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EGU 2021, session G5.2

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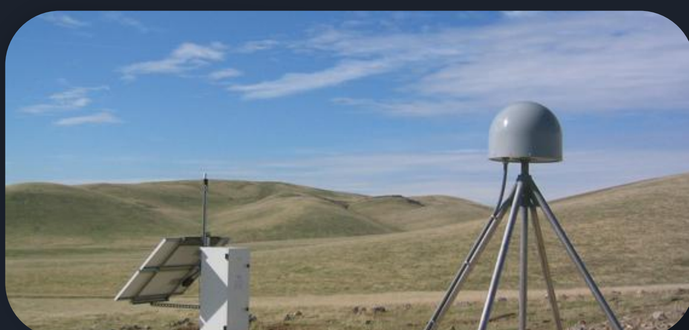
Precipitable water vapor from GPS tropospheric path delays over the Eastern Mediterranean: trends, diurnal and long-term variability



Remote sensing lab
headed by
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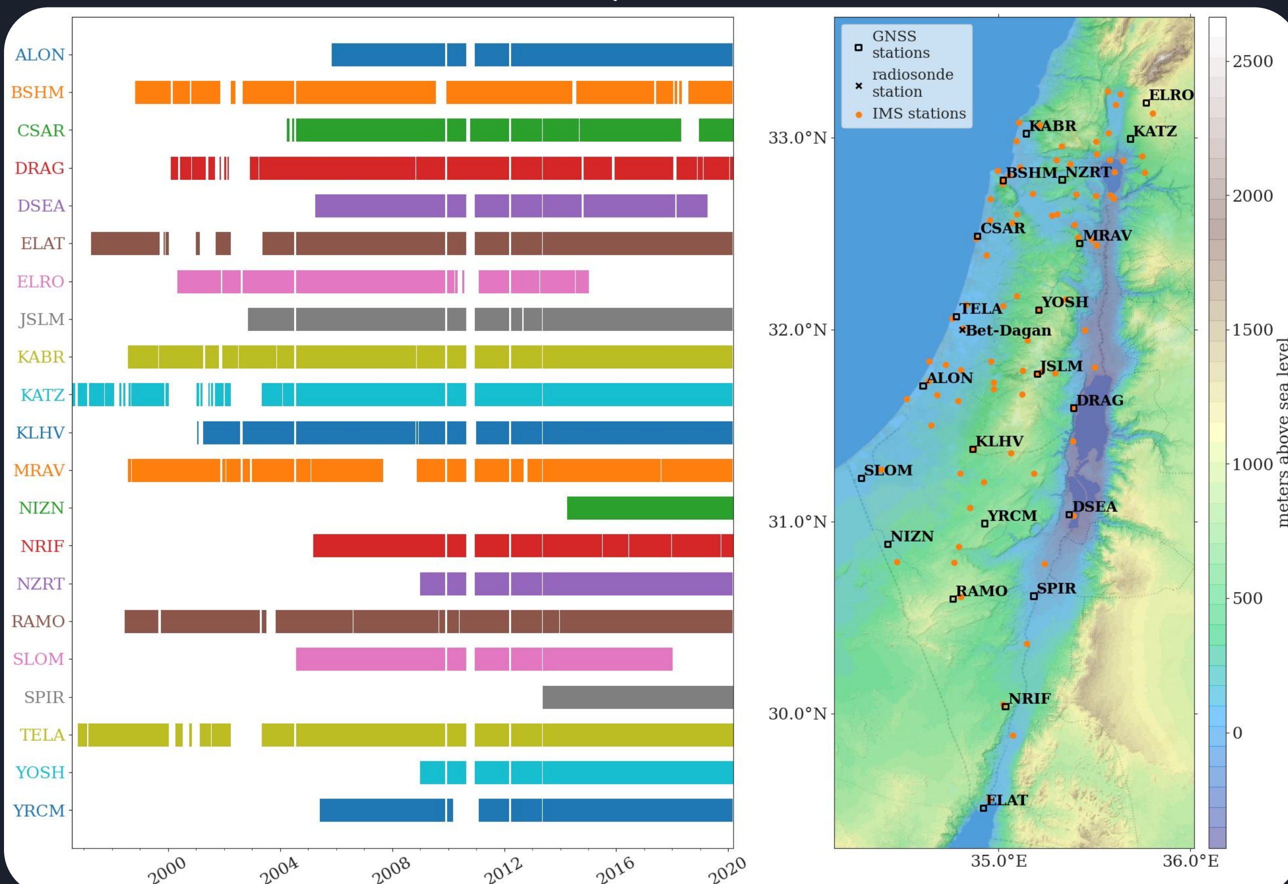
synopsis:

- EM Study area, GNSS network and processing
- PWV diurnal climatology (JJA mostly)
- PWV annual, inter-annual variations and trends
- Summary and conclusions

GNSS-PWV from Survey of Israel Active-Permanent Network



- 21 stations
- 5 to 20 years
- 5 mins sample rate
- good geographical coverage of area
- Temperature and GNSS stations are close

Ziv, S. Z., Yair, Y., Alpert, P., Uzan, L., & Reuveni, Y. (2021). The diurnal variability of precipitable water vapor derived from GPS tropospheric path delays over the Eastern Mediterranean. *Atmospheric Research*, *249*, 105307.

Processing:

- RINEX files → NASA's JPL GIPSY-X v1.1:
  - PPP mode
  - minimum elevation cutoff angle 15°
  - ocean loading
  - GMF mapping function
  - full parameter tree, and repo at Github.com
- ZWD: every 5 minutes

- PWV = κZWD [*Bevis et al.*, 1992]

(PWV = IWV = PW = TCWV) kg/m^2 or mm

$1/\kappa = 10^{-6}(k_3/T_m + k_2/R_v)$, R_v - Specific gas constant for WV

$k_3 = 3.776 \cdot 10^5 K^2 mbar^{-1}$, $k_2 = 22.2 mbar^{-1}$

T_m - Weighted mean temperature of the atmospheric column

Mean temperature:

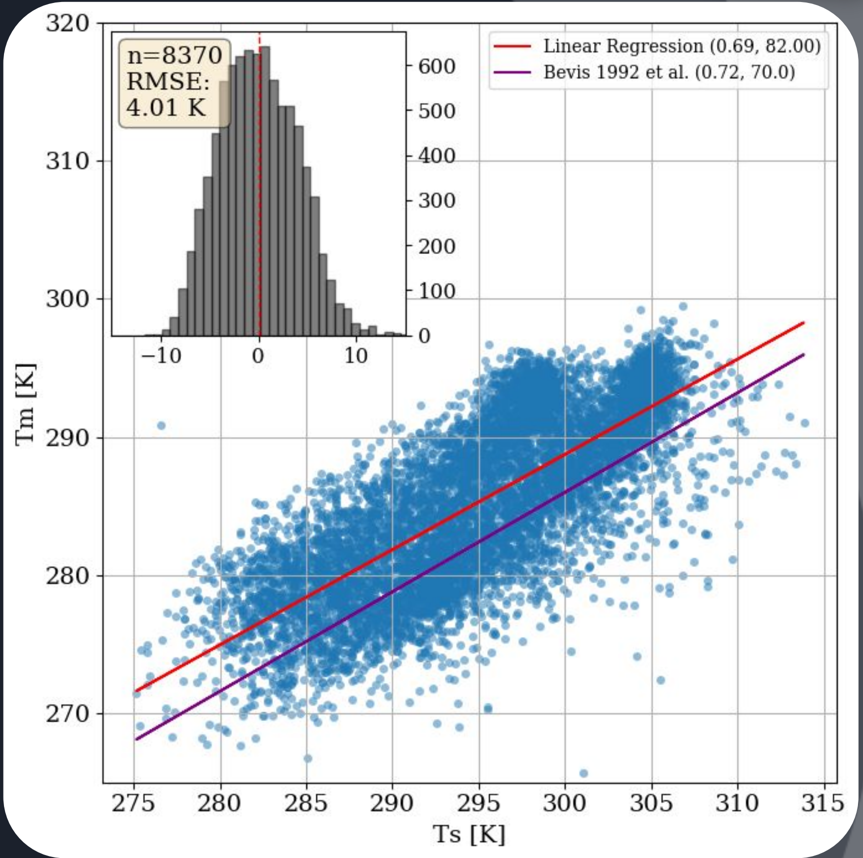
Weighted mean temperature of the atmospheric column calculated from one radiosonde station with 11.5 years of twice daily records:

$$T_m = \frac{\int_0^{toa} (P_v/T)dz}{\int_0^{toa} (P_v/T^2)dz}$$

P_v - water vapor partial pressure, T is the atmospheric temperature (toa=top of atmosphere)

Linear regression yields:

$T_m = 82+0.69T_s$



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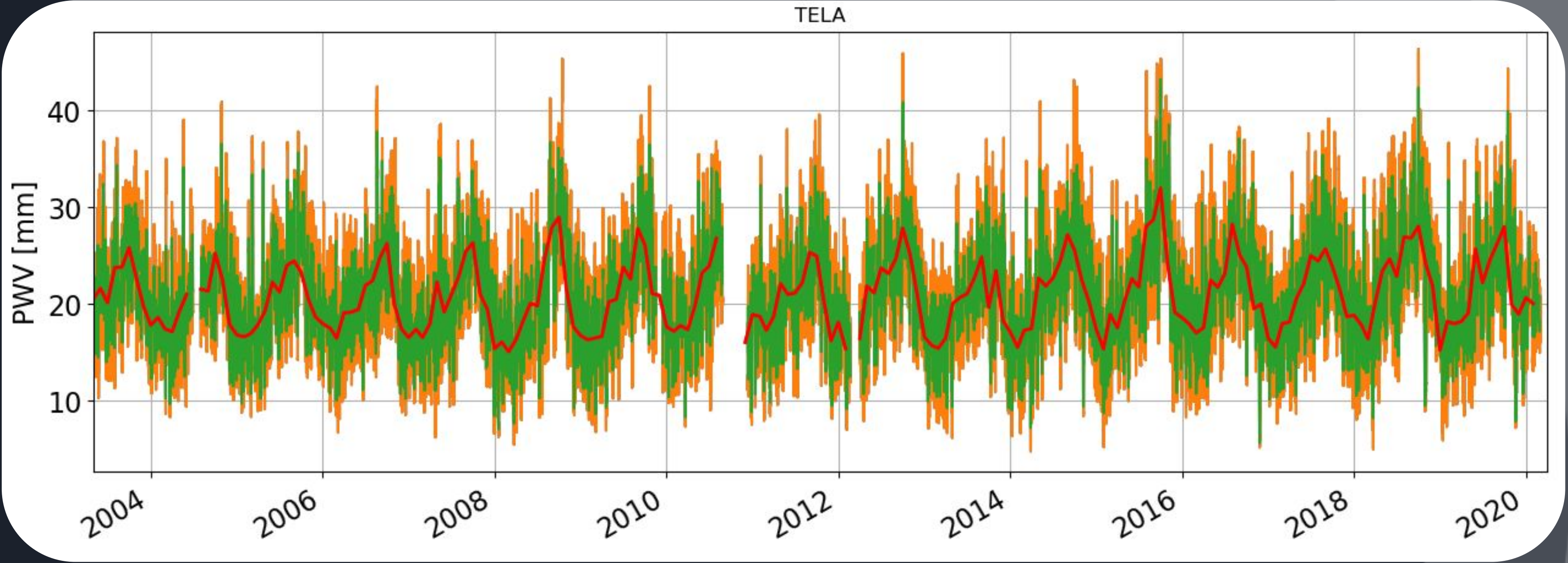
PWV time series (e.g., TELA):



- coastal station (~50 m above sea level)
- orange is 5 mins values
- green is daily means
- red is monthly means

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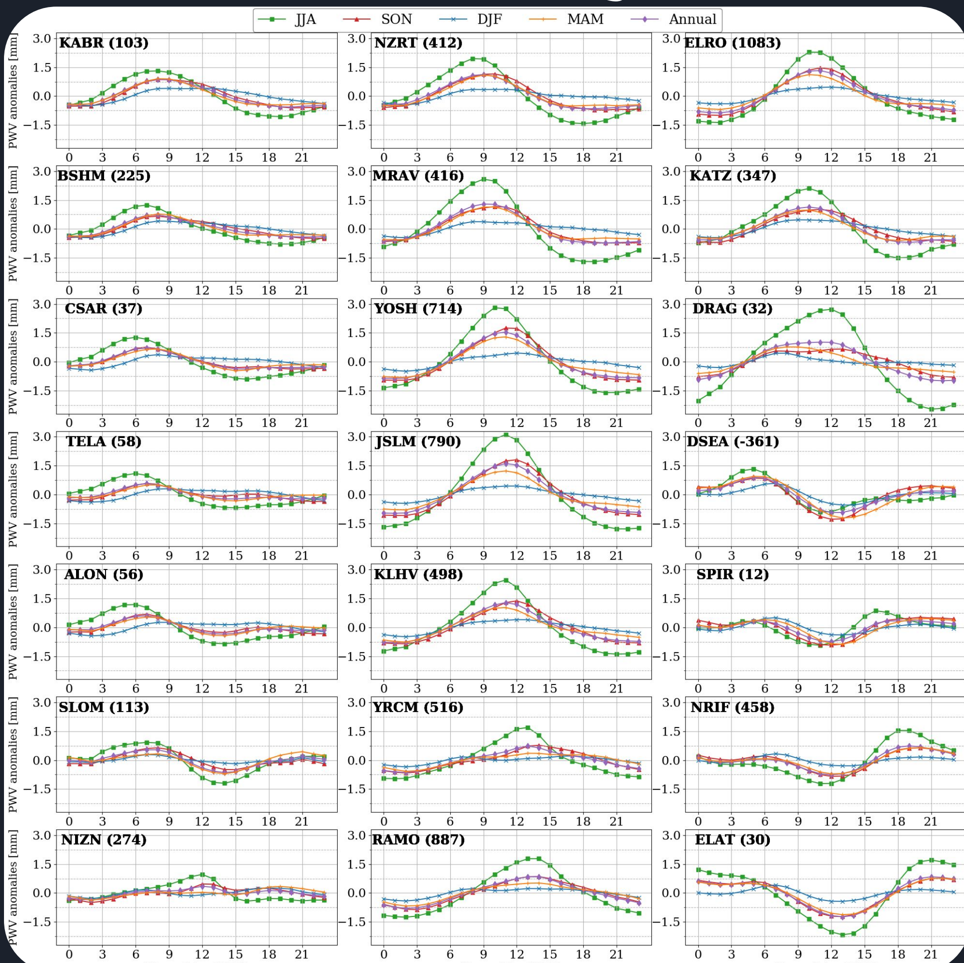
diurnal climatology (seasonal & annual)



diurnal anomalies for each station:

- remove the daily means
- groupby hour of the day and average
- for each season and annual

figure layout:

- left column is coastal
- middle is highland
- right is eastern
- rows are from north to south
- height above sea level is near station name
- time is in UTC (LST +3 for JJA)

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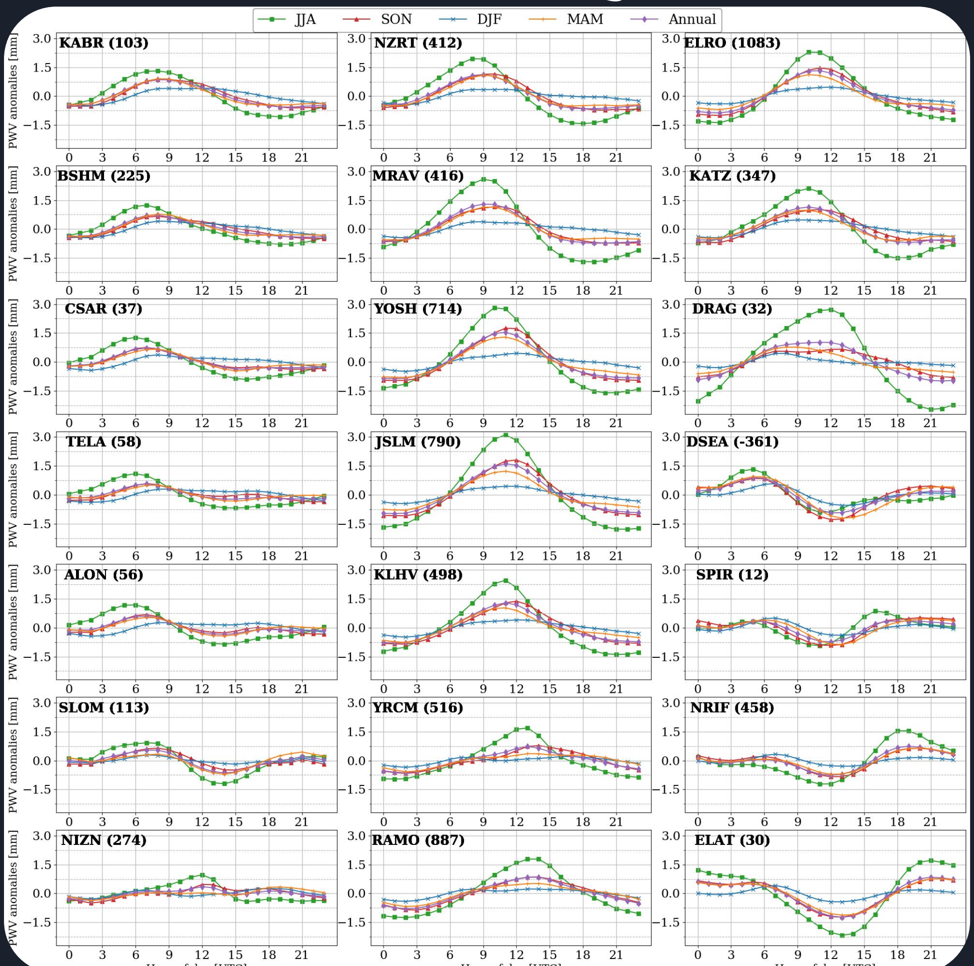
diurnal climatology (seasonal & annual)



- JJA signal is strongest probably due to high sea-land temperature differential that drives sea breeze
- diurnal amplitude is higher for highland stations and low for coastal stations
- coastal stations diurnal peak in the morning (~9 LST) while highland and eastern stations' peak hour propagates from north to south indicating a sea breeze penetrating inland

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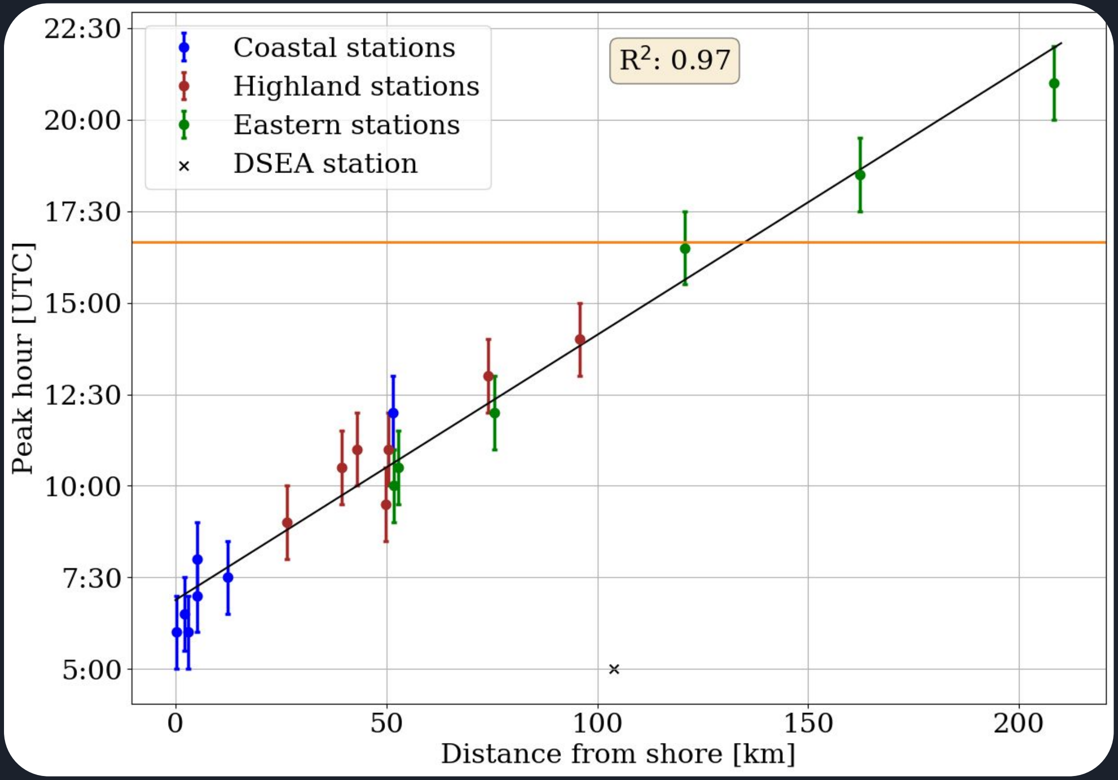
peak hour in JJA



meditreanean sea breeze (MSB) in JJA:

- average speed from regression is ~15 kph
- Dead Sea does not conform to line, probably due to own microclimate
- orange line is mean sunset time suggesting the MSB still drives humidity inland after dark

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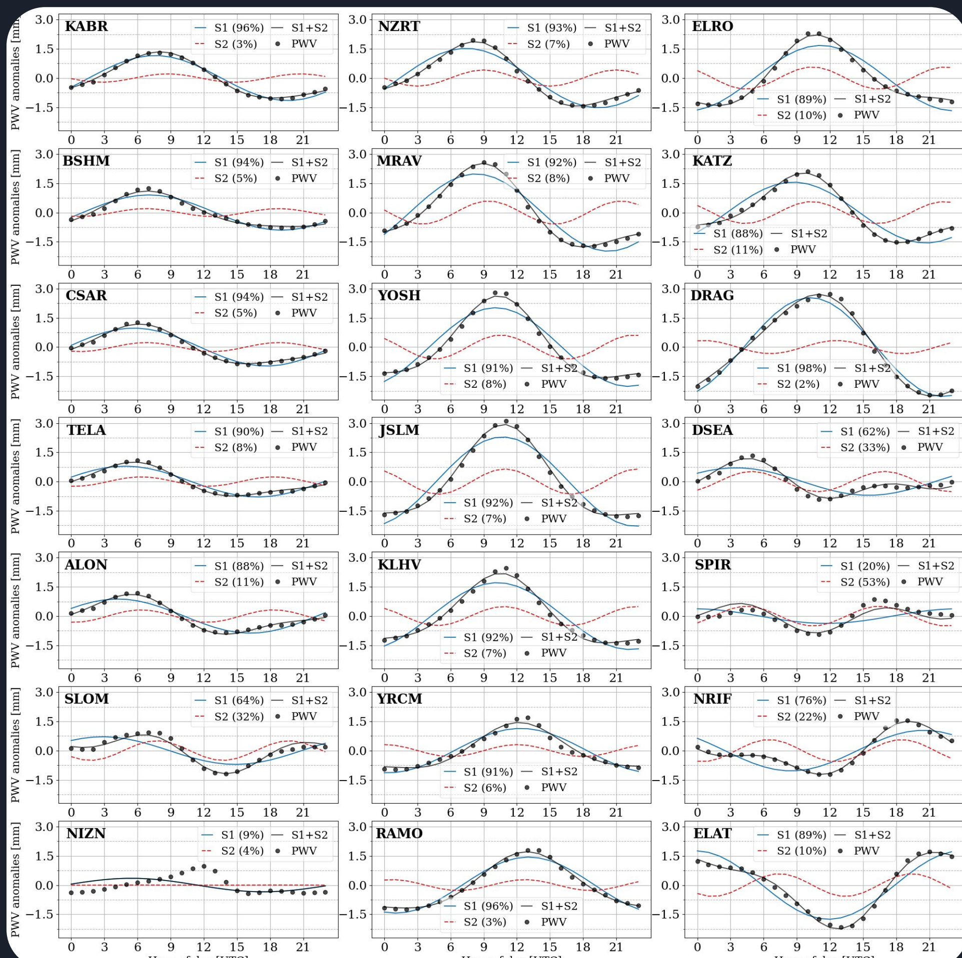
diurnal harmonics in JJA (S1 and S2)



- total sub-daily variance explained by S1 and S2 is >95% for 19 out of 21 stations
- harmonics fail to explain NIZN probably due to less data (~5 years)
- S2 generally explains less variance in the highlands as compared to the coastal/eastern stations
- Is there a physical mechanism for S2 ? (e.g., atmospheric tides) or is it just linear response to daily insolation harmonics ?

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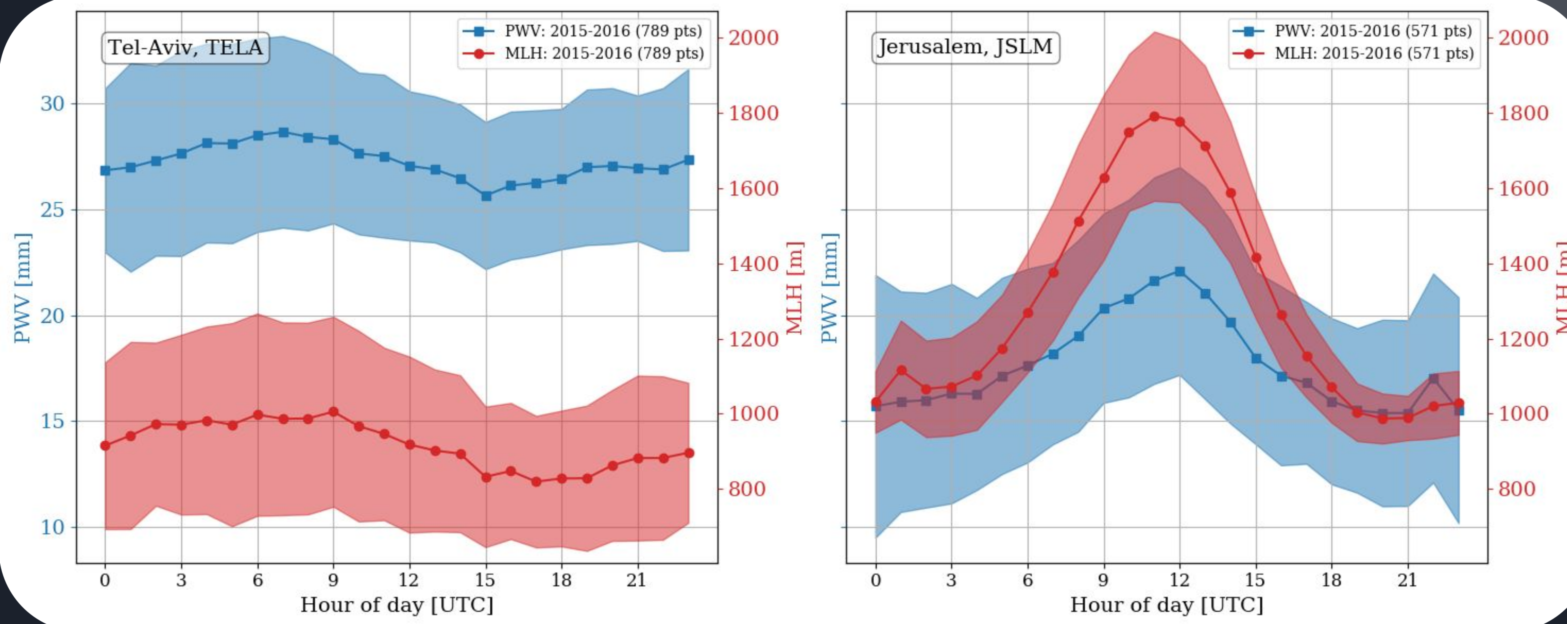
Mixing Layer Height correlation in JJA



- low MLH in the coast (left:Tel-Aviv) inhibits the effectiveness of the MSB to advect humidity hence the low PWV amplitude
- high MLH in the highlands (right:Jerusalem) allows the MSB to be more pronounced thus results in higher PWV amplitude
- this correlation still needs to be confirmed with more stations

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synopsis:

- EM Study area, GNSS network and processing
- PWV diurnal climatology (JJA mostly)
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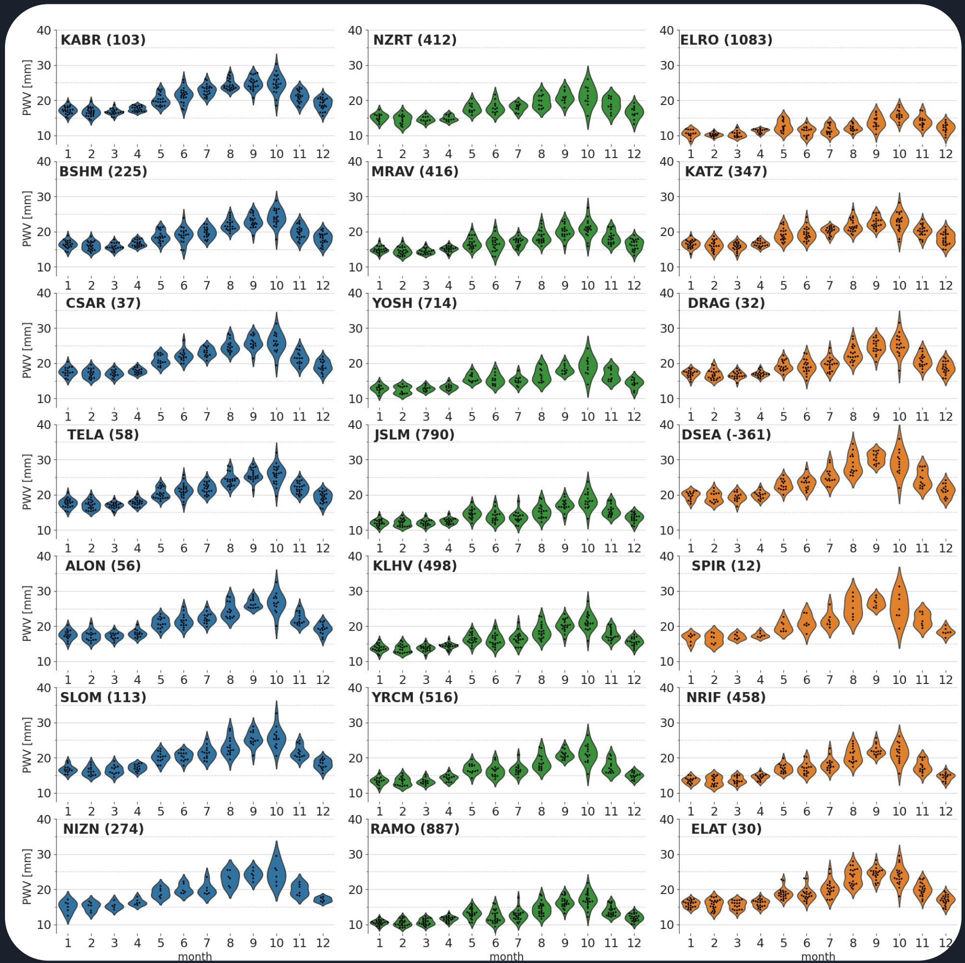
annual cycle climatology (monthly means)



- synoptic scale meteorology is more important here
- values decrease with station altitude
- high stations are less variable
- lowest values in Jan. to Apr. with low variability.
- highest values in Sep. Oct. where Oct. is highly variable.
- the drop from autumn to winter is 2-3 times steeper than the increase from winter-spring to autumn.
- local minima around June and July for most highland and eastern stations

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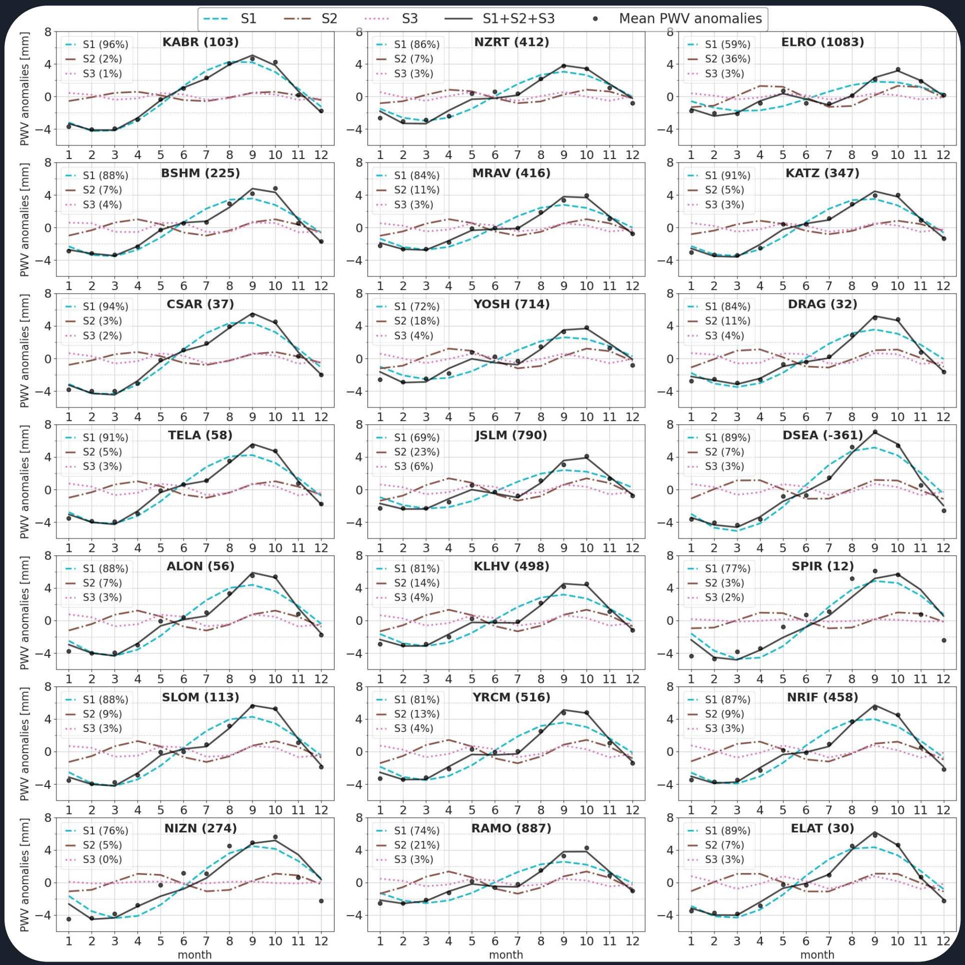
annual harmonics (S1, S2 and S3)



- total sub-annual variance explained by S1, S2 and S3 is >93% for 19 out of 21 stations
- S1 peaks in Sep. suggesting that the Meditrenean SSTs are more dominant for PWV than surface temp.
- S2 peaks are Apr. and Oct. slightly offset the S1 minimum in March.
- S2 minimum is in July which can explain the June-July local minima, however what is the physical mechanism ?

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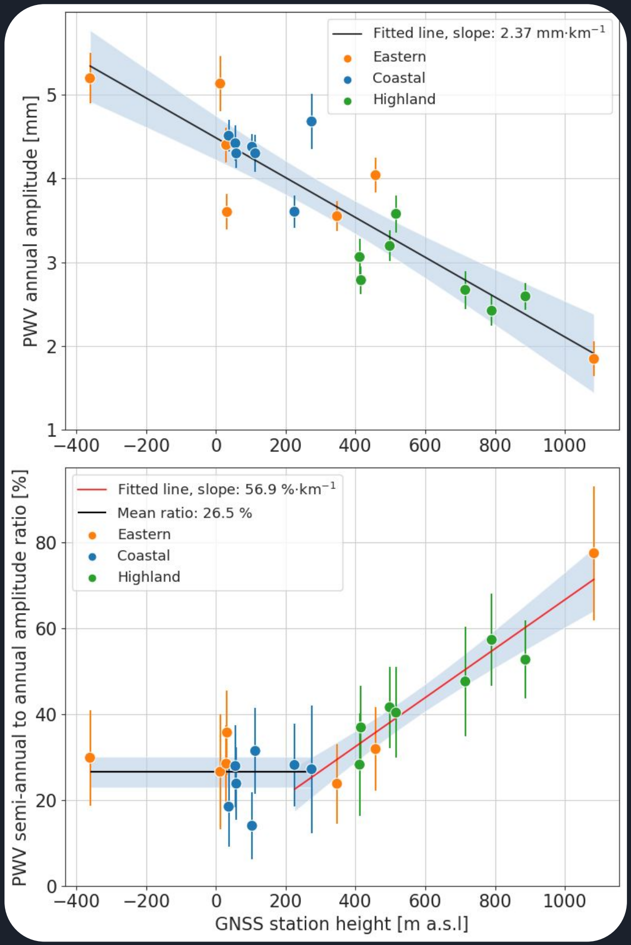
annual harmonics (annual mode and ratios)



- top: S1 drops with station altitude at ~2.37 mm per km, suggesting that S1 is mainly affected from the temperature drop with increasing station height
- bottom: S2/S1 increases with station altitude from around ~300 m at a 57% per km rate
- bottom: below ~300 m S2/S1 is constant at ~ 25%
- since S2 peaks in Apr. and Oct., suggesting that Red Sea Troughs (RSTs) synoptic system are more important to stations with higher altitude

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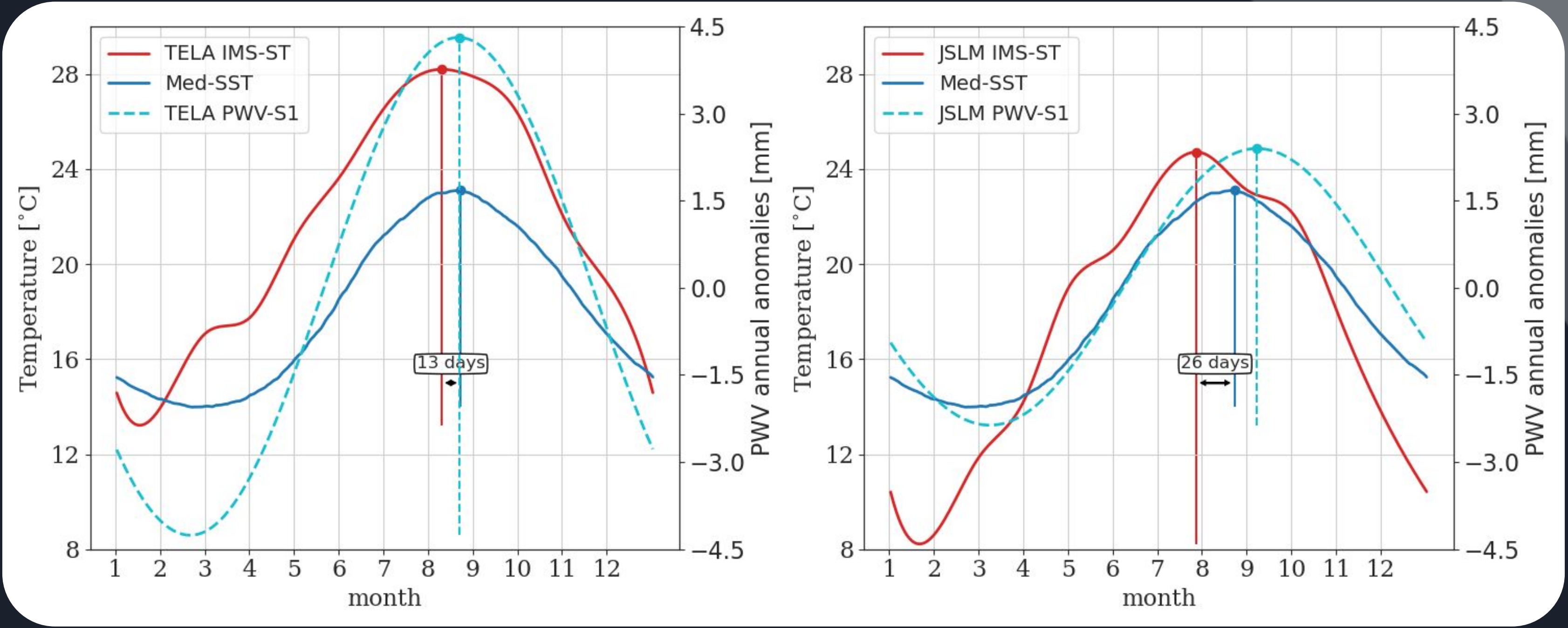
annual harmonics (surface temp. and SST)



- SI is in phase with the Med-SST in the coast (left:Tel-Aviv) where the Surface temp. lags 13 days behind it
- Med-SST lags 16 days behind SI in the highland (right:Jerusalem) suggesting that the SI responds late to the Med-SSTs
- the lag between the surface temp. and the Med-SST in the highland increases to 26 days as expected

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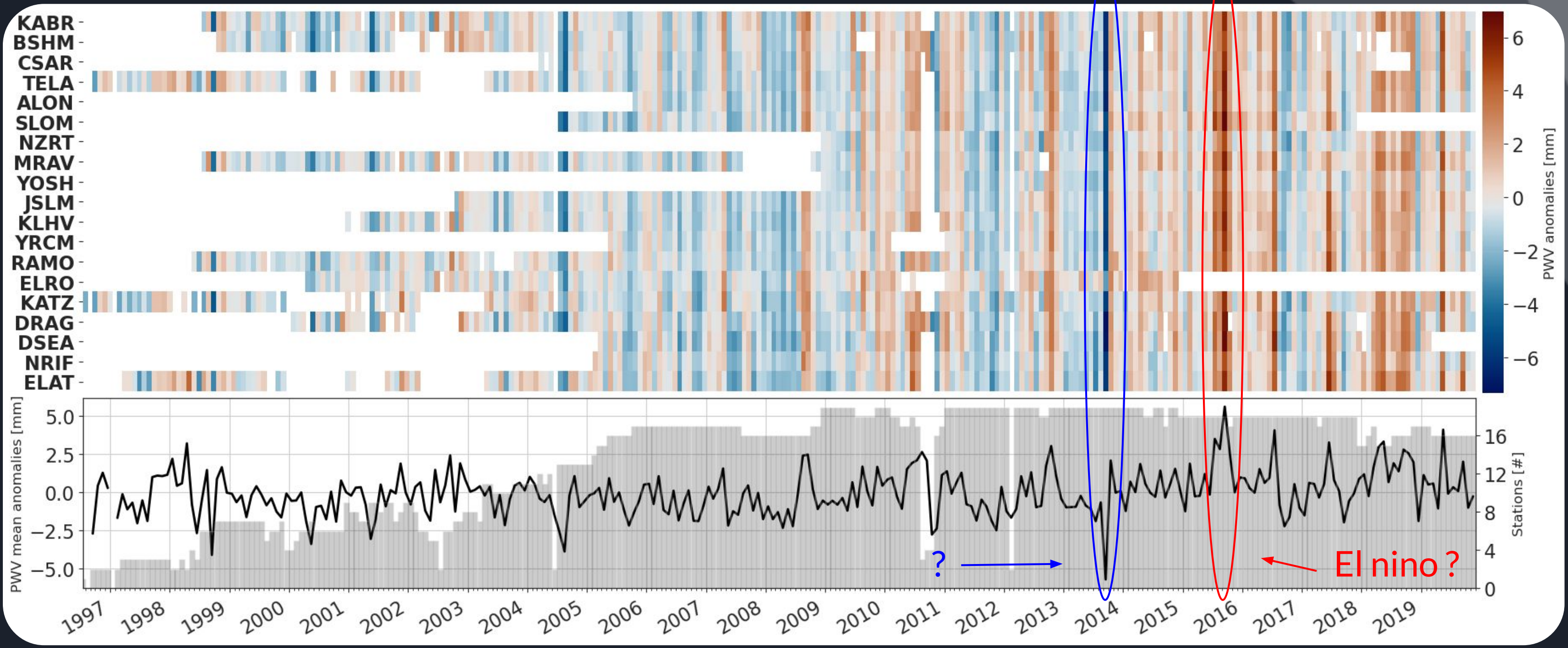
inter-annual variations



- top (heatmap): removed long term monthly means for each station
- bottom (time-series): station mean where grey bars are the number of stations with available data
- most extreme anomalies are both in Oct. (2013 and 2015)
- poor correlation with most relevant flow indices (e.g., NAO, ENSO).

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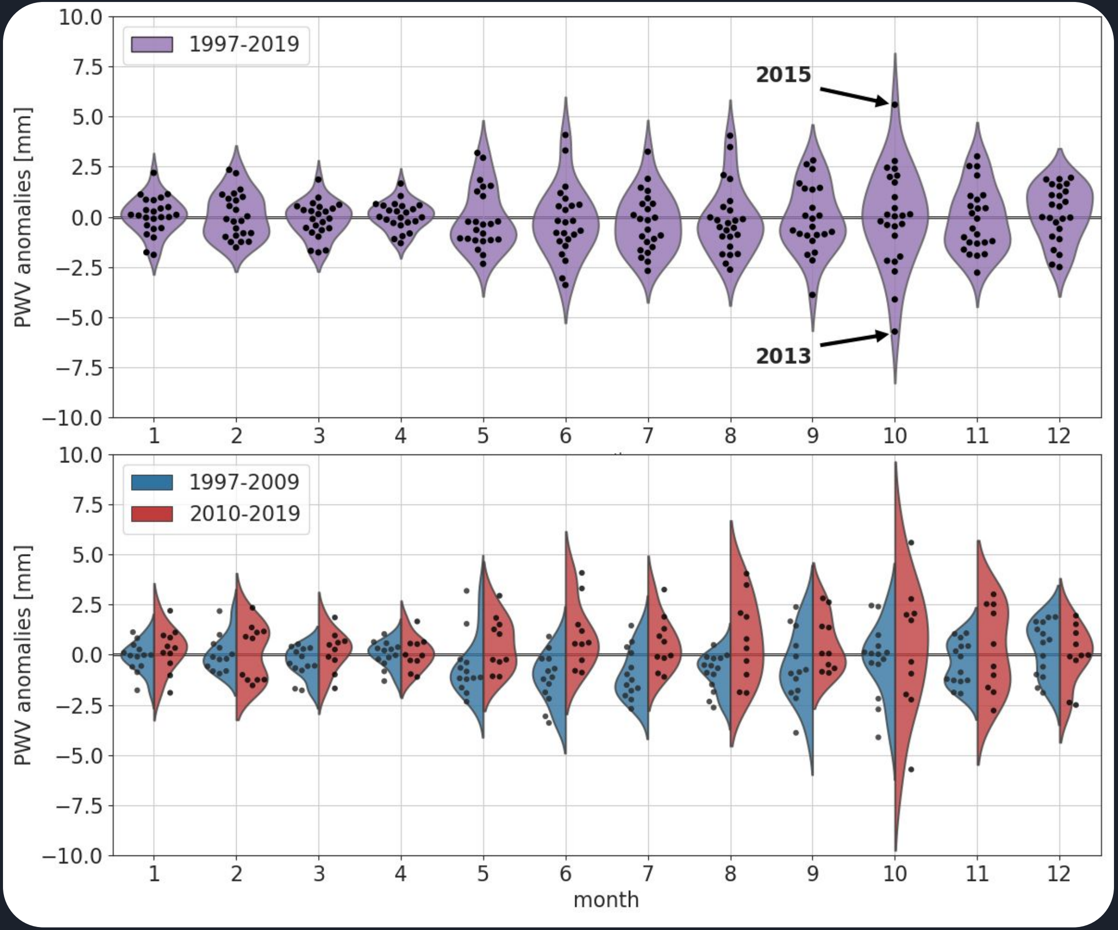
inter-annual variations (monthly breakdown)



- top: all anomalies (23 years)
- Apr. has the lowest variability, Oct. the largest
- without 2013 and 2015, Oct. would have had the same variability as May to Dec.
- bottom: last decade anomalies (red) as compared to 1997-2009 anomalies (blue)
- mean and variability are increased in the last decade

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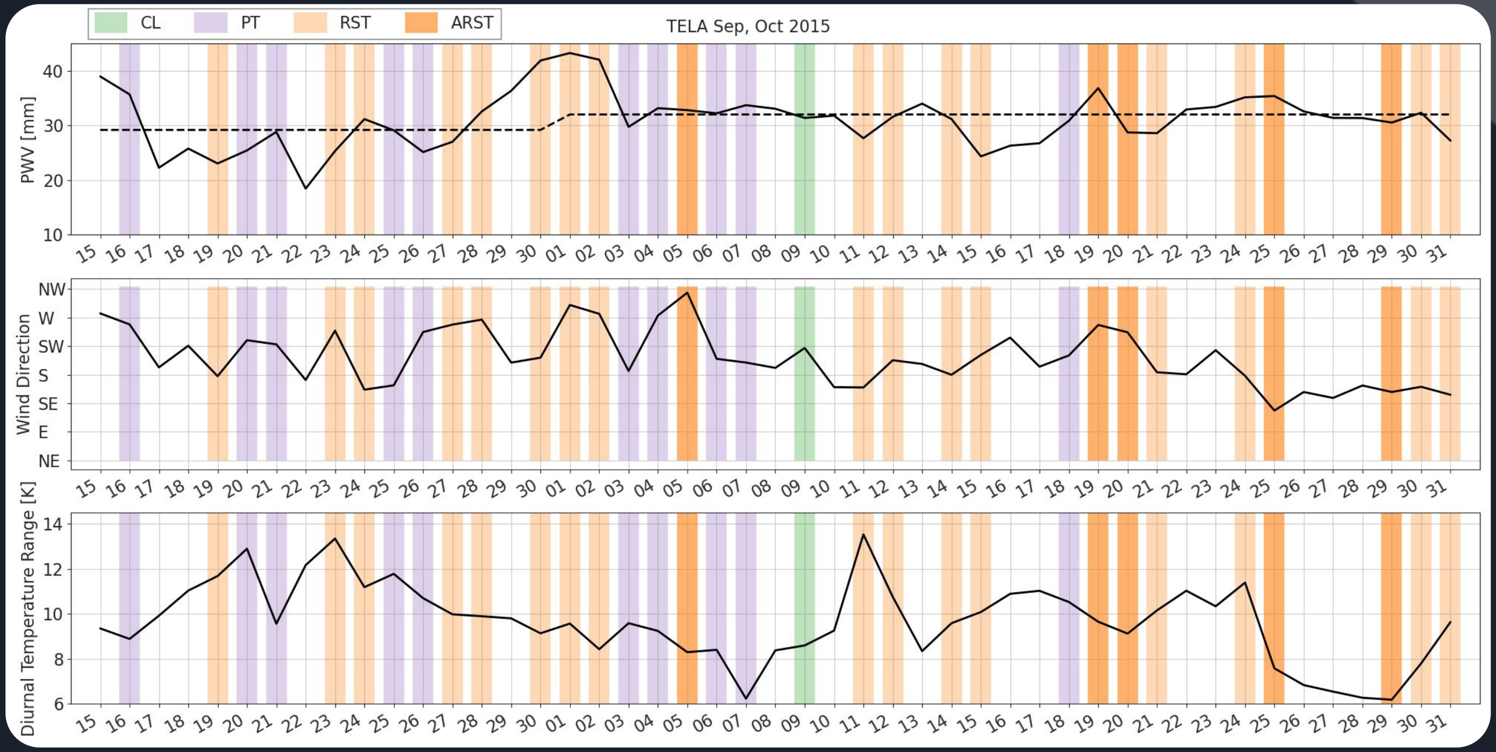
15 Sep. to Oct. 2015 daily synoptic breakdown



- top : daily PWV, center: wind direction, bottom: diurnal temperature range. Cyprus Lows (CL), Persion Troughs (PT), Red Sea Trough (RST) and Active Red Sea Trough (ARST) synoptic classes as colored bars
- 3 ARSTs + almost no dry events enabled high PWV values.

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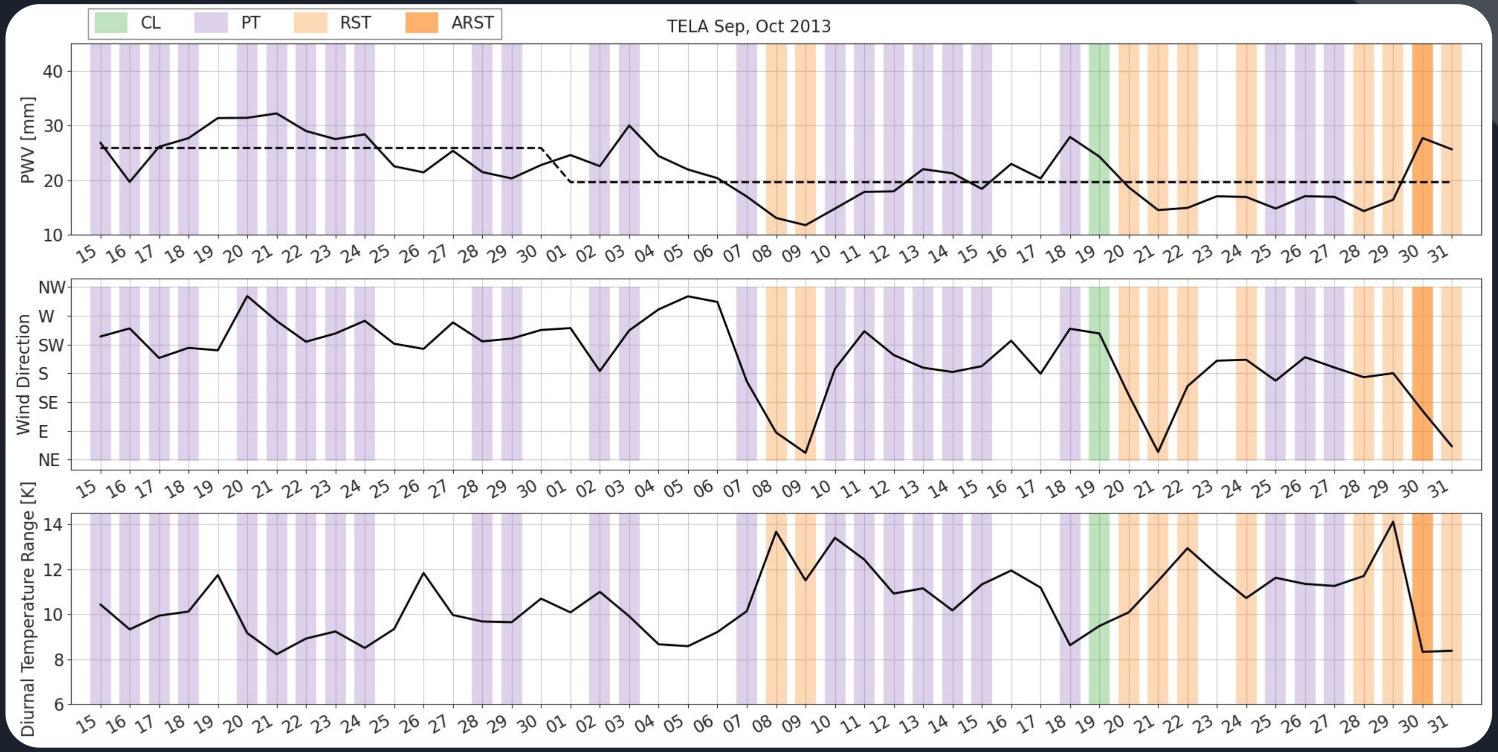
15 Sep. to Oct. 2013 daily synoptic breakdown



- RSTs + 2 major dry periods lowered the PWV values considerably
- without the ARST in Oct. 30th, the PWV values would have been even lower

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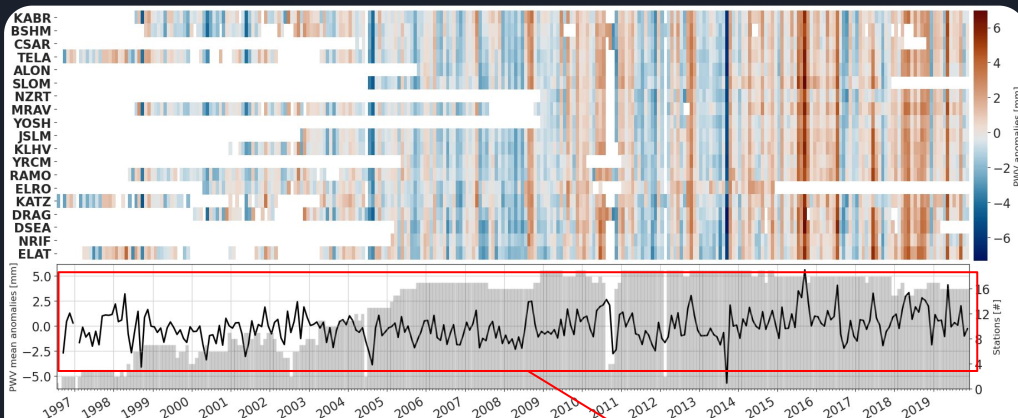
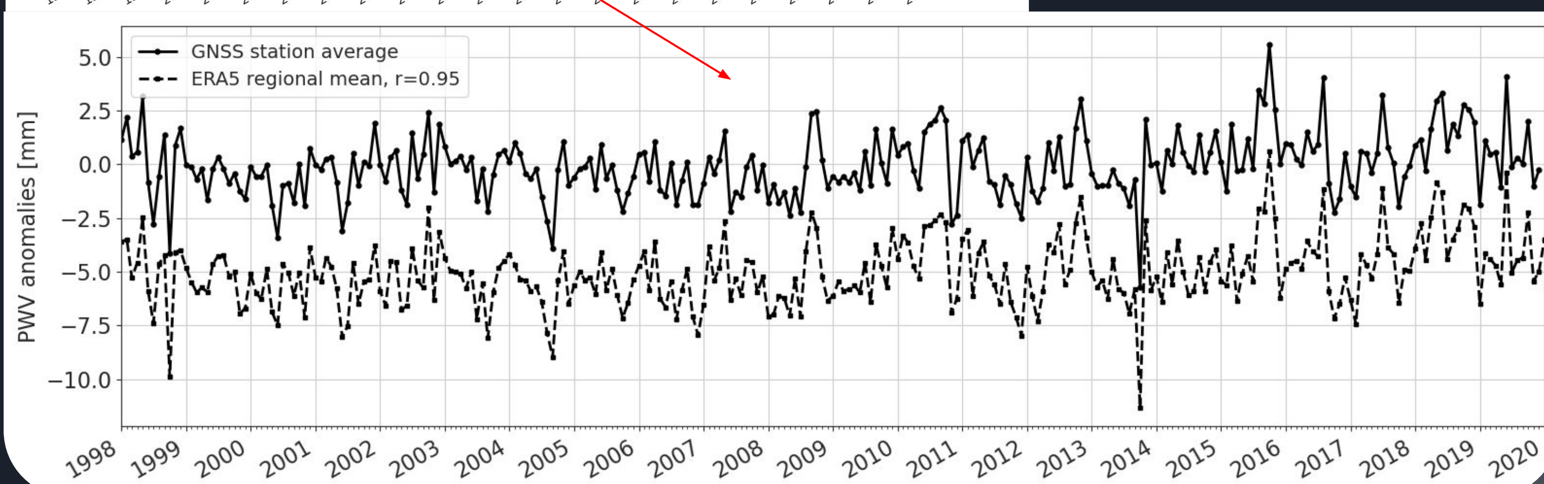
inter-annual variations vs. ERA5



- bottom: ERA5 TCWV regional mean (dashed) plotted 5 mm below the PWV station mean.
- ERA5 regional mean is computed the same way the PWV station mean
- correlation is 0.95!



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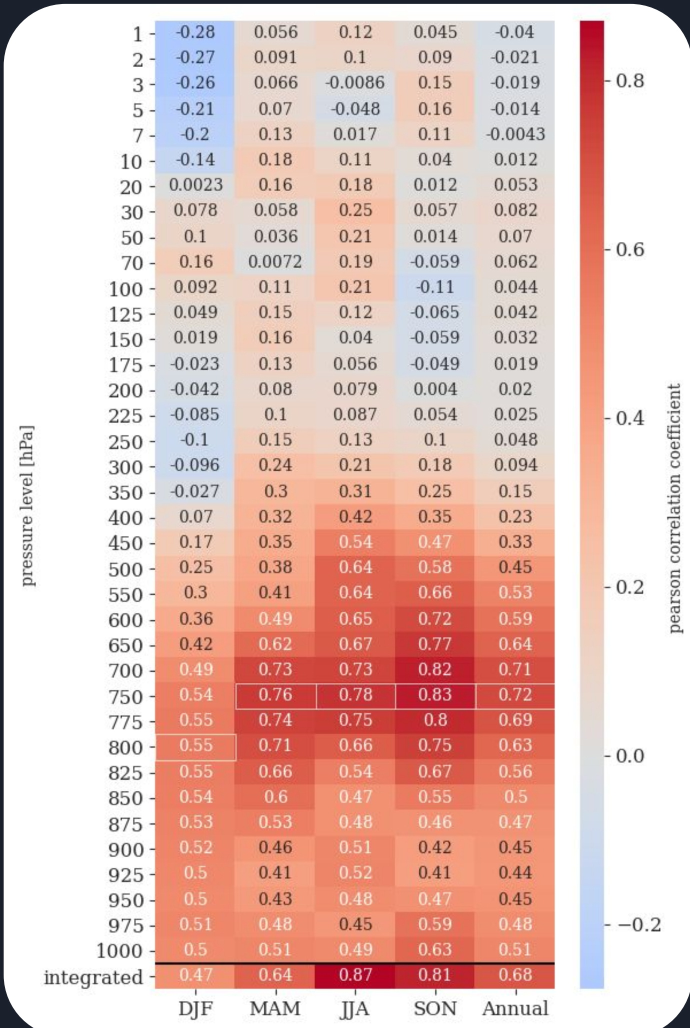
PWV anomalies and moisture flux anomalies correlation (seasonal and annual)



- moisture flux is the magnitude of specific humidity × wind velocity taken from ERA5
- integrated column values are in the last line
- annual max of 0.72 is at 750 hPa (~2.5 km) also for other seasons except DJF
- SON is at 0.83 suggesting the main humidity driver in autumn is RST and ARST.
- JJA is at 0.78, however no RSTs in this season, suggesting humidity transport from the west (Med-sea) but why 750 hPa and not lower levels (e.g., 900 hPa) ?

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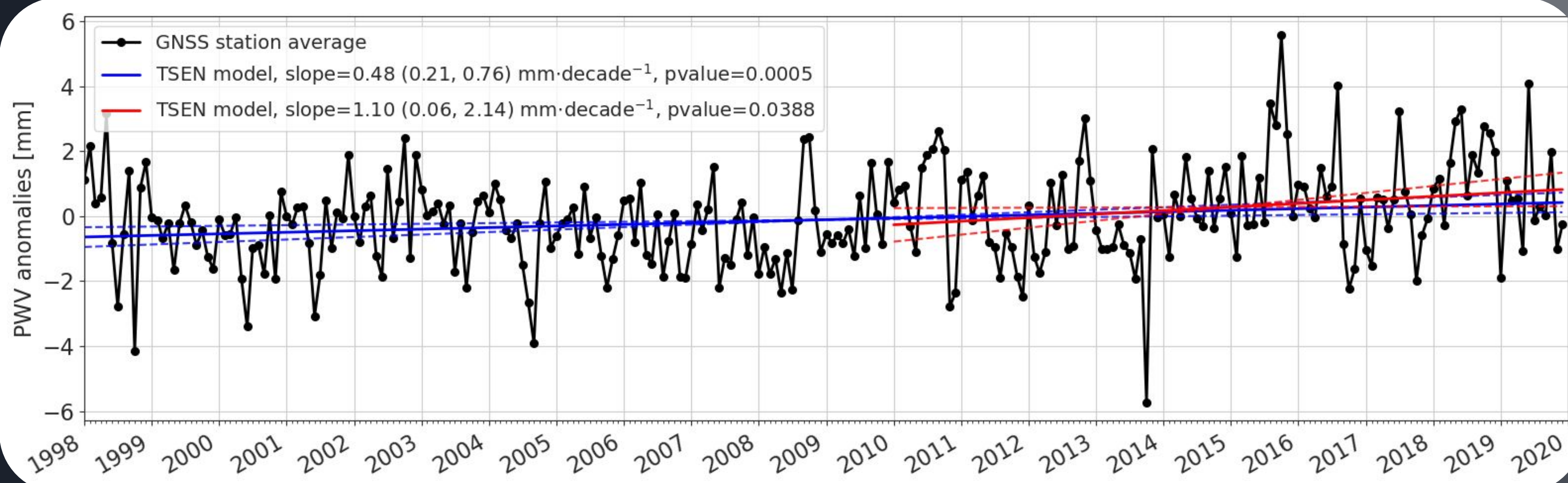
Long term trends



- whole period (blue) and last decade (red) trends are 0.48 and 1.1 mm per decade resp. with relative increase of ~3% and ~6% per decade resp.
- Clausius Clapyron ratio of 7% increase per 1°K implies 0.42 and 0.85 °K per decade trends resp. suggesting direct response to warming climate
- however, higher PWV variability in the last decade implies higher synoptic variability which is not necessarily due to a warming climate

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- Introduction to GPS meteorology
- PWV diurnal climatology in Israel (JJA mostly)
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summary and conclusions (I)

- GNSS meteorology is a useful tool for studying PWV diurnal and long term variations in the EM area
- The diurnal amplitude in summer is the highest compared to the seasonal mean for most stations followed by spring and autumn, while the weakest diurnal amplitude is in winter.
- Generally, the diurnal amplitude in the highlands is higher than in the eastern stations followed by the coastal areas which have the weakest diurnal amplitude compared to the mean.
- In summer, the peak hour of the diurnal cycle correlates with the distance of the station to the Mediterranean Sea shore, suggesting that the Mediterranean Sea Breeze is a key driver of humidity on the diurnal time scale.
- The PWV diurnal cycle is correlated with the Mixing Layer Height diurnal variations during summer, suggesting that the boundary layer height is modulating the PWV in this region, however, this needs to be further investigated.
- S1 and S2 harmonics in JJA explain ~95% of the sub-daily variance in most stations.
- it is unclear whether atmospheric tides can be found in the PWV diurnal variations

summary and conclusions (II)

- on a monthly mean time scale, PWV peak months are Sep.-Oct. while the minimum values are reached during Feb.-Mar. The variability is high from May to Nov. where Oct. is the most variable month probably due the high variability of moisture flow from different synoptic systems (e.g., PT, RST) that peak in Autumn. Apr. is the least variable month
- S1, S2 and S3 harmonics explain ~93% of the sub-annual variations for most stations. The annual mode amplitude is anti-correlated with station height suggesting a temperature dependence. The semi-annual mode to annual mode ratio is correlated with station height above ~300 m while under this height it is roughly constant at 25%
- The Med-SSTs are an important factor for the PWV annual mode, probably more than land surface temperatures. However, this relationship requires further investigation.
- The inter-annual variations of the last decade show an increased variability as opposed the 1997-2009 period. The PWV anomalies show ~0.8 correlation with the regional humidity moisture flux anomalies at 750 hPa in spring to autumn months and only 0.54 in winter months. However, the significance of the 750 hPa is unclear and requires further research.

summary and conclusions (III)

- The negative PWV anomaly in Oct. 2013 can be explained by two large dry events and the low frequency of moisture transporting synoptic systems (e.g., CLs, ARSTs). The positive PWV anomaly in Oct 2015 can be explained by a higher rate of ARSTs and the lack of strong dry events.

- The PWV long term trend in the study area for the entire data period (1998-2019) is ~0.5 mm per decade while the last decade (2010-2019) trend is ~1 mm per decade suggesting a regional accelerated moistening. Either this moistening is the result of a regional warming or the intensification of the humidity transporting synoptic systems remains unclear.

Thank you for watching !

for questions and/or additional information and/or collaboration proposals pls write to me:

shlomiziskin@gmail.com