CHC-NSC 2018
www.chc-nsc2018.ca
Victoria, B.C.
March 26-29, 2018
Victoria, C.B.
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Land and Sea Shaping the World
Terre et Mer Façonnant le Monde

Benefits and Impacts to Nautical Charting by Adopting a New Reference Frame

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Motivation for this study

NOAA's National Geodetic Survey

- New geometric reference system, NATREF – 2022
- Geocentric
- Aligned to latest ITRF / IGS reference frame
- Replaced NAD 83

- New geopotential reference system – 2022
- Based on airborne gravimetry
- Replaces NAVD88

Geospatial Foundation for Nautical Charts and Surveying

United States - NOAA's National Geodetic Survey

- North American Datum 1983 (NAD 83)
- North American Vertical Datum of 1988 (NAVD 88)

- National Spatial Reference System (NSRS)
- Latest realization – NAD 83 2011, Epoch 2010.00

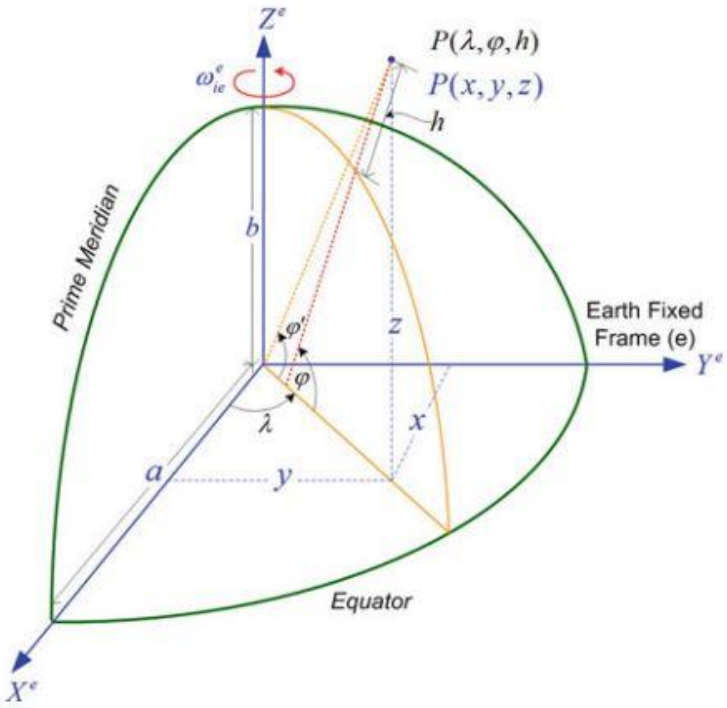
Global and Regional Reference Frames

World Geodetic System 1984 (WGS 84)

International Terrestrial Reference System (ITRF)

North American Datum 1983 (NAD 83)

- Geodetic coordinates – (lat, lon, hgt)
- Cartesian coordinates – (x, y, z)
- State Plane Coordinates



Global and Regional Reference Frames

ITRF/IGS	WGS84	NAD83 United States	NAD83 Canada
		NAD83 1986	V0 undefined epoch
ITRF88 1984.0			
ITRF89 1984.0			
ITRF90 1984.0			
ITRF91 1984.0	G730 1994.0		
ITRF92 1984.0			
ITRF93 1984.0			V1 1988.0
ITRF94 1984.0	G873 1997.0	NAD83 (HARN) 1989 - 1997 NAD83 (CSRS96) 1989	
ITRF96 1984.0			V2 1997.0
ITRF97 1984.0 IGS97		NAD83 (CSRS98) 1998	V3 1997.0
ITRF2000 1997.0 IGS00 / IGb00	G1150 2001.0	NAD83 (CORS96) 2002.00 2003.00 NAD83 (NSRS2007) 2002.00 2003.00 2007.00	V4 2002.0
ITRF2005 2000.0 IGS05			V5 2006.0
ITRF2008 2005.0 IGS08 / IGb08	G1674 2005.0 G1762 2005.0	NAD83 (2011), PACP00, MARP00 2010.00	V6 2010.0
ITRF2014 2010.0			V7 2010.0

NOAA's Office of Coast Survey

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Metadata and Geospatial Information

NOAA's Office of Coast Survey

- 1000+ Nautical Charts
- 95,000 miles of shoreline
- Man-made features
- Depths
- Rocks
- Aids and dangers to navigation
- Vessel traffic separation schemes

Coordinate Transformations

7 Parameter Transformation

$$X_2 = T + SRX_1$$

$$X_1 = \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}, T = \begin{bmatrix} Tx \\ Ty \\ Tz \end{bmatrix}, R = \begin{bmatrix} Cos\theta Cos\psi & Cos\psi Sin\theta Sin\varphi - Cos\varphi Sin\psi & Cos\varphi Cos\psi Sin\theta + Sin\varphi Sin\psi \\ Cos\theta Sin\psi & Cos\varphi Cos\psi + Sin\theta Sin\varphi Sin\psi & -Cos\psi Sin\varphi + Cos\varphi Sin\theta Sin\psi \\ -Sin\theta & Cos\theta Sin\varphi & Cos\theta Cos\varphi \end{bmatrix}$$

$$R = I + \delta R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} + \begin{bmatrix} 0 & -\delta\psi & \delta\theta \\ \delta\psi & 0 & -\delta\varphi \\ -\delta\theta & \delta\varphi & 0 \end{bmatrix}$$

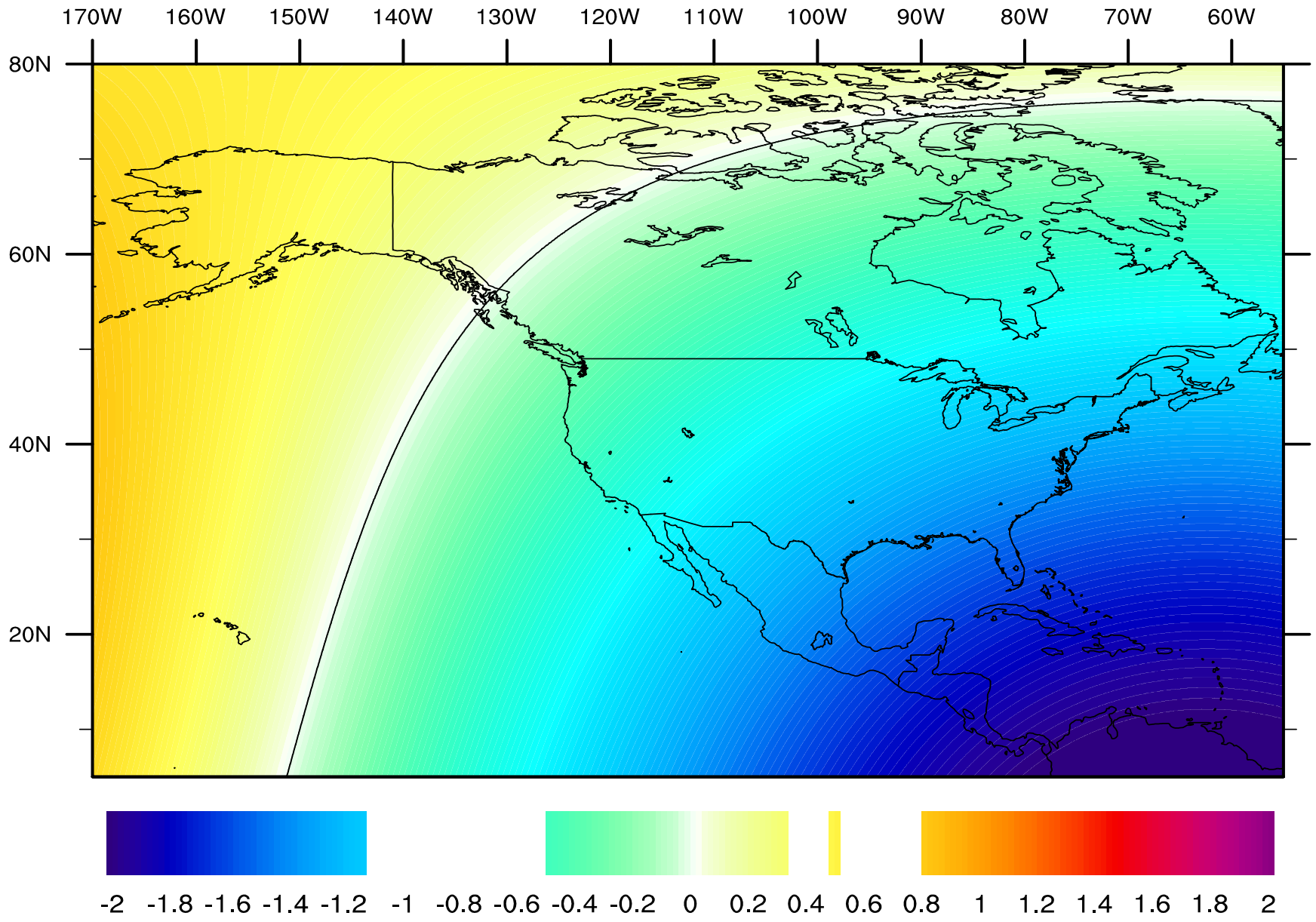
$$\frac{dX_2}{dt} = \frac{dX_1}{dt} + \frac{dT}{dt} + \frac{dS}{dt}X_1 + S\frac{dX_1}{dt} + \frac{dR}{dt}X_1 + R\frac{dX_1}{dt}$$

Analysis

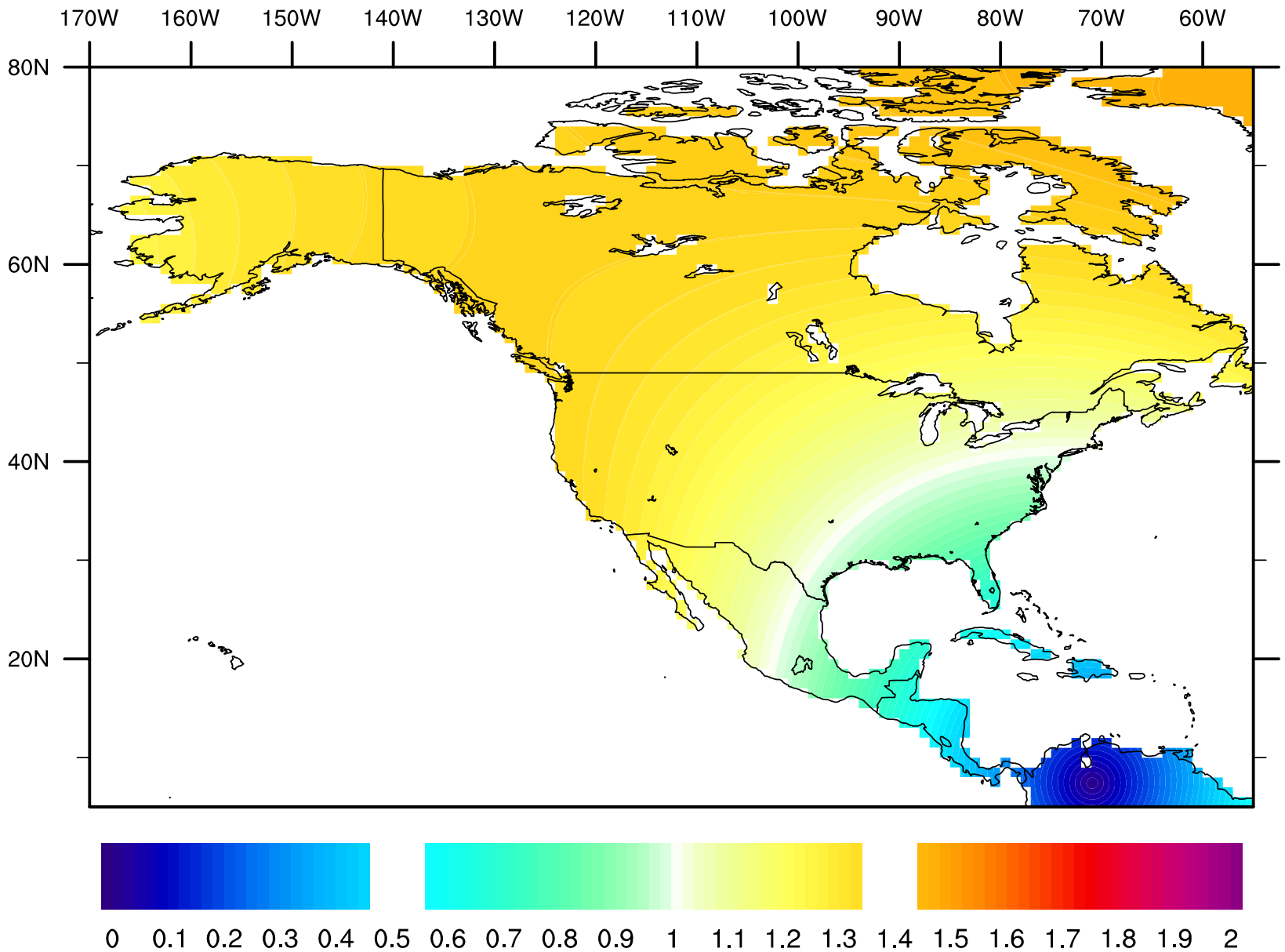
- Offset reference frame (NAD 83) to geocentric reference frame (ITRF2008)
- Epoch 2005.0
- Horizontal and vertical shifts are expected
- Magnitude of shifts depend on your latitude and longitude

- Study Region: 5.0° to 80.0° north latitude and 55.0° to 170.0° west longitude
- Node spacing: 0.05°
- 3.4 million nodes
- Study region covers all of NAD 83 as well as portions of the Pacific Ocean (PACP00)

Ellipsoid Height Changes (m)



Horizontal Shifts (m)



Location	North (m)	East (m)	Vertical (m)	Horizontal (m)	3-D Shift (m)
Anchorage, AK	-0.08	-1.37	0.43	1.38	1.44
Annapolis, MD	0.94	-0.40	-1.29	1.02	1.64
Baltimore, MD	0.94	-0.40	-1.29	1.02	1.64
Boston, MA	1.06	-0.28	-1.21	1.10	1.63
Charleston, SC	0.76	-0.48	-1.43	0.89	1.69
Chicago, IL	0.88	-0.70	-1.10	1.12	1.57
Cleveland, OH	0.94	-0.55	-1.17	1.09	1.60
Cold Bay, AK	-0.27	-1.29	0.67	1.31	1.47
Corpus Christi, TX	0.48	-0.90	-1.31	1.02	1.66
Guam	0.93	-0.87	1.98	1.28	2.35
Honolulu, HI	1.01	-2.60	0.28	2.79	2.81
Houston, TX	0.55	-0.85	-1.30	1.01	1.65
Jacksonville, FL	0.69	-0.50	-1.48	0.85	1.70
Juneau, AK	0.25	-1.39	0.11	1.42	1.42
Long Beach, CA	0.39	-1.30	-0.70	1.36	1.53
Miami, FL	0.57	-0.43	-1.62	0.71	1.77
Mobile, AL	0.63	-0.67	-1.40	0.92	1.67

Location	North (m)	East (m)	Vertical (m)	Horizontal (m)	3-D Shift (m)
New Haven, CT	1.02	-0.30	-1.24	1.07	1.64
New Orleans, LA	0.59	-0.73	-1.33	0.94	1.67
New York, NY	1.00	-0.34	-1.25	1.06	1.64
Newport, OR	0.41	-1.34	-0.35	1.41	1.45
Norfolk, VA	0.89	-0.38	-1.35	0.97	1.66
Philadelphia, PA	0.97	-0.37	-1.27	1.04	1.64
Portland, ME	1.08	-0.27	-1.19	1.11	1.63
Providence, RI	1.04	-0.27	-1.24	1.07	1.64
Québec City, QC	1.17	-0.28	-1.05	1.20	1.60
San Diego, CA	0.39	-1.28	-0.76	1.34	1.54
San Juan, PR	0.45	0.07	-1.88	0.45	1.93
San Francisco, CA	0.39	-1.34	-0.52	1.39	1.49
Savannah, GA	0.76	-0.48	-1.43	0.89	1.69
Seattle, WA	0.46	-1.32	-0.33	1.40	1.44
Tampa, FL	0.61	-0.50	-1.54	0.79	1.73
Toronto, ON	1.00	-0.50	-1.14	1.12	1.59
Vancouver, BC	0.46	-1.32	-0.31	1.40	1.44
Washington, DC	0.93	-0.41	-1.29	1.02	1.64
Wilmington, NC	0.82	-0.40	-1.42	0.91	1.68

Impacts to Hydrographic Surveys

- Data collected in WGS 84 and NAD 83 reference frames
- Currently these two are inconsistent at geodetic level

- Most data collection based on IHO Standards for Hydrographic Surveys – S-44
- S-44 5th Edition 2008, current
- S-44 6th Edition - soon, IHO HSPT

- Ellipsoidally Referenced Surveying

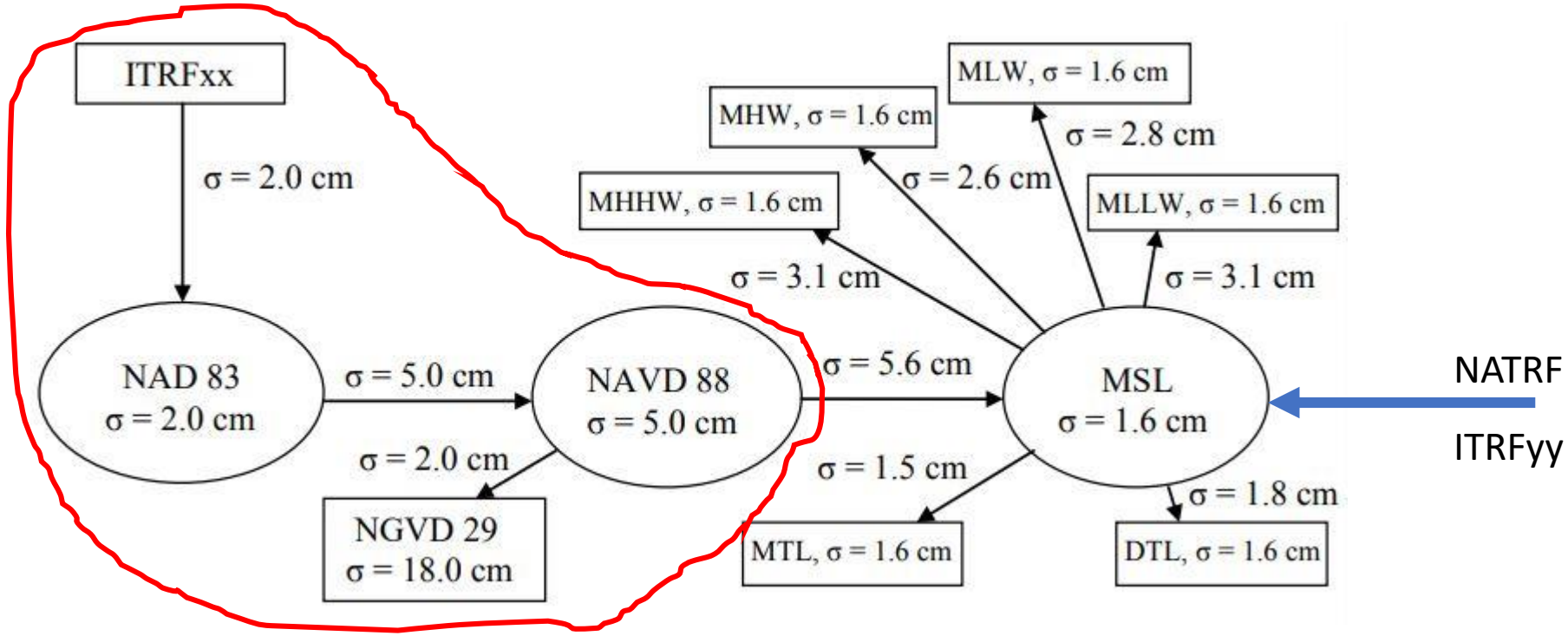
Order	Special	1a	1b	2
Description of areas.	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	**Areas shallower than 100** metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Maximum allowable THU 95% *Confidence level*	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Maximum allowable TVU 95% *Confidence level*	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Full Sea floor Search	Required	Required	Not required	**Not required**
Feature Detection	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Recommended maximum Line Spacing	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)	2 metres	2 metres	2 metres	5 metres
Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)	10 metres	20 metres	20 metres	20 metres
Mean position of floating aids to navigation (95% *Confidence level*)	10 metres	10 metres	10 metres	20 metres

Impacts to Nautical Charts and Aids to Navigation

- Aids to navigation – not set to assigned positions
- Average position taken over time – “Surveyed”
- Positions usually from AIS and internal GPS (WGS 84 or NAD 83?)
- NAD 83 positions on a chart will need to be updated
- No impact to WGS 84 positions
- Depths on a chart are not affected
- 1:2500 scale nautical charts 1 mm = 2.5 m
- ENC’s reference WGS 84 – no impact from reference frame update

Impacts to Water Levels

- Referenced to a specific point (MLLW) or other mark
- Offsets to other vertical marks or datums do not change
- VDatum



Impacts to Various Applications

- Geodesy and surveying
- Boundary surveys
- Precision navigation
- Bathymetry
- Crowdsourcing
- Data assimilation
- Base stations / CORS / corrector services
- State plane coordinates
- Software – Esri, CARIS, Applanix, NADCON, VERTCON
- Autonomous navigation

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Thank You

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