# COMPLETE 3rd Workshop

COMPLETE 3rd Workshop will be held in the Institute of Geophysics, Faculty of Physics, University of Warsaw in Warsaw, Poland 4-8 Feb 2019.

The workshop will include talks by:

1. Prof. Robert Breidenthal, University of Washington, Seattle, USA - experiments in fluids with entrainment (with additional demonstration in the lab by Szymon Malinowski), 4h,

2. Prof. Isztar Zawadzki, Mc Gill University, Montreal Canada - measurements and observations of clouds and precipitation with radar, 4h,

3. Dr. Iwona Stachlewska, University of Warsaw, Poland - observations of aerosols and clouds with multi-wavelength lidar - theory and practice
(lidar is on-site), 4+1h,

4. Dr. Sylwester Arabas, Jagiellonian University, Krakow, Poland - particle-level microphysics of soluble aerosol particles and cloud droplets (with hands-on session on cloud parcel model prototype in Jupyter), 4h,

5. Dr. Jun-Ichi Yano, Meteo France, France - climate modeling and subgrid scales (clouds), entrainment in cloud-convection dynamics, structure of the mass-flux convection parameterization and its generalization, 4h,

as well as ESR presentations (7 minutes each).

Workshop schedule is as follows:

<table>
<tr><td colspan="6">COMPLETE workshop, 4-8.02.2019 in Warsaw</td></tr>
<tr><td></td><td>4.02.2019</td><td>5.02.2019</td><td>6.02.2019</td><td>7.02.2019</td><td>8.02.2019</td></tr>
<tr><td>09:15-10:00</td><td></td><td rowspan="2">prof. Breidenthal</td><td rowspan="2">prof. Breidenthal</td><td rowspan="2">dr Yano</td><td rowspan="2">dr Yano</td></tr>
<tr><td>10:15-11:00</td><td></td></tr>
<tr><td>11:15-12:00</td><td></td><td rowspan="2">dr Arabas</td><td rowspan="2">dr Arabas</td><td rowspan="2">prof. Zawadzki</td><td rowspan="2">prof. Zawadzki</td></tr>
<tr><td>12:15-13:00</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>14:15-15:00</td><td rowspan="3">ESR presentations</td><td rowspan="2">dr Stachlewska</td><td rowspan="2">dr Stachlewska</td><td rowspan="4">trip</td><td></td></tr>
<tr><td>15:15-16:00</td><td></td></tr>
<tr><td>16:15-17:00</td><td>outreach</td><td>lidar presentation</td><td></td></tr>
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Lectures will take place at the Faculty of Physics, ul. Pasteura 5, Warsaw.

All participants are encouraged to bring their laptops with Jupyter and SciPy packages installed.

1. **Prof. Robert Breidenthal**, University of Washington, Seattle, USA - experiments in fluids with entrainment (with additional demonstration in the lab by Szymon Malinowski), 4h,

**1. Fundamentals of turbulent entrainment and mixing**
Laboratory experiments reveal the fundamental physics of turbulent entrainment and mixing in free shear flows. Instead of small-scale nibbling at the edge of the turbulence in the Corrsin-Kistler 'superlayer', Brown and Roshko discovered that entrainment was controlled by large-scale, 'coherent' vortices. Subsequent experiments lead to a simple model of turbulent mixing. Its predictions of the effects of Reynolds, Schmidt, and Damkohler number on mixing and chemical reaction are in accord with observation.

**2. Acceleration effects on entrainment**
In most turbulent flows, rapid acceleration of the rotation rate of vortices counter-intuitively reduces the normalized entrainment rate. First observed in the exponential jet, this phenomenon plays a central role in cumulus clouds. The release of latent heat increases the buoyancy, thereby increasing the rotation rate of vortices from baroclinic torques. Bhat & Narasimha discovered that the spreading angle of the jet is reduced with buoyancy addition. The 'tunneling eruptions' of volcanoes may also be explained by water vapor coming out of solution of a second magma introduced into a magma chamber that already contains a first magma. Krishnamurti has found that there is a critical slope for orographic rain, consistent with acceleration effects. The wettest places on the planet have steep slopes.

**3. The tops of stratocumulus clouds - Evaporative and radiative cooling**
Randall and Deardorff proposed that a cloud top would become unstable if cloudy air mixed with undersaturated air above, yielding mixed air parcels that are more dense that the cloudy air, due to evaporative cooling. However, marine stratocumulus have a very long lifetime, inconsistent with their theory. Simple laboratory experiments reveal that there is a critical value of a 'buoyancy-reversal' parameter, of order one, for the cloud-top entrainment instability. This observation is strong evidence for the central role of the large-scale vortices on mixing. Buoyancy at a cloud top is also reduced from radiative cooling. The resulting fluid motions can increase the entrainment rate.

**4. Entrainment at a stratified interface**
When turbulence impinges on a stratified interface, the resulting entrainment rate across the interface can vary by orders of magnitude, depending on the nature of the impinging turbulence. For example, the entrainment rate from a vertical jet impinging on the interface is much greater than if the jet is tilted slightly. This counter-intuitive observation is attributed to the stationarity, or persistence, of the entraining vortices. The concept is further tested for the case of a solid interface rather than a stratified one. Experiments reveal that a turbulent boundary layer is substantially relaminarized when stationary vortices are introduced in the layer. A general theory of entrainment at thin stratified interfaces and solid walls is proposed.

2. **prof. Isztar Zawadzki**, Mc Gill University, Montreal Canada - measurements and observations of clouds and precipitation with radar, 4h,

**Cloud Physics and Radar Observations**
Radar provides observations within dynamically active clouds. These observations are limited to backscattering properties of hydrometeors and their Doppler velocity. Nevertheless, combined with theoretical understanding, it is possible to infer from radar observations the dynamic and microphysical processes that govern the formation of hydrometeors.
This short course will start with a brief introduction to radar measurements. Within the background of well understood cloud physics principles, it will show radar observations that illustrate several phenomena occurring in natural clouds: the variety of dynamic conditions, the interaction of cloud dynamics and microphysics, the origin of mixed-phase clouds, the formation of the variety drop-size distributions, etc.
Finally, the limitations of the analysis methods presently used will be discussed as well.

3. **dr Iwona Stachlewska**, University of Warsaw, Poland - observations of aerosols and clouds with multi-wavelength lidar - theory and practice (lidar is on-site), 4+1h,

> **On aerosol and cloud properties derivation from complex quasi-continuous lidar measurements**
> Unique capabilities of complex Raman lidar instruments allow for conducting quasi-continuous measurements of atmospheric aerosol and cloud properties. Qualitative information on vertical structure of atmosphere, from almost ground-surface up to mid-stratosphere, can be evaluated in terms of aerosol/cloud abundance, in relation to atmospheric anisotropy and water vapor mixing ratio. Measurements in case of fog/smog or drizzle/virga are possible. High quality lidar signals, regarded as a mathematical system of equations in a 3-dim domain of time-height-wavelength, allow to obtain profiles of aerosol optical properties, such as particle extinction and backscattering coefficients, particle depolarization ratios, Angstrom exponent, aerosol optical depth. The derived optical properties, treated as an input for applying mathematical inversion techniques with regularization, allow to estimate at certain layers of interest the micro-physical characterization of aerosol particles, including particle size distribution, complex refractive index, concentrations, and even single scattering albedo. Based on the mentioned above parameters, influence and modifications of aerosols of natural (biomass burning, mineral dust) and anthropocentric origin (pollution), advected from long-range distances over lidar site can be studied.
> During the lecture, a holistic approach to the lidar research conducted over last 10 years at the Remote Sensing Laboratory of the Institute of Geophysics, Faculty of Physics, University of Warsaw will be introduced. Specifically including infrastructure developments for establishing the RS-Lab, major research goals and achievements, participation in research networks, as well as an outlook for future activities. Life demonstration of lidars-at-work will be a part of the lecture.

4. **dr Sylwester Arabas**, Jagiellonian University, Krakow, Poland - particle-level microphysics of soluble aerosol particles and cloud droplets (with hands-on session on cloud parcel model prototype in Jupyter), 4h,

> **1. On CCN growth kinetics: the Koehler curve and beyond**
> In this session we will take a closer look at particle-level microphysics of soluble aerosol particles and cloud droplets. We will start with the classical picture of droplet growth kinetics, i.e. the Maxwell-Mason equation and the Koehler curve. This will be followed with an overview of such "subtleties" as Ostwald ripening, charge-induced activation, Szyszkowski-Langmuir adsorption and thermal heating/cooling.
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> **2. A cloud parcel model prototype in Jupyter: hands-on session**
> This session will be aimed at developing a functional cloud parcel model prototype. We will use Jupyter and SciPy, all participants are encouraged to bring their own laptops with these packages installed.

5. **dr Jun-Ichi Yano**, Meteo France, France - climate modeling and subgrid scales (clouds), entrainment in cloud-convection dynamics, structure of the mass-flux convection parameterization and its generalization, 4h

> **1. What is the climate model?**
> The purpose of this talk is to go back to a very basic, and refresh our basic understanding of the climate science, and identify a role of clouds as subgrid-scale processes.
>
> **2. What we study entrainment?**
> This is a historical review about how a question of the entrainment got into the studies of convection and clouds.
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> **3. Convection parameterizations (1): mass flux formulation**
> We review the basic structure of the mass flux formulation, that is used as a standard approach for convection parameterization. watch out for a role of entrainment in this formulation.
>
> **4. Convection parameterizations (2): beyond mass flux**
> We discuss how the standard mass-flux formulation can be generalized to include various missing components therein. a key question here would be a generalization of the concept of entrainment.