Reuniwatt

Excellence in forecasting

Cloud detection and cloud base height retrieval using a ground thermal-infrared all sky imager

ISTP 2019, Toulouse

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10/07/2019

Reuniwatt : expert in cloud observation and forecasting

- Founded 2010

- Head Office in Reunion Island (France), Business offices in Paris and Toulouse

- Staff: >20 employees, 5 PhD

- Offering services for 3 markets:
  - Renewable energy
  - Atmospheric science
  - Defence & Space

- Particular emphasis on solar energy forecasting

- Strong investments in R&D: >50 scientific publications, 4 patents

A complete cloud presence forecasting portfolio

Solar InCell™
local irradiance monitoring

InstaCast™
intrahour solar forecasts

HourCast™
intraday solar forecasts

DayCast™
day-ahead solar forecasts

SunSat™ *time series*
historical solar data worldwide

SunSat™ *live*
live solar data worldwide

Resource assessment

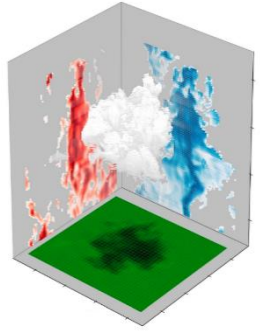**Real-time monitoring**

Forecasting

SOLAR DATA

SOLAR FORECASTING

Solutions for several applications

Meteorological applications

Small-scale weather-modelling processes

Long-term records for climate change studies

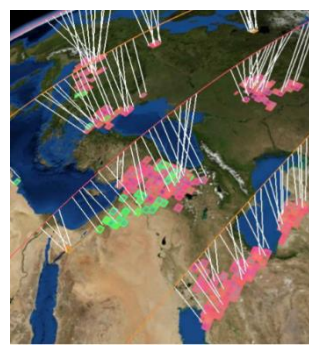Clear sky events notification

Other applications

Short-term solar energy forecast
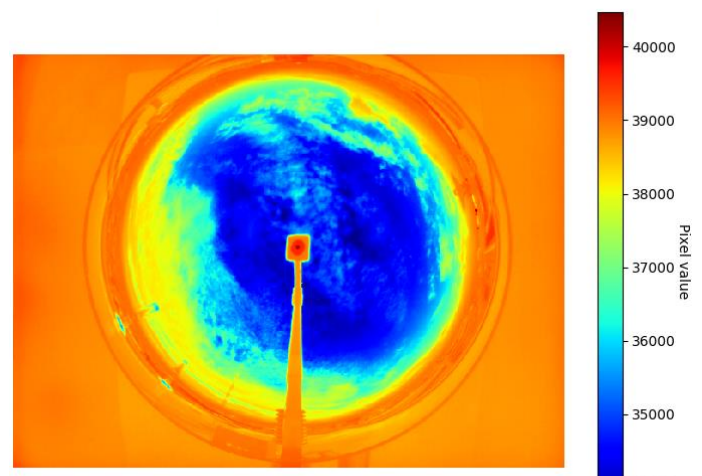
Air traffic management

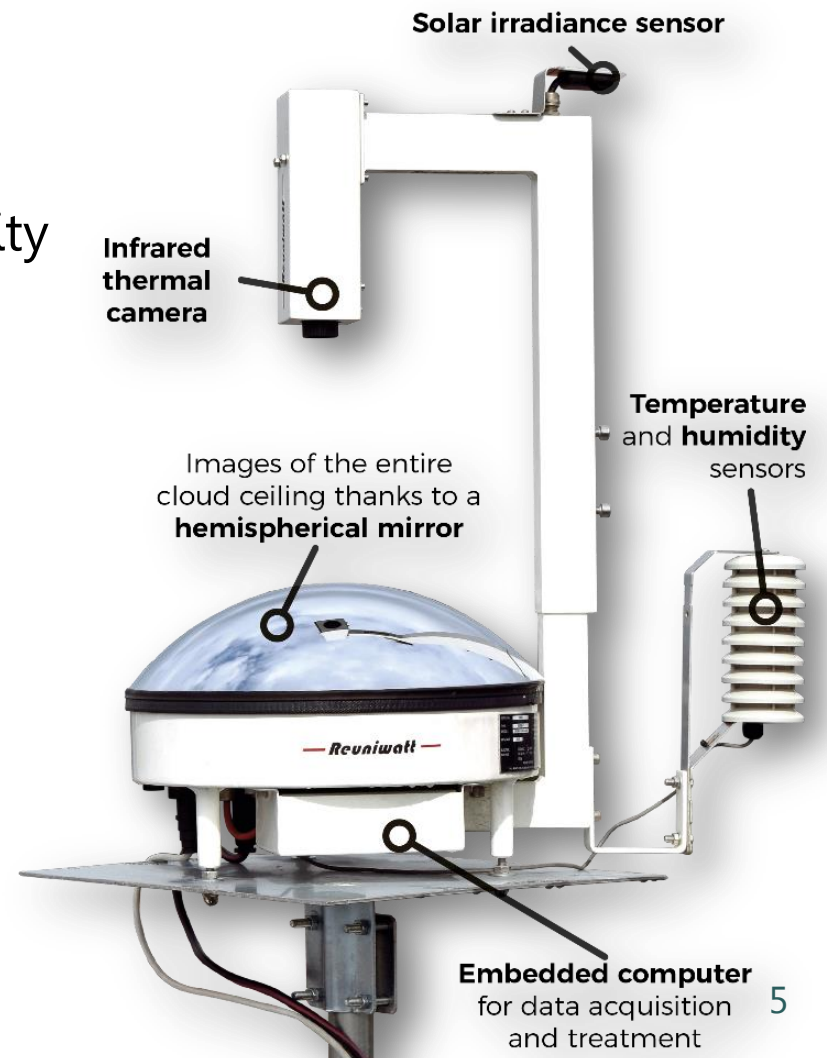Earth observation

Ground-satellite FSO communications

Sky InSight™: the thermal infrared sky imager

- Images of the entire cloud ceiling thanks to hemispherical mirror

- Data acquisition: GPRS, Wi-Fi…

- Irradiance, temperature and humidity sensors

- Industrial product deployed on several solar power plants

Raw Sky Insight image

Solar irradiance sensor

Infrared thermal camera

Images of the entire cloud ceiling thanks to a **hemispherical mirror**

Temperature and **humidity** sensors

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Embedded computer for data acquisition and treatment

5

Tested under different climatic conditions for solar applications

Bègles, Atlantic Ocean, France

St Leu, La Réunion, Indian Ocean

Paris, Urban Area, France

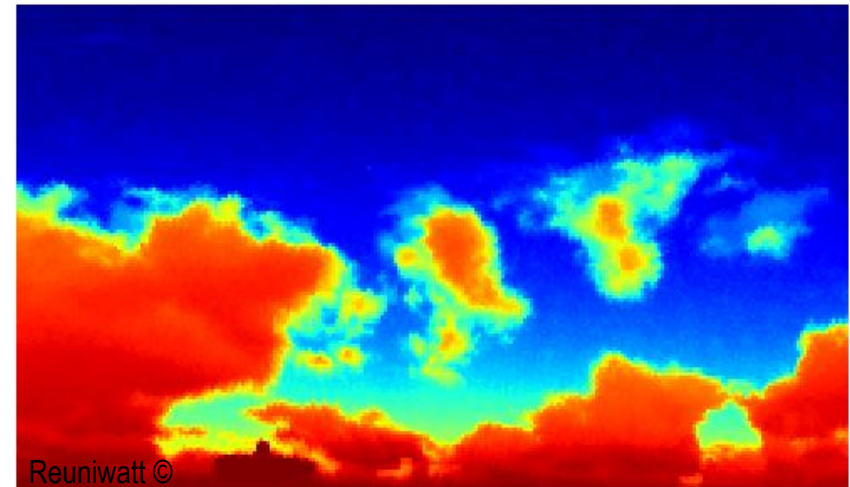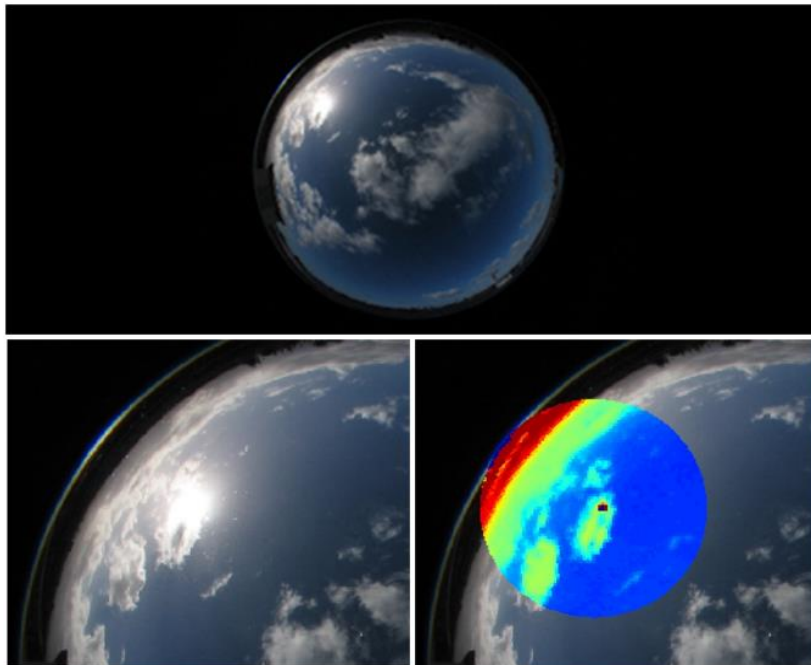Bulmann, Northern Territory, Australie

Table Mountain, Colorado, USA

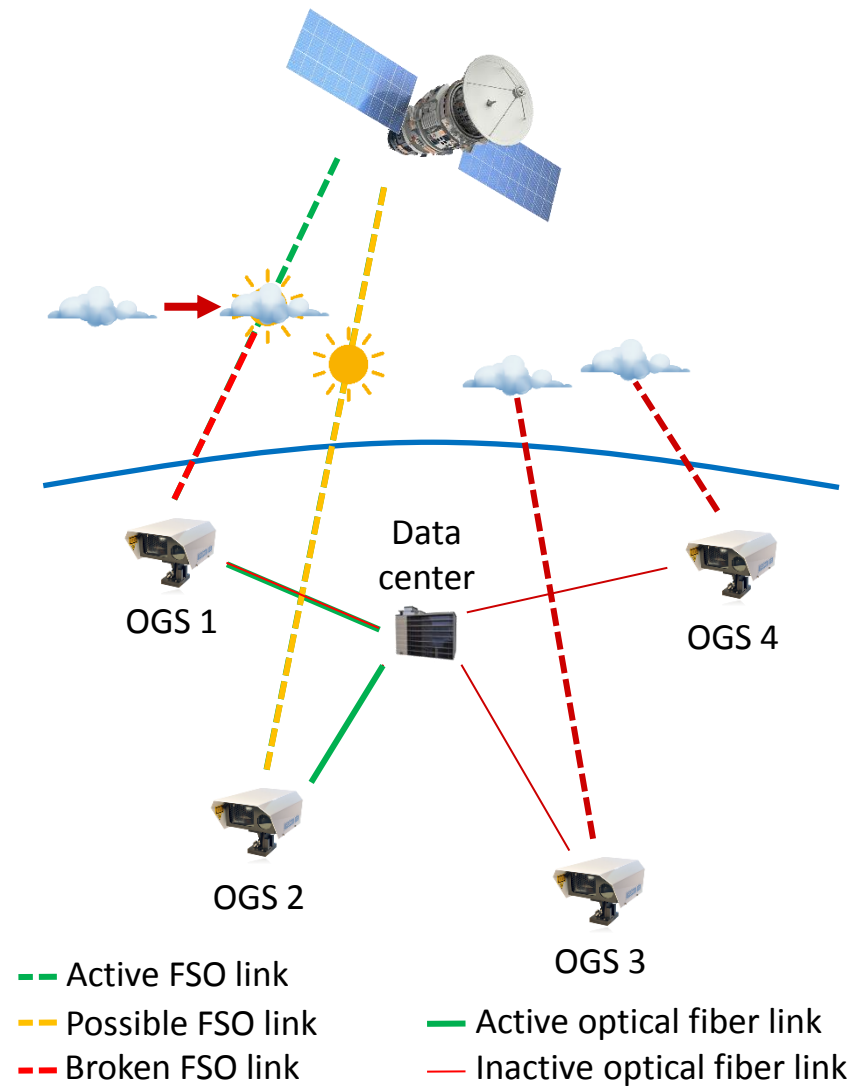Mediterranean sea, France

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Infrared imaging benefits

- Night and day operation without sensibility change

- No sun flare

- Radiometric contrast useful for cloud property retrieval

Horizon view, Toulouse, 2017-09-25

7/10/2019

Free Space Optical communication

- **Faster and safer than basic radiofrequency communications**

- **Anticipated use cases :**
  - Earth observation images transfert from LEO satellites
  - Data transfert to a geostationnary telecom satellite
  - Communication with a deep space probe

- **One big problem : laser doesn't cross most of the clouds**

- **Solution : site diversity**

- **With a cloud motion forecasting station associated to each optical ground station (OGS), broken links could be totally avoided.**

Data center

OGS 1

OGS 4

OGS 2

OGS 3

- - Active FSO link
- - Possible FSO link
- - Broken FSO link
— Active optical fiber link
— Inactive optical fiber link

Test bench for lasercom applications

■ Two test benches set up with IRT

Observatoire de la côte d'Azur (OCA), Nice :
Thermal and visible cameras
Since May 2015 – 4 years

Airbus Defense & Space, Toulouse :
thermal and visible cameras, pyrometer, pyrheliometer
Since July 2017 – 2 years

Sky Insight™ for FSO communications

- One Sky InsightTM associated to each optical ground station (OGS)

- Forecast cloud obstructions up to 30 minutes in advance

- Evaluate the obstruction potential of a cloud :
  - Some thin clouds are harmless for the laser signal
  - Depends on several cloud characteristics
    - Cloud optical depth (COD)
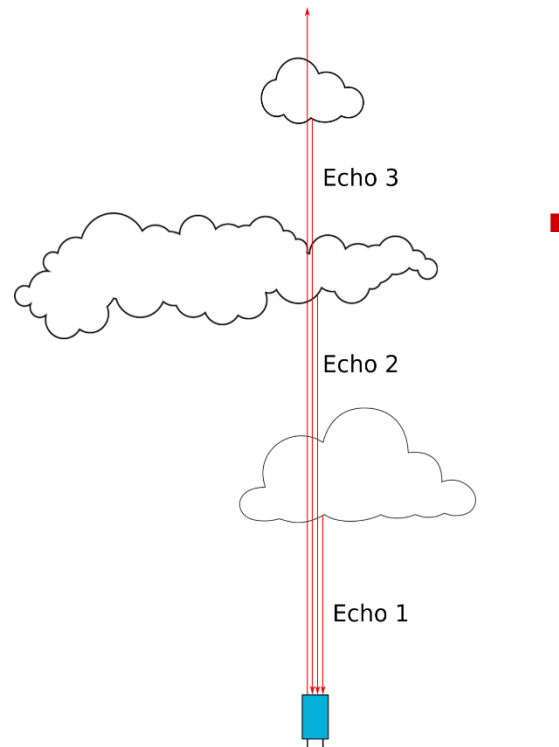   - **Cloud base height (CBH)**

CBH retrieval method : input data and equipment

The CHM15k-Nimbus celometer

Sky Insight data mask, only the yellow pixels are considered

Echo 3

Echo 2

Echo 1

CBH measurement process

- **Equipement :**
  - Sky Insight^{TM} device
  - Ceilometer CHM15k-Nimbus
  - Both located on the SIRTA laboratory, nearby Paris

- **Input data :**
  - Raw Sky Insight numerical counts
    - One value every 30 seconds
    - Averaged spatially in the nadir direction
    - Compensation of the lidar tilt
  - CBH ceilometer measurements (only the first echo is considered)
  - Radio probing atmospheric profiles conducted in Trappes, a nearby town
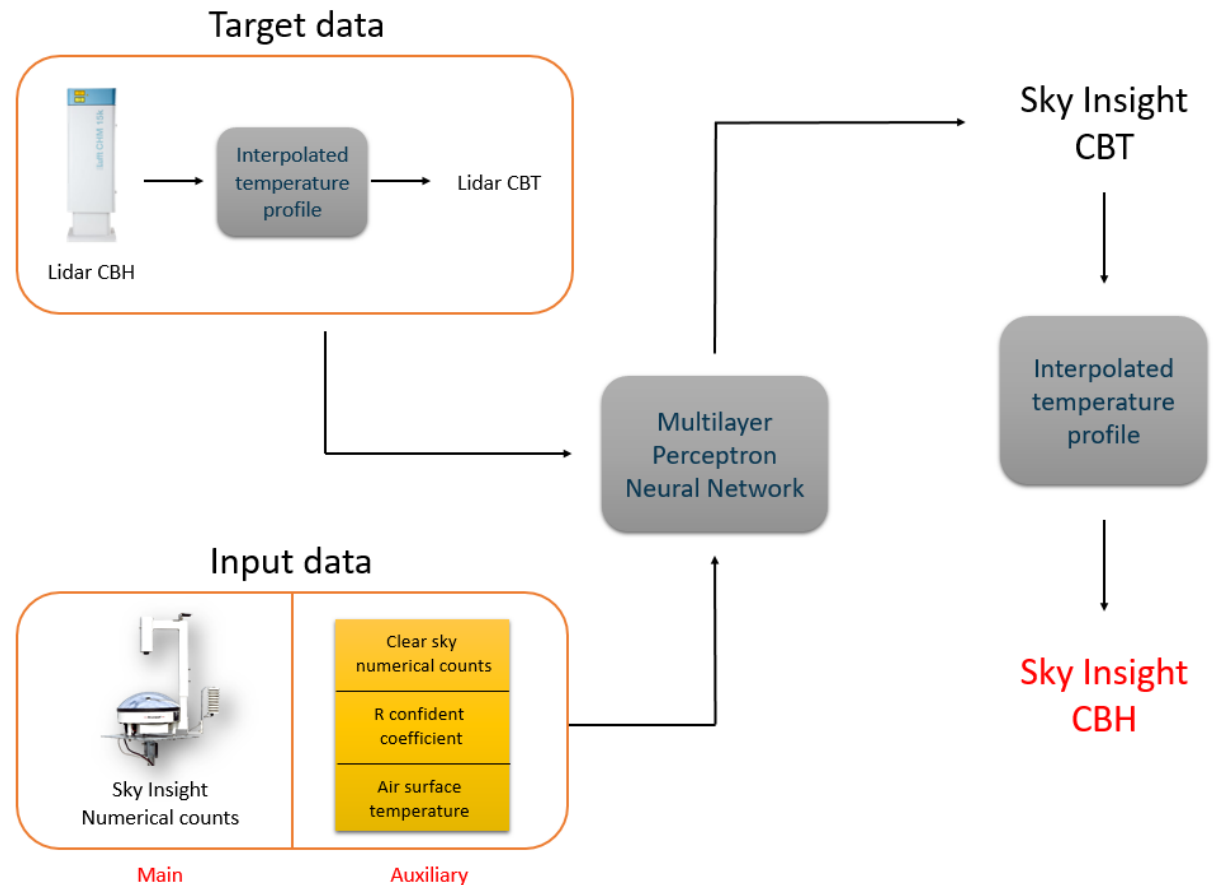 - Gathered over a period of 6 months, between january and july 2018
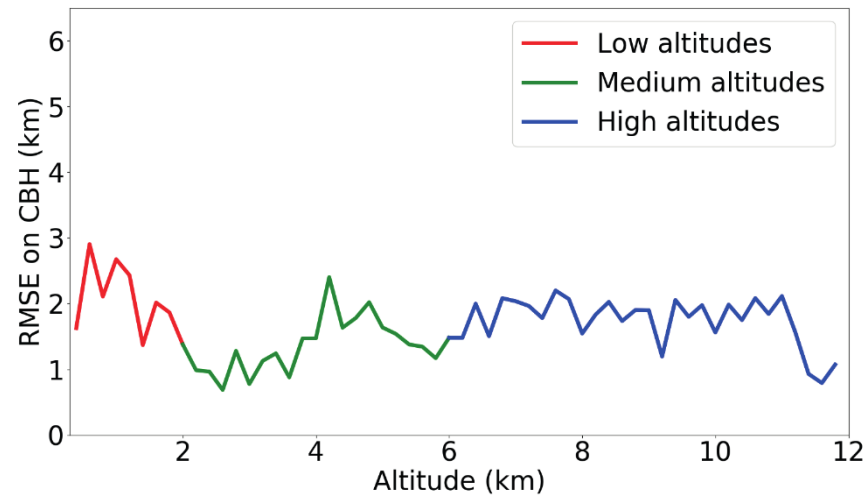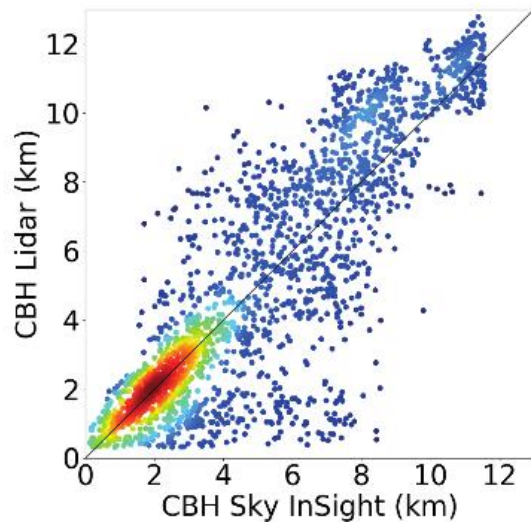
CBH retrieval method : basic assumption
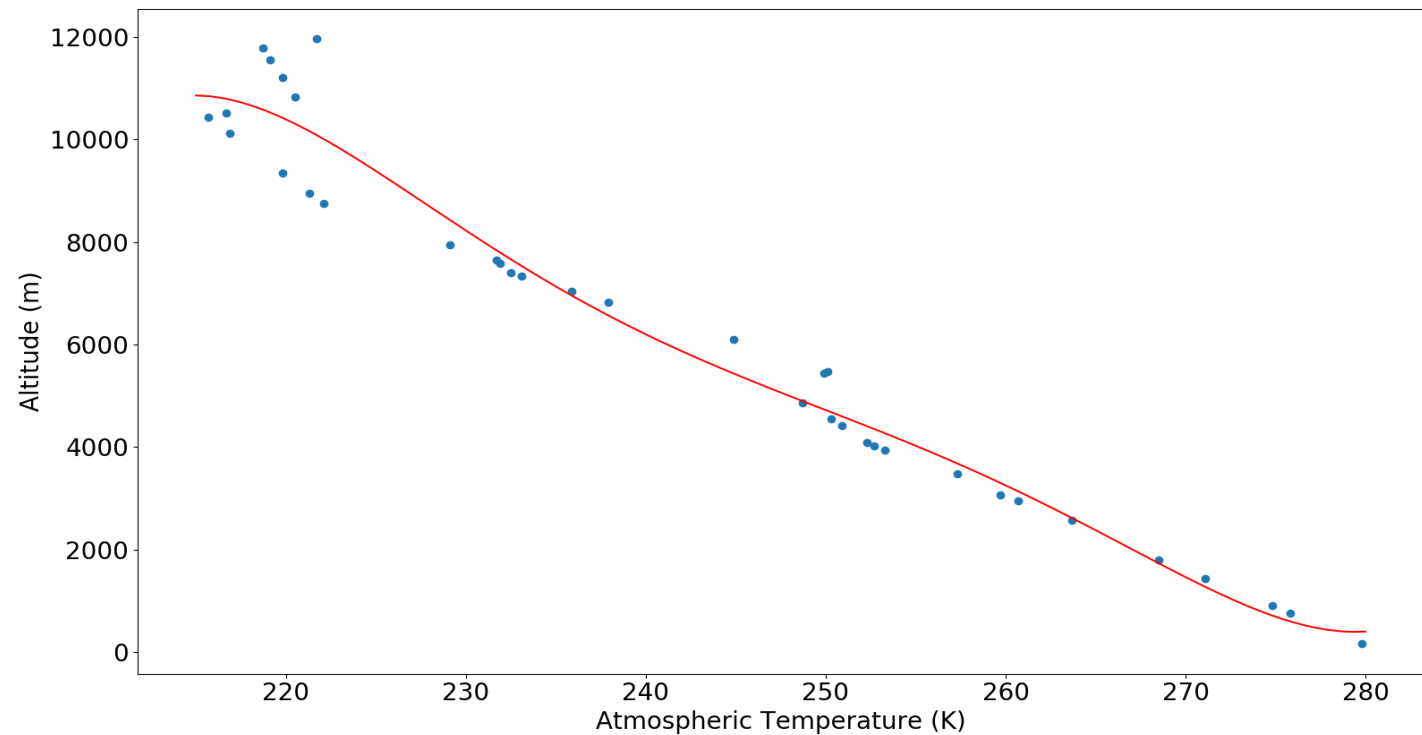
- Until 10 km, the relationship between atmospheric temperature and altitude is linear

- Hypothesis : the temperature of a cloud located at a specific altitude should be closed to the atmospheric temperature associated to this altitude

CBH retrieval method : process overview

- Hybrid method combining machine learning and physic concepts

- **First step :** lidar cloud base temperature (CBT) processing (target values)

- **Second step :** MLP training for the Sky Insight™ numerical counts conversion

- **Final step :** Sky Insight™ CBH computing using the associated radio probing profile

- A specific model is built for each month to account for the climate evolution during the year

Target data

Lidar CBH → Interpolated temperature profile → Lidar CBT

Input data

Sky Insight Numerical counts

Main | Auxiliary
- Clear sky numerical counts
- R confident coefficient
- Air surface temperature

→ Multilayer Perceptron Neural Network → Sky Insight CBT → Interpolated temperature profile → **Sky Insight CBH**

Preliminary results

- Good linear agreement between Sky Insight™ CBH and lidar CBH

- Error minimal on intermediary CBH (between 2 and 6 km)

- Small bias observed for high CBH => thinness and semi transparency characterizing many high altitude clouds

- Strong dispersion for low CBH => erroneous CBH due to low clouds border and clear sky average

Conclusion

- A thermal infrared instrument observing day and nightcloud cover at local scale have been presented

- Specific application for ground/space FSO communication : CBH assessment method

- Good linear relationship between Sky Insight™ CBH and lidar CBH

- Several solutions are considered in order to reduce the error :

  - A larger synergistic dataset with CBH reference sources

  - Using calibrated values of brightness temperature (calibration process with black body and climatic chamber)

  - Considering other sources of atmospheric profiles and assess the improvement

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