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Retrieval of Latent Heating Profiles in Various Cloud Systems from TRMM PR data

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Objectives:

- to develop a latent heating algorithm using PR data
- to apply the PRH algorithm to various 2A25 data

Contents:

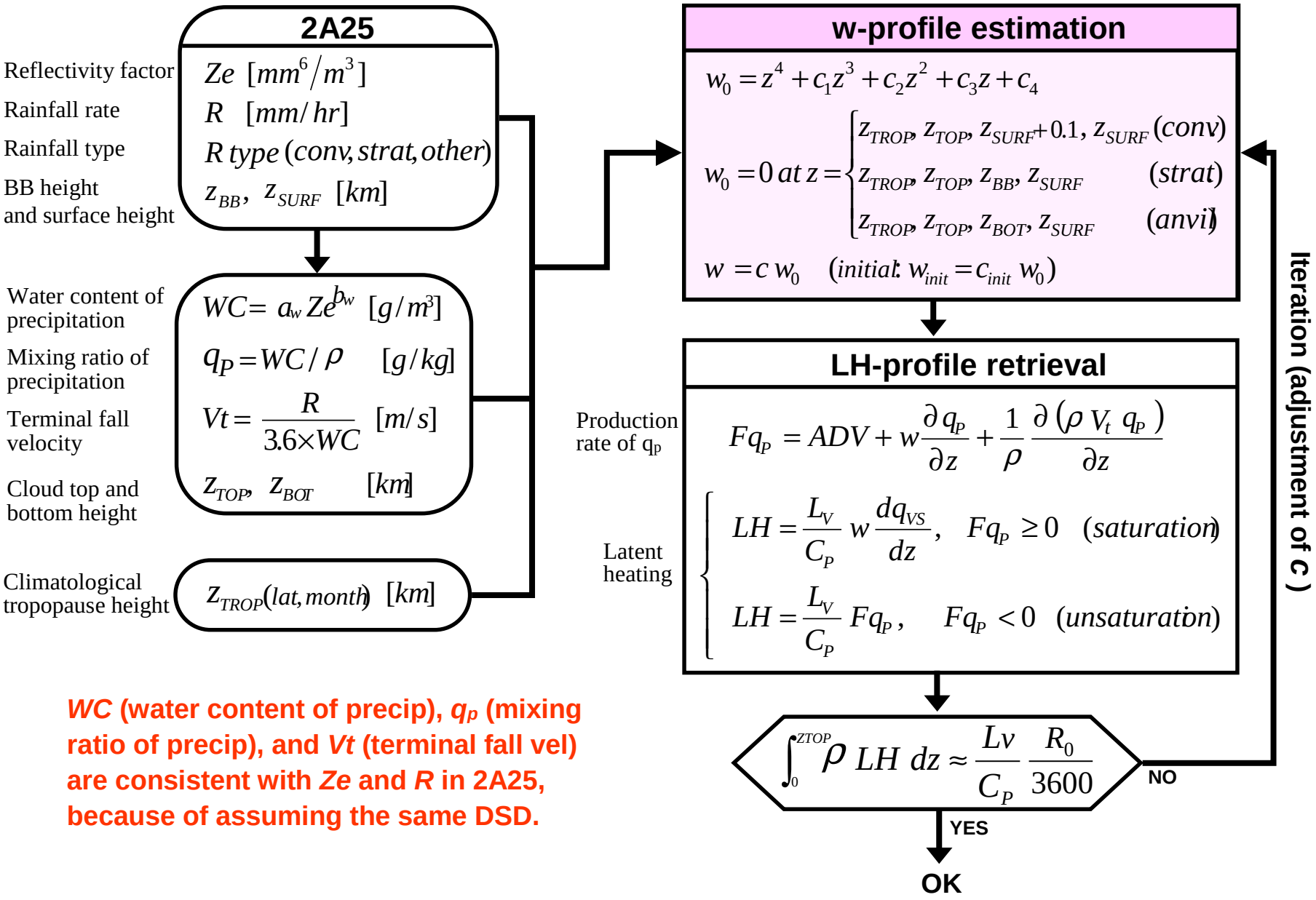
- Introduction (other proposed LHAs)
- Description of the PRH algorithm
- Application of the algorithm to squall-line, typhoon, monsoon, shallow-conv and global data

Strengths and Weakness of TRMM heating algorithms

	Strengths	Weaknesses	Applied data
GPROF (2A12)	-physical approach -random error by Bayesian method -10x10 km grid to 5x5 deg mean	-depends on the cloud/radiation model -leads to error of data-base	**TMI only** - wide swath observations - less information on storm structure - depends on 85 GHz data over land
HH	-physical approach -ready to use (from 2A12, 2B31) -10x10 km grid to 5x5 deg mean	-depends on the cloud/radiation model -sensitive to retrieved hydrometeors -uncertain in melting layer/terminal vel	
CSH	-based on diagnostic budget study -one single max heating level -5x5 deg. monthly mean	-sensitive to stratiform amount -sensitive to the look-up tables -no latent heating in no-rain region	**both TMI and PR**
PRH	-independent of cloud models -include precip top and melting level -5x5 km grid to 5x5 deg mean	-uncertain in estimating w-profiles -1 dim. retrieval in a small gird -no latent heating in no-rain region	**PR only** - more information on storm structure - uniform quality over sea and land - large sampling error
SLH	-include precip top and melting level -to 5x5 deg mean	-depends on the cloud model -sensitive to the look-up tables	

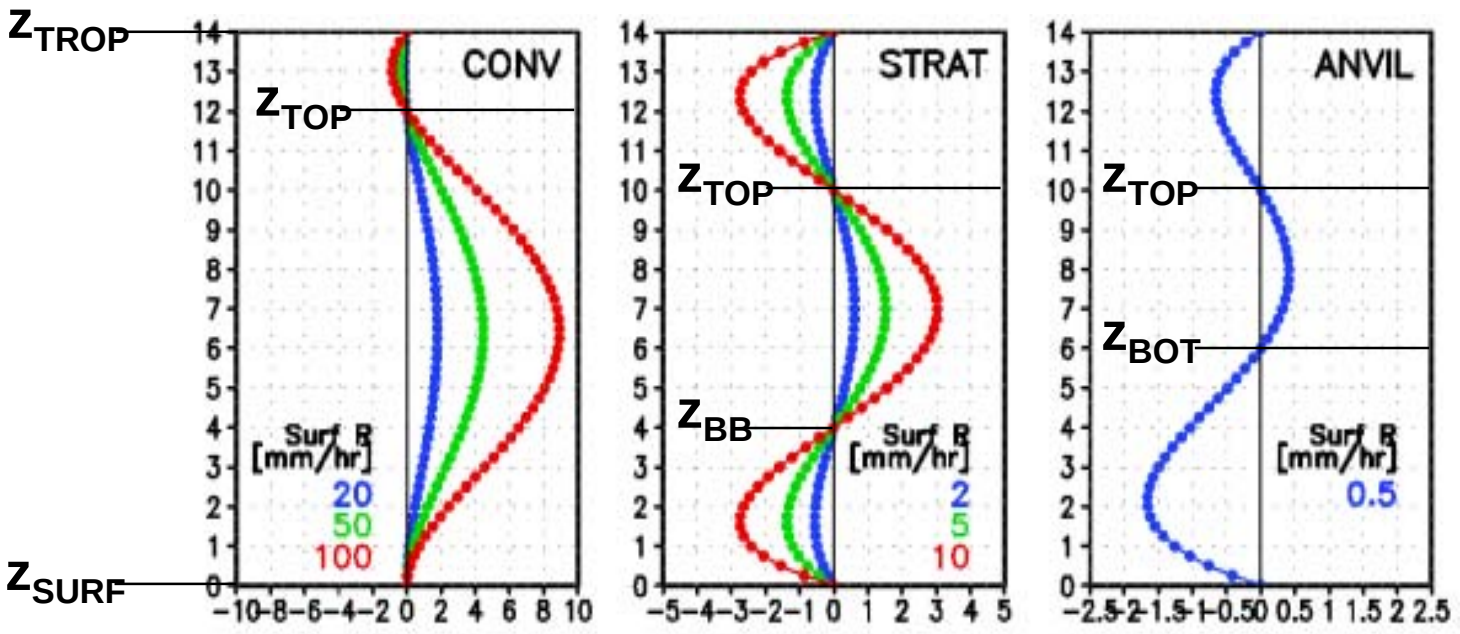
Goddard Profiling Heating Algorithm (GPROF) by Kummerow (1996), Olson(1996)
Hydrometeor/Heating Algorithm (HH) by Tao (1990)
Convective-Stratiform Heating Algorithm (CSH) by Tao (1993, 2001)
PR Heating Algorithm (PRH) by Satoh (2001)
Spectral Latent Heating Algorithm (SLH) by Shige and Takayabu (2001)

Flowchart of the PR heating algorithm



***WC* (water content of precip), q_P (mixing ratio of precip), and *Vt* (terminal fall vel) are consistent with *Ze* and *R* in 2A25, because of assuming the same DSD.**

Estimation of vertical wind velocity (*w*) profiles



Estimating w-profile using a 4th-order polynomial equation

$$w_0 = z^4 + c_1 z^3 + c_2 z^2 + c_3 z + c_4$$

$$w_0 = 0 \; at \; z = \begin{cases} z_{TROP},\, z_{TOP},\, z_{SURF} + 0.1,\, z_{SURF} & (conv/\,shallow) \\ z_{TROP},\, z_{TOP},\, z_{BB},\, z_{SURF} & (strat) \\ z_{TROP},\, z_{TOP},\, z_{BOT},\, z_{SURF} & (anvil) \end{cases}$$

$$w = c\, w_0 \quad (initial: w_{init} = c_{init}\, w_0)$$

Initial w-profile coefficient estimated from R_0 (assuming saturation in all updraft regions)

$$c_{init} = R_0 \Big/ \int_{z_0}^{z_{TOP}} \left(\rho\, w_0 \frac{dq_{vs}}{dz} \right) dz \times 3600$$

R_0 = surface rainfall [mm/hr]
$z_0 = z_{SURF}$ (*conv/shallow*), z_{BB} (*strat*), z_{BOT} (*anvil*)

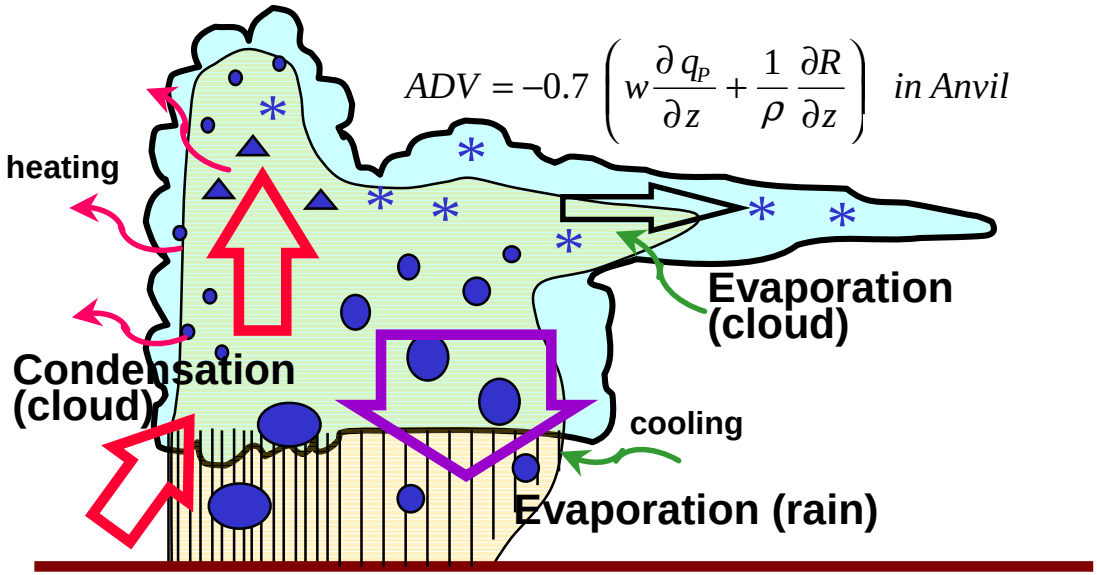
Retrieval of latent heating (*LH*) profiles

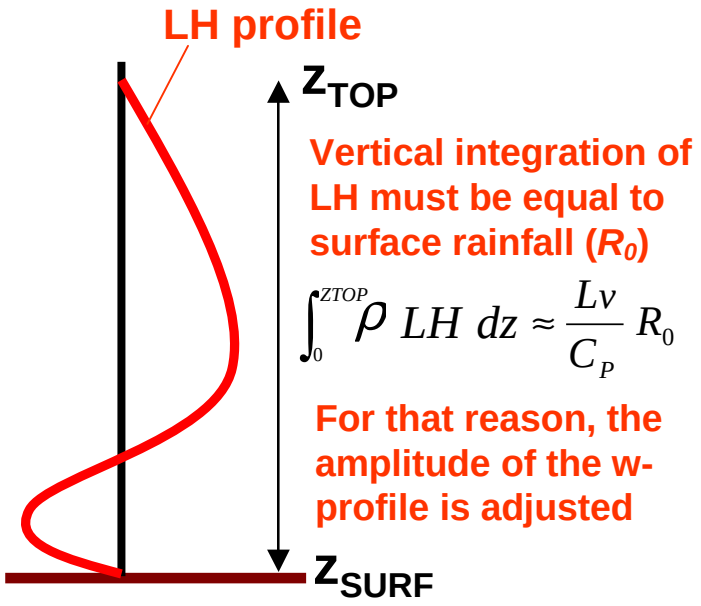
$$Fq_P = u\frac{\partial q_P}{\partial x} + v\frac{\partial q_P}{\partial y} + \overbrace{w\frac{\partial q_P}{\partial z}}^{ADV\ (\text{unknown})} + \frac{1}{\rho}\frac{\partial\left(\rho\, V_t\, q_P\right)}{\partial z}$$

$$\begin{cases} LH = \dfrac{L_V}{C_P}\, w\, \dfrac{dq_{VS}}{dz}, & Fq_P > 0 \quad (saturation) \\ LH = \dfrac{L_V}{C_P}\, Fq_P, & Fq_P \le 0 \quad (unsaturation) \end{cases}$$

q_{VS} is calculated from an estimated temperature profile (BB=3 C, Γ=6 C/km)

q_p	: mixing ratio of precipitation
Fq_p	: production rate of q_p
u, v, w	: 3 components of wind velocity
V_t	: terminal fall velocity
q_{VS}	: mixing ratio of saturated water vapor
LH	: latent heating



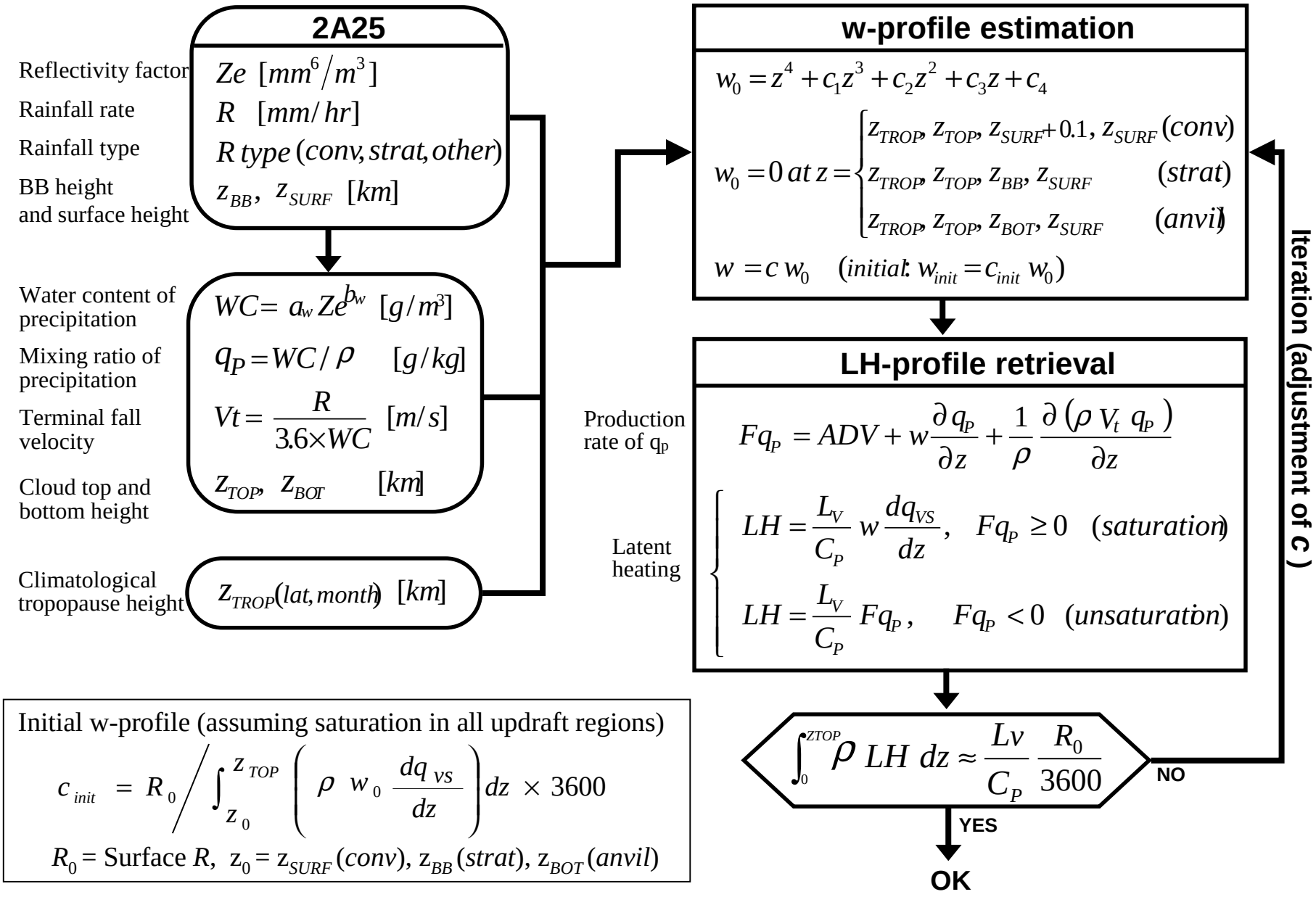


Vertical integration of LH must be equal to surface rainfall (R_0)

$$\int_0^{ZTOP} \rho\, LH\, dz \approx \frac{Lv}{C_P} R_0$$

For that reason, the amplitude of the w-profile is adjusted

Flowchart of the PR heating algorithm

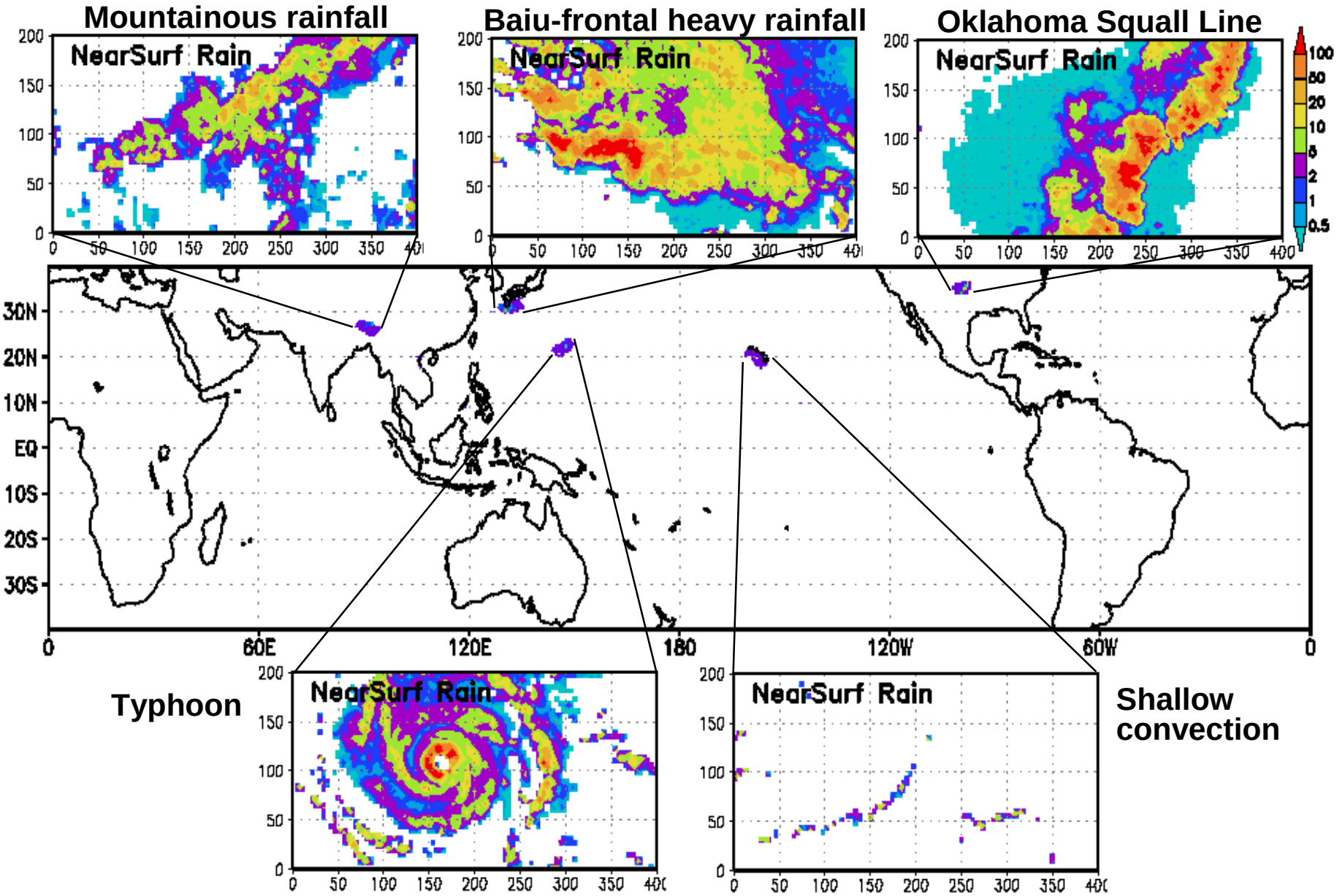


Initial w-profile (assuming saturation in all updraft regions)

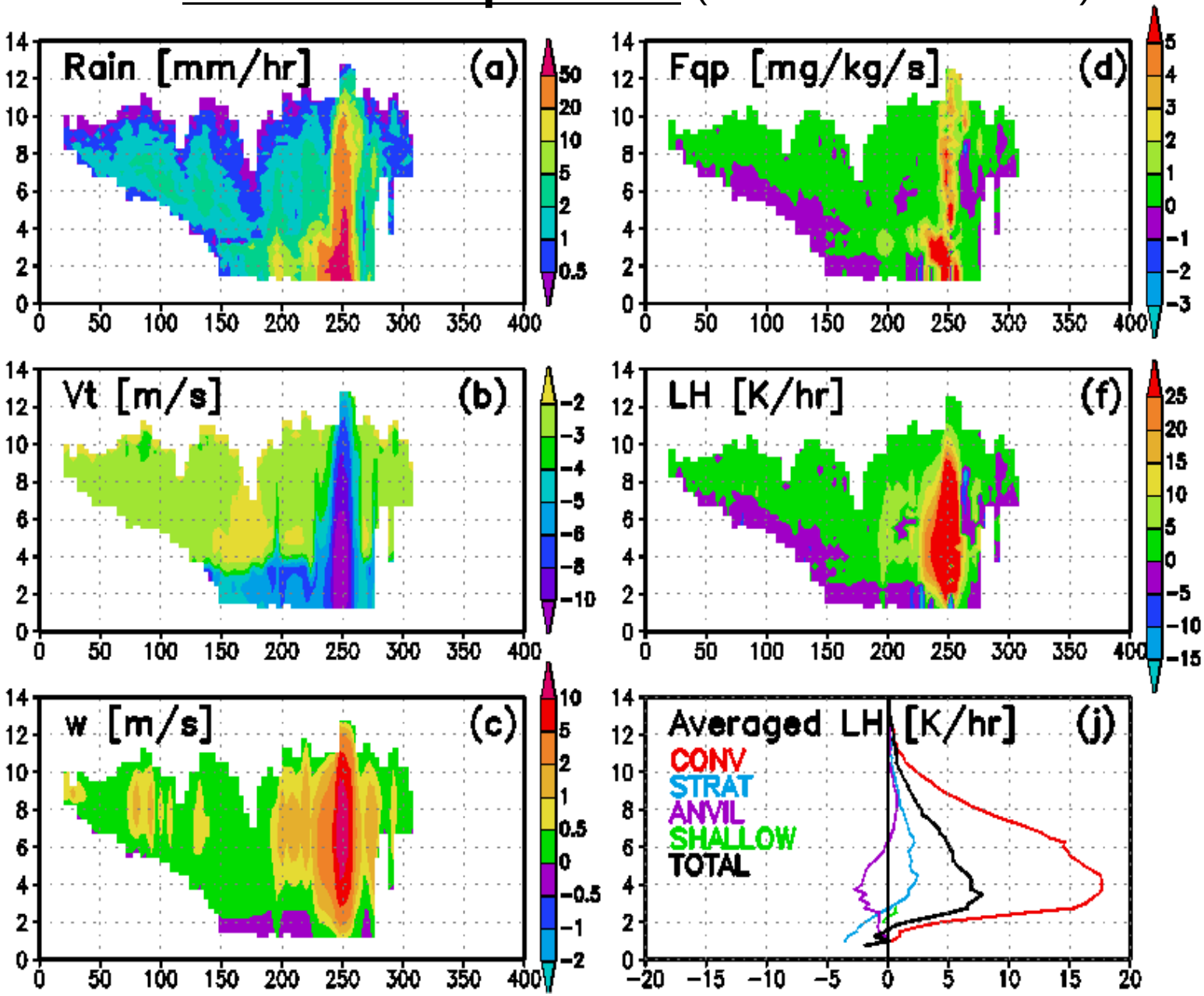
$$c_{init} = R_0 \Big/ \int_{z_0}^{z_{TOP}} \left(\rho\ w_0 \frac{dq_{vs}}{dz} \right) dz \times 3600$$

R_0 = Surface R, $z_0 = z_{SURF}(conv), z_{BB}(strat), z_{BOT}(anvil)$

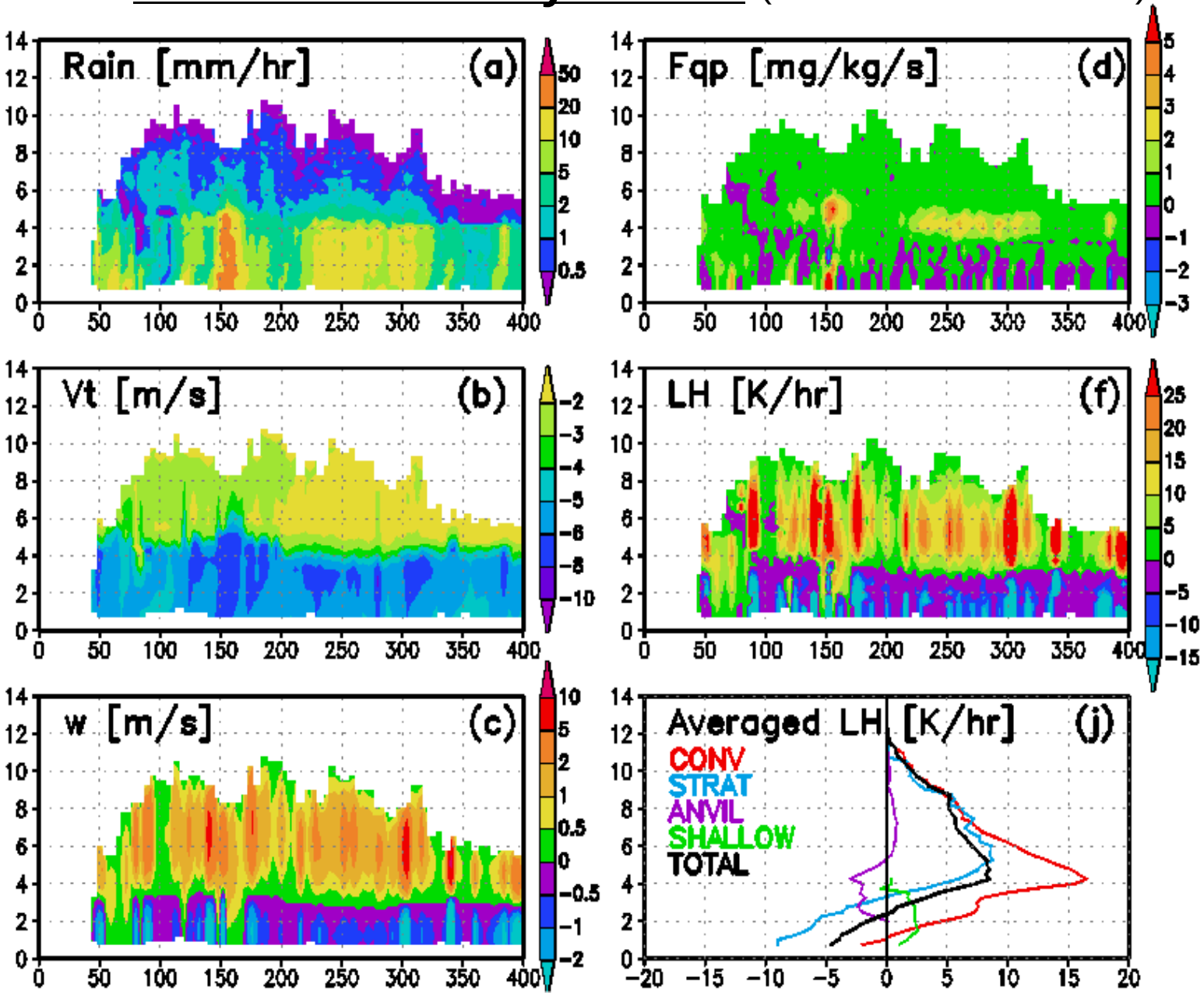
Five cloud systems for the application of the PRH algorithm



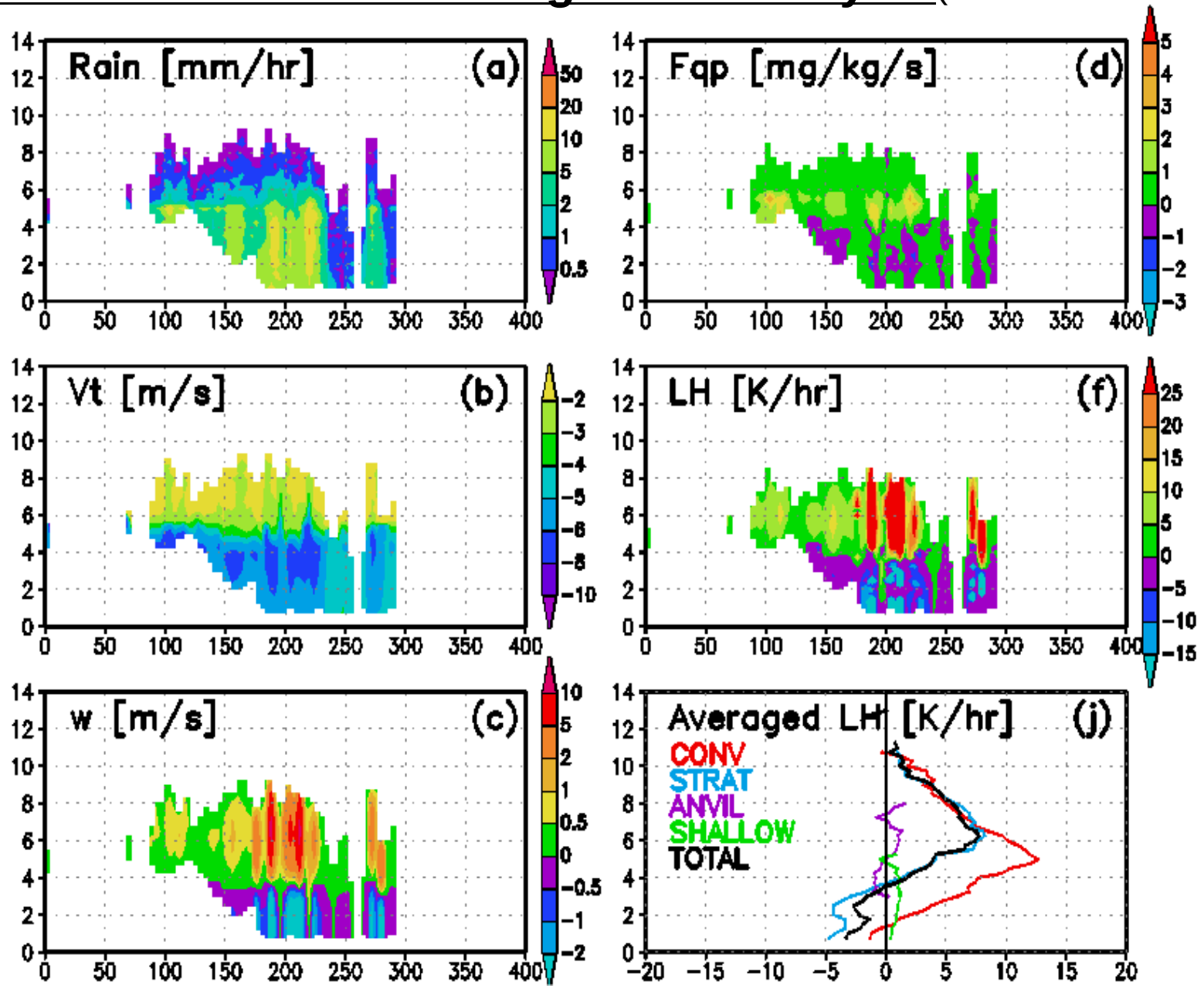
Oklahoma squall line (10 MAY 1999 #8329)



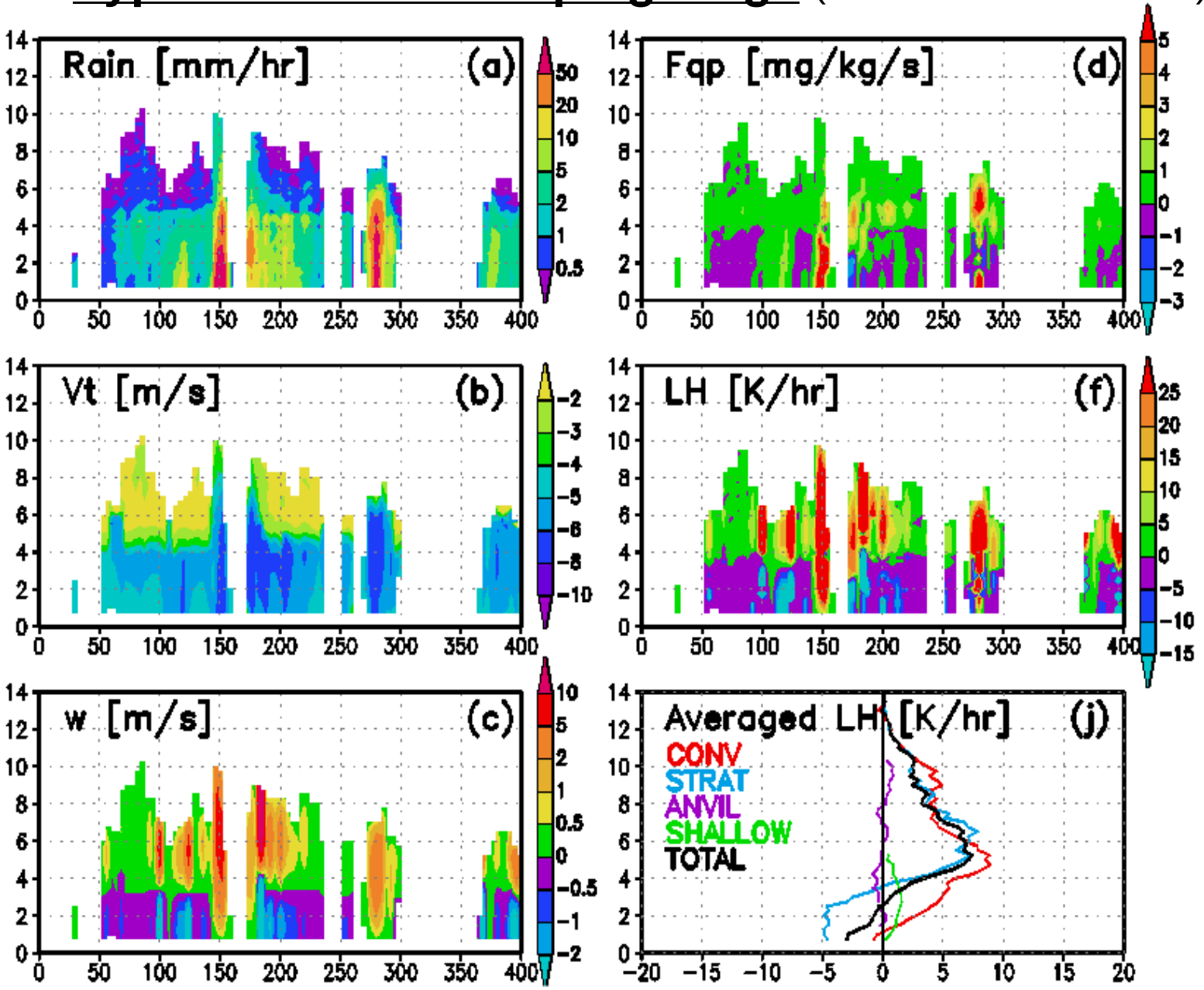
Baiu-frontal heavy rainfall (3 JUN 2000 #14492)



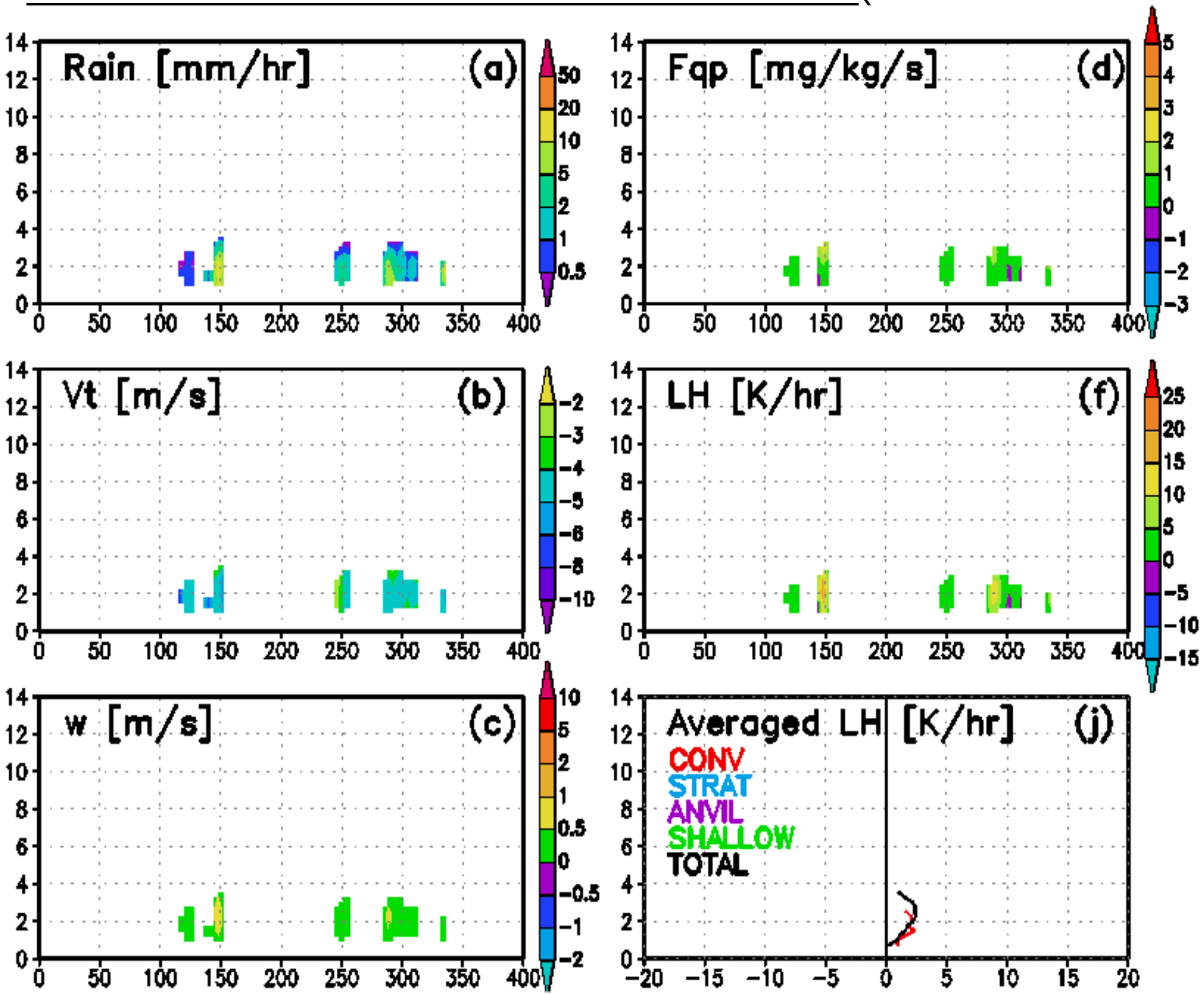
Mountainous rainfall along the Himalayas (1 AUG 2000 #15423)



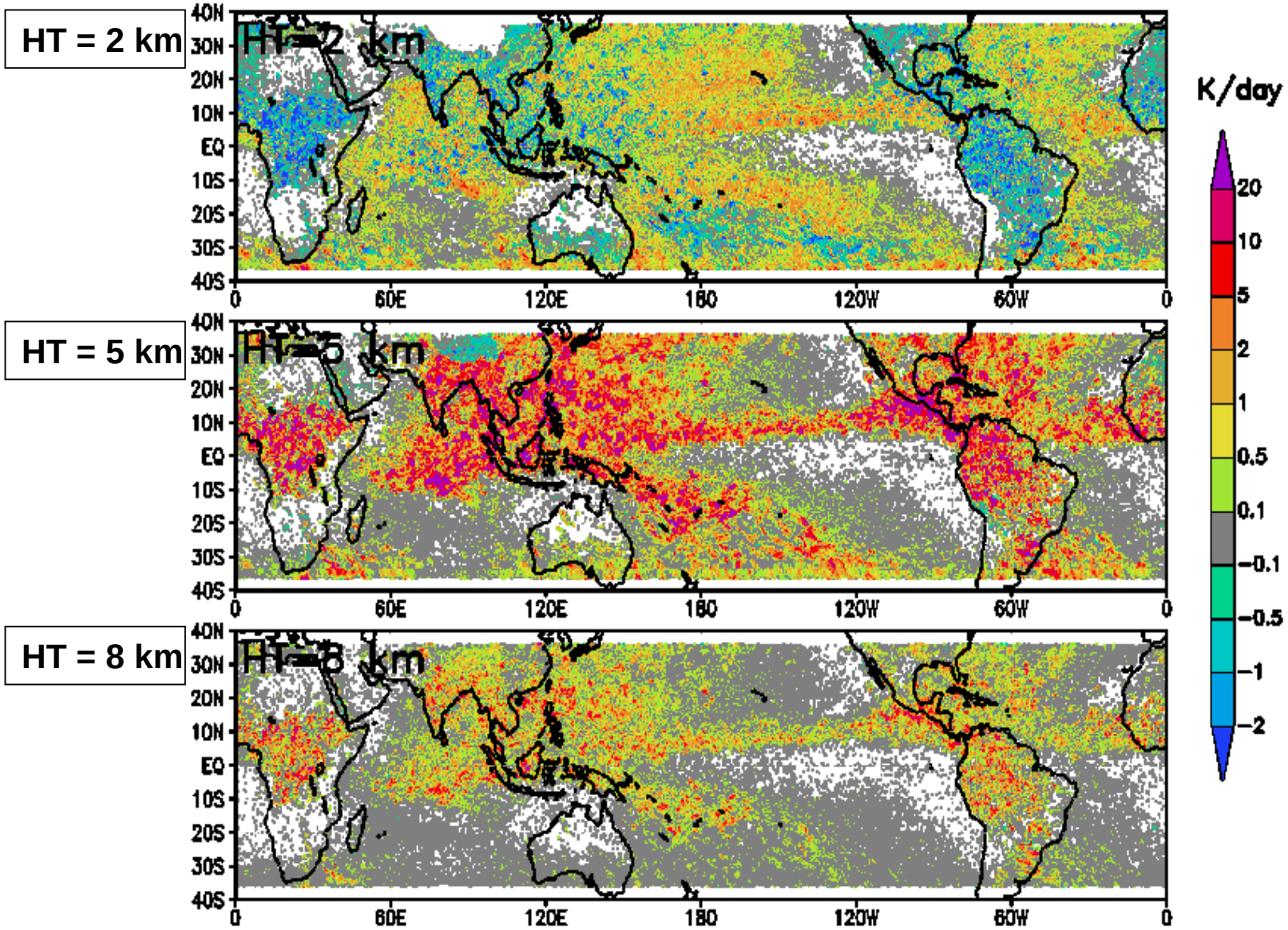
Typhoon in a developing stage (2 AUG 2000 #15432)



Shallow convection around Hawaii (22 SEP 1999 #10464)

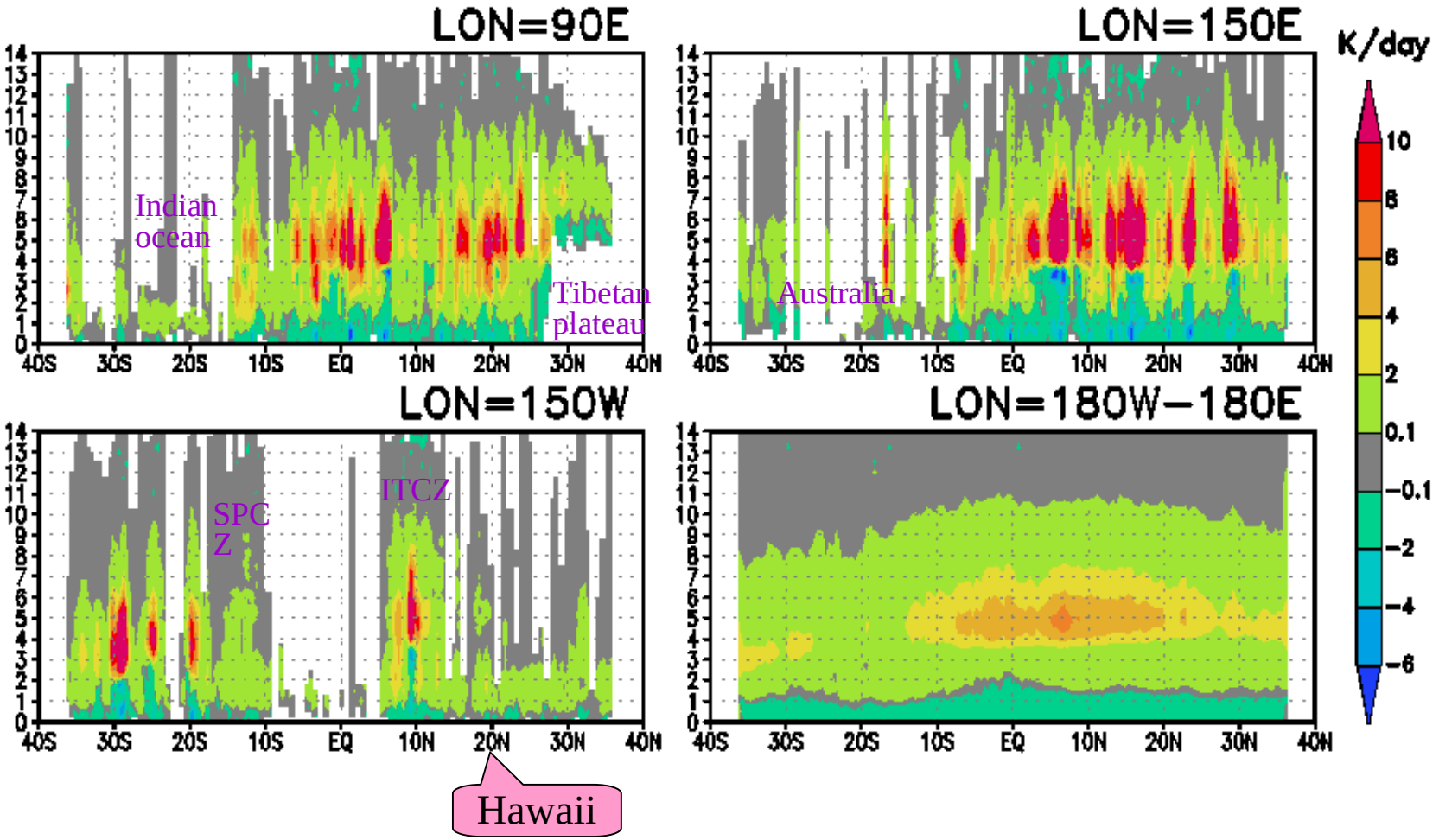


Monthly-mean latent heating in 0.5 deg grids (1-30 SEP 1999)



Meridional vertical section of monthly-mean latent heating

(1-30 SEP 1999)



Conclusions

(1) The PR heating (PRH) algorithm was developed. The LH profile is retrieved using a w-profile estimated by a fourth-order polynomial equation, which is determined by the storm height, the BB height, the rainfall type, and the surface rainfall.

(2) The PRH algorithm can reveal latent heating structure from a cloud scale (4 km grid) to a global scale (monthly mean in 0.5 deg grids).

(3) In future, we plan to validate the retrieved LH profiles using a cloud-resolving model and field-experiment data (or re-analysis data).