D3.4: SAR Mode for Ocean Corrections Theoretical Basis Document

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1. Introduction

1.1. Scope and purpose

This document is the Theoretical Basis Document for the ocean corrections (OCTBD) used to retrieve ocean geophysical parameters in CryoSat-2 SAR mode for the three ocean focus areas: Open Ocean, Polar Ocean and Coastal Zone.

This document provides the list of the corrections that are applied in the Level-2 data products for the LOTUS project.

1.2. Document structure

This document is structured into two chapters:

- an introductory chapter (this section), followed by
- the Section 2 which provides the complete list of the ocean corrections .

2. Ocean corrections for SAR mode data

For computing the Sea Level Anomalies (SLA), corrections are applied to the uncorrected sea level height as following:

$$SLA = Orbit - Range - \sum_{i=0}^{N} C_i - MSS$$

where

- *Orbit* corresponds to the distance between the satellite and the ellipsoid (above the reference ellipsoid - Cnes POE),
- *Range* is the distance measured by the altimeter between the satellite and the sea surface,
- *MSS* is the Mean Sea Surface of the ocean over a long period and
- $\sum_{i=0}^{N} C_i$ is the sum of all the corrections needed to take into account the atmospherically effects (wet and dry troposphere, ionosphere, inverse barometer) and the geophysical phenomena (ocean tides, high frequency atmospheric effects on ocean).

The additional sea-surface bias (electromagnetic sea-surface bias) correction has been computed for the SAR-mode over open ocean.

This section contains the description of all models and standards used.

2.1. Geophysical models

Model geophysical corrections are employed to provide relevant range measurements since the CryoSat-2 satellite does not carry a microwave radiometer to correct for water vapour path delay, and only operates at a single frequency (dual frequency allowing a direct estimate of the ionospheric delay).

It is also of high importance for any other missions which possess onboard MWR and C/Ku-bands radar antenna (e.g., Sentinel-3), to use model corrections since these corrections are less subject to instrumental instabilities and possible drifts that affect the corrections of some altimetric missions.

The various dynamic geophysical correction data that are needed to process the SAR sea level measurements are displayed in the following table.

Parameter	Description
Dry troposphere	Model dry tropospheric correction is computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag. A dry tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for dry tropospheric range delays of the radar pulse. From European Center for Medium Range Weather Forecasting
Wet troposphere	Model wet tropospheric correction is computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag. A wet tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for wet tropospheric range delays of the radar pulse. From European Center for Medium Range Weather Forecasting
Ionosphere	GIM ionospheric correction from NASA/JPL must be added (negative value) to the instrument range to correct this range measurement for ionospheric range delays of the radar pulse.
Ocean tide and loading tide	Geocentric ocean tide height (solution 1): GOT4.8 from GSFC Includes the loading tide and equilibrium long-period ocean tide height. The permanent tide (zero frequency) is not included in this parameter because it is included in the geoid and mean sea surface.
Solid Earth tide	Solid earth tide height is calculated using Cartwright and Taylor tables and consisting of the second and third degree constituents. The permanent tide (zero frequency) is not included. From Cartwright and Edden [1973] Corrected tables of tidal harmonics - J. Geophys. J. R. Astr. Soc., 33, 253-264.
Pole tide	Computed from Wahr [1985] Deformation of the Earth induced by polar motion - J. Geophys. Res. (Solid Earth), 90, 9363-9368.
Combined atmospheric correction	Also known as high frequency fluctuations of the sea surface topography which contains the combined atmospheric corrections (from MOG2D model + inverse barometer)
Sea State Bias	See following section
Mean Sea Surface CLS	MSS_CNES_CLS-2011: mean sea surface height above T/P reference ellipsoid from CLS/CNES 2011
Mean Sea Surface DTU	MSS_DTU10: mean sea surface height above T/P reference ellipsoid from DTU 2010

Table 2.1: Products corrections and models overview

2.2. High-wind and SSB model for SAR

SAR retrackers enable to perform well for the retrieval of Pu (Sigma0). This estimate has been validated for Cryosat-2 SAR-mode and its consistency has been well demonstrated by comparing with the estimated RDSAR Sigma0.

The SAR Sigma0 allows to derive the high-wind response and to develop any SAR SSB correction.

2.2.1. Retrieval algorithm for Cryosat-2 SAR-mode wind speed

Previous experiences with Ku-band data indicate that 2D model as a function of sigma0 and SWH provides better estimations of wind speed than 1D model. For example the Jason missions adopted a 2D model [Collard, 2005] to provide wind speed in their products. The Labroue and Tran's [2007] model was developed in a similar way for Envisat. The SWH is used in the 2D models as a proxy for long-wave roughness (unrelated to local winds).

By analysing the SWH impact on both Cryosat-2 SAR-mode sigma0 and retrieved wind speed by different models, results showed a clear SWH dependence on Cryosat-2 SAR 1D wind estimates at a given ECMWF wind speed bin. This SWH dependence is reduced over a larger interval of ECMWF values with the Labroue and Tran's estimates as shown in Figure 2.1. Results of the application of the Labroue and Tran's model on Cryosat-2 and Jason-2 data also display similar effects even though the Cryosat-2 SAR-mode data do not cover the global ocean as the Jason-2 samplings. Based on different results, the Labroue and Tran's model is used to compute 20-Hz wind speed for Cryosat-2 SAR-mode data.

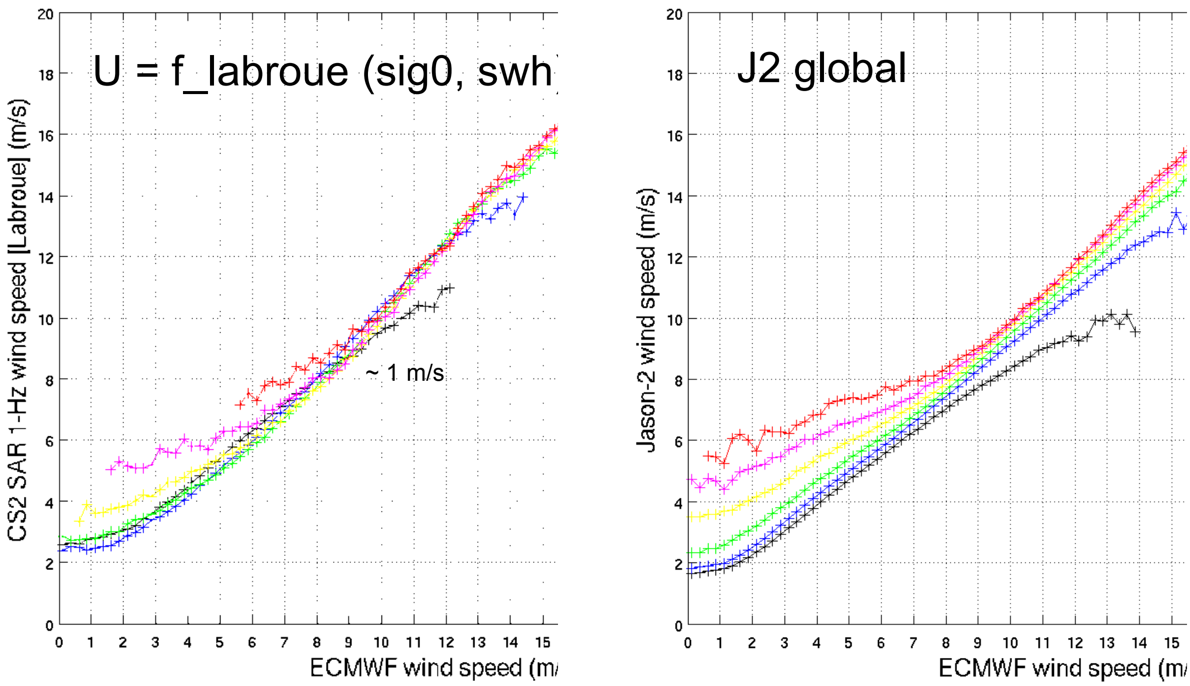

Figure 2.1: Bin-averaged relations for Cryosat-2 SAR (left) Labroue's estimations and (right) Jason-2 wind speeds against ECMWF ones respectively where each curve represents an interval of 1 m SWH (black: at ~1 m SWH and red: at ~6 m SWH).

Figure 2.2 presents maps of wind speed for the LRM and SAR modes, and also the merging of the two data types. As one can note, there is no apparent bias for both parameters between LRM and SAR values. Of course, due to each mode sampling, values of mean and standard deviation (STD) for each parameter are not the same but they are close over 11-month period. We observe a mean value of 7.64 m/s and a STD value of 3.65 m/s for the LRM mode. For the SAR mode, we get a mean of 7.77 m/s and a STD of 3.52 m/s.

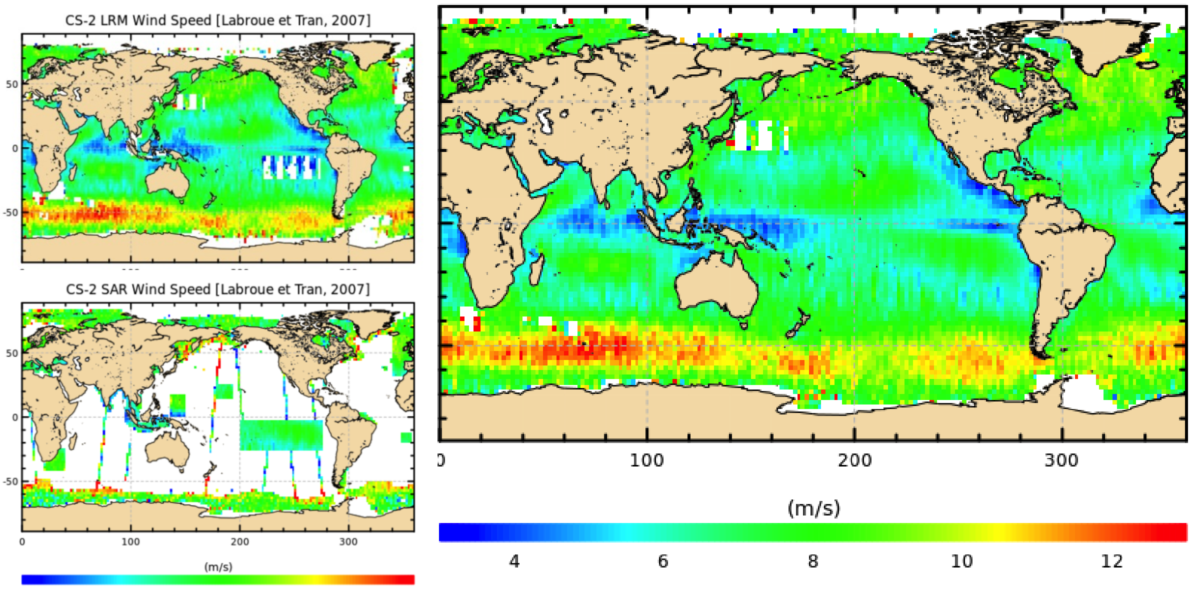

Figure 2.2: Left: maps of LRM and SAR wind speed computed with the Labroue and Tran [2007]'s algorithm. Right: map of merged data over 11-month period.

2.2.1.SSB model for Cryosat-2 SAR-mode data

A SSB correction in the 2D domain defined by SWH and wind speed must be added (negative value) to the instrument SAR-mode range to correct the range measurement for sea state delays of the radar pulse. However the SAR CryoSat-2 SSB cannot be directly calculated within restricted areas. The LRM sea state bias produced from a non-parametric method applied at crossovers is used to derive the SSB in SAR mode.

Due to the strategy proposed to develop the SAR model from the LRM one, it is necessary to verify in first that they are no bias between SAR and LRM estimates of SWH and wind speed respectively or if there are some biases to correct for them.

Figure 2.3 displays the range differences (RDSAR-SAR) in the (SWH, wind speed) domain. It shows a small dependence on SWH of approximately 0.25% SWH.

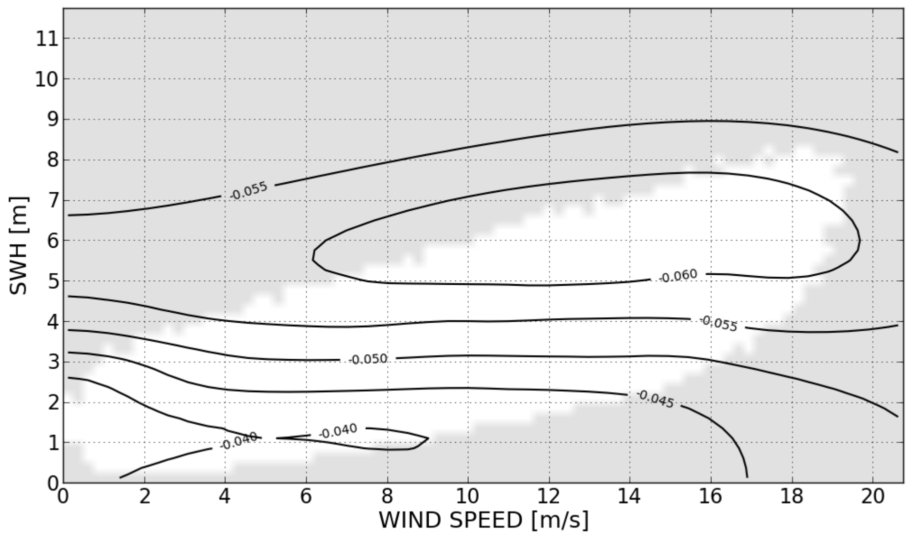

Figure 2.3: Range differences in the 2D domain (SWH, wind speed).

Figure 2.4 presents the Cryosat-2 SAR-mode SSB model derived from the LRM SSB solution plus the corrective term displayed in Figure 2.3 since we assume that the RDSAR and LRM SSB solutions are the same within a constant. We impose also the constraint that the SAR SSB is equal to zero when there is no wind and no wave so a shift has been applied to obtain Figure 2.3. This leads to get a model that corresponds approximately to -3.6% SWH. So the SSB differences between the SAR and the LRM model represent roughly 0.3% SWH since the LRM SSB model derived with the crossovers method is approximately -3.3% SWH.

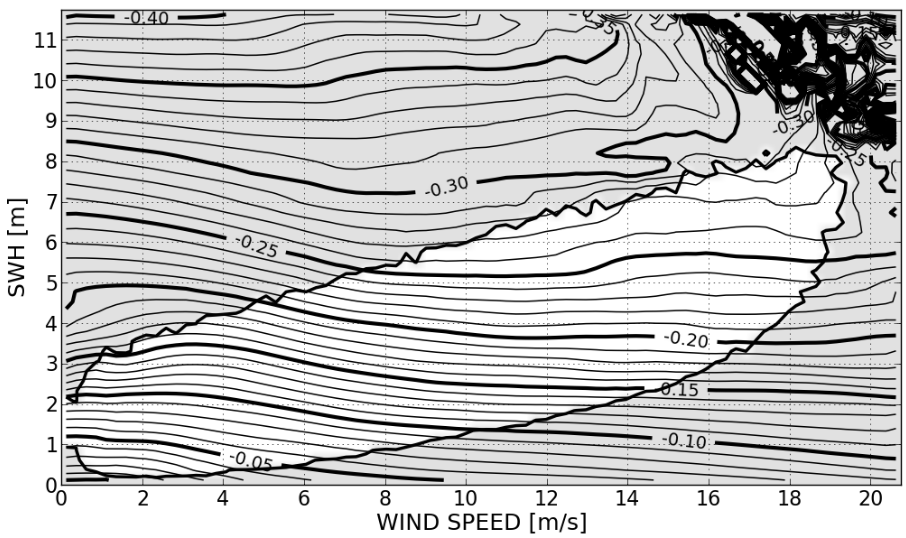

Figure 2.4: SAR SSB model derived from the LRM SSB model and the range differences (Figure 2.3).

The map of merged SLA data in Figure 2.5 shows good agreement between the LRM and SAR modes data after applying a bias when one computes the SAR SLA. Figure 2.6 provides two zooms of Figure 2.5 to focus on the eastern tropical Pacific Ocean and the European side of the Atlantic Ocean. The additional bias applied on SAR data seems to suit better to the Pacific area than to the Atlantic zone. This can thus be optimized.

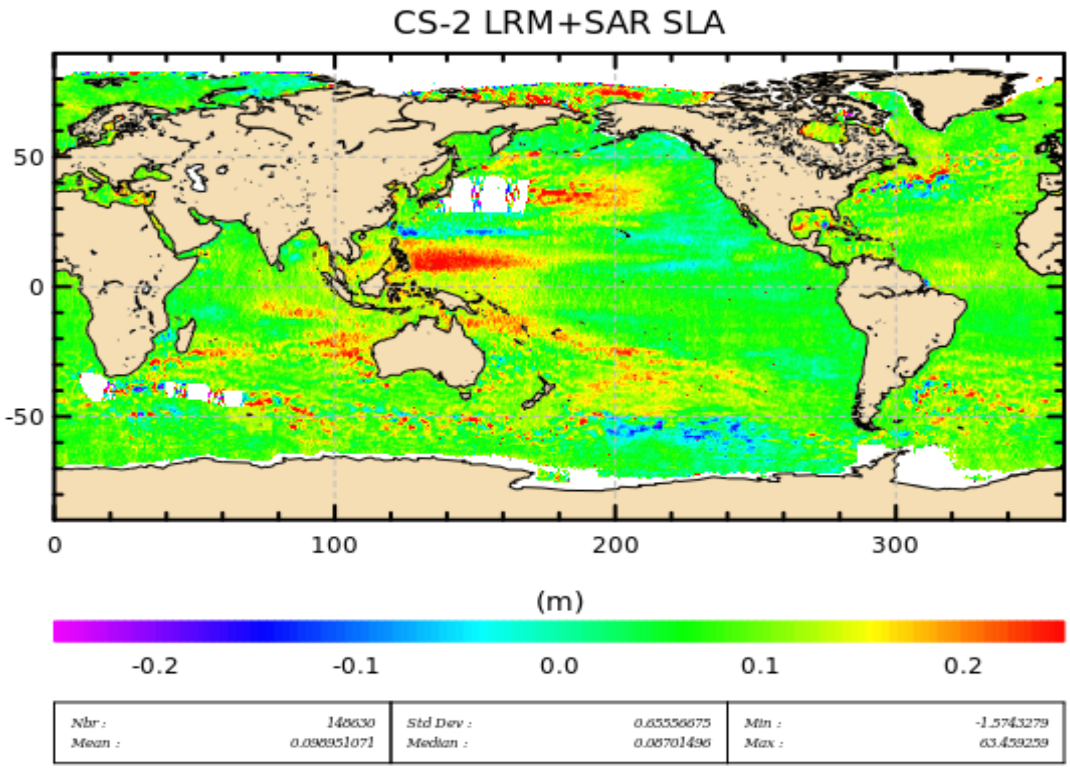

Figure 2.5: Map of merged LRM and SAR SLA estimates over 11-month period.

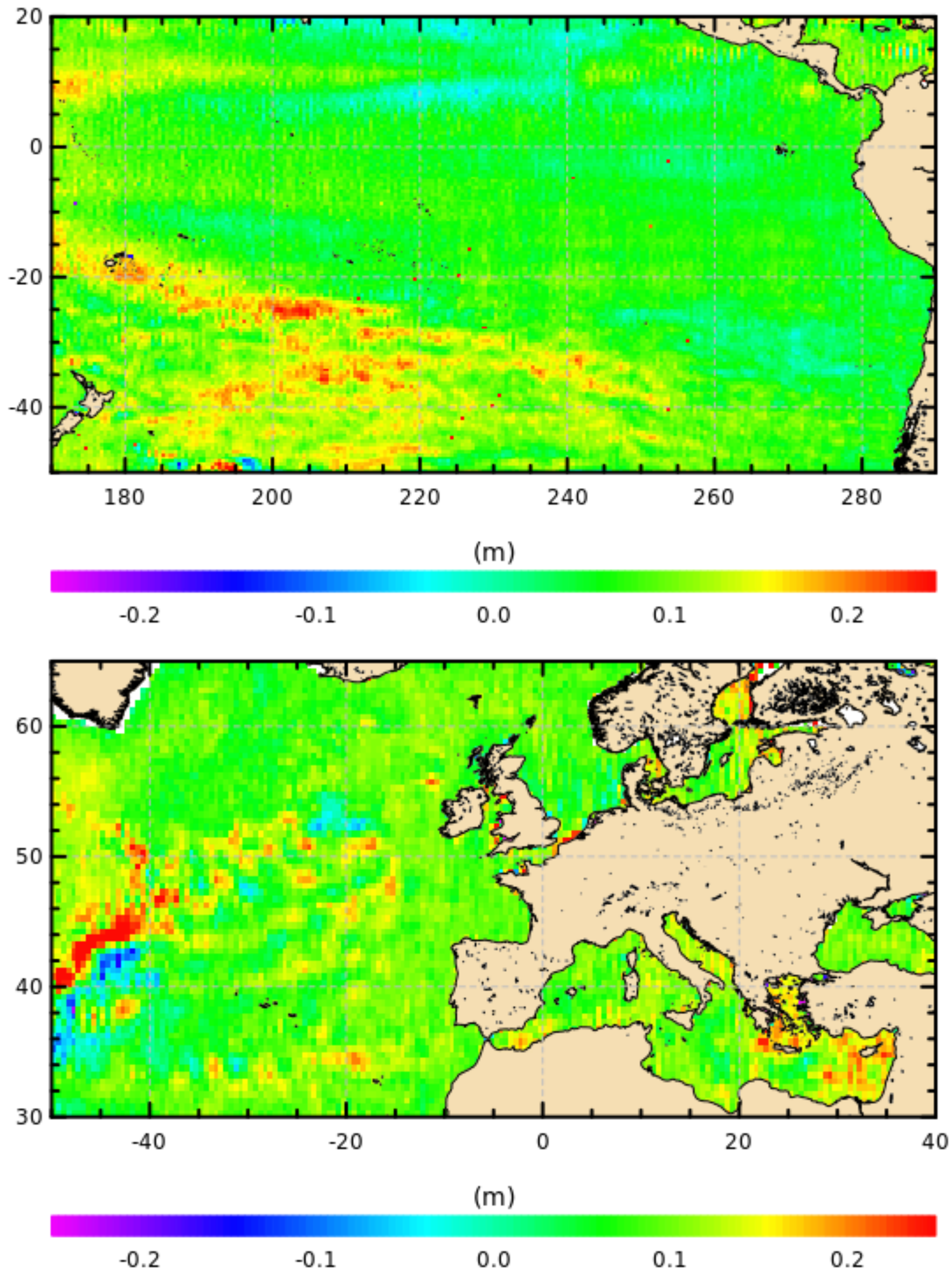

Figure 2.6: Top: same as Figure 2.5 but focused on Pacific area and bottom: focused on Atlantic zone.

This SAR SSB correction will be applied to Cryosat-2 data over open ocean at low rhythm (because of low SWH variation) then copied down to 20-Hz rate.

References

[Collard F., 2005]: *"Algorithmes de vent et période moyenne des vagues Jason-1 à base de réseaux de neurones"***,** BO-021-CLS-0407-RF, Boost Technologies.

[Labroue S. and N. Tran, 2007]: *"Envisat RA2 and MWR Product and Algorithm and evolution studies – WP1200*", Technical Report CLS-DOS-NT-07.133.

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