The high IWC (Ice Water Content) Hazard for aviation and satellite retrieval

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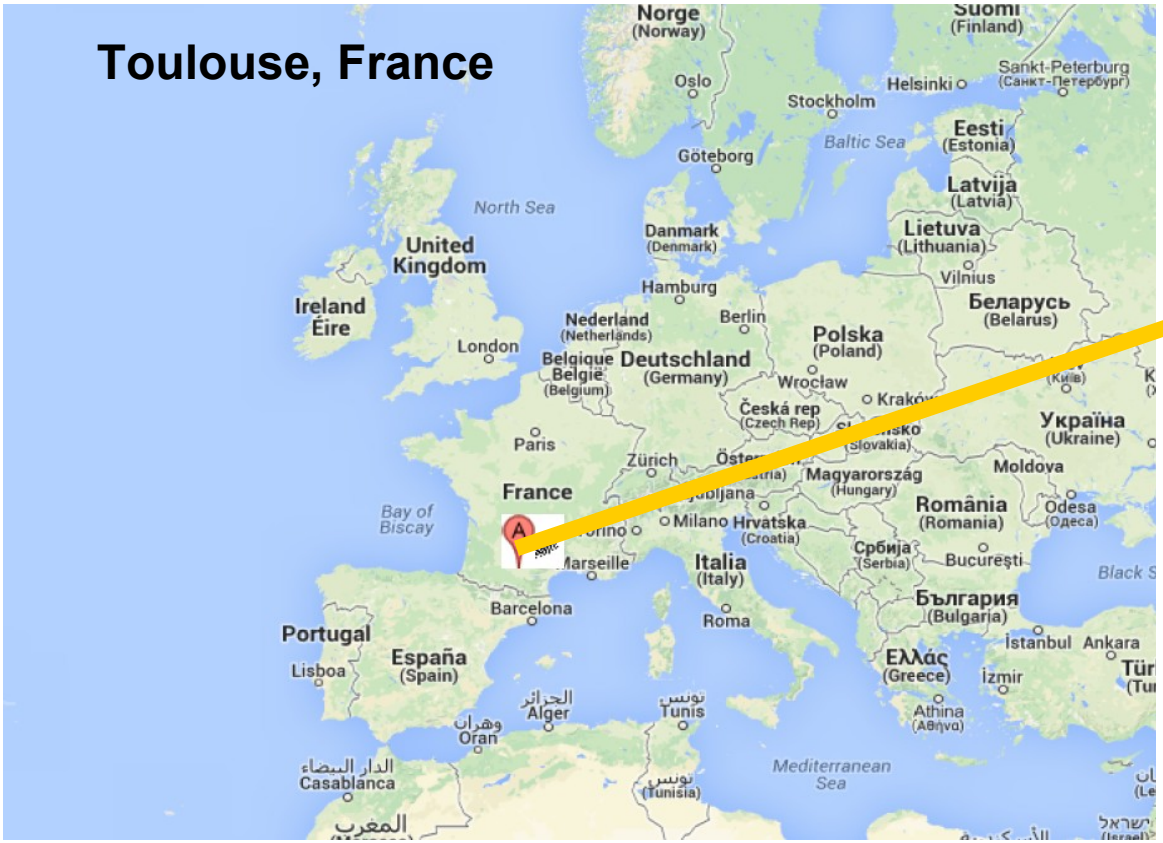
Several contributions issued from partners' works: NCAR, BOM, NASA, KNMI, LATMOS
Haggerty, J., Defer, E., de Laat, A., Bedka, K., Potts, R., Delanoë, J., Parol, F., Grandin, A.

Eumetrain - Aviation Week - December 2018

Presentation

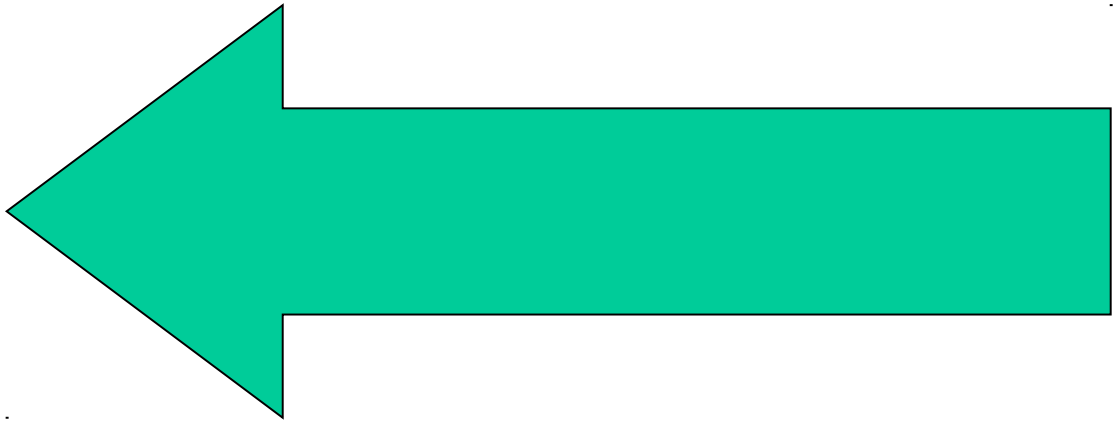


Météopole, Toulouse

Jean-Marc Moisselin
Nowcasting department

Overview

1.The hazard



2. The tools for the diagnosis

3. Focus on RDT

4. Conclusion

High IWC (Ice Water Content)

- Ice crystals: cold meteors of very small size. Often non visible though onboard radar.

- Different of classical icing.
  - High altitude, cold ambient temperature
  - Convective clouds or thunderstorms in the vicinity
  - Ambient temperature warmer than corresponding standard atmosphere temperature
  - Visible moisture (in cloud)
  - Moderate to heavy rain below aircraft
  - Light or no radar echoes at flight altitude on pilot's radar
  - Light to moderate turbulence
  - No significant airframe icing
  - No hail or lightning observations

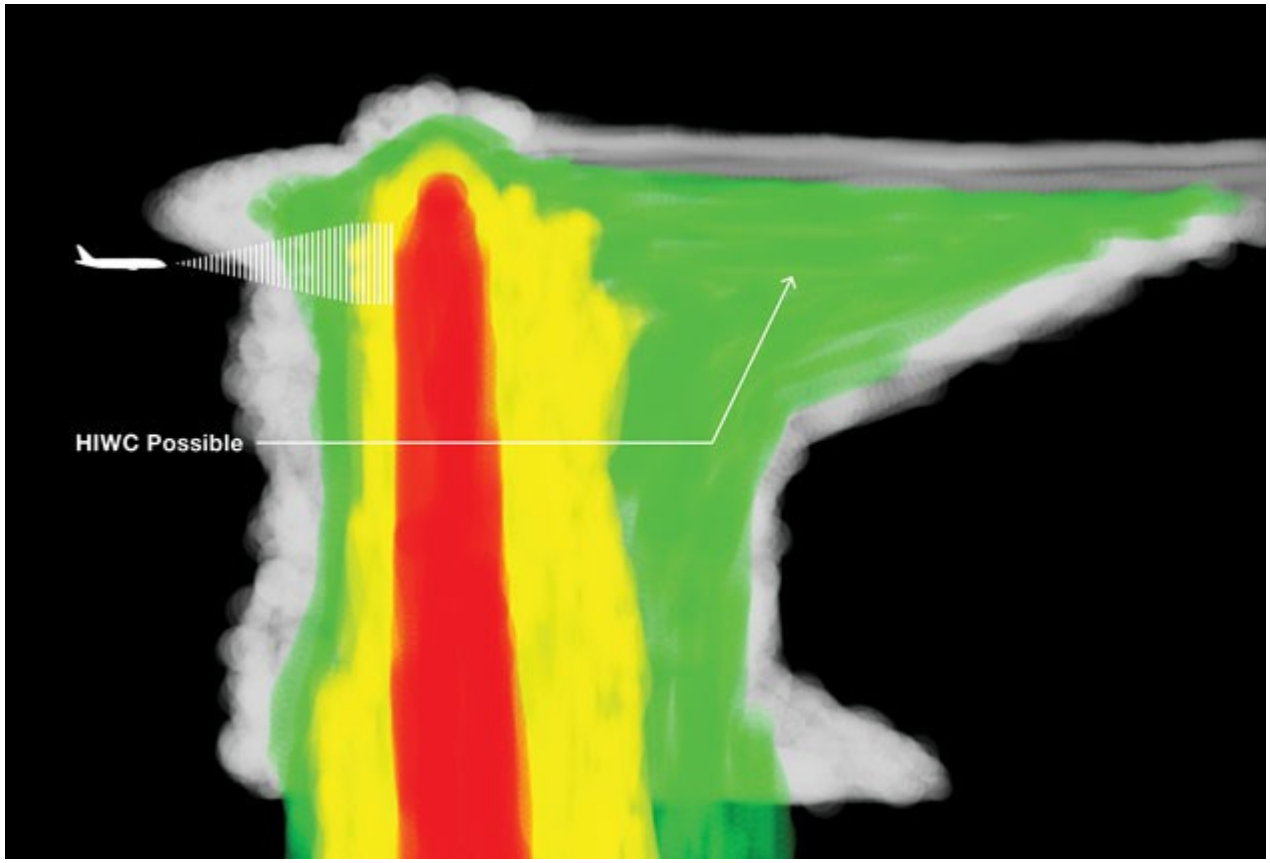
- Impact on probes
- Impact on engines

High IWC (Ice Water Content)

A series of fields experiment in tropical regions have been conducted separately or conjointly by HAIC and HIWC project.

High IWC (Ice Water Content) - Not only in Cb core

https://www.boeing.com/commercial/aeromagazine/articles/qtr_01_10/5/



Overview

1. The hazard

2. The tools for the diagnosis

3. Focus on RDT

4. Conclusion

Tools for diagnosis

The understanding of the phenomena, its detection and its forecast up to several time-horizon is a key issue for aviation. A recent paper reviews several methods to detect clouds associated with jet engine ice crystal Icing: Alpha, PHIWC, DARDAR, MSG-CPP High IWC Mask, RDT.

Haggerty, J., Defer, E., de Laat, A., Bedka, K., Moisselin, J.-M. Potts, R., Delanoë, J., Parol, F., Grandin, A., 2018, *Detecting Clouds Associated with Jet Engine Ice Crystal Icing*, BAMS-D-17-0252.1

Tools for diagnosis : Alpha

Australian Government

Bureau of Meteorology

Algorithm for the Prediction of HIWC Areas (ALPHA)

Ice Crystal Icing

- Over 150 ice crystal icing engine events near convective systems
- Flight in high mass concentrations of ice particles thought to be responsible
- Ice particles ingested into engine and melt, refreeze; ice chunks shed into engine core
- High ice water content (HIWC) regions may exist outside of the most vigorous convective region

Goals

- Develop a nowcasting system to identify hazardous areas using conventional meteorological data sources and fuzzy logic technology
- Use IWC measurements from research aircraft to train and validate the nowcasting system

Satellite

Find highest, coldest, thickest clouds from Total Water Path, Cloud Top Height and Cloud Top Temperature *– 2D field*

Satellite Interest

Model

Find deep cloud layer, heavy precipitation, high condensate, updrafts, temperature below -15°C *– 3D field*

Model Interest

3D Radar Mosaic

Find active updrafts, high reflectivity in column along with heights of 10 and 30 dBZ echo tops *– 2D field*

Radar Interest

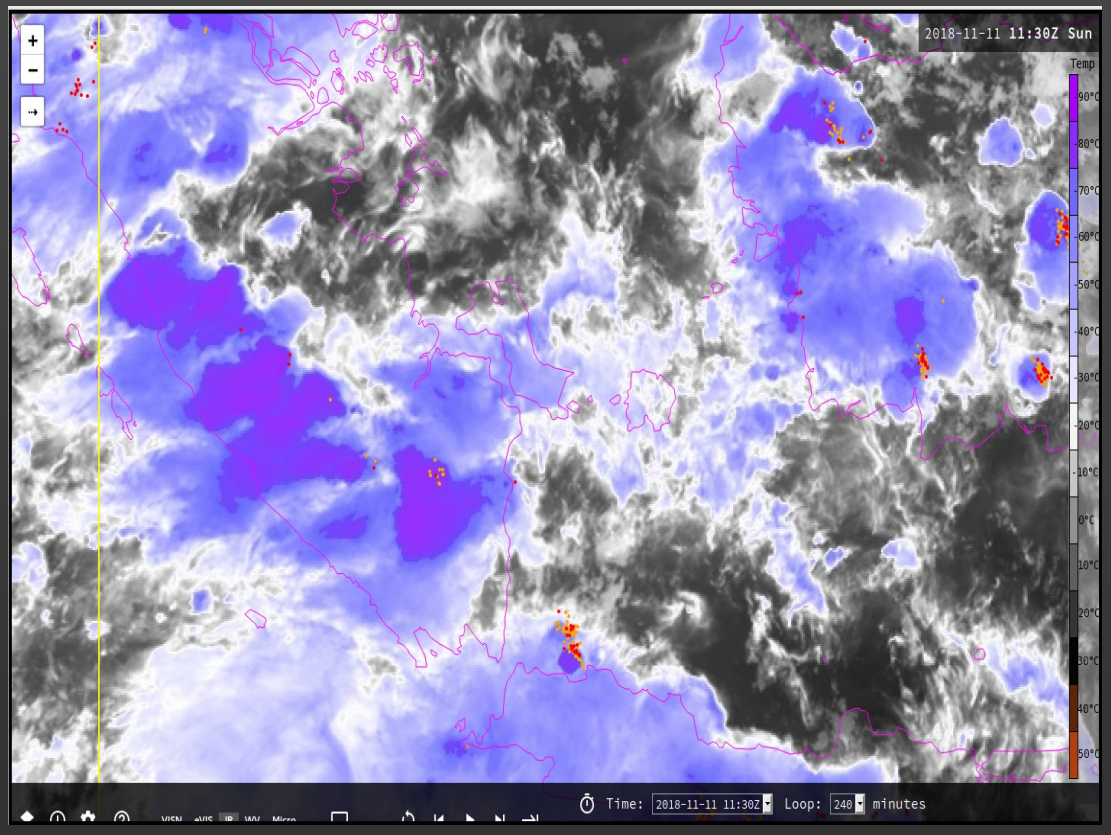
Total HIWC Interest

Weighted combination of Satellite, Model, and Radar Interest Fields estimates likelihood of high IWC conditions over a 3-dimensional gridspace

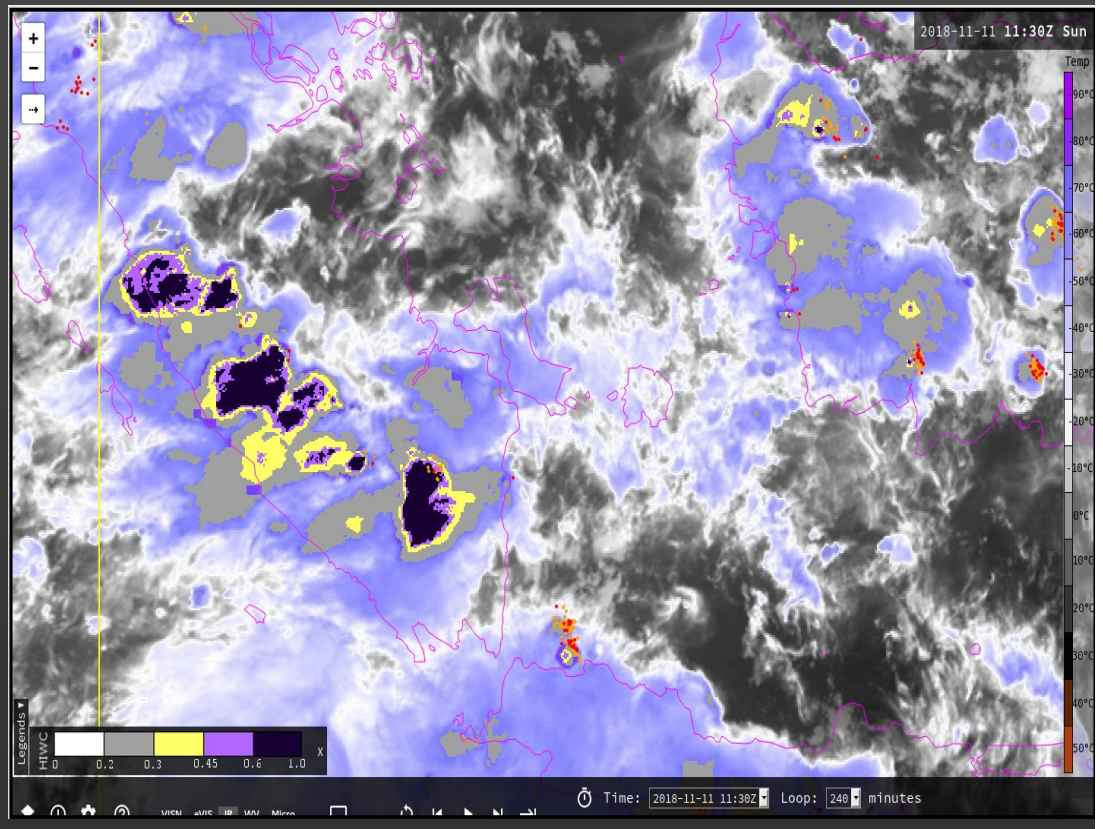
The HIWC Nowcasting Trial Exercise:

A collaborative effort with the Australian Bureau of Meteorology, National Center for Atmospheric Research, US Federal Aviation Administration, Qantas and Virgin Australia

HIWC guidance 1130Z, 11 Nov 2018
Himawari-8 infrared image



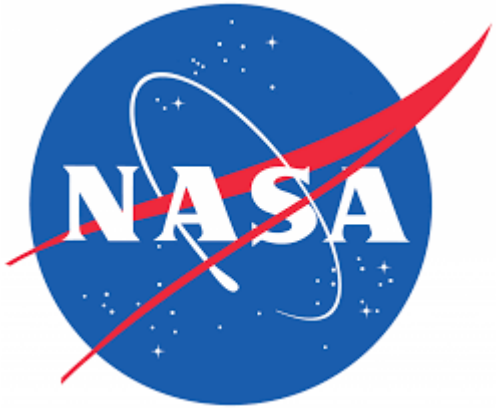
H08 infrared image + lightning



H08 infrared image + lightning + HIWC overlay

Tools for diagnosis : PHIWC

NASA Langley

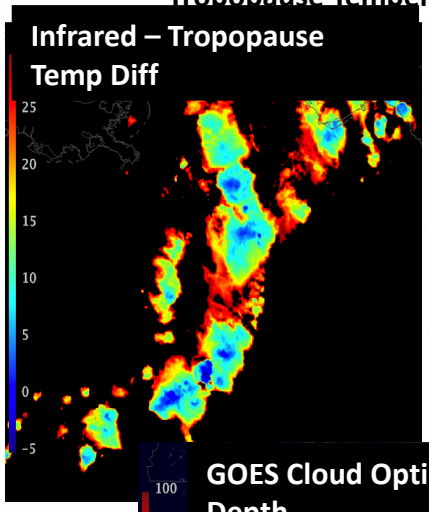


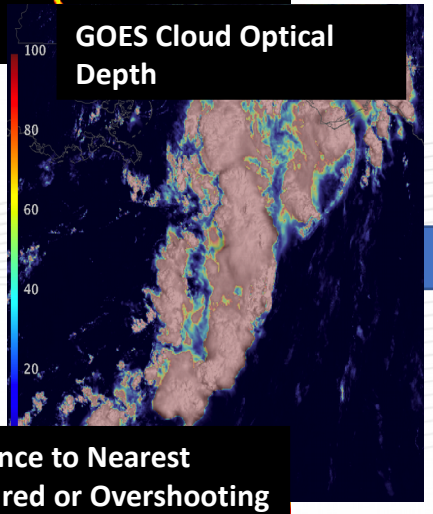
NASA Langley HIWC Probability Product Description

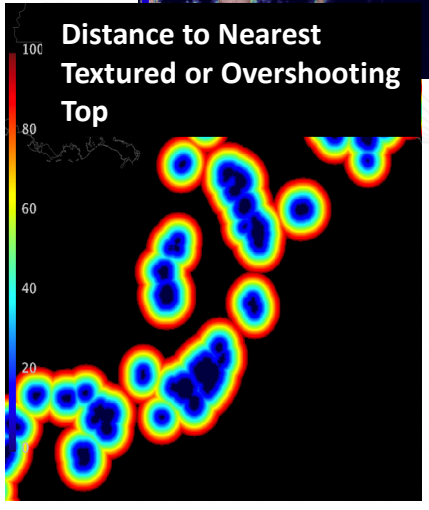
Kristopher Bedka, Science Directorate, NASA Langley Research Center

Input Satellite + NWP Data

Geostationary or LEO 0.5-1.0 km Visible Reflectance
2-4 km Infrared Brightness Temperature
Tropopause Temperature

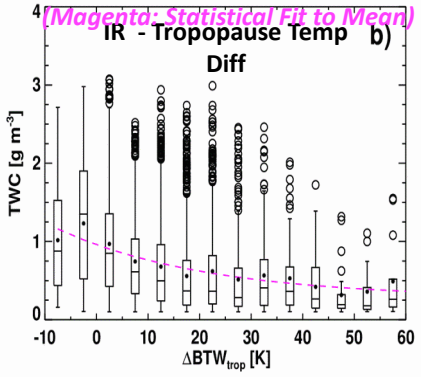


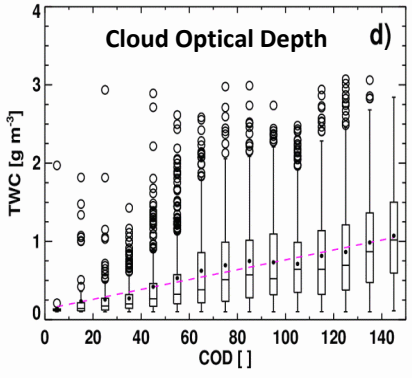


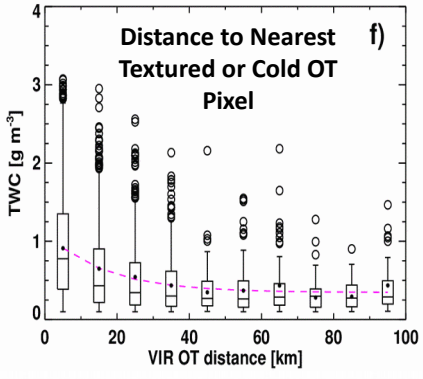


Statistical Relationships Between IKP-2 Ice Water Content and Satellite+NWP Fields

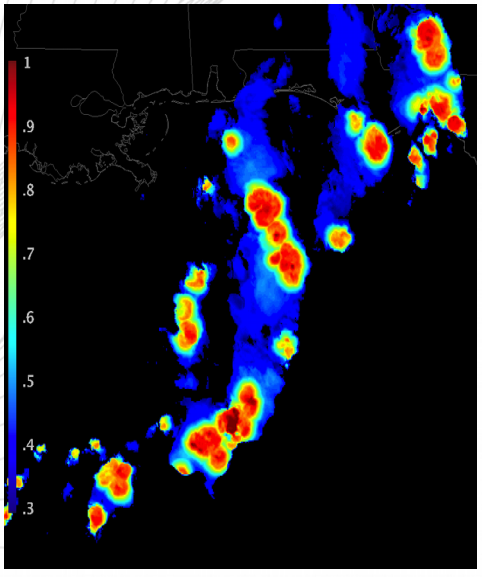
(Magenta: Statistical Fit to Mean)







HIWC Probability

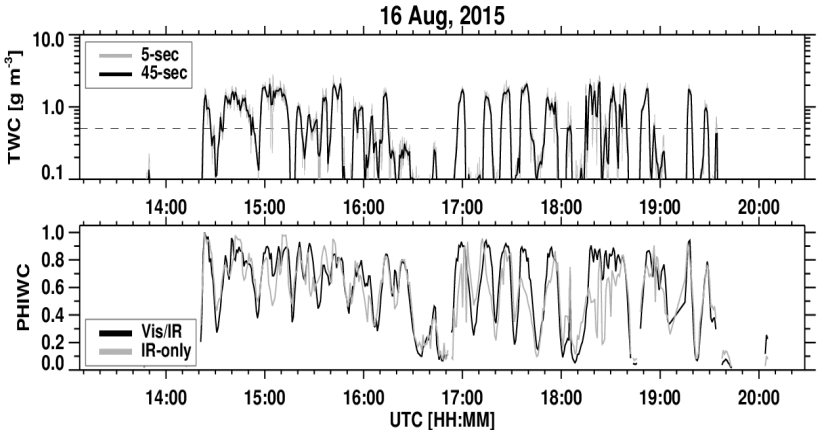


- **5371 matches between 45-sec (~8 km) in-situ total water content (TWC) and cloudy satellite pixels across 50 flights out of Darwin (Australia), Cayenne (French Guyana) and Ft. Lauderdale (U.S.)**
- **Flight within or beneath optically thick, cold anvils within 40 km of overshooting tops (OTs) were most likely to encounter HIWC (> 1 g m^{-3}). Little to no unique information for HIWC discrimination provided by other satellite- or NWP-based parameters**
- **These results suggest that commerical aircraft encountering engine / air probe anomalies are avoiding updrafts based on onboard radar, but flying within anvil close enough to updrafts to experience HIWC**
- **Yost, C. R., Bedka, K. M., Minnis, P., Nguyen, L., Strapp, J. W., Palikonda, R., Khlopenkov, K., Spangenberg, D., Smith Jr., W. L., Protat, A., and Delanoe, J., 2018: A prototype method for diagnosing high ice water content probability using satellite imager data, Atmos. Meas. Tech., 11, 1615-1637, https://doi.org/10.5194/amt-11-1615-2018**

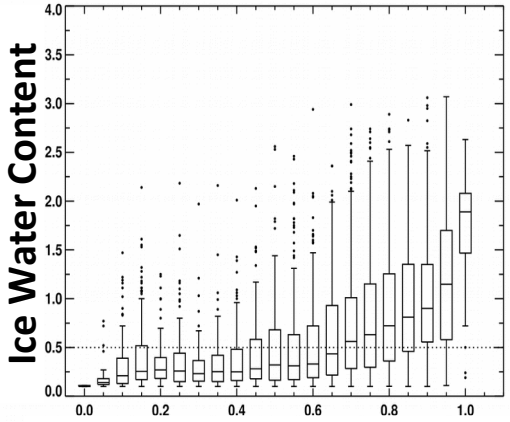
NASA LaRC HIWC Probability Validation and Future Work

backup slide

1-Minute GOES Super Rapid Scan HIWC Probability



- HIWC Probability (PHIWC) is quite well correlated with ice water content trends when applied to very high temporal resolution imagery



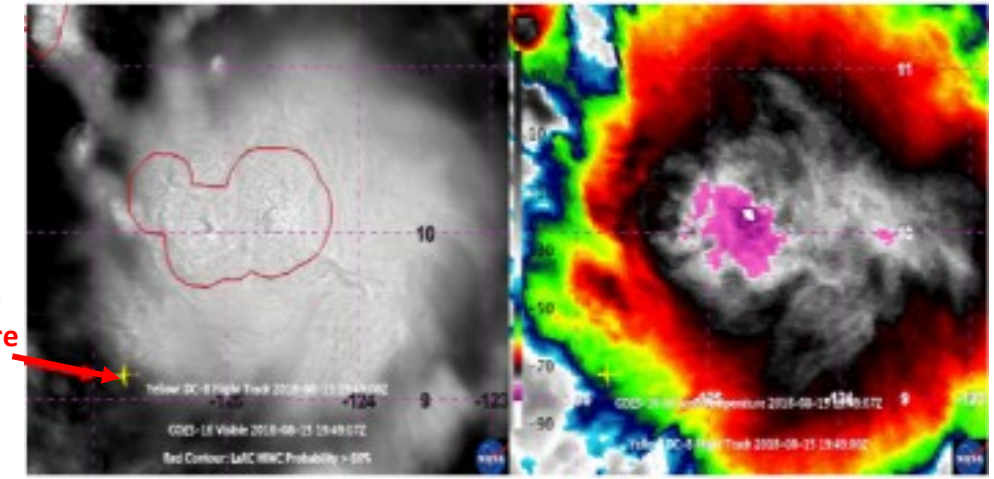
HIWC Probability vs Ice Water Content Across 50 Research Flights

- A steady increase in observed ice water content as a function of PHIWC
- HIWC research community has yet to agree upon validation methods, so stats cannot be compared between products. Some teams include correct negatives in clear sky conditions as "hits" which artificially reduces their false alarm rate. LaRC only includes cloudy pixels in their analysis, PHIWC POD 65-75%, FAR 20-30%

Summary and Future Work

August 15, 2018 NASA DC-8 HIWC Radar 2 Flight: Tropical Storm Lane

Yellow: NASA DC-8 Location, Red Contour, Left Panel: LaRC HIWC Probability > 60%



Pitot Tube De-Icing Procedure Due To Long Exposure To HIWC Conditions

- The LaRC PHIWC product is the one of the first of its kind in the aviation weather community
- Real-time LaRC GOES PHIWC was used extensively to guide the NASA DC-8 during the HIWC-Radar 2 flight campaign in August 2018. Upcoming research will analyze HIWC Radar 2 datasets for 7 flights and explore additional GOES-16/17 HIWC predictors
- LaRC overshooting top, HIWC and winter-time supercooled water airframe icing products are being evaluated by NOAA aviation weather forecasters at three Central Weather Service Units (CWSUs)
- Collaborations and Product Evaluations Welcomed!!!

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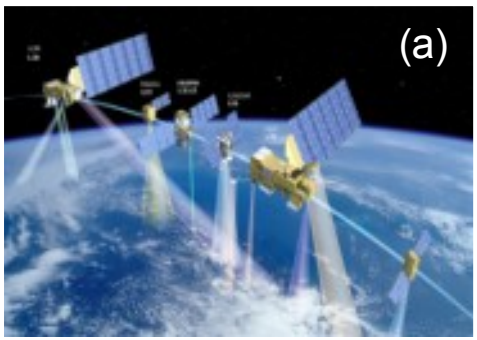
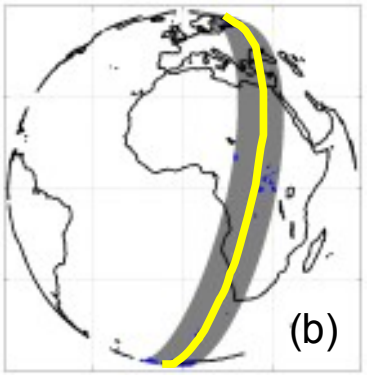
Tools for diagnosis: DARDAR

The aim of the **DARDAR** (raDAR/liDAR) project is to retrieve cloud properties by combining the LEO **CloudSat radar** and the LEO **CALIPSO lidar** measurements. This project originates from the collaboration between the LATMOS (Laboratoire Atmosphères, Milieux, Observations Spatiales) and the Cloud Group of the Department of Meteorology, University of READING.





Tools for diagnosis: MSG-CPP High IWC Mask

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Tools for diagnosis: MSG-CPP High IWC Mask

Goal: to detect atmospheric scenes with **IWC > 1.0 g/m^3** (≡ High IWC)

High IWC threshold may be exceeded anywhere in the cloud (vertical)

DARDAR-based MSG-CPP High IWC mask

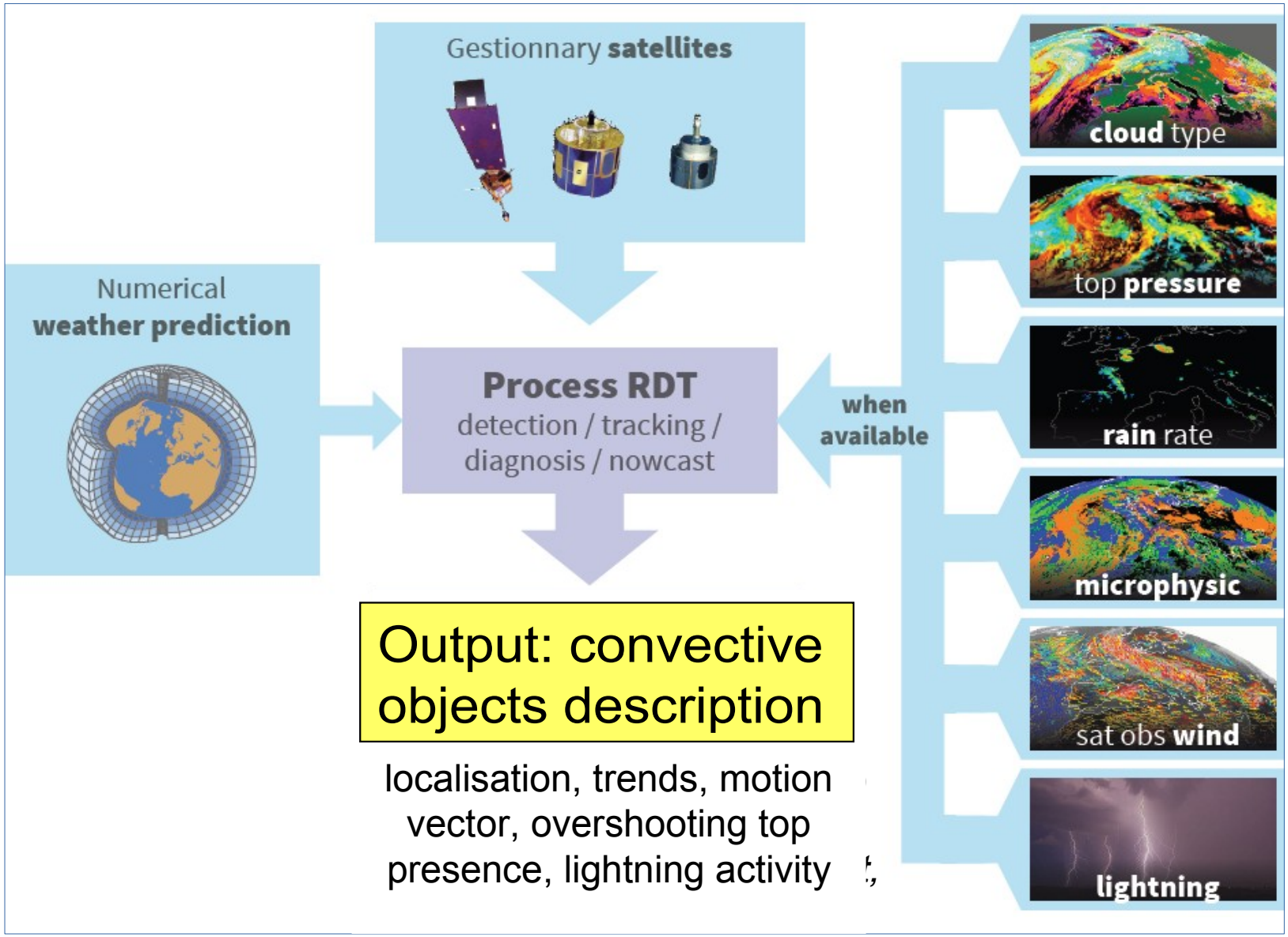
1. The cloud phase	ice
2. Condensed water path	> 100 g/m^2
3. Cloud top temperature	< 270 K
4. Cloud optical thickness	> 20

Mask identifies satellite cloud scenes most likely to contain HIWC

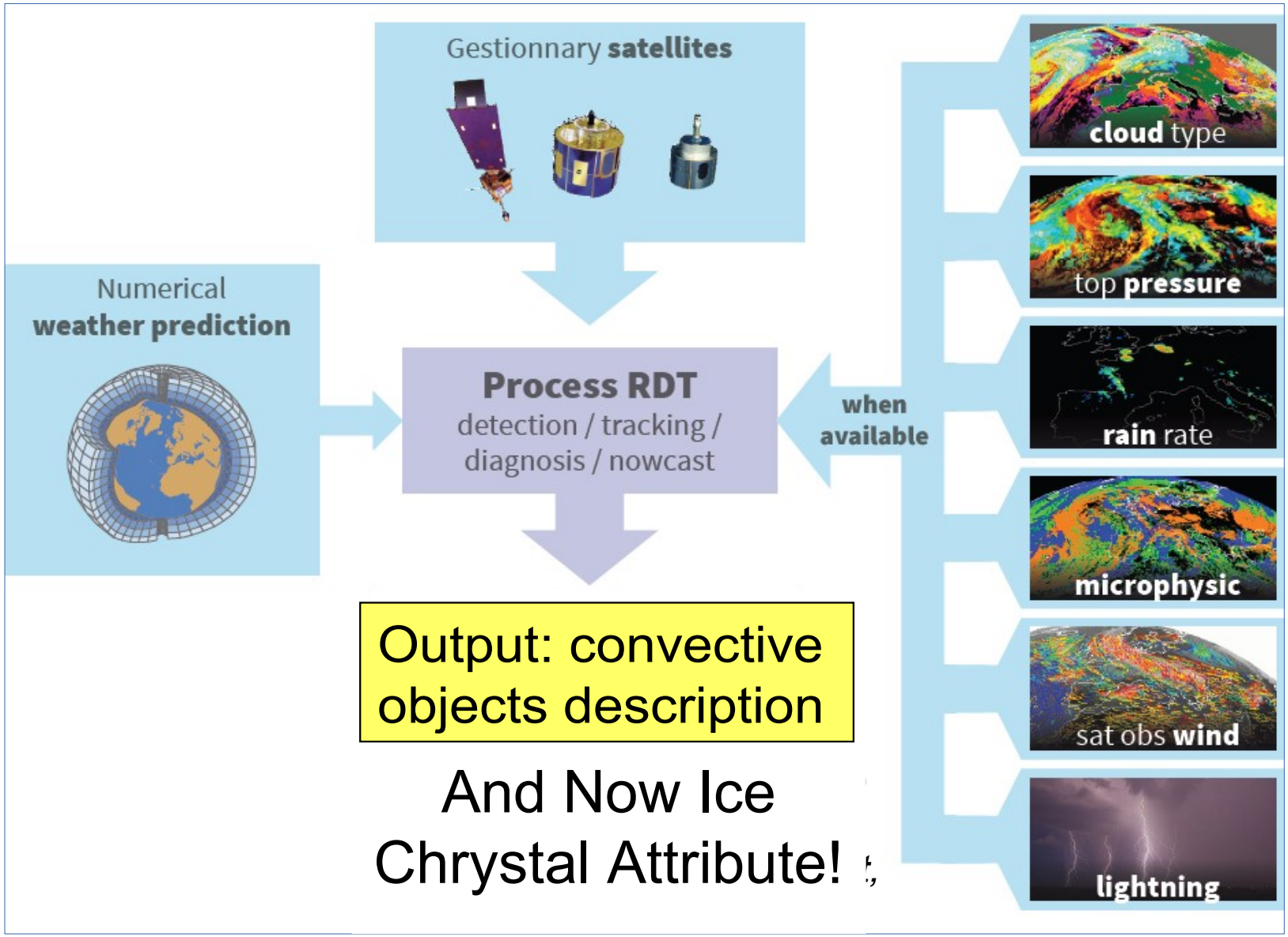
Paper: de Laat et al. [2017; doi:10.5194/amt-10-1359-2017]

Tools for diagnosis: RDT (Rapidly Developing Thunderstorm)

Tools for diagnosis: RDT (Rapidly Developing Thunderstorm)



Tools for diagnosis: RDT (Rapidly Developing Thunderstorm)

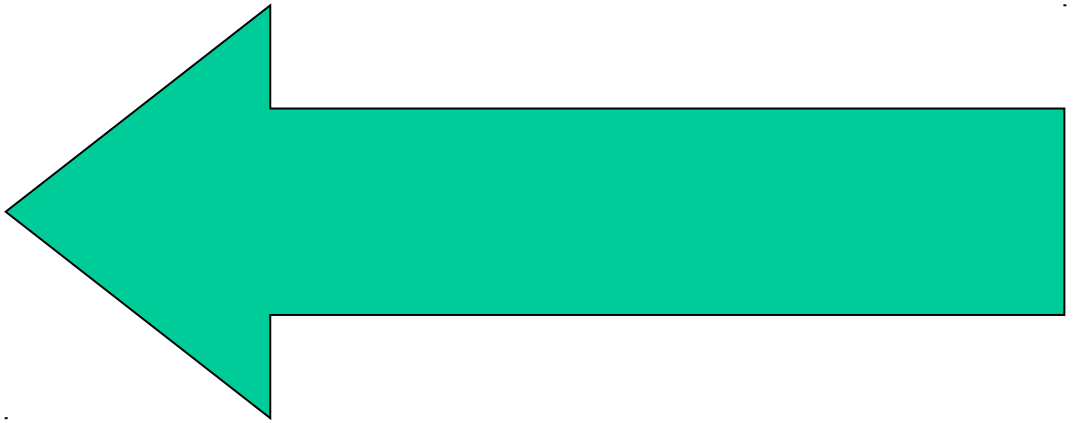


Overview

1. The hazard

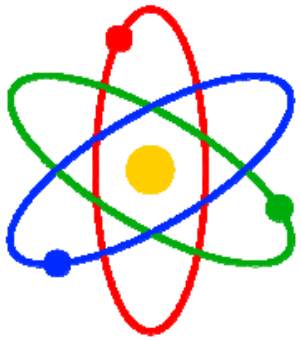
2. The tools for the diagnosis

3. Focus on RDT



4. Conclusion

RDT is a story...



...of SCIENCE

convection features (overshooting tops, convection Yes/No diagnosis, new channels, Lighning Jump, HAIC project)

...of SOFTWARE

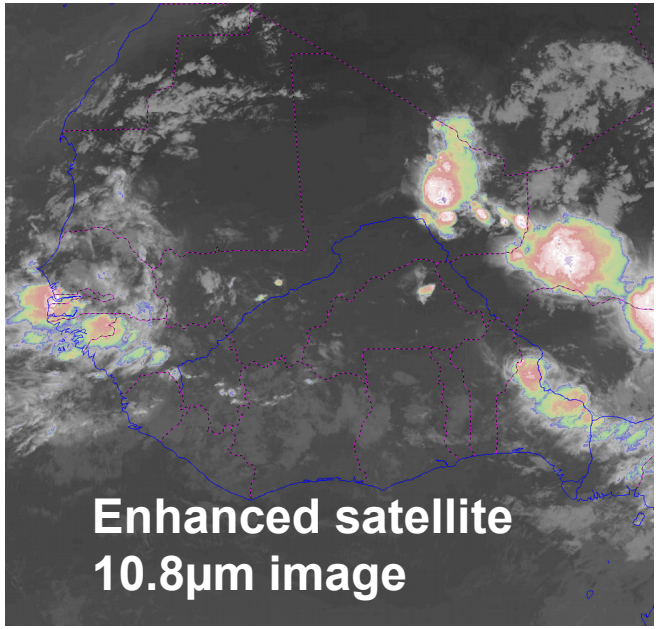
*in the framework of **NWCSAF** see **nwcsaf.org***

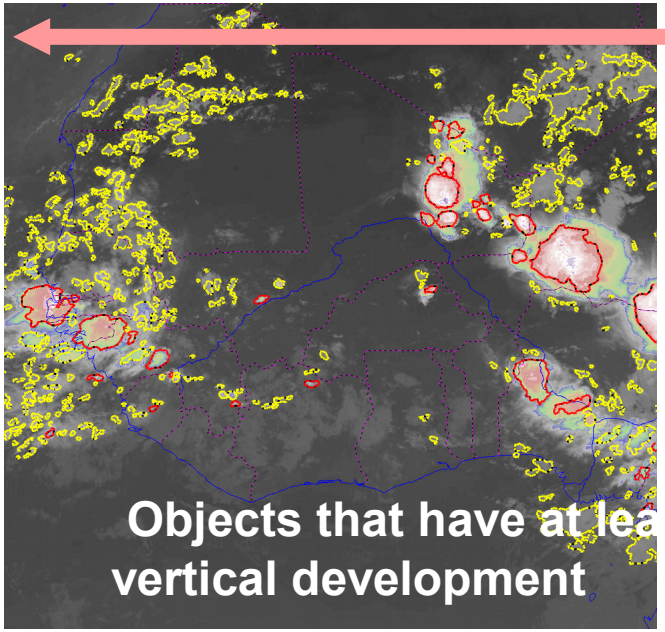
...of OPERATION

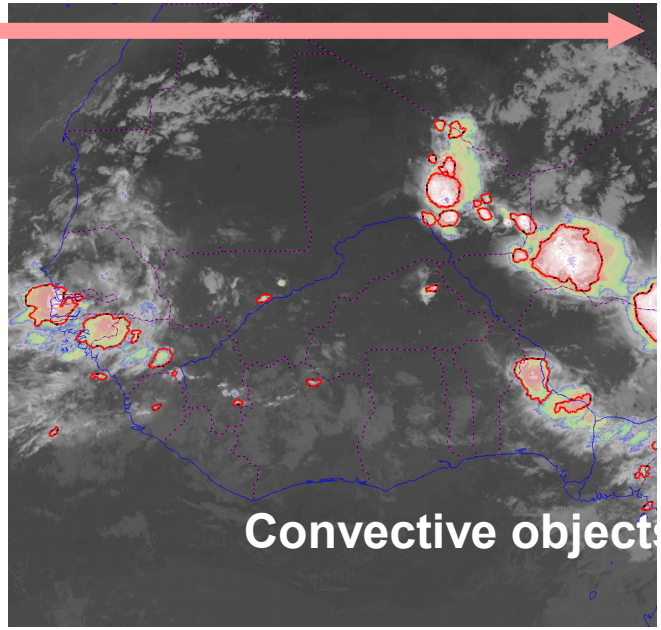
For example by Météo-France for forecasters or aviation end-users

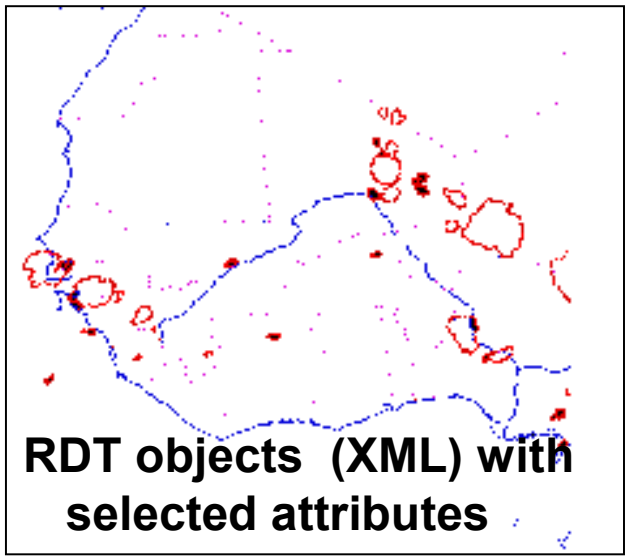
RDT: uplinked to aircraft in Research Campaigns

RDT process









UPLINK

RDT successfully operated during all HAIC or HAIC/HIWC flight campaigns

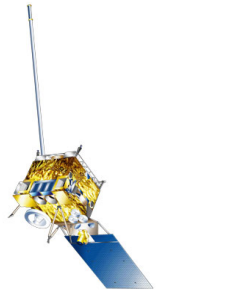
Darwin 2014

-New MTSAT RDT production

- RDT for ground operation
- RDT for post-campaign analysis

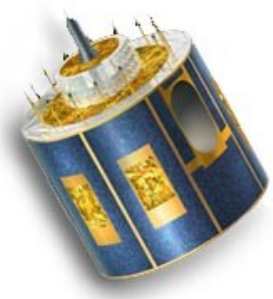
Cayenne 2015

- New MSG RDT production, existing produc GOES
- RDT for ground operation (MSG+GOES)
- RDT uplinked
- RDT for post-campaign analysis
- MET support from MF Cayenne Centre
- MF Support for satellite image dissemination



Darwin/La Réunion 2016

- New Himawari-8 RDT production, existing production for Meteosat 7 and MSG.
- RDT for ground operation
- RDT uplinked
- RDT for post-campaign analysis
- MET support from MF La Réunion Centre
- MF Support for satellite image dissemination,
special direct dissemination of Himawari-8 10.4µm channel

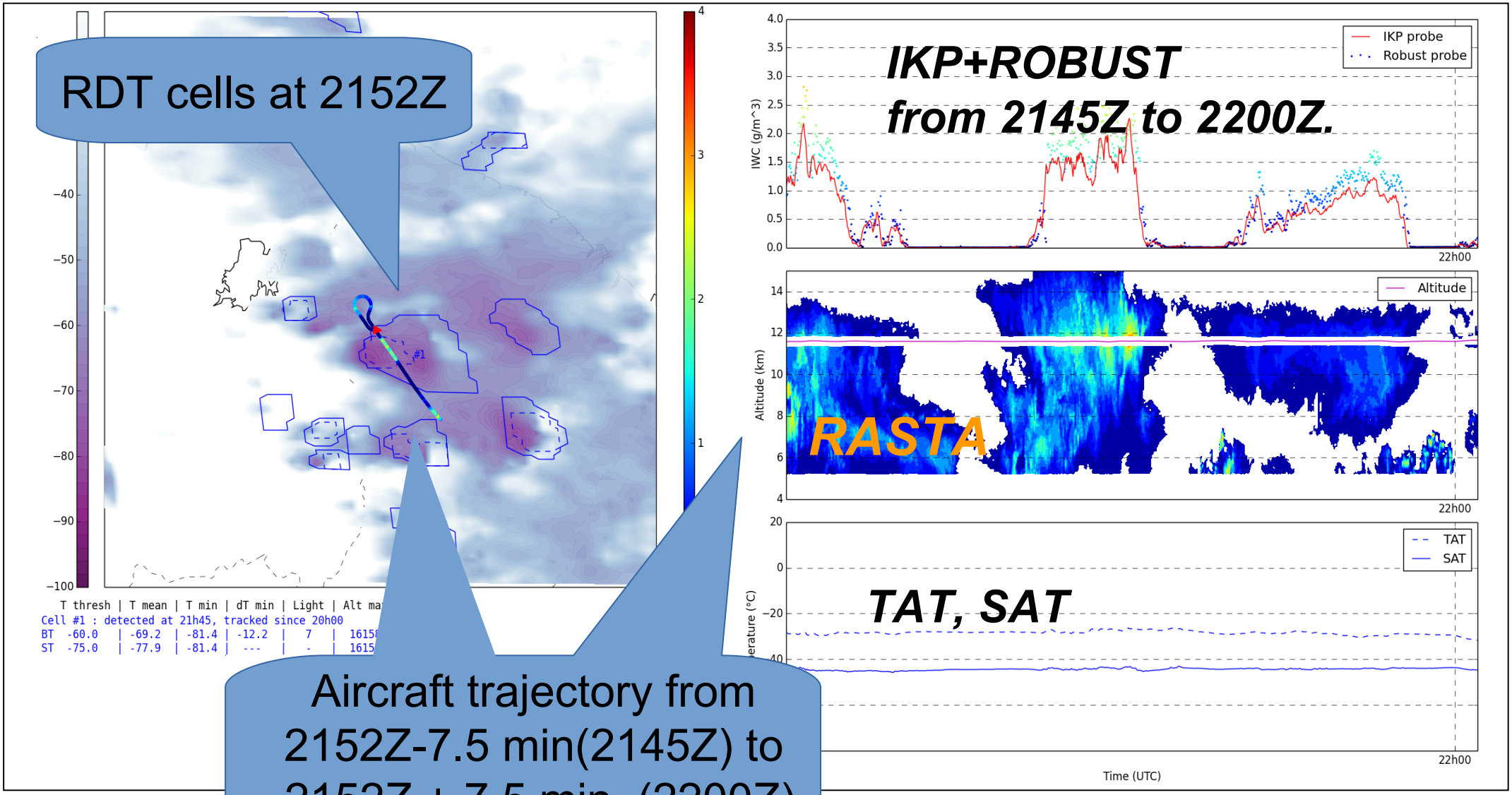


References for verification

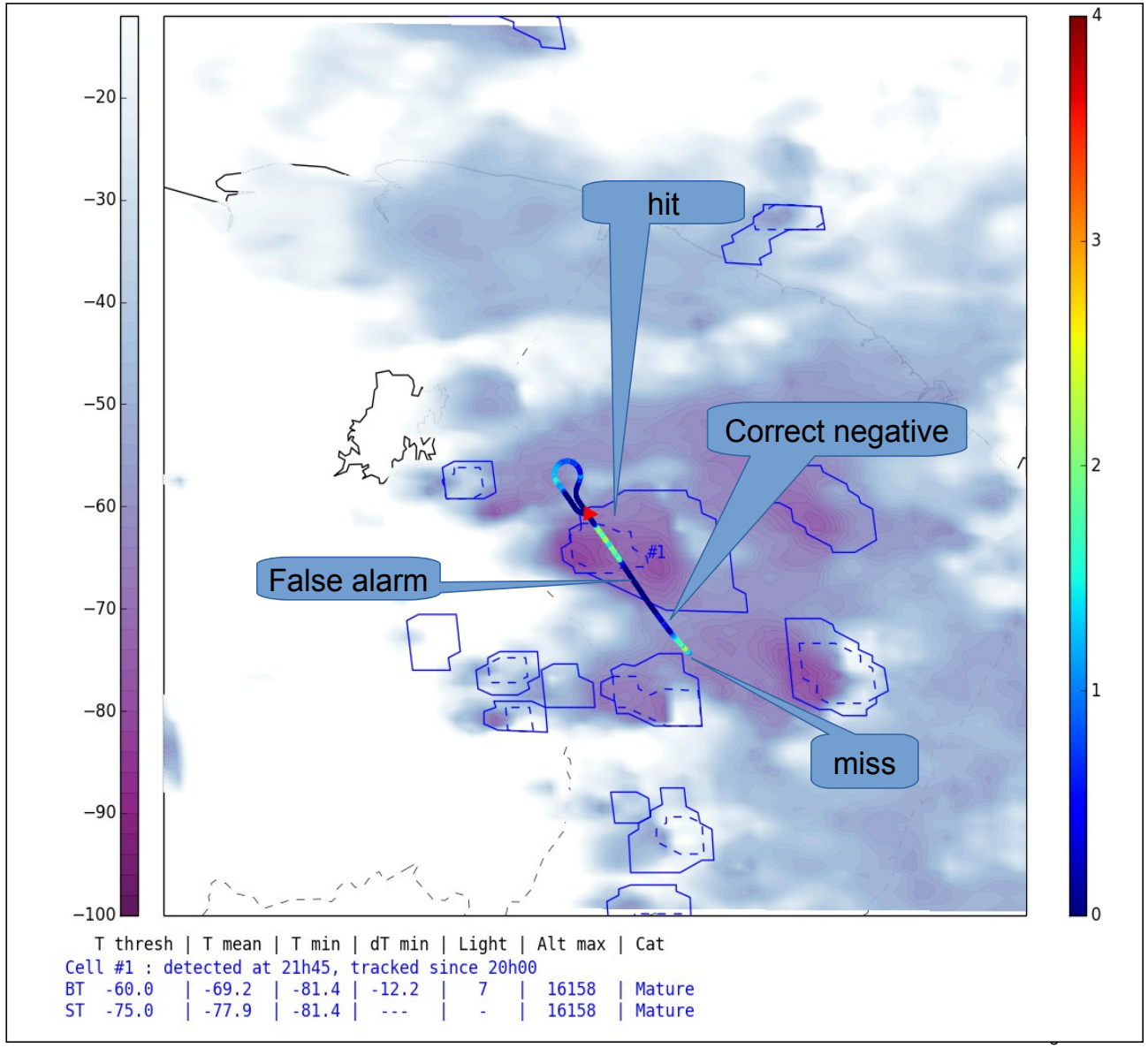
- **Airplane parameters** : SAT (Static Air Temperature), TAT (Airplane Temperature) for Darwin 2014, Cayenne 2015, Darwin-La Réunion 2016
- **Robust probe** data (TWC) provided by LAMP (Darwin 2014, Cayenne 2015, Darwin 2016, La Réunion 2016)
- **IKP** (Isokinetic probe) data (TWC) provided by NCAR (Darwin 2014, Cayenne 2015)
- **RASTA** (TWC profile, upward air velocity) provided by LAMP (Darwin 2014, Cayenne 2015)

- **DARDAR** product. Combination of coincident radar (95 GHz) and lidar (532 & 1064 nm) space-borne A-Train observations sensitive to different properties of the clouds (phase, particle size distribution). Capability to retrieve the vertical distribution of IWC

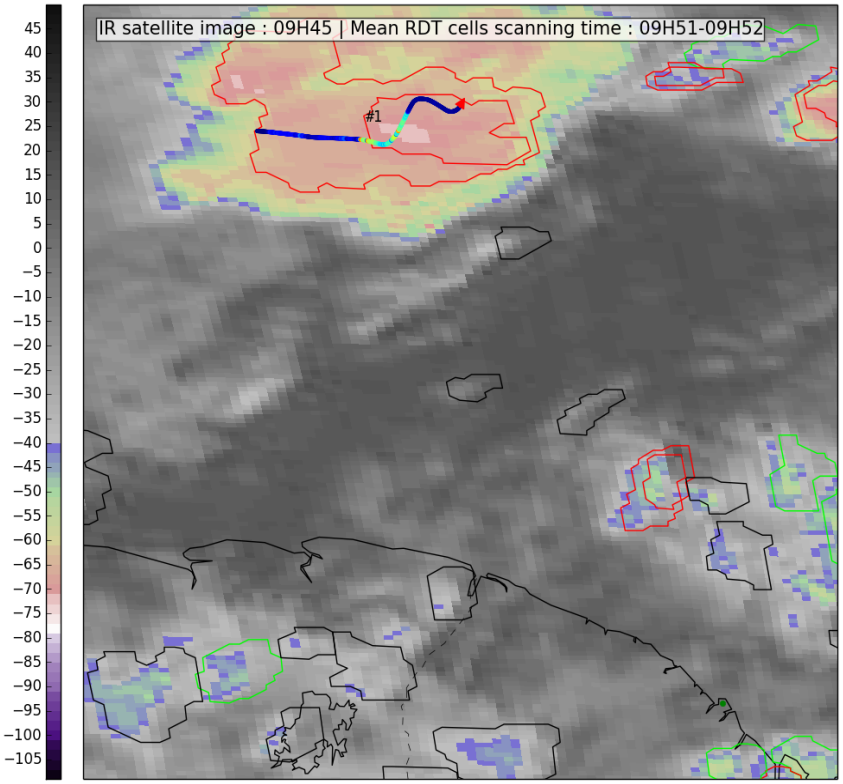
Cayenne 2015 Campaign methodology example



Cayenne 2015 Campaign methodology example



Subjective evaluation of Flight#24 of Cayenne Campaign

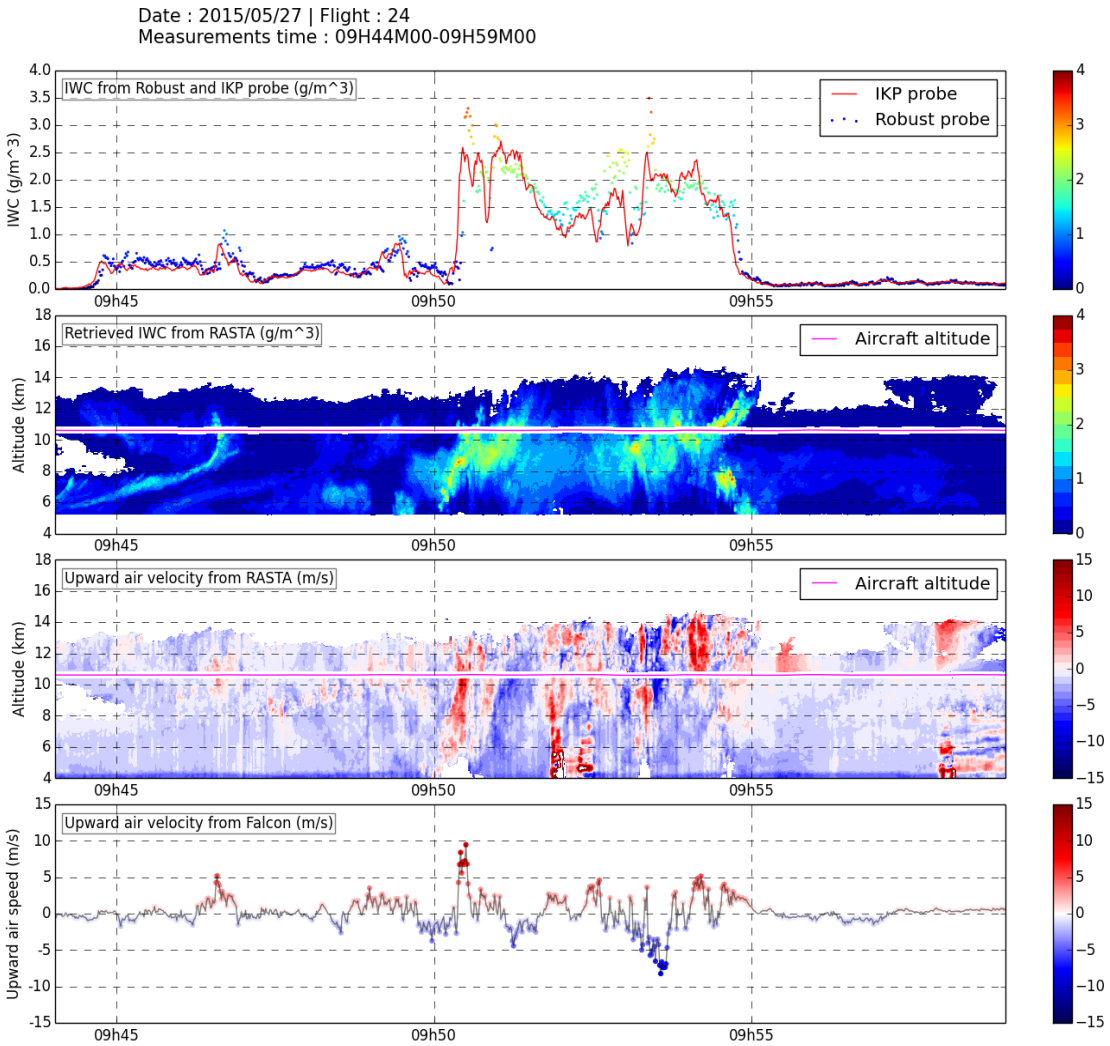


	T thresh	T mean	T min	dT min	Light	Alt max	Cat
Cell #1 : detected at 09h52, tracked since 04h45							
BT	-64.0	-67.2	-74.0	2.2	0	14786	Mature
ST	-68.0	-69.7	-74.0	---	-	14786	Mature

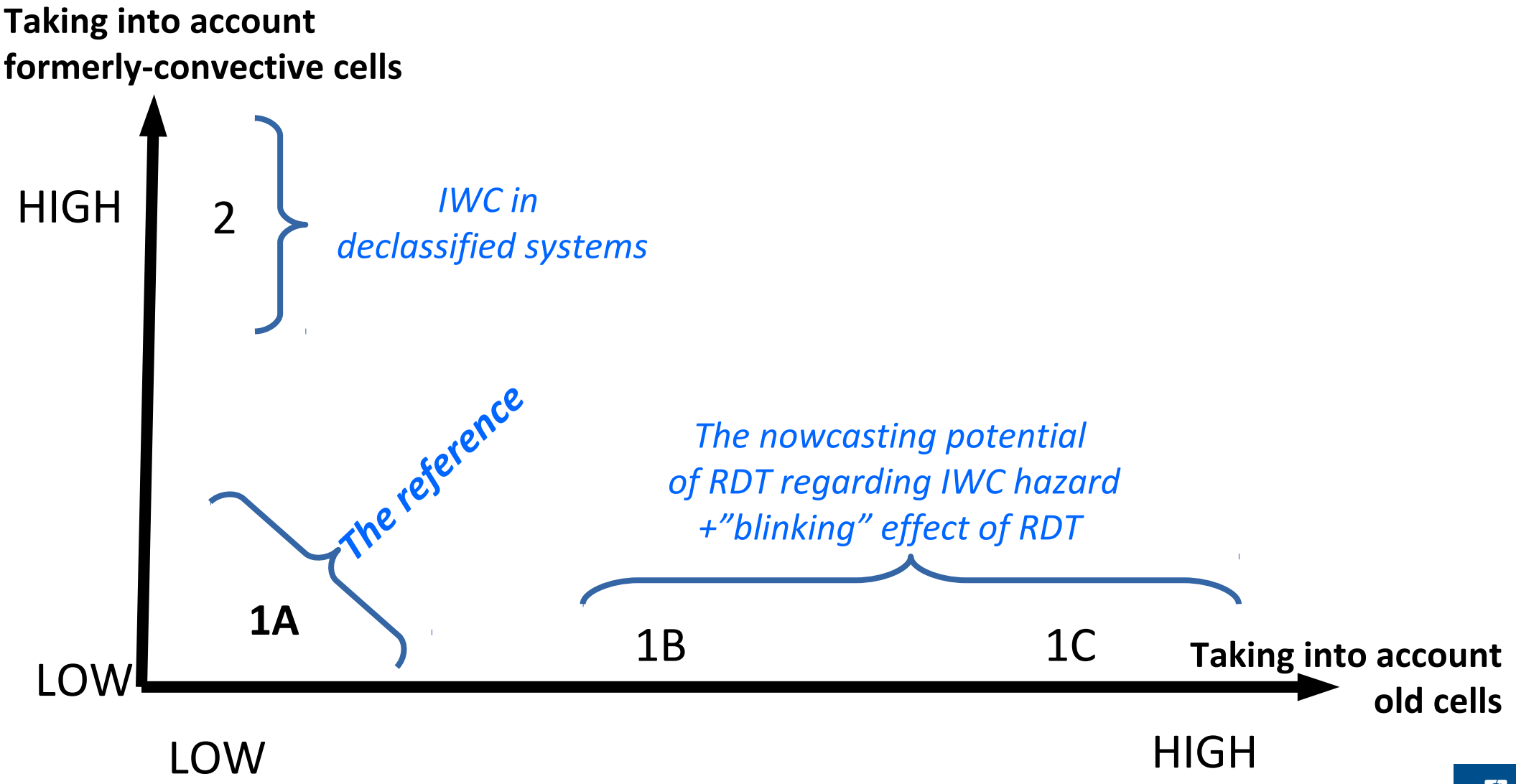
Flight 24

Good agreement

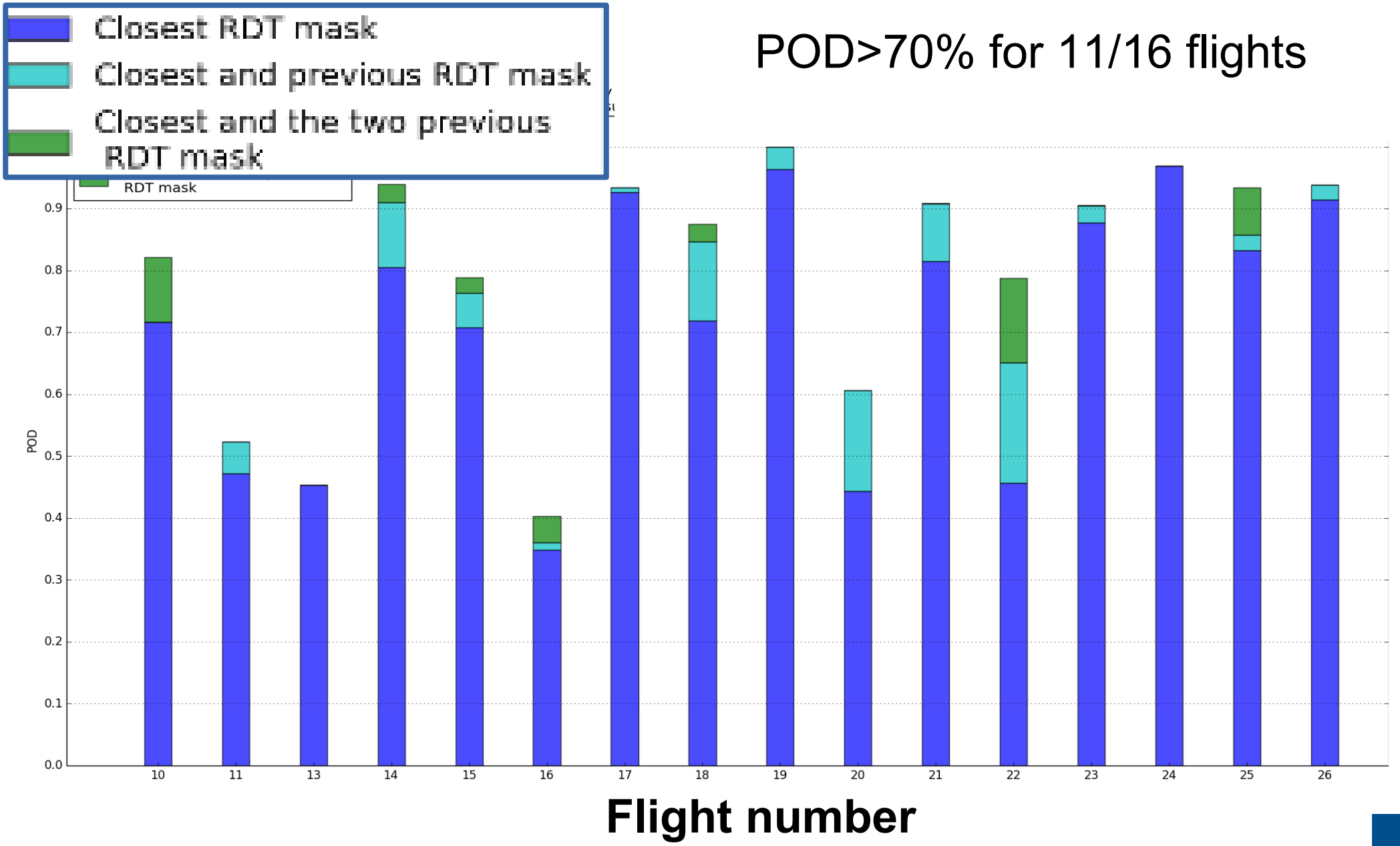
Interest of 2nd level



Four methodologies for pairing

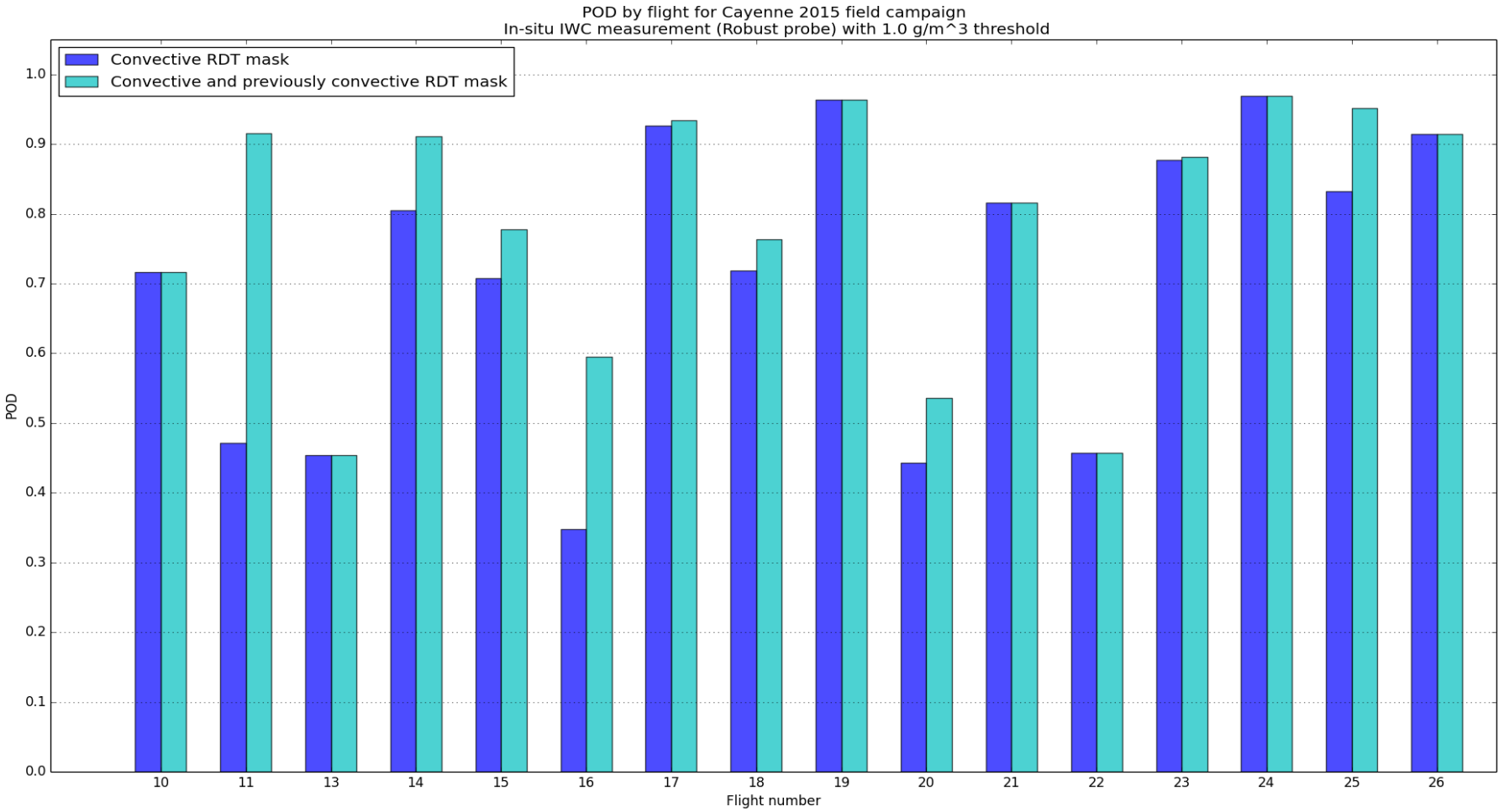


Cayenne 2015 Campaign results - 1A 1B 1C



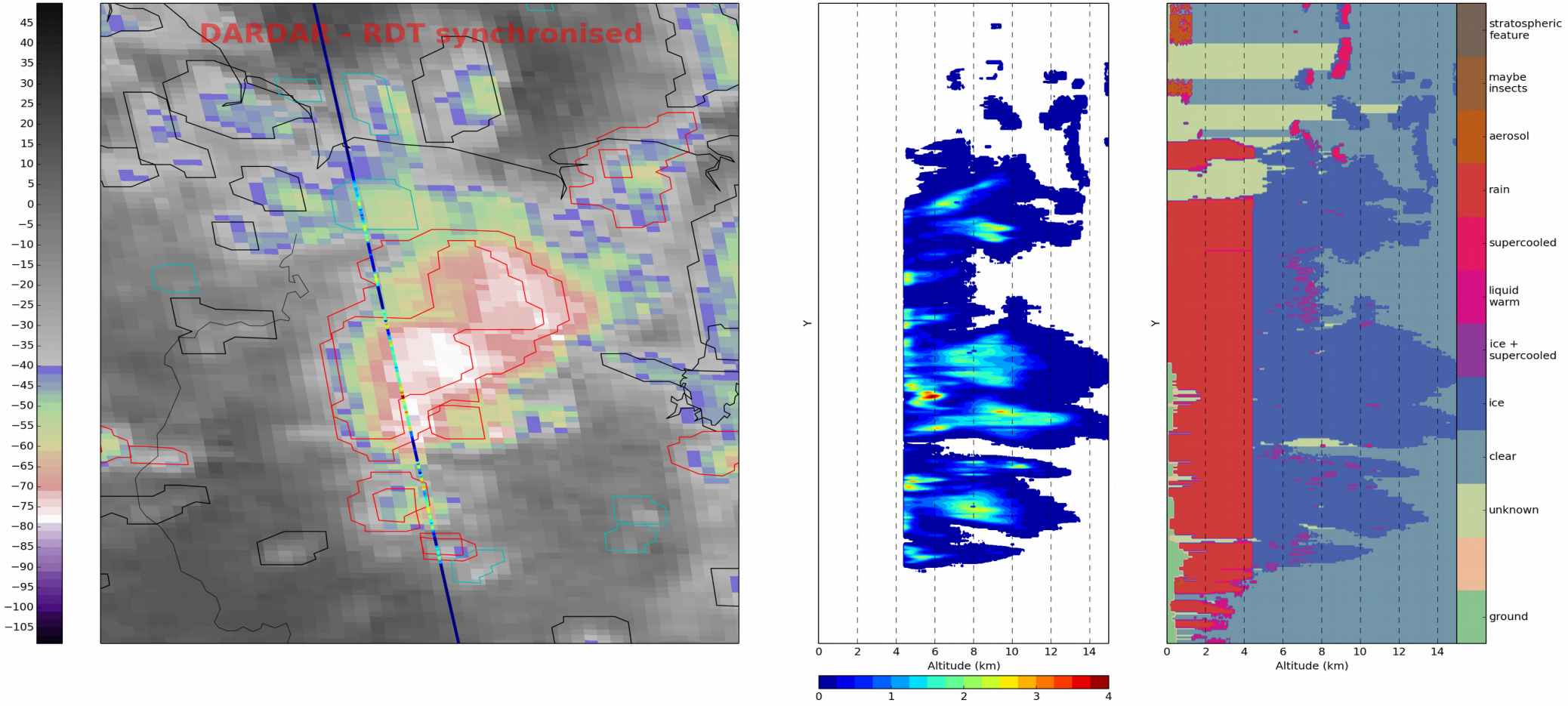
POD>70% for 11/16 flights

POD of Cayenne Campaign methods 1A and 2



Subjective verification with DARDAR

20150530



Sum-up of objective verification

	POD	*FAR*	nb of flights
Darwin2014	**0.84**	**0.69**	16
Cayenne 2015	**0.71**	**0.72**	16
Darwin 2016	**0.51**	**0.68**	2
La Réunion2016	**0.73**	**0.32**	3
DADAR2015 - First tests	**0.38**	**0.91**	21 paths

RDT in HAIC sum-up

- RDT successfully operated in all HAIC campaigns, with various generation of satellites: localisation of convective activity for Flight guidance + Uplink to Research Flights

- RDT as a tool for detection of large IWC areas. Reducing No detection cases. TRL5 level reached in HAIC (after TRL3 Level)

- Ways of improvement identified: mature systems handling + to follow cells or ensemble of cell at a defined temperature level

Some RDT improvement connected to HAIC works

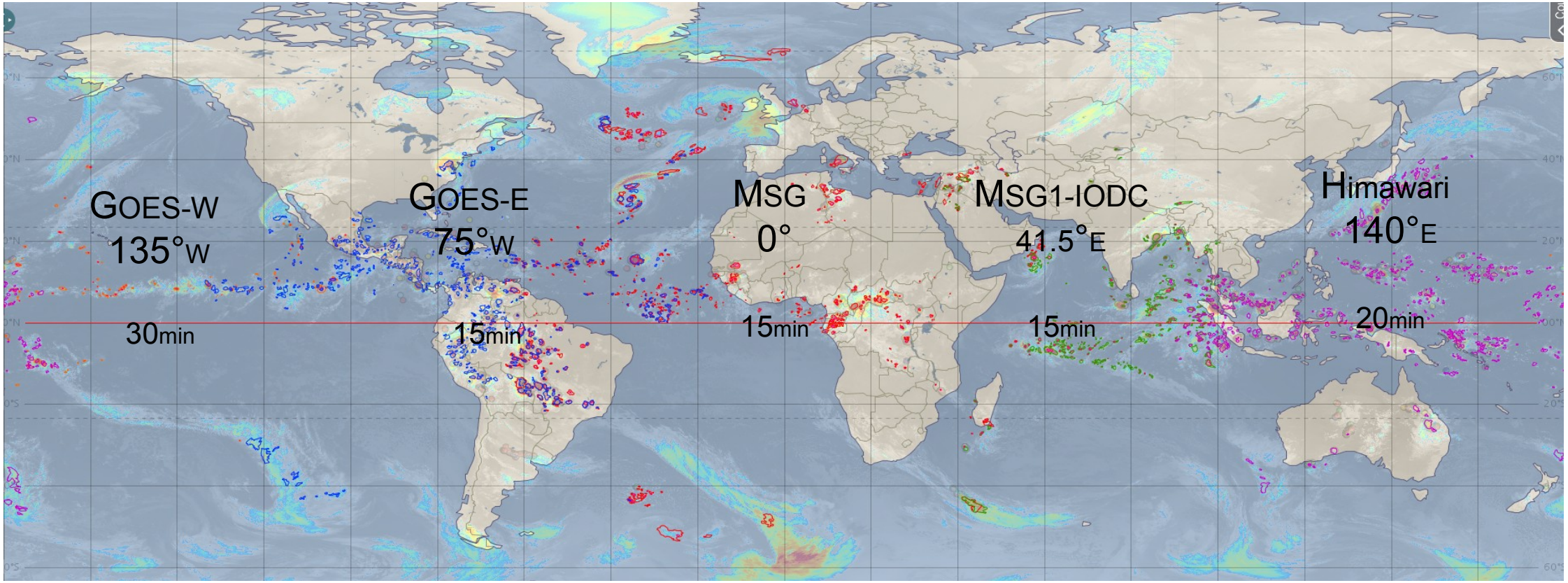
v2016 NWCSAF delivery: a new attribute concerning IWC hazard estimate (Day only): **KNMI algorithm developed in the framework of HAIC with Météo-France NWCSAF microphysics input**

v2018 NWCSAF: high IWC attribute inside a RDT cell improved (still following **KNMI** algorithm)

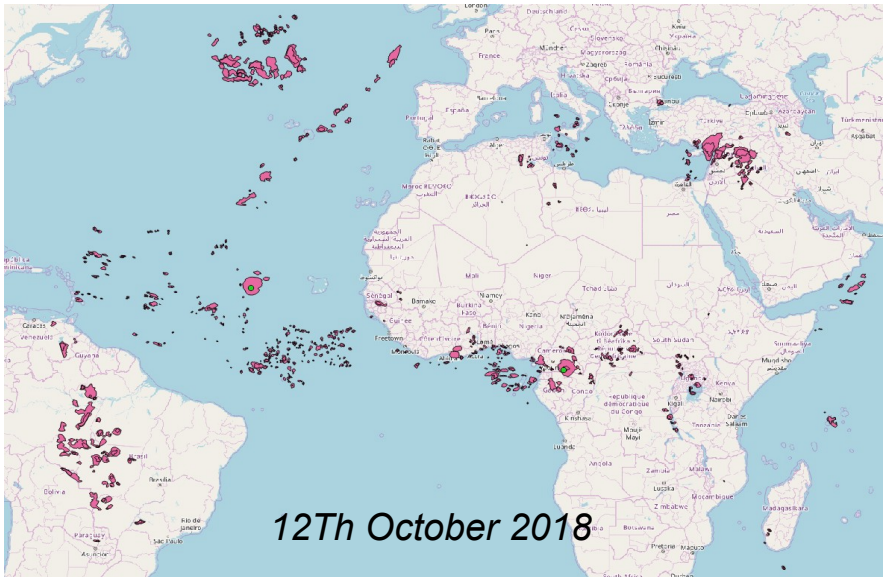
v2018: RDT blinking effect mitigated, new rules for declassification of mature systems

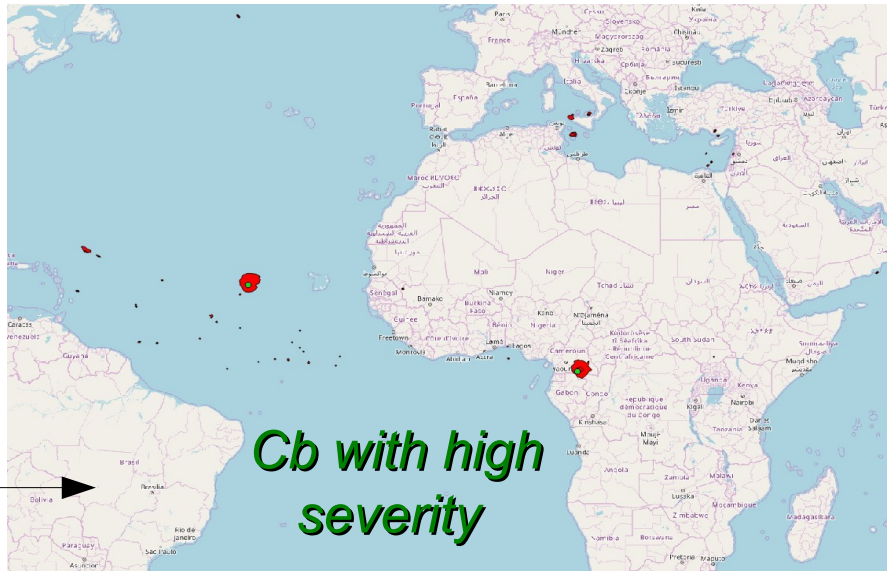
RDT operated with new satellites in HAIC and now RDT is GLOBAL!

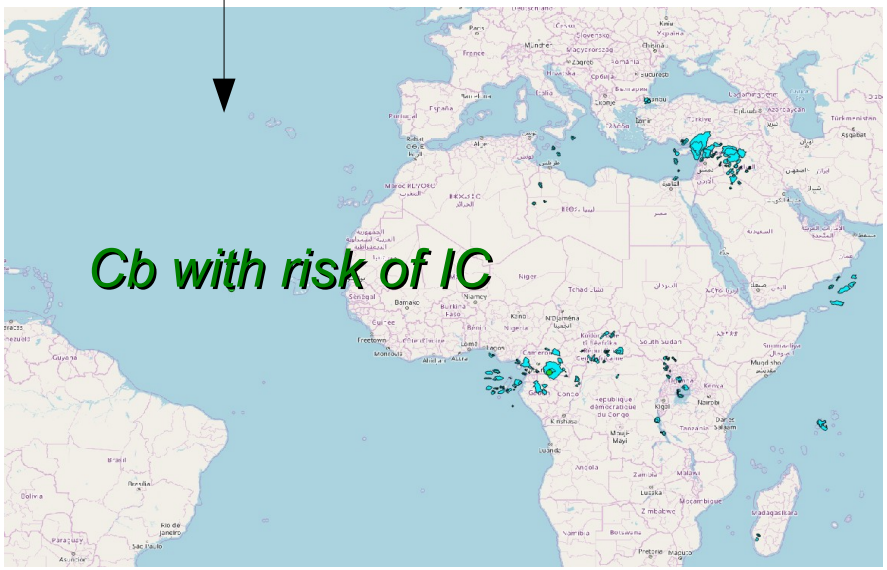
Global RDT by Météo-France – *where we are*



RDT parameters – *Severity , Ice Crystals risk*



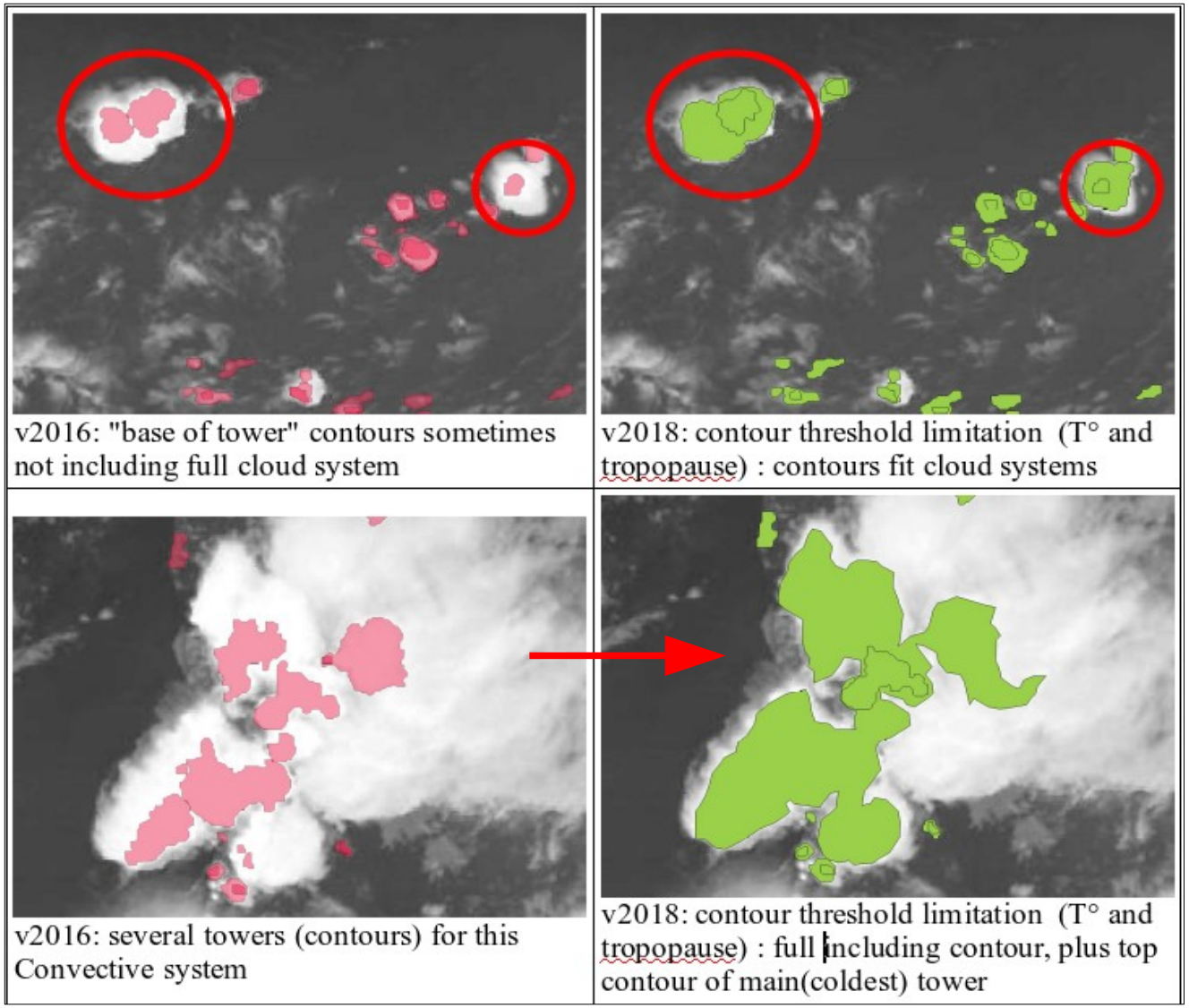




IWC attribute goal:
reduction of false alarms !

METEO FRANCE

RDT v2018 - a mitigation of blinking effect
Detection with less broke up systems



v2016: "base of tower" contours sometimes not including full cloud system

v2018: contour threshold limitation (T° and tropopause) : contours fit cloud systems

v2016: several towers (contours) for this Convective system

v2018: contour threshold limitation (T° and tropopause) : full including contour, plus top contour of main(coldest) tower

BT contours :

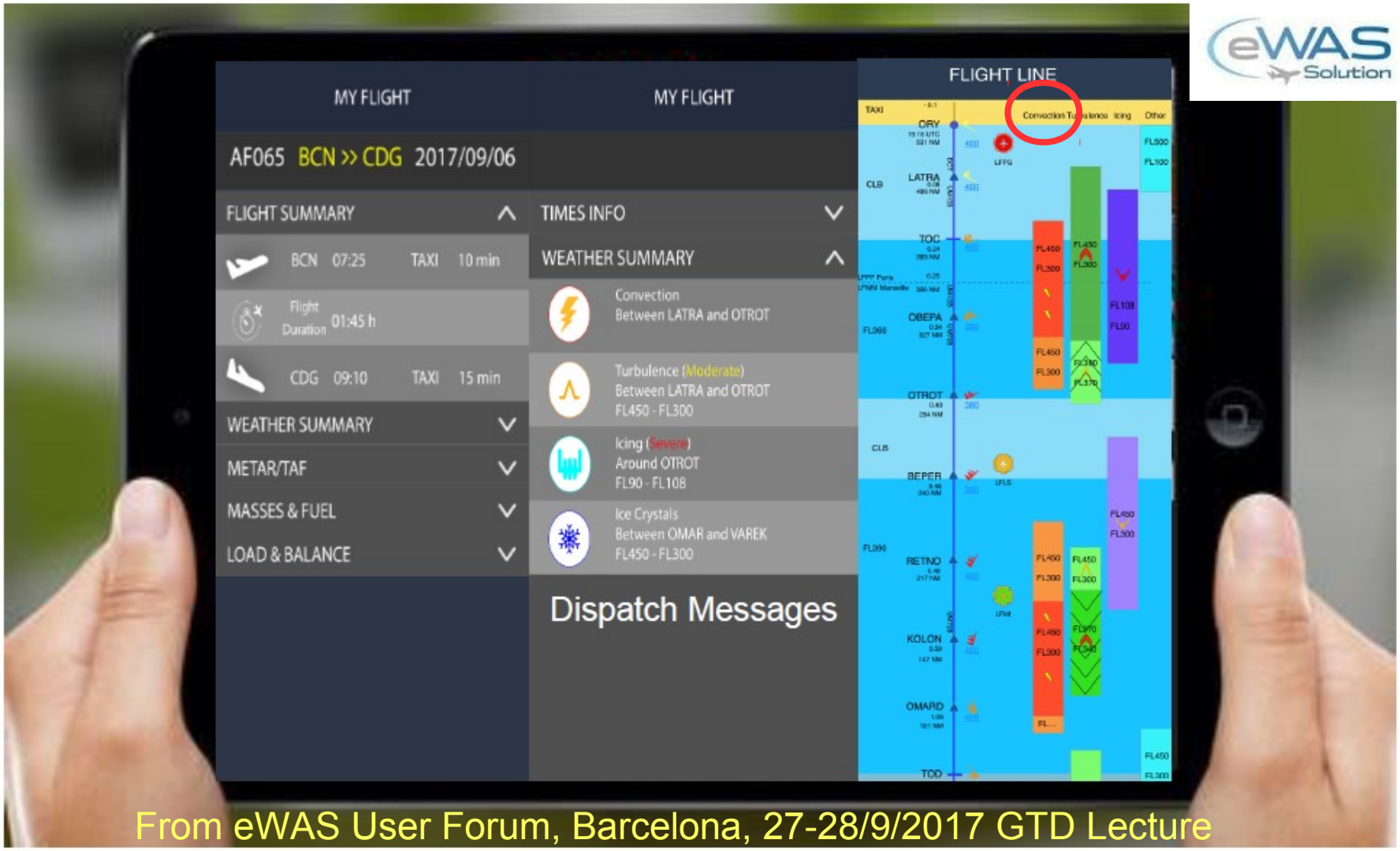
Activation of control parameters: BTLIMIT and tropopause LIMIT

A better match of cloud systems

A better tracking

RDT on-board eWas Solution

- ❑ OFP Details
- ❑ Airports details
- ❑ Weather details
- ❑ Dispatch Messages
- ❑ Fuel information
- ❑ App Launchers (Doc, Load & Balance)



32000 Pilots / Positive Feedback / Global

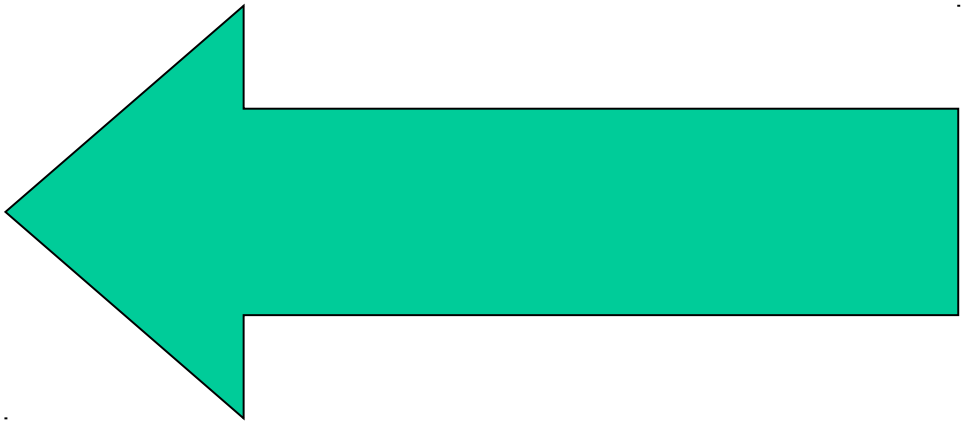
Overview

1. The hazard

2. The tools for the diagnosis

3. Focus on RDT

4.Conclusion



Conclusion

Some products to detect the high IWC hazard

Research campaigns helped to validate an improve the product

Operational applications with RDT and with other products increase. New generation of satellites will improve retrieval of the hazard.

Feedback on product performance and usage is expected to improve the products and define future research fields.

Thanks for your attention

Many thanks to Partners for their contribution

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