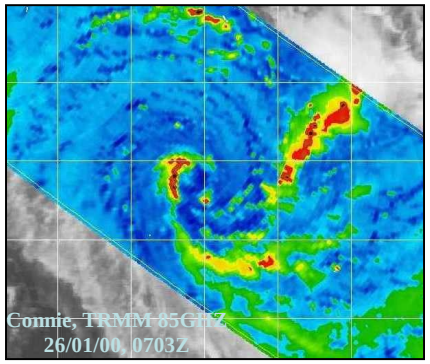
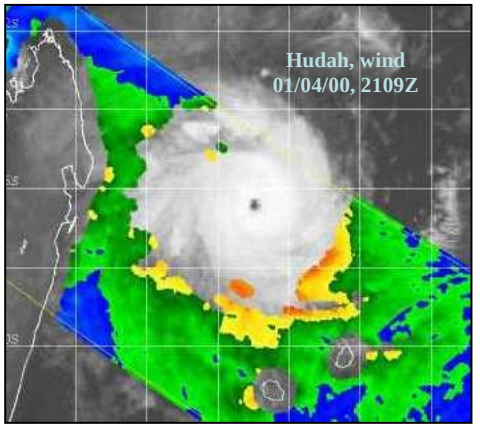
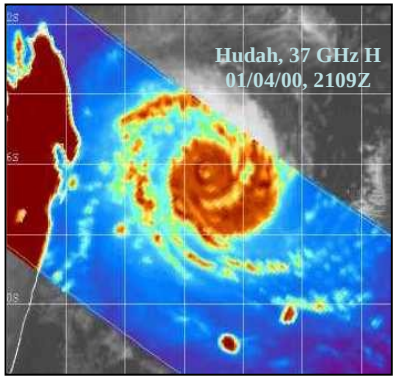


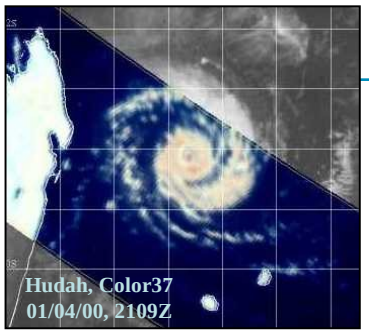




Satellite technology
Applications to tropical cyclones

9th training course about tropical cyclones

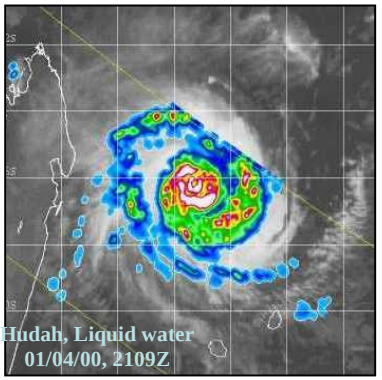
WMO / Météo-France

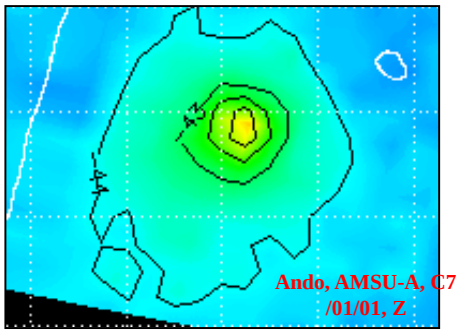


November 2019

Acknowledgements to COMET, NRL, CIMSS for many of the images shown here

Anne-Claire FONTAN
Thierry DUPONT
Sébastien LANGLADE
RSMC La Réunion





OUTLINE

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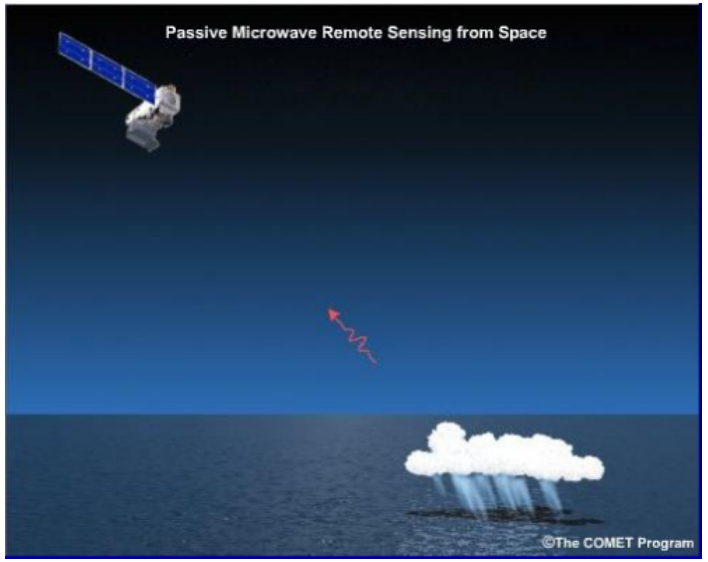
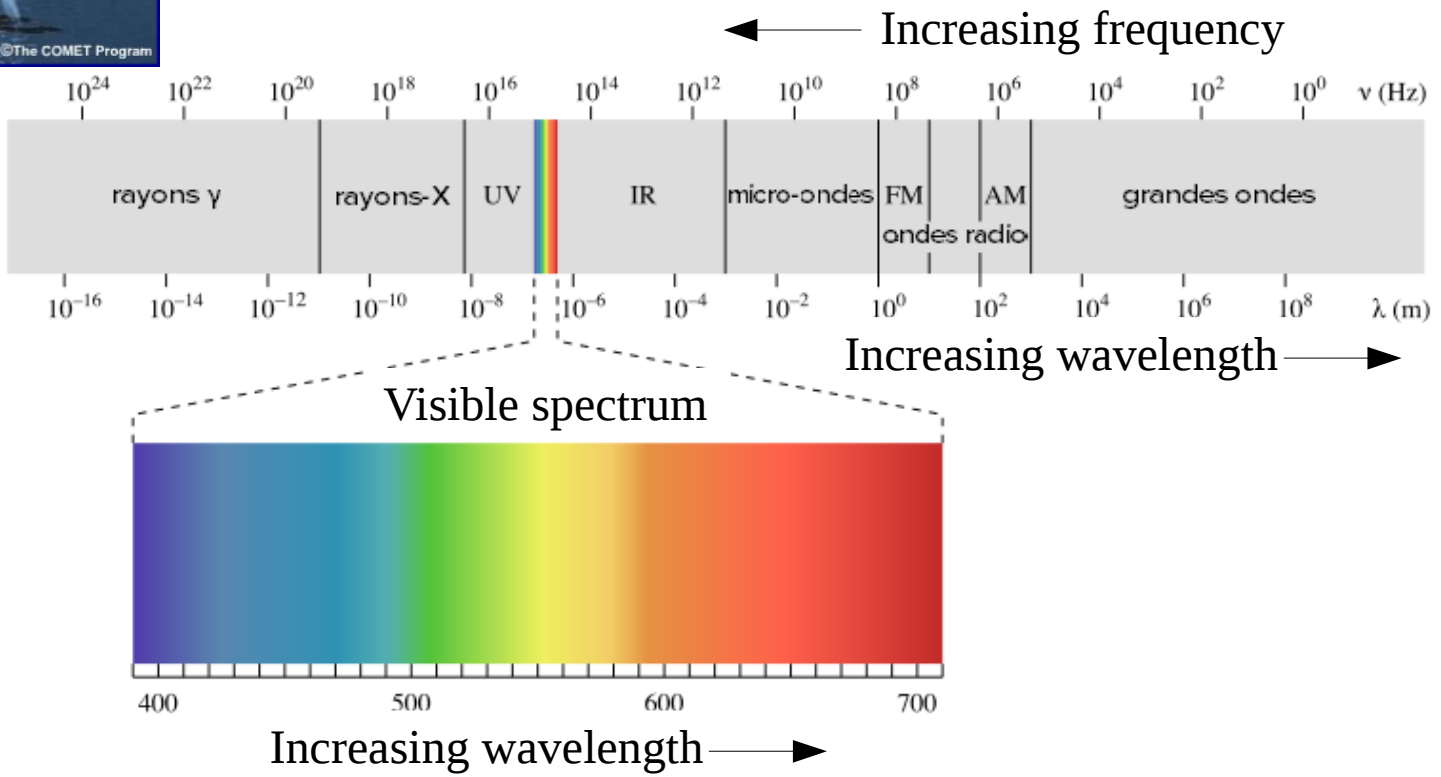
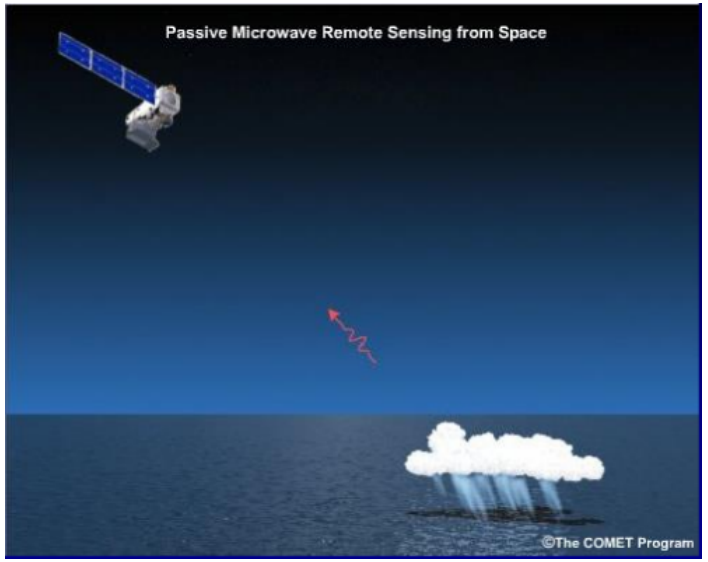
PASSIVE REMOTE SENSING FROM SPACE

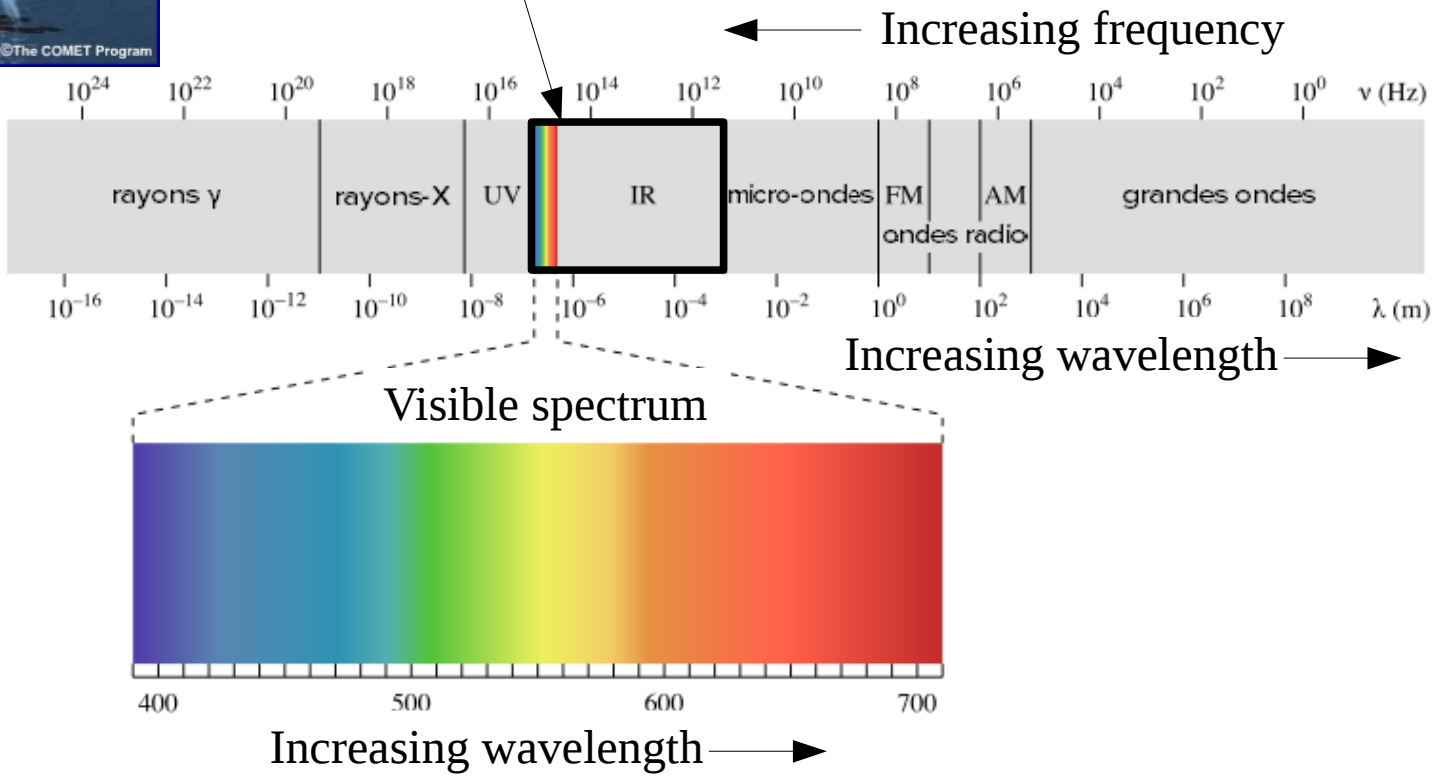




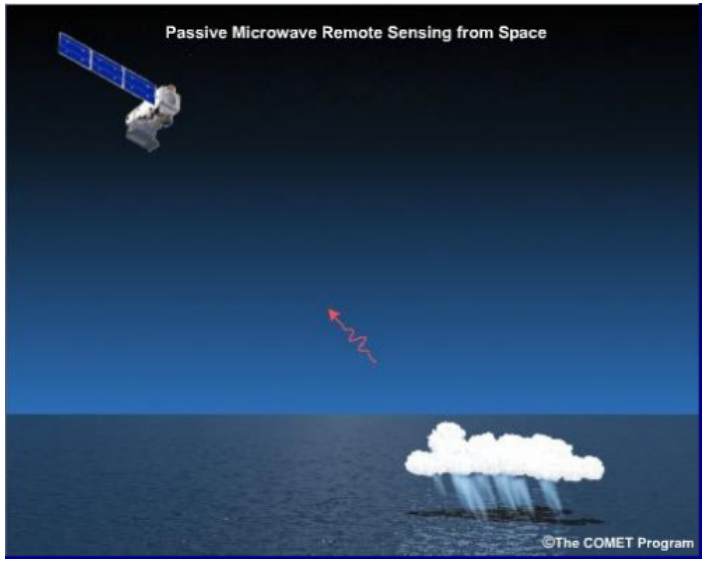
PASSIVE REMOTE SENSING FROM SPACE



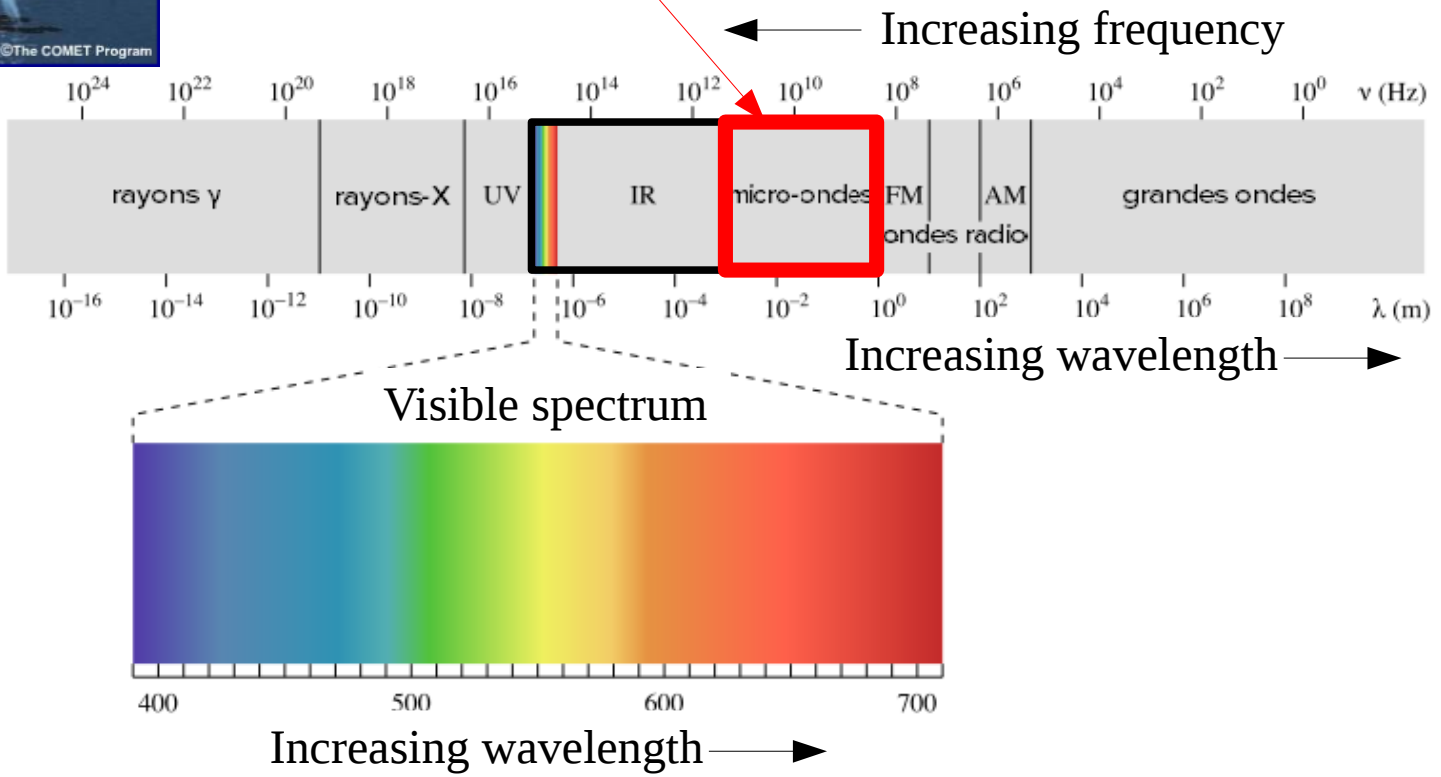
« Classical » imagery
Ex : Geostat MSG
VIS : 0.6-0.8 µm
IR : 4-13 µm



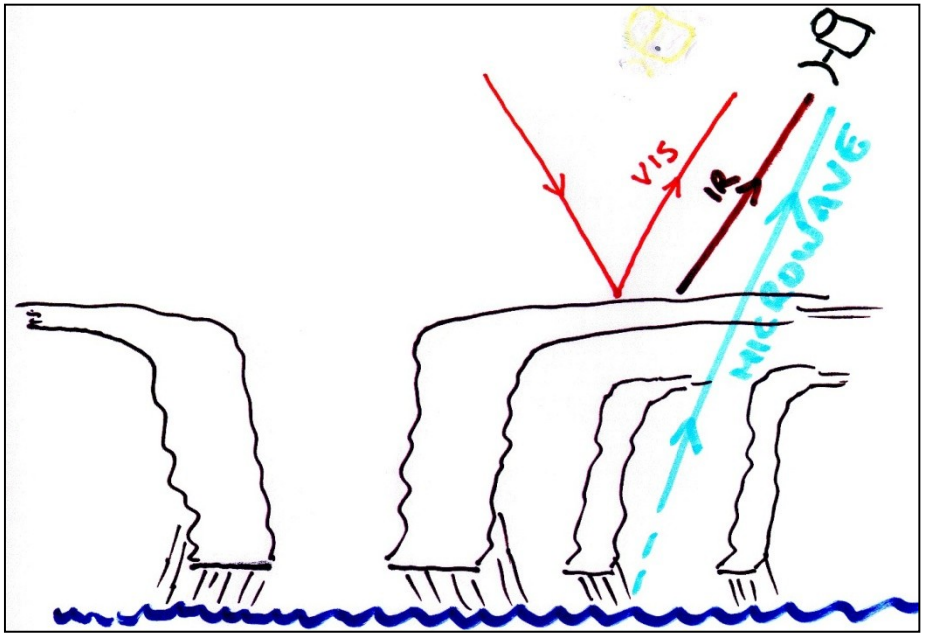
PASSIVE REMOTE SENSING FROM SPACE



Microwave spectrum :
300 MHz-300 GHz
1m - 1mm



MICROWAVE PROPERTIES

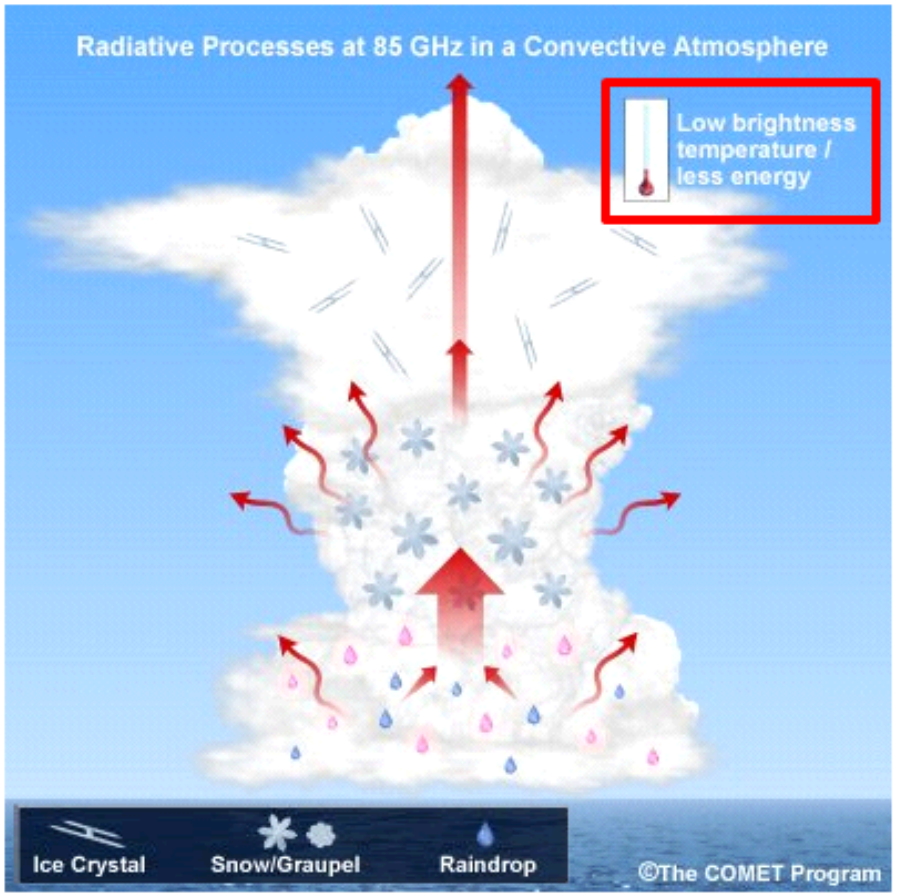


- ***Advantages***
  - *See through cirrus*
  - *Sensing whatever the atmospheric conditions*
- ***Drawbacks***
  - *Longer wavelength than VIS/IR so less energy and less horizontal resolution.*
  - *Only available on polar-orbiting satellites so less frequent coverage*
  - *Interpretation is more complex*

- **Avantages**
  - voient à travers les cirrus
  - détection dans presque toutes les conditions atmosphériques
- **Inconvénients**
  - Une longueur d'onde plus longue que le VIS ou IR (moins d'énergie et une résolution horizontale moindre)
  - Disponibles seulement sur les défilants donc une couverture moindre.
  - Interprétation plus complexe.

METEO FRANCE

RADIATIVE PROCESS AT 85 GHZ

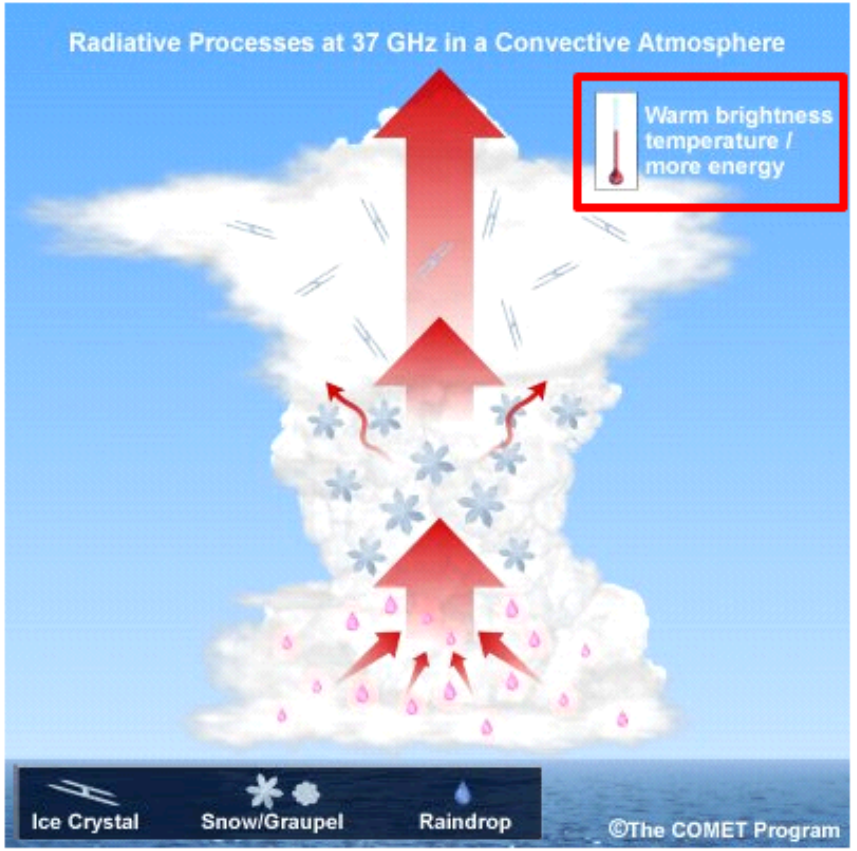


- **85 GHz. Energie radiative :**
  - **absorbée, réémise ou diffusée par les gouttes d'eau**
  - **Diffusée ensuite par les particules de glace**
  - **Peu d'effet des cirrus**
- **Peu d'énergie parvient au sommet**
- **DONC : températures de brillance très basses captées au dessus de la convection profonde à 85 GHz**

- ***85 GHz. Radiation :***
  - ***Absorbed, re-emitted or scattered by raindrops***
  - ***Scattered by precipitating ice particles***
  - ***Cirrus have little effect***
- ***Radiation seriously depleted when reaching the top***
- ***SO : very low brightness temperatures are sensed above deep convection at 85 GHz***

METEO FRANCE

RADIATIVE PROCESS AT 37 GHZ



- **A 37 GHz : énergie**
  - **absorbée par l'eau de pluie**
  - **Ré-émise par l'eau de pluie vers le le niveau supérieur**
  - **Peu diffusée par les particules de glace précipitantes**
  - **Pas d'effet des cirrus**
- **Energie abondante parvient au satellite**
- **DONC : hautes températures de brillance captées au sommet**

- ***At 37 GHz : radiation***
  - ***Absorbed by rain water***
  - ***Emitted from the rain water upwells further***
  - ***Minor scattered by precipitation ice particles***
  - ***Cirrus have no effect***
- ***Abundant energy reaches the satellite***
- ***SO : high brithness temperatures***

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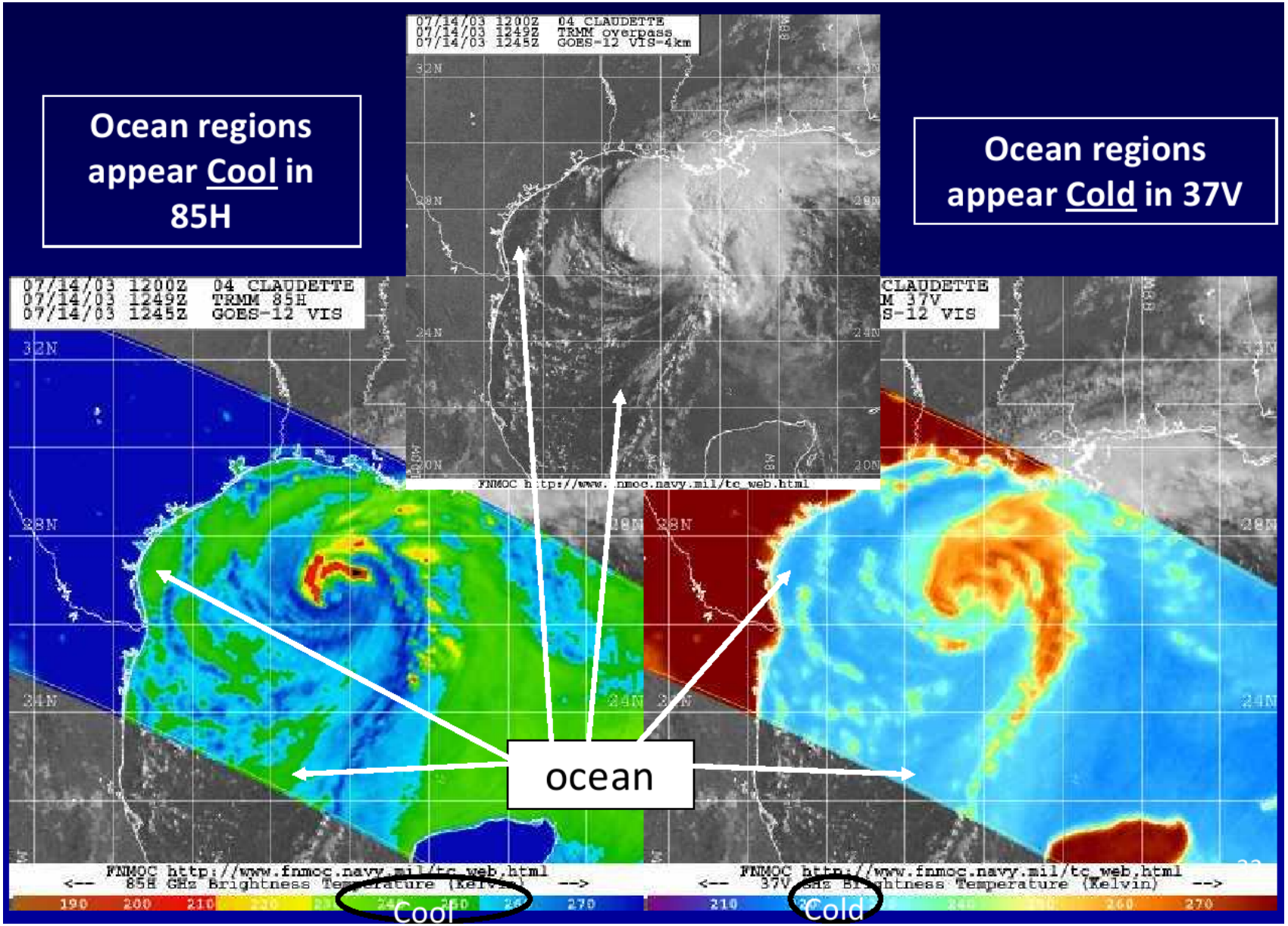
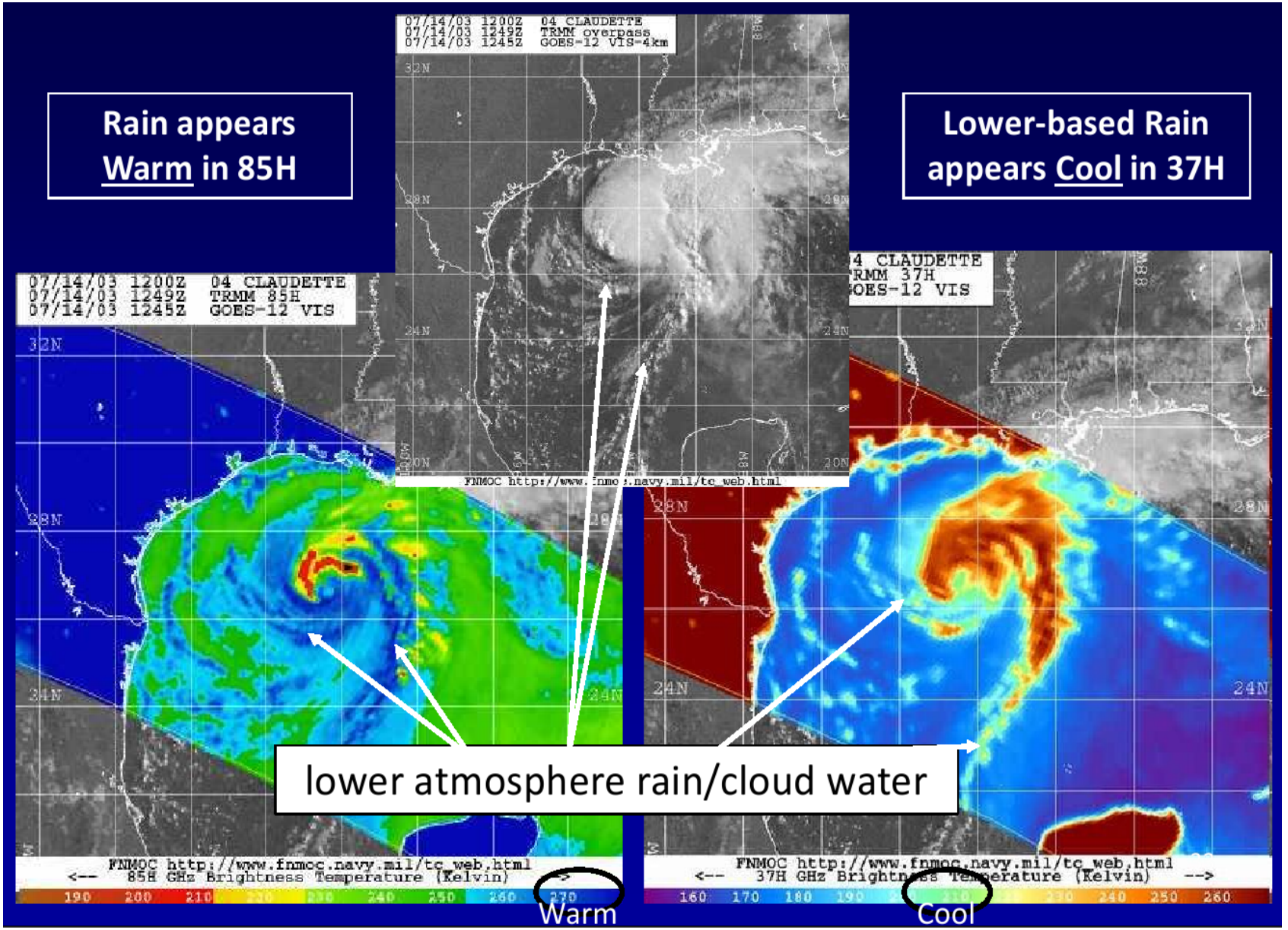
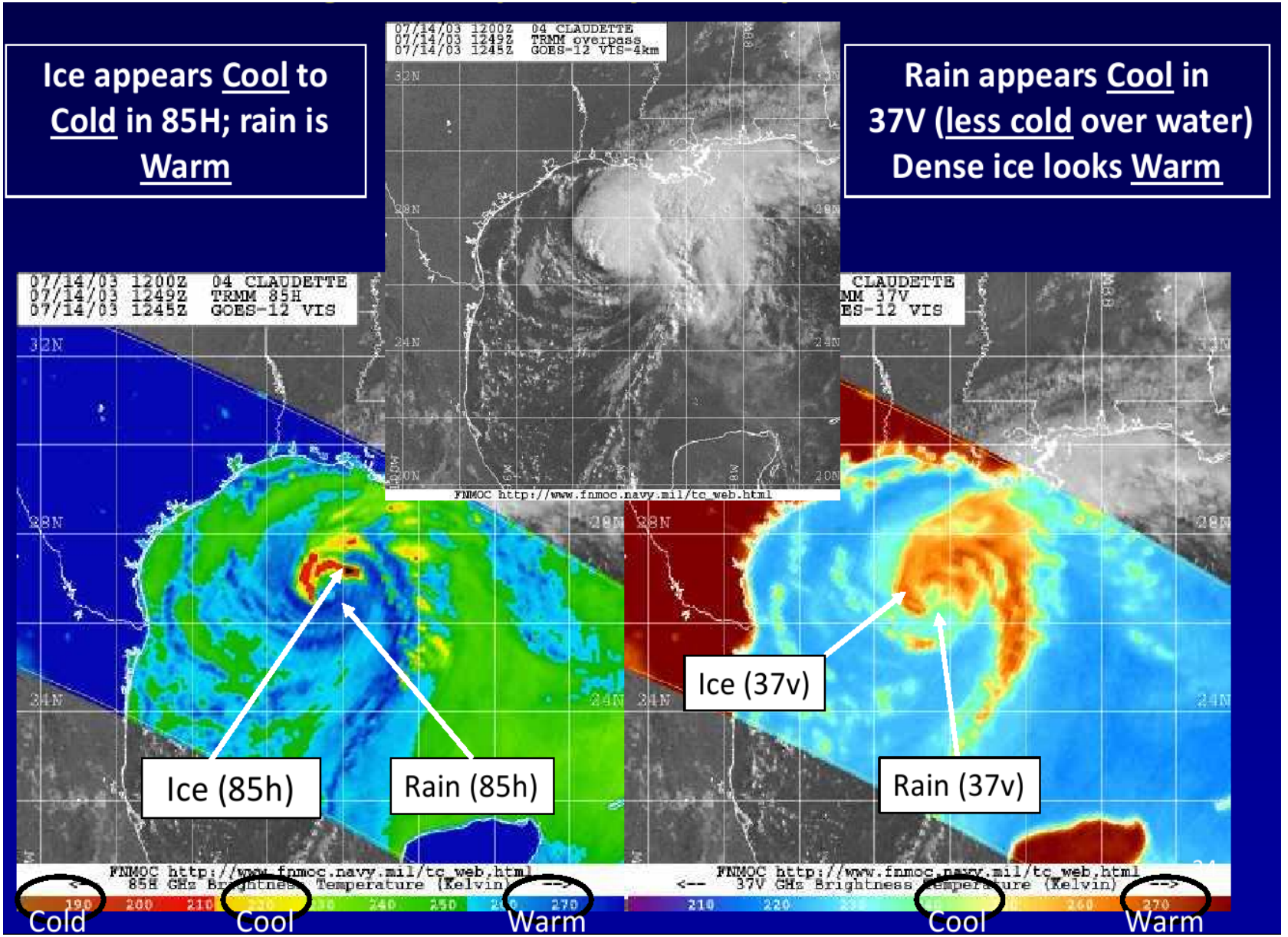
IMAGERY EXAMPLES AT 37 AND 85 GHZ



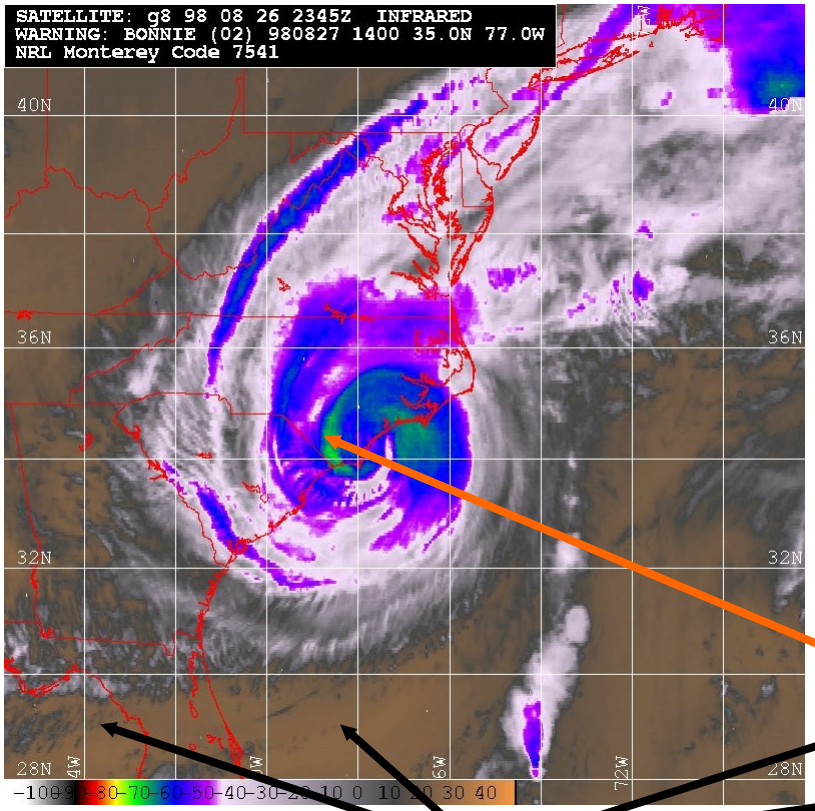
IMAGERY EXAMPLES AT 37 AND 85 GHZ



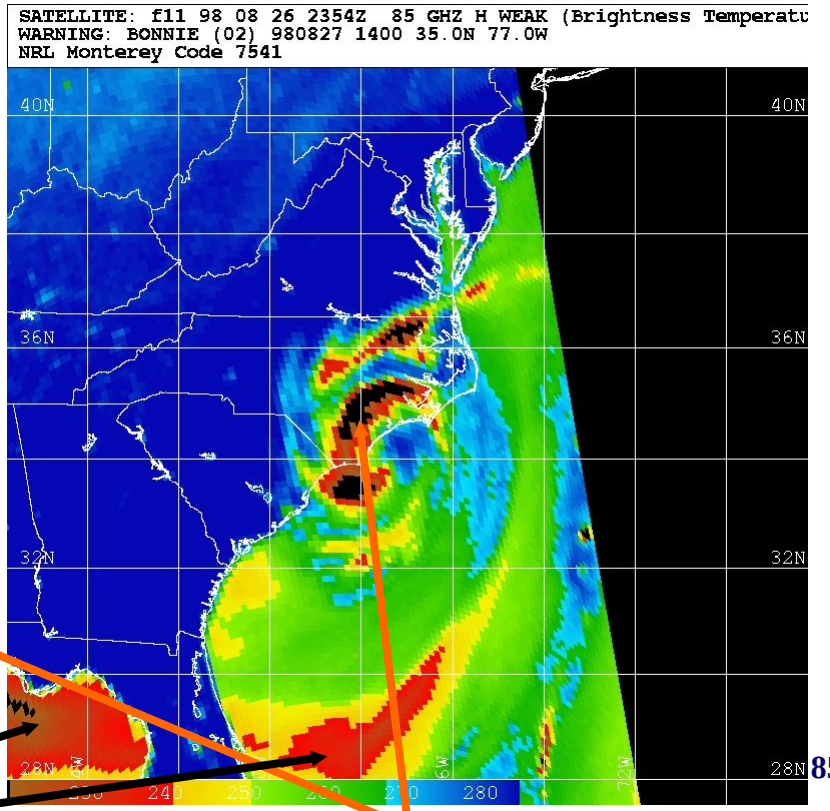
IMAGERY EXAMPLES AT 37 AND 85 GHZ



INTERPRETATION ISSUES AT 85 GHZ



IR



85 GHz

Air sec au dessus de la mer apparaît également froid en 85 Ghz, du fait de la faible émissivité.

Dry air over sea also appears cold on 85 GHz image due to low emissivity

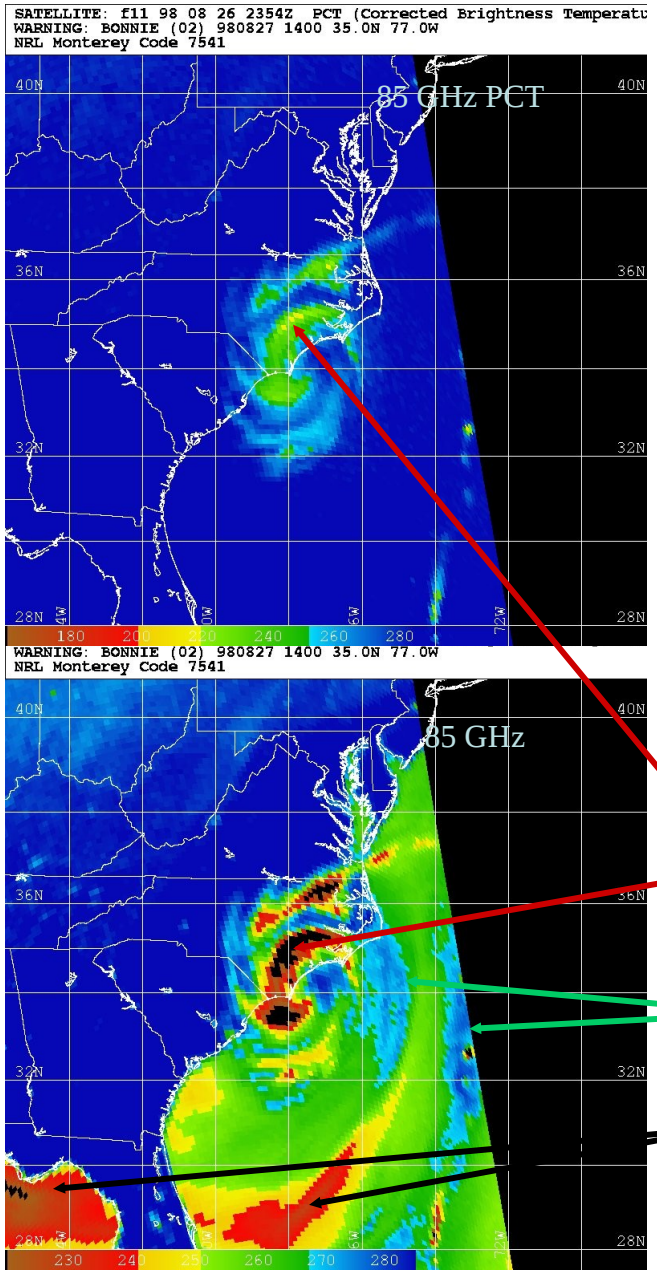
La convection du mur de l'œil apparaît froide en 85 Ghz, avec la diffusion de la glace.

Eyewall convection appears cold on 85 GHz image due to ice scattering.

Images: NRL

METEO FRANCE

INTERPRETATION ISSUES AT 85 GHZ



- Radiations émises de la mer polarisées, mais radiations diffusées par les grosses particules de glace non.
- Combinaison des polarisations verticale et horizontale : on s'affranchit des ambiguïtés.
- Appelé la PCT (Polarisation Corrected Temperature ou température corrigée de la polarisation)

- *Radiation from sea is polarised, while radiation scattered from large ice is not.*
- *By combining the H & V polarisations, we can get rid of the ambiguity.*
- *Called the PCT (polarisation corrected temperature).*

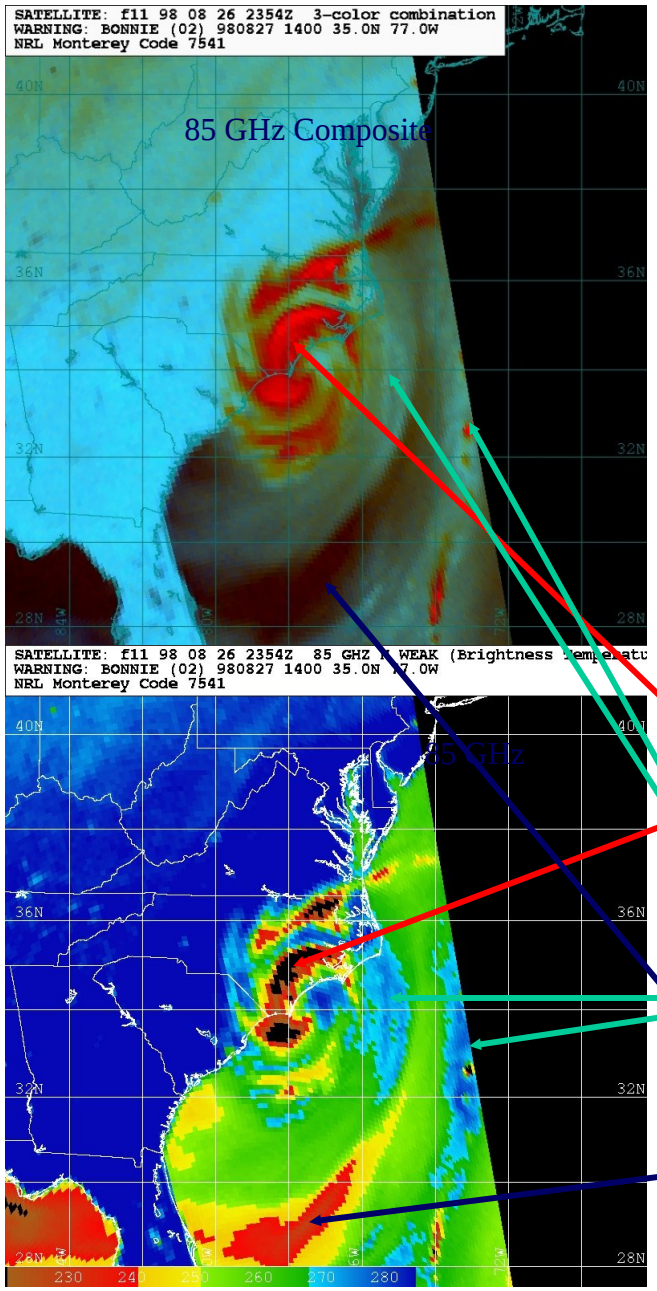
Eyewall convection appears cold on both images

Weak rainbands are washed out on PCT image

Dry air over sea not visible on PCT image

Images: NRL

INTERPRETATION ISSUES AT 85 GHZ



- Image composite montre le PCT en rouge et les 85 GHz en bleu-vert.

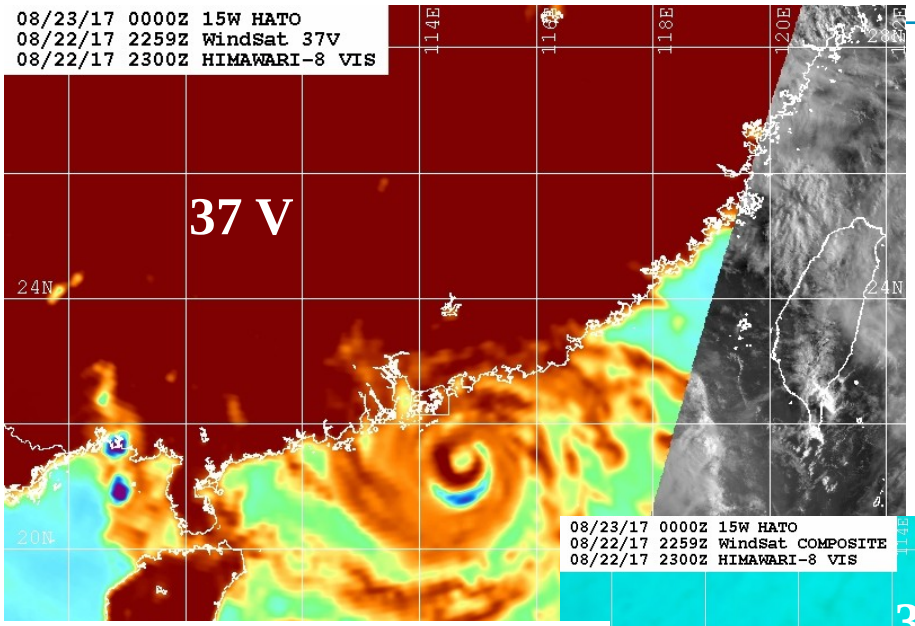
- *Composite image has PCT in red, 85GHz in blue-green, and captures both features.*

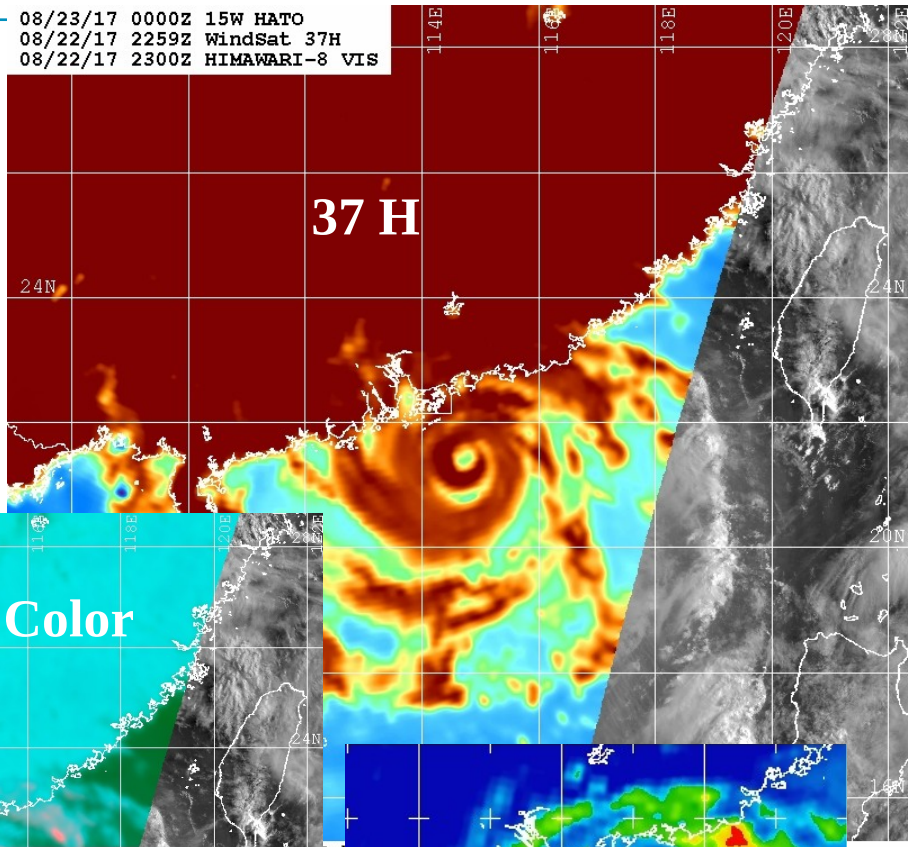
Eyewall convection apparent on both images

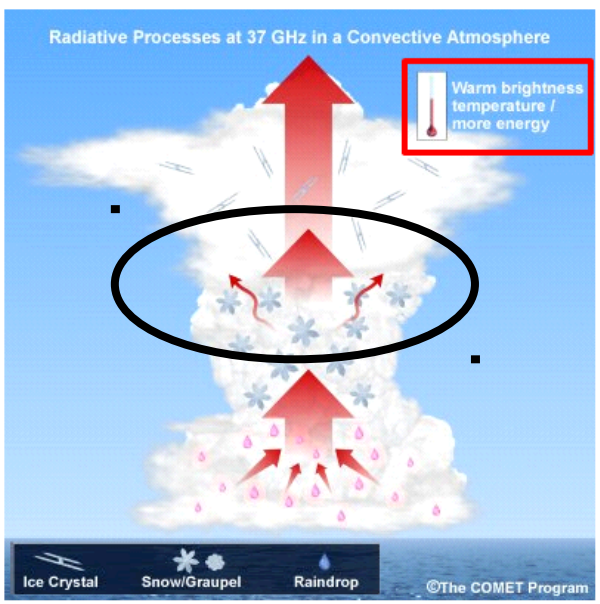
Weak rainbands are green-blue on composite image.

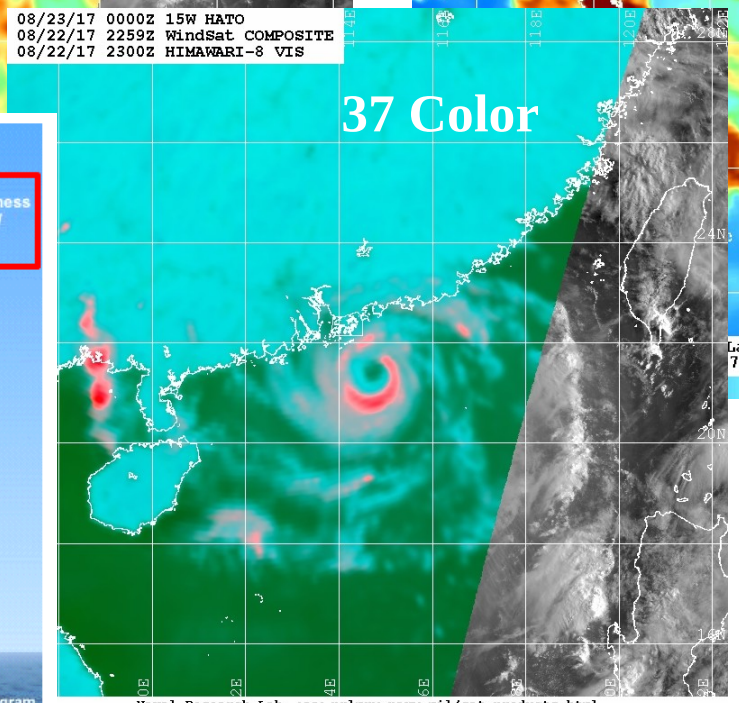
Dry air over sea near-black on composite image.

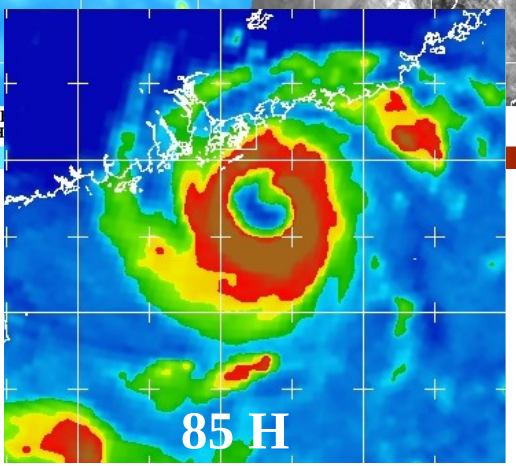
INTERPRETATION ISSUES AT 37 GHZ











METEO FRANCE

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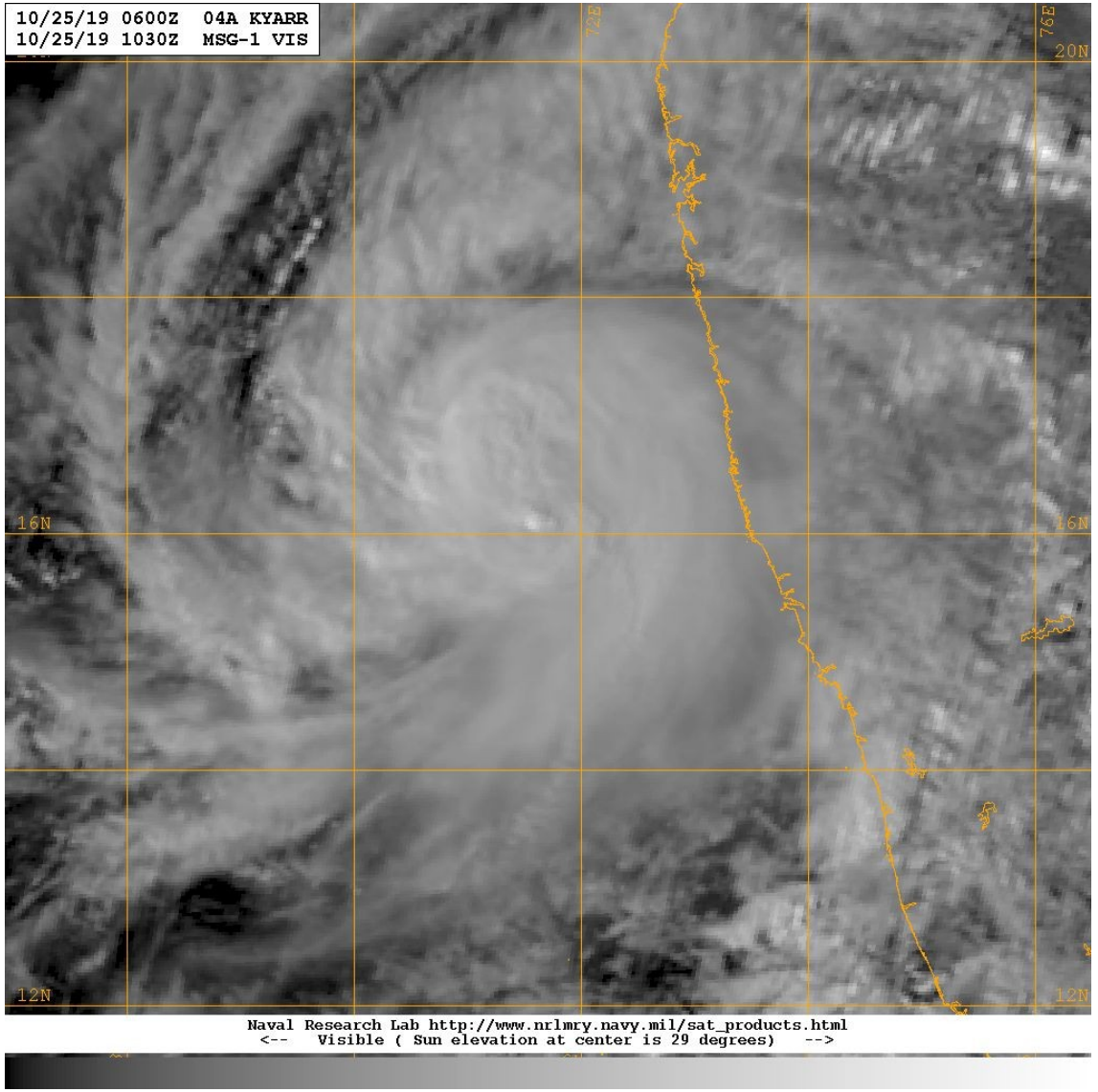
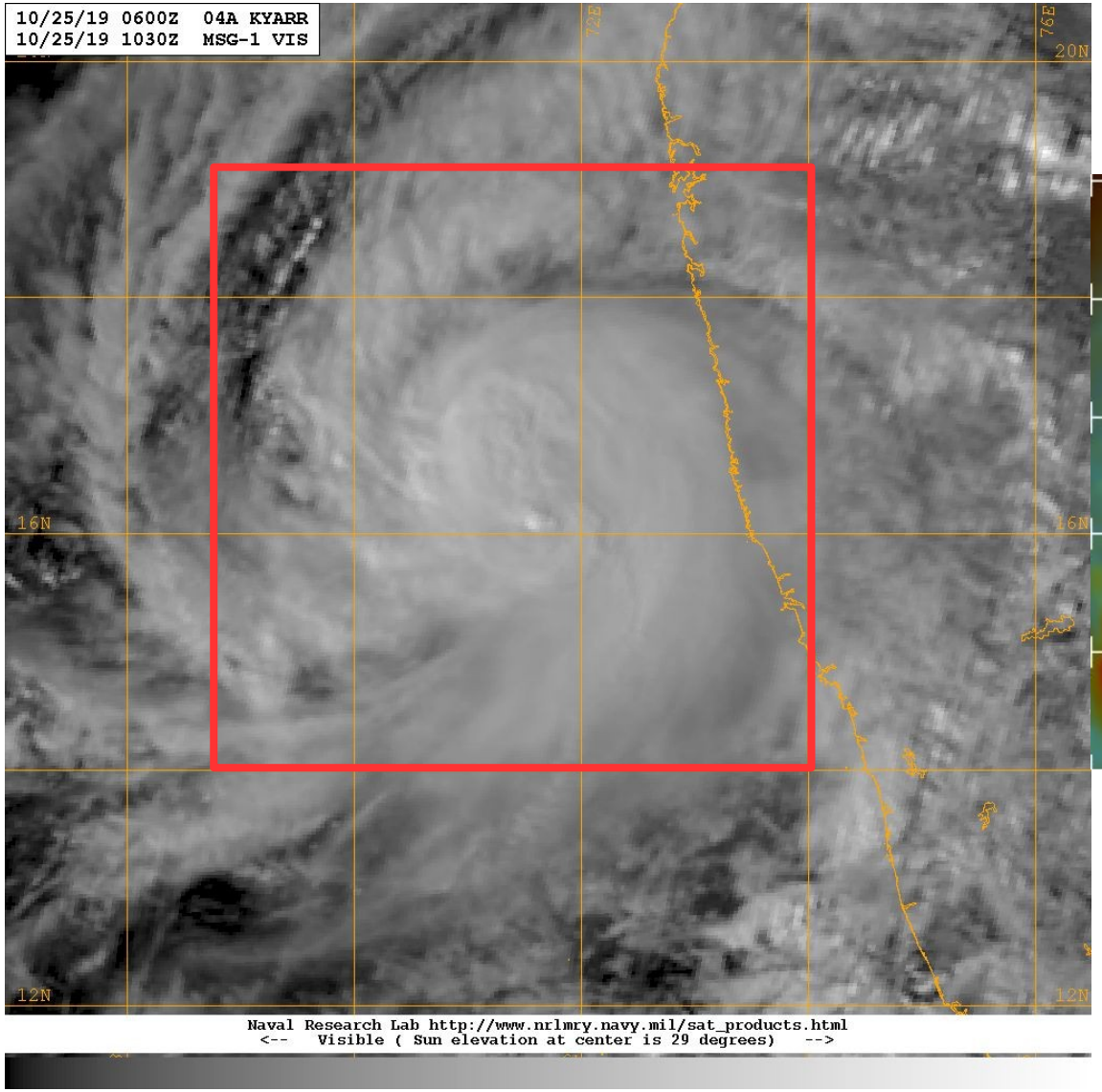
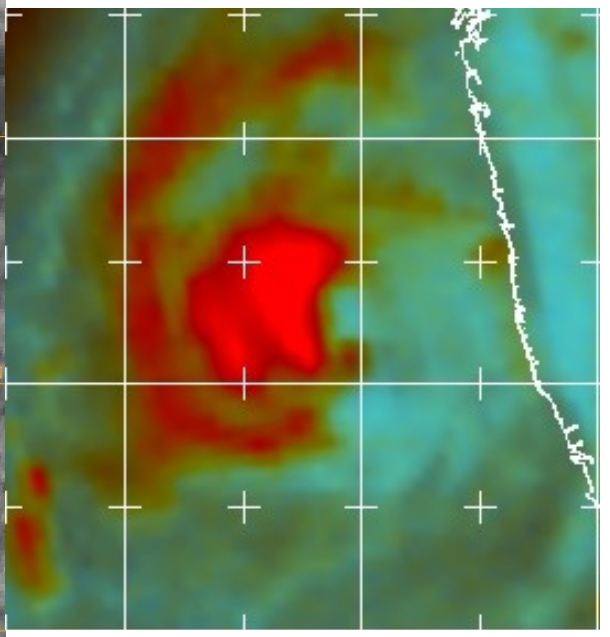
LOCATE THE CENTER



Tempête tropicale KYARR 2019 (NIND)
Tropical storm KYARR 2019 (NIND)

LOCATE THE CENTER

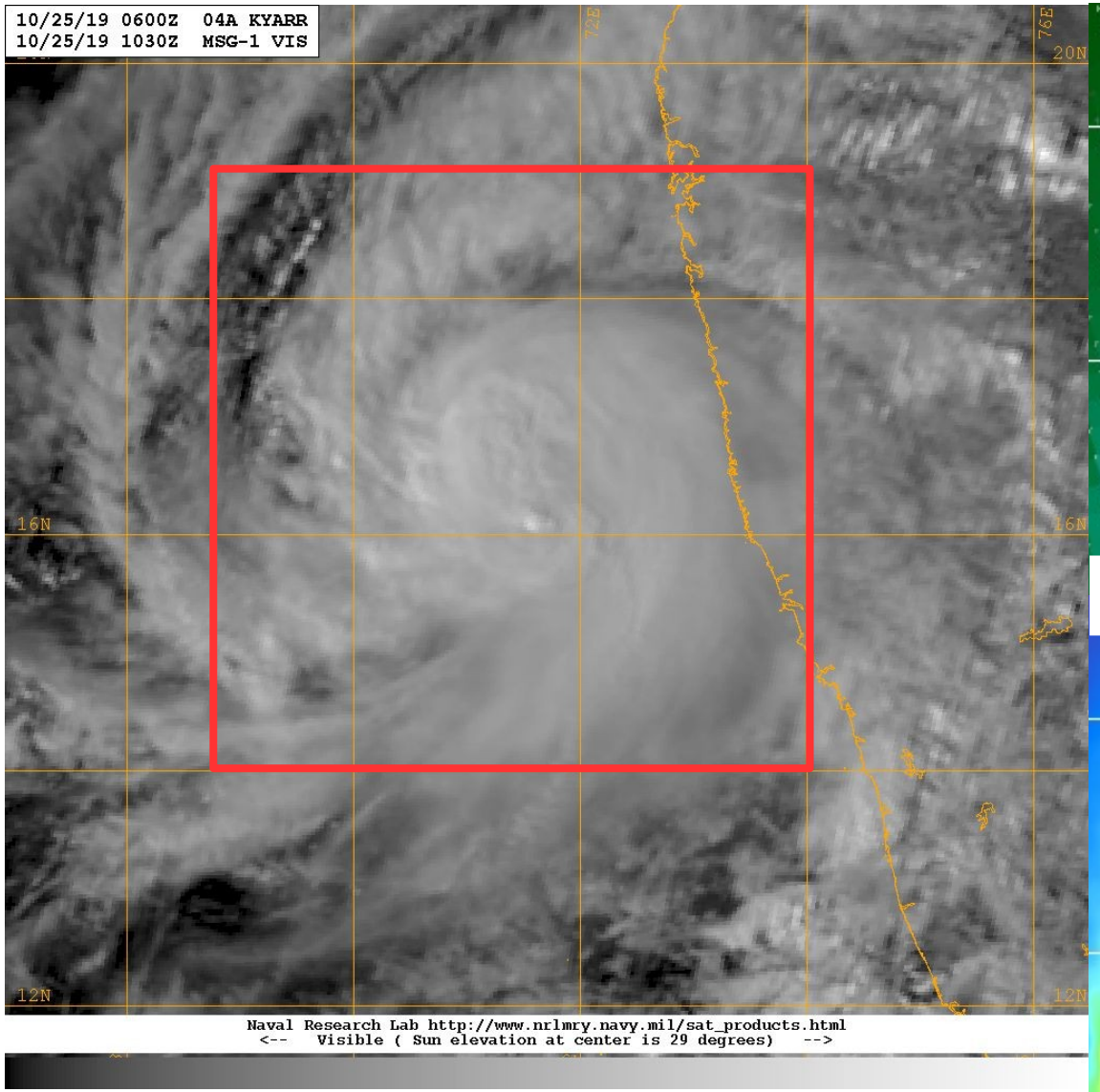


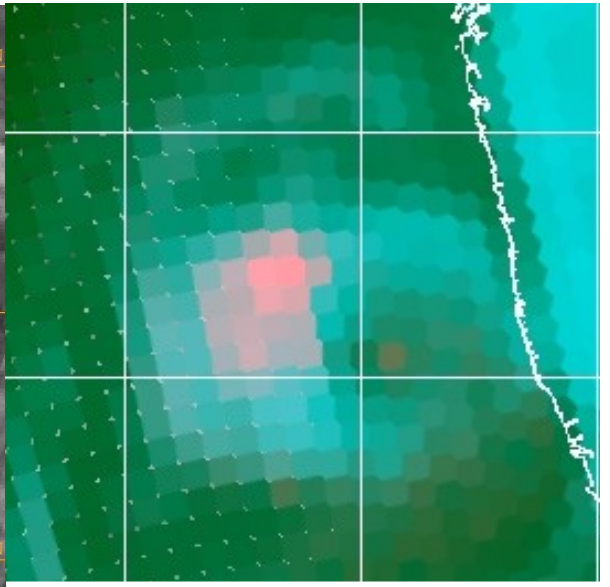


SSMI 85 Color 25/10/2019 1027Z

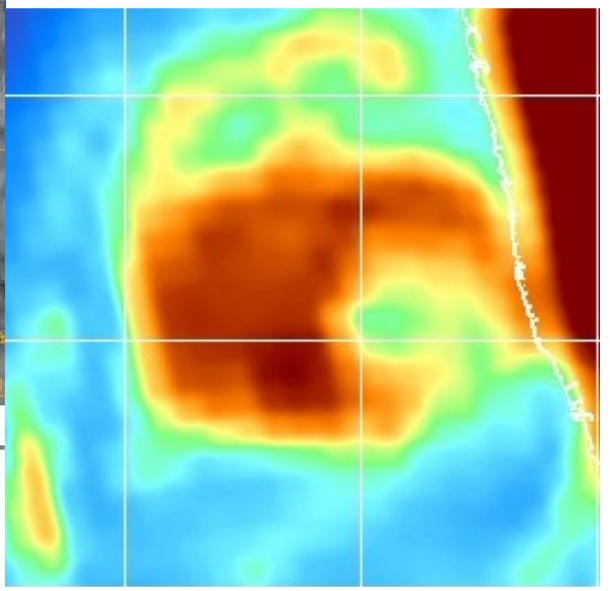
Tempête tropicale KYARR 2019 (NIND)
Tropical storm KYARR 2019 (NIND)

LOCATE THE CENTER





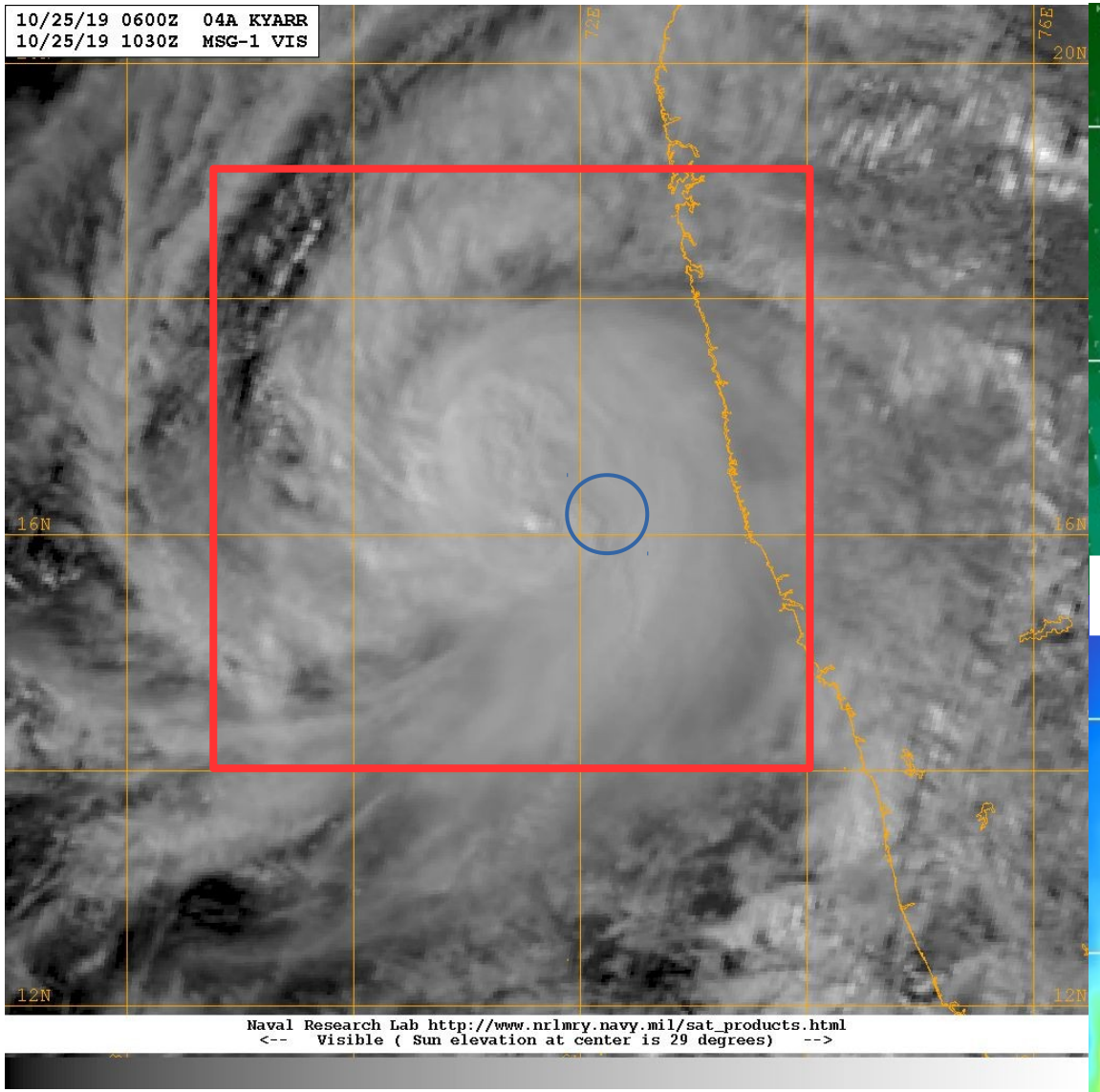
SSMI 37 Color / 37 H 25/10/2019 1027Z

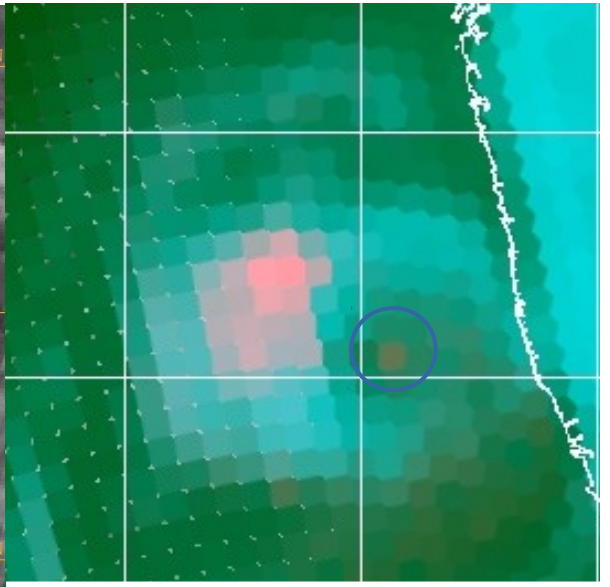


Tempête tropicale KYARR 2019 (NIND)
Tropical storm KYARR 2019 (NIND)

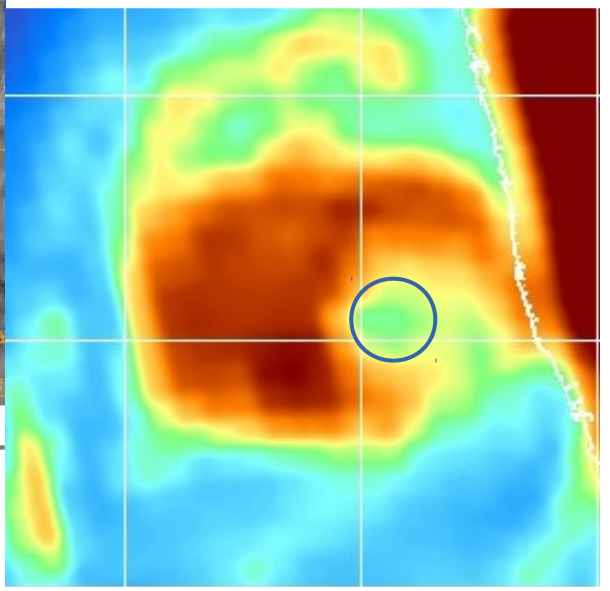
METEO FRANCE

LOCATE THE CENTER



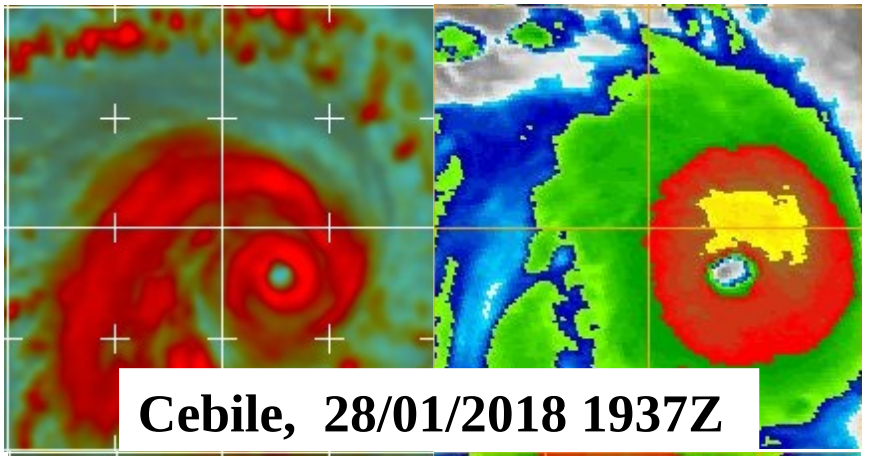


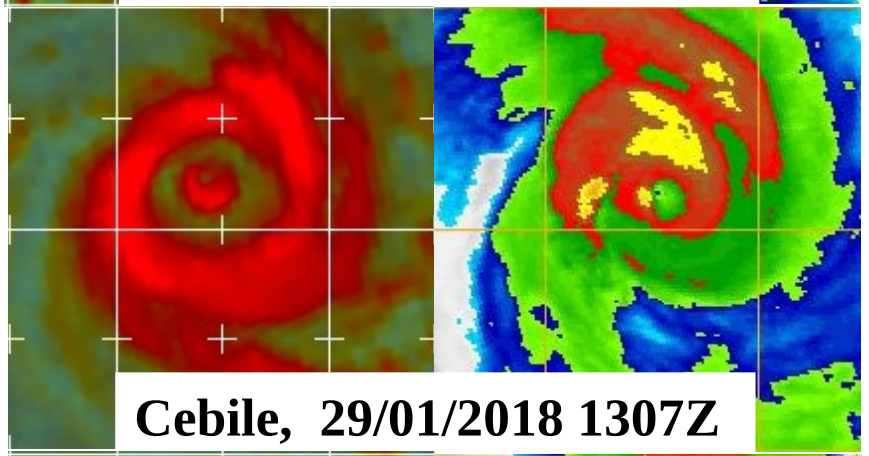
SSMI 37 Color / 37 H 25/10/2019 1027Z

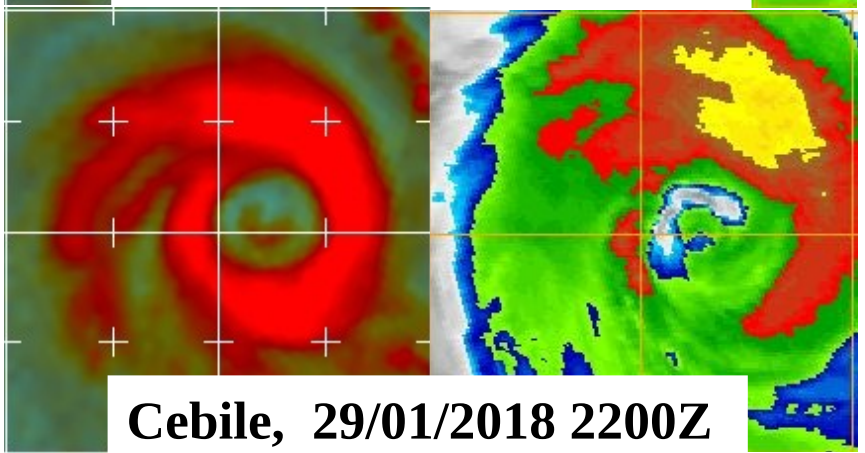


Tempête tropicale KYARR 2019 (NIND)
Tropical storm KYARR 2019 (NIND)

REVEAL EYEWALL REPLACEMENT CYCLE







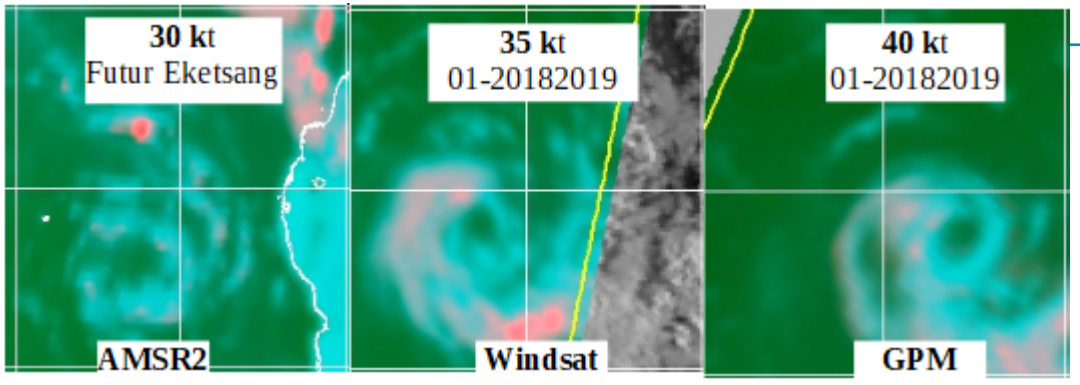
Phase I: Intensification (début ERC)
Phase I: Intensification (ERC onset)

Phase II: Affaiblissement
Phase II: Weakening

Phase III: Re-intensification
Phase III: Re-intensification

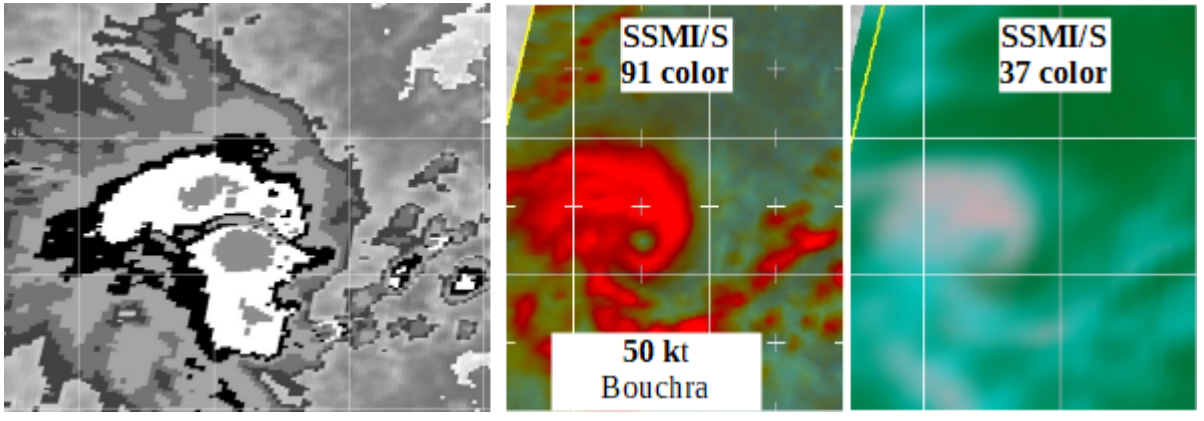
D'après/*according* Sitkowski, Kossin, Rozoff, 2011

INTERNAL STRUCTURE & INTENSITY ASSESSEMENT



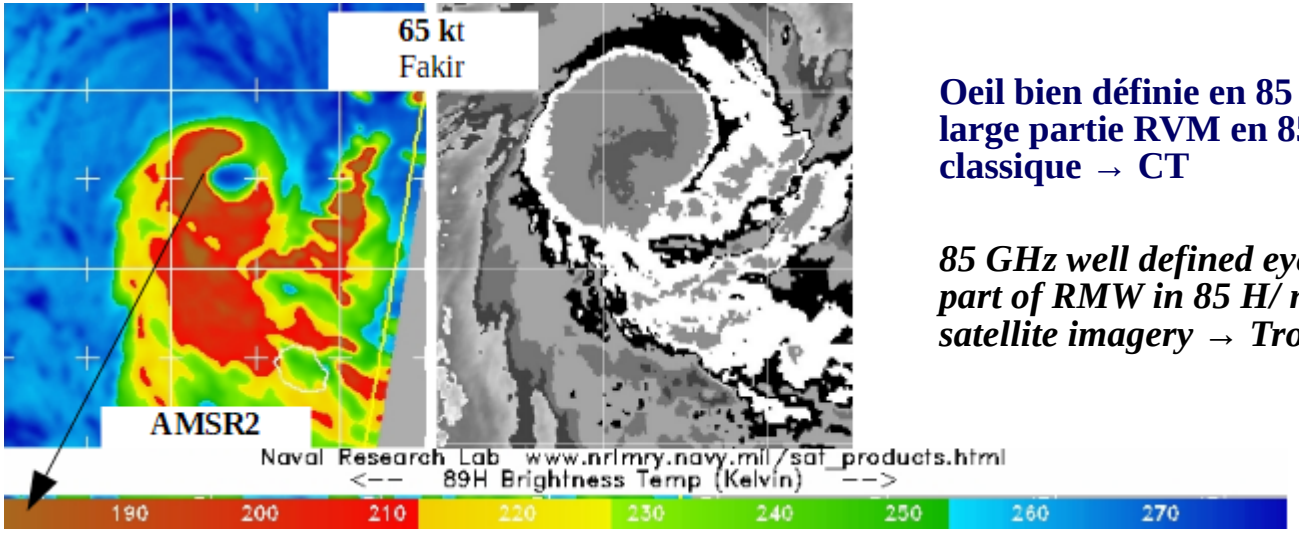
Oeil bien définie en 37 GHz / Pas d'oeil en 85 GHz / Pas d'oeil en imagerie classique → TTM

37 GHz well defined eye / no eye feature in 85 GHz nor with classical satellite imagery → Moderate Tropical Storm



Oeil bien définie en 85 GHz / alignement vertical / Pas d'oeil en imagerie classique → FTT

85 GHz well defined eye / no tilt / no eye feature with classical satellite imagery → Severe Tropical Storm

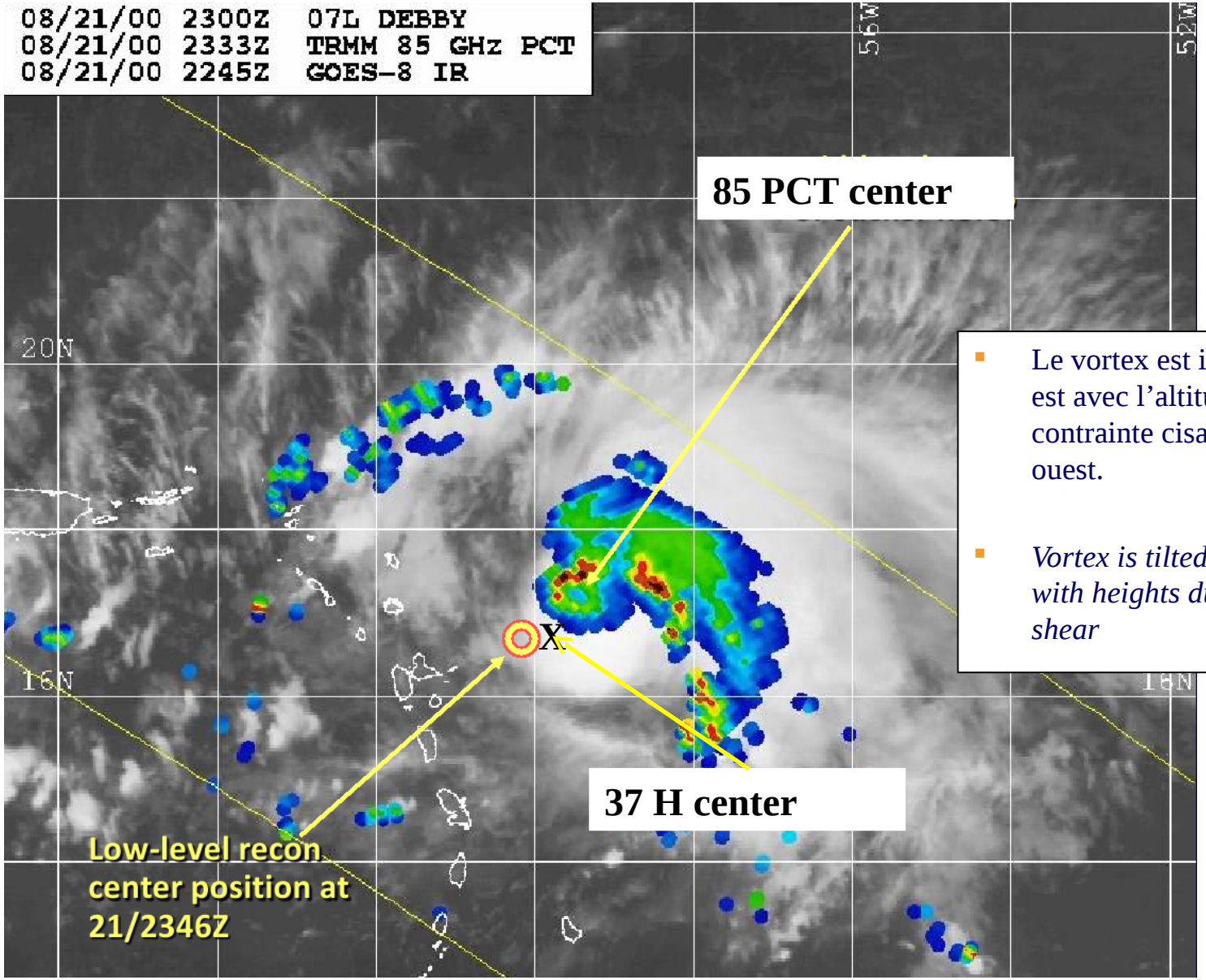


Oeil bien définie en 85 GHz / Tb très basses sur large partie RVM en 85 H / Pas d'oeil en imagerie classique → CT

85 GHz well defined eye / very low Tb over large part of RMW in 85 H/ no eye feature with classical satellite imagery → Tropical Cyclone

METEO FRANCE

3D VIEW OF INTERNAL STRUCTURE

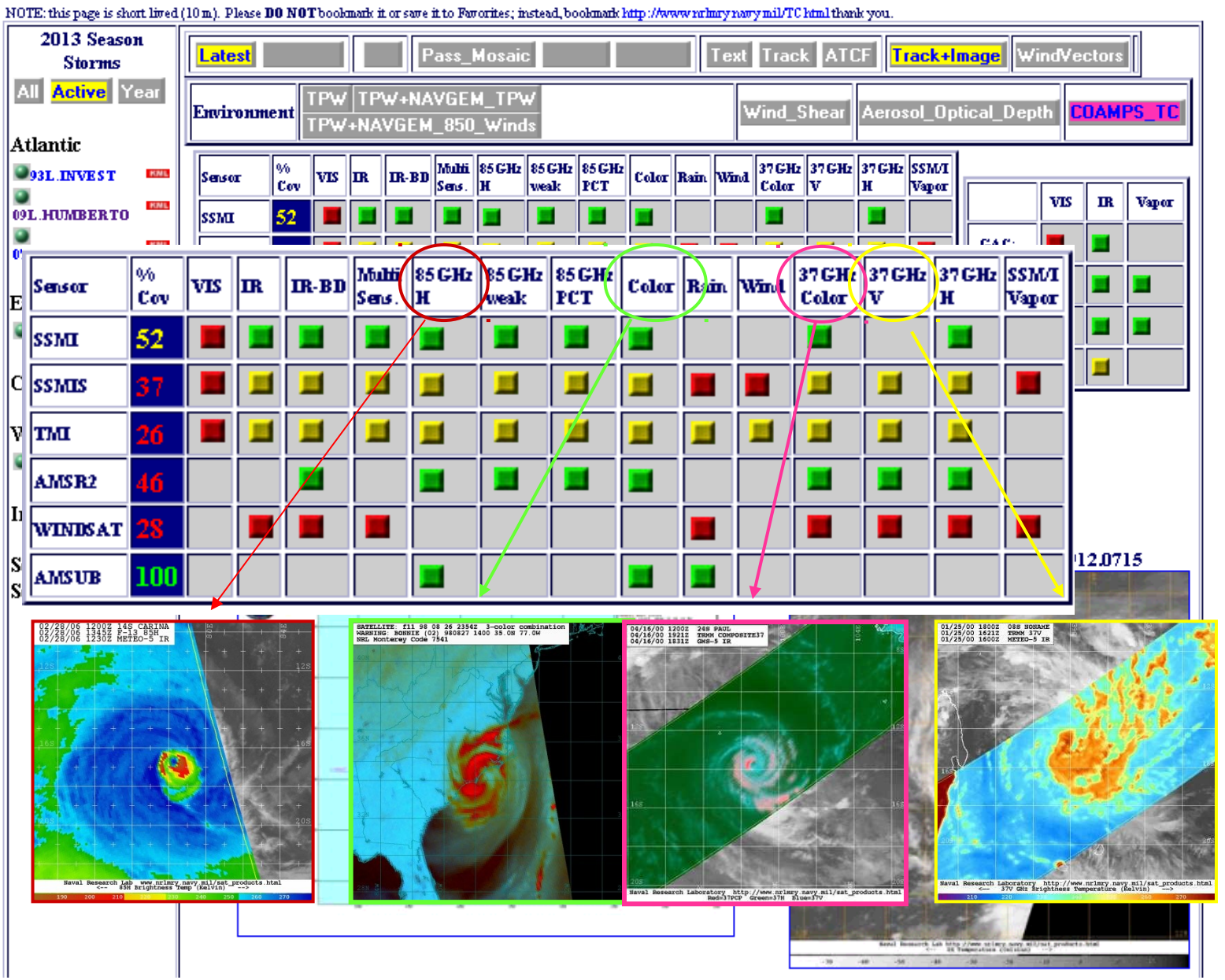


- Le vortex est incliné vers le nord-est avec l'altitude en raison d'une contrainte cisaillée de secteur sud-ouest.
- *Vortex is tilted north-eastwards with heights due to south-westerly shear*

METEO FRANCE

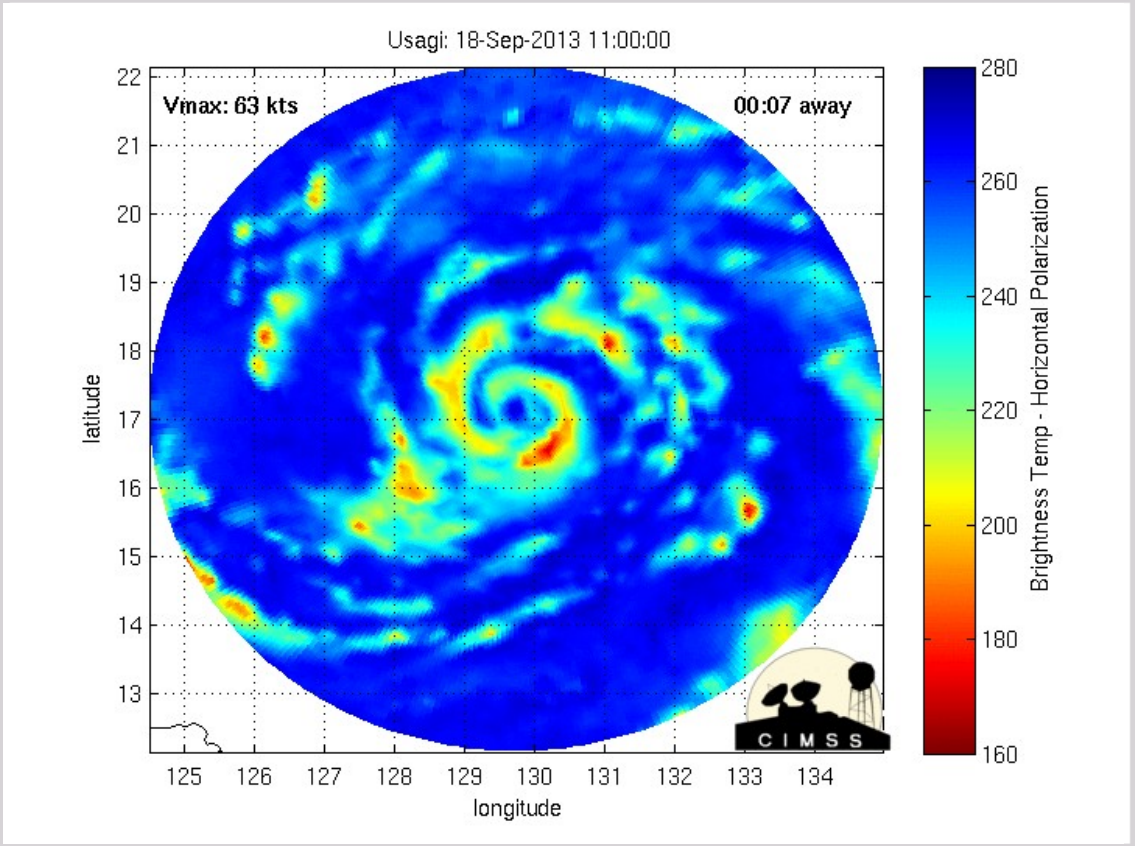
NAVAL RESEARCH LABORATORY - TC PAGE

→ https://www.nrlmry.navy.mil/TC.html



CIMSS – MIMIC TC
http://tropic.ssec.wisc.edu/real-time/mimtc/tc.shtml

Morphed Integrated Microwave Imagery at CIMSS (MIMIC)
Version 1



- Return to main storm menu -

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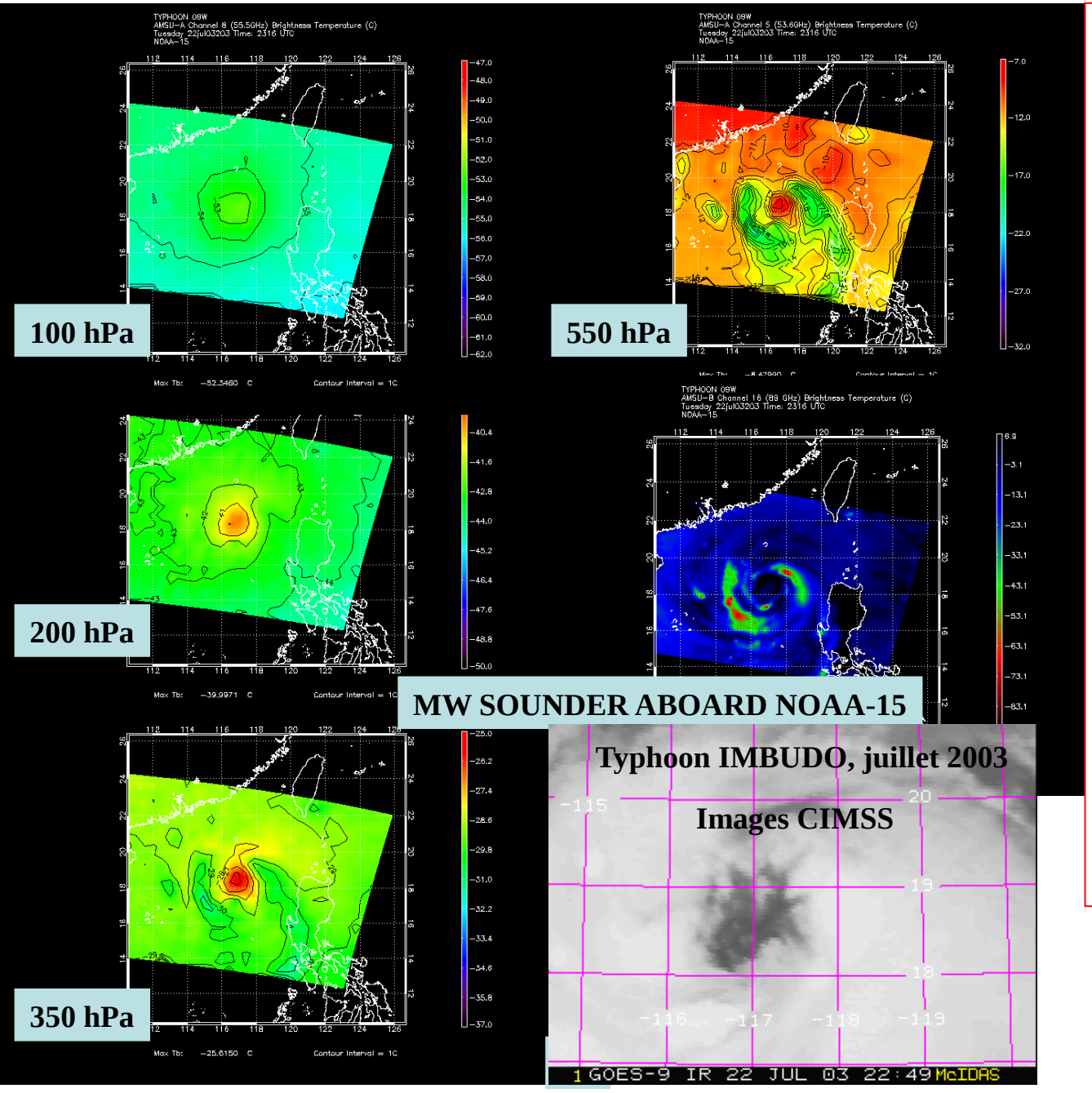
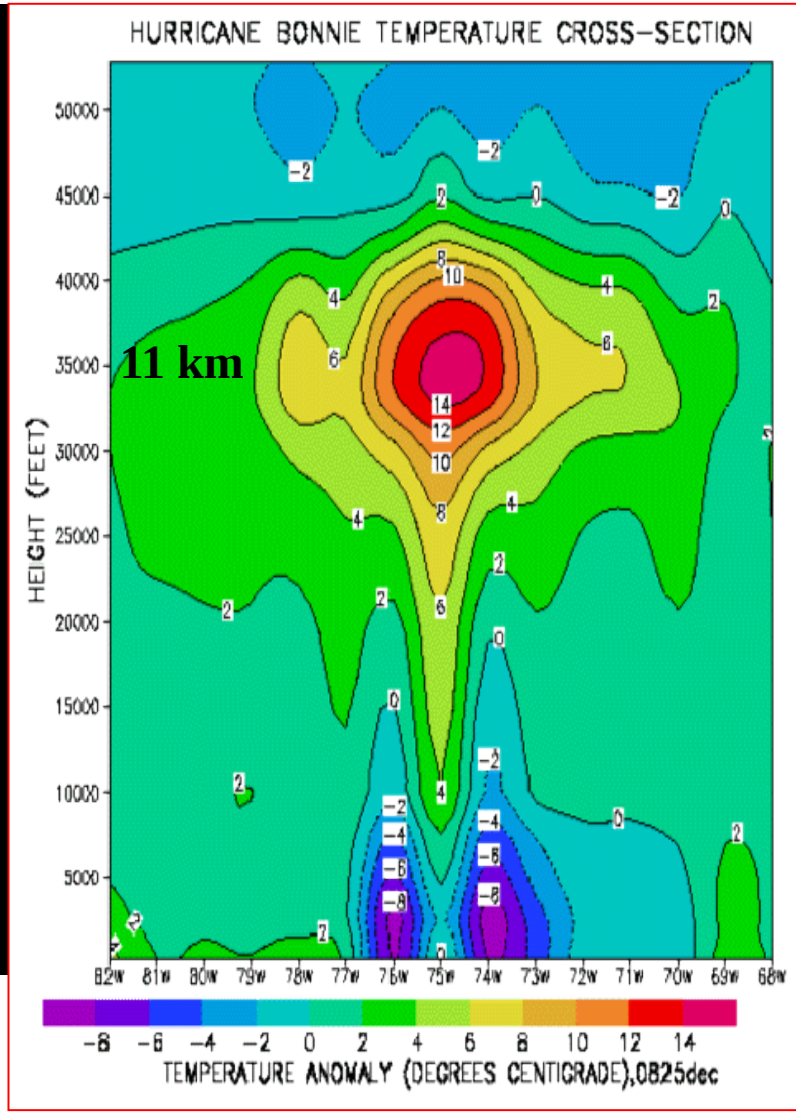
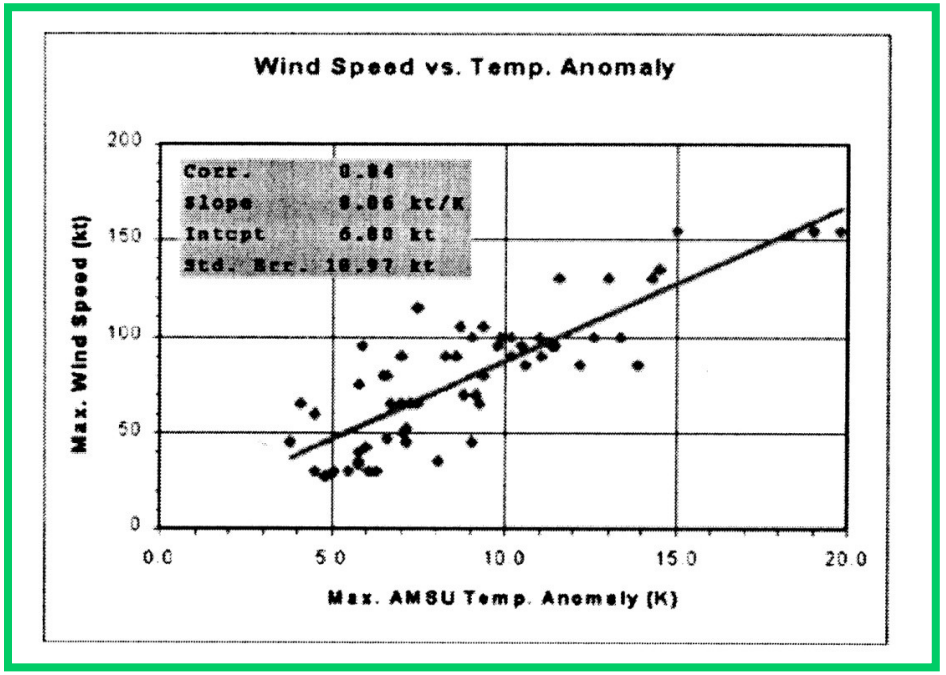
Scatterometers / SAR

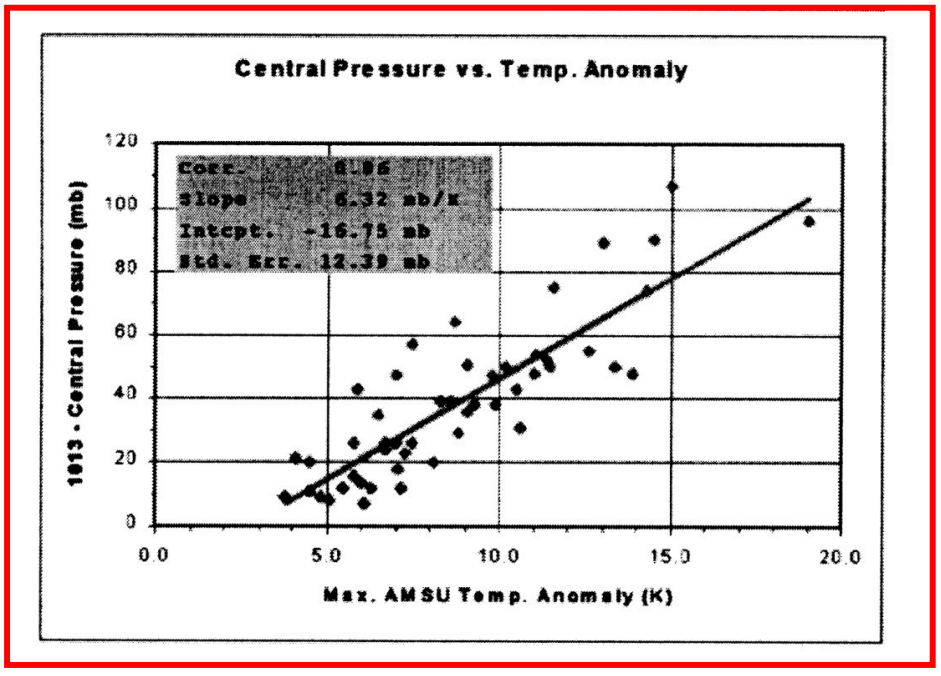
ADVANCED MW SOUNDING UNIT (AMSU)





ADVANCED MW SOUNDING UNIT (AMSU)





- **Les anomalies de de température obtenues d'après AMSU-A permettent**
  - d'estimer l'intensité du phénomène en obtenant
    - la vitesse du vent
    - la pression au centre.

  Via régression linéaire

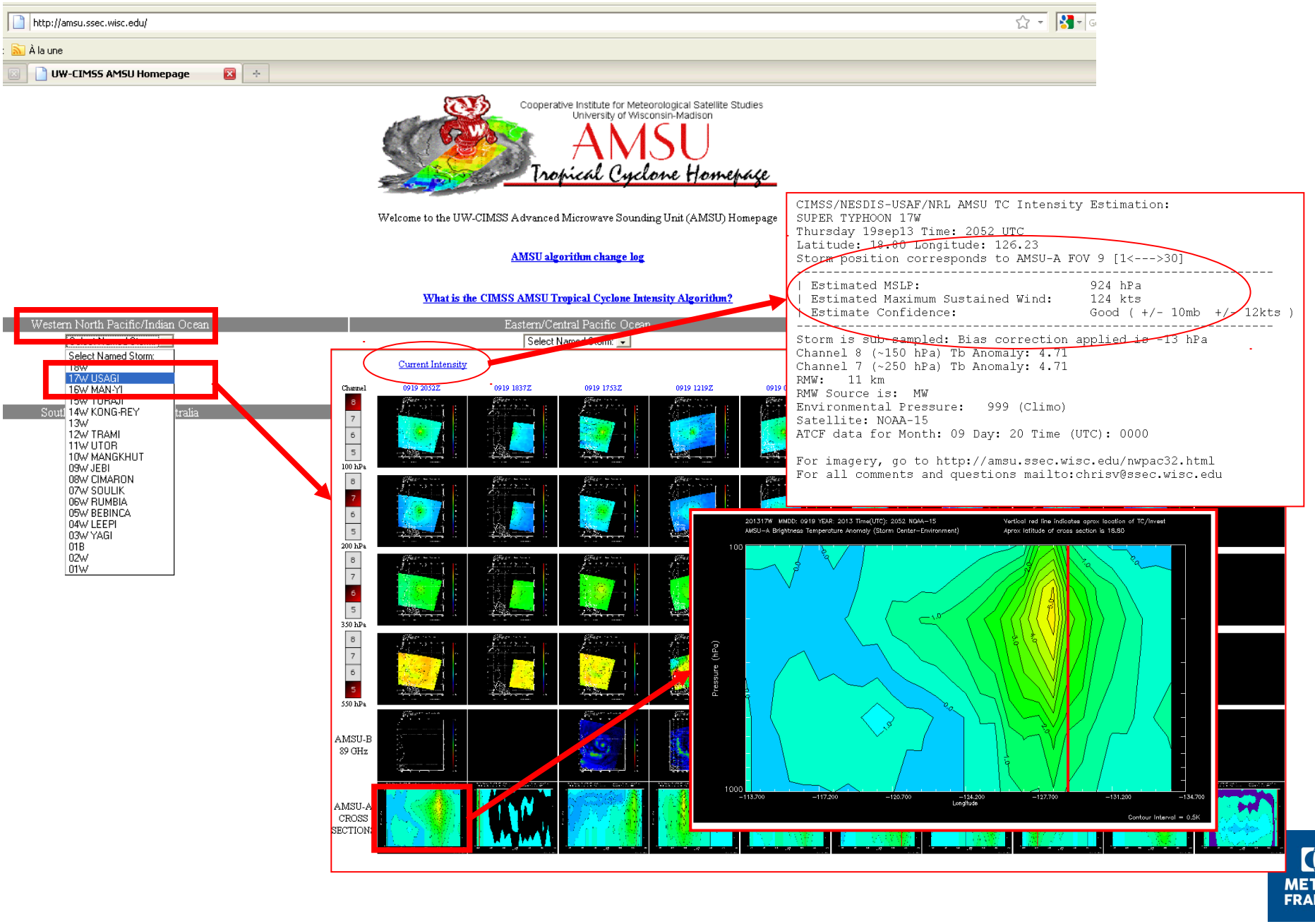
- ***Temperature anomalies calculated thanks to AMSU-A allow***
  - *Intensity estimation by providing*
    - Wind speed
    - *Minimal pressure*

  From linear regression

Source : Kidder et al (2000) :
Satellite analysis of tropical cyclone using the Advanced Microwave Sounding Unit (AMSU). *Bull. Amer. Met. Soc.*, 81, 1241-1259.

METEO FRANCE

ADVANCED MW SOUNDING UNIT (AMSU)
http://tropic.ssec.wisc.edu/real-time/amsu/



ADVANCED DVORAK TECHNIQUE

- **Inconvénients de la technique de Dvorak manuelle :**
  - Subjectivité (position, choix de la configuration nuageuse, mesures ...)
  - Prend du temps à maîtriser pour un analyste.
  - Méthode empirique sur la base de relation statistique perfectible …

- **ADT :**
  - « Dvorak automatique ou objectif » : détermination du centre, configuration nuageuse …
  - Analyse statistique robuste basée sur plus de 10 ans de données avions dans l'Atlantique et le Pacifique
  - Initié par Dvorak lui-même dans les années 90.
  - Utilisation objective de l'imagerie micro-ondes dans les dernières versions

- ***Drawbacks of the manual Dvorak technique:***
  - *Subjectivity (position, cloud pattern choice, measures ...)*
  - *Take time to master*
  - *Empirical method without the aid of computer analysis and robust statistical relationships*

- ***ADT:***
  - *« Automatic / objective Dvorak »: objective determination of the center, cloud pattern ...*
  - *Statistical analysis results from a 10+ year sample of North Atlantic and North Pacific storms*
  - *Work initiated by Dvorak in the 90's*
  - *Use of MW imagery in the latest version*

METEO FRANCE

ADVANCED DVORAK TECHNIQUE
http://tropic.ssec.wisc.edu/real-time/adt/adt.html

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ADT821 LIST 20S.ODT CKZ=YES
=====  ADT-Version 8.2.1 =====
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domainid_input=0
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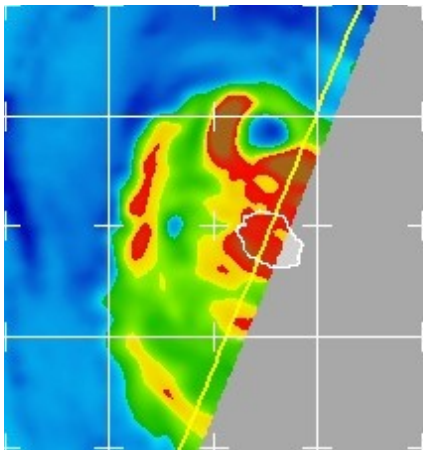
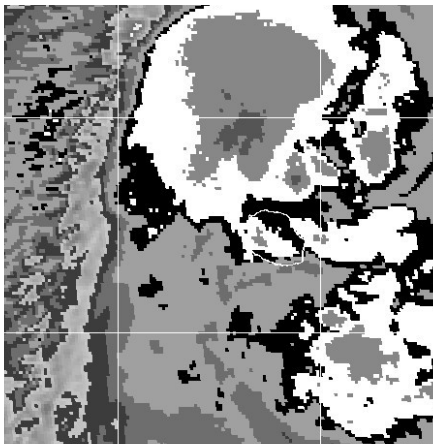
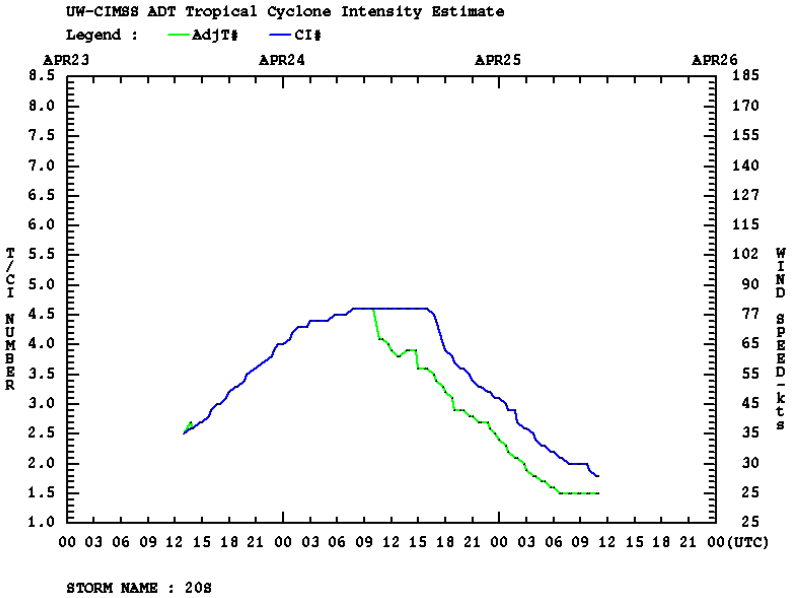
		----Intensity---		-Tno Values--			---Tno/CI Rules---			-Temperature-								
Date	Time (UTC)	CI	MSLP/Vmax (CKZ)/(kts)	Fnl Tno	Adj Raw	Ini Raw	Cnstrnt Limit	Wkng Flag	Rpd Wkng	Cntr Region	Mean Cloud	Scene Type	EstRMW (km)	MW Score	Storm Location Lat	Lon	Fix Mthd	Sat	VZA	Comments
2018APR23	130000	2.5	1006.5 35.0	2.5	2.5	2.5	NO LIMIT	OFF	OFF	-77.21	-74.45	UNIFRM	N/A	N/A	-16.04	-52.99	FCST	MSG1	23.0	
2018APR23	134500	2.6	1005.3 37.0	2.6	2.7	3.1	0.2T/hour	OFF	OFF	-80.75	-77.42	UNIFRM	N/A	N/A	-16.21	-53.07	FCST	MSG1	23.2	
2018APR23	140000	2.6	1005.3 37.0	2.6	2.6	3.2	MW Adjst	OFF	OFF	-81.37	-77.74	UNIFRM	N/A	N/A	-16.27	-53.09	FCST	MSG1	23.3	MWinit=2.7/2.6/2.6
2018APR23	144500	2.7	1004.0 39.0	2.7	2.7	3.3	MW Adjst	OFF	OFF	-80.75	-78.39	UNIFRM	N/A	-29.9	-16.44	-53.17	FCST	MSG1	23.5	MWinit=2.9/2.7/2.7
2018APR23	150000	2.7	1004.0 39.0	2.7	2.7	3.4	MW Adjst	OFF	OFF	-81.37	-78.52	UNIFRM	N/A	-29.9	-16.50	-53.20	FCST	MSG1	23.6	MWinit=2.9/2.7/2.7
2018APR23	154500	2.8	1002.7 41.0	2.8	2.8	3.5	MW Adjst	OFF	OFF	-80.14	-78.95	UNIFRM	N/A	-29.9	-16.67	-53.28	FCST	MSG1	23.8	MWinit=3.1/2.8/2.8
2018APR23	160000	2.9	1001.5 43.0	2.9	2.9	3.6	MW Adjst	OFF	OFF	-78.94	-79.42	UNIFRM	N/A	-29.9	-16.73	-53.31	FCST	MSG1	23.8	MWinit=3.1/2.8/2.8
2018APR23	164500	3.0	1000.2 45.0	3.0	3.0	3.6	MW Adjst	OFF	OFF	-78.36	-79.36	UNIFRM	N/A	-29.9	-16.90	-53.39	FCST	MSG1	24.1	MWinit=3.3/2.9/2.9
2018APR23	170000	3.0	1000.1 45.0	3.0	3.0	3.7	MW Adjst	OFF	OFF	-76.10	-78.72	UNIFRM	N/A	-29.9	-16.96	-53.42	FCST	MSG1	24.1	MWinit=3.3/3.0/3.0
2018APR23	174500	3.1	998.8 47.0	3.1	3.1	3.8	MW Adjst	OFF	OFF	-77.78	-75.90	UNIFRM	N/A	-29.9	-17.12	-53.51	FCST	MSG1	24.3	MWinit=3.5/3.1/3.1
2018APR23	180000	3.2	997.5 49.0	3.2	3.2	3.7	MW Adjst	OFF	OFF	-77.21	-74.88	UNIFRM	N/A	-29.9	-17.18	-53.54	FCST	MSG1	24.4	MWinit=3.5/3.2/3.2
2018APR23	184500	3.3	997.2 51.0	3.3	3.3	3.7	MW Adjst	OFF	OFF	-66.77	-72.62	UNIFRM	N/A	-29.9	-17.35	-53.63	FCST	MSG1	24.6	MWinit=3.7/3.3/3.3
2018APR23	190000	3.3	997.2 51.0	3.3	3.3	3.7	MW Adjst	OFF	OFF	-78.36	-72.65	UNIFRM	N/A	-29.9	-17.40	-53.66	FCST	MSG1	24.7	MWinit=3.7/3.4/3.4
2018APR23	194500	3.4	995.7 53.0	3.4	3.4	3.8	MW Adjst	OFF	OFF	-73.44	-73.91	UNIFRM	N/A	-29.9	-17.91	-54.33	FCST	MSG1	25.6	MWinit=3.3/3.4/3.4
2018APR23	200000	3.5	994.3 55.0	3.5	3.5	3.8	MW Adjst	OFF	OFF	-71.92	-74.22	UNIFRM	N/A	-29.9	-17.97	-54.36	FCST	MSG1	25.7	MWinit=3.3/3.4/3.4
2018APR23	224500	3.8	990.1 61.0	3.8	3.8	3.8	MW Adjst	OFF	OFF	-75.56	-76.48	UNIFRM	N/A	-49.6	-18.58	-54.72	FCST	MSG1	26.5	MWinit=3.6/3.4/3.4
2018APR23	230000	3.9	988.7 63.0	3.9	3.9	3.8	MW Adjst	OFF	OFF	-73.96	-75.89	UNIFRM	N/A	-49.6	-18.64	-54.76	FCST	MSG1	26.6	MWinit=3.7/3.5/3.5
2018APR23	233000	4.0	987.3 65.0	4.0	4.0	3.7	MW Adjst	OFF	OFF	-69.51	-73.57	UNIFRM	N/A	-49.6	-18.75	-54.83	FCST	MSG1	26.7	MWinit=3.7/3.6/3.6
2018APR24	000000	4.0	987.3 65.0	4.0	4.0	3.7	MW Adjst	OFF	OFF	-65.46	-71.21	UNIFRM	N/A	-49.6	-18.87	-54.90	FCST	MSG1	26.9	MWinit=3.7/3.6/3.6
2018APR24	004500	4.1	985.5 67.4	4.1	4.1	3.5	MW Adjst	OFF	OFF	-56.80	-67.33	UNIFRM	N/A	-40.0	-19.05	-55.01	FCST	MSG1	27.1	MWinit=3.5/3.6/3.6
2018APR24	010000	4.2	983.8 69.8	4.2	4.2	3.4	MW Adjst	OFF	OFF	-72.42	-66.82	UNIFRM	N/A	-40.0	-19.11	-55.05	FCST	MSG1	27.2	MWinit=3.4/3.6/3.6
2018APR24	014500	4.3	981.8 72.2	4.3	4.3	3.8	MW ON	OFF	OFF	-77.21	-74.92	UNIFRM	N/A	50.9	-19.91	-55.33	FCST	MSG1	28.1	





Fakir, 24/04/18 0156Z



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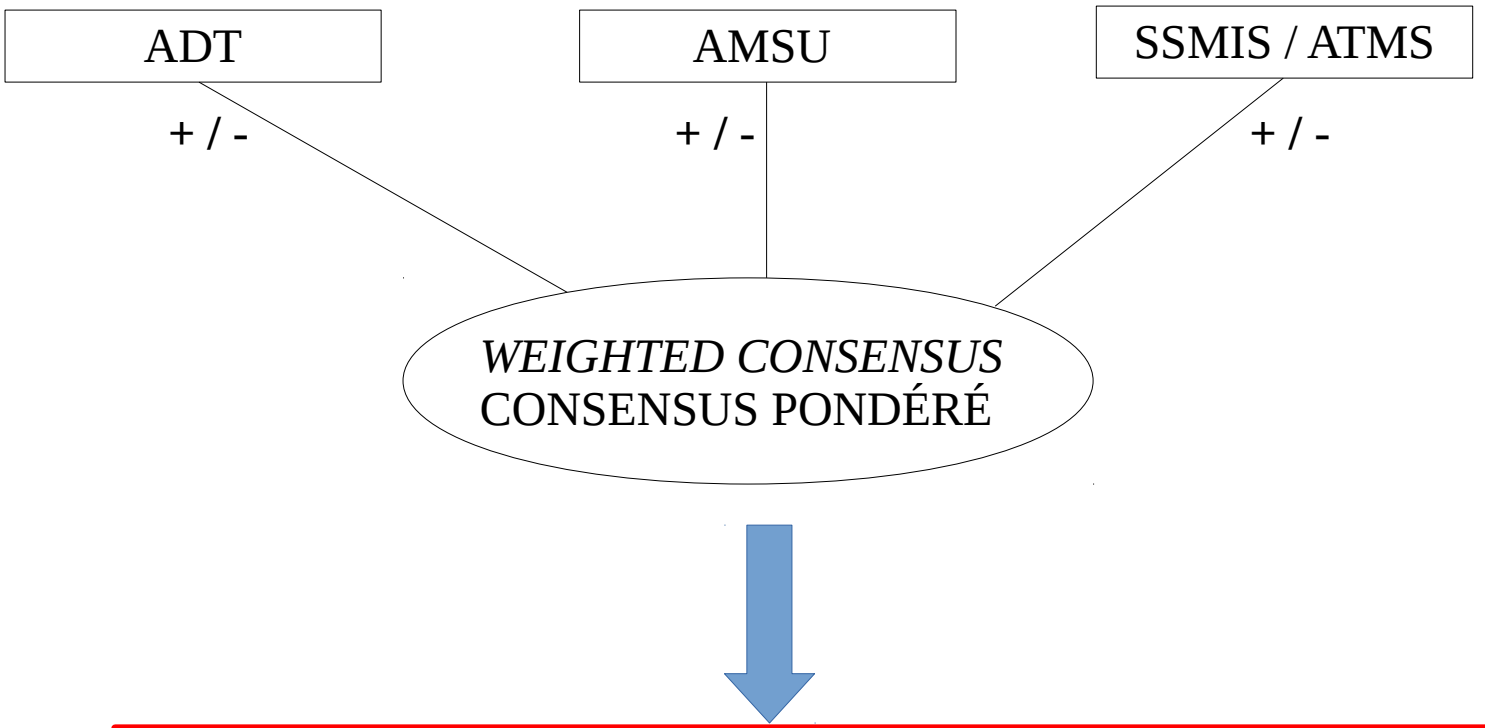
SATellite CONsensus



SATCON :

Better than individual inputs & simple average

Meilleur que les membres individuels et la moyenne des membres

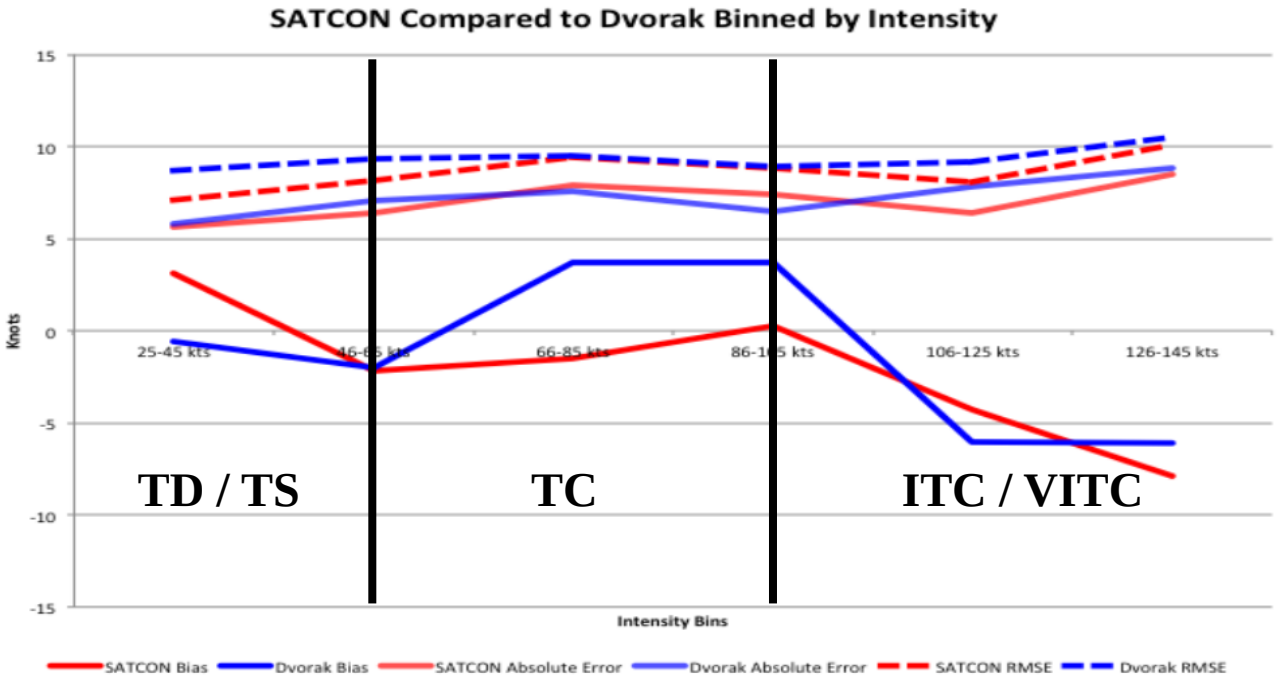
SATellite CONsensus

N = 4097	ADT	AMSU	SSMIS/ ATMS	SATCON Simple Avg	SATCON
BIAS	-1.6	-3.9	-2.2	-2.7	-0.2
ABS ERROR	10.0	9.7	8.6	7.3	7.2
RMSE	12.8	12.5	11.2	9.3	9.1

SATCON Vmax performance compared to individual members 2006-2015 All values are in knots. SATCON Simple Avg is a straight average of all members

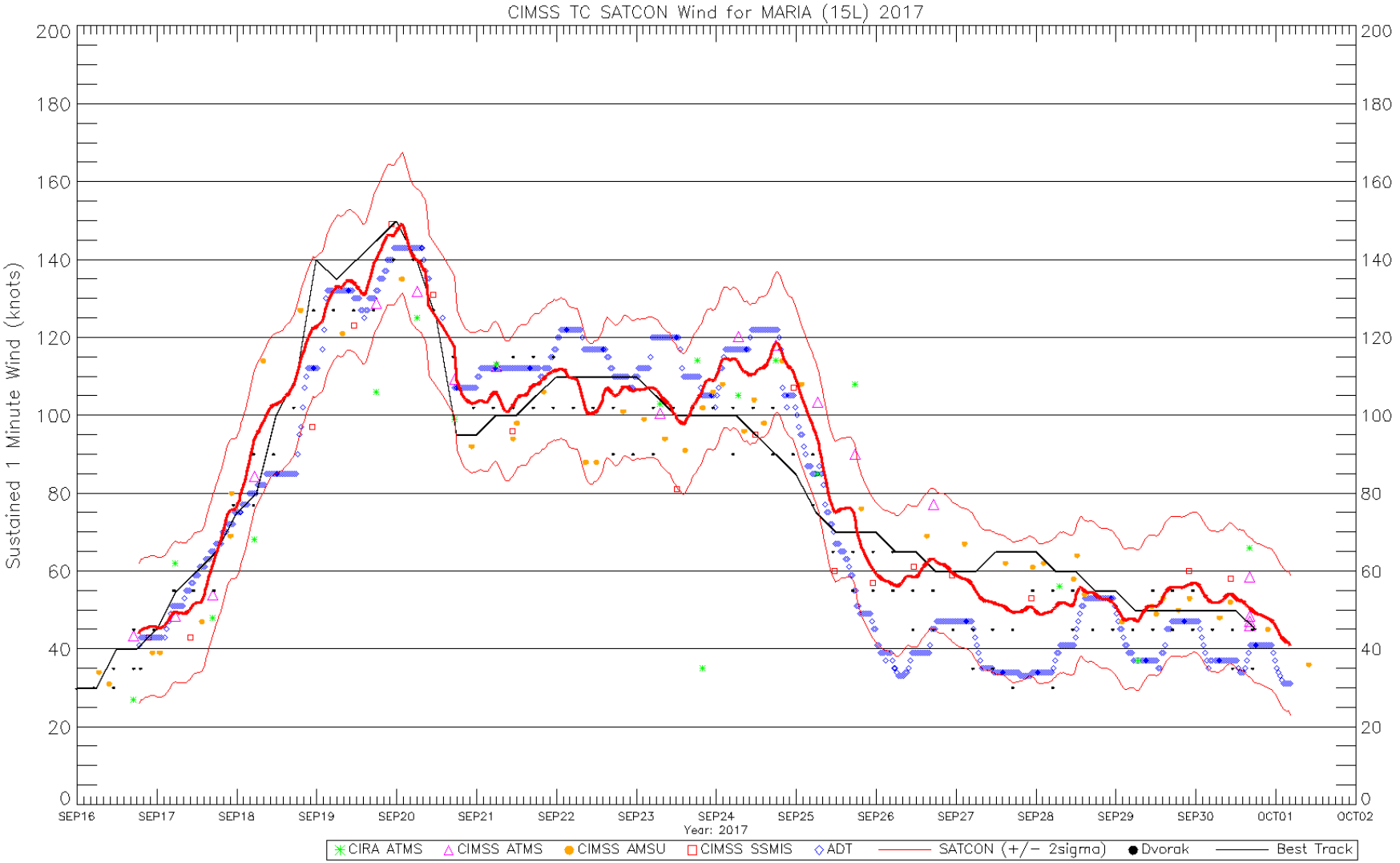
N = 4097	ADT	AMSU	SSMIS/ ATMS	SATCON Simple Avg	SATCON
BIAS	-0.8	-1.0	-1.5	-1.1	0.0
ABS ERROR	7.5	4.6	5.9	4.3	4.0
RMSE	10.3	6.3	8.0	5.8	5.3

SATCON MSLP performance compared to individual members 2006-2015 All values are in hPa. SATCON Simple Avg is a straight average of all



Velden and Herndon, 2014

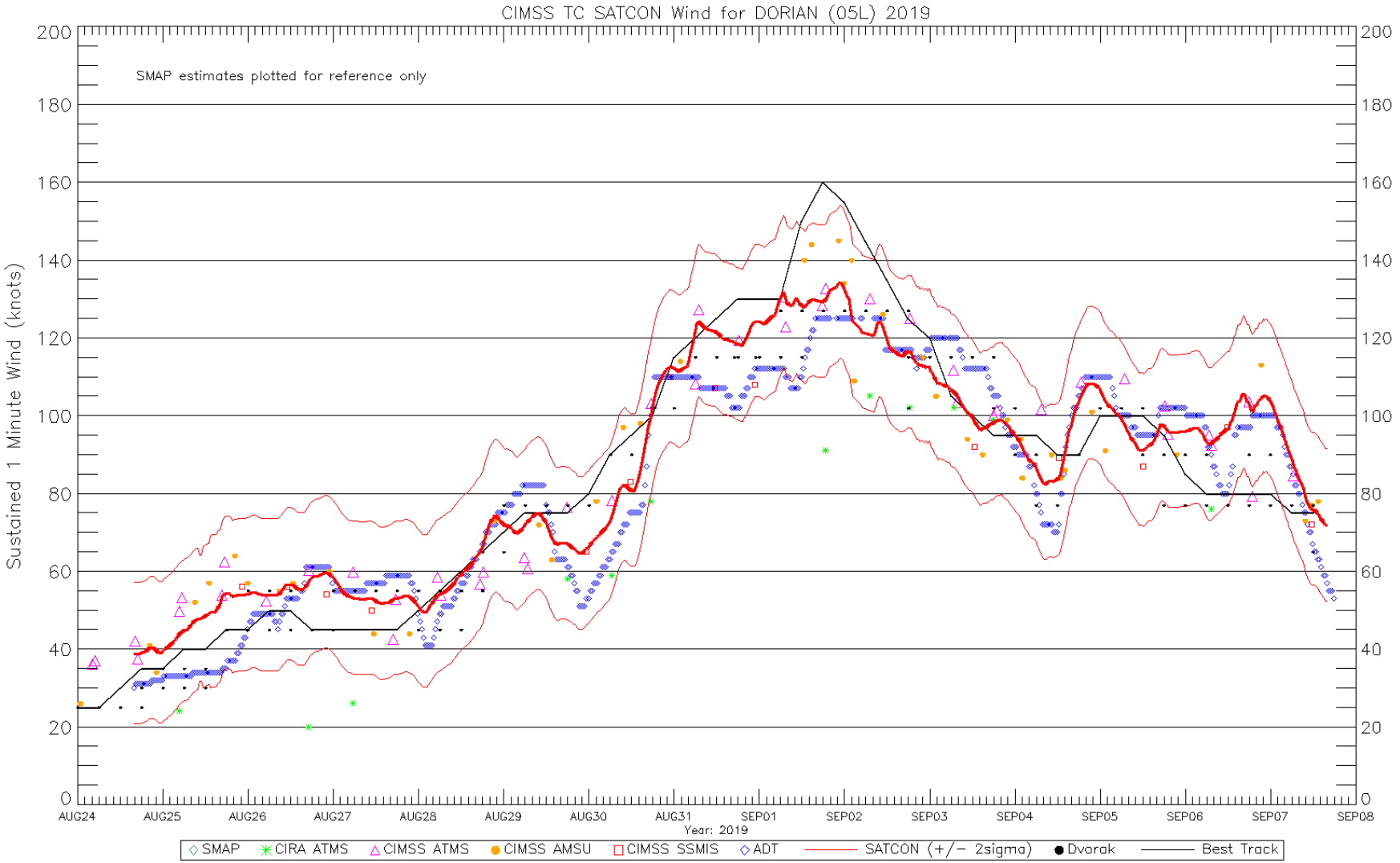
SATellite CONsensus
http://tropic.ssec.wisc.edu/real-time/satcon/



Ouragan MARIA 2017 (NATL) vu par SATCON
Hurricane MARIA 2017 (NATL) seen bye SATCON

METEO FRANCE

SATellite CONsensus
http://tropic.ssec.wisc.edu/real-time/satcon/



Ouragan DORIAN 2019 (NATL) vu par SATCON
Hurricane DORIAN 2019 (NATL) seen bye SATCON

METEO FRANCE

OUTLINE

Synopsis on microwaves

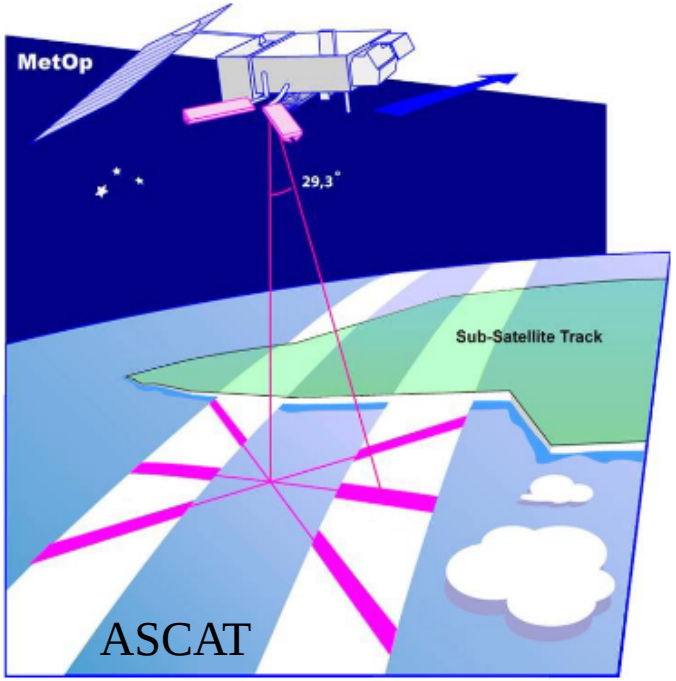
Interpreting microwave data

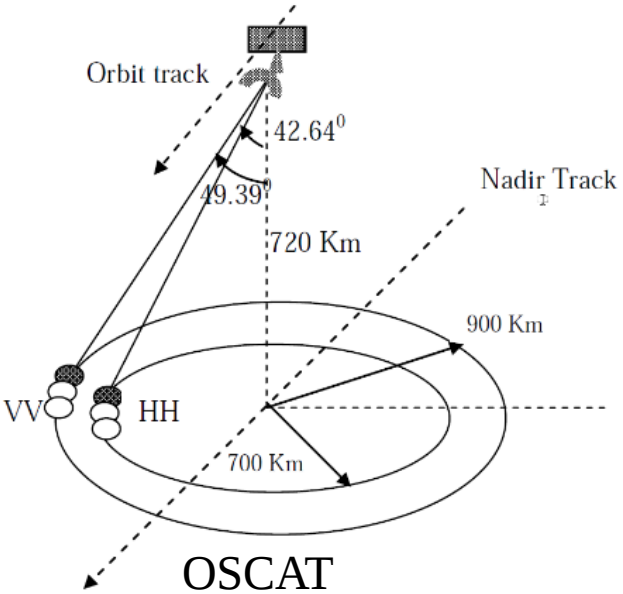
Applications in TC analysis

TC Intensity estimate: objective guidances

Scatterometers / SAR

HOW WORK SCATTEROMETERS ?

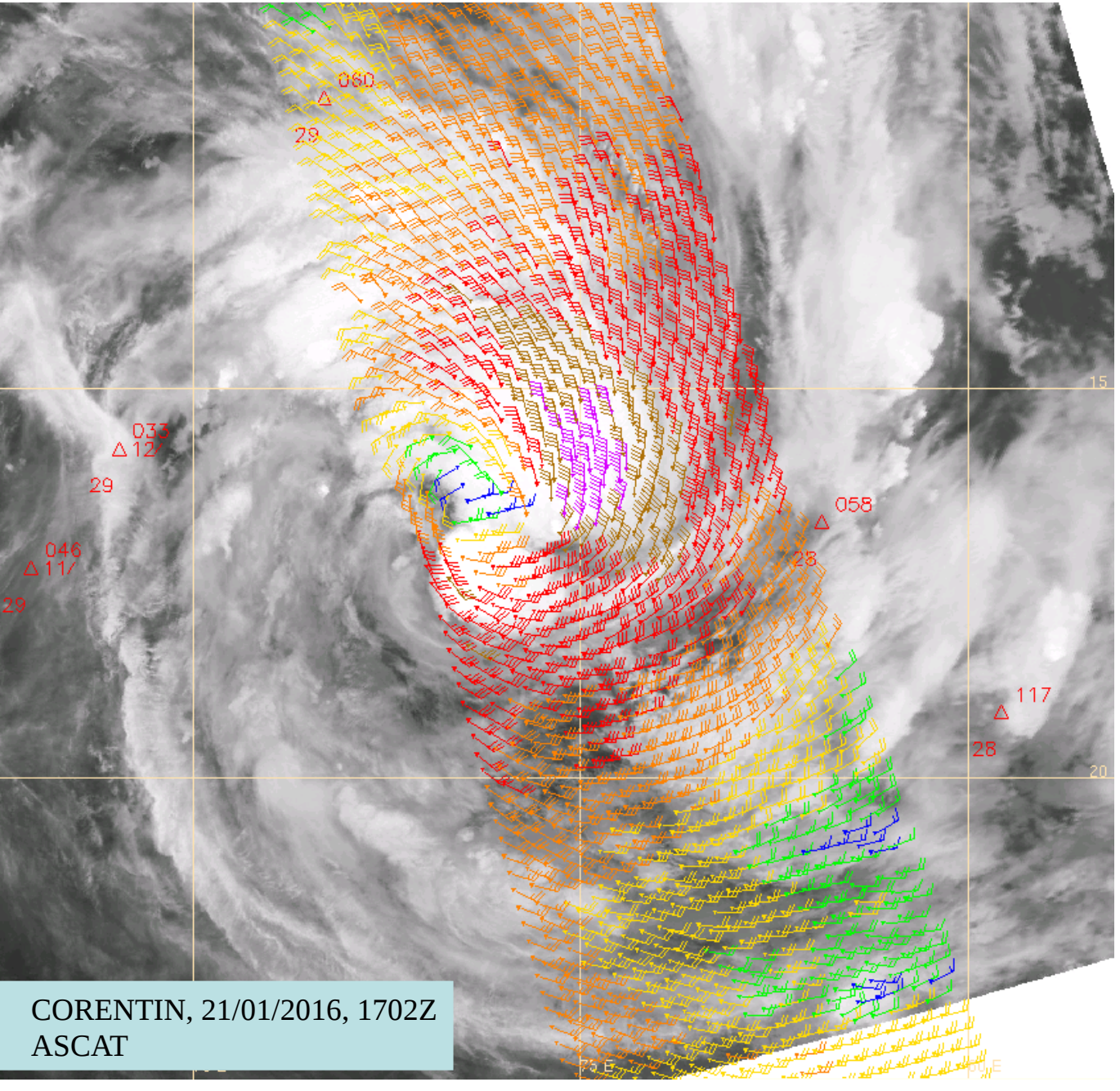




- Diffusiomètre : radar micro-ondes mesurant le signal rétro-diffusé par les ondes capillaires et de gravité à la surface de la mer
- L'analyse du signal retro-diffusé par une même surface océanique vue sous différents angles par le satellite permet de calculer la force et la direction du vent.
- La mesure est perturbée par tout phénomène qui détruit les ondes capillaires : la pluie, les vents très faibles ou très forts.
- Ambiguïté direction du vent : levée avec données modèles
- *Scatterometers measure radar reflectivity due to Bragg scattering from capillary and short gravity waves.*
- *By viewing the same patch of ocean from several angles, it is possible to derive wind speed and direction.*
- *Measure can be incorrect due to any parameter destroying capillary waves : rain, very weak or very strong winds*
- *Wind direction ambiguity : use of NWP data*

METEO FRANCE

OPERATIONAL SCATTEROMETERS (2019)



CORENTIN, 21/01/2016, 1702Z
ASCAT

- ASCAT A, B et C (Metop – UE)
Meilleure résolution à 12.5 km

- OSCAT (ScatSat – IND)
Meilleure résolution à 25 km

- Passage ~06Z et ~18Z

Intérêts suivi cyclonique :

- Localisation du centre

- Intensité (gamme : 20 → 45 kt)

- Extensions vents forts (Grand-Frais, Coup de vent, ~ Tempête)

- ASCAT A, B et C (Metop – EU)
Best horizontal resolution 12.5 km

- OSCAT (ScatSat – IND)
Best horizontal resolution 25 km

-Swath ~06Z and ~18Z

Advantage for TC monitoring :

- Locate the center

- TC intensity (maxwinds : 20 → 45 kt)

- Winds radii (Near Gale, Gale, ~Storm force winds)

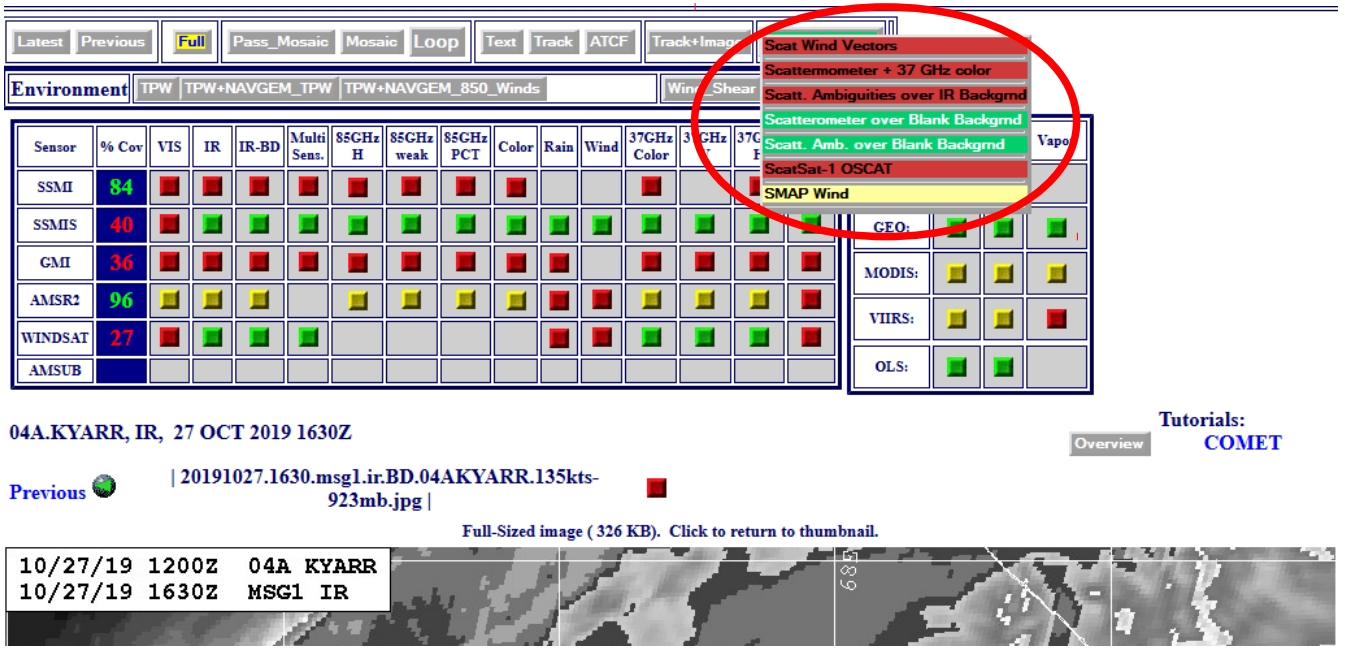
METEO FRANCE

SCATT PRODUCTS : DATA ACCESS

➔NOAA :
ASCAT-A : https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php
ASCAT-B : https://manati.star.nesdis.noaa.gov/datasets/ASCATBData.php
ASCAT-C : https://manati.star.nesdis.noaa.gov/datasets/ASCATCData.php

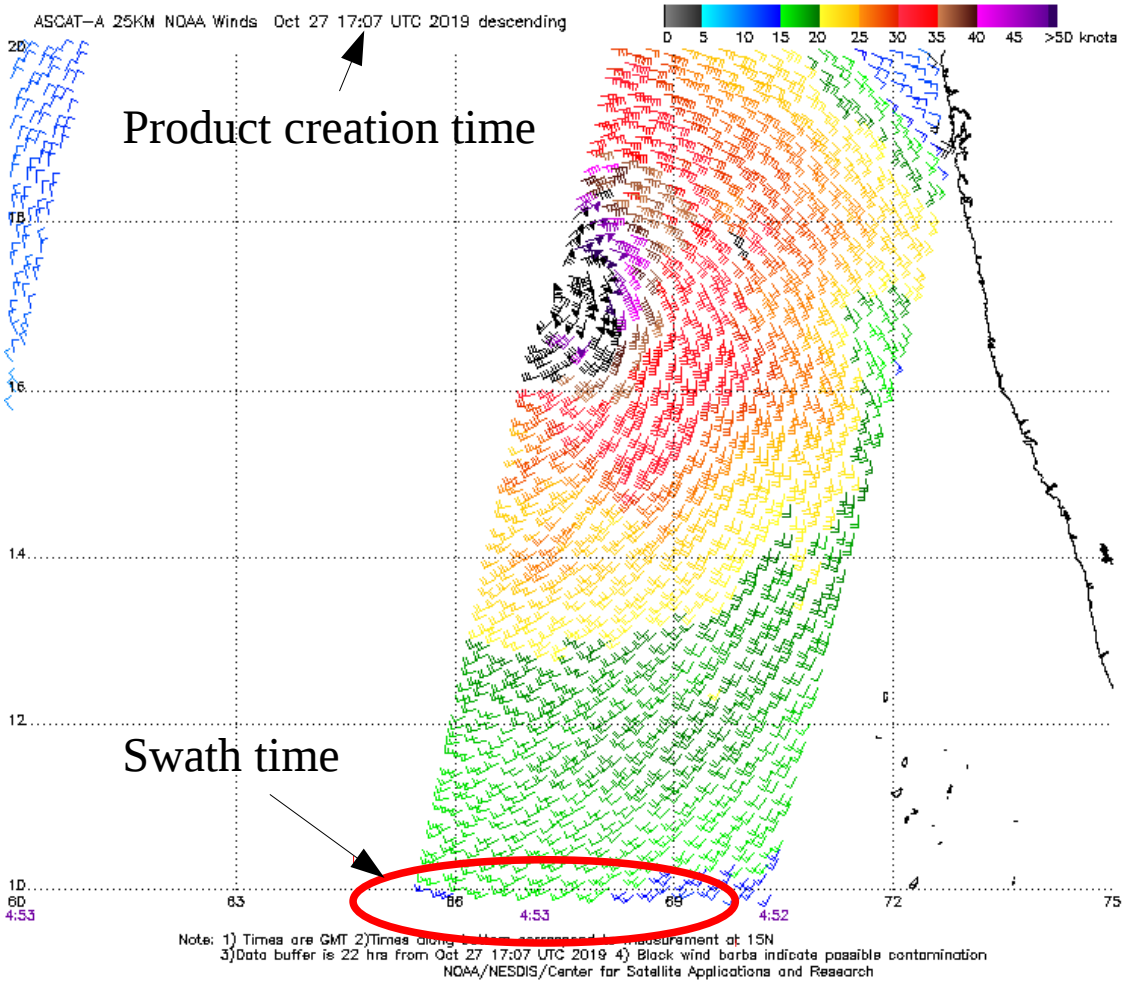
➔KNMI (EUMETSAT OSI SAF) :
ASCAT-A : http://projects.knmi.nl/scatterometer/ascat_osi_co_prod/ascat_app.cgi
ASCAT-B : http://projects.knmi.nl/scatterometer/ascat_b_osi_co_prod/ascat_app.cgi
ASCAT-C : http://projects.knmi.nl/scatterometer/ascat_c_osi_co_prod/ascat_app.cgi
OSCAT : http://projects.knmi.nl/scatterometer/scasa_25_prod/scasa_app.cgi

➔NRL TC PAGE :

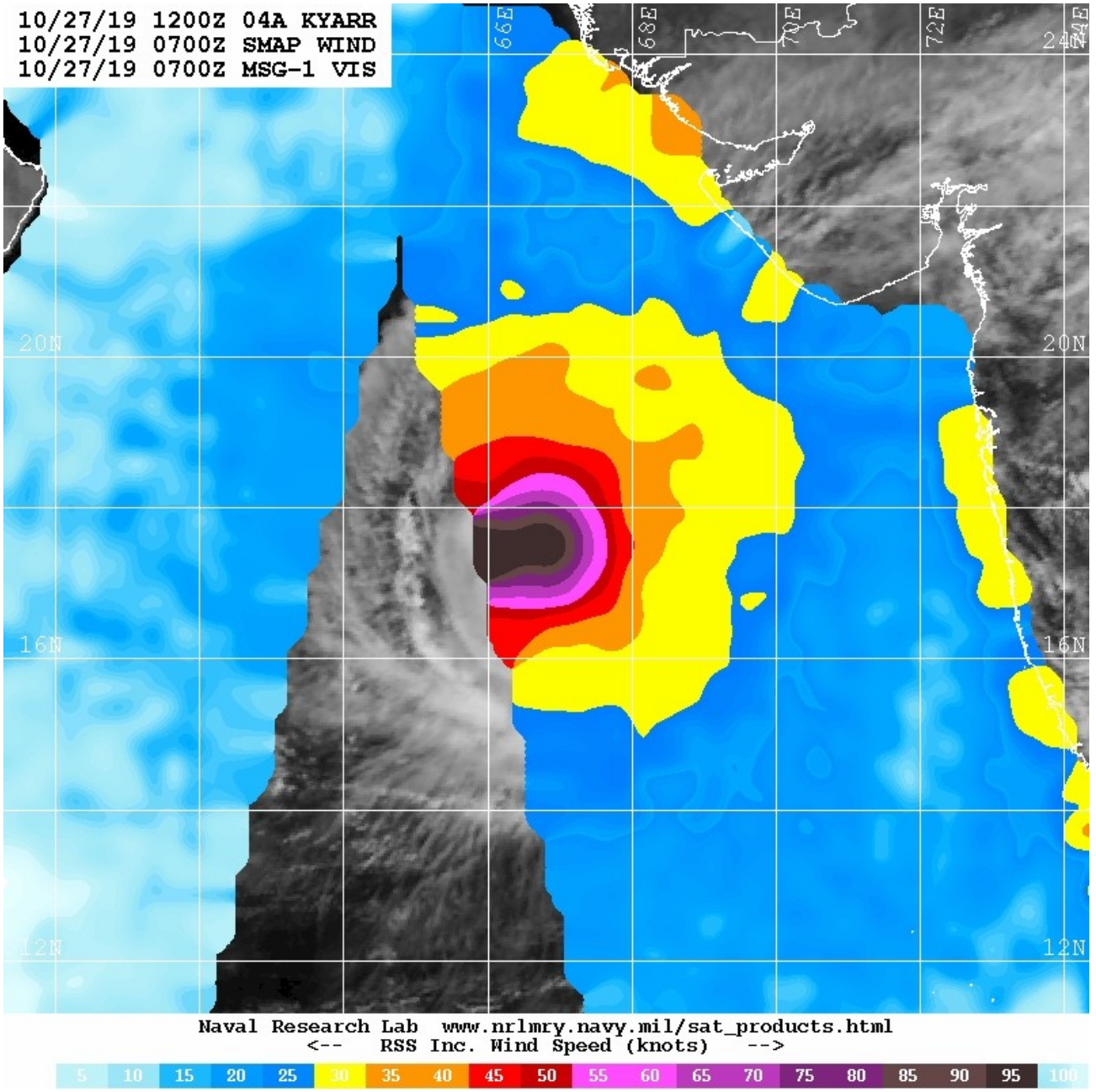


SCATT PRODUCTS : DATA ACCESS

➔NOAA :
ASCAT-A : https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php
ASCAT-B : https://manati.star.nesdis.noaa.gov/datasets/ASCATBData.php
ASCAT-C : https://manati.star.nesdis.noaa.gov/datasets/ASCATCData.php



REMOTE MEASUREMENT OF HIGH WIND SPEED
Soil Moisture Active Passive



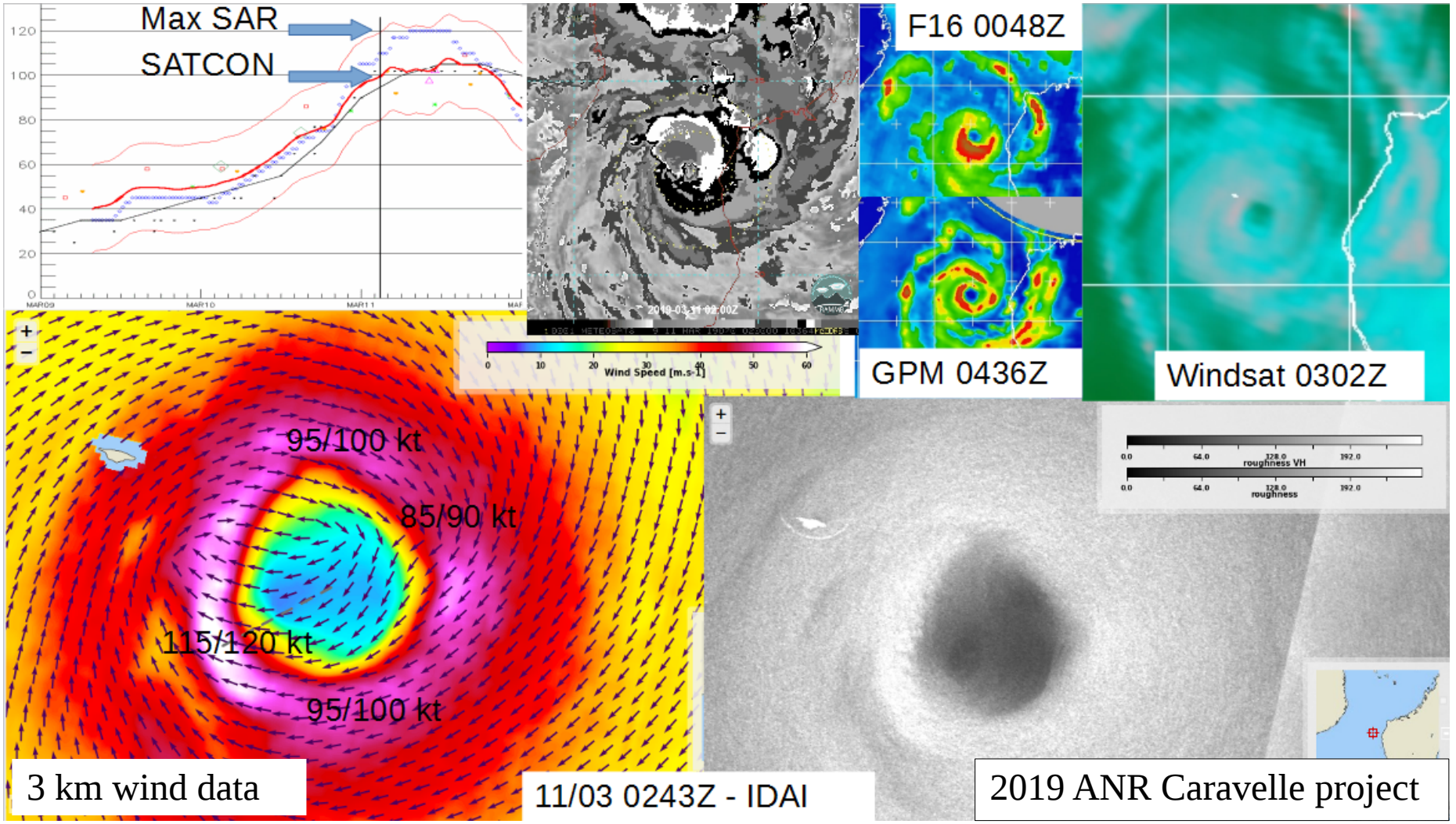
➔Passive radiometer sensitive to high wind speed and less sensitive to rain

➔ Allowing estimate intensity and strong winds radii despite coarse resolution (~40 km)

➔ NRT access on Manati (https://manati.star.nesdis.noaa.gov/datasets/SMAPData.php), NRL and RMSS (http://images.remss.com/smap/smap_data_daily.html)

METEO FRANCE

REMOTE MEASUREMENT OF HIGH WIND SPEED
Synthetic Aperture Radar (SAR)



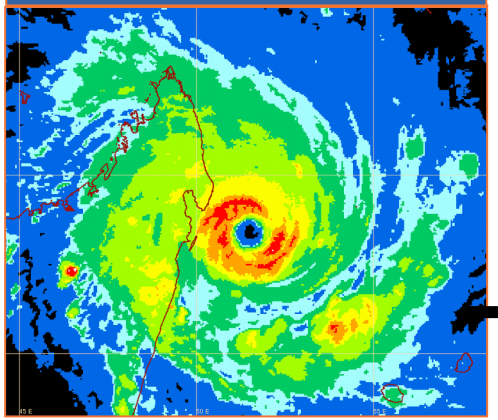
The only spaceborn instrument able to probe at very high resolution the sea surface under extreme weather conditions

→ Current mission with Sentinel 1 A-B, Radarsat 2

→ Still not operationnal … but work in progress to do so ...

CONCLUSION :
TC analysis is a blending of several inputs

DVORAK manual

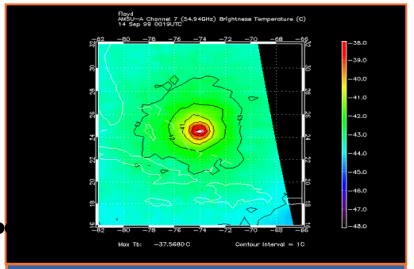


ADT

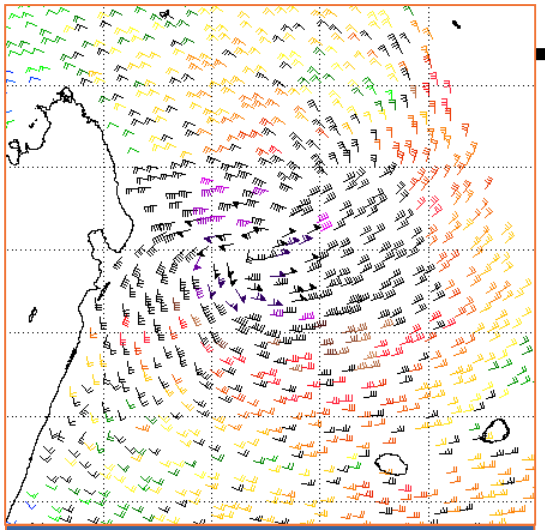
SATCON

1st GUESS

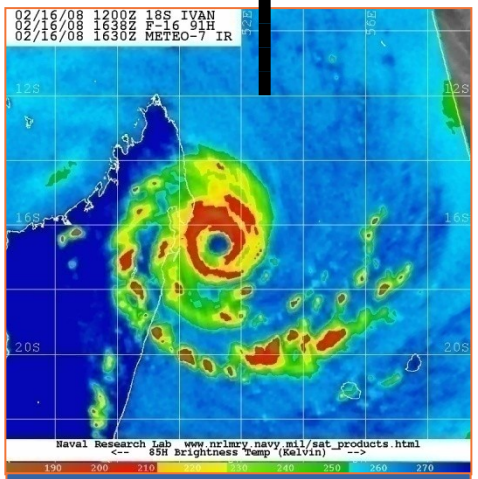
TC intensity and structure estimates



AMSU, ATMS, SSMI/S



Scatt data, SMAP, (SAR)



PASSIVE MICRO-WAVE

Surface OBS

METEO FRANCE