2.4 BREAK-UP AND ROLL-UP OF STRATOSPHERIC INTRUSIONS

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1. INTRODUCTION

When atmospheric motion is viewed in a isentropic framework it becomes apparent that at the tropopause break in mid-latitudes there is a rich dynamical structure characterized by stratospheric tongues and tropospheric humps. These tongues and humps are a key component in the development of mid-latitude weather systems and they contribute to the mixing of stratospheric and tropospheric air that substantially influences the distribution of the atmosphere's gases and aerosols. However, little is known about the detailed structure of the flow phenomena that evolve in this region of the upper-troposphere lower-stratosphere.

Here a sub-synoptic scale wave development evolving on an elongated stratospheric intrusion into the upper troposphere is examined (see also *Appenzeller and Davies*, 1992; *Appenzeller et al.*, 1995). To provide a detailed three dimensional insight into the development high resolution (~6 km) satellite measurements (METEOSAT 4) from the water-vapour absorption band (5.7 - 7.1 µm) are combined with the coarser grained (~60 km x 60 km x 2 km) potential vorticity data calculated from the analysis cycle of the ECMWF model. Contour advection experiments are used to explore the rich fine scale structure. The three diagnostic tools are mutually supportive: The analysis data give a coarse grained three dimensional depiction of the dynamically crucial PV and θ tracers where stratospheric air is marked with PV values greater than 2 pvu. The water vapor satellite images provide a vertically averaged but horizontally a one magnitude finer scaled depiction of the streamer's structure. Since the water-vapour content of the stratospheric intrusion is typically one order of magnitude smaller than that of the surrounding upper-tropospheric air, the intrusions will appear as a distinct "dark" dry-band on a water-vapor satellite image. The contour advection experiments link the coarse grained analysis data with the rich fine scale structure observed in the water-vapor satellite images.

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2. CASE STUDY

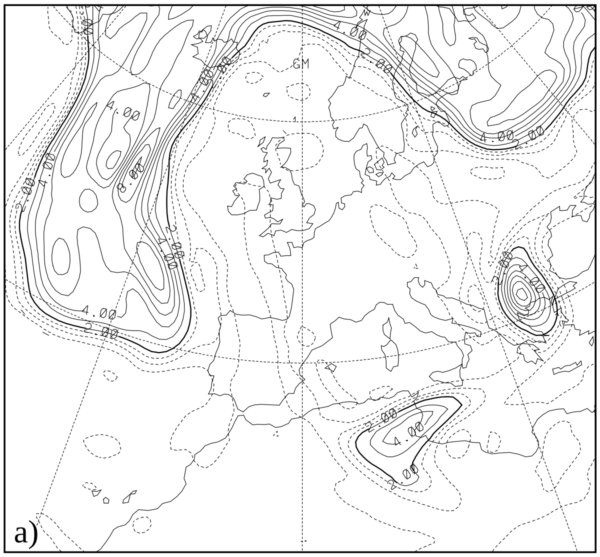
Fig. 1 shows a breaking-up stratospheric streamer over the region of Europe. A time sequence of isentropic PV charts indicated that a PV tongue progressed southward out of the mean stratospheric reservoir of high PV and then curved anticyclonically around a large high-pressure system that was dominating the European weather pattern. The streamer was thereby stretching and thinning to a length of ~3000 km and a width of ~300 km and subsequently on this streamer two distinct vortices developed (Fig. 1a). A first near the Black sea and a second 12 to 18 hours later and 1300 km away over Tunisia. The latter appeared as an anchor shaped pattern in the temperature distribution on the dynamically defined tropopause (2 pvu surface), where the streamer evolved as a band of cold potential temperature (not shown).

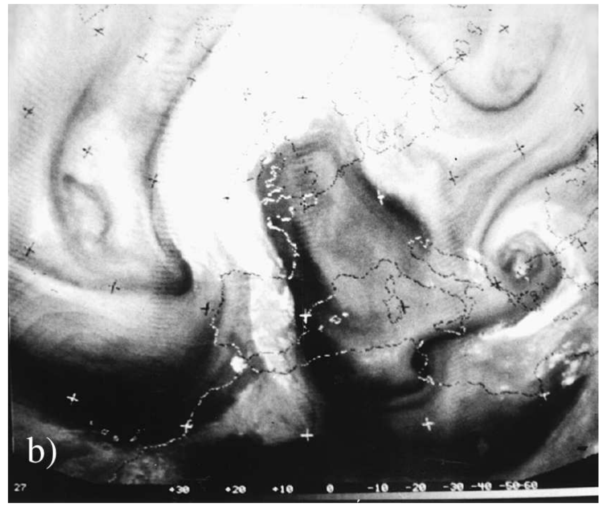
In the corresponding water-vapour satellite images (Fig. 1b) the stratospheric streamer appeared as a dry "dark" band stretching south-westward over eastern and southern Europe. They clearly reveal the non-linear evolution involved in the break-up process and show a spiral-like roll-up within the vortex body and a rapid thinning of the intermediate streamer. Some of the fine scale features where also reflected in the analyzed specific humidity distribution.

It is apparent that the fine scale flow structures are not fully resolved in the analyzed PV data. However, much of the observed fine scale structure can be observed using a contour advection technique (*Norton*, 1994). In this technique contours were initialized as isolines of PV from smoothed analysis on 12 GMT 10 May and then advected by analyzed isentropic winds. The evolving flow patterns (Fig. 1c) reveal a remarkable similarity with the observed water vapor satellite images (Fig. 1b). Both figures suggest that the lower part of the evolving cut-off vortices consist of a spiral-like roll-up of alternating stratospheric and tropospheric air.

3. DISCUSSION

Idealized life cycle experiments of mid-latitude cyclones show that ambient anticyclonic shear flow favors the evolution of the initial PV tongue into elongated streamers (*Davies et al.*, 1991). However, the subsequent break-up of the streamer itself into sub-vortices was not observed in these experiments.





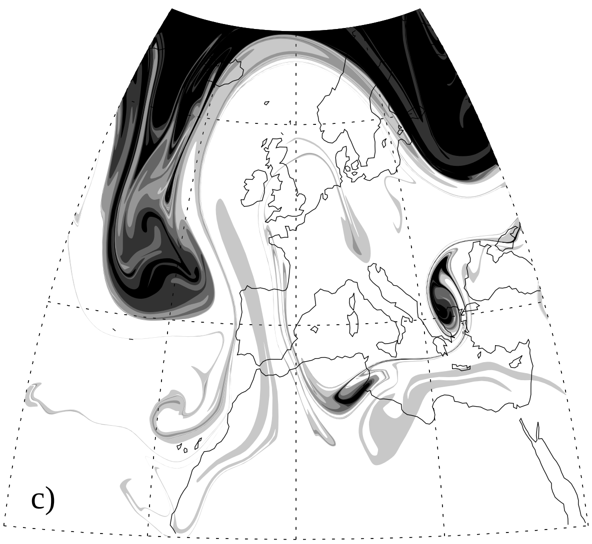


Fig. 1: Three displays of a breaking-up stratospheric streamer at 00 GMT on 14 May 1992. Panel a) potential vorticity (PV) fields on a isentropic surface with θ = 320 K, contours dashed for PV < 2 pvu (with 0.5 pvu spacing), continuous for PV > 2 pvu (with 1.0 pvu spacing). PV values greater than 2 pvu indicate air of stratospheric origin. Panel b) METEOSAT water vapour satellite images (dark regions represent high radiance values and therefore low moisture content in the upper troposphere lower stratosphere). Panel c) Contour advection calculation started at 12 GMT 10 May on a 320 K (dark regions signify essentially stratospheric air).

The streamer is subject to both deformation by the large-scale flow and to the non-linear in-situ dynamics. One response is the roll-up of the streamer's tip into a circular vortex another is the break-up of the streamer into waves and vortices. The latter is consistent with the occurrence of an instability analogous to the barotropic shear instability. The instability of a PV streamer might also be suppressed by a large-scale deformation field. A crude estimate of the deformation rate along the streamer axis amounts to ~ 1/100 of the streamers vorticity (~ $2 * 10^{-4}$ s^{-1}) and a comparison of the deformation rate with the one of a non breaking-up streamer shows a one magnitude smaller value (*Appenzeller et al.,* 1995).

The existence of the break-up and/or roll-up indicates, that on the 100 to 1000 km scale the flow near the tropopause has a rich structure. The evolving sub-vortices can potentially modify daily weather developments. The instability induced isentropic stretching and folding of different air masses indicates the occurrence of local irreversible quasi-isentropic mixing of stratospheric and tropospheric air.

4. REFERENCES

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