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Some peculiarities of the polar summer mesosphere

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Some peculiarities of the polar summer mesosphere

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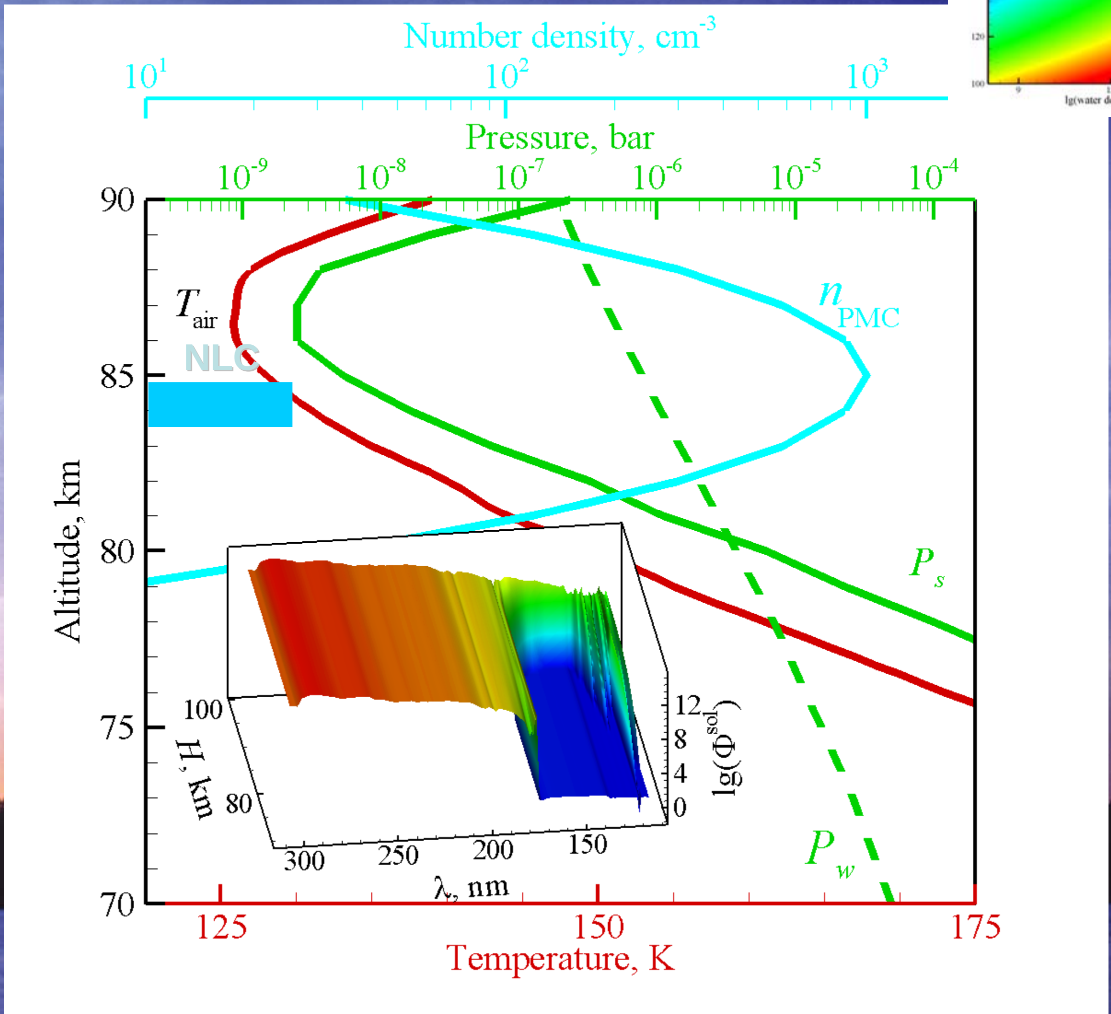
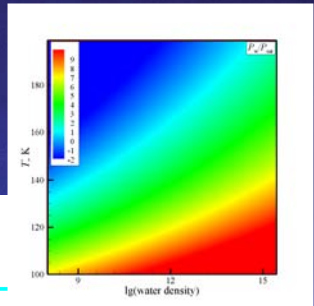
Trieste, 24-29 August 2009

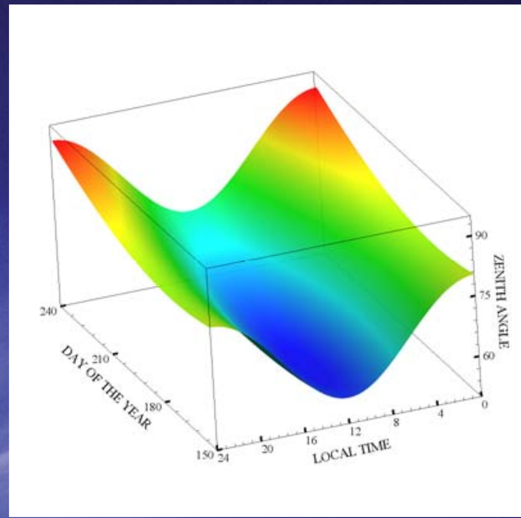
OUTLINE

- Polar summer mesosphere: important parameters
- Charging of an isolated dust particle in a plasma
- Impact of polar mesospheric clouds on ionospheric plasma: the simple model
- Heating of mesospheric particles by the solar radiation
- Growth/sedimentation/charging model of polar mesospheric clouds
- Ice particles formation in the RF chamber: experimental data and simulations
- Conclusions

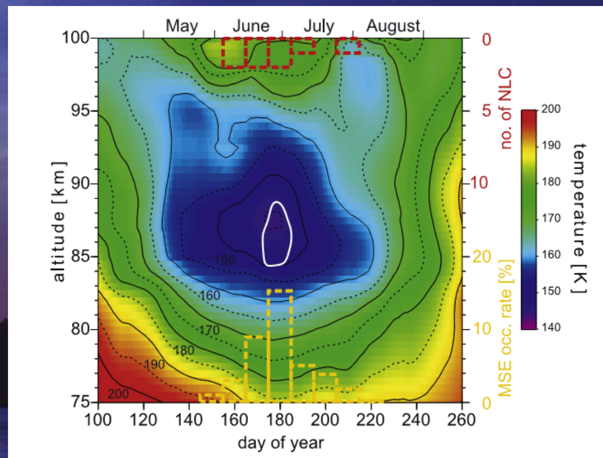
Polar summer mesosphere: the key NLC parameters







Solar zenith angle at NLC season

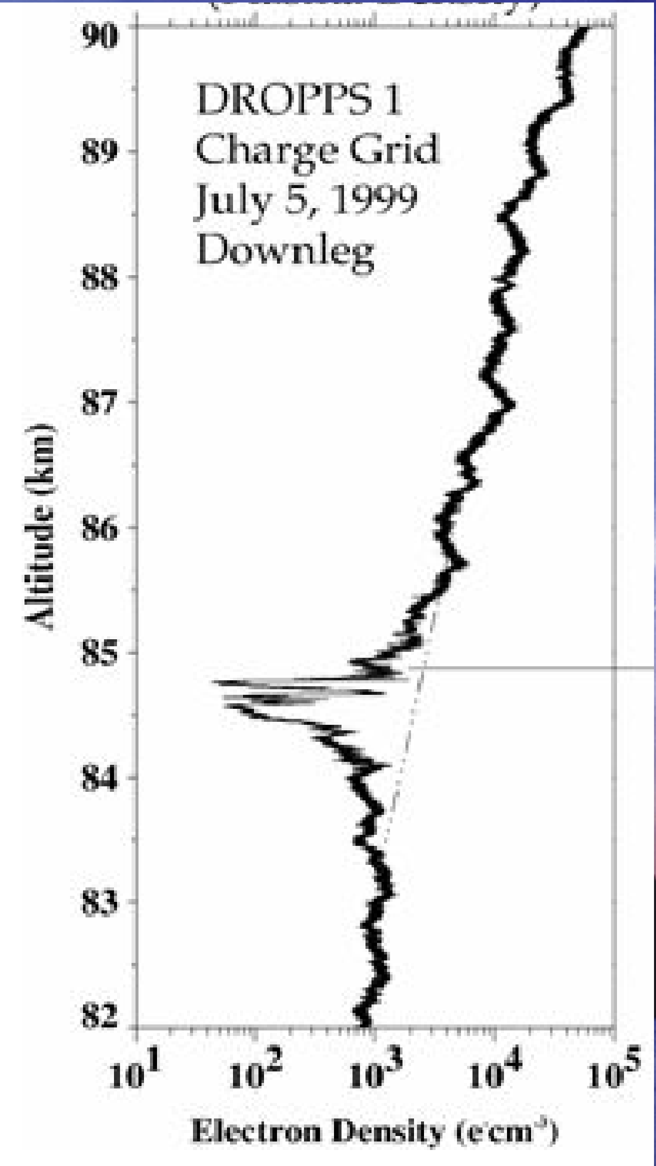


Temperature in the polar mesosphere
(Gerding et al, JGR, 2007)

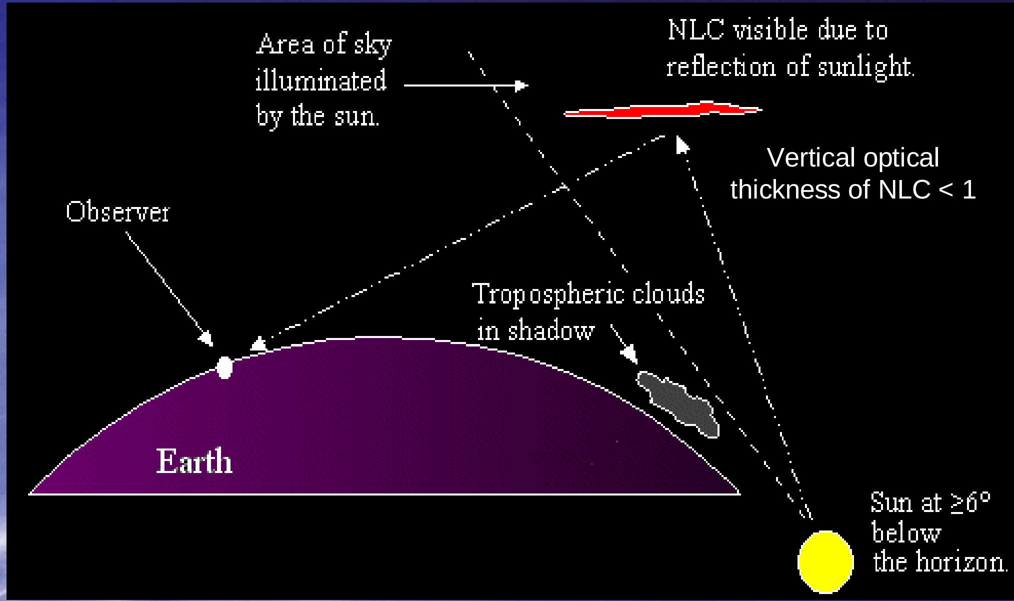
N.B. Updrift - few cm/s

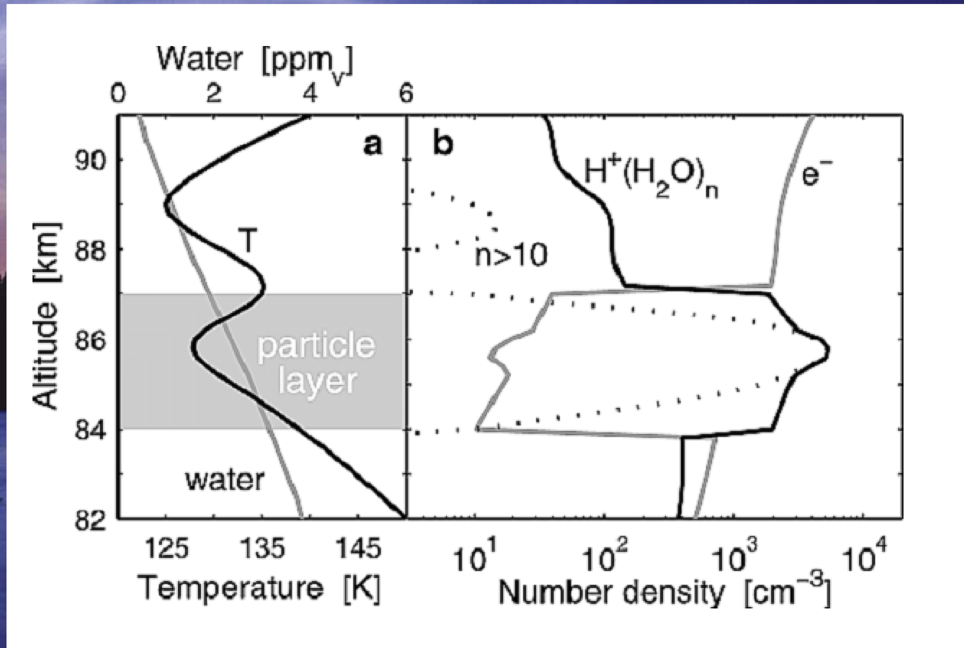
N.B. Source of smoke particles in mesosphere: meteoroid’s ablation & soot from volcanic eruptions

Polar summer mesosphere (cntnd)



Electron density versus altitude
(Pfaff et all, GRL, 2001)





Charging of isolated particle in mesospheric plasma

$$\frac{\partial n_e}{\partial t} = q_e - \alpha_s^{\rm rec} n_e n_i^s - \alpha_c^{\rm rec} n_e n_i^c + + \pi\langle \nu_{ed}^{\rm photo} a^2 n_d\rangle - \pi\langle \nu_{ed} a^2 n_d\rangle,$$

$$\frac{\partial n_i^s}{\partial t} = q_e - \alpha_s^{\rm rec} n_e n_i^s - \beta_c n_i^s - \pi\langle \nu_{sd} a^2 n_d\rangle,$$

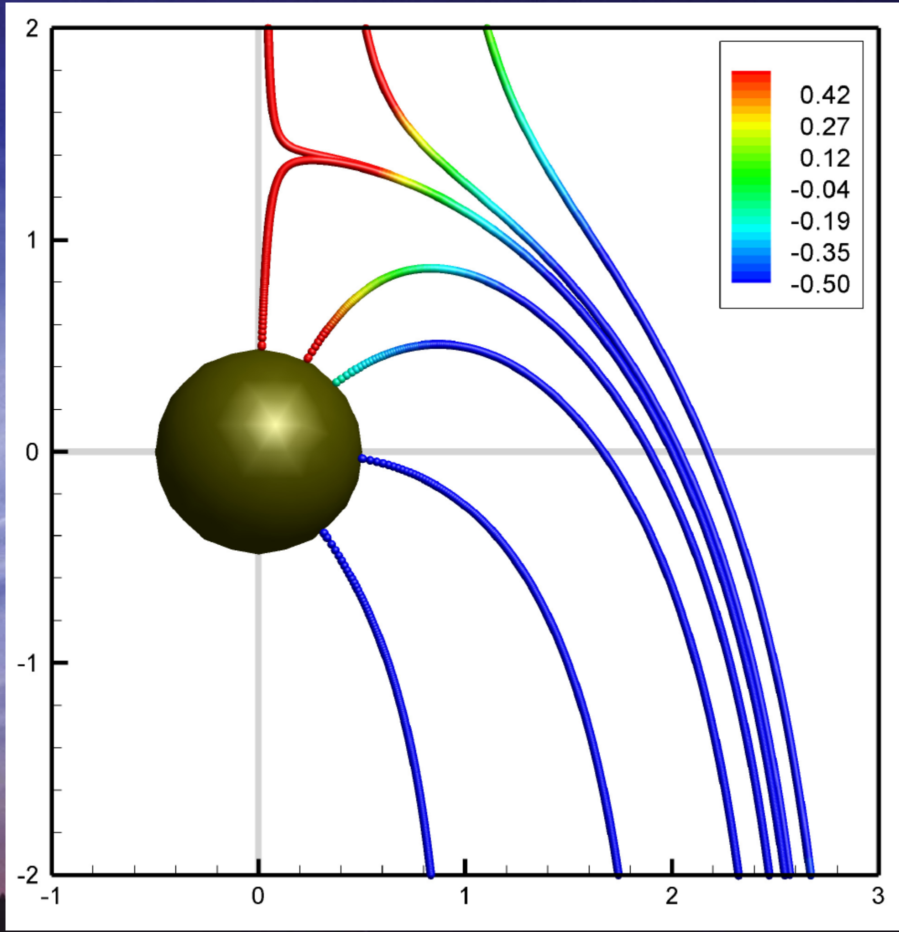
$$\frac{\partial n_i^c}{\partial t} = \beta_c n_i^s - \alpha_c^{\rm rec} n_e n_i^c - \pi\langle \nu_{cd} a^2 n_d\rangle,$$

$$\frac{\partial Z_d^a}{\partial t} = \nu_d^{\rm photo} + \nu_{sd} + \nu_{cd} - \nu_{ed},$$

$$\nu_{ed} = \begin{cases} \pi a^2 \left(\frac{8T_e}{\pi m_e}\right)^{\frac{1}{2}} n_e \exp\left(\frac{e^2 Z_d}{a T_e}\right) & \text{if } Z_d < 0, \\ \pi a^2 \left(\frac{8T_e}{\pi m_e}\right)^{\frac{1}{2}} n_e \left(1 + \frac{e^2 Z_d}{a T_e}\right) & \text{if } Z_d > 0. \end{cases}$$

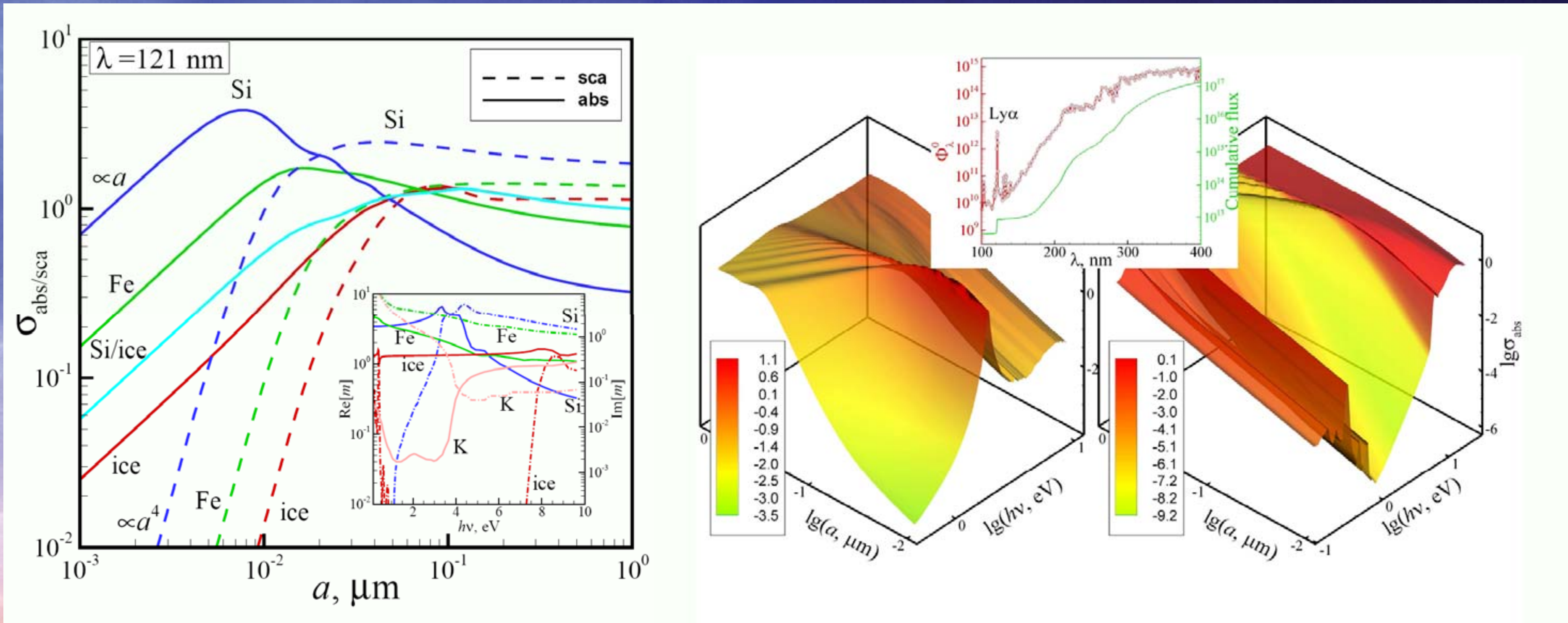
$$\nu_{id} = \begin{cases} \pi a^2 \left(\frac{8T_i}{\pi m_i}\right)^{\frac{1}{2}} n_i \left(1 - \frac{e^2 Z_d}{a T_i}\right) & \text{if } Z_d < 0, \\ \pi a^2 \left(\frac{8T_i}{\pi m_i}\right)^{\frac{1}{2}} n_i \exp\left(-\frac{e^2 Z_d}{a T_i}\right) & \text{if } Z_d > 0. \end{cases}$$

$$\nu_{ed}^{\rm photo} = \pi a^2 \int_0^{\lambda_W} \sigma_{\rm abs}(\lambda, a, m)\Phi_\lambda Y(\lambda, m, a) d\lambda,$$



- Impact of collisions on the charge of isolated particle: increase of ion flux due to the trapped particles, so decrease the particle charge.

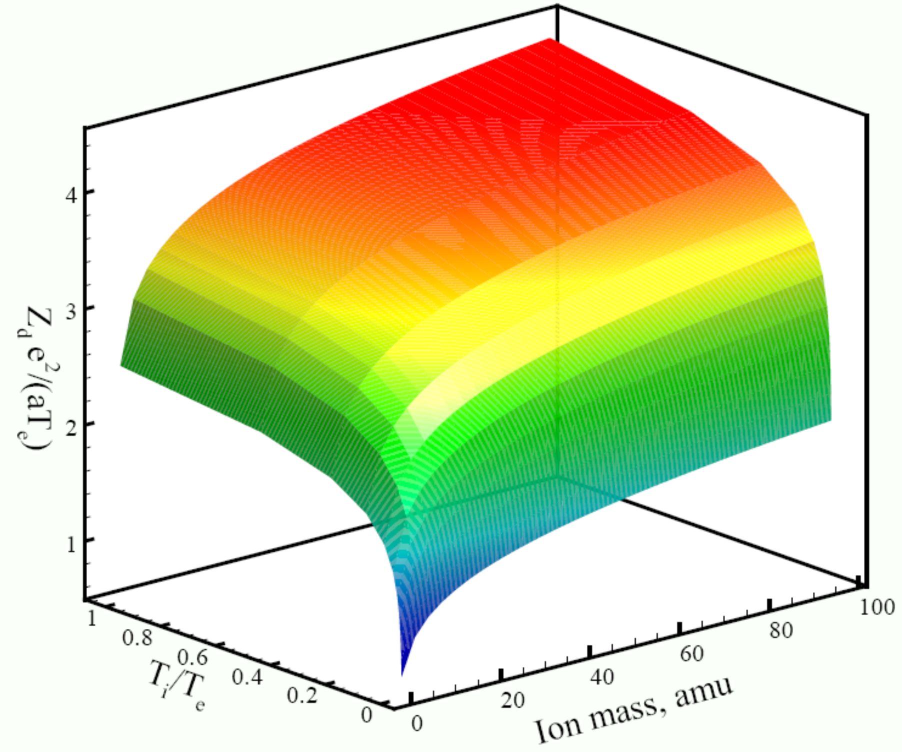
Optical properties of mesospheric particles



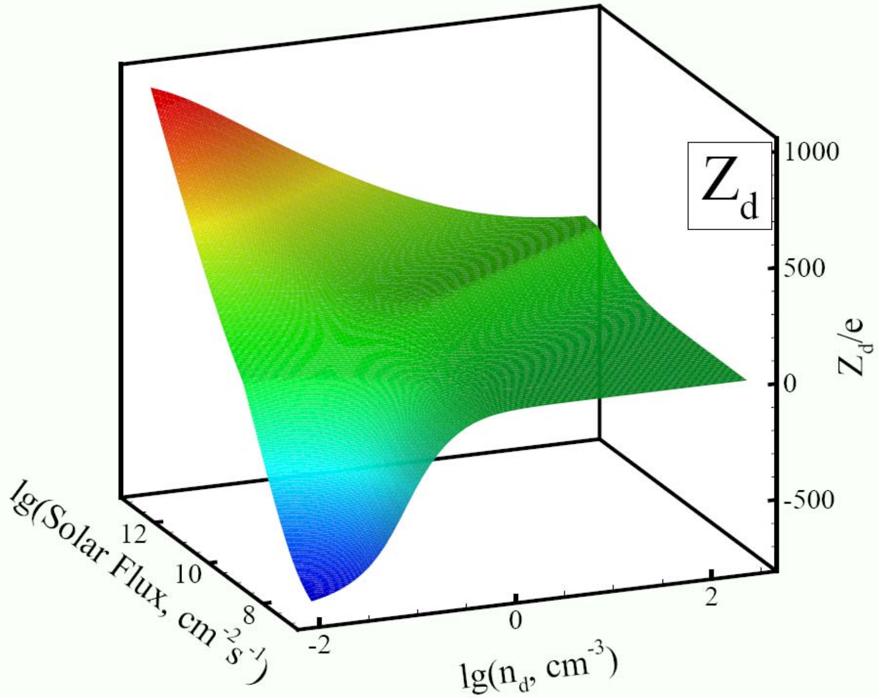
- Metals: low work functions (few eV), very effective photoelectric effect even for visible wavelenghts.

- Water ice: high work function (about 8 eV), photoelectric effect possible only for UV light (Lyman-alpha hydrogen)

Charging of dust particles (cntnd)

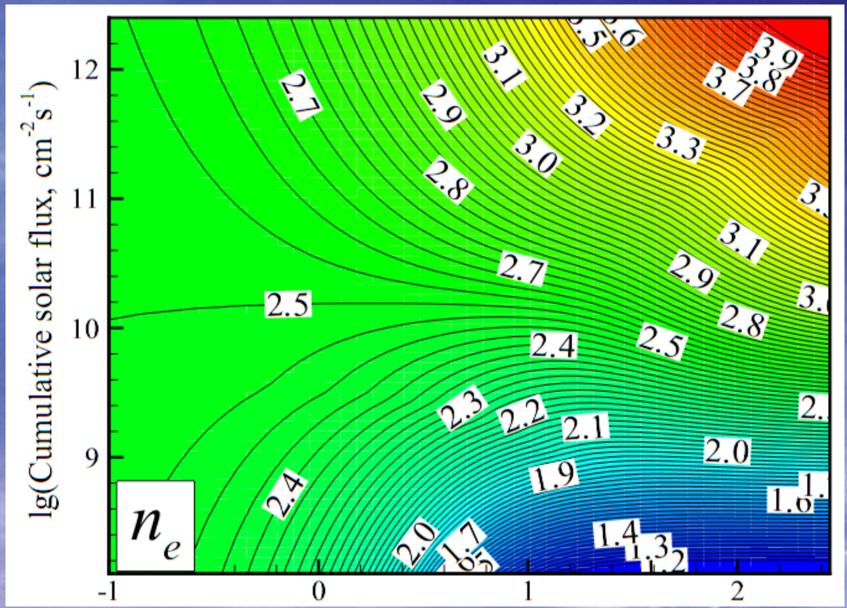


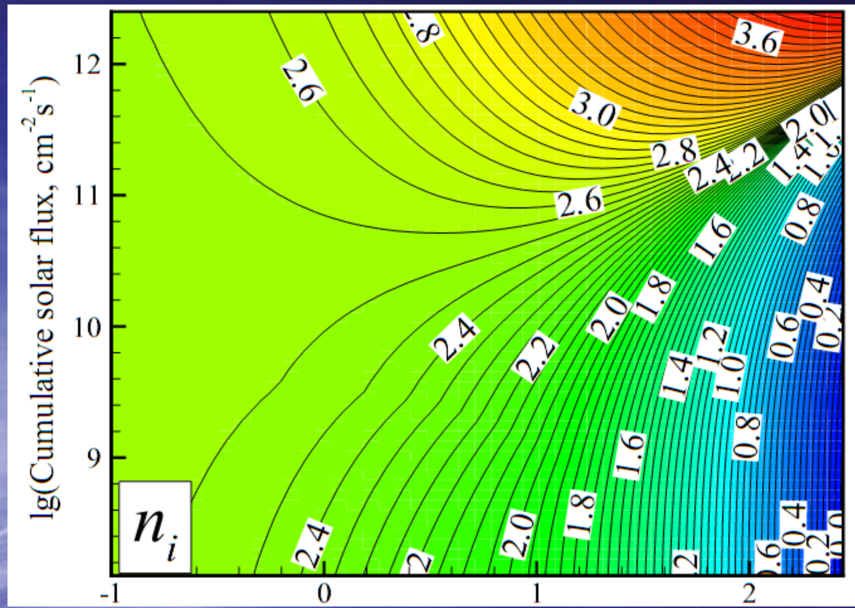
Dimensionless grain charge versus ion to electron temperature ratio and ion mass

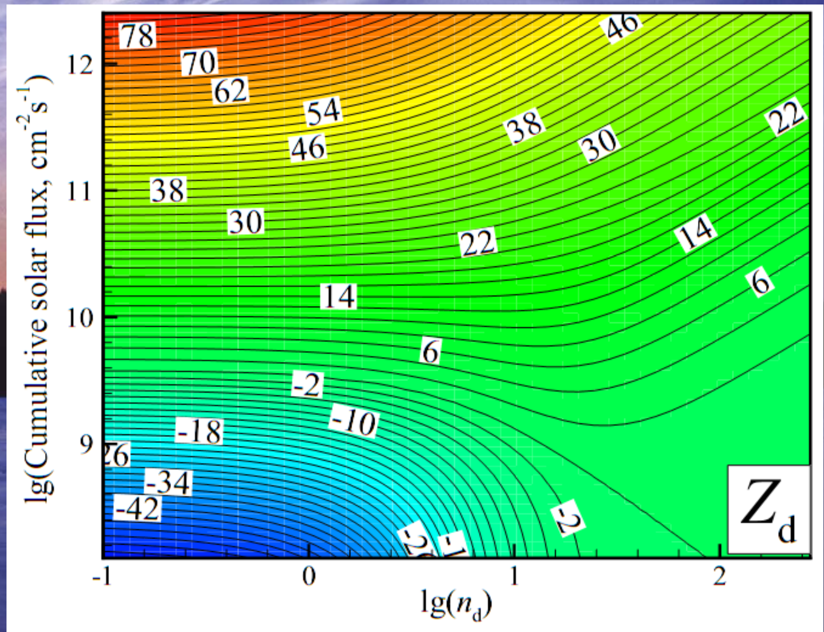


Dust grain charge (OML) in PSM versus dust number density and effective solar flux

Impact of dust on plasma parameters







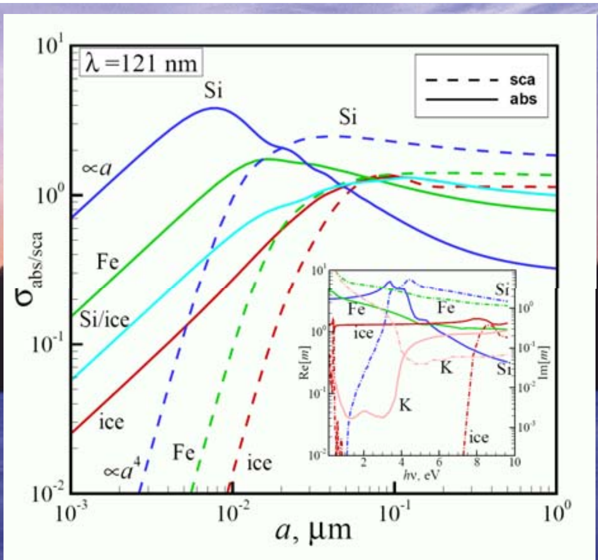
Heating of dust particles in the upper atmosphere

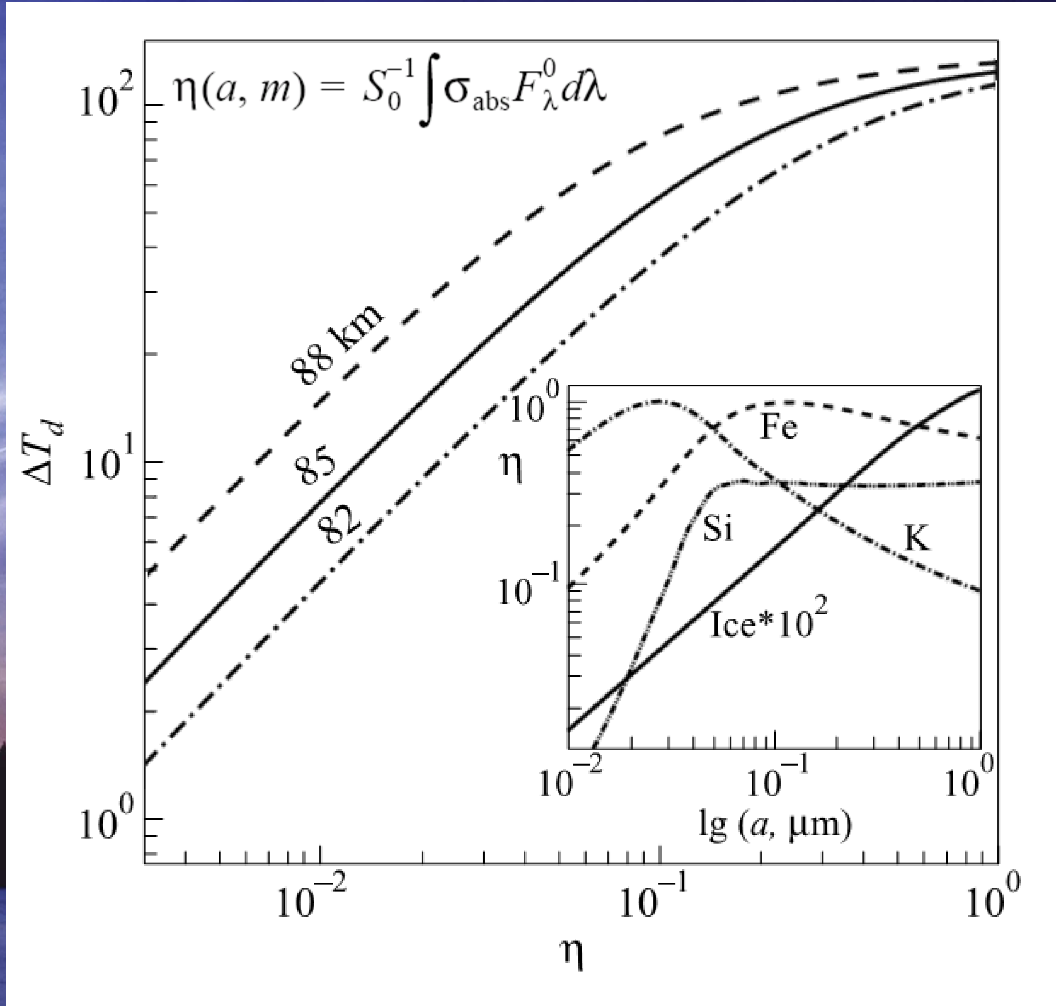
$$P^{\mathrm{sol}} + P^{\mathrm{rad}} + P^{\mathrm{col}} = 0$$

$$P^{\mathrm{sol}} = \pi a^2 hc \int \sigma_{\mathrm{abs}}(\lambda, a, m)(\Phi_\lambda^{\mathrm{sol}}(H, \alpha_{\mathrm{za}}) + \\ + \Phi_\lambda^{\mathrm{sca}}(H, \alpha_{\mathrm{za}}))d\lambda/\lambda,$$

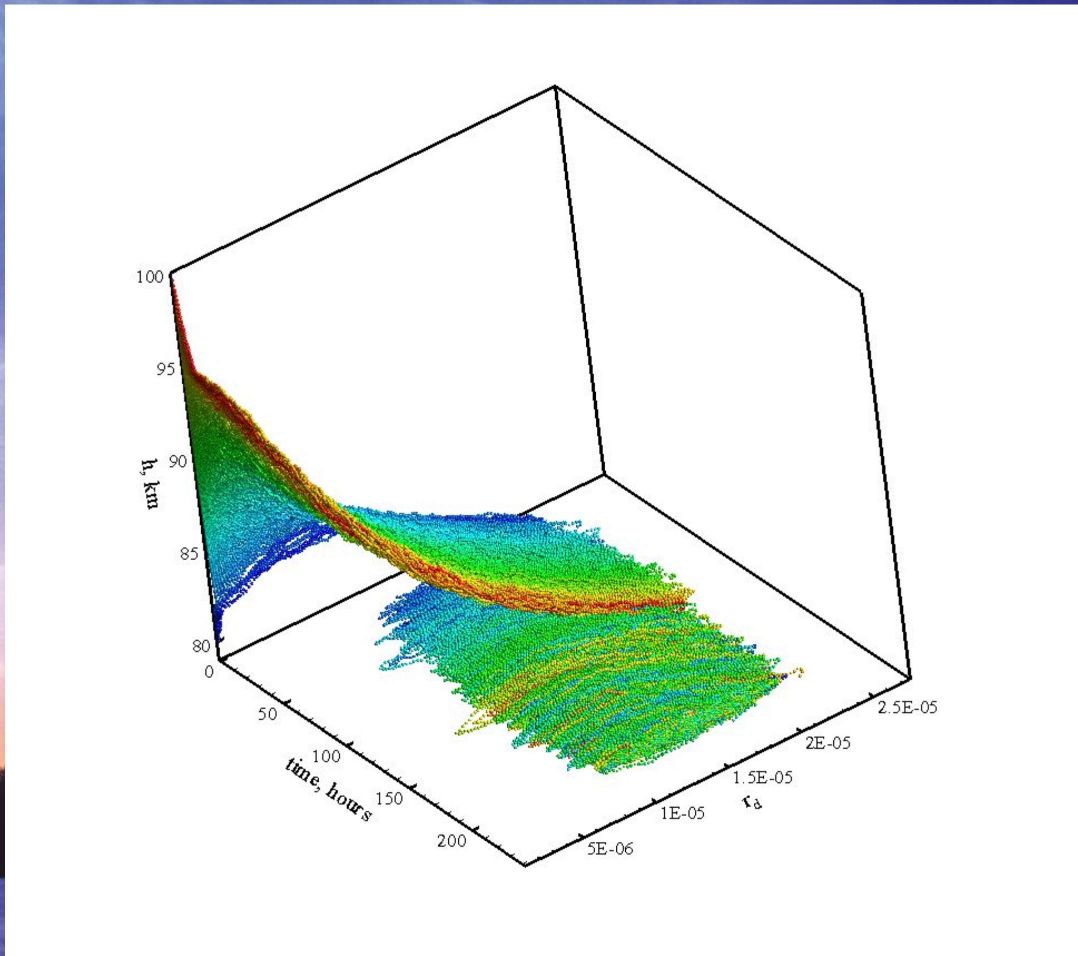
$$P^{\mathrm{rad}} = \pi a^2 hc \int \sigma_{\mathrm{abs}}(\lambda, a, m) B_\lambda(T_d) d\lambda/\lambda$$

$$P^{\mathrm{col}} \approx 4\pi a^2 \alpha_{\mathrm{T}} n_n v_{th} k_{\mathrm{B}}(T_d - T_n)$$

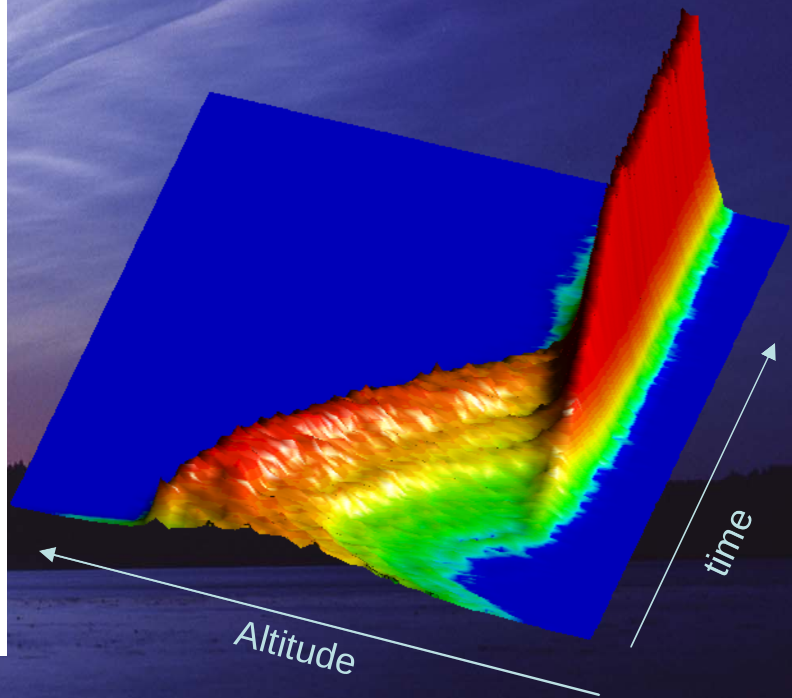




NLC: simple growth/sedimentation model

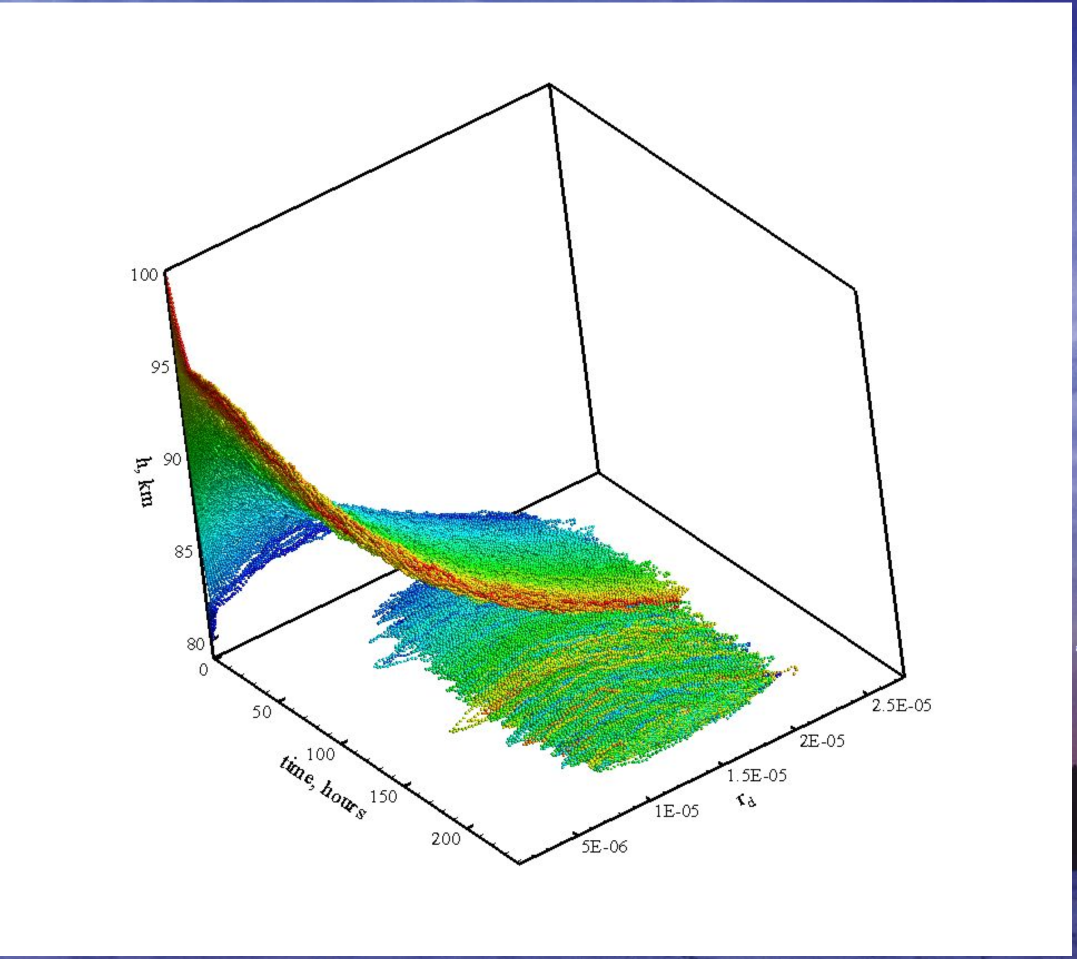


$$\frac{\partial f_d}{\partial t} + \frac{\alpha_{\rm w}}{4} m_{\rm w} v_{\rm w}^T \rho_d (n_{\rm w} - n_{\rm w}^s) \frac{\partial f_d}{\partial a} + v \frac{\partial f_d}{\partial H} + \\ + \left[g - \frac{\pi \rho c_s a^2 F_d (v + v_{\rm wind})}{m_d} \right] \frac{\partial f_d}{\partial v} = 0.$$



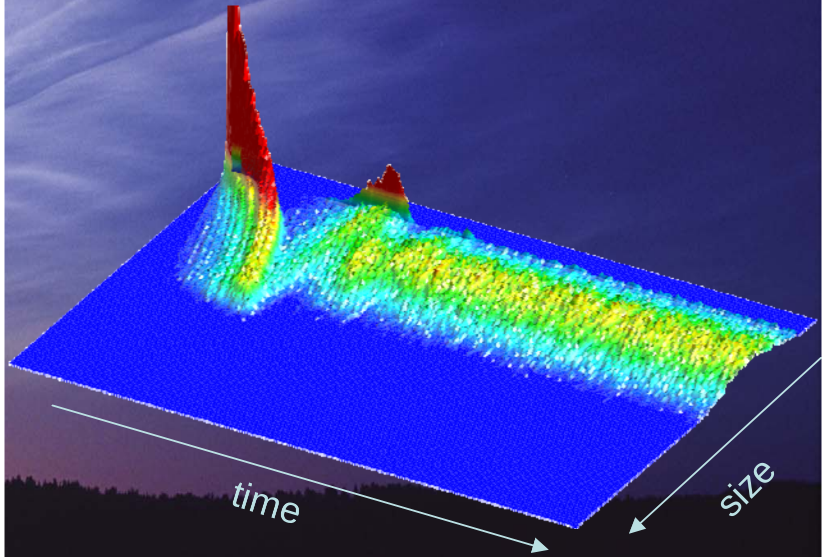
Particles growth/sedimentation in phase space: (*r*, *h*, *t*)

NLC: simple growth/sedimentation model



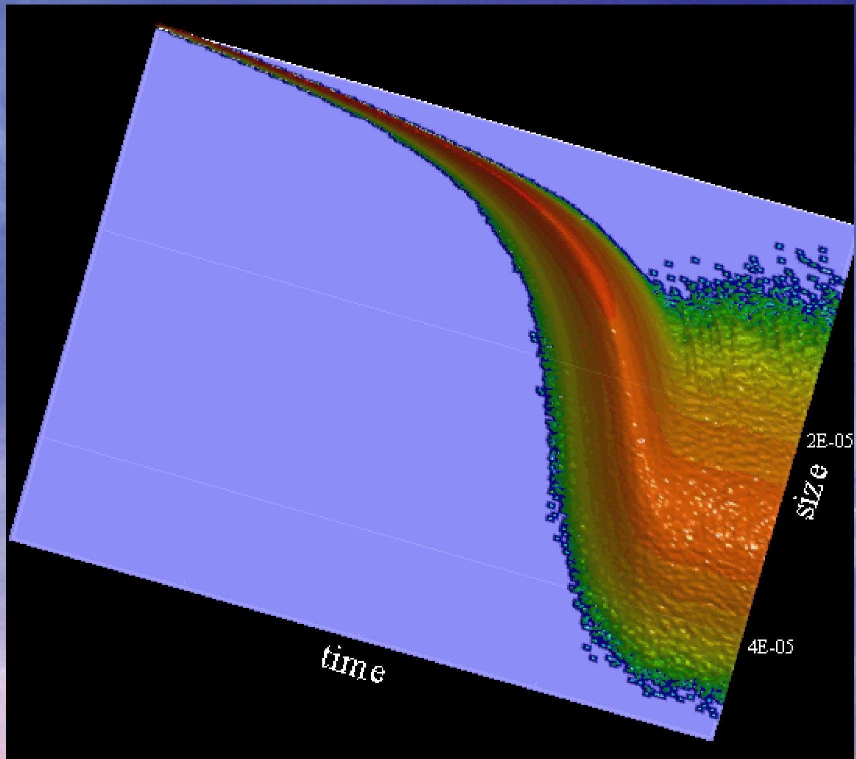
Particles growth/sedimentation in phase space: (*r*, *h*, *t*)

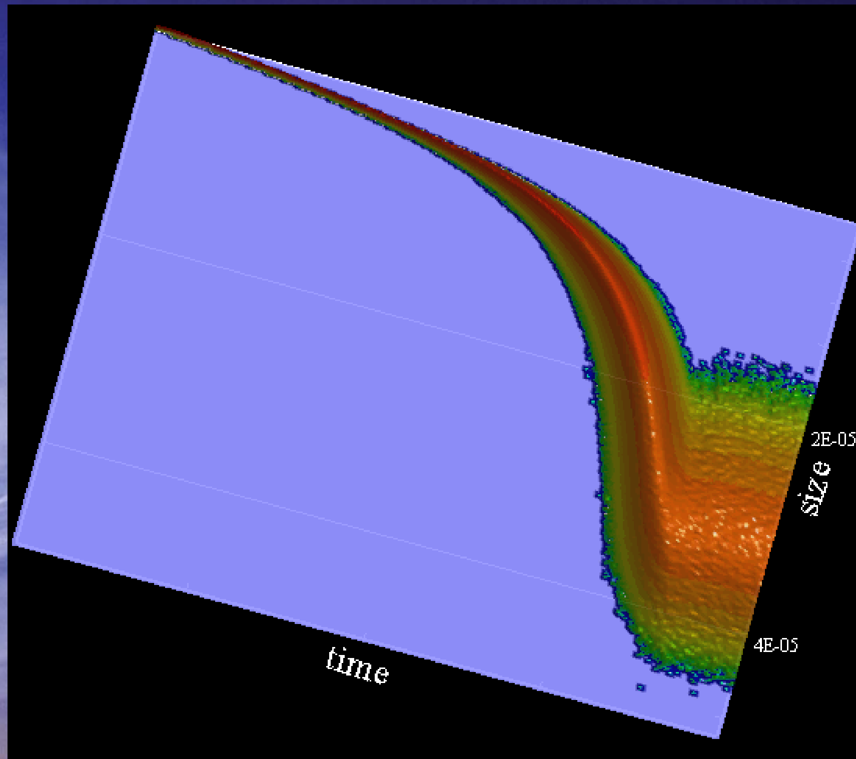
$$\frac{\partial f_d}{\partial t} + \frac{\alpha_w}{4} m_w v_w^T \rho_d (n_w - n_w^s) \frac{\partial f_d}{\partial a} + v \frac{\partial f_d}{\partial H} + $$
$$+ \left[g - \frac{\pi \rho c_s a^2 F_d (v + v_{\mathrm{wind}})}{m_d} \right] \frac{\partial f_d}{\partial v} = 0.$$



PMC's particle size distribution vs time

NLC: simple growth/sedimentation model

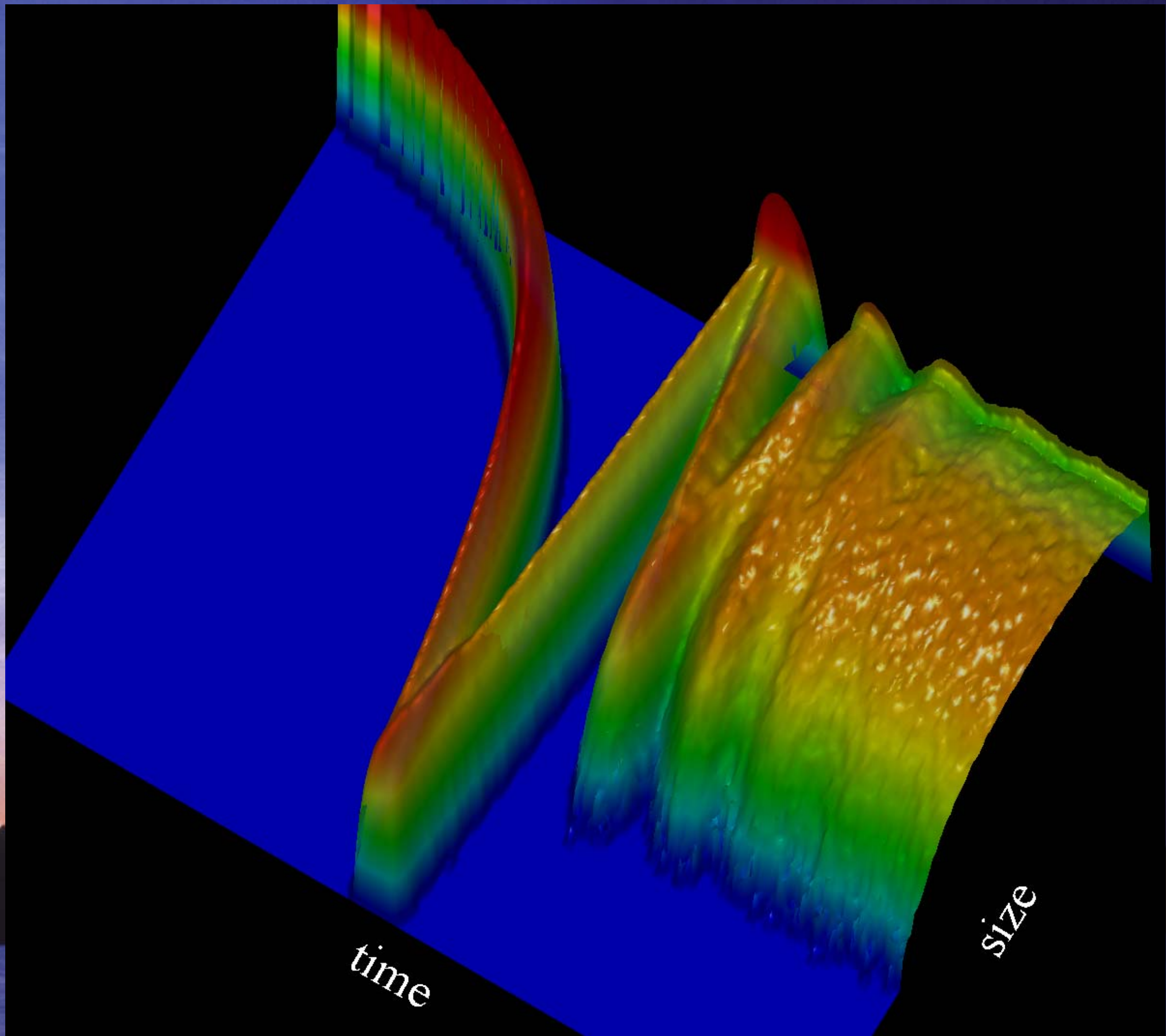




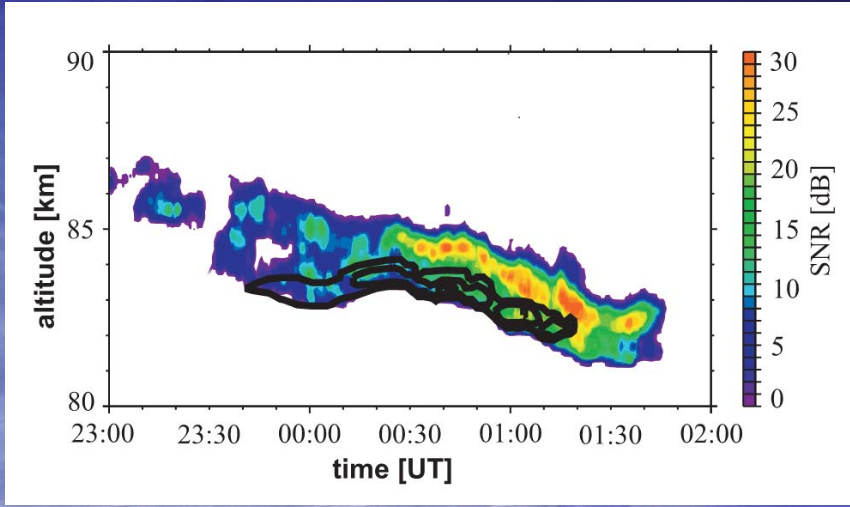
$$\frac{\partial f_d}{\partial t} + \frac{\alpha_{\rm w}}{4} m_{\rm w} v_{\rm w}^T \rho_d (n_{\rm w} - n_{\rm w}^s) \frac{\partial f_d}{\partial a} + v \frac{\partial f_d}{\partial H} +$$

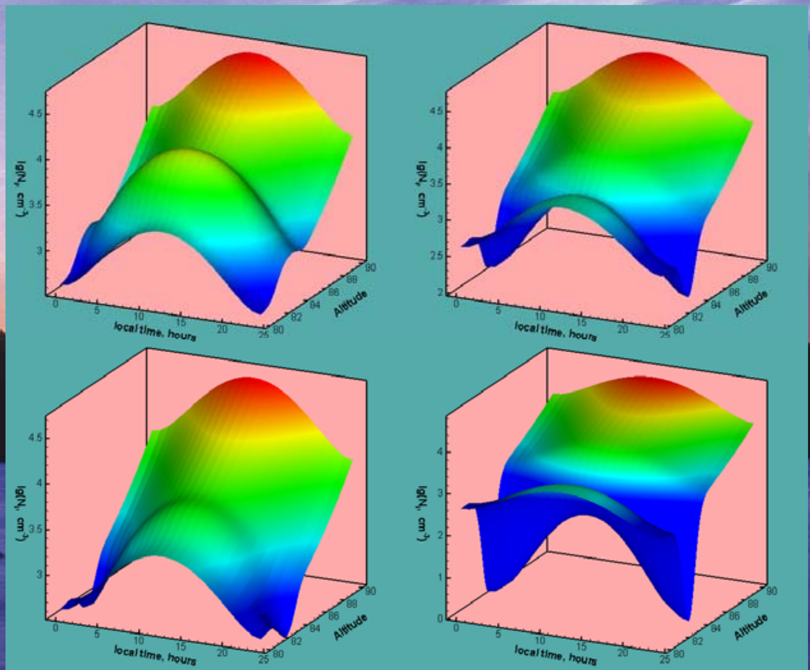
$$+ \left[g - \frac{\pi \rho c_s a^2 F_d (v + v_{\rm wind})}{m_d} \right] \frac{\partial f_d}{\partial v} = 0.$$

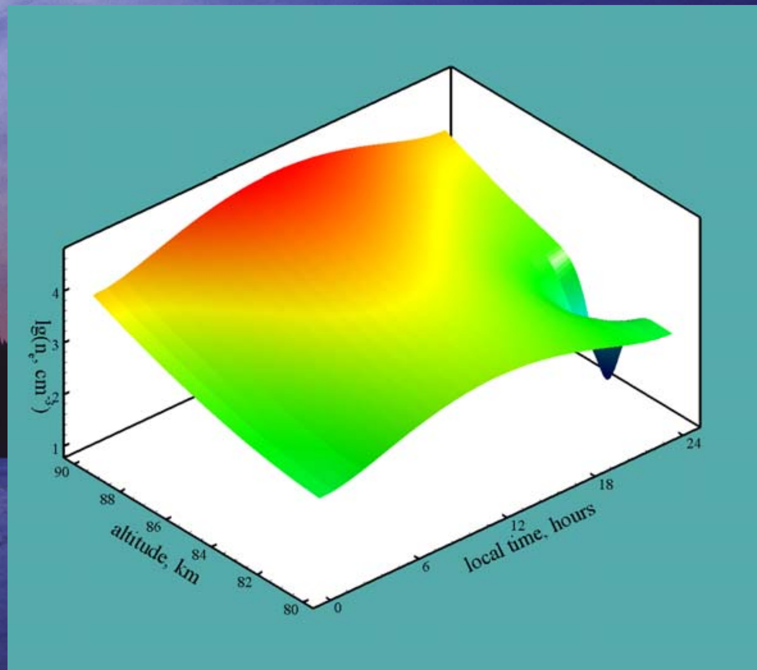
NLC: simple growth/sedimentation model



NLC: growth/sedimentation model (cntnd)

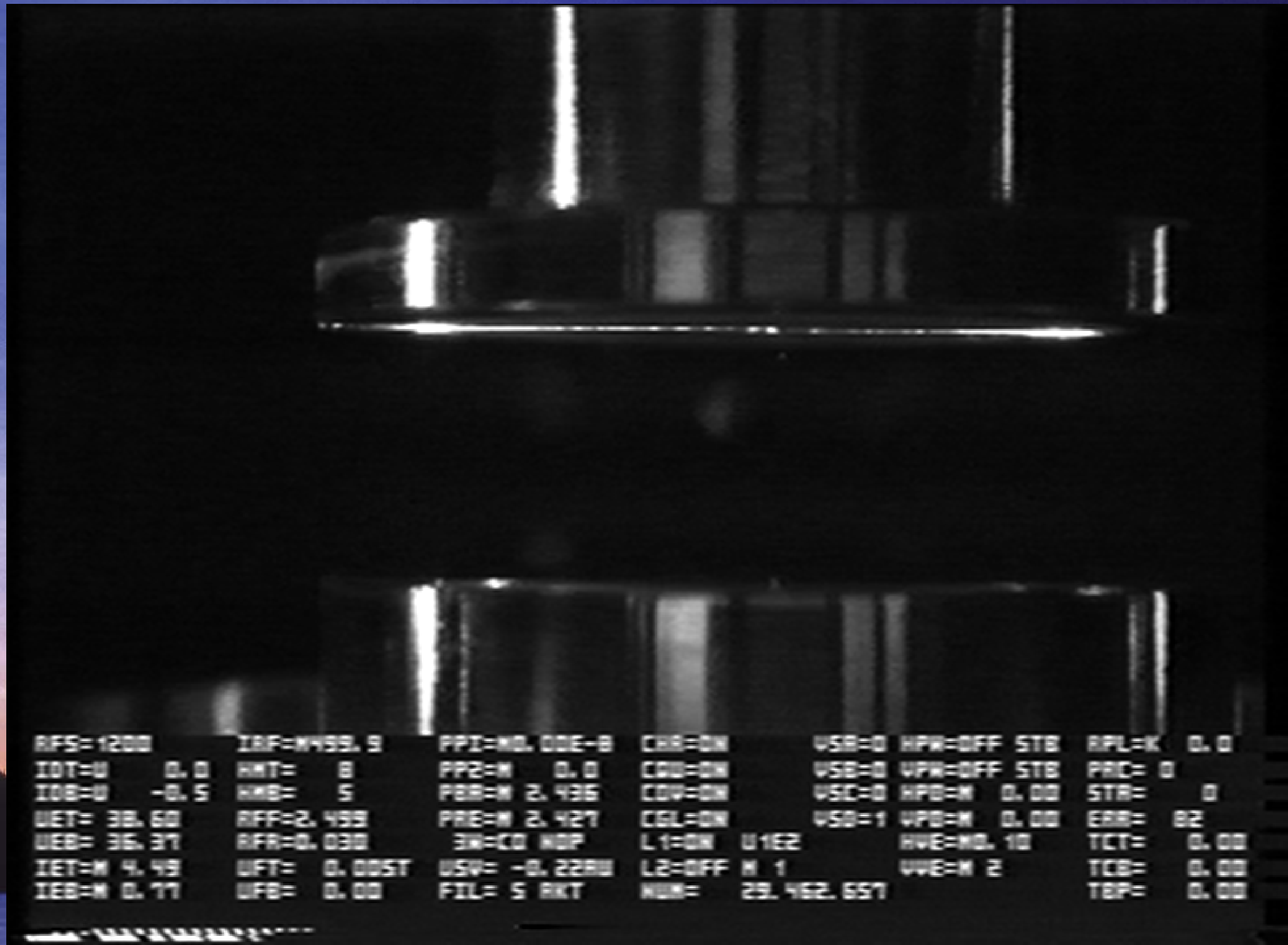






Ice particle formation in RF chamber

(S. Shimizu,T.Shimizu, 2009)

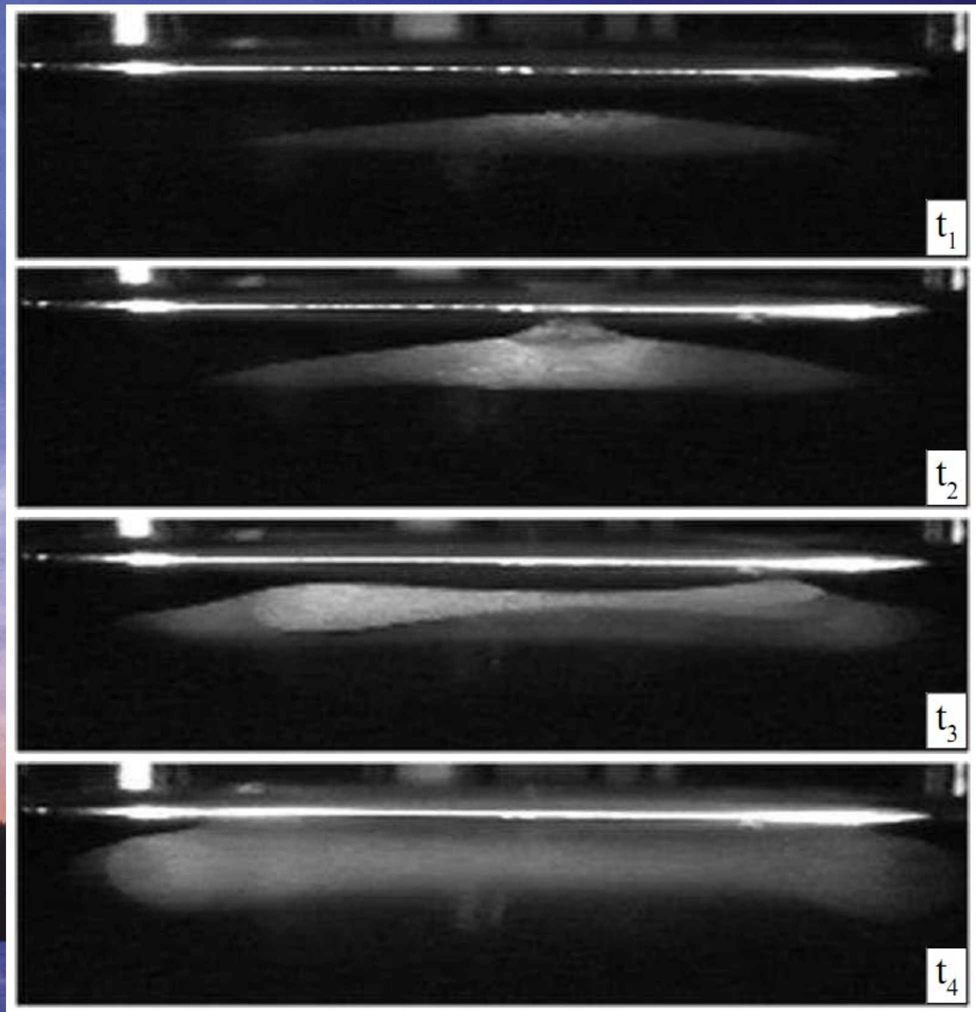


Pressure = 1 mbar, oxygen/hydrogen = 0.1

Typical size of ice particle is about 1 micron; the timescale <1s

Ice particle formation in RF chamber

(S. Shimizu,T.Shimizu, 2009)



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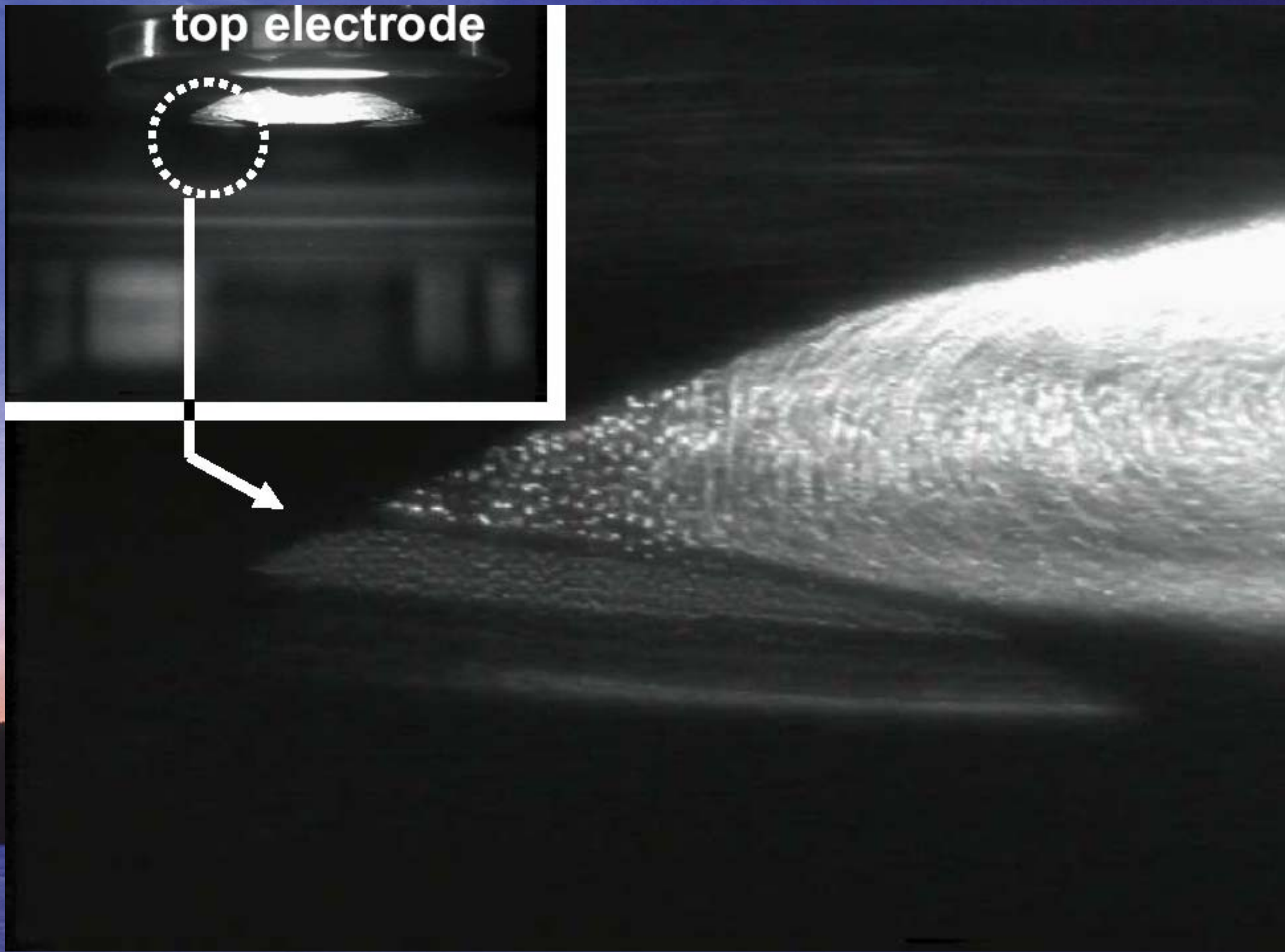

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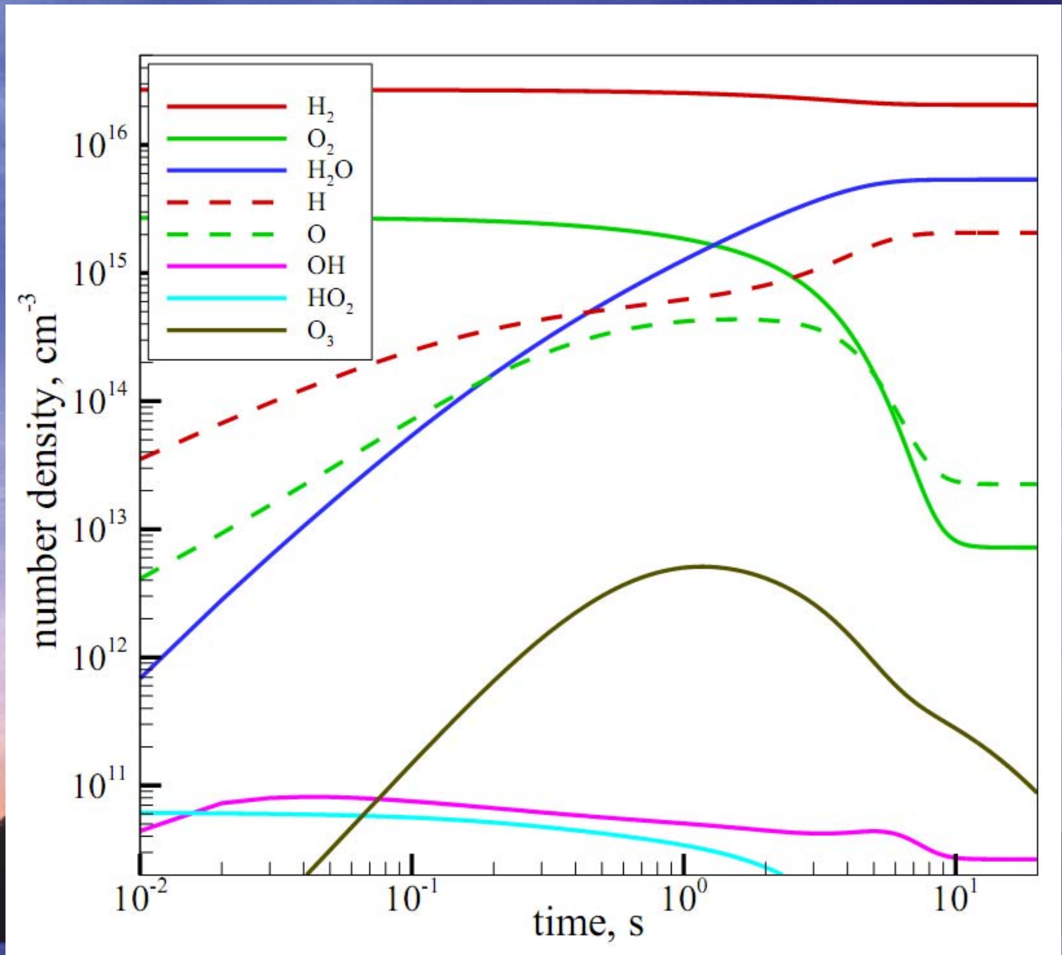


$$\frac{\partial n_j}{\partial t} = Q_j - n_j L_j$$

$$j = H_2, O_2, H, O, OH, HO_2, H_2O, O_3$$

$$OH + H + M \rightarrow H_2O + M$$

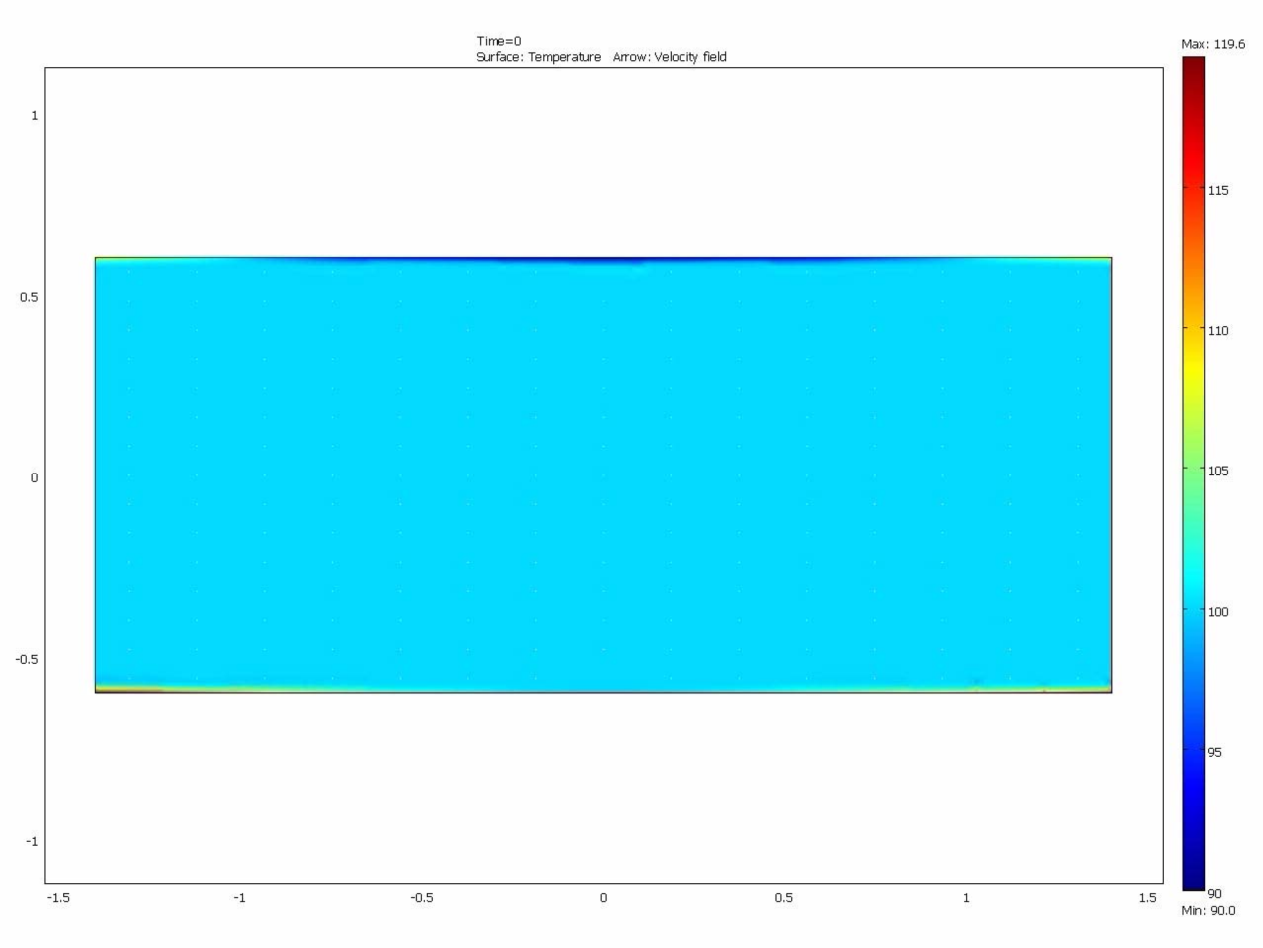
$$H + HO_2 \rightarrow H_2O + O$$

$$H_2O + \text{wall} \rightarrow \text{water ice}$$

Pressure = 1 mbar, oxygen/hydrogen = 0.1

Typical size of ice particle is about 1 micron

Ice particle formation in RF chamber
(S. Shimizu,T.Shimizu, 2009)



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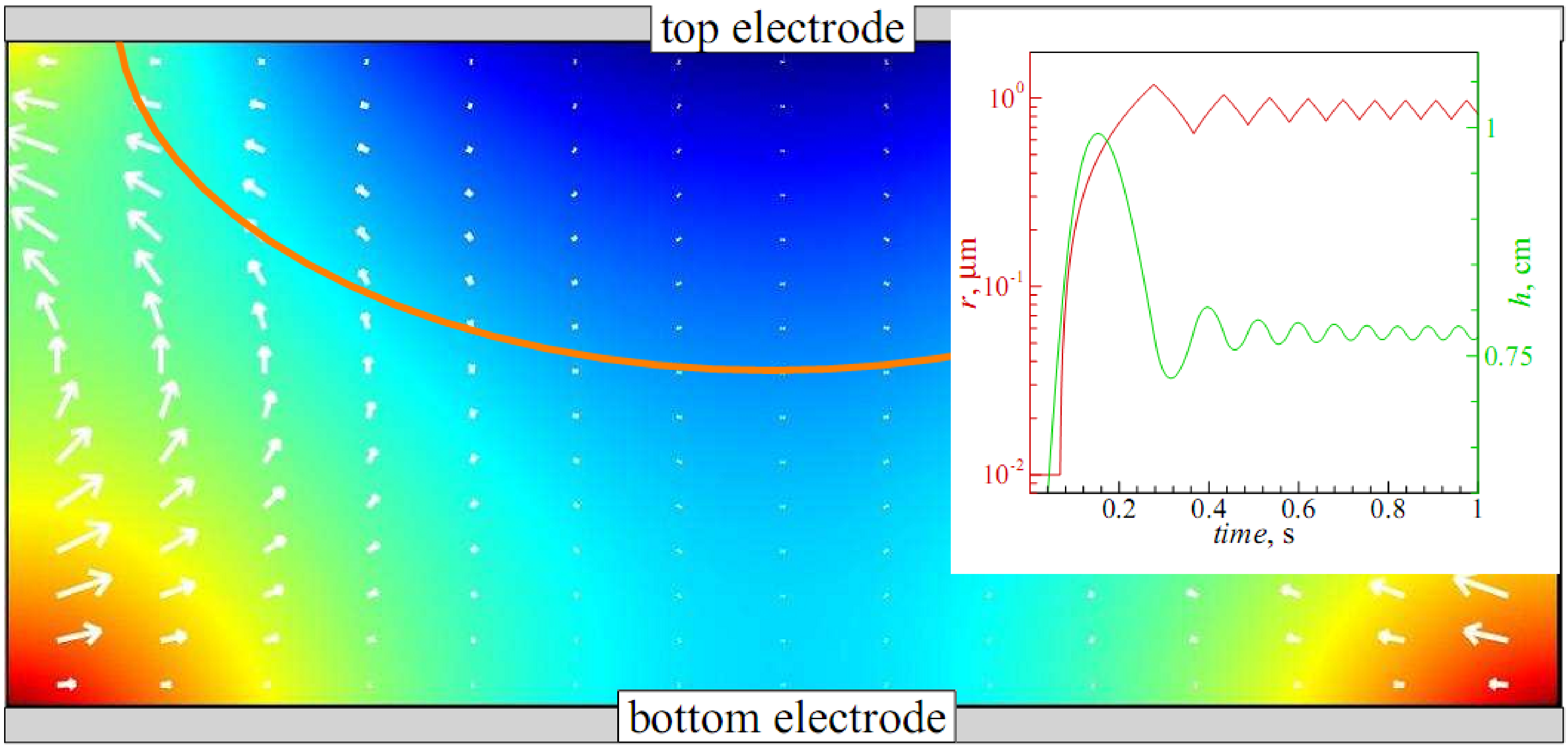

$$\frac{\partial f_d}{\partial t} + \frac{\alpha_w}{4} m_w v_w^T \rho_d (n_w - n_w^s) \frac{\partial f_d}{\partial a} + v \frac{\partial f_d}{\partial h} + \left[g + \frac{4\sqrt{2\pi}}{15} \frac{a^2}{v_{T_n} m_d} \kappa_n \nabla T_n \right] \frac{\partial f_d}{\partial v} = 0.$$

Pressure = 1 mbar, oxygen/hydrogen = 0.1

Typical size of ice particle is about 1 micron

Conclusions

- Simple model of dust-induced plasma chemistry of polar summer mesosphere is presented.
- Presence of dust particles significantly changes the plasma parameters @ very moderate dust densities:
  - both depletion and increase of electron density are possible
  - complicated behavior of ion density
  - fast charge-induced coagulation of dust particles
  - significant charge (as positive as negative) of dust particle depending on the photoelectric properties of the particle
- Growth/sedimentation model reproduces most of the NLC data
- Possible impact on neutral chemistry
- Water ice particles production if RF chamber was studied (both experimentally and numerically)