Convection in the Nocturnal Surface Layer- Stability and Impact on Micro-meteorology

K R Sreenivas
Engineering Mechanics Unit
JNCASR, BANGALORE

Dr. Dhiraj Kumar Singh
Mr. Mohammad Rafiuddin
Mr. Shaurya Kaushal

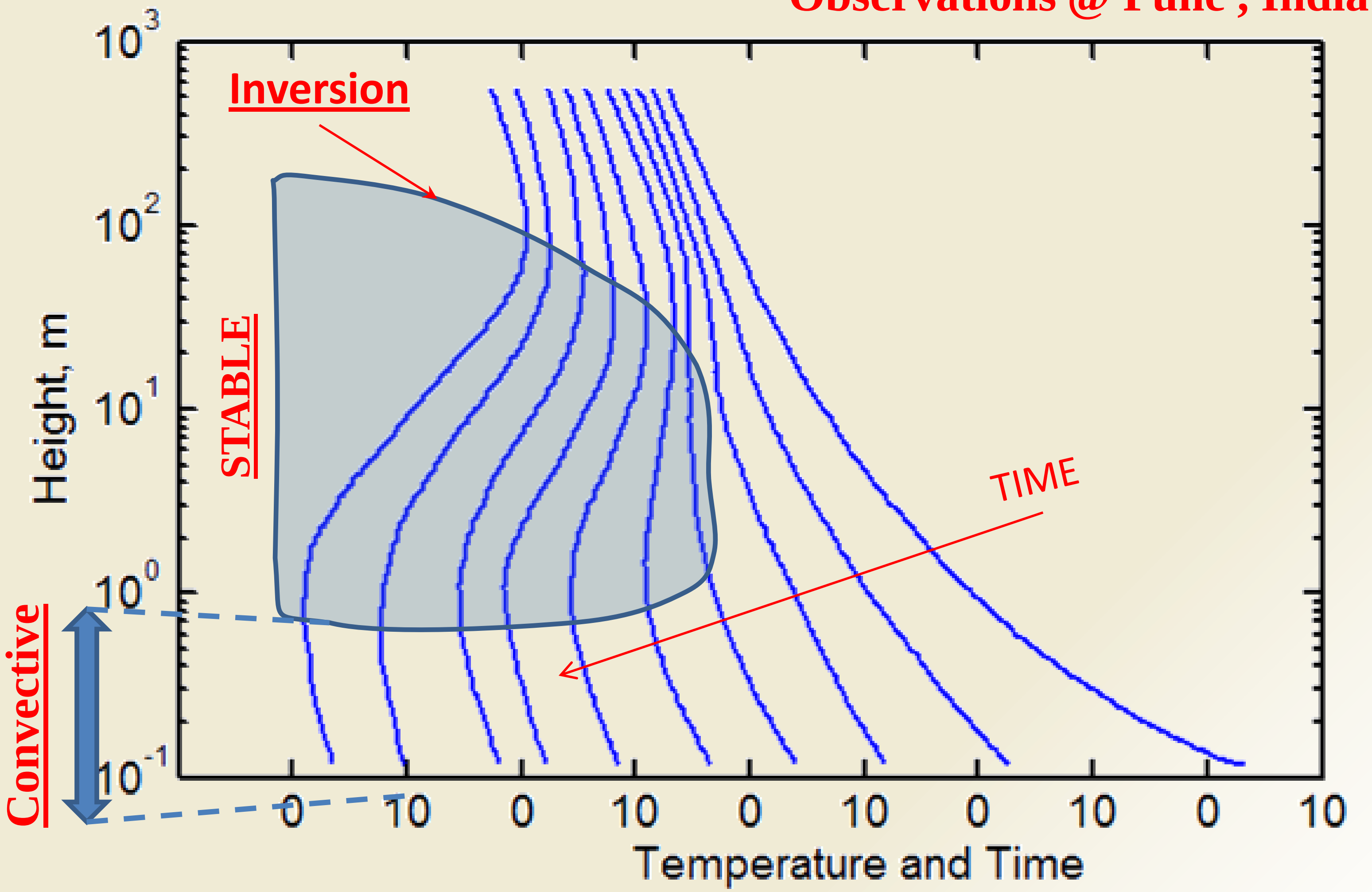
Prof. Ganesh Subramanian

ICTS INTERNATIONAL CENTRE *for* THEORETICAL SCIENCES

Summer school and Discussion Meeting on Buoyancy-driven flows
ICTS-Bangalore. June 16-20, 2017

25 Years Celebration

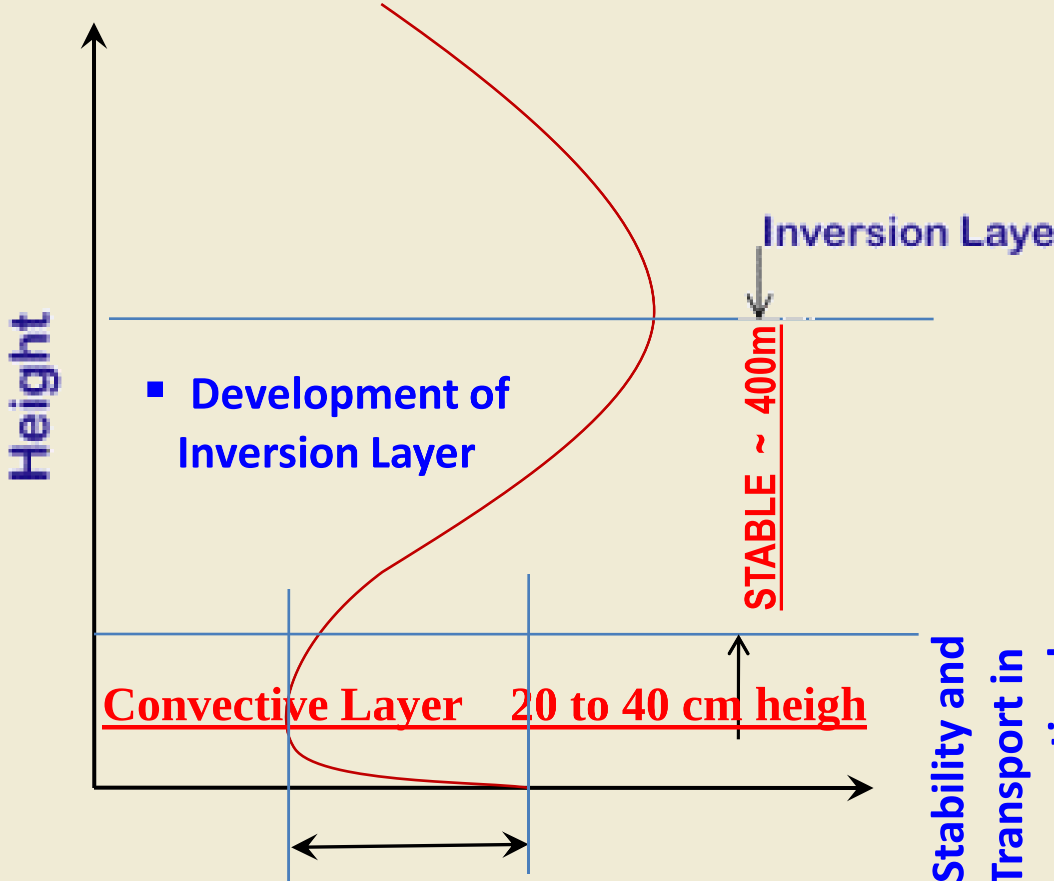
Observations @ Pune , India



Time evolution of Temperature Profiles in Pune at 17:00, 18:00, 19:00, 19:30, 20:00, 20:30, 21:00, 23:00, +1 day- 03:00 and 07:00 hrs Respectively

Ramdas LA, Atmanathan S (1932)

Nocturnal Atmospheric Surface layer :



- Development of Inversion Layer

Inversion Layer

STABLE ~ 400m

Convective Layer 20 to 40 cm heigh

Intensity of the minimum 2°-6° C

- Stability and Transport in convection layer

http://universe.byu.edu/wp-content/uploads/2014/01/UtahAir.jpg

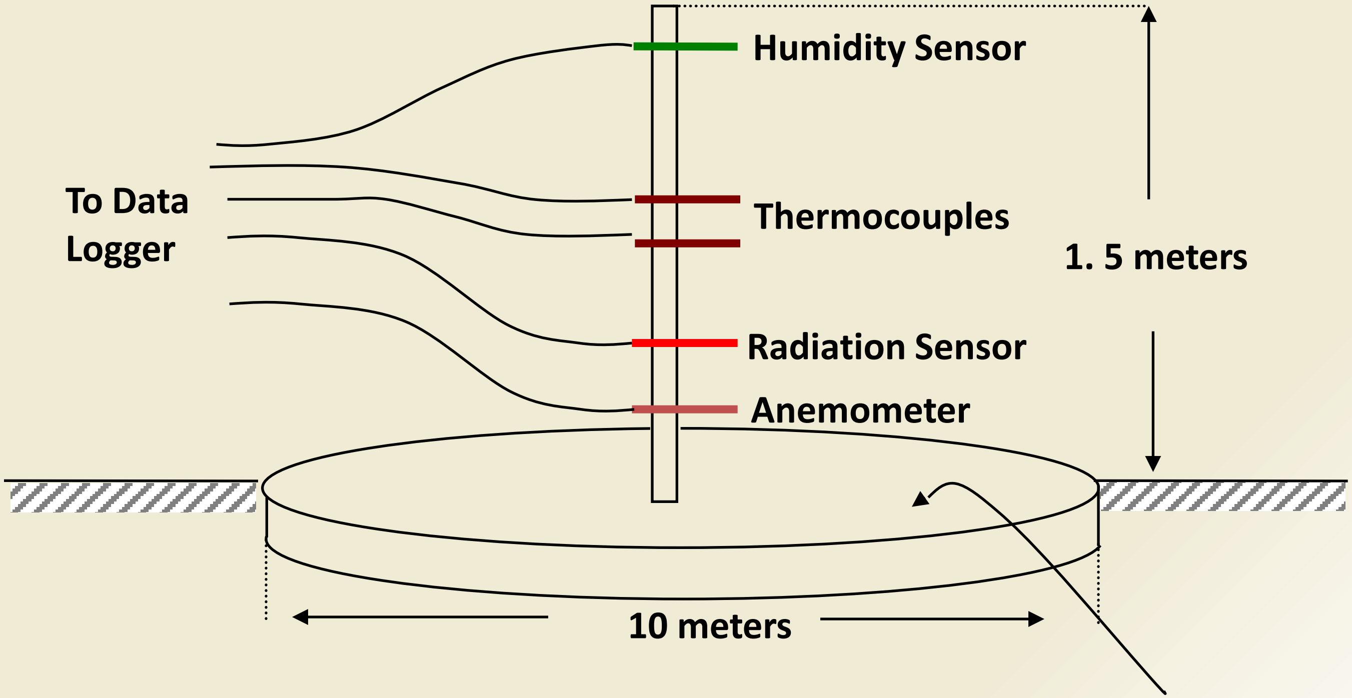
Implications:

- Processes in Nocturnal Boundary plays an important role in the development of (a) Inversion layer (b) Radiation-fog

- Origen and Development of Thermal structure
- Stability and Convection
- Modeling Radiation Fog – (approach)

Development of Thermal structure in Nocturnal Boundary Layer….

Field Experiments..



Surface Properties to be changed.

Temperature Sensors Copper Constantan Thermocouples.

Wind Sensor: Thermistor based sensor from Accusense.

Humidity Sensor: Capacitance based humidity sensor from Honeywell.

Radiation Sensors Fabricated using Peltier modules.

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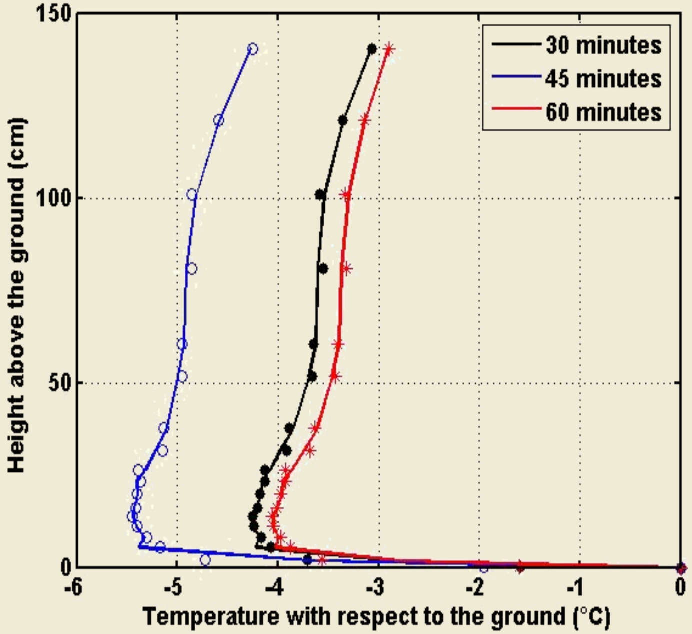
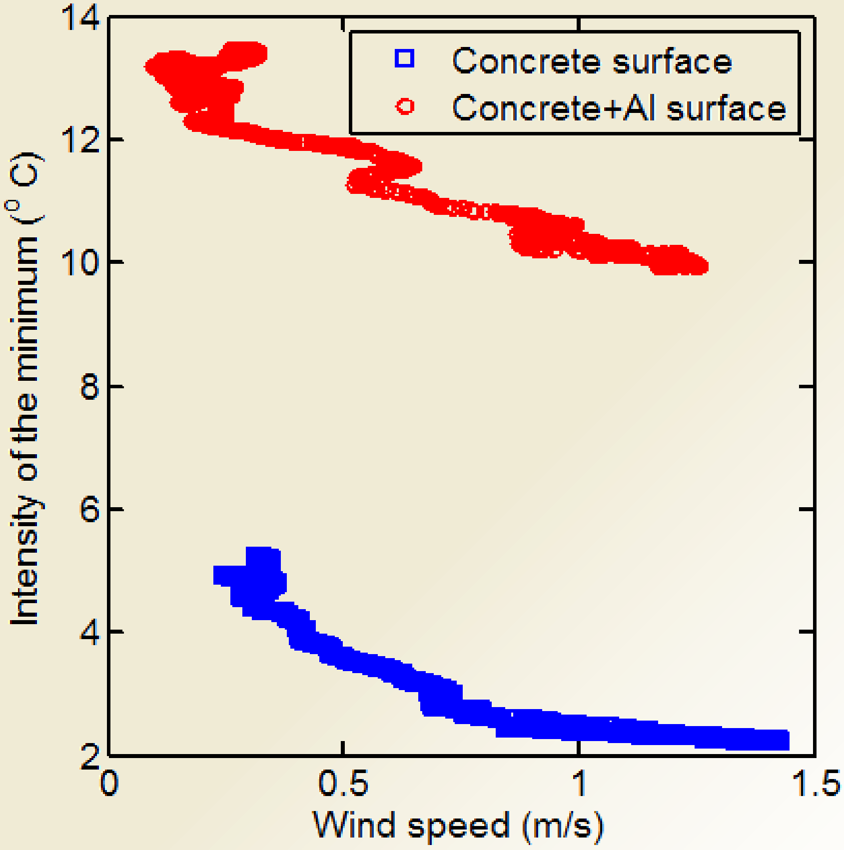
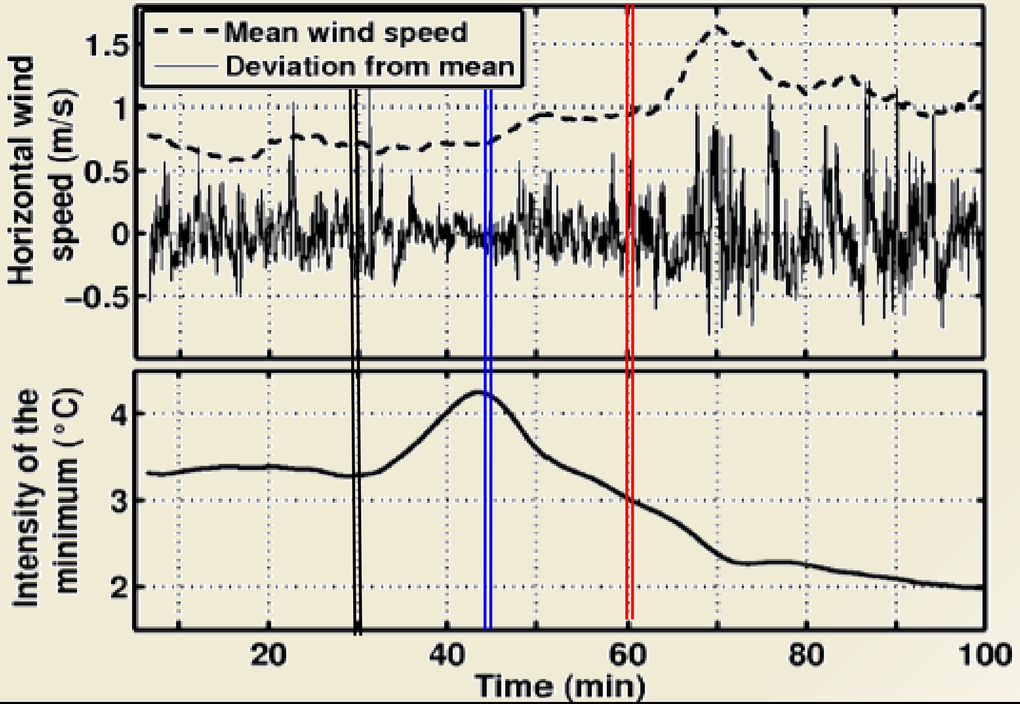
Field Experiments..







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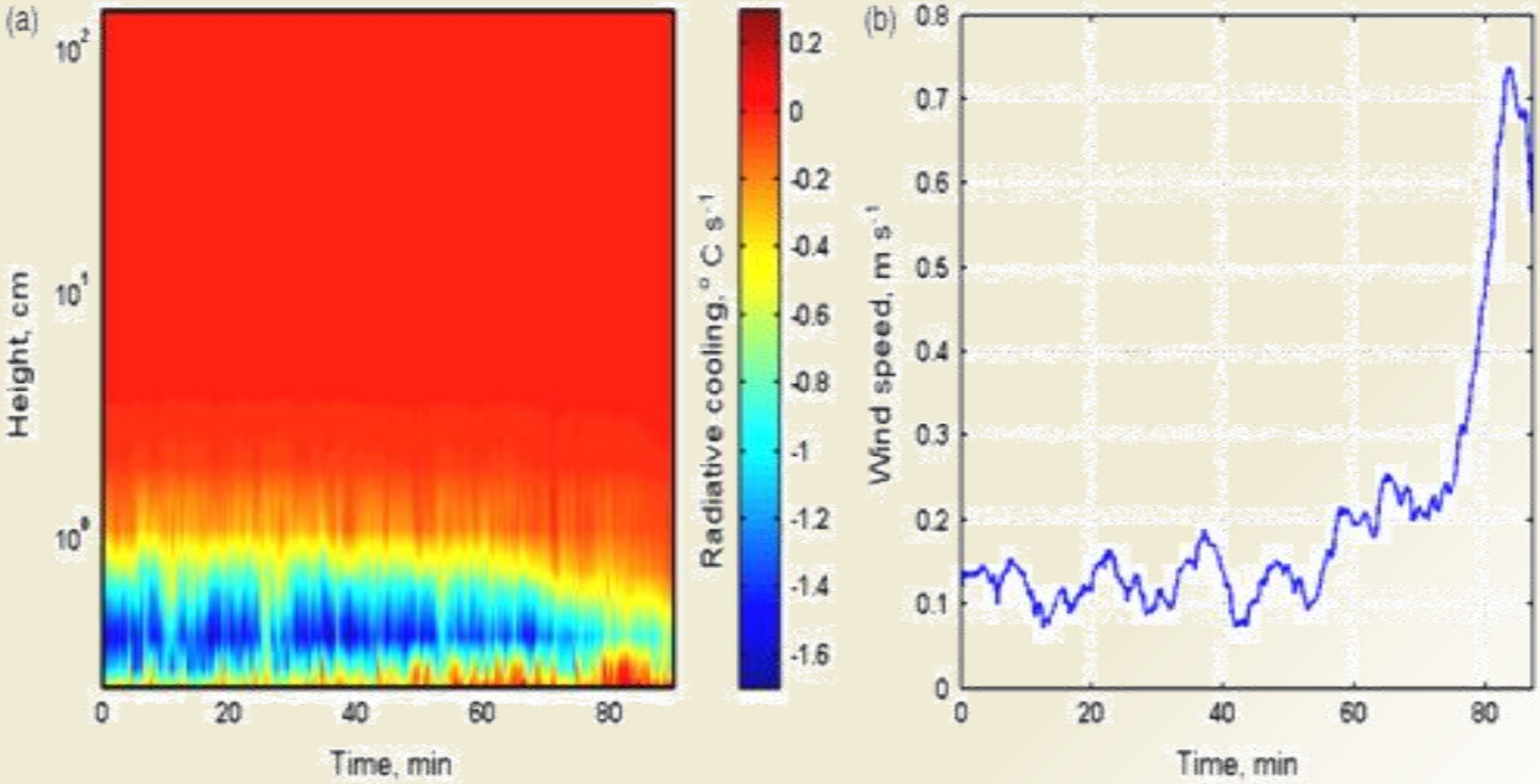

Figure 8. (a) Time evolution of the radiative cooling and (b) corresponding variation of wind speed. This figure is available in colour online at wileyonlinelibrary.com/journal/qj

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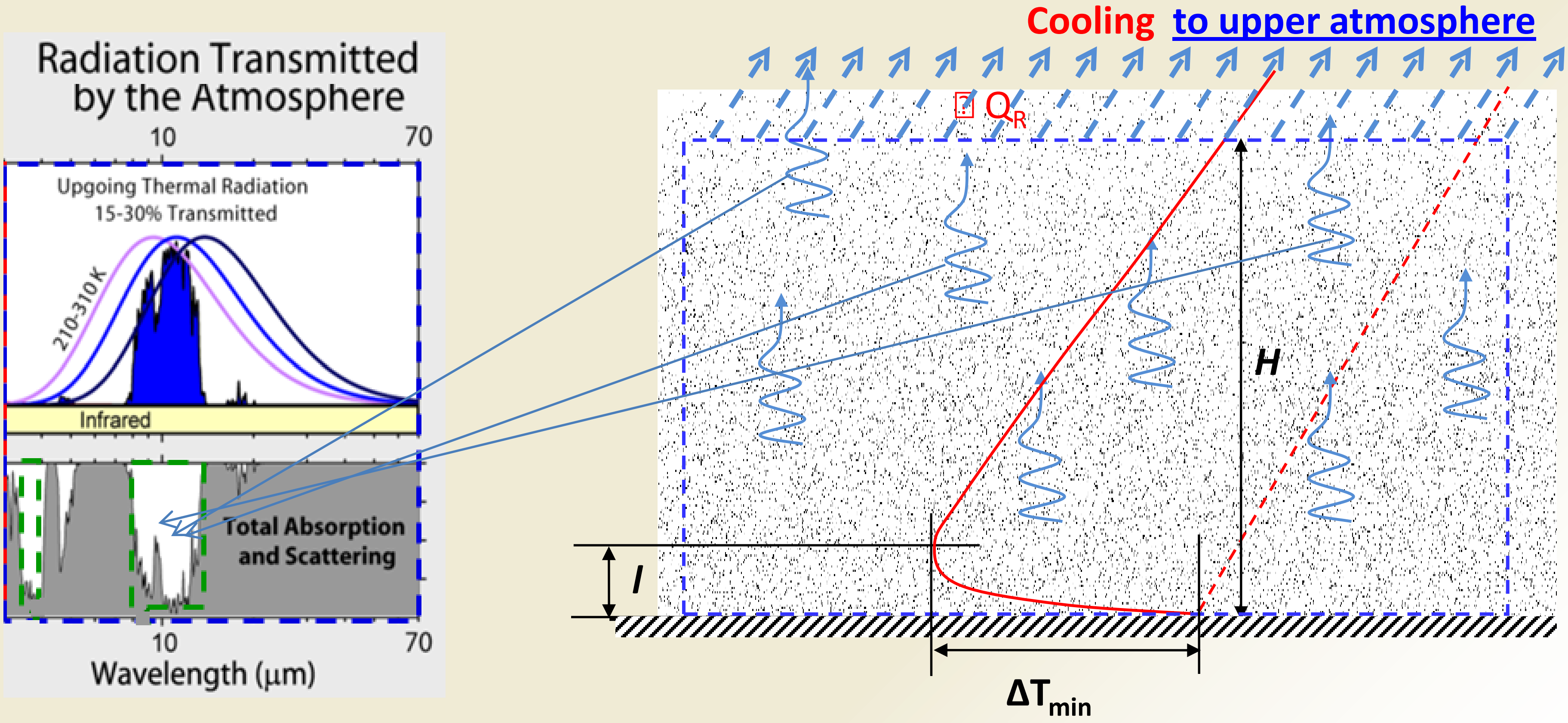
Explanation :

Radiative Cooling

Suggested Based on Time scale and behaviour

Heterogeneous atmospheric layer is a must for the formation LTM and Inversion Layer

Heterogeneity: Aerosols – Dust, droplets , any particulates



Emissivity (ε) of aerosols is >> air & can emit over all wavelengths . ∴ aerosols can cool to upper atmosphere

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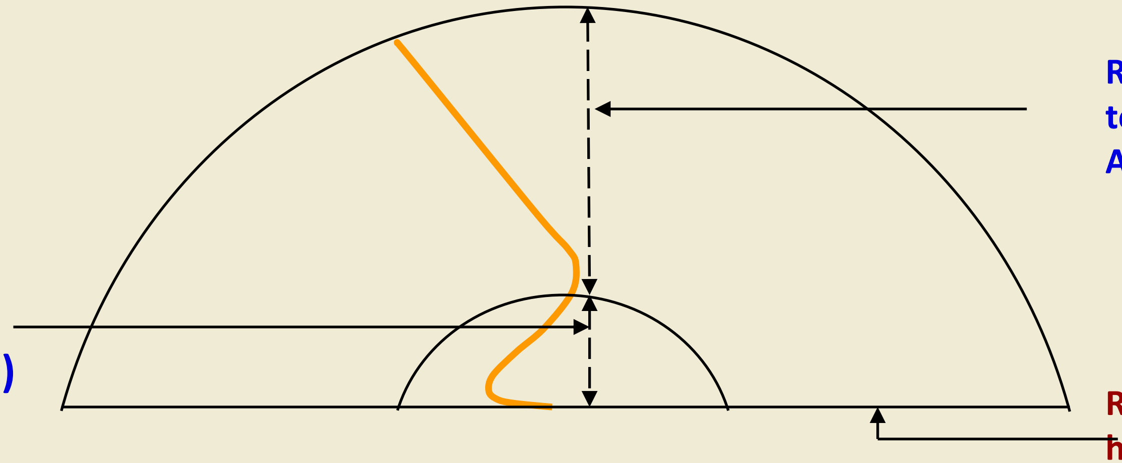
LABORATORY SETUP

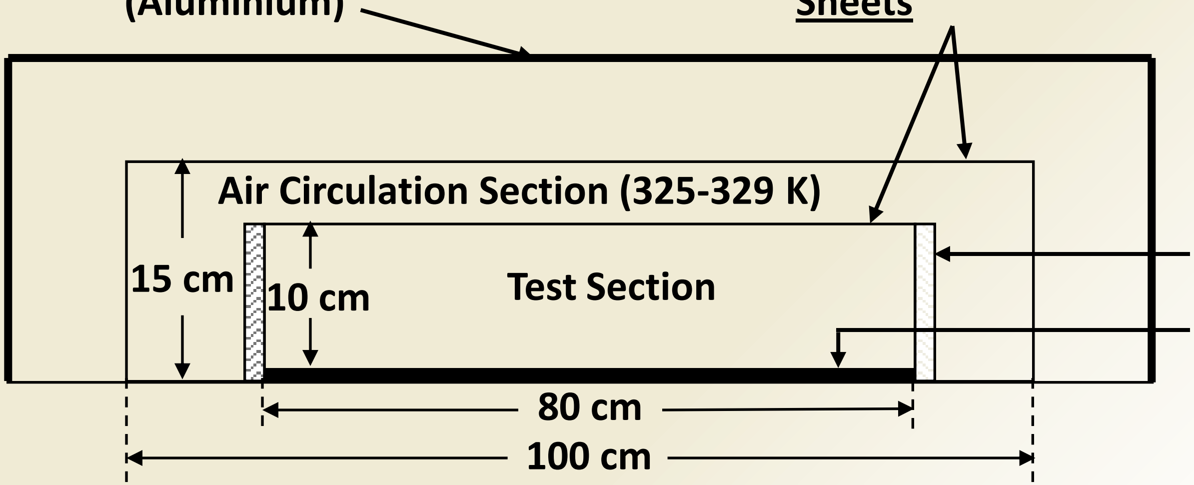


Radiative sink at low temp. (Cold upper Atmosphere)

Inversion layer (region of interest)

Radiative source at high temp. (ground)

Decoupling of radiation and conduction/convection boundary conditions — necessary to produce LTM in Lab



Outer Walls (Aluminium)

Polyethylene Sheets

Air Circulation Section (325-329 K)

15 cm

10 cm

Test Section

Thermofoam

Aluminium Plate

80 cm

100 cm

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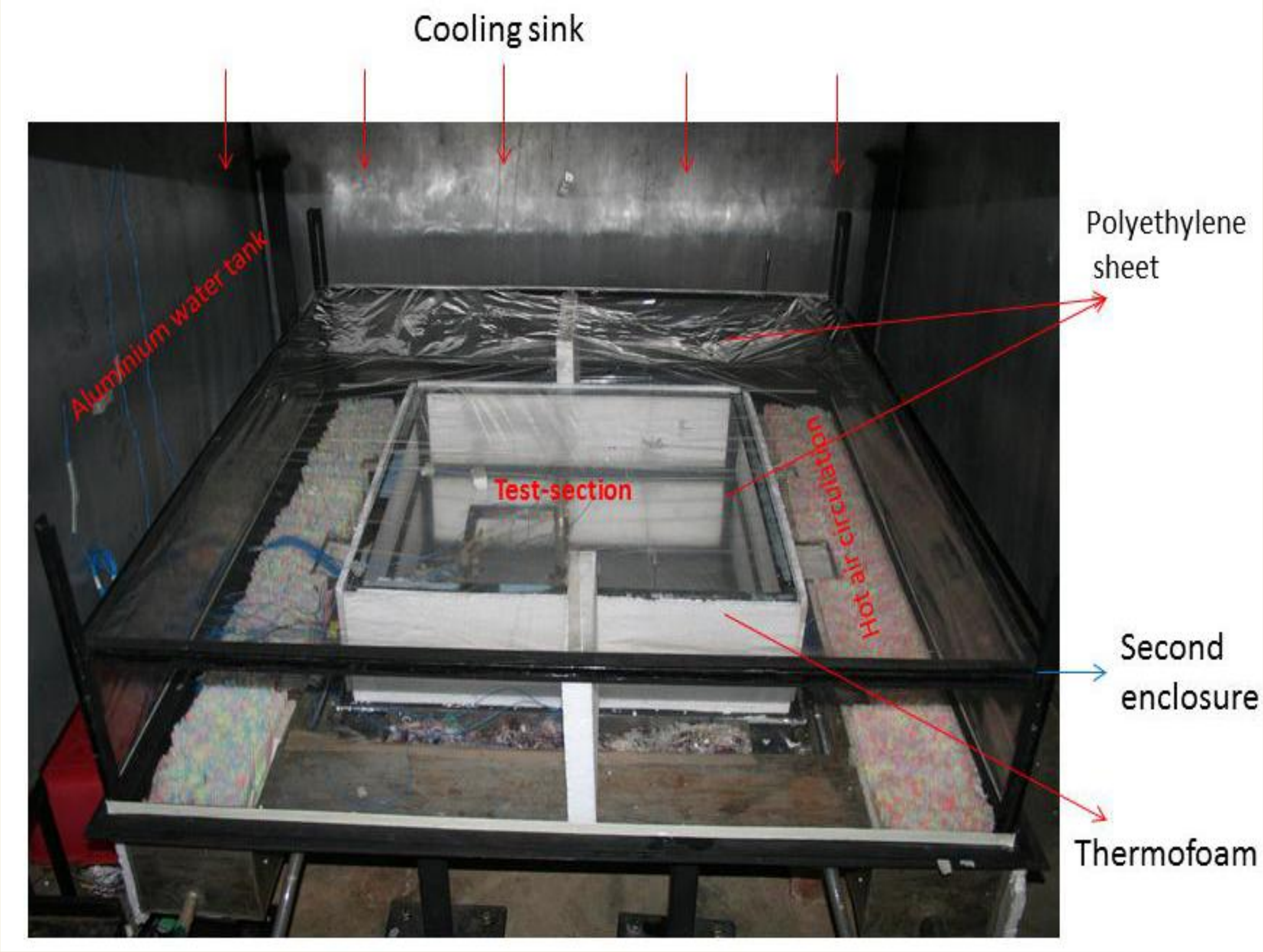
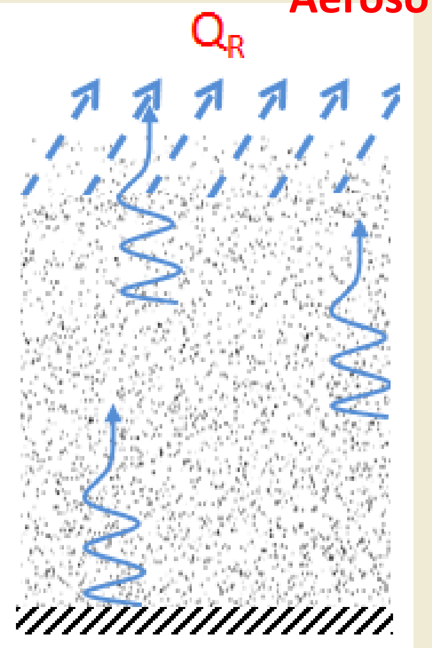
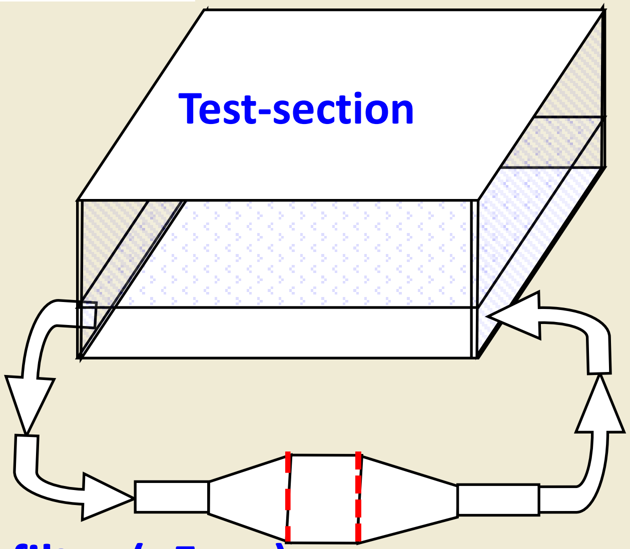
Lab setup: Decoupling Radiation Boundary condition



Aerosols cooling to upper atmosphere

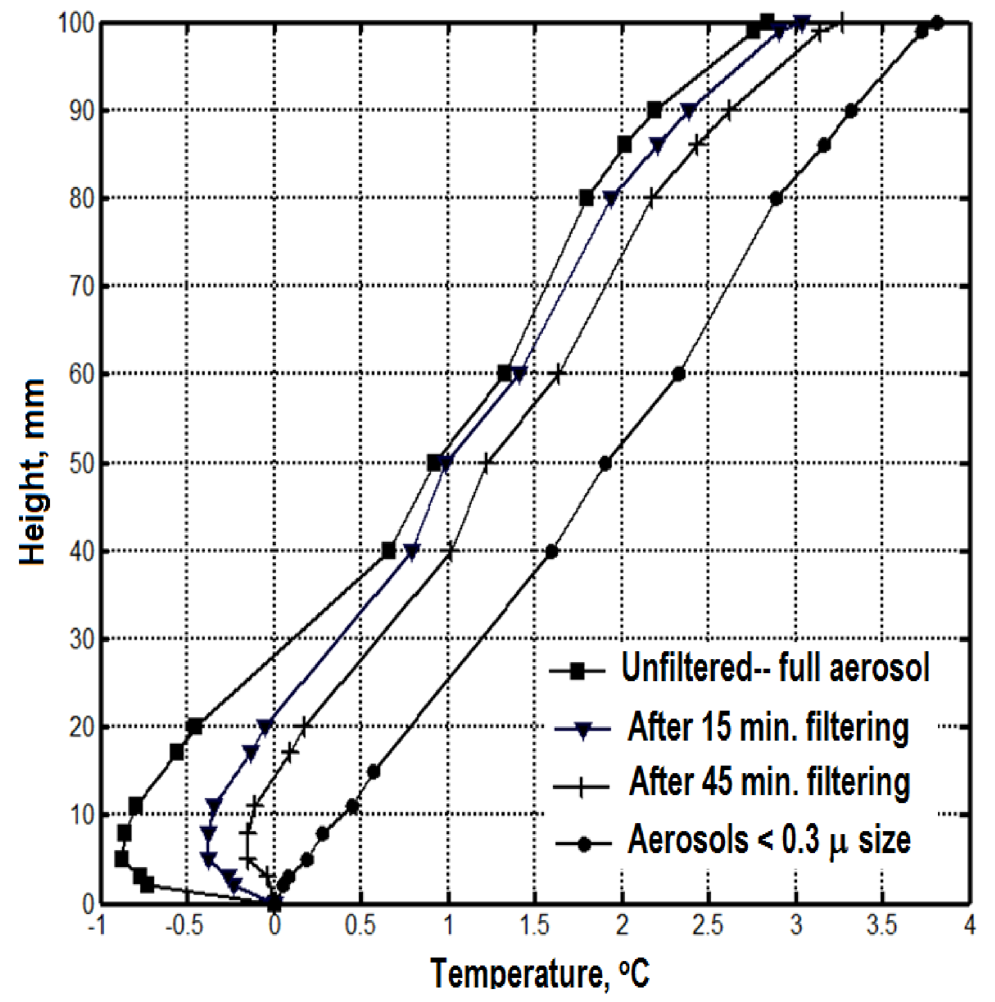




Test-section

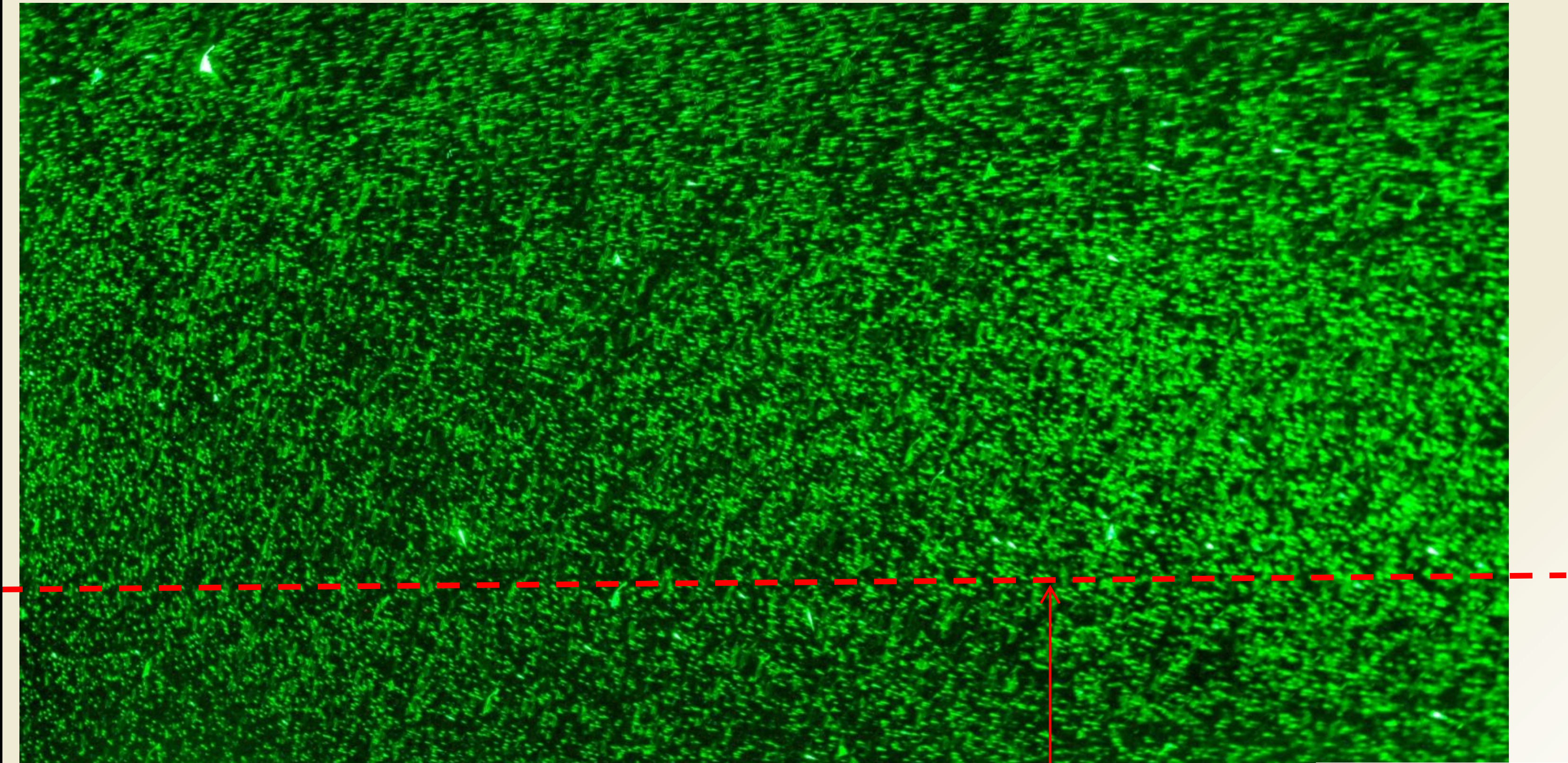
Pre-filter (>5µm)

HEPA filter (> 0.3µ)

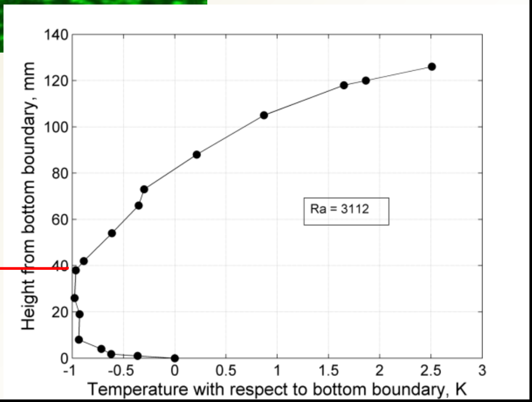


Stability & Convection in the surface layer:

Size of image : 100 mm X 50 mm, Exposure time : 2.5 sec,
15 mm from bottom boundary, **Ra = 3112**



Ra = 3112



Ra_{cr}(diff) ~1000

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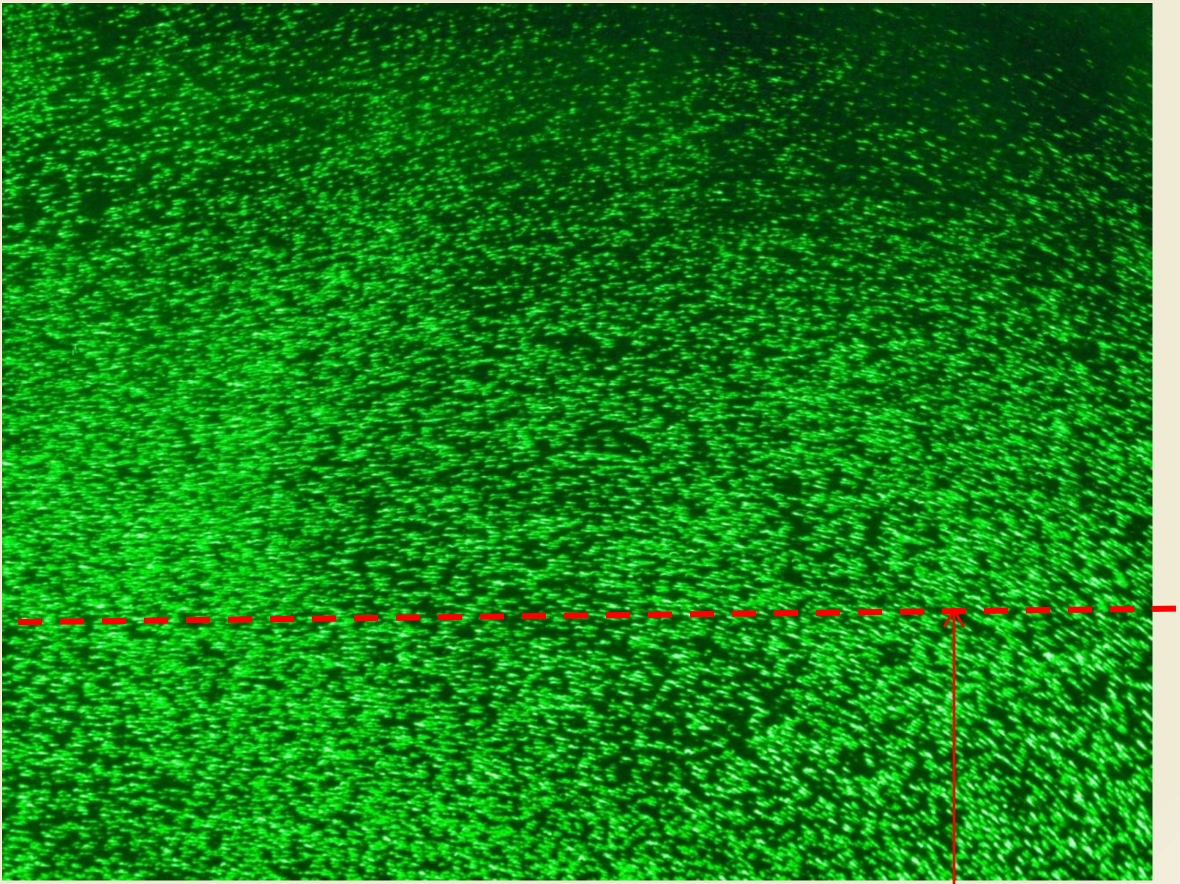
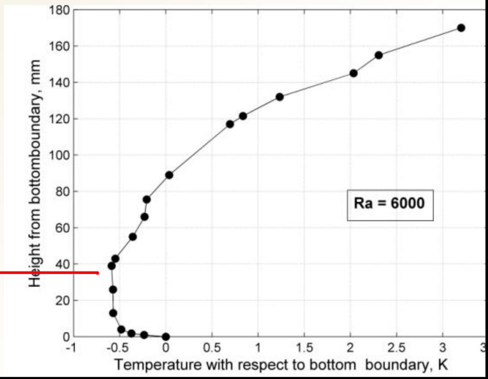
NO Convection

Stability & Convection in the surface layer:

Size of image : 90 mm X 80 mm, Exposure time :1 sec, 8 mm from bottom boundary, Ra=6000



Ra = 6000



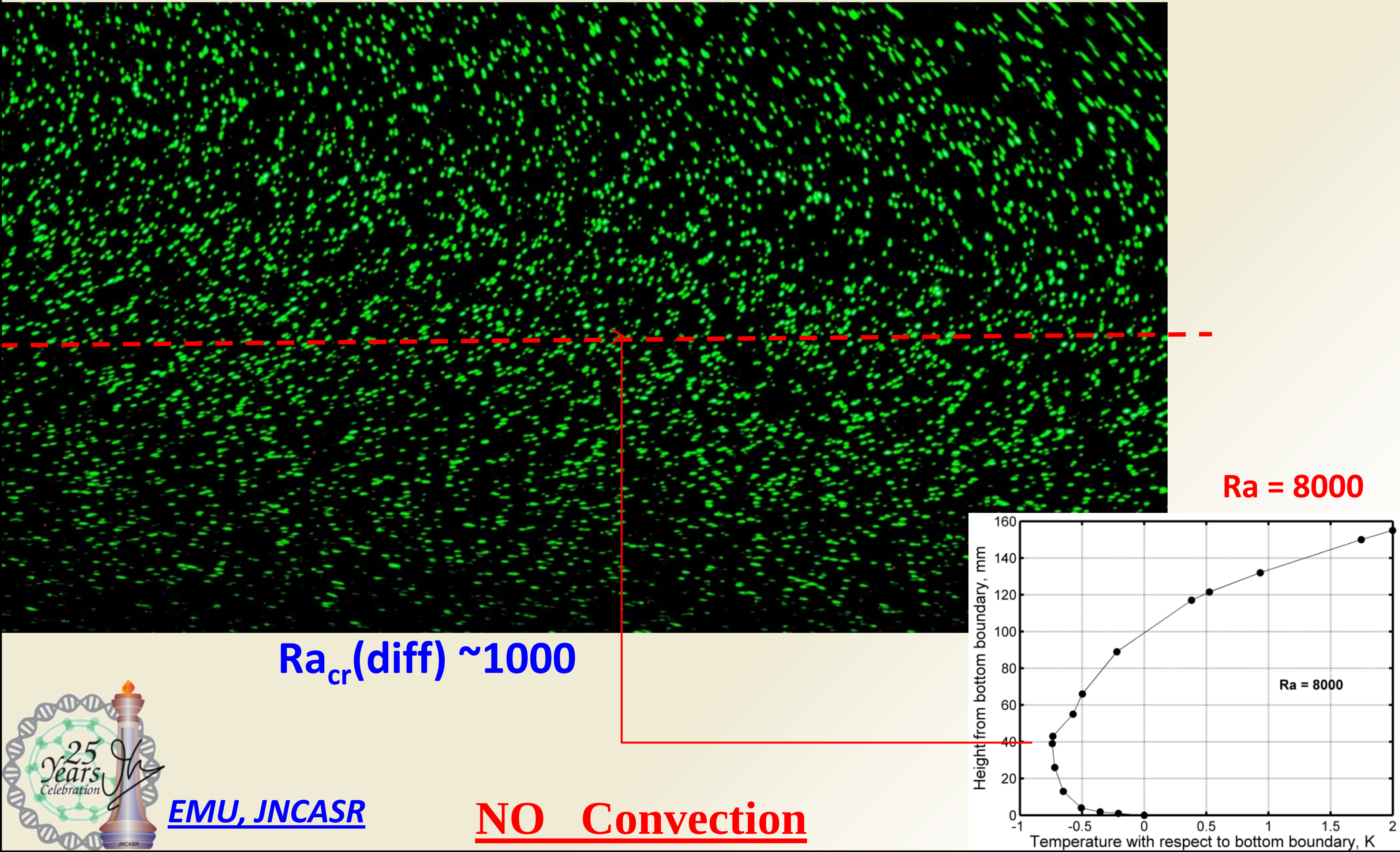
Ra_{cr}(diff) ~1000

EMU, JNCASR

NO Convection

Stability & Convection in the surface layer:

Size of image : 100 mm X 50 mm, Exposure time : 0.77 sec,
15 mm from bottom boundary, **Ra=8000**



Ra_{cr}(diff) ~1000

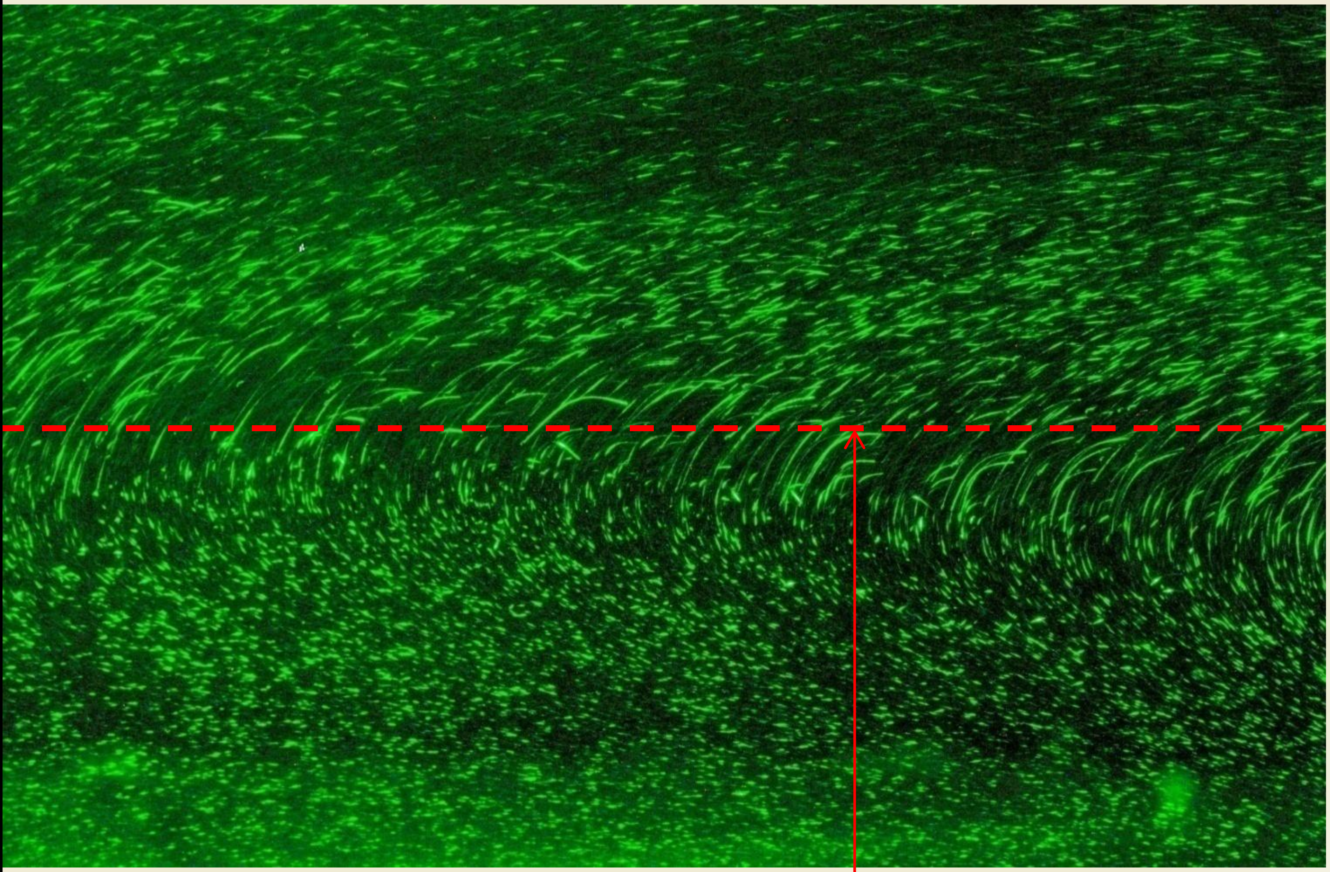
EMU, JNCASR

NO Convection

Stability & Convection in the surface layer:

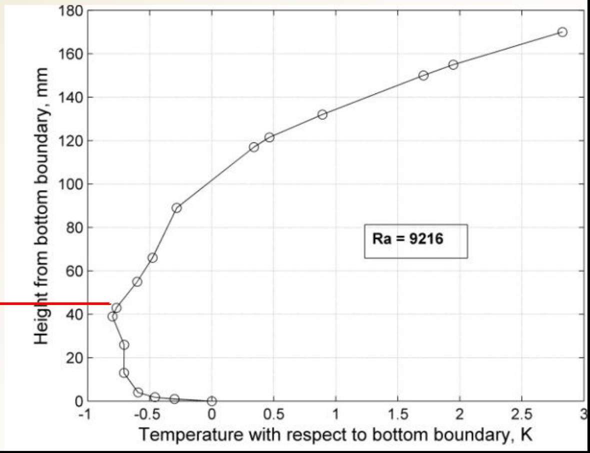
Size of image : 80 mm X 70 mm, Exposure time : 1 sec, 4 mm from bottom boundary

Ra = 9216



Ra_{cr}(diff) ~1000

Ra = 9216



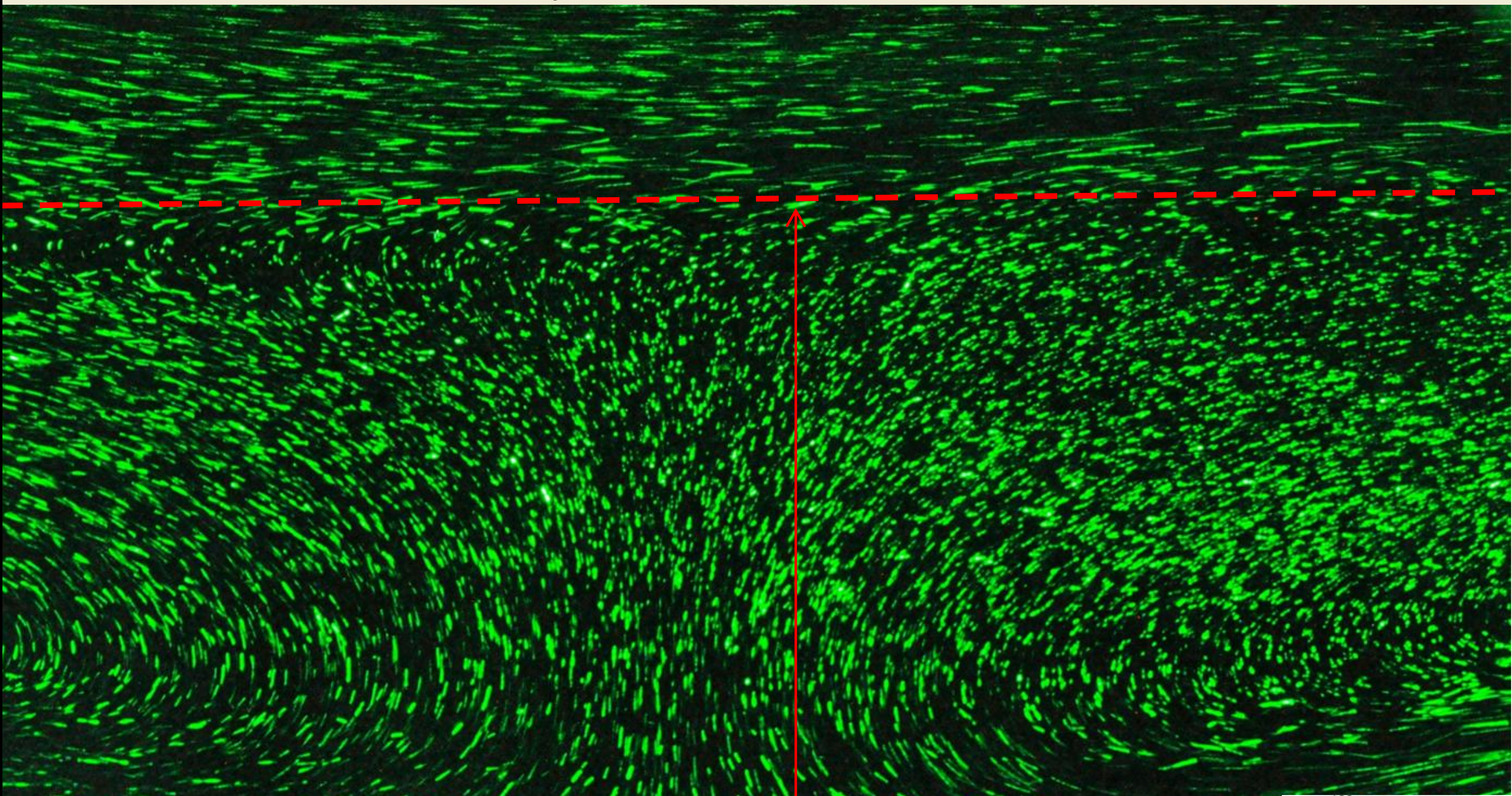
EMU, JNCASR

Partial Convection

Stability & Convection in the surface layer:

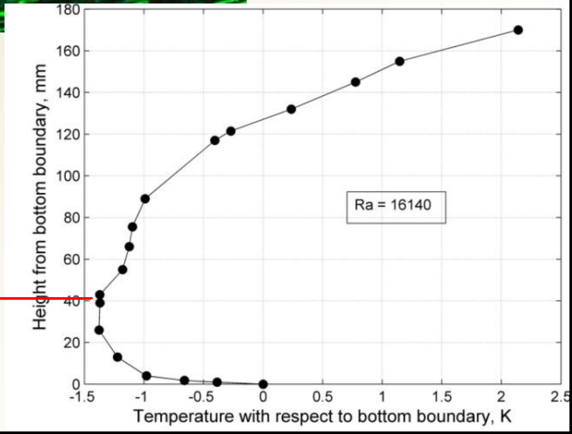
Size of image : 100 mm X 50 mm, Exposure time : 1 sec,

15 mm from bottom boundary, **Ra=16140**



Ra_{cr}(diff) ~1000

Ra = 16140



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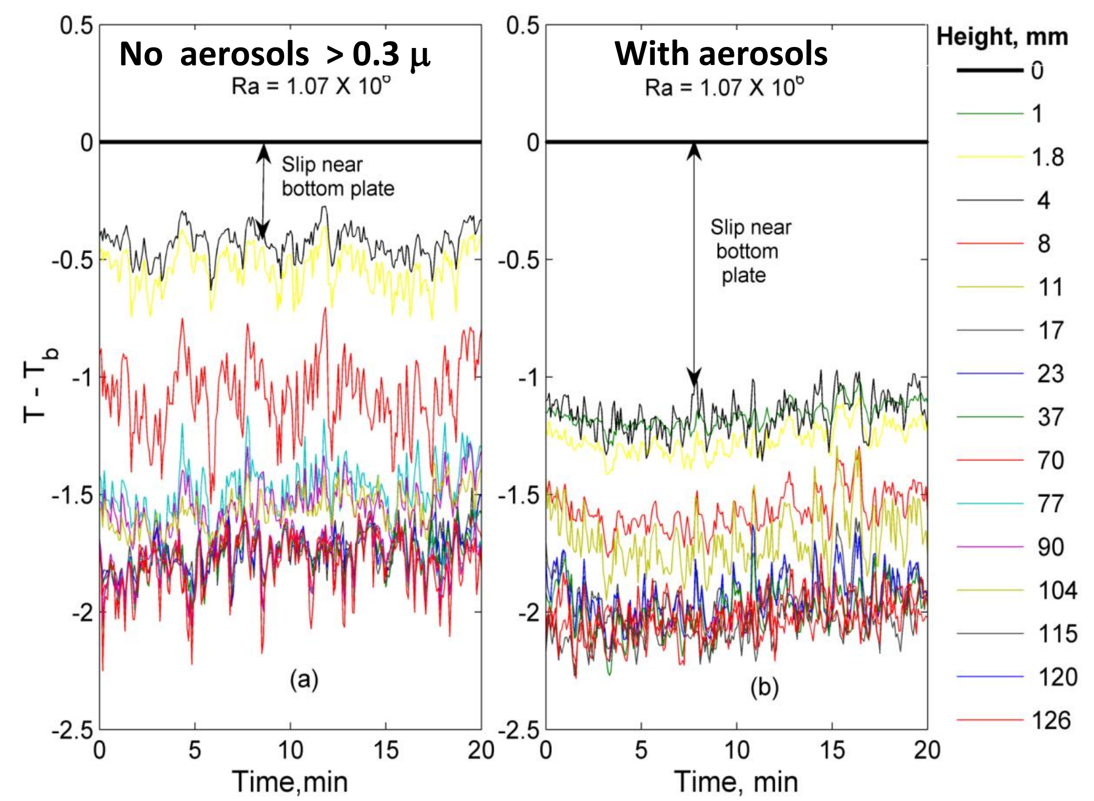
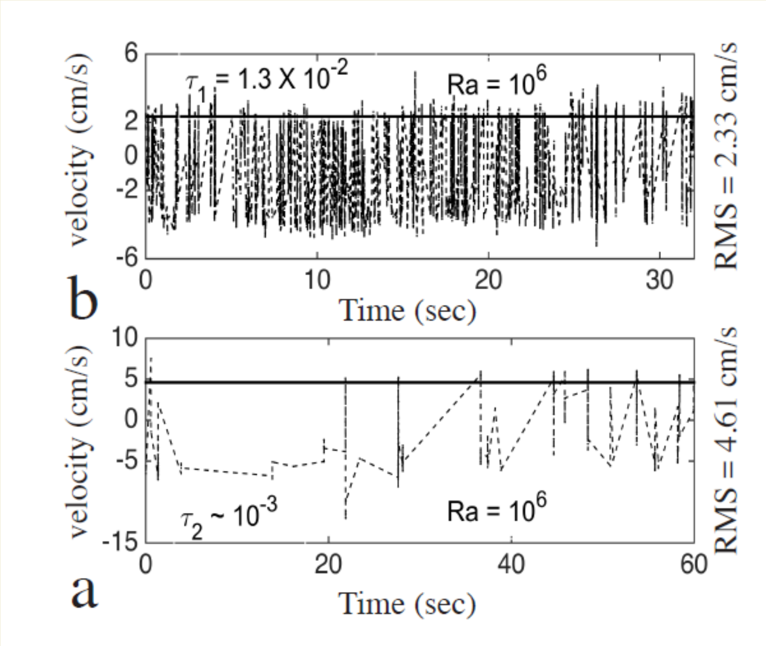
Convection

Temperature and velocity fluctuations in Clean and dirty Air





Temperature traces in the test section plotted with respect to the bottom plate at various vertical locations for case without (> 0.3 μ) and with aerosols.

Velocity fluctuations in LTM region

The emissivity of boundaries are 0.05. Rayleigh number is about 10^6 for both cases.

-ΔT (K)	d (mm)	Ra **(diff)**	S_β	S_H	$S_\beta S_H$	$\mathrm{Ra_c}$
0.91	26	2000 ± 525	2.8	2.42	6.77	6784 ± 1782
1.18	38	8000 ± 1464	2.84	4.04	11.47	11481 ± 2102
0.91	39	6628 ± 1193	2.74	4.2	11.5	11513 ± 2072
1.5	43	14645 ± 2336	2.5	4.89	12.24	12246 ± 1959

Goody (1964)

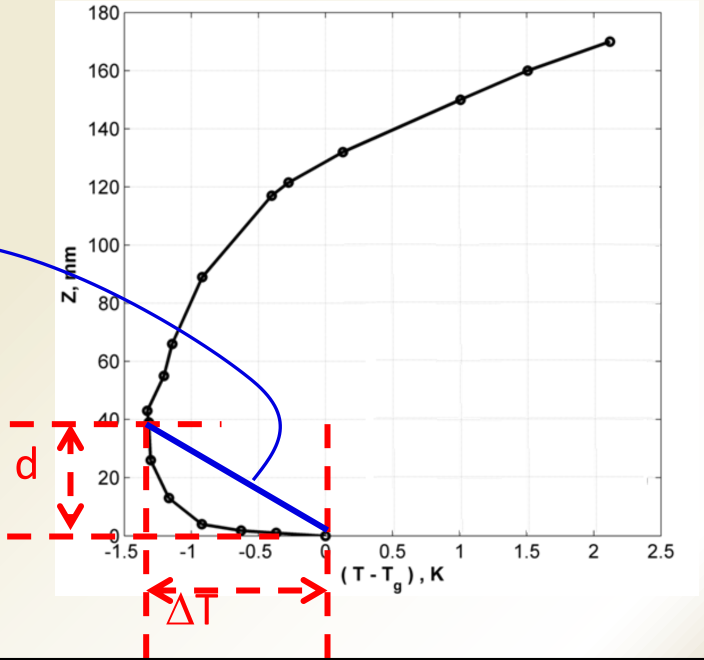
$\mathrm{Ra_c} = \mathrm{Ra_c}\,(\mathrm{diff})\ \mathrm{X}\ S_\beta\ \mathrm{X}\ S_H$

$S_\beta = \beta/\overline{\beta}$, $\overline{\beta} = \Delta T/d$ and

$\overline{\beta}$ is mean temperature gradient

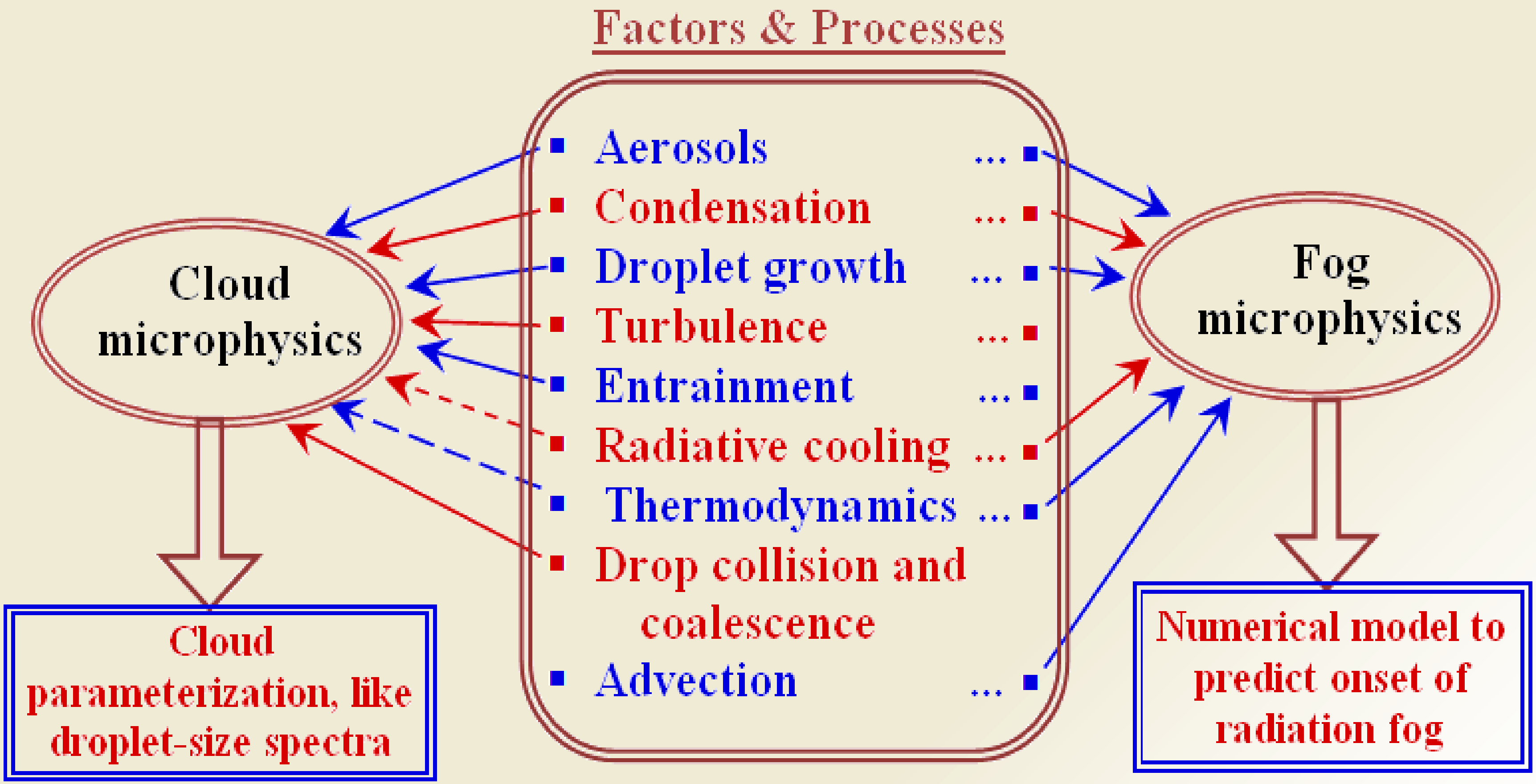
$S_H = 1 + \tau\,(\mathrm{diff})/\tau\,(\mathrm{rad})$

$\tau\,(\mathrm{diff}) = d^2/\alpha$ and $\tau\,(\mathrm{rad})$



Thermal structure and its Implication on Radiation Fog

Radiation Fog and Cloud Microphysics are closely linked



Factors & Processes

- Aerosols ...
- Condensation ...
- Droplet growth ...
- Turbulence ...
- Entrainment ...
- Radiative cooling ...
- Thermodynamics ...
- Drop collision and coalescence
- Advection ...

Cloud microphysics

Fog microphysics

Cloud parameterization, like droplet-size spectra

Numerical model to predict onset of radiation fog

Block diagram indicating commonality and differences between cloud and fog microphysics

Radiation Fog

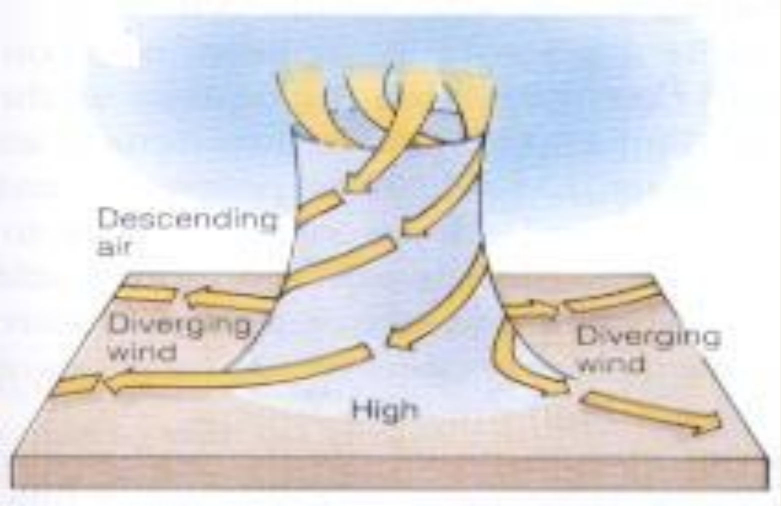
Key ingredients: **a) Clear skies and rapid cooling after sunset.**

b) High RH at low levels.

c) Calm or light winds.

The key low-level ingredients required to generate a radiation fog are moisture, rapid cooling, and calm or light winds.

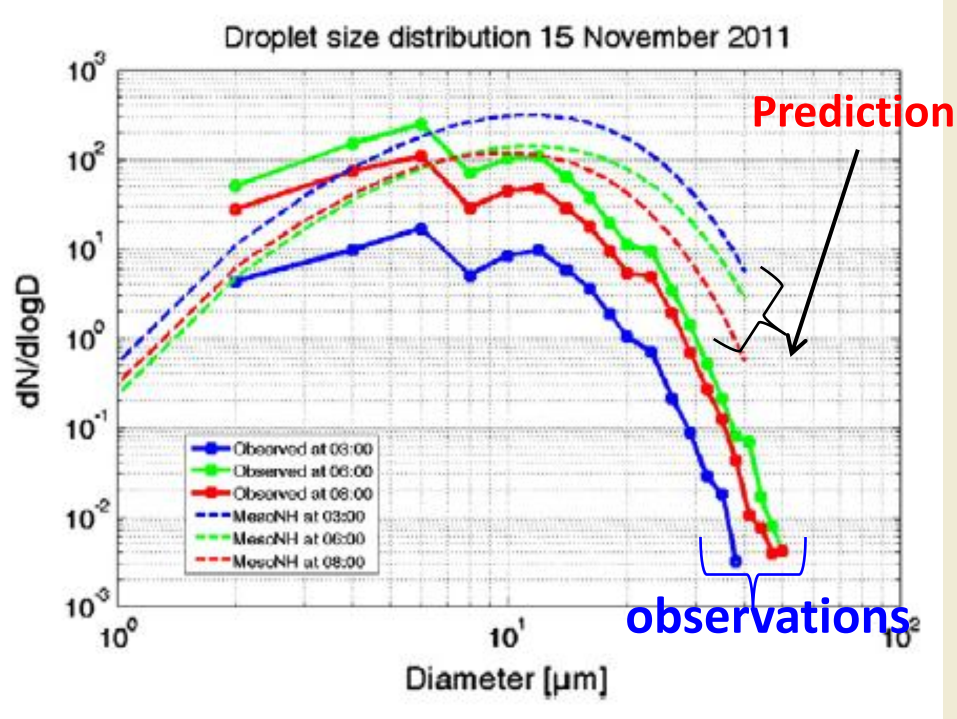
Low-level anticyclones can create favorable conditions for radiation fog by suppressing surface winds and drying the air at higher level through slowly sinking air. Dry air above enhances radiative cooling at the surface.



Fog droplet spectrum and Radiation Forcing ….

Fog observation and prediction ….

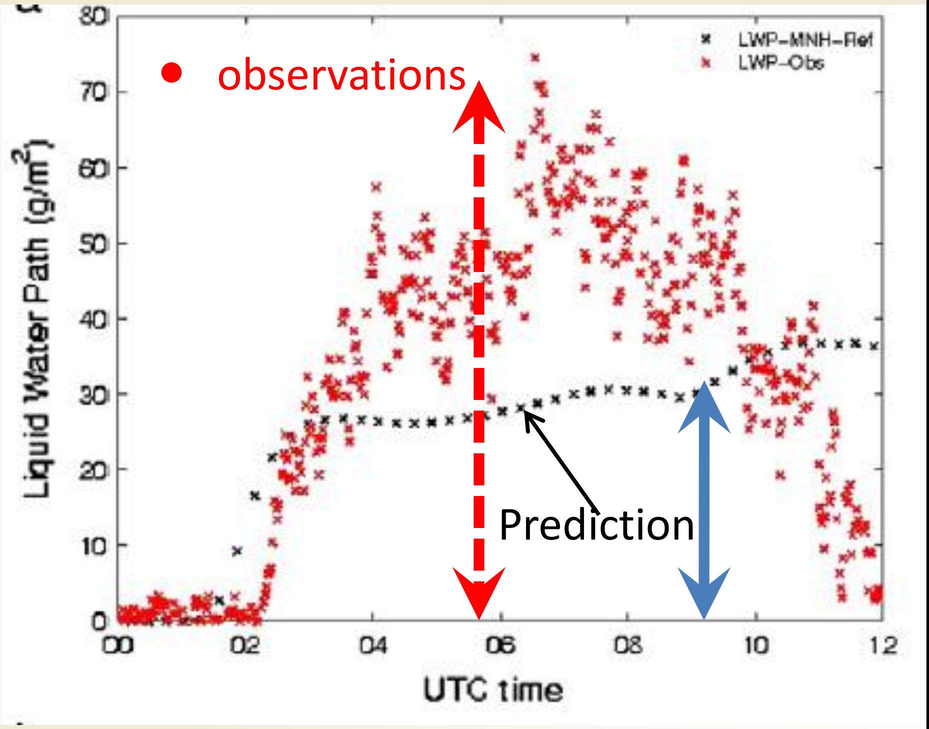
Impact on visibility prediction, and radiative properties



Predictions

observations

Fig. 8. Observed (FM-100) and modeled droplet size distribution at 03, 06 and 08 UTC. Reference run.

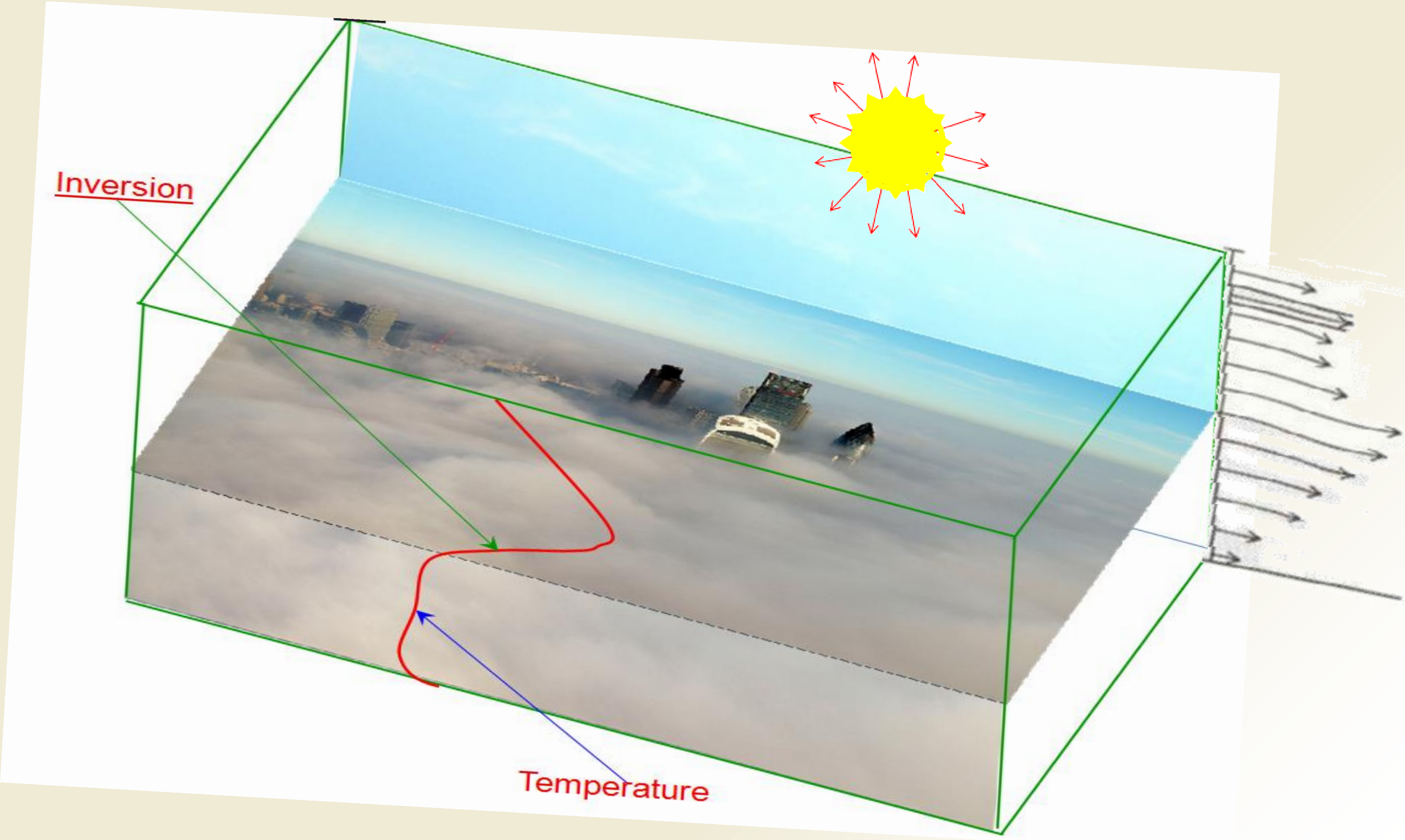


● observations

Prediction

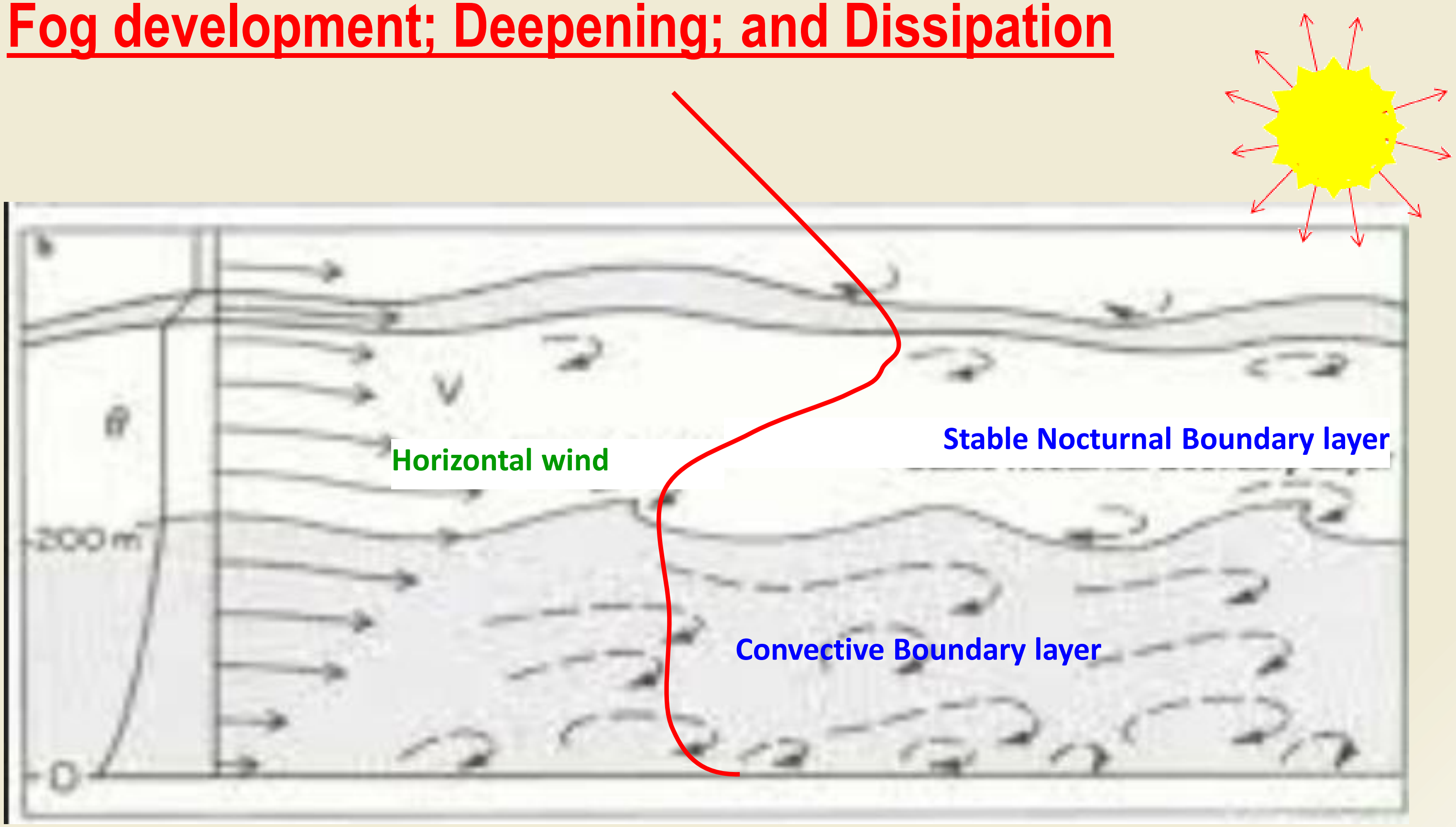
Stolaki, S., et al. "Influence of aerosols on the life cycle of a radiation fog event. A numerical and observational study." *Atmospheric Research* 151 (2015): 146-161.

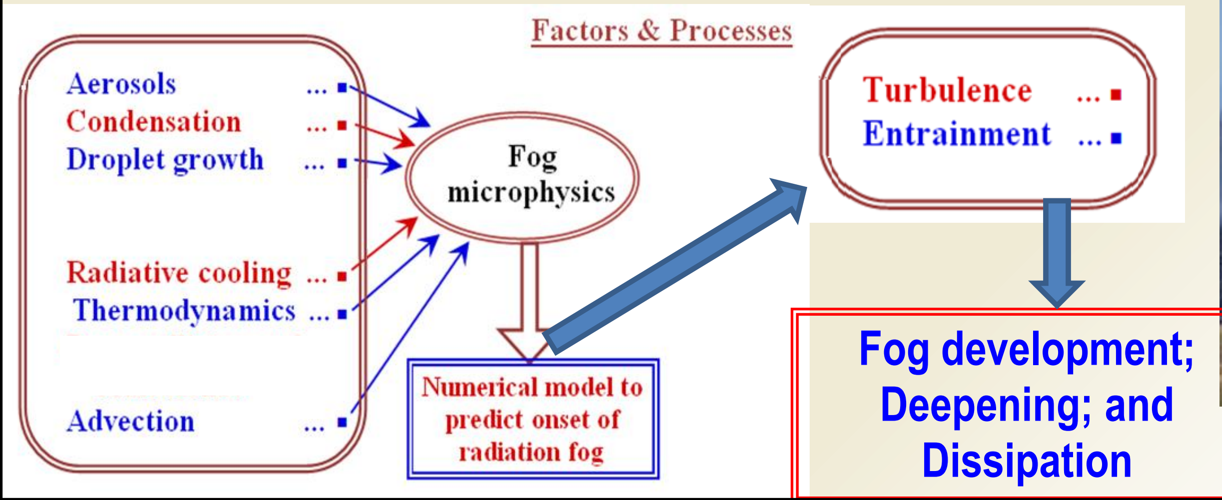
Fog development; Deepening; and Dissipation



Convection; Wind shear; Stratification; Solar heating;

Fog development; Deepening; and Dissipation





Factors & Processes

Aerosols ... ■
Condensation ... ■
Droplet growth ... ■

Radiative cooling ... ■
Thermodynamics ... ■

Advection ... ■

Fog microphysics

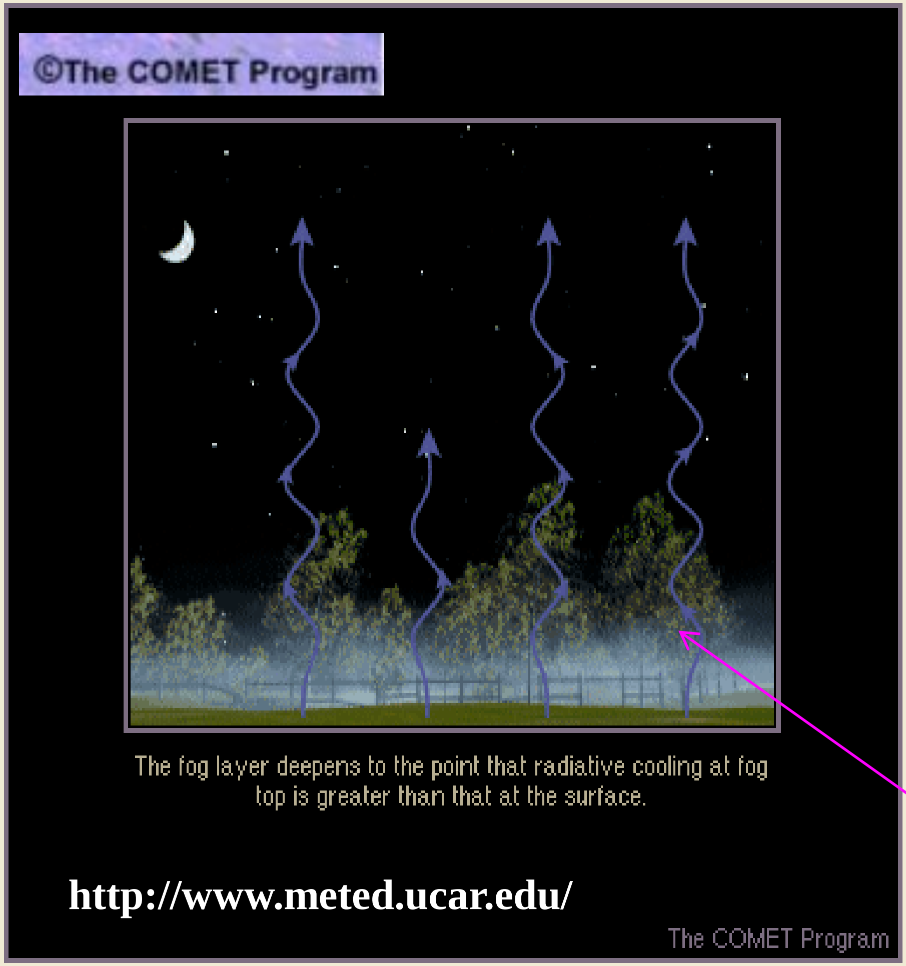
Numerical model to predict onset of radiation fog

Turbulence ... ■
Entrainment ... ■

Fog development; Deepening; and Dissipation

Radiation Fog

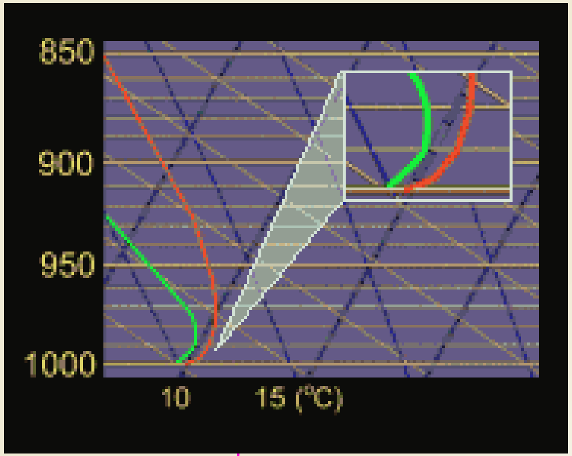
Local temperature falling bellow Dew point

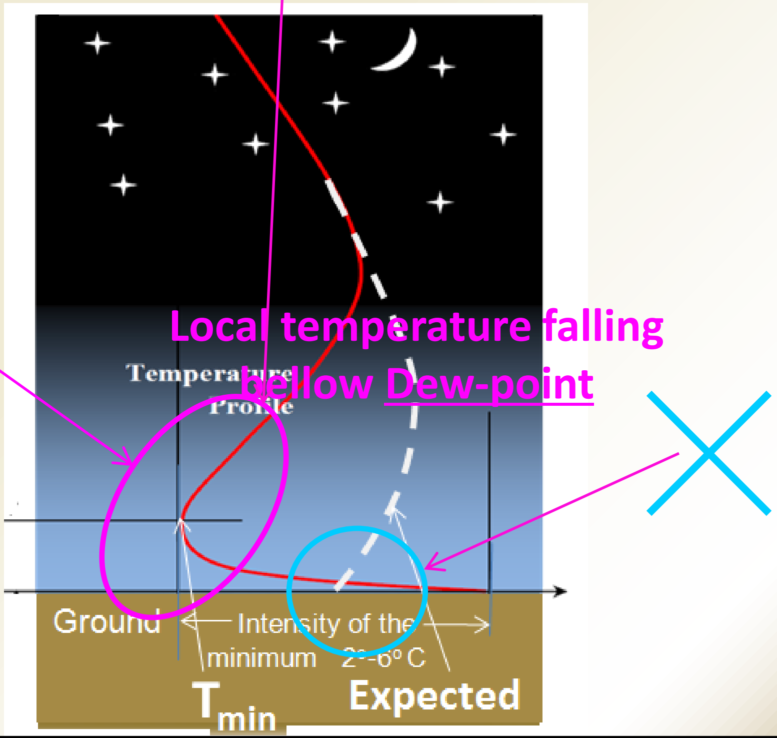


The fog layer deepens to the point that radiative cooling at fog top is greater than that at the surface.

http://www.meted.ucar.edu/

The COMET Program





Local temperature falling bellow Dew-point

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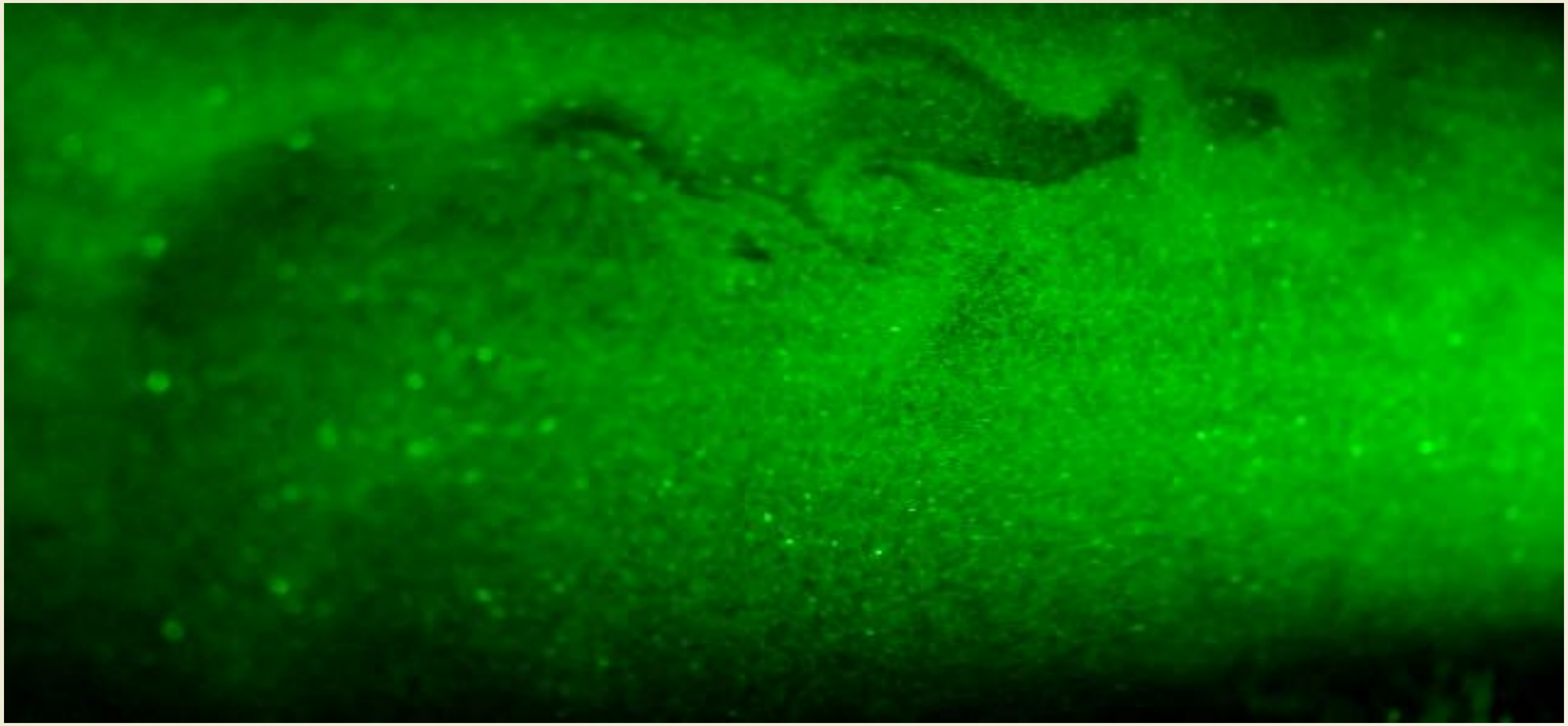
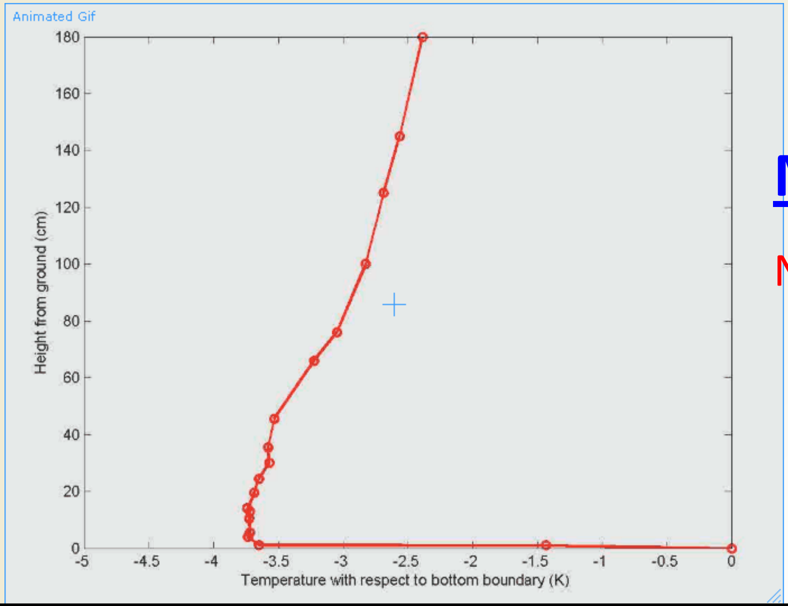
Movie-Fog

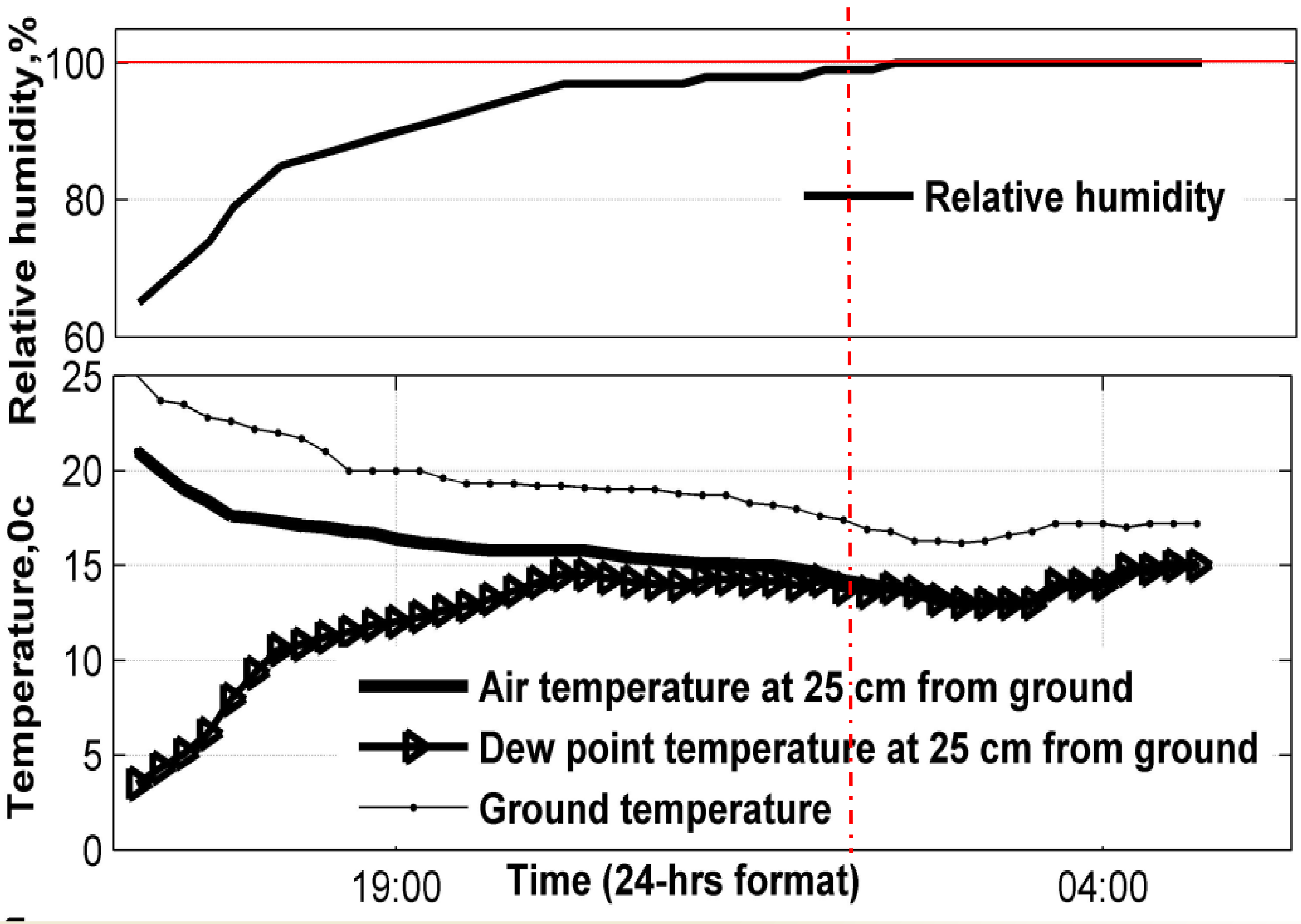


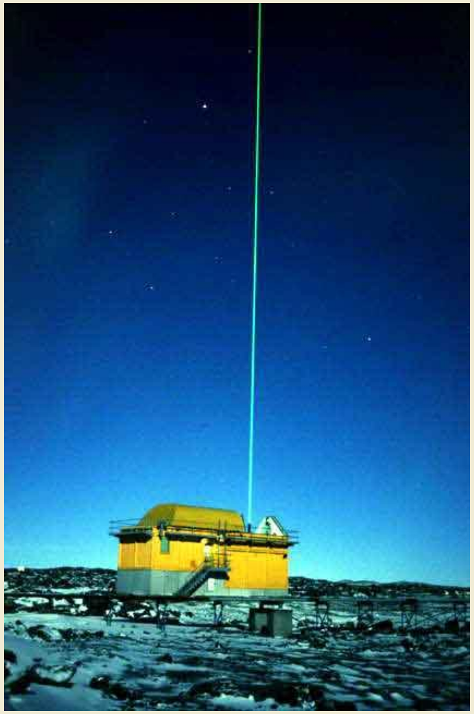


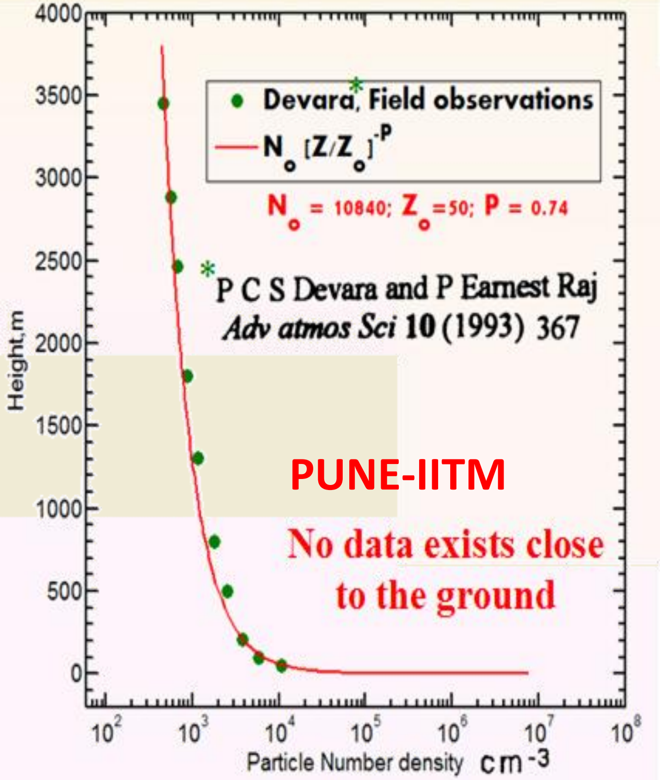
Movie-Temp

NOT synchronized

EMU, JNCASR


Relative humidity,%
100
80
60
Relative humidity
Temperature,0c
25
20
15
10
5
0
Air temperature at 25 cm from ground
Dew point temperature at 25 cm from ground
Ground temperature
19:00
Time (24-hrs format)
04:00

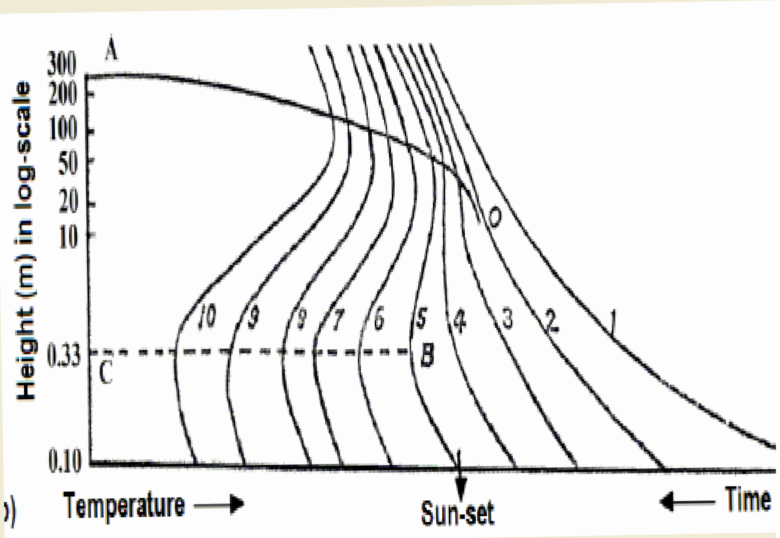


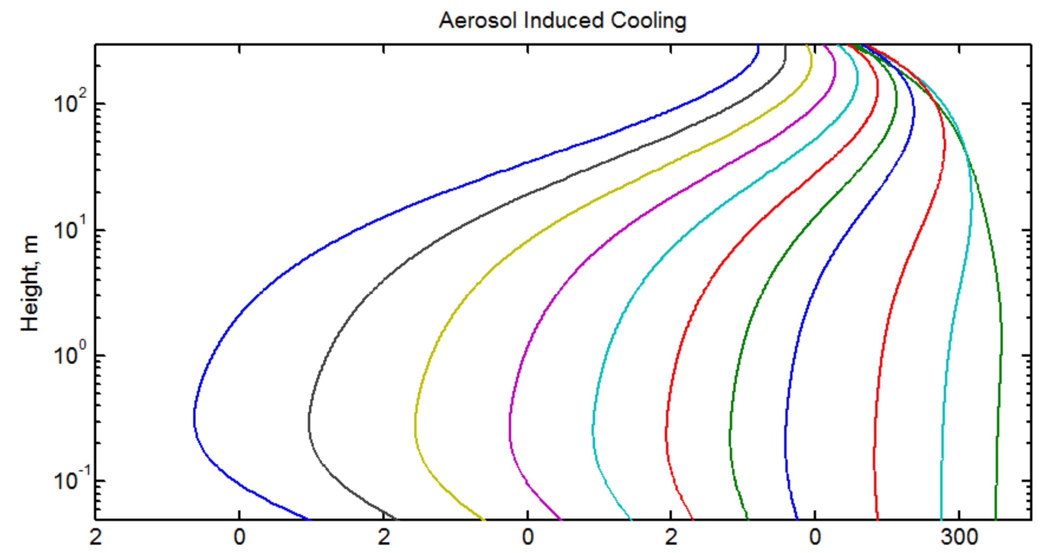


*P C S Devara and P Earnest Raj *Adv atmos Sci* **10** (1993) 367

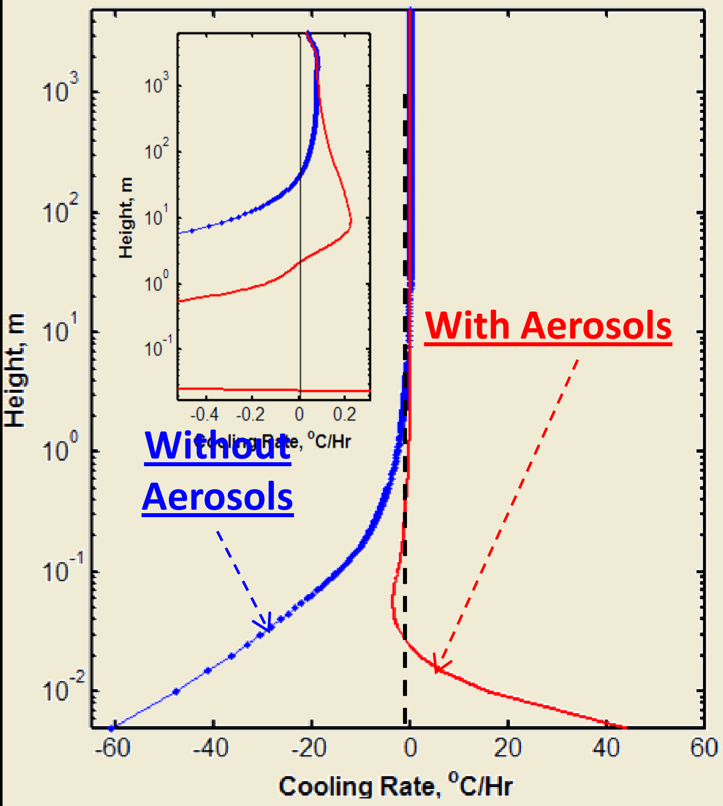
PUNE-IITM

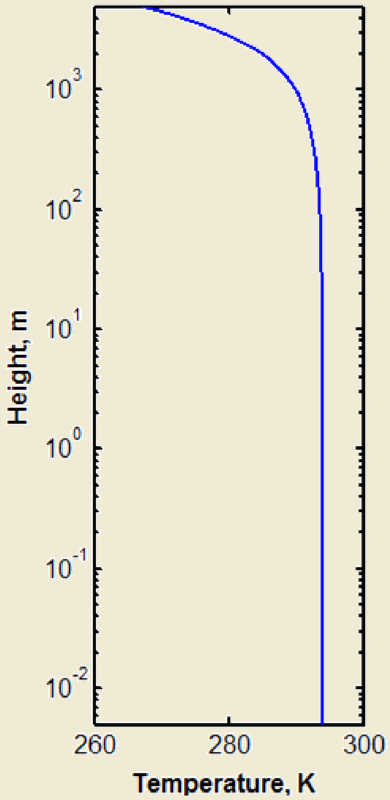
No data exists close to the ground

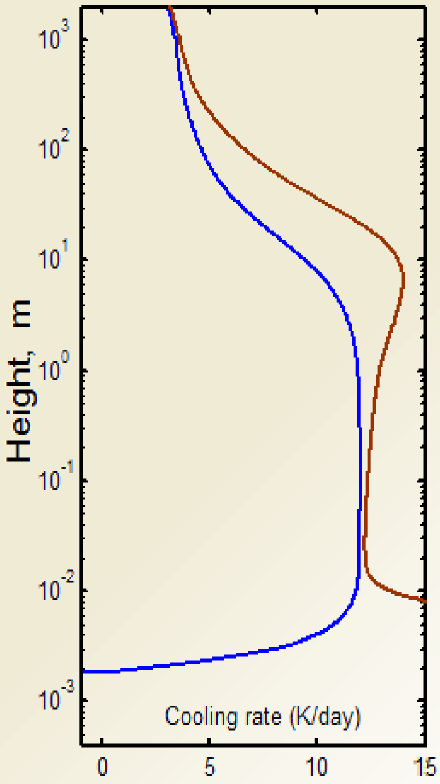




Inversion layer cooling- with and without Aerosols







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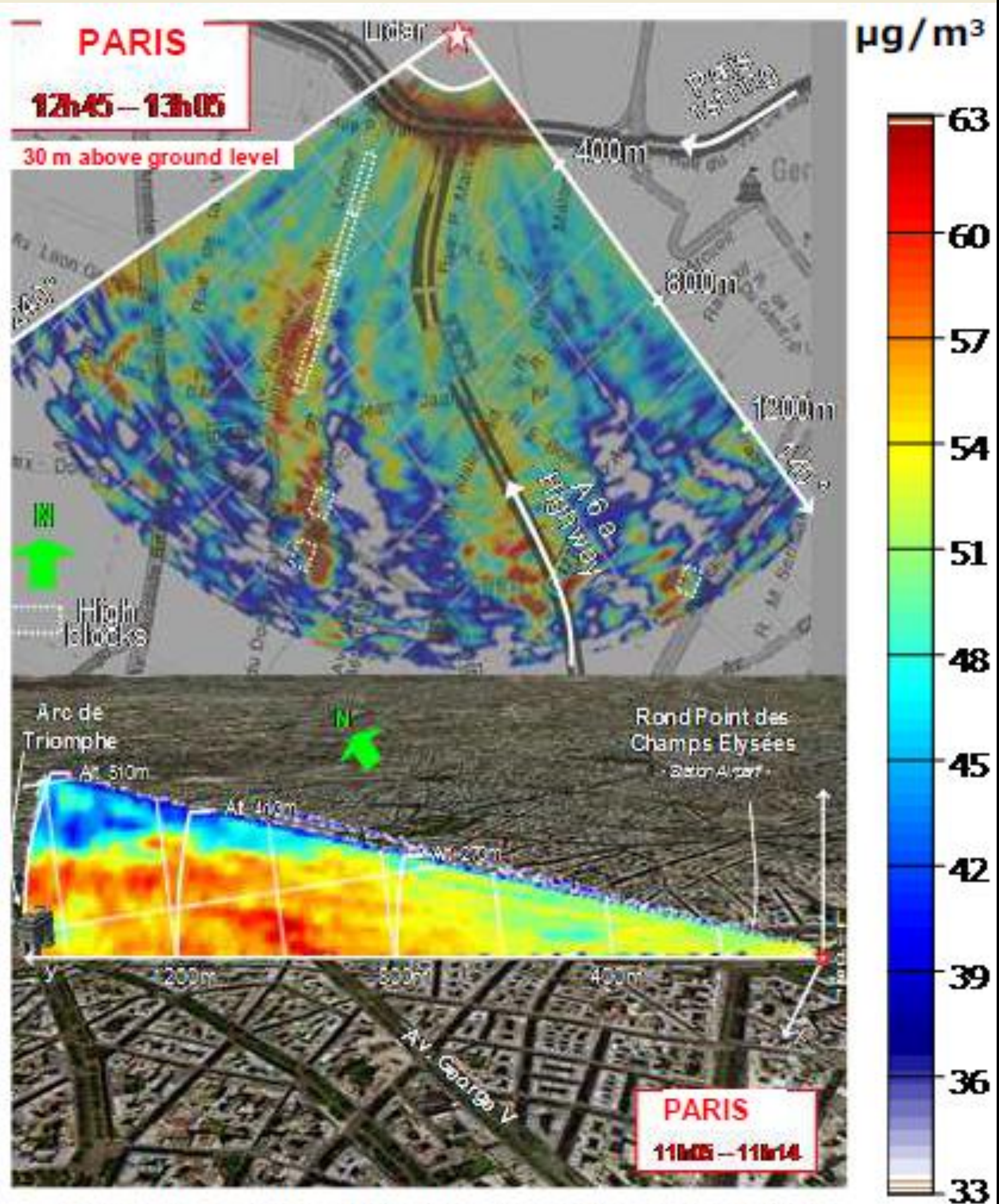
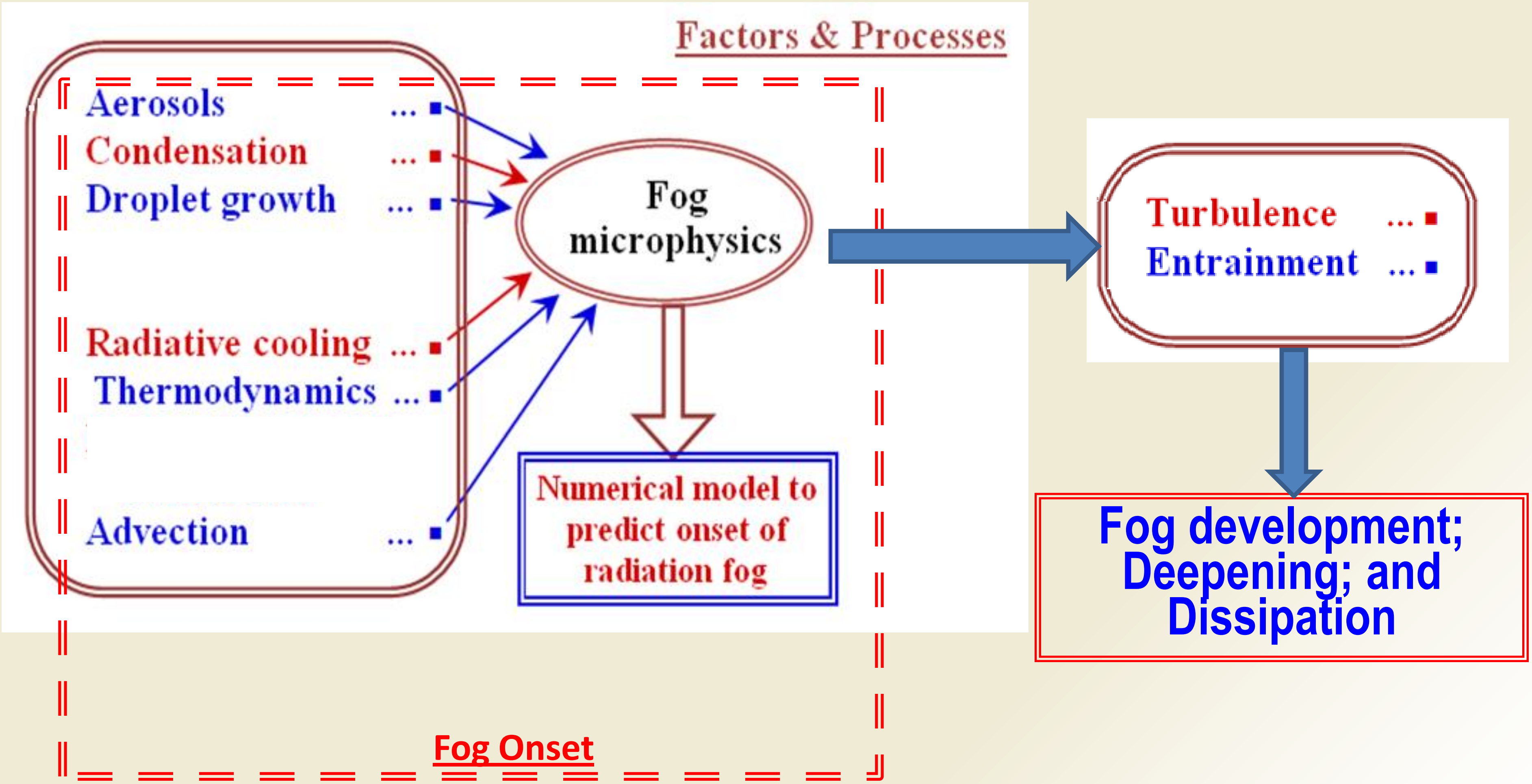
What is needed …



In collaboration with AIRPARIF - Air quality agency in Paris

Complete Numerical model



Factors & Processes

Aerosols ...
Condensation ...
Droplet growth ...
Radiative cooling ...
Thermodynamics ...
Advection ...

Fog microphysics

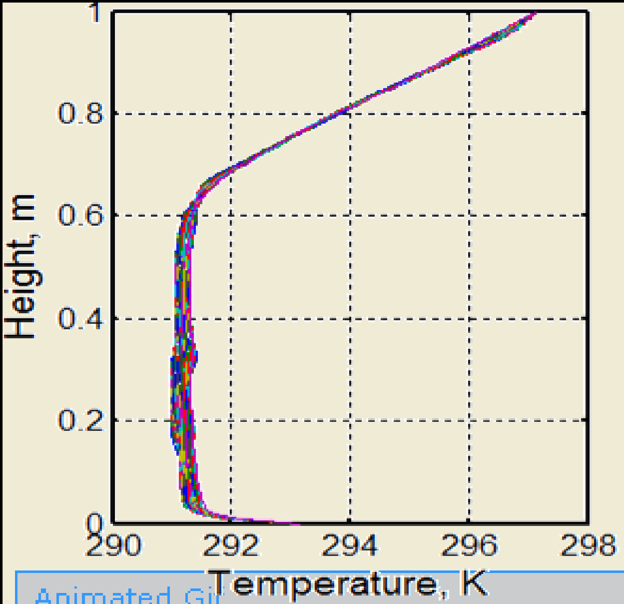
Numerical model to predict onset of radiation fog

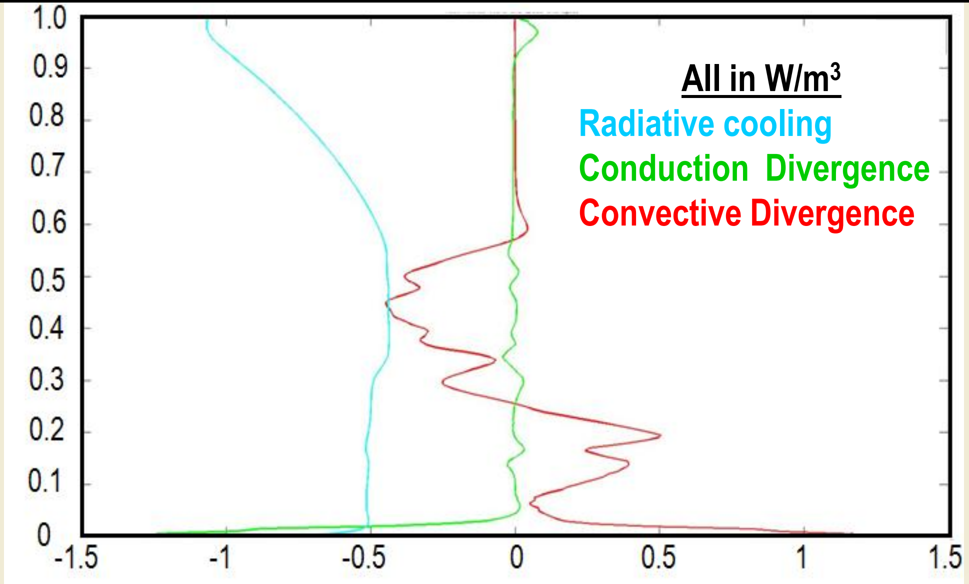
Turbulence ...
Entrainment ...

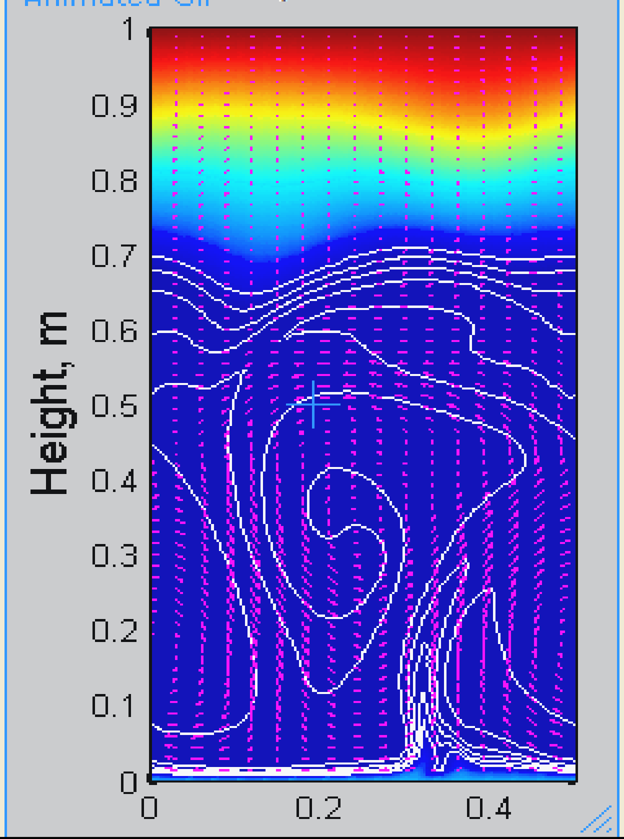
Fog development; Deepening; and Dissipation

Fog Onset

(a) Onset time
(b) Droplet spectrum
-- Visibility
-- Radiative properties
-- Vertical height
(c) Fog dissipation or lifting time







$$\frac{dh}{dt} = C_1 U_* Ri^{-n}$$

$$Ri = \frac{g\Delta\rho h}{\rho U_*^2} \qquad U_* = \left[\frac{g\beta Q h}{\rho C_P}\right]^{\frac{1}{3}}$$

n=1 and $C_1 = 0.2$

For convection driven erosion

Deardorff, J. W., Willis, G. E., & Lilly, D. K. (1969). Laboratory investigation of non-steady penetrative convection. *Journal of Fluid Mechanics*, *35*(01), 7-31.

1] Mukund, V., Ponnulakshmi, V. K., Singh, D. K., Subramanian, G., & Sreenivas, K. R. (2010). Hyper-cooling in the nocturnal boundary layer: the Ramdas paradox. *Physica Scripta*, *2010*(T142), 014041.

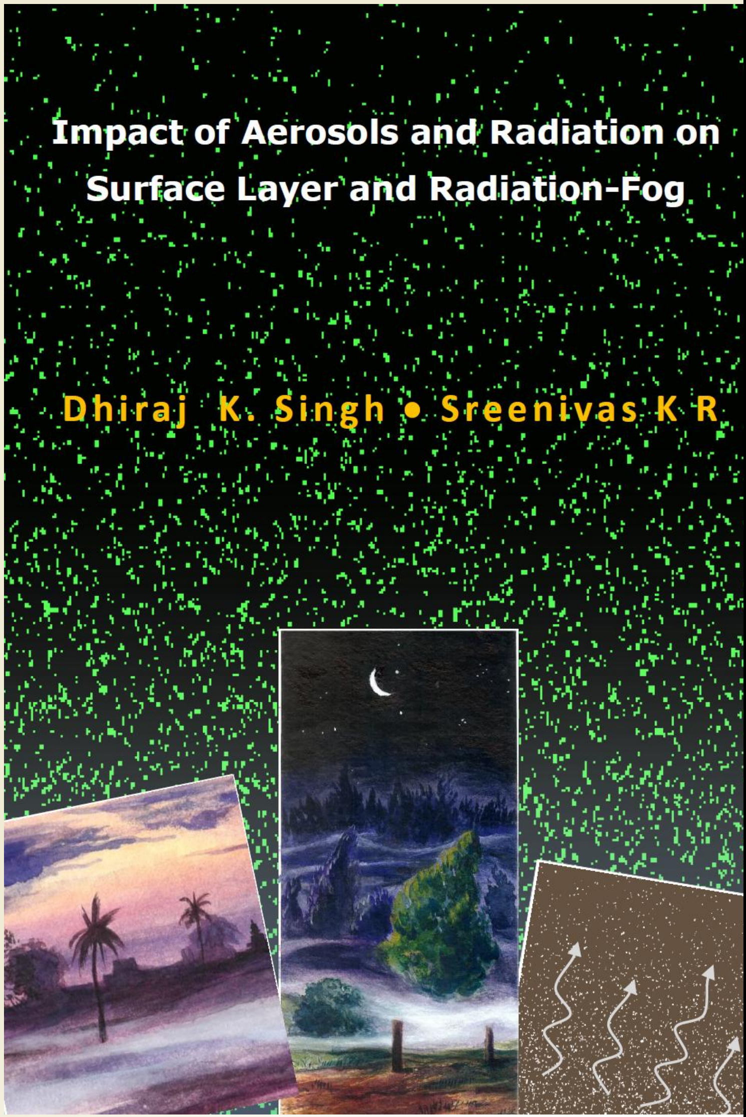
2] Ponnulakshmi, V. K., Mukund, V., Singh, D. K., Sreenivas, K. R., & Subramanian, G. (2012). Hypercooling in the nocturnal boundary layer: Broadband emissivity schemes. *Journal of the Atmospheric Sciences*, *69*(9), 2892-2905.

3] Ponnulakshmi, V. K., Singh, D. K., Mukund, V., Sreenivas, K. R., & Subramanian, G. (2013). Hypercooling in the atmospheric boundary layer: beyond broadband emissivity schemes. *Journal of the Atmospheric Sciences*, *70*(1), 278-283.

4] Mukund, V., Singh, D. K., Ponnulakshmi, V. K., Subramanian, G., & Sreenivas, K. R. (2013). Field and laboratory experiments on aerosol-induced cooling in the nocturnal boundary layer. *Quarterly Journal of the Royal Meteorological Society*.

5] Singh, D. K., et al. "Radiation forcing by the atmospheric aerosols in the nocturnal boundary layer." *RADIATION PROCESSES IN THE ATMOSPHERE AND OCEAN (IRS2012): Proceedings of the International Radiation Symposium (IRC/IAMAS)*. Vol. 1531. No. 1. AIP Publishing, 2013.

6] Modeling Radiation Fog, APS Division of Fluid Dynamics (Fall) 2016 69th Annual Meeting of the APS Division of Fluid Dynamics Volume 61, November 20–22, 2016; Portland, Oregon USA

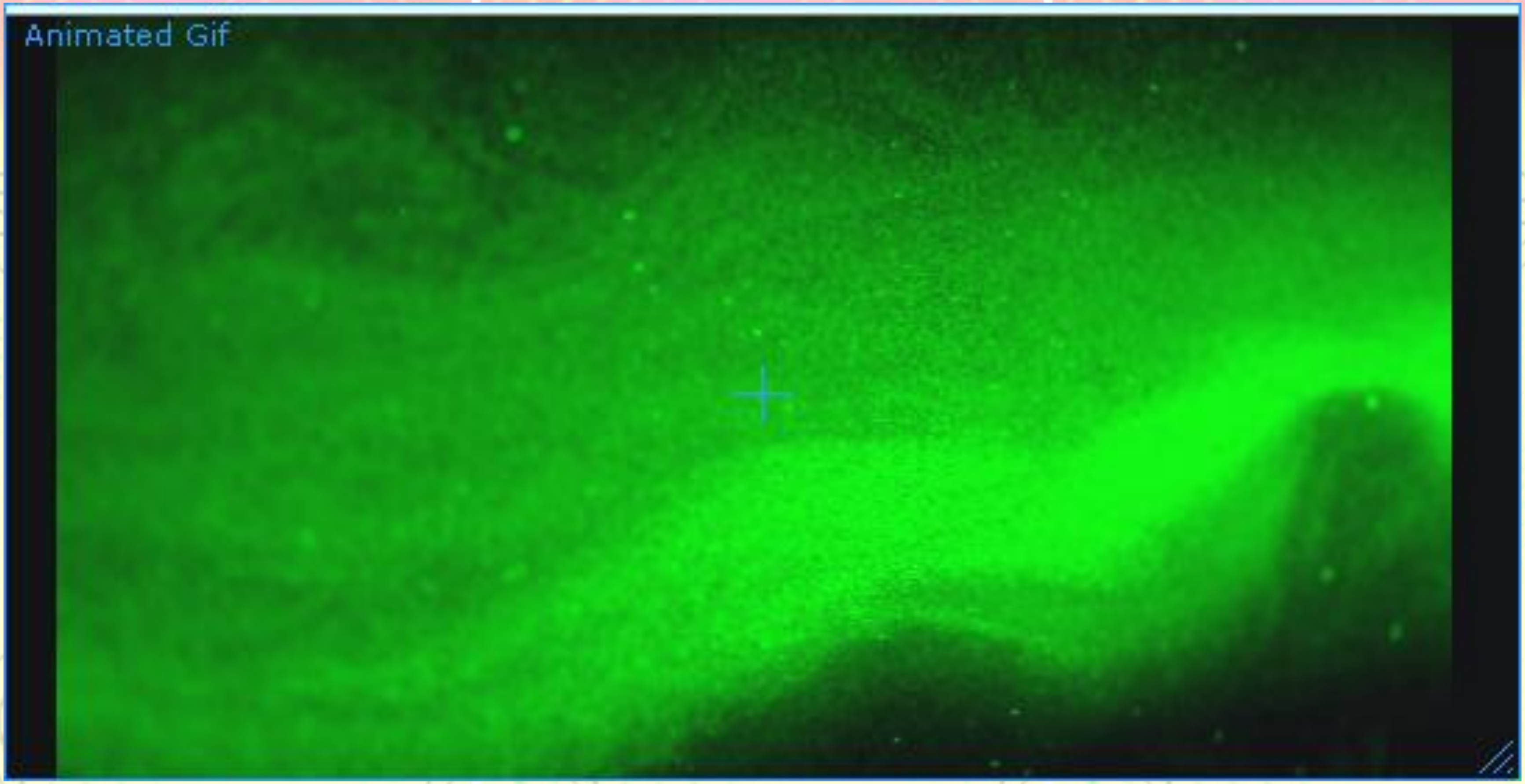


Impact of Aerosols and Radiation on Surface Layer and Radiation-Fog

Dhiraj K. Singh • Sreenivas K R

EMU, JNCASR

THANK YOU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