LESSONS LEARNED FROM QUASI-OPERATIONAL COASTAL OCEAN NOWCAST/FORECAST SYSTEMS FOR COASTAL OCEAN CIRCULATION

CHRISTOPHER N. K. MOOERS
OCEAN PREDICTION EXPERIMENTAL LABORATORY (OPEL) RSMAS/U.MIAMI
{INKWEON BANG, XINGLONG WU, & JEROME FIECHTER}

OUTLINE

- TWO NOWCAST/FORECAST SYSTEMS
- FORCING DATA
- VERIFICATION DATA
- SKILL ASSESSMENT
- SERENDIPITOUS SCIENTIFIC RESULTS
- LESSONS LEARNED

TWO EXAMPLE REAL-TIME NOWCAST/FORECAST SYSTEMS

- (1) EFSIS (EAST FLORIDA SHELF INFORMATION SYSTEM)
  - SINCE OCT04
  - LOCAL, LONG (1,000KM) LEAKY CHANNEL

- (2) EPWS/NFS (EXTENDED PRINCE WILLIAM SOUND/NOWCAST- FORECAST SYSTEM)
  - SINCE FEB05
  - REMOTE, SMALL (100KM) TWO-STRAIT, SEMI-ENCLOSED SEA

COMMON ATTRIBUTES

- NUMERICAL ENGINE = POM
- DOWNSCALE FROM Global NCOM
- SEPARATE TIDAL MODEL DRIVEN BY TIDAL HARMONIC COEFFICIENTS
  - (1) OSU
  - (2) MIKE FOREMAN/IOS'S
- MESOSCALE ATMOSPHERIC FORCING FROM NWP
  - (1) NCEP-NAM
  - (2) UAA-RAMS

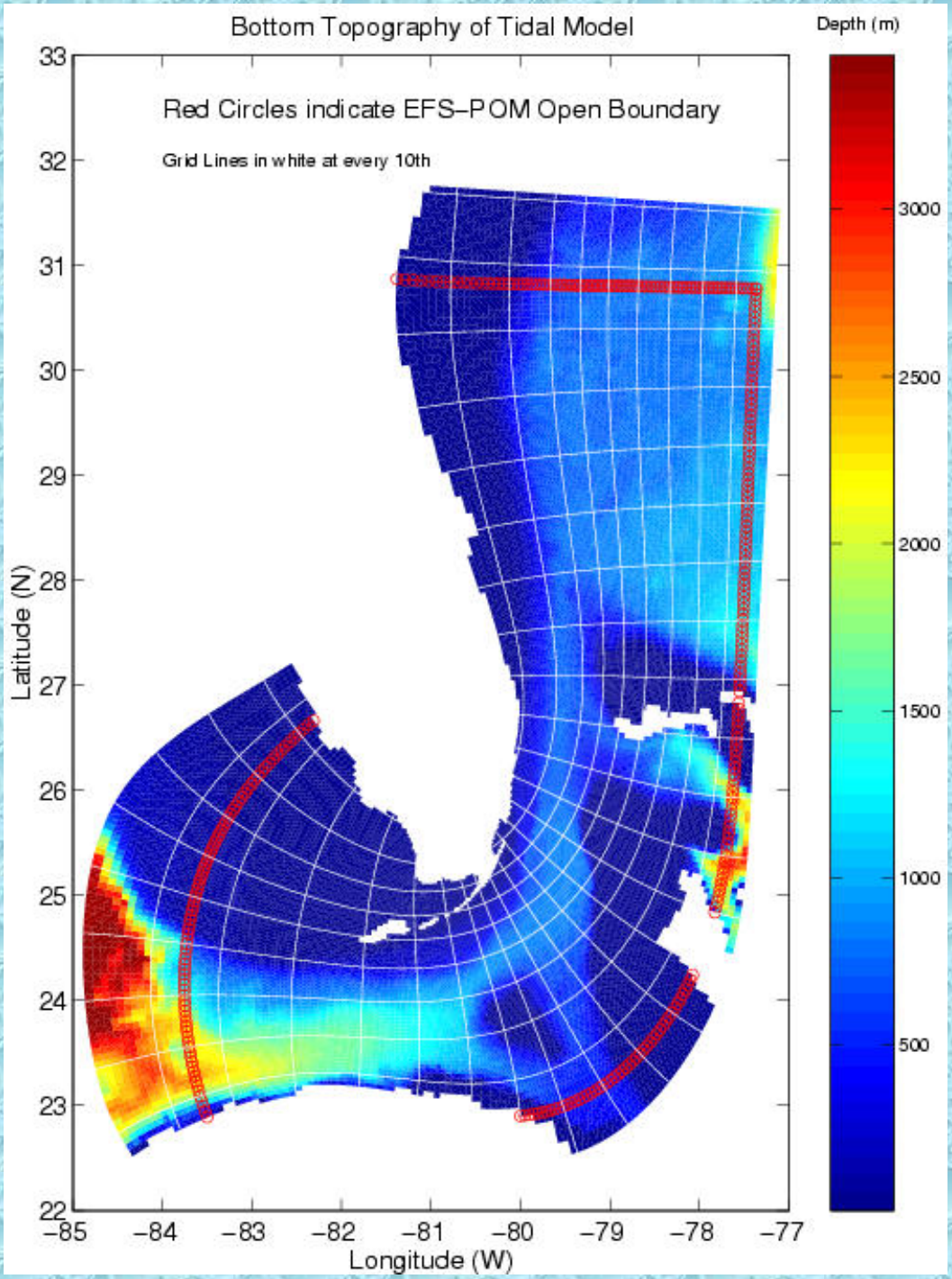
EFSIS

EAST FLORIDA SHELF INFORMATION SYSTEM

http://efsis.rsmas.miami.edu

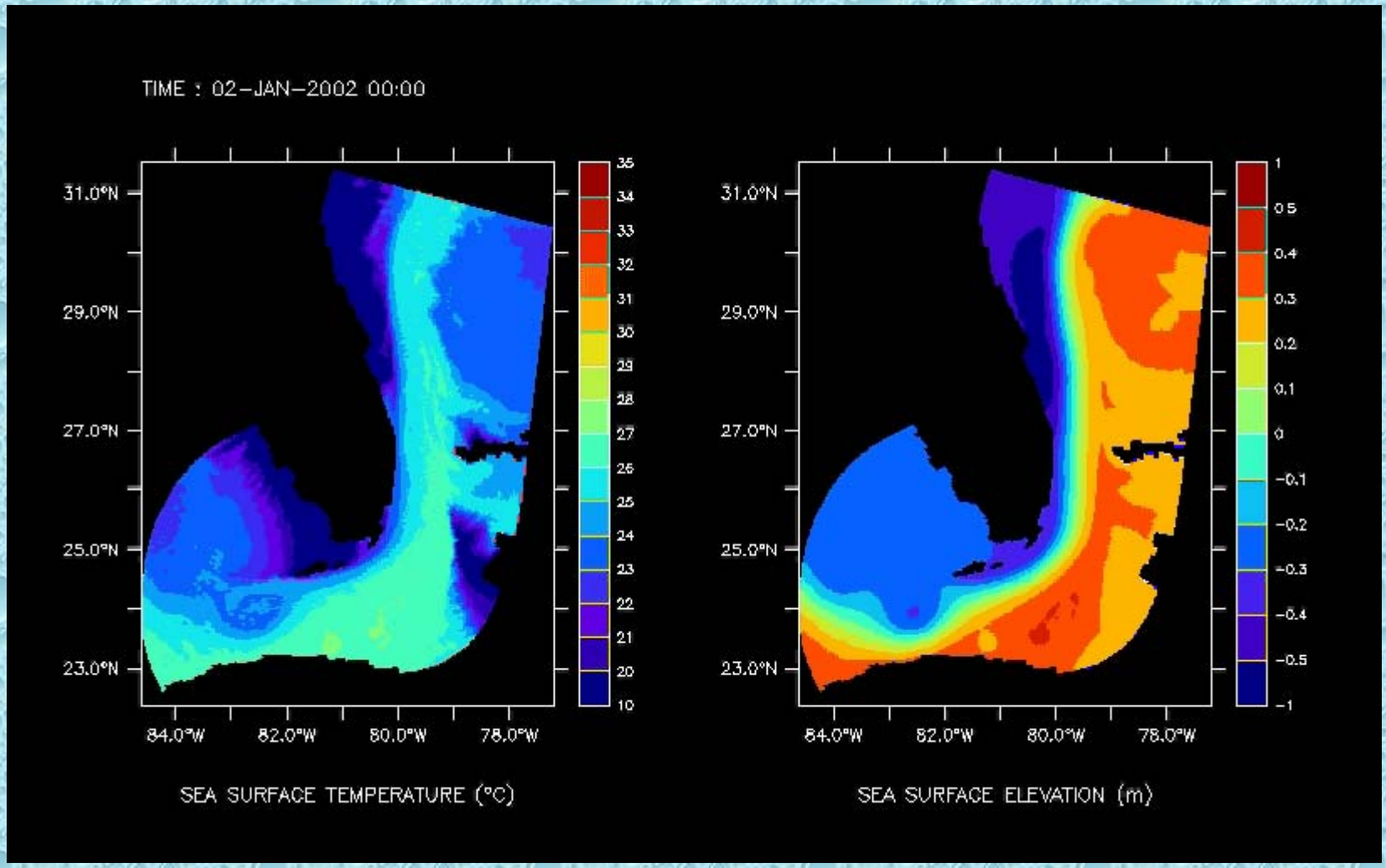
Tidal Model Grid
(251 X 101)

Baroclinic Model Grid
(223 X 97)



Simulation of Florida Current Frontal Eddies on East Florida Shelf

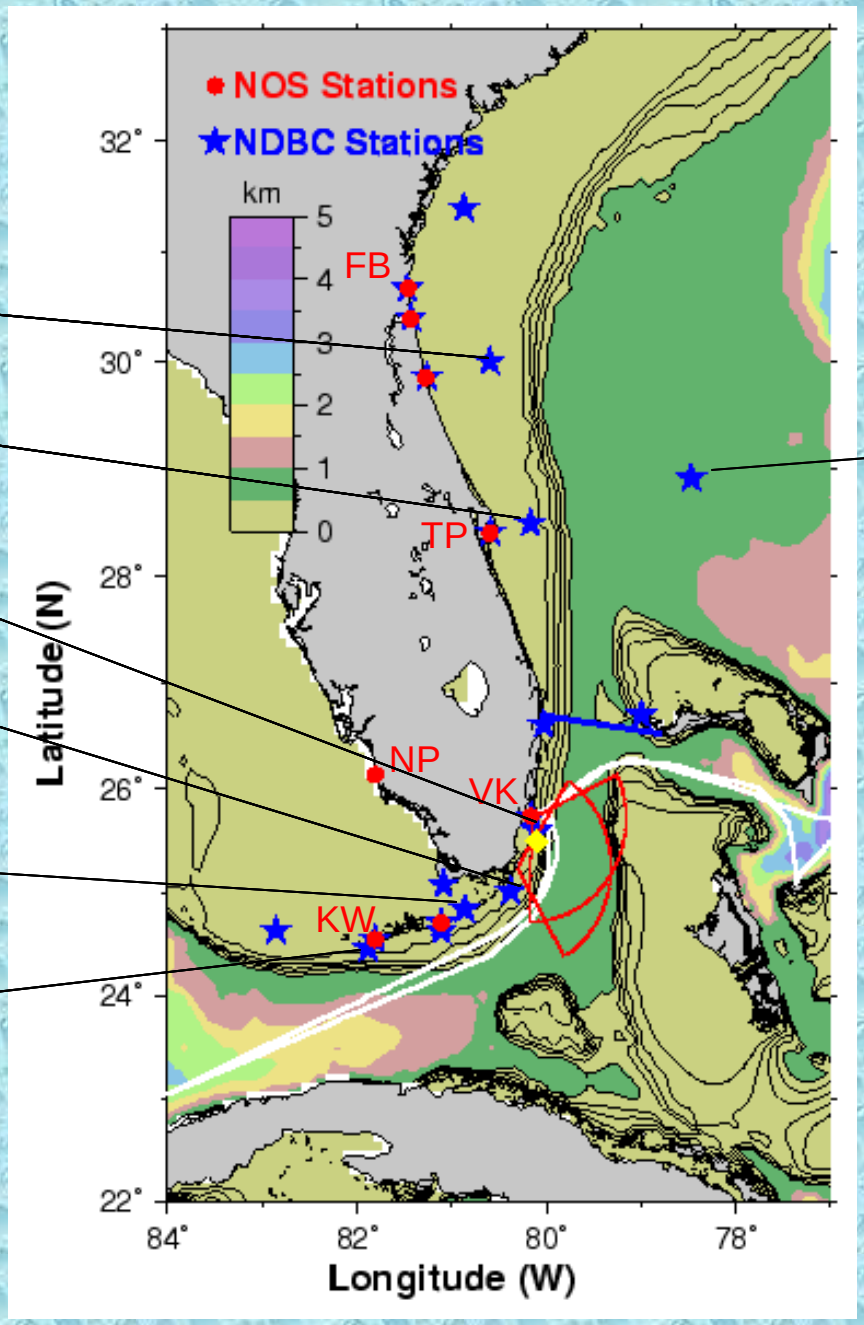
Animation: SST and SSH 1-year cycle (daily output)



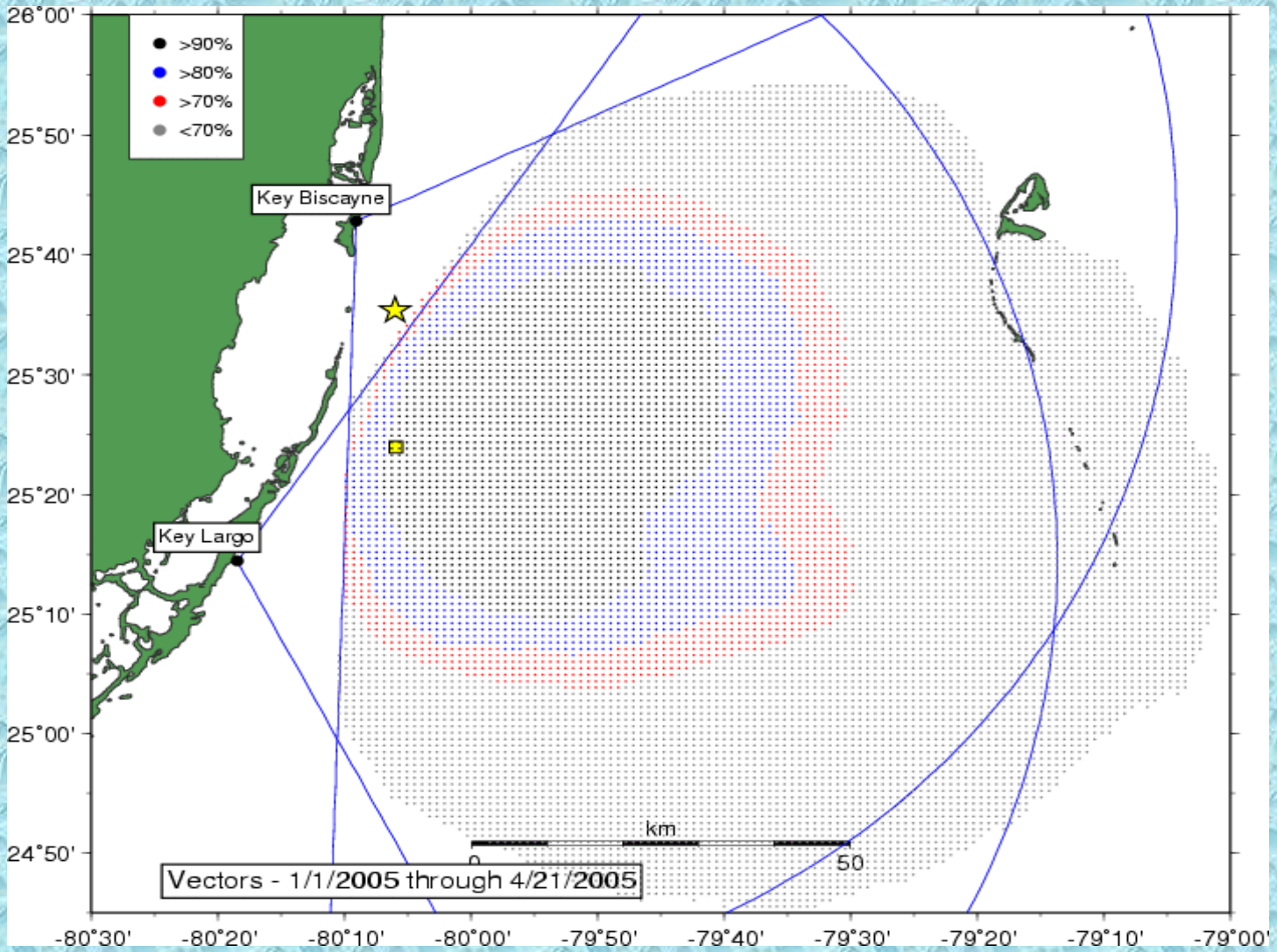
EFSIS SKILL ASSESSMENT

- SURFACE CURRENTS (UM COASTAL HF RADAR)
- VELOCITY PROFILES (NDBC & UM ADCPs)
- SURFACE TEMPERATURE (NDBC BUOYS & C-MAN STATIONS)
- COASTAL SEA LEVEL (CO-OPS TIDE GAUGES)
- VOLUME TRANSPORT (AOML SUBMARINE CABLE)

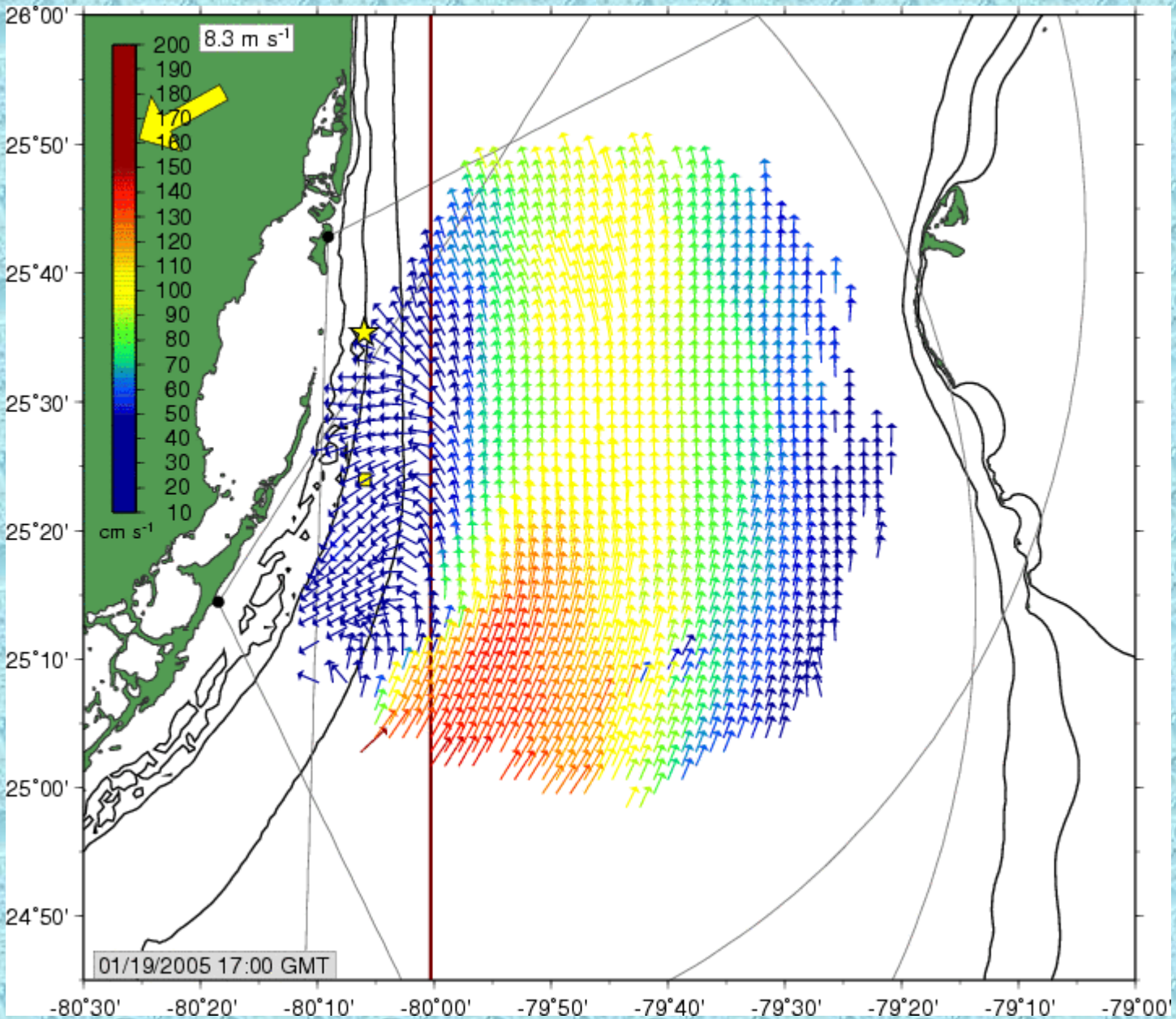
OBSERVING SUBSYSTEM



Distribution of Good WERA Data



Surface Currents (UM/WERA HF RADAR)

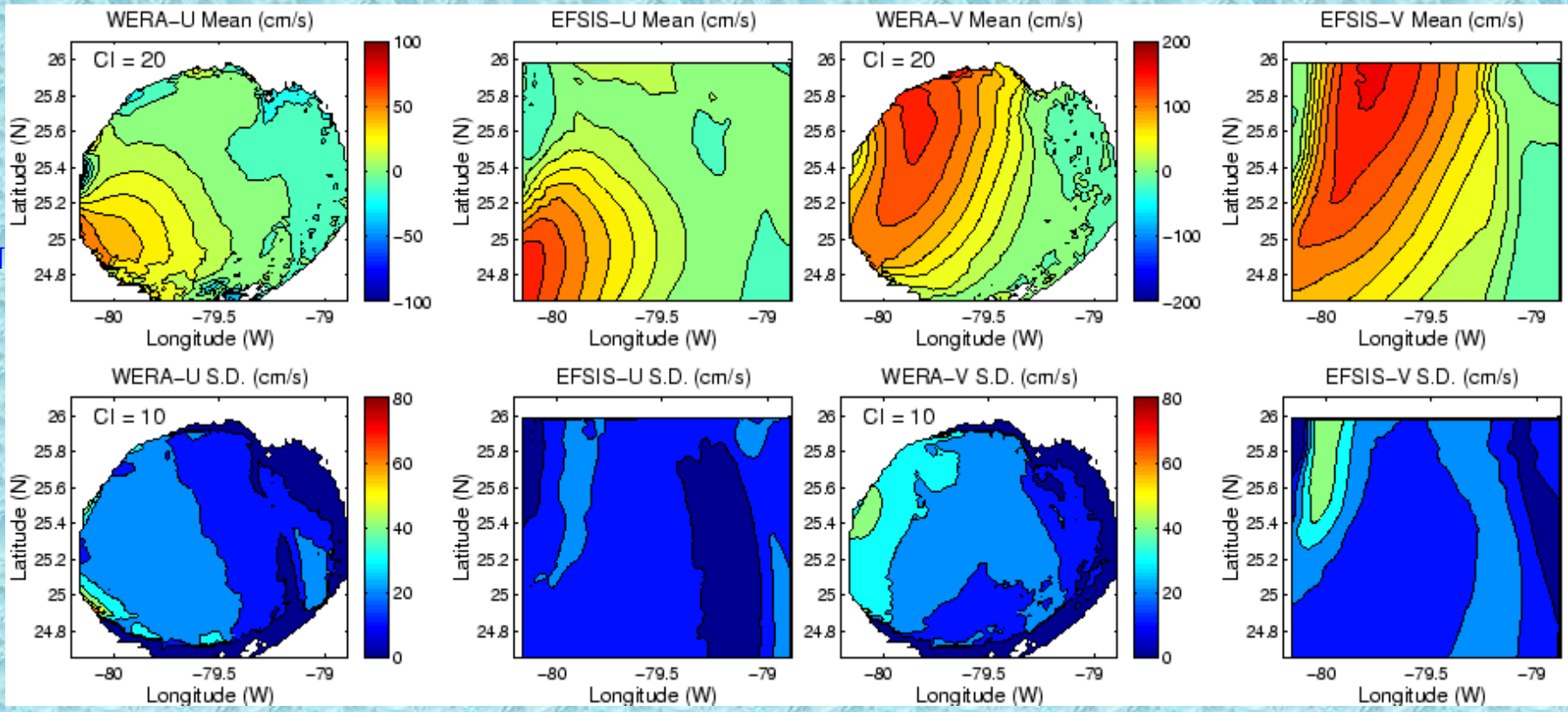


EFSIS COMPARISON of SURFACE CURRENT MEAN & STD with WERA /JAN-APR 05

U V

MEAN

STD

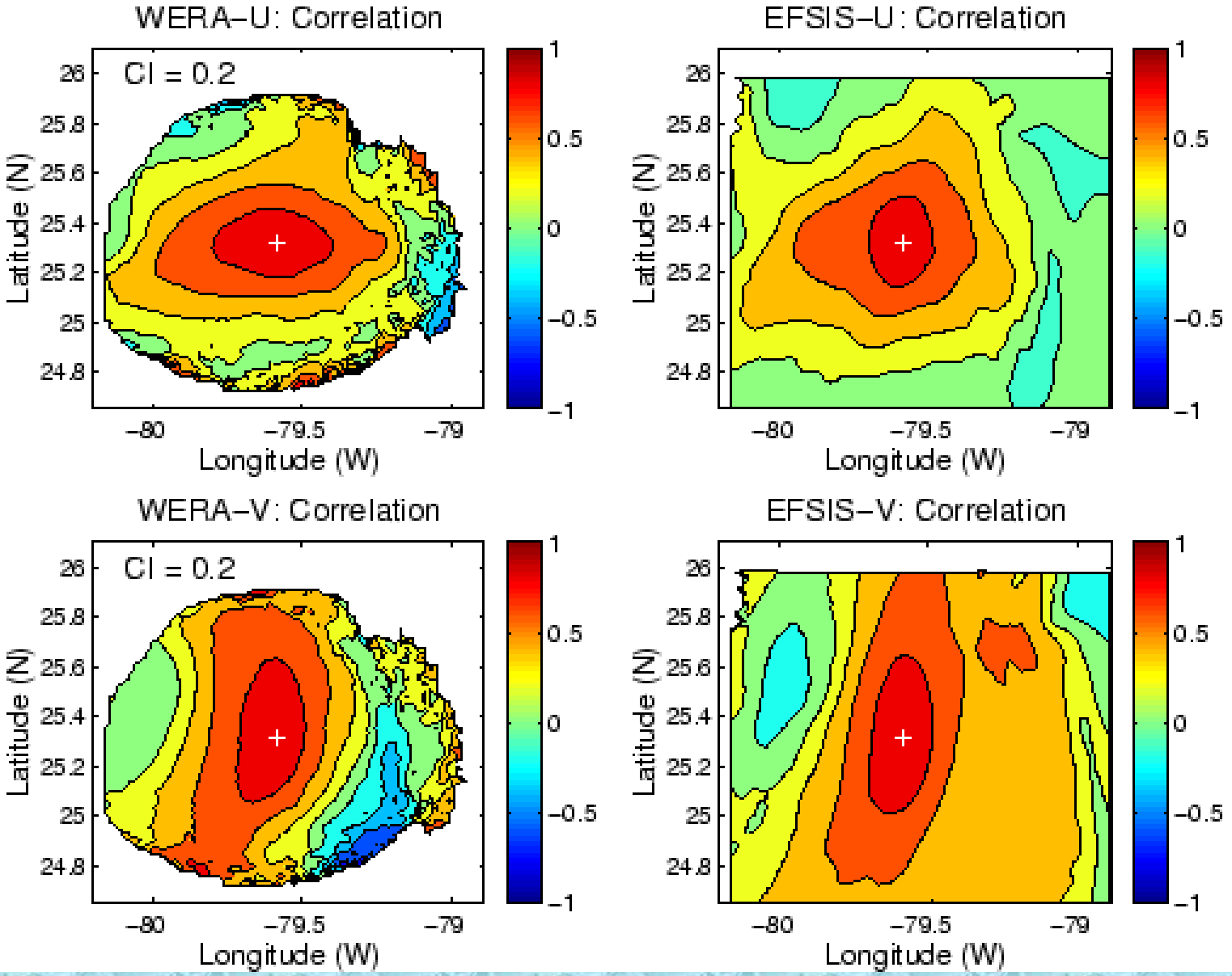


WERA EFSIS WERA EFSIS

EFSIS COMPARISON with WERA SPATIAL CORRELATION of SURFACE CURRENT /JAN-APR 05

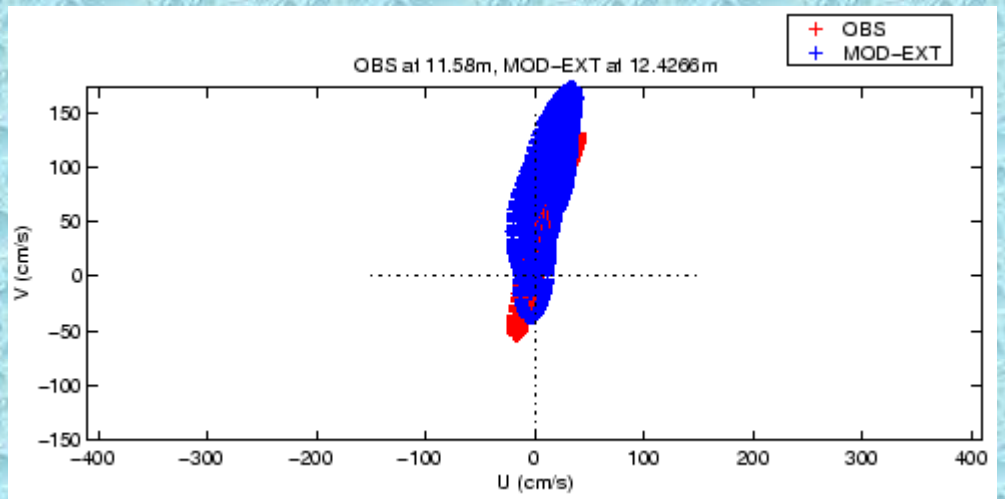
U

V

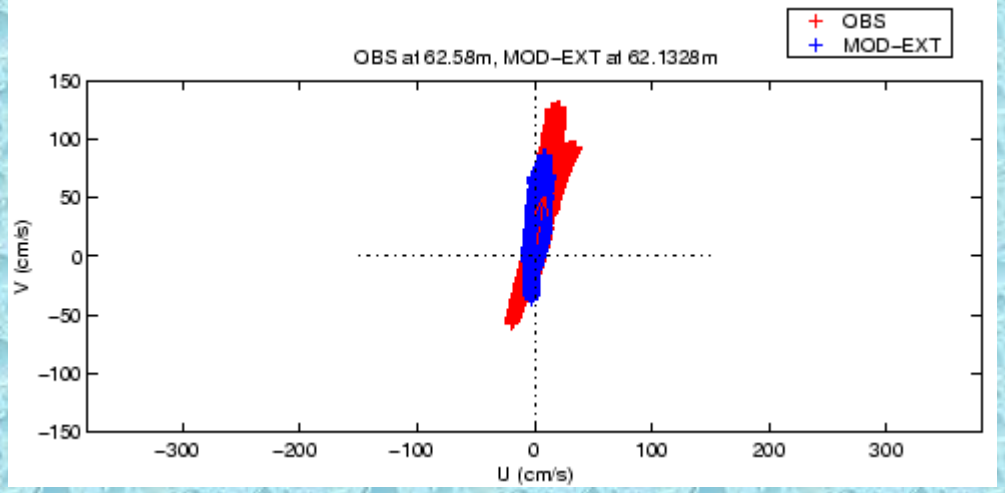


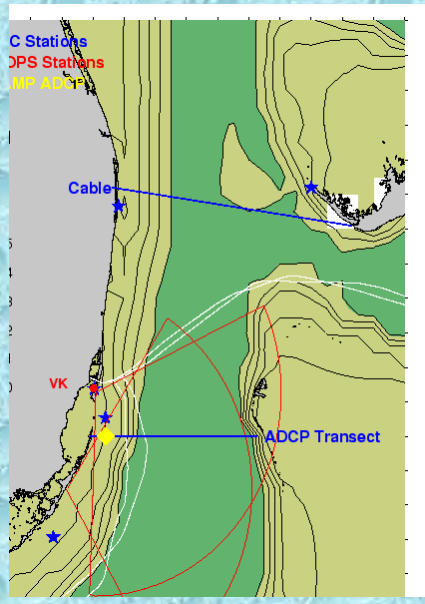
EFSIS COMPARISON with ADCP /OCT04 – MAY05
(red: ADCP, blue: EFSIS)

12 m



62 m

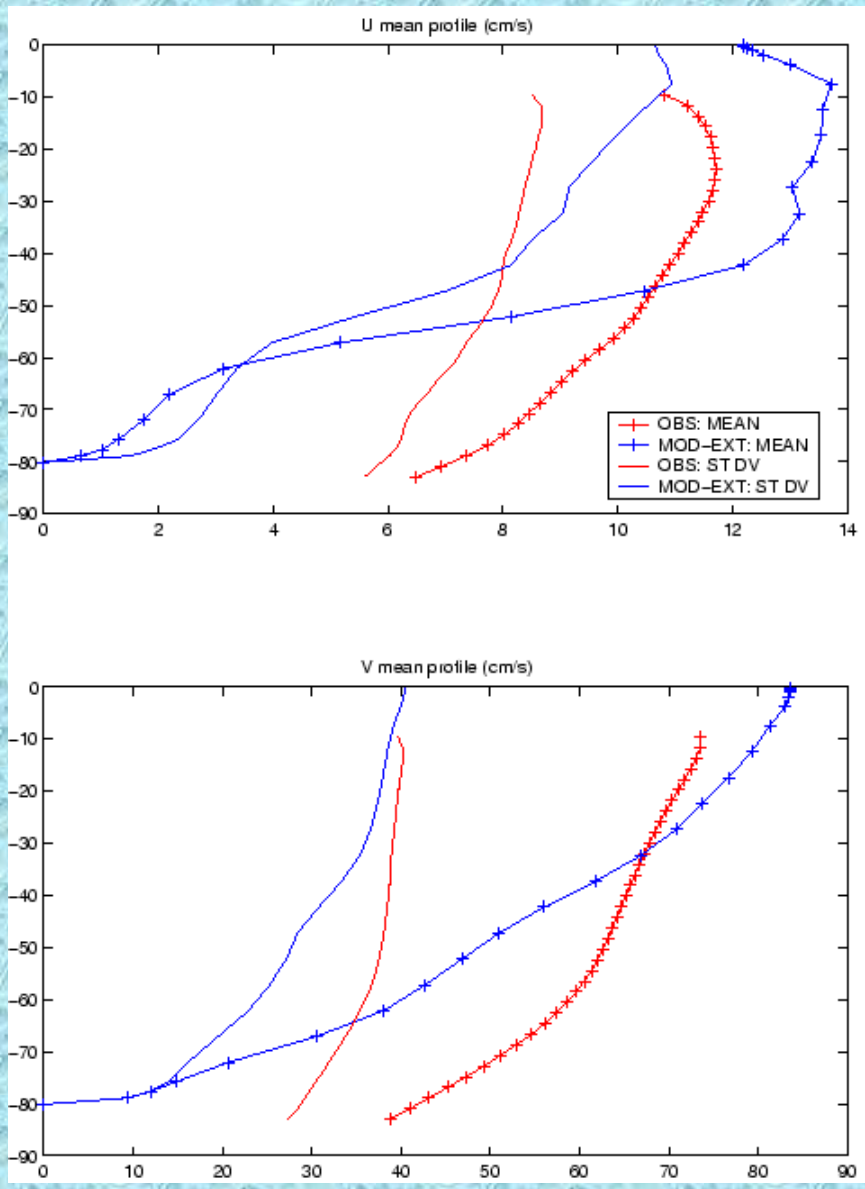




EFSIS COMPARISON with ADCP /OCT04 – MAY05
MEAN and STD PROFILES
(red: ADCP, blue: EFSIS
+: MEAN, no marker: STD)

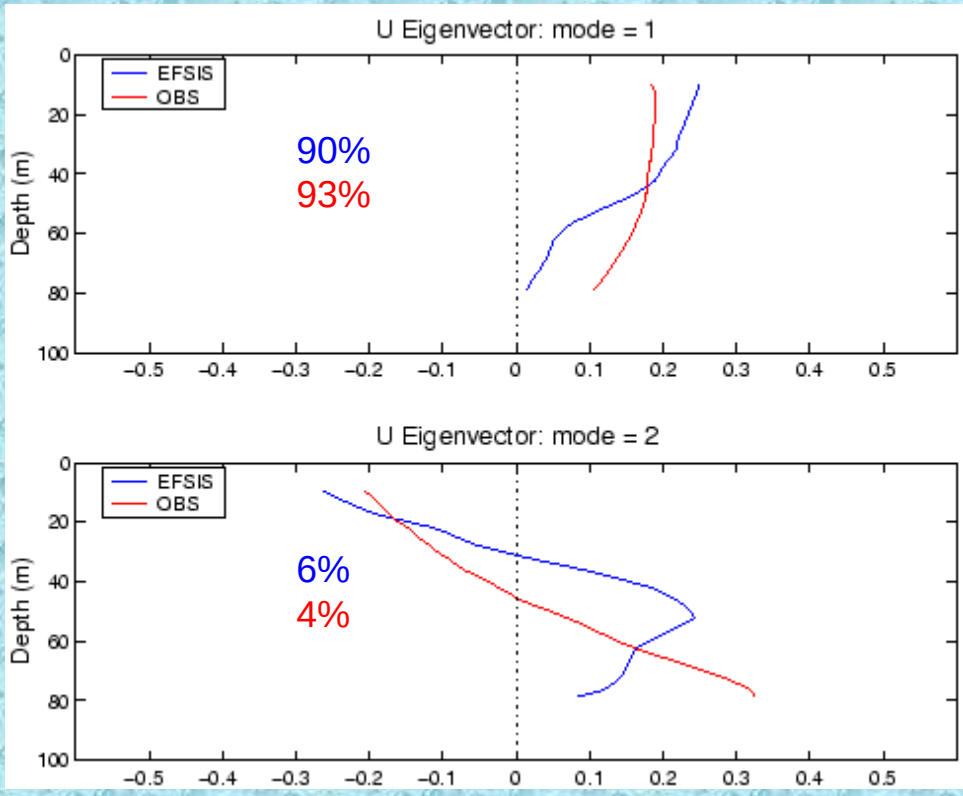
U

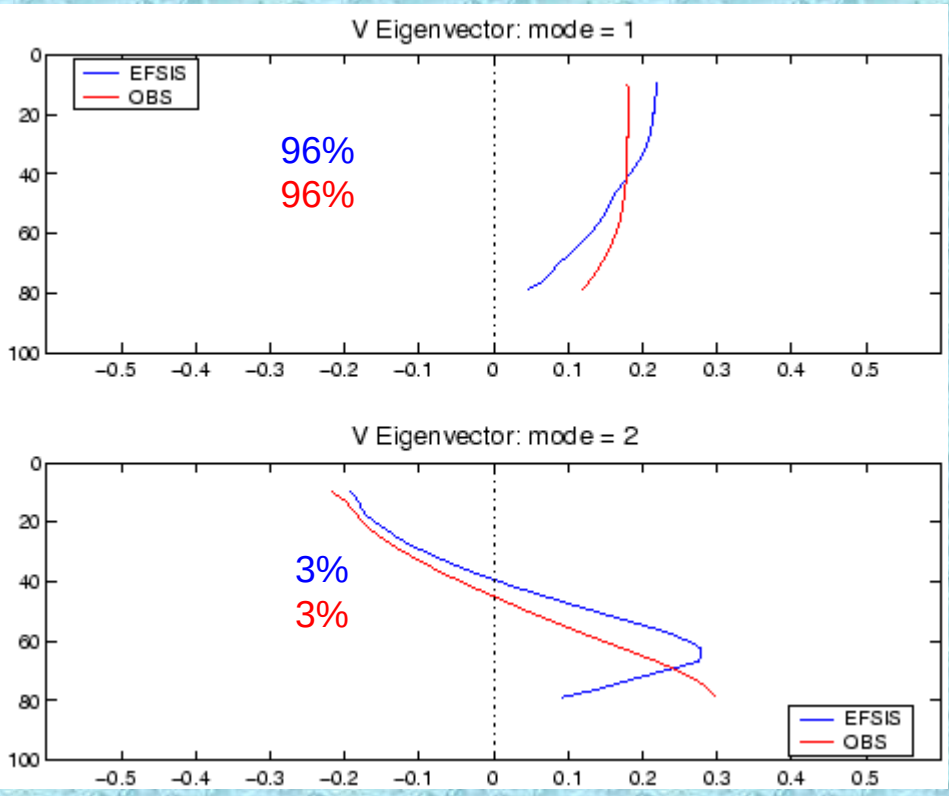
V



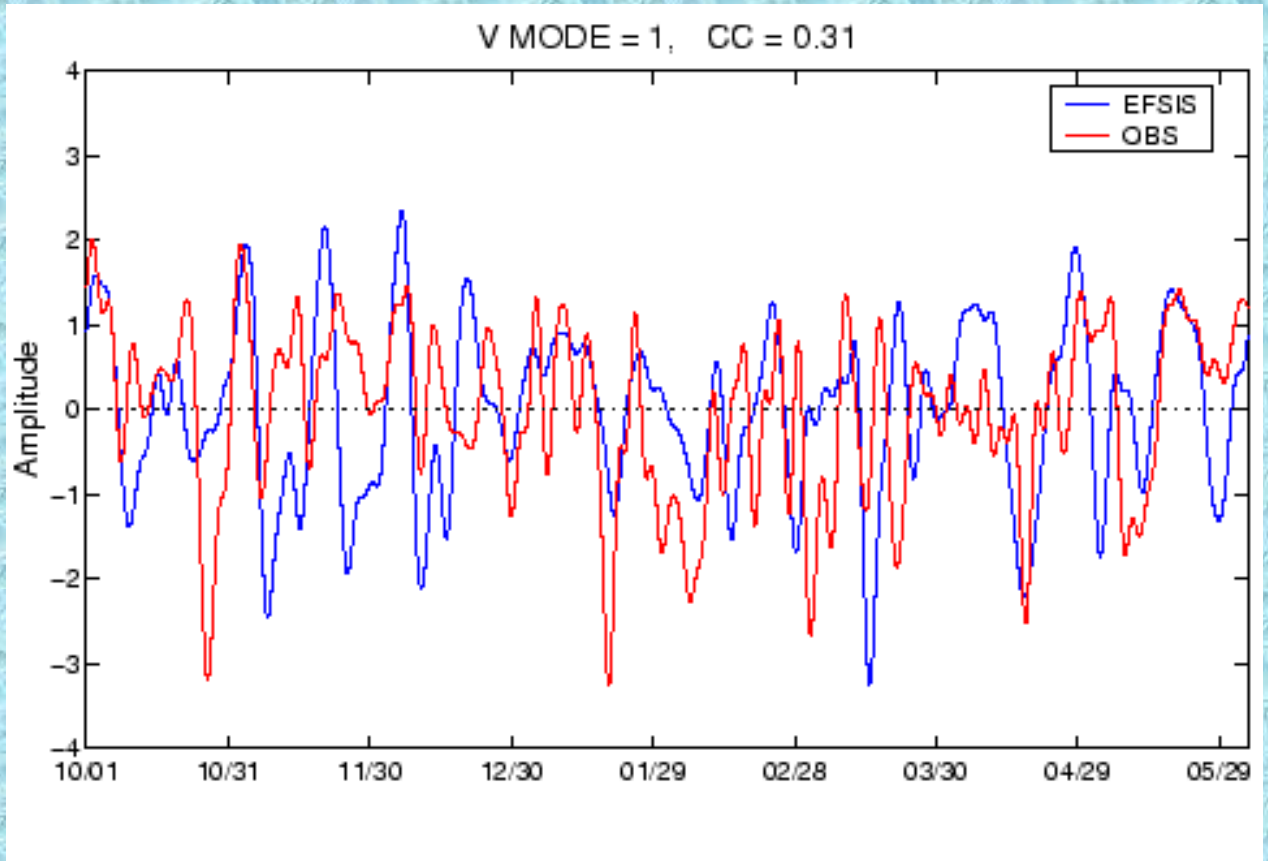
EFSIS COMPARISON with ADCP
EOF of VELOCITY
(red: ADCP, blue: EFSIS)

U **V**

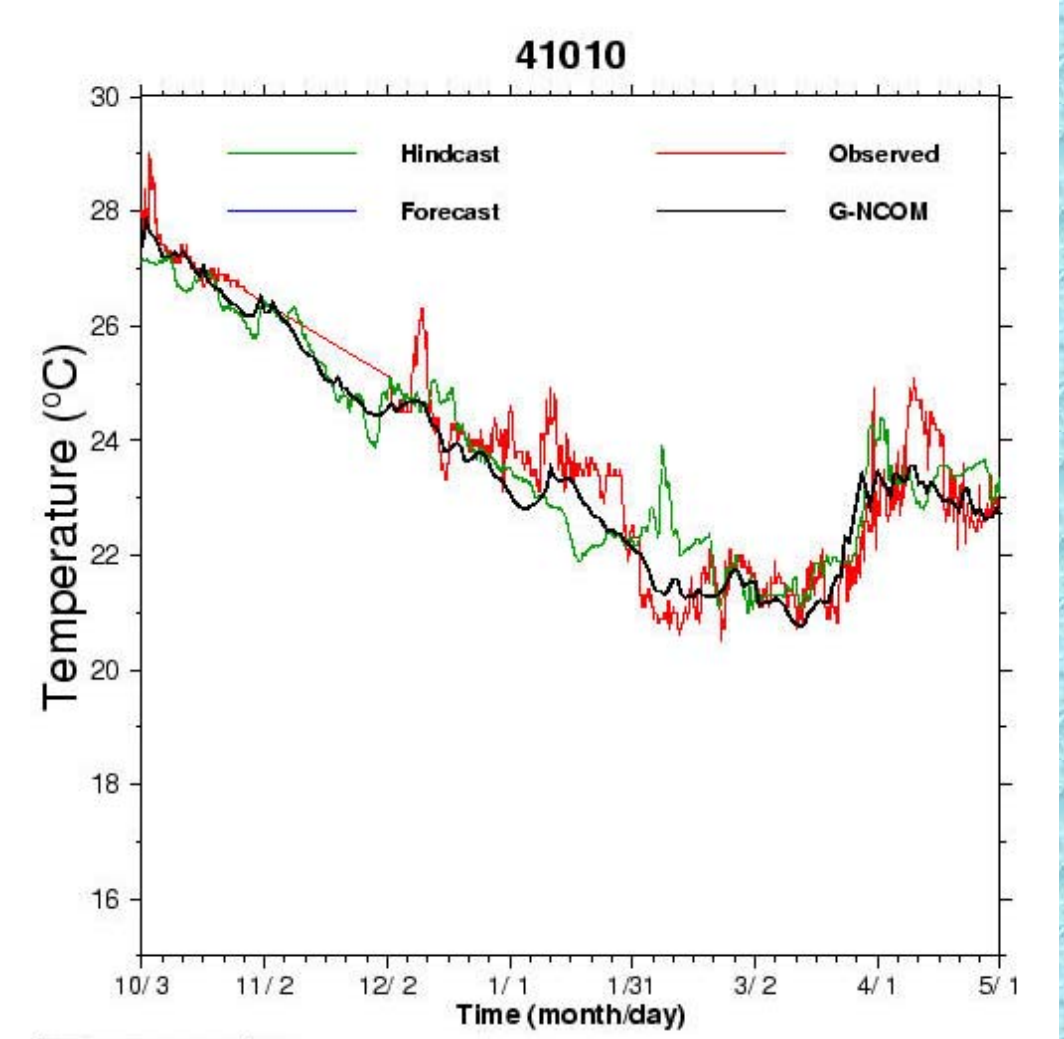




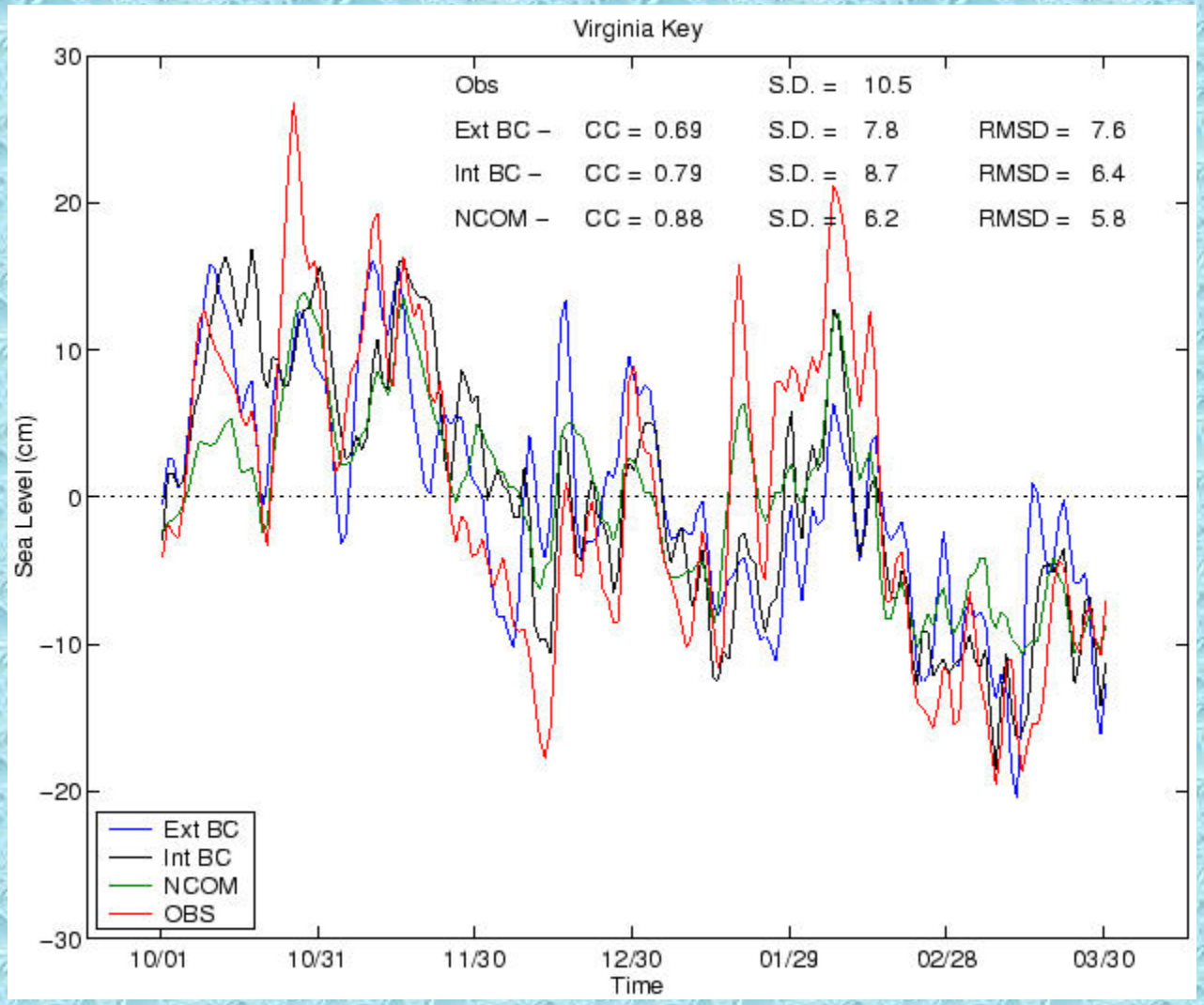
EFSIS COMPARISON with ADCP
EOF 1 of MERIDIONAL VELOCITY
AMPLITUDE TIME SERIES
(red: ADCP, blue: EFSIS)



EFSIS COMPARISON of SST with NDBC BUOY /OCT04 - APR05



EFSIS COMPARISON of SUB-TIDAL CSL with VK TIDE GAUGE /OCT04 - MAY05

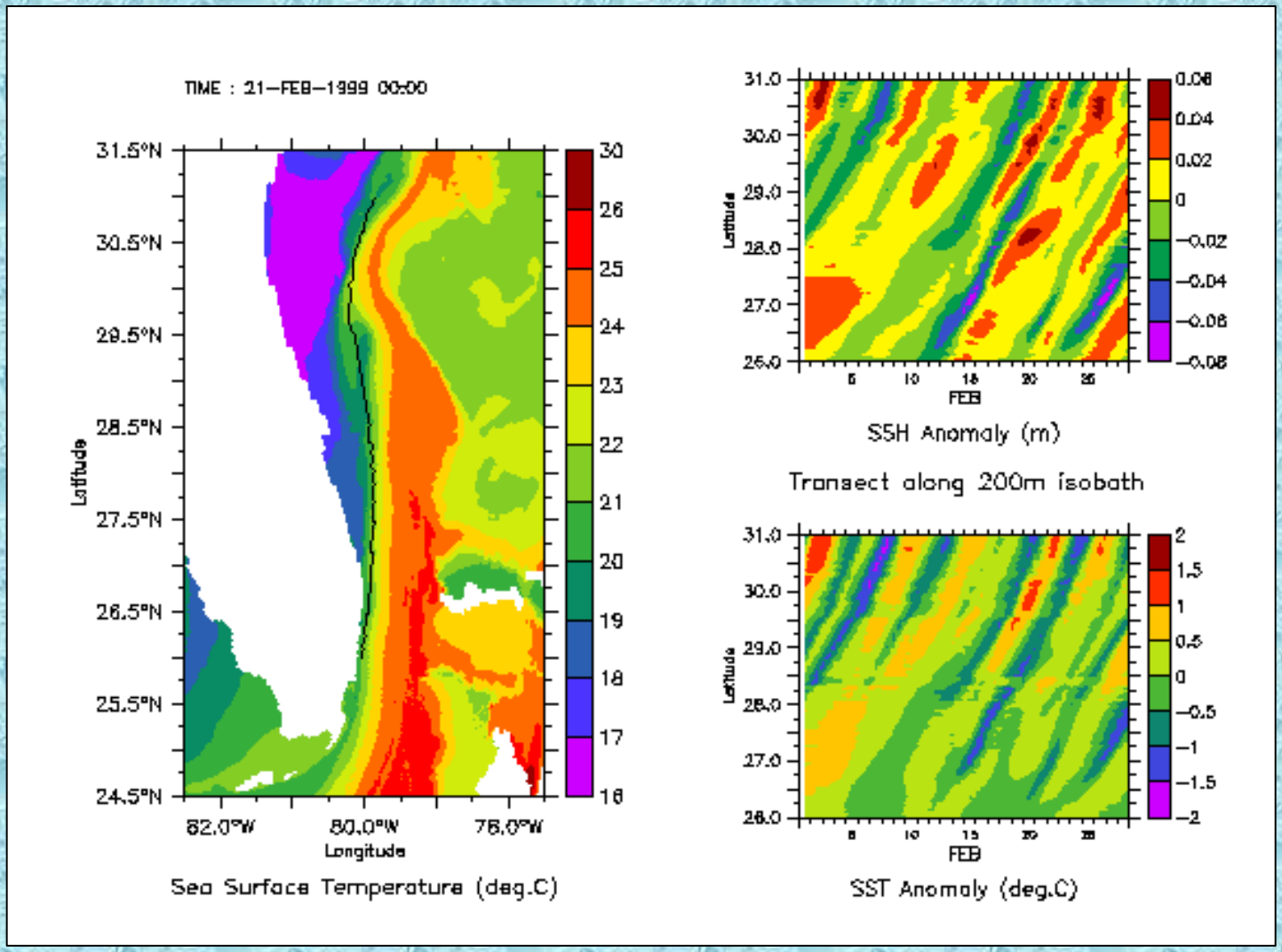


SERENDIPITY FOLLOWS

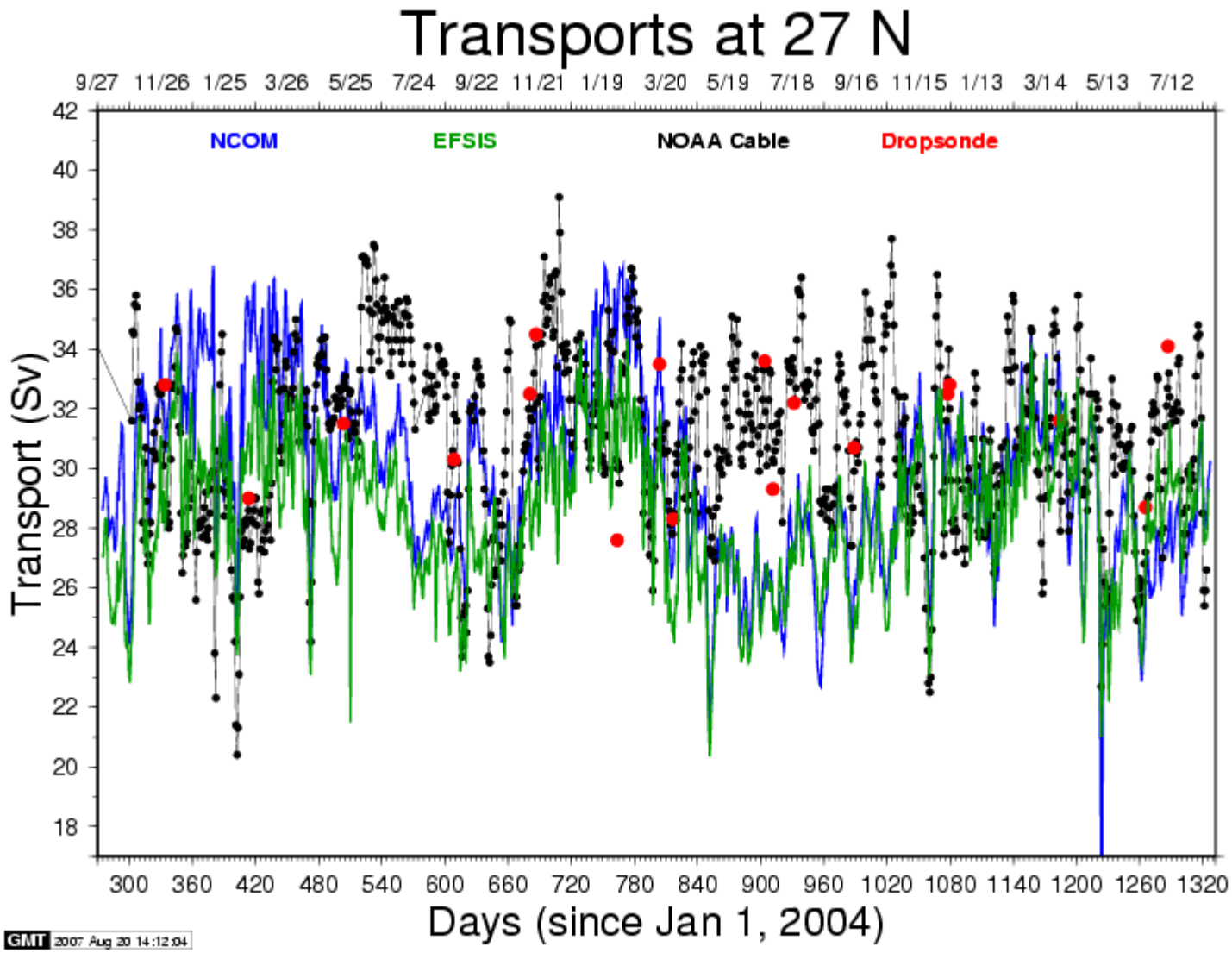
- A START

FRONTAL EDDY EVENTS on EAST FLORIDA SHELF

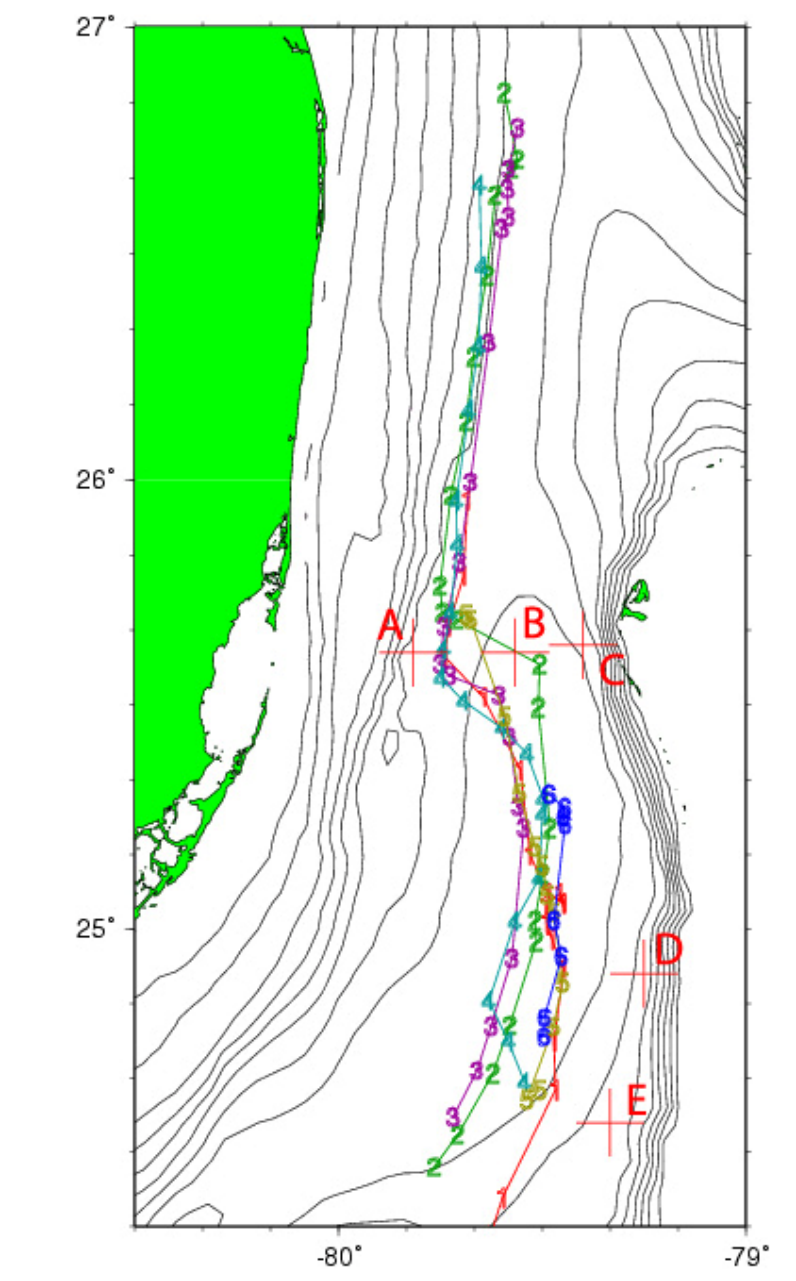
EDDY TRANSLATION along SHELF BREAK (200m)



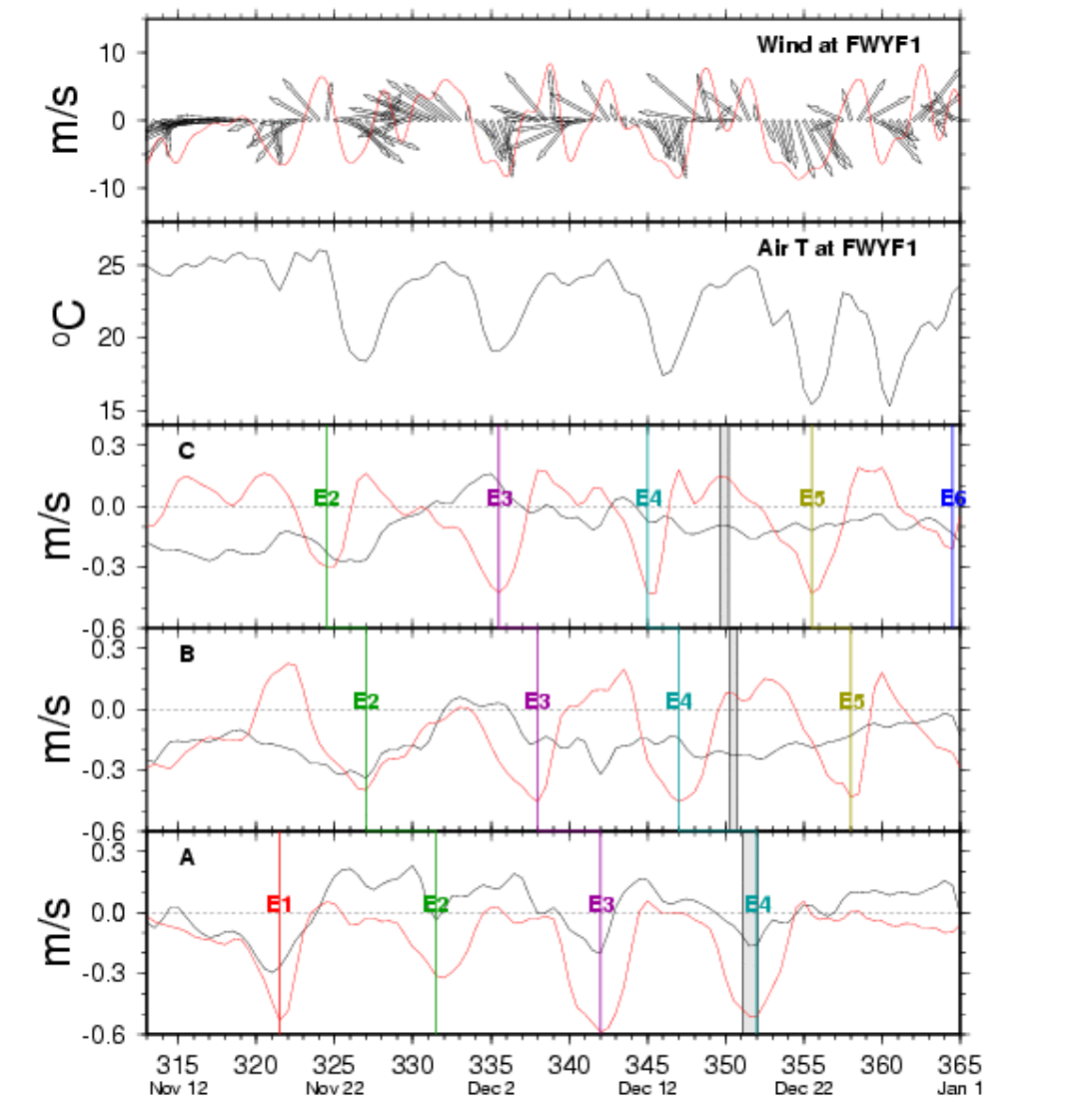
VARIOUS VOLUME TRANSPORT ESTIMATES



EFSIS TRAJECTORIES OF BOTTOM-TRAPPED CYCLONES



50-DAY TIME SERIES of NDBC WIND and AIR TEMPERATURE and EFSIS UPPER-LAYER & LOWER-LAYER CURRENTS

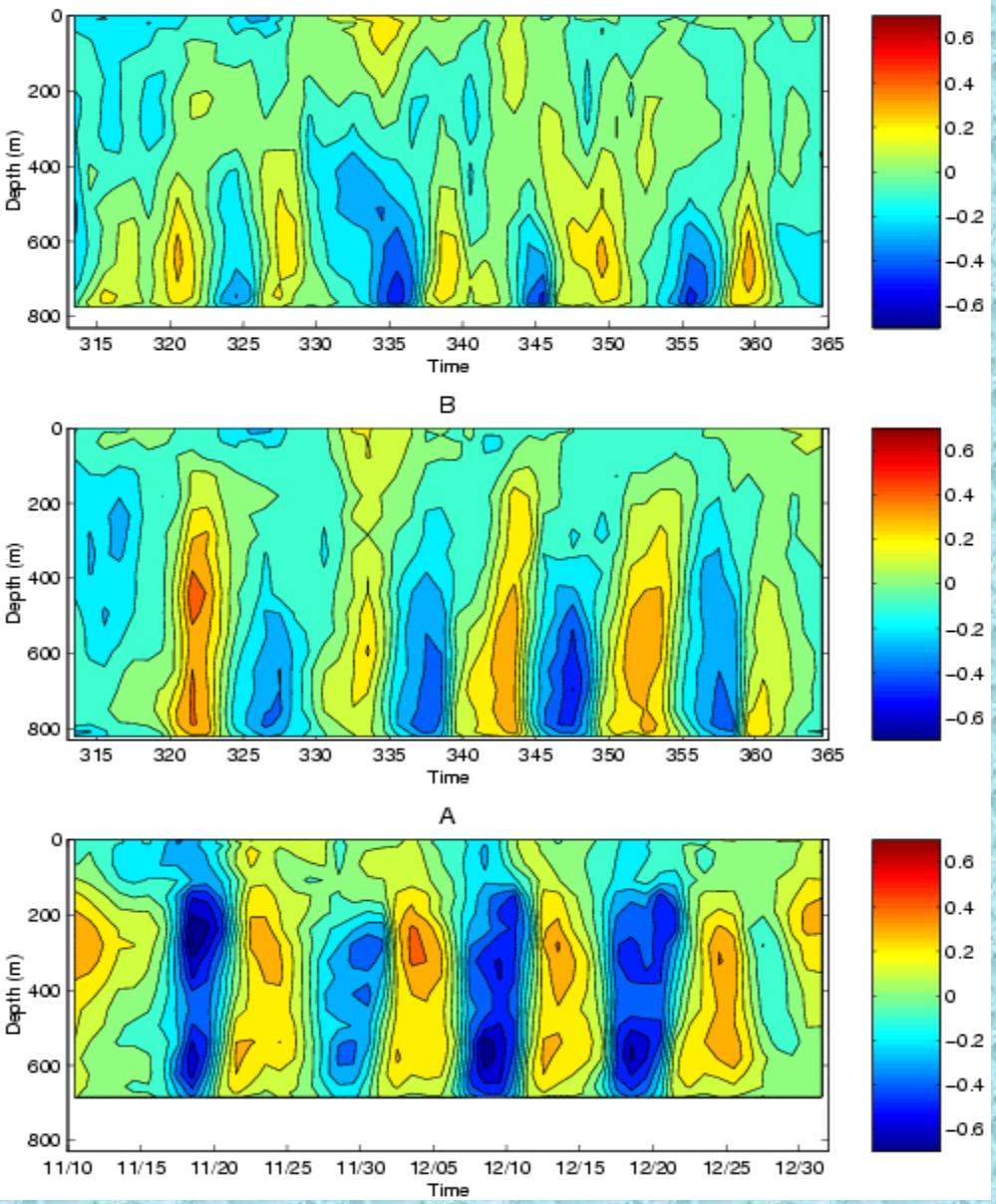


50-DAY TIME-DEPTH PLOT of EFSIS ALONG-CHANNEL FLOW

C

B

A



SERENDIPITOUS SCIENTIFIC RESULTS

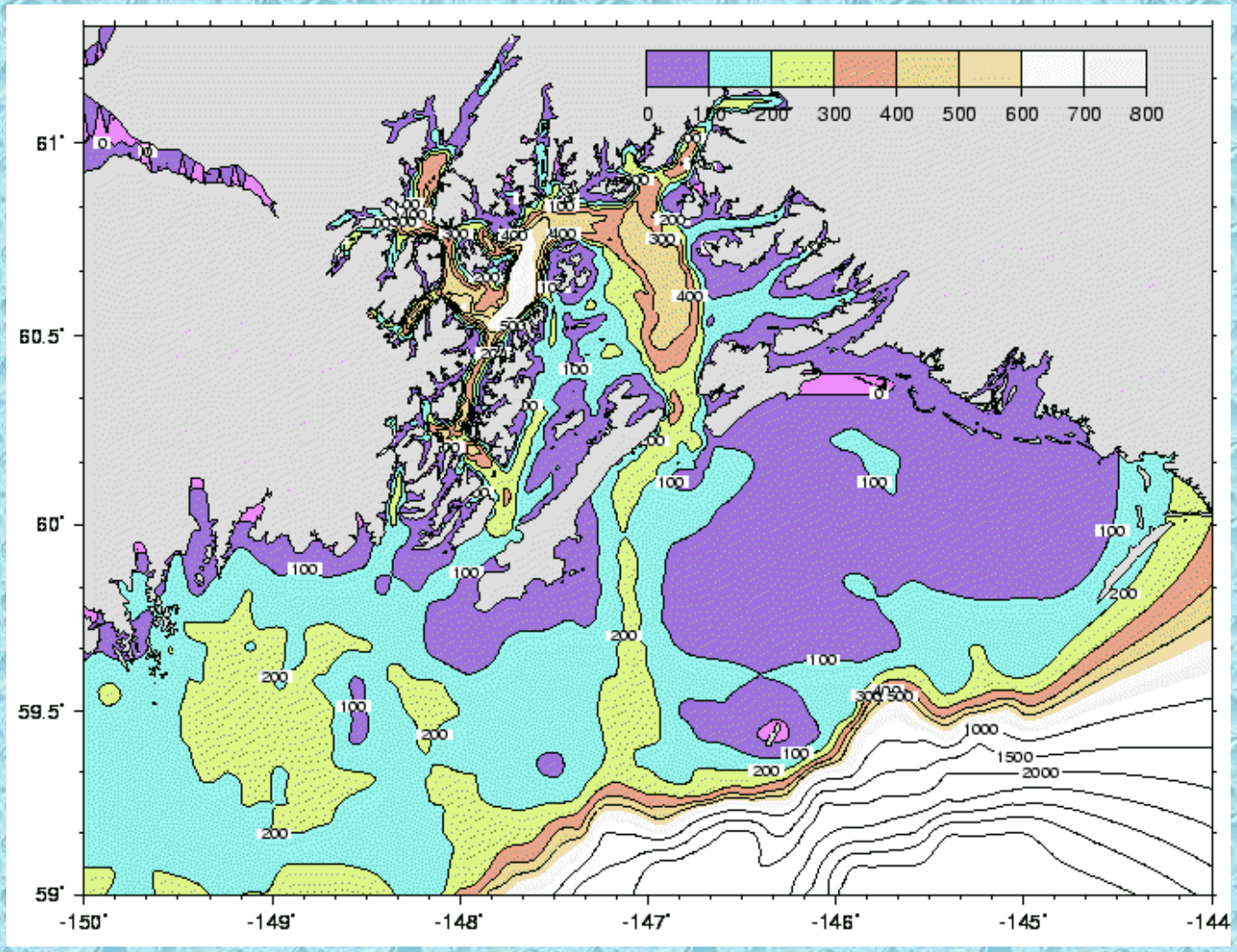
- FLORIDA CURRENT FRONTAL EDDIES FORM SPONTANEOUSLY ALONG THE SHELFBREAK BUT ARE MODULATED BY THE WEATHER CYCLE
- THE WEATHER CYCLE INDUCES CA. 10 Sv TRANSPORT VARIATIONS IN OBSERVED AND SIMULATED ESTIMATES
- THE WEATHER CYCLE ALSO INDUCES DEEP CYCLONES THAT TRANSLATE DOWNSTREAM FROM CAY SAL BANK TO MIAMI AND BEYOND

EPWS/NFS

EXTENDED PRINCE WILLIAM SOUND NOWCAST/FORECAST SYSTEM

http://epws-nfs.rsmas.miami.edu

PRINCE WILLIAM SOUND (PWS) BOTTOM TOPOGRAPHY



FORCINGS

TOPOGRAPHY
- SEMI-ENCLOSED
- FJORD-LIKE

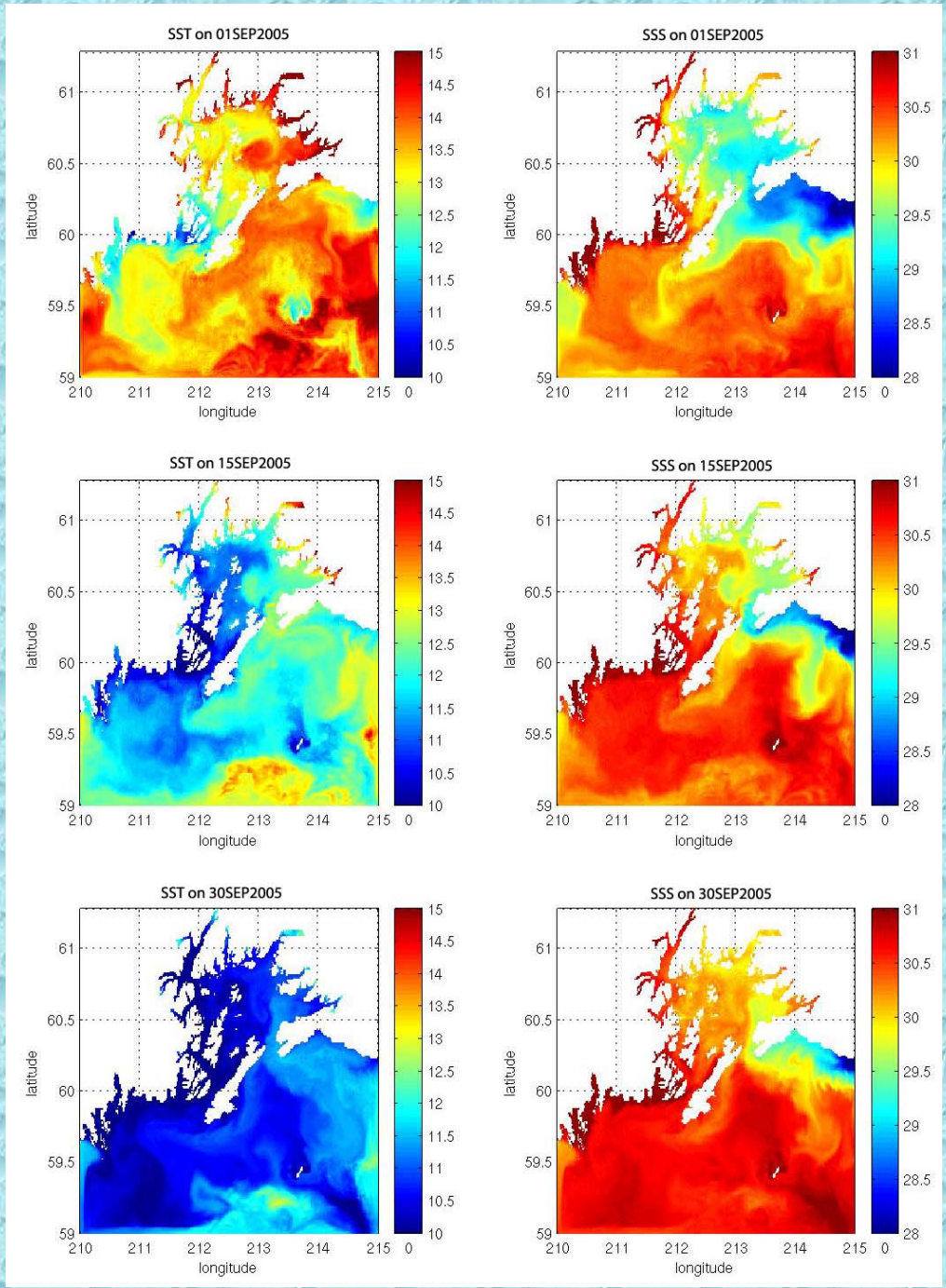
TIDES

WINDS
- ALEUTIAN LOW
- STORMS

BUOYANCY
- SNOWMELT
- HEAT FLUX

THROUGHFLOW
- ACC

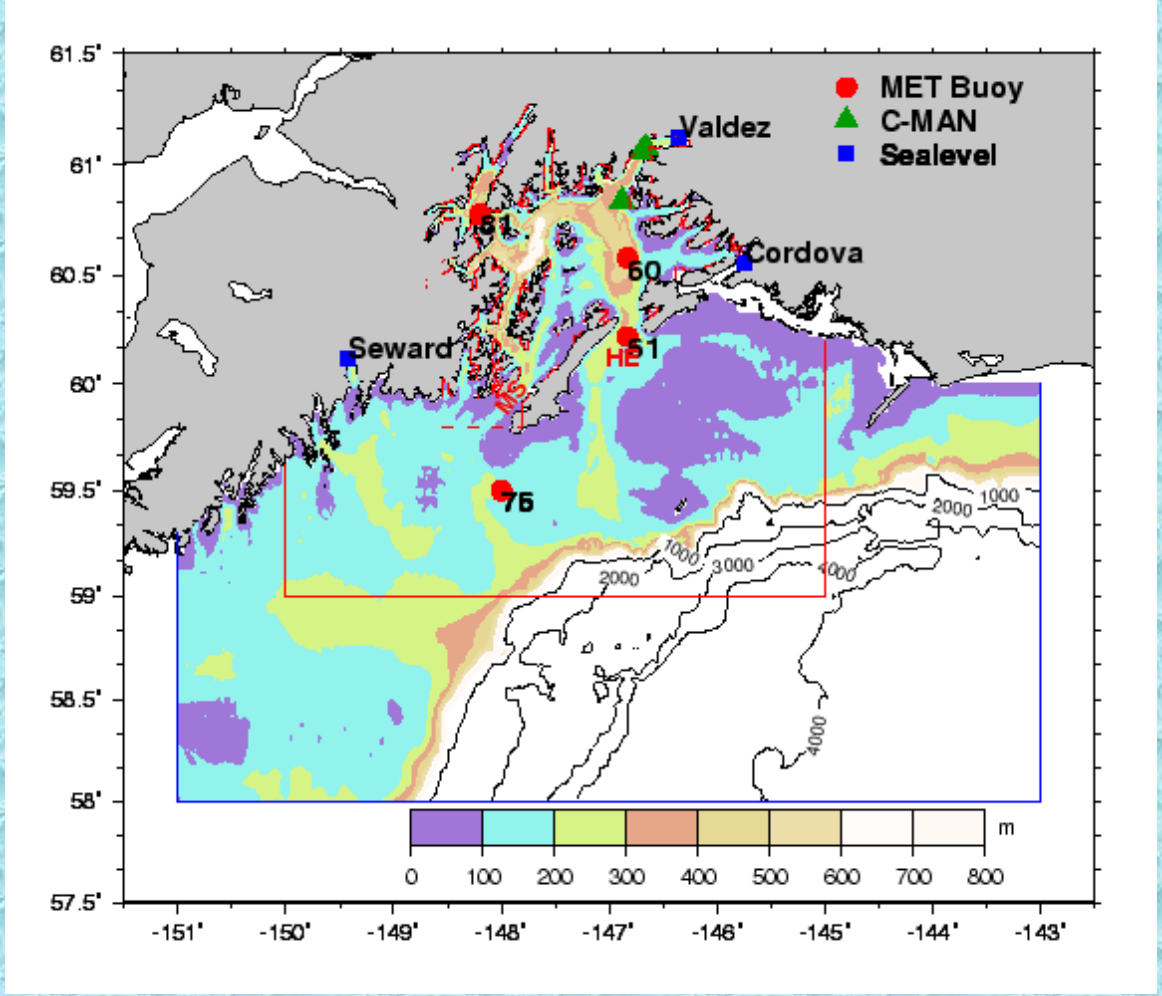
EPWS/NFS
SST and SSS in SEP05



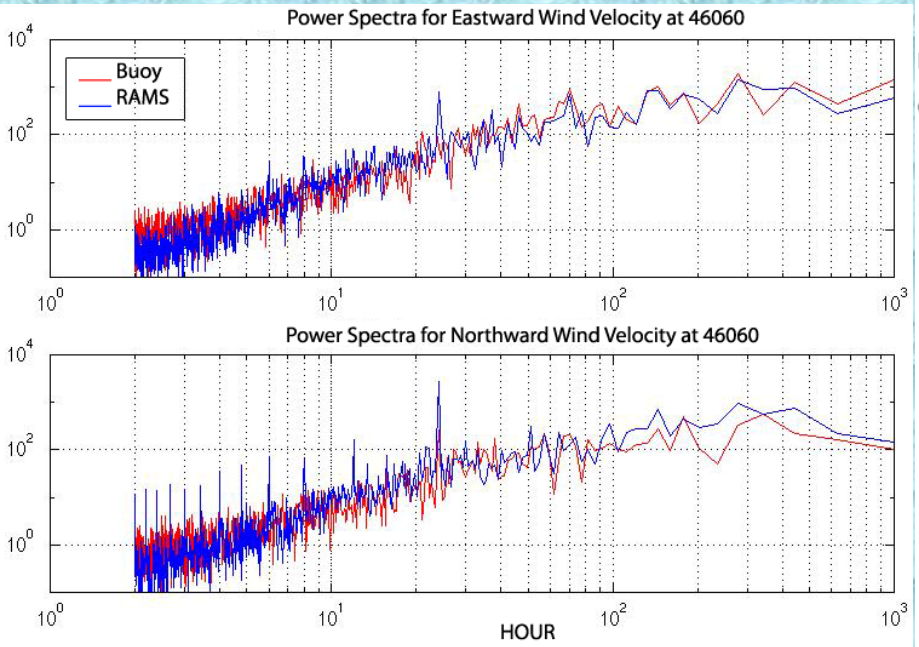
EPWS/NFS SKILL ASSESSMENT

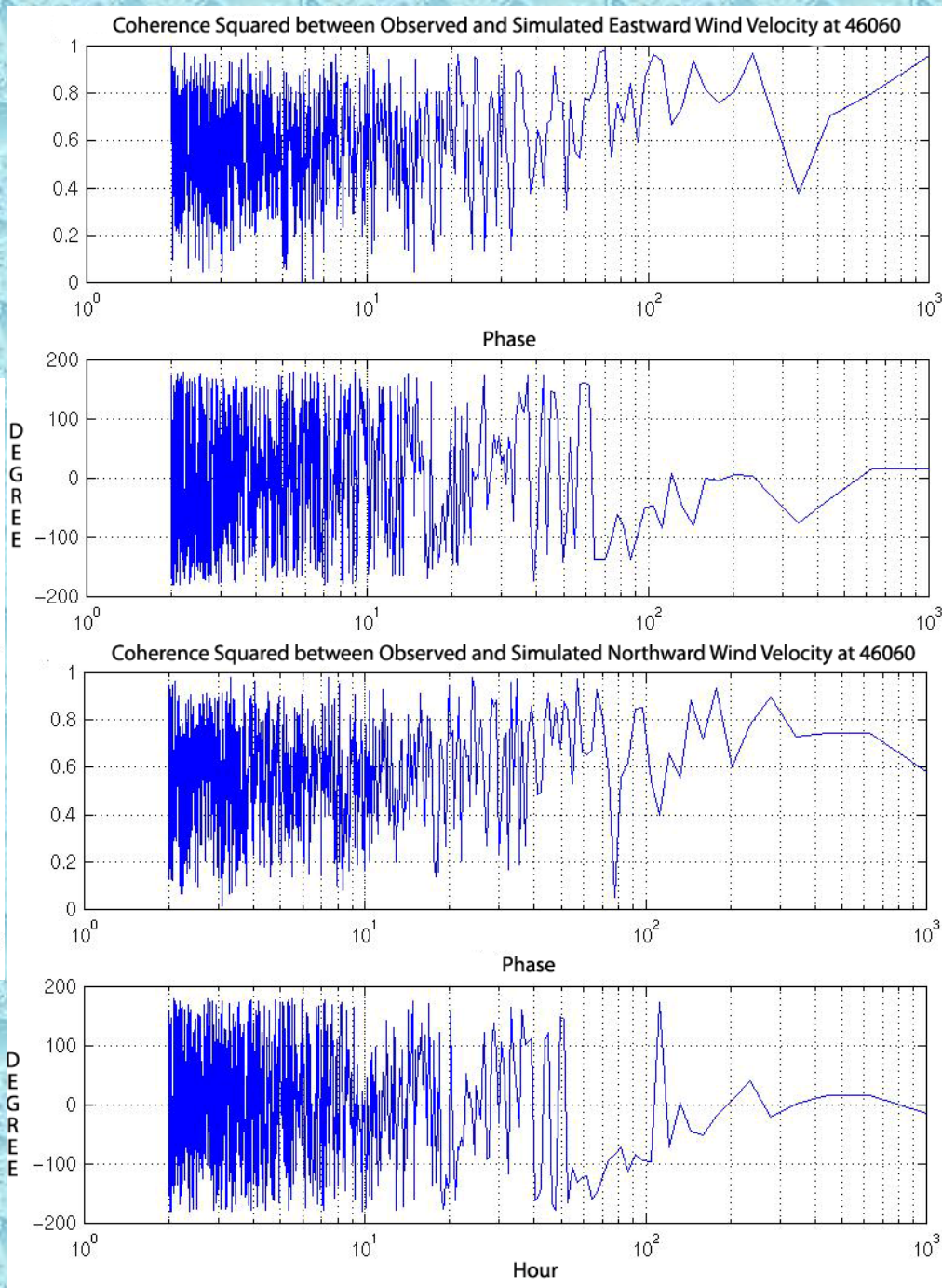
- NDBC BUOYS FOR WIND, PRESSURE, SST, AND ADCP VELOCITY PROFILES AT ONE SITE
- CO-OPS TIDE GAUGES FOR COASTAL SEA LEVEL AND COASTAL SST

MODEL DOMAINS (blue: TIDAL MODEL, red: EPWS) and NDBC & CO-OPS OBSERVING SUBSYSTEM



POWER SPECTRA AND COHERENCE BETWEEN OBSERVED AND SIMULATED WINDS IN PWS

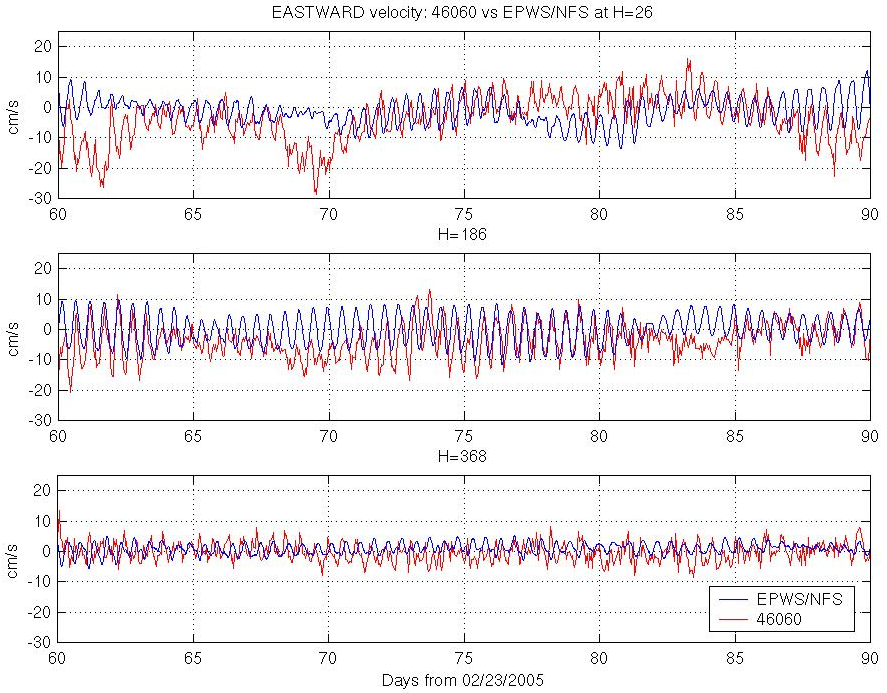


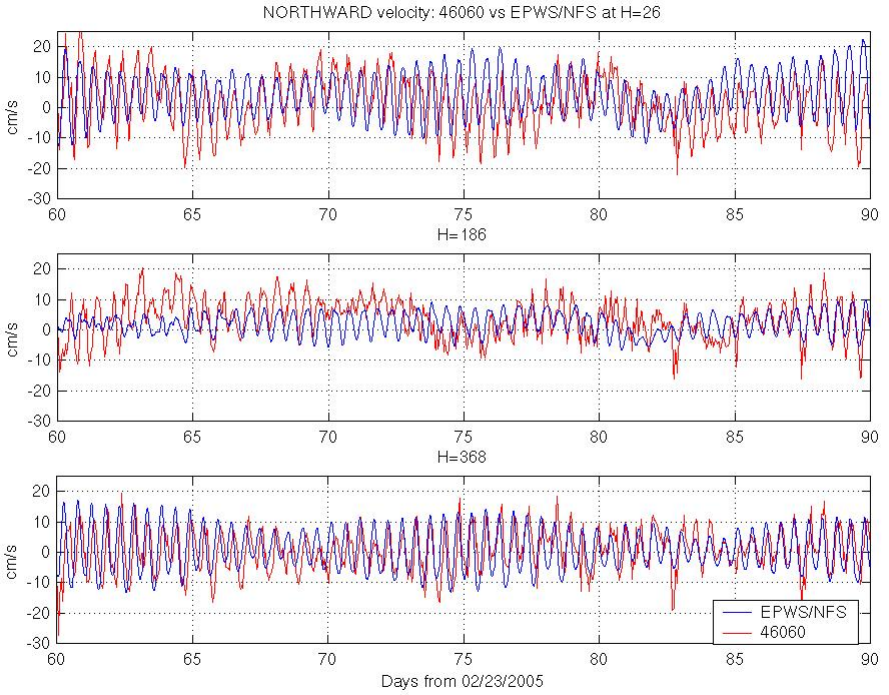


ONE-MONTH EPWS COMPARISON of HOURLY VELOCITY at THREE DEPTHS with NDBC 46060 ADCP

U

V

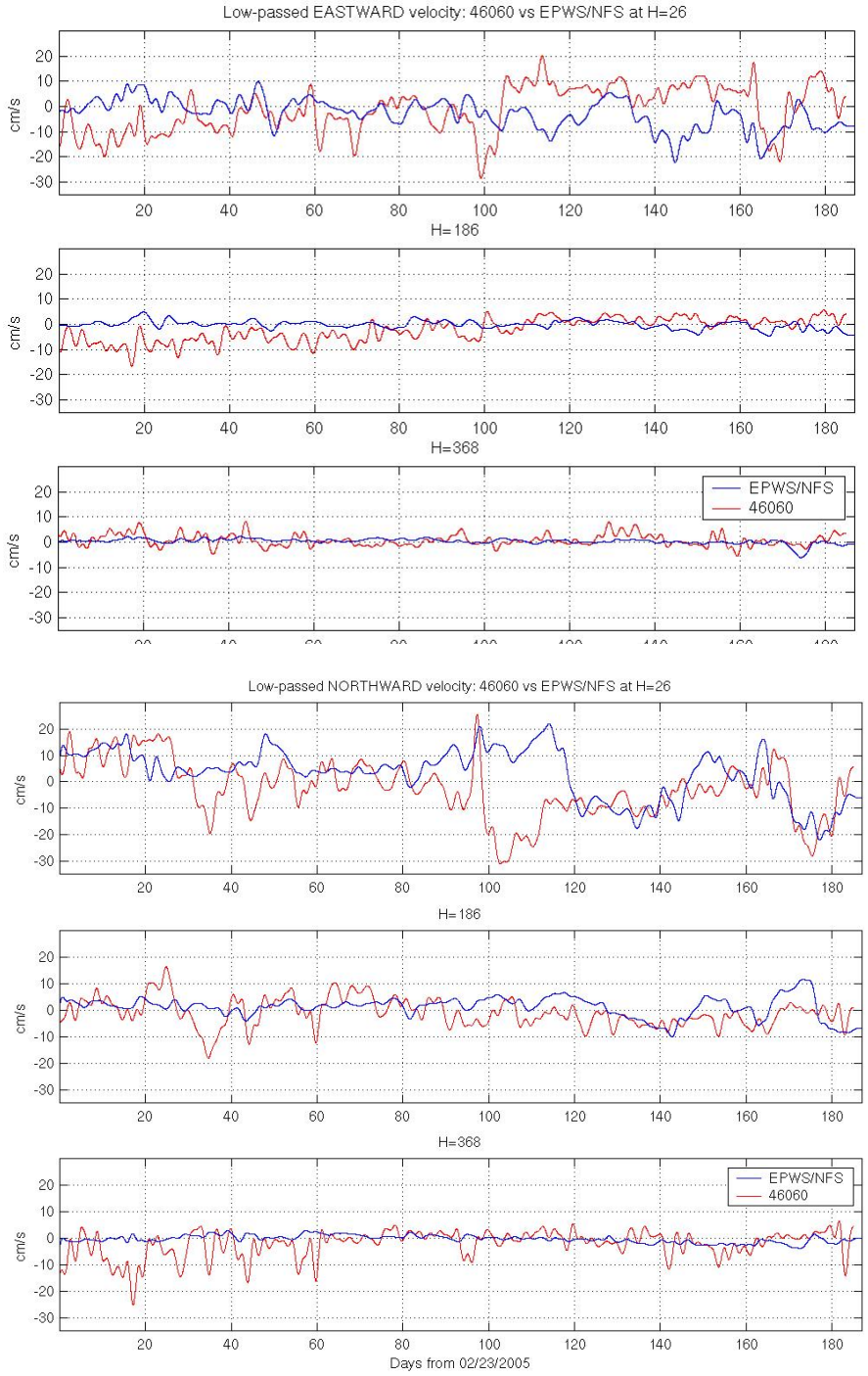




SIX-MONTH EPWS COMPARISON of 40-HR LOW-PASSED VELOCITY at THREE DEPTHS with NDBC 46060 ADCP

U

V

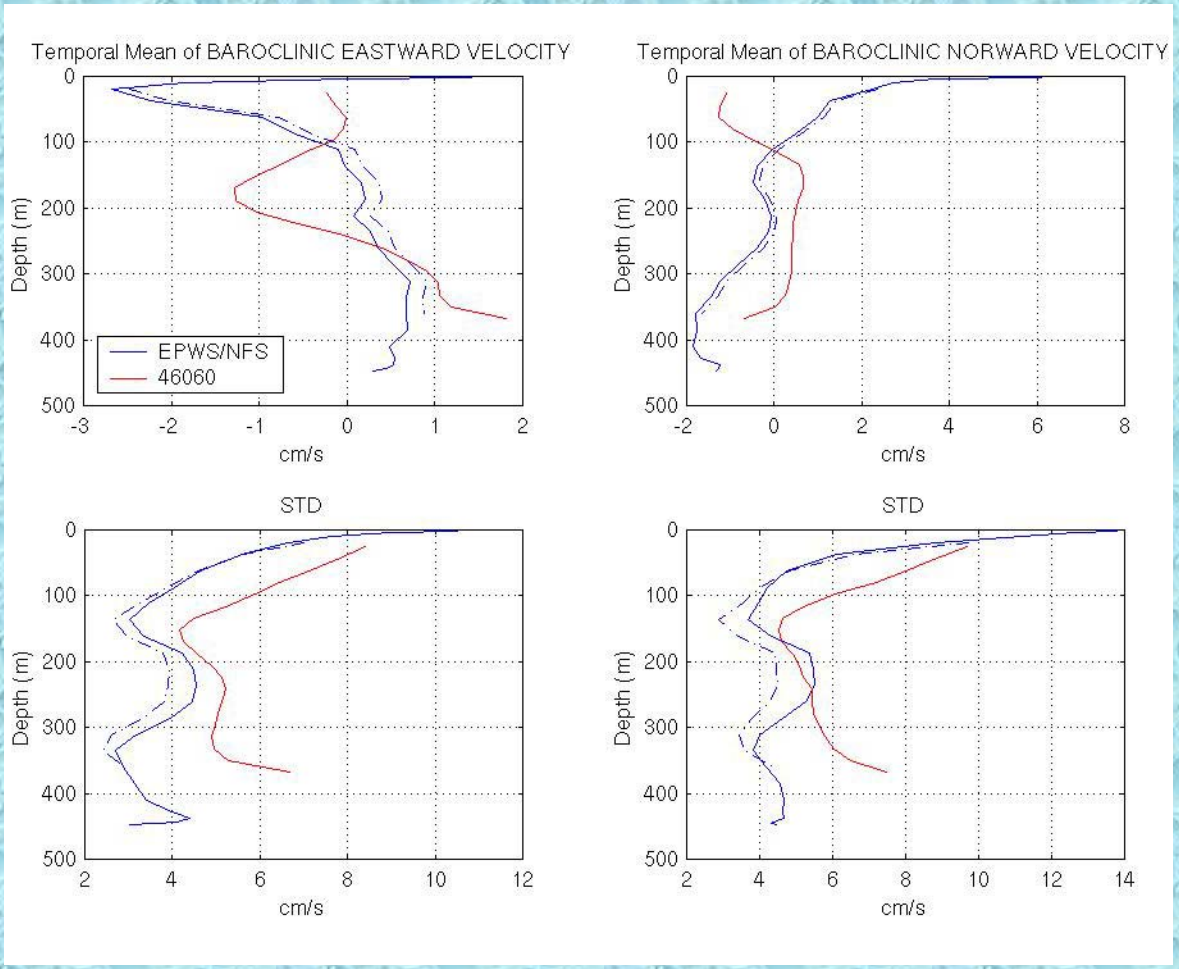


EPWS COMPARISON of 6-MONTH MEAN & STD BAROCLINIC VELOCITY PROFILES and BAROTROPIC CURRENTS with ADCP at NDBC 46060

U **V**

BAROTROPIC MEAN: -0.5 *vs.* -1.0

BAROTROPIC STD: 2.3 *vs.* 5.3



BAROTROPIC MEAN: -1.6 *vs* -2.7

BAROTROPIC STD: 5.6 *vs.* 7.6

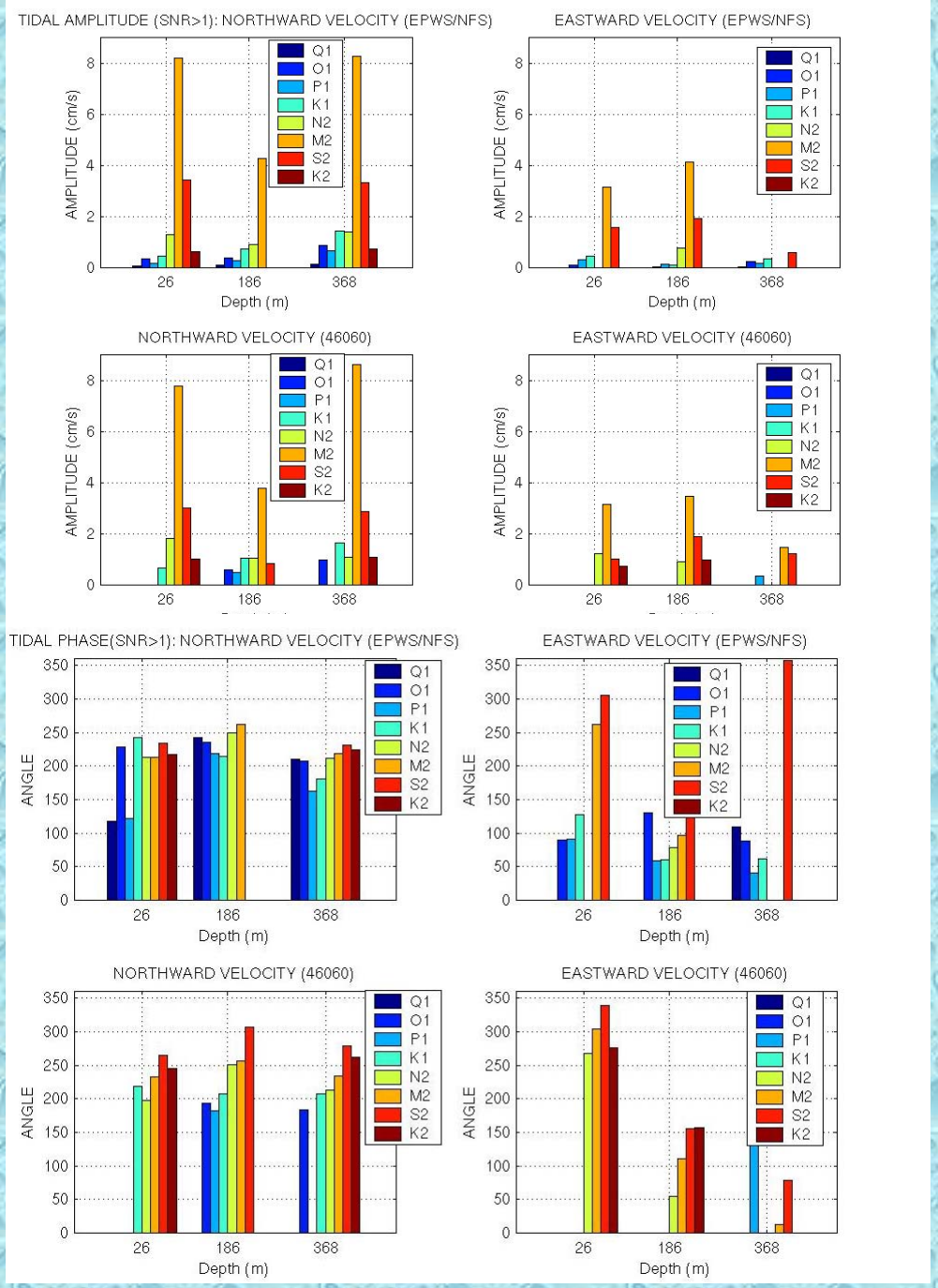
EPWS COMPARISON of TIDAL HARMONIC VELOCITIES for THREE DEPTHS with ADCP at NDBC 46060

EPWS-AMP

ADCP-AMP

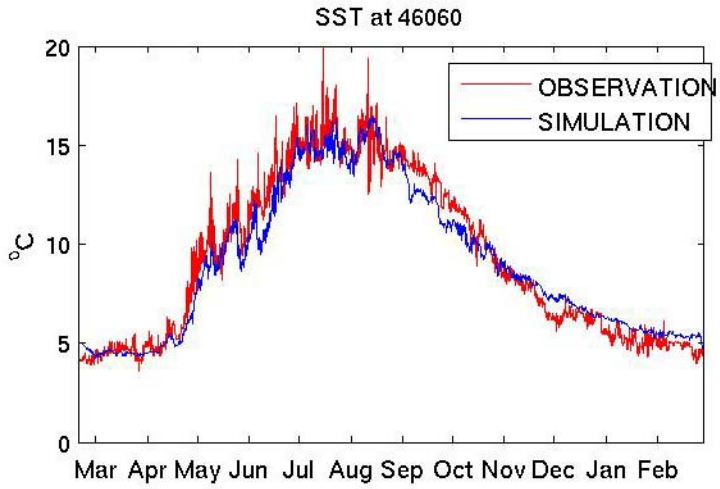
EPWS-PHA

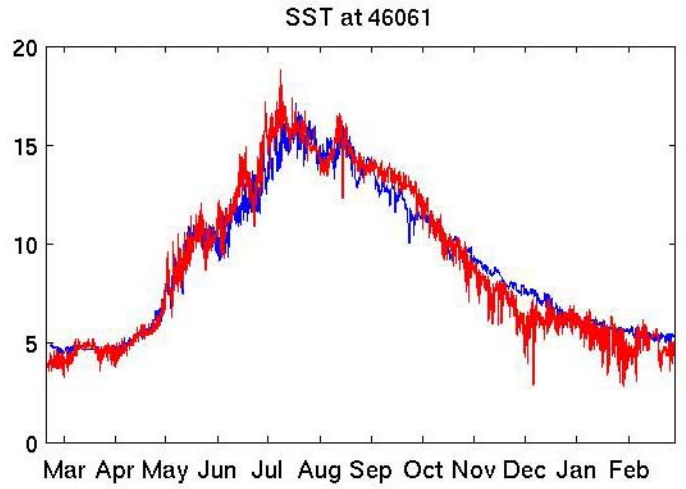
ADCP-PHA

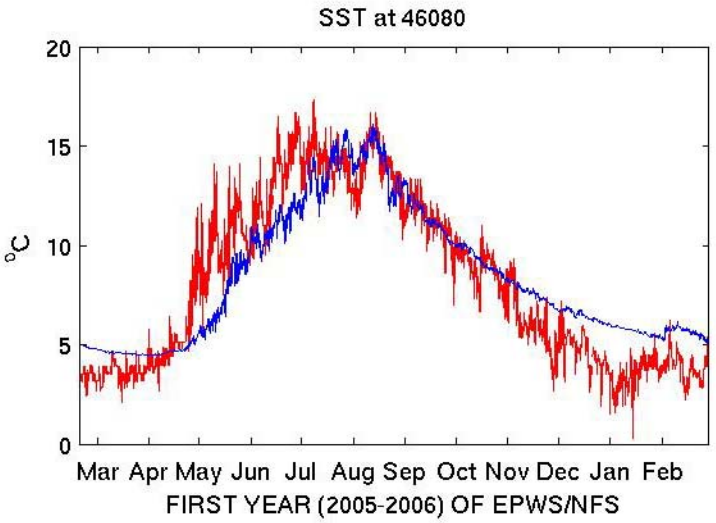


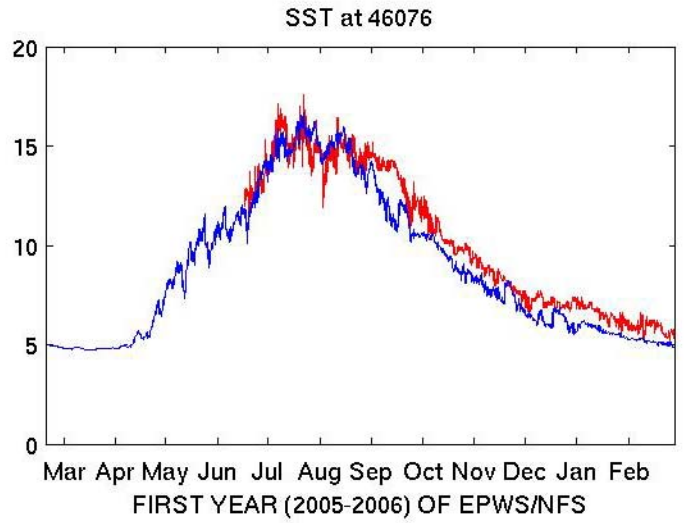
V U

ONE-YEAR EPWS COMPARISON of SST with NDBC BUOYS

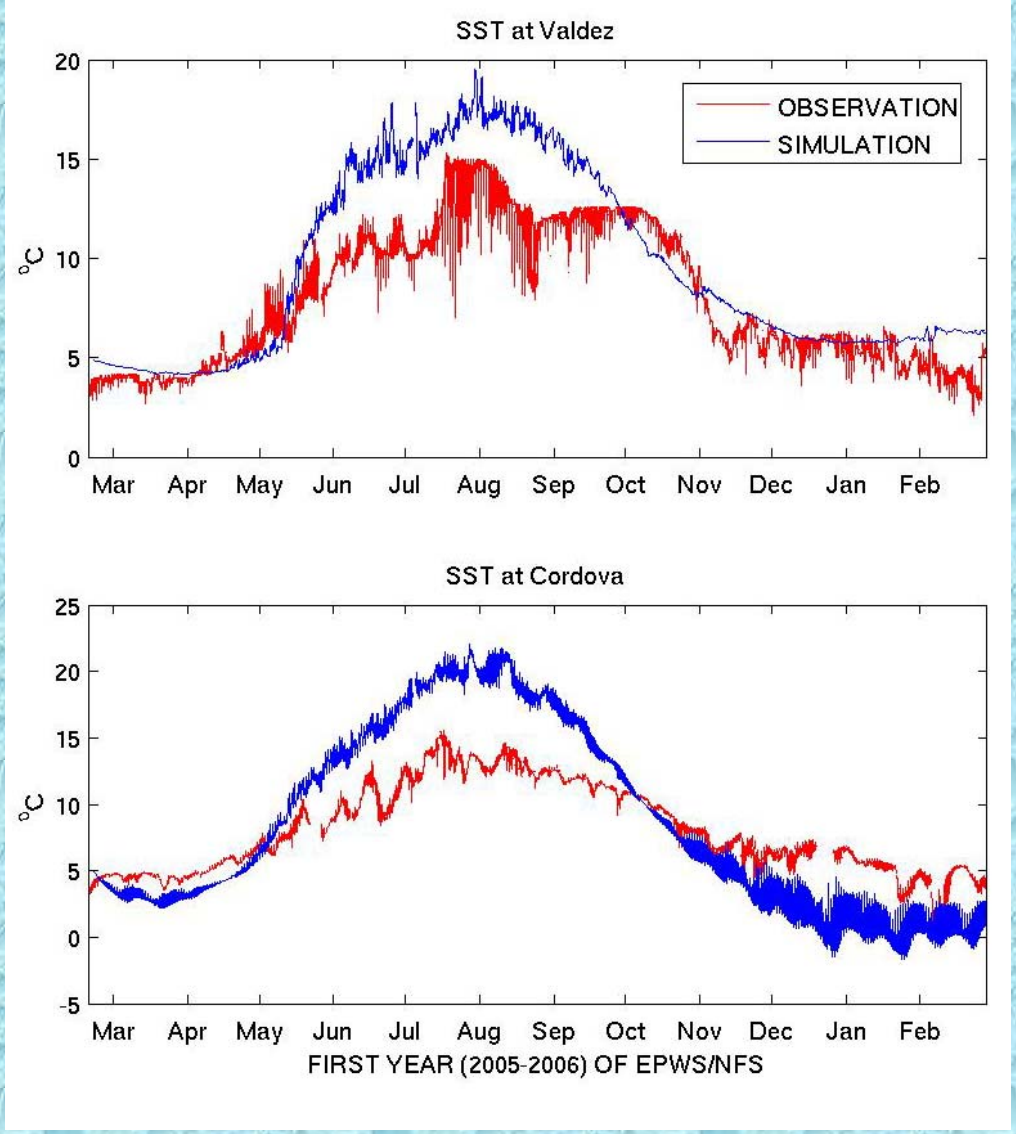








ONE-YEAR EPWS COMPARISON of CST with CO-OPS TIDE GAUGES

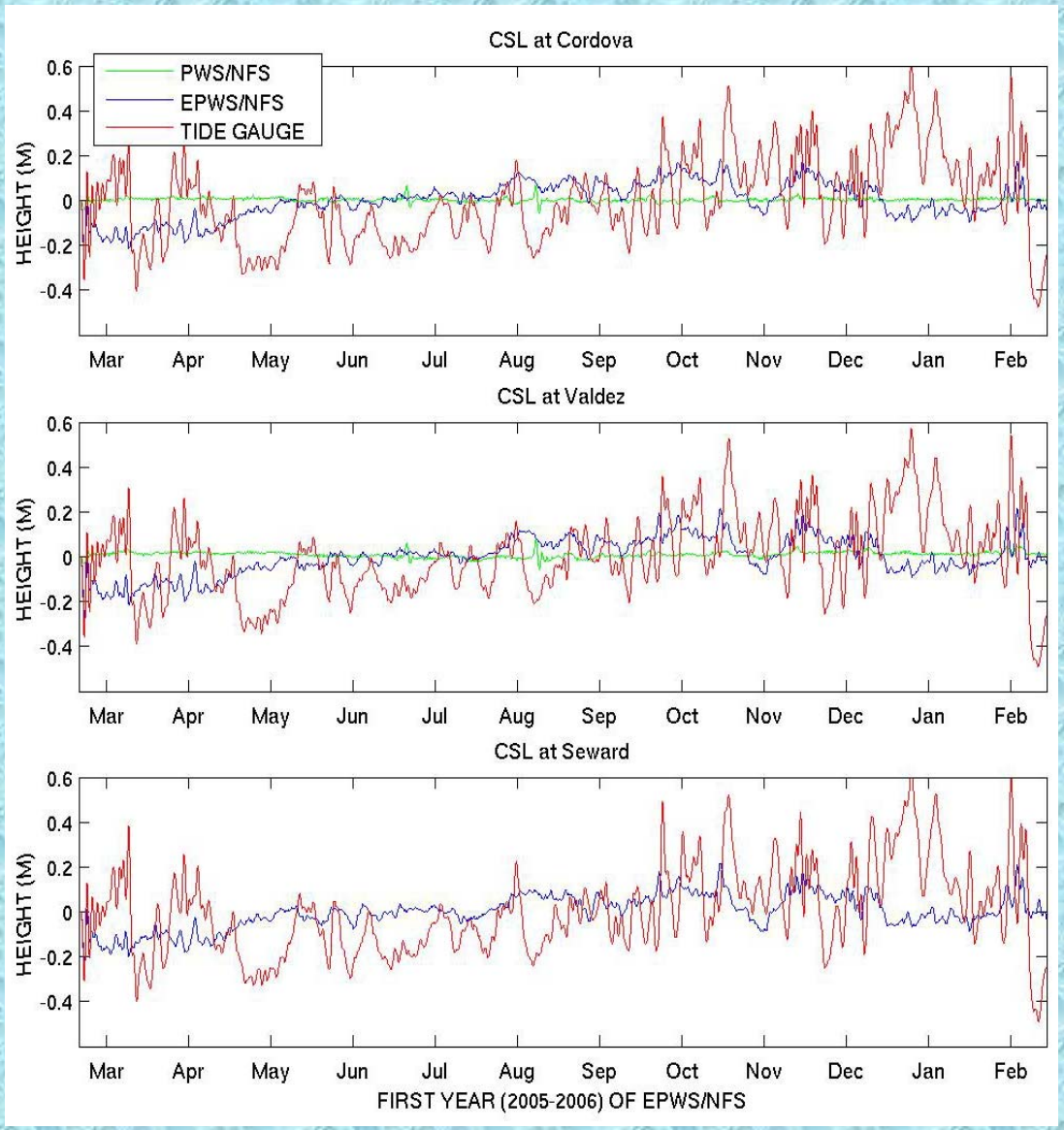


ONE-YEAR EPWS COMPARISON of 40-HR LOW-PASSED CSL with CO-OPS TIDE GAUGES

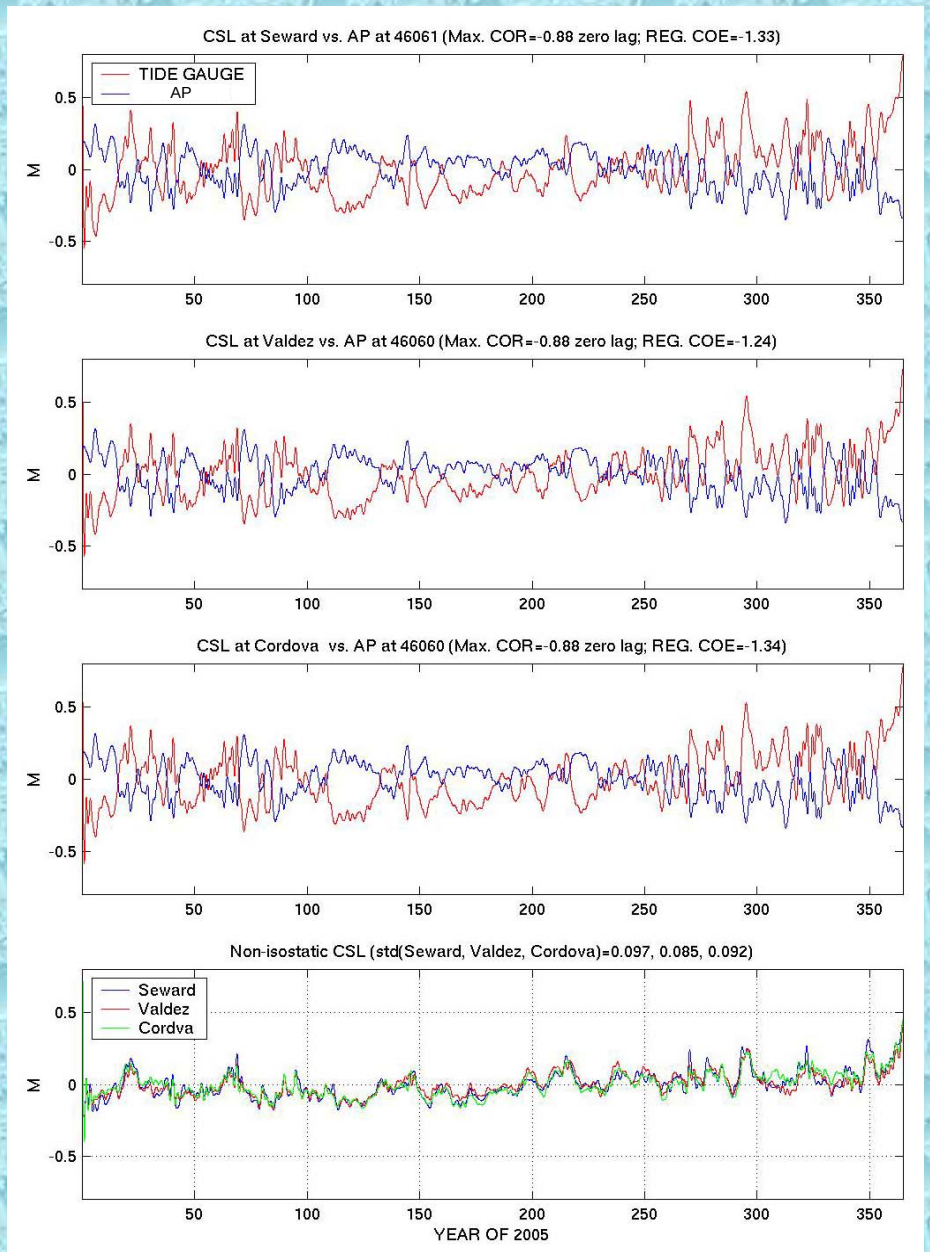
CORDOVA

VALDEZ

SEWARD



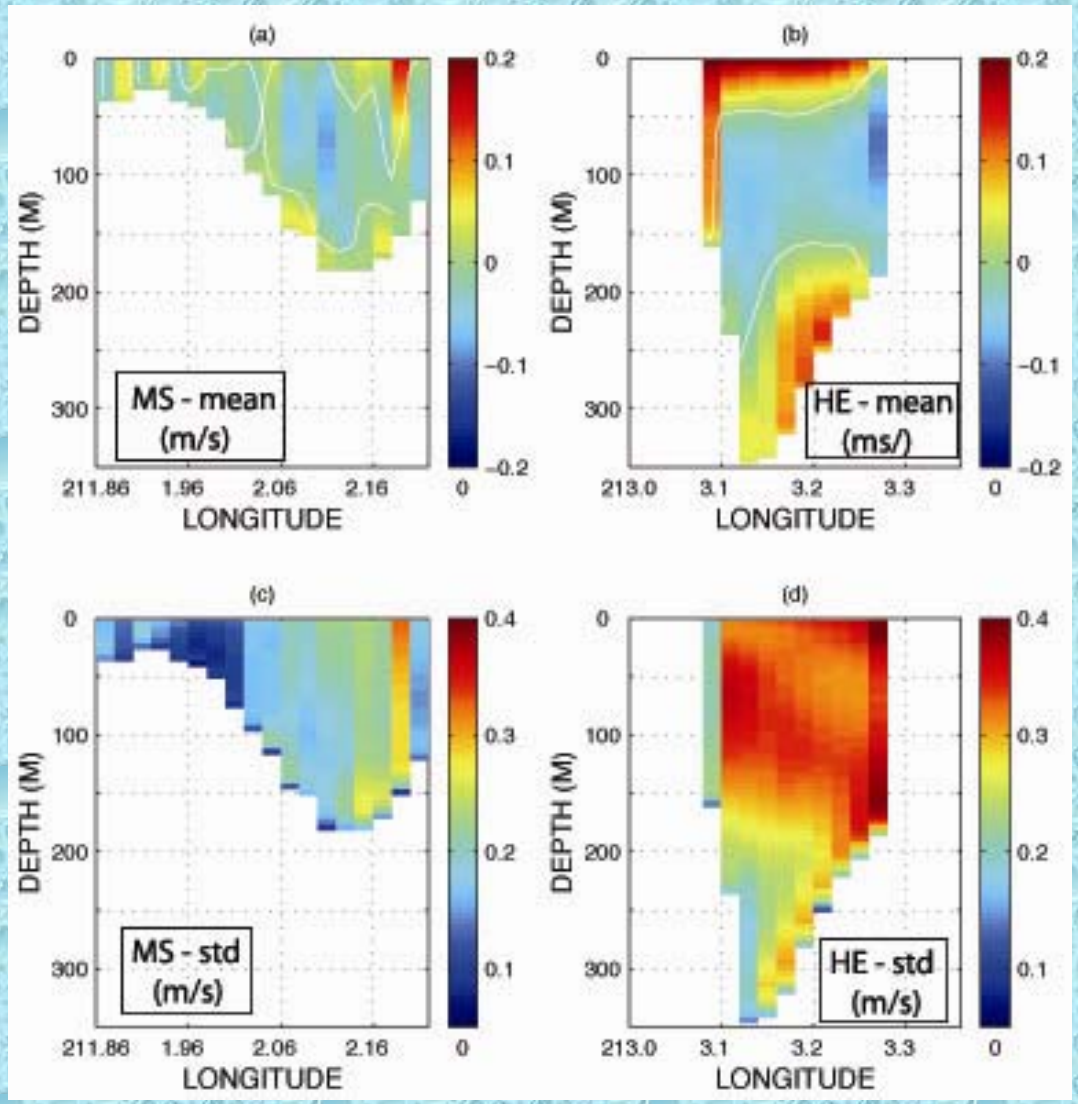
OBSERVED CSL and ATMOSPHERIC PRESSURE at CORDOVA, VALDEZ AND SEWARD



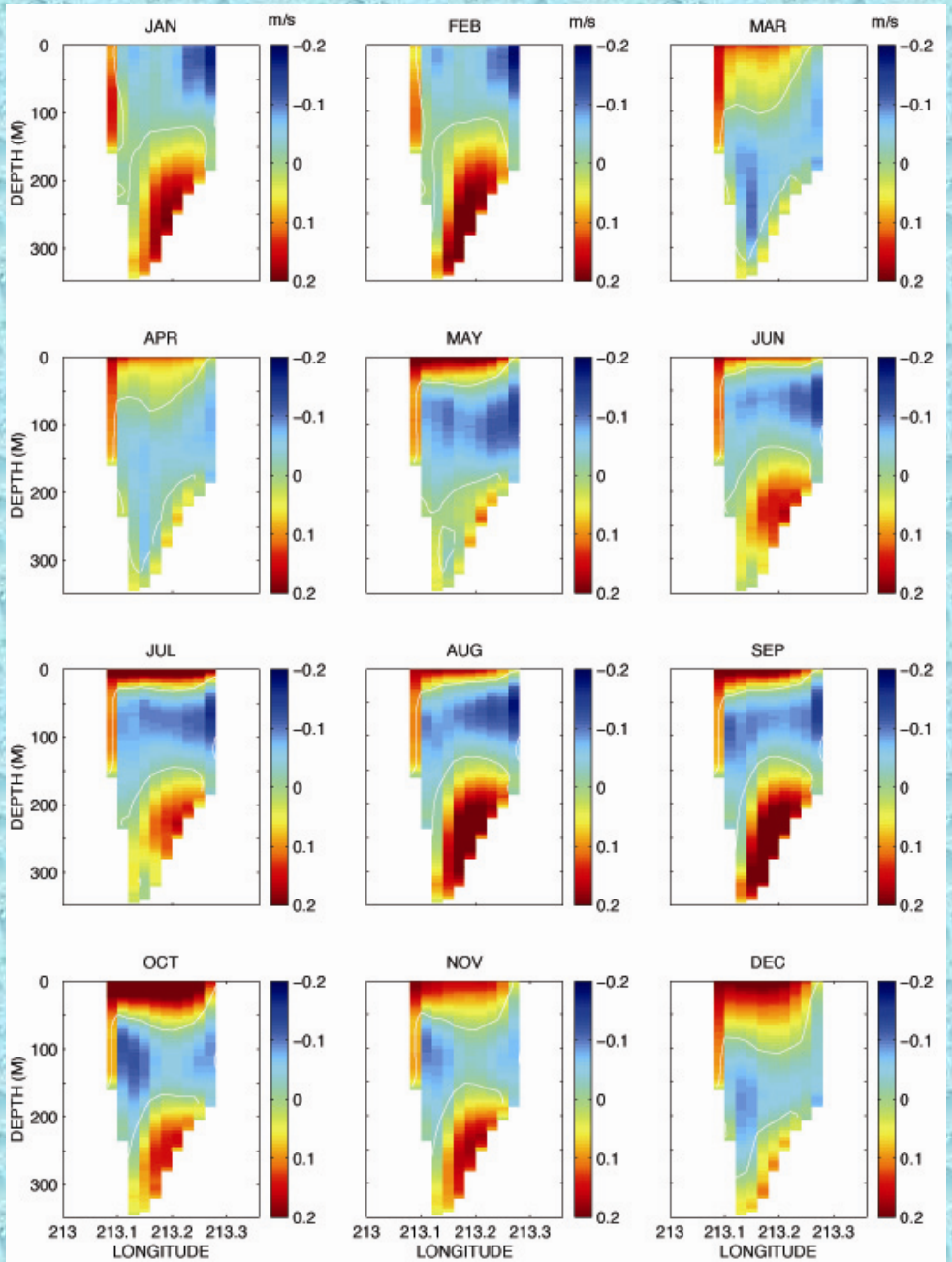
SERENDIPITY FOLLOWS

- AGAIN

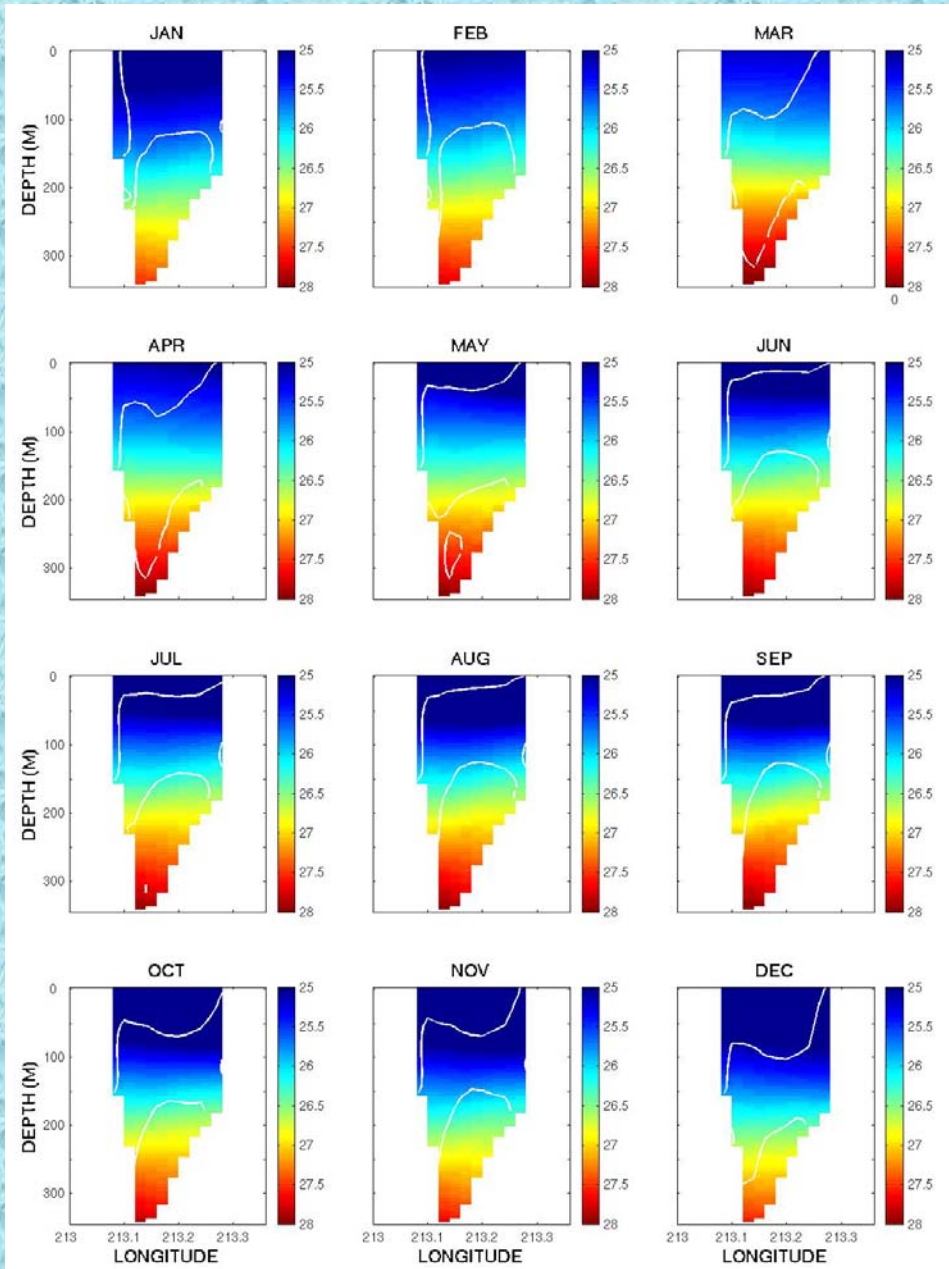
EPWS ANNUAL-MEAN & STD NORTHWARD VELOCITY



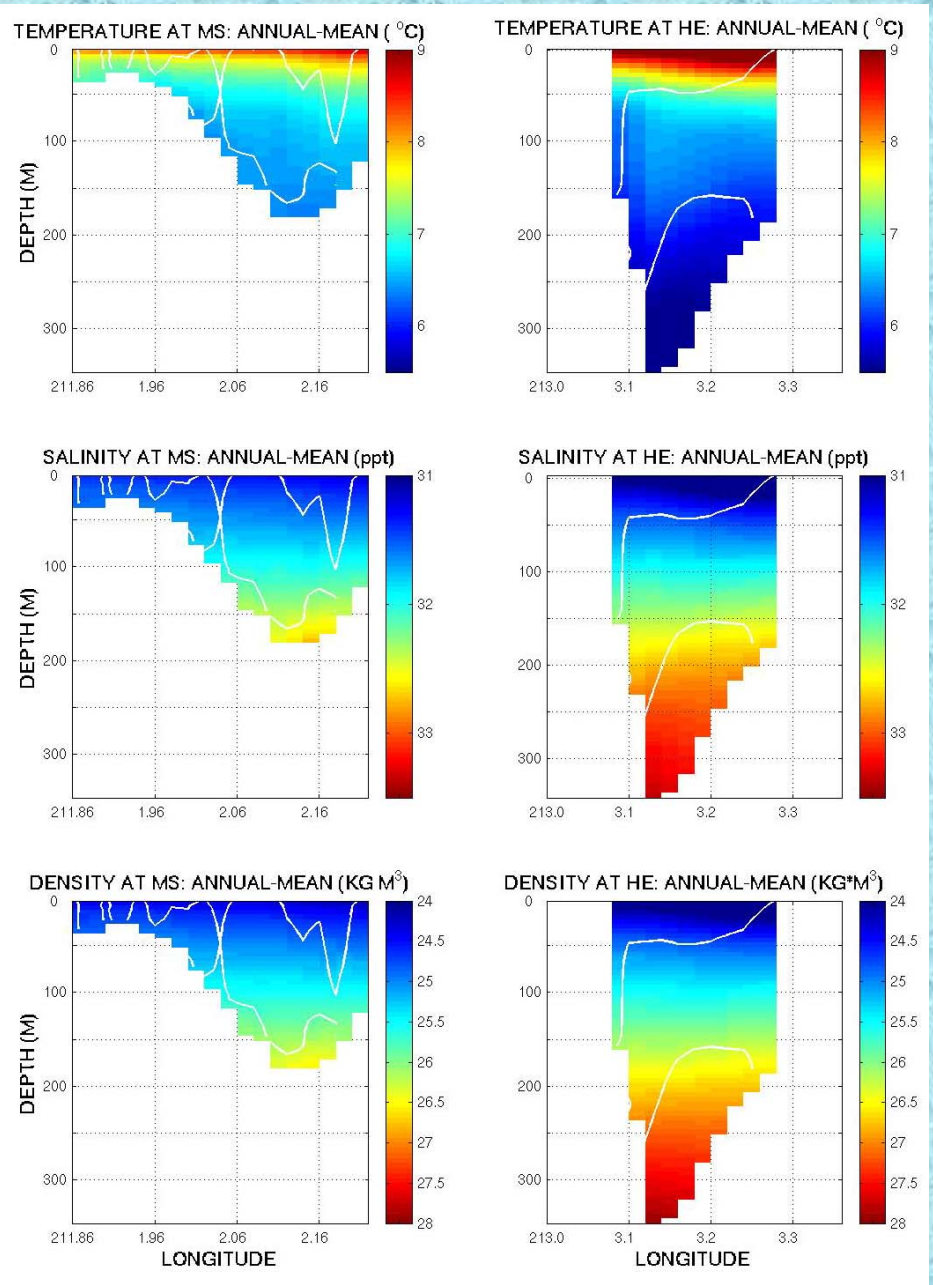
EPWS MONTHLY-MEAN NORTHWARD VELOCITY at HE



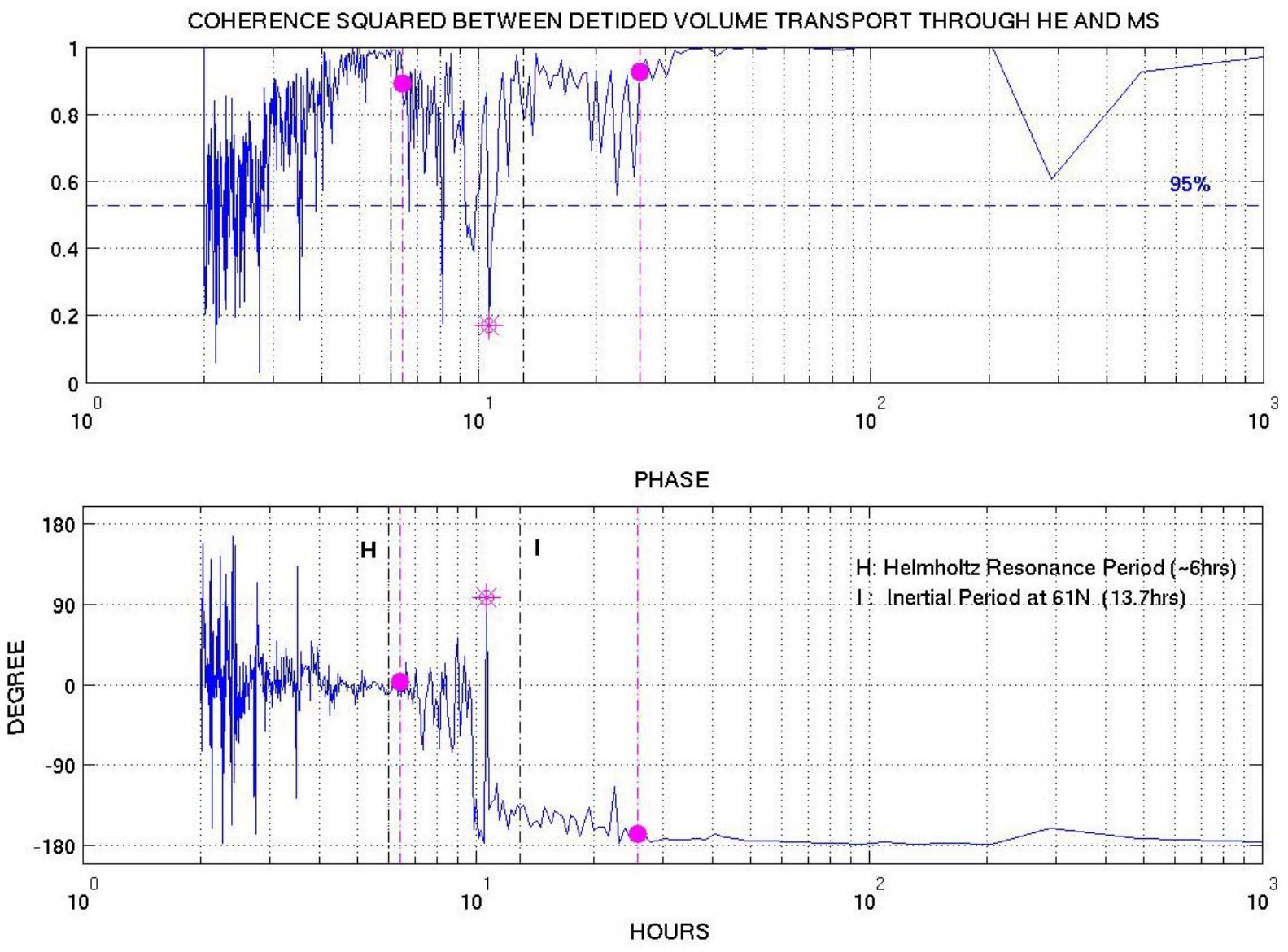
EPWS MONTHLY-MEAN DENSITY at HE



EPWS ANNUAL-MEAN T/S/RHO at HE and MS



EPWS COHERENCE between HE and MS ONE-YEAR DETIDED VOLUME TRANSPORTS



SERENDIPITOUS SCIENTIFIC RESULTS

- THREE-LAYERED ANNUAL MEAN FLOW THROUGH HE & MS STRAITS
- TWO-LAYERED FLOW IN WINTER & THREE-LAYERED FLOW IN SUMMER
- TRANSITION BAND BETWEEN THE LOW FREQUENCY NON-DIVERGENT FLOW AND THE HIGH FREQUENCY DIVERGENT FLOW

LESSONS LEARNED (1)

- **OPEN BOUNDARY FORCING**
  - **Global NCOM: "WONDERFUL" BUT INFLEXIBLE**

- **ATMOSPHERIC FORCING**
  - **NCEP-NAM & RAMS: "FINE" WINDS AND PRESSURE**
  - **BUT HEAT FLUX & E-P?**

- **TIDAL FORCING**

  - FOREMAN AND OSU: "SPLENDID" TIDAL HARMONIC COEFFICIENTS

- **BOTTOM TOPOGRAPHY (RESOLUTION & ACCURACY ARE ISSUES)**

- **REAL-TIME VERIFICATION DATA**
  - **COASTAL SEA LEVEL (CO-OPS TGs)**
  - **VELOCITY PROFILES (NDBC ADCPs)**
  - **RUNOFF (USGS & NWS PROBLEM)**

LESSONS LEARNED (2)

- **VALIDATION STUDIES ARE LIKELY TO LEAD TO DISCOVERIES AT THIS STAGE OF IOOS DEVELOPMENT**
- **NEED FORCING FUNCTION VALIDATION AND VERIFICATION, TOO**
- **NEED RESOURCES FOR SENSITIVITY STUDIES**
- **NEED ARCHIVES (HISTORICAL TIME SERIES, ETC.; MODEL FORCING; MODEL VERIFICATION, MODEL OUTPUT, ETC.)**
- **NEED EULERIAN MOORED VELOCITY, TEMPERATURE, AND SALINITY PROFILERS**
- **NEED LAGRANGIAN DRIFTERS WITH SENSORS**

BACKUP

EFS-POM configuration (OPEL)

- 3-D Baroclinic-POM
- Curvilinear grid (223 x 97), 24 sigma levels
- Minimum depth = 2 m
- Surface forcing
  - ✓ NCEP-ETA analysis winds, pressure (12 km, 6-hourly, 24-hr)
  - ✓ NCEP-ETA forecast winds, pressure (12 km, 3-hourly, 84-hr)
  - ✓ COADS monthly heat flux climatology
  - ✓ Relaxation to monthly SST climatology
- Open boundary forcing
  - ✓ Global NCOM T, S, sea level, external/internal velocities
  - ✓ Tidal model sea level, velocity
  - ✓ Flather boundary condition for external velocity
  - ✓ Radiation boundary condition for internal velocity
  - ✓ Or internal velocity from Global NCOM in another parallel run
- 24-hr hindcast + 84-hr forecast
  - ✓ Global NCOM forecasts 72 hours
  - ✓ Remaining 12 hours with the last (72h) forecast data

Global NCOM configuration (NRL & NAVOCEANO)

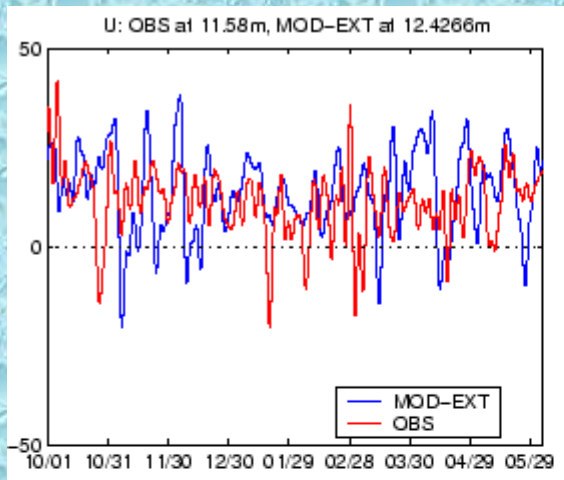
- 3-D Baroclinic – POM variant
- 1/8 degree, 40 sigma-z levels(19 sigma in upper 137 m, 21 z below)
- Minimum depth = 5 m (dbdb2)
- Level 2 M-Y turbulence closure w/ Large et al. enhancement
- Monthly discharge of 981 rivers
- Surface forcing
  - ✓ NOGAPS wind, air temp, air mixing ratio, net solar radiation (3-hourly)
  - ✓ Bulk formulae for sensible and latent heat fluxes (every time step)
- Data Assimilation:
  - ✓ SST and MODAS Synthetic T/S profiles based on operational 1/16 degree NLOM SSH and 1/8 degree MODAS2D SST
- 72-hr forecasts
- Daily download of T/S/V and sea level (98 W-56 W, 8 N-38 N)
- http://www.ocean.nrlssc.navy.mil/global_ncom

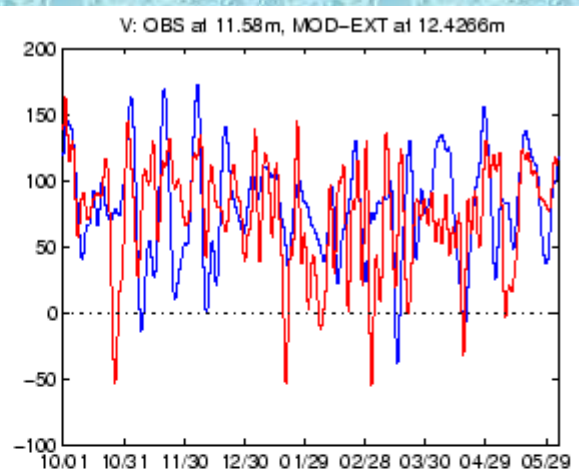
Comparisons with SWAMP ADCP
Low-passed (80 hr) velocities at two depths
(red: SWAMP, blue: EFSIS)

U

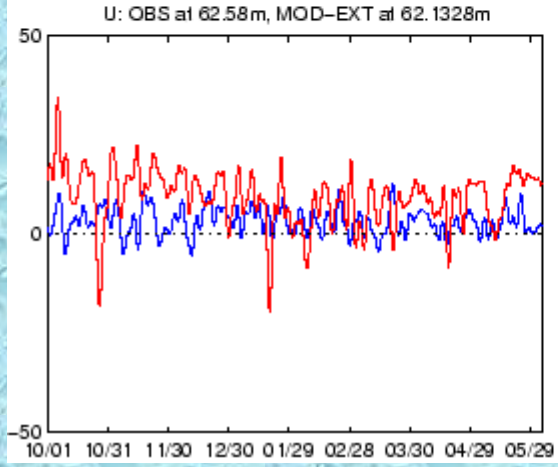
V

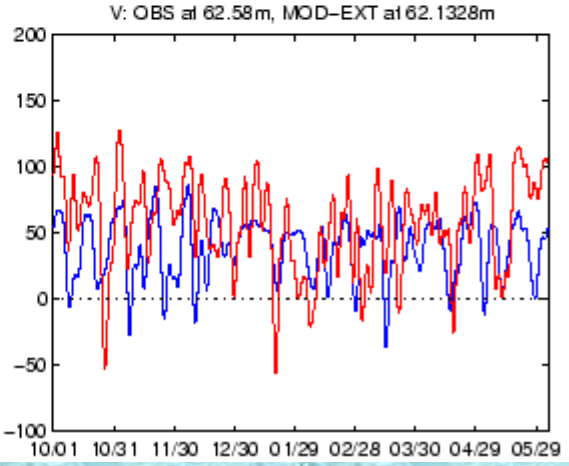
12 m





62 m





Tidal model configuration (OPEL)

- 3-D Barotropic-POM
- Curvilinear grid (251 x 101), 20 sigma levels
- Minimum depth = 2 m
- HORCON = 0.2
- Harmonic constants from OSU inverse tidal solution (TPXO.6, 1/12^{o})
  - M2, S2, N2, K2, O1, K1, P1, Q1
- Archive sea level, velocity at 12-minute intervals

Attributes of Tidal Model

- Ca 1 km resolution (401 x 329)
- Barotropic
- Minimum depth = 5 m
- HORCON = 0.2
- Harmonic constants from Mike Foreman (IOS, Canada)
  - M2, S2, N2, K2, O1, K1, P1, Q1
- Archive sea level and velocity

Attributes of EPWS-NFS

- Princeton Ocean Model (POM)
- Ca 1-km horizontal resolution, 26 sigma levels
- Since February 2005
- high-resolution (4 km) regional atmospheric forecast model (PWS-RAMS)
- 8 Tidal constituents (O_1,K_1,P_1,Q_1,M_2,S_2,N_2,K_2)
- Global NCOM open boundary forcing
- Tidal model open boundary forcing
- Global NCOM open boundary temperature and salinity
- Global NCOM surface temperature and salinity relaxation
- Monthly heat flux (COADS)
- Daily, non-uniform climatological freshwater flux (hydrological model)
- http://pws-nfs-osri.rsmas.miami.edu/epws

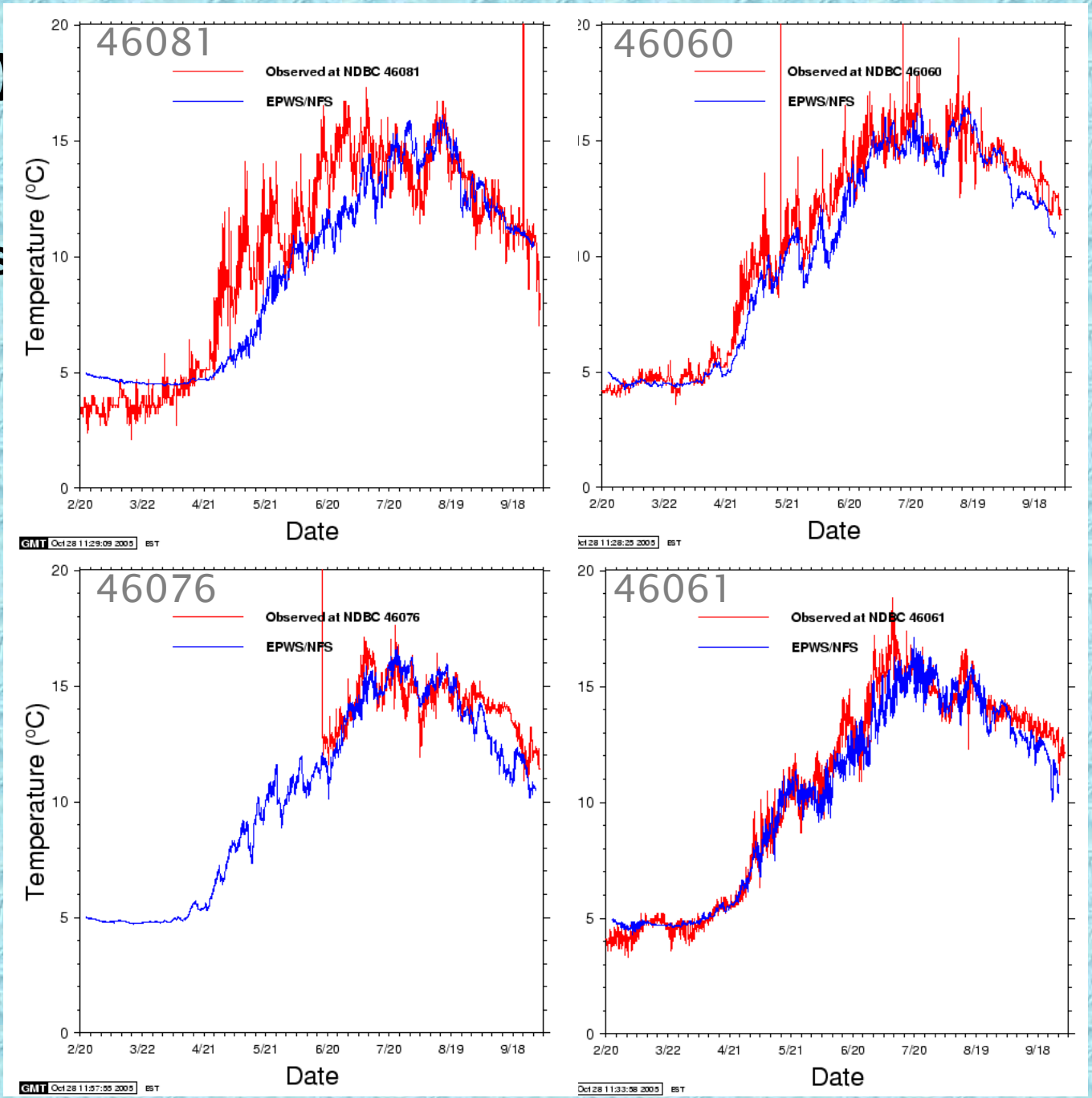
Some Attributes OF PWS-RAMS (Operated At AEFF, UAA)

- VERSION 4.3, NON-HYDROSTATIC
- TRIPLY NESTED (HORIZONTALLY)
  - ✓ PARENT GRID (50 X 50); DX,Y = 64 KM; (3200 KM X 3200 KM)
  - ✓ SECOND GRID (70 X 58); DX,Y = 16 KM; (1120 KM X 928 KM)
  - ✓ FINE GRID (102 X 82): DX,Y = 4 KM; (408 KM X 328 KM)
- VERTICAL COORDINATE IS STRETCHED SIGMA
  - ✓ 36 GRID POINTS
  - ✓ INITIAL DELTA_Z 50 M
  - ✓ STRETCHING FACTOR IS 1.13
  - ✓ MAXIMUM GRID SIZE IS 1 KM
- INITIALIZATION FROM NCEP ETA MODEL
  - ✓ INITIAL ANALYSIS & FORECAST FROM 12Z OPERATIONAL RUN
  - ✓ PROVIDES 3-DAY INITIALIZATION & TIME-VARYING BOUNDARY CONDITONS
- http://aeff.uaa.alaska.edu/

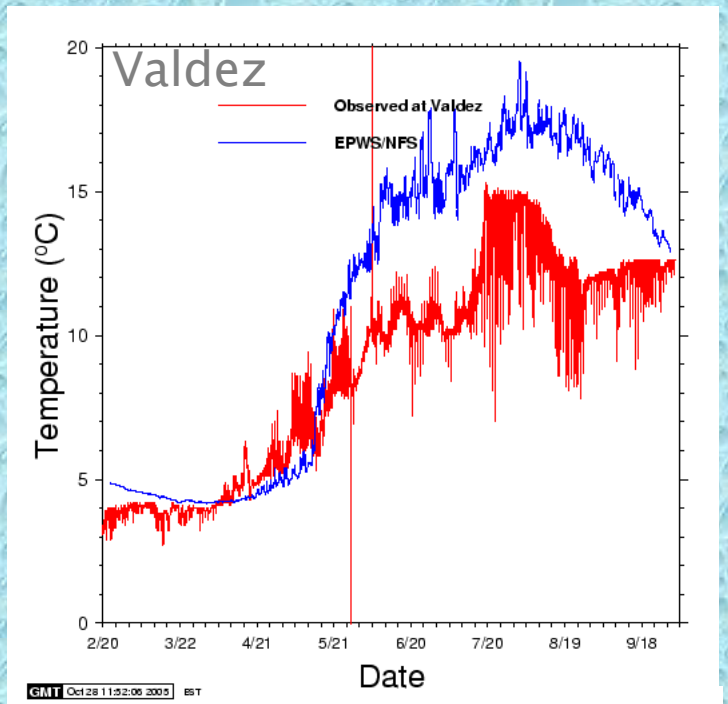
Attributes of Global NCOM

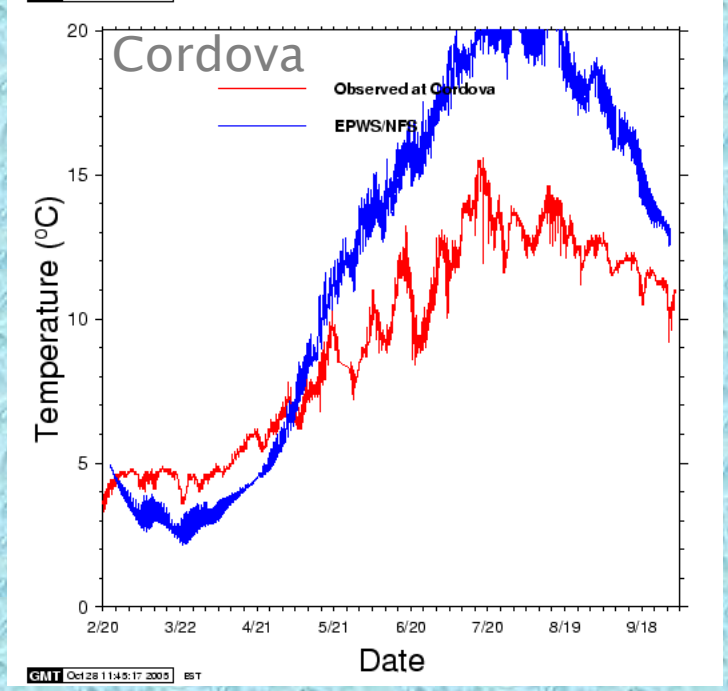
- Navy Coastal Ocean Model (NCOM)
- 1/8 degree, 40 sigma-z levels (19 sigma in upper 137 m, 21 z below)
- Minimum depth = 5 m (dbdb2)
- Level 2 M-Y Turbulence Closure w/ Large et al Enhancement
- Monthly Discharge of 981 Rivers
- Surface forcing
- NOGAPS wind, air temp, air mixing ratio, net solar radiation (3-hourly)
- Bulk formulae for Sensible and Latent heat fluxes (every time step)
- Data Assimilation:
- SST and MODAS Synthetic T/S profiles based on operational 1/16 degree NLOM SSH and 1/8 degree MODAS2D SST
- 72-hr forecasts
- Daily download of T/S/V and sea level (165 W-125 W, 50 N-62 N)
- http://www.ocean.nrlssc.navy.mil/global_ncom

Observed and Simulated (EPWS) Temperatures at NDBC Buoys For Seven Months

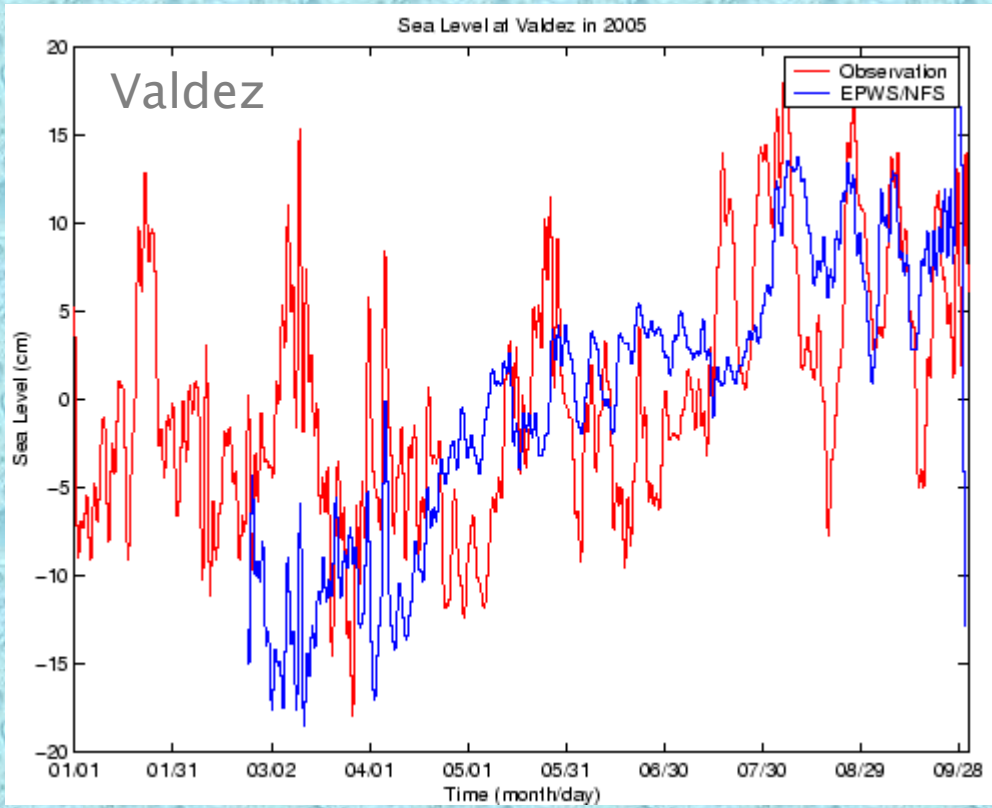


Observed and Simulated (EPWS) Temperatures at CO-OPS Stations For Seven Months

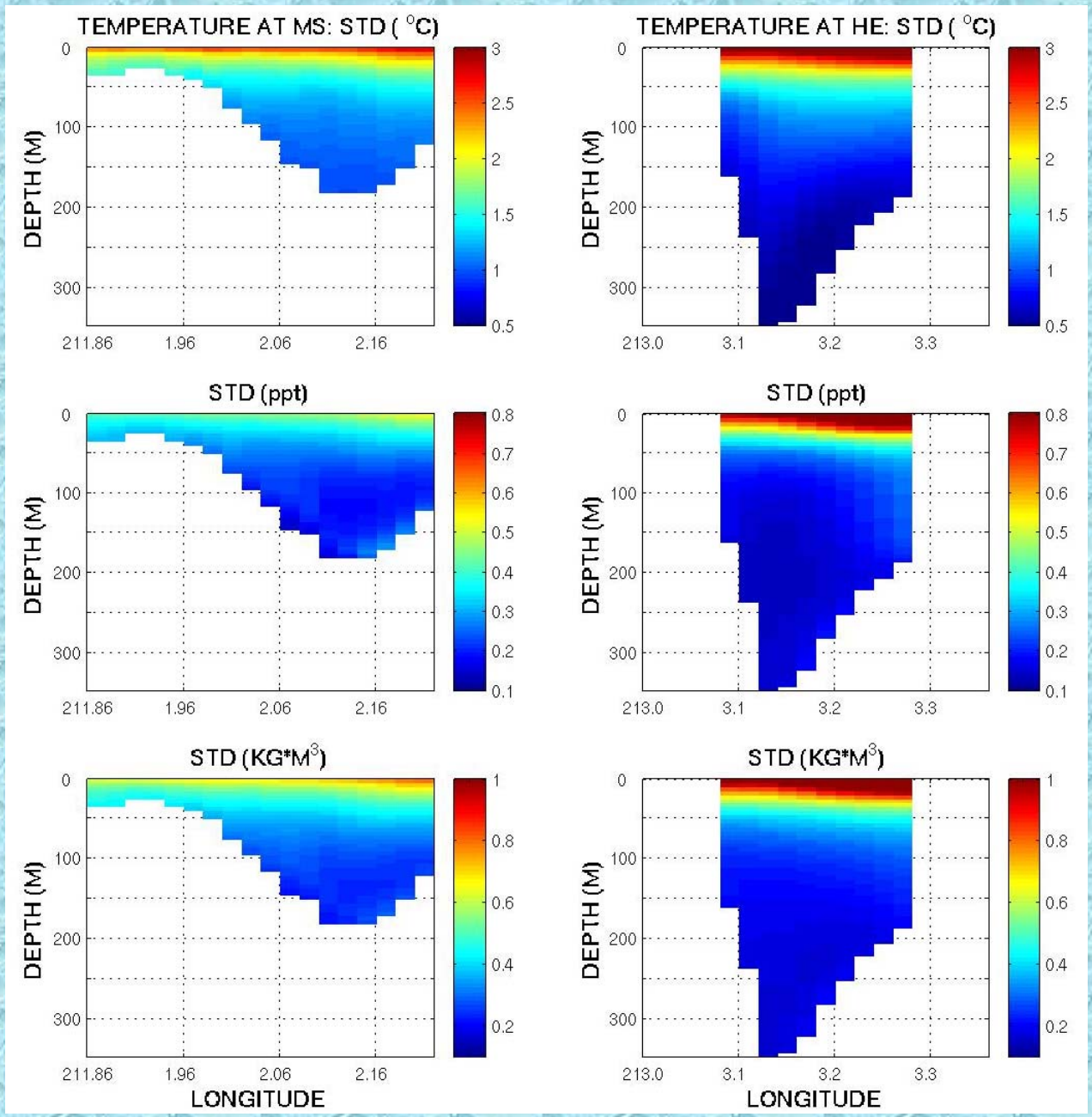




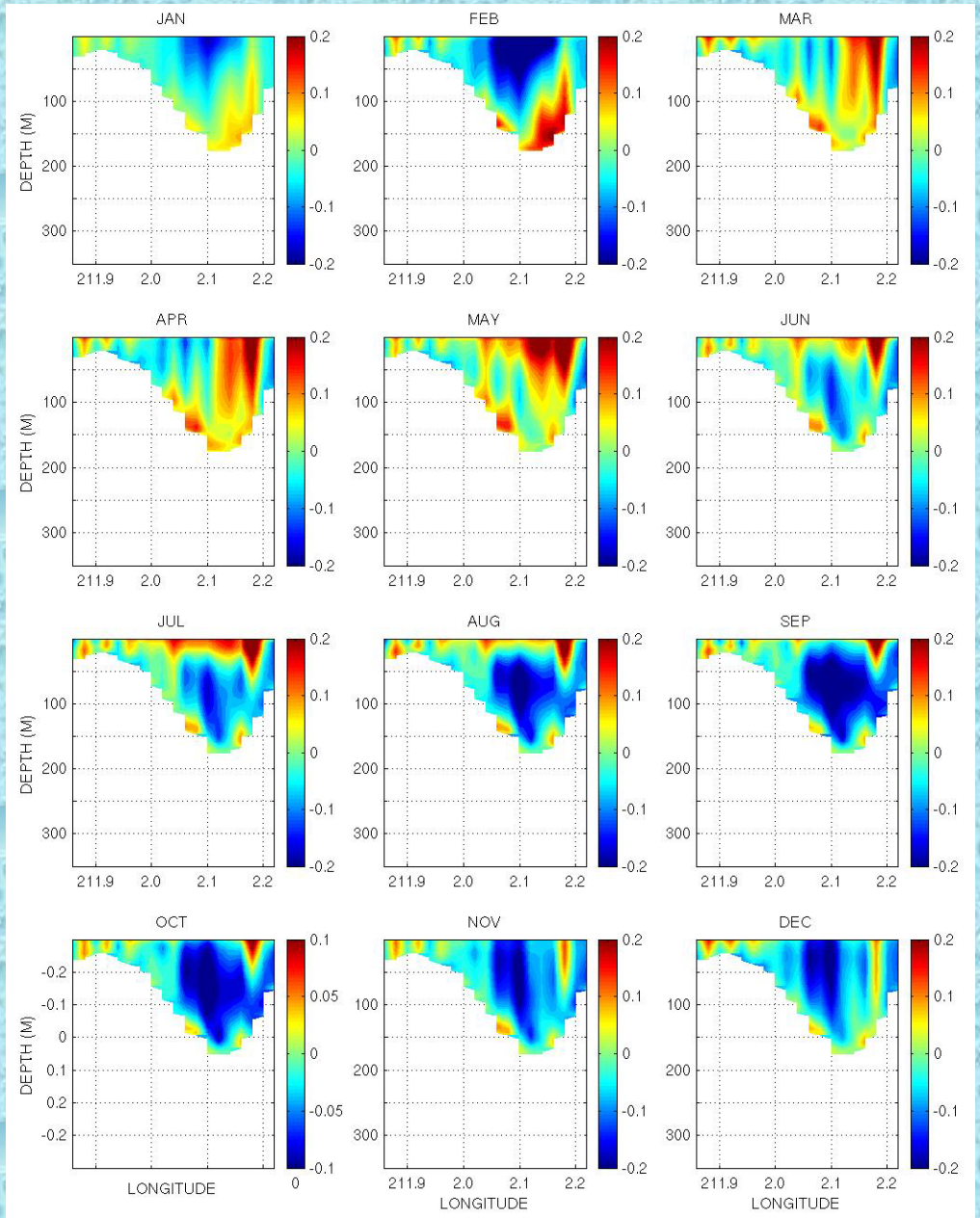
40 hr Low-Passed Observed and Simulated (EPWS) Sea levels at Valdez For Seven Months



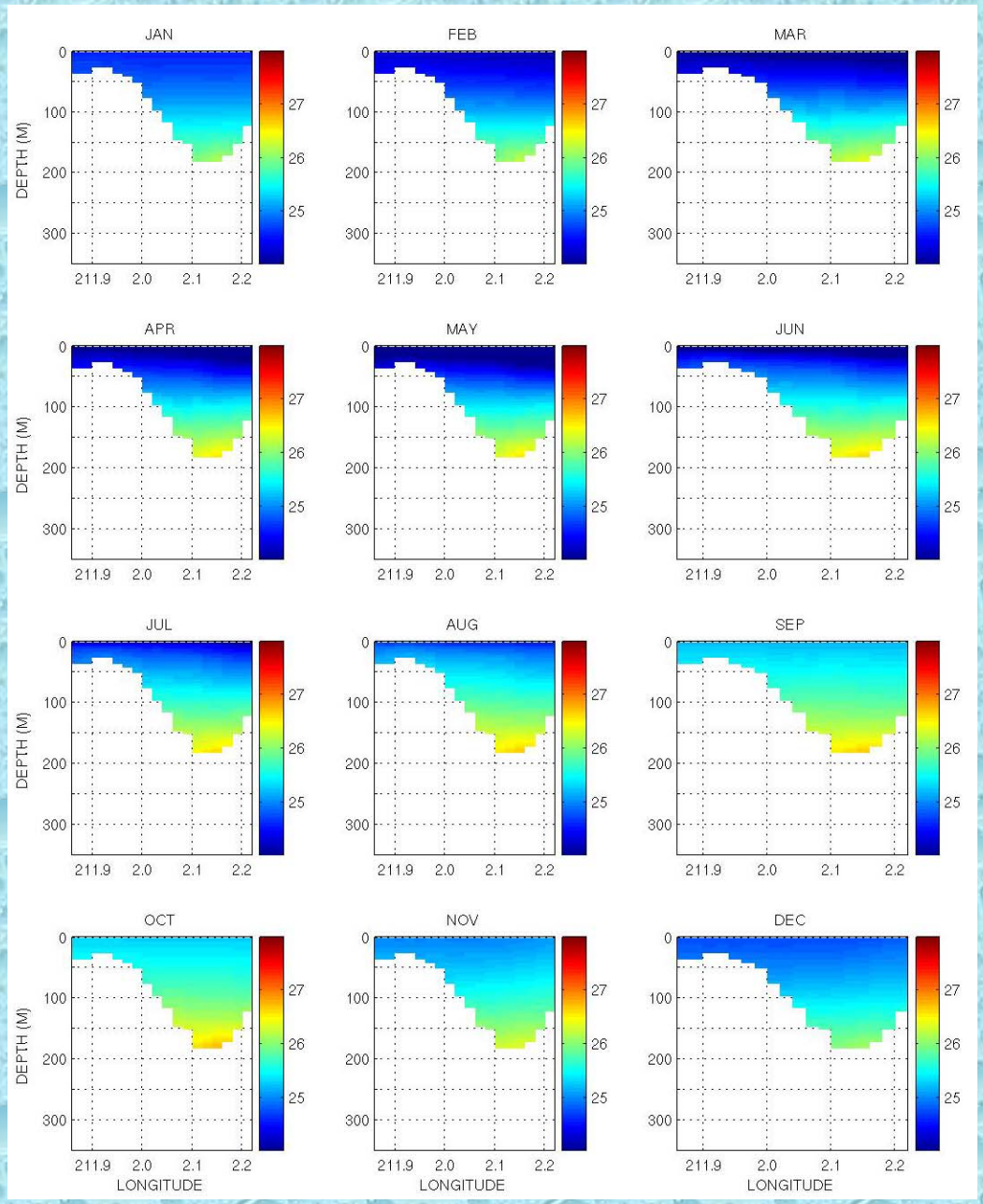
STD of Annual-Mean T/S/Rho at HE and MS



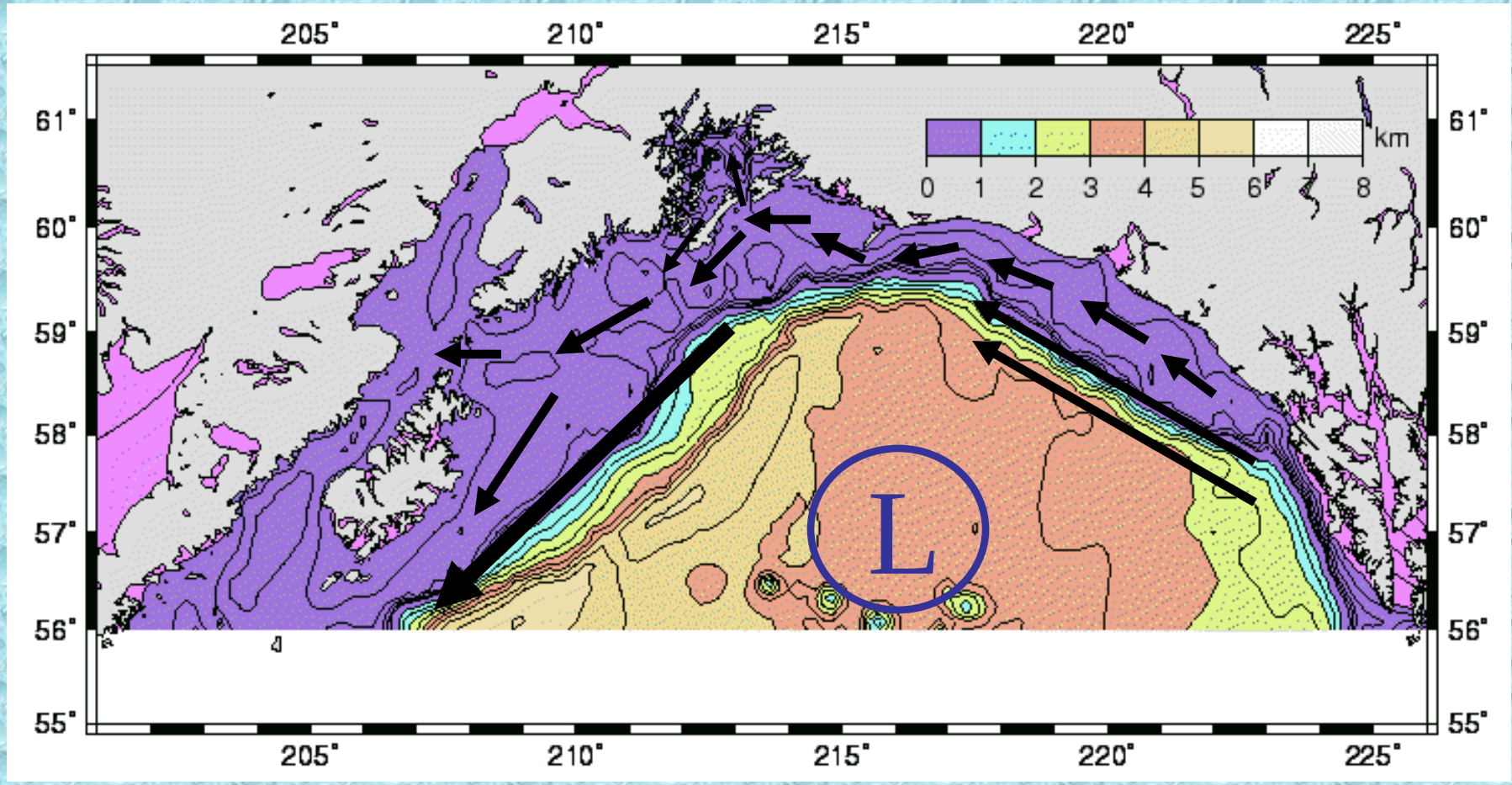
Monthly-Mean Northward Velocity at MS



Monthly-Mean Density at MS



Gulf of Alaska Circulation

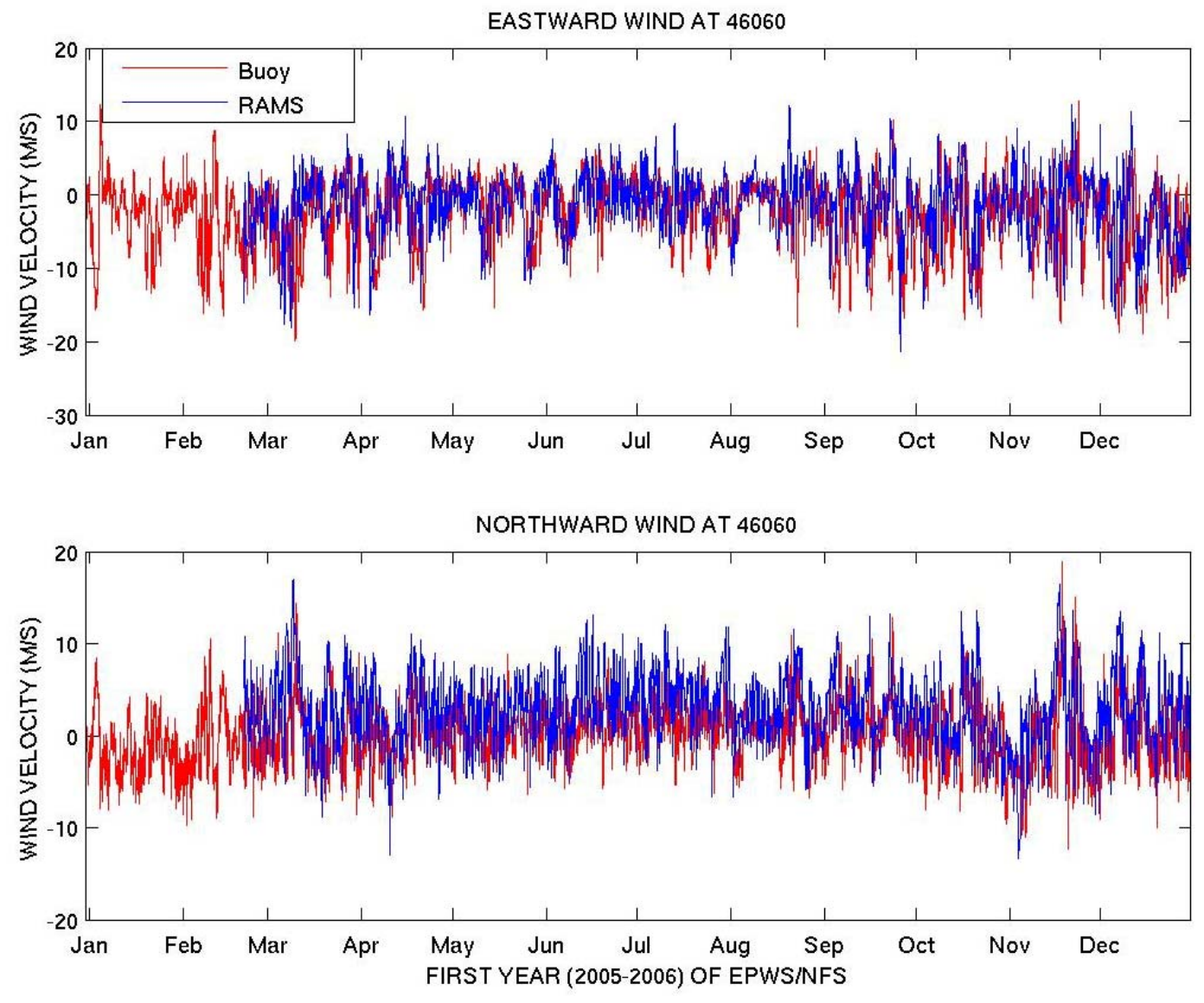


Aleutian Low

Alaska Current (EBC) & Alaska Stream (WBC)

Alaska Coastal Current (ACC)

RAMS Wind vs. NDBC Buoy 46060



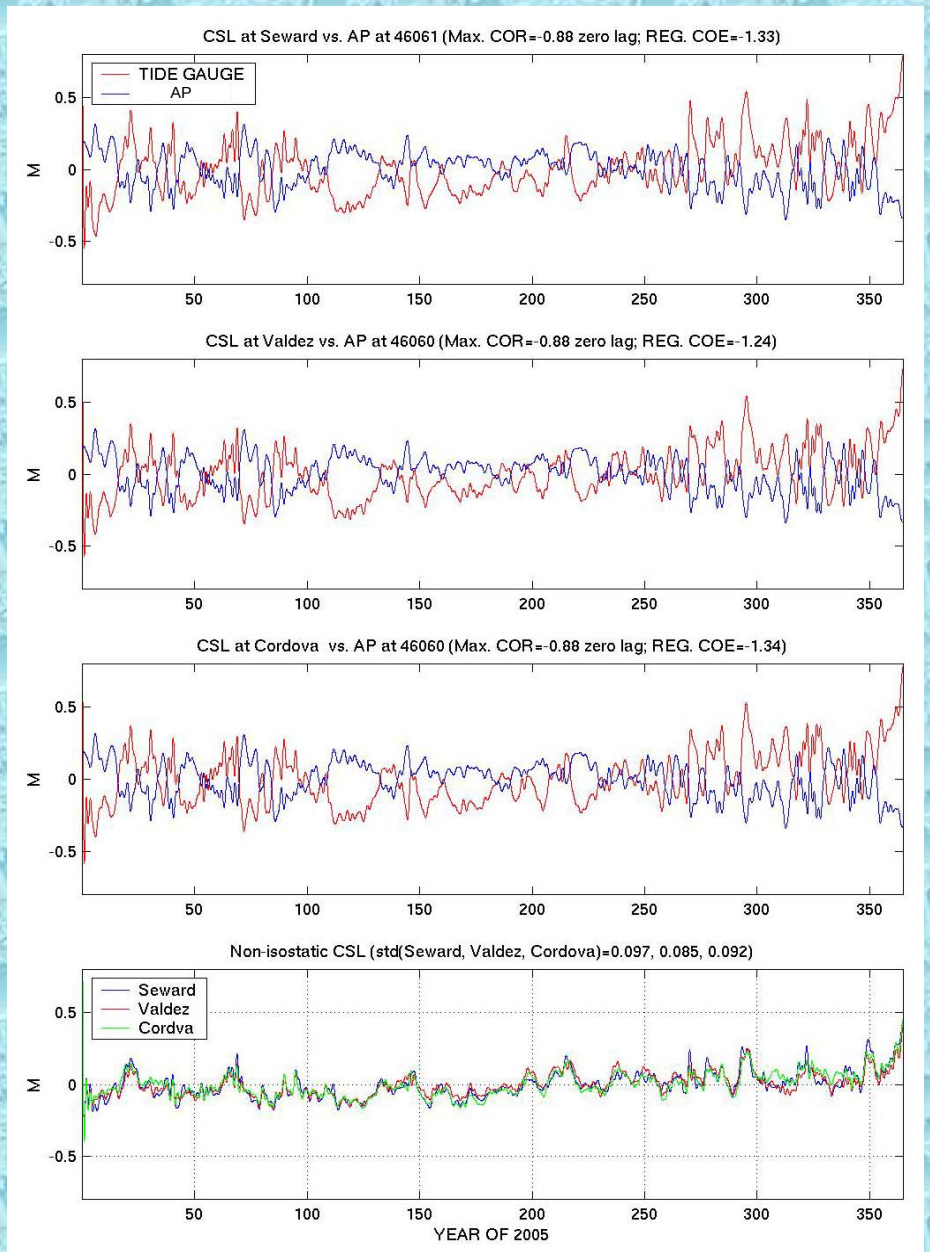
WERA (WEllen RAdar)

WERA is deployed in a phased array mode with cells of 600-750 m over a range of ~90 km.

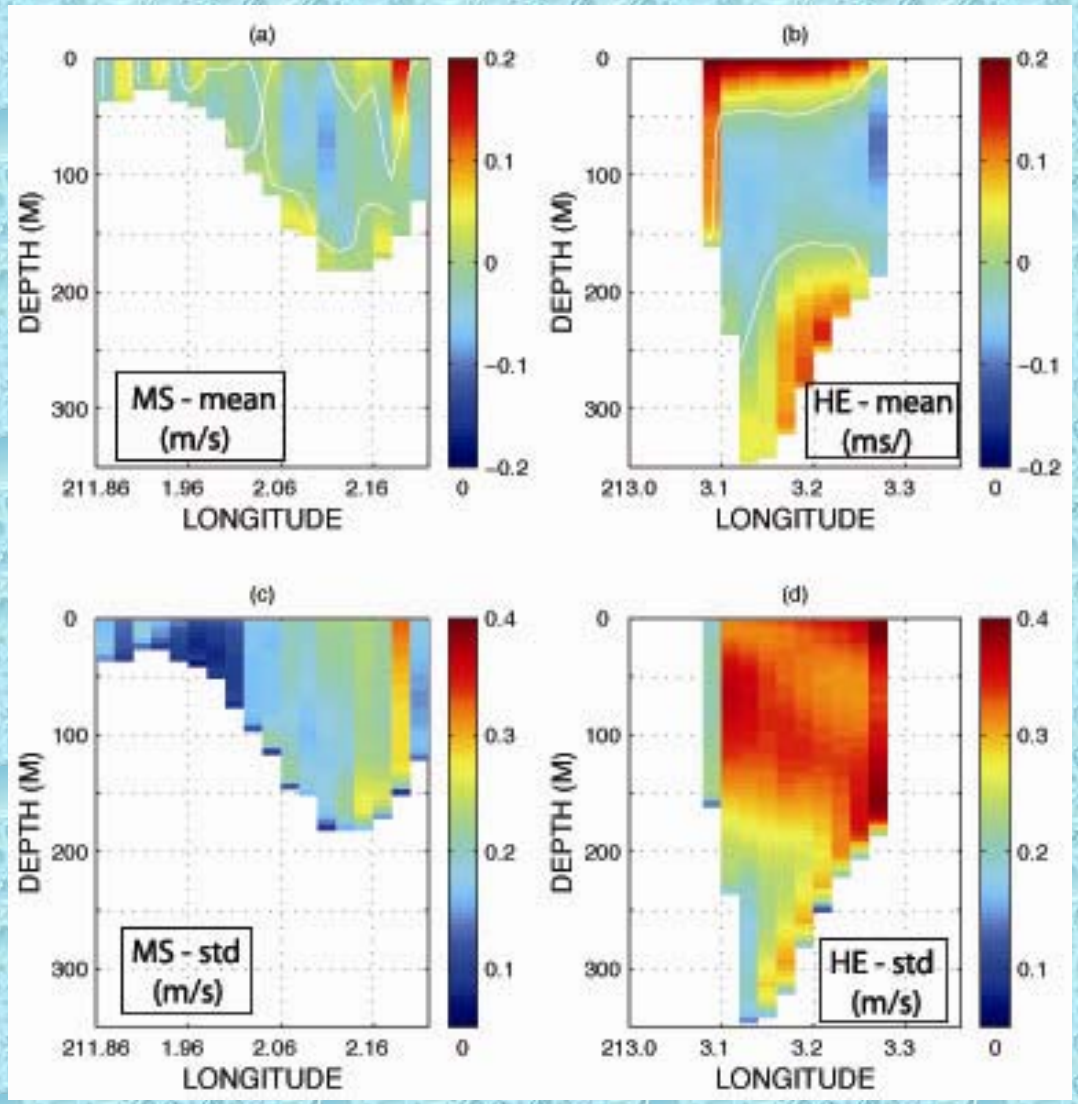
Provides radial and surface current vector fields at 2 km intervals each hour.

WERAs are deployed at Key Largo, Key Biscayne, and Ft. Lauderdale overlooking EFS.

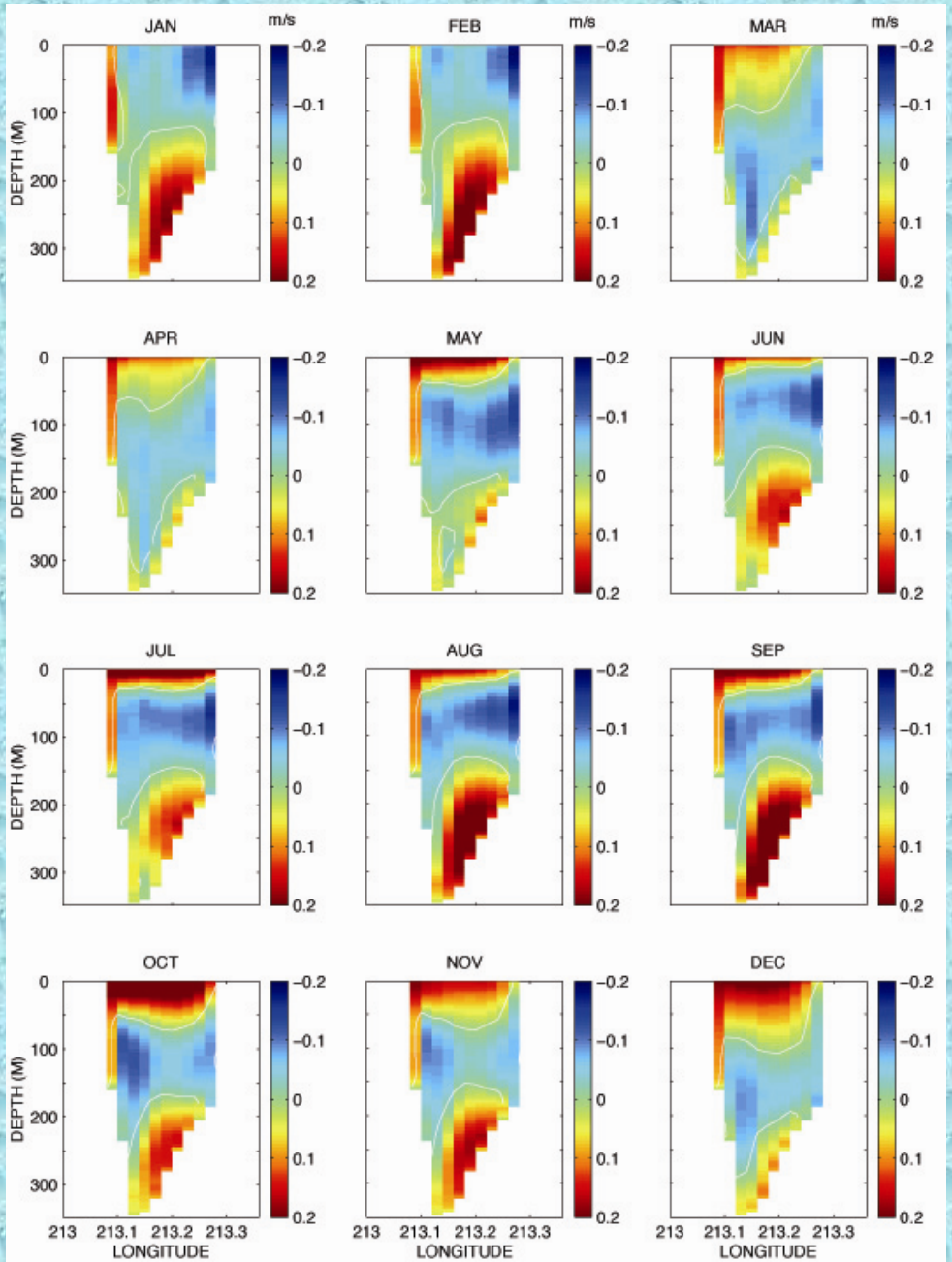
OBSERVED CSL and ATMOSPHERIC PRESSURE at CORDOVA, VALDEZ AND SEWARD



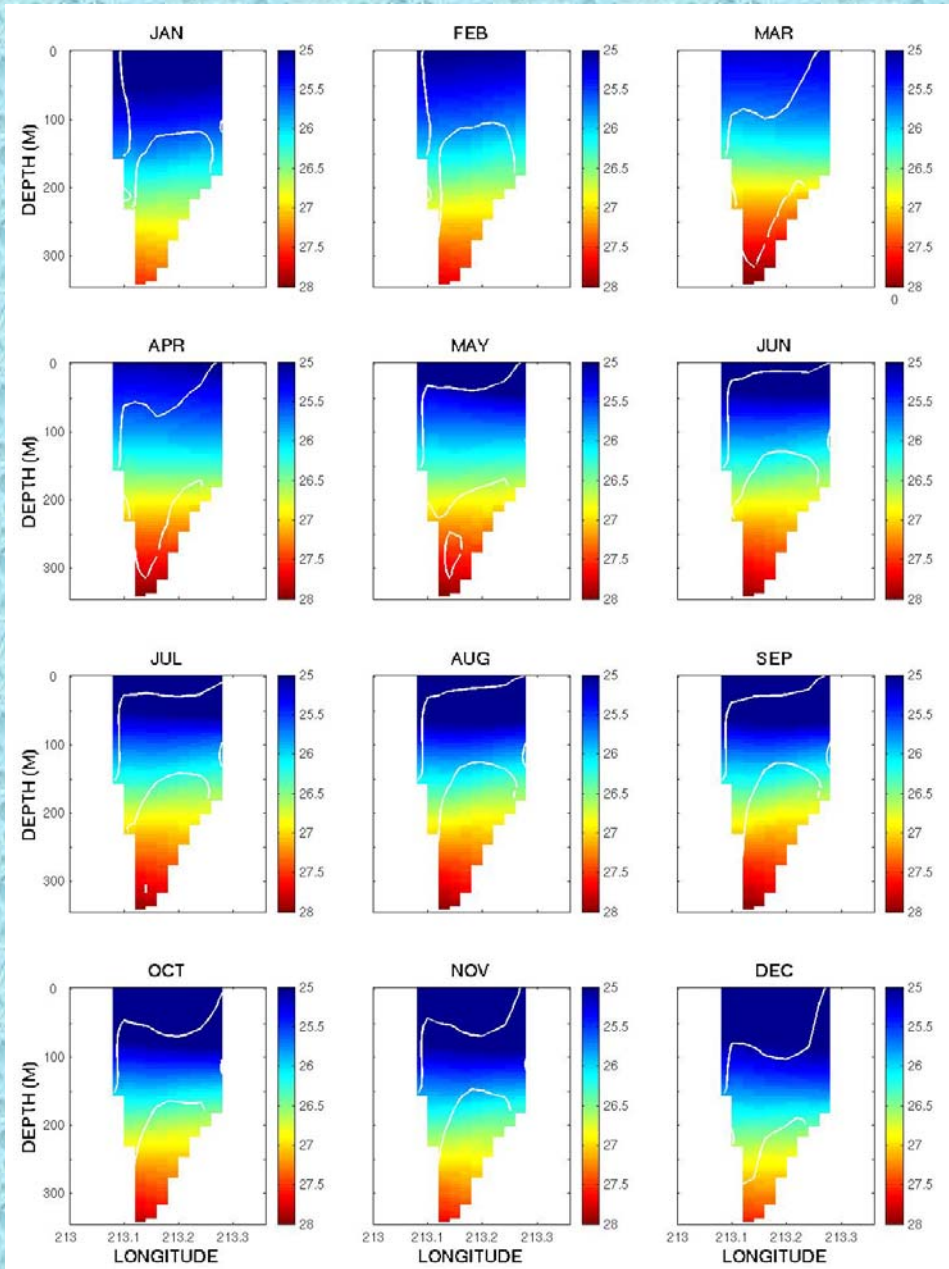
EPWS ANNUAL-MEAN & STD NORTHWARD VELOCITY



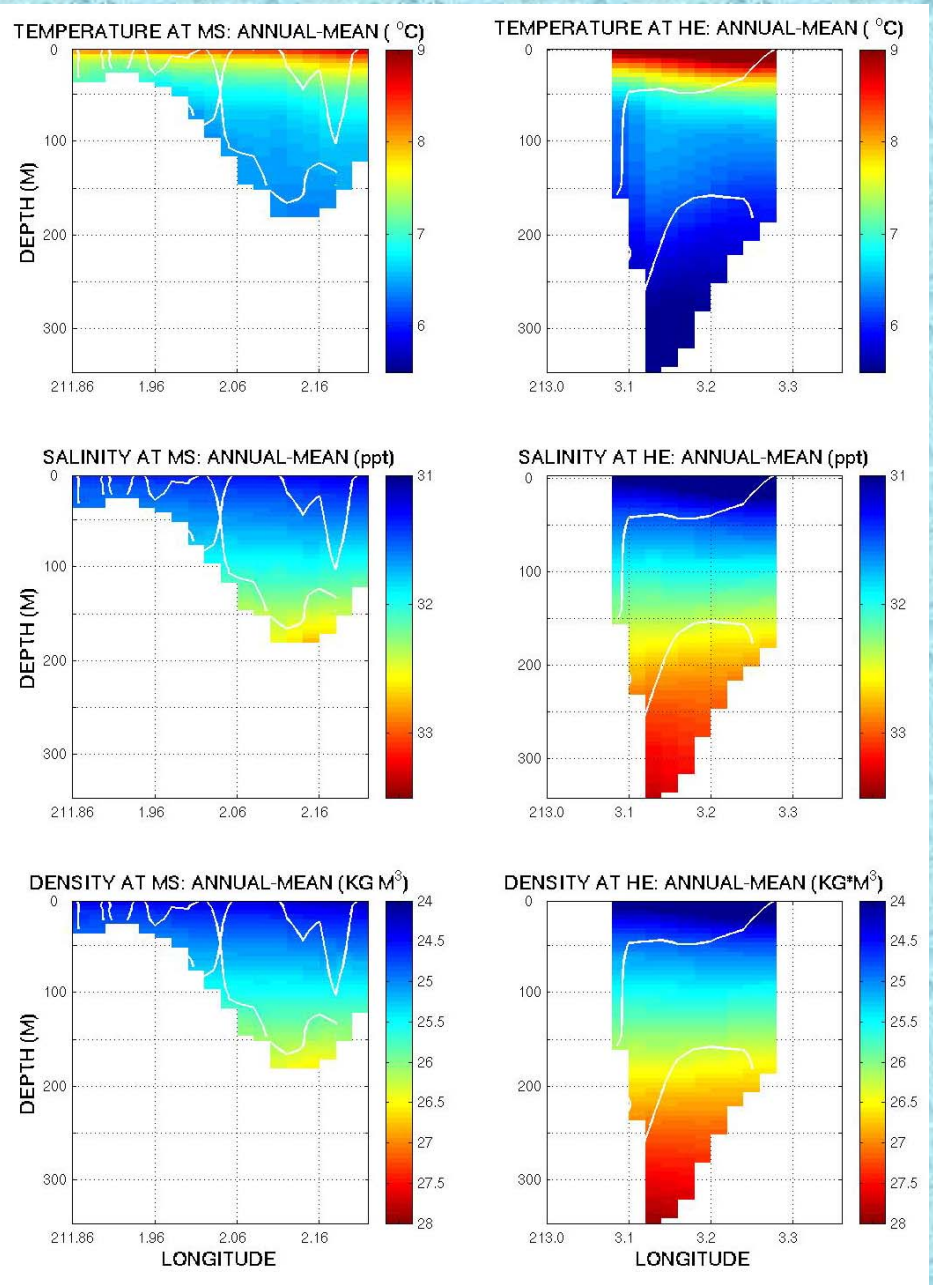
EPWS MONTHLY-MEAN NORTHWARD VELOCITY at HE



EPWS MONTHLY-MEAN DENSITY at HE



EPWS ANNUAL-MEAN T/S/RHO at HE and MS



Prof. Christopher N.K. Mooers
Division of Applied Marine Physics
Rosenstiel School of Marine & Atmospheric Science
University of Miami