HF-Radar Network Long Term Averages and Statistics

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Having collected radial velocities and processed total solutions in near real-time for a decade, the HF-Radar Network (HFRNet) can begin making valuable contributions to climatological studies by offering long term averages and statistics of surface current measurements. The initial release of long term averages will consist of monthly and annual statistics computed from near real-time total solutions (RTVs) archived since 2012. New statistics will become available in the second week of each month. Once HFRNet is able to support quality controlled versions of radial data and total processing, statistics will be made available as far back as 2004.

Monthly and annual averages are computed from hourly RTVs for all domains and resolutions. The mean, variance, minimum and maximum are computed on the eastward and northward velocity components of surface currents and are reported along with the number of observations. As a measure of quality control, only hourly RTV values with a geometric dilution of precision (GDOP) below 1.25 contribute to averages and a minimum temporal coverage of 70% and 75% are required for producing monthly and annual statistics, respectively. Long term averages derived from near real-time products may differ among processing centers due to the nature of real-time processing but differences are expected to be negligible.

Several regions spanning all domains and resolutions show surface current velocities are normally distributed. The mean and variance are given by:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}$$

where

$\bar{x} =$ mean
$s^2 =$ variance
$n =$ number of observations
$x_i = i^{th}$ observation

Rather than implementing a two-pass algorithm for computing variance whereby the mean is computed first followed by the calculation of variance, a one-pass sum of squares algorithm has been implemented. The one-pass algorithm computes the sum and sum of squares which can be used to compute the mean and variance simultaneously. The mean is computed as defined above while the variance is given by:

$$s^2 = \frac{\sum_{i=1}^{n} x_i{}^2 - (\sum_{i=1}^{n} x_i)^2/n}{n-1}$$

One advantage of the one-pass sum of squares algorithm is that the intermediate sums can be saved from monthly statistics and re-used for deriving annual statistics or, when more data becomes available, climatological statistics. One limitation of the one-pass sum of squares algorithm is that, when the mean is large relative to the variance, the algorithm is unsuitable because repeated numerical round-off leads to a loss in precision. However, surface current observations have a sufficiently small mean and relatively large variance such that there is no loss of precision when the one-pass sum of squares algorithm is used with double precision.

Data will be made available in Network Common Data Form (NetCDF) with Climate and Forecasting metadata conventions (CF version 1.1). Averaging parameters are recorded using the cell boundaries and methods defined by CF conventions (See Appendix 1 NetCDF header examples). The file naming convention is:

*yyyy[mm]*_hfr_*domain*_*resolution*_rtv_uwls_month_average_*node*.nc

where

yyyy = year
mm = month (monthly files only)
domain = dataset domain: {ushi, gak, akns, uswc, usegc, prvi}
resolution = dataset nominal resolution: {500m, 1km, 2km, 6km}
node = processing center: {SIO}

The ‘rtv_uwls’ portion of the file name indicates that statistics are for near real-time total solutions computed with the unweighted least squares combining method. Data will be disseminated by THREDDS data servers and visualization may become available through Google Maps interfaces.

Appendix A

Example NetCDF header in common data language (CDL) for monthly statistics

```
netcdf \201603_hfr_usegc_2km_rtv_uwls_month_average_SIO {
dimensions:
        time = UNLIMITED ; // (1 currently)
        lat = 1380 ;
        lon = 2103 ;
        nv = 2 ;
variables:
        int time(time) ;
                time:standard_name = "time" ;
                time:units = "seconds since 1970-01-01" ;
                time:calendar = "gregorian" ;
                time:bounds = "time_bnds" ;
        float lat(lat) ;
                lat:standard_name = "latitude" ;
                lat:units = "degrees_north" ;
        float lon(lon) ;
                lon:standard_name = "longitude" ;
                lon:units = "degrees_east" ;
        int time_bnds(time, nv) ;
        short u_mean(time, lat, lon) ;
                u_mean:standard_name = "surface_eastward_sea_water_velocity" ;
                u_mean:long_name = "mean eastward surface velocity" ;
                u_mean:units = "m s-1" ;
                u_mean:_FillValue = -32768s ;
                u_mean:scale_factor = 0.01f ;
                u_mean:cell_methods = "time: mean (interval: 1 hour comment: hourly averaged
                                        data)" ;
                u_mean:ancillary_variables = "n_obs" ;
        short v_mean(time, lat, lon) ;
                v_mean:standard_name = "surface_northward_sea_water_velocity" ;
                v_mean:long_name = "mean northward surface velocity" ;
                v_mean:units = "m s-1" ;
                v_mean:_FillValue = -32768s ;
                v_mean:scale_factor = 0.01f ;
                v_mean:cell_methods = "time: mean (interval: 1 hour comment: hourly averaged
                                        data)" ;
                v_mean:ancillary_variables = "n_obs" ;
        short u_min(time, lat, lon) ;
                u_min:standard_name = "surface_eastward_sea_water_velocity" ;
                u_min:long_name = "minimum eastward surface velocity" ;
                u_min:units = "m s-1" ;
                u_min:_FillValue = -32768s ;
                u_min:scale_factor = 0.01f ;
                u_min:cell_methods = "time: minimum (interval: 1 hour comment: hourly averaged
                                        data)" ;
                u_min:ancillary_variables = "n_obs" ;
        short v_min(time, lat, lon) ;
                v_min:standard_name = "surface_northward_sea_water_velocity" ;
                v_min:long_name = "minimum northward surface velocity" ;
                v_min:units = "m s-1" ;
                v_min:_FillValue = -32768s ;
                v_min:scale_factor = 0.01f ;
                v_min:cell_methods = "time: minimum (interval: 1 hour comment: hourly averaged
                                        data)" ;
                v_min:ancillary_variables = "n_obs" ;
        short u_max(time, lat, lon) ;
                u_max:standard_name = "surface_eastward_sea_water_velocity" ;
                u_max:long_name = "maximum eastward surface velocity" ;
                u_max:units = "m s-1" ;
                u_max:_FillValue = -32768s ;
                u_max:scale_factor = 0.01f ;
                u_max:cell_methods = "time: maximum (interval: 1 hour comment: hourly averaged
                                        data)" ;
                u_max:ancillary_variables = "n_obs" ;
```

```
        short v_max(time, lat, lon) ;
                v_max:standard_name = "surface_northward_sea_water_velocity" ;
                v_max:long_name = "maximum northward surface velocity" ;
                v_max:units = "m s-1" ;
                v_max:_FillValue = -32768s ;
                v_max:scale_factor = 0.01f ;
                v_max:cell_methods = "time: maximum (interval: 1 hour comment: hourly averaged
                                data)" ;
                v_max:ancillary_variables = "n_obs" ;
        short u_var(time, lat, lon) ;
                u_var:standard_name = "surface_eastward_sea_water_velocity" ;
                u_var:long_name = "eastward surface velocity variance" ;
                u_var:units = "m2 s-2" ;
                u_var:_FillValue = -32768s ;
                u_var:scale_factor = 0.0001f ;
                u_var:cell_methods = "time: variance (interval: 1 hour comment: hourly averaged
                                data)" ;
                u_var:ancillary_variables = "n_obs" ;
        short v_var(time, lat, lon) ;
                v_var:standard_name = "surface_northward_sea_water_velocity" ;
                v_var:long_name = "northward surface velocity variance" ;
                v_var:units = "m2 s-2" ;
                v_var:_FillValue = -32768s ;
                v_var:scale_factor = 0.0001f ;
                v_var:cell_methods = "time: variance (interval: 1 hour comment: hourly averaged
                                data)" ;
                v_var:ancillary_variables = "n_obs" ;
        short n_obs(time, lat, lon) ;
                n_obs:standard_name = "number_of_observations" ;
                n_obs:_FillValue = -32768s ;
                n_obs:cell_methods = "time: sum (interval: 1 hour)" ;

// global attributes:
                :netcdf_library_version = "4.1.3" ;
                :format_version = "HFRNet_1.0.0" ;
                :product_version = "HFRNet_1.1.05" ;
                :Conventions = "CF-1.1" ;
                :title = "Monthly Mean Near-Real Time Surface Ocean Velocity,\n",
                        "U.S. East and Gulf Coast, 2 km Resolution" ;
                :institution = "Scripps Institution of Oceanography" ;
                :source = "Surface Ocean HF-Radar" ;
                :history = "01-Oct-2016 00:51:36: NetCDF file created" ;
                :references = "Terrill, E. et al., 2006. Data Management and Real-time\n",
                        "Distribution in the HF-Radar National Network. Proceedings\n",
                        "of the MTS/IEEE Oceans 2006 Conference, Boston MA,\n",
                        "September 2006." ;
                :creator_name = "Mark Otero" ;
                :creator_email = "motero@ucsd.edu" ;
                :creator_url = "http://cordc.ucsd.edu/projects/mapping/" ;
                :summary = "Surface ocean velocities estimated from HF-Radar are\n",
                        "representative of the upper 0.3 - 2.5 meters of the\n",
                        "ocean.  The main objective of near-real time\n",
                        "processing is to produce the best product from\n",
                        "available data at the time of processing. Near\n",
                        "real-time surface current maps produced on a 2km\n",
                        "grid of the U.S. East and Gulf Coast are averaged on\n",
                        "a monthly basis for climatological applications." ;
                :comment = "Only velocities with a dilution of precision below\n",
                        "1.25 are used and a minimum of 70.0% temporal\n",
                        "availability is required for statistical calculations." ;
                :geospatial_lat_min = 21.7f ;
                :geospatial_lat_max = 46.49442f ;
                :geospatial_lon_min = -97.88385f ;
                :geospatial_lon_max = -57.19249f ;
                :grid_resolution = "2km" ;
                :grid_projection = "equidistant cylindrical" ;
                :regional_description = "Unites States, East and Gulf Coast" ;
}
```

Example NetCDF header in common data language (CDL) for annual statistics

```
netcdf \2015_hfr_uswc_6km_rtv_uwls_annual_average_SIO {
dimensions:
      time = UNLIMITED ; // (1 currently)
      lat = 367 ;
      lon = 234 ;
      nv = 2 ;
variables:
      int time(time) ;
            time:standard_name = "time" ;
            time:units = "seconds since 1970-01-01" ;
            time:calendar = "gregorian" ;
            time:bounds = "time_bnds" ;
      float lat(lat) ;
            lat:standard_name = "latitude" ;
            lat:units = "degrees_north" ;
      float lon(lon) ;
            lon:standard_name = "longitude" ;
            lon:units = "degrees_east" ;
      int time_bnds(time, nv) ;
      short u_mean(time, lat, lon) ;
            u_mean:standard_name = "surface_eastward_sea_water_velocity" ;
            u_mean:long_name = "mean eastward surface velocity" ;
            u_mean:units = "m s-1" ;
            u_mean:_FillValue = -32768s ;
            u_mean:scale_factor = 0.01f ;
            u_mean:cell_methods = "time: mean (interval: 1 hour comment: hourly averaged data)" ;
            u_mean:ancillary_variables = "n_obs" ;
      short v_mean(time, lat, lon) ;
            v_mean:standard_name = "surface_northward_sea_water_velocity" ;
            v_mean:long_name = "mean northward surface velocity" ;
            v_mean:units = "m s-1" ;
            v_mean:_FillValue = -32768s ;
            v_mean:scale_factor = 0.01f ;
            v_mean:cell_methods = "time: mean (interval: 1 hour comment: hourly averaged data)" ;
            v_mean:ancillary_variables = "n_obs" ;
      short u_min(time, lat, lon) ;
            u_min:standard_name = "surface_eastward_sea_water_velocity" ;
            u_min:long_name = "minimum eastward surface velocity" ;
            u_min:units = "m s-1" ;
            u_min:_FillValue = -32768s ;
            u_min:scale_factor = 0.01f ;
            u_min:cell_methods = "time: minimum (interval: 1 hour comment: hourly averaged
                                  data)" ;
            u_min:ancillary_variables = "n_obs" ;
      short v_min(time, lat, lon) ;
            v_min:standard_name = "surface_northward_sea_water_velocity" ;
            v_min:long_name = "minimum northward surface velocity" ;
            v_min:units = "m s-1" ;
            v_min:_FillValue = -32768s ;
            v_min:scale_factor = 0.01f ;
            v_min:cell_methods = "time: minimum (interval: 1 hour comment: hourly averaged
                                  data)" ;
            v_min:ancillary_variables = "n_obs" ;
      short u_max(time, lat, lon) ;
            u_max:standard_name = "surface_eastward_sea_water_velocity" ;
            u_max:long_name = "maximum eastward surface velocity" ;
            u_max:units = "m s-1" ;
            u_max:_FillValue = -32768s ;
            u_max:scale_factor = 0.01f ;
            u_max:cell_methods = "time: maximum (interval: 1 hour comment: hourly averaged
                                  data)" ;
            u_max:ancillary_variables = "n_obs" ;
      short v_max(time, lat, lon) ;
            v_max:standard_name = "surface_northward_sea_water_velocity" ;
            v_max:long_name = "maximum northward surface velocity" ;
            v_max:units = "m s-1" ;
            v_max:_FillValue = -32768s ;
            v_max:scale_factor = 0.01f ;
```

```
            v_max:cell_methods = "time: maximum (interval: 1 hour comment: hourly averaged
                                  data)" ;
            v_max:ancillary_variables = "n_obs" ;
      short u_var(time, lat, lon) ;
            u_var:standard_name = "surface_eastward_sea_water_velocity" ;
            u_var:long_name = "eastward surface velocity variance" ;
            u_var:units = "m2 s-2" ;
            u_var:_FillValue = -32768s ;
            u_var:scale_factor = 0.0001f ;
            u_var:cell_methods = "time: variance (interval: 1 hour comment: hourly averaged
                                  data)" ;
            u_var:ancillary_variables = "n_obs" ;
      short v_var(time, lat, lon) ;
            v_var:standard_name = "surface_northward_sea_water_velocity" ;
            v_var:long_name = "northward surface velocity variance" ;
            v_var:units = "m2 s-2" ;
            v_var:_FillValue = -32768s ;
            v_var:scale_factor = 0.0001f ;
            v_var:cell_methods = "time: variance (interval: 1 hour comment: hourly averaged
                                  data)" ;
            v_var:ancillary_variables = "n_obs" ;
      short n_obs(time, lat, lon) ;
            n_obs:standard_name = "number_of_observations" ;
            n_obs:_FillValue = -32768s ;
            n_obs:cell_methods = "time: sum (interval: 1 hour)" ;

// global attributes:
            :netcdf_library_version = "4.1.3" ;
            :format_version = "HFRNet_1.0.0" ;
            :product_version = "HFRNet_1.1.05" ;
            :Conventions = "CF-1.1" ;
            :title = "Annual Mean Near-Real Time Surface Ocean Velocity,\n",
                  "U.S. West Coast, 6 km Resolution" ;
            :institution = "Scripps Institution of Oceanography" ;
            :source = "Surface Ocean HF-Radar" ;
            :history = "05-Oct-2016 14:54:10: NetCDF file created" ;
            :references = "Terrill, E. et al., 2006. Data Management and Real-time\n",
                  "Distribution in the HF-Radar National Network. Proceedings\n",
                  "of the MTS/IEEE Oceans 2006 Conference, Boston MA,\n",
                  "September 2006." ;
            :creator_name = "Mark Otero" ;
            :creator_email = "motero@ucsd.edu" ;
            :creator_url = "http://cordc.ucsd.edu/projects/mapping/" ;
            :summary = "Surface ocean velocities estimated from HF-Radar are\n",
                  "representative of the upper 0.3 - 2.5 meters of the\n",
                  "ocean.  The main objective of near-real time\n",
                  "processing is to produce the best product from\n",
                  "available data at the time of processing. Near\n",
                  "real-time surface current maps produced on a 6km\n",
                  "grid of the U.S. West Coast are averaged on an\n",
                  "annual basis for climatological applications." ;
            :comment = "Only velocities with a dilution of precision below\n",
                  "1.25 are used and a minimum of 75.0% temporal\n",
                  "availability is required for statistical calculations." ;
            :geospatial_lat_min = 30.25f ;
            :geospatial_lat_max = 49.99204f ;
            :geospatial_lon_min = -130.36f ;
            :geospatial_lon_max = -115.8056f ;
            :grid_resolution = "6km" ;
            :grid_projection = "equidistant cylindrical" ;
            :regional_description = "Unites States, West Coast" ;
}
```