Evaluation of a 95 GHz Radar Simulator at SIRTA Observatory for the retrieval of fog Microphysical Properties by cloud radar and microwave radiometer synergy

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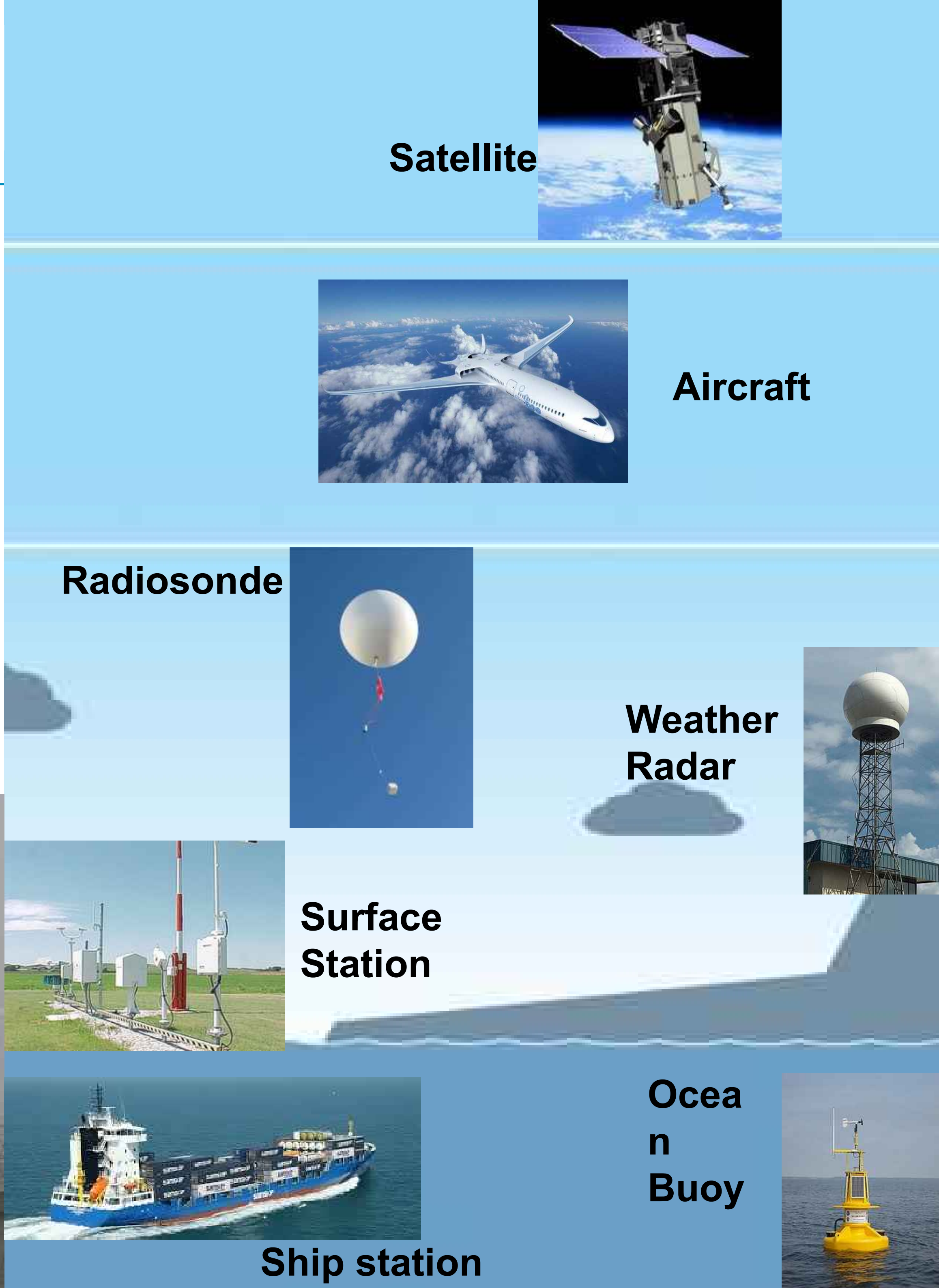
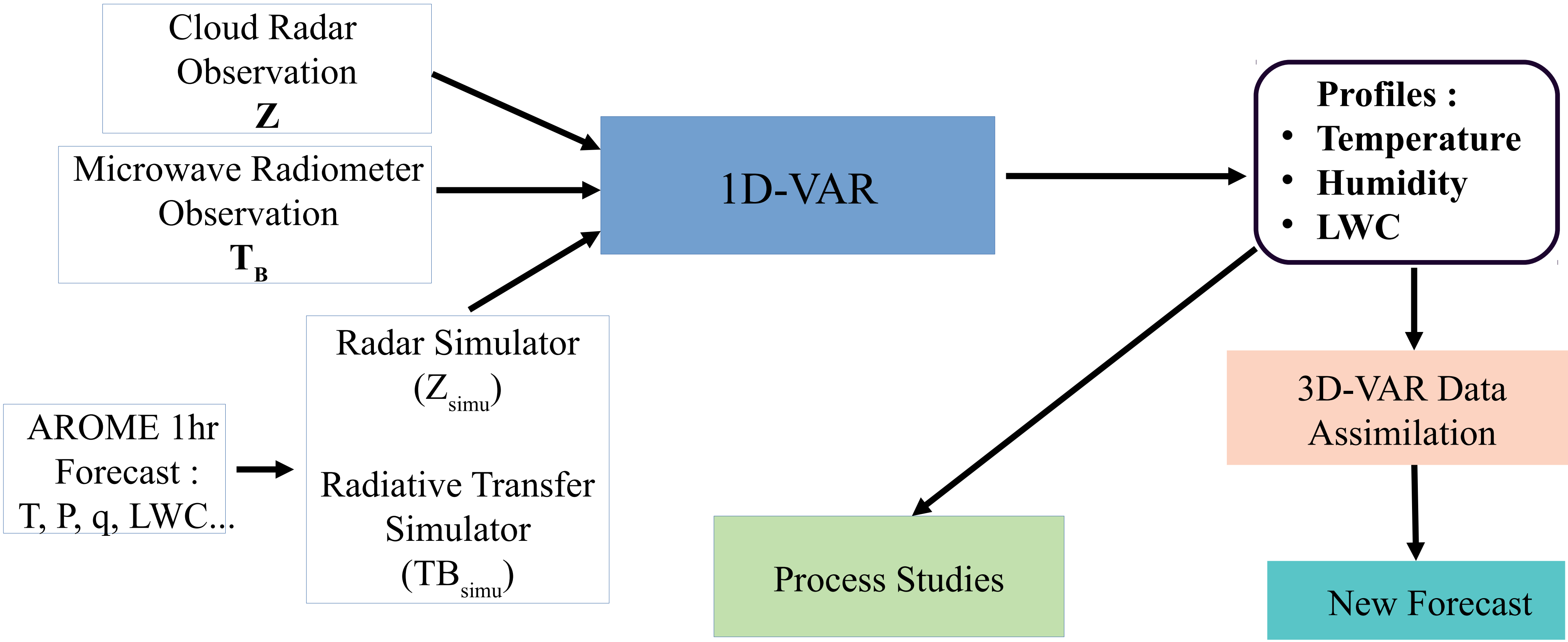
Context

- Incorrect **fog forecasting** has a large economic cost
- **Observation gaps** within the boundary layer
- Development of affordable ground-based remote sensing instruments
- Aim : Improvement of forecast through **assimilation** of **cloud radar/microwave radiometer** data



Phd Thesis : Improvements in Fog Forecasting through the instrumental synergy of Cloud Radars and Microwave Radiometers



Instrumentation

BASTA cloud radar

- Bistatic Radar Systems for Atmospheric Studies
- Retrieves Radar Reflectivity and Doppler Velocity
- 95 GHz transmission frequency
- Continuous transmission
- Frequency modulation allows for locating the target
- Lower cost than traditional weather radar
- Minimum measurement distance ~40m
- Scanning possible
- Four operational modes:
  - Resolution 12.5-200m
  - Range 12km- 24km

Sirta Observatory

- Dataset compiled from range of instruments at Sirta lab, Palaiseau :
- Cloud Radar (reflectivity)
- Radiometer (Liquid Water Path)
- Ceilometers (Cloud base height)
- Visibility monitors
- Anemometer (Wind speed, Direction)
- Precipitation Sensor
- LW/SW radiation sensors
- Soil sensors (heat flux, moisture, temperature)

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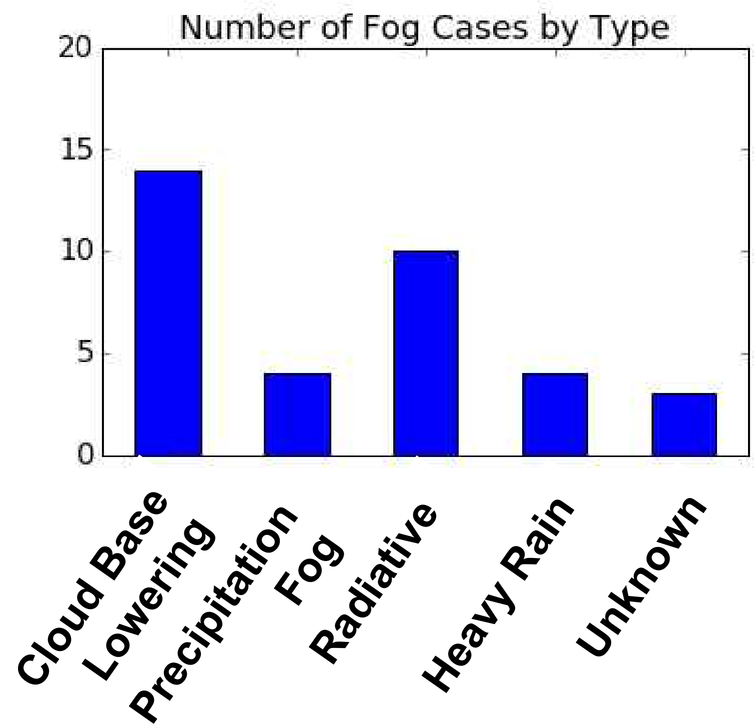
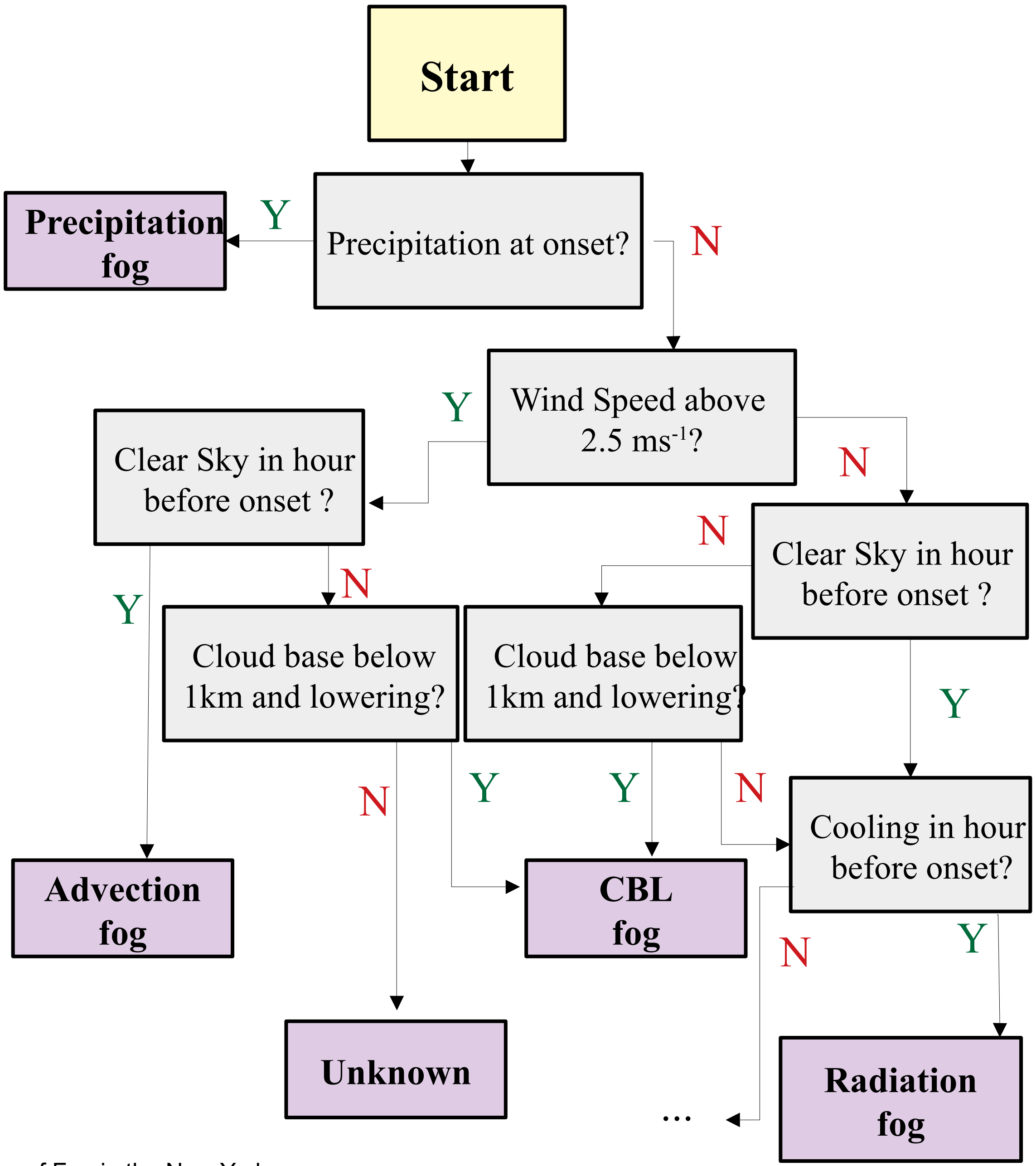
The fog 2018-2019 dataset at SIRTA

- Classification on Fog Case Based on Algorithm by Tardif and Rasmusen*
- 40 fog events found between October and February 2018/2019
- Most common – radiative and cloud base lowering
- Fewer advective than expected





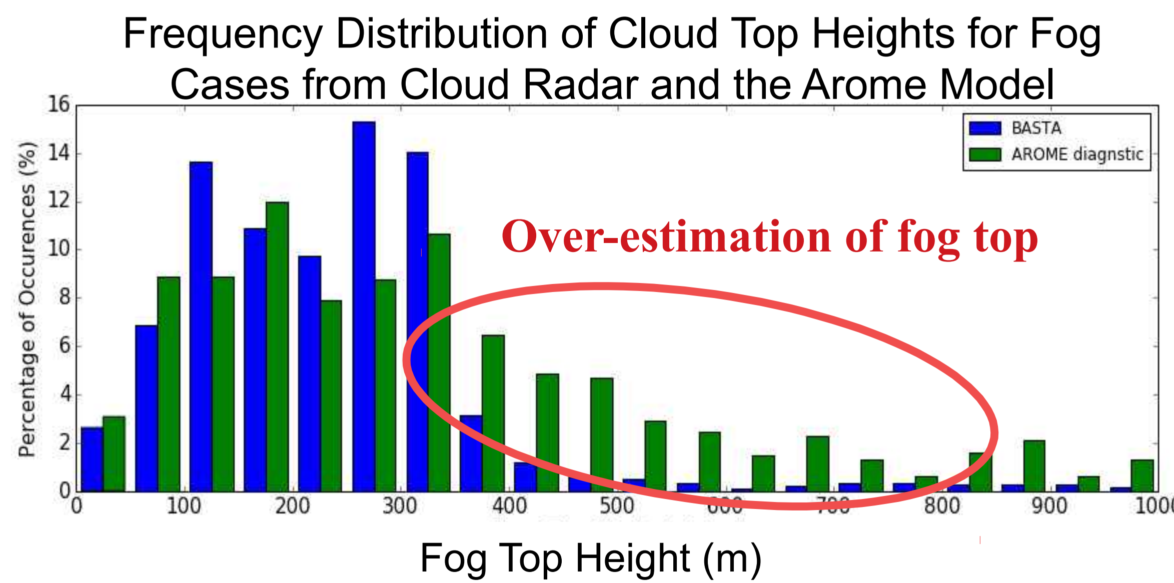
*Tardif, Robert & Rassmussen, Roy. (2007). Event-Based Climatology and Typology of Fog in the New York City Region. Journal of Applied Meteorology and Climatology. 46. 1141-1168. 10.1175/JAM2516.1.

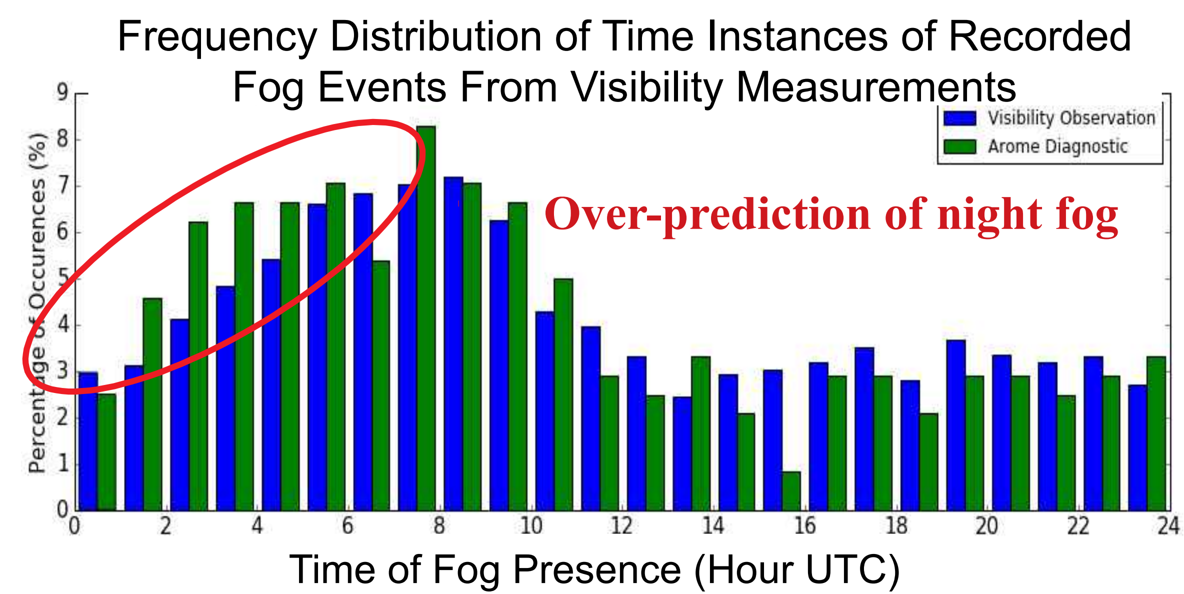
Overview of AROME Fog Forecast Errors

- Comparison performed on fog cases between model and Observations
- Fog top found from any reflectivity sensed
- Generally good capability of AROME to forecast fog

Observations

AROME





The Forward Operator / Radar Simulator

AROME Forecast:
T, q_v, q_{lwc}, q_r, q_s, q_i, q_g

→

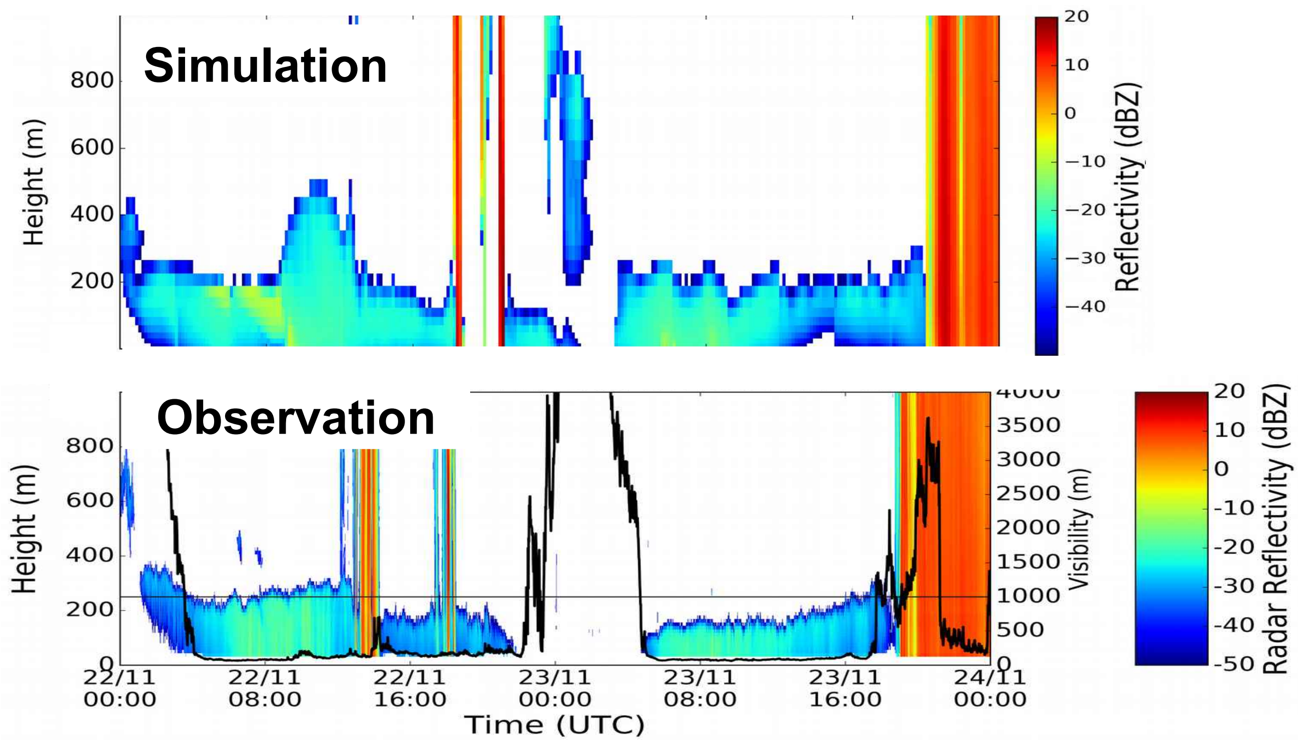
- Mie Scattering
- Ice-3 one-moment microphysical scheme
- Attenuation (Liebe, 1985)

→

Simulated Reflectivity Z

- Radar Simulator was designed by Borderies et al. 2018* which was adapted for ground based radar
- Forecasts from high-resolution NWP model AROME was used to initialise simulator

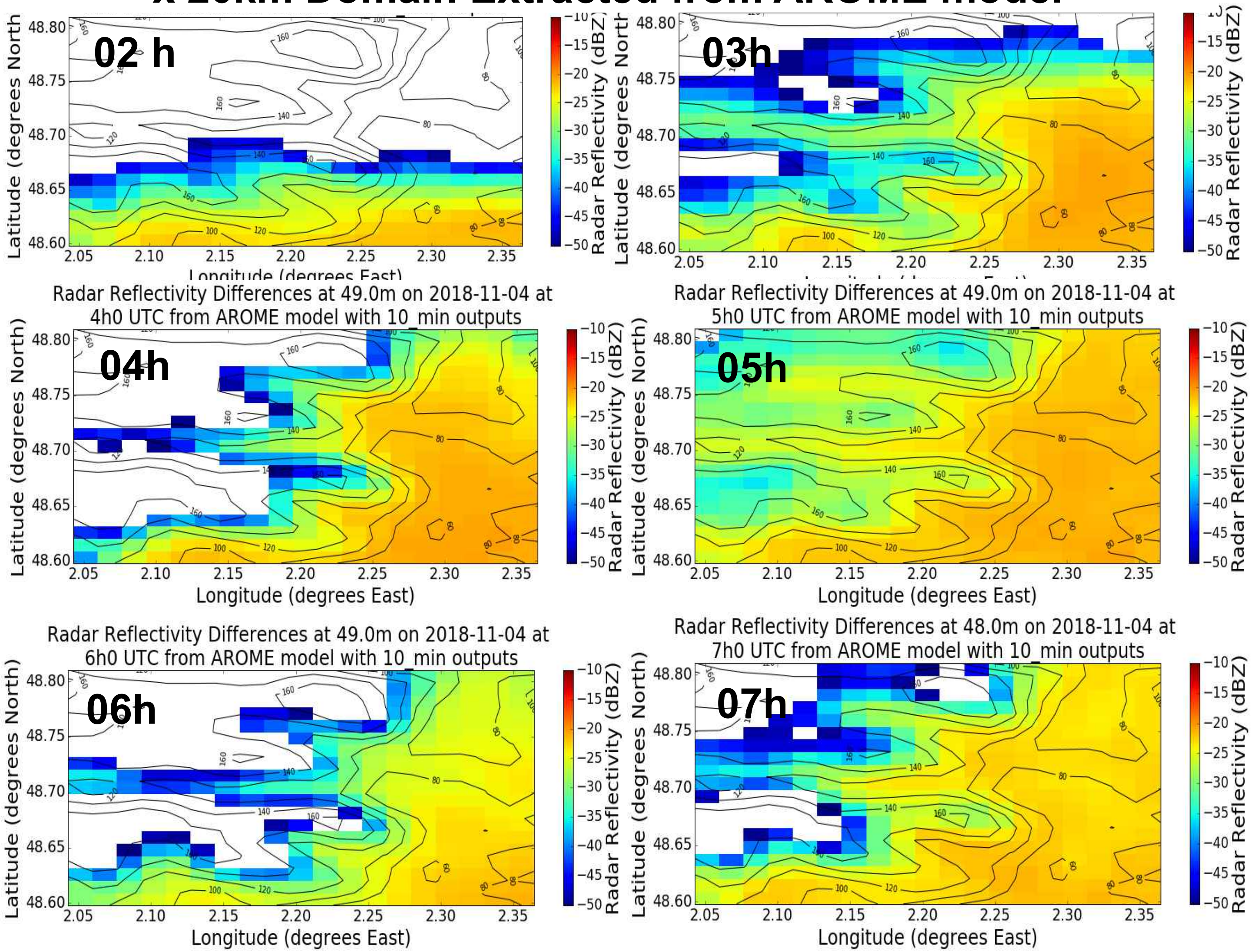
Radar Reflectivity at Sirta on 23/11/2018 - 24/11/2018



*M. Borderies, O. Caumont, C. Augros, J. Delanoë, V. Ducrocq (2018). Simulation of W-band radar reflectivity for model validation and data assimilation

Investigating Fog Spatial Variability (1)

Simulated Radar Reflectivity at 49m agl on 04/11/2018 20km x 20km Domain Extracted from AROME model



- Reflectivity appears to be similar for areas with similar surface heights
- In mature phase, reflectivity is more uniform than during formation/dissipation phase
- Reflectivity differences up to ~ 10 / 20 dBz

Optimal Profile Method

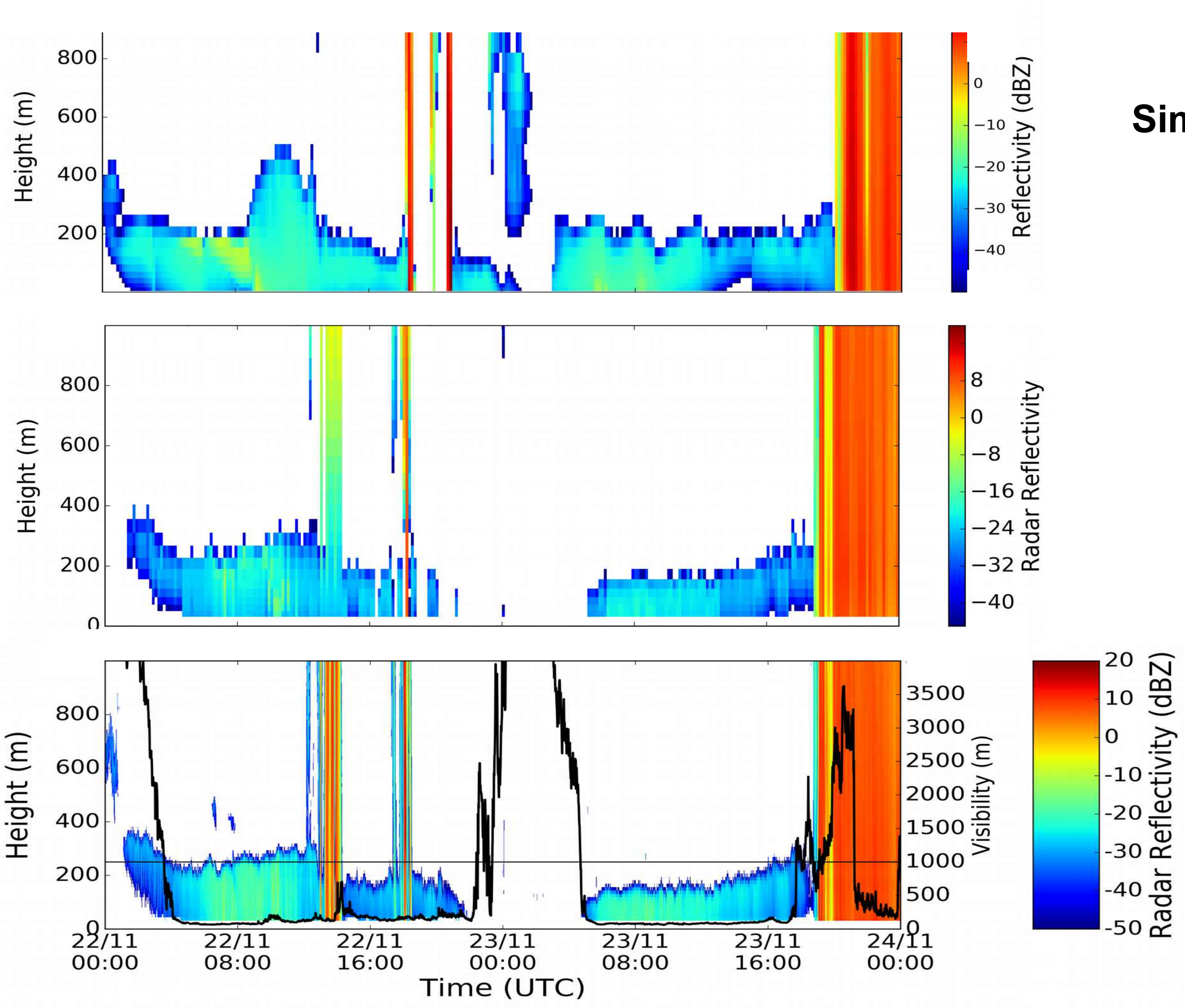
- Aim: Find best atmospheric profile for radar observation
- Simulate Reflectivity for all profiles in domain
- Score each profile according to weighted RMSE of all potential profiles found
- Weighting puts more importance on cells at lower altitudes
- Profile with lowest score chosen
- $h_{max} = 5\text{km}$

$$weighted\ RMSE = \sqrt{\frac{\sum_{i=0}^{i=level_{max}} \left[w_i \cdot \left(Z_{(Observation,\, i)} - Z_{(Simulation,\, i)} \right) \right]^2}{n}}$$

$$w_i = \frac{2}{\frac{h_i}{h_{max}} + 1}$$

Optimal Profile Selection: a stratus lowering case study

Radar Reflectivity at Sirta on 23/11/2018 - 24/11/2018



Simulated Reflectivity from AROME model

Optimal selection

Radar and Visibility Observations

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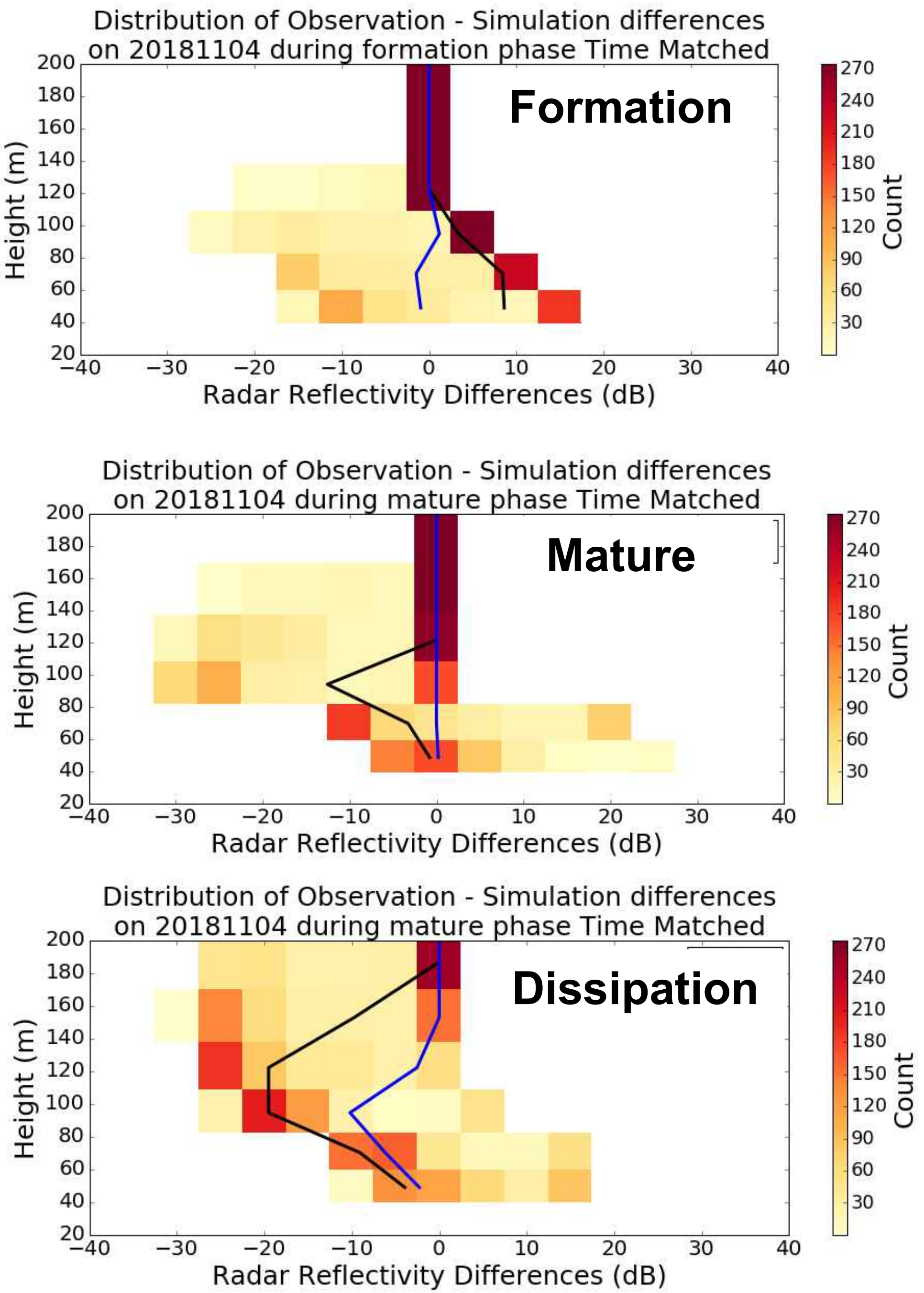
Impact of optimal profile selection: 2D histogram of observation minus simulated reflectivity



- Plots show distribution of all simulated profiles across domain for a single time
- At each stage, a simulation closer to the observation can be found in the domain

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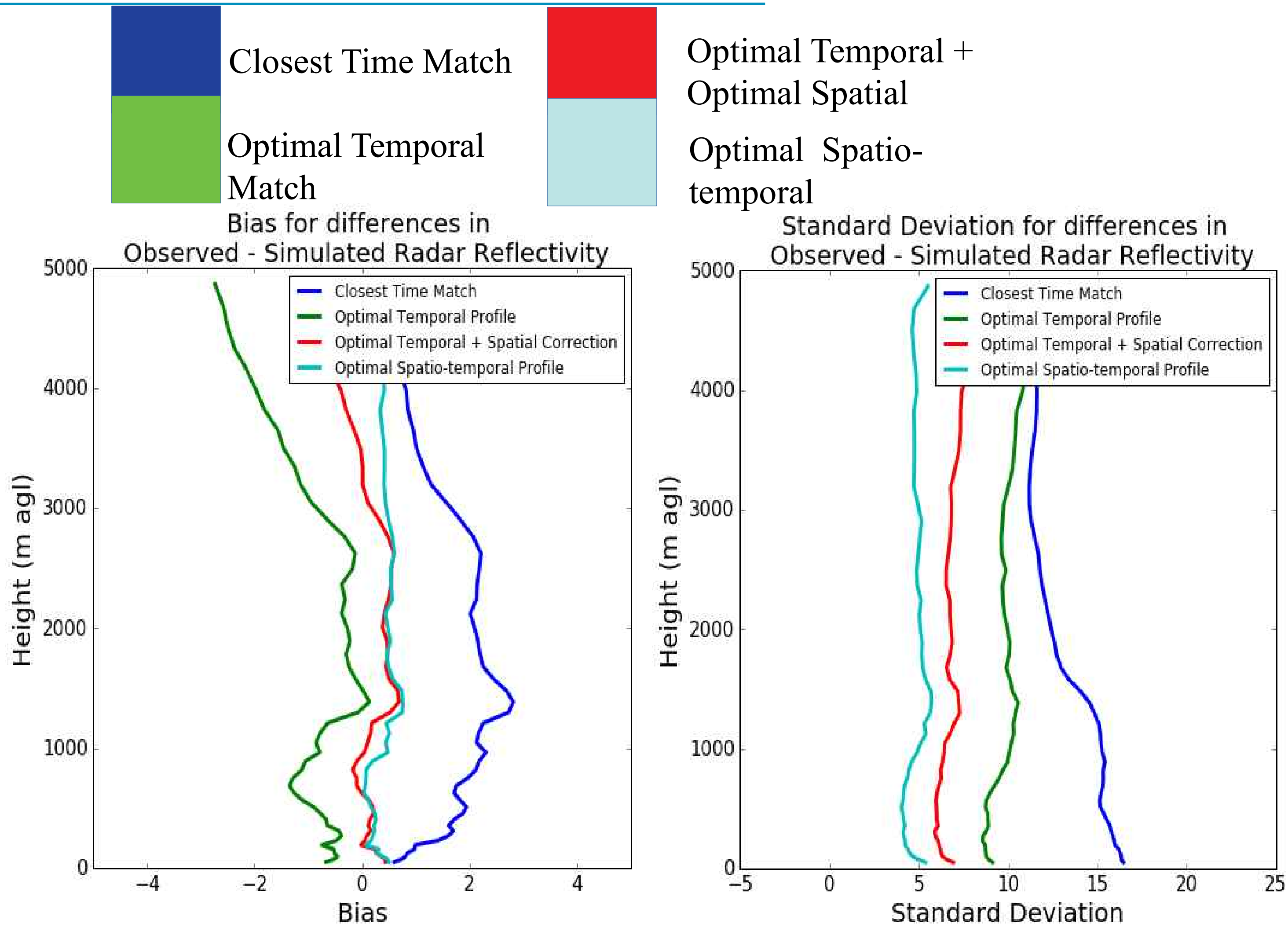
Improvement In Simulated Reflectivity Through Optimal Selection Method : Statistical study

Optimal profile method :

- Improvement in profile selection by use of optimal profile method
- By Selecting the time to choose and then the spatial profile improvements are made
- Best results by applying the method to all profiles and then selecting



Conclusions

- AROME model can generally forecast the presence of a fog event, but there are significant errors in the fog top height, and the formation and dissipation times
- The spatial variability of simulated reflectivity about a 20 x 20km domain is significant and is related to topography
- Large improvement of observation minus simulated reflectivity through an optimal selection of the background profile
- Optimal profile will be used to initialize 1DVAR retrievals of T,Q and LWC from cloud radar and microwave radiometer synergy.

Next Steps: SOFOG3D field campaign

- South-West France Winter 2019/20
- In-situ and remote instruments
- AROME run with 500m resolution
- Supersite instrumental base

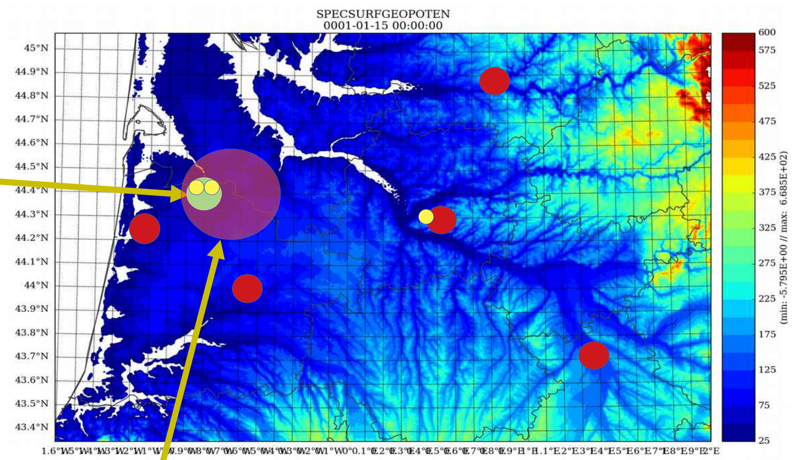
HATPRO Microwave Radiometer

BASTA 95 GHz cloud radar

UAV

Ceilometer

Super Site



Enhanced Radiometer Network

Radiometer Locations

BASTA locations

Tethered balloon with **Cloud Droplet Sensor**

Tower for cloud microphysical measurements, humidity sensors, visibility monitors...

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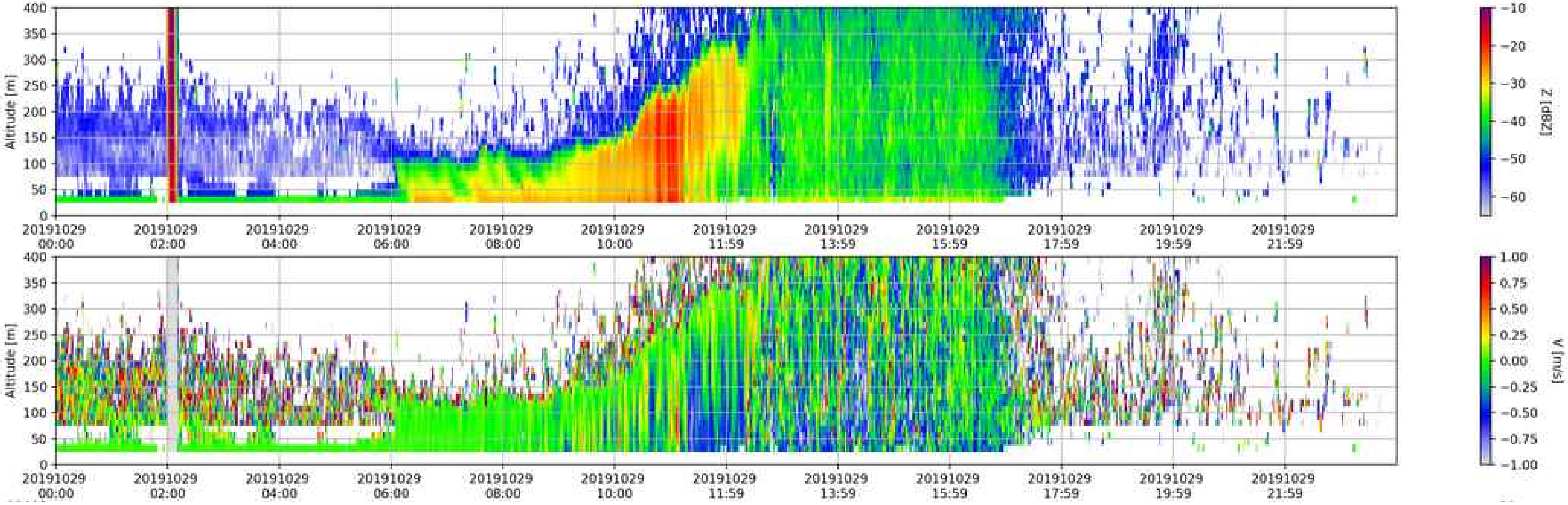
Thank you for your attention!

Radar Reflectivity from BASTA on 29/10/2019 at SOFOG3D field campaign



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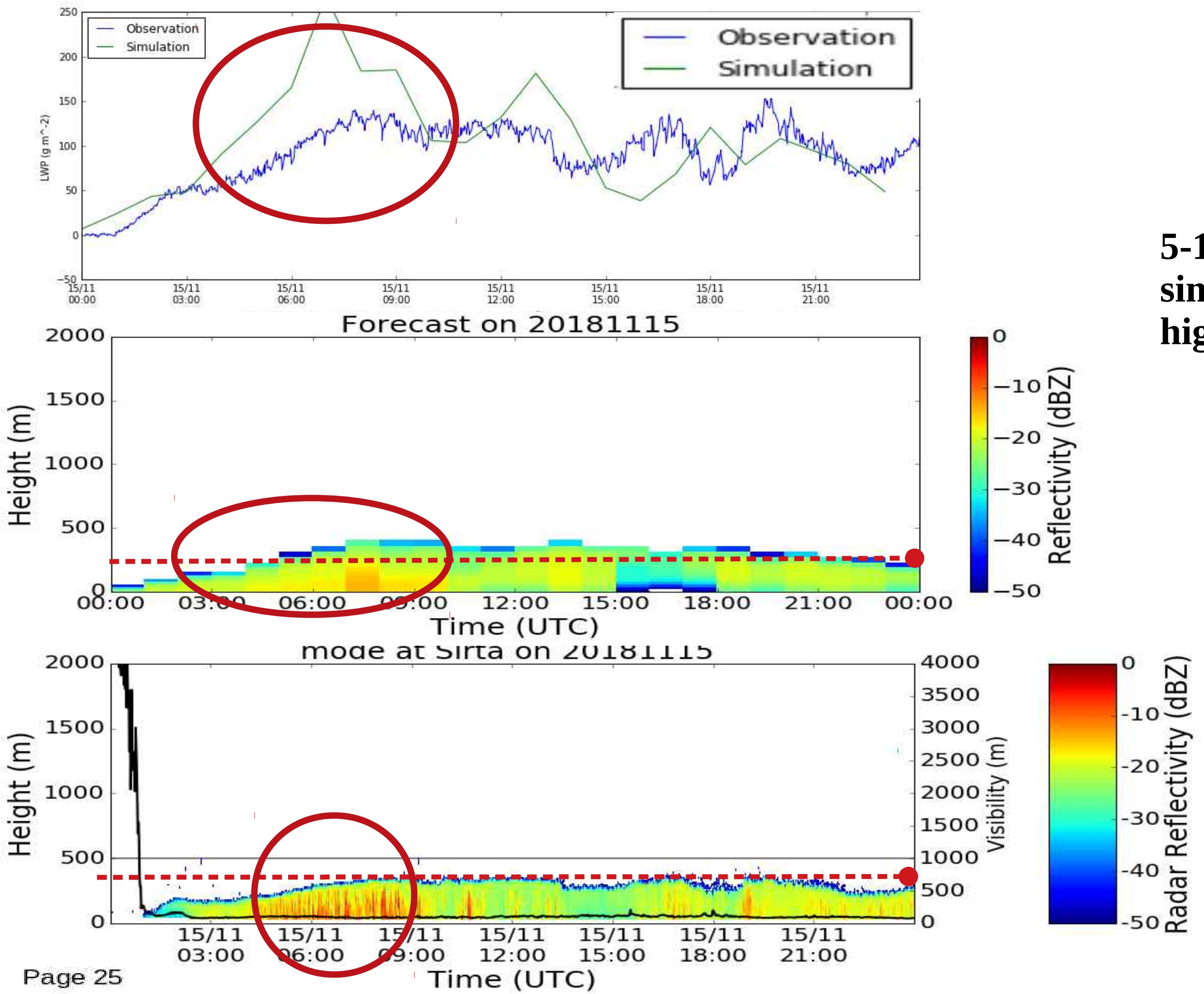
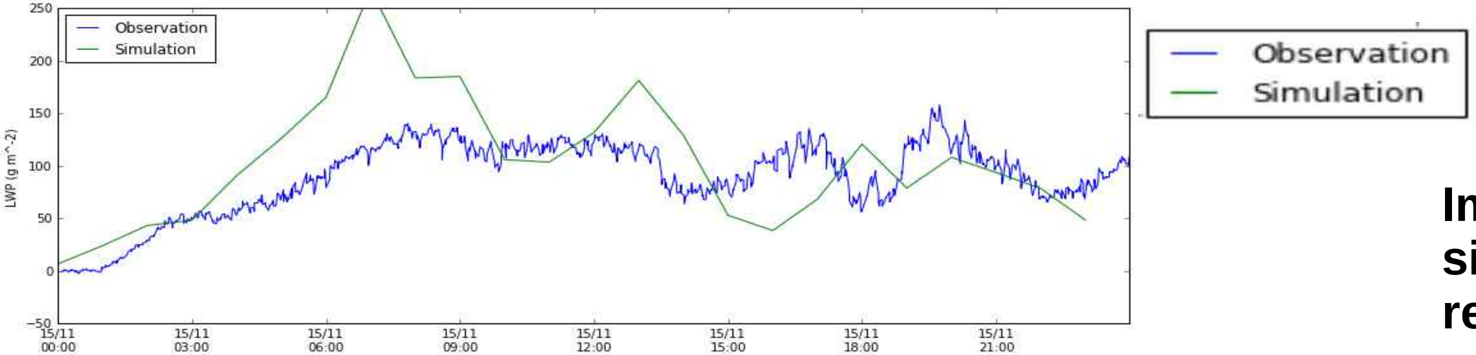
Constraining by LWP ?

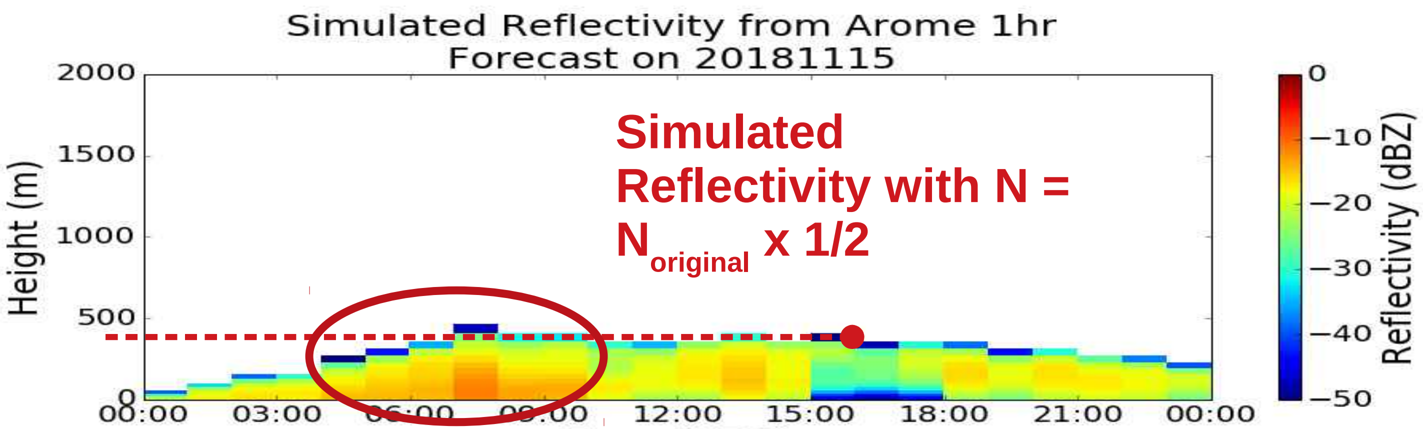
LWP from Hatpro and AROME model

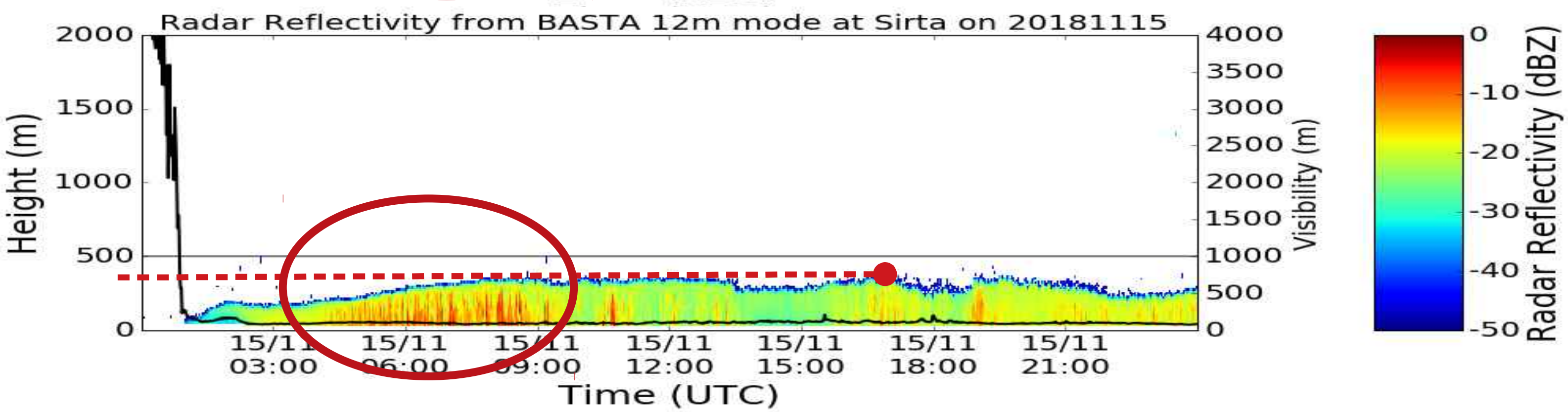


5-10 dB less reflectivity in simulation, even though LWP higher in AROME

LWP from Hatpro and AROME model







Improvement in simulated reflectivity by reducing number concentration by half