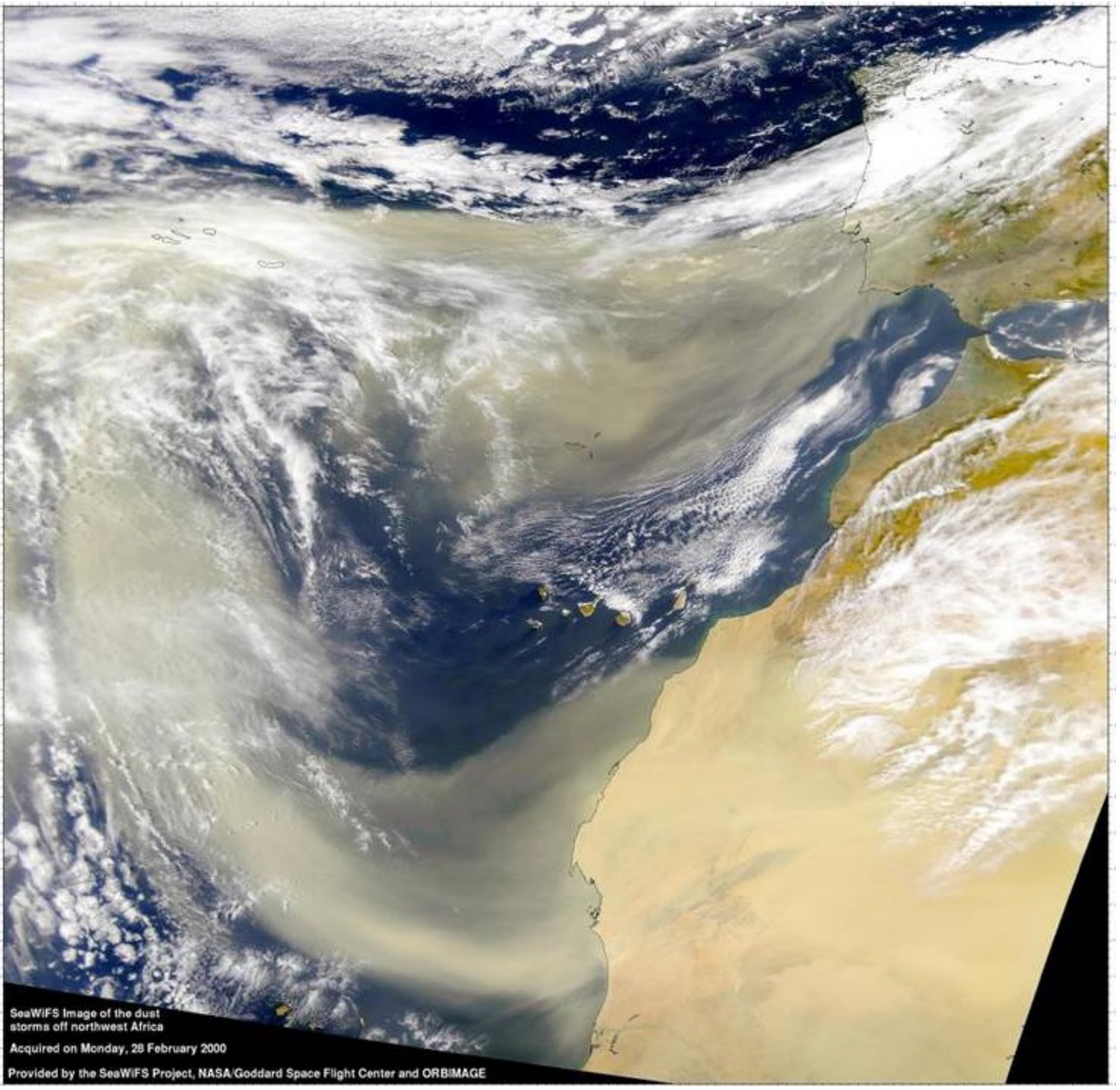
Clouds – Atmospheric Dynamics – Dust interactions in West Africa (CADDIWA)



PI: C. Flamant[1] CNRS/LATMOS

Jean-Pierre Chaboureau[2], Julien Delanoë[1], Marco Gaetani[3], Cédric Jamet[4,1], Christophe Lavaysse[5], Olivier Bock[6], Maurus Borne[7], Quitterie Cazenave[1], Pierre Coutris[8], Juan Cuesta[9], **Laurent Menut[10]**, Clémantyne Aubry[1], Pierre Bosser[11], Sophie Bounissou[1], Christophe Caudoux[1], Hélène Collomb[1], Thomas Donal[12], Guy Febvre[8], Thorsten Fehr[13], Paola Formenti[9], Nicolau Gomes Araujo[14], Eric Lecuyer[4], Mateus Neves Andrade[14], Cédric Gacial Ngoungué Langué[1,5], Tanguy Jonville[1], Alfons Schwarzenboeck[8], Azusa Takeishi[2] , Gérard Ancellet[1], Alain Dabas[15], Geneviève Seze[10]

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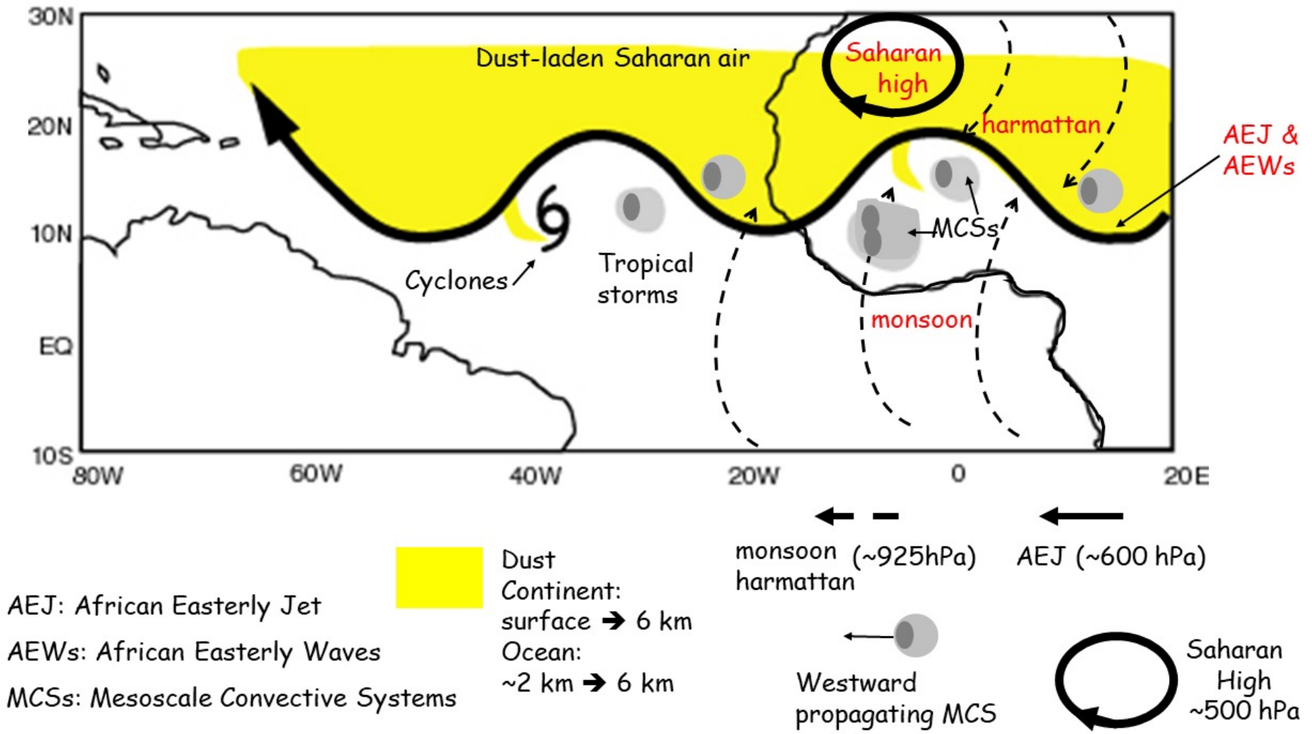
& SAFIRE: Thierry André, Hubert Bellec , Jean-Christophe Bourdinot, Aurélien Bourdon, Dominique Duchanoy, Tetyana Jiang, Gilles Vergez & DT-INSU: Oualid Aouji, Aurélien Clémençon

RATIONALE

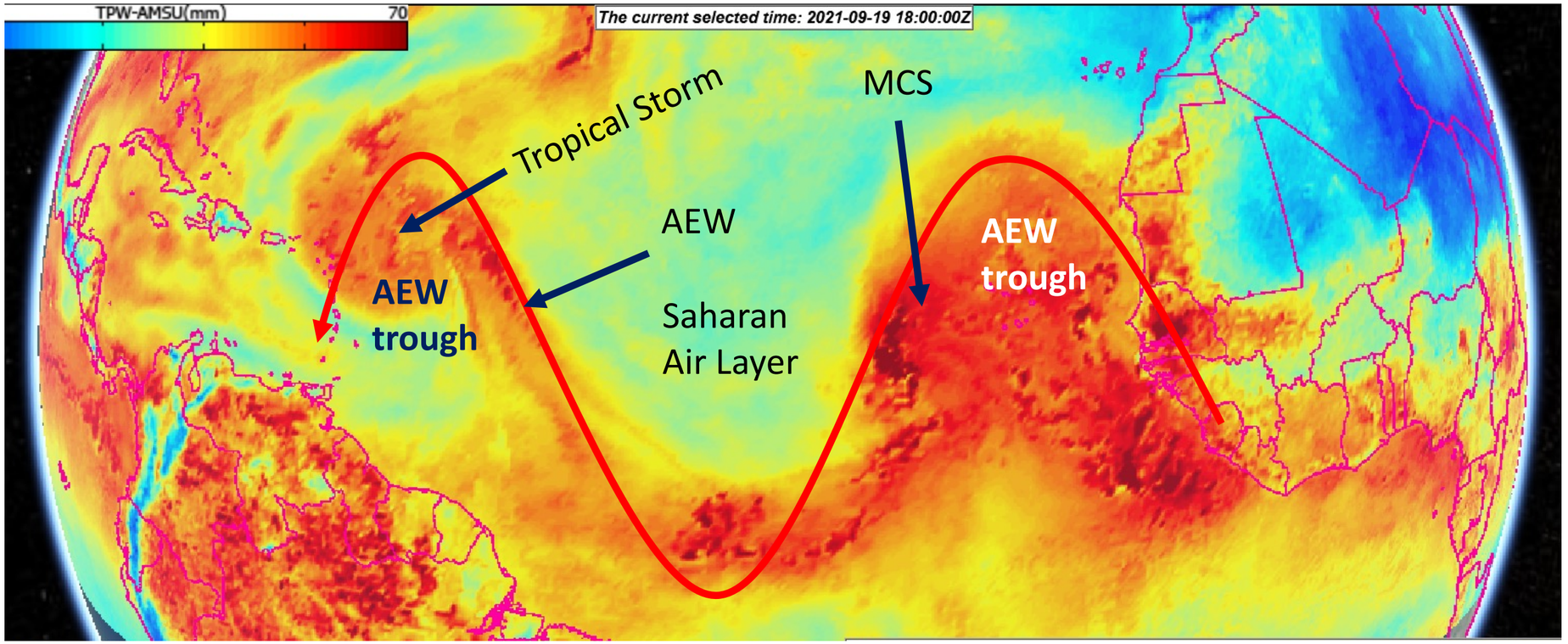
- During the boreal summer, mesoscale convective systems **MCSs** generated over West Africa propagate westward and interact with African easterly waves **AEWs** and other tropical waves, as well as with dust plumes originating from the Sahel and Sahara.

- Once off West Africa, the disturbances in the wake of these mesoscale convective systems evolve in a complex environment sometimes leading to the development of tropical storms and hurricanes, especially in September when **SSTs** are high in the tropical North Atlantic.

- Numerical weather predictions of cyclogenesis downstream of West Africa remains a key challenge due to the incomplete understanding of the clouds-atmospheric dynamics-dust interactions that limits the predictability horizon.



RATIONALE



Total Precipitable Water TPW over the North Atlantic

19 Sept 2021

© NASA CPEX-AW

Interactions between African easterly waves and other tropical waves with dust, radiation and convective systems induce (non-)linear effects in the development of these waves that current state-of-the-art Numerical Weather Prediction models struggle to represent.

Equatorial waves are a very important source of predictability on synoptic to planetary scales in the tropics.

Societal benefits: Improvement in understanding and forecasting **rainfall** in West Africa & **intensive storm and cyclones** development over the north Atlantic

OBJECTIVES

1. Assess DRE, SRE, IRE and atmospheric dynamics in the complex coastal environment (i.e. land/sea transition & upwelling area) offshore of Senegal in different dust load conditions and in a variety of synoptic conditions (monsoon intensity, Saharan heat low intensity and location, AEJ, AEWs and other tropical waves, MCSs, …)

2. Contribute to the CAL/VAL and the preparation of several space missions of interest to CNES and ESA, namely Aeolus, IASI, Earth-Care, Wivern

3. Model verification (regional & global models) & improvement

DRE=Direct Radiative Effect
SDRE=Semi-direct Radiative Effect
IRE=Indirect Radiative Effect

Q1 - what is the impact of the dust load on AEWs and other tropical wave development over the Atlantic Ocean? Are there non-linear effects in the development of AEWs as a function of dust load? Is there a "dust load" threshold above which non-linear effects appear?

Q2 - To what extend do the AEWs modulate the transport of desert dust over the Atlantic Ocean? What is the impact of the structure, growth, and propagation of the AEWs on the zonal dust transport? Does this control depend on the dust load and/or vertical distribution?

Q3 - Which of the three dust radiative effects dominates/controls the intensification of MCS wake cyclonic disturbances offshore and eventually their transition to tropical storms over the Atlantic Ocean? Does this hierarchy between DRE, SRE and IRE depends on the dust load and/or vertical distribution?

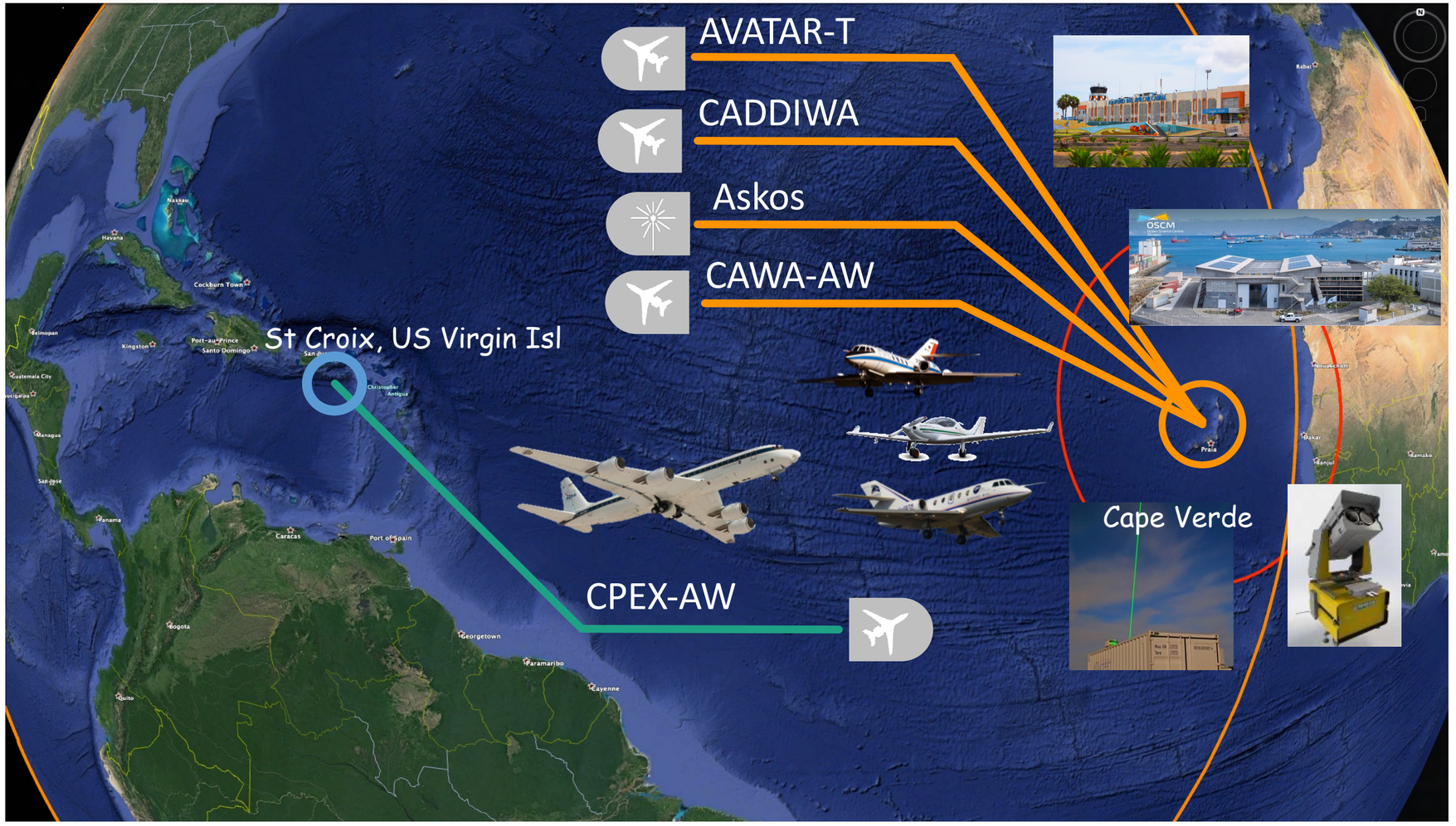
Can we provide observation evidence of these effects?

How well is the development of AEWs represented in state-of-the-art regional models and NWP models?

STRATEGY

To achieve CADDIWA goals, we needed to **gather insightful new observations pertaining to the assessment of DRE, SRE and IRE from dedicated ground-based and airborne platforms flying operating in the Eastern North Atlantic.**

This was achieved as part of the "Joint Aeolus Tropical Atlantic Campaign (JATAC) Campaign supported by ESA and NASA in August and September 2021.



Ilha do Sal ➔ CADDIWA: SAFIRE Falcon 20 AVATAR-T: DLR Falcon 20
Ihla do Sao Vincente ➔ CAWA-AW: AA WT-10 AKOS: Ground-based
St Croix ➔ CPEX-AW: NASA DC-8

FIELD CAMPAIGN

CADDIWA contribution to JATAC (August-September 2021)

- An aircraft campaign, based on the deployment of the SAFIRE Falcon 20 in the tropical environment of Cape Verde, offshore of Senegal from **8 to 21 September 2021**,
- A suite of complementary numerical simulations from the state-of-the-art regional models Meso-NH and WRF-CHIMERE ("Code Communautaire"), which include newly developed aerosol-cloud-interaction-parametrization ➔ **prepare daily aircraft operations**,
- A dedicated processing of IASI observations to retrieve the 3D distribution of the Saharan dust within the SAL, based on the AEROIASI approach and CALIOP/CALIPSO ➔ **contextualisation of airborne observations**,
- A GNSS station in Sal to monitor the evolution of TPW (along side an AERONET station to monitor AOD) ,
- A contribution to the balloon radiosounding effort in Sal coordinated by KIT ➔ **38 launches**,
- An Oceanic component ➔ **water column seawater optical properties in the upper-ocean**
- The implementation of the "CADDIWA Operational Center" in Sal for daily assessment of SAFIRE Falcon 20 operations as well as contribute to the JATAC coordination.

CADDIWA Ops Center

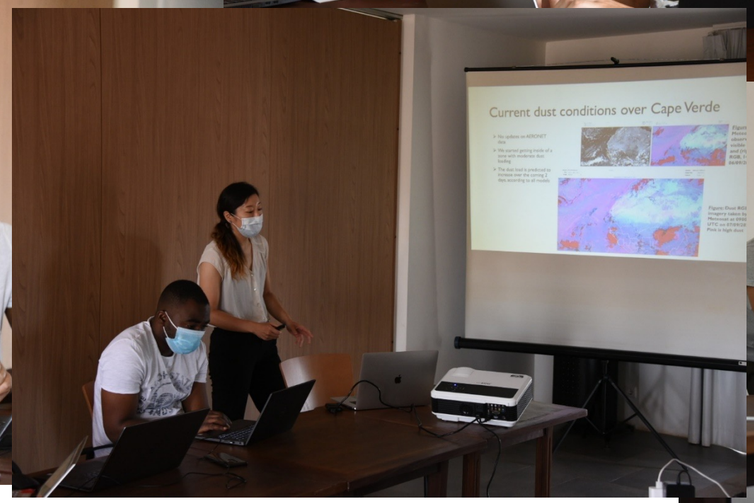
"CADDIWA Operational Center" in Sal

16 participants including 4 students (2 PhD students, 2 M2 students)
2 participants from Cape Verde, including one M2 student









ASSETS (1/4)

The SAFIRE Falcon 20

- Endurance: **3.5 flight hours**
- Maximum cruising altitude: **13 km**
- Max. distance: 2500 km

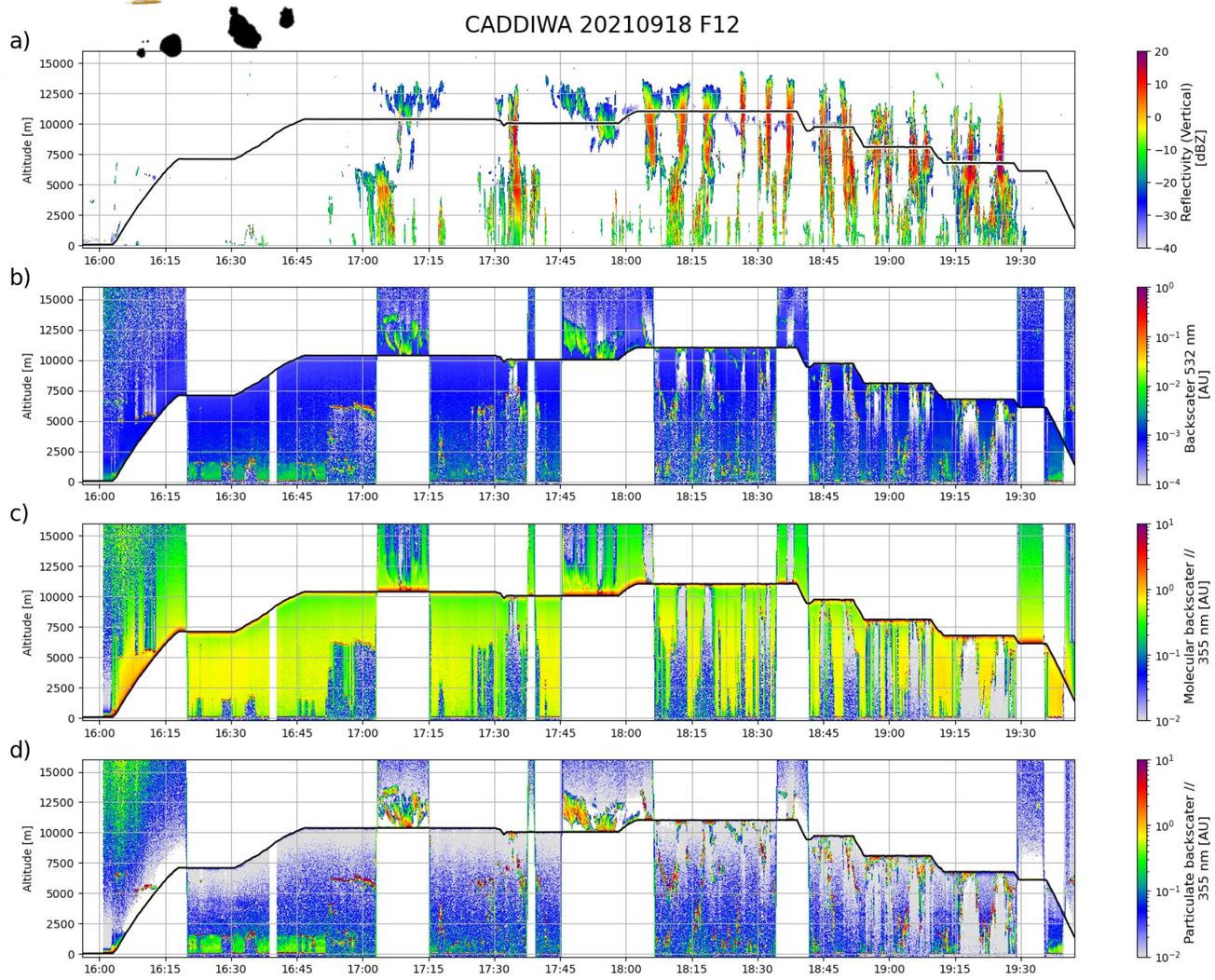
Payload on the SAFIRE Falcon 20 :

- **Remote sensing**
  - **LNG lidar (355 HSRL, 532 and 1064 nm)** – nadir or zenith or sideways (37°) pointing

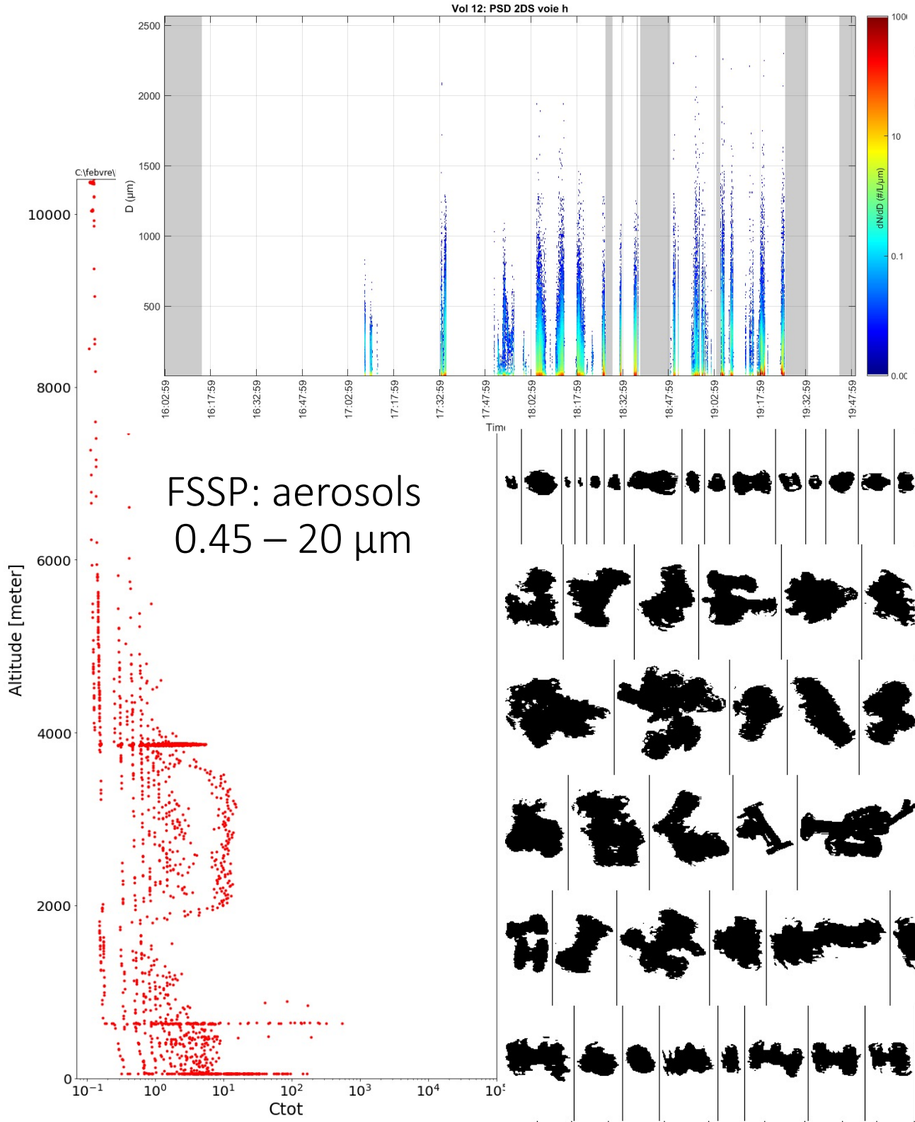
    aerosols, ice clouds, line-of-sight projected wind
  - **RASTA Doppler cloud Radar (95 GHz)** – 4 antennas (1 up, 3 down)

    in-cloud horizontal and vertical wind, cloud µphysics
  - **IR radiometer CLIMAT** (brightness temperature **8-10-12 µm**)
  - **LW/SW up- and down-looking fluxes** (broadband)
- **Dropsonde launching** (profiles of T, p, hum, u, v)
- **In-situ microphysics**
  - **UHSAS and FSSP** aerosol size distribution 40 nm – 25 µm
  - **CDP and 2DS** cloud droplet size distribution 2-1550 µm
  - **Nevzorov probe** (LWC and TWC)
- **In-situ p, T, hum, wind**

ASSETS (2/4)



© Julien Delanoë (LATMOS)



Radar Lidar

ASSETS (3/4)

EPjjj: 3-day forecasts with two models

Starting from t+12 ECMWF fst at 12 UTC

Available at 09 LT every day

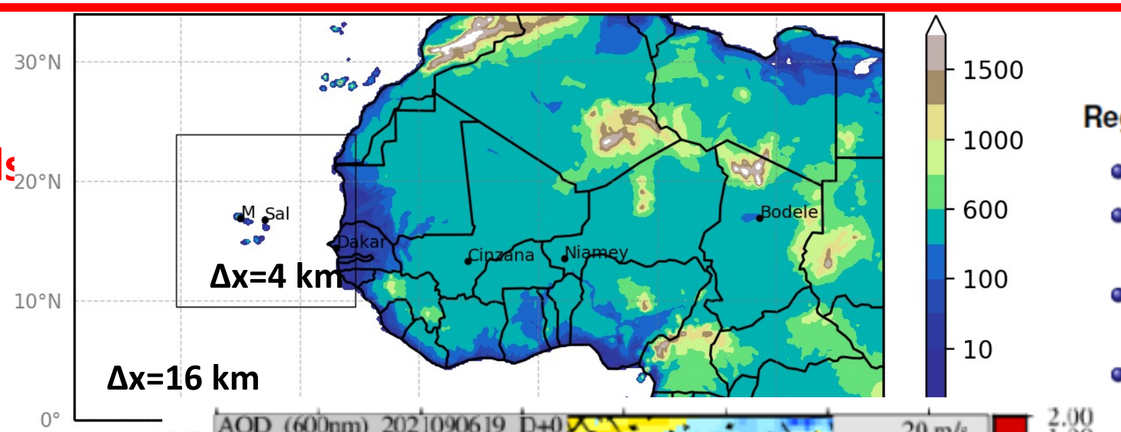
- 32 vertical levels, Δz=100m-1 km
- EDKF shallow convection scheme
- ICE3 one-moment microphysics
- DEAD dust scheme
- Lagrangrian on-line back trajectories
- RTTOV synthetic satellite images

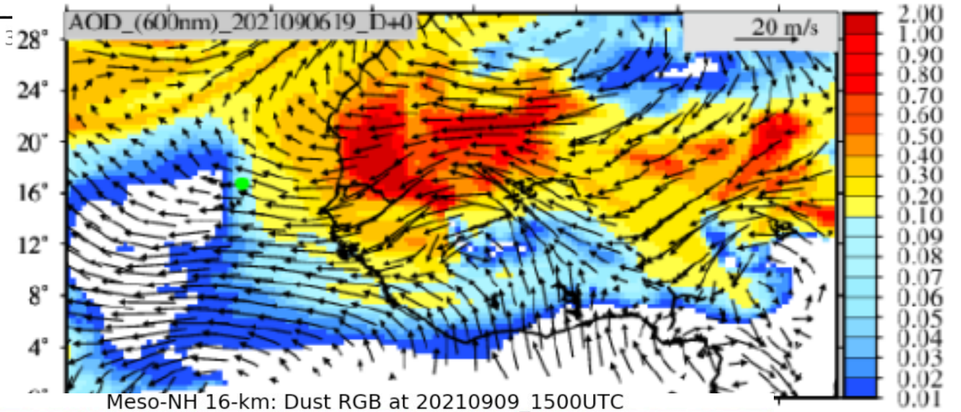
EPjjj: 5-day forecasts with one model

Starting from ECMWF analysis at 00 UTC

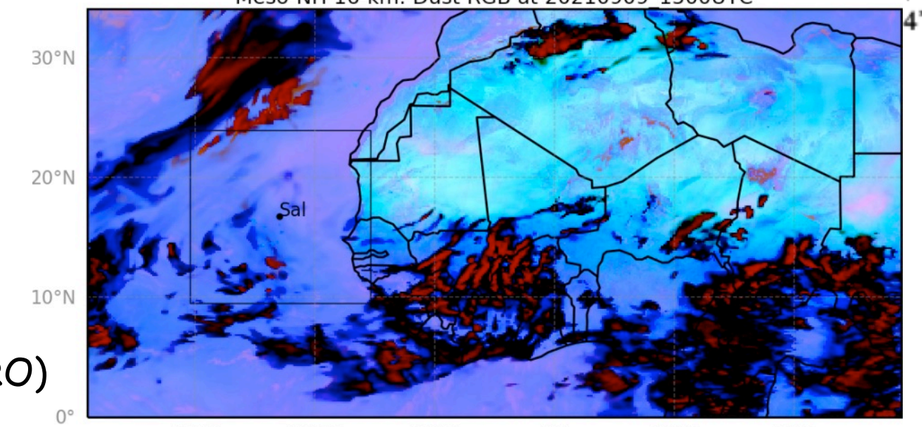
Available at 14 LT every day

- Same parameterizations as Epjjj





Meso-NH 16-km: Dust RGB at 20210909_1500UTC



Regional models:

- WRF: meteorology
- CHIMERE: chemistry-transport of gaseous and aerosol chemical species
- One domain with Δx=10 or 60km, 20 vertical levels from surface to 300hPa
- Emissions: anthropogenic, biogenic, sea-salt, mineral dust, biomass burning
- Hourly concentrations of gaseous species and aerosols.

e WRF and CHIMERE models are used to sim-ıte gas and aerosols concentrations in online ɔde, including direct and indirect effects.

r CADDIWA:

- During the campaign:
  Daily forecast (with hourly outputs), from (D-1) to (D+4)
- After the campaign:
  Analysis of simulation for the interactions between mineral dust and meteorology, with sensitivity analysis on direct and indirect effects.

© Laurent Menut (LMD)

Meso-NH
mesoscale non-hydrostatic model

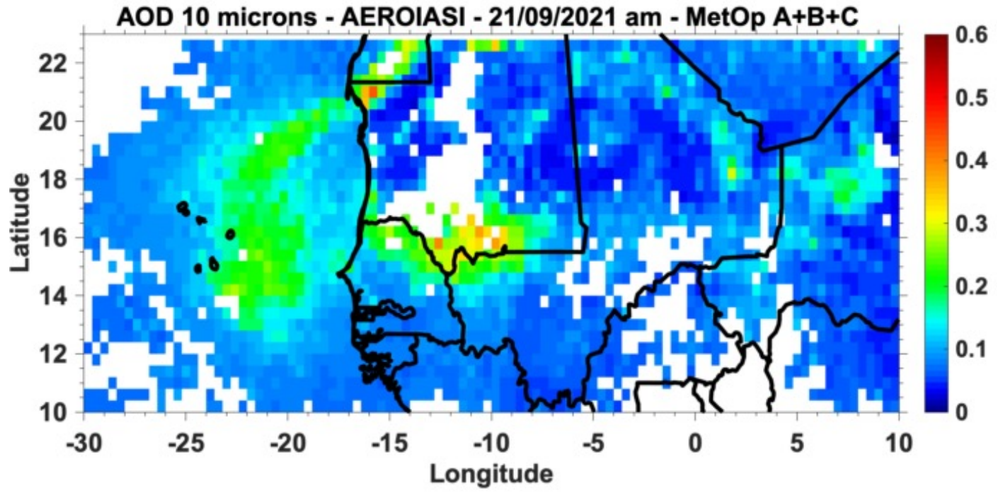
© Jean-Pierre Chaboureau (LAERO)

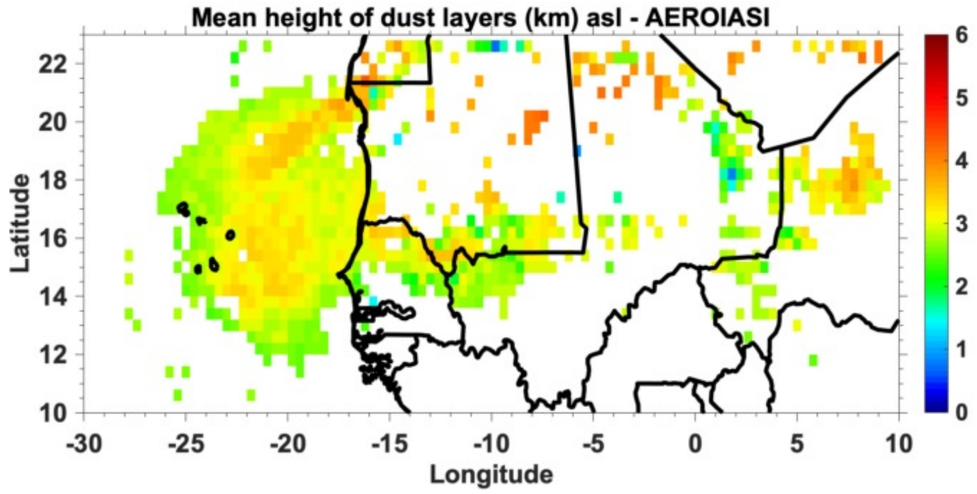
chimere

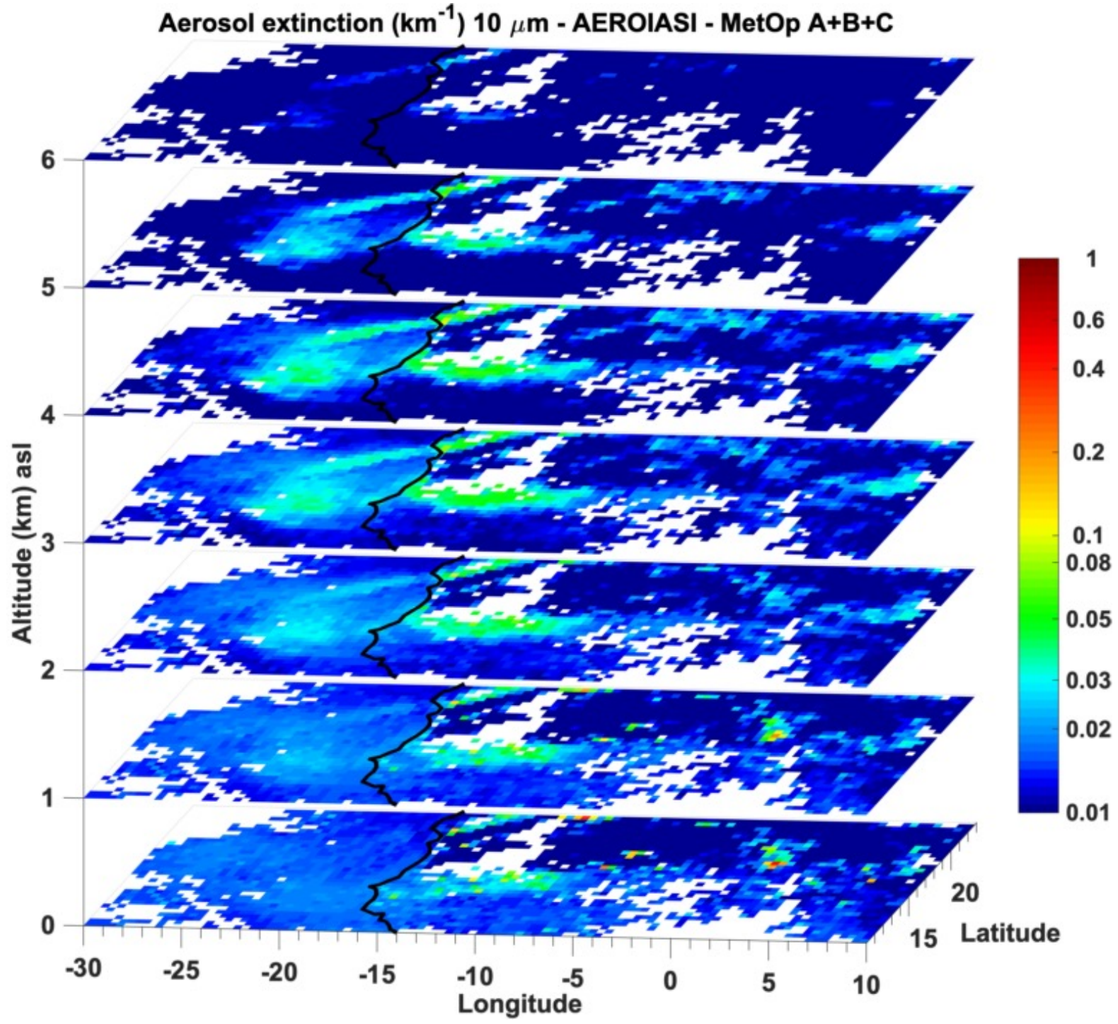
ASSETS (4/4)

AEROIASI

© Juan Cuesta (LISA)



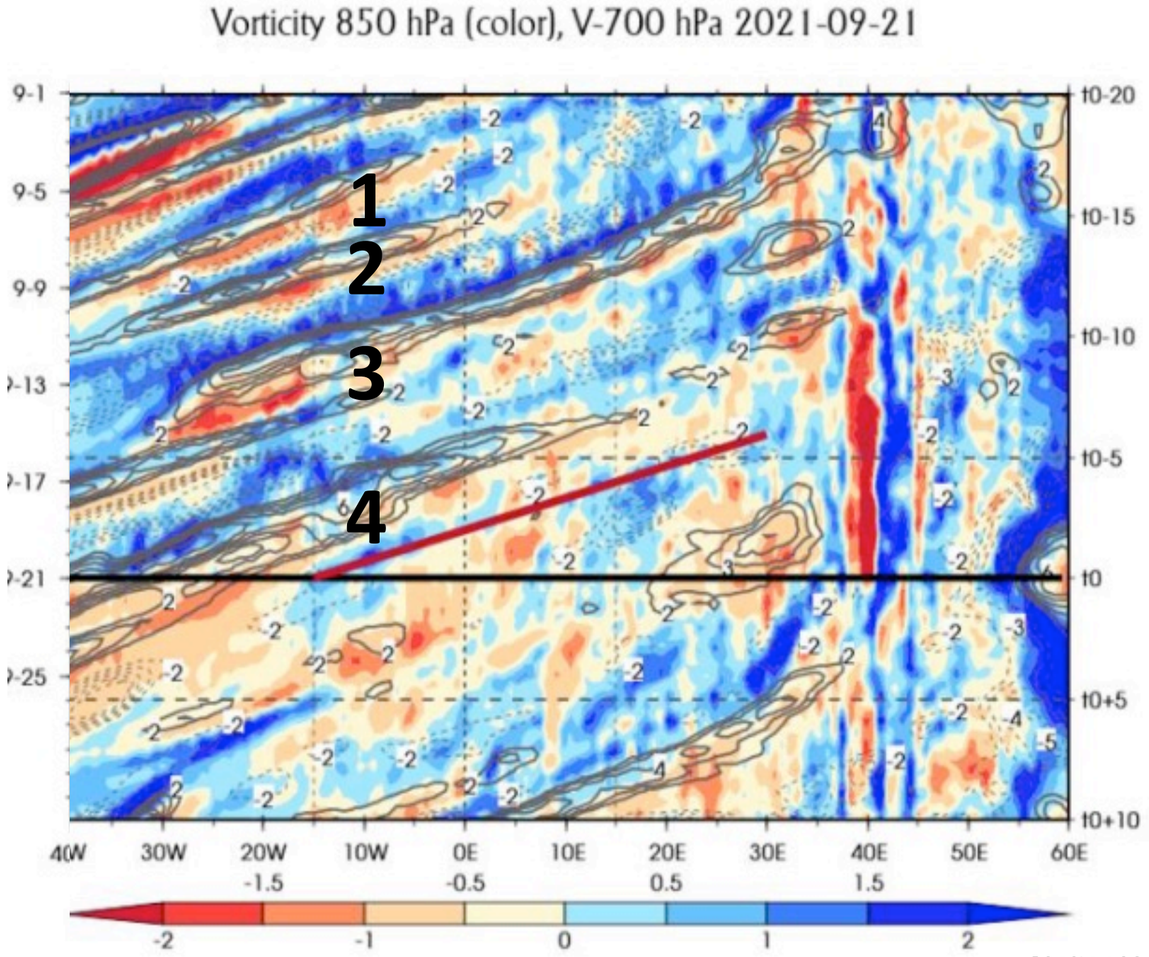


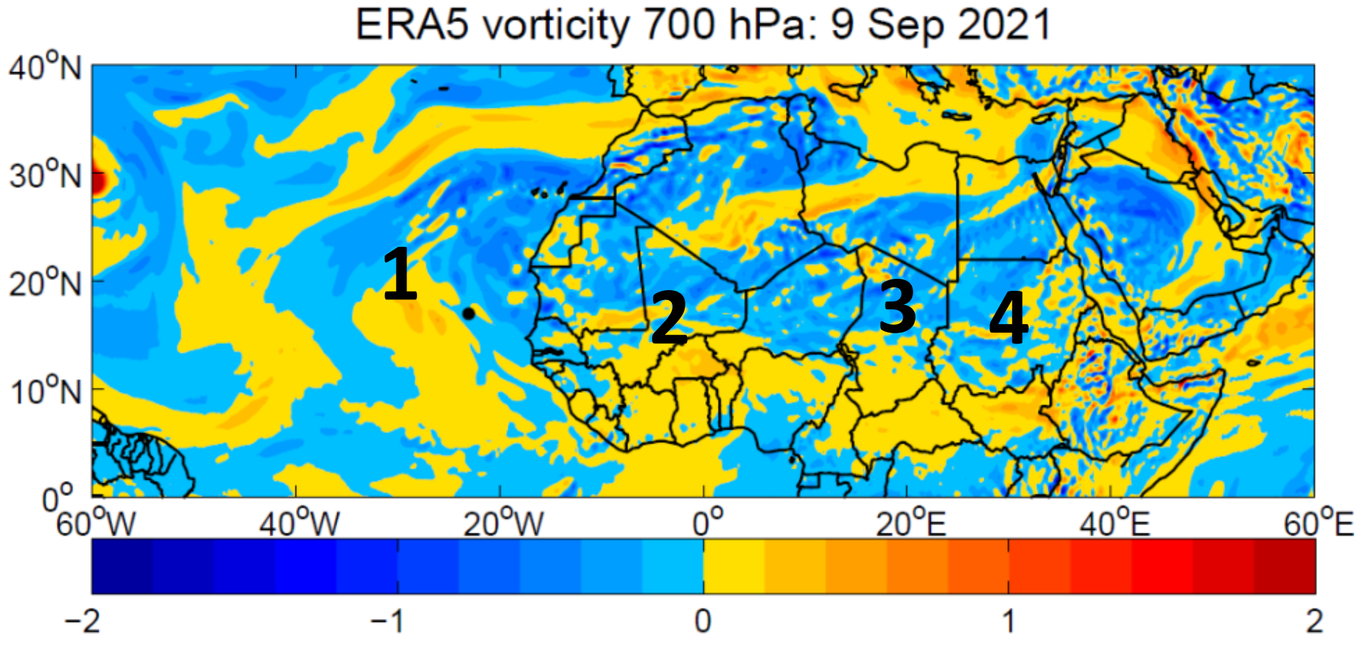


FIELD CAMPAIGN

AEWs: 3-5 day period; 5000 km wavelength

➔ 4 AEWs observed during the 3-weeks campaign





8-21 September: AEW development into

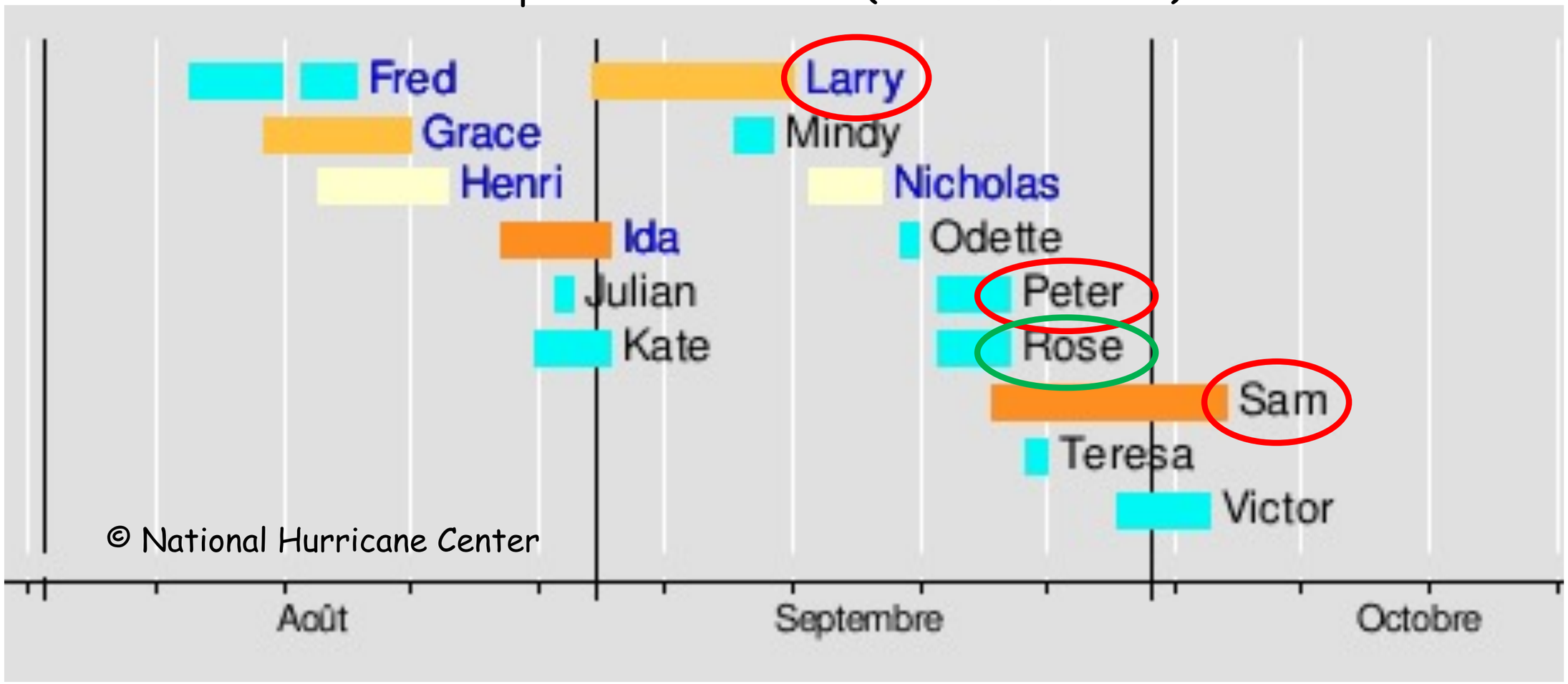
2 Tropical Storms (Peter, Rose – 19 September)

1 Tropical disturbance 11 September

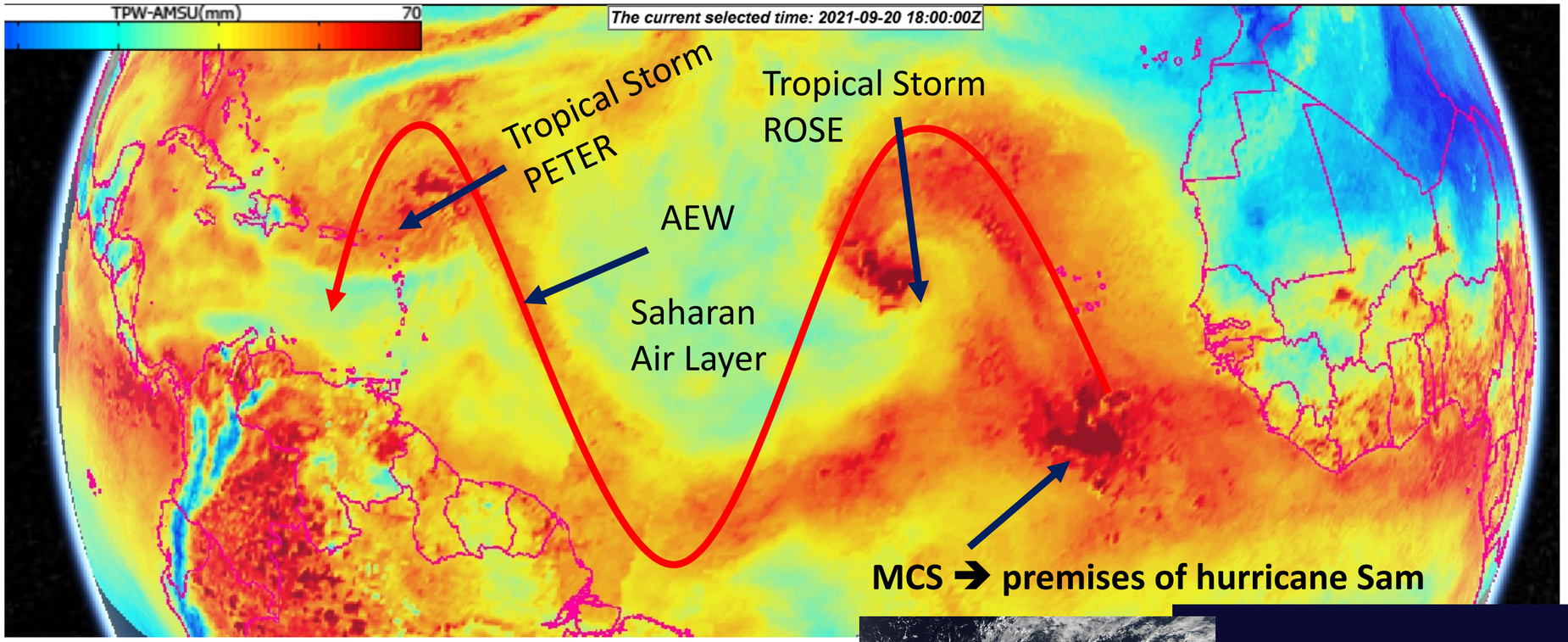
What did we miss ? … sampling the pre-environent of:

Hurricanes Larry (before we arrived) and Sam (too far)

Tropical Storm Peter (aircraft failure)



Tropical Storm ROSE



Total Precipitable Water over the North Atlantic

20/09/2021

© NASA CPEX-AW

September 15 ➔ a tropical wave approaching the Atlantic coast of Africa

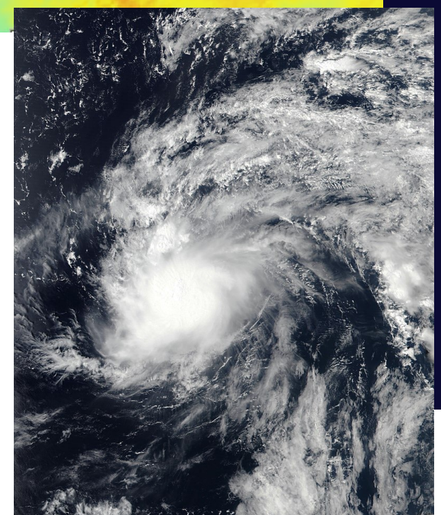
September 18 pm/19 am ➔ pre-ROSE environment probed by CADDIWA

September 19 ➔ designated a tropical depression

➔ upgraded to a tropical storm and given the name *Rose*

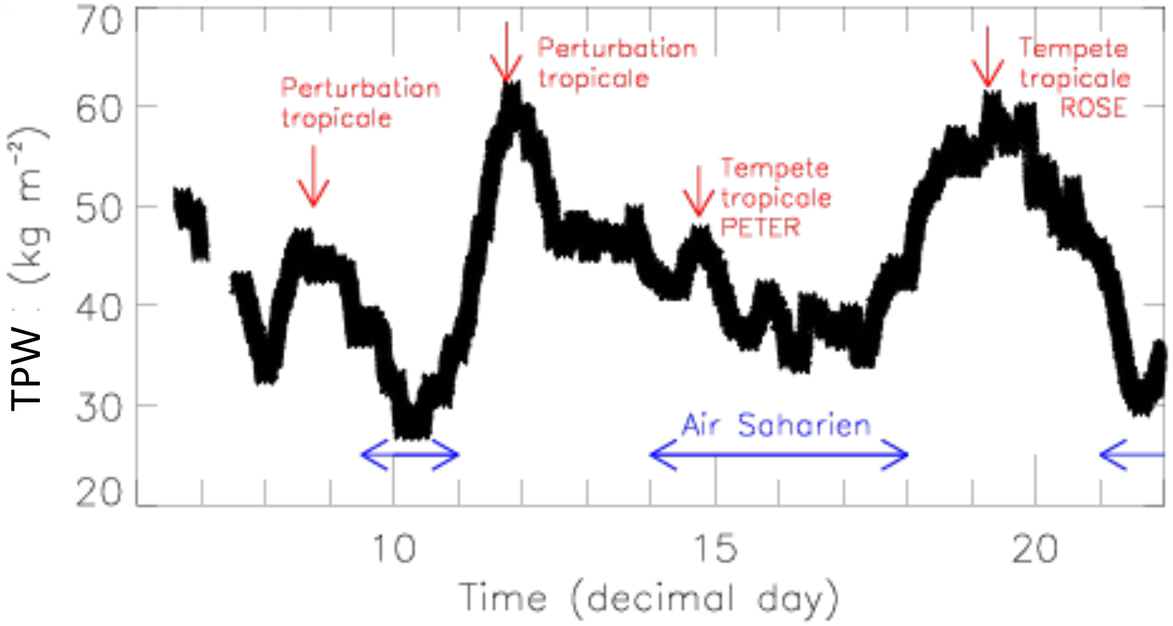
September 22 ➔ Rose weakened to a tropical depression

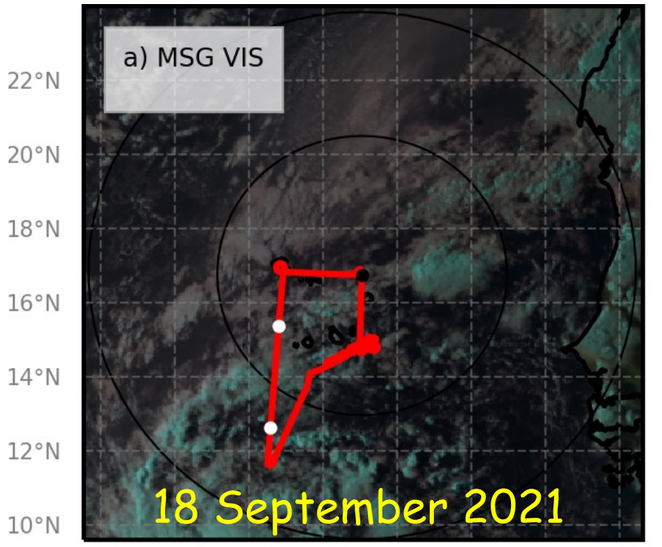
September 23 ➔ transitioned into a post-tropical cyclone the following day.

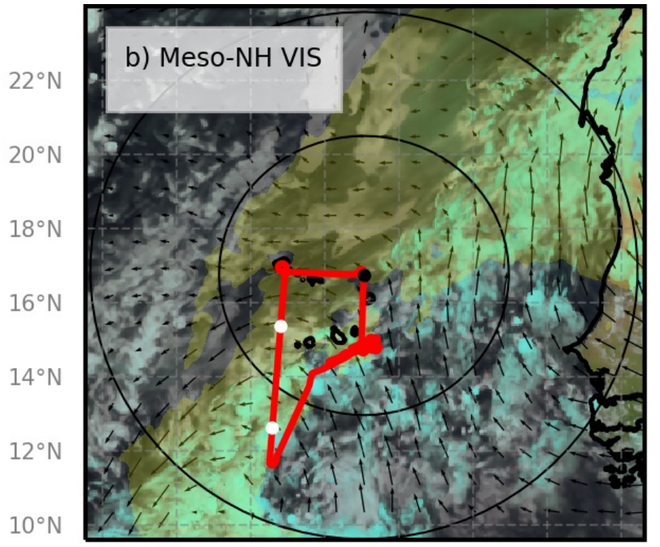


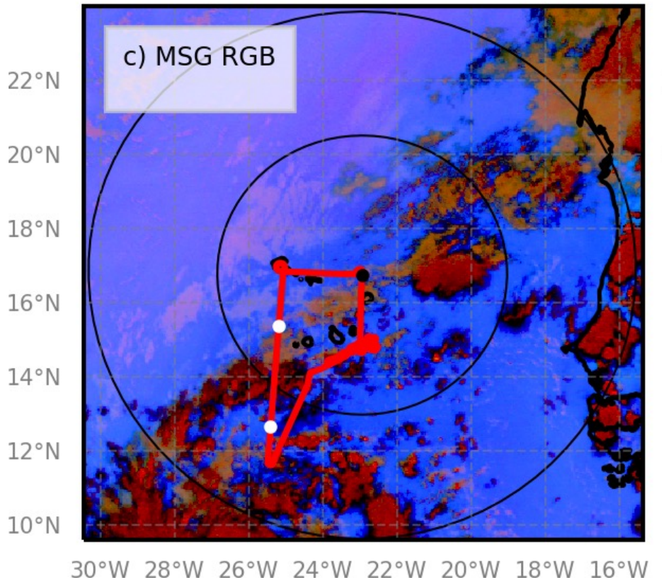
Tropical Storm ROSE

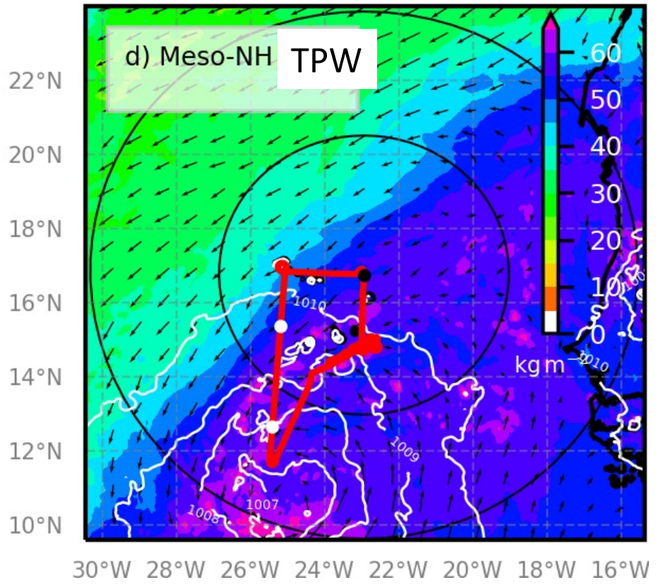
GNSS station in Sal











The upstream environment of the soon to be Tropical Storm ROSE was monitored with the SAFIRE Falcon 20 on 18 am and 19 pm September 2021

SAFIRE Falcon 20 flights

32 flight hours & 46 dropsondes

All instruments operated nominally

Date	Flight number	Time (UTC)	Nb of drops	Objectives	Coordination with
08 Sep 2021	fs21005	0636-0957	3	**Aeolus** West of Mindelo	DLR F20, AA WT-10
10 Sep 2021	fs21006	1842-2223	5	**Aeolus** Mindelo overpass	DLR F20, AA WT-10, Boat Gamboa
11 Sep 2021	fs21007	0916-1243	10	Tropical despression	
11 Sep 2021	fs21008	1447-1756	8	Tropical depression	AA WT-10
14 Sep 2021	fs21009	0626-0924	6	**Aeolus** Sal overpass	AA WT-10
16 Sep 2021	fs21010	1806-2116	6	**Aeolus** East of Sal	DLR F20, AA WT-10
17 Sep 2021	fs21011	1834-2216	3	**Aeolus** Mindelo overpass	DLR F20, AA WT-10, Boat Gamboa
18 Sep 2021	fs21012	1603-1940	2	Tropical storm Rose	Boat Gamboa
19 Sep 2021	fs21013	0906-1243	2	Tropical storm Rose	

Missions Cal/Val and preparation

- Correlative observation between Aeolus and the airborne and ground-based remote sensing and in-situ reference systems

Fs210007, Fs210008
Fs210012, Fs210013

- Tropical wind systems, e.g., Easterly Waves, ITCZ
- Aerosols, i.e., Saharan dust, smoke
- Tropical clouds and convection

Validation

Tropical Campaign

Science

Technology

Fs210005, Fs210006
Fs210009, Fs210010, Fs210011

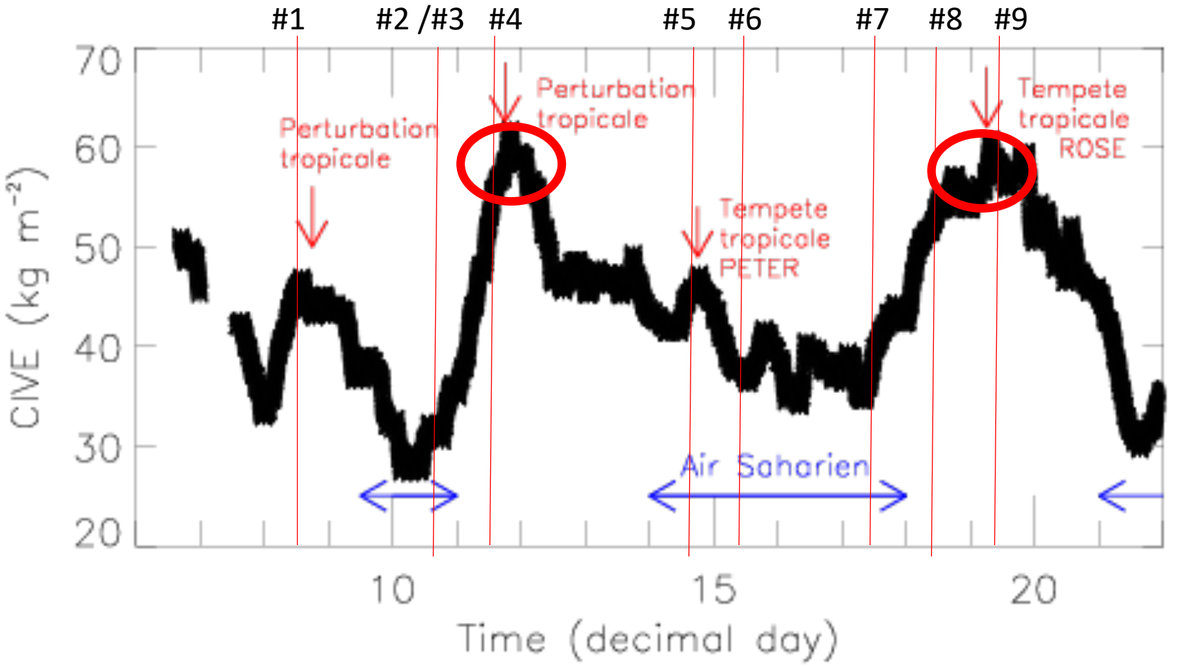
- Providing proxy data for EarthCARE E2E development
- Providing data for EE11 Wivern radar phase A studies
- Testing new validation technology

Fs2100xx SAFIRE Falcon 20 flight

Fs210007, Fs210008
Fs210012, Fs210013

Summary

- Nine flights realized in 8 days for:
  - 32 flight hours
  - 46 dropsondes dropped
  - 12000 km covered by the SAFIRE Falcon 20
- 5 flights along Aeolus orbits & documentation of Saharan air transport episodes (Aeolus & IASI Cal/Val)
- 4 flights for providing proxy data for EarthCARE E2E development and data for EE11 Wivern radar phase A studies (EartCARE & Wivern preparation)



- 4 flights in the environment of disturbances and tropical storms developing on African east waves, including the Tropical Storm ROSE ➔ **11 Sept case Vs 18/19 Sept case**
  - Contrasted cases of interaction with Saharan Air Layer (Tropical Disturbance on 11 Sept did not develop into a Tropical Storm because of dust?)
- GNSS station now in Praia with University of CV@Praia with Mateus and Nicolau ➔
  - Education and research purposes with new teaching program
- Check out #CADDIWA!

Further reading & wiewing

- Brèves in La Météorologie (to appear)
- Overview in BAMS (upcoming, proposal accepted)
- #CADDIWA

Échos

La campagne Caddiwa dans la région des îles du Cap-Vert[1]

Au cours de l'été boréal, les systèmes convectifs de méso-échelle générés au-dessus de l'Afrique de l'Ouest se propagent vers l'ouest et interagissent avec les ondes tropicales atmosphériques, et particulièrement les ondes d'est africaines, ainsi qu'avec les panaches d'aérosols terrigènes provenant du Sahel et du Sahara. Une fois au large de l'Afrique de l'Ouest, les perturbations dans le sillage de ces systèmes convectifs évoluent dans un environnement côtier complexe conduisant parfois au développement de tempêtes tropicales et d'ouragans, particulièrement en septembre lorsque les températures de surface de la mer sont élevées dans la région de l'Atlantique nord tropical et du Cap-Vert. Ces événements ont un impact significatif sur le temps en aval, depuis les Caraïbes jusqu'au États-Unis et l'Europe occidentale.

Les prévisions de la cyclogenèse dans la région du Cap-Vert sont aujourd'hui très difficiles en raison de la mauvaise compréhension des interactions « systèmes convectifs de méso-échelle-poussières terrigènes-ondes tropicales » qui limite l'horizon de prévisibilité des modèles de prévision numérique du temps. En effet, l'Afrique tropicale est la région du globe où l'on observe le plus grand nombre de systèmes convectifs de méso-échelle, dont la prise en compte constitue un défi pour les schémas de convection. En outre, les modèles actuels de prévision numérique du temps peinent à représenter le couplage entre les ondes tropicales et le flux atmosphérique moyen. Enfin, il semble que les interactions des ondes d'est africaines ainsi que d'autres ondes tropicales avec les poussières minérales, le rayonnement et les systèmes convectifs induisent des effets non linéaires dans le développement des ondes, qui sont particulièrement difficiles à prendre en compte dans les modèles de prévision numérique du temps actuels.

Objectifs de la campagne de terrain

L'objectif premier du projet Clouds-Atmospheric Dynamics-Dust Interactions in West Africa (Caddiwa) est d'étudier les interractions « systèmes convectifs de méso-échelle-poussières-ondes tropicales » dans la zone de l'Atlantique Nord tropical située au large de l'Afrique de l'Ouest en se basant sur des observations de pointe au sol, aéroportées et spatiales, ainsi que sur des simulations numériques régionales. Un deuxième objectif est de contribuer à la validation et à la préparation de plusieurs missions spatiales d'intérêt pour le Centre national d'études spatiales français (Cnes) et l'Agence spatiale européenne (ESA), avec en particulier la validation des missions lidar vent Aeolus, ainsi que celle de l'interféromètre atmosphérique de sondage infrarouge (Iasi) sur *MetOp-C* (validation) et la préparation des futures missions radar Wivern (dynamique des nuages et des précipitations) et radar-lidar EarthCare (impact radiatif des nuages et des aérosols). Un troisième objectif concerne la vérification et l'amélioration des modèles numériques de prévision régionaux.

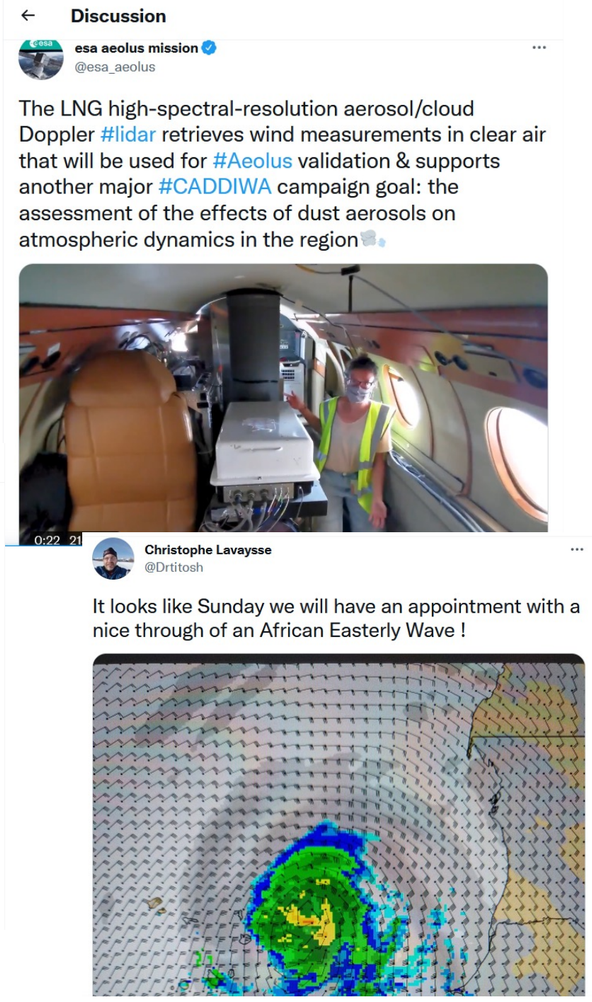
Les questions scientifiques posées dans le cadre du projet Caddiwa sont centrées sur la compréhension des effets radiatifs liés aux aérosols terrigènes, à savoir l'effet radiatif direct, semi-direct et indirect, ainsi que sur la dynamique atmosphérique et les systèmes convectifs de méso-échelle dans l'environnement côtier complexe au large du Sénégal. Plus particulièrement, il s'agit de comprendre et d'estimer la contribution respective des trois effets radiatifs liés aux aérosols terrigènes sur l'intensification des perturbations cycloniques de sillage des systèmes convectifs de méso-échelle au large et, éventuellement, leur transformation en tempêtes tropicales au-dessus de l'océan Atlantique nord tropical.

Mise en œuvre de la campagne

De nouvelles observations pertinentes pour l'évaluation des interactions « systèmes convectifs de méso-échelle-poussière-ondes » ont été recueillies lors d'une campagne de terrain organisée du 6 au 23 septembre 2021 dans l'environnement tropical de l'île de Sal au Cap-Vert, situé à 500 km au large du Sénégal. La campagne aéroportée Caddiwa, basée sur le déploiement du Falcon 20 de Safire depuis l'aéroport international Amilcar Cabral, fait partie d'un consortium expérimental international qui a opéré sous l'égide de la Joint Aeolus Tropical Atlantic Campaign (Jatac). Les mesures de la campagne Caddiwa ont été coordonnées avec le déploiement

1. *In memoriam*, Pierre H. Flamant (21 avril 1942-30 juin 2020), qui a été l'instigateur de nombreuses missions spatiales dont la mission spatiale *Aeolus*. Il devait participer à la campagne Caddiwa.

Figure 1. L'équipe Caddiwa devant le Falcon de Safire sur le tarmac de l'aéroport international Amilcar Cabral de Sal, aux îles du Cap-Vert.



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Thanks