Optical turbulence forecasts:
perspectives for an efficient management of the observing programs at LBT

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OUTLINE

- **Scientific drivers:** why the optical turbulence (**OT**) forecast for the ground-based astronomy ?

- Which parameters can be predicted with the technique we propose: ***atmospherical non-hydrostatical mesoscale models*** *?*

- Which benefits in terms of improvement of:
★ efficiency of management of observing programs
★ efficiency of management of instrumentation
★ image quality

- State of art - Selection of results obtained at:
★ **Mt. Graham** (**ForOT project** funded by the EU-MC Excellence Grant 2006-2010)
★ **Cerro Paranal** and **Cerro Armazones** (**MOSE project** funded by ESO since 2011)

- *Forthcoming activities on OT forecasts for LBT/Mt.Graham* ('LBT Premiale' funds)

- Conclusions

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 mandatory to optimize the exploitation of ELTs and top class telescopes

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

4) Cost of a night of observation for a top class telescope is of the order of 100 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 is already used in many top class telescopes even if, in almost all cases, it is based on real time turbulence measurements, **NOT** on turbulence forecast

LIMIT OF THE EFFICIENCY !

OP

1)

2)

3)

4)

5)

★ The *optical turbulence forecast* is fundamental for the
1) ***success*** of the ELTs
2) ***optimized exploitation*** of top class telescopes of present time

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

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

The Service Mode is already used in many top class telescopes even if, in almost all cases, it is based on real time turbulence measurements, **NOT** on turbulence forecast

LIMIT OF THE EFFICIENCY !

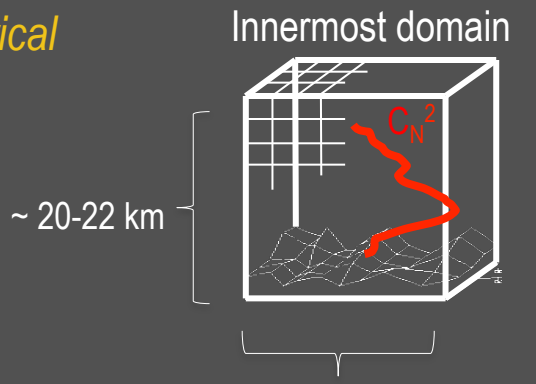
WHICH PARAMETERS CAN WE PREDICT ?

3D :
(x,y,z)

- Wind speed (WS)
- Wind direction (WD)
- Temperature (T)
- Pressure (p)
- Relative humidity (H)
- Dynamical outer scale (L_0)

Classical atmospherical parameters

Volumetric distribution of the OT (C_N^2)



2D :
(x,y)

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

wind speed

heigth

dynamic outer scale

Astroclimatic parameters

- 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

BENEFITS in TERMS OF EFFICIENCY of OBSERVATIONS

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

$BIAS_{med}$ and $RMSE_{med}$ < 1 °C (Lascaux et al., MNRAS, 2013)

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

$BIAS_{med}$ < 0.93 ms^{-1}; $RMSE_{med}$ ≤ 2.18ms^{-1} (Lascaux et al., MNRAS, 2013)

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

$BIAS_{med}$ < - 8.55°; $RMSE_{med}$ ~ [31-41]°; $RMSE_{REL}$ ~ [17-23]% (Lascaux et al.,MNRAS, 2013)

★**Vertical stratification [0,20km]**: among other the wind speed, main ingredient for the wavefront coherence time. There are not *monitors* that can routinely measure the wind speed stratification, particularly above mountain regions.

(Masciadri et al., MNRAS, 2013)

★**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.

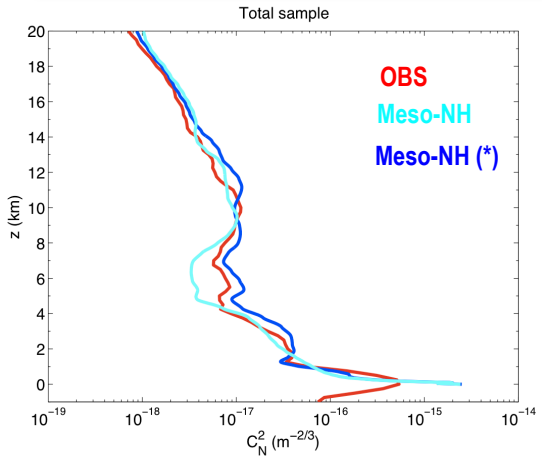
Examples of improvement of observing management we can obtain:

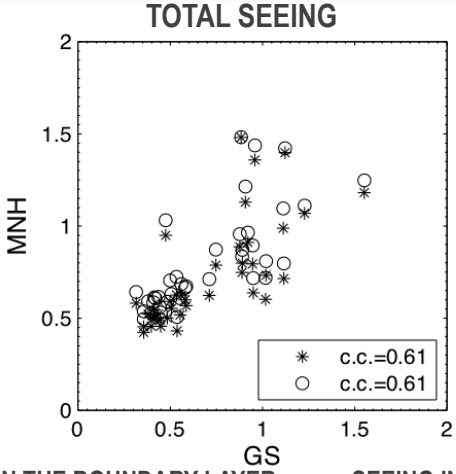
1) Identification of temporal windows in which AO can not work at all (ε > 1.5 arcsec or $\tau_0 < \tau_{0,threshold}$)
2) Identification of temporal windows in which the total seeing is extremely weak (ε < 0.7 arcsec) **for high-contrast imaging (extra-solar planets)**
3) Identification of temporal 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 !

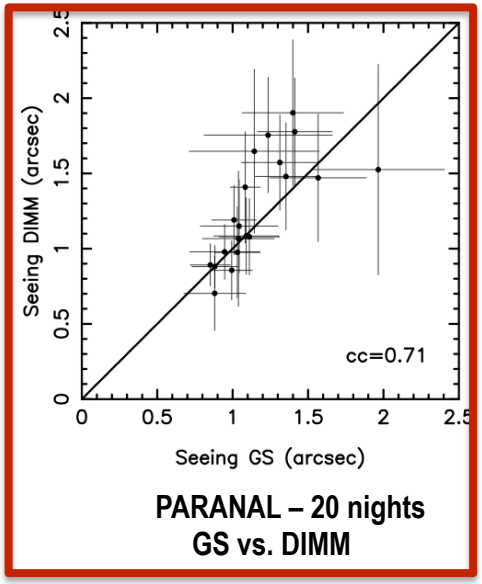
Mt.GRAHAM: optical turbulence

Hagelin et al., 2011, MNRAS

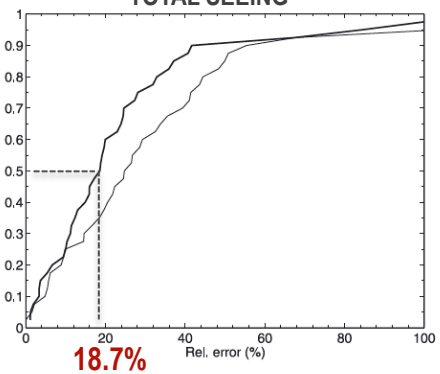


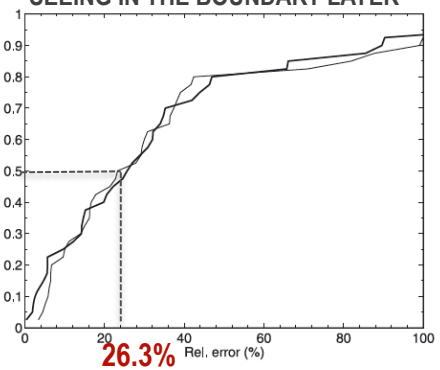


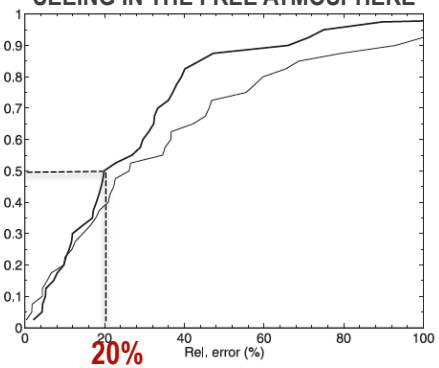
Generalized SCIDAR measurements related to 43 nights

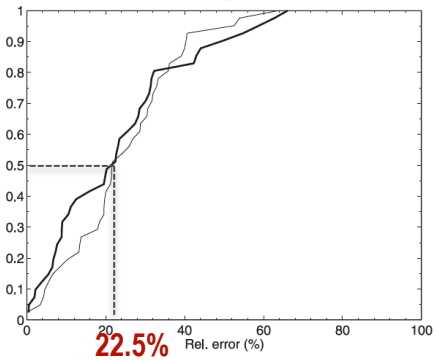


PARANAL – 20 nights
GS vs. DIMM

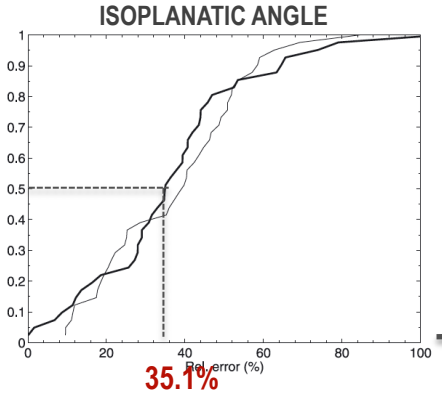






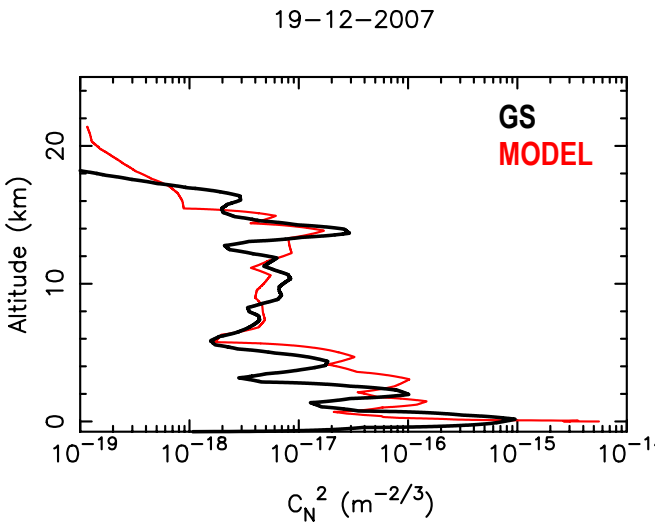


statistic done
on averaged estimates
on the whole night

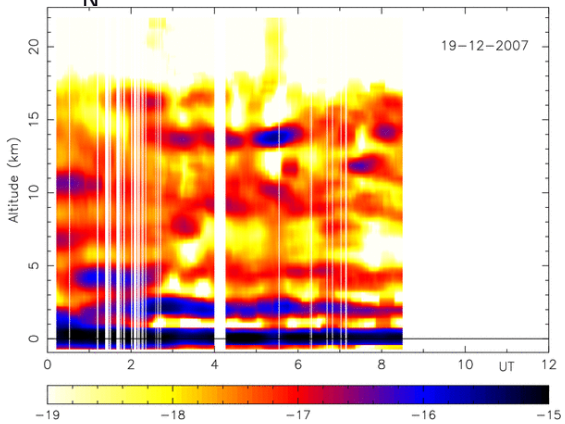


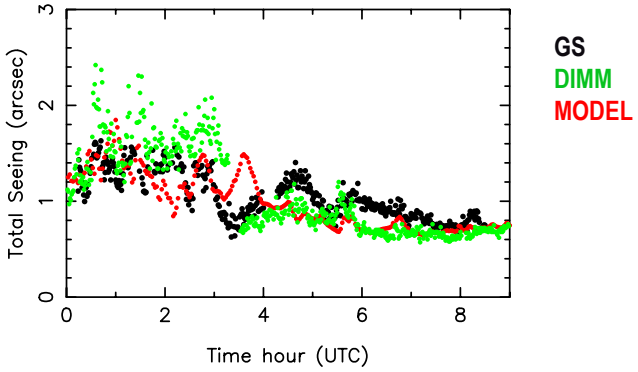
MODEL PERFORMANCES
ON INDIVIDUAL NIGHTS
(sample of 43 nights)

PARANAL – Night of 19/12/2007

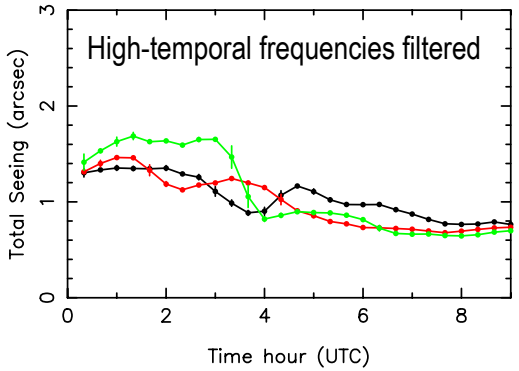


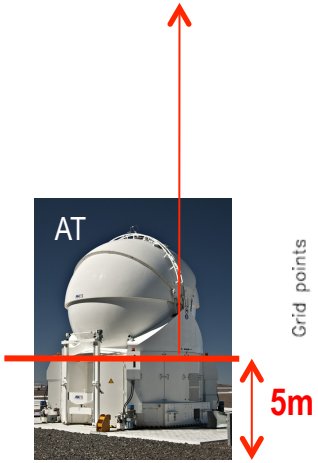
C_N^2 : GENERALIZED SCIDAR



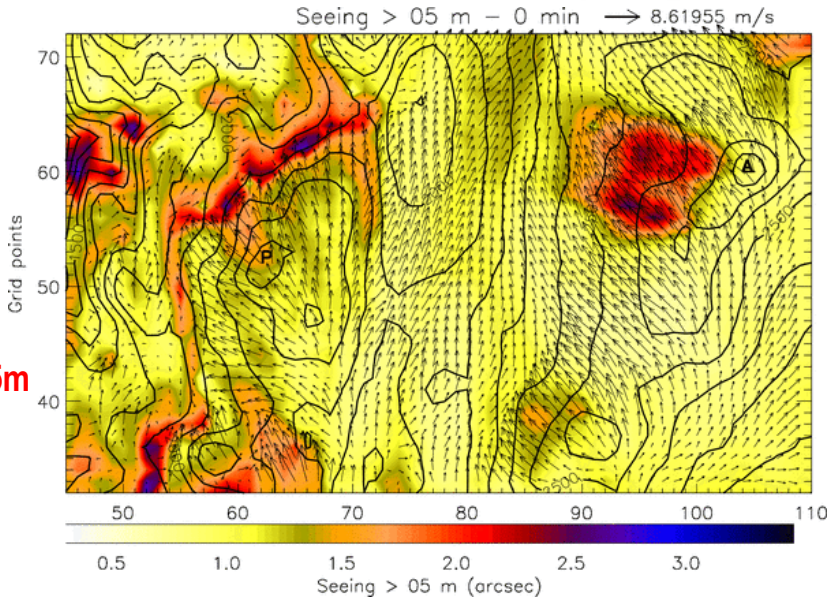


20071219; mov. aver.: +/− 30min; sampl.= 20min





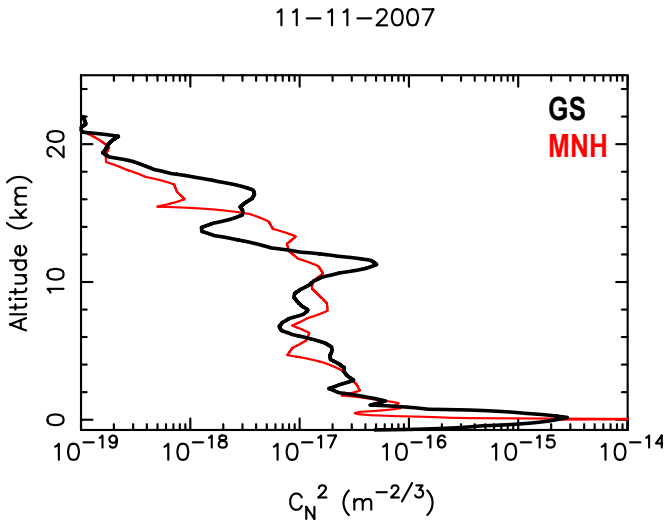
32.5 km x 20 km; Δx=500m; wind speed @ 10m



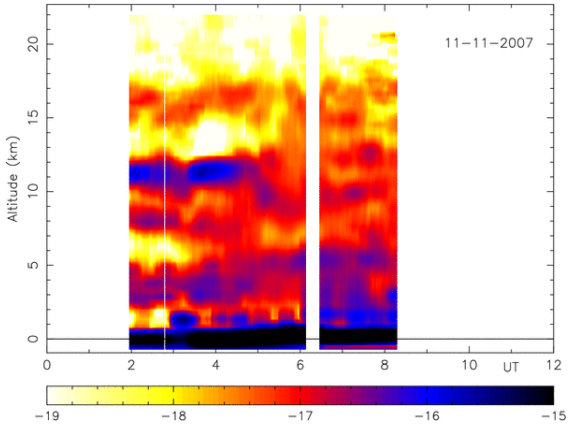
SIMULATIONS with the non-hydrostatic atmospherical meso-scale model + Astro package (Astro-Meso-Nh)

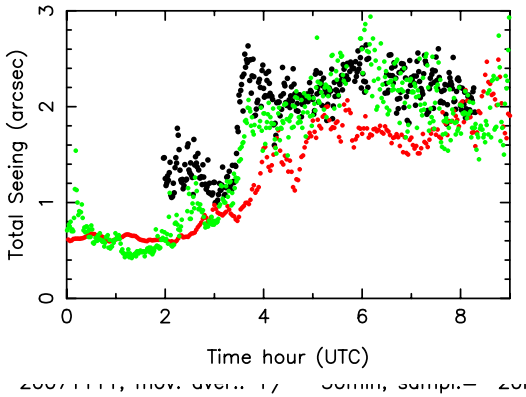
ΔT=9 hours - night ; (00:00 - 9:00) UT; sampling=5 min

PARANAL– Night of 11/11/2007

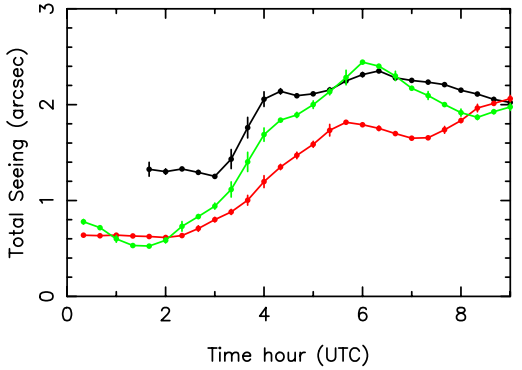


C_N^2 : GENERALIZED SCIDAR

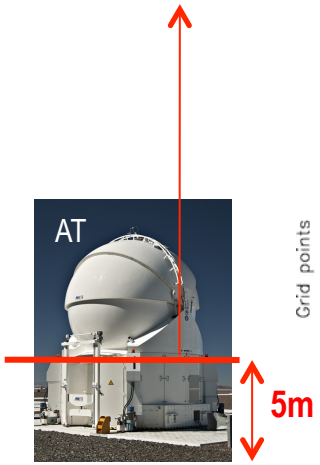


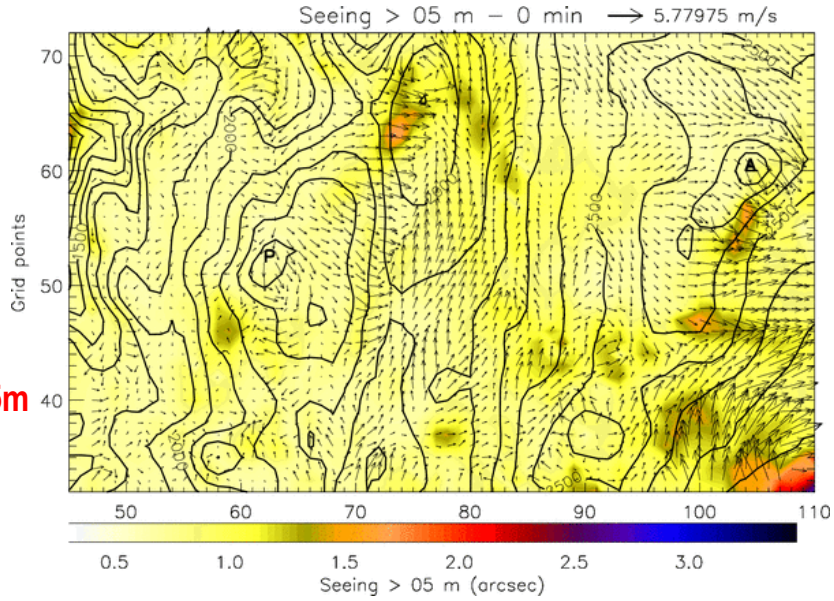


GS
DIMM
MNH



32.5 km x 20 km; Δx=500m; wind speed @ 10m



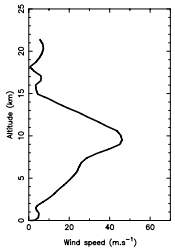


SIMULATIONS with the non-hydrostatic atmospherical meso-scale model + Astro package (Astro-Meso-Nh)

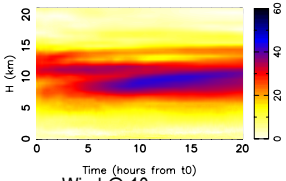
ΔT=9 hours - night; (00:00 - 9:00) UT; sampling=5 min

FORTHCOMING PLANS for OT forecasts @ LBT/Mt.Graham

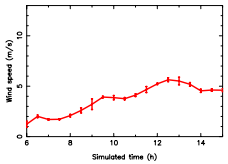
Wind

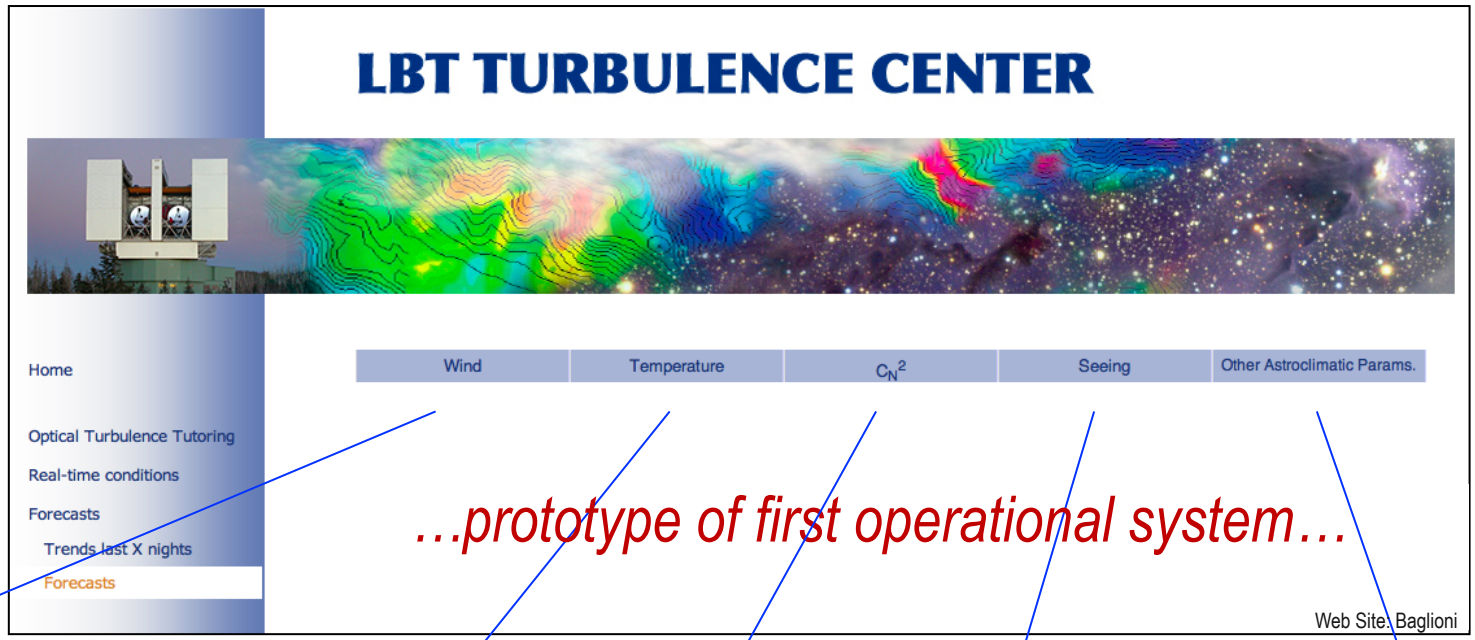


Wind



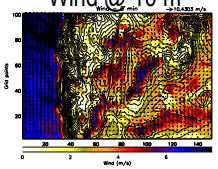
Wind @ 10 m



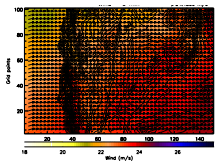


Vertical profile (average) - ΔT = 3 hours
Temporal evolution at the ground
Horizontal map at 200 mb (jet stream level)
Horizontal map at 10 m
Animation horizontal map

Wind @ 10 m

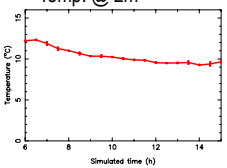


Wind @ 200 mb

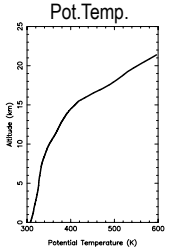


Vertical profile (average) - ΔT = 3 hours
Temporal evolution at 2m
Animation horizontal maps

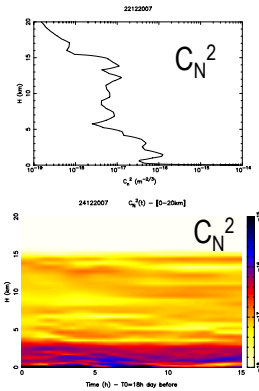
Temp. @ 2m



Pot.Temp.

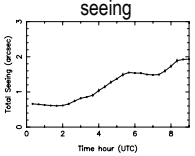


Vertical profile (average) - ΔT = 3 hours
Temporal evolution

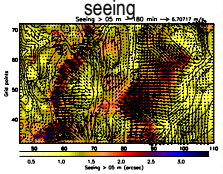


Temporal evolution
Horizontal map average
Polar map
Animation horizontal maps

seeing



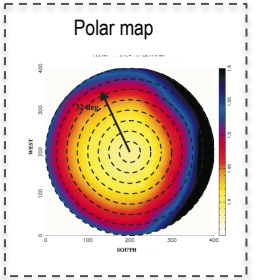
seeing



θ_0, τ_0
Temporal evolution
Horizontal map average
Animation horizontal maps

not yet implemented

Polar map



CONCLUSIONS

PROPOSED PROJECT: LTC (LBT Turbulence Center)

★ We propose to forecast:

- Atmospherical parameters in the surface layer [0-30] m : temperature, wind speed, wind direction, relative humidity,…
- Vertical stratification of atmospherical parameters on [0-20]km : temp., wind speed and direction, rel. humidity, dynamical outer scale,..
- Optical Turbulence: C_N^2 and integrated astroclimatic parameters (ε, θ_0, τ_0)

with the **atmospherical non-hydrostatical mesoscale model Meso-Nh + Astro-package**

★ I presented **HOW** and **WHY** the proposed technique can concretely improve the present image quality and an efficient exploitation of *observing programs* and *instrumentation.selection* during the night.

★ Feasibility studies have been already performed at **Mt.Graham** (***ForOT project***) and **Paranal and Armazones** (***MOSE project)*** and we **PROVED** the very promising model performances.
(ESO approved a Phase B study and they are talking about Phase C…)

★ **Ready to start a new phase: implementation of the first prototype of operational system for LBT (as soon as funds available)**
★ **Automatization: ~ 50 k€ (LBT Premiale 2012)**
★ **Hardware for forecasts (dedicated to LBT): ~ 10-20 k€**
★ **Yearly prediction costs: we estimate no more than 50 K€ for year (TBD precisely with details of all the output products)**

- Up-dating of master model version
- Up-dating of Astro-MNH version package
- Tuning of initialization data format (GRIB files)
- Up-dating repository (web page)
- Initialization data cost (for year)

} *service costs*

OT FORECAST:
very advantageous
ratio costs/benefits !!!