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SATELLITE INTERPRETATION NEAR JET STREAMS

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1.0 Introduction

Accurate interpretation of conventional visible and infrared satellite imagery has been the discussion of many papers. New interpretation methods have been built upon old methods which were usually accurate but needed further investigation, clarification, or detail. In the case of water vapor imagery, such is not the case. Interpretation has always been a problem and can be unique for each weather situation. A primary reason for the ambiguity in water vapor imagery interpretation is the character of the sensed radiance. The Geostationary Operational Environmental Satellite (GOES) measures water vapor at the 6.7 micrometer wavelength. However, the overall satellite sensed water vapor signature has contributions to the radiance which are functions of pressure. Hence, a vertical weighting function best describes the percent radiance coming from a particular pressure level. In the case of the 6.7 micrometer channel, the weighting function peaks near 400mb, decreases slowly upward through the tropopause and decreases rapidly downward through the troposphere. Consequently, about 80% of the total GOES water vapor channel signal comes from the 400mb-250mb layer. Levels below 600mb and above 150mb contribute little to the total radiance. A consequence of this is the fact that huge changes in lower tropospheric moisture produce little change in the GOES water vapor channel signature. In addition, complications come from: (1) water vapor being highly variable in the vertical, and (2) vertical lapse rates of temperature and horizonal changes in temperature and moisture along constant pressure surfaces being highly variable. Mixture of these atmospheric characteristics with the pressure dependent weighting function combine to produce non-unique signatures in water vapor imagery. In other words, two completely different vertical moisture structures can produce an identical total water vapor channel signature! This makes interpretation of water vapor imagery difficult. Papers by Ramond, et al. (1981), Weldon and Steinmetz (1984), and Ellrod (1990) address these ambiguities and attempt to clarify the interpretation of various meteorological signals using water vapor imagery.

2.0 Upper Level Jet Streams

Interpretation of upper level jet streams from satellite imagery has been ongoing for many years. With visible and infrared satellite imagery, a fairly clear model of jet stream signature has emerged. In the Northern Hemisphere on the southern edge of the jet stream and farther equatorward, there is cloud, while at the jet core and north of the jet stream, little or no cloud is present. This is particularly well defined on long subtropical jet streams which extend from the tropical and subtropical Pacific northeastward over the southern United States. This signature also appears near polar jet streams. This cloud pattern appears to be contradictory to the dynamical description of vertical motion associated with jet streams and particularly streaks, namely rising (sinking) motion on the south (north) side of the jet stream core in jet entrance regions and rising (sinking) motion on the north (south) side of the jet stream core in jet exit region. If in fact vertical velocity alone was responsible for the cloud/moisture distribution along jet streams, we would see very different cloud signatures on satellite imagery. Cloud would likely cross from the equatorward rear to poleward leading edge of jet streak cores. We do not typically see this pattern. Why not? Because vertical motion alone does not control cloud near jet streams and jet streaks.

3.0 Jet Stream Cloud Signatures

Meteorologists normally interpret visible, infrared and water vapor signatures associated with jet streams as being caused by vertical motion. South of a jet core air is rising and cloud forms, while north of a jet core air is sinking and no cloud forms (cloud dissipates). This contradicts the dynamically expected cloud and vertical motion fields in jet streaks as mentioned above. Durran and Weber (1988) produced an excellent paper which attempted to explain this conflict. By using a combination of satellite imagery, observations, and a simple model, they were able to reproduce cloud distributions for numerous jet stream events, which all had cloud south of the jet core, but were cloud-free north of the jet core. A brief summary of their results follows.

Vertical motion along, north and south of the jet stream was ***not*** consistent with rising motion on the south side and sinking on the north side of the jet stream in the Durran and Weber cases. Instead, vertical motion was upward, over, and on both sides of the jet stream in many cases. A primary mechanism for producing the well defined cloud/no cloud line along the jet core was horizontal confluence of tropical and polar air masses with significantly different moisture contents. The polar air mass was much drier, while the tropical air mass was much moister. Consequently, equal ascent of both air masses resulted in saturation and condensation of the tropical air mass, while the polar air mass remained unsaturated. As a result, cloud formed in the moist tropical air, but not in the dry polar air. Confluence of the two air masses can result in a long very narrow zone of air mass contrast "upper front" which produces a well defined line between cloudy and clear air observable on satellite imagery. An example of confluence and saturation levels of the air masses across a jet stream cloud edge is shown in Fig. 2, taken from Durran and Weber. For jet streams with well defined confluence of two air masses, cloud will form first (and possibly only) in the moist air mass for the same rate of ascent within each air mass. In the case of the subtropical jet stream, this is particularly prevalent. In the case of the polar jet stream upward motion may not be sufficient to bring relatively dry air masses on either side of the confluence zone between polar and mid-latitude or subtropical air to saturation, and a well defined cloud signature may not develop.

4.0 Jet Stream Water Vapor Signature

Jet stream signatures on water vapor imagery are typically not as recognizable as they are on visible and infrared imagery. However, unlike visible or infrared imagery, water vapor imagery gives significant information about moisture structure in clear as well as in cloudy areas. As a result, significant structure can be seen on water vapor imagery over and north of a jet stream core in air which is typically cloud-free. Water vapor signature is typically characterized by a high moisture content near 400mb on south sides of jet streams. Hence, water vapor imagery is typically light gray or white on the south side of jet streams. On north sides of jet streams, cloud may not be present; however, temperatures are typically colder in the polar air mass level for level, hence gray shades may appear light gray on the north side of the jet stream axis. At and slightly north of the jet stream core, there is often a dark (or dry) slot evident on water vapor imagery. Note that Weldon and Steinmetz (1984) have observed the dark slot to be poleward of the jet core for anticyclonically curved jets and equatorward of the jet core for cyclonically curved jets. Many meteorologists associate this with the sinking side of a jet stream in conjunction with absence of cloud as seen on visible and infrared imagery. These regions may not be associated with sinking motion at all. They have been correlated with areas of moderate to severe turbulence. These regions are often associated with tropopause folding and can be regions where significant tropospheric/stratospheric air mass exchange occurs. Hence, regardless of whether synoptic scale vertical motion is upward or downward near these "dry slots", dry air mixed into the troposphere from the stratosphere on turbulence scales can greatly affect moisture content at levels where the water vapor channel vertical weighting function is largest (250mb-400mb). The result is a narrow dry slot which elongates and stretches along the axis of tropopause folding and air mass mixing. Horizonal advection and stretching of this dry air can also result in enhanced elongations of dark (dry) gray lines on water vapor imagery (Fig. 3). These dry slots are best defined in polar jet streams where tropospheric/ stratospheric air mass exchange is particularly large and where the tropopause is low (near 350mb- 300mb in winter) and closer to the water vapor vertical weighting function maximum. In comparison, subtropical jet streams are normally high (near 150mb-200mb) and air mass exchange across the tropopause is, on average, weaker thus resulting in a weaker dry slot signature on water vapor imagery.

Where jet streams move over or into regions with homogeneous moisture content, often jet stream cores are lost on water vapor imagery. In these same cases there may be little or no cloud signature, hence visible and infrared imagery may not give good indications about jet stream location either. These situations are not typically associated with significant confluence of air masses in the upper troposphere or with tropopause folding.

5.0 Conclusions

Satellite signatures of jet streams have been briefly reviewed. Conflict between observed jet stream cloudiness and vertical motion have been discussed. Confluence of air masses of differing moisture contents, lifted vertically at the same rate, have been shown to result in sharp cloud/no cloud edges. Consequently, it is unwise for the forecaster to infer vertical motion along jet streams from spatial distributions of cloudiness on visible or infrared satellite imagery. An excellent example of this is frequently observed rapid thunderstorm development on the clear air poleward side of a jet stream within a water vapor dry slot. From lack of initial cloud cover and presence of a dry slot signature on water vapor imagery the unwary meteorologist would infer subsidence where ascent (of air which has not reached condensation) is actually taking place! In the case of water vapor imagery interpretation of jet stream features, an often used tracker of a jet stream is the dry slot which may follow the jet core. However, this dry slot may not be associated with strong subsidence, but rather mixing of dry stratospheric air into the troposphere in regions of strong turbulence and tropopause folding. This turbulence is typically strongest where horizontal and vertical gradients in jet stream wind speed are largest. Once formed, these dry zones may be advected and stretched downstream along the jet stream confluence zone for many hundreds of kilometers. Gray shades associated with water vapor radiances are often complicated combinations of vertical temperature and moisture distributions interacting with the water vapor vertical weighting function. Forecasters should be cautious when interpreting the sign of vertical motion near jet streams from satellite. A jet stream may be located and tracked clearly using satellite imagery in many cases; however, inferences about vertical motion from cloud and moisture fields on visible, infrared and water vapor imagery should be done with extreme caution.

References

Durran, D., and D. B. Weber, 1988: An investigation of the poleward edges of cirrus clouds associated with midlatitude jet streams. *Mon. Wea. Rev.*, 116, 702-714.

Ellrod, G. P., 1990: Applications of GOES water vapor imagery to severe storms analysis. 16th Conference on Severe Local Storms, AMS, 1990.

Ramond, D., H. Corbin, M. Desbois, G. Szejwach, P. Waldteufel, 1981: The dynamics of polar jet streams as depicted by the METEOSAT WV channel radiance field. *Mon. Wea. Rev.*, 109, 2164-2176.

Weldon, R., and S. Steinmetz, 1984: Characteristics of water vapor imagery . Satellite Appl. Lab., Washington, DC, 23pp.

Figures

Figure 1. Enhanced IR satellite photograph for 1200 UTC 7 March, 1979. (a) The corresponding 300mb isotachs (m/s) and (b.) 400mb vertical velocity (contour interval 1.6x10-3 mb s-1). Lower right: backwards trajectories along the jet core and cloud edge for the interval 1200 UTC 6 March to 1200 UTC 7 March. All trajectories terminate at 400mb. Pressure level and saturation pressure deficit are plotted in mb at the upstream end of each trajectory. The tens' digit of the pressure level is plotted along the trajectory to indicate vertical motion. The northernmost trajectory along which air parcels reach saturation is drawn with a heavy line. (From Durran and Weber, 1988).

Figure 2. Water vapor imagery showing jet stream oriented southwest-northeast over the Eastern North Pacific. The symbol "P" shows the location of the jet stream core with dry slot (dark gray shade). Top: well defined jet; bottom: weakening jet or ill-defined jet. (From Dvorak and Smigielski)

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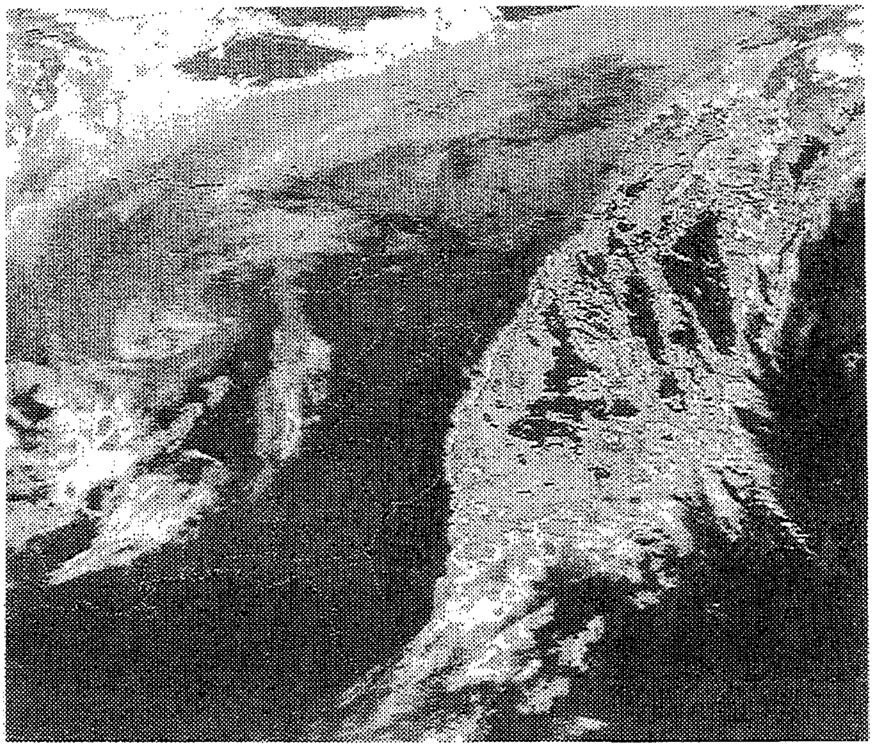
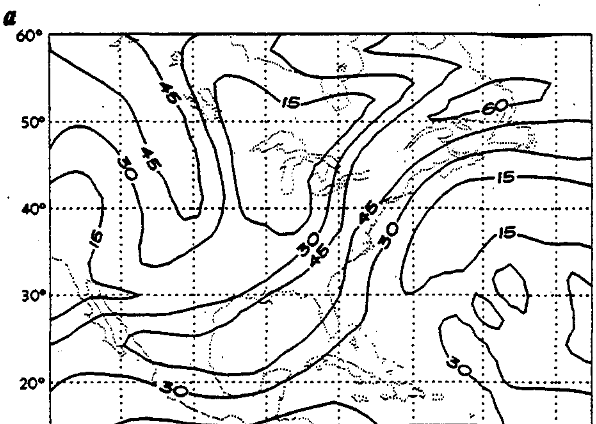
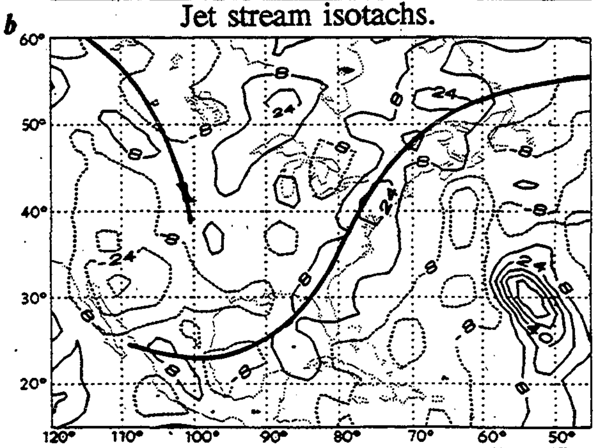
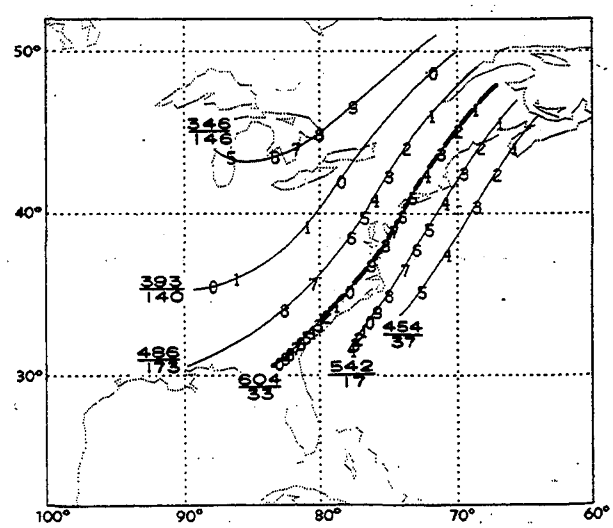


Enhanced infrared GOES satellite image for 1200 UTC 7 March 1979.



Jet stream isotachs.





Air parcel trajectories including the starting pressure level of the air and beneath the depth in millibars air must rise to become saturated.

Vertical velocity, positive values indicate upward.

Figure 1

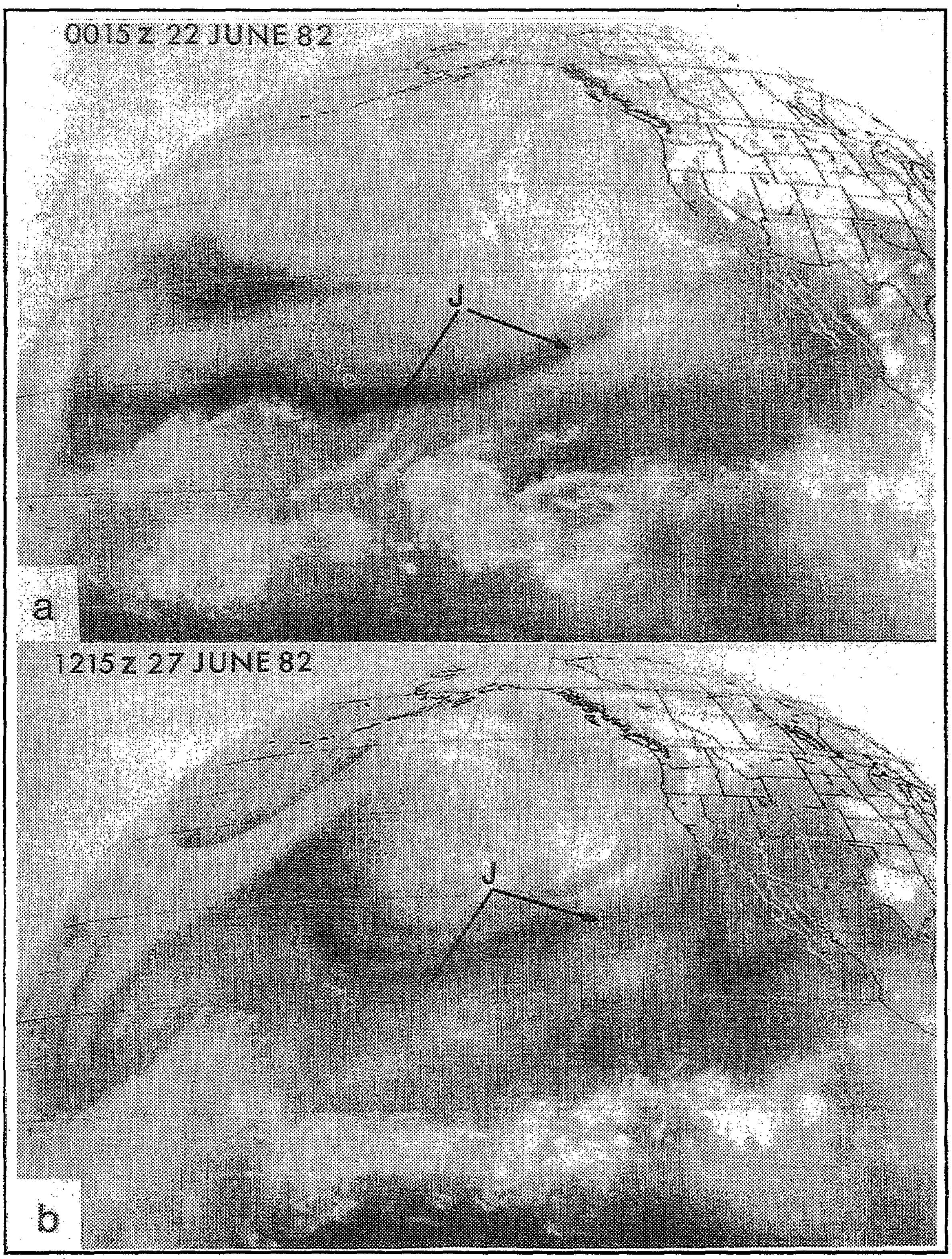


Figure 2. Water Vapor Images of the Eastern Pacific Ocean.