Aerosol flux, wave state and wind field measurements above the ocean surface using unmanned aerial systems

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Intensification of cyclonic activities

- **Idai** (4 – 21 March) and **Kenneth** (21 – 29 April 2019) struck Mozambique, Malawi, Zimbabwe and Madagascar
- More than 1 200 people died
- $2 billion loss in infrastructure

→ *Intensification and migration of cyclones* toward the poles (Kossin et al., Nature, 2014) due to climate change

→ Motivation of the **ReNovRisk** project in the Indian Ocean

Aim to improve resilience of the Reunion island and territories in the Indian Ocean to face natural hazards, and particularly **cyclones**

Scientific objective : improve the comprehension of cyclones and their representations in climatic models
Aerosols have been identified as playing a role in the cyclonic life cycle.

Comparison of UAV observations to model simulations in order to assess a parameterization of sea salt emissions (Ovadnevaite et al., 2014).

Conduct simulations with coupled ocean-wave-atmosphere models: the atmospheric model MesoNH, the oceanic model CROCO, and the wave model WW3 (Pianezze et al., 2018).
# UAV observations: scientific payload

## Atmospheric state
- Pressure, temperature, humidity
- Boundary layer stability; lifting condensation level

## Wind Speed & Flux
- Multi-hole probe
  - $U, V \rightarrow$ horizontal wind speed
  - $w \rightarrow$ vertical wind; eddy flux correlation

## Wave Height; Sea State
- Radar altimeter
  - Wave height
- Video camera
  - White cap fraction

## Sea surface temperature (SST)
- IR temperature
  - SST $\rightarrow$ kinematic viscosity

## Aerosol
- Optical Particle Counter
  - Number & mass concentration ($D_p > 0.3$ um)

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\[
\frac{dF}{d\log D} = \sum_{i=1}^{n} \frac{F_i(R e_{H_{wo}})}{\sqrt{2 \pi} \ln \sigma_i} \exp \left( -\frac{1}{2} \left( \frac{\ln \left( \frac{D}{C M X} \right)}{\ln \sigma_i} \right)^2 \right)
\]

Ovdenevaitė et al., 2014
• Designed to measure air-sea interactions: Aerosol concentration and size distribution, 3D winds and turbulence, sea surface temperature, wave height, video, solar flux, meteorological state.

• Payload data sent to ground-station in real-time for mission planning.
Platform: BOREAL

Specifications:

- Wingspan: 4.2 m; 25 kg max take-off
- Flight capacity up to 700 km with a 5 kg payload (ca. 7 hrs)
- Two-stroke gas engine
- 95 km/h cruise air speed (26.4 m/s); Range: 60-130 km/h
- Catapult take-off; belly landing

Onboard instrumentation during ReNovRisk:

- Transponder (mode S/ADS-B)
- Strobe
- C2Link RF communication & Iridium satellite with real-time video (up to 50 km from GCS)
- Radar altimeter to measure sea state and for security
Field operations in the Indian Ocean

Recent campaigns in **February – April 2019**

- **East and West coasts** of Reunion Island
- Restricted airspace with a **250 km** radius with a flight ceiling of 3500 ft (1067 m).
- Flight operations conducted by **BOREAL** (ground-station pilot and a security pilot)
- Coordination of BOREAL flights with **ATC and other users of the airspace** conducted by DroneXSolution.
- The **CNRM team** coordinated **scientific and logistical operations**.
Flight experience

- Total of 12 flights, 5012 km, 53:41 hours
- Average flight duration: 4.5 hours
- 3 flights farther than 200 km from ground operations
- Longest flight lasted 6.3 hours and covered 610 km
- Minimum altitude: 40 m.asl
- Observations on the perimeter of the Cyclone Joaninha
- Observed gradient in sea state during Southern Swell event
Integration into international airspace

- **Transponder** (S/ADS-B) allowed integration into airspace (ca. 200 km range; altitude dependent).

- **Real-time updates on:**
  - [http://www.flightradar24.com](http://www.flightradar24.com)
  - [http://www.adsbnetwork.com/FMEE](http://www.adsbnetwork.com/FMEE)

- **BOREAL** followed by **ATC**, commercial aircraft, and civilian users of airspace.
Real-time route planning

• Precipitation and wind vector overlay on flight trajectory for route planning (communication via SatCom PLANET)

• Tracking of marine traffic to avoid flying over vessels (AIS equipped)
Real-time visualization of data

- Data from **scientific payload** transmitted via RF or SatCOM to the ground station in **real time**
- Results used to **verify performance** and assist **mission planning**
Preliminary results

Case study 1: cyclone Joaninha east of Mauritius

Case study 2: Southern swell
Case study 1: cyclone Joaninha

- Strong steady winds over open ocean
- Real-time video shows white caps, swell, and clouds
- Aerosol concentrations ($D_p > 0.3$ um) relatively high – wind and swell-driven source of marine aerosol; well-mixed boundary layer (up to cloud base)
Case study 1: cyclone Joaninha

1) Agreement for
   • horizontal wind
   • Wake of the island

2) Legs at three altitudes
   • Higher turbulence for lower altitude

UAV measurements

MesoNH simulation
Case study 2: Southern swell

Purposing flight plan: Ascent from 100 to 1000 m asl
Legs at 400 and 100 m asl, 10 km-long

Waves: 2.7 – 3.7 m
Case study 2: Southern swell

Purposing flight plan: Ascent from 100 to 1000 m.a.s.l
Legs at 400 and 100 m.a.s.l, 10 km-long

Eddy covariance method
Sensible and latent heat fluxes, horizontal momentum, and aerosol flux
Case study 2: Southern swell

Aerosol size distribution → homogeneous during southern transect

Legs at 100 m.asl

Aerosol size distribution → lower concentration at 1000 m.asl
Conclusions

• **ReNovRisk/MIRIAD** field campaign with **Boreal UAV** (February-March 2019)

• **Airspace**: 
  - Flights up to 250 km from the ground station
  - Flights as low as 40 m.a.s.l above the ocean
  - Transponder → integration into airspace
  - Boreal seen by ATC, commercial flights and airspace users

• **Scientific payload**: **9 instruments on-board**, T, RH, P, turbulence, dry aerosol concentration and aerosol distribution, sea surface temperature, wave height, solar fluxes

• **Science objectives**: comparing UAV observations and model simulations from ocean-wave-atmosphere coupled models
  - to assess sea salt parameterization
  - fluxes calculation
  - Improve understanding of emissions of marine aerosols that impact cyclone life cycle
Thank you