Harnessing machine learning and deep learning methods to forecast whitecap fraction and sea-salt aerosol emissions in the ECMWF Integrated Forecast System (IFS-COMPO)

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Sharing is encouraged

1 Introduction and Motivations

Whitecaps are a major source of sea-salt aerosols and primarily occur when waves break or collide. Estimating the amount of aerosols they produce is particularly important for forecasting cloud formation and correcting satellite observations. Currently, the whitecap fraction is estimated using polynomial fits from remote sensing satellite acquisitions. This study aims to compare such traditional models with machine learning approaches providing a benchmark, and as a second step, a machine learning approach is integrated into the global IFS-COMPO model.

2 Data and Models

The current status of sea-salt aerosol emissions in cycle 49R1 IFS-COMPO is:

- The whitecap fraction (WF) is estimated by the Albert et al. (A16) [1] parameterisation: $WF = a(SST)[WSP+b(SST)]^2$
- Sea-salt aerosol emissions are derived using the Gong (2003) assumed size distribution

Ground truth : Whitecap fraction at 10.7 and 37 GHz derived from remote sensing (WindSat) [2]

Predictors : 8 predictors collected

From ERA5 :

- Wind Speed (WSP)
- Wind Direction
- Sea Surface Temperature (SST)
- Mean Wave Period
- Significant Wave Height

From HINDCAST :

- Total Wave Height
- Significant Wave Height
- Dissipation of turbulent energy from breaking waves

Time range : 2 years of data with an hourly resolution

Dimension : around 200 millions pixels

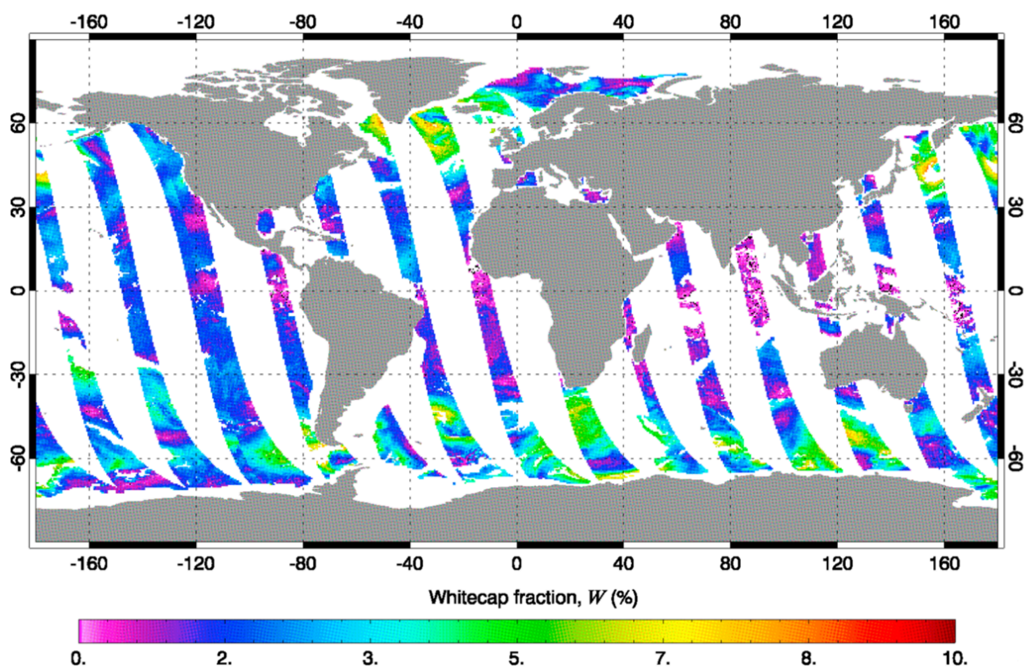

Figure 1 : Example of daily map of whitecap fraction from Windsat acquisition [2]

3 Offline Results

The following results have been obtained over 6 months of offline simulated whitecap fraction:

Main comments:

- Models of literatures (Monahan 80 (M80) [3], Albert 16) show a low bias as compared to our dataset at 37 GHz
- Deep Neural Network (DNN) and FMI parametrisation performances are close with slightly better performance for DNN model
- Models are mainly dependent on wind speed and perform less well for latitudes close to 0 (low wind speed)
- No dependency on SST found with respect to our dataset

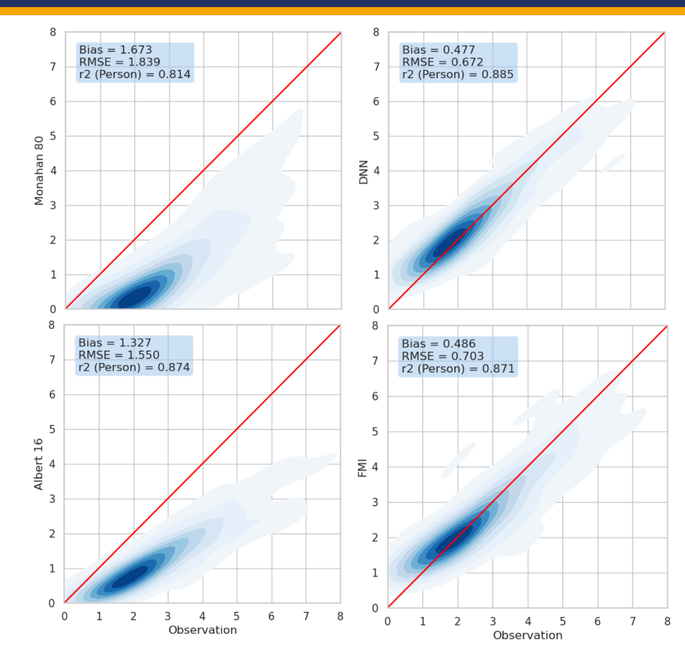

Figure 2 : Observation according to models predictions

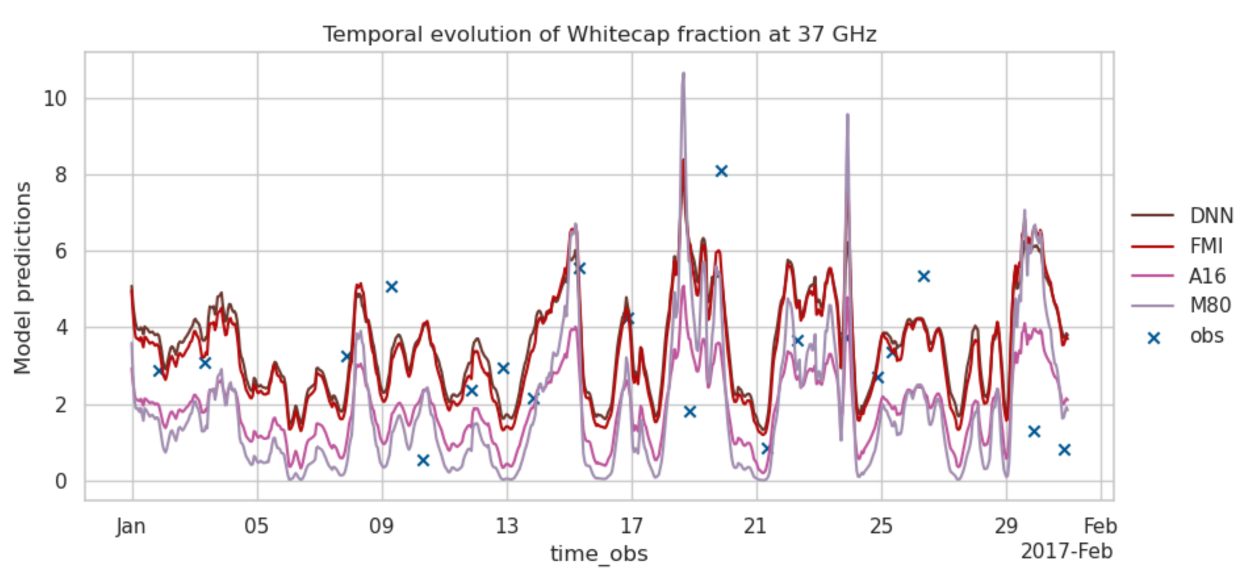

Figure 3 : Time series of Whitecap Fraction of several models over 1 month (January 2017) on a single pixel (30,-50)

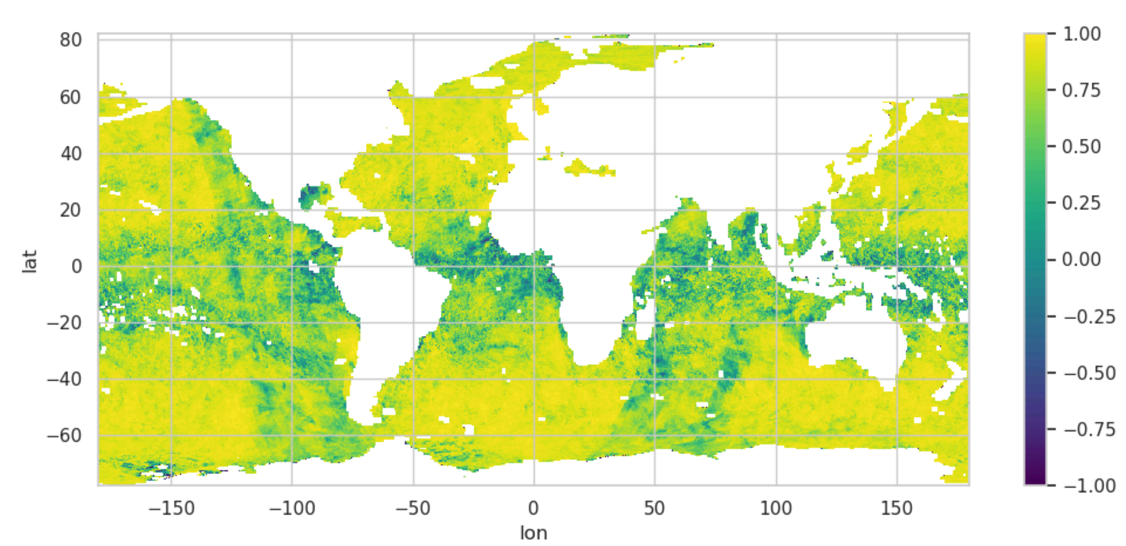

Figure 4 : Correlation map on WF between our Deep Learning model and our ground truth over 1 month (January 2017)

4 Integration in IFS-COMPO

Objectives : Incorporation of a reduced version of the DNN with only 5 predictors from ERA5 to make an initial estimate of its impact on the skill of simulated AOD over oceanic surfaces

How ? The INFERO library [4] has been integrated into IFS-COMPO to interface with Deep Learning models

Interest : runs a learning model in ONNX format from a Fortran script

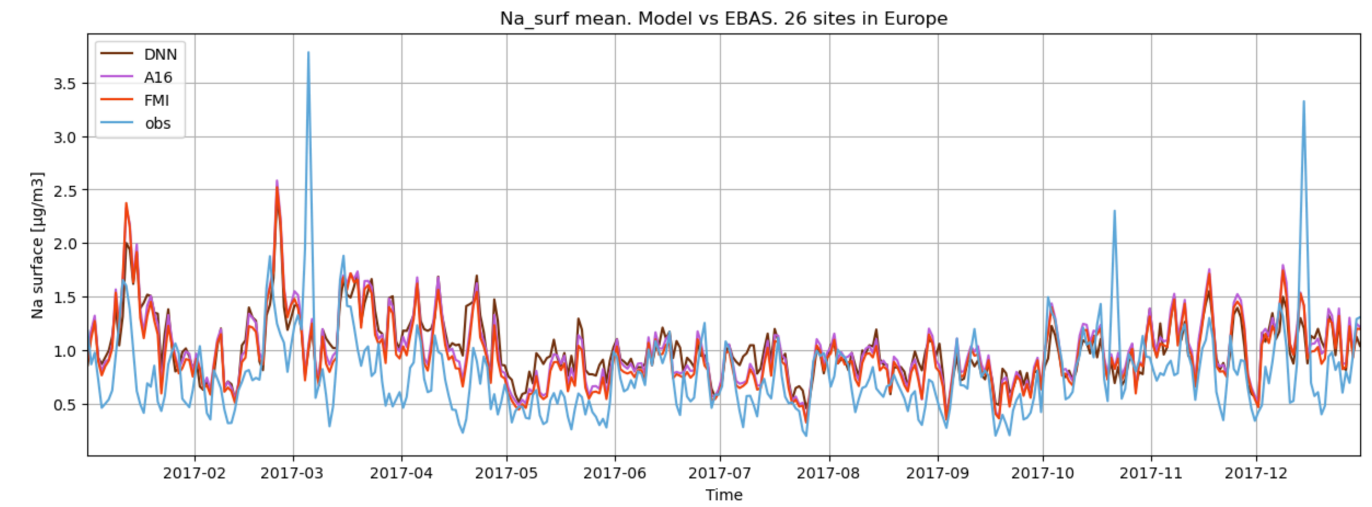

Figure 5 : Retrieved Na volume at surface with A16, FMI parametrisation and our Deep Learning model compared to EBAS observation

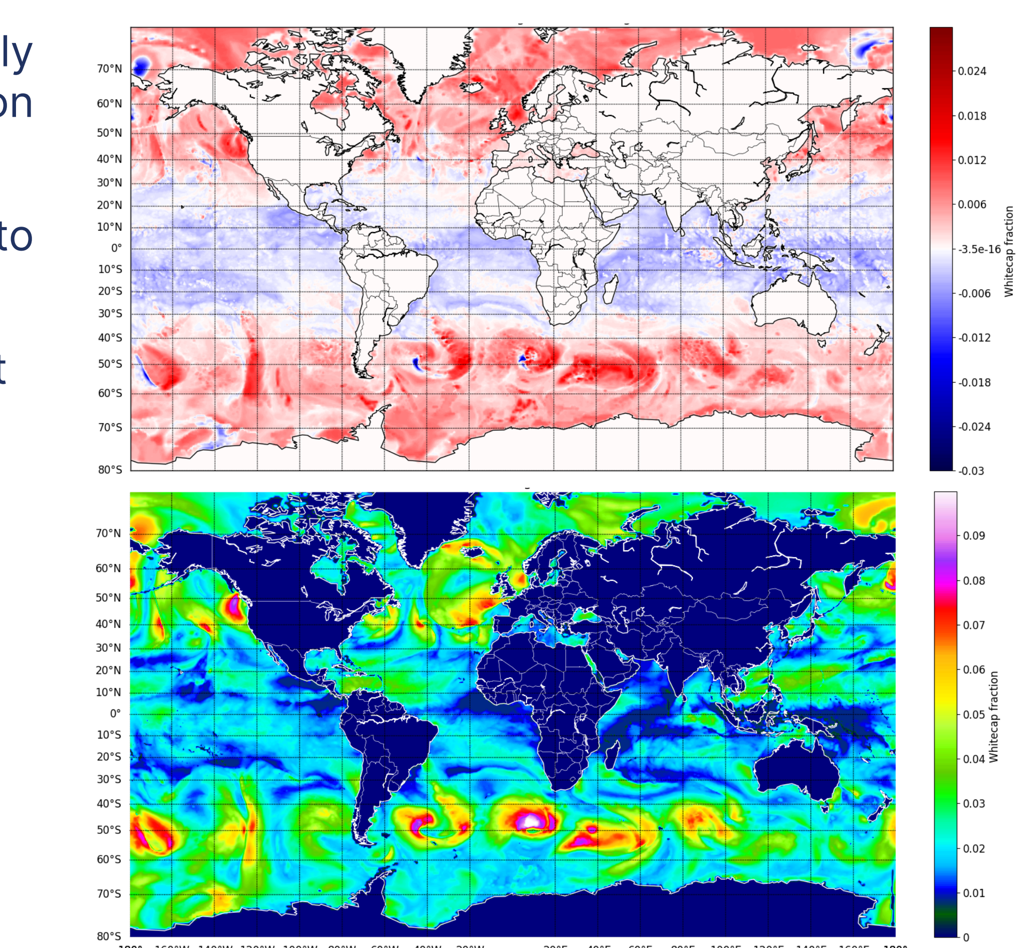

Figure 6 : Simulated whitecap fraction by IFS-COMPO using our deep learning model (bottom) and the difference with FMI scheme (top).

5 References

[1] Albert, M.F.; Anguelova, M.D.; Manders, A.; Schaap, M.; de Leeuw, G. Parameterization of Oceanic Whitecap Fraction Based on Satellite Observations. Atmos. Chem. Phys. 2016

[2] Anguelova, M. D., & Bettenhausen, M. H. (2019). Whitecap fraction from satellite measurements: Algorithm description. Journal of Geophysical Research: Oceans, 124, 1827–1857. https://doi.org/10.1029/2018JC014630

[3] Monahan, E.C.; Fairall, C.W.; Davidson, K.L.; Boyle, P.J. Observed Inter-Relations between 10m Winds, Ocean Whitecaps and Marine Aerosols. Q. J. R. Meteorol. Soc. 1983

[4] Bonanni, A.; Hawkes, J.; Quintino, T. - INFERO library. https://infero.readthedocs.io/en/latest/

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