Can InSAR Meteorology Contribute To A Digital Twin Of The Atmosphere?

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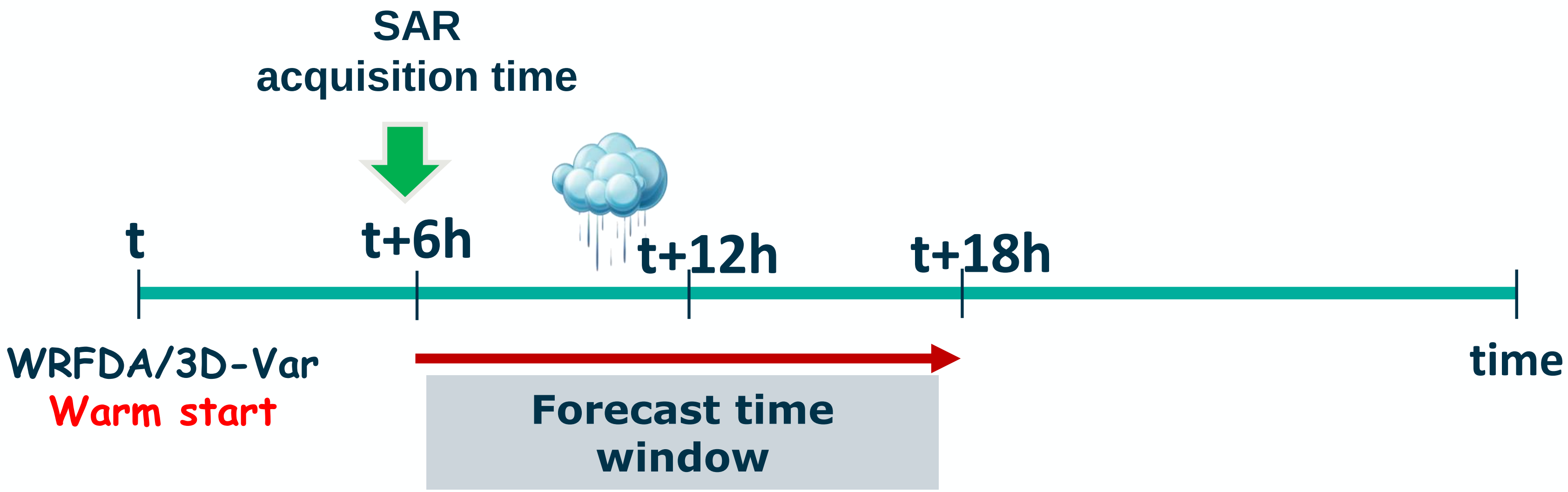
Outline

- ✓ InSAR meteorology and Digital Twin (DT) in meteorology
- ✓ Visualization tools in NWMs
- ✓ Can InSAR Meteorology contribute to a DT of the atmosphere?

esa

WRF setup for assimilation of InSAR data



1. CTRL: Re-analyses or Forecast models are used for setting initial conditions @ initial time t (and for updating boundary conditions every 6 hours

2. InSAR assimilation time at (approximately) acquisition time t_{SAR} : spin-up of 6h @ (t_{SAR} – 6h)

P. Mateus et al. (2021). Continuous multitrack assimilation of Sentinel-1 precipitable water vapor maps for numerical weather prediction: How far can we go with current InSAR data? Journal of Geophysical Research: Atmospheres, 126, e2020JD034171. https://doi.org/10.1029/2020JD034171

The WRFDA tool (based on 3D-Var) has been used

Assimilation output

SAR

$$J(x) = \frac{1}{2}\left(x - x^b\right)^T \cdot B \cdot \left(x - x^b\right) + \frac{1}{2}(y - H\{x\})^T \cdot R^{-1} \cdot (y - H\{x\})$$

The forecast covariance matrix B is estimated using the NMC method (computed from at least one months of solutions generated by starting the NWM every 12 hours and running it for 24 hours)

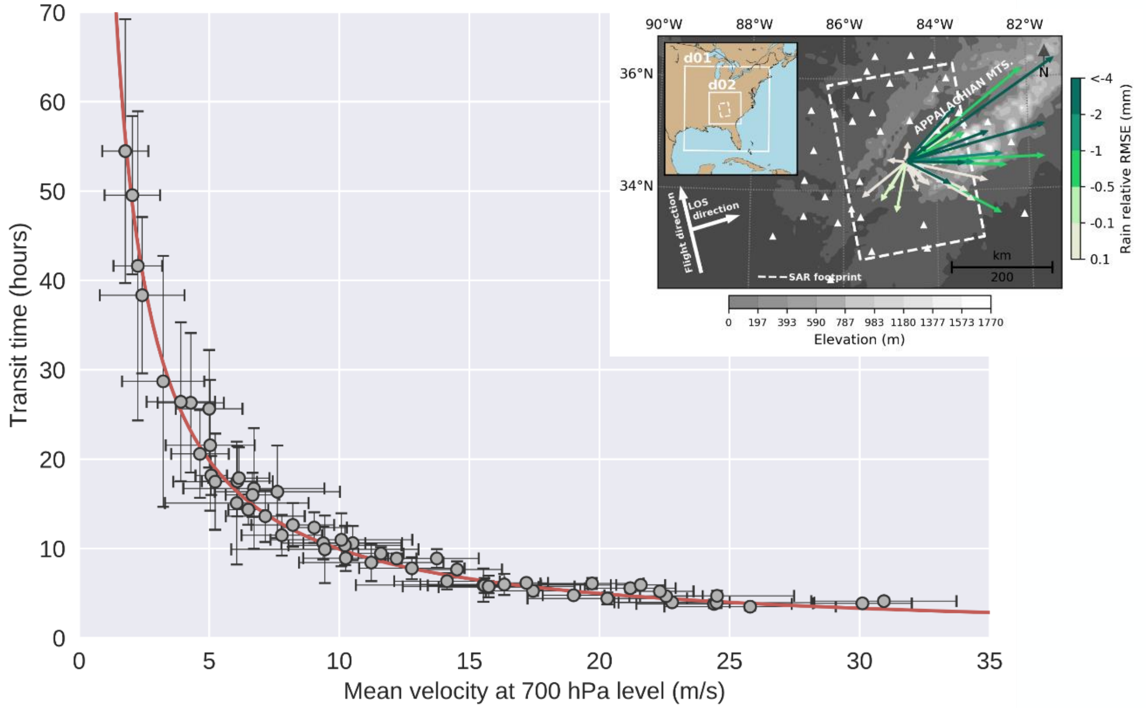
$$B \cong \overline{[x^f(t+24) - x^f(t+12)] \cdot [x^f(t+24) - x^f(t+12)]^T}$$

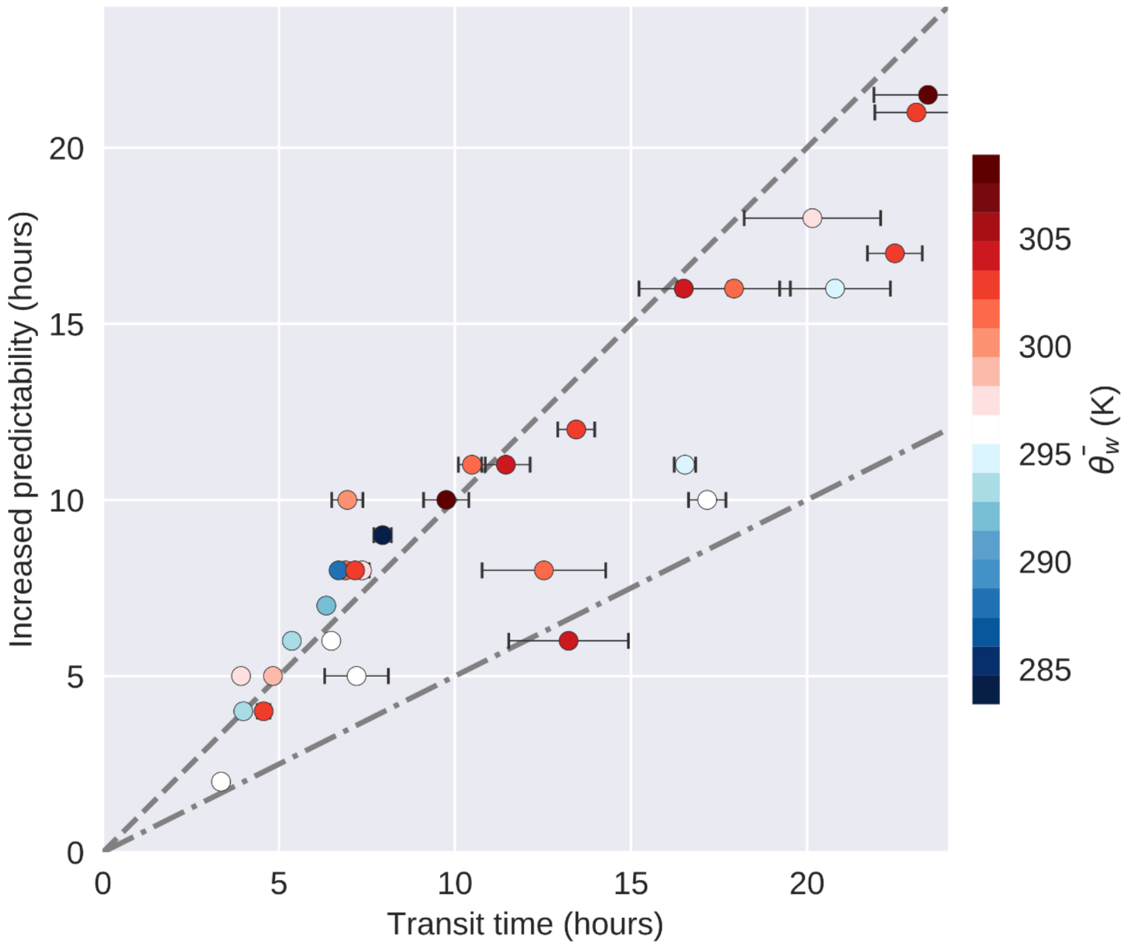
forecast (f) = background (b)

InSAR meteorology

Steering level and impact of assimilating SAR PWV maps

mean equivalent potential temperature ϑ_w





P. Miranda et al. (2019). InSAR meteorology: High-resolution geodetic data can increase atmospheric predictability. Geophysical Research Letters, 46, 2949–2955. https://doi.org/10.1029/2018GL081336

Digital Twin (DT)

There are two main approaches of applied mathematics to digitalization: Physics-Based and Data Driven:

Physics-based models (PBMs) can give

- ✓ useful information on the processes to be described without need for huge datasets
- ✓ a first idea on what variables shall be monitored
- ✓ generalization

Data-Driven approaches imply the use of methods from Machine Learning or even Deep Learning to “learn from data collected by sensors”.

AI tools needs very high amounts and can be used to find hidden patterns in the data. Such a pattern can be refined whenever new data are collected.

NWMs are an example of physics-based DT

Destination Earth (DestinE) initiative

Initiative of the EC to develop highly-accurate DTs of the Earth to monitor and simulate natural phenomena

Atmosphere is one of the domains of interest of DestinE to:

- ✓ Monitor and simulate
- ✓ Anticipate natural disasters (←→ extreme weather events)

Digital Twin and InSAR meteorology

In this presentation we focus on the use of WRF and InSAR meteorology to generate a DT of atmosphere

- ✓ Data Lake: S1 (high resolution PWV maps), ERA5, …
- ✓ DT engine: the 3D-Var assimilation of S1 data is a means to generate replicas of the WRF model

Other NWMs: AROME, COSMO, …

We want to get:

- Hints to change / modify the assumptions of NWMs
- Hints to reduce the extension of approximations
- Extend the limits of applications of WRF to better predict extreme weather events

Visualization tools in NWMs

The Lagrangian framework is used to study the movement of air masses

(E-W) $\int_{t_1}^{t_2} u_x \cdot dt$ → $x_2 = x_1 + \left\{ \frac{u_x(x_{t_1}, t_1) + u_x(x_{t_2}, t_2)}{2} \right\} \cdot \Delta t$

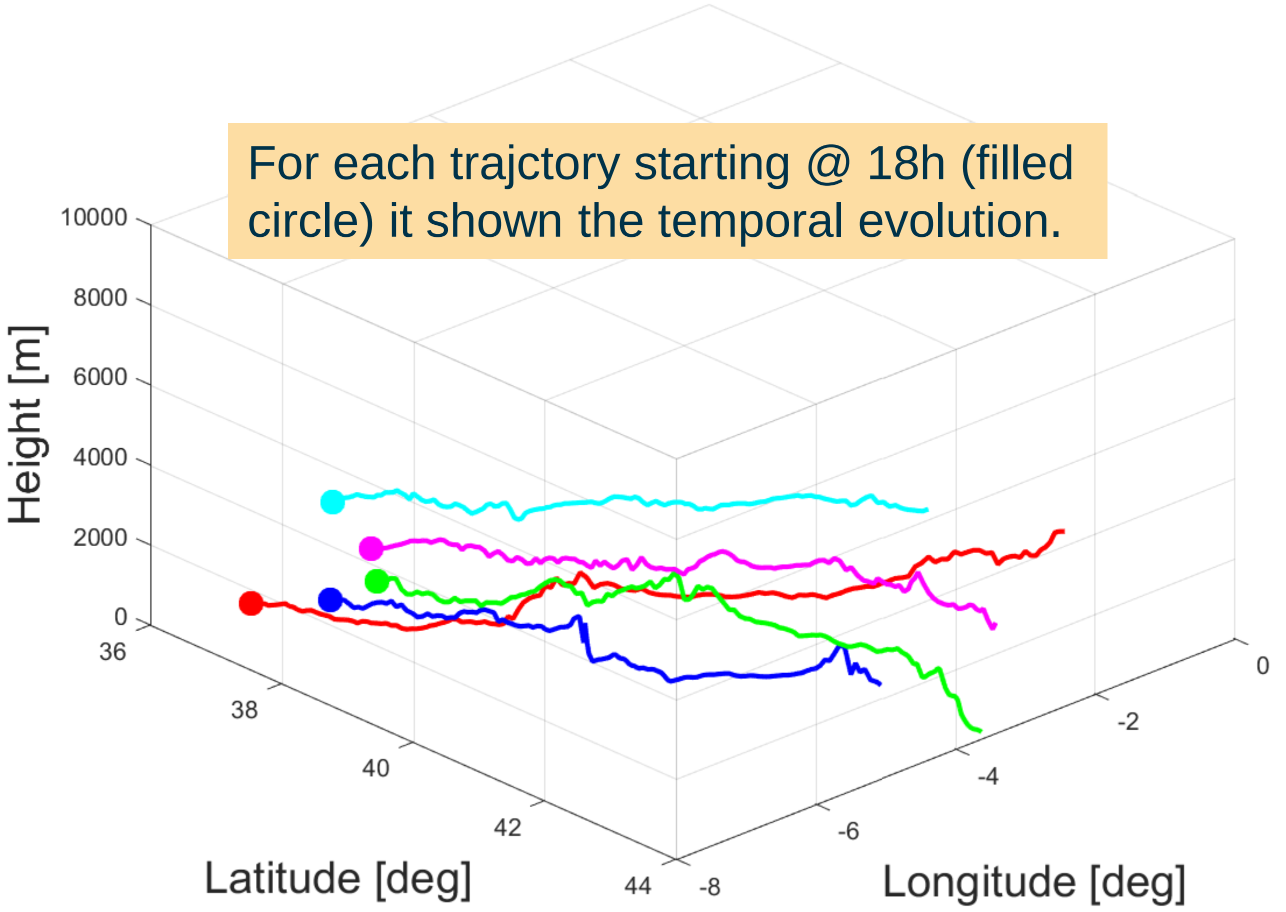
(S-N) $\int_{t_1}^{t_2} u_y \cdot dt$ → $y_2 = y_1 + \left\{ \frac{u_y(y_{t_1}, t_1) + u_y(y_{t_2}, t_2)}{2} \right\} \cdot \Delta t$

(L-U) $\int_{t_1}^{t_2} u_z \cdot dt$ → $z_2 = z_1 + \left\{ \frac{u_z(z_{t_1}, t_1) + u_z(z_{t_2}, t_2)}{2} \right\} \cdot \Delta t$

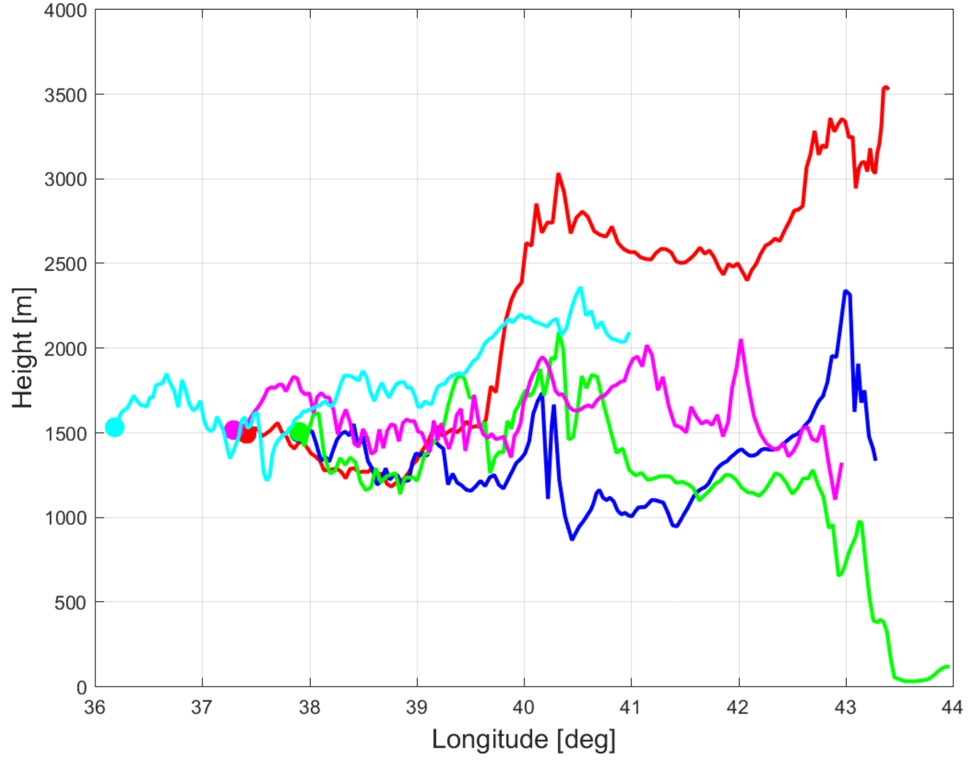
Visualization tools in NWMs

For each trajctory starting @ 18h (filled circle) it shown the temporal evolution.

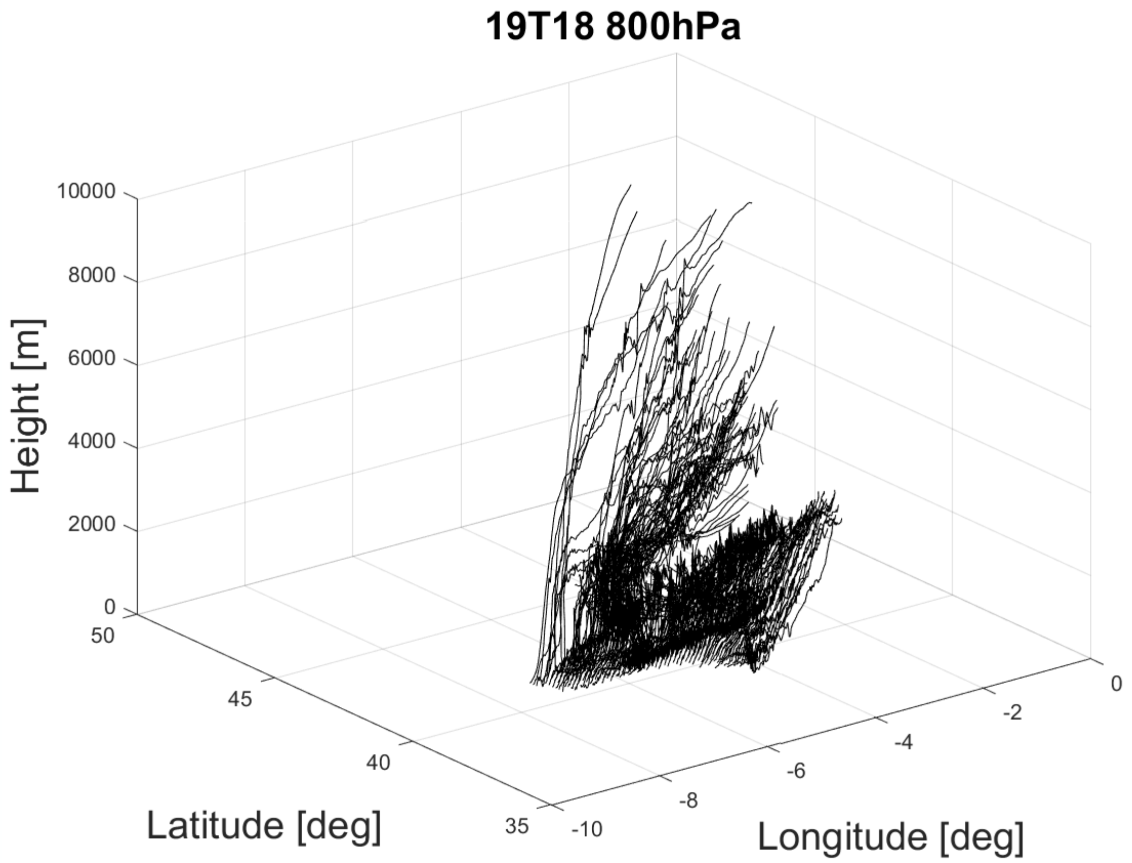
19T18 800hPa

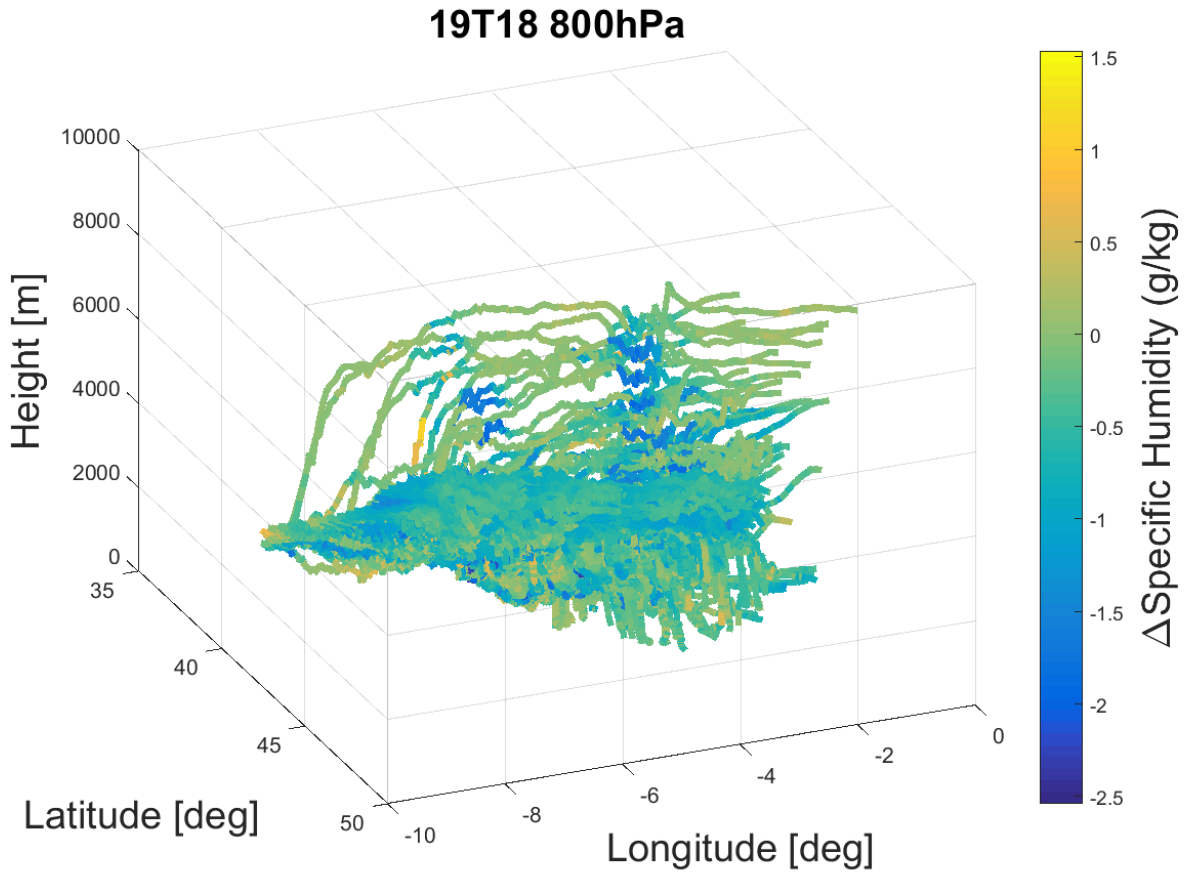


19T18 800hPa



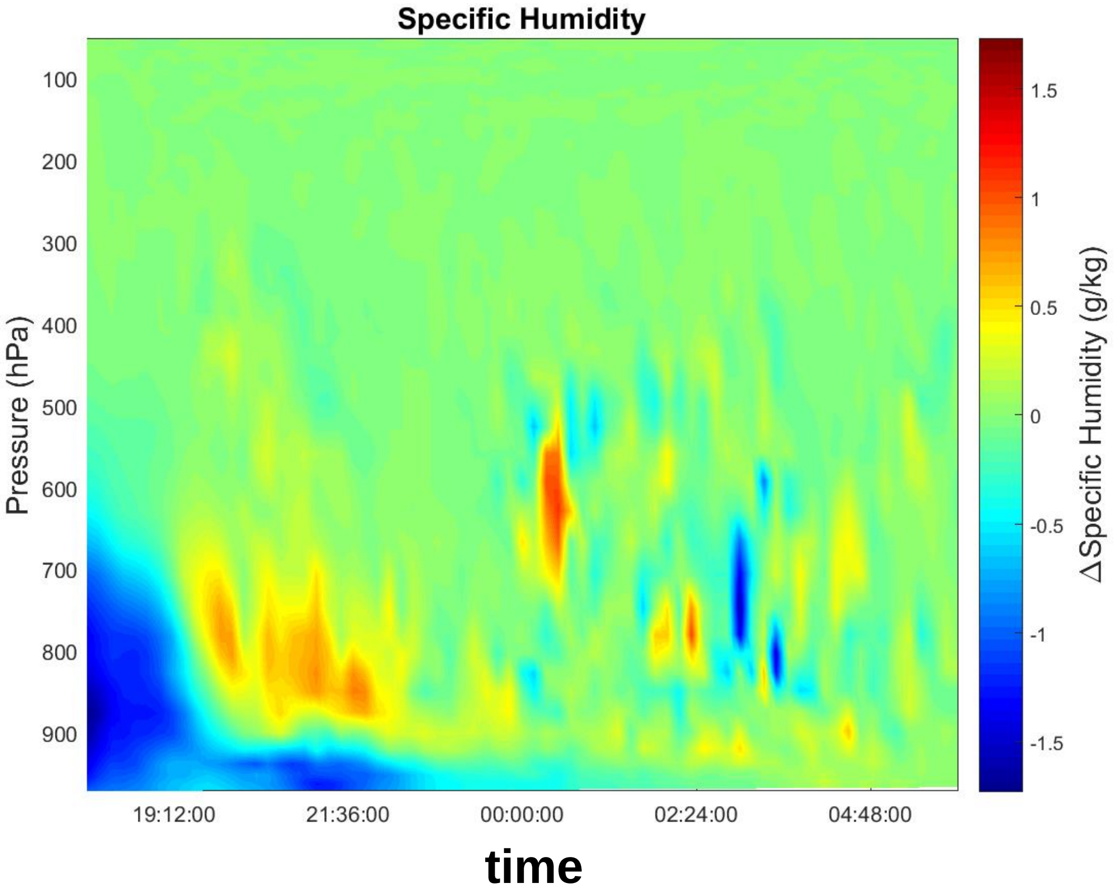
Visualization tools in NWMs

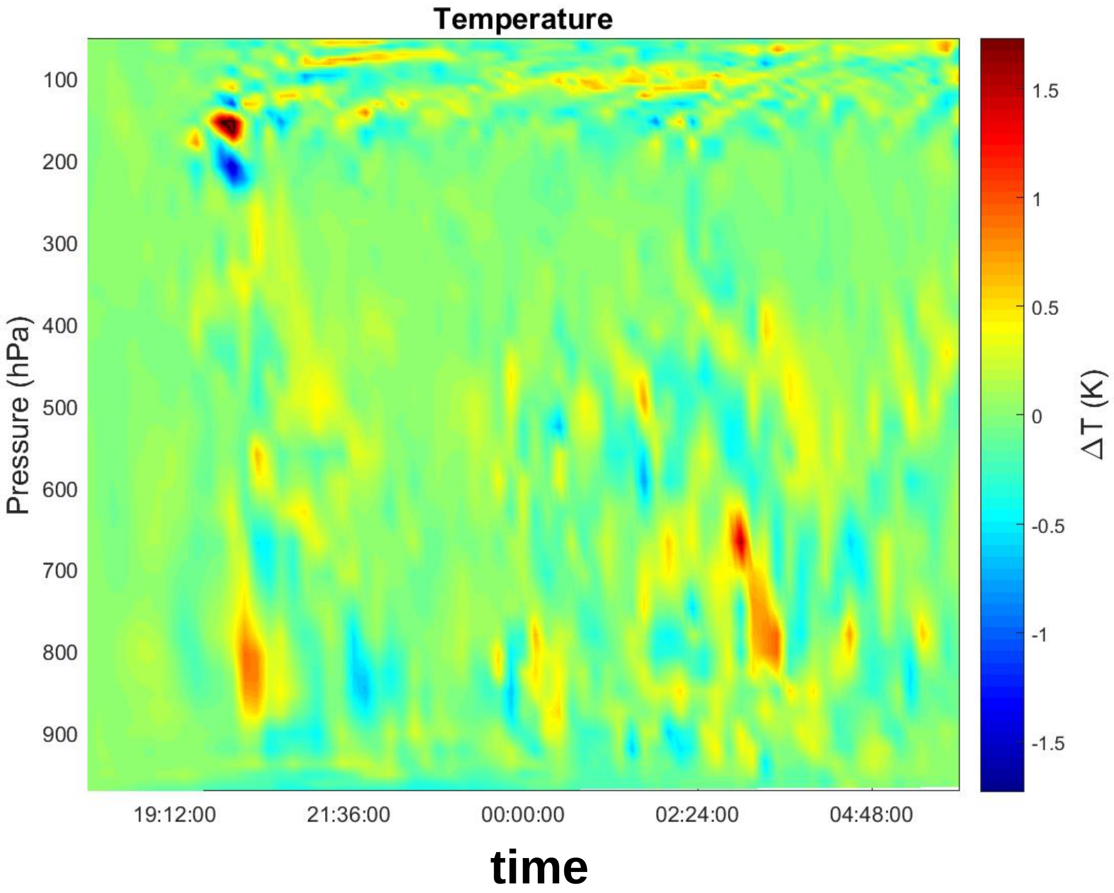




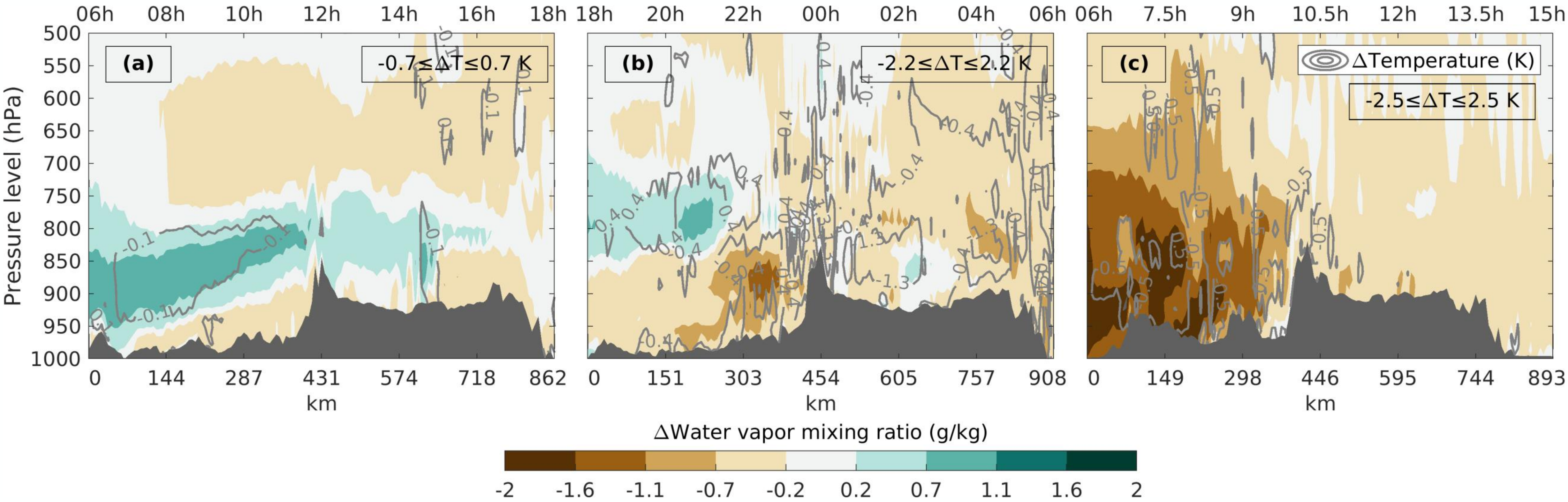
Visualization tools in NWMs

Hovemoller (static) diagram





Visualization tools in NWMs

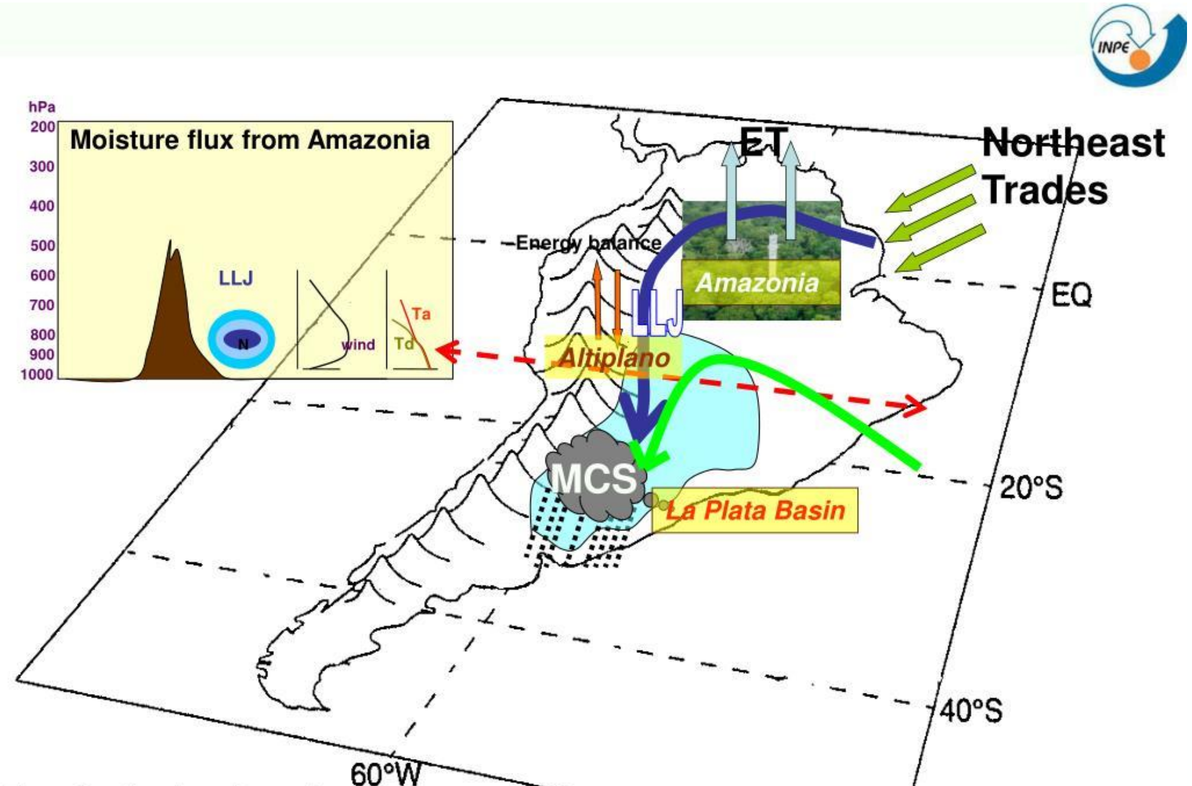


P. Mateus et al. (2018). Assimilating InSAR mapsof water vapor to improve heavyrainfall forecasts: A case study with two successive storms. Journal of Geophysical Research:Atmospheres,123, 3341–3355.https://doi.org/10.1002/2017JD027472

Can InSAR meteorology contribute to a DT of atmosphere?

The Low-Level Jet (LLJ) phenomenon is observed in South-America. It is due to Andes which blocks and deflects the low level circulation associated with the trade winds to higher latitudes (Northeast Trades) producing a low level current.

- ✓ LLJ is a northerly wind with a wind maximum located immediately to the east of the Andes (between 10°S and 20°S) close to Santa Cruz de la Sierra (18°S, Bolivia.
- ✓ LLJ has a maximum around 1-2 km from the surface.
- ✓ LLJ appears most frequently in spring and summer.
- ✓ LLJ has a strong diurnal oscillations.



The South American Low Level jet east of the Andes (Marengo et al 2004)

Can InSAR meteorology contribute to a DT of atmosphere?

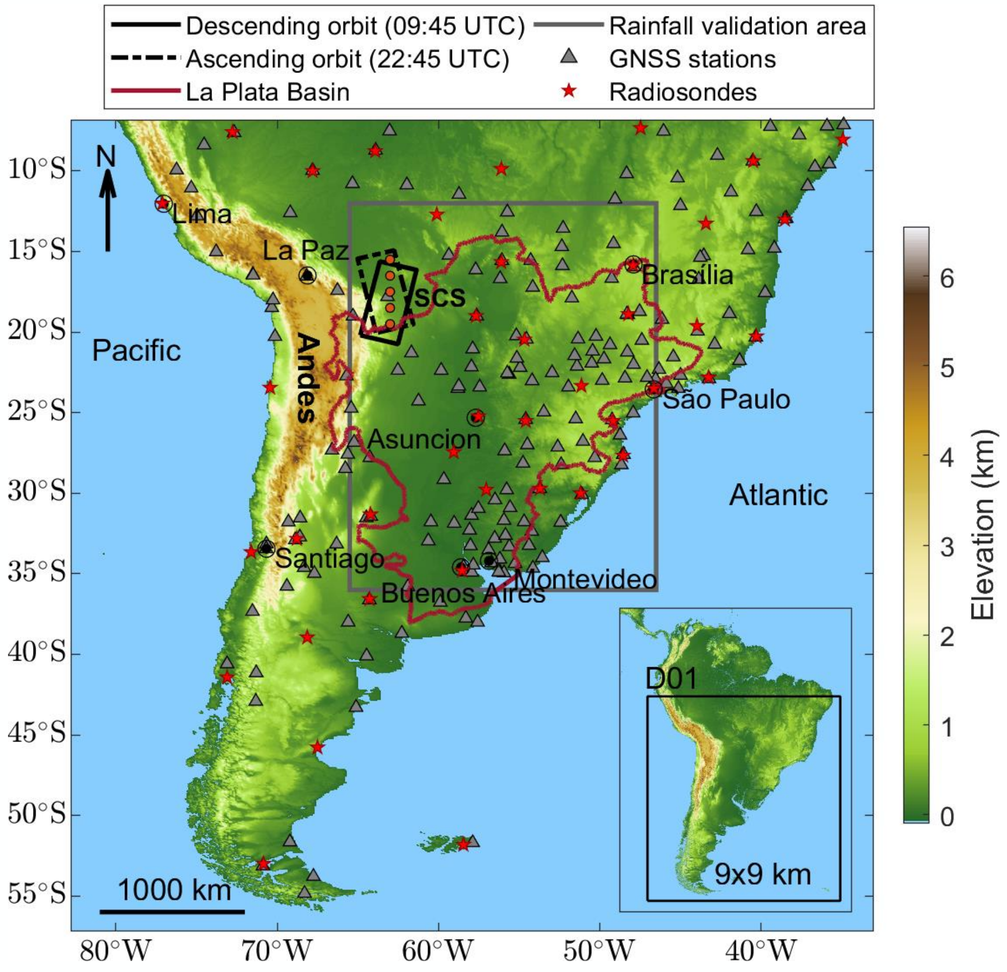
- ✓ InSAR captures the geometric characteristics of the “tube” within which the northerly wind is flowing and the atmosphere’s moisture is propagating (about 100 interferograms of which 30 imaging the LLJ)

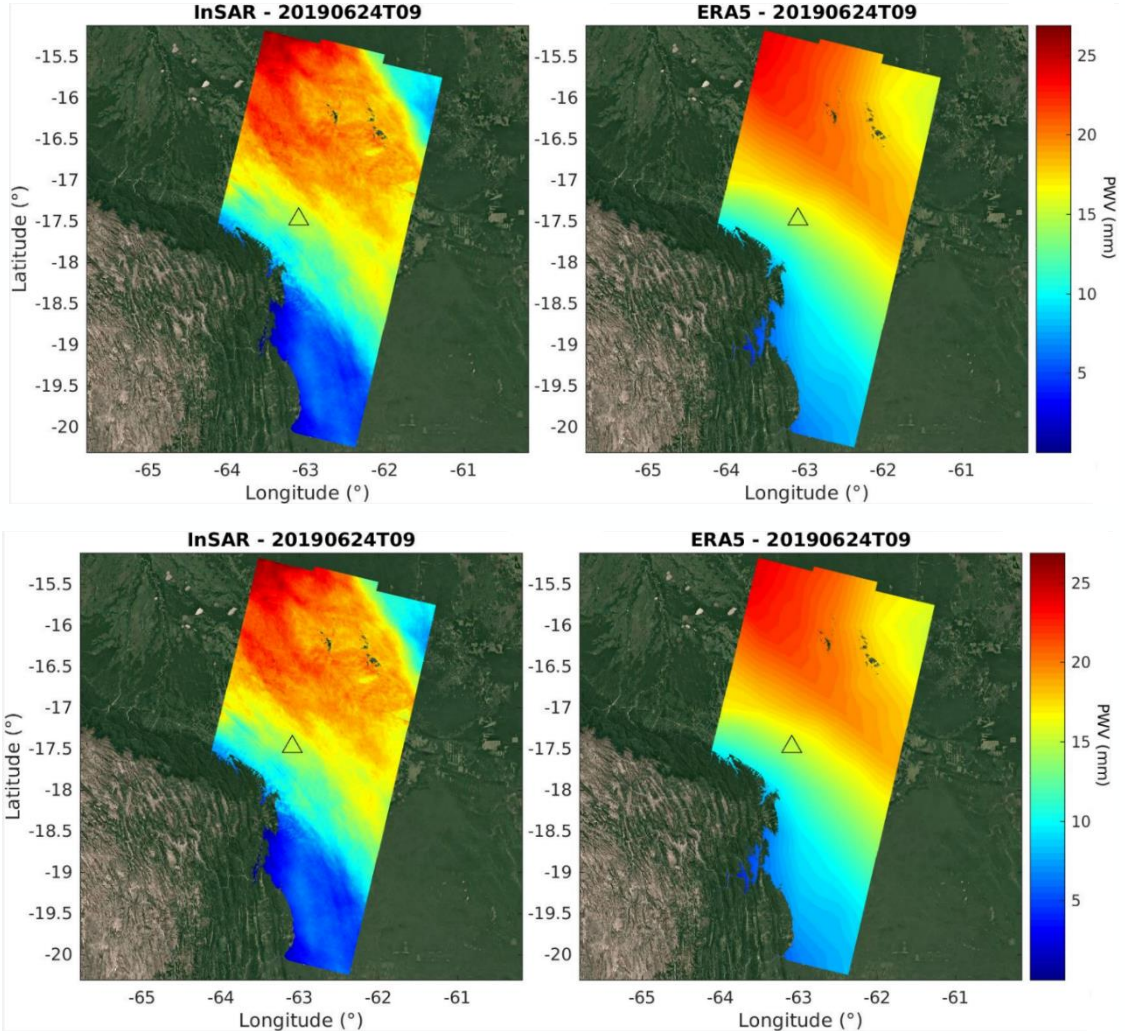
- ✓ After the assimilation of InSAR data, the position of the tube and the atmosphere’s moisture within the tube were more accurately modelled. This has been verified in two ways:

  1) Using the GNSS stations and radiosondes located along the lagrangian used to trace in time the propagation of moisture (and Lagrangian + Hovemoller diagram)

  2) Observing the localization and intensity of rainfall patterns (with GPM satellite data)

Can InSAR meteorology contribute to a DT of atmosphere?





P. Mateus et al., 2020, Mapping Precipitable Water Vapor Time Series From Sentinel-1 Interferometric SAR, IEEE Transactions on Geoscience and Remote Sensing, 58(2), 1373-1379, doi: 10.1109/TGRS.2019.2946077

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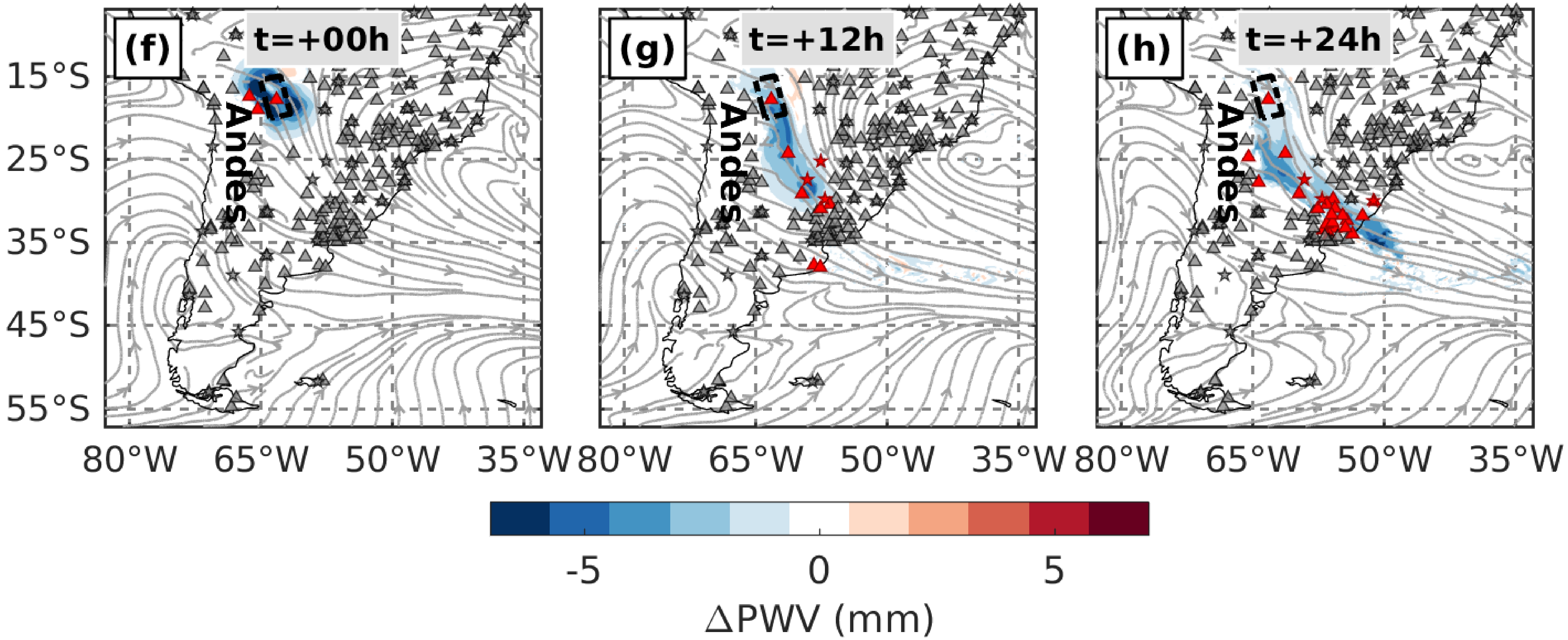
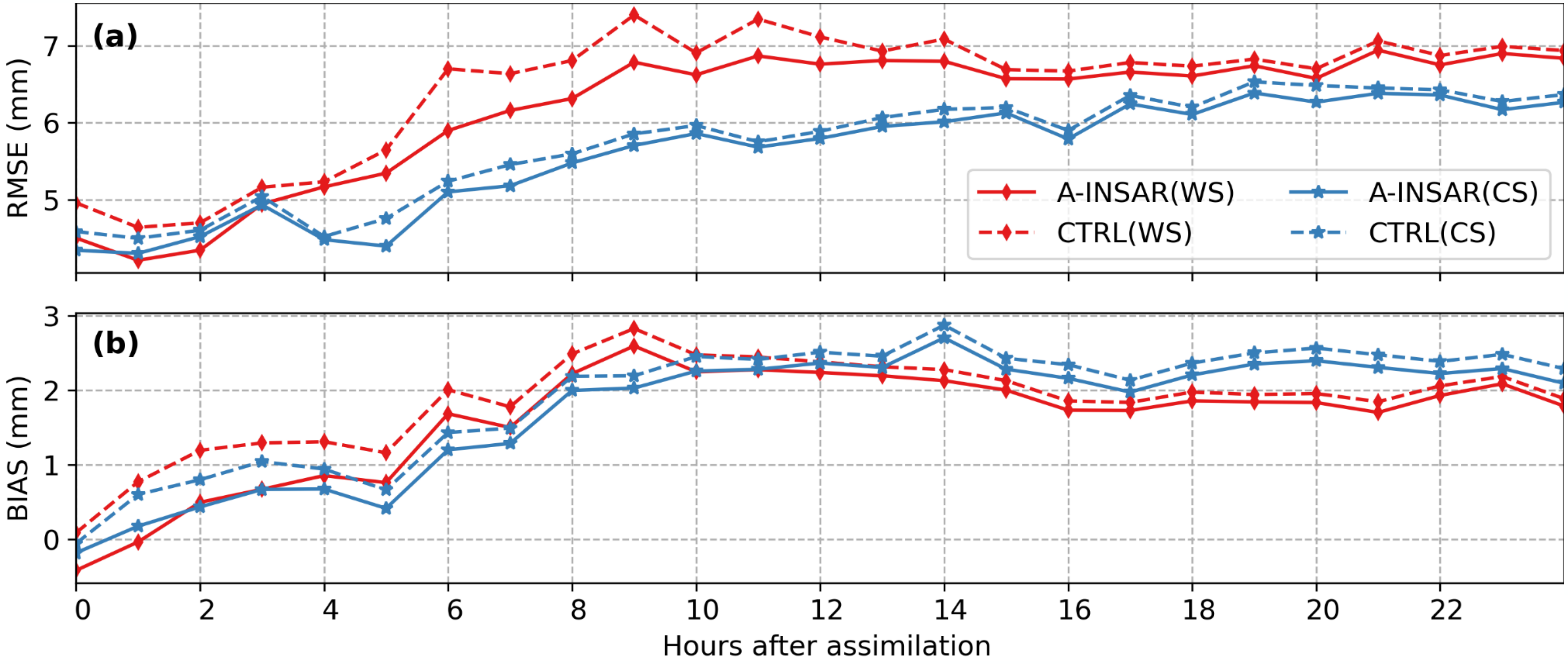


P. Mateus et al. (2022). Using InSAR data to improve the water vapor distribution downstream of the core of the South American Low-Level Jet. Journal of Geophysical Research: Atmospheres, 127, e2021JD036111. https://doi.org/10.1029/2021JD036111

Can InSAR meteorology contribute to a DT of atmosphere?

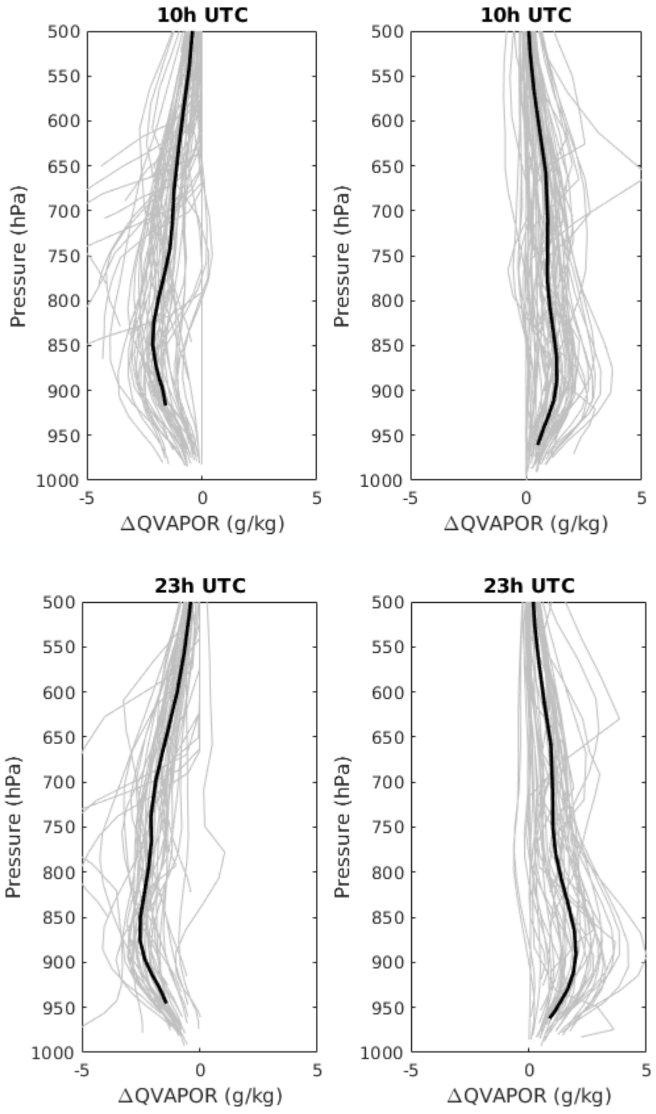
Summary of all 100 assimilations

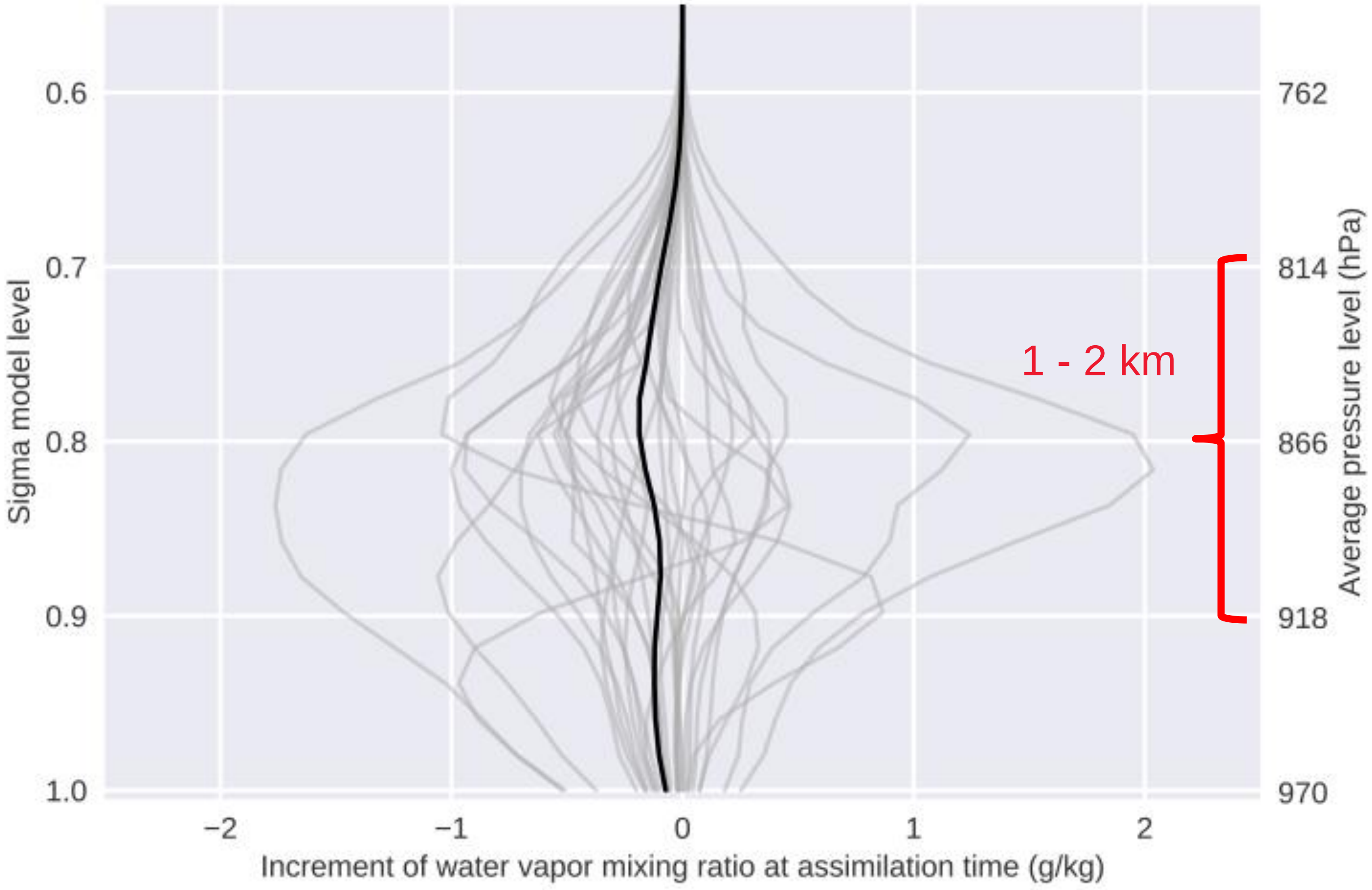


Cold season: March to August

Warm season: September to February

Can InSAR meteorology contribute to a DT of atmosphere?





Can InSAR meteorology contribute to a DT of atmosphere?

Assimilation InSAR PWV maps in WRF (finer resolution 9 km to be similar to that of GPM)

✓ Better approximation in the knowledge of atmosphere’s water (both the spatial and vertical localization) within the LLJ “tube”

✓ Get hints to derive a lower complexity DT at small/shorter spatial and temporal scales to be used to enhance the prediction of extreme weather events

Conclusions

- ✓ Even if NWMs can be considered examples of mature DTs, there is still space for improvements

- ✓ The assimilation of S1 PWV maps could improve the weather forecasting by updating predictions provided by NWMs ←→ precision meteorology useful for a better prediction of extreme weather events)

- ✓ The assimilation of S1 PWV maps could also be useful to generate synthetic observation from NWMs (e.g. related to the SALLJ tube) needed to test new models and assimilation tools before adopting them into new operational NWMs