Tropical Atlantic data buoys in the global observing system:
Impact on global weather forecasts

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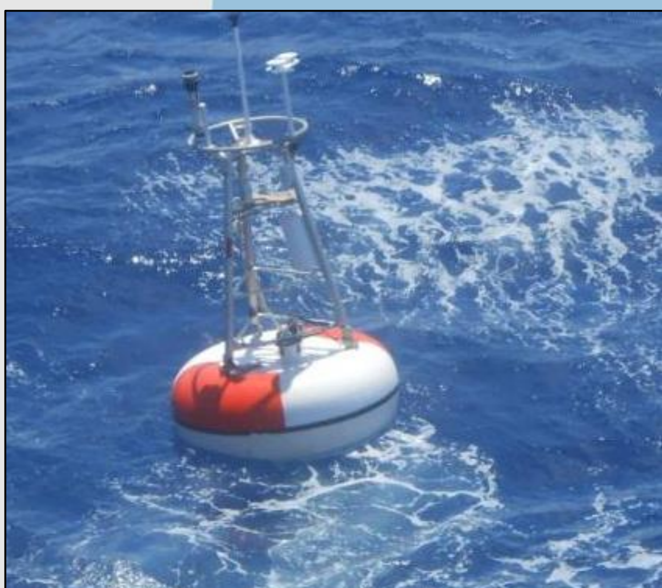
Acknowledgements
Several contributions named in this talk

22-24 October 2018
Marseille, France

Data buoys



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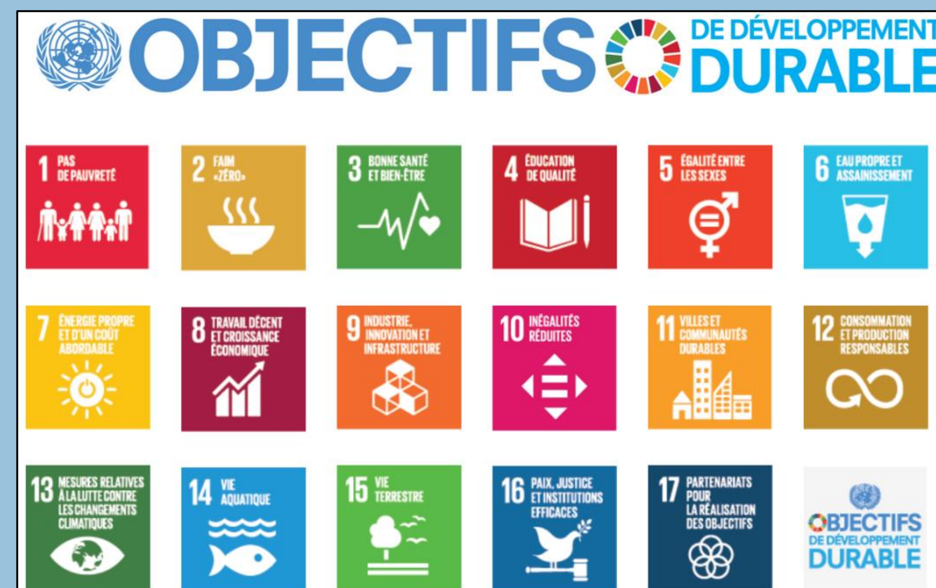
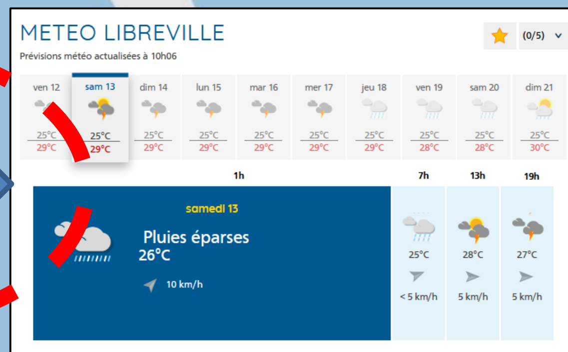
United Nations Sustainable Development Goals



Data buoys

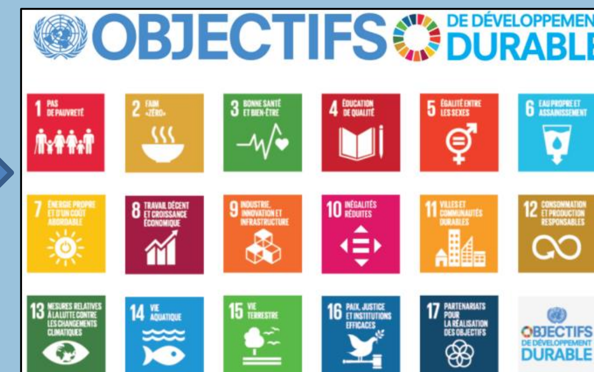
?

Weather Forecasts



Socio-economic studies estimating value

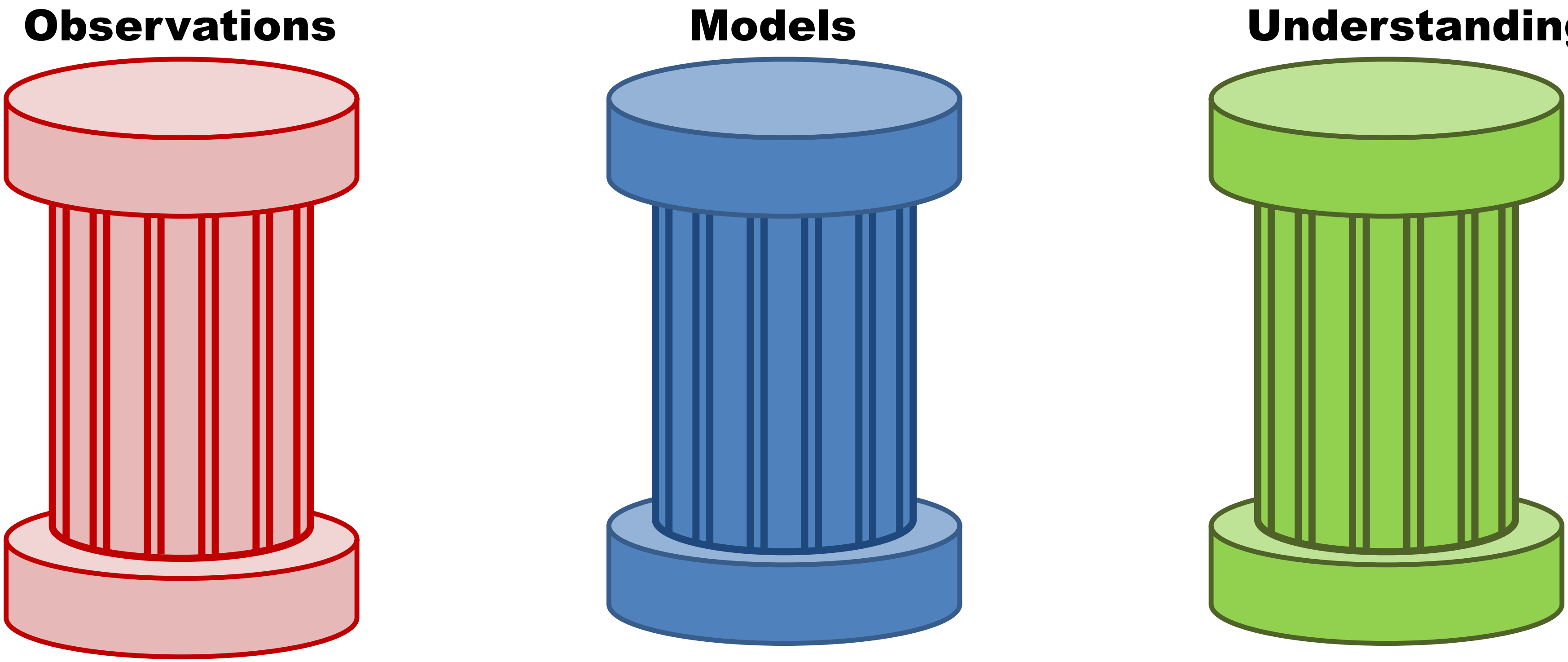
UN SDGs



Climate services

The 3 pillars of geosciences

Concept inspired by Prof. Ulbrich (Freie U. Berlin)



Observations

- At precise time and location (L0, L1)
- In physical space (L2)
- Averages (L3, L4 products)

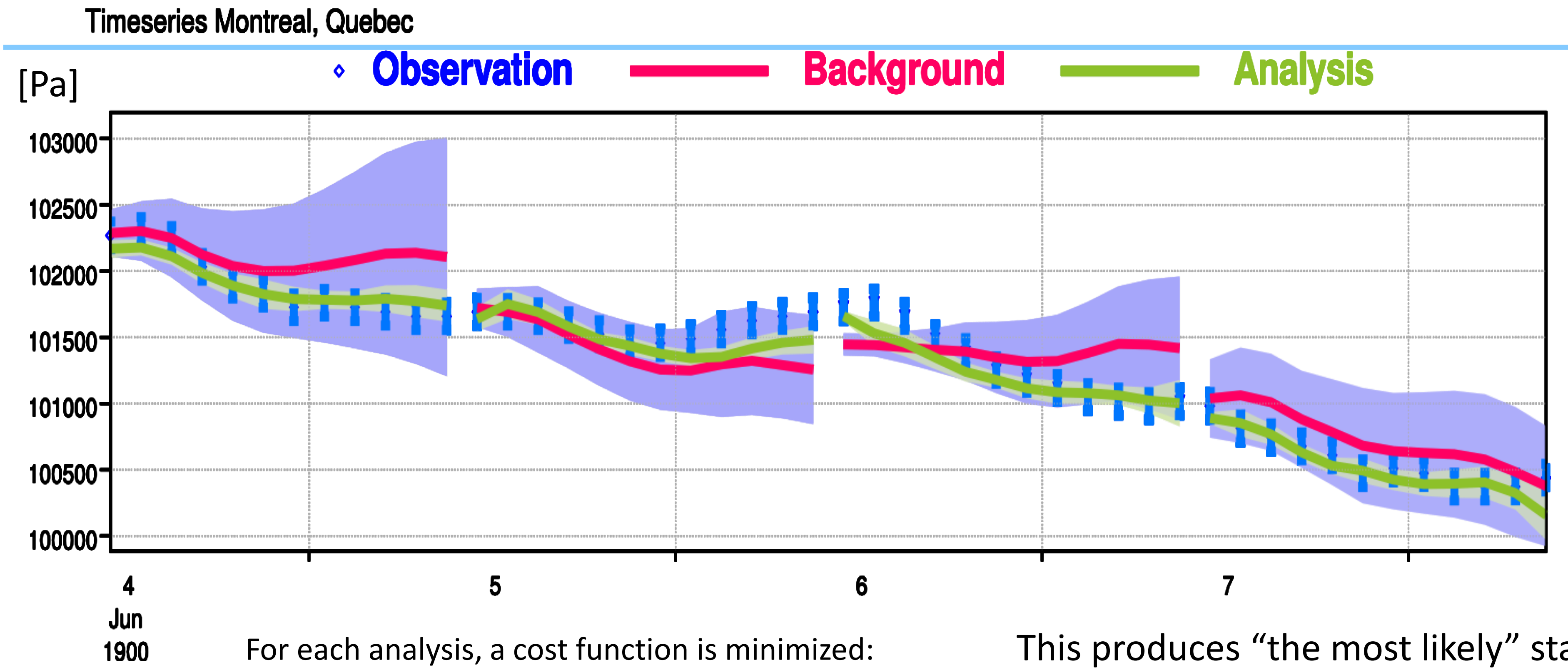
Models

- Physical
- Statistical

Understanding

- Natural variability
- Natural predictability
- Uncertainties in observations
- Uncertainties in models

State Estimation: Example with ensemble of four-dimensional variational (4D-Var) data assimilation



For each analysis, a cost function is minimized:

Background constraint

$$J(x) = (x_b - x)^T B^{-1} (x_b - x) +$$

$$[y - h(x)]^T R^{-1} [y - h(x)]$$

Observation constraint

$$h(x) = h[M(x)]$$

h: Observation operator

Météo-France

This produces "the most likely" state *

* Under the sense of maximum likelihood, which is equivalent to the cost function minimum (sum of variances), provided that background and observation errors are properly specified, centered on zero, non-correlated between each other, and the model errors are negligible during the few hours of integration.

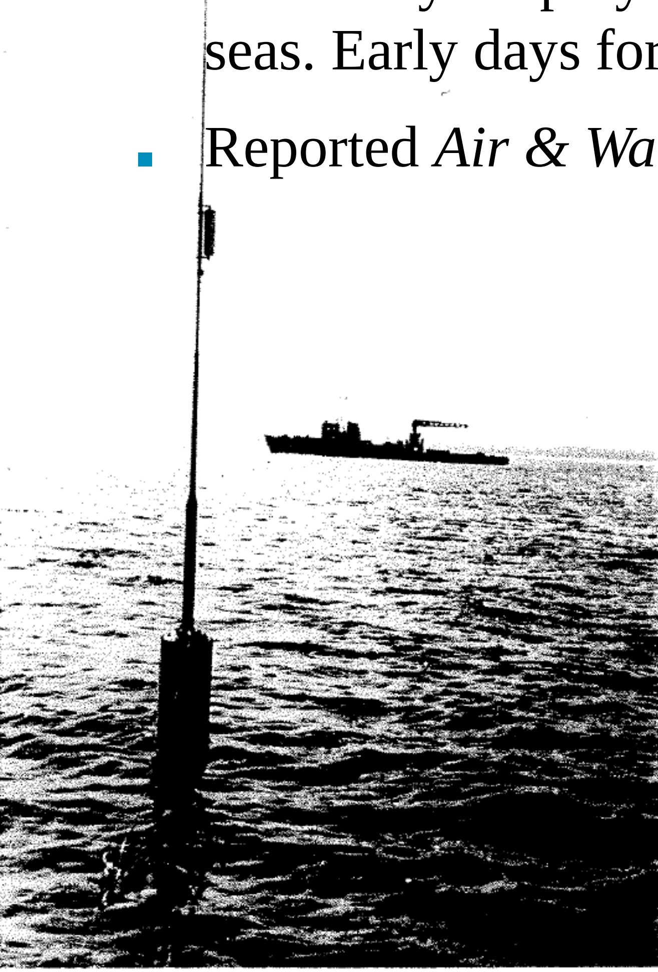
Tropical Atlantic Buoys in the Global Observing System

Outline

1. Data buoys
2. The Global Observing System
3. Numerical Weather Prediction
4. Methodology to assess observation impact in NWP
5. Results
6. Conclusions and future prospects

Data buoys: early days in the Atlantic

- Data buoys deployed by WWII submarines to observe weather in the high seas. Early days for automatic weather stations.
- Reported *Air & Water Temperatures*, and *Air Pressure*, 4 times/day

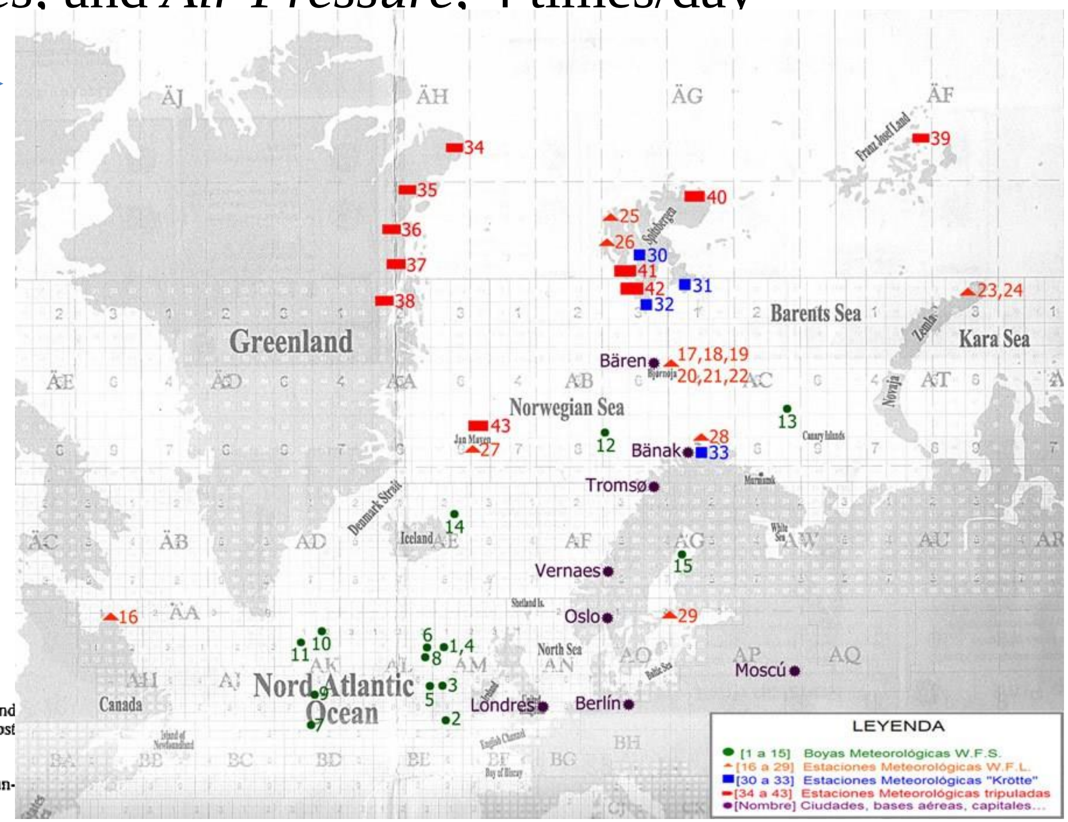


Credits to Dani J.Åkerberg (U-Historia 2006), *La meteorología en la guerra submarina*, https://mundialino.wordpress.com/2015/03/20/la-meteorologia-en-la-guerra-submarina/

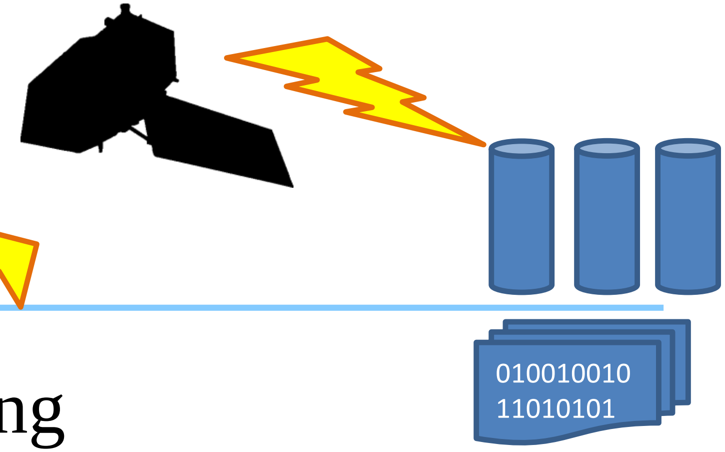
Credits to Franz Selinger, *Deutsche automatische Wetterstationen in der Arktis 1942-1945*, Polarforschung **55** (1): 55-67, 1985.

Abb. 4: Wetterboje W. F. S. schwimmend nach dem Aussetzen in der Ostsee im Herbst 1941.

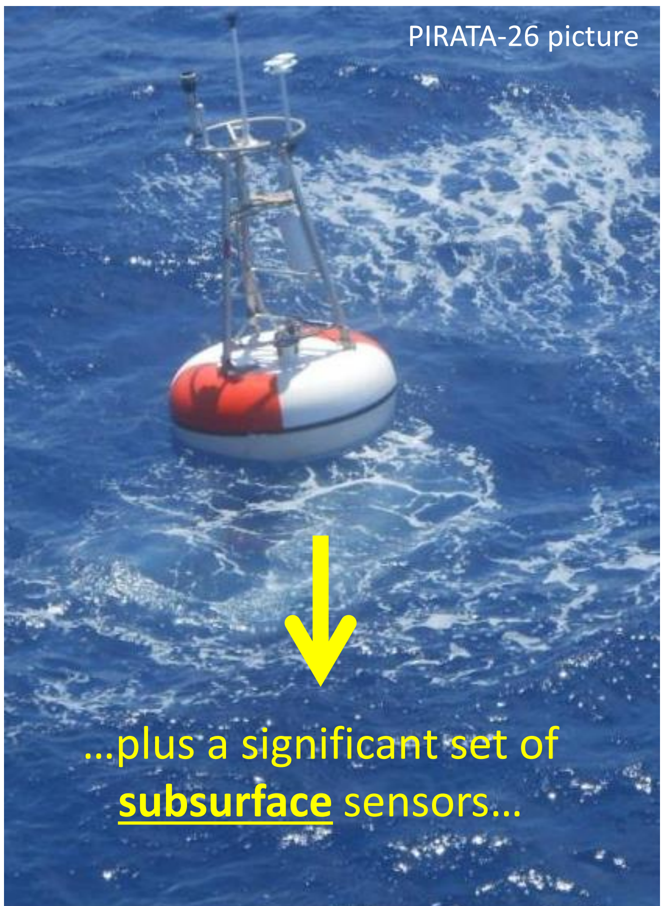
Fig. 4: Waether buoy floating after launching in the Baltic Sea in the fall 1941.



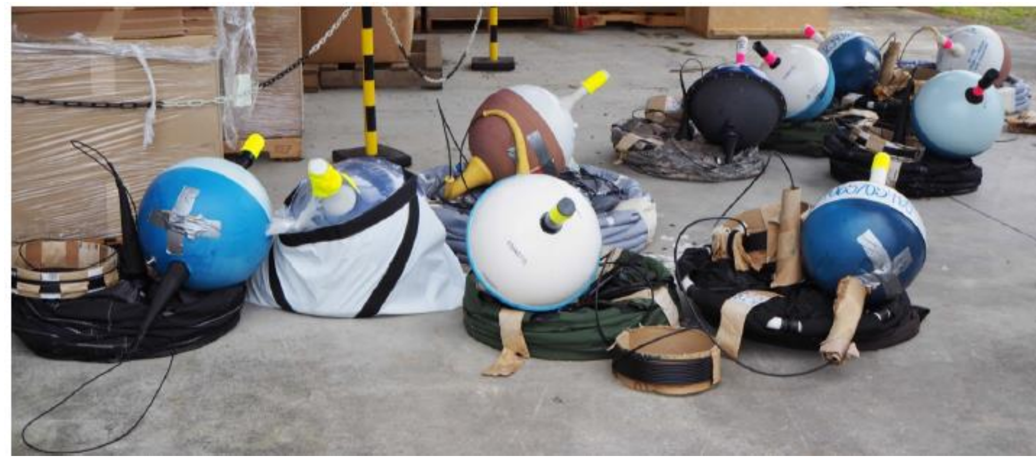
Data Buoys in the Oceans Today



- Moored



- Drifting

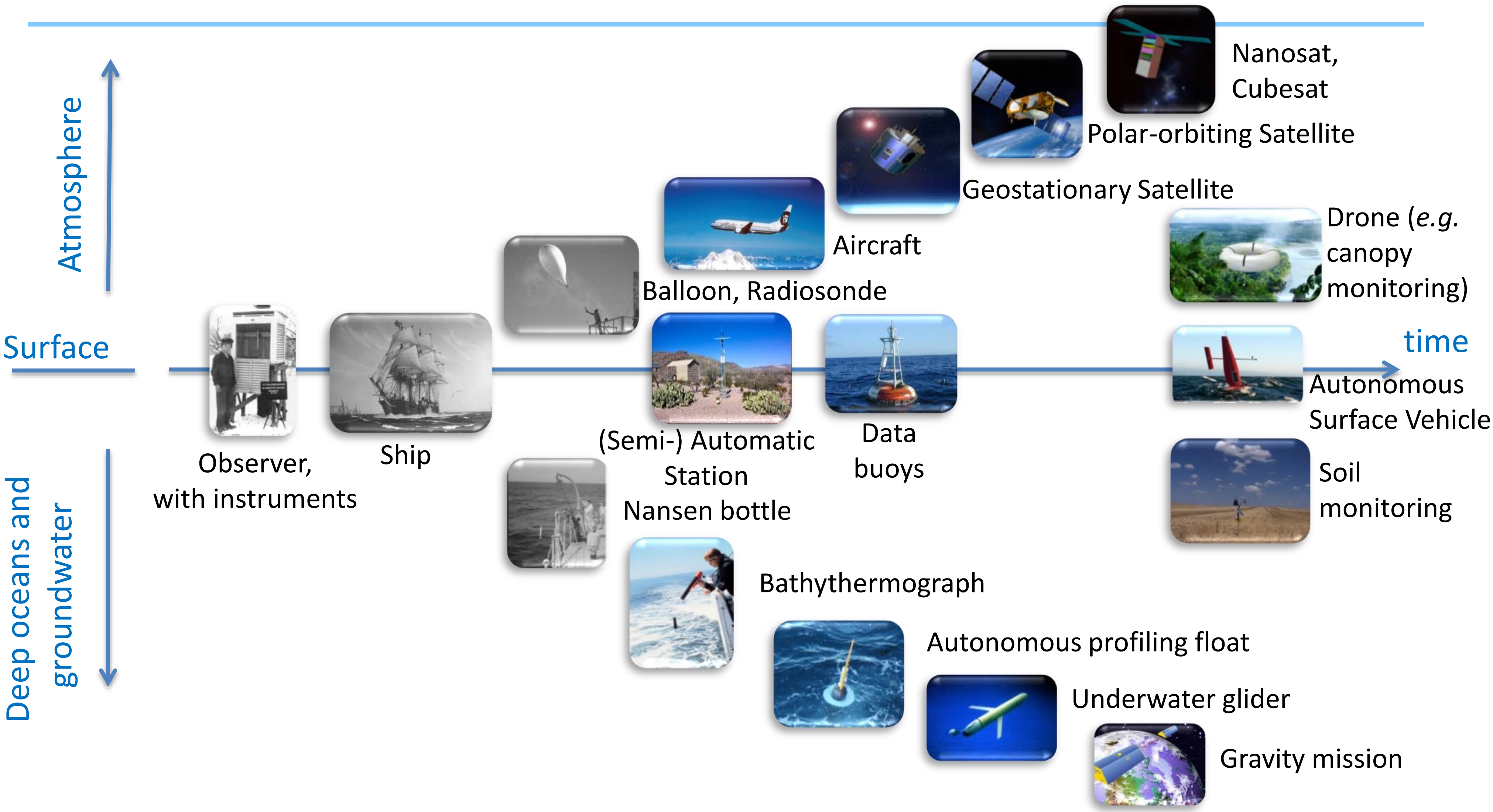


Variety of models… Usually all reporting **hourly**: *Position*, *water temperature*, and *air pressure.* Surface Velocity Platform with Barometer = SVP-B

Several trials with bathythermic strings, but these were found to impair the drift characteristics(*)

(*) Development of bathythermic string drifters, Rousselot et al., 2017, AtlantOS deliverable D3.5

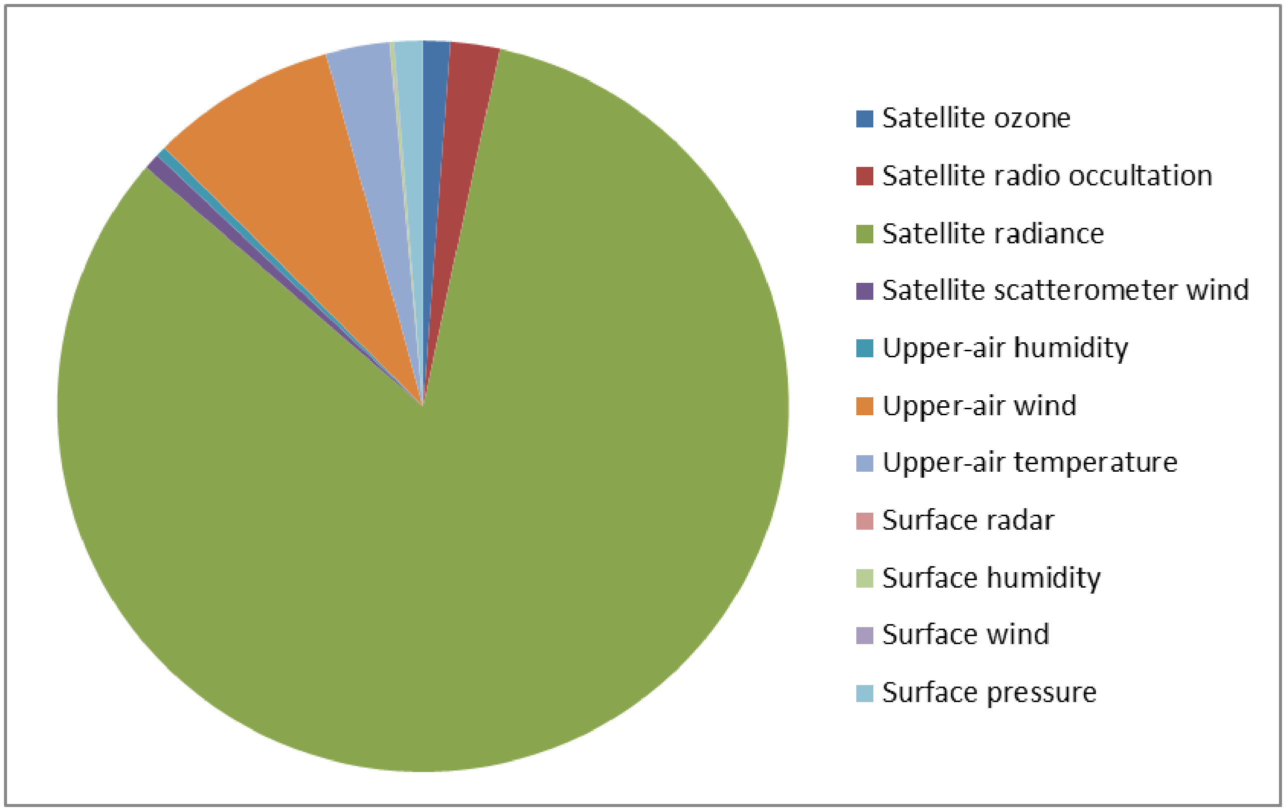
The Global Observing System



Numerical Weather Prediction (NWP) systems

- So far *generally* uncoupled
  - — atmospheric model and data assimilation
  - — initial conditions (for start-up), plus forcing conditions:
    - ► e.g. aerosol loading, if not explicitely analyzed or evolving
    - ► For the sea-surface: temperature, sea-ice cover, …
    - ► For the land-surface: ground water content, land-use, …
  - — State-of-the-art global NWP
    - ► Model and data assimilation coupled with ocean (+waves)
- Reanalyses (ERA-Interim, JRA-55, MERRA-2, CFSR, …)
  - — Based approximately on the same methods as NWP
  - — Follow/Lead approximately the same developments

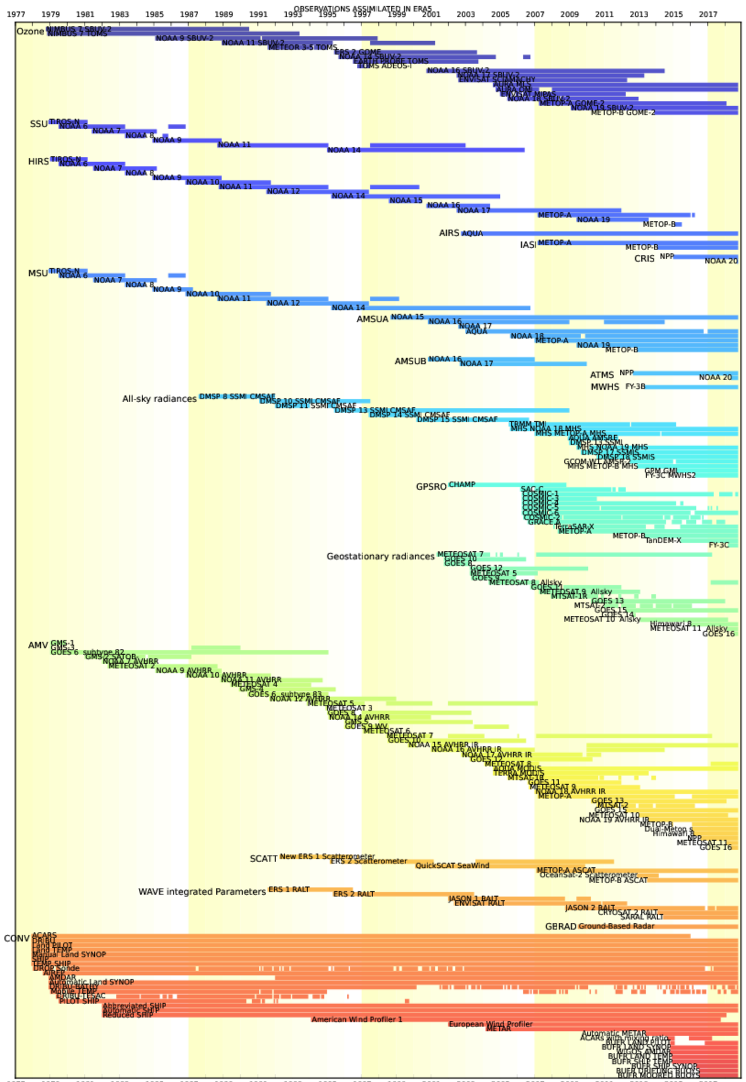
Sources of observations assimilated by ECMWF operational Integrated Forecasting System (IFS)



Numbers of observations assimilated, May 2015-April 2018

Timeline of observations assimilated in ERA5

1979 2018



Satelllite ozone retrievals

Satellite infrared sounders

Satellite microwave sounders

Satellite water vapor and precipitation sounders and imagers

Satellite radio occultation

Satellite infrared radiances from geostationary orbit

Satellite atmospheric motion vectors from imagery

Satellite ocean surface wind (scatterometry) & wave (altimetry)

Ground-based radar

"Conventional" observations: surface stations and observers, ships, buoys, aircraft, radiosondes, wind profilers

How to measure impact in a global weather forecast system?

- "Sanity check"
  Observation Influence

  also known as Analysis Sensitivity to Observation,
  or Degrees of Freedom for Signal

  — Estimate by how much the observations influence the analysis

  ▸ Not an indication of the forecast impact

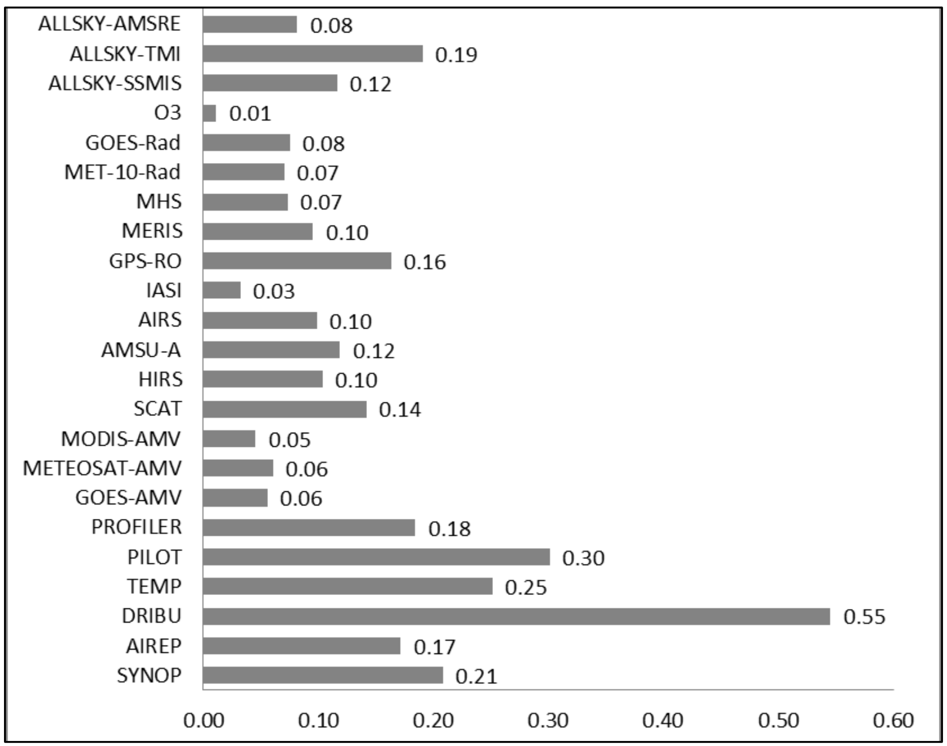
  — Largely dependent on assimilation settings

  ▸ Bearing in mind that incorrect settings will degrade forecasts

Observation Influence results in 2 global systems

ECMWF (IFS)

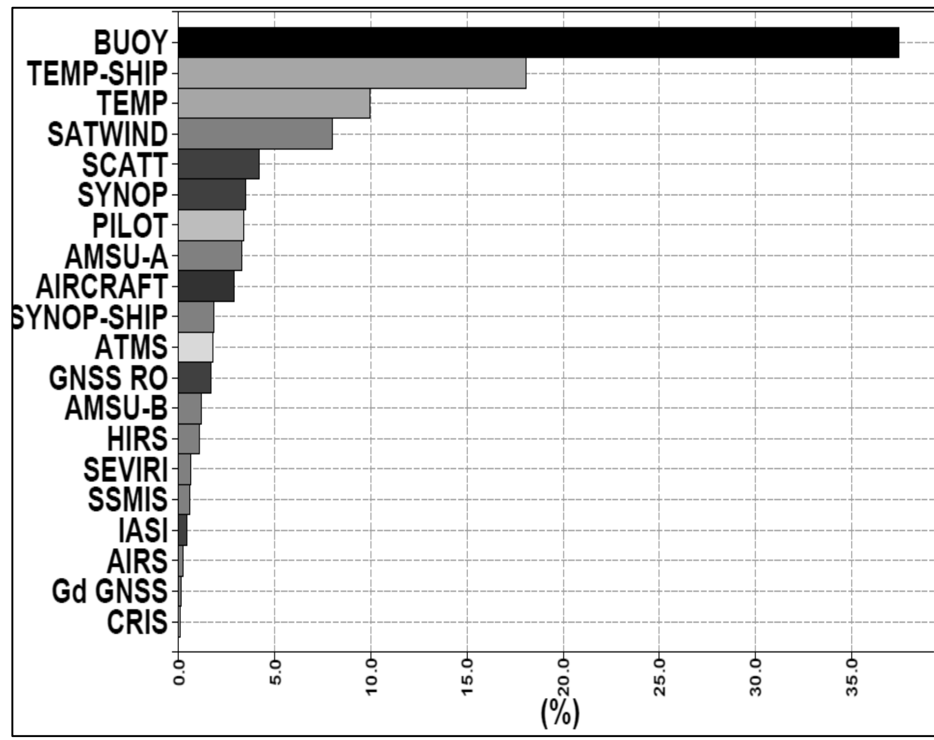
Nov-Dec 2010



Horányi, A. , C. Cardinali, and L. Centurioni, 2017: The global numerical weather prediction impact of mean-sea-level pressure observations from drifting buoys. *Q.J.R. Meteorol. Soc.*, DOI:10.1002/qj.2981.

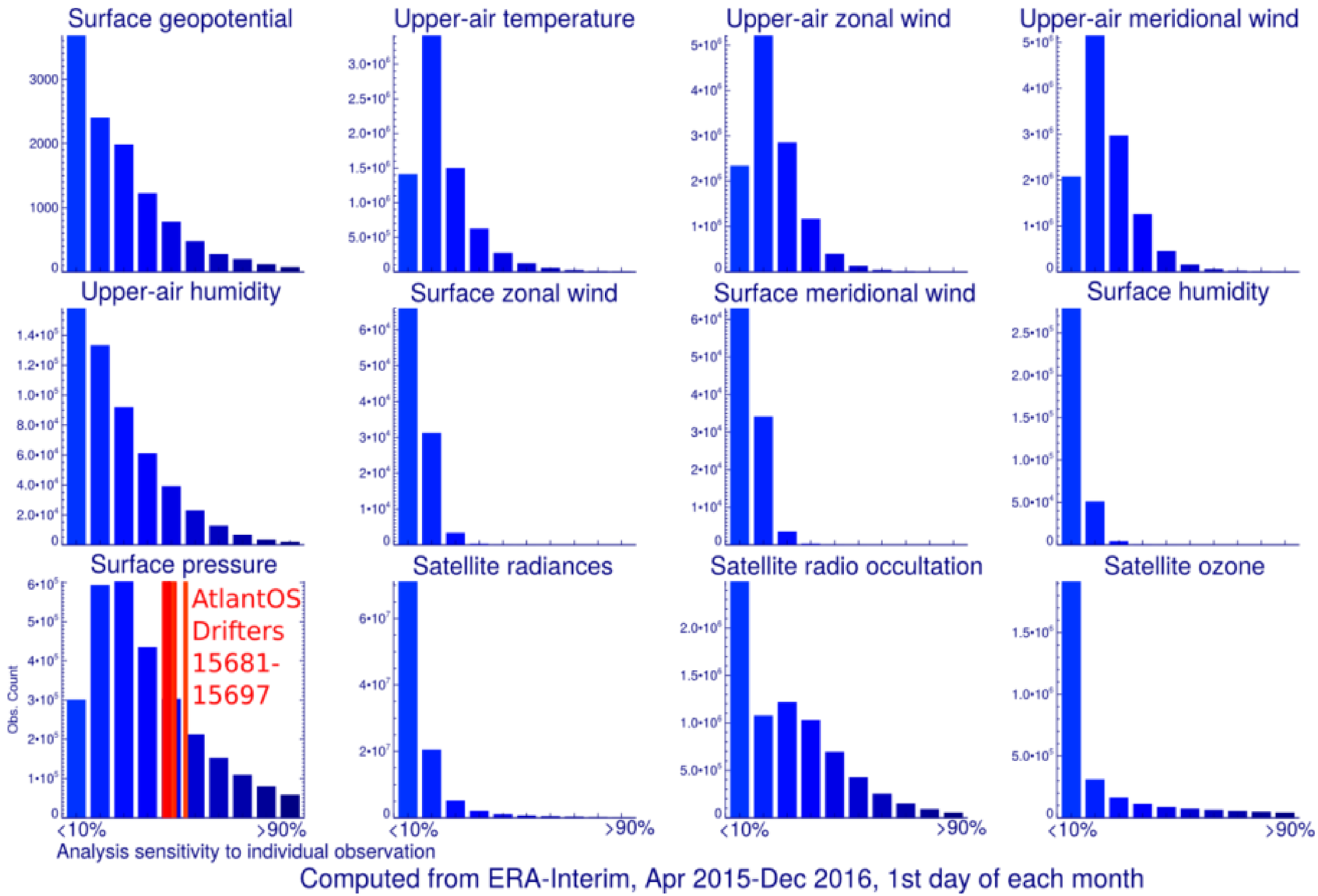
Météo-France (Arpège)

Sep 2013



Doerenbecher, A., J.-F. Mahfouf, N. Boullot, 2014: E-SURFMAR impact study, presented to EUMETNET Observation Programme Scientific Expert Team.

Zoom on the Observation Influence of drifters in the Tropical Atlantic



How to measure *forecast* impact?

- "Invasive method": **OSE**

  Observing System Experiment

  — Withhold observations from data assimilation

  ► Compare *With* -vs- *Without*

  — Reliable results, but:

  — Usually limited in terms of statistical significance

- "Non-invasive method": **FSO**

  Forecast Sensitivity to Observations (*)

  — Result reliability depends on assimilation settings

  ► Requires a priori validation by comparison with OSE

  — Greater statistical significance

  ► Study long time periods

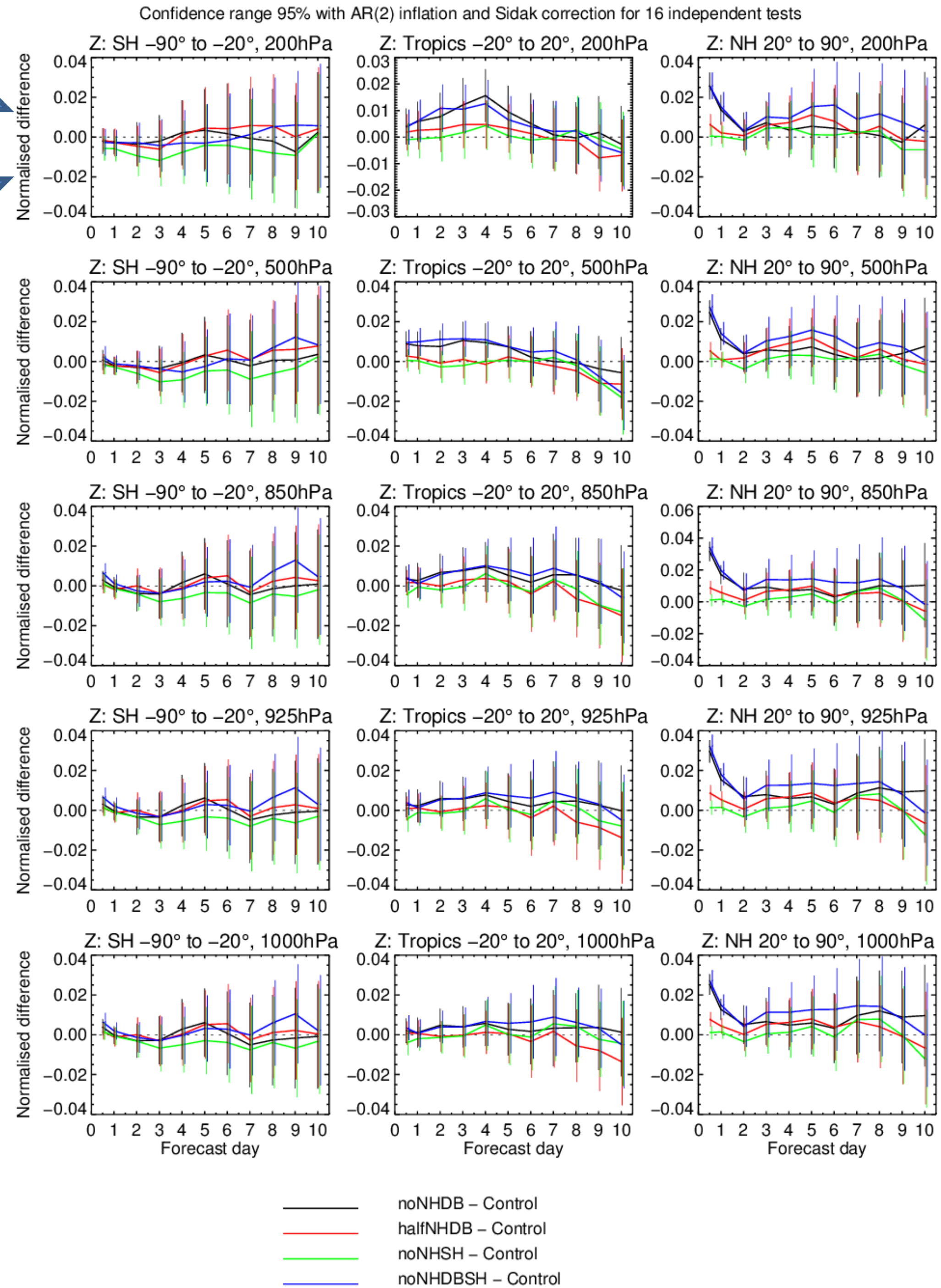
The two are complementary

(*) Cardinali, C., 2009: Monitoring the observation impact on the short-range forecast. *Q. J. Roy. Meteor. Soc.* **135**: 239-250, doi:10.1002/qj.366.

OSE results

Worse

Better



Excerpt from a study by Ingleby and Isaksen: ‘Change in RMS geopotential height verification (against own analysis for the period 2/11/2015-28/2/2016) for all the trials (see colour legend above) relative to the control for three latitude bands and various pressure levels. The vertical bars give a confidence range.’

Impact of withholding NH drifter data

Impact of withholding half of NH drifter data

Impact of withholding NH ship data

Impact of withholding NH drifter and ship data

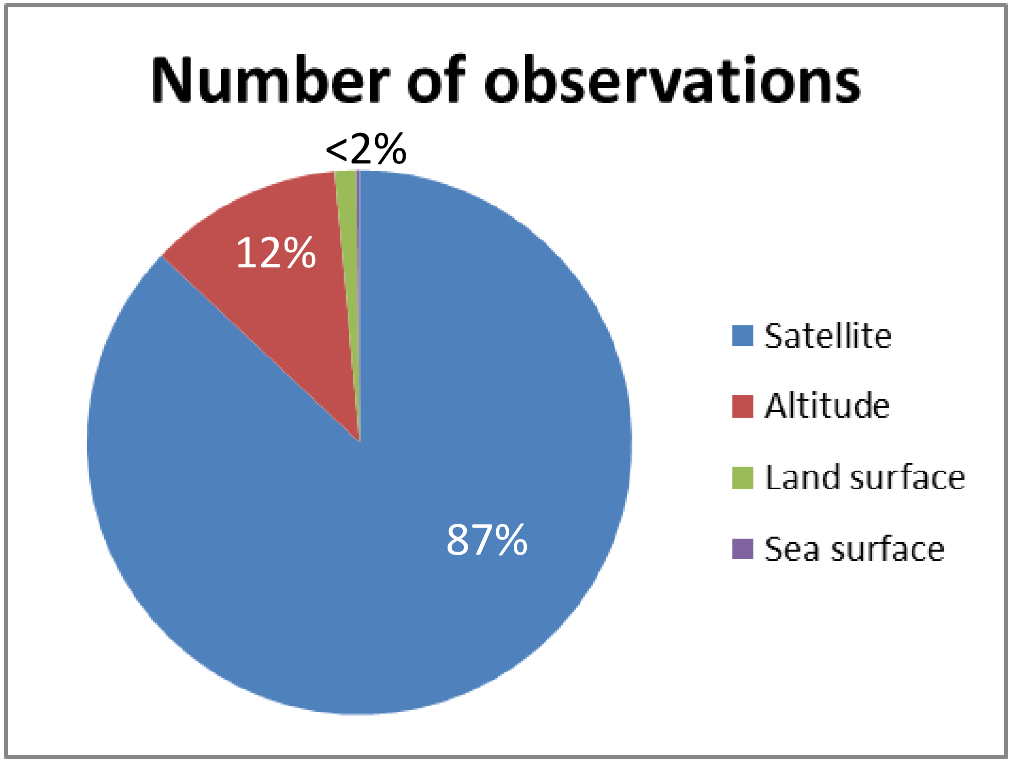
Ingleby B., and L. Isaksen, 2018: Drifting buoy pressures: Impact on NWP. *Atmos Sci Lett.* DOI:10.1002/asl.822

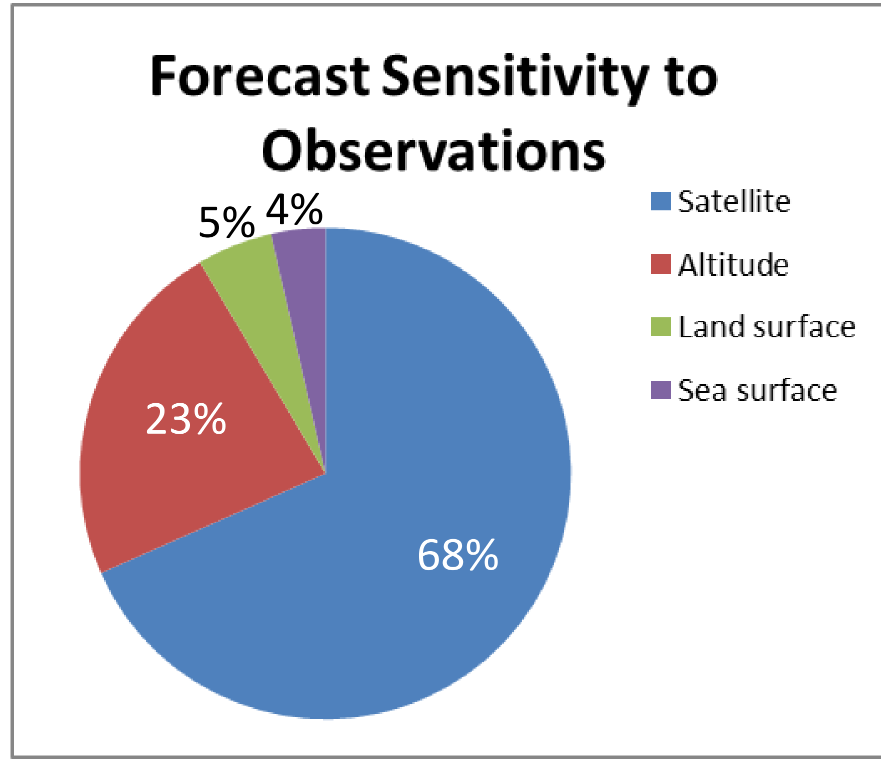
Forecast Sensitivity to Observations

- Measures the reduction in global 24-hour forecast error induced by each assimilated observation: an *adjoint* method.
  - — Error norm is total dry energy (in J)
  - — Computed operationally by ECMWF
- Large sample considered: over 200 assimilation cycles
  - — May 2015 to April 2018 (3 years)
  - — 3 days per month (day nos. 1/10/20)
  - — 2 assimilation cycles per day (00/12 UTC)
    - ► Considering more cycles in between may not add significance, since weather events are highly correlated from one day to the next
- Separate the global observing system in key components:

  Surface marine / Surface land / Upper-air / Satellite

FSO Results

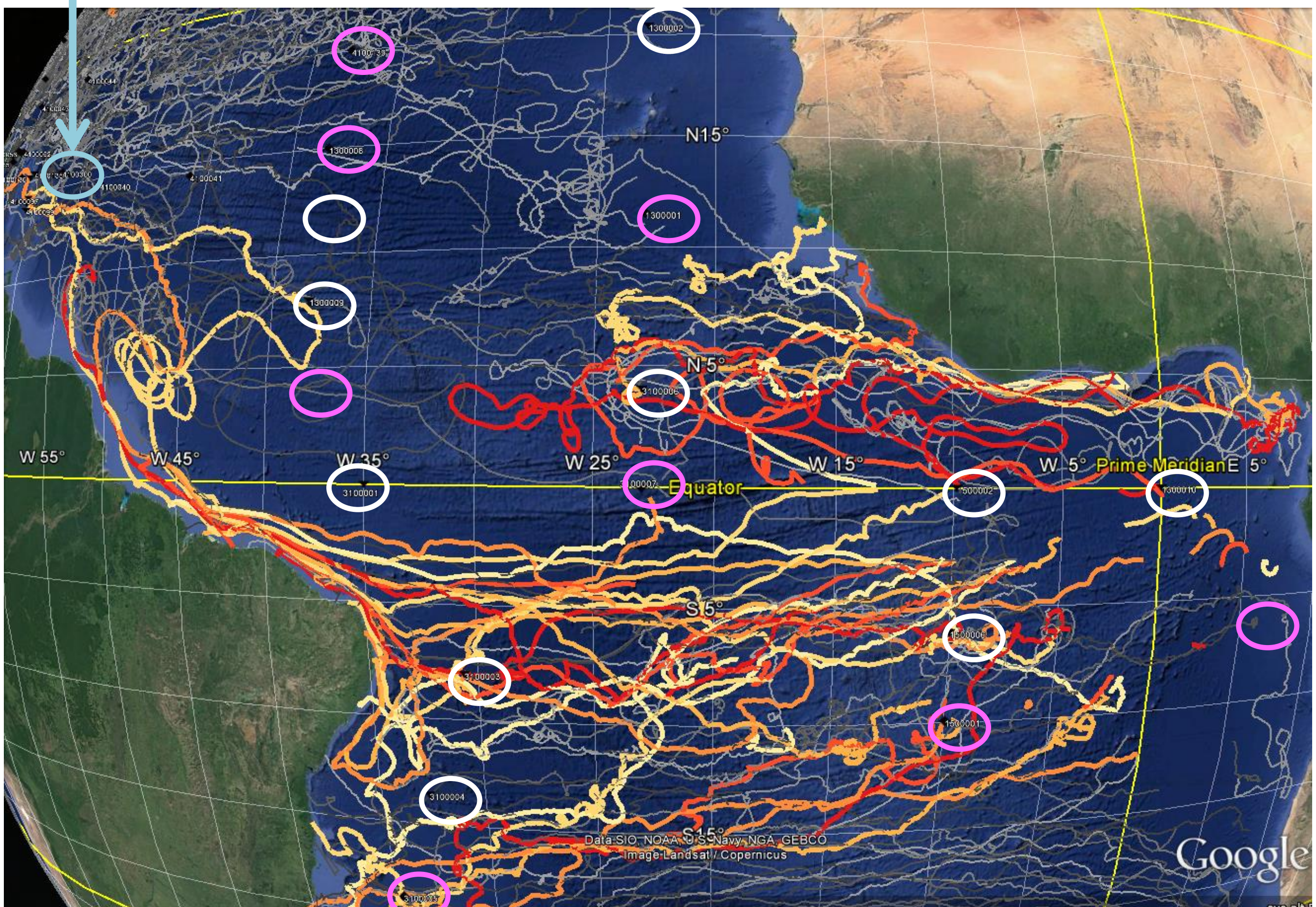




	Impact factor	+/- robust std. dev.
Satellite	0,79	+/- 0,04
Altitude	2,03	+/- 0,24
Land surface	3,97	+/- 1,08
Sea surface	18,75	+/- 6,48

Data Buoys in the Tropical Atlantic

Météo-France "Antilles" moored buoy



1 April 2015 – 31 May 2018

AtlantOS

Trajectories of drifters with functioning barometers

Grey: buoys deployed by programs or projects other than AtlantOS

Many deployments by PIRATA cruises (thanks to B. Bourlès and collaborators) and other partners (such as UK Met Office & CMA-CGM)

Circles: PIRATA moorings (pink: with barometer)

Zoom on the buoy impact, estimated by FSO

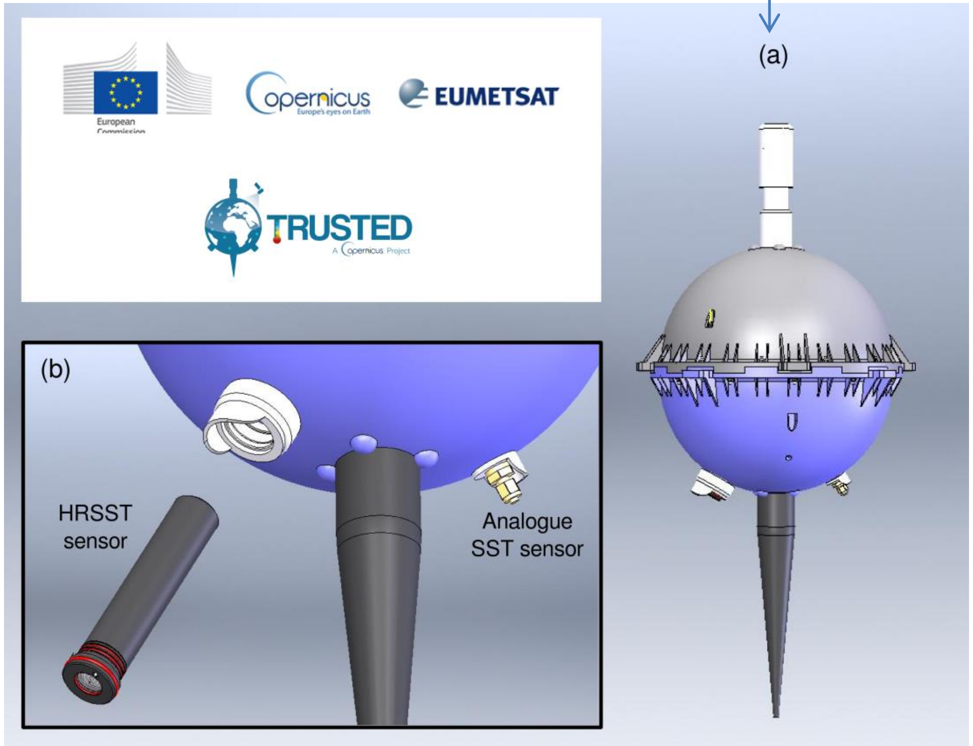
- Two contributions are set apart:
  - AtlantOS-funded drifting buoys in the Tropical Atlantic, reporting surface pressure
    - ► impact factor of **16.0 (± 19.0)**
  - PIRATA moored buoys in the Tropical Atlantic, reporting surface pressure and/or wind
    - ► impact factor of **10.4 (± 17.3)**
      - with greater impact from the surface pressure observations, as compared to the wind observations
- Note: Barometers
  - on AtlantOS-funded drifters: ‘meteorological-grade’
  - on PIRATA moorings: ‘laboratory-grade’

New drifters, towards Fiducial Reference Measurements (FRM) of SST

For cal/val of Copernicus satellite SST

- SST resolution **0,001 °C**
- Expanded calibration uncertainty of the temperature measurement, after integration in the buoy: **0,01 °C**
- Sensor response time: **0,1 s/°C** (to reach 63 % of the response)
- Data measured at 1 Hz over 5 min., processed to extract percentiles (10%, 30%, 50%, 70%, 90%)
  - opens the way to new ensemble applications for satellite cal/val
  - the spread of the ensemble is indicative of the reliability and representativity of 5-min. mean

barometer air intake



holey sock tether, includes strain gauge to detect loss

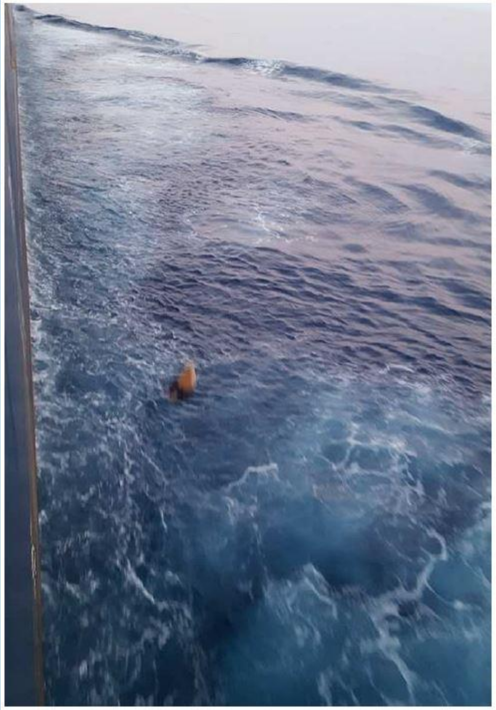
Conclusions

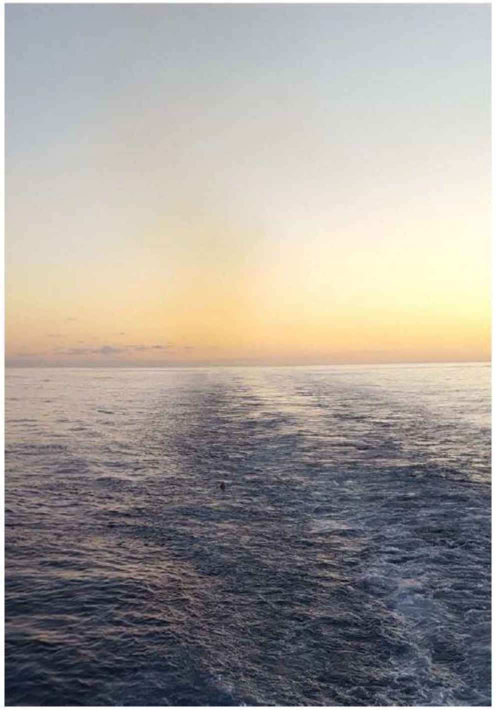
- Data buoys in the Tropical Atlantic
  - Only a small part of the global observing system (in numbers)
  - Yet significant impact on reduction of total 24-h forecast errors

- Continued prospects:
  - Interest in more surface pressure observations
  - Serve developments of coupled prediction systems
  - Reference measurements:
    - For cal/val of satellite products
    - For climate products and reanalyses
  - Convergence of fields: atm / ocean / bio

PIRATA-28

CMA-CGM





Thank you for your attention!

Météo-France

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http://eumetnet.eu/activities/observations-programme/current-activities/e-surfmar/