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VARIATIONS OF TEMPERATURE AND SALINITY AT FINNISH FIXED HYDROGRAPHIC STATIONS IN THE BALTIC SEA

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ABSTRACT

SEASONAL AND LONG-TERM VARIATIONS OF TEMPERATURE AND SALINITY WERE STUDIED USING FINNISH FIXED HYDROGRAPHIC STATION DATA, AVAILABLE SINCE THE EARLY 1900's. IN ADDITION TO THE RESULTS OF SEASONAL AND LONG-TERM VARIATIONS AND TRENDS, FURTHER INFORMATION E.G. ABOUT WATER EXCHANGE PROPERTIES WAS ALSO OBTAINED. INTERESTING CORRELATIONS IN THE COMPARISON OF SALINITY AND RIVER RUNOFF DATA REVEAL THE COMPLEXITY OF THE HYDROGRAPHIC PROCESSES IN THE BALTIC SEA. LONG-TERM SURFACE TEMPERATURE VARIATIONS WERE FOUND TO FOLLOW THOSE OF AIR TEMPERATURE INDICATING THE ROLE OF AIR-SEA COUPLING.

RÉSUMÉ:

ON A ÉTUDIÉ LES VARIATIONS SAISONNIÈRES ET À LONG TERME DE LA TEMPÉRATURE ET SALINITÉ À PARTIR DES DONNÉES DES STATIONS HYDROGRAPHIQUES FIXED FINLANDAISES DISPONIBLES DEPUIS LE DÉPUT DU SIÈCLE. EN-PLUS DES RÉSULTATS CONCERNANT LES VARIATIONS SAISONNIÈRES ET LES TENDANCES, DE L'INFORMATION SUR L'ÉCHANGE MOYEN DES EAUX ENTRE LES DIFFERENTES REGIONS DE LA BALTIQUE FURENT RECUEILLIES. LA COMPARAISON DES DONNÉES DE SALINITÉ ET D'APPORT FLUVIAL A MIS EN EVIDENCE DES CORRELATIONS INTERESSANTES, RELEVANT LA COMPLEXITÉ DES PROCESSUS HYDROGRAPHIQUES DANS LA BALTIQUE. LES VARIATIONS A LONG TERME DE LA TEMPERATURE SUPERFICIELLE SUIVENT CELLES DE LA TEMPERATURE DE L'AIR INDIQUANT LE ROLE DES COUPLAGES ATMOSPHERE-OCEAN AU NIVEAU DES ECHELLES DE TEMPS CLIMATOLOGIQUES.

SYNOPTIC TEMPERATURE AND SALINITY OBSERVATIONS HAVE BEEN MADE AT FINNISH FIXED HYDROGRAPHICAL STATIONS SINCE THE EARLY 1900's. IN THE COURSE OF YEARS, THE NUMBER OF STATIONS HAS VARIED FROM 10 TO 45; TWELVE STATIONS (FOUR AUTOMATIC) ARE WORKING CURRENTLY (FIG. 1). LONG-TERM DATA (MORE THAN 30 YEARS) ARE AVAILABLE FROM OVER TWENTY STATIONS AND ALL THE OLD DATA HAVE BEEN PUT INTO AUTOMATIC DATA REGISTER FORM. OBSERVATIONS HAVE BEEN MADE THREE TIMES A MONTH AT DIFFERENT DEPTHS ACCORDING TO THE DEPTH CONDITIONS OF EACH OBSERVATION SITE. DURING THE OBSERVATION PERIOD, CERTAIN METHODOLOGICAL CHANGES ESPECIALLY IN THE DETERMINATION OF SALINITY HAVE OCCURED BUT THEY ARE NOT, HOWEVER, EXPECTED TO BE CRITICAL FROM THE POINT OF VIEW OF THE OVERALL STUDY OF THE LONG-TERM DATA. THE PRESENT STUDY IS A PART OF THE WORK WITH THE ABOVE DATA, PRESENTING OVERALL CHARACTERISTICS AND THE MOST IMPORTANT RESULTS FOUND. THEY MAY BE BRIEFLY LISTED AS FOLLOWS:

A. THE SEASONAL VARIATION OF TEMPERATURE IN SURFACE LAYERS IS RELATED, WHERE RELEVANT, TO THE LATITUDE AND OPEN WATER LOCATION OF THE OBSERVATION SITE (FIGS. 2 AND 3). THE MEAN SEASONAL VARIATION OF SALINITY IS RATHER LOW EXCEPT NEAR RIVER MOUTHS AND AT EFFECTIVE ENTRANCE MIXING AREAS AS IN THE QUARK REGIONS (CF. FIGS. 5-7). THE SEASONAL VARIATION OF SALINITY IS GENERALLY SOMEWHAT LOWER IN THE GULF OF BOTHNIA THAN IN THE GULF OF FINLAND (FIG. 6).

B. THERE EXISTS APPARENT DIFFERENCES IN HYDROGRAPHIC CONDITIONS BETWEEN THE ARCHIPELAGO SEA (UTÖ, FIG. 1) AND THE ÅLAND SEA (MÄRKET). THESE DIFFERENCES MAY BE SEEN IN TEMPERATURE AND SALINITY VARIATIONS AS WELL AS IN STRATIFICATION IN THE WHOLE WATER COLUMN OF THE OBSERVATION SITES (90 M AT UTÖ, 100 M AT MÄRKET). THUS THE SEASONAL WARMING OCCURS EARLIER AND MORE INTENSIVELY AT UTÖ THAN AT MÄRKET (FIG. 4), WHILE THE WATER COLUMN AT MÄRKET IS DISTINCTLY LESS SALINE AND SOMEWHAT MORE UNIFORMLY STRATIFIED THAN AT UTÖ (FIG. 7 AND 13). THESE CHARACTERISTICS REPRESENT WATER MASSES OF DIFFERENT PROPERTIES AND SUGGEST THAT, STATISTICALLY SPEAKING, THE OUTFLOW FROM THE GULF OF BOTHNIA THROUGH THE ÅLAND SEA EXTENDS FAR BELOW THE SURFACE LAYER. THE STRATIFICATION

CONDITIONS AT UTÖ (FIG. 7) INDICATE THE VERTICAL MIXING OF THE WHOLE WATER COLUMN DOWN TO THE BOTTOM OF 90 M DURING THE WINTER TIME. THE FACT THAT THIS MIXING THROUGH THE HALOCLINE OCCURS, INDICATE A RATHER STRONG DYNAMICAL ACTIVITY IN LATE AUTUMN, WHICH SEEMS TO BE CONNECTED WITH FLOWS BETWEEN THE GULF OF FINLAND AND THE GULF OF BOTHNIA THROUGH THE ARCHIPELAGO SEA.

C. AN APPARENT CORRELATION BETWEEN THE RIVER RUNOFF AND THE SURFACE LAYER SALINITY MAY BE FOUND FOR THE GULF OF FINLAND (FIG. 9A) AS QUANTITATIVELY SHOWN IN FIG. 9B. THE QUANTITATIVE EXPLANATION OF FIG. 9B MAY BE REGARDED AS RATHER GOOD BECAUSE IT IS TO BE NOTED THAT THE LOCAL RIVER RUNOFF ONLY CANNOT CONTROL THE SALINITY BUT IN THE MORE ADVANCED QUANTITATIVE PARAMETRIZATION, OTHER QUANTITIES WHICH AFFECT AND CHARACTERIZE THE SALINITY CIRCUMSTANCES AND TRENDS IN THE WHOLE BALTIC SEA MUST ALSO BE INVOLVED. CONTRARY TO THE GULF OF FINLAND, THE RESULTS FOR THE GULF OF BOTHNIA DO NOT SHOW ANY APPARENT CORRELATION BETWEEN THE RIVER RUNOFF AND THE SURFACE SALINITY, EXCEPT POSSIBLY LONG-TERM TRENDS. THIS SEEMS TO BE REFELECTED BY THE MUCH HIGHER SHORT-PERIOD VARIATIONS OF RIVER RUNOFF INTO THE GULF OF BOTHNIA THAN INTO THE GULF OF FINLAND, ON THE ONE HAND, AND BY THE LOCATION OF OBSERVATION POINTS WITH RESPECT TO BIG RIVERS AND THE LARGE-SCALE COUNTERCLOCKWISE CURRENT PATTERN, ON THE OTHER HAND.

D. THE DEEP AND BOTTOM WATER (80-90 M) SALINITY AT UTÖ IS IN AN INTERESTING WAY NEGATIVELY CORRELATED TO THE RIVER RUNOFF (FIG. 10A). THE PHYSICS CAUSING THIS MAY BE RATHER COMPLICATED BUT IT MAY BE UNDERSTOOD BY CONSIDERING THE DYNAMIC BALANCE OF THE WATER MASSES IN THE BALTIC SEA; THE ISOHALINES AND PYCNOCLINES ARE INCLINING (FIG. 10B). WHEN THE AMOUNT OF FRESH WATER RUNOFF IS CHANGED IT WILL CAUSE A DYNAMIC CHANGE IN THE DESCRIBED SYSTEM, AND AT A PROPER SITE THIS MAY BE OBSERVED ALSO BELOW THE HALOCLINE AS A NEGATIVE CORRELATION BETWEEN THE RIVER RUNOFF AND SALINITY. A CASE IN POINT IS GIVEN QUANTITATIVELY IN FIG. 10C.

E. AN INCREASE OF SALINITY, ESPECIALLY FROM THE 1930-1940's TO THE MIDDLE OF THE 1950'IES MAY BE FOUND AT MOST STATIONS IN THE GULF OF FINLAND (FIG. 9A), ARCHIPELAGO SEA AND IN THE BOTHNIAN SEA (FIGS. 11 TO 13). IN THE GULF OF FINLAND AND ARCHIPELAGO SEA THIS TREND HAS CONTINUED UNTIL TO THE END OF THE 1970's (FIG. 12). THERE MAY BE EVIDENCE FOR A VERY SLIGHT WAVELIKE VARIATION OF SALINITY IN THE BOTHNIAN BAY FROM THE 1930-1940's TO THE 1960's BUT THERE ARE NO LONG-TERM TRENDS (FIG. 11). WHEN INTERPRETING THESE RESULTS AS WELL AS SALINITY TRENDS OBTAINED IN SOME OTHER BALTIC SEA STUDIES, IT IS INTERESTING TO NOTE THAT ONE OF THE MOST IMPORTANT PROCESSES CONTROLLING THE WATER EXCHANGE AND SALINITY BUDGET OF THE BALTIC SEA, THE TOTAL FRESH WATER RUNOFF, DECREASED BY OVER 30 % FROM THE 1930's TO THE BEGINNING OF THE 1940's (FIG. 10A) AND THE LONG-TERM DATA AVAILABLE FOR SOME LARGE RIVERS FLOWING TO THE BALTIC SEA, (VUOKSI, WISTULA, VÄNERN-GÖTA, FIG. 14A) SHOW THAT IN THE LONG-TERM AVERAGES (30 Y) THERE WAS A GENERAL DECREASING TREND DURING THE 20TH CENTURY UNTIL THE 1950's. SINCE THEN AT LEAST IN VUOKSI, THE MEAN RUNOFF HAS BEEN LOWER THAN THE OVERALL AVERAGE FOR THE WHOLE HISTORICAL PERIOD (FROM THE MIDDLE OF THE 1800's) AND FINLAND THROUGHOUT THE 1970'IES, EXCEPT A COUPLE OF YEARS, WAS VERY DRY AND RIVER RUNOFFS WERE LOW. IT SEEMS THAT THE DISCHARGE DATA FROM THE RIVER VUOKSI (EASILY OBTAINED FROM THE RUNNING STATISTICS OF A HYDRO-ELECTRICAL POWER PLANT) MAY SERVE AS A RATHER ACCURATE BASIS FOR THE ESTIMATION OF THE RUNOFF INTO THE WHOLE BALTIC SEA, FIG. 14B, AT LEAST FOR A FEW YEARS IF NOT FOR LONGER PERIODS, AND THUS ONE MAY BE RELEASED FROM THE VERY BIG AND CUMBERSOME DATA COLLECTION TASK OF SAMPLING DATA FROM ALL THE RIVERS DISCHARGING INTO THE BALTIC SEA. THE DISCHARGE DATA FROM VUOKSI ARE AVAILABLE SINCE 1847.

F. LONG-TERM VARIATIONS OF WATER TEMPERATURE ARE, DUE TO LARGE SEASONAL VARIATIONS, VERY DIFFICULT AND INACCURATE TO DETERMINE AND OUR DATA DO NOT SHOW ANY APPARENT LONG-PERIOD TRENDS IN DEEP WATER TEMPERATURES. HOWEVER, IT IS INTERESTING TO COMPARE THE LONG-TERM WATER SURFACE TEMPERATURE VARIATIONS TO THE AIR TEMPERATURE, WHICH HAS BEEN QUALITATIVELY SIMILAR TO (INCREASING) AND CHARACTERISTIC OF THE WHOLE NORTHERN EUROPE DURING THE LAST CENTURY. THE WATER TEMPERATURE CHANGES MAY BE SEEN TO BE RATHER SIMILAR TO THOSE OF AIR AND REVEAL THE AIR-SEA COUPLING (FIG. 15).

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HYVÄRINEN, V. 1977: STATISTICAL ANALYSIS OF DISCHARGE DATA. - VESIHALLITUS - NATIONAL BOARD OF WATERS, FINLAND. PUBL. WATER RES. INST. 22:1-247.

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MIKULSKI, Z. 1980: RIVER INFLOW TO THE BALTIC SEA. - UNIVERSITY OF WARSAW, FACULTY OF GEOGRAPHY AND REGIONAL STUDIES AND POLISH NATIONAL COMMITTEE OF THE IHP UNESCO. SUMMARY LIST OF TABLES, 17 PP. (MIMEOGR.)

WORLD WEATHER RECORDS. - U.S. DEPARTMENT OF COMMERCE, NOAA, NATIONAL CLIMATIC CENTER ASHEVILLE, N.C.

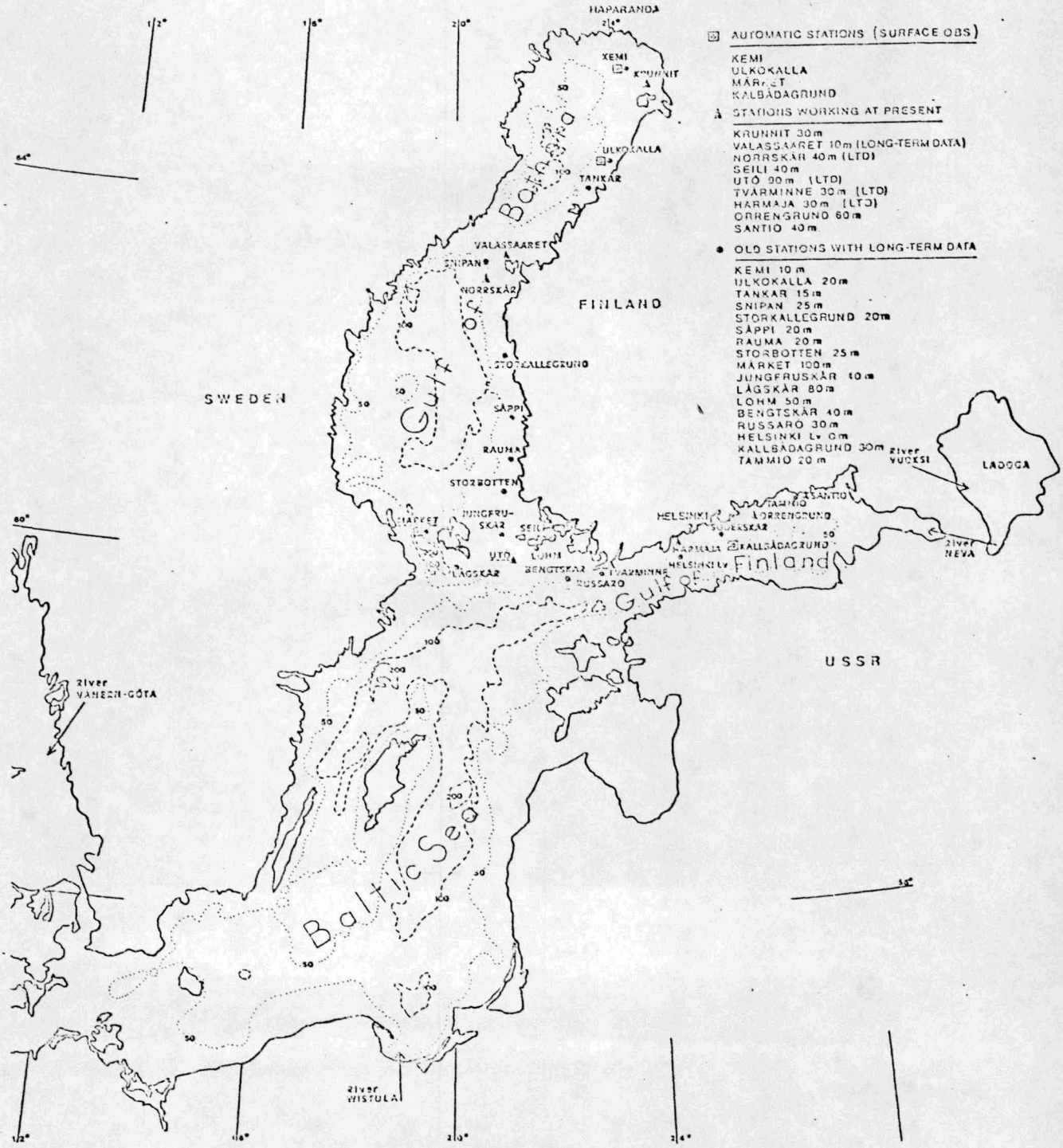


FIG. 1. LOCATION OF THE FINNISH FIXED HYDROGRAPHIC OBSERVATION STATIONS IN THE BALTIC SEA.

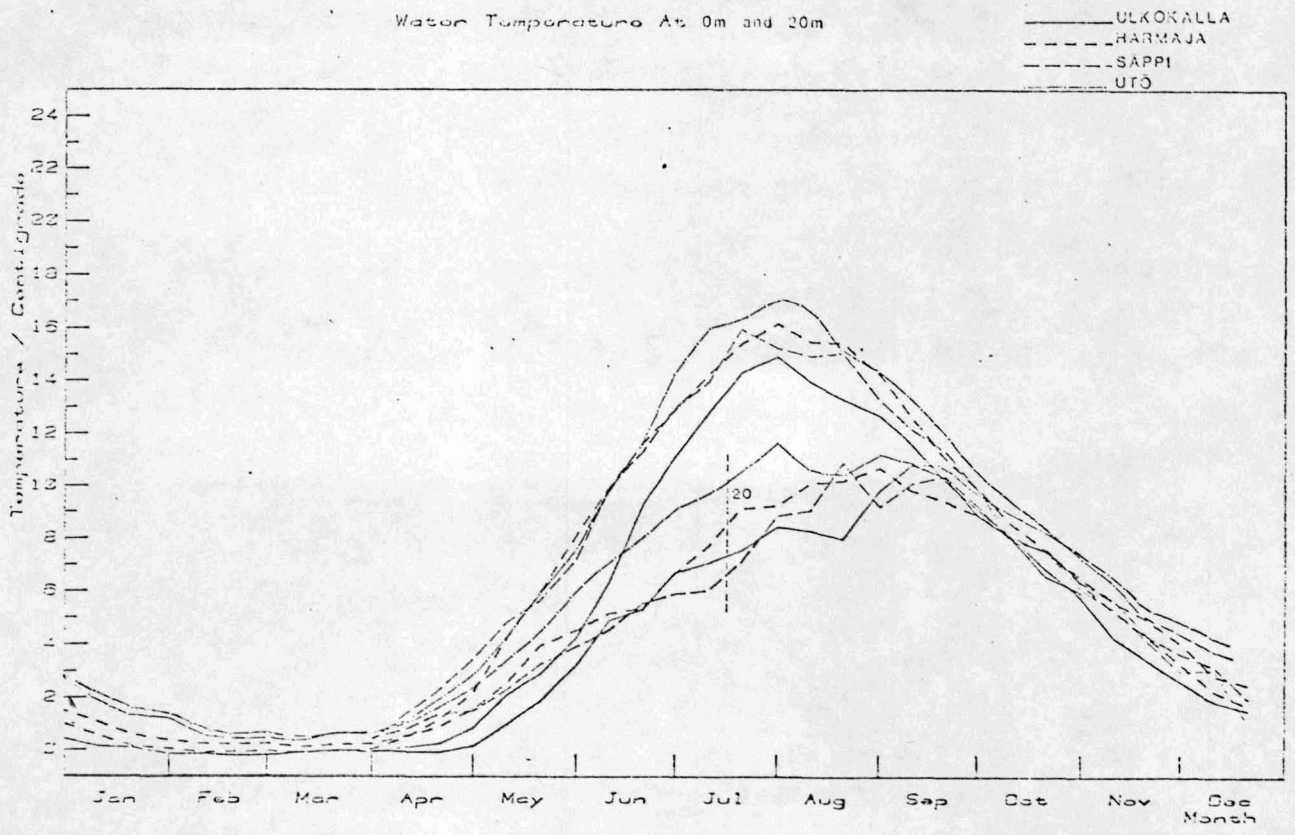


FIG. 2. MEAN SEASONAL VARIATION OF SURFACE LAYER TEMPERATURE IN WATERS AROUND FINLAND.

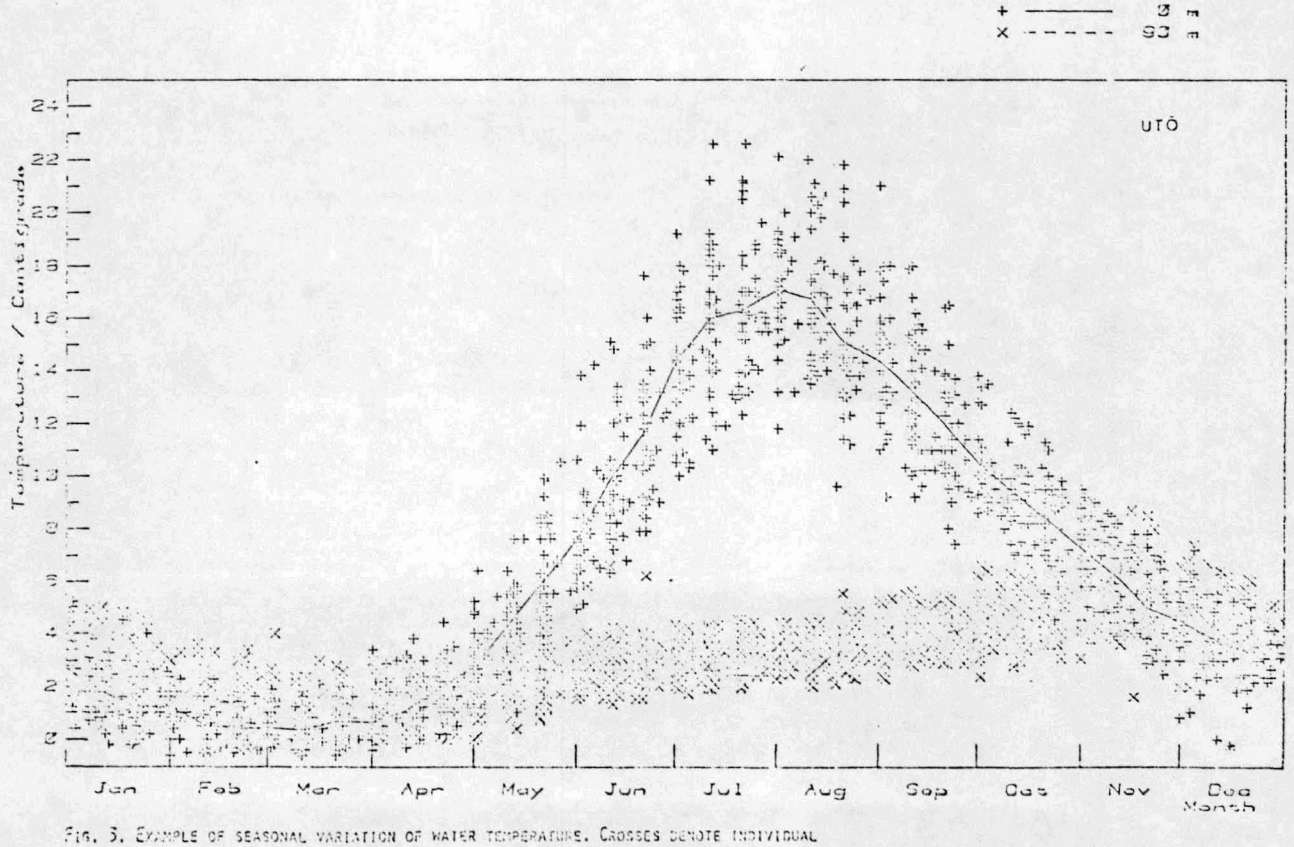
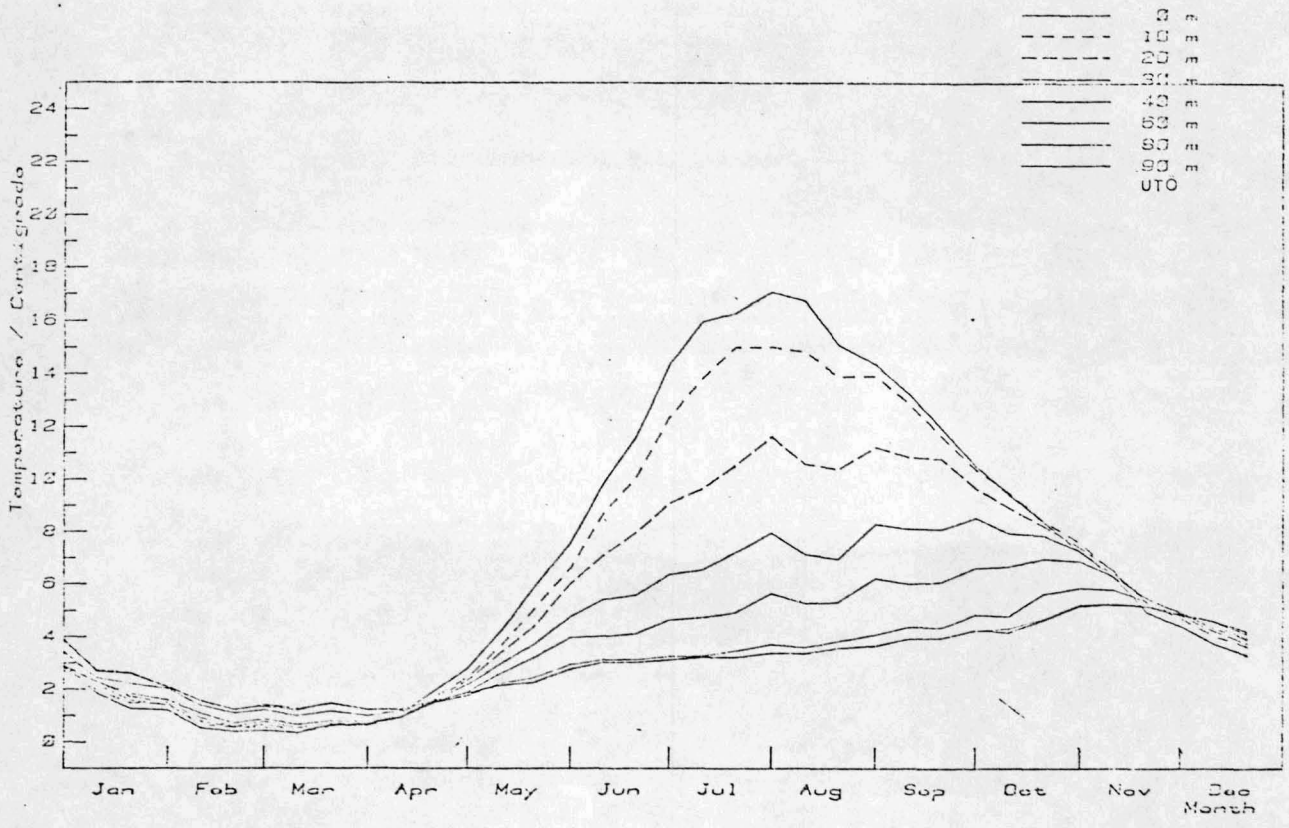


FIG. 3. EXAMPLE OF SEASONAL VARIATION OF WATER TEMPERATURE. CROSSES DENOTE INDIVIDUAL OBSERVATIONS GIVING THE CHARACTERISTIC MAGNITUDE OF VARIATIONS OF DIFFERENT YEARS.



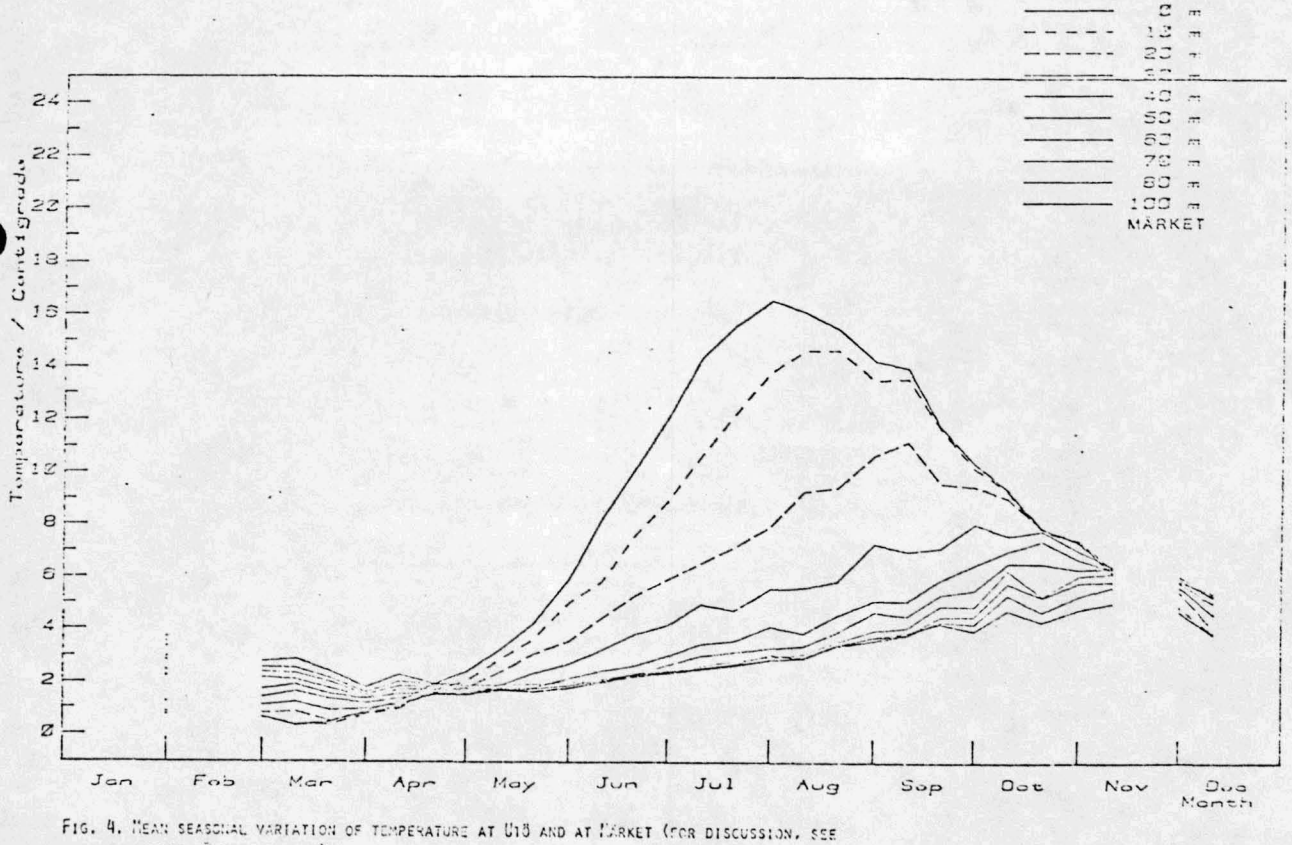


FIG. 4. MEAN SEASONAL VARIATION OF TEMPERATURE AT U10 AND AT MARKET (FOR DISCUSSION, SEE PARAGR. 5 IN THE TEXT).

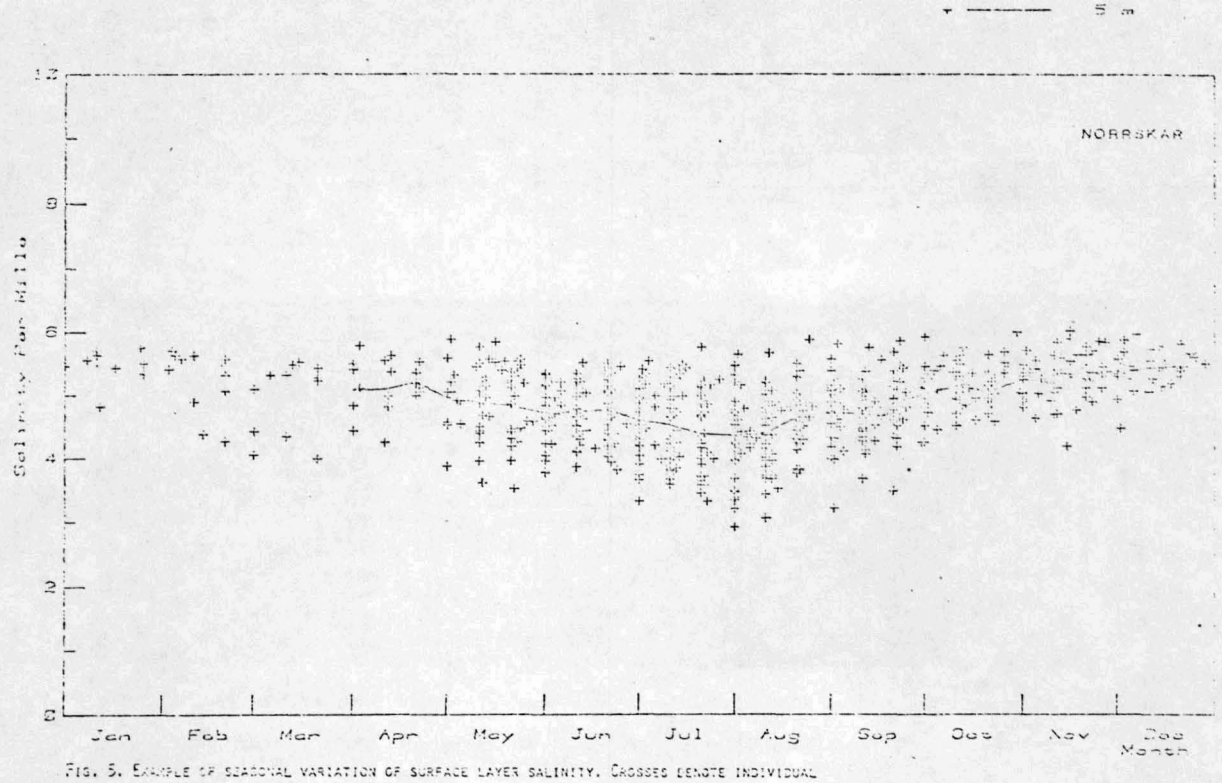


FIG. 5. EXAMPLE OF SEASONAL VARIATION OF SURFACE LAYER SALINITY. CROSSES DENOTE INDIVIDUAL OBSERVATIONS.

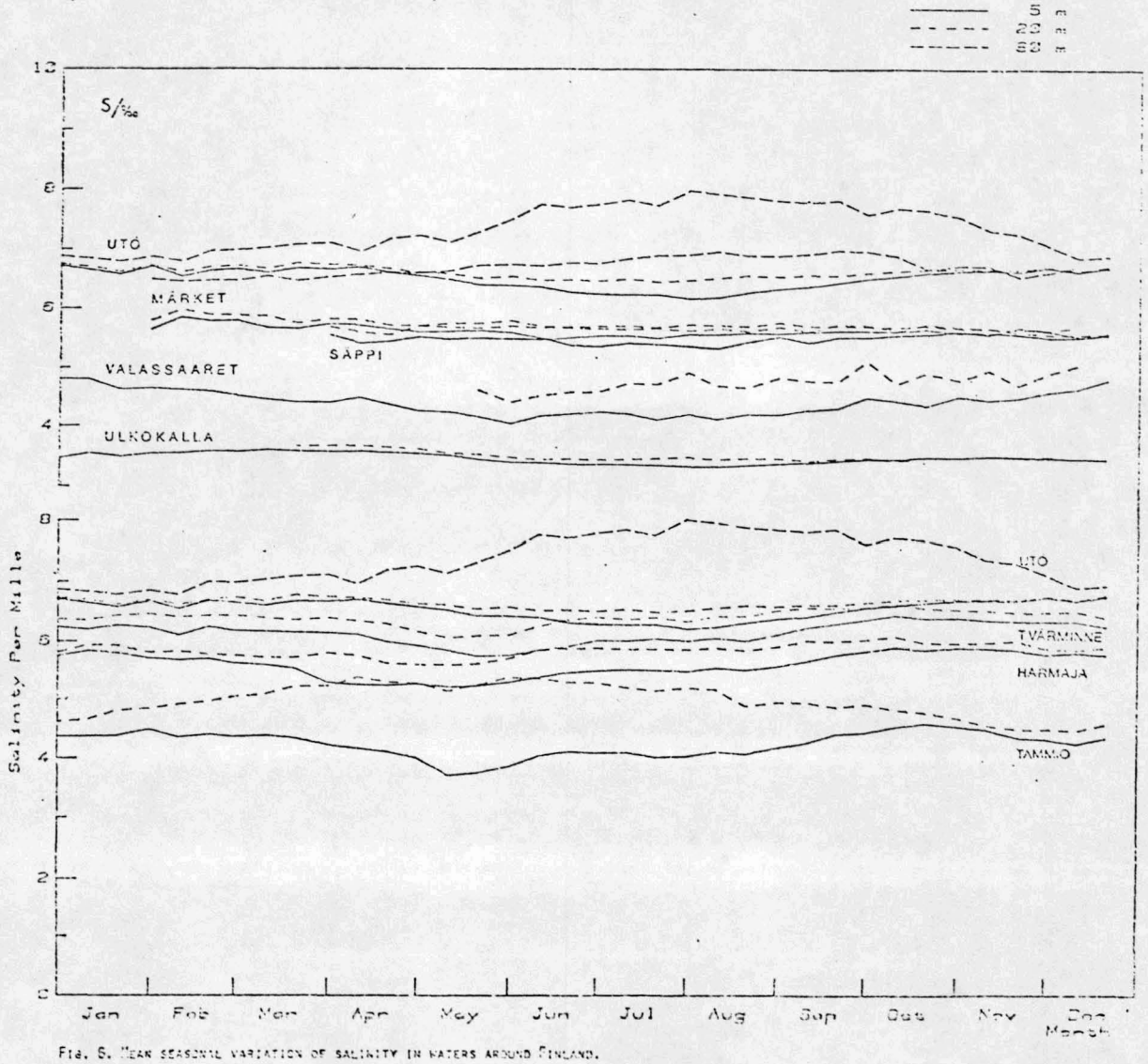


FIG. 6. MEAN SEASONAL VARIATION OF SALINITY IN WATERS AROUND FINLAND.

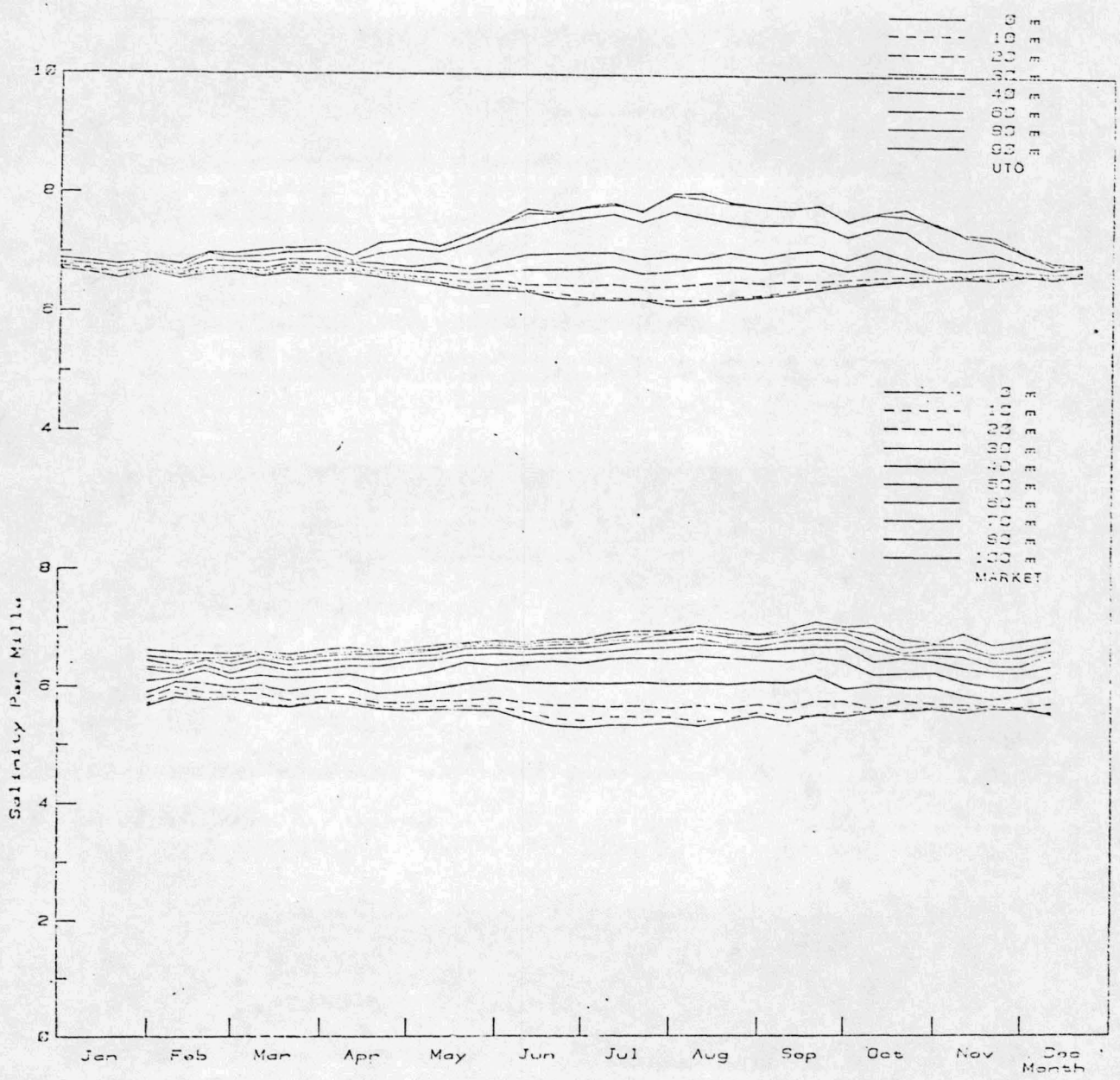
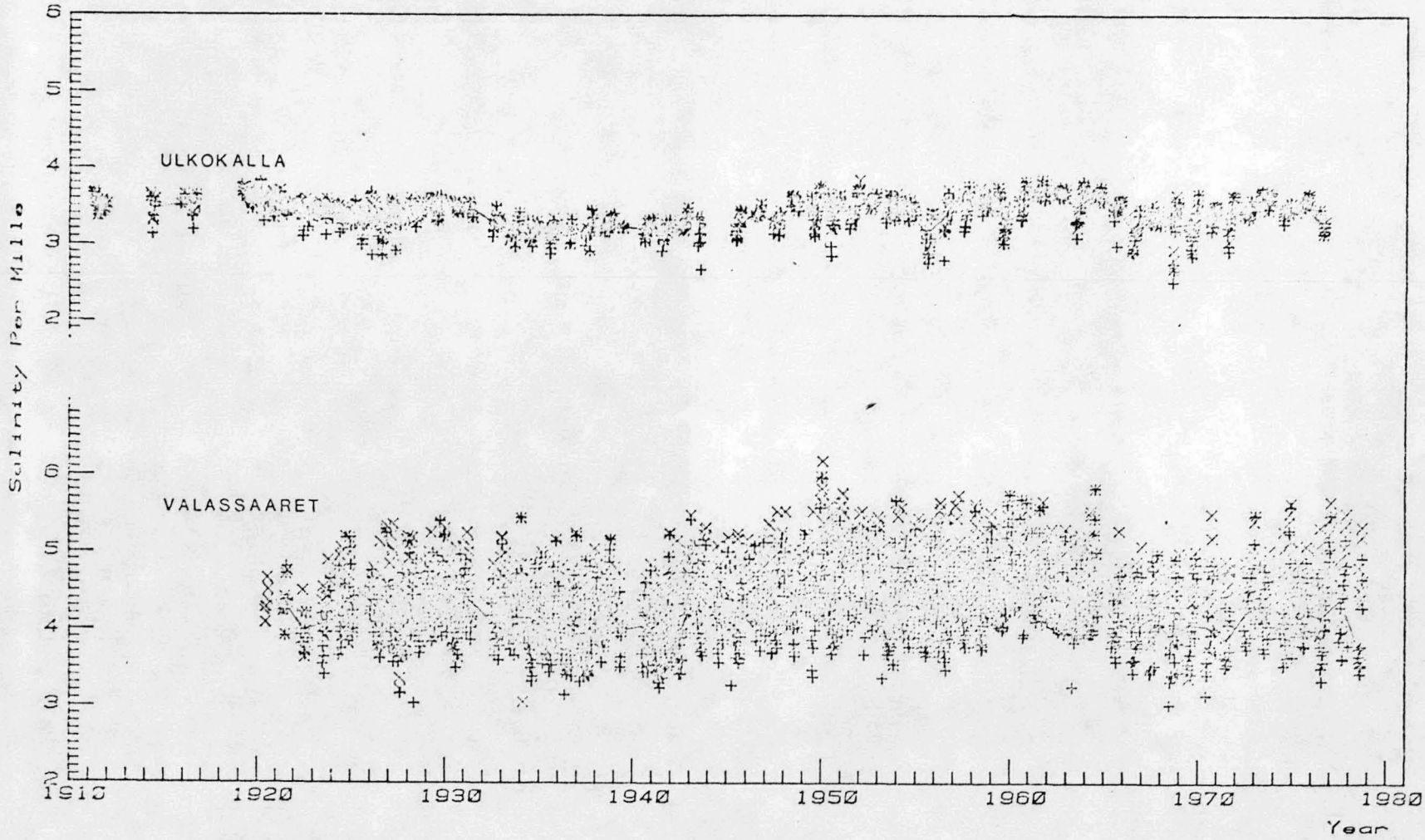


FIG. 7. MEAN SEASONAL VARIATION OF SALINITY AT UTÖ AND MÄRKET. (FOR DISCUSSION, SEE PARAGR. 5 IN THE TEXT.)

FIG. 8. EXAMPLES OF TIME SERIES OF SURFACE LAYER SALINITY. CROSSES DENOTE INDIVIDUAL OBSERVATIONS. THE LARGE DIFFERENCE IN VARIATIONS OF THE STATIONS REVEAL DIFFERENCES IN HYDROGRAPHIC MIXING CONDITIONS.



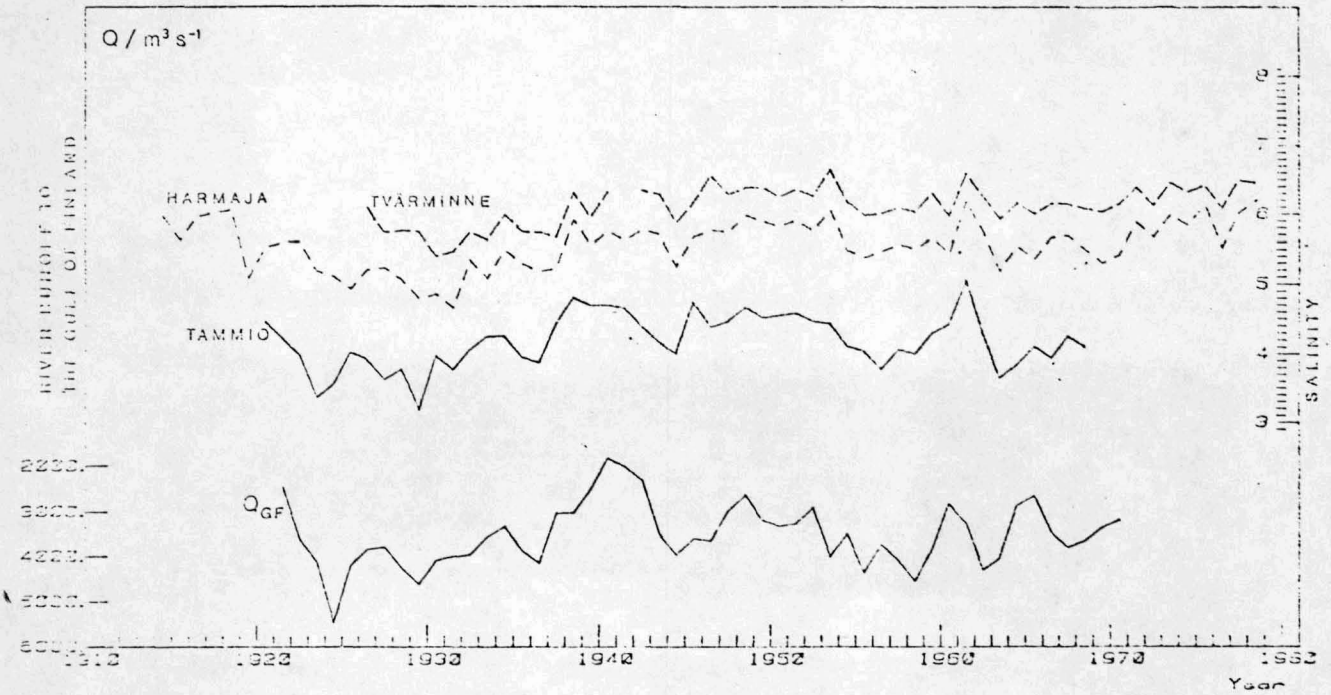


FIG. 24. TIME SERIES OF THE SURFACE LAYER (5 M) SALINITY AND THE RIVER RUNOFF TO THE GULF OF FINLAND. ANNUAL MEANS. (RUNOFF DATA FROM MIKULSKI 1986).

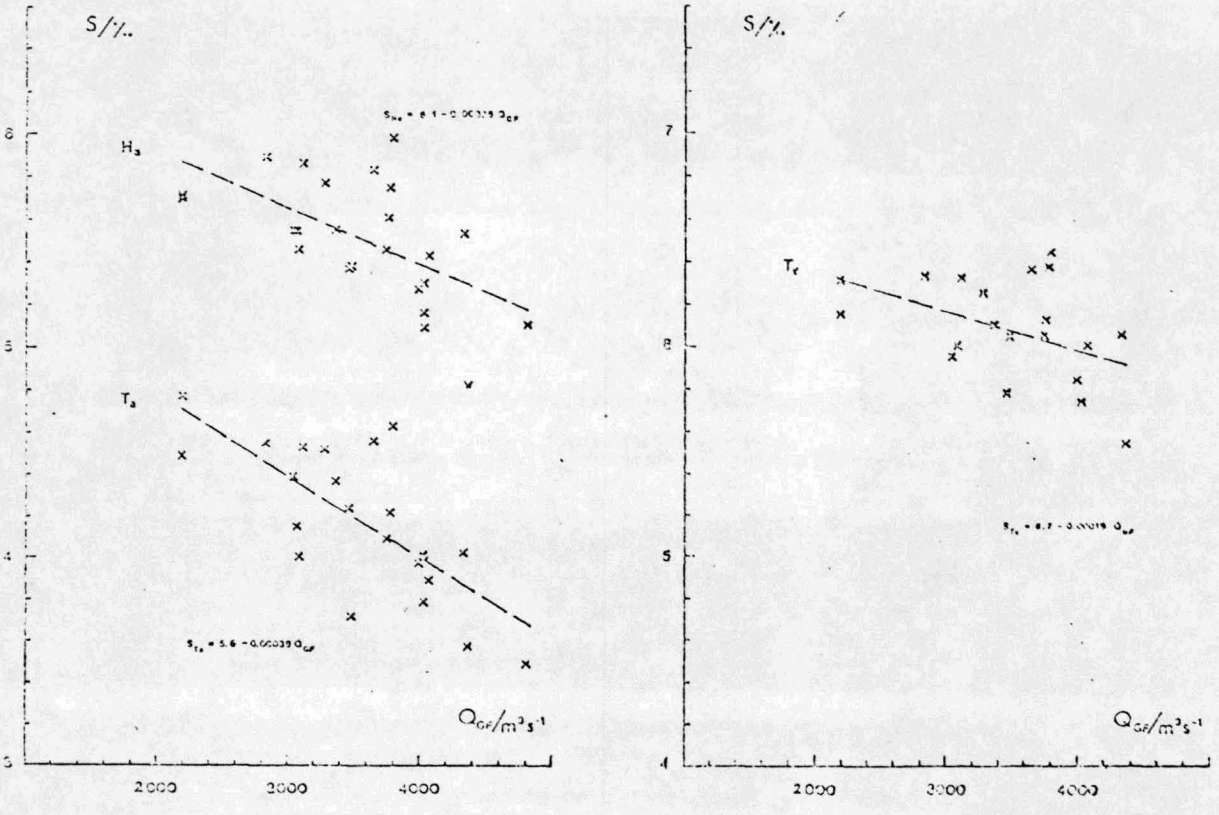
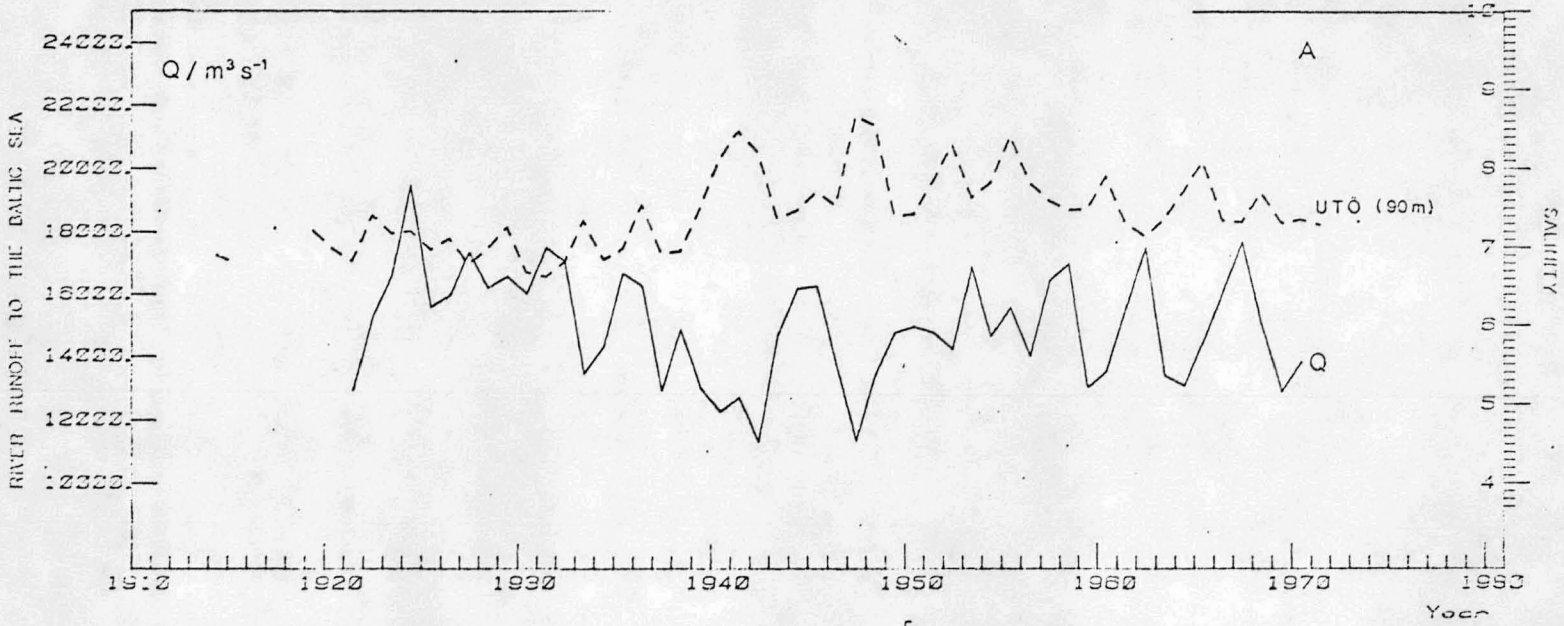


FIG. 93. SURFACE LAYER (5 M) SALINITY VERSUS RIVER RUNOFF TO THE GULF OF FINLAND. TWO YEARS' MEANS. H_a = HARMAJA, T_A = TAMMIO, T_V = TVÄRMINNE. (RUNOFF DATA FROM MIKULSKI 1986). SEE PARAGR. C.

FIG. 10A. TIME SERIES OF THE ANNUAL MEAN RIVER RUNOFF TO THE BALTIC SEA AND THE ANNUAL MEAN SALINITY OBSERVED NEAR THE BOTTOM AT UTÖ. (RIVER RUNOFF DATA FROM MIKULSKI 1980). FOR DISCUSSION, SEE PARAGR. D IN THE TEXT.



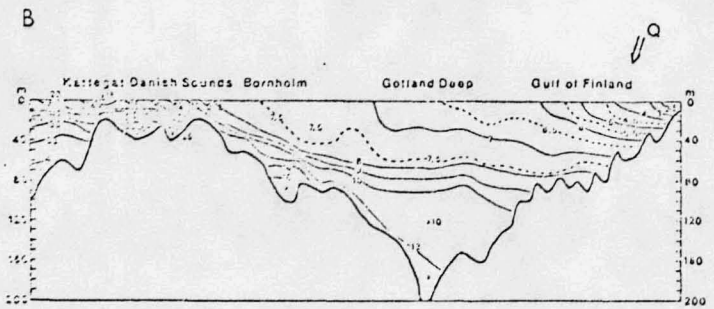


FIG. 10B. LENGTH PROFILE OF SALINITY SHOWING THE INCLINATION OF ISOHALINES AND INDICATING THE DYNAMICAL CHARACTER OF THE WATER BALANCE OF THE BALTIC SEA (REDRAWN FROM ICES/SCOR 1973).

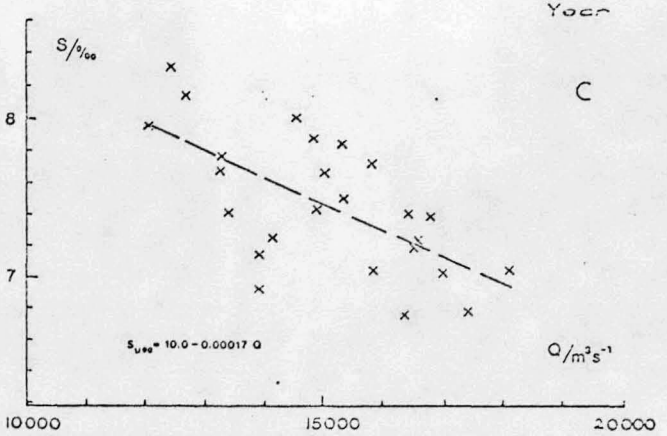


FIG. 10C. BOTTOM SALINITY AT UTÖ (90 M) VERSUS RIVER RUNOFF TO THE BALTIC SEA. TWO YEARS' MEANS. (SEE PARAGR. D).

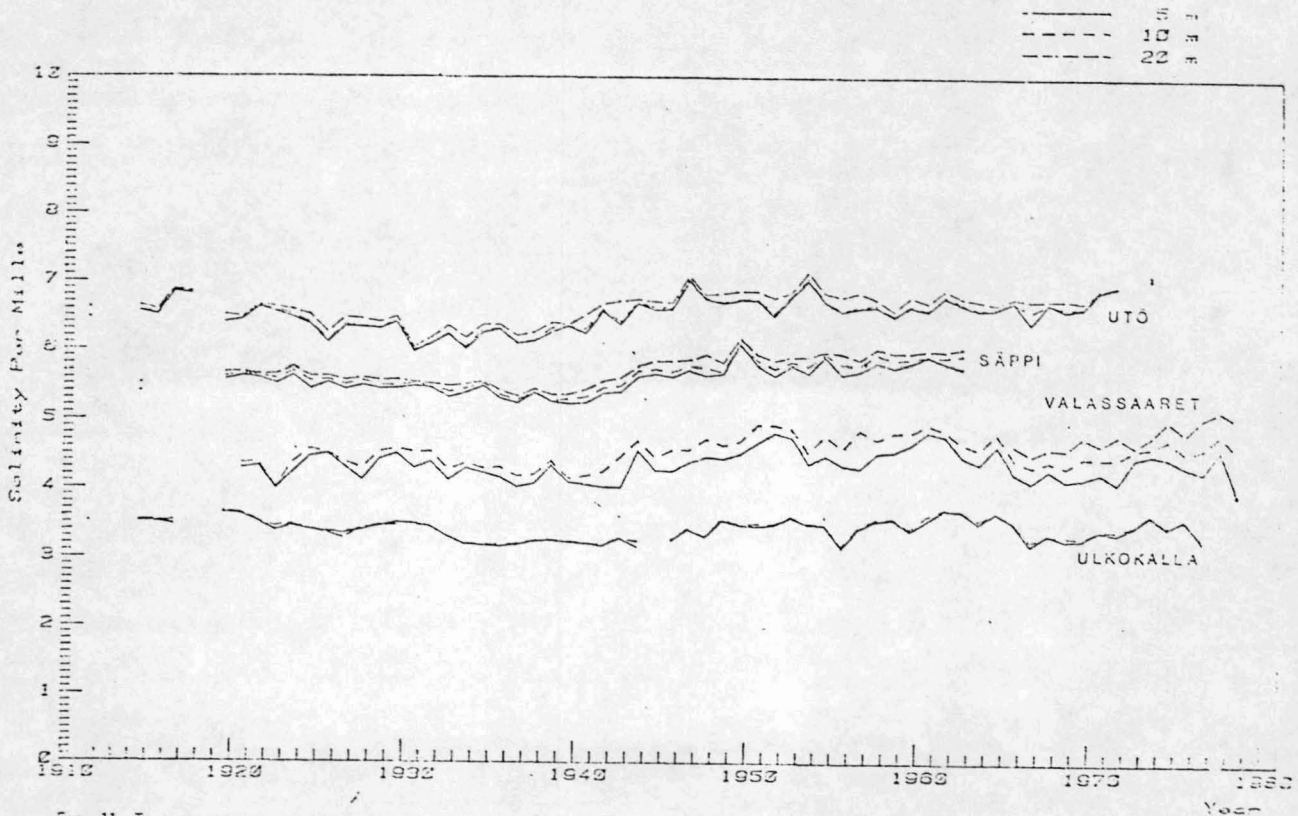


FIG. 11. TIME SERIES OF SURFACE LAYER SALINITY IN THE GULF OF BOTHNIA. ANNUAL MEANS. (SEE PARAGR. E.)

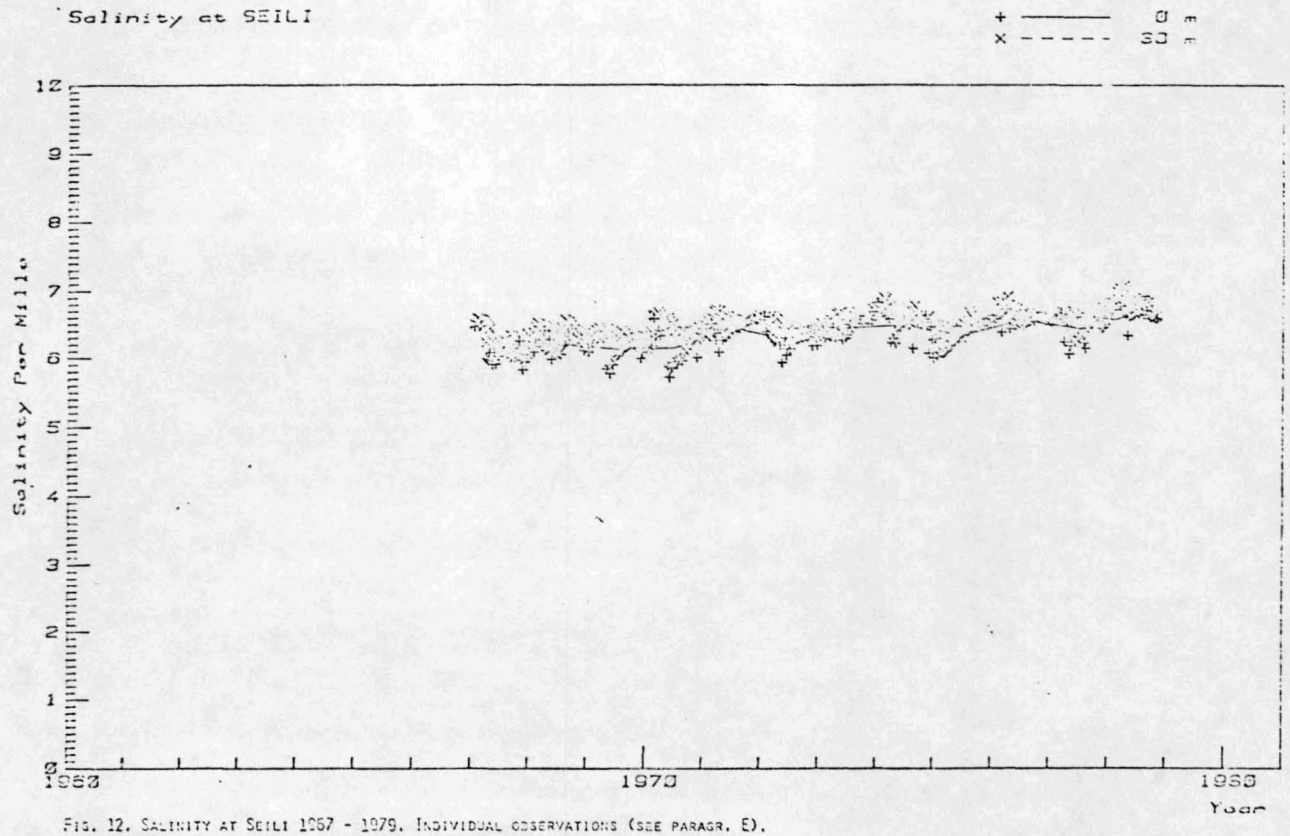


FIG. 12. SALINITY AT SEILI 1967 - 1979. INDIVIDUAL OBSERVATIONS (SEE PARAGR. E).

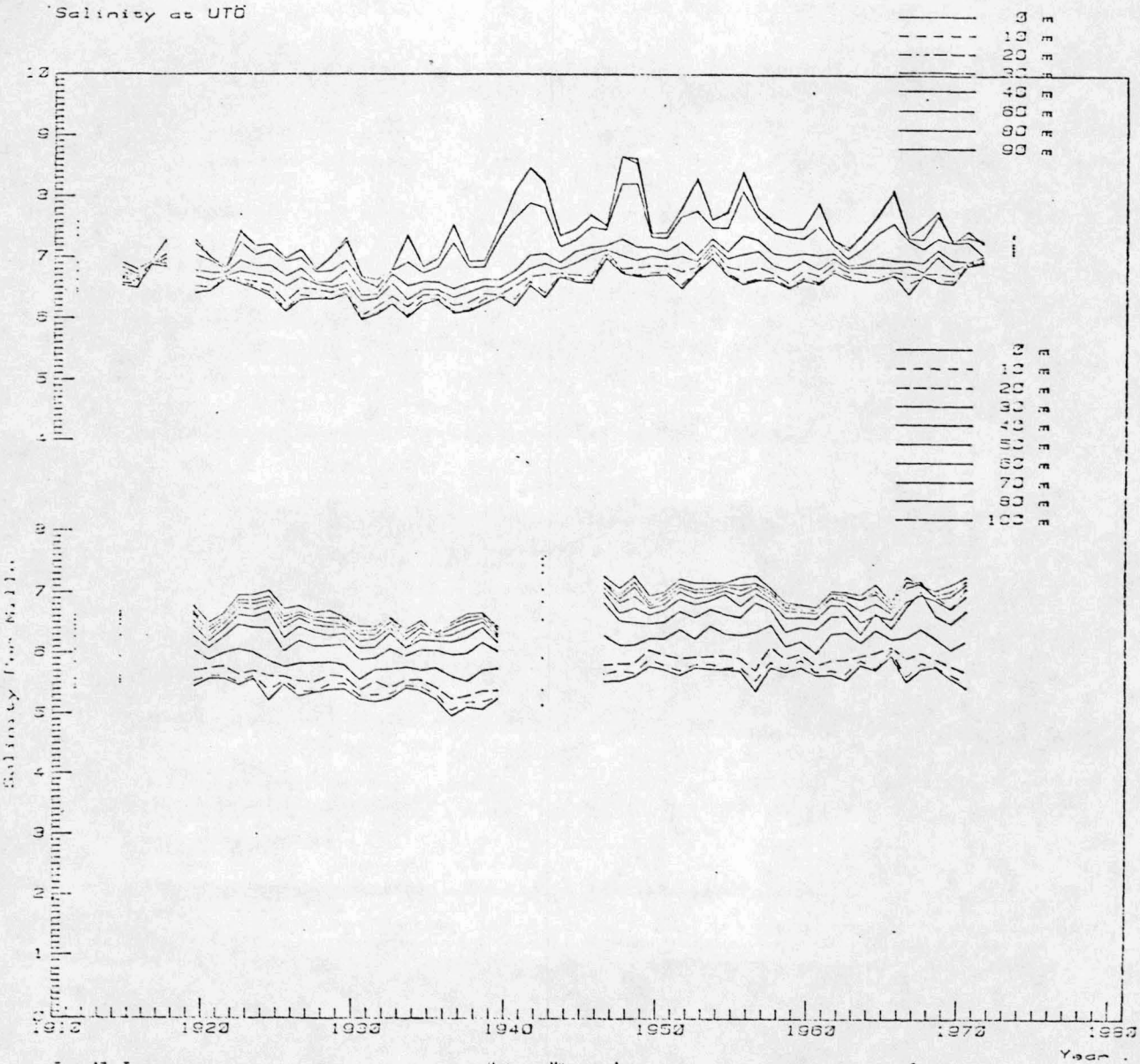


FIG. 13. TIME SERIES OF SALINITY OF THE WATER COLUMN AT UTÖ AND MARKET. ANNUAL MEANS.
(FOR DISCUSSION SEE PARAGR. 8 IN THE TEXT).

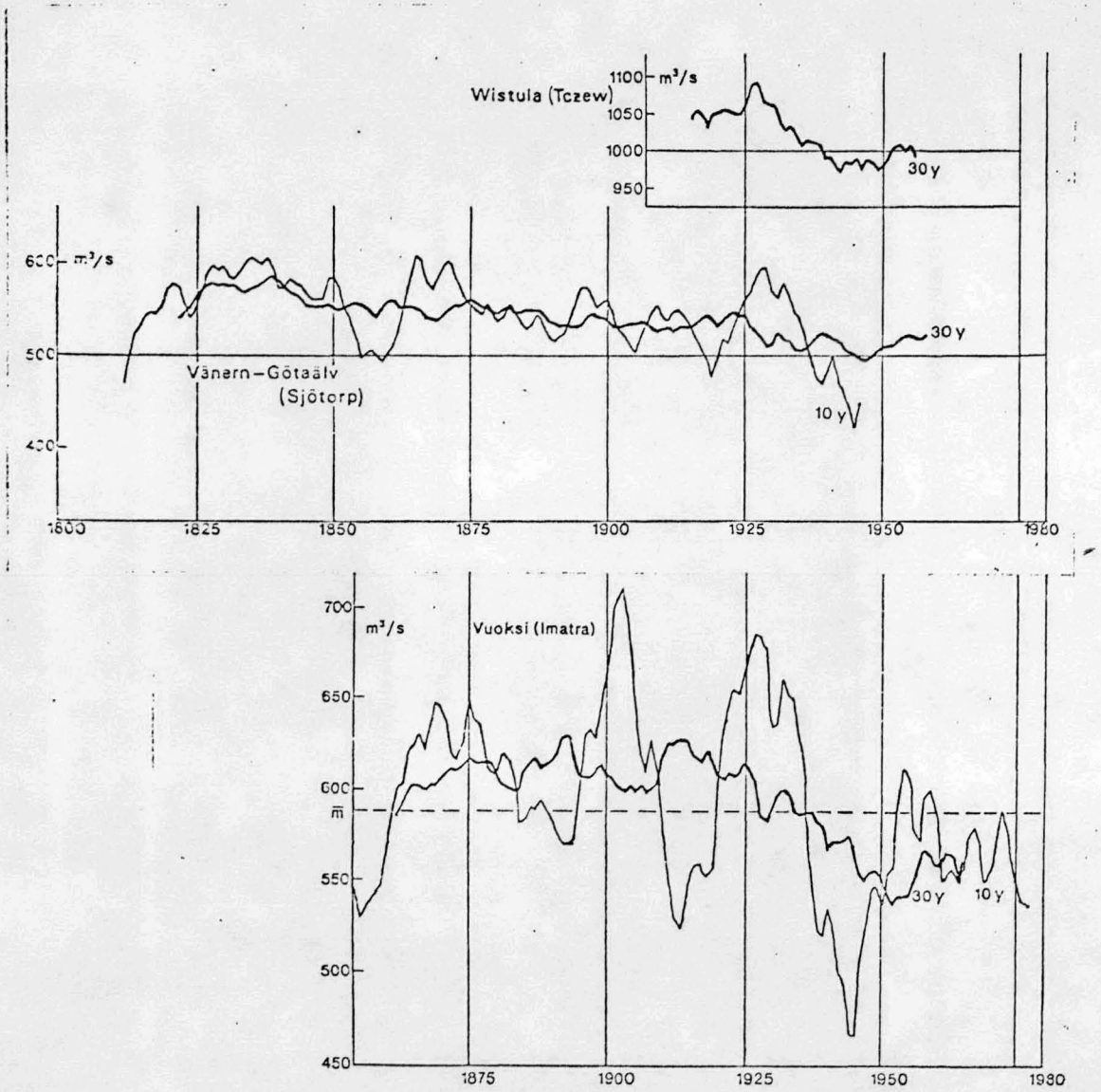
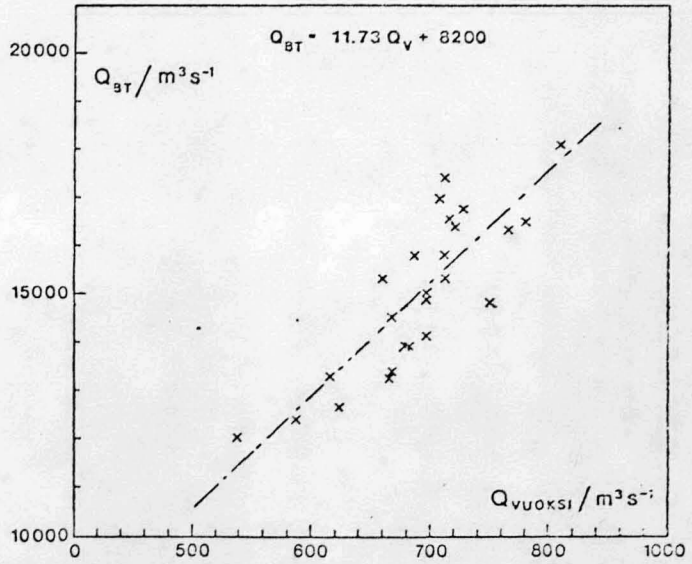


FIG. 14A. LONG - TERM VARIATION OF DISCHARGE OF THREE BIG RIVERS DISCHARGING TO THE BALTIC SEA: VUOKSI, VÄNERN - GÖTA, WISTULA. TEN YEARS' (10Y) AND THIRTY YEARS' (30Y) RUNNING AVERAGES (REDRAWN FROM HYVÄRINEN 1977 AND 1981). (FOR DISCUSSION, SEE PARAGR. E).



14B. VUOKSI RIVER DISCHARGE VERSUS THE TOTAL RIVER RUNOFF TO THE BALTIC SEA. TWO YEARS' MEANS. (THE TOTAL BALTIC SEA RIVER RUNOFF DATA FROM MIKULSKI 1980).

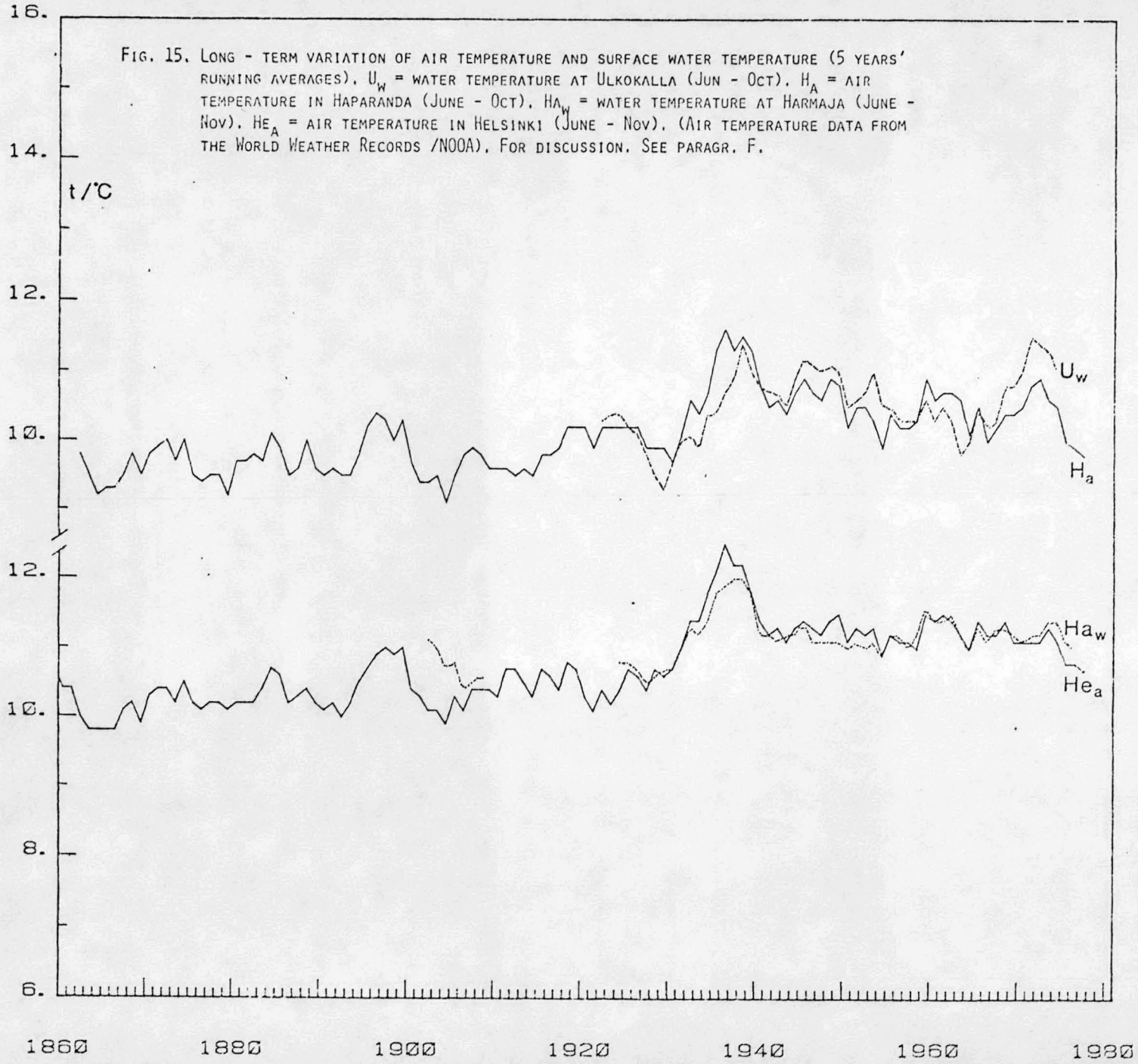


FIG. 15. LONG - TERM VARIATION OF AIR TEMPERATURE AND SURFACE WATER TEMPERATURE (5 YEARS' RUNNING AVERAGES). U_W = WATER TEMPERATURE AT ULKOKALLA (JUN - OCT). H_A = AIR TEMPERATURE IN HAPARANDA (JUNE - OCT). HA_W = WATER TEMPERATURE AT HARMAJA (JUNE - NOV). HE_A = AIR TEMPERATURE IN HELSINKI (JUNE - NOV). (AIR TEMPERATURE DATA FROM THE WORLD WEATHER RECORDS /NOOA). FOR DISCUSSION, SEE PARAGR. F.