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SSC
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CTA Site Candidates Evaluation ver 0.9

Introduction

Goal of the study:
To perform the meteorological, and environmental characterization of CTA candidate sites.

The sites:

South:

- Argentina – Leoncito
- Argentina – San Antonio de Los Cobres (SAC)
- Chile – Armazones
- Namibia – Aar
- Namibia - HESS

North

- Mexico – San Pedro Martir
- Spain - Teide
- United States – Meteor Crater
- United States - Yavapai

Site Requirements

- Described in the Environmental Requirements Document
- Short summary:
  - Flat, 3kmx3km south, 1kmx1km North
  - Dark sky
  - Cloudless weather
  - Good infrastructure
  - Wind, temperature humidity far from extremes

Basic site data

Site	Centre of site	Elevation	Nature of terrain	Extent NS	Extent EW	Typical slope NS	Typical slope EW
Northern Hemisphere							
San Pedro Martir	31.01º N 115.48° W	2434m	Shallow Valley	±1km	± 0.8km	0.5%	0.5%
Teide	28.28° N 16.54° W	2290m	Saddle on volcano	±2km	± 0.8km	3.2%	3.7%
Meteor Crater	35.04° N 111.03° W	1680m	plateau	> ±2km	±2km	0.7%	0.5%
Yavapai	35.14° N 112.87° W	1630m	Undulating hillside	±0.8km	±0.8km	3.5%	3.5%
Southern Hemisphere							
San Antonio	24.05° S 66.24° W	3610m	Wide valley	±2km	±2km	1.5%	0.9%
Leoncito	31.72° S 69.27° W	2640m	Valley slope	> ±2km	±2km	1.5%	6.9%
Armazones	24.58° S 70.24° W	2500m	Basin	±2km	±2km	3.7%	3.2%
HESS	23.27° S 16.50° E	1810m	Plateau	> ±2km	> ±2km	1.0%	0.5%
Aar	26.69° S 16.44° E	1650m	Small plateau	±1.5km	±2km	2.0%	1.6%

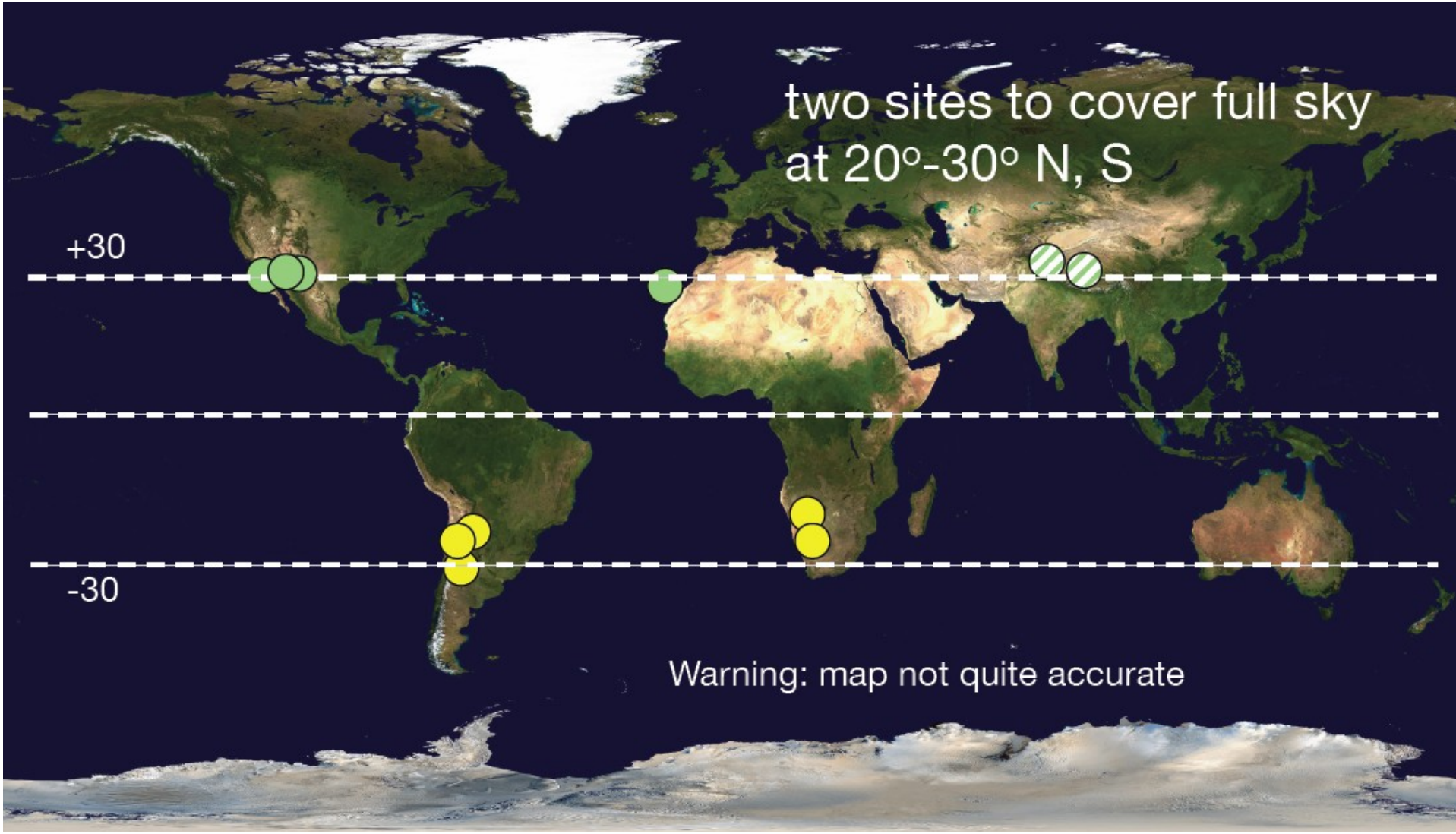
Extent = flat area with slope <8% and no permanent water courses.

Table 12: Summary of topography of the candidate sites. The typical slope values are obtained from GeoMapApp [27] and the maps in section 10.1.

Candidate Sites List

- South
  - Argentina: Leoncito
  - Argentina: San Antonio de Los Cobres
  - Chile: Armazones
  - Namibia: HESS
  - Namibia: Aar
- North
  - Mexico: San Pedro Martir
  - Spain: Tenerife
  - USA: Meteor Crater
  - USA: Yavapai

Candidate sites



Southern sites summary

Southern Sites	Armazones	HESS	Aar	Leoncito	San Antonio
ACCESSIBILITY					
Distance to nearest town / city (population)	120 km to Antofagasta (27000)	100 km to Windhoek (350000)	22 km to Aus (300), 140km Luderitz (13000), 700 km Windhoek (350000)	35 km to Barreal (4000), 240 km to San Juan (450000), 250km to Mendoza (850000)	22 km to San Antonio (6.000), 190 km to Salta City (550.000).
Type of road to nearest town /city	paved road, part gravel	gravel road	mainly paved, part gravel	mainly paved, part gravel	mainly paved, part gravel
Freight railway?	no	100 km, Rehoboth	22 km, Aus	no	no, only passenger
Time from nearby city	1.5 hr, Antofagasta	1.5h hr, Windhoek	1.5 hr, Luderitz	3 hr, San Juan	2.5hr, Salta
Distance to a commercial airport	150 km	160 km	140 km	240 km	190 km
Close (<50km) air landing strip?	yes	yes	yes	yes	yes
Accessible to container lorries?	yes	yes	yes	yes	yes
Distance to car rental	160 km	100 km	140 km	240 km	190 km
Distance to hotel / restaurant	160 km 25km to Paranal	100 km 20 km farm	22 km	35 km	22 km
Nearby Observatory	Paranal	HESS	none	CASLEO	none

Northern sites summary

Northern Sites	San Pedro Martir	Meteor Crater	Yavapai	Teide
ACCESSIBILITY				
Distance to nearest town / city (population)	250 km to Ensenada (250000), 350 to San Diego, USA (1300000)	40 km to Winslow (9600), 70 km to Flagstaff (65000)	27 km to Seligman (500), 160km to Flagstaff (65000)	30 km to La Orotava (42000), 40 km to La Laguna (150000)
Type of road to nearest town /city	paved	paved	paved plus dirt	paved plus dirt
Freight railway	no	11 km	27 km	no
Time from nearby city	4.5 hr, Ensenada	1 hr, Flagstaff	2 hr, Flagstaff	1 hr, Laguna
Distance to a commercial airport	350 km, Tijuana	70 km, Flagstaff	160 km, Flagstaff	40 km, Tenerife N
Close (<50km) air landing strip?	yes	No	yes	yes
Accessible to container lorries?	yes	yes	yes	yes
Distance to car rental	250 km	40 Km	160 km	40 km
Distance to hotel / restaurant	250 km	40 Km	27 km	40 km
Nearby Observatory	San Pedro Martir	Lowell	Lowell	Teide

Evaluation of site quality

- Night Sky background
- Environmental factors
- Cloudiness
- Final result – number of usable hours for observations per year

Means of characterizing the sites

- Ground based instruments
- Satellite data
- Meteorological long term simulations

Method:

Use long term studies: simulations satellites, nearby observatories, correlate them with our ground based stations and have an unbiased comparison of sites

Ground equipment: ATMOSCOPES and All Sky Cameras

- ATMOSCOPE:
  - LoNS
  - SQMs
  - Weather stations
- All Sky cameras
- Mirror samples on all locations

Technical details

- Currently all masts are 10m

ATMOSCOPE installation

Location	Date of installation	anemometer at 10m since	Volume of LoNS data to be analysed	ASC since	SQM since
Leoncito	Jan-12	Aug-12	12 months	Nov-12	Nov-12
San Antonio	Aug-12	Aug-12	2.5 months	Feb-12	
Hess	Jul-11 to Nov-11	Oct-12	5 months	**None, use ATOM**	Sep-12
	Aug-12		5.5 months		
Aar	Nov-11	Apr-12	6 months	Nov-11	Sep-12
Teide	Aug-11	Dec-12	7 months	Oct-12	Dec-12
San Pedro Martir	Jun-12	Sep-12	7.5 months	Sep-12	Nov-12
Yavapai	Jun-12	Sep-12	7.5 months	Sep-12	Oct-12
Meteor Crater	Jun-12	Sep-12	5.5 months	Sep-12	Oct-12
Armazones	Jan-13	Jan-13	1 month	Coming soon	Jan-13

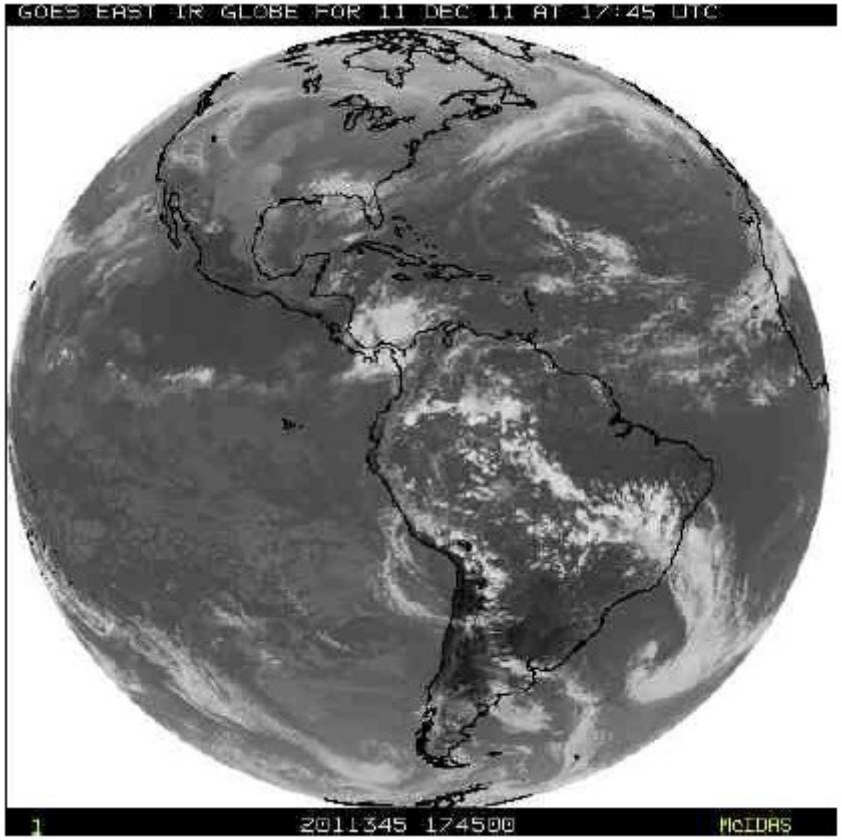
Satellite data

- Polar satellites: every point on Earth observed with the same
  - MODIS
  - AVHRR

- every point on Earth observed with the same instrument, but only one or two measurements per night

- Geostationary satellites
  - METEOSAT
  - GOES
- Various locations observed all the time, comparison of north and south locatins, difficult comparison between satellites

GOES and METEOSAT



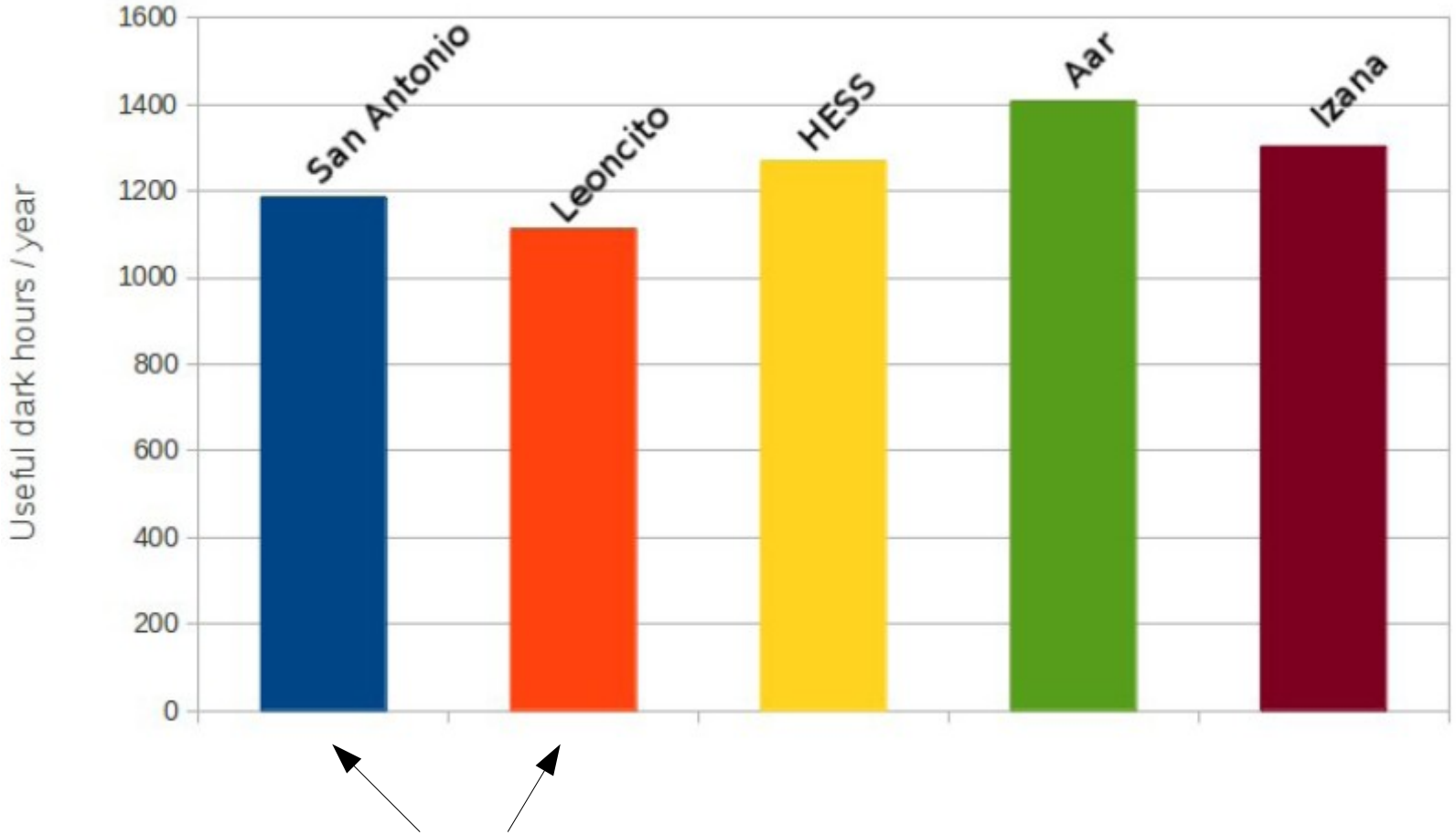
Amount of satellite data and status

- MODIS: 10 years all sites, current data being downloaded and analyzed now
- AVRHH: 1 month trial analysis, decided not to use it
- METEOSAT: 8 years analyzed
- GOES: data available since 2002. Difficulties in analyzing. Currently working on the code by Erasmus.

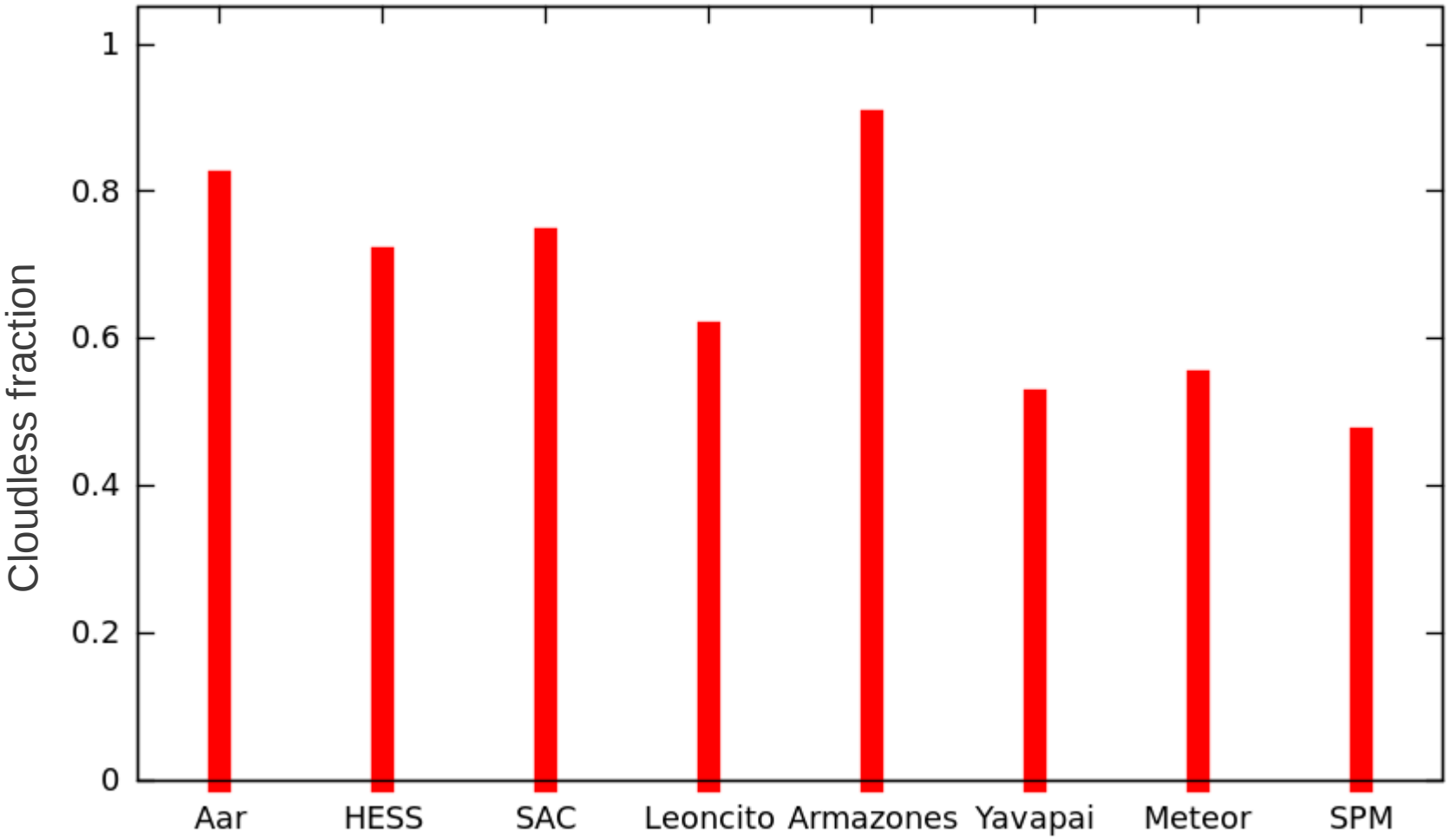
Amount of satellite data and status

- MODIS: 10 years all sites, current data being downloaded and analyzed now
- AVRHH: 1 month trial analysis, decided not to use it
- METEOSAT: 9 years analyzed
- GOES: data available since 2002. Difficulties in analyzing. Currently working on the code by Erasmus.

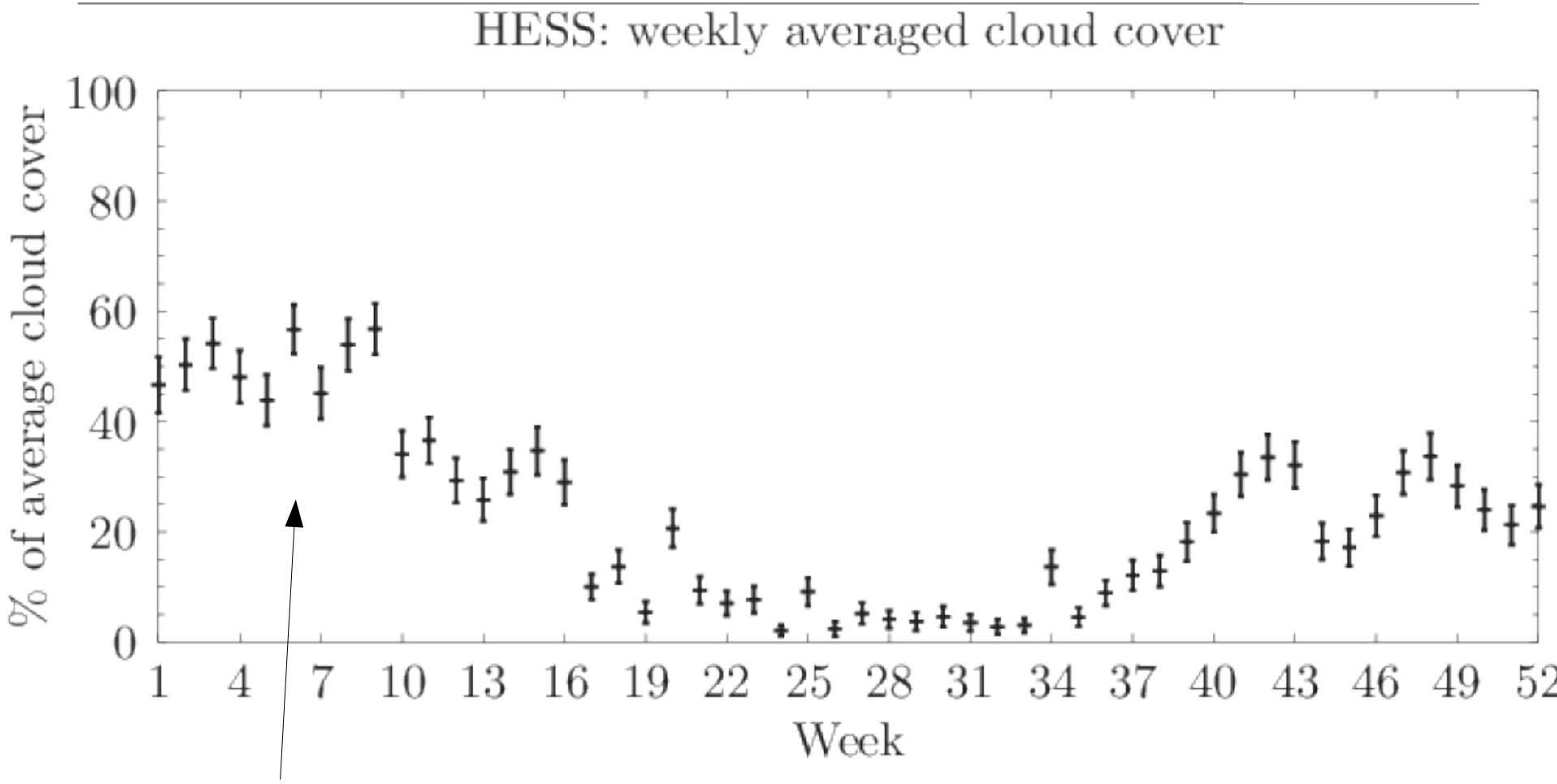
METEOSAT results



MODIS results



MODIS seasonal changes



Summer rain in Namibia

Weather Simulations

- Contract with an external company (SENES, Ontario, Canada)
- Amount of data: 10 years for each site
- Data provided: hourly data on the site and nearby locations. Provide 24 various quantities like temperature, humidity, wind speed, wind gust, low, medium high clouds, precipitation, albedo etc.
- Status: Received results for all sites for 10 years:
  - 2001-2010: Argentina, Namibia
  - 2003-2012: Chile, Mexico, Spain, US
- Further orders: ordered data simultaneous with ATMOSCOPES

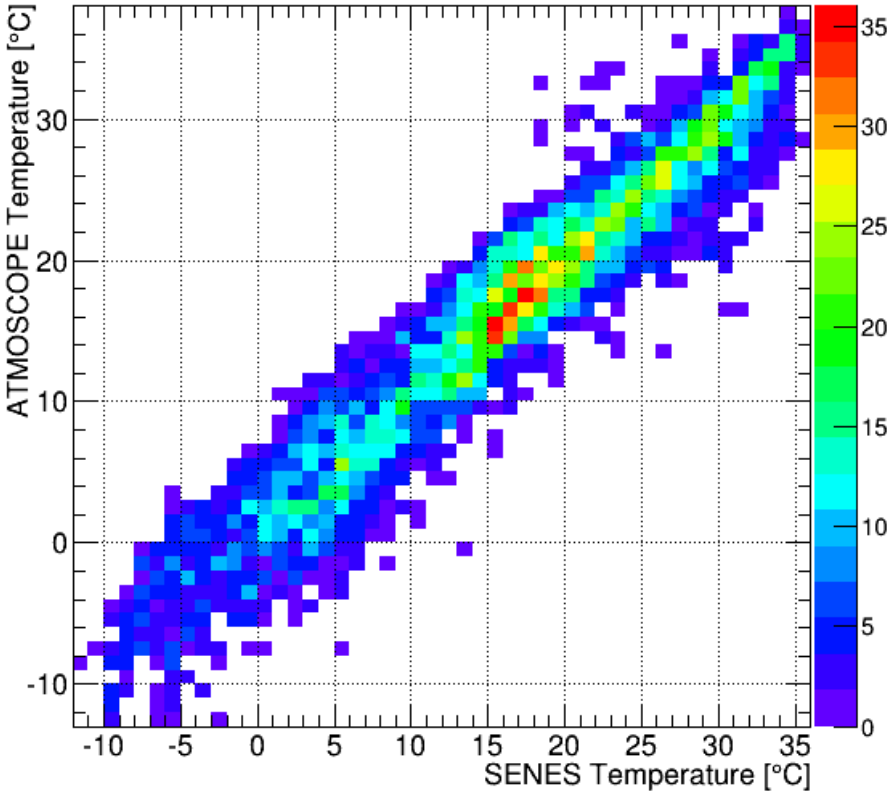
The SENES results (no errors)

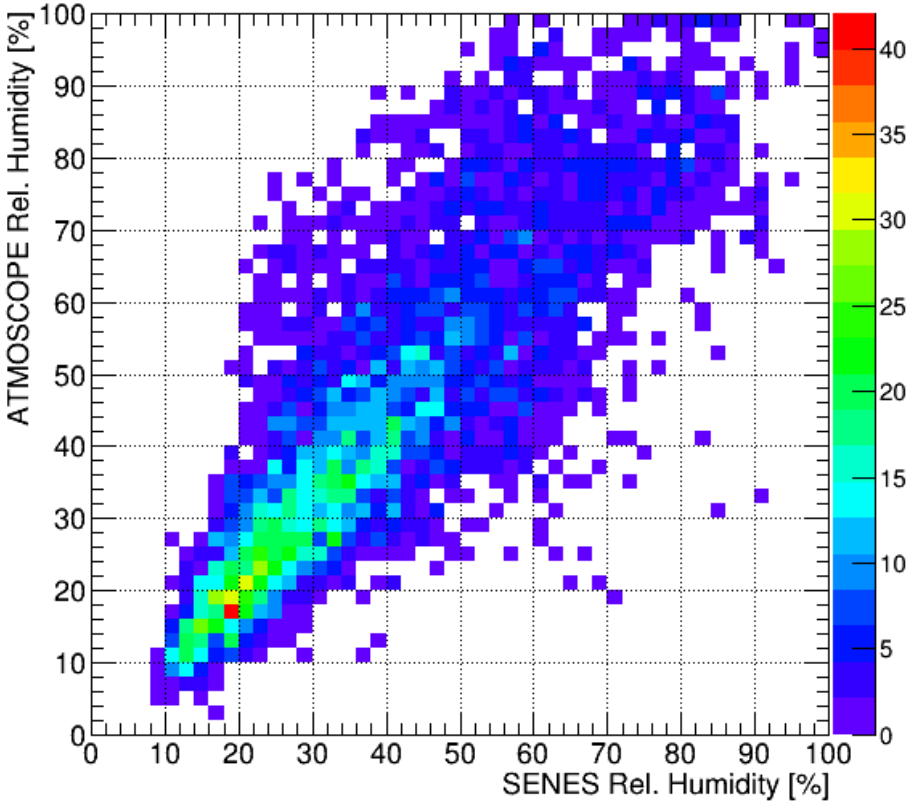
	HESS	Aar	Leoncito	SAC	Armazones	SanPedro	Meteor	Yavapai	Izana
temp	1.000	0.999	0.990	0.984	1.000	0.995	0.986	0.985	1.000
humidity	0.983	0.968	0.965	0.864	0.990	0.943	0.970	0.954	0.967
wind	0.994	0.943	0.986	0.997	0.891	0.947	0.958	0.987	0.931
Env	0.976	0.916	0.942	0.845	0.888	0.908	0.915	0.928	0.908
clouds	0.787	0.804	0.510	0.773	0.842	0.678	0.633	0.645	0.479
clouds20	0.852	0.878	0.798	0.795	0.918	0.770	0.728	0.730	0.594
All	0.769	0.751	0.487	0.681	0.774	0.647	0.580	0.612	0.464
All20	0.831	0.813	0.756	0.694	0.817	0.730	0.659	0.682	0.571

Environmental conditions

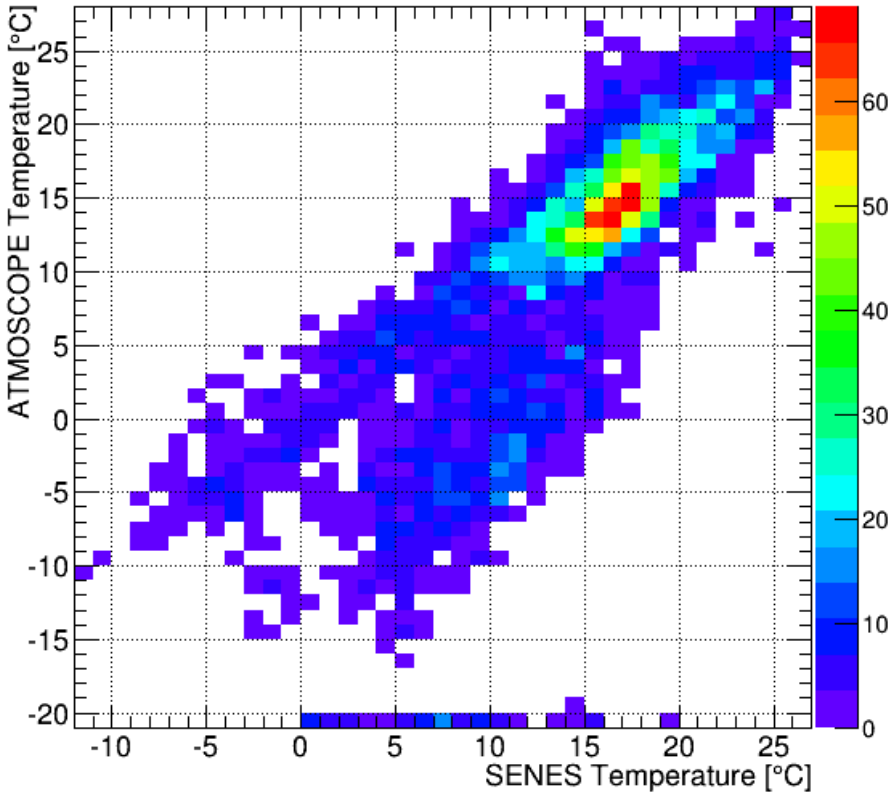
- Methodology:
  - Compare SENES simulations with ATMOSCOPE measurements
  - Find correlation
  - Estimate the real conditions given the results of the SENES simulation
  - Do it for all the simulated period.
- Results:
  - So far: only for Northern sites
  - Only places with simultaneous data and SENES
  - Recently the results for southern sites were received

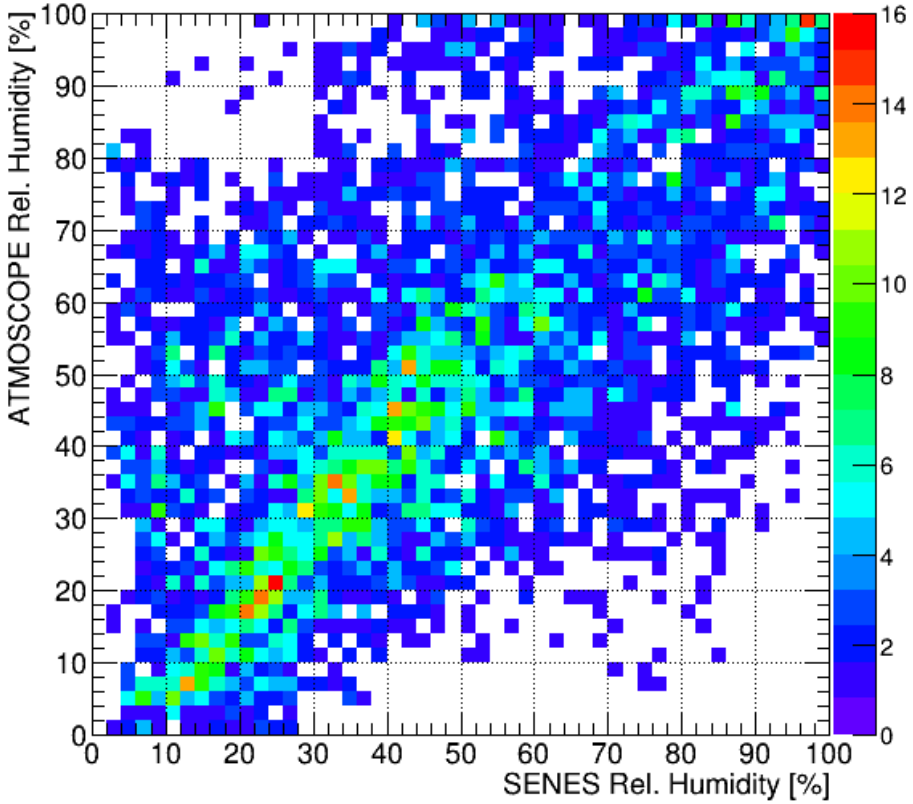
SENES Validation: Meteor crater temperature





SPM Temperature





Cloudiness indicators and strategy

- More than one source of information
  - SENES, MODIS, METEOSAT, GOES, All Sky Cameras,
- Need to average with proper errorbars
- Errorbars: comparison with all sky camera results.

$$F_{clear} = \frac{\sum_i \frac{F_i}{\sigma_i^2}}{\sum \frac{1}{\sigma_i^2}}$$

Cloudiness estimate

Site	Fraction of partially clear night hours with < 20% cloud cover: $F_{clear}(20\%)$							
	Satellite data un- calibrated			Weather Simulation un-calibrated	Other information		Combination	
	MODIS	METEOSAT	GOES	SENES	Nearby observatory	Proposal	Weighted average	RMS
San Pedro Martir	57%			77%	80%		76%	11%
Teide	54%	81%		58%	73-84%.		75%	14%
Meteor Crater	59%			74%			64%	8%
Yavapai	54%			75%			60%	11%
San Antonio	77%	69%		79%		80%	76%	5%
Leoncito	67%	67%		80%		82%, 72%	72%	6%
Armazones	90%			88%			89%	1%
HESS	73%	78%		82%			77%	4%
Aar	82%	87%		87%			86%	2%
Error estimate	*±10%*	*±5%*		*±15%*	*±5%*	*±5%*		

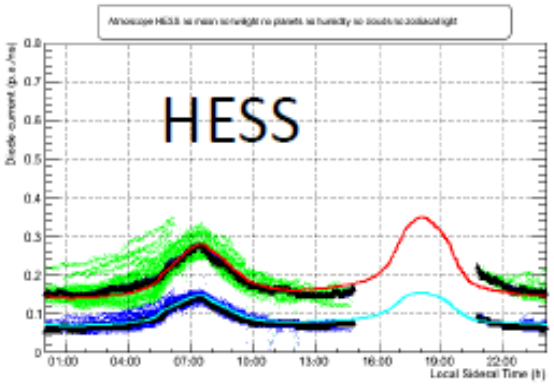
Table 14: Fraction of partially clear night hours with criterion that the fraction of cloud cover is less than 20%. The data shown here use un-calibrated satellite and SENES data. The entry "RMS" is the root mean square of all data for the site to the relative to the weighted average and give an estimate of the consistency of the various measurements. Preliminary data.

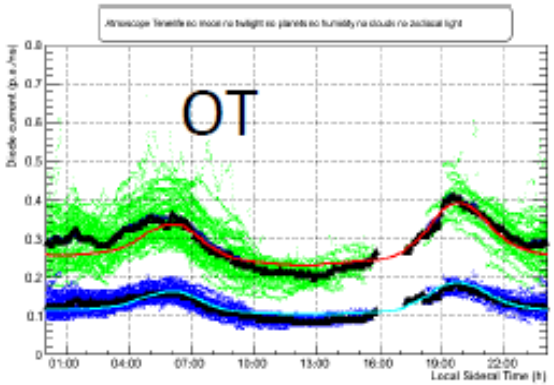
This is an example – not the final numbers! Errors need to be worked on.

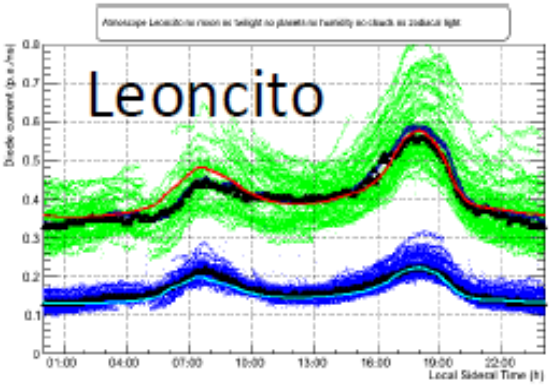
Night Sky Background

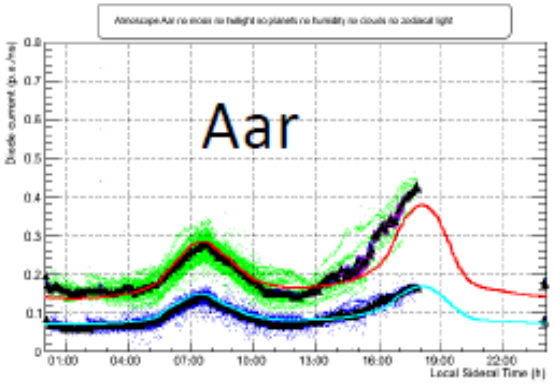
• Corrected **Starlight model** (to 20^{m}) for each site	✓
• **Scattered light** model	✓
• **Zodiacal light** model	✓
• **Planets** light model	✓
• **Atmospheric Extinction** models	night-by-night fits ongoing
• Model for airglow	✓
• Satellites model (needed?)	✗
• LONS spectra (needed?)	*ongoing*
• Atmoscope **angular acceptance**	✓
• Atmoscope **filters** calibrated and understood	✓
• Quality **cuts** (clouds, humidity, moon, twilight)	✓
• Atmoscope **clock drifts** corrected	✓
• LONS sensor **inclination** corrected	✓, except several sites with discrepancies
• LONS sensor **orientation** corrected	✓
• Shadows on LONS sensor	✗
• Systematic uncertainties	*ongoing*
• Cross-calibration with other instruments / methods	*ongoing, gathered reference studies, plus SQMs*

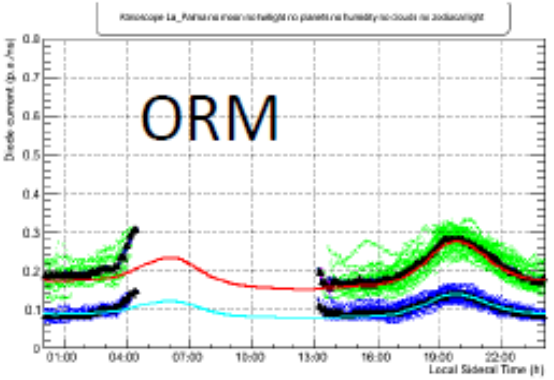
Starlight fits

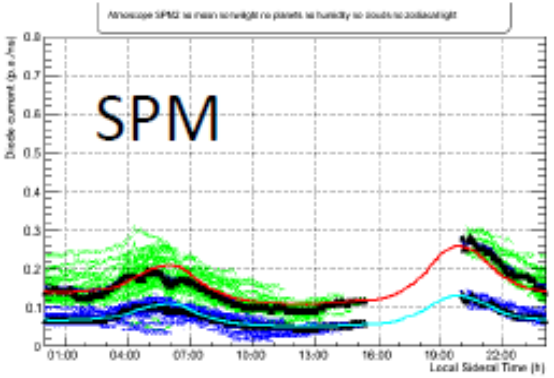


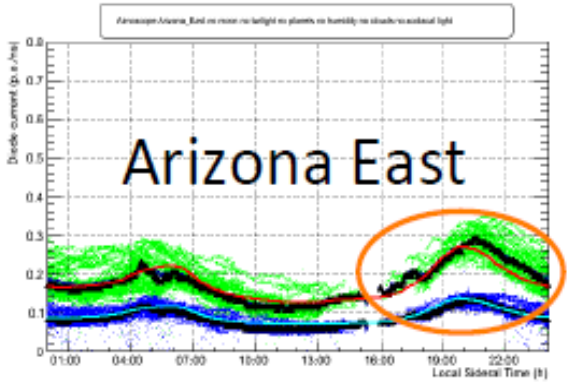


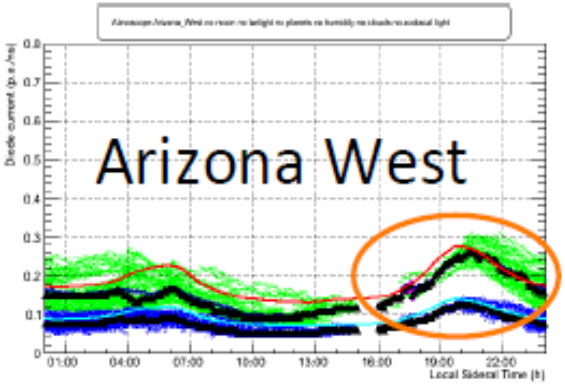


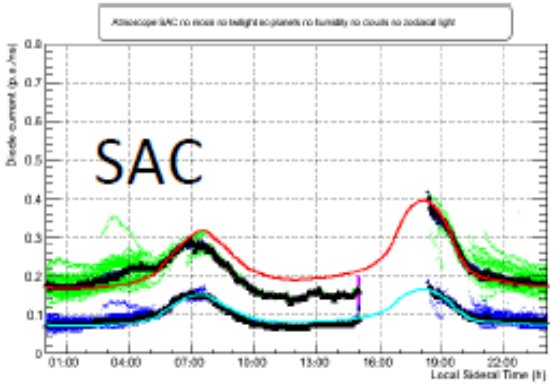












NSB results

- Waiting for final slides from Markus

Amount of useful time calculation

$$T_{usable} = T_{moonless} \times F_{cloud} \times F_{env}$$

Moonless time averaged over 30 years

Cloud free fraction

Fraction of time when all environmental specs are satisfied

Moonless time

Site	Latitude	Moonless night hours: H_{observ}	
		Hours/ year averaged 2017-2046	Ratio to maxi-mum
Teide	28.28° N	1565	0.98
San Pedro Martir	31.01° N	1545	0.96
Meteor Crater	35.04° N	1509	0.94
Yavapai	35.14° N	1508	0.94
San Antonio	24.05° S	1598	1.0
Leoncito	31.72° S	1550	0.97
Armazones	24.58° S	1596	1.0
HESS	23.27° S	1602	1
Aar	26.69° S	1584	0.99

Annual observing time estimate

Site	Annual Average Observing Time: $O_{time} = H_{observ} F_{clear} (1 - F_{bad})$				
	Average hours/year potential observations H_{observ} (Table 20)	Fraction clear night hours with <20% cloud F_{clear} (Table 13)	Loss due to bad weather conditions F_{bad} (Table 15)	Annual Average Observing Time O_{time}	
				Hours/year	Fraction of max.
San Pedro Martir	1545	76%	5%	**1109**	**0.89**
Teide	1565	75%	4%	**1126**	**0.91**
Meteor Crater	1509	64%	14%	**826**	**0.67**
Yavapai	1508	60%	10%	**820**	**0.66**
San Antonio	1598	76%	21%	**960**	**0.77**
Leoncito	1550	71%	6%	**1047**	**0.84**
Armazones	1596	89%	13%	**1241**	**1**
HESS	1602	77%	4%	**1190**	**0.96**
Aar	1584	86%	14%	**1167**	**0.94**

Table 21: Estimates of Annual Average Observing Time for the candidate sites. The three terms contributing to the observing

Preliminary!

Summary

- Data
  - Satellite data in place
  - Weather simulations done
  - Ground based data partially acquired
- Analysis
  - Satellite data: done except GOES
  - Weather simulations, being analyzed comparison with ground based data
  - Ground based data: essential in assessing quality of remote data
  - Night Sky Background analysis done for most sites
- Still need to calculate the final numbers

Summary plot – all sites