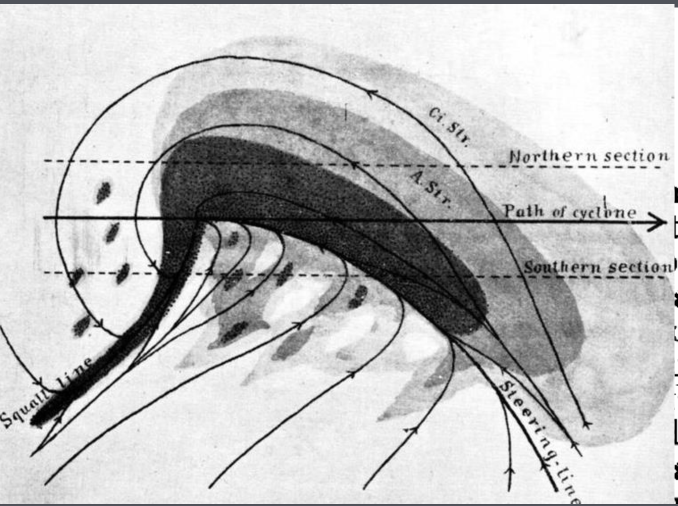
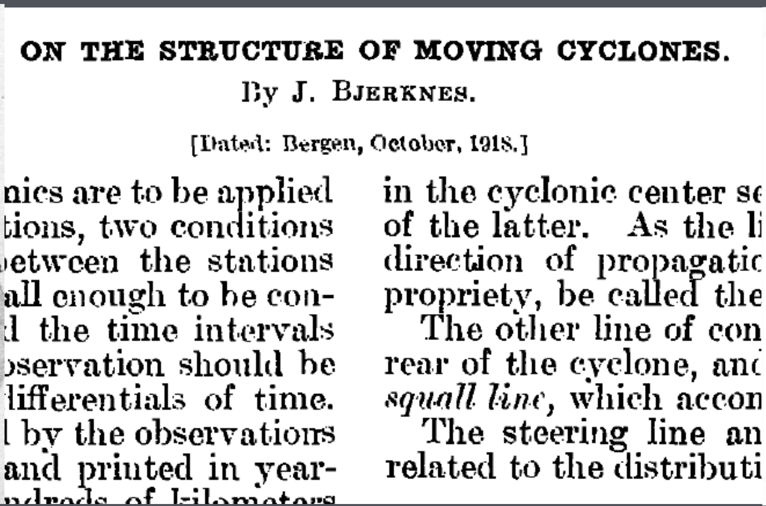
Department of Meteorology

Re-examining

‘~~RESOLVING~~ THE PERPLEXITY OF CYCLONE COMPLEXITY’ (Ralph Jewell)





ON THE STRUCTURE OF MOVING CYCLONES.

By J. Bjerknes.

[Dated: Bergen, October, 1918.]

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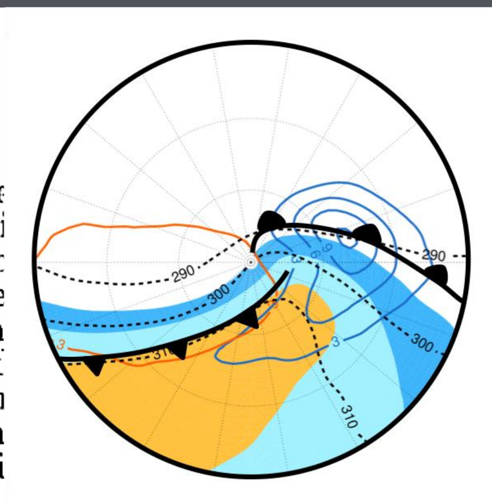
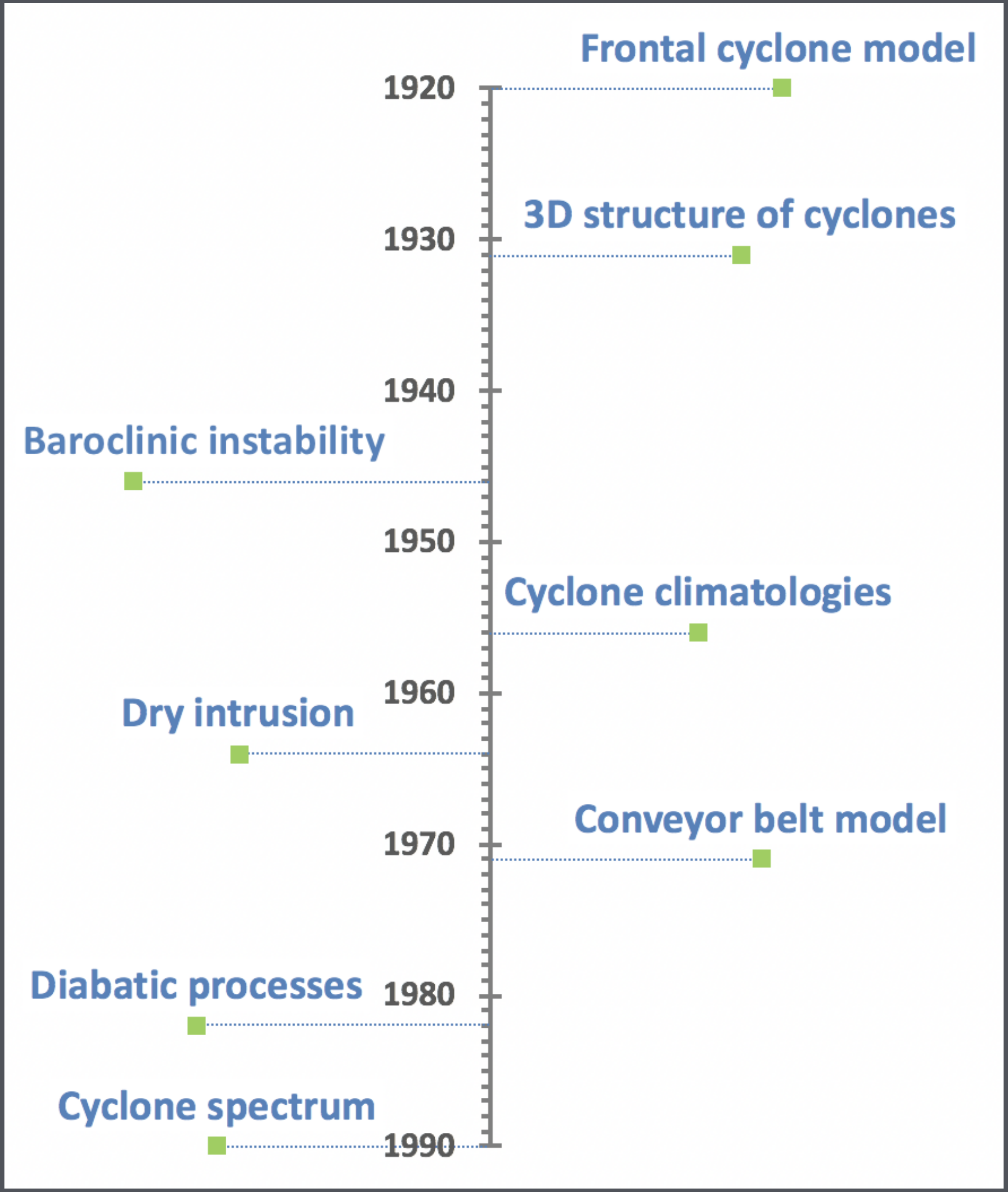


Bjerknes (1919). On the structure of moving cyclones. *Monthly Weather Review* **47**, 95–99
Dacre et al. (2019): Linking Atmospheric Rivers and Warm Conveyor Belt Airflows. *J. Hydromet.*, **20**, 1183–1196

Helen Dacre, O. Martinez-Alvarado and C. Mbengue

(With thanks to: J. Bjerknes, E. Palmen, S. Petterssen, E. Danielson, K. Browning, F.Sanders and many others)

Talk Outline



Review of synoptic extratropical cyclone research

- Conceptual models
- Reconciling the atmospheric river and warm conveyor belt conceptual models of moisture transport

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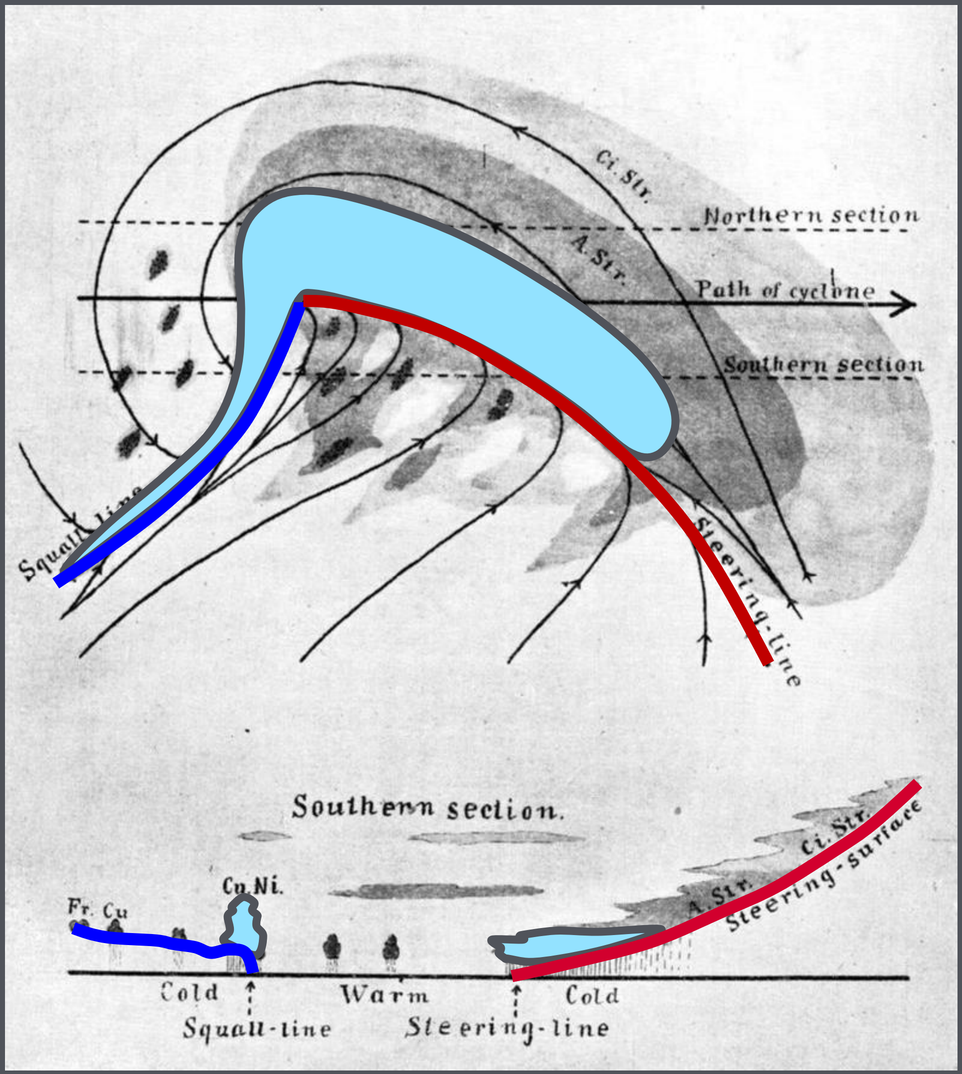
1920s Lifecycle of cyclones



Bjerknes, J. (1919). On the structure of moving cyclones. *Monthly Weather Review* **47**, 95–99.

European telegraph network

Bjerknes (1919) includes a description of:

- warm and fronts
- evolution of clouds and precipitation along frontal zones

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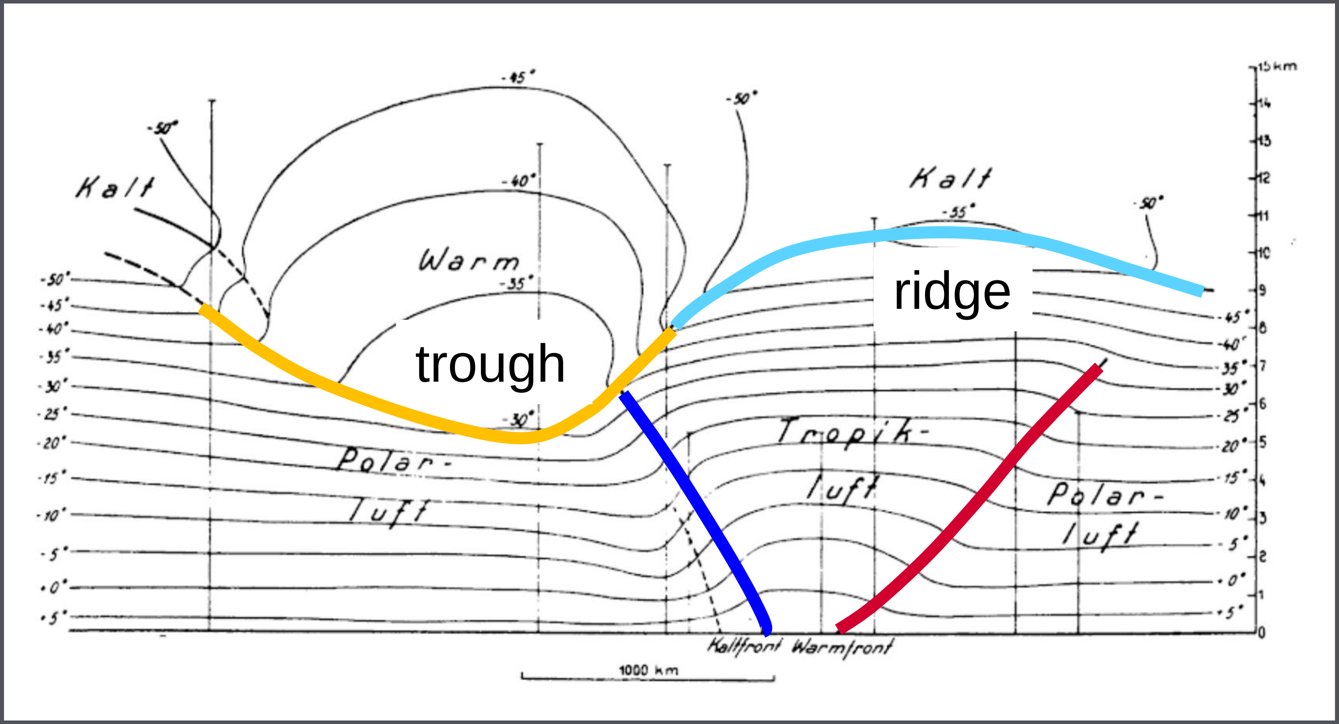
1930s 3D structure of cyclones

Palmén (1931) described the 3D structure of cyclones including:

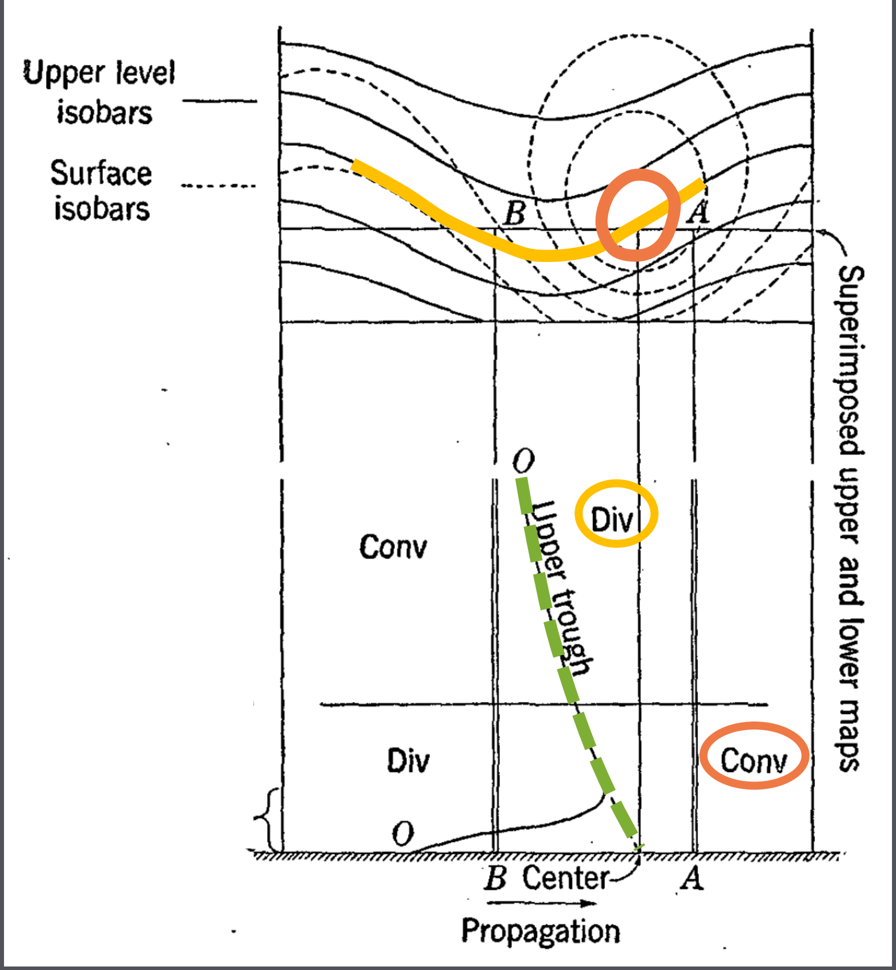
- Warm low tropopause heights over cold air sector
- Cold high tropopause height over warm air sector



Balloon borne instruments

Palmen, E. (1931). Zur Bestimmung des Triftstromes aus Terminbeobachtungen. *ICES Journal Marine Science*, *6*(3), pp.387-401

1940s Cyclone Development Mechanisms



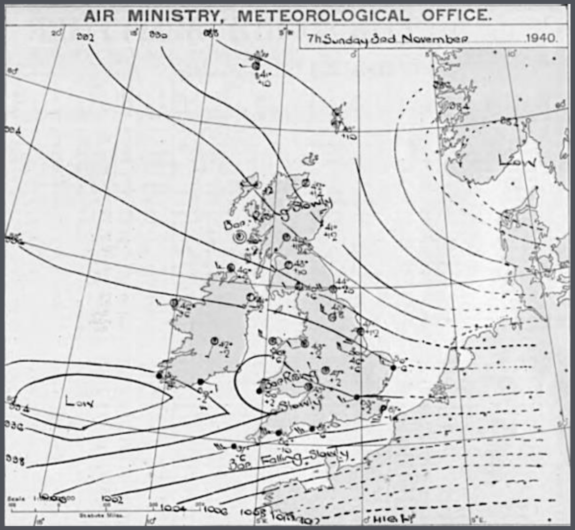
Bjerknes, J. and Holmboe, J., 1944. On the theory of cyclones. *Journal of Meteorology*, *1*(1), pp.1-22

Bjerknes and Holmboe (1944) explained:

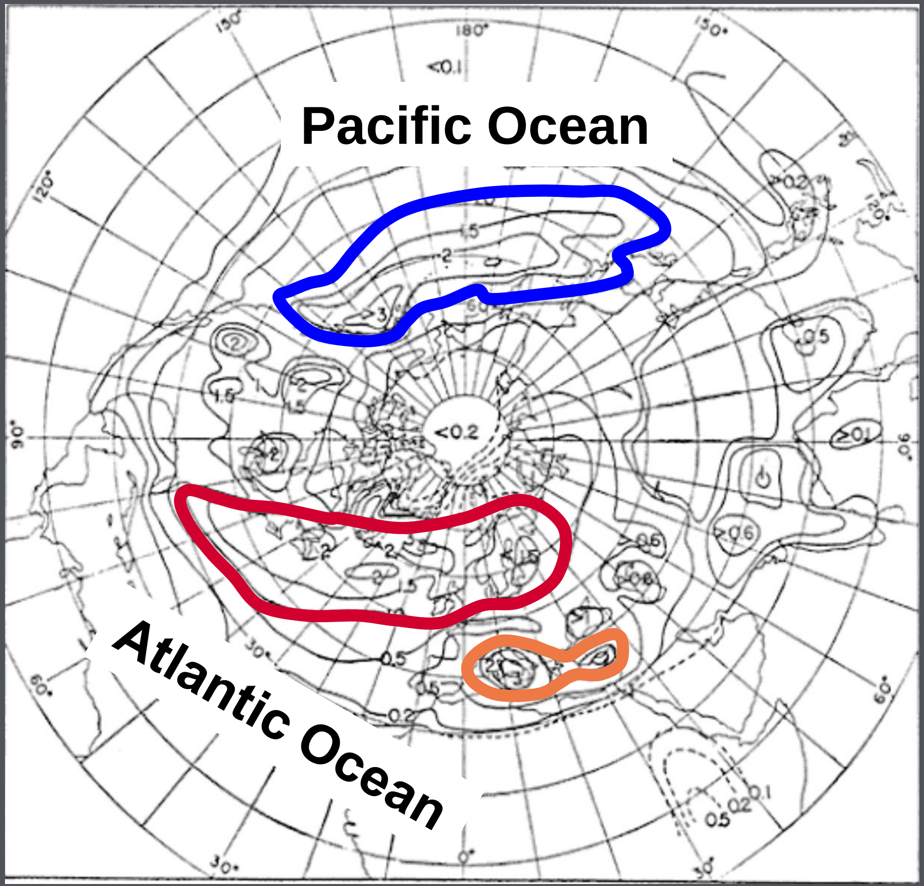
- divergence ahead of upper-level trough
- westward tilt with height of cyclone and trough axis
- lower-tropospheric convergence
- the interaction between upper and lower-levels in sheared environment (baroclinic instability)

1950s Cyclone Climatology

Studies of daily manually analysed synoptic charts



Daily manually analysed synoptic charts



Petterssen, S., 1956. *Weather analysis and forecasting* (No. 551.59 P48)

Petterssen (1956) constructed a cyclone climatology identifying storm tracks in:

- North Atlantic
- Pacific
- Mediterranean

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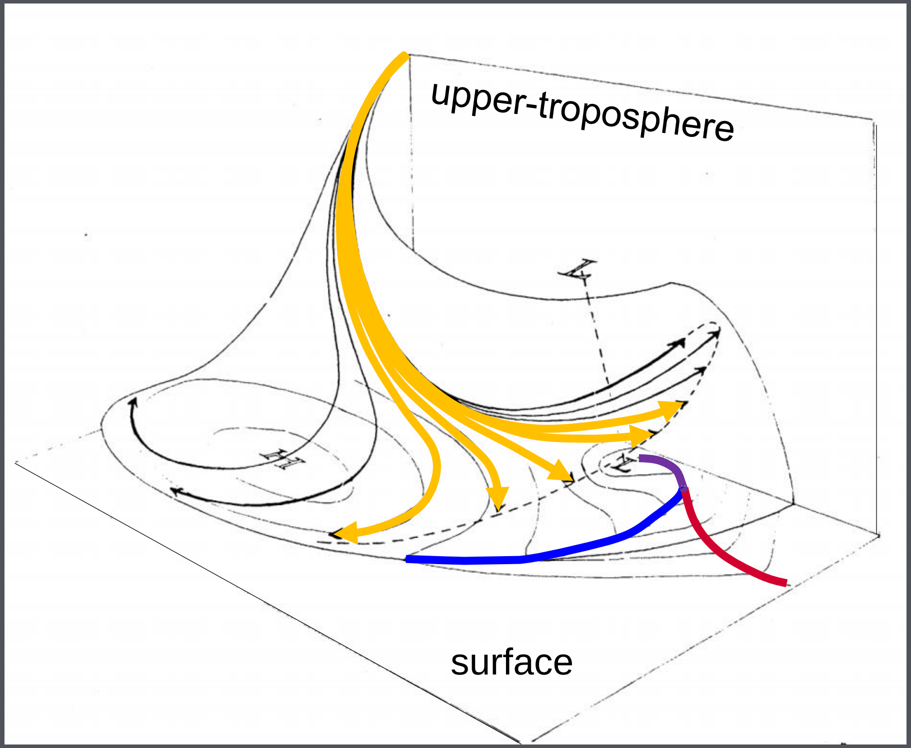
1960s Cyclone Airflows

Studies of radioactive debris above atomic test sites increased the availability of research aircraft observations

Atomic weapons testing

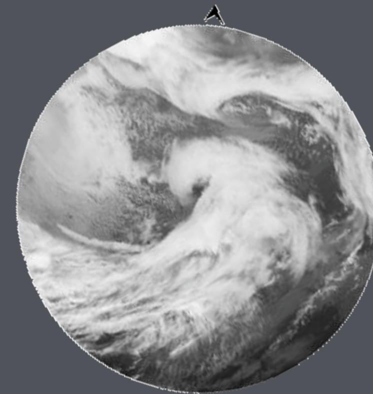


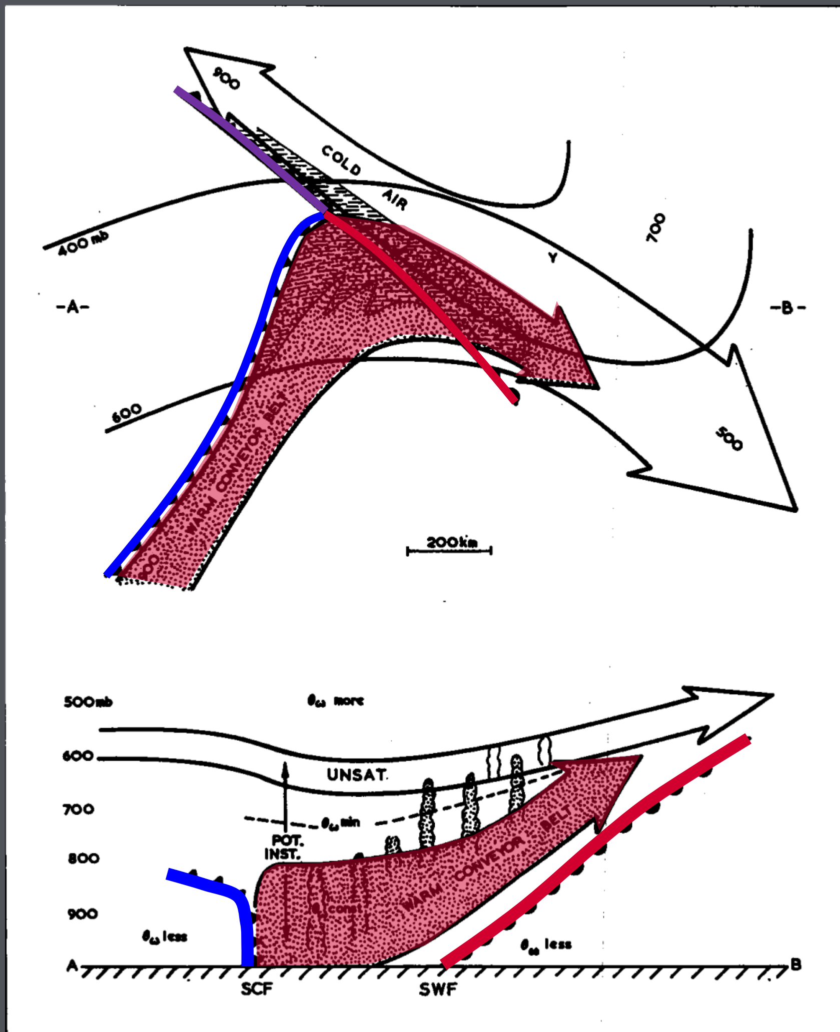
Danielsen, E.F., 1964. *Project springfield report*. Isotopes Inc Westwood NJ.

Danielson (1964) discovered:

- Air descending from the upper-troposphere to the surface behind the cyclone
- The existence of comma cloud shape in clouds (prior to widespread satellite obs)

1970s Cyclone Airflows





Combination of radar images, satellite observations and system-relative flow analysis

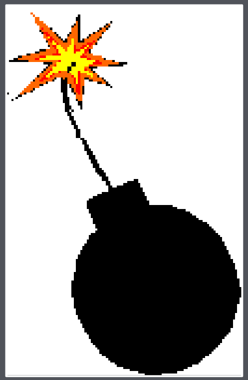
Browning (1971) identified:

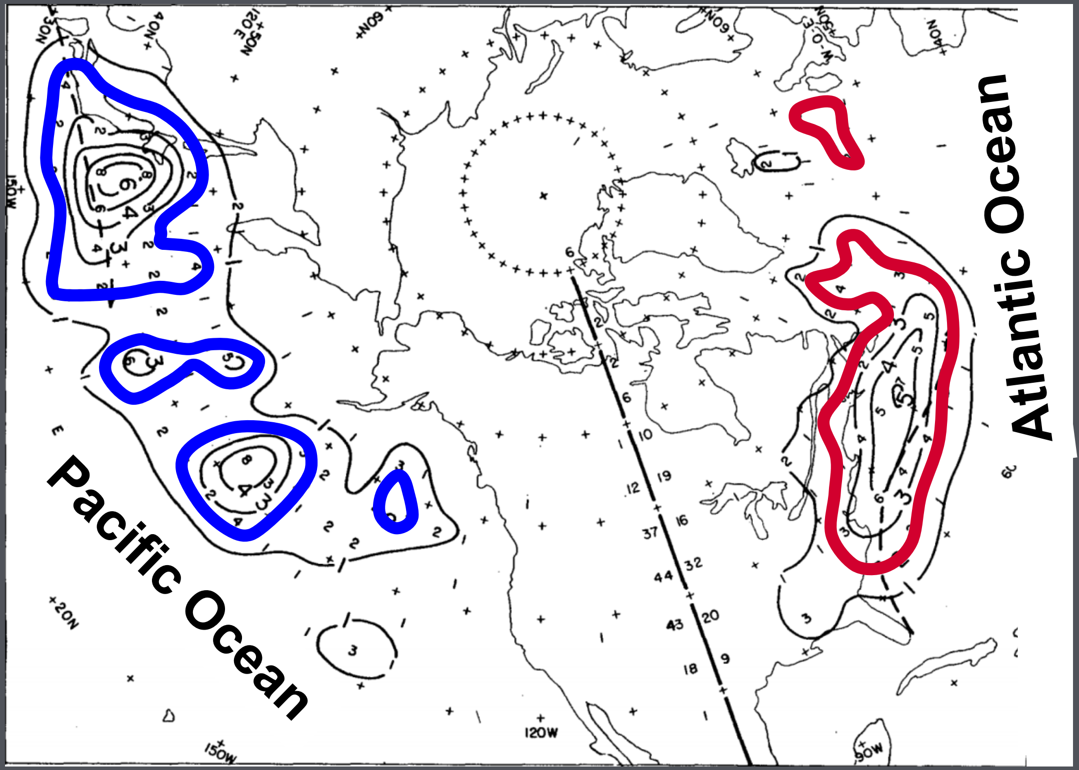
- Region of ascent associated with the comma-shaped cloud
- Known as the warm conveyor belt

Browning, K.A., 1971. Radar measurements of air motion near fronts. *Weather*, *26*(8), pp.320-340.

1980s Moist Processes

Sanders and Gyakum (1980) investigated the climatology of explosively deepening cyclones - ‘bombs’

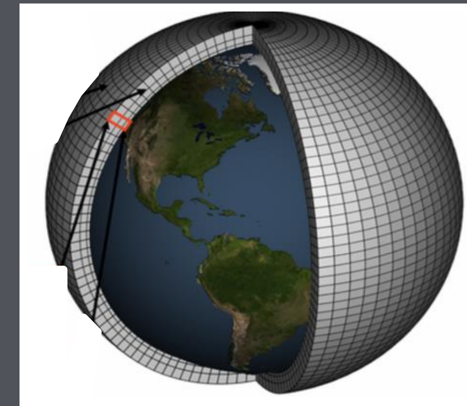




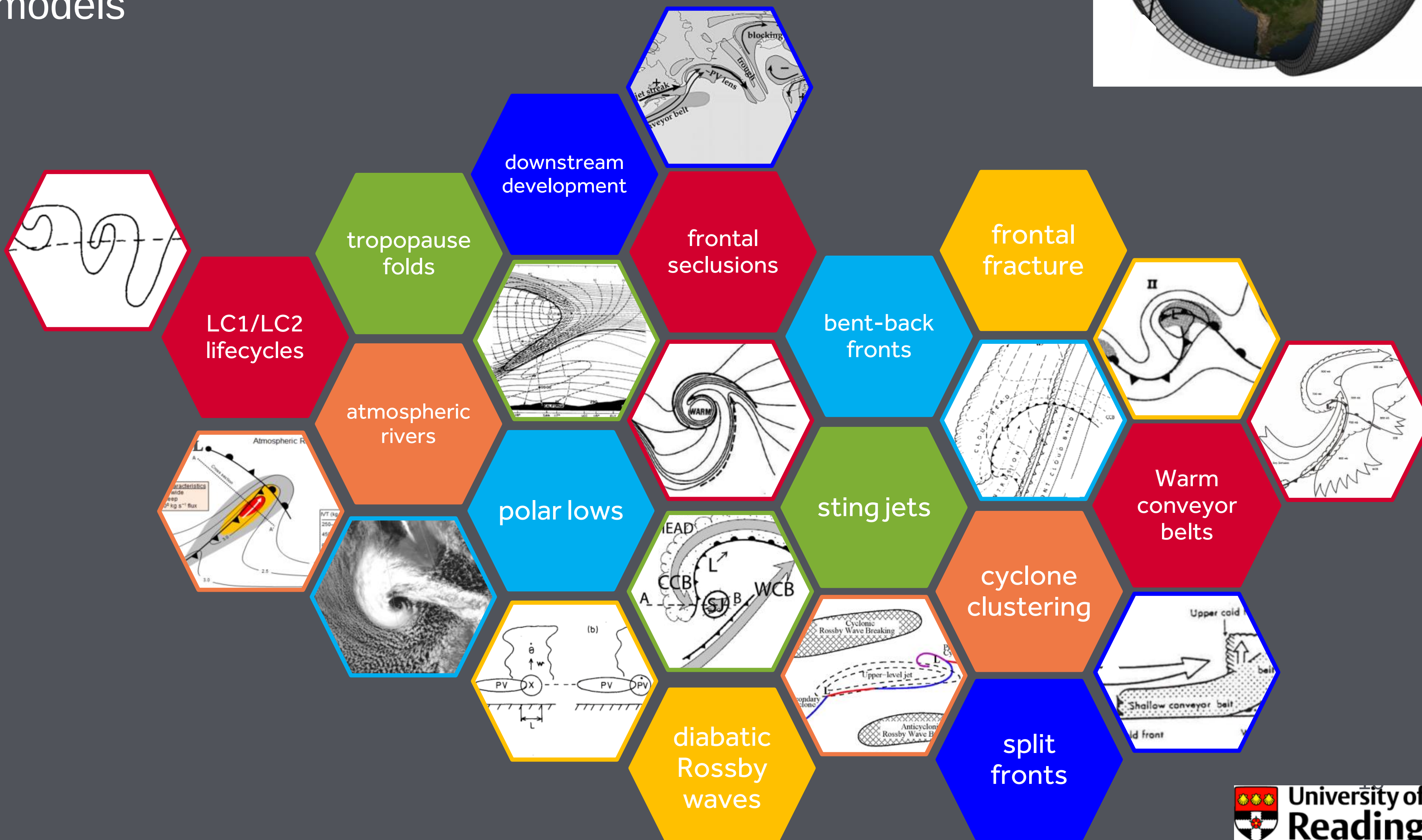
- Deepening rates were faster for marine cyclones than continental cyclones
- Stimulated research into the importance of surface fluxes, convection and latent heat release in cyclones

Sanders, F. and Gyakum, J.R., 1980. Synoptic-dynamic climatology of the “bomb”. *Monthly Weather Review*, *108*(10), pp.1589-1606.

1990s – now Numerical Modelling



In the last 30 years advances in computational modelling has led to a continuum of new conceptual models



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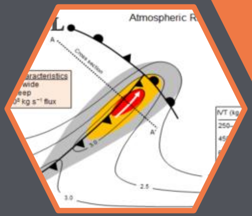
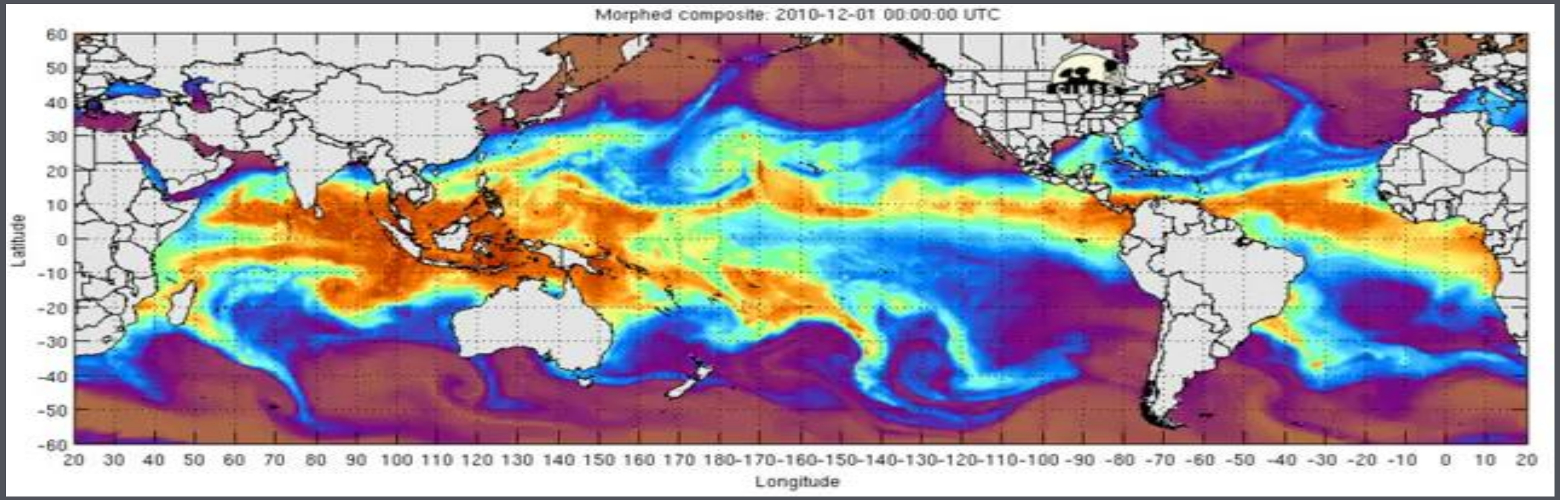
How are atmospheric rivers and warm conveyor belts linked?



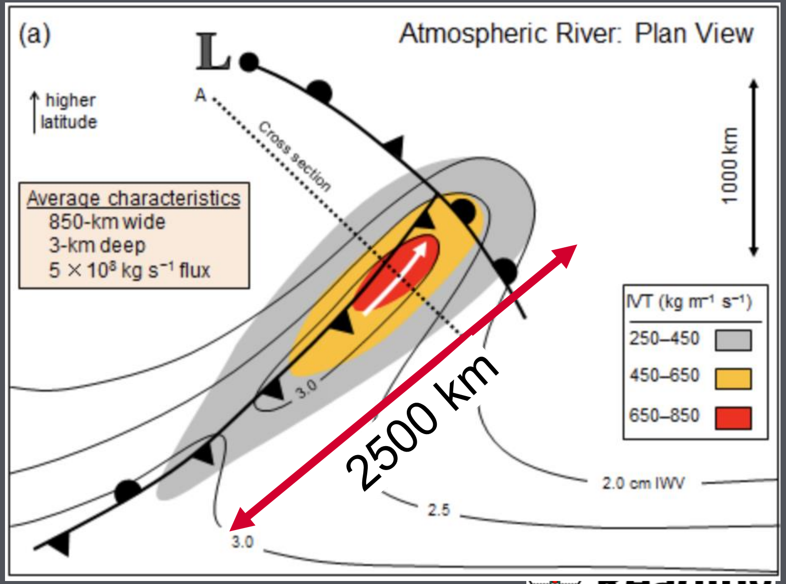
atmospheric rivers

Warm conveyor belts

What are atmospheric rivers?

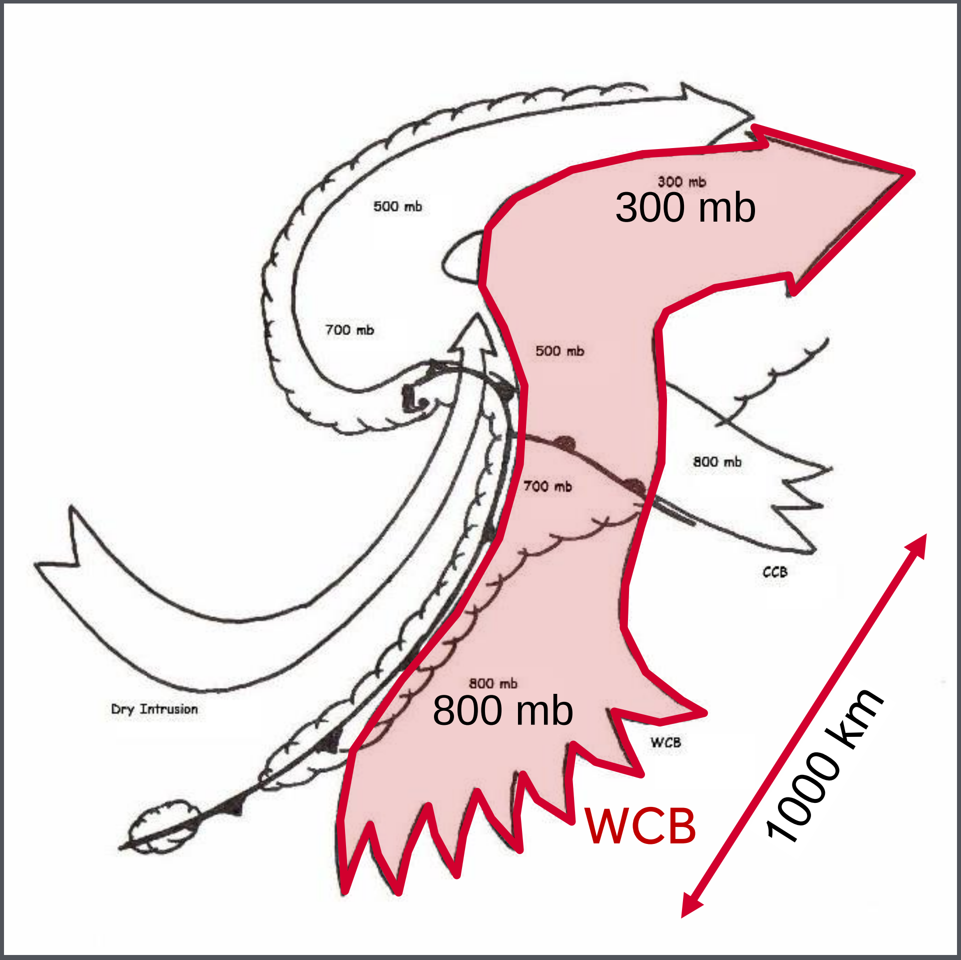


- 2D filaments of high TCWV flux extending from the subtropics - termed atmospheric-rivers (Newell et al. 1992)
- ARs structure (WMO):
  - shallow (3 km deep)
  - narrow (850 km wide)
  - elongated (> 2000 km in length)
  - water vapour flux (> 250 kg/m/s)



What are warm conveyor belts?

- Cyclone airstream analysed in a cyclone-relative framework
- Subtract vectorially cyclone propagation velocity from absolute wind velocity
- Cyclone-relative winds are represented on surfaces of constant θ or θ_w
- WCB is a cyclone-relative airstream on a warm θ_w surface ascending by ~ 600hPa from the top of boundary layer to upper-troposphere



Adapted from Carlson (1980)

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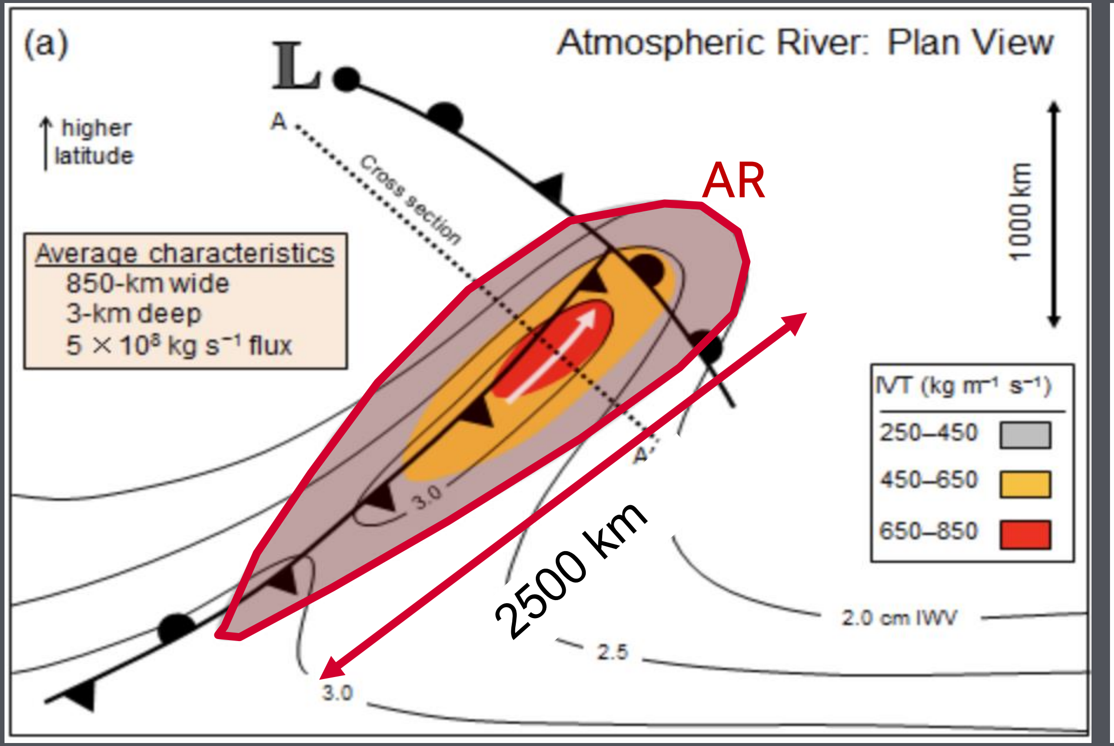
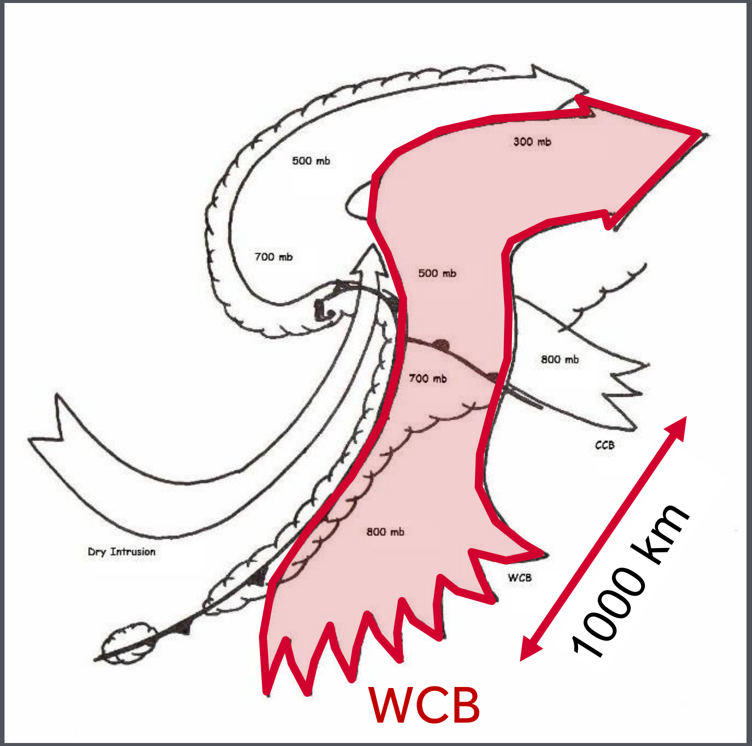
How are warm conveyor belts and atmospheric rivers linked?

Schematic of an atmospheric river airstream



Schematic of a warm conveyor belt airstream



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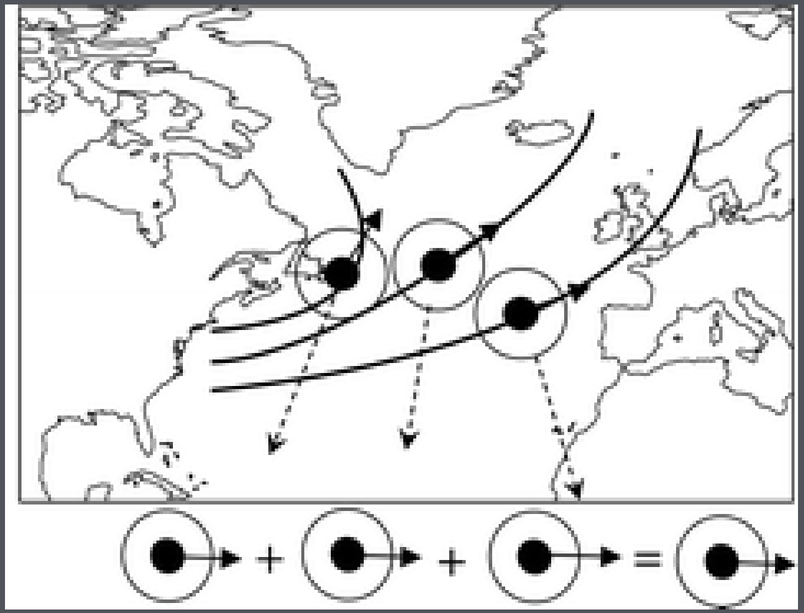
Cyclone Compositing Method

Dacre et al. (2012)

Catto et al. (2010)



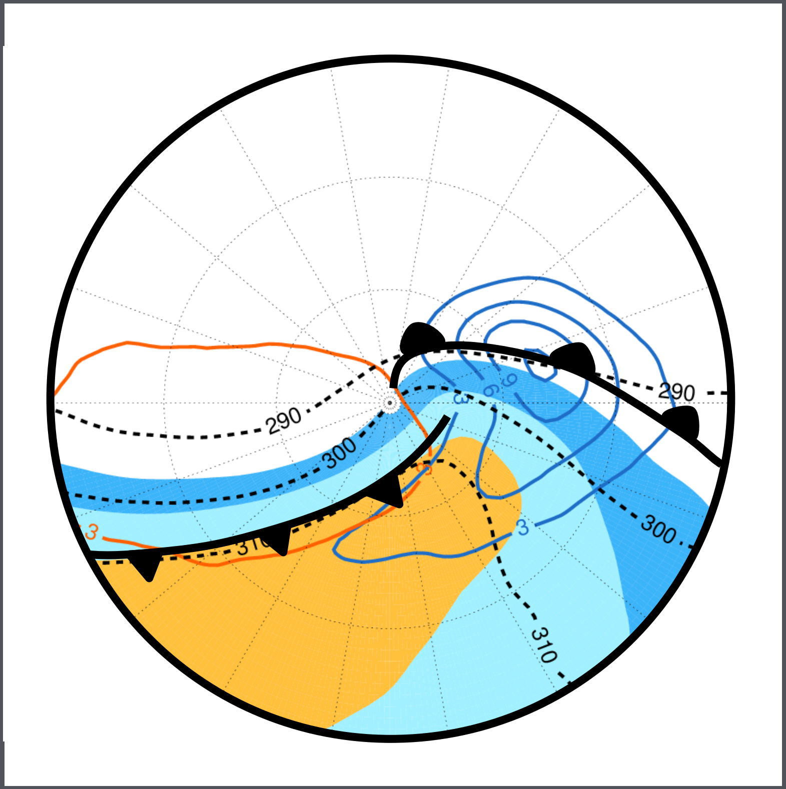
1. Extract fields from ERA-I along cyclone tracks within 1500km radius surrounding the identified cyclone position
2. Rotate cyclone centred fields so direction of travel is left to right
3. Average 200 most intense cyclones at times relative to max intensity

A band of high TCWV is located ahead of the cold front

Composite cyclone-centred fields 24 hours prior to time of maximum intensity

3000km

Cyclone propagation



TCWV (filled contours, kg m^{-2}), 6-hr Precipitation (blue, mm), 6-hr Evaporation (orange, mm), 925 hPa θ_e (black dashed)

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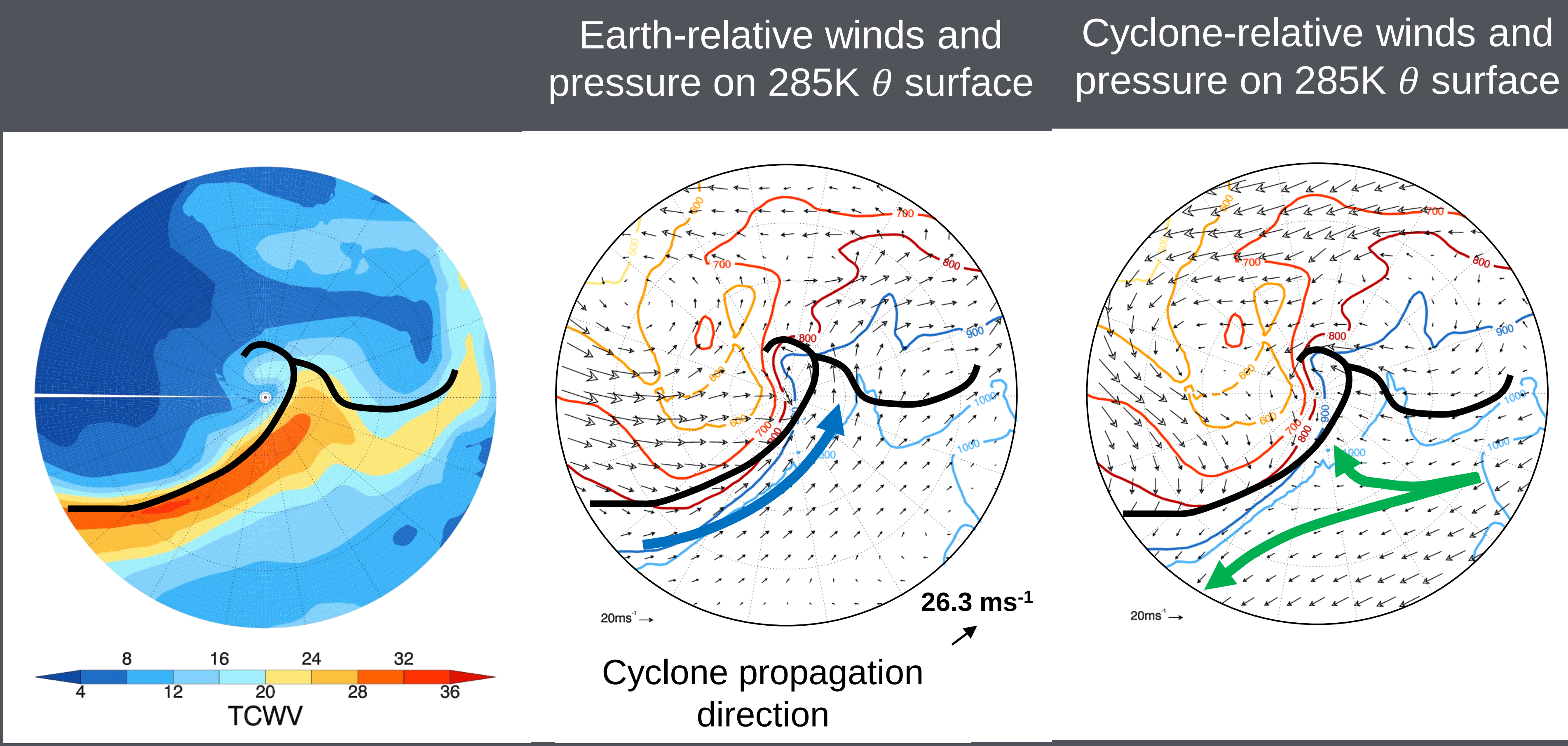
Cyclone relative airflows on isentropic surfaces



- Air is transported rearwards from the pre-cyclone environment towards the cold front
- The low-level cyclone-airflow (feeder airstream) splits into 2 branches at the cold front

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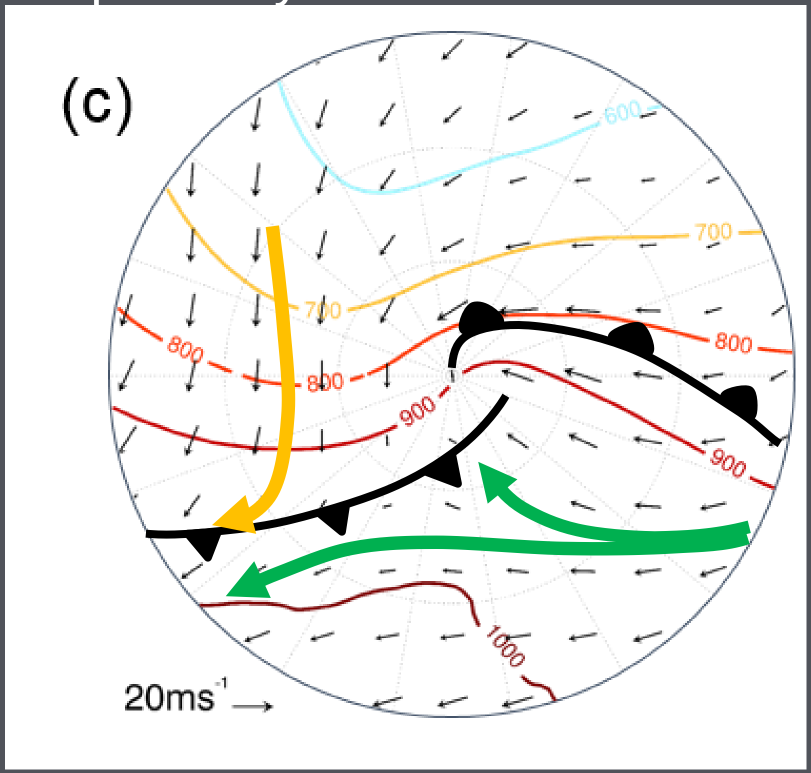
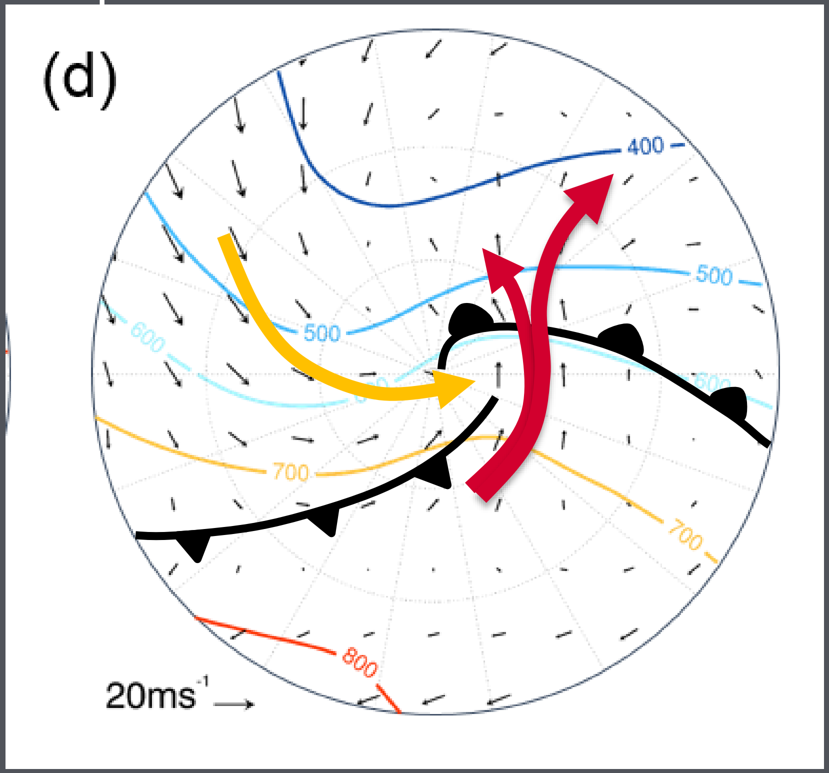
3D Cyclone relative airflows are identified on isentropic surfaces

Composite cyclone-centred fields 24 hours prior to time of maximum intensity



Pressure in hPa (contours) and cyclone-relative winds on 285 K θ surface



Pressure in hPa (contours) and cyclone-relative winds on 300 K θ surface

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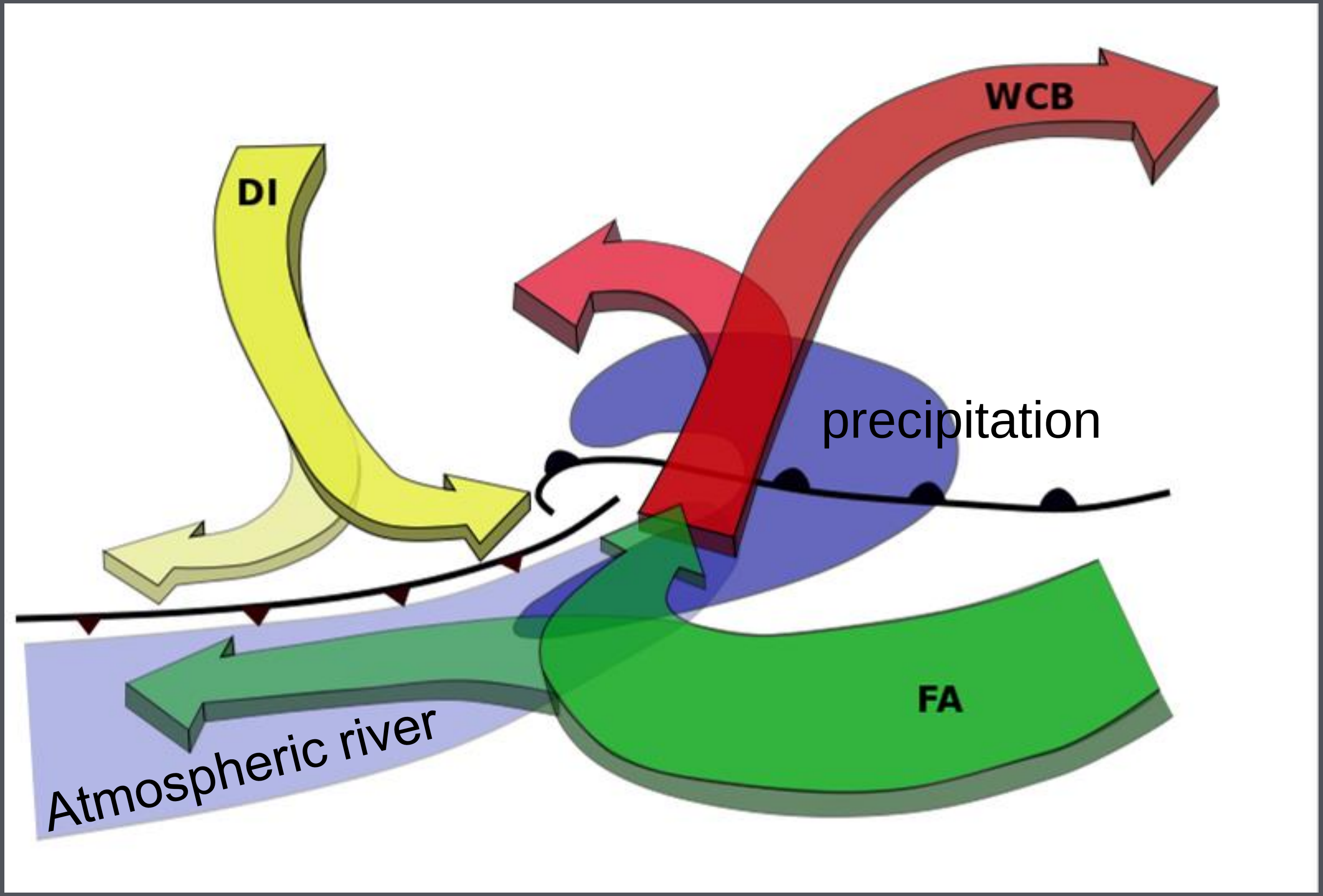
The feeder airstream transports air towards the cold front

Schematic of cyclone-relative airflows overlaid on surface features



Precipitation (dark blue), high TCWV (light blue), Warm conveyor belt (red), Dry intrusion (yellow), Feeder airstream (green)

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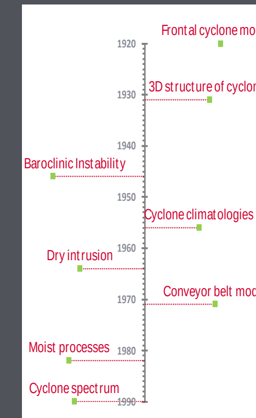
Summary and Future Work

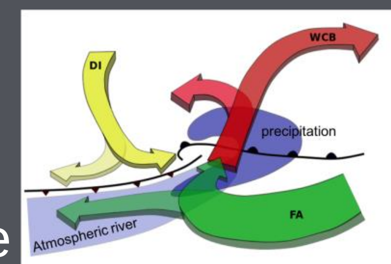


Progress in synoptic cyclone research since 1919

- Cyclone lifecycles, 3D structure, development mechanisms, climatologies, cyclone airflows, moist processes …

How are atmospheric rivers and warm conveyor belts linked?

- Feeder airstream transports moisture to the base of the WCB where it then ascends
- Feeder airstream exports moisture from the cyclone creating a filament of high TCWV marking track of cyclone



What's still left to understand about extratropical cyclones?

- Moist processes – ridge formation, tropopause evolution, downstream development, sting jet formation, embedded convection …
- Coupling – air-sea fluxes, aerosol-cloud interaction, wave-atmosphere ..
- Climate change – number, intensity, location, structure …
- Reconciling weather and climate perspectives of cyclones

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