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,　　　　　　　　　　　　　　　　　.　　　　　　　ρ

$$\rho = \rho_d + \sum_j \rho_v^{(j)} + \sum_j \rho_s^{(j)} \tag{1}$$

　　　　　.

　　　　　　　,　　　　　　　　$+\infty$　　　,
　　　　　.　　　　　　ρ　　　　　　(
)　　　.

$$\beta_d \equiv \frac{\rho_d}{\rho}, \tag{2}$$

$$\beta_v^{(i)} \equiv \frac{\rho_v^{(i)}}{\rho}, \tag{3}$$

$$\beta_s^{(i)} \equiv \frac{\rho_s^{(i)}}{\rho}. \tag{4}$$

β_v　　　　　　　　　　　　.

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- 　　,　　　　　　　　　　　　　.
- 　　,　　　　　　　　　　　　.

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　　　　　　　　　$u,$　　　$w,$　　$\theta,$　　　　　$\Pi,$
　　β_v, β_s　　　.

$$\frac{du}{dt} = -c_{pmj}\theta_v\frac{\partial\Pi}{\partial x} + D(u), \tag{5}$$

$$\frac{dw}{dt} = -c_{pmj}\theta_v\frac{\partial\Pi}{\partial z} - g + D(w), \tag{6}$$

$$\frac{d\theta}{dt} = \frac{1}{\Pi}\dot{Q} + D(\theta), \tag{7}$$

$$\frac{d\Pi}{dt} = \frac{c_s{}^2}{c_{pmj}\theta_v}\Bigg[-\frac{\partial u}{\partial x} - \frac{\partial w}{\partial z} + \frac{1}{\rho}\sum_j M_{fall}^{(j)} + \frac{1}{\theta}\frac{d\theta}{dt}$$
$$+ \frac{1}{\beta_{mj} + \sum_j \beta_{mn}^{(j)} M_{mj}/M_{mn}^{(j)}}\left(\frac{d\beta_{mj}}{dt} + \sum_j \frac{M_{mj}}{M_{mn}^{(j)}}\frac{d\beta_{mn}^{(j)}}{dt}\right)\Bigg], \tag{8}$$

$$\frac{d\beta_v^{(i)}}{dt} = -\frac{\beta_v^{(i)}}{\rho}\sum_j M_{fall}^{(j)} - \frac{1}{\rho}M_{src}^{(i)} + D(\beta_v^{(i)}), \tag{9}$$

$$\frac{d\beta_s^{(i)}}{dt} = -\frac{\beta_s^{(i)}}{\rho}\sum_j M_{fall}^{(j)} + \frac{1}{\rho}M_{fall}^{(i)} + \frac{1}{\rho}M_{src}^{(i)} + D(\beta_s^{(i)}). \tag{10}$$

mj, mn , .

$$\theta = T\left(\frac{p}{p_0}\right)^{R_{mj}/c_{pmj}}, \tag{11}$$

$$\Pi = \left(\frac{p_0}{p}\right)^{R_{mj}/c_{pmj}}, \tag{12}$$

$$\theta_v = \frac{1}{1 - \sum_j \beta_s^{(j)}}\left(\beta_{mj} + \sum_j \beta_{mn}^{(j)}\frac{R_{mn}^{(j)}}{R_{mj}}\right)\theta, \tag{13}$$

$$c_s{}^2 = \frac{c_{pmj}}{c_{vmj}}R_{mj}\Pi\theta_v. \tag{14}$$

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$$
\begin{array}{rcl}
u(x,z,t) & = & u'(x,z,t), \hfill (15) \\
w(x,z,t) & = & w'(x,z,t), \hfill (16) \\
\theta(x,z,t) & = & \overline{\theta}(z) + \theta'(x,z,t), \hfill (17) \\
\Pi(x,z,t) & = & \overline{\Pi}(z) + \Pi'(x,z,t), \hfill (18) \\
\beta_v^{(i)}(x,z,t) & = & \overline{\beta_v}(z) + \beta_v^{(i)'}(x,z,t), \hfill (19) \\
\beta_s^{(i)}(x,z,t) & = & \beta_s^{(i)'}(x,z,t). \hfill (20)
\end{array}
$$

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$$
\frac{\partial u'}{\partial t} = -u'\frac{\partial u'}{\partial x} - w'\frac{\partial u'}{\partial z} - c_{pmj}\overline{\theta_v}\frac{\partial \Pi'}{\partial x} + D(u'), \tag{21}
$$

$$
\frac{\partial w'}{\partial t} = -u'\frac{\partial w'}{\partial x} - w'\frac{\partial w'}{\partial z} - c_{pmj}\overline{\theta_v}\frac{\partial \Pi'}{\partial z} + D(w')
$$
$$
+ \left[\frac{\theta'}{\overline{\theta}} + \frac{\beta'_{mj} + \sum_j \beta_{mn}^{(j)'} M_{mj}/M_{mn}^{(j)} + \sum_j \beta_s^{(j)'}(\overline{\beta_{mj}} + \sum_j \overline{\beta_{mn}^{(J)}} M_{mj}/M_{mn}^{(j)})}{\overline{\beta_{mj}} + \sum_j \overline{\beta_{mn}^{(j)}} M_{mj}/M_{mn}^{(j)}} \right] g, \tag{22}
$$

$$
\frac{\partial \theta'}{\partial t} = -u'\frac{\partial \theta'}{\partial x} - w'\frac{\partial \theta'}{\partial z} + \frac{\overline{\theta}}{\overline{T}}\dot{Q} + D(\theta), \tag{23}
$$

$$
\frac{\partial \Pi'}{\partial t} = -\frac{\overline{c_s}^2}{c_{pmj}\overline{\rho}\overline{\theta_v}}\left[\frac{\partial(\overline{\rho}\overline{\theta_v}u')}{\partial x} + \frac{\partial(\overline{\rho}\overline{\theta_v}w')}{\partial z} \right] + \frac{\overline{c_s}^2}{c_{pmj}\overline{\rho}\overline{\theta_v}}\sum_j M_{fall}^{(j)}
$$
$$
+\frac{\overline{c_s}^2}{c_{pmj}\overline{\theta_v}}\left\{ \frac{1}{\overline{\rho}}\left(\frac{d\theta}{dt}\right)' + \frac{1}{\overline{\beta_{mj}} + \sum_j \overline{\beta_{mn}^{(j)}} M_{mj}/M_{mn}^{(j)}} \right.
$$
$$
\left. \left[\left(\frac{d\beta_{mj}}{dt}\right)' + \sum_j \frac{M_{mj}}{M_{mn}^{(j)}}\left(\frac{d\beta_{mn}^{(j)}}{dt}\right)' \right] \right\}, \tag{24}
$$

$$
\frac{\partial \beta_v^{(i)'}}{\partial t} = -u'\frac{\partial \beta_v^{(i)'}}{\partial x} - w'\frac{\partial \beta_v^{(i)'}}{\partial z} - w'\frac{\partial \overline{\beta_v^{(i)}}}{\partial z} - \frac{\overline{\beta_v^{(i)}}}{\overline{\rho}}\sum_j M_{fall}^j - \frac{1}{\overline{\rho}}M_{src}^{(i)} + D(\beta_v^{(i)}), \tag{25}
$$

$$
\frac{\partial \beta_s^{(i)'}}{\partial t} = -u'\frac{\partial \beta_v^{(i)'}}{\partial x} - w'\frac{\partial \beta_v^{(i)'}}{\partial z} + \frac{1}{\overline{\rho}}M_{fall}^{(i)} + \frac{1}{\overline{\rho}}M_{src}^{(i)} + D(\beta_s^{(i)'}). \tag{26}
$$

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ρ_d, $\rho_v^{(i)}$, $\rho_s^{(i)}$

$$\frac{\partial \rho_d}{\partial t} + \frac{\partial}{\partial x_j}(\rho_d u_j) = 0, \tag{27}$$

$$\frac{\partial \rho_v^{(i)}}{\partial t} + \frac{\partial}{\partial x_j}(\rho_v^{(i)} u_j) = -M_{src}^{(i)}, \tag{28}$$

$$\frac{\partial \rho_s^{(i)}}{\partial t} + \frac{\partial}{\partial x_j}(\rho_s^{(i)} u_j) = M_{src}^{(i)} + M_{fall}^{(i)} \tag{29}$$

. (27), (28), (29)   , ρ

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = \sum_j M_{fall}^{(i)} \tag{30}$$

. (27), (28), (29), (30)

$$
\begin{aligned}
\frac{\partial}{\partial t}\left(\frac{\rho_d}{\rho}\right) &= -\frac{\rho_d}{\rho^2}\frac{\partial \rho}{\partial t} + \frac{1}{\rho}\frac{\partial \rho_d}{\partial t} \\
&= -\frac{\rho_d}{\rho^2}\left[-\frac{\partial}{\partial x_j}(\rho u_j) + \sum_j M_{fall}^{(j)}\right] + \frac{1}{\rho}\left[-\frac{\partial}{\partial x_j}(\rho_d u_j)\right] \\
&= -u_j\frac{\partial}{\partial x_j}\left(\frac{\rho_d}{\rho}\right) - \frac{\rho_d}{\rho^2}\sum_j M_{fall}^{(j)}, \tag{31}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial}{\partial t}\left(\frac{\rho_v^{(i)}}{\rho}\right) &= -\frac{\rho_v^{(i)}}{\rho^2}\frac{\partial \rho}{\partial t} + \frac{1}{\rho}\frac{\partial \rho_v^{(i)}}{\partial t} \\
&= -\frac{\rho_v^{(i)}}{\rho^2}\left[-\frac{\partial}{\partial x_j}(\rho u_j) + \sum_j M_{fall}^{(j)}\right] + \frac{1}{\rho}\left[-\frac{\partial}{\partial x_j}(\rho_v^{(i)} u_j) - M_{src}^{(i)}\right] \\
&= -u_j\frac{\partial}{\partial x_j}\left(\frac{\rho_v^{(i)}}{\rho}\right) - \frac{\rho_v^{(i)}}{\rho^2}\sum_j M_{fall}^{(j)} - \frac{1}{\rho}M_{cond}^{(i)}, \tag{32}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial}{\partial t}\left(\frac{\rho_s^{(i)}}{\rho}\right) &= -\frac{\rho_s^{(i)}}{\rho^2}\frac{\partial \rho}{\partial t} + \frac{1}{\rho}\frac{\partial \rho_s^{(i)}}{\partial t} \\
&= -\frac{\rho_s^{(i)}}{\rho^2}\left[-\frac{\partial}{\partial x_j}(\rho u_j) + \sum_j M_{fall}^{(j)}\right] + \frac{1}{\rho}\left[-\frac{\partial}{\partial x_j}(\rho_s^{(i)} u_j) + M_{src}^{(i)} + M_{fall}^{(i)}\right] \\
&= -u_j\frac{\partial}{\partial x_j}\left(\frac{\rho_s^{(i)}}{\rho}\right) - \frac{\rho_s^{(i)}}{\rho^2}\sum_j M_{fall}^{(i)} + \frac{1}{\rho}M_{src}^{(i)} + \frac{1}{\rho}M_{fall}^{(i)}. \tag{33}
\end{aligned}
$$

$$\frac{d\beta_d}{dt} = -\frac{\beta_d}{\rho} \sum_j M_{fall}^{(j)} + D(\beta_d^{(i)}), \tag{34}$$

$$\frac{d\beta_v^{(i)}}{dt} = -\frac{\beta_v^{(i)}}{\rho} \sum_j M_{fall}^{(j)} - \frac{1}{\rho} M_{src}^{(i)} + D(\beta_v^{(i)}), \tag{35}$$

$$\frac{d\beta_s^{(i)}}{dt} = -\frac{\beta_s^{(i)}}{\rho} \sum_j M_{fall}^{(j)} + \frac{1}{\rho} M_{fall}^{(i)} + \frac{1}{\rho} M_{src}^{(i)} + D(\beta_s^{(i)}). \tag{36}$$

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$$\begin{aligned}
p &= p_{mj} + \sum_j p_{mn}^j \\
&= (\rho_{mj} R_{mj} + \sum_j \rho_{mn}^{(j)} R_{mn}^{(j)}) T \\
&= \rho_g \frac{\rho}{\rho_g} \left(\frac{\rho_{mj}}{\rho} R_{mj} + \sum_j \frac{\rho_{mn}^{(j)}}{\rho} R_{mn}^{(j)} \right) T \\
&= \rho_g \frac{1}{1 - \sum_j \rho_s^{(j)}/\rho} \left(\frac{\rho_{mj}}{\rho} R_{mj} + \sum_j \frac{\rho_{mn}^{(j)}}{\rho} R_{mn}^{(j)} \right) T \\
&= \rho_g R_{mj} \frac{1}{1 - \sum_j \beta_s^{(j)}} \left(\beta_{mj} + \sum_j \beta_{mn}^{(j)} \frac{R_{mn}^{(j)}}{R_{mj}} \right) T.
\end{aligned} \tag{37}$$

ρ_g . T_v

$$T_v \equiv \frac{1}{1 - \sum_j \beta_s^{(j)}} \left(\beta_{mj} + \sum_j \beta_{mn}^{(j)} \frac{R_{mn}^{(j)}}{R_{mj}} \right) T \tag{38}$$

. θ_v

$$\theta_v \equiv \frac{T_v}{\Pi} \tag{39}$$

,

$$\theta_v = \frac{1}{1 - \sum_j \beta_s^{(j)}} \left(\beta_{mj} + \sum_j \beta_{mn}^{(j)} \frac{R_{mn}^{(j)}}{R_{mj}} \right) \theta \tag{40}$$

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$$\frac{du}{dt} = -\frac{1}{\rho_g}\frac{\partial p}{\partial x} + D(u), \tag{41}$$

$$\frac{dw}{dt} = -\frac{1}{\rho_g}\frac{\partial p}{\partial z} - g + D(w), \tag{42}$$

. (37), (38), (39)

$$\rho_g = \frac{p}{R_{mj}\Pi\theta_v} = \frac{p_0\Pi^{c_{vmj}/R_{mj}}}{R_{mj}\theta_v} \tag{43}$$

,

$$\frac{1}{\rho_g}\frac{\partial p}{\partial x_i} = c_{pmj}\theta_v\frac{\partial\Pi}{\partial x_i} \tag{44}$$

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