How has global warming impacted the altimeter wet path delay over the altimetry record?

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Outline

- Introduction and scope
  - Wet path delay (WPD)
    - Motivation
    - Objective
- 30-year analysis of air temperature and water vapor (1993-2022)
- Impact of global warming on radar altimeter WPD
- Main conclusions and take-home message

Wet Path Delay (WPD)

- Thirty years of satellite radar altimetry allow the monitoring of sea level changes at global and regional scales.

- The accurate determination of these changes depends directly on the estimation of the wet path delay (WPD) in the altimeter measurements.

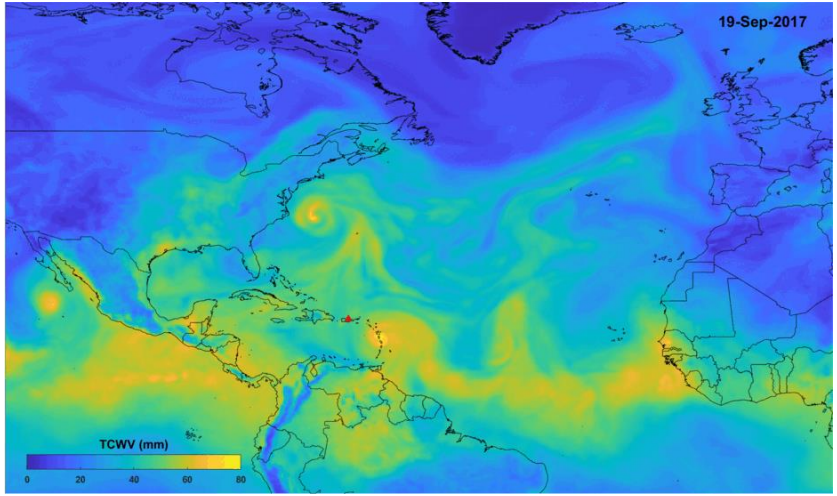
  ✓ **It is crucial to ensure the accuracy and long-term stability of the WPD estimation.**

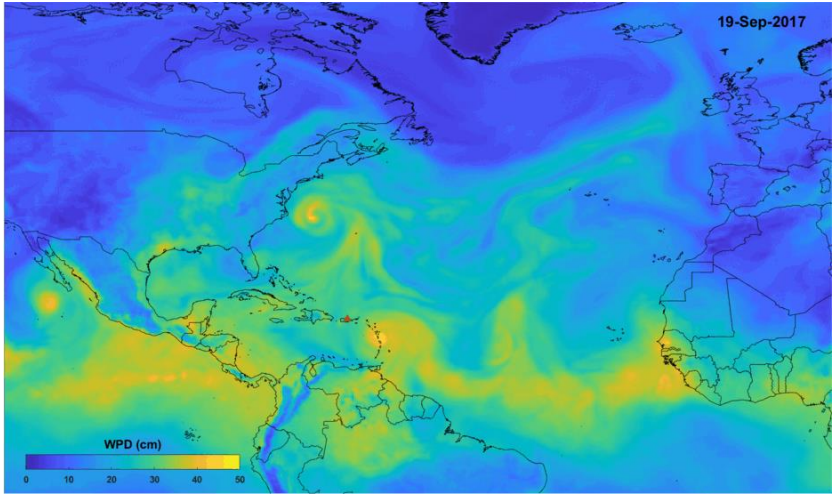
- With a maximum instantaneous value of 50 cm, the WPD is mainly due to the presence of water vapor in the atmosphere.

  ✓ **WPD has a direct and strong dependence on the water vapor content in the atmosphere** and possesses its characteristics, namely the spatial and temporal variability.

Water vapor and WPD

Water vapor (left) and **WPD** (right) for 19-21 Sep 2017 (Hurricane Maria over Puerto Rico)





▲We are here.

Motivation and objective

- Water vapor in the atmosphere increases at a global average rate of 7% per 1°C increase in air temperature.

  ✓ **Due to global warming, the Earth's atmosphere is getting wetter.**

- Since WPD is mainly dependent on atmospheric water vapor, which in turn depends on air temperature, **WPD has a direct dependence on air temperature.**

- **Objective:** to assess and quantify the impact of global warming on WPD over the satellite altimetry record (1993-2022).

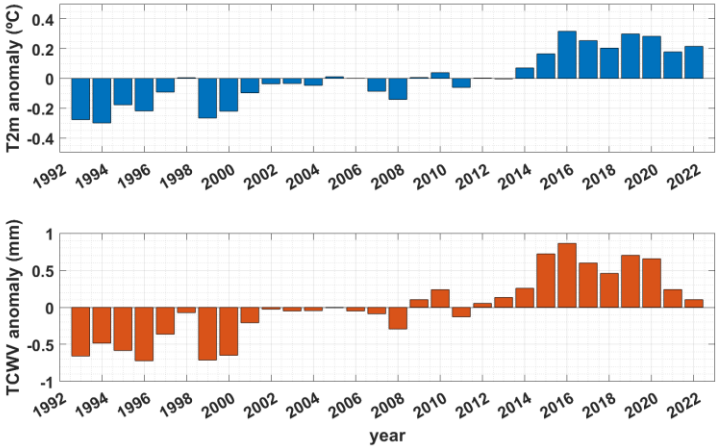
Data

- ECMWF ERA5 monthly averaged data on single levels
  - Spatial resolution: 0.25°×0.25°
  - Time span: 1993-2022 (30 years)
- Analyzed variables:
  - ✓ near surface air temperature (2m temperature, **T2m**), in °C;
  - ✓ atmospheric water vapor (total column water vapor, **TCWV**), in mm or kg m^{-2};
  - ✓ other variables (**temperature** and **atmospheric humidity**) for the computation of **WPD** at sea level.

Global analysis <u>only over sea</u> (ERA5 land-sea mask).

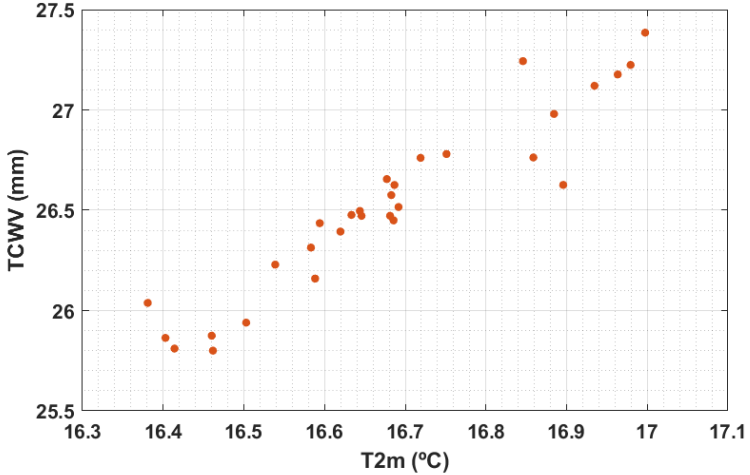
Temperature and water vapor: 30-year temporal analysis

↓ Annual global mean anomalies of **T2m** and **TCWV**, relative to 1993-2022 averages (**16.68 °C** and **26.52 mm**)



Linear trends: **0.18 °C/decade** and **0.43 mm/decade**

↓ Annual global means for the 30 years: **T2m** versus **TCWV**

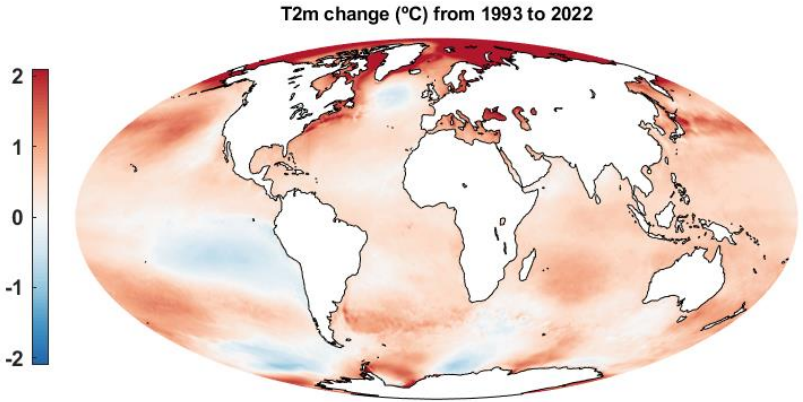


Linear trend: **2.38 mm/°C** (**9%** of the 30-year average)

Temperature and water vapor: 30-year spatial analysis

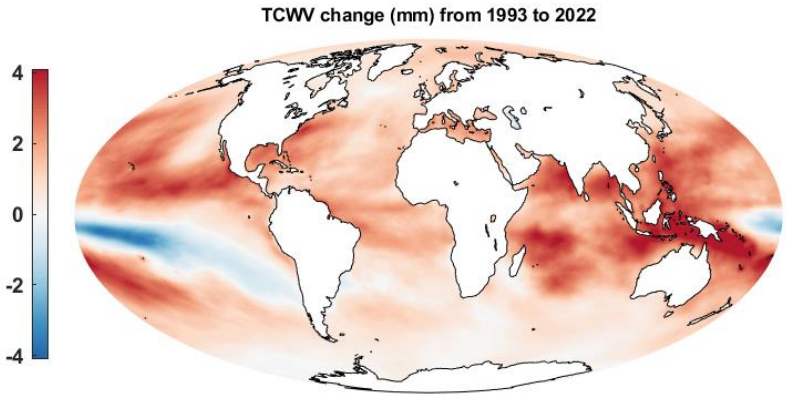
↓ Global map of **T2m** change, in °C, from 1993 to 2022

Global mean: **+0.53 °C**
(0.18 °C/decade × 3)



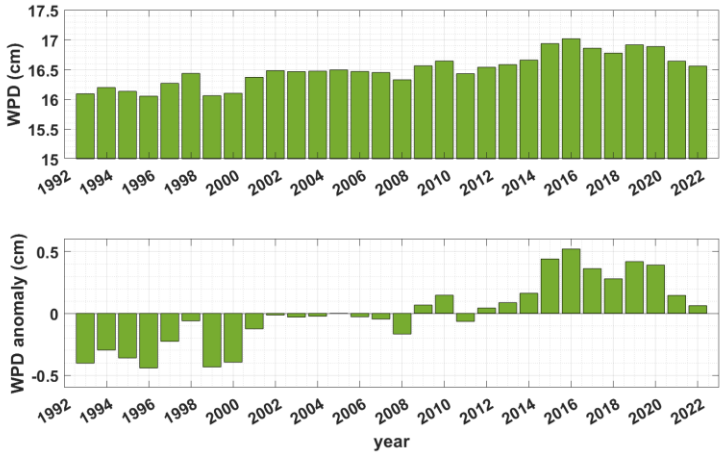
↓ Global map of **TCWV** change, in mm, from 1993 to 2022

Global mean: **+1.28 mm**
(0.43 mm/decade × 3)



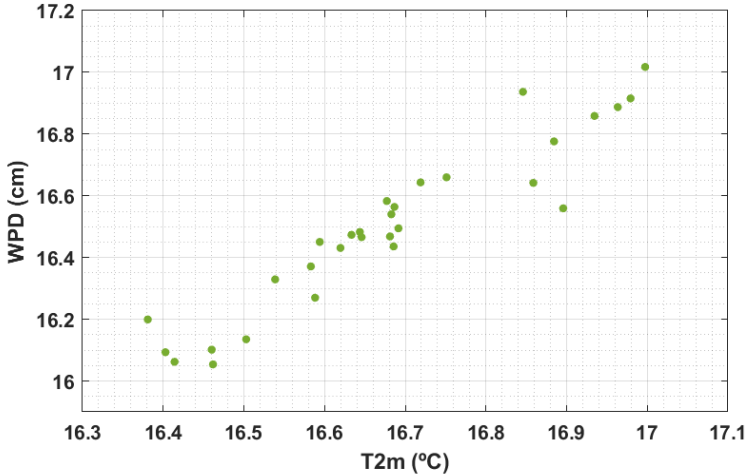
WPD: 30-year temporal analysis

↓ Annual global means and anomalies of **WPD**, relative to 1993-2022 average (**16.50 cm**)



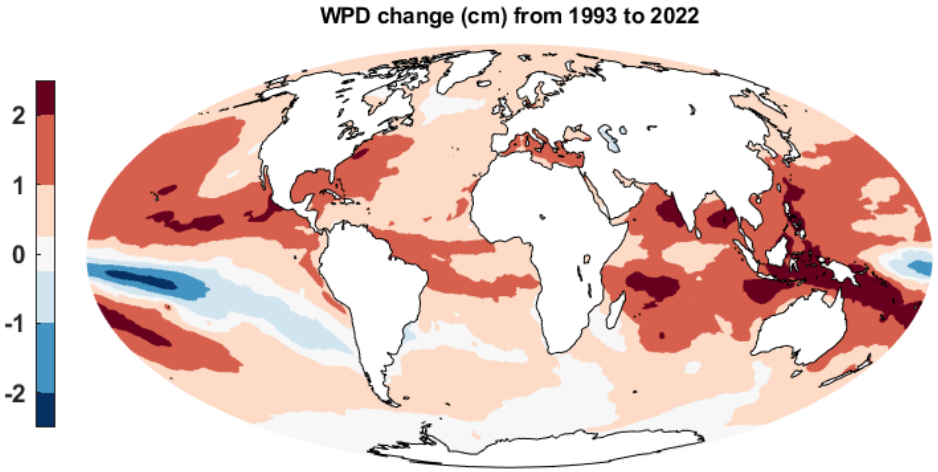
Linear trend: **0.26 cm/decade**

↓ Annual global means for the 30 years: **T2m** versus **WPD**



Linear trend: **1.44 cm/°C**
(**9%** of the 30-year average)

WPD: 30-year spatial analysis



← Global map of **WPD** change, in cm, from 1993 to 2022

Global mean: **+0.79 cm**
(0.26 cm/decade × 3)

- On average, **WPD has increased 0.8 cm** in the last 30 years.
- In some regions, **this increase exceeds 2 cm.**

Conclusions

- Over ocean, for the satellite altimetry period (1993-2022):

  ✓ **T2m** has increased:
  0.18°C/decade
  0.53 °C in total

  ✓ **TCWV** has increased:
  0.43 mm/decade
  1.28 mm in total

  ✓ **WPD has increased:**
  0.26 cm/decade
  0.79 cm in total

  ✓ **Per 1°C of warming:**
  TCWV increases 2.38 mm (9%)
  WPD increases 1.44 cm (9%)

Take-home message

- Over 1993-2022, **WPD has increased at an average rate of 0.26 mm/year** over the global ocean, which represents:

  - ✓ a total increase of **0.8 cm** (5%);
  - ✓ an average rate of **1.44 cm** (**9%**) per 1°C of warming;
  - ✓ about **8%** of the total GMSL trend for about the same period (3.3 mm/year);
  - ✓ the estimated GMSL trend error (± 0.3 mm/year).

- Due to the global warming over these 30 years, **this is a physical signal that should not be misled with any kind of drift**.

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