Improving WRF simulations of coastal storms with better water vapour initial fields from InSAR interferometry

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Outline

Coastal storms can be extreme, due to high input of water vapor and strong mesoscale forcing (topography)

A state of the art model, such as WRF, such be able to deal with those systems (at the right resolution)

However one needs a good initial state, and the water vapor field may be critical. Here:

- We estimate PWV maps by Sentinel-1 data (and GNSS)
- WRF 3dVar assimilation experiments

GNSS, InSAR and water vapor

GNSS (GPS) data is a new source of water vapor data at relatively coarse resolution (50 km) but with frequent sampling (minutes to 1 h)

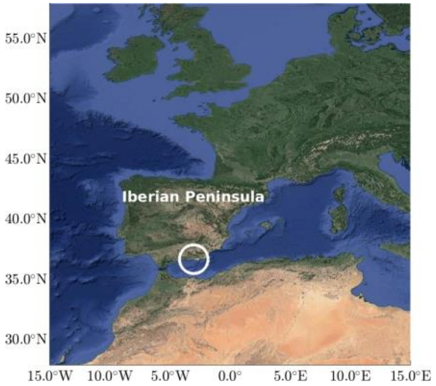
We propose to use an even newer source of data, InSAR (Synthetic Aperture Radar) interferometric maps, produced by Sentinel 1a,b

2-SAR images are available (now) every 6 days (ascending+descending)

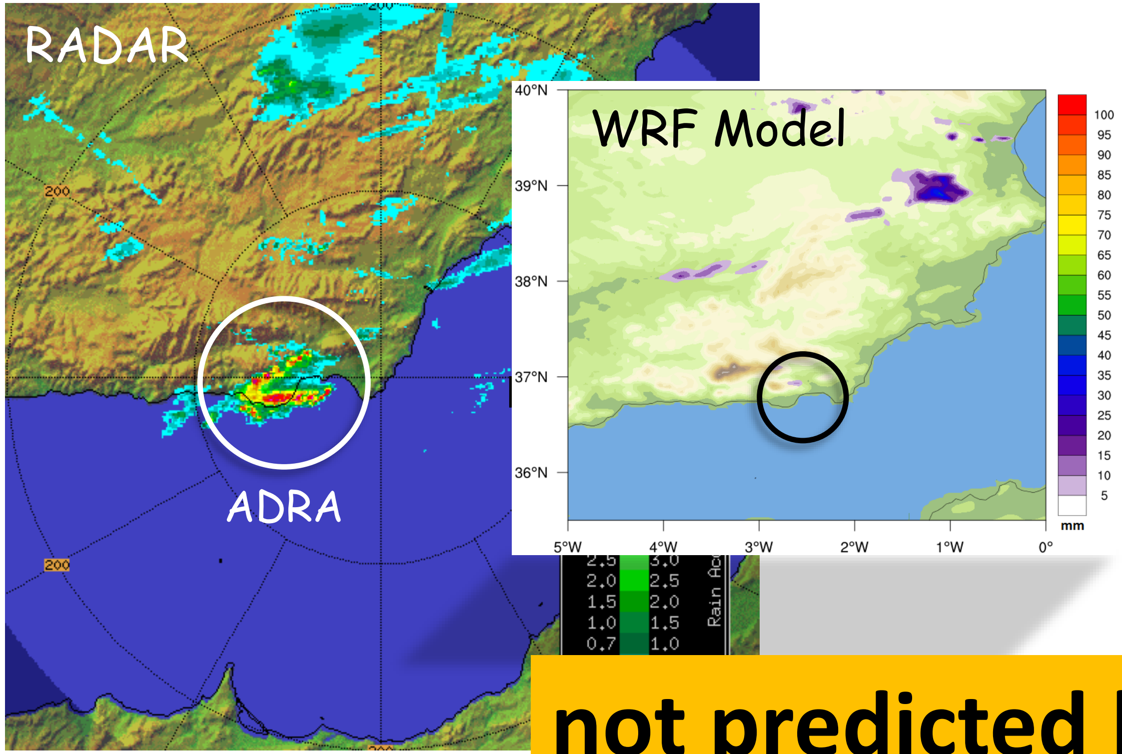
InSAR images (made from 2 co-located SAR maps) are produced to infer land movements, but are affected by water vapor (as GNSS): if there are no land movements we may infer anomalies of water vapor.

The Adra Storm (Sep 2015)

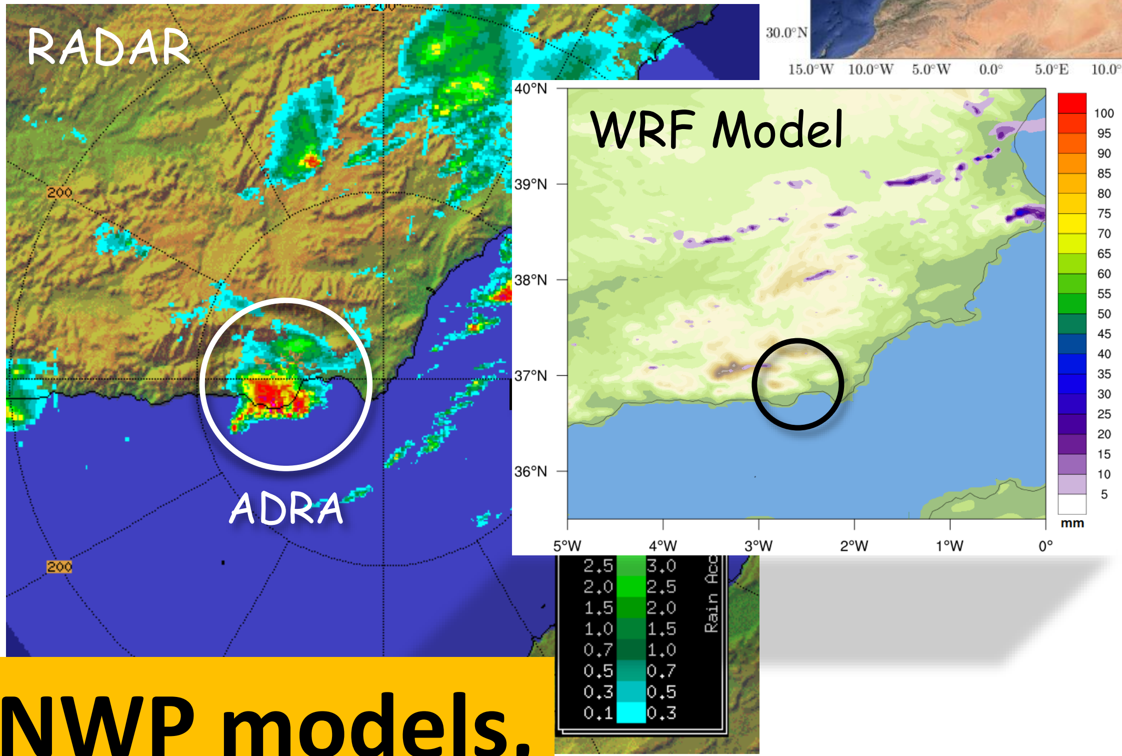
Two severe weather events over Adra (Almeria, Spain):
6th-7th September 2015 <u>with 12-13h apart</u>



6th Sep. 2015 - 22h



7th Sep. 2015 - 11h



not predicted by NWP models, each ~6h after Sentinel!

The Adra storm

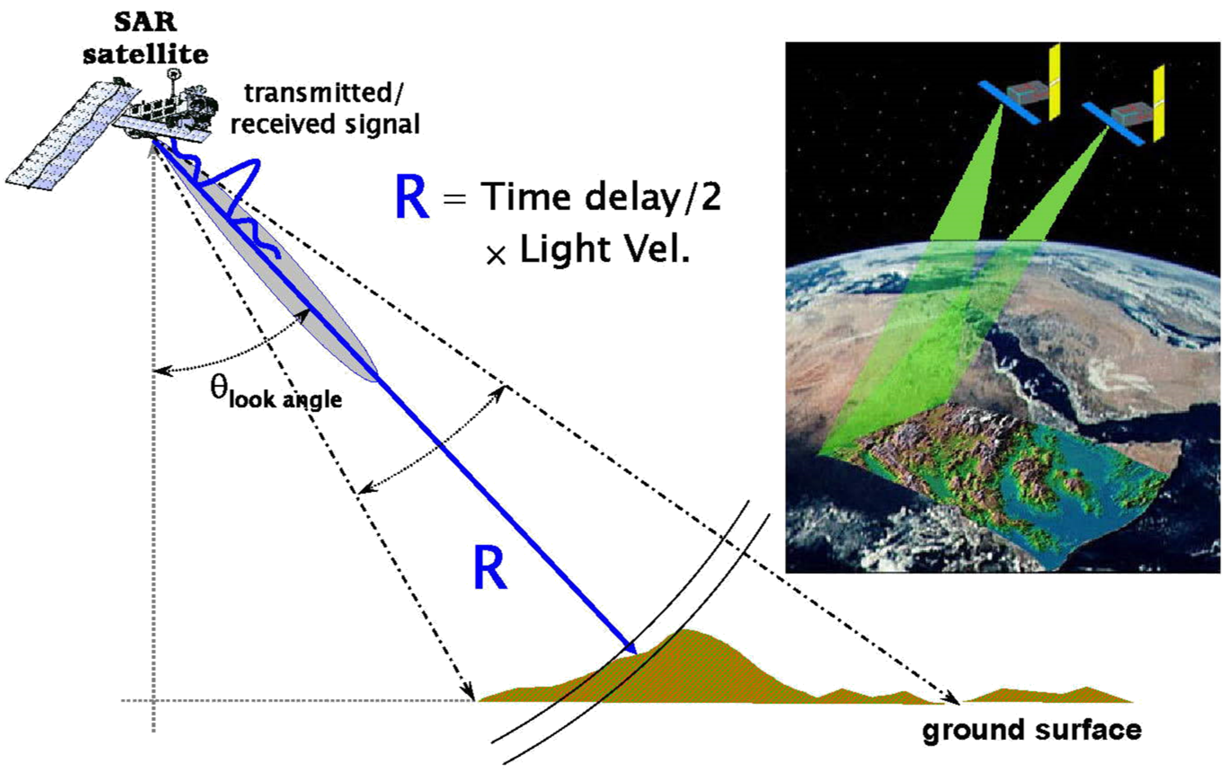
Questions

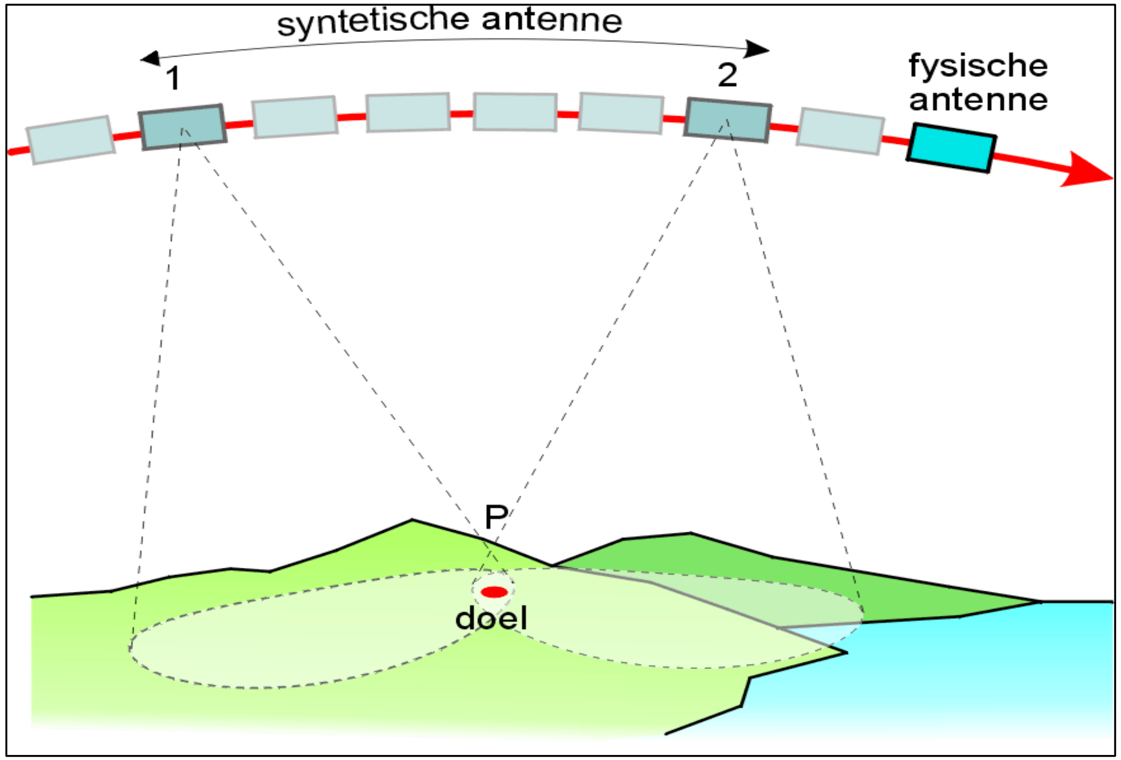
What impact would GNSS data at the available resolution would have in the forecast?

Is there any added value in the much higher resolution InSAR data?

What dynamical changes are produced by the new data: if we get a storm (we do!) why is that?

The SAR product



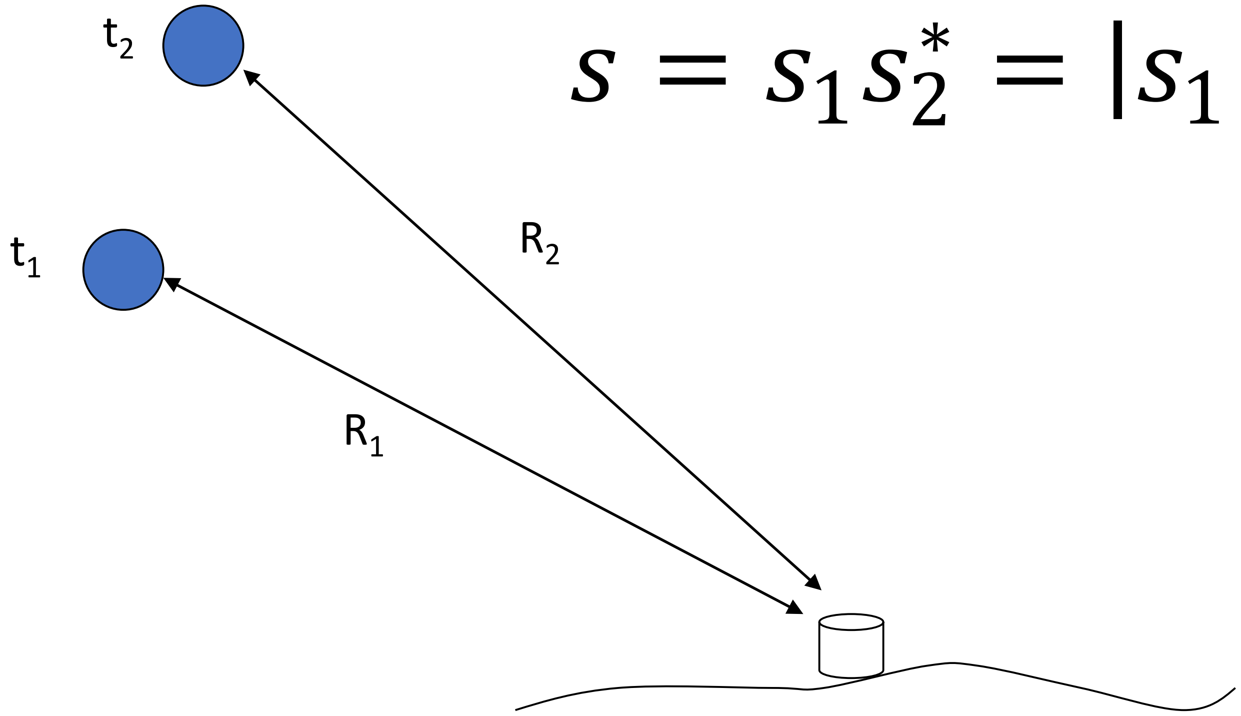


Synthetic Aperture Radar

$$s_1 = A.\mathrm{e}^{(j\phi_B)}.e^{\left(-j\left(\frac{4\pi}{\lambda}\right).r_1\right)}$$

InSAR: SAR interferometry

2 SAR images with the “same” view
(now 6 days apart)



Interferogram

$$s = s_1 s_2^* = |s_1||s_2|\, e^{-j\left(\frac{4\pi}{\lambda}\right).R_1 + j\left(\frac{4\pi}{\lambda}\right).R_2}$$

Phase difference

$$\phi_I = -\frac{4\pi}{\lambda}(R_1 - R_2)$$

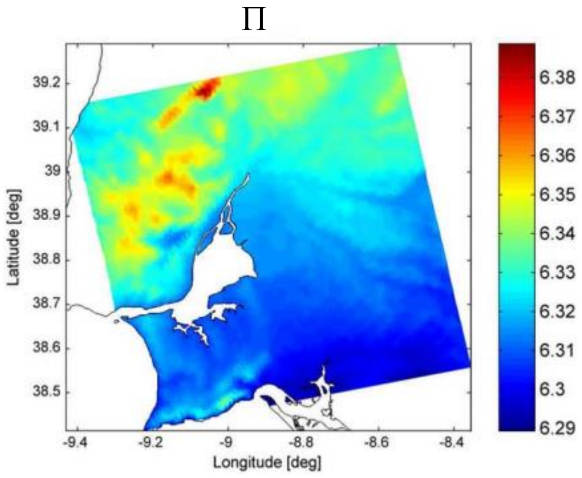
If the land is quiet it is a difference in water vapor (PWV)

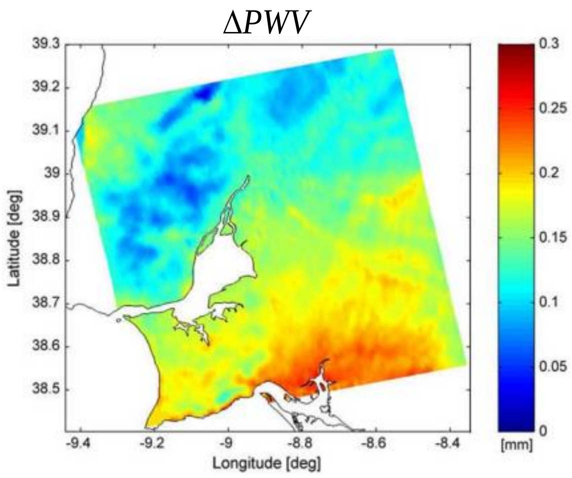
Previous work @IDL: ΔPWV maps from InSAR

If the terrain deformations can be neglected, hydrostatic and ionospheric contributions removed, InSAR provides maps of differential slant wet delay (ΔSWD)

$$\Delta SWD\ (t_M, t_S) = \frac{\lambda}{4\pi} \Delta\varphi_{wet}$$

$$\Delta PWV\ (t_M, t_S) = \boxed{\Pi} \cdot \Delta SWD \cdot M\left(\vartheta_{look}\right) \longrightarrow \boxed{\Pi = 10^{-6} \cdot \rho_{H_2O} \cdot R_v \cdot \left[\frac{k_3}{T_m} + k_2'\right]}$$





T_m : change with mean temperature profiles

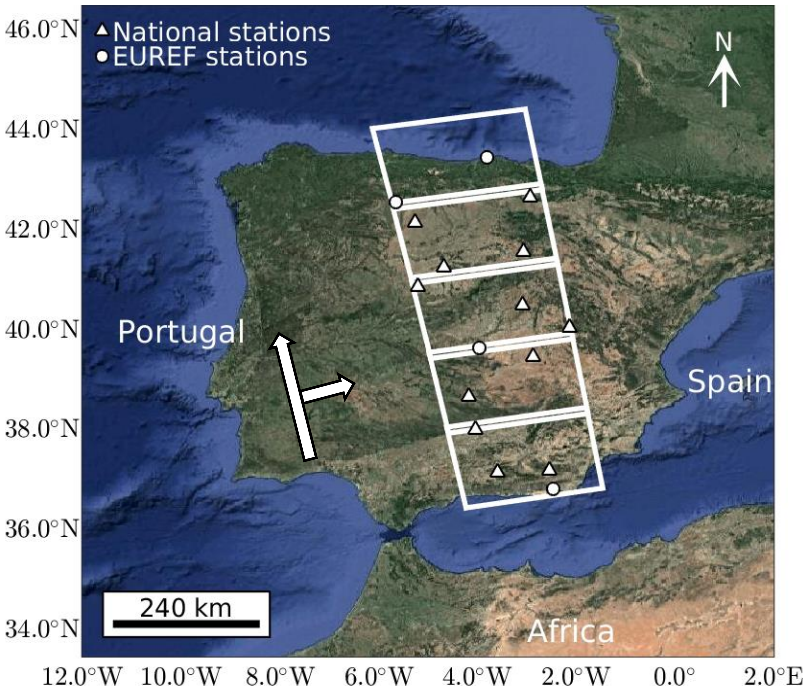
$$T_m = \frac{\int \frac{e}{T}\, dh}{\int \frac{e}{T^2}\, dh}$$

For more details see:

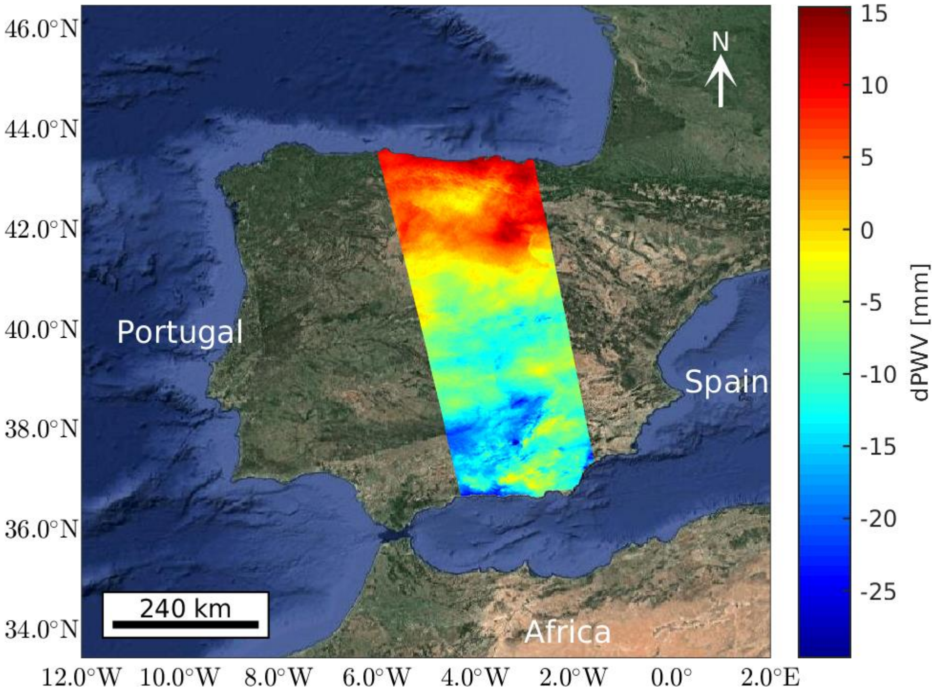
P. Mateus, G. Nico, J. Catalão, **“Maps of PWV Temporal Changes by SAR Interferometry: A Study on the Properties of Atmosphere’s Temperature Profiles”**, IEEE Geoscience and Remote Sensing Letters, 11(12), 2065–2069, 2014.

Previous: PWV maps by Sentinel-1 data

- ✓ **Data with a 250 km swath at 5 m by 20 m spatial resolution (single look)**
- ✓ **6 days revisiting time**



ΔPWV



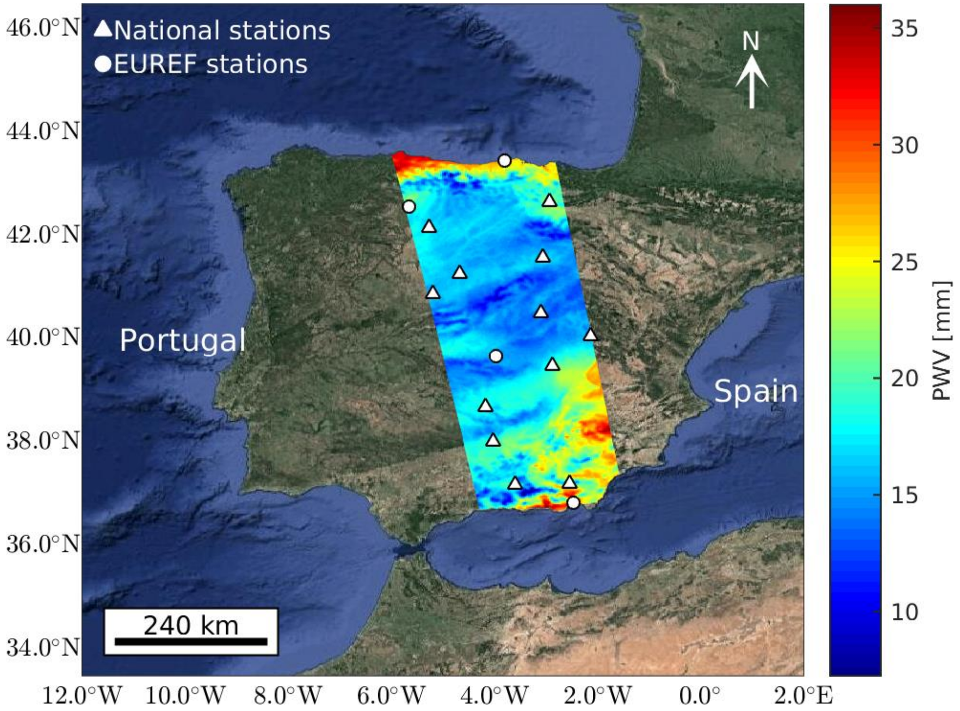
Merging and calibration are made with a small GNSS network

For more details see: P. Mateus, J. Catalão and G. Nico, **"Sentinel-1 Interferometric SAR Mapping of Precipitable Water Vapor Over a Country-Spanning Area"** in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 55, no. 5, pp. 2993-2999, May 2017. doi: 10.1109/TGRS.2017.2658342

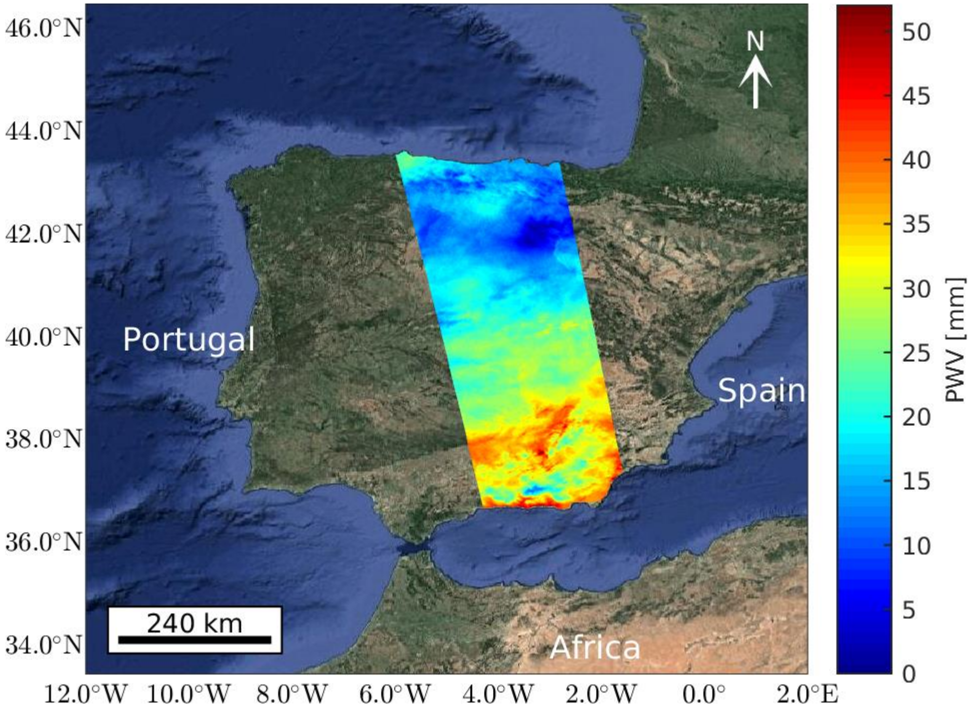
Previous: PWV maps by Sentinel-1 data

From ΔPWV to PWV

PWV at SLAVE date

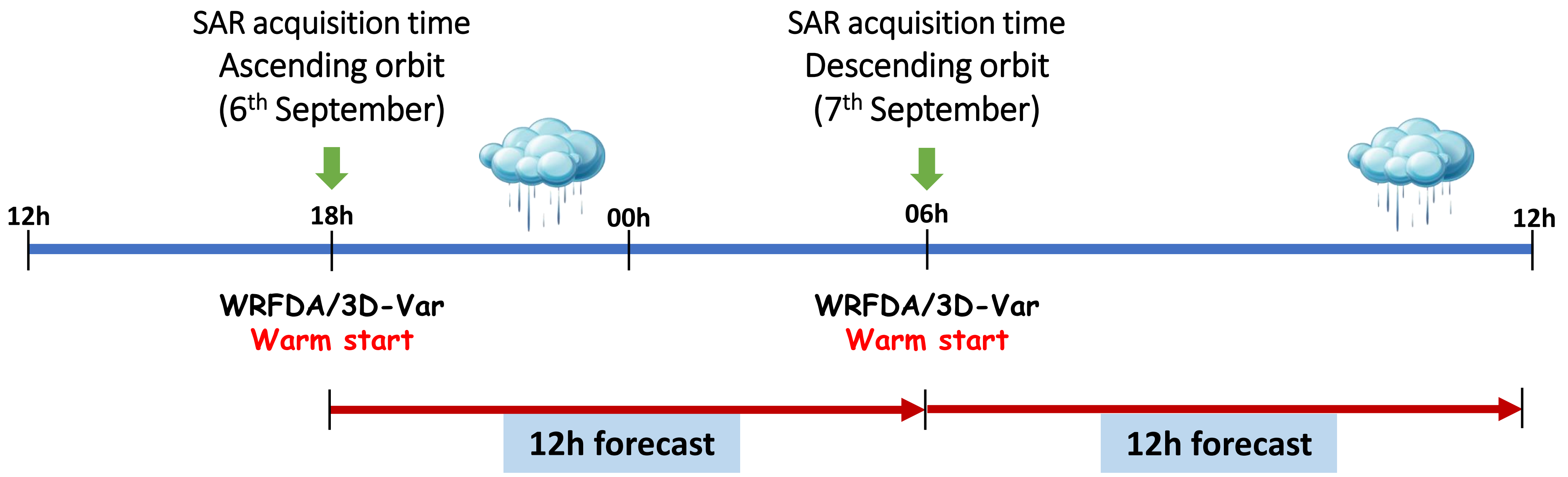


PWV at MASTER date



PWV(master) = ΔPWV + PWV(slave)

ADRA 3dVar assimilation experiments



1. CTRL:
    1. 12h to 06h UTC
    2. 00h to 12h (spin-up time of 6h)

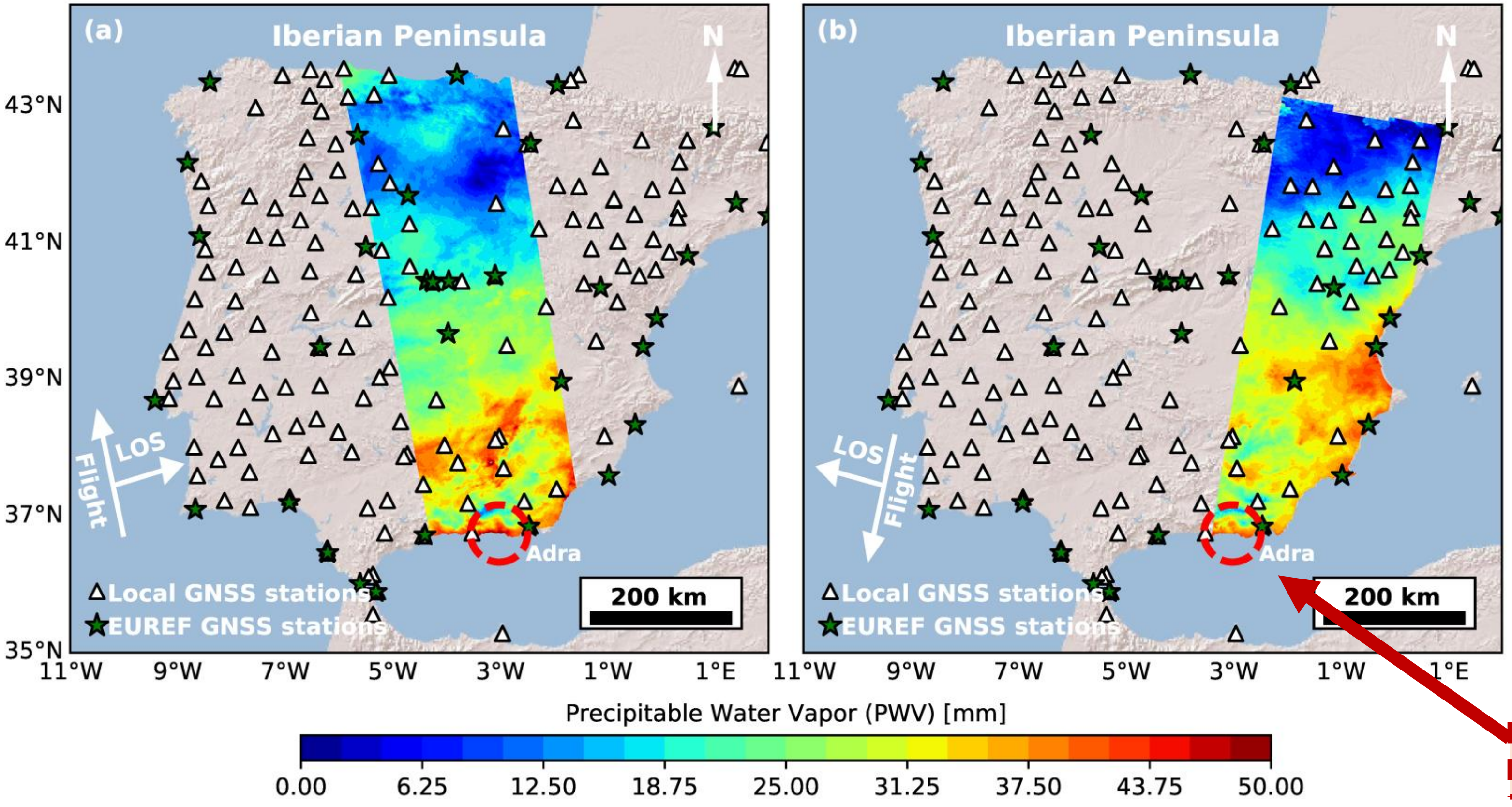
Same setup for all experiments

1. GNSS: assimilation time at 18h and 06h (130 GNSS-PWV values)

3. InSAR: assimilation time at 18h (ascending orbit, 1st segment) and 06h (descending orbit, 2nd segment)

Setup of the Adra 3dVar assimilation experiments

(1) Ascending orbit **(2) Descending orbit**



<u>Two interferometric sets of **Sentinel-1** **data**:</u>

(1)	Slave	: 25 August 2015
	Master	: 6 September 2015
	Hour	: **18:00 UTC**
(2)	Slave	: 26 August 2015
	Master	: 7 September 2015
	Hour	: **06:00 UTC**

ADRA

△ 130 local GNSS stations used for the GNSS experiment

★ 35 GNSS stations belonging to EUREF Network 🡸 **VALIDATION**

wrf3DVAR
T,q

@ level 4
(~400m)

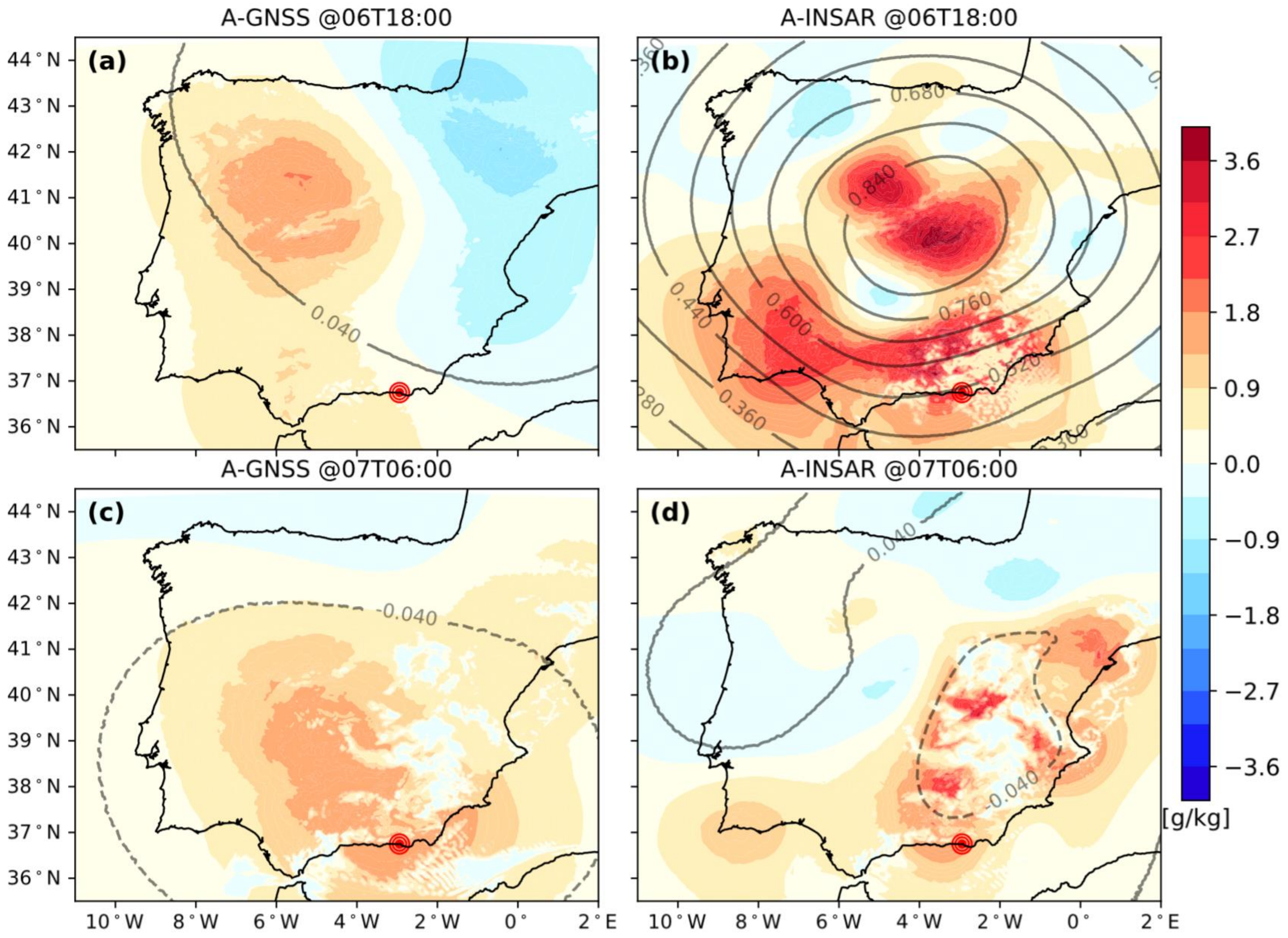


Figure 2. Anomalies of the water vapor mixing ratio and potential temperature at the data assimilation time

Anomalies at assimilation time(s)

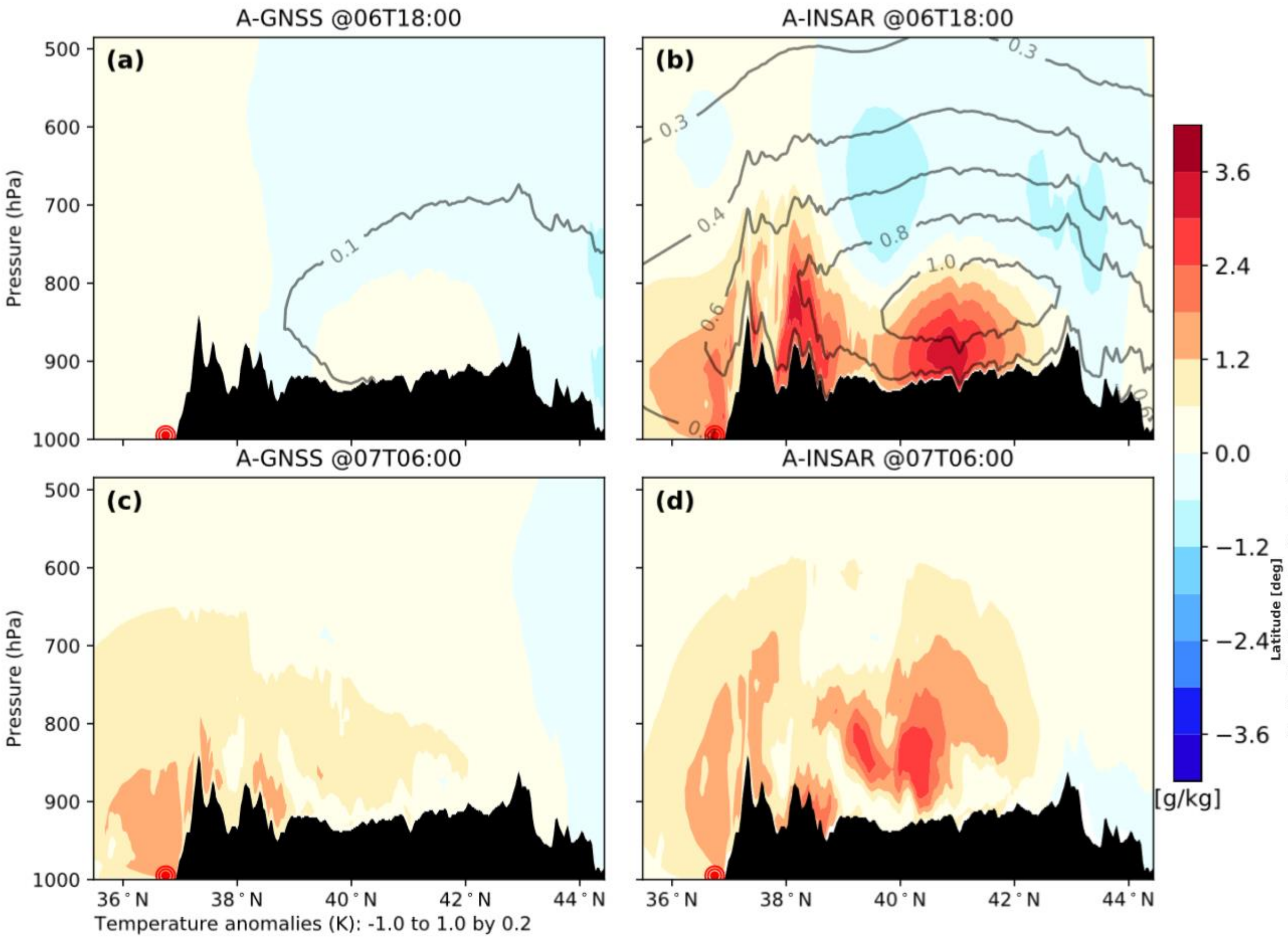
South-North cross sections

GNSS

INSAR

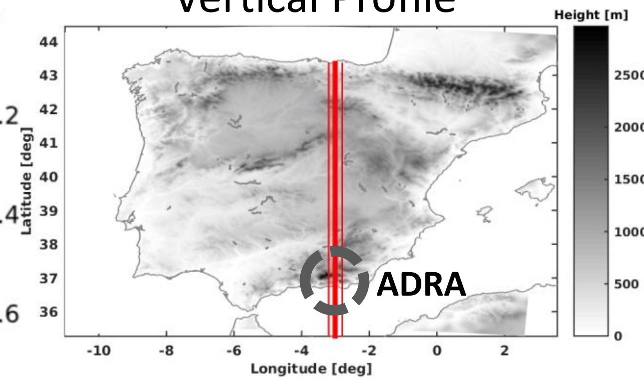
18h

06h



Anomalies of water vapor and temperature (related to the CTRL run)

Vertical Profile

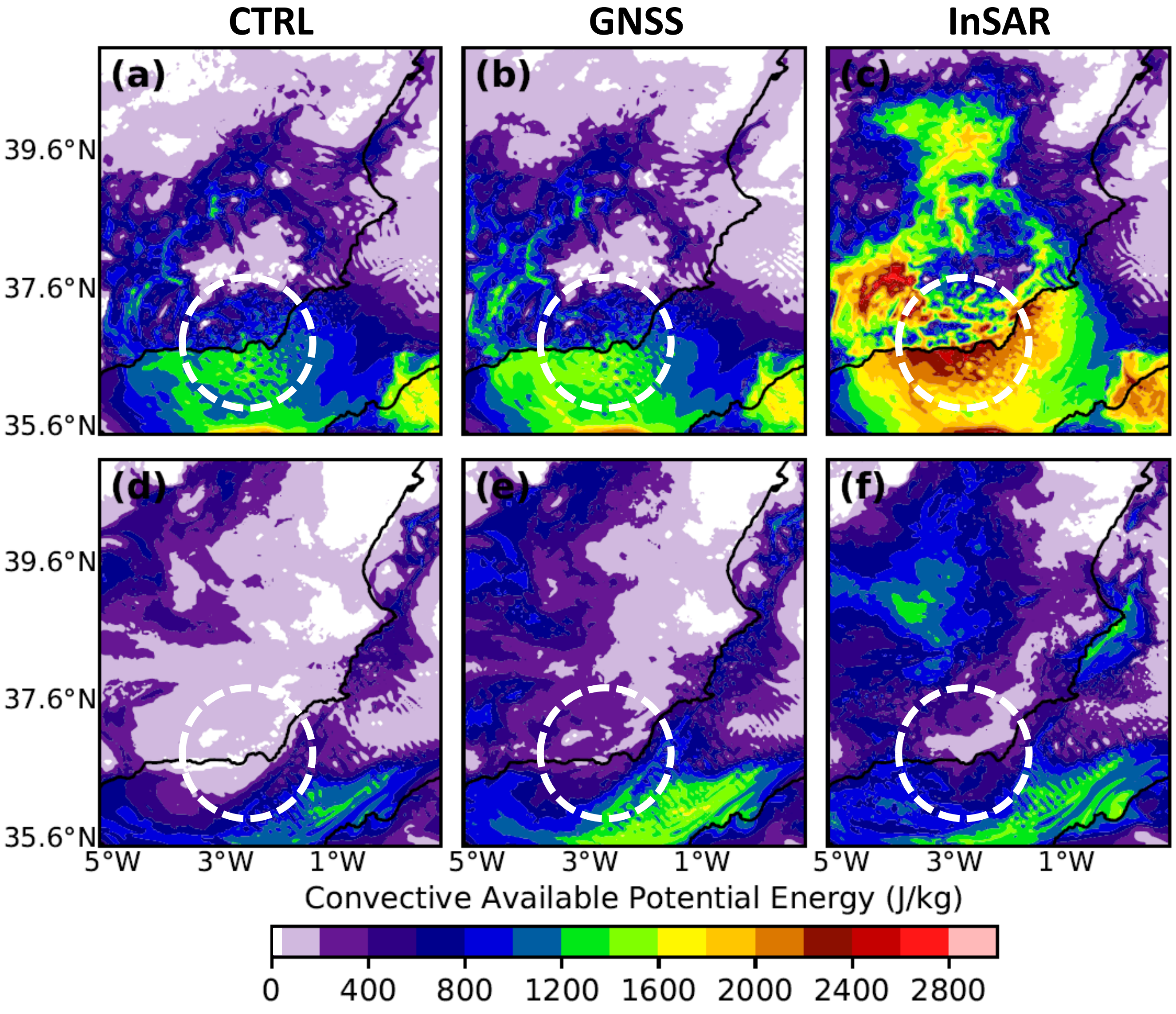


CAPE at assimilation time(s)

Convective Available Potential Energy (CAPE)

18h

06h



> 2500 J/kg is typical of deep convection

Higher values indicate greater potential for severe weather.

Convective Available Potential Energy (CAPE)

Low level

streamlines

<1h before storm

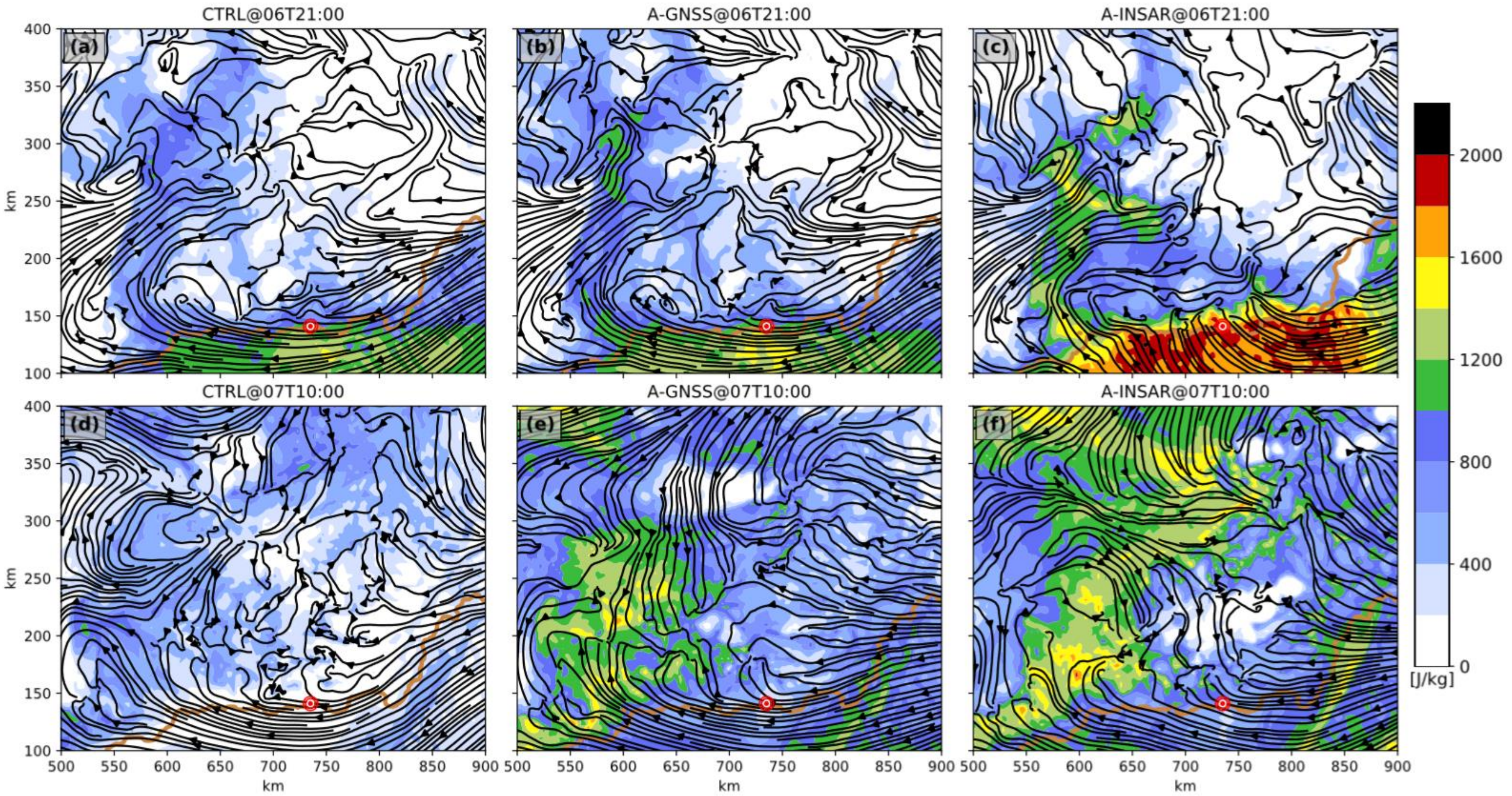
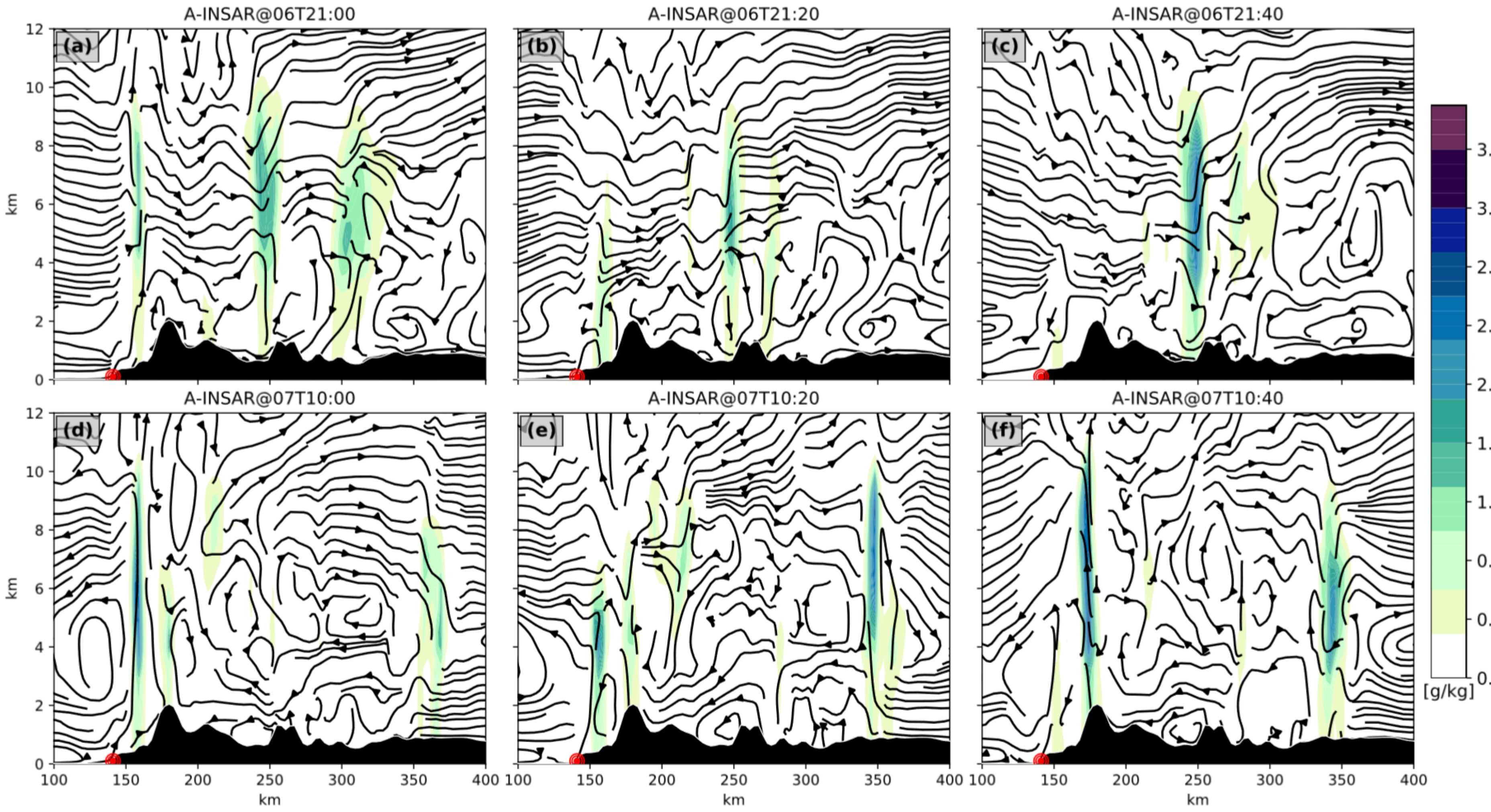


Figure 4. Convective available potential energy (CAPE, in J/kg, color shading), and streamlines of the low level flow (at the 4^{th} model level), before the onset of each storm: (a,d) CTRL, (b,e) A-GNSS, (c,f) A-INSAR.

The storm with InSAR assimilation (20 min)

21:00

10:00

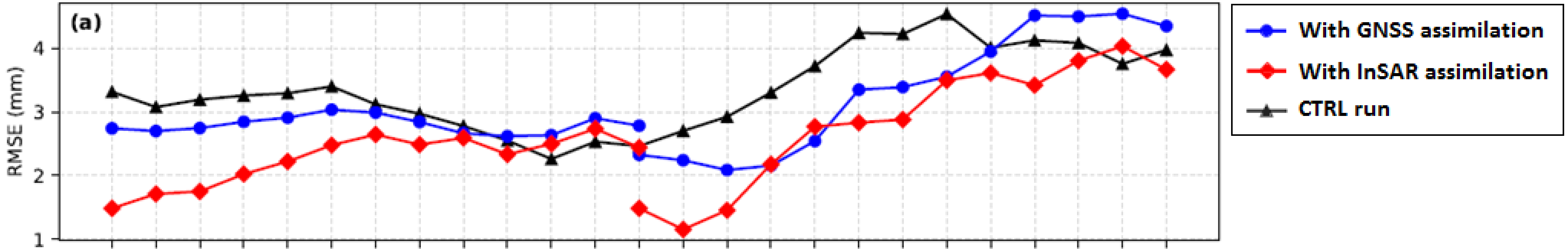


Validation with independent GNSS data

Statistical analysis over the 12h forecast using an independent set of **35 GNSS stations** during the 12h forecasting

RMS error (mm)

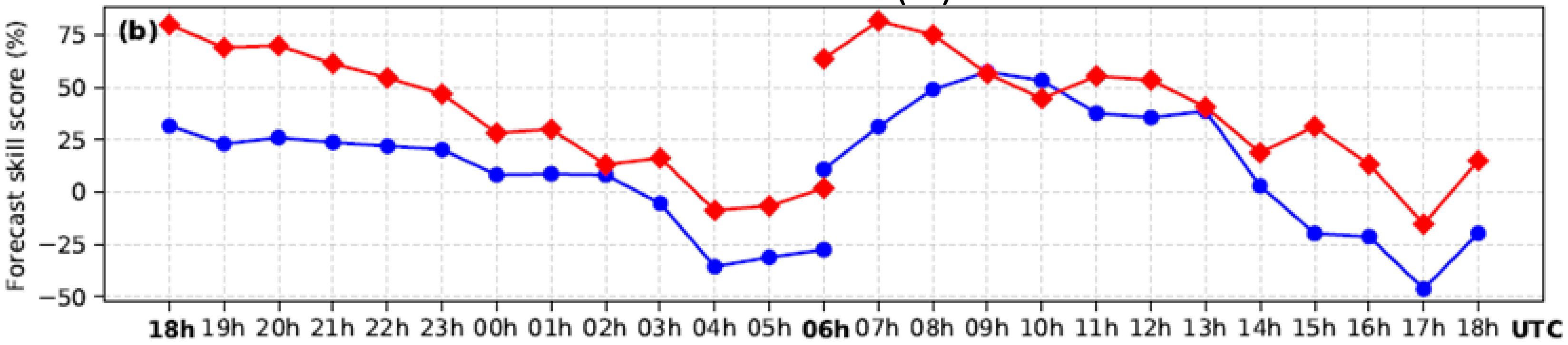
Lower values are better



Skill score (%)

> 0 : improving over CTRL run

Perfect score: 100



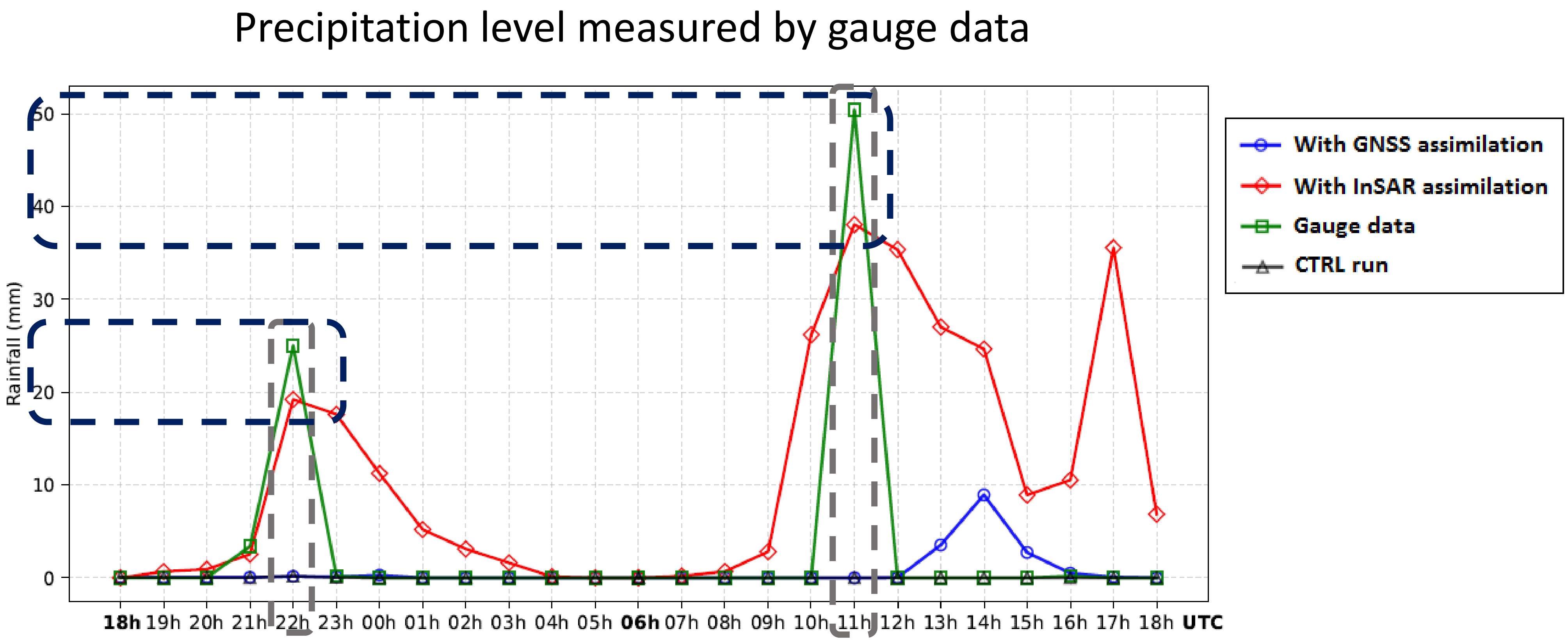
$$SS = \frac{A_f - A_r}{A_p - A_r}$$

A_p : "true" forecast accuracy

A_r : CTRL forecast accuracy

A_f : InSAR/GNSS forecast accuracy

Validation against udometer

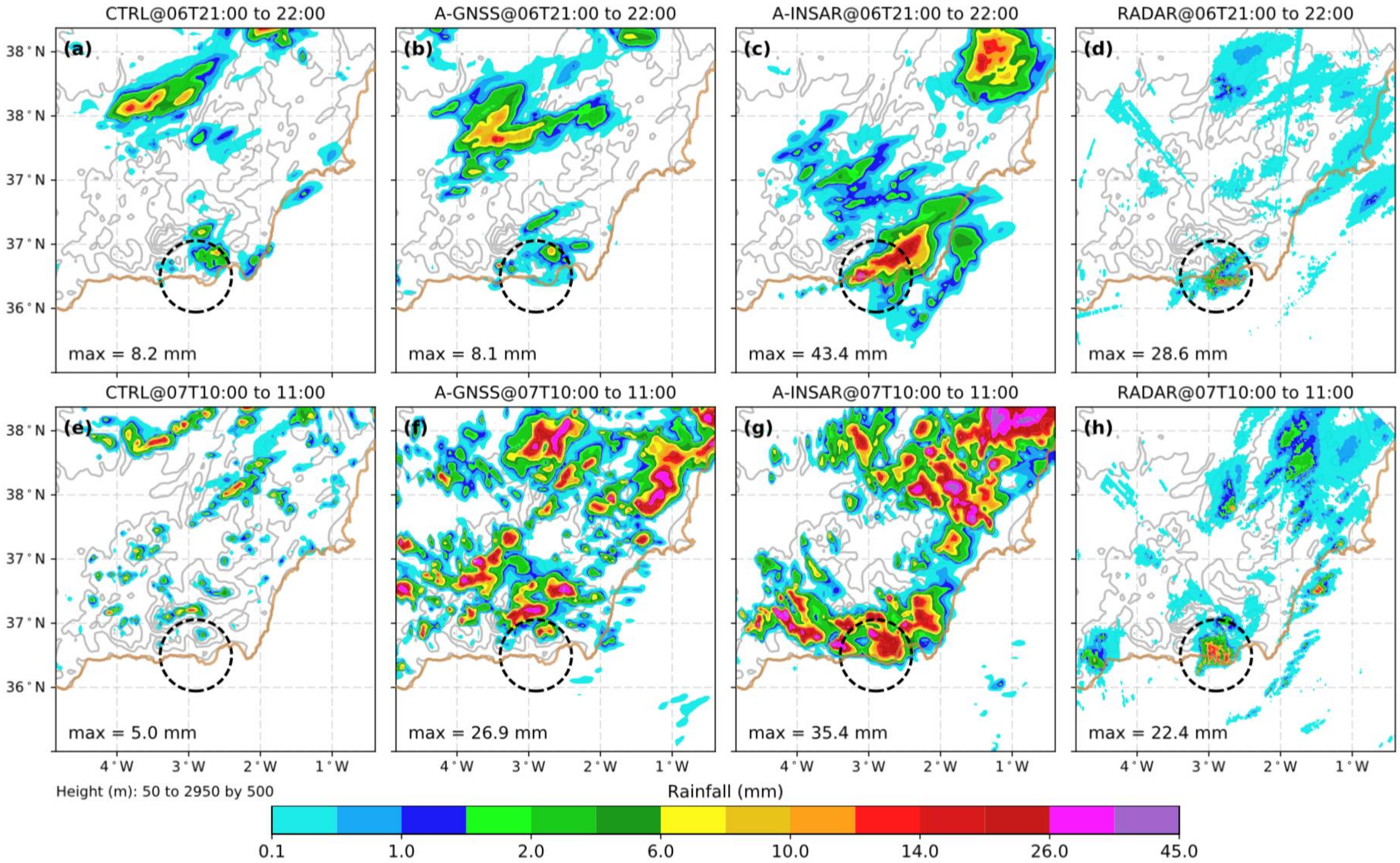


- ✓ The INSAR experiments correctly forecast both, the **time** and **intensity** of rainfall. The GNSS did not significantly modified the CRTL forecast.
- ✓ Slow decay indicating an inertial effect of the WRF system when modeling quick effects as local severe precipitations having a short duration (about 3 hours).

Control GNSS InSAR Radar

21-22

10-11



3h after the assimilation time

4h after the assimilation time

Discussion

3dVar assimilation of InSAR-PWV fields in a state-of-the-art model (WRF) can **improve the forecast of severe events**

Improving the:

- ✓Temporal scale
- ✓The location
- ✓Amount of precipitation

A dense GNSS network does not capture the **fine spatial details of InSAR-PWV fields**, in conditions that are favorable to the onset of deep convection

InSAR information was found to be useful for about **8 hours** into the simulation

Changes appear to affect the initial state of humidity, temperature and wind

However: we still only have these data every 6 days…