Intercomparisons of Harmonic Tidal Analyses between International Partners

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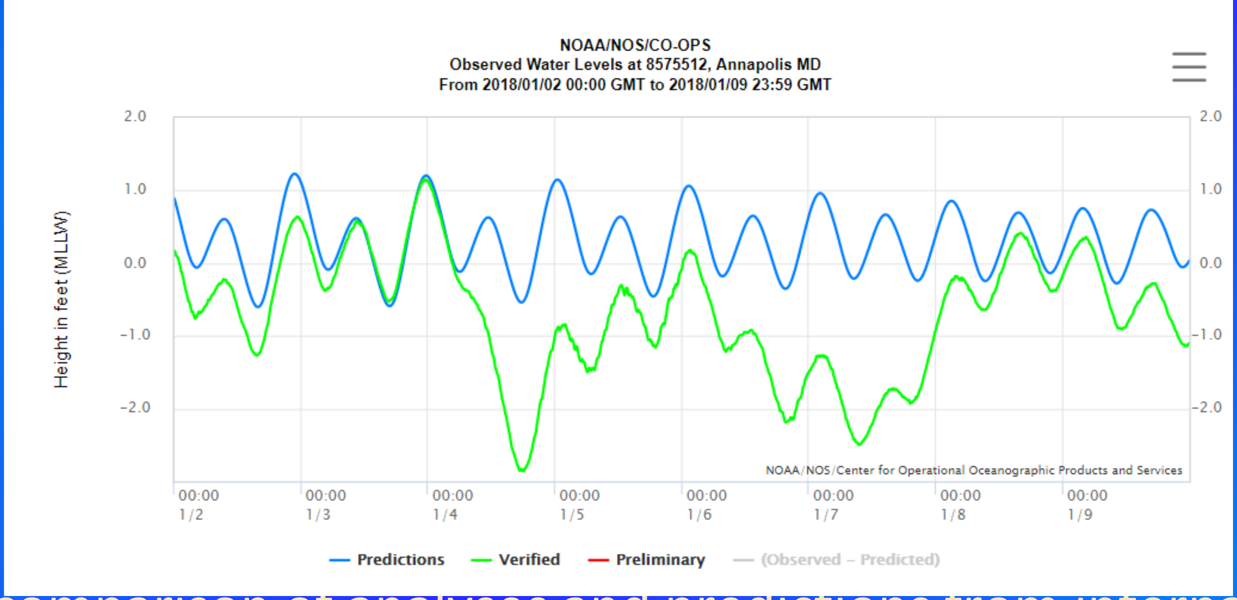
Introduction

- Accurate tide prediction is critical for marine navigation and other applications
- The tidal component of water level is deterministic



- Intercomparison of analyses and predictions from international partners can help characterize the accuracy of each nation's tidal prediction systems
- Opportunity to fine tune approaches and share best practices internationally

International Hydrographic Organization

Tides, Water Level and Currents Working Group (TWCWG)

- IHO ensures accurate surveying and charting of the world's oceans and sets standards for water level and current information that are precise and widely distributed
- TWCWG provides technical advice and coordination on tides, water levels, and currents and the distribution of information
- TWCWG members have expressed concern about the accuracy of their tidal analyses and the age of the software used for said analyses
- Members have exchanged water level data sets and the resultant harmonic constituents
- The goal is to characterize differences in the accuracy and precision of tidal analysis results between the different organizations.

https://iho.int/en/twcwg

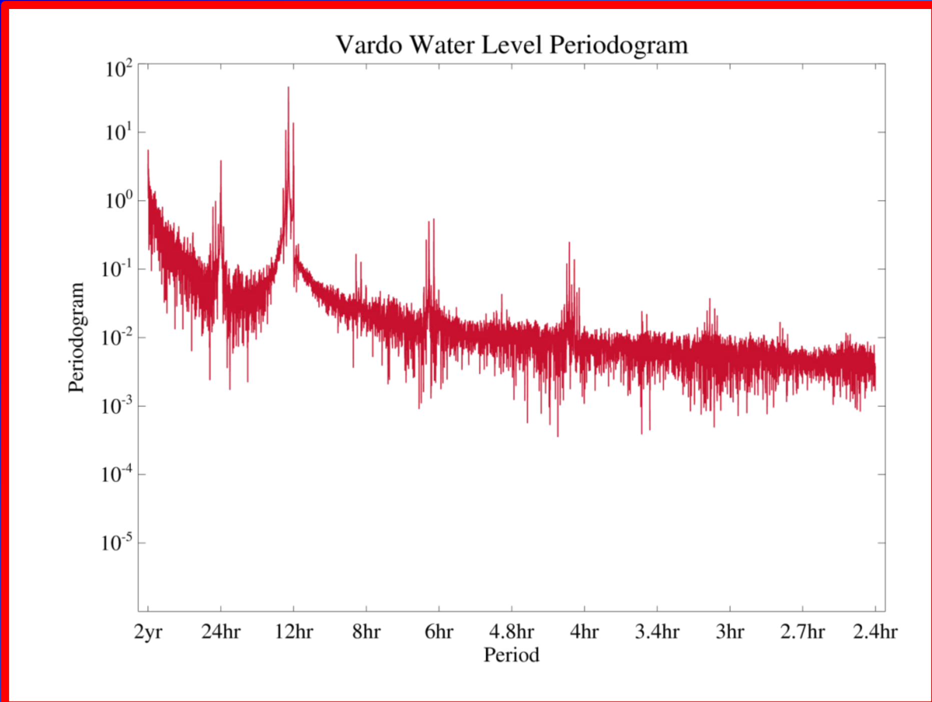
CO-OPS Priority

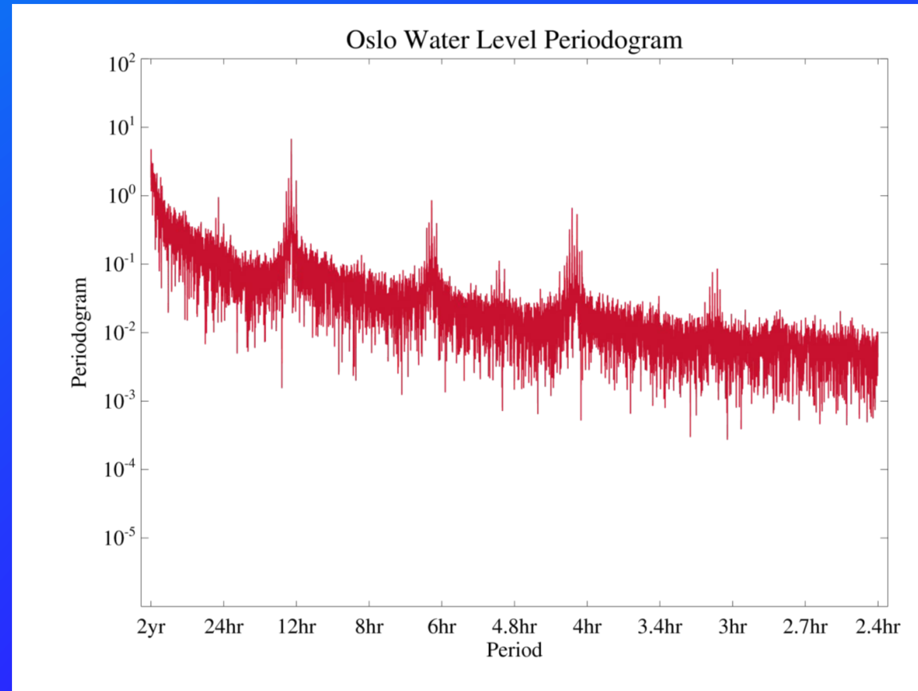
- CO-OPS supports TWCWG’s concerns and plan
- HA software was originally developed in the early 1960’s using FORTRAN4 and has been updated in a patchwork manner since then
- Interest in either completely rewriting the software in modern code or adopt other code that works as well/better
- Comparing our methodology with those used by other authoritative national organizations may help improve our methods and produce more accurate tidal predictions.

Data Sets

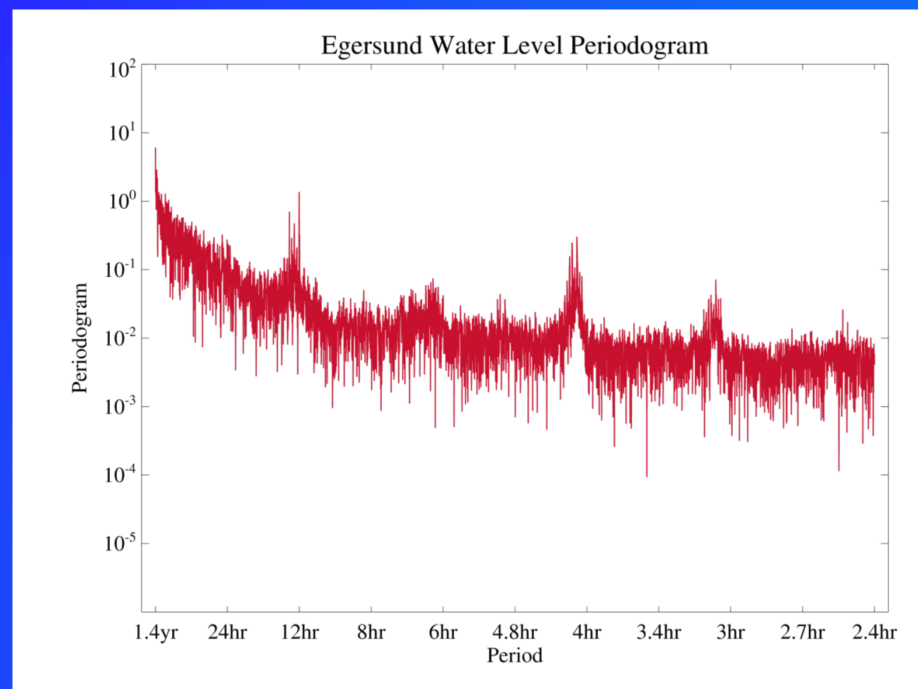
- Norway: water level and constituents for Vardø, Oslo, and Egersund
- Spain: constituents and predictions for Vardø, Oslo, Egersund, Boston, Panama City, and Seattle
- NOAA: water level, constituents, and predictions for Boston, Panama City, and Seattle; and official predictions for Boston

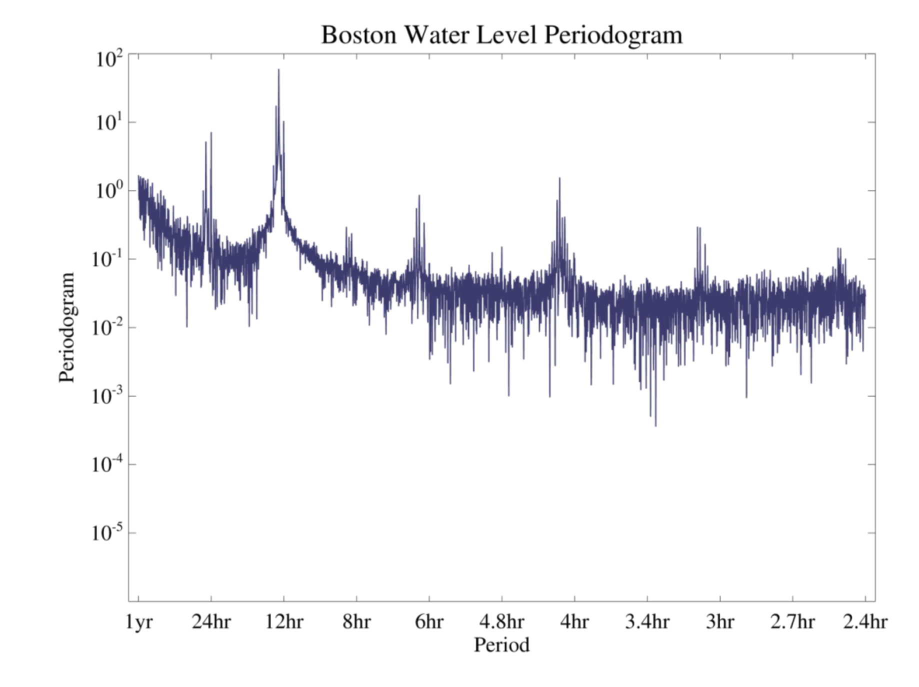
Station	Latitude	Longitude	Record Start	Record End
Vardø	70.375 N	31.104 E	01/01/2014	12/31/2015
Oslo	59.909 N	10.734 E	01/01/2014	12/31/2015
Egersund	58.449 N	5.993 E	11/22/2012	04/23/2014
Boston	42.355 N	71.053 W	01/01/1980	12/31/2019
Panama City	30.152 N	85.667 W	01/01/2009	12/31/2013
Seattle	47.603 N	122.339 W	01/01/2009	12/31/2013

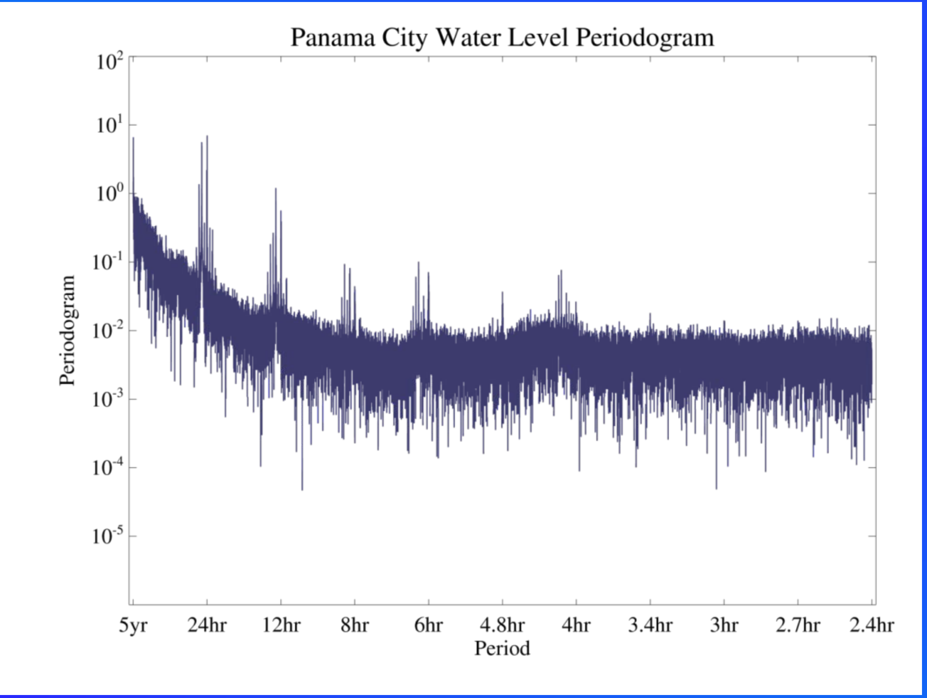




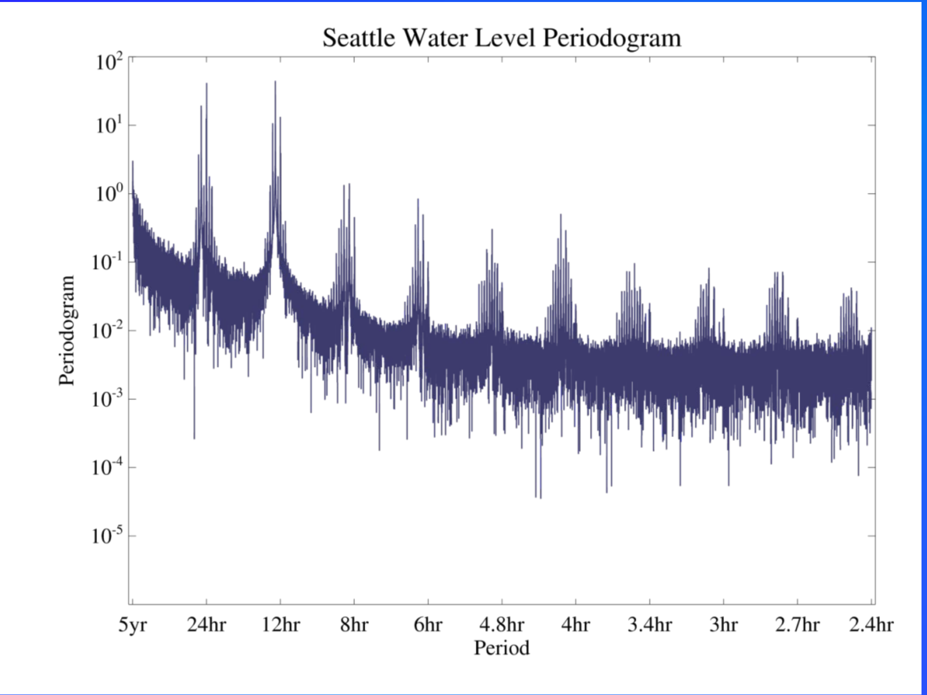
- A periodogram identifies the energetic frequencies in a time series
- Computed using a Fourier Transform
- Vardø has more pronounced spectral energy in semi-diurnal and diurnal bands versus Oslo and Egersund.







- Boston has a primary semi-diurnal peak and a secondary diurnal peak
- Panama City has a primary diurnal peak
- Seattle has dominant semi-diurnal and diurnal peaks and considerable energy in higher-order constituents



Harmonic Analysis Methodology

- Harmonic analysis is used to identify tidal constituents and their attributes: frequency (speed), phase, and amplitude
- Can be done using Fourier analysis, which results in the reconstruction of an input time series as the linear superposition of a finite set of sinusoidal waves
- In practice, it is more efficient to perform harmonic analysis using a least squares approach
- Once harmonic analysis is performed over a specified time series, tidal predictions can be easily calculated for any point in time

Intercomparison of Constituents

- Norway
  - Unknown constituents H1 and H2
  - We shifted phases from UTC+1 to UTC+0
  - Does not include some low-frequency constituents (e.g., Ssa, Mf, Msf, or Mm)
- Spain
  - Uses a larger pool of constituents (237)
  - Many unknown 'X' constituents (e.g., X1, X2, … X22, etc.)
- NOAA
  - All 120 constituents appear in IHO's Standard List except for MKL2 and 3M10
  - PDF reports truncate the constituent names to a length of 4 characters, resulting in duplicates (e.g., "2MS8" appears 4 times)

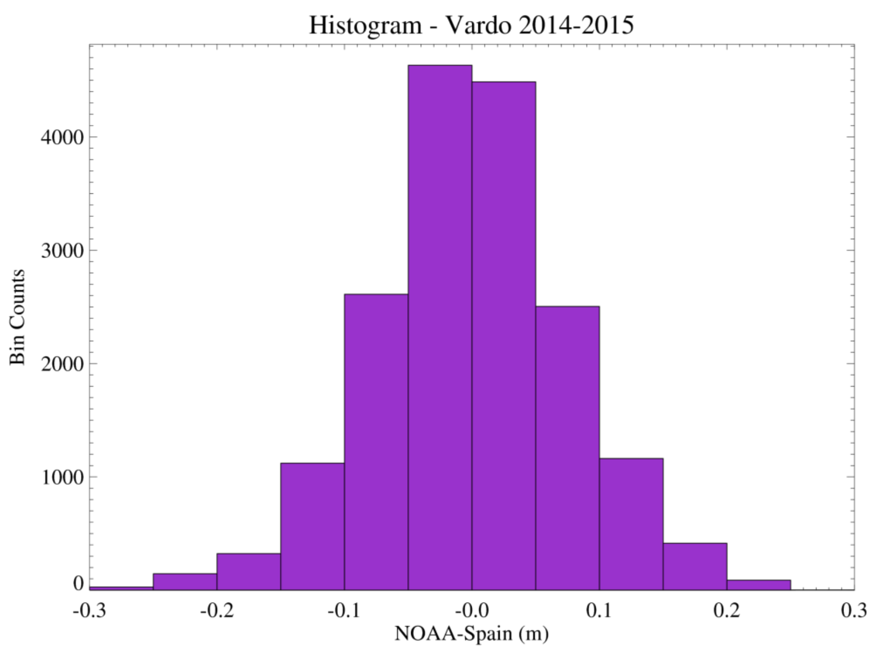
Vardø	Norway			Spain			NOAA		
	Name	Amp	κ'^{*}	Name	Amp	κ'	Name	Amp	κ'
1	M2	1.019	102.4	M2	1.018	102.8	M2	1.019	102.9
2	S2	0.286	147.0	S2	0.283	147.6	S2	0.283	147.2
3	N2	0.222	72.8	N2	0.223	73.5	N2	0.224	73.7
4	Sa	0.130	328.5	K1	0.123	251.9	K1	0.124	251.3
5	K1	0.121	252.2	Sa	0.113	341.9	Sa	0.117	269.5
6	K2	0.080	146.6	K2	0.079	145.9	K2	0.080	146.3
7	Nu2	0.044	79.9	X2	0.048	86.1	Mf	0.069	189.8
8	P1	0.034	247.5	Ssa	0.047	102.2	Nu2	0.045	81.0
9	2N2	0.034	44.0	Nu2	0.045	78.5	P1	0.035	246.3
10	L2	0.028	135.2	X3	0.045	125.5	L2	0.031	151.6
11	O1	0.025	68.4	P1	0.035	246.5	2N2	0.030	54.5
12	Mu2	0.025	37.4	Mf	0.034	157.6	Mm	0.029	260.1

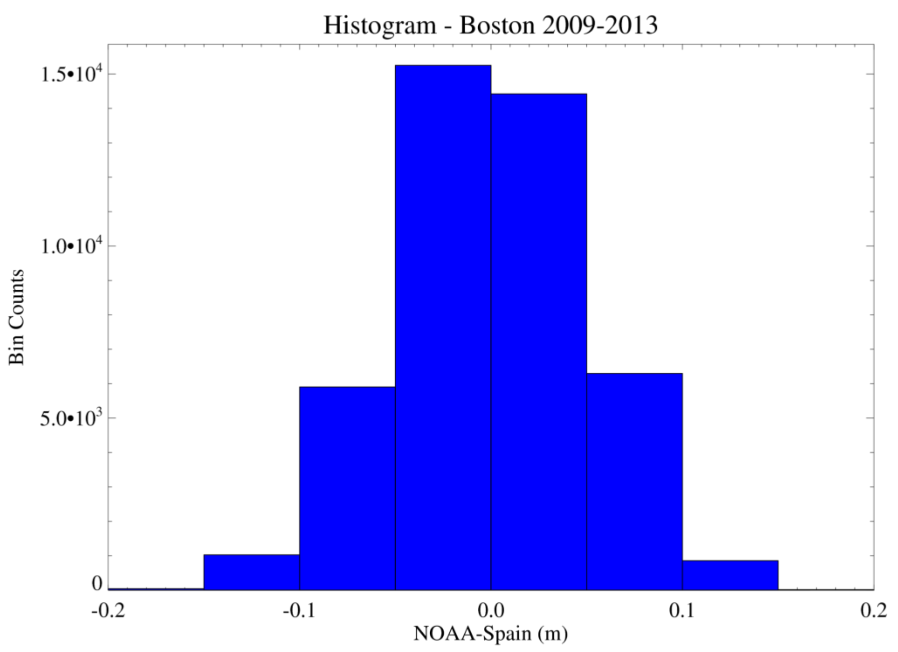
Boston	Spain			NOAA		
	Name	Amp	κ'	Name	Amp	κ'
1	M2	1.375	109.4	M2	1.382	109.3
2	N2	0.315	78.8	N2	0.304	79.3
3	S2	0.210	146.1	S2	0.215	146.6
4	K1	0.140	205.0	K1	0.138	205.0
5	O1	0.114	187.3	O1	0.118	186.6
6	Nu2	0.067	85.4	Nu2	0.067	82.3
7	K2	0.058	146.5	K2	0.063	144.8
8	L2	0.058	151.3	Sa	0.057	108.1
9	P1	0.045	202.4	2N2	0.046	64.7
10	2N2	0.044	54.4	P1	0.045	204.4
11	Sa	0.038	205.4	L2	0.044	155.4
12	M6	0.031	281.0	Ssa	0.038	330.4

Comparing Predictions

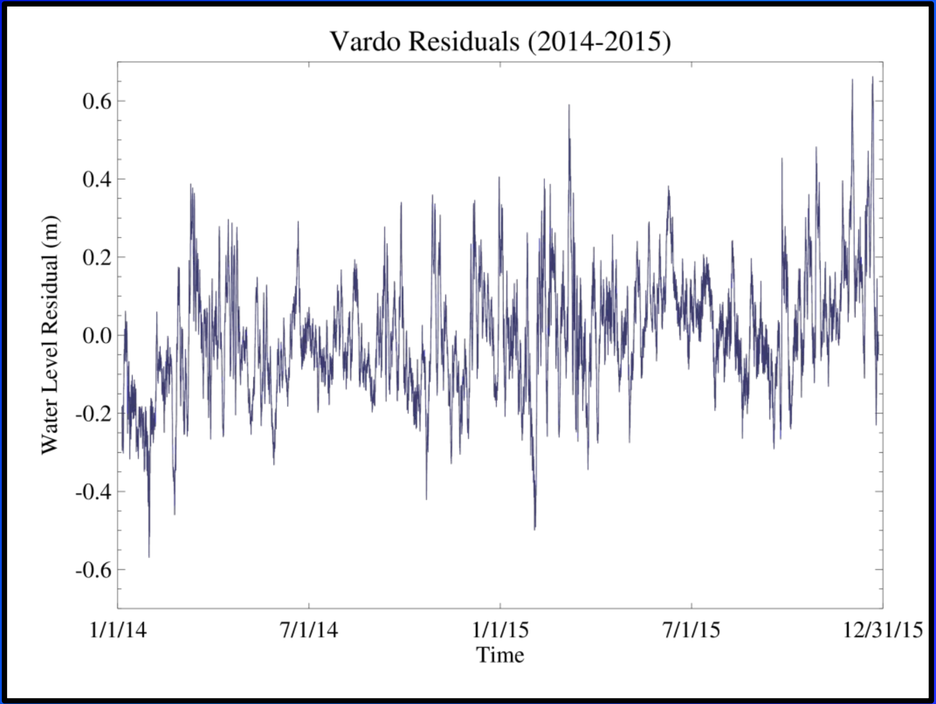
Vardø	2014-2015
US range (m)	3.742
Spain range (m)	3.743
Correlation	0.995
MAD (m)	0.060
Max Difference (m)	0.258
Min Difference (m)	-0.273

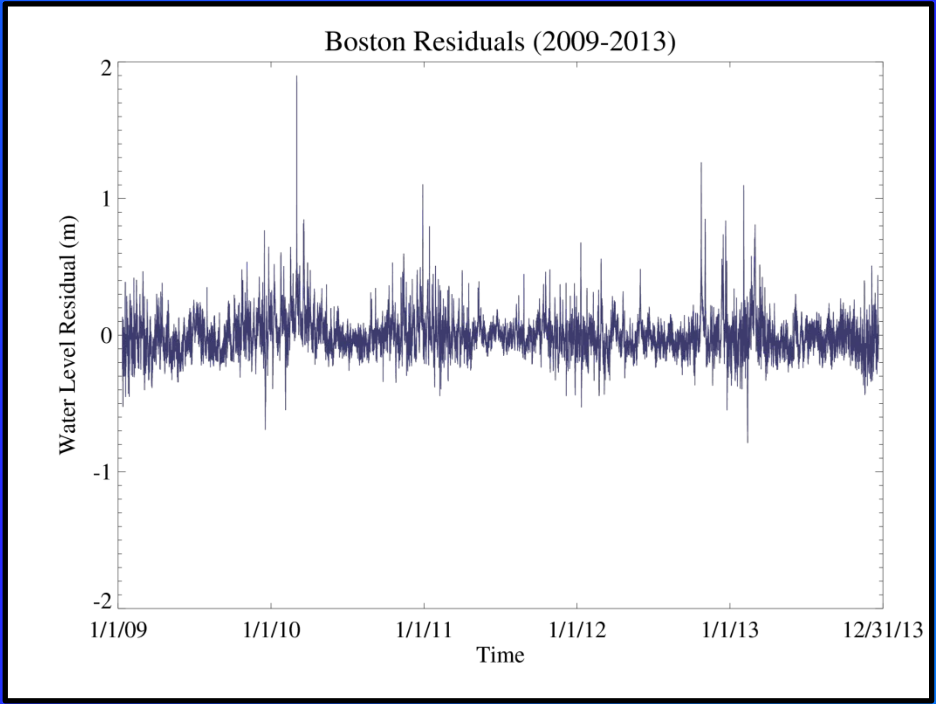
Boston	2009-2013
US range (m)	4.456
Spain range (m)	4.509
Correlation	0.999
MAD (m)	0.040
Max Difference (m)	0.184
Min Difference (m)	-0.179



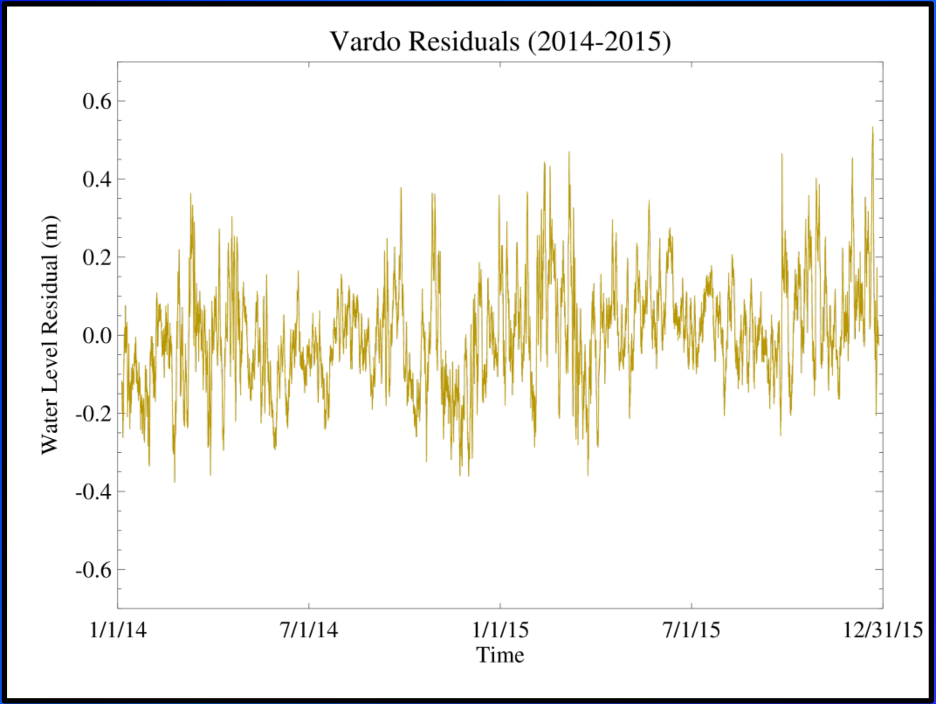


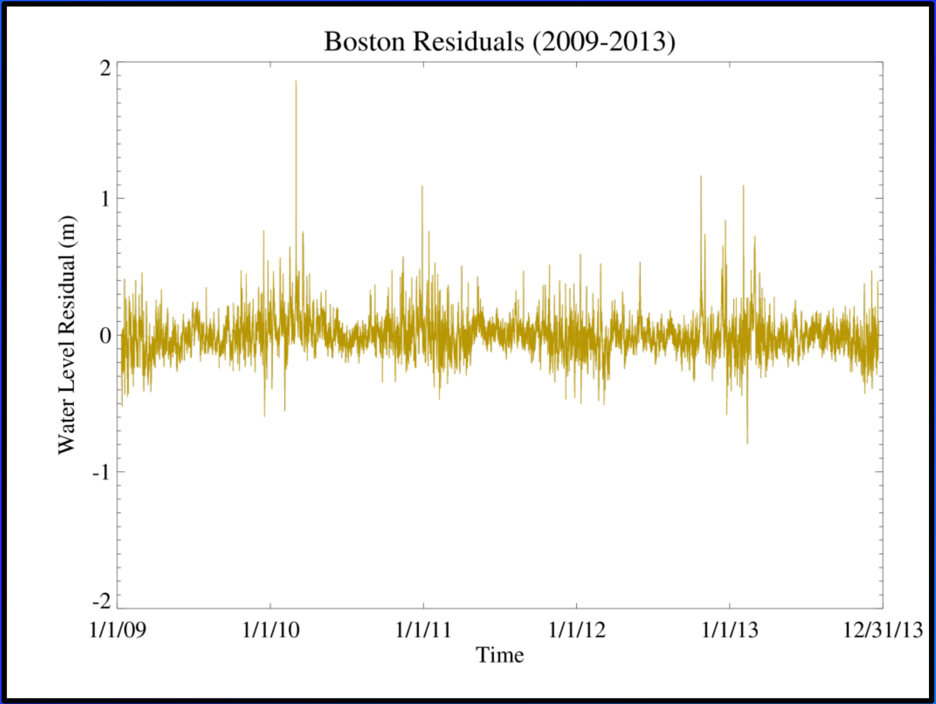
Residuals


Vardo Residuals (2014-2015)
Water Level Residual (m)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1/1/14
7/1/14
1/1/15
7/1/15
12/31/15
Time


Boston Residuals (2009-2013)
Water Level Residual (m)
2
1
0
-1
-2
1/1/09
1/1/10
1/1/11
1/1/12
1/1/13
12/31/13
Time

Residuals

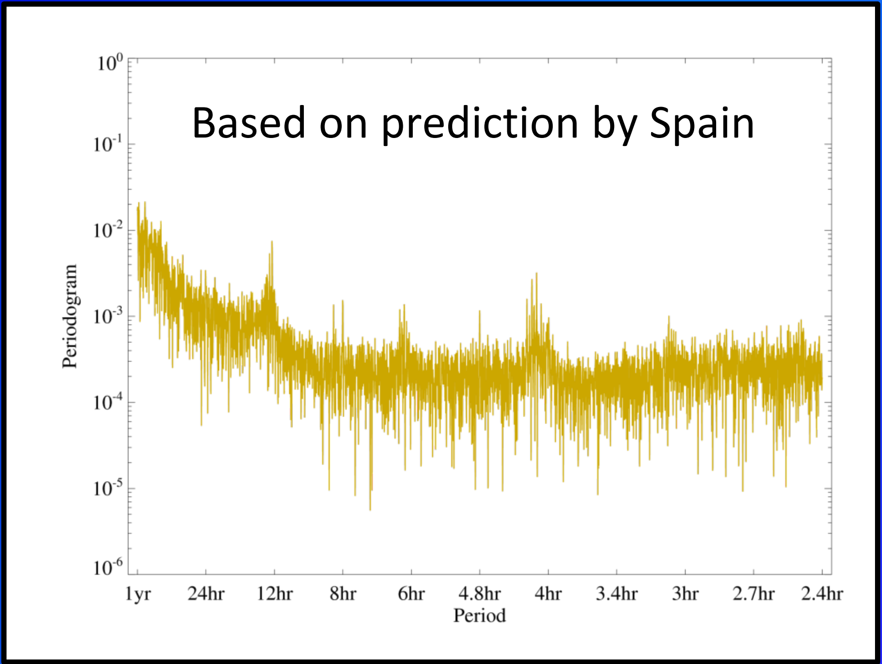


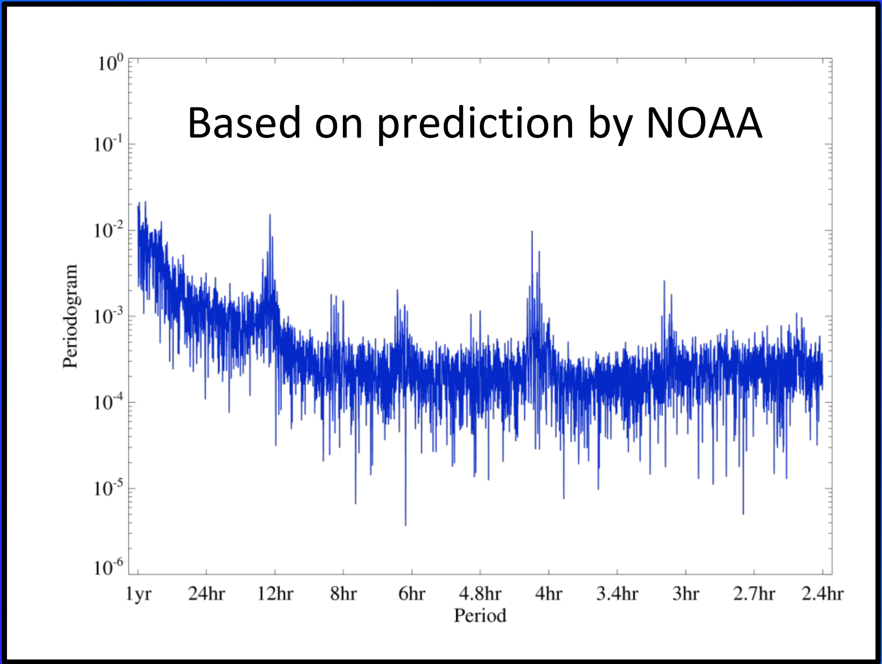


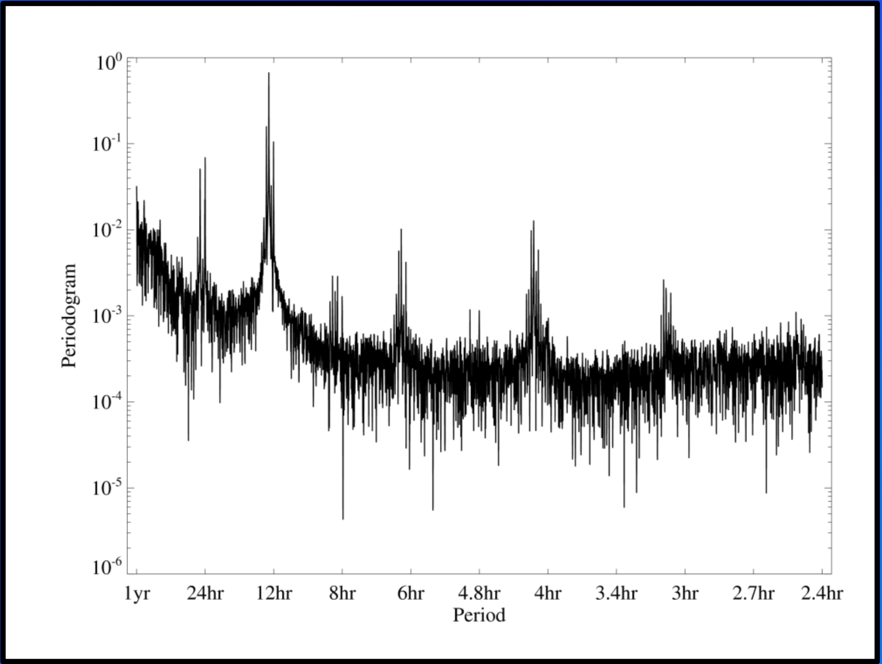
Vardø	Mean Absolute Residual (m)
NOAA	0.118
Spain	0.102

Boston	Mean Absolute Residual (m)
NOAA	0.101
Spain	0.094

Spectral Energy of Residuals (Boston, 2019)

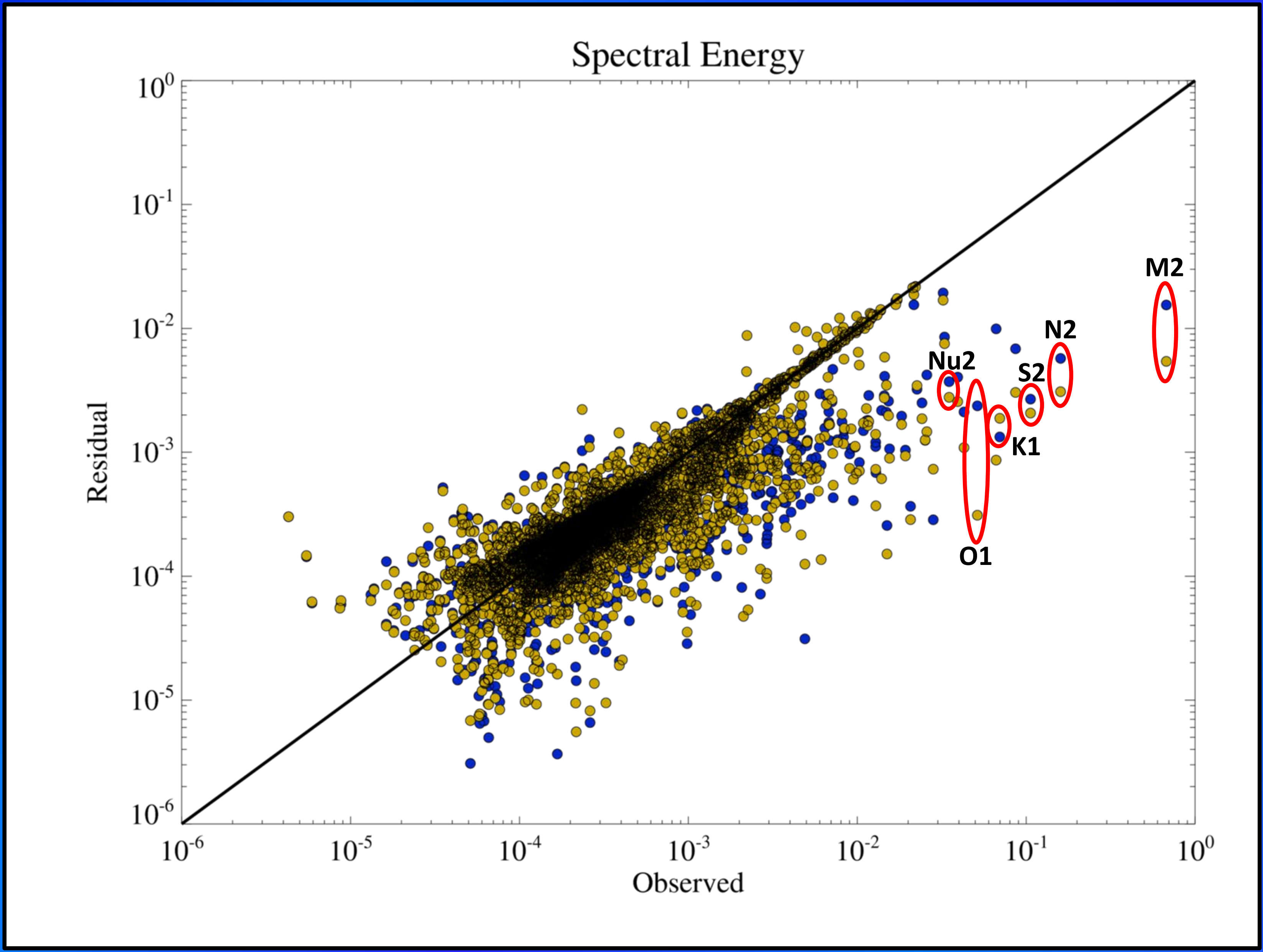




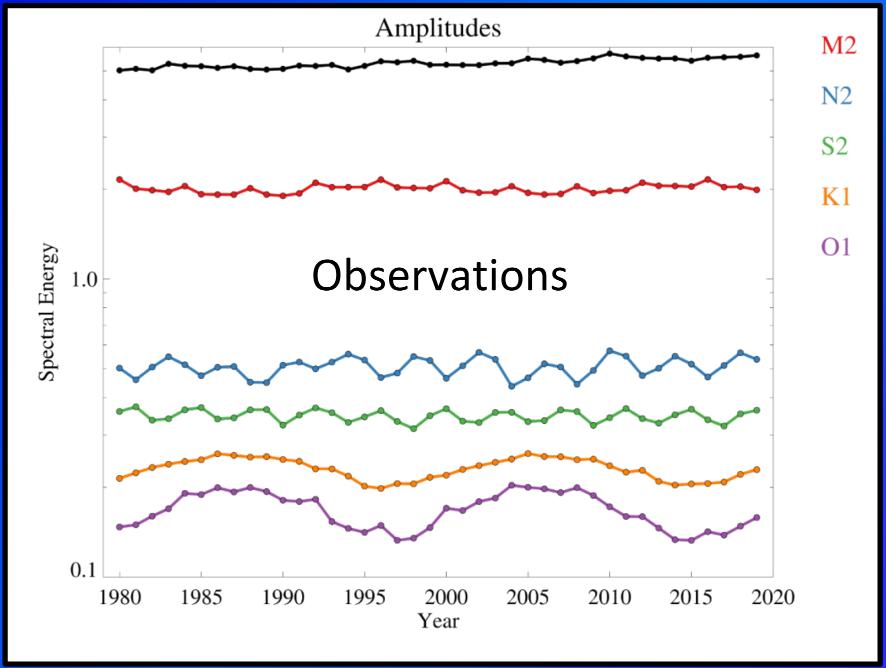


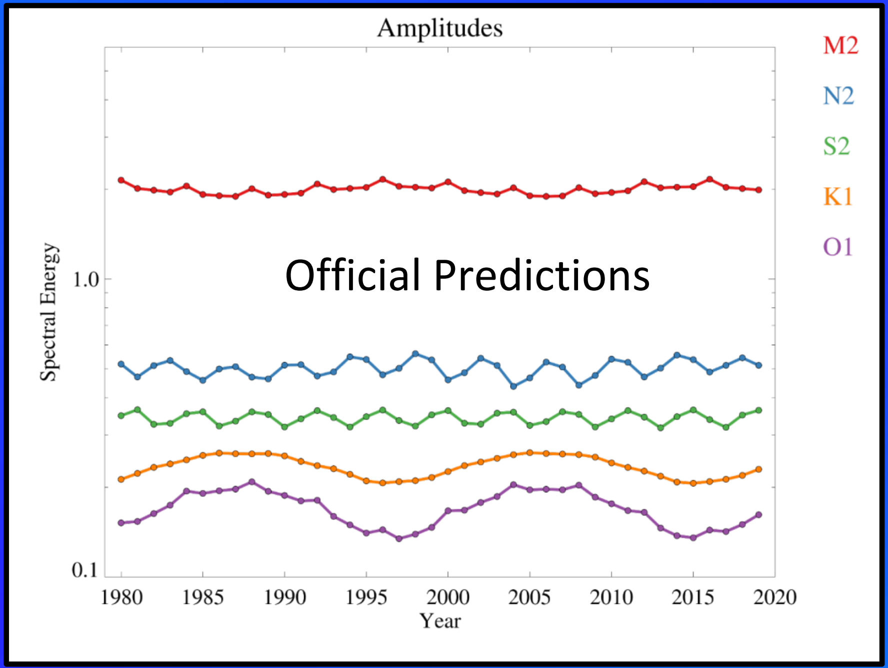
Overall variance reduction of ~98%.

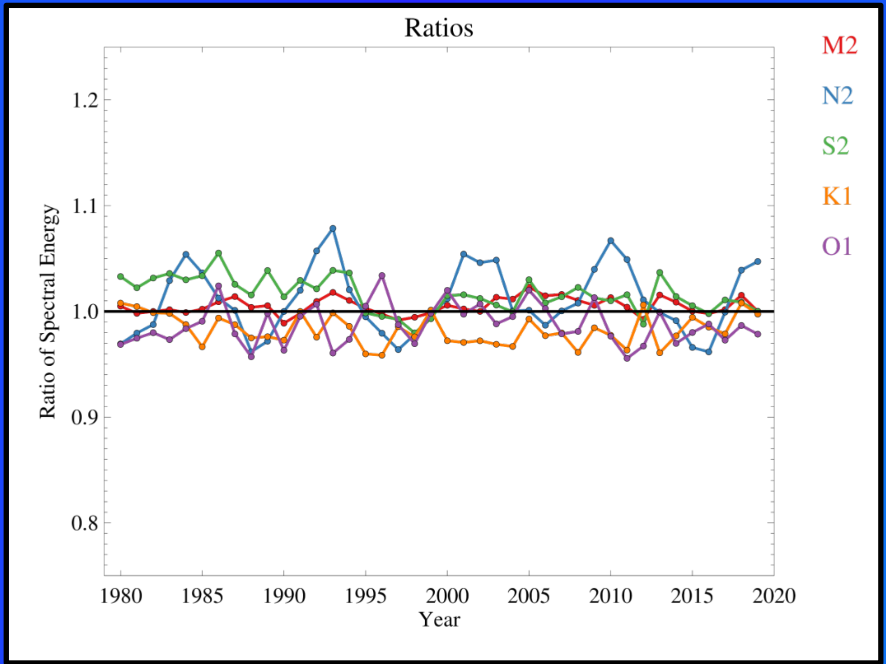
Spectral Energy of Residuals (Boston, 2019)



Spectral Energy Over Time (Boston)







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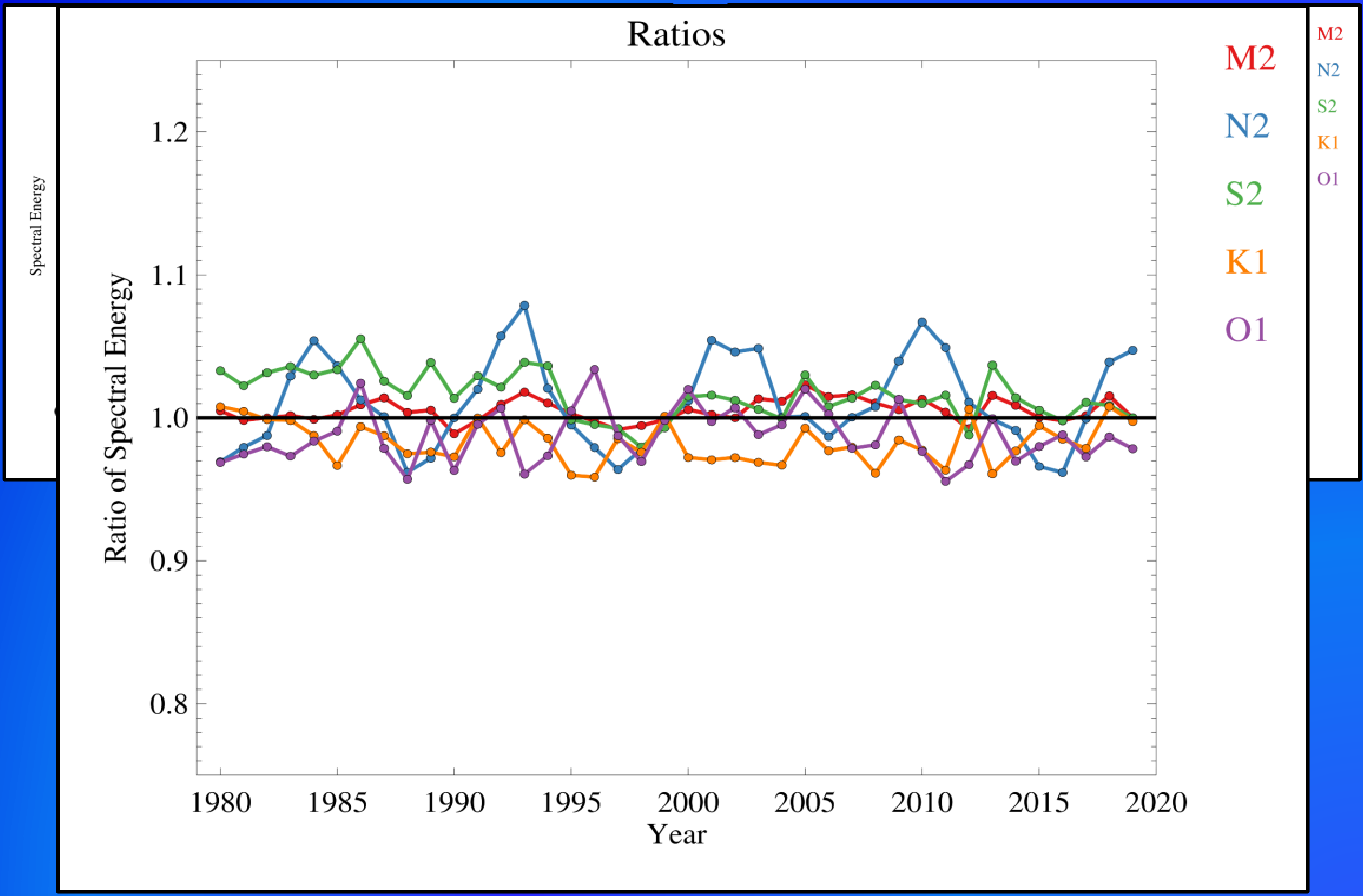

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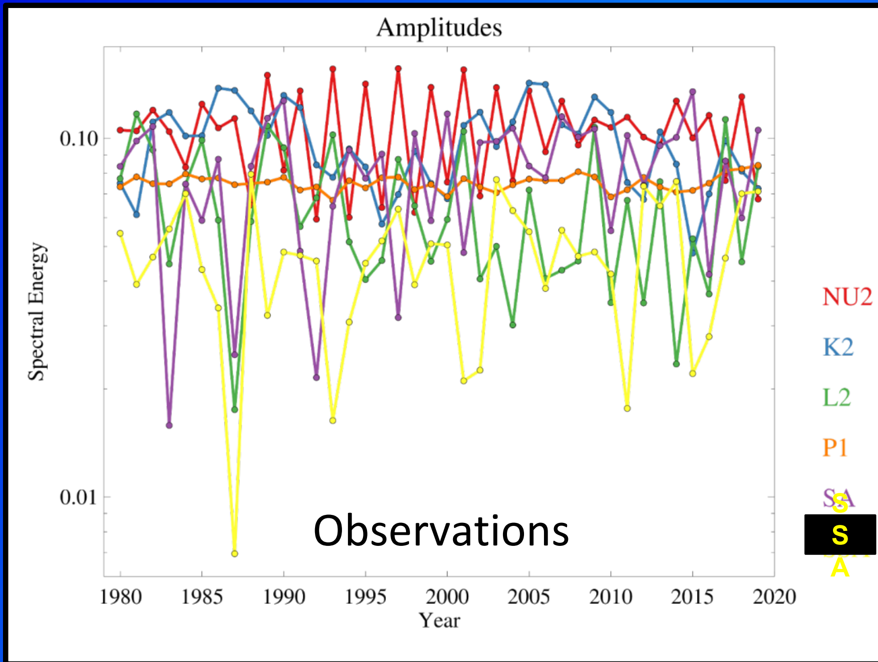

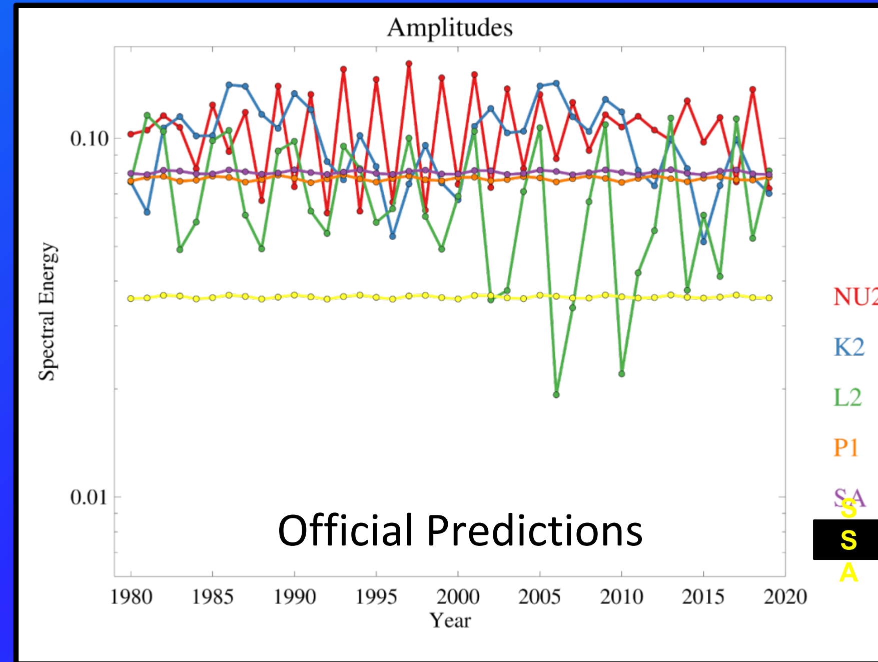

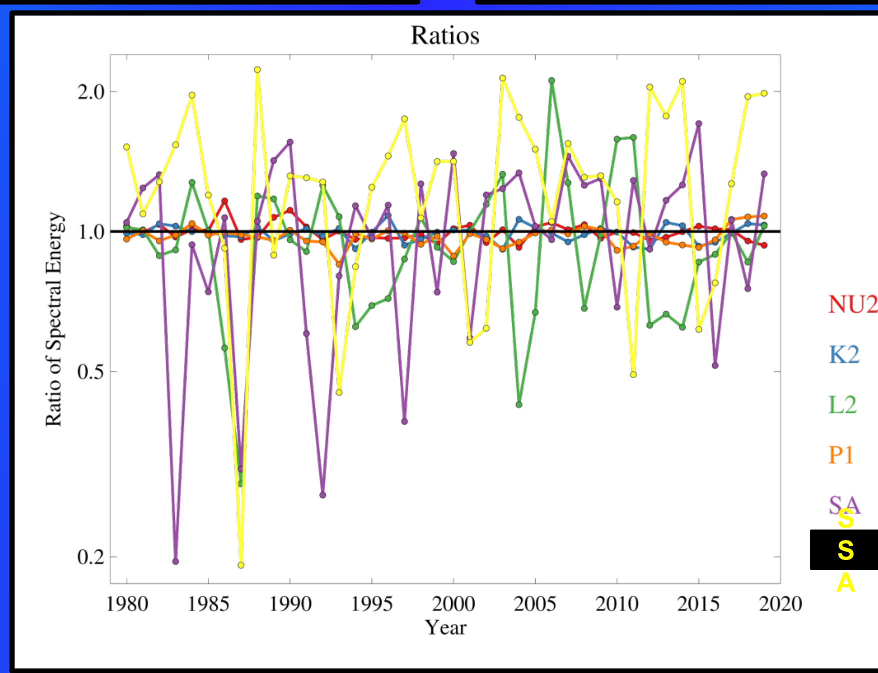

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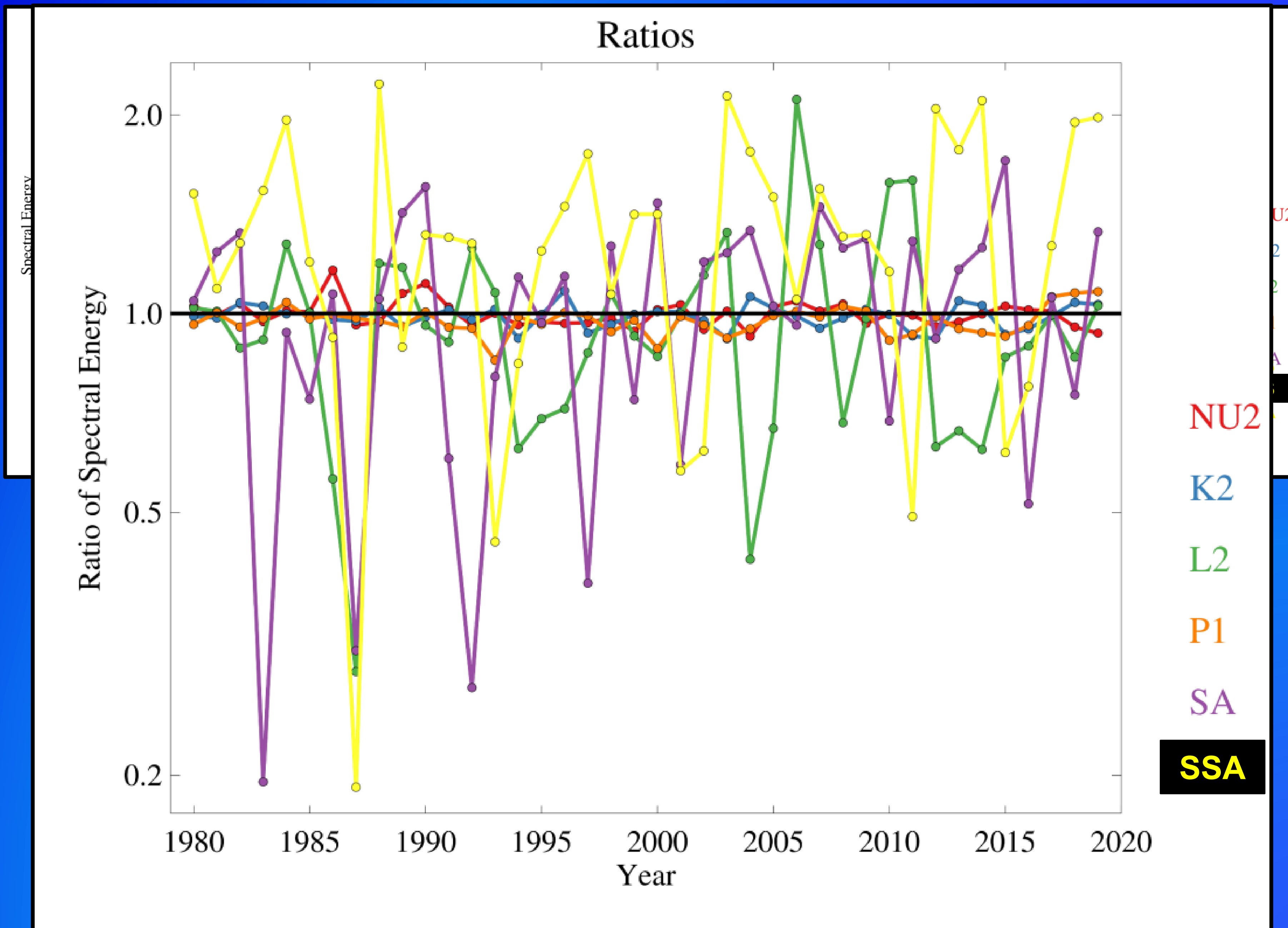

Summary and Recommendations

- Intercomparison results suggest broad agreement between analyses by Norway, Spain, and NOAA
- However, subtle and important differences were observed
- Norway, Spain, and NOAA use different constituents, and we recommend that IHO members consider working toward utilizing a standard set of constituents
- While predictions by Spain and NOAA are similar to each other, the mean absolute residuals were 7% and 14% lower in the predictions by Spain for Boston and Vardø, respectively.
- We recommend additional analysis and collaboration, and the modernization of the tidal prediction system at CO-OPS

Thank you!

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- Janet Culp
- Todd Ehret