Comparisons of Altimetry and Model Products with High-Frequency Radar Observed Radial Currents in the Straits of Florida

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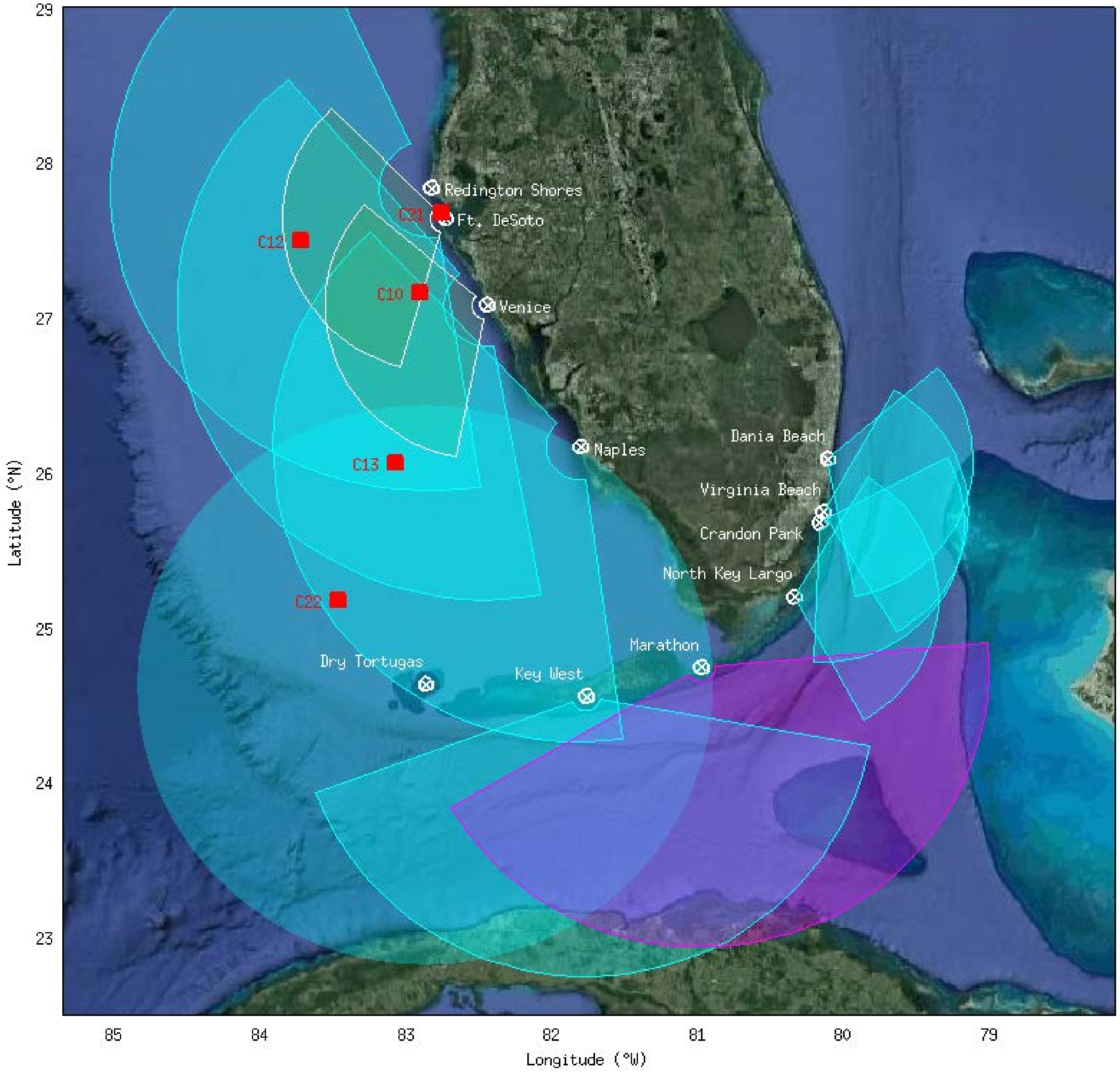


Theoretical Coverages High-Frequency Radars Along South Florida Coast

Recently the National Academies of Sciences, Engineering and Medicine (NASEM) implemented the Understanding Gulf of Mexico System (UGOS) Gulf Research Program (GRP) to advance our knowledge on what controls the Gulf of Mexico Loop Current evolution. Part of UGOS is the deployment of a set of three High-Frequency Radars (HFR) along the Florida Keys (Marathon, Key West and Dry Tortugas). These radars will help to fill the gaps between the 5-site HFR network on the West Florida Shelf and the 4-site HFR network along the Miami coast.

Whereas the Dry Tortugas and Key West HFRs are still awaiting site permits, the Marathon HFR was successfully installed in mid-December 2019.

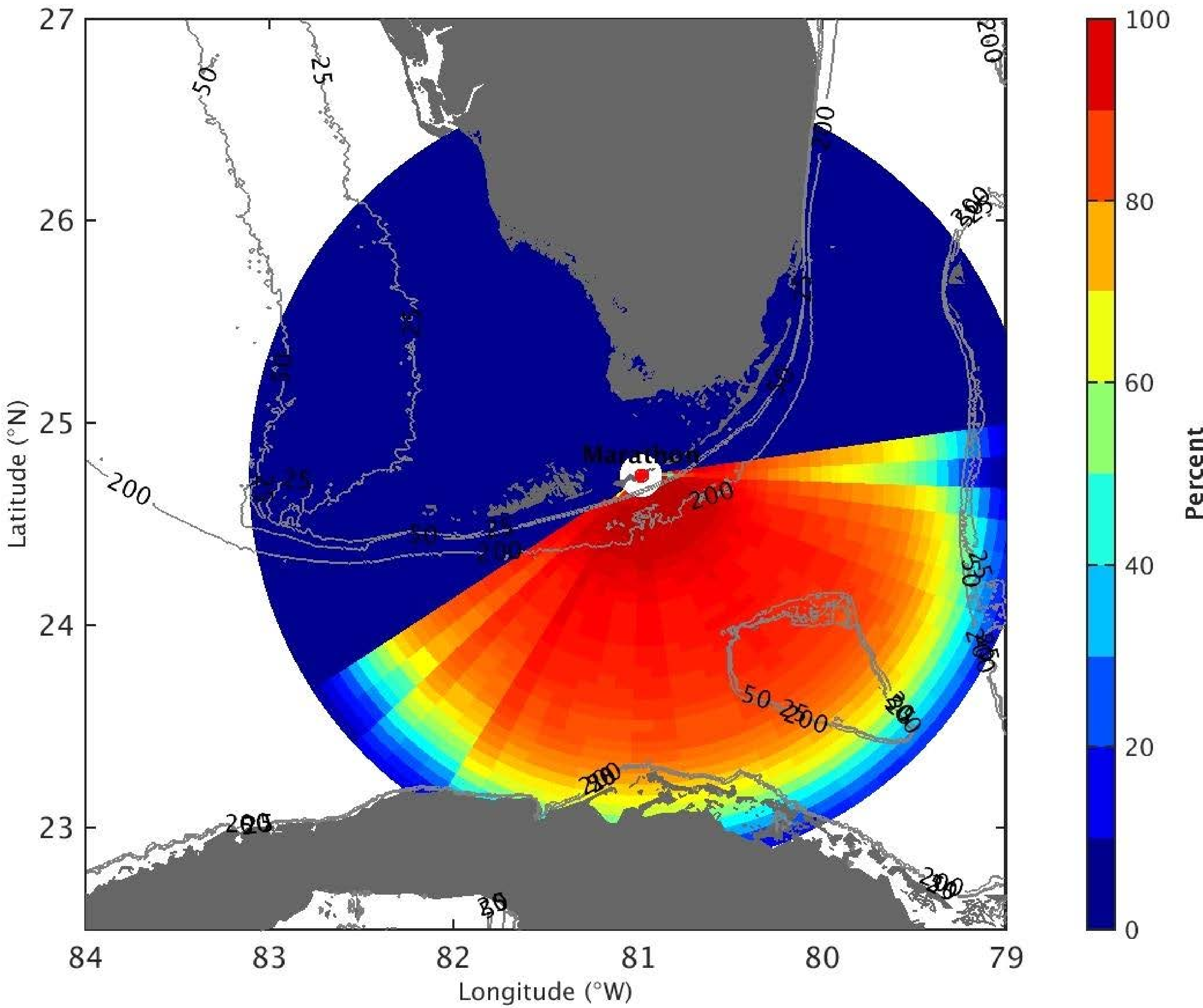
Radial velocity components are used in this study, because they are more accurate than HFR “total” velocity, which is subjected to GODP errors.

Spatial Coverage of Radial Data

(02/12/2020 – 09/10/2020)

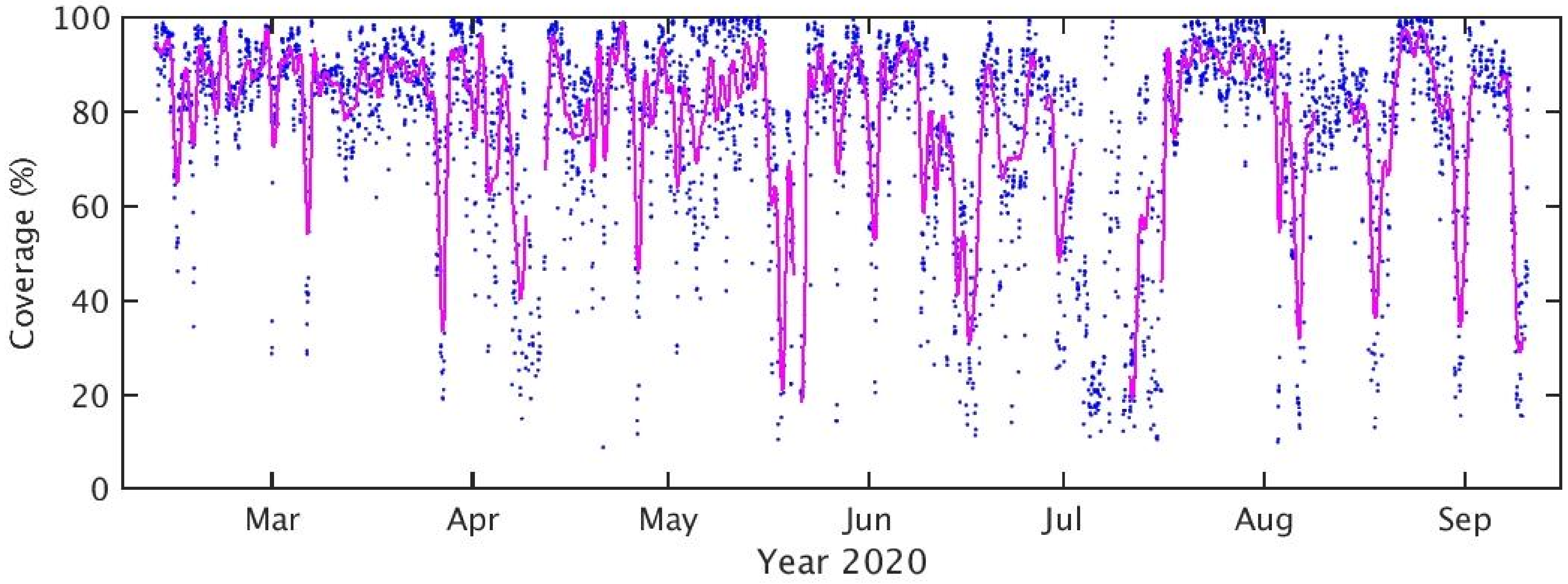
The Marathon HFR is a CODAR SeaSonde that operates at a nominal transmit frequency of 4.9 MHz with the intended purpose of observing surface currents out to an offshore working range of about 200 km thereby extending across the Straits of Florida to Cuba with nominal range and bearing resolutions of 5.8 km and 5°, respectively.

For each sector, the total number of valid radial velocity component data points are divided by the record length and is shown as percent. Higher data return occur near the site origin and lower data returns sometimes occur towards the outermost ranges. Certain bearing directions also show reduced data returns.

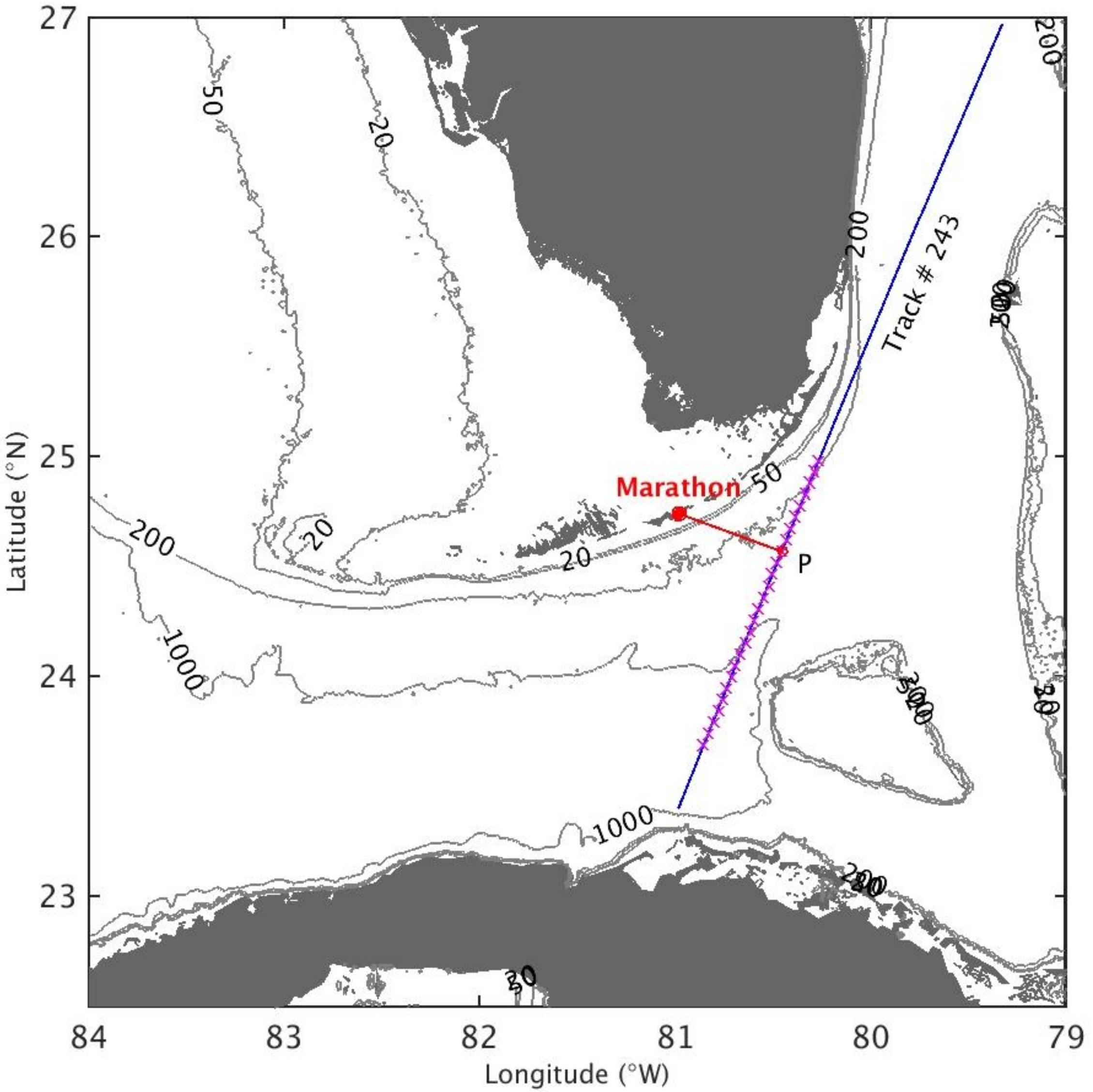


Time Series of CODAR Radial Data Return (Percent Coverage)

(02/12/2020 – 09/10/2020)



Coverage is defined as the number of sectors returning valid data each time normalized by the maximum number of sectors. In this way we see the wax and wane of HFR coverage over time. Most of the sampling interval shows more than 80% coverage, although there are times when the coverage decreases rapidly to 40%. The blue dots indicate the original percent coverage, and he magenta line shows the 36-hour lowpass filtered time series.



Locations of the HFR site origin (Marathon) and Jason-3 altimeter satellite ground track # 243. The magenta crosses along the track indicate the locations of the geostrophic velocity estimates.

Comparison of Along-Track Altimetry Product with High Frequency Radar Observations

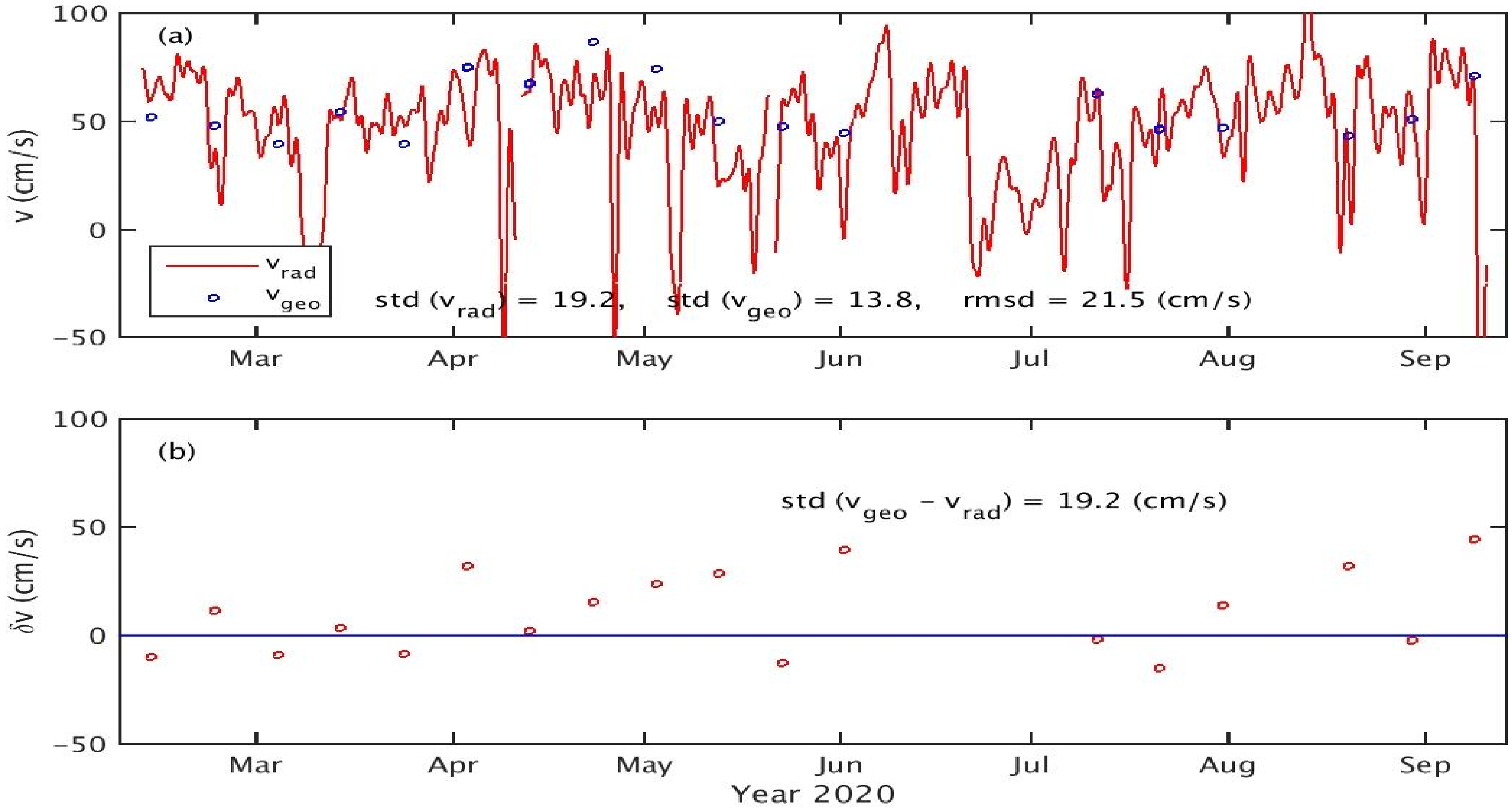
The Jason-3 altimeter has two ground tracks overlapping the Marathon HFR footprint. Only one of these track (#243) has a point that is both in the HFR footprint and has a perpendicular intersection with an HFR radial. It is at this particular location (Point P in the figure) that both the HFR radial velocity and the along-track altimetry-derived surface geostrophic velocity components are in the same direction, and thus can be compared without further rotation (Liu et al. 2012).

The ‘filtered’ version of the near real time (NRT) SLA is already corrected for atmospheric effects and tides. Adding a mean dynamic topography (MDT_CNES-CLS13) transforms the SLA to an absolute dynamic height. Surface geostrophic velocity is estimated as $v_g = \frac{g}{f}\frac{\Delta h}{\Delta x}$, where *g* is acceleration of gravity, *f* is Coriolis parameter, Δ*h* and Δ*x* are the along-track sea level difference and distance between two adjacent points, respectively. The optimal difference operator (*Powell & Leben, 2004*; with an error in the code fixed by *Liu et al. 2012*) is applied to minimize the noises when computing *Δh/Δx* by weighted smoothing along-track SSH.

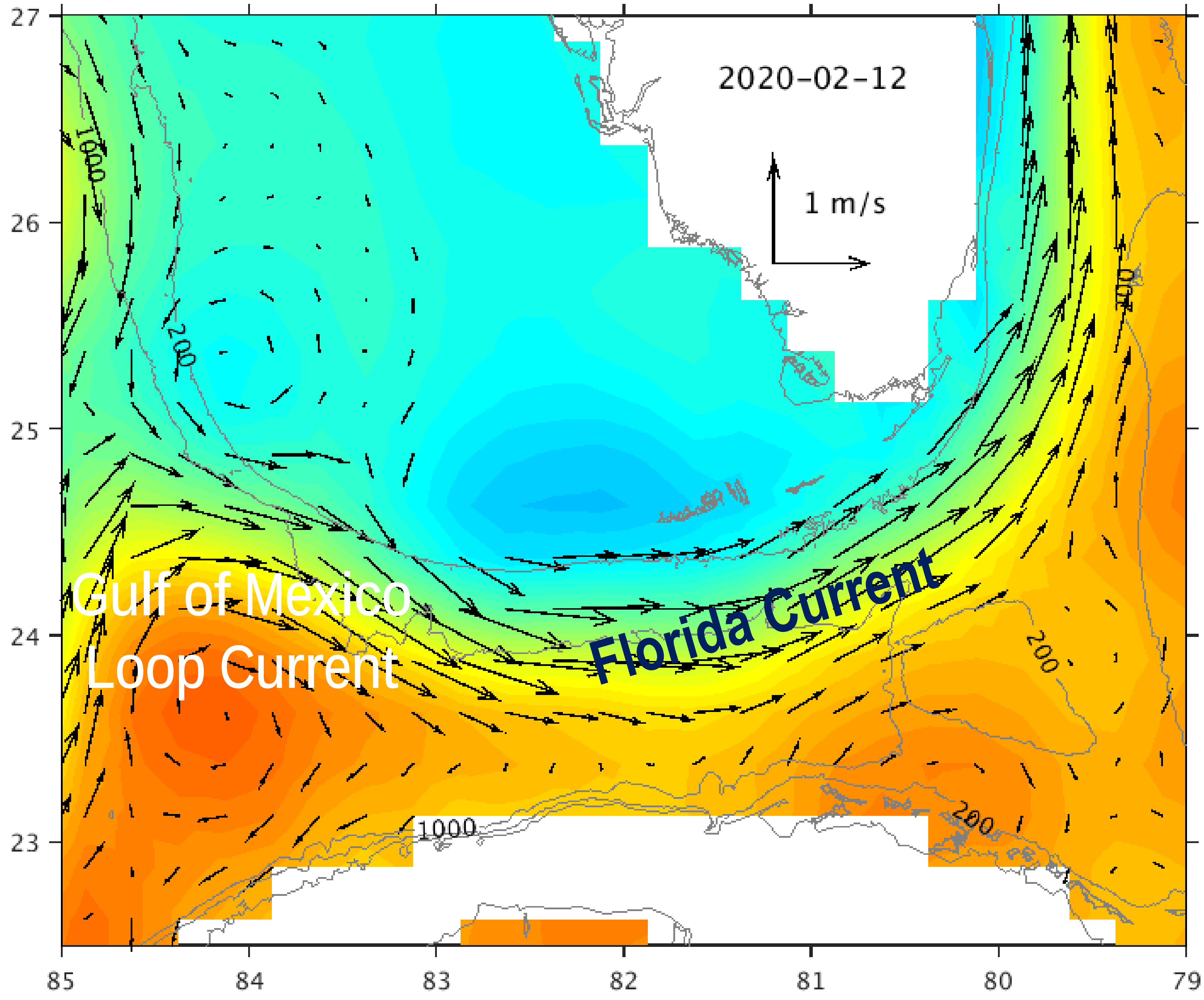
Comparison of Altimetry-Derived Surface Geostrophic Velocity Component with High Frequency Radar Observations at Point P

Velocity components:

Difference:



The HFR data are hourly time series, while the altimetry-derived currents are sampled every about 9 days. Statistics are made on common data time stamps only, i.e., when both data are available. The mean current speeds of HFR and altimetry-derived current radial speeds are 45.3 cm/s and 55.8 cm/s, respectively, with standard deviations of 13.8 cm/s and 19.2 cm/s, respectively. Their RMSD is 21.5 cm/s. The difference between the two time series range from -15.1 cm/s to 44.4 cm/s, with mean difference of 10.6 cm/s and standard deviation of 19.2 cm/s.



Altimetry-Derived Geostrophic Currents

NRT merged/gridded sea level anomaly data are produced by AVISO+ with support from CNES, provided by CMEMS. The gridded altimetry SSH data is a global product with a horizontal solution of 1/4° and daily time stamps.

A mean dynamic topography (MDT_CNES-CLS13) is used, and surface geostrophic velocities are estimated.

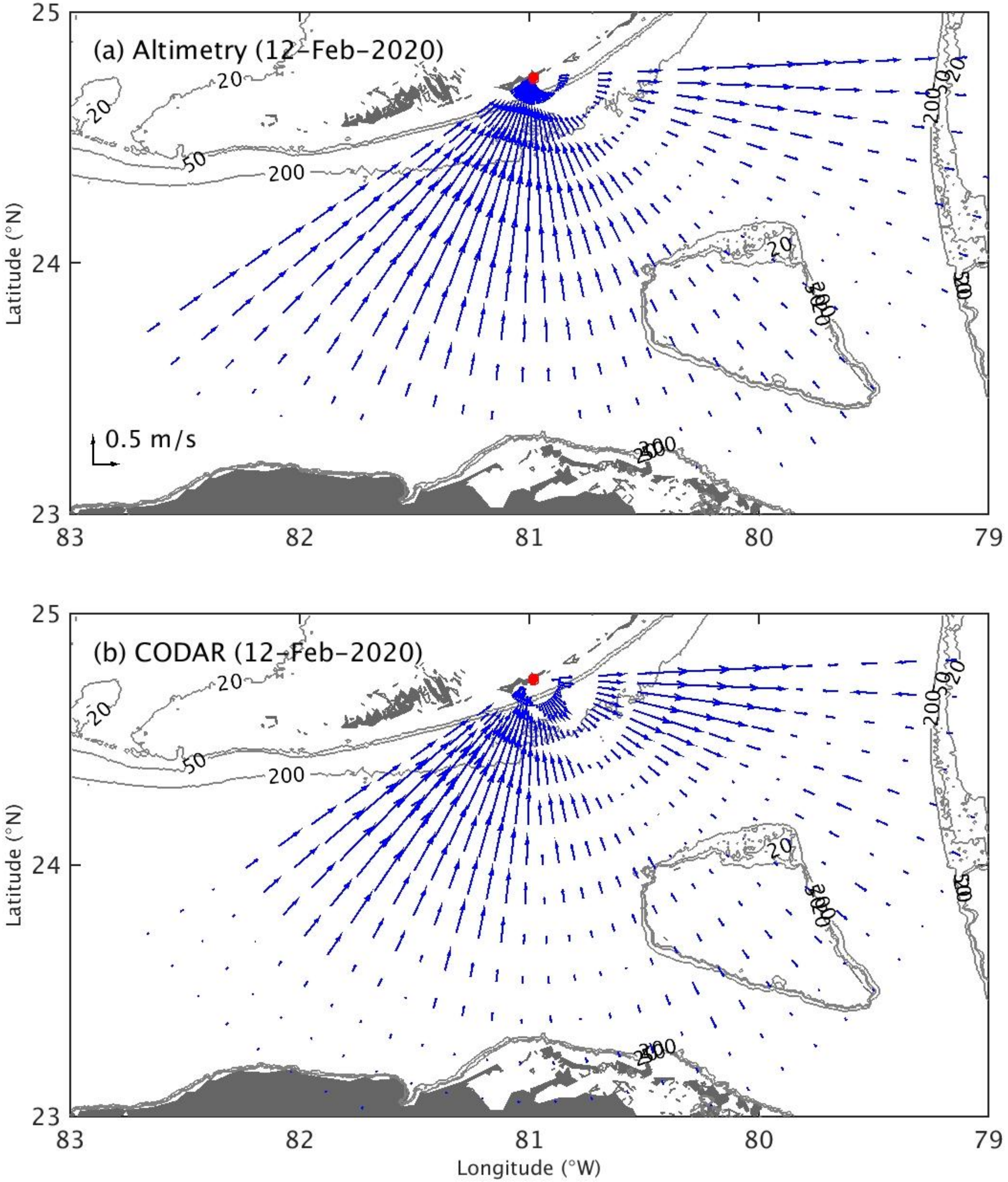
Color coded is SSH with warm color indicating high SSH values.

The dominant feature of ocean circulation in the Straits of Florida is the Florida Current.

Radial Components of the Altimetry-Derived Geostrophic Currents vs. CODAR Radial Currents (daily averaged)

The altimetry-derived surface geostrophic velocity vectors are projected onto the HFR bearing angles to get the radial currents that are equivalent to the CODAR radials.

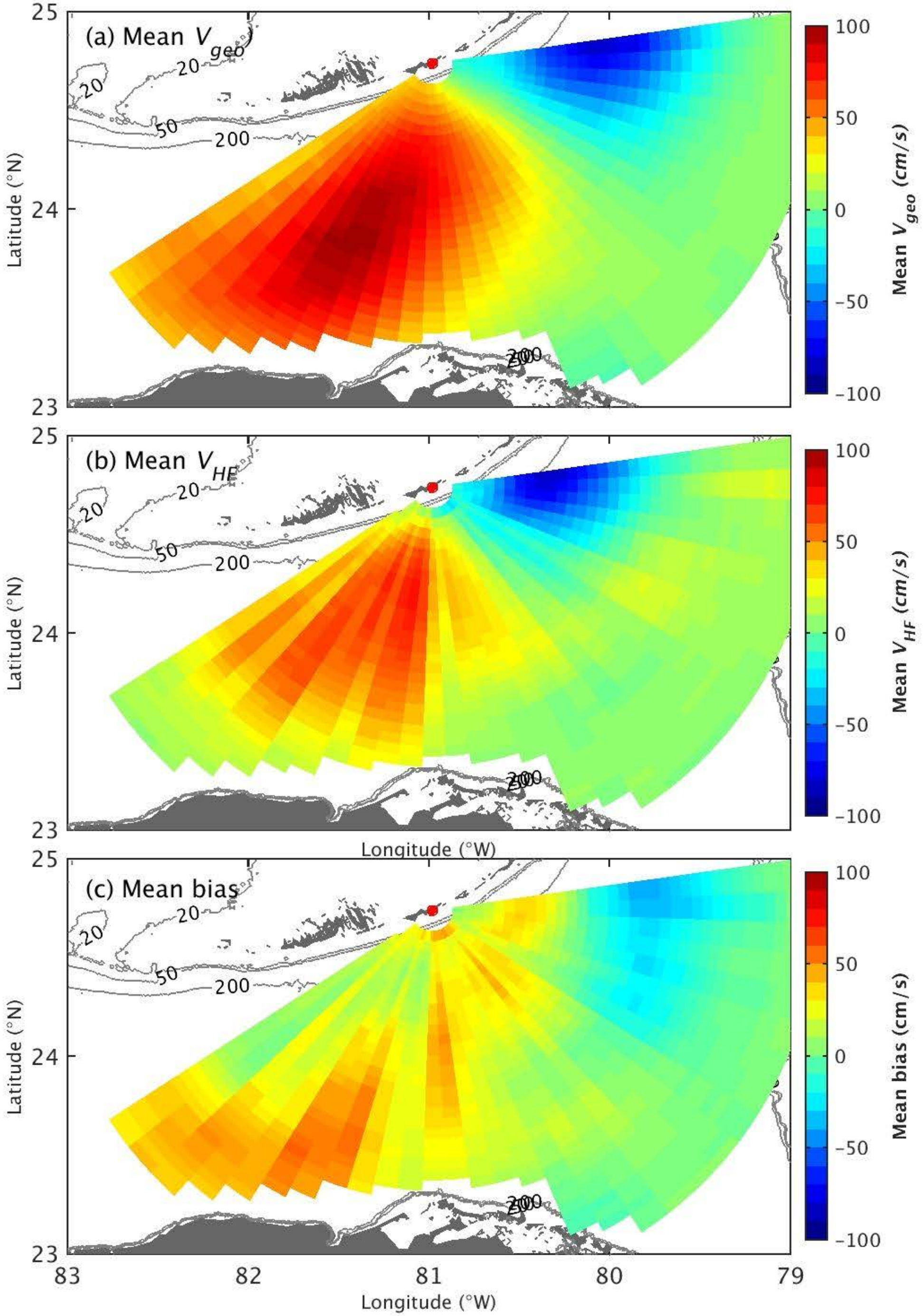
As the Florida Current flows eastward in the Straits of Florida, the radial currents on the western part of the HFR footprint are in the direction towards the HFR site origin, and those on the eastern part are in the direction away from the HFR site origin. The strongest radial currents also generally correspond well with locations of the center of the Florida Current on that day. All these indicate successful interpolation and projection of the geostrophic currents onto the radial sectors.



Altimetry-derived radials

CODAR radials

Mean bias



Record-Length Mean Radial Currents

The altimetry product is continuous in time, while the daily averaged HFR data may still have gaps. The following quantitative comparisons are made only on the sectors and dates when both radial data are available.

Both data sets agree well within the main Florida Current flow regions of the HFR footprint, with large positive values (indicating radial currents towards the site origin) on the western side, and negative values (indicating radial currents away from the site origin) on the eastern side. The minimum and maximum values of the record-long mean altimetry-derived radial currents are -87.1 cm/s and 93.2 cm/s, respectively; and those of the HFR data are -87.0 cm/s and 69.8 cm/s, respectively. On the eastern part of the domain, the two data show almost the same magnitude of the outflow component (-87 cm/s). However, the altimetry-derived mean currents are generally stronger than the HFR observed mean currents with a mean bias of about 20 – 40 cm/s in the strong current areas. Large mean bias is also seen along the outer range of the HFR foot map. The mean bias is 10.7 cm/s within the entire HFR radial domain.

Standard Deviations of Radial Currents

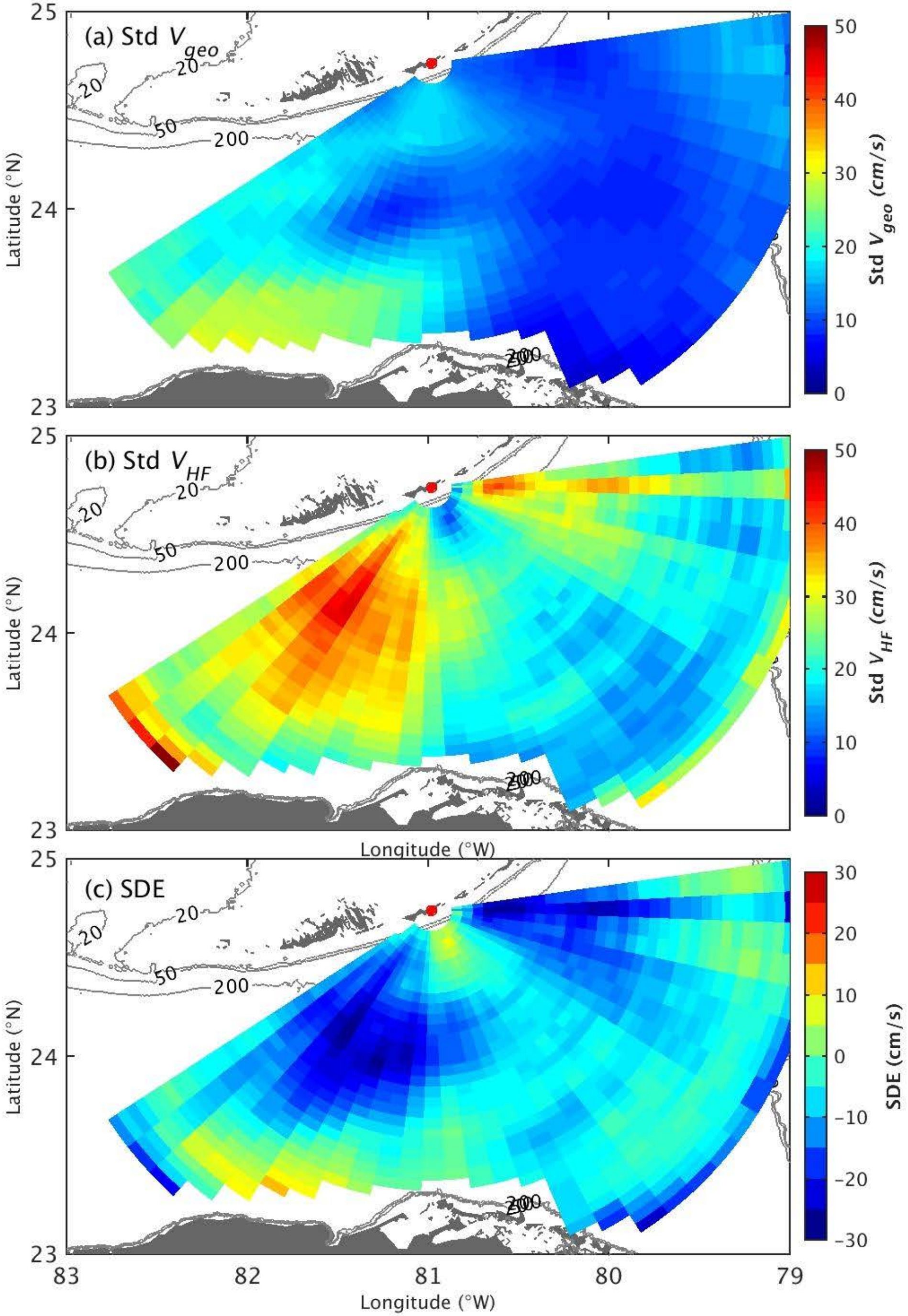
The standard deviations of the two data sets are shown in the top two panels. The difference between the two standard deviations is shown as the standard deviation error (SDE) (bottom panel).

In general, the standard deviations show more differences than agreements. The altimetry-derived radial currents generally have smaller standard deviations (maximum 30.0 cm/s, mean 13.0 cm/s) than the HFR observed radial currents (maximum 58.7 cm/s, mean 24.3 cm/s). The large standard deviations in the HFR data are located in several bearing directions that correspond to the low data return rates. It may also be the case that the altimetry product underestimate the standard deviations of the currents, while the HFR data may overestimate the standard deviations because of low data availability and quality issues within certain radial sectors.

Altimetry-derived radials

CODAR radials

Standard deviation error

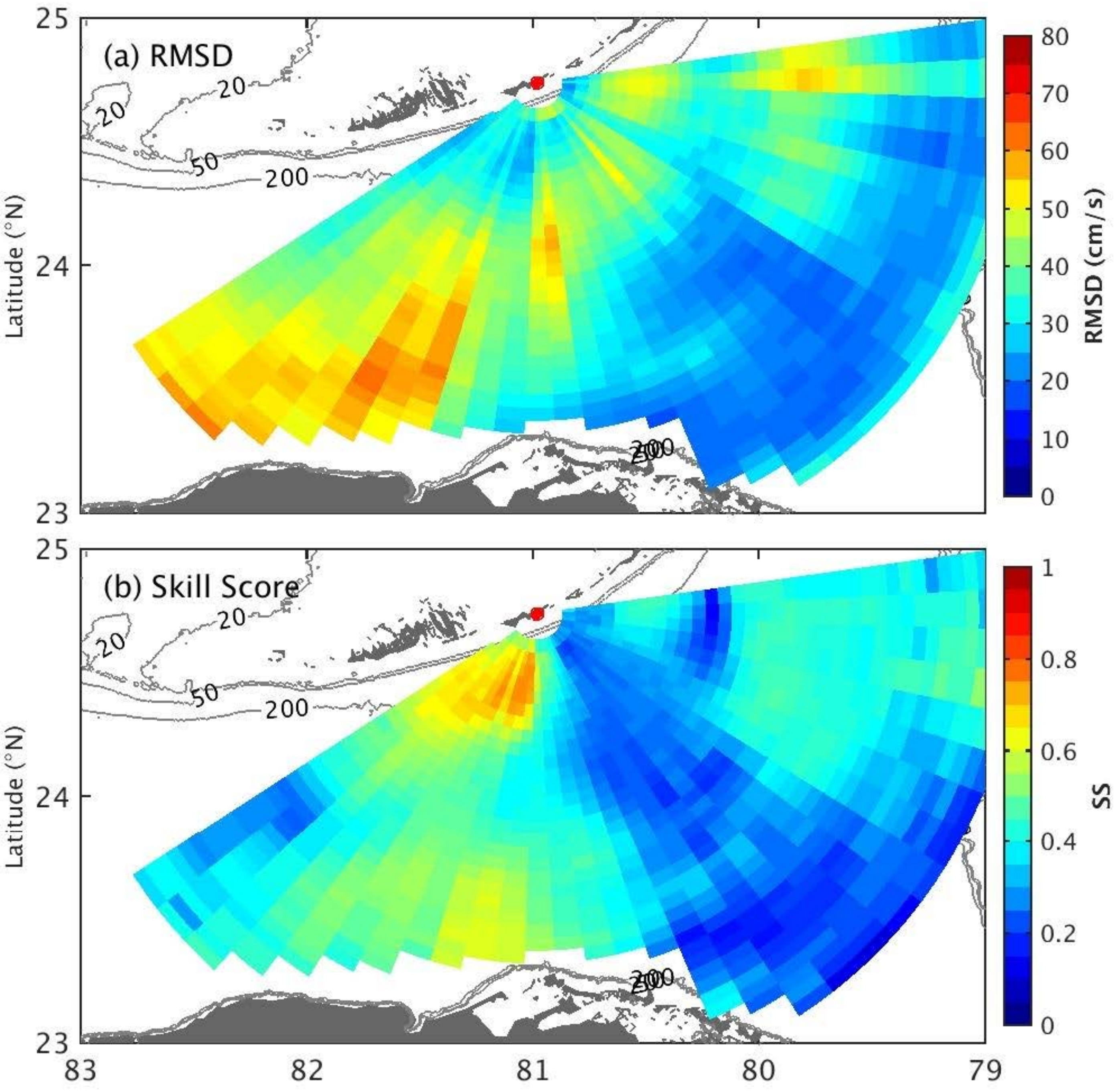


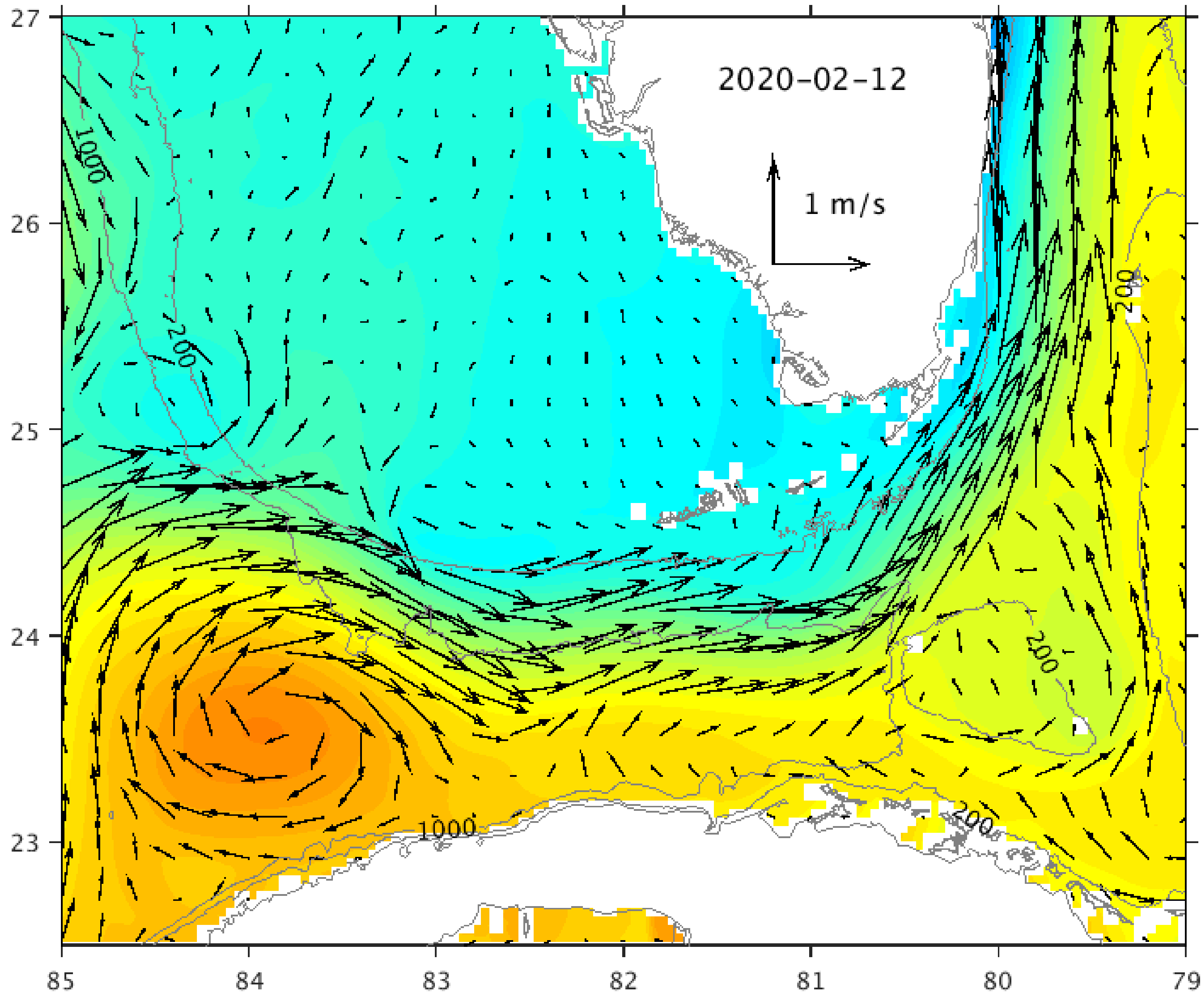
RMSD Between the Altimetry-Derived Radials and the CODAR Radials

The RMSD ranges from 11.2 to 61.2 cm/s in the HFR radial domain, with a mean value of 34.1 cm/s across all radial sectors. Large RMSD values are seen in certain bands corresponding to low data return sectors.

Skill Score of the Altimetry-Derived Radials Evaluated Against the CODAR Radials

The Willmott skill score (Willmott, 1986) measures agreement between two variables, and is widely used in performance evaluation of numerical ocean models (e.g., Liu et al. 2009). It is a non-dimensional number ranging from 0 to 1, with 1 indicating perfect skill. The HFR domain area mean of the skill score is 0.37, with a highest score of 0.73 occurring on the western side within 50 km range of the site origin. The region of highest skill score corresponds with that of the lowest RMSD.





Gulf of Mexico HYCOM Simulated Surface Currents

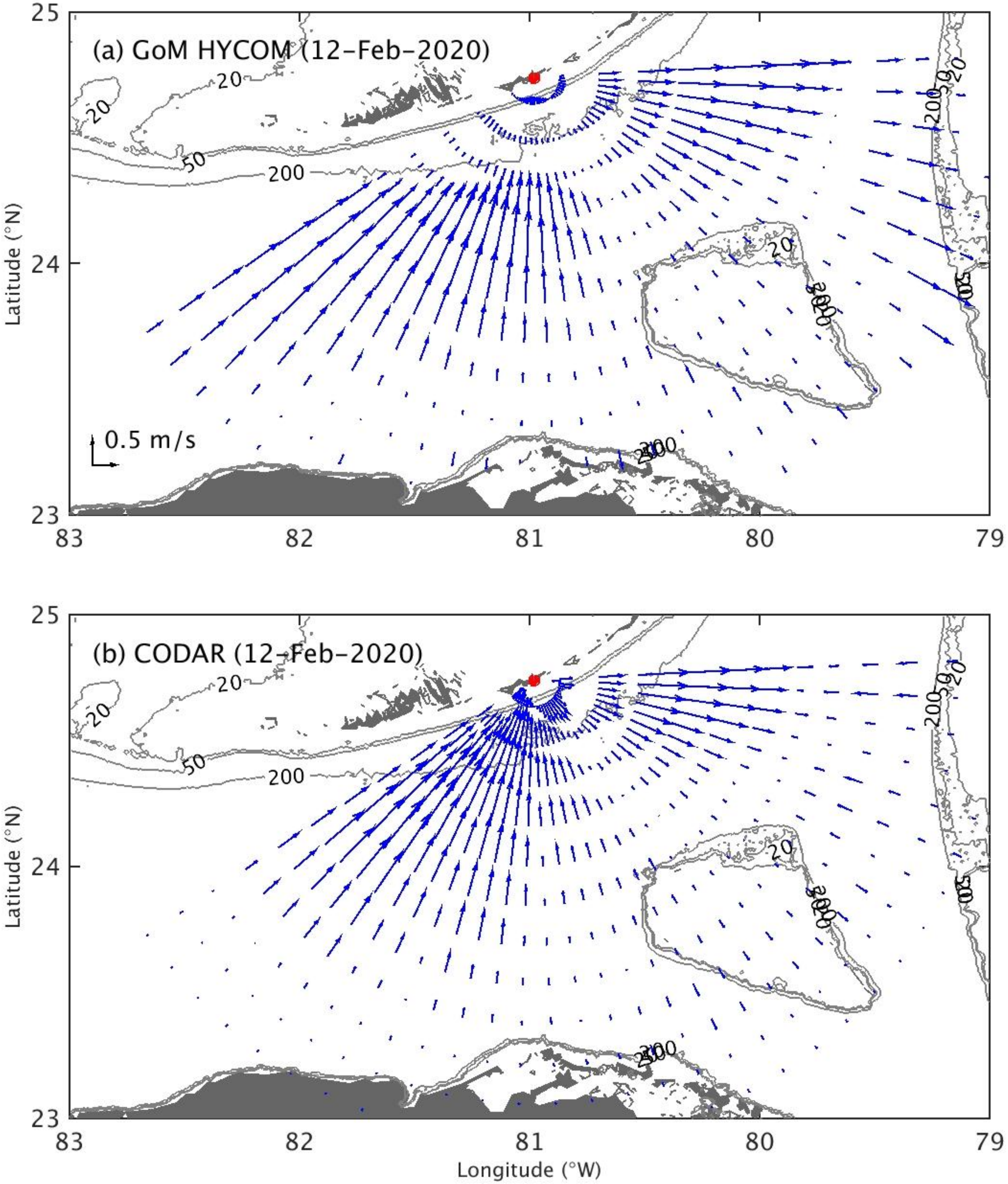
Surface currents output from the HYCOM + NCODA Gulf of Mexico (GoM) (GOMu0.04/expt_90.1m000) 1/25° Analysis are used. GoM HYCOM is a data assimilative, operational model covering the entire GoM region including the Straits of Florida. The output of hourly time series are openly available through the HYCOM Consortium (hycom.org).

The GoM HYCOM assimilates altimetry data in its operational analysis, but unlike the altimetry data alone the HYCOM dynamics allow for ageostrophic motions as also exist within the HFR domain. Thus it is instructive to also compare the model simulated surface currents with HFR observations.

Radial Components of the GoM HYCOM Surface Currents vs. CODAR Radial Currents (both daily averaged)

The GoM HYCOM surface current vectors are projected onto the HFR bearing angles to get the radial currents that are equivalent to the CODAR radials.

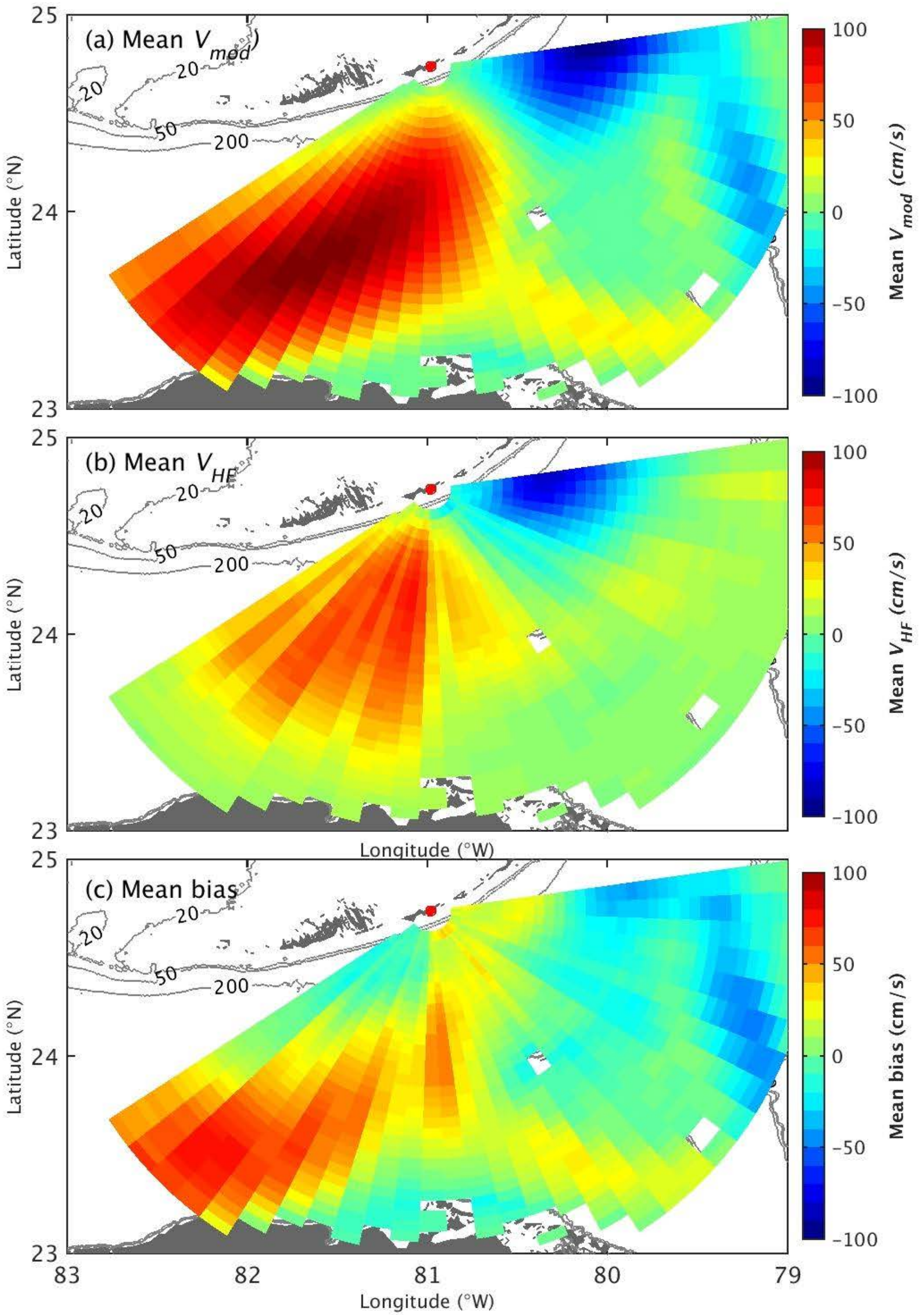
The model-derived radial currents generally compare well with HFR observations. The different pattern near the site origin on the western side is due to the presence of the flow curvature which may possibly be associated with a mesoscale eddy. Such small-scale surface variability between the Florida Current and the coastal region was observed in previous observations (e.g., Parks et al. 2009; Zhang et al. 2019).



GoM HYCOM radials

CODAR radials

Mean bias



Record-Length Mean Radial Currents: GoM HYCOM vs. CODAR

Both data sets show the main Florida current components to be large and positive on the western side of the HFR radial coverage domain (indicating radial currents towards the site origin) and negative (indicating radial currents away from the site origin) values on the eastern side.

The minimum and maximum values of the record-long mean model-derived radial currents are -99.5 cm/s and 99.6 cm/s, respectively. These values shows a stronger mean modeled Florida Current than the altimetry-derived currents. Similar to the altimetry-derived mean currents, the model currents are generally stronger than the HFR observed mean currents with a mean bias of about 20 – 60 cm/s in the strong current areas. Large mean bias is also seen along the outer range of the HFR domain, which may be due to the HFR data quality issues. The mean bias averaged within the entire HFR radial domain is 17.0 cm/s, which is larger than that of the altimetry product.

Standard Deviations of Radial Currents: GoM HYCOM vs. CODAR

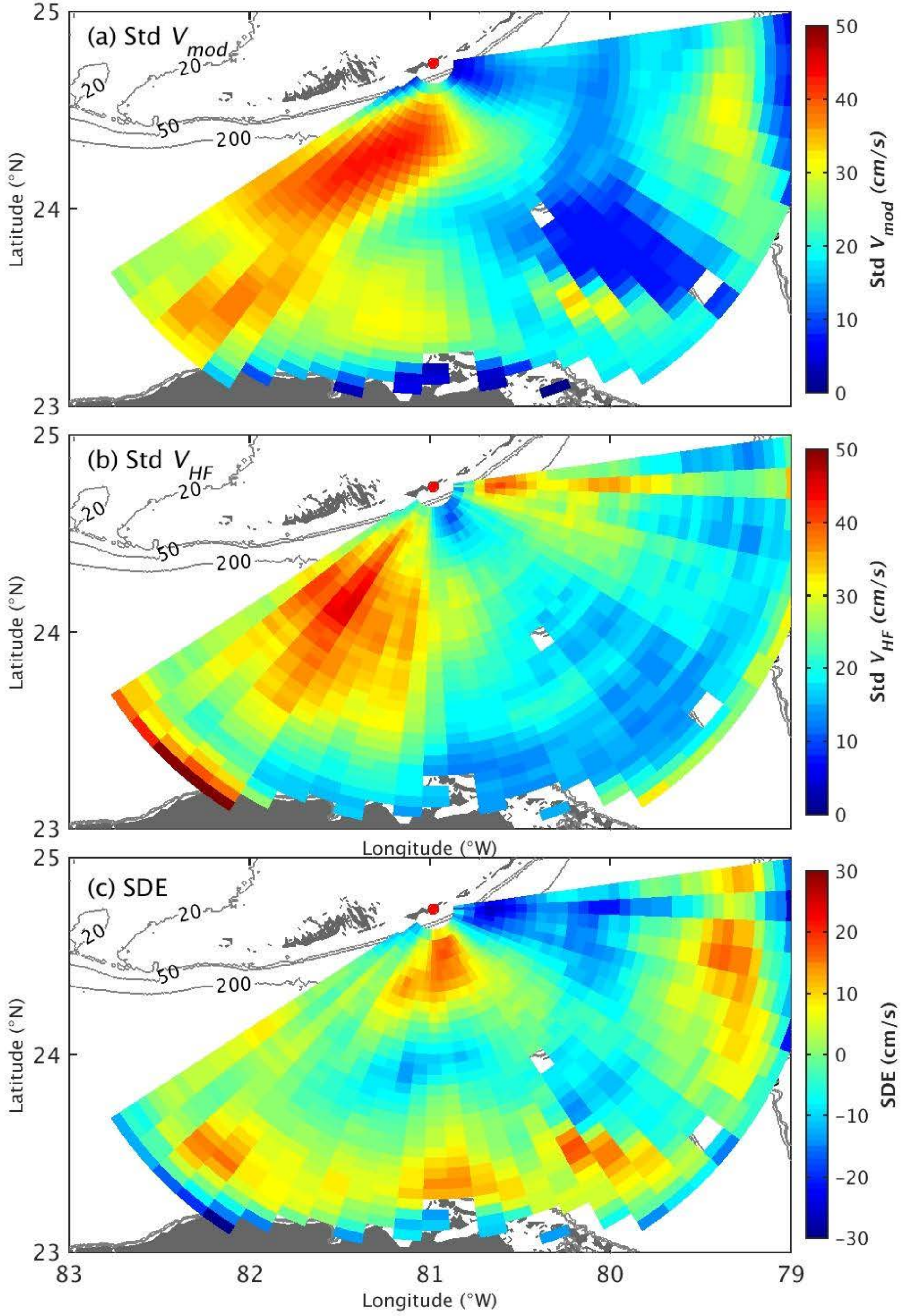
The standard deviations of the model radial currents are generally larger than those of the altimetry-derived radial currents. Their maximum and mean values are 43.0 and 22.5 cm/s, respectively.

The mean standard deviation value is close to that of HFR radial currents (24.1 cm/s).

GoM HYCOM radials

CODAR radials

Standard deviation error

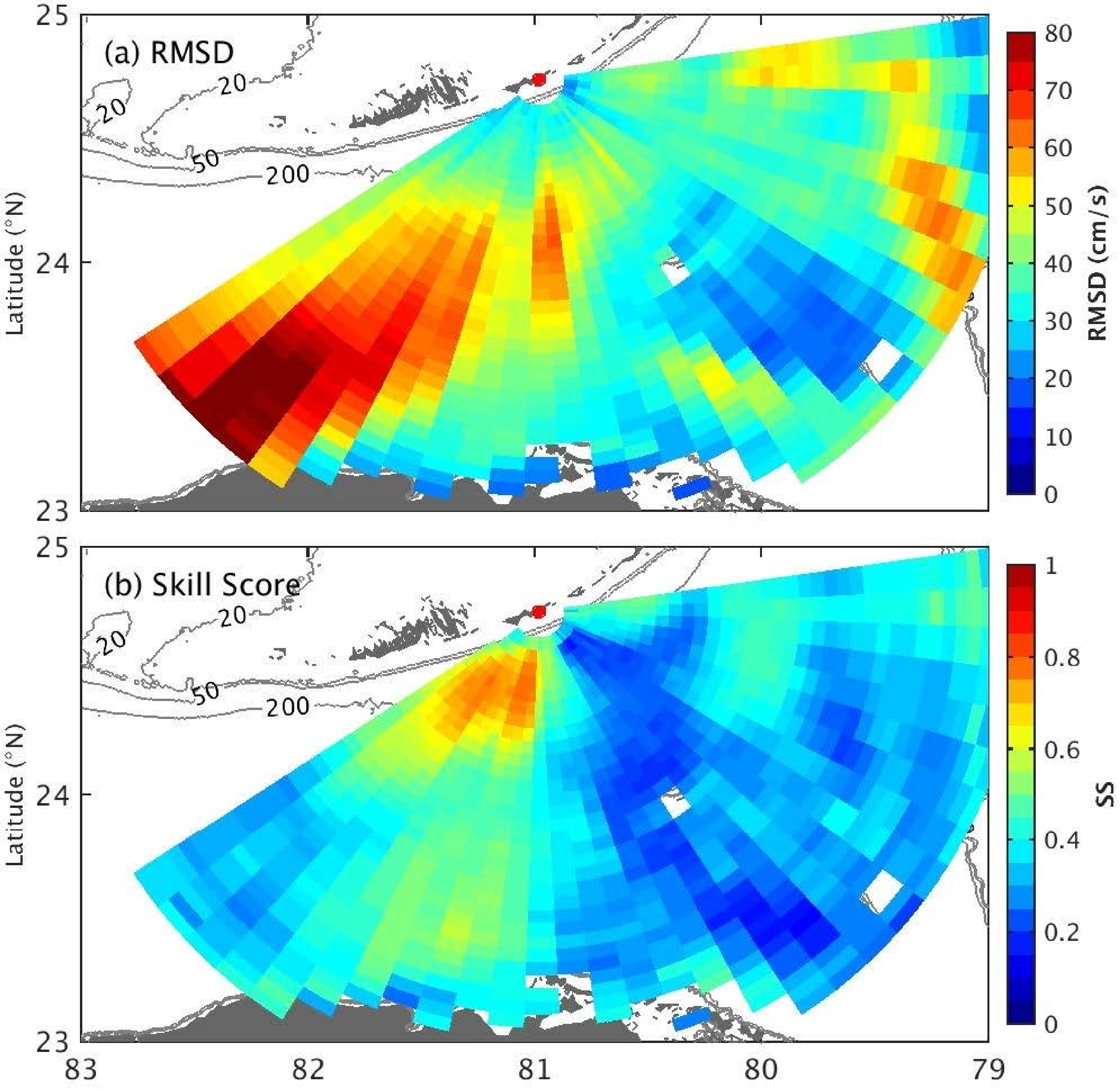


RMSD Between the GoM HYCOM and the CODAR Radials

The RMSD values of the model radial currents are larger than those of the altimetry-derived currents, with a range of 15.2 – 82.3 cm/s and a mean value of 39.9 cm/s for all the radial sectors.

Skill Score of the GoM HYCOM Evaluated Against the CODAR Radials

The Willmott skill scores of the GoM HYCOM have an area mean value of 0.37 (same as that of the altimetry-derived product), with the highest score of 0.76 similarly within the 50 km range of the site origin on the west side.



Summary & Discussion

- The radial currents measured by the Marathon long-range CODAR HFR SeaSonde which overlooks the Straits of Florida to Cuba were used to evaluate the along-track and merged/gridded altimetry-derived geostrophic current products (AVISO+) and the surface currents output from the data assimilative ocean circulation model (GoM HYCOM).

- Among the three current products, the along-track altimetry-derived radial speeds agreed the best with the HFR radial currents, with the RMSD of about 21 cm/s. This value is larger than those obtained from similar comparisons on the West Florida Shelf (8–11 cm/s) (Liu et al. 2012). However, considering the much stronger currents in the Straits of Florida than on the shelf (100–200 cm/s vs. 10–30 cm/s) and that HFR's accuracy could vary with environmental conditions, this larger RMSD value is reasonable. Also, the altimetry-derived geostrophic currents lack ageostrophic influences that are part of this dynamically complex region with frequent mesoscale and submescoscale eddies where nonlinear dynamics might also be in play.

- The agreement between the merged/gridded altimetry product and the HFR radial currents was reduced with the RMSD of 34.1 cm/s. The RMSD varied among the HFR radial sectors with a range of 16.2 – 61.2 cm/s. This was mainly because many more data points (radial sectors) were considered in the analysis.

- The least agreement was found with the numerical model output in terms of RMSD, which varied in a range of 15.2 – 82.3 cm/s among the HFR radial sectors. The spatial mean value was 39.9 cm/s. However, the Willmott skill scores did show the GoM HYCOM and the AVISO+ merged/gridded altimetry product had about the same performance when they were compared with the HFR radial data.

Acknowledgements

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