Presented by

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HAIC-HIWC Science Meeting 05-09 December 2016

Overview of HAIC SP3 activities since Toronto HAIC-HIWC Science Meeting

High Altitude Ice Crystals
Content

- Context
- The HAIC Project
- The SP3 Activities
- Status at M51
- Way Forward

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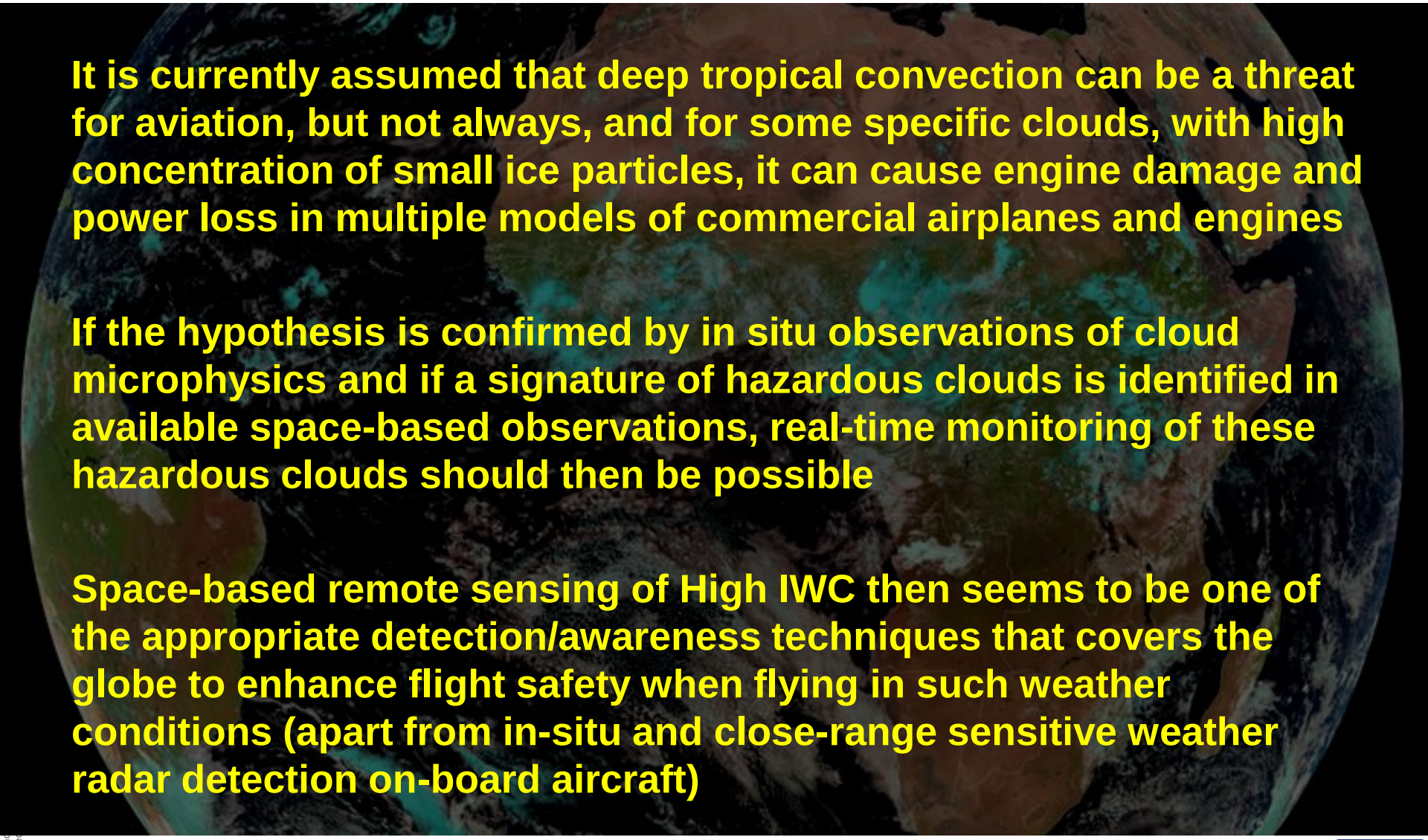
High Altitude Ice Crystals
Context



It is currently assumed that deep tropical convection can be a threat for aviation, but not always, and for some specific clouds, with high concentration of small ice particles, it can cause engine damage and power loss in multiple models of commercial airplanes and engines

If the hypothesis is confirmed by in situ observations of cloud microphysics and if a signature of hazardous clouds is identified in available space-based observations, real-time monitoring of these hazardous clouds should then be possible

Space-based remote sensing of High IWC then seems to be one of the appropriate detection/awareness techniques that covers the globe to enhance flight safety when flying in such weather conditions (apart from in-situ and close-range sensitive weather radar detection on-board aircraft)

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High Altitude Ice Crystals
The HAIC Project [www.haic.eu] (1/2)

- FP7 large-scale integrated project which aims at enhancing aircraft safety when flying in mixed phase and glaciated icing conditions

- Coordinated by AIRBUS, the HAIC Consortium brings together 35 partners from 11 European countries and 6 international partners from Australia (BOM), Canada (EC, NRC), and the United States (FAA, NASA, NCAR)

- Started in August 2012, the project will be completed by January 2017

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High Altitude Ice Crystals
The HAIC Project [www.haic.eu] (2/2)

- Activities:
  - SP1 Instrumentation
  - SP2 High IWC Flight tests Campaigns
  - **SP3 Space-borne Observation & Nowcasting of High IWC Regions**
  - SP4 High IWC Detection & Awareness Technology
  - SP5 High IWC Test Capability Enhancement
  - SP6 High IWC Tools & Simulation Development
  - SP7 Consortium management, Technical management and Integration

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High Altitude Ice Crystals
Collaborating with the HIWC Project

- Common scientific and operational interests from both HAIC and HIWC Satellite and Nowcasting teams
- Support and contribution during the different HAIC-HIWC campaigns
- Common investigations through case studies discussed during several HAIC-HIWC Satellite and Nowcasting meetings, including the HAIC 2016 Forum
- Strong desire between HAIC and HIWC Satellite and Nowcasting teams to further collaborate in inter-comparing and developing new products to go global

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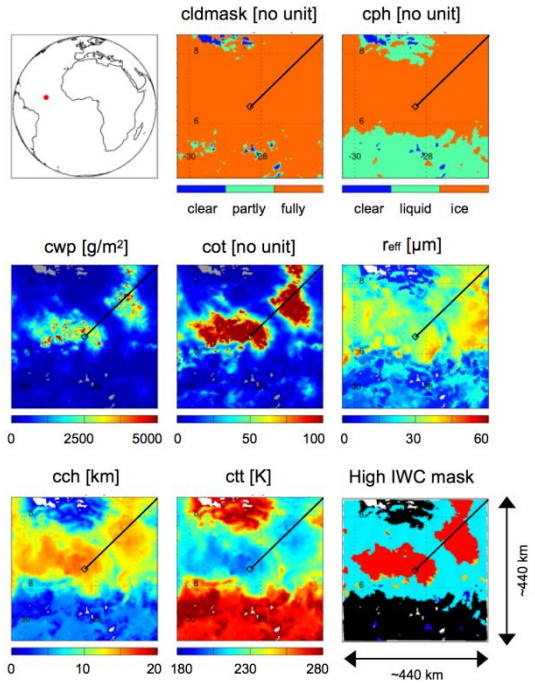
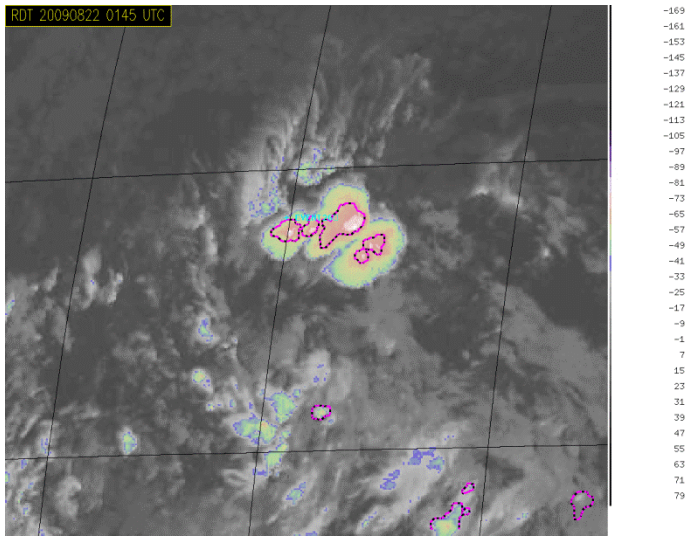
High Altitude Ice Crystals
The HAIC SP3 Activities (1/2)

- Objective : To develop **space-borne remote <u>detection</u> and <u>nowcasting</u> techniques of convective systems** to support the first (Darwin, 2014) second (Cayenne, 2015) and third (Darwin & La Réunion, 2016) HAIC flight test campaigns, and to ultimately provide near real-time weather data through ATM



Cloud parameters retrieved from the CPP algorithm and High IWC mask (panel i) developed within HAIC for an in-service AIRBUS event



RDT detection and tracking of a cloud system at the origin of an in-service AIRBUS event

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High Altitude Ice Crystals
The HAIC SP3 Activities (2/2)

- **Geostationary Space-borne Retrievals of High IWC [KNMI]**
  - Detection of high IWC cloud regions in daytime mainly from the VIS/IR SEVIRI imager on MSG (Europe, Africa, Atlantic Ocean)
  - Validate the MSG-SEVIRI-based retrievals of ice cloud properties
- **Polar Orbiting Space-borne Retrievals of High IWC [CNRS]**
  - Detection of any specific signature of High IWC in concurrent visible, infrared and microwave passive and active observations of the space-based A-Train mission
  - Develop a reference global-scale climatology of frequency of high IWC occurrence
- **Nowcasting of Tropical Convection [Météo-France]**
  - Develop and validate a detection and nowcasting application for deep convection over the Tropical Atlantic for real-time guidance of the aircraft during the HAIC flight campaign and further support to ATM

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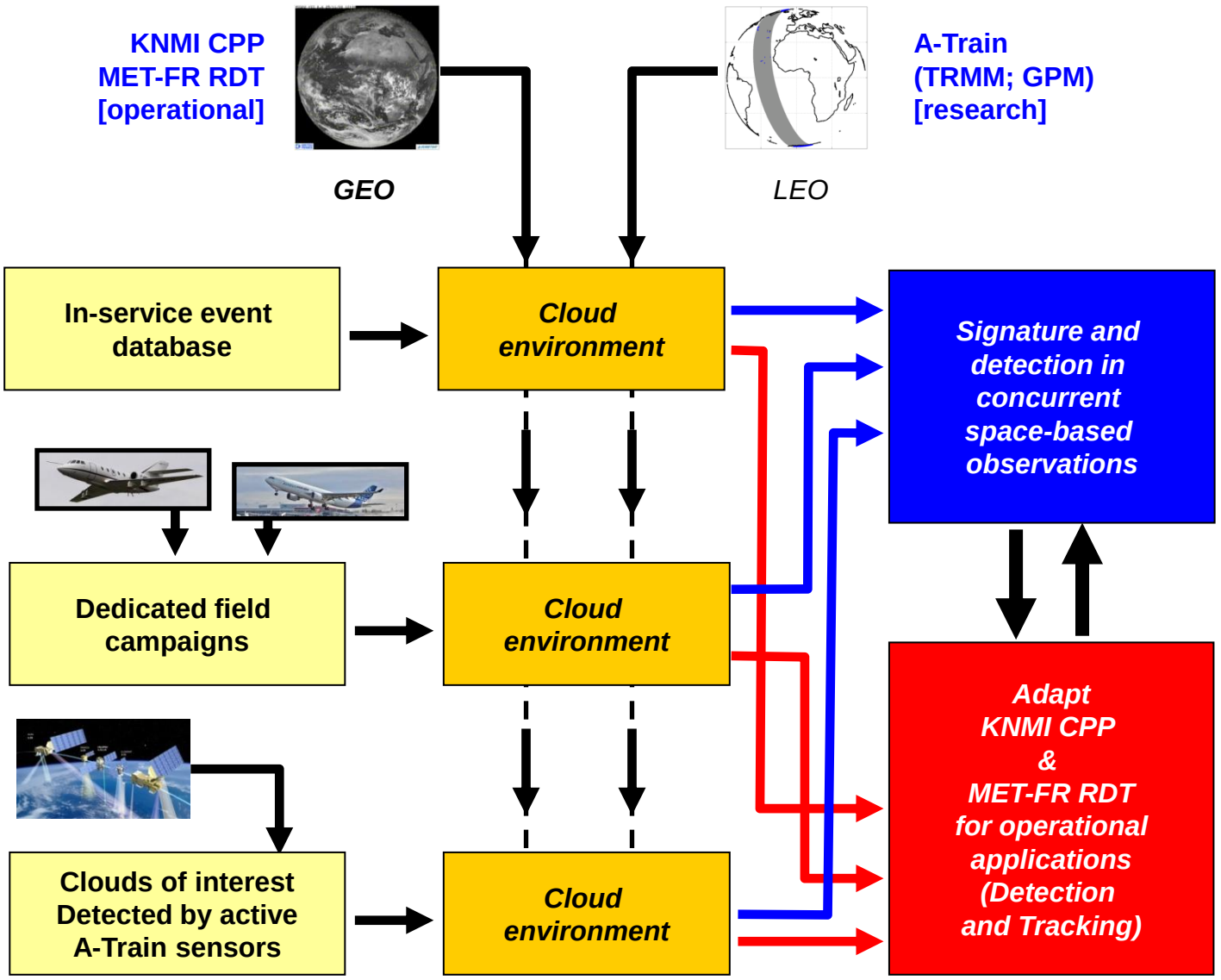
High Altitude Ice Crystals
Methodology



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High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (1/8)

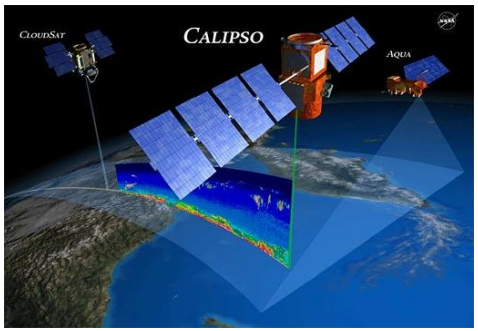
Goal: to detect atmospheric scenes with **IWC > 1.0 g/m³** (**≡ High IWC**)

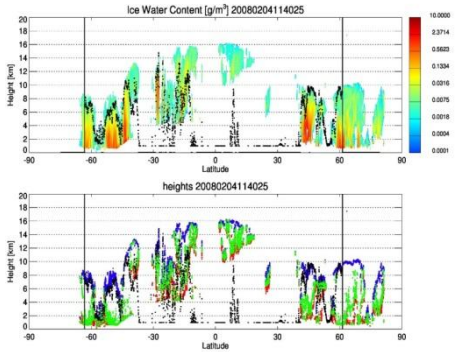
High IWC threshold may be exceeded anywhere in the cloud (vertical).

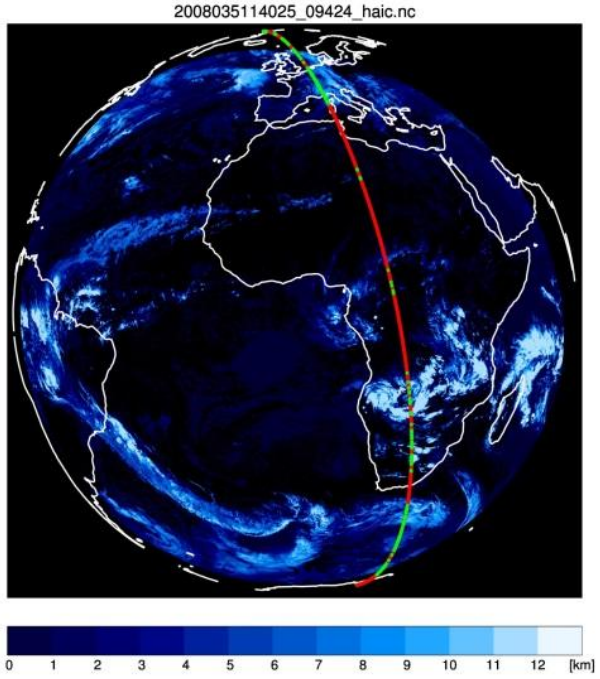
Important: SEVIRI (geostationary) is passive sensor, looking down to earth ➔ no information in/below clouds.

➔ use of locally measured IWC is insufficient

➔ use remote sensing data from active cloud sensors
- CLOUDSAT/CALIPSO (DARDAR product; Univ. Lille)
- "curtain plots" ➔ cloud slices







example: SEVIRI cloud height & orbit DARDAR orbit

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High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (2/8)

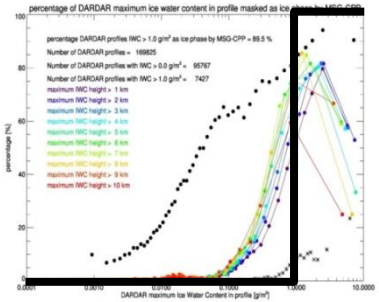
Goal: to detect atmospheric scenes with **IWC > 1.0 g/m³ (≡ High IWC)**

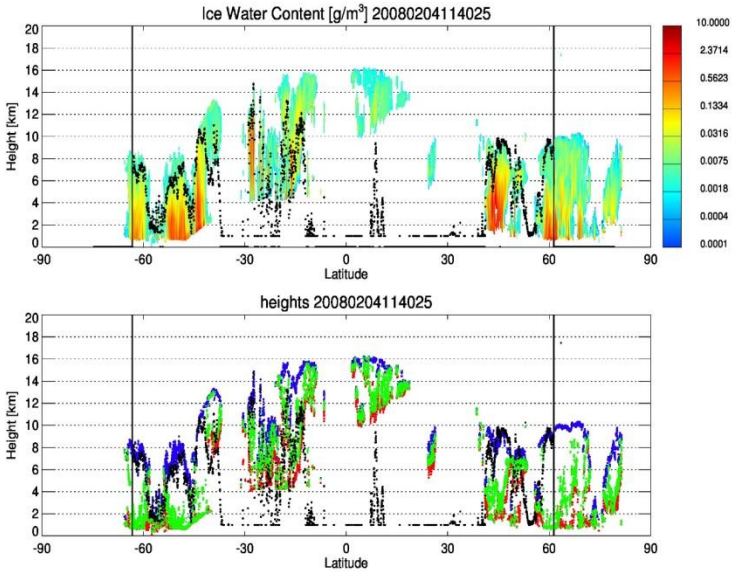
High IWC threshold may be exceeded anywhere in the cloud (vertical).

- Use approximately 25 DARDAR (CloudSat + Calipso) orbits in 2008, two per month.

DARDAR-based **MSG-CPP** High IWC mask

1. The cloud phase	ice
2. Condensed water path	> 100 g/m²
3. Cloud top temperature	< 270 K
4. Cloud optical thickness	> 20





For more information, a paper is available at AMTD
[de Laat et al., 2016; doi:10.5194/amt-2016-246]

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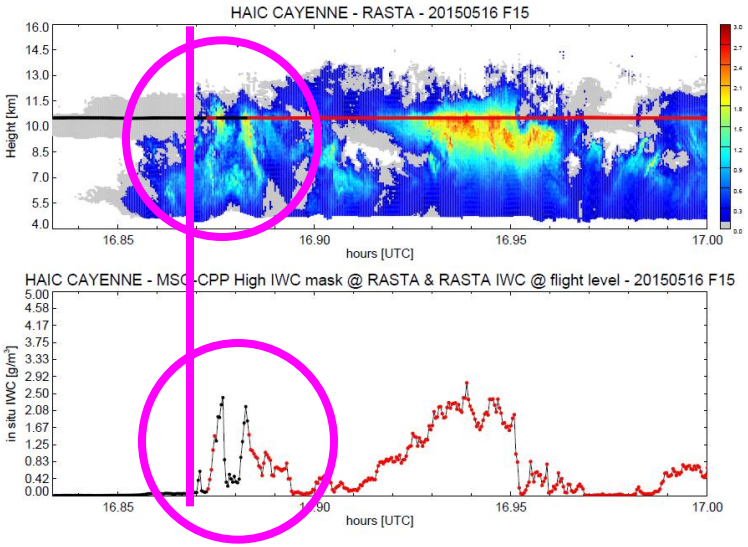
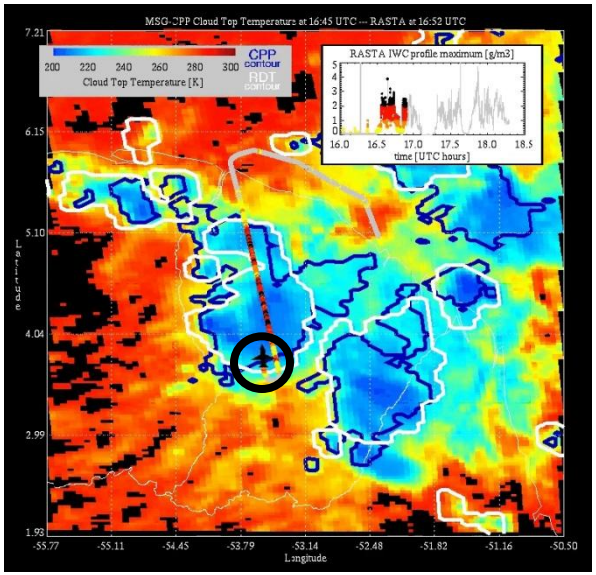
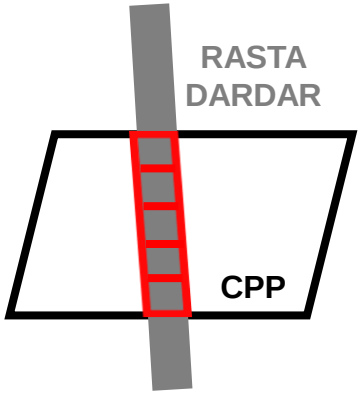
High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (3/8)





Comparing CPP with DARDAR/RASTA (RASTA = aircraft cloud radar)

Differences in spatial resolution
- DARDAR/RASTA ~ few 100 m
- CPP ~ few km (~ 30 seconds)



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High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (4/8)

I. One full year of DARDAR data (25 orbits➔ 3424 orbits)
2008 ➔ 3424 orbits, 1 profile every 1 km, processing 1.2 Tb of data, …

Most important results:

1. Probability Of Detection improves with increasing altitude of High IWC
2. Probability Of Detection improves by excluding SZA + VA > 60° (without much cost)
3. accounting for small scale spatial structure of High IWC (DARDAR, RASTA)

   improves POD (> 95%) and reduces FAR (from > 80% to < 30% and better)
4. For larger continuous High IWC areas POD can increase > 99%

   (= large High IWC are very likely to be detected by CPP)

5. no relation of High IWC mask performance and distance of High IWC to cloud top.
6. no seasonal dependency (obviously for occurrences there are seasonal and diurnal patterns)

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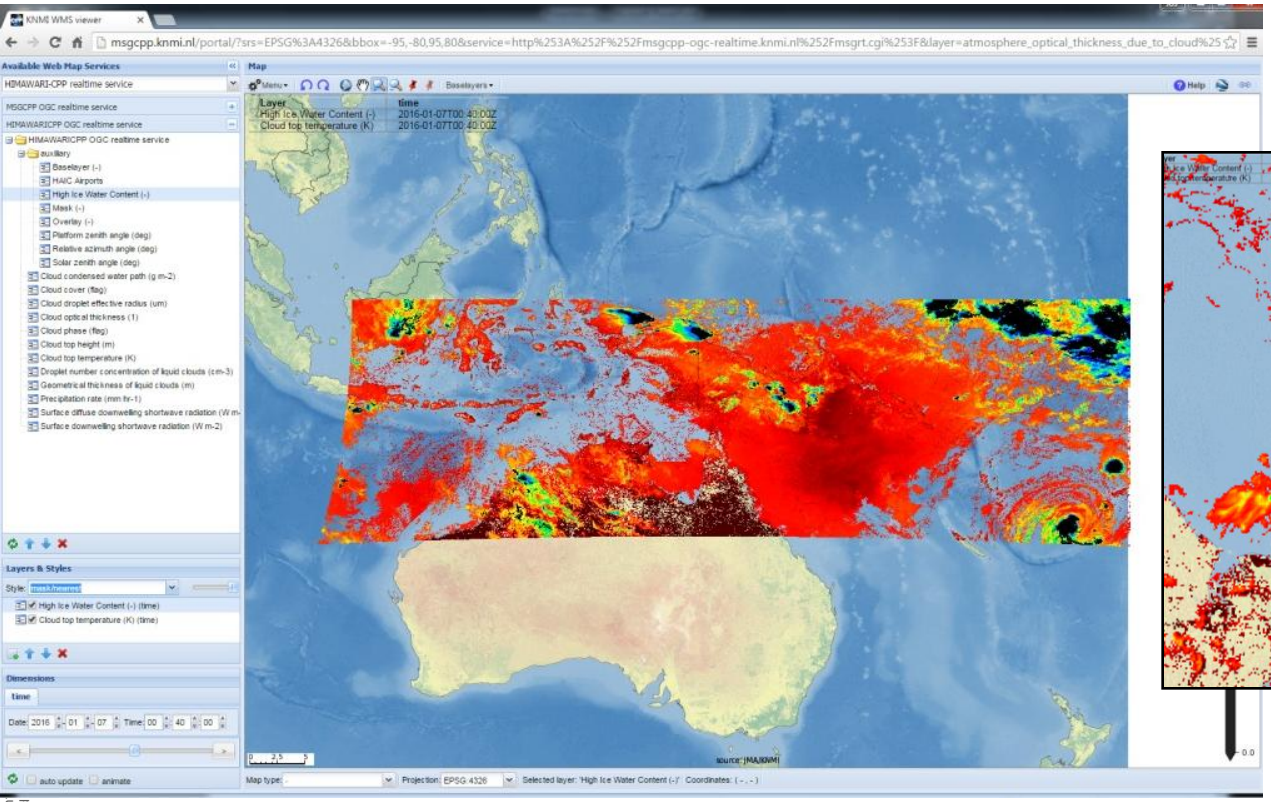
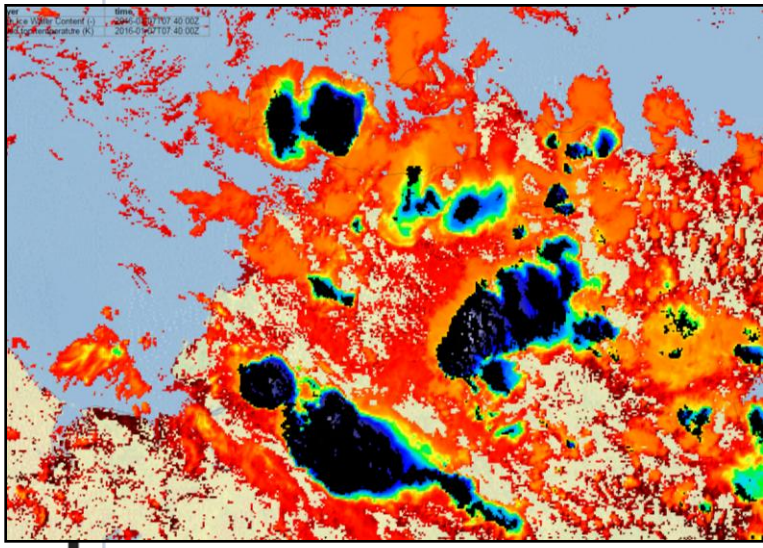
High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (5/8)

- Development of dedicated HIM-CPP chain by KNMI (data only public late 2015 by JAXA)
  - Adaptation and tuning of the CPP algorithms to the HIMAWARI/AHI channels
  - Implementation for real time display via KNMI web portal
  - Limited area (not full disc) to get fast access to data on ftp-sever
  - **<u>“test of product in different environment”</u>**





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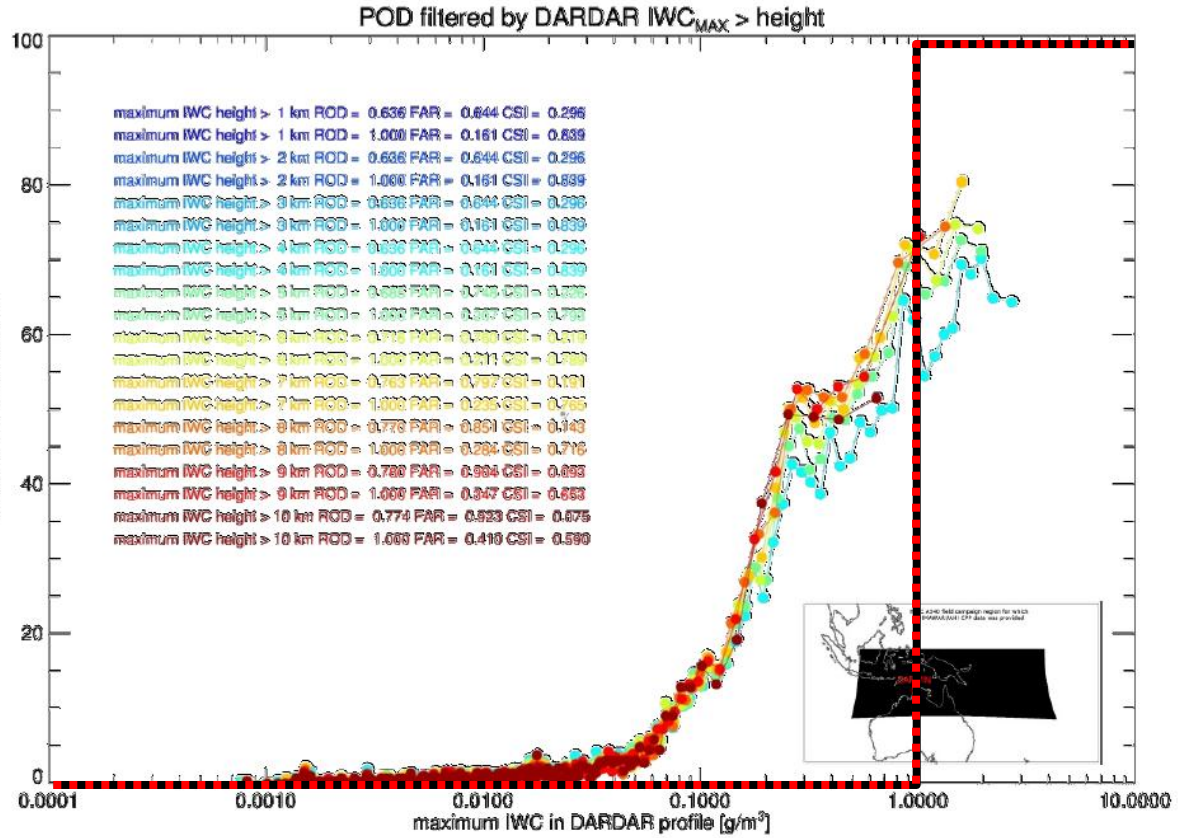
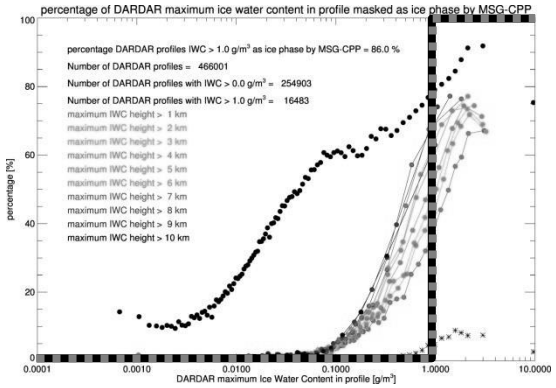
High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (6/8)





DARDAR maximum Ice Water Content (logarithmic scale; g/m^3)

- Limited DARDAR data (6-27 January 2016, not full disc)
- Less data than the original “25 orbit” verification
- HIMAWARI has smaller spatial pixel size than SEVIRI (2°×2° *vs* 3°×3°)
- Results are OK and consistent with previous results

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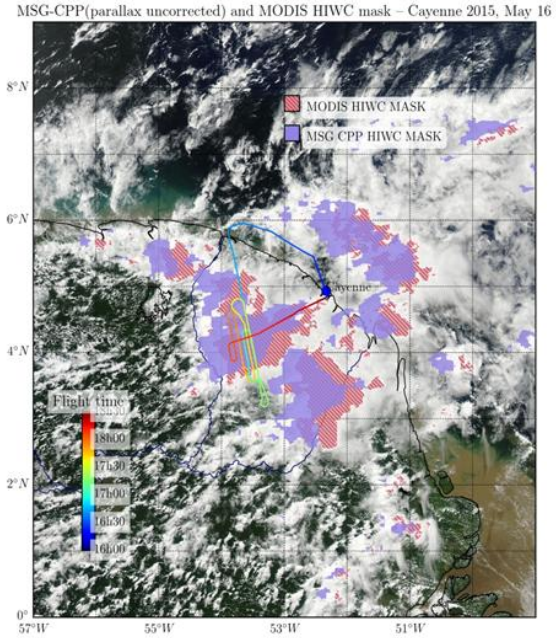
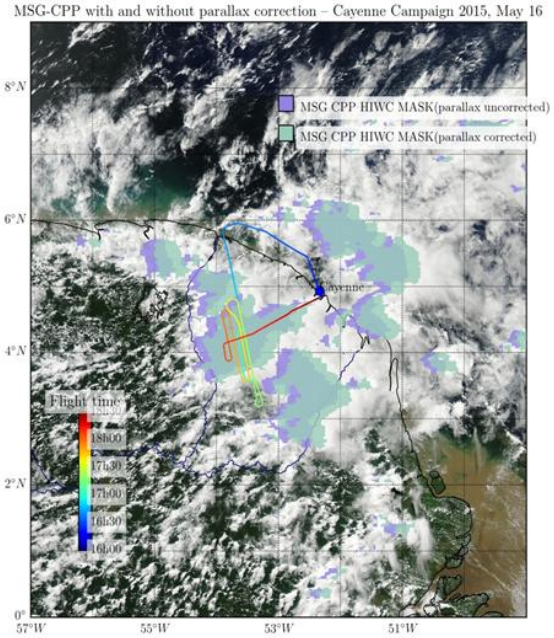
High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (7/8)





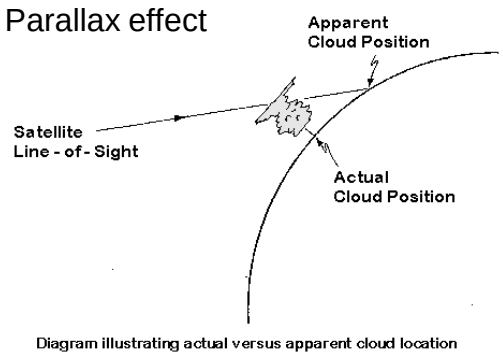
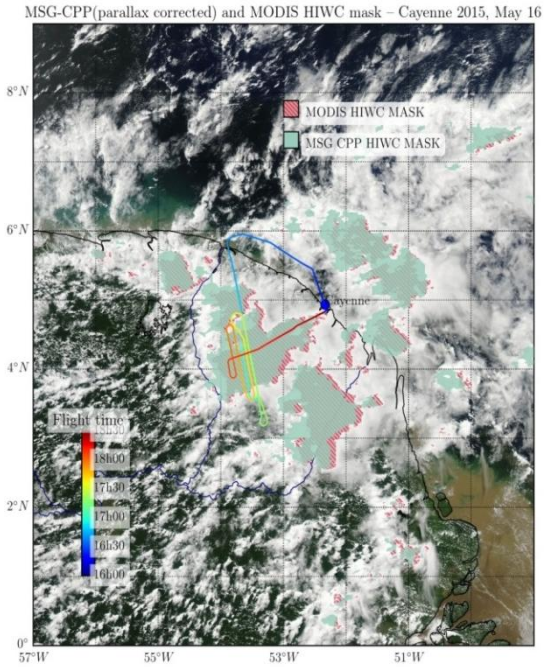


Diagram illustrating actual versus apparent cloud location



- MODIS – MSG-CPP comparison
- MODIS and CPP provide similar cloud parameters
- MODIS has much smaller pixels and fewer viewing angle issues
- MSG = 36000 km altitude, MODIS = 800 km altitude

- Test of CPP High IWC mask in different environment
- First preliminary visual comparison looks quite OK

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High Altitude Ice Crystals
Geostationary Space-borne Retrievals of High IWC (8/8)

Performance of CPP High IWC mask

✓ Evaluated against on-board RADAR measurements during field campaign
✓ Evaluated against satellite RADAR/LIDAR measurements (full year 2008)

✓ Applied to other geostationary satellite data (HIMAWARI) for 2016 A340 campaign
✓ Performance of HIM-CPP High IWC mask during 2016 A340 campaign evaluated with satellite LIDAR
✓ Applied to MODIS

✓ Successful in detecting scenes with high IWC (> 1 g/m^3) somewhere in the vertical (cloud)
- ✓ Probability of detection 80-99%
- ✓ Probability of detection better for High IWC higher up in cloud
- ✓ Probability of detection improves when discouning large solar zenith angles & large viewing angles
- ✓ False alarms < 30% considering:
  - ✓ spatial scale of IWC
  - ✓ differences in spatial resolution of MSG-CPP & DARDAR/RASTA

✓ Occurence of High IWC > 8 km altitude (FL 27000) exceedingly rare (< 1% of clouds)
✓ Occurence of large scale High IWC even more rare

➢ *TRL6 reached in November 2016*

➢ *Operationally available via KNMI MSG-CPP web portal*

Limitations

- Daytime only
- Latency approximately 30 minutes
- Trade off: better detection = more falses (but still with fairly high IWC)
  - >95% of fases still have IWC > 0.1 g/m^3 somewhere in cloud

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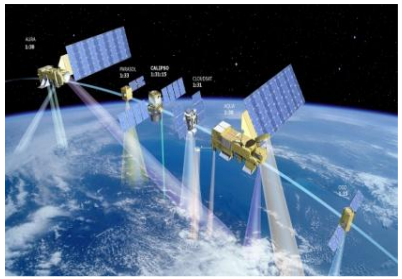
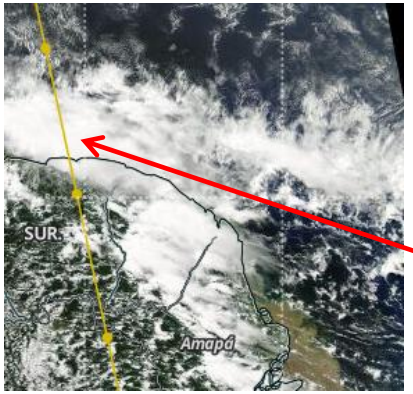
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (1/17)

- **MODIS** : VIS/IR spectral imager on-board the Aqua mission of the A-Train constellation (also on-board the Terra mission).
- Global coverage but limited swath (~2300 km). Geophysical parameters at 1 km spatial resolution at nadir.
- Capability to retrieve different properties of the clouds (cloudiness, phase, cloud optical thickness, LWP, Cloud top temperature, particle size …)
- Always concurrent radar (95 GHz) and lidar (532 & 1064 nm) observations available of the A-Train mission

The A-Train mission

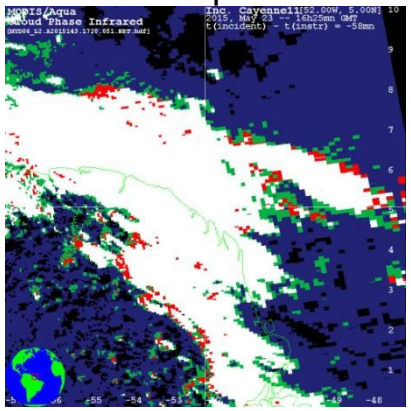


10°

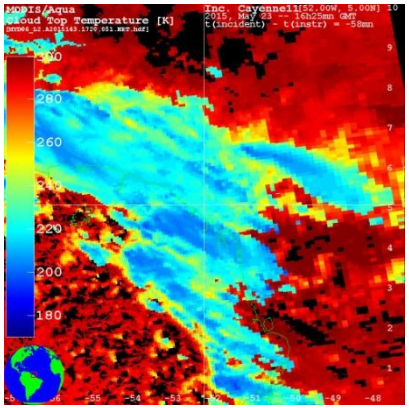


Calipso and Cloudsat track

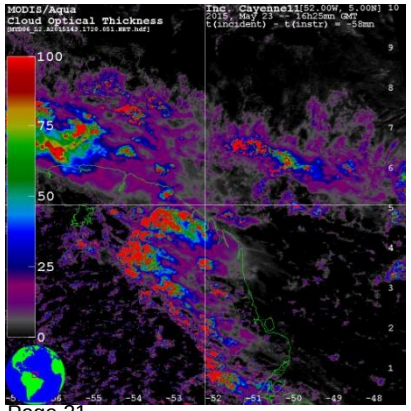
Cloud phase



Cloud top temperature



Cloud optical thickness



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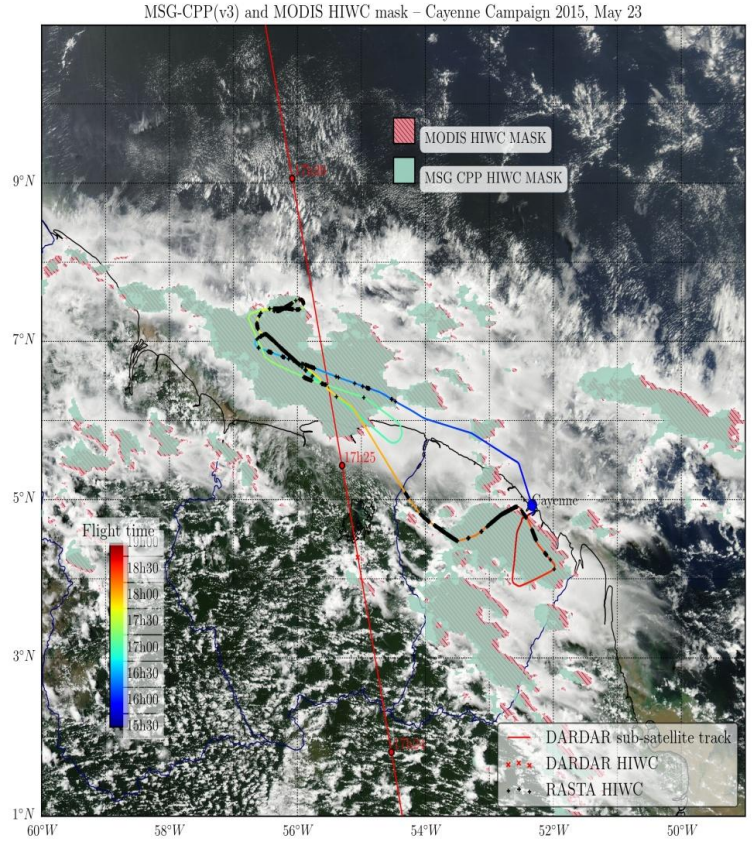
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (2/17)

- Goal : To detect any specific signature of High IWC in concurrent visible, infrared passive observations of the space-based A-Train mission

MSG-CPP and MODIS (Aqua) CPP - like HIWC mask
CAYENNE campaign, 2015/05/23



➢ MSG-CPP High IWC mask is applied to MODIS

- Comparison of CPP-like MODIS mask to MSG-CPP one

support the MSG-CPP high IWC mask -> TRL6

- First preliminary visual comparison looks quite OK

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High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (3/17)

- Evaluation of the CPP-like MODIS high IWC mask using in-situ (ROBUST, IKP), RASTA radar and DARDAR dataset during the second (Cayenne, 2015) and third (Darwin & La Réunion, 2016) HAIC flight test campaigns

Table of MODIS acquisitions for 2015 and 2016 campaigns

#	Date	T-Off – (Landing) Time (UTC)	MODIS Terra (DAY) (UTC)	MODIS Aqua (DAY) (UTC)	MODIS Terra (NIGHT) (UTC)	MODIS Aqua (NIGHT) (UTC)
Cayenne						
F06	16/05/2015	16:00	14:10	17:10		
F11	23/05/2015	15:30	14:20	17:20		
Darwin						
F1652	13/01/2016	06:45 – (09:00)	00:55	05:25	13:10	16:15
F1653	14/01/2016	04:45 – (08:50)	01:40	04:25	13:55	16:55
F1654	15/01/2016	03:55 – (09:00)	02:25	05:15	14:40	16:00
La Réunion						
F1657	23/01/2016	02:20 – (09:30)	06:30	11:00 (*)	18:00	21:05
F1658	24/01/2016	00:50 – (07:40)	05:35 & 07:15 (**)	10:00	18:50	21:50
F1659	27/01/2016	00:50 – (06:55)	06:10	10:35	19:20	20:40

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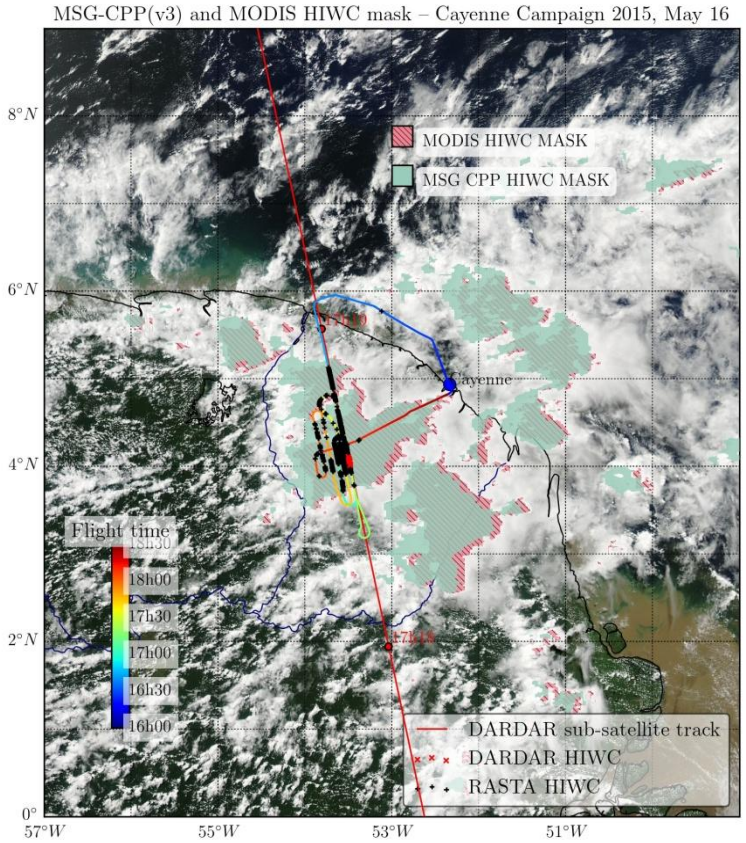
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (4/17)

CAYENNE campaign 2015/05/16

- **MSG-CPP and MODIS (Aqua) CPP-like HIWC mask - DARDAR - RASTA**

DARDAR and RASTA : IWC > 1 g.m^{-3} and Z > 8 km



- A good correlation between MSG-CPP and MODIS CPP-like HIWC mask and RASTA HIWC
- DARDAR HIWC coincides with MSG-CPP and MODIS mask, but shows a limited number of points

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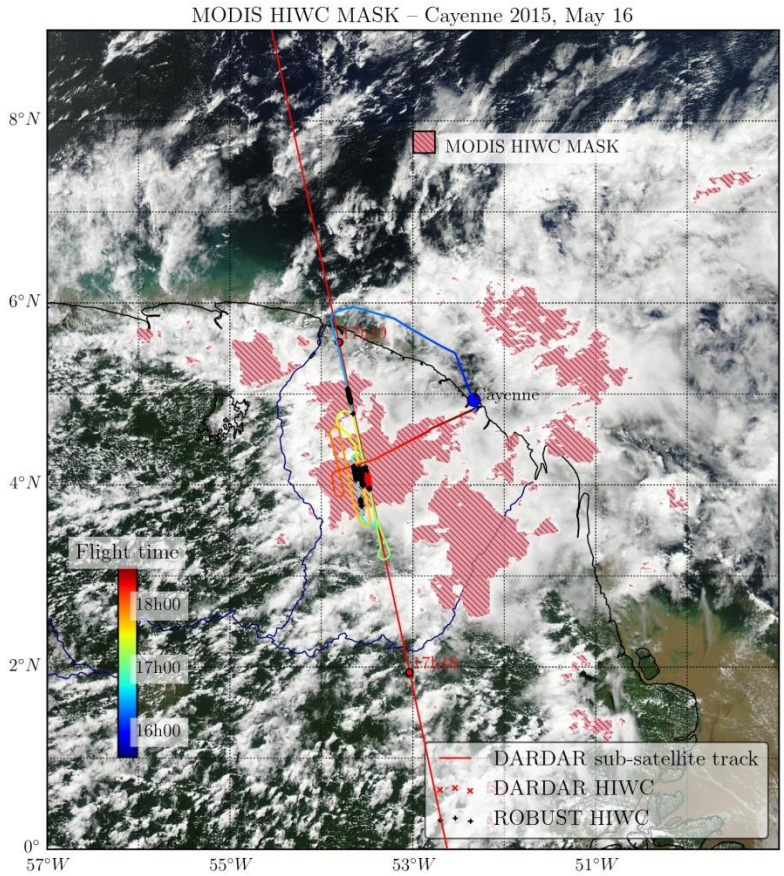
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (5/17)

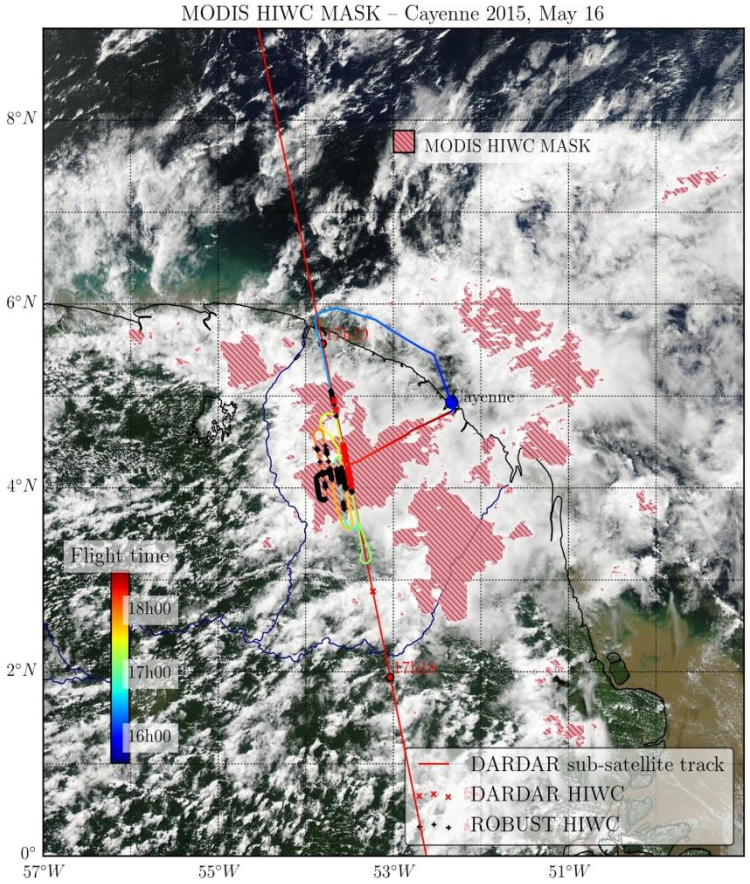
CAYENNE campaign 2015/05/16

- **MODIS (Aqua) CPP - like HIWC mask - DARDAR - ROBUST**

DARDAR and ROBUST : IWC > 1 g.m^{-3} and Z > 8 km



DARDAR and ROBUST : IWC > 1 g.m^{-3} and Z > 6 km



- A larger number of DARDAR HIWC and ROBUST HIWC for IWC > 1 g.m^{-3} and Z > 6 km, with a good coincidence with MODIS mask

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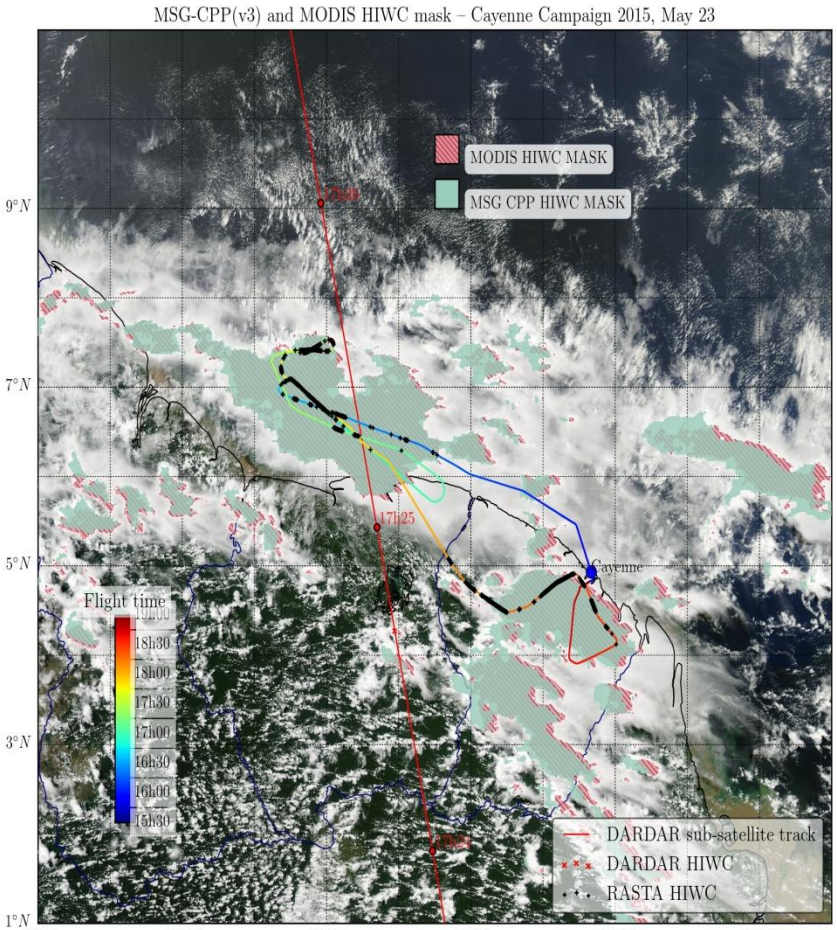
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (6/17)

CAYENNE campaign 2015/05/23

- **MSG-CPP and MODIS (Aqua) CPP-like HIWC mask - DARDAR - RASTA**

DARDAR and RASTA : IWC > 1 g.m^{-3} and Z > 8 km



- A good correlation between MSG-CPP and MODIS CPP-like HIWC mask and RASTA HIWC

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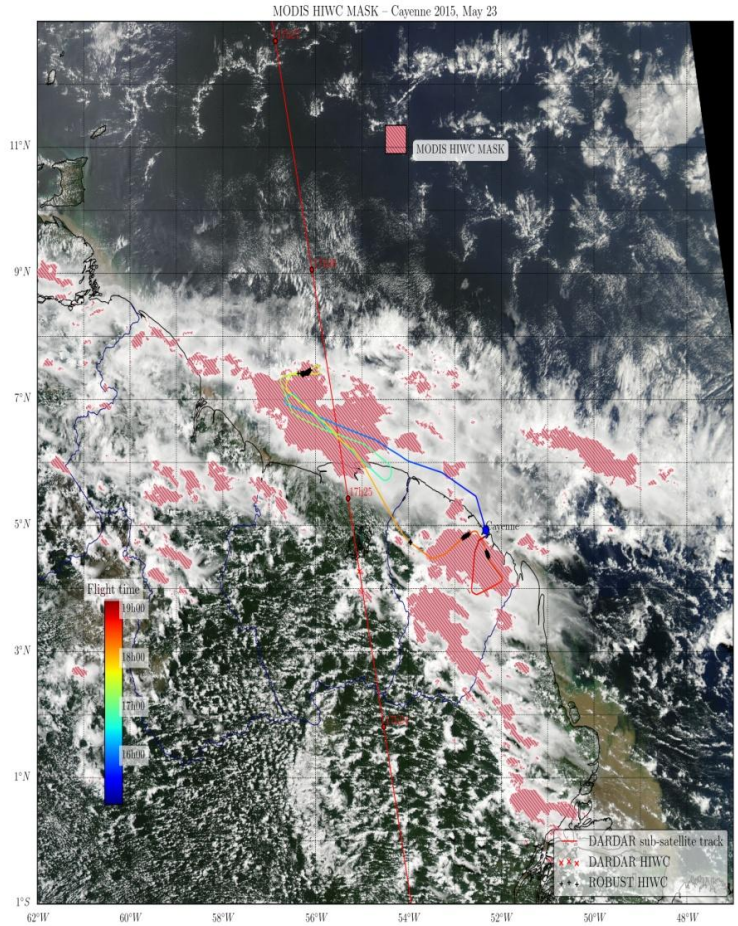
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (7/17)

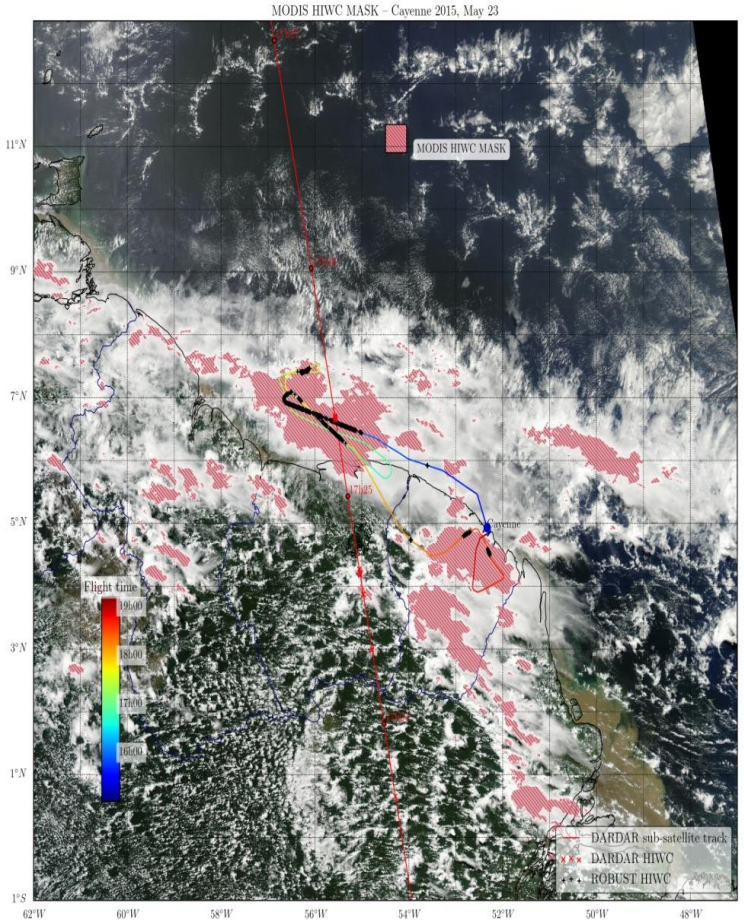
CAYENNE campaign 2015/05/23

- **MODIS (Aqua) CPP - like HIWC mask - DARDAR - ROBUST**

DARDAR and ROBUST : IWC > 1 g.m^{-3} and Z > 8 km



DARDAR and ROBUST : IWC > 1 g.m^{-3} and Z > 6 km



- DARDAR HIWC and ROBUST HIWC coincide with MODIS mask (for IWC > 1 g.m^{-3} and Z > 6km)

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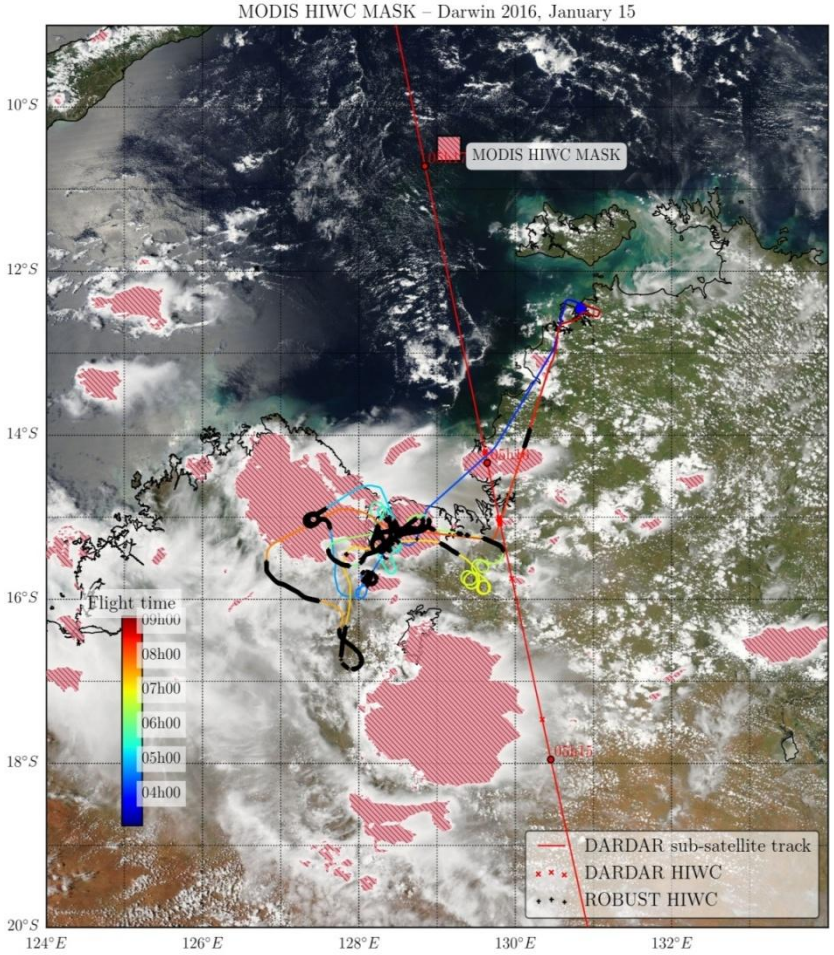
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (8/17)

DARWIN & La Réunion campaign

Darwin 2016/01/15

DARDAR and ROBUST : IWC > 1 g.m^{-3} and Z > 8 km

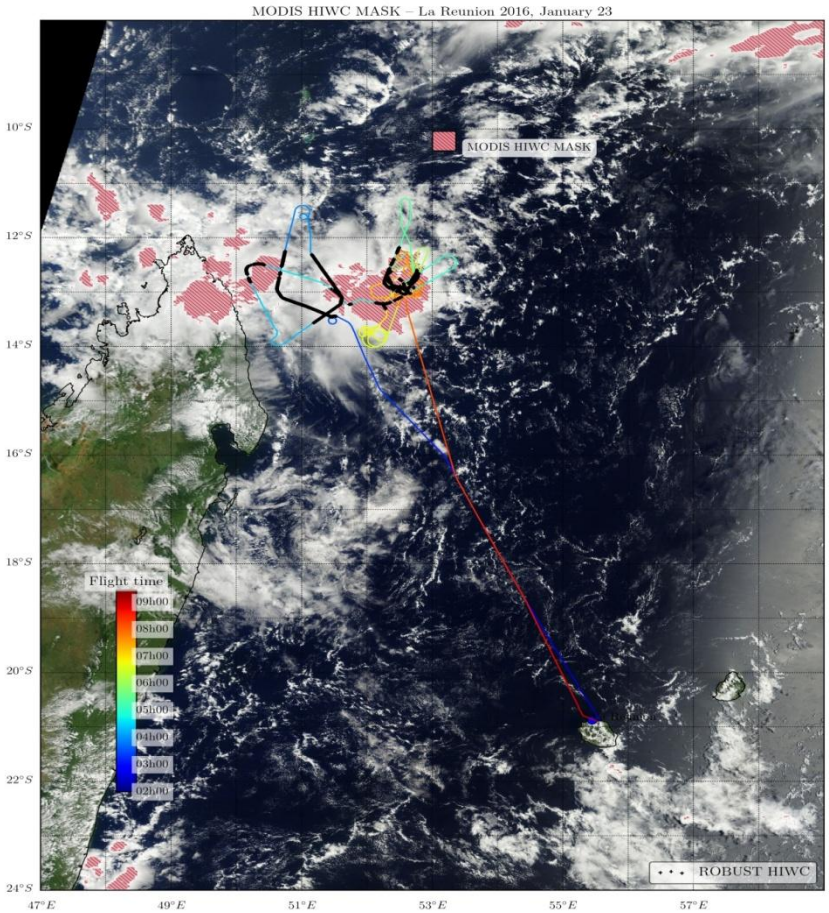


MODIS Aqua Time (UTC) = 05:15

MODIS CPP - like HIWC mask

La réunion 2016/01/23

ROBUST : IWC > 1 g.m^{-3} and Z > 8 km



MODIS Terra Time (UTC) = 06:30

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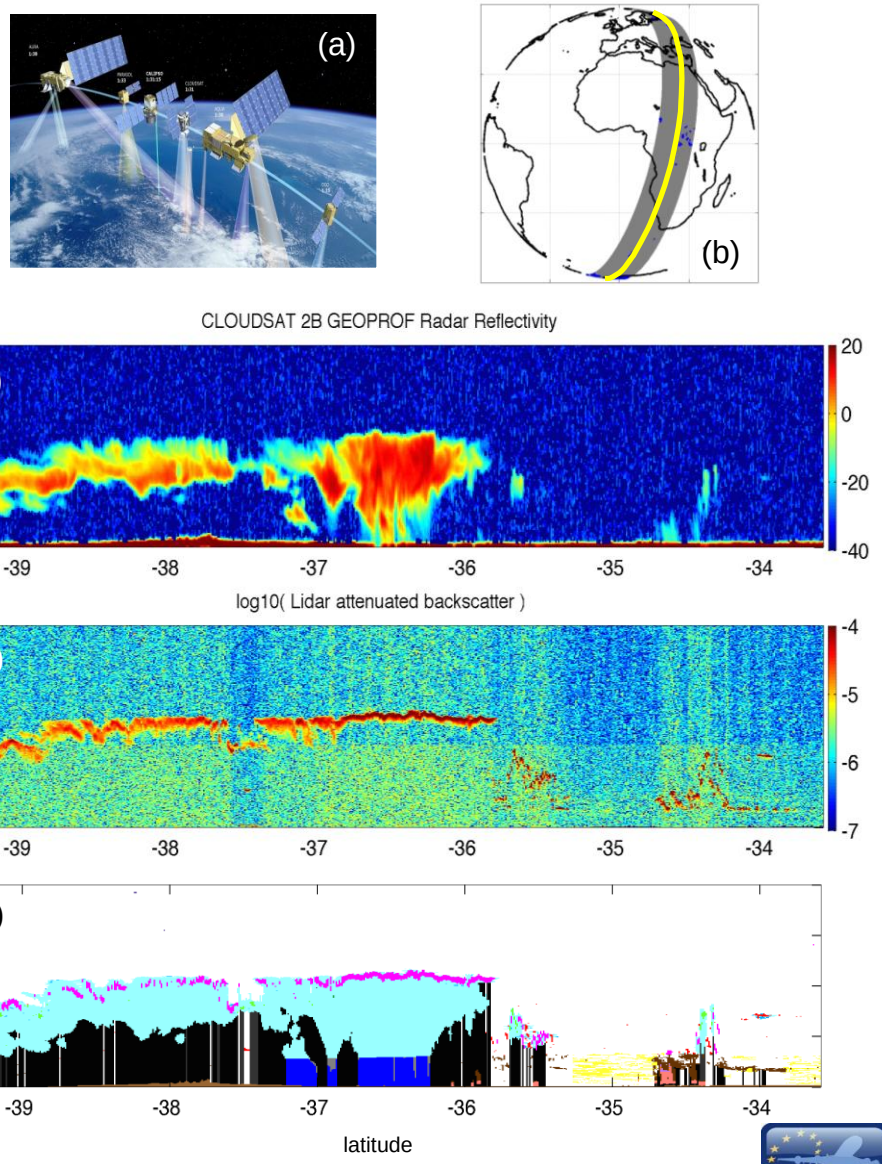
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (9/17)

- **DARDAR** : 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 and r_e through a variational approach
- Capability to classify the cloud type at each altitude bin
- Always concurrent visible, infrared and microwave observations available of the A-Train mission
- Global coverage but small swath
- *RASTA mimics the A-Train radar*



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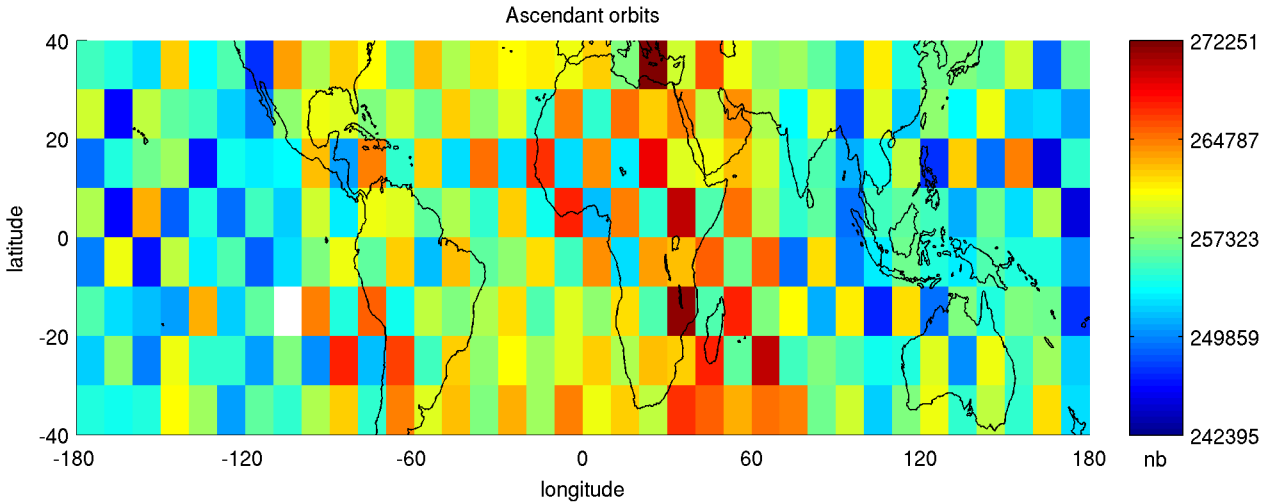
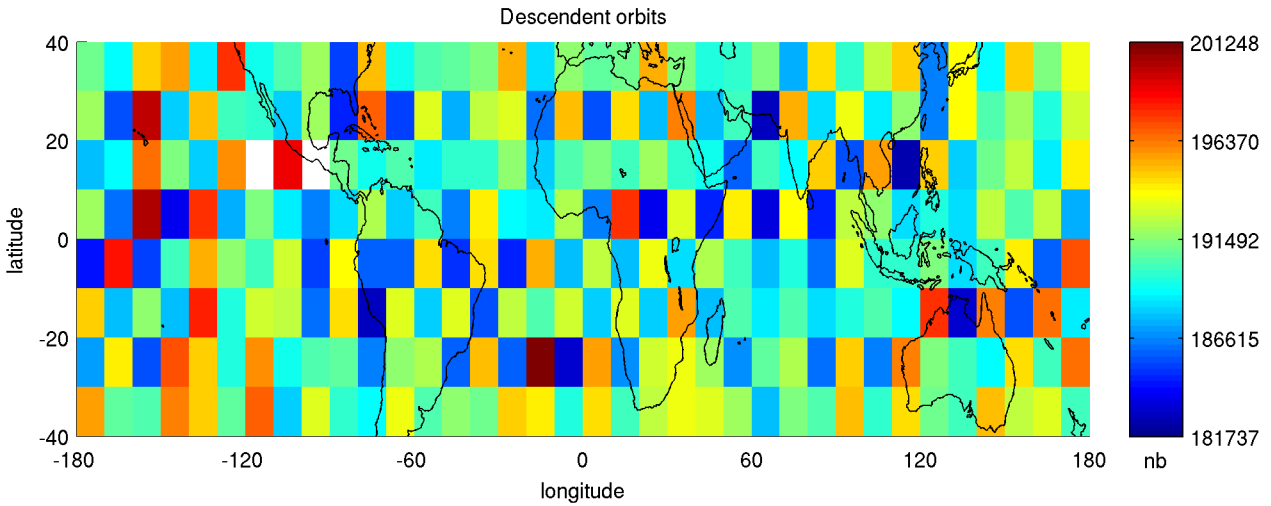
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (10/17)

Number of DARDAR profiles

DARDAR, ascendant, 2008 + every 5 days from 2009 to 2014 daytime



DARDAR, descendant, 2008 + every 5 days from 2009 to 2012 nighttimes



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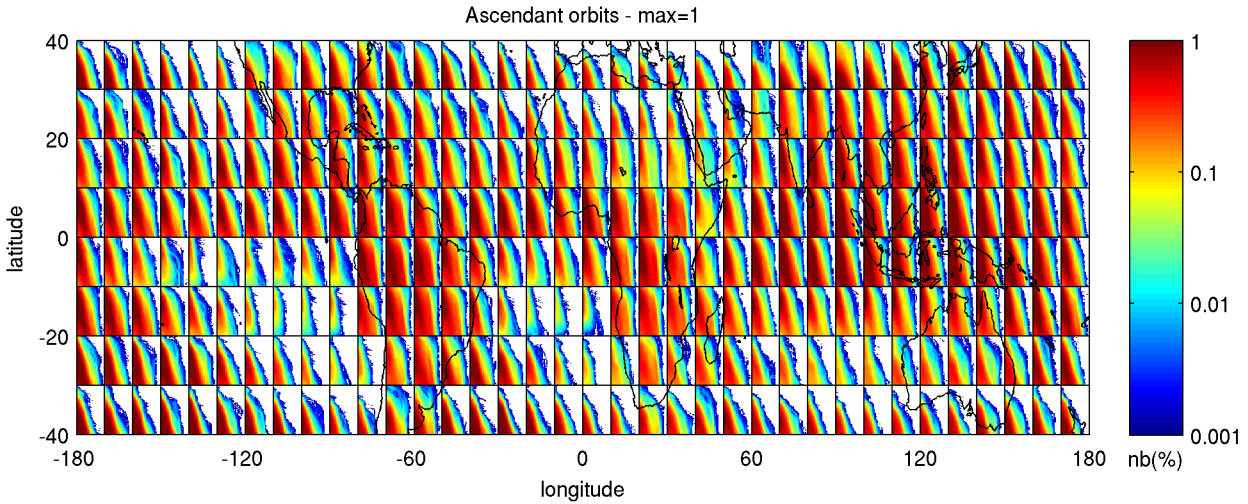
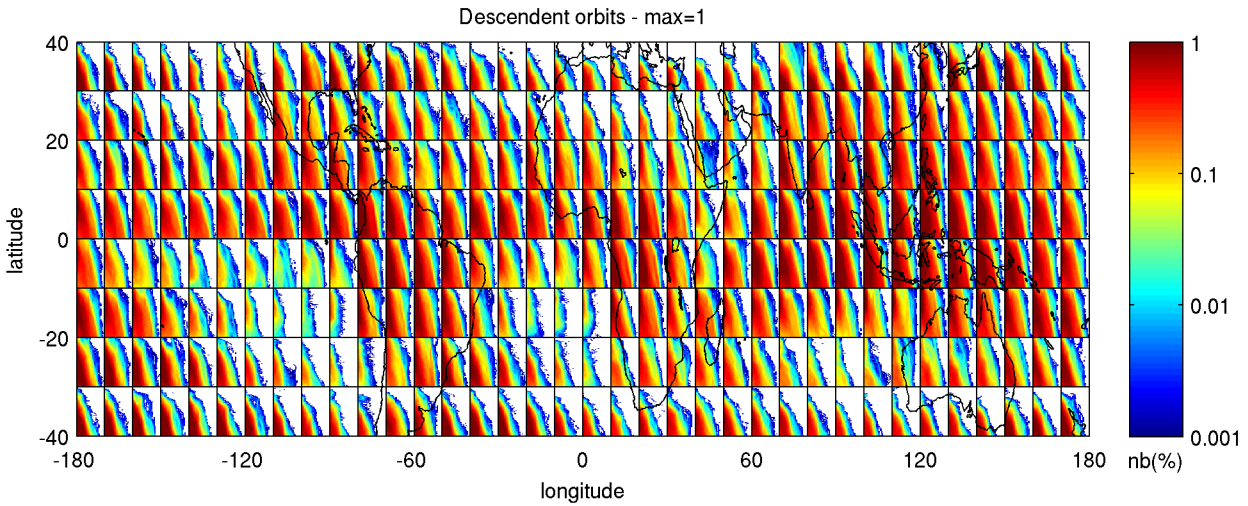
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (11/17)

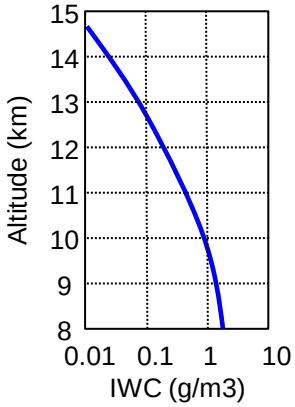
Number of IWC values above 8 km

DARDAR, ascendant, 2008 + every 5 days from 2009 to 2014 daytime



DARDAR, descendant, 2008 + every 5 days from 2009 to 2012 nighttimes





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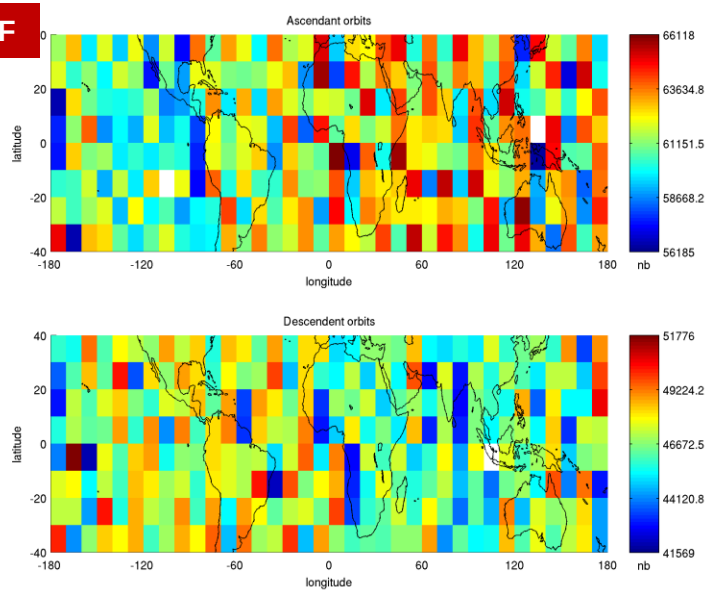
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (12/17)

DJF



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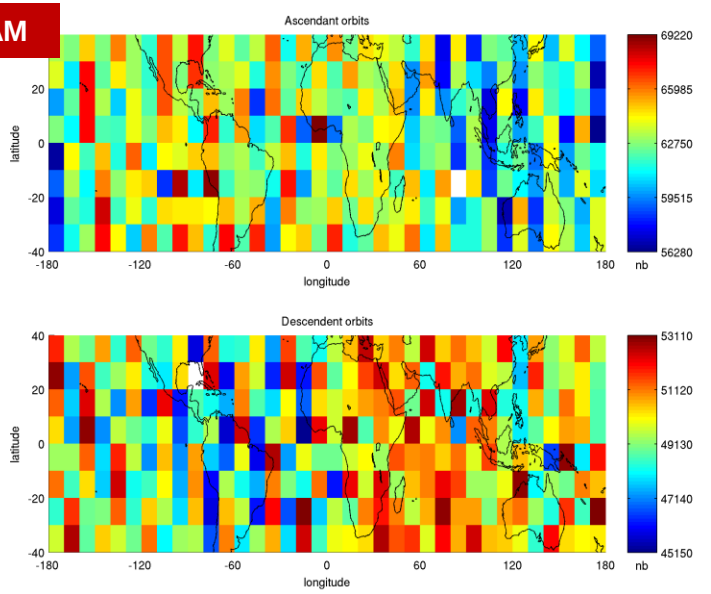

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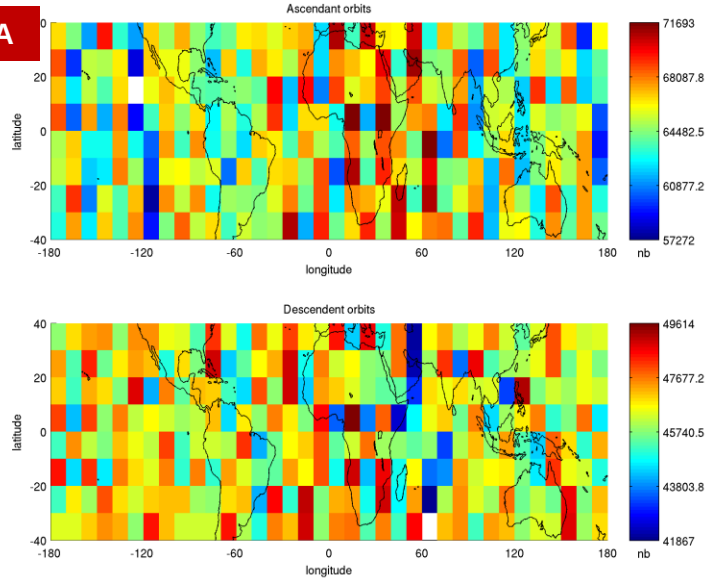

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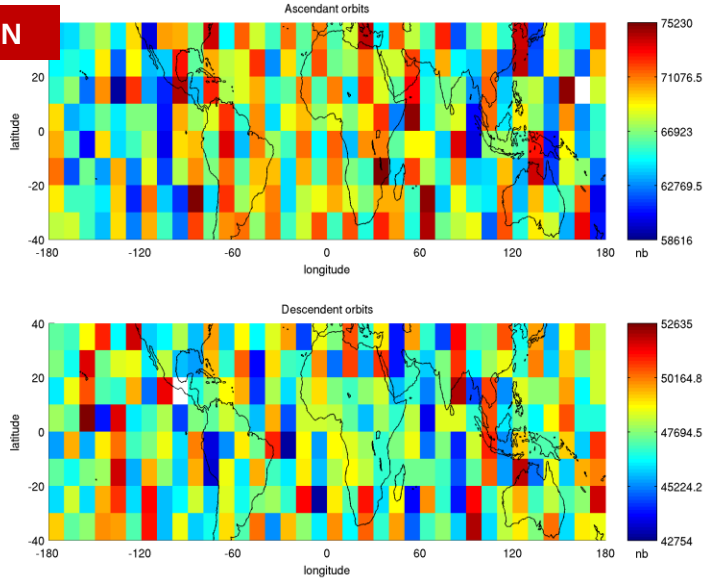
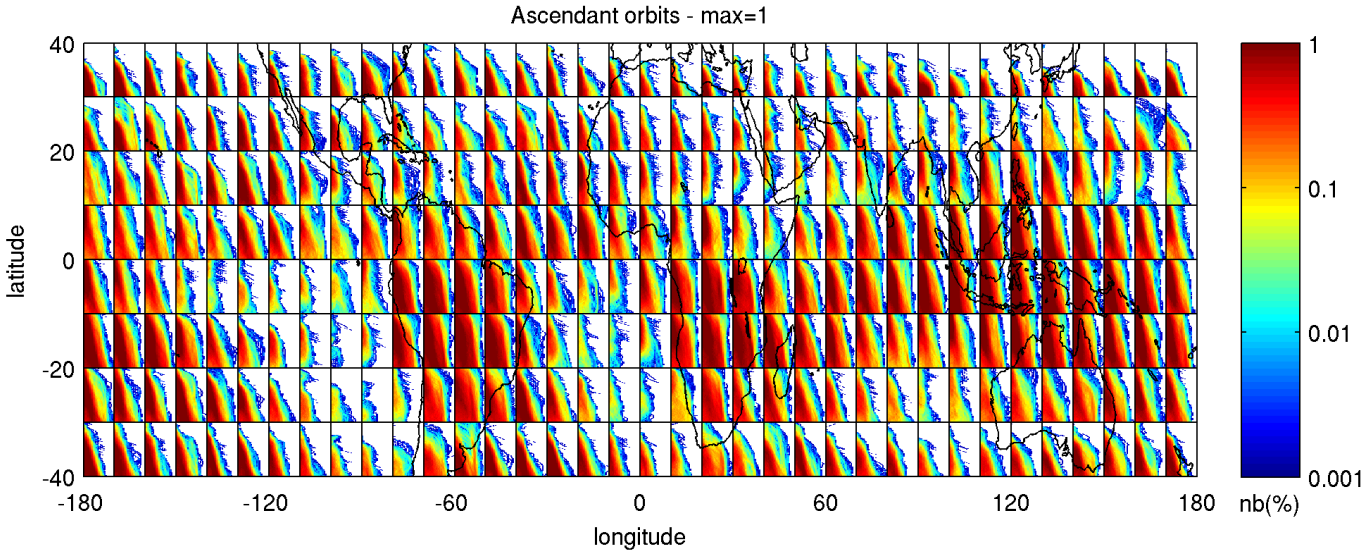
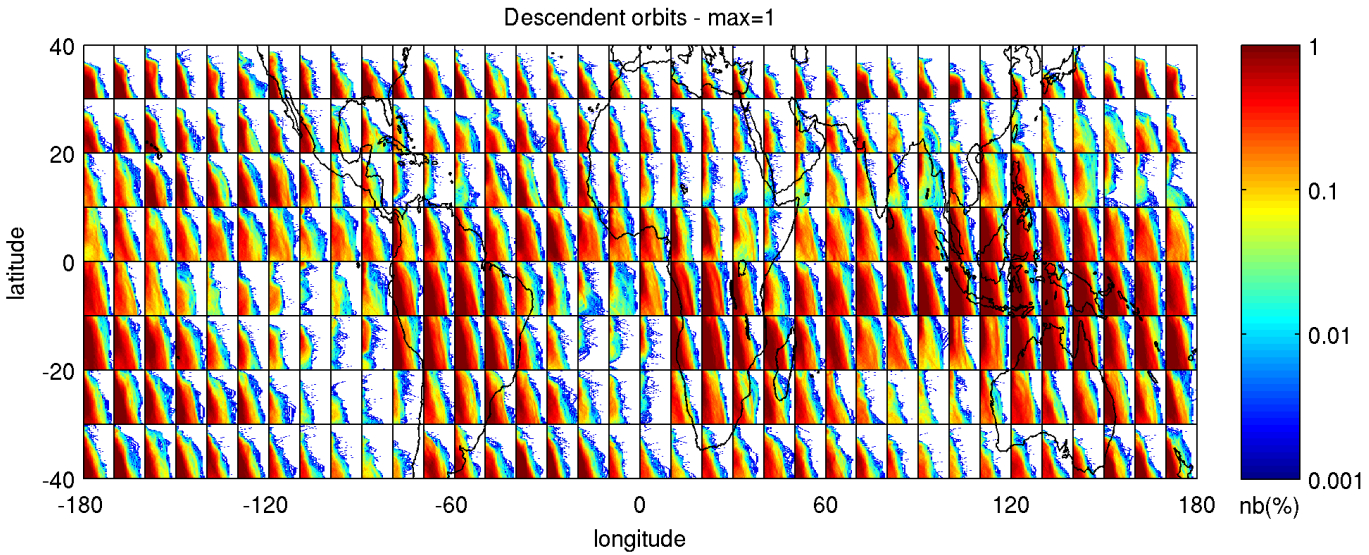
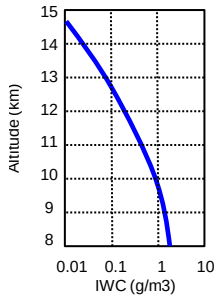


High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (13/17)

DJF

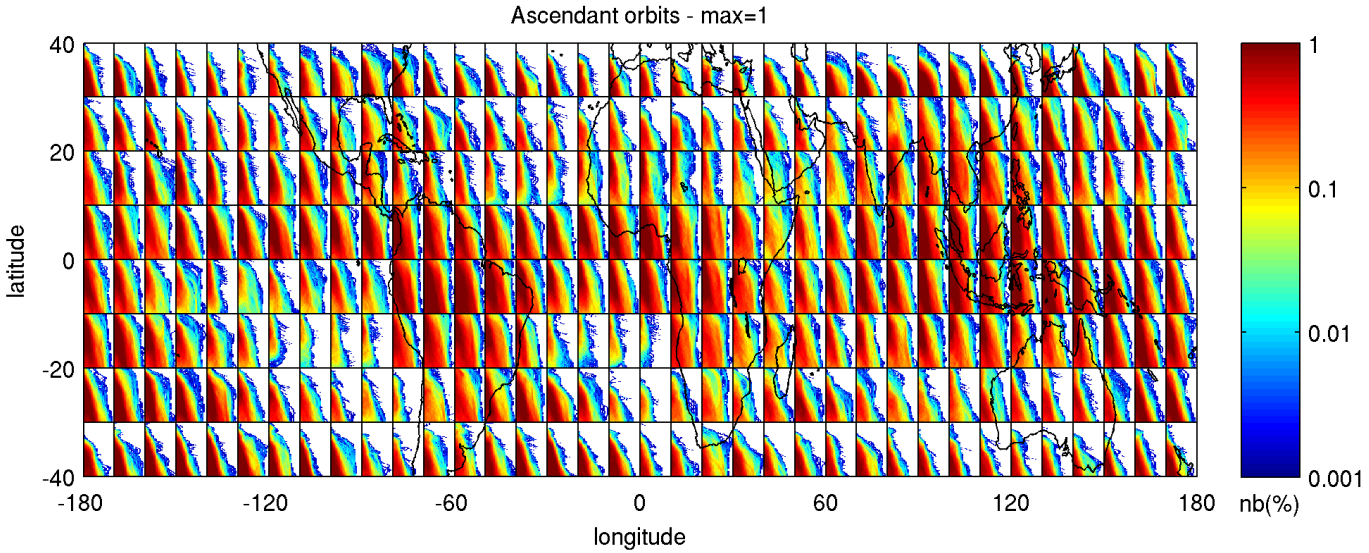


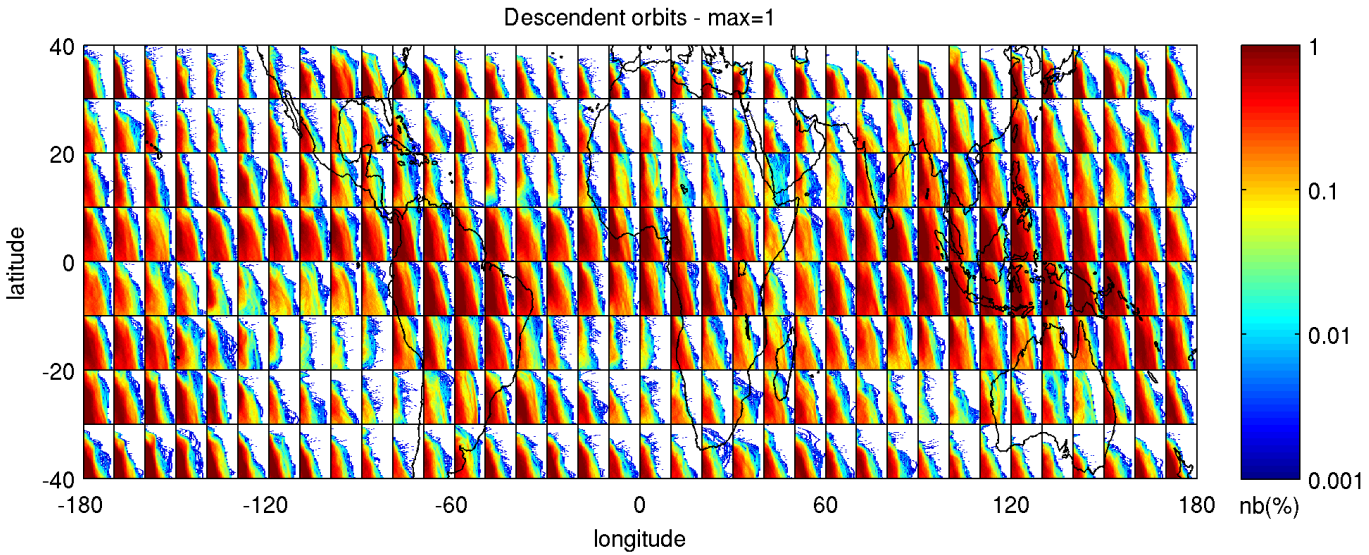


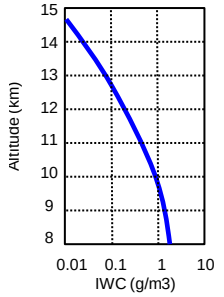


High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (14/17)

MAM

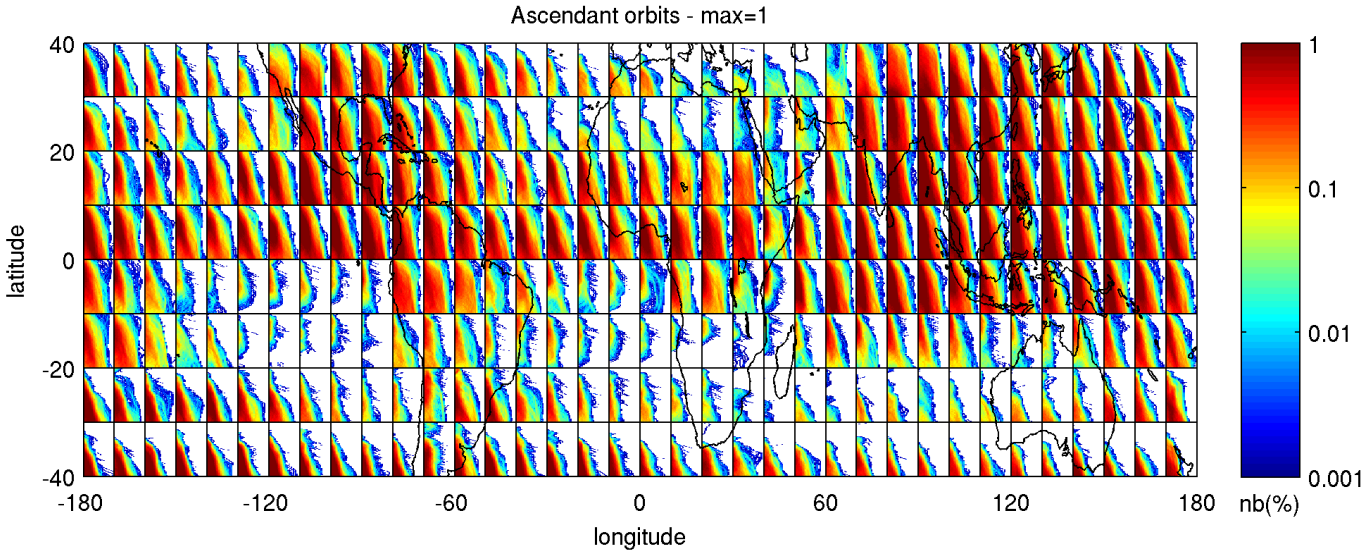


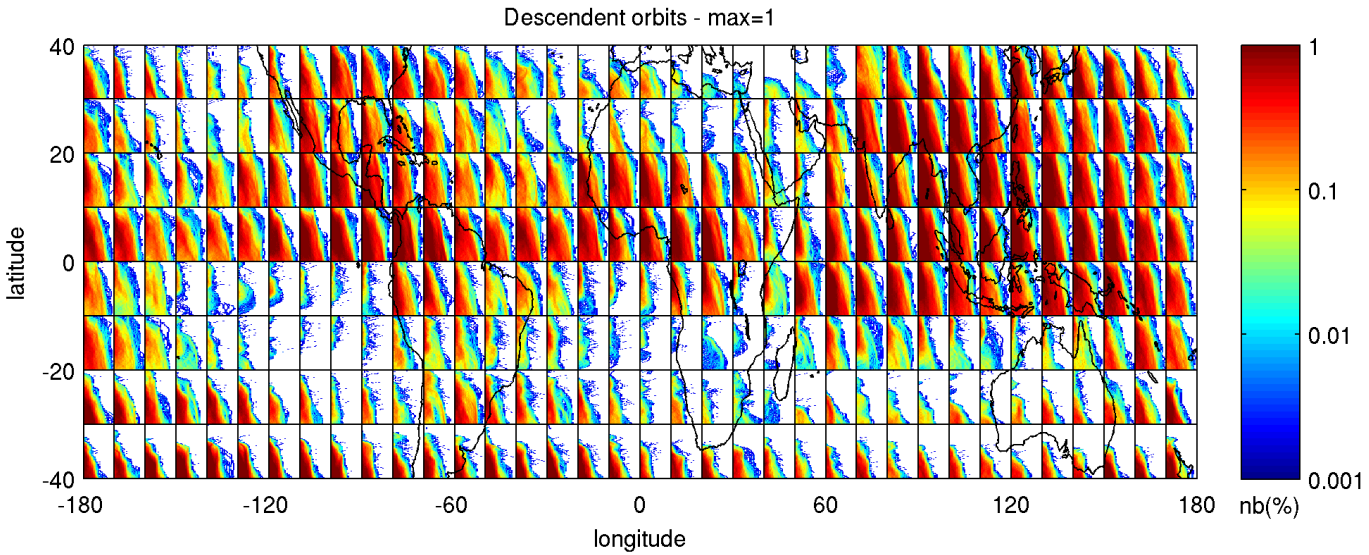


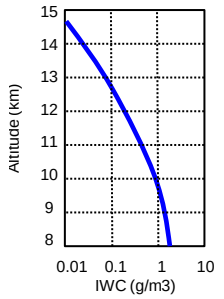


High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (15/17)

JJA

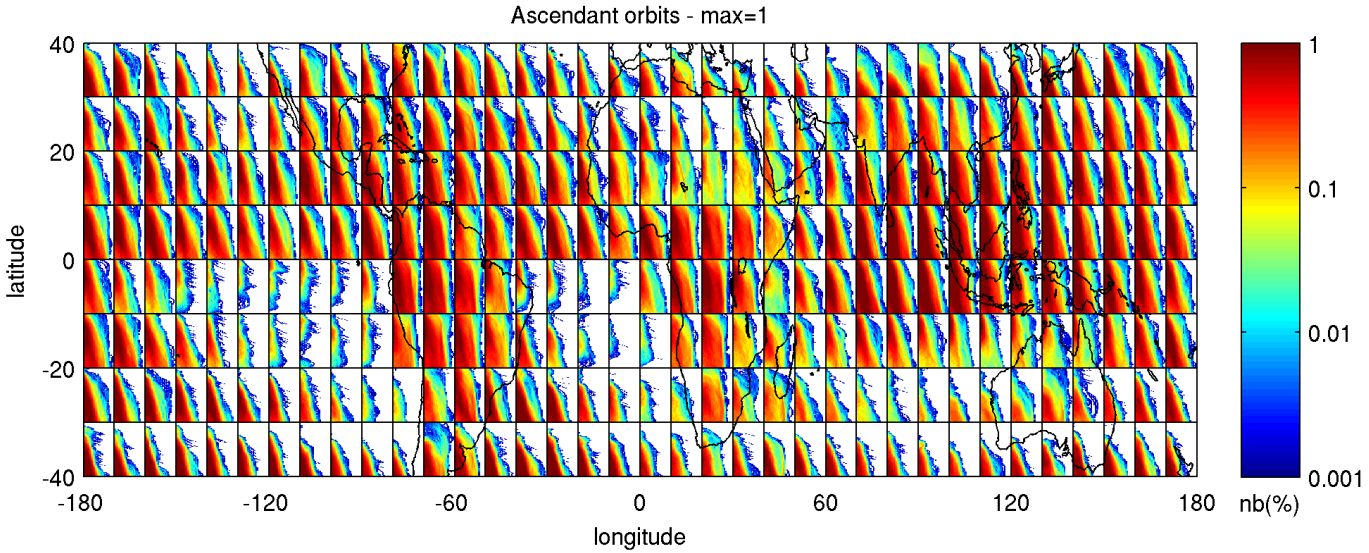


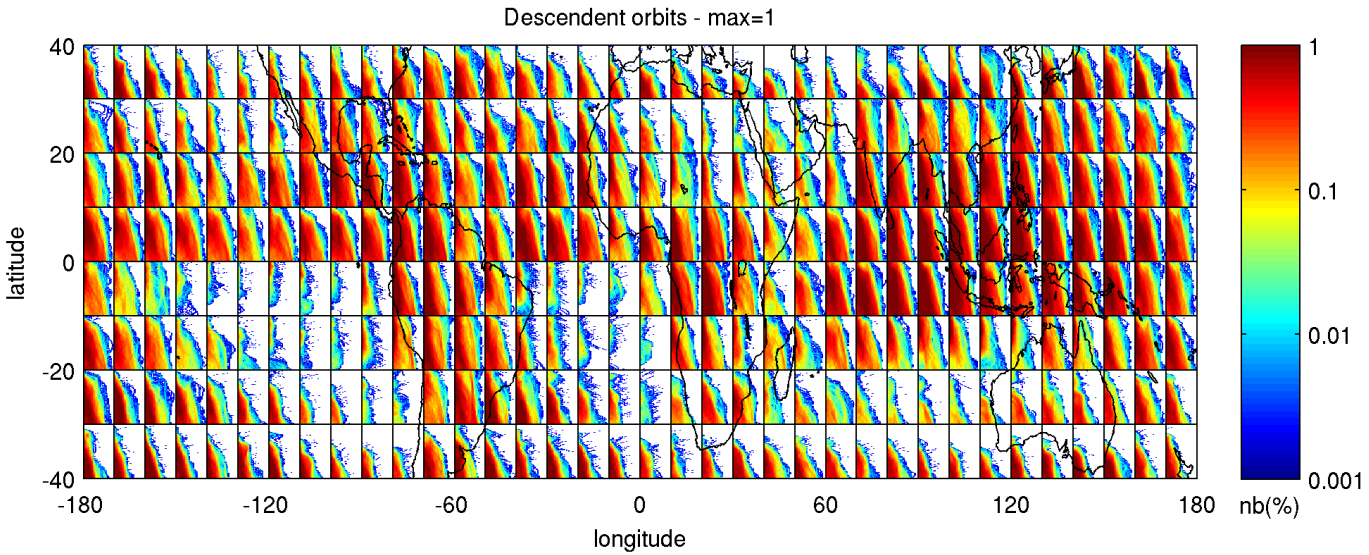


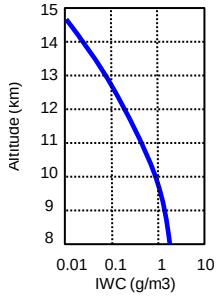


High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (16/17)

SON

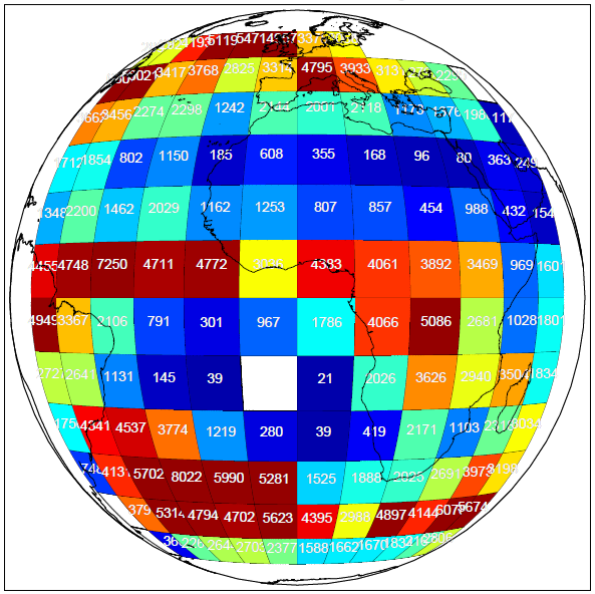




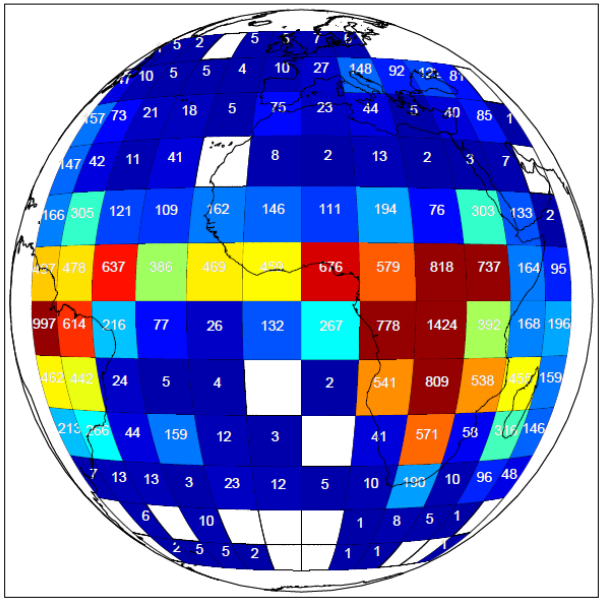


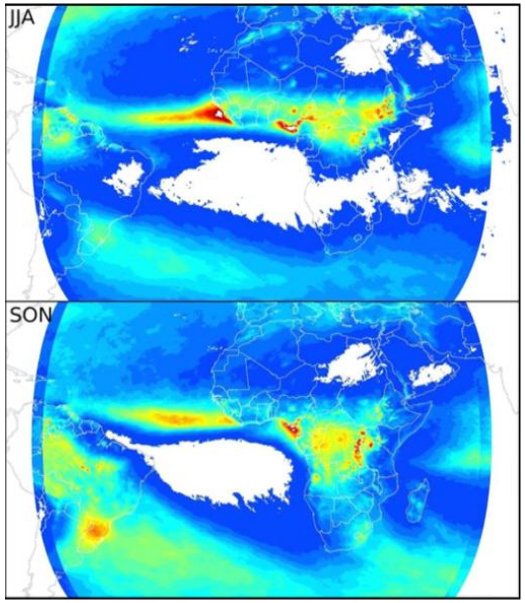
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (17/17)

- Comparison between DARDAR climatology and KNMI CPP High IWC mask climatology



DARDAR 2008 IWC occurences > 1.0 g/m^3





MSG CPP High IWC climatology 2005-2014

- numbers indicate the total number of occurences within 10º × 10º intervals
- colors are associated with numbers, colors are only indicative

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High Altitude Ice Crystals
Nowcasting of Tropical Convection (1/9)

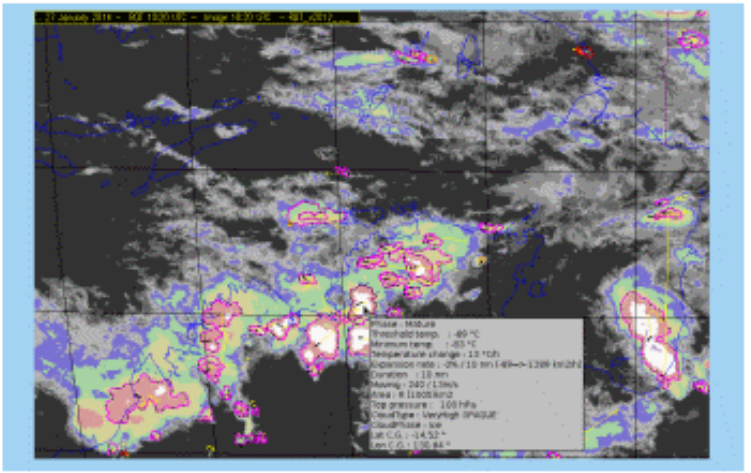
Technology Overview

Object:
Detection of convection
Change:
- Detection of high IWC areas
- New operation areas
- Output file adapted for uplink
Key Requirement:
Key1: Detection, tracking and characterization of convective areas
Key2: Detection requirements concerning convection detection can follow those defined by EUMETSAT. Target accuracy concerns early detection (before first lightning occurrence), late detection (after first lightning occurrence), overall thunderstorm detection skill.
Key3: Detection requirements concerning IWC analyzed with HAIC campaign.
Key4: Reasonable elaboration/dissemination delay of the product

Product environment:
- Main scientific development in the context of NWCSAF
- Fields campaign case studies, Airbus event database analysis, HAIC specific development and operation suite. HAIC and SESAR programs

Deliverable focal point:
Jean-Marc Moisselin

Product Illustration



Benefits:
Life and property Security. Economical optimization
Warning of convective areas for aviation. Possibility to estimate the intensity of storm via its radiative, dynamical and morphological characteristics. Possibility to plan and adjust the flight trajectory according to the forecast of the thunderstorm position.

Position vs. Competition:
Other satellite-based products, developed for example by DLR Institute of Atmospheric Institute (Germany), NCAR (US).
Numerous convection products based on meteorological radars. RDT can used different kind of GEO satellites

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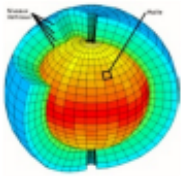
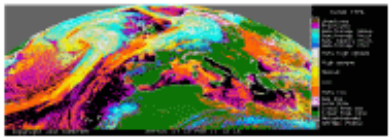
High Altitude Ice Crystals
Nowcasting of Tropical Convection (2/9)

Input Data: Multisource



NWP data



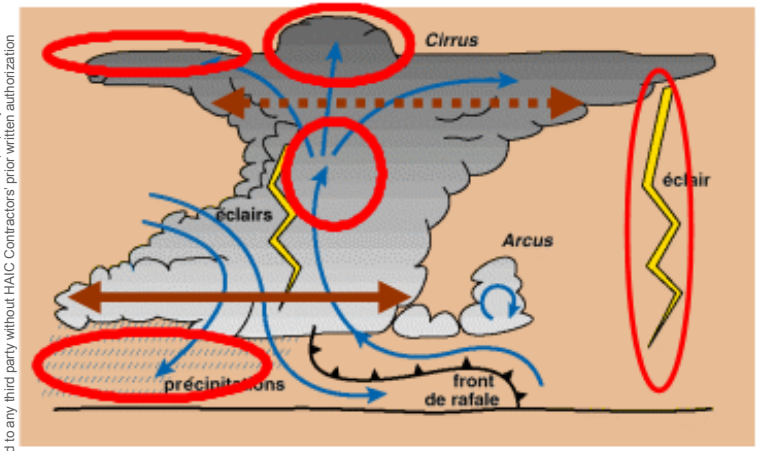
GEO data
(5 IR channels + VIS)

RDT

Lightning Data

Other NWCSAF products

Output: Multilevel Description Of Convection



- Main description of cell: Yes/No convection diagnosis, cell-development phase, position, surface, T, gap to tropopause, cloud type and phase, cloud top pressure. Severity Index high IWC hazard. Displacement Relevant trends are calculated
- Overshooting Tops, Lightning Activity, Convective Index, Rainfall Activity

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High Altitude Ice Crystals
Nowcasting of Tropical Convection (3/9)

PR3: Demonstration of interoperability (1/3)

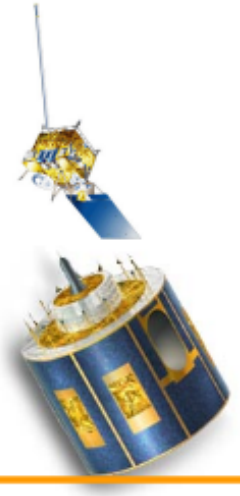
Darwin 2014

-New MTSAT RDT production

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

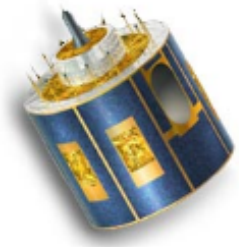
Cayenne 2015

- New MSG RDT production, existing production for GOES
- RDT for ground operation (MSG+GOES)
- RDT uplinked
- RDT for post-campaign analysis



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



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High Altitude Ice Crystals
Nowcasting of Tropical Convection (4/9)

PR5.1 Commonly agreed validation methodology

		Name	Comments
Convective cells vs high IWC value	**Convective RDT cells from the closest slot in time**	**Method 1A** Convective/ Closest RDT	**The reference. Minimizing the time-difference between measurements and satellite image**
	Convective RDT cells from the closest slot in time AND the previous one	**Method 1B** Convective/ closest+previous RDT	-To take into account the blinking effect of RDT -To assess the nowcasting potential of RDT concerning IWC risk
	Convective RDT cells from the closest slot in time AND the two previous ones	**Method 1C** Convective/ closest+2previous RDT	
Convective or previously convective cells vs high IWC values	RDT cells from the closest slot. Convective cells OR at least once convective in the past hour.	**Method 2** Last-hour 1x convective/ closest cell	Compensates some too early declassification of mature systems (regarding IWC hazard)

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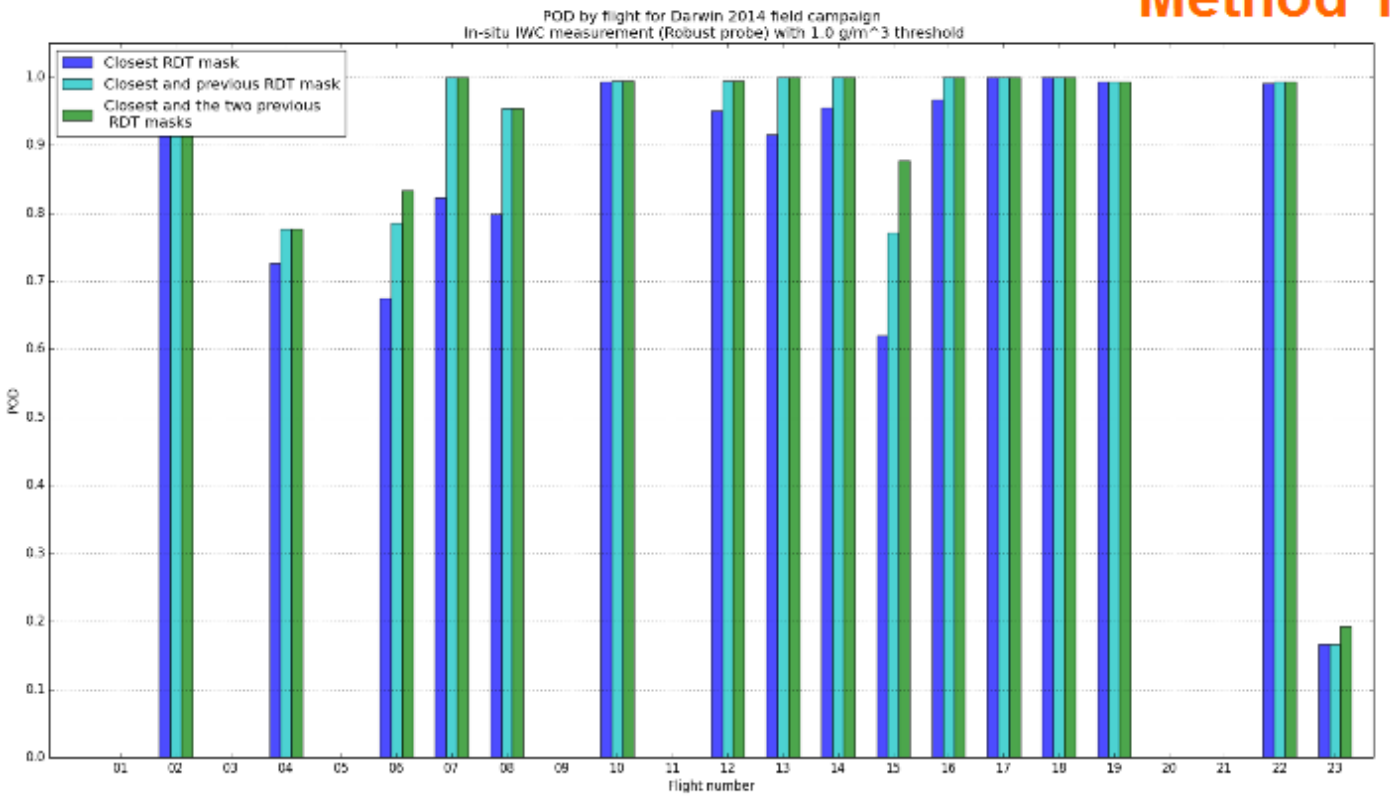
High Altitude Ice Crystals
Nowcasting of Tropical Convection (5/9)

PR5.2: HAIC/HIWC Darwin 2014

Ref=Probe

Method 1A 1B 1C



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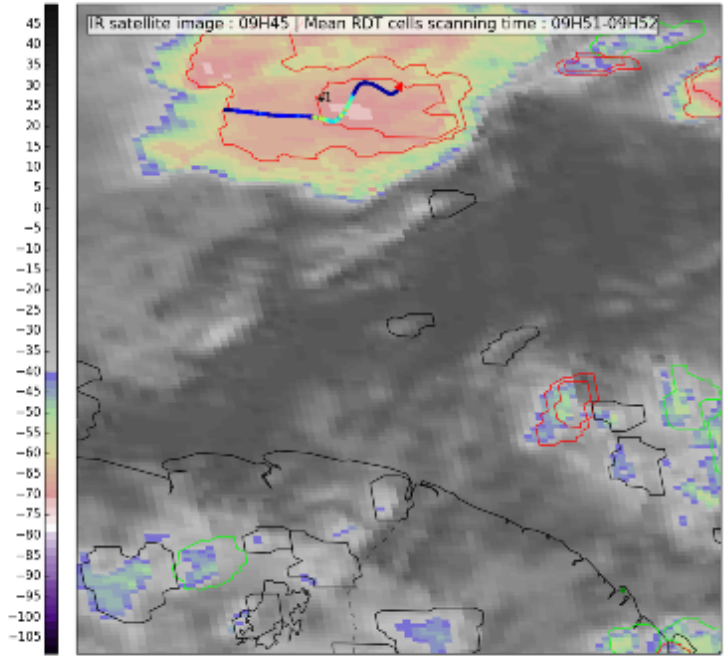
High Altitude Ice Crystals
Nowcasting of Tropical Convection (6/9)

PR5.3: HAIC/HIWC Cayenne 2015

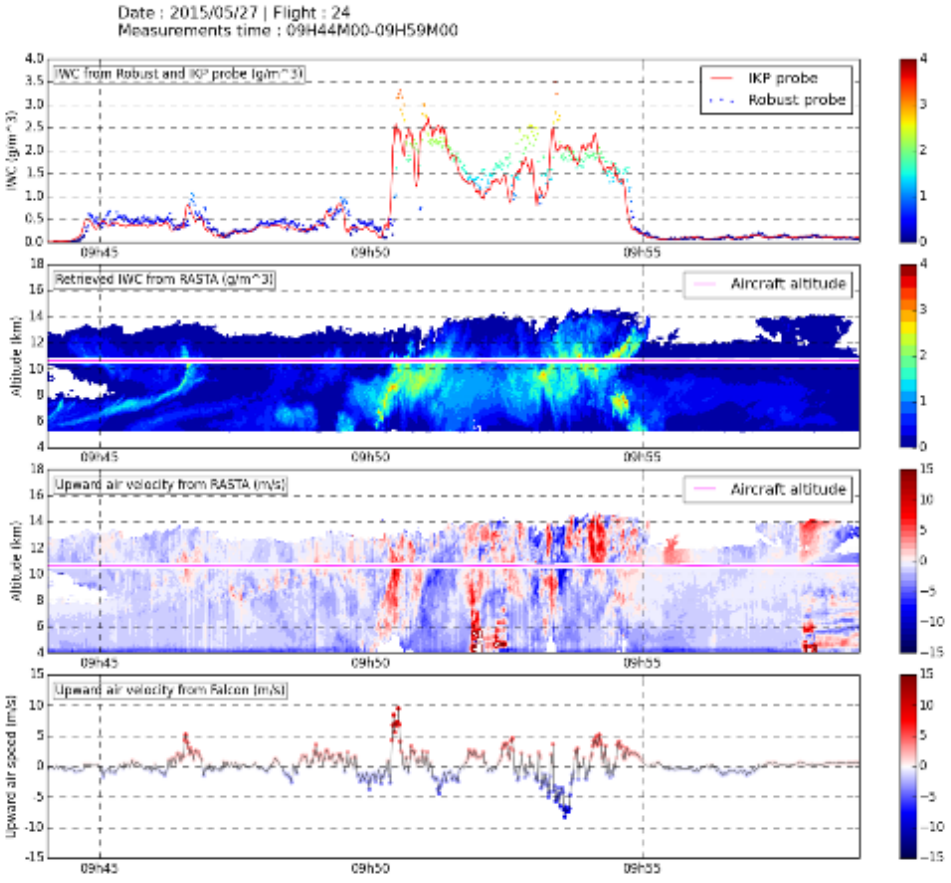


T thresh	T mean	T min	dT min	Light	Alt max	Cat
Cell #1 : detected at 08H52, tracked since 08H45						
BT -64.8	-67.2	-74.9	2.2	0	14786	Nature
ST -68.8	-69.7	-74.9	---	-	14786	Nature

Flight 24

Good agreement

Interest of 2nd level



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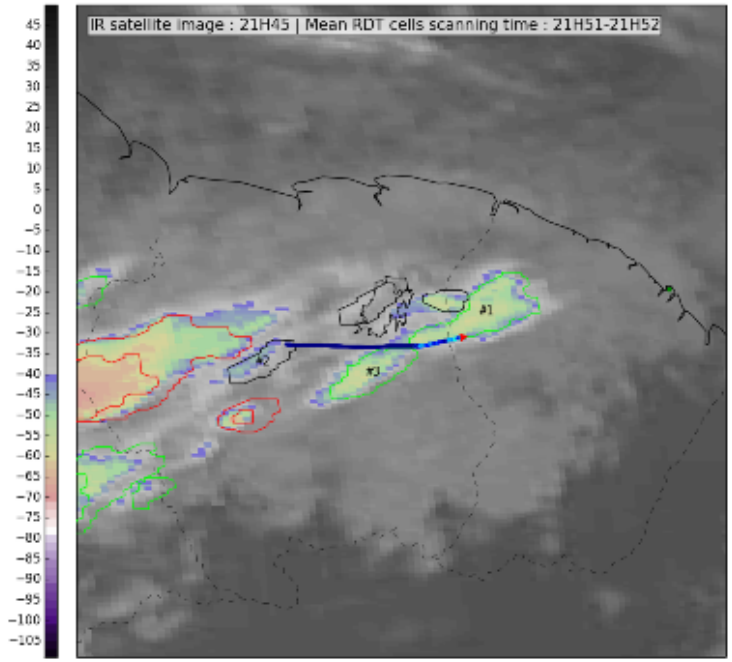
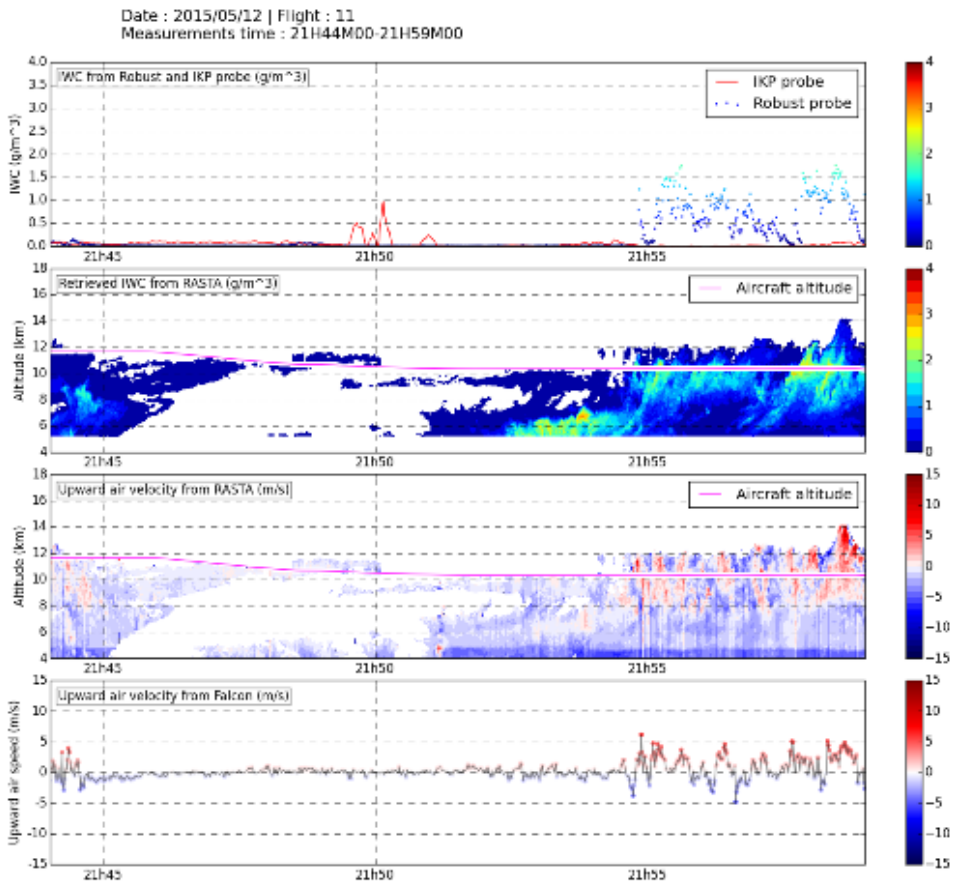
High Altitude Ice Crystals
Nowcasting of Tropical Convection (7/9)

PR5.3: HAIC/HIWC Cayenne 2015



	T thresh	T mean	T min	dT min	Light	Alt max	Cat
Cell #1 : detected at 21h52, tracked since 19h45							
BT	-49.8	-53.6	-58.3	-8.4	6	12652	Mature
Cell #2 : detected at 21h51, tracked since 21h30							
BT	-46.8	-44.5	-49.8	-4.0	6	11737	Mature
Cell #3 : detected at 21h51, tracked since 19h45							
BT	-47.8	-52.4	-57.6	15.1	6	12652	Decroissance



Flight 11

Interest of Method 2

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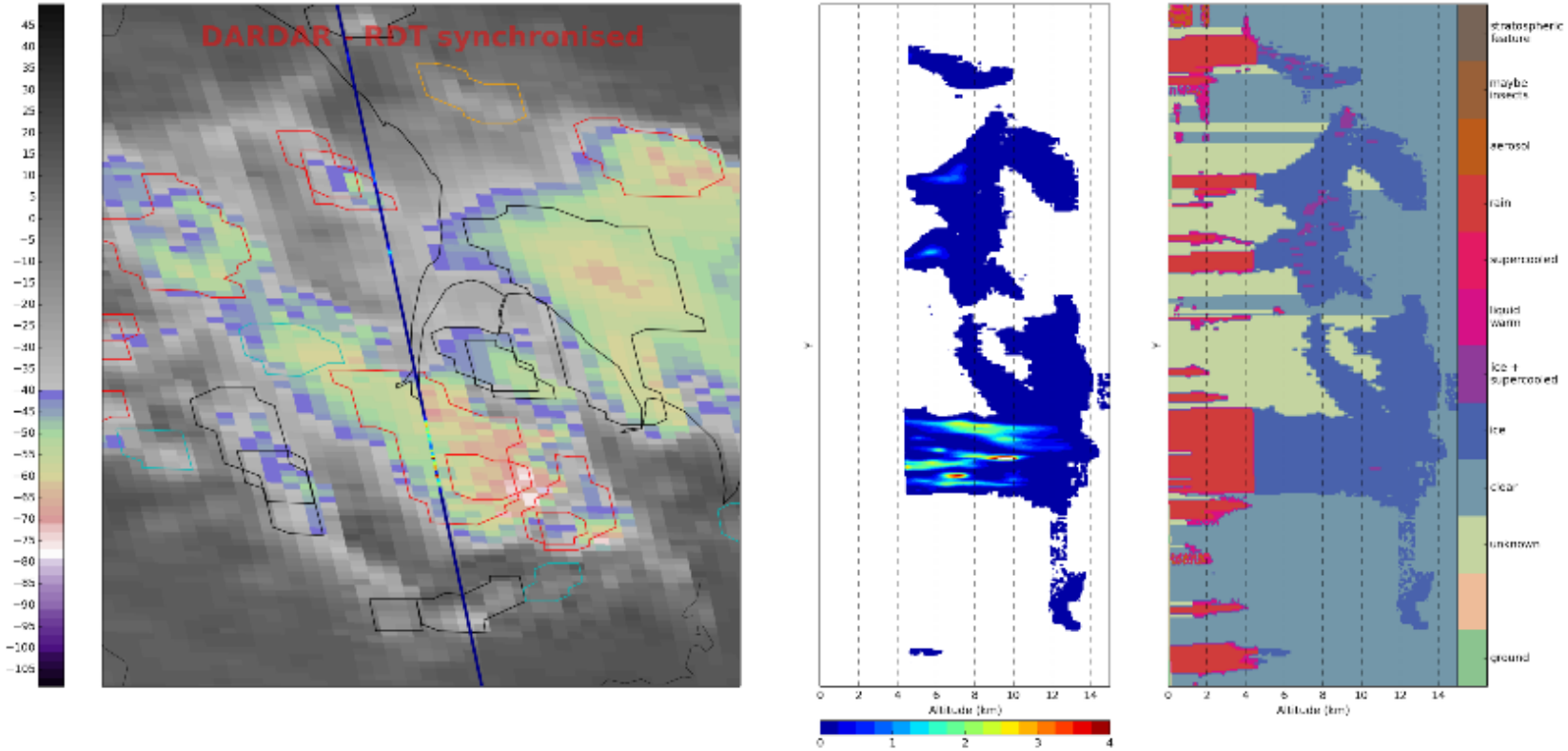
High Altitude Ice Crystals
Nowcasting of Tropical Convection (8/9)

PR5.5: A-TRAIN / DARDAR



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High Altitude Ice Crystals
Nowcasting of Tropical Convection (9/9)

Conclusion concerning RDT

- RDT is global (GOES-W GOES-E MSG METEOSAT-7/MSG1 Himawari-8)
- RDT is ready for uplink
- « Global RDT » already used by aeronautical end-users
- RDT is day and night product
- RDT has been operated for all HAIC campaign, uplinked to Research flight for 2015 and 2016 campaigns
- RDT has been evaluated against all HAIC campaigns and against DARDAR
- RDT provides high POD concerning high IWC Detection
- Some ways of improvement have been prototyped (e.g. prototype 2). Some mitigation strategies concerning other issues have been identified (e.g. blinking effect)
- v2016 SW delivered contains an high IWC attribute at cloud scale.

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High Altitude Ice Crystals
Content

- Context
- The HAIC Project
- The SP3 Activities
- **Status at M51**
- Way Forward

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High Altitude Ice Crystals
Status at M51, 2 months to go to the end of the HAIC project…

Milestone #	Milestone name	Status
MS168	Key TRL3 – Geostationary space-borne retrieval of High IWC regions (WP32)	✓
MS166	Design and development of a new RDT production over Tropical Atlantic	✓
MS169	Key TRL3 – Detection of Rapidly Developing Thunderstorm RDT (WP34)	✓
MS165	Cross-validation of SEVIRI retrievals with LEO sensors	✓
MS098	Pre-operational application of SEVIRI high IWC retrieval implemented at KNMI and merged with RDT	✓ X
MS105	Key TRL5 – Geostationary space-borne retrieval of High IWC regions (WP32)	✓
MS099	Pre-operational RDT application implemented	✓
MS106	Key TRL5 – Detection of Rapidly Developing Thunderstorm RDT (WP34)	✓
MS127	F/T (WP22, WP23 on a best effort basis) & analysis & final assessment completed	✓
MS136	Key TRL6 – Geostationary space-borne retrieval of High IWC regions (WP32)	✓
MS166	F/T (WP22, WP23) & analysis & final assessment completed	✓
MS137	Key TRL6 – Detection of Rapidly Developing Thunderstorm RDT (WP34)	X

WPs	To deliver	Delivered	In review	Publications
WP31	4	3	1	1
WP32	5	3	2	1
WP33	4	2	2	--
WP34	5	3	2	1

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High Altitude Ice Crystals
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High Altitude Ice Crystals
Summary and Way Forward

- **Development and validation of High IWC detection schemes through GEO and LEO (MODIS) visible observations and products**
  - **TRL6 maturity for KNMI High IWC product, TRL5 for MET-FR RDT**
  - **1st generation with demonstration on different GEO satellites**
  - **Toward a global product → MSG, HIM, GOES-R → daytime climatology**
  - **Detection scheme adapted to MODIS → better spatial resolution and better coverage at higher latitude but low orbit**
  - **But nighttimes product still to be developed through IR channels and passive microwave**
- **Support to the three HAIC campaigns with display of satellite products in the research aircraft**
  - **Strategic use as acquisition & latency time extremely limit tactical use**
  - **To be use in combination with on-board awareness detection**
- **New missions available or coming soon:**
  - **GEO : GOES-R (ABI; GLM), MTG (FCI; LI)**
  - **LEO : EarthCARE, METOP-SG (3MI, MWI/ICI)**

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High Altitude Ice Crystals (HAIC, 314314)

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Project co-funded by the European Commission within the Seventh Framework Programme (2012-2016)

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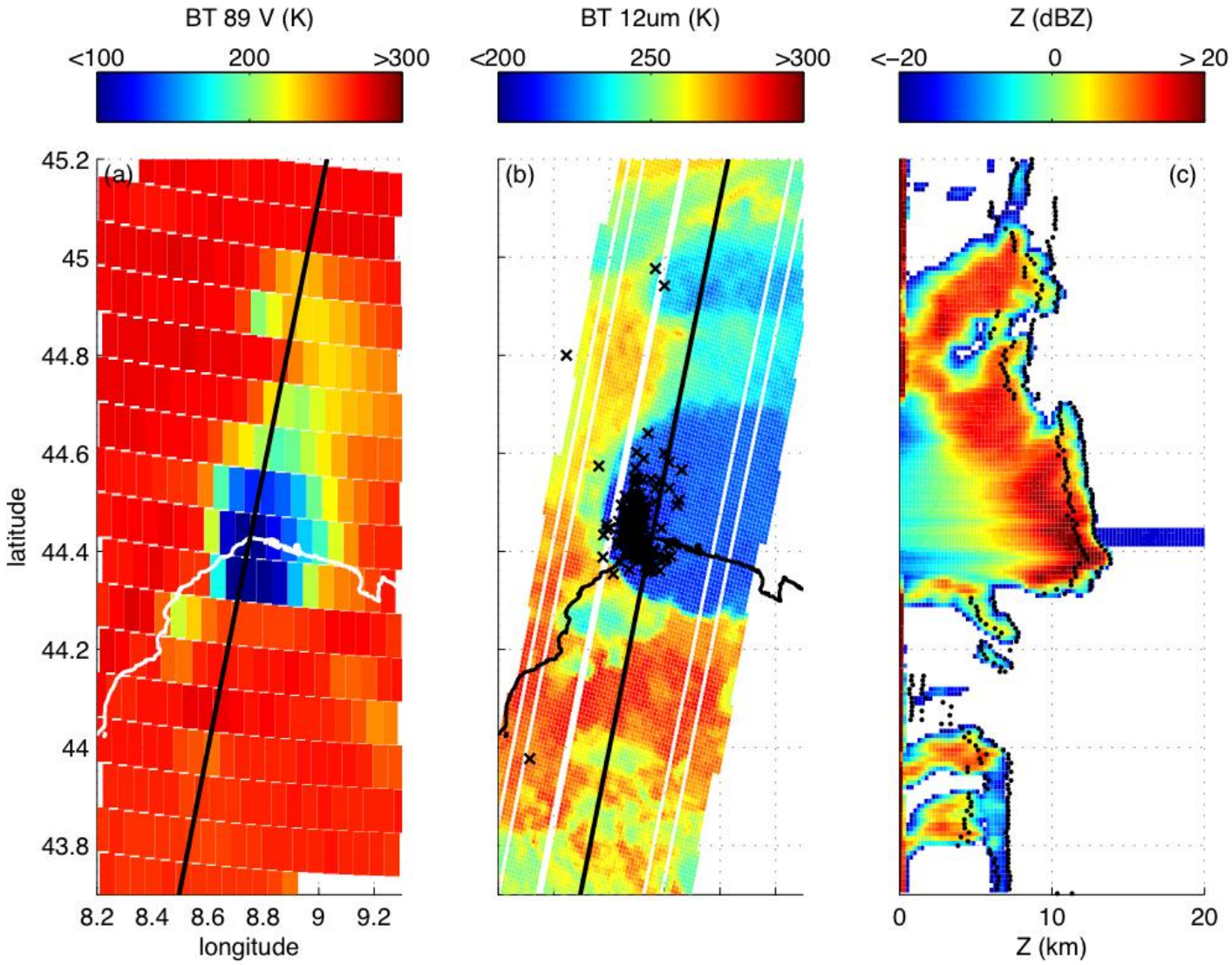
HAIC – High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (9/23)



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HAIC – High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (10/23)

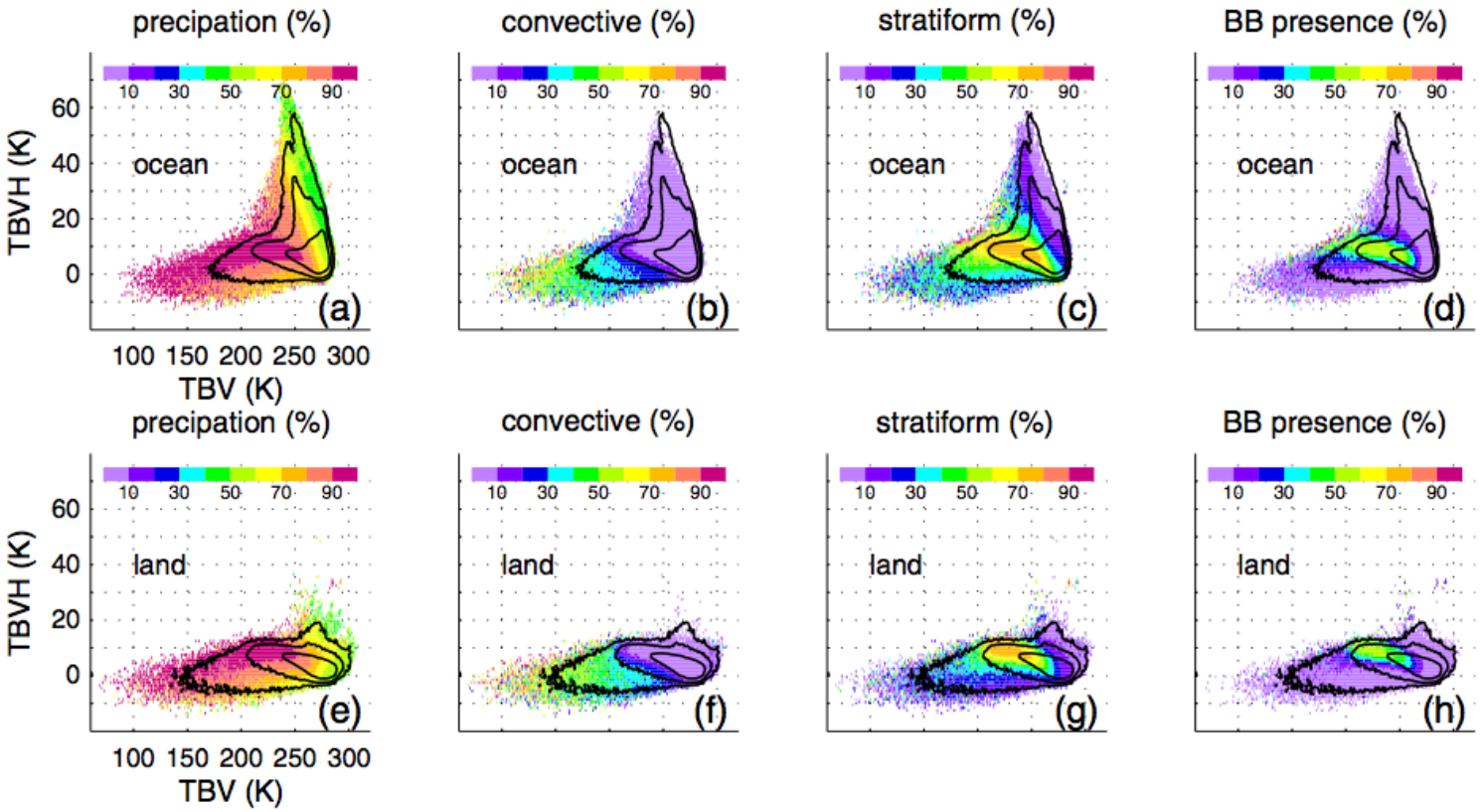

Figure 3. Scatter plot of the polarization difference (TBVH) versus the vertical polarization (TBV) at 85 GHz, for 2006 and 2007 data, over ocean (top) and over land (bottom), of the (a and e) probability of precipitation, of (b and f) convective rain, of (c and g) stratiform rain, and of (d and h) the presence of a BB. Black iso-lines delineate the population that represents 10^{-3}, 10^{-2}, and 0.1% of the total number of samples.

Galligani et al., 2013, JGR

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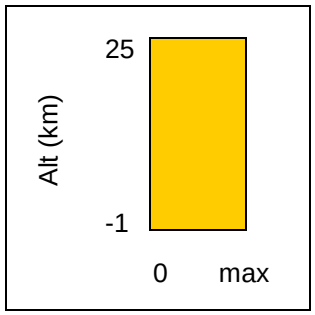
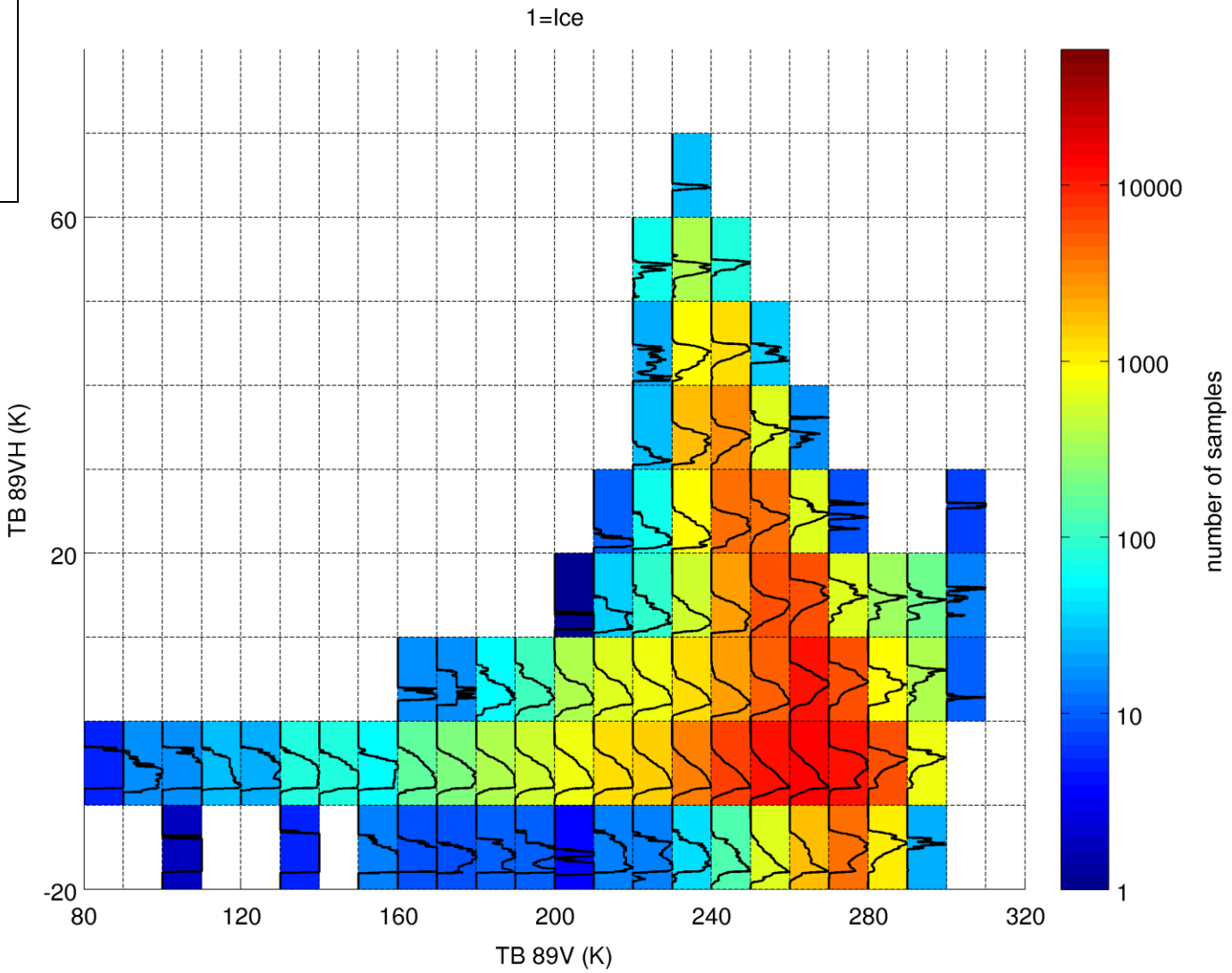
HAIC – High Altitude Ice Crystals

Polar Orbiting Space-borne Retrievals of High IWC (11/23)





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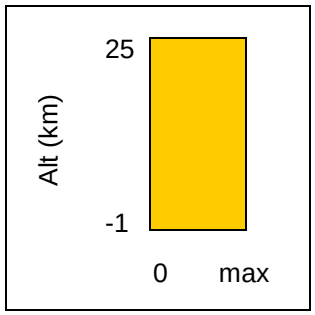
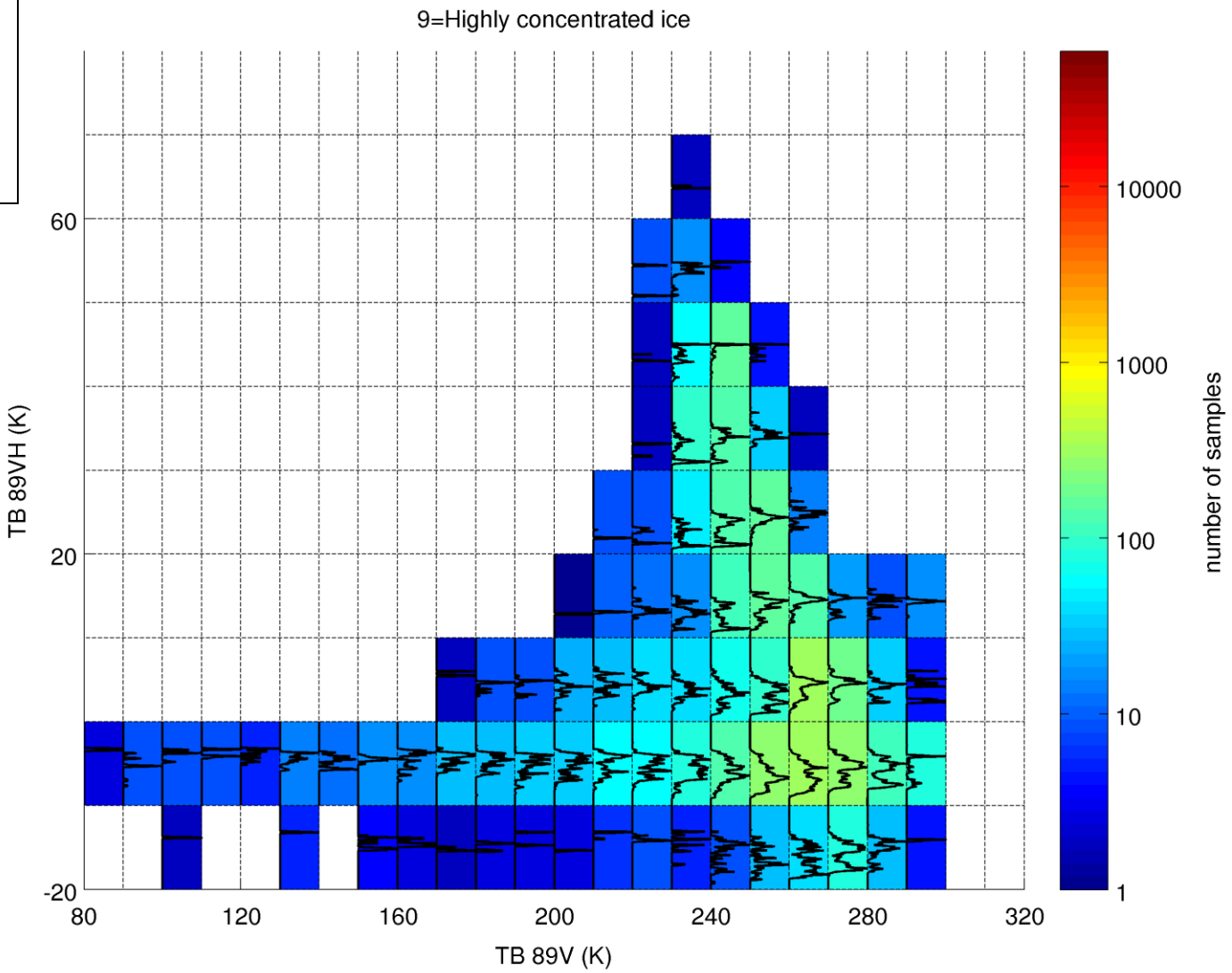
HAIC – High Altitude Ice Crystals

Polar Orbiting Space-borne Retrievals of High IWC (12/23)





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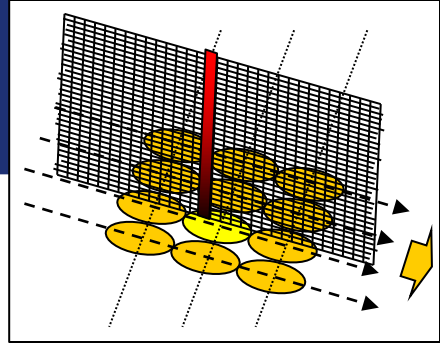
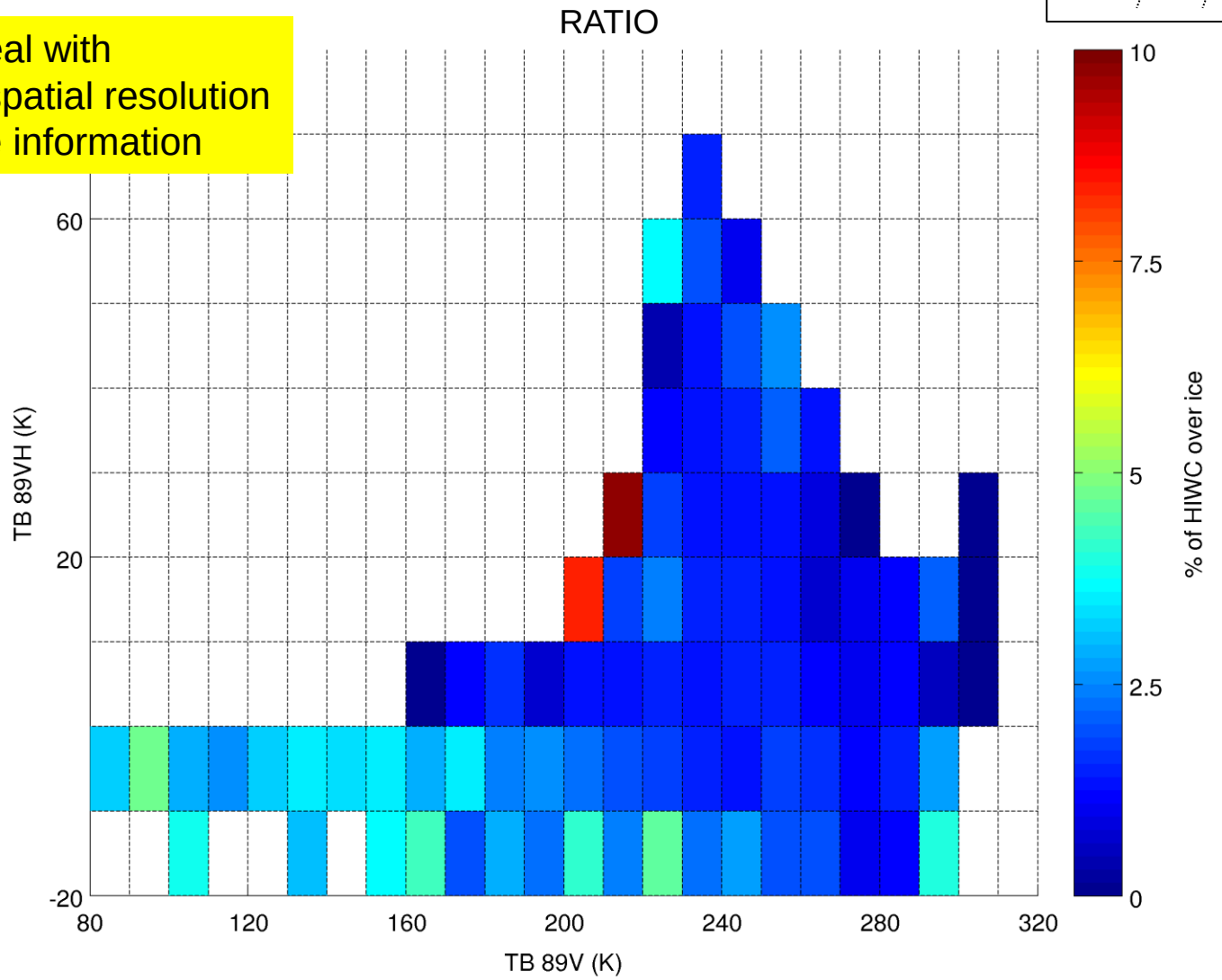
HAIC – High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals IWC (20/22)



Do NOT deal with
- different spatial resolution
- the profile information



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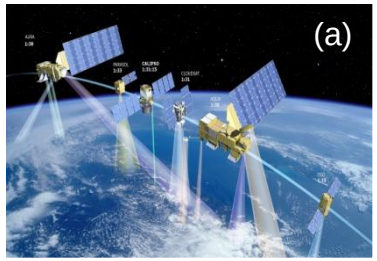
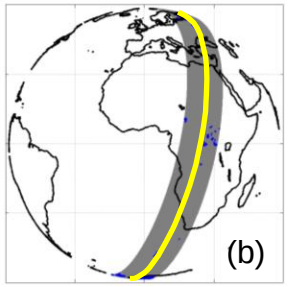
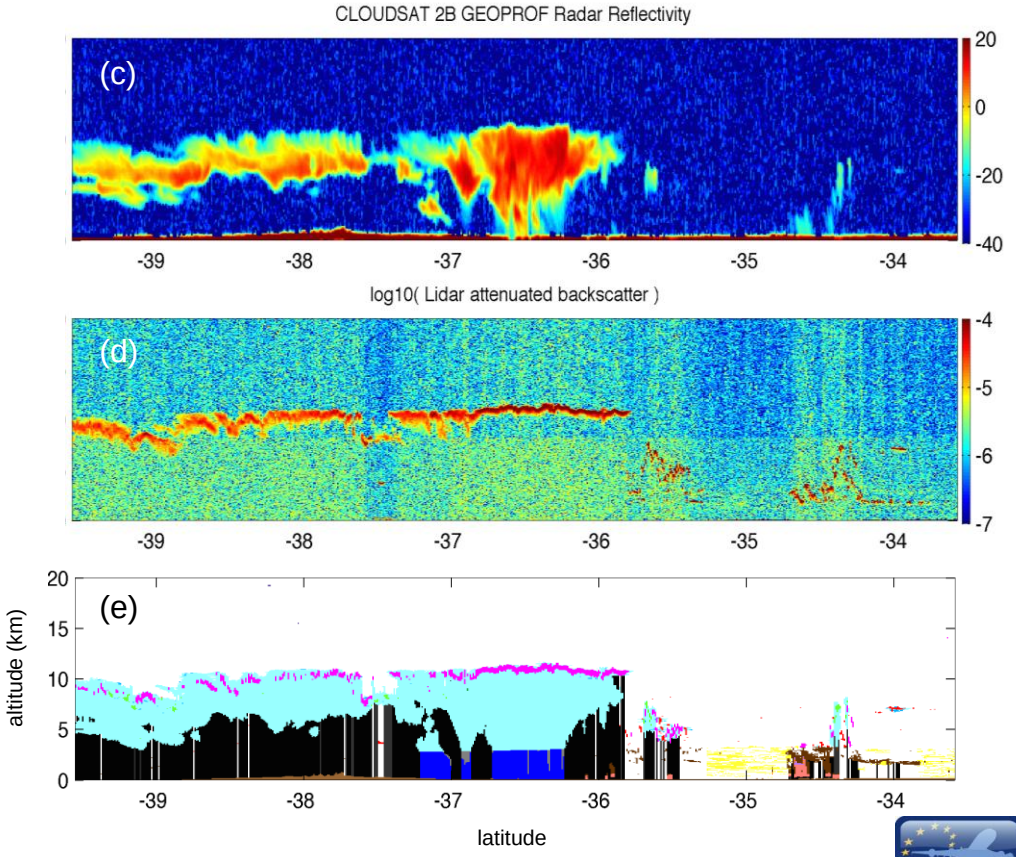
High Altitude Ice Crystals
Polar Orbiting Space-borne Retrievals of High IWC (20/22)

- **DARDAR** : 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 and r_e through a variational approach
- Capability to classify the cloud type at each altitude bin
- Always concurrent visible, infrared and microwave observations available of the A-Train mission
- Global coverage but small swath
- *RASTA mimics the A-Train radar*







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