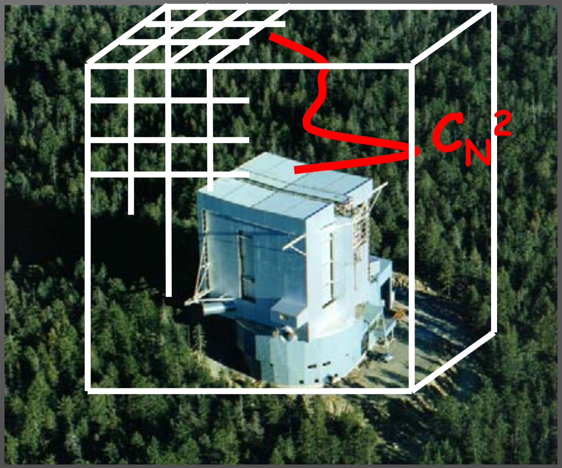
OPTICAL TURBULENCE SIMULATIONS WITH MESO-SCALE MODELS

" TOWARDS A NEW GROUND-BASED ASTRONOMY ERA "



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Kona – Hawaii March 2007

1997 - 2007

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3D Optical Turbulence Forecasts above Astronomical Sites

http://forot.arcetri.astro.it

Outline

- Meso-scale models challenges in Astronomy
- Dynamic and Optical Turbulence Parameterization
- Review "mesoscale simulations" in astronomic field
- MESO-NH* Model Reliability
- ForOT: an answer to the missing link between astronomy/meteorology

**Meso-Nh code: CNRM-LA, Toulouse, France*
Astro Meso-Nh code: Masciadri et al. 1999

Meso-scale models potentiality

Ground-based astronomy is still competitive with respect to the space-based one

- Lower financial investment
- Longer typical lifetime
- Better angular resolution thank to the larger pupils size of ground-based telescopes

AO techniques can correct perturbations induced by atmospheric turbulence

PROBLEM

Instruments provide LOCAL measurements

?

Meso-scale models potentiality

$$D_N(\rho) = \left\langle \left[n(r) - n(r+\rho) \right]^2 \right\rangle = C_N^2 \cdot \rho^{2/3}$$

$l_0 < \rho < L_0$

Kolmogorov Model

3D V, T, p, L_0, C_N^2

(x,y,z)

wind speed

2D

(x,y)

$$\int_0^\infty F(h, V, L_0) \cdot C_N^2 dh \quad \Rightarrow \quad \varepsilon, \theta_0, \tau_0, \sigma^2, \mathcal{L}_0, h_M, \theta_M \; (M=1,2,3)$$

heigth

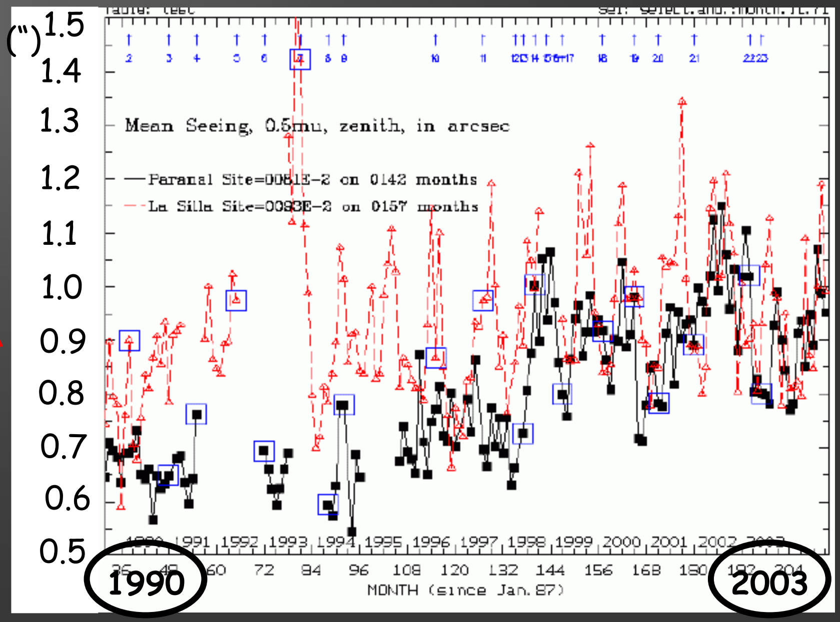
dynamic outer scale

Meso-scale models challenges in Astronomy

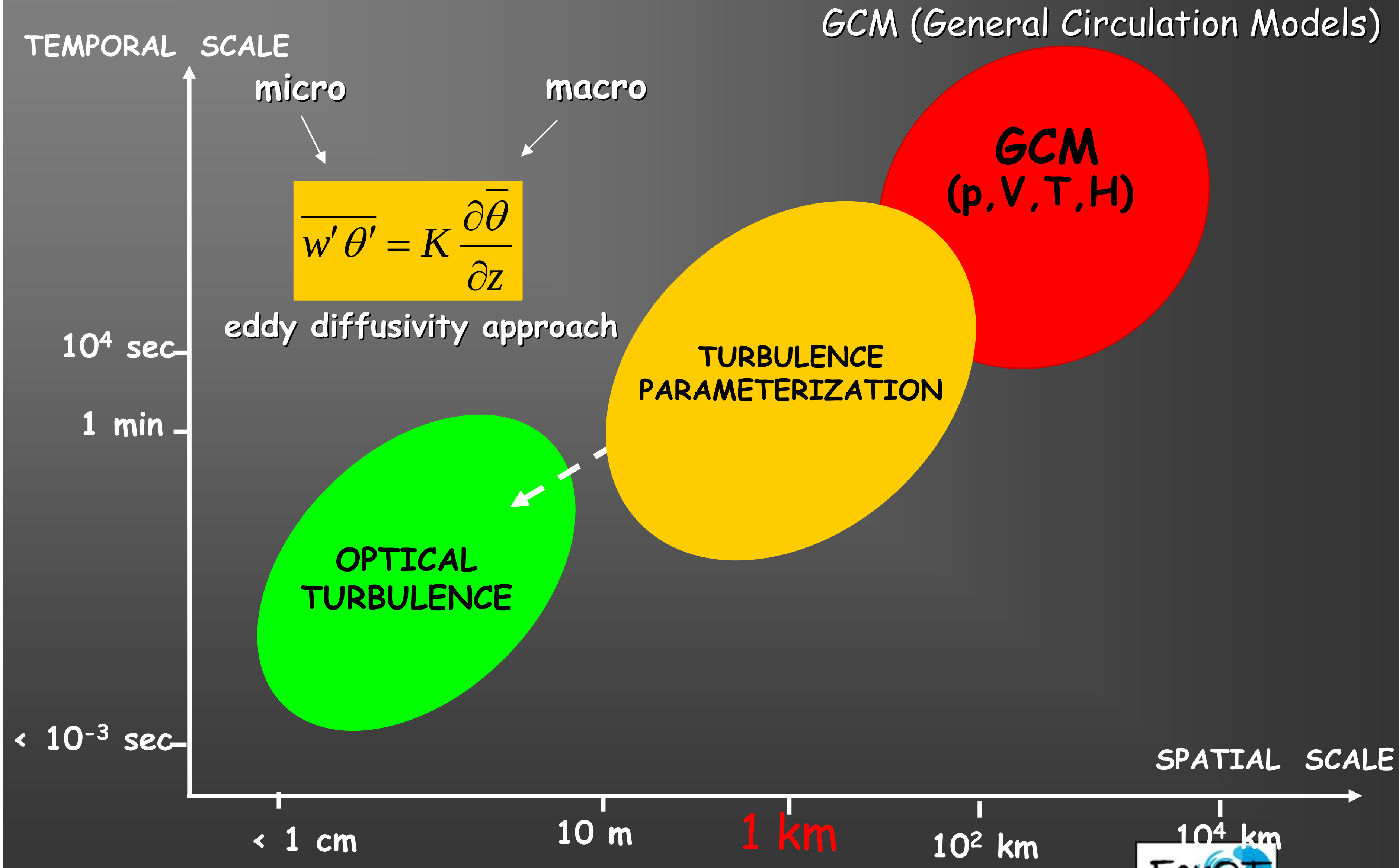
- To *forecast* the optical turbulence → flexible-scheduling
- To reconstruct *3D C_N^2 maps* in a region around a telescope
- To perform a *climatology* of the optical turbulence extended over decades (access to "past")

No other tools of investigation
for these scientific goals

Seeing @ Cerro Paranal – black dots



Parameterization



GCM (General Circulation Models)

TEMPORAL SCALE

micro

macro

$$\overline{w'\theta'} = K\frac{\partial\overline{\theta}}{\partial z}$$

eddy diffusivity approach

GCM
(p,V,T,H)

TURBULENCE PARAMETERIZATION

OPTICAL TURBULENCE

10^4 sec

1 min

< 10^{-3} sec

SPATIAL SCALE

< 1 cm

10 m

1 km

10^2 km

10^4 km

Parameterization in MESO-NH

Dynamic Turbulence Parameterization

Bougeault et al. 1989
Cuxart et al. 1995

mixing length - $L_0(h)$

turbulent kinetic energy

$$w'\theta_v' = \underbrace{-0.16 \cdot L \cdot \sqrt{e} \cdot \phi_3}_{K} \cdot \frac{\partial \overline{\theta}_v}{\partial z}$$

microscopic

macroscopic

thermo-dynamic stability term
Redelsperger & Sommeria 1981

Buoyancy term
of
TKE equation

Optical Turbulence Parameterization (Astro-MesoNh)

mixing length - $L_0(h)$

potential temperature

$$C_T^2 = 0.58 \cdot \phi_3 \cdot L^{4/3} \cdot \left(\frac{\partial \overline{\theta}}{\partial z}\right)^2 \quad \Rightarrow \quad C_N^2 = \left(\frac{80\times10^{-6} \cdot P}{T^2}\right)^2 C_T^2$$

Masciadri et al. 1999a
Masciadri et al. 2001

Gladstone's law

Review in Astronomical field (1)

- 1986 Coulman *[Ref: 1986, PASP, 98, 376]*
- 1995 Bougeault et al. *[Ref:Applied Optics, 1995, 34, 3481]*
  - First Hydrostatic model (PERIDOT)
  - Orographic model (3-10 km)
- 1999/2001 Masciadri, Vernin, Bougeault *[Ref:1999a, A&ASS, 137, 185]*
  - First Non-hydrostatic model (MESO-NH) *[Ref:1999b, A&ASS, 137, 203]*
  - Orographic model ($\Delta x < 1$km) *[Ref:2001, A&A, 365, 699]*
  - First employment of vertical turbulence distribution (C_N^2 profiles)
- 2001 Masciadri & Jabouille *[Ref: 2001, A&A, 376, 727]*
  - New calibration method
- 2002 Masciadri, Avila, Sanchez *[Ref: 2002, A&A, 382, 378]*
  - First evidence of the horizontal finite extent turbulent layers

Review in Astronomical field (2)

- 2002 Businger et al. *[Ref: 2002, BAMS, 858]*

  - The Mauna Kea Weather Center is announced

- 2003 Masciadri *[Ref:2003, RMxAA, 39, 249]*

  - Mesoscale models and near ground wind speed for ELT site selection
  - Mesoscale models (25-45) % better than GCMs

- 2004 Masciadri, Avila, Sanchez *[Ref: 2004, RMxAA , 40, 3]*

  - First model validation in statistic terms (10 nights – San Pedro Mártir)
  - Measurements: GS, thermosondes, mast, DIMM

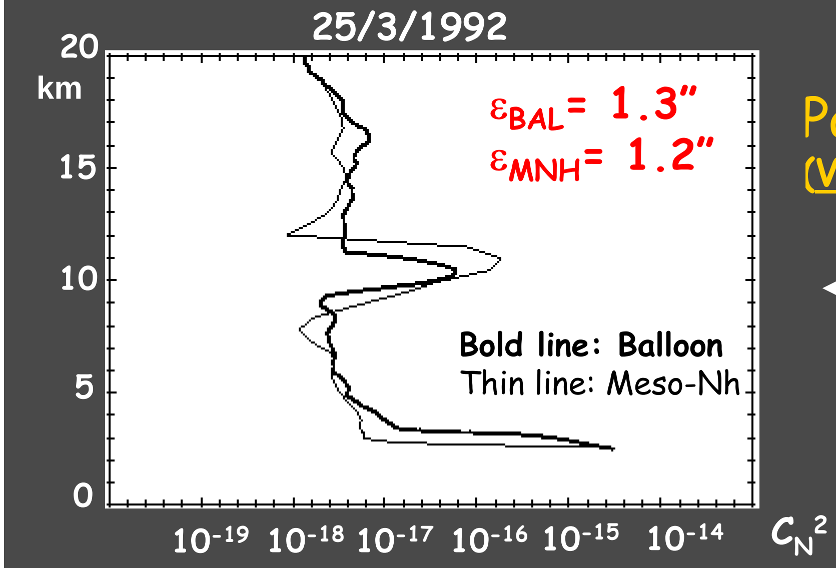
- 2006 Masciadri & Egner *[Ref: 2006, PASP, 118, 849, 1604]*

  - First statistic analysis (1 year) of C_N^2 & ALL astro-climatic parameters

    ε, θ_0, τ_0, σ^2, $\mathcal{L}_0$, h_M, θ_M (M=1,2,3)

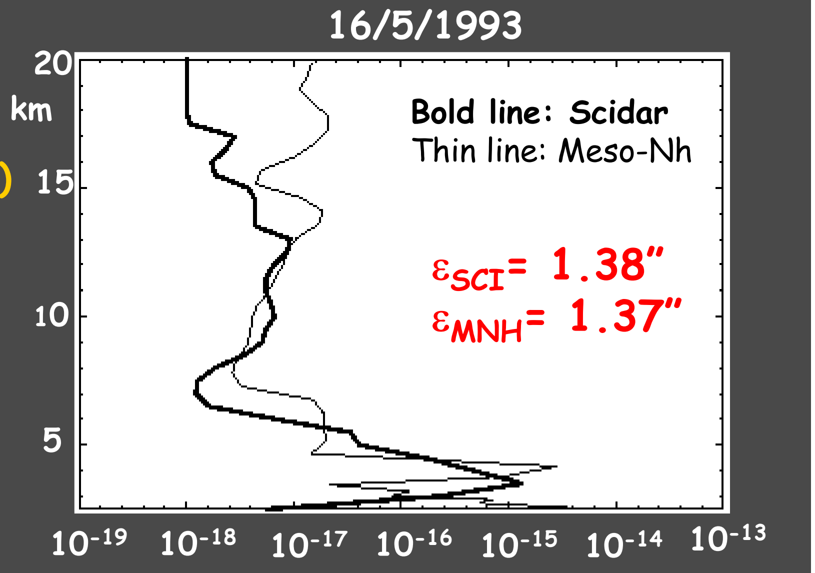
Cherubini
Adair } MM5 developed by NCAR (US)

Can we simulate the optical turbulence ?



25/3/1992

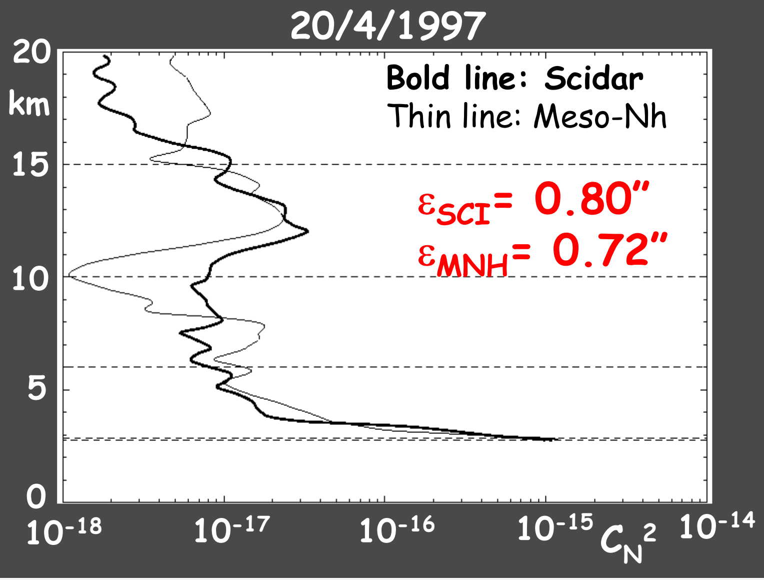
Paranal 1992
(VLT site testing)



16/5/1993

Paranal 1993
(VLT site testing)

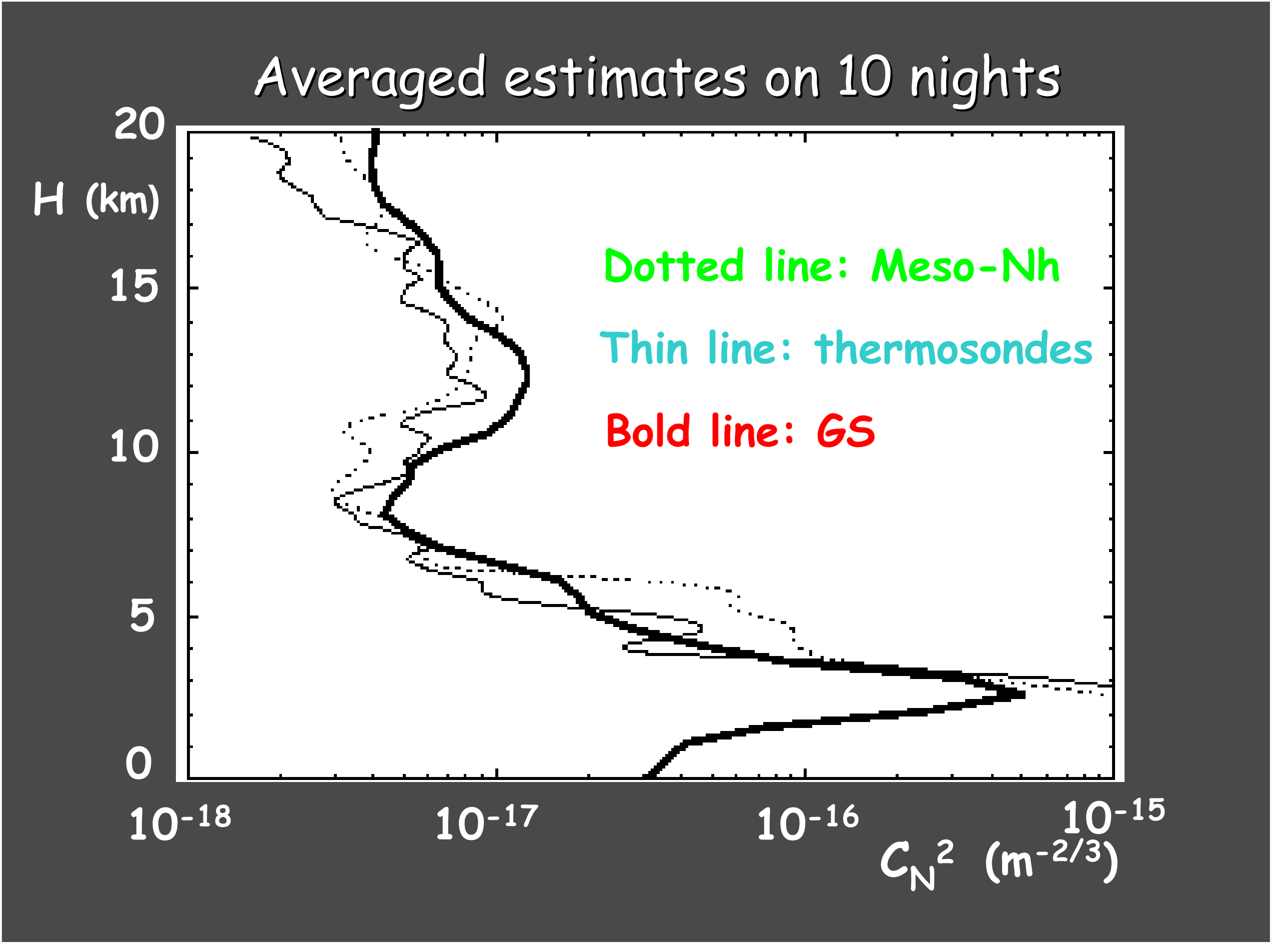
San Pedro Martir
1997



20/4/1997

Meso-Nh model Validation & Reliability (1)

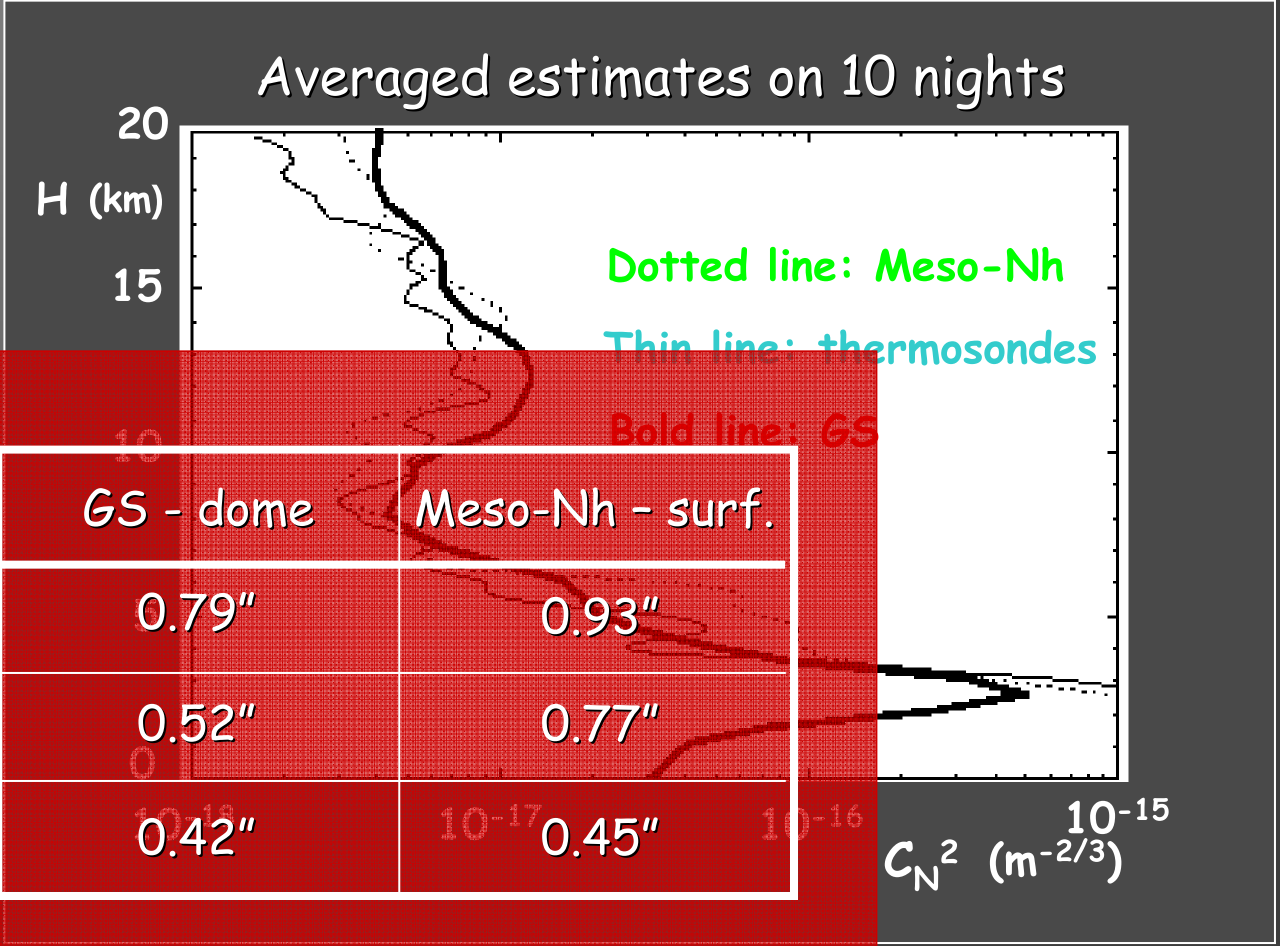
San Pedro Martir - Baja California, Mexico



Masciadri, Avila, Sanchez, 2004, RMxAA, 40, 3

Meso-Nh model Validation & Reliability (2)

San Pedro Martir - Baja California, Mexico



	GS - dome	Meso-Nh - surf.
ε_{TOT}	0.79"	0.93"
ε_{BL}	0.52"	0.77"
ε_{FA}	0.42"	0.45"

$\Delta\varepsilon_{TOT}$ = 0.14"

Masciadri, Avila, Sanchez, 2004, RMxAA, 40, 3

Meso-Nh model Validation & Reliability (3)

- GS/Meso-Nh $\Delta\varepsilon \sim 30$ % San Pedro Martir

Masciadri, Avila, Sanchez, 2004, RMxAA, 40, 3 10 nights

- GS/thermosondes $\Delta\varepsilon \sim 30$ %

Masciadri, Avila, Sanchez, 2004, RMxAA, 40, 3 San Pedro Martir

Azouit & Vernin, 2005, PASP 4 weeks Cerro Pachon

- GS/MASS $\Delta\varepsilon \sim 20$ % @ 8-16 km

  $\Delta\varepsilon \sim 50\text{-}100$ % @ 0-4 km

Tokovinin et al., 2005, PASP, 117, 395 4 nights Mauna Kea

Meso-Nh model Validation & Reliability (4)

- **GS/Meso-Nh $\Delta\varepsilon \sim 30$ %** San Pedro Martir

  Masciadri, Avila, Sanchez, 2004, RMxAA, 40, 3 10 nights

- **GS/thermosondes $\Delta\varepsilon \sim 30$ %**

  Masciadri, Avila, Sanchez, 2004, RMxAA, 40, 3 San Pedro Martir

  Azouit & Vernin, 2005, PASP 4 weeks Cerro Pachon

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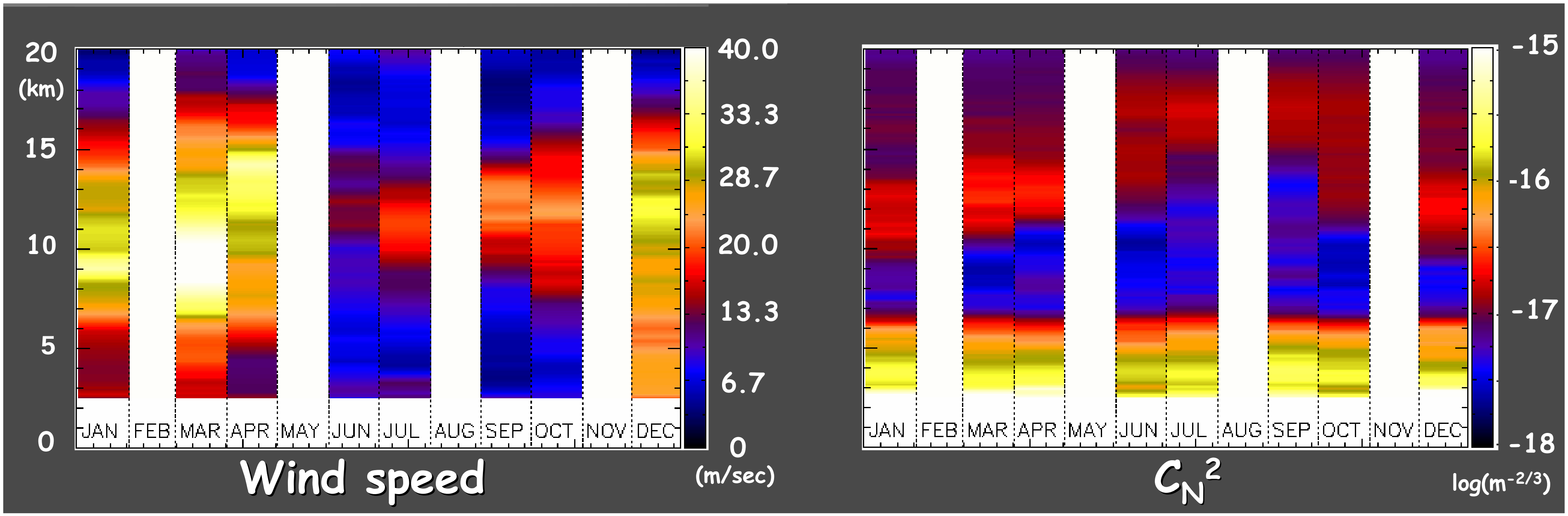
Meso-Nh can be used to characterize
OT on long time extent

↓

Optical Turbulence Climatology

First statistical analysis of ALL astroclimatic parameters (1)

SPM - 80 nights – uniformly distributed along 1 year

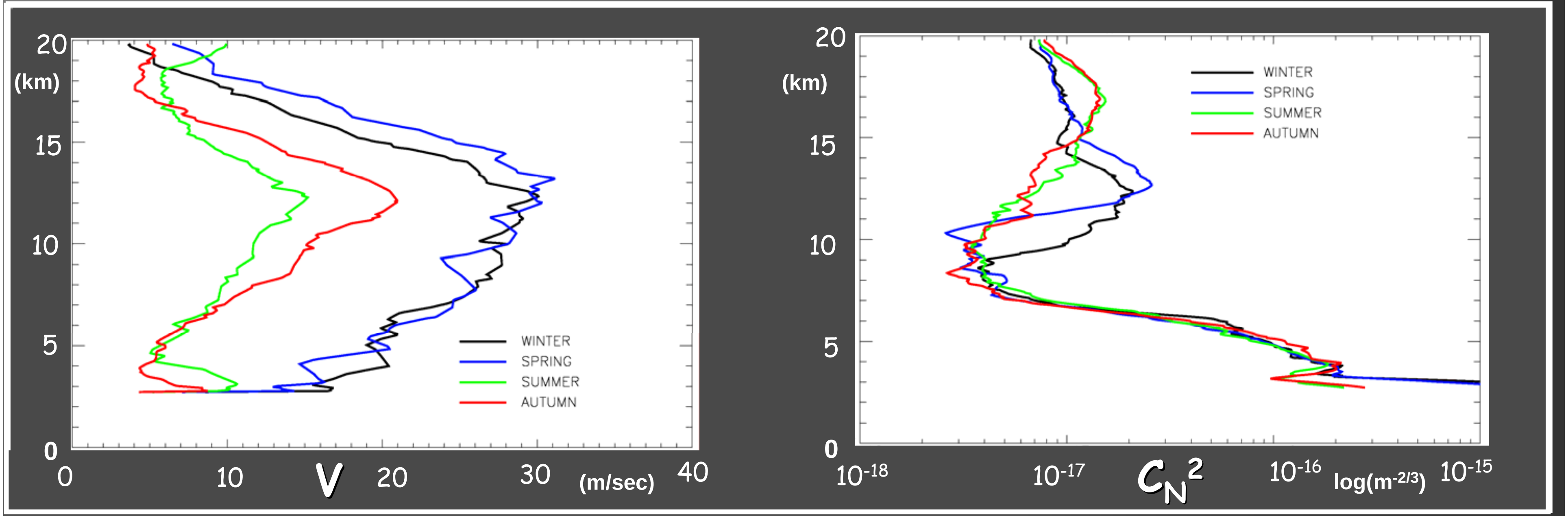


Masciadri & Egner, PASP, 2006

- Is this seasonal trend universal ?
- Which is the physical explanation of such a trend ?
- Which effects on other astro-climatic parameters ?

First statistical analysis of *ALL* astroclimatic parameters (2)

SPM - 80 nights – uniformly distributed along 1 year



Masciadri & Egner, PASP, 2006

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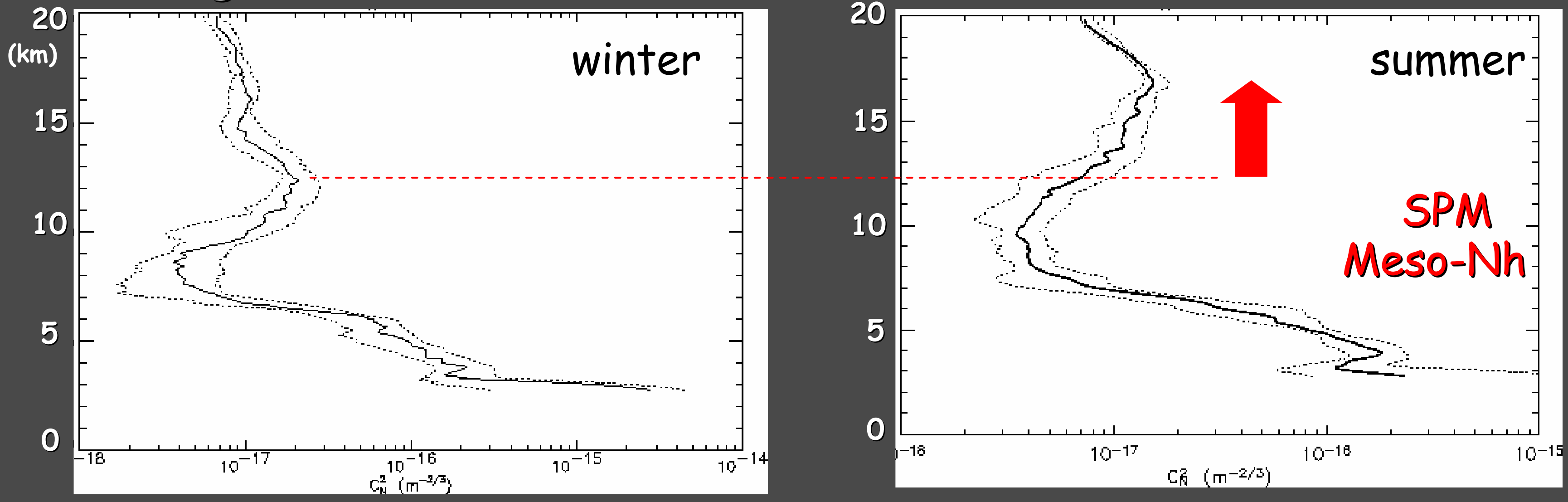
- Which effects on other astro-climatic parameters ?

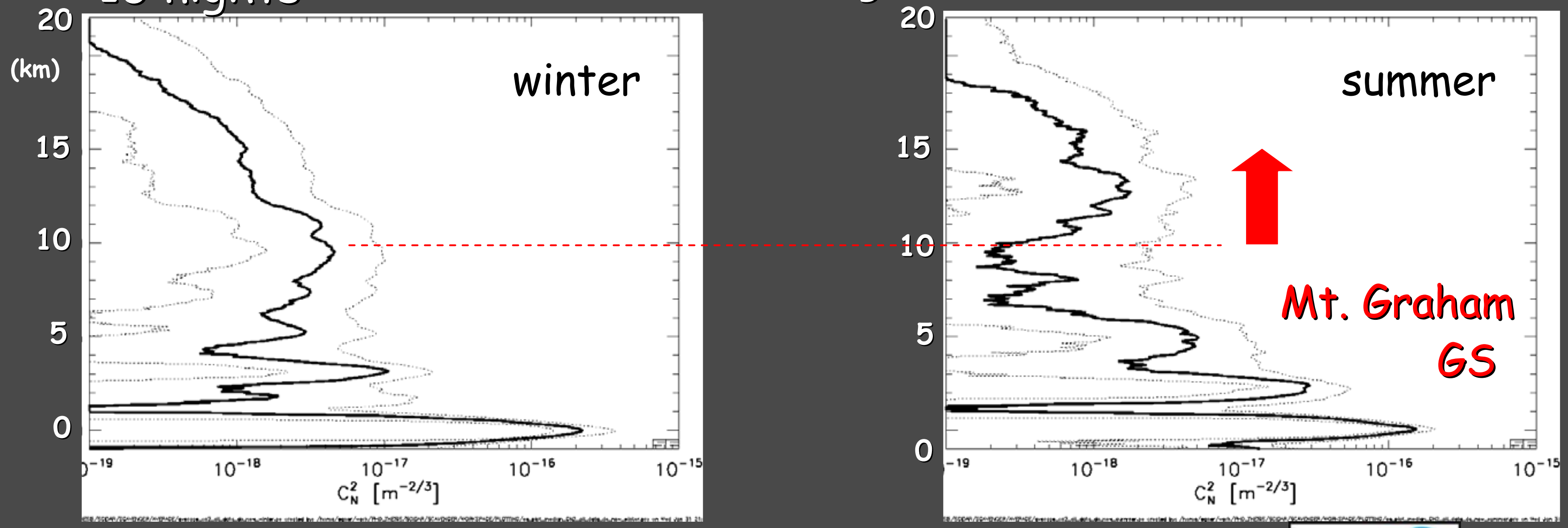
80 nights

Masciadri & Egner, PASP, 2006



16 nights

Egner, Masciadri, McKenna, to be submitted



Simulations vs. Measurements

Masciadri & Egner, PASP, 2006

SIMULATIONS

- *Masciadri & Egner (2006)*

  $\varepsilon_{(10-15)km} \sim 0.22''$

  $\theta_0 \sim 1.42''$

MEASUREMENTS

- *Avila et al. (2004)*

  $\varepsilon_{(10-15)km} \sim 0.24''$

  $\theta_0 \sim 1.87''$

$\}$ median $\{$

Seasonal variation

$\Delta\varepsilon_{summer-winter}$

- *Masciadri & Egner (2006)*

  $\Delta\varepsilon_{sum.-wint.} \sim 0.22''$

- *Michel et al. (2003)*

  $\Delta\varepsilon_{sum.-wint.} \sim 0.22''$ (DIMM)

- *Echevarria et al. (1998)*

  $\Delta\varepsilon_{sum.-wint.} \sim 0.11''$ (SST)

ForOT: an answer to the missing link astronomy/meteorology

NEXT STEPS

1. Forecast of the optical turbulence
2. Search and selection of NEW sites
3. Implementation of models on autonomous machines → research group

ForOT

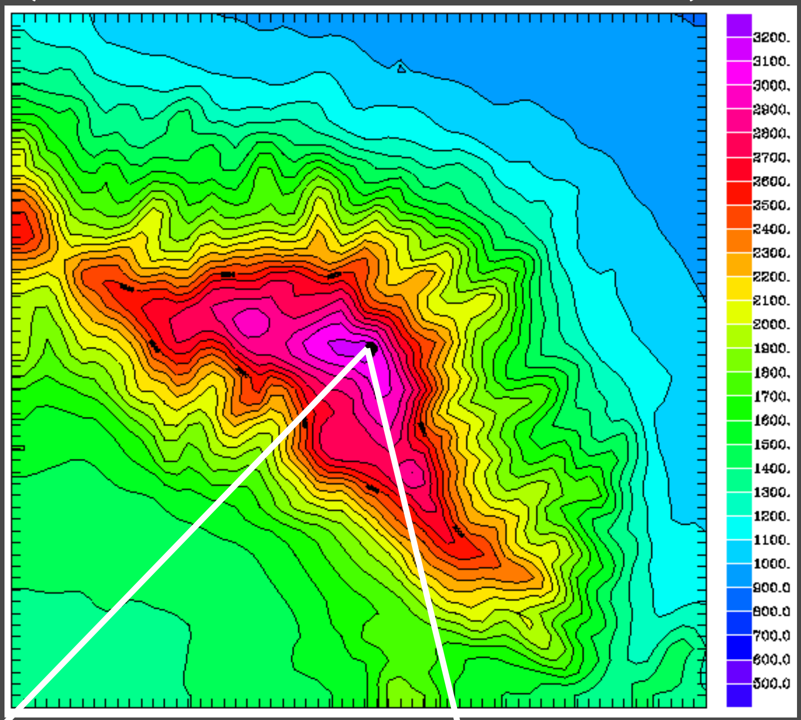
an indipendent research group

funded by the European Community

ForOT Core Project (1)

Mt. GRAHAM

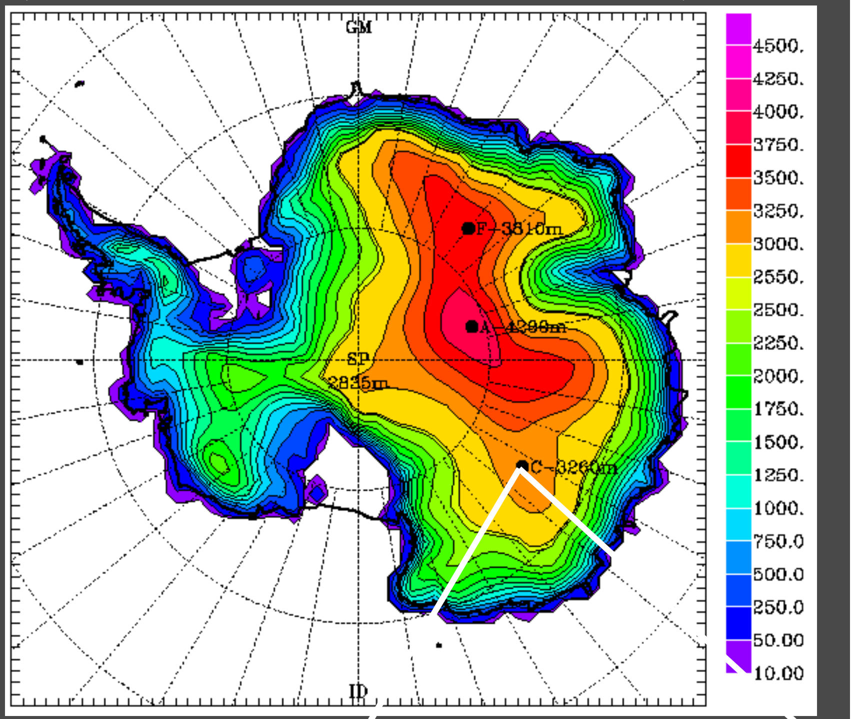
30 km



Δx = 500 m

ANTARCTIC PLATEAU

6000 km



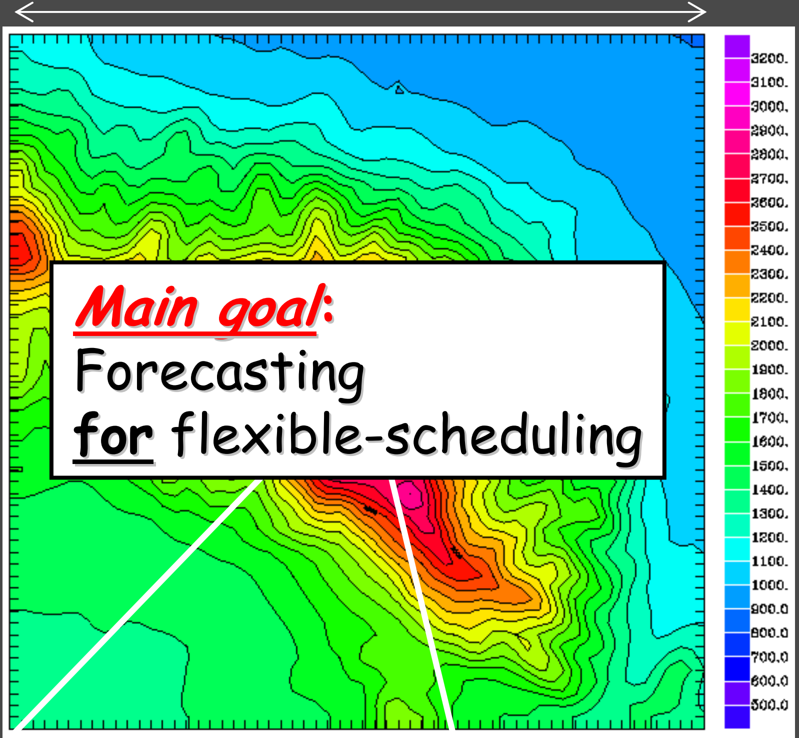
Δx = 100 km

MESO-NH
model

ForOT Core Project (2)

Mt. GRAHAM

30 km

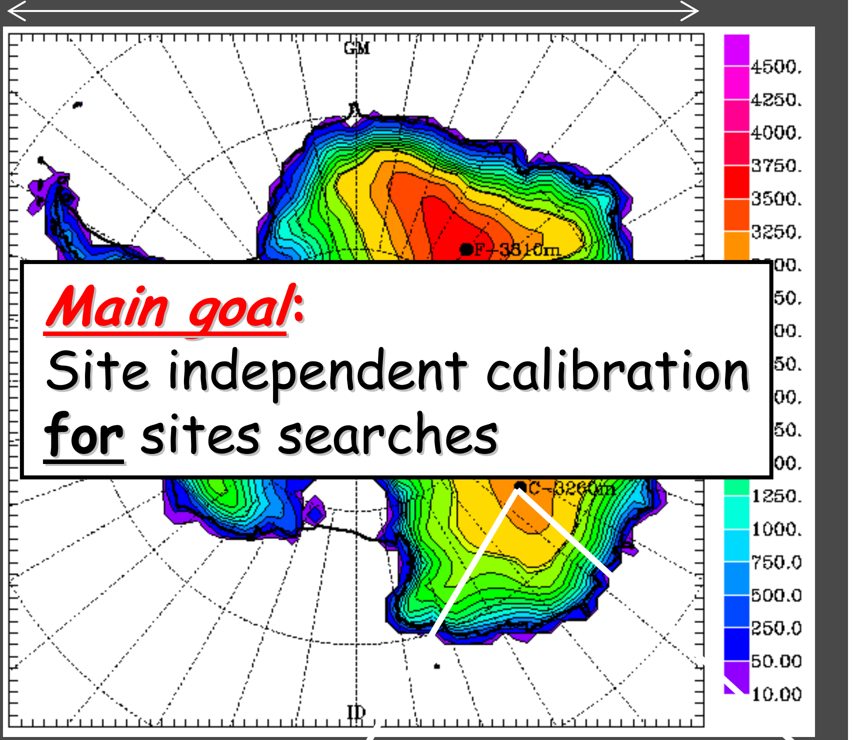


***Main goal*:**
Forecasting
for flexible-scheduling

Δx = 500 m

ANTARCTIC PLATEAU

6000 km



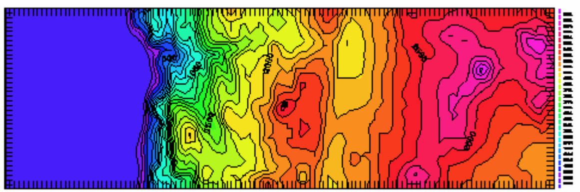
***Main goal*:**
Site independent calibration
for sites searches

Δx = 100 km

MESO-NH model

ELTs

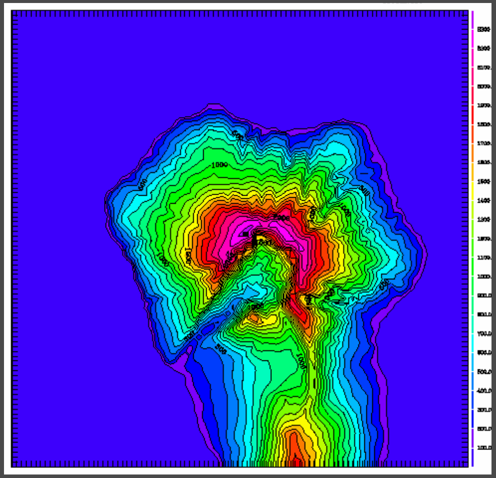
Cerro Paranal - Chili



60 km, Δx=500 m

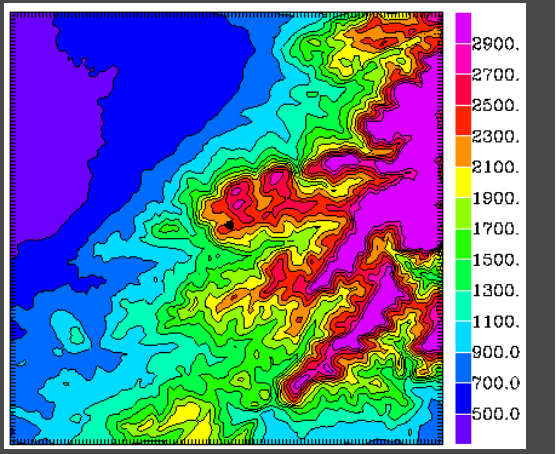
2008 – FP6 ELT Design Study
(MASS, GS, SLODAR, DIMM)

Roque de Los Muchachos
Canaries Island



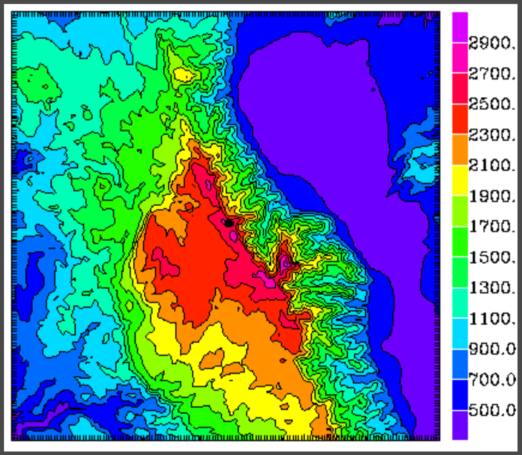
32.8 km, Δx=400m

Maidanak
Uzbekistan



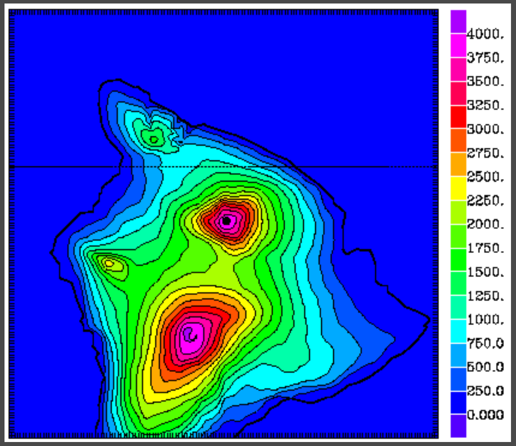
120 km, Δx=1km

San Pedro Mártir
Baja California



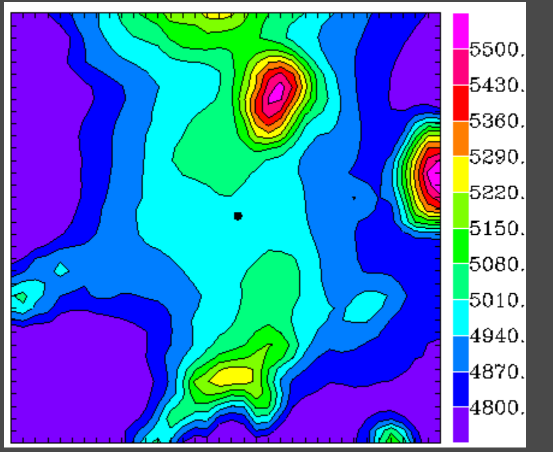
60 km, Δx=400m

Mauna Kea - Hawaii

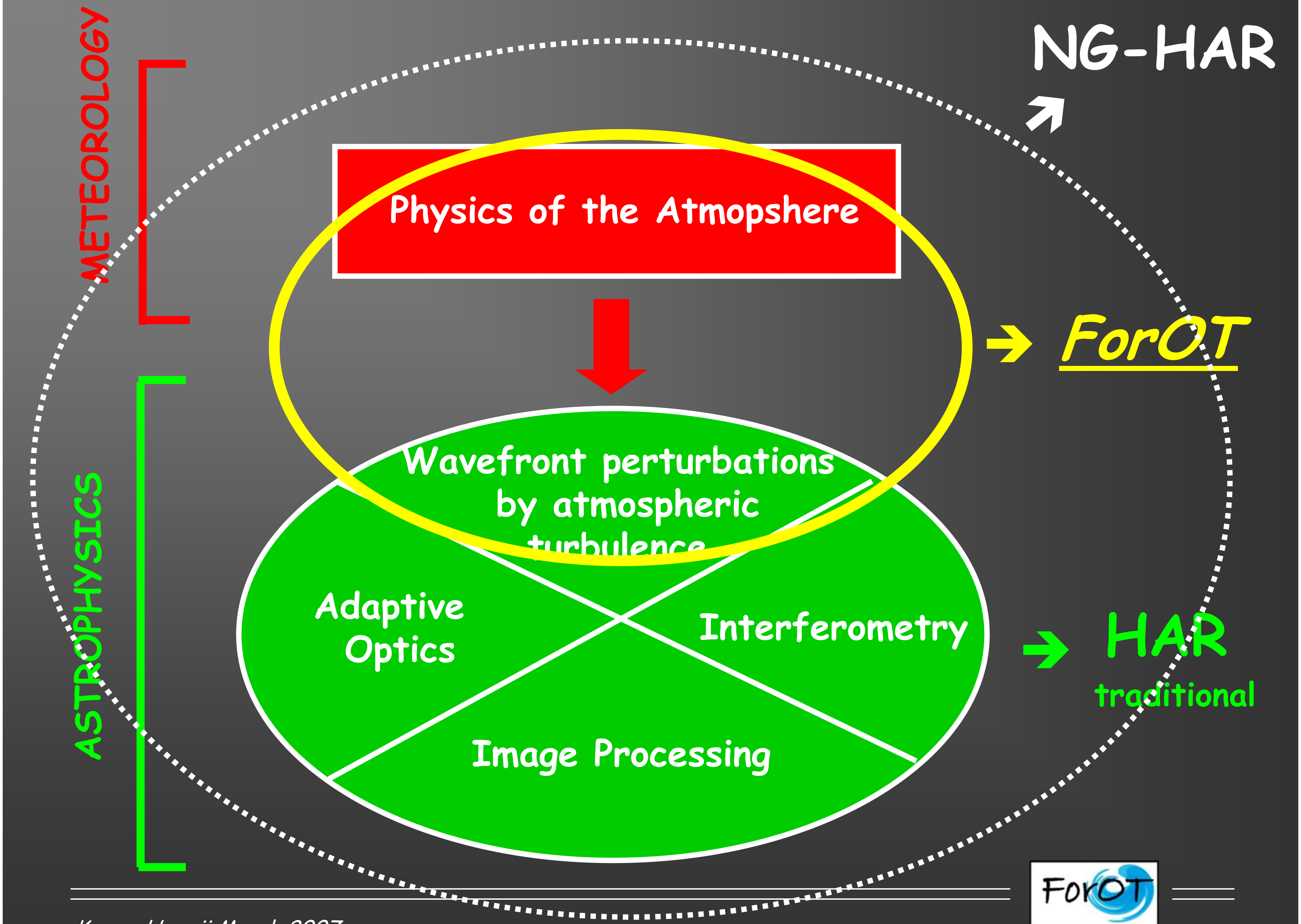


150 km, Δx=1km

Cerro Chajantor - Chili



14.4 km, Δx=400m



NG-HAR

METEOROLOGY

ASTROPHYSICS

Physics of the Atmopshere

Wavefront perturbations by atmospheric turbulence

Adaptive Optics

Interferometry

Image Processing

→ ForOT

→ HAR

traditional

END

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MARIE CURIE ACTIONS