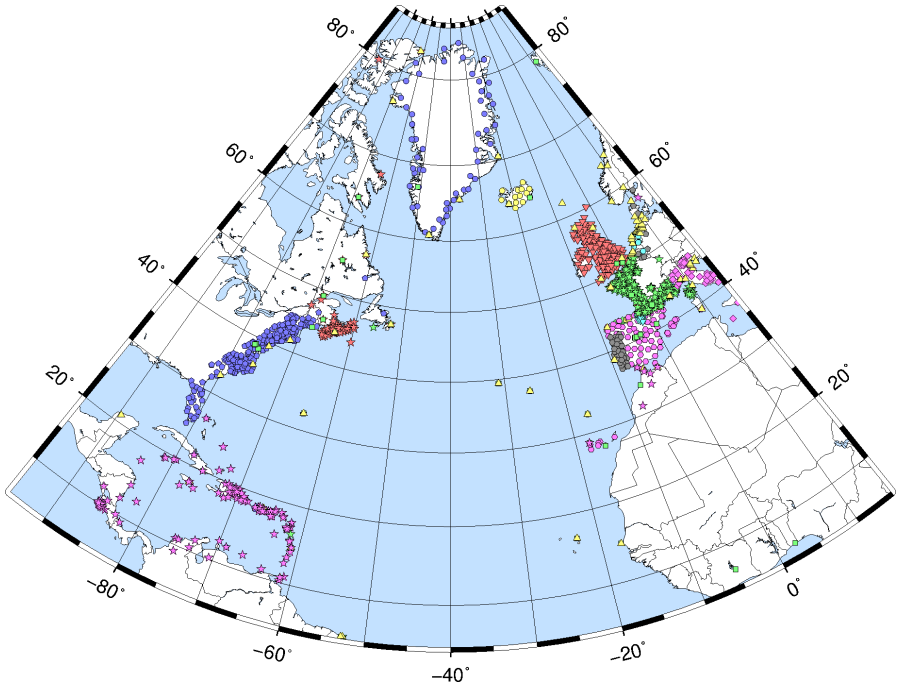



# IWV retrieval from ground and shipborne GPS receivers during NAWDEX

Pierre Bosser[1], Olivier Bock[2] and Nicolas Laurain[3]

[1] ENSTA Bretagne - Lab-STICC, Brest, France

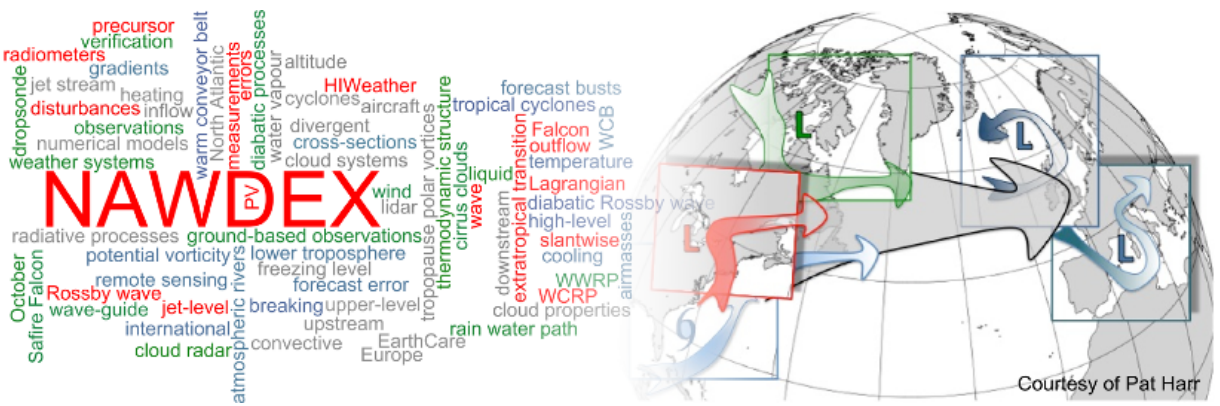
[3] IGN - IPGP, Paris, France

[2] IGN - ENSG, Marne-La-Vallée, France

# Context: NAWDEX campaign

**N**orth **A**tlantic **W**aveguide and **D**ownstream Impact **Ex**periment (NAWDEX) campaign [Sch+18]:

- Objective:
  - Better understanding of diabatic process on the evolution of atmospherics disturbances along the North Atlantic jet stream
  - Better representation of these processes in Numerical Weather Prediction models
- Observational field experiment for 1 month (mid-Sept. to mid-Oct. 2016)
- Deployment of four research aircraft and ground-based instrumentation.
  - ➥ **Use of GNSS CORS to complete this instrumentation.**

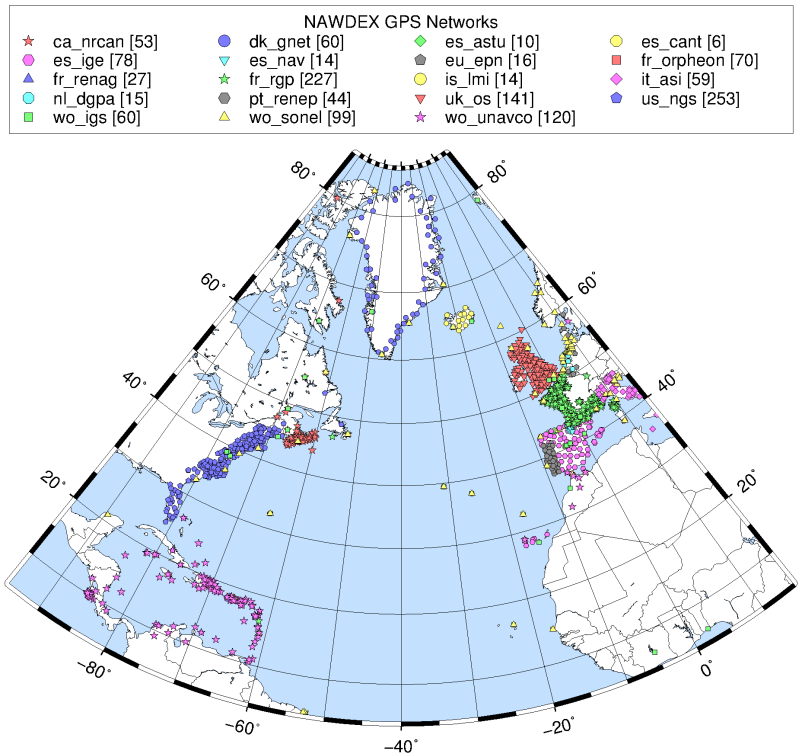


# Outlines

# Outlines

# Network and processing

- Around **1,200 COR stations** along the North Atlantic
- DOY 240 to 310 (August 27 to November 5)
- 19 data providers (free or private).
- GPS processing in PPP_AR mode using Gipsy-Oasis II 6.4




Troposphere modeling:

- Use of VMF1 / VMFgrid for troposphere modeling [Boe+06]
- Random walk process for ZWD (5 mm·h$^{-1/2}$) and horizontal gradients (0.5 mm·h$^{-1/2}$) ; 5 min resolution
- Screening of estimates with rejection rate around 0.3% [Boc+16]

# Outlines

# Methodology

ERAI (6h x 0.75°) and ERA5 (1h x 0.25°): $P_{surf}$ and *IWV* interpolated & extrapolated from grid at GPS antenna height:

- Horizontal: bilinear interpolation
- Vertical: extrapolation [Par+18]

GPS IWV (5min):

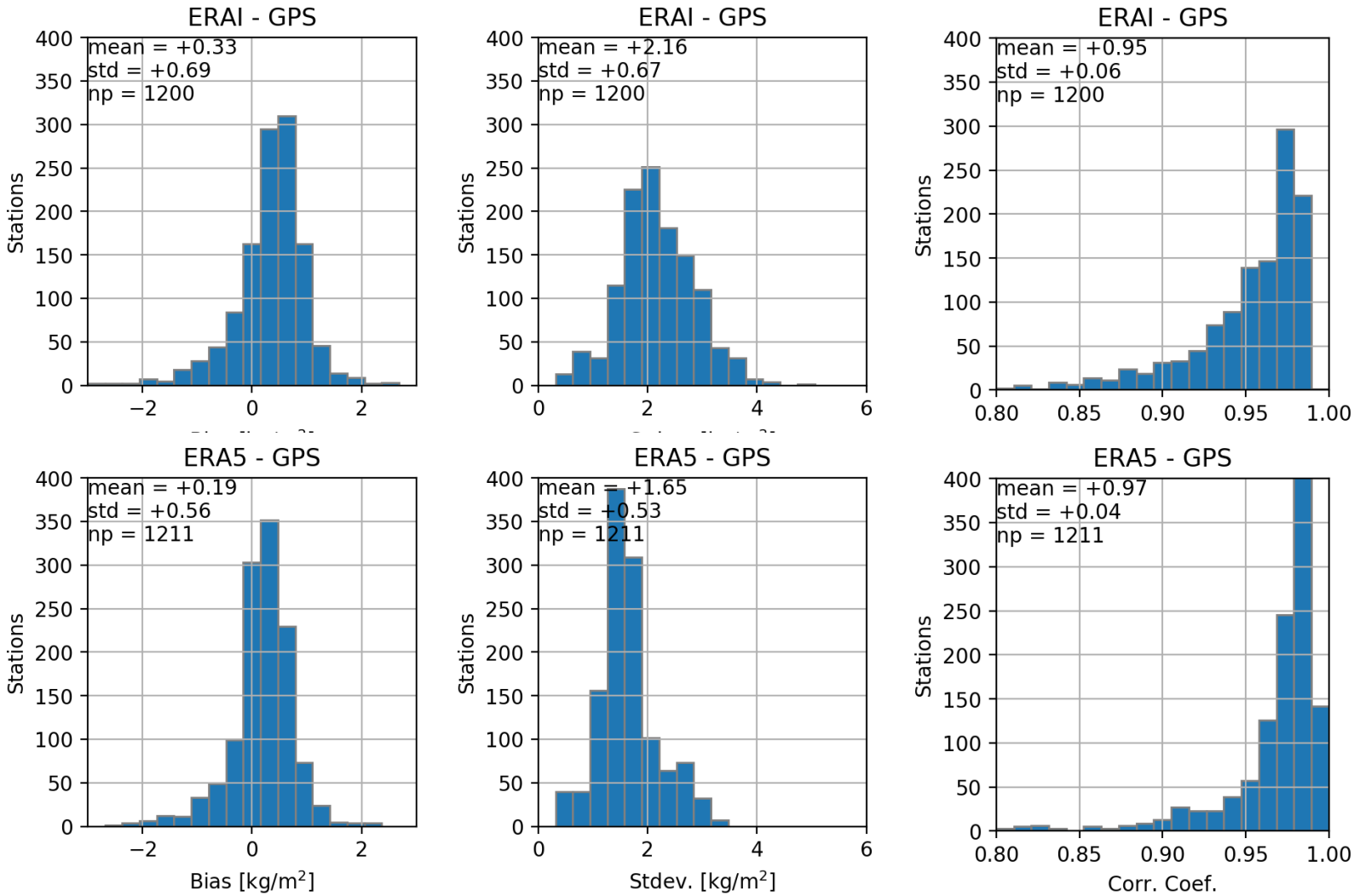
- Use of ERAI/ERA5 surface pressure field extrapolated at GPS antenna height for ZHD computation.
- Conversion from *ZWD* to *IWV* using $T_m$ from TU Wien.

[Reminder: 1kg/m$^2$ IWV = 1mm PWV $\approx$ 6.5mm ZWD]

Comparisons are limited to stations with at least 50 measurements co-incident with ERAI / ERA5 data.

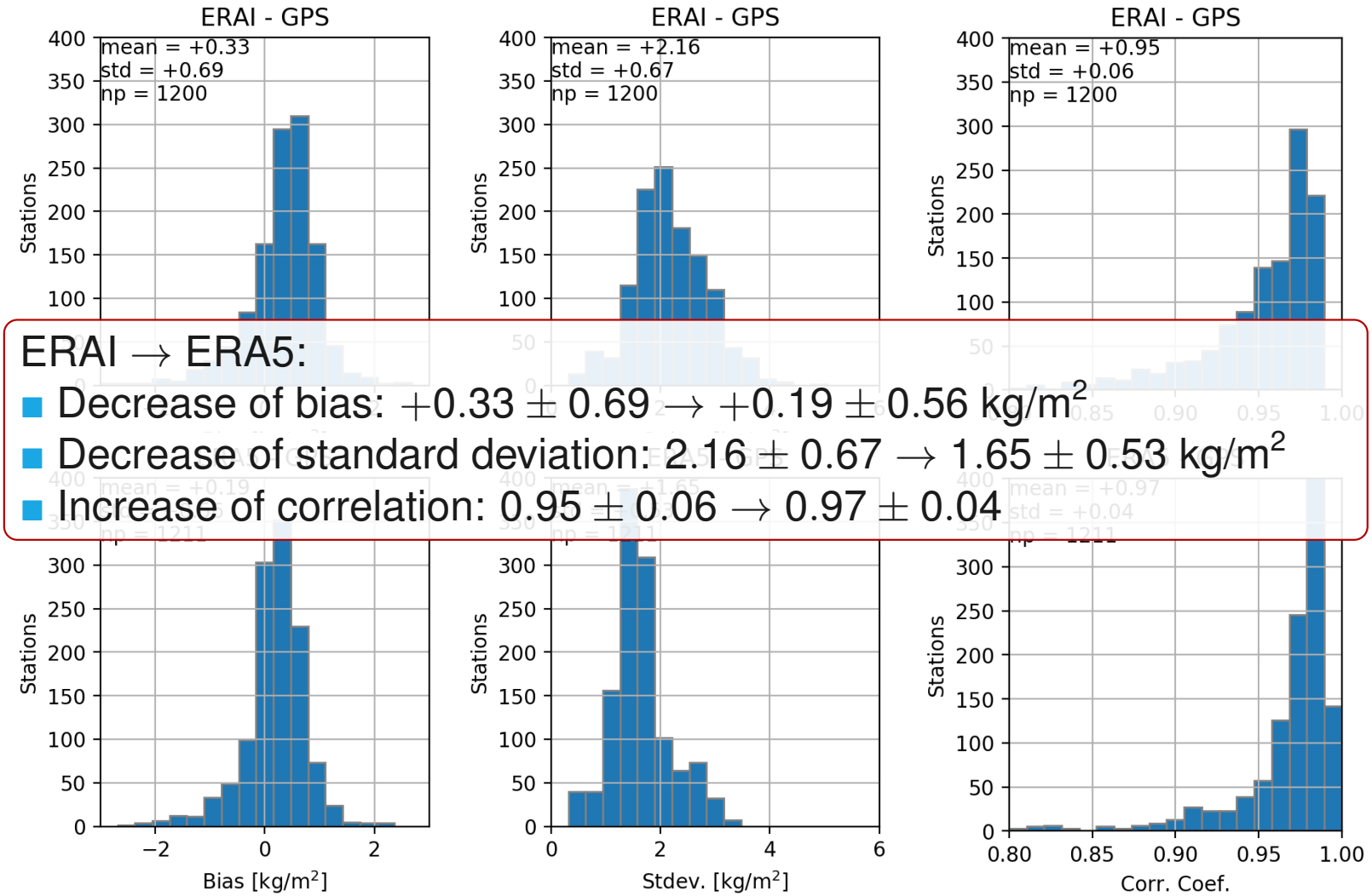
# Global differences (ERAI/ERA5 – GPS)

## ERAI (↑) / ERA5 (↓) Bias (←) / Standard-deviation (–) / Correlation (→)



# Global differences (ERAI/ERA5 − GPS)

## ERAI (↑) / ERA5 (↓) Bias (←) / Standard-deviation (−) / Correlation (→)



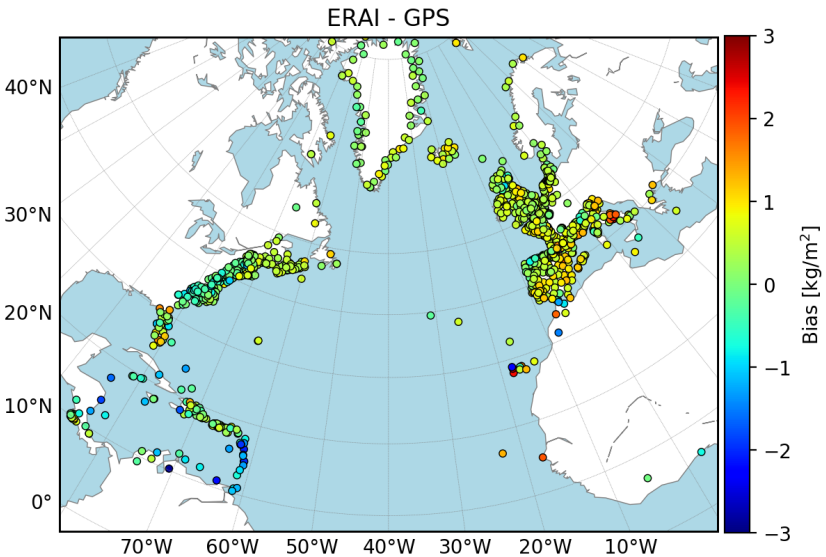

ERAI → ERA5:

- Decrease of bias: $+0.33 \pm 0.69 \rightarrow +0.19 \pm 0.56$ kg/m$^2$
- Decrease of standard deviation: $2.16 \pm 0.67 \rightarrow 1.65 \pm 0.53$ kg/m$^2$
- Increase of correlation: $0.95 \pm 0.06 \rightarrow 0.97 \pm 0.04$

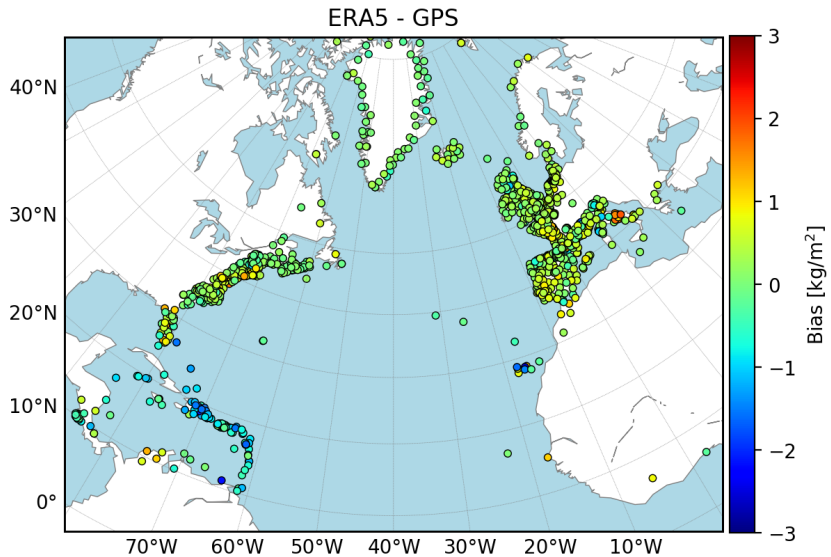
# Spatial distribution of differences

## ERAI/ERA5 – GPS

Bias




**ERAI**

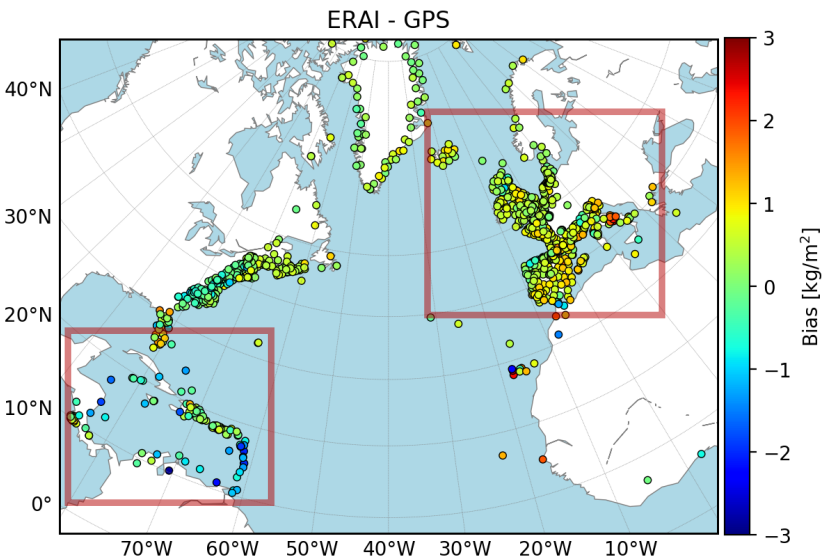



**ERA5**

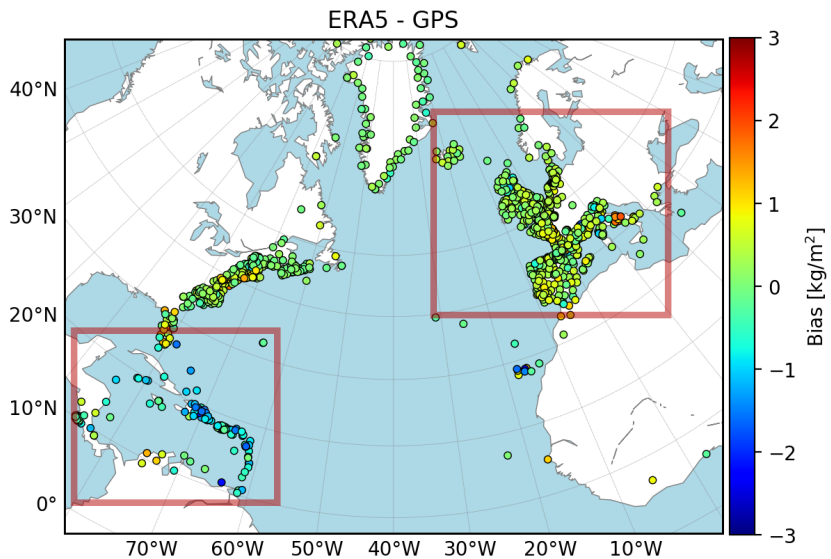
# Spatial distribution of differences

## ERAI/ERA5 – GPS

Bias




**ERAI**



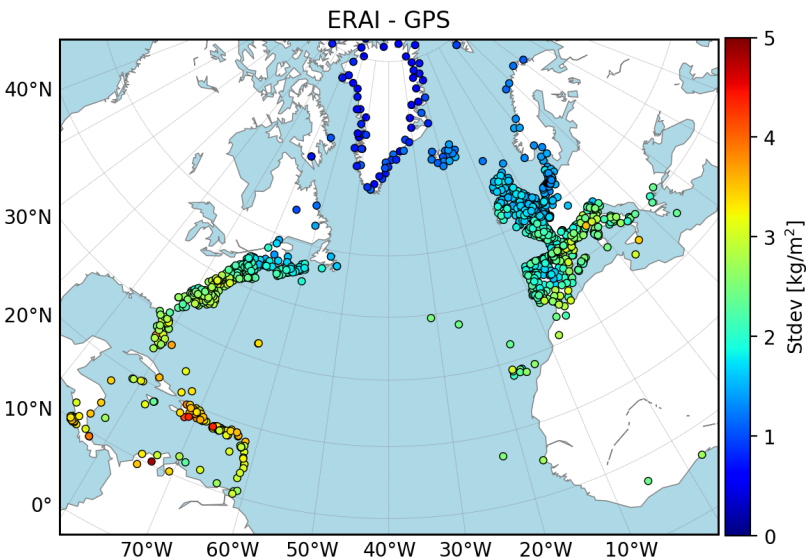

**ERA5**

- Spatial consistency of differences; higher values in Caribbean region, bias is reduced as latitude increases
- Spatial variability of bias increases when latitude decreases
- Decrease over Europe and Caribbean (slight) with ERA5.

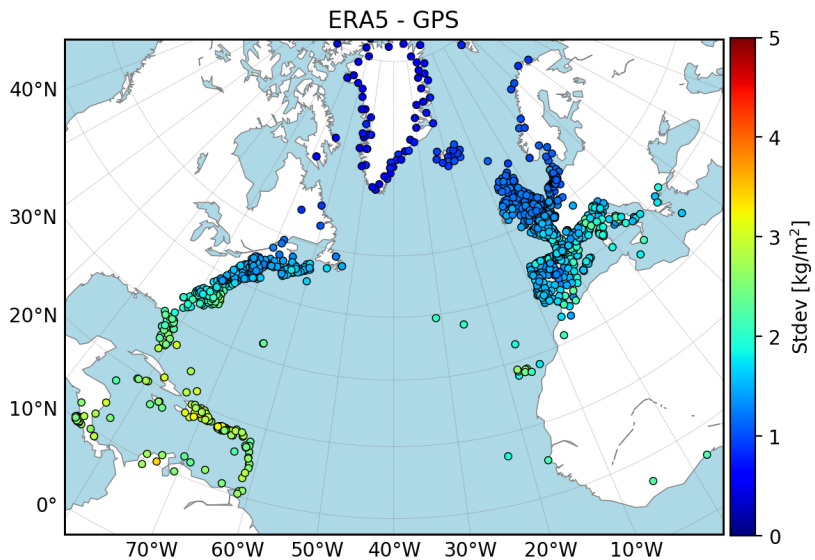
# Spatial distribution of differences

## ERAI/ERA5 – GPS

Standard deviation




**ERAI**

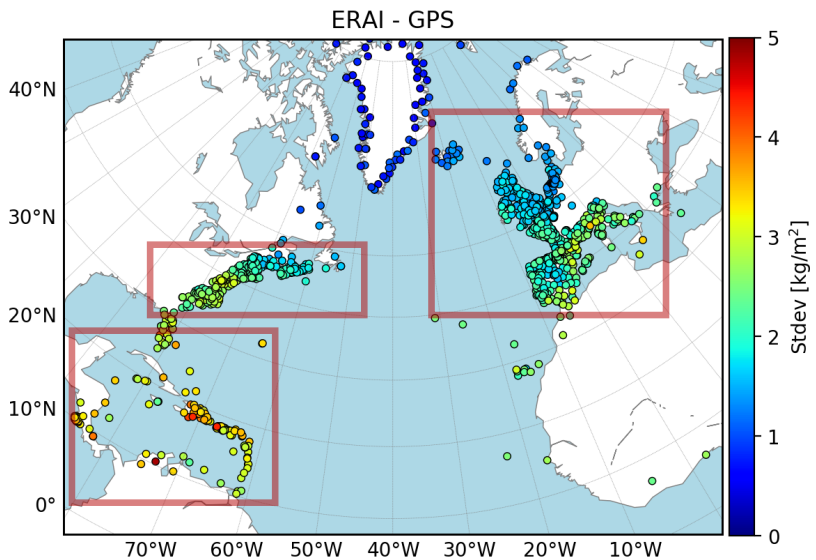



**ERA5**

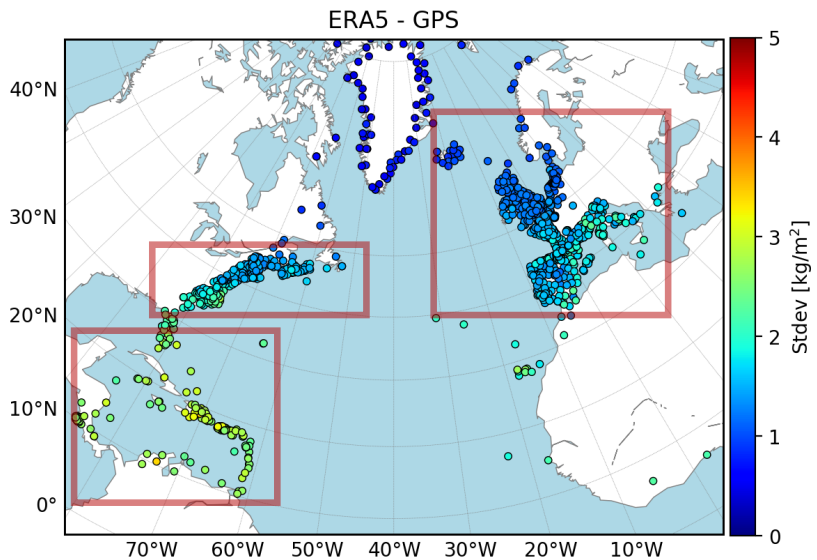
# Spatial distribution of differences

## ERAI/ERA5 – GPS

Standard deviation




**ERAI**



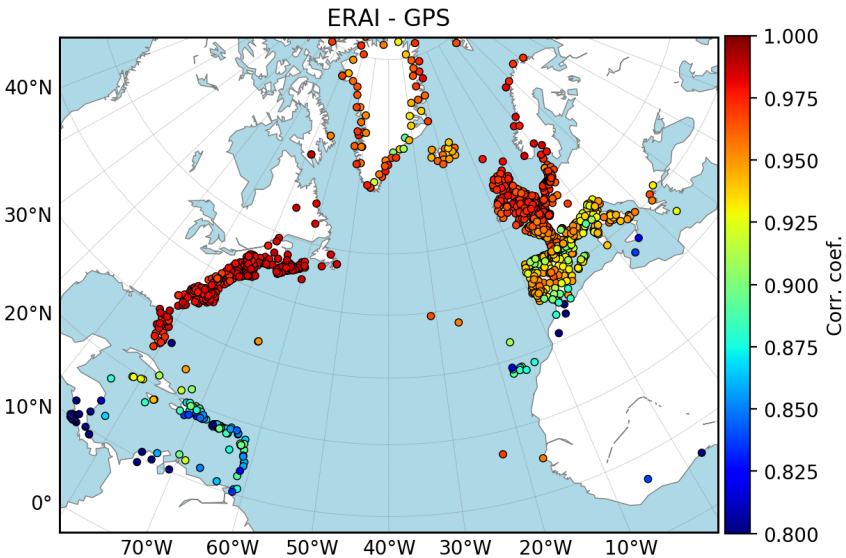

**ERA5**

- Spatial consistency of differences; higher values in Caribbean, lower values as latitude increases
- Decrease over Europe, US East Coast and Caribbean with ERA5.

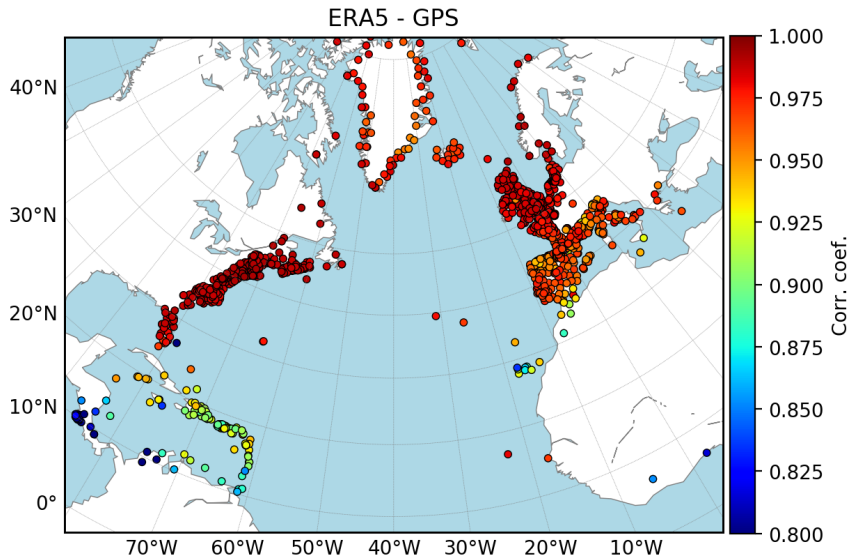
# Spatial distribution of differences

## ERAI/ERA5 – GPS

Correlation coefficient




**ERAI**

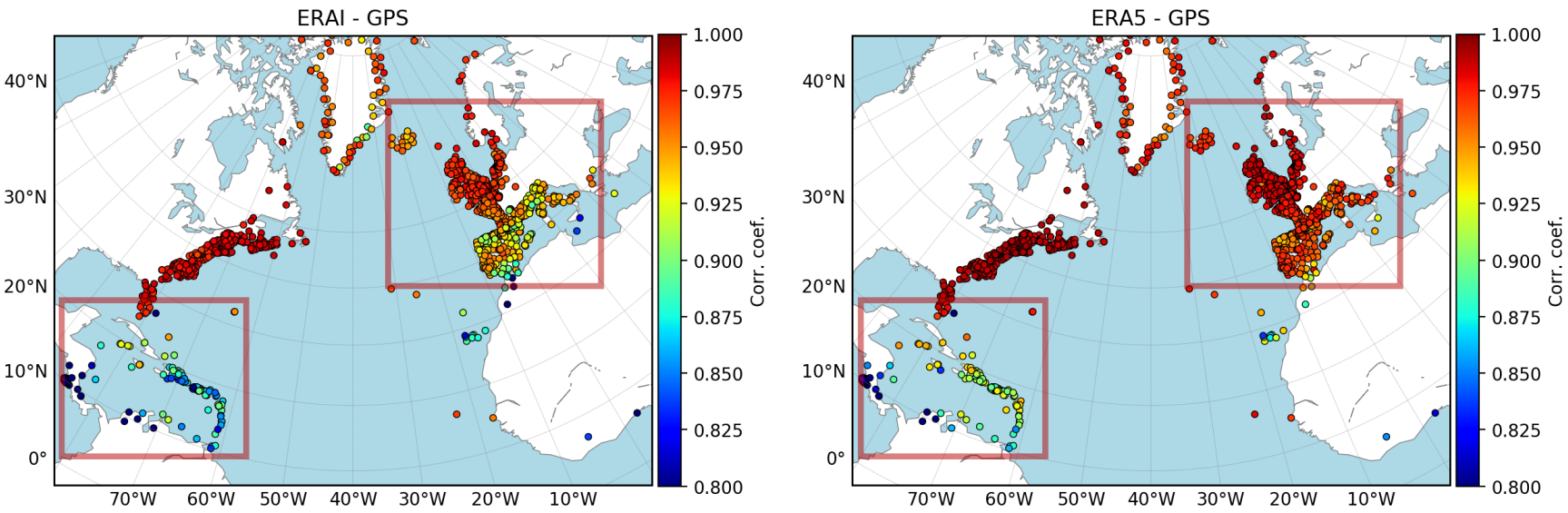



**ERA5**

# Spatial distribution of differences

## ERAI/ERA5 – GPS

### Correlation coefficient




**ERAI** **ERA5**

- Lower correlation over Caribbean ; slight improvements with ERA5.
- Significant increase over Europe and Greenland with ERA5.

# Case study example: CO Sanchez

Cutoff Sanchez over Mediterranean Area (IOP9)

From [Sch+18]:

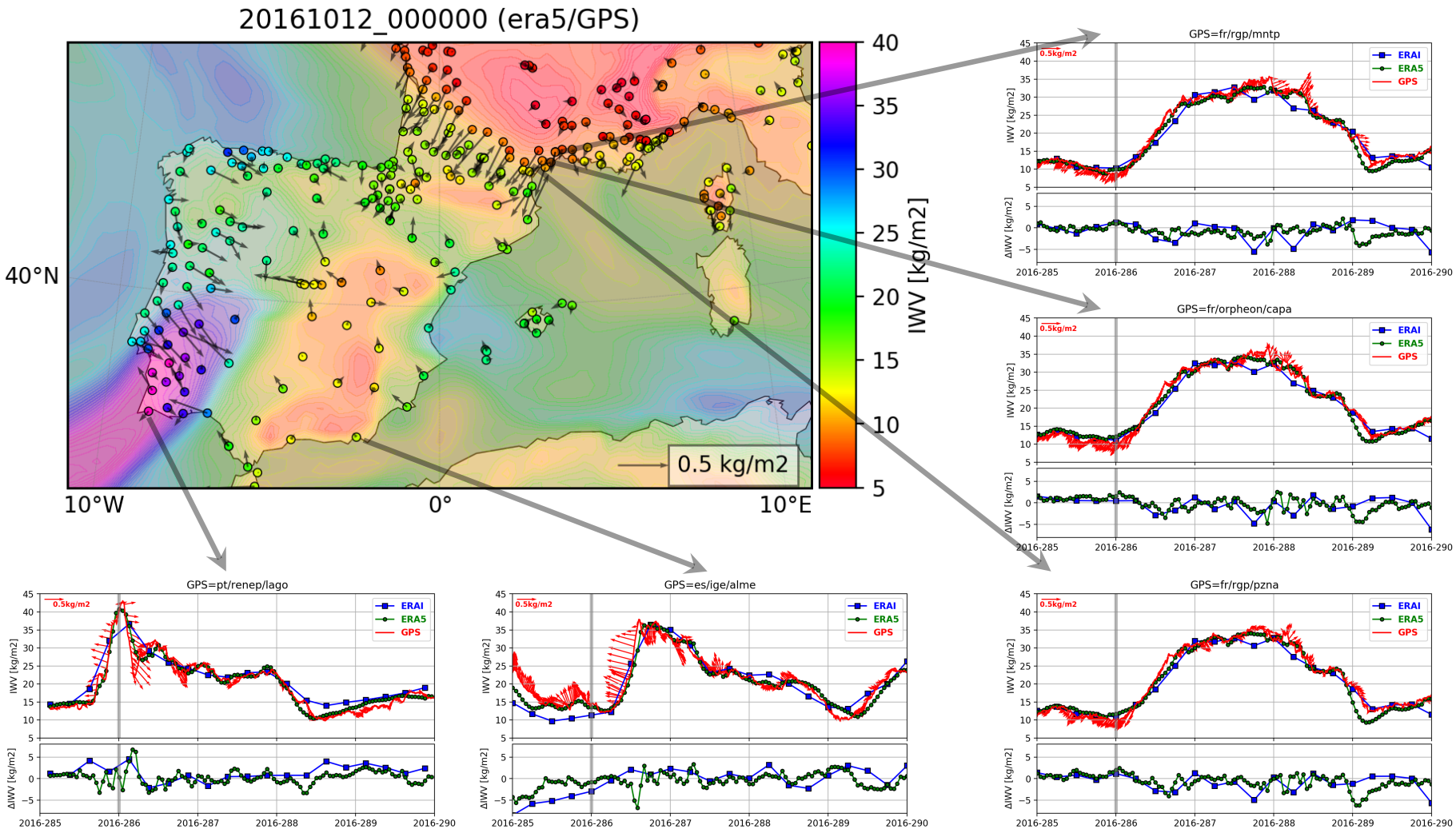
- Surface cyclone Sanchez formed in the middle of the Atlantic Ocean (35°W, 40°N) around 2016/10/08 18:00 UTC.
- Associated high-impact weather event over Southern France on 13-14 Oct 2016 (heavy precipitations and strong winds over France and Italy).

Use of:

- GPS IWV and IWV gradients (5 min)
- ERAI IWV & Total precipitation fields (6h / 0,75° $\times$ 0,75°)
- ERA5 IWV & Total precipitation fields (1h / 0,25° $\times$ 0,75°)
- Total precipitation from NCDC /NOAA

# CO Sanchez: IWV space and time evolution

## GPS IWV + gradient, ERAI, ERA5 (+colormap)



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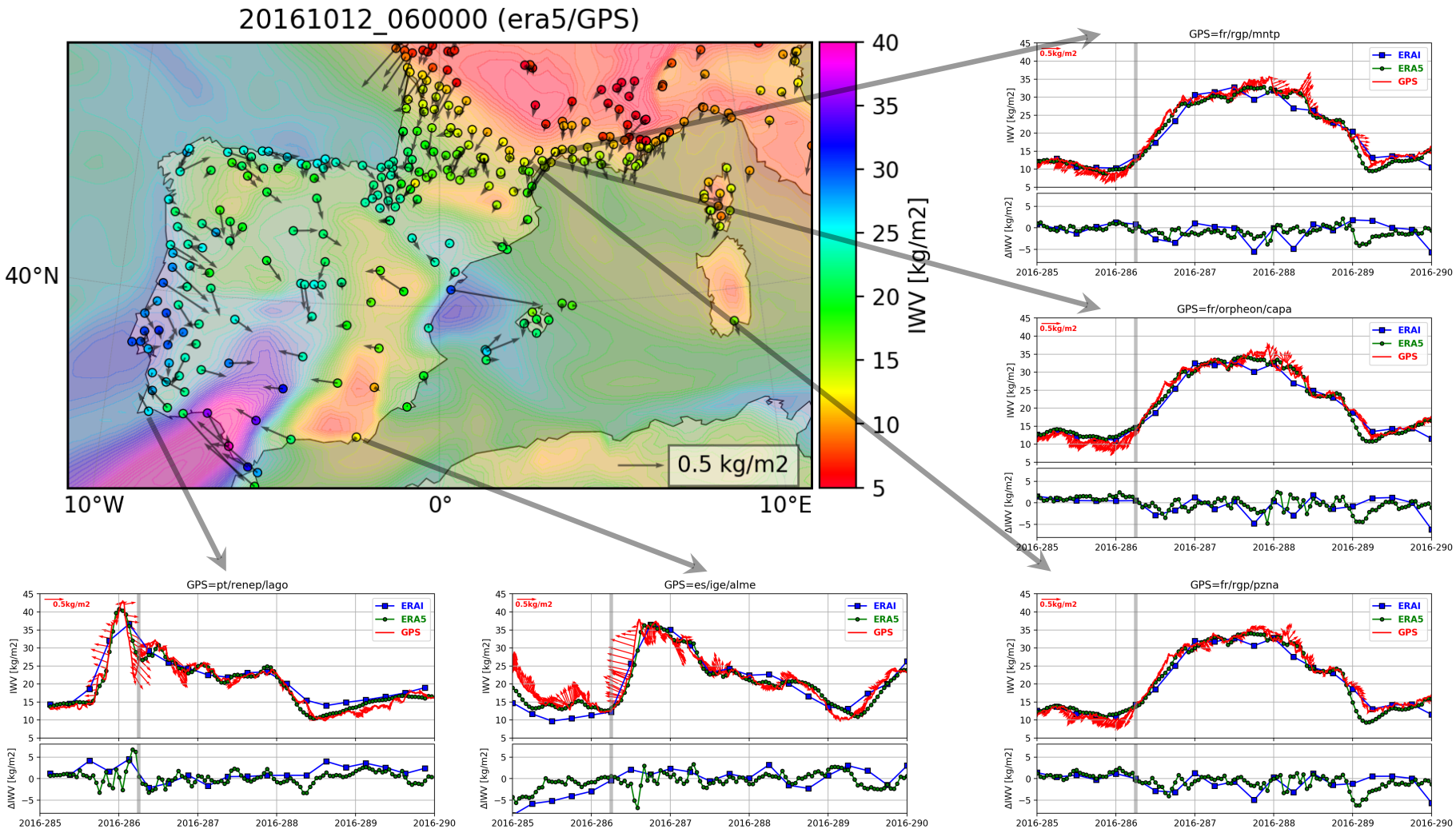

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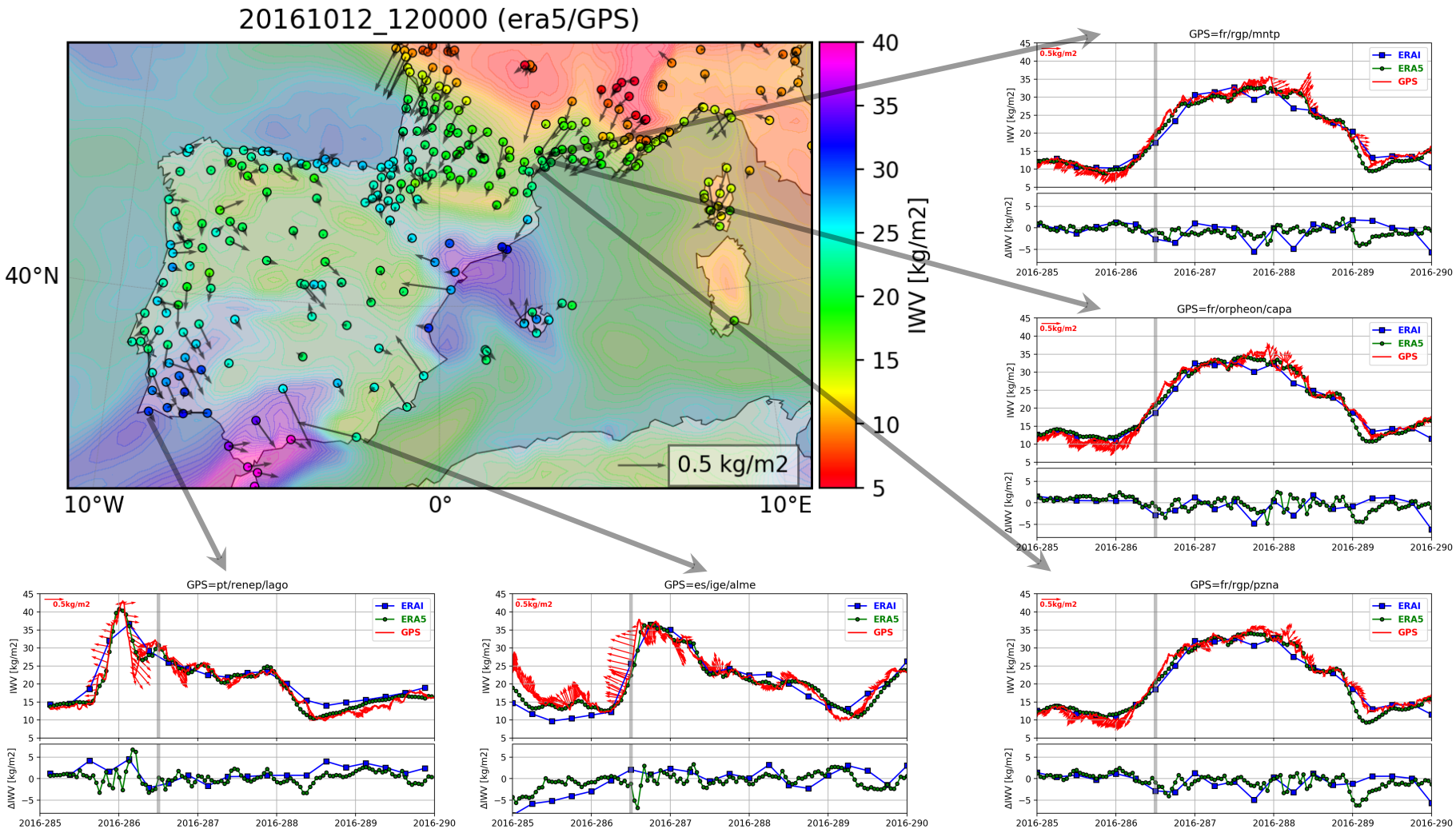

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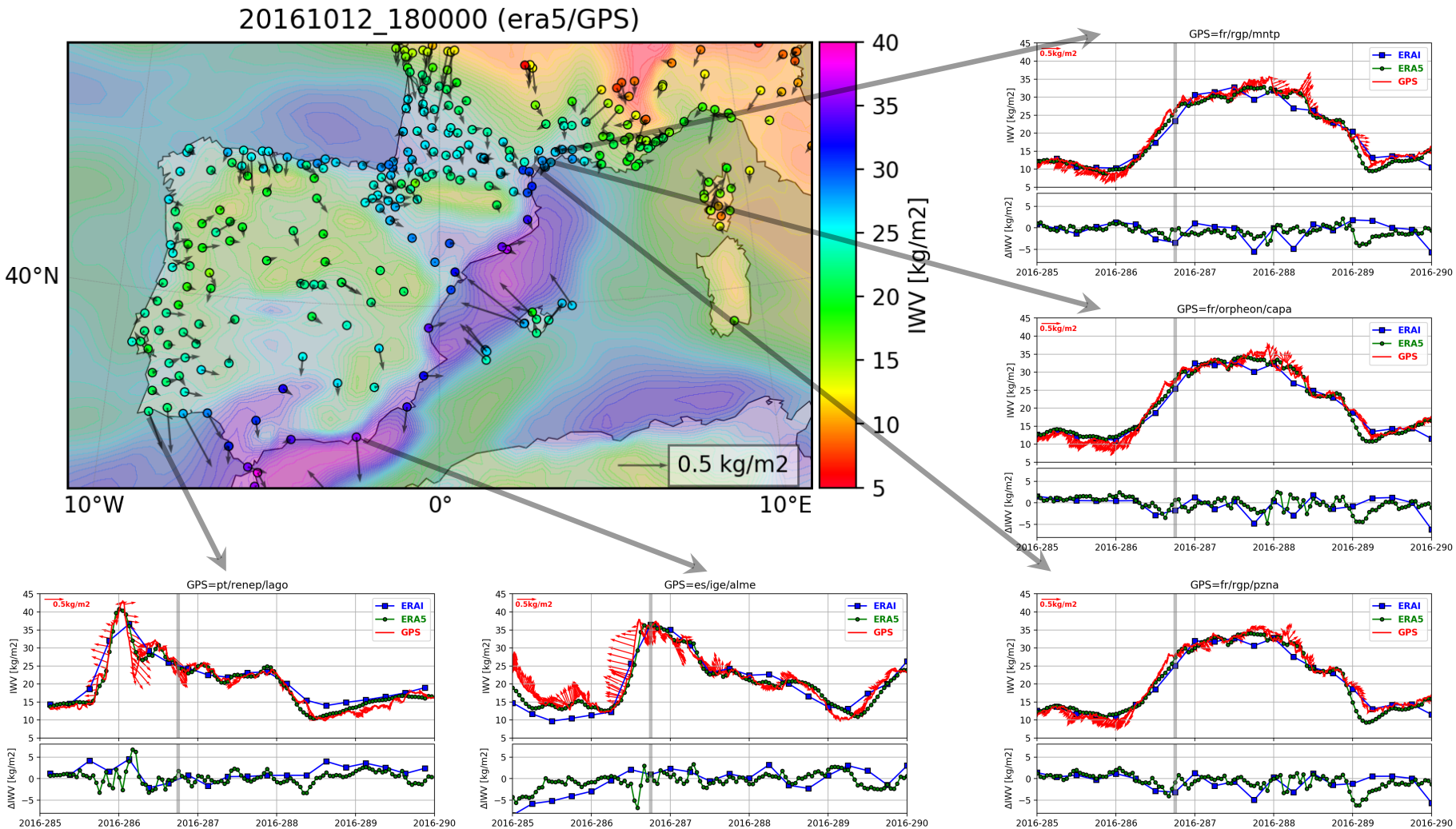

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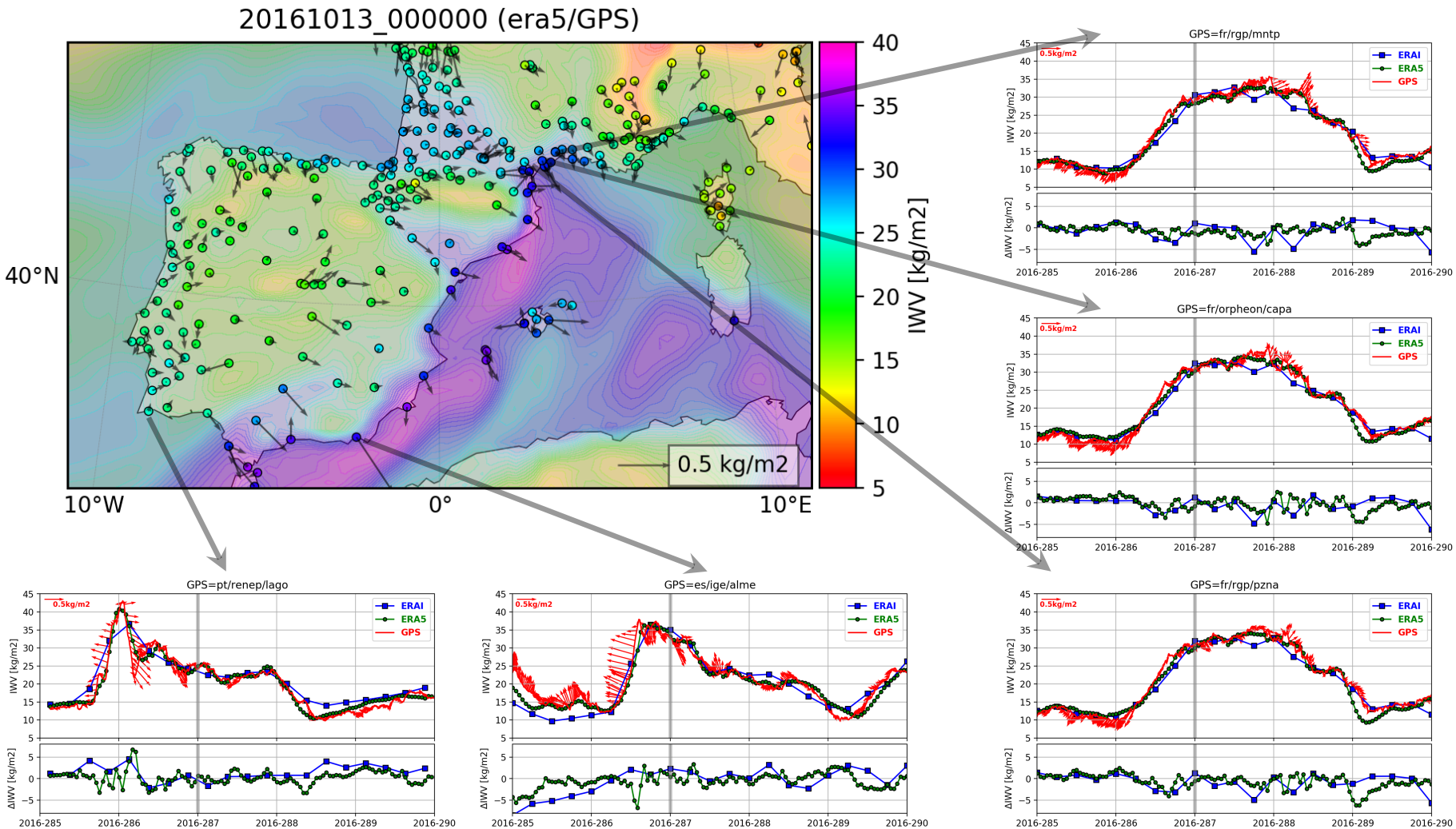

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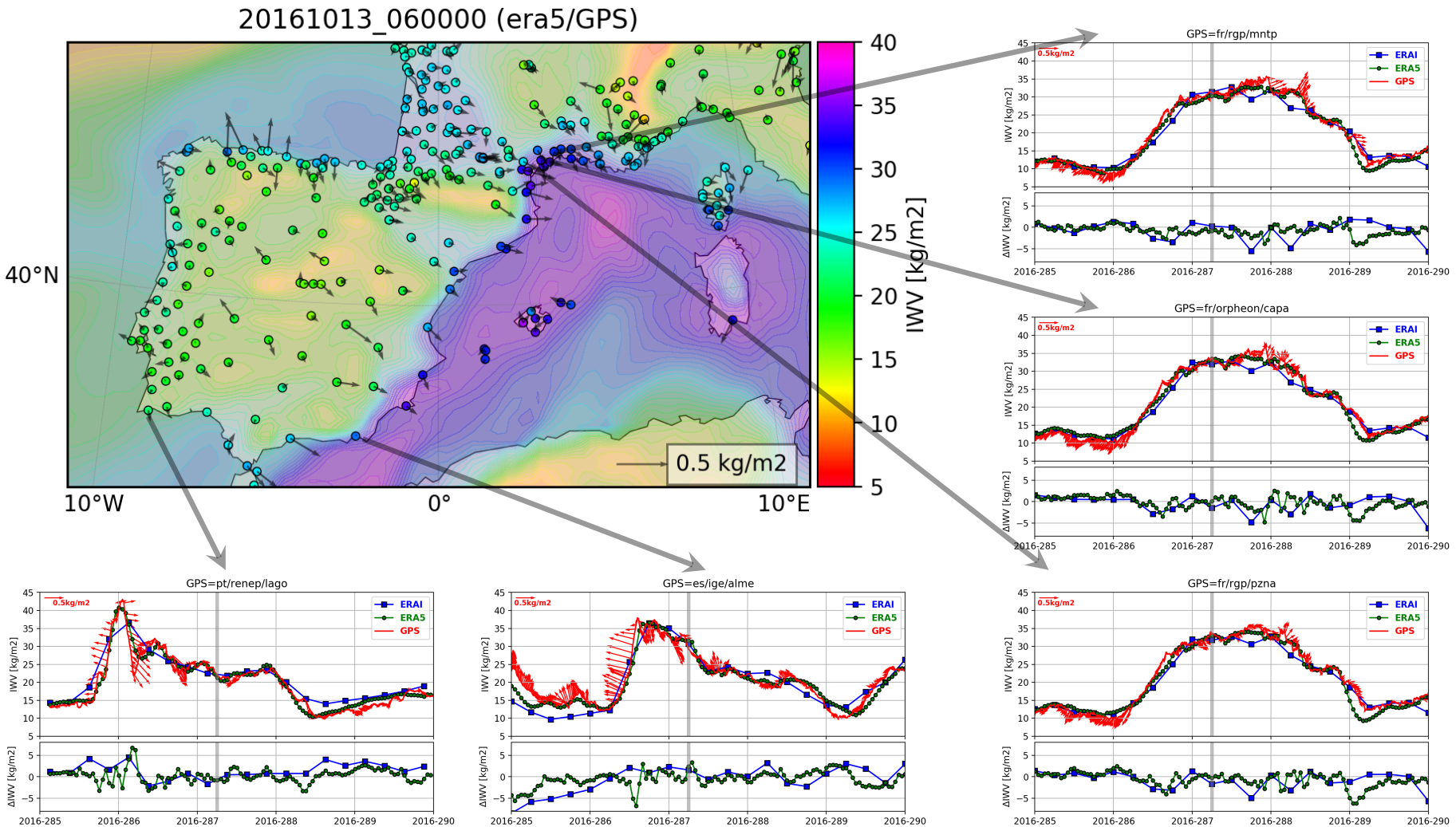
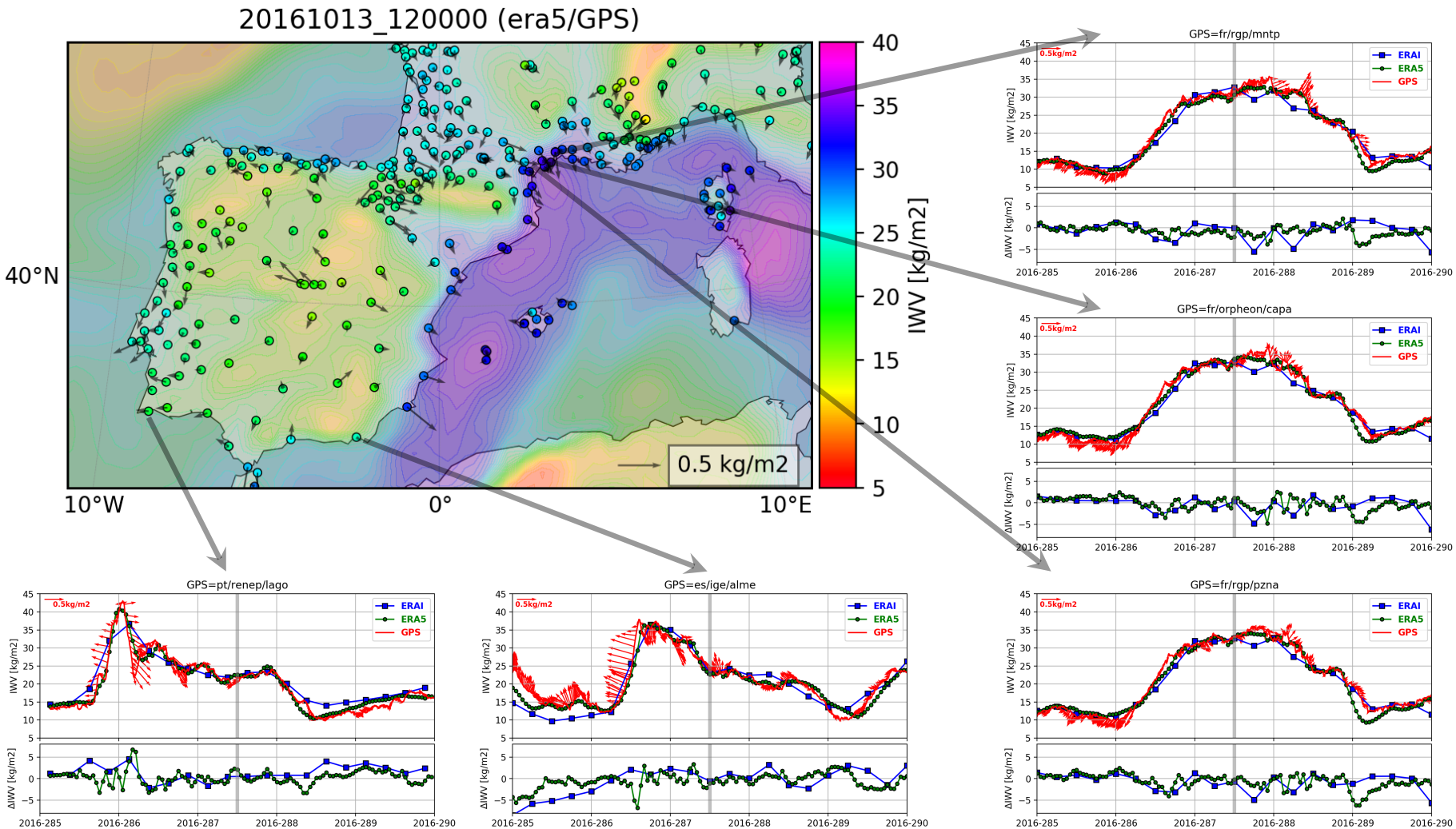


# CO Sanchez: IWV space and time evolution

## GPS IWV + gradient, ERAI, ERA5 (+colormap)



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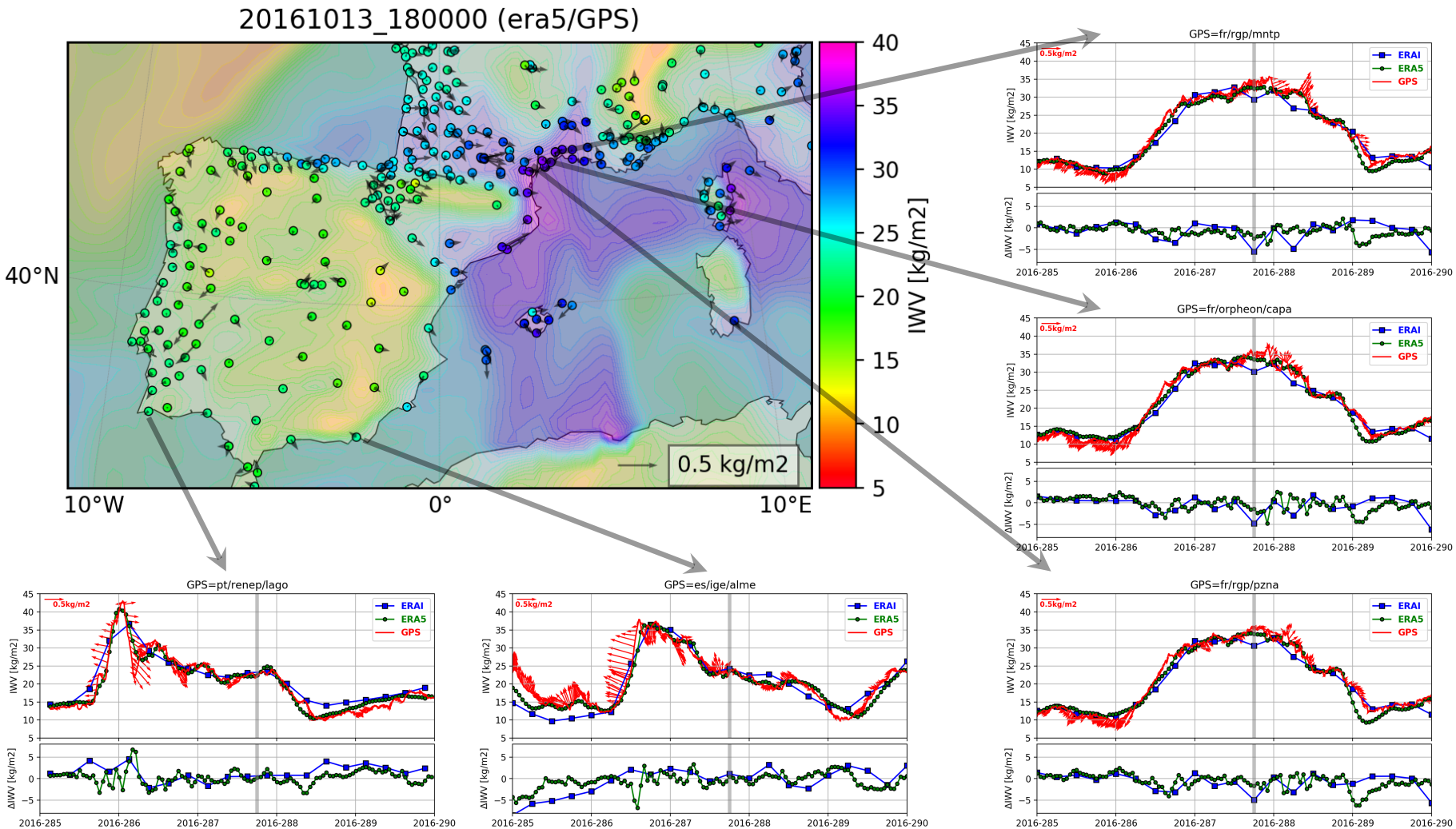

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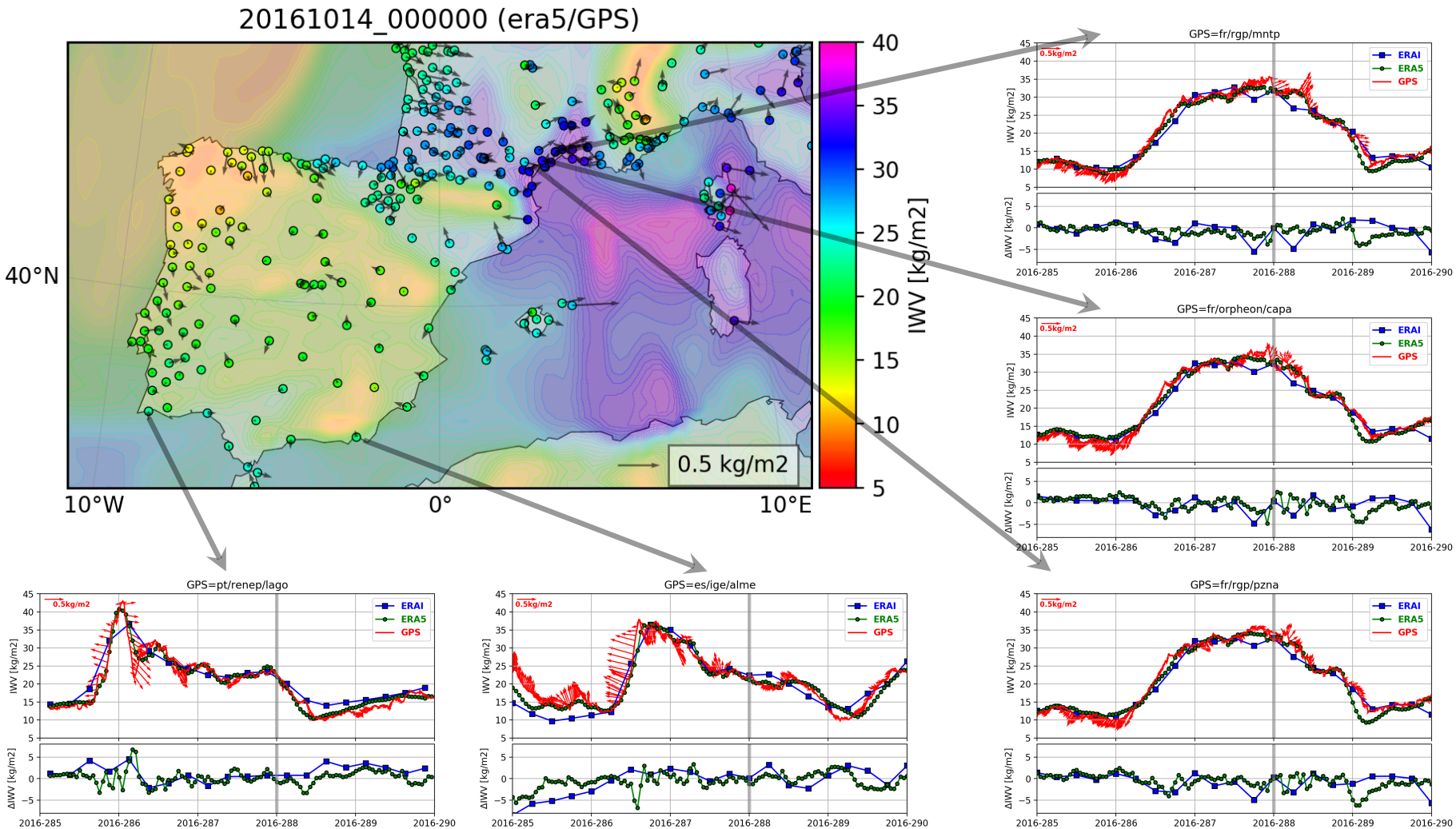

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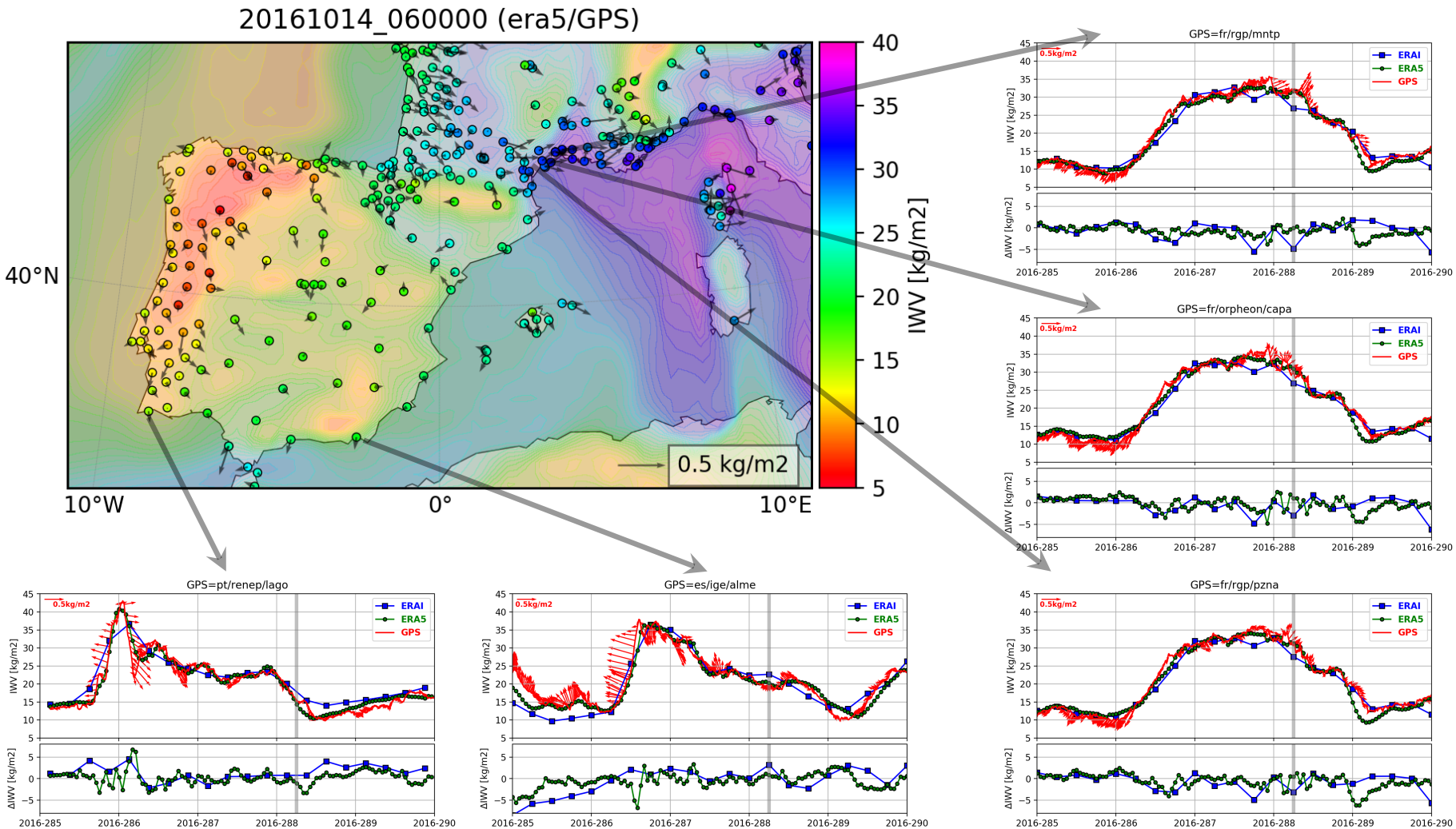

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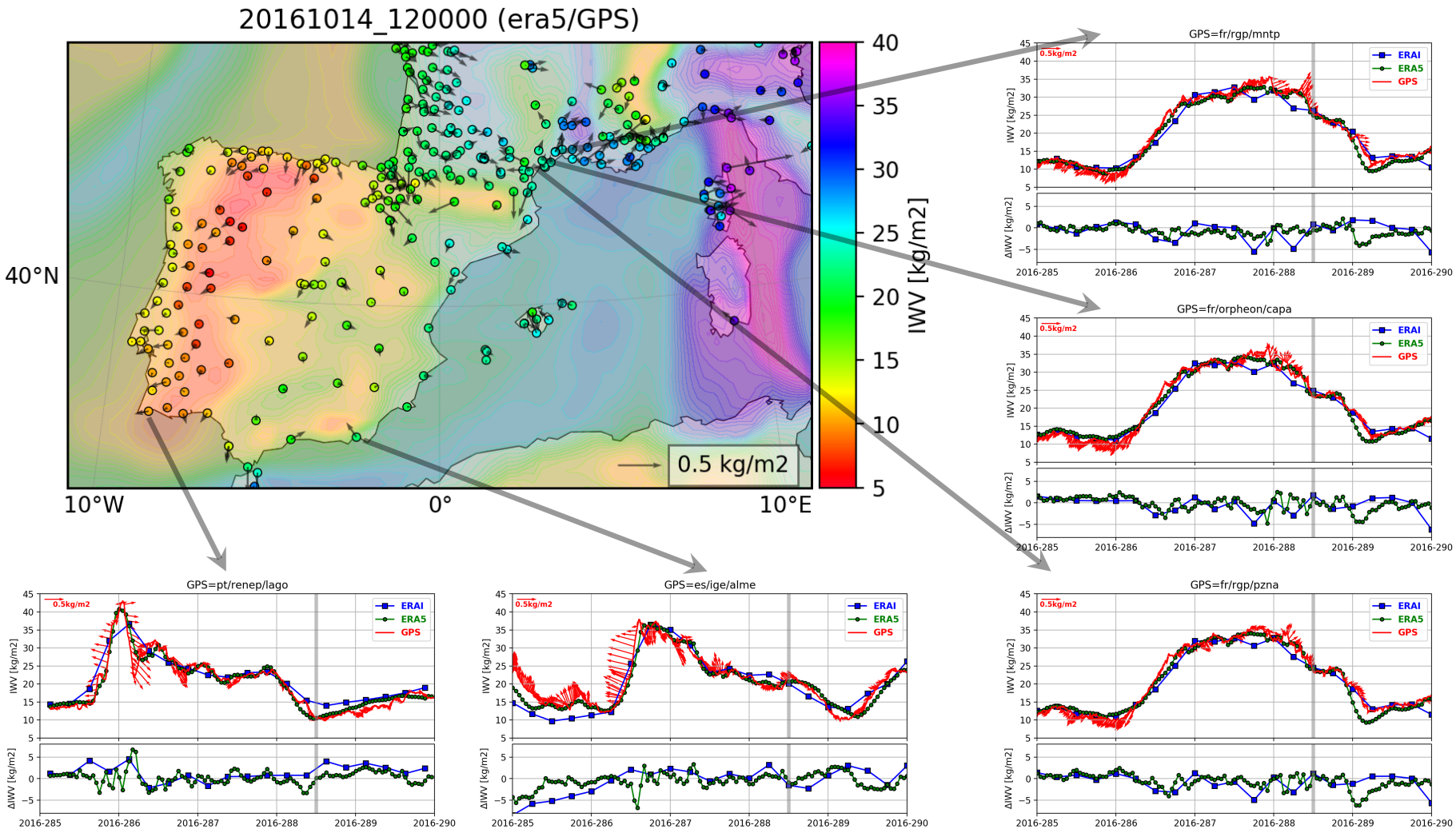
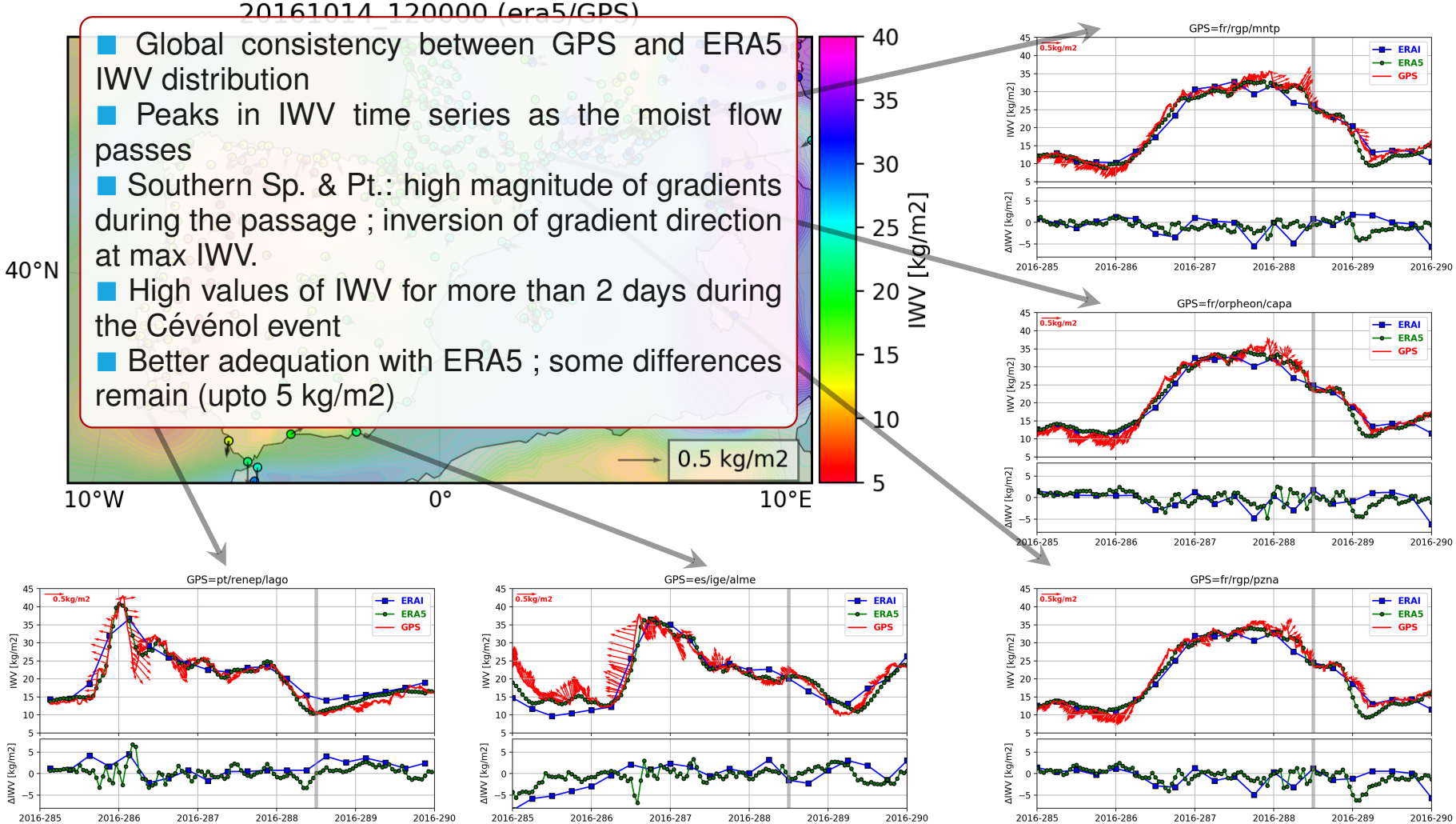


# CO Sanchez: IWV space and time evolution

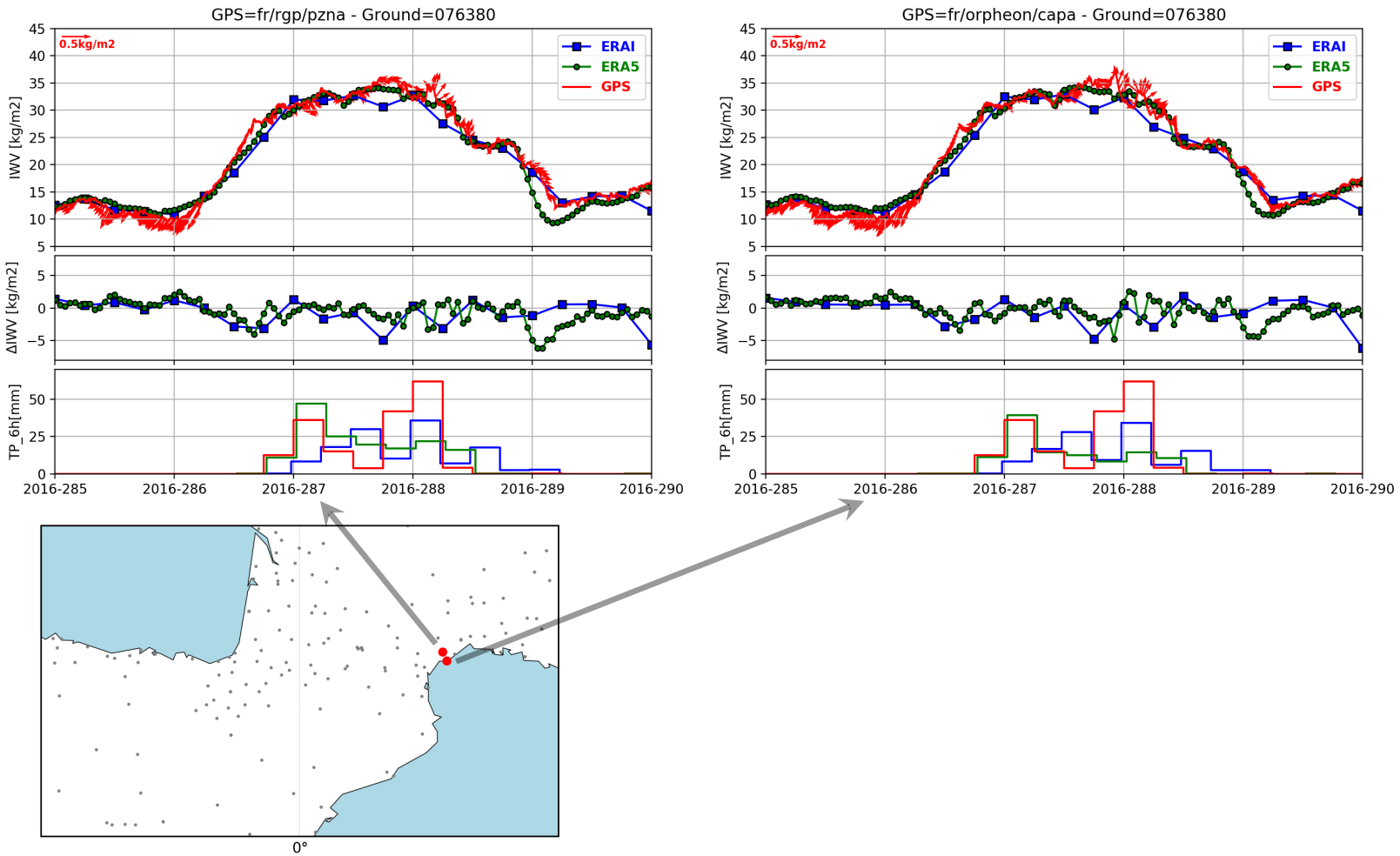
## GPS IWV + gradient, ERAI, ERA5 (+colormap)

- Global consistency between GPS and ERA5 IWV distribution
- Peaks in IWV time series as the moist flow passes
- Southern Sp. & Pt.: high magnitude of gradients during the passage ; inversion of gradient direction at max IWV.
- High values of IWV for more than 2 days during the Cévénol event
- Better adequation with ERA5 ; some differences remain (upto 5 kg/m2)



# CO Sanchez: Rainfall

## GPS IWV, Total Precipitation obs. (6h), ERAI, ERA5



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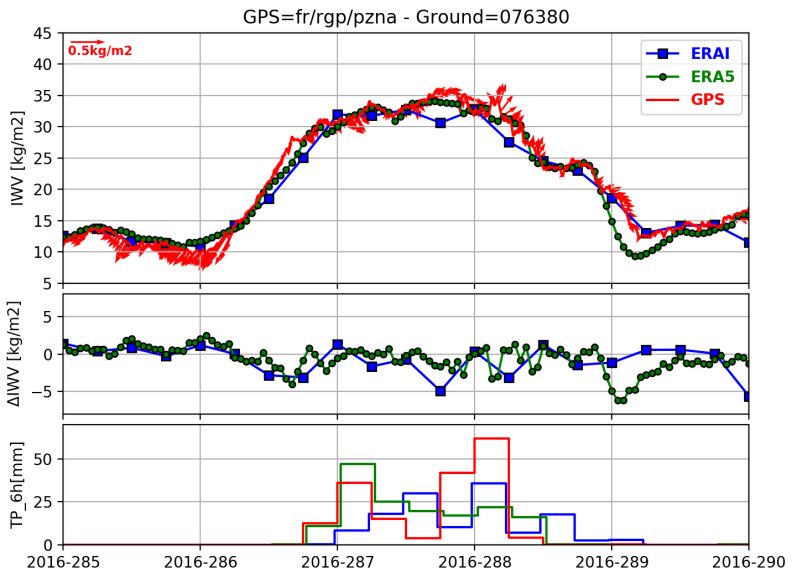
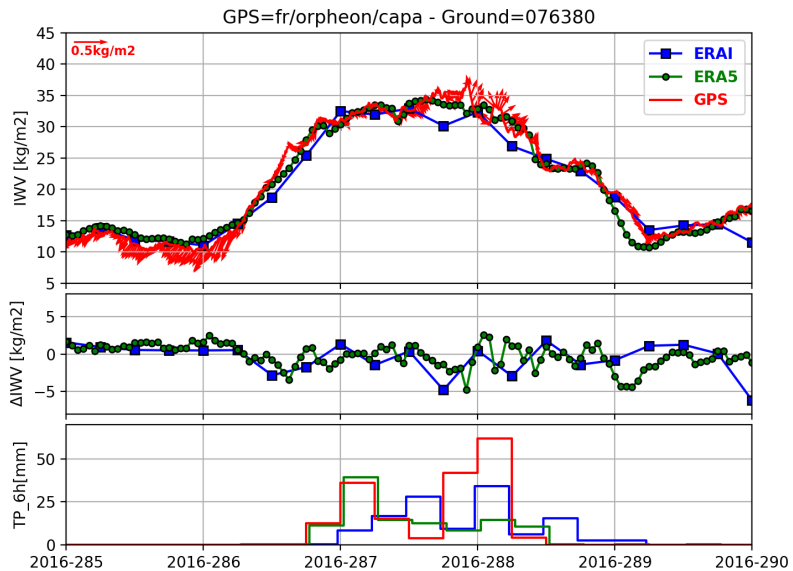
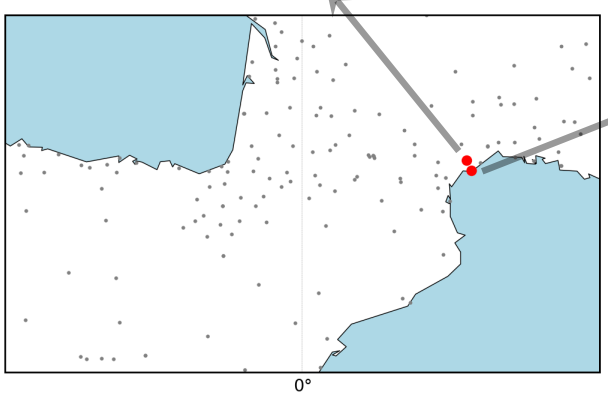


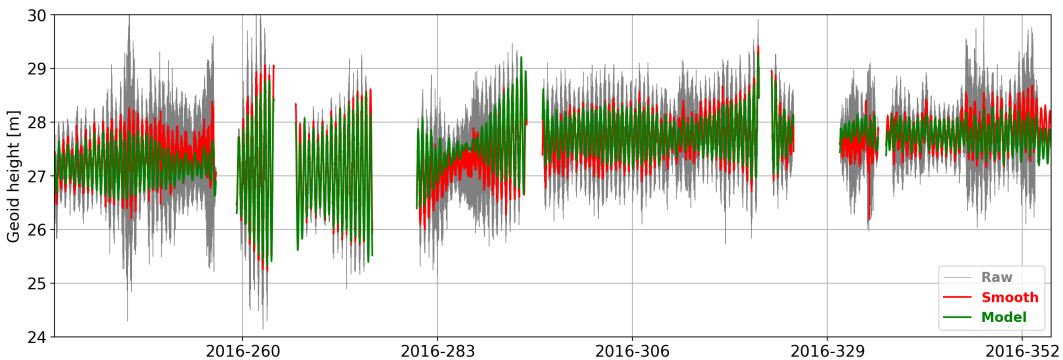

- Differences could exceed 5 kg/m$^2$
- High IWV values for more than 2 days
- High rainfall rates are followed by a significant decrease of IWV
- Still significant differences in the representation of precipitation

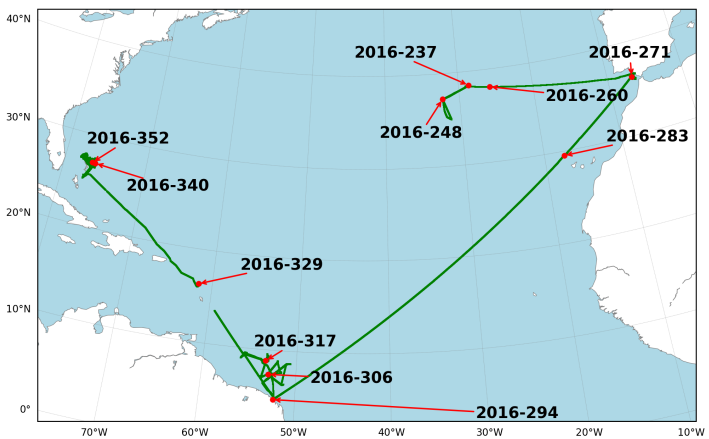
# Outlines

# Overview

- GNSS data acquired during a 120 days cruise in the North Atlantic.
- Kinematic analysis in PPP_AR (Gipsy-Oasis II 6.4)
- IWV extraction using ERA5 atmospheric pressure fields at MSL.

➥ Comparison of **GPS** geoid height (EGM2008) with **model** (FES2014 + MSS_CNES_CLS2015).



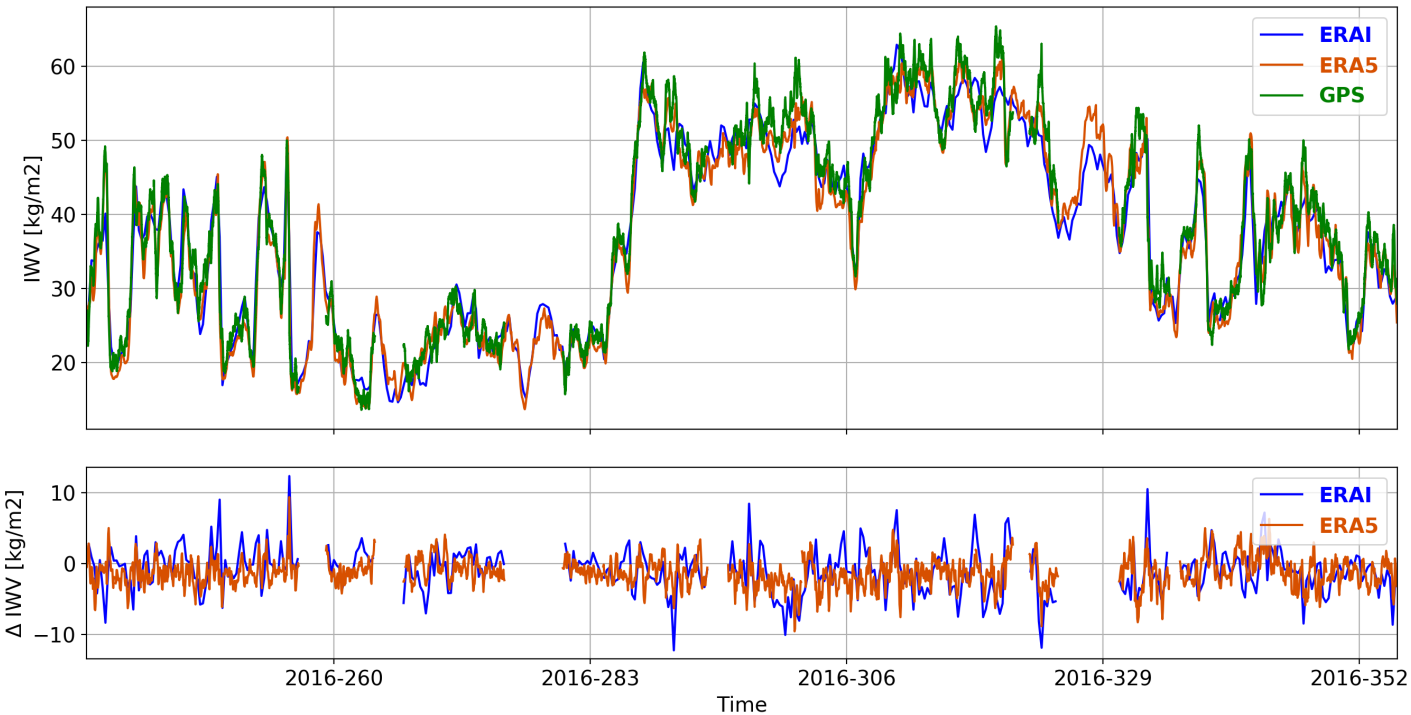

Raw GPS $\Delta H = 0.003 \pm 0.326$m

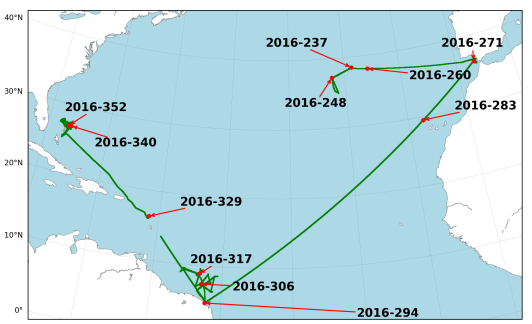
Smoothed GPS* $\Delta H = 0.003 \pm 0.176$m

** : 5min-median filter*

# IWV comparisons wrt ECMWF reanalysis

## GPS IWV, ERAI, ERA5



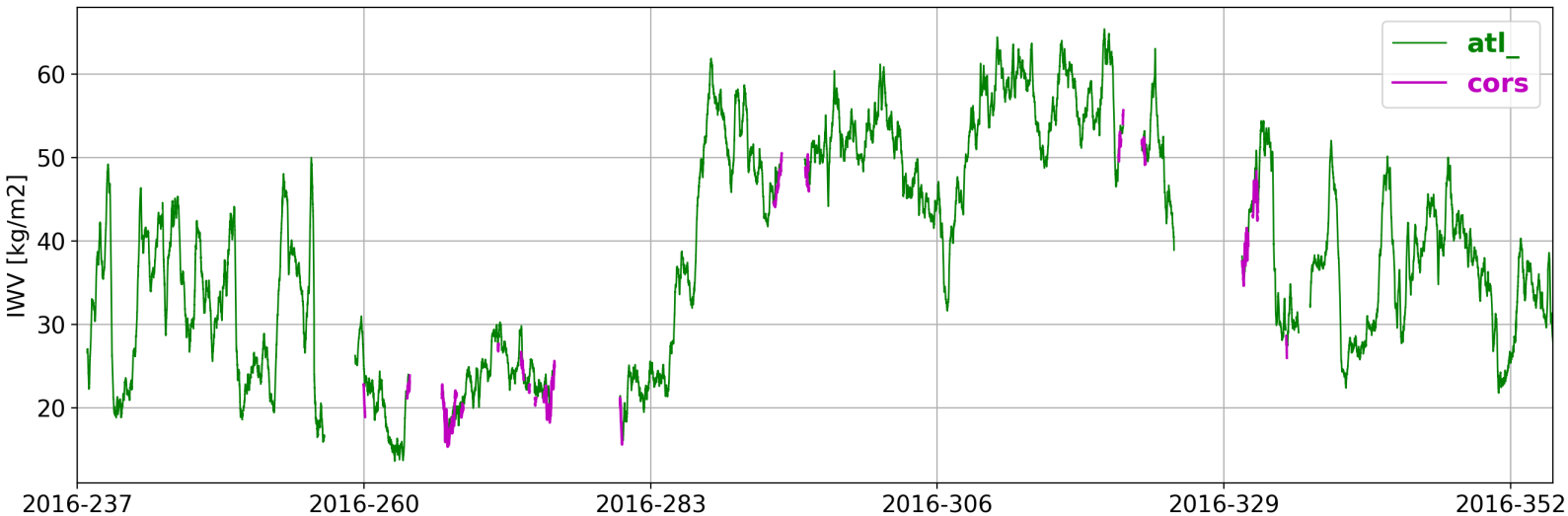

Differences [kg/m$^2$]:

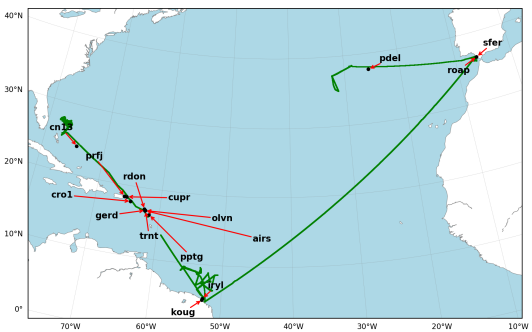
| | | | |
|---|---|---|---|
| **ERAI** (392) | -0.98±3.19 | -12.22 ⇄ 12.33 | +0.969 |
| **ERA5** (2349) | -1.31±2.00 | -9.54 ⇄ 9.37 | +0.988 |

- Improvements considering ERA5 instead of ERAI
- Consistency with differences observed previously for CORS

# IWV comparisons wrt CORS

## GPS IWV, CORS



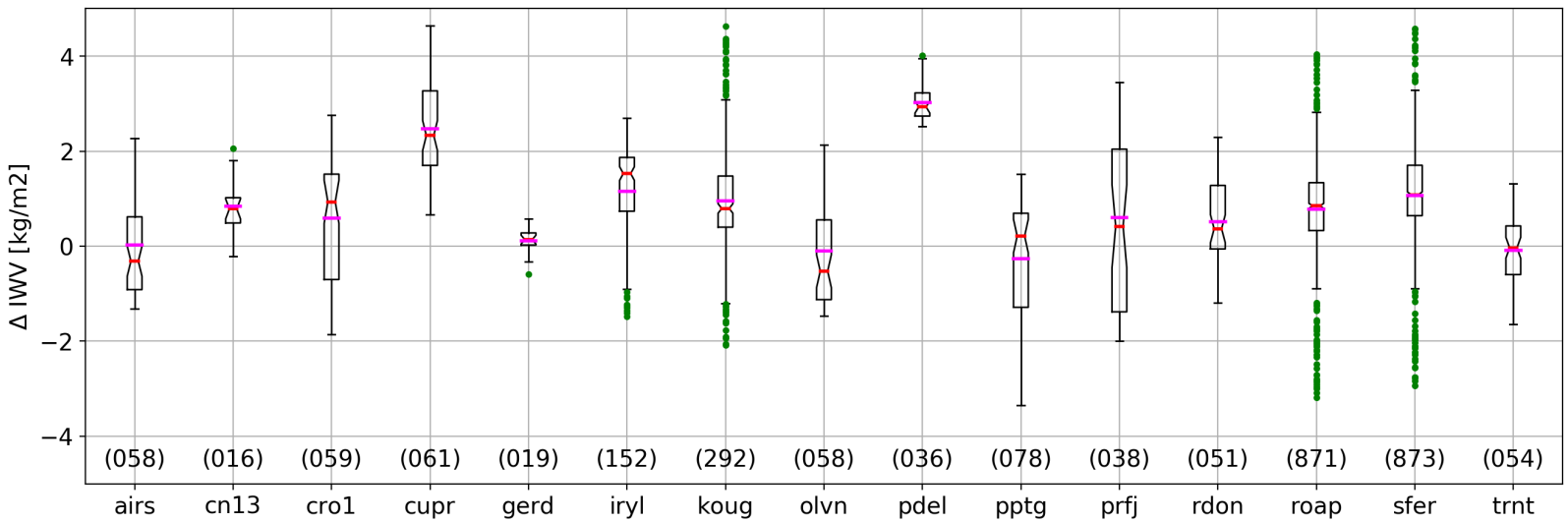

Use of CORS with distance inferior to 50 km

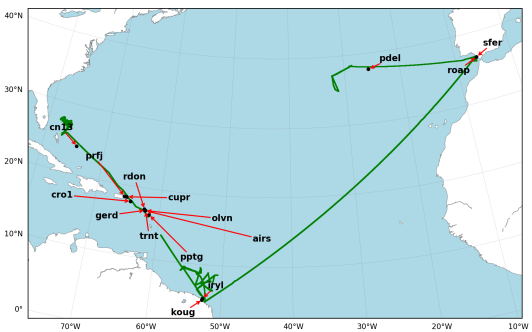
Overall differences [kg/m$^2$]:

**CORS** (2716) -0.88$\pm$1.22 -3.35 $\rightleftarrows$ 4.64

# IWV comparisons wrt CORS

## GPS IWV, CORS

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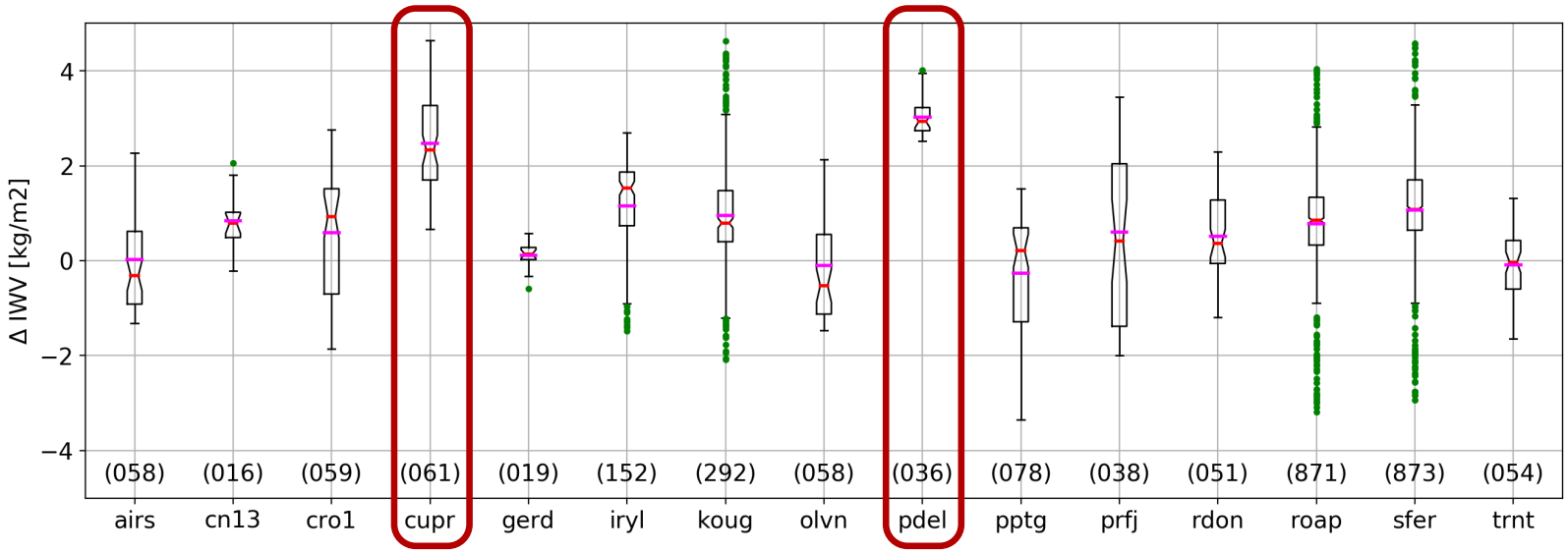
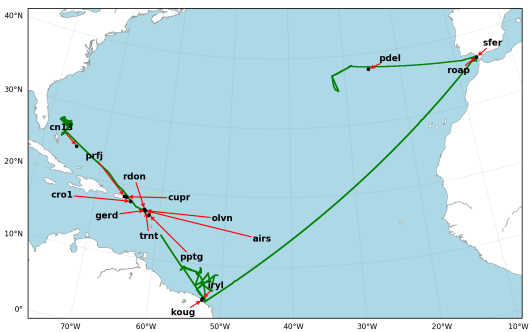
Deviations vary from station to station

# IWV comparisons wrt CORS

## GPS IWV, CORS




Use of CORS with distance inferior to 50 km

Overall differences [kg/m$^2$]:

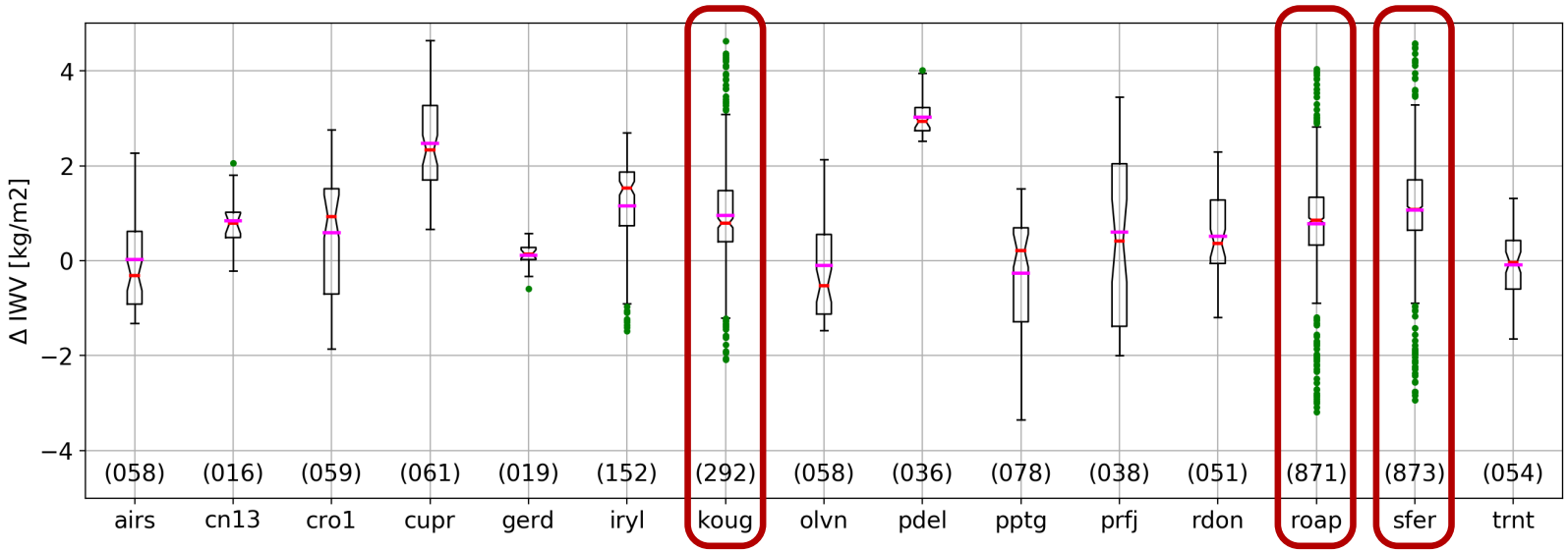
**CORS** (2716) -0.88$\pm$1.22 -3.35 $\rightleftarrows$ 4.64

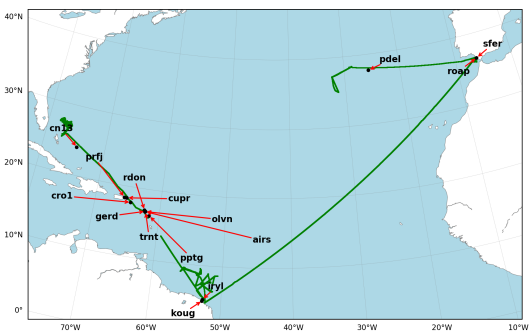
Deviations vary from station to station

➥ Significant bias for PDEL (Azores) and CUBR (Porto-Rico)

# IWV comparisons wrt CORS

## GPS IWV, CORS

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**CORS** (2716) -0.88$\pm$1.22 -3.35 $\rightleftarrows$ 4.64

Deviations vary from station to station

➥ Significant bias for PDEL (Azores) and CUBR (Porto-Rico)

➥ Outlying differences mainly occur as the distance between Ship and CORS is superior to 40 km.

# Outlines

# Conclusion & perspectives

**GPS-derived IWV dataset** produced for NAWDEX from more than 1,200 CORS along North Atlantic:

- Comparison with **ERAI** and **ERA5** reanalysis highlight **improvements induced by ERA5**.
  Some **significant differences** remain, part. in the **Caribbean**.
- **HIW case study**: large scale agreement with the analyses, part. ERA5.
  GPS IWV is more suitable to reproduce variations at **small spatial and temporal scale**.
  ➥ Further investigations using **high resolution NWP** to investigate bad precipitation forecast.
  ➥ Documentation of other cases (Walpurga Cyclon, etc.).

The CORS dataset is completed with **IWV from shipborne GPS antenna**:

- Consistency with ECMWF reanalysis ; **agreement increases with ERA5**.
- Good **agreement** with **CORS IWV**.
  ➥ Further analysis of Atalante data acquired during other campaigns across the oceans.

# Acknowledgments

Work supported by the French ANR / DIP-NAWDEX (ANR-17-CE01-0010).

GPS data providers:

- DTU Space (DK) [Kha+16].
- British Isles continuous GNSS Facility (UK / IR).
- NRCAN (Ca), IGE, RGAPA, (Es), RENAG, Orpheon, RGP (Fr), LMI (Is), Asi (It), DGPA (Nl), NGS (Us), RENEP (Pt), UNAVCO, SONEL, IGS, EPN.

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