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Regional correction of ocean surface specific humidity derived from satellite sensor data

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Abstract. A method is proposed to increase the accuracy of satellite sensor-derived near-surface humidity estimates. The method uses an operational atmospheric circulation model to correct the satellite sensor estimates of humidity from their regional bias. The method was applied to twelve orbits of the Special Sensor Microwave/Imager (SSM/I) selected between 1997 and 1998. The SSM/I-derived humidity estimates were corrected with respect to analyses of the European Centre for Medium-Range Weather Forecasts (ECMWF) model. The SSM/I humidities were compared to observations of the Comprehensive Ocean-Atmosphere Data Set (COADS), before and after correction with respect to the ECMWF products. The results show that the proposed method decreased the rms. error between SSM/I and COADS specific humidity by 20%. Independent application of the method in the context of a field experiment indicated that the deviation between satellite sensor-derived humidity and *in situ* observations was decreased by 13% if the correction was applied.

1. Introduction

Global fields of specific humidity (q_A) just above the ocean surface may be obtained from general circulation models (GCMs) or satellite sensor data. Over the last decade, the accuracy of humidity fields derived from operational GCMs has increased due to the assimilation of more observations and the use of new assimilation schemes. However, the number of surface observations assimilated in GCMs is still insufficient in many locations for rendering accurately the horizontal structures of q_A. This is especially noticeable at the meso-β scale, that is over areas of 20–200 km (Orlanski 1975), where the structures of q_A are often mislocated and deformed. Satellite sensor data are expected to locate accurately those structures because they are observations with an adequate spatial resolution, namely 10–100 km for the current space-borne passive microwave radiometers. The disadvantage is that the satellite sensor-derived estimates of q_A often have large

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systematic errors (or biases) at regional scale (20–2000 km), as reported by Esbensen *et al.* (1993) and Bourras *et al.* (2003). The reason is that the algorithms applied to satellite sensor data for estimating q_A are global statistical relationships between q_A and the integrated water vapour content in the atmosphere (e.g. Liu and Niiler 1984). The accuracy of such relationships depends on the shape of the vertical humidity profiles (the relationship between specific humidity and altitude), which may vary from one region to another. Overall, there is no reliable method to obtain fields of q_A that would be accurate from the meso-β scale to the global scale.

This Letter presents a method that combines the advantages of satellite sensor observations and GCM analyses to produce accurate fields of q_A.

2. Method

The principle of the correction method is to adjust the regional bias of satellite sensor derived estimates of q_A (satellite sensor q_A hereafter) to regional averages of q_A from GCMs (GCM q_A). The method is based on the hypothesis that inside each region, the shapes of the vertical humidity profiles are identical. This ensures that the satellite sensor q_A of each region have the same bias. The size of a region may be selected between 200×200 km and 2000×2000 km. Beyond 2000×2000 km, the hypothesis described above may not be valid for several reasons such as the presence of large spatial gradients of sea surface temperature that may affect the shape of the humidity profiles, or the advection of different kinds of air masses over the region. On the other hand, below 200×200 km the accuracy of the GCM q_A is questionable, because of a possible lack of assimilated data (section 1). In the following, the size of a region is 1000×1000 km, which is halfway between 200×200 km and 2000×2000 km.

The application of the method consists of four steps. First, one delimits a region R_L around the location L of each satellite sensor q_A. R_L is defined as the section of satellite orbit of 1000×1000 km of area that has its geometrical centre C located on the perpendicular (P) to the trajectory of the satellite in L, as represented in figure 1. Note that all the satellite sensor q_A located on (P) share the same R_L. The second step is to gather and average all the satellite sensor q_A and the GCM q_A available inside R_L. Next, the difference (or regional bias) between the averaged satellite sensor q_A and GCM q_A is calculated. Finally, the regional bias obtained is subtracted from the satellite sensor q_A in L.

A comparable approach was already applied with success for the sea surface temperature by Reynolds (1988). These authors produced so-called blended fields, in which satellite sensor data and *in situ* data were merged. They used an interpolation method to fill the gaps between the *in situ* data. In the present study, GCM analyses were chosen instead of *in situ* data to correct the regional bias of the satellite sensor q_A estimates. The reason is that operational analyses can be considered as physically interpolated *in situ* data.

3. Data

The proposed method was applied to humidity fields derived from observations of the Defense Meteorological Satellite Program Special Sensor Microwave/Imager (DMSP-SSM/I). Operational analyses from the European Centre for Medium-Range Weather Forecasts (ECMWF) model were used to correct the satellite sensor-derived fields. To assess the accuracy of the method, the corrected satellite

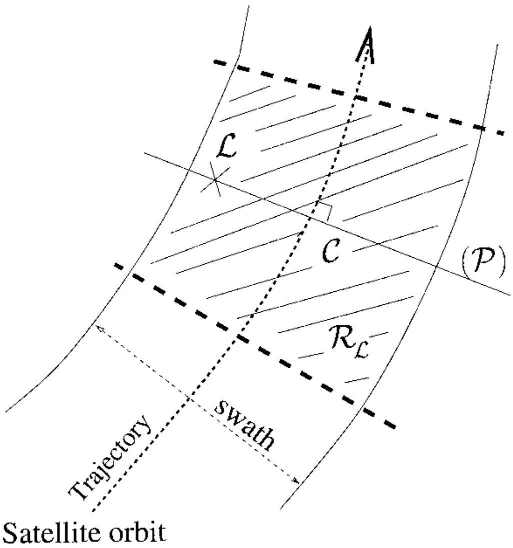


Figure 1. Principle of the correction method. The satellite sensor q_A estimate in L is corrected with respect to GCM q_A values averaged over a region R_L. L and the centre C of R_L are located on the perpendicular (P) to the trajectory of the satellite.

sensor-derived q_A estimates were compared to surface observations of the Comprehensive Ocean-Atmosphere Data Set (COADS, Woodruff *et al.* 1987) data and the Structure des Echanges Air-Atmosphère, Propriétés des Hétérogénéités Océaniques: Recherche Expérimentale (SEMAPHORE) experiment (Eymard *et al.* 1996). The data described above were used to create two datasets, namely a global dataset and a regional dataset.

The global dataset consists of twelve SSM/I orbits and ECMWF analyses, the dates of which were randomly selected between 1997 and 1998 (table 1). The maximum shift in time between the analyses and the corresponding satellite orbits was $\pm$1h30min. The SSM/I data used were brightness temperatures (T_B) measured

Table 1. Dates of the SSM/I orbits and ECMWF analyses of the global dataset.

Date (day month year)	SSM/I orbit start time (hour: second)	ECMWF time (hour: second)	Satellite identification number
21 February 1997	11:09	12:00	F13
6 April 1997	05:39	06:00	F10
8 July 1997	05:46	06:00	F10
4 August 1997	11:37	12:00	F14
14 October 1997	00:34	00:00	F13
2 December 1997	00:30	00:00	F13
3 January 1998	12:20	12:00	F14
9 March 1998	12:24	12:00	F14
8 May 1998	05:58	06:00	F13
17 June 1998	11:56	12:00	F14
9 August 1998	05:38	06:00	F14
27 September 1998	11:01	12:00	F14

The SSM/I orbits selected are the closest in time to the ECMWF analyses.

in two polarizations and five frequencies ranging from 19–85 GHz. q_A estimates were derived from the SSM/I T_B using the algorithm of Schluessel *et al.* (1995). The spatial resolution of the q_A estimates was $0.3^\circ \times 0.3^\circ$ while the ECMWF analyses had a spatial resolution of $1.125^\circ \times 1.125^\circ$. COADS data were also included in the global dataset. All 1997 COADS observations within a $\pm 0.5^\circ$ radius in space and $\pm$1h30min in time from the SSM/I observations were selected, which resulted in 132 points of comparison (figure 2).

The regional dataset is based on measurements of q_A performed during the SEMAPHORE experiment on board *Le Suroît*, a research vessel that belongs to Institut Français de Recherche pour l'Exploitation de la Mer (Ifremer). SEMAPHORE was conducted in a region delimited by 30N to 38N and 20W to 28W, from October to November 1993. All available SSM/I T_B and ECMWF q_A at $\pm$45 min and $\pm 0.5^\circ$ from the location of the ship were gathered. Next, the Schluessel *et al.* (1995) algorithm was used to derive q_A from the T_B.

4. Results

The SSM/I q_A and the corrected SSM/I q_A were compared to COADS data (figure 3 and table 2). Table 2 reveals that the rms. deviation between corrected SSM/I q_A and COADS q_A was $2.12\,\mathrm{g\,kg^{-1}}$, which was 20% smaller than the deviation between SSM/I q_A and COADS data. However, the correlation coefficient between SSM/I q_A and COADS data did not markedly increase if the correction was applied, as reported in table 2. One may notice that the corrected q_A were biased by $0.66\,\mathrm{g\,kg^{-1}}$. This bias corresponded to the bias of the ECMWF analyses with respect to COADS. Note also that the slope of the linear fit between corrected SSM/I q_A and surface q_A was decreased by 11%. This meant that the application of the method slightly affected the range of the satellite sensor-derived q_A estimates.

For the SEMAPHORE dataset, the corrected SSM/I q_A were closer to the ship data than the SSM/I q_A, as shown in figure 4. The rms. deviation between SSM/I q_A and ship q_A decreased by 13% if the correction was applied (table 2). The increase in correlation coefficient between SSM/I q_A and ship data was small, namely 0.02, which was consistent with the results found at global scale. Additionally, the slope

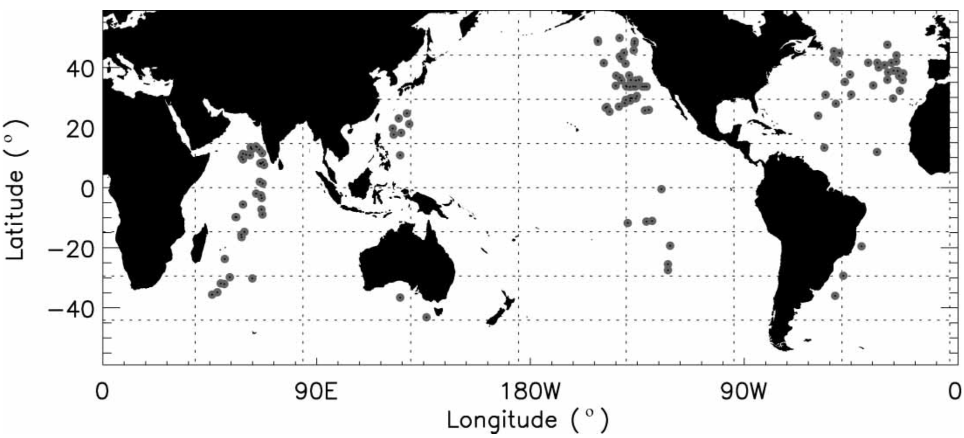
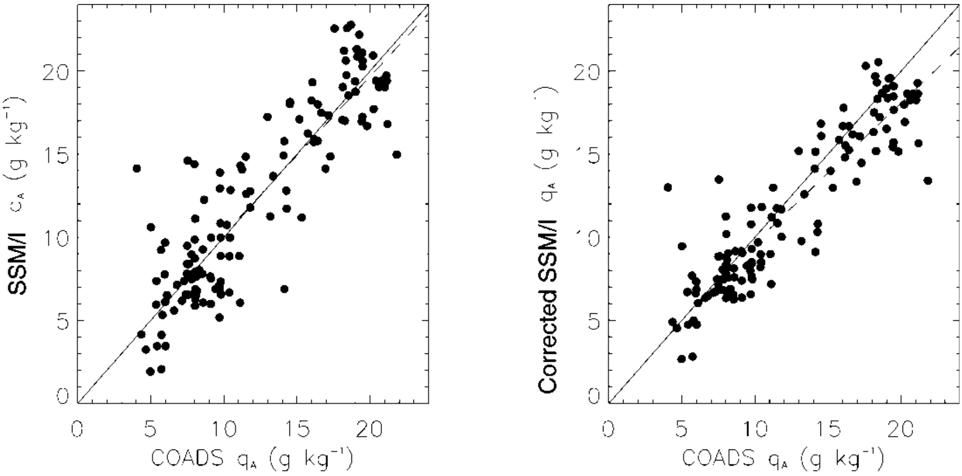


Figure 2. Locations of the COADS observations of the global dataset. Each location is represented by a dot.



(*a*) (*b*)

Figure 3. Comparison of (*a*) SSM/I q_A and (*b*) corrected SSM/I q_A with COADS observations. The dashed lines represent the first-degree polynomial fits to the data, while the bold lines represent $y = x$.

Table 2. Comparison between satellite sensor-derived estimates of q_A and *in situ* measurements of q_A.

Correction	*in situ* data	Correlation coefficient	rms. ($g\,kg^{-1}$)	Bias ($g\,kg^{-1}$)	Linear fit ($g\,kg^{-1}$)
no	COADS	0.88	2.65	0.06	$0.95x + 0.66$
yes	–	0.91	2.12	−0.66	$0.84x + 1.26$
no	SEMAPHORE	0.89	0.90	2.11	$0.94x + 2.70$
yes	–	0.91	0.78	0.00	$0.82x + 1.62$

The column labelled ‘Correction’ indicates whether the correction method was applied to the satellite sensor estimates of q_A. The *in situ* q_A are either COADS or SEMAPHORE observations. The biases are given with respect to the *in situ* q_A.

of the linear fit between corrected SSM/I q_A and ship q_A was smaller by 13% than the slope between SSM/I q_A and ship q_A, which closely corresponded to the decrease in slope found on the global dataset.

5. Summary

A method was proposed to increase the accuracy of satellite sensor-derived humidity estimates. The method combines satellite sensor observations and operational analyses from a GCM. The accuracy of the method was checked at global scale and at regional scale with data of the SEMAPHORE experiment (North Atlantic, autumn 1993). The proposed method decreased the rms. deviation between SSM/I derived q_A estimates and *in situ* observations by 20% at global scale and by 13% for SEMAPHORE. The results also suggest that the correction slightly affects the range of estimated humidity for both datasets. As the nominal error of the q_A algorithm used was $1.1\,g\,kg^{-1}$ (Schluessel *et al.* 1995), the proposed

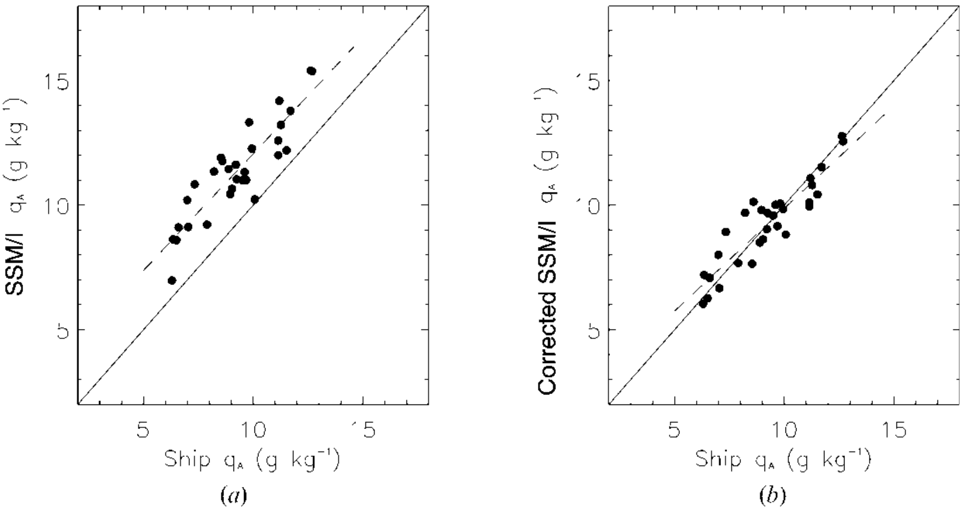


Figure 4. Comparison of (*a*) SSM/I q_A and (*b*) corrected SSM/I q_A with ship data of the SEMAPHORE dataset. The dashed lines represent the first-degree polynomial fits to the data, while the bold lines represent $y=x$.

correction should increase the rms. accuracy of the q_A algorithm by 0.14–0.22 g kg^{-1}, that is the rms. error of the corrected SSM/I derived q_A estimates is expected to be 0.88–0.96 g kg^{-1}. Although encouraging, these preliminary results must be confirmed for other regions like the Tropics, where the accuracy of q_A from both satellite sensor data and GCMs is questionable (Esbensen *et al.* 1993, Nuret and Chong 1996).

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