GOES-R AWG Aviation Team: Flight Icing Threat

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Outline

- Executive Summary
- Algorithm Description
- Examples of Product Output
- Validation Approach
- Validation Results
- Steps to 100%
- Summary

Executive Summary

- This ABI Flight Icing Threat (FIT) detection algorithm generates an Option 2 product
- Software Version 3 was delivered in March. ATBD (80%) and test datasets are scheduled to be delivered in June 2010
- Algorithm utilizes ABI cloud products to identify areas icing is likely to occur and crudely estimate the icing severity
- Validation Datasets: Icing PIREPS, TAMDAR, and ground-based icing remote sensing data.
- Validation studies indicate that the product is meeting spec.

Requirements and Product Qualifiers
Flight Icing Threat

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Aircraft Icing Threat	GOES-R	FD	Day and night	Quantitative out to at least 60 degrees LZA and qualitative at larger LZA	Clear conditions associated with threshold accuracy	Over specified geographic area

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Product Refresh Rate/Coverage	Product Refresh Rate/Coverage	Vendor Allocated Ground Latency	Product Measurement Precision
Aircraft Icing Threat	GOES-R	FD	Cloud Top	2 km	5 km	Day: None, Light, Moderate or Greater (MOG); Night: None, Possible Icing	50% correct classification	60 min	5 min	806 sec	NA

FD – Full Disk

Algorithm Description

What Is Flight Icing?

Flight Icing: The formation of ice, rime, or hoarfrost on an aircraft in flight (from the AMS Glossary)

- **Due to the natural occurence of super-cooled liquid water (SLW) in clouds which often freezes on the airframe upon contact**
- **Ice accumulation on the airframe is hazardous because it alters the airflow (increased drag, decreased lift) which may lead to control problems**
- **The hazard may be reduced by avoidance or with anti-icing and de-icing equipment (e.g. wing boots, heaters)**
- **Current icing diagnosis and forecasting methods tend to overestimate areal coverage of icing threat, thus avoidance can be expensive, resulting in increased flight times or flight delays**
- **Severe icing can overwhelm an aircraft's icing protection system**
- **No phase of of aircraft operations is immune to the icing threat**

Ice accretion on wing leading edge

(a) while in cloud

(b) after ascending above cloud

Satellites Detect Icing Conditions

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)*)

Thus satellite data can be used to infer the flight icing threat in certain conditions

Satellites Detect Icing Conditions

Forecasters have successfully used satellite-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

Flight Icing Threat Processing Schematic

INPUT: Cloud Phase, Tau, LWP, Re

↓

Determine 'icing' pixels (optically thick SLW pixels)

↓

Mask the remaining pixels as 'none' (cloud free, warm clouds) or 'unknown' (optically thick high clouds)

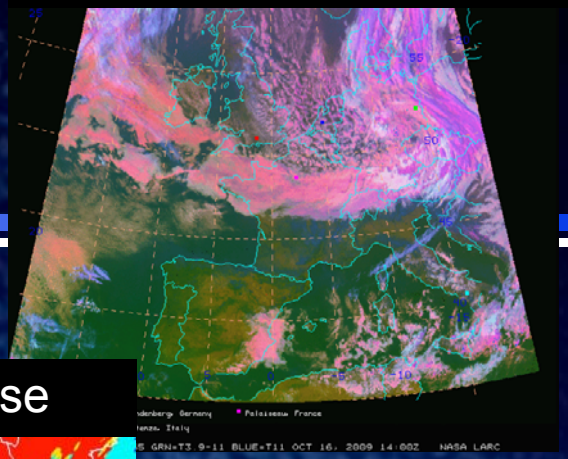
↓

During daytime, estimate icing probability and severity from LWP, Re for icing pixels

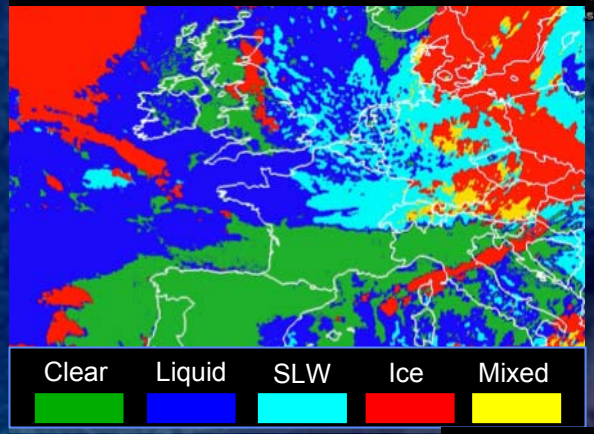
↓

Output Icing Mask and Severity Estimate

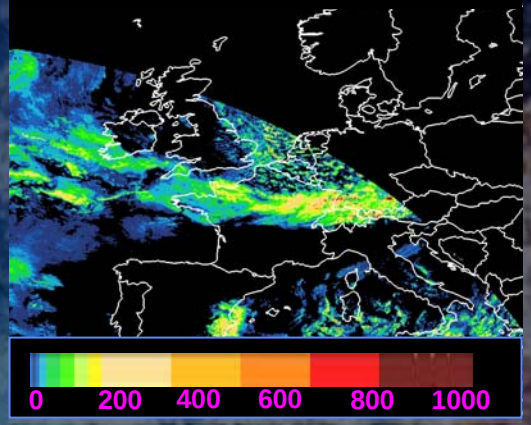
SEVIRI RGB 10/16/2009



AWG Cloud Phase



AWG Liquid Water Path



Algorithm Summary

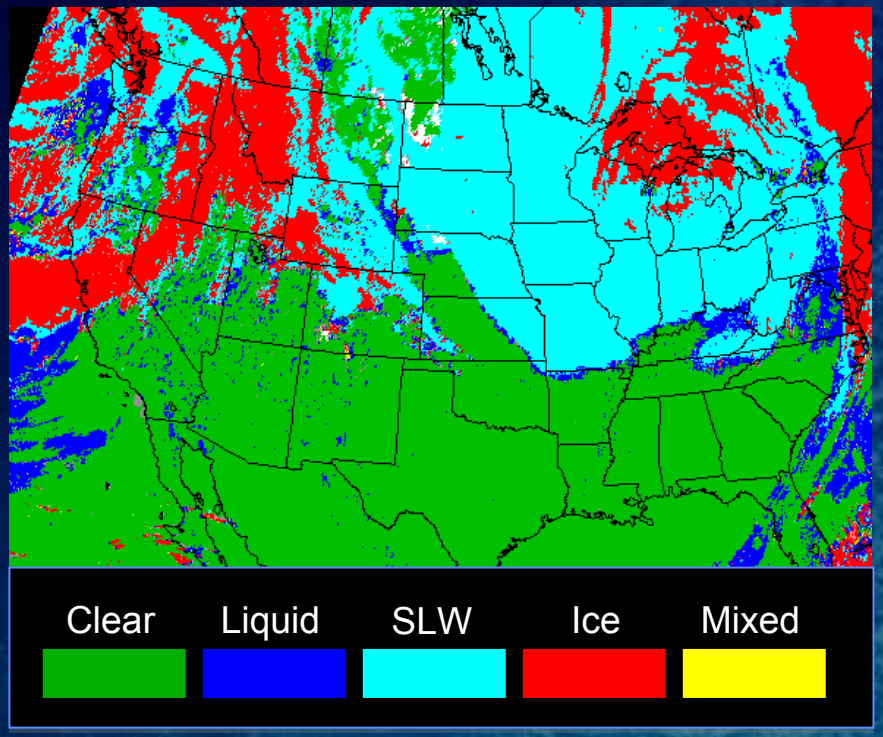
- The flight icing threat is determined using theoretically based cloud parameter retrievals
- Input Datasets: NASA LaRC cloud products derived routinely from current GOES and SEVIRI data. AWG Cloud Products derived from MODIS and SEVIRI proxy data for select cases
- The icing mask is first constructed (icing, none, unknown) using the cloud phase and optical depth
- During daytime, the icing probability and severity are computed for each 'icing' pixel using the retrieved LWP and Re
- Additional output parameters include quality control flags and estimates of the icing altitude boundaries
- FIT is indeterminate when high thick clouds obscure view

Examples of Product Output

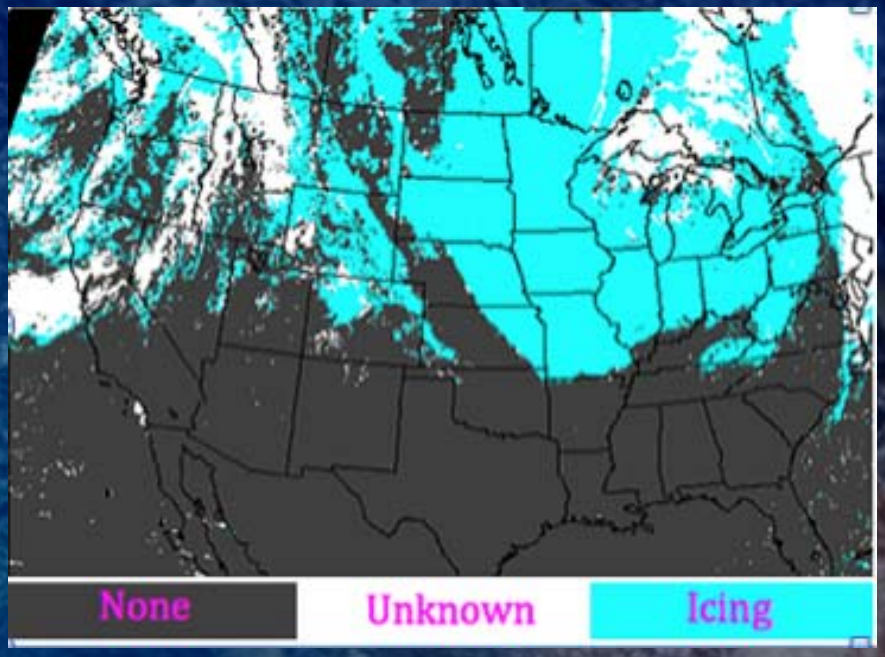
Flight Icing Threat Product Output

November 8, 2008 (1745 UTC) GOES

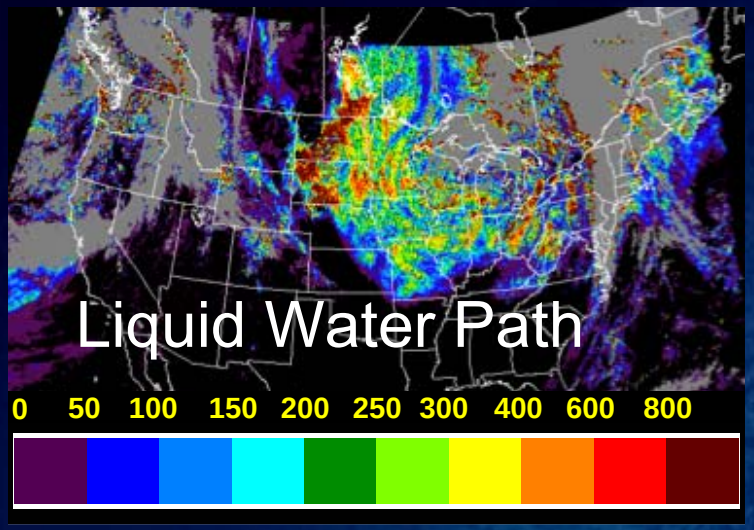
Cloud Phase

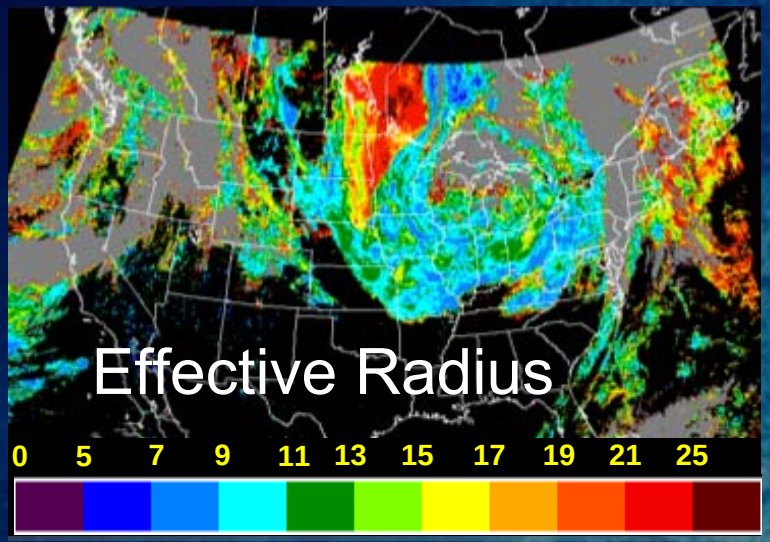


Icing Mask



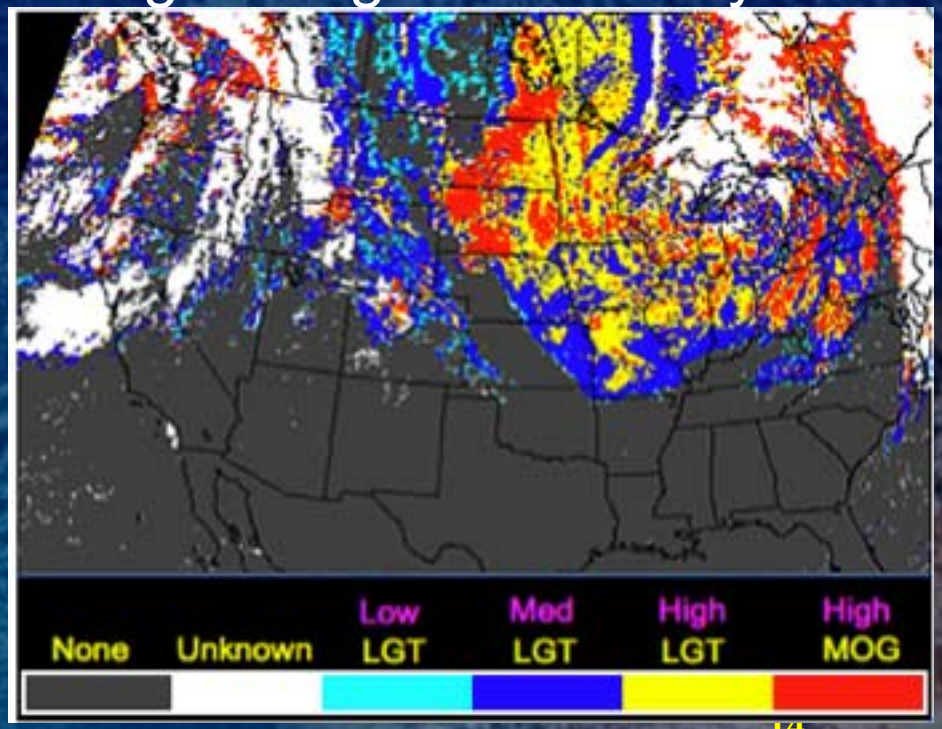
Flight Icing Threat Product Output





November 8, 2008 (1745 UTC)
GOES-E, W

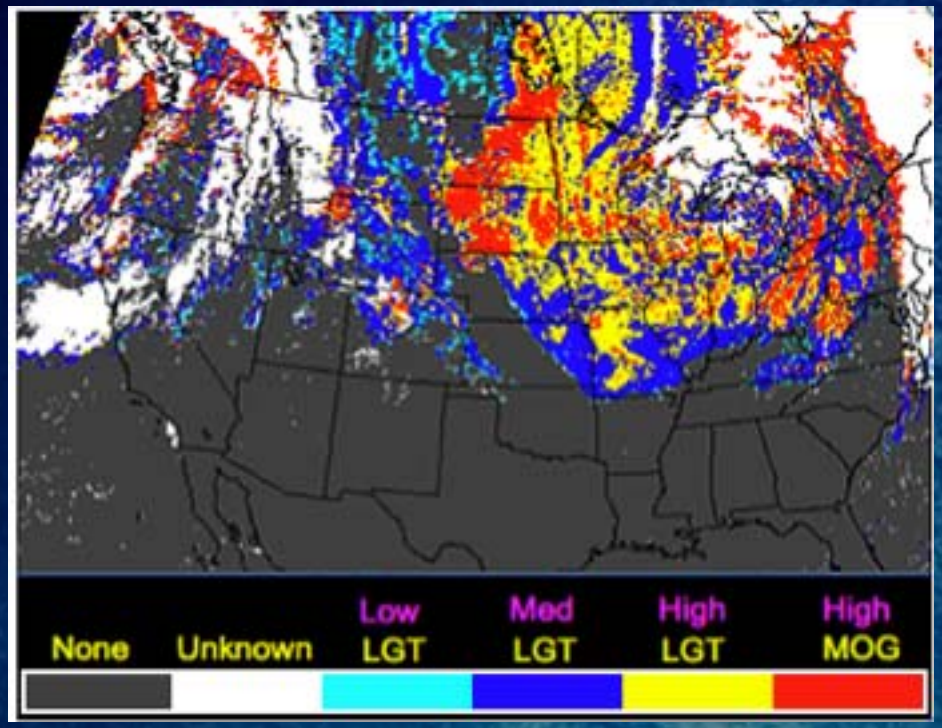
Flight Icing Threat - Daytime

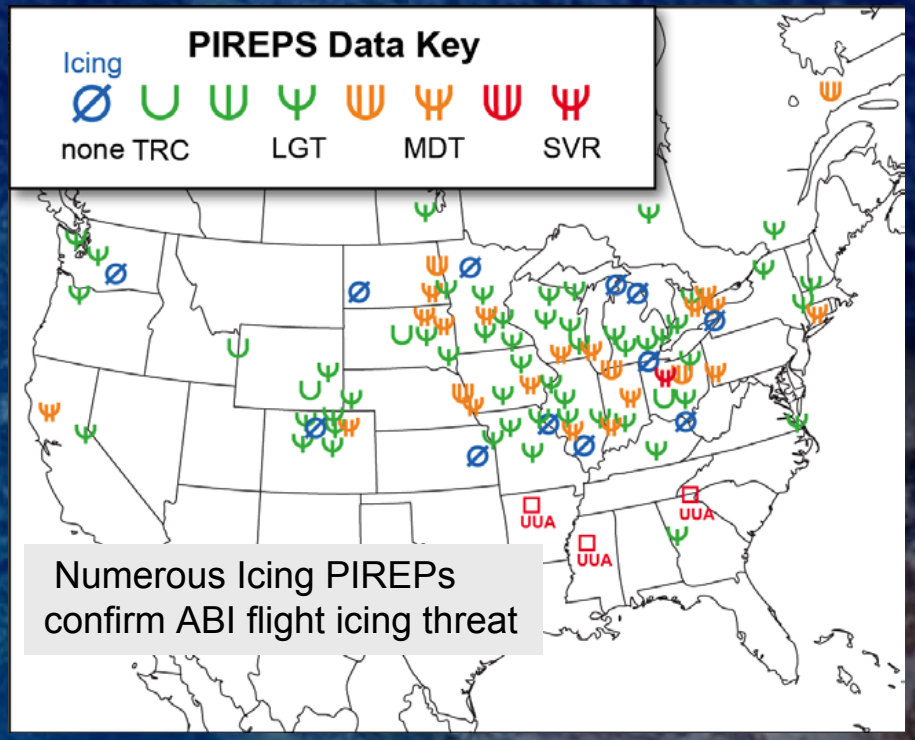


Flight Icing Threat Product Output

November 8, 2008 (1745 UTC) GOES

Flight Icing Threat

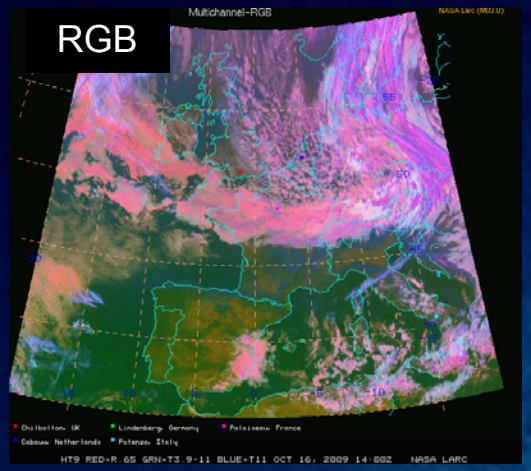


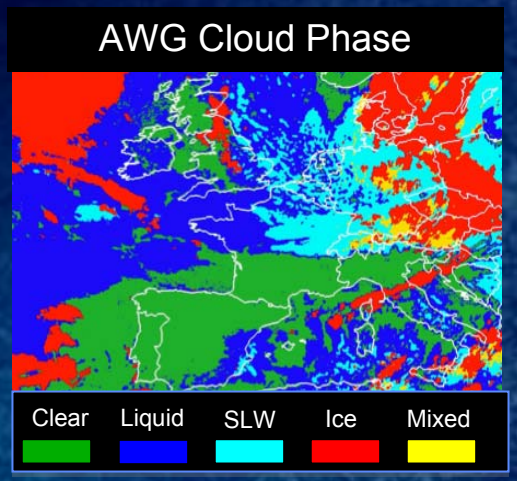


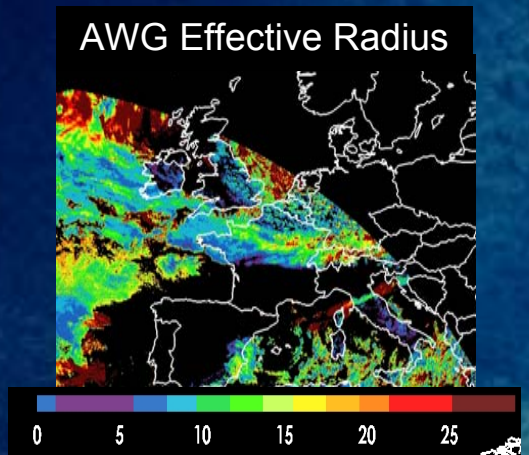
Numerous Icing PIREPs confirm ABI flight icing threat

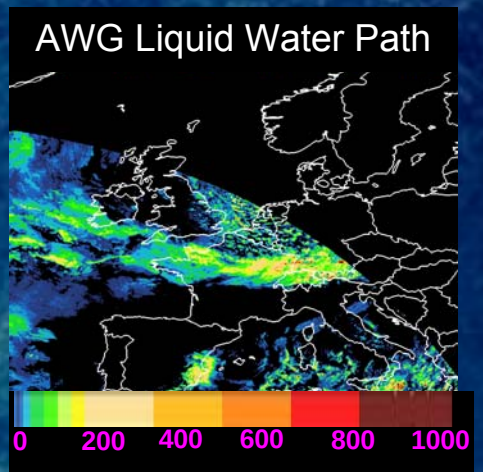
Flight Icing Threat Product Output

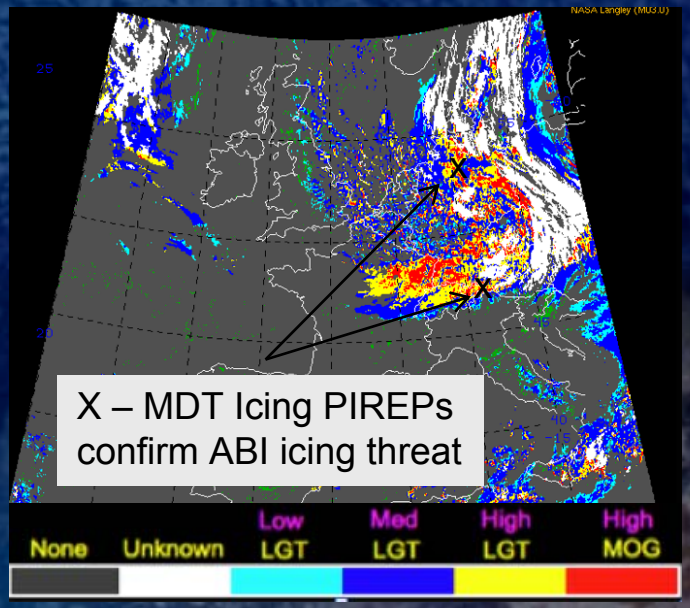
Oct 16, 2009 (1400 UTC) SEVIRI











Validation Approach

Validation Approach: Datasets

- Test Data
  - » Current GOES (NASA LaRC derived Cloud products)
  - » SEVIRI (NASA and AWG derived cloud products)
  - » MODIS (NASA and AWG derived cloud products

- Truth Data
  - » Icing PIREPS (Two years over CONUS, N=4455)
  - » TAMDAR icing sensor on ~400 commercial aircraft (N=12,082)
  - » Ground-based icing remote sensing products at NASA GRC, Cleveland, OH (5 years, N=3454)

Validation Approach: Qualifier

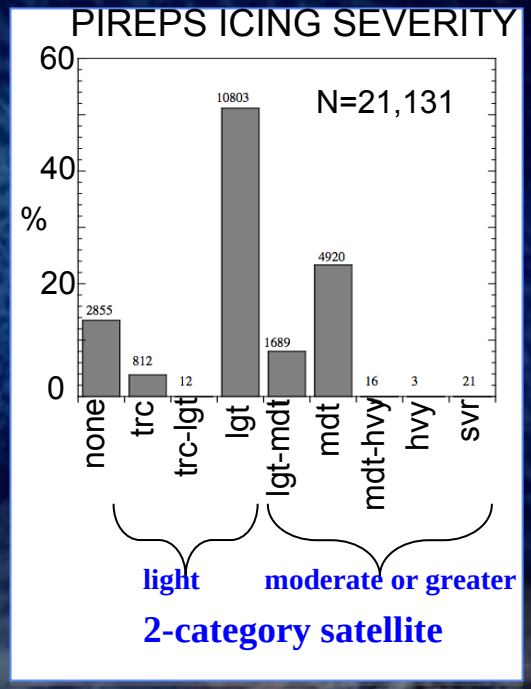
- Aircraft icing also depends on airframe/flight characteristics
- Truth datasets each have their own associated uncertainties and limitations

FIT Algorithm validation and calibration are difficult

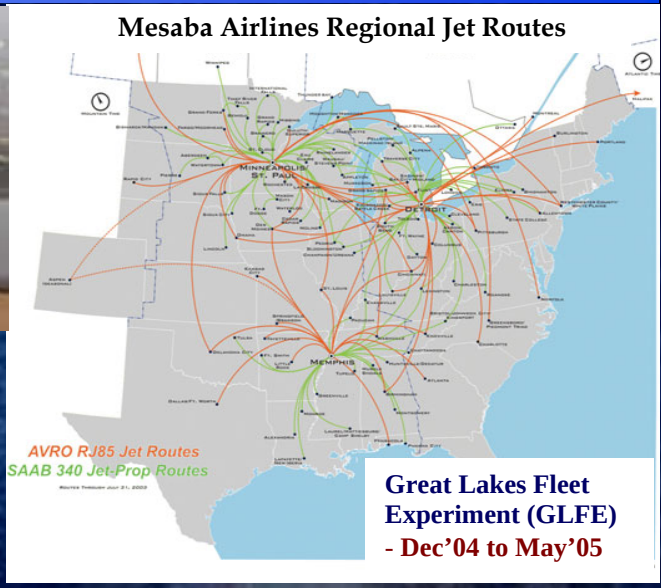
Validation Approach: Icing PIREPS

- Advantages
  - » Widely available over CONUS, few over Europe
  - » In-flight severity reported by Pilots
  - » Useful for validating icing detection (PODY)

- Disadvantages
  - » Not appropriate for estimating false alarms, PODN
    - *Inherently biased (few negative reports)*
    - *Only valid at flight level*
  - » Difficult to use to validate severity
    - *Cloud parameters that impact severity highly variable in nature*
    - *Temporal and spatial reporting errors*
    - *Icing depends on airframe/flight characteristics*
    - *Pilot reports are subjective*



Validation Approach: AirDat's TAMDAR System



- Advantages
  - » Continuous operation since 2004
  - » ~400 aircraft operating over CONUS/Alaska
  - » Direct, objective measure of icing
  - » Useful to verify satellite based icing detection/mask, PODY
  - » Severity/intensity estimate possible (in development)
- Disadvantages
  - » Not appropriate for characterizing false alarms, PODN
    - *Difficult to differentiate clear air/cloud data in no icing conditions*
    - *Only valid at flight level*

Validation Approach: NIRSS

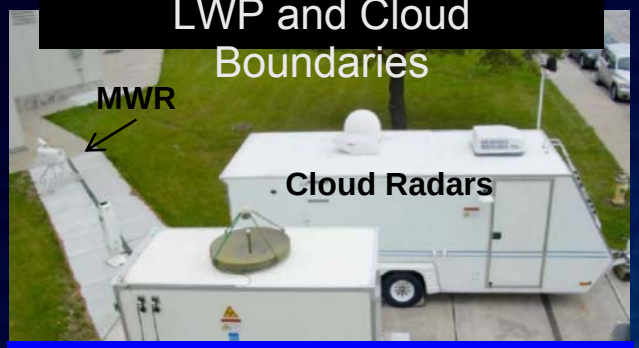
NASA Icing Remote Sensing Site (NIRSS)

Data Analysis just started

- Advantages
  - » Located in Cleveland, Ohio for 5+ years
  - » Profiling capability (microwave radiometer, cloud radars)
  - » Useful for improving satellite algorithm
  - » Could help quantify false alarms, PODN
  - » Accurate matching with satellite
  - » Products being developed for terminal area flight icing
  - » Technique could be applied at other surface sites (Europe?)
- Disadvantages
  - » Spatial representation (point measurement at one site)
  - » Icing inferred from remote sensing data, not measured directly

Validation Approach: NIRSS

LWP and Cloud Boundaries



Ground-based Sensors at NASA GRC

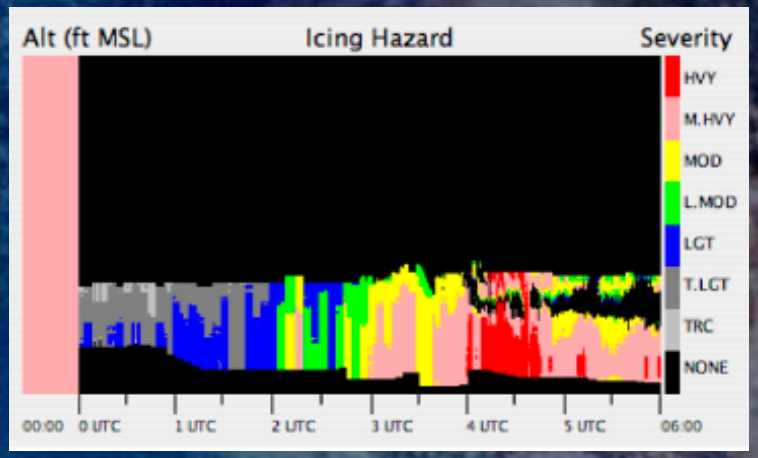
(Reehorst et al. 2009)

NIRSS approach takes data from microwave radiometer, cloud radars, experience/data from aircraft icing program to derive super-cooled LWC profiles which can be mapped to icing severity profiles

Convert LWC to 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

Icing Severity profiles



NIRSS should be valuable for improving the satellite technique

Validation Results

Validation with PIREPS
Winter 2006/07, 2007/08

- Excellent detection of icing conditions
- False reports common, but small % of total
  - 'No Icing' not reported often

Probability of Detecting Icing

		PIREPS Y	PIREPS N
Satellite	Y	3703	328
	N	273	151

PODy = 93% PODn = 32% Skill= 87%

- Classification of severity has skill but not as much as icing detection
- Icing severity often subjective & depends on A/C
- FIT Severity based on total LWP rather than super-cooled LWP

Probability of Detecting Light/Moderate Icing

		PIREPS L	PIREPS M
Satellite	L	1279	487
	M	1157	780

POD(light) = 53% POD(mdt) = 62%

Aircraft Icing Threat Test Plan Offline Validation: Results

TAMDAR Validation of GOES-12 Icing April 2005 (12,082 matches)

TAMDAR

GOES	YES	NO	Total
YES	1047	5532	6579
NO	152	5351	5503
Total	1199	10883	12082

PODv = 87.3%
PODn = 49.2%
Skill = 75.0 %

GOES Indeterminate with TAMDAR icing excluded from statistics

GOES false alarm found to be 75% but is explained by cloud boundary errors

Aircraft Icing Threat Test Plan Offline Validation: Results

NASA Icing Remote Sensing Site (NIRSS)

PRELIMINARY

A2-3569	Icing Mask			Severity	
	NIRSS_Y	NIRSS_N		NIRSS_L	NIRSS_M
Sat_Y	683	698	Sat_L	408	69
Sat_N	170	1903	Sat_M	73	133
POD_Y	0.80		POD_L	0.85	
POD_N	0.73		POD_M	0.66	
Skill	0.60				
FA	0.27				

- NIRSS data only recently releases – still some processing issues
- Screening not very selective in this preliminary comparison
- Includes partly cloudy & mixed phase scenes which complicates the comparison.
- More work needed to refine this comparison.

Flight Icing Threat Validation Results: Summary

Product Measurement Range	Product Measurement Accuracy	Icing Validation using GOES-11/12 data over CONUS Icing Detection Binary Yes/No Day & Nite	Icing Validation using GOES-11/12 data over CONUS Two-Category Severity POD (Light, MOG) Daytime Only
Day: Unknown, None, Light, Moderate or Greater (MOG); Night: Unknown, None, Possible Icing	50% correct classification	PIREPS: 87% (N=4455) TAMDAR: 75% (N= 12082) NIRSS: 60% (N=3454)	PIREPS (N=3703) Light: 53% MOG: 62% NIRSS (N=683) Light: 85% MOG: 66%

Steps to Reach 100%

- One potential shortcoming in 80% version is use of LWP as proxy for super-cooled LWC since LWP may include warm cloud water or ice
  - » Use CloudSat, ARM, and NIRSS data to develop methods to address this (see Poster)
  - » Develop new algorithm coefficients and validate
- Work closely with AWG Cloud Team regarding product validation
  - » Check AWG and LaRC cloud products for consistency and make appropriate adjustments to the FIT
- More algorithm testing needed on proxy ABI data with AWG cloud products
- More validation/evaluation, particularly over snow and in mixed phase conditions

Summary

- The ABI Flight Icing Threat algorithm provides a new capability for objective detection of the in-flight icing threat to aircraft
- Improved ABI spectral coverage, spatial and temporal resolution should offer better detection capability
- Algorithm meets all performance and latency requirements but improvements are still possible with more research
- We are working closely with NCAR and NASA GRC to ensure the ABI product will be useful and consistent with other icing products (NCAR CIP/FIP, Terminal area icing remote sensing system)