Summary of recent modelling work
(within VERTIGO)

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About me….

Andreas Vogel

PhD Student (Marie Curie ITN research fellowship) – VERTIGO Project

Supervised by:
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PEOPLE MARIE CURIE ACTIONS

Marie Curie Initial Training Networks (ITN)
Call: FP7-PEOPLE-2013-ITN

"VERTIGO": **V**OLCANIC ASH: FI**E**LD, EXPE**R**IMEN**T**AL AND NUMER**I**CAL INVESTI**G**ATIONS OF PR**O**CESSES DURING ITS LIFECYCLE

NILU

UiO : University of Oslo

VERTIGO

Motivation – PhD project

What is the effect of different particle characteristics?

(chem. Composition | shape/morphology

What effect has the first engine stage?
Fan blade centrifugal effects?
Core ingestion concentration?

Can the engine **relevant particle size distribution** be used for FLEXPART parametrisation?

FLEXPART – atmospheric dispersion model (like NAME)

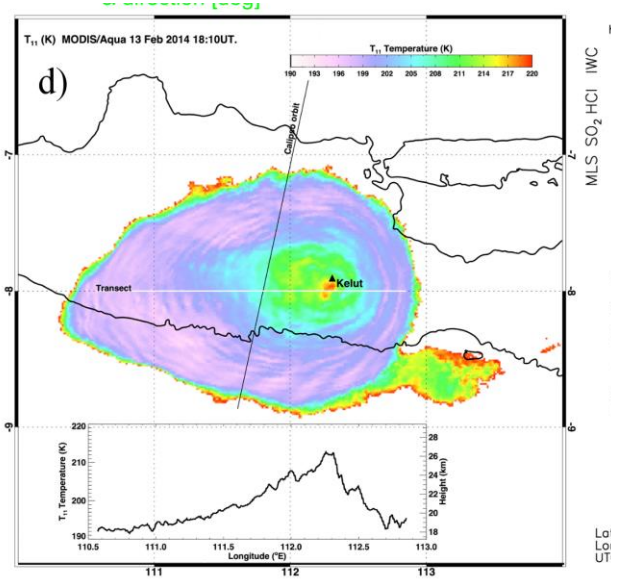
Modelling aeroengine fan-particle interactions during volcanic ash ingestion

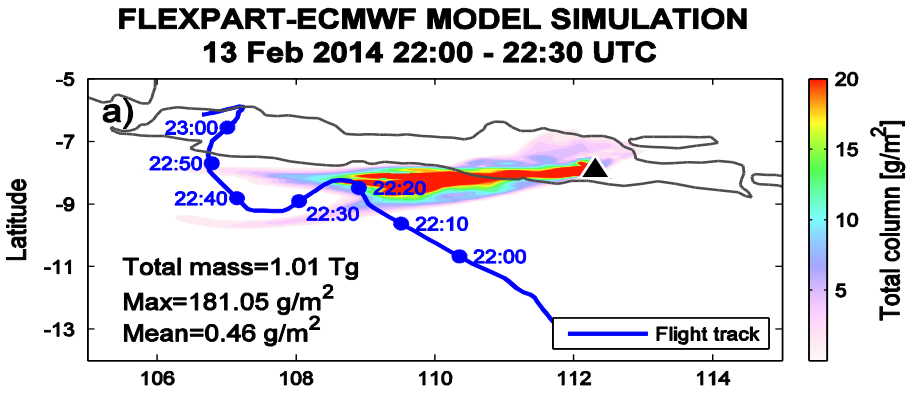
In cooperation with:

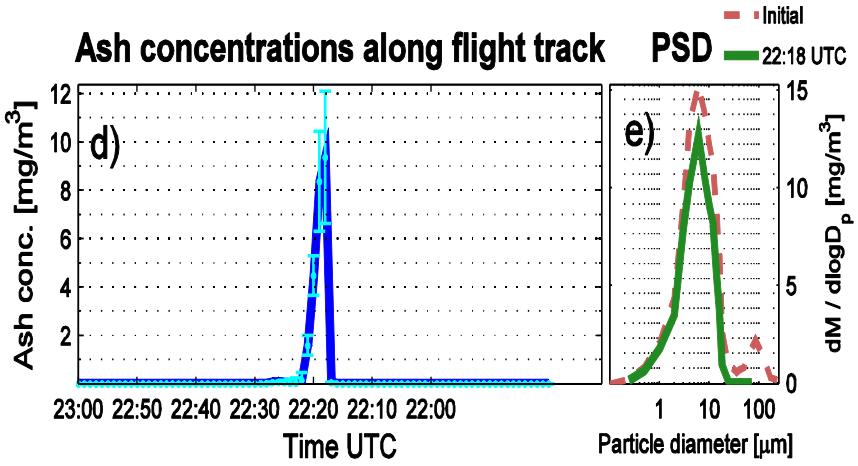
Latest encounter

Mt. Kelud 2014

- Mt. Kelud, Indonesia, February 2014
- Max. concentration 9±3 mg/m3 in about 11km (33.000ft)
- Duration 10-11 min in 2 mg/m^3
- Dosage about **1.2 ± 0.3 g s m^{-2}**







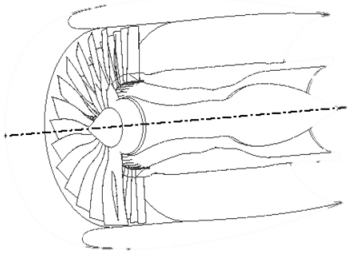
[Kristiansen et al. 2015]

Particle ingestion assessment

CFD modelling of engine fan-particle interactions – Model setup

CAD
Fan blade model

Quality check



Meshing of geometry

Multiple Reference Frame (MRF)

Compute the **absolute** Cartesian **velocity** components, using the flux relative to the **rotation** of the local frame of reference

Fluid solver input

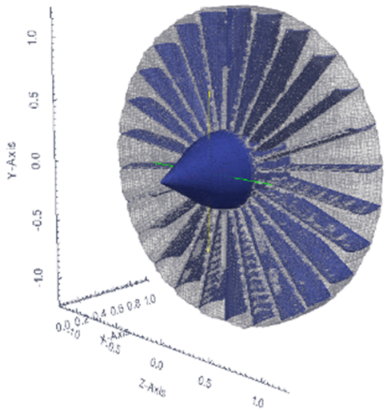
- Reynolds-Averaged Navier Stokes equation (RANS)
- Turbulence model k-omegaSST (Shear stress transport)
  -> steady state flow
- Wall function

Computational Mesh

- Hexahedral cells
- unstructured

Lagrangian approach particle

- Total mass flow of particles
- Particle size distribution
- Particle inertial velocity
- Particle multiphysics
- Particle forces e.g. spherical and nonspherical shape
- Collision
- Stochastic spreading of particles



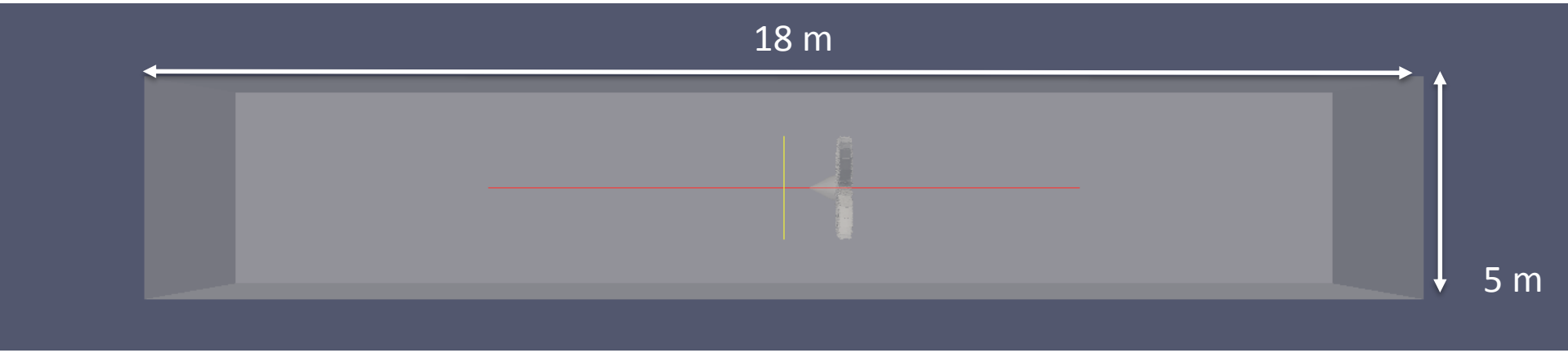
Solving steps

Particle injection

rhoSimpleReactingParcel - Fluid dynamic solver

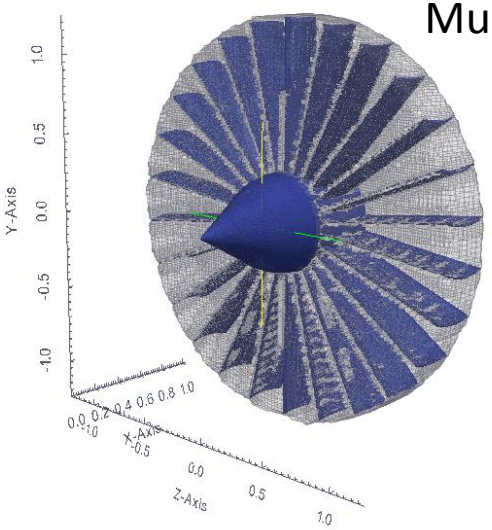
Simple simulations - wind tunnel setup

Rotating fan blade in simple wind tunnel tube



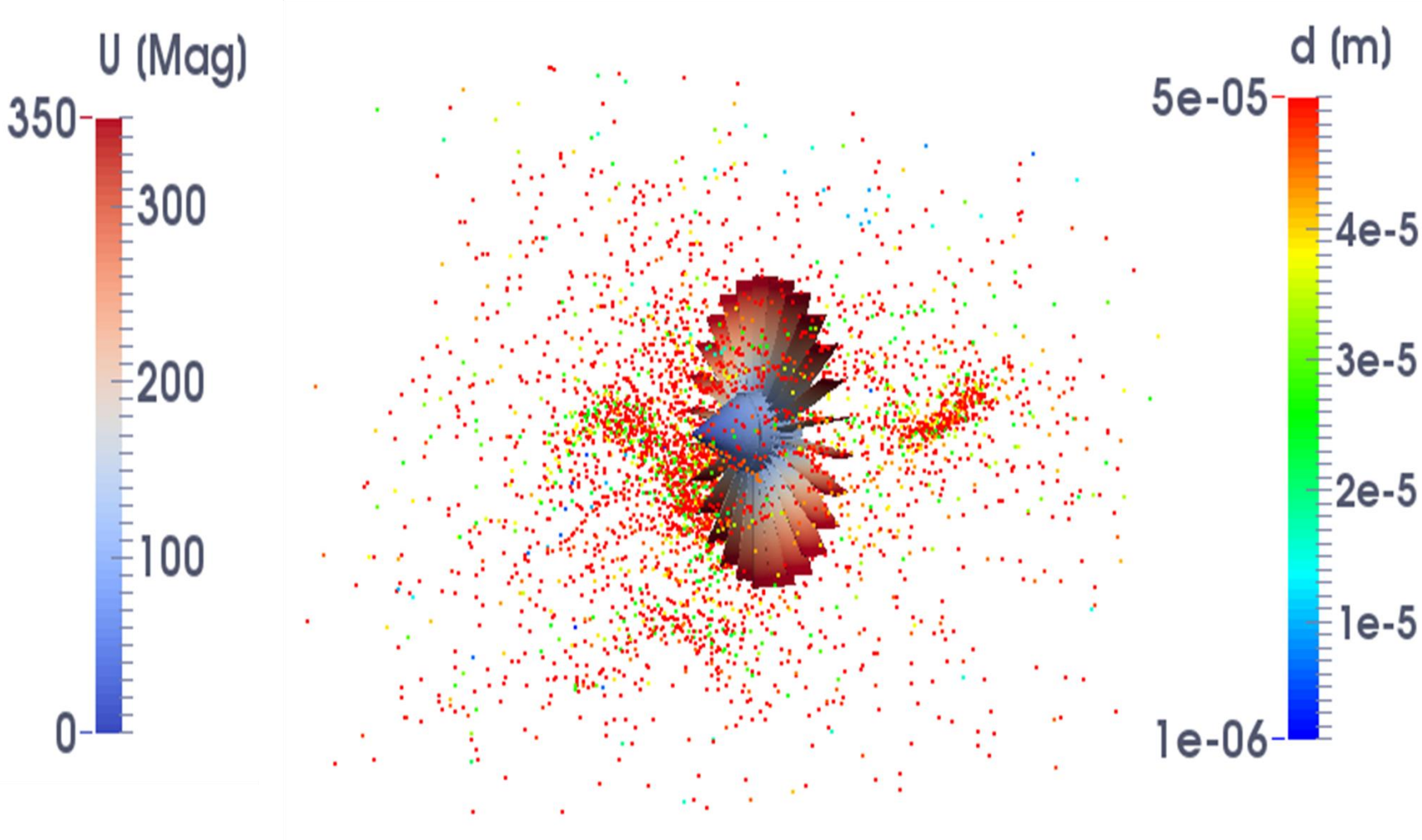
- Simple wind tunnel
- Simple fan blade
- No inertial inlet velocity
- Atmospheric pressure

Multiple reference fram



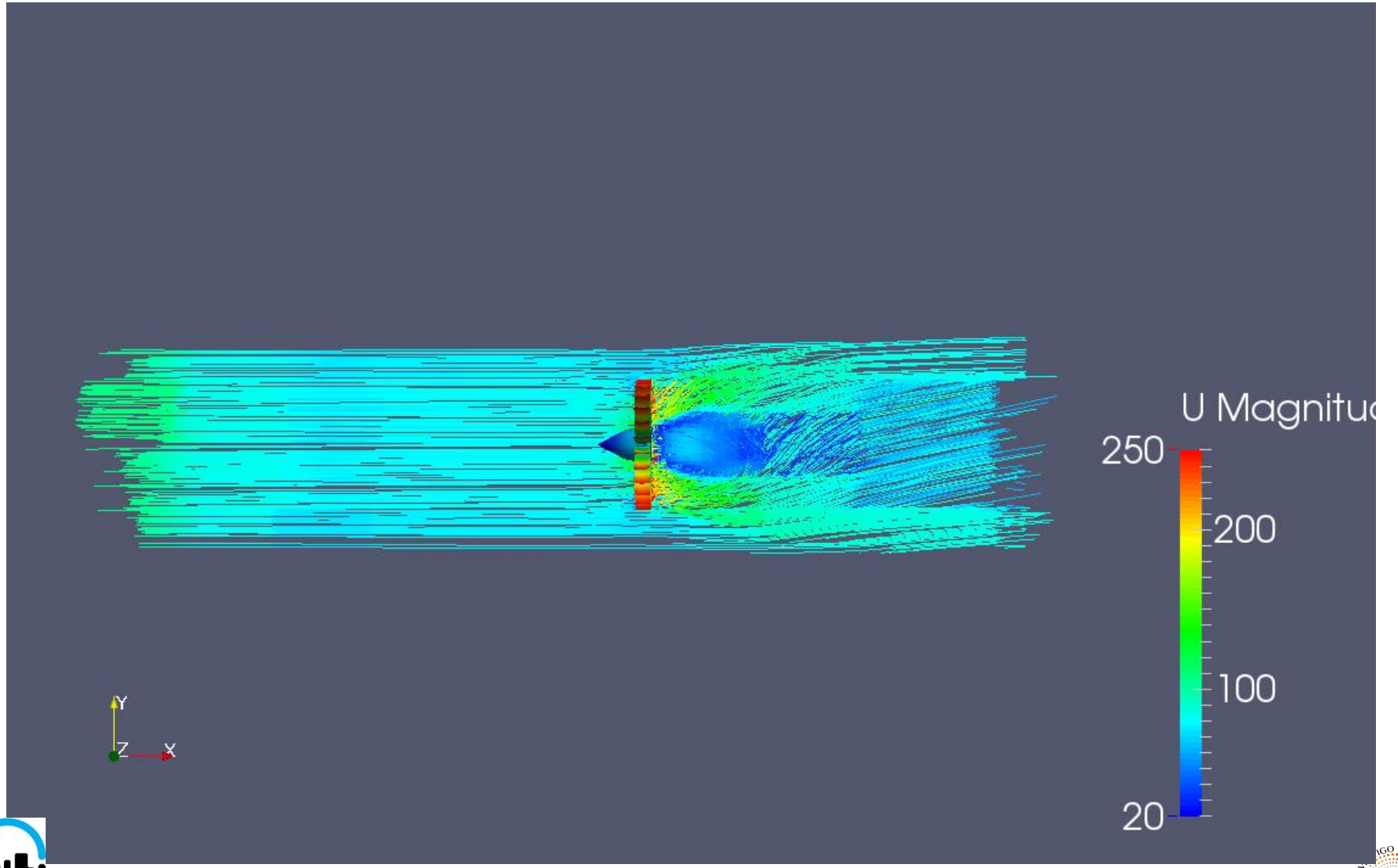
Particle ingestion assessment

Simulation of particle-laden airflows through an aeroengine



Simple simulations - wind tunnel setup

Velocity streamline



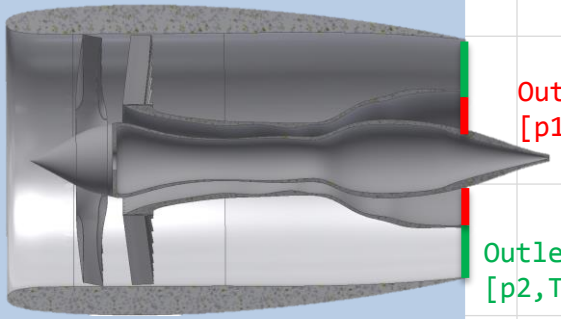
Complex CFD simulation setup

Background mesh (fully-structured hexahedral meshes)

Air + particles

high quality hex-dominant meshes

Particles
- particle number and distribution
- Particle velocity=cruising speed



Outlet Core
[p1,T1]

Outlet Bypass
[p2,T2]

Rotating fan stage (rpm)
Boundary conditions

Inlet
Atmosphere
[p,T,v]

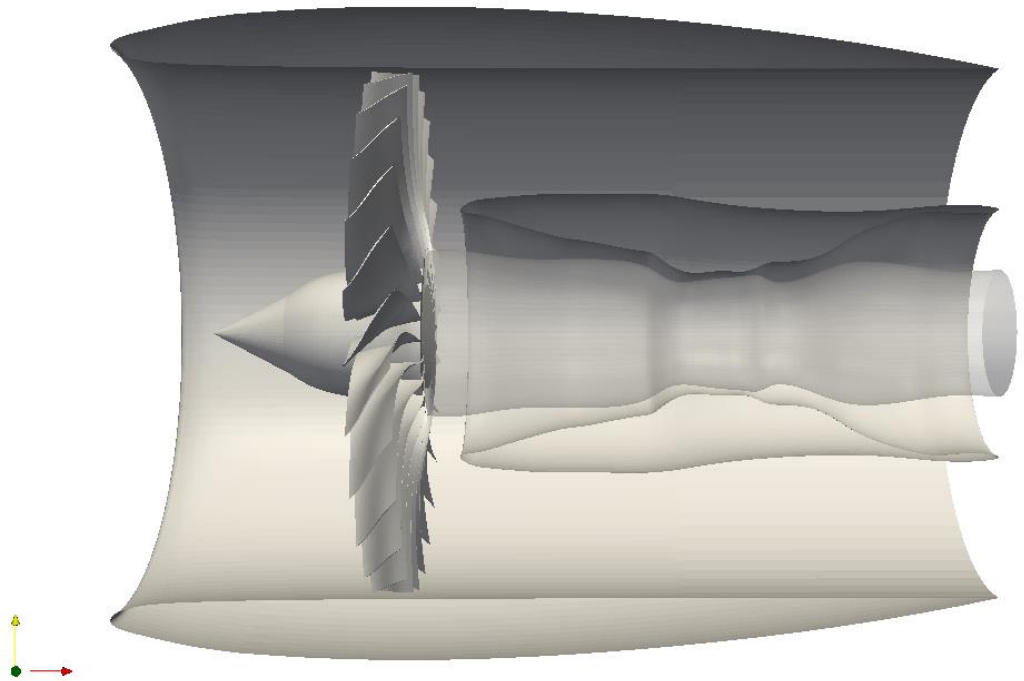
Outlet
Atmosphere
[p,T]

Planned working steps/improvements

Outlook

- Improvement of mesh quality
- Validation of model results
- Add other turbulence models (κ-ω-SST)
- Add other particle forces
- Nonspherical drag
- Collision model (wall collision)
- Particle kinetic energy model
- **ADVANCED/REALISTIC GEOMETRIES**

Setup 2 – advanced geometry



Factors Influencing Damage Mechanisms

Ash particle characterisation (physical, chemical optical properties of VA)

In cooperation with:

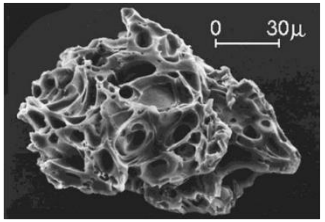
SINTEF

UNIVERSITÉ DE GENÈVE

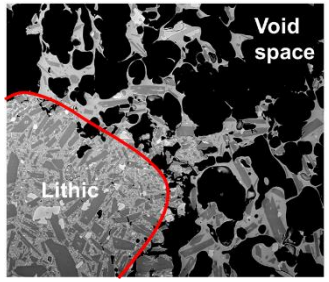
Particle characterisation and detection

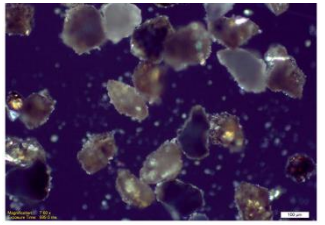
Factors Influencing Damage Mechanisms

- Influence of particle properties
- Relate ambient atmospheric concentration to particle measurement inside and outside aeroengine
- Particle characteristics (chemical, physical and optical)



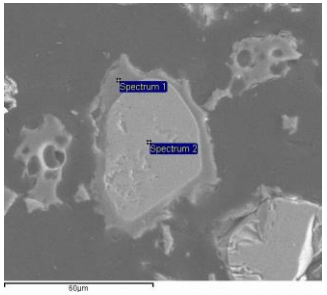
Vesicular volcanic glass





Glass chips

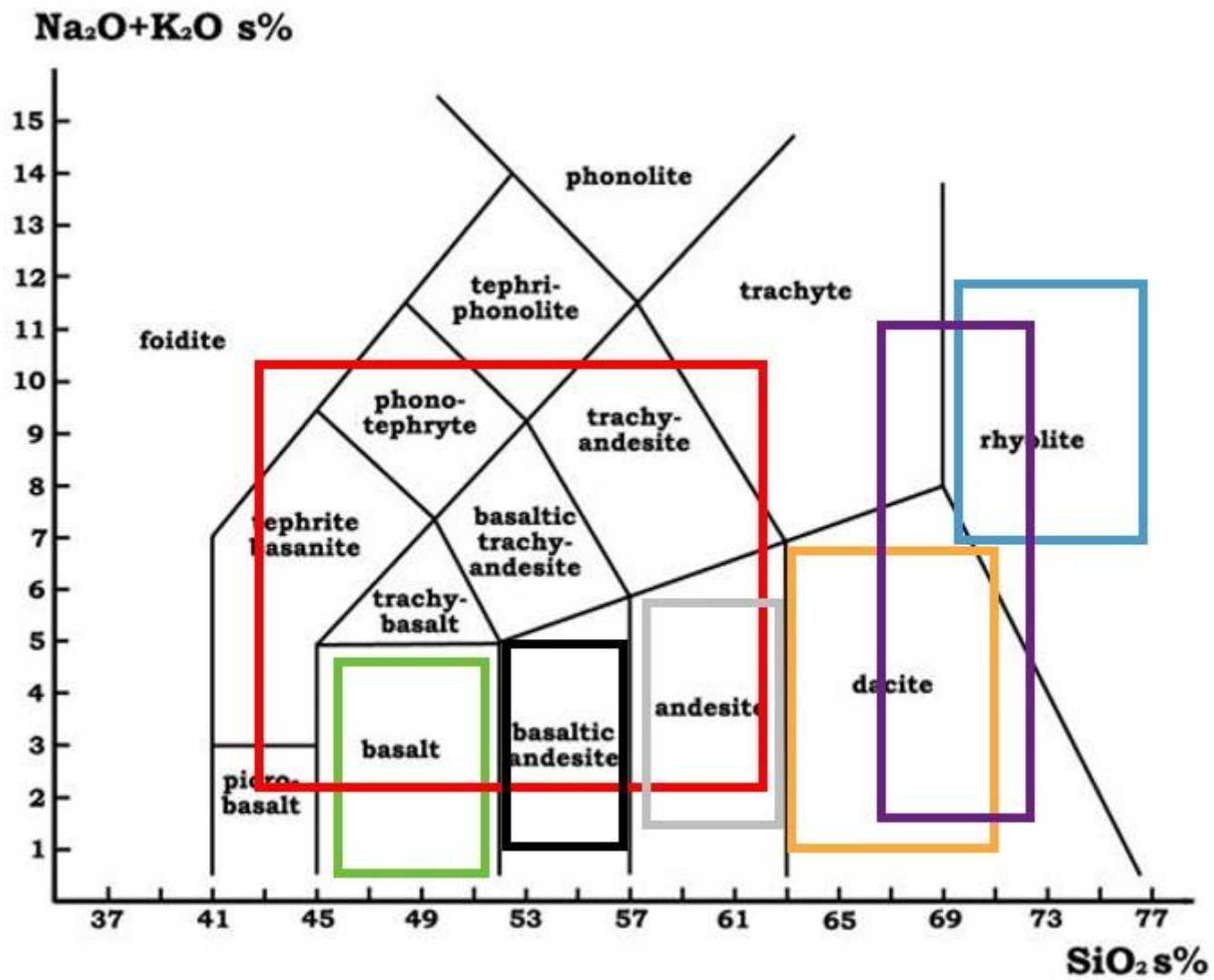
Lieke et al. 2012



List of volcanic ash samples

Volcano	eruption date	sample location	notes	ref
Pacaya, Guatemala	27.5.10	Guatemala City	basaltic ash; coarse particle size	Bill Rose/Sam Bonis
Mount St Helens	18.5.80	pumice plain, 5 km N MSH	dacitic ash; coarse particle size; good test ash	Bill Rose
Mount St Helens	18.5.80	~700 km from MSH	dacitic ash	Durant et al. (2011)
Ogallala Ash	~11 Ma		ryholitic; extreme distal ash; glass	Rose et al. (2003)
Crater Peak (Mt Spurr)	18.1.92	Cordova, AK	basaltic andesite	McGimsey et al. (2002); Durant et al. (2009)
Hudson, Chile	1991	DP2		Scasso et al. (1994)
Chaiten, Chile	2008			Durant et al. (2012)
Redoubt, AK	17.3.90		dacite/ryholite; KLM 867 ash	KLM 867 ash
Fuego, Guatemala	1974		basaltic ash	Rose et al. (2008)
Eyjafjallajoekull, Iceland	2010	Hvolsvollur	andesite ash	
Grimsvotn, Iceland	2011	Kirkubaelaklaustur	basaltic ash	
Kelud, Indonesia	2014		basaltic/andesit ash	

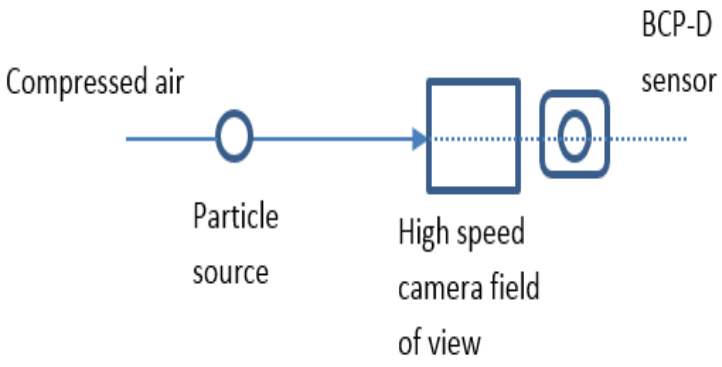
Particle characterisation

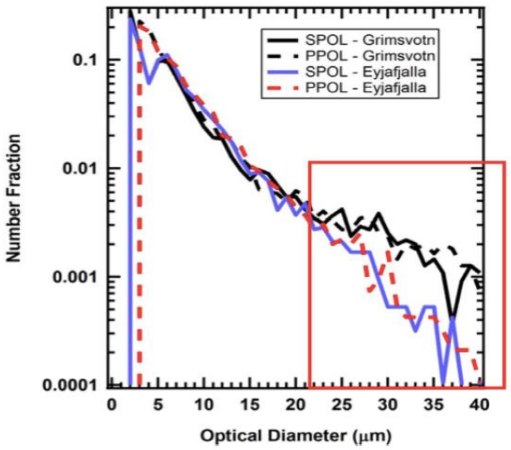


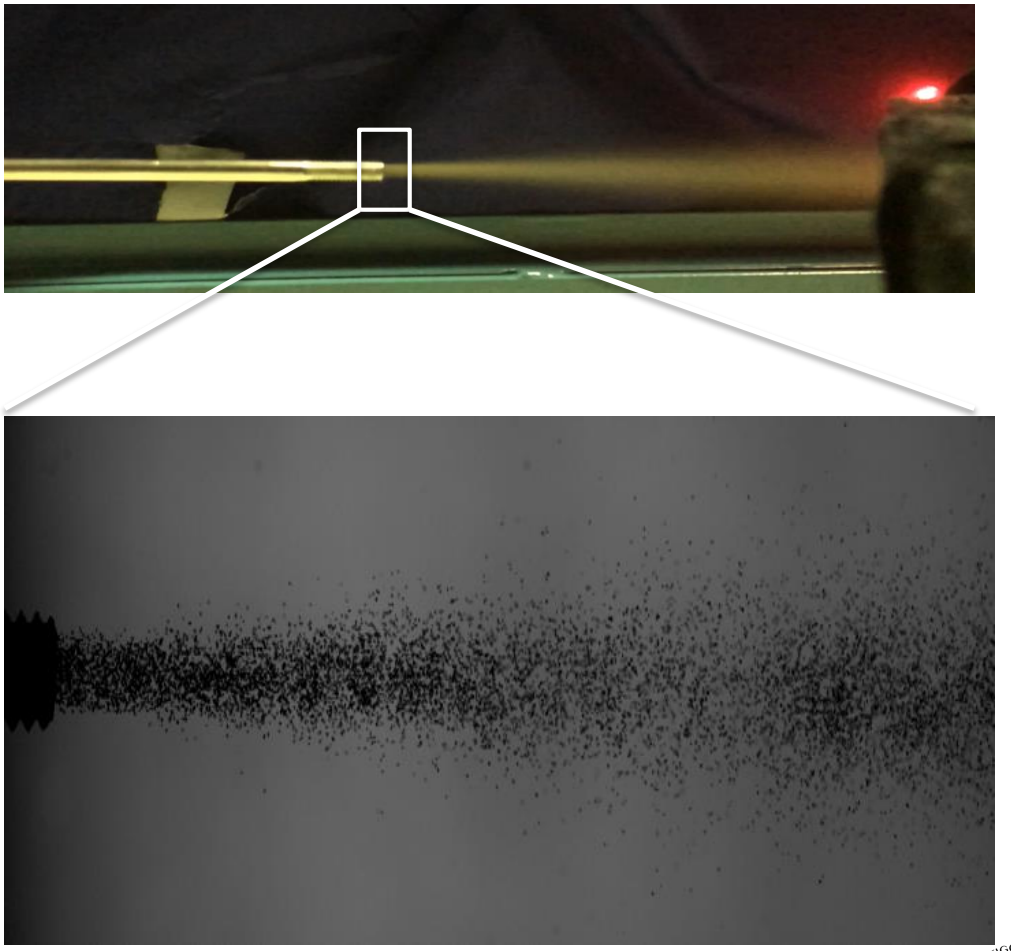
Particle characterisation

Measurements of particle size distribution

relate to optical and chemical properties of ash particles







Indication of damage in the core

Particle interaction with coatings-laboratory-based component testing

In cooperation with:

ONERA

THE FRENCH AEROSPACE LAB

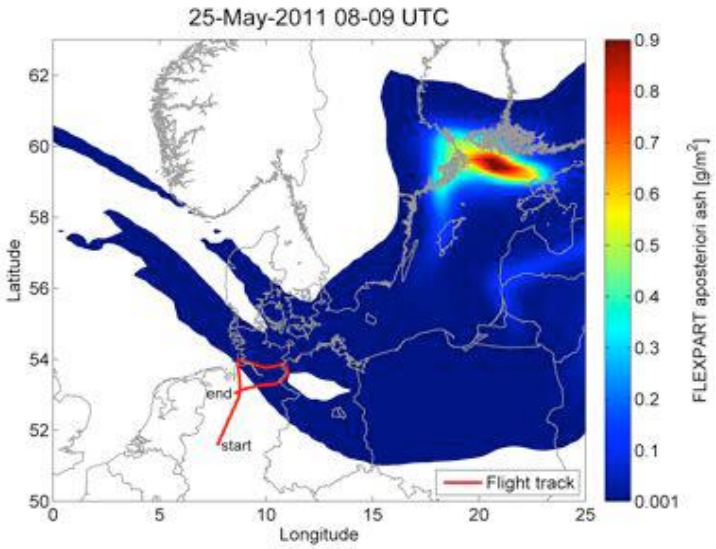
Flight operations assessment
Atmospheric dispersion of ash particles

In cooperation with:

NILU

Flight operations assessment

- FLEXPART, Lagrangian transport model output [Stohl et al., 2005; Moxnes et al 2012]
- Update particle size distribution used in model (now 4-25µm)
- Use real aviation flight track data (e.g. from Eurocontrol) to “virtually” fly aircraft through the FLEXPART model output of Grímsvötn
- Quantify EXPOSURE and DOSE along these flight tracks



Moxnes, Kristiansen, Stohl, Clarisse, Durant, Weber, Vogel (2013), **Separation of ash and sulfur dioxide during the 2011 Grímsvötn eruption,** *J. Geophys. Res.*, 2013JD021129

Thank you for your attention!

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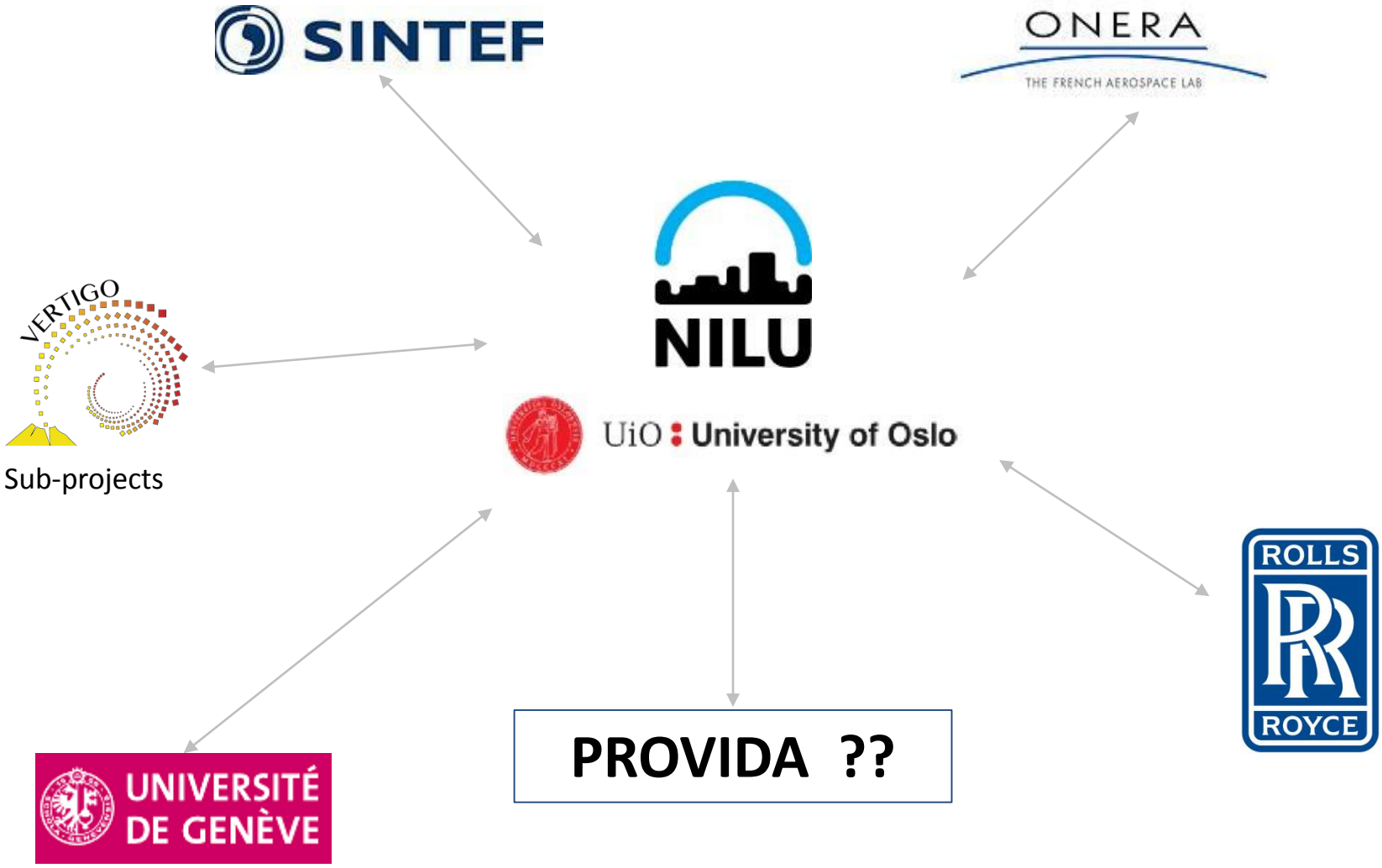

Sub-projects