Mesoscale Modelling of Optical Turbulence in the Atmosphere: Quantifying the Impact of Ultra-High Vertical Resolution

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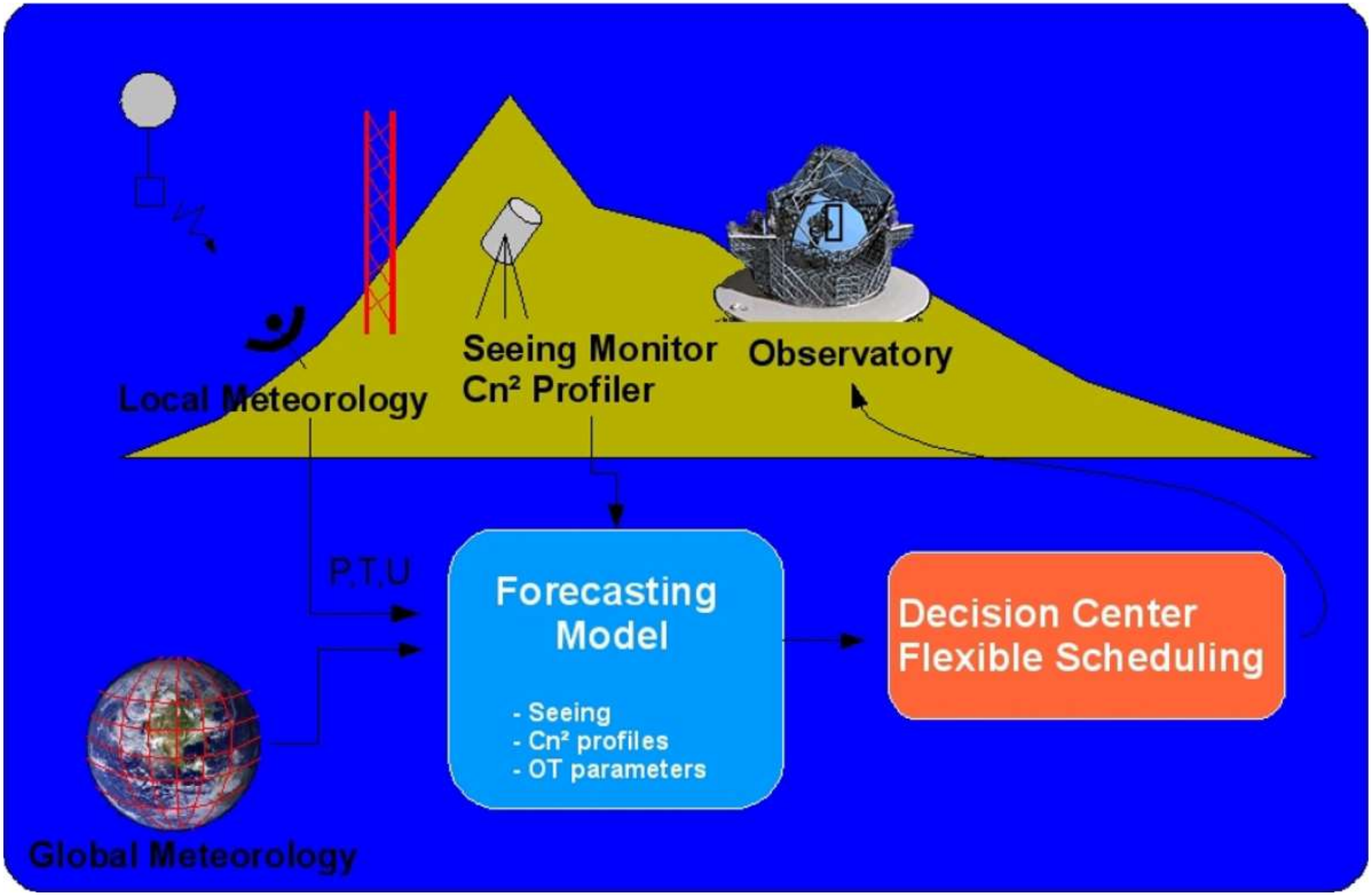
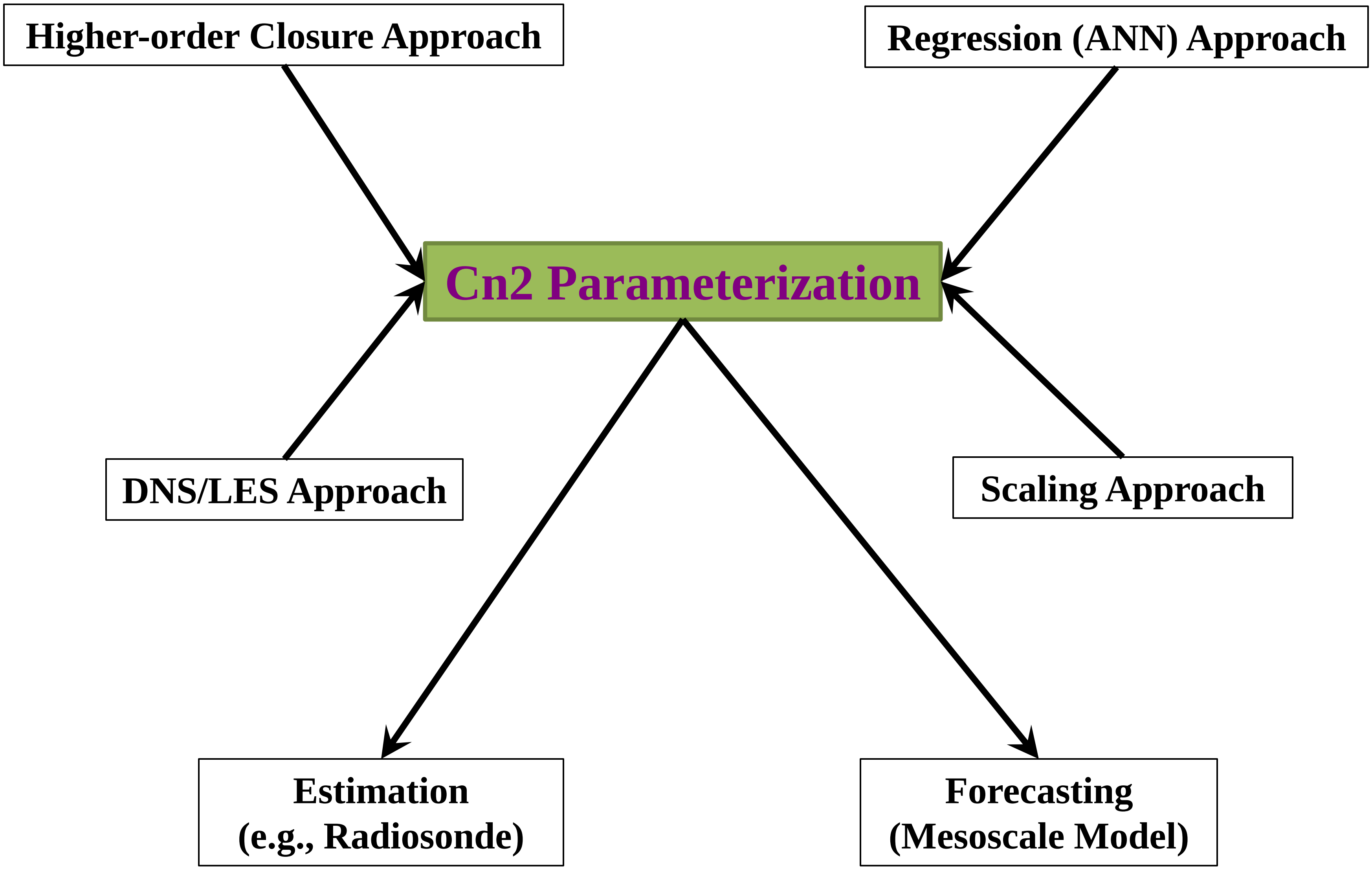
Acknowledgement: Ping He

Optical Turbulence Forecasting

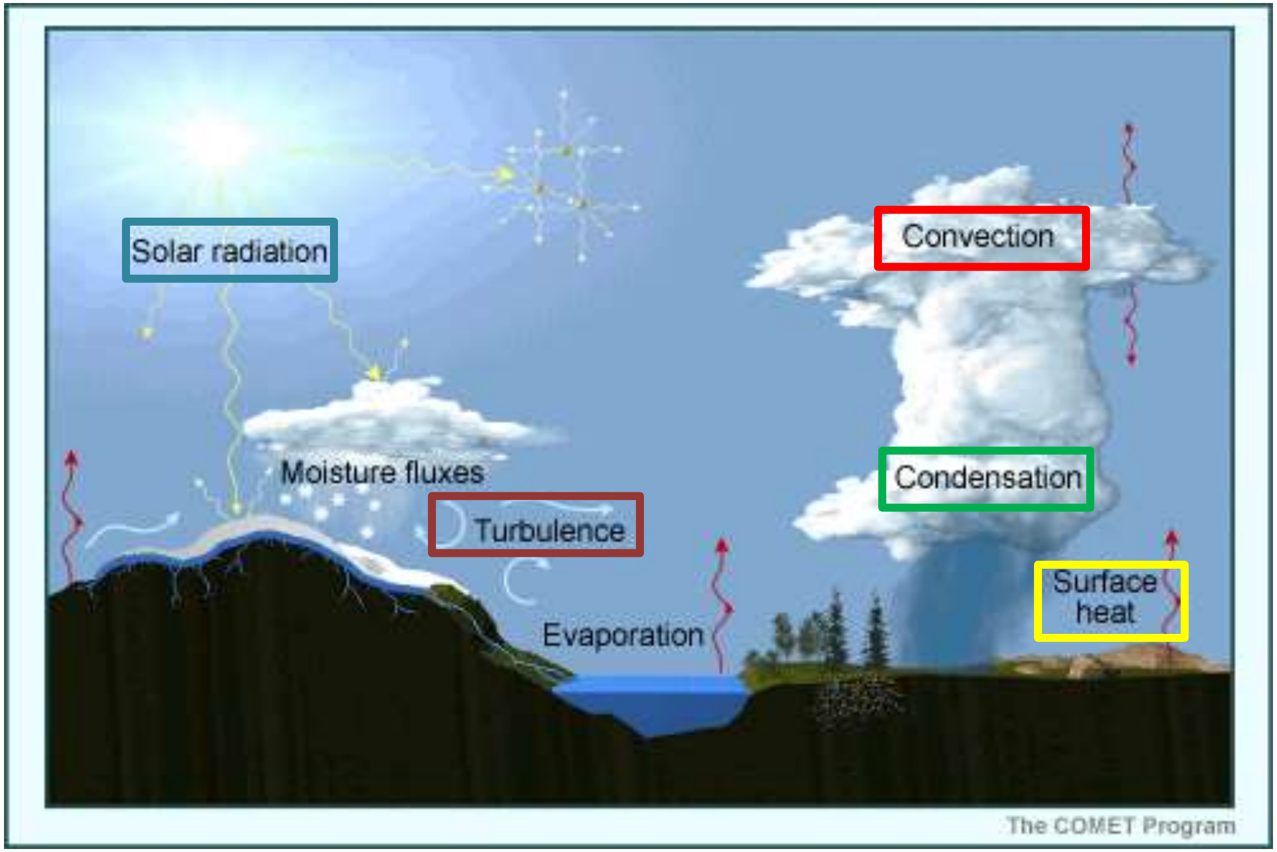


Source: Trinquet and Vernin (2009)

All Roads Lead to Rome



Mesoscale Modeling



Convection

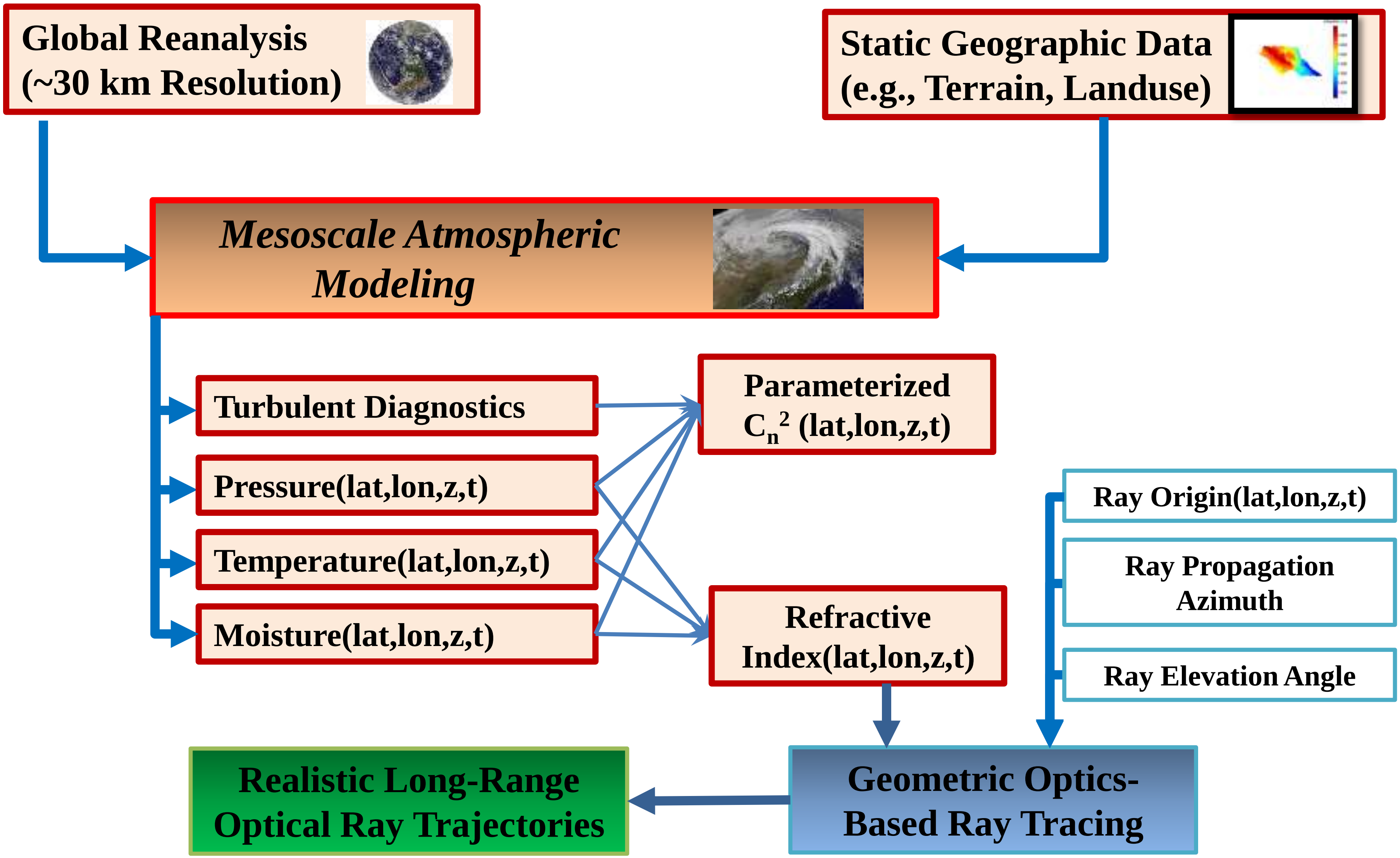
Microphysics

Land Surface

Planetary Boundary Layer

Radiation

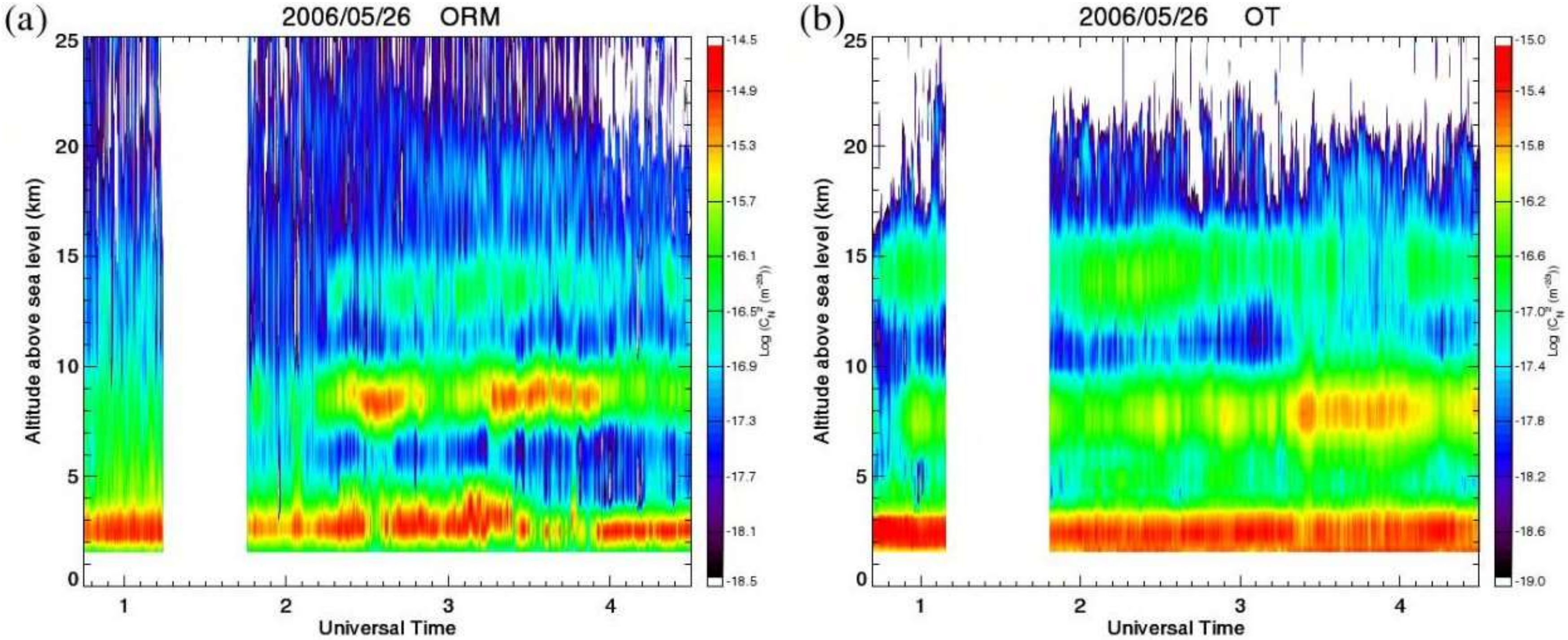
Modeling Framework



Objective

Intermittent Optical Turbulence in Free Atmosphere

Time-Height Plot of C_n^2 from G-SCIDARs



May 26, 2006; **Masciadri et al. (2008)**

ORM: Roque de los Muchachos on the island of La Palma

OT: El Teide on the island of Tenerife

Both observatories are on the Canary Islands and about 160 km from each other

Intermittent Optical Turbulence in Free Atmosphere (Cont.)

letters to nature

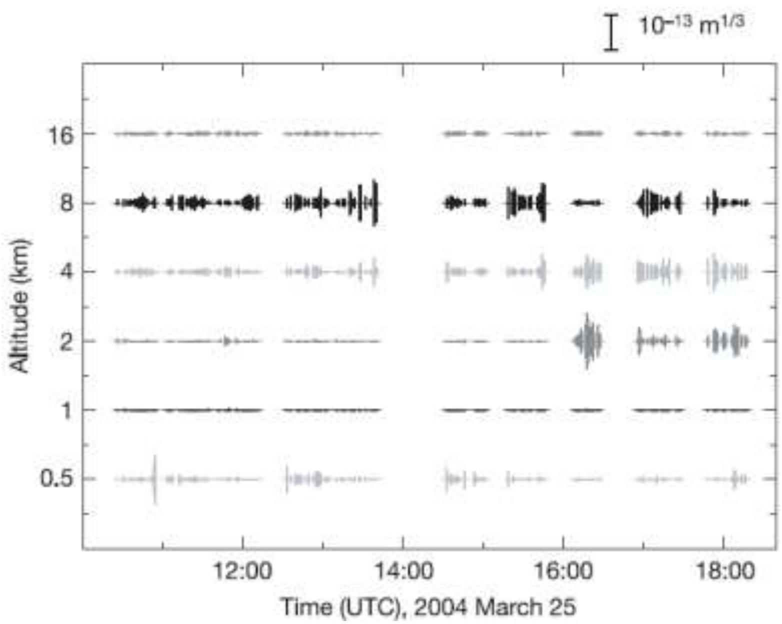
and/or heat sources were involved in the formation history of these objects. □

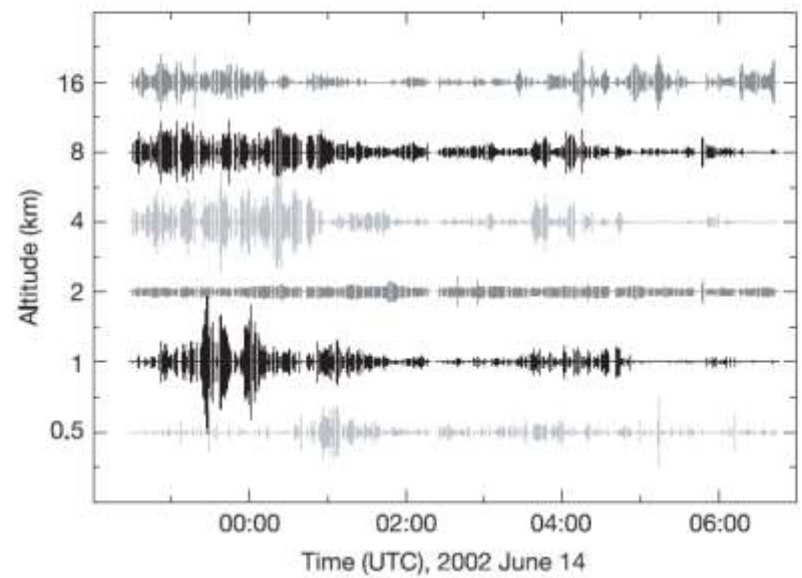
Received 21 May; accepted 21 July 2004; doi:10.1038/nature02882.

1. Alexander, C. M. O'D., Boss, A. P. & Carlson, R. W. The early evolution of the inner solar system: A meteoritic perspective. *Science* 293, 64–68 (2001).
2. MacPherson, G. J. in *Meteorites, Comets and Planets* (ed. Davis, A. M.) 201–246, Vol. 1 of *Treatise on Geochemistry* (eds Holland, H. D. & Turekian, K. K.) (Elsevier-Pergamon, Oxford, 2003).
3. Rubin, A. E. Petrologic, geochemical and experimental constraints on models of chondrule formation. *Earth Sci. Rev.* 50, 3–27 (2000).
4. Shu, F. H., Shang, H., Gounelle, M., Glassgold, A. E. & Lee, T. The origin of chondrules and refractory

Exceptional astronomical seeing conditions above Dome C in Antarctica

Jon S. Lawrence[1], Michael C. B. Ashley[1], Andrei Tokovinin[2] & Tony Travouillon[1]

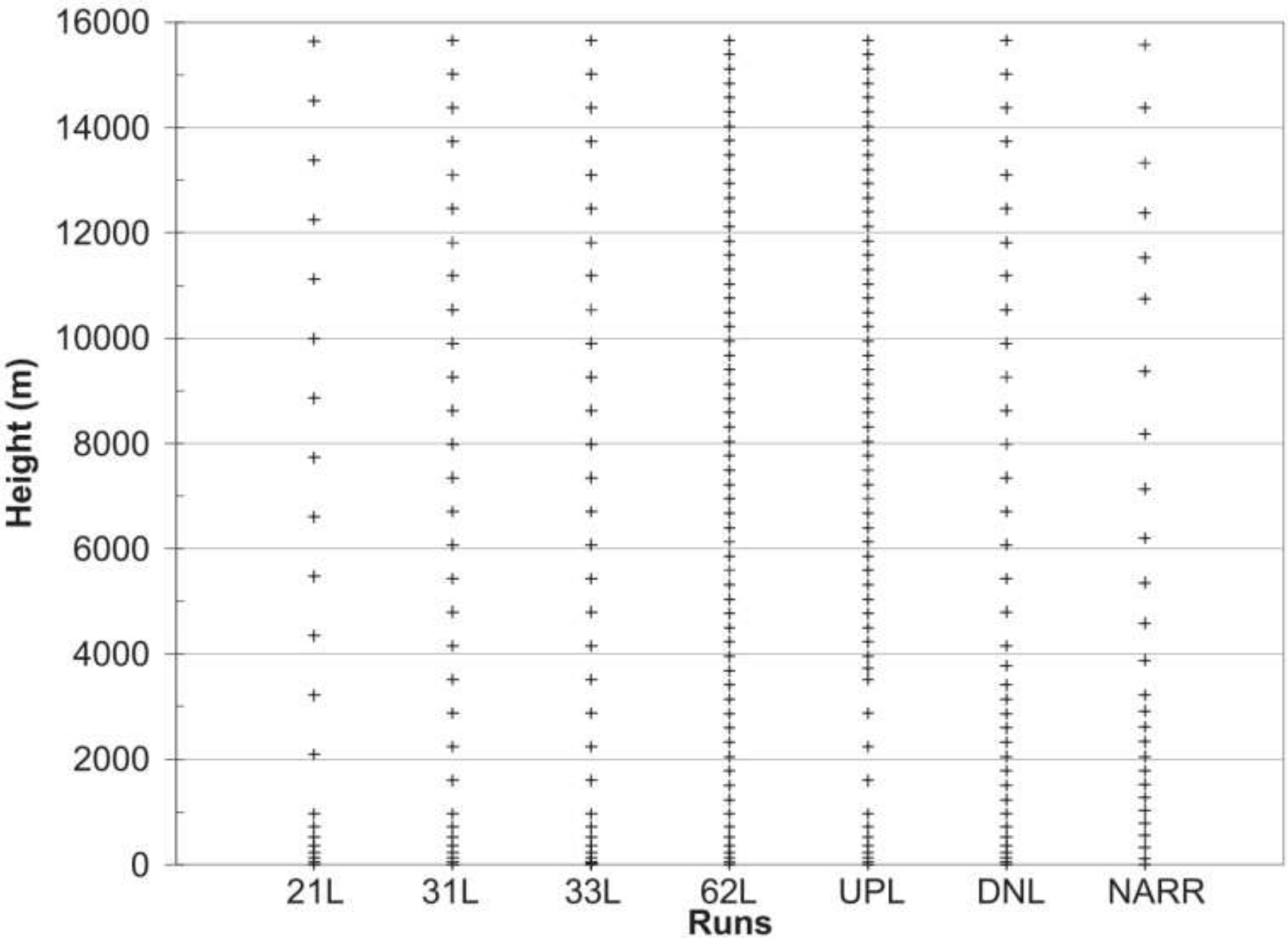




Dome C, Antarctic **Cerro Tololo, Chile**

Challenge

Vertical Grids in Mesoscale Models



Source: Alligo et al. (2009)

Relevant Literature

Vertical Resolution Requirements in Atmospheric Simulation

WILLIAM C. SKAMAROCK, CHRIS SNYDER, AND JOSEPH B. KLEMP

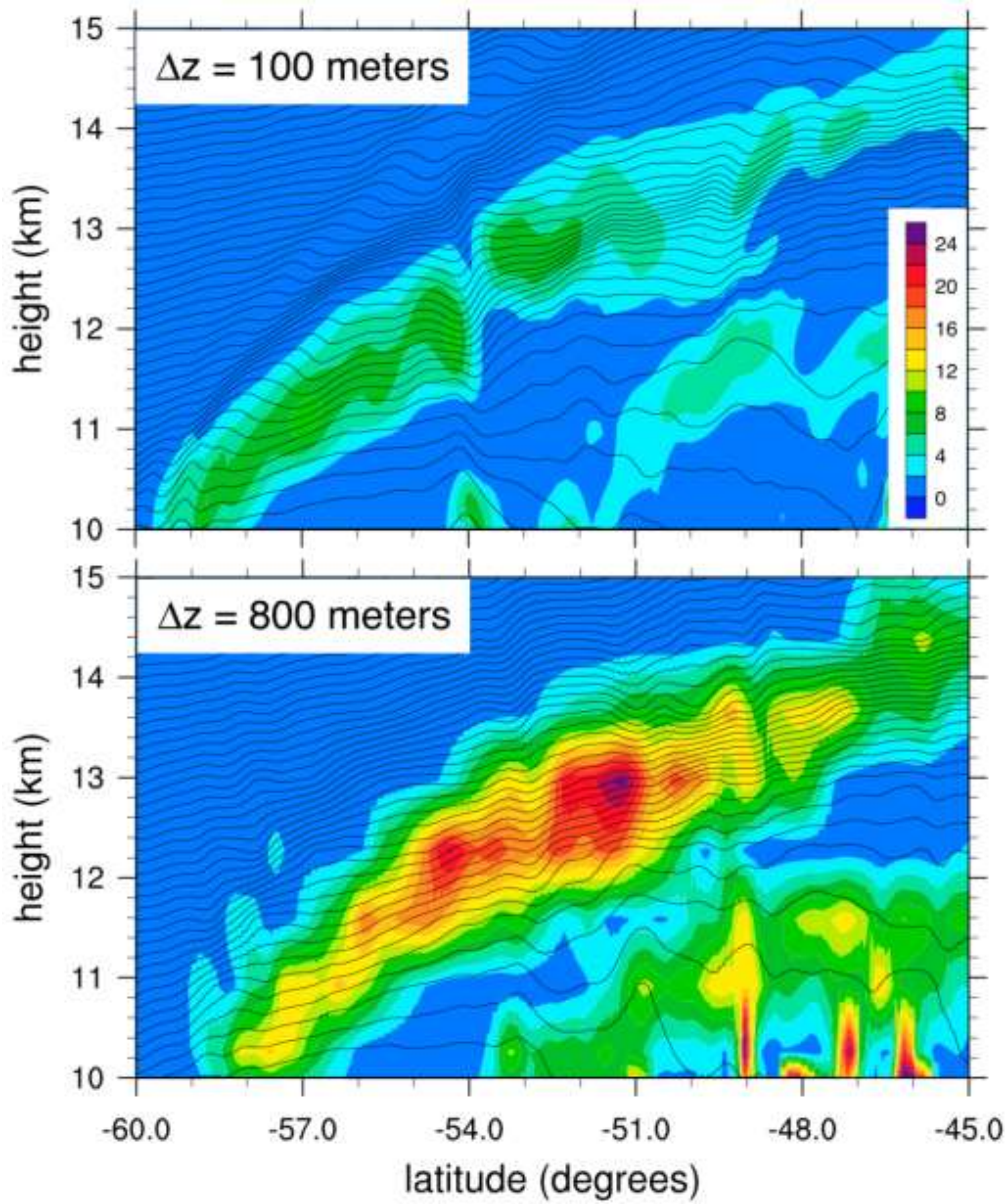
National Center for Atmospheric Research, Boulder, Colorado

SANG-HUN PARK

Yonsei University, Seoul, South Korea

(Manuscript received 19 February 2019, in final form 24 April 2019)

Effects of Vertical Resolution on Eddy Viscosity



Source: Skamarock et al. (2019)

Methodology

4 September 2015

Select Language

Translator Disclaimer

Mesoscale modeling of optical turbulence (C^2_n) utilizing a novel physically-based parameterization

Ping He; *Sukanta Basu*

Author Affiliations +

Proceedings Volume 9614, Laser Communication and Propagation through the Atmosphere and Oceans IV; 96140K (2015) https://doi.org/10.1117/12.2188227

Event: SPIE Optical Engineering + Applications, 2015, San Diego, California, United States

Higher-order Closure (HOC) Approach

$$C_n^2 = (7.9 \times 10^{-5} P/T^2)^2 C_T^2,$$

$$C_T^2 = 3.2 \chi \varepsilon^{-1/3},$$

$$\varepsilon = \frac{(2e)^{3/2}}{B_1 L_M},$$

$$\chi = \frac{(2e)^{1/2}}{B_2 L_M} \overline{\theta'^2},$$

HOC Approach (Cont.)

$$\frac{\partial e}{\partial t} = -\frac{1}{2}\frac{\partial}{\partial z}\overline{w'(u'^2 + v'^2 + w'^2 + 2P/\rho)} - \left(\overline{u'w'}\frac{\partial u}{\partial z} + \overline{v'w'}\frac{\partial v}{\partial z}\right) + \frac{g}{\theta_0}\overline{w'\theta'_V} - \varepsilon$$

$$\frac{\partial \overline{\theta_l'^2}}{\partial t} = -\frac{\partial}{\partial z}\overline{w'\theta_l'^2} - 2\overline{w'\theta_l'}\frac{\partial \theta_l}{\partial z} - 2\chi_l$$

$$\frac{1}{L_M} = \frac{1}{L_S} + \frac{1}{L_T} + \frac{1}{L_B},$$

HOC Approach (Cont.)

$$L_S = \begin{cases} kz/3.7, & \zeta \geq 1 \\ kz(1+2.7\zeta)^{-1}, & 0 \leq \zeta < 1 \\ kz(1-100\zeta)^{0.2}, & \zeta < 0, \end{cases}$$

$$L_T = 0.23\frac{\int_0^\infty (2e)^{0.5} z\,dz}{\int_0^\infty (2e)^{0.5}\,dz},$$

$$L_B = \begin{cases} (2e)^{0.5}/N, & \partial\theta/\partial z > 0, \text{and } \zeta \geq 0 \\ [1+5(q_c/L_T N)^{0.5}]q^{0.5}/N, & \partial\theta/\partial z > 0, \text{and } \zeta < 0 \\ \infty, & \partial\theta/\partial z \leq 0, \end{cases}$$

Case Study:

Hawaii 2002 Thermosonde Campaign

Hawaii 2002

AIR FORCE RESEARCH LABORATORY
BATTLESPACE ENVIRONMENT DIVISION
AFRL/VSBL, 29 RANDOLPH RD.
HANSCOM AFB, MASSACHUSETTS

HAWAII 2002
THERMOSONDE
CAMPAIGN

USAF PA
CHARA

Publications of the Astronomical Society of the Pacific, **120**:1318–1324, 2008 December

Balloon Thermosonde Measurements over Mauna Kea and Comparison with Seeing Measurements

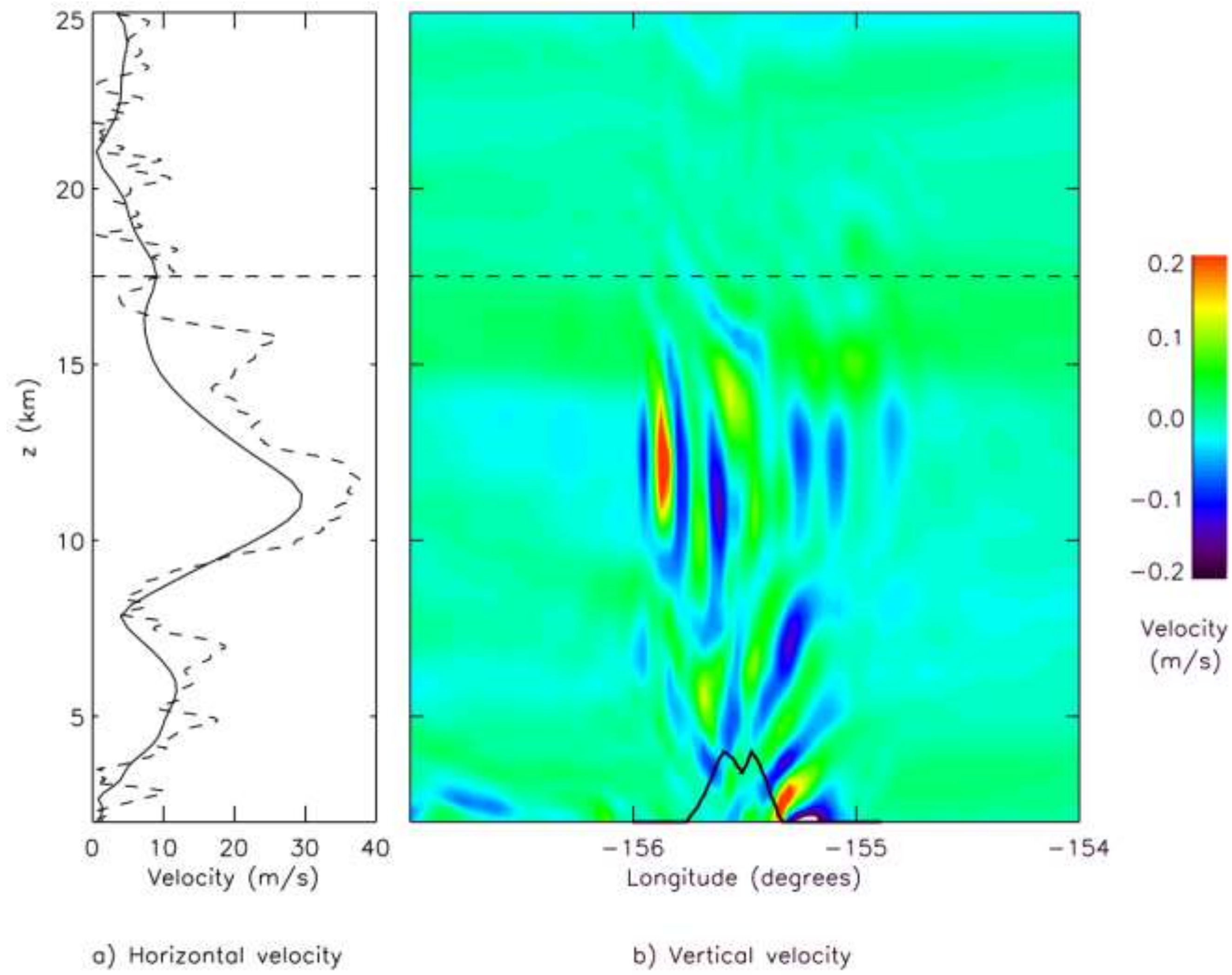
John P. McHugh
University of New Hampshire, Durham, NH

George Y. Jumper
U. S. Air Force Research Laboratory, Hanscom Air Force Base, MA

and

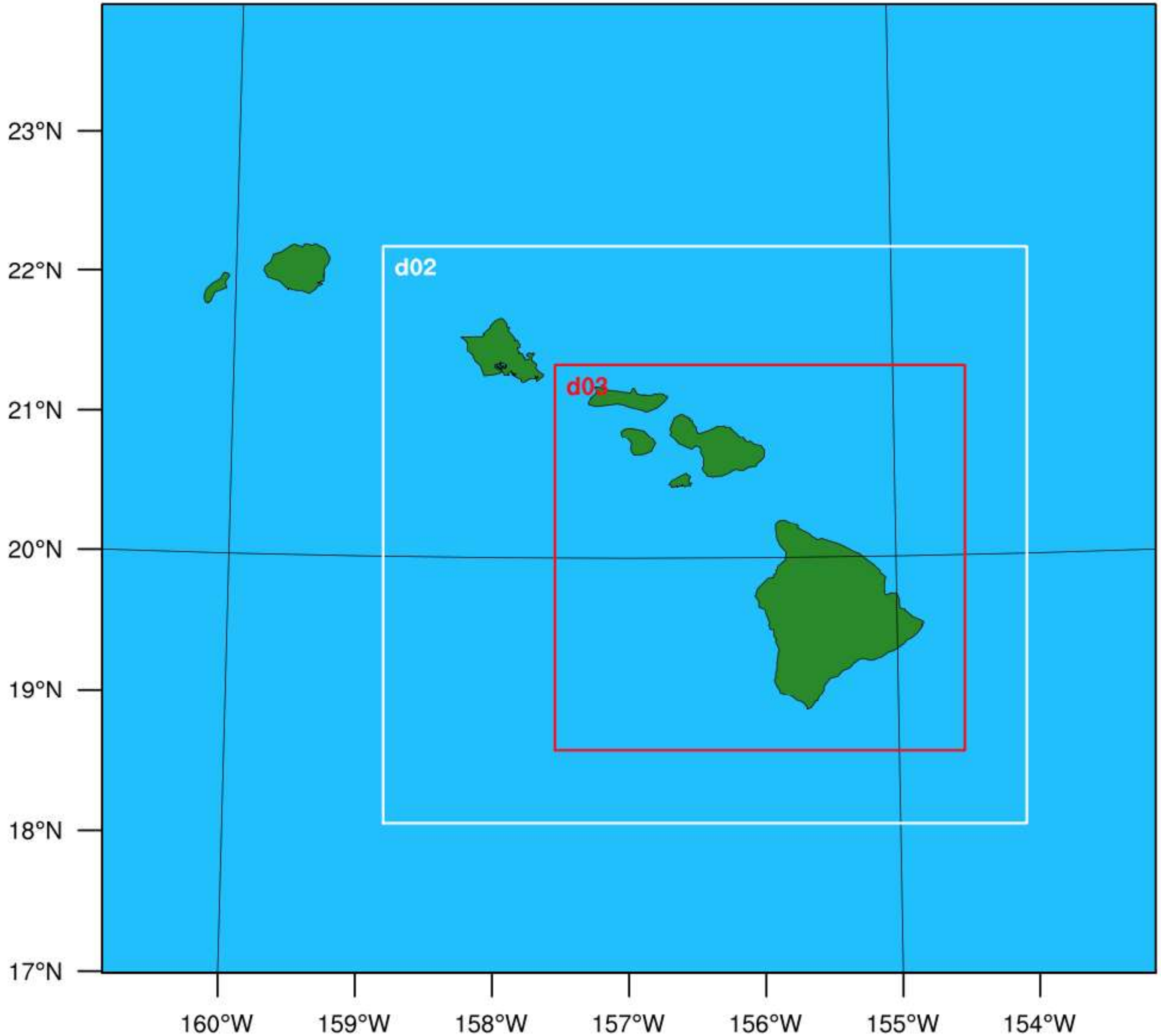
Mark Chun

Large-Scale Behavior of Ascent Rate

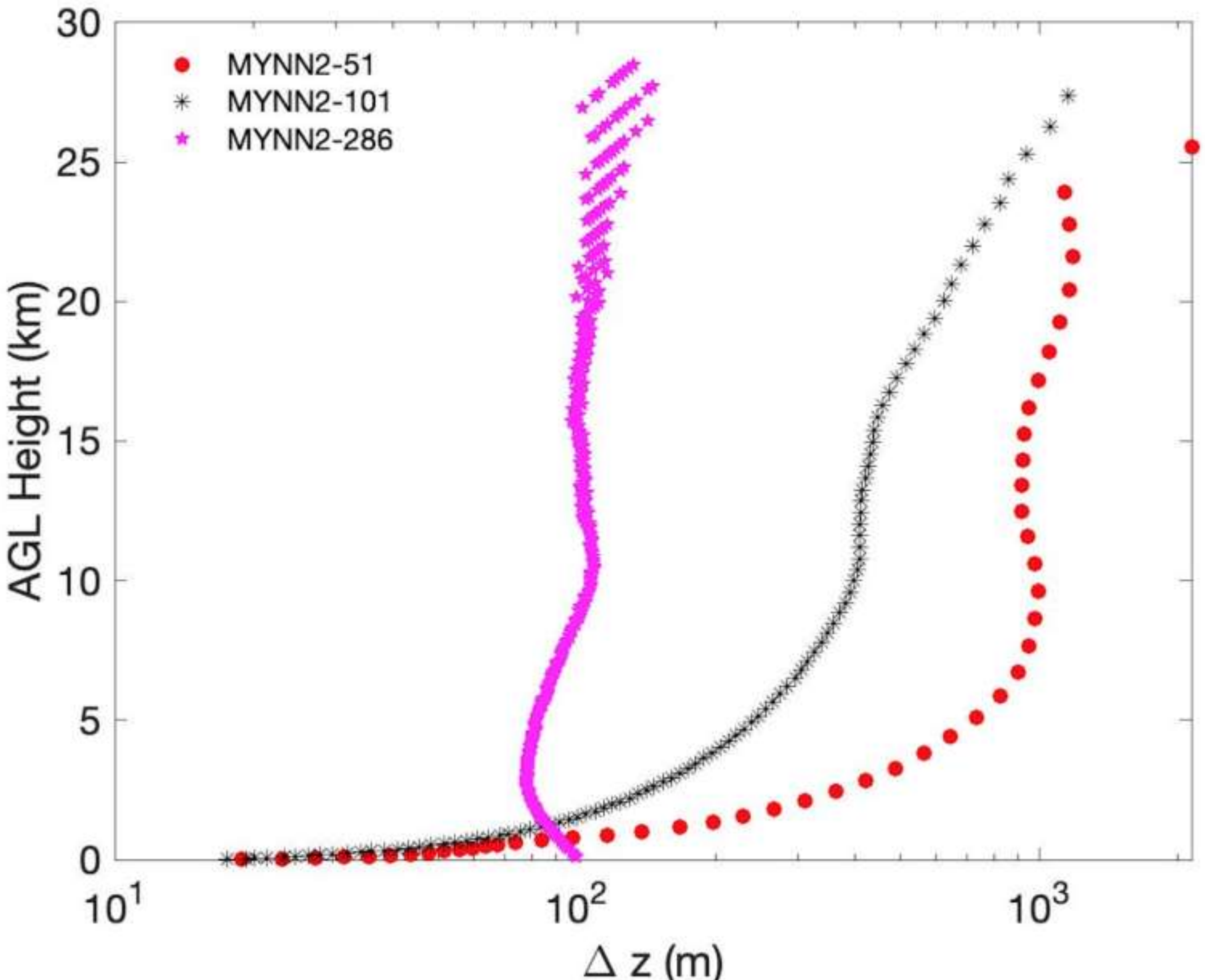


Source: McHugh et al. (2008)

Computational Domain (9/3/1 km)

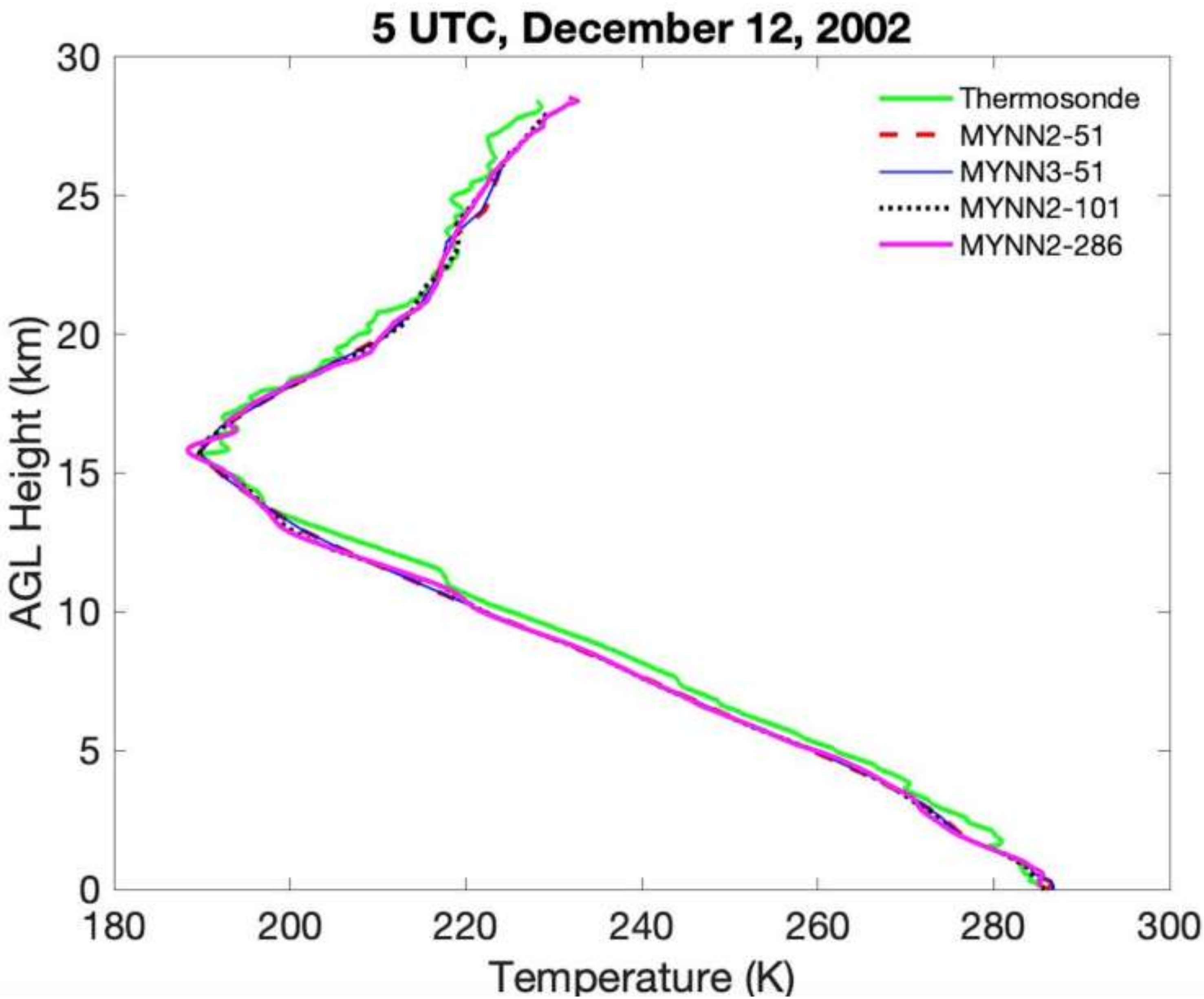


Vertical Grids in WRF Runs

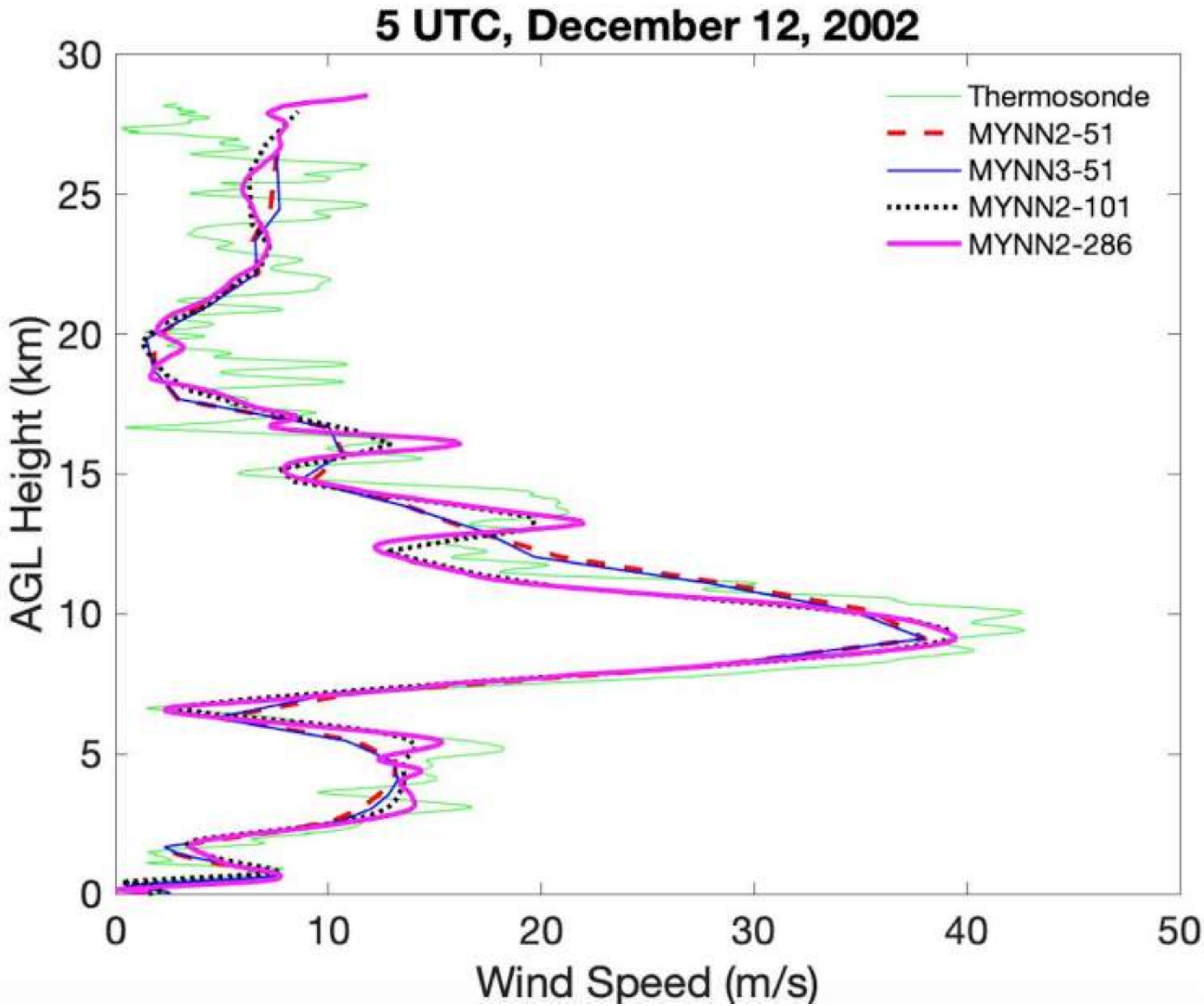


Dec 11-12, 2002

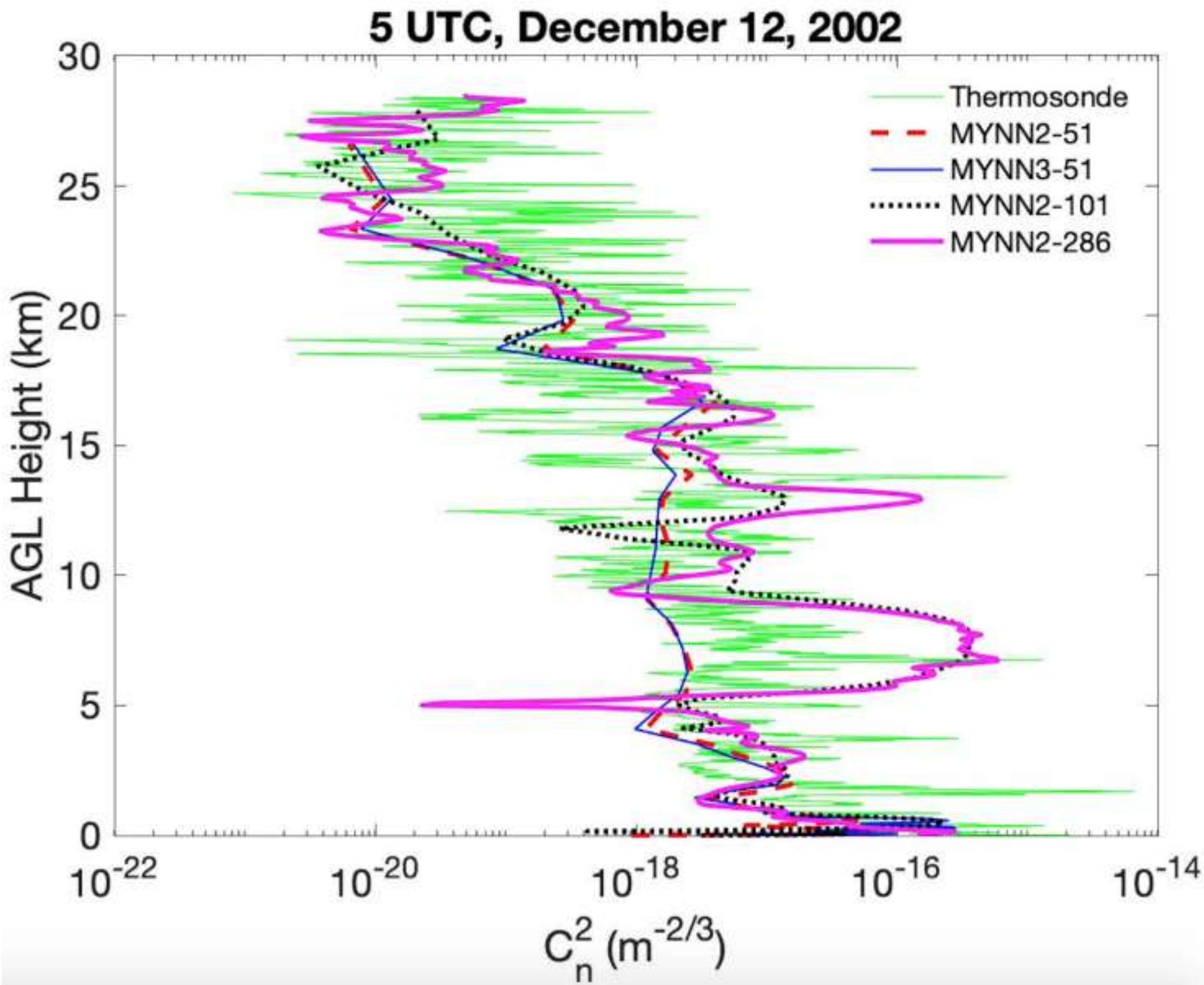
Mean Temperature Profiles



Mean Wind Speed Profiles

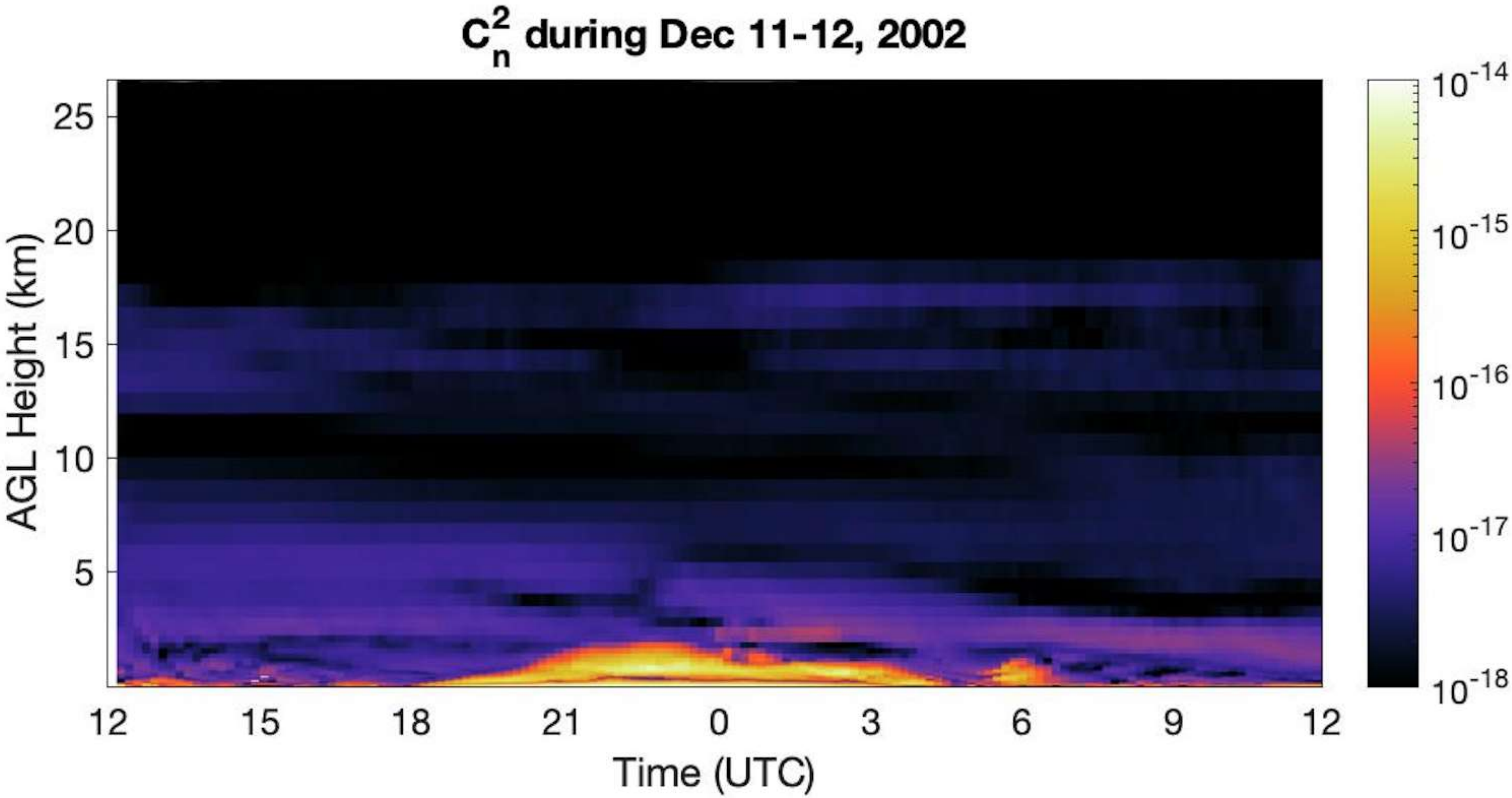


C_n^2 Profiles



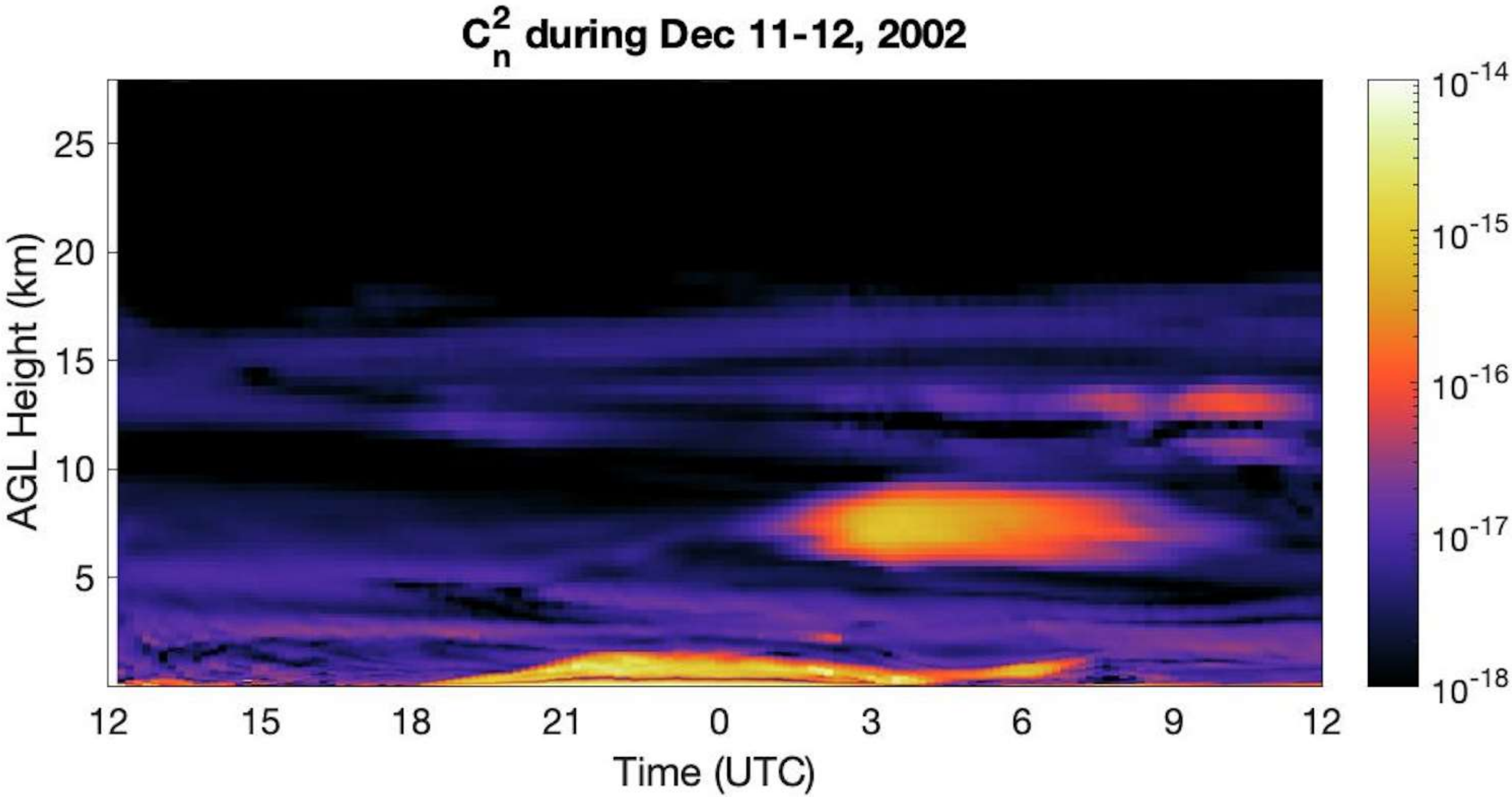
Simulated C_n^2 over Hawaii and Pacific Ocean

 # vertical grid points: 51



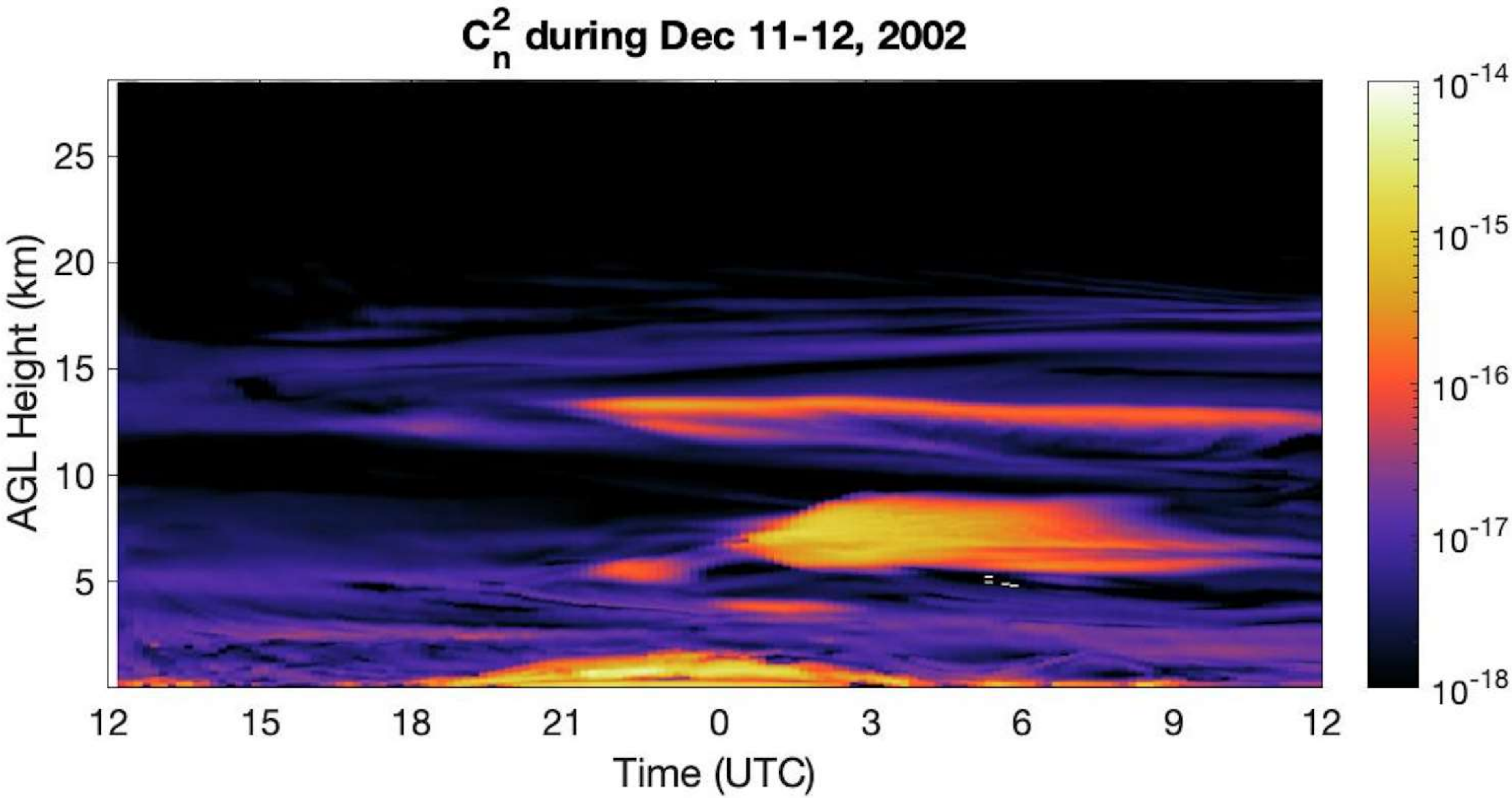
Simulated C_n^2 over Hawaii and Pacific Ocean (Cont.)

 # vertical grid points: 101

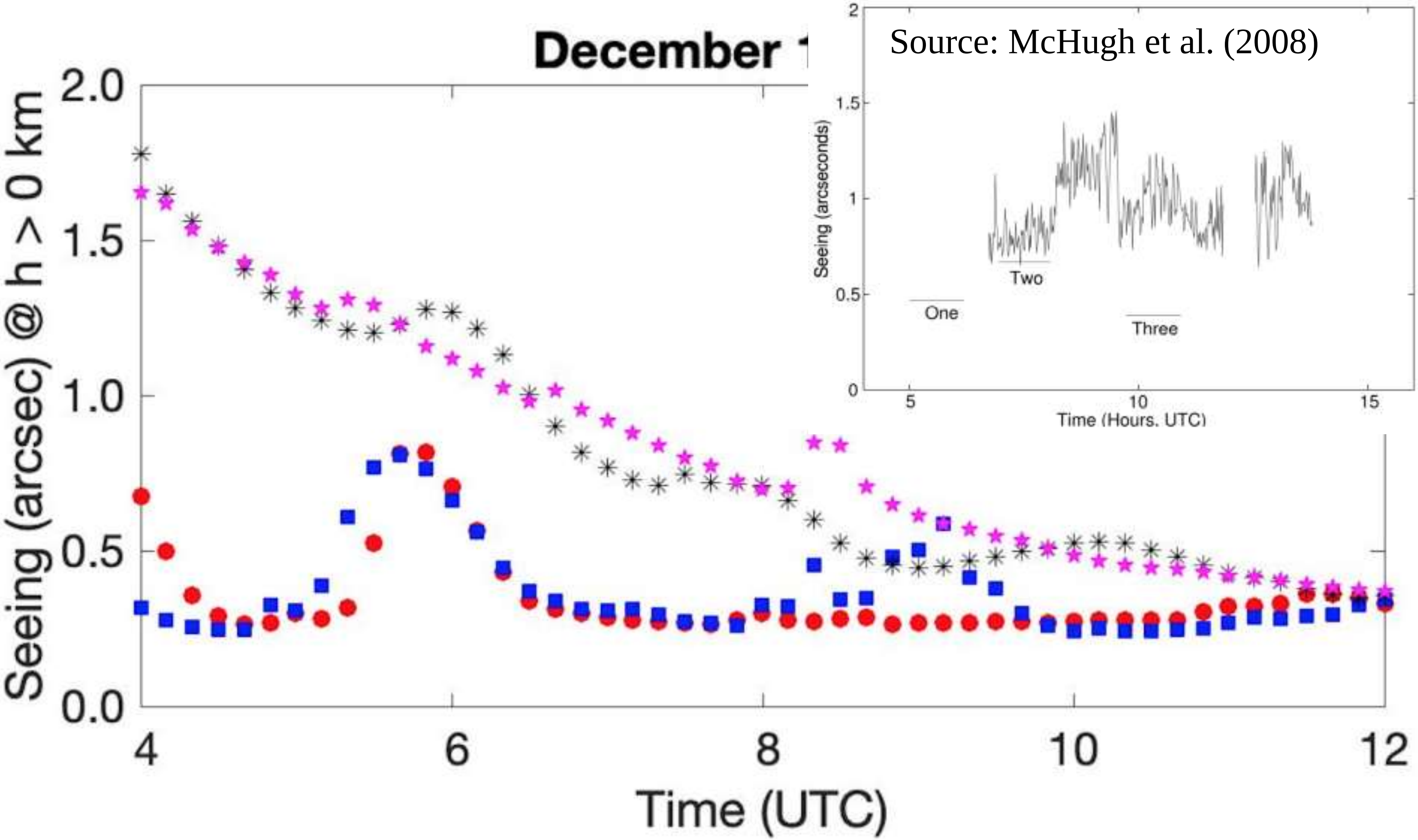


Simulated C_n^2 over Hawaii and Pacific Ocean (Cont.)

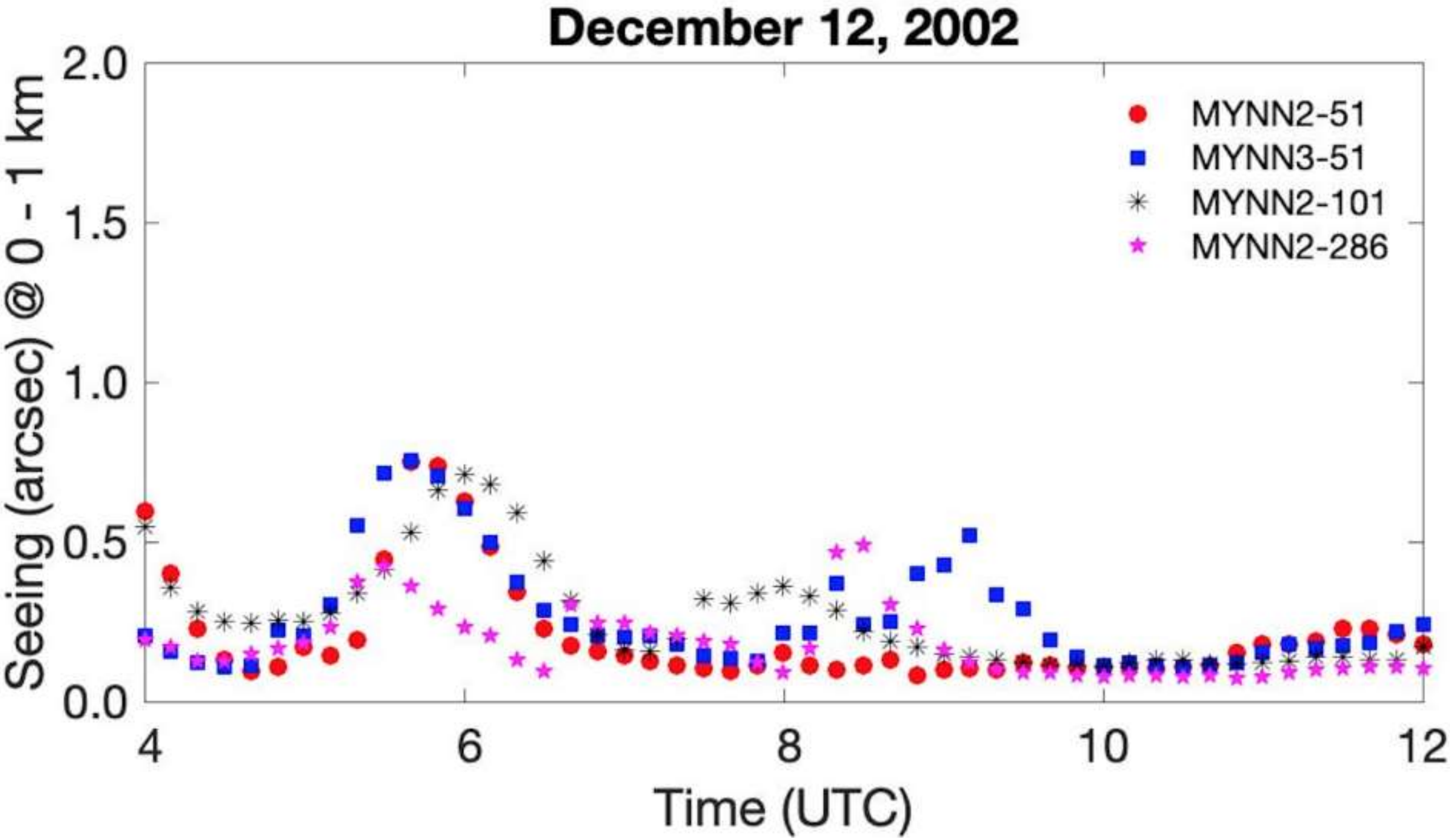
 # vertical grid points: 286 (uniform grid spacing of 100 m)



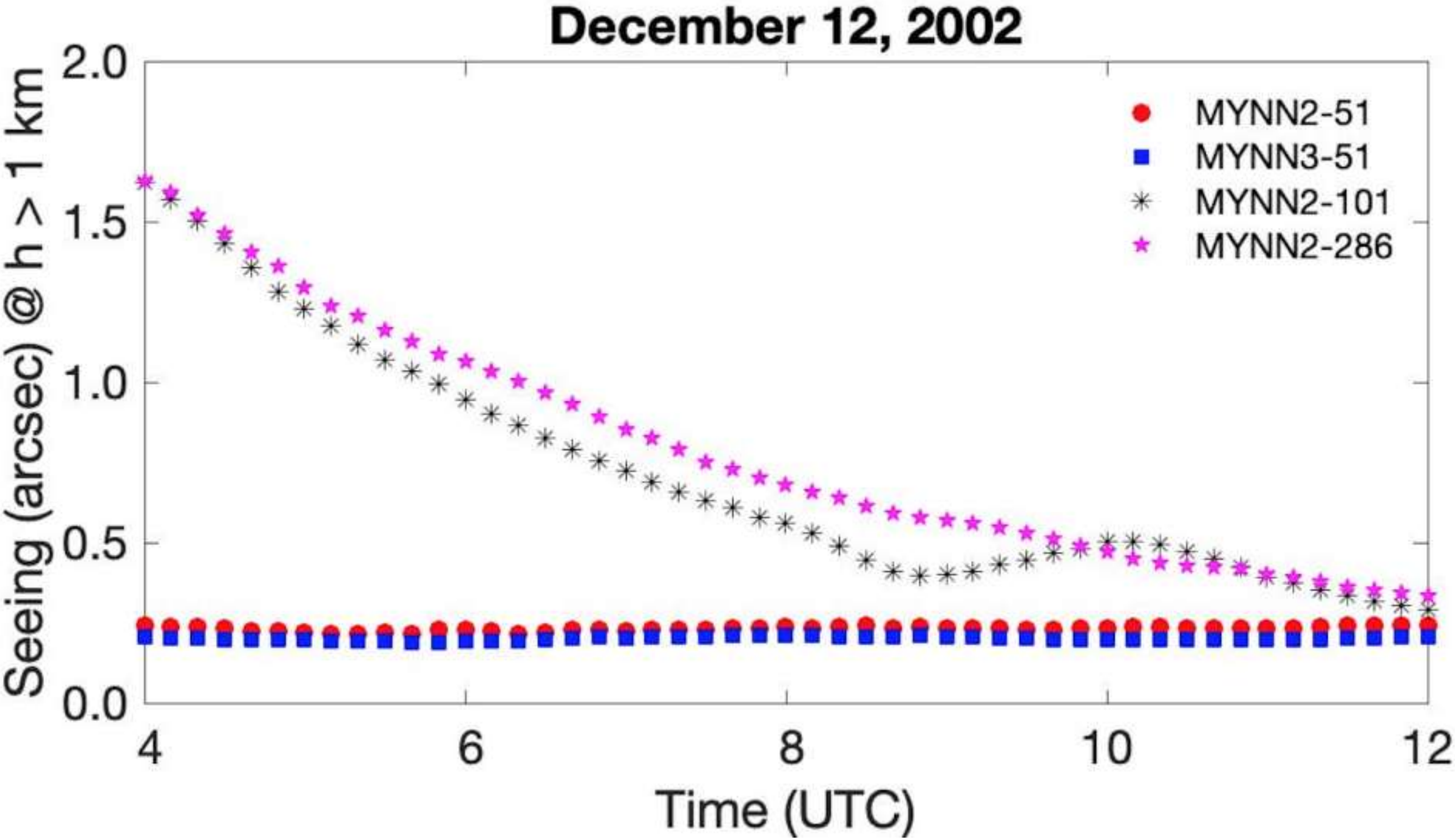
Simulated "Seeing" (Total)



Simulated “Seeing” (Ground Layer)

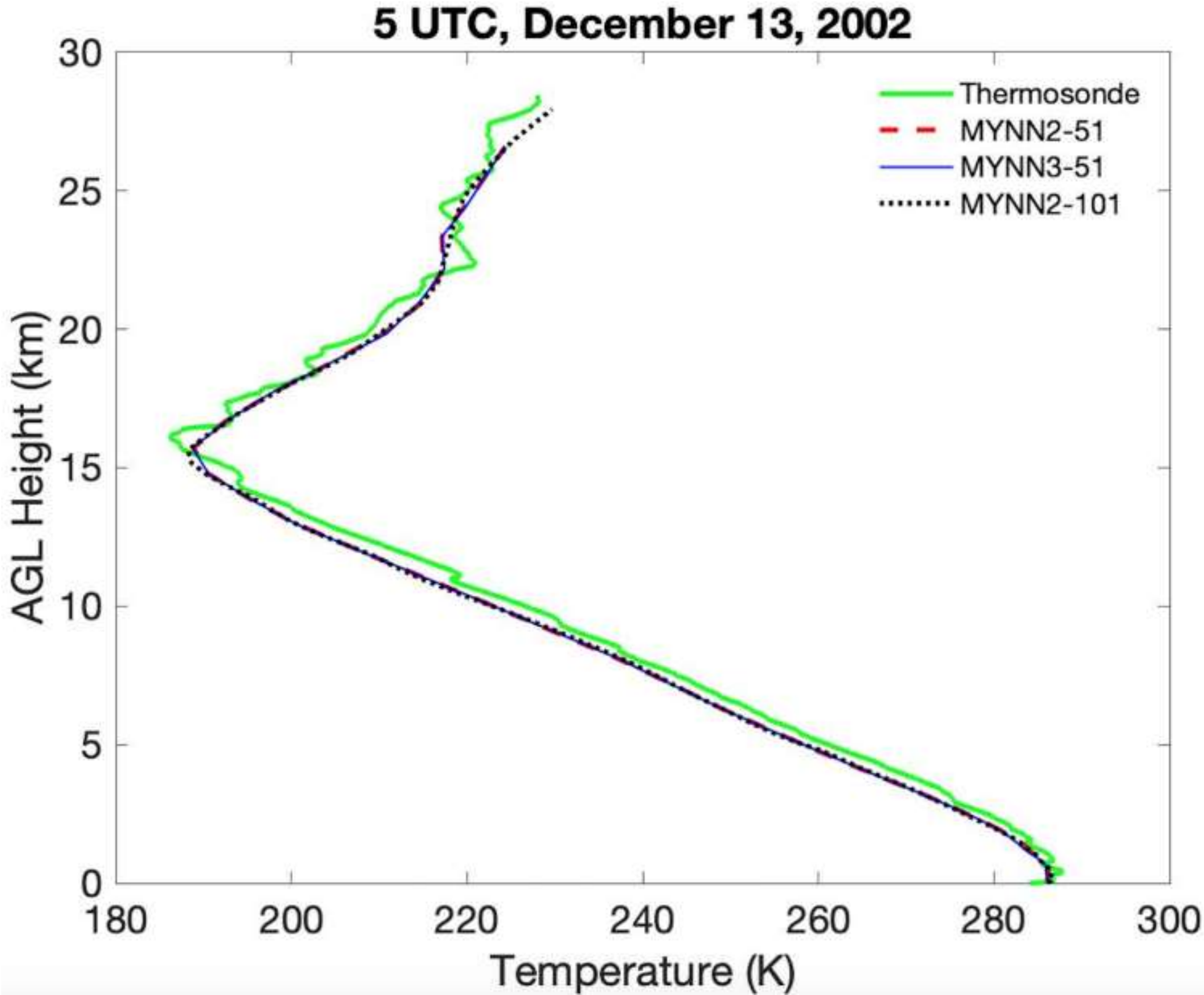


Simulated “Seeing” (Upper Layer)

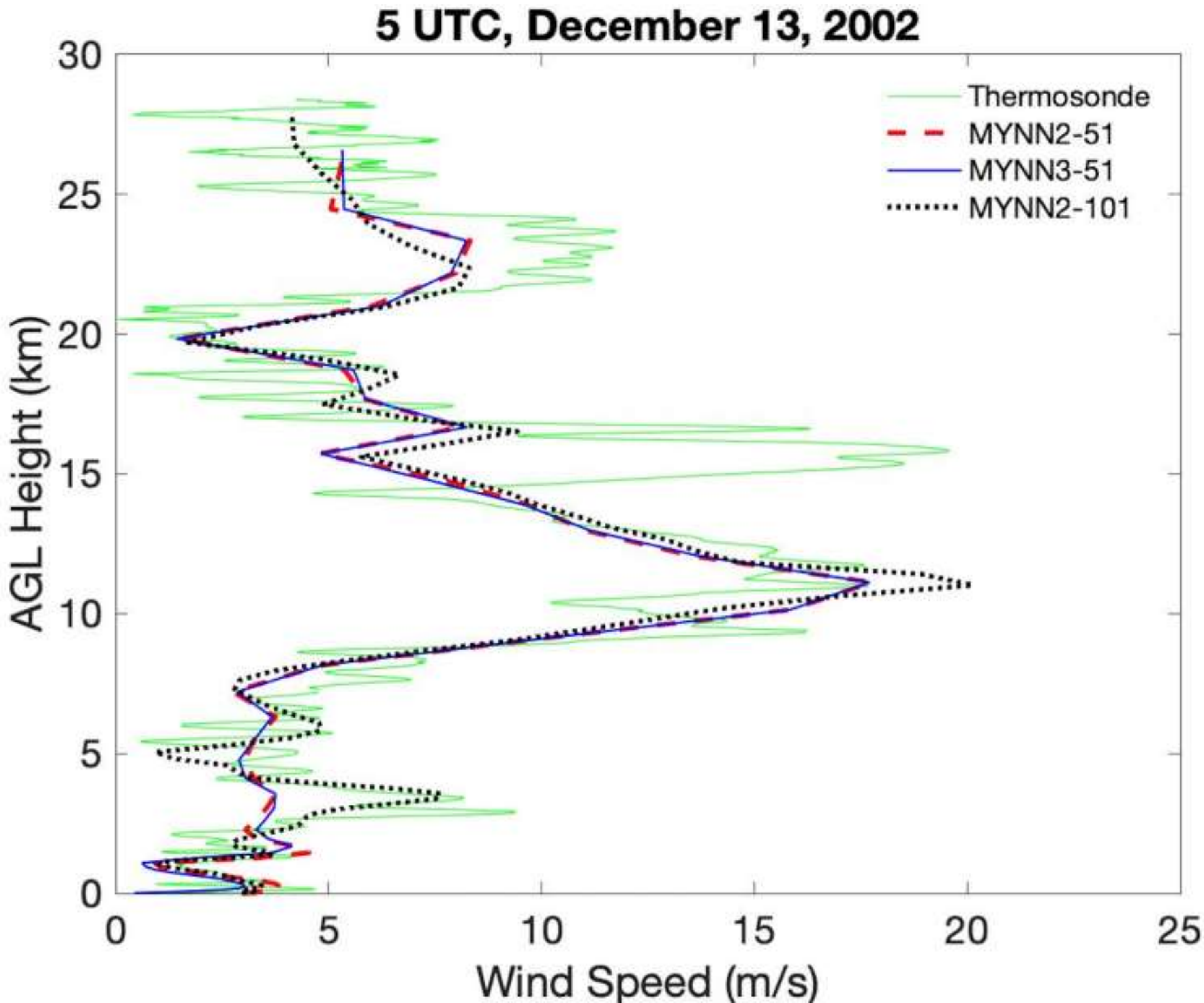


Dec 12-13, 2002

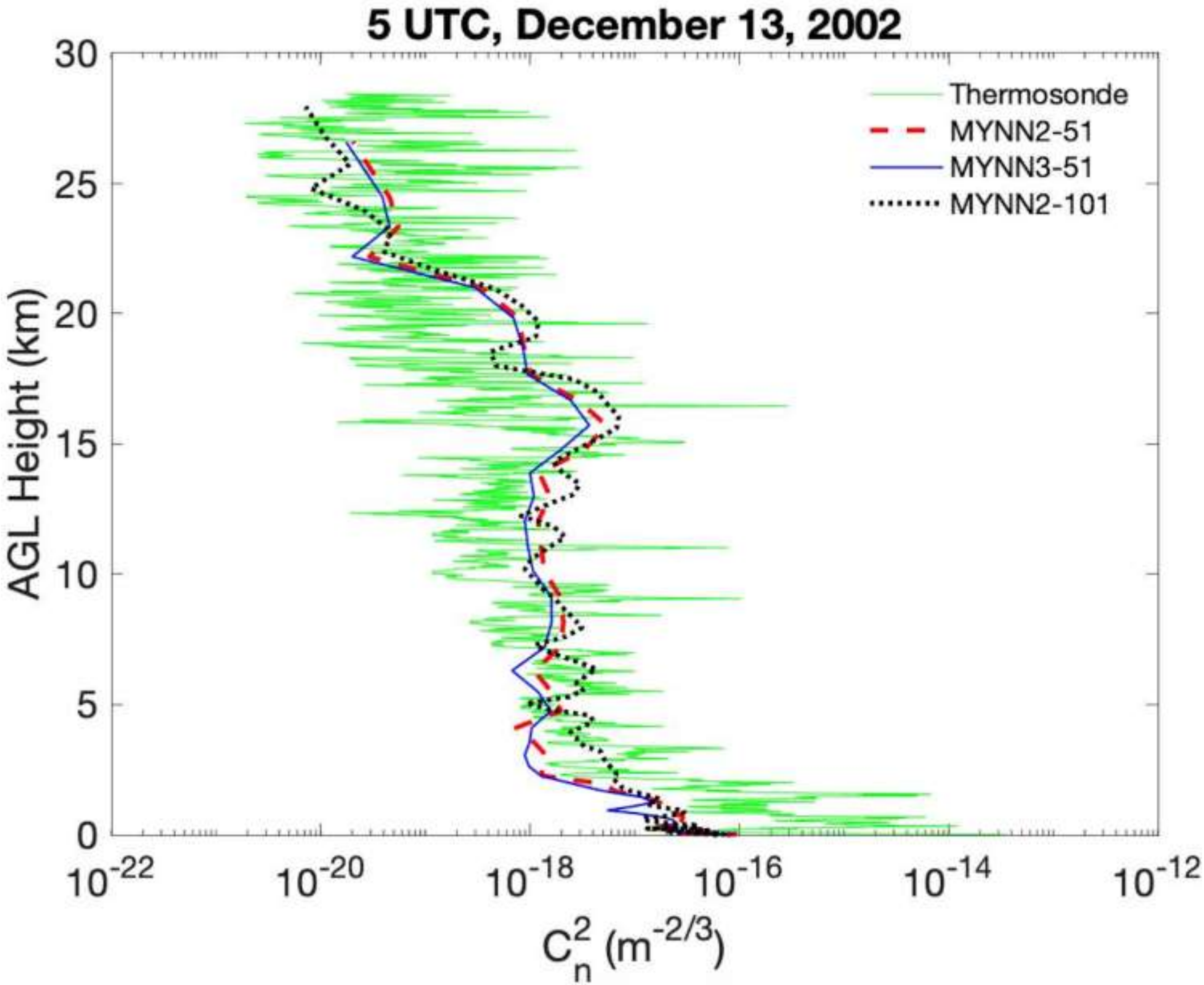
Mean Temperature Profiles



Mean Wind Speed Profiles

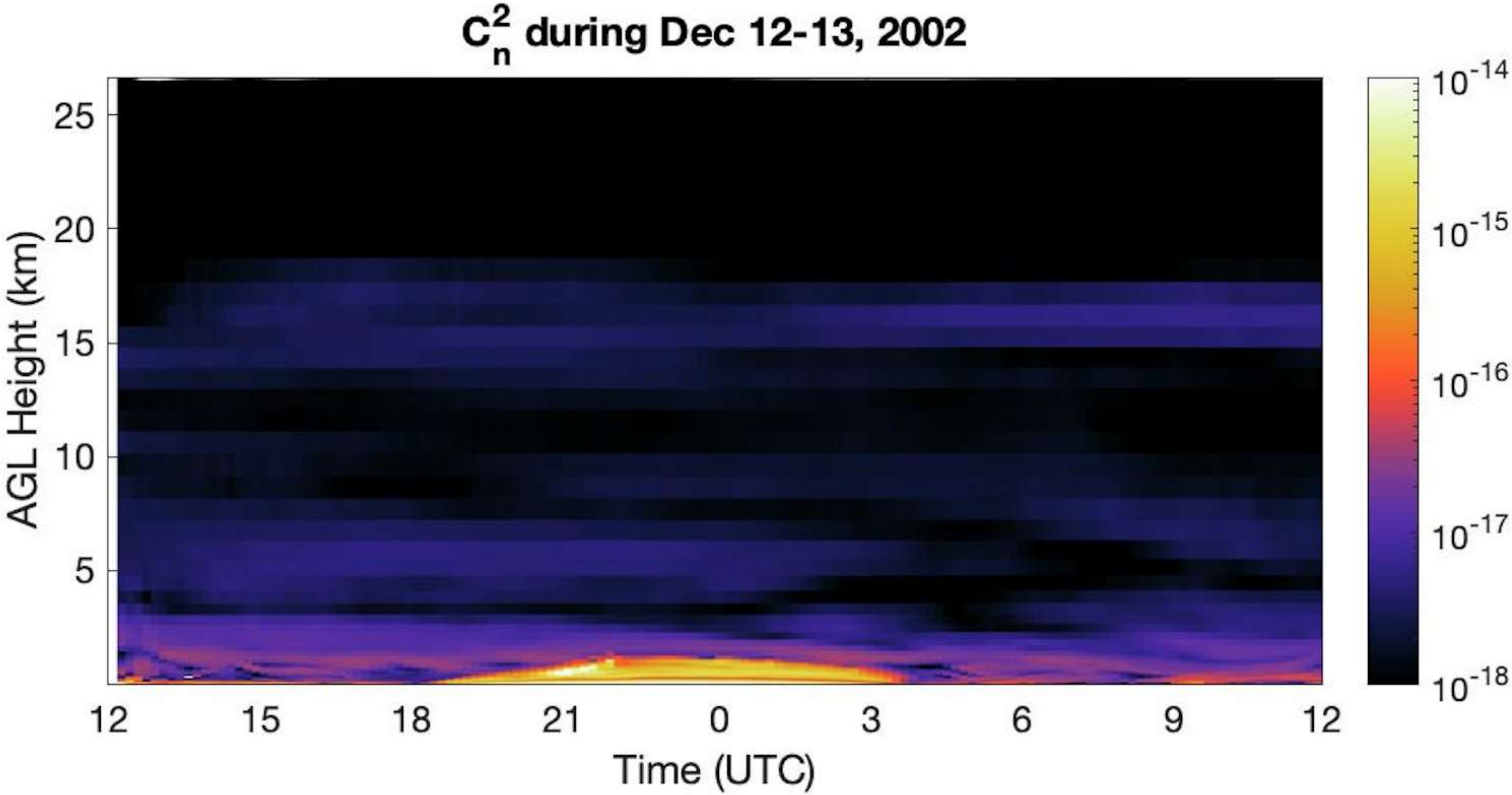


C_n^2 Profiles



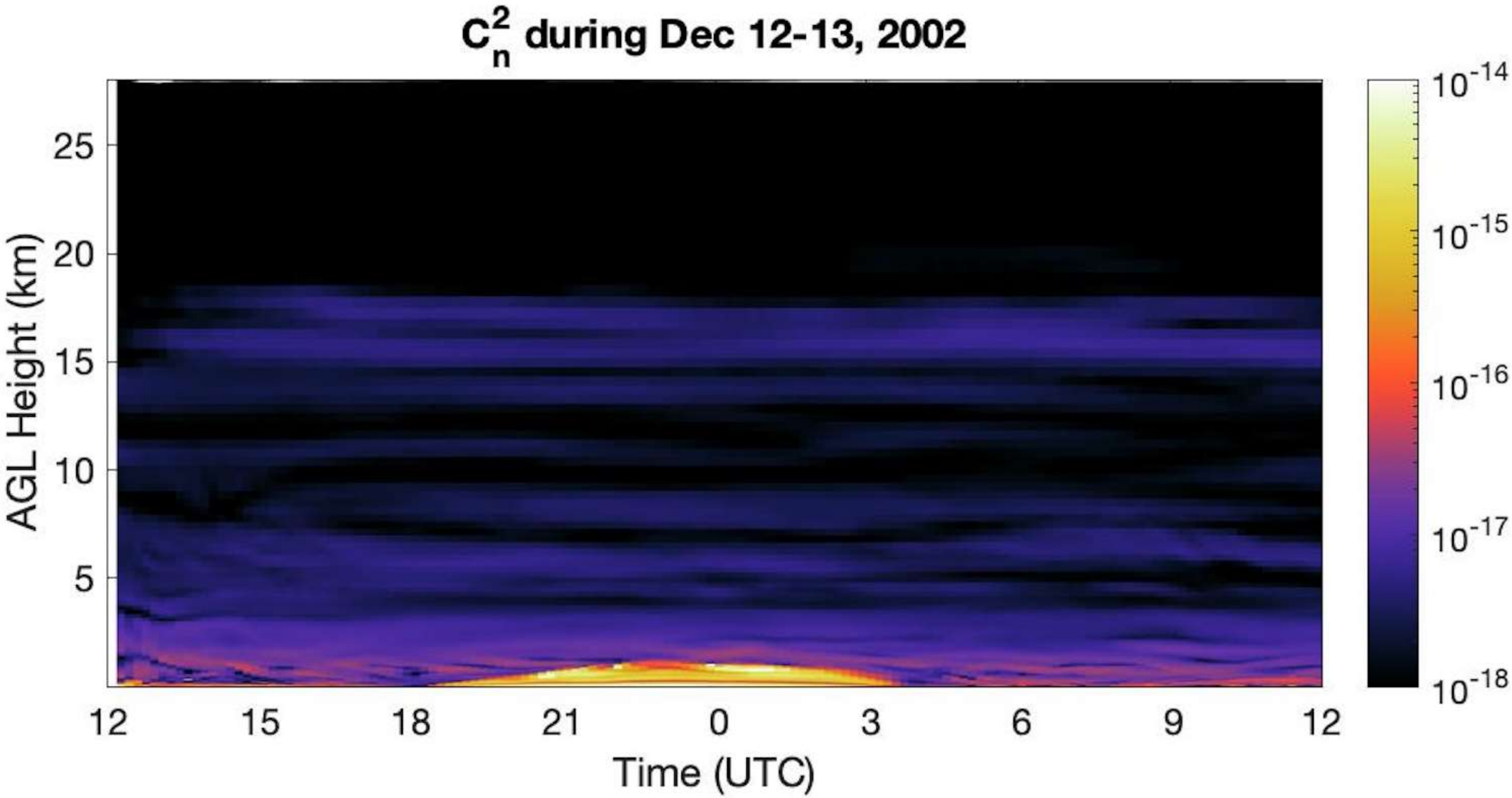
Simulated C_n^2 over Hawaii and Pacific Ocean

 # vertical grid points: 51

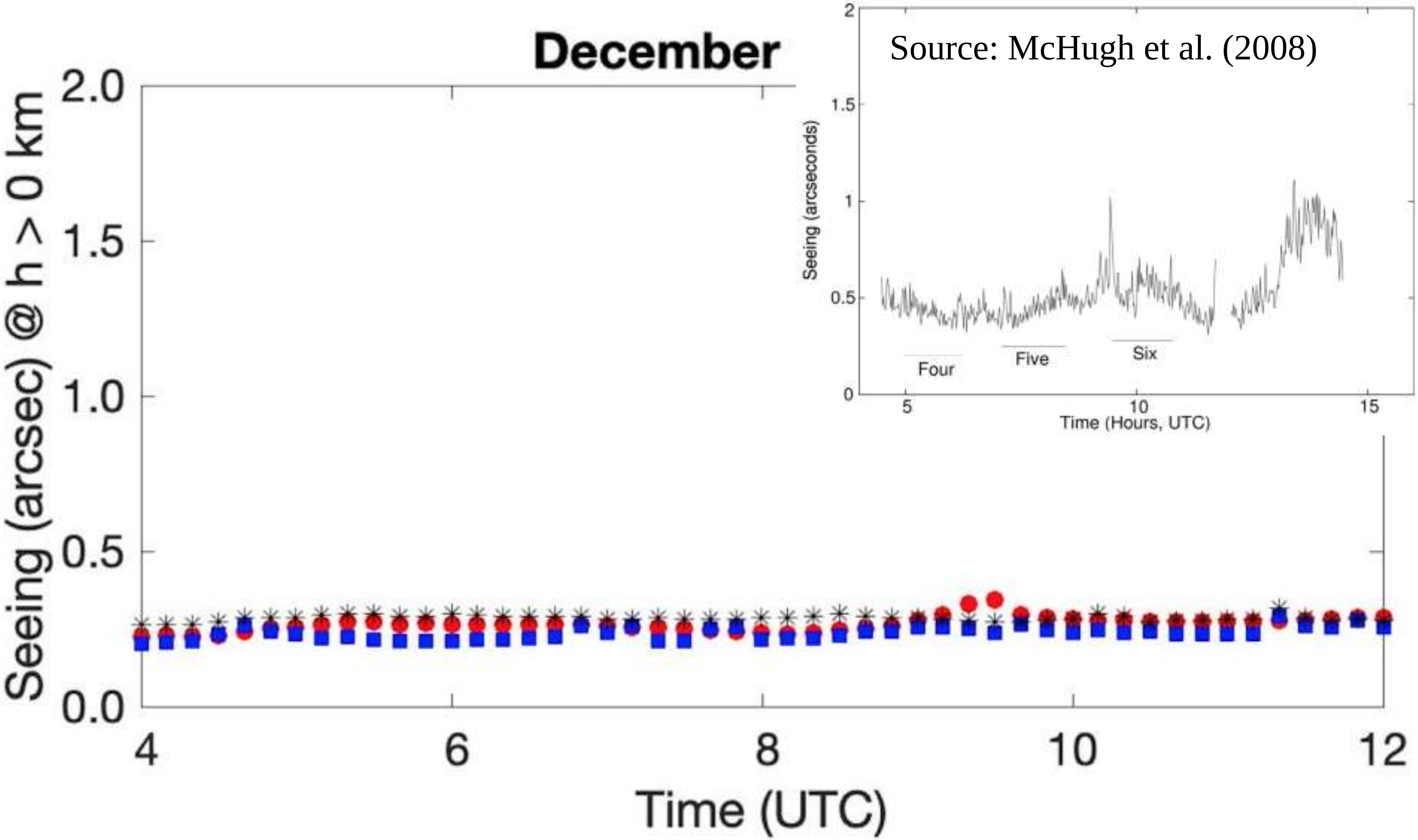


Simulated C_n^2 over Hawaii and Pacific Ocean (Cont.)

 # vertical grid points: 101



Simulated “Seeing” (Total)

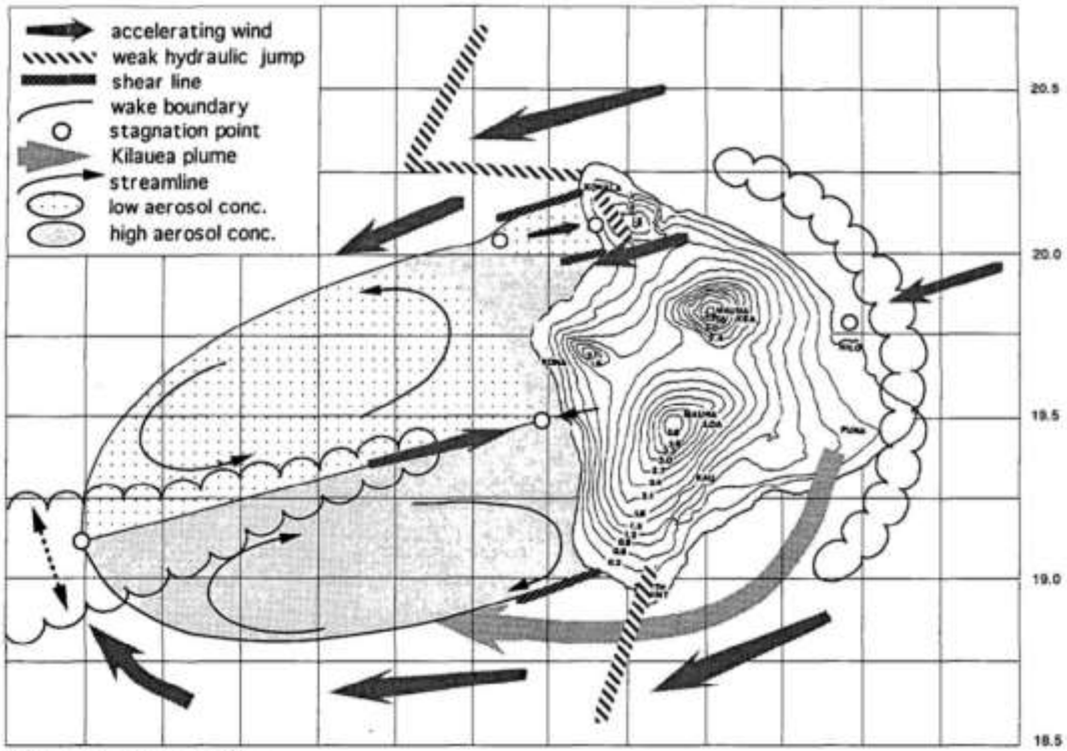


Horizontal Cross-Sections

Island Wakes

Source: NASA

Flow Structures around Big Island



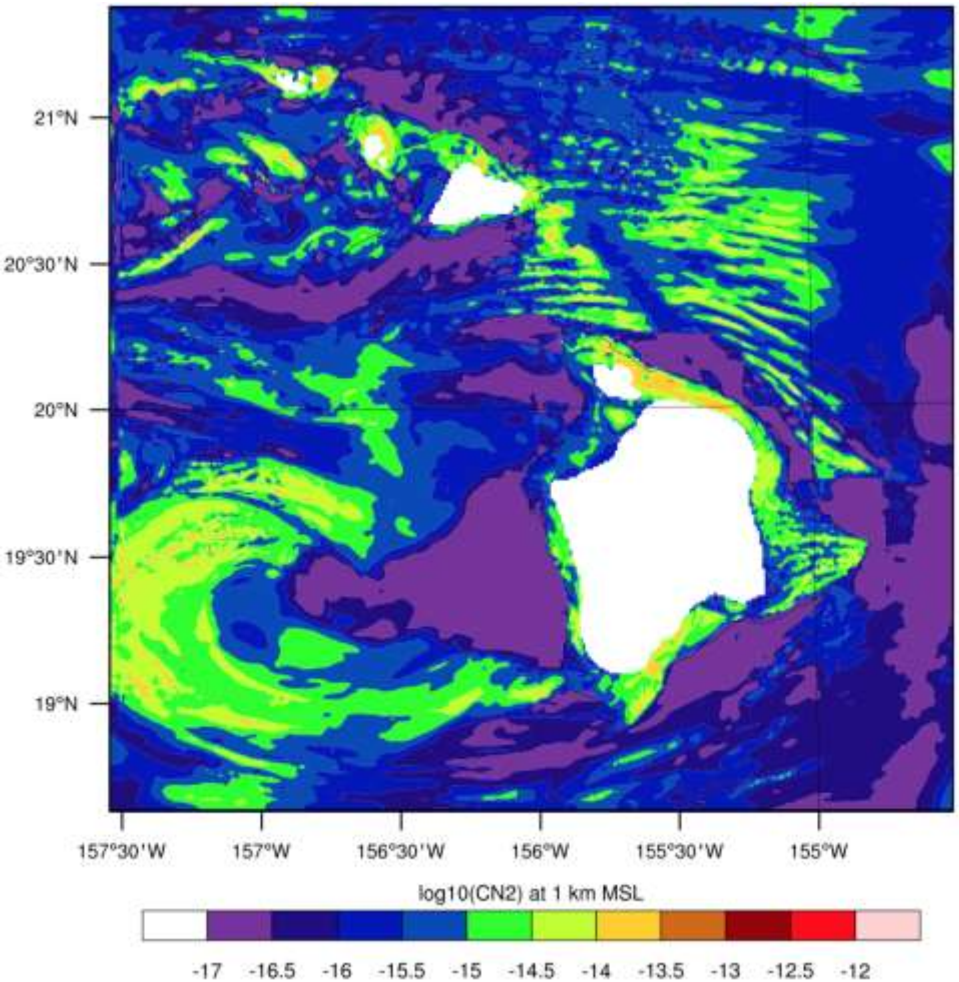
Meteorol Atmos Phys
DOI 10.1007/s00703-015-0366-4

ORIGINAL PAPER

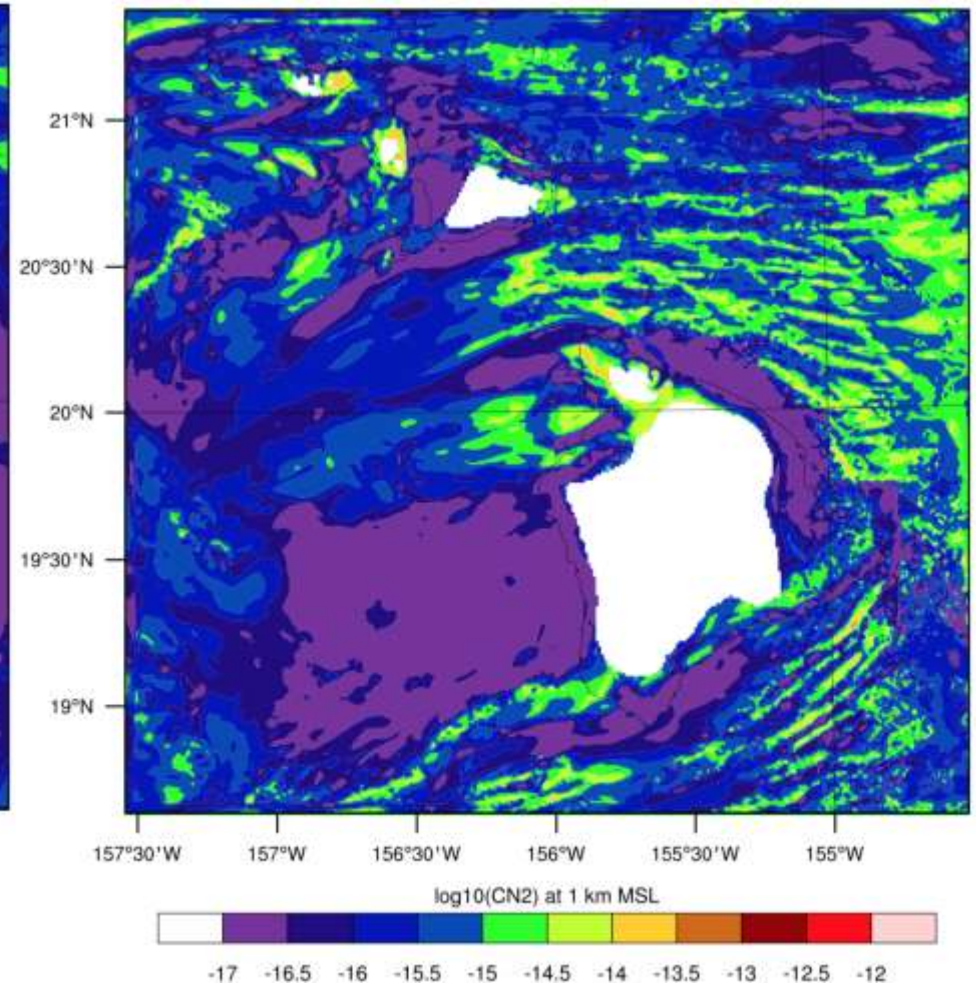
Mapping optical ray trajectories through island wake vortices

**Christopher G. Nunalee · Ping He ·
Sukanta Basu · Jean Minet · Mikhail A. Vorontsov**

Spatial Distribution of C_n^2 (# Vertical Grid Points = 286; 1 km MSL)

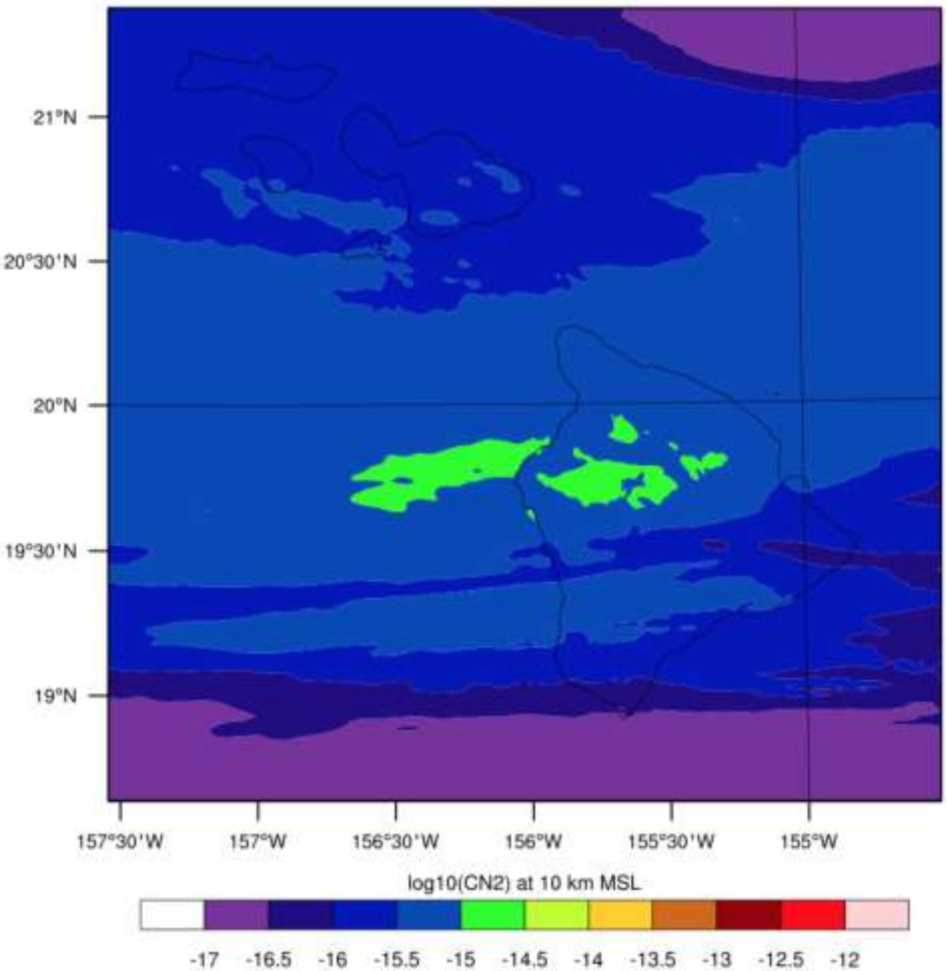


2 UTC, Dec 12

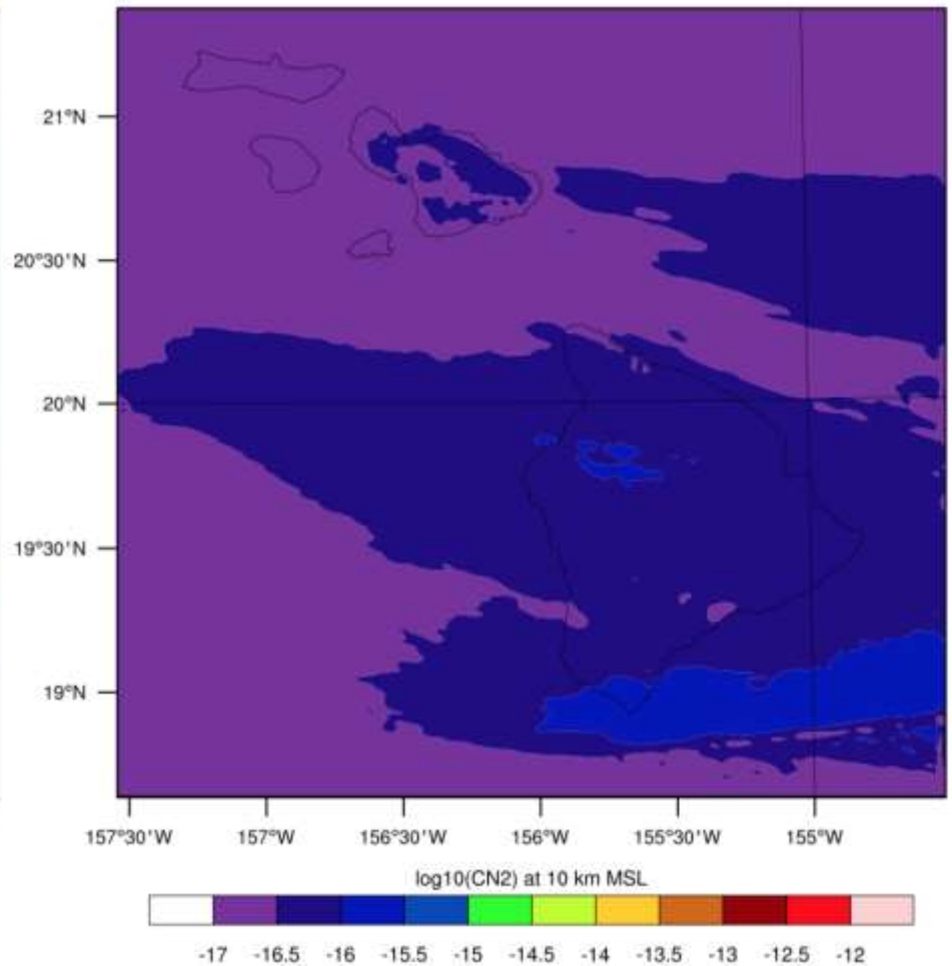


7 UTC, Dec 12

Spatial Distribution of C_n^2 (# Vertical Grid Points = 286; 10 km MSL)



2 UTC, Dec 12

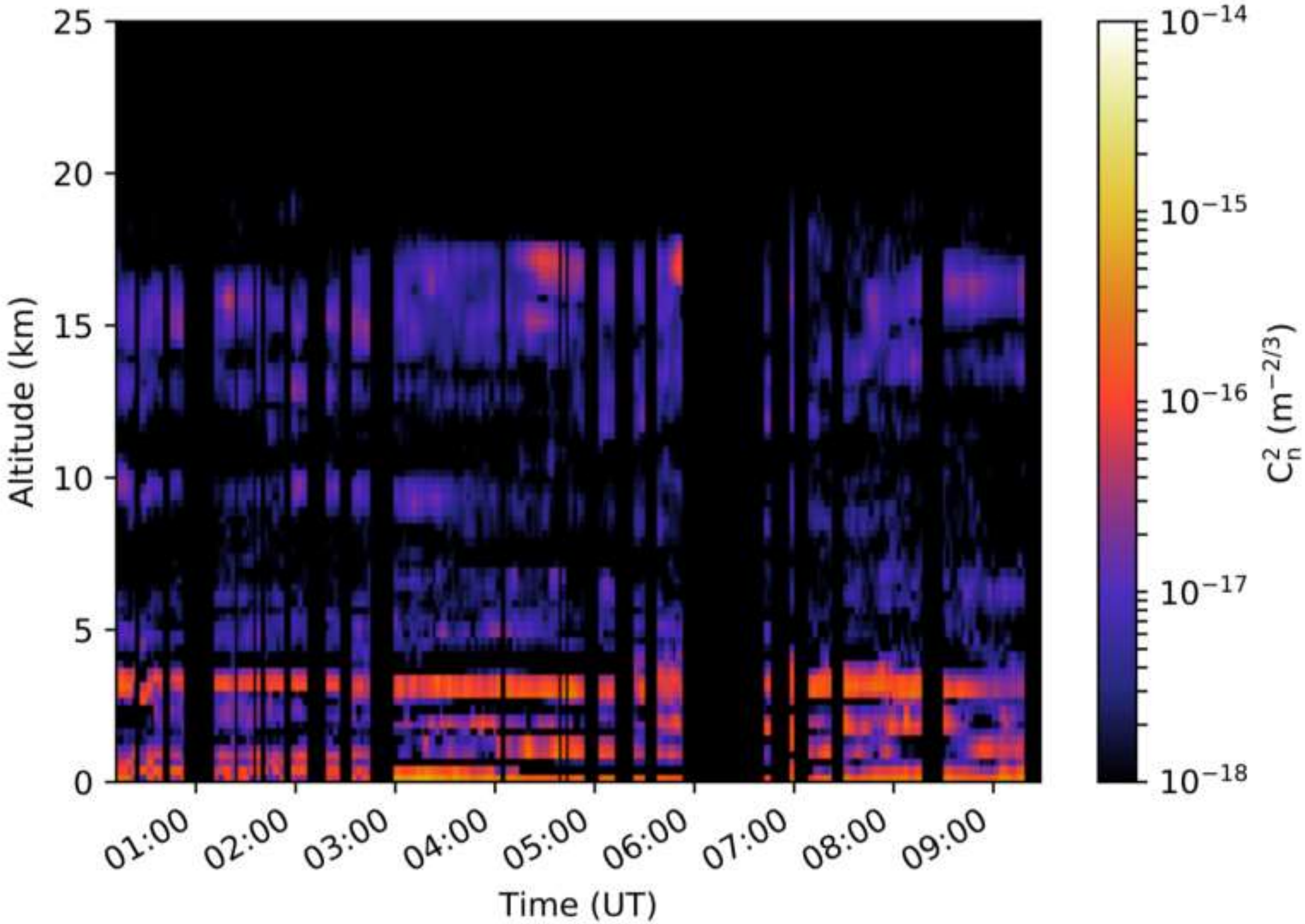


7 UTC, Dec 12

Case Study:

Paranal 2017

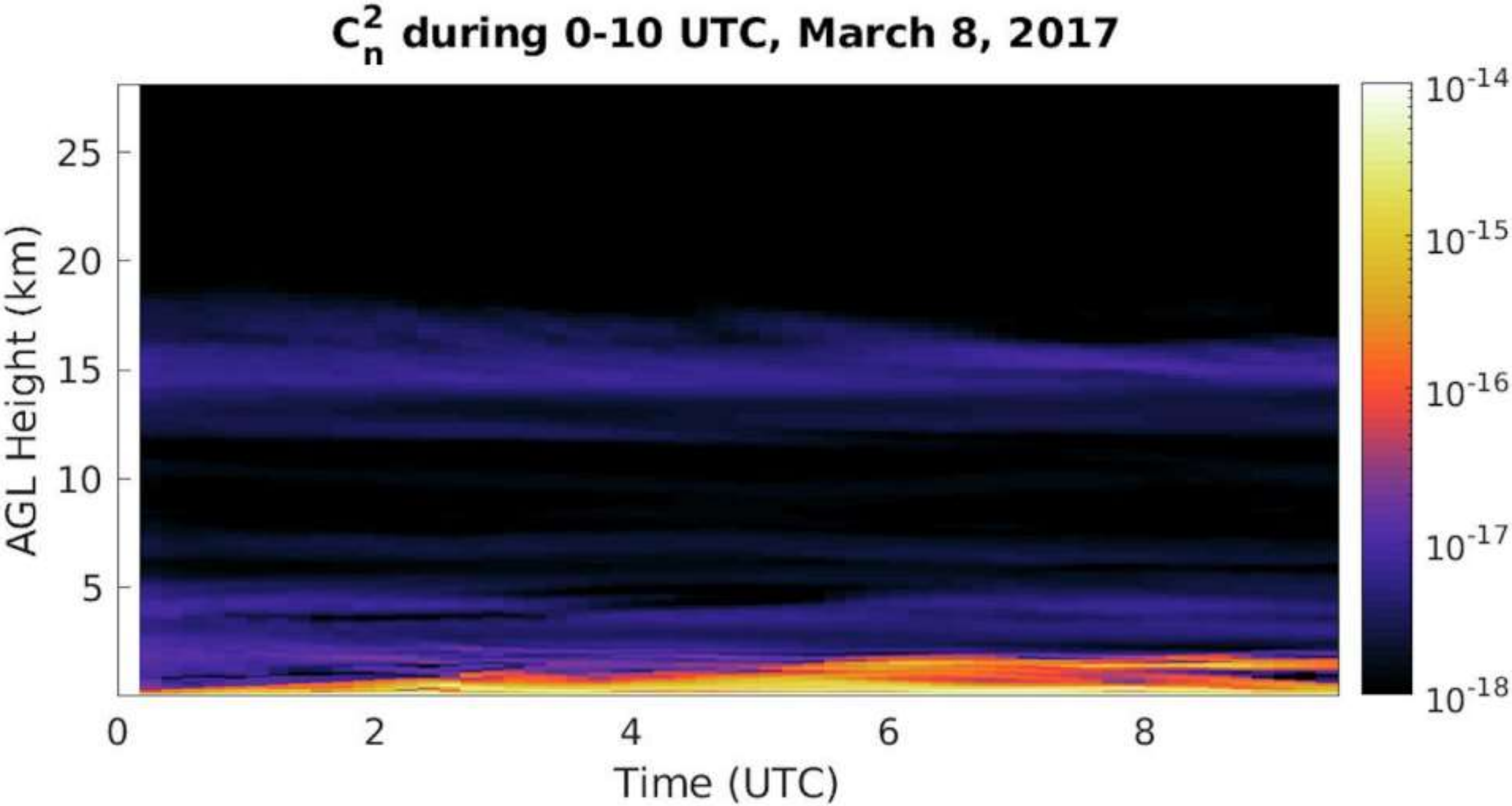
Observed C_n^2 over Paranal



Courtesy: James Osborn

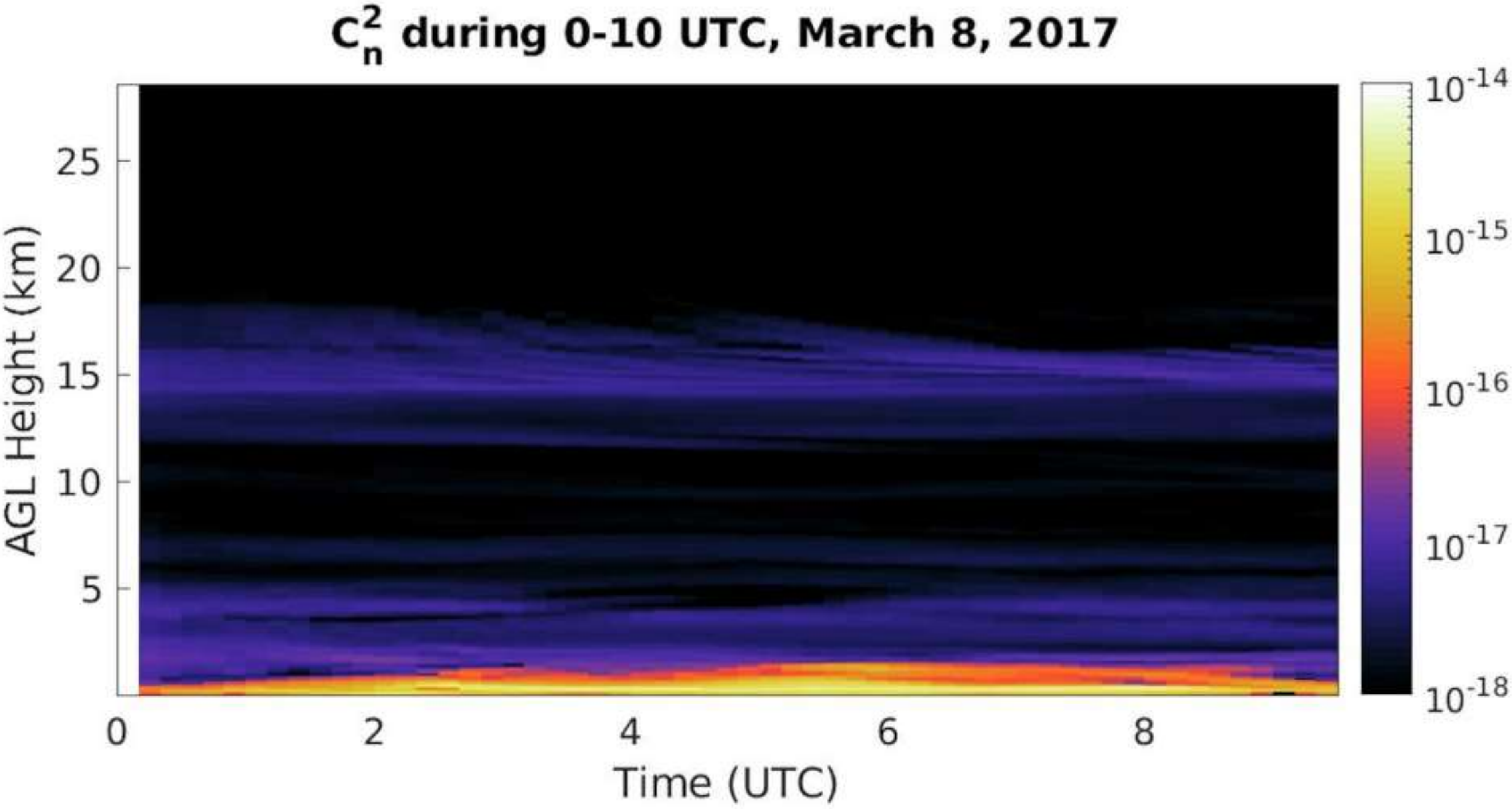
Simulated C_n^2 over Paranal

 # vertical grid points: 201



Simulated C_n^2 over Paranal (Cont.)

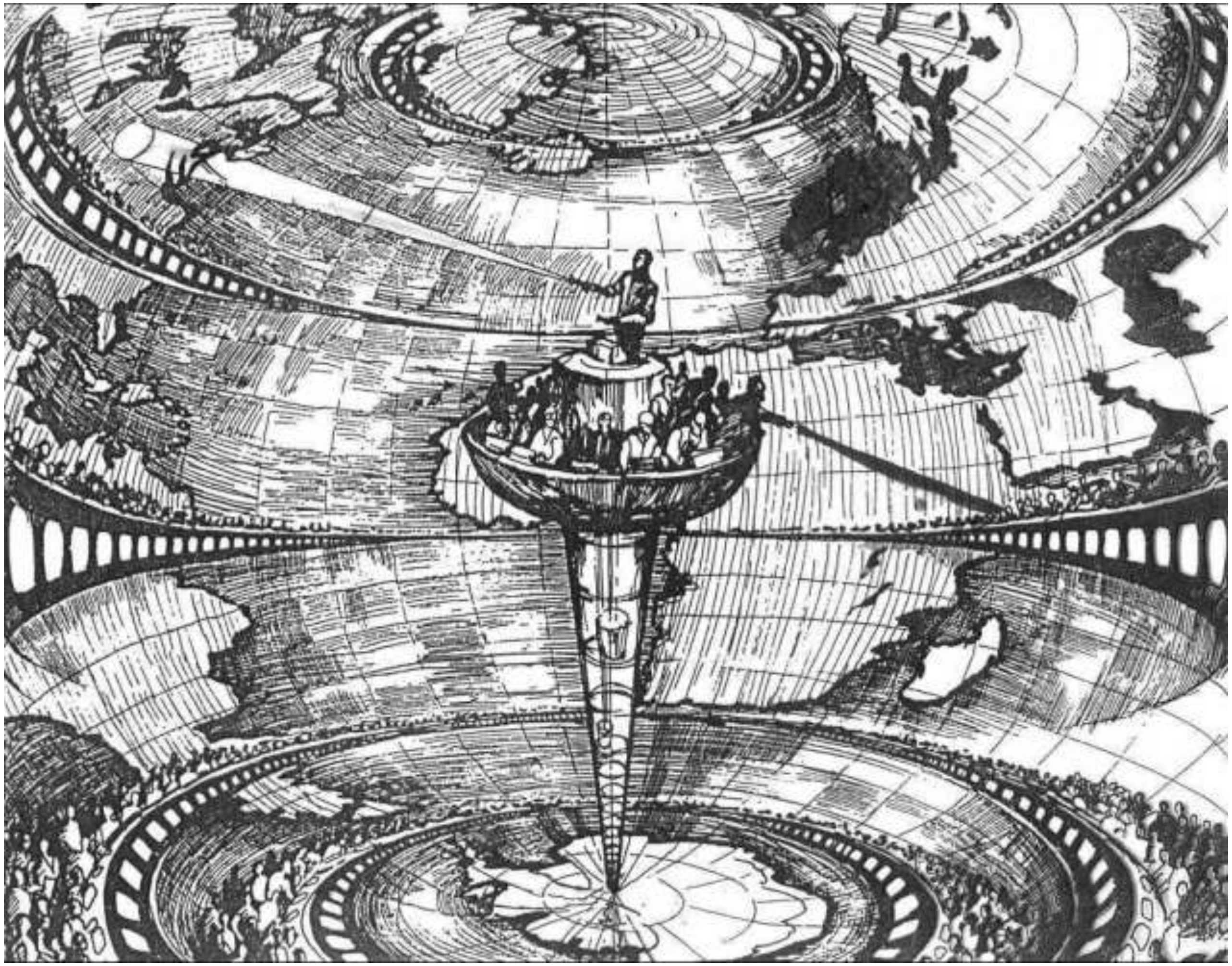
 # vertical grid points: 286 (uniform grid spacing of 100 m)



To be continued…

Richardson (1922)

"Perhaps some day in the dim future it will be possible to advance the computations faster than the weather advances and at a cost less than the saving to mankind due to the information gained. But that is a dream."



Richardson's
forecast factory
Source: Bengtsson