Ice Cloud – Cirrus Model for the EarthCARE Simulator

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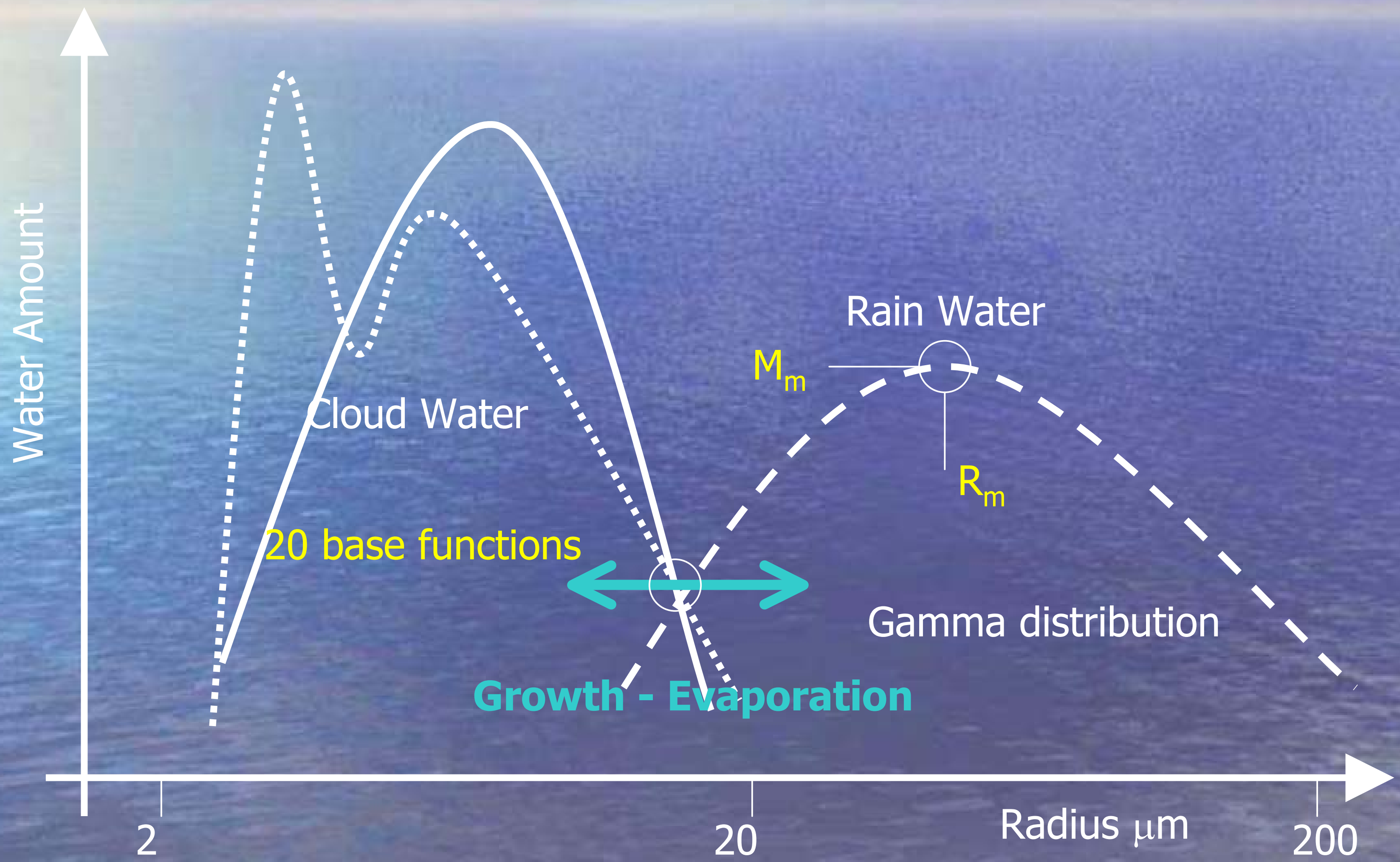
ESTEC, December 2, 2002

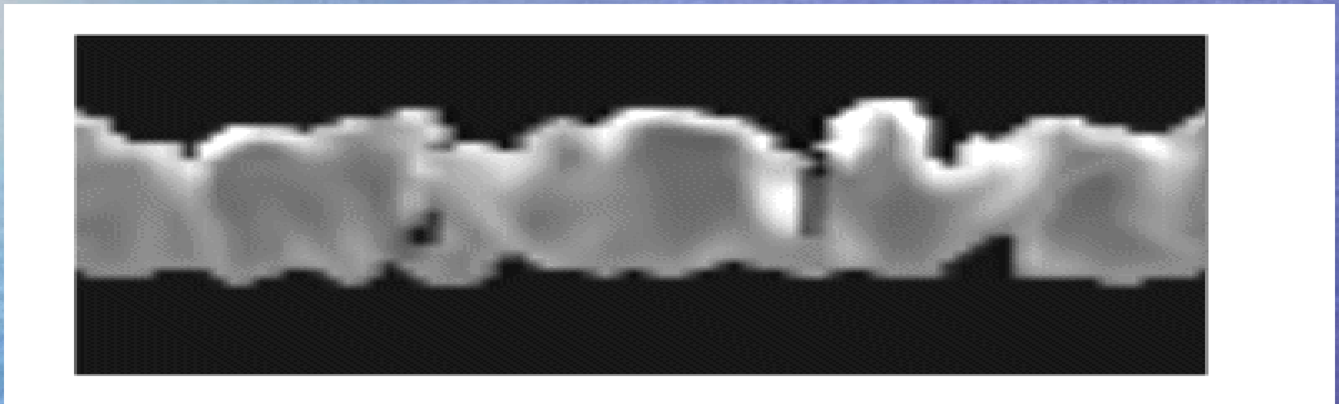
Objectives

- Introduce the concept
- Describe the model
- Show preliminary results

Low Clouds and Drizzle Microphysics (Sc, Cu, Tcu and St)



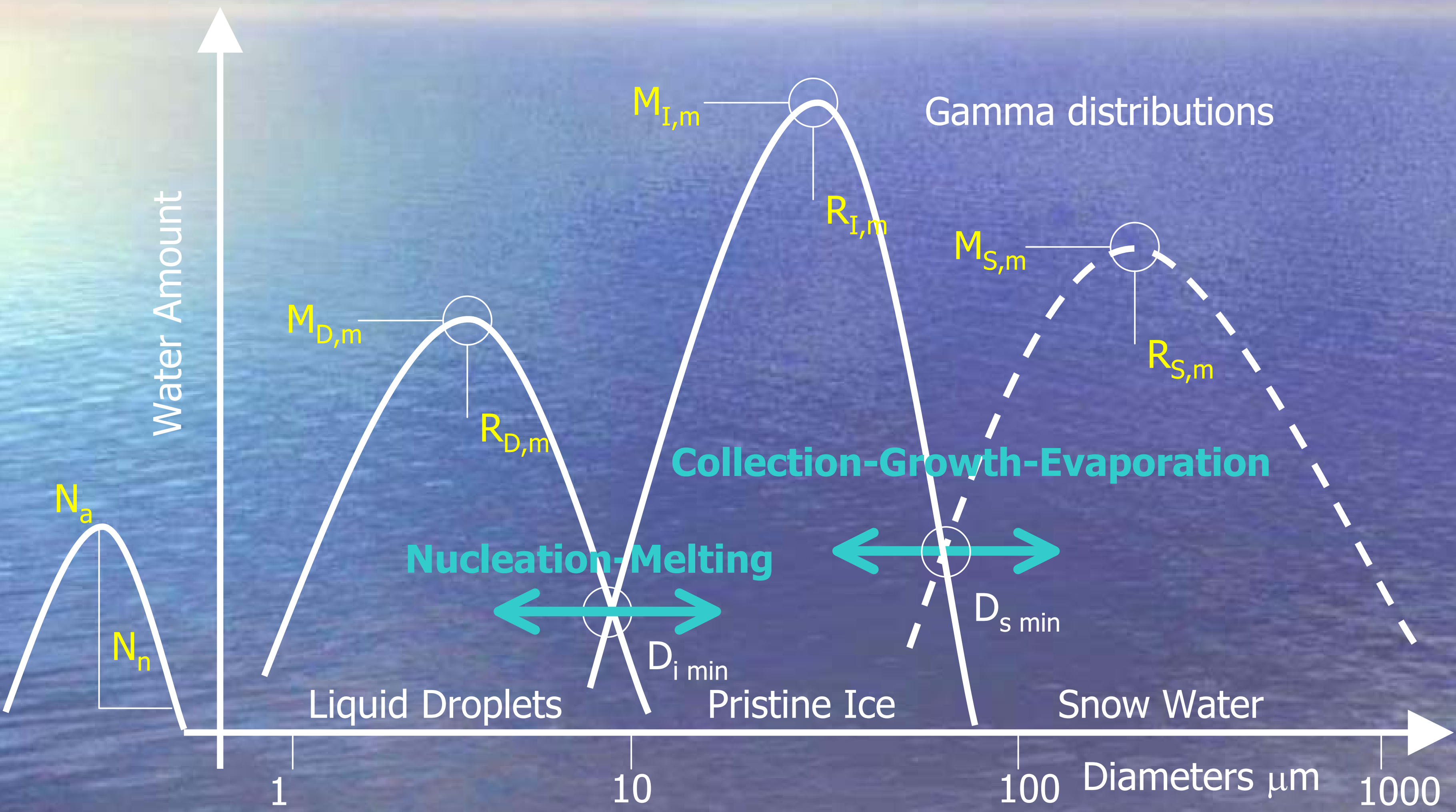
Near cumulus clouds



Bulk Microphysics for Cirrus

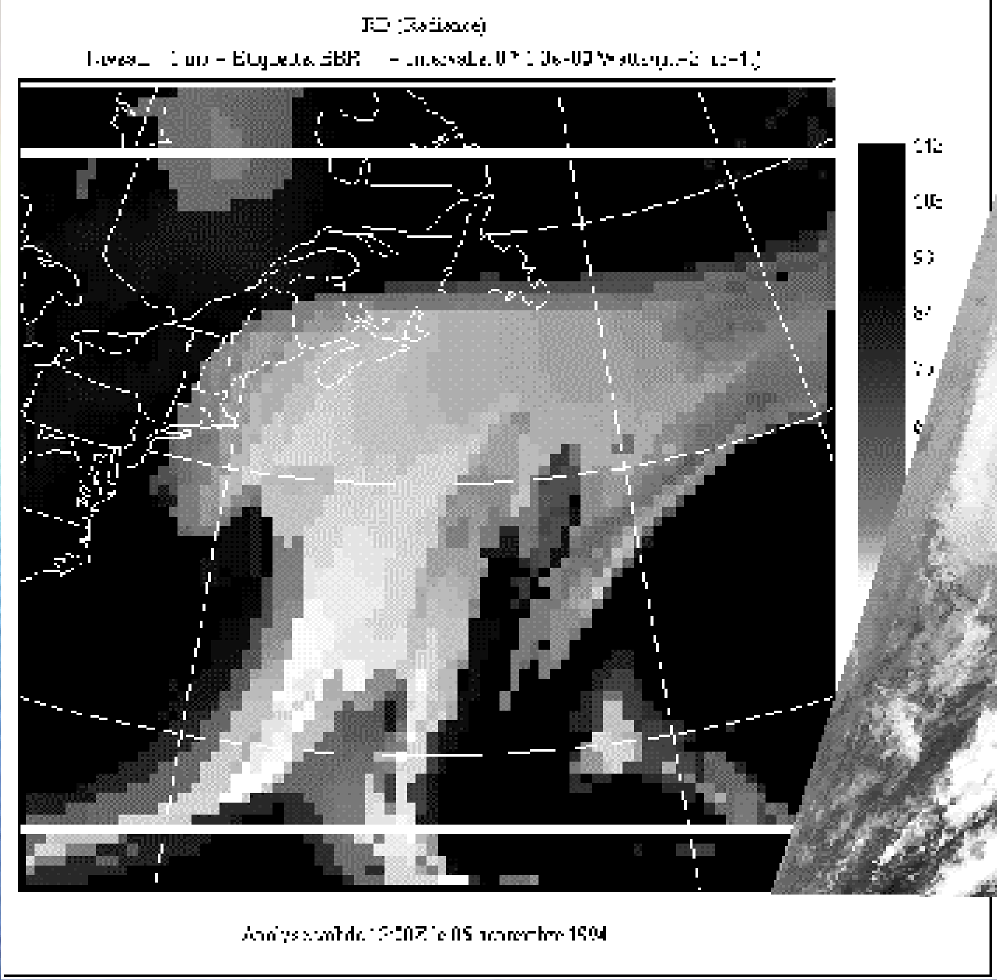
- Double moments scheme (mass & number)
- Cloud droplets
- Pristine (small) ice crystals $D < D_{S\,min}$
- Snow crystals $D > D_{S\,min}$
- Aerosol particles $> 0.1\ \mu m$
- Number of potential IFN $N_n < N_a$
- = 8 prognostic variables for cirrus

Cirrus and Snow Microphysics

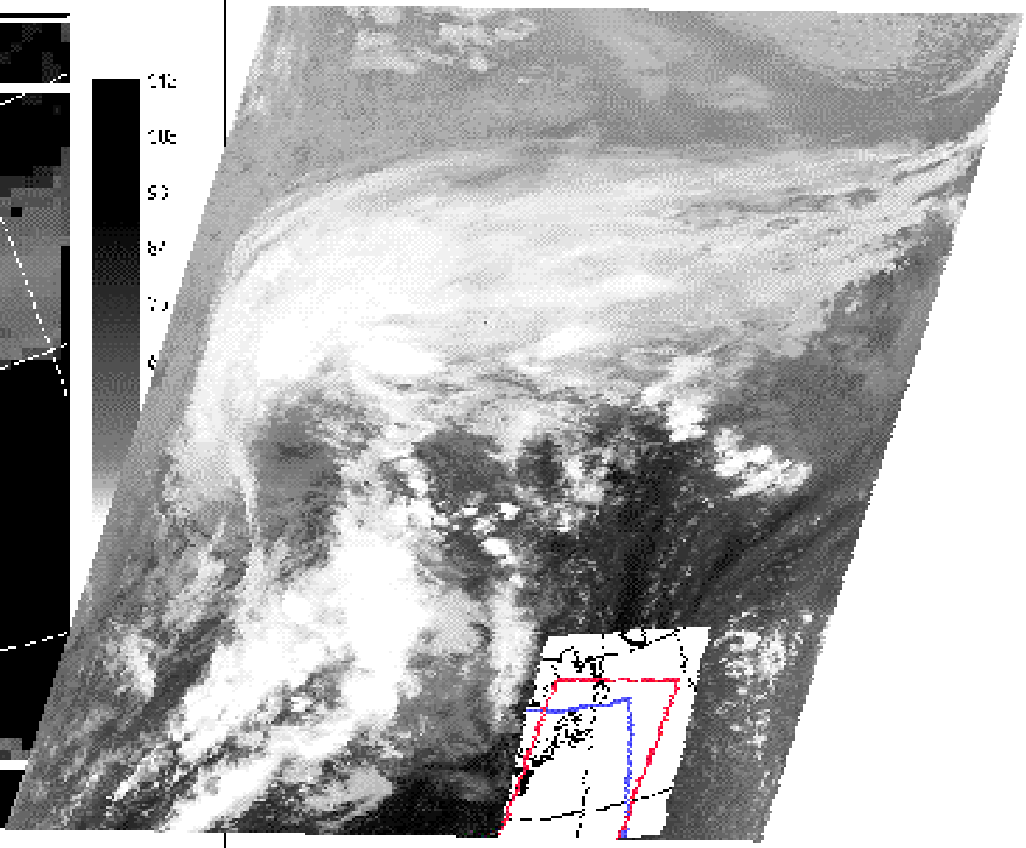


Comparaison of BBR IR Images for 5 September 1994

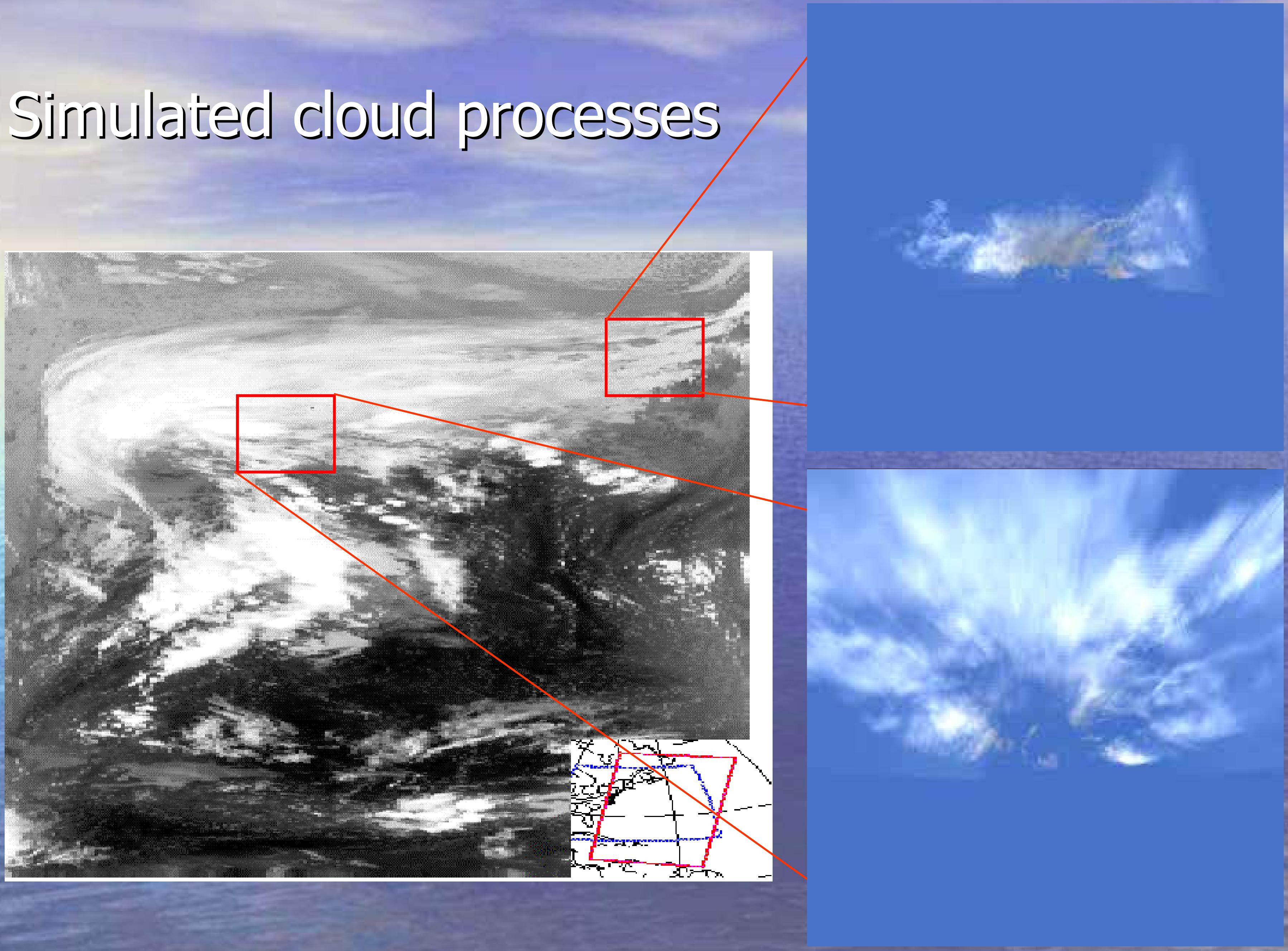
Model



Observed



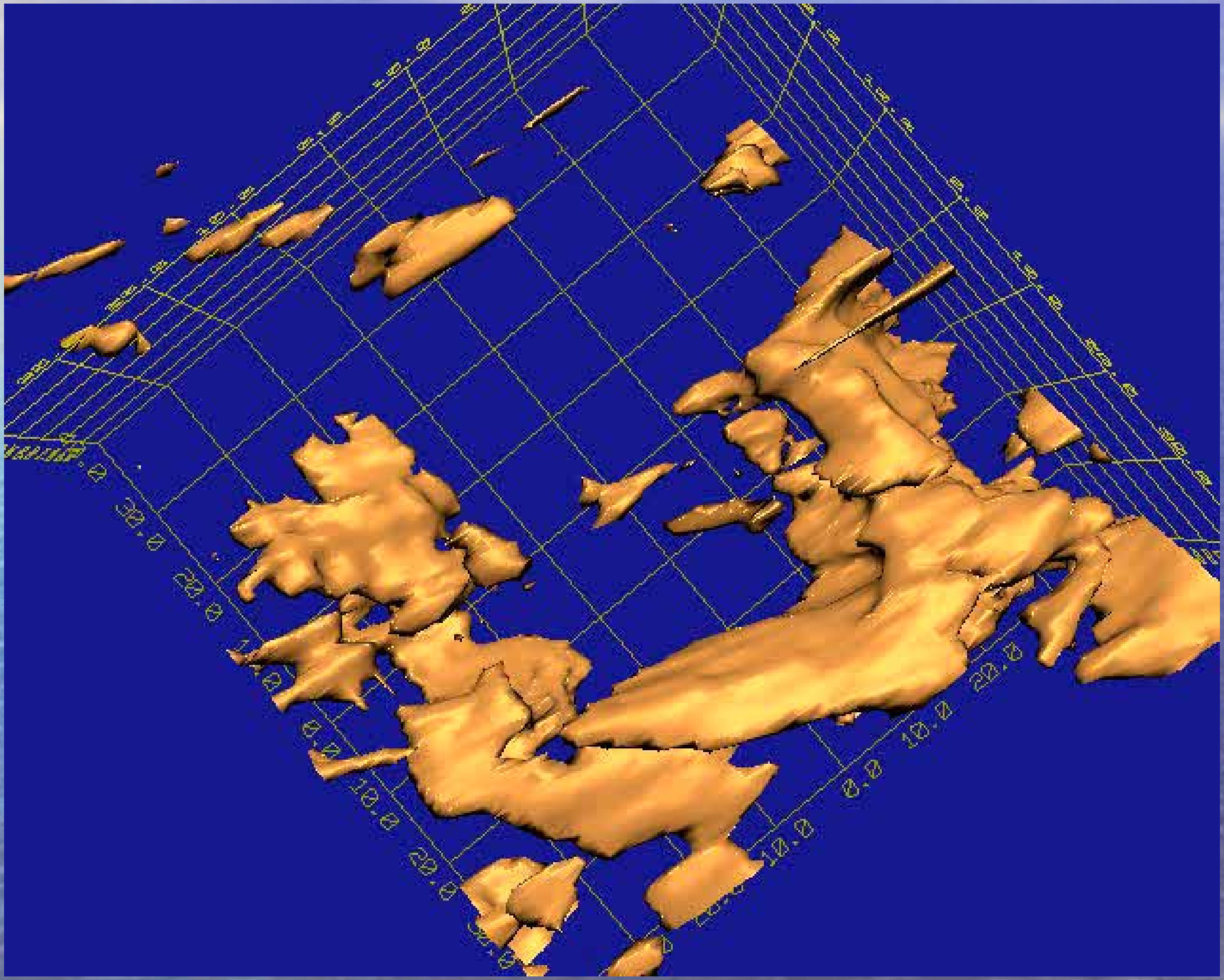
Simulated cloud processes



(Ref.: Eloranta et al, U Wisconsin)

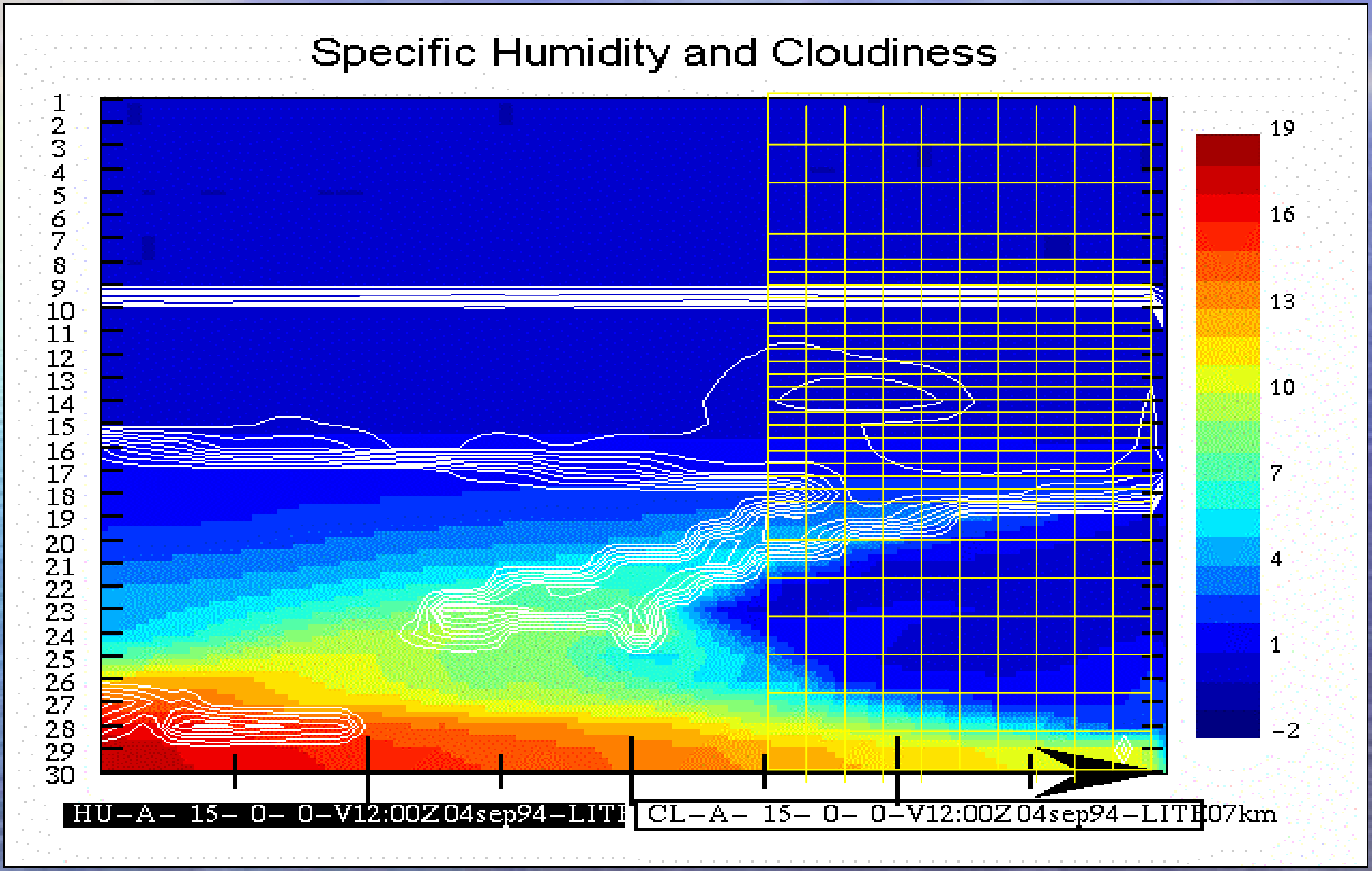
Nested LES Cirrus Microphysics in RCM

Volume Imaging Lidar (VIL)



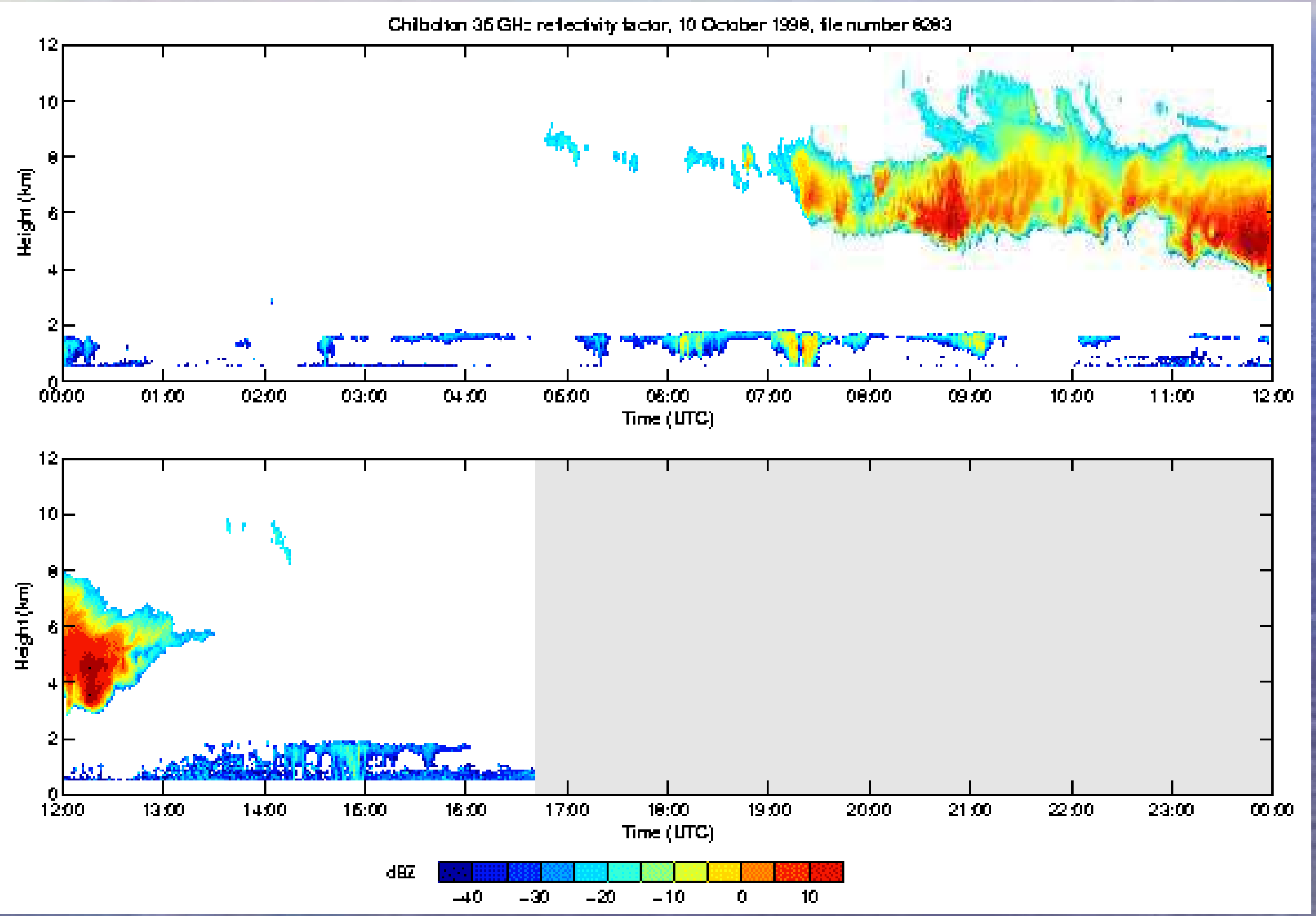
(Ref.: Eloranta et al, U Wisconsin)

North Atlantic Storm & Warm Front



Vertical Structure with Snow

CLARE'98 (Illingworth et al.)



Cirrus Microphysics

Generalized Gamma Distribution

Walko et al. (1995):

$$n(\xi) = N \frac{1}{\Gamma(\mu)} \frac{1}{\xi_n} \left(\frac{\xi}{\xi_n} \right)^{\mu-1} \exp\left[-\frac{\xi}{\xi_n} \right]$$

N_i :	Total concentration of particles per unit volume of air (cm^{-3}) for non truncated distribution.
μ :	Shape of the distribution,
ξ :	Scaling dimension, volume (droplets) or diameter (ice), i.e.

$$\bar{\xi} = \frac{\int_0^{\infty} \xi n(\xi) d\xi}{\int_0^{\infty} n(\xi) d\xi} = \mu \xi_n$$

Ice Habits

For category x and particle size D: mass (m_x), projected area (p) and terminal velocity (u_x)

$$m_x(D) = \alpha_{m,x} D^{\beta_{m,x}}$$

$$p_x(D) = \alpha_{p,x} D^{\beta_{p,x}}$$

$$u_x(D) = \alpha_{u,x} D^{\beta_{u,x}}$$

Crystal terminal velocity

Khvorostyanov & Curry (2002)

$$U_{Mx} \equiv \frac{\int_{X_{\min}}^{X_{\max}} u_x(D) m_x(D) n_x(D) dD}{\int_{X_{\min}}^{X_{\max}} m_x(D) n_x(D) dD} \approx \frac{\Gamma(\mu_x + \beta_{u,x} + \beta_{m,x})}{\Gamma(\mu_x + \beta_{m,x})} \alpha_{u,x} D_{nx}^{\beta_{u,x}} f_z = g_{u,x} u_x\left(D_{\bar{m},x}\right) f_z$$

$$g_{u,x} \equiv \frac{\Gamma(\mu_x + \beta_{u,x} + \beta_{m,x})}{\Gamma(\mu_x + \beta_{m,x})} \left[\frac{\Gamma(\mu_x)}{\Gamma(\mu_x + \beta_{m,x})} \right]^{\beta_{u,x}/\beta_{m,x}}$$

$$U_{Nx} \equiv \frac{\int_{X_{\min}}^{X_{\max}} u_x(D) n_x(D) dD}{\int_{X_{\min}}^{X_{\max}} n_x(D) dD} \approx \frac{\Gamma(\mu_x + \beta_{u,x})}{\Gamma(\mu_x)} \alpha_{u,x} D_{nx}^{\beta_{u,x}} f_z$$

$$U_{Nx} = g_{ur,x} U_{Mx}$$

Nucleation processes

Local or Lagrangian approach?

Meyers (1995), Girard & Blanchet (2001)

$$NUC_x \equiv \left.\frac{dN_x}{dt}\right|_{NUC} = \frac{1}{\Delta t}\max\left[N_{nx} - N_x, 0\right]$$

$$NUC_x \equiv \left.\frac{dN_x}{dt}\right|_{NUC} = -\frac{dN_{nx}}{d\gamma}\frac{d\gamma}{dt}$$

Droplet Nucleation

$$N_{nc}\left(N_{CCN}\right) = C_a s_w^{k_a}$$

$$NUC_c = \frac{1}{\Delta t}\left[\left(N_a + N_c\right)\left(s_w / s_{w\max}\right)^{k_a} - N_c\right]$$

$$\left(NUC_c \cdot \Delta t\right)_{\max} = \frac{1}{m_{CNN}} \frac{q_v - q_{sw}}{1 + \frac{\varepsilon L_v^{\,2} e_s}{R_v c_p p T^2}}$$

Heterogeneous Ice Nucleation from Vapor

$$N_{ni}(N_{IFN(D,F)}) = exp[a_i \cdot s_i - b_i] \text{ (in } l^{-1})$$

$$NUC_{i(D,F)} = \left.\frac{dN_i}{dt}\right|_{NUC_{(D,F)}} = \frac{dN_{IFN(D,F)}}{ds_i}\frac{ds_i}{dt} = a_i N_{IFN(D,F)}\frac{ds_i}{dt}$$

$$ds_i / dt > 0$$

Heterogeneous Ice Nucleation by Contact

$$N_{IFN(C))} = exp[-2.8 - 0.2629\, T_c] \quad (in\ l^{-1})$$

$$NUC_{i(C)} = \frac{1}{\Delta t} F_{ct} D_{ae}$$

$$F_{ct} = 4\pi r_{c,\bar{m}} N_{IFN(C)} N_c \; r_{c,\bar{m}}$$

Immersion-Freezing Nucleation

$$V_c^0 = \frac{a_{htn} \ln 2}{B_{htn}} \left(- \frac{dT}{dt} \right) \exp\left[- a_{htn} T_{\sup} \right]$$

$$\frac{V_c^0 (t + \Delta t)}{V_c^0 (t)} = \exp\left[a_{htn} \Delta T \right] \equiv R_{vol}$$

$$N_c (t + \Delta t) = N_c (t) \frac{1 - \exp\left[- R_{vol} X_v \right]}{1 - \exp\left[- X_v \right]}$$

$$- \Delta N_c = N_c (t) \left\{ 1 - \frac{1 - \exp\left[- R_{vol} X_v \right]}{1 - \exp\left[- X_v \right]} \right\}$$

$$\frac{V_c^0}{V^{-}_{c,m}} = \frac{1}{\dfrac{1}{X_v} - \dfrac{\exp\left[- X_v \right]}{1 - \exp\left[- X_v \right]}}$$

$$NUC_{i(I)} = \Delta N_c / \Delta t$$

Homogeneous Ice Nucleation

Droplets Vapor Diffusional Growth

$$VDF_c = \frac{1}{\rho_{air}} N_c \frac{dm_c}{dt}\bigg|_{V_c = V_{\bar{m},c}}$$

$$\frac{dm_c}{dt} = 4\pi \left(\frac{3}{4\pi\rho_{liq}} \right)^{1/3} \frac{\delta_w}{q_{sw}\left(A' + B'\right)} \frac{m_c^{2/3}}{m_c^{1/3} + l_o^*}$$

$$l_o^* = \left(\frac{4\pi}{3} \rho_{liq} \right)^{1/3} l_o \qquad l_o = 5\,\mu m$$

Ice Vapor Diffusional Growth

$$VDF_i = \frac{1}{\rho_{air}} N_i \left(a_{k1} \overline{m}^{a_{k2}} \right) G_i$$

Simultaneous Diffusion Growth

$$\left.\frac{dm_x}{dt}\right|_{XCY} = \int_0^\infty \frac{\pi}{4}\left(D_x + D_y\right)^2 \left|u_x(D_x) - u_y(D_y)\right| E(D_x, D_y) m_y(D_y) n_y(D_y) dD_y$$

$$E_{xy} = \frac{\iint E(D_y, D_x) m_y(D_y) n_y(D_y) n_x(D_x) dD_y dD_x}{\iint m_y(D_y) n_y(D_y) n_x(D_x) dD_y dD_x}$$

$$XCY = \frac{1}{\rho_a}\int \left.\frac{dm_x}{dt}\right|_{XCY} dN_y = \frac{\pi}{4}\left(\bar{D}_{m,x} + \bar{D}_{m,y}\right)^2 \left|u_x(\bar{D}_{m,x}) - u_y(\bar{D}_{m,y})\right| E_{xy} q_x \rho_a N_y$$

$$E_{cs} = 0.572\log_{10}\left[464\bar{D}_{m,c} - 0.25\right] + 1.69$$

$$E_{is} = E_{o\chi}\exp\left[0.05T_c\right]$$

$$-\left.\frac{dN_y}{dt}\right|_{XCY} = \frac{N_y}{M_y} XCY$$

Simultaneous Diffusion Growth

$$-\left.\frac{dN_s}{dt}\right|_{SCS} = g_{ss} E_{ss} U_{Ms} q_s \rho_a N_s$$

$$g_{ss} = \frac{\pi}{4} \frac{I_{Pass}\left(\mu_s - 1, \beta_{u,s}\right)}{\Gamma\left(\mu_s\right)\Gamma\left(\mu_s + \beta_{u,s} + 2\right)} \frac{1}{\alpha_{m,s}}$$

$$I_{Pass}\left(\mu_s - 1, \beta_{u,s}\right) = \int\int \left(x_1 x_2\right)^{\mu_s - 1} \left(x_1 + x_2\right)^2 \left| x_1^{\beta_{v,s}} - x_2^{B_{v,s}} \right| \exp\left[-\left(x_1 + x_2\right)\right] dx_1 dx_2$$

Conversion Small Crystals to Snow

$$ITS = -\left.\frac{dq_i}{dt}\right|_{ITS} = \left.\frac{dq_s}{dt}\right|_{ITS} = \frac{1}{\rho_a} m\left(D_{s\min}\right)\left.\frac{dD}{dt}\right|_{VDF\ for\ D=D_{s\min}} \cdot n_i\left(D_{s\min}\right) + \frac{1}{\rho_a}\int_{D_{s\min}}^{\infty} \frac{dm}{dt} n_i(D)\,dD$$

$$= \frac{1}{\rho_a}\frac{4\pi}{q_{si}(A''+B'')} I_{\delta_i} \frac{1}{\Gamma(\mu_i)} N_i \chi_i D_{s\min}\left[\frac{1}{\beta_{m,i}} X_{bi}^{\mu_i}\exp(-X_{bi}) + \Gamma(\mu_i+1, X_{bi})\frac{1}{X_{bi}}\right]$$

$$-\left.\frac{dN_i}{dt}\right|_{ITS} = \left.\frac{dN_s}{dt}\right|_{ITS} = n_i\left(D_{s\min}\right)\left.\frac{dD}{dt}\right|_{VDF\ for\ D_i = D_{s\min}}$$

$$= \frac{4\pi}{q_{si}(A''+B'')} I_{\delta_i} \frac{1}{\Gamma(\mu_i)} N_i \chi_i D_{s\min} \frac{1}{\beta_{m,i}} X_{bi}^{\mu_i}\exp\left[-X_{bi}\right]\cdot\left[\alpha_{m,i} D_{s\min}^{\beta_{m,i}}\right]^{-1}$$

$$X_{bi} = \frac{D_{s\min}}{D_{ni}} = \frac{D_{s\min}}{g_{ni}\bar{D}_{m,i}} \qquad g_{ni} = \left[\frac{\Gamma(\mu_i)}{\Gamma(\mu_i + \beta_{m,i})}\right]^{1/\beta_{m,i}}$$

$$\Gamma(n+1, X) \equiv \int_X^{\infty} Y^n \exp(-Y)\,dY = n!\exp(-X)\sum_{i=0}^{n}\frac{1}{i!}X^i$$

Region Subsaturated w.r.t. Ice

$$STI = -\left.\frac{dq_s}{dt}\right|_{STI} = \left.\frac{dq_i}{dt}\right|_{STI} \approx -\frac{1}{\rho_a} m\left(D_{s\min}\right)\left.\frac{dD}{dt}\right|_{VDF\ for\ D=D_{s\min}} \cdot n_s\left(D_{s\min}\right)$$

$$= \frac{1}{\rho_a}\frac{4\pi}{q_{si}\left(A''+B''\right)} I_{\delta_i} \frac{1}{\Gamma\left(\mu_s\right)} N_s \chi_s D_{s\min} \frac{1}{\beta_{m,i}} X_{bs}{}^{\mu_{si}} \exp\left(-X_{bs}\right)$$

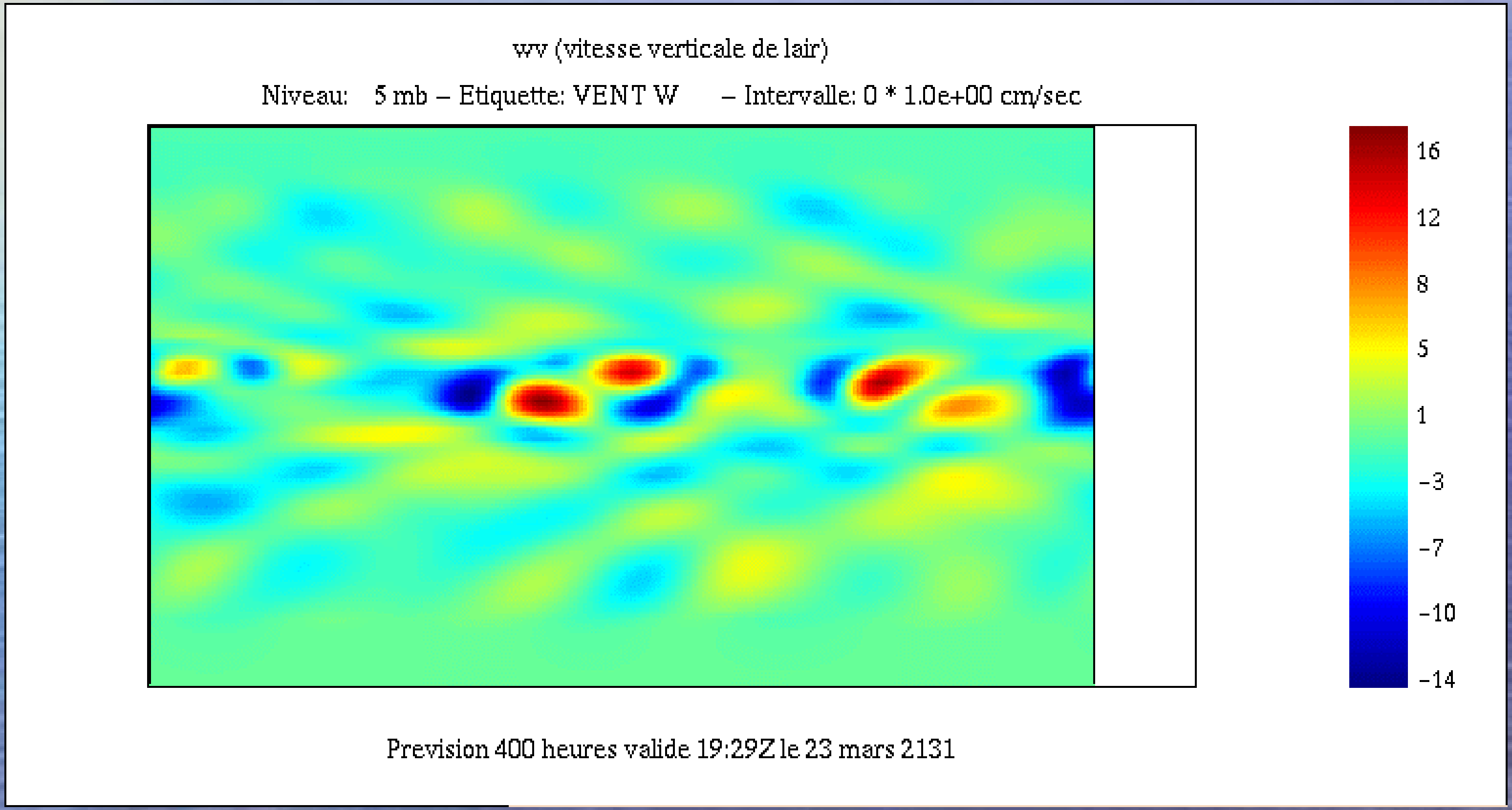
$$-\left.\frac{dN_s}{dt}\right|_{STI} = \left.\frac{dN_i}{dt}\right|_{STI} = -n_s\left(D_{s\min}\right)\left.\frac{dD}{dt}\right|_{VDF\ for\ D_i\ =\ D_{s\min}}$$

$$= \frac{4\pi}{q_{si}\left(A''+B''\right)} I_{\delta_i} \frac{1}{\Gamma\left(\mu_s\right)} N_s \chi_s D_{s\min} \frac{1}{\beta_{m,s}} X_{bs}{}^{\mu_s} \exp\left[-X_{bs}\right] \cdot \left[\alpha_{m,s} D_{s\min}{}^{\beta_{m,s}}\right]^{-1}$$

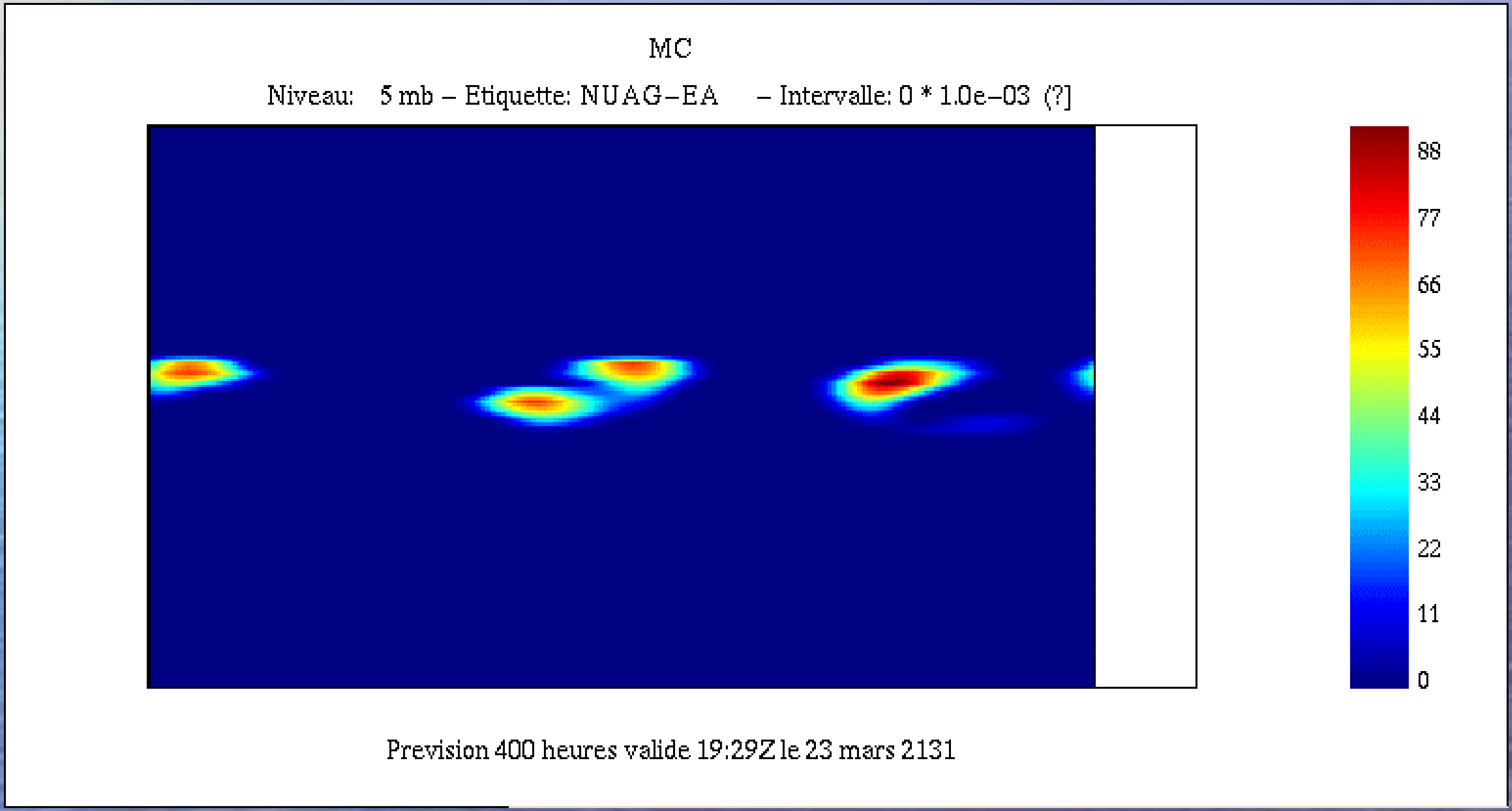
$$X_{bs} = \frac{D_{s\min}}{D_{ns}} = \frac{D_{s\min}}{g_{ns} \bar{D}_{m,s}} \qquad g_{ns} = \left[\frac{\Gamma\left(\mu_s\right)}{\Gamma\left(\mu_s + \beta_{m,s}\right)}\right]^{1/\beta_{m,s}}$$

Preliminary Results

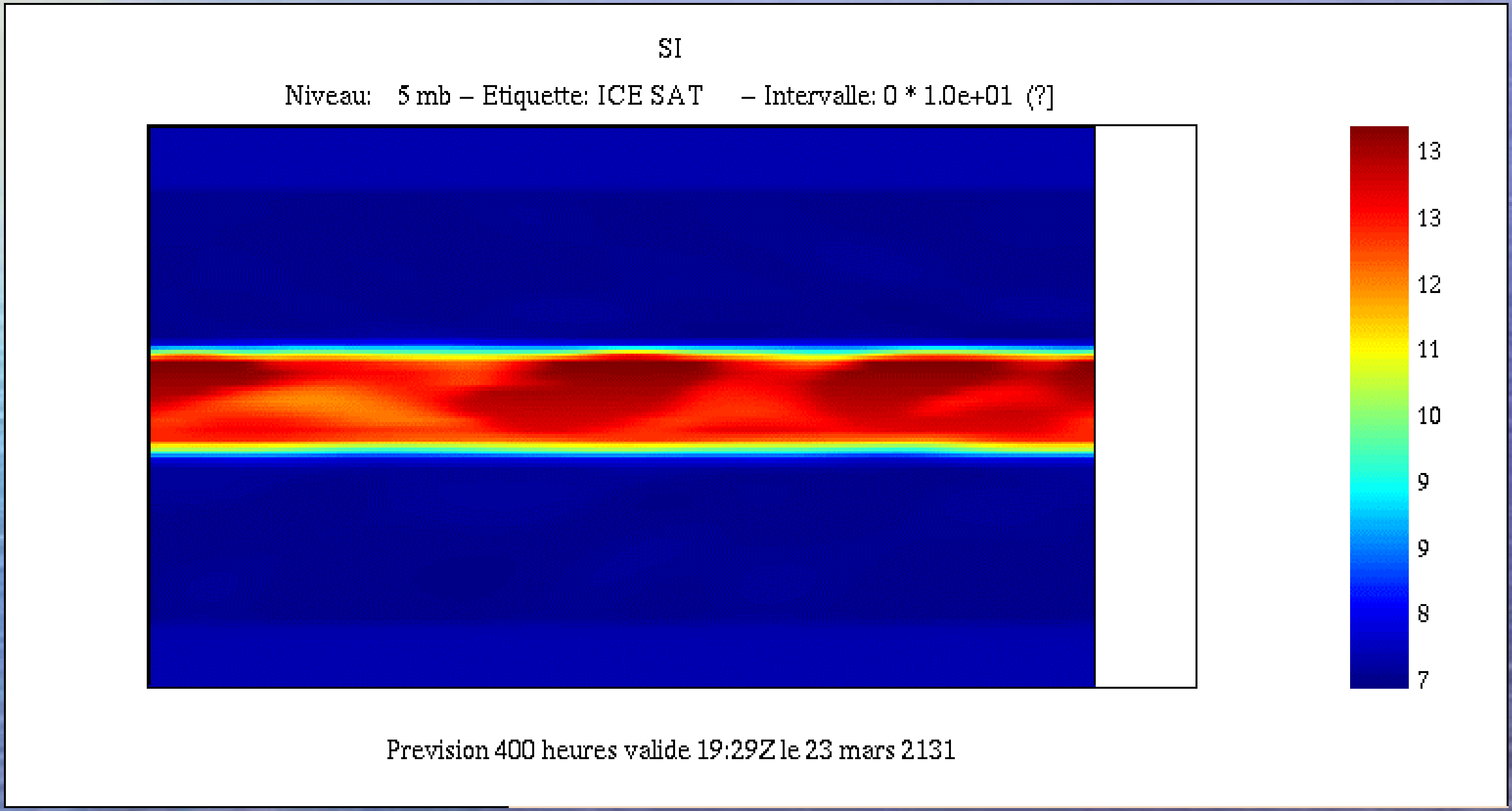
Vertical Velocity



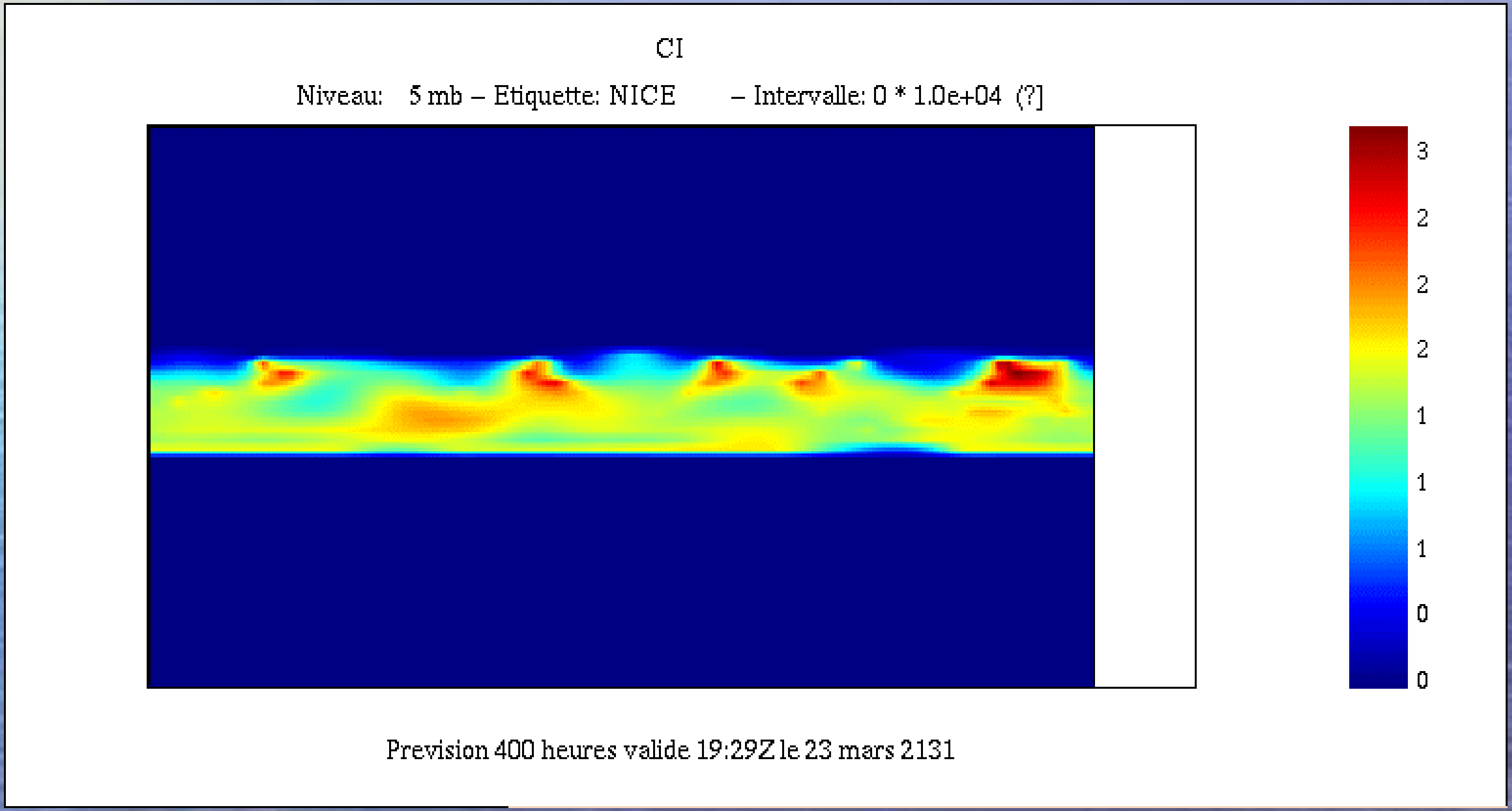
Liquid Water Content



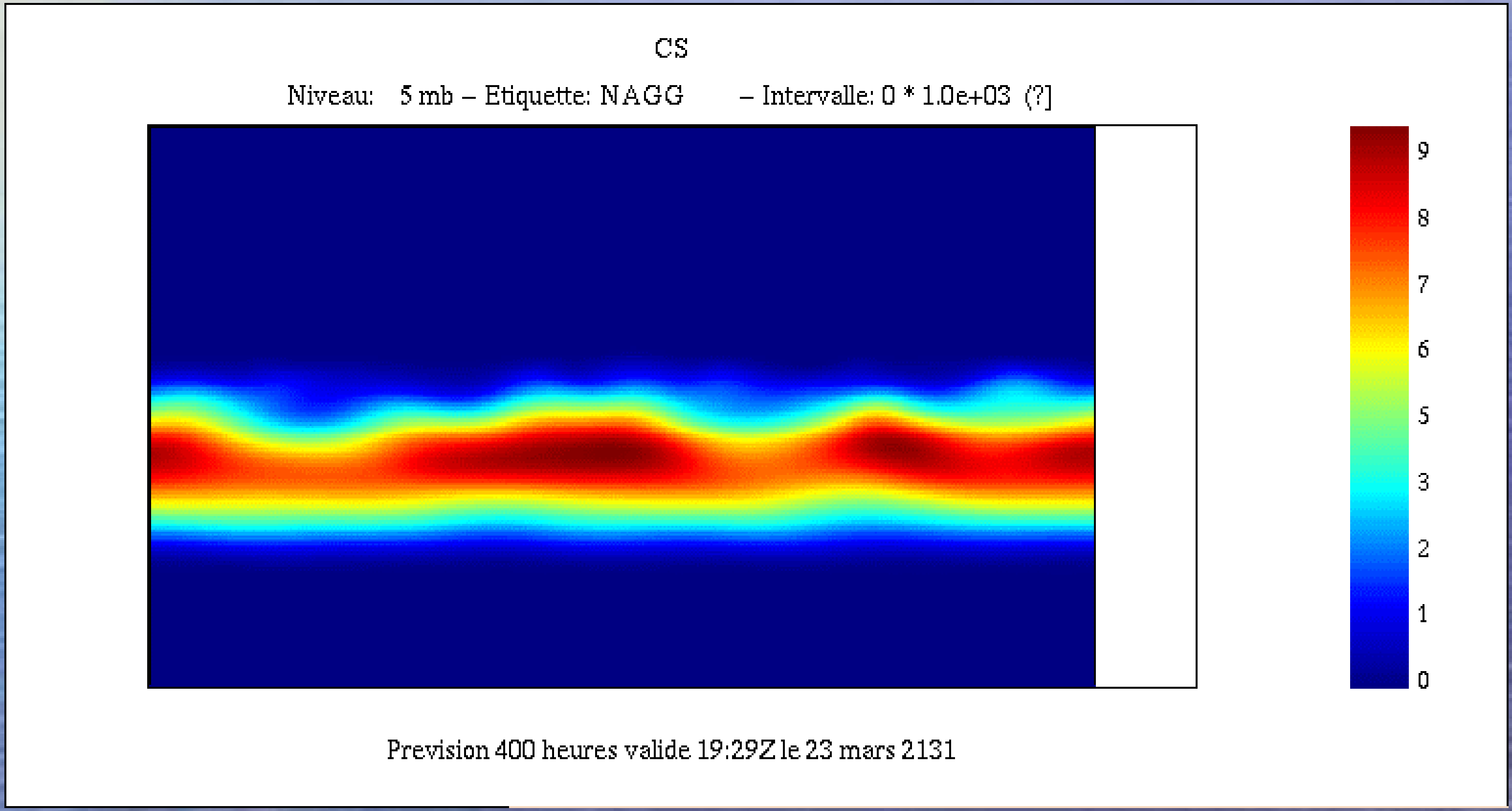
Ice Saturation



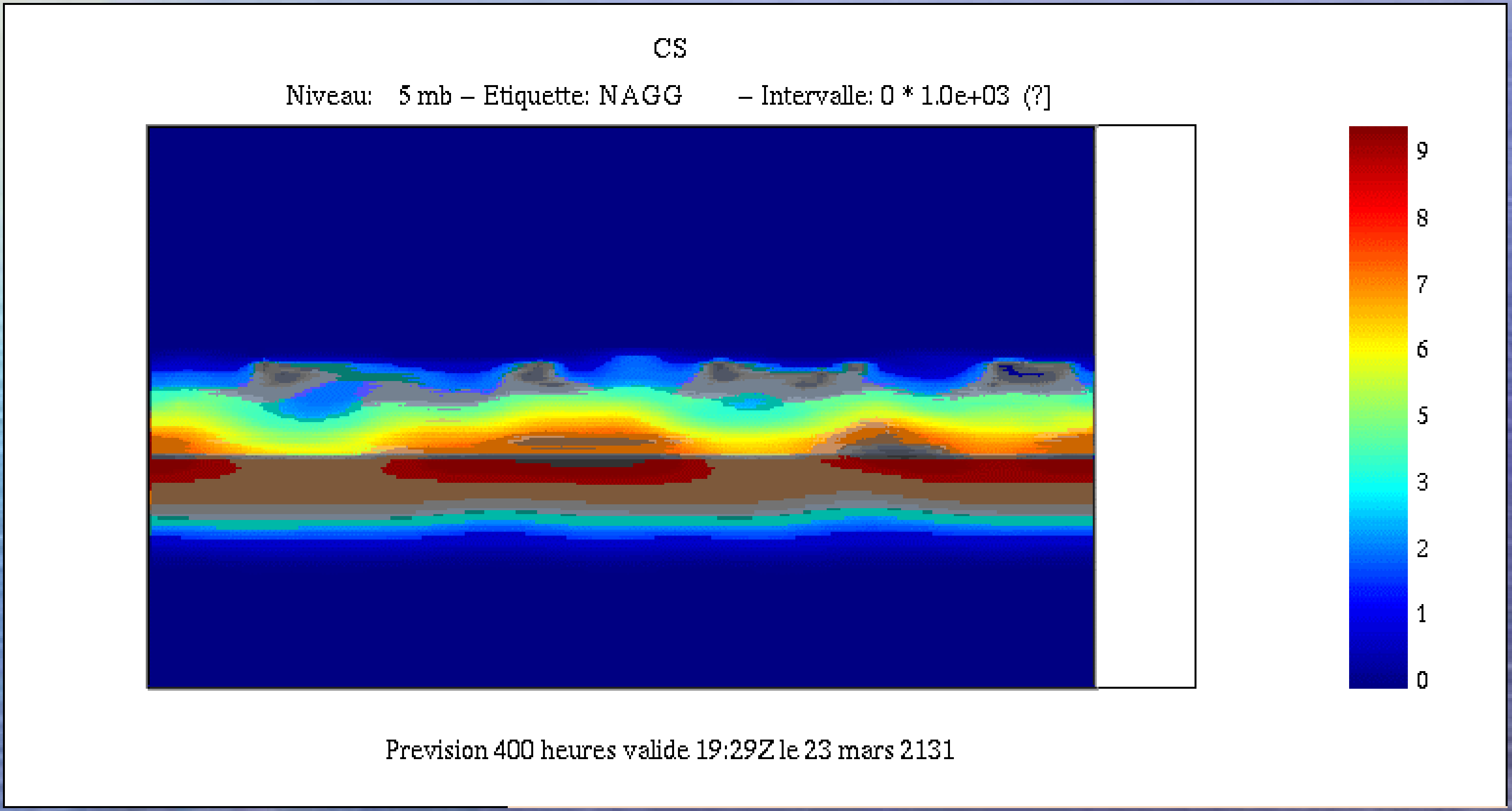
Small Ice Number Concentration



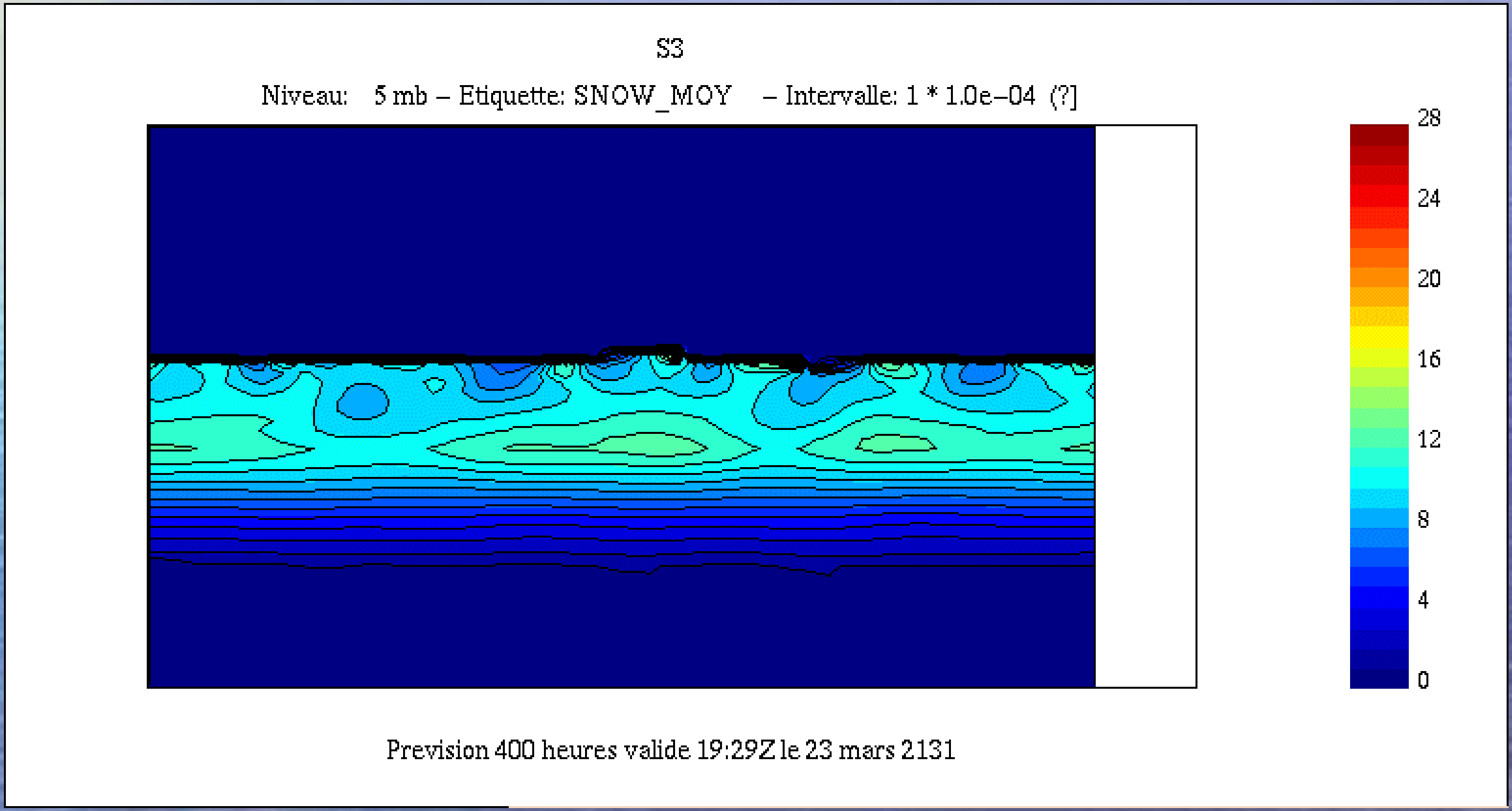
Snow Concentration



Small Crystals and Snow



Snow Mass


S3
Niveau: 5 mb – Etiquette: SNOW_MOY – Intervalle: 1 * 1.0e–04 (?]
28
24
20
16
12
8
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Prevision 400 heures valide 19:29Z le 23 mars 2131