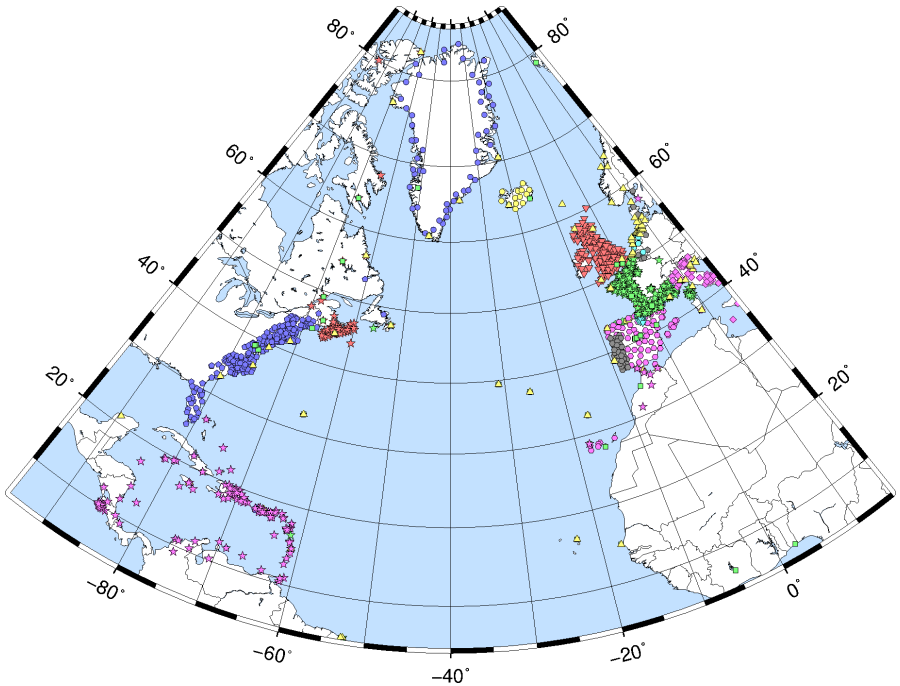


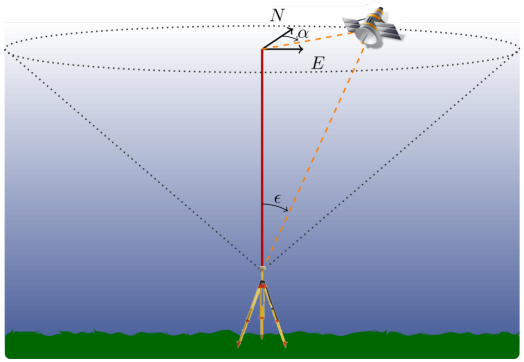
IWV from ground based GPS observations during the NAWDEX experiment

Pierre Bosser[1], Olivier Ntayagabiri[1] and Olivier Bock[2]

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

[2] IGN - Lareg, Paris, France

Introduction : GPS meteorology concept



Troposphere propagation delay :

$$\Delta L_{\text{tropo}}(\alpha,\epsilon) = \Delta L_h^z \cdot mf_h(\epsilon) + \Delta L_w^z \cdot mf_w(\epsilon) + m_\alpha(\epsilon)[\Gamma_{ns}\cos\alpha + \Gamma_{ew}\sin\alpha]$$

- $\Delta L_{\text{tropo}}(\alpha,\epsilon)$: troposphere delay for a given direction
- ΔL_h^z: Zenith Hydrostatic Delay (**ZHD**) retrieved from ground pressure measurements.
- ΔL_w^z: Zenith Wet Delay (**ZWD**) estimated during the processing.
- Γ_{ns}, Γ_{ew}: horizontal gradients
- mf_h, mf_w, m_α: mapping functions for delays and gradients.

ZWD is closely linked to IWV:

$$IWV = k(T_m) \times \Delta L_w^z$$

Outlines

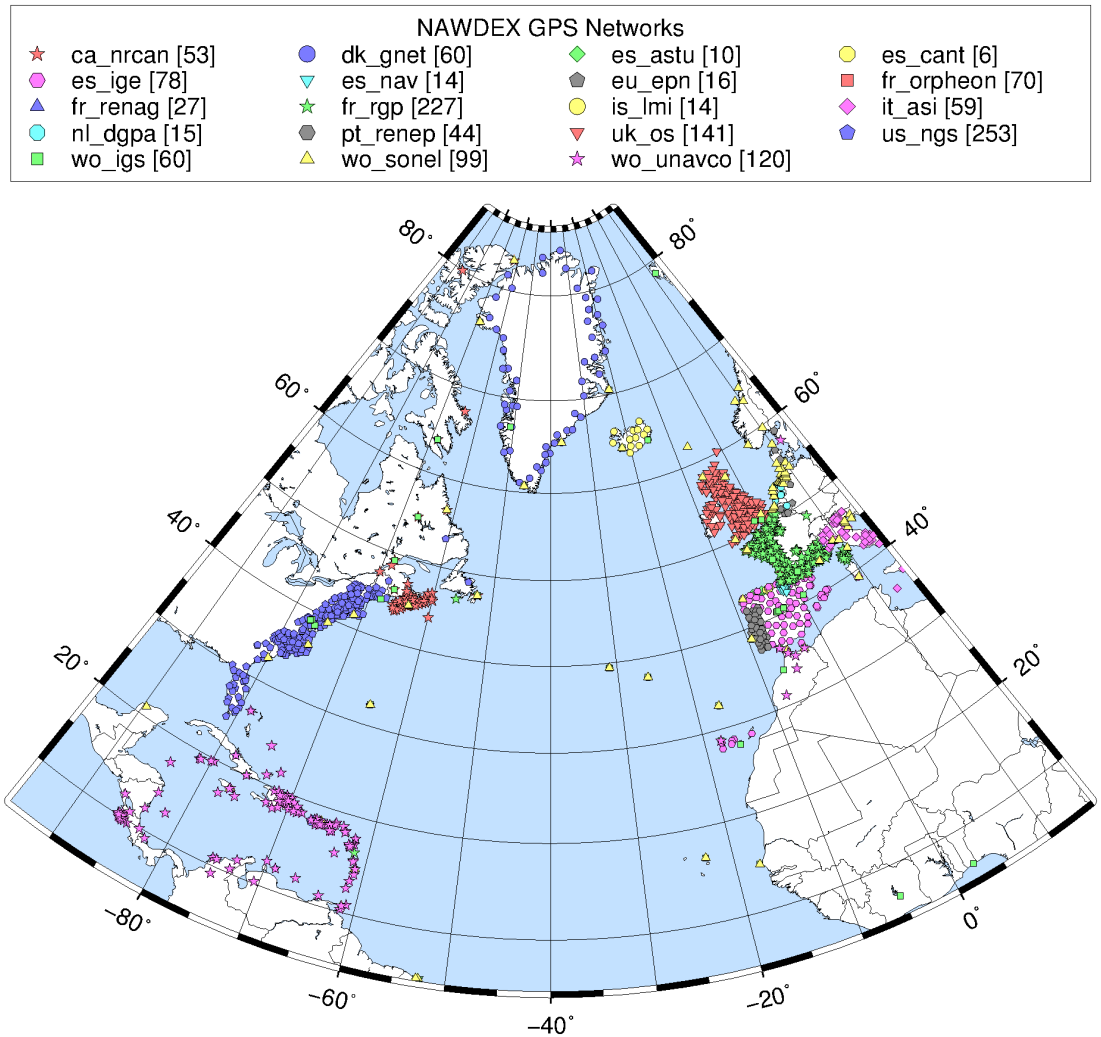
Outlines

Providers

Use of more than **1,200 COR stations** around the North Atlantic area.

- 19 data providers (free or private data)
  ➥ Specific request to some providers (Nottingham Geospatial Institute, DTU Space, LMI, Direção-Geral do Território).
- Period of interest: day-of-year 240 to 310 (August 27 to November 5)

Networks


NAWDEX GPS Networks
ca_nrcan [53]
dk_gnet [60]
es_astu [10]
es_cant [6]
es_ige [78]
es_nav [14]
eu_epn [16]
fr_orpheon [70]
fr_renag [27]
fr_rgp [227]
is_lmi [14]
it_asi [59]
nl_dgpa [15]
pt_renep [44]
uk_os [141]
us_ngs [253]
wo_igs [60]
wo_sonel [99]
wo_unavco [120]
80°
60°
40°
20°
−80°
−60°
−40°
−20°
0°

Precise Point Positioning

GPS processing using **PPP** strategy:

- **Absolute** and **post-processed** positioning using **GPS carrier phase measurements**.
- Use of **Gipsy-Oasis II 6.4** (JPL / NASA)
- Further details:
  - SRIF for filtering / estimation
  - PPP with fixed ambiguities
  - 30h session around midday
  - Use of IERS 2010 standard
  - One position per sessions
  - troposphere parameters modeled as random walk processes.

Troposphere modeling

Use of ECMWF-based data (VMFgrid):

- Values for ZHD
- A priori values for ZWD
- Mapping function, for hydrostatic and wet delays, horizontal gradients

Estimation as random walk process:

- ZWD, 5 $mm \cdot h^{-1/2}$
- Horizontal gradients, 0.5 $mm \cdot h^{-1/2}$
- 5 min resolution

Conversion into IWV for further comparisons

Troposphere solution

Screening of ZWD estimates using formal errors

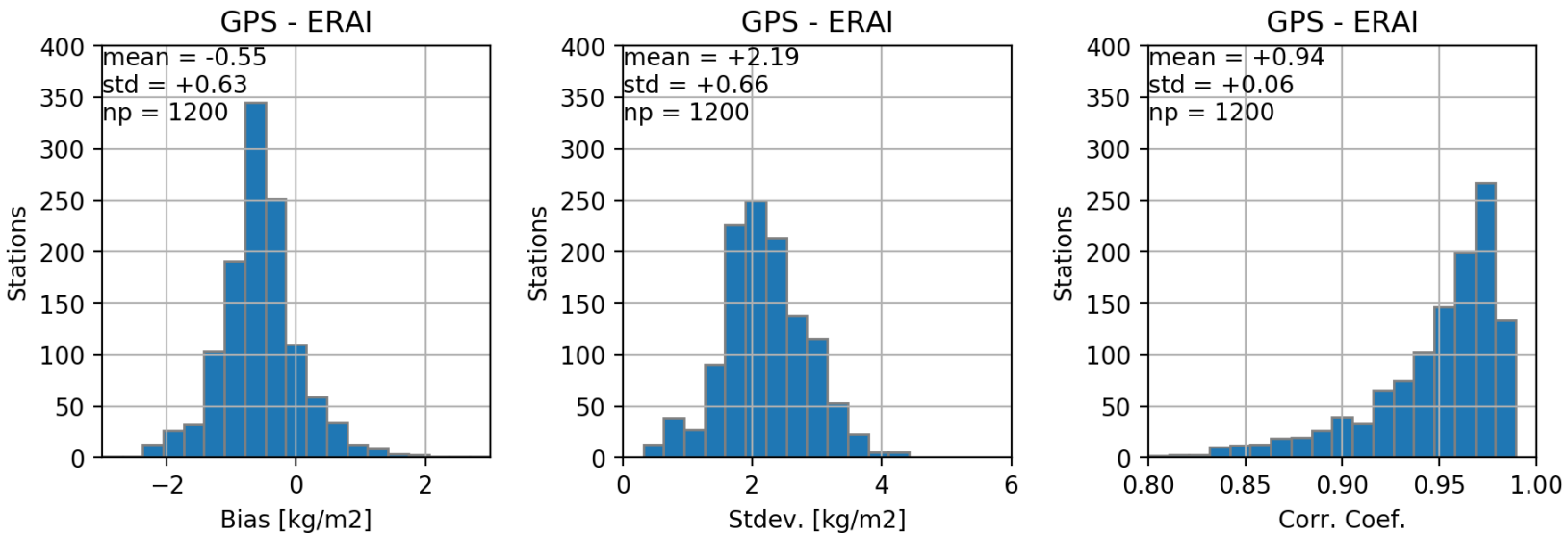
- Rejection rate about 0.3%
- Validation of screening with the improvement of weighted outputs (positions, RMS, etc.)

Outlines

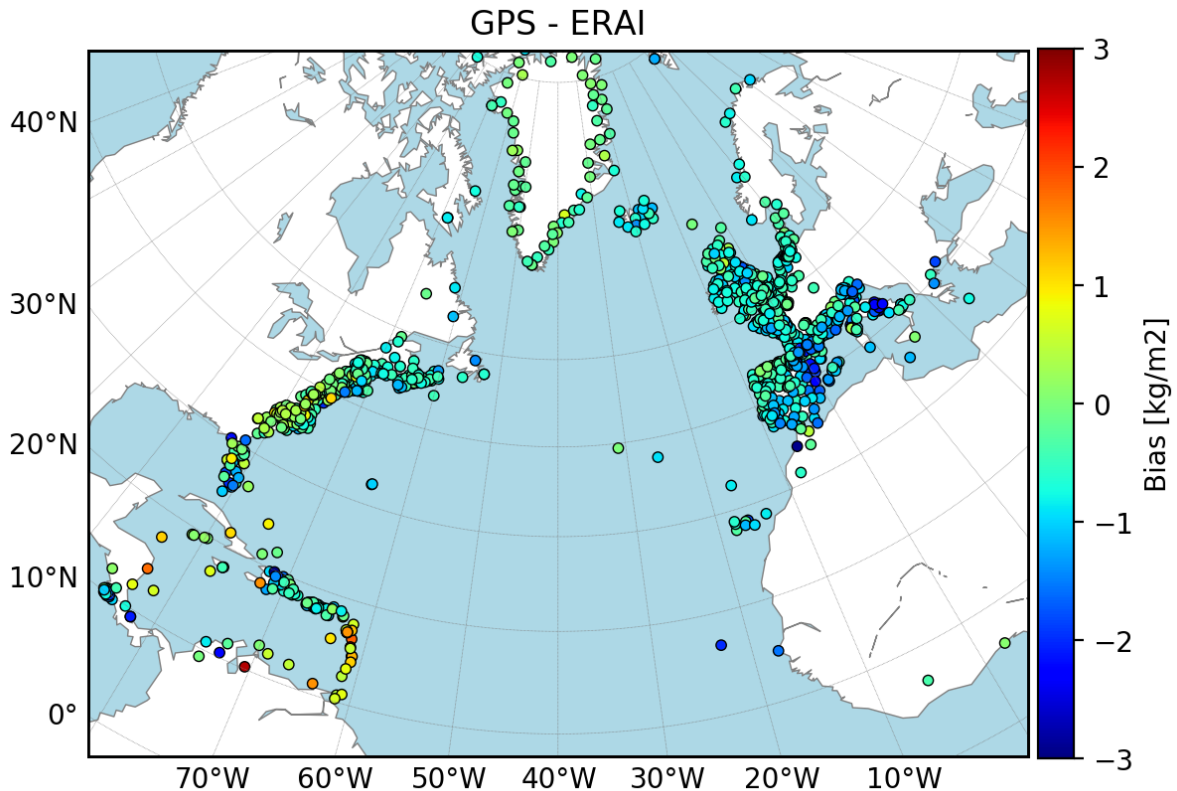
Global differences

- Extraction of IWV time series from ERAI for each GPS station
- Statistics of IWV differences:
  - 1200 stations providing at least 50 comparisons
  - Dry mean bias of GPS wrt ERAI
  - Mean standard deviation about 2.2 kg/m2
  - Good correlation between time series (about 0.94%)

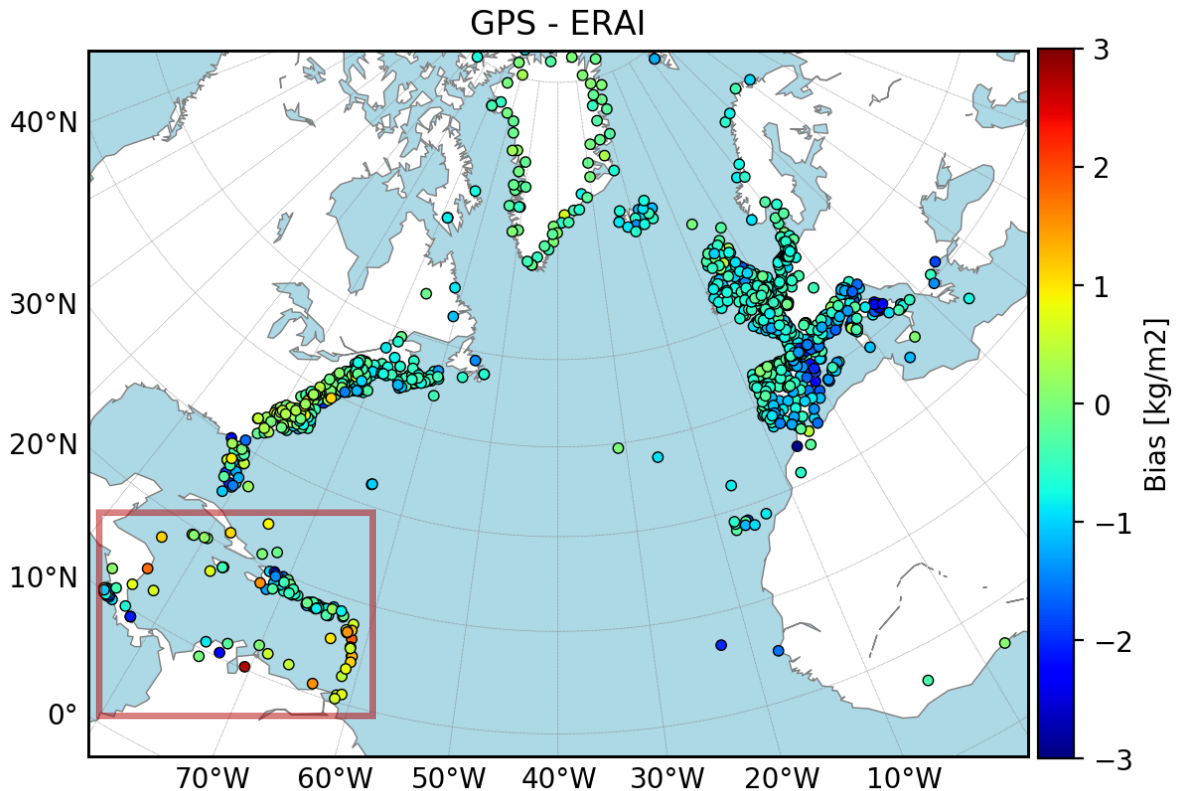
➥ Consistent with previous studies [Parracho et al., 2018 - ACP]



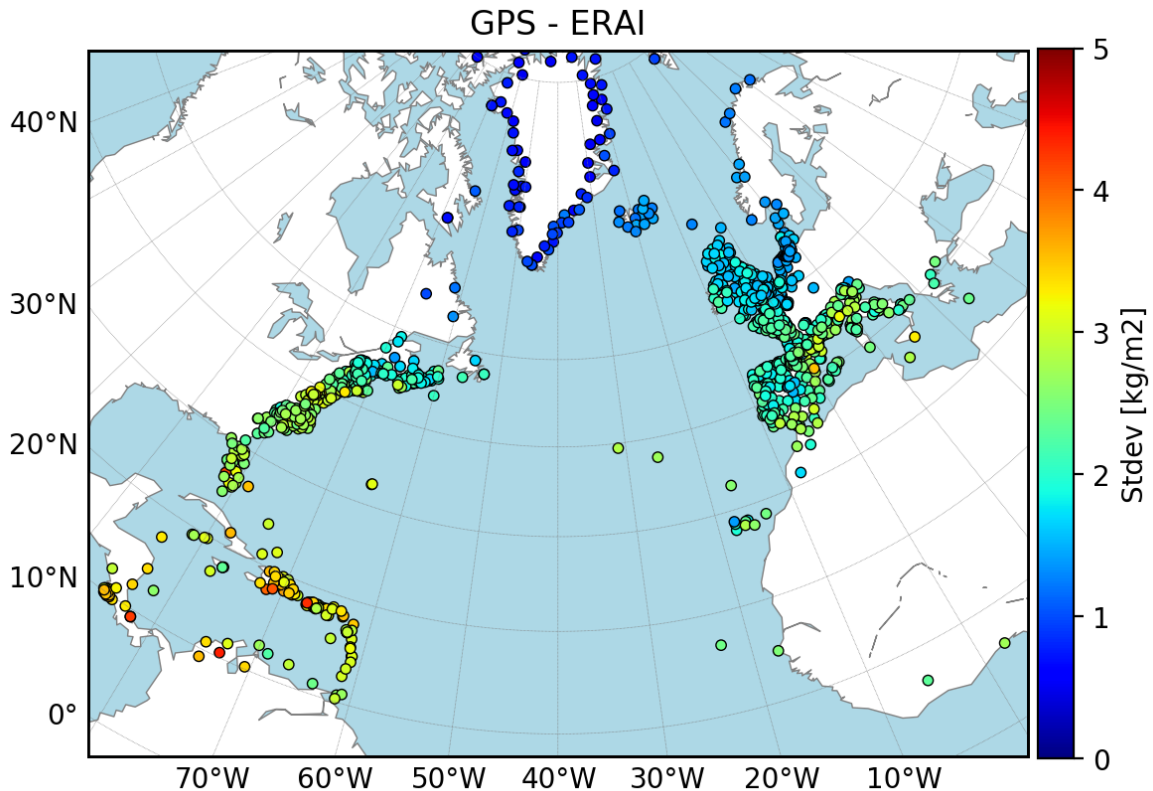
Spatial distribution of differences



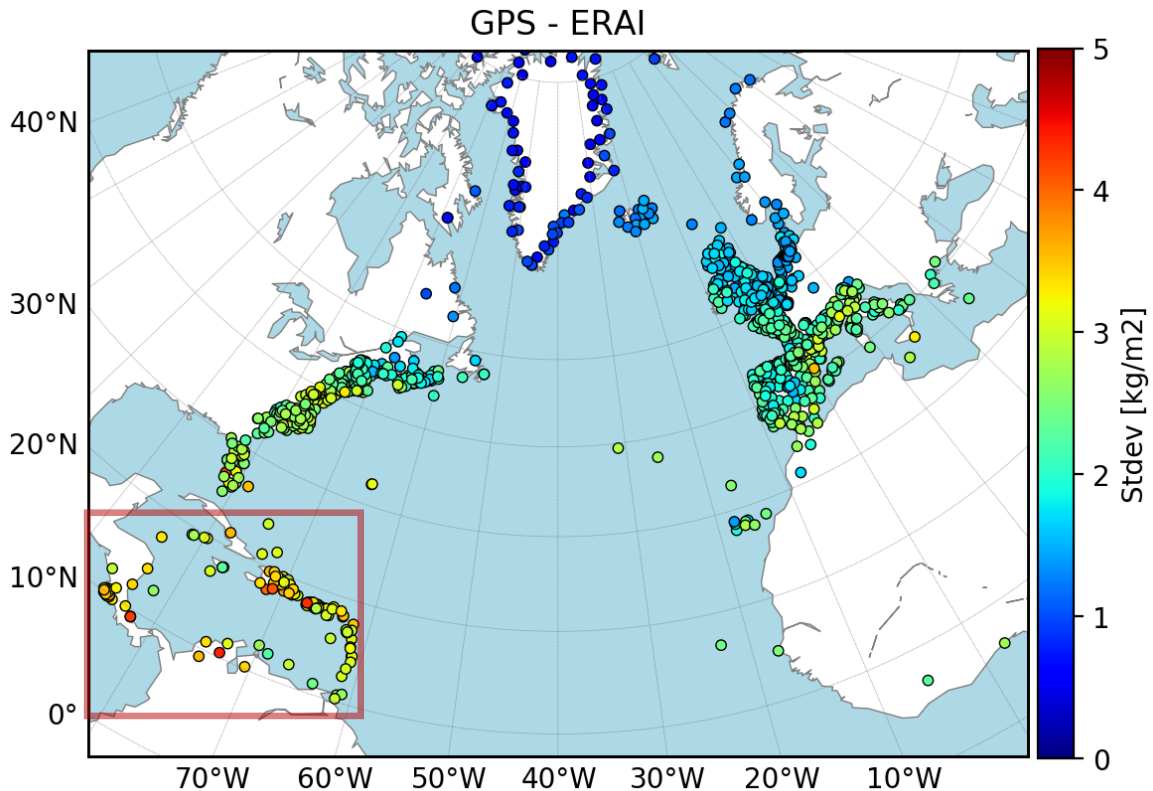
Spatial distribution of differences



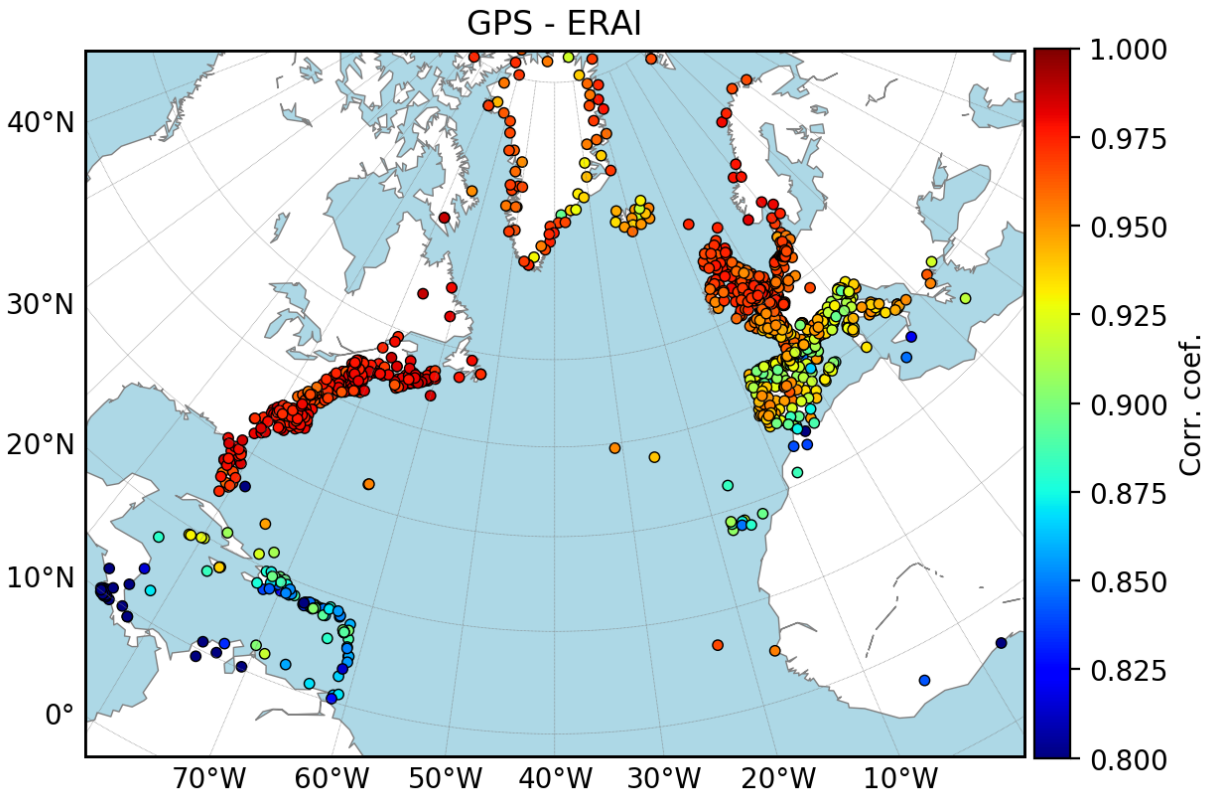
Spatial distribution of differences



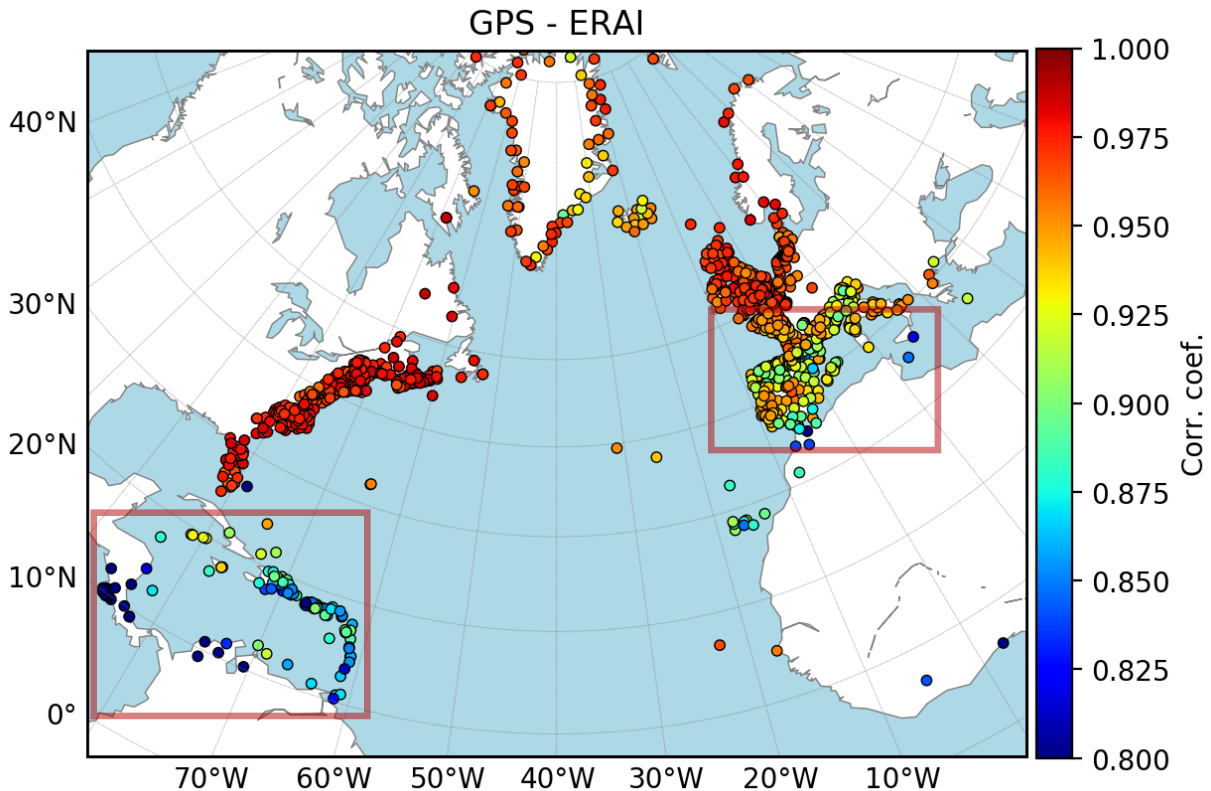
Spatial distribution of differences



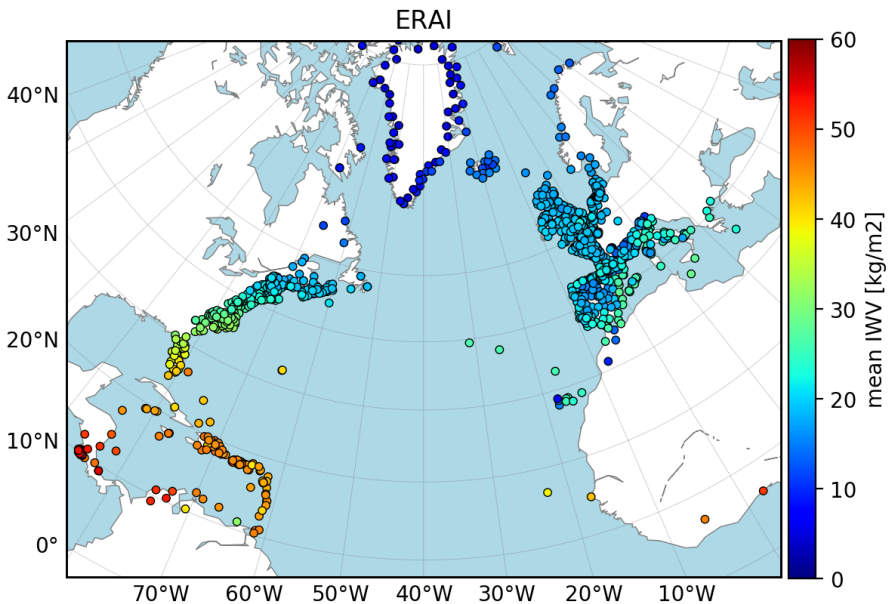
Spatial distribution of differences

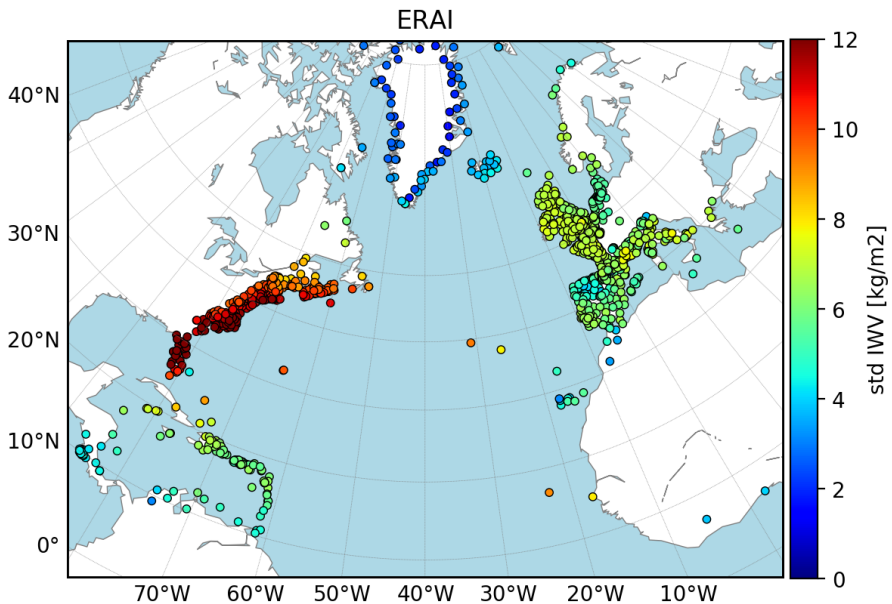


Spatial distribution of differences

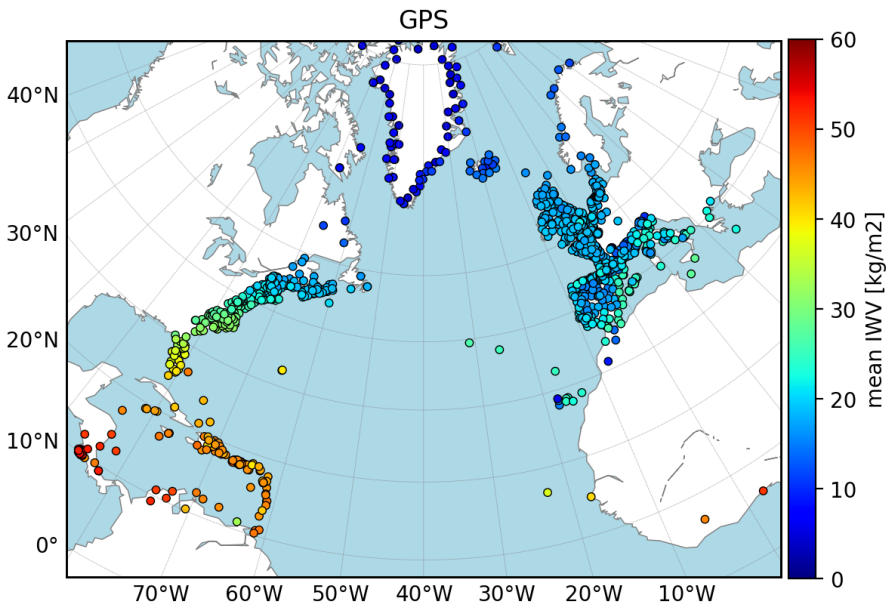


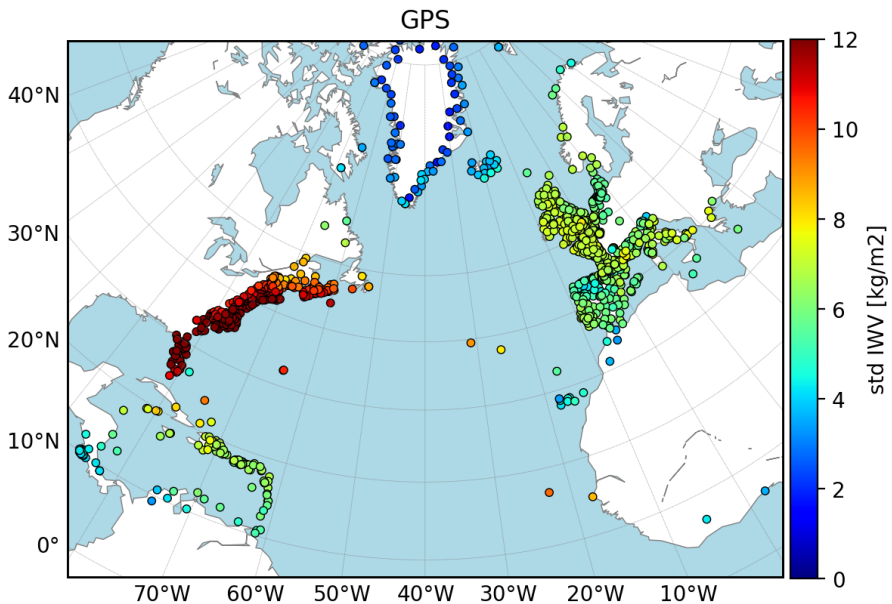
Spatial distribution of IWV



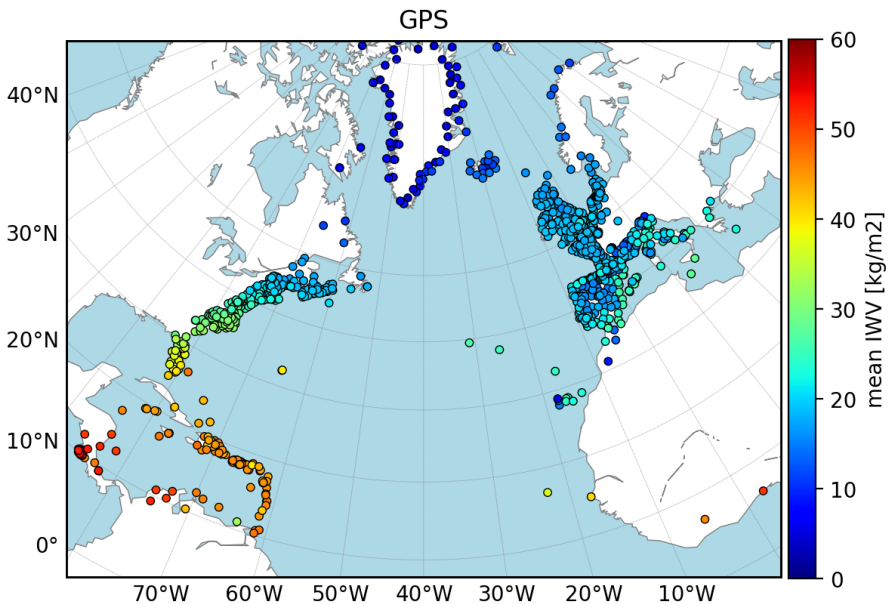


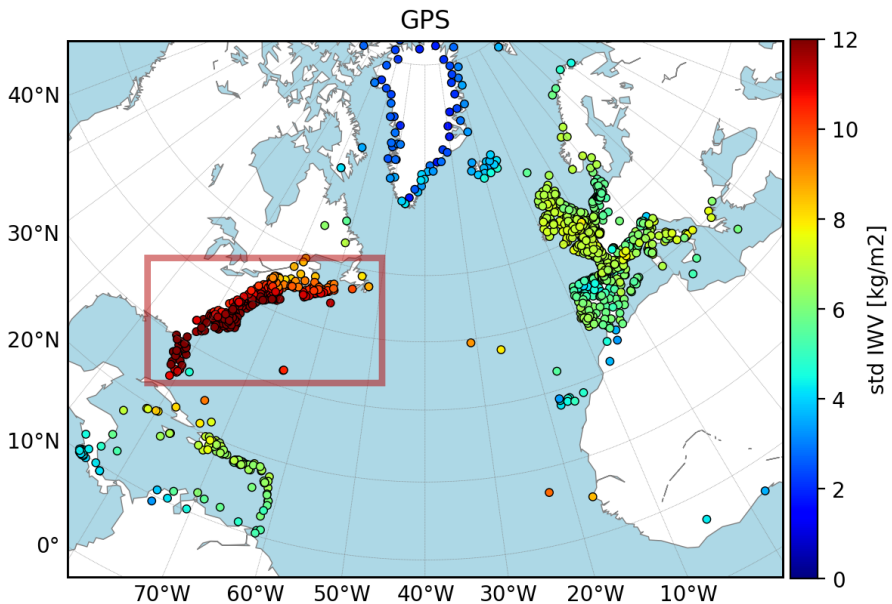
Spatial distribution of IWV





Spatial distribution of IWV



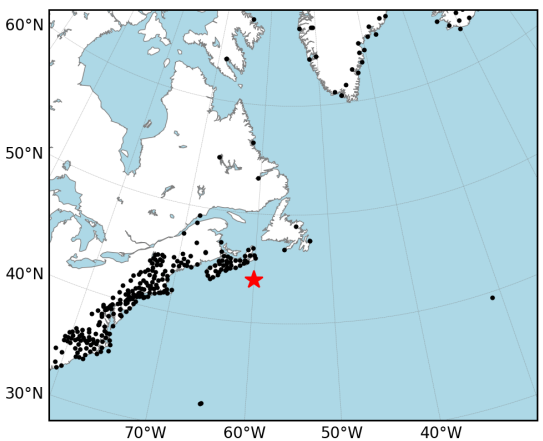


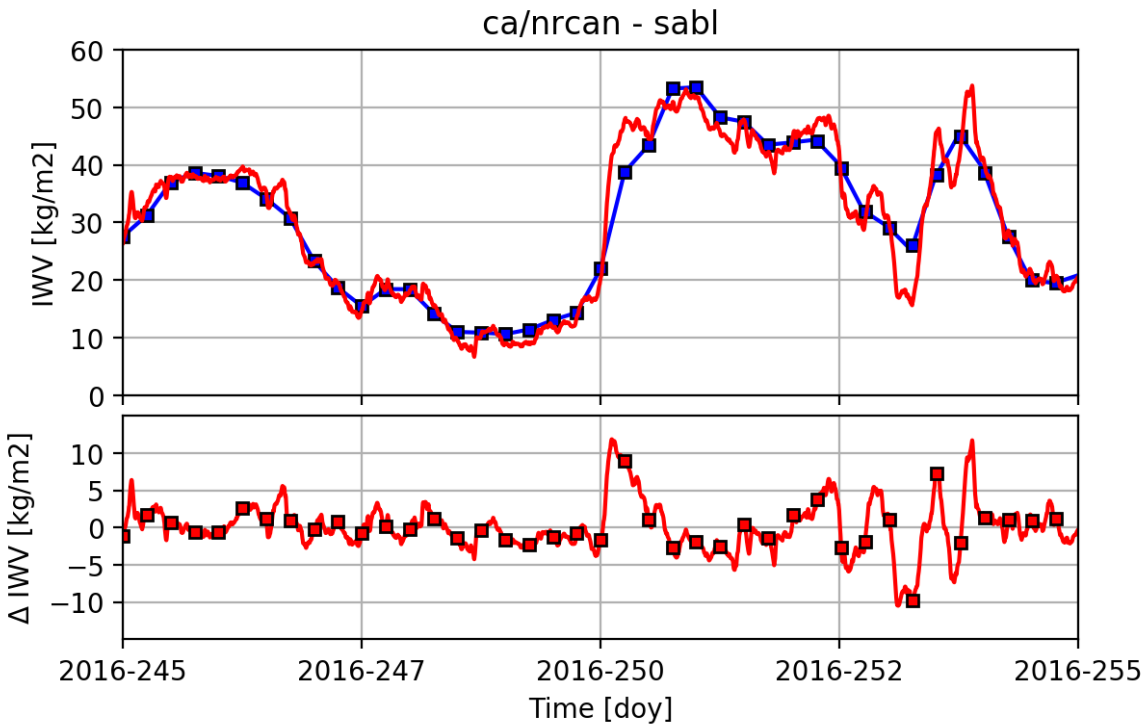
Sensing WV variabilty

GPS – ERAI

Overall differences [kg/m2]

σ_E	σ_G	b	σ	ρ
10.9	11.4	-0.4	2.1	98.4



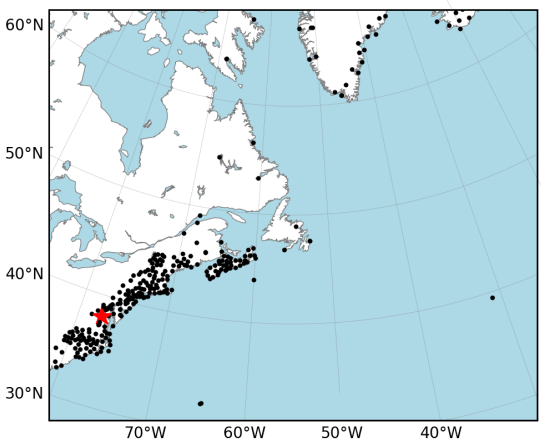


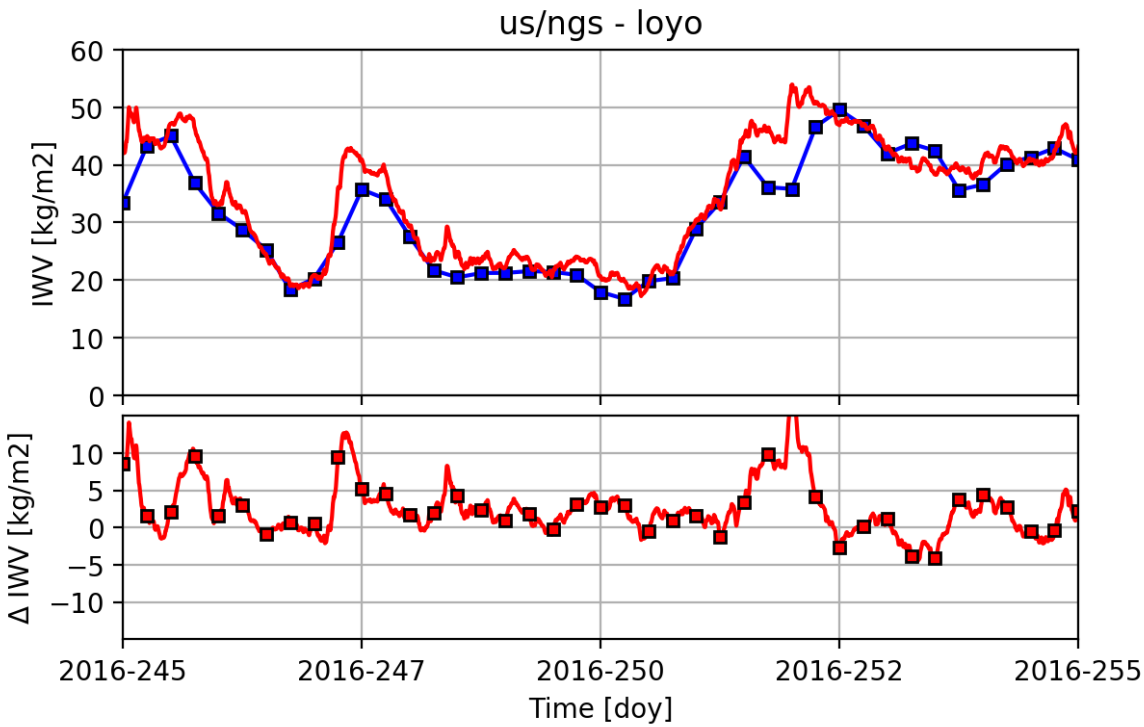
Sensing WV variabilty

GPS – ERAI

Overall differences [kg/m2]

σ_E	σ_G	b	σ	ρ
10.3	11.6	1.0	3.1	96.6



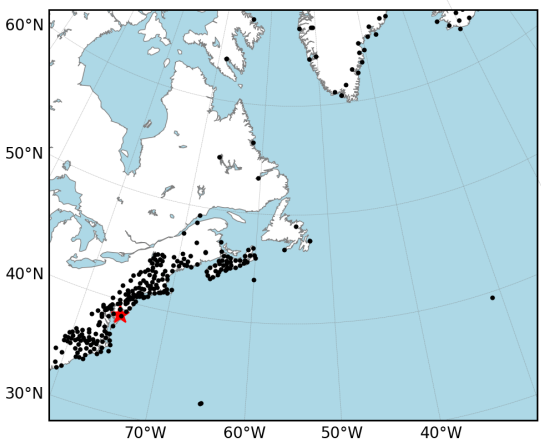


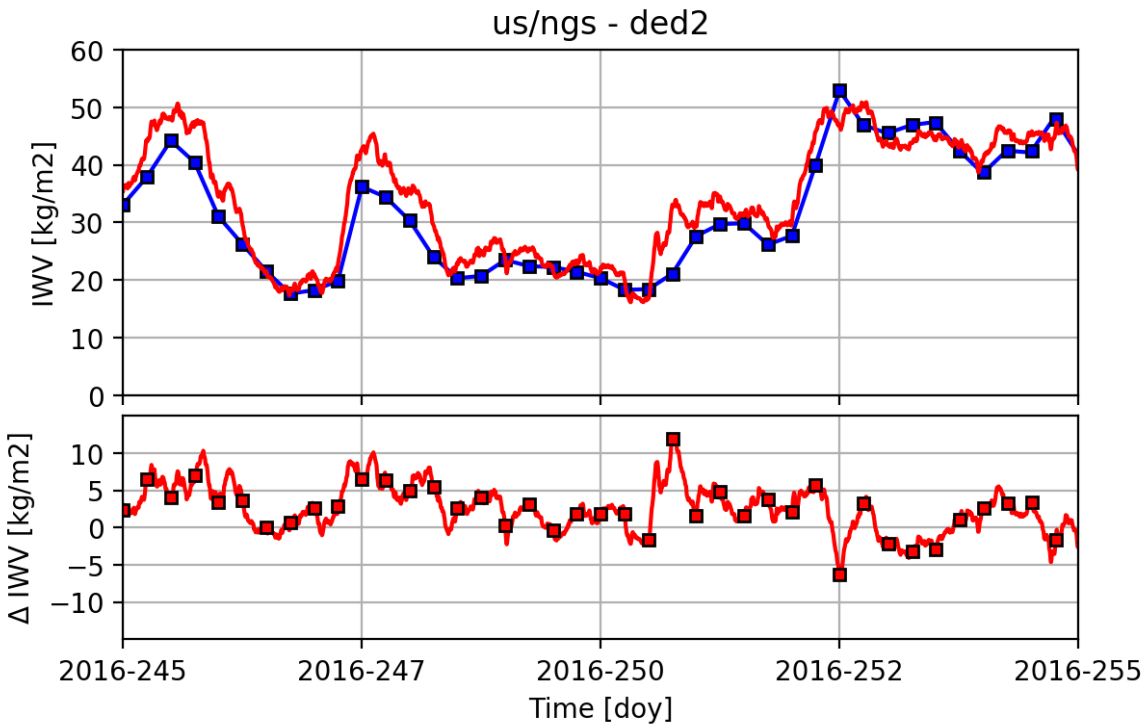
Sensing WV variabilty

GPS – ERAI

Overall differences [kg/m2]

σ_E	σ_G	b	σ	ρ
10.6	11.9	1.3	3.4	96.1





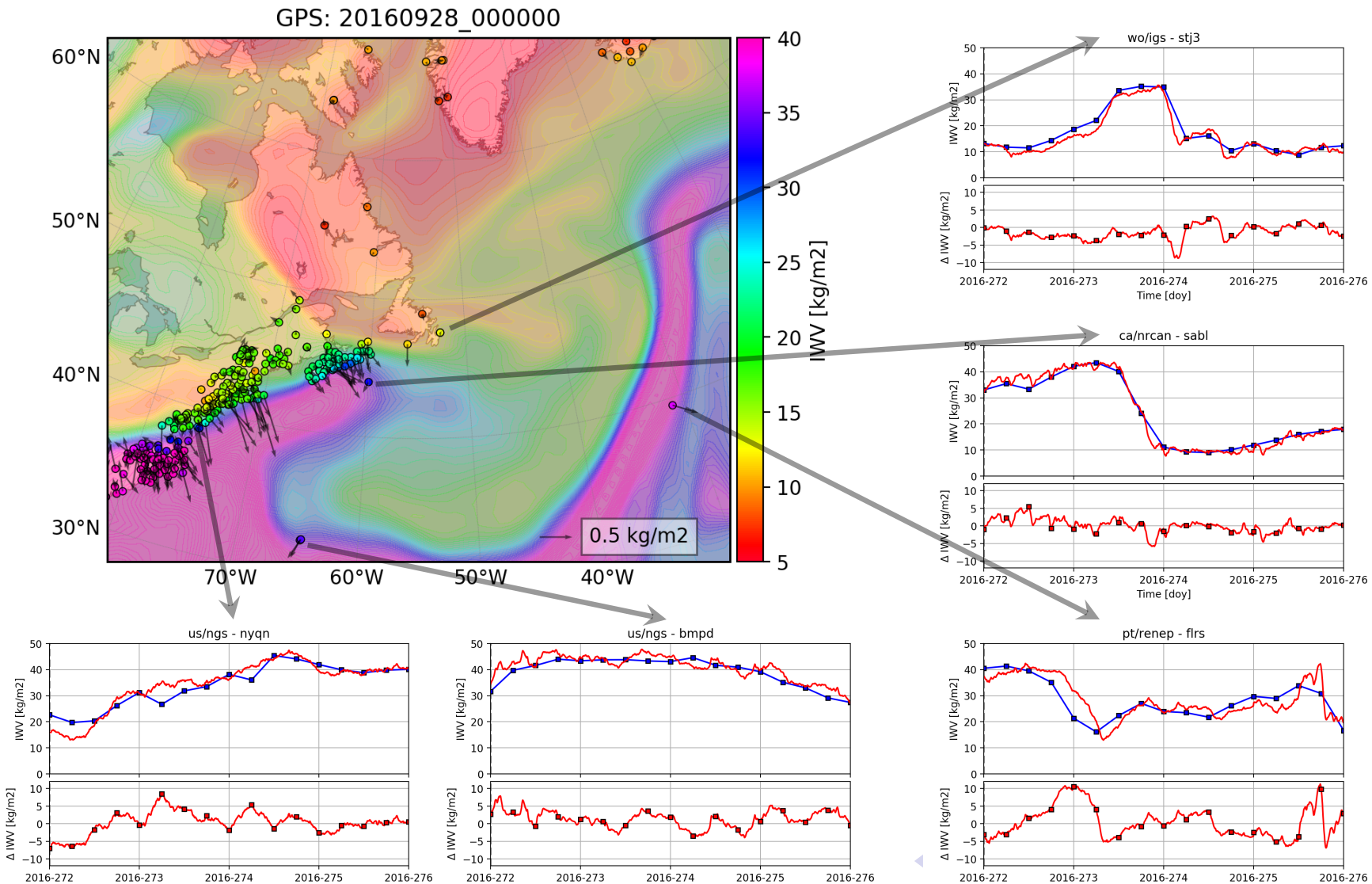
Outlines

IWV from ERAI, GPS and gradients

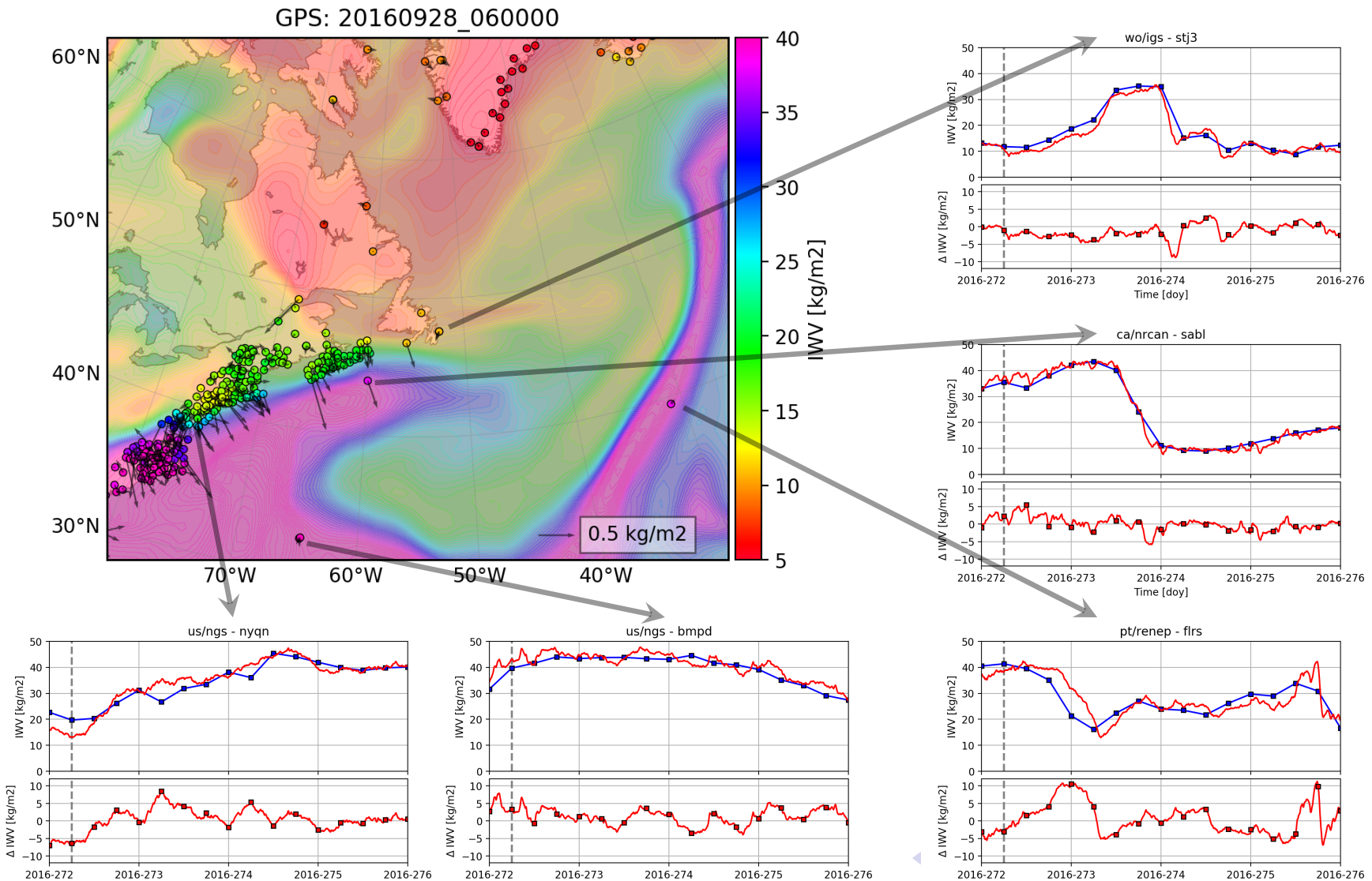
Use of :

- GPS IWV (5 min)
- GPS IWV gradients (5 min)
- ERAI IWV fields (6h / 0,75° $\times$ 0,75°)

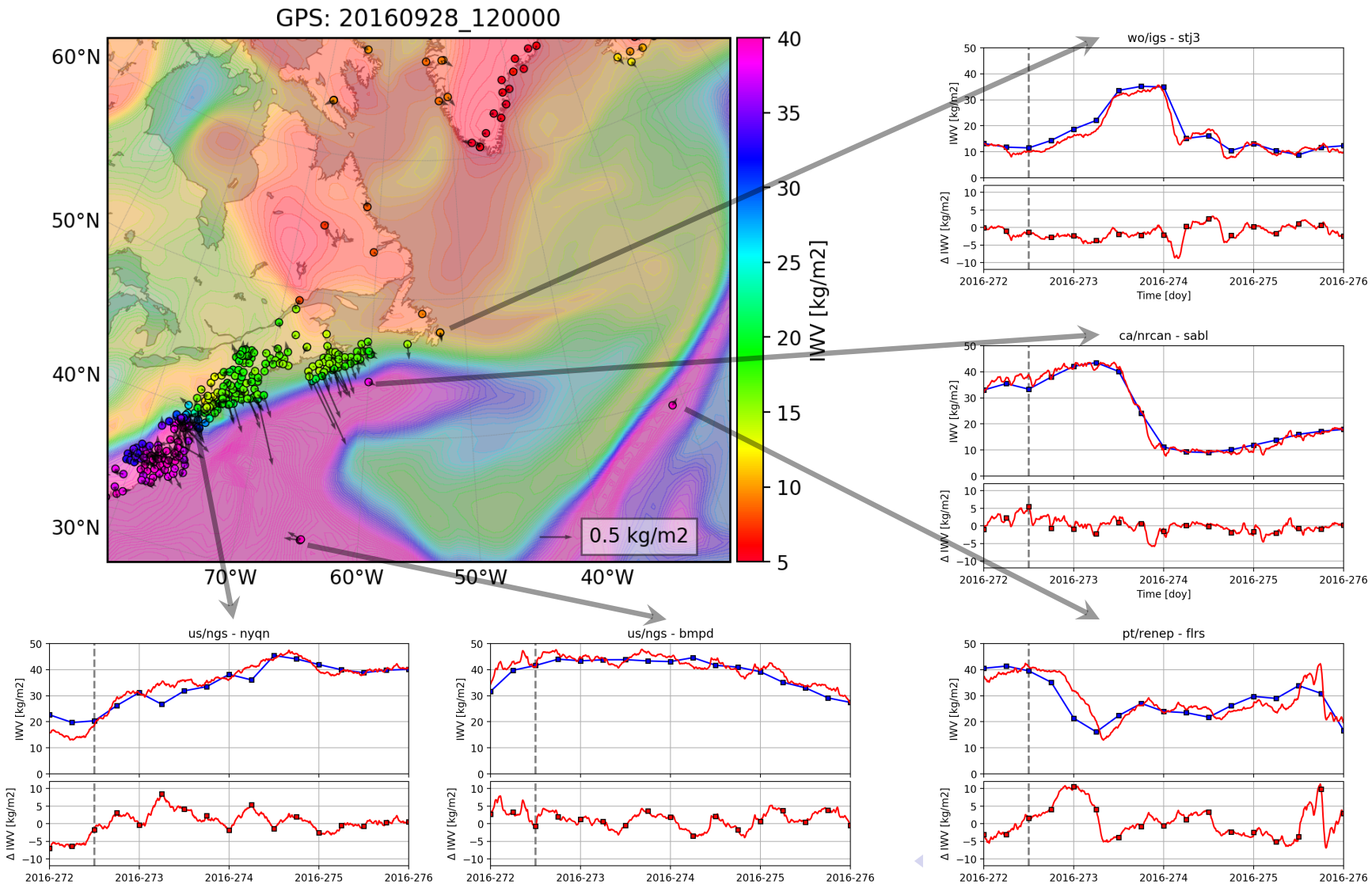
Spatio-Temporal Variability of IWV



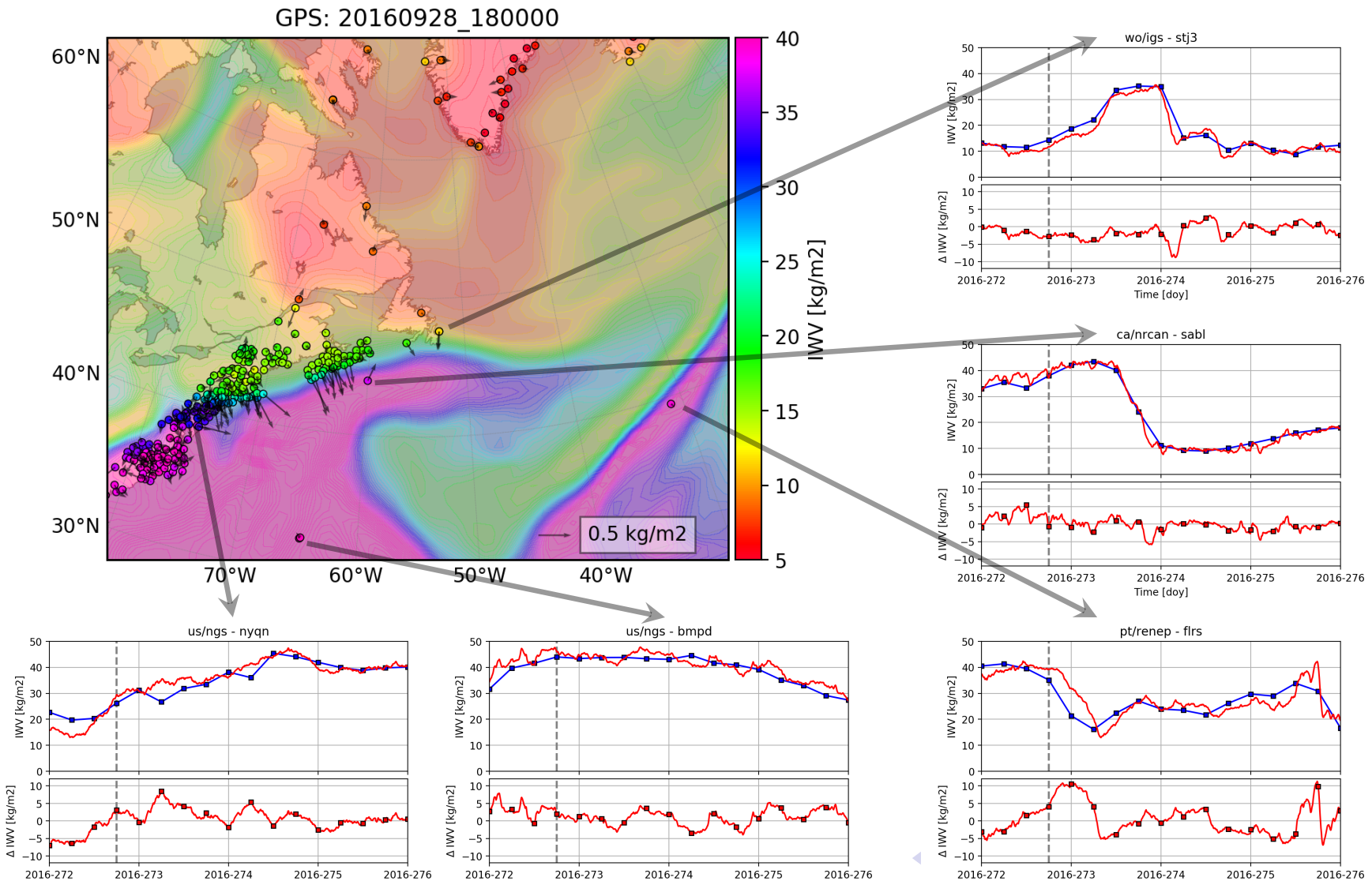
Spatio-Temporal Variability of IWV



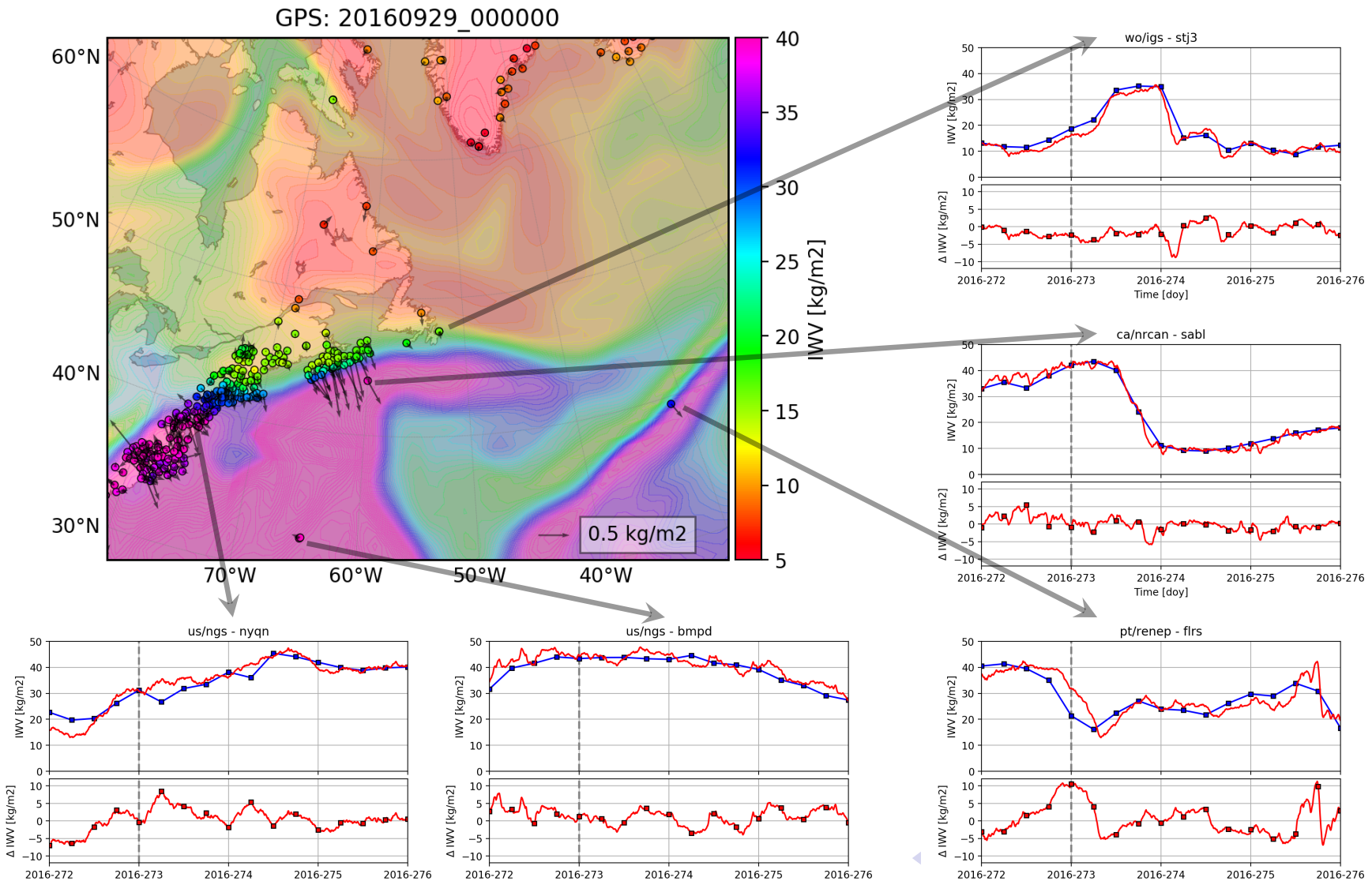
Spatio-Temporal Variability of IWV



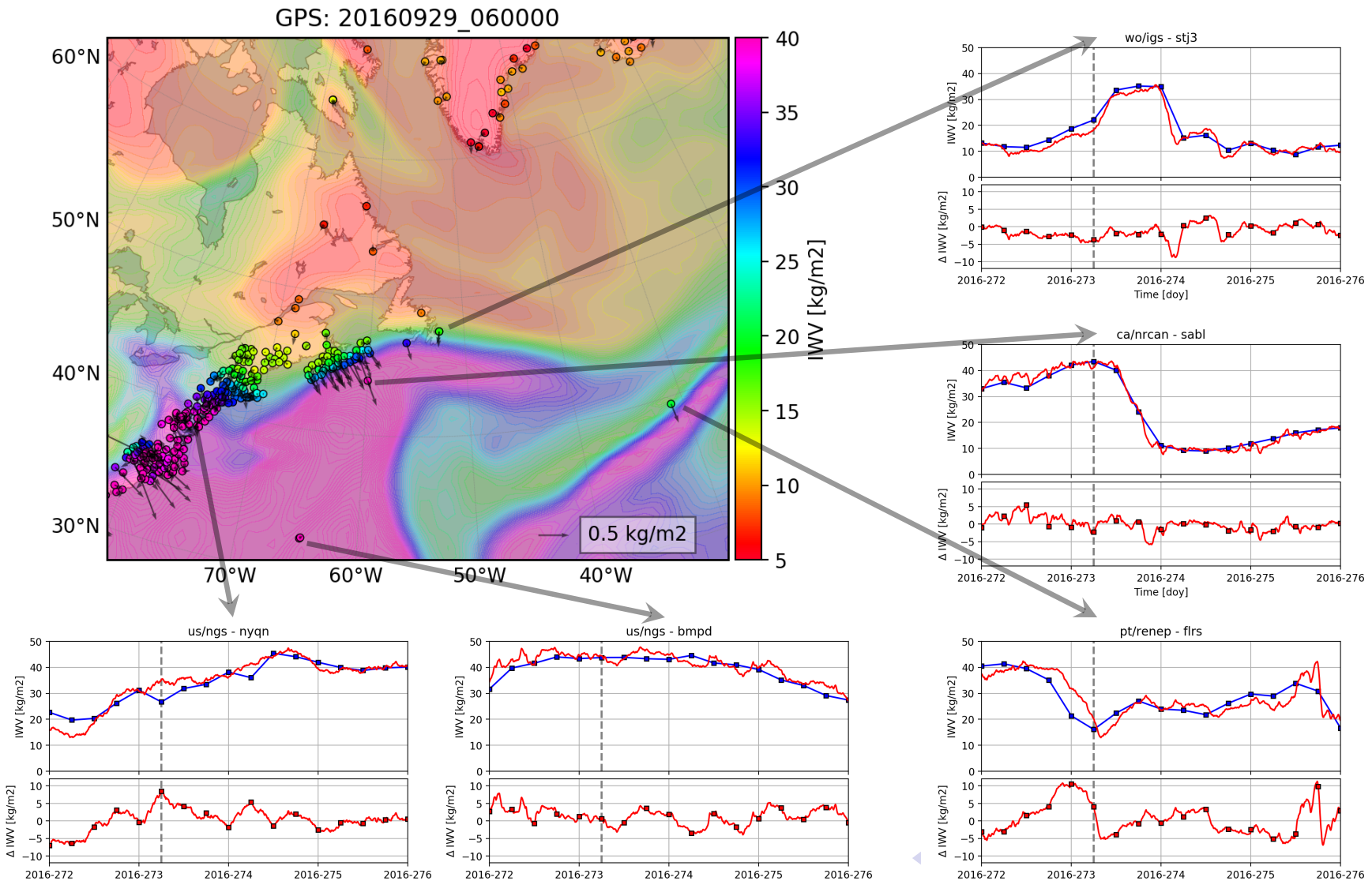
Spatio-Temporal Variability of IWV



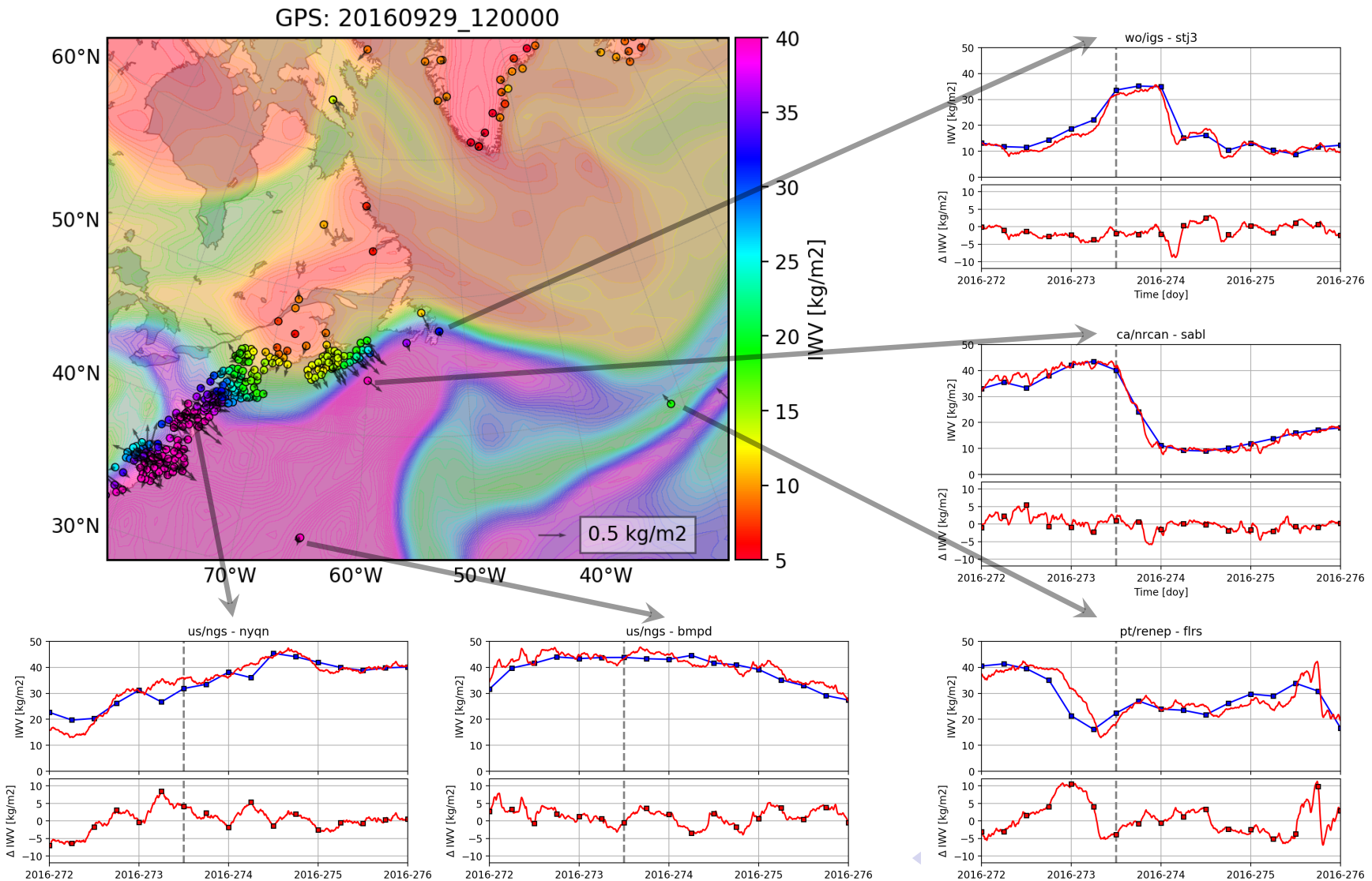
Spatio-Temporal Variability of IWV



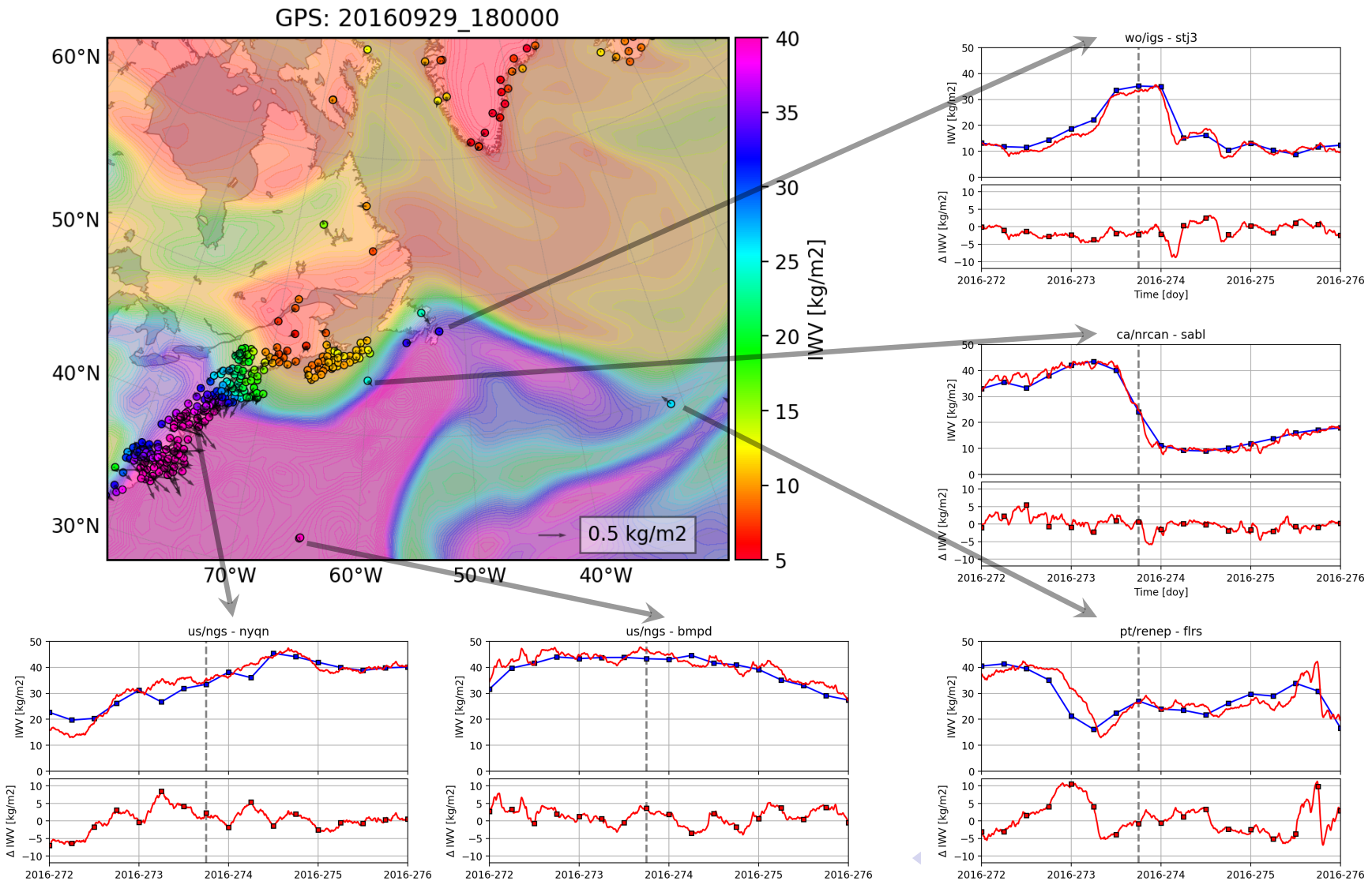
Spatio-Temporal Variability of IWV



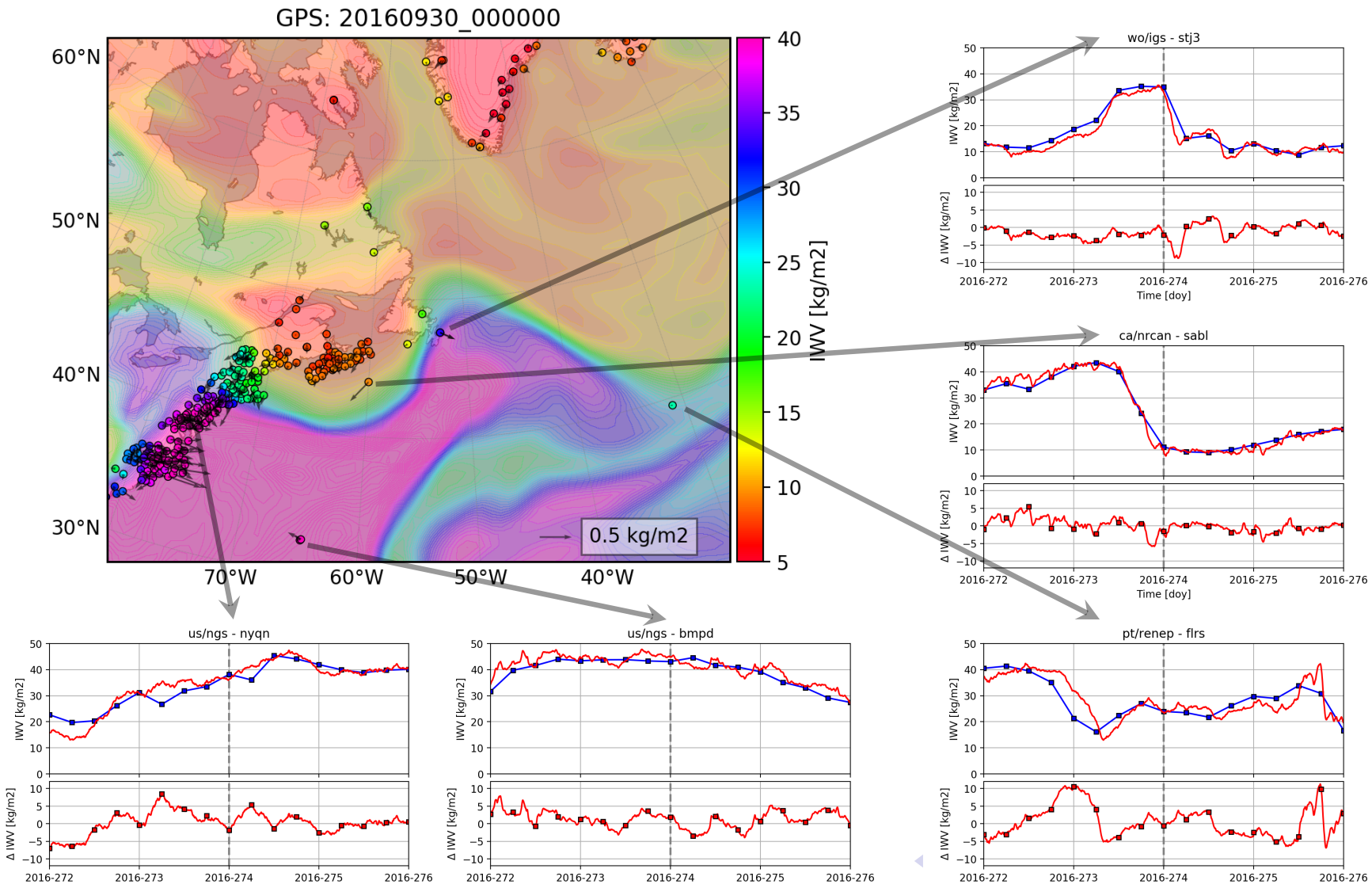
Spatio-Temporal Variability of IWV



Spatio-Temporal Variability of IWV



Spatio-Temporal Variability of IWV



Outlines

Summary

- A ground based GPS dataset was produced for the NAWDEX campaign.
  ☹ Dataset limited to inshore area...
- IWV are estimated for more than **1200 ground based GPS stations** from Aug. 28 to Nov. 5 at **5 min. time resolution**.
- This dataset is validated with a screening procedure.
- A **pretty good agreement** between ERAI and GPS IWV is observed at a large space / time scale :
  - Bias / standard deviations are consistent with previous studies.
  - GPS IWV might better fit WV spatiotemporal variability.
- This dataset is intended to be used for the documentation of IOPs.

Outlook

- Further investigations on Stalactite Cyclone.
- **New Internship** : IWV retrieval from offshore GPS measurements on RV Atalante (Ifremer)
- Further studies :
  - Use of higher resolution model than ERAI for comparisons?
  - Comparisons with radiosoundings (NAWDEX launch, higher resolution / better quality check)?
    ➥ First study from O. Ntayabagiri with UWYO database, should be explored more deeply...
  - Comparisons with humidity products from satellites in coastal area.
  - New investigations on horizontal gradients.

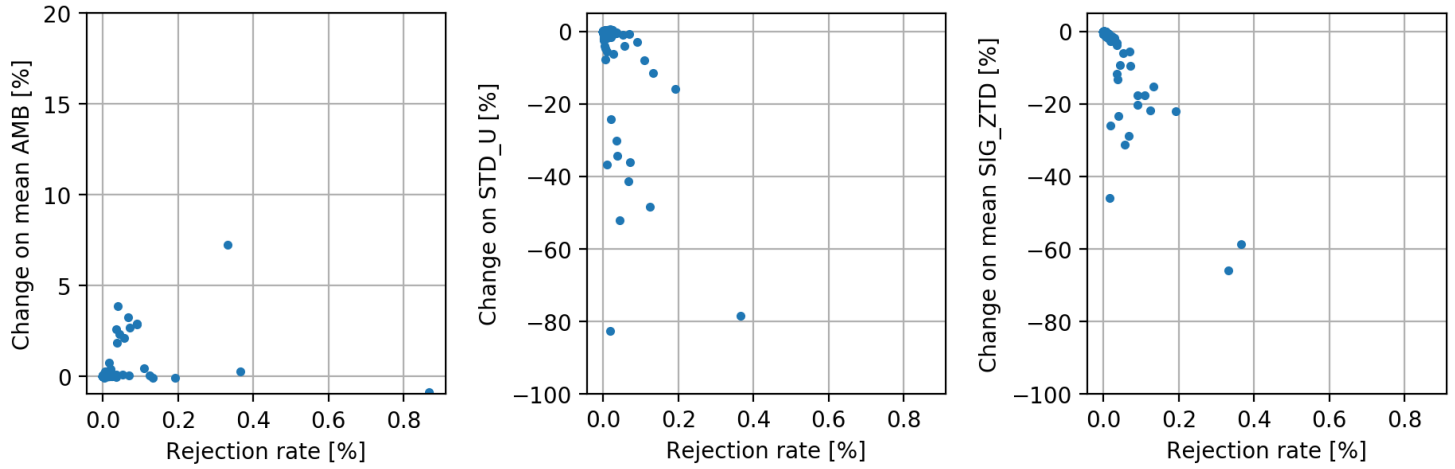
Acknowledgments

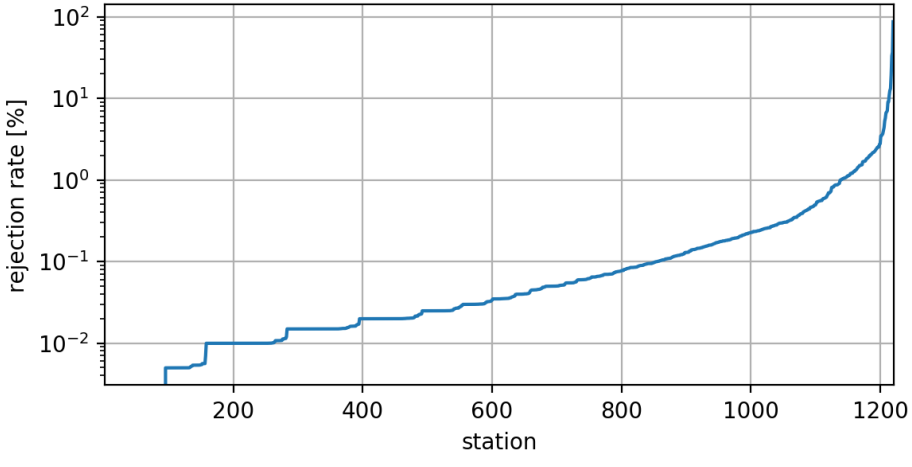
- GPS data providers :
  - DTU Space (Dk) [Khan et al., 2016 - Sci. Adv.].
  - British Isles continuous GNSS Facility (Uk / Ir).
  - NRCAN (Ca), IGE, RGAPA, (Es), RENAG, Orpheon, RGP (Fr), LMI (Is), Asi (It), DGPA (Nl), NGS (Us), RENEP (Pt), UNAVCO, SONEL, IGS, EPN.
- ANR / DIP-NAWDEX (ANR-17-CE01-0010).

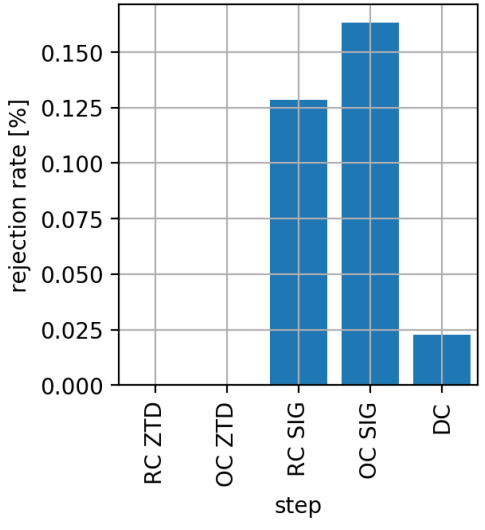
ENSTA Bretagne

Backup slides

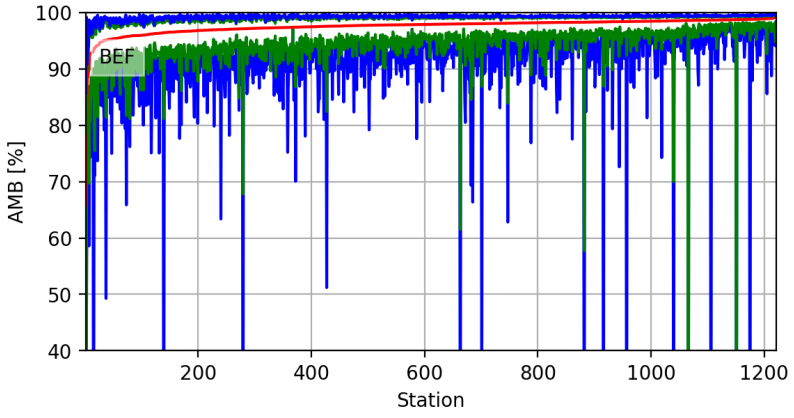
Screning

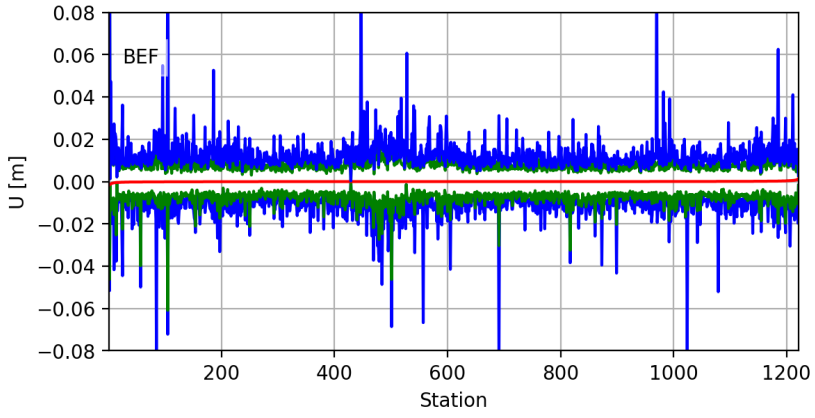

Change on mean AMB [%]
Rejection rate [%]
Change on STD_U [%]
Rejection rate [%]
Change on mean SIG_ZTD [%]
Rejection rate [%]

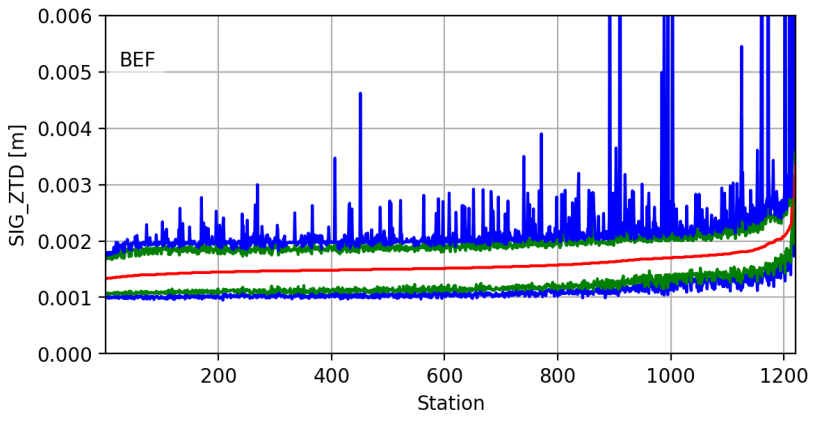

rejection rate [%]
station


rejection rate [%]
RC ZTD
OC ZTD
RC SIG
OC SIG
DC
step

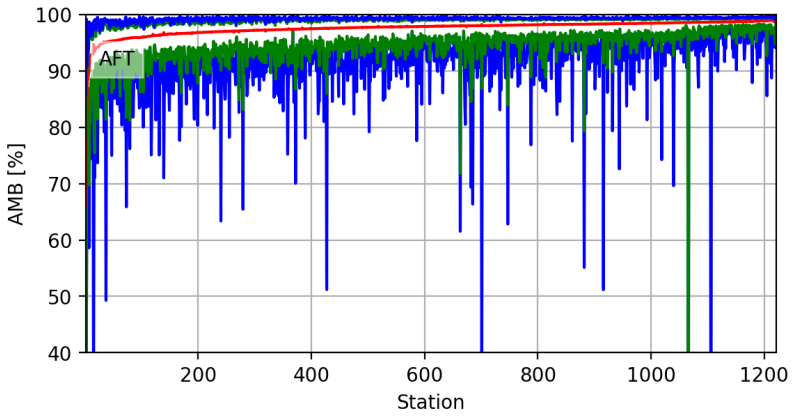
Screning

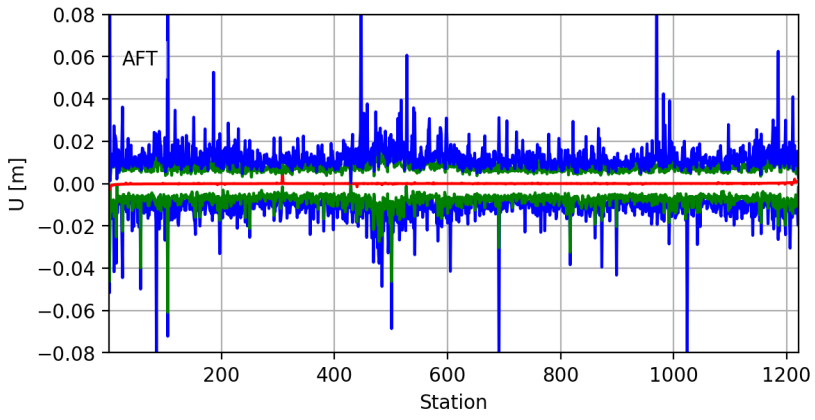

BEF
AMB [%]
Station
100
90
80
70
60
50
40
200
400
600
800
1000
1200

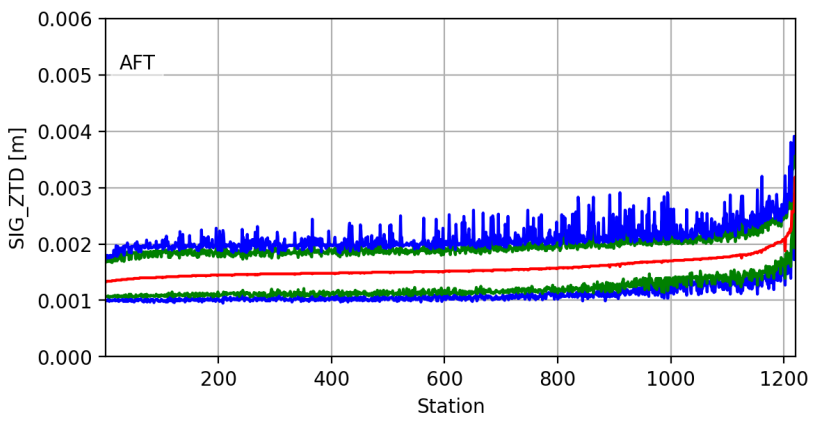

BEF
U [m]
Station
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.08
200
400
600
800
1000
1200


BEF
SIG_ZTD [m]
Station
0.006
0.005
0.004
0.003
0.002
0.001
0.000
200
400
600
800
1000
1200

Screning


AFT
AMB [%]
Station
100
90
80
70
60
50
40
200
400
600
800
1000
1200


AFT
U [m]
Station
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.08
200
400
600
800
1000
1200

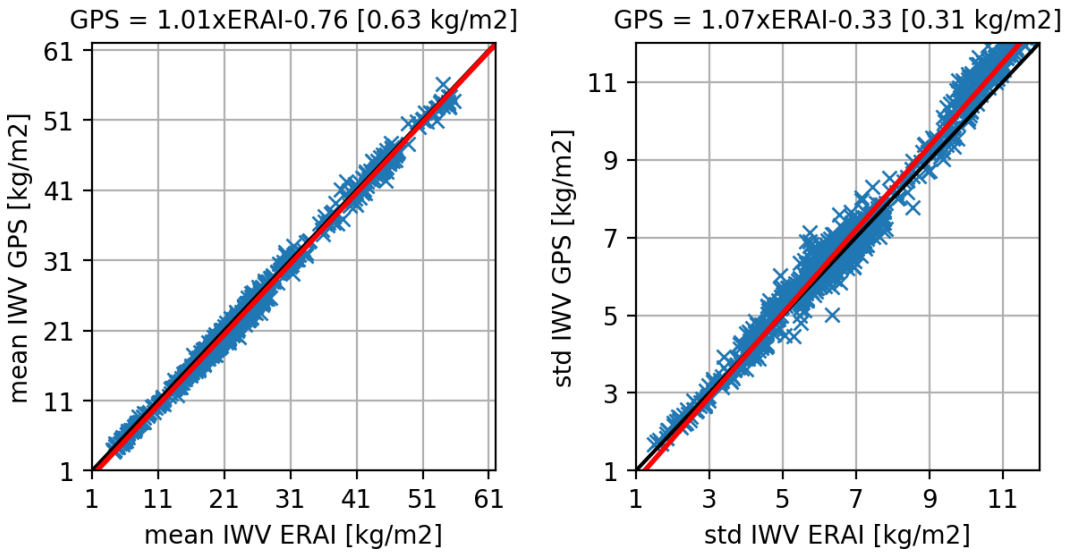

AFT
SIG_ZTD [m]
Station
0.006
0.005
0.004
0.003
0.002
0.001
0.000
200
400
600
800
1000
1200

GPS - RS

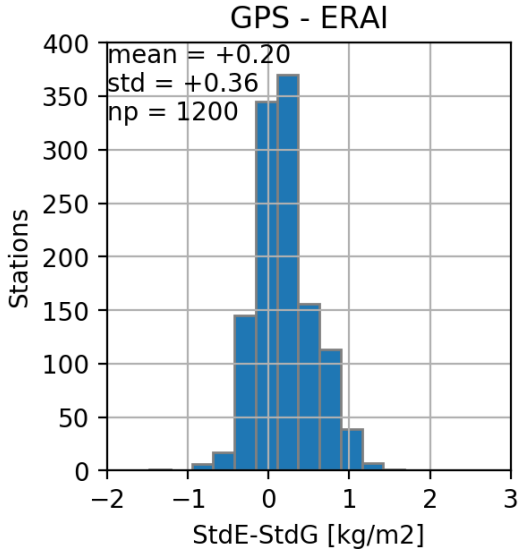
- Difficulties to manage RS form NAWDEX database
- Use of RS from UWYO database
- 45 collocations $<$ 50 km (H) / 50 m (V).

	b [kg/m2]	σ [kg/m2]	ρ
GPS-RS	-0.58 $\pm$ 0.89	1.4 $\pm$ 0.63	0.979
GPS - ERAI	-0.54 $\pm$ 0.49	2.0 $\pm$ 0.75	0.947

ERAI / GPS IWV cross-plot



GPS-ERAI Stdev IWV



RV Atalante


France
Portugal
Espagne
Océan Atlantique Nord
Maroc
Algérie
Mauritanie
Mali
Niger
Nigeria
Cuba
Mer des Caraïbes
Costa Rica
Panama
Venezuela
Colombie
Guyana
Suriname
Guinée
Sierra Leone
Libéria
Côte d'Ivoire
Ghana
Togo
Bénin
Sénégal
Gambie