ON PRESSURE AND TEMPERATURE CORRELATION PATTERNS

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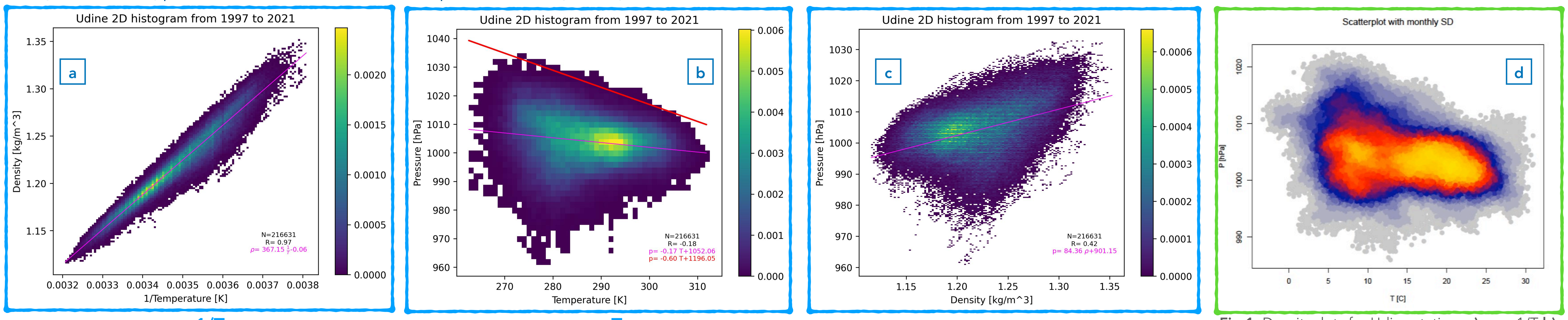
ABSTRACT

Temperature (T), **pressure** (p), **and density** (ρ) are three fundamental variables that describe the local behavior of the atmosphere. This study aims to investigate the interdependence of these variables near the Earth's surface in the real-world atmosphere. Firstly, analyzing hourly data reveals a weak relationship between temperature and pressure when compared to density and temperature. Secondly, the density plot of hourly pressure and temperature data exhibits a triangular shape, observed in various stations at different latitudes in extratropical areas. Additionally, the upper side of the triangle has been fitted with a line at the Udine station, and when the line is rescaled for all other stations, this relationship holds true. Finally, it has been found that the correlation R(p, T), calculated on an hourly scale, exhibits a sinusoidal shape that is strongly correlated with the average daily temperature cycle.

PRESSURE, TEMPERATURE AND DENSITY IN UDINE

In Figure 1 densityplots show the relation between p,T and ρ using hourly data of the Udine Sant'Osvaldo (North-eastern Italy) meteorological station from 1997 to 2021.



ρ vs. 1/T — LINEAR SHAPE — strong positive correlation

p vs. T — TRIANGULAR SHAPE — no clear and unique correlation

p vs. ρ — TRIANGULAR SHAPE — positive correlation

Fig.1. Densityplots for Udine station. **a)** ρ vs. 1/T **b)** p vs. T **c)** p vs. ρ **d)** T vs. p but with synthetic data obtained from a simple mathematical model (equations in the orange box)

- Density and temperature are strongly correlated because they are local variables dependent on local processes near the surface and have short timescales.
- Pressure is more independent because it is the result of an integration along the air column. It is the result of processes developing at different heights and with longer timescales.
- On average, the normalized hourly change in pressure ($\partial p/p$) is very low with respect to temperature ($\partial T/T$) and density ($\partial\rho/\rho$) variations: ρ and T change quickly, p changes slowly.
- Fig. 1d shows p vs. T densityplot with synthetic hourly data computed from a simple mathematical model that sums **i)** a daily cycle **ii)** a yearly cycle **iii)** gaussian noise to resemble hourly fluctuations **iv)** gaussian stochastic term to resemble Rossby waves (*equations are shown in the orange box next to the Table*). A key process to obtain the triangle is to include in the model information about the average monthly standard deviation (σ_p^{month}), that is much higher for p than for T (in comparison with their mean value trends).

EXTRATROPICS, TROPICS AND HIGH ALTITUDES

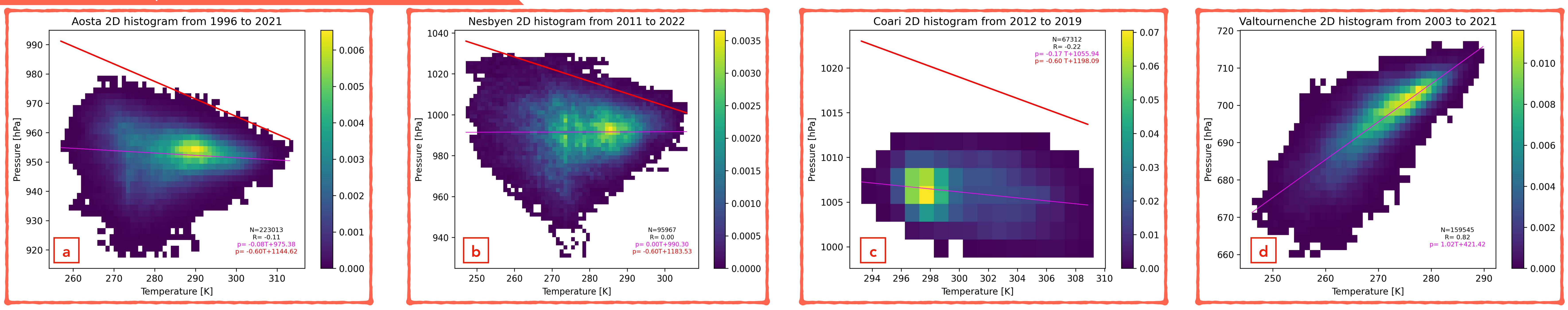


Fig. 2. Densityplots p vs. T for: **a)** ET - Aosta, Italy **b)** ET - Nesbyen, Norway **c)** T - Coari, Brazil **d)** HA - Valtournenche, Italy (3100 masl)

Fig.2 shows p vs. T densityplots for other locations: results are summarized in the Table.

Moreover, from the densityplot of Udine (Fig. 1b), the upper side of the triangle is fitted with a line (red line). Then the line has been rescaled to the different densityplots in the extratropics keeping the same slope but varying the intercept proportionally to the average pressure of that location.

- The red lines in all extratropical locations (e.g. Aosta, in Fig.2a and Nesbyen in FIg. 2b) correctly fit the upper side of the triangle.
- On the other hand, in the tropics (Coari in Fig. 2c) or in the top of the mountains (Valtournenche in Fig. 2d) as in the free atmosphere the p-T relation is very different.

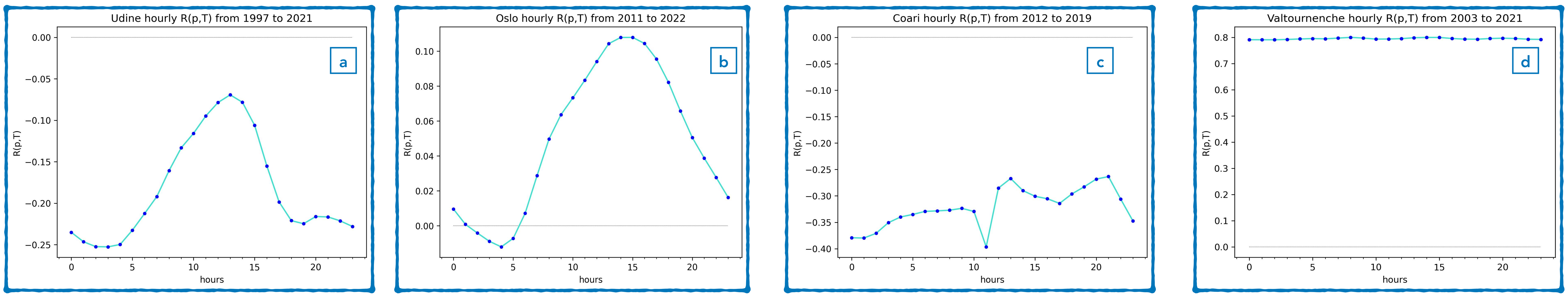


Fig.3. Dependence of temperature and pressure correlation R(p,T) on hour of the day for **a)** Udine, Italy **b)** Oslo, Norway **c)** Coari, Brazil **d)** Valtournenche, Italy (3100 masl)

Temporal correlations has also been examined to explore the physical connection between pressure and temperature. A strong pattern of correlation R(p,T) exists for the different hours of the day (Fig.3). Results are summarized in the Table.

$$T^{1d}_{cycle}(HH) = -2\cos\left(\pi\frac{HH-2}{12}\right) \qquad p^{1d}_{cycle}(HH) = -2\frac{HH}{24}\sin\left(\pi\frac{HH}{6}\right)$$

$$T^{1yr}_{cycle}(JJJ) = -8\cos\left(\pi\frac{JJJ-10}{182.5}\right) \qquad p^{1yr}_{cycle}(JJJ) = 2\cos\left(\pi\frac{JJJ-10}{182.5}\right)$$

$$T(t) = T_0 + T^{1d}_{cycle}(HH) + T^{1yr}_{cycle}(JJJ) + Gauss(\mu=0, \sigma=\sigma_T^{1hr}) + Gauss(\mu=0, \sigma=\sigma_{\mathbf{T}}^{\mathbf{month}})$$

$$p(t) = p_0 + p^{1d}_{cycle}(HH) + p^{1yr}_{cycle}(JJJ) + Gauss(\mu=0, \sigma=\sigma_p^{1hr}) + Gauss(\mu=0, \sigma=\sigma_{\mathbf{p}}^{\mathbf{month}})$$

	EXTRATROPICS (Fig. 2-3 a,b)	TROPICS (Fig. 2-3 c)	HIGH ALTITUDES (Fig. 2-3 d)
DENSITYPLOTS	TRIANGULAR shape *monthly p and T PDFs of other locations resemble Udine*	almost 2D GAUSSIAN shape *radiation is constant along the year: weak variation of p and T*	LINEAR shape *p and T are strongly correlated at higher altitudes (R=0.82)*
R(p,T) on hours	SINUSOIDAL, no unique value *pattern strongly correlated with the average temperature daily cycle*	almost CONSTANT and negative	CONSTANT and strongly positive *independent of the hour of the day*

CONCLUSIONS

- Temperature and density exhibit a strong negative correlation, whereas the correlation between pressure and temperature varies over time. This can be explained by the fact that temperature and density are influenced solely by local thermodynamic conditions with faster timescales, while pressure integrates over the entire vertical column.
- Density plots of pressure and temperature data from extratropical stations display a distinctive triangular shape. This behavior has been successfully replicated by a synthetic model that incorporates the significant variations in the monthly standard deviation of pressure.
- In all locations studied, it was consistently possible to fit the upper side of the triangular pattern with a line having the same slope, and an intercept proportional to the mean pressure of the respective station. This suggests the presence of a physical boundary in the extratropics beyond which pressure and temperature data cannot be observed.
- The findings of this study have several potential applications: Firstly, they contribute to improving our understanding of the interdependence between meteorological variables at the local level. Secondly, they offer a means to objectively classify stations, such as distinguishing between valley floor stations and top stations or differentiating between extratropical and tropical stations, based on the relationships between physical parameters. Lastly, the results can aid in identifying implausible observations of meteorological variables.