Department of Meteorology

A climatological link between slantwise instability and surface weather conditions

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Introduction

Frontal precipitation bands, cloud head development in rapidly developing cyclones and sting jets all involve the release of conditional symmetric instability (CSI), a type of moist symmetric instability, resulting in slantwise convection (see the review by Schultz and Schumacher , 1999). Unlike for the release of conditional instability leading to upright convection, the release of CSI is not resolved by most large-domain operational weather forecast models (or climate models) nor are parameterizations employed by models .

Open questions:

- How does CSI influence the development of heavy precipitation and severe winds in extra-tropical cyclones?
- Would a slantwise convective parameterization be beneficial to the performance of a numerical weather prediction model?

The aim of this project is to quantify the climatological relationship between CSI, the release of CSI, and surface weather conditions such as intensified precipitation bands and strong winds.

Case studies demonstrate an association between large SCAPE values and precipitation in models. An example of this is shown in Figs. 1 and 2. Frontal forcing can lead to the release SCAPE. Hence all three ingredients required for CSI release are present: lift from the frontal forcing, instability measured by the SCAPE and moisture (evident by the frontal cloud and rain bands). Here we present the first regional climatology of slantwise convective available potential energy (SCAPE), a metric for CSI, and relate the presence of SCAPE (and the upright equivalent, CAPE) to precipitation in re-analysis data.

Slantwise Convective Available Potential Energy (SCAPE)

SCAPE is a measure of the kinetic energy a parcel would gain during a slantwise ascent from the combined work performed by the buoyancy anomaly in the vertical and the momentum anomaly in the horizontal. It is analogous to CAPE for a vertical parcel ascent and can be calculated as CAPE along a momentum surface.

$$CAPE = \underbrace{\int_{z_{launch}}^{z_{LNB}} g\left(\frac{T_{v\,par} - T_{v\,env}}{T_{v\,env}}\right) dz}_{\text{Work done by buoyancy}}$$

$$SCAPE = \underbrace{\int_{z_{launch}}^{z_{LNB}} g\left(\frac{T_{v\,par} - T_{v\,env}}{T_{v\,env}}\right) dz}_{\text{Work done by buoyancy}} + \underbrace{\int_{x_{launch}}^{x_{LNB}} f(M_{par} - M_{env})dx}_{\text{Work done by momentum}},$$

where $T_{v\,par}$ and $T_{v\,env}$ are the virtual temperatures of the parcel and environment respectively, g is the acceleration due to gravity, f is the Coriolis parameter, M_{par} and M_{env} are the geostrophic absolute momentums of the parcel and environment respectively.

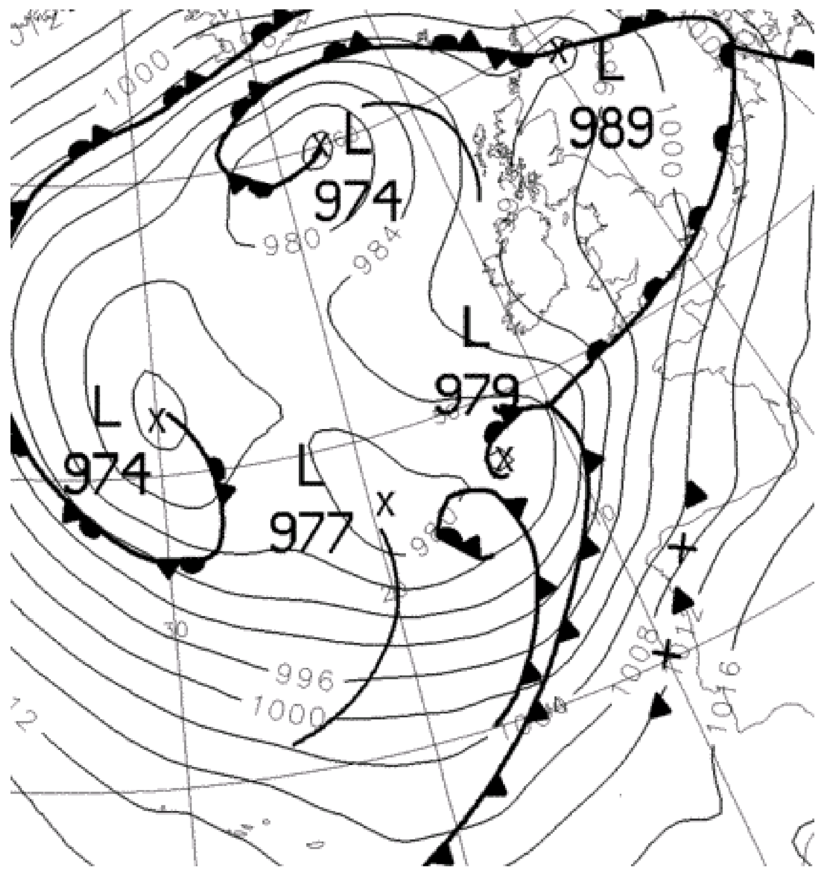

Figure 1 – Met Office Analysis at1200UTC 13 November 2009.

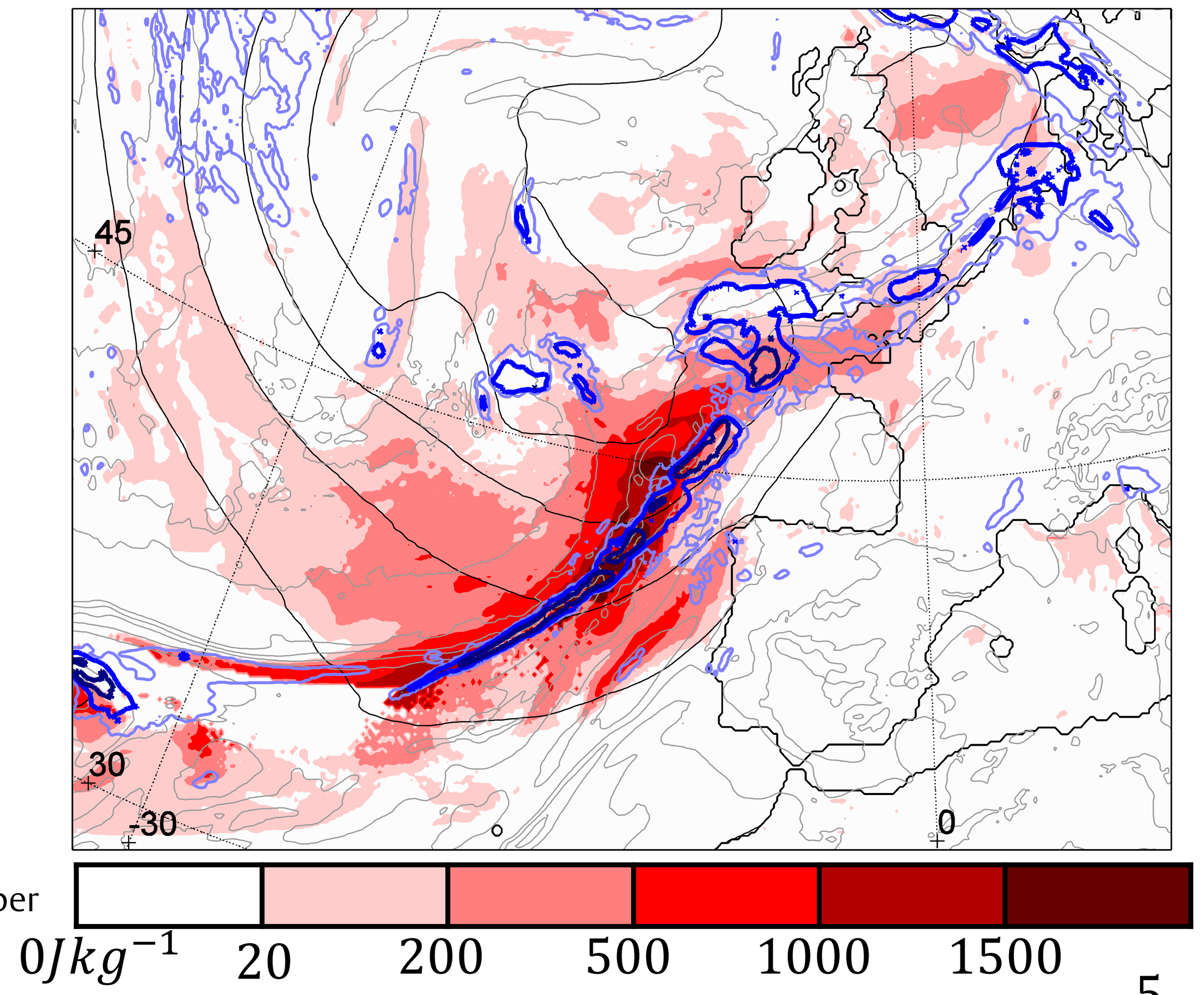

Figure 2 – Met Office Analysis at1200UTC 13 November 2009, SCAPE (Jkg^{-1}) shaded red, instantaneous large-scale precipitation contoured in blue, mean sea level pressure contoured black every 10mb.

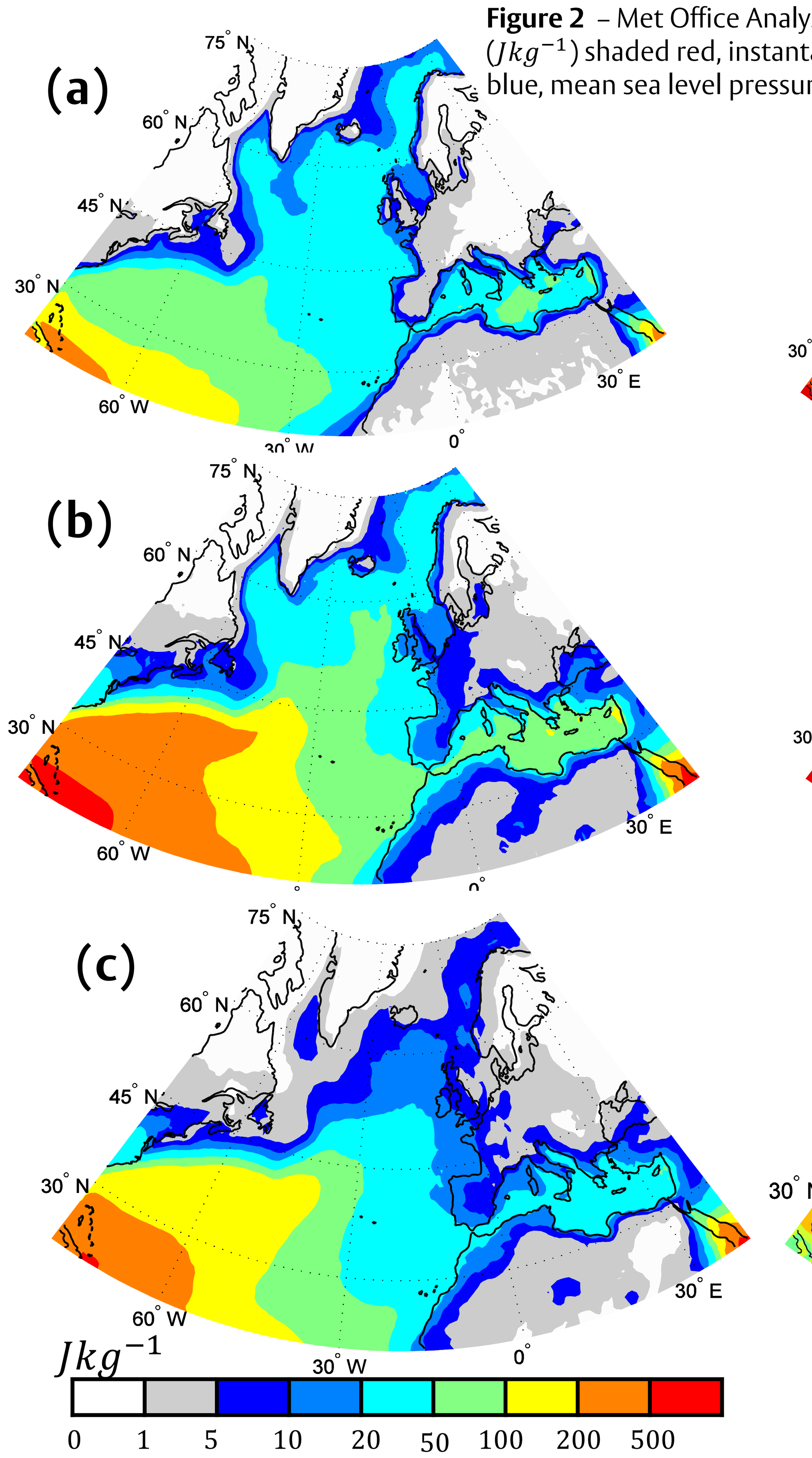

Figure 3 –(a) Mean CAPE, (b) Mean SCAPE and (c) Mean (SCAPE - CAPE), all for December using ERA-interim data at 0000UTC, 0600UTC, 1200UTC and 1800UTC from 1979-2010.

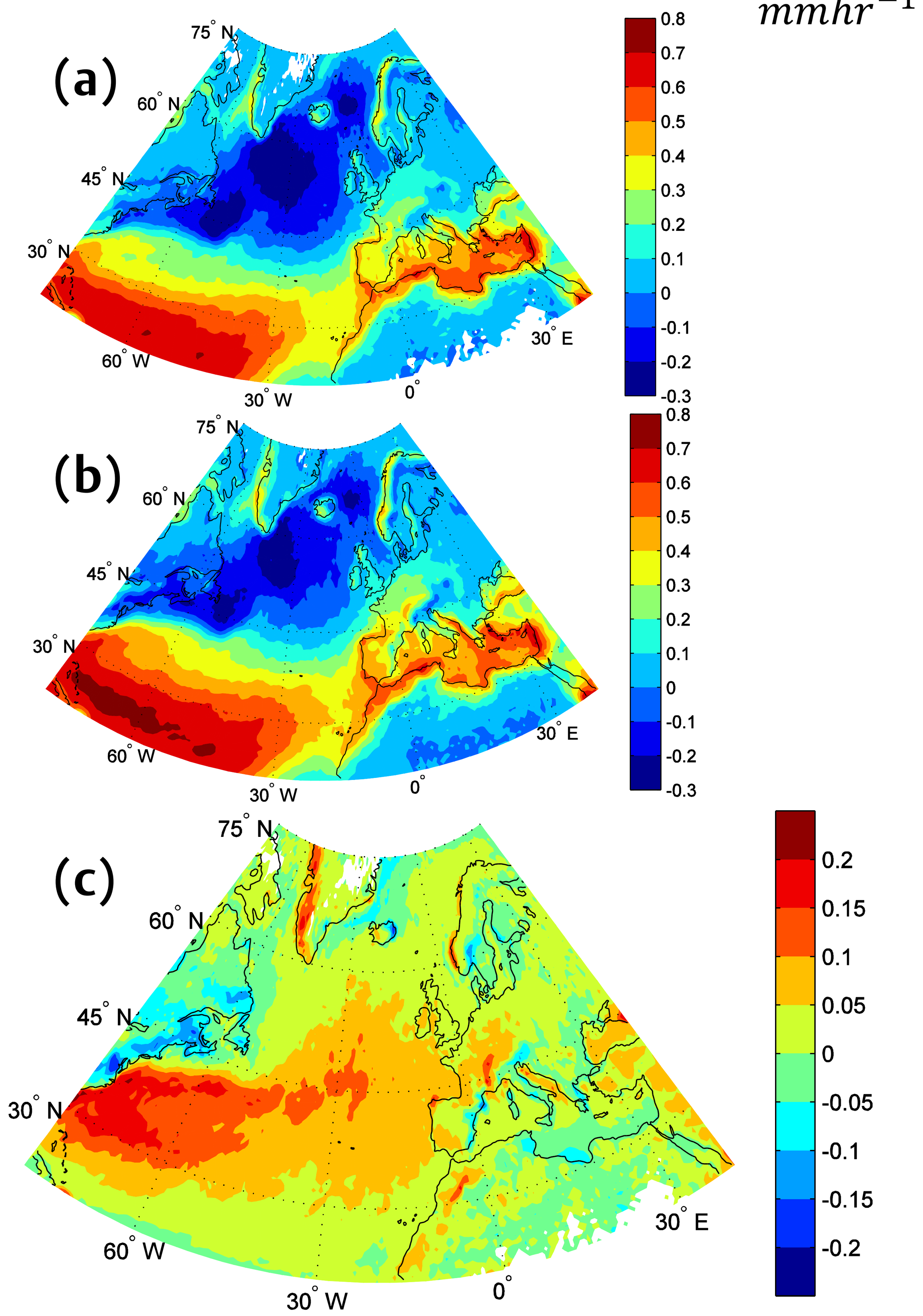

Figure 4 –(a) Spearman ranked correlation between CAPE at 00UTC and the large-scale precipitation accumulated between 00UTC and 12UTC. (b) The same as (a) but with SCAPE instead of CAPE. (c) The difference between these, i.e. (b) – (a). All use ERA-interim data for December, January and February 1979-2010.

SCAPE Climatology

Monthly climatologies of SCAPE and CAPE have been calculated using the ECMWF re-analysis, ERA-Interim. Mean values for CAPE, SCAPE and (SCAPE-CAPE) during December, when the storm tracks are active, are presented in Fig. 3. As expected, SCAPE exceeds CAPE and in the North Atlantic storm track region SCAPE values dominate negligible CAPE values. This is consistent with Shutts (1990) who showed that some rapidly developing extra-tropical cyclones are associated with large values of SCAPE and low values of CAPE.

To our knowledge, this is the first SCAPE climatology. Climatologies using other CSI metrics have been produced by Korty and Schneider (2007) and Czaja and Blunt (2011) who respectively use the saturated moist potential vorticity and a type of slantwise lifting index to focus on the investigation of the tropospheric stratification and the influence of atmosphere-ocean coupling.

The correlations (Spearman ranked) between surface-based CAPE, SCAPE and the accumulated large-scale precipitation in winter in ERA-Interim are shown in Fig. 4. This difference between these correlations (Fig. 4c) highlights the North Atlantic storm track. Here, the extra correlation for SCAPE above CAPE is associated with frontal activity and so CSI release is likely.

Summary

•Monthly mean SCAPE can exceed double monthly mean CAPE in regions of strong baroclinicity (e.g. over the Gulf Stream in December). Hence CSI release is likely in these regions.

•Both CAPE and SCAPE are strongly correlated with rain rate in re-analysis data.

•In the storm track region SCAPE is far more strongly correlated with precipitation than CAPE.

Future Work

•Investigate the relationship between CSI metrics and observations of rain and wind speed from land surface stations.

•Carry out a high resolution (convection-permitting) study to determine how metrics for CSI related to weather at these resolutions.

References

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