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Lagrangian tracking of the wireless sensor nodes inside warm clouds

Shahbozbek Abdunabiev

Supervisors: Prof. Daniela Tordella, Prof. Eros Pasero

Research context and motivation

- Clouds are the largest source of uncertainty in weather prediction and climate science
- Cloud microphysics: particle nucleation, droplet growth, collision/coalescence, modeling are still well not understood
- Turbulence dynamics: entrainment, transport, decay, Lagrangian fluctuations, dispersion and diffusion

Need for more explorative observations

- **Numerical simulations**
- Laboratory experiments
- **In-field measurements**

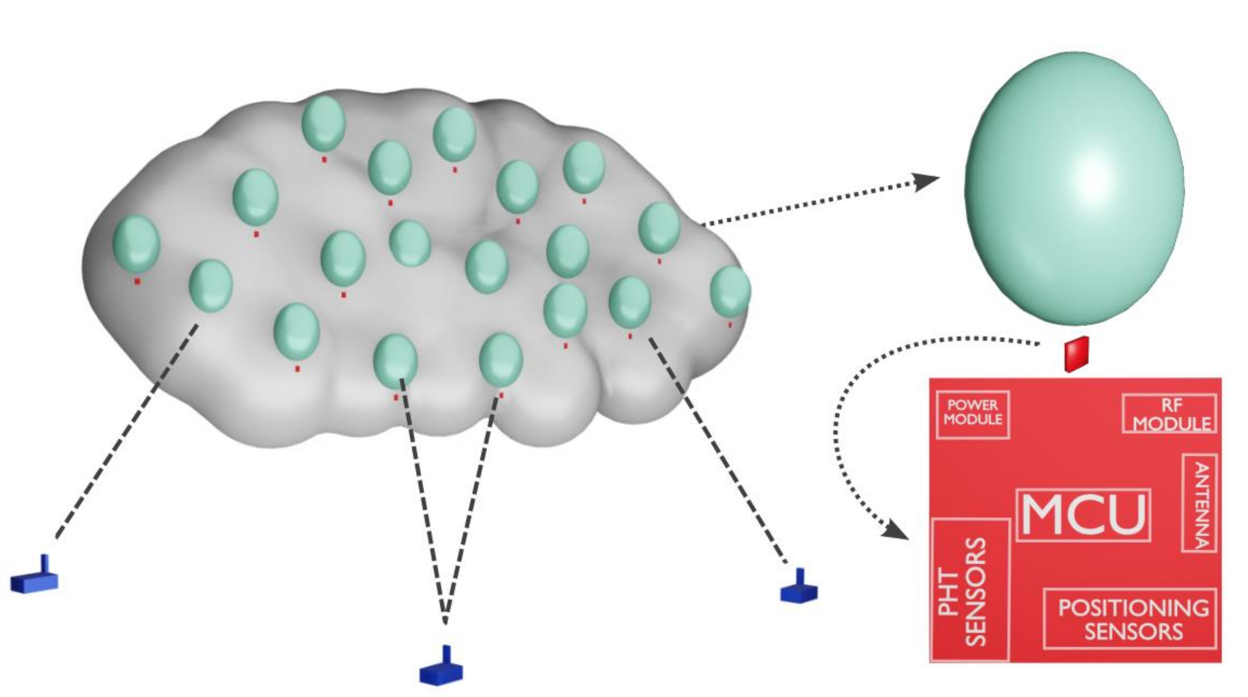

Figure 1. In-field measurement system: context and description.

Addressed research questions/problems

- Tracking **small-scale cloud dynamics**, observing variations of physical quantites such as *velocity, accelaration, pressure, humidity, temperature, position*,...
  - Correlation of physical quantities based on their relative positioning
  - *Turbulent kinetic energy spectrum* analysis
- Turbulent dispersion and diffusion inside clouds, clear-air and cloud-clear-air interface
  - Via *distance-neighbor graph* function by *Richardson L.F. (1926)*
- An **innovative Lagrangian measurement** technique for atmopsheric observations
- **Relative position tracking** of radiosondes **via sensor fusion** during their lifetime inside clouds, clear-air and cloud-clear-air interface
  - *Single* radiosonde
  - *Cluster* of radiosondes

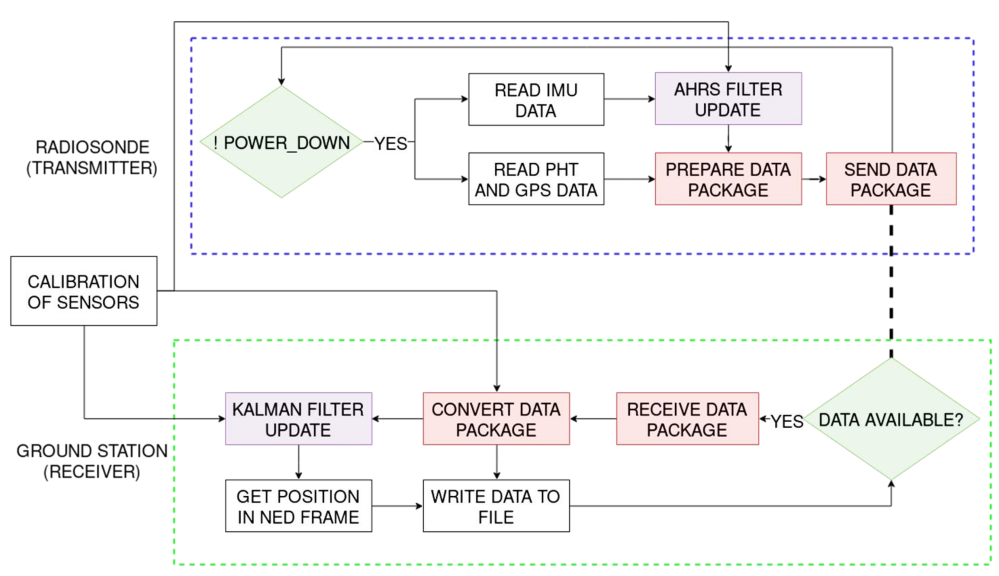

Figure 2. Radiosonde system processing flow.

Submitted and published works

- Paredes, M., **Abdunabiev, S.**, Allegretti, M., Merlone, A., Musacchio, C., **Pasero, E., Tordella, D.**, Canavero, F. (2021). "*Innovative Mini Ultralight Radioprobes to Track Lagrangian Turbulence Fluctuations within warm clouds: electronic design*", Sensors, 21(4), 1351. https://doi.org/10.3390/s21041351
- Golshan, M., **Abdunabiev, S.**, Tomatis, M., Fraternale, F., Vanni, M., **Tordella, D.** (2021). "*Intermittency acceleration of water droplet population dynamics inside the interfacial layer between cloudy and clear air environments*", International Journal of Multiphase Flow, 140, 103669. https://doi.org/10.1016/j.ijmultiphaseflow.2021.103669
- Fossà, L., **Abdunabiev, S.**, Golshan, M., **Tordella, D.** (2022). "*Microphysical timescales and local supersaturation balance at a warm cloud top boundary*", Physics of Fluids, 34(6), 067103. https://doi.org/10.1063/5.0090664
- Gallana, L., **Abdunabiev, S.**, Golshan, M., **Tordella, D.** (2022). "*Diffusion of turbulence following both stable and unstable step stratification perturbations*", Physics of Fluids, 34(6), 065122. https://doi.org/10.1063/5.0090042
- **Abdunabiev, S.**, Golshan, M., Abba, A., **Tordella, D.** (2022). "*Turbulent dispersion analysis via distance-neighbor graphs from direct numerical simulations*", In preparation.
- **Abdunabiev, S.**, Merlone A., Musacchio C., Caporali A., Paredes M., **Pasero E., Tordella, D.** (2022). "*Validation and traceability of multi-parameter miniaturized radiosondes for environmental observations*", In preparation.

Novel contributions

- Direct quantification of turbulent dispersion and diffusion from Lagrangian tracking of flow dynamics inside warm clouds (clear-air, cloud-clear-air interface, etc.)

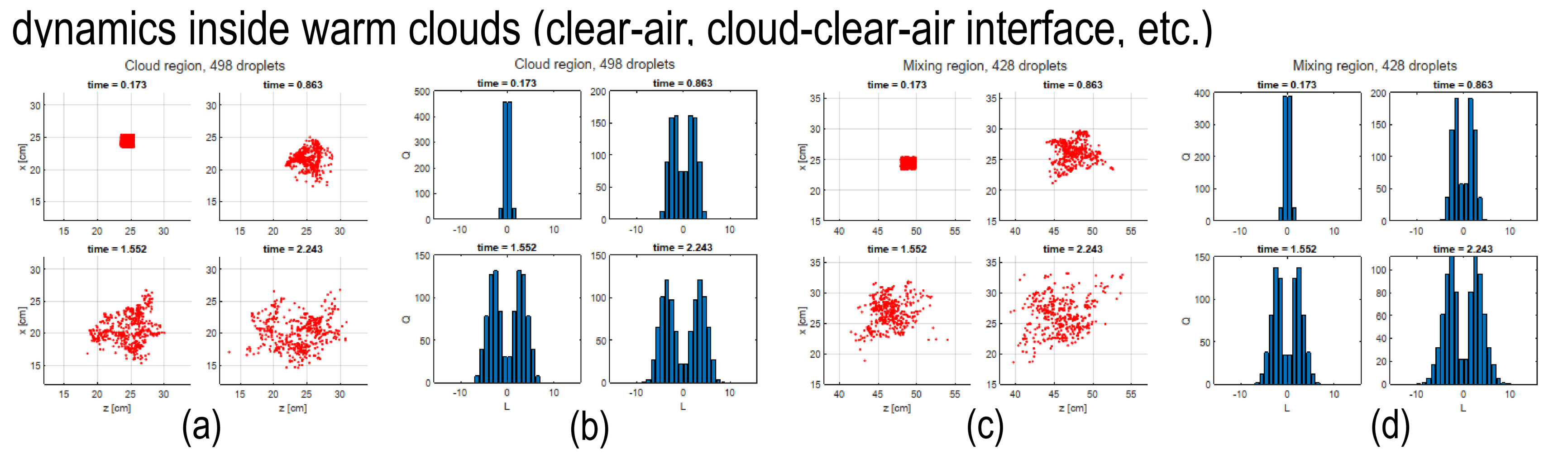

Figure 3. (a,c) Water droplet diffusion inside cloud and cloud-clear-air interface (mixing). (b,d) Turbulent dispersion via distance neighbor graph.

- Tracking atmospheric physical quantities

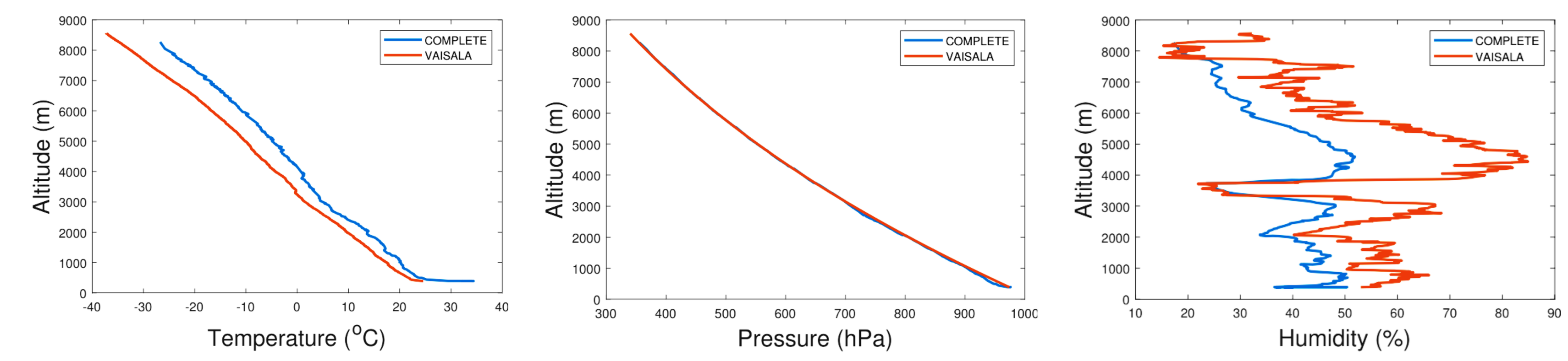

Figure 4. Temperature, pressure and humidity readings from in-field measurements with respect to altitude.

Adopted methodologies

- LoRa - low power long range transmission protocol was adopted for wireless sensor network.

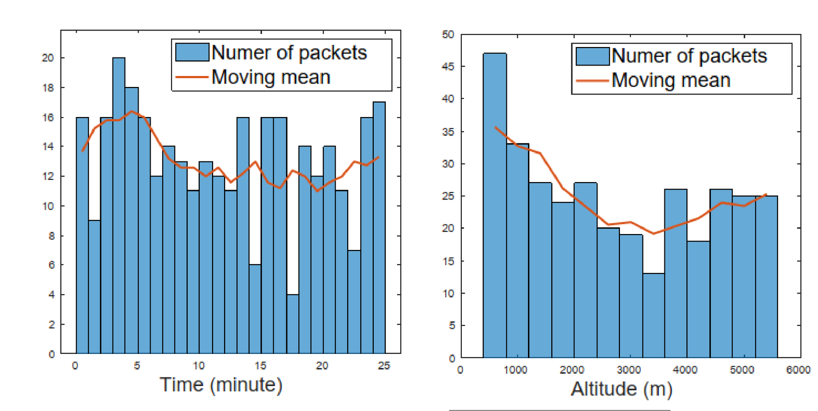

Figure 5. Packet transmission rate with respect to time and altitude.

- Position tracking with sensor fusion: Kalman and AHRS filters are used.

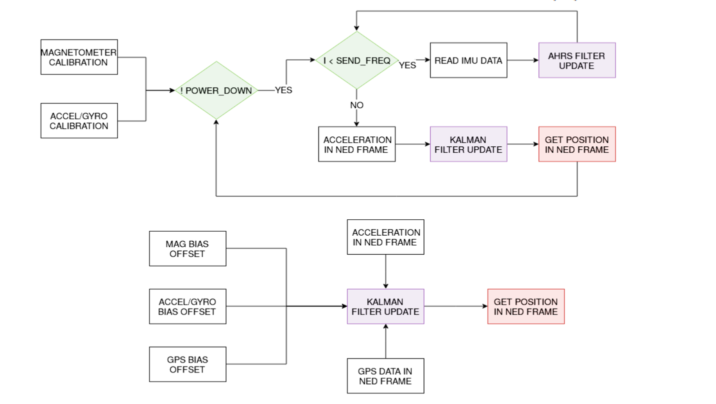

Figure 6. Processing flow for the relative position tracking.

- Distance neighbor graph function analysis by Richardson L.F. (1926)

$$Q_{n,n+1} = \frac{1}{N}(D^1_{n,n+1} + D^2_{n,n+1} + D^3_{n,n+1} + \dots + D^N_{n,n+1}) \quad (1)$$

$$\frac{\partial Q}{\partial t} = \frac{\partial}{\partial l}\left(F(l)\frac{\partial Q}{\partial l}\right) \quad (2)$$

$$F(l,\epsilon) \sim C\,\epsilon^{1/3}\,l^{4/3} \quad (3)$$

Future work

- *In-field measurement with a large cluster* of radiosondes inside warm clouds (clear-air, cloud-clear-air interface)
  - *Testing and validaion*
- **Minimize packet losses** by improving tranmission and data acquisition system
- *Improve accuracy of the relative position tracking*
- **Application of the measurement technique** in relevant turbulent ambients, such as:
  - *Areas of wildfire,*
  - *Volcanic eruptions*
  - *Areas of chemical plumes spreading*
- Commercialization of the measurement system

List of attended classes

- 01UKCRO – 3D motion tracking in body mechanics (22/04/2021, 3)
- 02LCPRV – Experimental modeling: costruzione di modelli da dati sperimentali (28/05/2021, 7)
- 02SFURV – Programmazione scientifica avanzata in matlab (21/04/2022, 6)
- 01VPORW – Statistical Methods with application to Climate Variability and Change Assessments (10/06/2022, 5)
- 01QAAAA – Information visualization and visual analytics (30/06/2022, 4)
- External - Advanced School on Parallel Computing (22/03/2021, 5)

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