Satellite Diagnoses of Icing Conditions and HIWC for Aviation

W. L. Smith, Jr.[1], P. Minnis[1],
K. Bedka[2], F.-L. Chang[2], C. Fleeger[2],
D. A. Spangenberg[2], R. Palikonda[2], Chris Yost[2]

[1]NASA Langley Research Center, Hampton, VA 23681 USA
[2]SSAI, Hampton, VA 23666 USA

Aircraft Icing

• Aircraft structures act as ice nuclei in supercooled clouds

- ice collects, weight increases, plane falls

• Pilots need to know where and when icing can occur

- PIREPS are first order: *sparse, aircraft dependent, location uncertain*

- Model analyses and forecasts: *freezing levels, cloud expectations*

- radar => *precipitation*

• All combined in NCAR/FAA/NOAA/NASA program to provide Current Icing Product (CIP) & Forecast Icing product (FIP) analyses to pilots (CONUS)

- some inadequacies remain

- NWP uncertainties, intensity, altitude of icing, etc.

• Operational satellites can add valuable information

- indirectly: input of cloud properties to CIP & NWP

- directly: ***determination of icing threat from real time satellite data***

Flight Icing Threat Inferred from Satellite

In-flight Aircraft Icing depends on

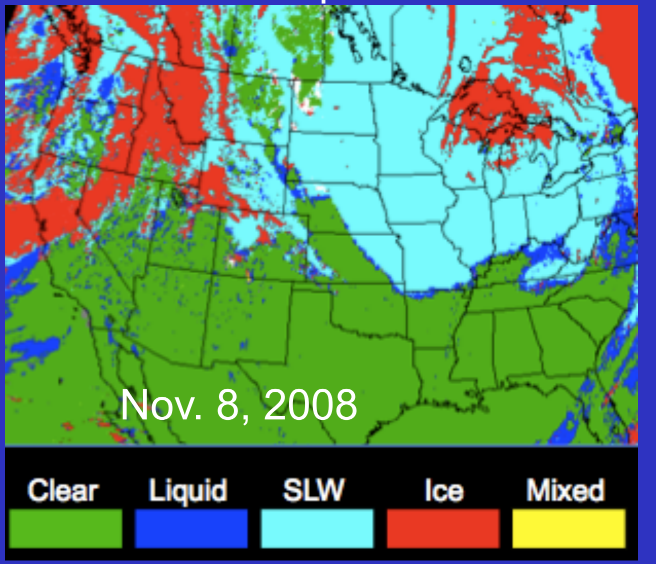
- presence of super-cooled liquid water (*SLW*)
- liquid water content, *LWC*
- Droplet size distribution, N(r)
- Temperature, T(z)

Satellite remote sensing can provide

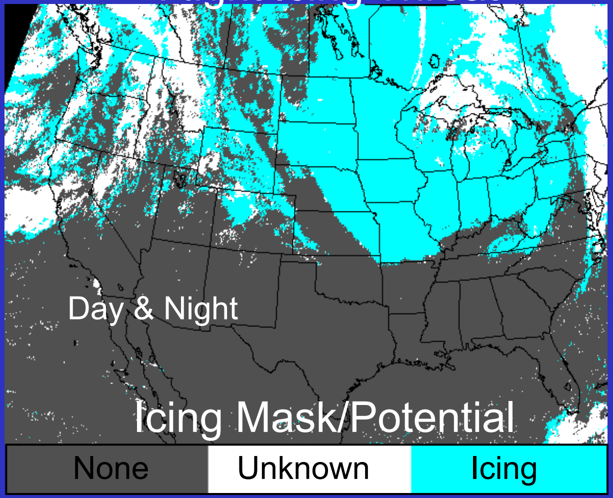
- Cloud top temperature and phase: SLW
- liquid water path: *LWP* = f(*LWC*)
- effective radius, r_e = f(*N(r)*)

- assumes satellite-derived cloud parameters are correlated with the parameters that determine icing (namely, LWP proxy for LWC; R_e proxy for N(r) at some level in the cloud)

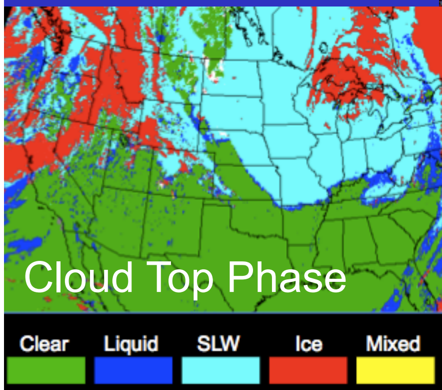
Cloud Top Phase

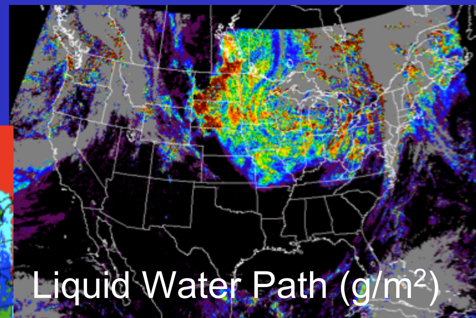


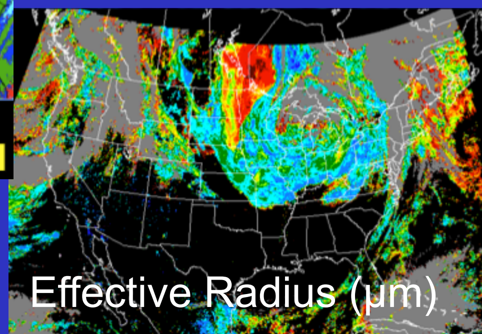
Flight Icing Threat

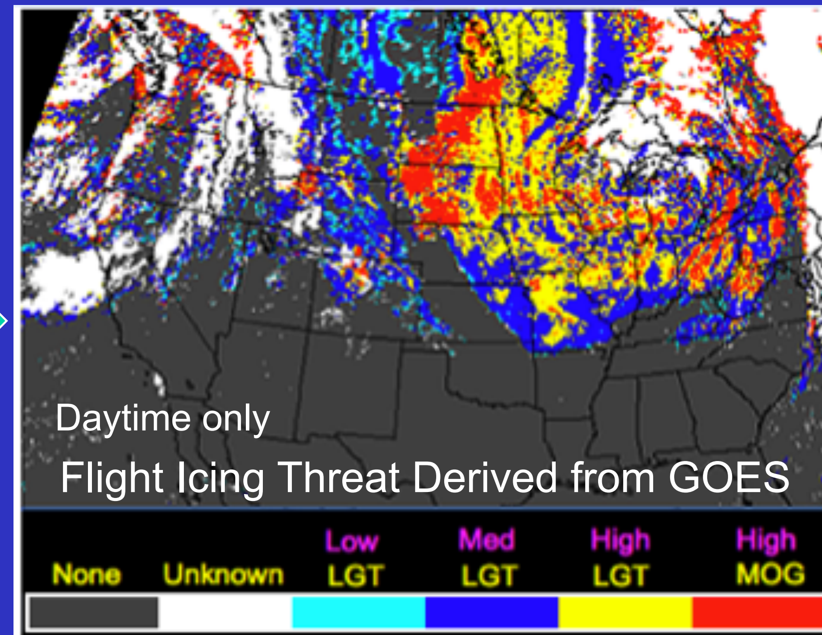


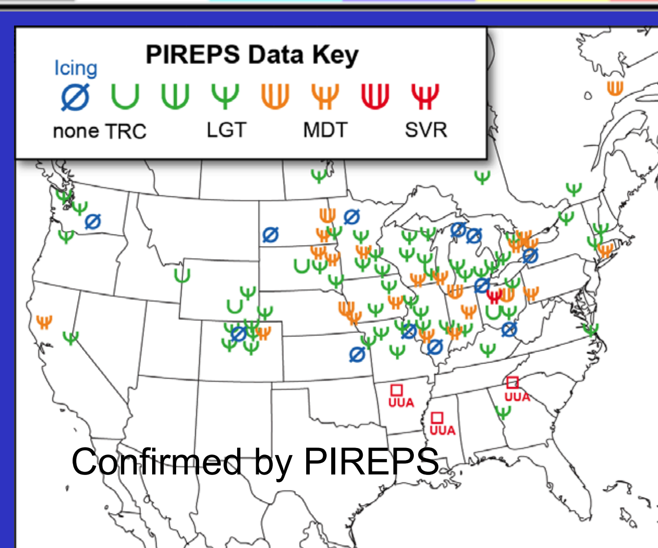
Map Satellite-derived Cloud Parameters to Flight Icing Threat









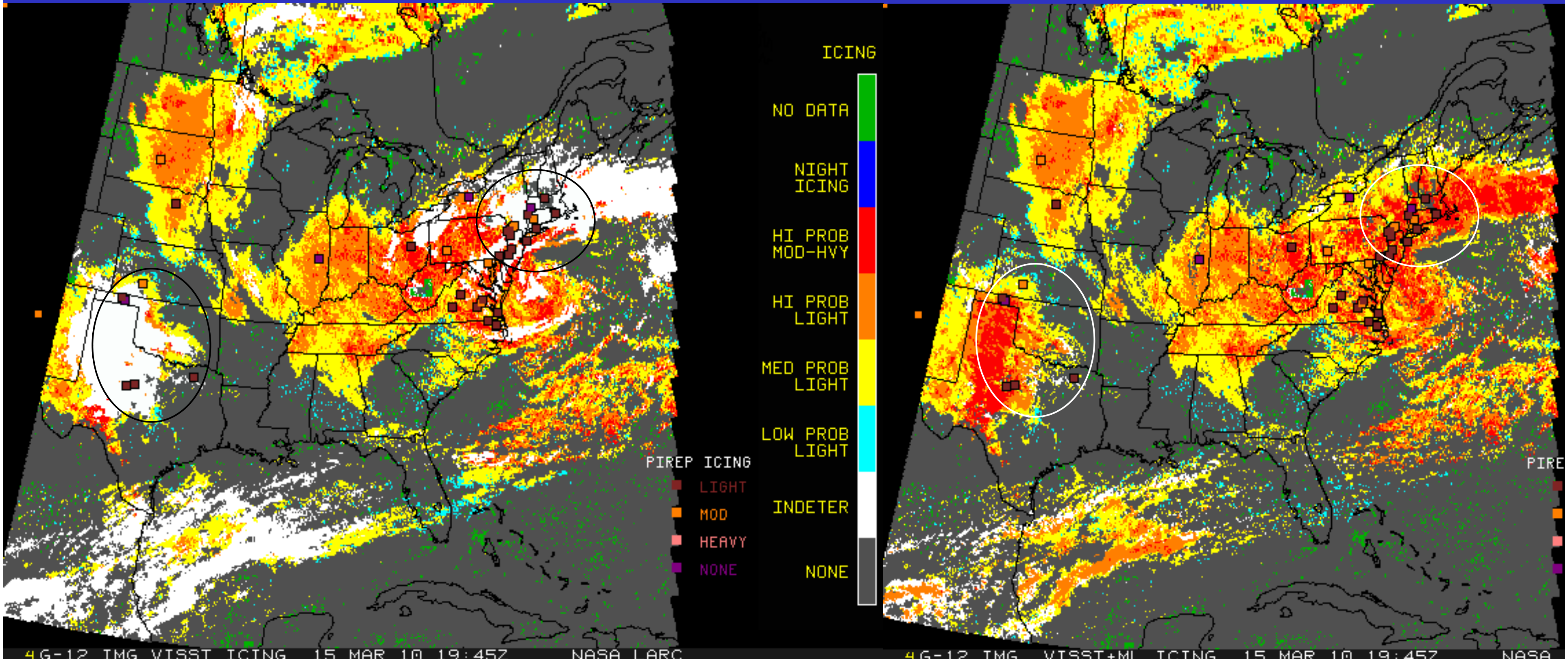


- Algorithm is based on correlations between satellite cloud parameters and Icing PIREPS using data from several winter seasons
- Provides horizontal resolution to FIT
- Prototype algorithm for GOES-R
- Note unknown/indeterminate areas

Multilayer Icing Diagnosis

- Identify ML clouds with Modified CO2 Absorption Technique (*Chang et al. 2010a,b*)
- Retrieve cloud properties for upper and lower layer, estimate FIT for lower layer

Standard SL Results — With ML Results



- Including ML cases dramatically reduces indeterminate areas
- Icing conditions appear to be well detected in ML areas

Satellite Flight Icing Threat Verification Summary

Icing Detection Skill Scores (daytime, SL):

PIREPS: 87% (N=4455, 2 winter seasons)
TAMDAR: 75% (N=12082, 1 month)
NIRSS: 60% (N=3454, several years)

2-category severity POD (daytime, SL):

PIREPS (N=3703)	Light: 53% MOG: 62%
NIRSS (N=683)	Light: 85% MOG: 66%

Severity validation difficult: known issues with PIREPS, NIRSS indirect

Satellite Flight Icing Threat Verification Summary

Multi-layer and Nighttime Validation vs. PIREPS (Feb/Mar2010)

Daytime icing detection enhanced with multi-layer technique

- Indeterminate area drops from 28% to 15%
- Skill remains at same high level (~ 98%)

Nighttime icing detection skill ~62%

- ML algorithm enhances night skill to ~79%

Satellite Flight Icing Threat Verification Summary (User Feedback)

Forecasters have successfully used GOES-derived LWP as a proxy for Icing:

- Wolff et al. (2005) provide examples where LWP field was used to guide NASA Glenn Twin Otter into regions where relatively large super-cooled LWC was measured with in-situ probes

- Bernstein et al. (2006) provide examples where LWP field used successfully to guide Pilots into significant icing regions for the purpose of aircraft icing certification

Looking forward to upcoming GOES-R Proving Ground/Testbed activities

Current and Future Work

• Improve cloud definition in terminator conditions
  - use temporal sequencing

• Test skill using other approaches (e.g. aircraft data from field campaigns – ICE-L, PLOWS, NASA Glenn Twin Otter)
  - need satellite component in future field campaigns

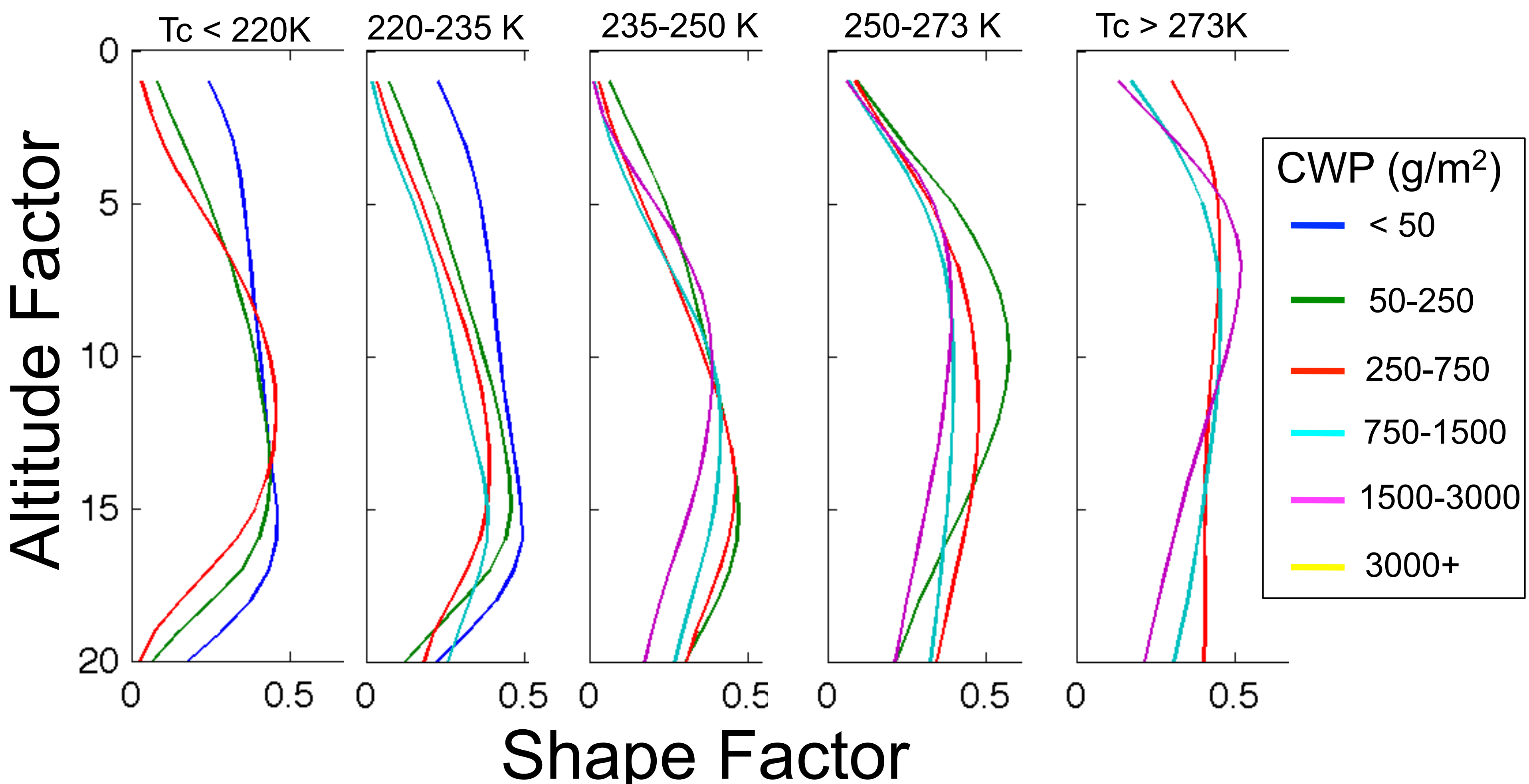
• Improve multilayer & low cloud detection at night
  - use 6.7-μm data to better define high cloud OD
  - use 8.6-μm data to better define low clouds

• Refine intensity estimation technique
  - employ objective dataset for tuning (e.g. NIRSS)

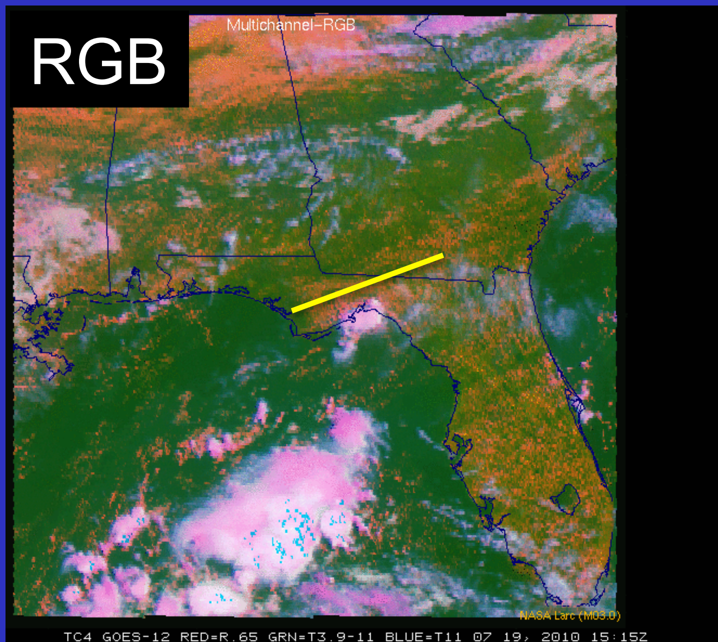
• Develop 3-D icing field - T, LWC and thus FIT vary with altitude
  - no info on ice beneath SLW cloud tops
  - use CloudSat and other data to define cloud profiles
  - find spectral signatures (use MODIS, proxy for GOES-R)

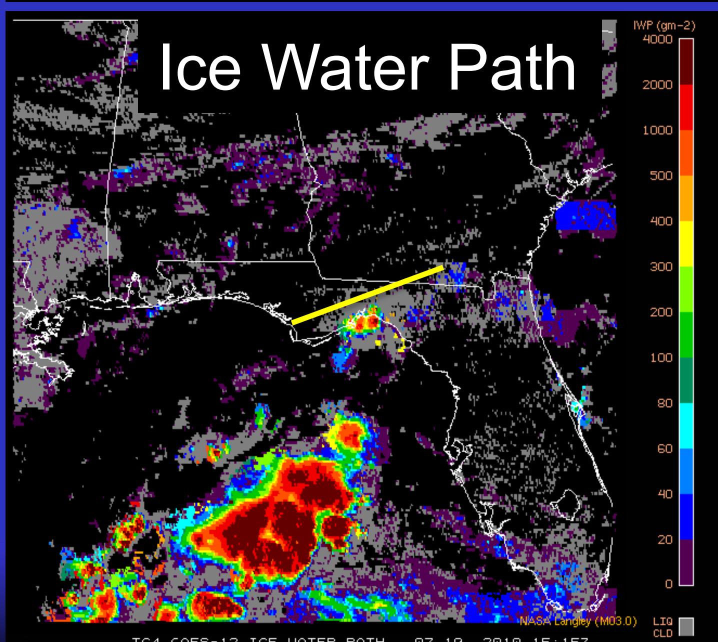
Climatological CWC Profile derived from CloudSat for 75 Cloud Types

- used in R/T system to derived 4-d distribution of cloud water constrained by passive satellite retrievals

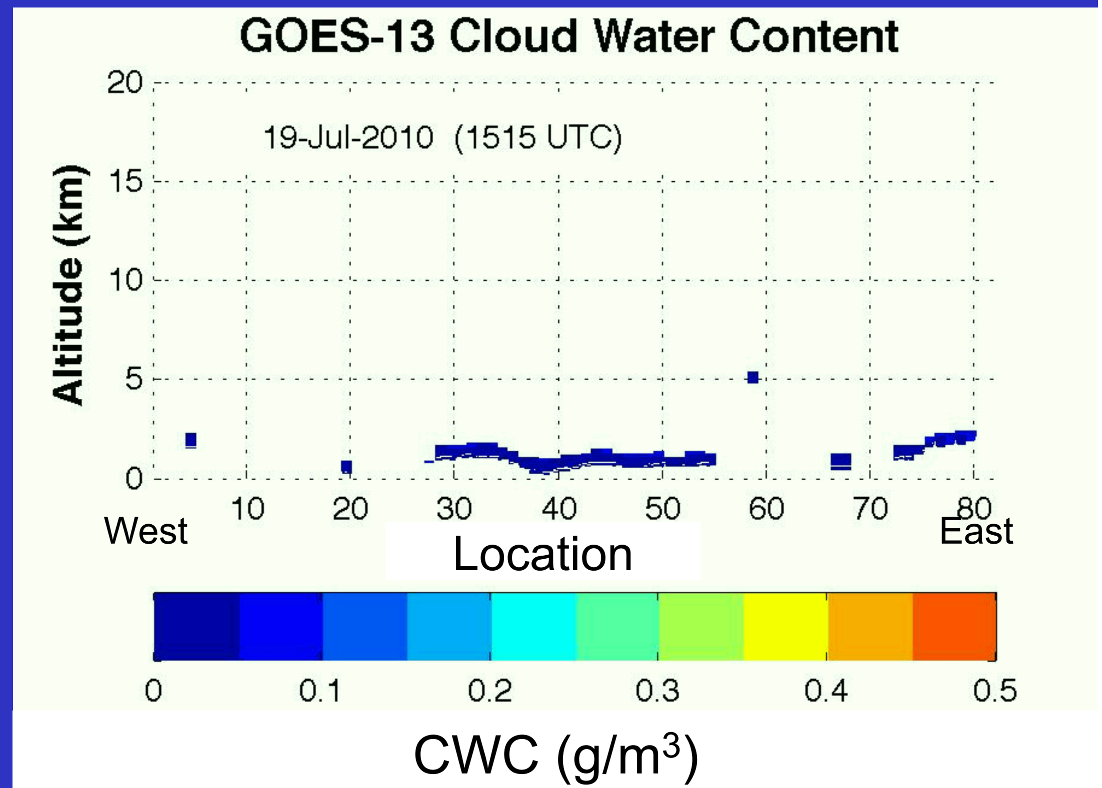


GOES-13 Rapid Scan July 19, 2010





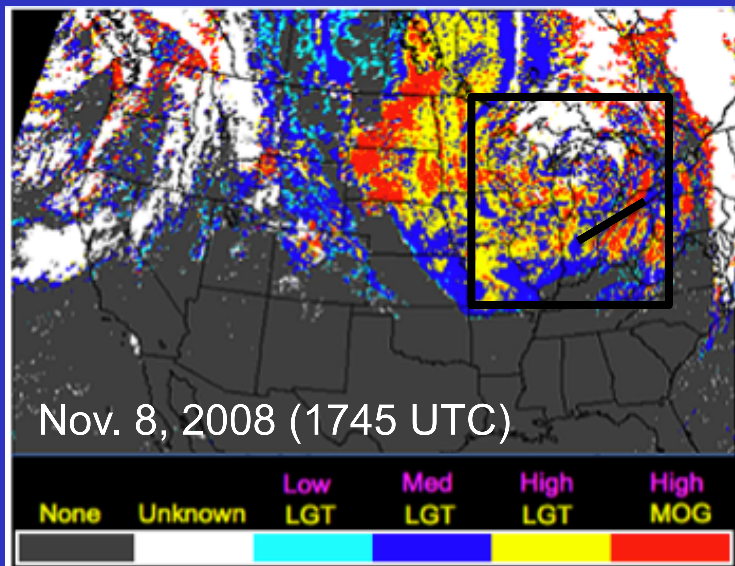
4-d Cloud structure from operational satellite data



Application of Profiling Concept to Flight Icing Threat

Construct CloudSat LWC(z) Climatology for SLW clouds (winter 2007 & 2008)

Current 2-D Icing Product

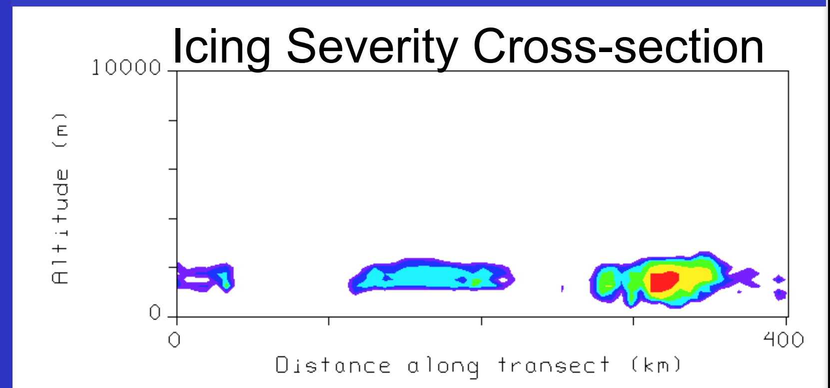


Derive LWC(z), convert to Icing Severity

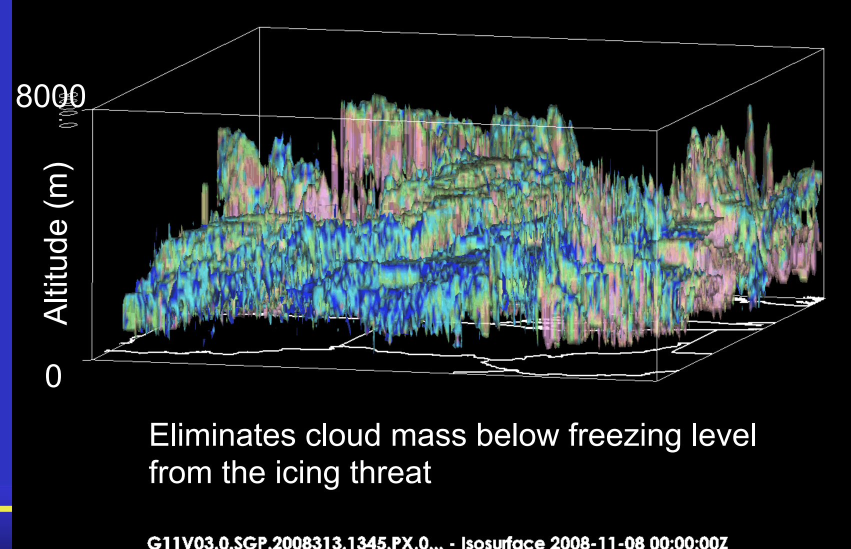
LWC (gm^{-3})	Icing category
<0.01	No icing
0.01 to 0.017	Trace
0.017 to 0.03	Trace-light
0.03 to 0.066	Light
0.066 to 0.12	Light-moderate
0.12 to 0.2	Moderate
0.2 to 0.37	Moderate-heavy
>0.37	Heavy

From Politovitch (2003)

Prototype Profiling Technique



4-D Icing Severity from GOES-12



Eliminates cloud mass below freezing level from the icing threat

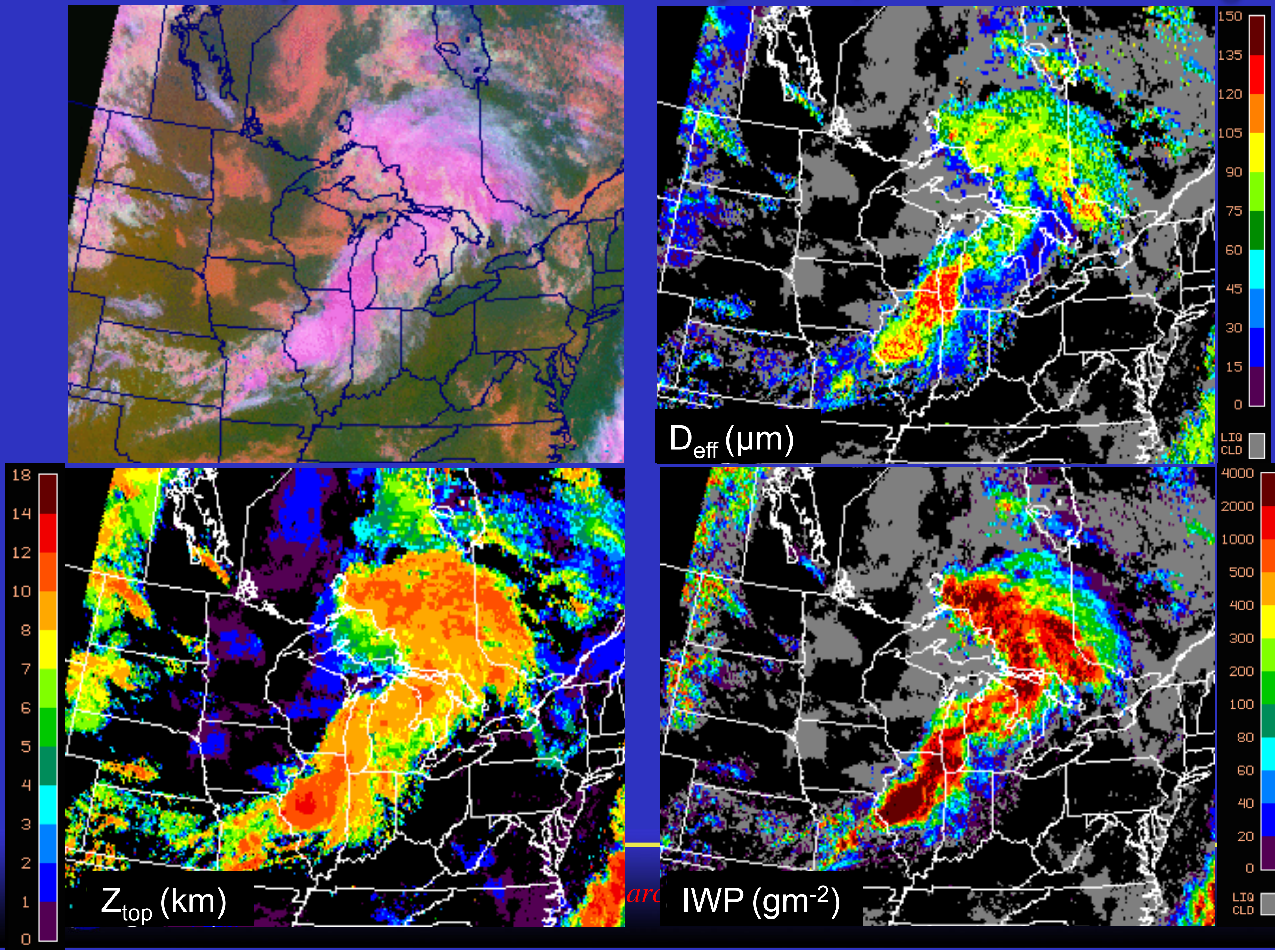
High Ice Water Content, HIWC, Challenge for Forecasting & Nowcasting

- HIWC – large concentrations of ice in convective clouds suffocate jet engines causing power failure & dangerous altitude loss
  - could be cause for Air France demise off Brazil
  - not well understood
  - difficult to forecast (what defines it exactly?)
  - difficult to detect

- Langley objectives
  - work with NCAR (Haggerty) to find indicators in satellite data
  - support HIWC field programs to serve objective 1

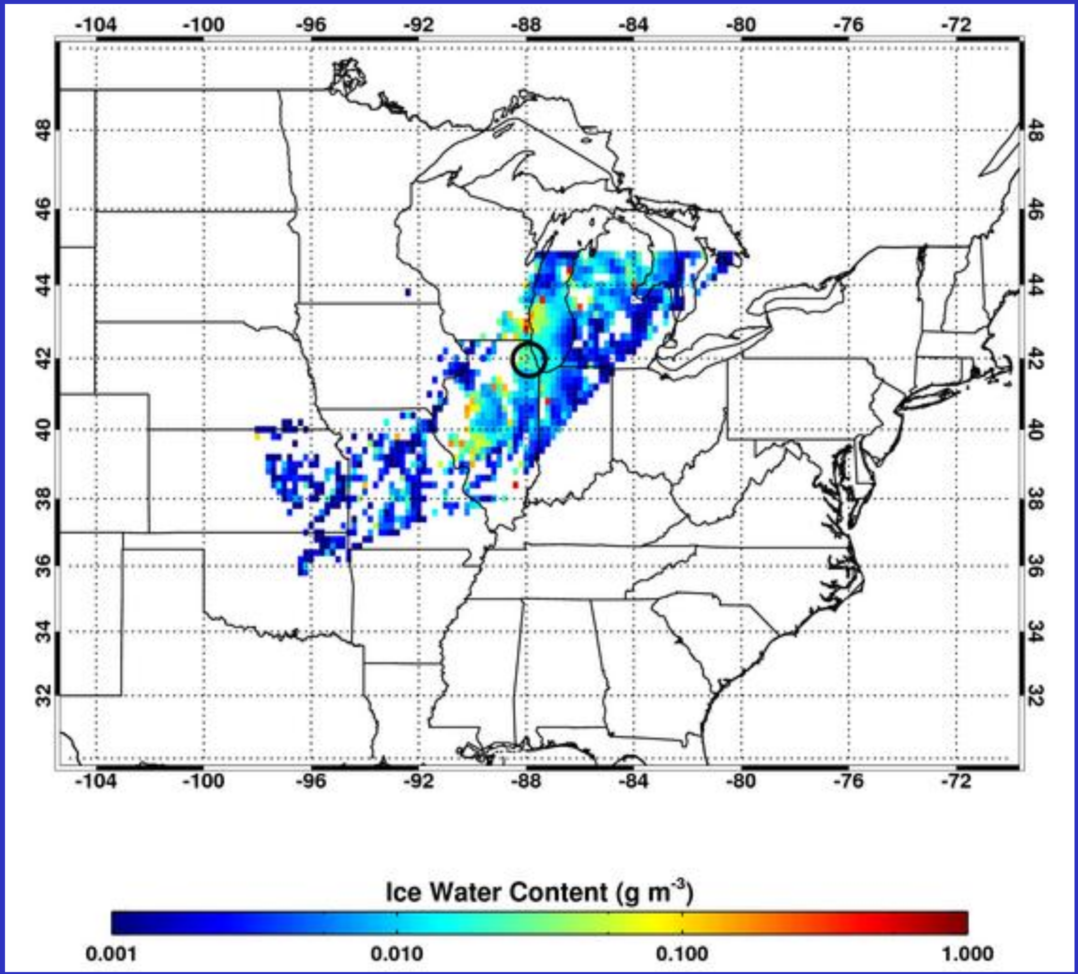
- Proto study – examine satellite retrievals in & around known cases
  - derive standard cloud properties
  - derive IWC for top portion of clouds using 2-satellite view

HIWC Example: 1400 UTC, 26 July 2007; Descent to Chicago



HIWC Example: 1400 UTC, 26 July 2007; Descent to Chicago

Ice Water Content Derived From Matched GOES-E and GOES-W Pixels

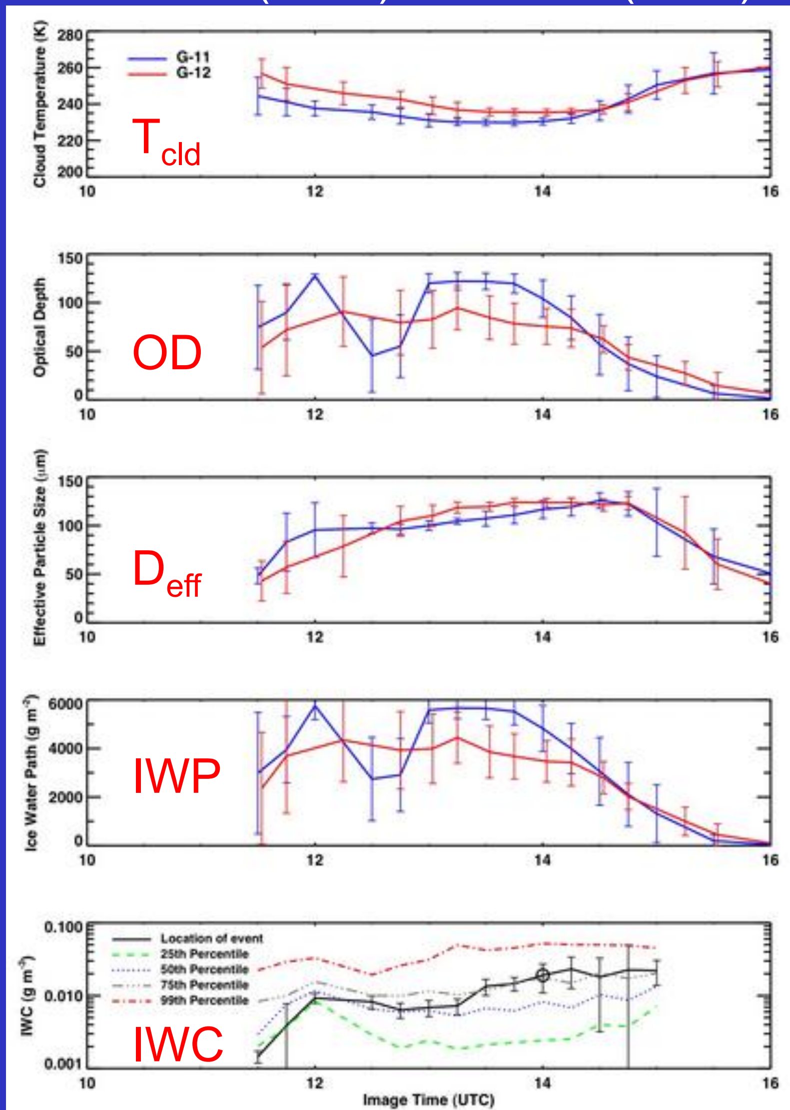


Yost et al., 2010
JGR

- IWC near Chicago is only ~0.02 gm^{-2} in the top of the cloud

Cloud Statistics in circle around Chicago, 26 July 2006

GOES-E (G-12) GOES-W (G-11)



Event occurs

- near coldest cloud temperature
- relatively high optical depth
- large particle size
- large ice water path > 4000 gm^{-2}
- average IWC (0.02 gm^{-3})

Summary to date (3 cases)

- No distinct signal evident
- top of cloud IWC nothing special
- need more cases with exact times & locations of events