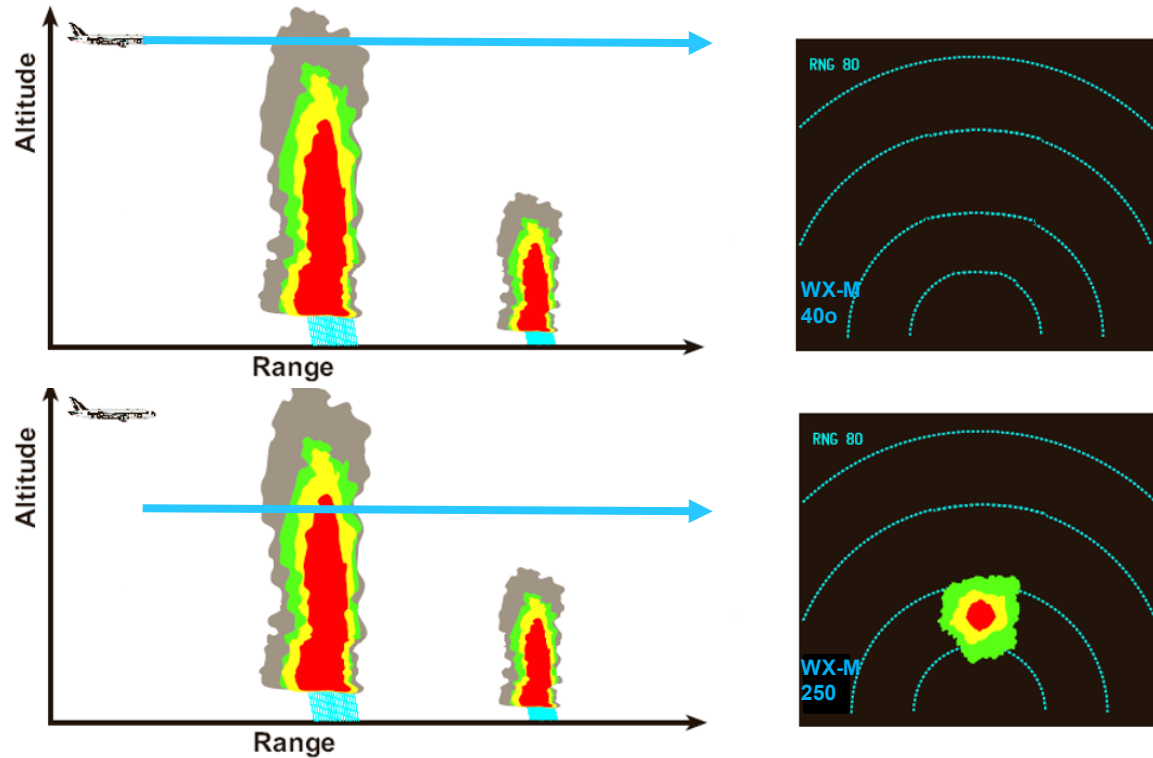


Note: Max radar range is 320nmi (in forward direction)

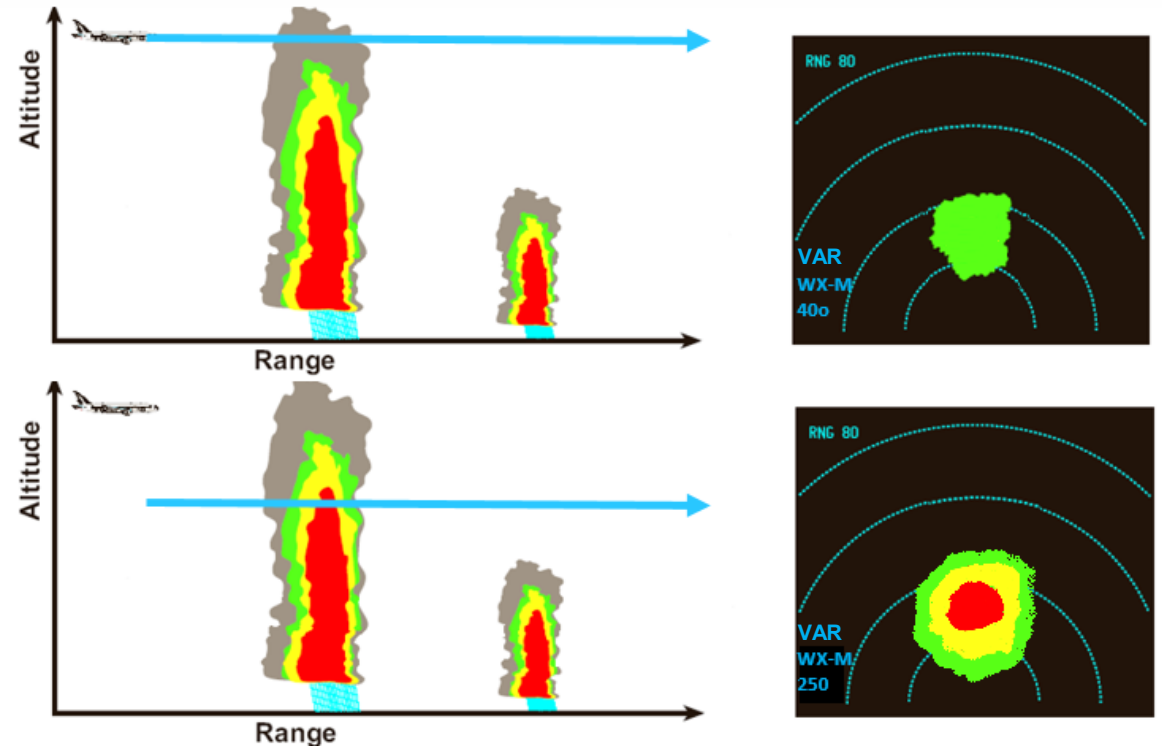
Avoid any solid green, yellow or red weather when cues indicate ICI

Honeywell RDR-4000 IntuVue WXR (Manual Mode)

- In Manual Mode, the pilot selects an altitude using the WXR control panel. Only weather at the selected altitude is displayed (in solid colors).



Manual Mode - Calibrated Gain

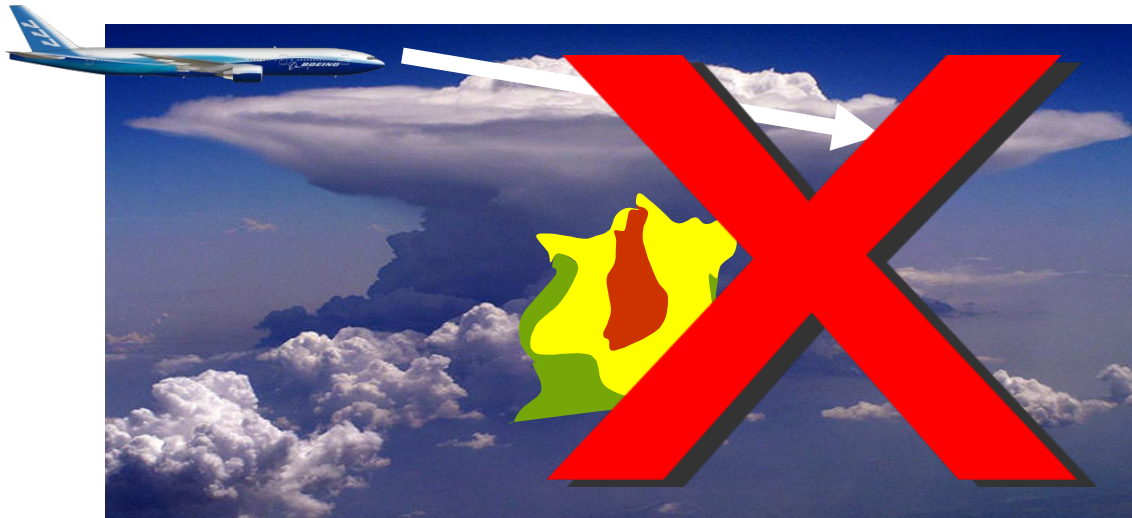


Manual Mode - MAX Gain

MAX gain may be used when looking at altitude slices above the freezing level where particles are less reflective.

Paradigm Shift


- In IMC, flying over amber and red below the aircraft is no longer recommended
- Regions of HIWC can not be avoided by flying over them – typically these storms reach the tropopause
 - Flying above the reflectivity is exactly where events are occurring
- Avoiding laterally is the best approach



Minimize time above amber and red weather radar returns. If conditions allow, exit the ice crystal icing conditions.

Mitigation - Engine ICI or TAT Probe Icing is Suspected

- The unannunciated checklist steps vary for each model – please review the specifics for your airplane/engine combination

 **BOEING**

757 Flight Crew Operations Manual

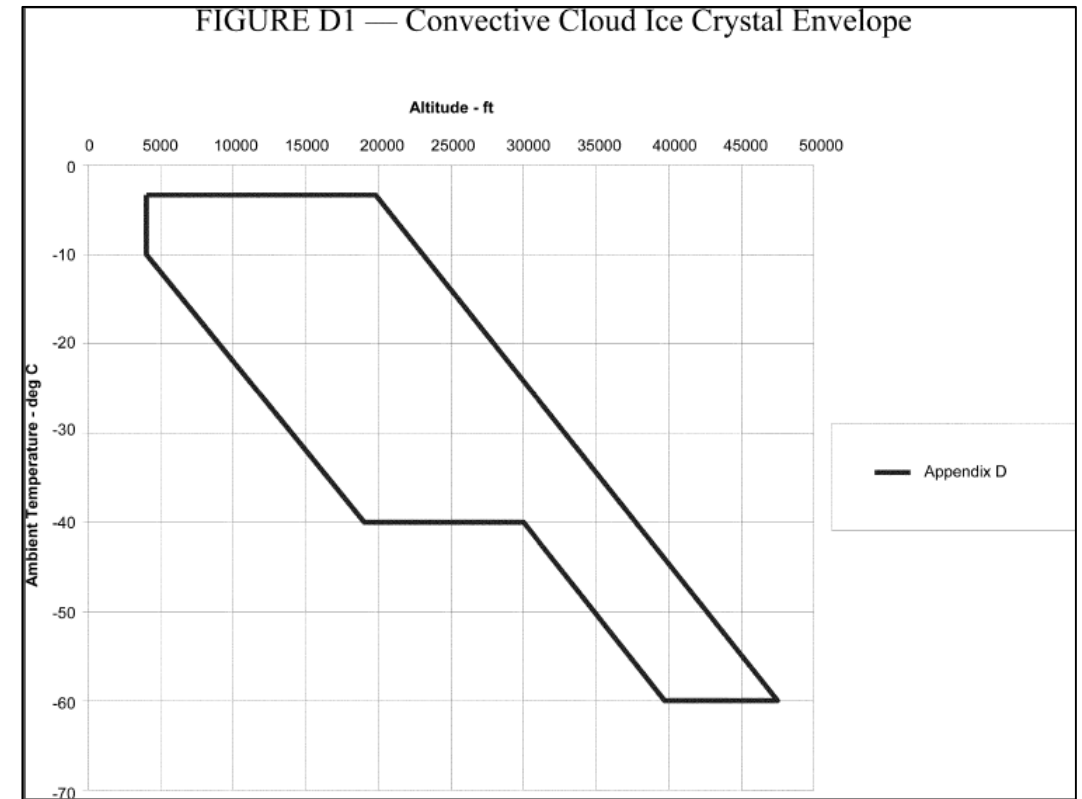
3.7

▼ Ice Crystal Icing continued ▼

- 1 ENG START selectors (both).FLT
This increases engine flameout protection.
- 2 ENGINE ANTI-ICE switches (both)ON
This increases engine stall margins.
- 3 Minimize time above amber and red weather radar returns. If conditions allow, exit the ice crystal icing conditions.
- 4 When in ice crystal icing conditions, the maximum EPR line (amber) can be unreliable.

ICI Environmental Envelope Recharacterization

- The ICI envelope published in 2015 was created from flight testing during the 1950s and was based on conservative environmental assumptions
- International consortium (HAIC-HIWC) formed to validate envelope in 2014-2015 with campaigns in Darwin (AUS), Cayenne (FG), Reunion Island (FR), Florida (US)
- ARAC preliminarily launched with a goal to establish a new environmental envelope



Summary

- Reviewed physics of ice crystal icing weather and engine effects
- Recognition and avoidance of ICI
- ICI Environmental Envelope update (ARAC)
- Boeing and the aerospace industry are striving to provide the most up-to-date advisory and training materials for flight in ice crystal icing weather conditions





BACKUP SLIDES

Typical Tilt Values vs. Freezing Level in Manual Mode

Cruise Altitude (Ft)	Freezing Level (Ft)	Antenna tilt [As selected from WXR CP] (degrees)	Freezing Level Intersection range [bottom of 3.5 degree beam] (nm)	Ground Returns Intersection range [bottom of 3.5 deg beam] (nm)
30,000	17,000	-3	26	59
30,000	17,000	-4	21	49
30,000	17,000	-5	18	42
30,000	17,000	-6	16	36
36,000	17,000	-3	38	71
36,000	17,000	-4	31	59
36,000	17,000	-5	26	50
36,000	17,000	-6	23	44
42,000	17,000	-3	50	83
42,000	17,000	-4	41	69
42,000	17,000	-5	35	58
42,000	17,000	-6	30	51

- Freezing level for events to date has been on the order of 15,000 to 19,000 ft MSL.
- These are median values provided to give a rough idea of how much of a down tilt may be required to intersect the freezing level and where weather may be masked with ground returns.

Typical Tilt Values vs. Freezing Level in Manual Mode

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42,000	17,000	-4	41	69
42,000	17,000	-5	35	58
42,000	17,000	-6	30	51

Rule of thumb: for an ISA + 10 day, the freezing level is roughly $\frac{1}{2}$ way between the airplane and the ground return ring