Synoptic Systems

Peter Knippertz, Karlsruhe Institute of Technology

Slides prepared by Douglas J Parker, University of Leeds / Met Office

Most material taken from Forecasters' Handbook Chapter 2 (Cornforth et al. 2017)

Introductory remarks

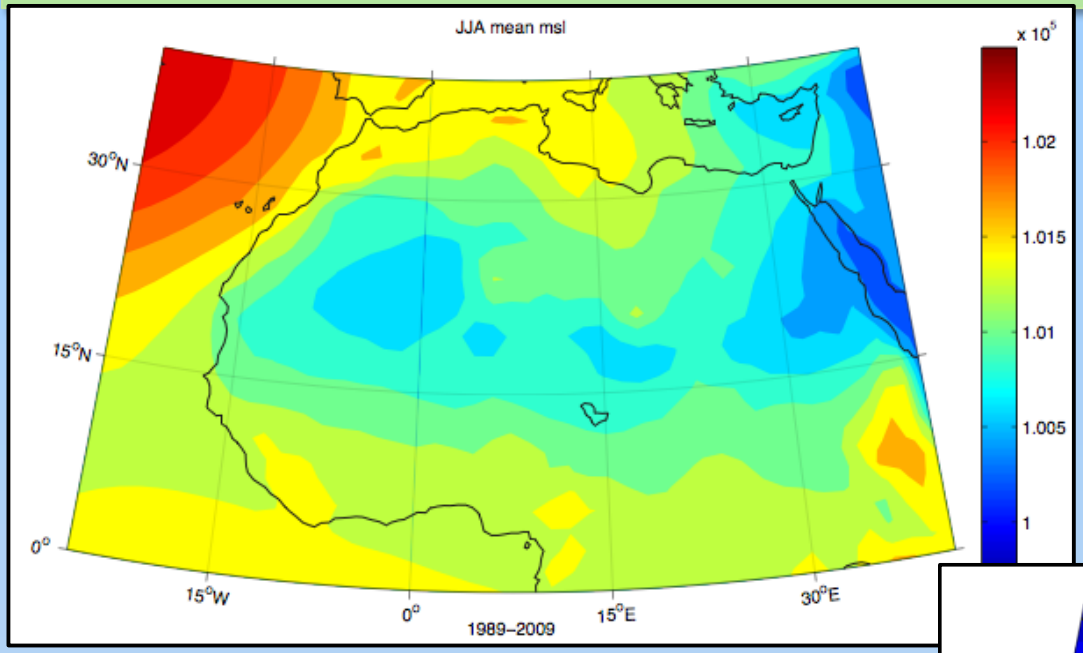
- Synoptic analysis provides a **common scientific framework** to explain and understand the atmosphere.
- It involves scientific concepts and is independent of language.
- It is often done with output from NWP models and satellite images.
- NWP data is 5-dimensional (space x time x parameter)
  → we need to reduce it to most important features
- NWP forecasts of convective rainfall are still very poor.
- NWP forecasts of the synoptic state are much better
  → they can help infer areas of convection / convective organisation

Outline

- Part I: Large-scale setting
- Part II: African Easterly Wave (AEW) structure
- Part III: AEW initiation and development
- Part IV: Extratropical influences
- Part V: Guinea Coast region
- Part VI: Conclusions

Part I: Large-scale setting

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker



Saharan heat low (SHL)

- Pressure gradient from Gulf of Guinea to Sahara drives the monsoon.
- The Intertropical discontinuity (ITD) separates Saharan from monsoon flow. Diagnosed by
  - Confluence of winds
  - dew point = 15°C

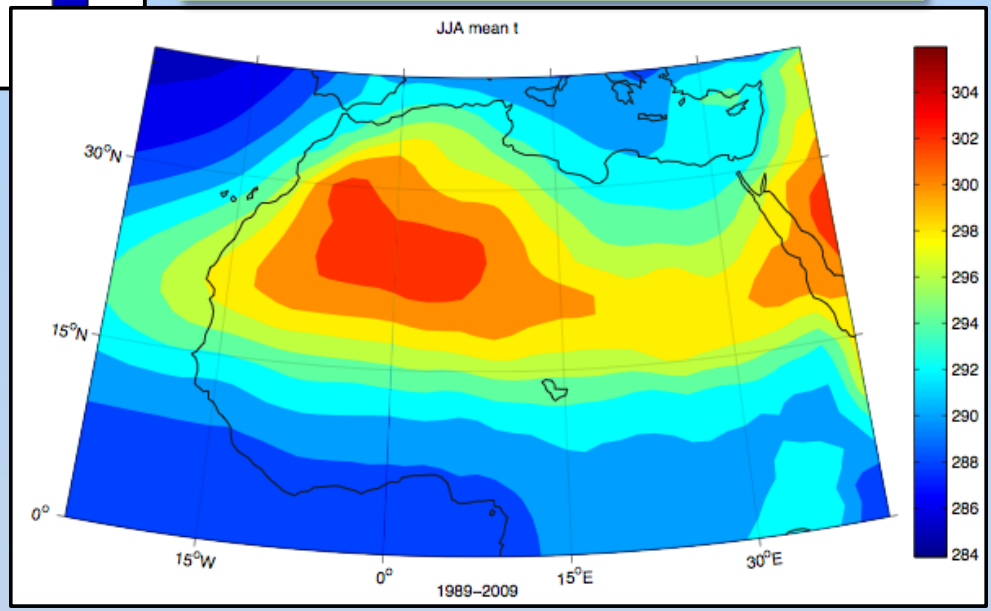


Figure 2.1: Characteristics of the Saharan Heat Low seen in ECMWF ERA Interim climatological mean (1989-2009) fields for June / July / August (JJA) for (a) **mean sea level pressure**, (b) **temperature at 850 hPa**.

African Monsoon Multidisciplinary Analysis

ACMAD

WMO

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

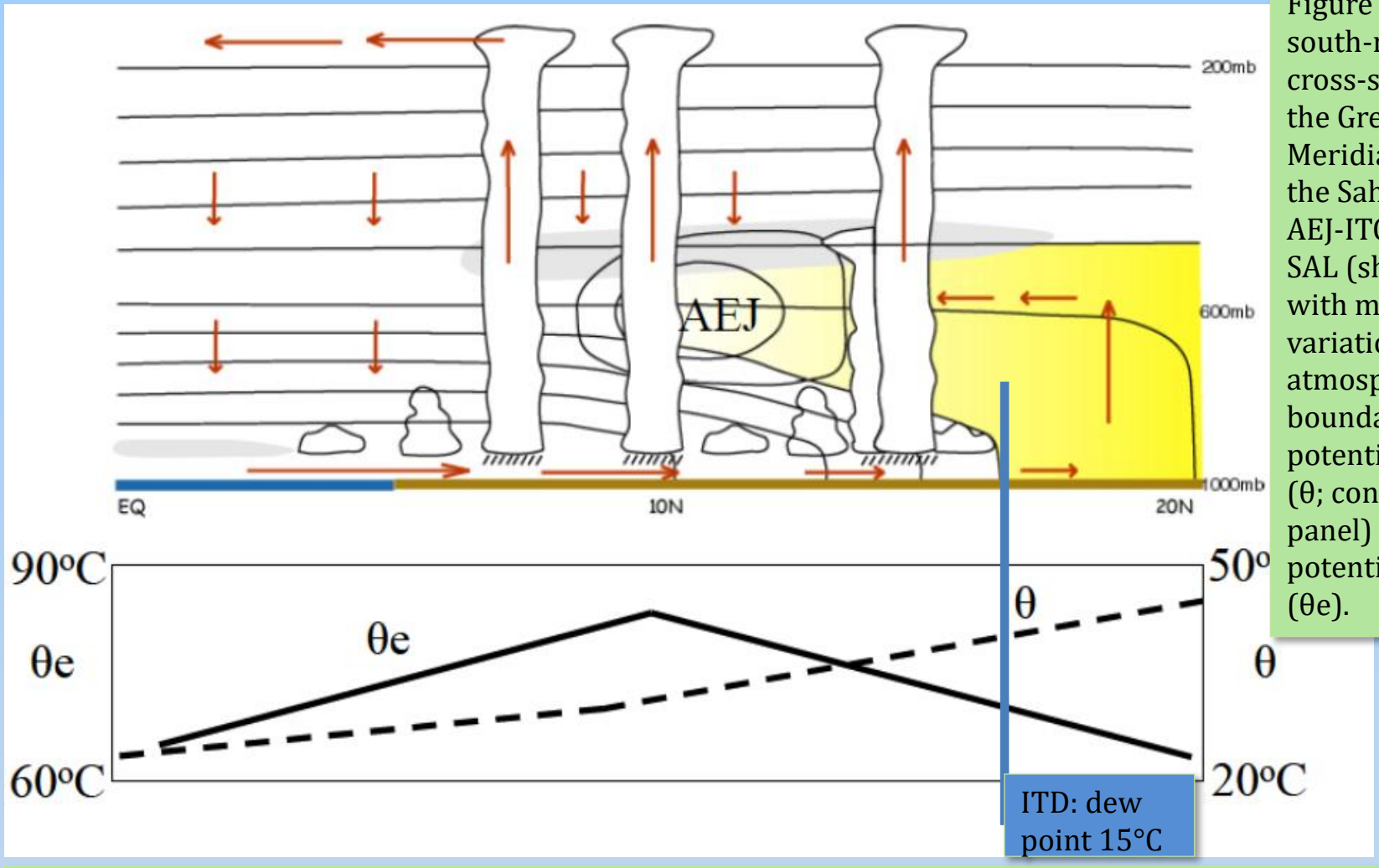


Figure 2.2: Schematic south-north vertical cross-section along the Greenwich Meridian, highlighting the Saharan heat low-AEJ-ITCZ system and SAL (shaded yellow), with meridional variations in atmospheric boundary layer potential temperature (θ; contoured in upper panel) and equivalent potential temperature (θe).

The monsoon trough is located just to the south of the AEJ.

Part II: AEW structure

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

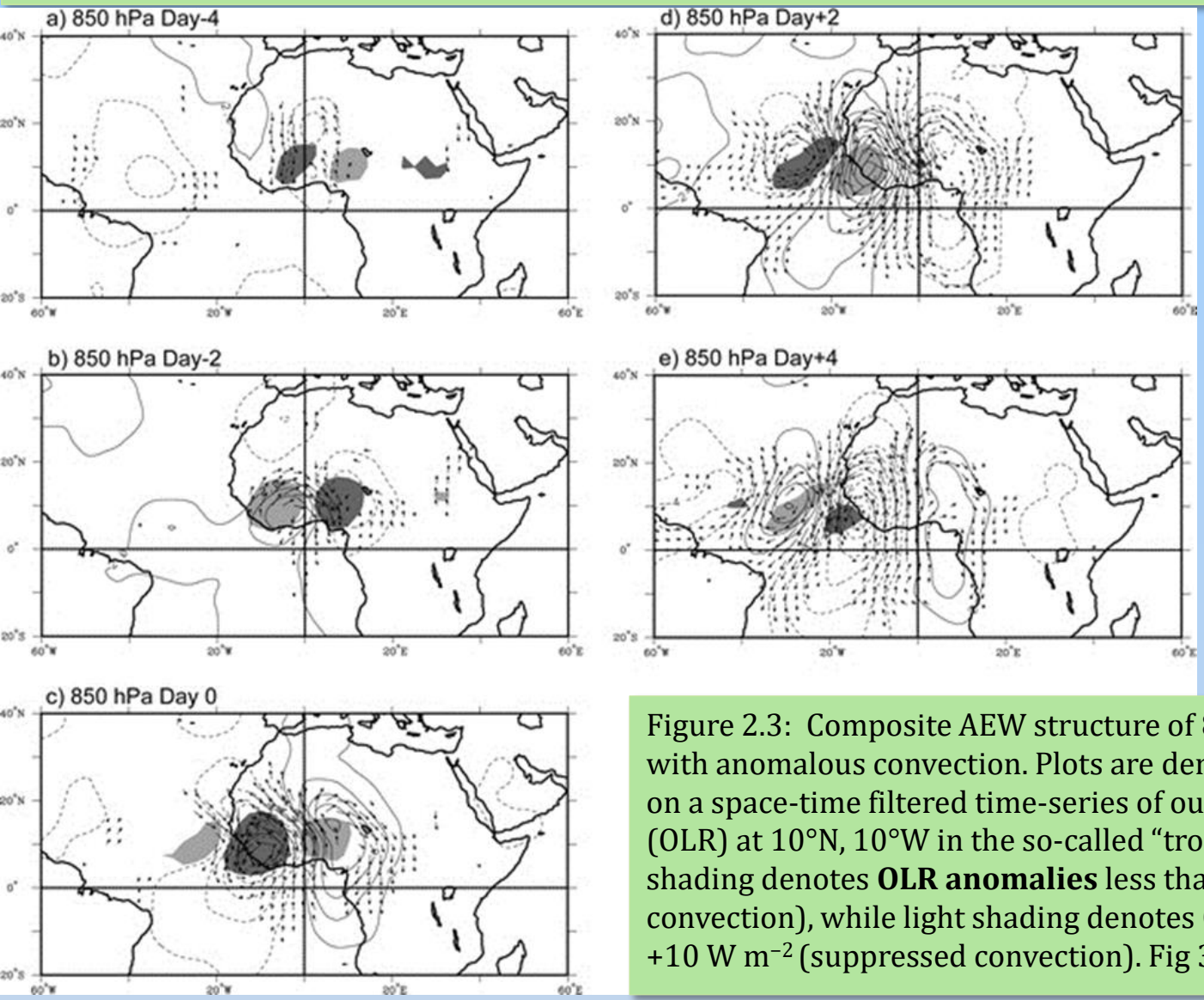


Figure 2.3: Composite AEW structure of **850 hPa streamfunction** with anomalous convection. Plots are derived from a regression based on a space-time filtered time-series of outgoing long-wave radiation (OLR) at 10°N, 10°W in the so-called "tropical depression" band. Dark shading denotes **OLR anomalies** less than –10 W m^{-2} (active convection), while light shading denotes OLR anomalies greater than +10 W m^{-2} (suppressed convection). Fig 3 from Kiladis et al. (2006).

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

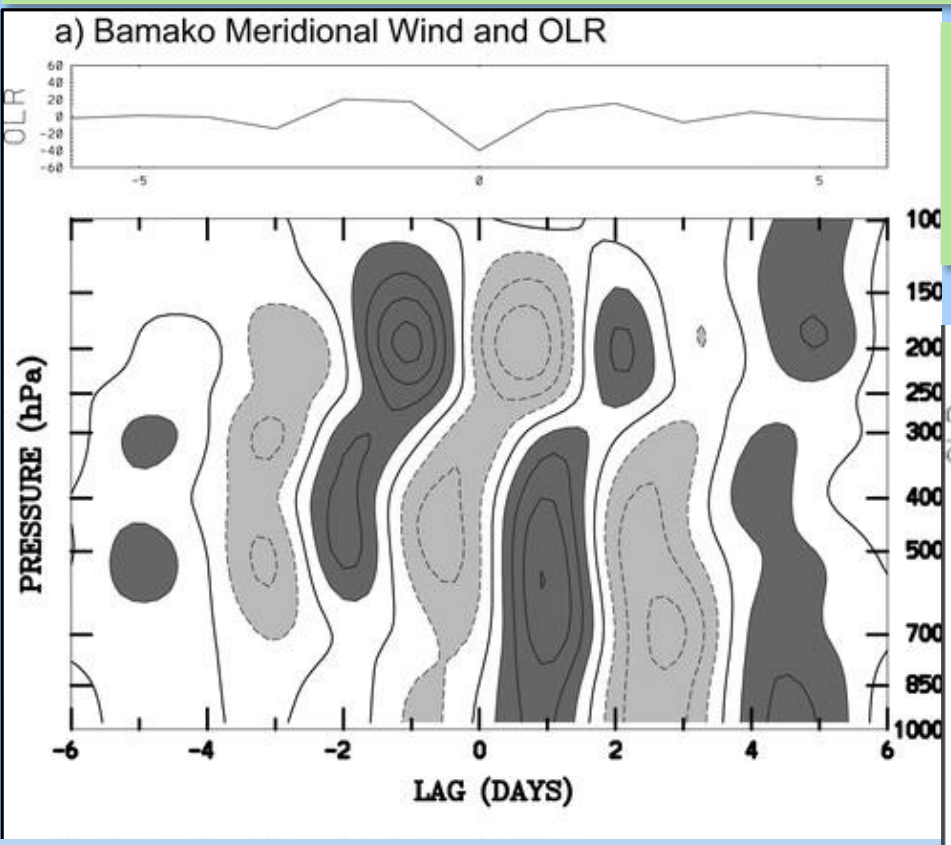
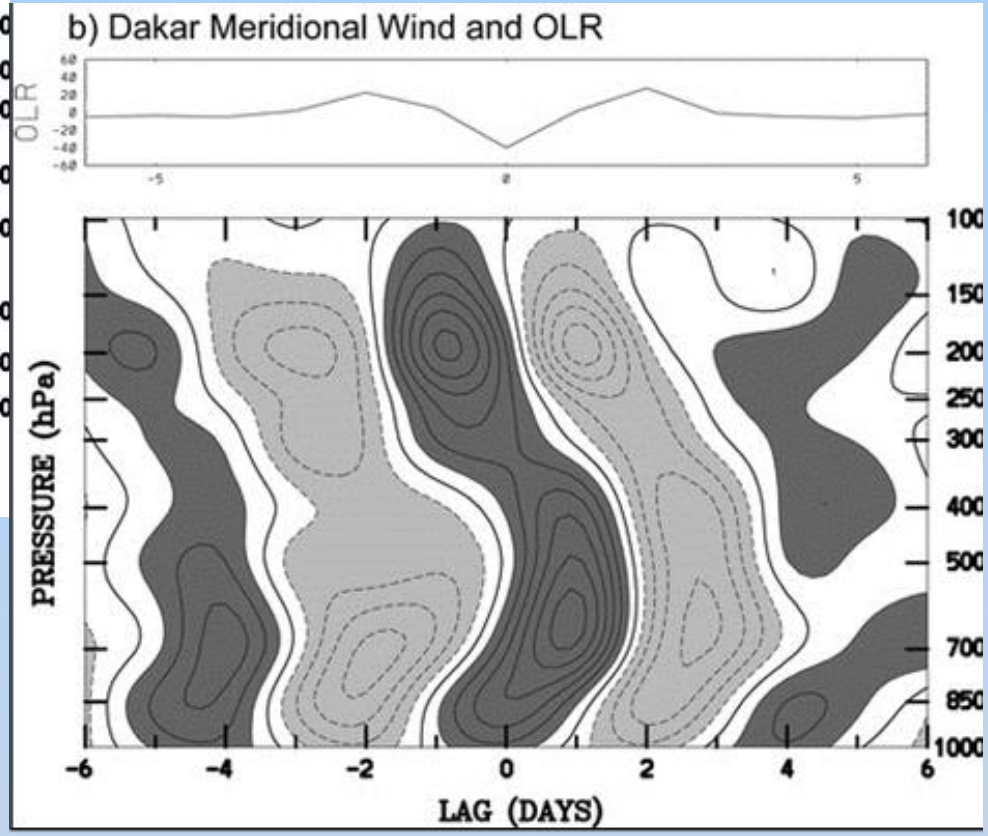


Figure 2.4: Time-height cross-section of the **meridional wind anomaly** at (a) Bamako and (b) Dakar, scaled to a −40 W m^{-2} perturbation in tropical depression-filtered **OLR** at the nearest grid point to each station. Contour interval is 0.5 m s^{-1}, negative contours dashed.



Dark (light) shading denotes anomalies greater than (less than) 0.5 m s^{-1}. The associated OLR anomaly is shown at the top in W m^{-2}.
Figure 10 from Kiladis et al. (2006)

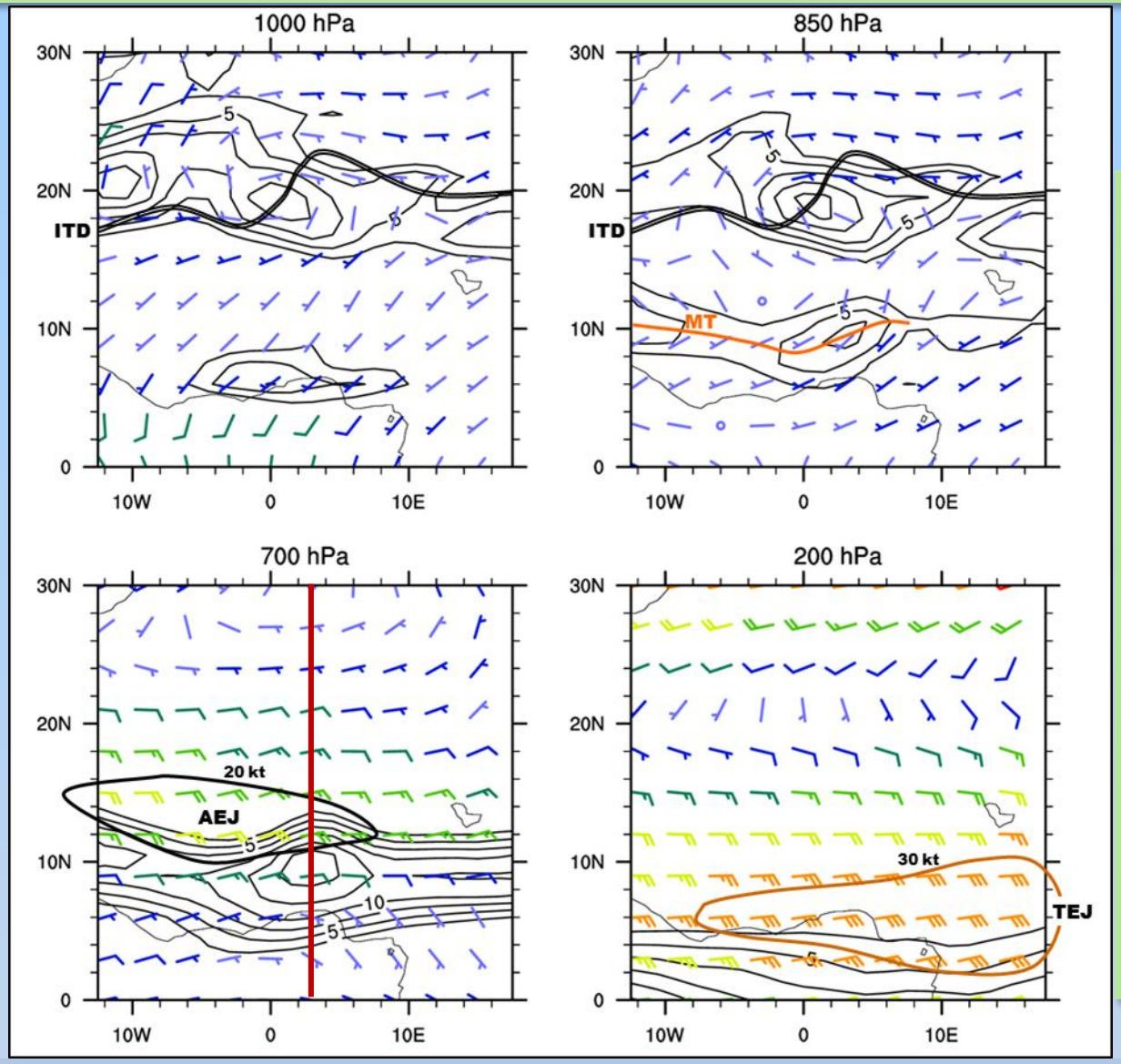


Figure 2.5: Vertical structure of AEW **vorticity and winds**, from a composite of AEW cases, based upon the 700 hPa trough axis passing the longitude of Niamey (2.5ºE), and comprising 803 cases between 1989 and 2008, identified by the objective identification method of Berry et al. (2007). Composite winds (barbs, coloured in knots) and relative vorticity (positive values greater than $5x10^{-6}$ s^{-1} contoured every $5x10^{-6}$ s^{-1}) are shown on different pressure levels from the ERA-Interim reanalysis dataset.

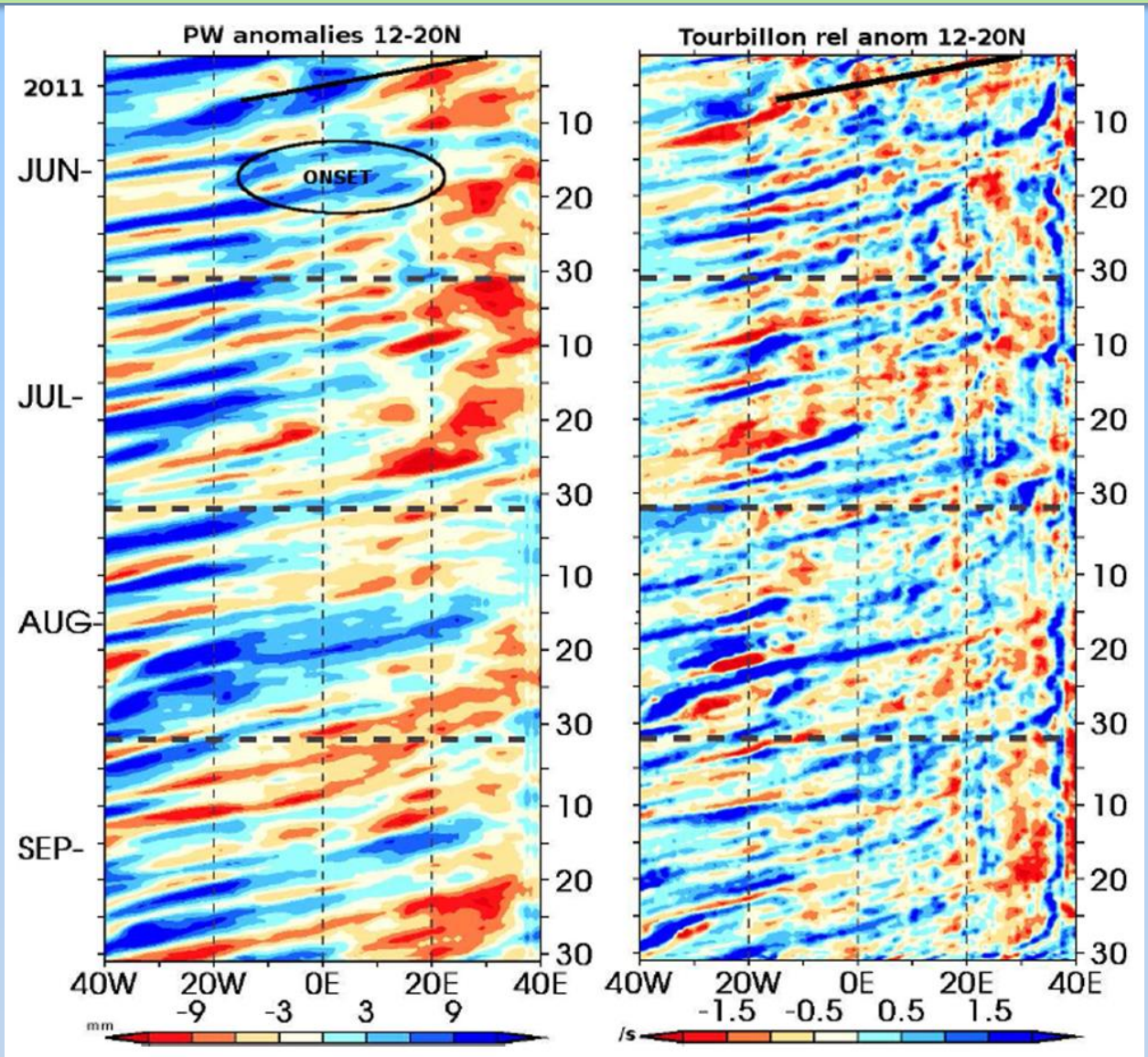


Figure 2.6: Time–longitude diagram of the 2011 June to September intra-seasonal anomalies averaged over 12°–20°N (a) **precipitable water (PW)** (mm) and (b) **850-hPa relative vorticity** ($x10^{-5}$ s^{-1}). The black solid lines materialize a slope of a -9 m s^{-1} velocity.
From Poan (2013).

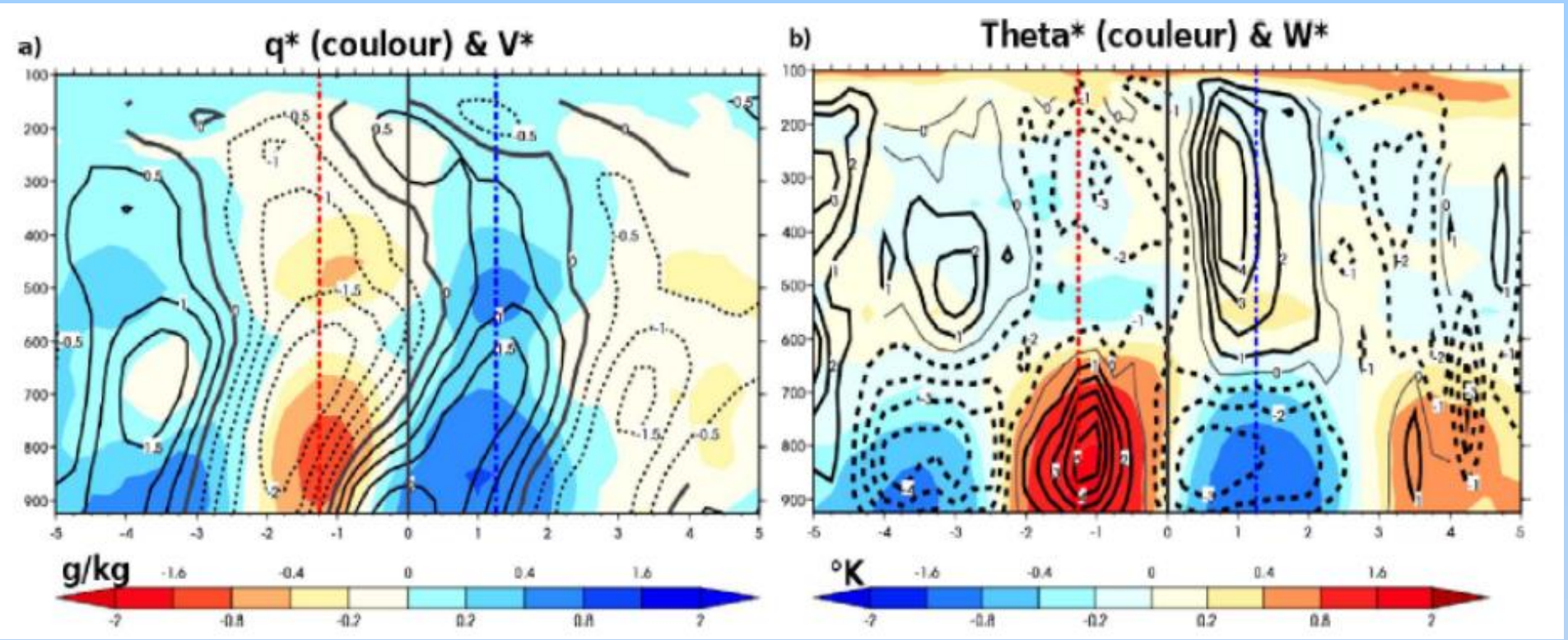


Figure 2.8 Vertical–lag composite of (a) **specific humidity** (g kg^{-1}, shaded) and **meridional wind** (m s^{-1}, contours) anomalies, (b) **potential temperature** (K, shaded) and **vertical wind** (mm s^{-1}, contours) anomalies, based on a composite on the PW* field of AEWs. The vertical black line corresponds to the trough location at t0, whereas vertical dashed red and blue lines correspond to the passage of the dry/warm and moist/cold stages respectively (at t0-1.25 and t0+1.25). From Poan (2013).

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

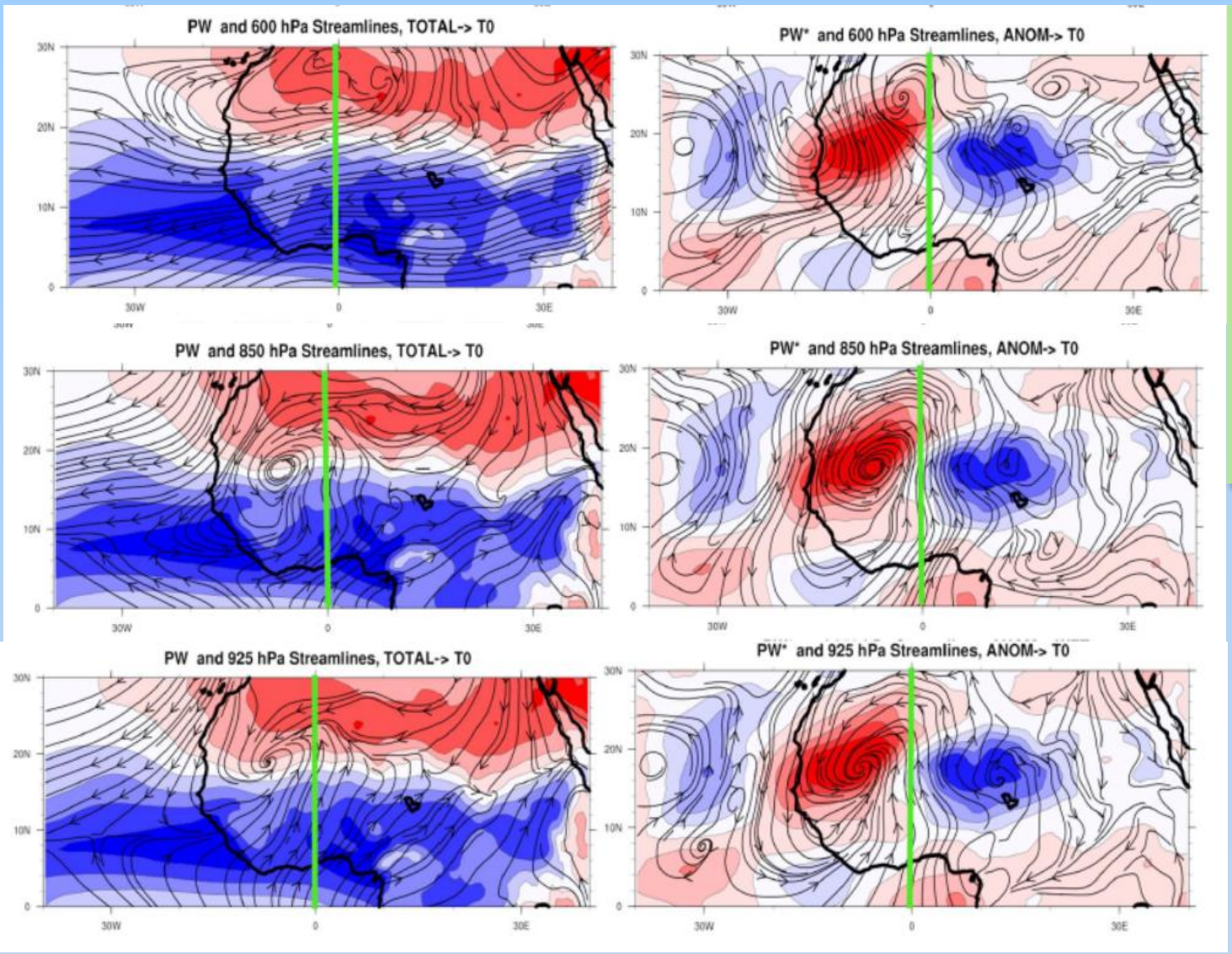


Figure 2.9: Composites of **streamlines** and **PW** (mm, shaded) fields at 925, 850 and 600 hPa at the passage (t0) of the AEW at 0°E. The left and right columns correspond to the full and anomaly fields respectively.
From Poan (2013).

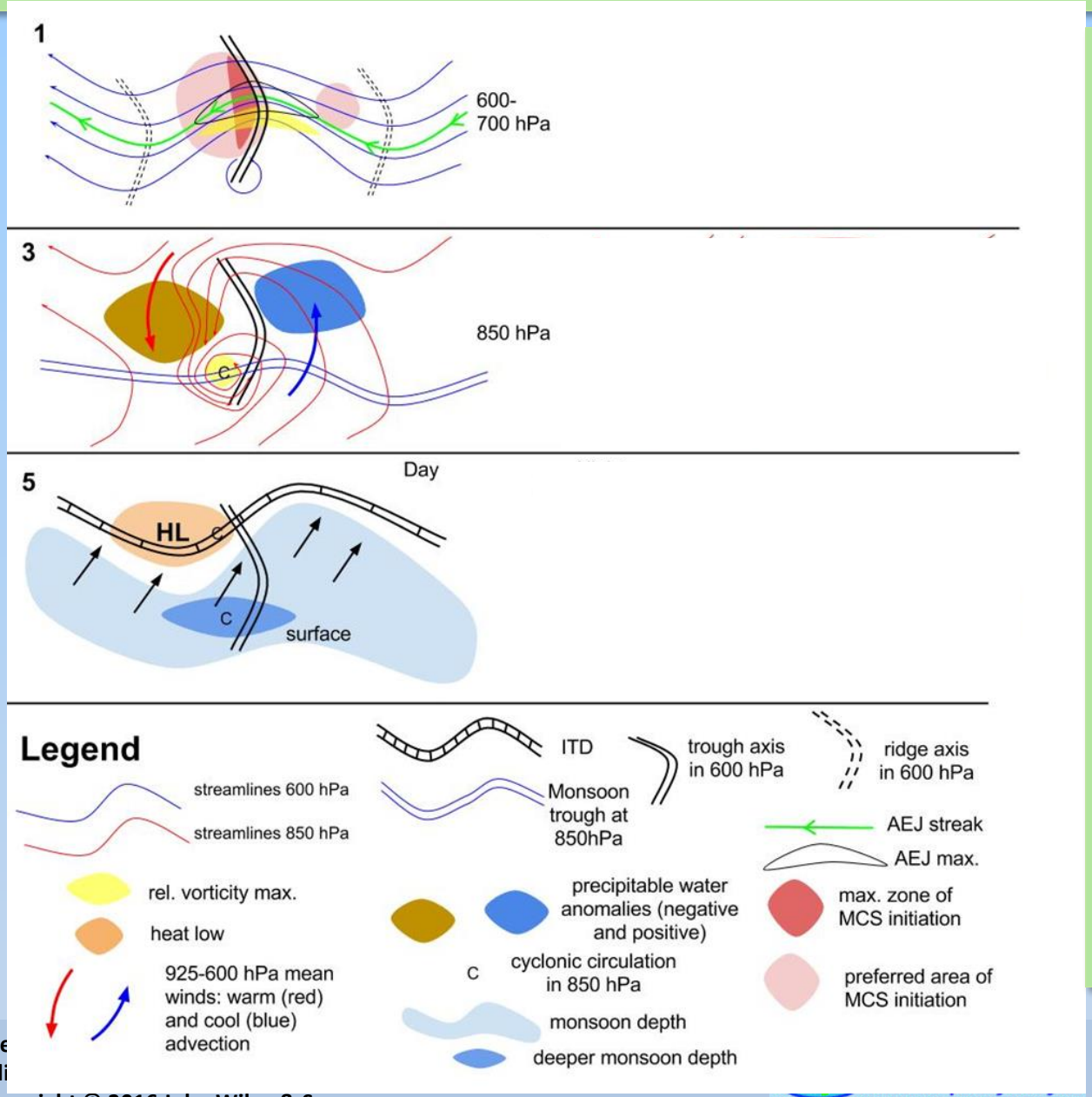


Figure 2.10: Schematic of the various observable elements of an AEW, and likely relationships between these. Left hand panels show a "normal" situation, as far as this exists, while right hand panels show common alternatives. For example, the structure in panel 2 would be expected in an environment with additional barotropic shear, with a stronger easterly wind to the north (i.e. Uy < 0).

Part III: AEW initiation and development

AEW initiation and development

1. AEWs typically form over the continent to the east of 10°E.

2. Normally AEWs are generated by some large-amplitude trigger, e.g.
   – Extratropical influence (e.g. upper level trough)
   – Major deep convective event

3. AEWs are maintained on the AEJ, due to the north-south gradient of **potential vorticity (PV),** which admits unstable, growing waves.

4. Deep convection is found to be necessary to the continued growth of waves – but how this happens is an open research question.

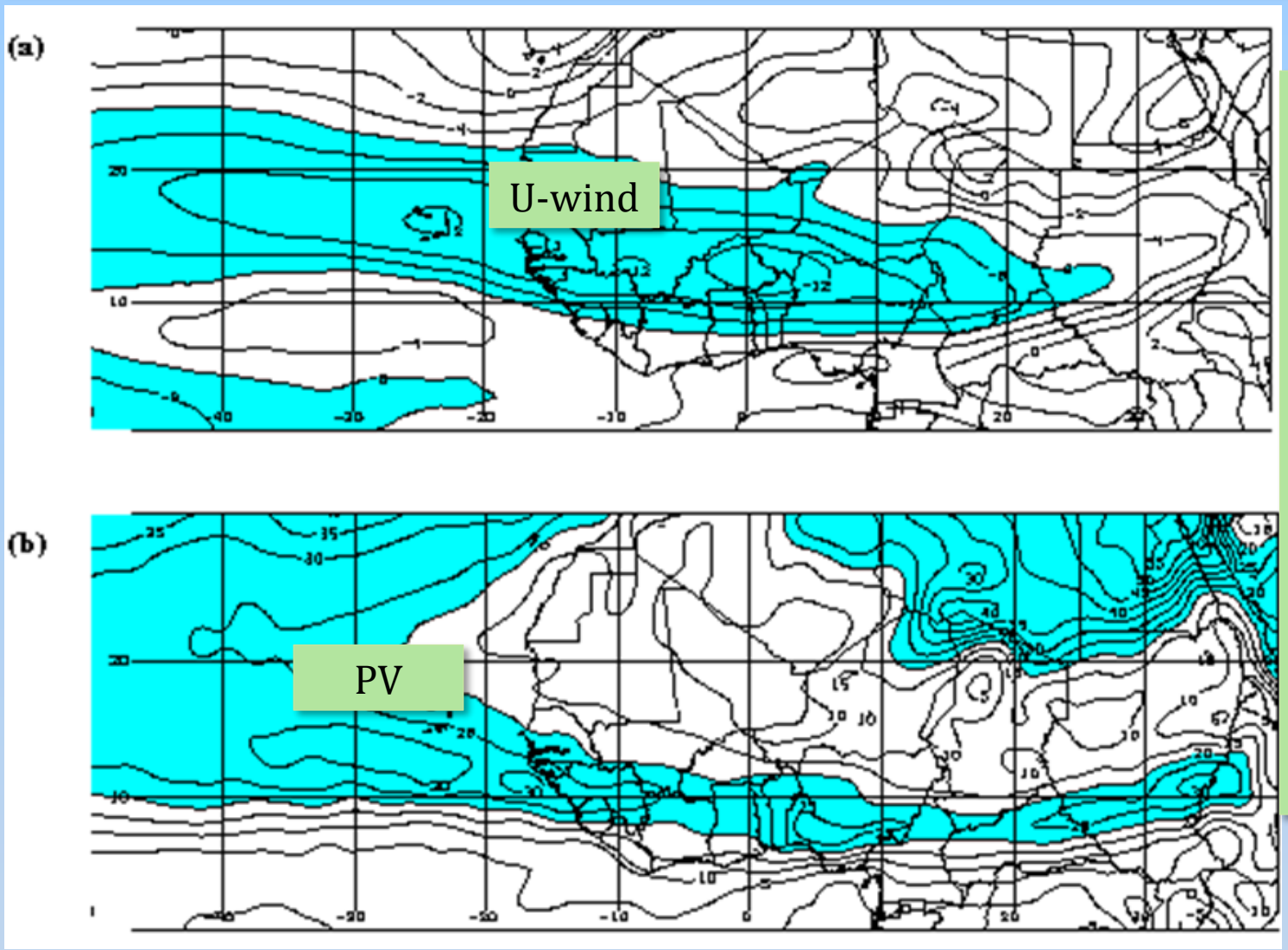


Figure 2.11: Illustration of the meridional **potential vorticity (PV)** reversal. Panels (a) and (b) (based on operational ECMWF analyses and adapted from Figure 1 in Thorncroft et al. (2003)) show (a) zonal wind and (b) PV, on the 600 hPa surface. The maximum PV on this level is to the south of the AEJ maximum (each shaded blue), with low PV to the north of the AEJ.

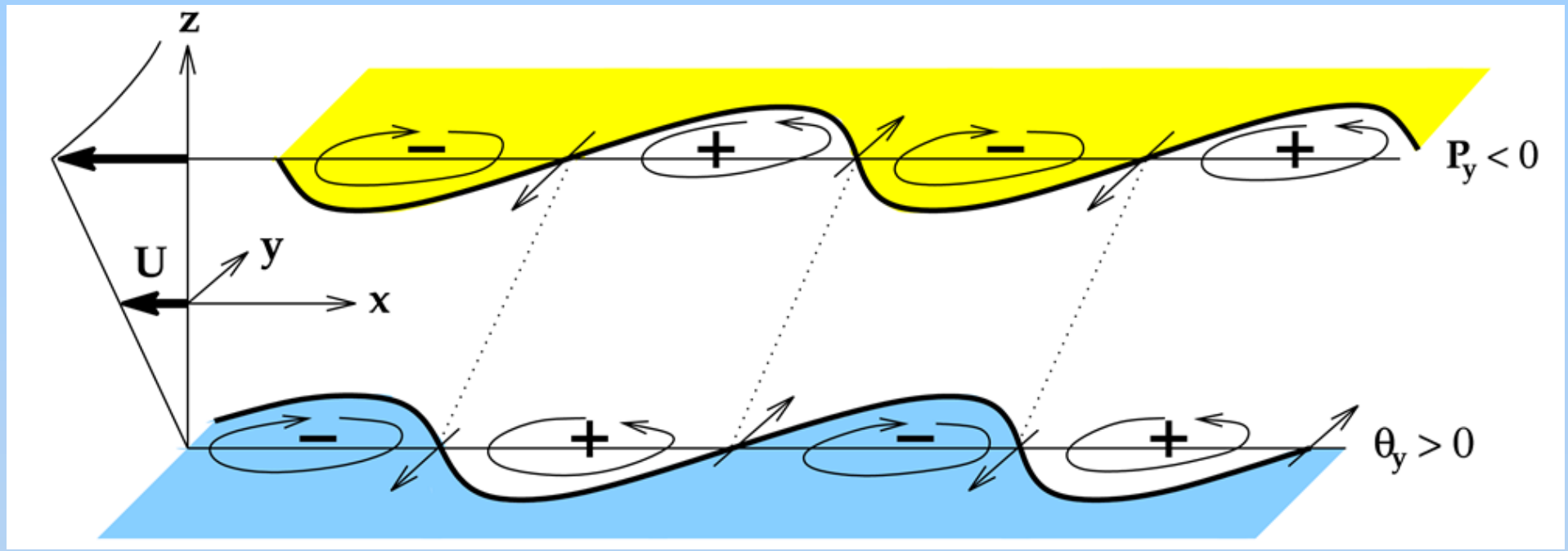


Figure 2.12: A schematic depicting the meridional displacements of air and associated circulations within an African Easterly Wave that are predicted for a "baroclinic" growth configuration. An "upper Rossby wave component" propagates along the African Easterly Jet and interacts with a "lower wave" propagating westwards.

AEW relationship with deep convection.

- Over Africa, convection is less closely coupled with the synoptic state than in midlatitudes.
- Convection can occur in the "wrong" synoptic conditions, for instance when triggered over orography.
- There is good evidence that strong synoptic control **increases the predictability of convective storms.**
- This is a key area for research to improve synoptic forecasting of rainfall over Africa.

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

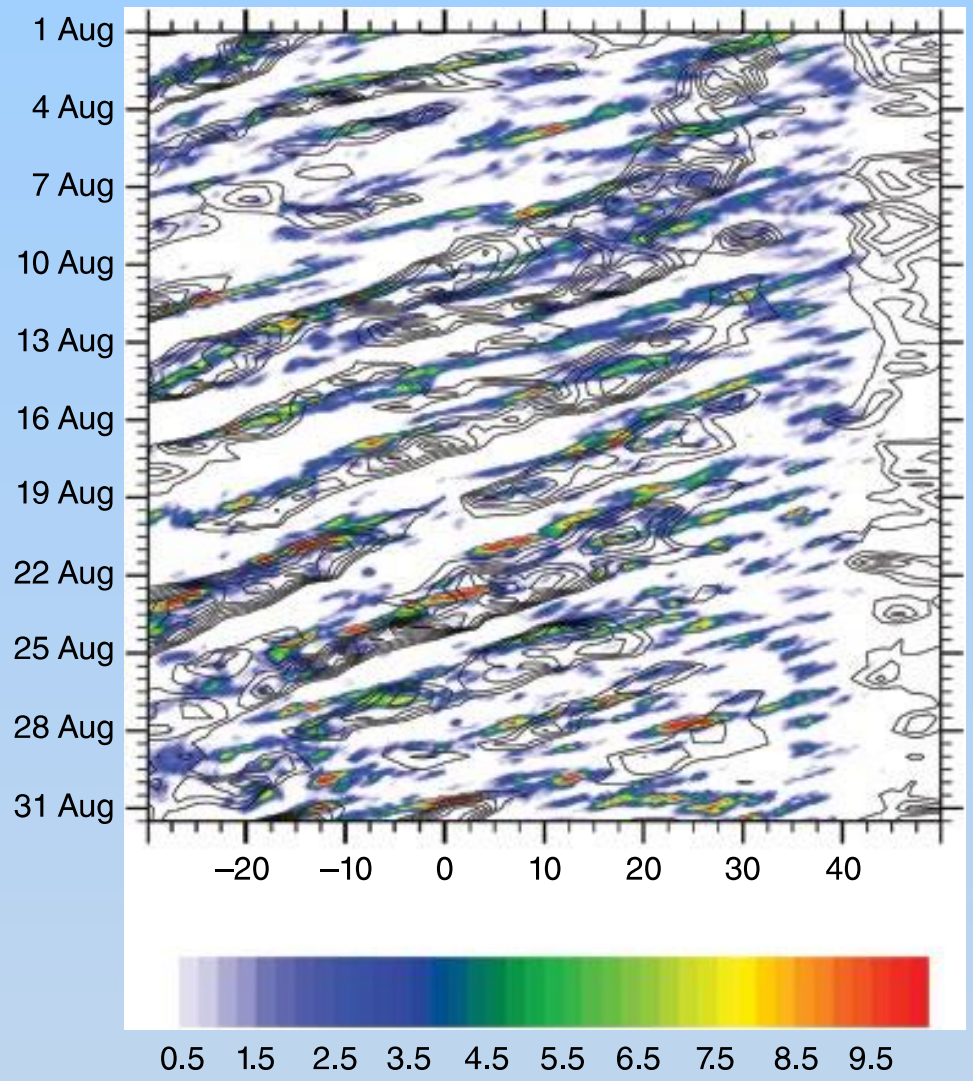


Figure 2.14: Hovmoller space-time diagram of **700 hPa curvature vorticity** (positive values greater than $2x10^{-6}$ s^{-1} contoured every $2x10^{-6}$ s^{-1}) from GFS operational analyses and CMORPH **precipitation** estimate (shaded in mm hr^{-1}, according to colour bar), both averaged **5–15°N** for the month of August 2004.

See how the convective activity (colours) is modulated by the AEW (contours).

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

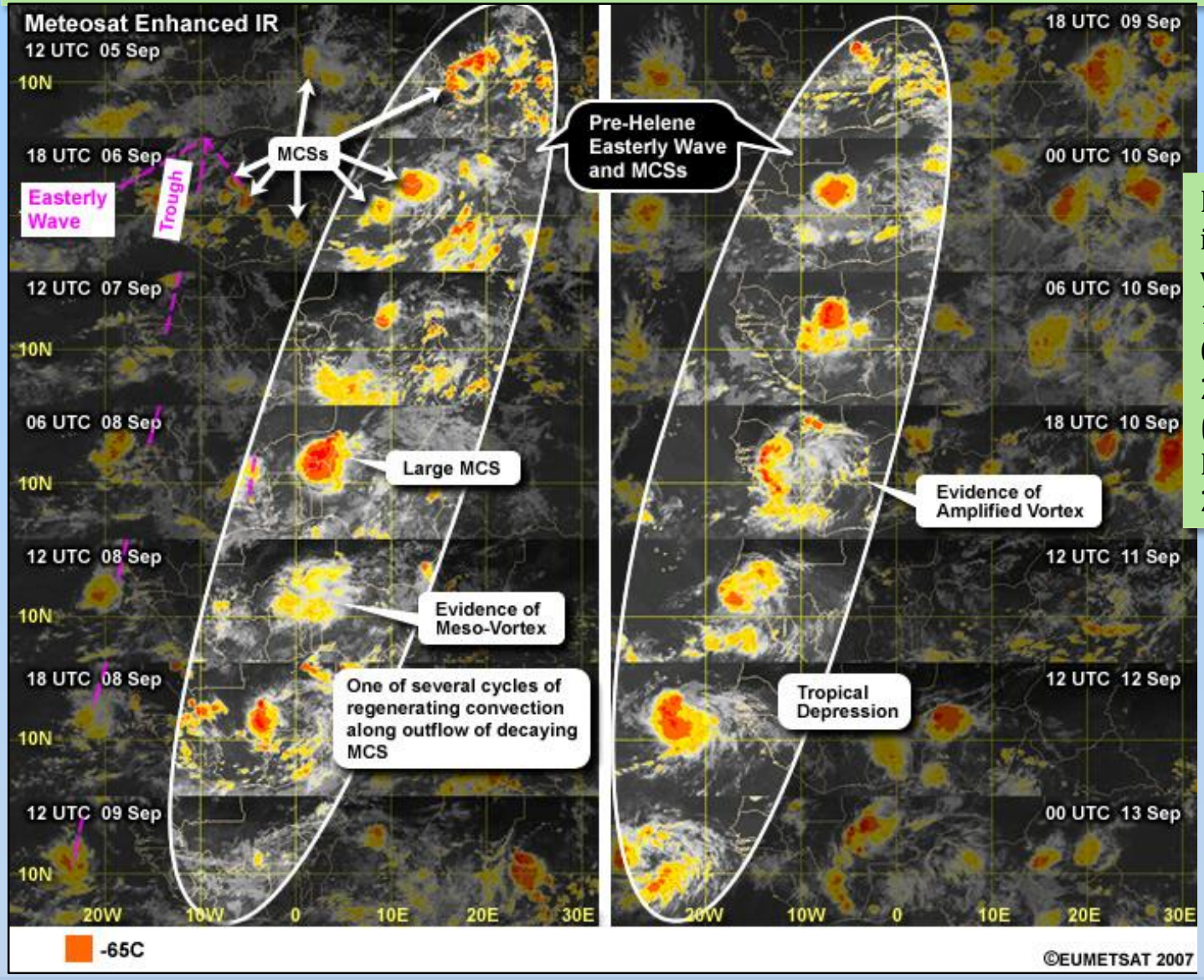
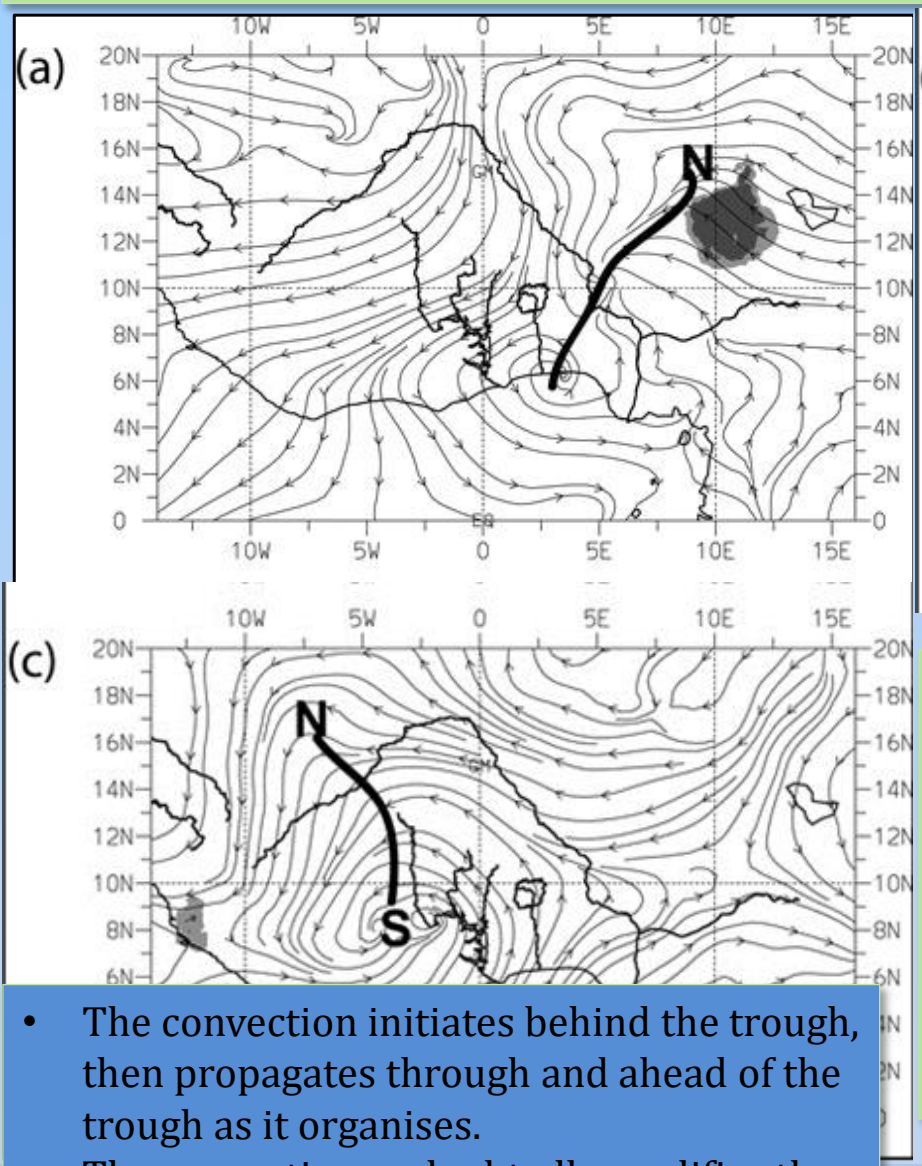


Figure 2.15: Enhanced IR images of African Easterly waves and MCSs between 1200 UTC 5 September and 0000 UTC 13 September 2006, precursors to Helene (2006).
From Laing and Evans, 2015

Meteorology of Tropical West Africa: The Forecasters' Handbook

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker



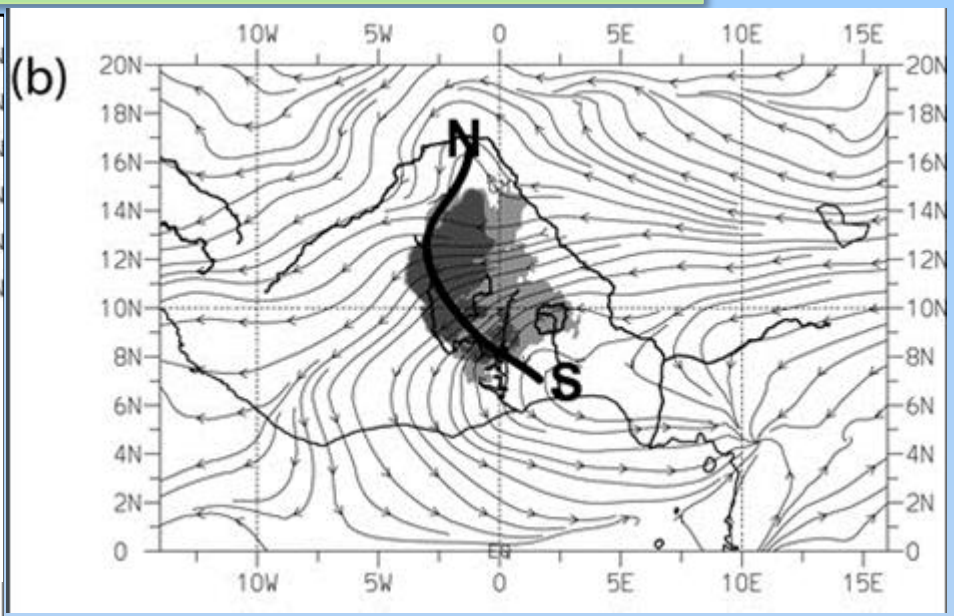


Figure 2.16 (a) **Streamlines on the 850-hPa** surface at 0600 UTC 3 September, (b) 0000 UTC 4 September, and (c) 1800 UTC 4 September 2002. Also shown are the location of the Upper Ouémé Valley and the areas enclosed by the 233- (light grey) and 213-K (dark grey) **brightness temperatures** used to track this and all other sub-type Ia (advective Organized Convective Systems) cloud systems. The analysed cyclonic centres of northerly and southerly AEWs are labelled "N" and "S," respectively. (Figure 11 from Fink et al., 2006).

- The convection initiates behind the trough, then propagates through and ahead of the trough as it organises.
- The convection undoubtedly modifies the trough too.

African Monsoon Multidisciplinary Analysis

ACMAD

WMO

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

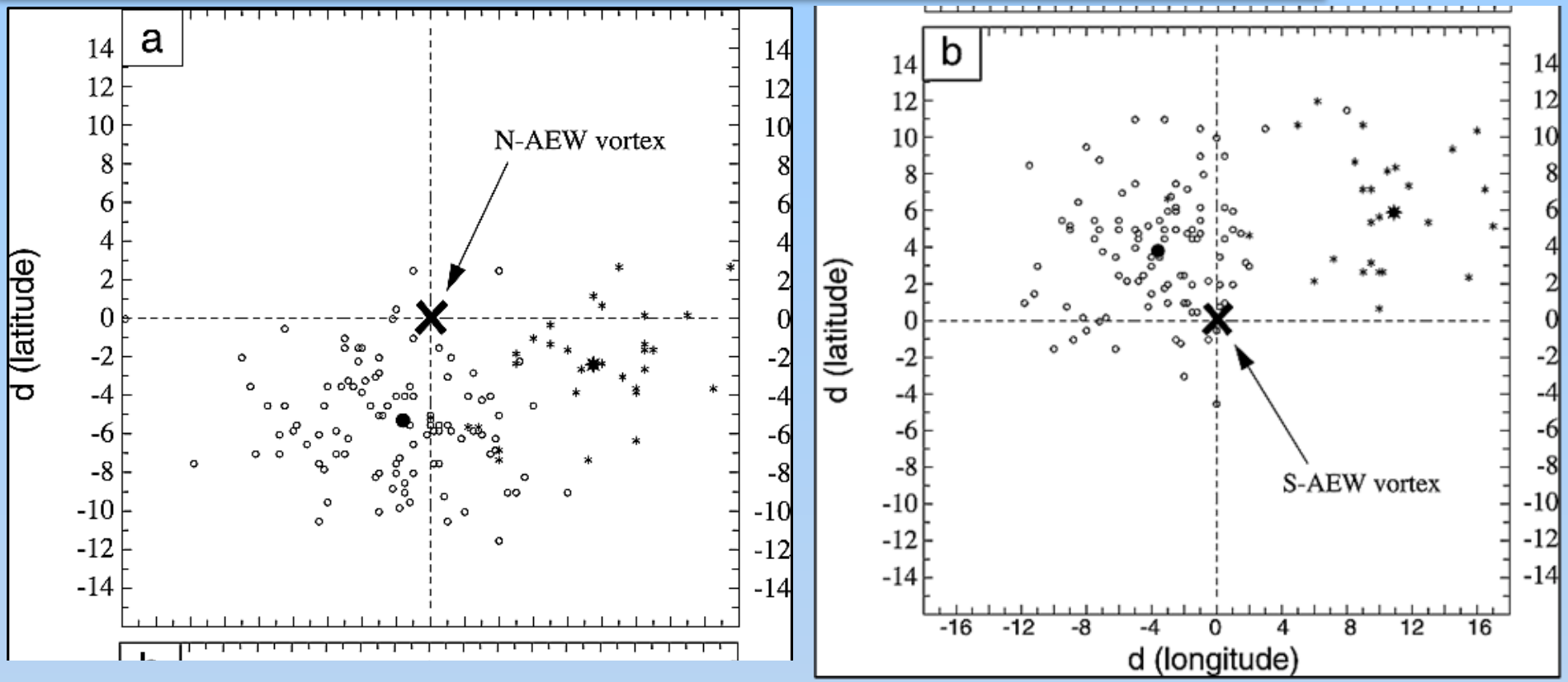


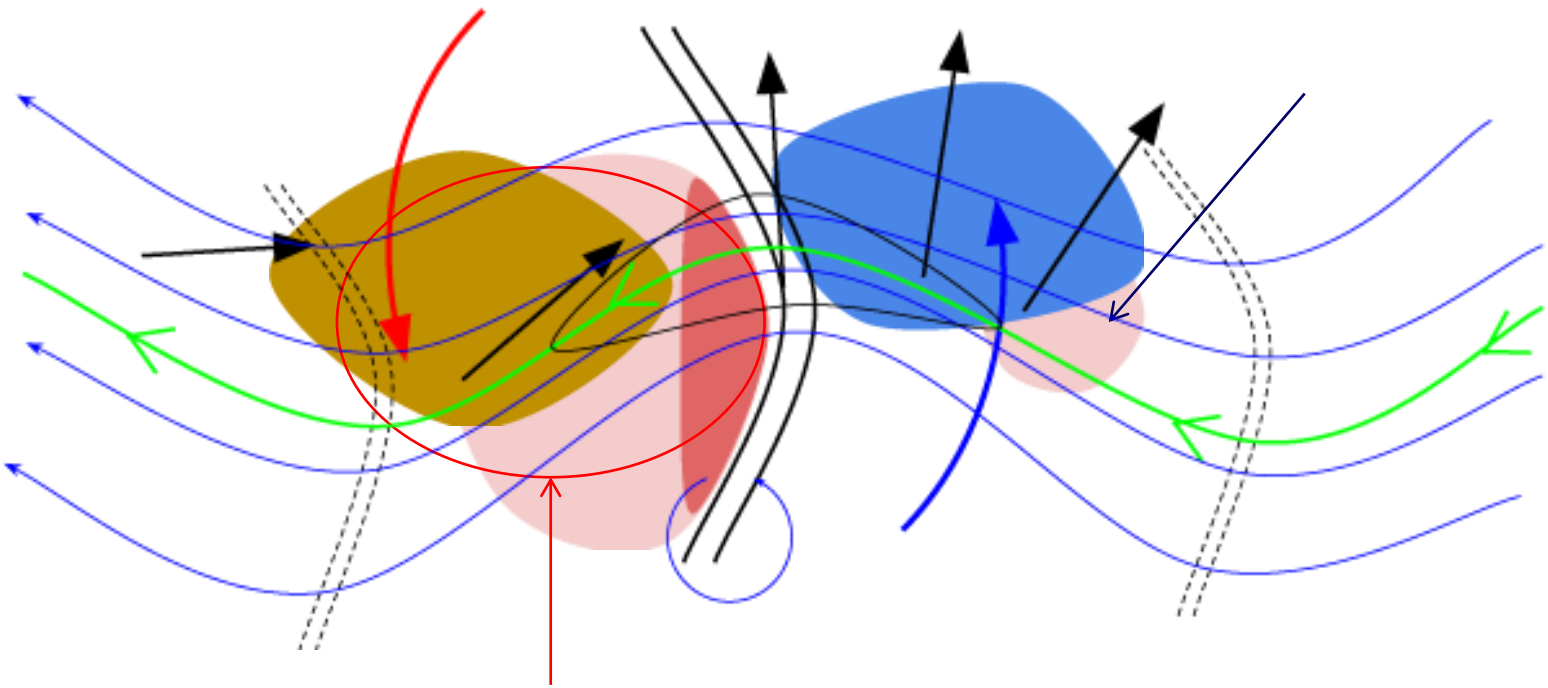
Figure 2.17: Scatterplots of the positions of origin points of Squall Lines relative to the simultaneous locations of the accompanying (a) northerly and (b) southerly AEW vortices. The abscissa (ordinate) denotes the longitudinal (latitudinal) distance with negative values indicating that the Squall Line origin is west (south) of the respective vortices. (Figure 11 from Fink and Reiner, 2003).

Convective initiation is very widely scattered relative to the AEW location: this is hard to predict!

Analysing the synoptic structure is essential for understanding the controls on convection over West Africa.

surface 850 hPa 600-700 hPa

Weaker shear , moisture surge and moister mid-levels: less well organised convection.



High shear and dry mid-levels: recipe for organised convection.

Part IV: Extratropical influence

Extratropical influences.

- Can be very strong, especially in northern winter.
- Can provide significant predictability, e.g. 5–10 days.
- Countries of the West can be directly influenced by upper tropospheric troughs (UTT).
- UTTs can be diagnosed in potential vorticity or geopotential height.
- Whole West Africa can experience large-scale northward shifts of main rainy zone due to UTTs.
- Dry air intrusions at midlevels can
  – suppress convection, especially small storms in the afternoon,
  – allow CAPE to accumulate in the boundary layer,
  – intensify downdraughts (strong evaporation of rain!),
  – organise storms into very intense systems.

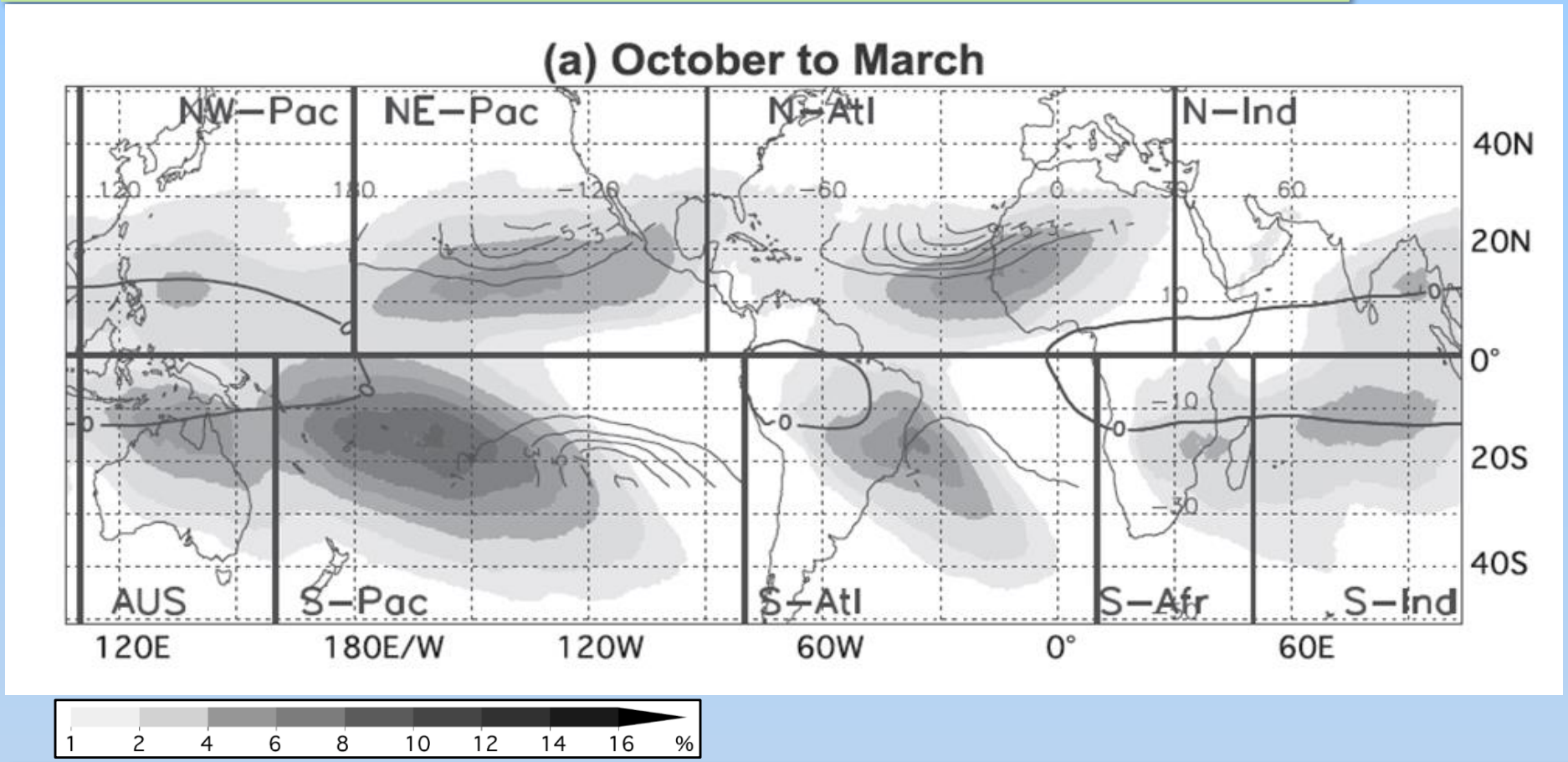


Figure 2.18: Mean **Tropical Plume frequency** (%; shaded) for Oct–Mar between 1983/84 and 2005/06. The contours display the mean frequency of **troughs at low latitudes** (%) detected by Fröhlich and Knippertz (2008) in the ERA-40 data between 1980 and 2001. The bold grey contour presents the zero line of the mean zonal wind at 200 hPa indicating equatorial easterlies from the western Pacific to the eastern Atlantic and over South America, with westerlies elsewhere. (Figure 4a from Fröhlich et al., 2013.)

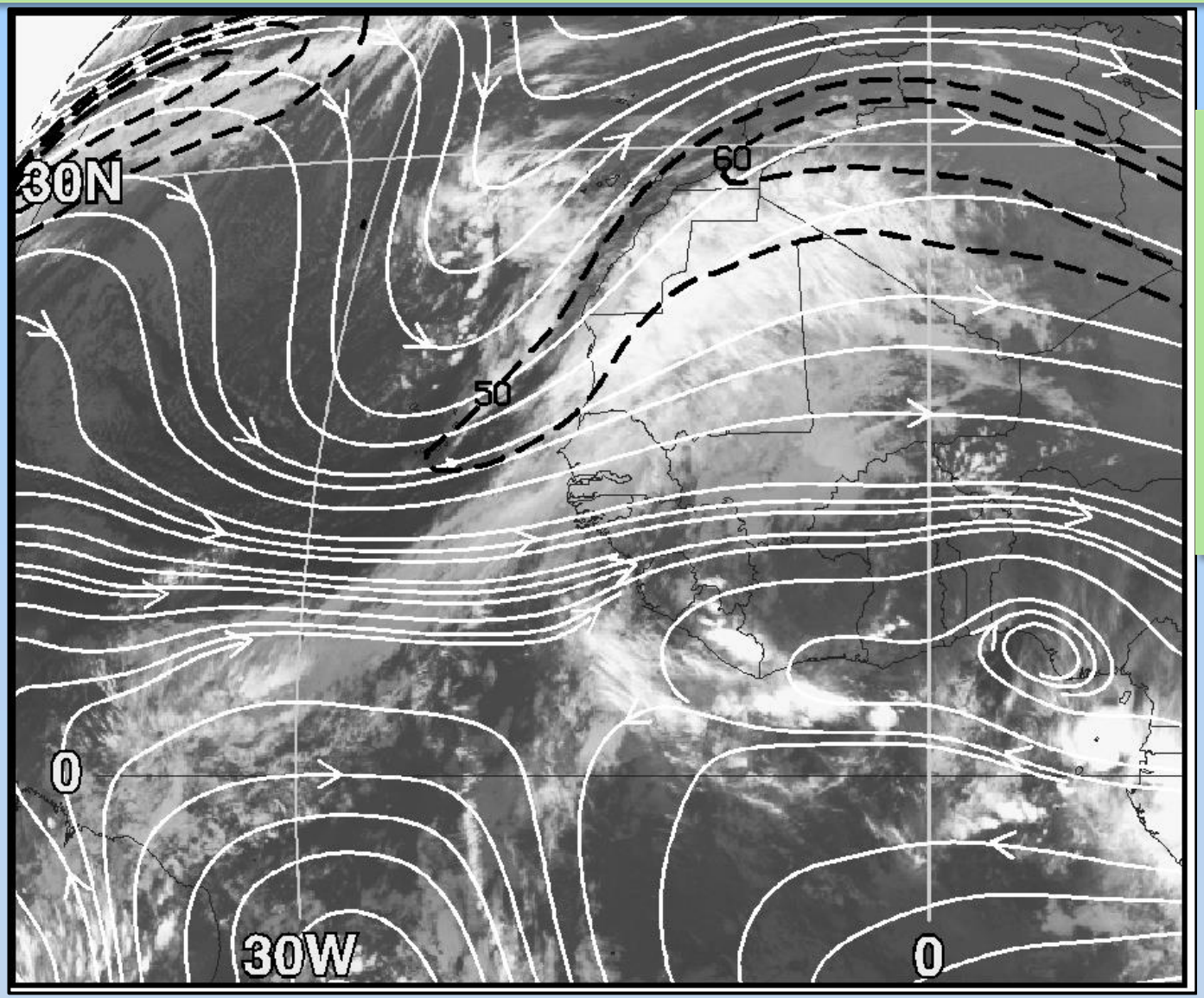


Figure 2.19: Meteosat infrared satellite image for 0000 UTC 10 January 2002 with superimposed isotachs (dashed black in m s^{-1}) and streamlines (in white), both at the 345 K isentropic level. (slightly modified version of Fig 2c from Knippertz and Martin, 2005.)

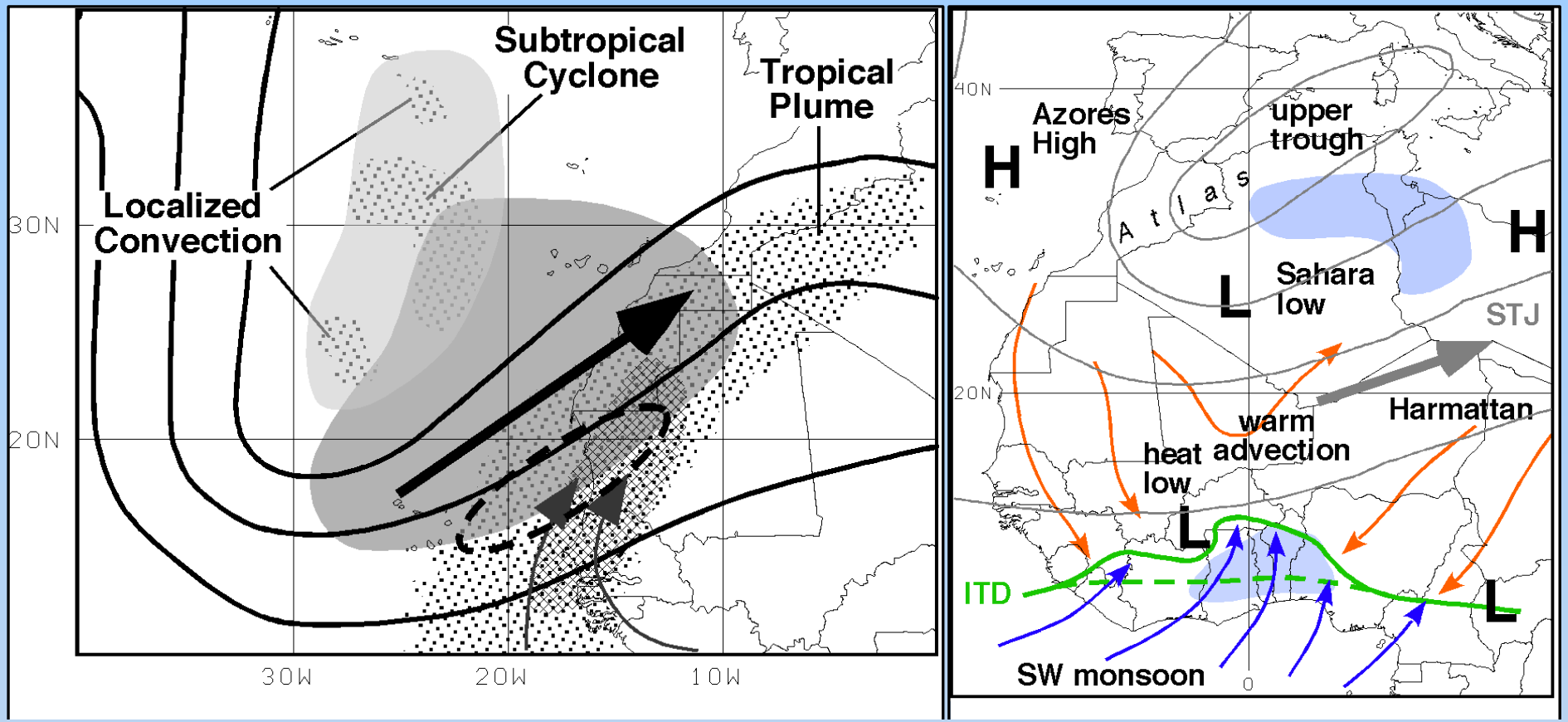


Figure 2.20: Schematic depictions of the large-scale circulation associated with dry-season precipitation over West Africa associated with low-latitude upper-level disturbances from the extratropics. Left panel: Cases with a direct influence form the upper-trough, mostly affecting the western Sahel. Figure 11 from Knippertz, 2007.
Right panel: Cases with an indirect influence from the upper-trough, mostly affecting the Soudano-Sahelian zone.

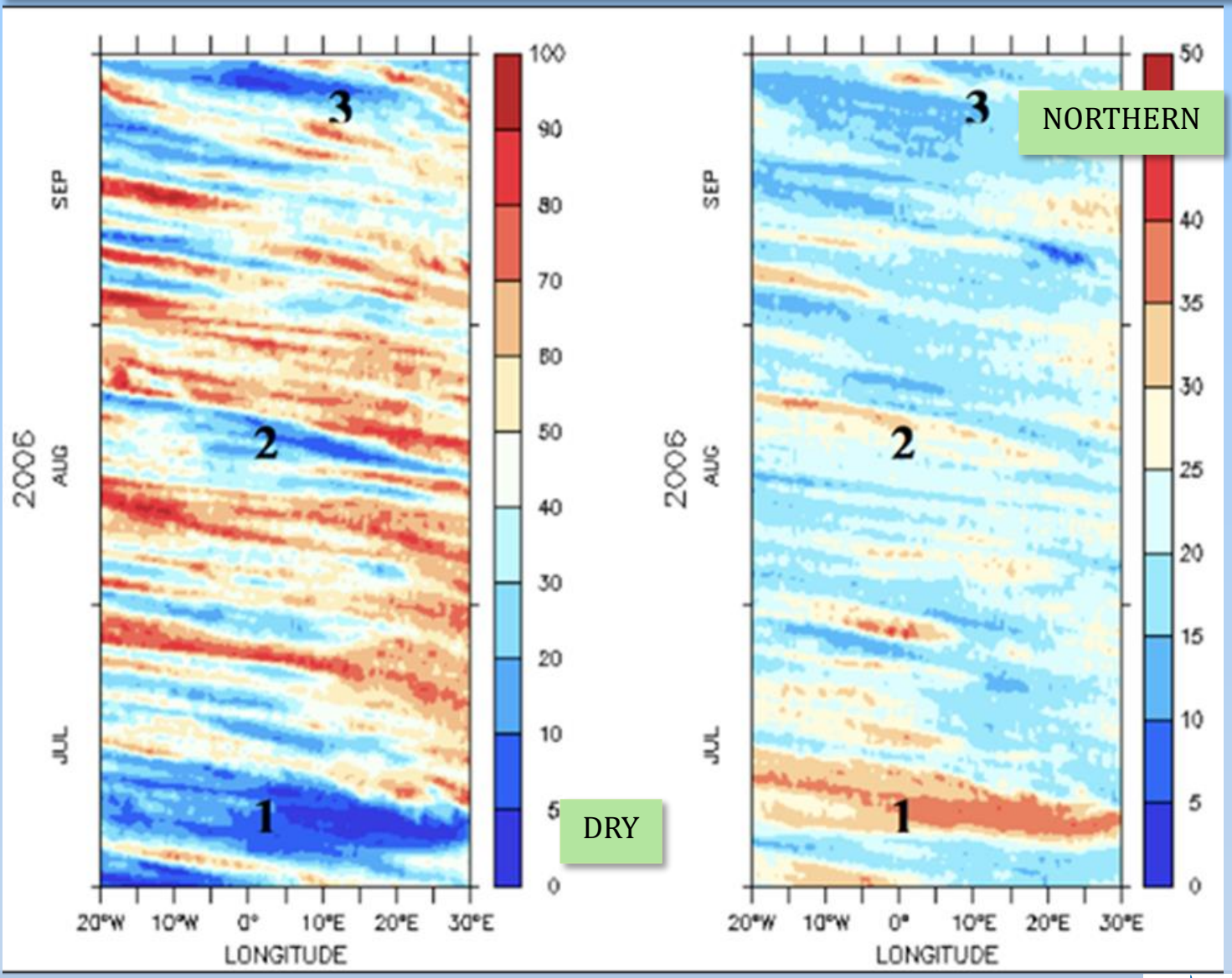


Figure 2.22: Time longitude diagram averaged over the **12.5°N-17.5°N** belt for the 2006 season. Left: **relative humidity at 500 hPa.** Right: **latitude of last saturation** (degrees North).

Part V: Guinea Coast region

Guinea coast region

- Various rainfall types occur such as
  – isolated storms
  – organised convection (MCSs)
  – "Monsoon" or "vortex" rains with widespread rain and low electrical activity
- Coastal effects, e.g. sea-breeze, have a significant control.
- Dry-season rain can have high impact (e.g. destruction of stored produce).
- Low-level flow and moisture advection leads to sensitive control on low cloud and fog.
- Much more research is needed → DACCIWA project

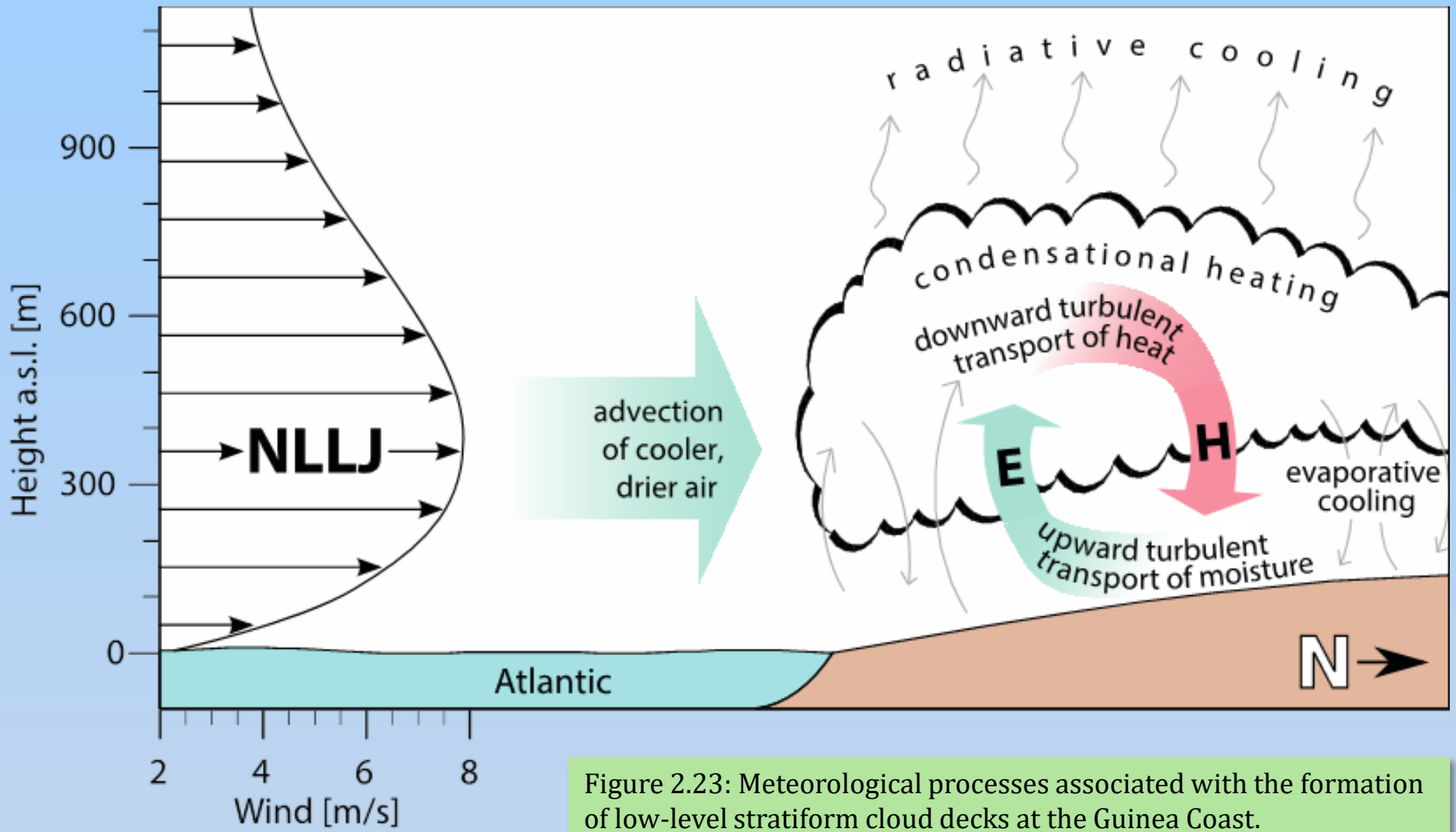


Figure 2.23: Meteorological processes associated with the formation of low-level stratiform cloud decks at the Guinea Coast.

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

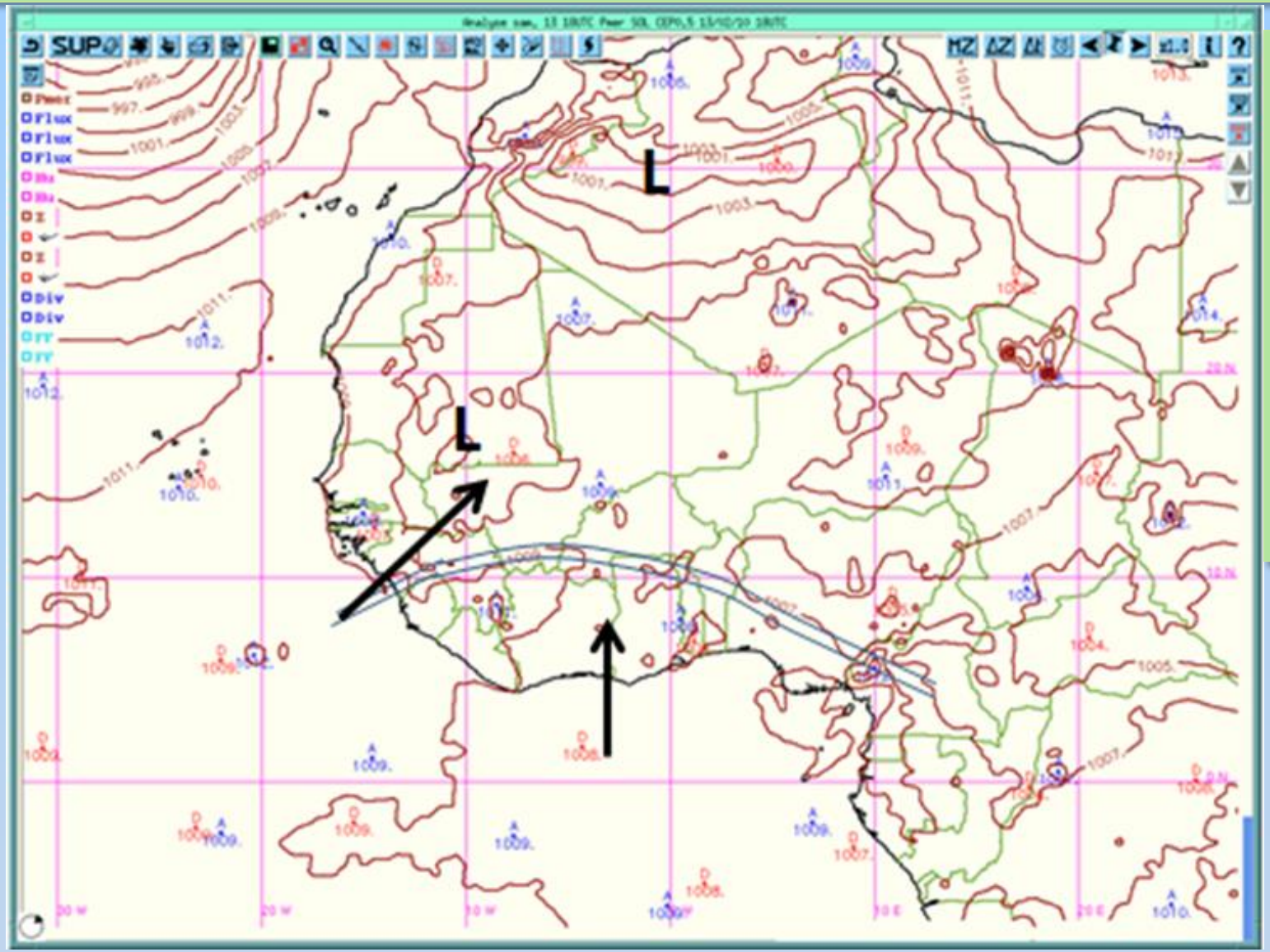


Fig. 2.33 (a) Synoptic situation at 1200 UTC on 13 February 2010, indicating **ITD**, **low level winds** (schematic vectors) and trough connecting low **pressure** systems over Algeria and southern Mauritania.

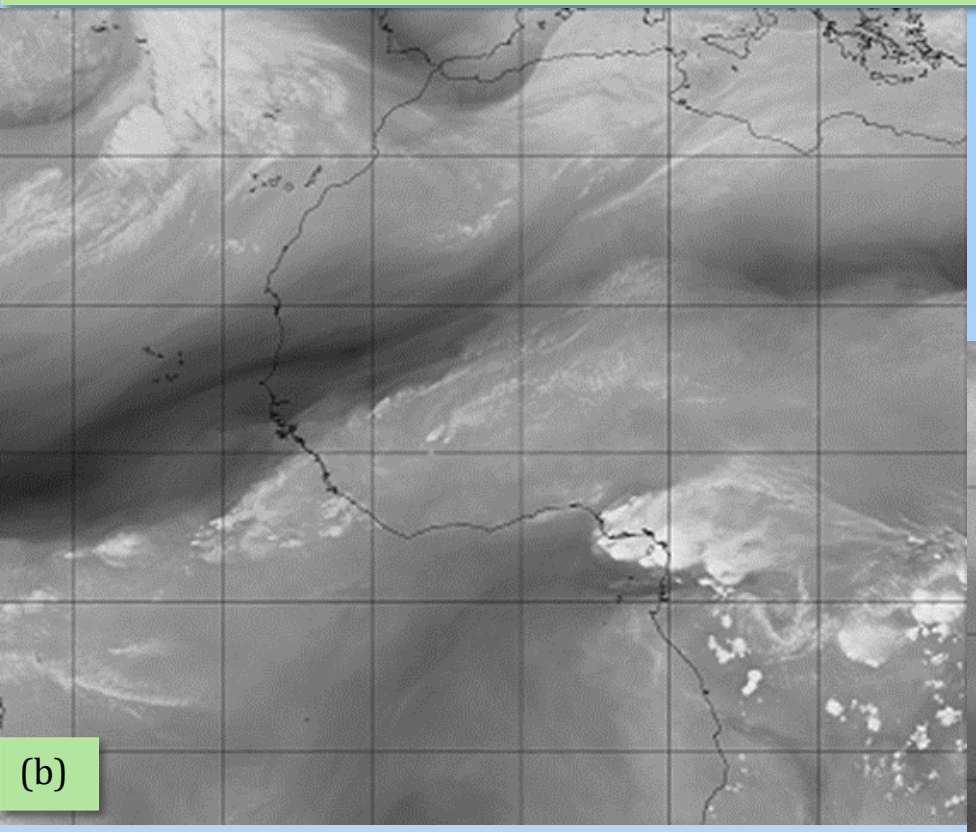
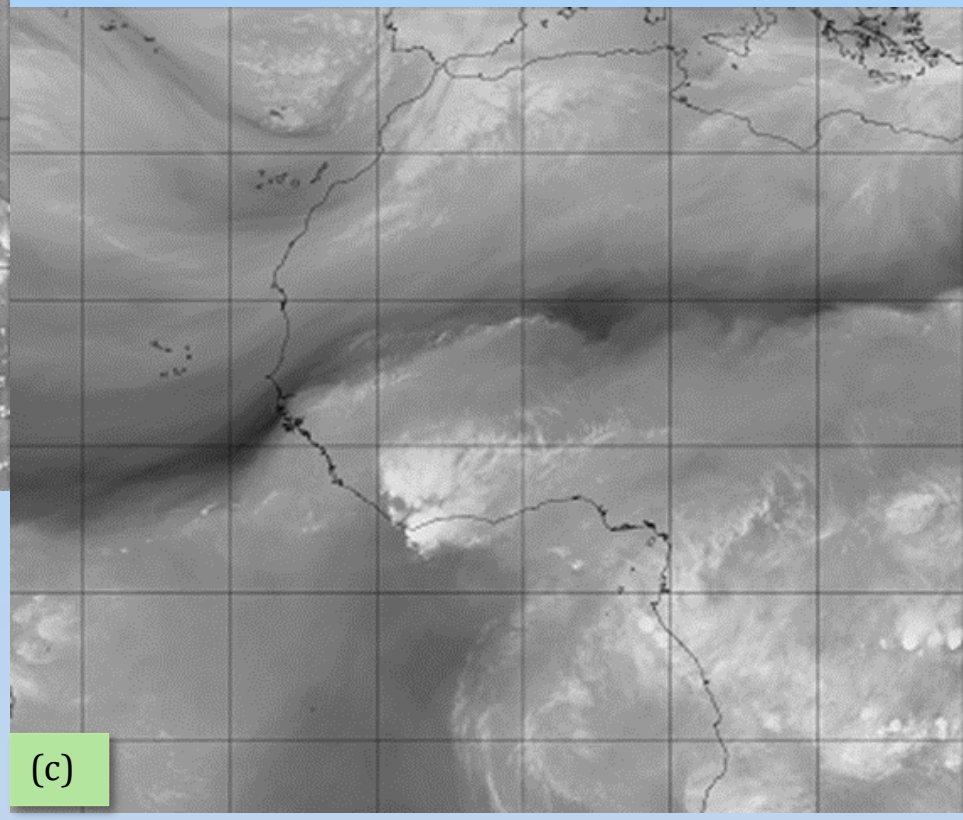


Fig. 2.33 Meteosat SEVERI water vapour imagery at (b) 1200 UTC 13 February and (c) 0000 UTC 15 February 2010.



Part VI: Conclusions

Chapter 2: *Synoptic Systems* - Lead Authors: R Cornforth, Z Mumba, DJ Parker

- West Africa has a number of important synoptic features that modify the environment in which "weather" forms.
- Large-scale setting is determined by the heat low, ITD and AEJ.
- AEWs have a complicated vertical structure and significantly modulate moisture and winds.
- AEWs form and intensify along the PV gradient of the AEJ.
- Extratropical influences (UTT, dry intrusions) consist a source of predictability, particularly in northern winter.
- Guinea coastal region has different types of rainfall and cloud systems that need more research.
- Synoptic analysis provides a common scientific framework.
- Synoptic control of convective rainfall can increase predictability, (although) convection can "disobey" the synoptic rules.