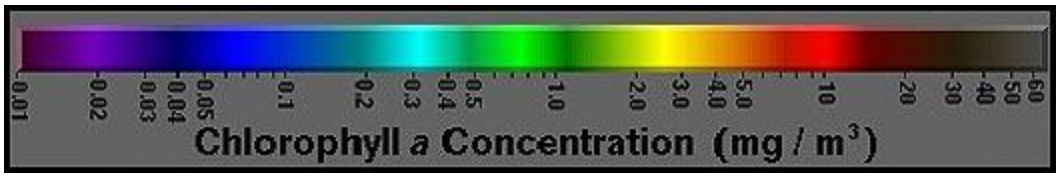
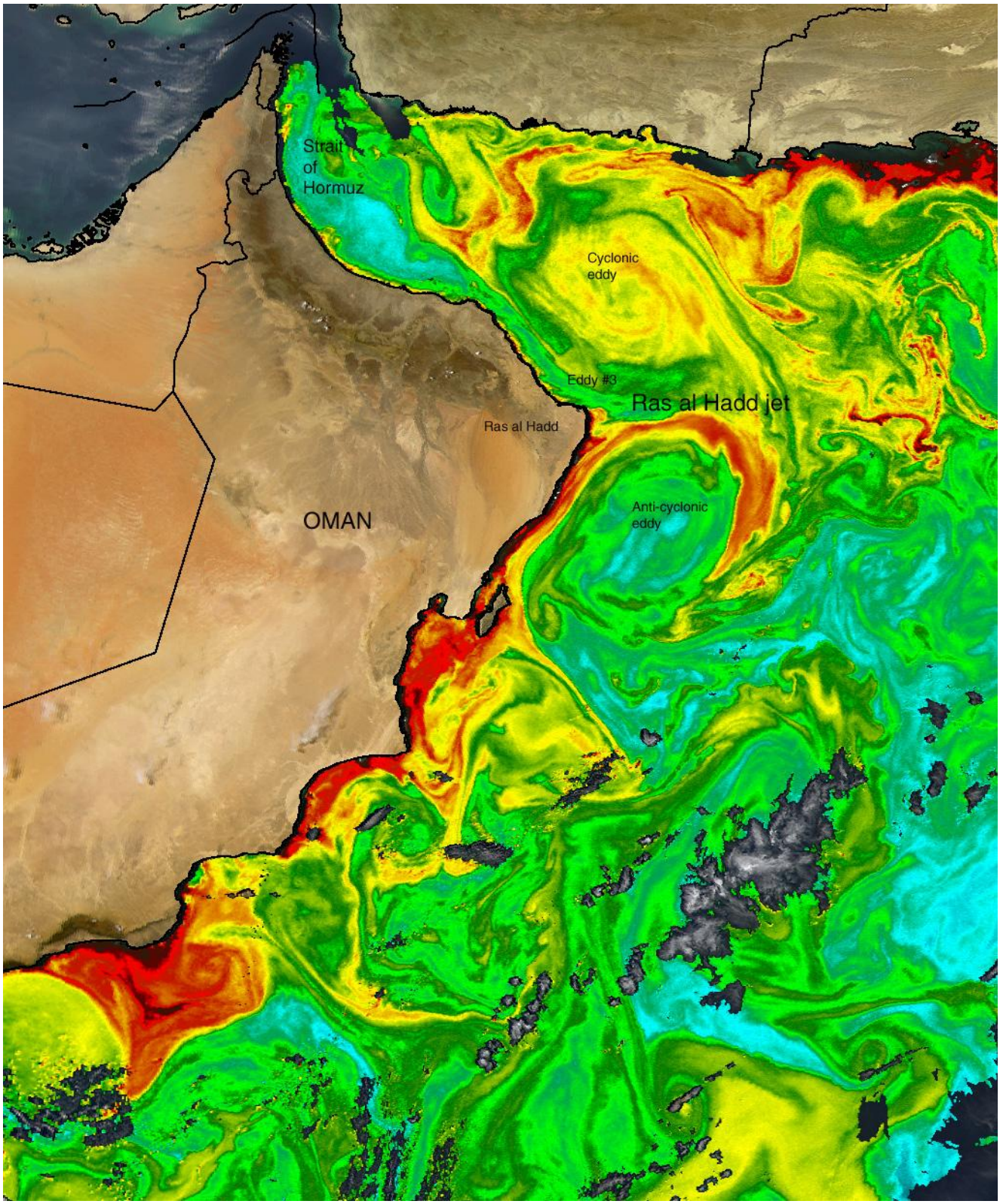
SCIENCE FOCUS: Ocean Circulation

The Ras al Hadd Jet
Stirring the Arabian Sea



SeaWiFS image of the Arabian Sea from November 4, 2002, showing the Ras Al Hadd jet and related circulation features. On the next page is an image with labeled features that are referred to in the subsequent text.


Strait
of
Hormuz
Cyclonic
eddy
Eddy #3
Ras al Hadd jet
Ras al Hadd
OMAN
Anti-cyclonic
eddy

Every year, commencing in May and June, winds began to blow northward from the Saudi Arabian peninsula across the Arabian Sea. As these winds intensify, they foster the powerful Southwest Monsoon, which brings torrential rains to the subcontinent of India. During the height of the Southwest Monsoon in July and August, the thick layer of clouds over the Arabian Sea makes visible remote-sensing of the sea surface by sensors such as SeaWiFS and MODIS, virtually impossible.

But when the clouds clear in autumn, ocean color sensors reveal a roiled, colorful sea surface. The prevailing oceanic currents created by the winds of the Southwest Monsoon bring cold, nutrient-rich water to the ocean surface, fostering intense phytoplankton activity that is the base of the one of the world's last great unspoiled marine ecosystems.

The most powerful current feature in the Arabian Sea during the Southwest Monsoon is an extension of the northward flowing (from May-December) Somali Current and Oman Coastal Current. At the easternmost point of Oman—Ras Al Hadd—this current veers abruptly off the coast into the Arabian Sea, forming the Ras Al Hadd jet (also termed the Ras Al Hadd front). As the Southwest Monsoon peaks in intensity through the month of August, it significantly enhances the strength of the northward-flowing coastal current and the Ras al Hadd Jet extending into the Arabian Sea.

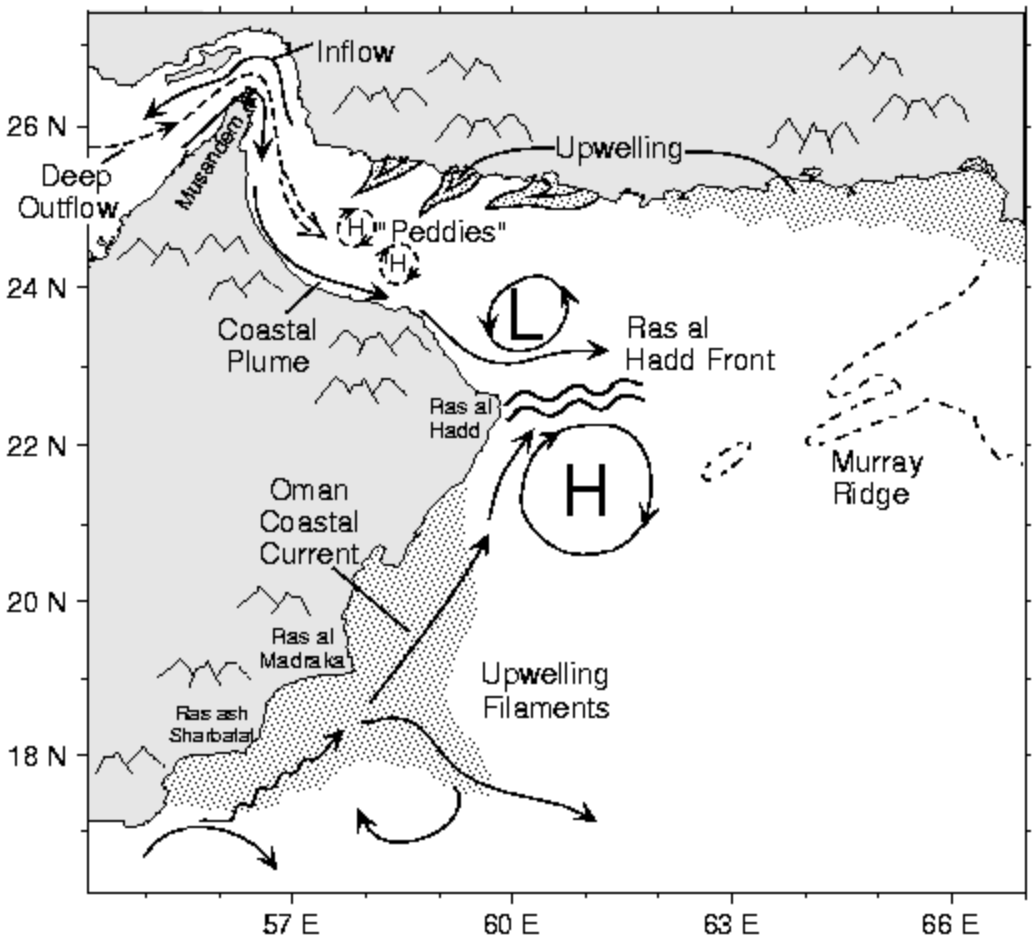
The largely uninhabited coastal region of Ras Al Hadd is famous for one particular reason: its pristine beaches provide a safe haven for the nests of green sea turtles that inhabit the Indian Ocean. The Ras al Hadd beaches are the largest of three main green turtle nesting areas in the Indian Ocean. The nesting season for the turtles is September to November.

The circulation pattern created by the Ras al Hadd Jet is quite obvious. During the period that the jet exists off of Oman, it creates a twin, or dipole, gyre system. The jet forms the northern boundary of a large anticyclonic (clockwise) eddy. Though phytoplankton concentrations in the jet are elevated, the concentrations in the anticyclonic eddy are low. North of the Ras al Hadd jet, a cyclonic (counter-clockwise) eddy forms, and this eddy contains higher concentrations of nutrients and phytoplankton. Late in the monsoon season, a third smaller eddy forms near the coast, forming a "tri-pole" circulation pattern.

The image at the top of the page actually captures a transitional period during the monsoon season. In September, the monsoon winds weaken, and this results in a corresponding decrease in the strength of the wind-forced current. As the Ras Al Hadd Jet "collapses", which can be visualized in the image as the jet curves around the anticyclonic eddy, both the cyclonic and anticyclonic eddies drift to the south.

Further to the east, in the central Arabian Sea, convoluted circulation patterns formed by the dynamic effects of the sustained monsoon winds and interwoven ocean currents seem to marbleize the ocean surface.

The diagram below shows the main features of the monsoonal circulation in this region.



Schematic diagram of oceanic circulation in the Arabian Sea during the southwest monsoon. Courtesy of the Rosenstiel School of Marine and Atmospheric Science, University of Miami.

The image below, which is derived from SeaWiFS data acquired on November 6, 1999, provides another view of the Ras al Hadd jet and the associated eddy circulation. The tri-pole circulation is particularly evident; the arrows show the anticyclonic circulation to the south, and the cyclonic circulation of the coastal eddy.

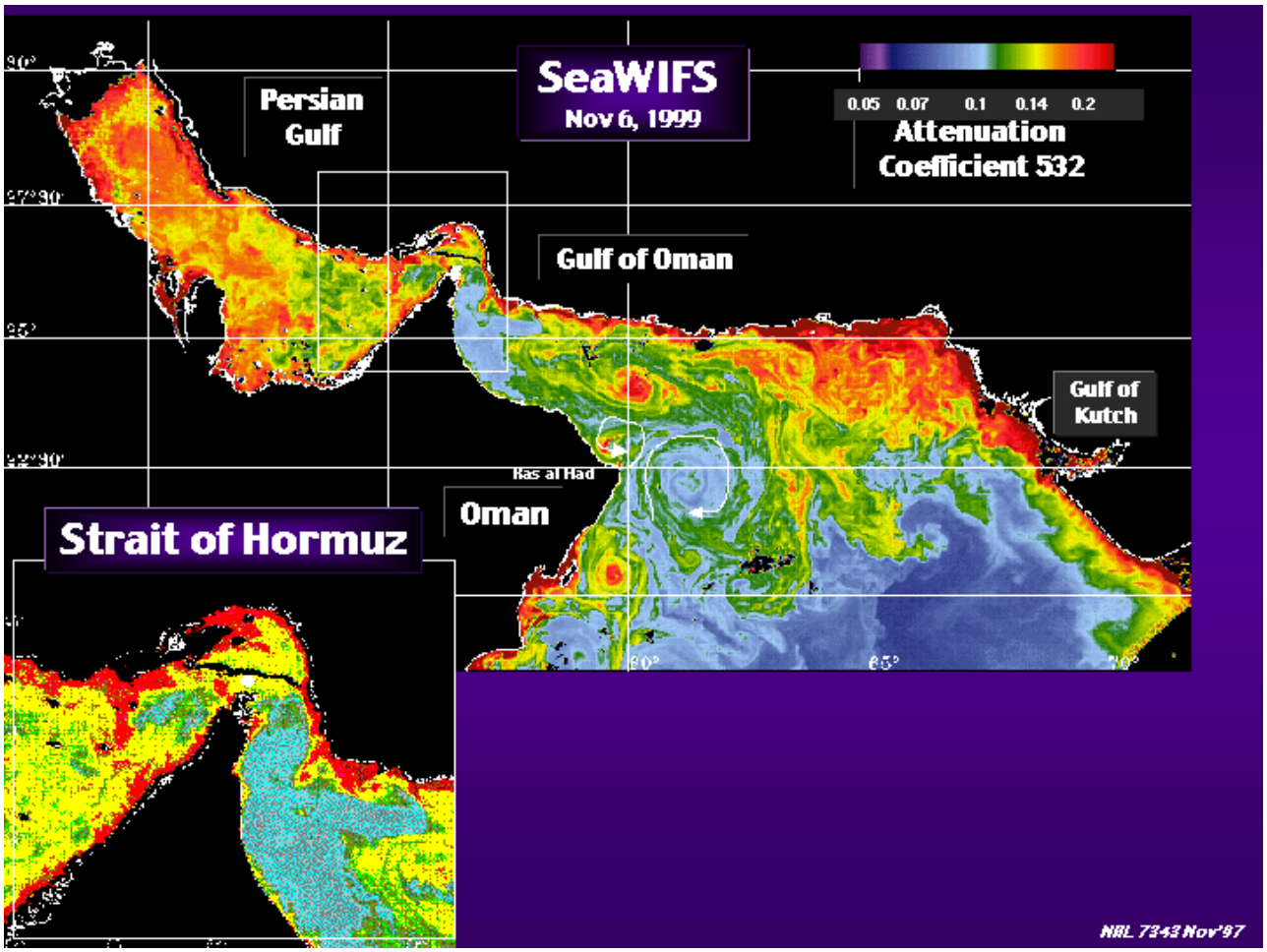


Image of the diffuse attenuation coefficient at 532 nanometers (nm), derived from SeaWiFS data acquired on November 6, 1999. Although SeaWiFS does not have a 532 nm band, calculations using SeaWiFS data at 555 nm allow derivation of this quantity for comparison to MODIS data acquired at the 532 nm wavelength. Image courtesy of Naval Research Laboratory, Stennis Space Center, Mississippi.

Sea surface temperature data allows further insight into the dynamics of the circulation in this region. The main features in the image below are the upwelling regions caused by the flow of the Oman Coastal Current. The cold water creates a connected upwelling zone near the coast, with jets and filaments of cold water shooting into the warm Arabian Sea. The productivity of these jets is evident in the SeaWiFS image at the beginning of the article.

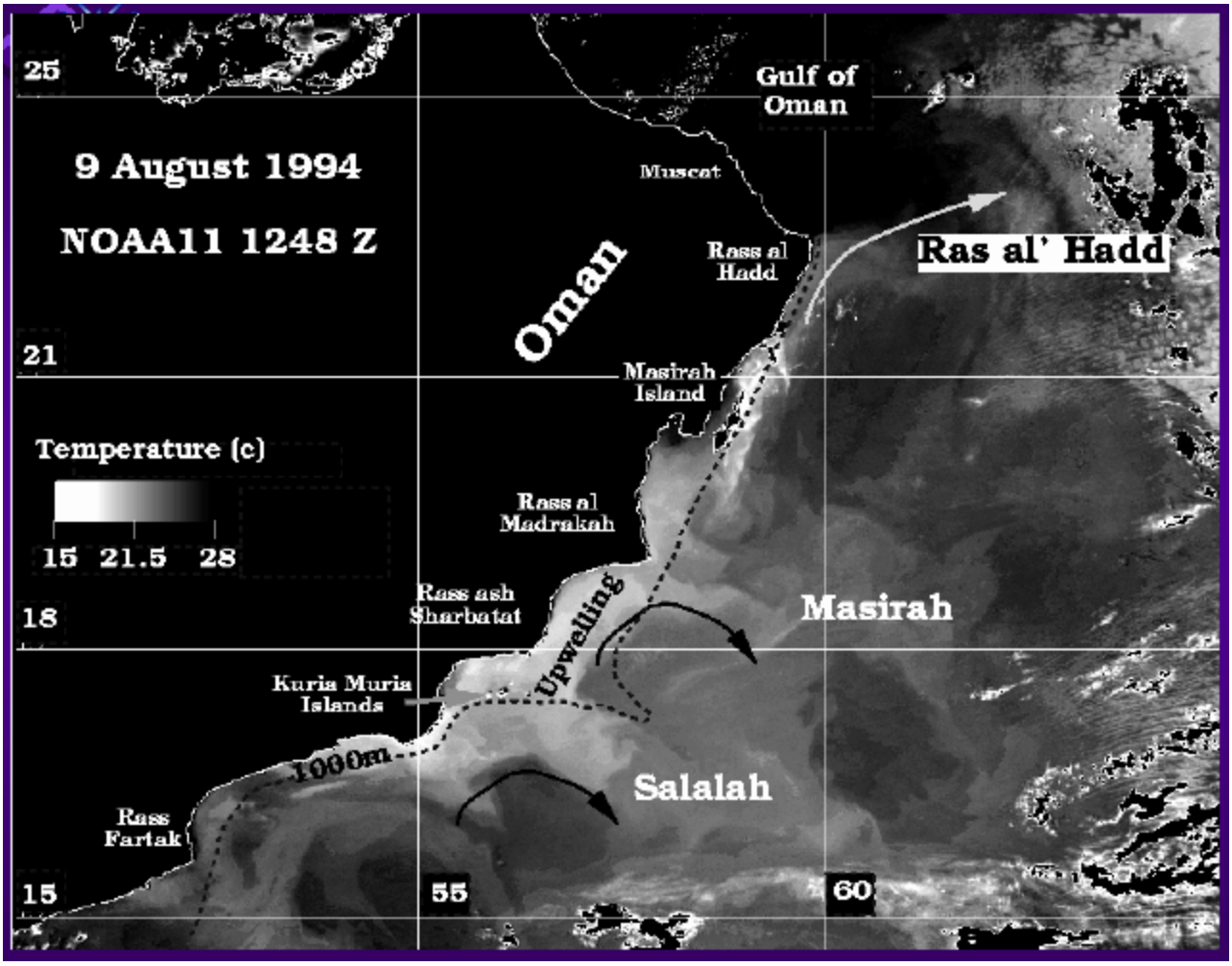


Image of sea surface temperature in the Arabian Sea, August 9, 1994. The sea surface temperature data for this image were acquired by the Advanced Very High Resolution Radiometer (AVHRR) instrument which orbits on polar-orbiting satellites operated by the National Oceanic and Atmospheric Administration (NOAA).

Though the Ras al Hadd jet seems like an easy-to-observe feature in these images, the difficulty of conducting oceanographic research in the Arabian Sea has made elucidating the details of this circulation pattern a fairly recent development. From 1994 to 1996, the Joint Global Ocean Flux Study (JGOFS) conducted the Arabian Sea Process Study, a focused study of the physical and biological dynamics of this region. This study vastly increased scientific understanding of the biological processes of the Arabian Sea. The use of sea surface temperature data during the study, and subsequent analysis of ocean color data from SeaWiFS, facilitated a much-improved understanding of how the swift-flowing oceanic currents are related to the marine productivity of this remarkable region.

However, the effect of the Ras Al Hadd jet can also be seen in Coastal Zone Color Scanner (CZCS) imagery. The *CZCS Classic Scenes* chapter "The Arabian Sea" includes a time-series of monthly CZCS scenes of this region. The image for October 1981 provides a clear view of the Ras Al Hadd jet and its associated eddies.

So, even as ocean color remote-sensing progresses in the 21st century with an armada of ocean color satellite instruments, there is still considerable value in the historical data provided by the plucky instrument that started it all.

Acknowledgments

Dr. Robert Arnone, Head of the Ocean Sciences Branch at the Naval Research Laboratory located at the Stennis Space Center, Mississippi, provided valuable editorial comments for this Science Focus! *article.*

Links

JGOFS Arabian Sea Process Study

Arabian Marginal Seas and Gulfs Report (PDF)

Short –term variability of phytoplankton blooms associated with a cold eddy in the northwestern Arabian Sea (abstract)

The influence of mesoscale eddies of the Arabian Sea on the slope currents of Red Sea and Persian Gulf Outflow water (PDF slide presentation)