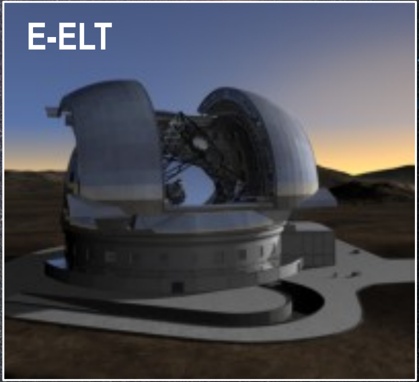
MOSE

A demonstrator for an automatic operational system for the optical turbulence forecast for ESO sites

Cerro Paranal



Cerro Armazones

Elena Masciadri(1)

Franck Lascaux(1), Alessio Turchi(1), Luca Fini(1)

INAF – Osservatorio Astrofisico di Arcetri, Italy(1)

Credit: ESO/S.Guisard

OUTLINE

- Scientific drivers and challenges related to the OT forecasts
- MOSE scientific goals (Phase A and Phase B) ~ 3 years
- How to forecast the optical turbulence
- Most relevant results achieved on model performances at conclusion of MOSE
- Benefits in terms of astronomical observations:
  1. **AO efficiency**: **how** and **when** to use a specific AO system and/or **which** typology of AO system is preferable at a specific time
  2. **Optimization of the scientific exploitation of all the ground-based facilities**
  3. **New scenarios for operation of most sophisticated AO systems (WFAO)**
- Next step: **demonstrator** for an automatic operational system for VLT and E-ELT.
- Snapshots from a similar system we implemented for LBT (ALTA Center)

OPTICAL TURBULENCE FORECAST: SCIENTIFIC DRIVERS

1) Traditional queue system : *High scientific challenge of the program* **PARADOX** → *Low probability that the program is executed*

2) Service Mode is a must to optimize the exploitation of top class telescopes and ELTs

3) Adaptive Optics techniques are strongly dependent from the OT conditions

4) Cost of a night of observation at a top-class telescope is of a few hundreds of K$!!!

5) The advantages of the Service Mode can be fully achieved **ONLY** if most of the available observing time is scheduled in this mode

The Service Mode:

★ extensively used at the VLT (Paranal)

★ baseline observing mode at the E-ELT (Armazones)

Permanent instruments at different focal stations. Typical time required to move the beam from an instrument to another one: $\mathbf{\Delta T_{min}}$ **~ 10-20 min**. (E-ESO-SPE-066-0283)

OPTICAL TURBULENCE FORECAST: SCIENTIFIC DRIVERS

1) Traditional queue system : *High scientific challenge of the program* **PARADOX** → *Low probability that the program is executed*

2) Se

3) A

4) C

5) T

th

★ The *optical turbulence forecast* is fundamental for the ***success*** of TCTs and ELTs

★ *Measurements* ***can not*** provide this information

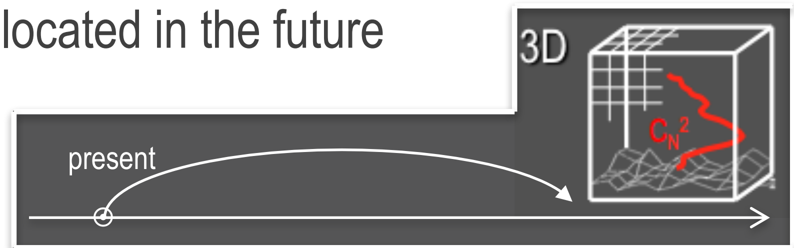
★ *Non-hydrostatical mesoscale models* are ***the unique tool*** that can attain such a scientific goal

★ baseline observing mode at the E-ELT (Armazones)

Permanent instruments at different focal stations. Typical time required to move the beam from an instrument to another one: ΔT_{min} **~ 10-20 min**. (E-ESO-SPE-066-0283)

OPTICAL TURBULENCE FORECAST: SCIENTIFIC DRIVERS

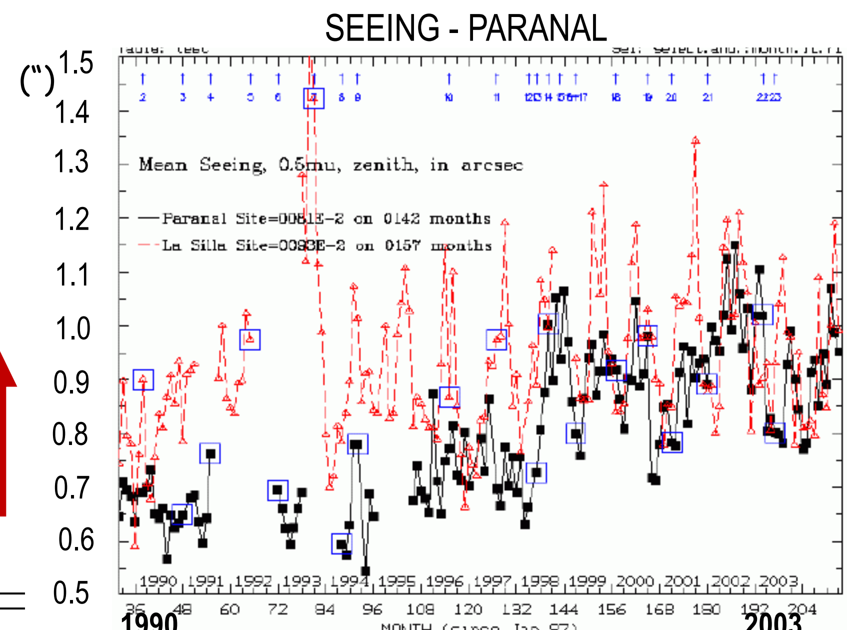
- ★ **Instruments** provide **only local** measurements
- ★ The **meso-scale models** are the **unique** tool that can provide 3D C_N^2 maps calculated at a time located in the future



- ★ The **meso-scale models** are the **unique** tool that directly solves the Navier-Stokes equations

The most appropriate tool to detect rapid changes of the atmosphere

- ★ **Meso-scale models** can provide OT climatology extended over decades (**measurements can not access the past**)



MOSE: MOdelling Sites ESO

Cerro Paranal

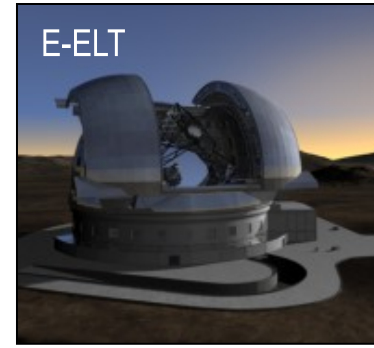
SCIENTIFIC GOALS

Feasibility study to evaluate the opportunity for the set-up of an automatic system for the ***forecast*** of:

★ All classical atmospherical parameters:

- Temperature
- Wind Speed and Direction
- Relative humidity

★ Optical Turbulence: C_N^2, ε, ϑ_0, τ_0



Cerro Armazones

Tool/method: mesoscale atmospherical model **Meso-NH** and **Astro-Meso-NH**

Masciadri et al., 1999

2D (x,y)

$$\int_0^\infty F(h^a, V^b, L_0^c)\, C_N^2\, dh$$

wind speed

heigth

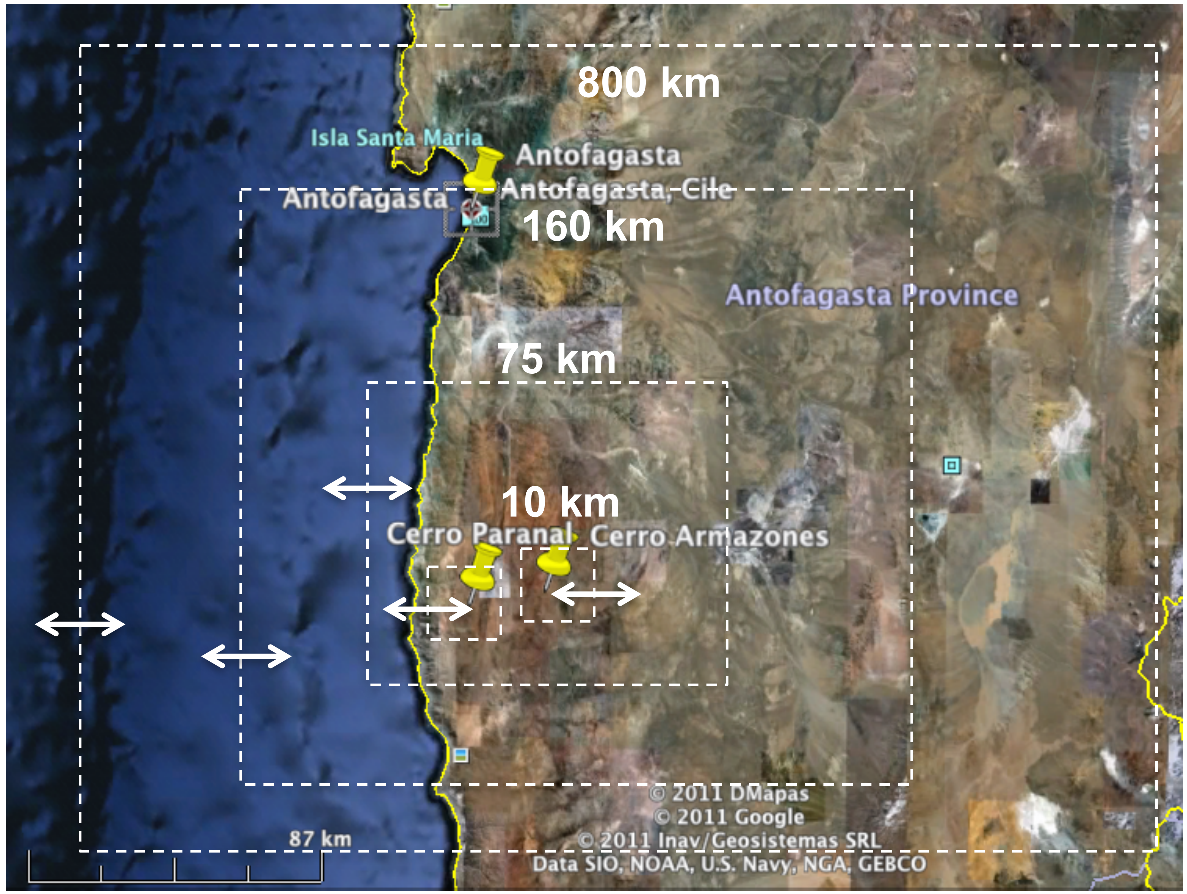
dynamic outer scale

- ε: seeing
- ϑ_0: isoplanatic angle
- τ_0: wavefront coherence time
- σ^2 : scintillation rate
- $\mathcal{L}_0$: spatial coherence outer scale
- ϑ_M : isoplanatic angle for the MCAO

MODEL CONFIGURATION - GRID NESTING

- **Paranal-Armazones: ~22km**
- Paranal-Antofagasta: ~110km
- Paranal-coast: ~16km
- Armazones-coast: ~36km

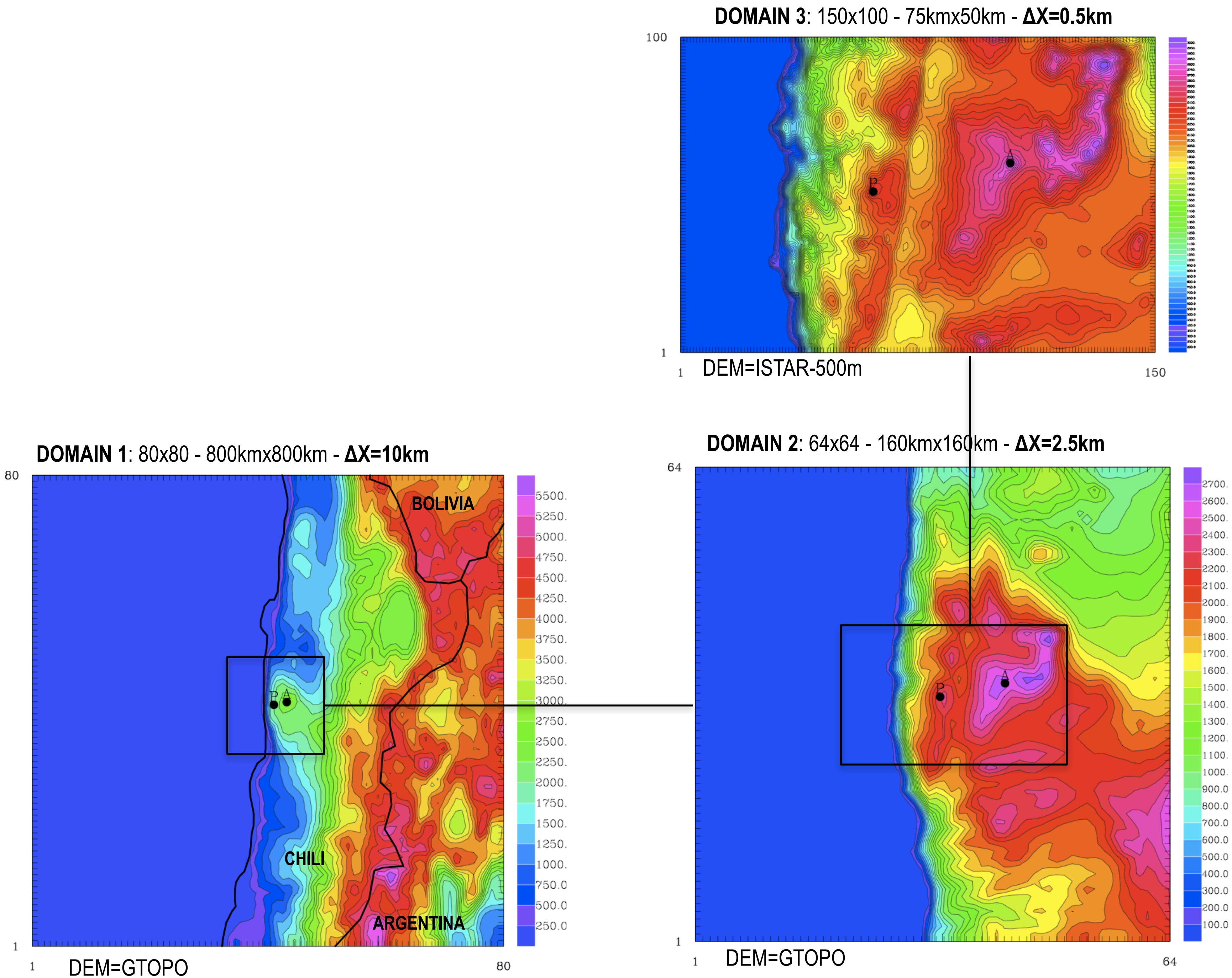
SATELLITE IMAGE

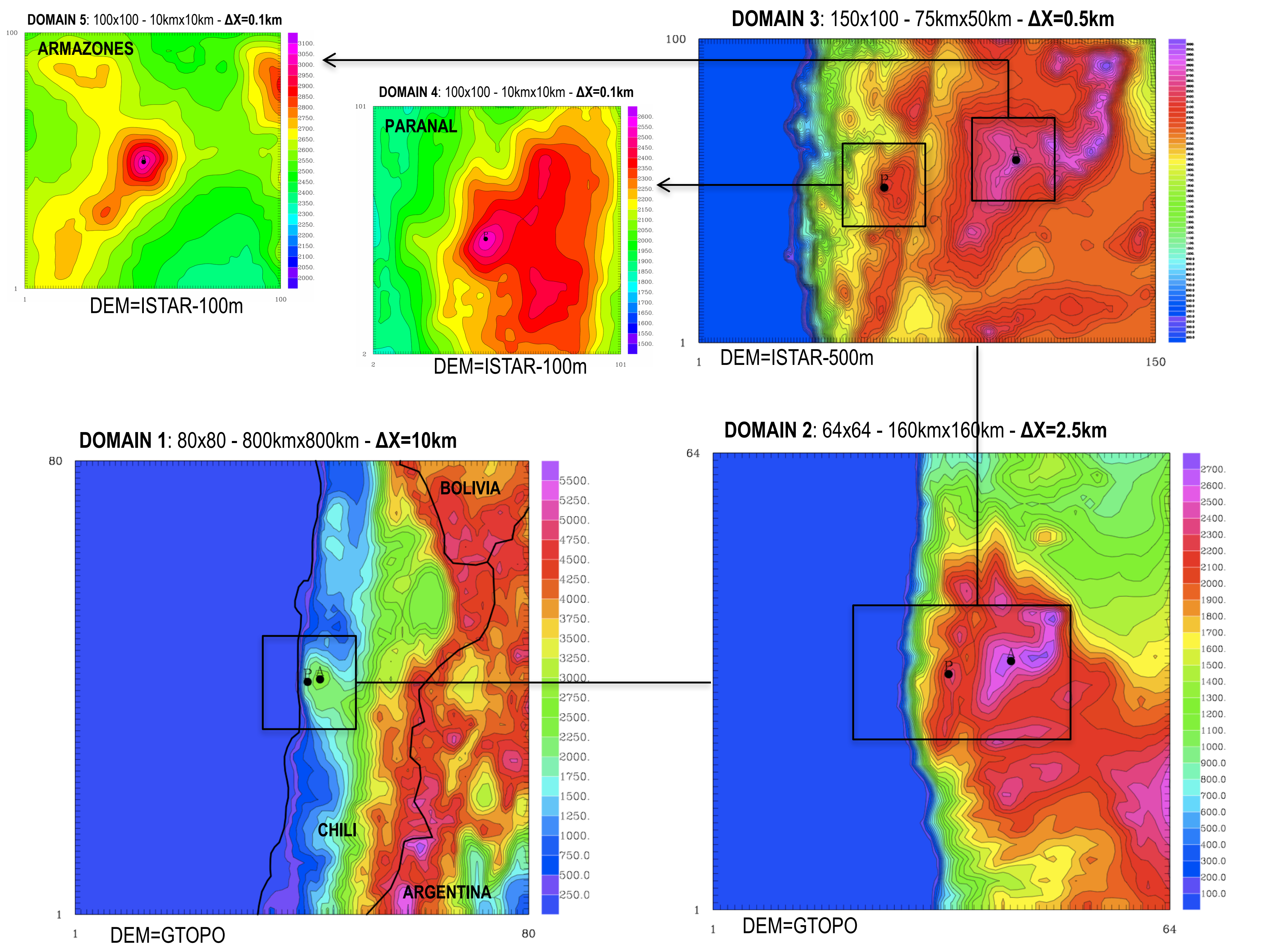


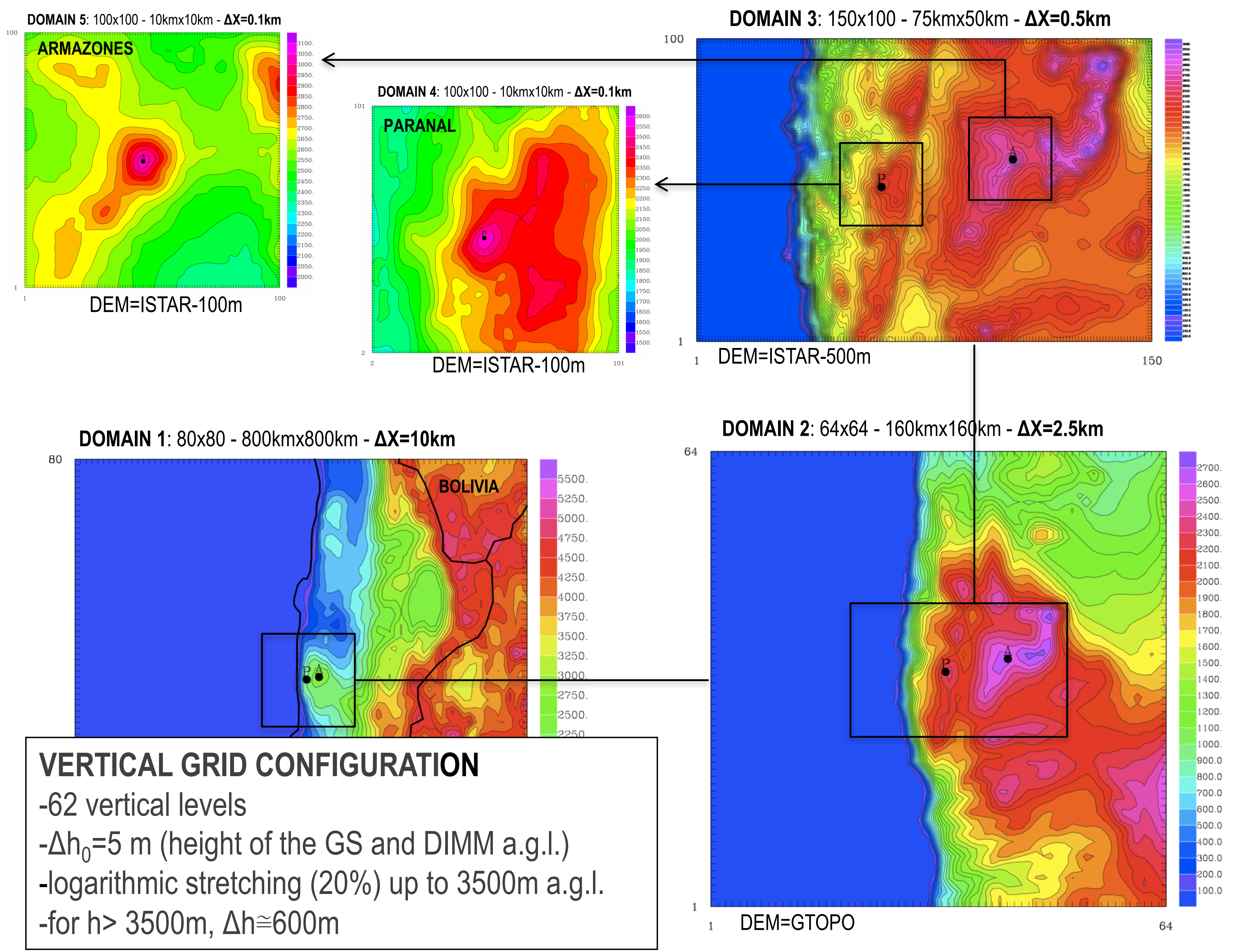
Grid-nesting TWO WAY: mutual interaction between each father and son domain

★ Standard configuration: 3 domains (with innermost domain resolution **ΔX=500m**)

★ High-resolution configuration: 5 domains (with innermost domain resolution **ΔX=100m**)


DOMAIN 3: 150x100 - 75kmx50km - ΔX=0.5km
100
1
1
150
P
A
DEM=ISTAR-500m
DOMAIN 1: 80x80 - 800kmx800km - ΔX=10km
80
1
1
80
BOLIVIA
CHILI
ARGENTINA
P
A
5500.
5250.
5000.
4750.
4500.
4250.
4000.
3750.
3500.
3250.
3000.
2750.
2500.
2250.
2000.
1750.
1500.
1250.
1000.
750.0
500.0
250.0
DEM=GTOPO
DOMAIN 2: 64x64 - 160kmx160km - ΔX=2.5km
64
1
1
64
P
A
2700.
2600.
2500.
2400.
2300.
2200.
2100.
2000.
1900.
1800.
1700.
1600.
1500.
1400.
1300.
1200.
1100.
1000.
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
DEM=GTOPO


DOMAIN 5: 100x100 - 10kmx10km - ΔX=0.1km
ARMAZONES
DEM=ISTAR-100m
DOMAIN 4: 100x100 - 10kmx10km - ΔX=0.1km
PARANAL
DEM=ISTAR-100m
DOMAIN 3: 150x100 - 75kmx50km - ΔX=0.5km
DEM=ISTAR-500m
DOMAIN 1: 80x80 - 800kmx800km - ΔX=10km
BOLIVIA
CHILI
ARGENTINA
DEM=GTOPO
DOMAIN 2: 64x64 - 160kmx160km - ΔX=2.5km
DEM=GTOPO



DOMAIN 5: 100x100 - 10kmx10km - ΔX=0.1km
ARMAZONES
DEM=ISTAR-100m
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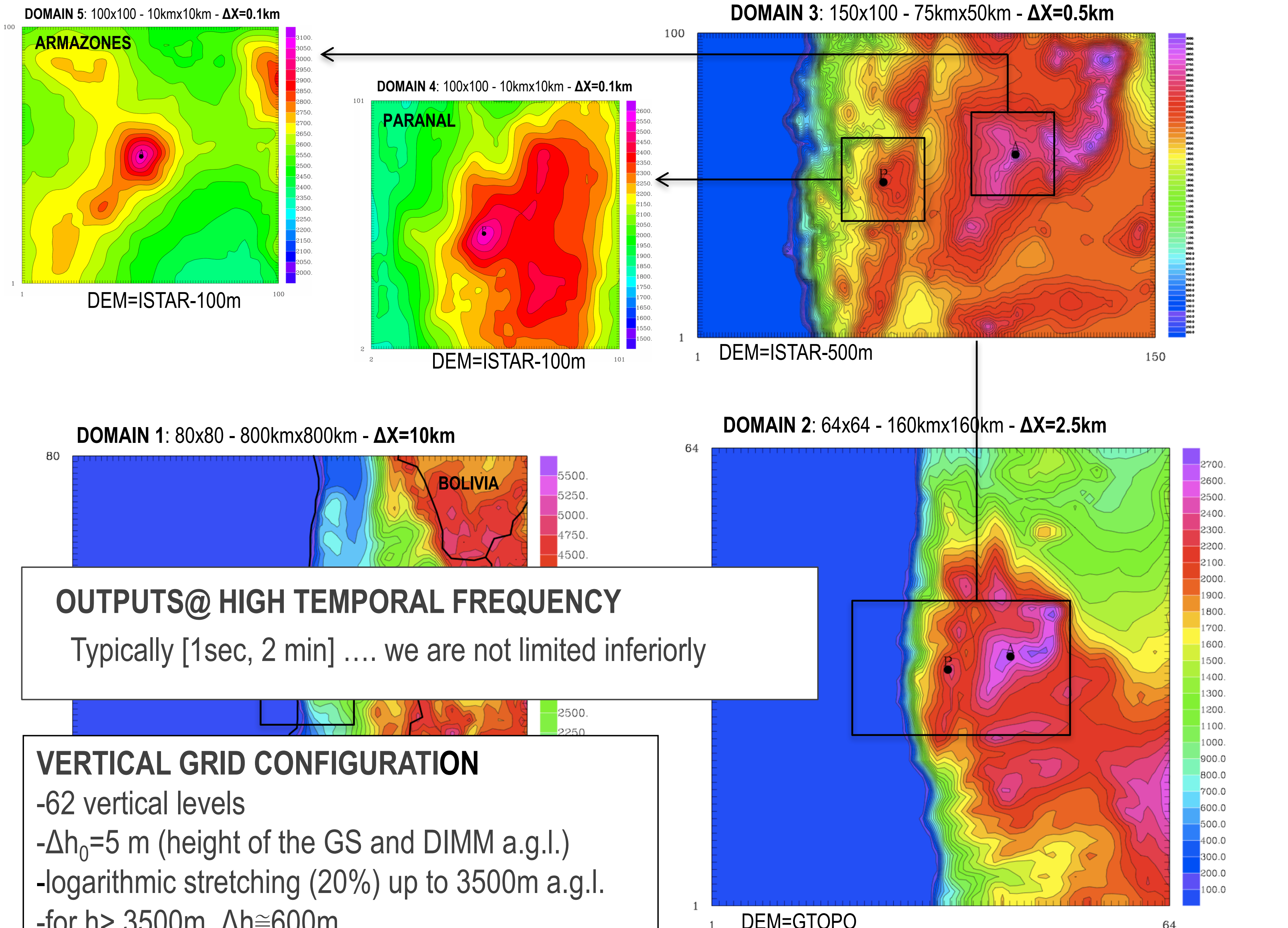
DEM=ISTAR-100m
DOMAIN 3: 150x100 - 75kmx50km - ΔX=0.5km
DEM=ISTAR-500m
DOMAIN 1: 80x80 - 800kmx800km - ΔX=10km
BOLIVIA
DOMAIN 2: 64x64 - 160kmx160km - ΔX=2.5km
DEM=GTOPO
VERTICAL GRID CONFIGURATION
-62 vertical levels
-Δh0=5 m (height of the GS and DIMM a.g.l.)
-logarithmic stretching (20%) up to 3500m a.g.l.
-for h> 3500m, Δh≅600m



OUTPUTS@ HIGH TEMPORAL FREQUENCY

Typically [1sec, 2 min] …. we are not limited inferiorly

VERTICAL GRID CONFIGURATION

- -62 vertical levels
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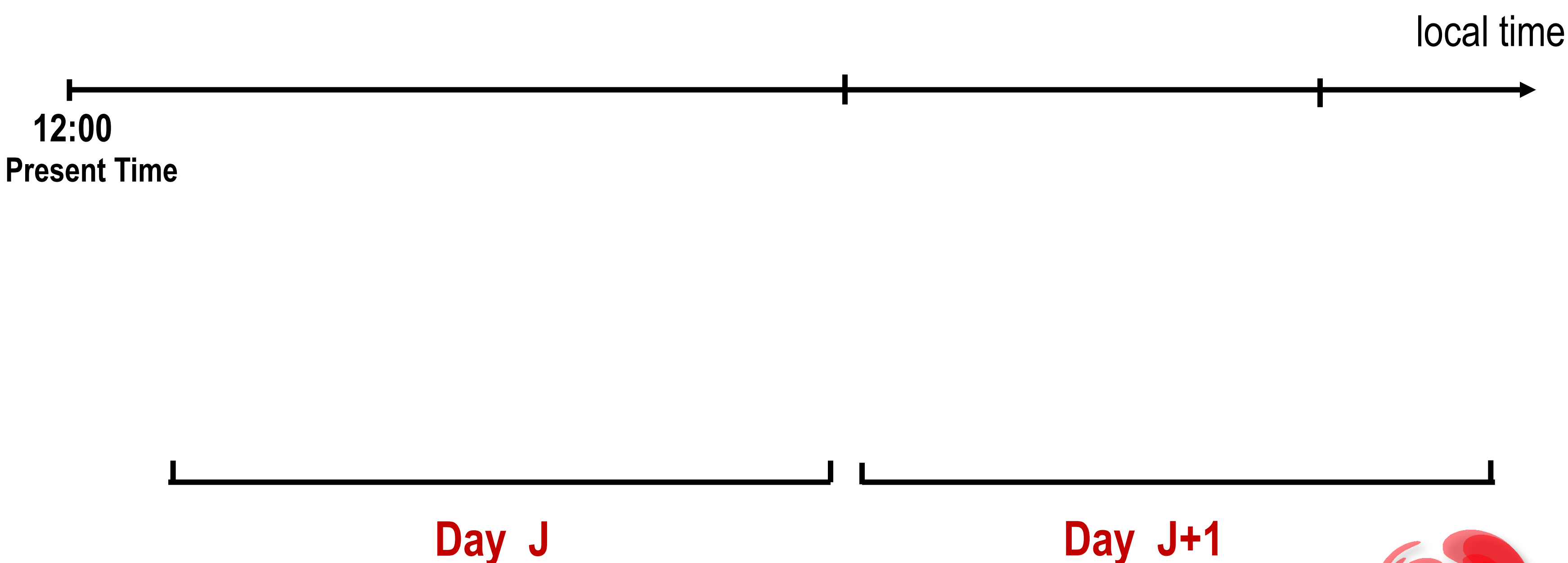
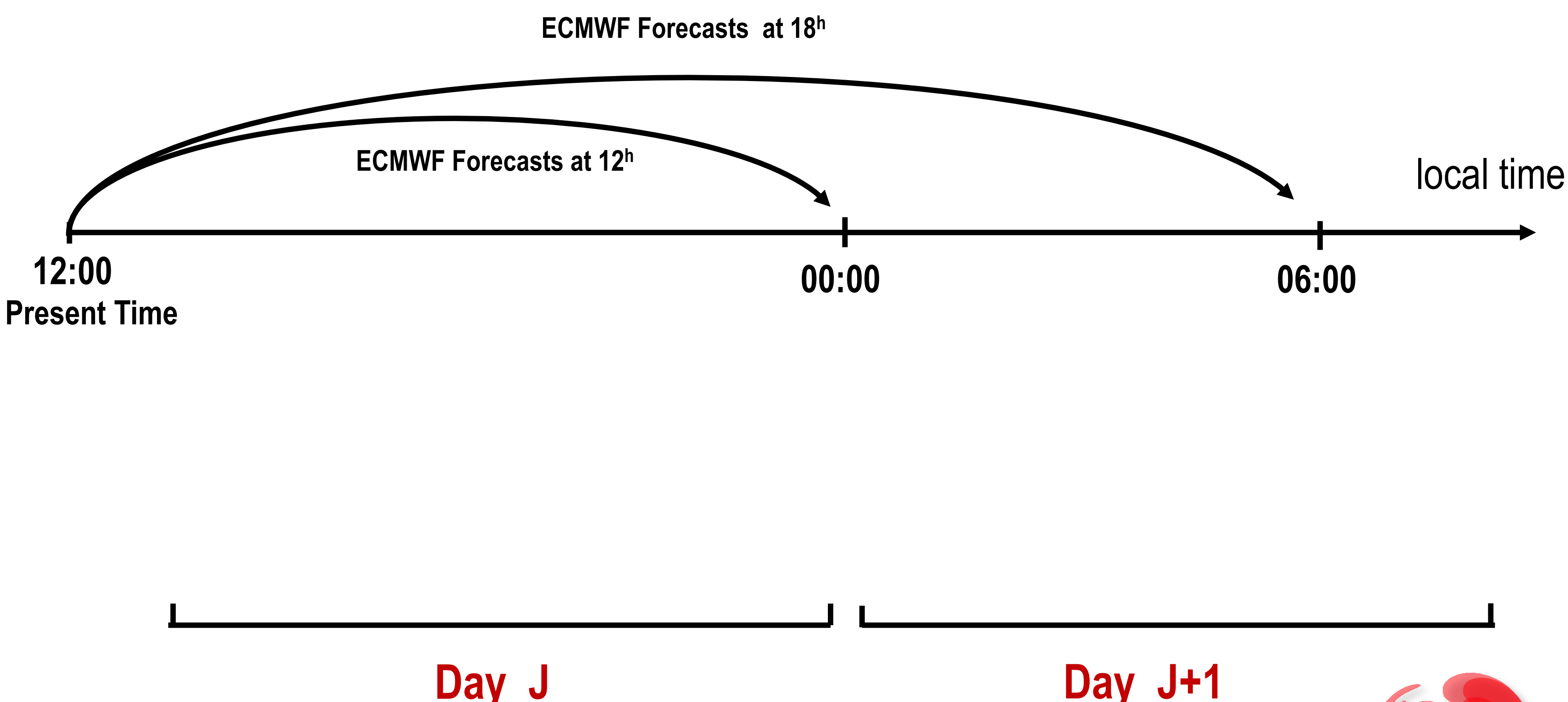
HOW TO FORECAST THE OT: PRINCIPLE

TOY MODEL



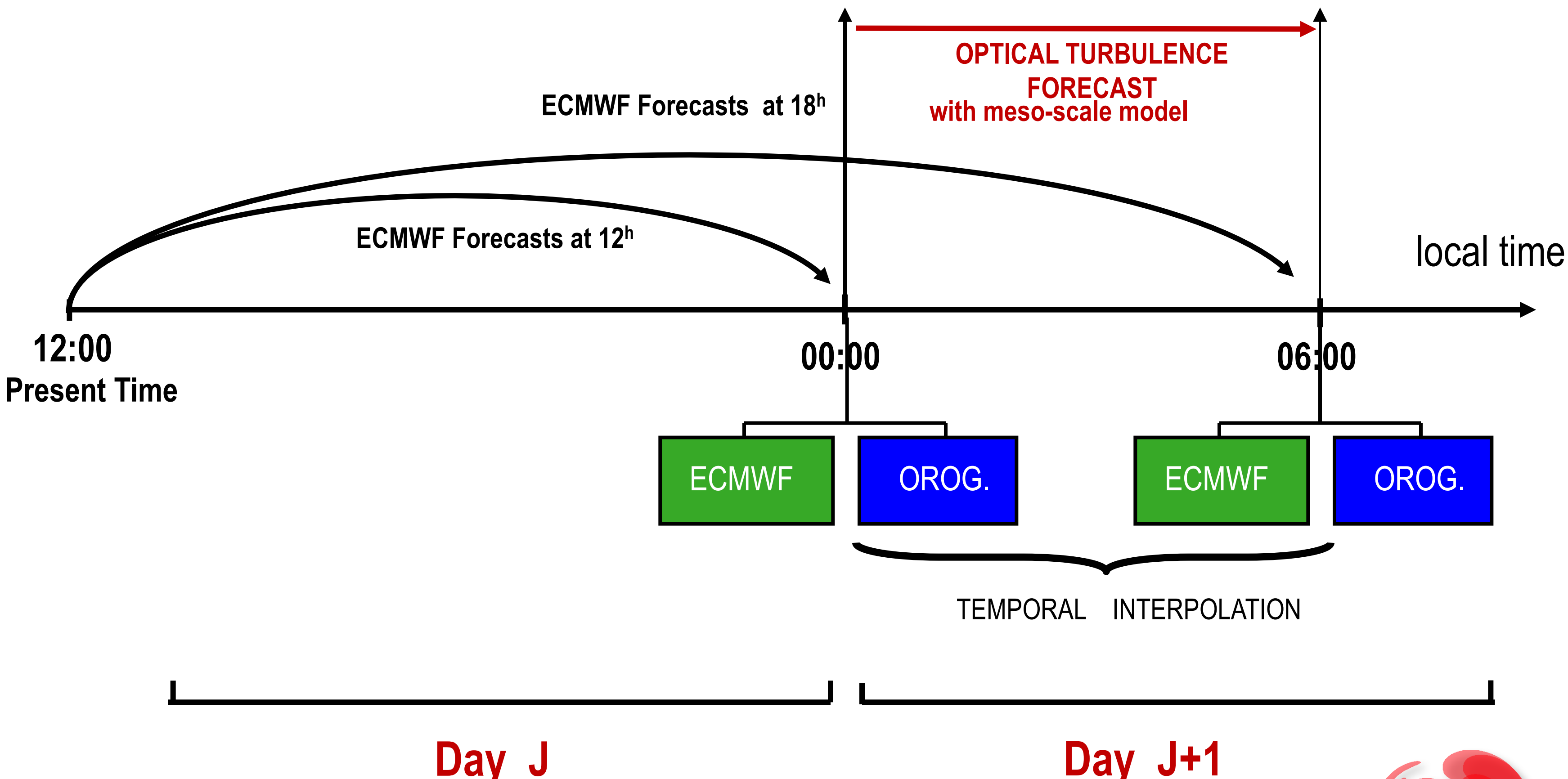
HOW TO FORECAST THE OT: PRINCIPLE

TOY MODEL



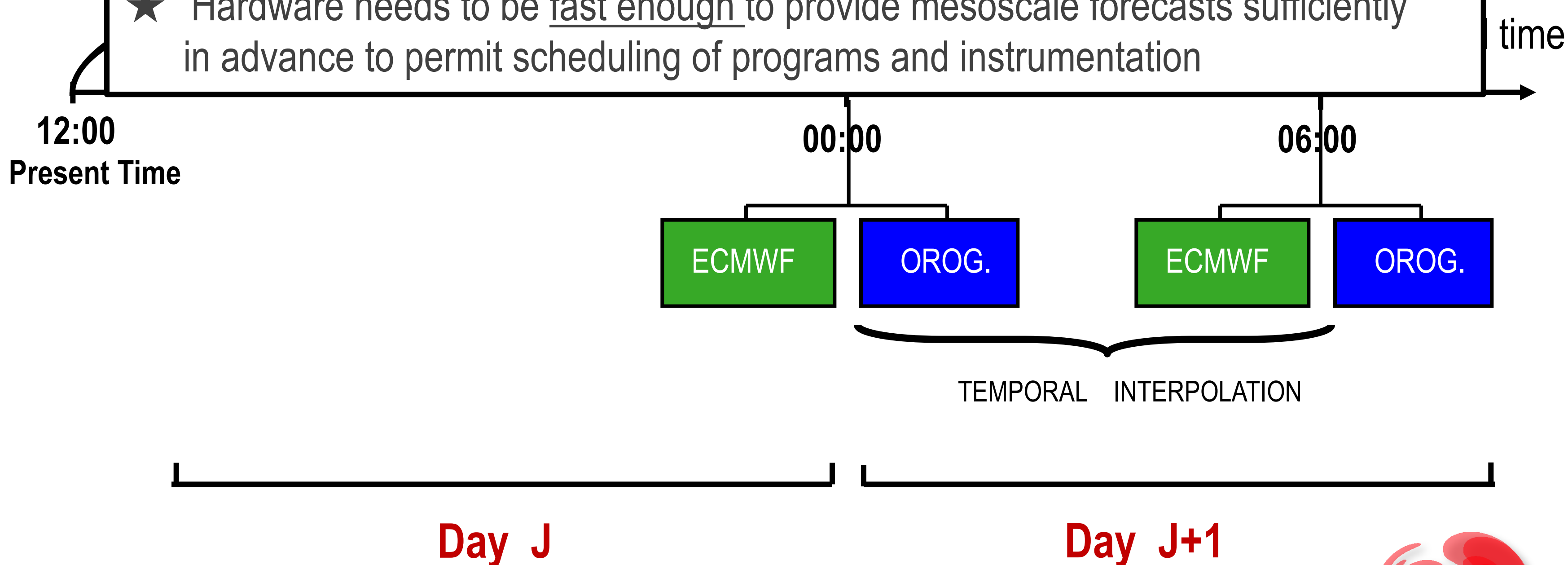
HOW TO FORECAST THE OT: PRINCIPLE

TOY MODEL



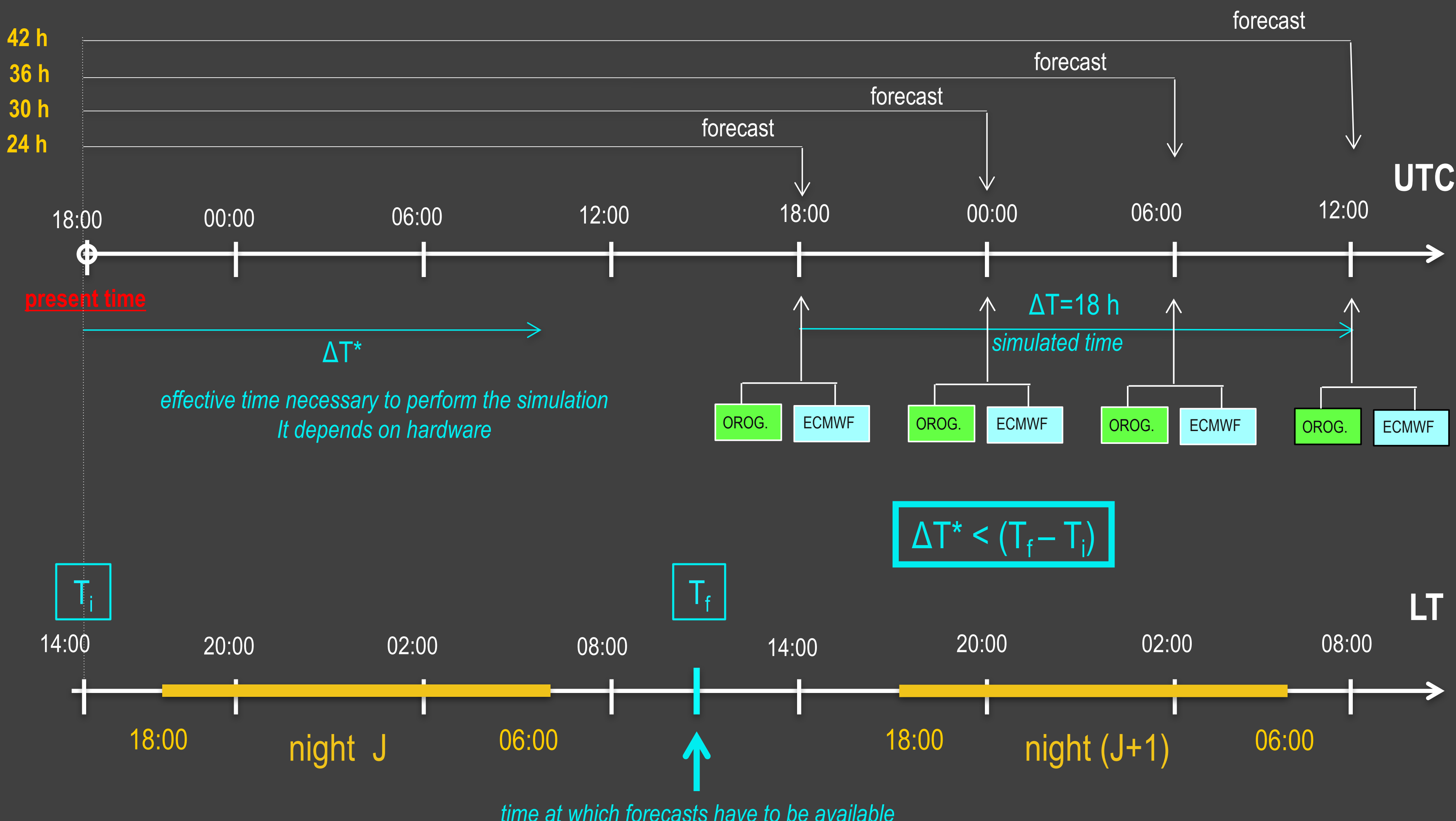
HOW TO FORECAST THE OT: PRINCIPLE

- ★ Simulations are forced each six hours (00:00, 06:00, 12:00, 18:00) with forecasts from the ECMWF available in the meanwhile
- ★ Simulations are performed with _grid-nesting technique_ that permits to increase the resolution in a region around the telescope with a set of imbricated models
- ★ Hardware needs to be fast enough to provide mesoscale forecasts sufficiently in advance to permit scheduling of programs and instrumentation



OT FORECAST SCHEME

TOY MODEL



BENEFITS in TERMS OF ASTRONOMICAL OBSERVATIONS

Lascaux et al., MNRAS, 2013 and 2015 (surface parameters)

★**Surface temperature**: fundamental to eliminate the thermal gradient air/mirror and eliminate the *'mirror seeing'* contribution.

129 nights: $BIAS_m \leq 0.5^\circ C$; $RMSE_m \leq 0.9^\circ C$, $\sigma_m \leq 0.54^\circ C$

★**Surface wind speed**: it is the main source of vibrations of critical structures: adaptive secondary, primary mirror.

129 nights: $BIAS_m \leq 0.85\ ms^{-1}$; $RMSE_m \leq 2.3 ms^{-1}$; $\sigma_m \leq 1.45\ ms^{-1}$

★**Surface wind direction**: the atmospheric parameter more easily correlated to the seeing conditions.

129 nights: $BIAS_m \leq 4^\circ$; $RMSE_{REL,m} \leq 16\%$; $\sigma_{REL,m} \leq 9\%$

★**Vertical stratification atm. parameters on [0,20km]**:

- Particularly **wind speed**, main *'ingredient'* for the wavefront coherence time (τ_0). Masciadri et al., 2013, MNRAS (vertical stratification)
- There are not *monitors* that can routinely measure the wind speed stratification in an Observatory. *50 radiosoundings*

★**Optical Turbulence**: mesoscale models represents the **unique** method that is able to provide 3D maps of the C_N^2 from which we can retrieve all the astroclimatic parameters integrated along whatever line of sight.

Masciadri et al., 2017, MNRAS (optical turbulence)

Practical examples of optimization of the AO observations that we can obtain:

1) Identification of temporal windows in which AO can not work at all ($\varepsilon > \varepsilon_{threshold}$ or $\tau_0 < \tau_{0,threshold}$)
2) Identification of temporal windows in which the total seeing is particularly weak ($\varepsilon < \varepsilon_{0,threshold}$) *for high-contrast imaging (extra-solar planets)*
3) Identification of temporal windows in which the turbulence in the free atmosphere is weak ➔ *GLAO, MCAO and WFAO*

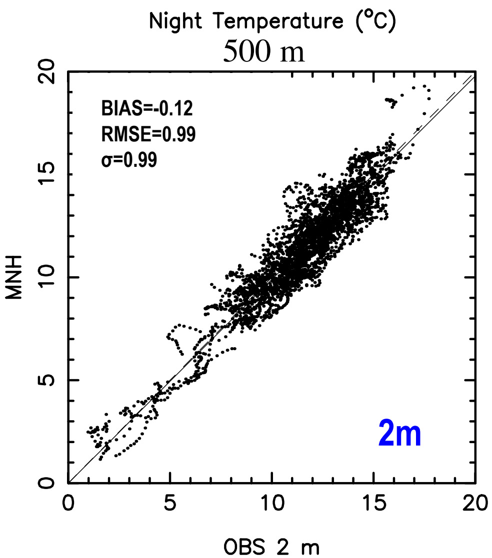
Just one tool for a huge number of benefits in different contexts !

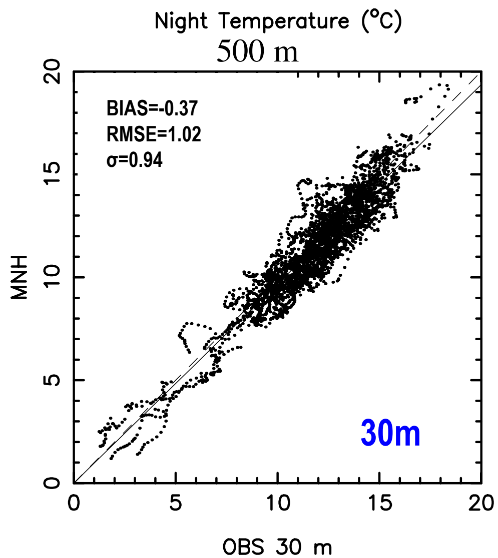
SURFACE TEMPERATURE ➡ DOME SEEING ELIMINATION

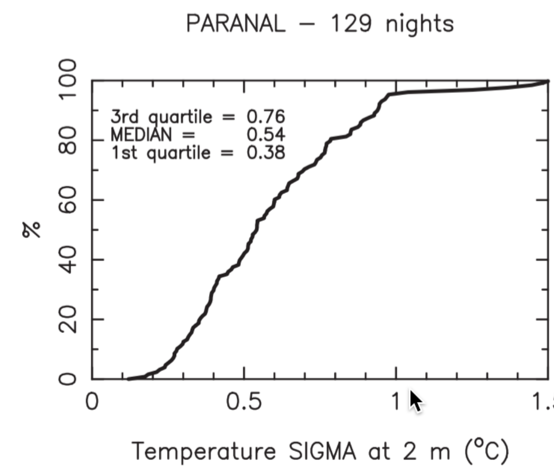
★**Surface temperature**: fundamental to eliminate the thermal gradient air/mirror and eliminate the *'mirror seeing'* contribution.

129 nights: **$BIAS_m \leq 0.5^{\circ}C$; $RMSE_m \leq 0.9^{\circ}C$, $\sigma_m \leq 0.54^{\circ}C$**

Lascaux et al., MNRAS, 2015







ΔX=500m

	Temperature 2 m	Temperature 30 m
BIAS	$-0.18^{+0.40}_{-0.73}$	$-0.48^{+0.12}_{-0.92}$
RMSE	$0.91^{+1.19}_{+0.60}$	$0.92^{+1.25}_{+0.58}$
σ	$0.54^{+0.76}_{+0.38}$	$0.48^{+0.69}_{+0.34}$

CONCLUSION: bias, RMSE, σ < 1°C !!!

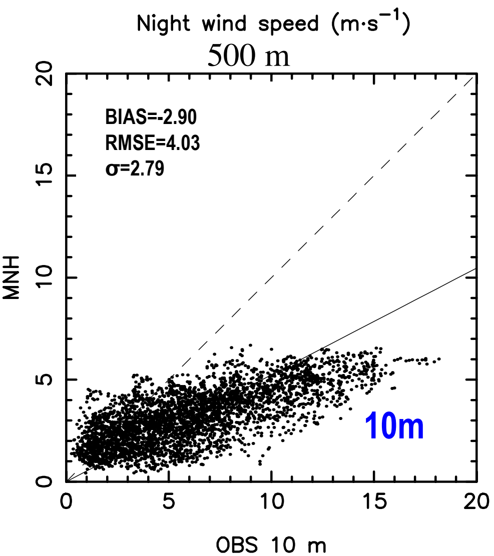
Dome seeing can be eliminated !

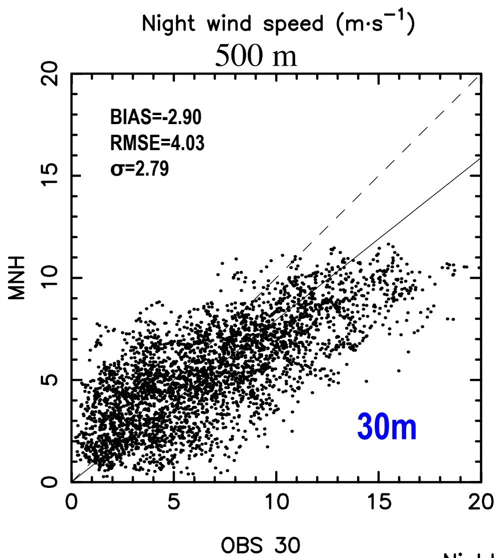
WIND SPEED @ SURFACE

★**Surface wind speed**: it is the main source of vibrations of critical structures: adaptive secondary, primary mirror.

129 nights: **$BIAS_m \leq 0.85$ ms^{-1}; $RMSE_m \leq 2.3$ms^{-1} ; $\sigma_m \leq 1.45$ ms^{-1}**

Lascaux et al., MNRAS, 2015



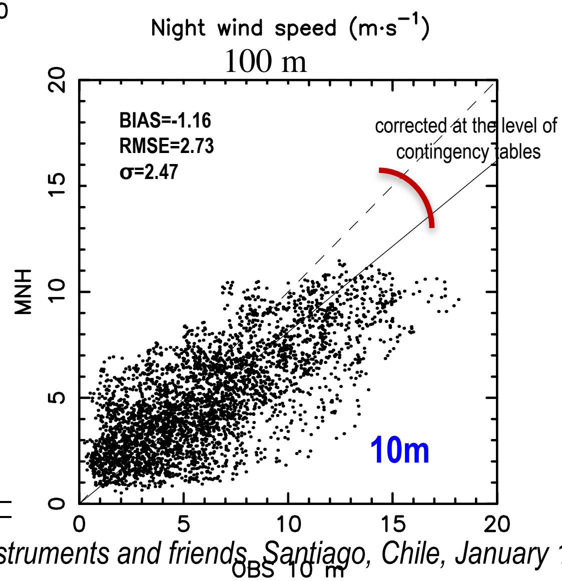


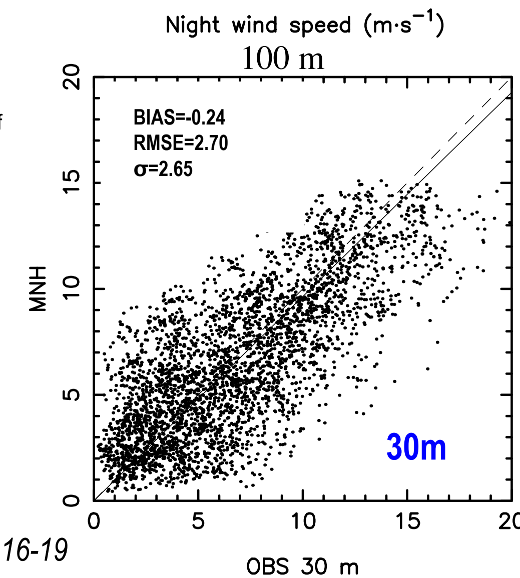
ΔX=500m

high horizontal resolution (100m) necessary for the wind speed

NECESSITY OF A HIGH HORIZONTAL RESOLUTION

ΔX=100m





CONTINGENCY TABLES

- BIAS, RMSE, σ from scattering plots (systematic and statistical errors)
- **Proportion of correct detection**
- **Probability of detection of a specific event (ex: ε < 1", wind speed > 12 ms^{-1})**

RANDOM CASE
a=b=….=n/9
PC=33.33%
$POD_{1,2,3}$=33.33%

Example of a 3x3 contingency table

Intervals		OBSERVATIONS 1	2	3	Total
MODEL	1	a (hit 1)	b	c	a+b+c 1 (Model)
	2	d	e (hit 2)	f	d+e+f 2 (Model)
	3	g	h	i (hit 3)	g+h+i 3 (Model)
	Total	a+d+g 1 (OBS)	b+e+h 2 (OBS)	c+f+i 3 (OBS)	n=a+b+c+d+e+f+g+h+i Total of events

A 3x3 table is identified by two threshold limits

Proportion of Correct detection
PC=[(a+e+i)/n]x100; 0 ≤ PC ≤ 100%

Probability of Detection of event 1
POD_1=[a/(a+d+g)]x100; 0 ≤ POD ≤ 100%

Probability of Detection of event 2
POD_2=[e/(b+e+h)]x100; 0 ≤ POD ≤ 100%

Probability of Detection of event 3
POD_3=[i/(c+f+i)]x100; 0 ≤ POD ≤ 100%

Extremely bad detection
EBD=[(c+g)/n]x100; 0 ≤ POD ≤ 100%

Defined in: Lascaux et al., MNRAS, 2015

ATMOSPHERICAL PARAMETERS CLOSE TO THE GROUND [0,30m]

CERRO PARANAL: 129 nights

Lascaux et al., MNRAS, 2015

[2007-2013]

TEMPERATURE

1st tertile → $T < 11°C$; 3rd tertile → $T > 13.5°C$

2m

Division by tertiles (climatology) C. Paranal - 2 m		OBSERVATIONS $T < 11°C$	$11°C < T < 13.5°C$	$T > 13.5°C$
MODEL	$T < 11°C$	1157	315	0
	$11°C < T < 13.5°C$	96	972	258
	$T > 13.5°C$	8	178	499

Total points = 3483; PC = 75.5%; EBD=0.2%
POD1= 91.8%; POD2= 66.3%; POD3=65.9%

30m

Division by tertiles (climatology) C. Paranal - 30 m		OBSERVATIONS $T < 11.5°C$	$11.5°C < T < 13.5°C$	$T > 13.5°C$
MODEL	$T < 11.5°C$	1250	422	2
	$11.5°C < T < 13.5°C$	68	663	292
	$T > 13.5°C$	16	117	653

Total points = 3483; PC = 73.7%; EBD=0.5%
POD1= 93.7%; POD2= 55.2%; POD3=69.0%

WIND SPEED

10m

Division by tertiles (climatology) C. Paranal - 10 m		OBSERVATIONS $WS < 4\ m{\cdot}s^{-1}$	$4\ m{\cdot}s^{-1} < WS < 7\ m{\cdot}s^{-1}$	$WS > 7\ m{\cdot}s^{-1}$
MODEL	$WS < 4\ m{\cdot}s^{-1}$	641	283	50
	$4\ m{\cdot}s^{-1} < WS < 7\ m{\cdot}s^{-1}$	395	510	269
	$WS > 7\ m{\cdot}s^{-1}$	103	281	924

Total points = 3456; PC = 60.6%; EBD=4.4%
POD1= 56.2%; POD2= 47.5%; POD3=74.3%

30m

Division by tertiles (climatology) C. Paranal - 30 m		OBSERVATIONS $WS < 4\ m{\cdot}s^{-1}$	$4\ m{\cdot}s^{-1} < WS < 8\ m{\cdot}s^{-1}$	$WS > 8\ m{\cdot}s^{-1}$
MODEL	$WS < 4\ m{\cdot}s^{-1}$	554	289	27
	$4\ m{\cdot}s^{-1} < WS < 8\ m{\cdot}s^{-1}$	400	559	234
	$WS > 8\ m{\cdot}s^{-1}$	101	311	981

Total points = 3456; PC = 60.6%; EBD=3.7%
POD1= 52.5%; POD2= 48.2%; POD3=79.0%

WIND DIRECTION when WIND SPEED > 12 ms^{-1}

CERRO PARANAL: 129 nights

Lascaux et al., MNRAS, 2015

C. Paranal - 10 m		OBSERVATIONS N-E	S-E	S-W	N-W
MODEL	N-E	367	0	0	37
	S-E	1	9	0	0
	S-W	0	0	0	0
	N-W	18	0	0	91

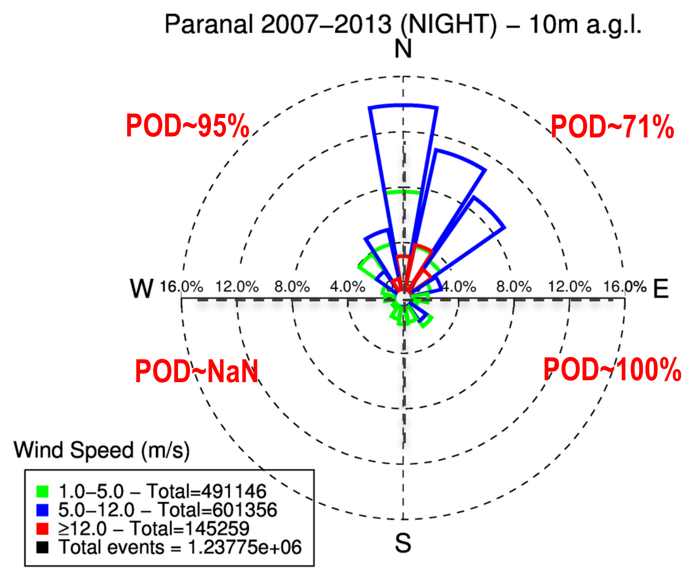
Total points = 523 ; PC=89.3%; EBD=0%
$POD(NE)$=95.1%; $POD(SE)$=100%
$POD(SW)$=NaN ; $POD(NW)$=71.1%

…when the wind speed is strong

very high level of confidence of the model in predicting the right wind direction …

Exactly what we need !

Paranal Observations
Wind direction night time
2007-2013

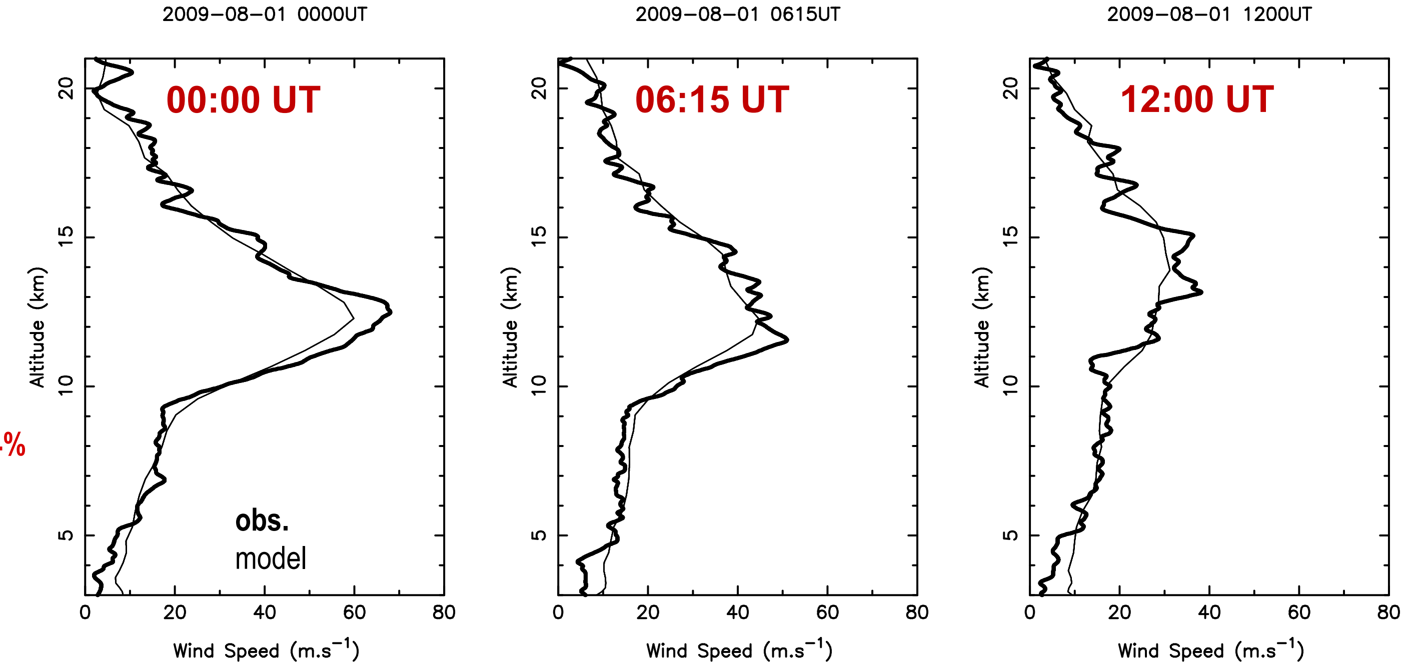


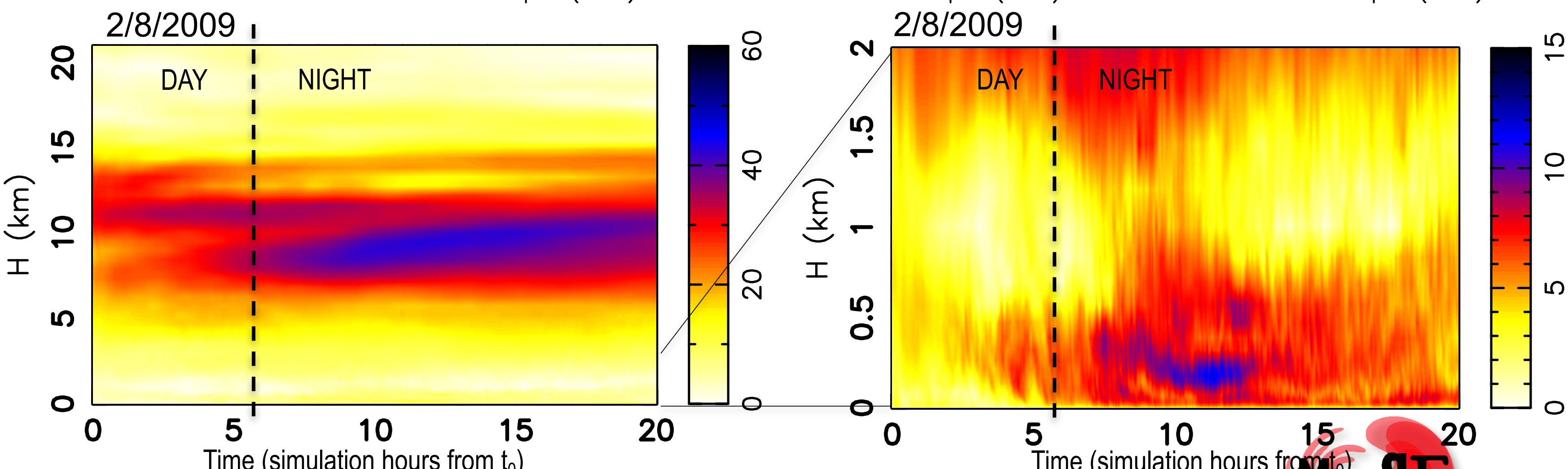
WIND SPEED VERTICAL DISTRIBUTION

Masciadri et al., 2013, MNRAS

INDIVIDUAL NIGHTS
MODEL VALIDATION

relative error
$(V_{MNH}-V_{OBS}/V_{OBS})_{max}$ x 100 **~14%**

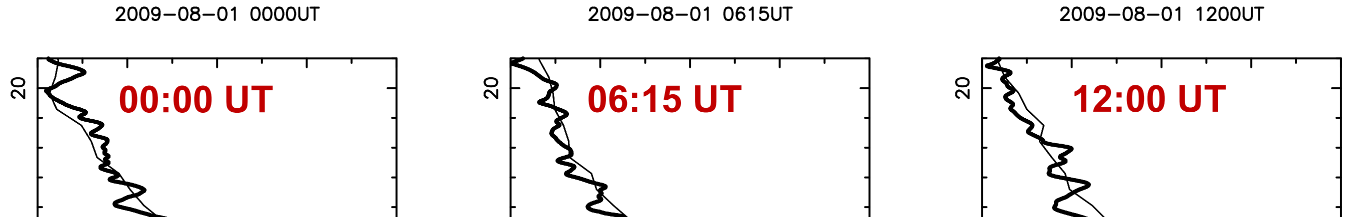




WIND SPEED VERTICAL DISTRIBUTION

Masciadri et al., 2013, MNRAS

INDIVIDUAL NIGHTS
MODEL VALIDATION



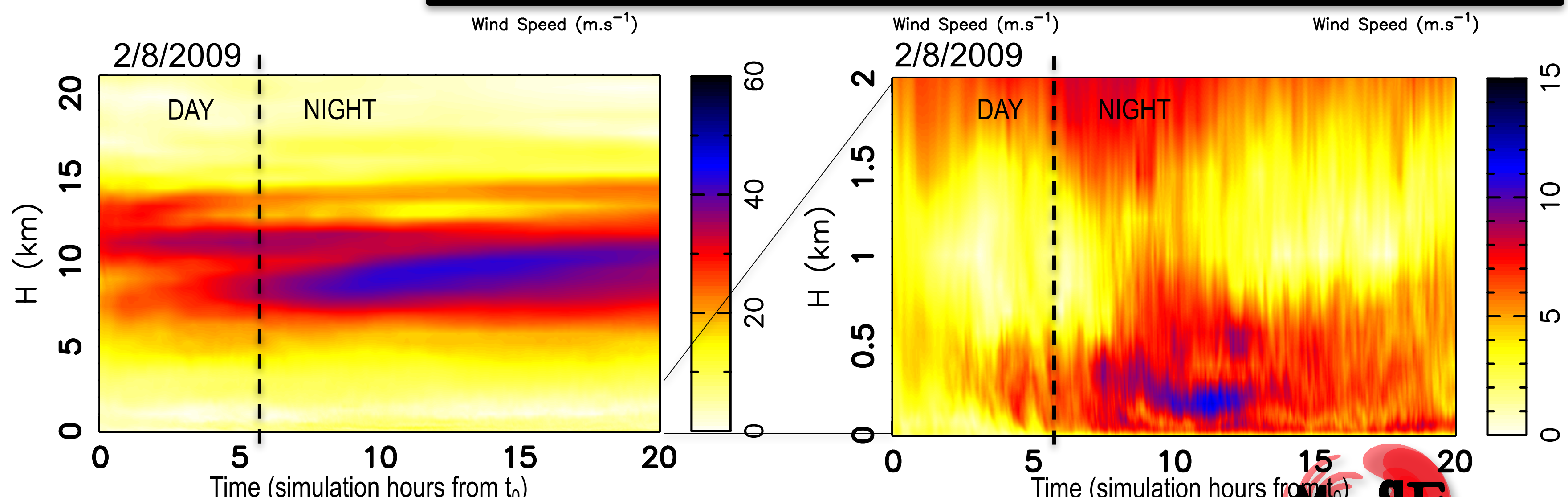
1) GCMs (ECMWF) data are weakly reliable in the low part of the atmosphere

2) GCMs (ECMWF) data are available only at discrete hours (typically 6 hours)

$$\tau_0(t) = 0.057 \cdot \lambda^{6/5} \cdot \left[\int_0^\infty |V(h,t)|^{5/3} \cdot C_N^2(h,t) \cdot dh \right]^{-3/5}$$

Wind speed temporal sampling: **2 minutes**

It is possible to arrive to a few seconds !!



WIND SPEED INDIVIDUAL NIGHTS

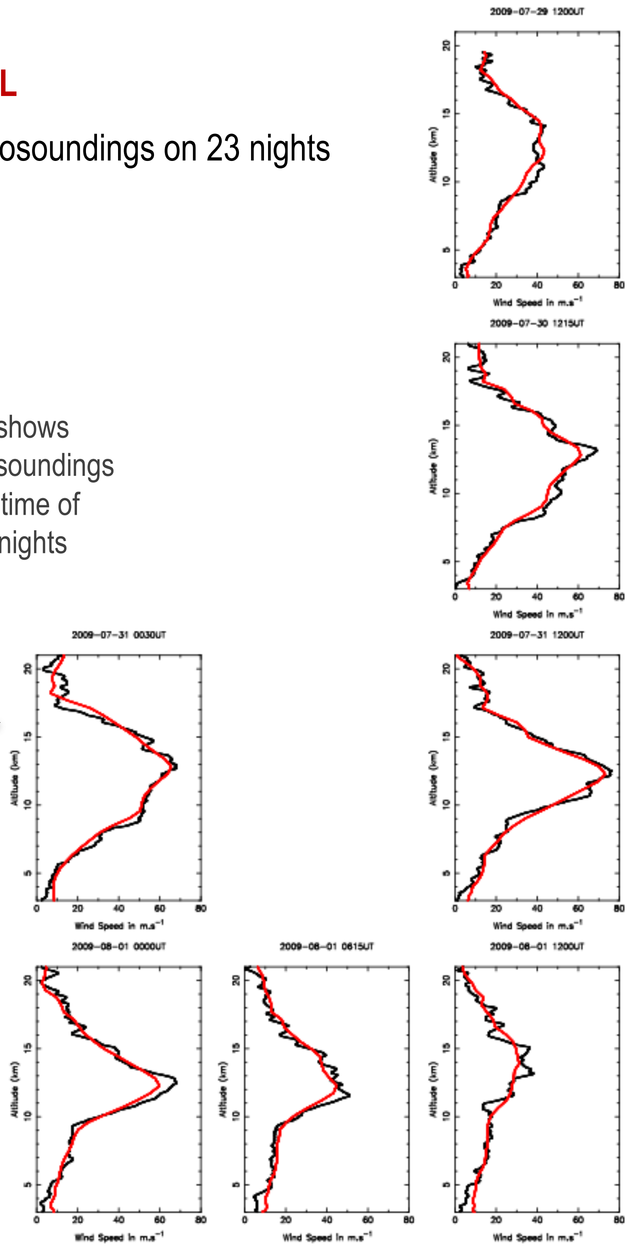
Masciadri et al., 2013, MNRAS

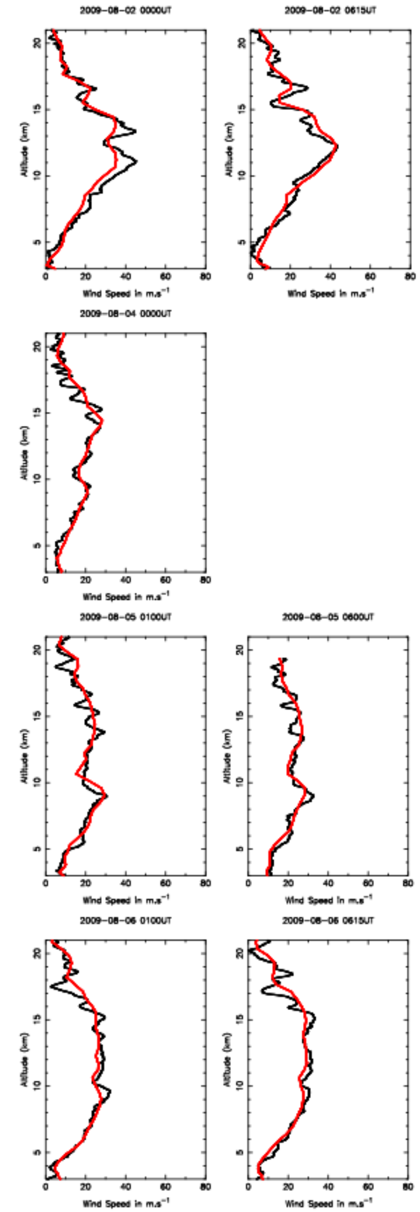
OBS

MODEL

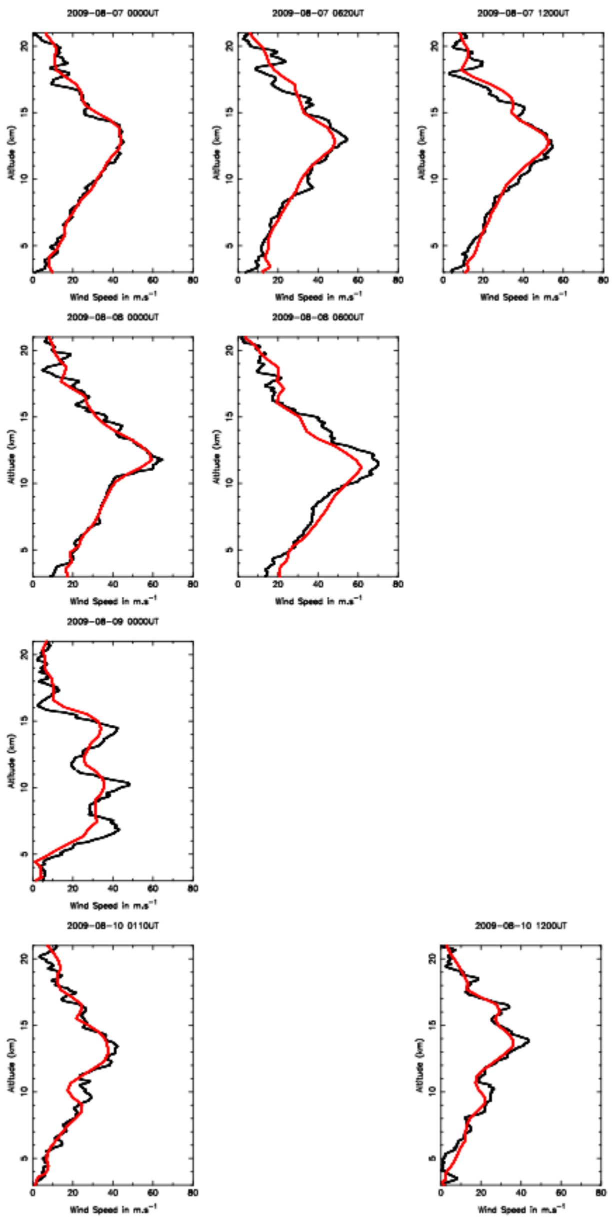
50 radiosoundings on 23 nights

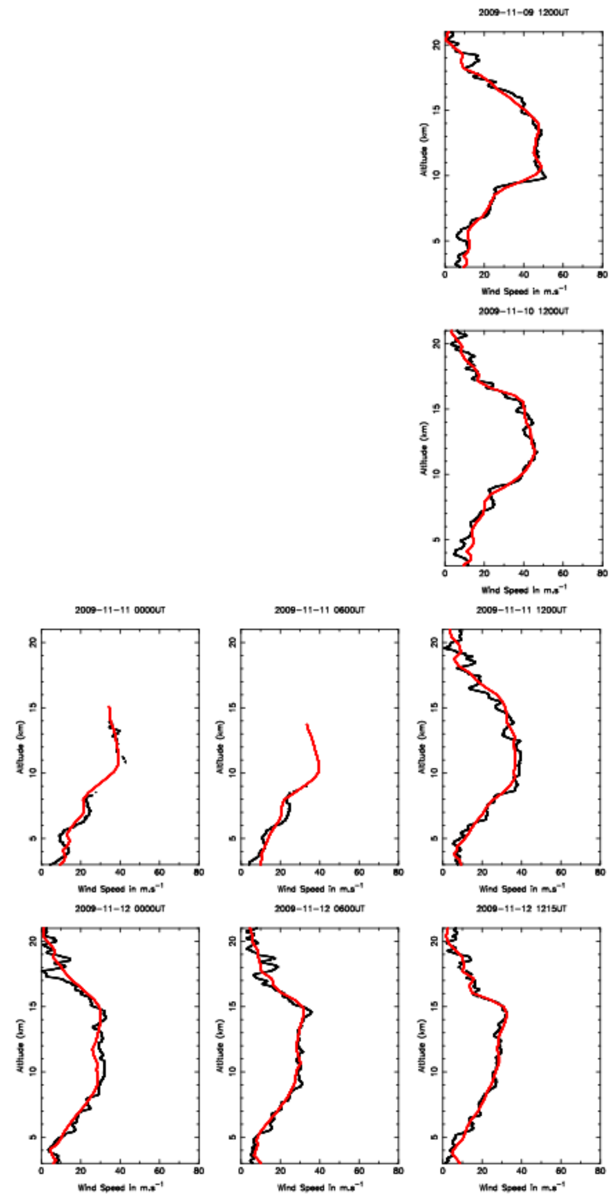
Each line shows different radiosoundings at different time of the same nights



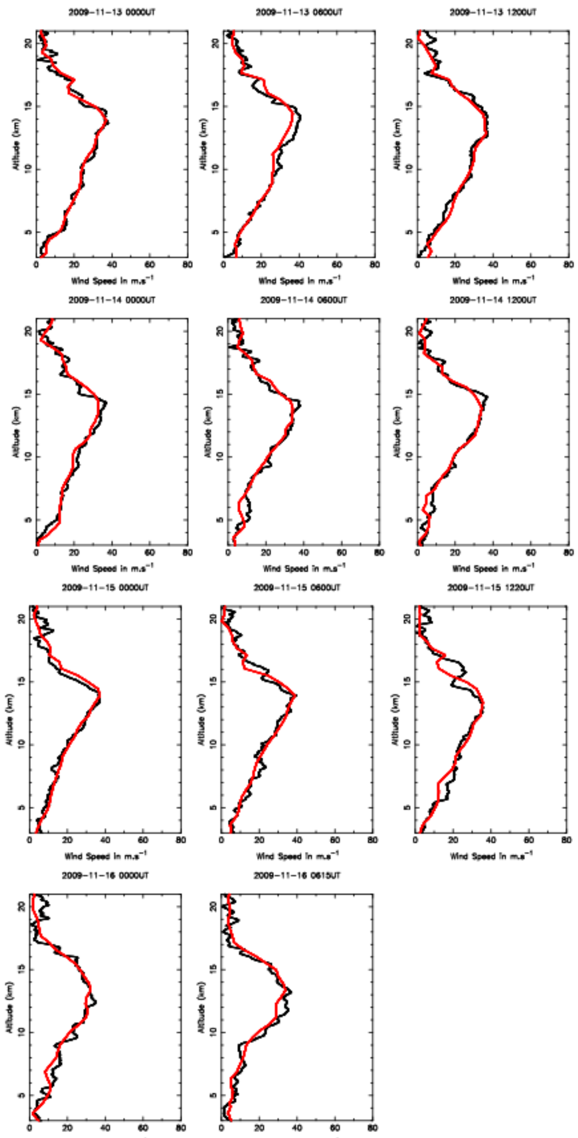


WIND SPEED INDIVIDUAL NIGHTS

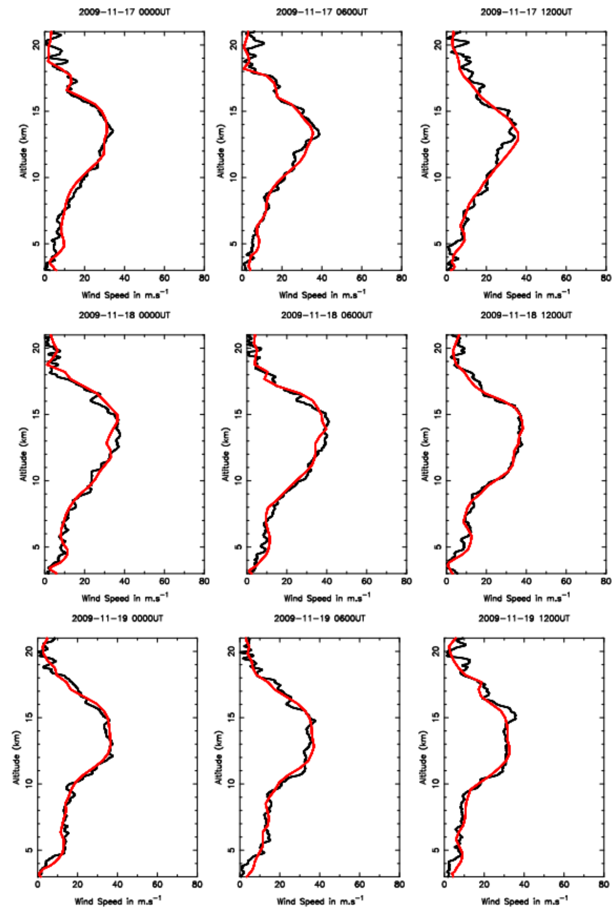




WIND SPEED INDIVIDUAL NIGHTS



ε_{max}~ 23%



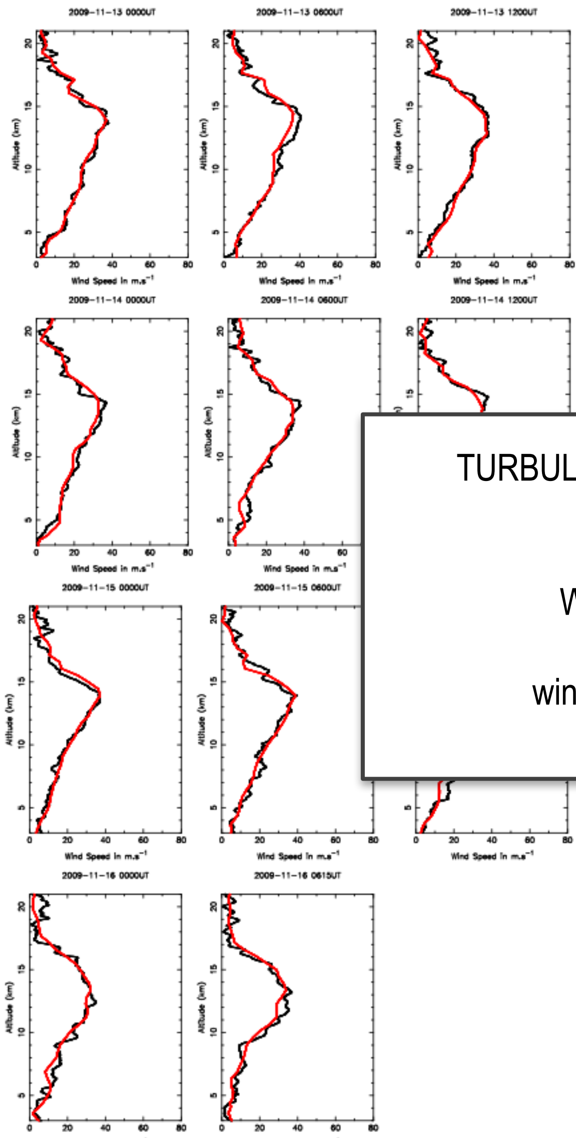
Obs:

Δt=2sec

Δh~10m

without convolution
(re-interpolated at Δh=5m)

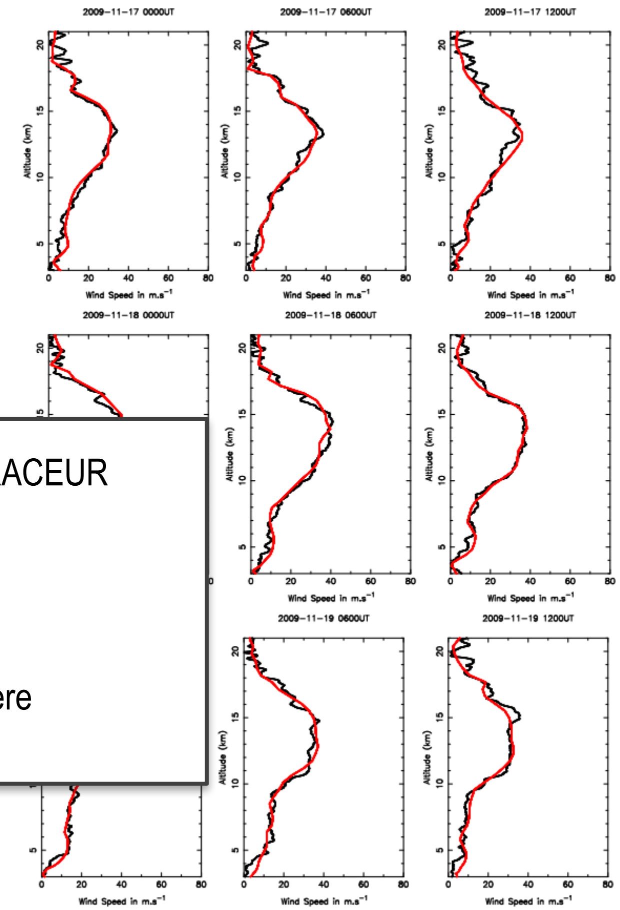
WIND SPEED INDIVIDUAL NIGHTS



ε_{max}~ 23%

TURBULENCE IS A PASSIVE TRACEUR

Wind speed of turbulence
is the same than
wind speed of the atmosphere



Obs:
Δt=2sec
Δh~10m

without convolution
(re-interpolated at Δh=5m)

extended statistical analysis
in Masciadri et al. 2013, MNRAS

WIND STRATIFICATION TO DO WHAT ?

(a) V(h,t) model → Forecasted V(h,t)

(b) V(h,t) model, C_N^2(h,t) model → Forecasted τ_0(t)

(c) V(h,t) model, C_N^2(h,t) Instrument → "Measured τ_0(t)" *real time*

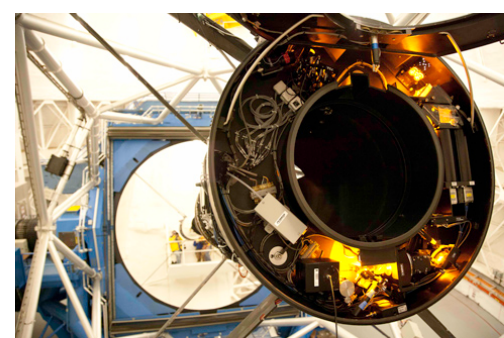
} With very high temporal sampling

★ Nightly estimates of the vertical stratification of the wind speed
At present we have no instruments suitable for an operation application (monitoring)
Optical instruments (such as SCIDAR technique) require large telescopes - D=1 is not enough
(with a D=1m we should have a V_{max}~ 36 ms^{-1}***…and V can be much larger at jet-stream heights !)***

★ Due to its excellent reliability, model can be used as a reference to validate other techniques for "turbulence wind speed" measur. (related to OT too…)

GeMS
MCAO system
(SLODAR principle)

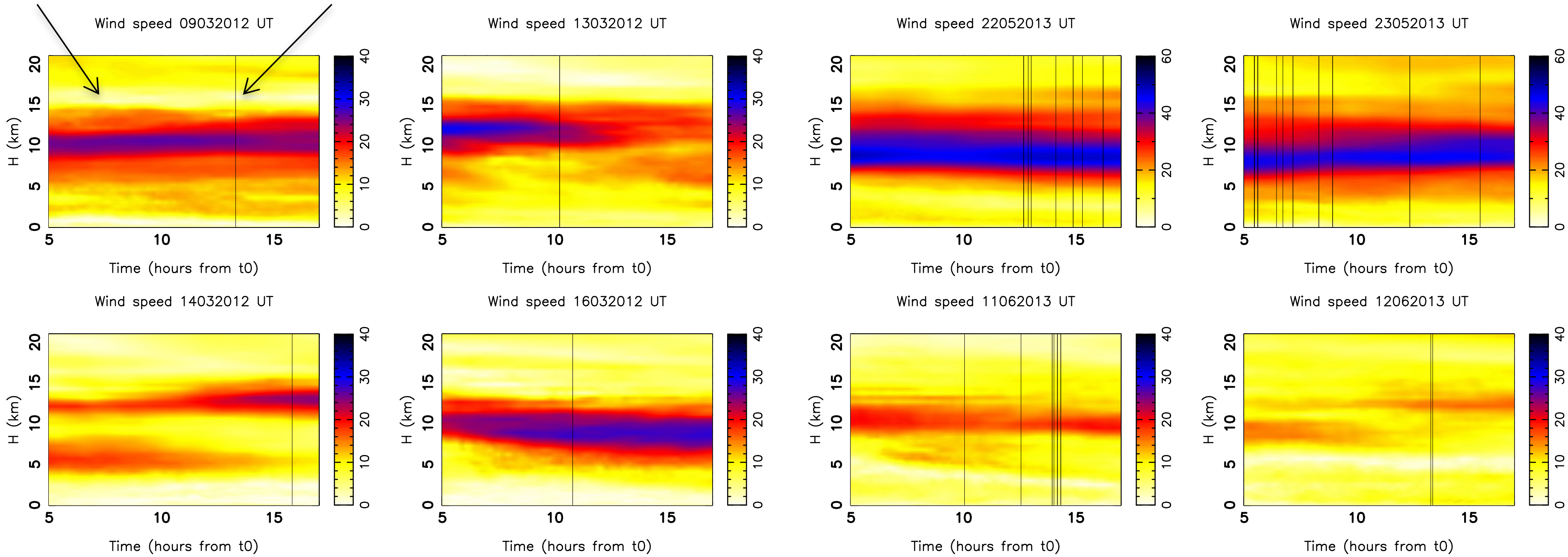
Collab. with GeMS team (Neichel, Guesalaga, Sivo)

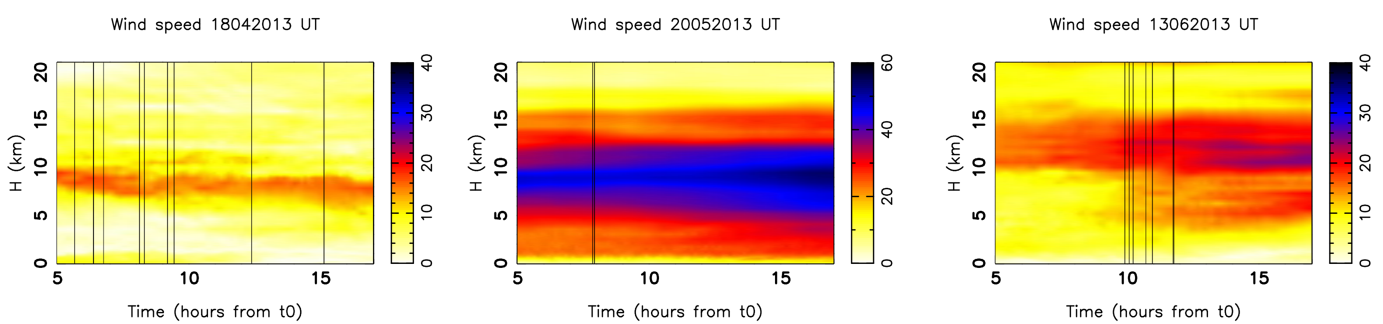


AO application: GeMS versus Meso-Nh (used as a reference)

@ Cerro Pachon

Meso-NH **GeMS**

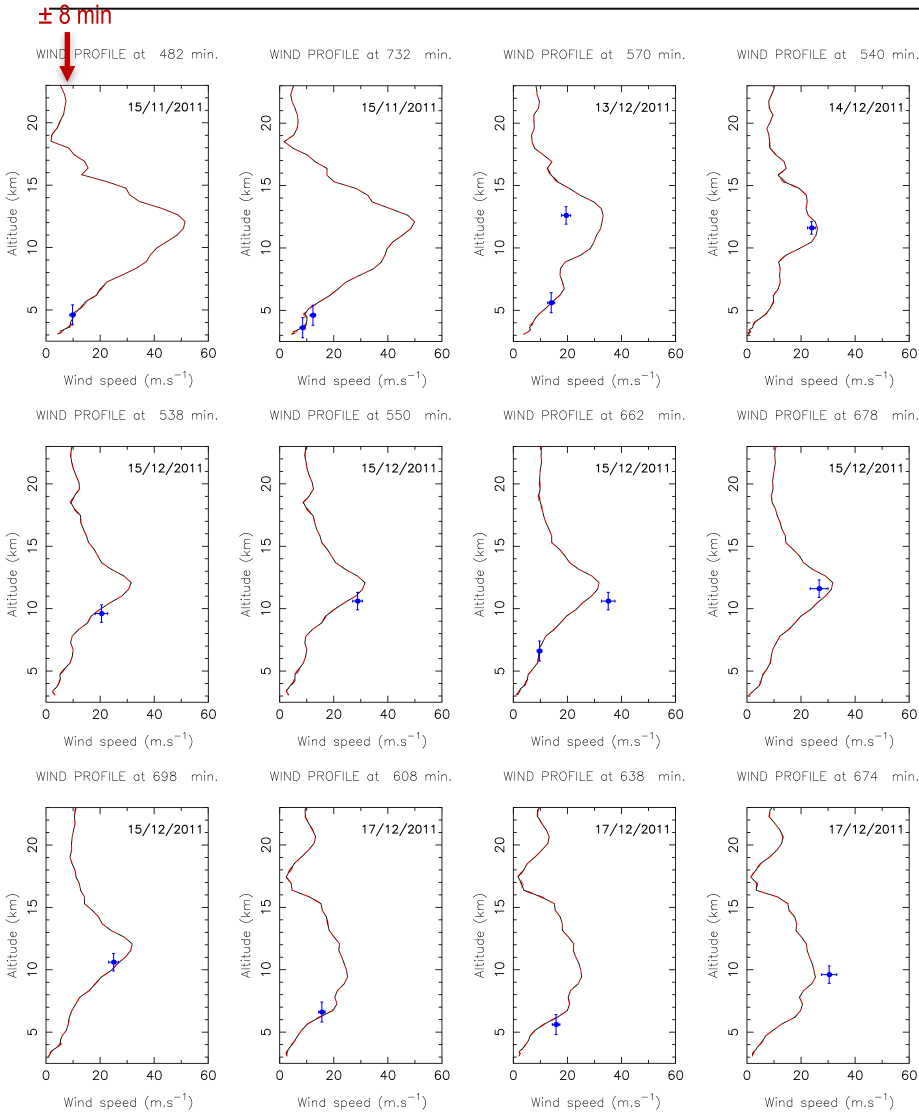




Total sample: 43 nights
~ 400 measurements

In the slide just the first 11 nights

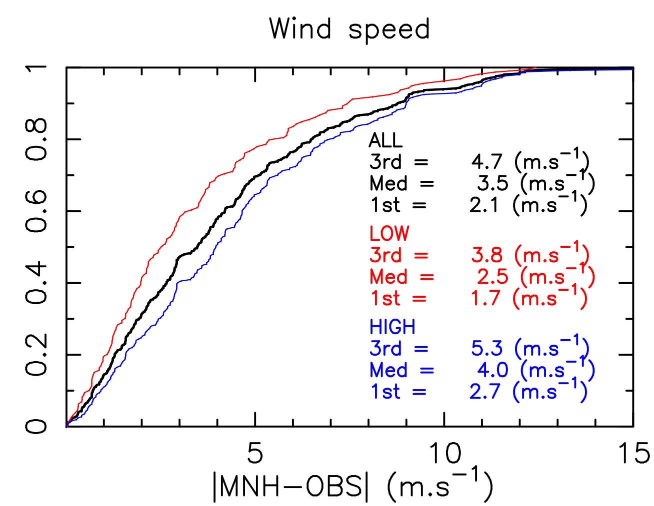
@Cerro Pachon: GeMS versus Meso-Nh (model)



Dot: GeMS

Line: Model

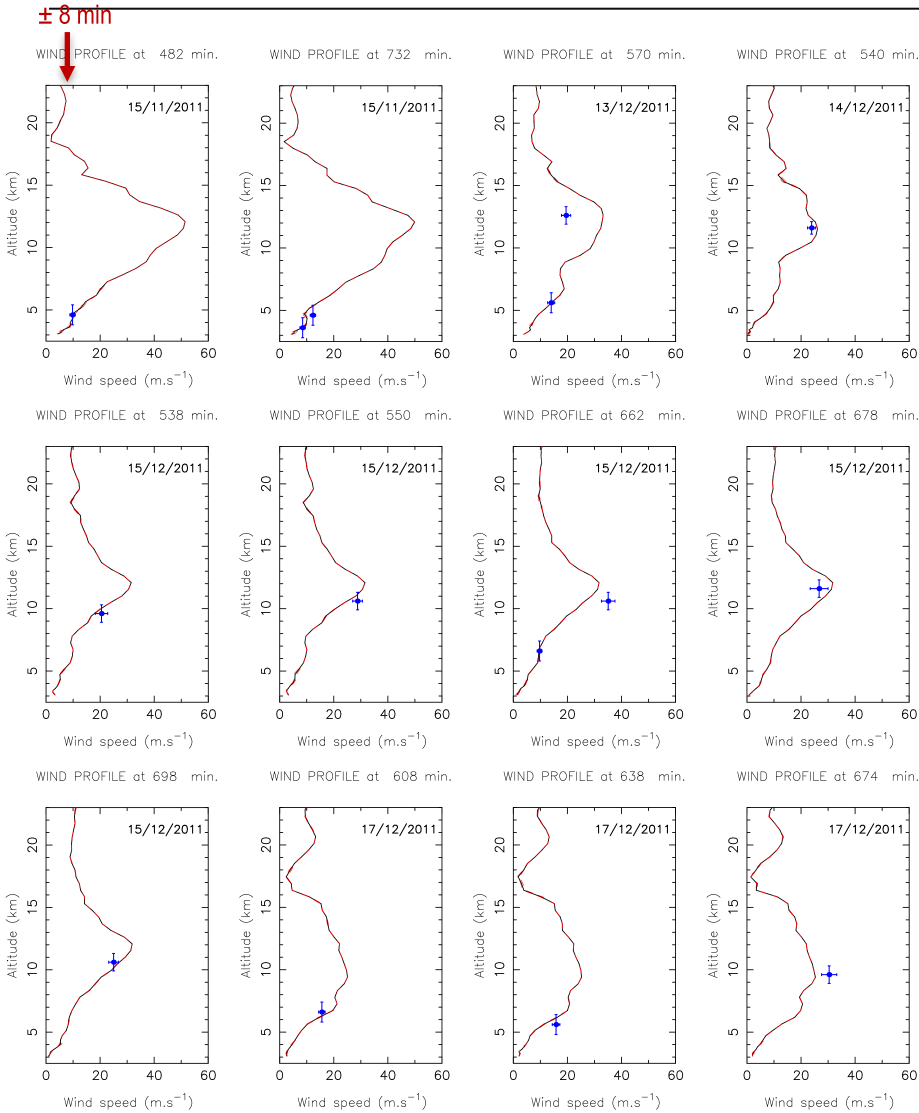
MNRAS in preparation
(collaboration with GeMS team)



	RMSE	
	GeMS vs. Meso-NH 43 nights	Masciadri et al. 2013 50 nights
LOW: H < 5 km	4.36 ms-1	3 ms-1
HIGH: H > 5km	5.15 ms-1	3.5 ms-1

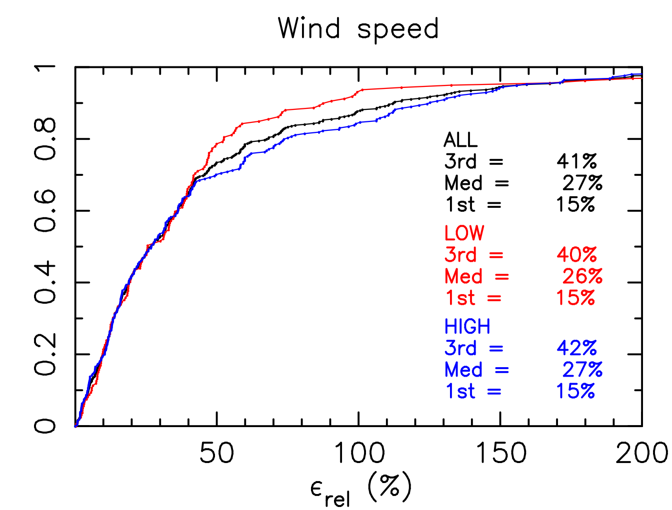
σ_X=RMS of wind estimates (Wang et al., 2008); σ_Y~1.5km

@Cerro Pachon: GeMS versus Meso-Nh (model)



Dot: GeMS
Line: Model

MNRAS in preparation
(collaboration with GeMS team)



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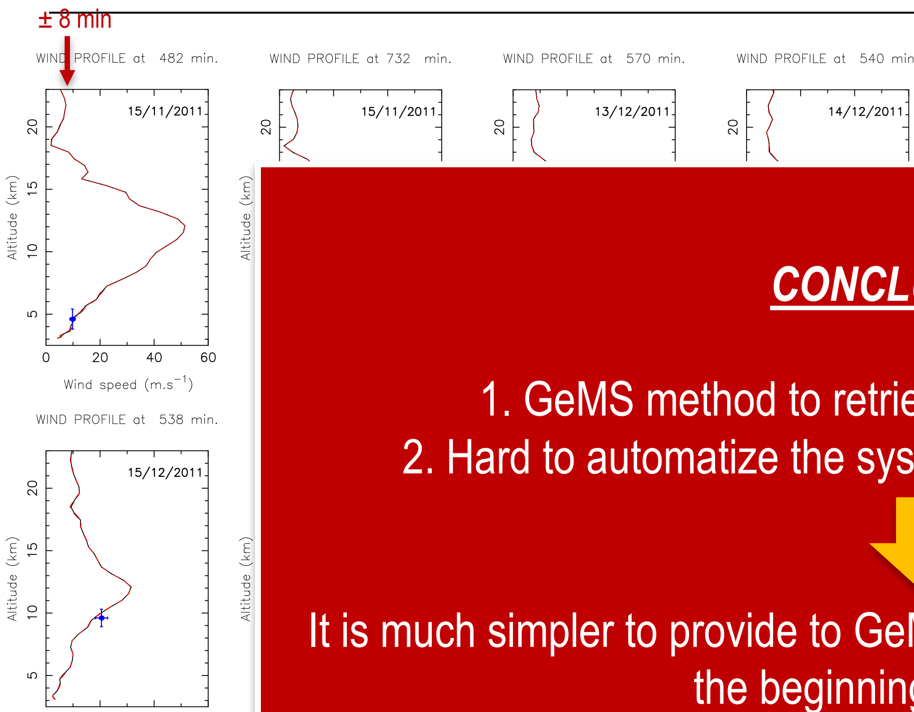
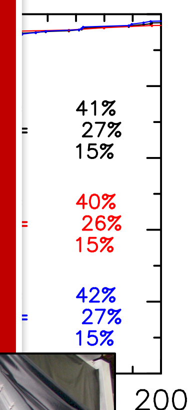


Dot: GeMS

Line: Model

MNRAS in preparation
(with GeMS team)

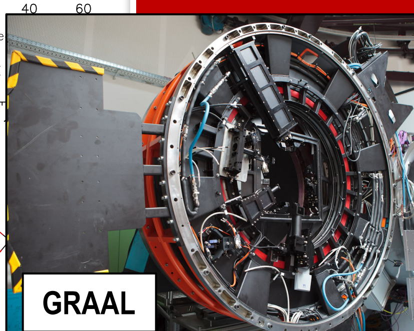


CONCLUSIONS

1. GeMS method to retrieve wind speed is reliable
2. Hard to automatize the system and not practical solution

It is much simpler to provide to GeMS the outputs of the model before the beginning of the night
(injecting model outpits inside GeMS)

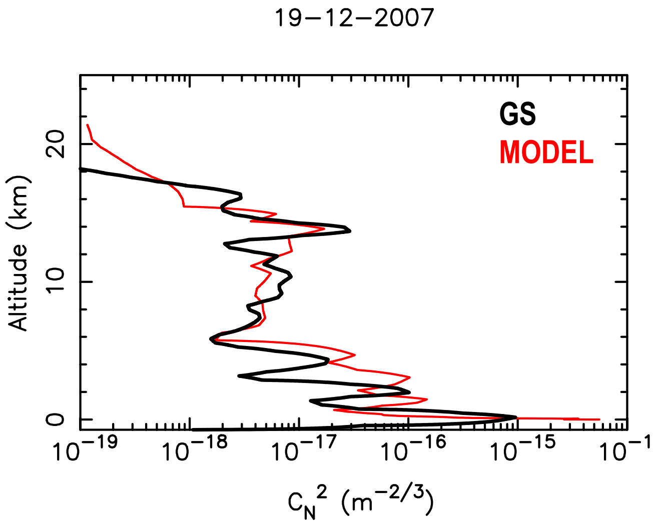
similar thing might be done with AOF



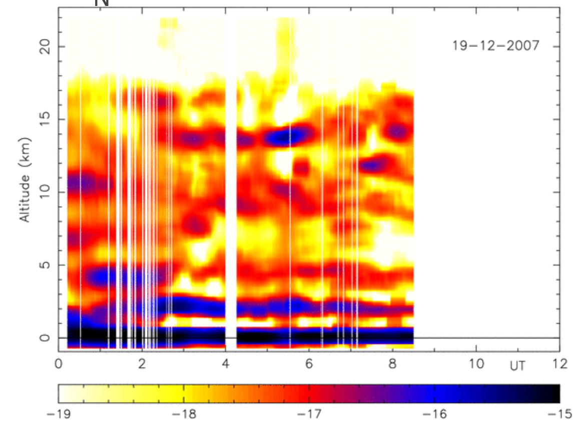
		...ri et al. 2013 ... nights
LOW: H < 5 km	[illegible]	**...5 ms-1**
HIGH: H > 5km	**5.15 ms-1**	**3.5 ms-1**

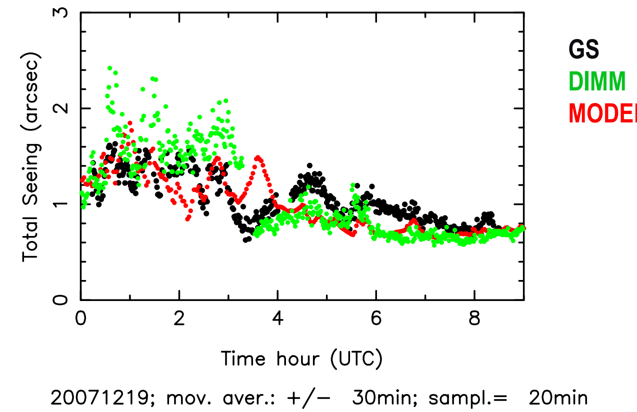
σ_X=RMS of wind estimates (Wang et al., 2008); σ_Y~1.5km

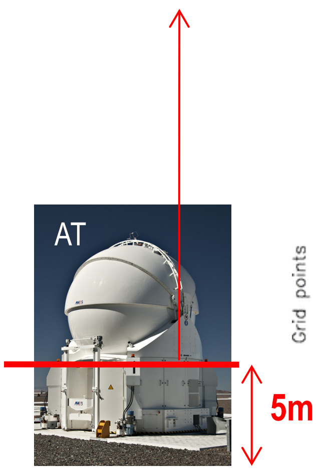
PARANAL – Night of 19/12/2007



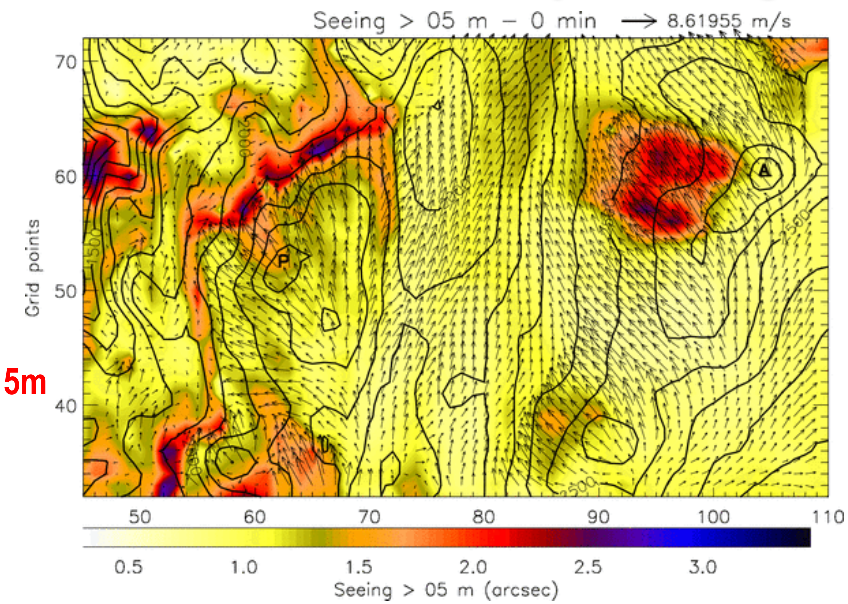
C_N^2 : GENERALIZED SCIDAR

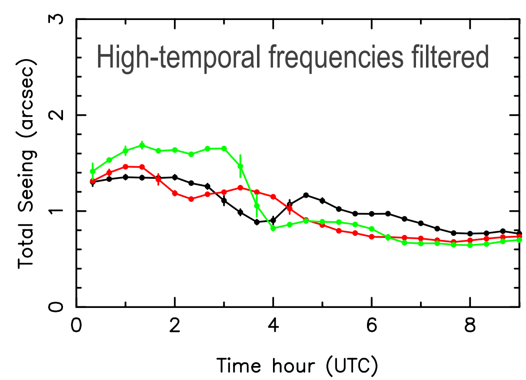






32.5 km x 20 km; Δx=500m; seeing > 5m + wind @ 10m

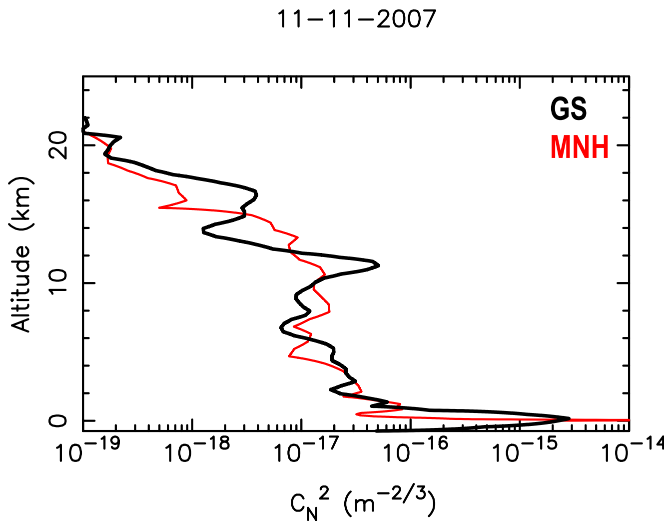




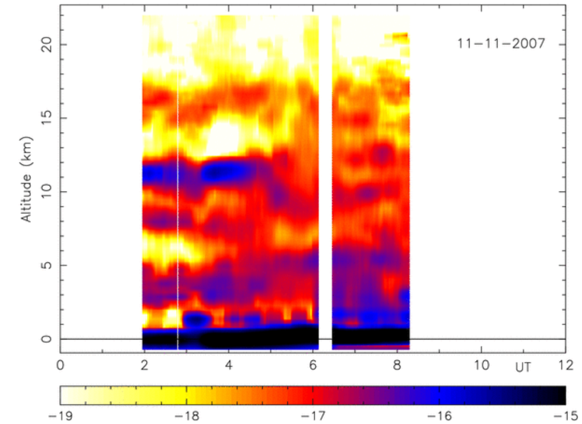
SIMULATIONS with the non-hydrostatic atmospherical meso-scale model + Astro package (Astro-Meso-Nh)

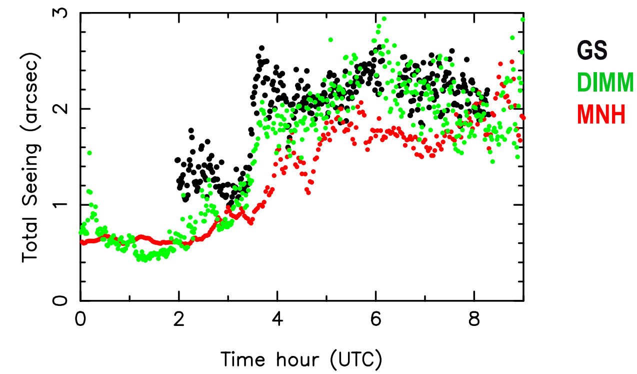
ΔT=9 hours - night ; (00:00 - 9:00) UT; sampling=5 min

PARANAL– Night of 11/11/2007

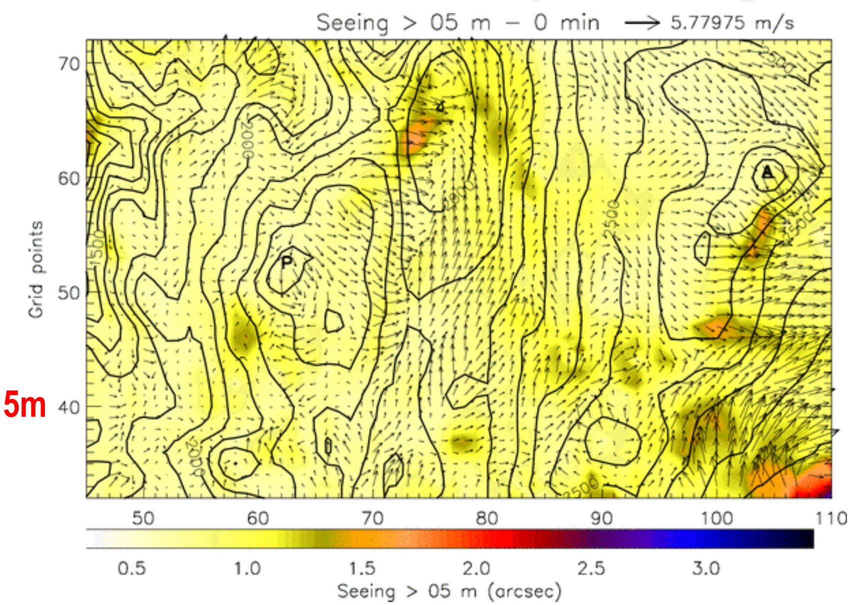


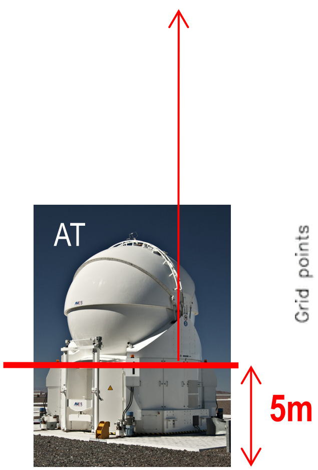
C_N^2 : GENERALIZED SCIDAR



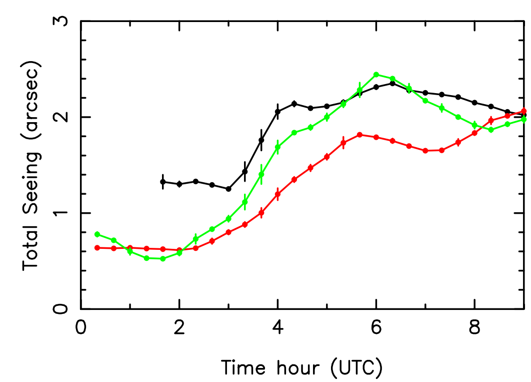


32.5 km x 20 km; Δx=500m; seeing > 5m + wind @ 10m





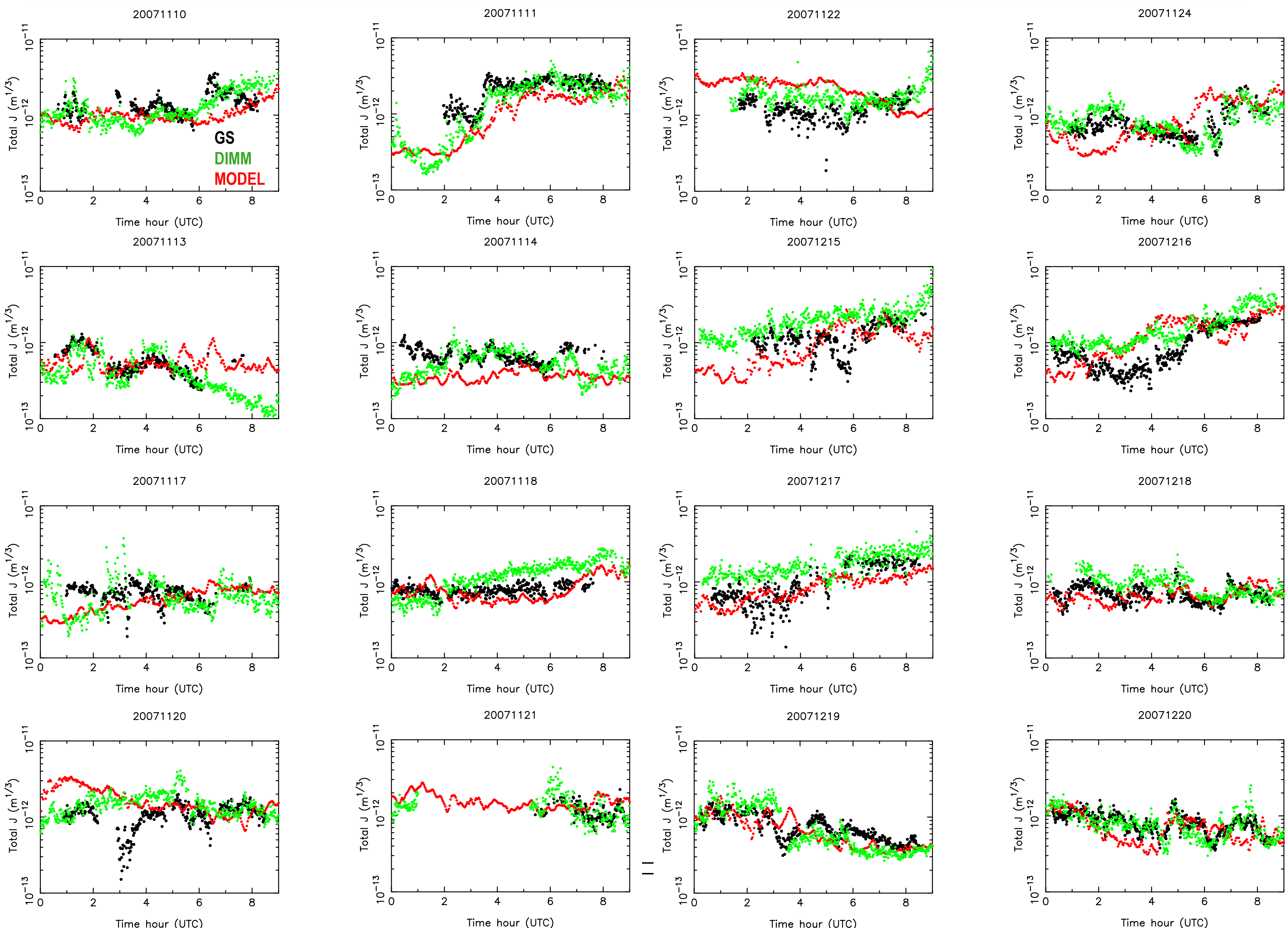
20071111; mov. aver.: +/− 30min; sampl.= 20min



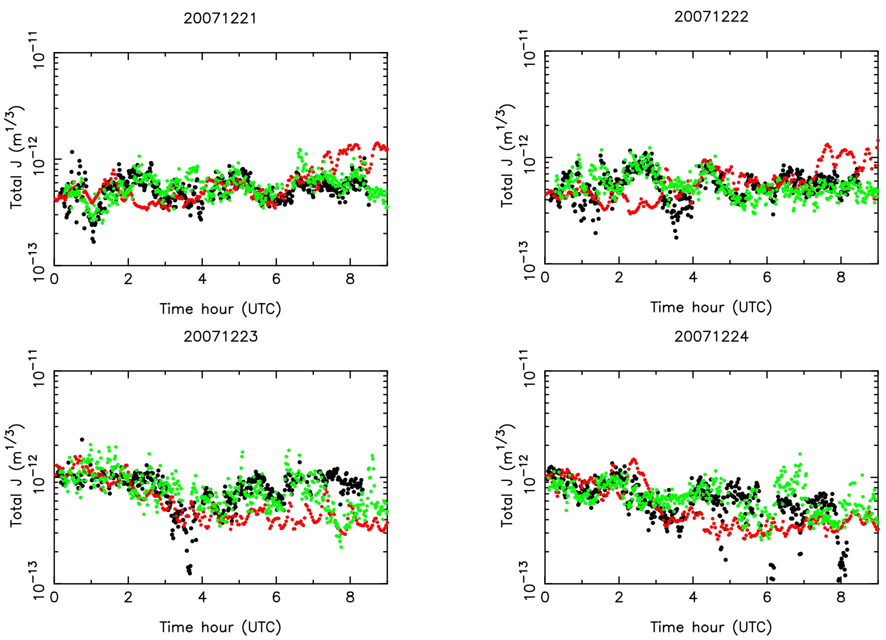
SIMULATIONS with the non-hydrostatic atmospherical meso-scale model + Astro package (Astro-Meso-Nh)

ΔT=9 hours - night; (00:00 - 9:00) UT; sampling=5 min

TOTAL J – TEMPORAL EVOLUTION (PAR2007: 20 nights)



TOTAL J – TEMPORAL EVOLUTION (PAR2007: 20 nights)



Masciadri et al., 2017, MNRAS

SEEING: CONTINGENCY TABLES

Masciadri et al., 2017, MNRAS

(*) PAR2007 Nov./Dec. 2007

OBS. vs. OBS.

20 nights (*)

MODEL vs. OBS.

1st tertile ↘ ↙ 3rd tertile

	ε 20 nights	GS $\varepsilon < 0.97''$	GS $0.97'' < \varepsilon < 1.24''$	GS $\varepsilon > 1.24''$
DIMM	$\varepsilon < 0.97''$	108	45	5
DIMM	$0.97'' < \varepsilon < 1.24''$	39	60	14
DIMM	$\varepsilon > 1.24''$	21	63	149

Total points=504; PC=62.90%; EBD=5.16%
POD1=64.29%; POD2=35.71%; POD3=88.69%

	ε 20 nights	GS $\varepsilon < 0.97''$	GS $0.97'' < \varepsilon < 1.24''$	GS $\varepsilon > 1.24''$
MODEL	$\varepsilon < 0.97''$	138	115	15
MODEL	$0.97'' < \varepsilon < 1.24''$	18	35	48
MODEL	$\varepsilon > 1.24''$	12	18	105

Total points=504; PC=55.16%; EBD=5.36%
POD1=84.12%; POD2=20.84%; POD3=62.50%

	ε 20 nights	DIMM $\varepsilon < 1''$	DIMM $1'' < \varepsilon < 1.42''$	DIMM $\varepsilon > 1.42''$
GS	$\varepsilon < 1''$	120	52	13
GS	$1'' < \varepsilon < 1.42''$	48	103	77
GS	$\varepsilon > 1.42''$	0	13	78

Total points=504; PC=59.72%; EBD=2.58%
POD1=71.43%; POD2=61.31%; POD3=46.43%

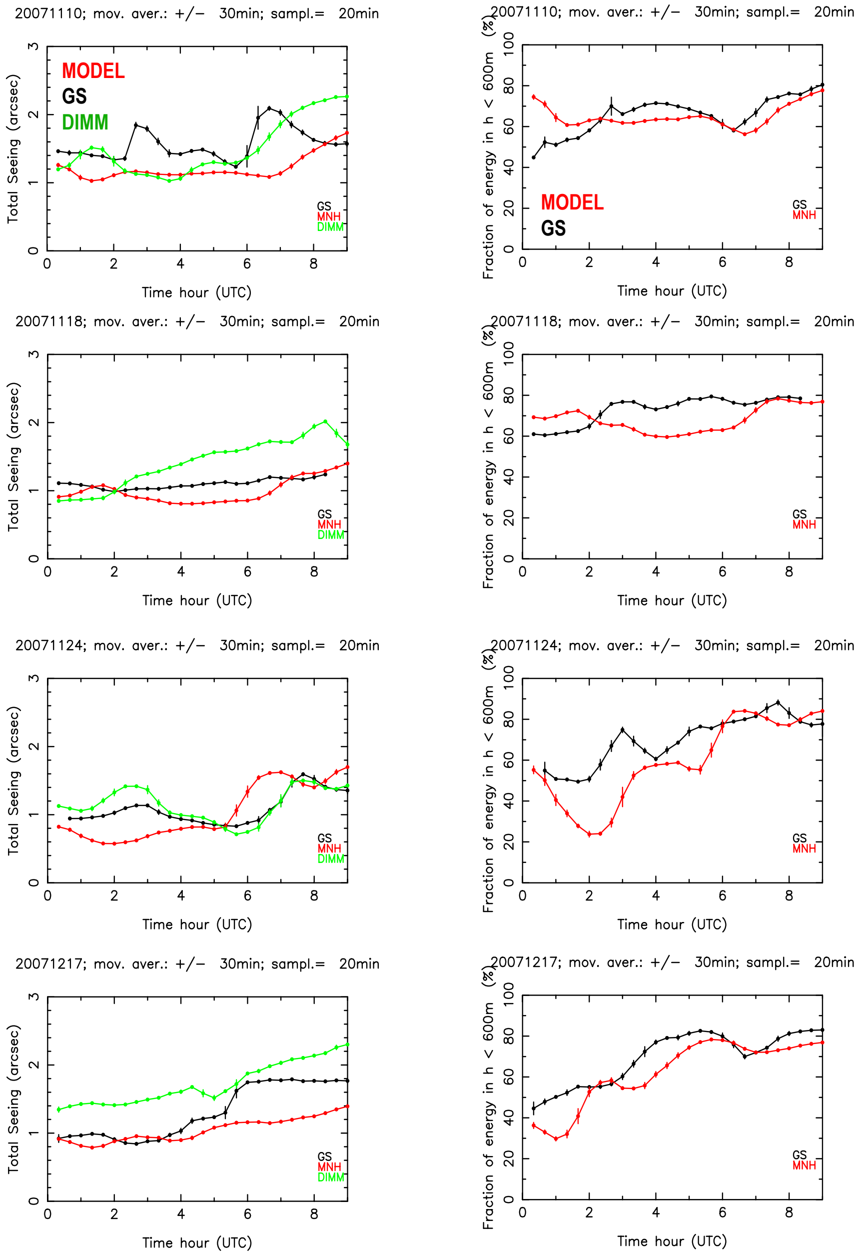
	ε 20 nights	DIMM $\varepsilon < 1''$	DIMM $1'' < \varepsilon < 1.42''$	DIMM $\varepsilon > 1.42''$
MODEL	$\varepsilon < 1''$	156	102	27
MODEL	$1'' < \varepsilon < 1.42''$	17	60	70
MODEL	$\varepsilon > 1.42''$	4	14	79

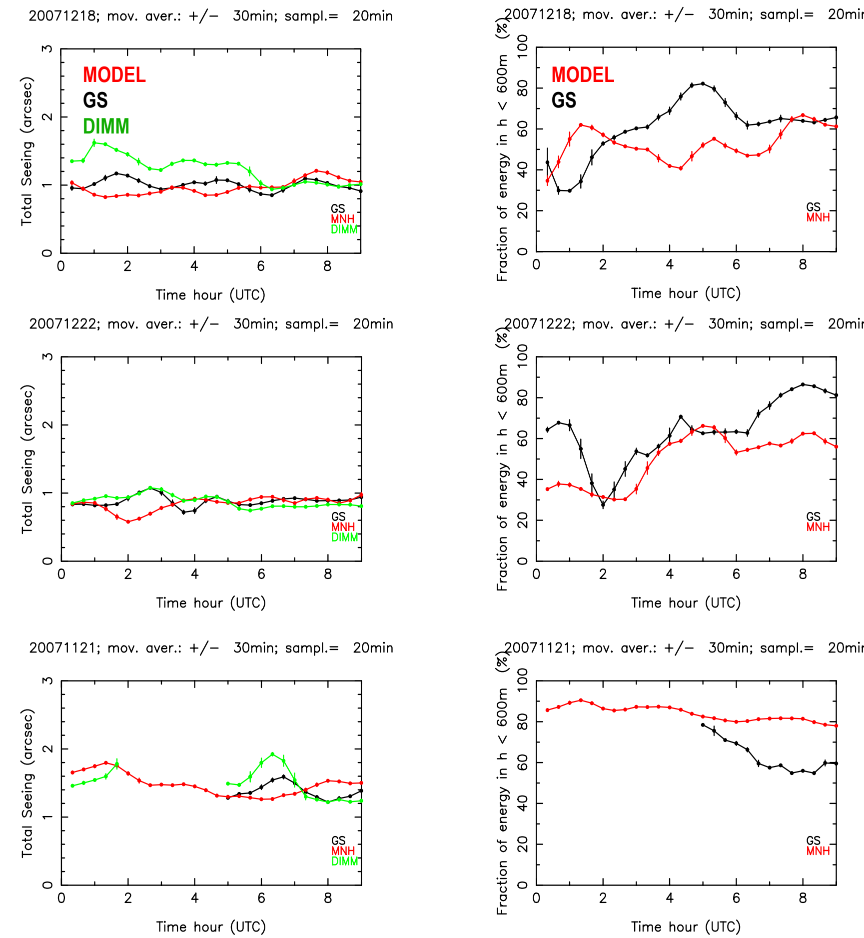
Total points=529; PC=55.76%; EBD=5.86%
POD1=88.13%; POD2=34.10%; POD3=44.89%

Definitely comparable results !!

MOSE

TOTAL SEEING | **J_{BL}/J_{TOT} BL=[0,600m]** | **TOTAL SEEING** | **J_{BL}/J_{TOT} BL=[0,600m]**





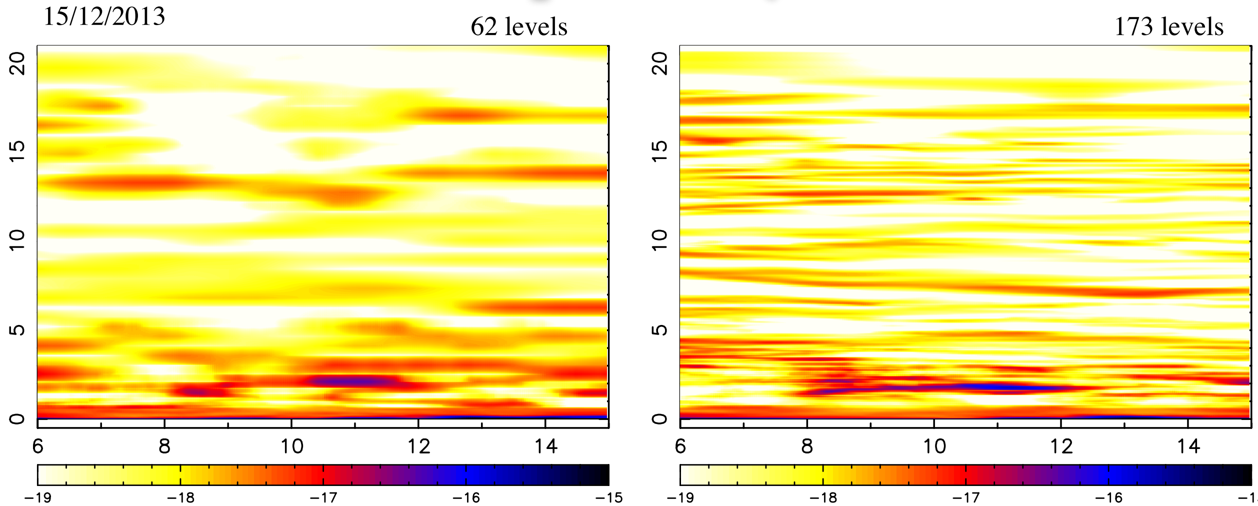
Fraction of turbulent energy close to the ground

J_{BL}/J_{TOT} : very useful figure of merit for the AOF !

Masciadri et al., 2017, MNRAS

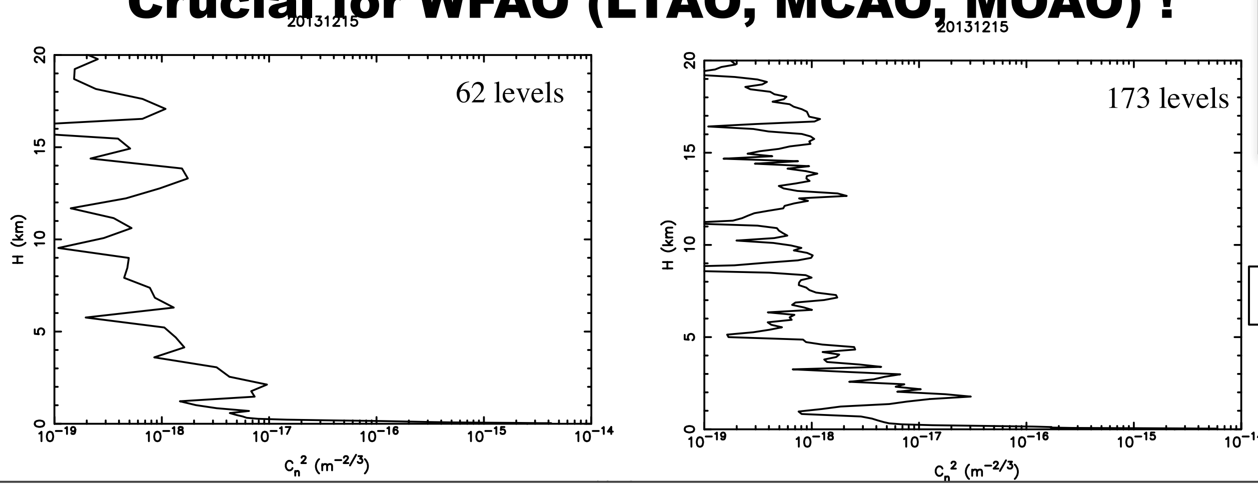
HIGH VERTICAL RESOLUTION C_N^2 PROFILES

Masciadri et al., 2017, MNRAS



up to Δh~150m

Crucial for WFAO (LTAO, MCAO, MOAO) !



Used for estimation of the ultimate limitation of tomographic reconstruction error for WFAO at E-ELT (LTAO, MCAO and MOAO)

Fusco et al. 2016, SPIE

Used to evaluate HARMONI perf.

Neichel et al. 2016, SPIE

Thanks to a new C_N^2 algorithm we obtained its realistic spatio-temporal variability on the whole 20km *web page grab….*

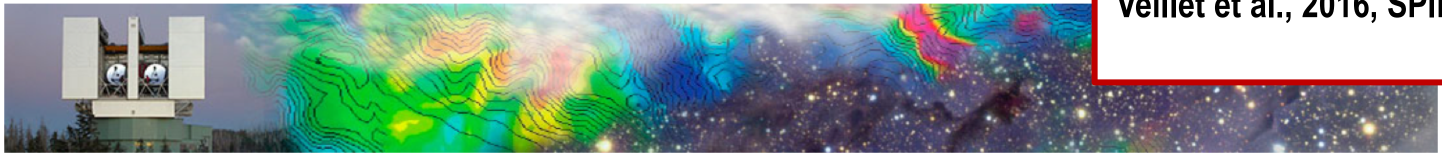
ALTA Center PROJECT @ LBT

Integral part of the LBTO Operational Observing Strategy

paper by LBTO Director Veillet et al., 2016, SPIE, 99100S

ALTA Center

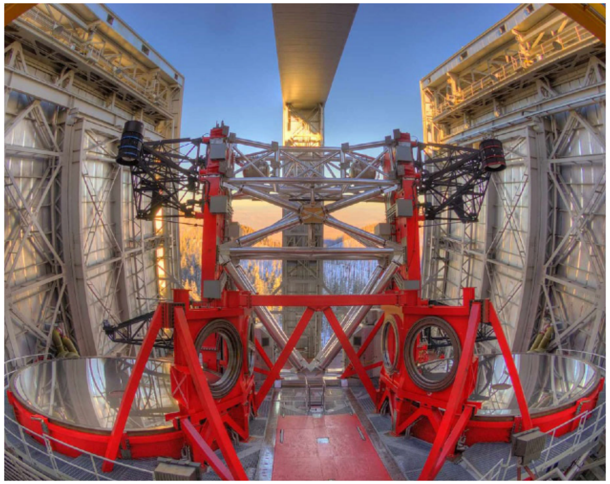
Advanced **L**BT **T**urbulence and **A**tmosphere

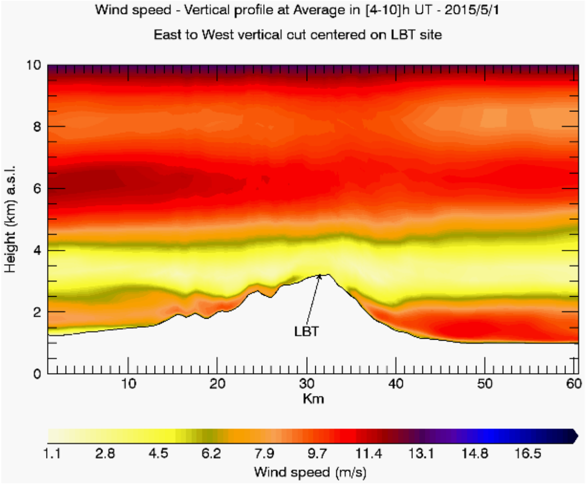


- Home
- Optical Turbulence Tutoring
- Forecasts Legend
  - Forecasts
    - Today
    - Yesterday
  - Trends
- Team
- Bibliography
- Contact

The ALTA Center is a project aiming at forecasting automatically and nightly the optical turbulence and other integrated astroclimatic parameters as well as atmospheric parameters relevant for ground-based astronomical observations, mainly supported by Adaptive Optics systems. The project has been conceived for the Large Binocular Telescope (LBT) located at Mt.Graham, Arizona, Us.

The project is lead by INAF - Arcetri Astrophysical Observatory.





http://alta.arcetri.astro.it

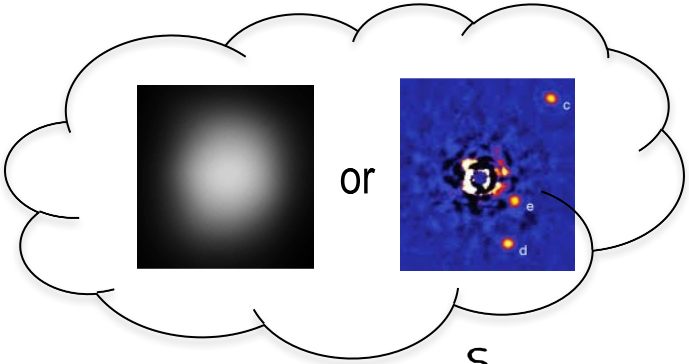
June 2016: *commissioning of the automatic operation of atmospheric parameters*

December 2016*: commissioning of automatic operation of OT*

Turchi et al., 2017, MNRAS

ADVANCED CONCEPTUAL DESIGN

- ✓ Estimation of variation of the model performances as a function of the forecasts step
- ✓ Identification of the key components (computer power-hardware, real time access to local data, real time access to initialization data, result display)
- ✓ Identification of an end-to-end conceptual design permitting to provide the output forecasts including: initialization data, topograpy at high resolution and Astro-Meso-Nh (mesoscale model)
- ✓ Cost estimate for installing and testing an operational model at ESO premises, including software for data display and dissemination
- ✓ Cost estimate for full operational development, including man power, software licence, initialisation data



At 14:00 Paranal LT the resident astronomer can access through the web site to ALL the forecasts outputs

MIXING RATIO and PWV

VISIR
mid-infrared spectrometer

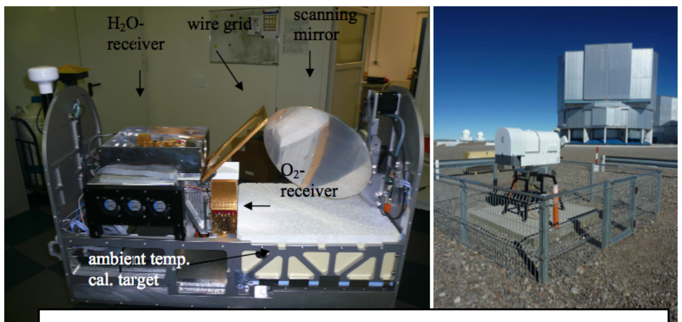
it is requested the knowledge of PWV

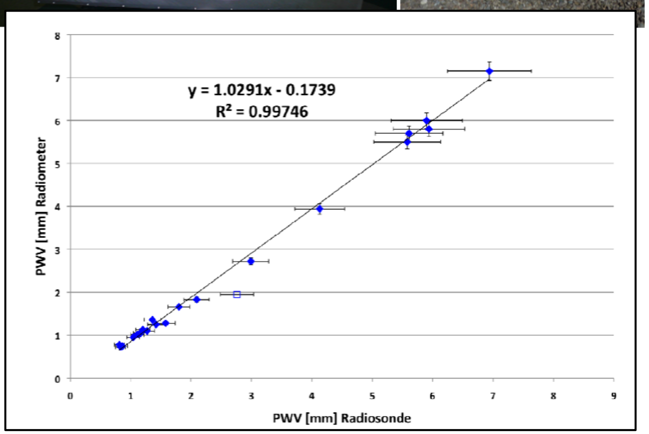
LHATPRO
Low Humidity (183GHz) and temperature (51GHz) profiling microwave radiometer

$$PWV = \int_{z=0}^{z=top} r(h)dh \quad (mm)$$

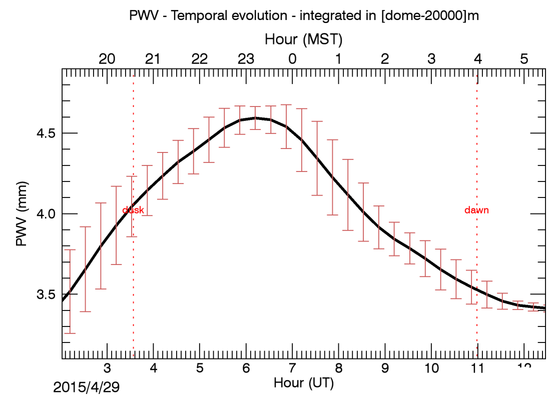
$$r(h) = \frac{m_w(h)}{m_d(h)} = \frac{\rho_w(h)}{\rho_d(h)}$$

water vapor density (kg·m^{-3})



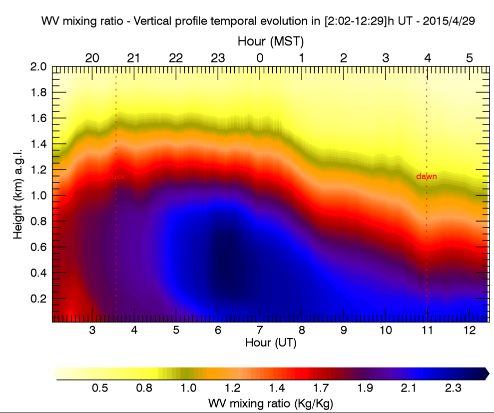


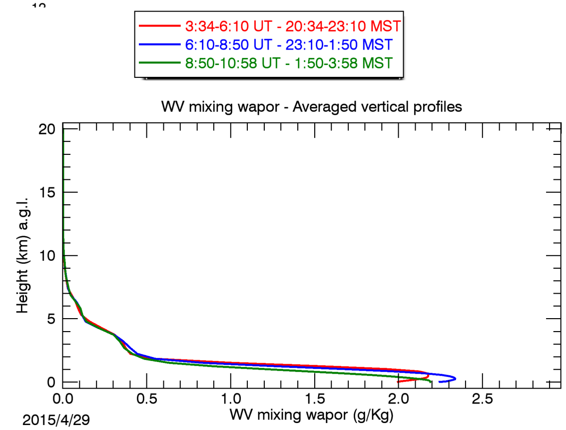
Florian Kerber et al., 2012, SPIE



Implemented in ALTA Center for LBTI

LBTO planned to buy LHATPRO





CONCLUSIONS

- We proved that we are able to forecasts the atmospherical parameters and the OT with a score of success that **is already sufficiently good** to definitely guarantee a useful impact on the service mode of top-class telescopes (VLT) and the E-ELT.
  [MOSE Final Review (Phase A and Phase B) took place successfully]

- We proved we are able to reconstruct C_N^2 profiles with ***turbulence layers as thin as 150 m*** !!!

this opens new perspectives for **WFAO**

- Our tool will have a direct application on most of the instruments at the VLT (e.g. AOF, SPHERE, ERIS, VISIR), and on new generation instruments for E-ELT (e.g. MOSAIC-MAORY, HARMONY, MOSAIC).

- Calibration Workshop Proposal (ref: Kerber)
  Enabling AO-assisted high precision astrometry for current and future imagers
  Our role: Scheduling astrometric observations

- **March 2016:** we concluded the negotiation with ESO for the implementation of an automatic operational system ***DEMOSTRATOR*** conceived for Paranal and Armazones
  We defined:
  - Budget
  - Duration of the project: two years
  - Starting data: we hope within 2017 (we are waiting for measurements from Stereo-SCIDAR)

- We are already involved in a similar project for LBT (**ALTA Center project**).
  Interesting synergies between the two systems

Waiting for the……

FATE Center

Forecasts of **A**tmosphere and **T**urbulence at **E**SO sites

Thanks for the attention

REFERENCES

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Lascaux, et al., 2015, MNRAS, 449, 1664

surface layer (forecast)

Masciadri, et al., 2013, MNRAS, 436, 1968

Masciadri, et al., 2015, Journal of Physics: Conference Series, 595, 012020
doi: 10.1088/1742-6596/595/1/012020

Vertical stratification on the whole 20km (forecast)

Masciadri, et al., 2017, MNRAS, 466, 520

Optical turbulence (forecast)

Masciadri, et al., 2014, MNRAS, 438, 983

Masciadri, et al., 2012, MNRAS, 420, 2399

Annexed studies on OT measurements from GS, MASS and DIMM used in the MOSE study