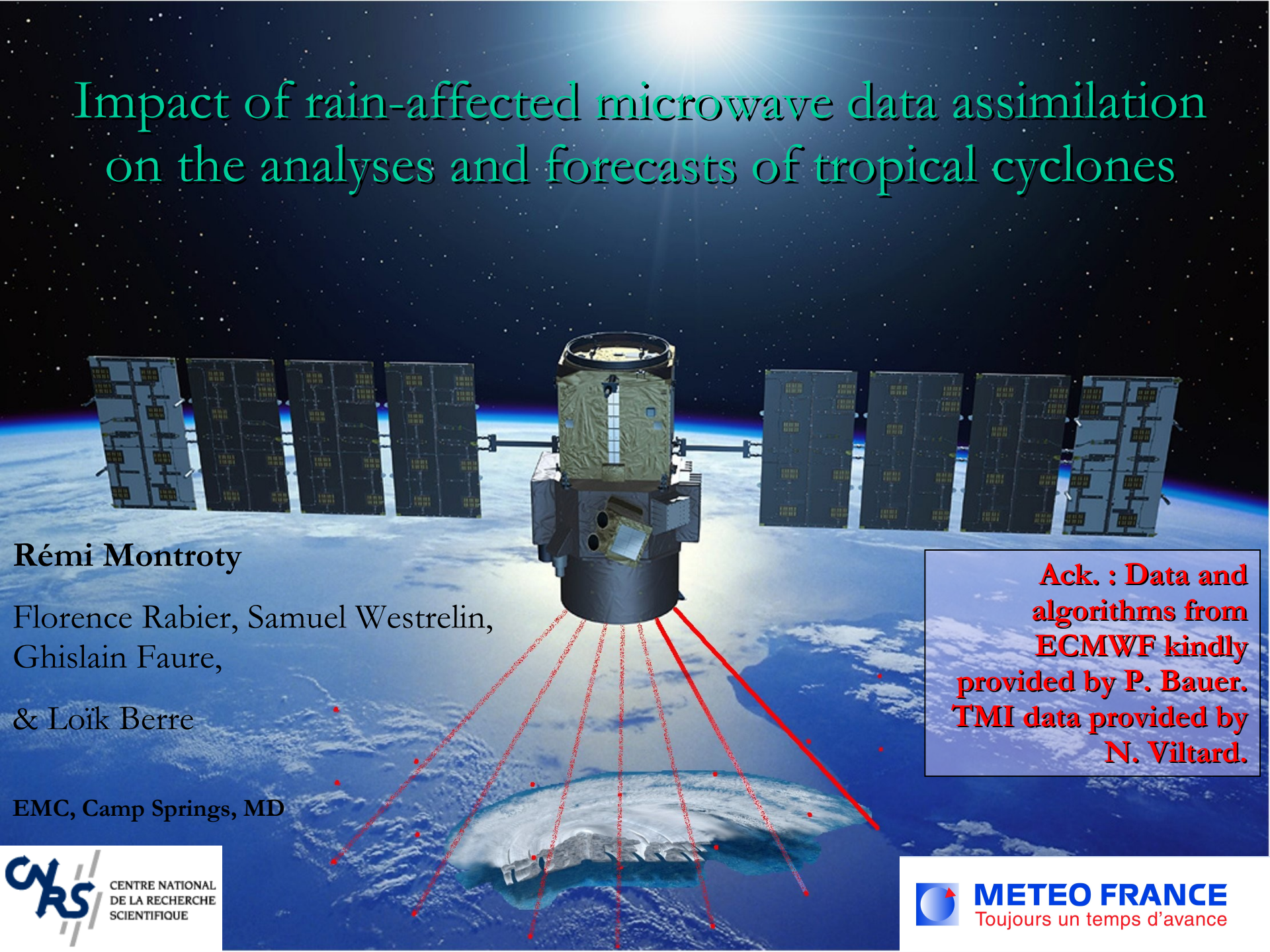
Impact of rain-affected microwave data assimilation on the analyses and forecasts of tropical cyclones



Rémi Montroty

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EMC, Camp Springs, MD

Ack. : Data and algorithms from ECMWF kindly provided by P. Bauer. TMI data provided by N. Viltard.

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Outline

I. Assimilating rain-affected SSM/I data and its impact on analyses & forecasts of TCs.

II. Effects on downscaling to 4 km with AROME

III. Diagnosing the flow-dependent variability of background errors

IV. Impacts of those filtered errors on TC forecasting

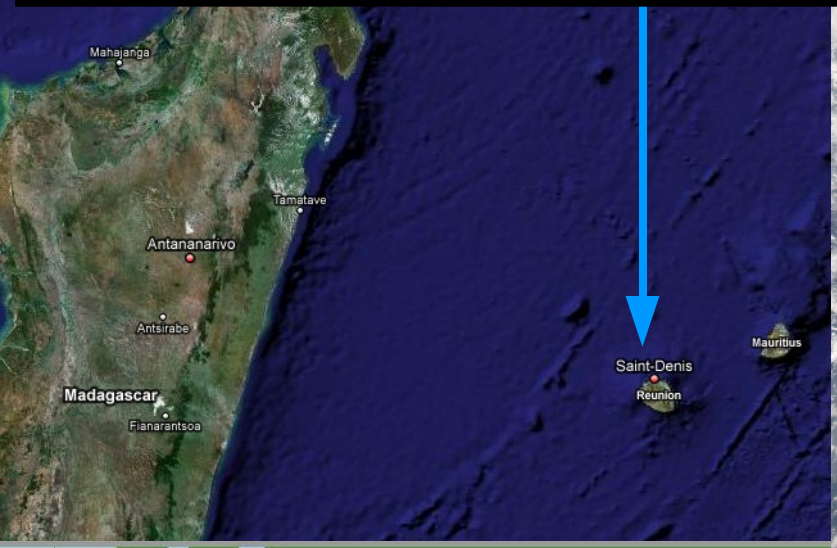
V. Conclusions

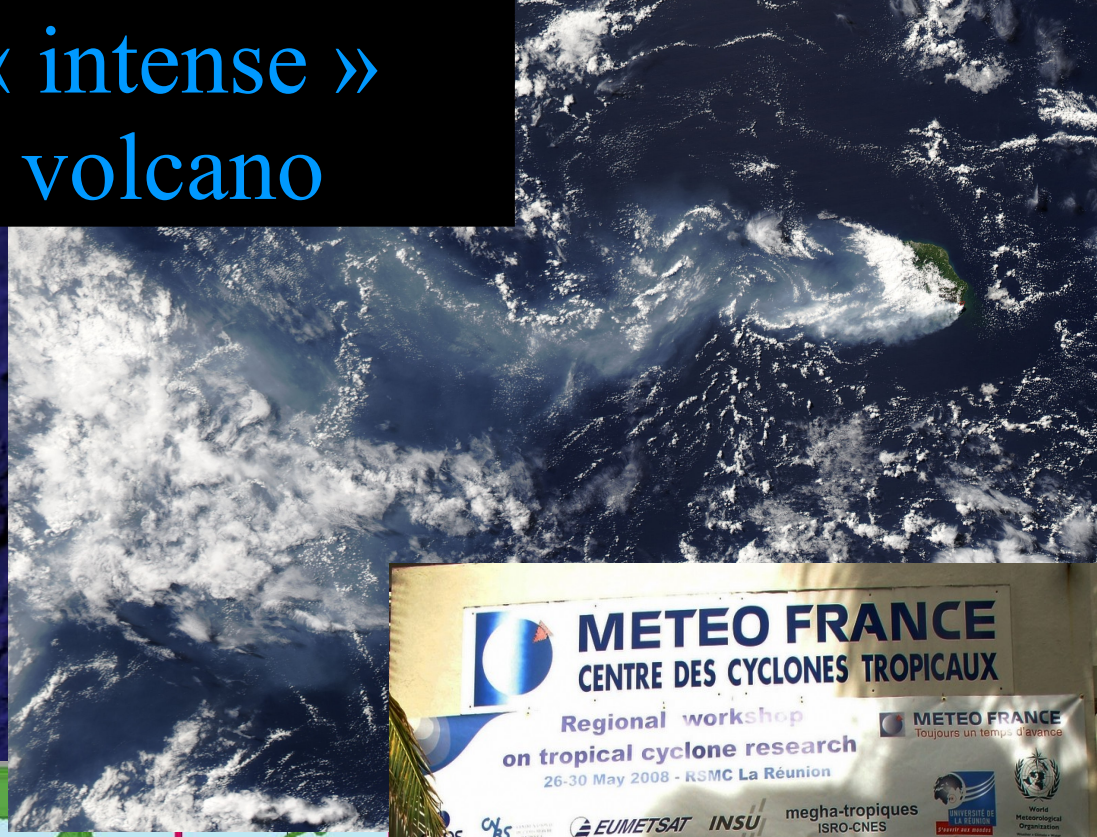
PART I:
Assimilating rain-affected SSM/I data and its impact on analyses & forecasts of TCs.

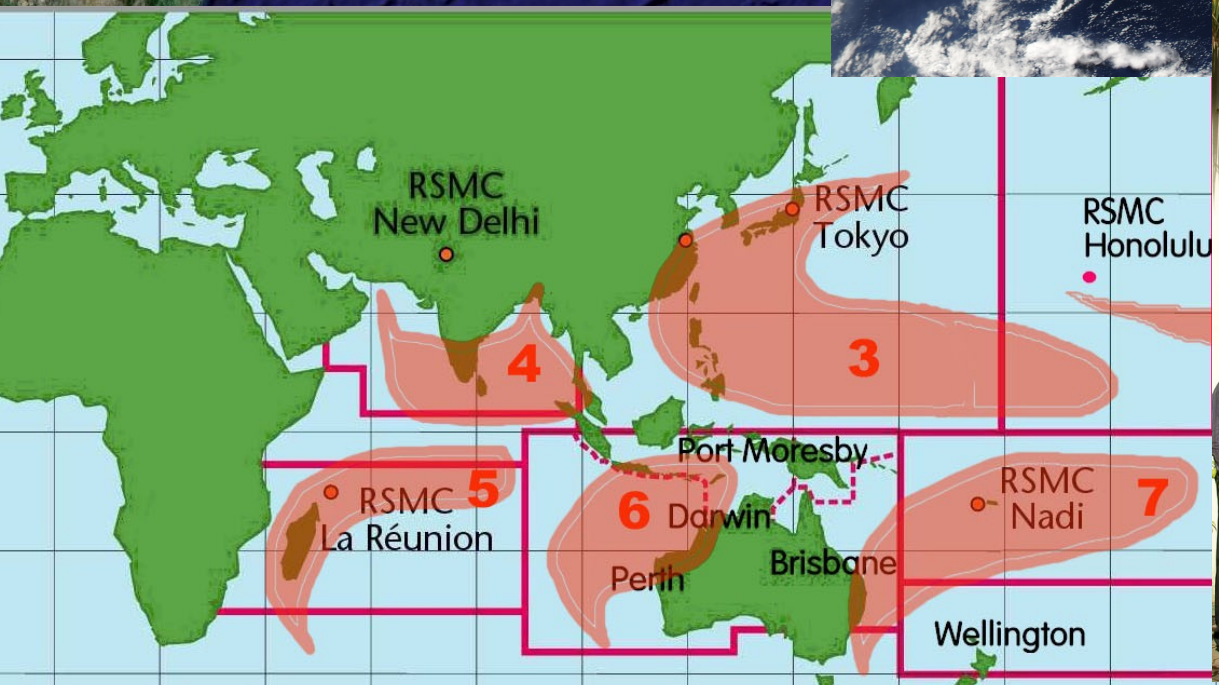
A quick introduction

- La Réunion (french overseas department) is the official Regional Specialized Meteorological Center for Tropical Cyclone (TC) Watch, under the WMO's supervision.
- This thesis work was funded in order to support the operational need of a hi-res model (ALADIN) and to investigate possible ways to improve TC forecasts.

Reunion Island, the « intense » island : cyclones & a volcano

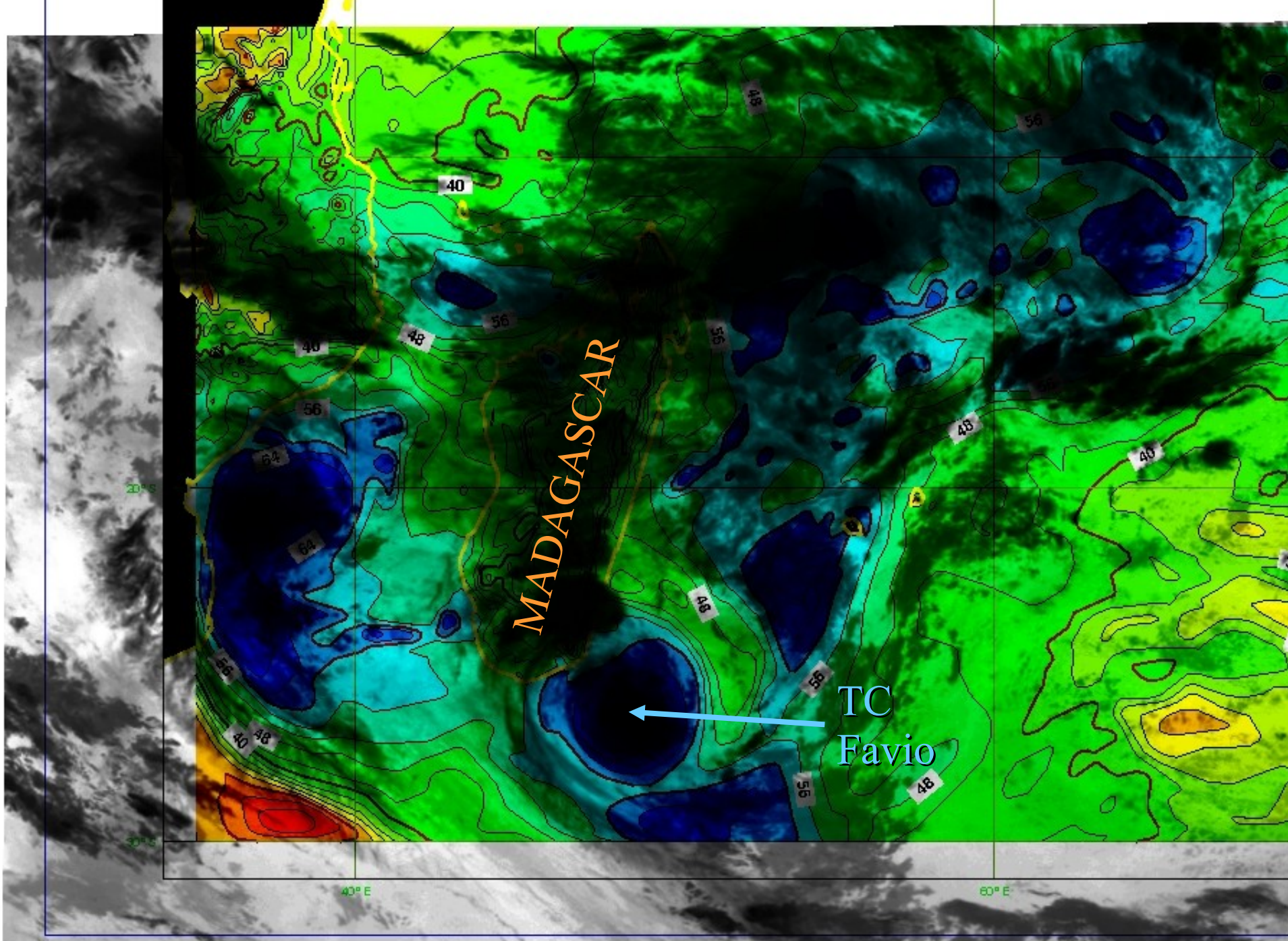






Motivation for this study

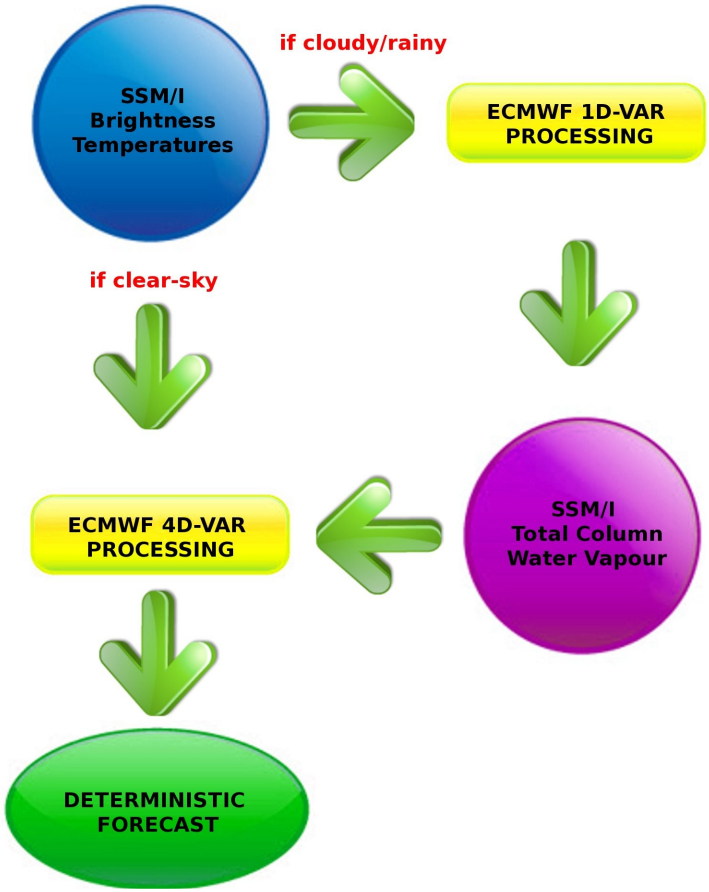
- NWP, and more specifically TC forecasting, is highly dependent on satellite observations
- These observations are usually not assimilated in cloudy and/or rainy conditions NCEP!
- Assimilation of rainy satellite radiances proves very costly (complex obs operators)


MADAGASCAR
TC
Favio
40
48
56
64
40° E
60° E

Methodology (1/3): Rainy SSM/I at ECMWF

The characterization of the cloudy/rainy condition is purely observation-based. Namely:

- If TB_{37H}-TB_{37V} < 40 K, the pixel is considered rainy.
- If LWP> 0.01 kg.m^{-2} , the pixel is considered cloudy; with



UNREADA
V-H??

$$LWP = A_0 + A_1 * \log(280-TB_{22V}) - A_2 * \log(280-TB_{37H})$$

where A_0=4.2993, A_1=0.399635 and A_2=-1.406920

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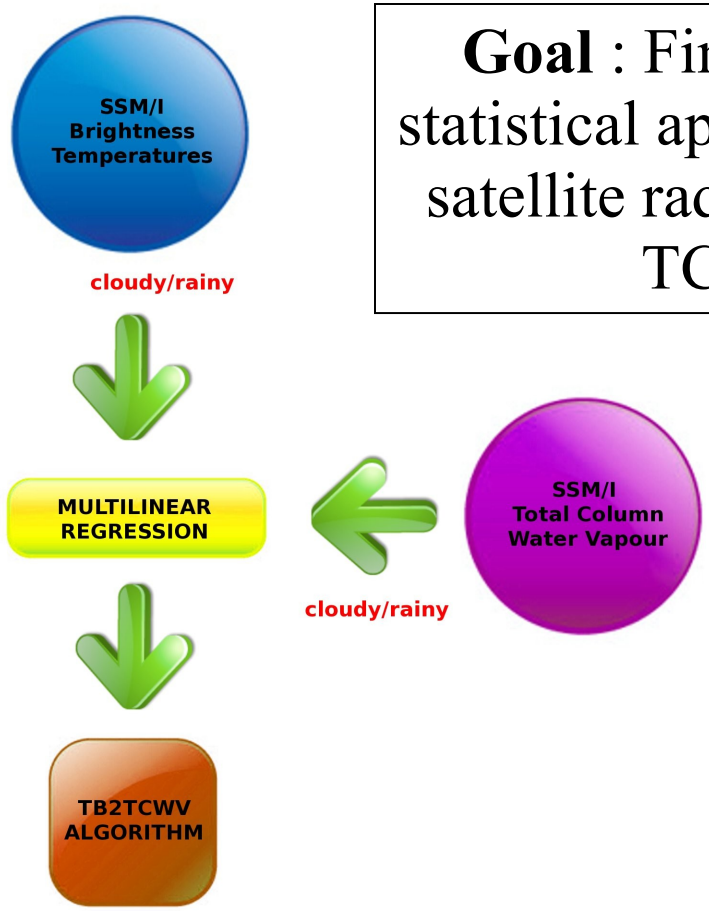
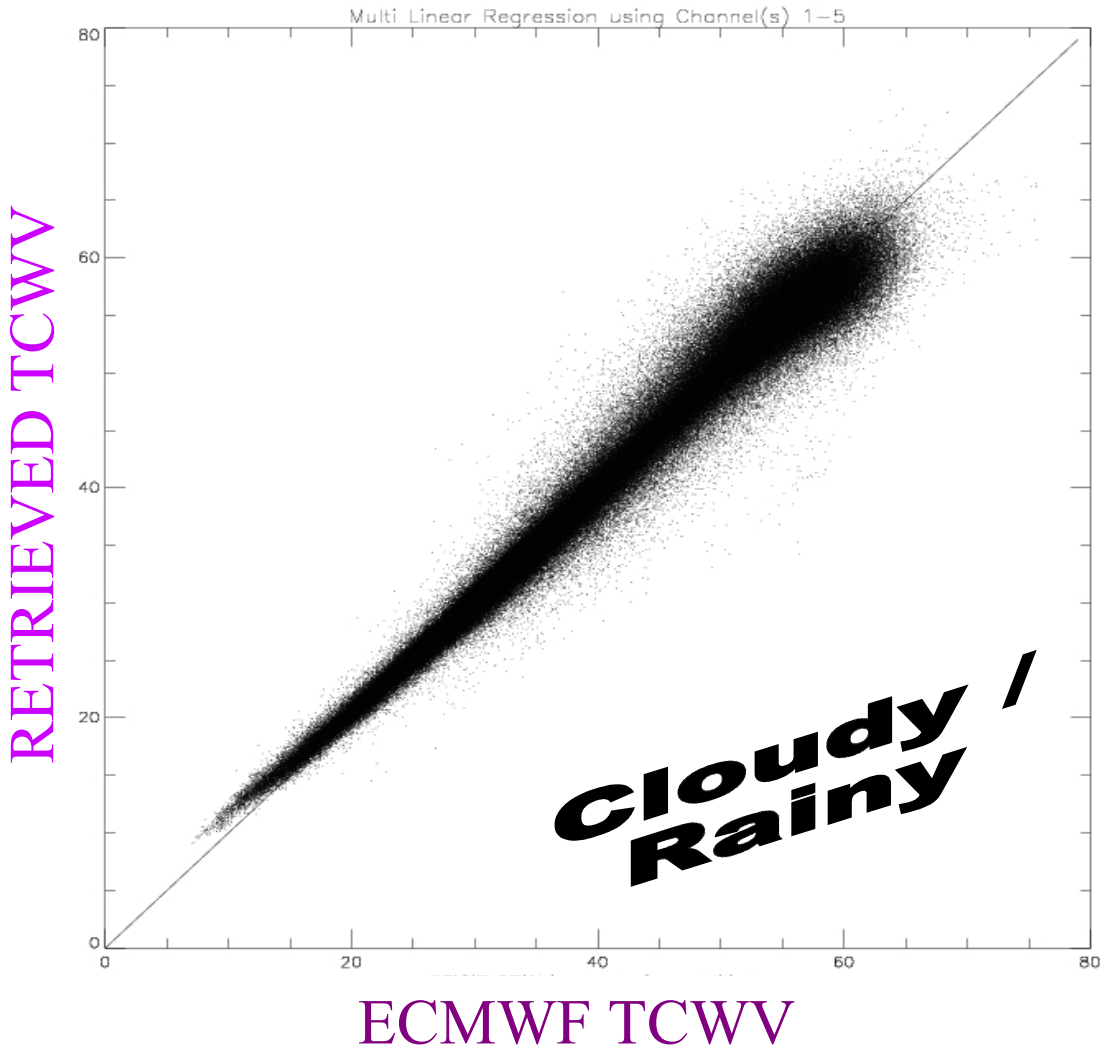
Methodology (2/3): Retrieving the algorithm

Goal : Find a simple, statistical approach to link satellite radiances to the TCWV

$$TCWV_{predicted} = \alpha_0 + \sum_{i=1}^{5} \alpha_i * \ln$$



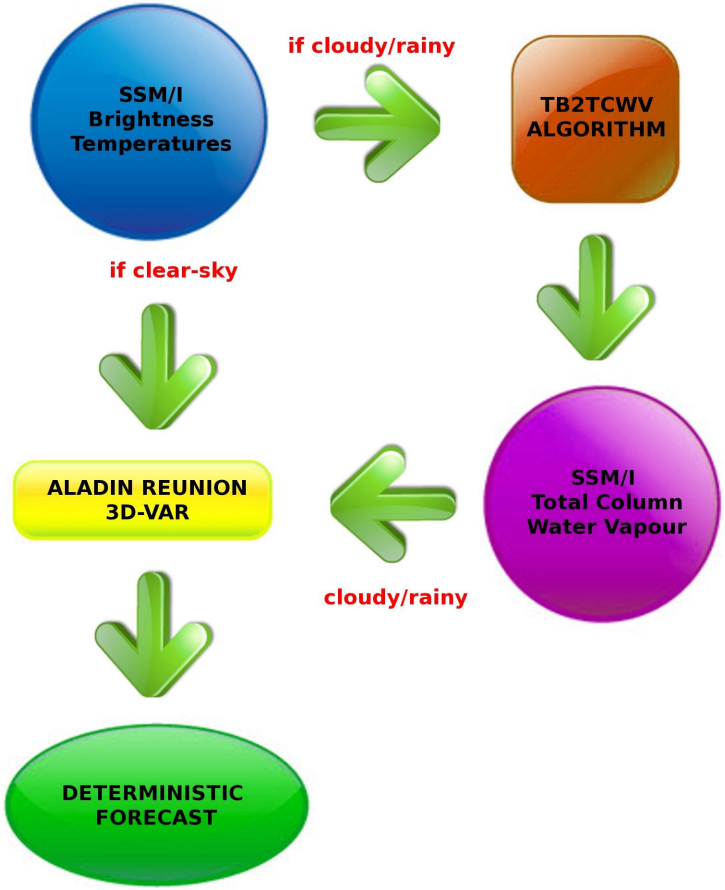
- One algorithm per SSM/I satellite
- Learning period from Nov 27, 2006 until Feb 11, 2007. Area is the SWIO.
- 250000 to 350000 points
- 3 TC and 1 Tropical Storm sampled

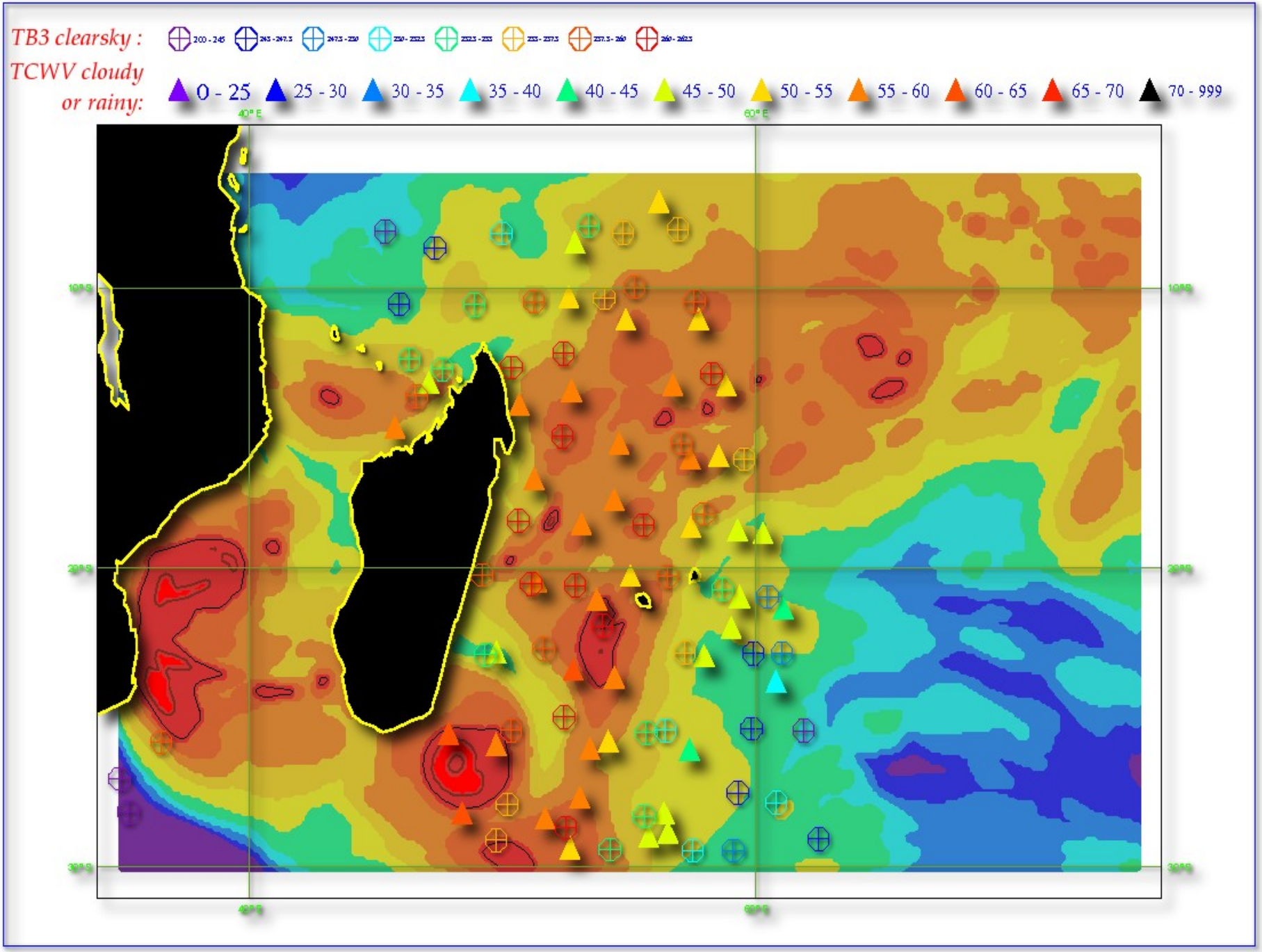


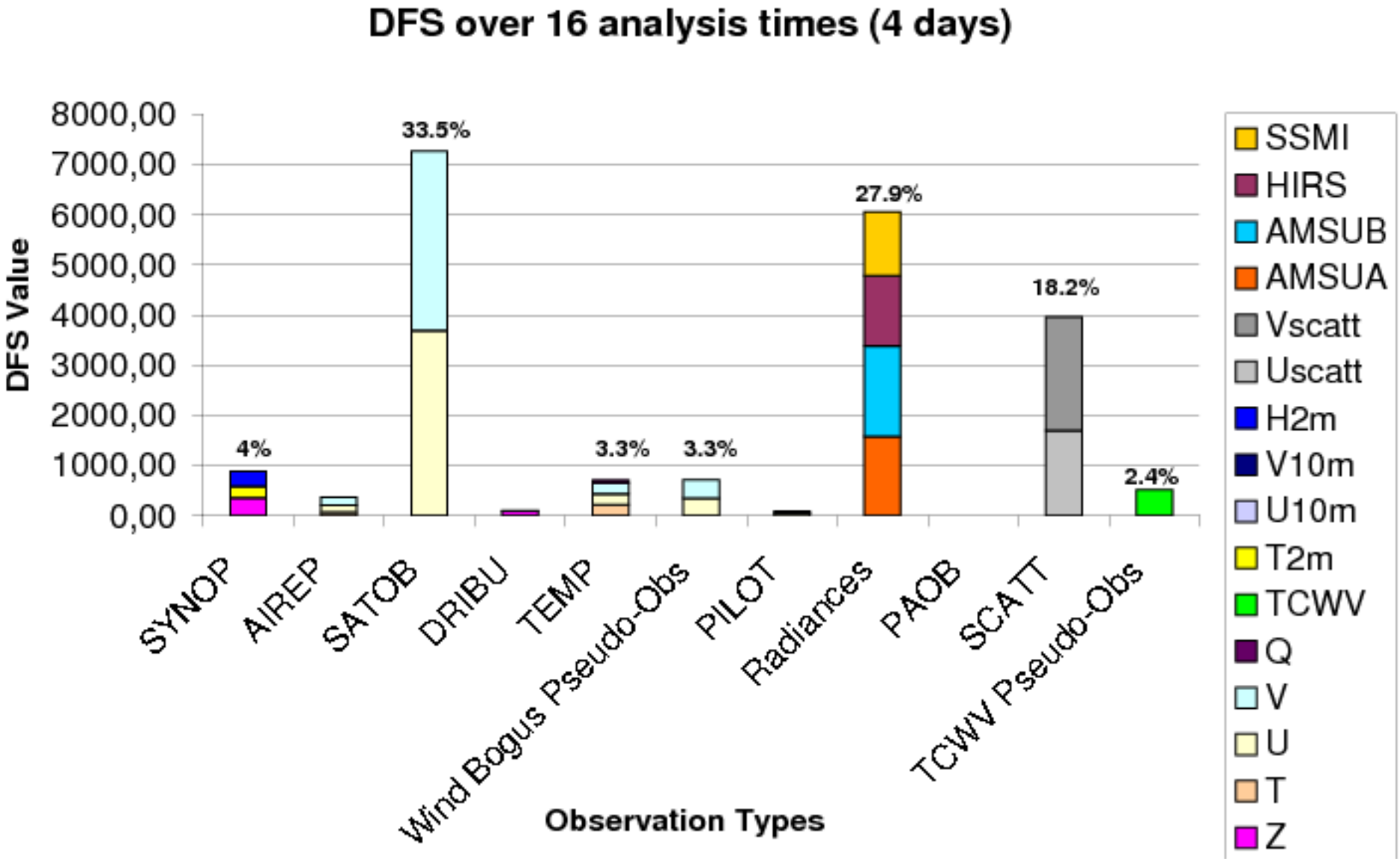
➢ Std dev < 2.2 kg/m² ; Correlation > 0.985

Methodology (3/3): Applying the algorithm

- The obtained TCWV is then assimilated in the ALADIN Reunion model (10km resolution, covers the SWIO)
- A 3D wind bogus following the UKMO technique (Heming, 1995) is used for cyclonic cases
- Several experiments were ran with the combination of TCWV and the 3D wind bogus

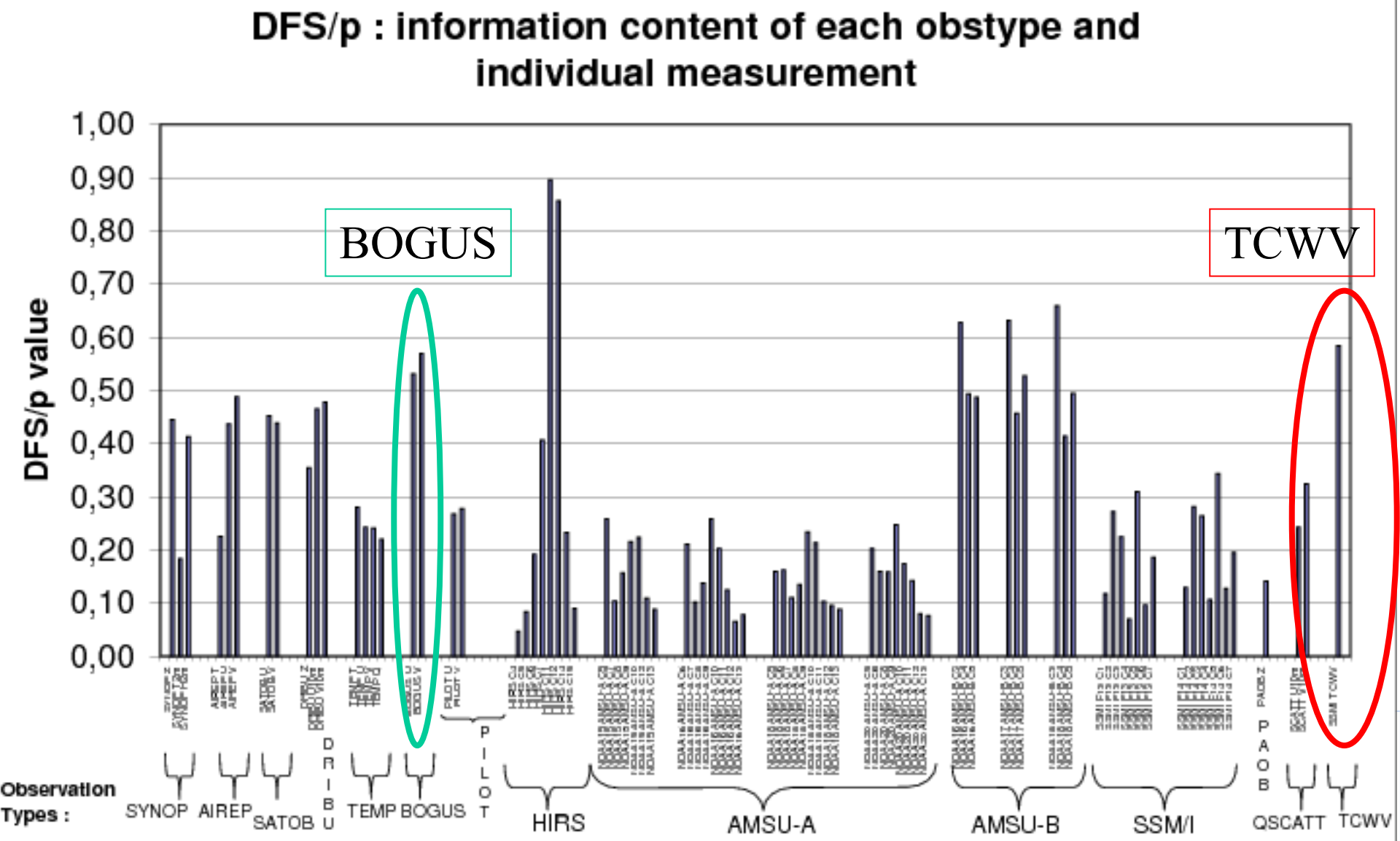



TB3 clearsky :
TCWV cloudy or rainy:
200 - 245
245 - 247.5
247.5 - 250
250 - 252.5
252.5 - 255
255 - 257.5
257.5 - 260
260 - 262.5
0 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 999
40° E
60° E
10° S
20° S
30° S

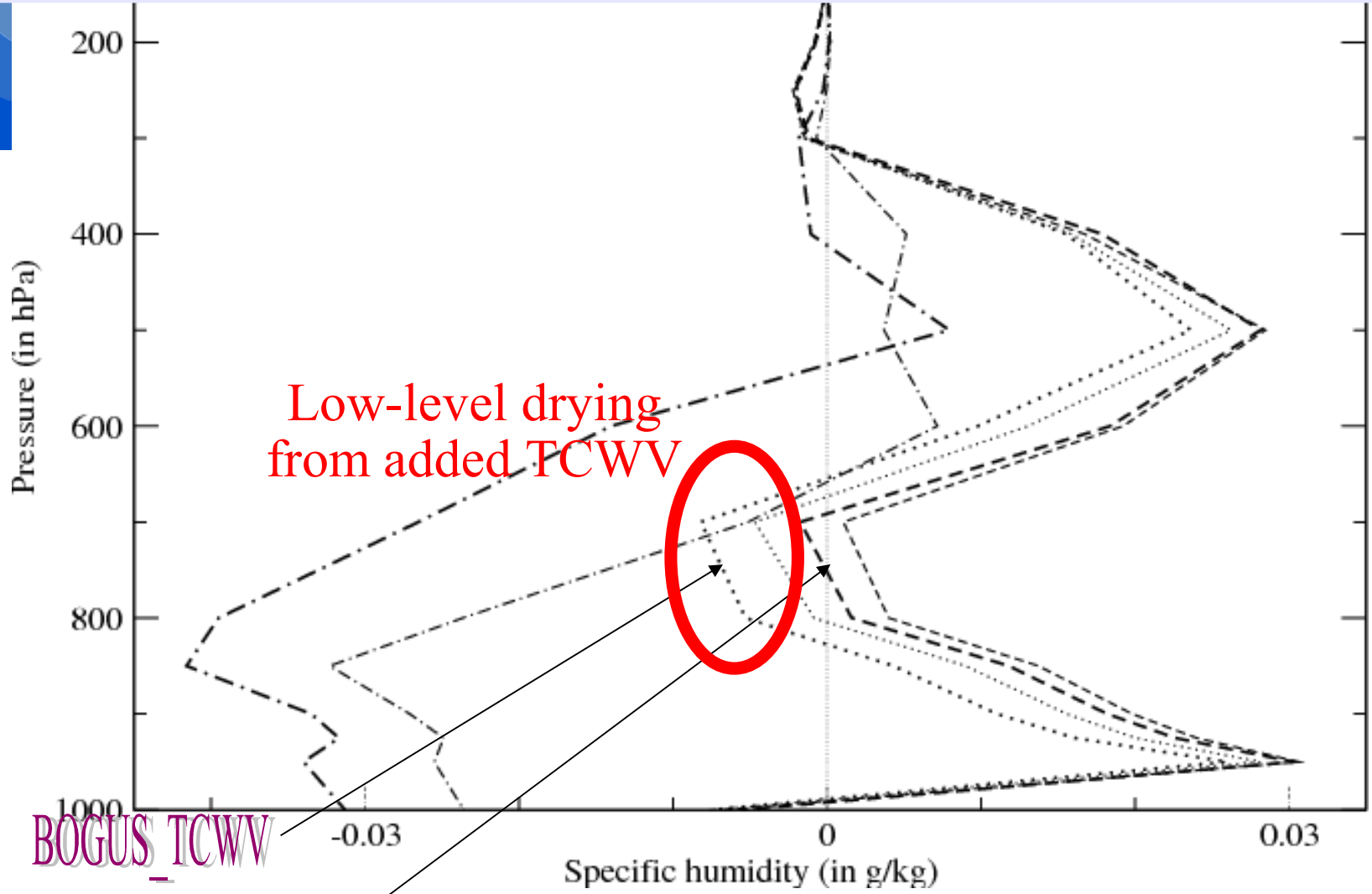

DFS over 16 analysis times (4 days)
DFS Value
8000,00
7000,00
6000,00
5000,00
4000,00
3000,00
2000,00
1000,00
0,00
4%
33.5%
3.3%
3.3%
27.9%
18.2%
2.4%
SYNOP
AIREP
SATOB
DRIBU
TEMP
Wind Bogus Pseudo-Obs
PILOT
Radiances
PAOB
SCATT
TCWV Pseudo-Obs
Observation Types
SSMI
HIRS
AMSUB
AMSUA
Vscatt
Uscatt
H2m
V10m
U10m
T2m
TCWV
Q
V
U
T
Z

DFS=?

OBSERVATIONAL IMPACTS ON THE 3DVar ANALYSES



IMPACT ON HUMIDITY FIELDS



BOGUS_TCWV

BOGUS

Mean Increments

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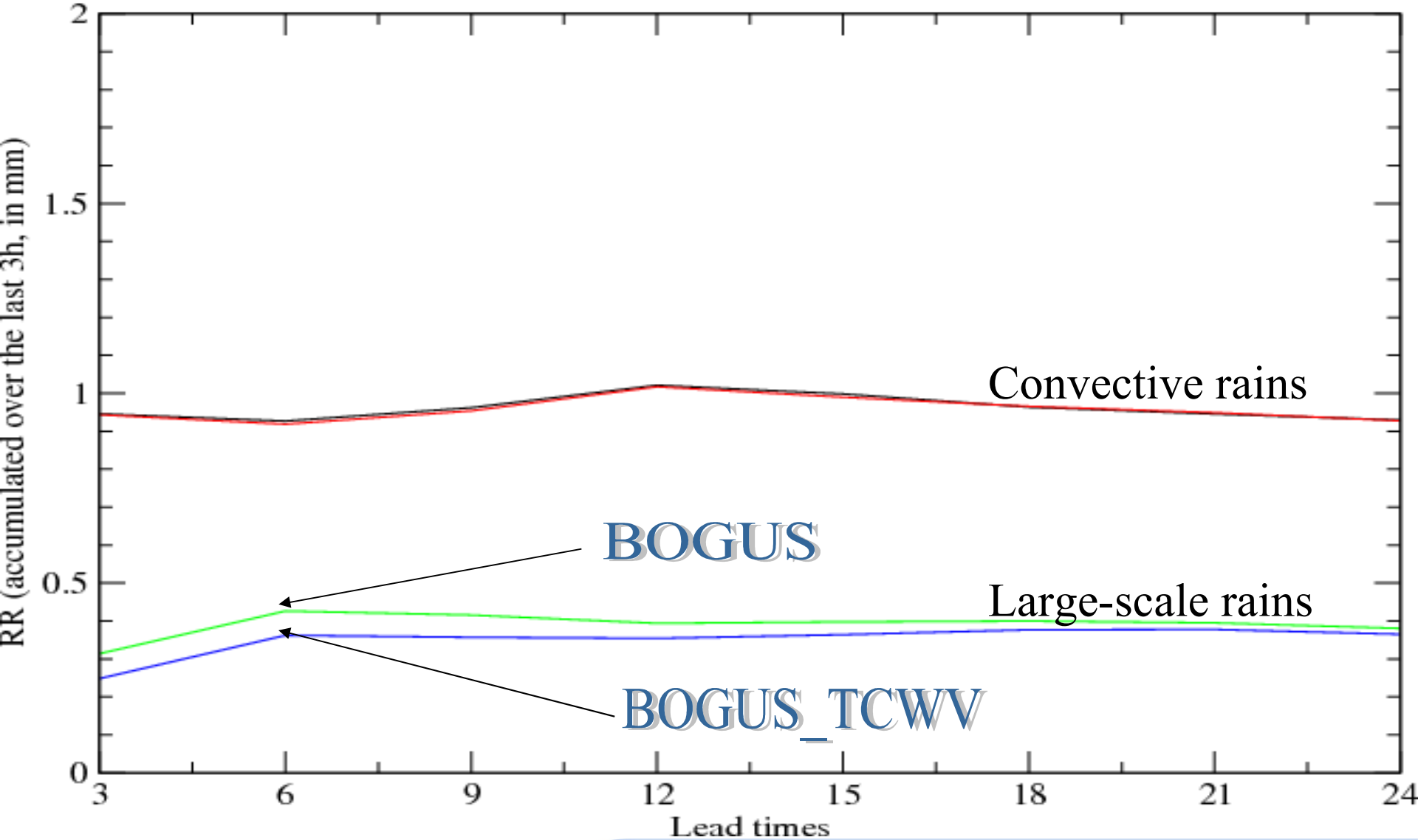
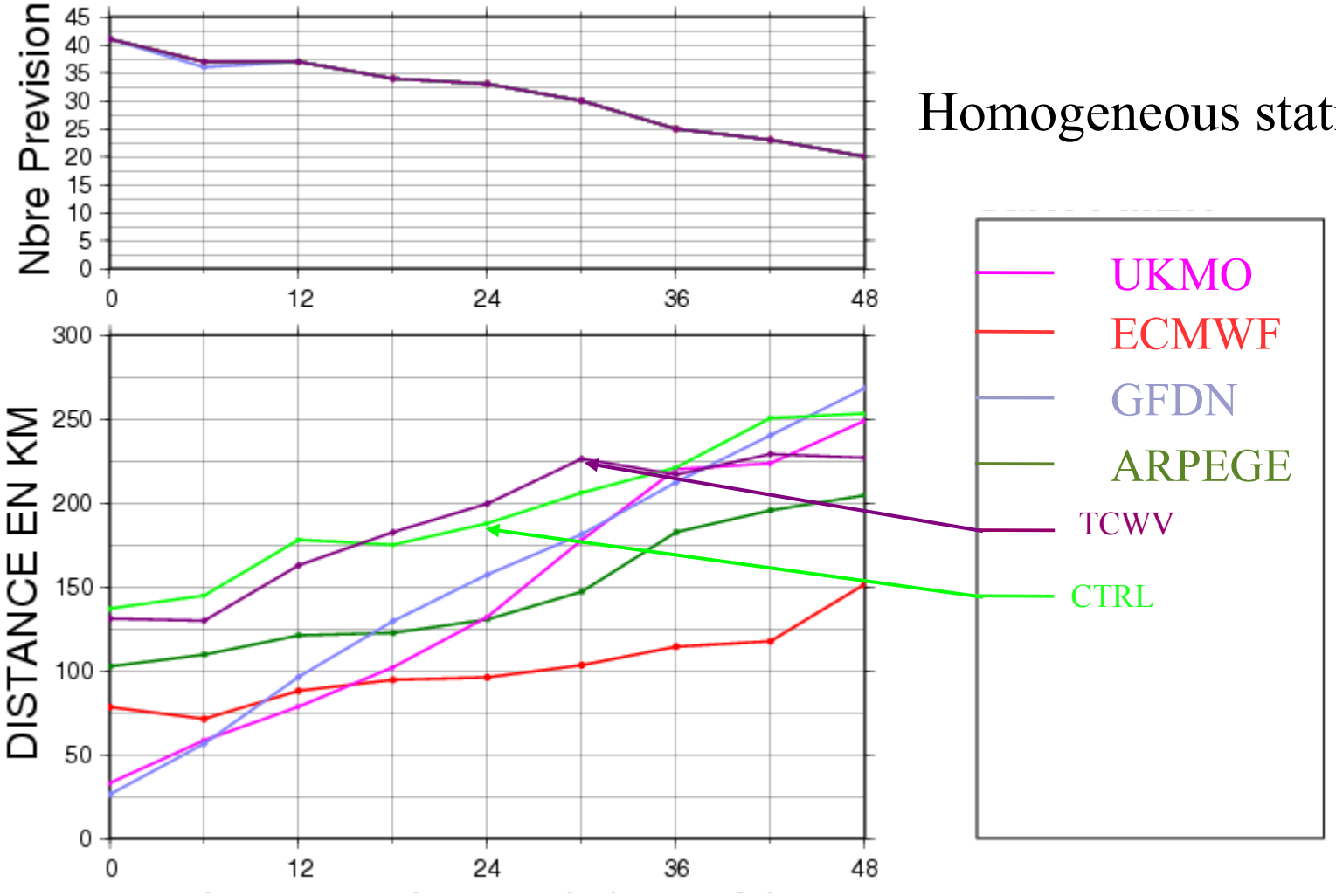
Spin-up comparison for the first 24h of model integration

(averaged over the whole domain, for the full 5 weeks of each experiment)



5-WEEK STATISTICS IN TERMS OF TRACK ERROR

Between 2007/02/12 and 2007/03/17



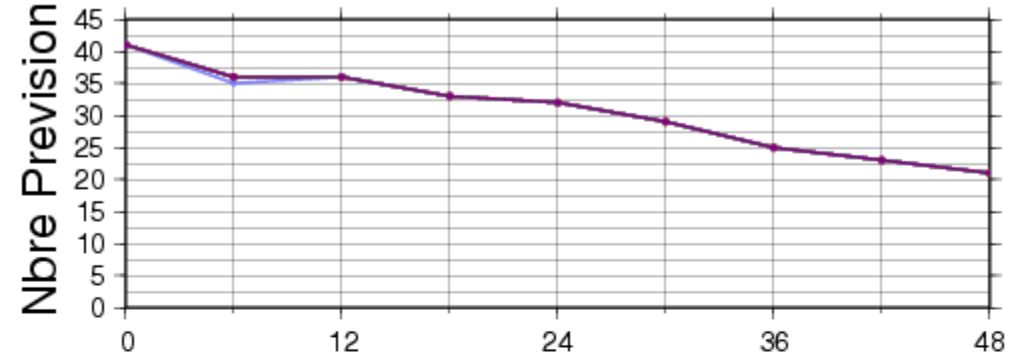
Homogeneous statistics

Leadtime (h)

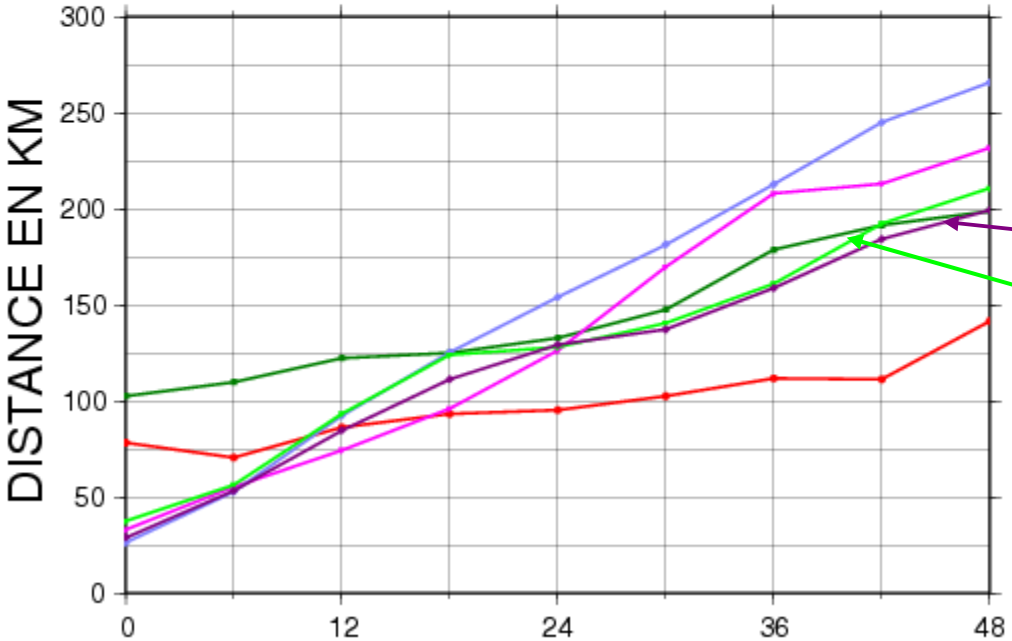
NCE
'avance

5-WEEK STATISTICS IN TERMS OF TRACK ERROR

Between 2007/02/12 and 2007/03/17

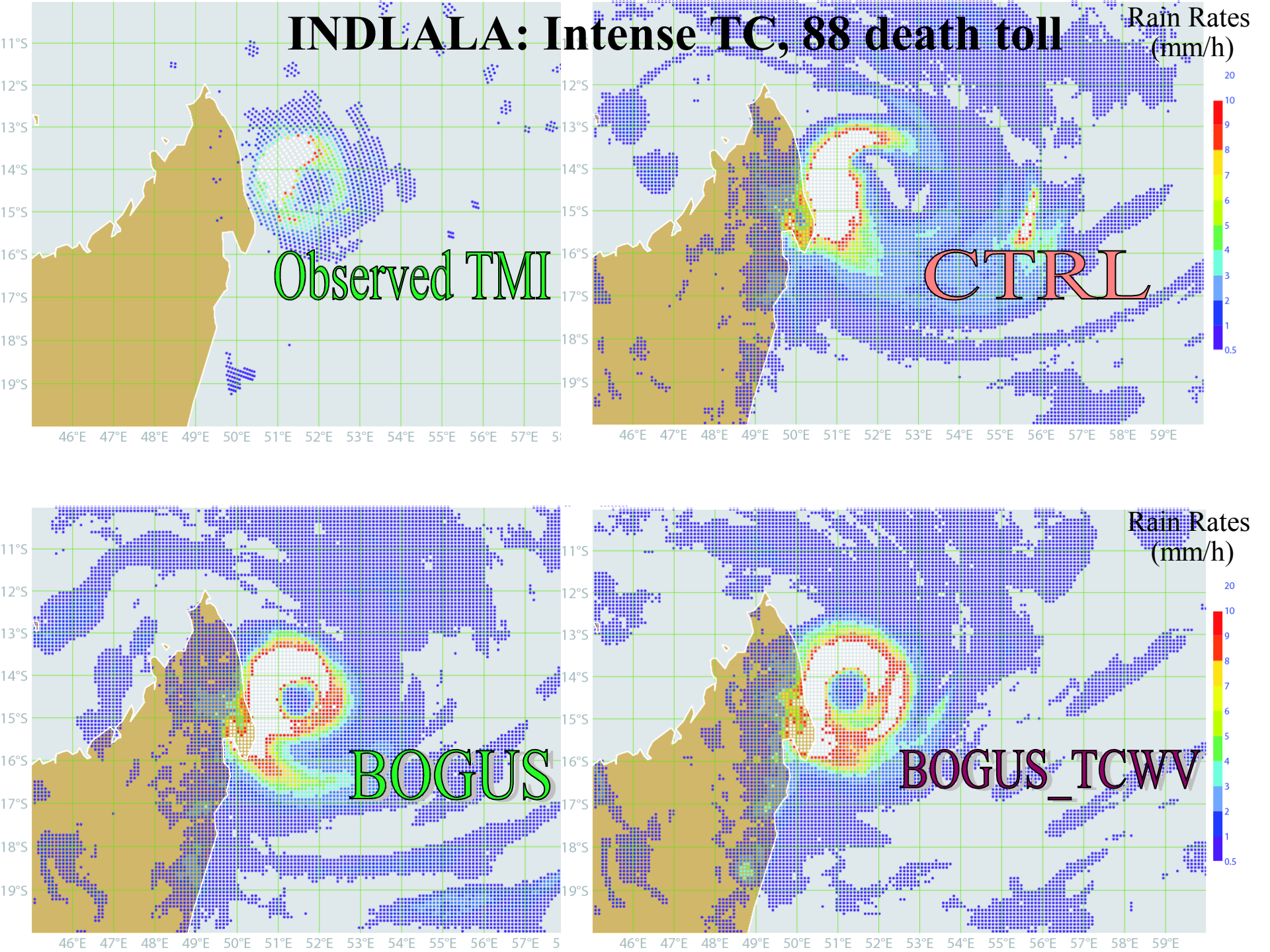


Homogeneous statistics



Leadtime (h)

INDLALA: Intense TC, 88 death toll



Conclusions on Part I:

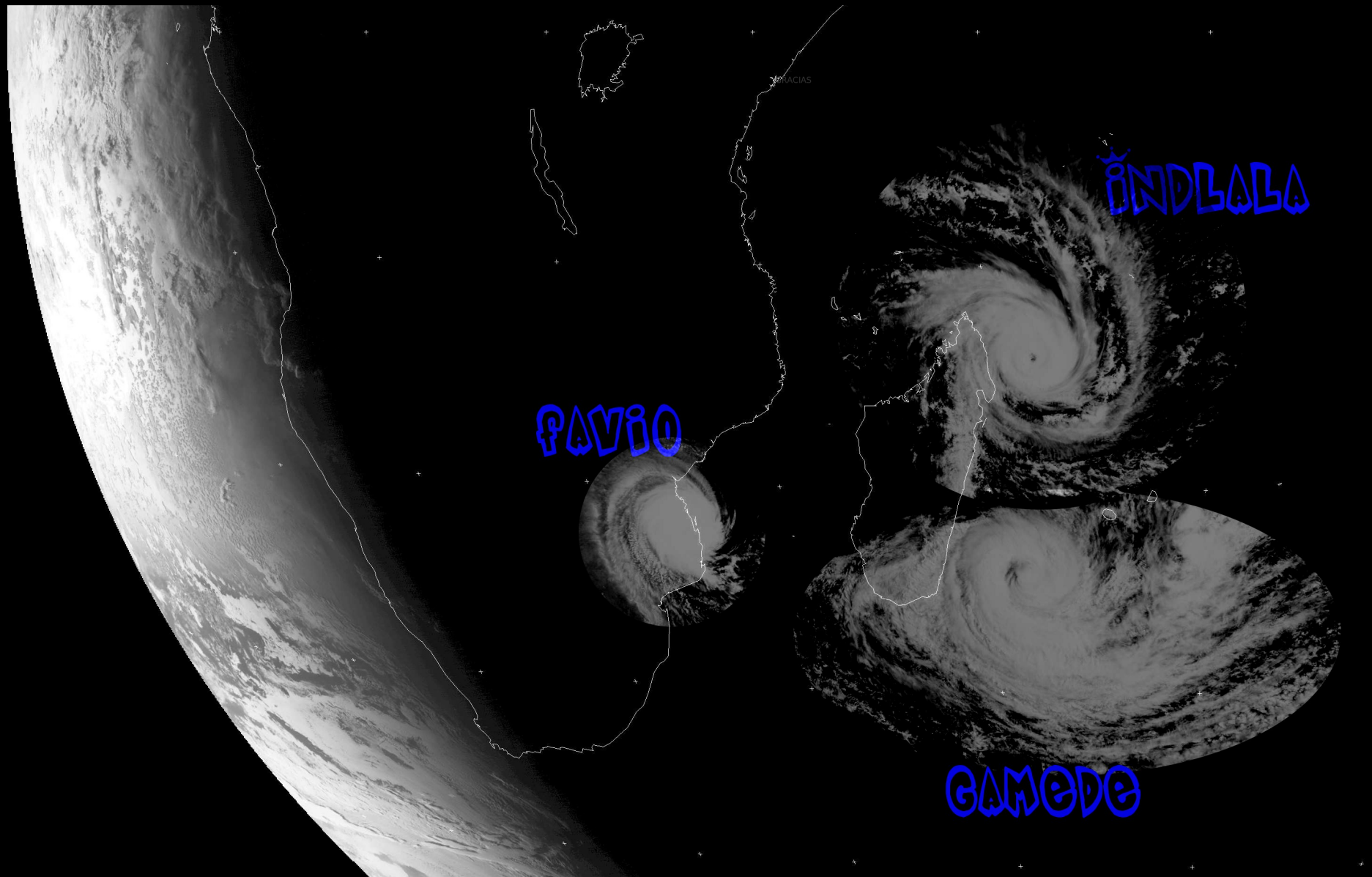
- This technique works and is definitely beneficial for the model: TCWV data assimilation helps constrain the analysis in cloudy/rainy conditions and leads to more realistic TC features, and to a better depiction of tropospheric humidity content (not shown).
- Possible expansion of the method to other satellites and other basins is to be investigated
- Up to 100% more SSM/I data points are gained in previously unsampled areas
- All these results are coming out soon in QJRMS (paper accepted)

PART II:
Effects on downscaling to 4 km with AROME

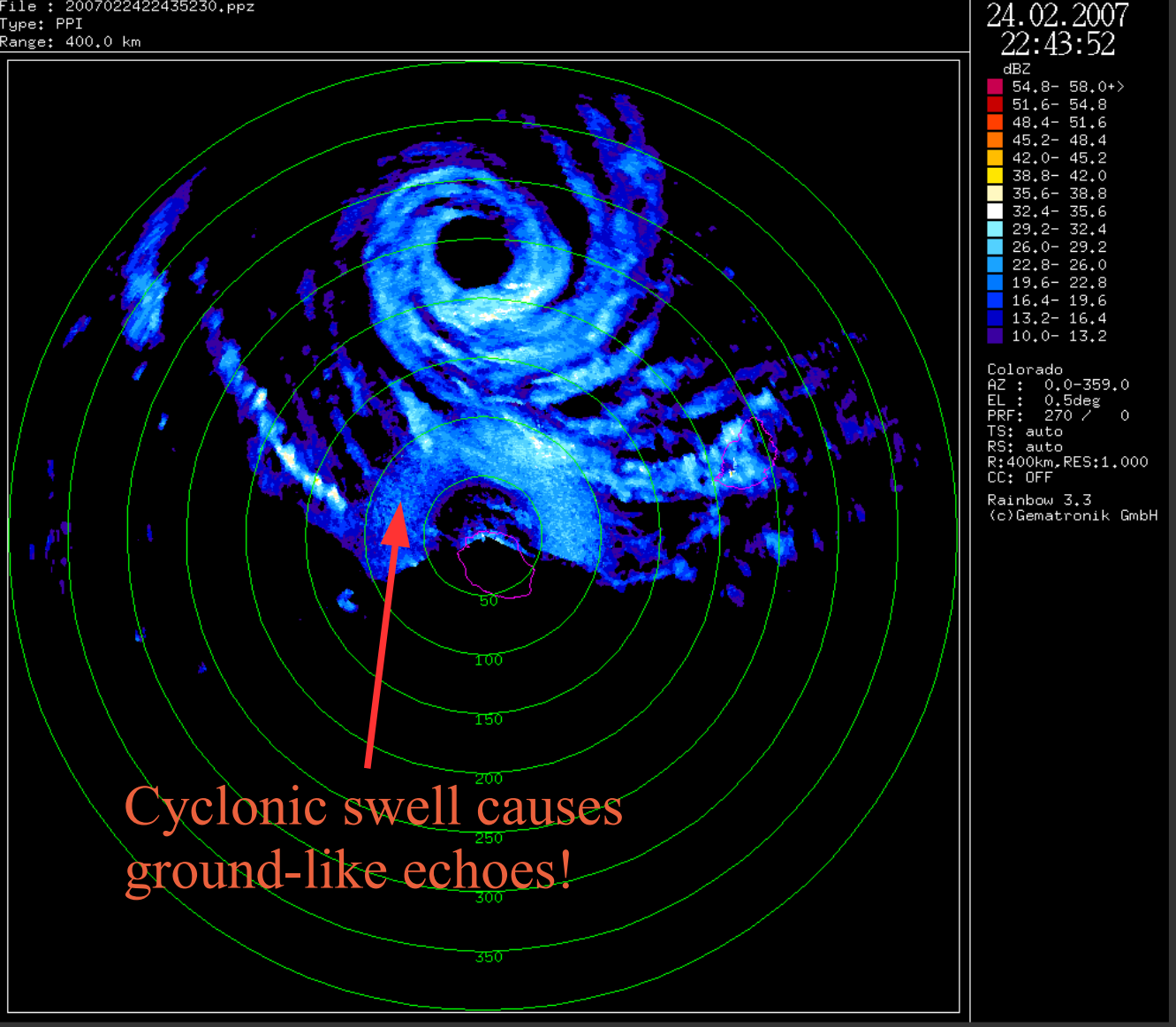
AROME

- AROME is the future weather forecast model of Météo-France, with non-hydrostatic dynamics, 2.5 km resolution and a sophisticated physical package with an explicit microphysical scheme, ICE3.
- Based on the physics developped for the LES model MESO-NH; built on ALADIN-NH dynamical core (bi-Fourier, spectral lam)
- Reproduces accurately deep convective events
- AROME France is now assimilating radar reflectivities
- AROME Reunion was implemented during my stay at Reunion Island in order to test its impact on TC forecast and sensitive weather that can occur on very small spatial scales

The three cyclones studied in ALADIN for the cyclonic season 2006/2007 of SWIO.



TC GAMEDE

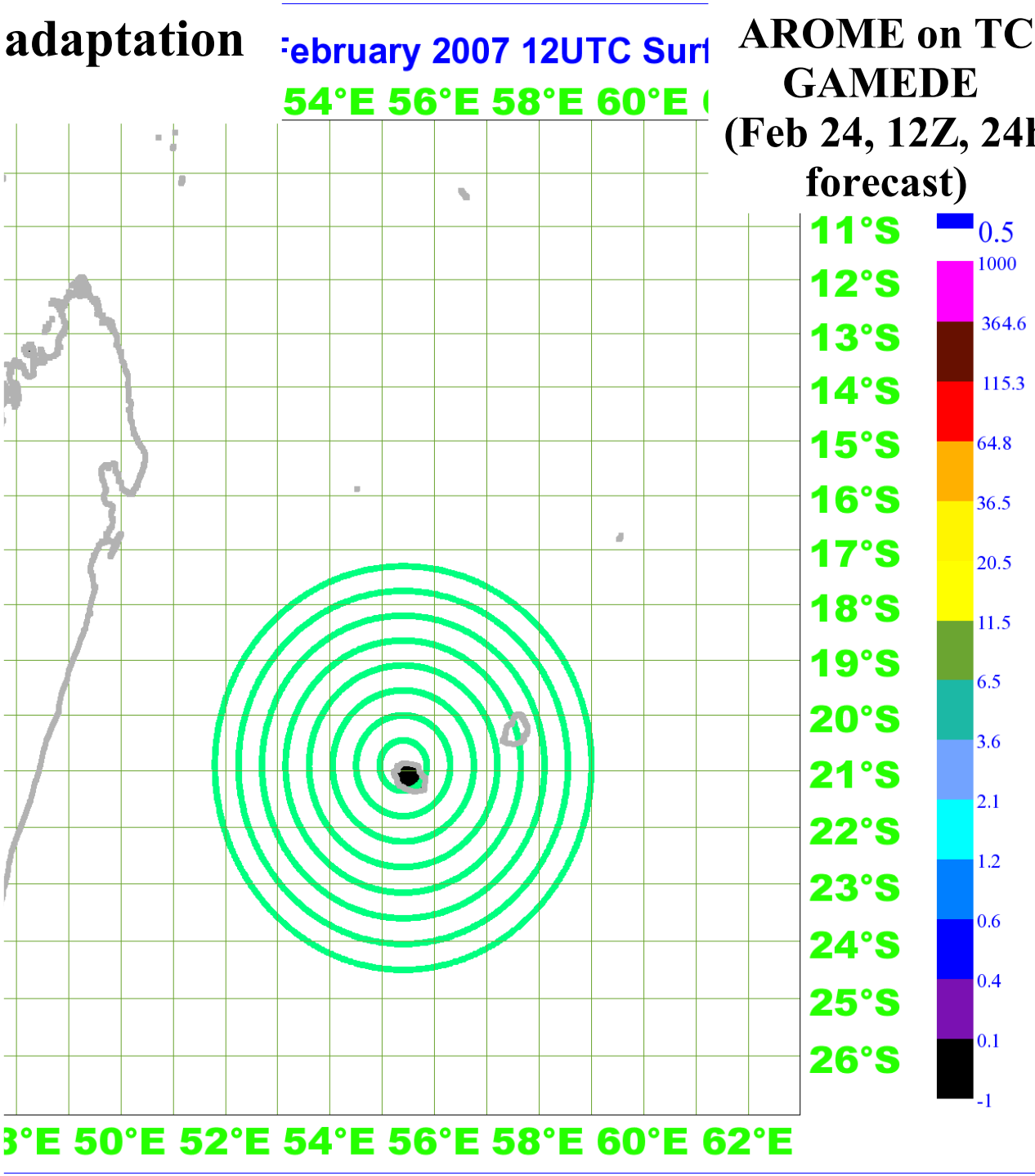


We downscale our two most promising experiments (BOGUS & BOGUS_TCWV) down to 4 km.
Radar imagery is used to validate TC structures.
Here is a PPI image from Feb. 24, 2007 at 22h43 GMT.
Owing to the sharp volcanic orography, 1/3 of the island is in the « no sight » zone of the radar

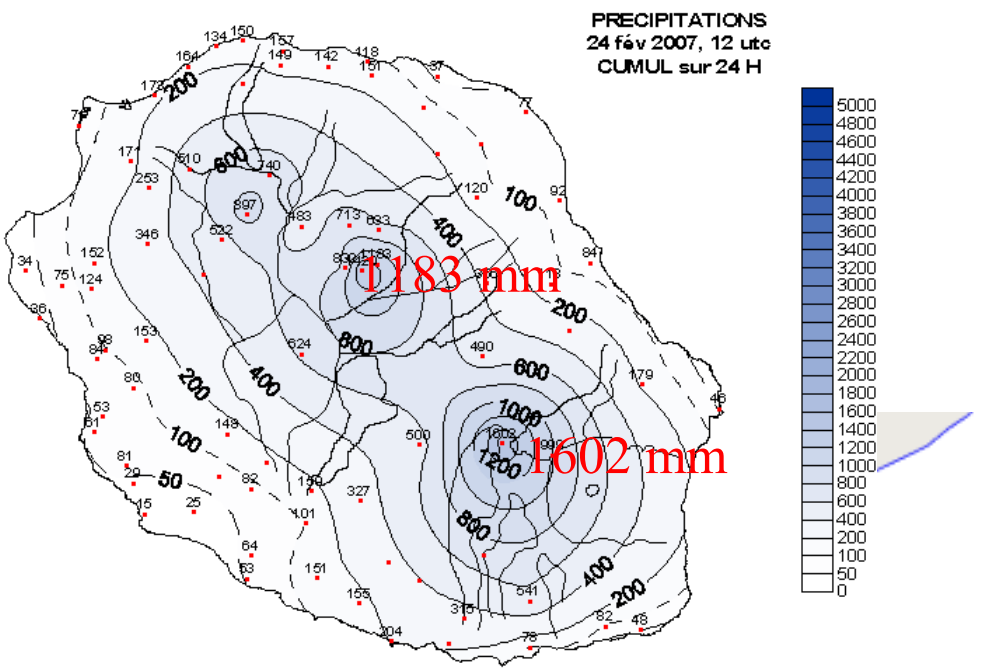
=> TC Gamede (23-28 Feb. 2007) : a monster in size and the **TC rainfall world record holder** with accumulated precipitations of 3929 mm to 5512 mm from 3 to 9 days (strong rains on days 3 to 5), at the Commerson Crater rain gauge.

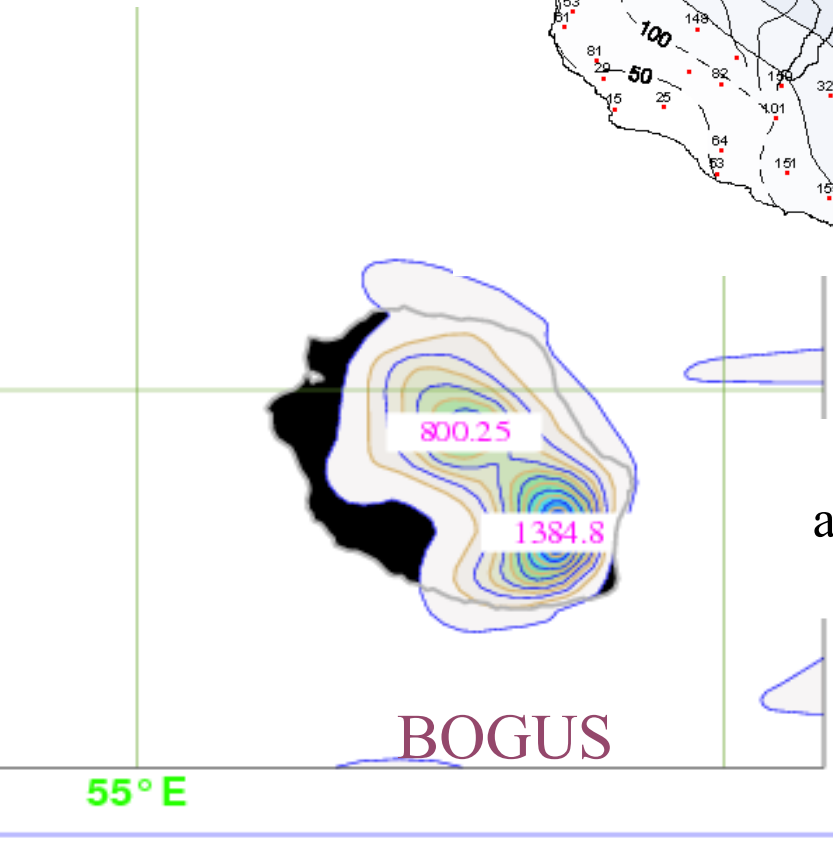
Results of dynamical adaptation

- Dynamical adaptation of ALADIN to AROME does a realistic job in producing TC-structures.
- Unfortunately, we notice a 6h spin-up time for the model to reproduce fine-structure information: since the information is not cycled, we lose 6h on each successive 24h-forecast
- The need for some kind of data assimilation is obvious, so as to be able to cycle that information: work being done on 3D-Var
- Lack of hi-res observations on this 90% oceanic domain that we could assimilate

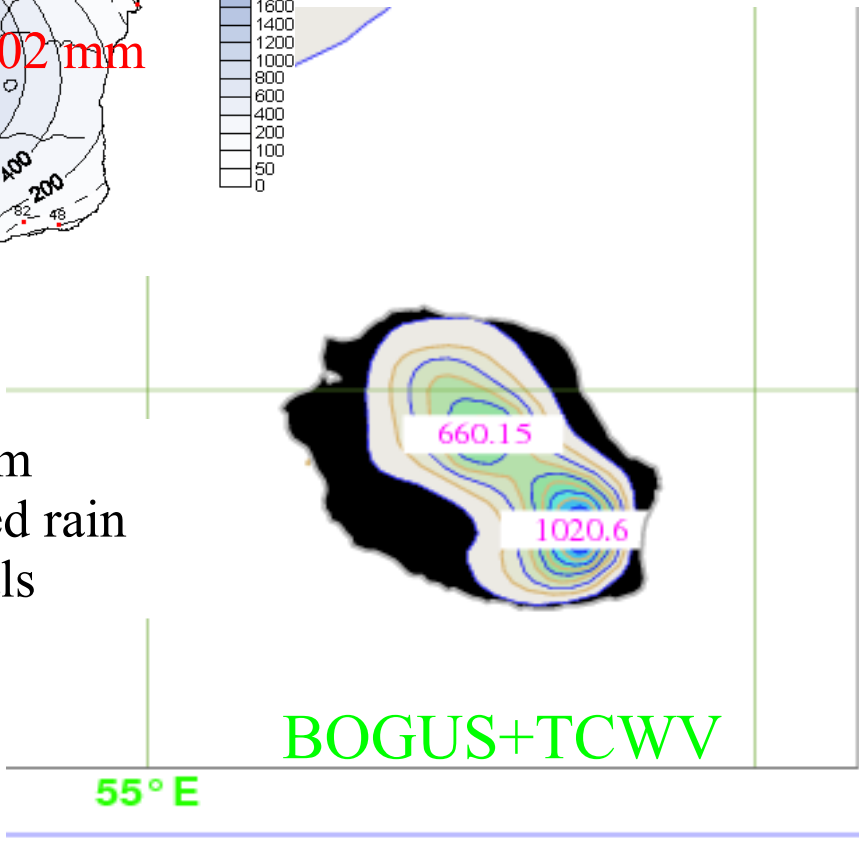


AROME on TC GAMEDE (Feb 24, 12Z, 24h forecast)





100 mm
accumulated rain
intervals



=> The low-level drying results in less intense accumulated precipitations but the overall spatial distribution of precip enveloppes is better with TCWV.

PART III:
Diagnosing the flow-dependent variability of background errors

Ensemble assimilation:
background errors « of the day »

Gérald Desroziers, Loïk Berre, Laure Raynaud, Olivier Pannekoucke, Bernard Chapnik, Simona Stefanescu, Benedikt Strajnar,Rachida El Ouaraini, Pierre Brousseau, Rémi Montroty Eric Sevault

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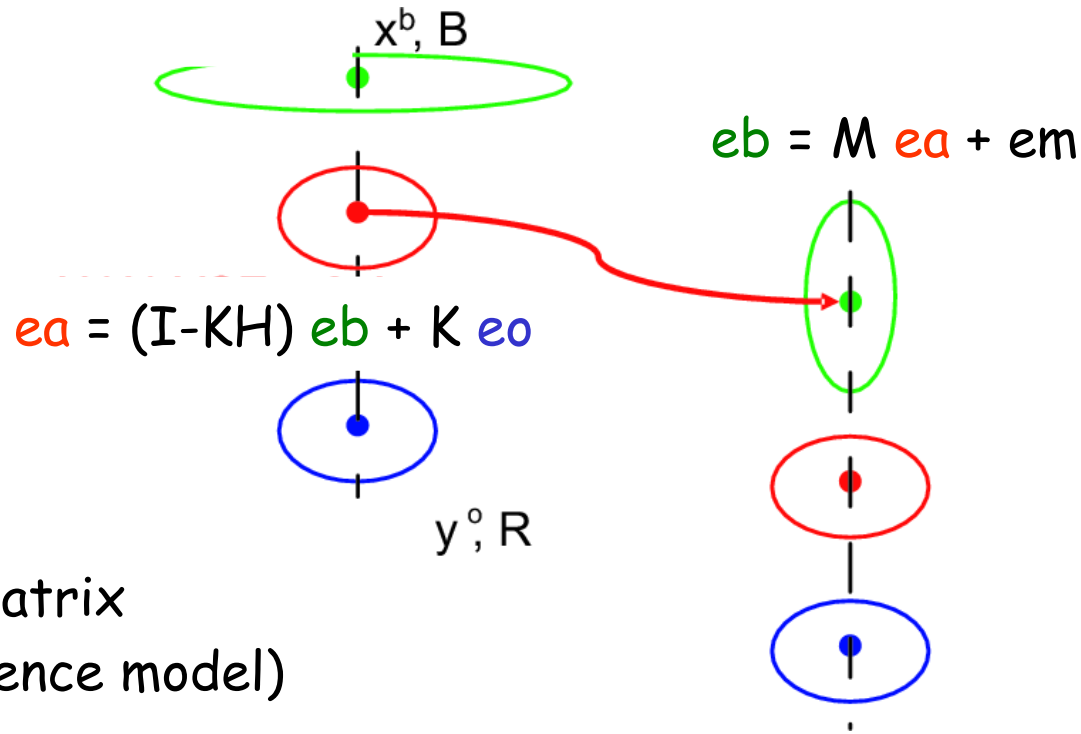
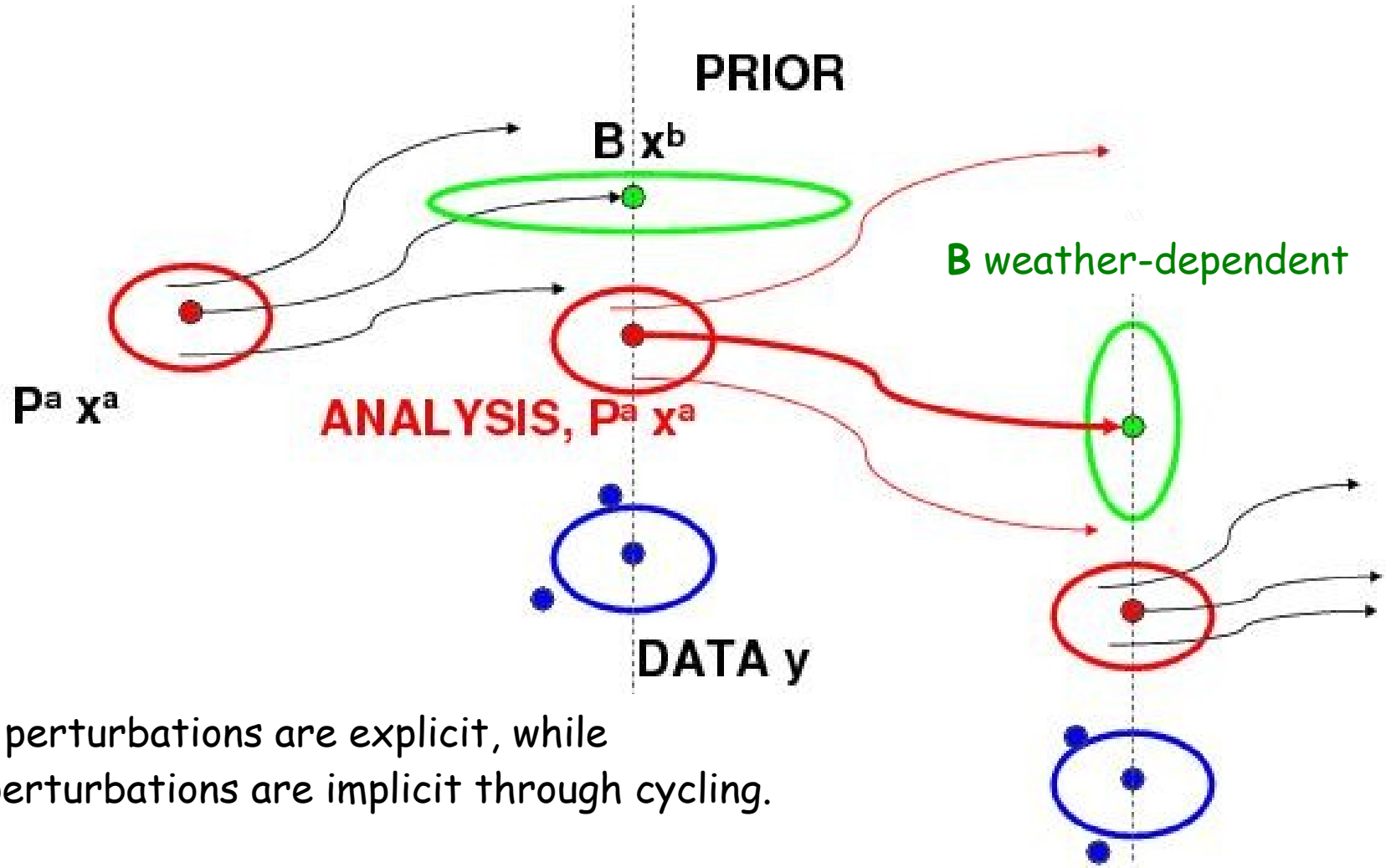
The unperturbed data assimilation cycle and the cycling of errors



K = gain matrix
(from the reference model)

Idea is to simulate the error cycling in the reference system through a perturbed assimilation ensemble

Perturbed ensemble data assimilation: simulating the cycling of errors



Obs perturbations are explicit, while
FG perturbations are implicit through cycling.

(Houtekamer et al 1996; Fisher 2003 ;
Ehrendorfer 2006 ; Berre et al 2006)

Modeling & filtering **B**: ensemble strategies

There are two « extreme » approaches used to model **B** in variational or EnKF approach.

In Variational : the correlations are usually averaged globally (spatially)

+ : robust even with a very small ensemble

- : does not yield any horizontal heterogeneity

In EnKF : the correlations are purely local (computed at a gridpoint)

+ : Many spatial variations can be represented

- : Requires a large ensemble and ignores the local structure of local covariances

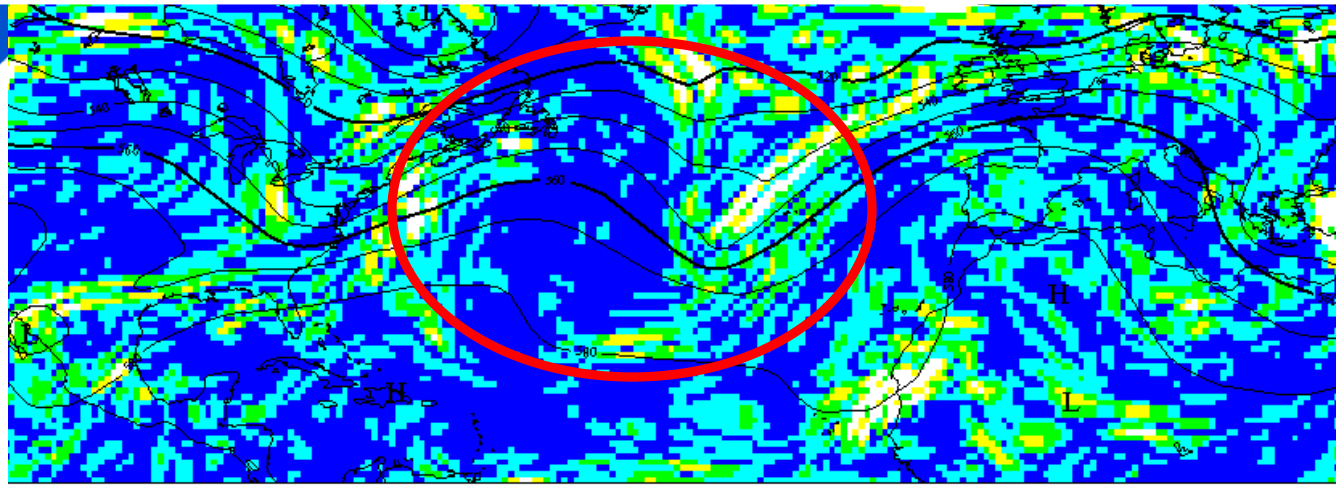
=> **Compromise**: compute local spatial averages of the covariances using a small ensemble which takes the coherent variations of the local covariances into account

"RAW" σ_b (Vorticity, 500 hPa)

from two 3-member ensembles

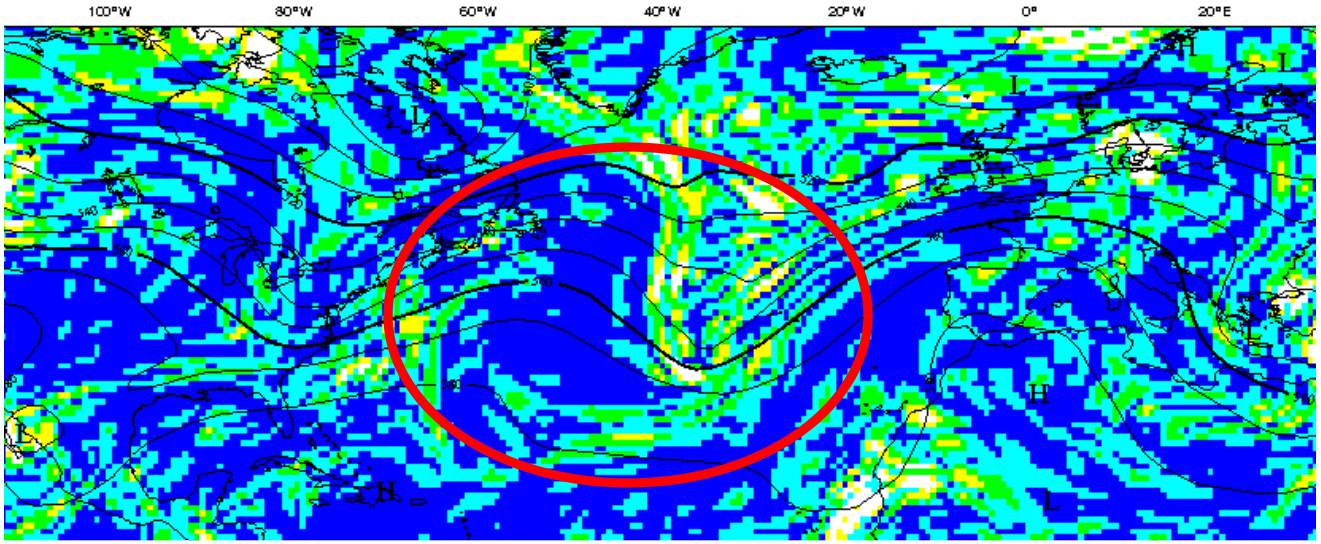
« RAW » σ_b

ENS #1



« RAW » σ_b

ENS #2

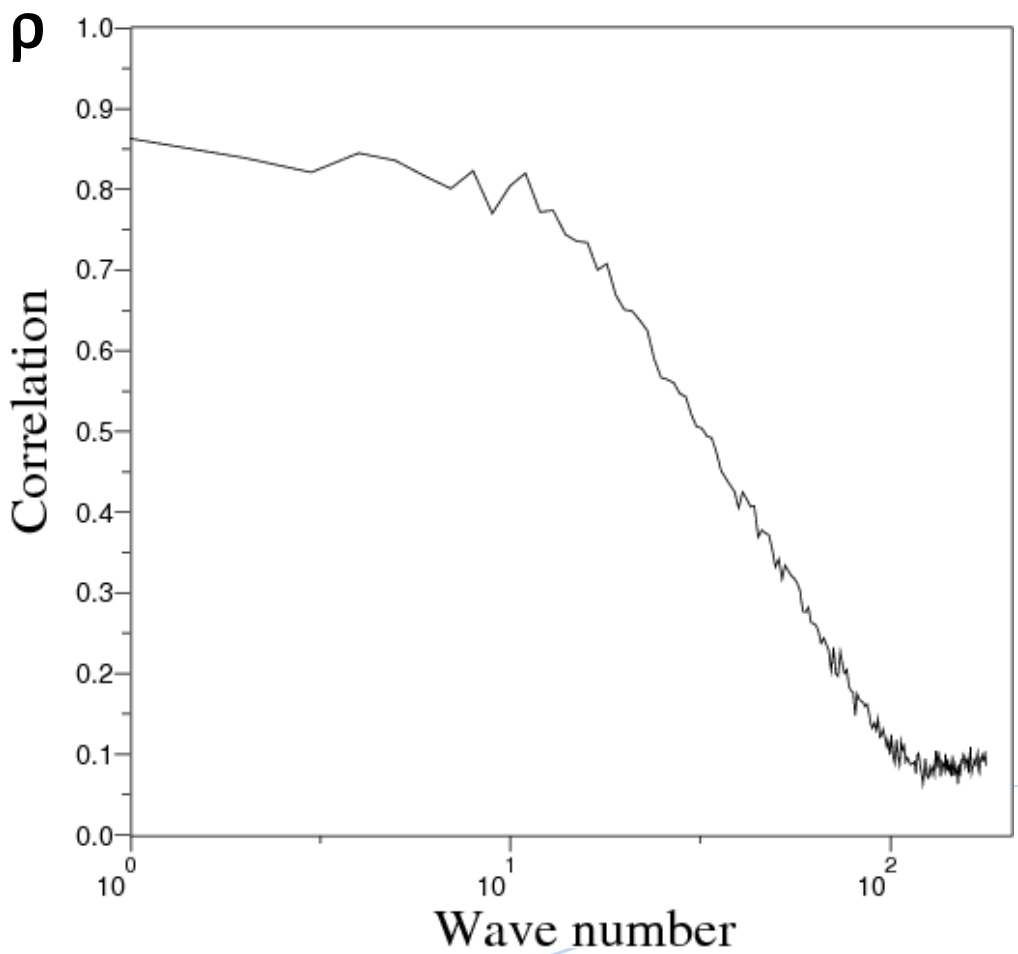


Large-scale structures are similar & flow-dependent

⇒ How do we optimize the estimate, while taking spatial structures into account?

Optimal filtering of the signal

=> Apply the classical Best Linear Unbiased Estimator with a ρ filter that takes into account spatial structures of both noise & signal



$$\sigma_b^* \sim \rho\, \sigma_b$$

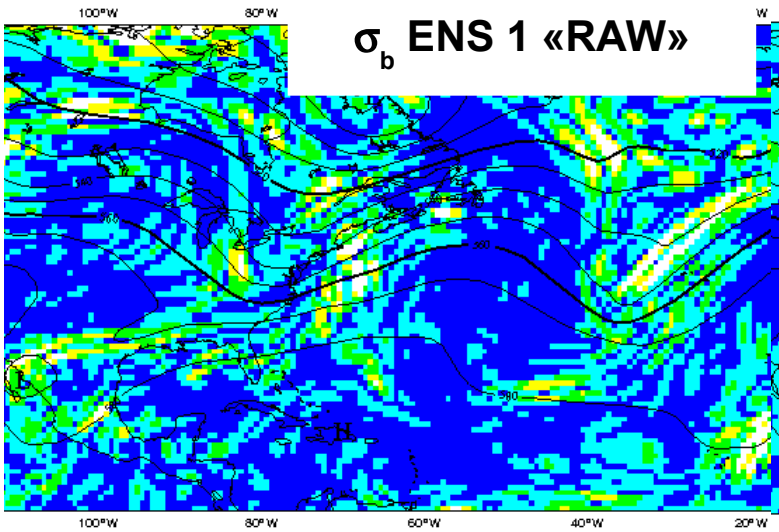
with

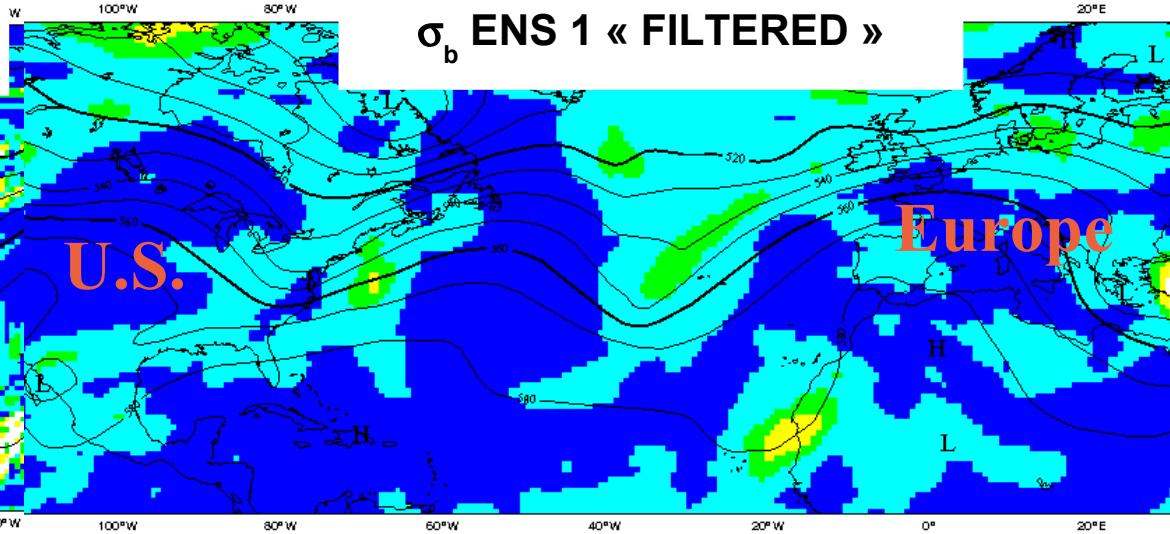
ρ = signal / (signal+noise)

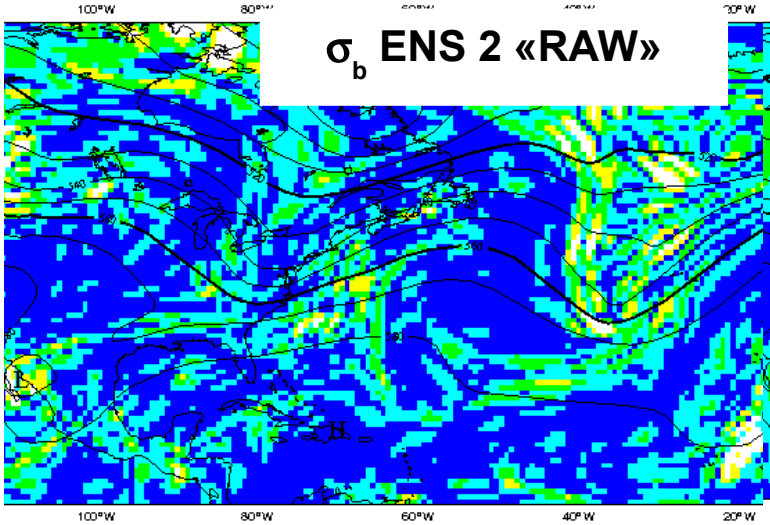
⇒ ρ is a low-pass filter (like K in data assim°).

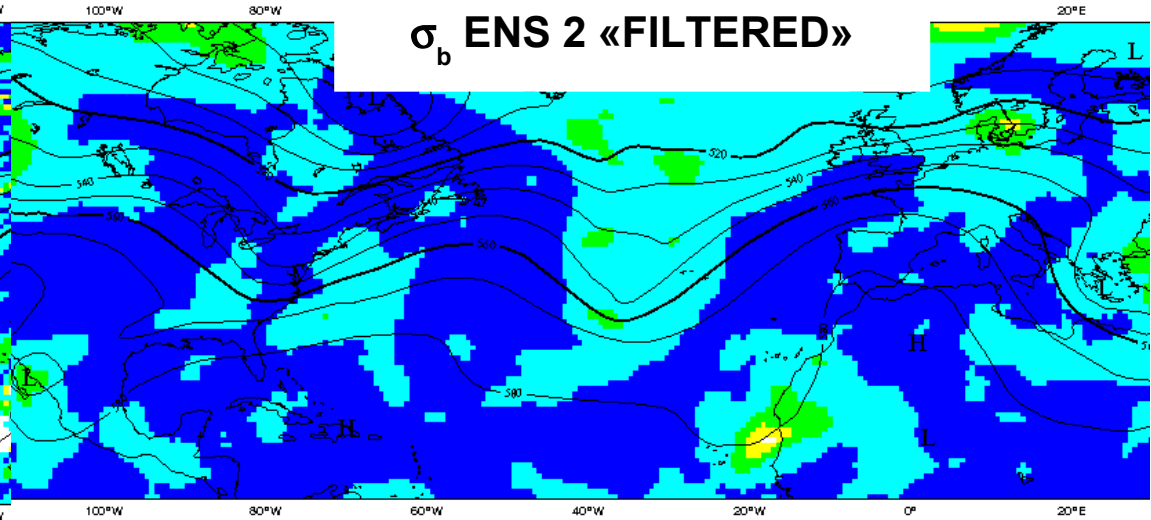
(Raynaud et al 2008a, 2008b)

Results of the filtered σ_b









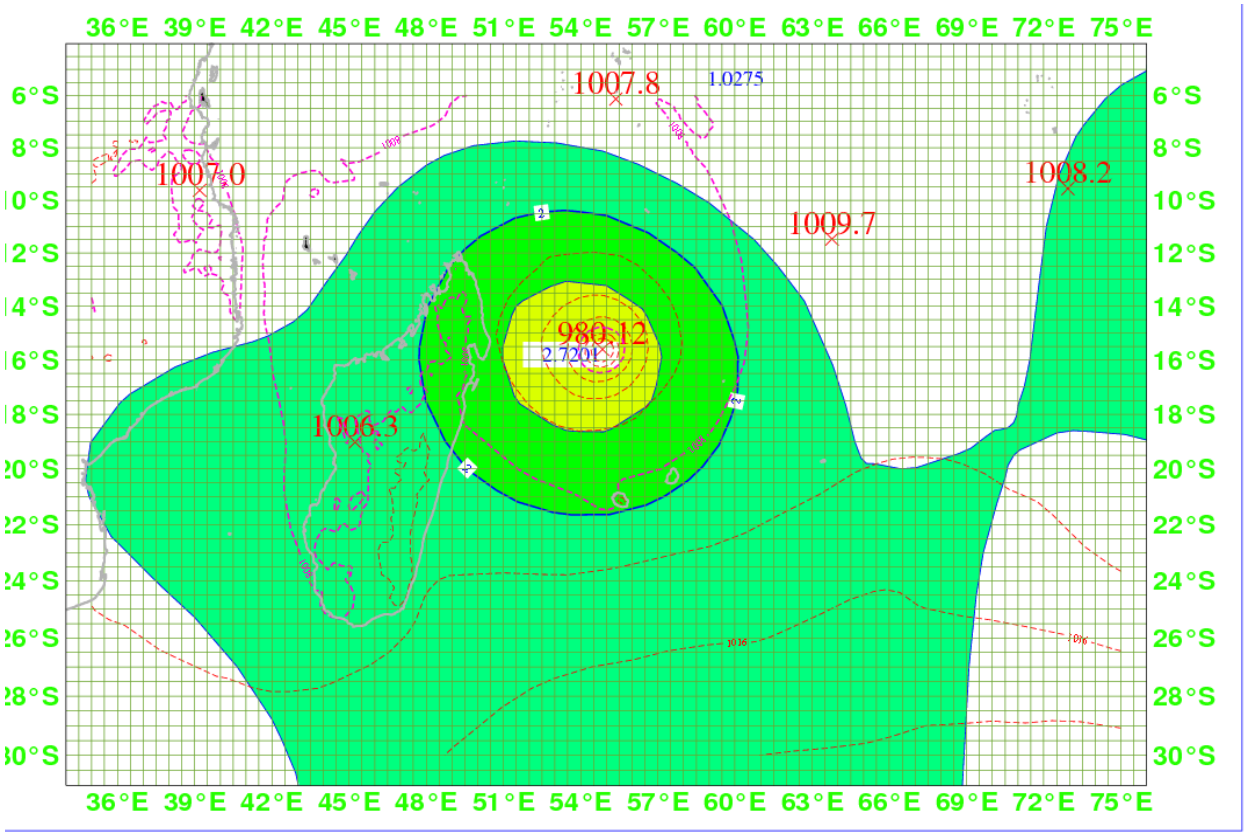
Relation between σ_b "of the day" and a strong meteorological event (TC Ivan, 980 hPa, 15/02/2008 , 12UTC)

Color field:

σ_b of η_{850hPa}

Dashed lines:

MSLP



(Montroty, 2008)

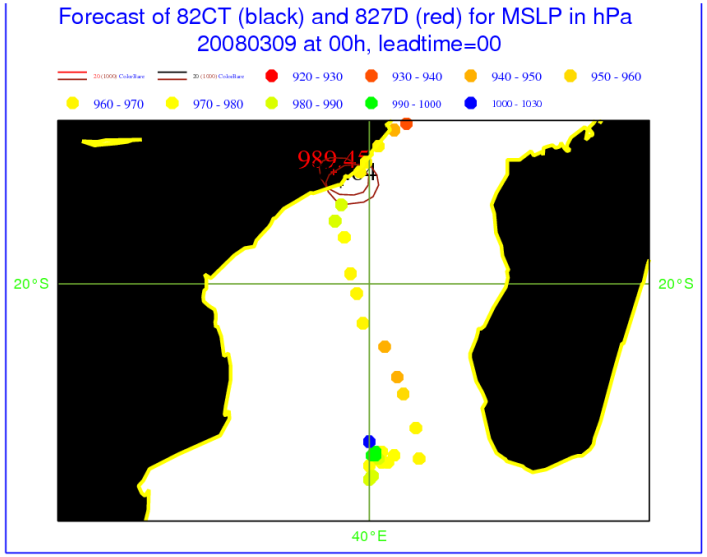
=> As one might expect, strong σ_b values are found close the TC center. This holds good potential for impacting the DA.

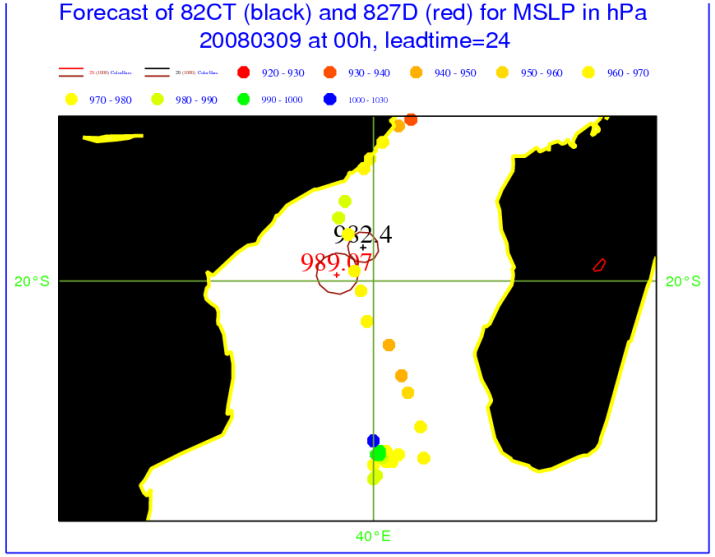
PART IV:
Impacts of those filtered errors on TC forecasting (ongoing)

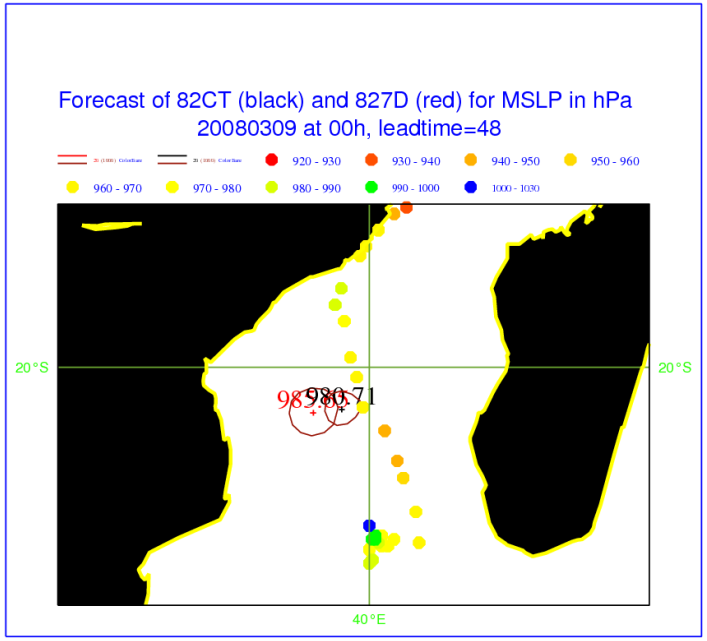
Ensemble assimilation in real-time at Météo France (Loïk Berre)

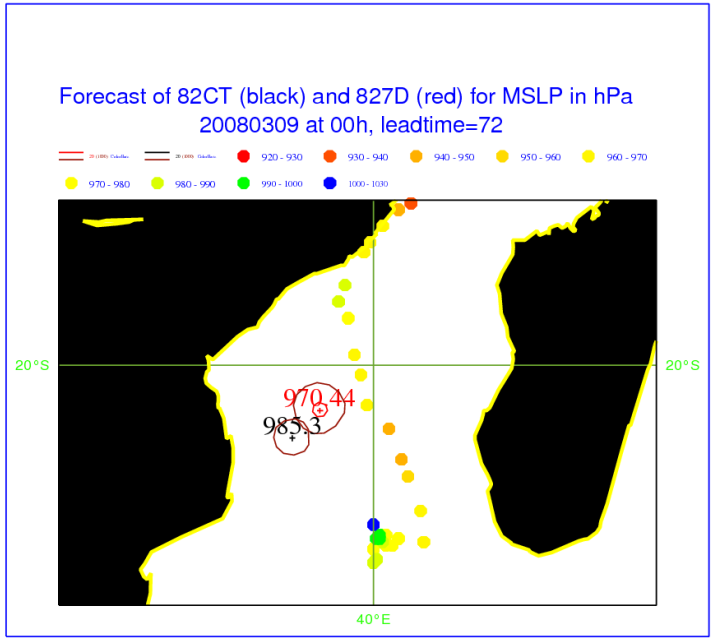
- 6 global and uniform members are run daily at T358C1 L60 with 3D-Fgat (ARPEGE).
- Variances « of the day » are filtered spatially to increase the sample size and the robustness
- The operational suite (4D-Var, T538C2.4 L60) uses those σ_b "of the day » since July 1st, 2008
- The parallel suite was coupled to 6 members of the ALADIN France model (10km) and the next generation model Arome (2.5 km), for 2 seasons of 2 weeks.
- In our studies, we couple ALADIN Reunion to two sets of σ_b coming from two 6-member ensembles: one is the old operational suite equivalent with T42 filtering (FIXED_FILTER), the other one is a refined filtering that is z-dependent and variable-dependent (VARIABLE_FILTER) (Raynaud2008b).

Preliminary results ! FIXED_FILTER (red) and VARIABLE_FILTER (black)

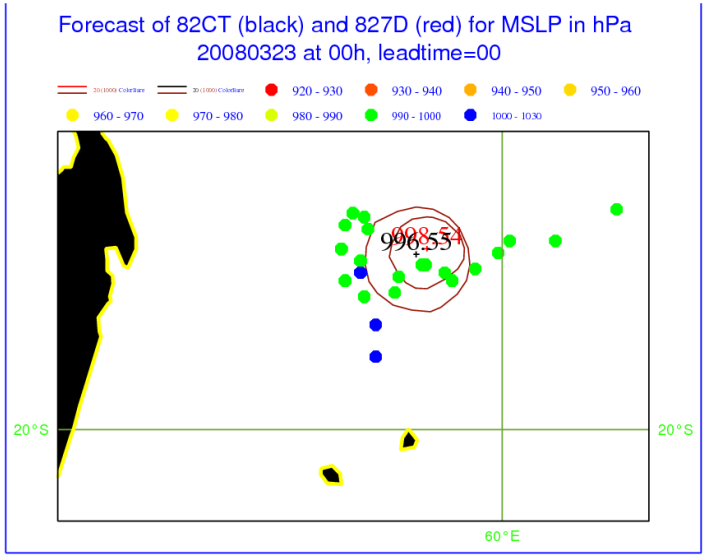


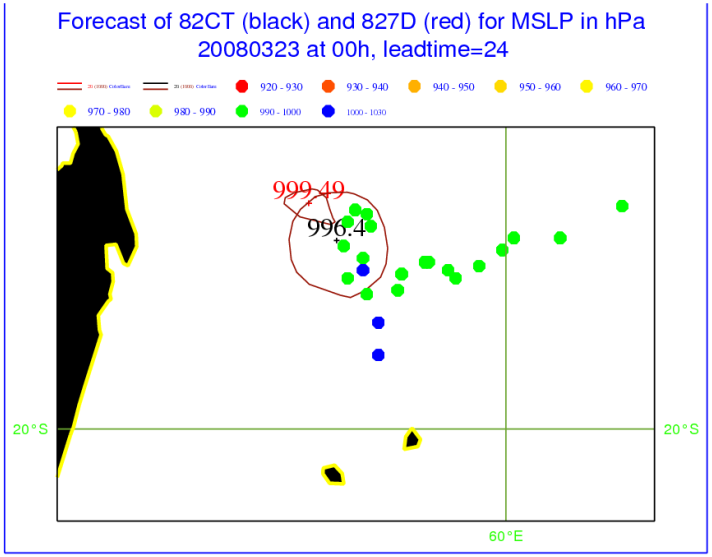


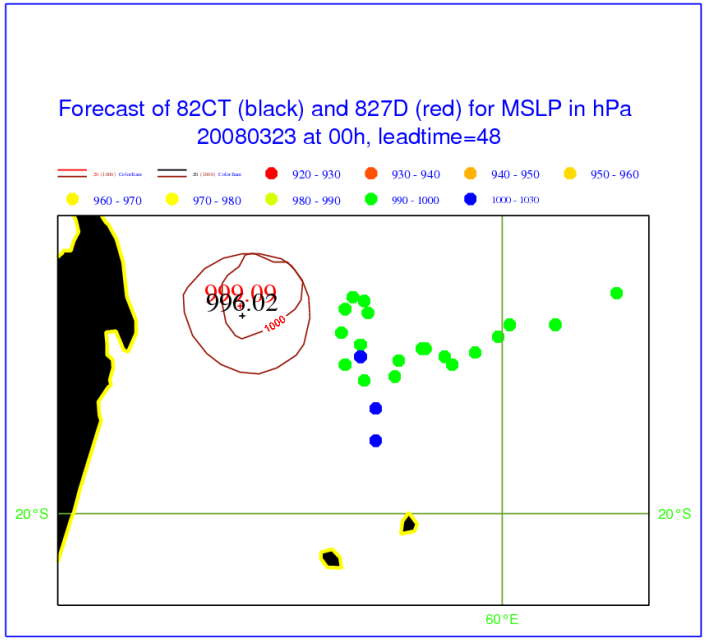


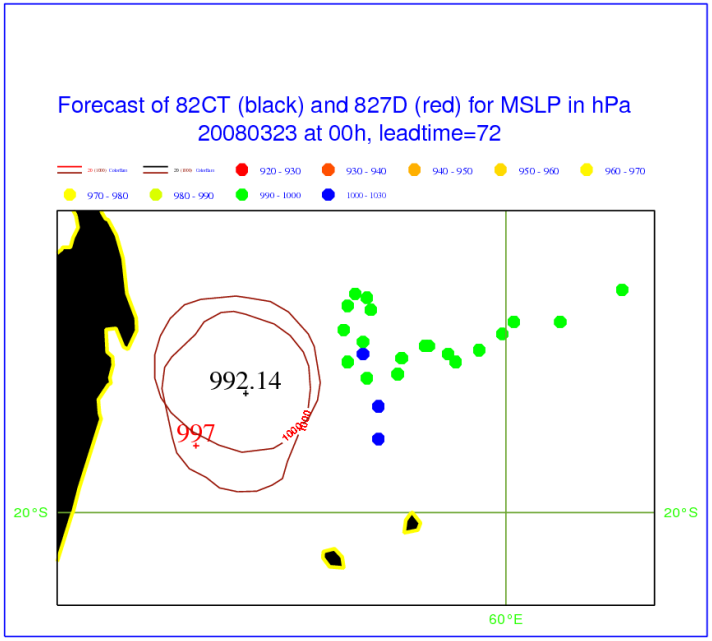


Preliminary results ! FIXED_FILTER (red) and VARIABLE_FILTER (black)









PART V:
Conclusions

Conclusions (1/2)

- A technique for assimilating SSM/I rainy data was presented through the use of TCWV as an intermediary product: thanks to a multi-linear regression applied to the ECMWF's analyses, a simple algorithm was built to go directly from Tbs to TCWV
- The information contained in this new data is assimilated and improves cyclonic structures in the ALADIN model. Further improvements concern fit to observations and reduced track errors.
- The improved model was downscaled at 4 km: it is found that it reproduces accurately the observed cyclonic signal but a simple dynamical adaptation proves to be too simple in order to accurately position fine structures: 3D-Var assimilation is thus being developped but presents challenging issues at the α-mesoscale level!
- 24h-accumulated precipitation is rather well reproduced in both terms of spatial distribution and intensity

Conclusions (2/2)

- Flow-dependence of background errors is investigated using a 6-member ensemble of a high-resolution, global, uniform ARPEGE model : strong dependence to cyclonic events is found for cyclonic cases which holds great potential for impacting positively the data assimilation scheme.
- Impacts of the filtered background errors on TC forecasting are only beginning to be investigated but, while it seems that intensity might be degraded, track errors seem to be reduced by the use of a z-dependent and variable-dependent filter on the background error covariances.
- The flow-dependent $\boldsymbol{\sigma_b}$ « of the day » has gone operational on July 1st, 2008 at Météo-France and, in time, the ensemble computation is expected to be transferred to the Ensemble Forecast System (PEARP).

Future Work

The impact studies need to be thoroughly investigated and further computations are needed:

(1) normalization of the ensemble σ_b fields by ALADIN's statistical level-mean σ_b must be introduced (currently, the normalization is made from the level-mean value contained in the statistical **B** from ARPEGE: a factor 2/3 is expected between the two!)

(2) Assimilation of all five model variables' error covariances must be implemented (currently, only vorticity and humidity can be assimilated)

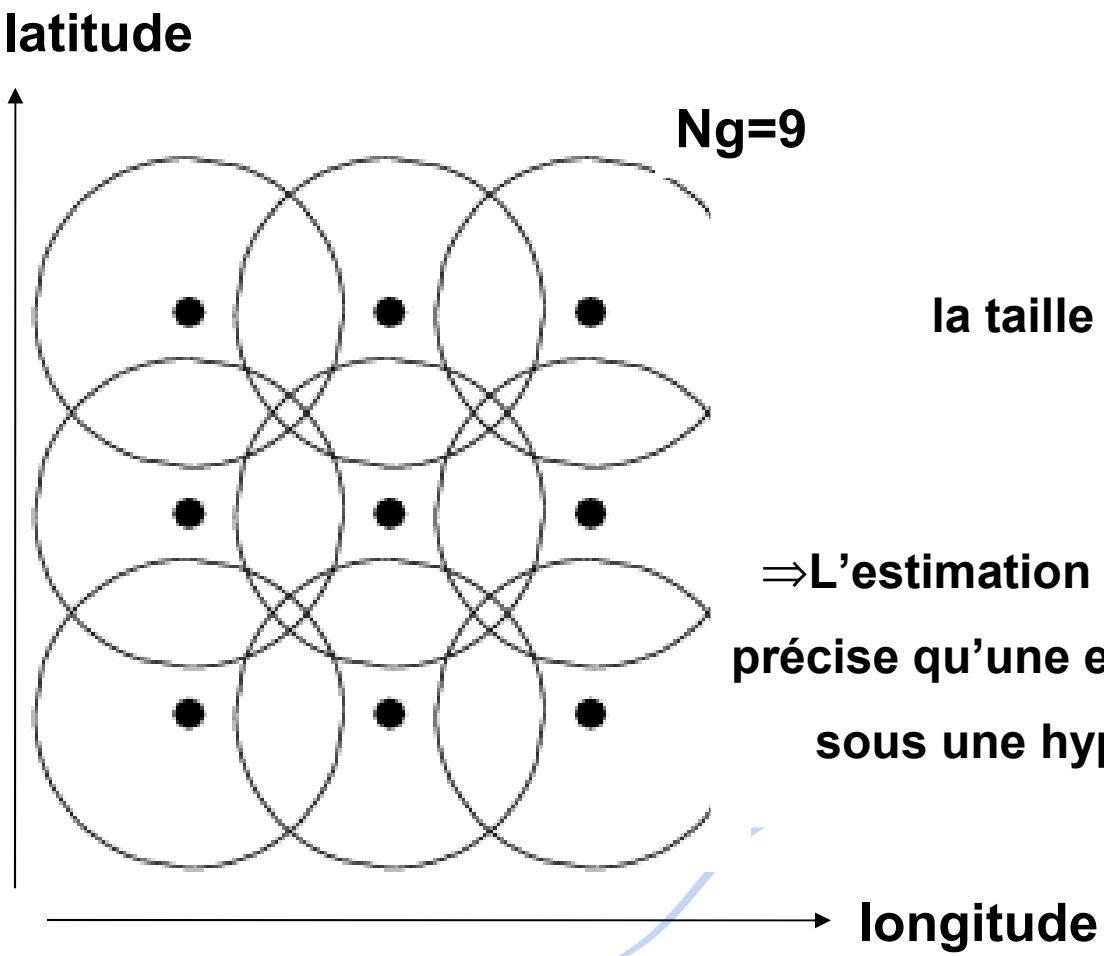
(3) Impact of cloudy/rainy SSM/I data on the most efficient of those system is to be tested. (still in off-line processing)

ANNEXES:
for curiosity's sake!

AUGMENTATION DE L'ECHANTILLON
PAR MOYENNE SPATIALE LOCALE :
CONCEPT

Idée: MULTIPLIER(!) la taille d'ensemble Ne

par un nombre Ng de points de grille échantillonnés.



Si Ne=6, alors

la taille totale de l'échantillon est

Ne x Ng = 54.

⇒L'estimation filtrée avec 6 membres est aussi précise qu'une estimation brute avec 54 membres, sous une hypothèse d'homogénéité locale.

METEO FRANCE
Toujours un temps d'avance