USE OF VAS DATA FOR SIMULATION OF FUTURE METEOSAT PRODUCTS

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Abstract

In the context of the future Meteosat imager definition, channels at 13.3 μm, 14.0 μm, 4.5 μm and 4.4 μm have been proposed for monitoring the atmospheric stability processes. To evaluate this option simulations of stability products have been performed using observations from the corresponding VAS channels. Image products were derived from different combinations of channels and statistical computations were performed. Results have shown that the proposed Meteosat channels are well suited for this type of application. Indication of the particular usefulness of the channels at 13.3 μm and 4.5 μm has been derived.

1. INTRODUCTION

Useful information to assist nowcasting and mesoscale developments can be provided by observations of horizontal variation of relative stability and water vapour. In order to expand the Meteosat imager capabilities and include the monitoring of the stability processes in the lower troposphere, it was suggested that additional channels at 13.3 μm, 14 μm, 4.4 μm and 4.5 μm be added to the basic VIRI channels (the proposed imager for Meteosat Second Generation), listed in Table 1. This option has been evaluated using the experience gained with the GOES VISSR Atmospheric Sounder (VAS), which accomplishes missions similar to those defined for EVIRI (enhanced VIRI) by measurements made in the same spectral bands. Some work was carried out at the Space Science and Engineering Center (SSEC) within the Cooperative Institute for Meteorological Satellite Studies (CIMSS) in Madison, Wisconsin, to simulate potential EVIRI products from VAS data and indicate some priority for the proposed channels.

EVIRI

Channel and Bandwidth		Sampling	NEDT or S/N
1	0.60-0.67 um	2 km	S/N 3:1 at 1 % albedo
2	0.77-0.89 um	2 km	S/N 3:1 at 1 % albedo
3	1.53-1.70 um	2 km	S/N 3:1 at 1 % albedo
4	3.5-3.9 um	2 km	0.25 K at 300 K
5	5.8-6.7 um	2 km	0.6 K at 250 K
6	6.9-7.3 um	2 km	0.6 K at 250 K
7	10.3-11.3 um	2 km	0.25 K at 300 K
8	11.5-12.5 um	2 km	0.25 K at 300 K
9	9.7 um +/- 12 cm-1	2 km	1.0 K at 220 K
10	13.4 um +/- 8 cm-1	2 km	1.0 K at 270 K
11	14.0 um +/- 8 cm-1	2 km	1.0 K at 250 K
12	0.4-0.9 um	0.5 km	
13	4.46 um +/- 12 cm-1	2 km	1.0 K at 250 K
14	4.57 um +/- 12 cm-1	2 km	1.0 K at 270 K

Table 1 **Proposed channels for the Enhanced Visible Infrared Imager (EVIRI)**
Channels 1 to 8 correspond to the proposed Visible and Infrared Imager (VIRI)

Spectral Band	Atmos. Press. (mb)	ν (cm^{-1})	λ (μm)	$\Delta\nu$ (cm^{-1})	Nominal Single-Sample S/N for 320 K Scene Temperature		Remarks	
					6.9-km IGFOV	13.8-km IGFOV	Band	Detector Type
1	70	678.7	14.73	10	NA	37.4	CO_2	HgCdTe
2	125	690.6	14.48	16	NA	92.3	CO_2	HgCdTe
3	200	701.6	14.25	16	50.4	100.8	CO_2	HgCdTe
4	500	713.6	14.01	20	65.3	130.6	CO_2	HgCdTe
5	920	750	13.33	20	64.1	128.3	CO_2	HgCdTe
6	850	2210	4.525	45	NA	108.9	N_2O	InSb
7	Surf.	790	12.66	20	60.7	121.4	H_2O	HgCdTe
8	Surf.	895	11.17	140	607.1*	953.5	Window	HgCdTe
9	600	1377.2	7.261	40	24.2	48.5	H_2O	HgCdTe
10	400	1487	6.725	150	73.7	147.4	H_2O	HgCdTe
11	300	2250	4.444	40	NA	83.7	N_2O	InSb
12	Surf.	2535	3.945	140	NA	111.1	Window	InSb

*For 340 K scene temperature.

Table 2 VAS Infrared Spectral Bands

From NASA Reference Publication 1151, October 1985

2. VAS SOUNDING IMAGES OF STABILITY PARAMETERS

2.1 Instrument characteristics

The VAS radiometer has 8 visible channel detectors at 1 km resolution and 6 thermal detectors that sense infrared radiation at 7 or 14 km resolution. A filter wheel in the optical path allows selection of any one of twelve spectral bands between 3.9 μm and 15 μm (Table 2). The EVIRI channels 10, 11, 13 and 14 correspond respectively to the VAS channels 5, 4, 11 and 6 whose weighting functions are shown in Figure 1. A microprocessor on the satellite programs the filter wheel and the scan mirror to work in one of the two possible modes of operation: the multispectral imaging mode (MSI) or the dwell sounding (DS) mode.

The DS mode of operation permits multiple samples of the upwelling radiance in a given spectral band to be sensed by the same detector (by leaving the filter position and mirror position fixed during multiple spins of the spacecraft). It is designed to achieve the improved Signal to Noise Ratio required to interpret the spectral radiance measurements in terms of vertical temperature and moisture structure. MSI images, which usually include the IR 11 μm and two selected spectral bands, are available every 30 minutes. The DS 12 channel measurements, used to derive vertical temperature and moisture profiles simultaneously, are available every 90 minutes.

2.2 Precipitable water and Lifted index

VAS experience at SSEC has shown that retrieved VAS soundings, whose major limitation is a poor vertical resolution, are very useful for deriving integrated quantities. Work carried out to determine which types of predictors are the most reliable indicators of stability has shown good forecast skills for the two thermodynamic parameters of Precipitable Water vapour (PW) and Lifted Index (LI).

Precipitable water vapour is the total moisture vapour in a column of air condensed into millimiters of water. Lifted index is the difference between environmental and calculated temperatures. Negative LI values indicate potential buoyancy (i.e. instability).

2.3 Image product generation

Full vertical profiles of temperature and moisture are simultaneously retrieved by finding the solution to a perturbation form of the radiative transfer equation using matrix inversion. The solution coefficients known at each retrieval location, covering an 11x11 FOV box, are then used to solve for the particular product. These high resolution data are stored in a digital area for display as an image

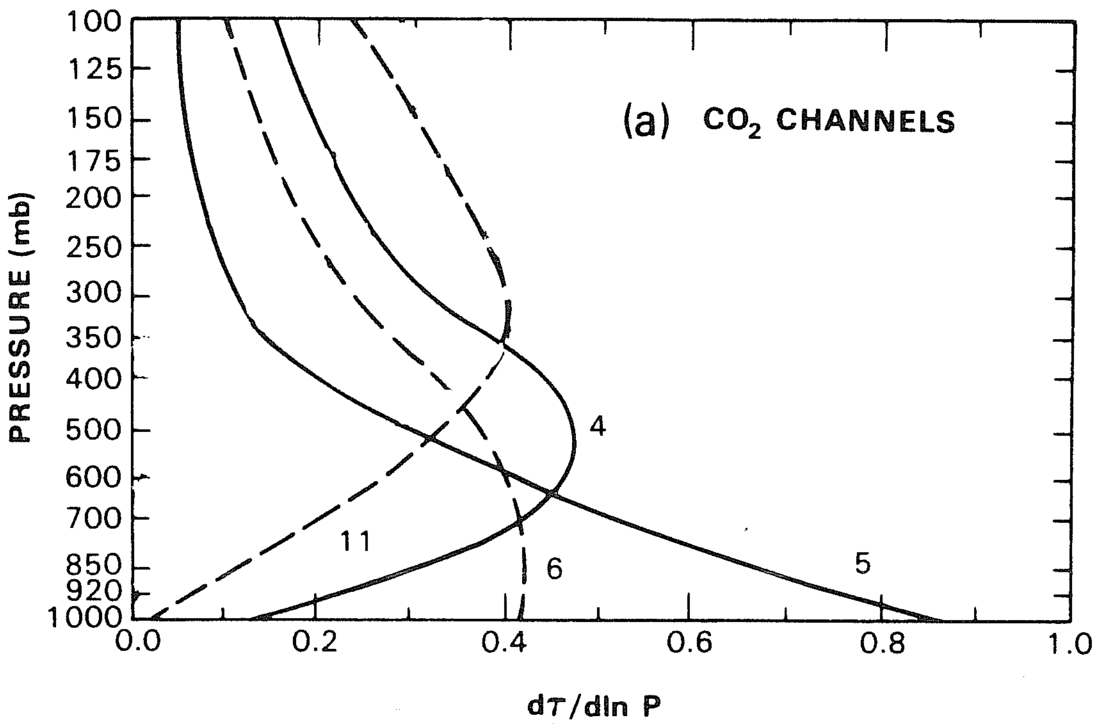


Figure 1 Standard VAS Weighting Functions corresponding to the four propsed EVIRI channels
From NASA Reference Publication 1151, October 1985

VAS channel 4 = 14.0 μm
5 = 13.3 μm
6 = 4.5 μm
11 = 4.4 μm

with the objective of monitoring the state of the atmosphere in severe storm situations with high temporal (1-3 hours) and high horizontal (7-12 km) resolution data. Almost all of the computer time is spent solving the radiative transfer equation, while the product image is created with a little additional calculation. Currently Lifted Index (LI) and Precipitable Water vapour (PW), are derived from MSI (channels 7, 8 and 10) in response to the National Severe Storm Forecast Center's (NSSFC) request for more frequent and timely images. Using MSI images instead of dwell soundings improves both frequency and timeliness of the product, which however has to be generated using three instead of twelve measurements. This simplified approach was encouraged by the previous work on VAS product images by Chesters et al. at NASA/GSFC who developed a split window technique for low-level water vapor estimates.

The physical retrieval algorithm was adapted to the use of three channels only. The first guess received early in the morning, before the products are derived, allows the computation of coefficients (which are the kernel of the integrals in the physical solution of the RTE). The coefficients are interpolated at even hours and then multiplied by a vector of brightness temperature differences (observed-calculated from the first guess). The retrieval in real time is computationally efficient improving the timeliness of the product so as to meet the needs of NSSFC.

The VAS MSI are currently processed on the hour 7 through 18 UTC daily. Comparisons between MSI and almost simultaneous DS images have shown that the same information in terms of relative spatial and temporal gradients is contained in both products.

2.4 Use of data for nowcasting

At SSEC emphasis has been placed on the use of VAS MSI and DS data for nowcasting, in particular the short-term forecasting of severe convective weather. Such experience represents a good indication of possible future Meteosat applications.

LI and PW are generated in real time from VAS data on the McIDAS (Man/Computer Interactive Data Access System) at SSEC. Such products are sent via computer telecommunications to the National Severe Storm Forecast Center and to the National Hurricane Center, where interactive display terminals are installed.

For real-time subjective use of the sounding information a presentation technique has been developed, which combines the sounding values in an image format (i.e. grey level) with the cloud image information provided by the VAS infrared window (11 μm) observations. Through a sequence of looped images stability products indicate the areas where the most severe convection can be expected to occur, while the infrared cloud imagery allows monitoring the growth of the convective clouds.

Experience with lifted index and precipitable water images have demonstrated the importance of such products as compared to infrared or water vapour (WV) images. Sequences of images in the IR and WV reveal convective areas only a few hours after indication of their potential development is given by the products imagery.

These products have proven extremely useful in detecting the formation of severe weather systems and tracking their course, intensification and decay They could be thought of as possible future products for Meteosat, providing the desired information about stability in the lower troposphere. It is interesting to note that this imagery can play an important role in the dynamic verification and reinitialization of numerical weather prediction model used for short-range prediction of intense weather.

3. EVALUATION OF EVIRI CHANNELS FOR DERIVING STABILITY INFORMATION

3.1 Product imagery case

To evaluate the impact of the additional EVIRI channels and give a qualitative indication of the information expected, VAS derived product images of precipitable water and lifted index were generated from the following sounding data sets:
- full DS (12 VAS channels)
- VIRI (VAS channels 7, 8, 9, 10, and 12)
- VIRI + one each of the additional EVIRI channels (VAS channels 4, 5, 6 and 11)

The 8 November 1988 was selected as a test case because of fairly clear conditions and strong moisture gradient distribution. The values from the full DS were assumed to be the most precise and therefore were taken as reference in the comparisons of the five products displayed in an image format on McIDAS (Fig. 2). All the estimates were also compared to the radiosonde values. Each combination of spectral bands in the case studied showed consistent gradients but different absolute magnitudes.

From a qualitative assessment VAS channels 5 and 6 at 13.3 μm and 4.5 μm seemed to provide images more similar to the DS images.

MSI product images were also derived for the test case from the combinations of VAS channels 7-8-10, channels 5-7-8 and 6-7-8 and compared to the DS product images. PW and LI images were compared to those resulting from the full retrieval using the DS 12 spectral bands, as it is shown in Figure 3. Although channels 5 and 6 also seemed to give LI

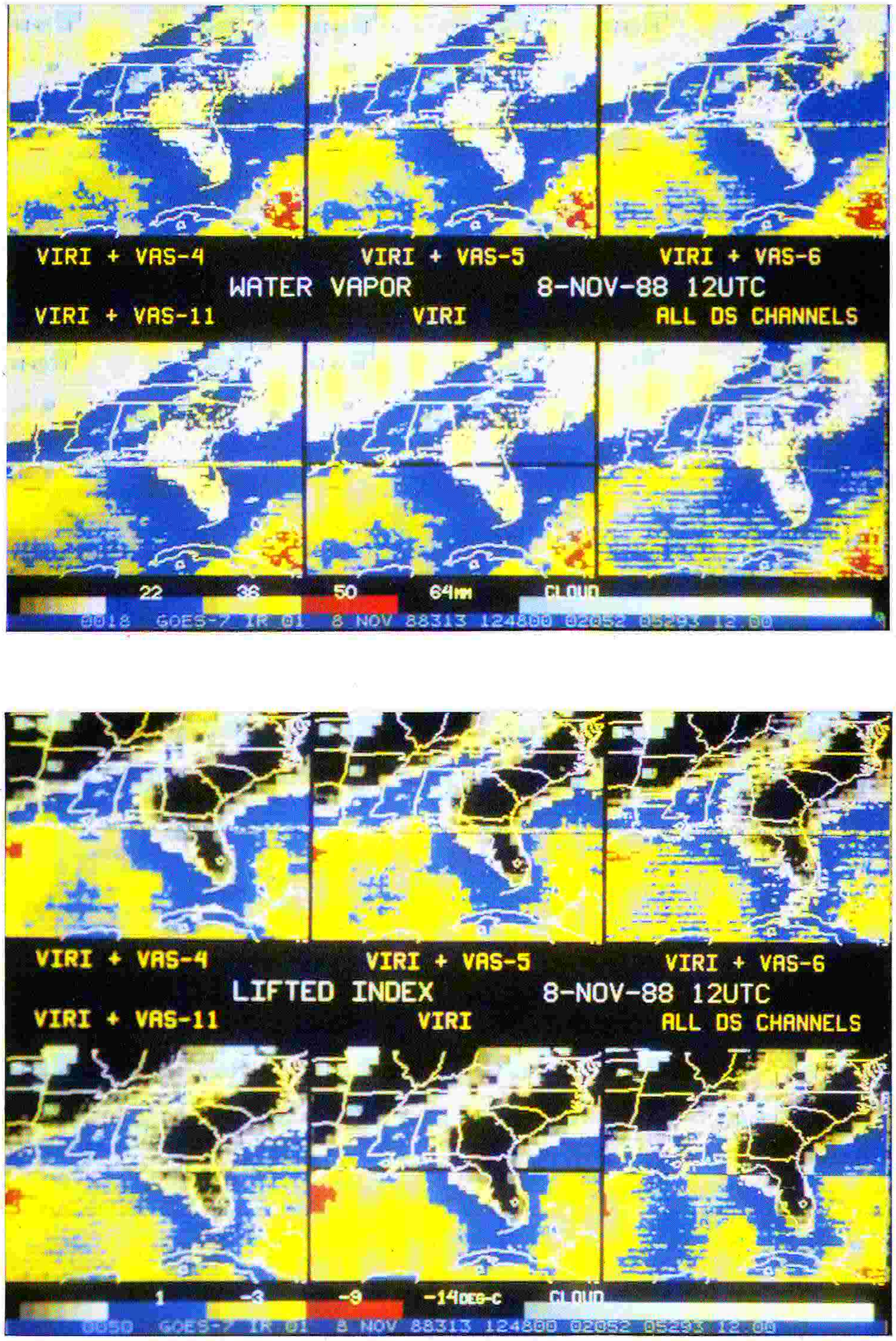


Fig. 2 Lifted Index (LI) and precipitable water vapour images from combination of VAS spectral bands (corresponding to the EVIRI spectral bands).

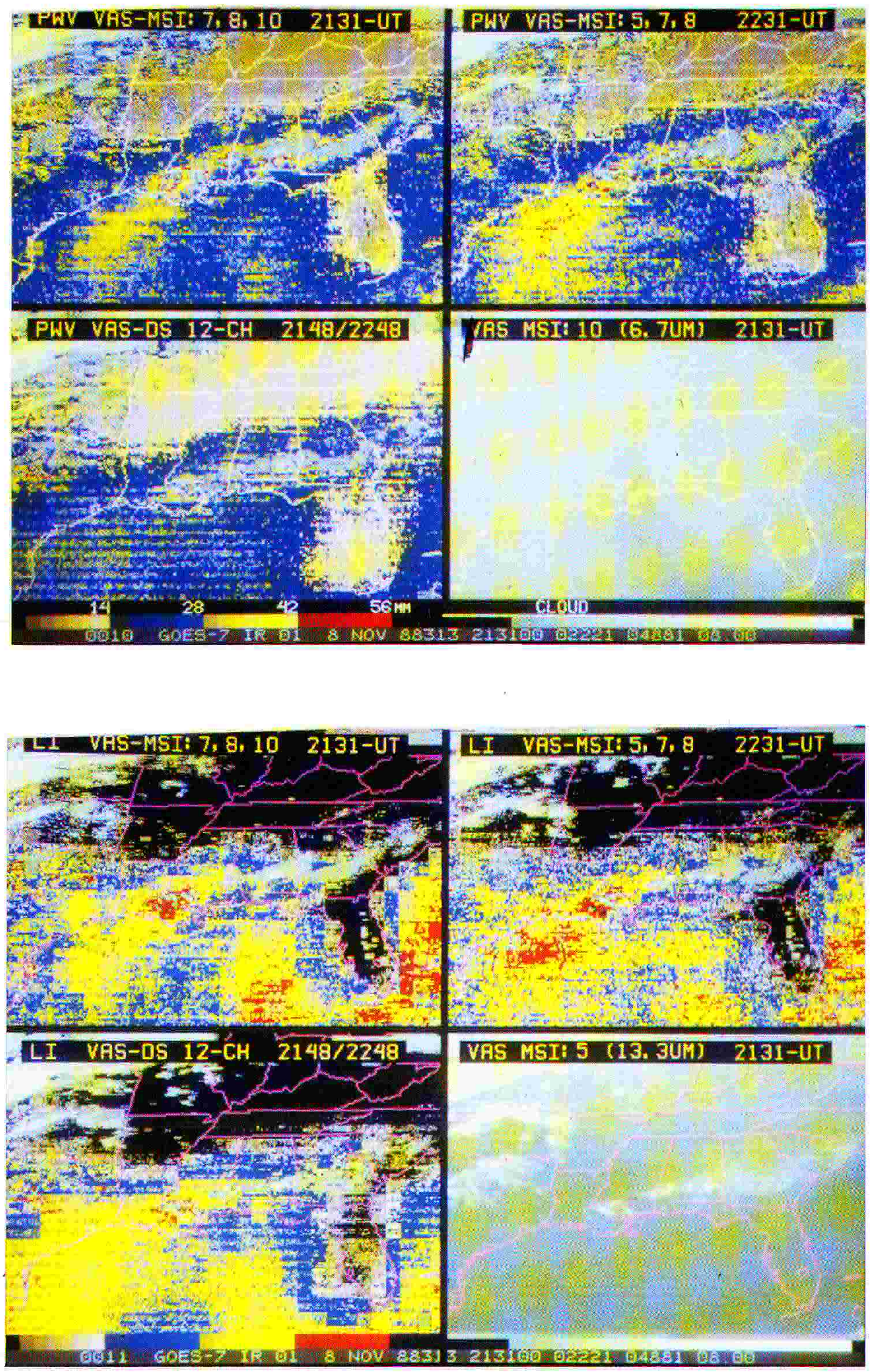


Fig. 3 MSI Lifted Index and precipitable water vapour images from combination of VAS spectral bands (corresponding to the EVIRI spectral bands).

and PW values close to the DS, all the combinations showed both strengths and weakenesses. Furthermore the products were obtained from data sets differing by about one hour (21:30-22:30). Stability changes may take place during this time introducing uncertainty in the evaluation of the results.

3.2 Statistical Analysis

A statistical analysis was carried out to evaluate the contribution of the individual EVIRI channels to the derivation of the stability product in a more quantitative way.

Values of LI and PW derived from the DS were assumed as the most precise. This assumption is not obvious but it provided a good reference for the comparisons.

Brightness temperatures

First correlation coefficients were computed between the LI, and PW (calculated from the DS) and the VAS brightness temperatures to estimate the channel contributing most to the computation of the stability parameters. The computations were performed for cases with representative convective developments in different seasons and at different times of the day. Results indicated no noticeble diurnal trend for channels 4,5,6. Further analysis was carried out independently of any concern for diurnal variation.
Six days were considered, with a sample size of about 400 points on each day. Representative sounding locations are shown in Fig. 4.

Fig. 5 indicates that although some common trends can be found for the days in November and May results from the statistics do not show any clear pattern. This might be due to the lack of sufficient scene variability so that noise rather than representative information was put into the analysis. This effect is best visualized when the data is represented in the form of scattered plots. One example is shown in Fig. 6. Note that in Fig. 5 signs of the coefficients depend on how the temperature differences were defined.

Retrieved parameters

The test day 8 November 1988 characterized by a very high scene variance was selected to allow for a clear indication of the channels impact. Correlation coefficients were computed between the products derived from the DS and the products obtained from the core VIRI channels plus one among the four additional EVIRI ones. The estimated coefficients represent the contribution given by the additional EVIRI channels to the computation of the stability parameters. The results are shown in Figure 7. Most of the contribution to LI comes from VAS channel 5, and to PW from VAS channel 6.

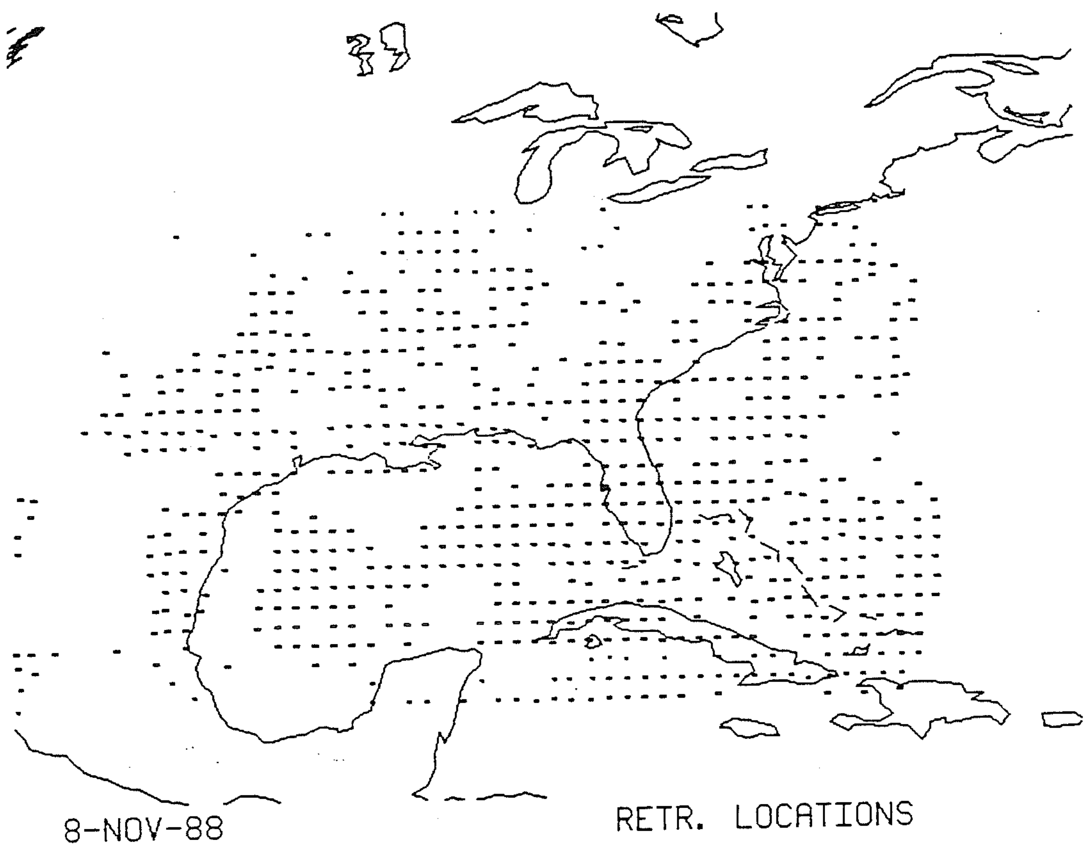
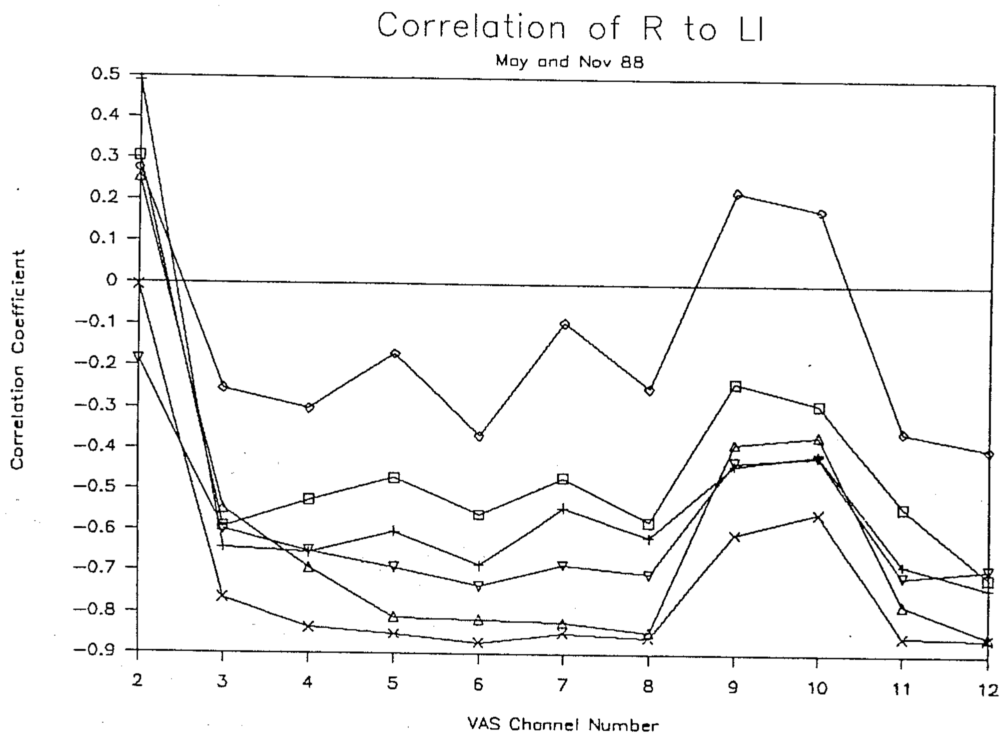


Figure 4 Sounding locations



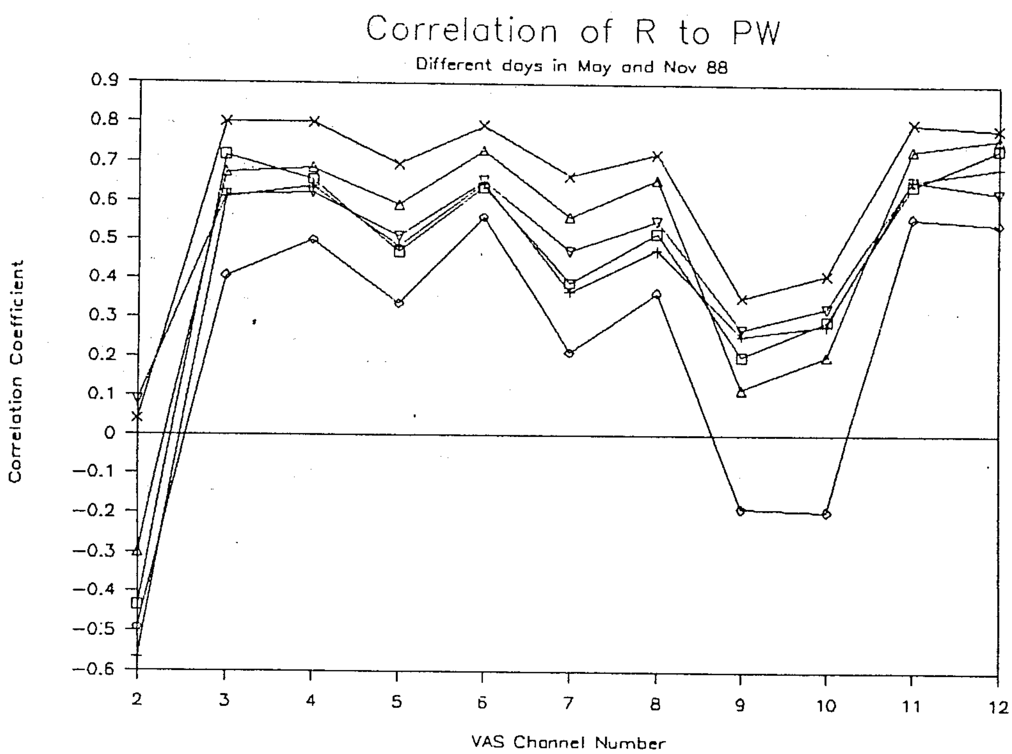


Figure 5 Correlation coefficients between LI and PW calculated from the DS channels and VAS channels brightness temperatures

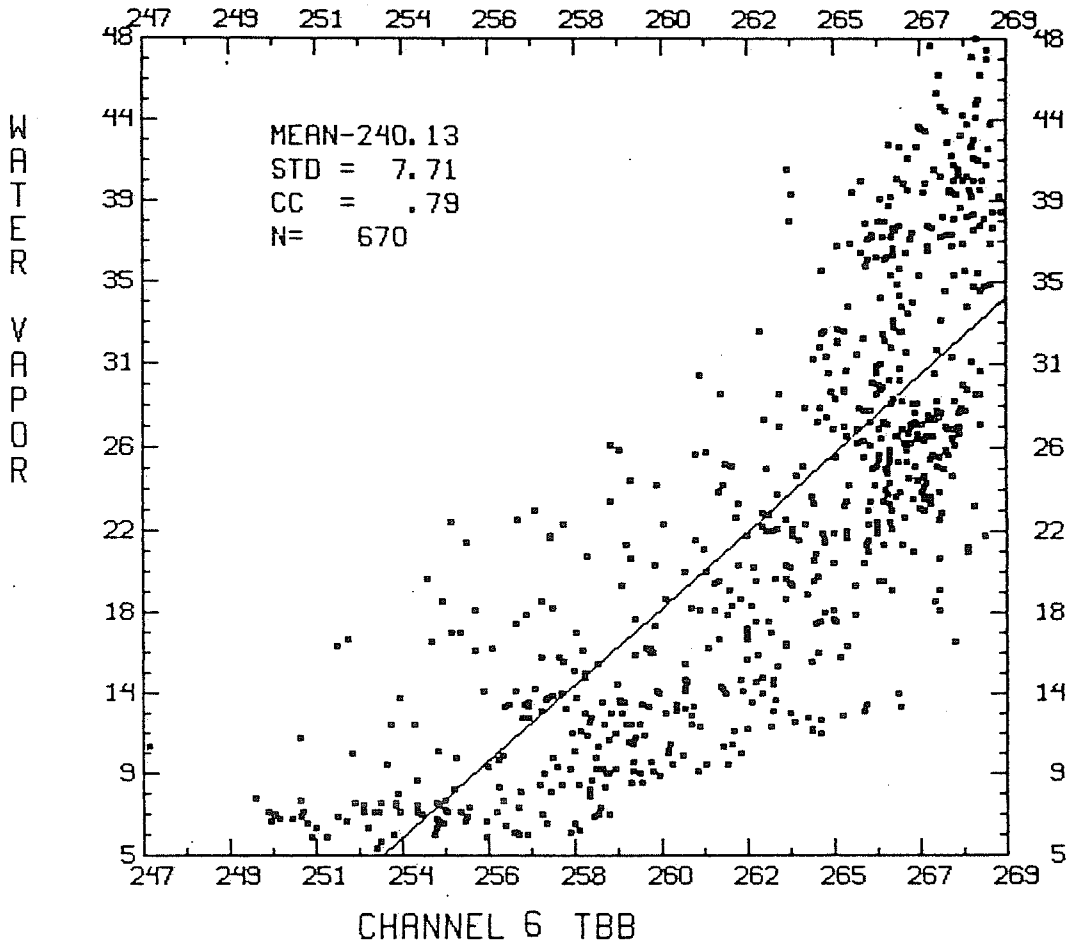
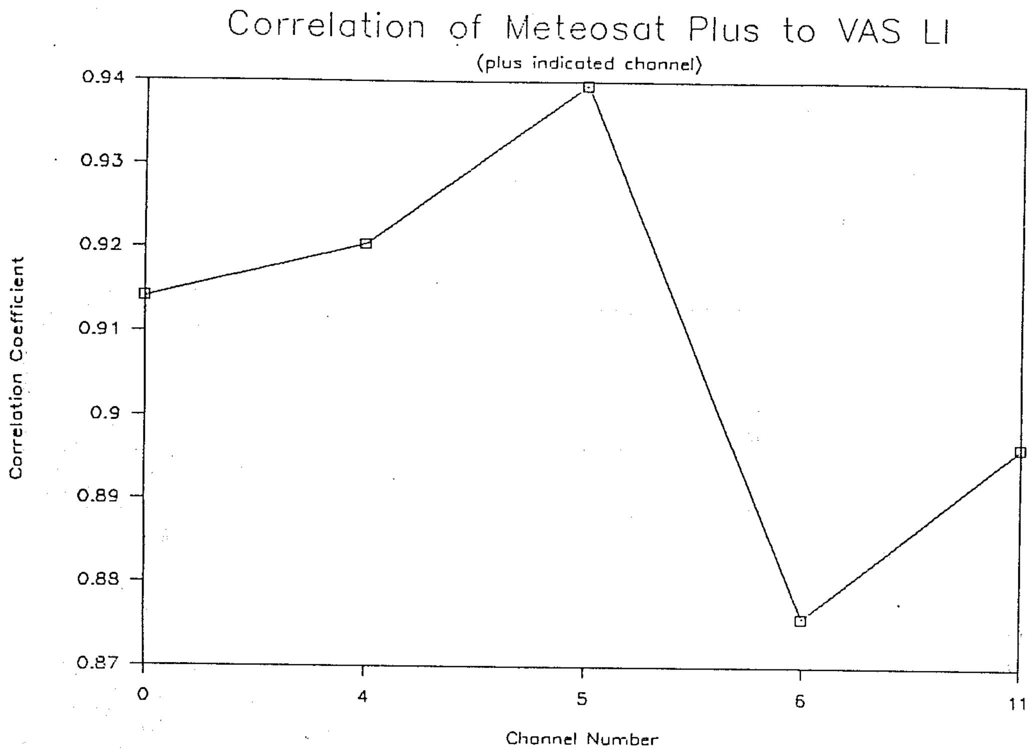


Figure 6 **Example of scattered plot Precipitable Water vapour and VAS channel 6 brightness temperature**



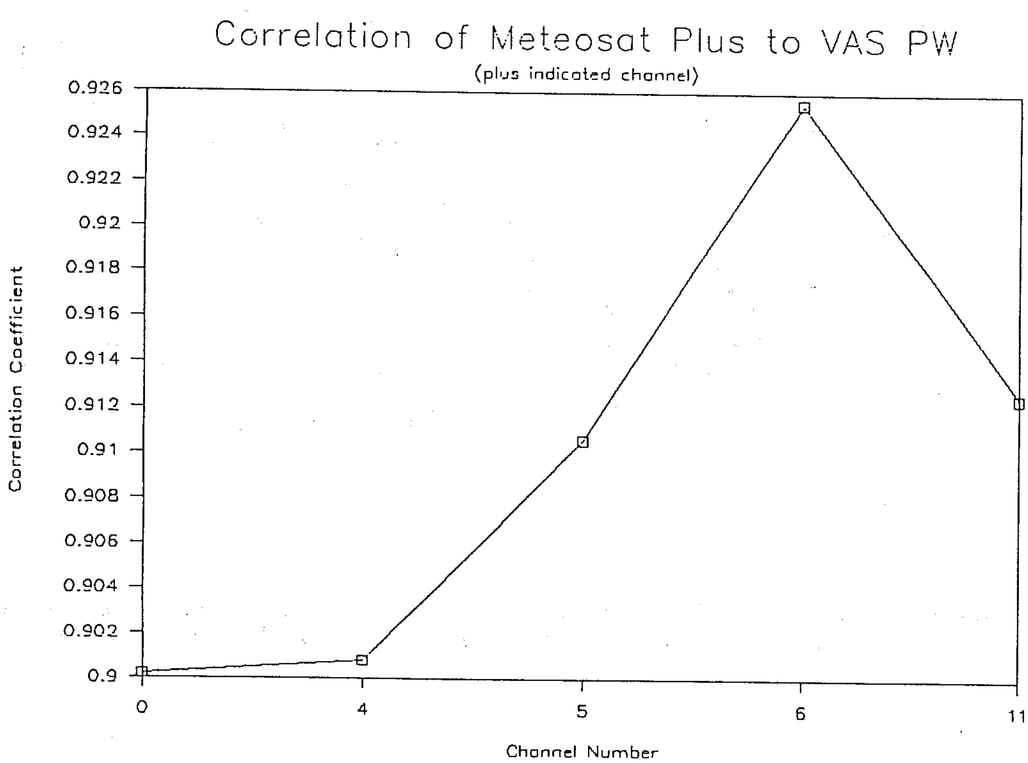


Figure 7 Correlation coefficients between:
- LI and PW computed from DS channels
- LI and PW computed from the imager core channels plus one of the four additional EVIRI channels

The decrease of the correlation coefficients for the LI when adding channels 5 and 6 as compared to the DS values could be due to solar contamination.

Some ambiguity in the interpretation of the results is introduced by the influence of the first guess profile on the retrieved stability products.

Pairs of channels

Correlation coefficients were also computed between LI, PW and differences of brightness temperatures for pairs of channels in the 4.3 μm and in the 13 μm band.

The calculations were done to validate the approach suggested for EVIRI of deriving information on stability by using the combination of two channels in the same band, peaking at two different heights in the atmosphere.

The results listed in Table 3, show that the approach of dealing with pairs of channels should not be pursued. Channels should be evaluated on the basis of their individual information content.

4. FURTHER CONSIDERATIONS

The analysis of the product imagery and the statistical computations showed that the EVIRI channels at 13.3 μm and 4.5 μm would be useful for the derivation of products such as LI and PW. The importance of measurements in these spectral bands is also supported by the following considerations:

Weighting functions

For most of the European areas the high zenith angle (50°) increases the atmospheric path and shifts the weighting functions towards higher levels in the atmosphere. Figure 8 shows one example (sounding of Jackson Mississipi, 8 Nov. 88), representing weighting functions calculated for the four additional EVIRI channels. The objective of analysing the conditions of the lower atmosphere suggests the selection of channels with weighting functions peaking at lower levels such as the channels at 13.3 μm and 4.5 μm.

Other products

Another ranking criterion for the channels relates to the number of products that the measurements would provide. In this respect, the most useful channel is the 13.3 μm channel, which can be effectively used for cloud top height assignment. UW/CIMSS is currently demonstrating a technique, which is the simplified version of the CO2 method, making use of the VAS channels at 13.3 μm and of the window

LIFTED INDEX:

CHANNELS	CORRELATION COEFFICIENT
4 - 5	.718
11 - 6	.829
7 - 8	.719
6 - 7	.476

PRECIPITABLE WATER VAPOUR:

CHANNELS	CORRELATION COEFFICIENT
4 - 5	.459
11 - 6	.693
7 - 8	.778
6 - 7	.150

Table 3 **Correlation coefficients between LI and PW calculated from DS and differences of brightness temperatures**

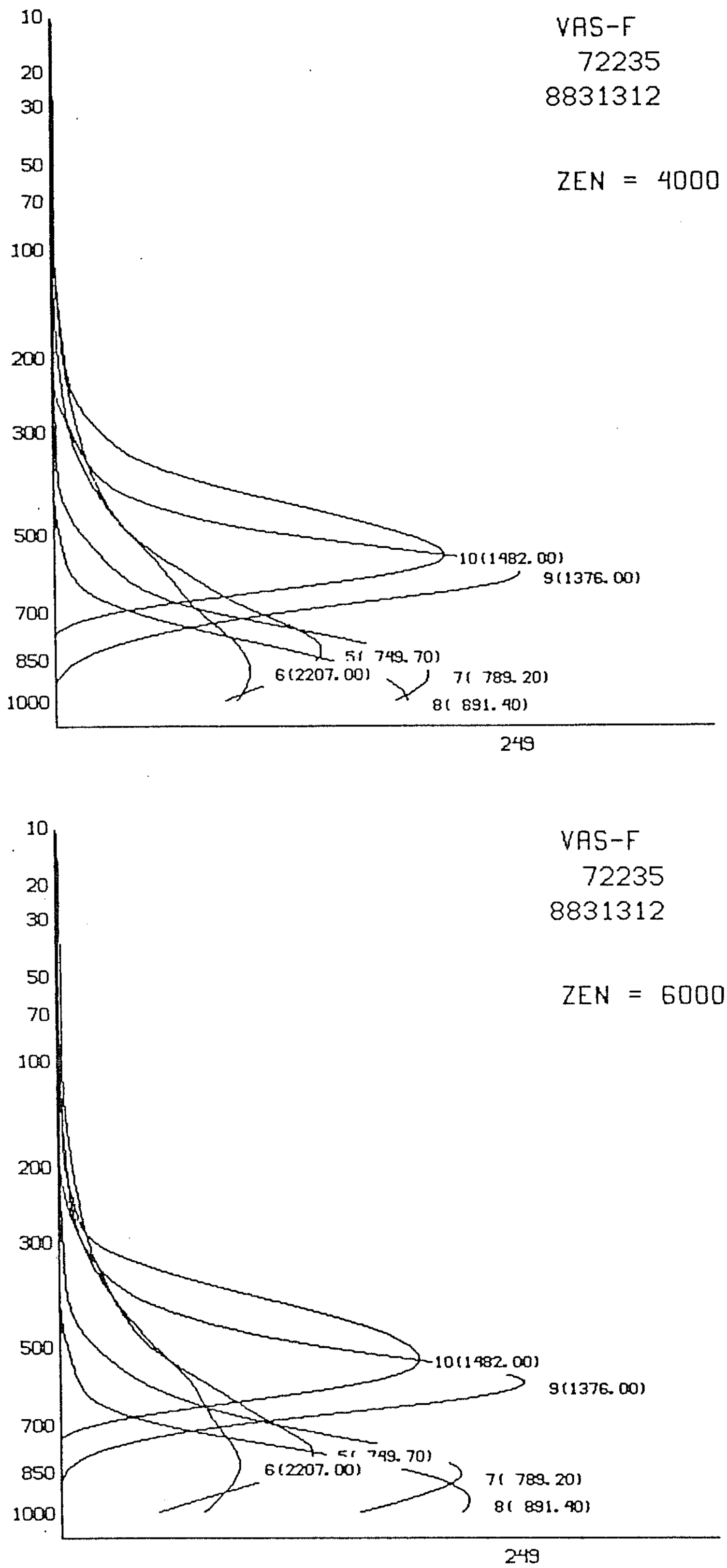


Figure 8 Example of weighting functions at different zenith angles (40 and 60)
Sounding of Jackson, Mississippi, 8 November 1988

channel. The results obtained until now indicate that the 13.3 μm channel should receive a high priority when instruments are being planned for future geostationary satellites.

Temperature information

Experience with the TOVS and operational sounding processing from VAS has shown that the greatest impact on a temperature retrieval is given by the 4.5 μm channel. Since the assumption made to derive stability parameters is the availability of a full temperature retrieval the channel at 4.5 μm should be included to add such capability to the instrument.

Compatibility with other instruments

In selecting the additional channels to the VIRI some considerations should be given to the compatibility with instruments that will fly on other satellites of the global system at the same time as Meteosat Second Generation. Instruments such as the polar platform MODIS, will have channels (30 and 37) corresponding to the VAS channels 5 and 6 (EVIRI channels 7 and 8). The simultaneous availability of measurements from the same spectral bands on polar orbiters and geostationary satellites will allow interesting applications in many areas, for example in the field of atmospheric corrections.

5. Summary

Potential stability products from the proposed future Meteosat imager (EVIRI) were evaluated on the basis of the experience gained with the GOES VISSR Atmospheric Sounder (VAS). The use of stability parameters derived from VAS observations has been shown very effective for the forecasting of severe convective storms. Products are displayed to the forecaster in an image format, allowing portrayal of all the mesoscale detail of the observations.

Simulations confirm that the channels proposed for EVIRI would satisfy the mission of monitoring the stability processes in the lower troposphere. Detection of areas where atmospheric conditions favour the development of severe weather could be provided at high temporal and spatial resolution.

Among the proposed channels to be added to the eight core channels of the imager, the spectral bands with the highest impact on the Meteosat missions would be the 13.3 μm, the 4.5 μm and then the 4.4 and 14 μm. Further analysis will be needed to optimize the channels and the algorithms for the European area.

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