THE PATTERN OF AIR-SEA INTERACTION OVER THE MEDITERRANEAN SEA AND ITS EFFECT ON THE STABLE ISOTOPE COMPOSITION OF ATMOSPHERIC MOISTURE AND WATER MASSES OF THE EASTERN MEDITERRANEAN SEA

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Abstract

The isotope composition of winter precipitation in the eastern Mediterranean Sea area suggests that the source of moisture is derived from evaporation under conditions of a large humidity gradient, such as occurs when cold (dry) continental air meets relatively warm sea waters. Direct measurement of the isotopic composition of atmospheric moisture, collected over the sea during January 1996 by the research vessel *Meteor*, confirmed this hypothesis. "d-excess" values of up to 33‰ were encountered close to the shores of the European continent south of the Adriatic Sea and Turkey, compared to values of d ~10‰ over the continent itself. The continuing trajectory of the continental air masses over the sea resulted in a moderation of this high d-excess, reaching values of close to d = 20‰ which are typical for the precipitation on the eastern shores of the Mediterranean and further downwind into the Middle East.

Key words: air-sea interactions, Eastern Mediterranean

It has been recognized that the isotope composition of atmospheric waters and, in particular, the d-excess value [defined as d ≡ δ(d) -8xδ(O-18) (1), where δ is the measure of the isotope composition expressed as the relative deviation from the standard SMOW (2) with δ(D) and δ(O-18) referring to the hydrogen and oxygen heavy isotopes, respectively] is established through the air-sea interaction at the source region of the atmospheric moisture (3). The Atlantic air masses, which give rise to precipitation throughout Europe and western North-Africa are characterized by d = 10‰ (4), close to the worldwide average (5). Winter precipitation in the Mediterranean region, on the other hand, shows a higher "d" value (6, 7). This excess has been explained by the special situation of cold and dry continental air masses which come into contact with a relatively warm sea, resulting in evaporation over a large humidity gradient accompanied by extreme isotope fractionation. From the geographic distribution of this parameter (Fig. 1), which is based on GNIP (Global Network of Isotopes in Precipitation), one infers this interaction to be most effective in the coastal regions on the leeward side of the European continent, especially in the Aegean Sea and along the Turkish coast (8). A year long survey of the isotopic composition of air moisture at Rehovot (Israel's coastal plain) showed this high deuterium excess to be a winter feature, especially marked in precipitating air masses (9).

Fig. 1. The average d-excess values in winter precipitation in the Mediterranean Sea region, based on the IAEA (GNIP) data.

A recent set of water vapour samples obtained at mast height above the sea during the cruise of the research vessel *Meteor* in January 1996, confirmed this inferred pattern. As shown in Fig. 2, d-excess values of more than 30‰ were found in the Adriatic Sea and south of Turkey. Over the open sea, further from the coastline and where humidities increase, these high values are lowered indicating the moderating effect of continuing air-sea interaction. This pattern indeed parallels the buildup and dissipation of tritium values in the atmospheric moisture, reported in 1970 by Gat and Carmi (8). The d-excess over the eastern Mediterranean then attain lower values characteristic of Middle Eastern precipitation, namely close to d = 20‰.

A simple model of the vapour buildup over the sea as dry air from the continent picks up moisture is shown in Fig. 3. The advecting

Fig. 2. The d-excess value in atmospheric moisture over the Mediterranean Sea, January 1969, from the *Meteor*-cruise vapour collection. Numbers shown are the values of the d-excess at the site of the vapour collection during the cruise.

continental air is characterized during winter by a low relative humidity (normalized relative to the saturated water pressure over the sea at SST), whose isotopic composition is depleted in the heavy isotopes O-18 and deuterium. Typical δ values of this moisture are $\delta(^{18}O)$ = -5‰ to -30‰ and d~10‰. As the air picks up evaporated vapour from the sea to form a blanket of modified (marine) vapour, the isotopic composition is also modified because of the extreme isotope separation which accompanies the evaporation process (which takes place over a large humidity gradient). The expected changes in the isotope composition of the marine air, resulting from the admixture of the evaporation flux into the advected air under conditions of increasing humidity, were calculated based on the Craig-Gordon evaporation model (10). The results, shown in Fig. 4, illustrate how the d-excess increases in the initial phases of the air-sea interaction, reaching a maximum value of about d = 40‰ at humidities around 35%. As humidity builds up further, the calculation shows the relaxation of these high d-excess values. The measured values show a pattern which is basically in accord with this simple model (for the case of the near-coastal sites, Fig. 4). However, in order to achieve a quantitative agreement with all the data, some refinement of the model will be necessary.

The extreme and intense air-sea interaction in the Mediterranean during winter affects not only the atmospheric moisture but also controls the isotope enrichment of the surface waters on the leeward-side of the continent. Under usual marine conditions the heavy water

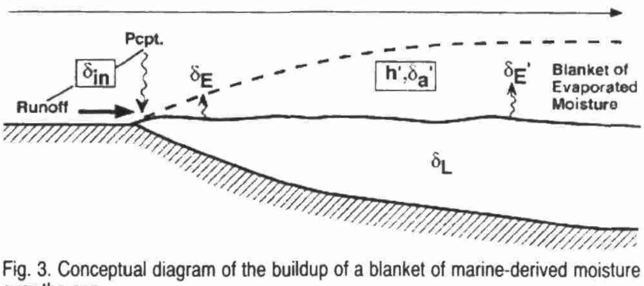

Fig. 3. Conceptual diagram of the buildup of a blanket of marine-derived moisture over the sea.