CAM prognostic condensate and precipitation parameterization

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Controlling equations

- Water vapor mixing ratio

$$\frac{\partial q}{\partial t} = A_q - Q + E_r$$

- Temperature

$$\frac{\partial T}{\partial t} = A_T + \frac{L}{c_p}(Q - E_r)$$

- Total cloud condensate (water)

$$\frac{\partial l}{\partial t} = A_l + Q - R_l$$

Controlling Equations

- A_q, A_T, A_l

  tendencies other than large-scale cond/evap of cloud and rain. Advective, expansive, radiative, turbulent, and convective tendencies.

- Q

  net stratiform condensation of cloud meteors (cond-evap)

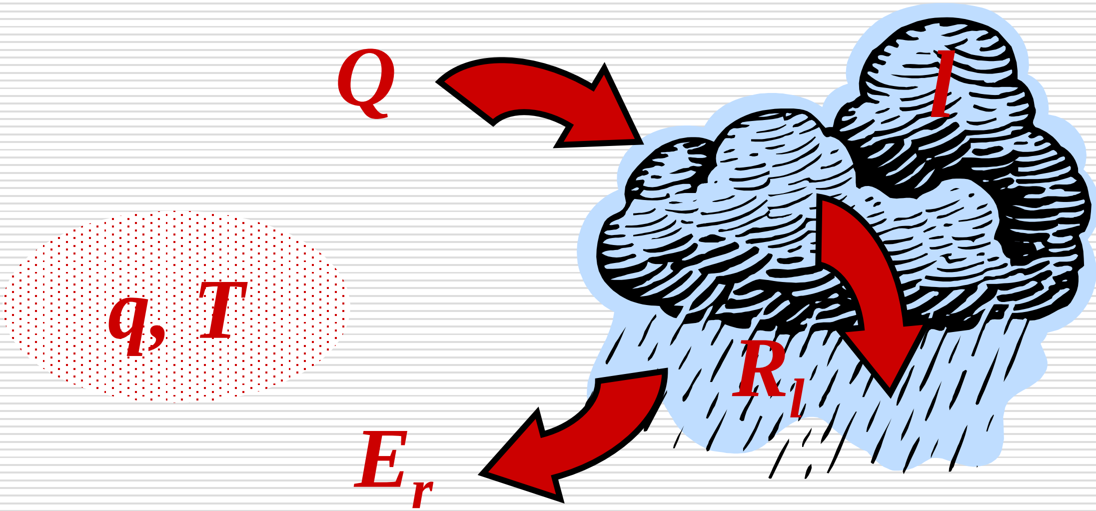
- E_r

  evaporative rate of rain and snow

- R_l

  Conversion rate of cloud water to rain and snow

The system



$$\frac{\partial q}{\partial t} = A_q - Q + E_r$$

$$\frac{\partial T}{\partial t} = A_T + \frac{L}{c_p}(Q - E_r)$$

$$\frac{\partial l}{\partial t} = A_l + Q - R_l$$

$$\frac{\partial U}{\partial t} = \alpha\frac{\partial q}{\partial t} - \beta\frac{\partial T}{\partial t}$$

$$= \alpha A_q - \beta A_T - \gamma(Q - E_r)$$

$$\alpha = \frac{1}{q_s}, \quad \beta = \frac{q}{q_s^2}\frac{\partial q_s}{\partial T} \quad \gamma = \alpha + \frac{L}{c_p}\beta$$

Empirical(1)

Two component

- Macroscale

  exchange of water substance between condensate and the vapor pressure.

  Q

- Microphysical

  the conversion from condensate to precipitation.

  E_r and R_l

Macroscale

- $E_r = 0$ and $U = 1$

$$\frac{\partial U}{\partial t} = \alpha \hat{A}_q - \hat{\beta}\hat{A}_T - \hat{\gamma}\hat{Q} = 0.$$

$$\hat{Q} = \frac{\alpha \hat{A}_q - \hat{\beta}\hat{A}_T}{\hat{\gamma}}$$

=> $$\frac{\partial l}{\partial t} = A_l + Q - R_l$$

- In cloud condensate equation

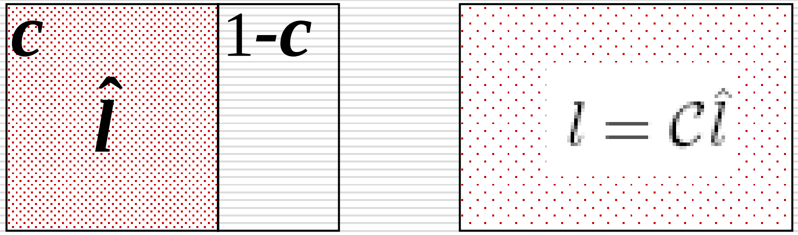
$$\frac{\partial \hat{l}}{\partial t} = \hat{A}_l + \frac{\alpha \hat{A}_q - \hat{\beta}\hat{A}_T}{\hat{\gamma}} - \hat{R}_l.$$

Grid Cell

- The total cloud condensate

$$l = c\hat{l}$$

$$\frac{\partial l}{\partial t} = c\frac{\partial \hat{l}}{\partial t} + \hat{l}^*\frac{\partial c}{\partial t}$$



***C* = cloud fraction**

existing clouds — Newly formed/dissipated clouds

Theoretically, this part of cloud should have zero cloud water content. Because of the finite time step, this part is nonzero.

$$\hat{l}^* = \hat{l}$$

[Rasch and Kristjansson, 1998]

Link Q and $\frac{\partial \mathcal{C}}{\partial t}$

- Insert $\frac{\partial l}{\partial t} = A_l + Q - R_l$ and $\frac{\partial \hat{l}}{\partial t} = \hat{A}_l + \frac{\alpha \hat{A}_q - \hat{\beta} \hat{A}_T}{\hat{\gamma}} - \hat{R}_l.$

  into $\frac{\partial l}{\partial t} = \mathcal{C}\frac{\partial \hat{l}}{\partial t} + \hat{l}^* \frac{\partial \mathcal{C}}{\partial t}$ with $R_l = \mathcal{C}\hat{R}_l$ $A_T = \hat{A}_T$, $A_q = \hat{A}_q$, and $A_l = \hat{A}_l$

$$\hat{l}^* \frac{\partial \mathcal{C}}{\partial t} = (1 - \mathcal{C})A_l + Q - \mathcal{C}(\frac{\alpha A_q - \hat{\beta} A_T}{\hat{\gamma}})$$

- Q is linked with C as required by the total water budget.

Link *C* and *U*

- *C* is related to relative humidity *U*

$$\mathcal{C} = \mathcal{C}(U, b)$$

B denotes a generic variable for vertical stability, local Ri #, cumulus mass flux, etc

- $$\frac{\partial \mathcal{C}}{\partial t} = \frac{\partial \mathcal{C}}{\partial U}\frac{\partial U}{\partial t} + \frac{\partial \mathcal{C}}{\partial b}\frac{\partial b}{\partial t}$$

$$F_a = \frac{\partial \mathcal{C}}{\partial U}$$

$$F_b = [(\frac{\partial \mathcal{C}}{\partial b})/(\frac{\partial \mathcal{C}}{\partial U})]\frac{\partial b}{\partial t}$$

$$F_a^{-1}\frac{\partial \mathcal{C}}{\partial t} = \frac{\partial U}{\partial t} + F_b$$

$$\frac{\partial U}{\partial t} = \alpha A_q - \beta A_T - \gamma(Q - E_r)$$

$$F_a^{-1}\frac{\partial \mathcal{C}}{\partial t} = \alpha A_q - \beta A_T - \gamma(Q - E_r) + F_b$$

The budget of condensation

- $$Q = c_q A_q - c_T A_T - c_l A_l + c_r E_r + \sigma \hat{l}^* F_b$$

Moist advection

Cold advection

Import of cloud water

Evaporation of rain/snow water

Non-water source, require condensation

$$c_q = \frac{\alpha}{\hat{\gamma}}\mathcal{C} + \left(1 - \frac{\gamma}{\hat{\gamma}}\mathcal{C}\right)\sigma\alpha\hat{l}^*$$

$$c_T = \frac{\hat{\beta}}{\hat{\gamma}}\mathcal{C} + \left(1 - \frac{\gamma}{\hat{\gamma}}\frac{\hat{\beta}}{\beta}\mathcal{C}\right)\sigma\beta\hat{l}^*$$

$$c_l = (1 - \mathcal{C})\,\sigma F_a^{-1}$$

$$c_r = \sigma\gamma\hat{l}^*$$

$$\sigma = \frac{1}{F_a^{-1} + \gamma\hat{l}^*}$$

Four cases for obtaining Q

- If U = 1, $\hat{Q} = \dfrac{\alpha \hat{A}_q - \hat{\beta} \hat{A}_T}{\hat{\gamma}}$

- If $1 > U \geq U_{00}$

$$Q = c_q A_q - c_T A_T - c_l A_l + c_r E_r + \sigma \hat{l}^* F_b$$

- If $U < U_{00}$ but $l > 0$, $Q = -l$

- If $U < U_{00}$ and $l = 0$, $Q = 0$

Microscale

- Bulk microphysics: formation and dissipation of precipitation E_r and R_l
- Four types of condensate in mixing ratio
  - liquid and ice phase for suspended condensate

    q_l and q_i
  - Liquid and ice phase for falling condensate (precipitation) q_r and q_s
- Currently, only q_l and q_i integrated in time; q_r and q_s are diagnosed.

Partitioning of liquid and ice

- $$f_i = \frac{T - T_{max}}{T_{min} - T_{max}}, \quad T_{min} \leq T \leq T_{max}$$

  $T_{max} = -10^\circ$ C $\quad T_{min} = -40^\circ$ C
- Liquid and ice mass mixing ratio (***l*** and ***q***) are *independently* advected, diffused, and transported by convection.
- Recalculated from total cloud condensate

$$\ell_{n'} = (\ell_n + I_n)(1 - f_i)$$

$$I_{n'} = (\ell_n + I_n) f_i$$

Empirical(3), adjustable(2)

Evaporation of precipitation E_r

- At level k, rain + snow

$$E^k = k_e(1-c^k)\left(1-\min(1,\frac{q^k}{q_*^k})\right)(F^{k-})^{1/2}$$

k_e is an adjustable constant. For stratiform precipitation $k_e = 1\times 10^{-5}$. For convective precipitation, resolution and dy-core dependent.

Parameter	FV	T85	T42	T31
$k_{e,conv}$	1.0E-6	1.0E-6	3.0E-6	3.0E-6

$(1-C^k)$: random overlap assumption (precip. Falling into the existing cloud in a layer does not evaporate).

F^{k-} the mass flux at upper interface $F^{k+} = F^{k-} + \frac{\delta^k p}{g}(P^k - E^k)$

Empirical(4), adjustable(3)

Evaporation and melting of snow

- Evaporation, E_s

  Proportion to the fraction of snow in the precipitation flux on the upper interface

$$E_s^k = E^k F_s^{k-} / F^{k-}$$

$$F_s^{k+} = F_s^{k-} + \frac{\delta^k p}{g}(P_s^k - E_s^k - M^k)$$

production, evaporation, Melting

- Melting, M

$$T^k > 0C, \quad M^k = F_s^k \frac{g}{\delta^k p}$$

Empirical(4), adjustable(3)

Production of precipitation, P

- P = PWAUT, conversion of liquid water to rain

  \+ PRACW, collection of cloud water by rain

  \+ PSAUT, auto-conversion of ice to snow

  \+ PSACI, collection of ice by snow

  \+ PSACW, collection of liquid by snow

Production of precipitation, *P*

- $$PWAUT = C_{l,aut}\hat{q}_l^2 \rho_a/\rho_w(\hat{q}_l\rho_a/\rho_w N)^{1/3} H(r_{3l} - r_{3lc})$$

  $$C_{l,aut} = 0.55\pi^{1/3}k(3/4)^{4/3}(1.1)^4 \quad k = 1.18 \times 10^6 \text{ cm}^{-1}$$

  N is $400/cm^3$ over land near the surface, $150/cm^3$ over ocean, and $75/cm^3$ over sea ice.

  $H(x) = (0, 1)$ for $x(<, \geq)0$. R_{3lc} is 15 *um*

- $$PRACW = C_{racw}\rho^{3/2}\hat{q}_l q_r$$

  $$C_{racw} = 0.884(g/(\rho_w\, 2.7\times10^{-4}))^{1/2}s^{-1}$$

Empirical(7), adjustable(8)

Production of precipitation, *P*

- $PSAUT = C_{i,aut} H(\hat{q}_i - q_{ic})$

  $C_{i,aut}$ is set to $10^{-3} s^{-1}$

Parameter	FV	T85	T42	T31	
$q_{ic,warm}$	8.e-4	4.e-4	4.e-4	4.e-4	$T = 0°C$
$q_{ic,cold}$	11.e-6	16.e-6	5.e-6	3.e-6	$T = -20°C$

- $PSACI = C_{sac} e_i \hat{q}_i$

  $C_{sac} = c_7 \rho_a^{c_8} \tilde{P}^{c_5}$

  $c_1 = \pi N_s c \Gamma(3+d)/4$

  $c_2 = 6(\pi \rho_s N_s)^{d+4} / [c\Gamma(4+d)\rho_0^{0.5}]$

  $c_5 = (3+d)/(4+d)$

  $c_6 = (3+d)/4$

  $c_7 = c_1 \rho_0^{0.5} c_2^{c_5} / (\rho_s N_s)^{c_6}$

  $c_8 = -0.5/(4+d)$

  $d = 0.25$

  $c = 152.93$

  $N_s = 3. \times 10^{-2}$

Empirical(9), adjustable(13)

Production of precipitation, *P*

- $PSACW = C_{sac} e_w \hat{q}_l$

  $e_w = 0.1$

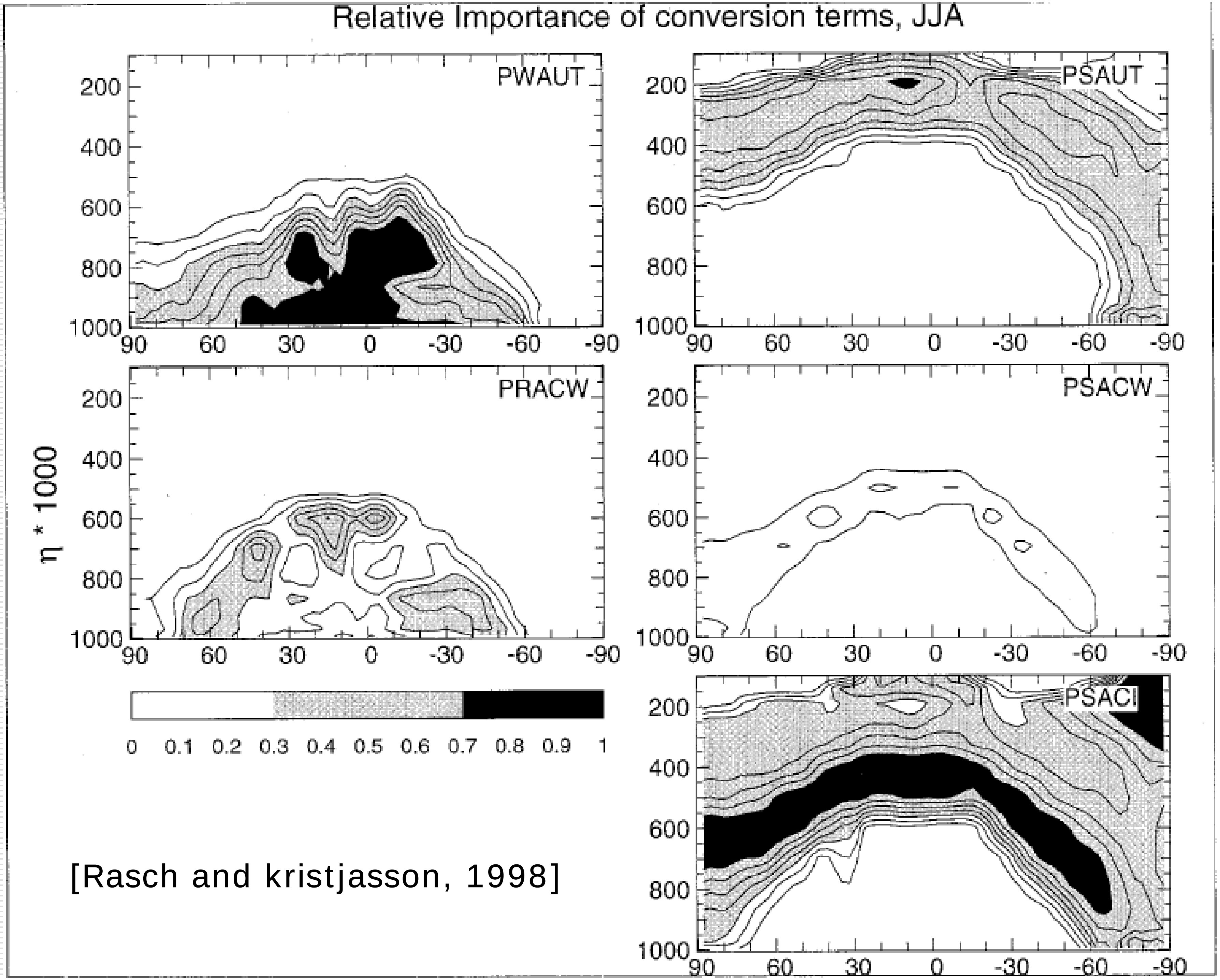
- Snow production, P_s

$$P_s^k = f_s P^k$$

$$f_s = \frac{T - T_{s,max}}{T_{s,min} - T_{s,max}}, \quad T_{min} \le T \le T_{max}$$

Adjustable constants $T_{min} = -5^\circ$ C $T_{max} = 0^\circ$ C

Empirical(11), adjustable(16)



[Rasch and kristjasson, 1998]

Sedimentation of liquid and ice

- Fluxes are computed at interfaces, using fall velocities and concentration at midpoints.
- Particles only evaporate if the cloud fraction is larger in the layer above.

$$f_o = \min\left(\frac{f_c^k}{f_c^{k-1}}, 1\right)$$

- Sedimenting particles evaporate if they fall into the cloud free portion of a layer. If supersaturated, the evaporated portion will be accounted for the subsequent cloud condensate tendency calculation.

Empirical(11), adjustable(16)

Fall velocity

- Ice particles
  - Effective radius $R_e < 40 \times 10^{-6}$ m

    Stokes formula $$v_i = \frac{2}{9}\frac{\rho_w g R_e^2}{\eta}$$

    $\eta = 1.7 \times 10^{-5}$ kg m/s is the viscosity of air

  - $R_e > 40 \times 10^{-6}$ m

    Linear dependence on $r = 10^{-6} \times R_e$

    $$v_i(r) = v_i(40) + (r - 40)\frac{v_{400} - v_i(40)}{400 - 40}$$

Empirical(13), adjustable(18)

Fall velocity

- Liquid particles

$$v_l = v_l^{land} f^{land} + v_l^{ocean} f^{ocean}$$

f^{land} and f^{ocean} are the land and ocean fractional areas of the cell

$v_l^{land} = 1.5$ and $v_l^{ocean} = 2.8$ cm/s

Empirical(13), adjustable(20)

Conclusion

- The non-convective cloud scheme is set up by solving a set of conservation equations for water vapor, temperature, and cloud condensate.
- Macroscale: The condensation rate Q, is obtained by connecting with the cloud fraction as required by total water budget.
- Microscale: use a bulk microphysical scheme to obtain the conversion from condensate to precipitation (E_r and R_l).
- The parameterization are engineering code based on physics. There are 13 explicit empirical relations and 20 adjustable constants.
- Can be replaced be a LUT.

Reference:

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- Rasch, P. J., and J. E. Kristjansson, A comparison of the CCM3 model climate using diagnosed and predicted condensate parameterizations, J. Climate, 11, 1587—1614, 1998.
- Zhang, M., W. Lin, C. S. Bretherton, J. J. Hack, and P. J. Rasch, A modified formulation of fractional stratiform condensation rate in the NCAR community atmospheric model CAM2, J. Geophys. Res., 108 (D1), 2003.