Design for green, disposable, mini radiosondes to track fluctuations along isopycnic surfaces in cloud environments

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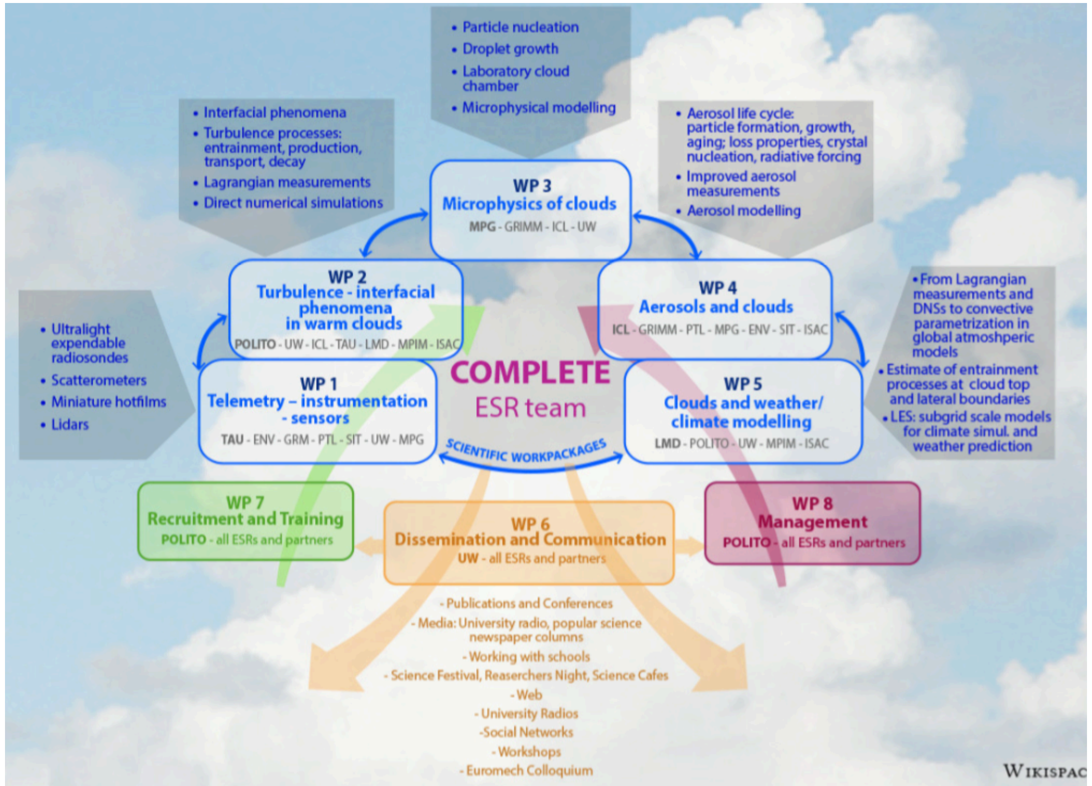
COMPLETE – ClOud-MicroPhysics-turbuLEnce-TElemetry

*Inter/multidisciplinary training network that will prepare early stage researchers (ESRs) with both scientific and industrially-oriented skills that will advance our understanding in **multi-scale complex natural phenomena**.*

Field experiments + Laboratory and numerical simulations + Design and development of advanced fast temperature probes + Velocity MEMS + Innovative atmospheric mini radiosondes



*Production of new, Lagrangian based, **cloud fluctuation datasets**, required to reduce the fragmentation of results and knowledge in the field of **cloud physics** and related **turbulent dynamics**.*

https://www.complete-h2020network.eu/

COMPLETE – ClOud-MicroPhysics-turbuLEnce-TElemetry

BENEFICIARIES

ASSOCIATED PARTNERS

COMPLETE – ClOud-MicroPhysics-turbuLEnce-TElemetry

The presentation contains both ideas previously conceived and ideas to be developed with these partners

Sources: S. Bertoldo, C. Lucianaz, M. Allegretti, and G. Perona, “Disposable falling sensors to monitor atmospheric parameters”, Proceedings of SPIE 10001, Remote Sensing of Clouds and the Atmosphere XXI, Edinburgh (SCO), 26-29 September 2016
S. Bertoldo, C. Lucianaz, and M. Allegretti (2016), “Hail sensing probes: feasibility analysis for probes to monitor and study hail”, Advances in Remote Sciences, 5(1), pp. 43-50.

Aim

Presenting innovative, expendable, green radiosondes to be designed, prototyped and used within the H2020 – MSCA ITN-COMPLETE

- **Motivation**
  - Why clouds
- **Microphysics of clouds**
  - Cloud classification
  - What has been measured
- **Radiosondes**
  - Concepts & Requirements
  - Two configurations
  - Smart materials
- **Conclusions –** Future developments

Motivation – why clouds?

Clouds

$nm - \mu m$

$mm - km$

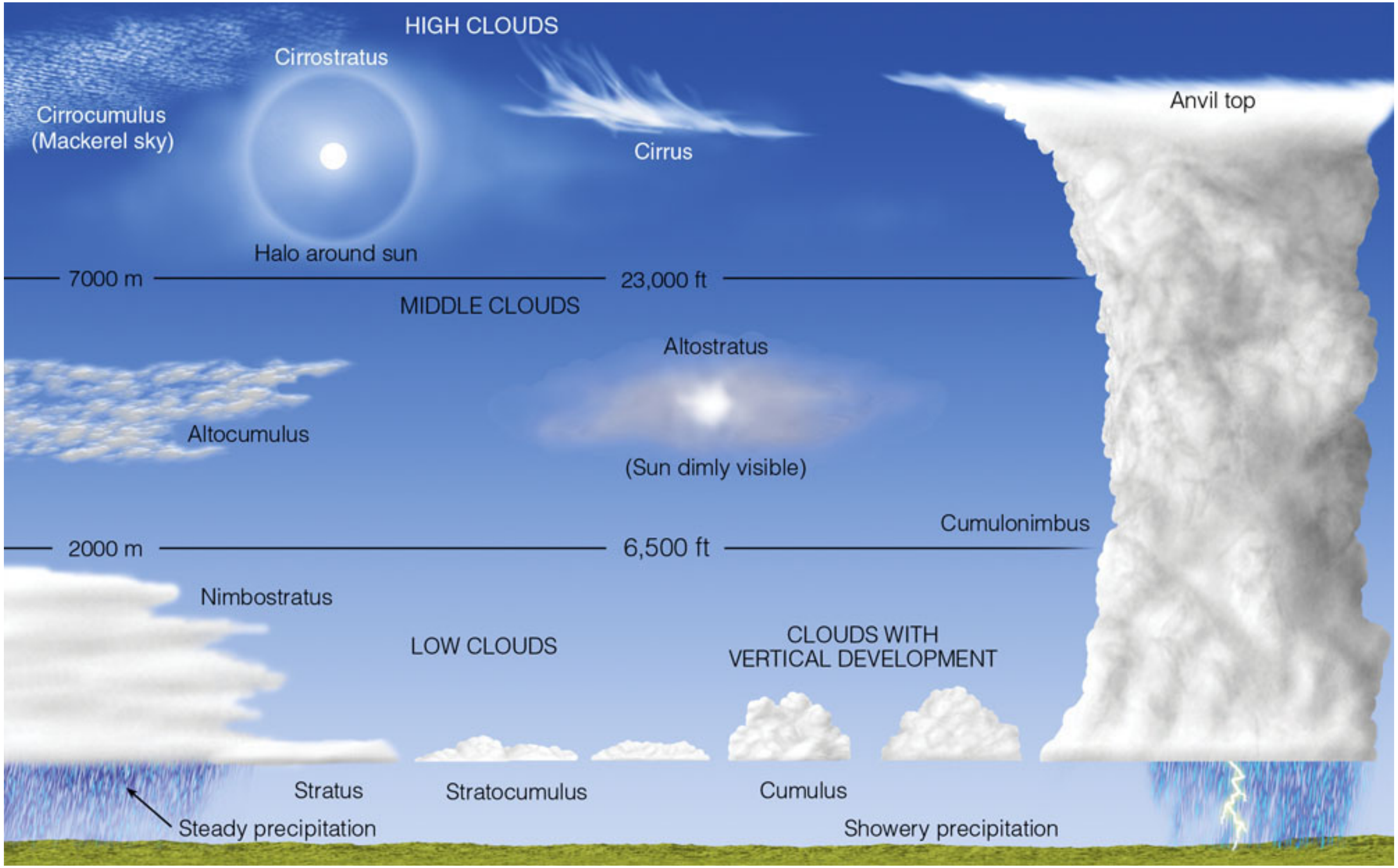
Nucleation and coalescence (or fragmentation) of droplets and formation of rain

Air fluctuation dynamics – different inside and outside clouds

Uncertainty in weather prediction and climate modelling

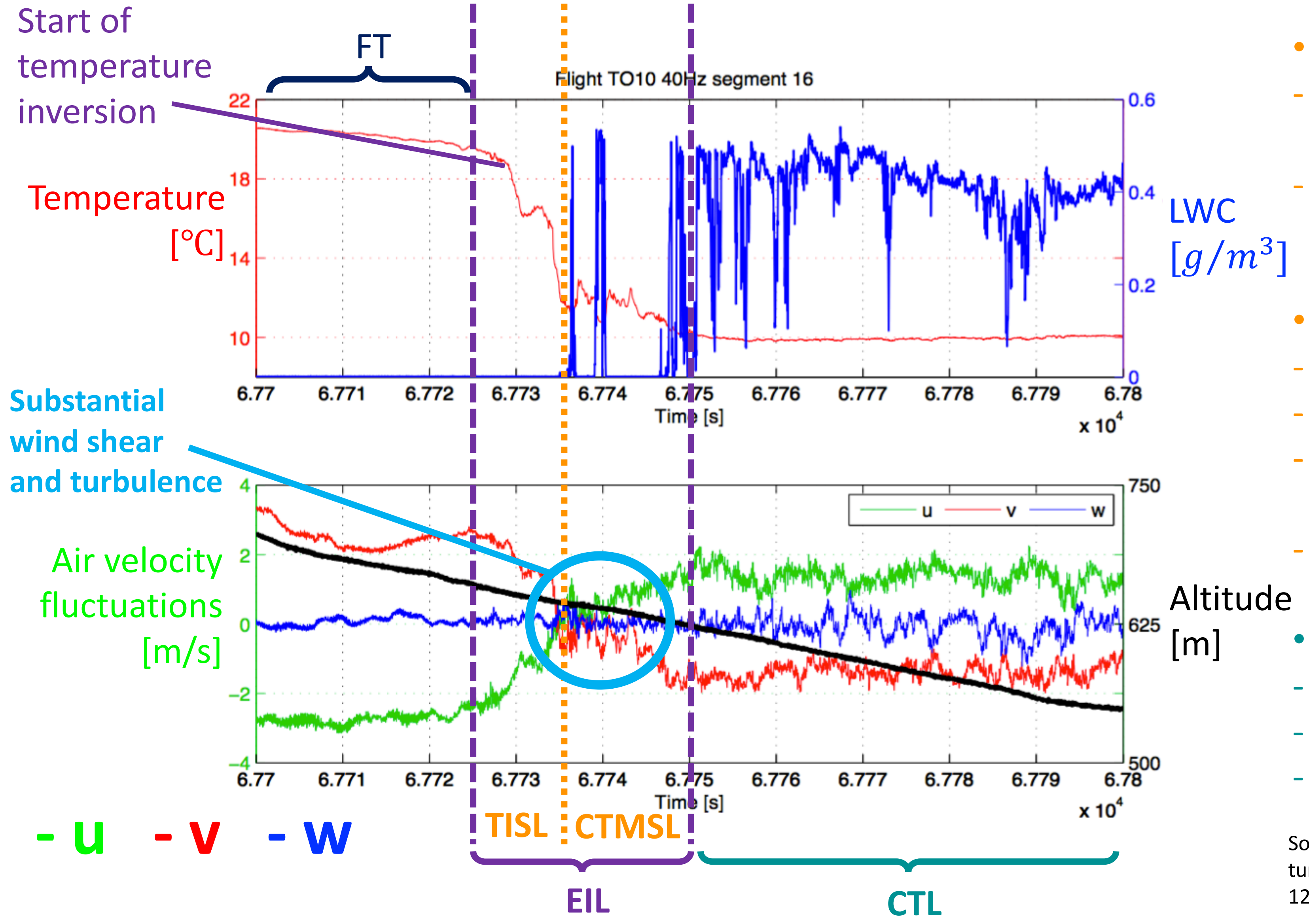
Need for more explorative observations

Microphysics of clouds – cloud classification



Source: R. Gabler, J. Peterson, L. Trapasso, "Essentials of Physical Geography", Cengage Learning, Edit. 8, 2006.

Microphysics of clouds – what has been measured so far



- **Turbulent Inversion Sublayer (TISL):**
  - Temperature begins to fluctuate and fall rapidly
  - Velocity shows substantial wind shear and turbulence

- **Cloud Top Mixing Sublayer (CTMSL):**
  - LWC > 0
  - Temperature fluctuations (~ 2 K)
  - Horizontal velocities (u and v) indicate wind shear (weaker than in TISL)
  - Turbulent velocity fluctuations increased

- **Cloud Top Layer (CTL):**
  - Small temperature fluctuations (~ 0.2 K)
  - LWC fluctuations remain above 0
  - Large vertical velocity (w) fluctuations

Source: S. P. Malinowski et al, "Physics of Stratocumulus Top (POST): turbulent mixing across the capping inversion", Atmos. Chem. Phys., 13, 12171-12186, 2013.

Radiosondes – Concept & Requirements

MINI RADIO PROBES

Lightweight | Hydrophobic | Low cost | Biodegradable | Isopycnic

Microprocessors and solid state sensors

- Velocity
- Acceleration
- Pressure
- Temperature
- Humidity

} Fluctuations

Radiosondes – Concept & Requirements

Ability to follow small scale turbulence fluctuations inside clouds and in surrounding air (Lagrangian tracking)

Float on an isopycnic level

Target weight : $\sim 20\ g$

Required:

- Omnidirectional antenna
- Battery
- Low consumption microcontroller
- Flash memory
- Configurable set of sensors

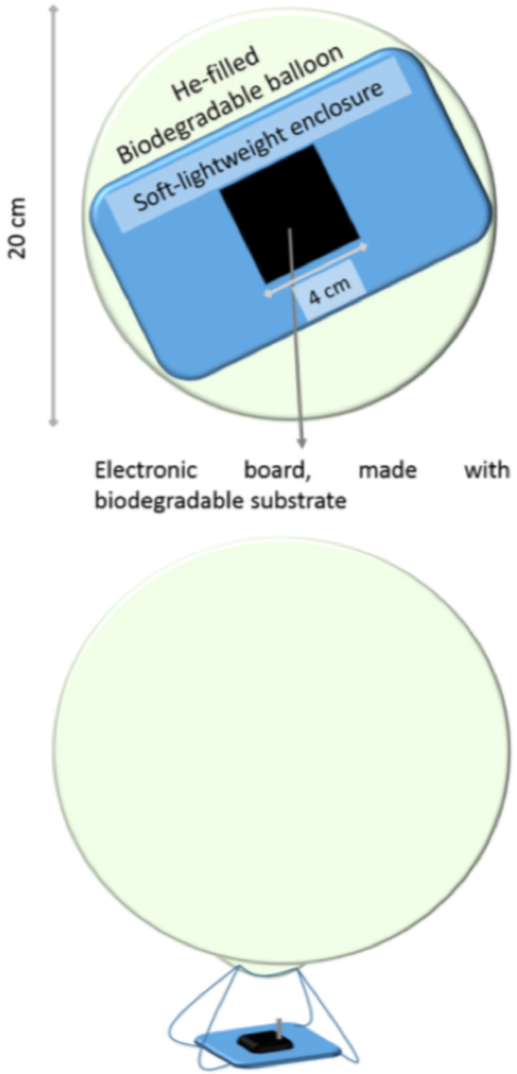
Balloon filled with Helium gas and air

$\gamma = lapse\ rate$ **(Rate at which atmospheric temperature decreases with increasing altitude)**

Atmospheric data (with γ= 6.5 K/km)					Balloon Dimensions	
Z [m]	T [K]	P ×10^4 [Pa]	ρ [kg/m^3]	μ ×10^{-5} [kg/ms]	V [m^3]	R [cm]
0	288	10.0	1.22	1.79	0.019	16.5
500	285	9.5	1.17	1.78	0.020	16.8
750	283	9.3	1.13	1.77	0.020	16.9
1000	282	9.0	1.11	1.76	0.021	17.1
1250	280	8.7	1.08	1.75	0.021	17.2
1500	278	8.5	1.06	1.74	0.022	17.4
2000	275	7.9	1.01	1.73	0.023	17.7
3000	269	7.0	0.90	1.70	0.026	18.3

Source: T. C. Basso, M. Iovieno, S. Bertoldo, G. Perotto, A. Athanassiou, F. Canavero, G. Perona, D. Tordella (2017), "Disposable radiosondes for tracking Lagrangian fluctuations inside warm clouds".

Radiosondes – Two configurations

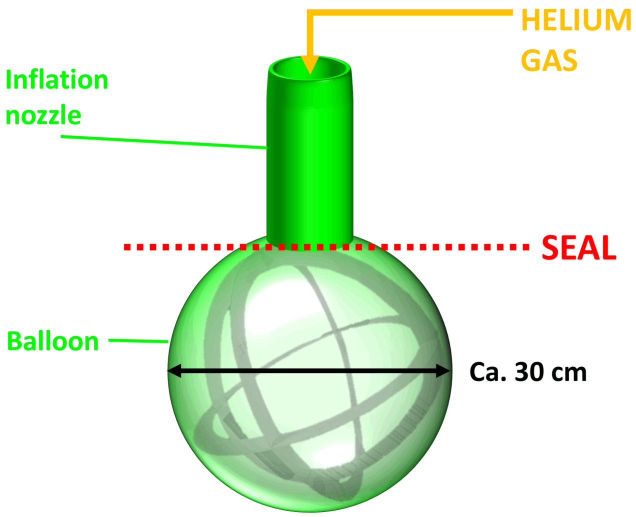


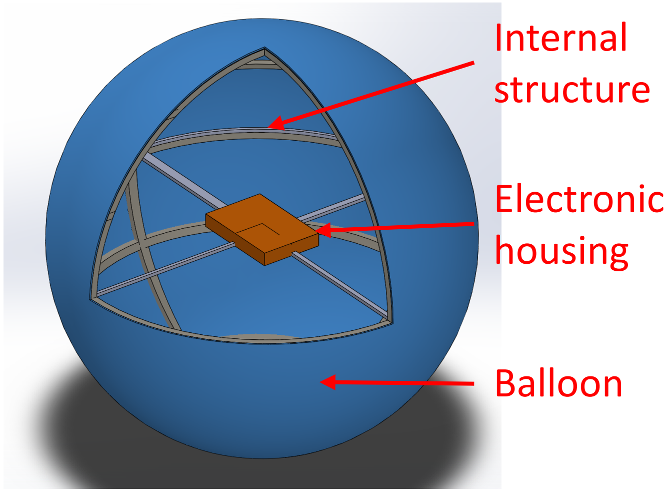
Electronic board, made with biodegradable substrate

1. **Simple:**
   - Electronics inside the balloon casing
   - Measure acceleration, position, and temperature

2. **Complex**
   - Electronics outside balloon
   - Measure liquid water content, temperature, pressure and in some cases particles (with an optical particle counter)

Special version equipped with small size Differential Optical Absorber Spectroscopy (DOAS) or with optical/infrared scatterometers





Source: T. C. Basso, M. Iovieno, S. Bertoldo, G. Perotto, A. Athanassiou, F. Canavero, G. Perona, D. Tordella, "Disposable radiosondes for tracking Lagrangian fluctuations inside warm clouds", 2017.

Radiosondes – Smart Materials

DISPOSABLE PROBES → BIODEGRADABLE → MINIMIZE ENVIRONMENTAL IMPACT

Balloon
MaterBi or bioelastomer substrate

Skeleton
Bioelastomer substrate or bioplastic

(Left) Red beetroot bio-elastomer and (right) red beetroot and starch compound.

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Sources: T. C. Basso, M. Iovieno, S. Bertoldo, G. Perotto, A. Athanassiou, F. Canavero, G. Perona, D. Tordella (2017), “Disposable radiosondes for tracking Lagrangian fluctuations inside warm clouds”
T.N. Tran, A. Athanassiou, A. Basit, I.S. Bayer, (2017), “Starch-based bio-elastomers functionalized with red beetroot natural antioxidant”, Food Chemistry, 216.

Future developments – climate chambers

Calibration of radioprobes will be carried out before infield measurement campaign

- Temperature Range:
  - $-40^{o}C \;-\; 50^{o}C$
- Pressure Range:
  - $40\; kPa \;- 101.325\; kPa$
- Generates winds up to $30\; ms^{-1}$

Fluctuation timescales

- Temperature: minutes
- Pressure: seconds
- Velocity: quasi-instantaneously

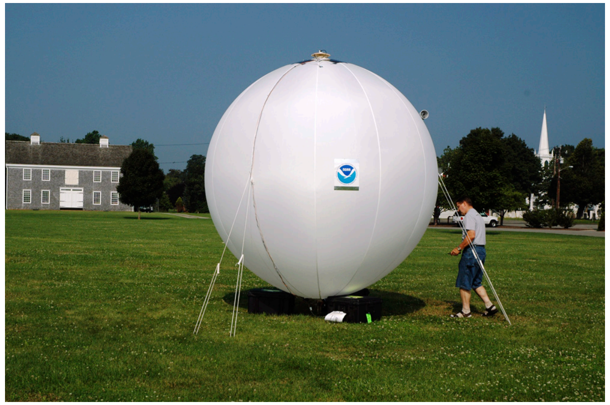
Wind tunnel EDDIE for the characterization of temperature sensors. Source: www.inrim.eu

Conclusions – Future Developments

Measurement campaign on UFS where swarm of probes released by manned and unmanned aerial vehicles (drones)

Each probe has own frequency slightly different to identify them

http://www.schneefernerhaus.de/startseite.html



NOAA Smart balloons and hurricane hunters
http://www.noaa.gov/

GCOS GRUAN for upper-air climate observations
https://www.gruan.org/

These radiosondes will contribute to the current understanding of microphysical processes in clouds in a range of a few 100m with the purpose of improving weather prediction and climate modelling.

THANK YOU FOR YOUR ATTENTION!

Acknowledgments

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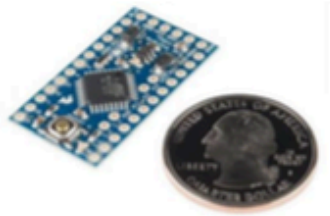
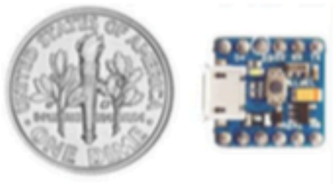
Extra Slides – Arduino protocol

Open-source platform used for designing, developing and building electronic projects.

Hardware	Software
Physical programmable circuit board (microcontroller and other electronic components)	Arduino Programming Language APL (write and upload code to the board)

Arduino Pro Mini 	3.3 5	33x18	<2	10
Arduino Pico 	5	15.24x15.24	1.1	Not available