GC51B - 12

Effects of Moisture on Baroclinic Waves

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MODEL: Primitive Equations

f-plane, Boussinesq, simplified moisture

rigid lid, no stratosphere

$$u_t + uu_x + vu_y + wu_z - f_o v = -c_P \theta_o \pi_x + \nu \nabla^2 u$$

$$v_t + uv_x + vv_y + wv_z + f_o u = -c_P \theta_o \pi_y + \nu \nabla^2 v$$

$$\theta_t + u\theta_x + v\theta_y + wN^2 = \nu \nabla^2 \theta$$

incompressible, hydrostatic

$$u_x + v_y + w_z = 0$$

$$c_P \theta_o \pi_z = \frac{g}{\theta_o} \theta$$

Upraft always saturated: maximum possible moisture effect

$$N^2 = \begin{cases} N^2_{dry} & \text{where } w < 0 \\ N^2_{moist} << N^2_{dry} & \text{where } w > 0 \end{cases}$$

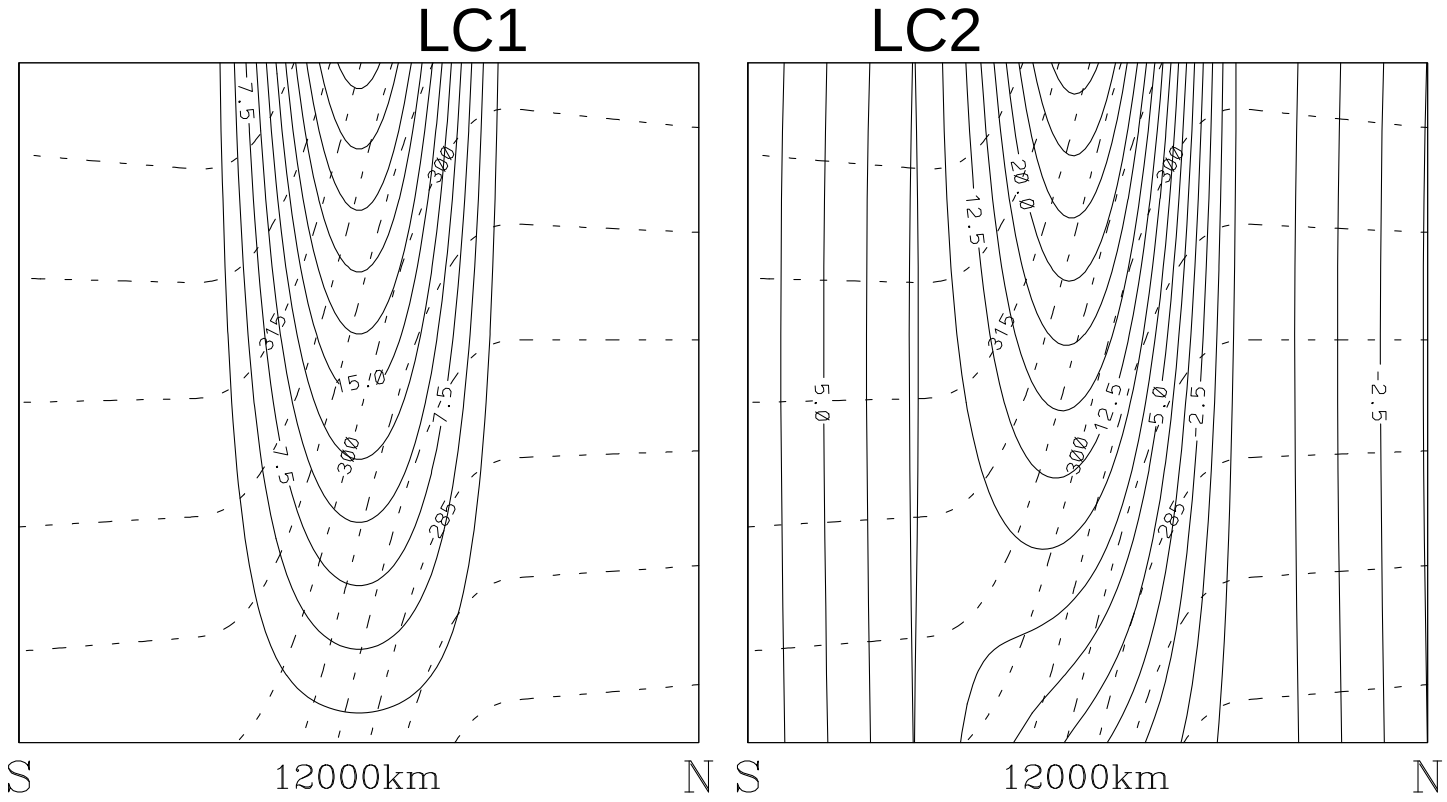
(ref: Emanuel et al, 1987; Fantini, 1997)

Domain: doubly periodic. Integrated over 6000 x 12000 km.

Grid: 128 x 128 x 11 levels. Two wavelengths shown.

AIM: study baroclinic life cycles modified by latent heat release

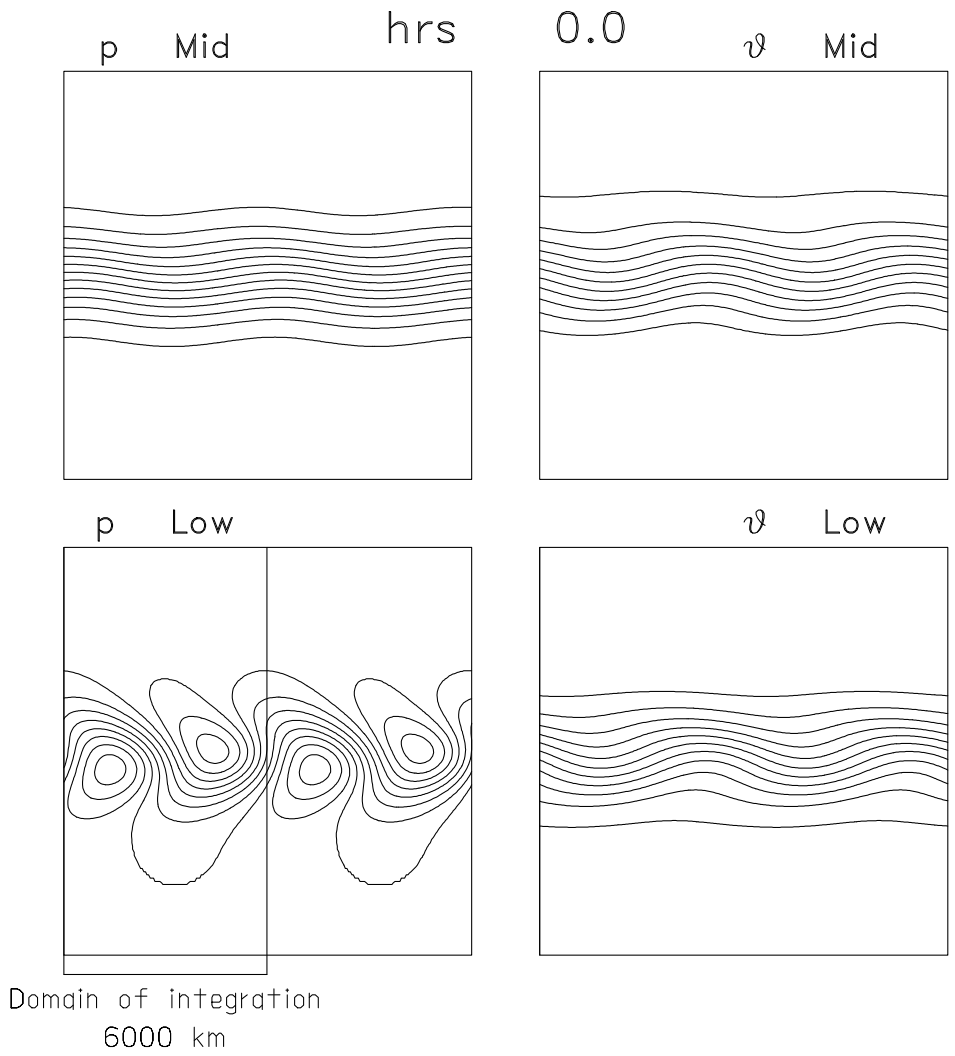
Initial mean zonal states for



HW jet

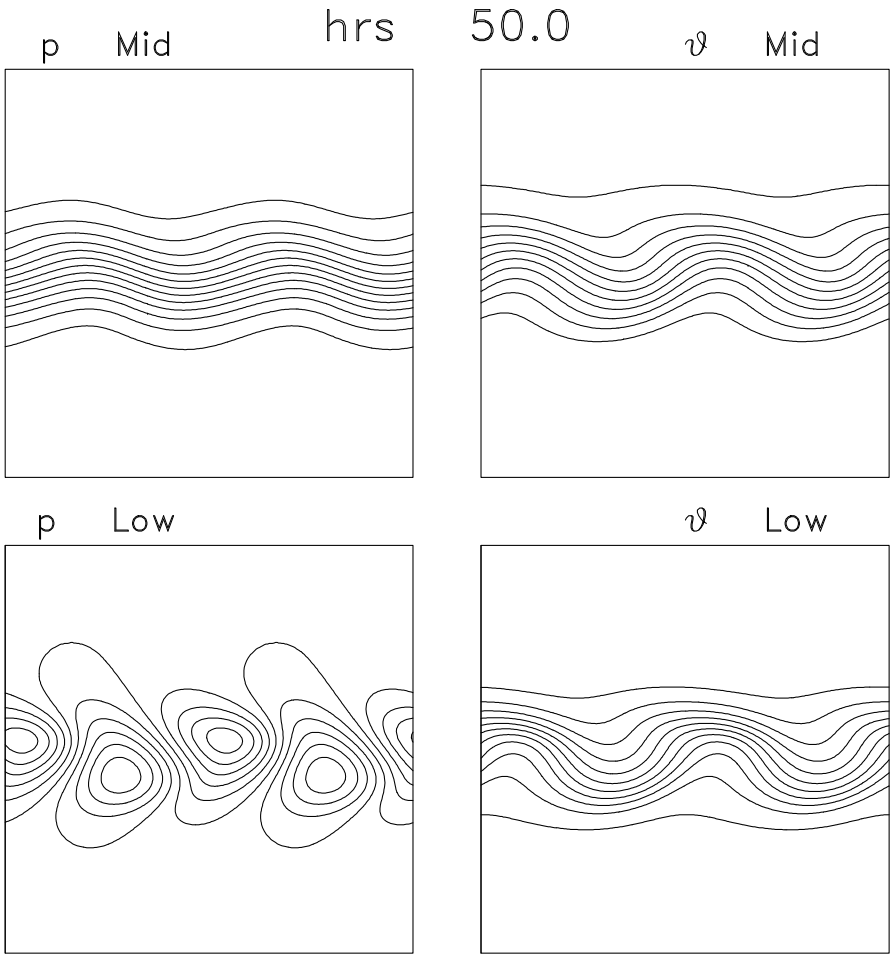
jet+barotropic
cyclonic shear

LIFE CYCLE 1 : DRY



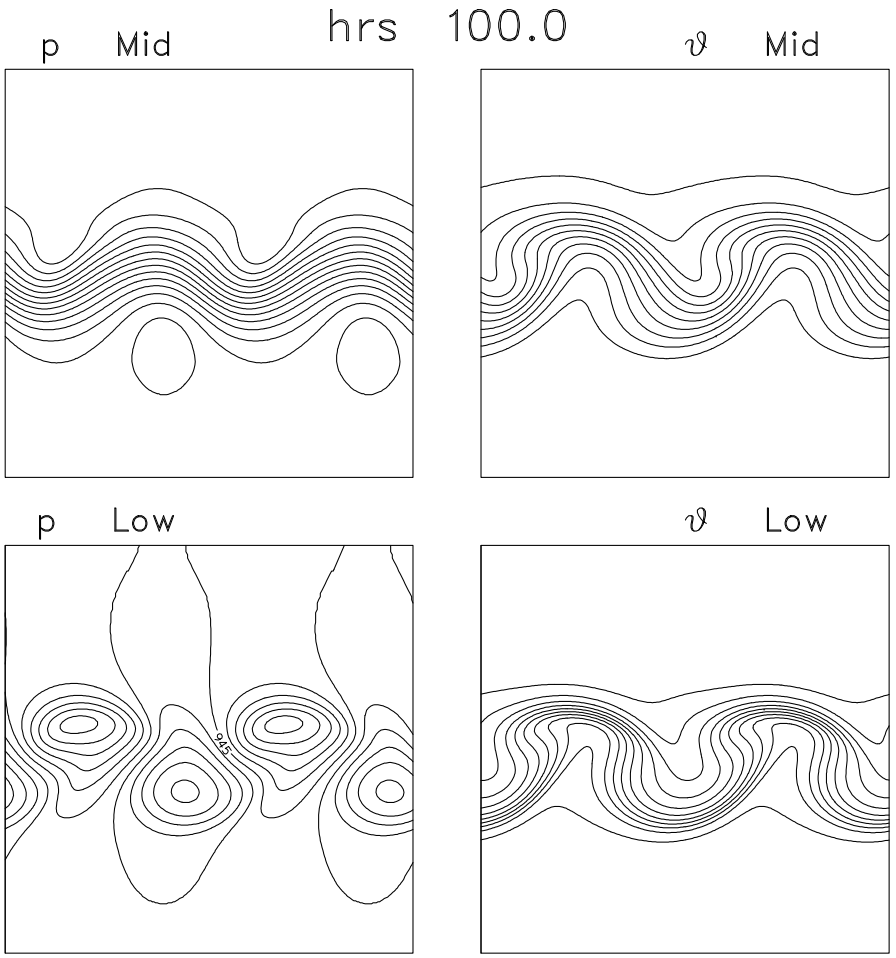
Contour plots of: pressure (lower left - contour interval 1 mb) and potential temperature (lower right - c.i. 2.5 K) at lowest internal level (454 m); pressure (upper left - c.i. 2.5 mb) and potential temperature (upper right - c.i. 2.5 K) at the model's midlevel (5 km)

LIFE CYCLE 1 : DRY



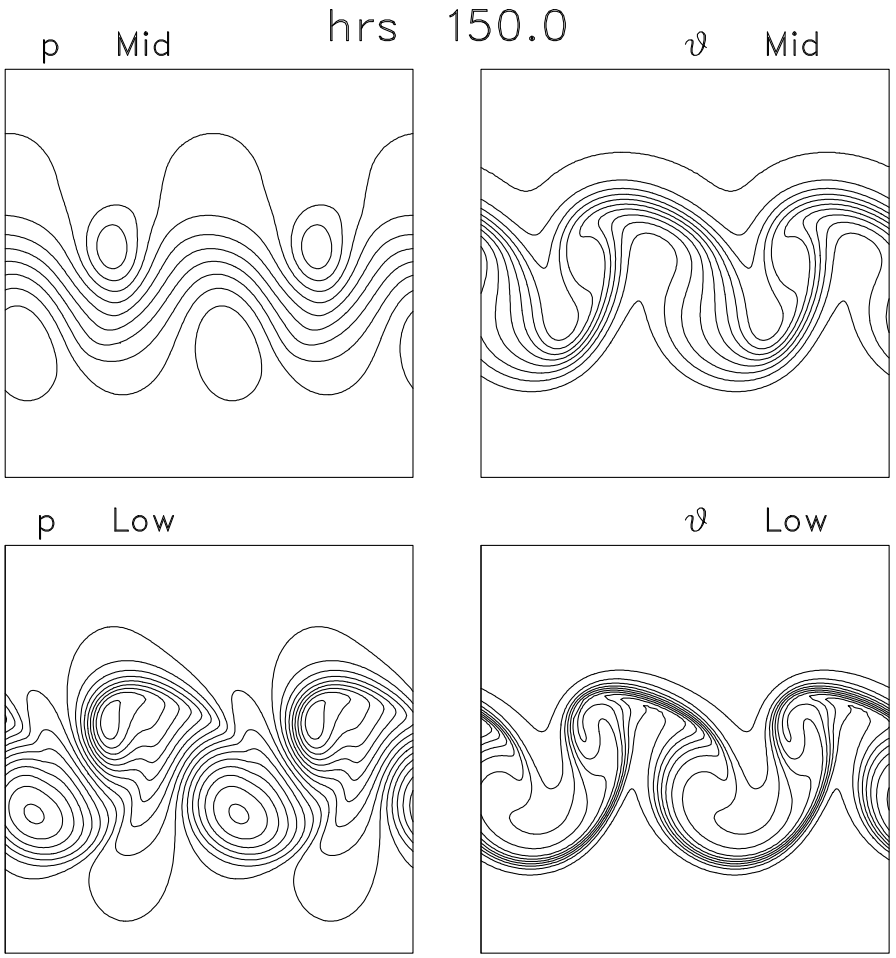
Same as 0.00 hours except c.i. for "surface" pressure 2.5 mb

LIFE CYCLE 1 : DRY



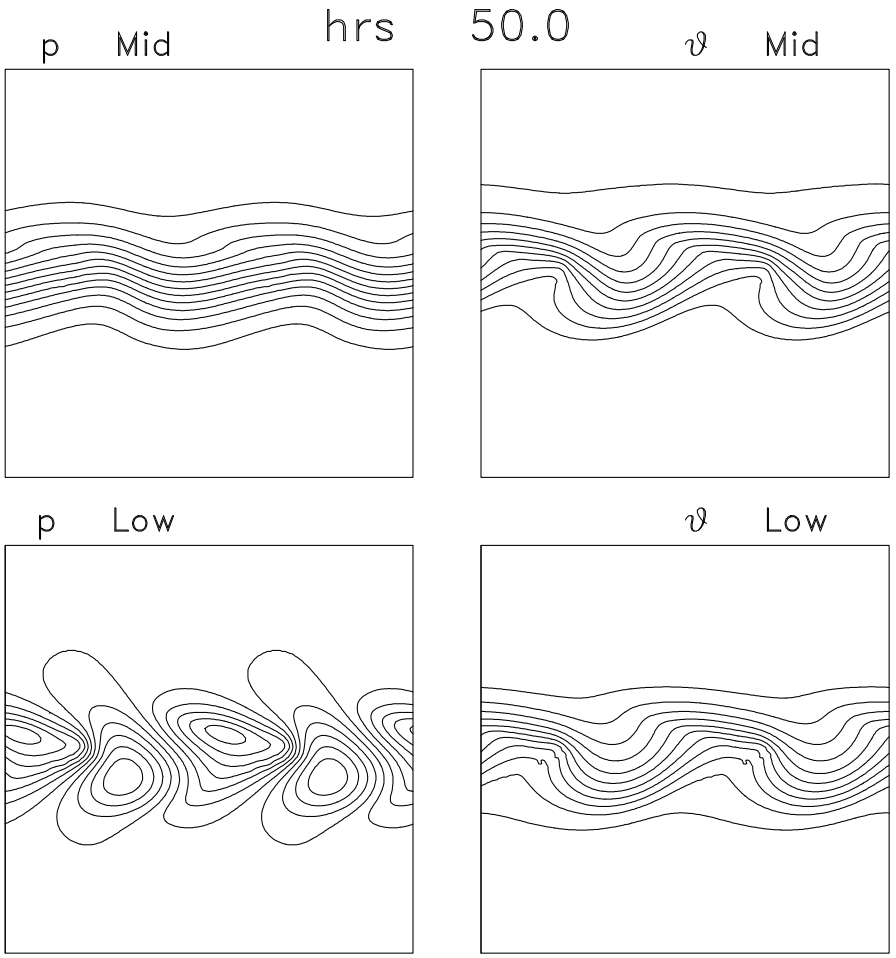
Same as 0.00 hours except c.i. for "surface" pressure 5 mb

LIFE CYCLE 1 : DRY



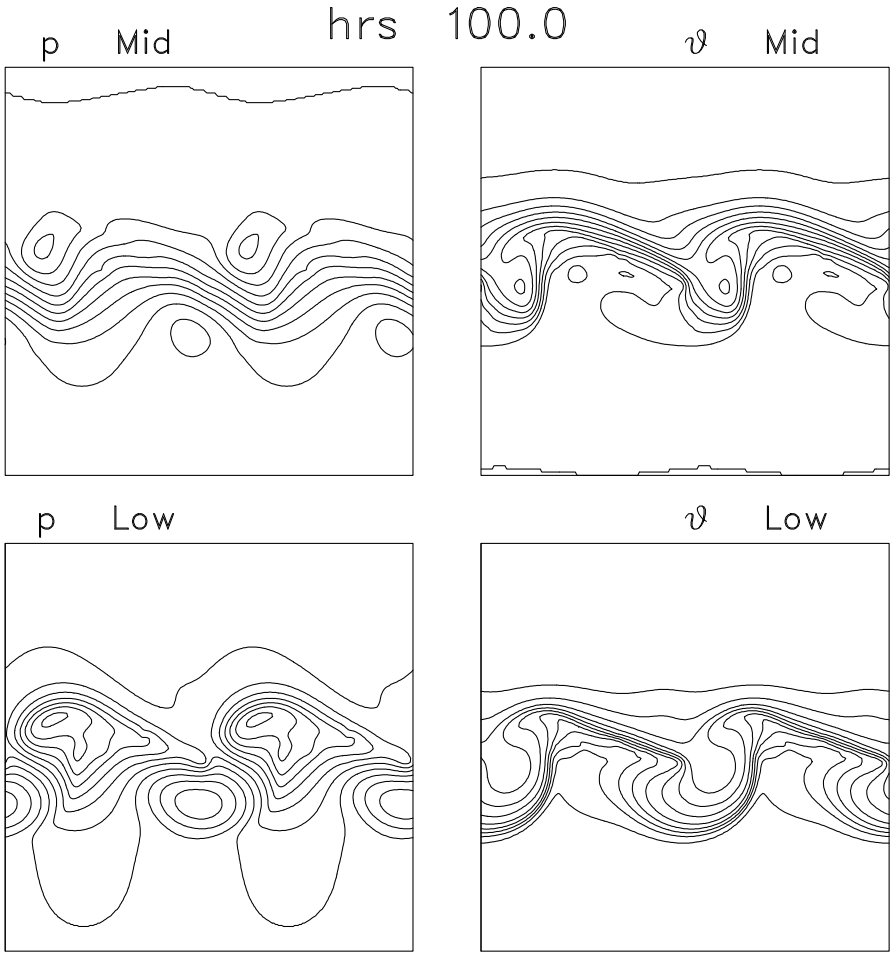
Same as 0.00 hours except c.i. for "surface" and midlevel pressure 5 mb

LIFE CYCLE 1 : MOIST



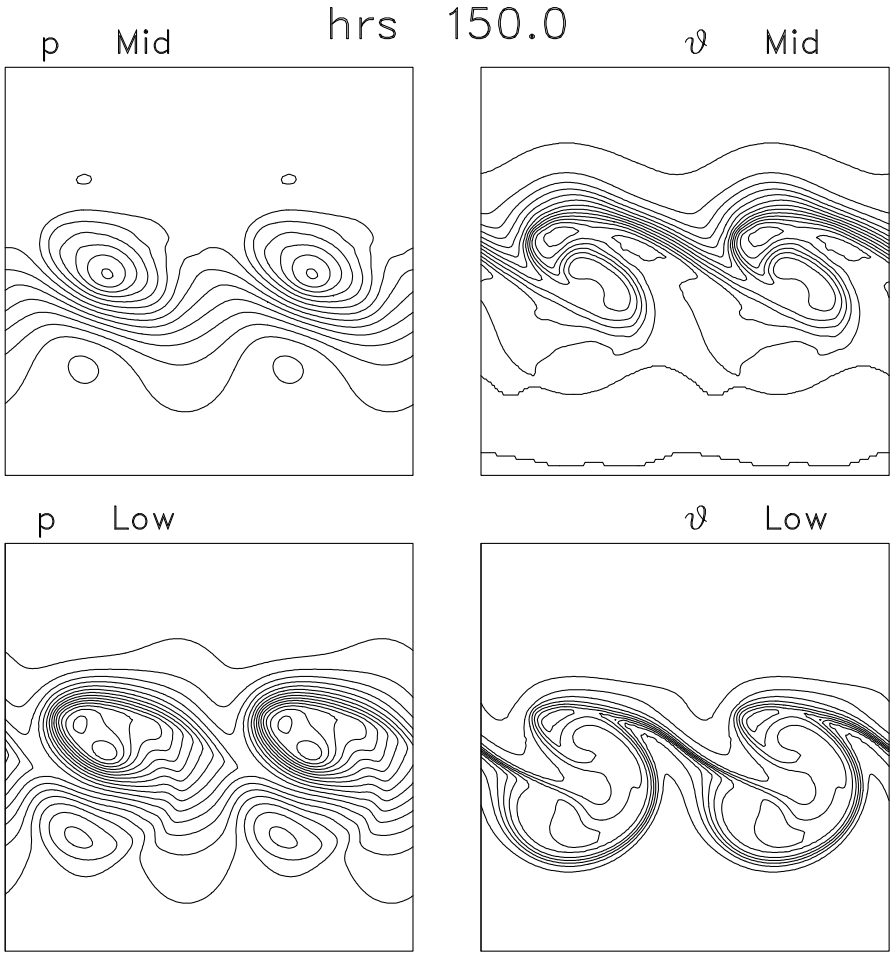
Contour intervals: pressure 2.5 mb; Potential temperature 2.5 K

LIFE CYCLE 1 : MOIST



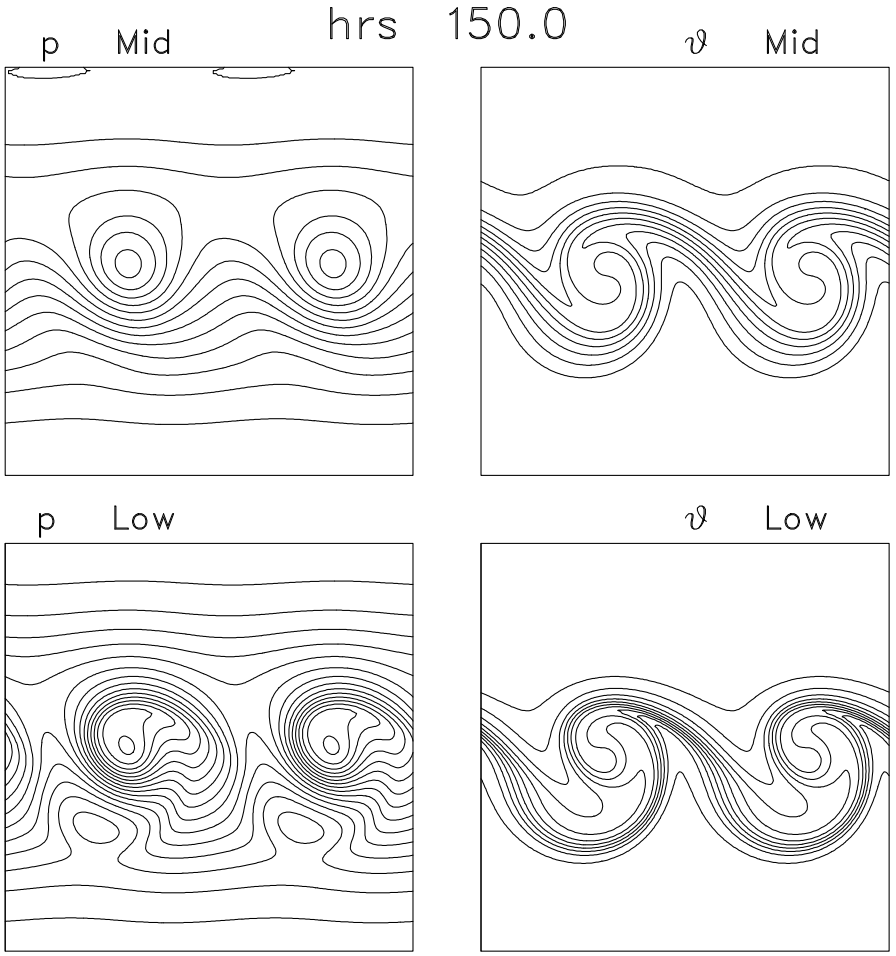
Contour intervals: pressure 2.5 mb; Potential temperature 2.5 K

LIFE CYCLE 1 : MOIST



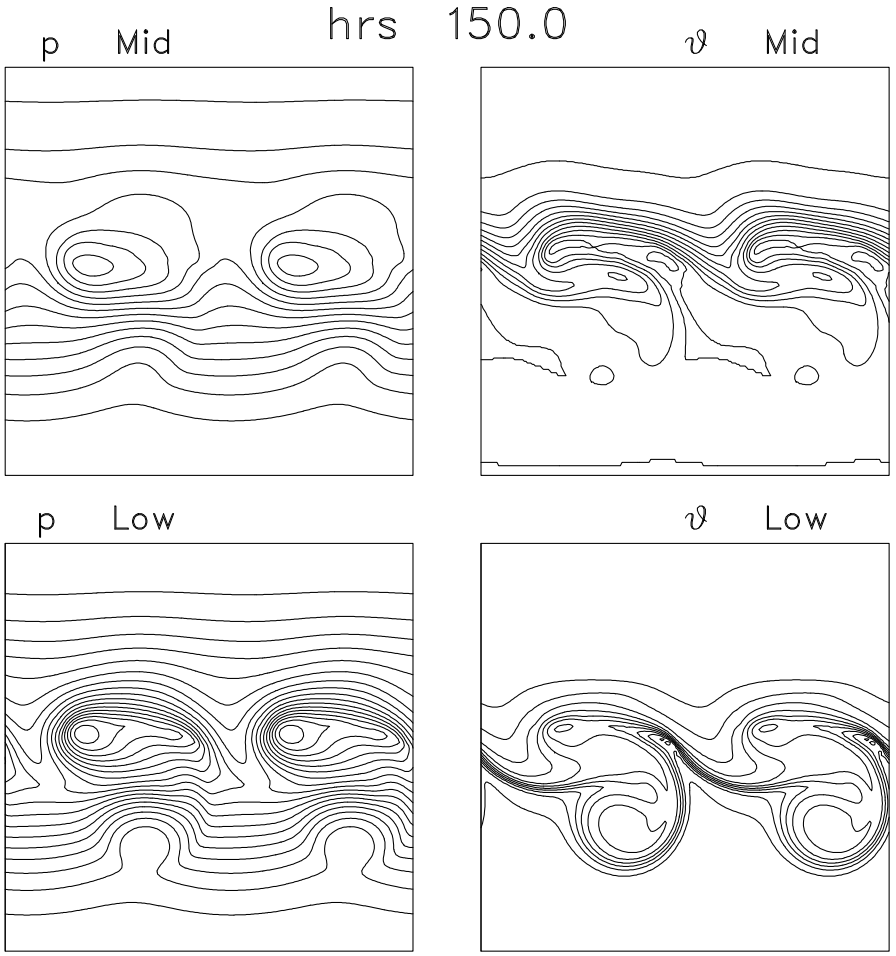
Contour intervals: "surface" pressure 5 mb; midlevel pressure 4 mb; Potential temperature 2.5 K

LIFE CYCLE 2 : DRY



Contour intervals: pressure 5 mb; Potential temperature 2.5 K

LIFE CYCLE 2 : MOIST



Contour intervals: pressure 5 mb; Potential temperature 2.5 K

FIGURES

1,2,3,4: Time evolution (0,50,100,150 hours) for dry life cycle 1.
Initial perturbation is the most unstable linear mode
for the HW jet

5,6,7: Time evolution (50,100,150 hours) for moist life cycle 1.
Same i.c. as dry case (NOT the most unstable moist mode)

8,9: Fields at 150 hours for dry life cycle 2.

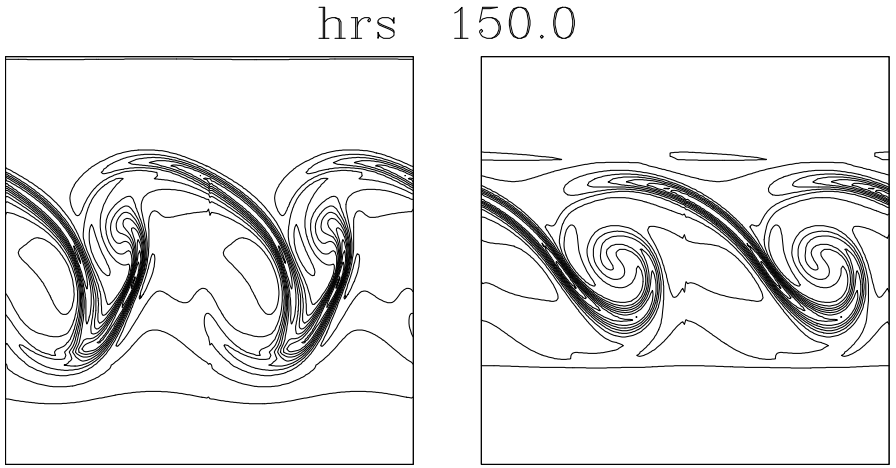
10: Potential vorticity near the model's top for final state of the dry LC's

11,12,13: Mean zonal wind (solid) and potential temperature (dashed)
on the mean meridional plane for initial and final states of the four
experiments, as labeled.

The initial perturbation for all runs is the 6000 km normal mode (nearly the most unstable) of the dry HW jet.
The most unstable moist mode would be shorter.

Potential vorticity aloft (9 km)

LC1 LC2



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Dry LC's reproduced correctly (e.g. Thorncroft *et al*, 1993)

PRELIMINARY RESULTS

Moist runs exhibit stronger fronts especially aloft.

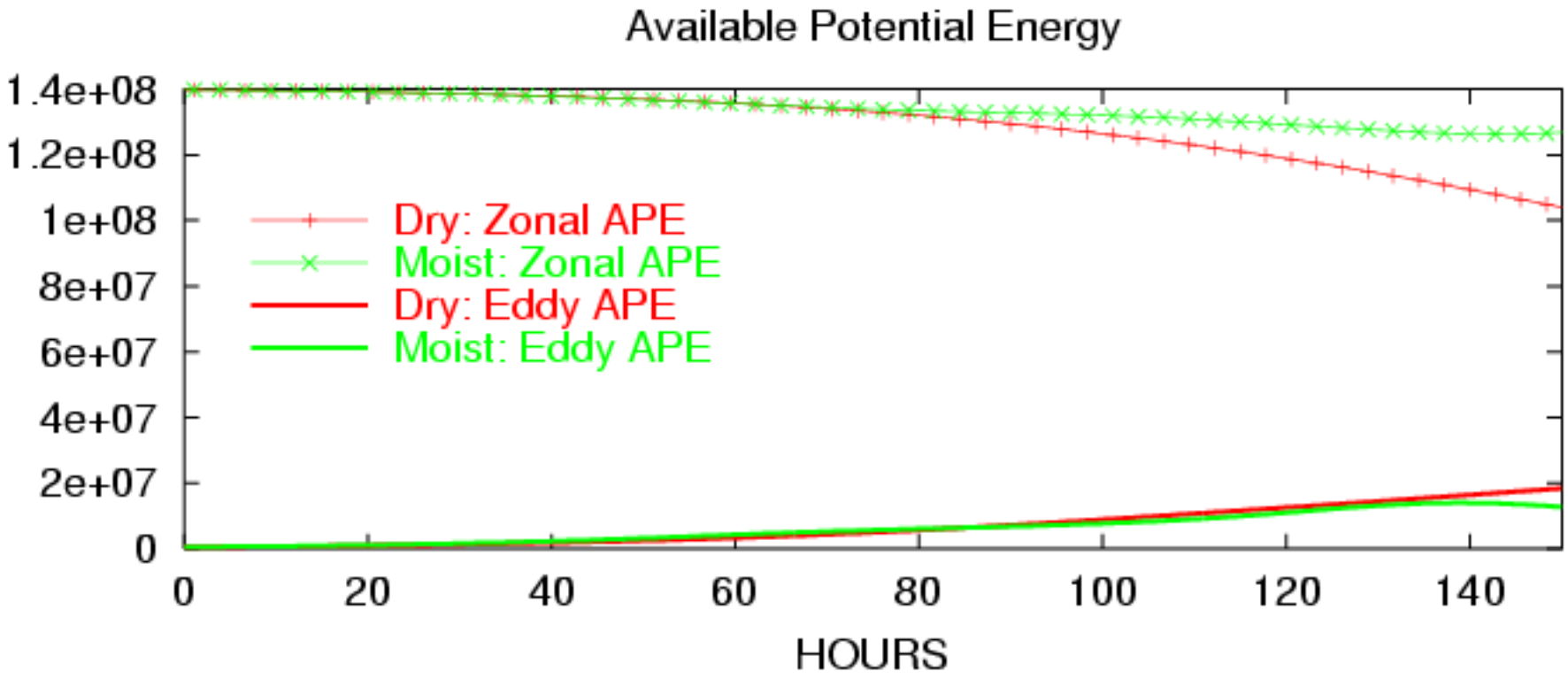
Warm front assumes a cyclonic curvature.

Moist cyclone grows faster even at this wavelength.
The moist most unstable wavelength (approx. 4000 km)
is trying to appear out of the background.

Shorter (meso-) scale features appear in later stages.

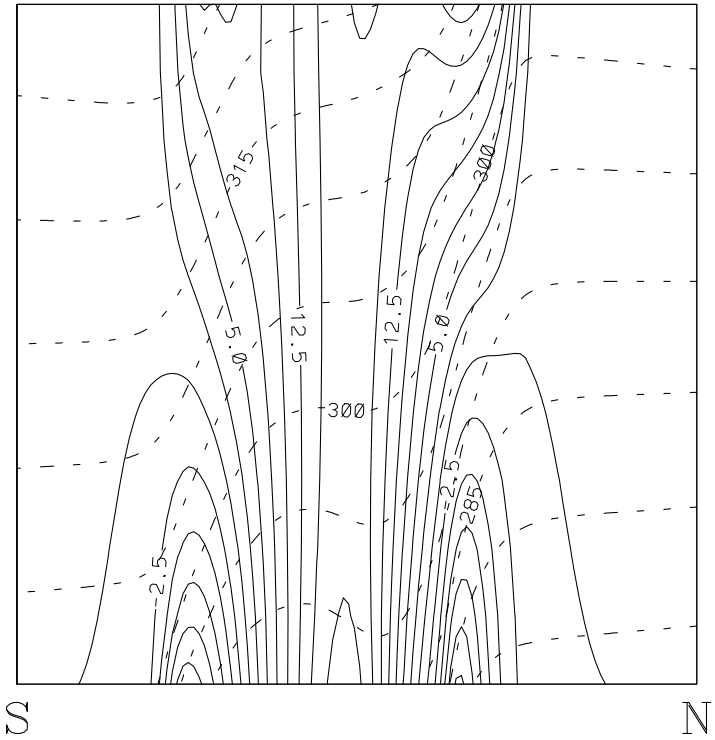
Deep structures confined to northern side of jet
where a strong baroclinic zone is reformed.

In "dry" final states baroclinicity in midlatitudes is destroyed. Easterly jets are formed near the surface at the sides of the original baroclinic zone. "Moist" final state has a strong baroclinic zone on the northern side where the perturbation can continue to grow. Zonal APE is depleted more slowly than in dry case (despite faster eddy growth)

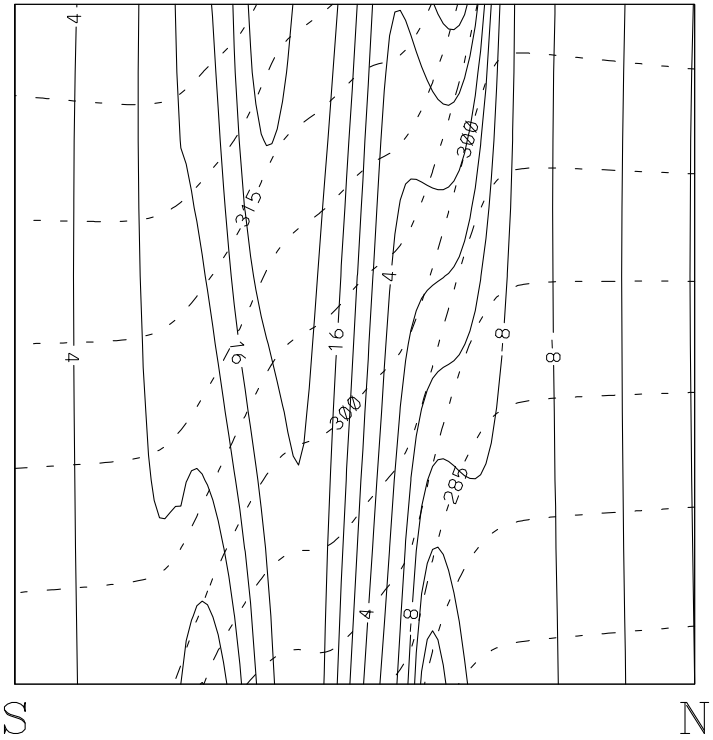


Final (150 hrs) mean zonal states for

LC1 DRY



LC2 DRY



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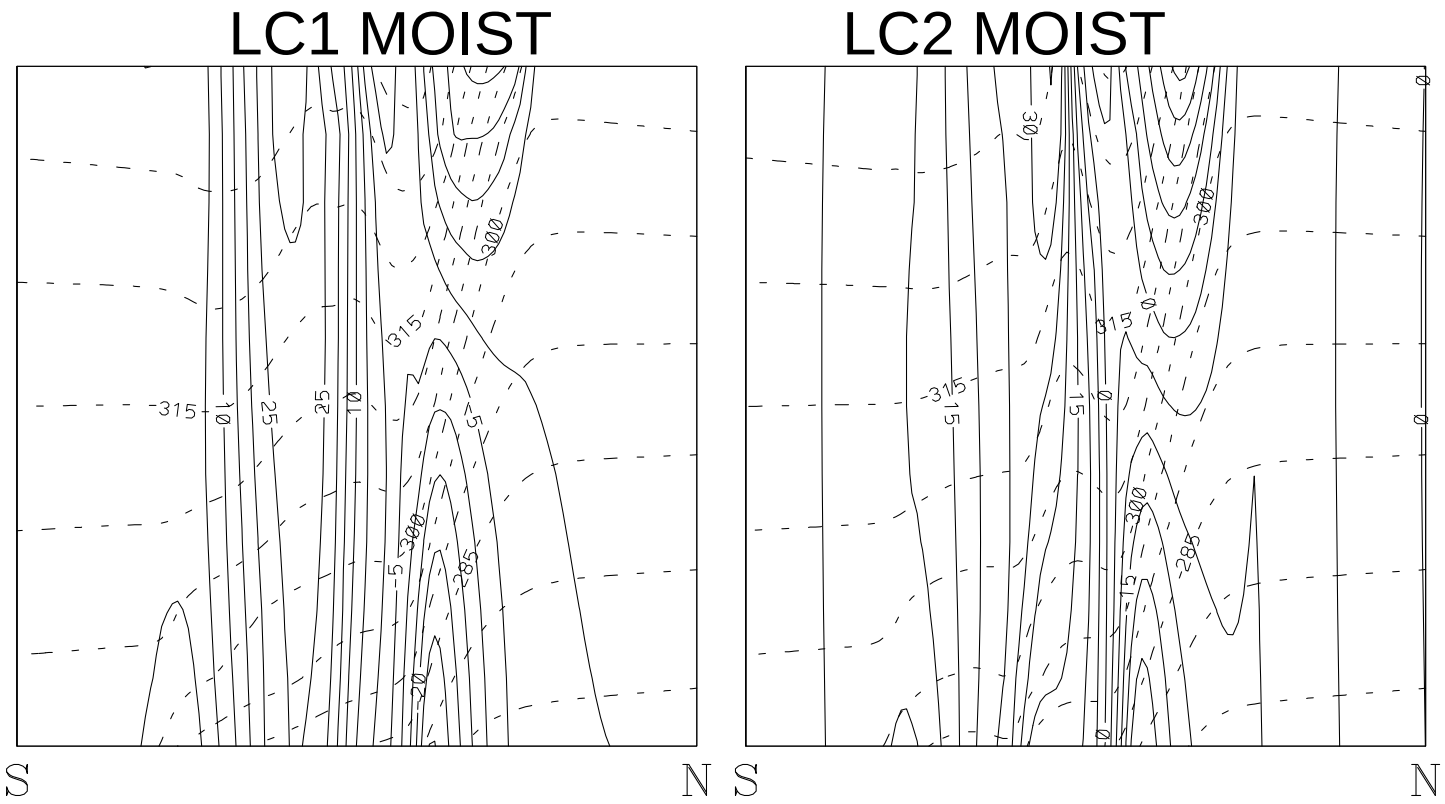
Final (150 hrs) mean zonal states for



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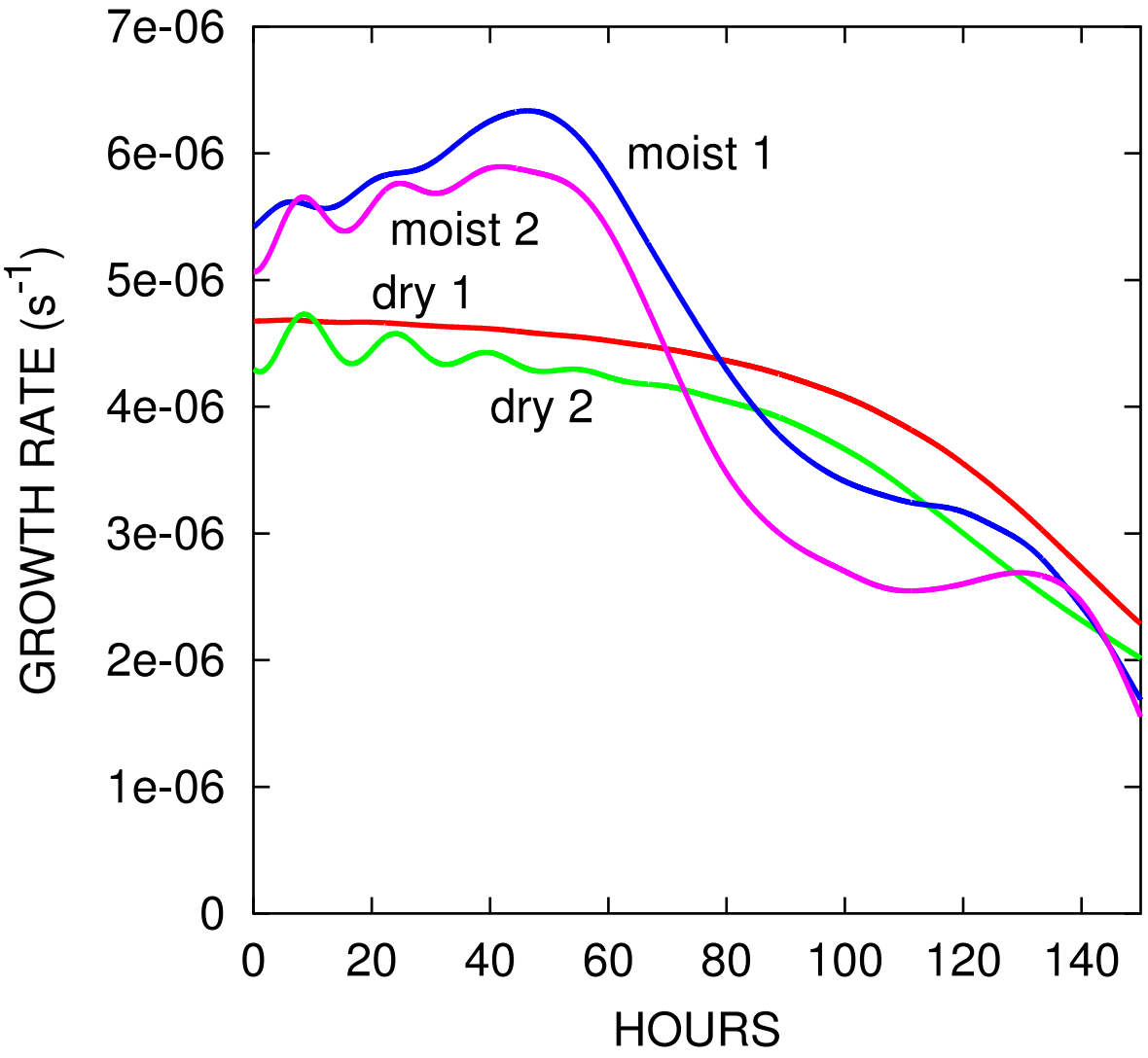
Growth Rates

$$\sigma = \frac{1}{2\Delta t} \ln \left[\frac{EKE(t+\Delta t)}{EKE(t)} \right]$$



Energy: dominant terms

$$\frac{d}{dt}\int_V \frac{u'^2+v'^2}{2}dV = \frac{g}{\theta_o}\int_V w'\theta' dV + \cdots$$

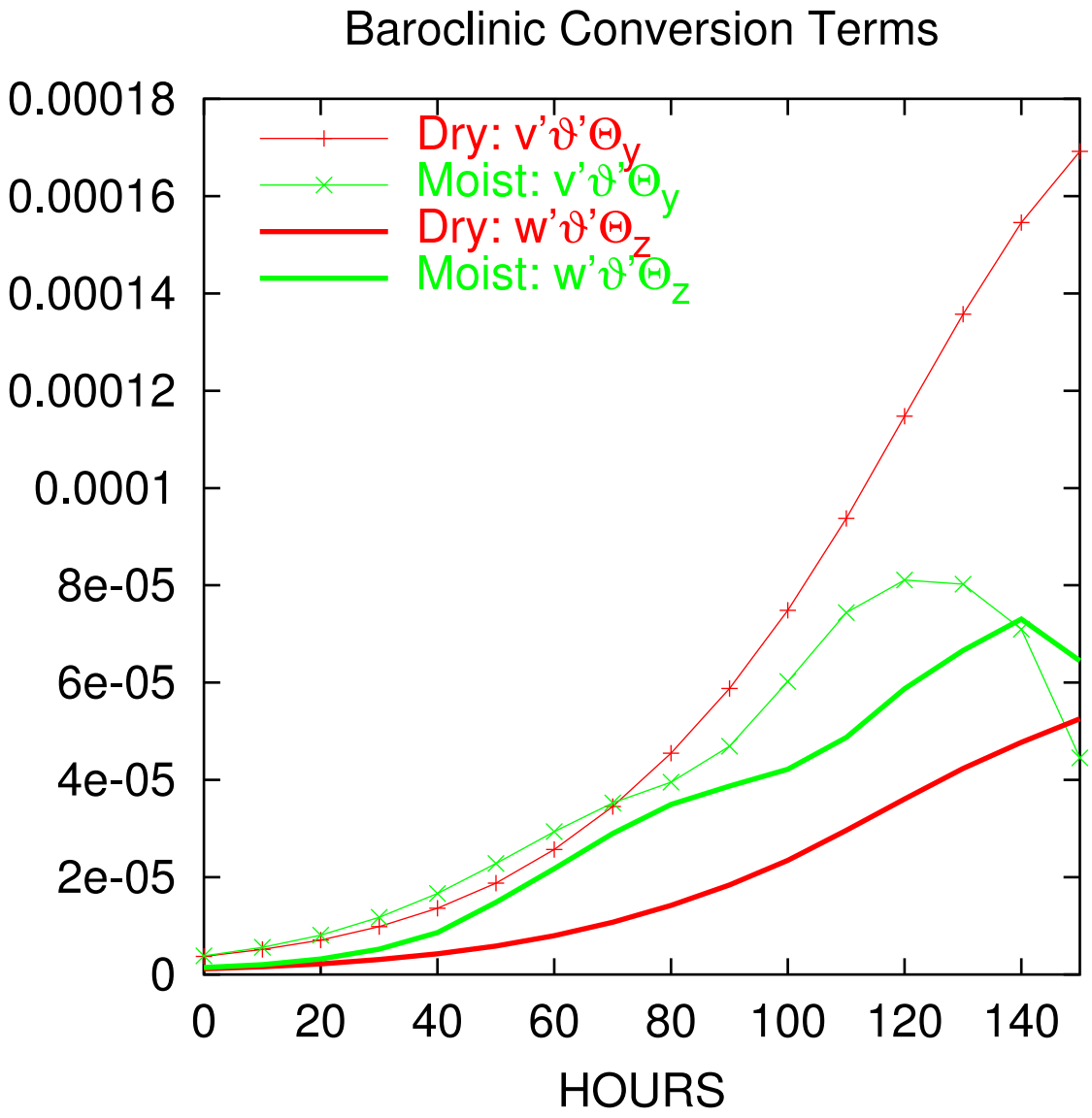
$$\frac{d}{dt}\int_V \frac{\theta'^2}{2}dV = -\int_V v'\theta'\bar{\theta}_y - \int_V w'\theta'\bar{\theta}_z + \cdots$$

baroclinic conversion

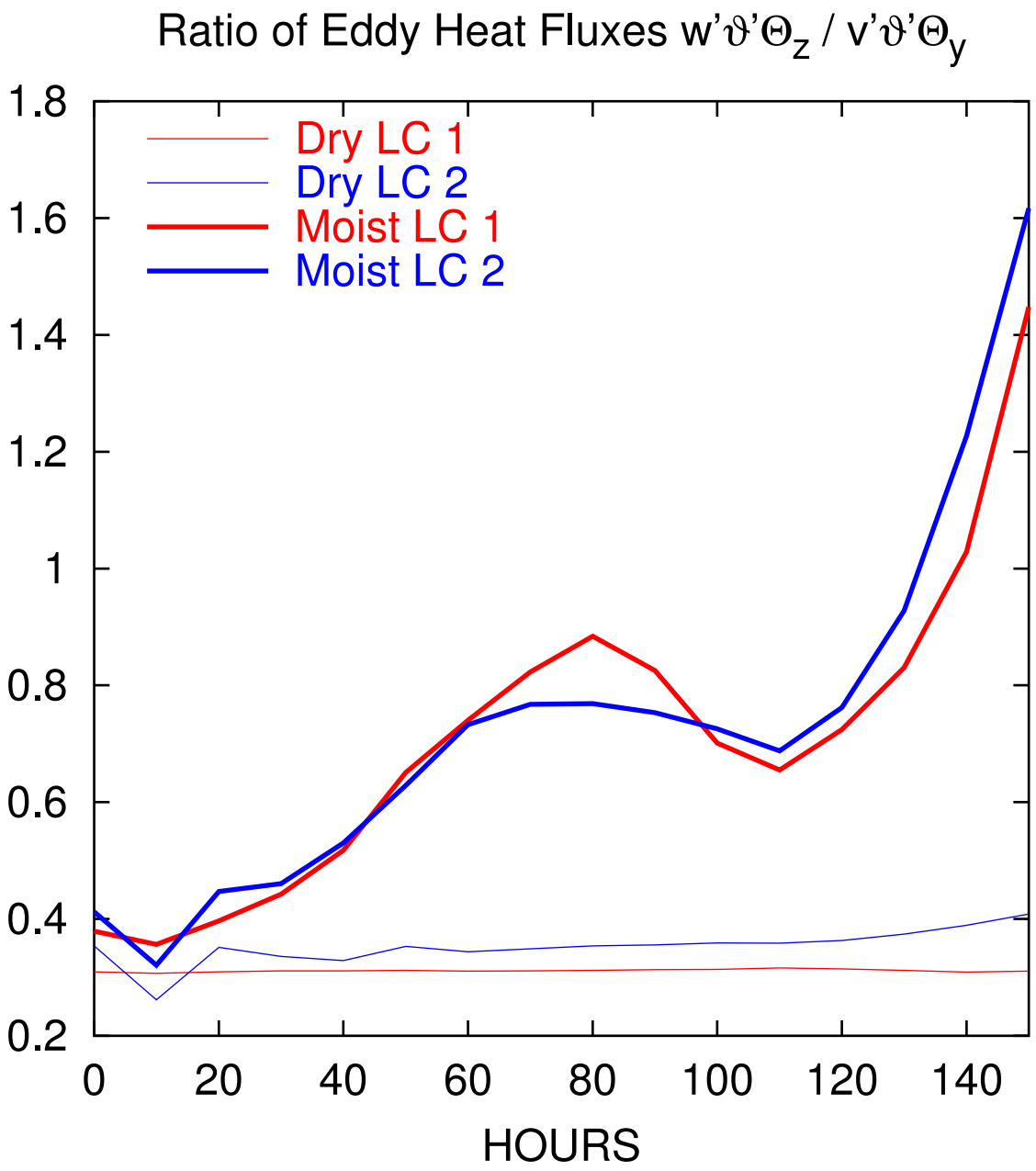
$\int_V w'\theta'\bar{\theta}_z dV$: Eddy APE $\longrightarrow$ Eddy KE

$\int_V v'\theta'\bar{\theta}_y dV$: Zonal APE $\longrightarrow$ Eddy APE

LIFE CYCLE 1



Moist w'Theta' includes energy from latent heat release



More energy appears in eddies than is removed from APE.
Latent heat as additional source for baroclinic development.

REFERENCES

Emanuel, K.A., M. Fantini and A.J. Thorpe, 1987, *JAS*

Fantini, M., 1997, *QJRMS*

Hoskins, B. J. and N. V. West, 1979, *JAS*

Thorncroft, C. D., B. J. Hoskins and M. E. McIntyre, 1993, *QJRMS*

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