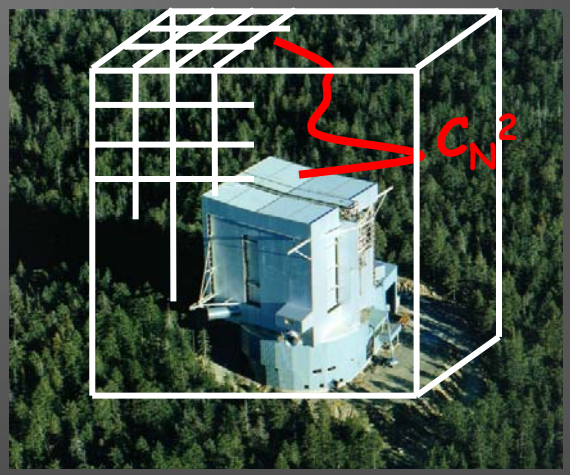
OPTICAL TURBULENCE SIMULATIONS WITH MESO-SCALE MODELS

" TOWARDS A NEW GROUND-BASED ASTRONOMY ERA "



Elena Masciadri

INAF- Osservatorio Astrofisico di Arcetri, Italy

1997 - 2007

Avila Remy
Azouit Max
Bougeault Philippe
Egner Sebastian
Garfias Tania
Geissler Kerstin
Jabouille Patrick
* Hagelin Susanna
* Lascaux Franck
McKenna Dan
Sanchez Leonardo
* Stoesz Jeff
Vernin Jean

* FOROT Team

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

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

(x,y)

heigth

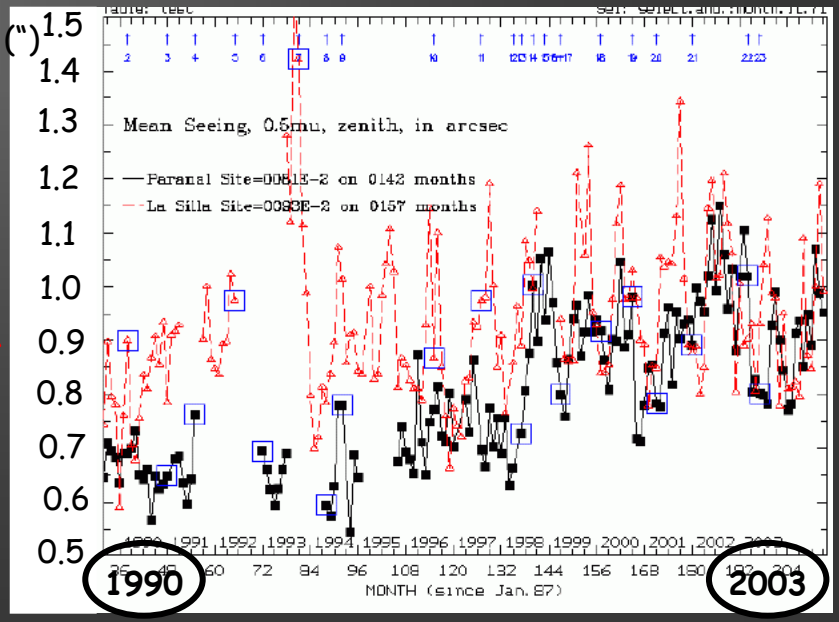
dynamic outer scale

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

Meso-scale models challenges in Astronomy

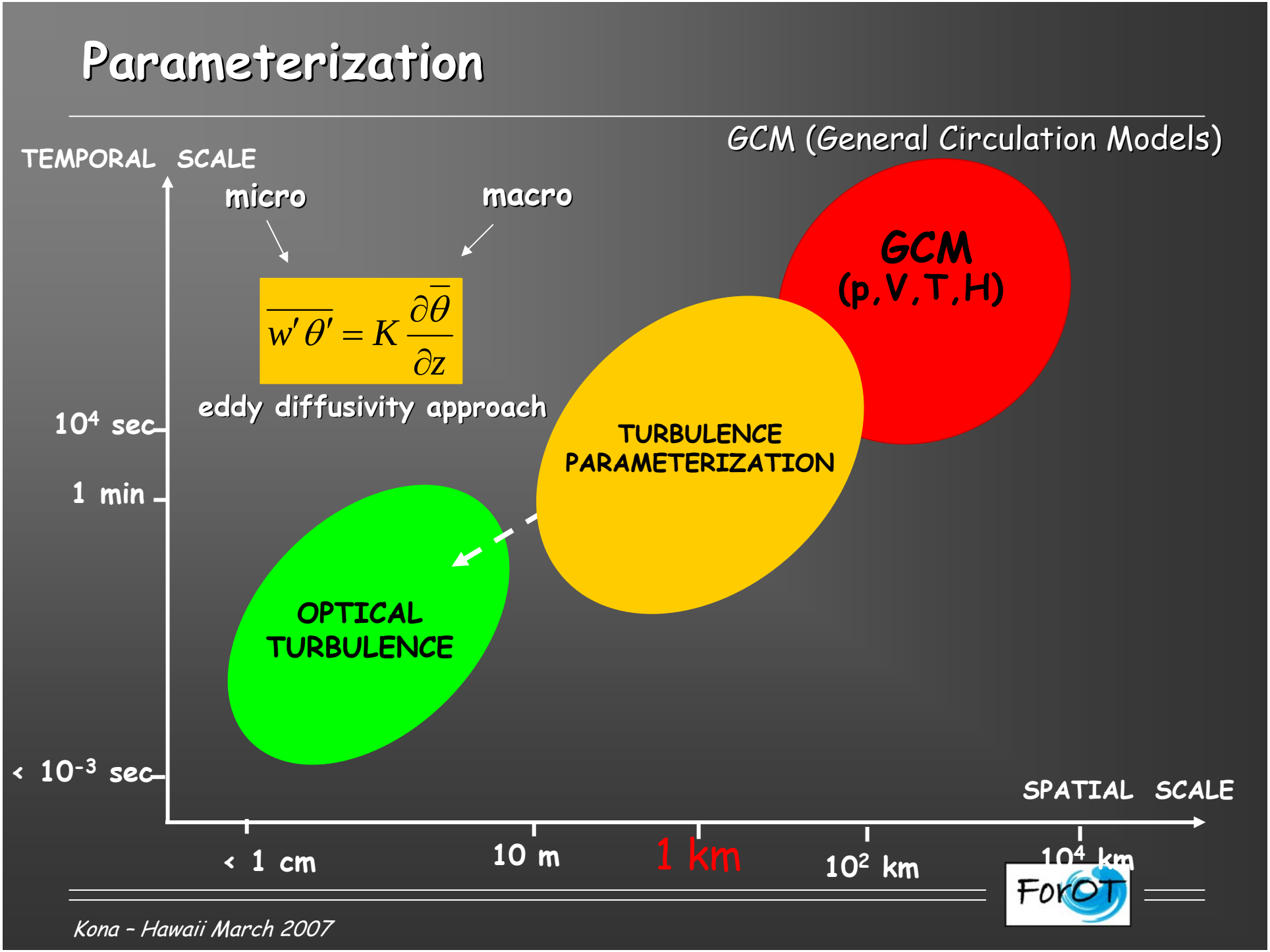
- To *forecast* the optical turbulence ➔ flexible-scheduling
- To reconstruct *3D C_N^2 maps* in a region around a telescope
- To perform a *climatology* of the optical turbulence extended over decades (access to "past")

Seeing @ Cerro Paranal – black dots



No other tools of investigation for these scientific goals

Parameterization



Parameterization in MESO-NH

Dynamic Turbulence Parameterization

Bougeault et al. 1989
Cuxart et al. 1995

mixing length - $L_0(h)$

turbulent kinetic energy

$$\overbrace{w'\theta_v'}^{\text{microscopic}} = \underbrace{-0.16 \cdot L \cdot \sqrt{e} \cdot \phi_3}_{K} \cdot \overbrace{\frac{\partial \bar{\theta}_v}{\partial z}}^{\text{macroscopic}}$$

thermo-dynamic stability term
Redelsperger & Sommeria 1981

Buoyancy term of TKE equation

Optical Turbulence Parameterization *(Astro-MesoNh)*

mixing length - $L_0(h)$

potential temperature

$$C_T^2 = 0.58 \cdot \phi_3 \cdot L^{4/3} \cdot \left(\frac{\partial \bar{\theta}}{\partial z} \right)^2 \Rightarrow C_N^2 = \left(\frac{80 \times 10^{-6} \cdot P}{T^2} \right)^2 C_T^2$$

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]* *[Ref:1999b, A&ASS, 137, 203]* *[Ref:2001, A&A, 365, 699]*
  - First Non-hydrostatic model (MESO-NH)
  - Orographic model ($\Delta x < 1$km)
  - 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

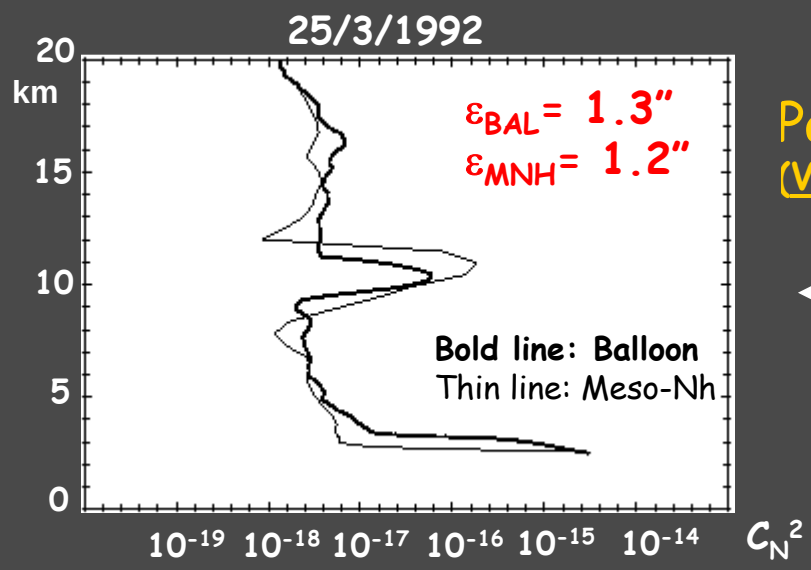
Review in Astronomical field (2)

- 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

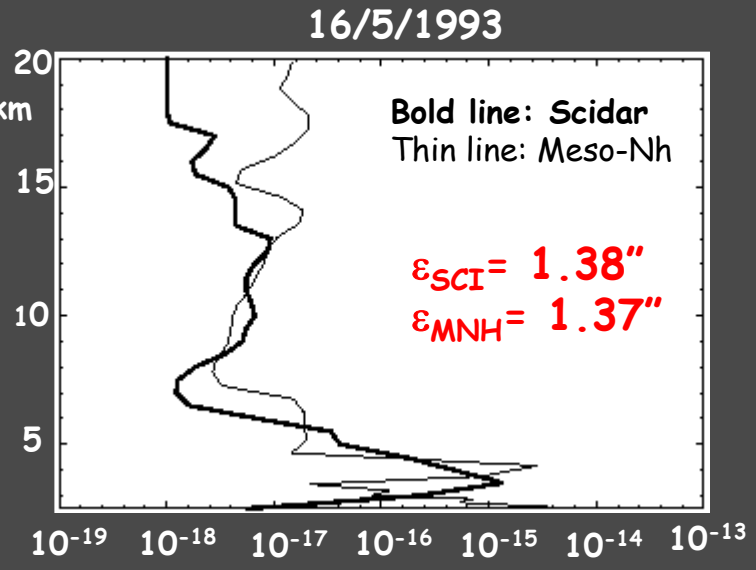
    ε, θ_0, τ_0, σ^2, $\mathcal{L}_0$, h_M, θ_M (M=1,2,3)

Cherubini, Adair } MM5 developed by NCAR (US)

Can we simulate the optical turbulence ?

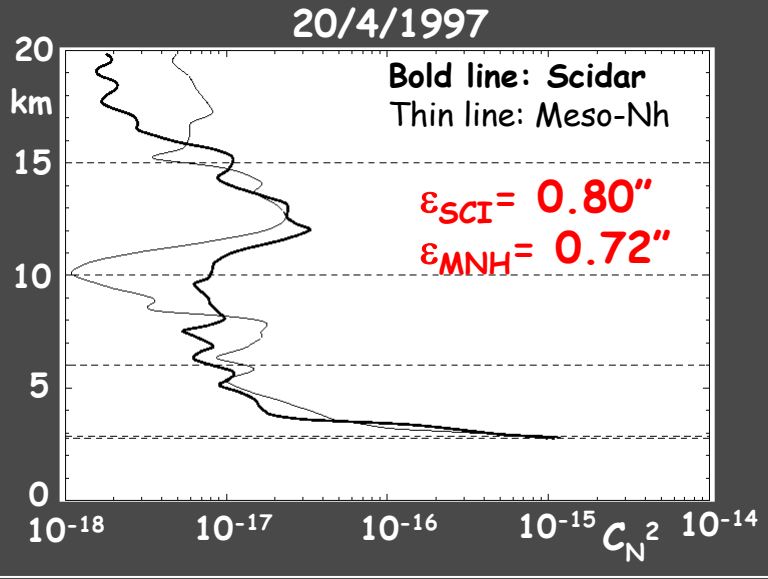


Paranal 1992
(VLT site testing)



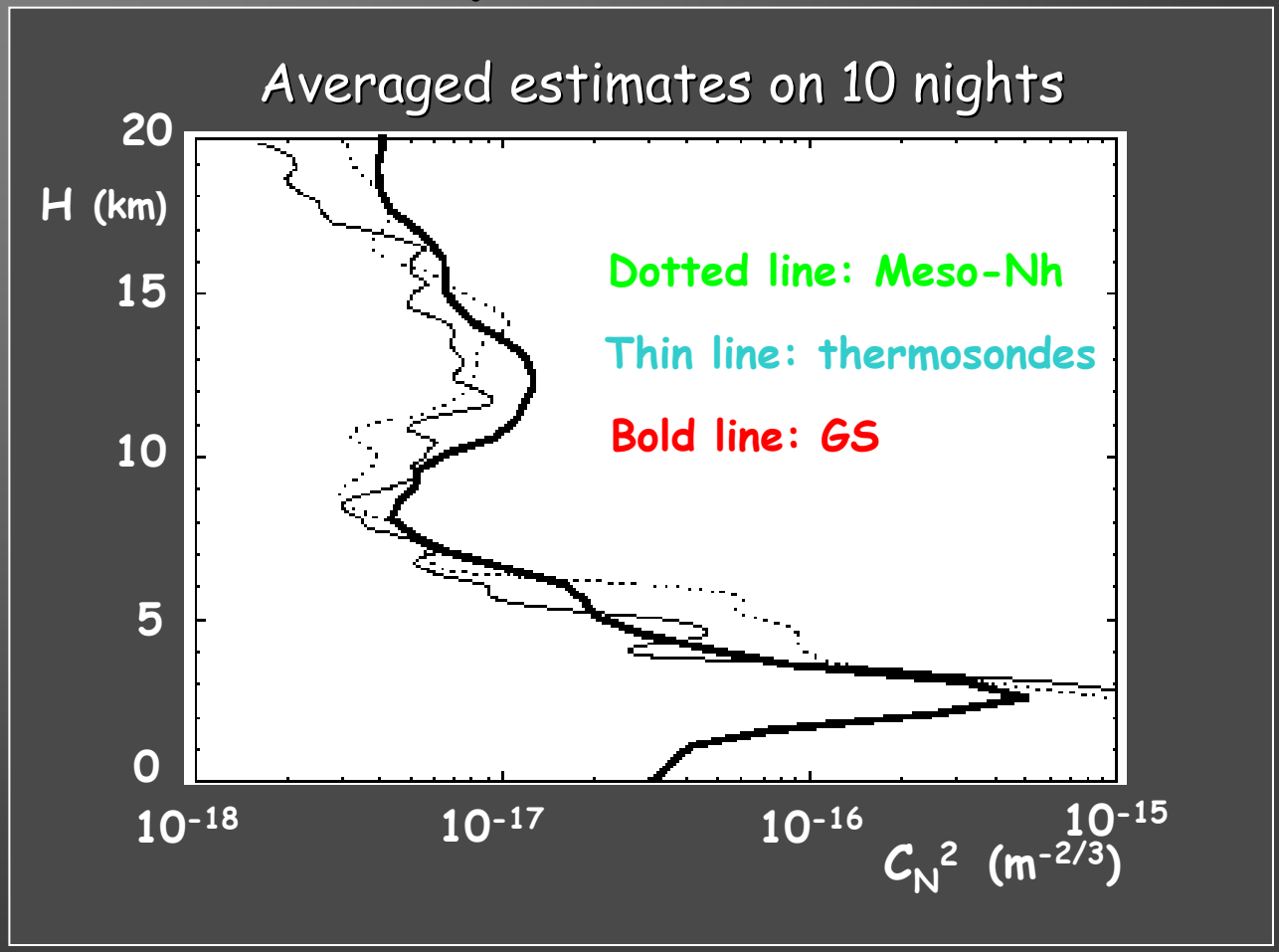
Paranal 1993
(VLT site testing)

San Pedro Martir
1997



Meso-Nh model Validation & Reliability (1)

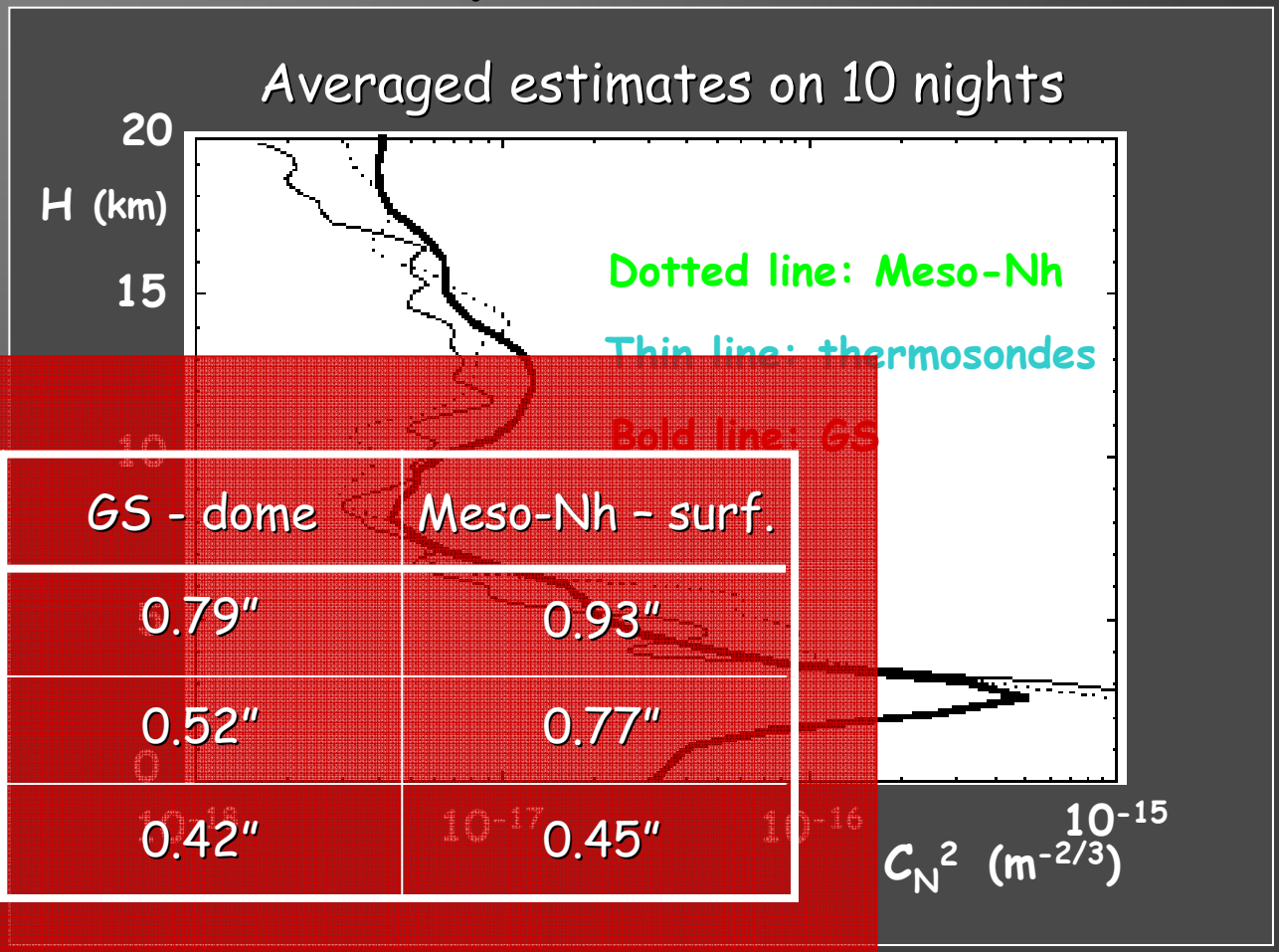
San Pedro Martir – Baja California, Mexico



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 $\Delta\varepsilon$ ~ 30 %** — San Pedro Martir

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

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

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

  Azouit & Vernin, 2005, PASP — 4 weeks — Cerro Pachon

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

  $\Delta\varepsilon$ ~ 50-100 % @ 0-4 km

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

Meso-Nh model Validation & Reliability (4)

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

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

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

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

  Azouit & Vernin, 2005, PASP — 4 weeks — Cerro Pachon

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

$\Delta\varepsilon$ ~ 50-100 % @ 0-4 km

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

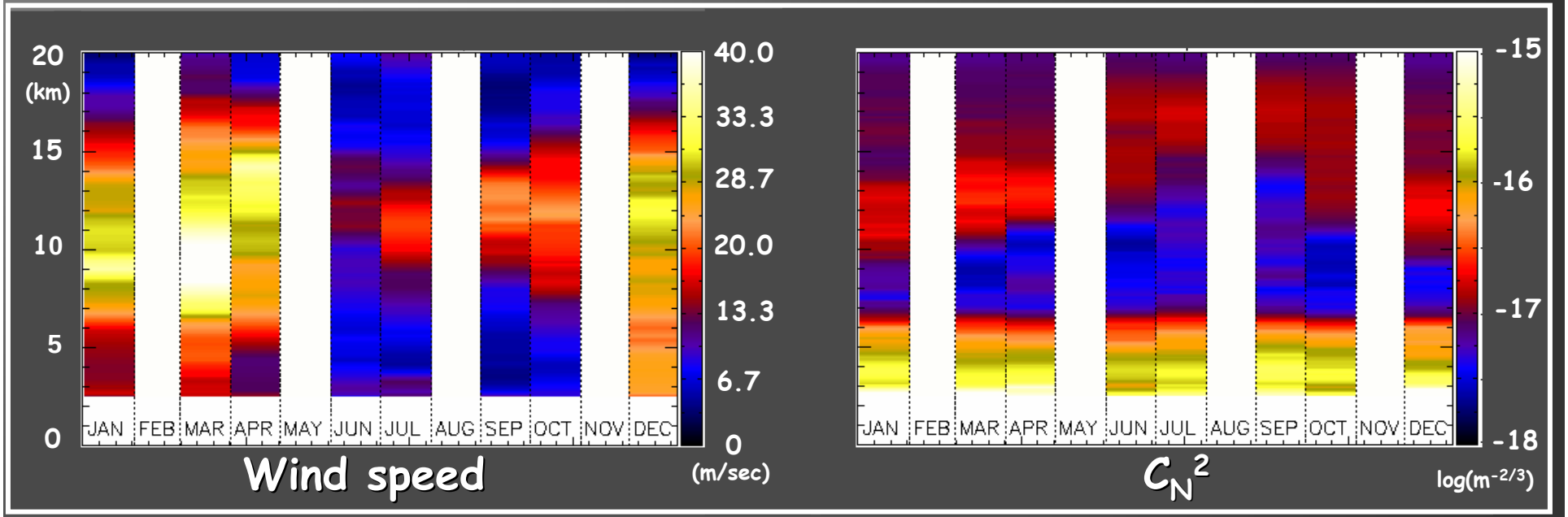
Meso-Nh can be used to characterize OT on long time extent

⇓

Optical Turbulence Climatology

First statistical analysis of *ALL* astroclimatic parameters (1)

SPM - 80 nights – uniformly distributed along 1 year

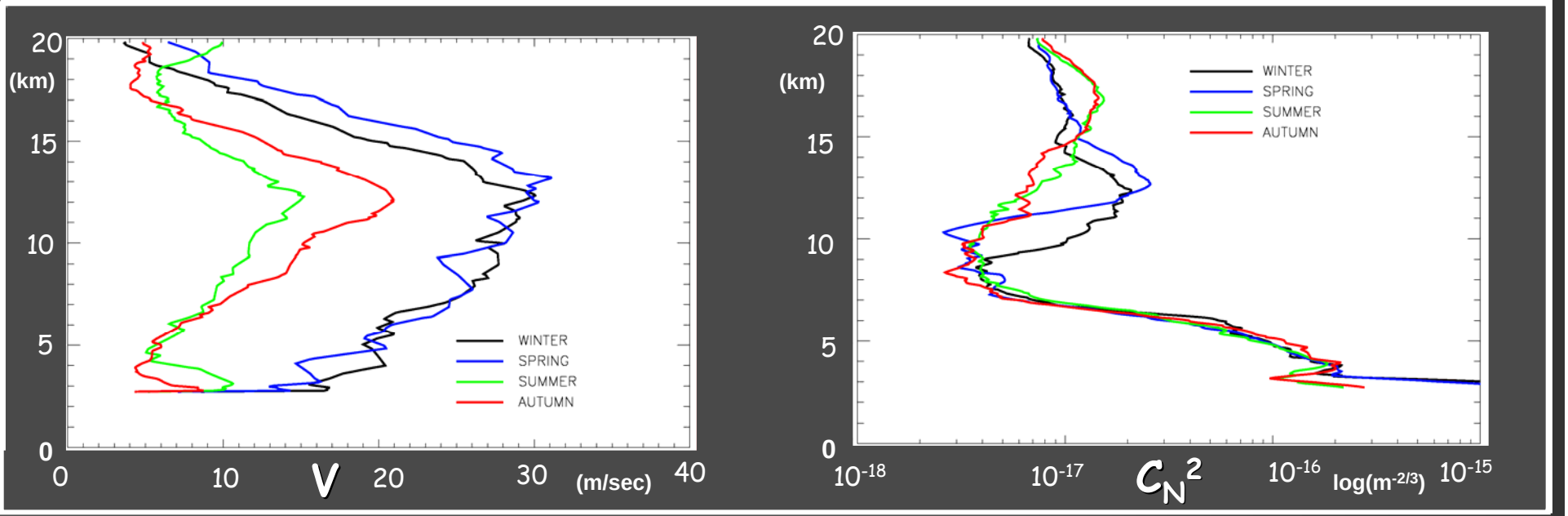


Masciadri & Egner, PASP, 2006

- 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)

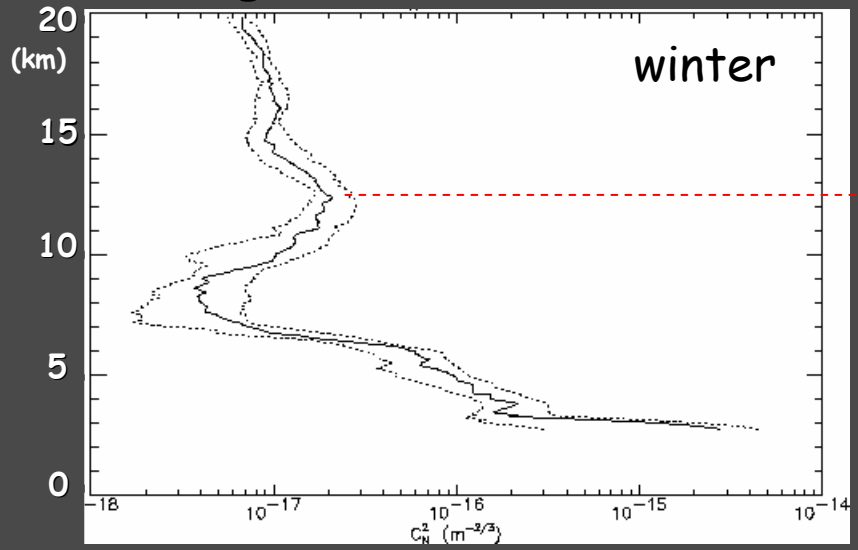
SPM - 80 nights – uniformly distributed along 1 year



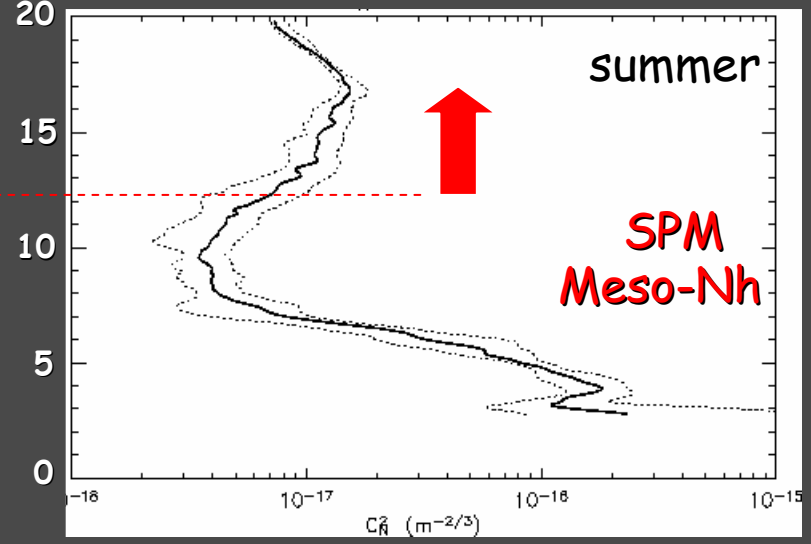
Masciadri & Egner, PASP, 2006

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

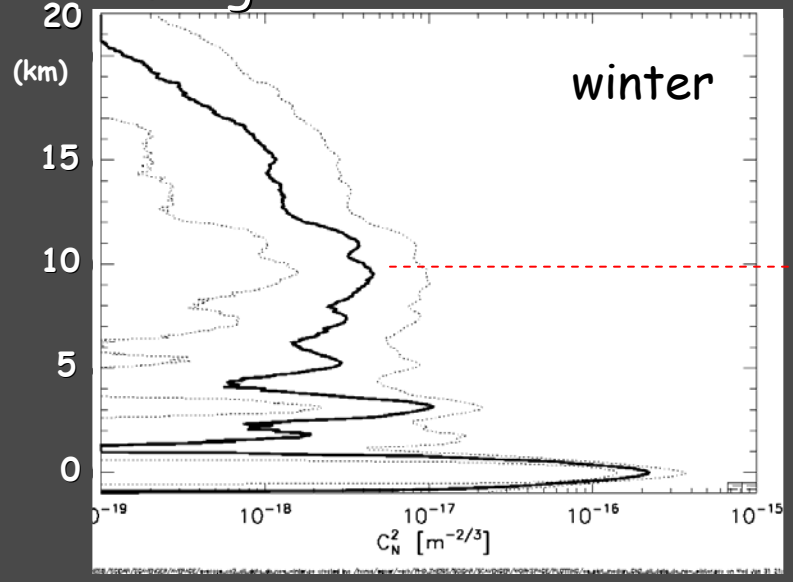
80 nights



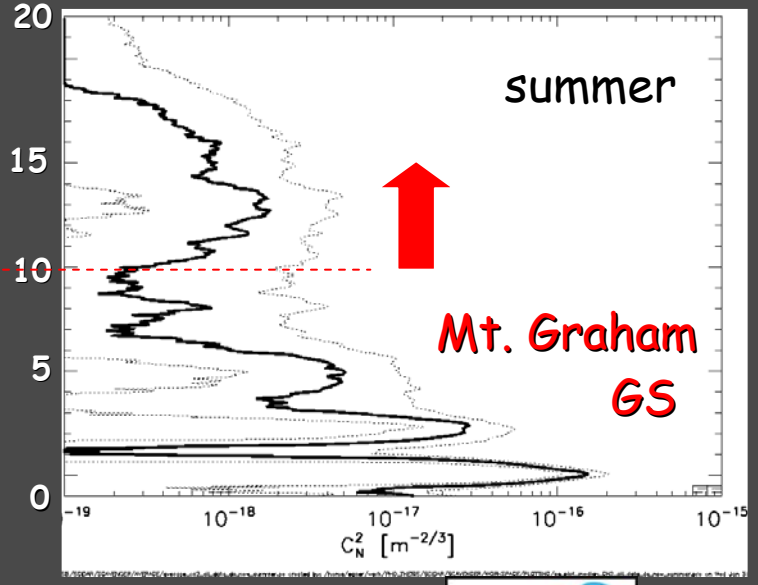
Masciadri & Egner, PASP, 2006



16 nights



Egner, Masciadri, McKenna, to be submitted



ForOT

Simulations vs. Measurements

Masciadri & Egner, PASP, 2006

SIMULATIONS

- *Masciadri & Egner (2006)*

  $\varepsilon_{(10\text{-}15)km}$ ~ 0.22″

  θ_0 ~ 1.42″

MEASUREMENTS

- *Avila et al. (2004)*

  $\varepsilon_{(10\text{-}15)km}$ ~ 0.24″

  θ_0 ~ 1.87″

median

Seasonal variation

$\Delta\varepsilon_{summer\text{-}winter}$

- *Masciadri & Egner (2006)*

  $\Delta\varepsilon_{sum.\text{-}wint.}$ ~ 0.22″

- *Michel et al. (2003)*

  $\Delta\varepsilon_{sum.\text{-}wint.}$ ~ 0.22″ (DIMM)

- *Echevarria et al. (1998)*

  $\Delta\varepsilon_{sum.\text{-}wint.}$ ~ 0.11″ (SST)

NEXT STEPS

1. Forecast of the optical turbulence

2. Search and selection of NEW sites

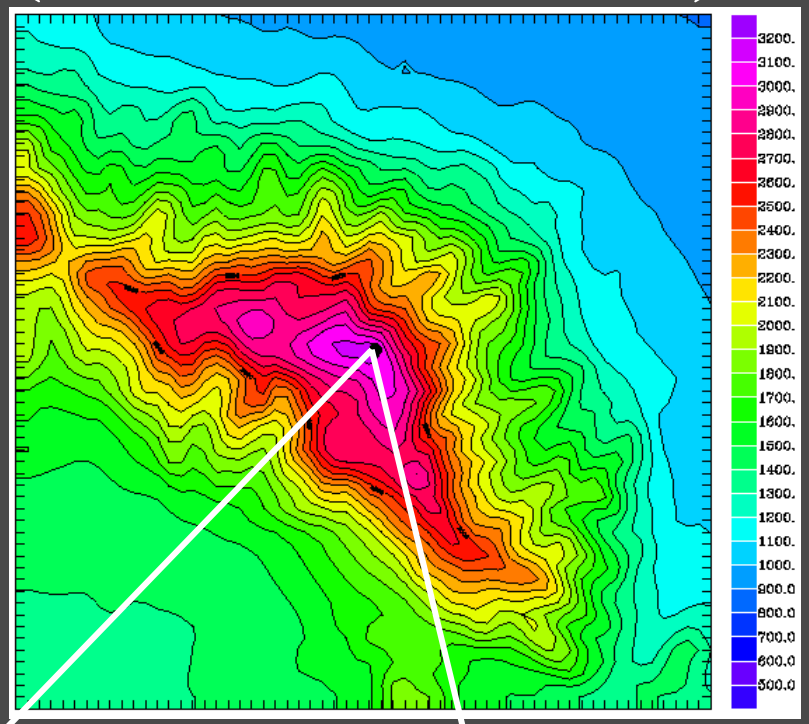
3. Implementation of models on autonomous machines → research group

ForOT
an indipendent research group
funded by the European Community

ForOT Core Project (1)

Mt. GRAHAM

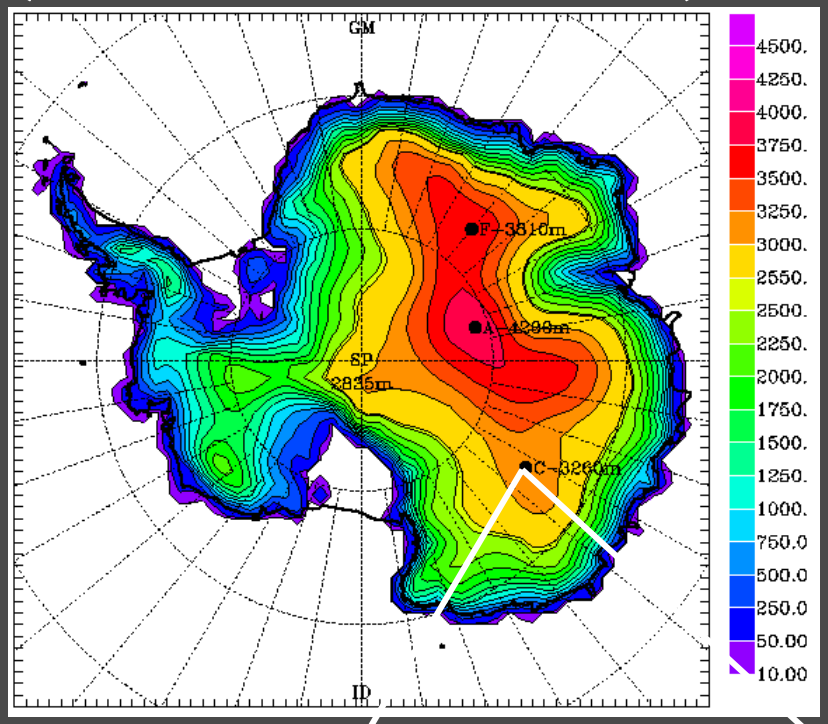
30 km



Δx = 500 m

ANTARCTIC PLATEAU

6000 km



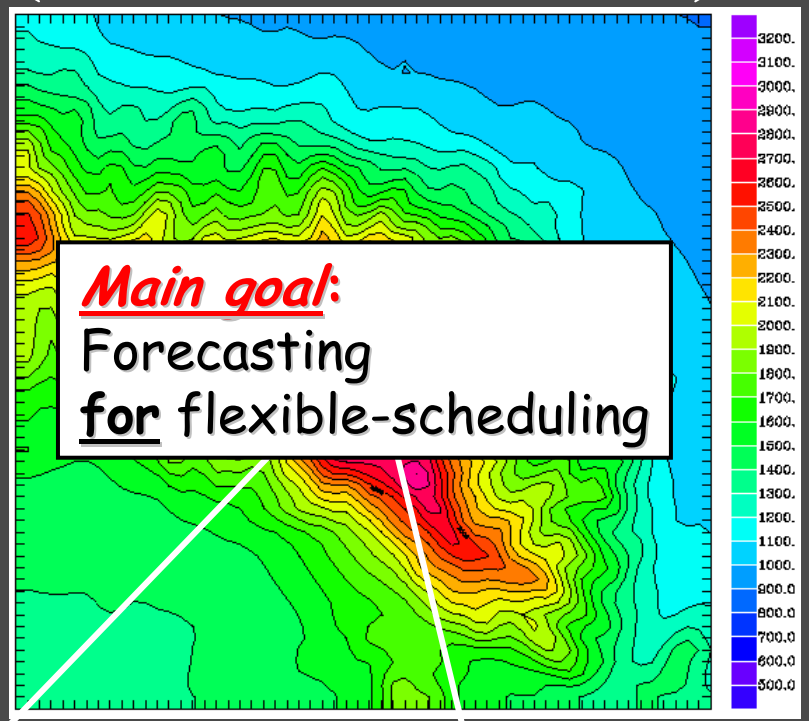
Δx = 100 km

MESO-NH model

ForOT Core Project (2)

Mt. GRAHAM

30 km

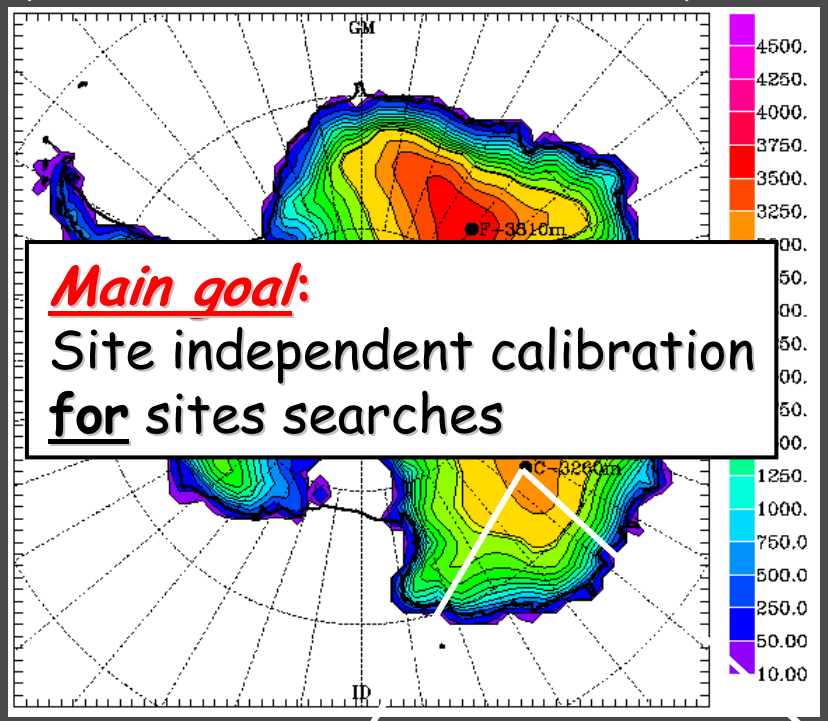


***Main goal*:**
Forecasting
for flexible-scheduling

Δx = 500 m

ANTARCTIC PLATEAU

6000 km



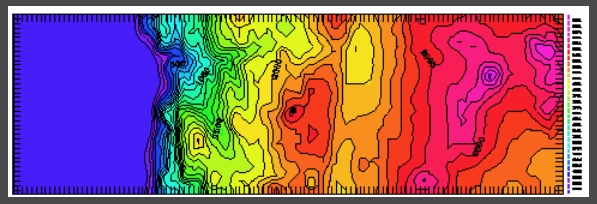
***Main goal*:**
Site independent calibration
for sites searches

Δx = 100 km

MESO-NH model

ELTs

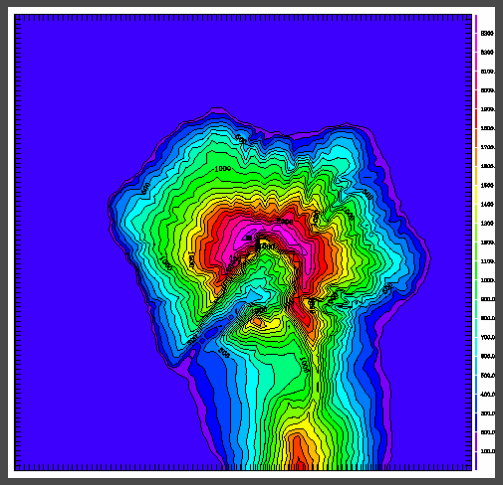
Cerro Paranal - Chili



60 km, Δx=500 m

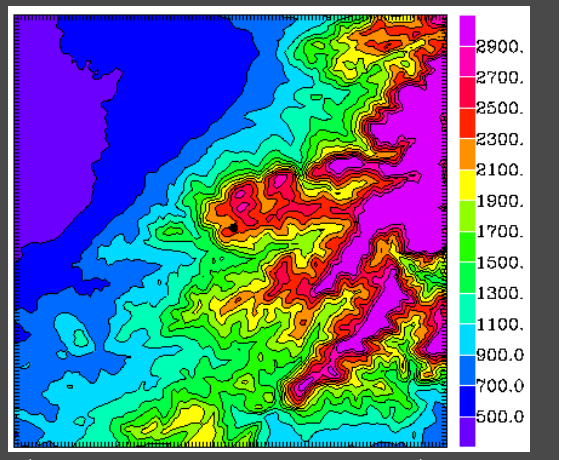
2008 – FP6 ELT Design Study
(MASS, GS, SLODAR, DIMM)

Roque de Los Muchachos
Canaries Island



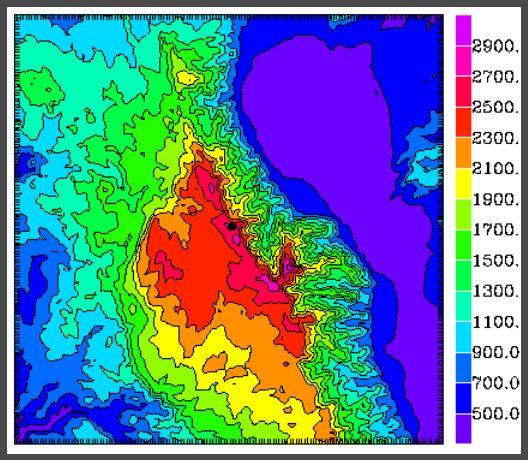
32.8 km, Δx=400m

Maidanak
Uzbekistan



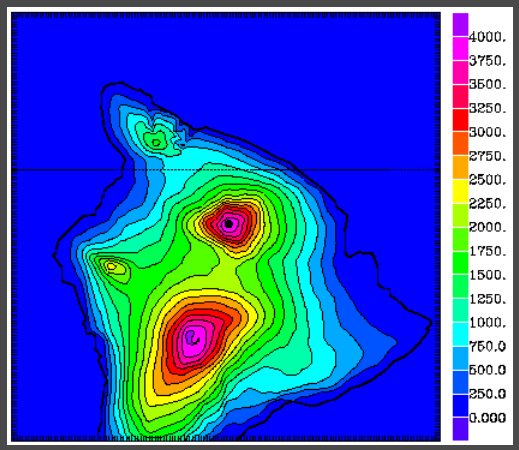
120 km, Δx=1km

San Pedro Mártir
Baja California



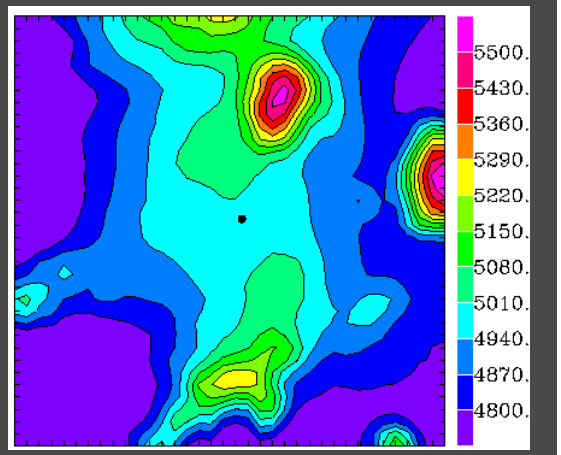
60 km, Δx=400m

Mauna Kea - Hawaii

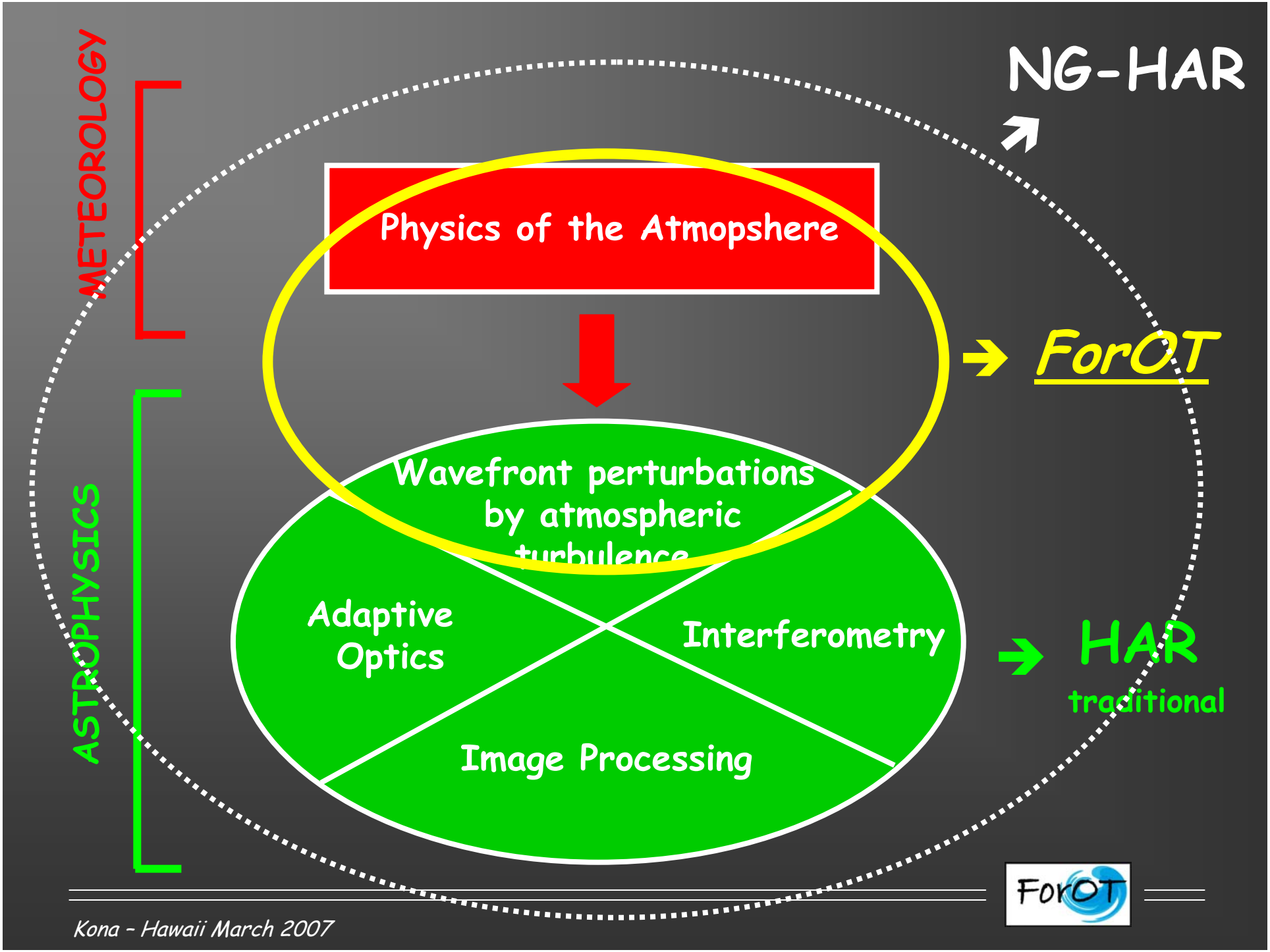


150 km, Δx=1km

Cerro Chajantor - Chili



14.4 km, Δx=400m


METEOROLOGY
ASTROPHYSICS
NG-HAR
Physics of the Atmopshere
ForOT
Wavefront perturbations by atmospheric turbulence
Adaptive Optics
Interferometry
Image Processing
HAR
traditional
ForOT

END

Special Thanks

Philippe Bougeault
Rene Racine
Irene Cruz Gonzalez
Piero Salinari

This work has been funded by the
"*Marie Curie Excellence Grant*" (ForOT) MEXT-CT-2005-023878