Moisture Transport in Cyclone Waves

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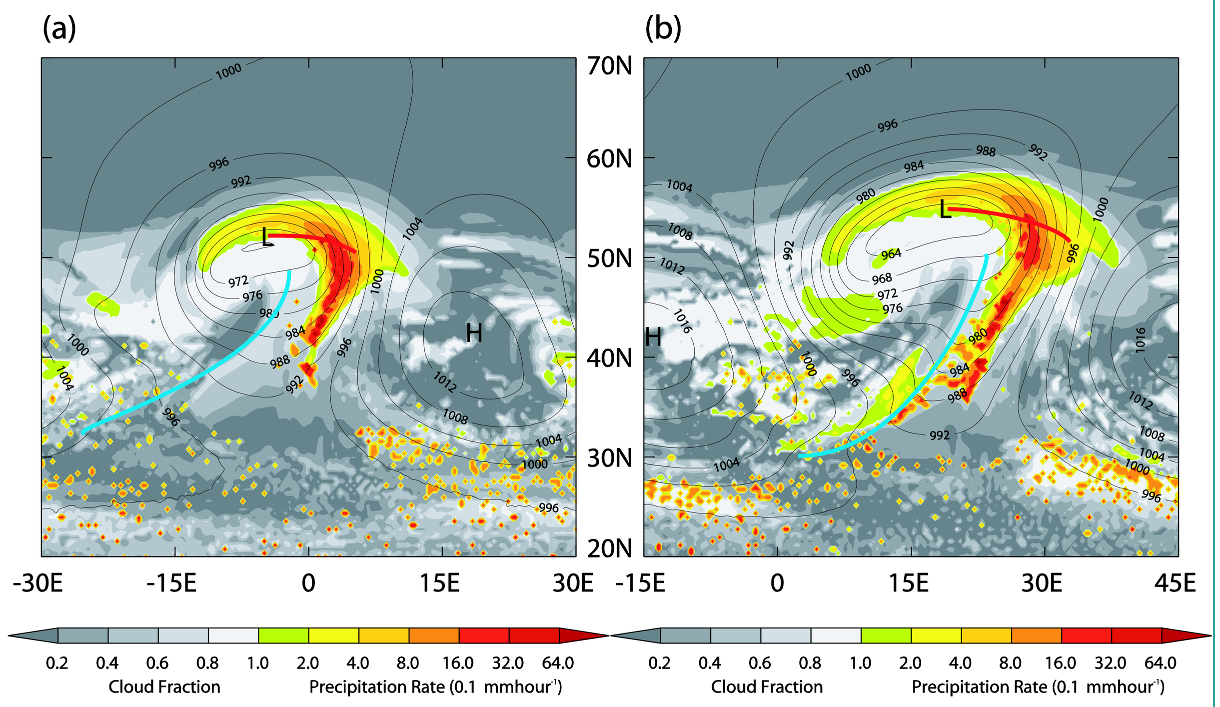
Introduction

Mid-latitude cyclone waves are key contributors to the poleward movement of atmospheric water vapour, but how is this transport achieved at the scale of individual storms? Warm-conveyor belts are often considered as the primary mechanism, but are other processes involved? We investigate how the atmospheric boundary layer plays a crucial role in the water cycle of a cyclone wave, and quantify how this cycle depends on large-scale and boundary-layer parameters.

I. Cyclone Simulation

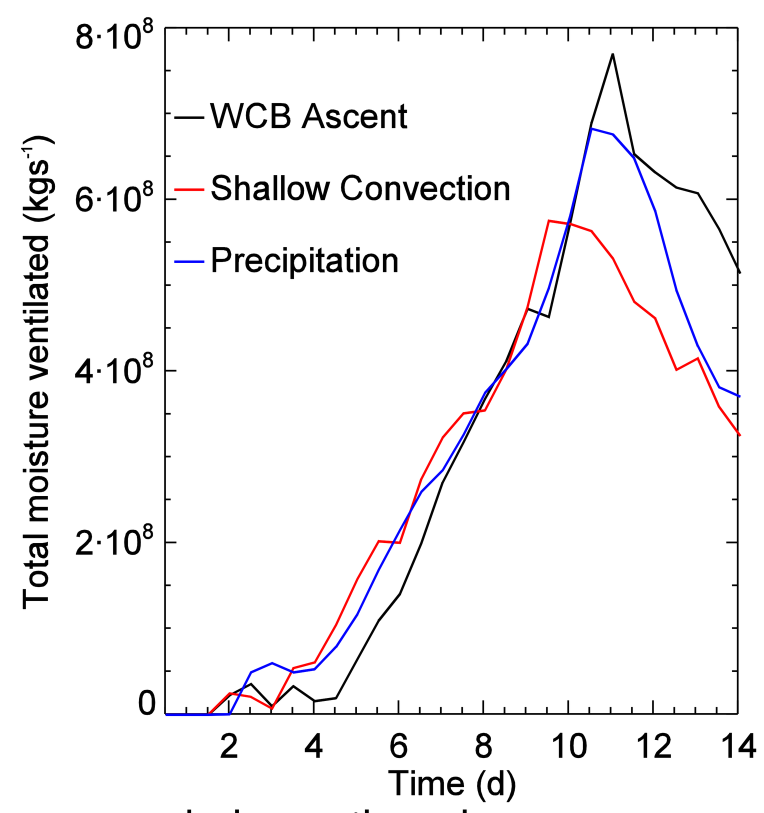
- The Met Office Unified Model is used in idealised configuration
- Cyclones are similar to LC1 (Thorncroft et al. 1993)
- Simulations include parameterisations of the boundary layer, microphysics, convection and cloud
- Same resolution as current operational global forecasts



- Realistic frontal features are formed
- Precipitation located within the warm-conveyor belt
- Shallow cumulus formed behind the cold front

III. Boundary layer Moisture Ventilation

- The total moisture flux out of the boundary layer is given by a spatial integration of terms (1) and (2)

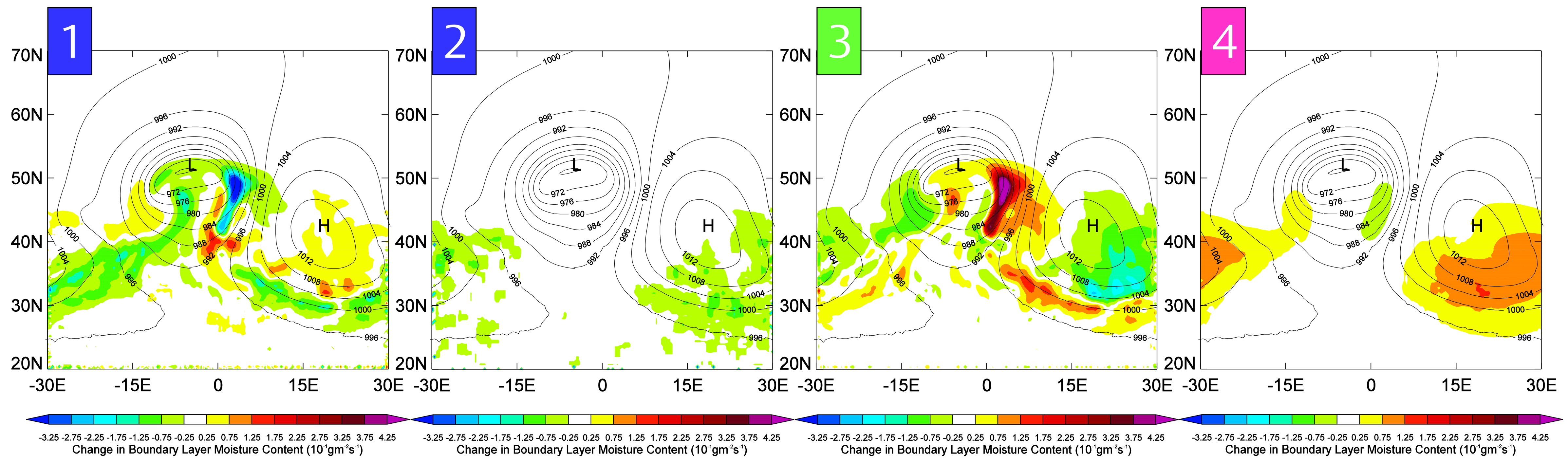


- Warm-conveyor belt ventilates large amounts of moisture, which is quickly and efficiently precipitated back to the surface
- Shallow convection ventilates similar amounts of moisture, but this stays within the troposphere, being moved polewards and towards the cold front by the jet

II. Boundary-layer Moisture Budget

$$\frac{\partial}{\partial t}\widehat{\rho q} = (\rho q)_h \frac{\partial h}{\partial t} - (\rho q)_h \mathbf{u.n} - \nabla_2.\widehat{\rho q \mathbf{v}} - (\overline{\rho w'q'})_h + (\overline{\rho w'q'})_0 + \hat{S}$$

- Rate of change of total moisture in the boundary layer
- Eulerian change in the boundary-layer height
- Transport across the boundary-layer top by resolved processes (1) and parameterised convection (2)
- Horizontal divergence within the boundary layer (3)
- Net vertical transport by boundary-layer turbulence (4)
- Source and sink from microphysical processes

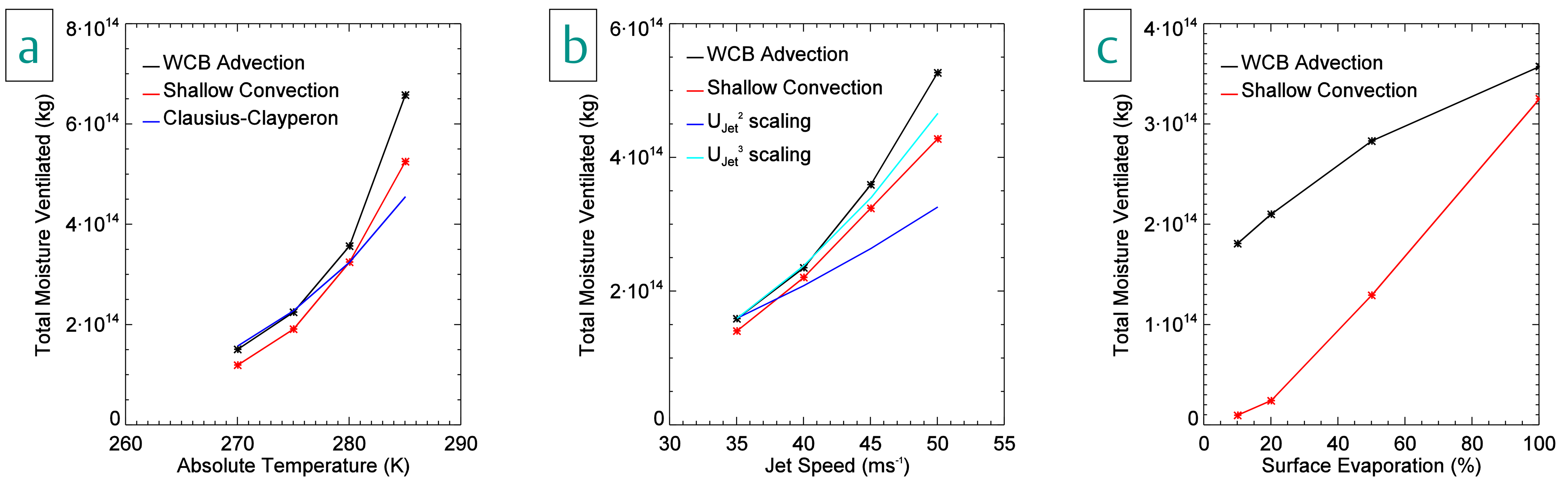


1. Strongest ventilation occurs in the warm-conveyor belt region
2. Large amounts of ventilation done by shallow convection behind the cold front
3. Divergent motions transport moisture from high pressure to low pressure within the boundary layer
4. Evaporation behind the cold front is the main source of moisture

Flow of moisture through boundary layer: 4 → 3 → 1

IV. Factors Influencing Moisture Transport

$$\text{Ventilation} = \iint (\rho q)_h \mathbf{u.n}\, dA\, dt$$



a. Warm-conveyor belt and shallow convective ventilation scale the same way. Both processes are governed by changes to q_h, given by the Clausius-Clayperon equation. However, at very high temperatures, increased moisture feeds back onto cyclone development, intensifying the system and increasing **u**.

b. Warm-conveyor belt and shallow convective ventilation scale the same way. Both processes are governed by changes in **u**, which scales like U_{Jet}^2 (Sinclair et al. 2009), and changes in q_h, which scales like U_{Jet}, giving an overall scaling of U_{Jet}^3.

c. Warm-conveyor belt and shallow convective ventilation scale differently. Large-scale dominated by reduced supply of moisture, reducing q_h. Convection is closely linked to surface evaporation and doesn't trigger at low evaporation rates, hence no ventilation. Linear increase since moisture input at the surface is just removed at the top of the convecting regions.

Conclusions

A budgeting technique has demonstrated the important role the atmospheric boundary layer plays in the water cycle of a mid-latitude cyclone wave. The moisture source for warm-conveyor belt precipitation is not local, within the low pressure system, but rather moisture is transported within the boundary layer from neighbouring systems. Shallow convection behind the cold front has been shown to be an equally important method of ventilating moisture from the boundary layer. Whilst large-scale atmospheric changes influence both ventilation processes in the same way, their dependence on the underlying boundary-layer structure is markedly different.

References

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