Atmospheric Characterization for High Ice Water Content in Deep Convective Cloud

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Jet Engine Powerloss in Deep Convective Clouds

- Has been documented as early as 1998 (BAe-146), and more recently for a broad range of manufacturers and engines by the EHWG
  - *Mason, J.G., J.W. Strapp, and P. Chow, 2006: The Ice Particle Threat to Engines in Flight, 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, Jan 9-12, 2006, AIAA 2006-206.*

- Engine events are caused by flight into very high Ice Water Content (IWC) regions caused by deep lift associated with convective cloud.
- IWC = ice particle mass concentration
- Supercooled liquid water is not required

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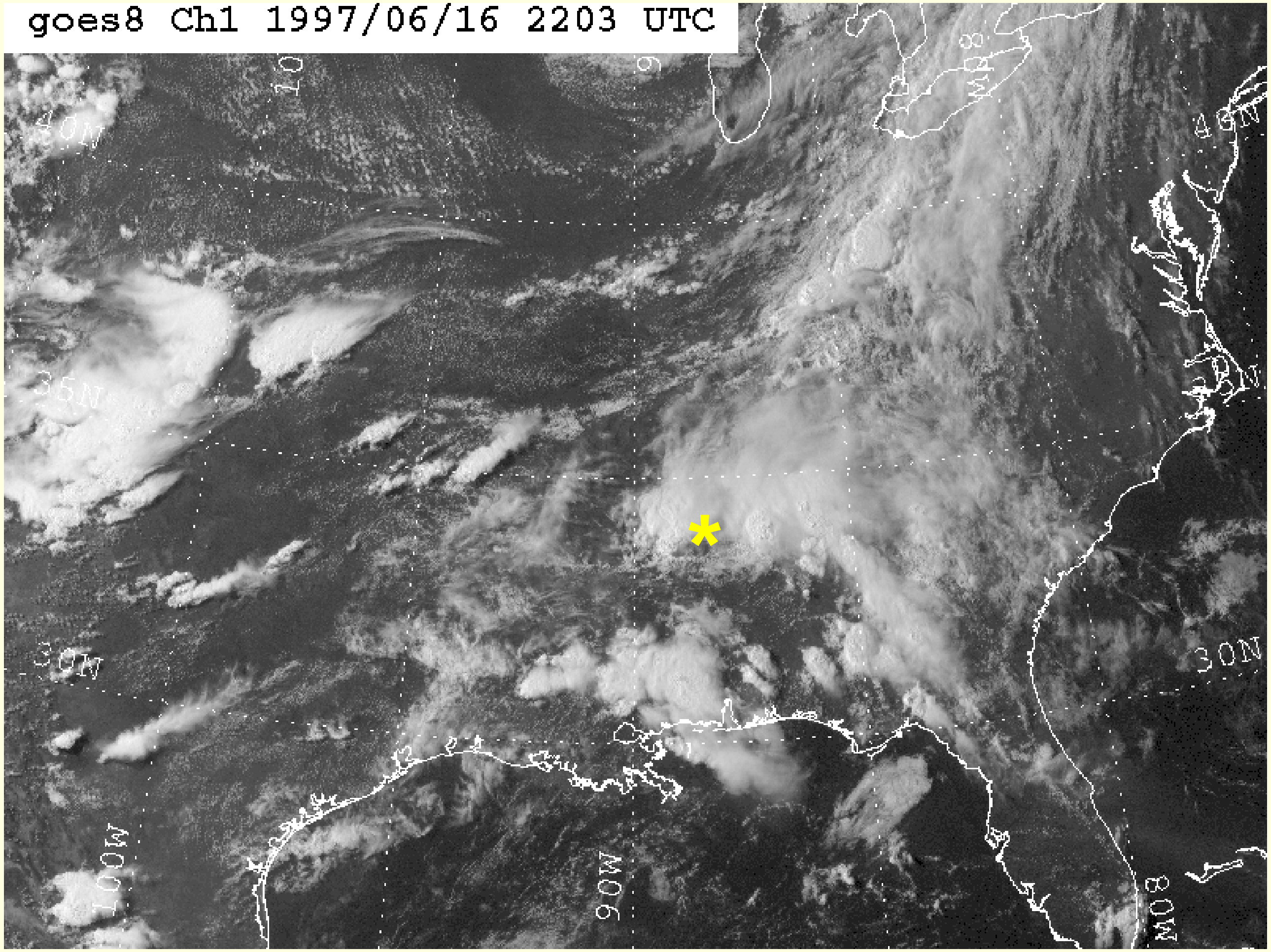
Example of Continental Convection

- broad areas of North America routinely covered by thunderstorm anvils
- Asterisk shows approximate location of BAe-146 during rollback investigation (23:20)



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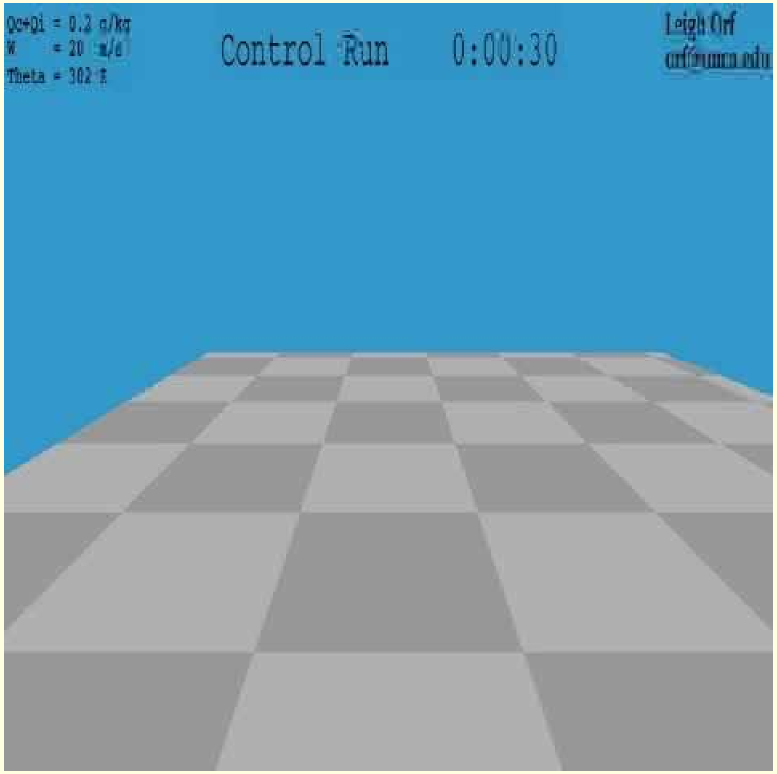
3-D Simulation of Deep Convection



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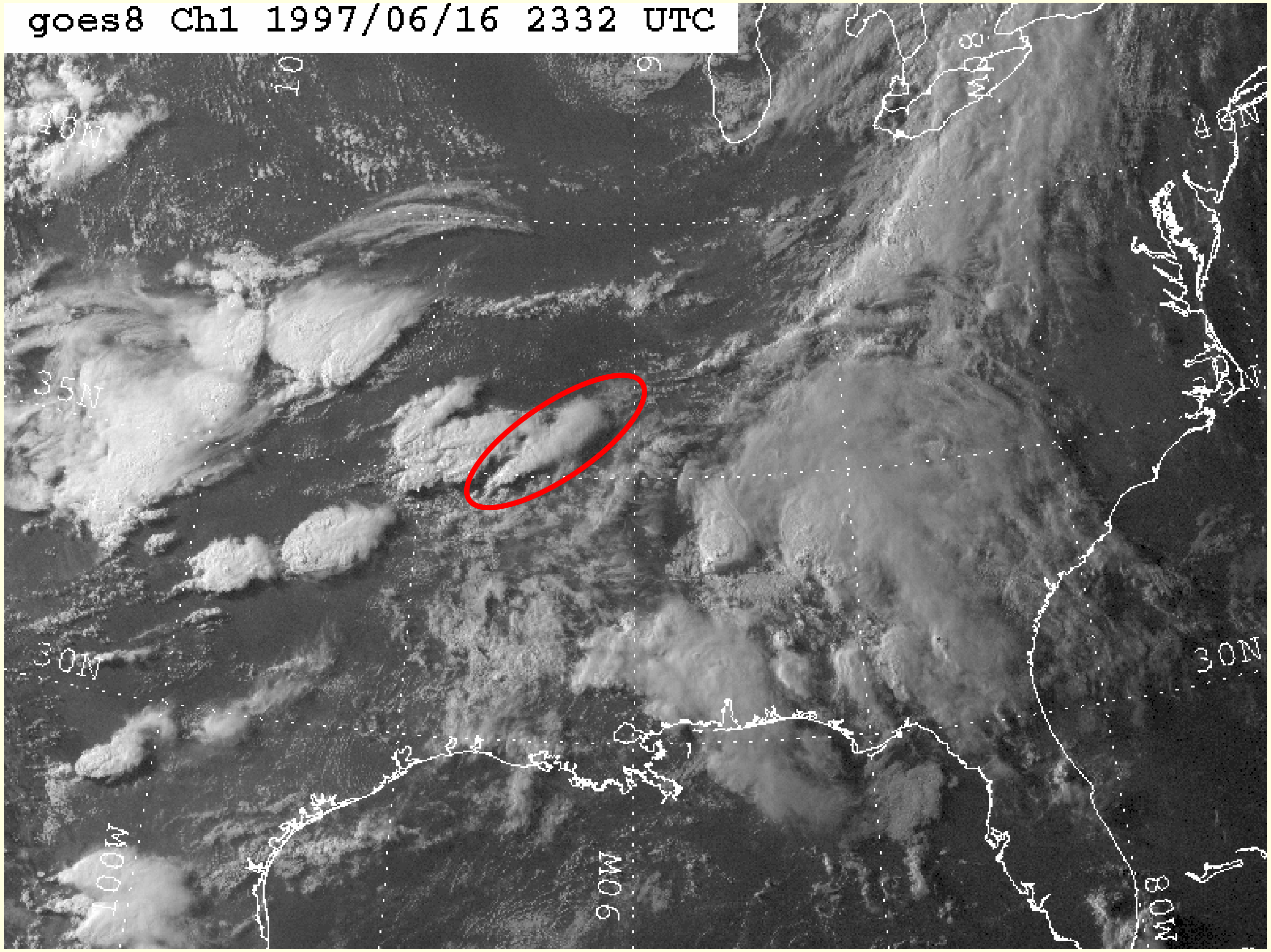
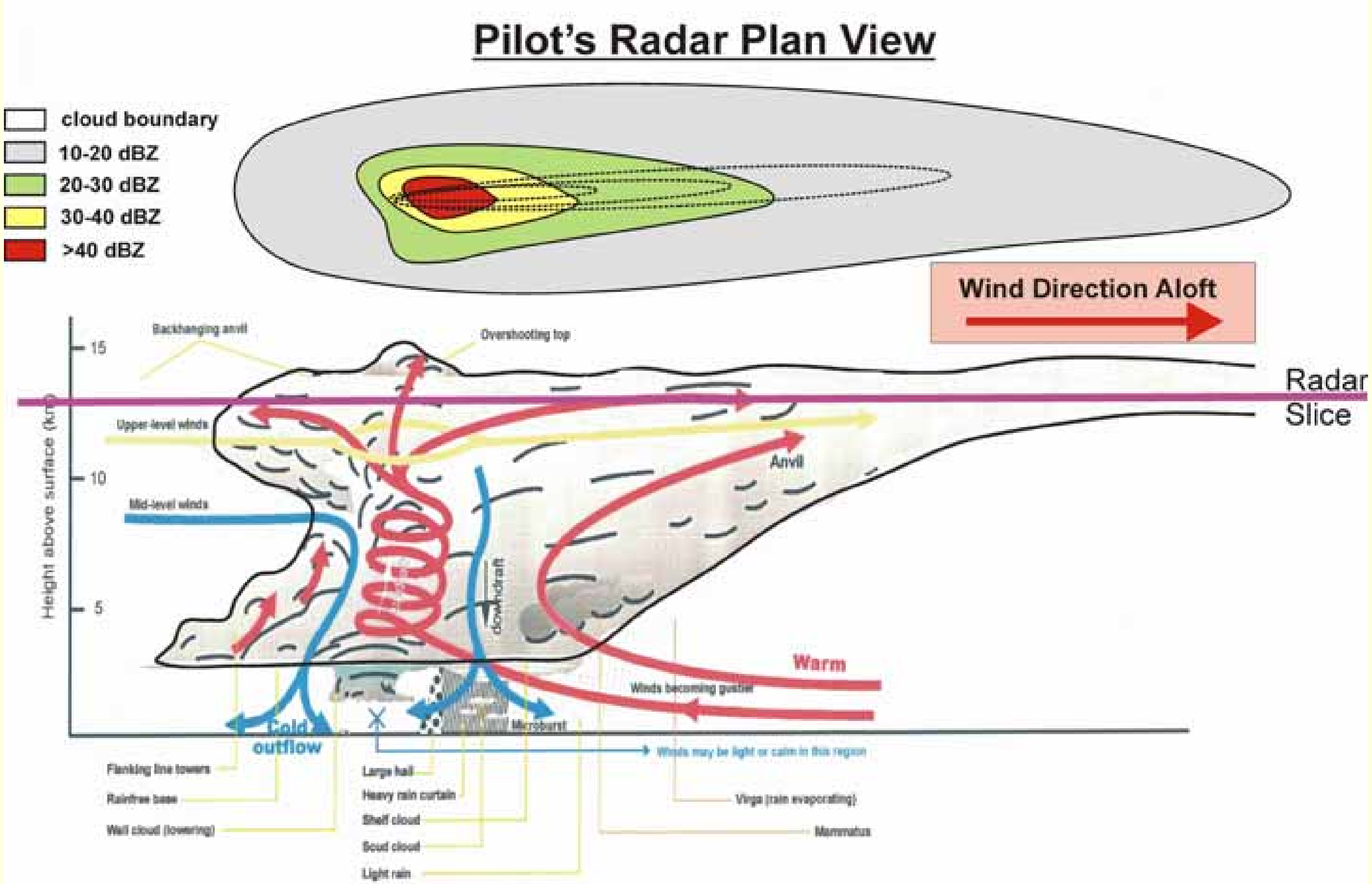
Example of Continental Convection

- anvils spread downwind of core are at high altitude where winds are higher
- Note classic case encased in red to right
- Other anvils are less ventalted at altitude, and mushroom more around core



Cumulonimbus (CB) Cloud and associated features



Adapted from original by Geoff Coulson, ESB

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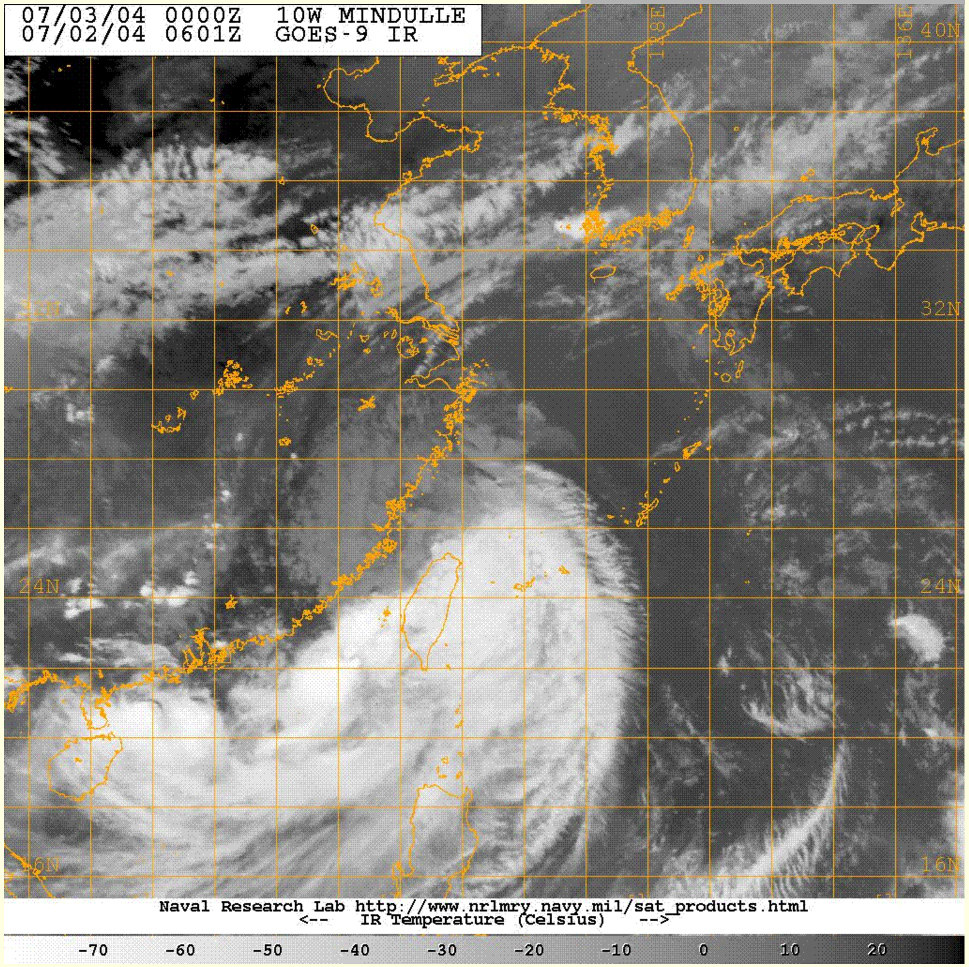
Oceanic Deep Convection

- note convective elements southwest of Taiwan grow and merge into massive convective complex
- growth of bright cloud tops in this region indicate potential for dense ice crystal zones at high altitude



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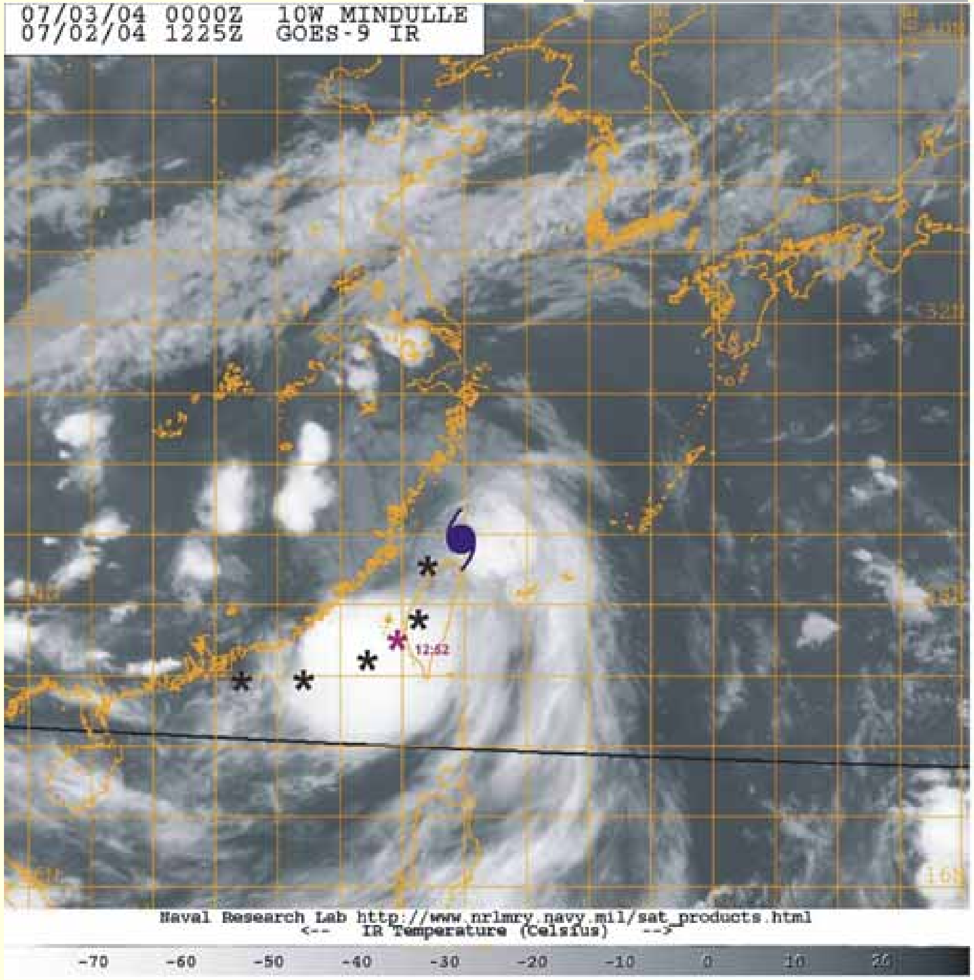
A Large Transport Aircraft Engine Event

• occurred while descending into tops of deep oceanic convection

 no significant echoes at altitude on pilot's radar



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Oceanic versus Continental Convection

Attribute	Continental	Oceanic
depth	10-20 km	10-20 km
Updrafts	Strong (~20 m/s)	Weak-moderate (~5 m/s)
lightning	abundant	rare
hail	possible	no
Red echo at altitude	frequent	unlikely

- Continental convection much more likely to have dangerous core areas at high altitude
- Oceanic convection may have ‘radar-invisible’ cores at altitude, with little or no lightning
- Both types have the same potential for high IWC – same deep lift creating same potential condensed water and ice
- Engine events associated with both types

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Information on Microphysical Properties of Deep Convection

- Indirect information from the Flight Data Recorders and from pilot interviews for engine powerloss events
- Atmospheric sciences research community – not much available on high IWC regions near convective cores
- Royal Aircraft Establishment Flights 1956-1958 in equatorial areas
- BAe-148 industry flight test program in 1997

Dominance of Ice phase

- measurements indicate that trailing stratiform anvil regions of deep convection composed entirely of ice particle
- core region is dominated by the ice phase, and liquid regions only expected near the main updraft regions
- cloud volume above the freezing level dominated by ice particles

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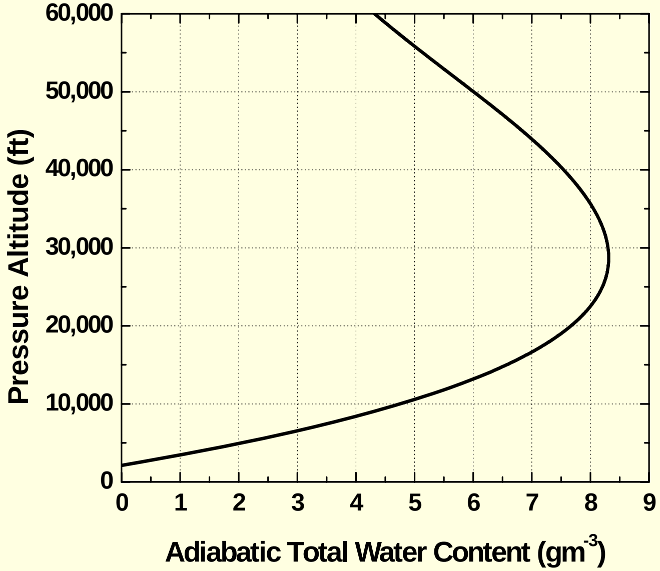
Levels of IWC

- Simple calculations of adiabatic parcel lift and condensation provide first approximation of maximum IWC – shown at right approaches 9 gm^{-3}
- More complicated processes at play – entrainment dilution, redistribution by precipitation, etc.



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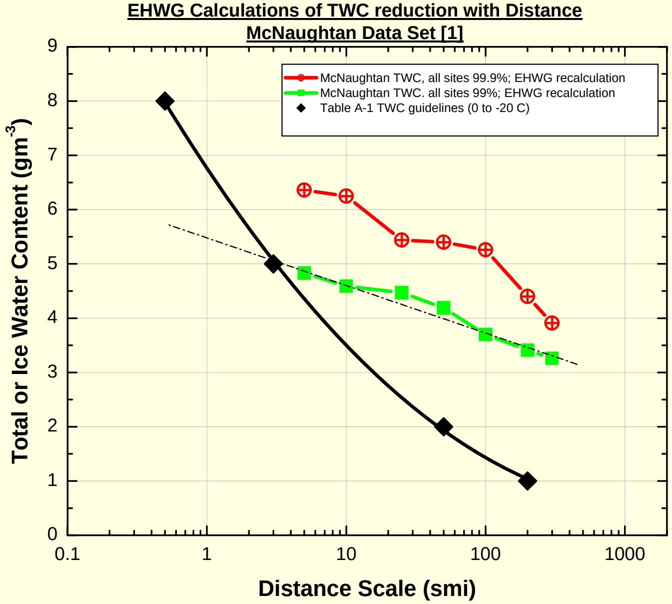
Levels of IWC (cntd)

- Joint Airworthiness Committee Guidelines 1958 (right, black), based on RAE measurements
- EHWG recalculations of RAE TWC versus distance – green 99%, red 99.9%
- Other measurements from Atmospheric Research Community are not focused on high IWC regions



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Characteristic Particle Size

- no data from RAE aircraft measurements – Guidelines state 1 mm for size
- Some limited data from industry and atmospheric research community – point to relatively small characteristic size
  - BAe-146 rollback trials ~40 um median mass diameter (MMD)
  - Hurricane flights in remnants of deep convection ~185 um MMD
- Some controversy over the accuracy of characteristic size measurements

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Measurement Accuracy Problems

• RAE measurements had multiple correction factors, and accuracy is no longer traceable

• Current measurements techniques for IWC from aircraft saturate well below the expected IWCs in deep convection – a variety of technical problems must be overcome

• Airborne instruments need to be modified to optimize their ability to measure characteristic size in deep convection, and multiple independent techniques are required to have confidence in size results.

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EHWG Conclusions and Recommendations on Characterization

Current guidance on the properties of deep convective clouds is not traceable, and not sufficiently accurate for long-term needs.

Instruments must be improved and developed to provide sufficient accuracy for this environment

New airborne measurements should be made to characterize deep convection

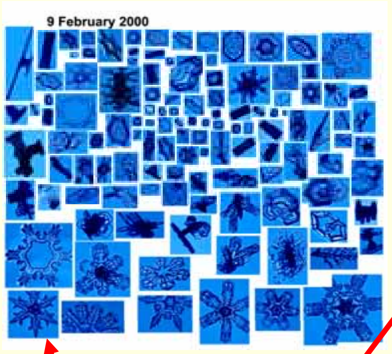
APPROACH :

- interim Appendix-D based on RAE data
- instrumentation work
- Flight Program to Characterize Deep Convection

Instrumentation Work

- Update current cloud measurement instrumentation to operate in the hostile high-altitude deep tropical convection environment
- develop a new isokinetic TWC instrument to target a maximum value of 10 gm^{-3} at 200 m/s
- calibrate an NRC tunnel with an ice cloud simulation (shaved ice) for absolute estimates of IWC

CPI Facetted Ice



Standard PMS 2D Imagery

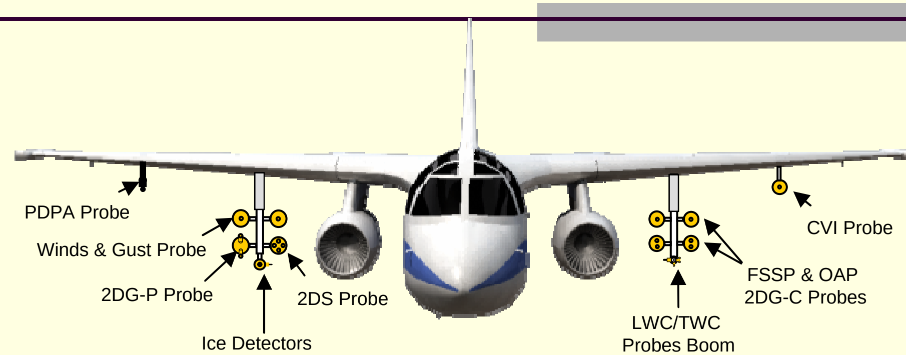
CPI data courtesy of Alexei Korolev

Under-wing particle probes

Characterization Measurements

- instrument NASA S3 for high altitude cloud sampling

- perform a characterization program of continental and oceanic convection out of a tropical location (northern Australia is proposed for January 2010)



End of Presentation

Thank You.

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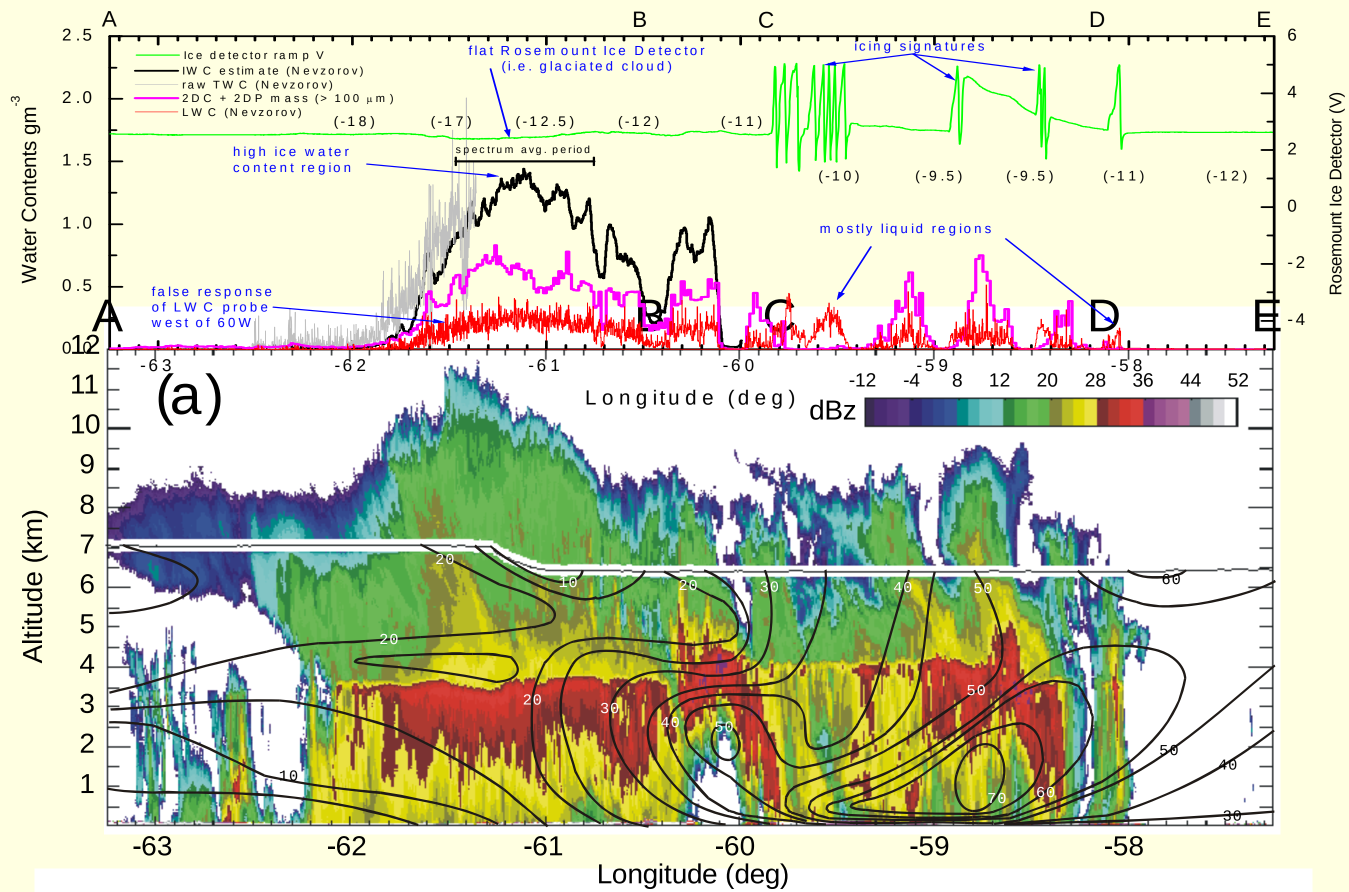
Example: Hurricane Michael (Oct. 19, 2000 (Convair-580) ;

radar and dropsonde wind speed cross-section



Surface pressure	987.5	985.2	985.3	982.8	982.8	n/a	975.9	978.4	985.6	989.1
Dropsonde #	1	2	3	4	5	6	7	8	9	10

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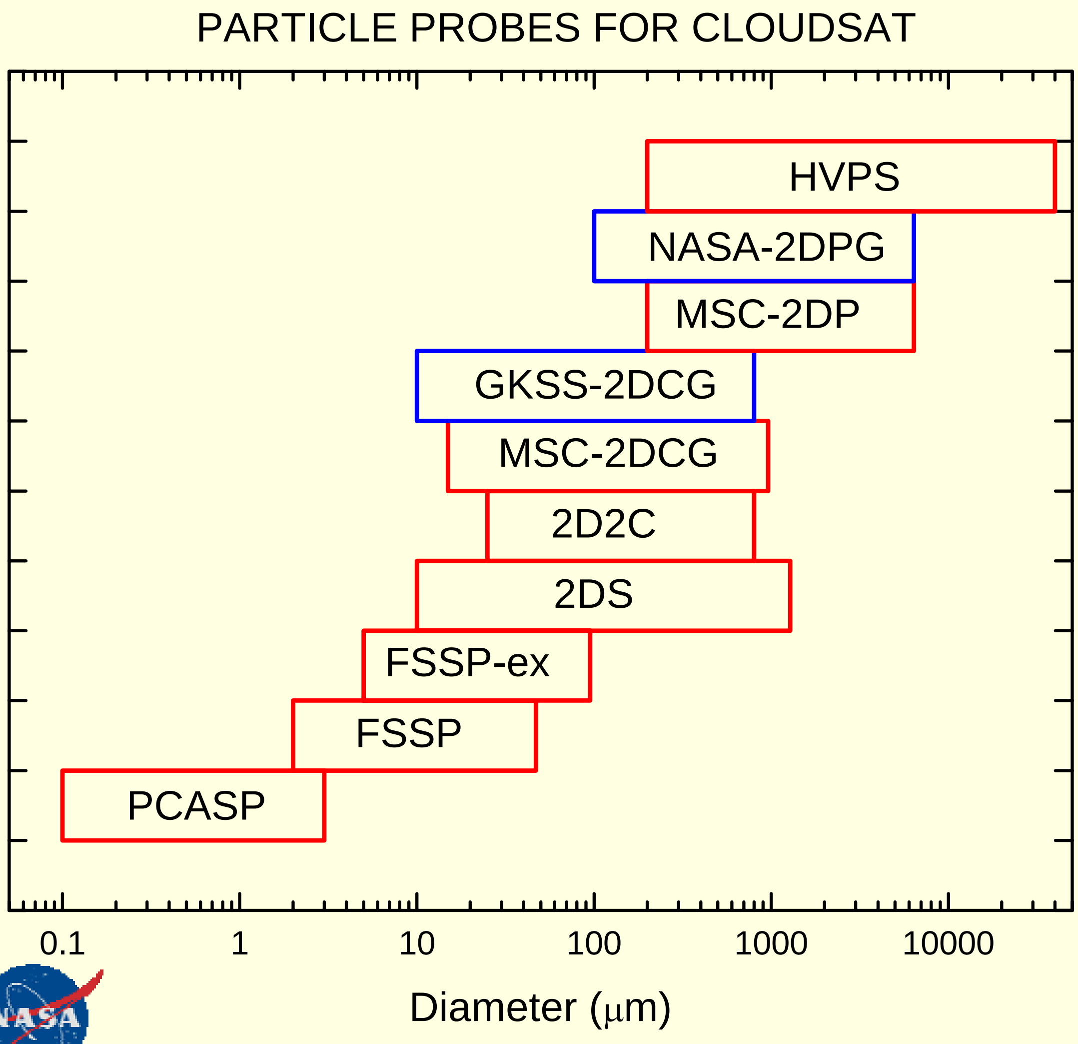
Particle Probe Ranges



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