

# THE USE OF AIRCRAFT-BORNE MAS DATA FOR MAPPING SEDIMENT TRANSPORT ALONG THE LOUISIANA COAST\*

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## ABSTRACT

Sediment-rich effluent from the Mississippi River distributary system flows into clear Gulf of Mexico waters along the Louisiana coast. The sediment, which serves as material for shoreline progradation, is transported by nearshore currents to various portions of the coastal zone. Modis Airborne Simulator (MAS) 50 meter resolution data from NASA's ER-2 platform is used to monitor suspended sediment transport in the Atchafalaya Bay region of the Louisiana coastal zone. MAS repeat coverage visual/near infrared images from a typical 3-6 hour ER-2 mission, are georeferenced, remapped and animated for manual tracking of inwater turbidity features. MAS atmospherically corrected red channel (745 nm) data is used to create estimates of suspended sediment concentration (SSC) using a regression relationship based on in situ SSC samples. The MAS SSC and water motion estimates are combined to produce estimates of sediment transport for the near-surface water column (upper 1 meter). Results for 24 January 1995, a day of light surface winds from the east, show strong transport from the Atchafalaya Bay into the East and West Cote Blanche Bays and relatively weak transport to the Gulf of Mexico continental shelf. Based on previous work, the transport pattern is expected to respond to surface wind forcing, especially associated with the cold front wind system.

## 1.0 INTRODUCTION

The Louisiana coastal zone is affected by sediment influx from the Mississippi River distributary system. One of those distributaries, the Atchafalaya River, carries high sediment loads (up to 1000 mg/l) into the Atchafalaya Bay region of the coast (figure 1), sustaining a nearshore sediment dominated turbid water mass. Sediment is

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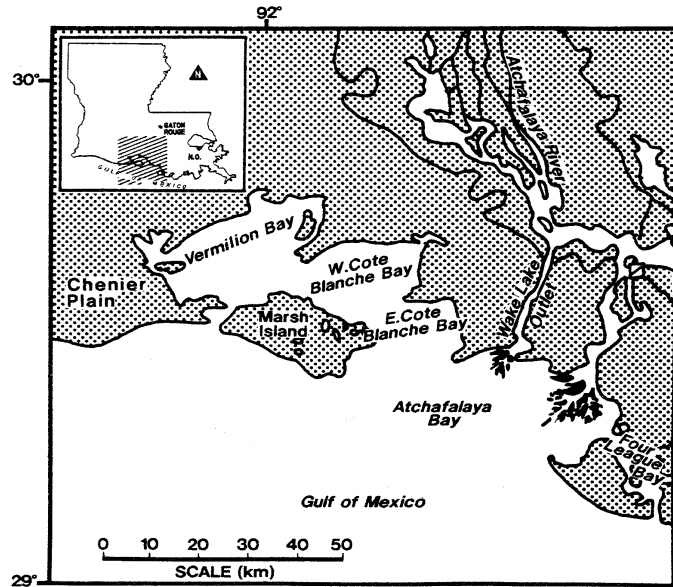


Figure 1. Atchafalaya Bay Region of Louisiana Coastal Zone.

transported variously into coastal bays, estuaries, and out onto the continental shelf of the Gulf of Mexico by variable coastal currents, which are modulated by surface winds and astronomical tides. Previous work has identified new (beginning in 1987) sediment accumulation on coastal shorelines downdrift of the Atchafalaya Bay region (Huh et al., 1991). Moeller et al. (1993) and earlier, Roberts et al. (1987) have indicated that the pattern of sediment transport is strongly affected by surface winds associated with cold front systems. These winds act to drive up and set down water levels in the microtidal Louisiana coastal zone. This paper will focus on the transport patterns on 24 January 1995 as seen by the MODIS Airborne Simulator (MAS) (King et al., 1996). MAS flies on NASA's ER-2 high altitude aircraft, collecting 50 meter resolution data across its 37 km scanning swath in 25 laboratory calibrated visible/near infrared and 25 onboard calibrated infrared channels (Table 1). MAS and, earlier, the MAMS (Multispectral Atmospheric Mapping Sensor) instrument have flown some 20 missions over the Louisiana coast since 1988. Three MAS overpasses of the Atchafalaya Bay over a 2 hour period are used to generate water motion vectors using georeferenced visible/near infrared data; MAS atmospherically corrected visible/near infrared data are investigated to estimate suspended sediment concentration (SSC). These quantities are combined to produce estimates of sediment transport.

## 2.0 DATA SET COLLECTION

Under clear skies on 8 and 24 January 1995, MAS was flown on the ER-2 over the Louisiana coast. On both days, boat teams from the Coastal Studies Institute (CSI), Louisiana State University (LSU) collected in situ water samples (from top 1 meter of the water column) in the Fourleague Bay region and off the Chenier Plain coast in

TABLE 1. Spectral characteristics of the 50-channel MODIS Airborne Simulator (MAS),

MAS channel	Central wavelength (μm)	Spectral resolution (μm)	MAS channel	Central wavelength (μm)	Spectral resolution (μm)	MAS channel	Central wavelength (μm)	Spectral resolution (μm)
1	0.547	0.044	18	2.030	0.048	35	4.36	0.15
2	0.657	0.053	19	2.080	0.047	36	4.51	0.15
3	0.704	0.042	20	2.129	0.047	37	4.66	0.16
4	0.745	0.041	21	2.178	0.047	38	4.82	0.16
5	0.786	0.041	22	2.227	0.047	39	4.97	0.15
6	0.827	0.042	23	2.276	0.046	40	5.12	0.15
7	0.869	0.042	24	2.327	0.047	41	5.28	0.16
8	0.909	0.033	25	2.375	0.047	42	8.59	0.44
9	0.947	0.046	26	2.96	0.16	43	9.77	0.62
10	1.609	0.052	27	3.11	0.16	44	10.54	0.49
11	1.663	0.052	28	3.27	0.16	45	11.01	0.54
12	1.723	0.050	29	3.42	0.17	46	11.97	0.45
13	1.775	0.049	30	3.58	0.16	47	12.85	0.46
14	1.825	0.046	31	3.74	0.16	48	13.24	0.48
15	1.879	0.045	32	3.90	0.16	49	13.71	0.60
16	1.932	0.045	33	4.05	0.15	50	14.19	0.42
17	1.979	0.048	34	4.21	0.16			

coordination with ER-2 overpasses. Locations of in situ data collection are chosen to maximize turbidity variance, improving the value of the limited sample size (~ 30 samples). On 24 January, the ER-2 flew a racetrack pattern, making 3 overpasses of the Atchafalaya Bay between about 1525 and 1715 UTC (45 minute repeat cycle) (figure 2). Morning data collection was chosen to minimize sunglint in the imagery. Surface winds were relatively light (5 m/s ENE) as atmospheric high pressure lay just to the north. The clear, dry, post-frontal atmospheric conditions optimized the MAS data depiction of coastal water features.

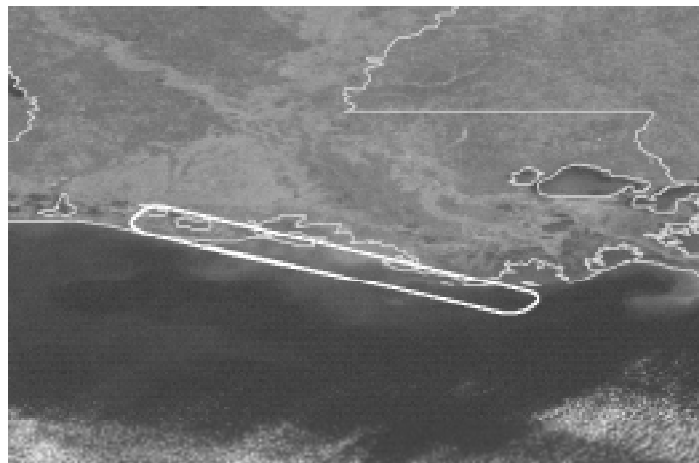


Figure 2. GOES-8 Image on 24 January 1995 with ER-2 Flight Pattern.

## 3.0 DATA PRODUCTS

### 3.1 Water Motion Vectors From MAS Data

Tracking water (and atmospheric) features for estimating motion vectors is not new (see recount in Breaker et al., 1994). Historically, both manual (analyst in the production stream) and automated (e.g. maximum cross correlation) techniques have been applied. For estimating water motions with MAS, a simple manual approach was applied to track turbidity features in MAS orange-red (657 nm) and near infrared (869 nm) data. In a manual approach, the analyst subjectively identifies trackable features, determining the feature position in each subsequent image. The MAS imagery are georeferenced and remapped to common projection to facilitate viewing a temporal sequence of images with minimal land motion or "jitter" (during ER-2 flight, data on the three axis (pitch, yaw, roll) aircraft orientation, altitude and nadir latitude/longitude is recorded for use in positioning MAS imagery on the earth geoid). Viewing three or more images in sequence is desirable as the additional image(s) help to fix the feature's progress in the mind of the analyst as well as establish the conservation characteristic of the feature. For the 24 January data set in this paper, a three image sequence was animated on the University of Wisconsin's Man-computer Interactive Data Access System (McIDAS). Velocity vectors are computed from the manually determined position of the feature and associated time data. In the future, automated feature tracking techniques, including feature rotation and deformation (e.g. Kuo and Yan, 1994) will be tested.

### 3.2 Suspended Sediment Estimate

Isolating the inwater scattered radiance contribution requires the removal of atmospheric scattering (molecular and aerosol) and sunglint contributions to the sensor observed total radiance. MAS visible/near infrared calibrated radiances are atmospherically corrected using the approach outlined in Moeller et al. (1993). This approach is based on single scattering atmospheric modeling work developed by Gordon (1978) and furthered by many (e.g. Gordon et al., 1983, Guzzi et al., 1987). Removing the atmospheric contribution isolates the water leaving radiance (radiance upwelling out of the water column) quantity which is convertible to a SubSurface Reflectance (SSR) quantity following Gumley (1990). The SSR is essentially the water leaving radiance normalized by the solar incoming radiance entering the water column. The 24 January MAS SSR for channels 1-9 (547 - 947 nm) were regressed against the fifteen in situ SSC samples collected in Fourleague Bay. The best relationships were produced by red to near infrared channels (MAS channels 4-6; 745, 786, 827 nm). This is not surprising because the water penetration depth in this region of the spectrum is small (~ 1 meter or less in turbid water), and as such the turbidity signal will originate from a level similar to the in situ samples. Shorter wavelength channels integrate over larger columns and may pick up bottom reflectance in the shallow bay waters, while longer wavelength channels see progressively less of the water column and are adversely affected by atmospheric water vapor absorption in the 900 - 1000 nm spectral region. The channel 4 (745 nm) regression was chosen for application (figure 3). A quadratic provided a good fit of the

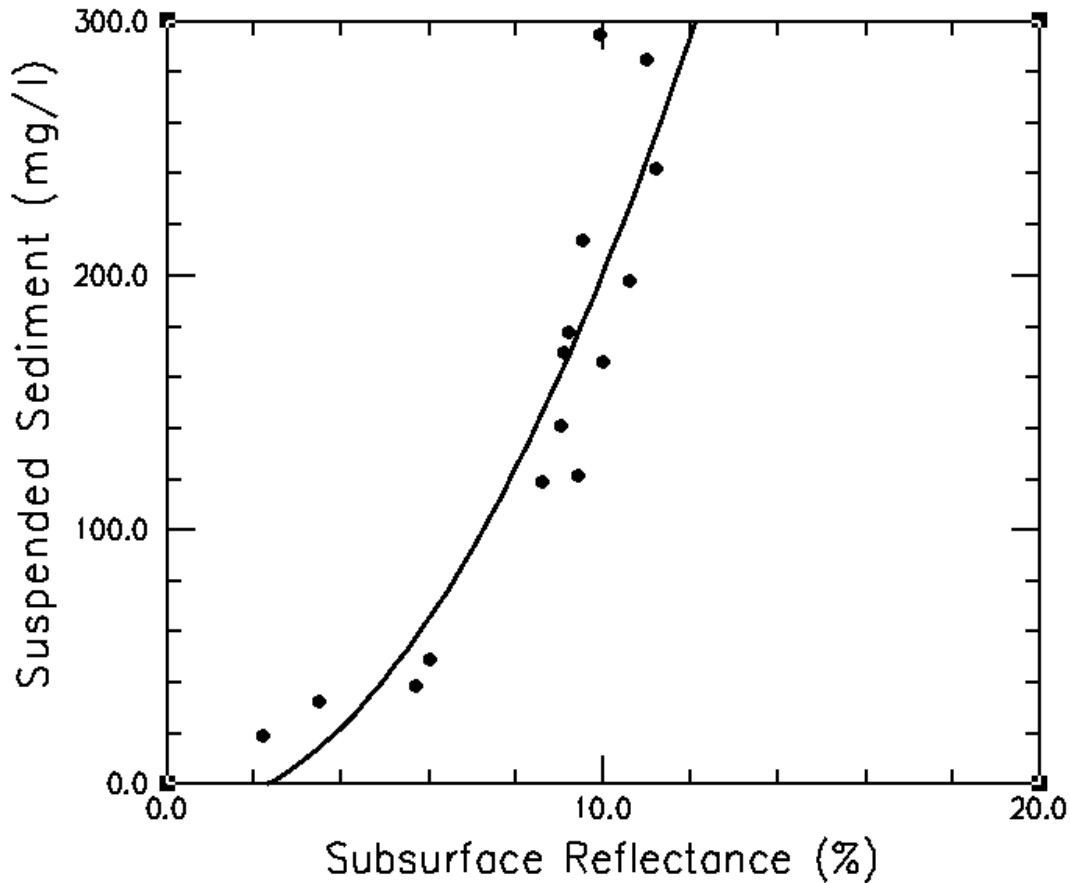


Figure 3. MAS Atmospherically Corrected 745 nm Relationship With In Situ SSC.

data, with an RMS of 37.8 mg/l. The 2nd order nature of the SSR-SSC relationship is suggestive of the nonlinear relationship that exists between optical depth and reflectance in the radiative transfer equation.

### 3.3 Sediment Transport Estimate

The MAS water motion vectors and SSC estimates are combined with water penetration depth to produce estimates of sediment transport ST,

$$ST(\text{kg/s}) = V * SSC * Z * D \quad (1)$$

where V is the water motion velocity (m/s), SSC is the MAS regressed suspended sediment concentration (mg/l), Z is the water penetration depth (m) and D is the MAS footprint width (m). Physically, eqn. (1) represents a sediment transport through the cross section represented by the MAS footprint width and the water column layer from which the sediment scattering signal originates. From work performed by Gordon (1975), Z is

estimated to be about 1 meter or less for the MAS red channel at 745 nm. Much of the Atchafalaya Bay is about a meter or so in depth; surrounding bays (East, West Cote Blanche, etc.) are probably somewhat deeper although good bathymetry for the region is difficult to obtain given the dynamic impact that the sediment influx and resuspension/precipitation processes have on the local bathymetry. As such, the sediment transport estimates reported herein do not necessarily represent full water column transport. However, it is plausible that water motions are fairly uniform in shallow columns (with exception of surface drag at subaqueous bottom), and transmissometer profiles in the Atchafalaya Bay region can be used to model the vertical profile of SSC (they indicate an SSC maximum near the subaqueous bottom which is likely a result of resuspension activity). These assumptions, coupled with good knowledge of the water column depth could be applied to adjust the MAS sediment transport estimates to full column estimates.

#### 4.0 RESULTS AND DISCUSSION

Figures 4 and 5 show water motion velocity and sediment transport data for 24 January 1995, respectively, plotted over MAS remapped SSC imagery. Vector scaling is shown in the figures; vectors point in the direction of flow. For sediment transport estimation, the SSC quantity is averaged over a 3 X 3 pixel box centered at the water motion vector location (base of vector). Water motion velocity relative error (georeference error over the displacement distance) was estimated in the 10-20% range based on tracking land motion in the MAS images. This error translates directly into a 10-20% relative error in the sediment transport estimates as well. It is clear when comparing figures 4 and 5 that relatively high water motion velocity does not imply high sediment transport. It's noteworthy though that the SSC maximum (southwest side of the Atchafalaya Bay) exists in a region of high water motion velocity. The high velocities may be enhancing resuspension activity near this SSC maximum. Outdated bathymetry charts indicate that water depths are about 1-2 meters around the SSC maximum and increase towards the southwest (where velocities remain high but SSC is much lower). A review of MAS imagery collected on 8 January 1995 did not show an SSC maximum at this location; thus it is not likely that this maximum is caused by bottom reflectance. Continuous sediment influx into the Atchafalaya Bay takes place primarily at two locations, the Atchafalaya River and Wax Lake Outlet (located at the right and left newly forming deltas, respectively). A 26.7 kg/s sediment transport is estimated at the mouth of the Atchafalaya River (no trackable feature was available for estimate at mouth of Wax Lake Outlet). Using eqn. (1) and assuming constant water motion velocity and SSC with depth, total sediment transport from the mouth of the Atchafalaya River (~1200 meters wide, dredged to about 15 meters deep for shipping purposes) is estimated at 9612 kg/s. This rate comes to about  $3.0 \times 10^{11}$  kg/yr. Approximating the volume of the high turbidity zone in the Atchafalaya Bay at 20 km X 20 km X 1 meter depth, and using an average MAS SSC of 200 mg/l over this domain, the total sediment load of the Atchafalaya Bay is estimated at 80,000,000 kg. Thus, for the estimated total transport rate at the mouth of the Atchafalaya River, the time required for the Atchafalaya River to replace the sediment load is on the order of a few hours. This simple approximation shows that the sediment transport rate in the Atchafalaya River has a continuous significant impact on the

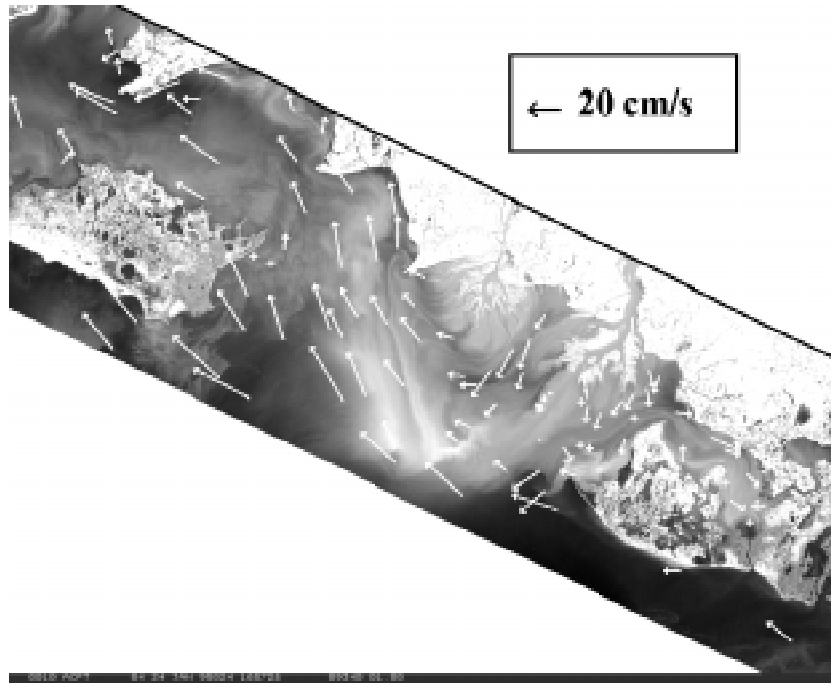


Figure 4. Water Motion Velocity Estimates from MAS 24 January 1995 Data.

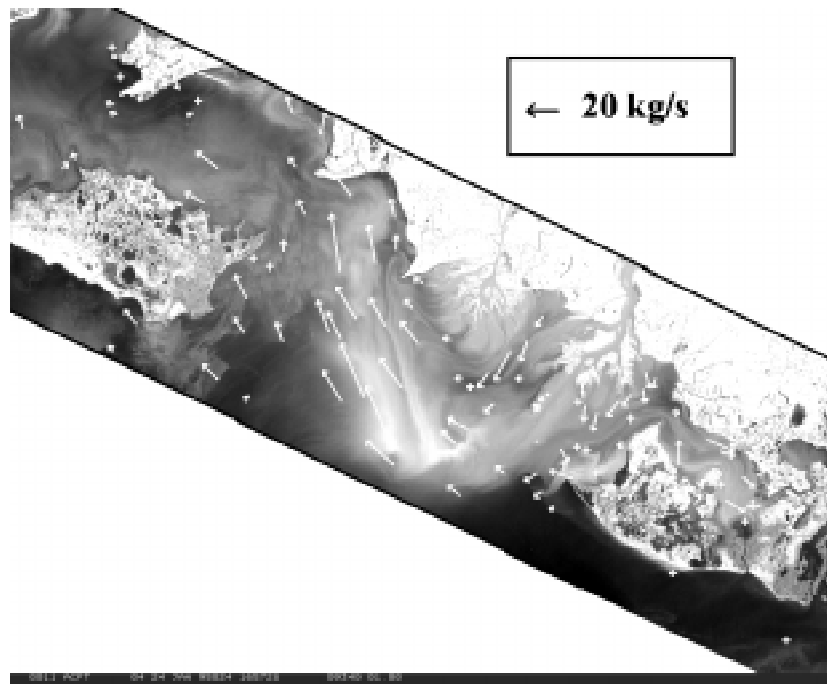


Figure 5. Sediment Transport in the Atchafalaya Bay Region on 24 January 1995.

sediment load in the Atchafalaya Bay. Reducing or increasing the sediment transport in the Atchafalaya River (e.g. local heavy rains, upstream heavy rain or seasonal drought/flooding) will cause near term variation in the Atchafalaya Bay sediment load (tempered by resuspension/precipitation activity). This sediment load is available for transport to other bays and shoreface. For example, in figure 5, East Cote Blanche Bay is the recipient of strong sediment transport from the Atchafalaya Bay as water velocities in excess of 30 cm/s advect highly turbid water. Water motion velocities and sediment transport in East Cote Blanche Bay are smaller, suggesting a net positive flux of sediment in that region. The Fourleague Bay basin also appears to be experiencing a net positive flux of sediment from the Atchafalaya Bay. No sediment transport from Fourleague Bay into the Gulf of Mexico is indicated through the thin southern outlet connecting them. Instead sediment appears to be transported into waterways on the east side of Fourleague Bay.

Previous MAS (and MAMS) data have indicated that local transport patterns vary greatly in the Atchafalaya Bay region. This has been inferred from variant positioning of SSC maxima and minima as well as through animation of the imagery. SSC maxima have been variously positioned Gulfward over the continental shelf, westward in East and West Cote Blanche Bay and Vermillon Bay, as well as eastward in Fourleague Bay. Obvious indications of SSC transport from Fourleague Bay into the Gulf of Mexico have also been observed. SSC patterns are related to variation of sediment transport from the Atchafalaya River, resuspension activity, and nearshore transport currents (a function of astronomical tides, and atmospheric forcing). A case study in Moeller et al. (1993) showed that southwesterly surface winds retarded sediment transport from the Atchafalaya Bay westward to the Chenier Plain region. AVHRR data have shown sediment transported southward from the Atchafalaya Bay region onto the Gulf of Mexico continental shelf following cold front passages (Walker et al., 1992). Most recently, Moeller et al. (1996) used GOES-8 1 km visible data to show variation in general transport patterns associated with changing surface wind conditions. These investigations point to surface wind as an important influence on transport patterns in and around the Atchafalaya Bay region. In the future, additional MAS data sets will be collected and analyzed for transport patterns and their relationship to atmospheric forcing. In situ data will be expanded to include continuous monitoring of inwater transmission (for SSC data collection enhancement) and the deployment of drifting buoys for estimating water motion velocities.

## 5.0 SUMMARY

A demonstration using ER-2 mounted MAS 50 meter resolution data for estimating water motion velocity and sediment transport in turbid coastal waters has been presented. MAS georeferenced visible/near infrared data viewed in sequence is used to manually track turbidity features to yield small scale water motion velocity estimates. The ER-2 platform shows itself to be of sufficient stability during repeat flight track coverage to allow the production of useful water motion velocities from MAS data (within 10-20% relative accuracy). MAS atmospherically corrected visible/near infrared data have been used to estimate suspended sediment concentration (SSC) using a regression relationship

generated with in situ SSC data collected during ER-2 overflight. The MAS red channel (745 nm) was chosen as producing the best relationship. Sediment transport estimates generated from the water motion velocities and SSC data indicate variable sediment accumulation in the Atchafalaya Bay coastal region. Such data are informational for hydrodynamic, coastal geomorphic, and marine ecological investigations. The relationship of sediment transport to surface wind forcing, especially associated with cold front wind systems is being solidified by this work and will continue to be pursued.

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