OCEANOLOGICA ACTA 1984 - VOL. 7 - N° 3

Kinematical interpretation of infrared surface pattern in the North Atlantic

North Atlantic
Satellite imagery
Drifting buoy
Sea-surface temperature
Atlantique Nord
Thermographie
Bouée dérivante
Température de surface

P. G. Hardtke, J. Meincke
Institut für Meereskunde, University of Kiel, D 2300 Kiel 1, FRG.

Received 12/83, in revised form 27/12/83, accepted 10/1/84.

ABSTRACT

Mesoscale structures from satellite-derived infrared images in three areas of the North Atlantic are related to simultaneous tracks of free drifting buoys and hydrographic measurements. Whereas under conditions of moderate stratification the IR-temperature distributions match the kinematical pattern obtained from measurements in the surface layer, there is no clear correspondence in the presence of a strong seasonal thermocline.

Oceanol. Acta, 1984, **7**, 3, 373-378.

RÉSUMÉ

Interprétation cinématique d'images infrarouges dans l'Atlantique Nord.

Des structures à moyenne échelle ont été observées en trois régions de l'Atlantique Nord à partir d'images satellitaires dans l'infrarouge; elles sont comparées aux trajectoires simultanées de bouées dérivantes et aux mesures hydrologiques. Lorsque la stratification est faible, la répartition des températures observée dans l'infrarouge suit le modèle cinématique obtenu par les mesures dans la couche de surface, tandis que la correspondance disparaît en présence d'une forte thermocline saisonnière.

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INTRODUCTION

Very high resolution infrared data from NOAA-satellites are available for large areas of the world ocean. Providing conditions are cloudfree, the IR-structures of the sea surface suggest a wealth of synoptic kinematical information on spatial scales from one to several hundred kilometres. Interactions of motions on these scales dominate the oceans' internal energy transfer. Since the time scales involved range from days to months, adequate sampling by *in situ* oceanographic methods is an onerous process, and any assistance that may be provided by remote sensing is desirable, whether for direct analysis of changing surface patterns or for selecting an oceanic area prior to actual field work. This use of IR-sensors, however, requires knowledge of the coupling between structures of the surface layer itself and the kinematical features in the geostrophically balanced ocean interior. The present paper shows, by examples from three areas (Fig. 1), the extent to which IR-surface patterns correspond to information obtained simultaneously by satellite-tracked drifting buoys and hydrographic measurements.

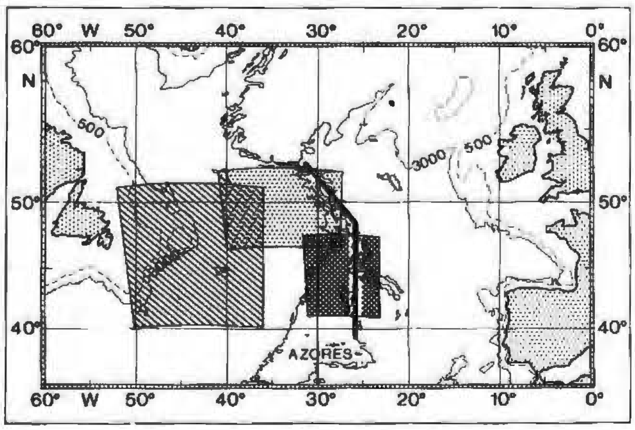

Figure 1
Location of study areas and orientation of hydrographic section shown in Figure 5.

THE DATA BASE

The IR-images are produced from archived 11 µm-AVHRR-HRPT data of daytime passes of NOAA-7, using the photowrite facility of the satellite receiving station of the University of Dundee, Scotland (Baylis, 1981). The contrast enhanced images are corrected for earth curvature in scan direction and are area-conserving around the satellite nadir. They are gridded at the light table by means of computer-plotted reference images whose coastlines are fitted to those of the IR-images. The reference images also contain drift buoy trajectories. It may be supposed that the accuracy of any geographical coordinates drawn on the images is better than two nautical miles in each direction.

The derivation of sea-surface temperature from IR-raw data has been done by using the calibration procedure as suggested by NOAA (Lauritzen *et al.*, 1979) and using the split window algorithm for correction of atmospheric attenuation published by McClain (1980). Atmospheric signals originating with clouds are detected and eliminated by means of criteria based on climatological knowledge of monthly sea surface temperature and the albedo data of the visible AVHHR spectral channel for each pixel.

Data on kinematical features to be compared with IR-signatures were obtained using trajectories from free drifting surface buoys tracked by the ARGOS-system. All buoys had a 20 m^2 window-shade drogue attached.

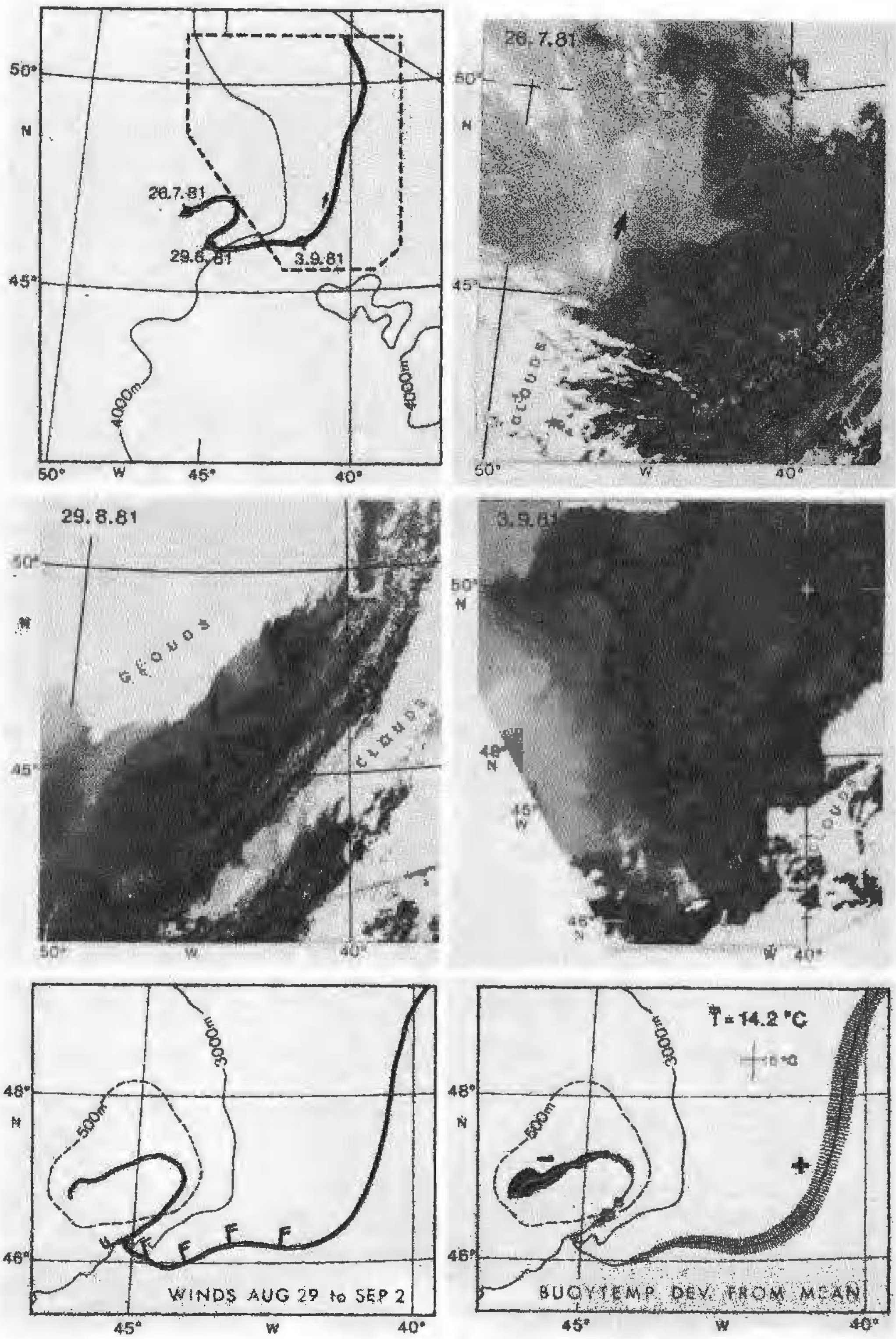

Figure 2
Study area east of Newfoundland: track of drifting buoy drogued at 10 m depth from 15 June-15 September 1981. IR-images for 3 dates indicated along trajectory. Arrows in the IR-Image represent momentary buoy location and drift direction. Lower panels show winds and temperature deviation from temporal mean.

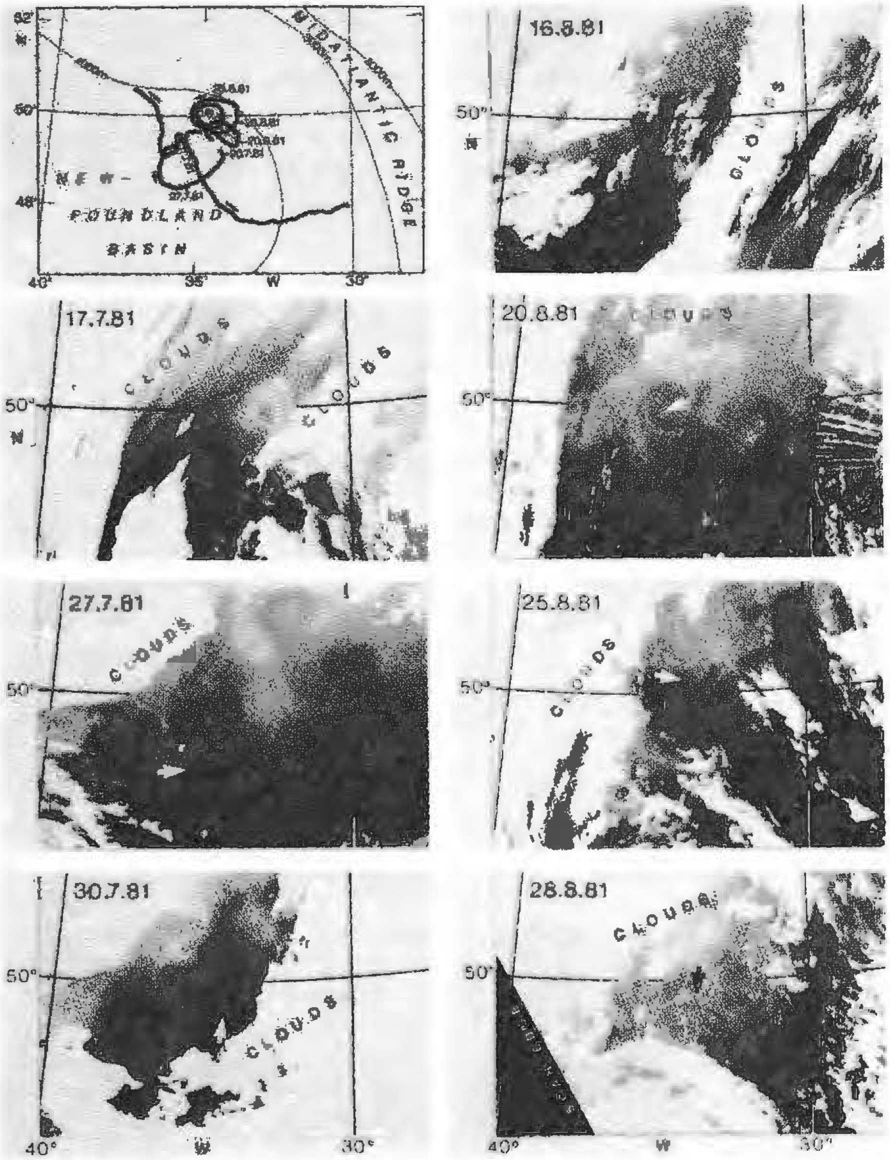

Figure 3
Study area subpolar front: track of drifting buoy drogued at 10 m depth from 1 July-30 September 1981. IR-images (see Fig. 1) for 7 dates indicated along trajectory. Arrows in the IR-images represent momentary buoy location and drift direction.

Positioning was carried out 4 to 6 times per day and is accurate within a few hundred metres, *i.e.* well below the resolution used in the context of this paper. The second set of data that will be used for comparison with IR-images are "surface" temperatures and salinities obtained from a research vessel that worked simultaneously in one of the areas of discussion. Whereas the surface temperatures were read from a hull-mounted resistance thermometre at 4.5 m depth, salinities were solely obtained from CTD-readings at 5 m depth while the vessel was on station.

OBSERVATIONS IN THE FRONT RELATED TO THE NORTH ATLANTIC CURRENT

The first example (Fig. 2) shows a drifting buoy trajectory and three infrared images obtained for the frontal area east of Newfoundland (Mann, 1967) within the period 15 July-15 September 1981. Three features permit a joint interpretation: during July and August the drifter with its drogue at 13 m depth follows an anticyclonic path around a dark (*i.e.* warm) anomaly in the IR-image. This anomaly corresponds to what is known as the Flemish Cap trapped eddy (Ross, 1980). Near the end of August the drifter is found in the base of a narrow filament stretching eastward, which represents cold Labrador water extruding across the shelf edge into the deep ocean (Clarke, La Violette, 1981). From several years of scattered IR-observations, this kind oe event is known to occur preferably at the same location at a period" of 2 to 3 months. In early September, the drifter is located just south of the filament, headling eastward parallel to the IR-contours. The water temperature has risen from 14°C to 19°C and the speed has increased to 1.2 m sec.$^{-1}$, both values characteristic for the North Atlantic current (Mann, 1967).

In Figure 2, significant IR-features and the drifter trajectory have been found congruent for certain intervals. In an attempt to explain the intermediate "transfers" of the drifter from one feature to its neighbour, the winds at the buoy location were estimated from atmospheric pressure distributions and plotted along the trajectory. It is evident that the transfers correspond to wind-events, although they were not particularly strong. As an example, the period 30 August-30 September is considered, when northerly winds of 5 to 8 m sec.$^{-1}$ were encountered. Superimposed onto the rapid eastward drift of the buoy was a displacement of about 10 km in a southerly direction, *i.e.* out of the cold filament into the warm North Atlantic water. The average displacement speed of 2 cm sec.$^{-1}$ is a realistic value for a slip of a drogued system due to windage and wave effects (Cresswell, Garrett, 1980).

The second set of observations was obtained in the subpolar frontal region west of the Mid-Atlantic ridge (Fig. 3). After travelling along the front at a relatively high zonal speed, a drifter encountered an eddy field at about 36°W, as shown in the sequence of IR-images. In mid-July the trajectory is cyclonic, following a light (cold) IR-anomaly. In August it circles a dark (warm) anomaly three times in an anticyclonic sense before leaving this feature at 35°W and resuming its zonal path. A detailed survey of part of this region by R. V. "Poseidon" in July/August 1981 has shown the quasi-geostrophic mesoscale features of the subpolar front which dominate the kinematics of the upper layers (Woods, pers. comm.). As in the previous case, the transfer of the drogued drifter from one IR-feature to the next coincides with events in the wind field. In addition, the sequence of IR-images also suggests a coincidence between the weakening of an IR-feature and the transfer of the drifter from it. However, varying cloud coverage prevents a detailed investigation of this possible mechanism.

OBSERVATIONS SOUTH OF THE NORTH ATLANTIC CURRENT FRONT

The foregoing examples have shown that for limited periods a close agreement is found between IR-features

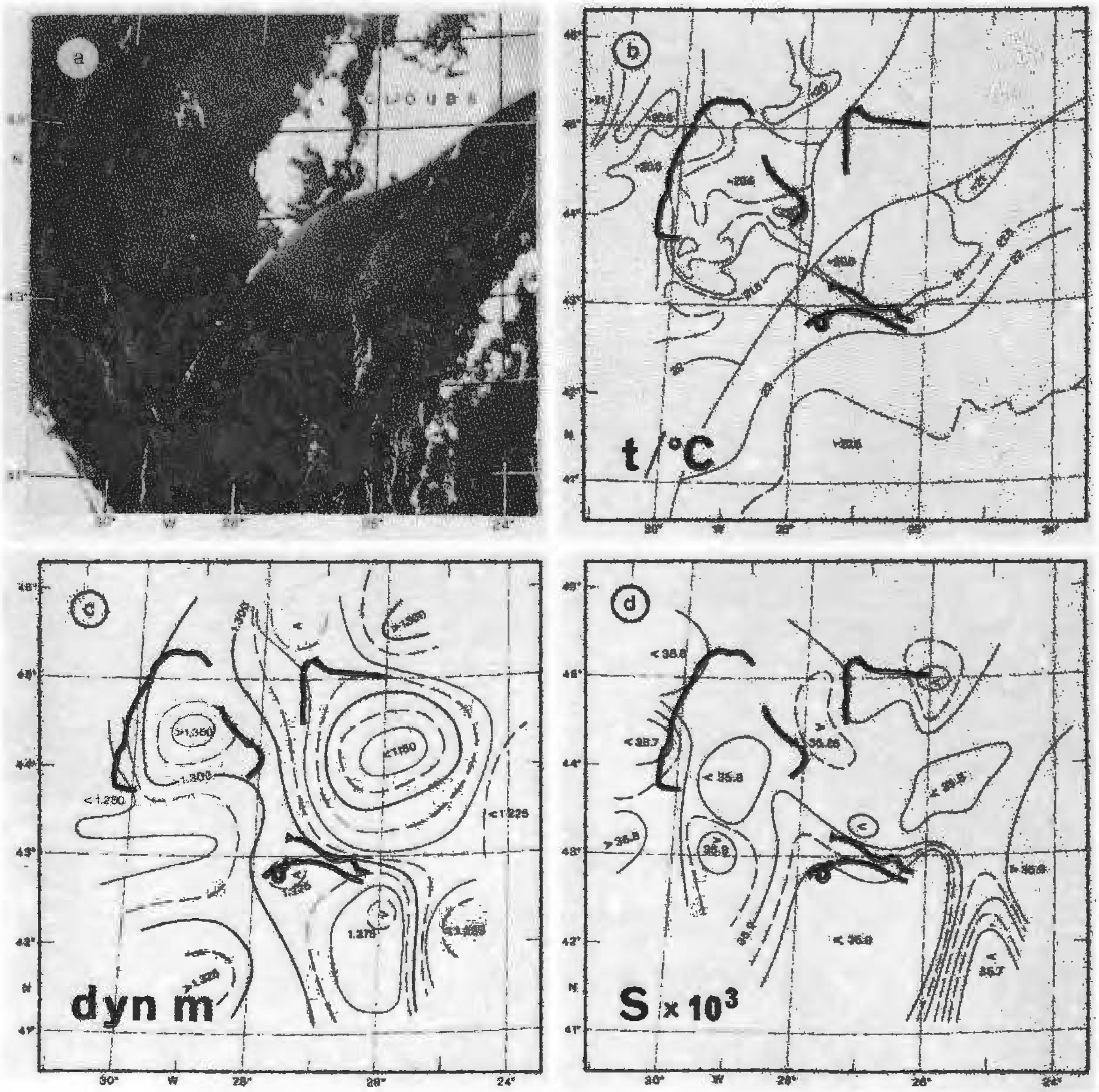

Figure 4
Study area north of the Azores:
a) *IR-images* (see *Fig.* 1) *composed of two satellite passes on August* 23/24, 1981;
b) *sea surface temperature derived from IR-image by split window technique* (*McClain,* 1980), *tracks of* 5 *drifting buoys drogued at* 30/100 *m depth from* 13 *August-2 September,* 1981;
c) *dynamic topography* 20/1 500 *dbar;*
d) *surface salinity derived from CTD-measurements.*

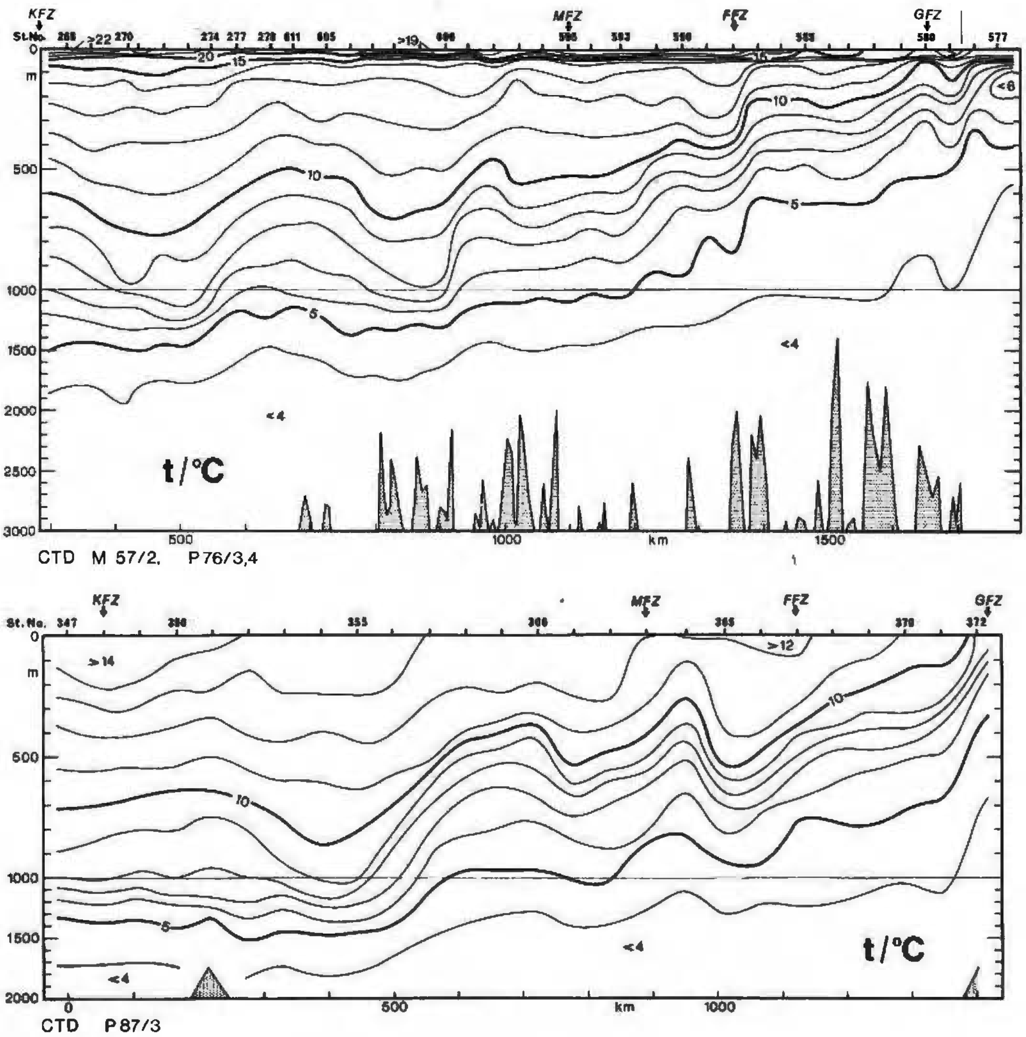

Figure 5

Vertical temperature sections along the eastern 3000 m depth line of the Mid-Atlantic ridge from CTD-measurements (see *Fig.* 1):
a) *August* 11-16, 1981;
b) *April* 16-21, 1982.

and trajectories of drogued drifters. Since, as mentioned, the character of these features is known from independent investigations, the IR-images in fact provide an insight into the kinematics of the upper ocean. Before discussing this further, a third example with not such clear correlation is presented in Figure 4.

In a 400 x 650 km wide area north of the Azores, 5 drifting buoys drogued at 30 m and 100 m respectively were deployed in the period 13 August-2 September, while 2 vessels covered the field with hydrographic stations (Krauß, Meincke, 1982). The dynamic topography 20/1 500 m (Fig. 4 *c*) is dominated by mesoscale eddies, and the drifter trajectories show close agreement. The IR-image (Fig. 4 *a*) and the corresponding SST (Fig. 4 *b*), however, is quite different. Its major feature is a complex zonal front. Faint similarity between the dynamic topography and the IR-pattern is only found in the convergence zone between the two northeasterly eddies and in the relatively cold surface feature extending southward along the western flank of the northeasternmost cyclonic eddy. The explanation for this discrepancy may be read from Figure 5 *a*, which shows the results of a simultaneous temperature-section running northward from the Azores to the North Atlantic Current Front (for orientation, *see* Fig. 1). In the area discussed, mesoscale eddies are the dominant signature in the temperature distribution. At the same time Figure 5 *a* demonstrates how this signature is topped off by the strong seasonal thermocline at a depth less than 30 m. Like the IR-image, the surface salinity map (Fig. 4 *d*) and the surface temperature map (not shown) from shipborne measurements show the same dissimilarity with the dynamic topography.

The complete data set obtained for the area north of the Azores allows us to add a comment on the realiability of identifying oceanic mesoscale surface structures from satellite-derived IR surface skin temperatures. Figure 6 compares the traditional bulk sea surface tem-

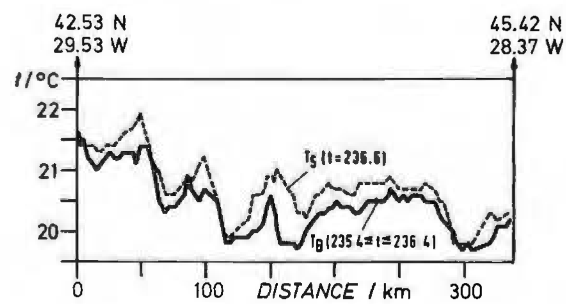

Figure 6

Comparison of ship and satellite sea surface temperature. The wind speed during the time interval (235.4 *d* $\leq t \leq$ 236.6 *d*) *was* 5 *Bft. and there was also no significant temperature difference between air and water. The mean difference between satellite temperature* T_S *and ship temperature* T_B *is* .23°C, *the rms-deviation* .34°C.

perature sampled at a high rate with the remotely-sensed skin temperature taken nearly simultaneously from pixels enclosing the ship's track. This comparison supports the assumption underlying the foregoing presentations, namely that the skin temperature distribution images the bulk temperature distribution pattern of the oceanic near surface layer.

DISCUSSION

Trying now to answer the original question, *i.e.* how close is the coupling between the kinematics of the upper ocean interior and the surface-governed IR-pattern, the three examples suggest the intensity of the seasonal thermocline to be of major importance. Whereas during summer in the area north of the Azores the maximum vertical gradient within the upper 50 m was 5°C/20 m, the corresponding value for the frontal area was 1°C/20 m. According to the foregoing discussion, the possibility for interior kinematical features to "surface" seems to lie somewhere within the interval between 5 and 1°C/20 m. Considering now Figure 5 *b*, which is a winter-time repitition of the section shown in Figure 5 *a*, the whole area north of the Azores, *i.e.* the northern portion of the Warm Water Sphere, should be favourable for the detection of kinemetical features by IR-images. Another difference between the areas was found for the intensity of the current features as deduced from the mean and the rms-amplitude of the drfiter speed. It was observed to be 30 cm $sec.^{-1}$ (5 cm $sec.^{-1}$) and 15 cm $sec.^{-1}$ (9 cm $sec.^{-1}$) for the northern (southern) area respectively. Thus it may be concluded that without sufficient information on the seasonal status of near surface stratification and on the intensity of mesoscale fluctuations, any kinematical interpretation of IR-images should be avoided.

Acknowledgements

We acknowledge the participation of A. Sy, who provided the dynamic topography shown in Figure 4, and T. Viehoff, who derived the SST in Figures 4 and 6 from AVHRR-HRPT raw data. The authors also wish to thank the satellite receiving station of the University of Dundee, Scotland, for its excellent cooperation.

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