

# **The atmospheric circulation of the EBUSs: the coastal inversion, winds, and weather systems**

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# **Outline:**

**I. Coastal inversion and the coastal jet**

**II. Tropospheric temperatures and the inversion**

**III. Weather systems**

**IV. Observations and models**

# **I. The coastal inversion and the coastal jet**

# ERA-Interim: zonal section along 22.5S, October

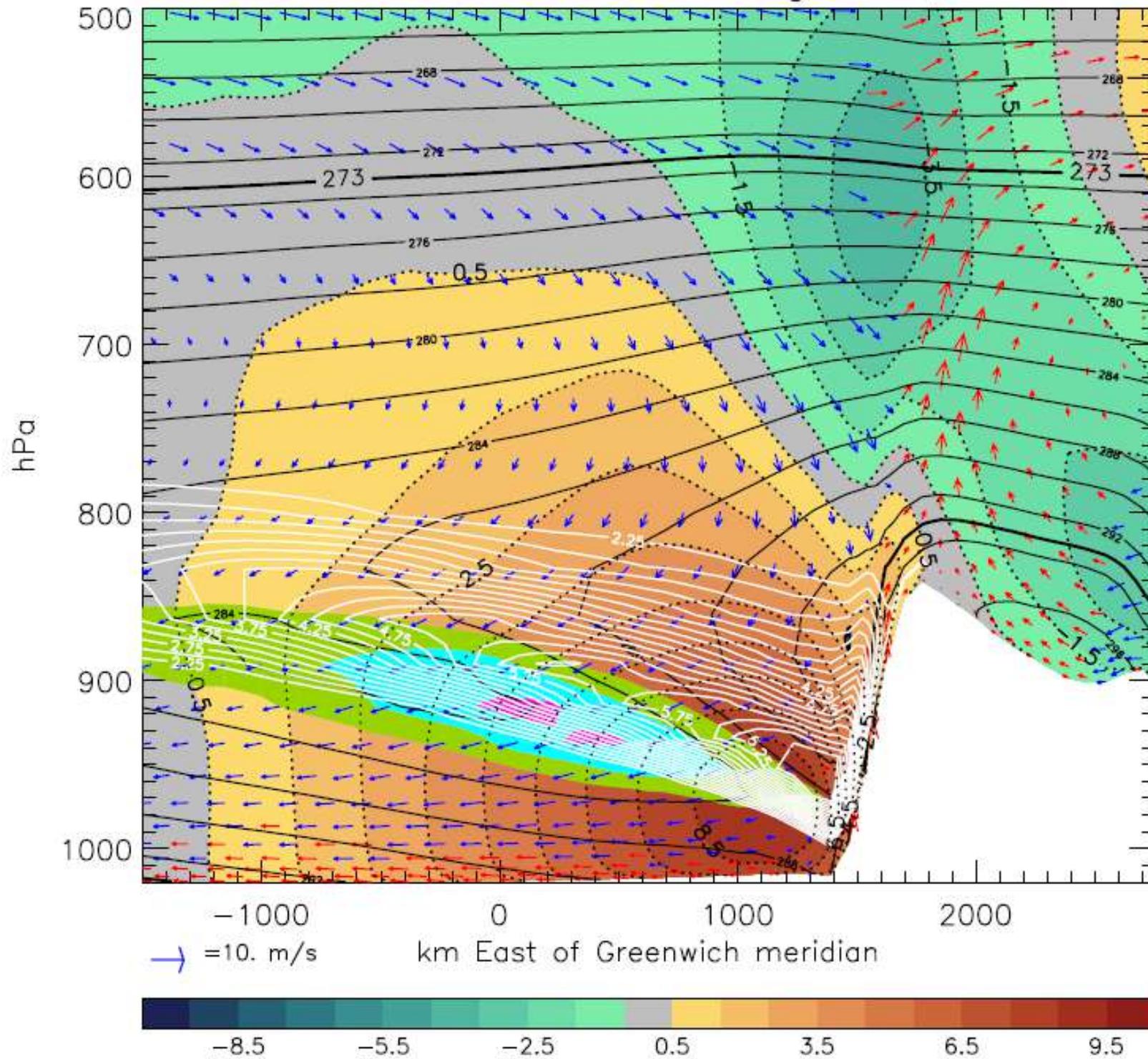


Figure 5: Zonal section along 22-23S in the Eastern Atlantic, illustrating the distribution of meridional (colour-filled, black dashed contours, spacing 0.5 m/s), zonal and vertical wind components (arrows, in red for ascent and in blue for descent; scale on the bottom left, in m/s for the zonal component, and mPa/s for the vertical component), temperature (black solid contour lines, spacing 2 K, plus 0 °C and 20 °C isotherms as thicker black lines), static stability (white contour lines, spacing  $0.5 \times 10^{-2} \text{s}^{-1}$  and  $4.25 \times 10^{-2} \text{s}^{-1}$ , and cloud concentration (above 0.2, 0.3 and 0.4, colour-filled in green, cyan, and magenta, respectively). October climatology from ERA-Interim data.

# Thermal wind balance of the meridional jet

Geostrophic balance:  $f v = \partial_x \Phi$

Hydrostatic balance:  $f \partial_p v = -\frac{R}{p} (\partial_x T)_p$   
 $= -\frac{1}{\rho} (\partial_x \ln \theta)_p$

Assume:  $\partial_x \theta \approx \partial_p \theta \partial_x p_i$

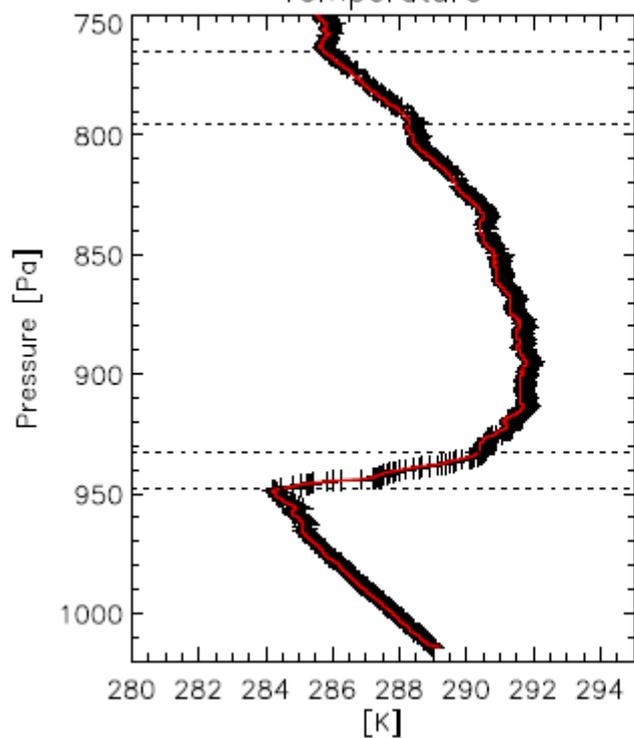
where  $p_i$  is the level of the inversion; then

$$\partial_p v \approx -\frac{N_i^2}{f g^2 \rho_i^2} (\partial_x p_i)_p$$

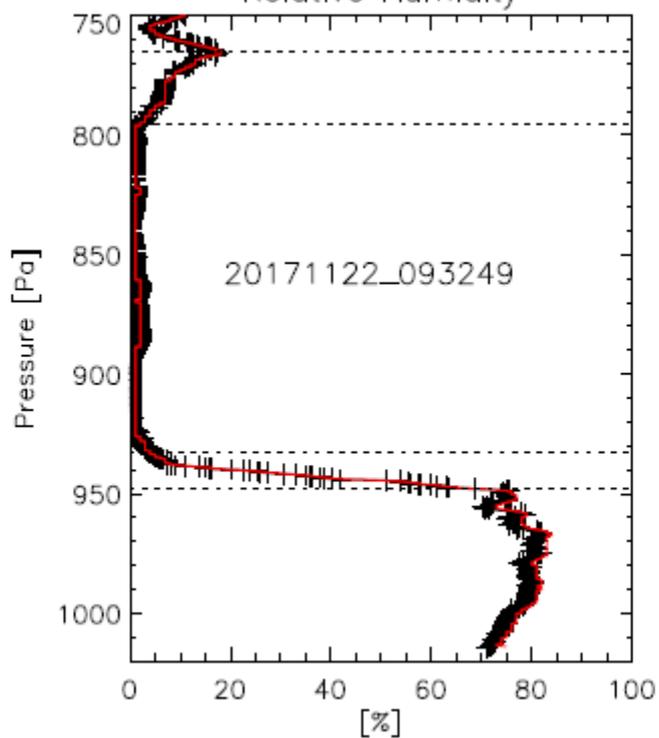
or also

$$\partial_z v \approx \frac{N_i^2}{f g \rho_i} (\partial_x p_i)_p$$

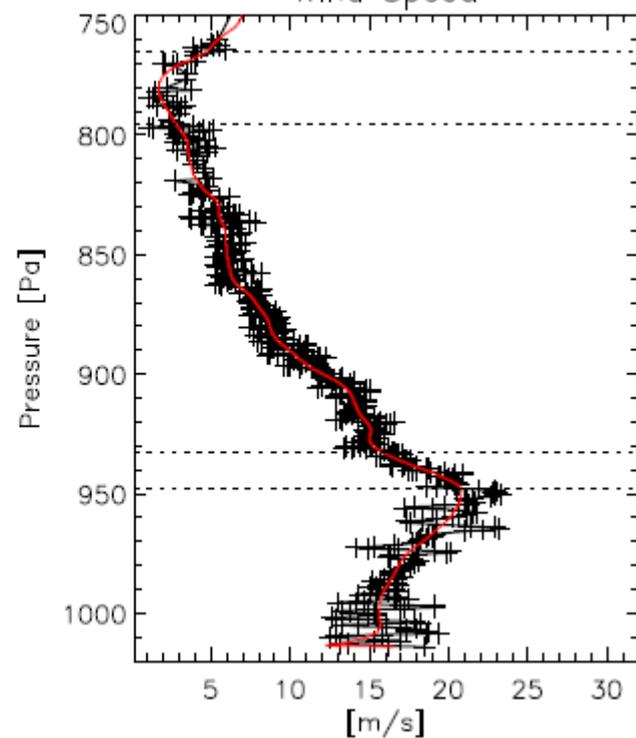
Temperature



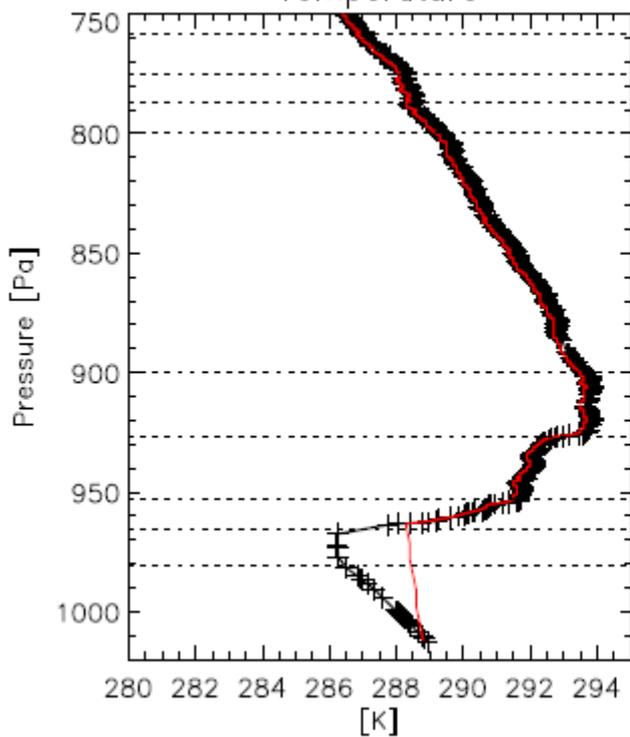
Relative Humidity



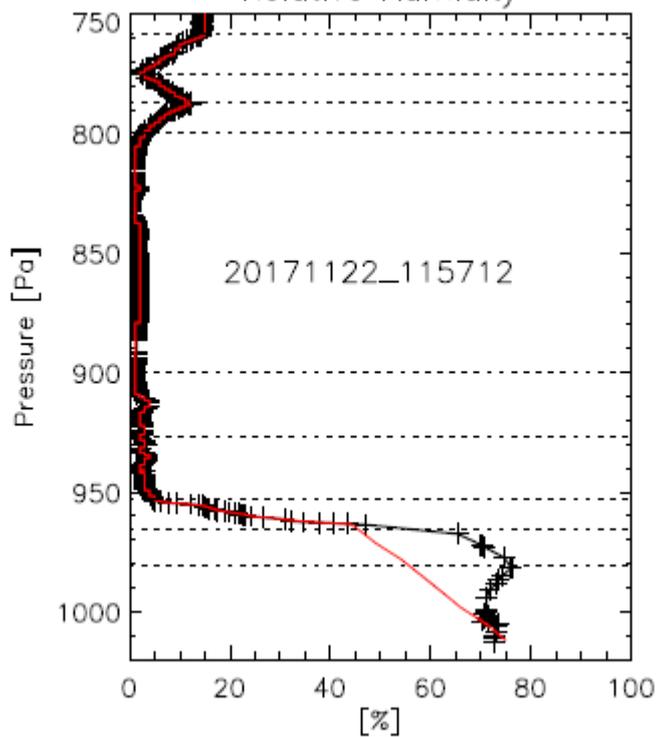
Wind Speed



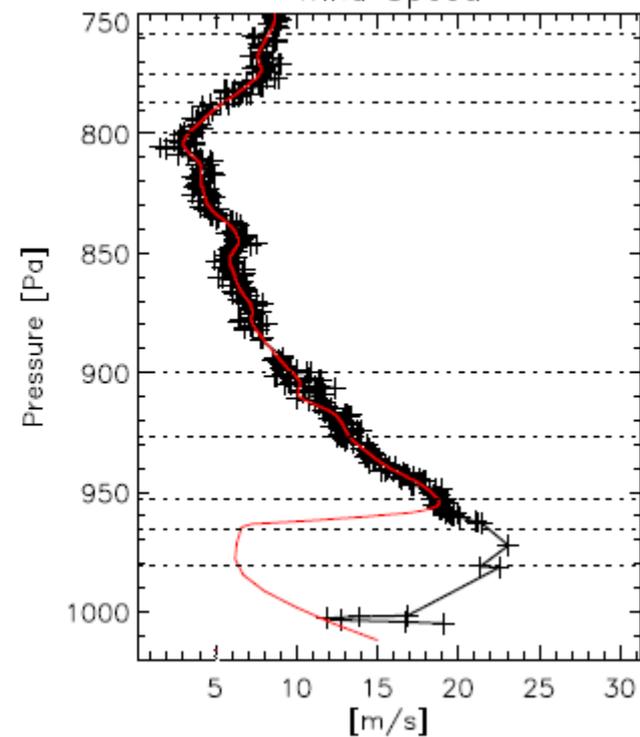
Temperature



Relative Humidity



Wind Speed



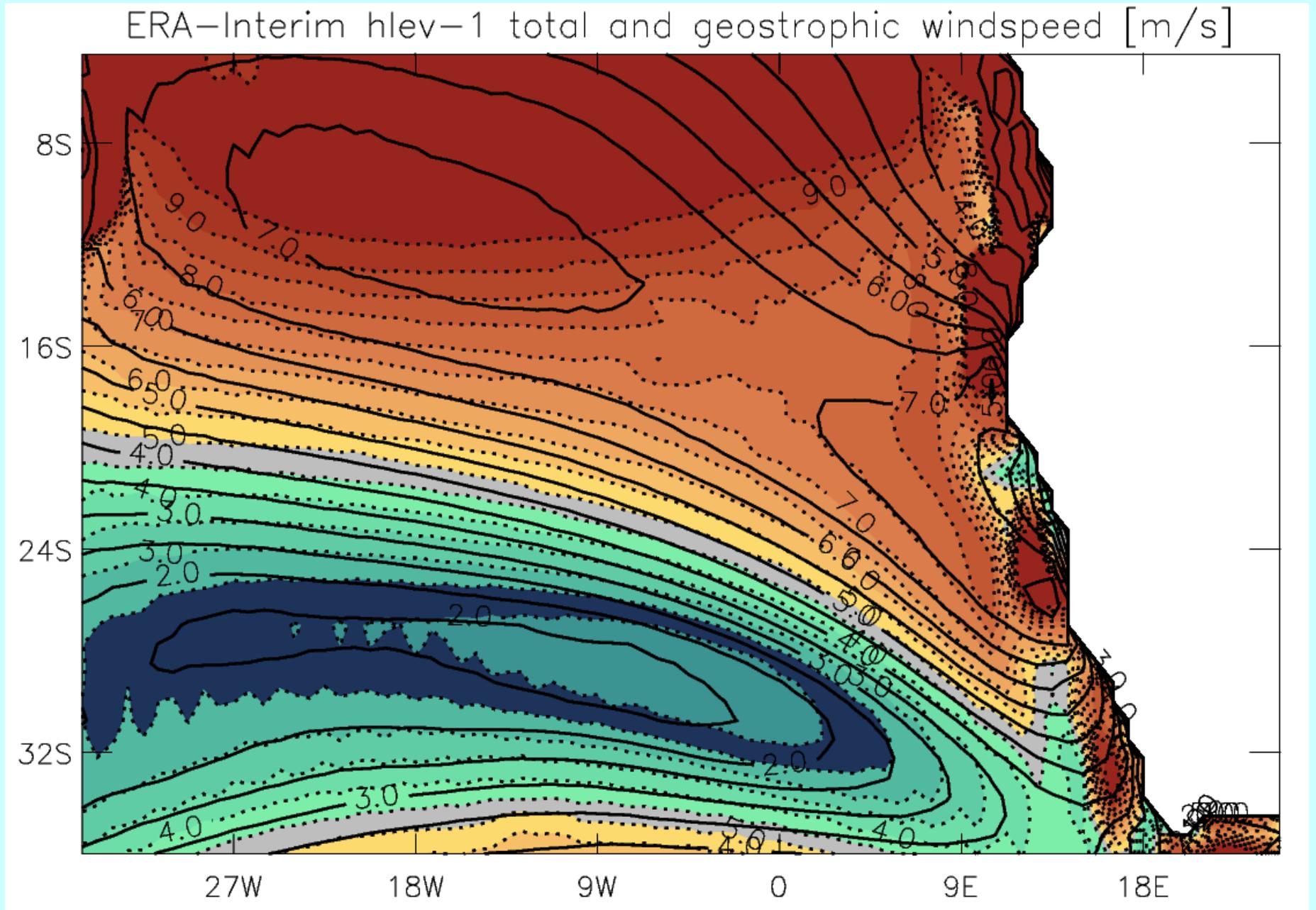
**Inversion slope ~18hPa/39km**

**Using:**

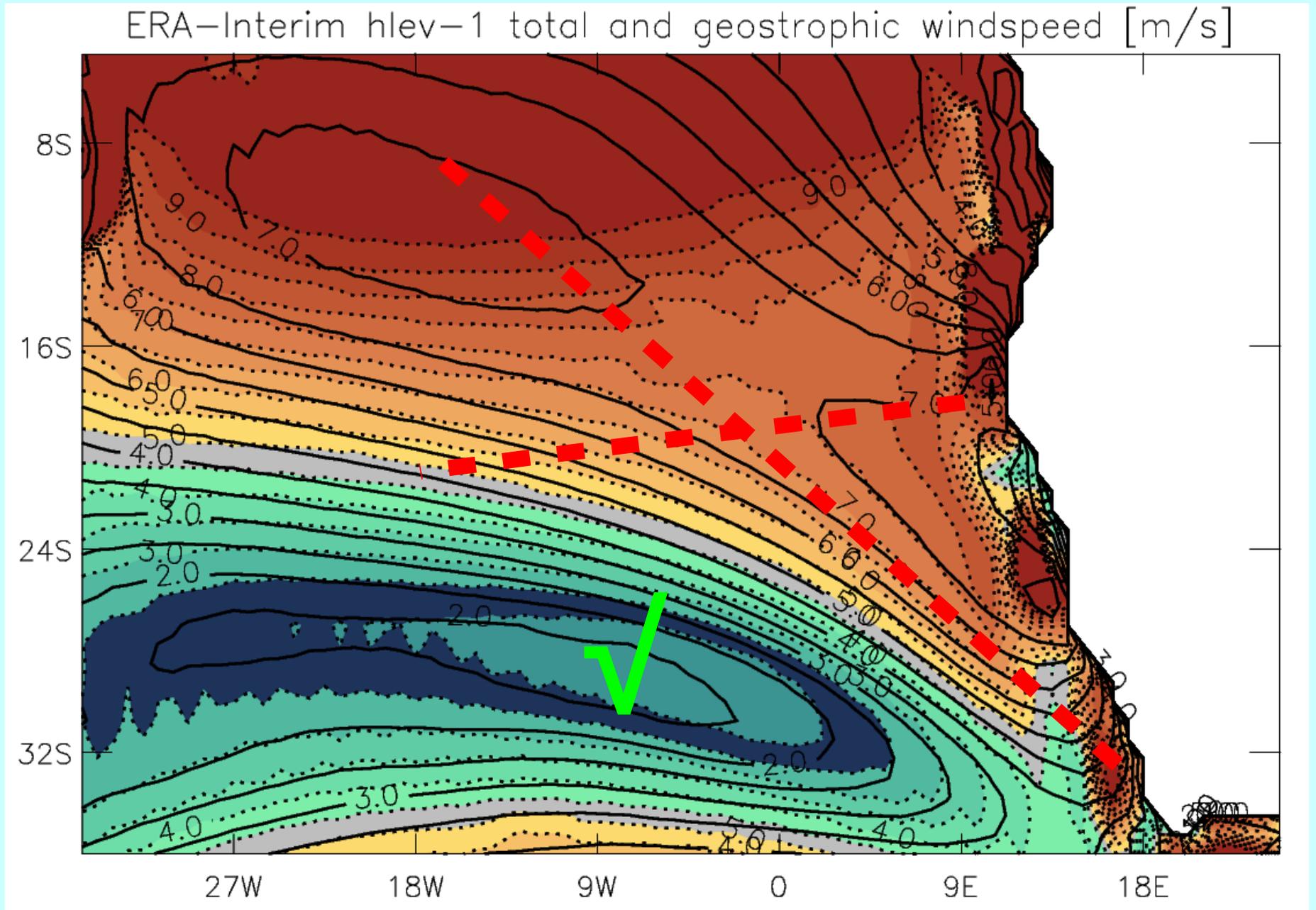
$$\partial_z v \approx \frac{N_i^2}{fg\rho_i} (\partial_x p_i)_p$$

$$\Delta v \approx \frac{(\Delta\theta)_i}{f\theta\rho_i} \frac{\Delta p_i}{\Delta x} \approx 15 \text{ m/s}$$

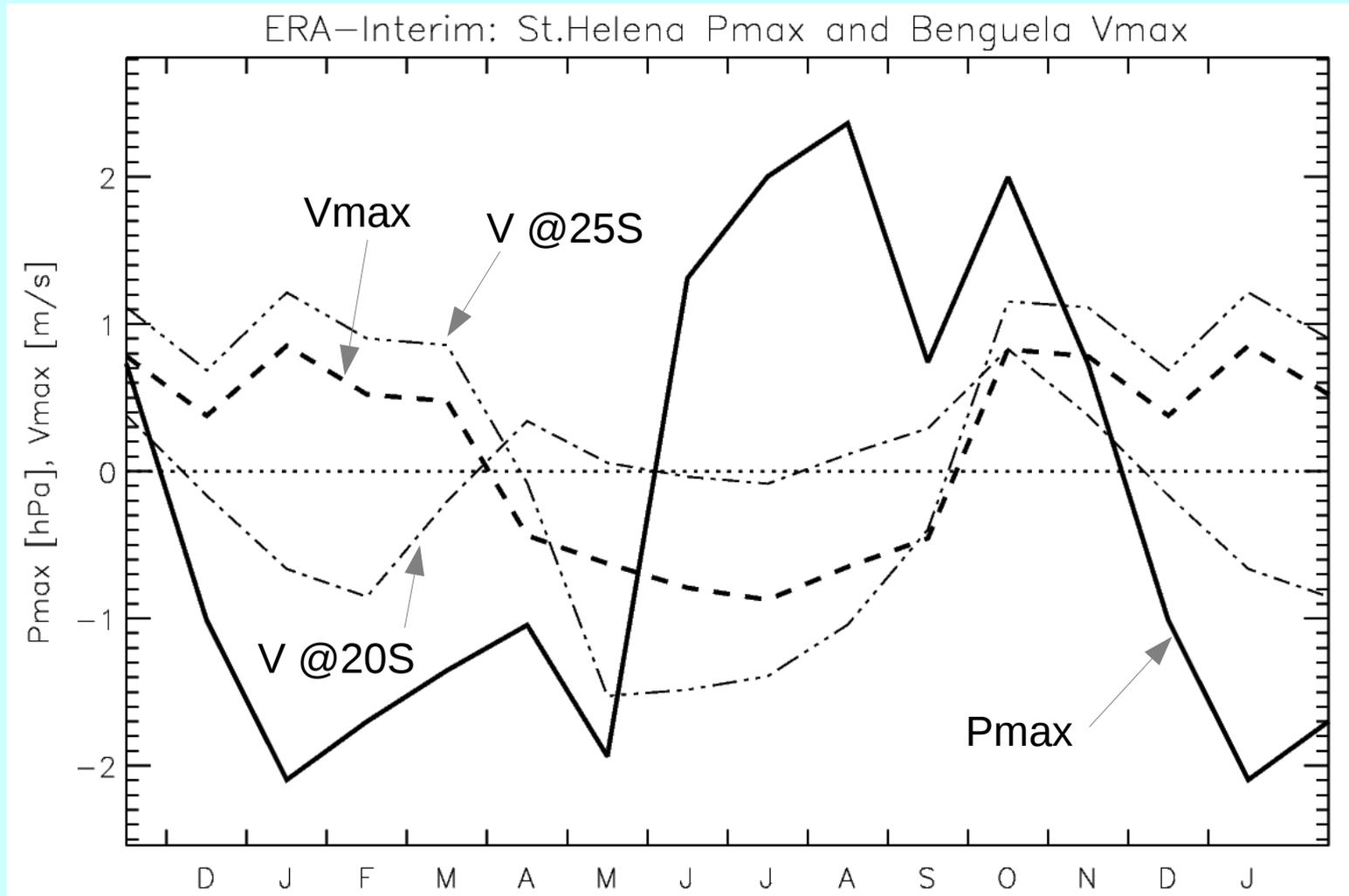
# Back to the trade winds and the Benguela jet



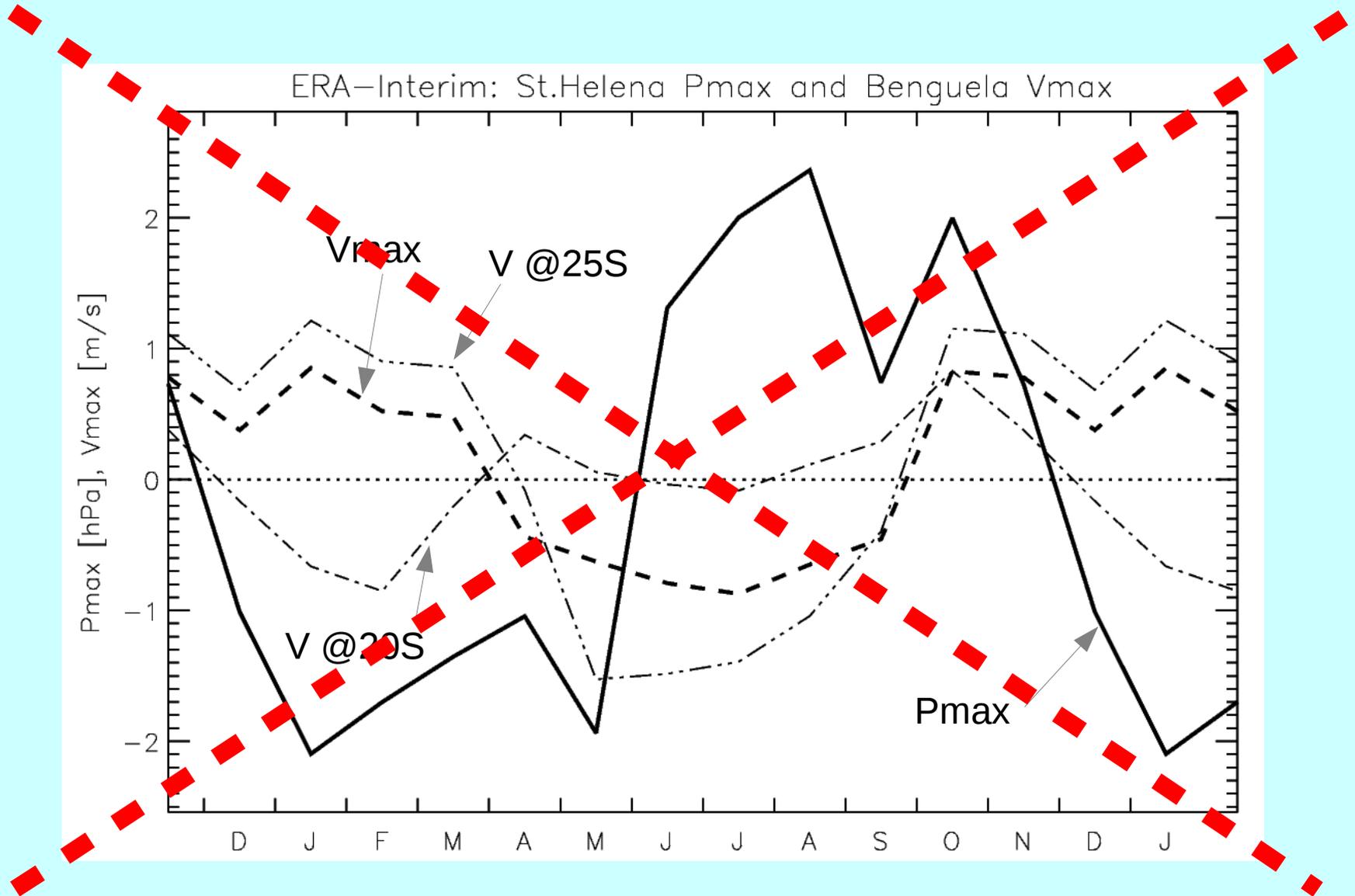
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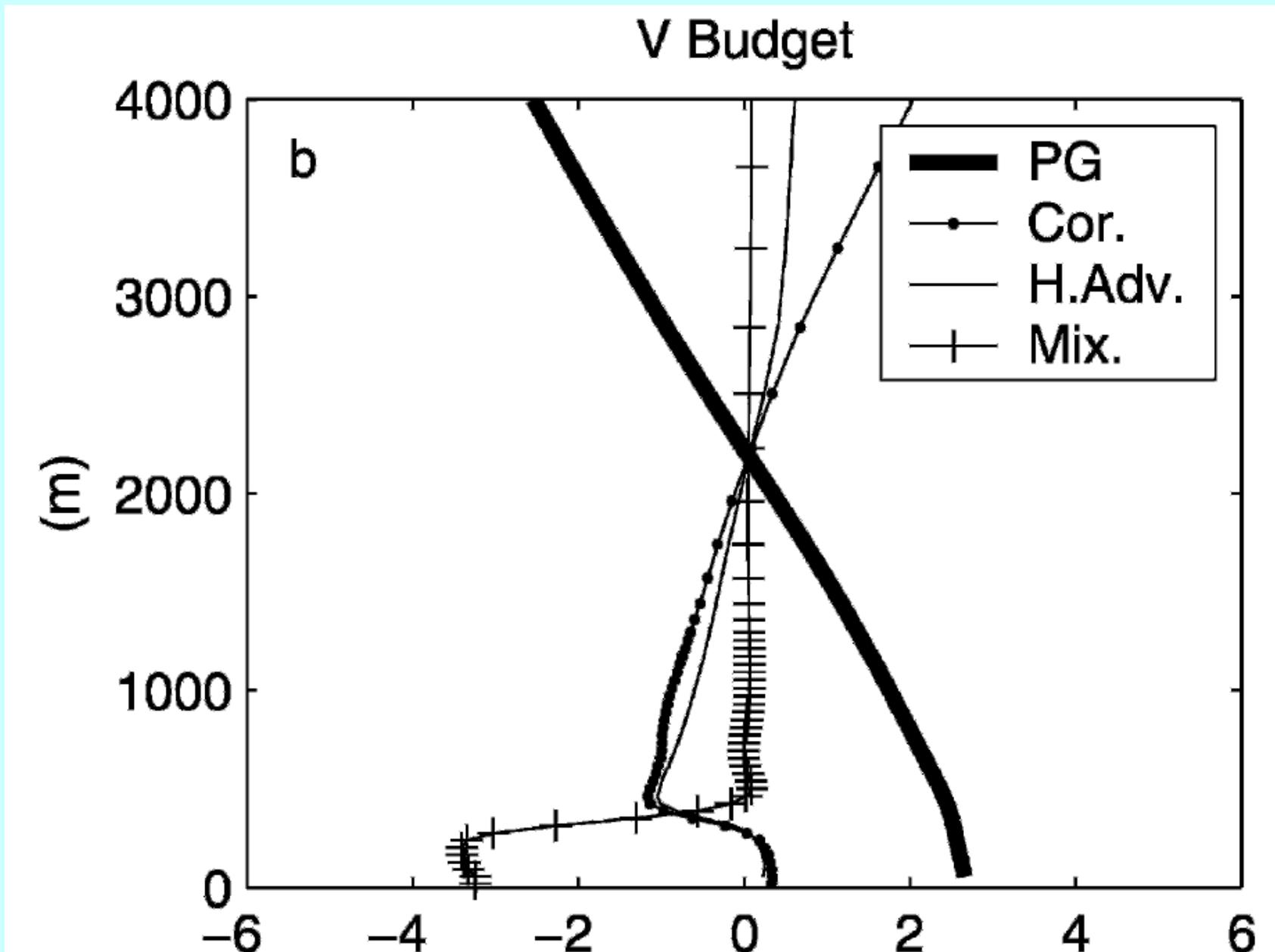
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# Back to the trade winds and the Benguela jet

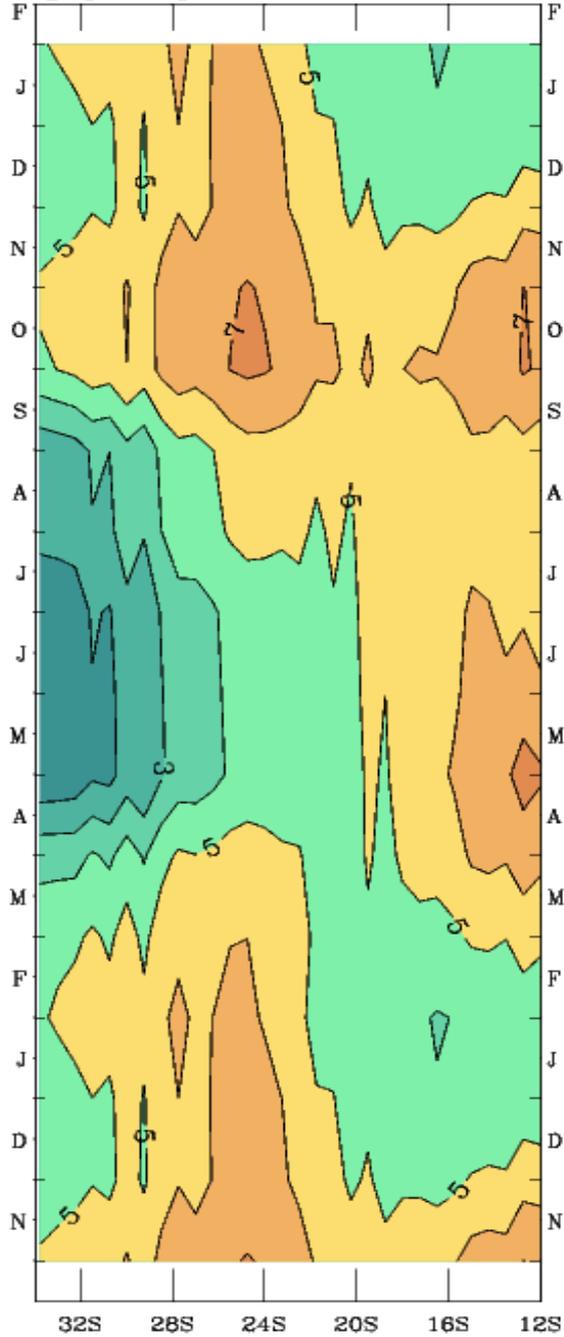


# Munoz & Garreaud (2005): momentum budget of the Chilean coastal LLJ

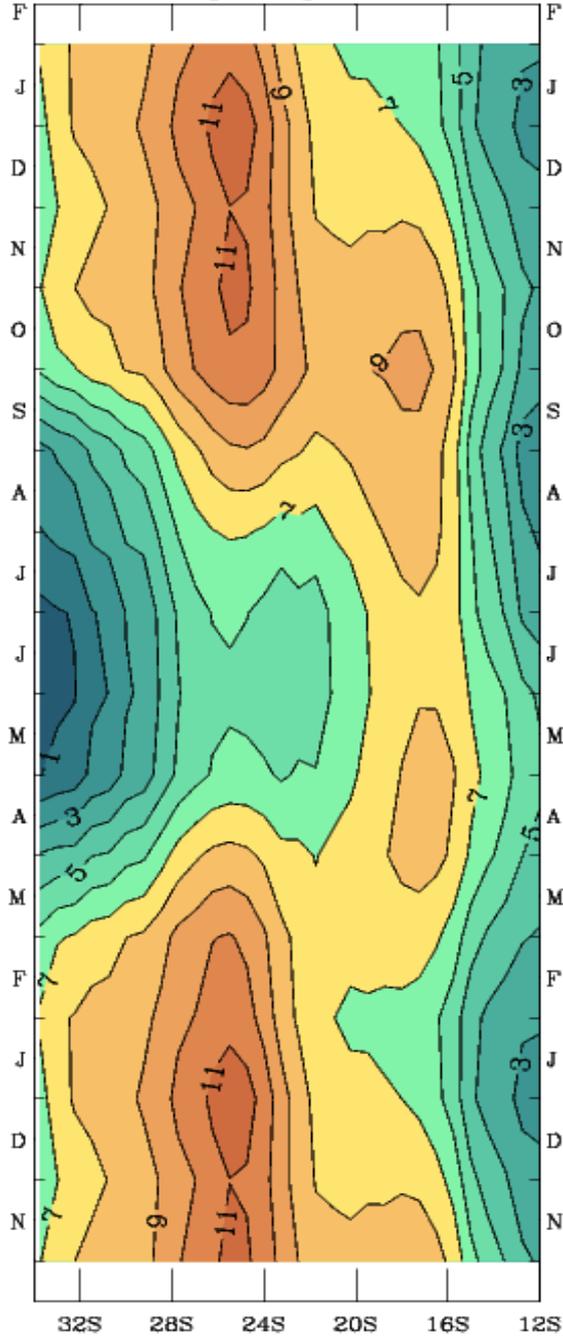


# The BLLJ

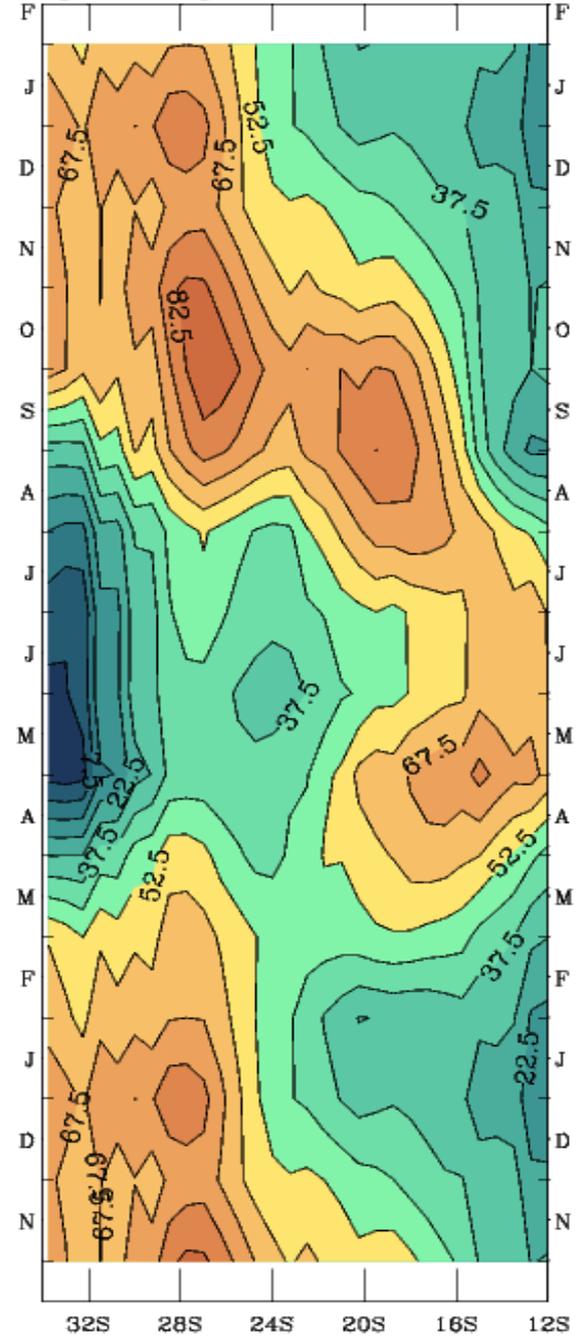
Vg [m/s] at 970 hPa: c=0.4



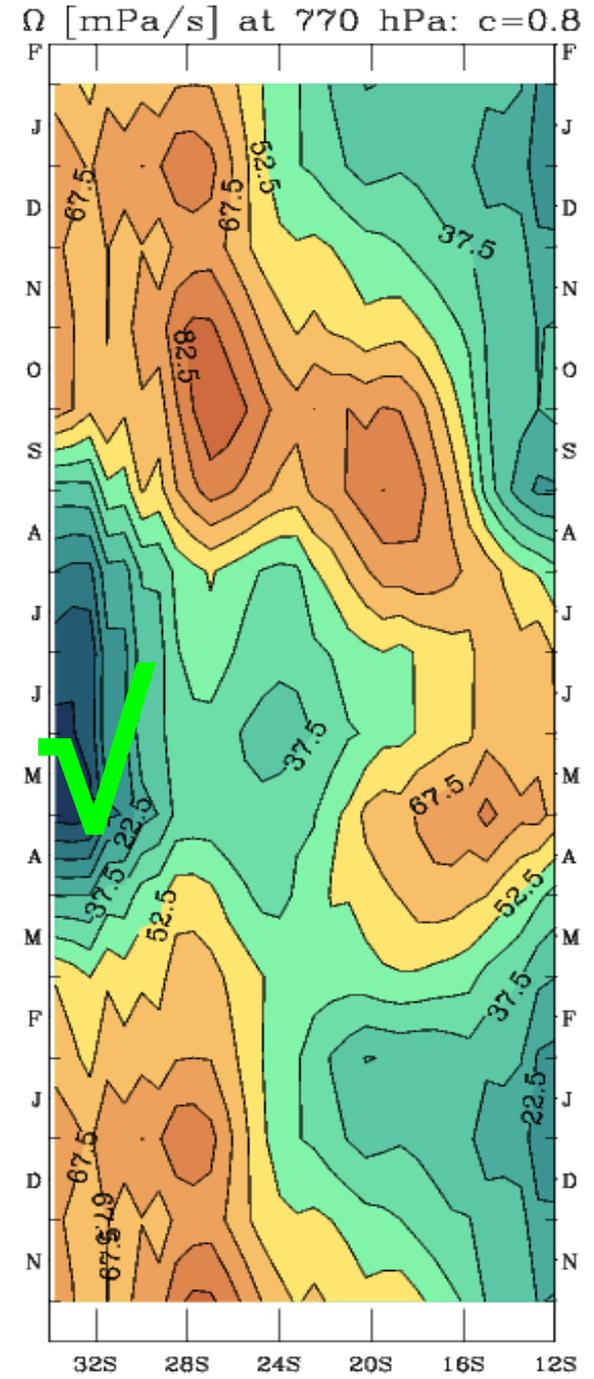
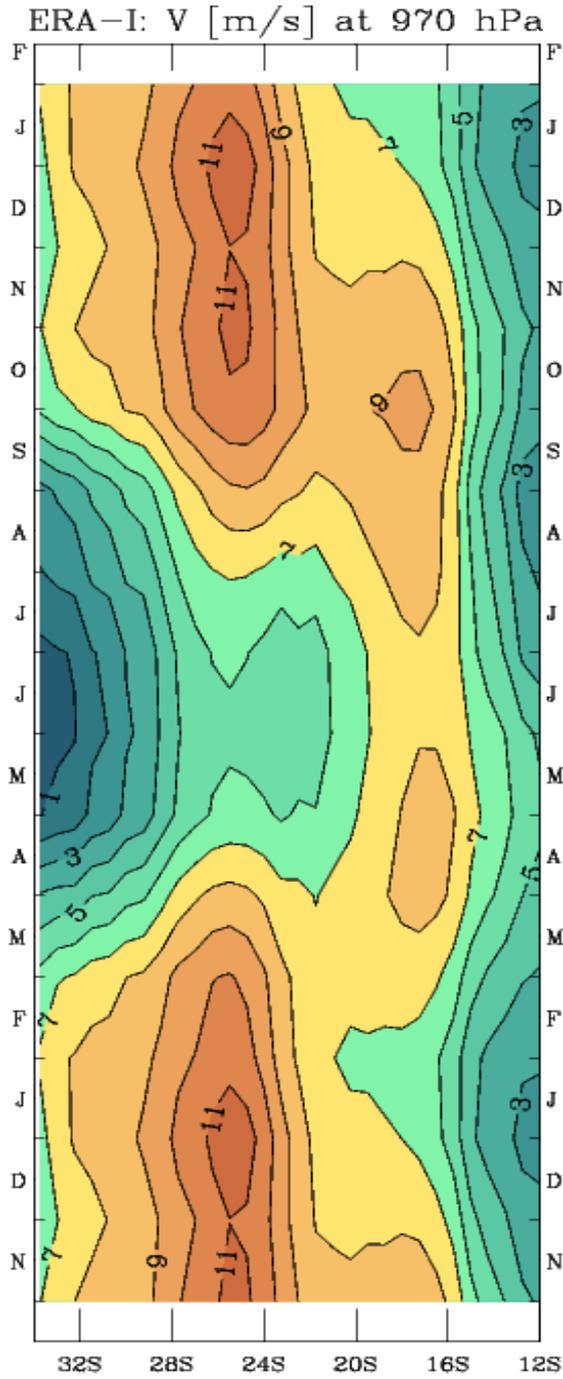
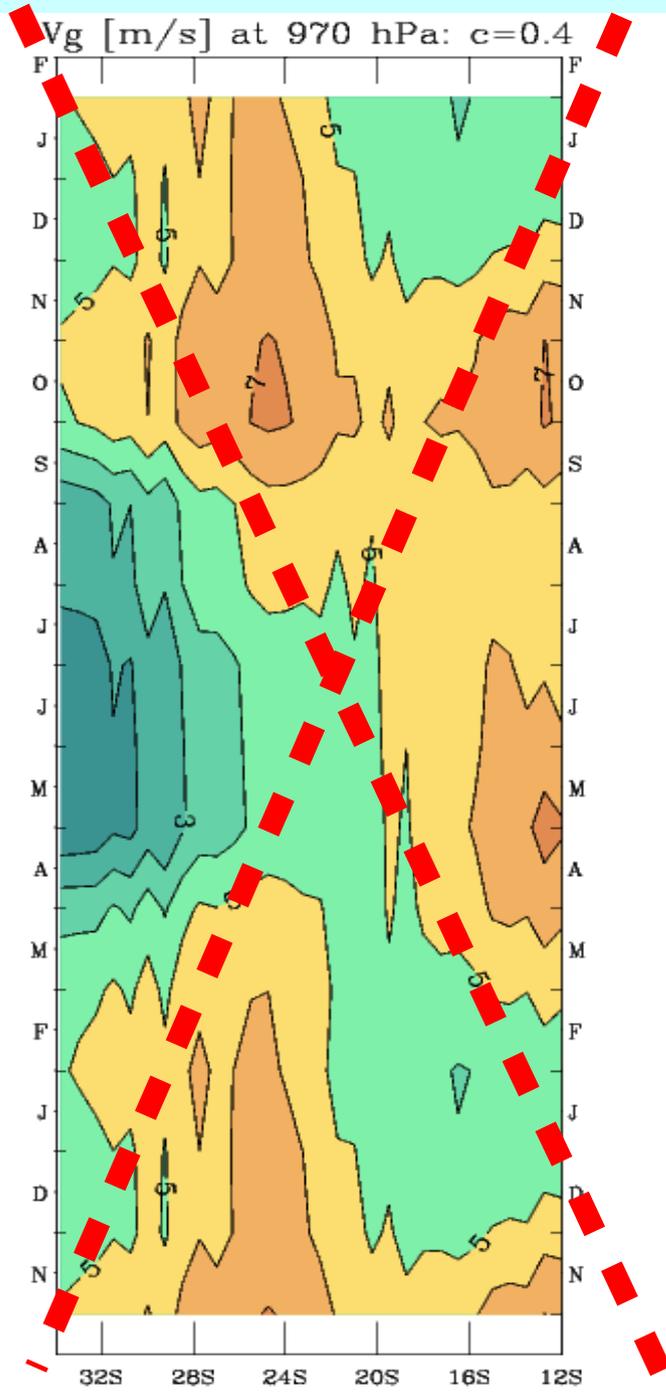
ERA-I: V [m/s] at 970 hPa



$\Omega$  [mPa/s] at 770 hPa: c=0.8



# The BLLJ is primarily controlled by subsidence



# ERA-Interim: zonal section along 22.5S, October

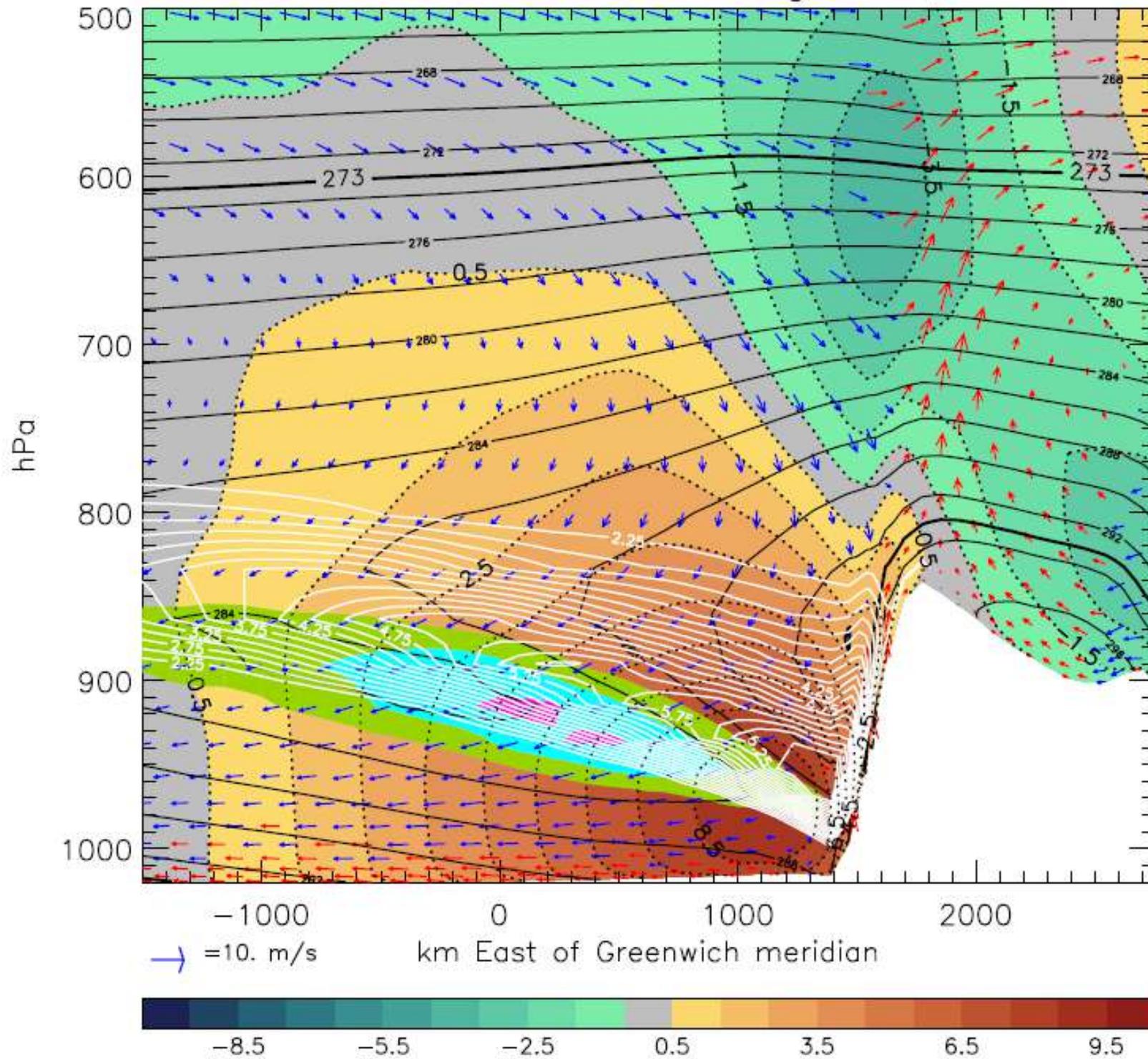
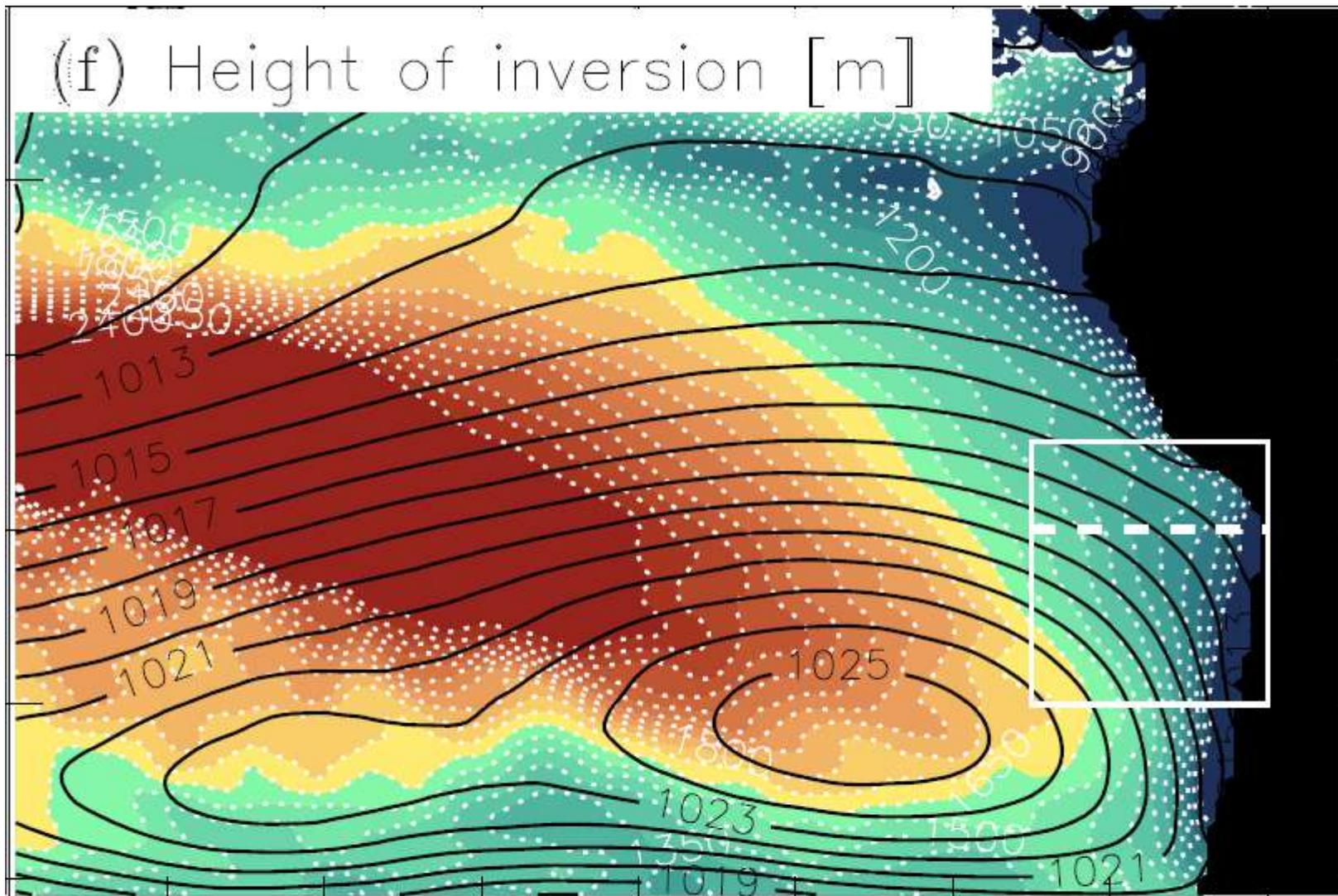


Figure 5: Zonal section along 22-23S in the Eastern Atlantic, illustrating the distribution of meridional (colour-filled, black dashed contours, spacing 0.5 m/s), zonal and vertical wind components (arrows, in red for ascent and in blue for descent; scale on the bottom left, in m/s for the zonal component, and mPa/s for the vertical component), temperature (black solid contour lines, spacing 2 K, plus 0 °C and 20 °C isotherms as thicker black lines), static stability (white contour lines, spacing  $0.5 \times 10^{-2} s^{-1}$  between  $2.25 \times 10^{-2} s^{-1}$  and  $4.25 \times 10^{-2} s^{-1}$ , and cloud concentration (above 0.2, 0.3 and 0.4, colour-filled in green, cyan, and magenta, respectively). October climatology from ERA-Interim data.

## **II. Tropospheric temperatures and the inversion**

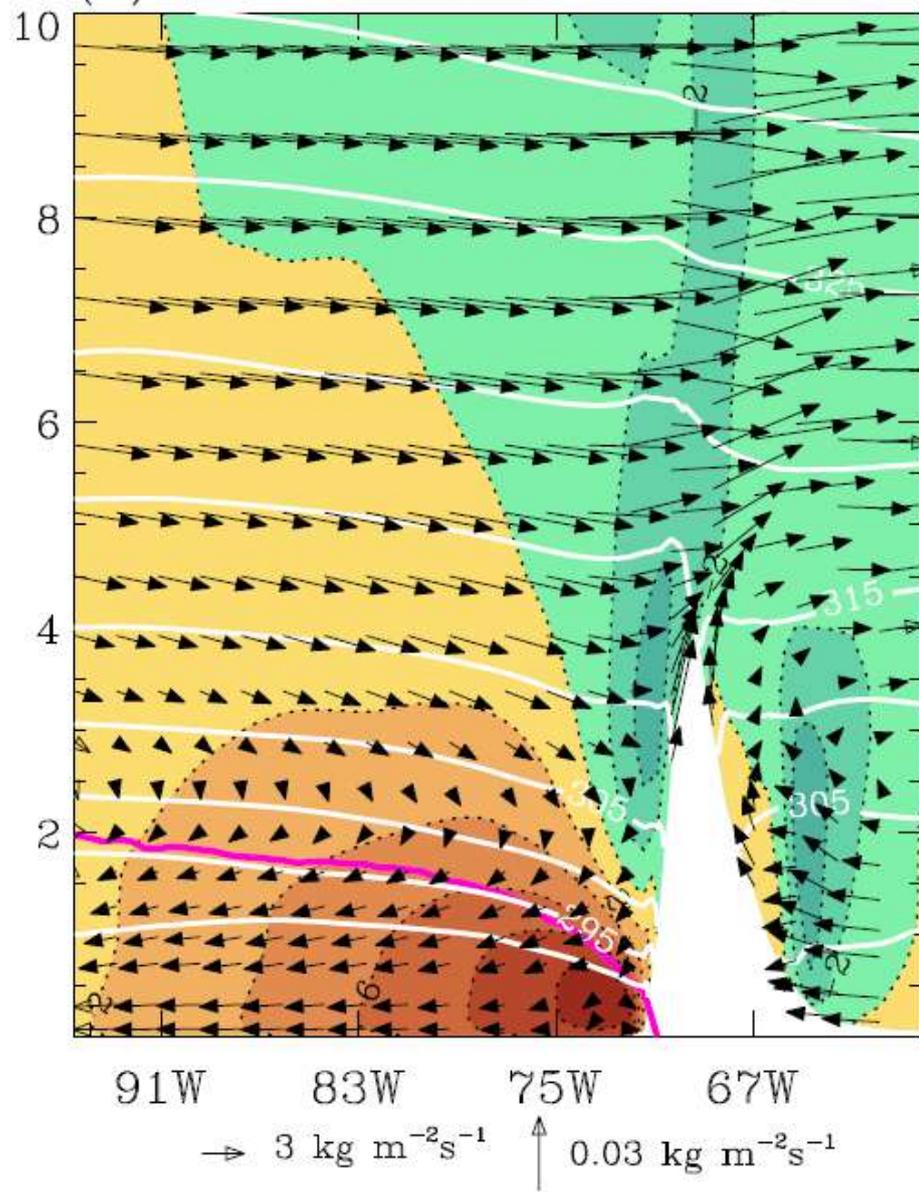
(f) Height of inversion [m]



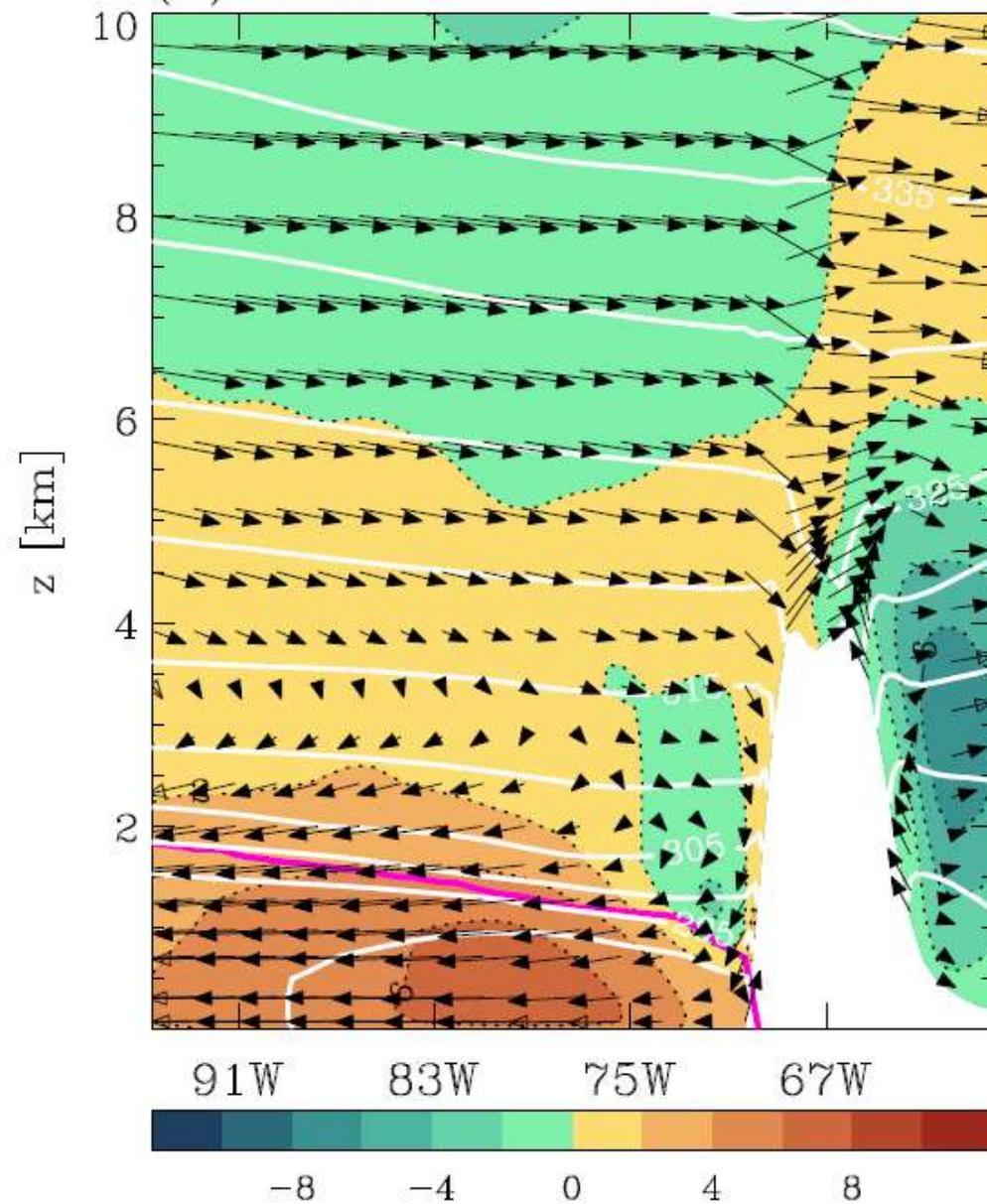
140W 130W 120W 110W 100W 90W 80W 70W



(a) 29.5S–28.5S Oct–Nov 2008



(b) 20.5S–19.5S Oct–Nov 2008

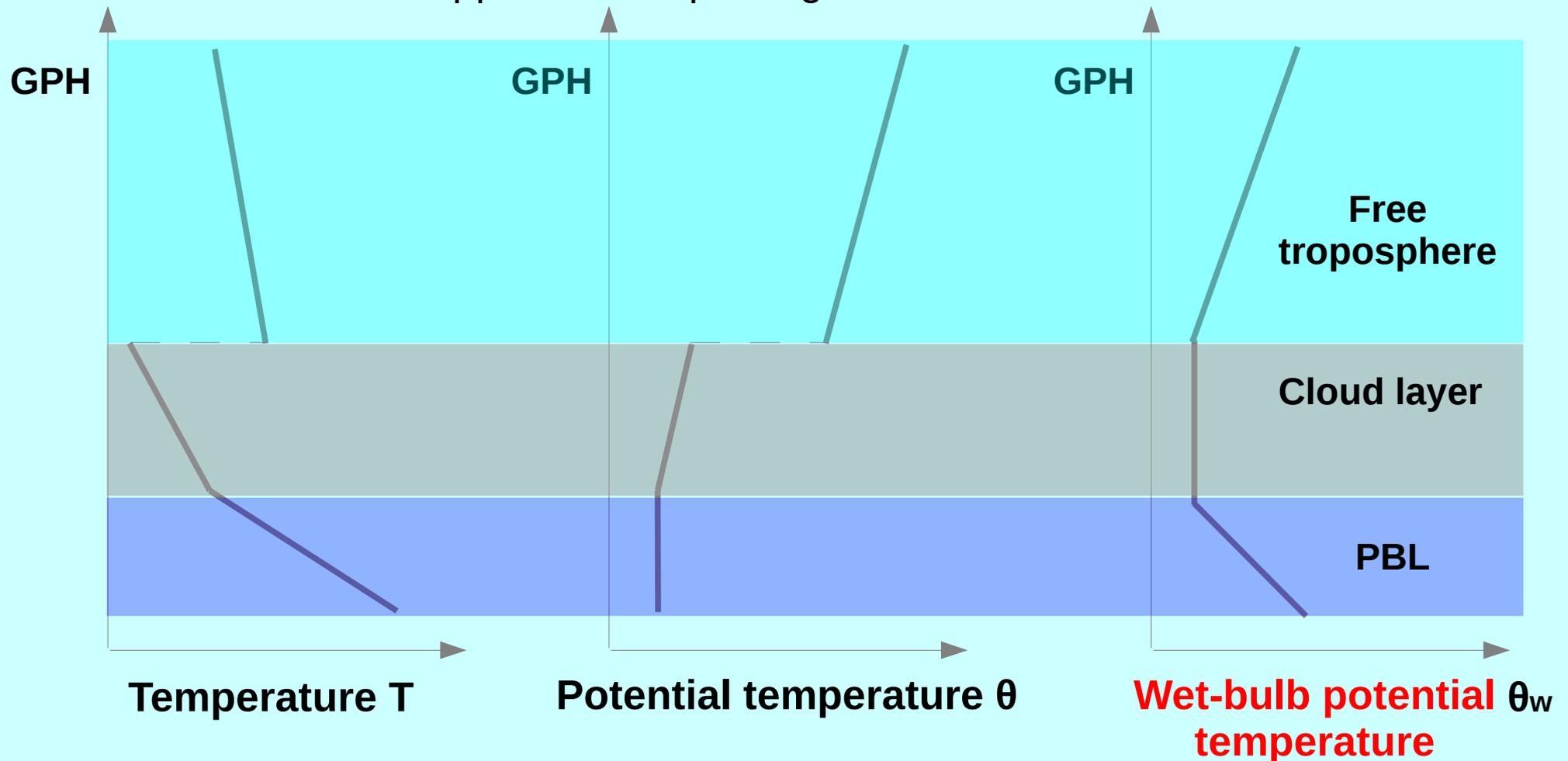


# Characteristics of the PBL inversion

(Toniazzi et al, 2011; & other VOCALs-REx work)

## A typical vertical temperature profile in the STAC

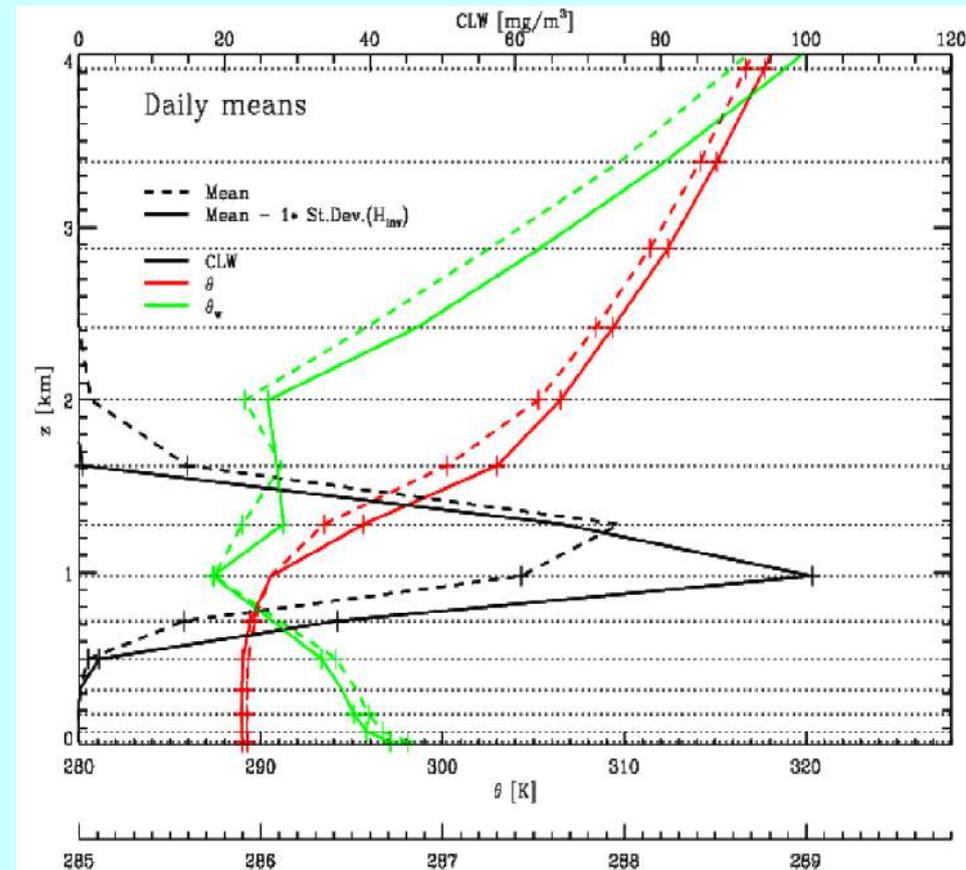
- The PBL is nearly dry-adiabatic
- The cloud layer is moist-adiabatic
- The FT is superadiabatic, due to radiative cooling
- A miracle happens when plotting  $\theta_w$



# Characteristics of the PBL inversion

(Toniazzi et al, 2011; & other VOCALs-REx work)

- $\theta_w$  is conserved under adiabatic mixing.
- $\Delta\theta_w \leq 0 \Rightarrow$  (marginal) instability for mixing of FT and cloudy air.
- This allows energy-efficient entrainment in balance with FT subsidence.
- $\Delta\theta_w > 0$  (absolute stability)  $\Rightarrow$  reduced entrainment, inversion sinks
- $\Delta\theta_w \ll 0 \Rightarrow$  PBL deepening
- In-situ data show a tendency for  $\Delta\theta_w \approx 0$  to be maintained for time-scales longer than 1-2 days



# An interesting corollary: mixing-length scaling of entrainment process

$$\frac{\rho c_p}{\theta} (\partial_t + \underline{u} \cdot \underline{\nabla}) \theta = \frac{1}{T} \left[ R - \dot{\rho}_e \left( c_p T \frac{\Delta\theta}{\theta} + L_c q_l \right) \right]$$

$$-\dot{m}_i \partial_z \theta_i \frac{c_p}{\theta}$$

(radiative cooling)

$$-\rho \partial_z (\kappa \partial_z \theta_L)$$

$$\Delta z \sim \sqrt{\kappa}$$

(Deardorff 1975)

Scaling from mixing-length (diffusive) approximation

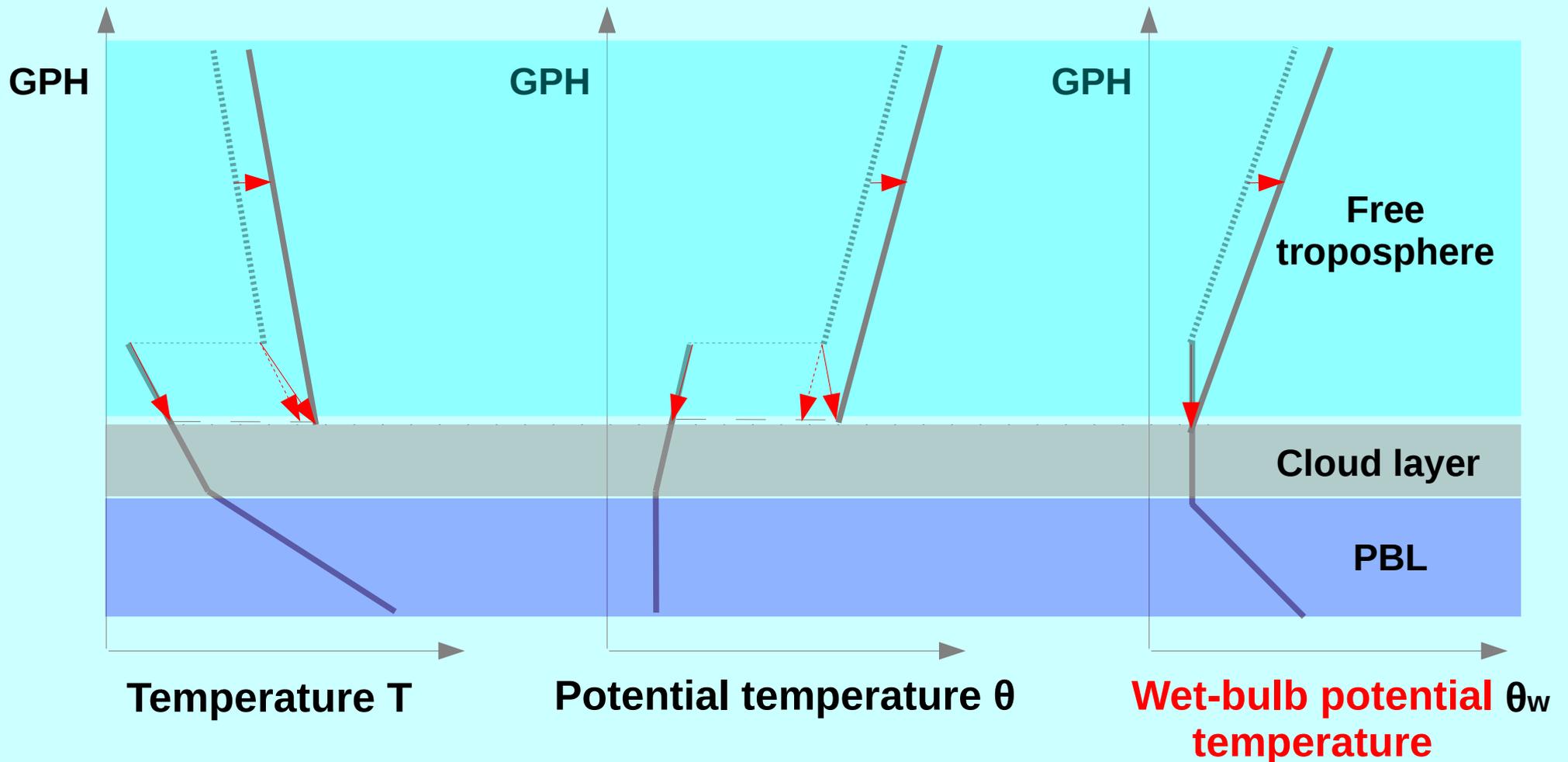
$$\Delta z \sim \lambda_e := \dot{m}_i / \dot{\rho}_e \sim \dot{m}_i / \rho$$

$$\lambda_e \text{Ex}(p) \frac{\partial \theta}{\partial z} \simeq \text{Ex}(p) \Delta \theta + \frac{L_c}{c_p} q_l$$

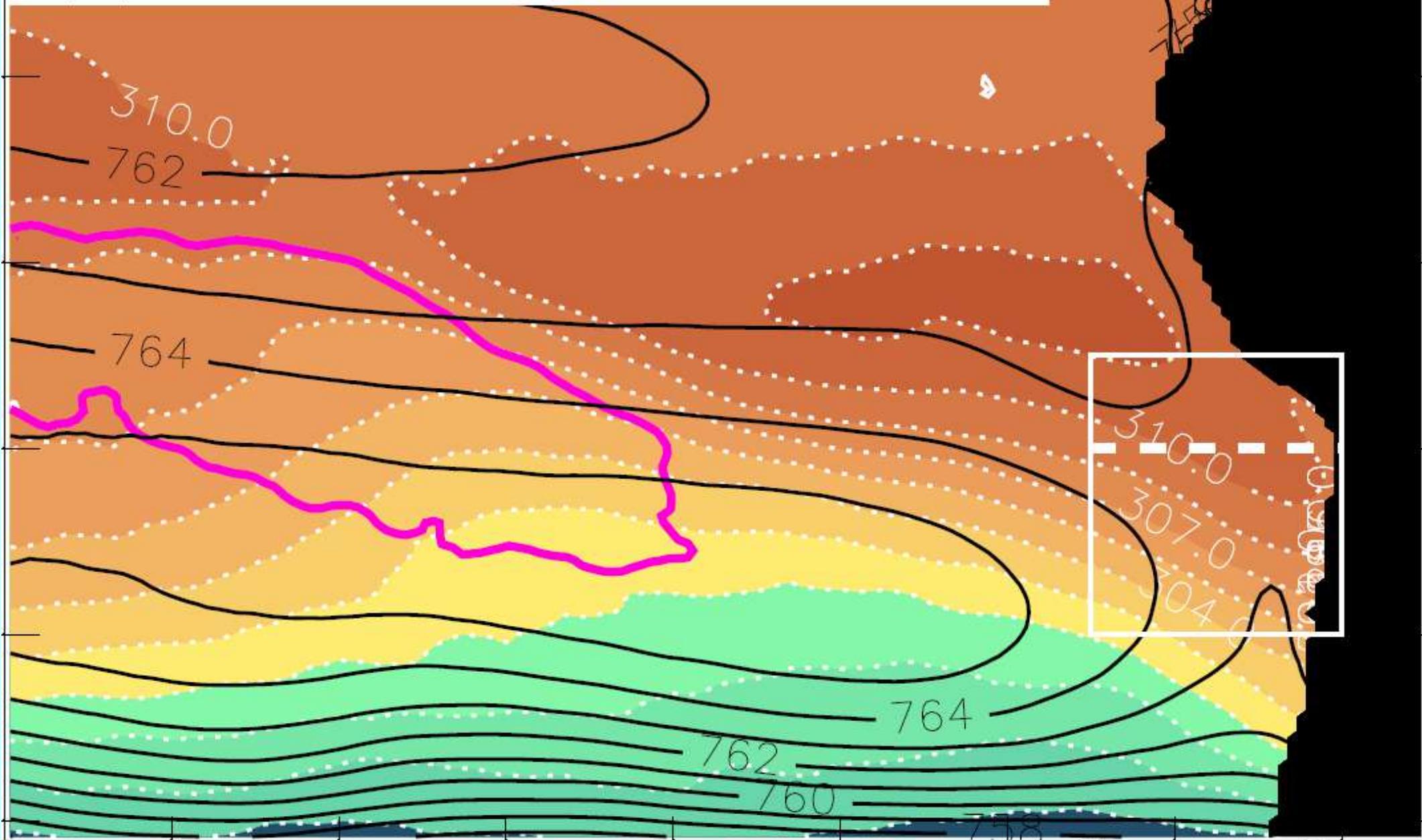
# Characteristics of the PBL inversion

(Toniazzo et al, 2011; & other VOCALs-REx work)

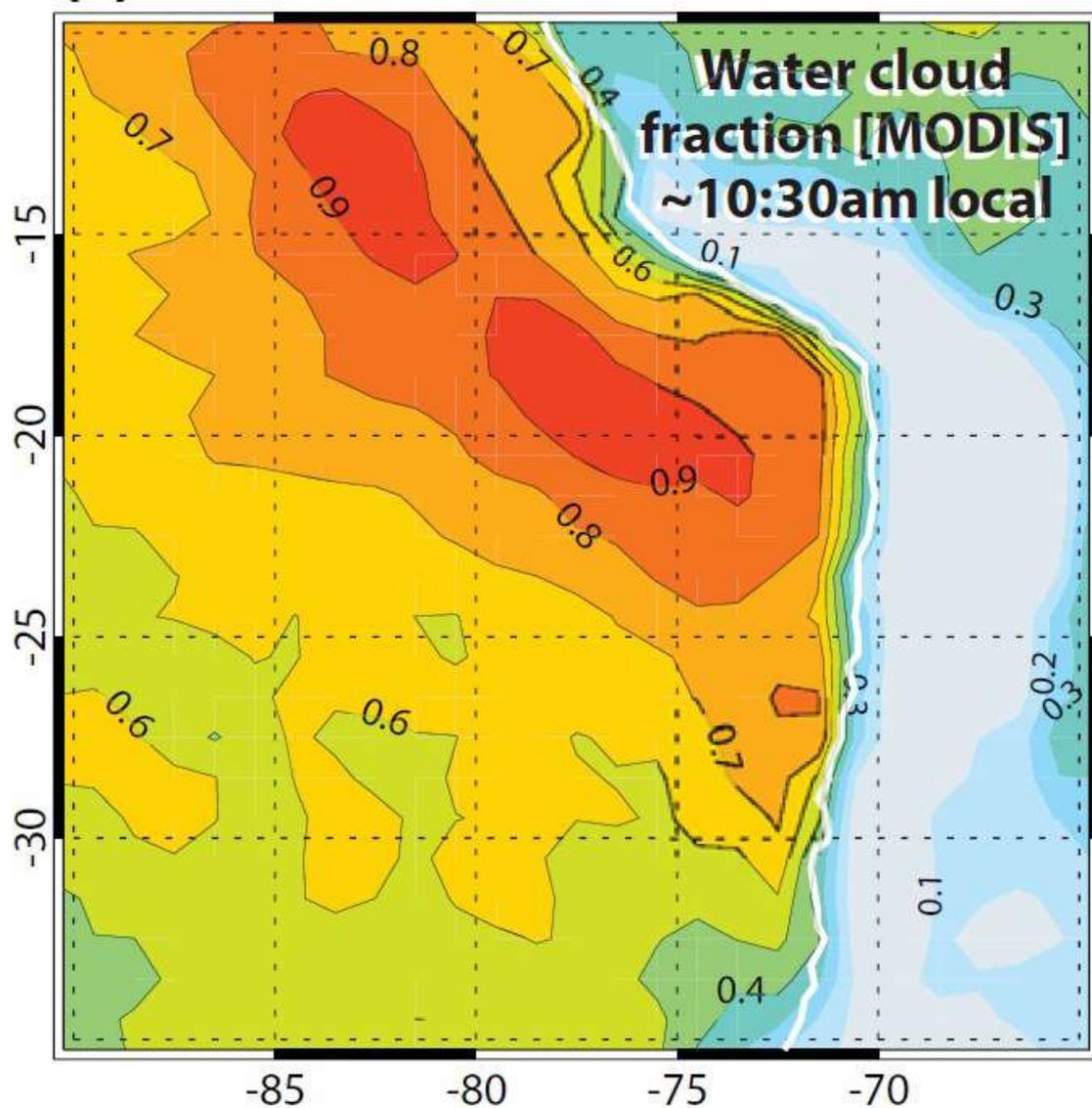
→ a warming of the FT causes the inversion to sink and to strengthen



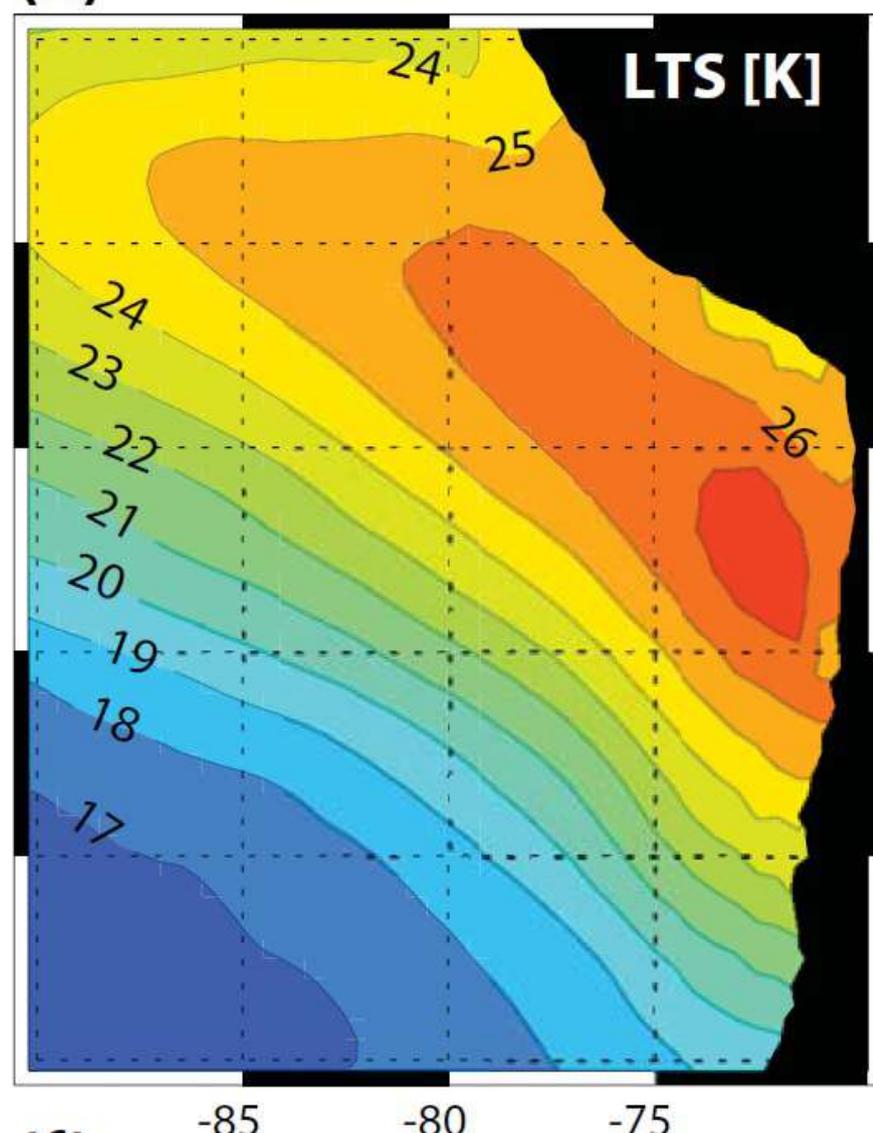
(d)  $z=2420\text{m}$ ,  $\langle P \rangle = 763\text{hPa}$



(c)



(d)

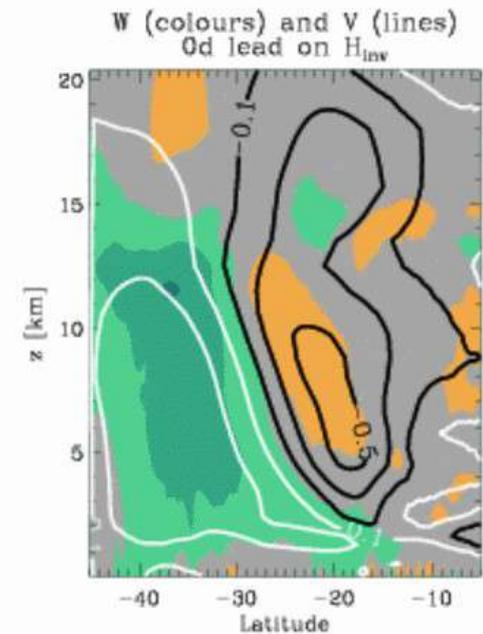
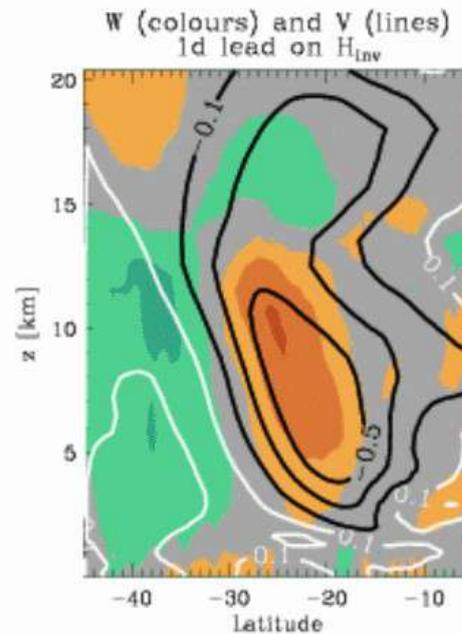
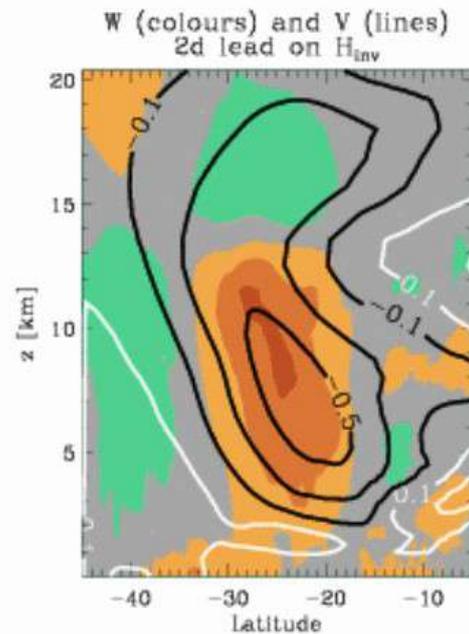
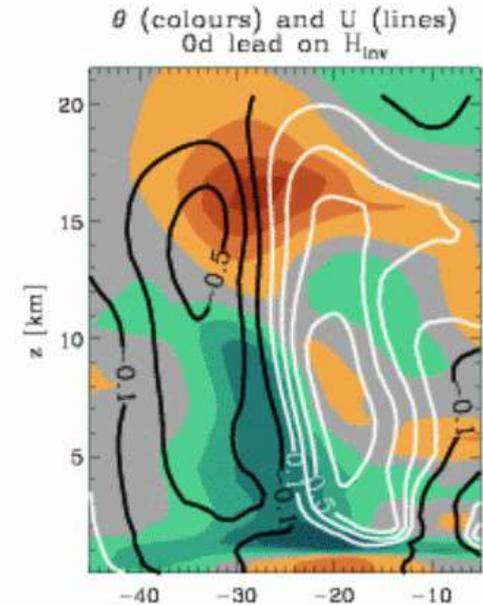
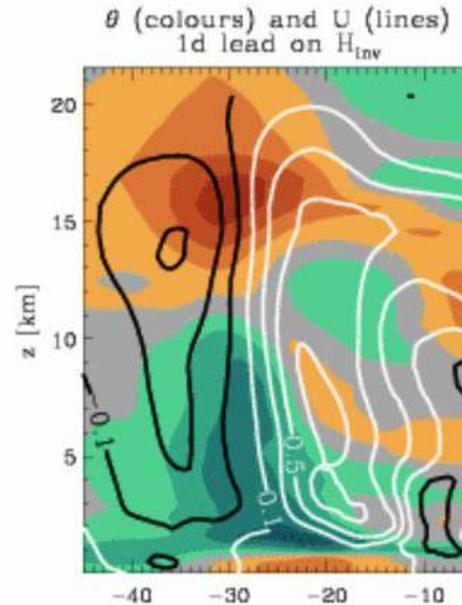
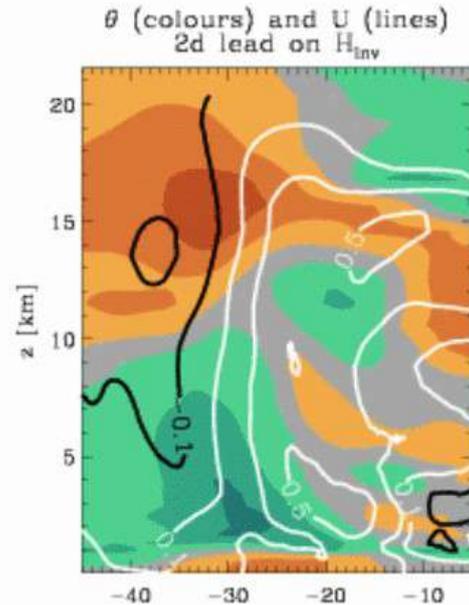


1. FT cooling favour high, weak inversion and low cloud cover.

2. Driven by cold, esp. **vertical advection**

3. FT warming has the opposite effect

4. Strong mid-latitude influences.



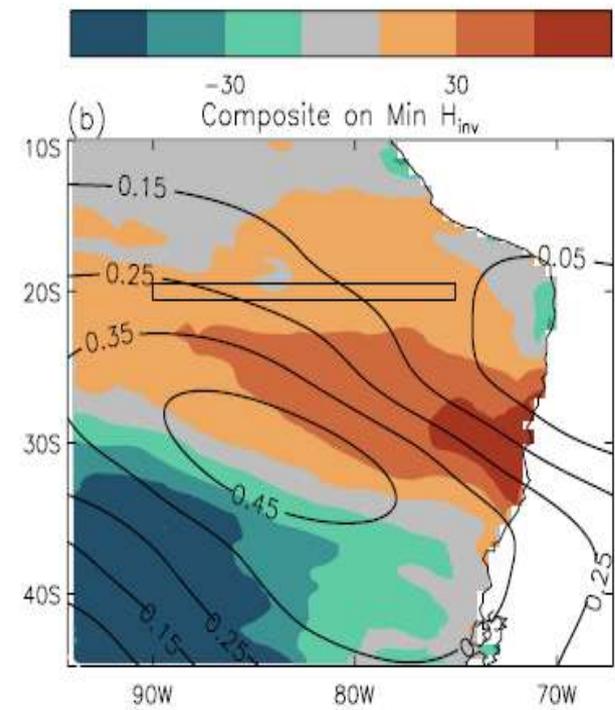
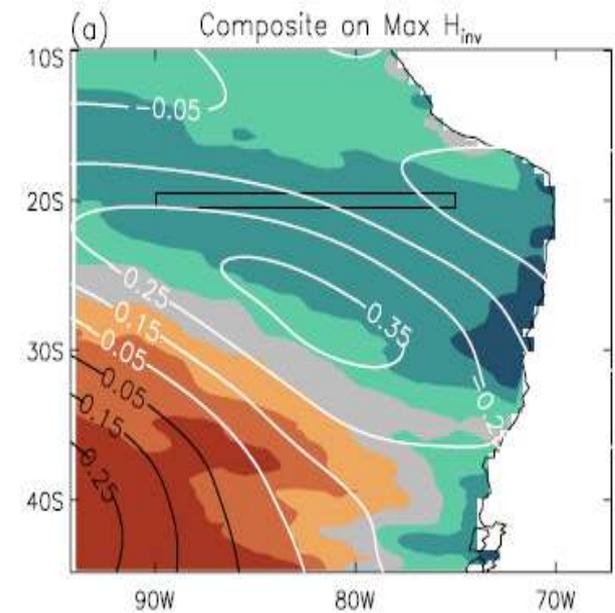
## Interim 2:

1. FT cold advection favour high, weak inversion and low cloud cover.

2. FT warming has the opposite effect

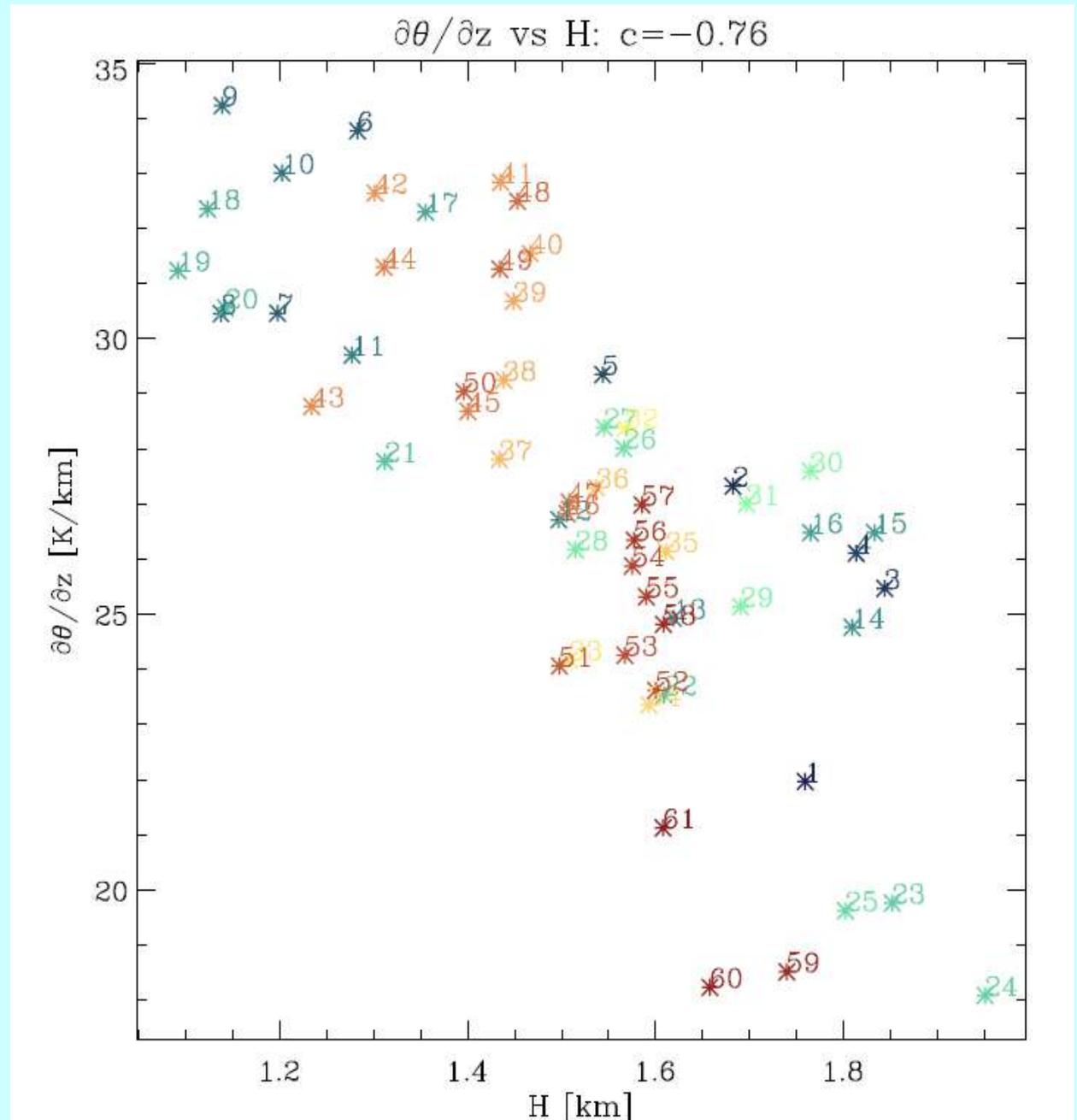
3. Strong mid-latitude influences

4. Advection often dominated by vertical motion.

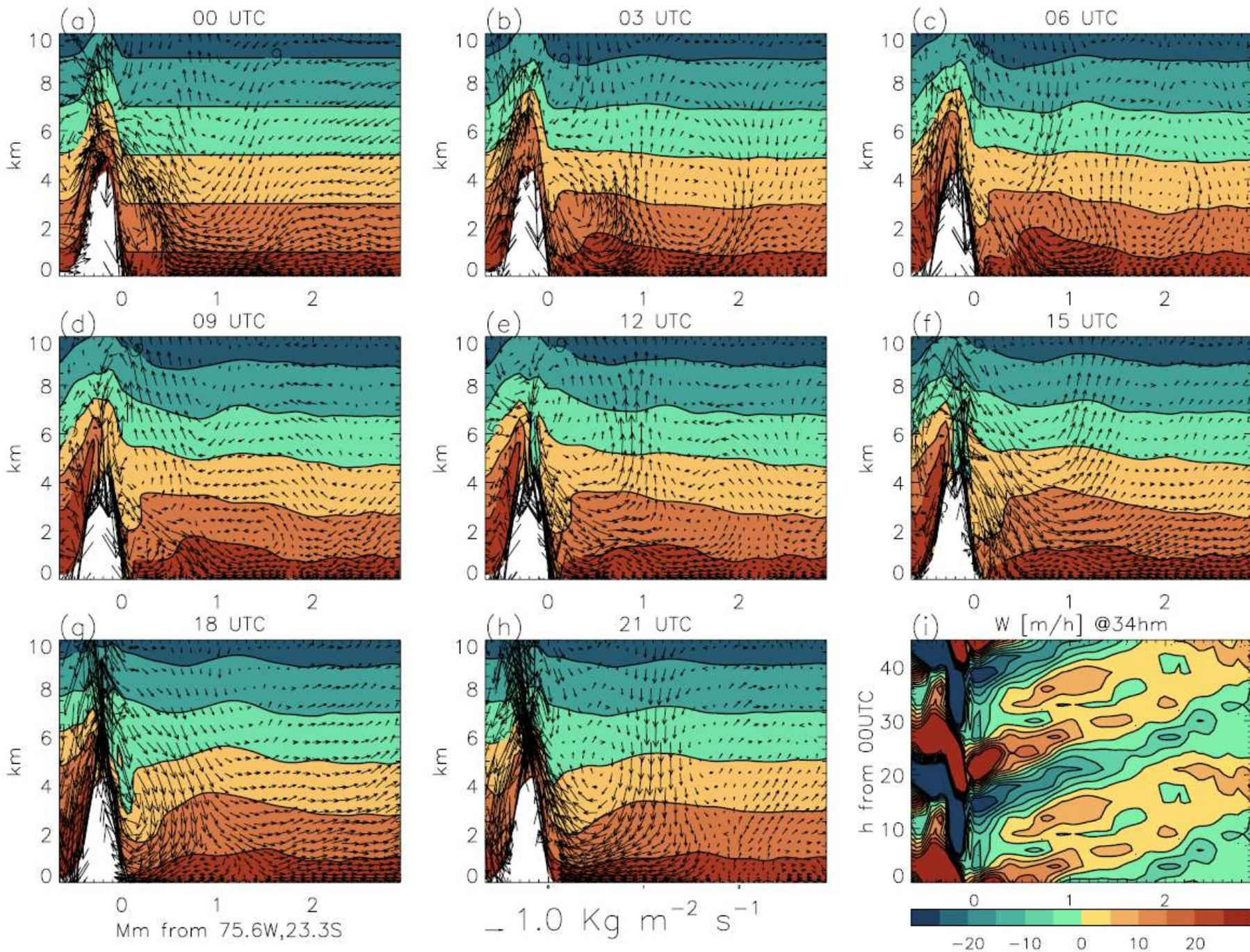


## Interim 3:

1. Subsidence and inversion strength are strongly related through dynamical-physical processes

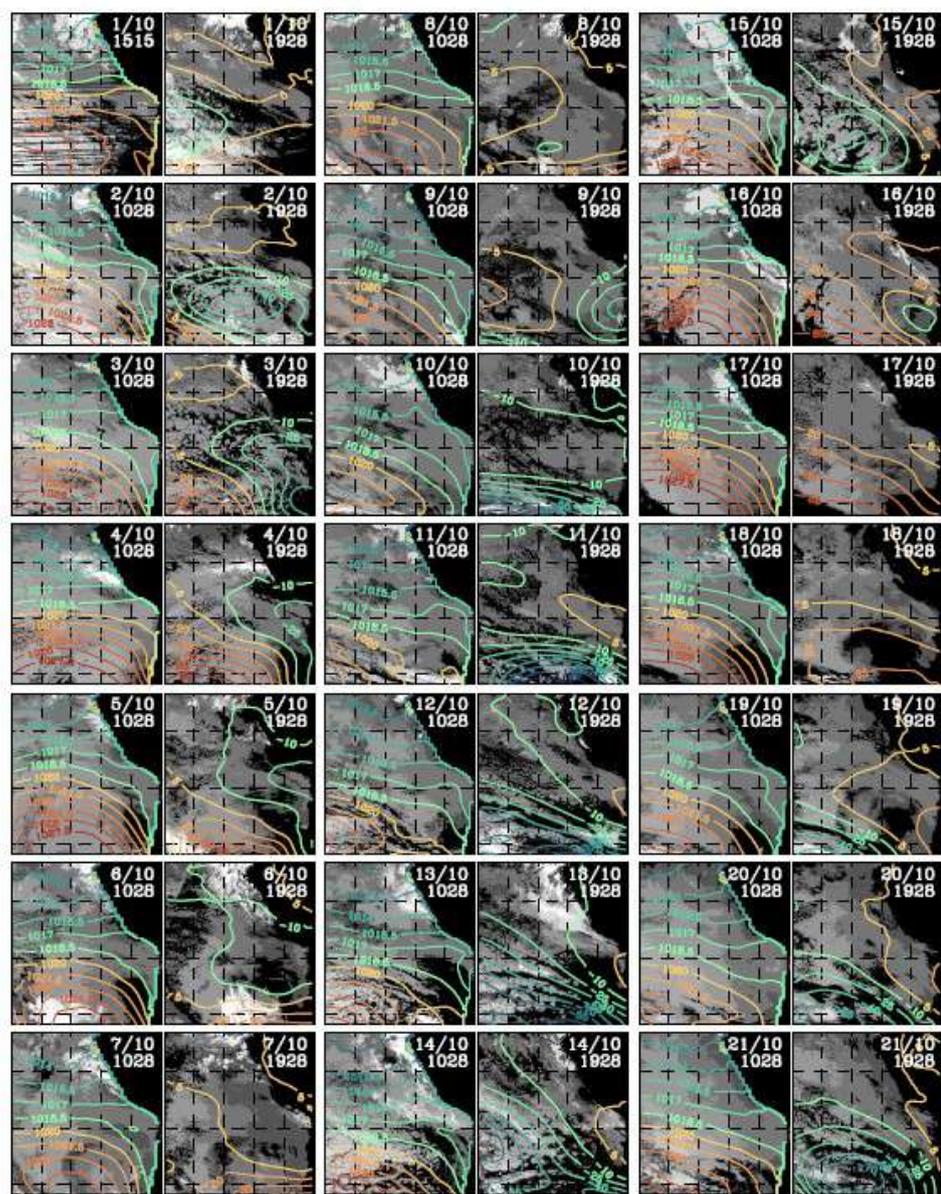


# Importance of the diurnal cycle at low latitudes

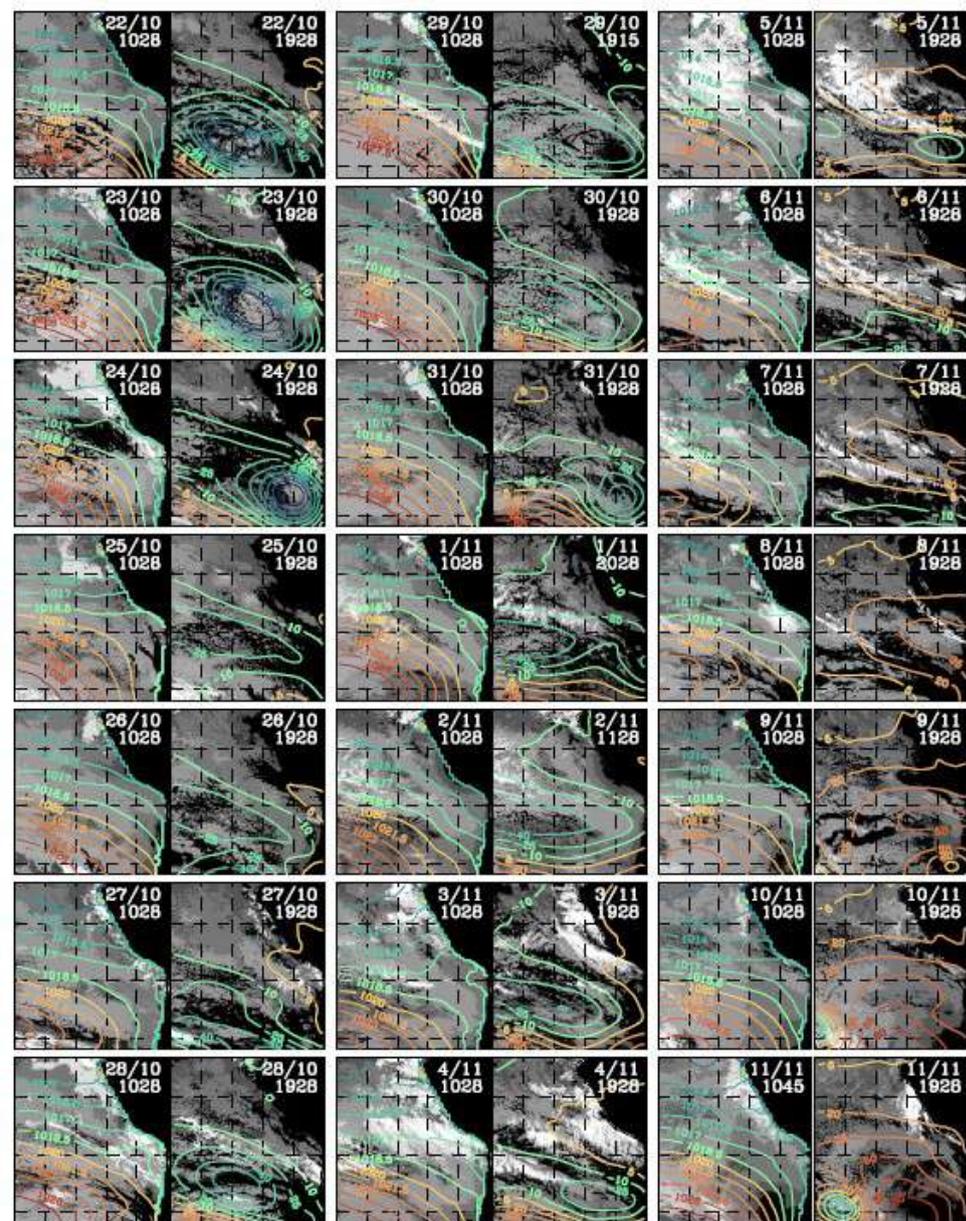


**Fig. 6.** (a-h) Snapshots of the mean circulation through a daily cycle along a great circle at a right angle to the South-Peruvian orographic slope and intersecting the coastline at 75.6°W, 23.3°S. The long-term mean circulation has been removed and average anomalies for the time of the day are shown as indicated at the top of each panel in hours UTC. The abscissae indicate offshore and onshore distances in Mm, and the ordinate vertical heights in km. The arrows represent two components of the flow, the offshore and the vertical mass fluxes (scale arrow at the bottom of panel a). The colour-filled contour lines depict the nominal displacement (exaggerated 10-fold) of constant-height surfaces at 00 UTC (panel a, shown at intervals of 2 km starting from 1 km) as obtained from the time-integrated anomalies in the vertical velocity. (i) Hovmöller diagram for the vertical velocity anomalies, in metres per hour, as a function of time (increasing upwards) and offshore distance for a twice repeated daily cycle.

## **III. weather systems in the EBUS**



**Fig. 14a.** Twice-daily snapshots (UTC time as indicated) of the temperature difference  $\Delta T$  between the OSTIA SSTs and the GOES Channel 5 brightness temperature. The gray colours indicate the presence of low clouds, with lighter shades indicative of higher clouds in deeper boundary layers. The contour interval for the shading is 3 K. Values of  $\Delta T$  below 5 K are shown in black, and values above 35 K are shown in white (cf. Fig. 14c). See text for full details. The contour lines in the night-time panels show the sea-level pressure for the previous 00:00 UTC. The contour interval is 1.5 hPa; the 1020 hPa line is drawn in light orange colour, and the 1018.5 hPa line in light cyan. On the day-time panels, contours of the zonally asymmetric part of the 500 hPa geopotential height field are drawn, for the subsequent 00:00 UTC. A contour interval of 15 m is used, with positive values (at and above 5 m) in orange/red, and negative values (at and below  $-10$  m) in cyan/blue.



**Fig. 14b.** Continued.

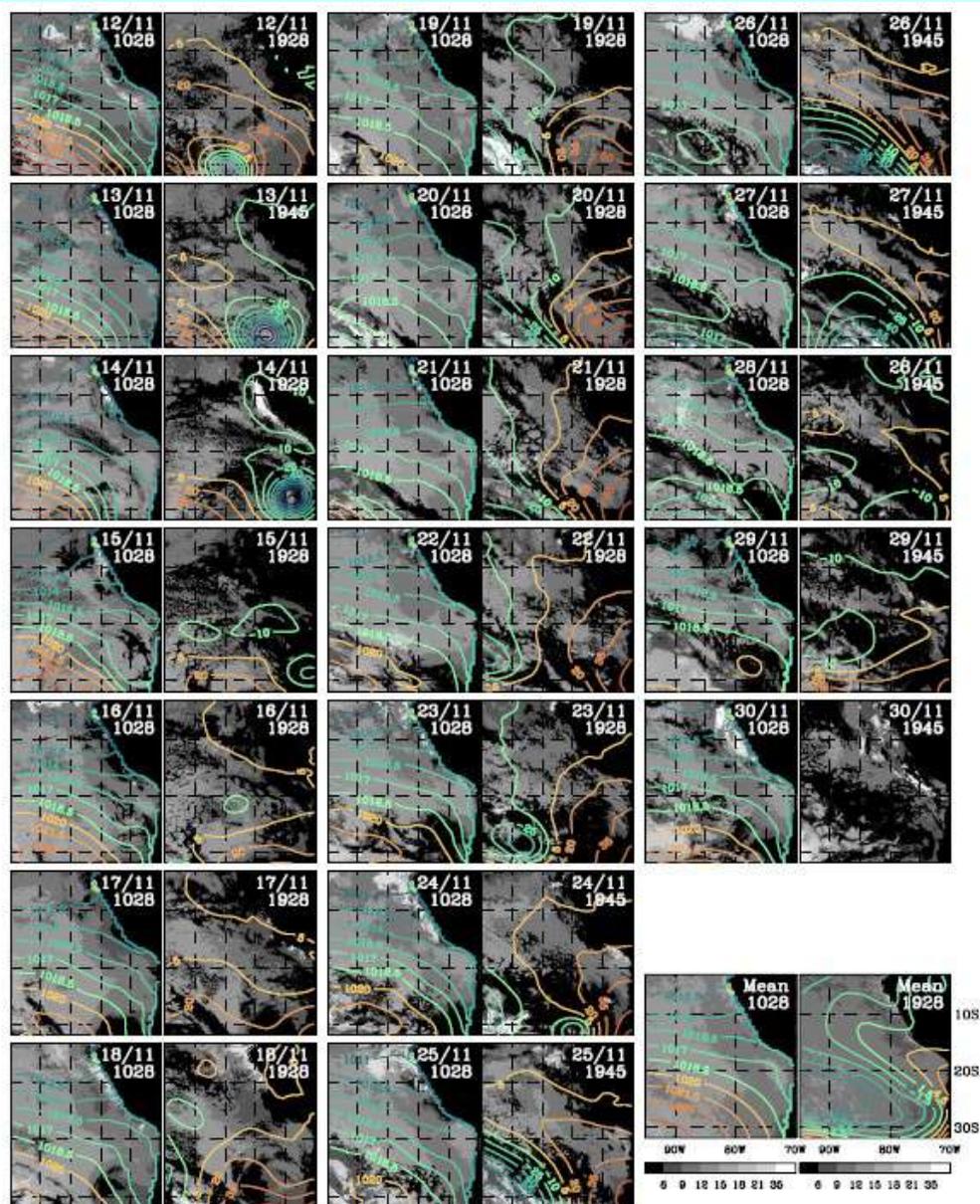


Fig. 14c. The final two panels show the October–November mean values of  $\Delta T$  when cloud is present (determined as being when  $3 < \Delta T < 35$  K) for the morning and afternoon times, with contours of mean pressure (overlaid on morning) and 500 hPa geopotential height (afternoon).

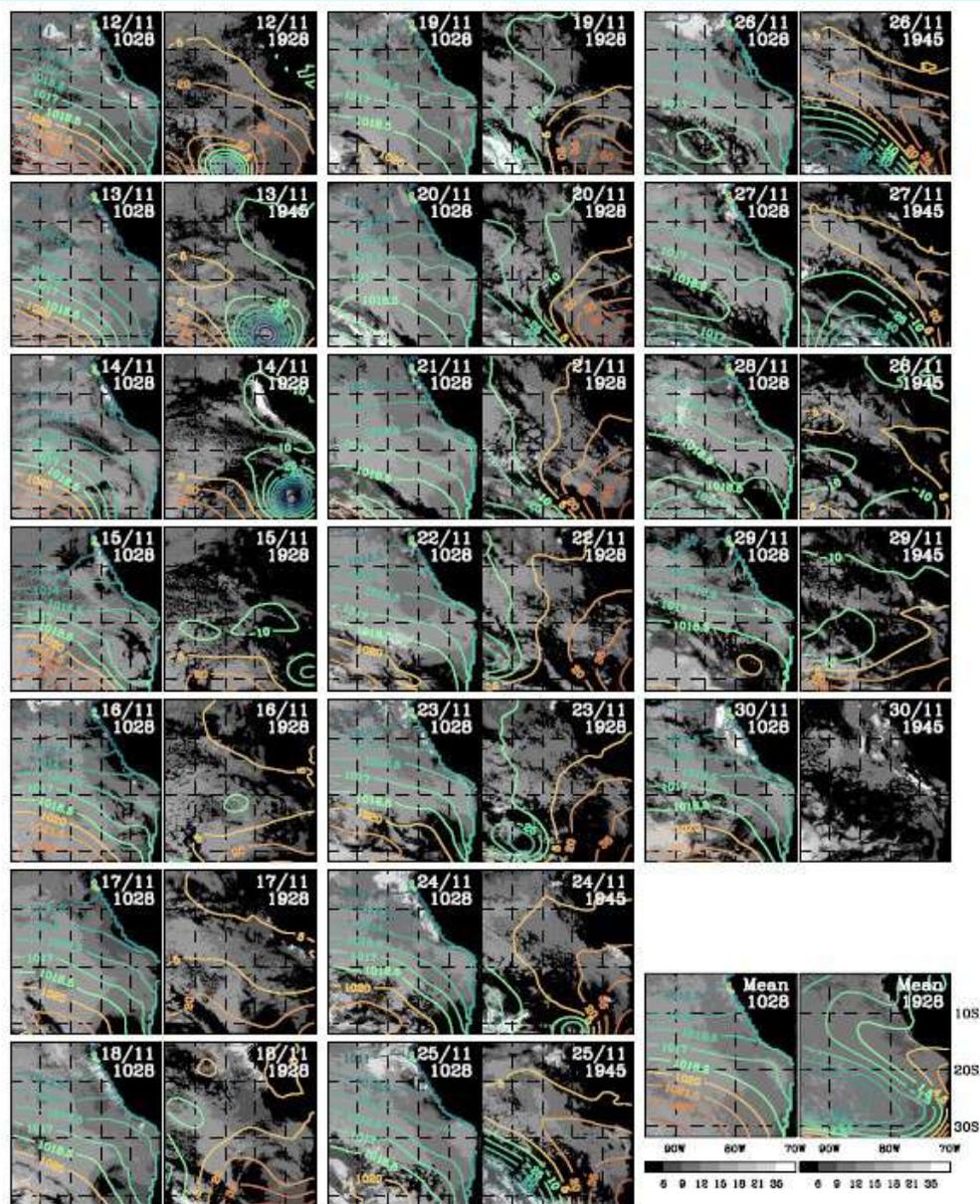
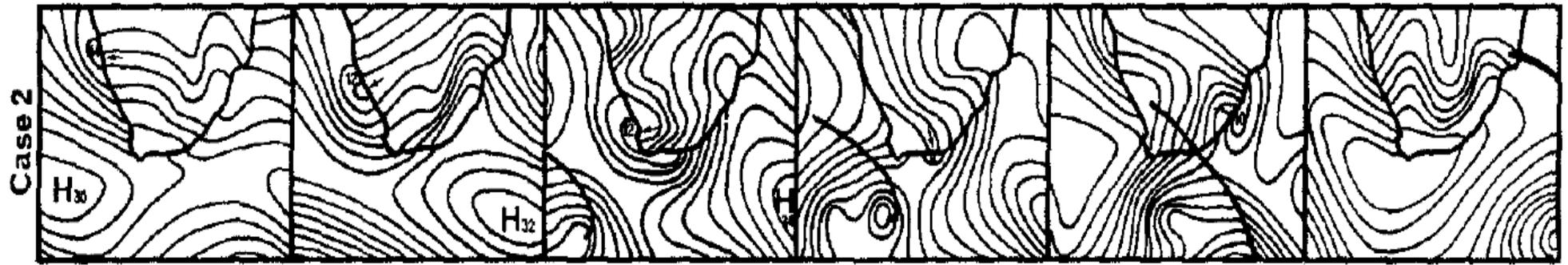


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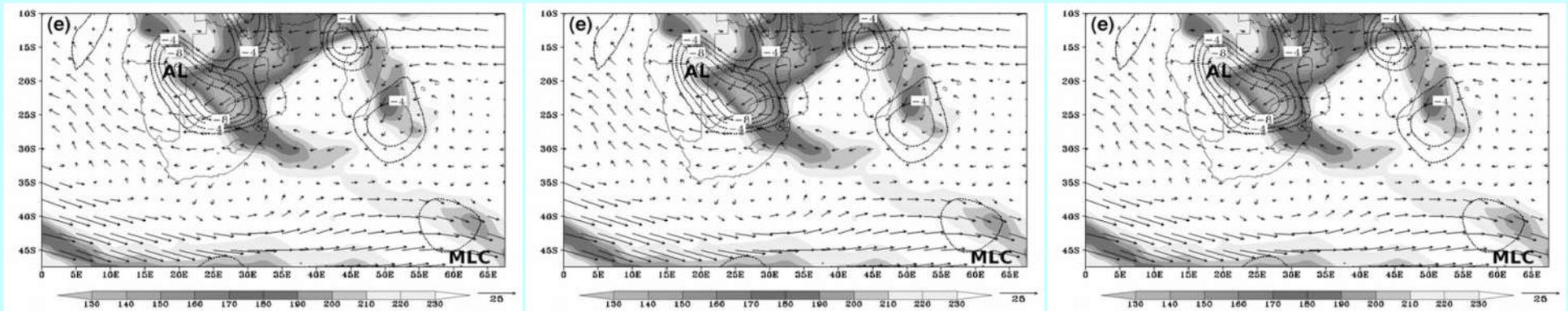
# Main synoptic-scale disturbances affecting the Benguela coast

## Coastally trapped lows (warm seasons)



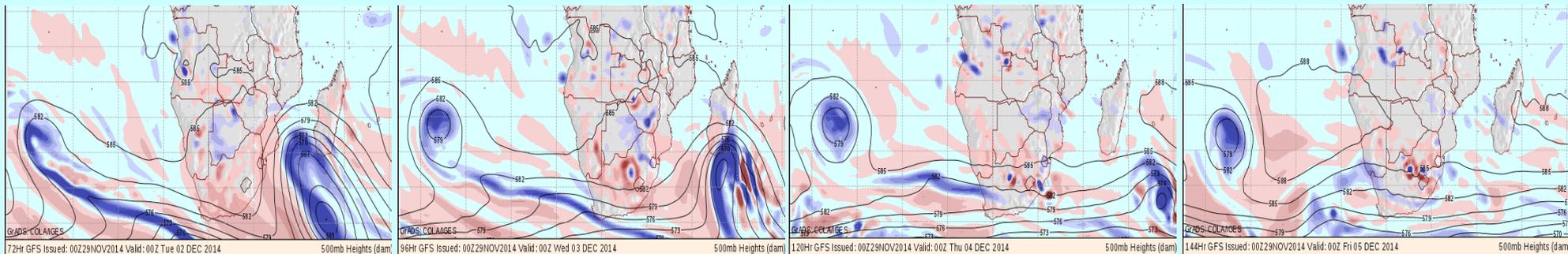
Reason 1996

## Tropical-temperate troughs (DJF)



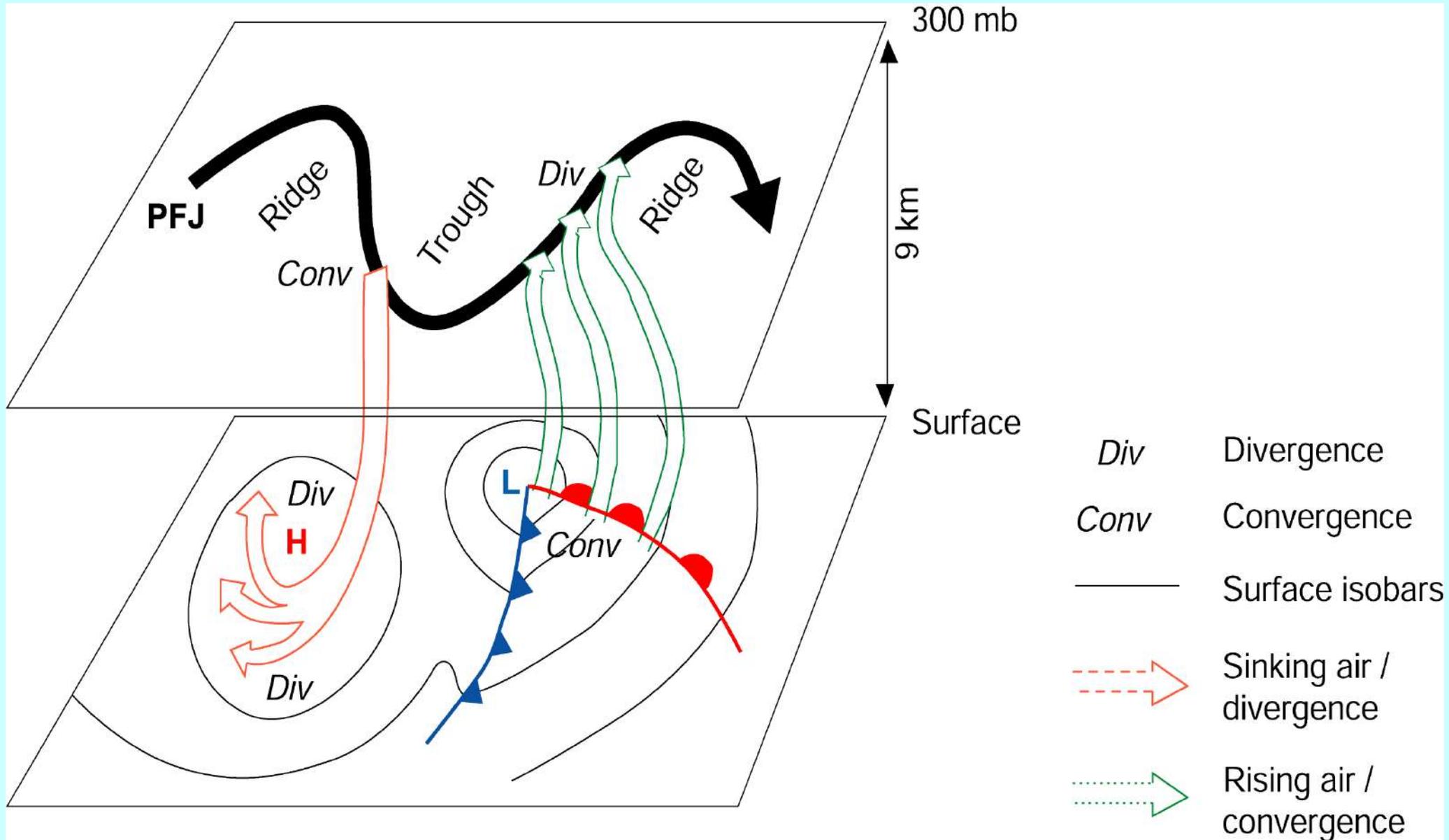
Hart et al. 2010

## Cut-off lows



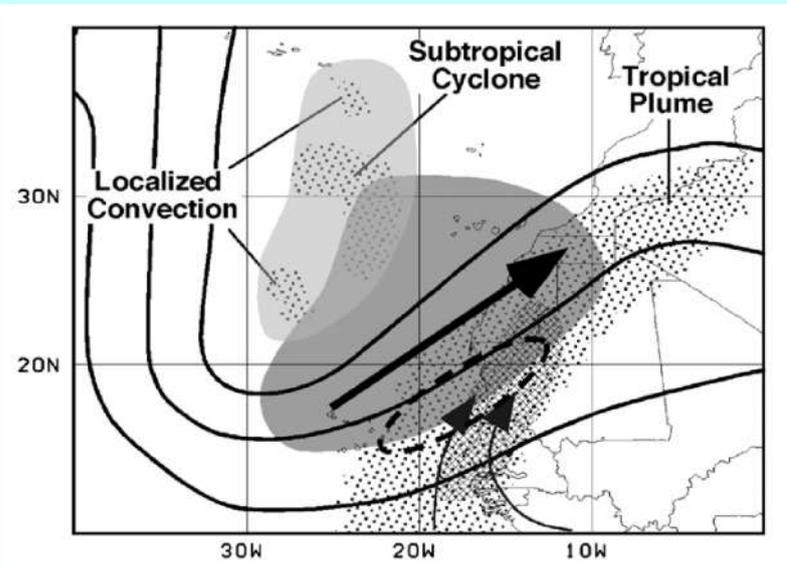
A few days ago

# The link between mid-latitudes Rossby waves and surface weather



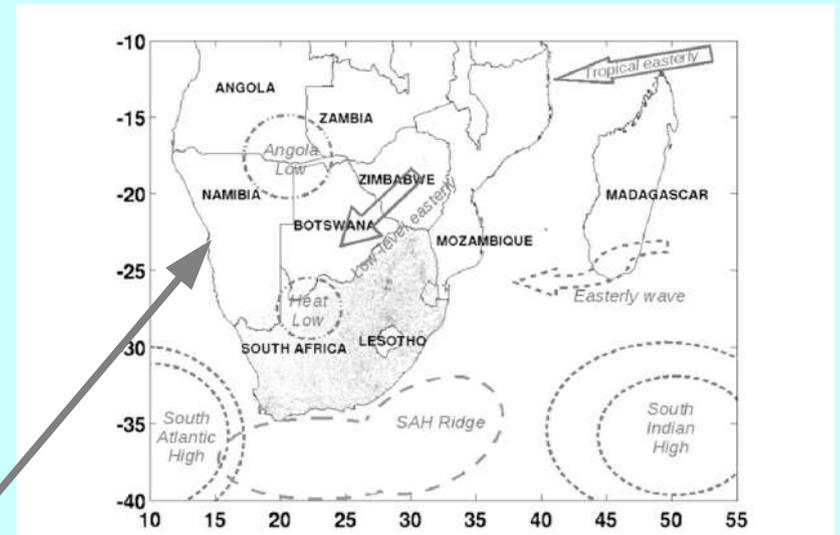
# TTTs

- Breaking LC1 cyclone wave(train) with low-latitude PV streamer provides low-level vorticity and dynamic uplift

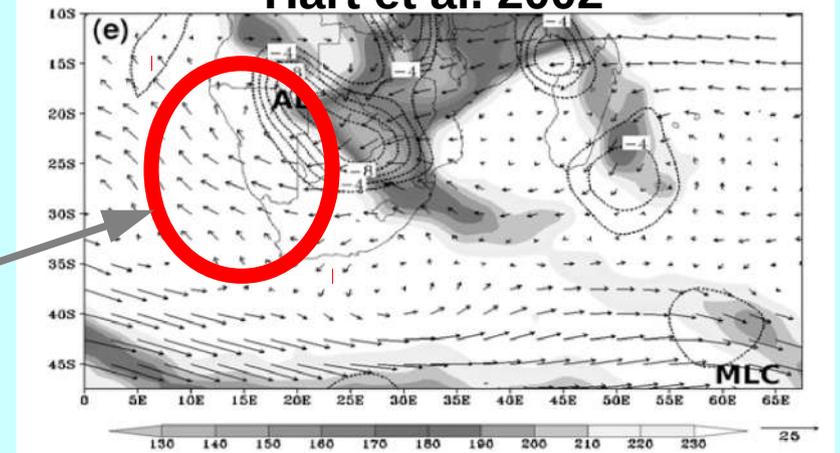


Knippertz 2006

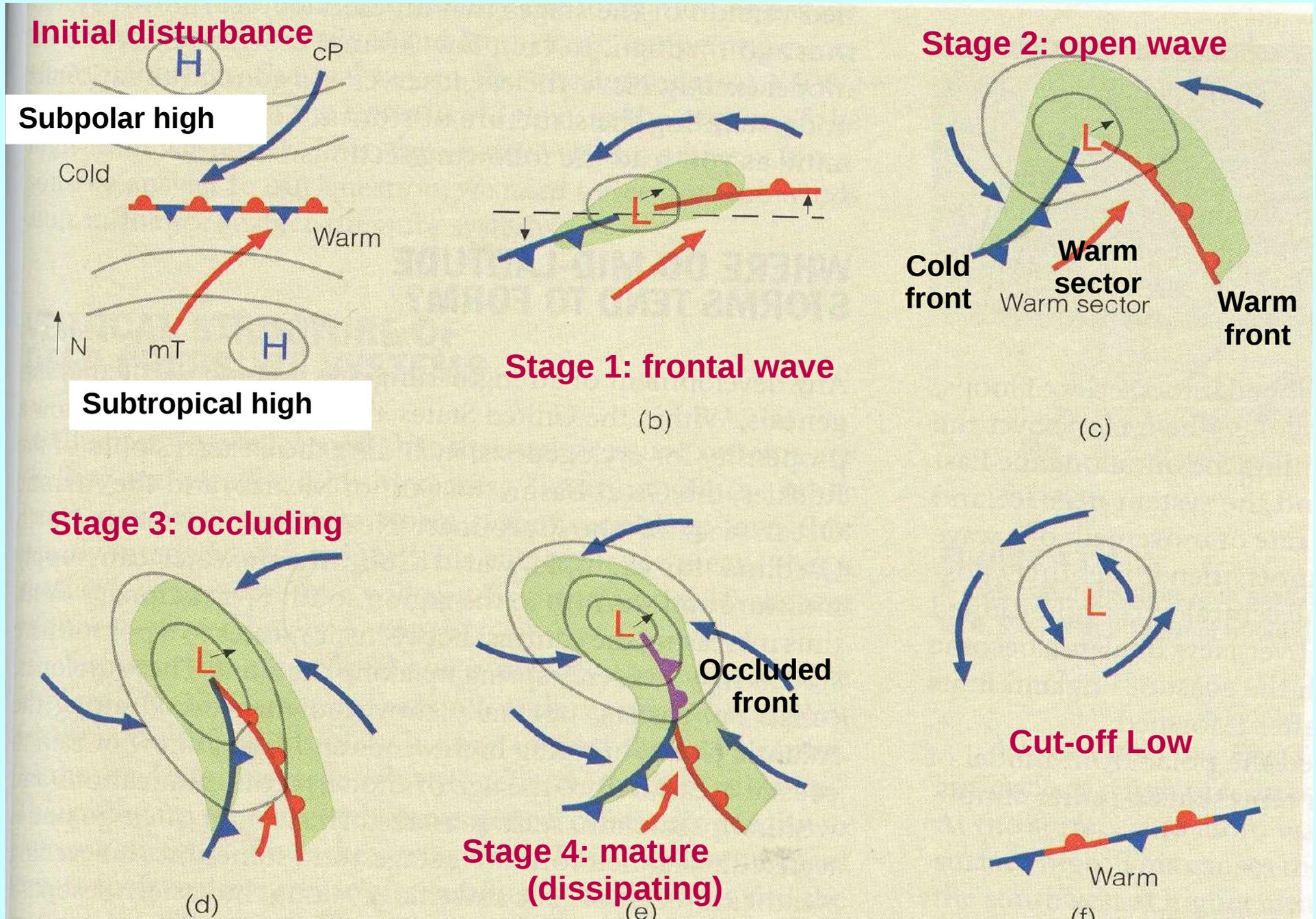
- Couples with tropical low-level winds providing moisture & triggering convection
- Over southern Africa, important role of the Angola Low
- Can cause intense both on- and off-shore wind anomalies of the duration of a few days



Hart et al. 2002

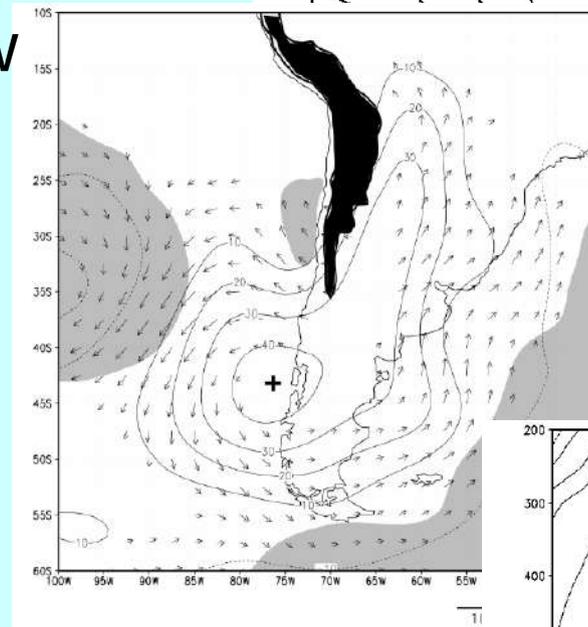
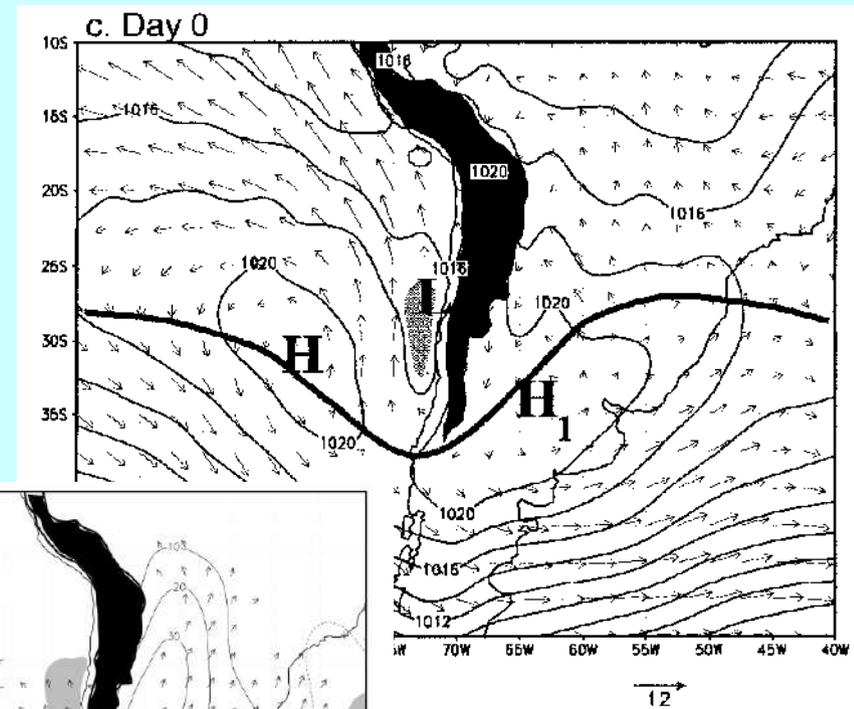


# Mid-tropospheric cut-off lows: genesis

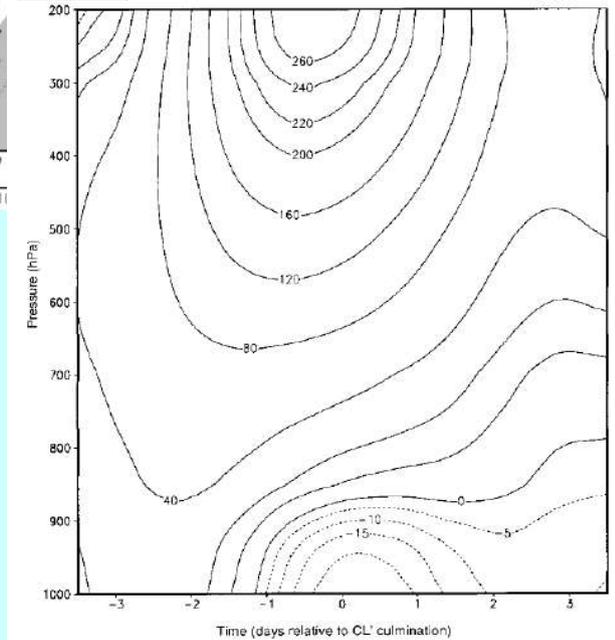


# CLs

- Brief (1-4 days) but ubiquitous
- Synoptic forcing provided by large-scale mid-latitude ridging
- Generates down-slope flow into the LLJ area
- Warm advection etc
- Shallow system
- Moves along inversion as coastal Ke wave, with typical speed of  $\sim 20$  m/s (Reason 1996)
- Can go round all of Southern Africa (Gill 1982)



Garreaud et al. 2002



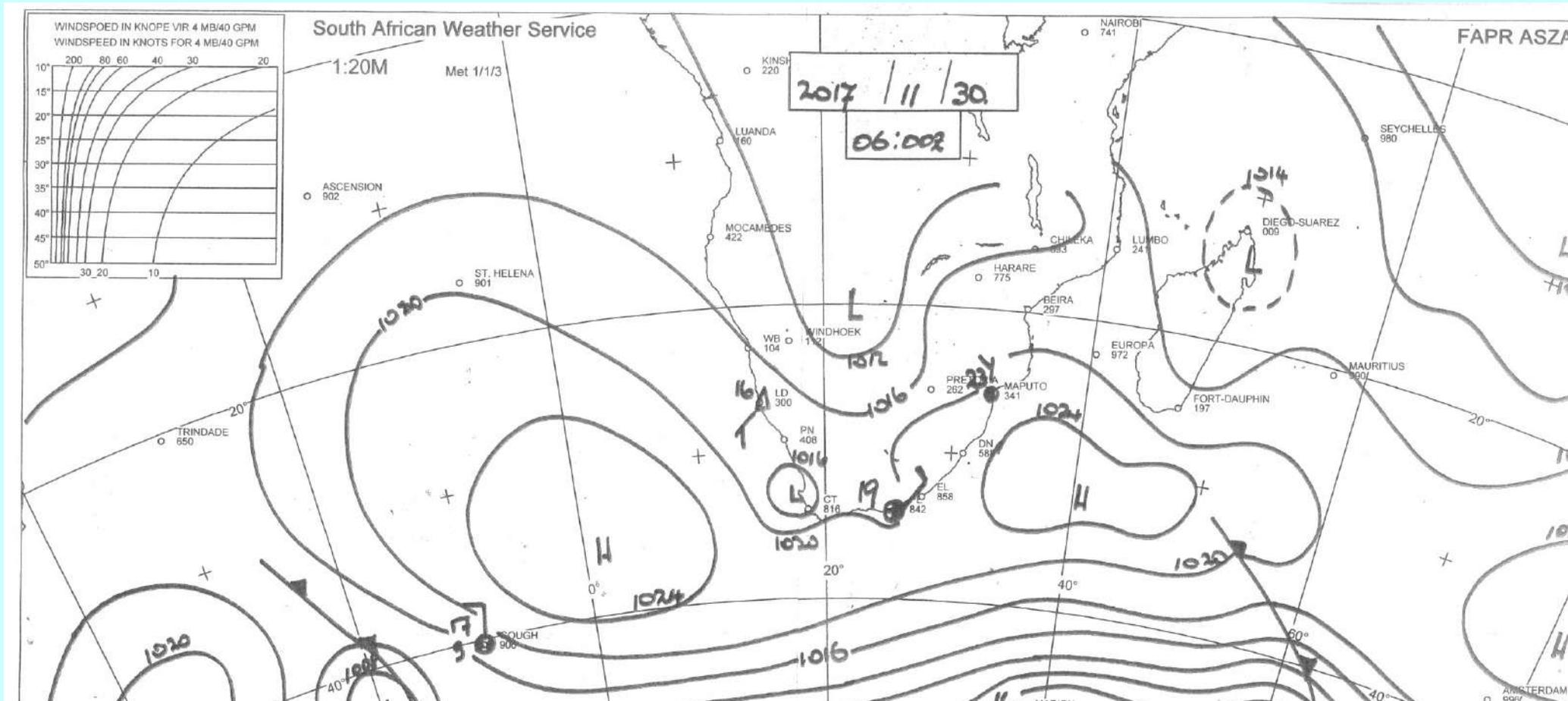
# Coastal Lows along the Subtropical West Coast of South America: Mean Structure and Evolution

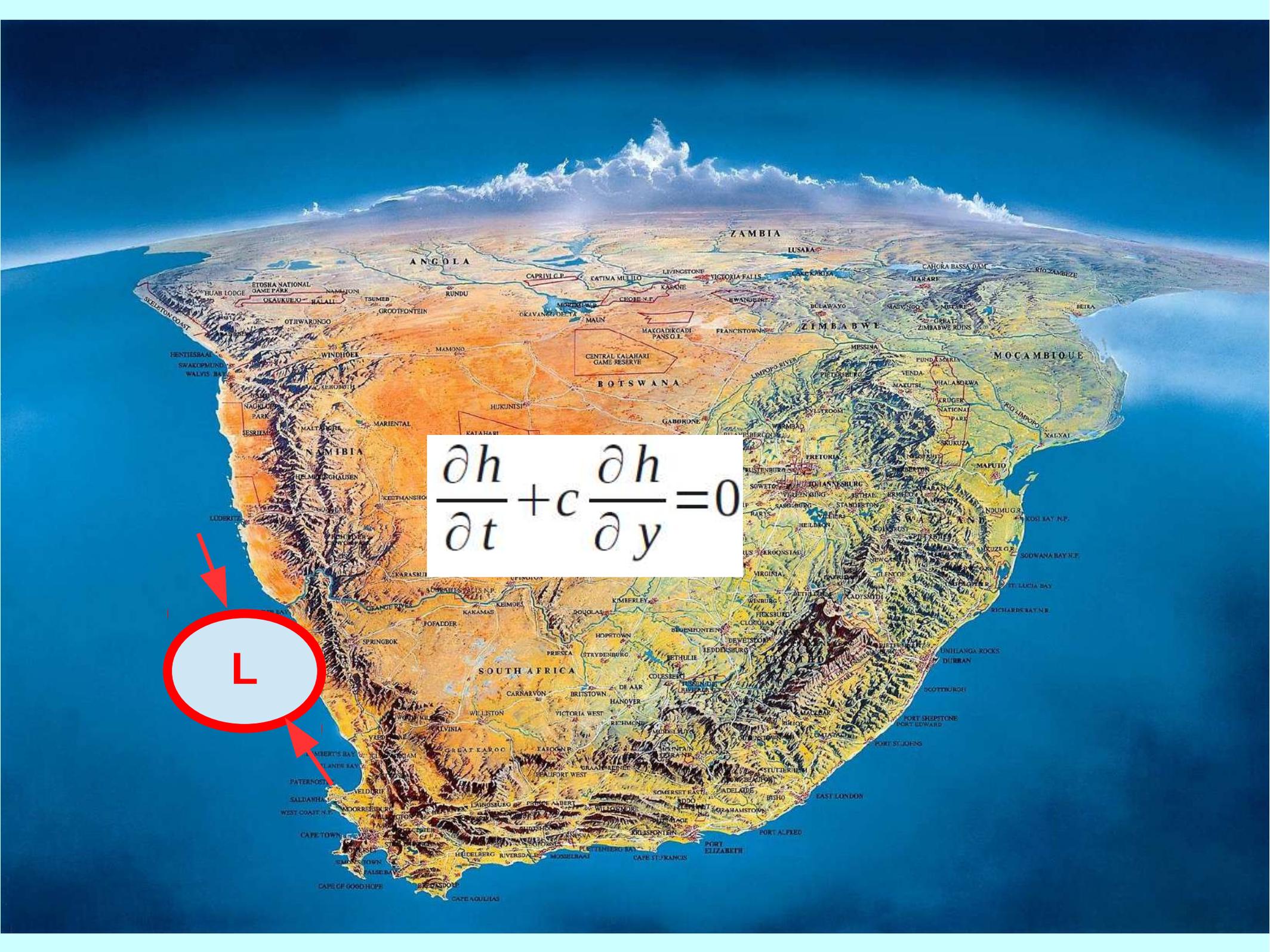
RENÉ D. GARREAUD, JOSÉ A. RUTLLANT, AND HUMBERTO FUENZALIDA

*Department of Geophysics, Universidad de Chile, Santiago, Chile*

(Manuscript received 22 November 2000, in final form 7 June 2001)

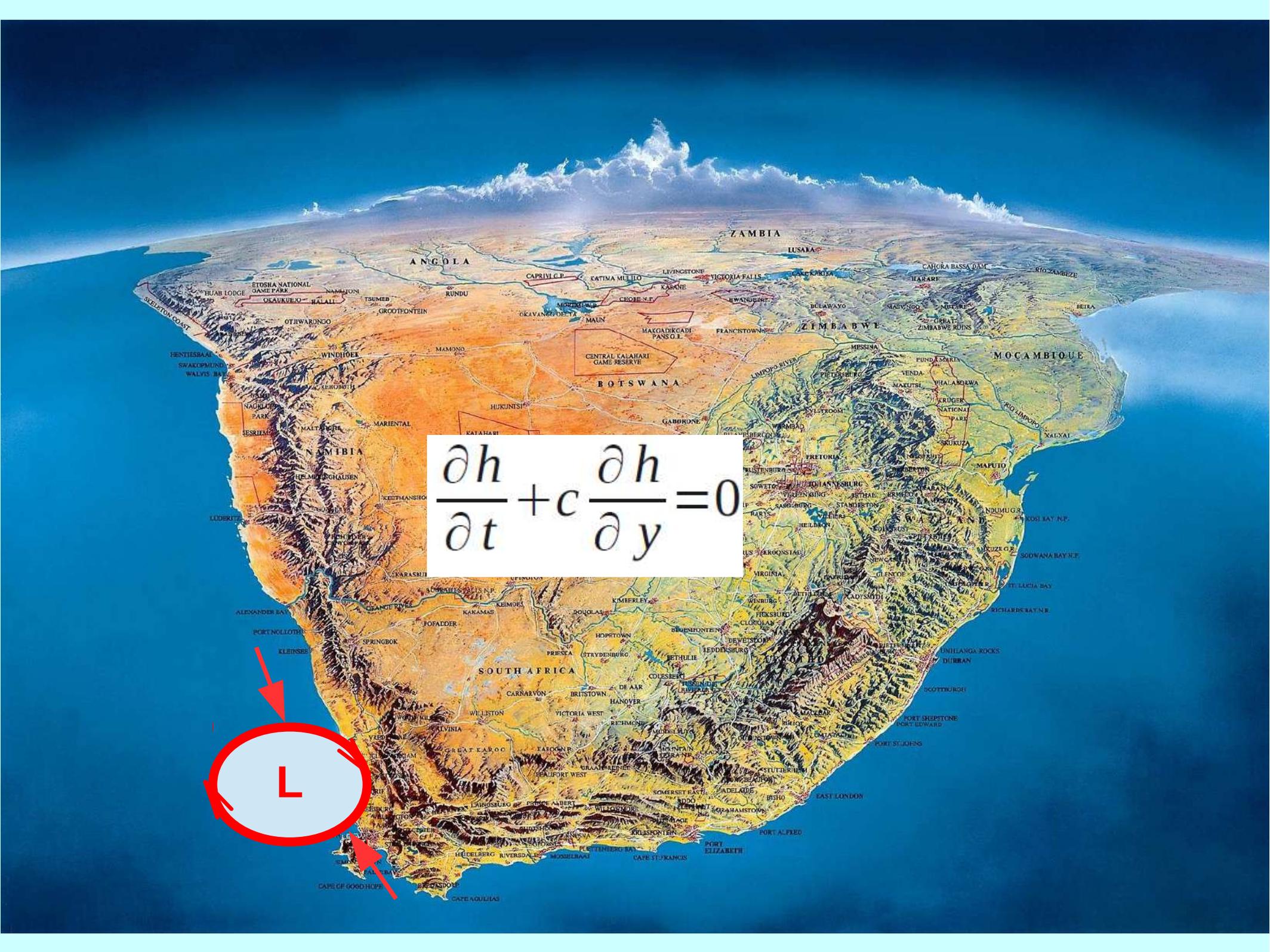
*These so-called coastal lows (CLs) occur up to five times per month in all seasons, although they are better defined from fall to spring.*





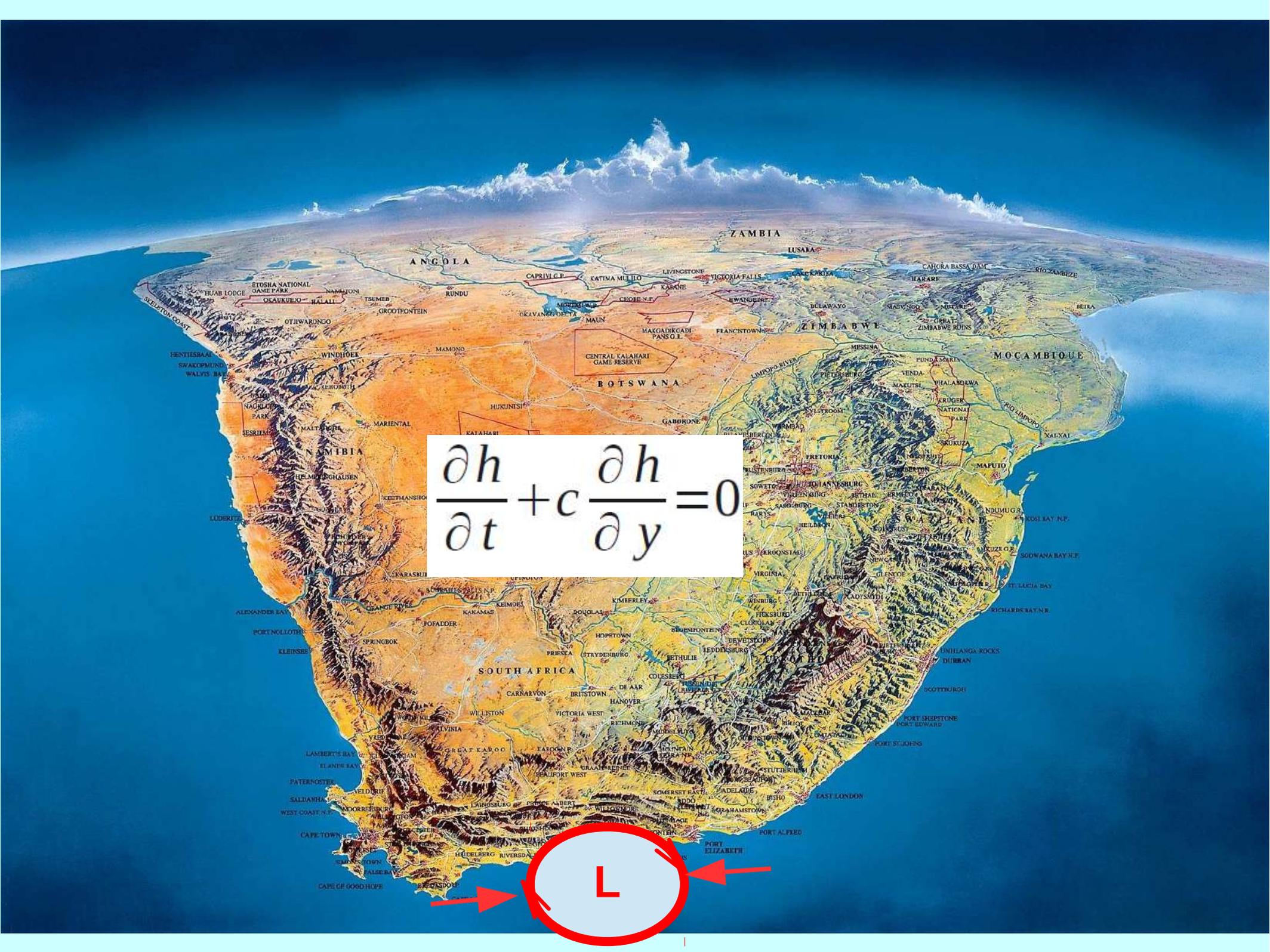
$$\frac{\partial h}{\partial t} + c \frac{\partial h}{\partial y} = 0$$

L



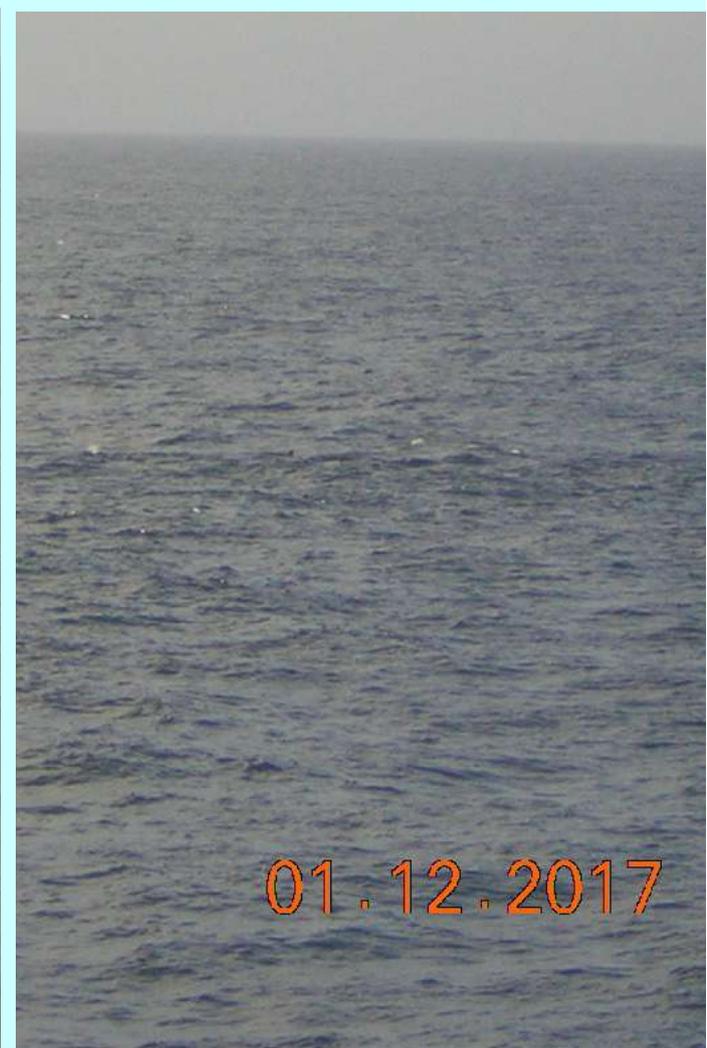
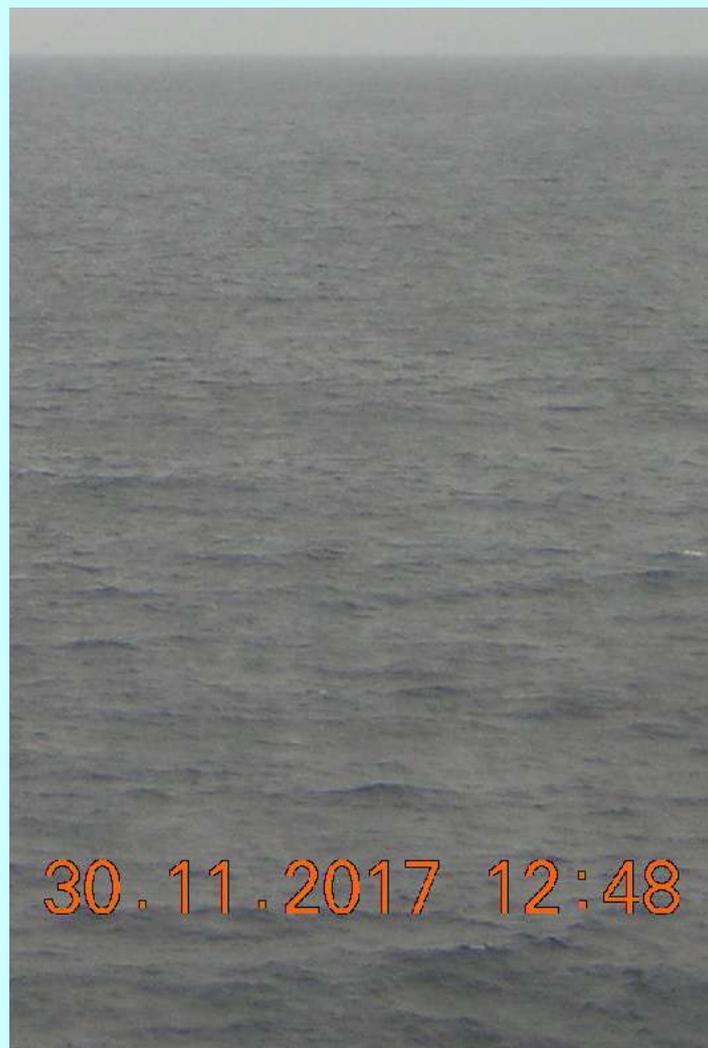
$$\frac{\partial h}{\partial t} + c \frac{\partial h}{\partial y} = 0$$





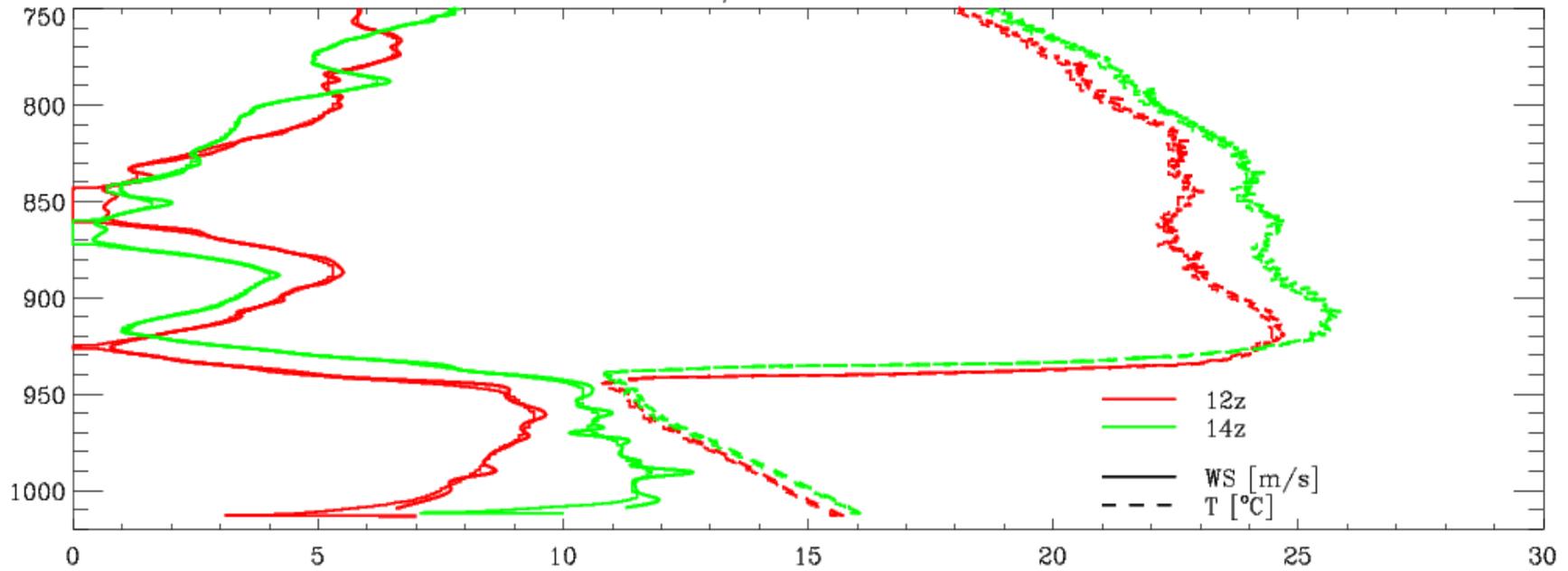
$$\frac{\partial h}{\partial t} + c \frac{\partial h}{\partial y} = 0$$



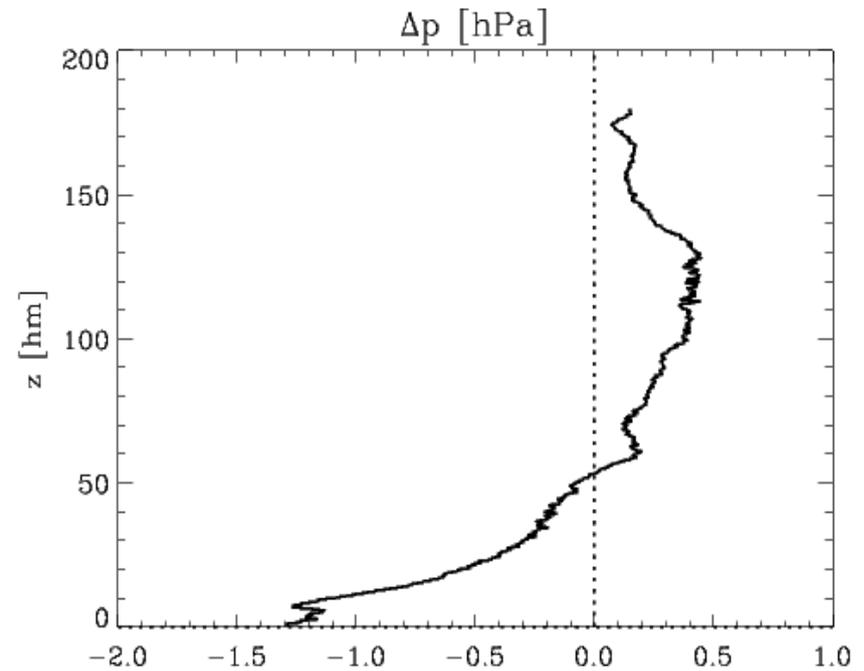
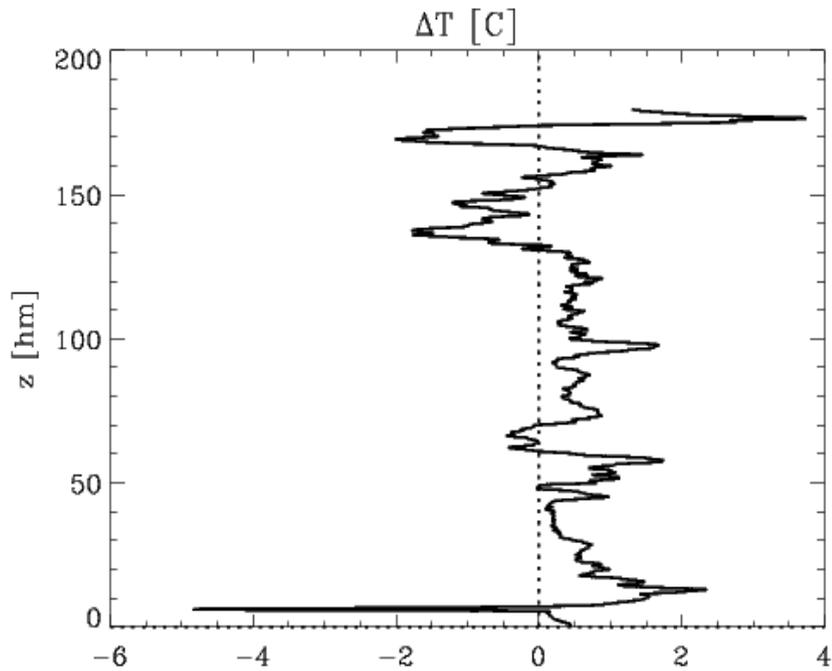


# Synoptic-scale frontal forcing can dominate short time scales

30/11 13.0900E



Mv



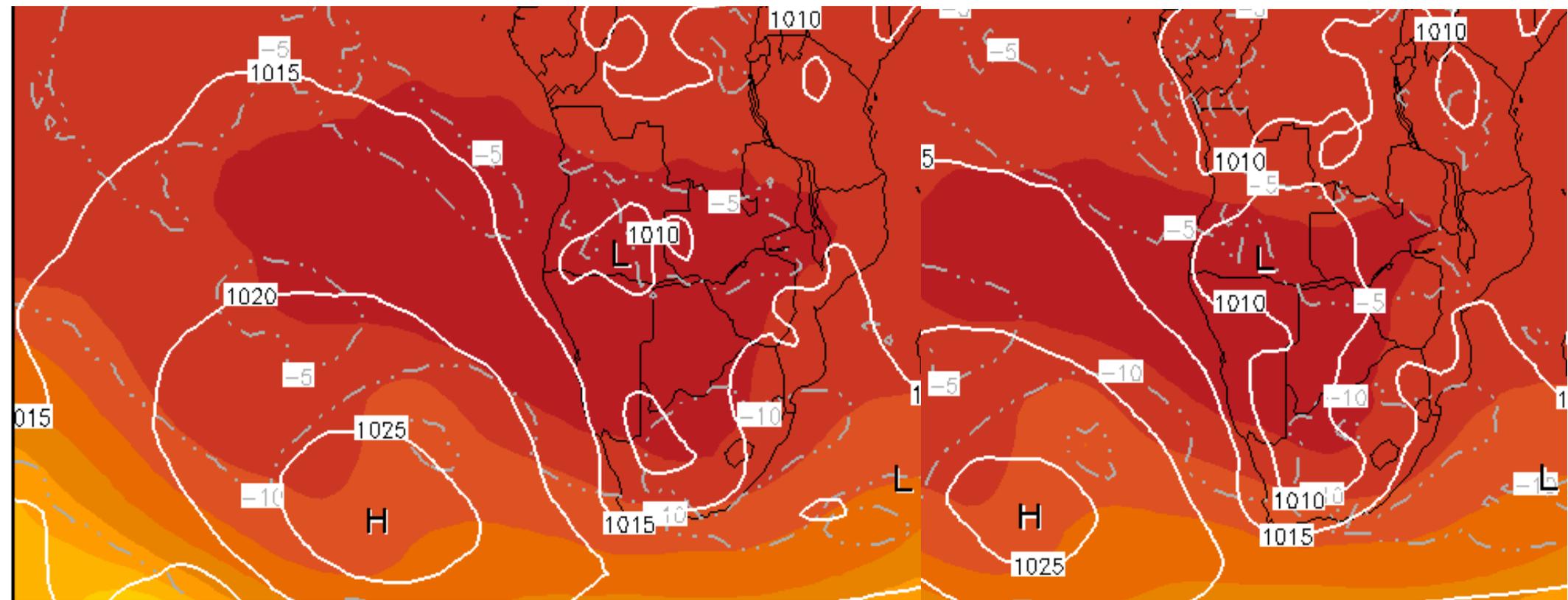


30.11.2017 14:28



30.11.2017 14:57

Init: Thu,30NOV2017 12Z 500 hPa Geopot. (gpdm), T (C), Bodendruck (hPa)



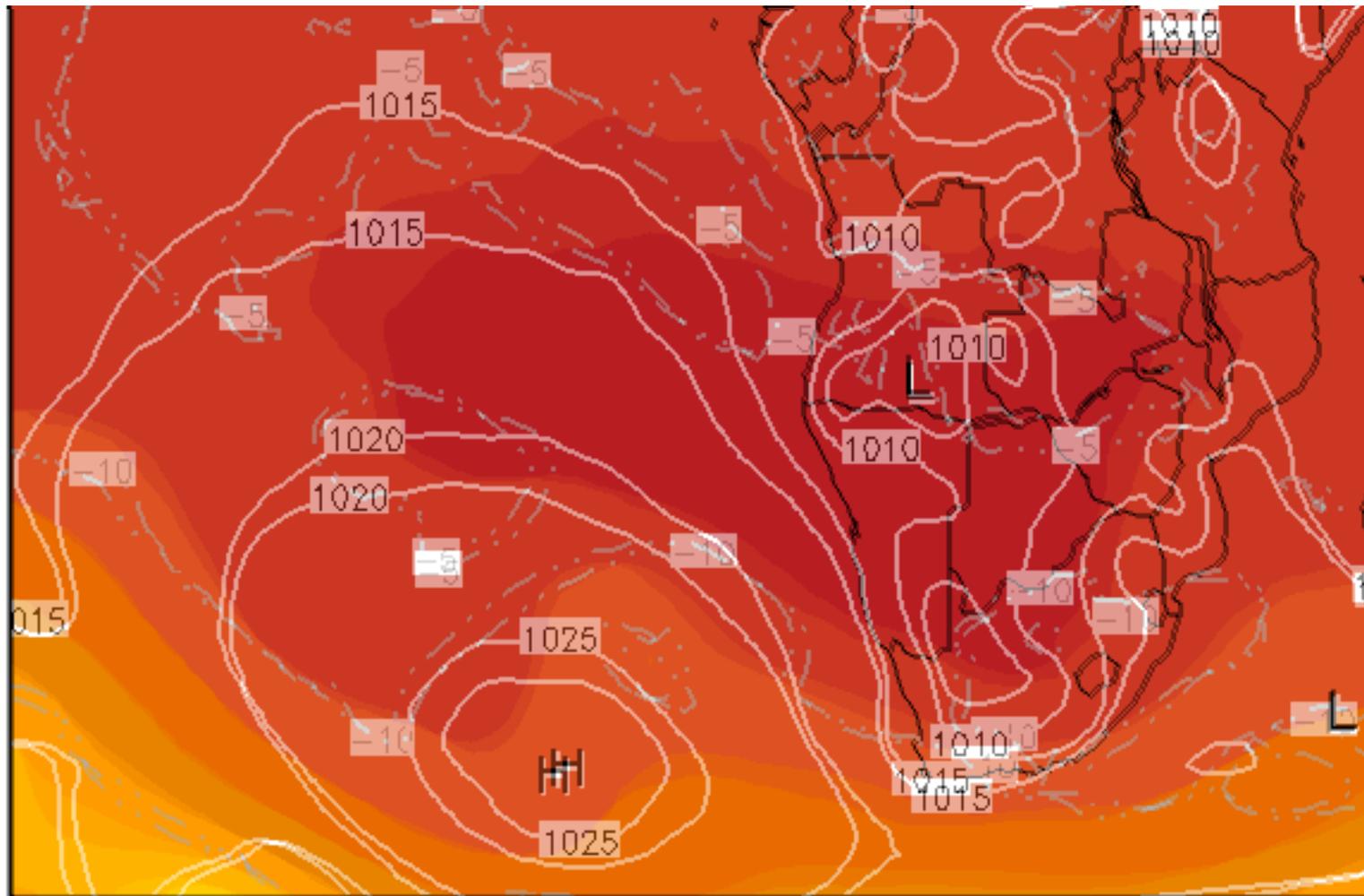
OPERATIONAL 0.250°  
zentrale  
zentrale.de

Valid: Thu,30NOV2017 12Z

Valid: Thu,30NOV2017 15Z



Init: Thu,30NOV2017 12Z 500 hPa Geopot. (gpm), T (C), Bodendruck (hPa)



OPERATIONAL 0.250°  
zentrale  
zentrale.de

Valid: Thu,30NOV2017 12Z

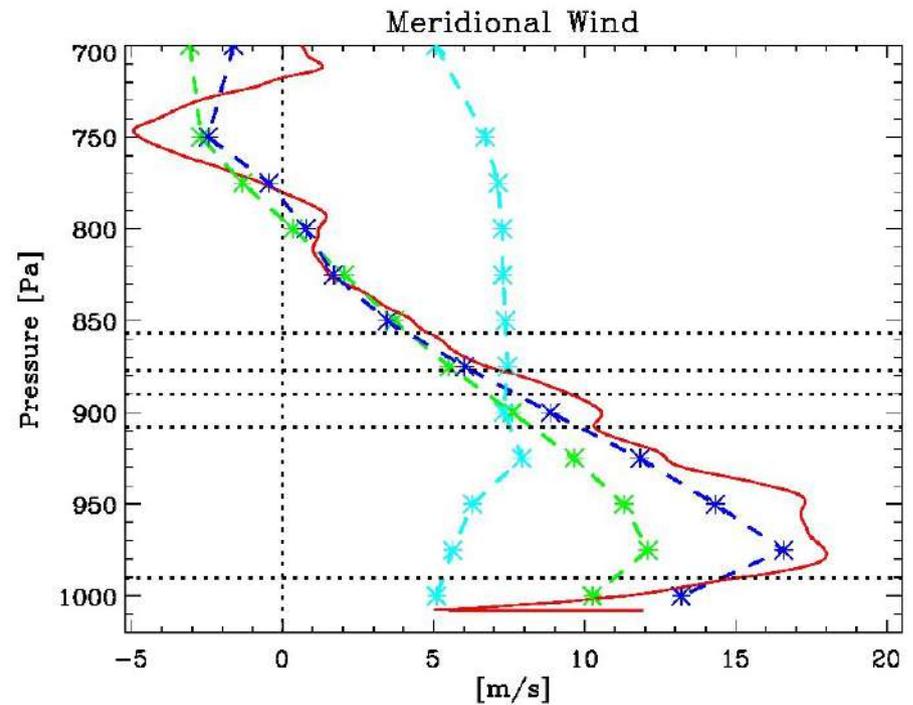
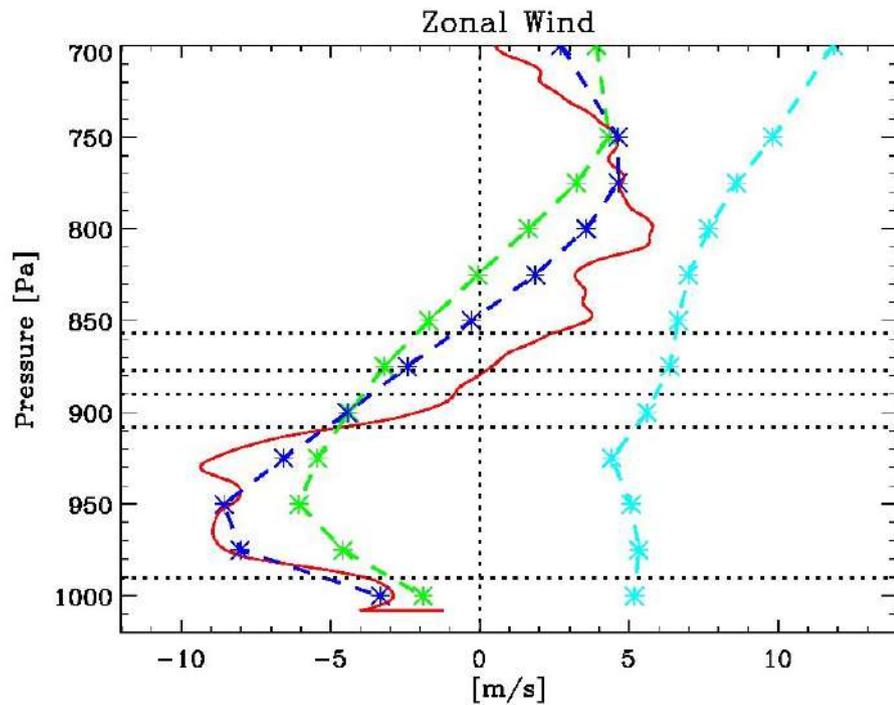
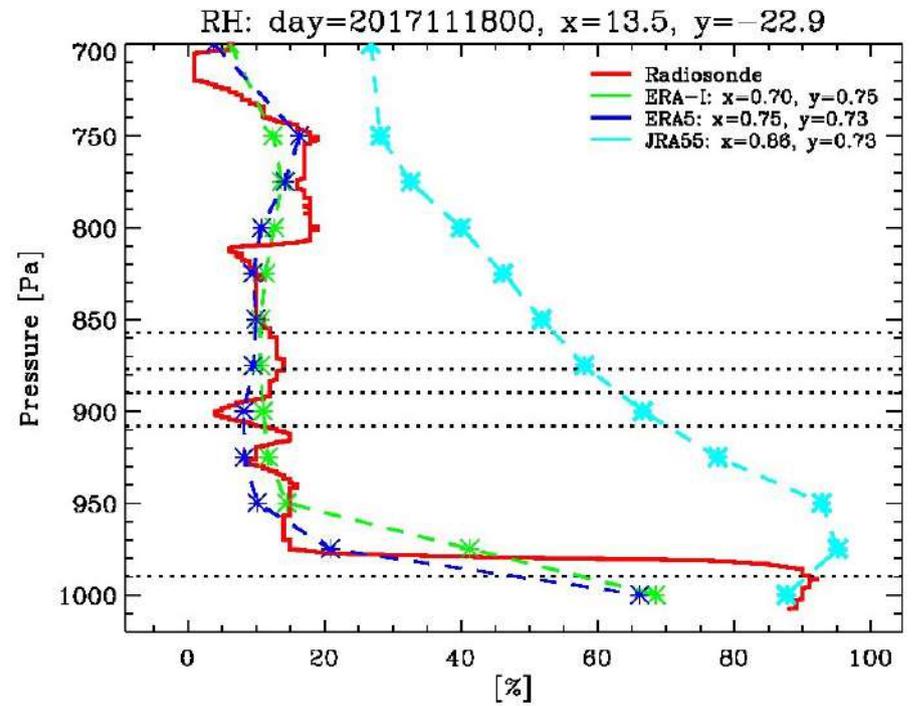
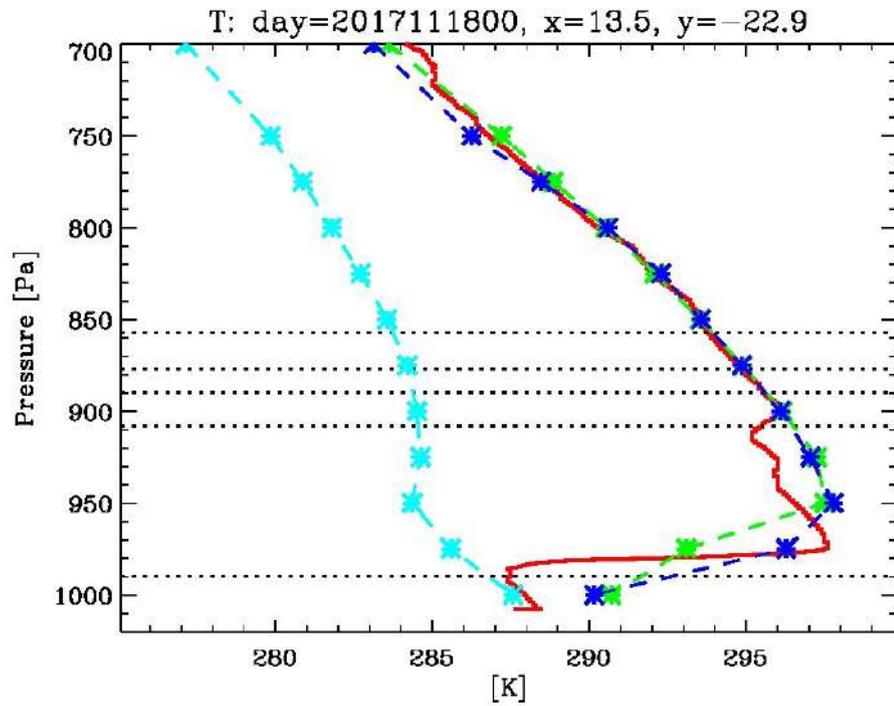


## **IV. atmospheric observations and models in the EBUS**

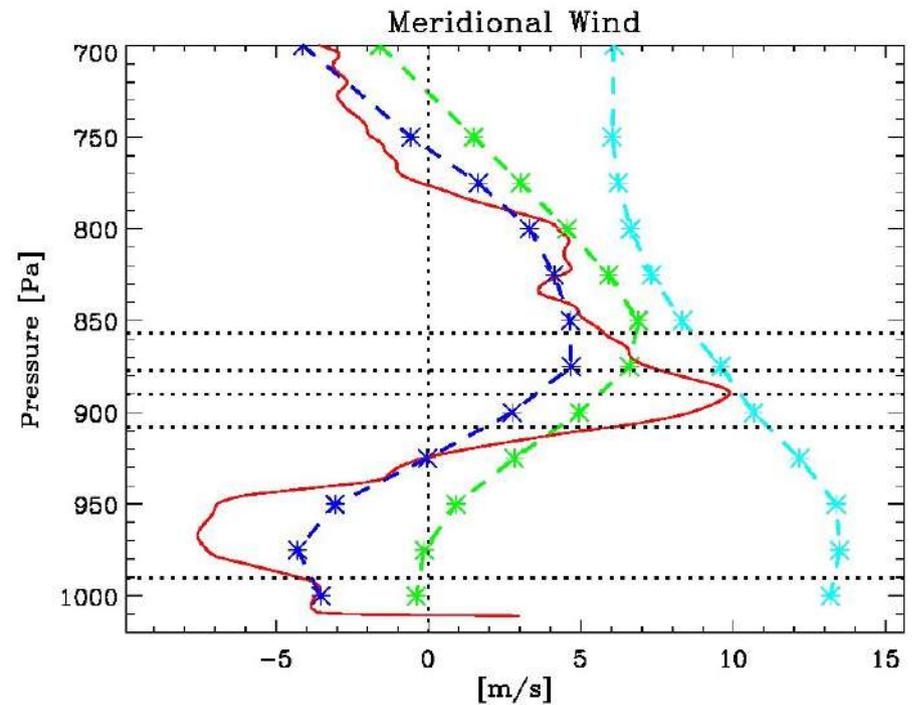
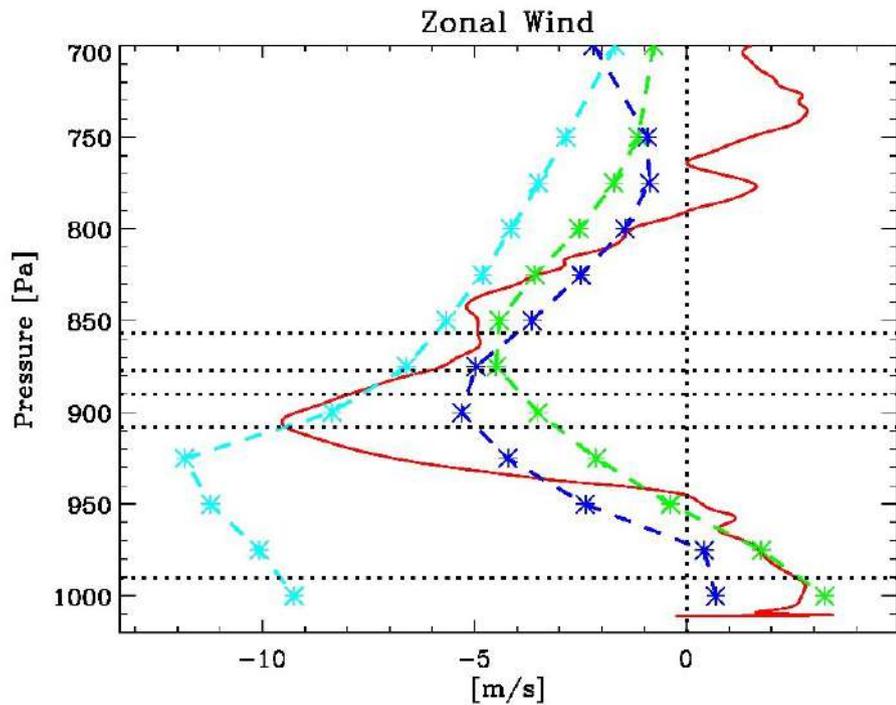
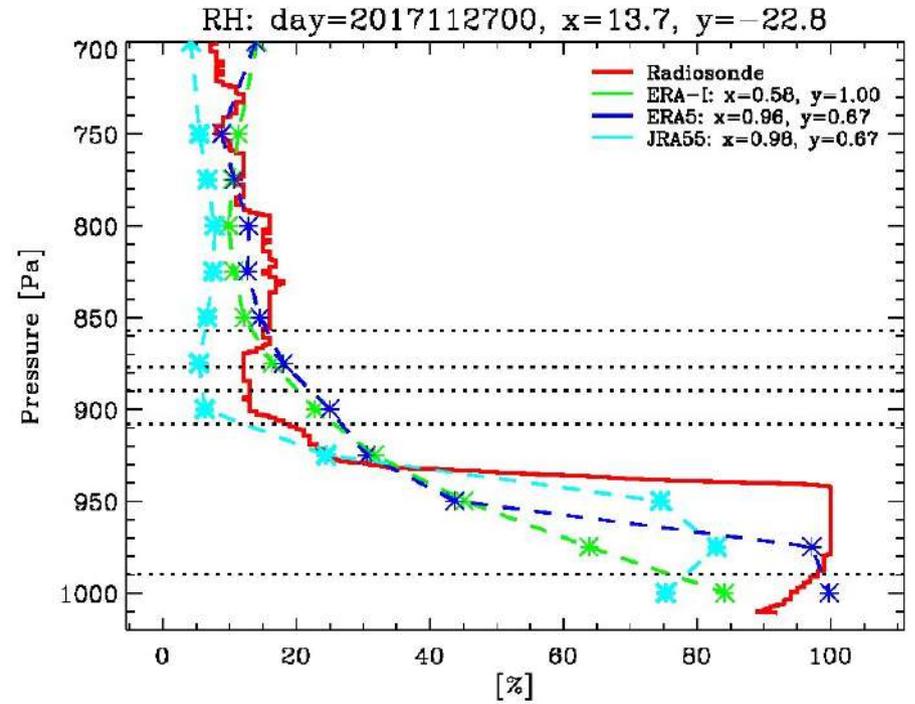
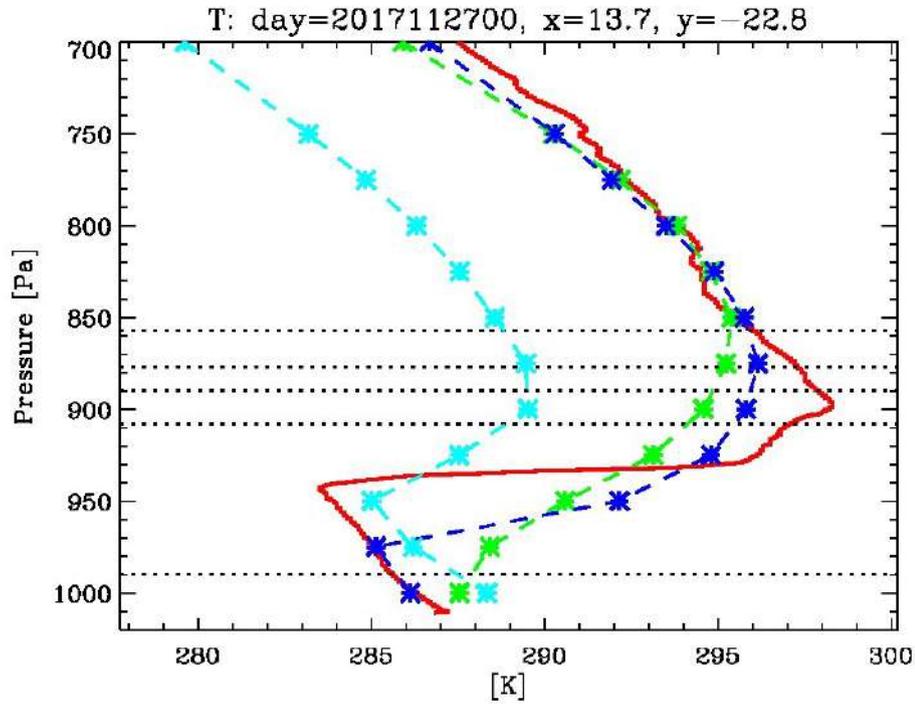
# IV. atmospheric observations and models in the EBUS



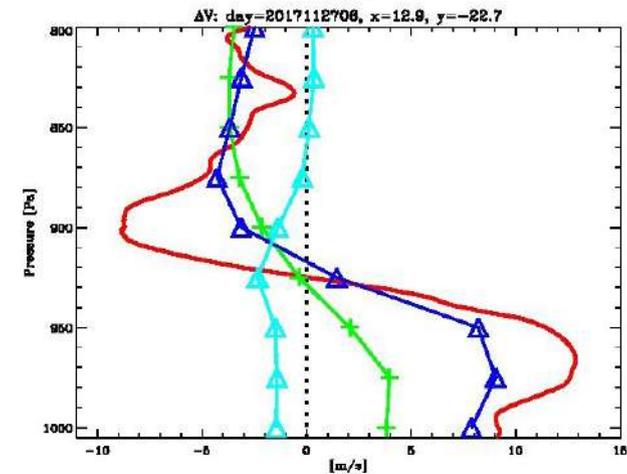
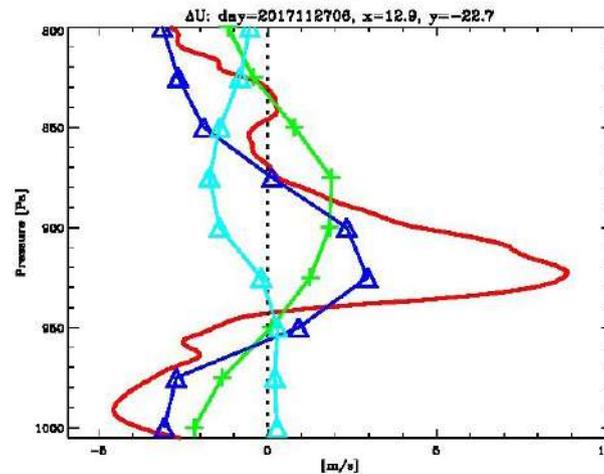
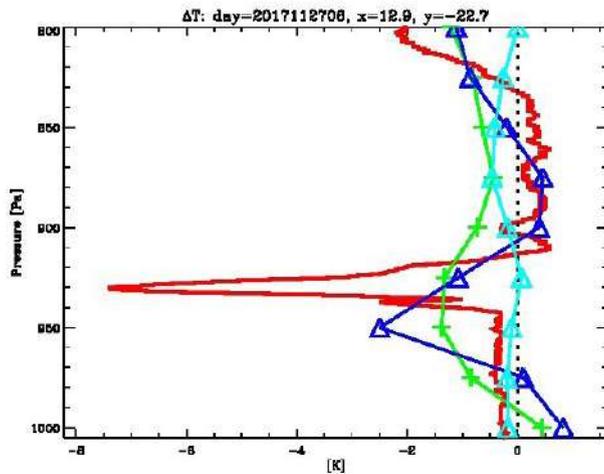
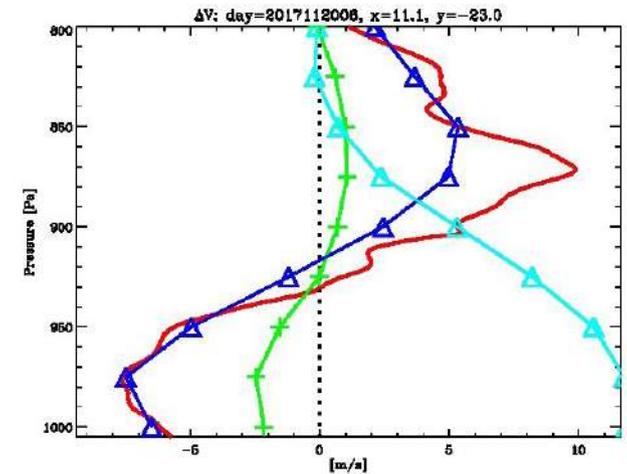
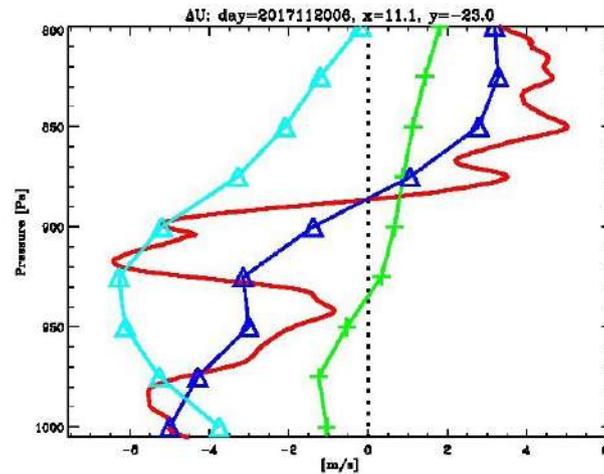
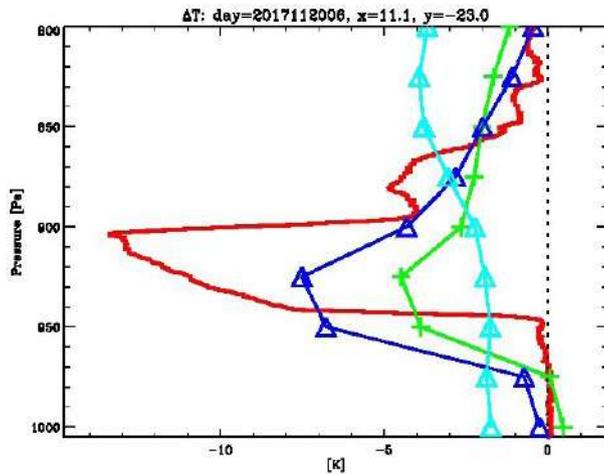
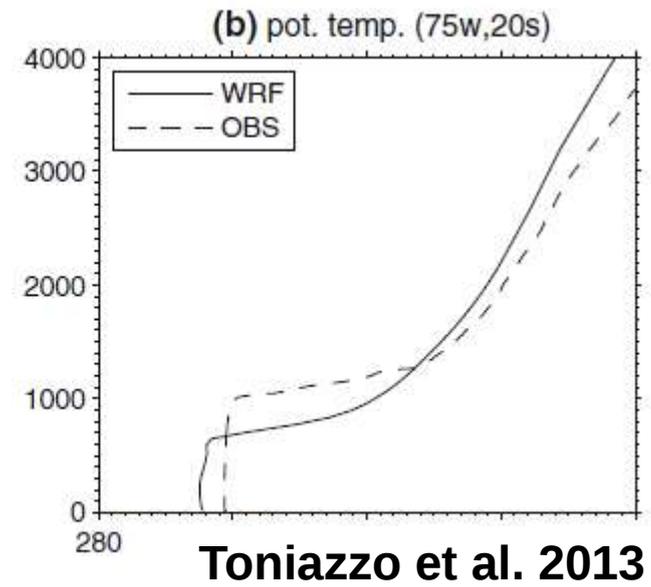
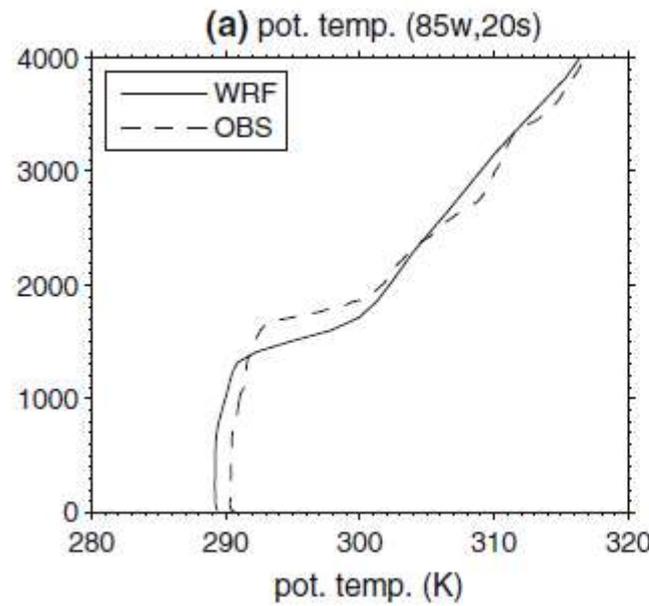
# Radiosonde profiles against reanalysis products in the Benguela



# Radiosonde profiles against reanalysis products in the Benguela



The scarcity of in-situ data acquisition in operation product leads to systematic biases in the reanalyses which tend to reflect common model biases.

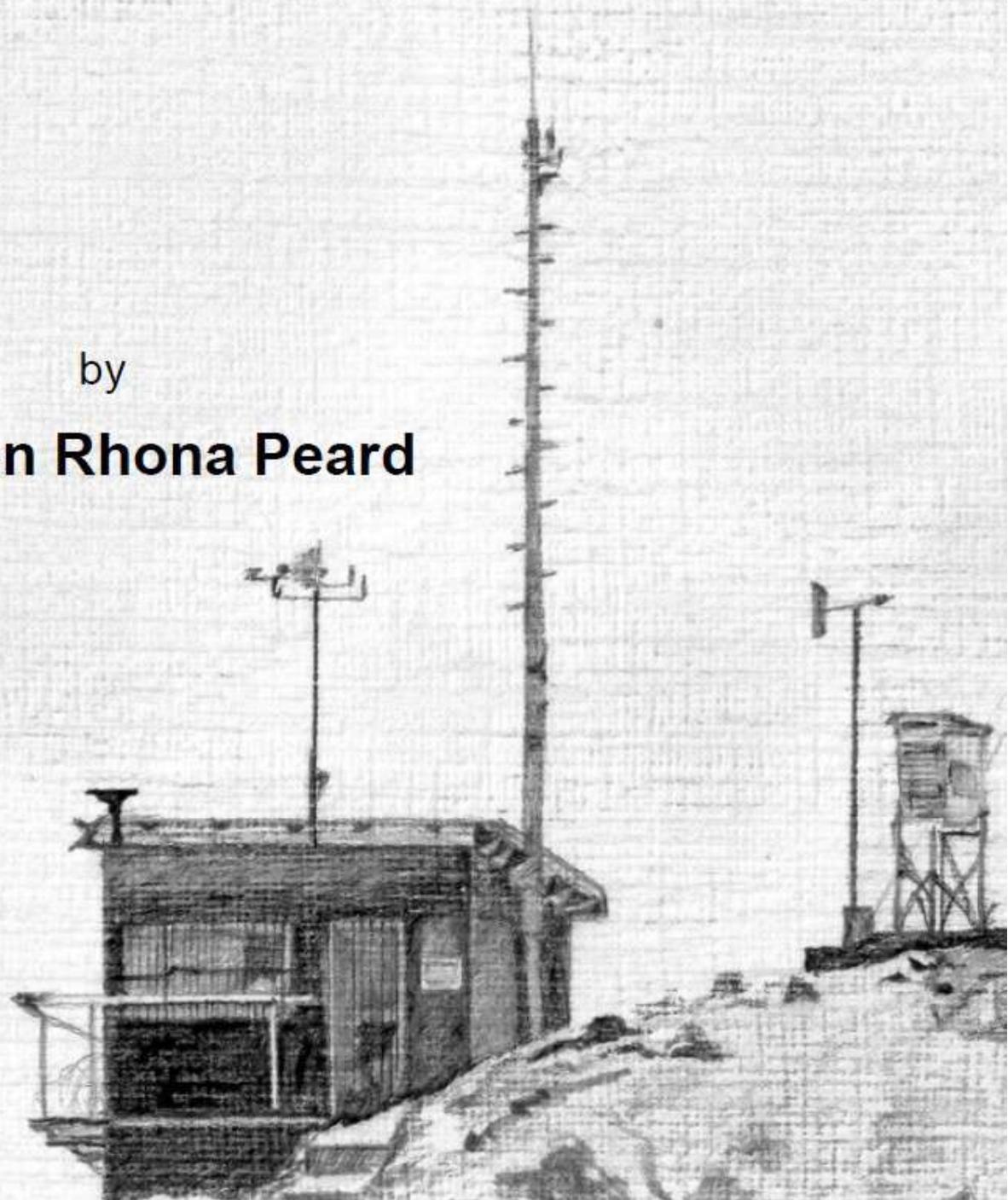


by

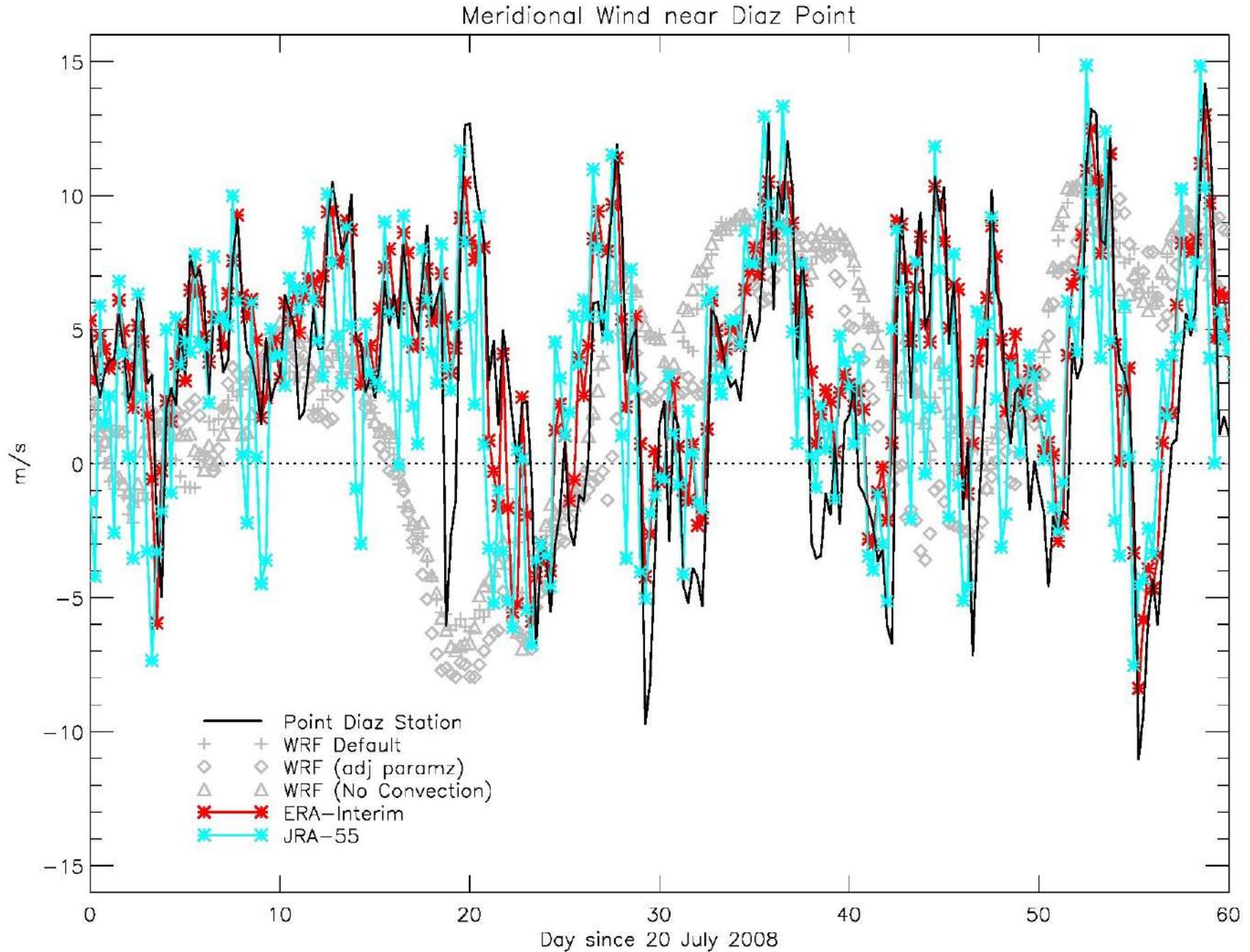
**Kathleen Rhona Peard**

Thesis Presented for the Degree of  
MASTER OF SCIENCE  
In the Department of Oceanography  
UNIVERSITY OF CAPE TOWN

May 2007



# Acquired in-situ wind observations (Cape Diaz, Luedritz)



Courtesy: Jean-Paul Roux

# A recent *intercomparison* of reanalysis and satellite products



ELSEVIER

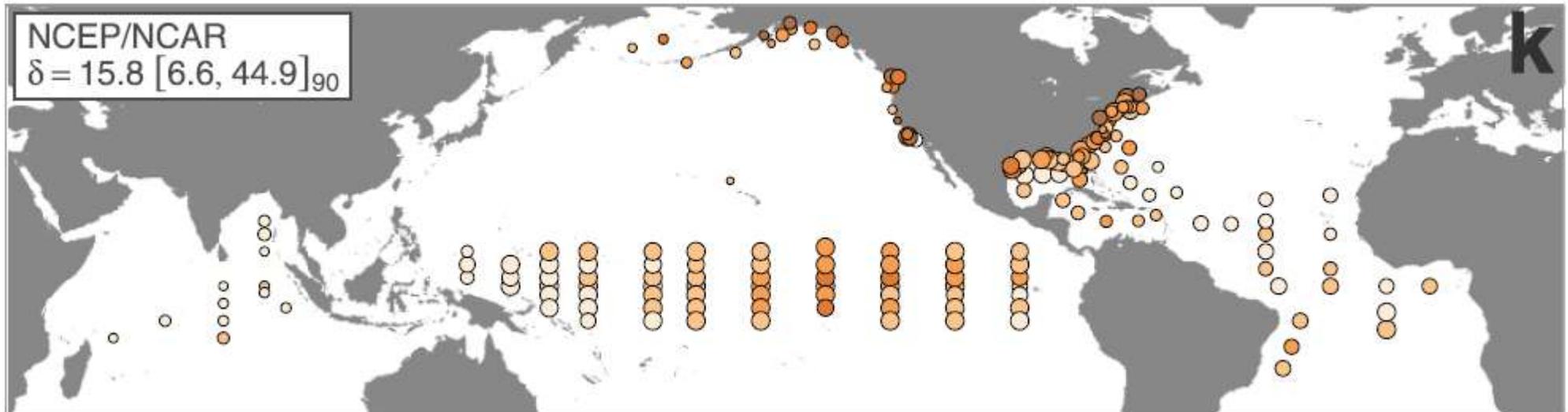
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## Ocean Modelling

journal homepage: [www.elsevier.com/locate/ocemod](http://www.elsevier.com/locate/ocemod)

Surface winds from atmospheric reanalysis lead to contrasting oceanic forcing and coastal upwelling patterns

Fernando G. Taboada<sup>\*,a,b</sup>, Charles A. Stock<sup>a</sup>, Stephen M. Griffies<sup>a</sup>, John Dunne<sup>a</sup>, Jasmin G. John<sup>a</sup>, R. Justin Small<sup>c</sup>, Hiroyuki Tsujino<sup>d</sup>



# A few important points

- I. In contrast with the large-scale trade winds, the surface winds of the EBUS undergo significant high-frequency variability***
  - i. Inertial (diurnal cycle)***
  - ii. Mesoscale (coastal lows)***
  - iii. Synoptic (TTTs and mid-latitude ridges/troughs)***
- II. This variability is controlled by changes in temperatures in the free troposphere, mainly via vertical advection**
- III. In-situ observations are (increasingly) scarce in some EBUS (e.g. Benguela)**
- IV. Reliance on model-generated data can lead to misestimations of the “true” atmospheric state in these areas.**