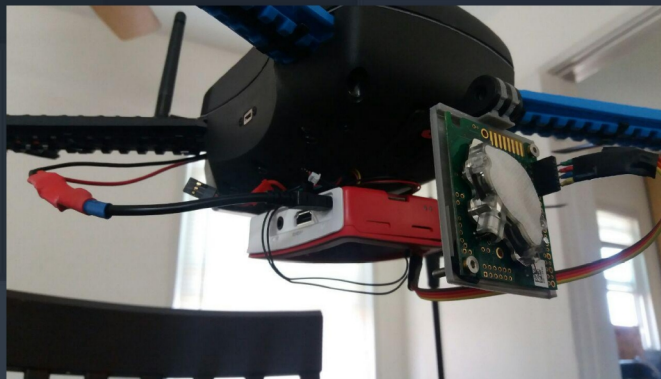


# Low cost sUAS GHG monitoring

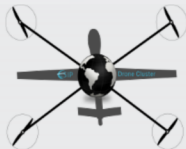
L. Barbieri, Doctoral Student  
University of Vermont  
lkbar@uvm.edu

J. Wyngaard, Data Science Technologist,  
University of Notre Dame  
jwyngaar@nd.edu



# Introduction

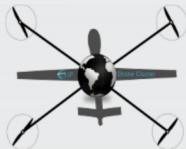
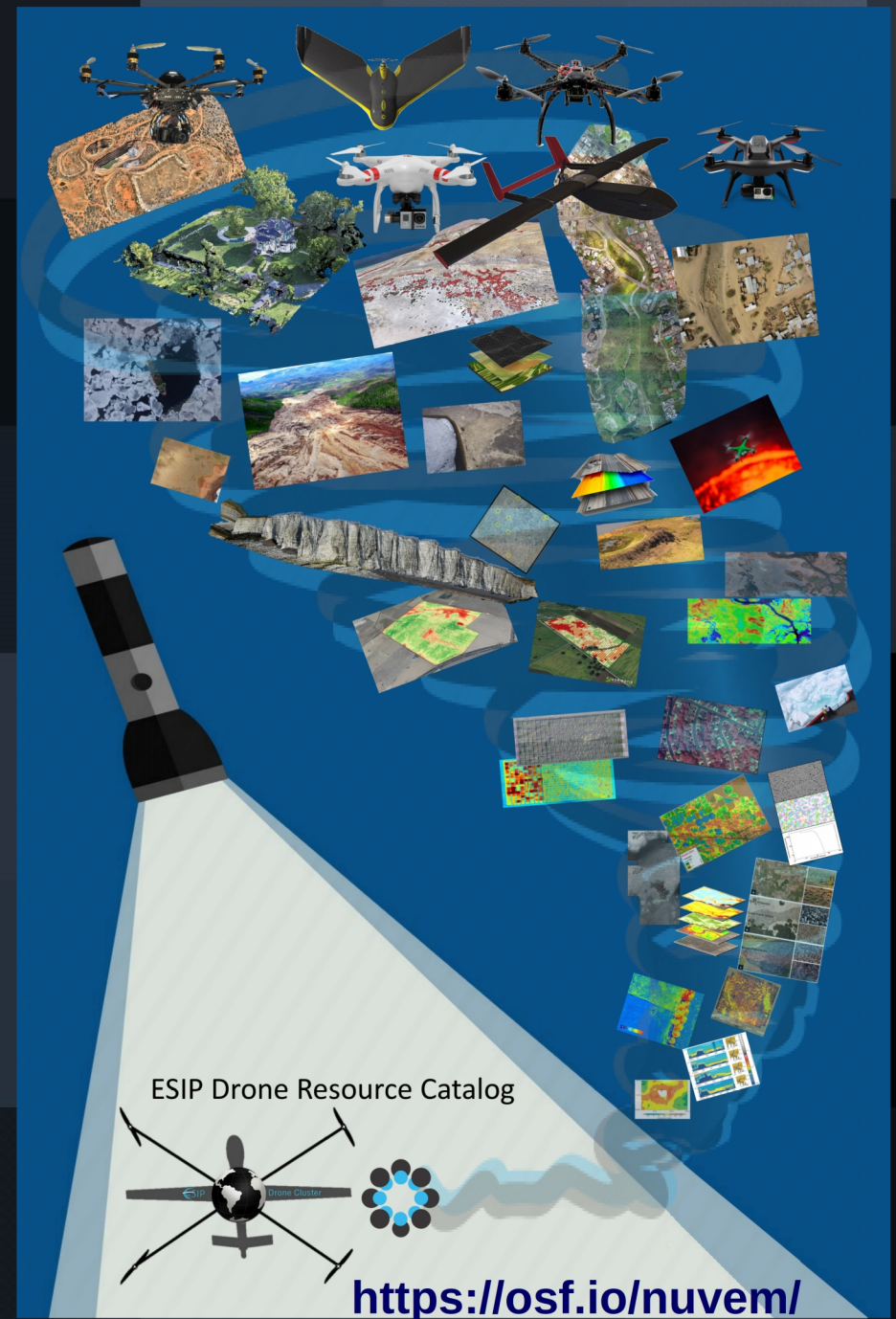
- ESIP Drone Cluster
  - Ag GHG monitoring
  - Engineering developments
- Other ongoing work
  - CO2 sensor platform - Max Planck
  - Climate Systems Analysis Group - UCT
    - Wind speed sampling





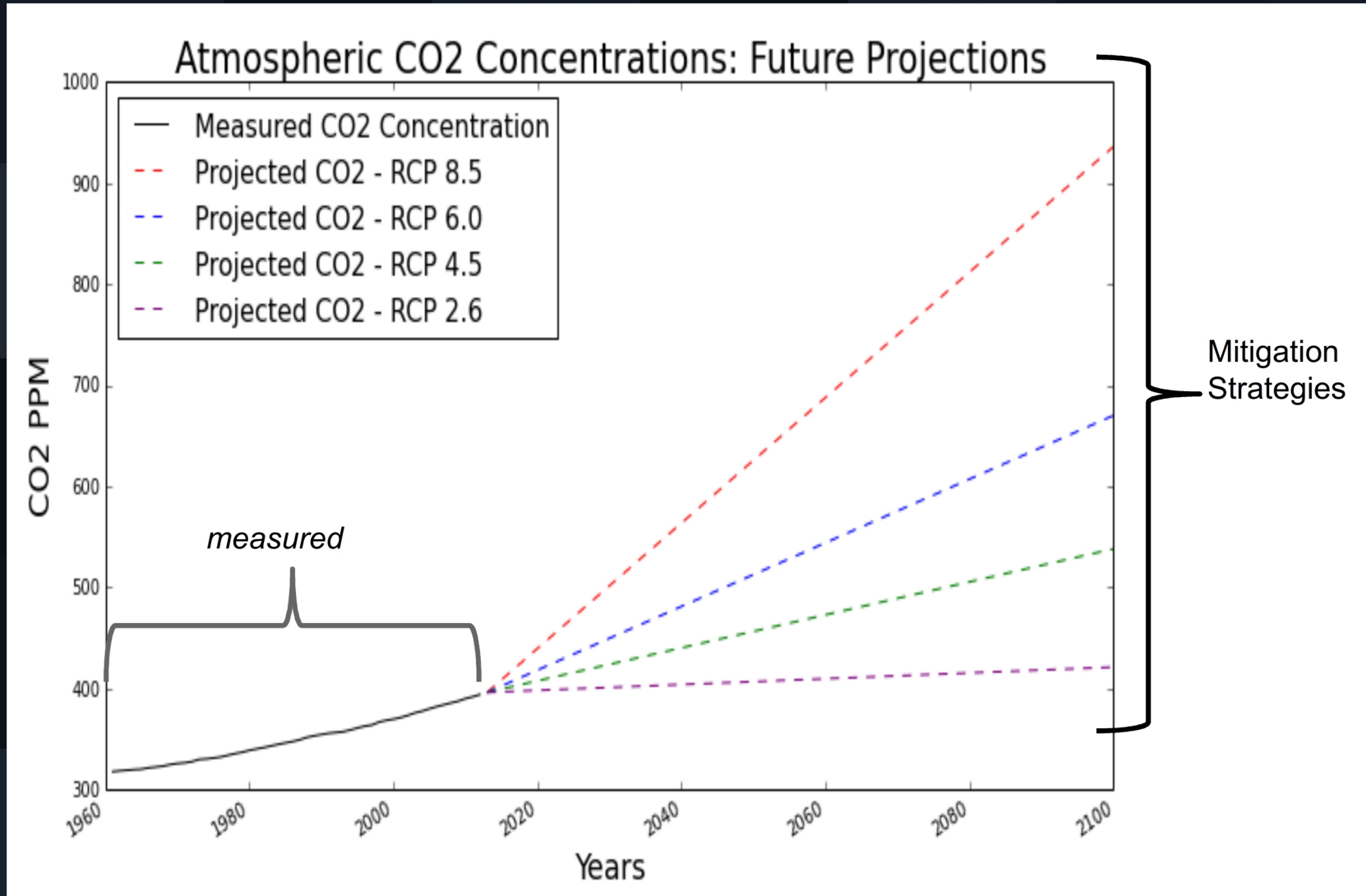
# ESIP Drone Cluster

- Earth Science Information Partners (ESIP)
  - NOAA
  - NASA
- Drone Cluster
  - Started June 2015
  - Seed funding
  - Intern
  - Standards



# Ag GHG monitoring motivation

## Atmospheric Carbon Dioxide Levels Measured and Projected





# Ag GHG monitoring motivation

## Impact of Agriculture

- Ag produces 19-29% of all GHG emissions [1]
- Ag is the largest (56%) contributor of non-CO2 GHGs [1]

**Table 5**

Emission coefficient for agricultural residue burning.

Biomass type	CH <sub>4</sub>	CO <sub>2</sub>	CO	Reference
<i>Emission factor (g/kg)</i>				
Agricultural residue	2.70	1515 ± 177	92 ± 84	[44]
Wheat straw	7.37 ± 2.72		156 ± 22	[45]
Rice straw	5.32 ± 3.08		82 ± 20	[45]
Wheat straw	3.55 ± 2.66	1787 ± 35	28 ± 20	[43]
Wheat stubble			21.1 ± 1.9	[89]
Wheat fire			38.20	[89]
Wheat			44.1 ± 7.4	[89]
Wheat			59.00	[89]
Wheat			35.00	[89]
Cereal waste		1400	35.00	[53]
Wheat residue	2.62-8.97	959-1320	61.1-179	[86]
Wheat residue	0.59-2.04	1540-1615	26-64	[87]
Wheat straw	0.41		34.65	[88]
<i>Default emission ratio</i>				
Agricultural residue	0.01		0.06	[20]

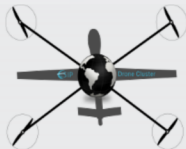
agricultural activity x emissions factor =  
greenhouse gas estimations!

[1] US-EPA 2011, Vermaulen et al 2012



# Ag GHG monitoring goals

- Low cost (developed and developing world Ag sector)
- Easy to use
- Efficient
- Qualified



# Sample area

## Monitoring 2 hay fields



### Edge of Field Station

Air Temperature  
Precipitation  
Water quality and field runoff

*\* sampled every 15 minutes*

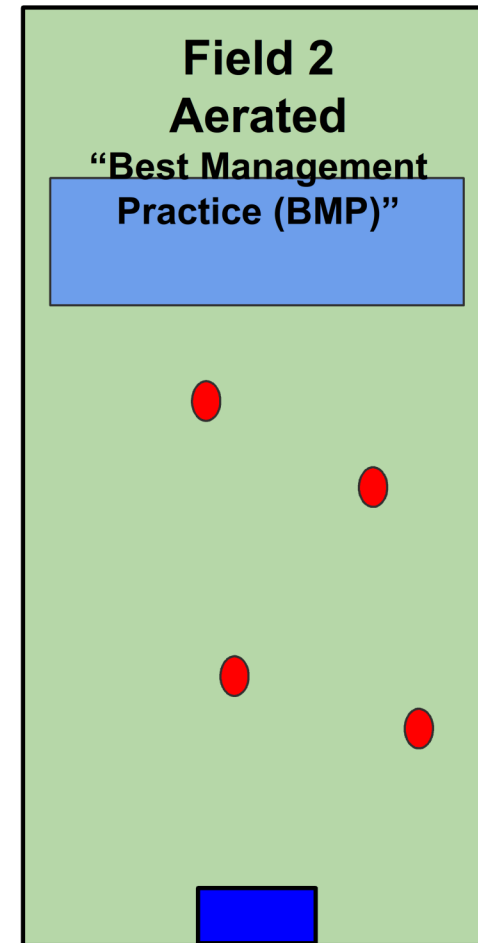
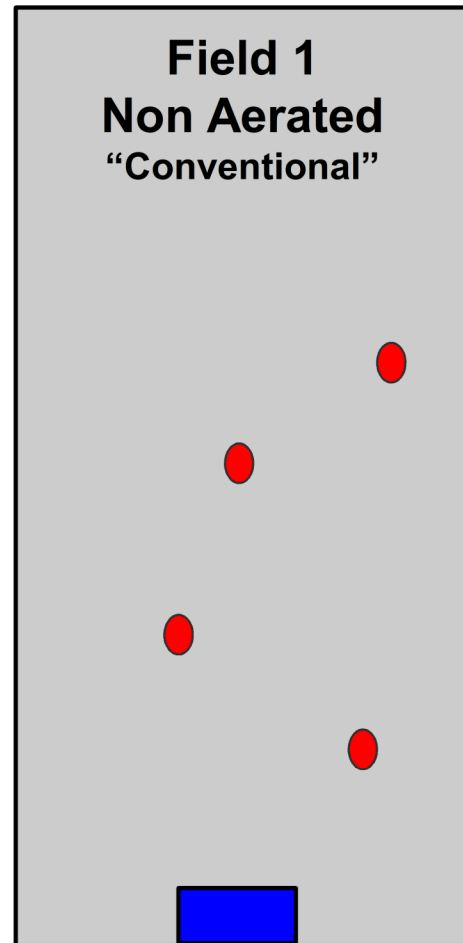


### Static Chambers

Soil Gas Flux  
Soil Temperature  
Soil Moisture

*\* sampled ~once a week*

*June - October 2015*





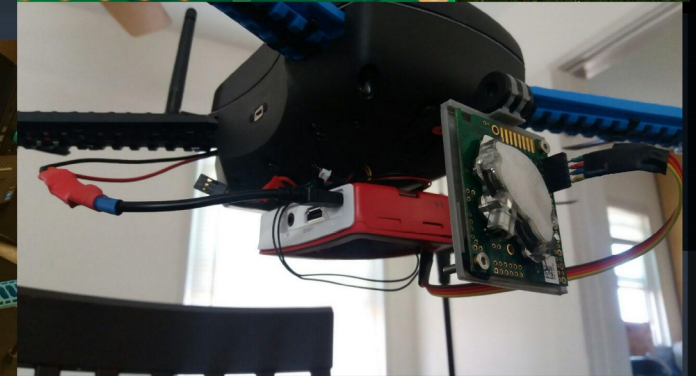
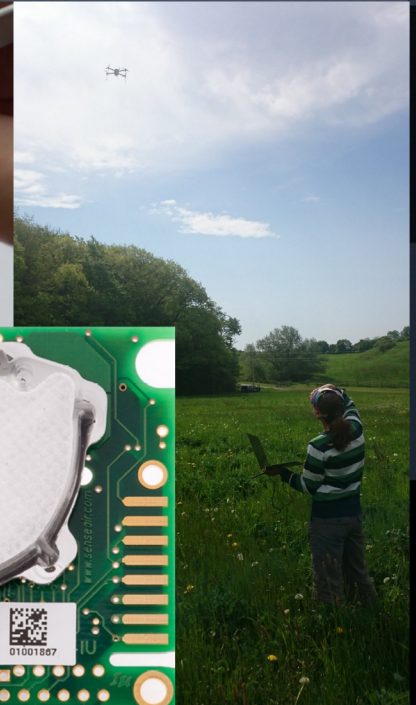
# Traditional sampling method



All Day Sampling Is Fun... but...  
**TIME CONSUMING, & expensive**

# sUAS Campaign 1

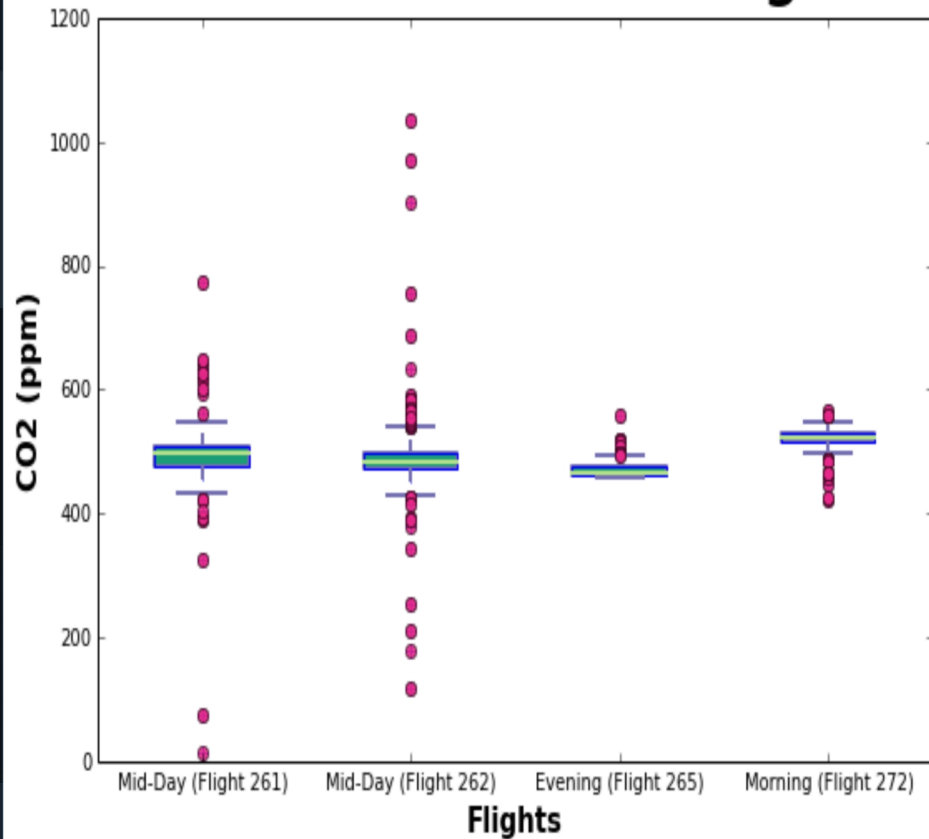
- CO2meter K33 - NDIR
  - +/-30ppm
  - 2Hz
  - Low power, “no maintenance”
- Canon S100 + Optical Filter for NIR
  - 12M
  - 198g
  - Modable (NIR)
  - Hackable (CHDK)



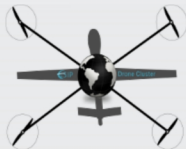
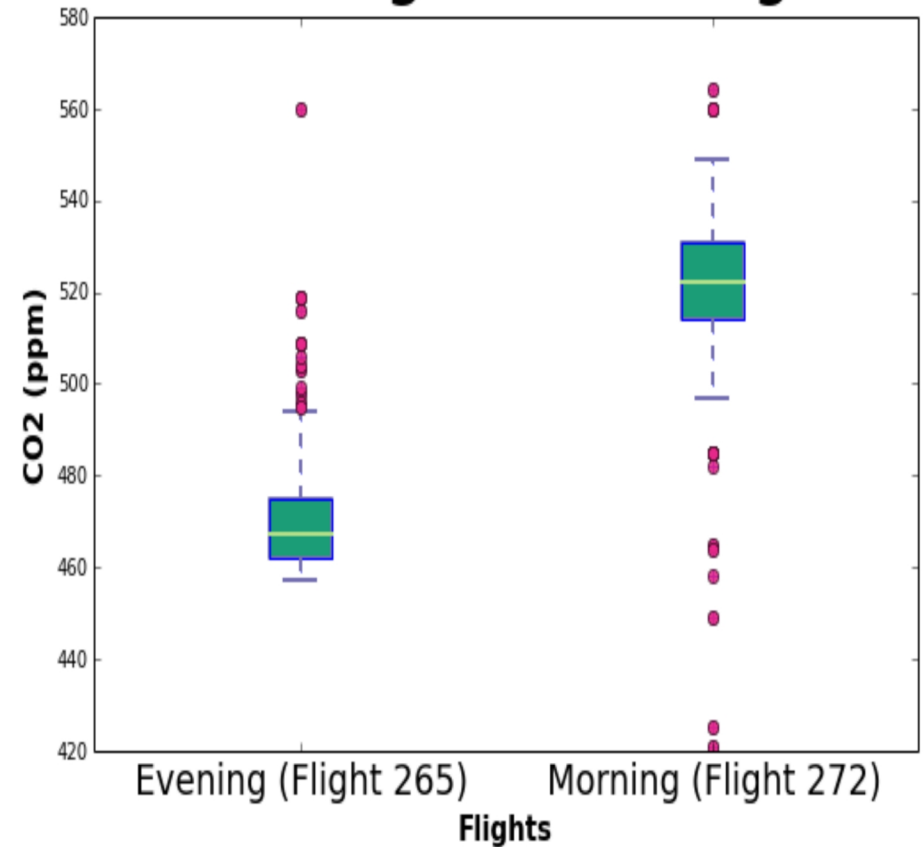


# sUAS Campaign 1

## Four Vertical Profile Flights



## Evening and Morning



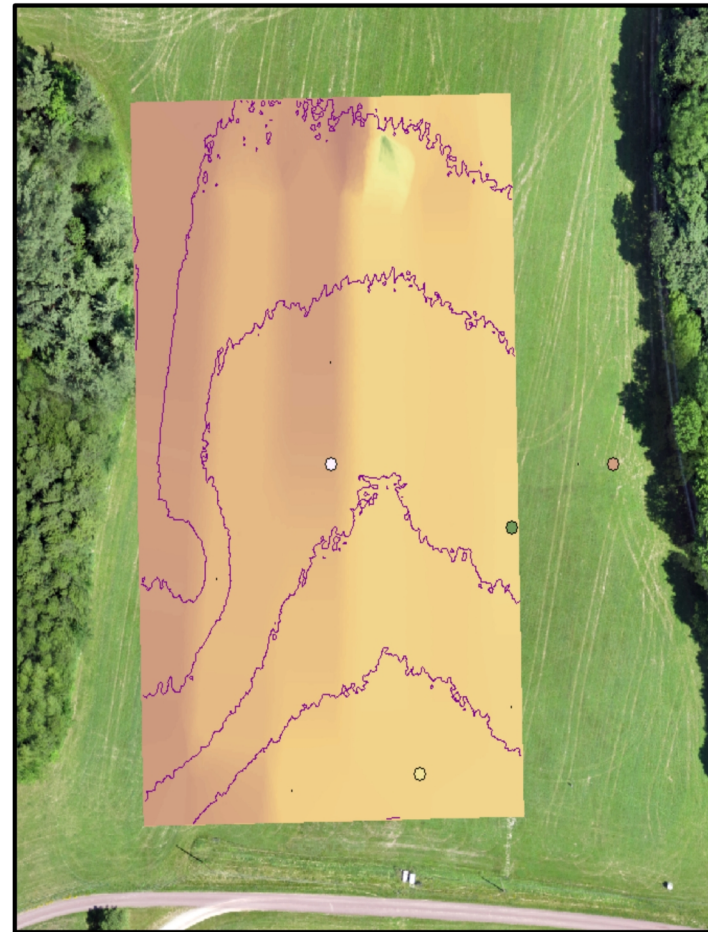


# sUAS Campaign 1

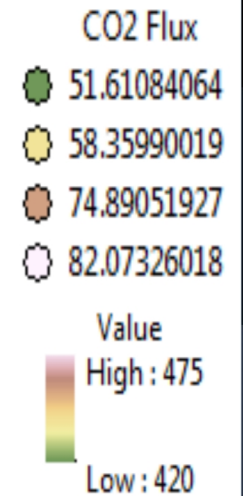
## Carbon Dioxide Concentrations from sUAS: Heat Map



5 Meters



10 Meters



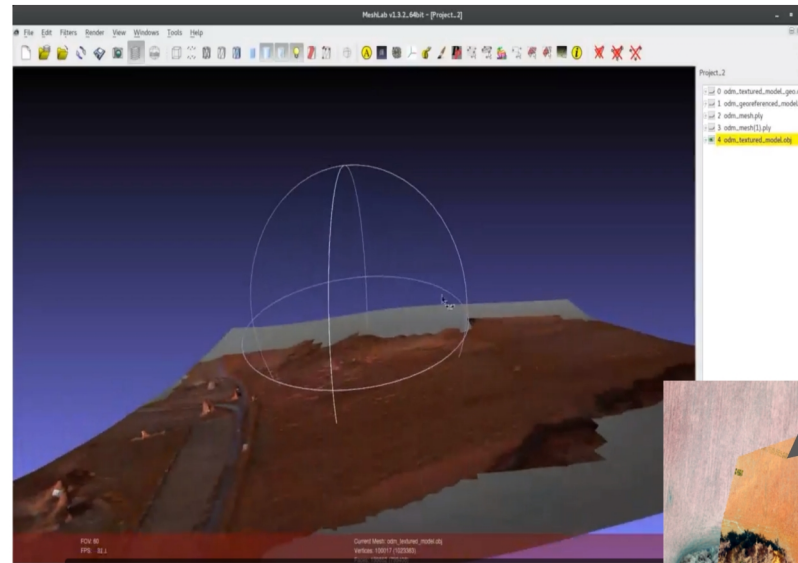
# sUAS Campaign 1

Near Infrared Camera Imagery  
(Open source drone)

Create mesh and Mosaic  
(Open Drone Map)

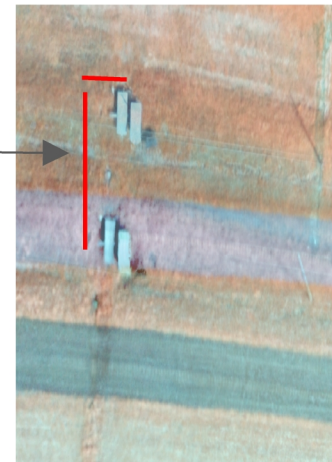
Visualise textured mesh/point cloud  
(Meshlab)

Imagery Analysis!  
Digital Elevation Model / NIR  
(QGIS)



3D DEM

Offset:  
1.3m  
7.3m



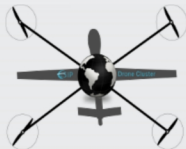
TimeStamps





# Sensor calibration

- K33 shows good emissions flux rate agreement with Photoacoustic Analyzer (PAS - Picaro),
  - Absolute accuracy is off ~15-30ppm.
- CO2 Sensor (K-30) needs to be re-calibrated at least every week
  - Possible before each flight
  - Rate of drift test not yet complete
- Temperature, pressure and humidity all need to be measured along with CO2 and properly accounted for - iMet-XQ UAV





# Engineering outcomes

## Open Data Kit flight monitoring

- Open Data Kit [ODK]



- Aggregate server (Self host/AWS/Gdocs)
- Customise Excel spreadsheets to create forms
- Android app



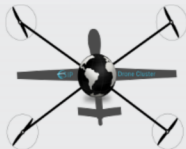
# Engineering outcomes

## Open Data Kit flight monitoring

- Example forms



- Preflight checklist multirotor
- Inter-flight checklist multirotor
- CO2 science mission metadata
- Battery logger
- [github.com:r4space/sUAS-ODK-forms.git](https://github.com:r4space/sUAS-ODK-forms.git)



# Engineering outcomes

## Open Data Kit flight monitoring

	A	B	C	D	E	F	G	H	I
1	type	name	label	hint	constraint	constraint_message	required	appearance	default
2	today	Date	Metadata						
3	start	Meta_Time	Time of submission						
4	deviceid	Device_ID	IMEI (International Mobile Equipment Identity)						
5	select_one PIC	PIC	PIC	Pilot in Command			yes	field-list	
6	begin group	Dual_Pilot	Dual_Pilot						
7	text	PIC1	PIC when flying Dual	Instructor name			yes		
8	text	CPIC	Co-Pilot	Instructor name			yes		Self
9	end group	Dual_Pilot							
10	begin group	RPA	RPA					field-list	
11	select_one RPA_type	RPA_type	RPA type				yes		
12	select_one Engines	Engines	Engines	If failure of 1 engine will cause catastrophic failure then it's a single engine			yes		
13	end group	RPA							
14	begin group	Flight	Flight					field-list	
15	decimal	Flight_Time	Flight time (decimal hrs)	Flight time in decimal hours	Flight time is expressed in decimal fractions of the (<1)		yes		
16	text	Remark	Remark	Purpose of flight			yes		
17	end group	Flight							
18	begin group	Optional	Optional additional parameters					field-list	
19	geopoint	geopoint_test	Record your location co-ordinates (optional)						
20	image	Site_image	Take a picture of the flight site and weather conditions (optional)						
21	end group	Optional							
22	begin group	Summary	Summary					field-list	
23	note	SUM_PIC1	PIC1 \$(PIC1)						\$(PIC1)
24	note	SUM_CPIC	CPIC \$(CPIC)						\$(PIC1)
25	note	SUM_PIC	PIC \$(PIC)						not
26	note	SUM_FT	\$(Flight_Time)hrs						
27	end group	Summary							
28	begin group	Summary_cont	Summary continued					field-list	
29	note	SUM_RPA	\$(RPA_type)						
30	note	SUM_Date	\$(Date)						
31			Sign log entry	Checking this box acts as a digital signature that the details supplied here are correct					
32	acknowledge	ack					yes		
33	end group	Summary							
34									

ODK Collect >...

Optional additional parameters

**Record your location co-ordinates (optional)**

Start GeoPoint

Latitude: N 34°42'49"  
Longitude: E 33°9'42"  
Altitude: 0m  
Accuracy: 20.5m

**Take a picture of the flight site and weather conditions (optional)**

Take Picture

ODK Collect >...

Airframe Structure

**Airframe**

Inspect the airframe structure, including undercarriage, all flight control surfaces and linkages

OK. Please continue.

**Markings**



Inspect registration markings for proper display and legibility

OK. Please continue.

**Landing gear**

Inspect moveable control surface(s), including airframe attachment point(s)

Previous **PilotLogBook01** Next

Date	Meta_Time	Device_ID	PIC	Dual_Pilot PIC1	Dual_Pilot CPIC	RPA RPA_type	RPA Engines	Flight Flight_Time	Flight Remark	Optional geopoint_test Latitude	Optional geopoint_test Longitude	Optional geopoint_test Altitude	Optional geopoint_test Accuracy	Optional Site_image
2017-02-21 00:00:00.0	2017-02-21 18:48:46.021	356521077244734	2	Dane	Self	Fixedwing	Multi_engine	0.4000000000	Lesson 5	34.7138000000	33.1616853000	0E-10	20.8980000000	
2017-02-21 00:00:00.0	2017-02-21 18:50:40.33	356521077244734	self			Fixedwing	Single_engine	0.2000000000	Lesson8	34.7138000000	33.1616853000	0E-10	20.5280000000	
2017-02-21 00:00:00.0	2017-02-21 19:12:37.346	356521077244734	self			Multicopter	Single_engine	0.2000000000	CO2 VProfile					

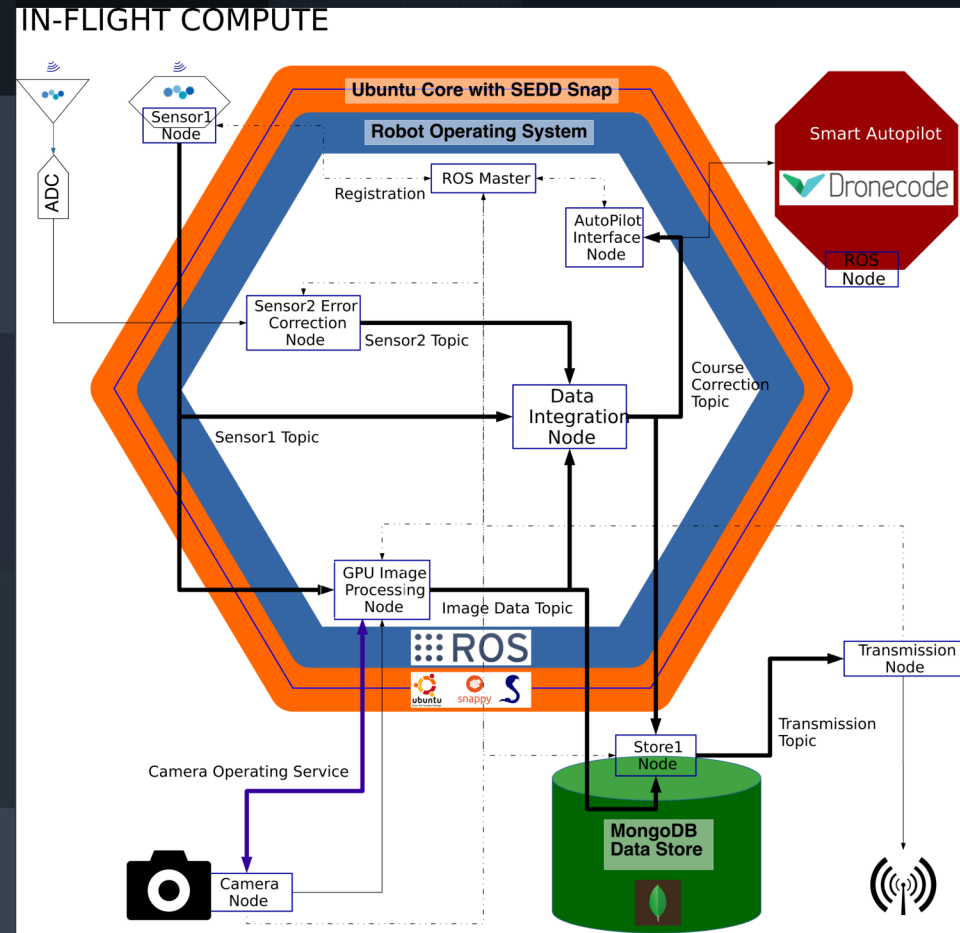
for  
ning



# Engineering outcomes

## Science Standard Embedded Data infrastructure for Drones


- Ubuntu Snappy
- X-DOMES sensor repository
- ROS
- Ardupilot
- MongoDB
- Open Standards





# AMS 2017

- COCAP at the Max Planck Institute for Biogeochemistry
- CO2 analyser for sUAS
  - 1kg
  - Within 2ppm (2 calibration points per flights)
  - Temperature compensated

 Max Planck Institute  
for Biogeochemistry 

☰

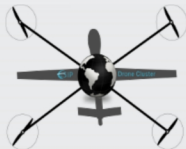
**Measuring carbon dioxide with drones – new prospects for climate research**  
July 22, 2016

During the „ScaleX“ measurement campaign, which took place last June and July under coordination by IMK-IFU (Garmisch-Partenkirchen, Germany), an international team of about 60 researchers, technicians, and students investigated a grassland in Peißenberg-Fendt. The



Octocopter measuring carbon dioxide (Photo: Martin Kunz)

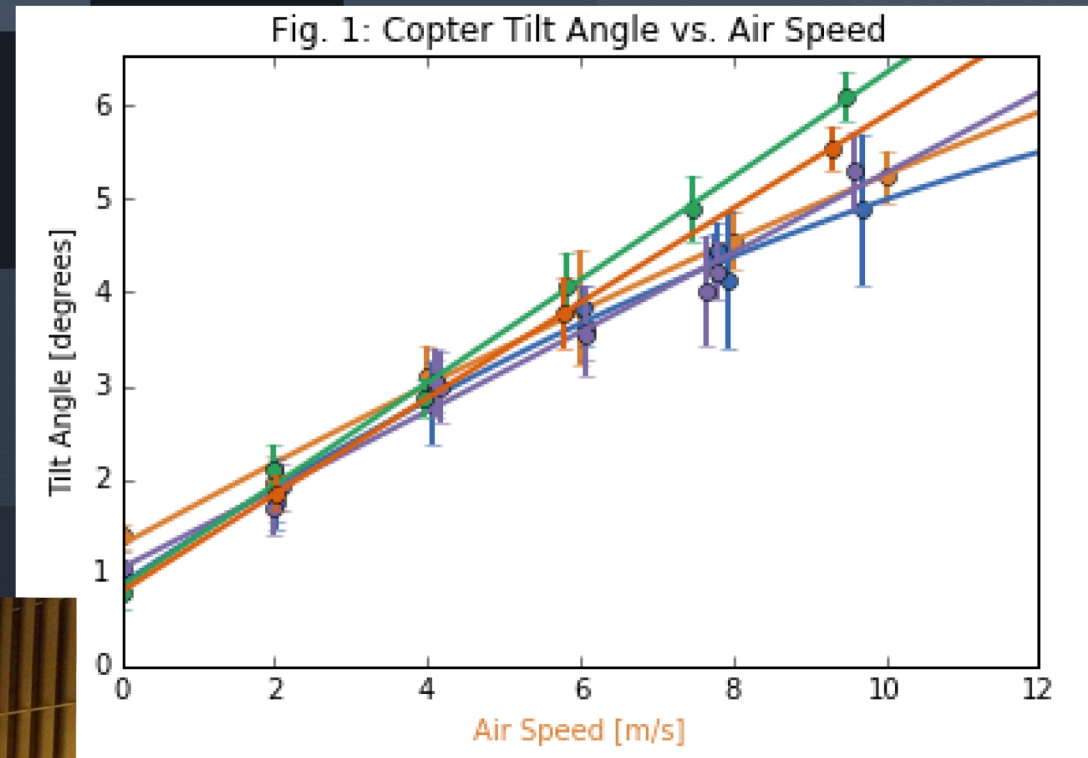
<https://www.bgc-jena.mpg.de/www/index.php/PublicRelations/NewsSingle?jahr=2016&id=1469104752>



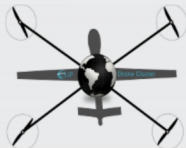
# Climate Systems Analysis Group

## Wind speed

- CSAG – University of Cape Town
- Wind tunnel calibrated title angle
- Anticipate  $\sim < 1\text{m/s}$  error
- Error dependant only on IMU and Wind Tunnel error



<https://github.com/rodgerduffett/rotmat>



# Conclusions

- GHG sUAS monitoring ...developing...
- Open source is possible
  - Reproducible science
  - Easier to customise
  - Data is yours to publish
    - FAIR data: Findable, Accessible, Interoperable, Reproducible
  - Lowered costs

