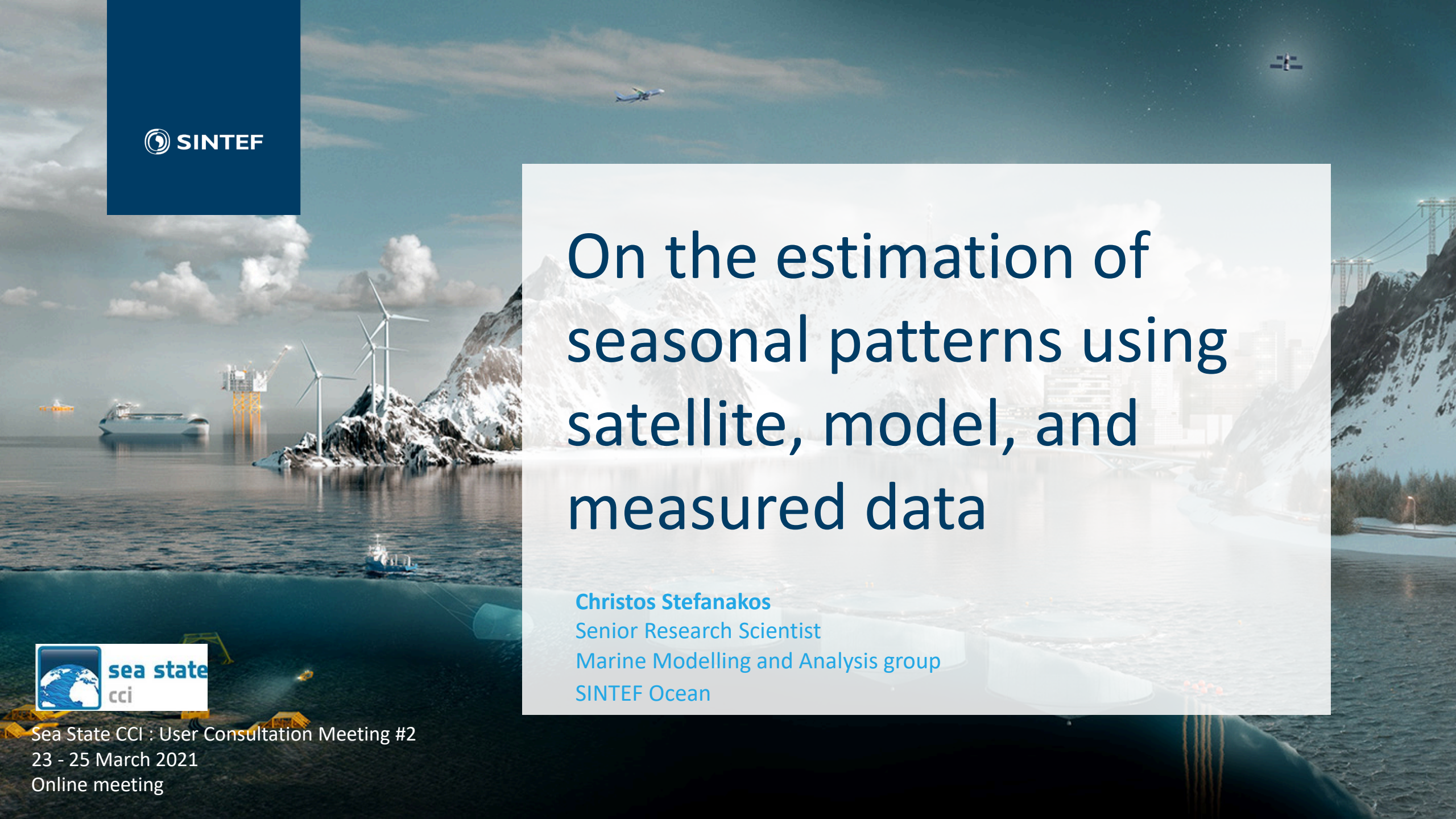


On the estimation of seasonal patterns using satellite, model, and measured data

Christos Stefanakos
Senior Research Scientist
Marine Modelling and Analysis group
SINTEF Ocean

Sea State CCI : User Consultation Meeting #2
23 - 25 March 2021
Online meeting

Sources of long-term wave data

- ***In situ* (buoy) measurements**

  Parameter(s): $S(f,\theta)$ or $\{H_S, T_p, \bar{\theta}, \ldots\}$

  Advantage(s): Accurate description of the local wave climate

  Disadvantage(s): Strongly site-dependent. Difficult to find large data sets for most sea areas

- **Model data**

  Parameter(s): $S(f,\theta)$ or $\{H_S, T_p, \bar{\theta}, \ldots\}$

  Advantage(s): Global coverage

  Disadvantage(s): Not very accurate in closed basins, or areas with complexes of islands

- **Satellite measurements**

  Parameter(s): $\{H_S, U_W, T_{alt}(?), \ldots\}$

  Advantage(s): Global coverage. Up-to-date measurements

  Disadvantage(s): Poor time resolution at any specific site.
  Not accurate data near the coast (as it leaves the land, entering the sea)

Nature of long-term data

- **Time series:** $\{X(\tau_i), \quad i = 1,2,\ldots I\}$

buoy, model data

- **Time-space series:** $\{X^{sat}(\tau_i, \chi_\ell), \quad i = 1(1)I, \quad \chi_\ell = 1(1)L_m\}$

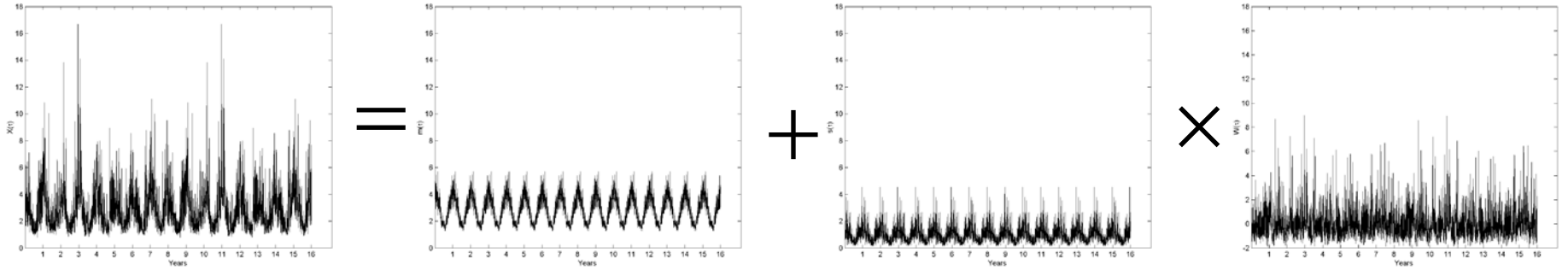
satellite data

Altimeter (*)	Repeat cycle (days)
GEOSAT, GFO	17.5
ERS-1, ERS-2, ENVISAT, SARAL/AltiKa	35
TOPEX/Poseidon, Jason-1, Jason-2	10
Cryosat-2	369

(*)
P. Cipollini, H. Snaith, A short course on Altimetry, 3rd ESA Advanced training on Ocean Remote Sensing, 23-27 September 2013, Cork, Ireland

Nonstationary time series modelling

1995, *J. Geophys. Res., Oceans*, 100(C8), 14149-14162
2006, *J. Geophys. Res., Oceans*, 111(C10), 10001–10012



$$X(\tau) = m(\tau) + s(\tau) \times W(\tau)$$

i. buoy
ii. model
iii. satellite

i. buoy
ii. model

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Estimation of seasonal patterns

i. buoy
ii. model

1. Re-indexing time series:

$$\{X(j,m,\tau_k),\quad j=1(1)J,\ m=1(1)12,\ k=1(1)K_m\}$$

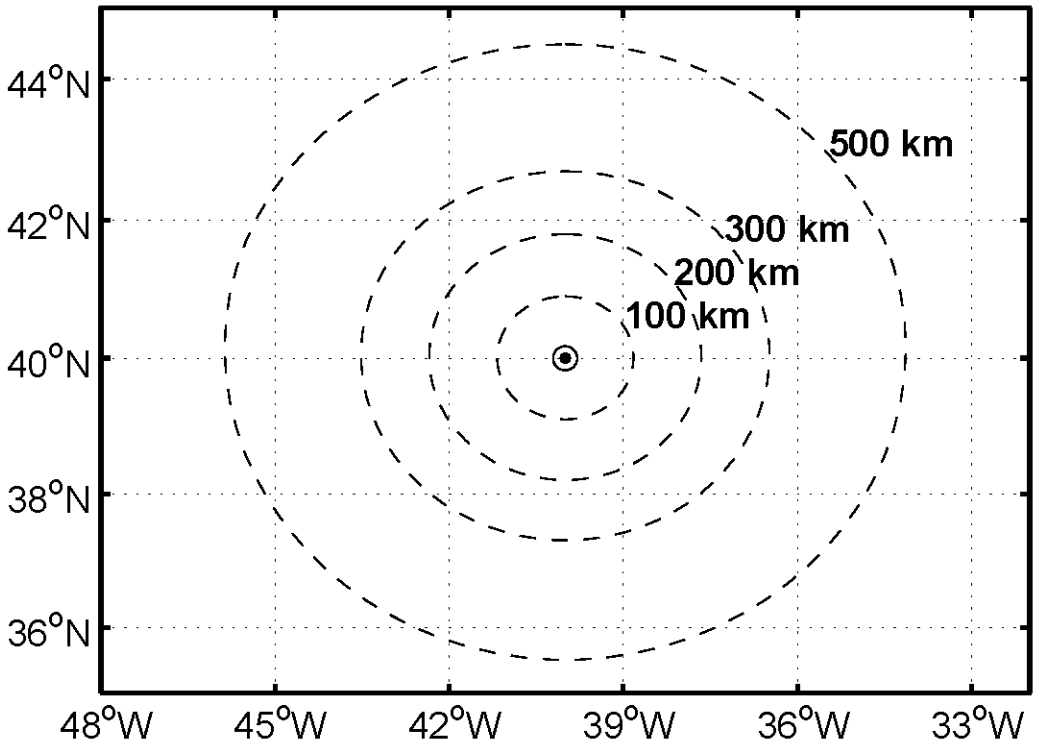
2. Monthly mean values and standard deviations:

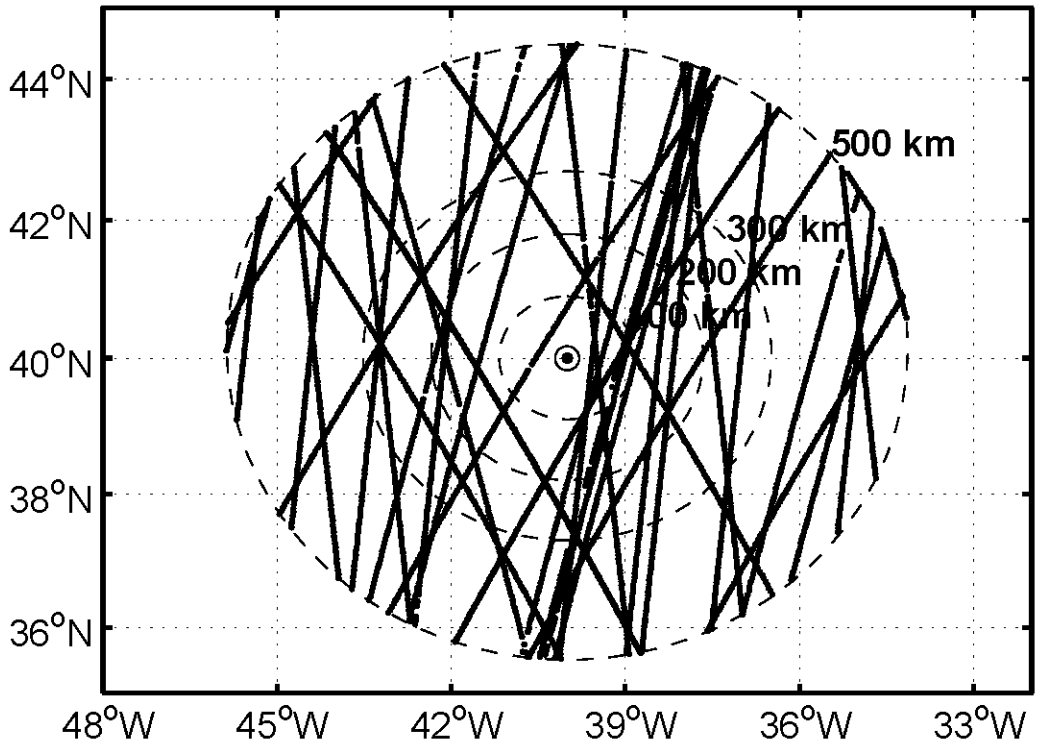
$$M_3(j,m)=\frac{1}{K_m}\sum_{k=1}^{K_m}X(j,m,\tau_k)\qquad S_3(j,m)=\sqrt{\frac{1}{K_m}\sum_{k=1}^{K_m}\left[X(j,m,\tau_k)-M_3(j,m)\right]^2}$$

3. Seasonal mean value and standard deviation:

$$\tilde{M}_3(m)=\frac{1}{J}\sum_{j=1}^{J}M_3(j,m)\qquad \tilde{S}_3(m)=\frac{1}{J}\sum_{j=1}^{J}S_3(j,m)$$

Estimation of seasonal patterns





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Estimation of seasonal patterns

iii. satellite

1. Re-indexing time series:

$$\left\{ X(\,j,m,\tau_k\,),\quad j=1(1)J\,,\ m=1(1)12,\ k=1(1)K_m \right\}$$

2. Monthly mean values and standard deviations:

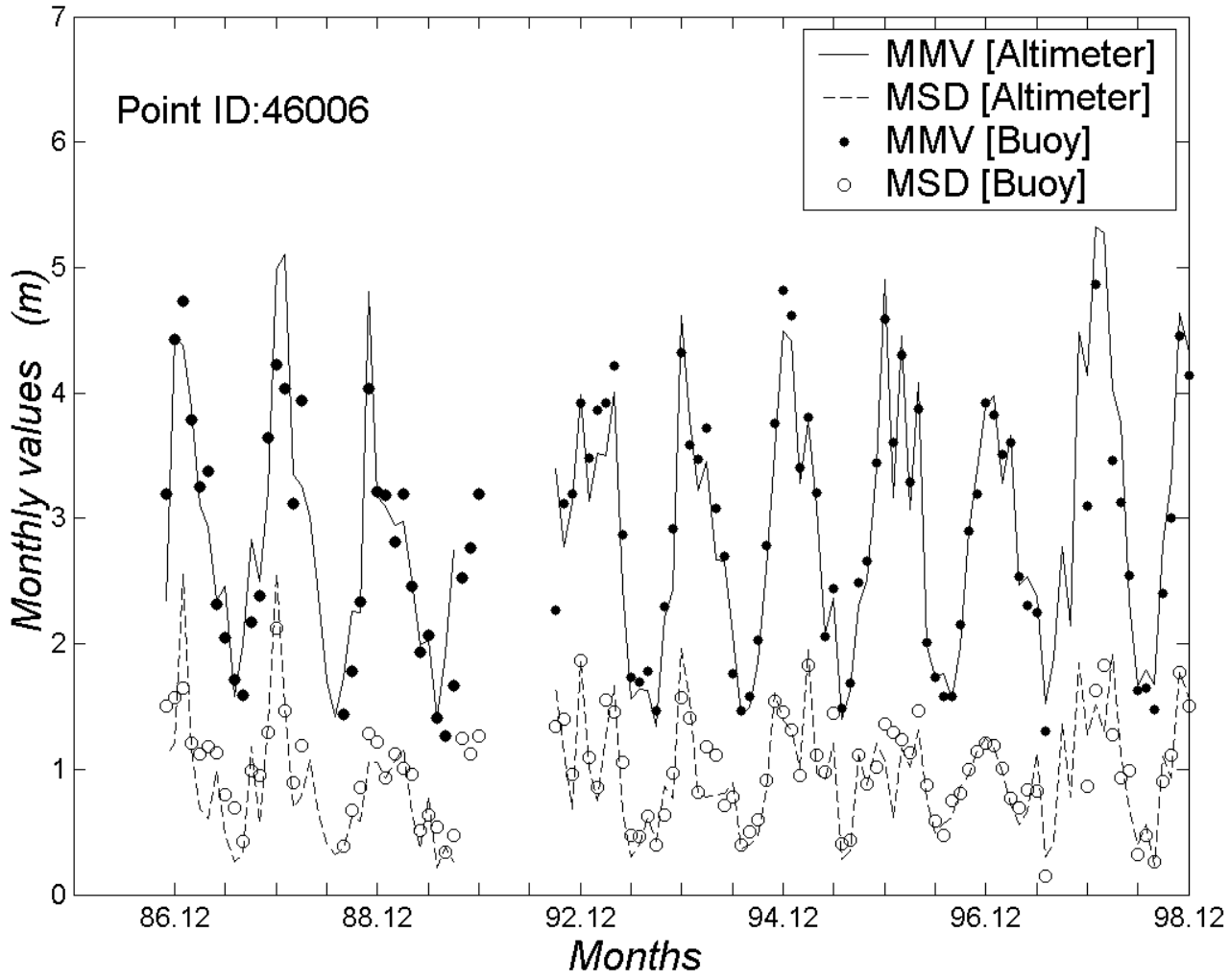
$$M_3^{sat}(\,j,m\,)=\frac{1}{L_m}\sum_{\ell=1}^{L_m} X^{\,sat}(\,j,m,\chi_\ell\,) \qquad S_3^{sat}(\,j,m\,)=\sqrt{\frac{1}{L_m}\sum_{\ell=1}^{L_m}\left[\,X^{\,sat}(\,j,m,\chi_\ell\,)-M_3^{sat}(\,j,m\,)\right]^2}$$

3. Seasonal mean value and standard deviation:

$$\tilde{M}_3^{sat}(\,m\,)=\frac{1}{J}\sum_{j=1}^{J} M_3^{sat}(\,j,m\,) \qquad \tilde{S}_3^{sat}(\,m\,)=\frac{1}{J}\sum_{j=1}^{J} S_3^{sat}(\,j,m\,)$$

Estimation of seasonal patterns

2. Monthly mean values (MMV) and monthly standard deviations (MSD):



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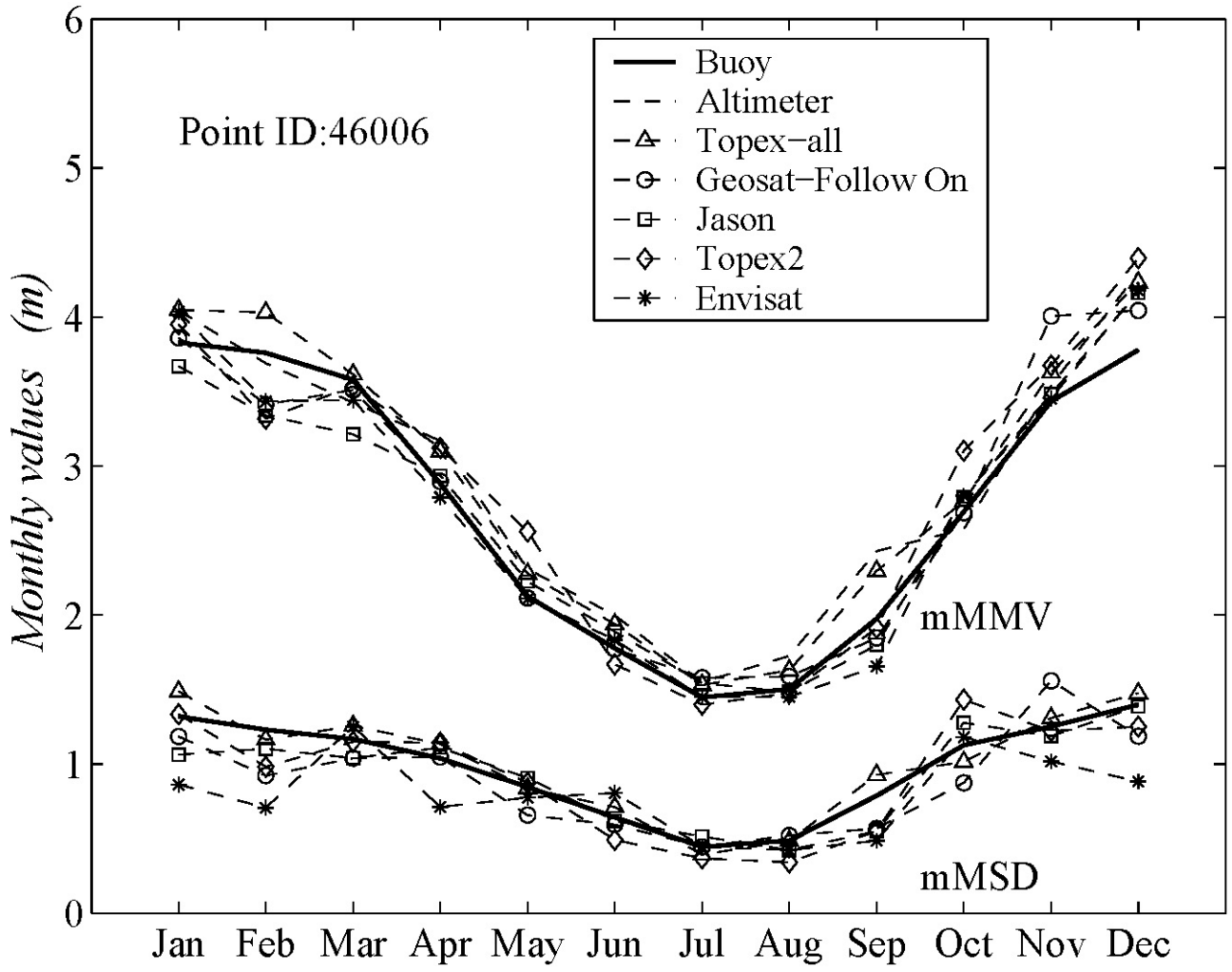
Estimation of seasonal patterns

3. Seasonal mean value (mMMV) and seasonal standard deviation (mMSD):



New analysis

Ch.N. Stefanakos, “Nonstationary time series forecasting of wind and waves, combining hindcast, measured and satellite data”, *International conference on Time Series and Forecasting, ITISE 2018*, Granada, Spain, September 19-21, pp. 1385-1405, 2018.

Ch.N. Stefanakos, “Intercomparison of Wave Reanalysis based on ERA5 and WW3 Databases”, *29th International Offshore and Polar Engineering Conference, ISOPE’2019*, Honolulu, Hawaii, USA, June 16–21, 2019.

Data set (satellite)

Global altimeter data set (February 2017), from the archive of IFREMER (partially coincides with L3 ESA Sea State Product) **.**

- The archive contains data from nine (9) altimeter missions: ERS-1,2, ENVISAT, TOPEX/Poseidon, Jason-1,2, GEOSAT-FO, Cryosat-2, SARAL.
- Comparisons with buoy data (Queffeulou 2003, 2004) showed:
  - Hs_alt in good agreement (stand.dev. of diff. ~0.30 m)
  - little overestimation of low values/underestimation of high values
  - Corrections to Hs (per satellite) have been established; see Queffeulou and Croizé-Fillon (2017)
- August 1991 - April 2017

Data sets (model)

Fields of **significant wave height** from 2 different models:

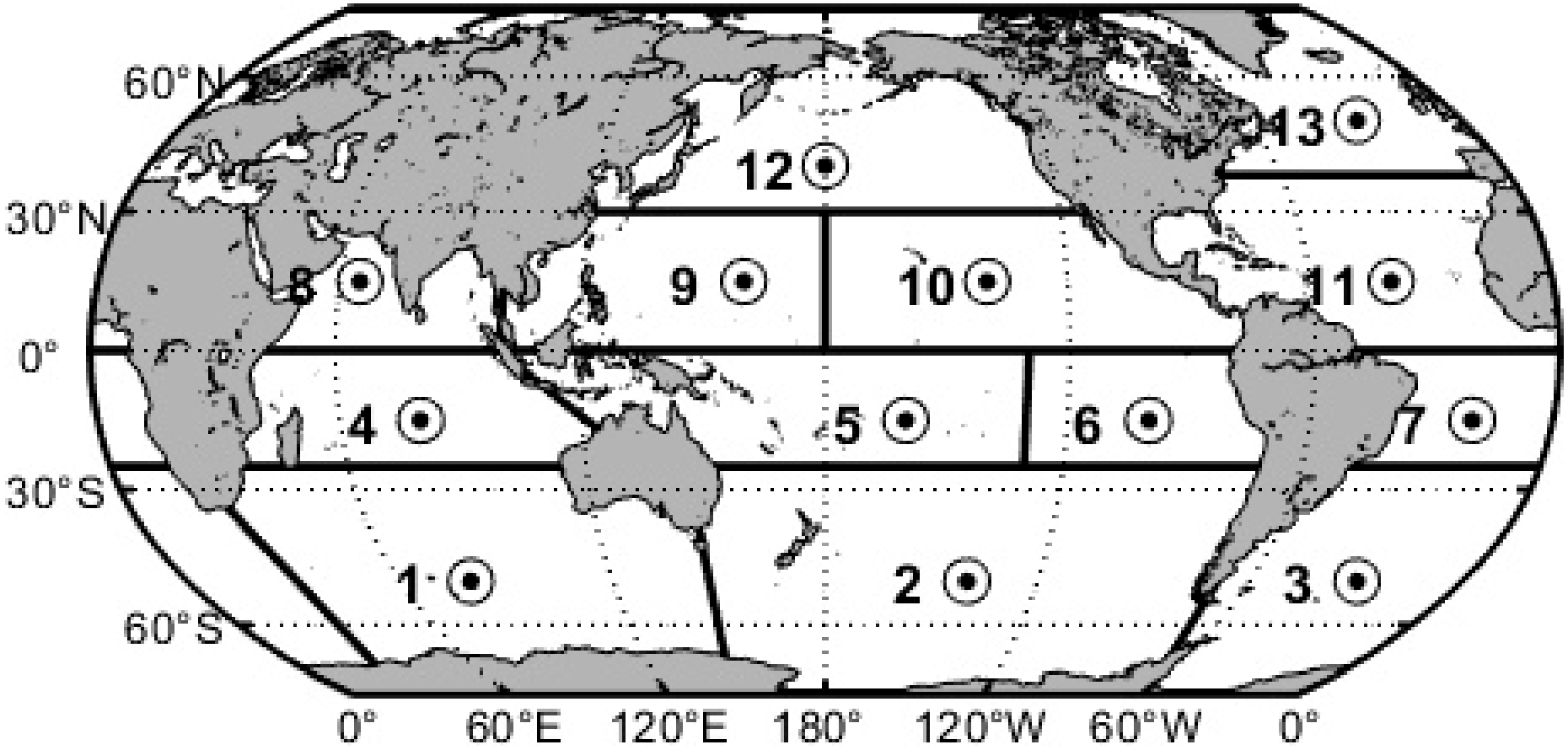
WW3: WAVEWATCH III wave model with NCEP/CFSR winds and ice fields as input forcing fields. No wave data assimilation

- 1979 – 2009 (30 years)
- 3-hourly intervals
- Lat: -90:0.5:90, Lon: 0:0.5:359.5
- **259 920** gridpoints (361 lat x 720 lon)

ERA5: 5th generation of ECMWF reanalyses, replacement for ERA-Interim wave reanalysis, newer assimilation system, higher resolution wind forcing

- 1979 – 2009 (30 years)
- hourly intervals
- Lat: -90:0.5:90, Lon: 0:0.5:359.5
- **259 920** gridpoints (361 lat x 720 lon)

Regional seasonality (points)



Alves, 2006, *Ocean Modelling*

Discrete non-overlapping subregions, such that the wave conditions within each of them to be similar.

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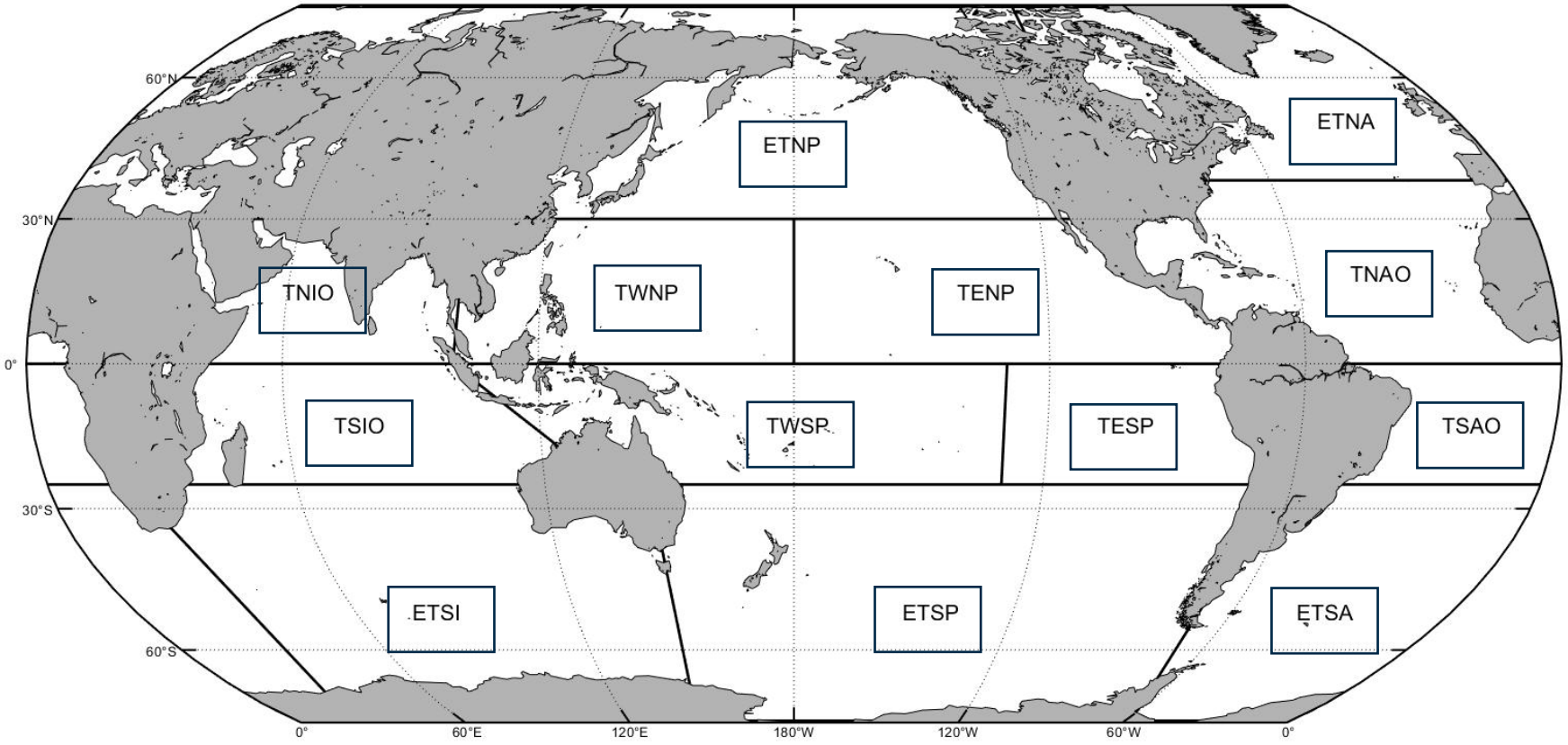
Regional seasonality (areas)



Alves, 2006, *Ocean Modelling*

Discrete non-overlapping subregions, such that the wave conditions within each of them to be similar.

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Error analysis (regions, MV)

	ETSI	ETSP	ETSA	TSIO	TWSP	TESP	TSAO	TNIO	TWNP	TENP	TNAO	ETNP	ETNA
Jan	1%	2%	3%	3%	9%	10%	2%	9%	7%	2%	5%	7%	15%
Feb	2%	3%	0%	0%	6%	8%	7%	4%	10%	0%	2%	5%	11%
Mar	1%	4%	4%	0%	5%	8%	9%	4%	18%	1%	8%	10%	15%
Apr	0%	0%	3%	5%	4%	4%	5%	14%	15%	5%	11%	19%	25%
May	4%	3%	2%	7%	4%	7%	4%	22%	10%	0%	7%	12%	14%
Jun	2%	1%	4%	7%	2%	8%	2%	16%	0%	5%	6%	6%	23%
Jul	5%	1%	4%	5%	1%	2%	4%	8%	1%	5%	3%	4%	21%
Aug	6%	0%	6%	8%	6%	2%	1%	19%	6%	1%	2%	5%	9%
Sep	5%	7%	9%	5%	7%	2%	2%	25%	2%	2%	1%	8%	3%
Oct	12%	9%	3%	8%	13%	1%	0%	17%	4%	5%	1%	3%	1%
Nov	9%	10%	5%	2%	7%	2%	1%	2%	0%	7%	1%	4%	6%
Dec	5%	7%	10%	1%	1%	3%	1%	3%	1%	4%	3%	0%	7%

	11-20%
	21-30%

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Error analysis (points, MV)

	ETSI	ETSP	ETSA	TSIO	TWSP	TESP	TSAO	TNIO	TWNP	TENP	TNAO	ETNP	ETNA
Jan	1-7%	5-7%	9-21%	1-10%	3-13%	4-7%	0-6%	10-14%	0-12%	2-8%	5-8%	6-12%	17-25%
Feb	1-3%	8-10%	5-9%	0-6%	3-12%	2-6%	2-6%	0-28%	1-4%	2-11%	1-9%	1-4%	1-9%
Mar	0-4%	2-9%	6-9%	2-10%	2-11%	4-12%	4-14%	1-7%	9-15%	1-3%	5-16%	12-24%	8-18%
Apr	7-11%	12-18%	5-7%	0-9%	1-10%	0-4%	1-3%	10-17%	10-22%	1-6%	5-17%	10-14%	12-14%
May	0-4%	2-9%	11-26%	2-4%	8-27%	1-3%	2-6%	31-35%	17-24%	2-5%	2-5%	3-8%	11-20%
Jun	9-12%	0-6%	5-9%	0-4%	1-6%	3-11%	2-8%	31-40%	0-6%	0-2%	2-5%	10-15%	18-25%
Jul	3-11%	2-7%	1-8%	8-11%	1-4%	8-14%	0-19%	14-18%	12-27%	4-17%	9-14%	1-11%	10-20%
Aug	5-13%	0-5%	12-14%	6-10%	4-7%	7-15%	3-11%	20-28%	2-8%	8-14%	0-4%	1-9%	2-7%
Sep	11-16%	2-7%	5-7%	6-22%	6-11%	0-9%	1-5%	35-50%	1-3%	2-12%	0-5%	17-17%	1-7%
Oct	17-22%	9-22%	3-15%	0-8%	14-16%	9-25%	0-3%	15-31%	4-9%	1-8%	1-8%	7-18%	2-2%
Nov	16-24%	1-6%	3-12%	0-11%	0-7%	1-5%	2-4%	2-7%	0-10%	3-5%	4-9%	5-12%	1-12%
Dec	1-5%	17-25%	9-11%	6-18%	1-2%	1-5%	3-7%	5-11%	1-2%	4-8%	5-11%	1-3%	1-2%

	11-20%
	21-30%
	31-40%
	41-50%

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Error analysis (regions, SD)

	ETSI	ETSP	ETSA	TSIO	TWSP	TESP	TSAO	TNIO	TWNP	TENP	TNAO	ETNP	ETNA
Jan	1%	2%	3%	3%	9%	10%	2%	9%	7%	2%	5%	7%	15%
Feb	2%	3%	0%	0%	6%	8%	7%	4%	10%	0%	2%	5%	11%
Mar	1%	4%	4%	0%	5%	8%	9%	4%	18%	1%	8%	10%	15%
Apr	0%	0%	3%	5%	4%	4%	5%	14%	15%	5%	11%	19%	25%
May	4%	3%	2%	7%	4%	7%	4%	22%	10%	0%	7%	12%	14%
Jun	2%	1%	4%	7%	2%	8%	2%	16%	0%	5%	6%	6%	23%
Jul	5%	1%	4%	5%	1%	2%	4%	8%	1%	5%	3%	4%	21%
Aug	6%	0%	6%	8%	6%	2%	1%	19%	6%	1%	2%	5%	9%
Sep	5%	7%	9%	5%	7%	2%	2%	25%	2%	2%	1%	8%	3%
Oct	12%	9%	3%	8%	13%	1%	0%	17%	4%	5%	1%	3%	1%
Nov	9%	10%	5%	2%	7%	2%	1%	2%	0%	7%	1%	4%	6%
Dec	5%	7%	10%	1%	1%	3%	1%	3%	1%	4%	3%	0%	7%

	11-20%
	21-30%

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Error analysis (points, SD)

	ETSI	ETSP	ETSA	TSIO	TWSP	TESP	TSAO	TNIO	TWNP	TENP	TNAO	ETNP	ETNA
Jan	46-77%	48-82%	33-76%	16-44%	14-27%	39-55%	28-49%	1-60%	47-71%	53-66%	43-61%	46-80%	42-77%
Feb	45-76%	50-78%	39-73%	36-65%	35-51%	33-41%	35-63%	9-30%	46-61%	40-58%	46-67%	51-81%	38-80%
Mar	45-70%	53-82%	42-74%	24-55%	31-55%	38-52%	35-48%	6-28%	35-66%	47-64%	46-62%	52-74%	45-70%
Apr	40-73%	36-75%	33-74%	38-62%	24-52%	35-53%	50-63%	2-42%	26-52%	44-66%	47-56%	50-78%	53-75%
May	46-70%	48-74%	42-73%	48-66%	27-55%	43-64%	45-72%	52-65%	33-58%	28-52%	26-40%	40-76%	39-63%
Jun	37-73%	50-79%	41-78%	55-73%	39-61%	48-72%	34-66%	61-77%	10-30%	28-59%	24-49%	38-69%	34-77%
Jul	35-76%	52-79%	48-77%	55-70%	42-61%	49-60%	47-68%	39-68%	21-43%	33-50%	21-36%	42-68%	36-72%
Aug	41-70%	49-79%	32-75%	47-67%	36-66%	57-68%	45-69%	30-67%	26-48%	9-25%	31-50%	45-65%	41-77%
Sep	40-70%	41-81%	43-81%	44-61%	26-65%	45-66%	38-66%	39-66%	22-53%	3-46%	23-57%	62-82%	56-75%
Oct	38-75%	40-71%	50-77%	36-66%	25-58%	43-61%	41-67%	4-35%	34-65%	32-57%	32-57%	58-84%	43-80%
Nov	31-64%	43-79%	42-79%	47-68%	15-32%	37-52%	37-59%	17-46%	24-61%	47-68%	43-60%	39-75%	41-77%
Dec	41-76%	45-77%	45-69%	31-50%	30-55%	39-57%	43-60%	11-59%	41-68%	45-62%	53-72%	52-82%	48-81%

	11-20%
	21-30%
	31-40%
	41-50%
	51-60%
	61-70%
	71-80%
	>80%

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Conclusions

- Satellite altimeter data can be considered as a good substitute for the estimation of wave characteristics evolving in slower time scales (months, years,…)
- A homogenized altimeter dataset from the archives of IFREMER (partially coinciding with L3 ESA Sea State Product) has been used for the analysis.
- 13 points/regions (non-overlapping with similar wave conditions) around the globe have been studied.
- Results for the subregions are in good accordance with 2 long-term wave reanalyses (ERA5 and WaveWatch III).
- Results for the points are acceptable for monthly mean values, but very bad for the monthly standard deviations.
- The latter issue should be further investigated.


Questions?

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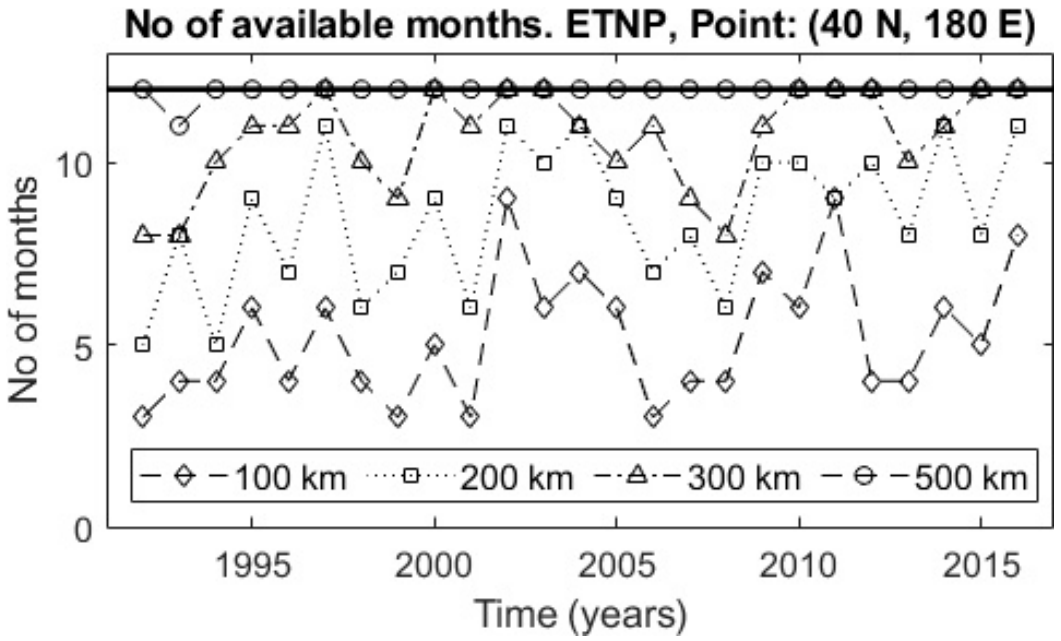
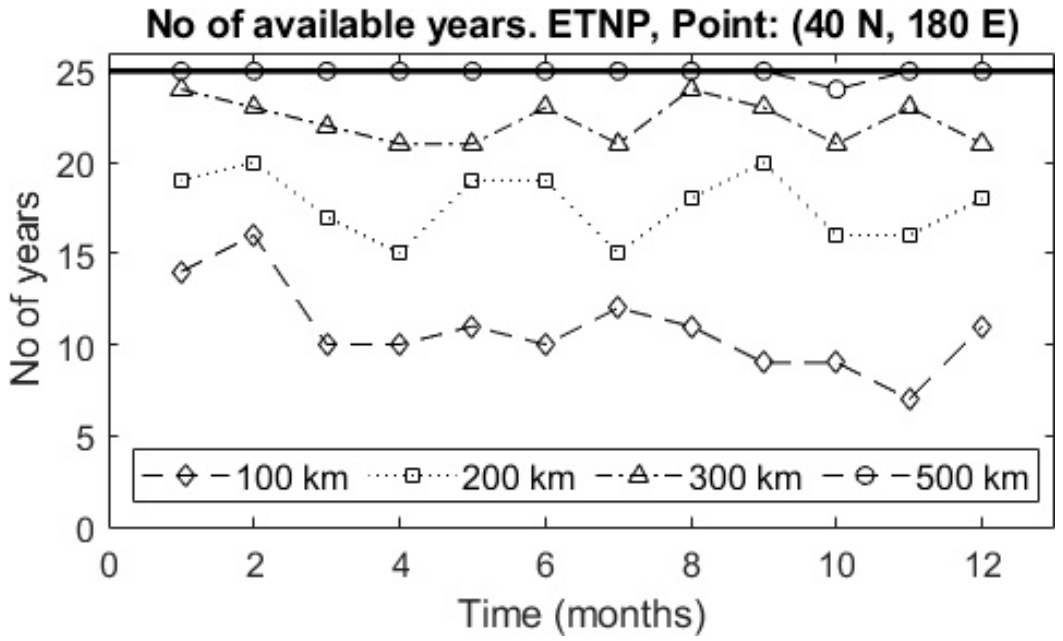
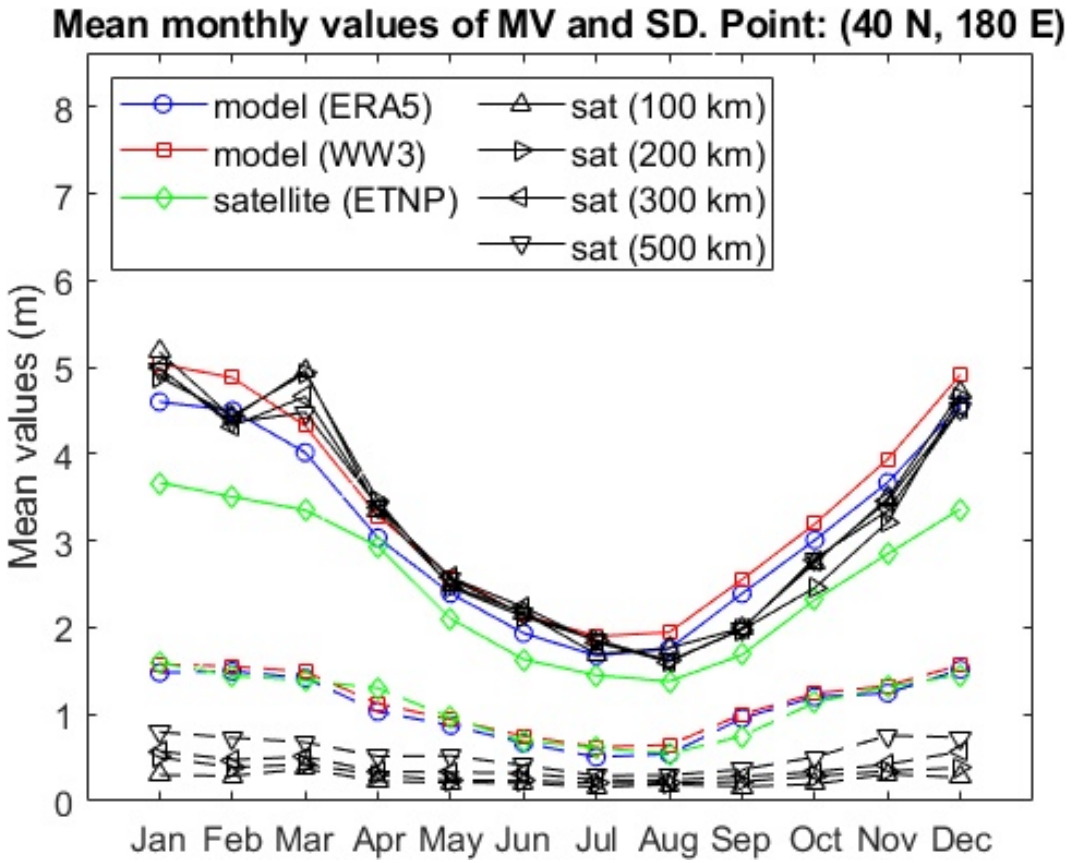
Teknologi for et bedre samfunn

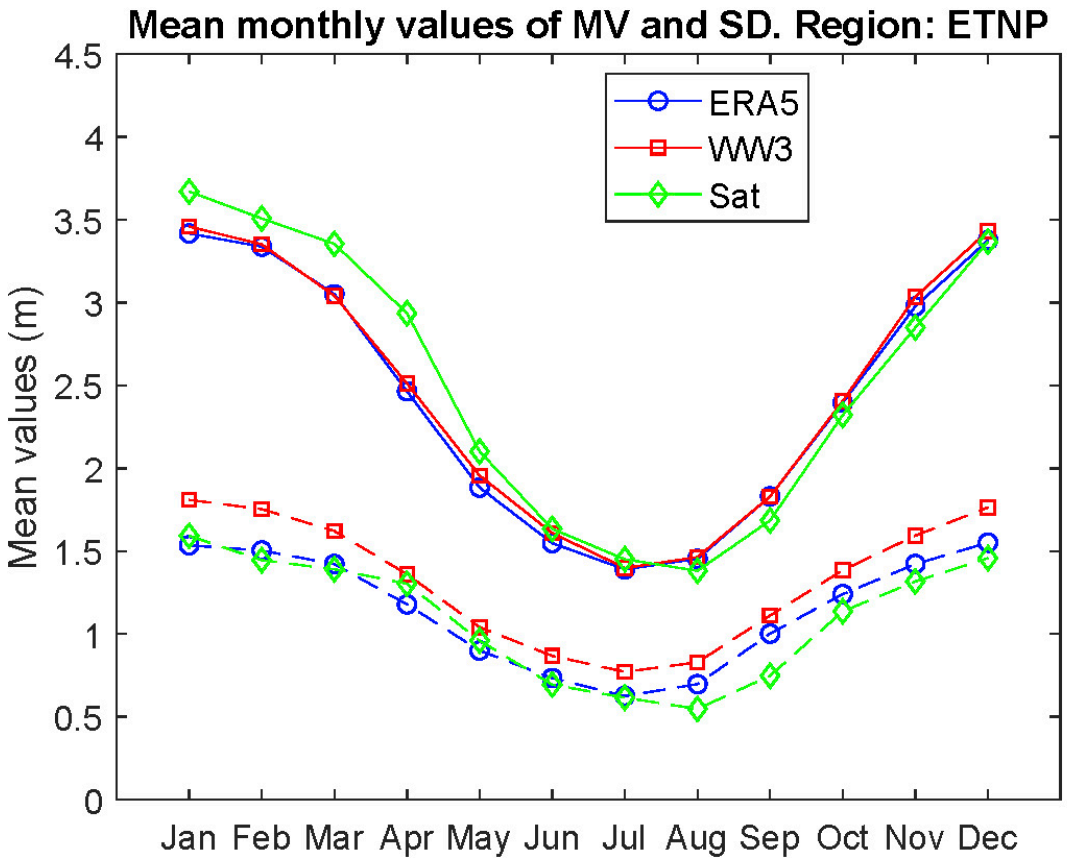
Regional seasonality (availability, ETNP)





Regional seasonality (points, ETNP)





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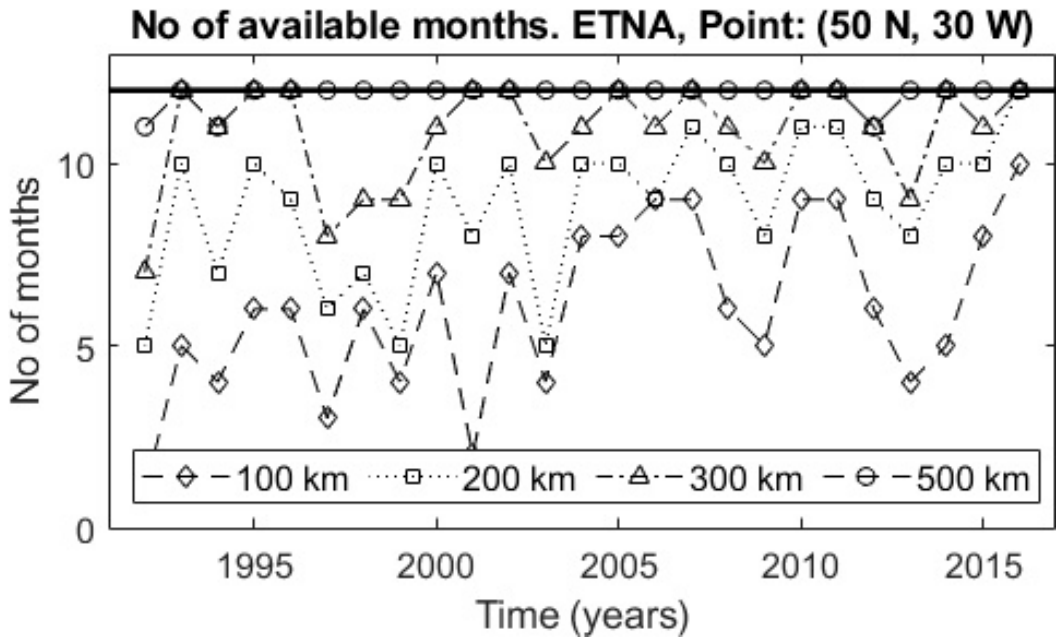
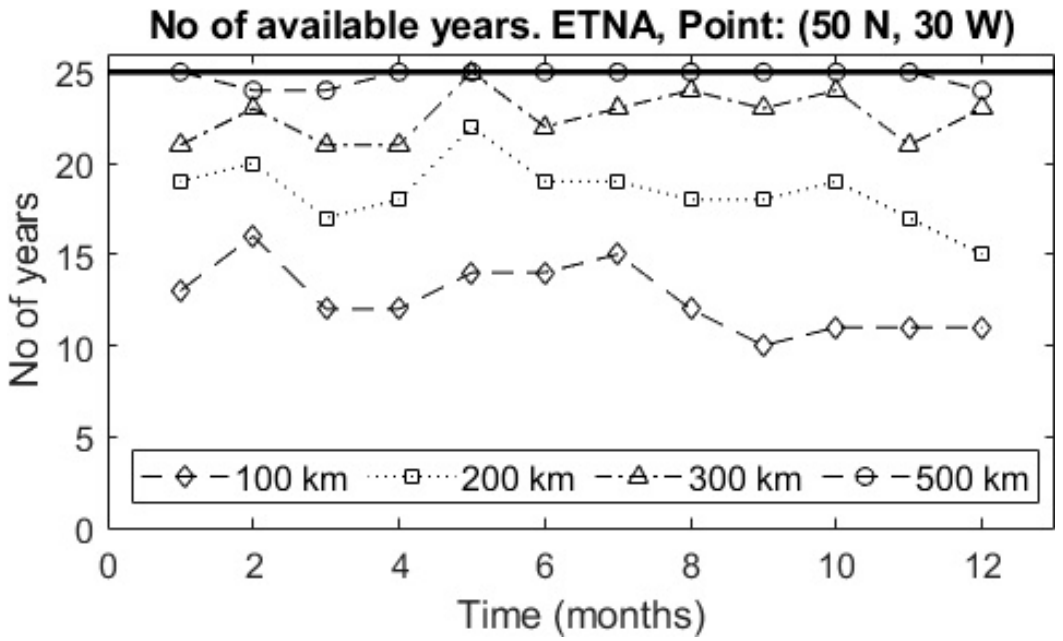
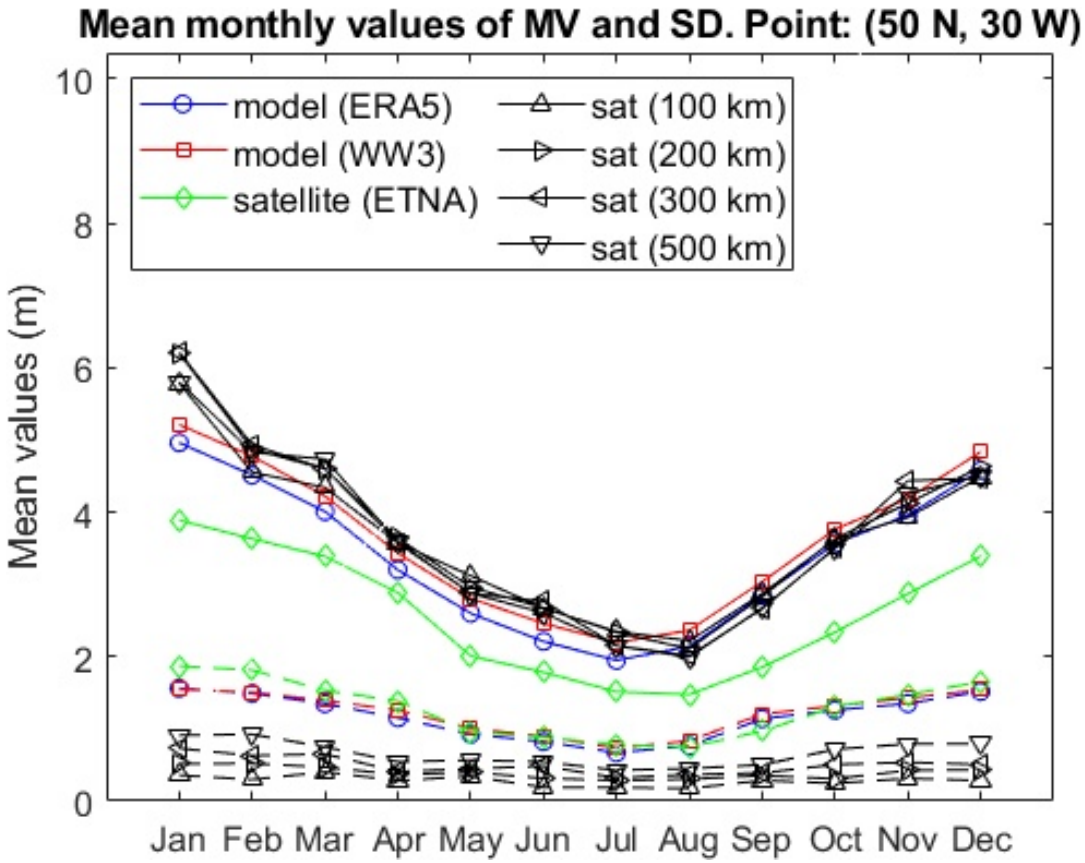
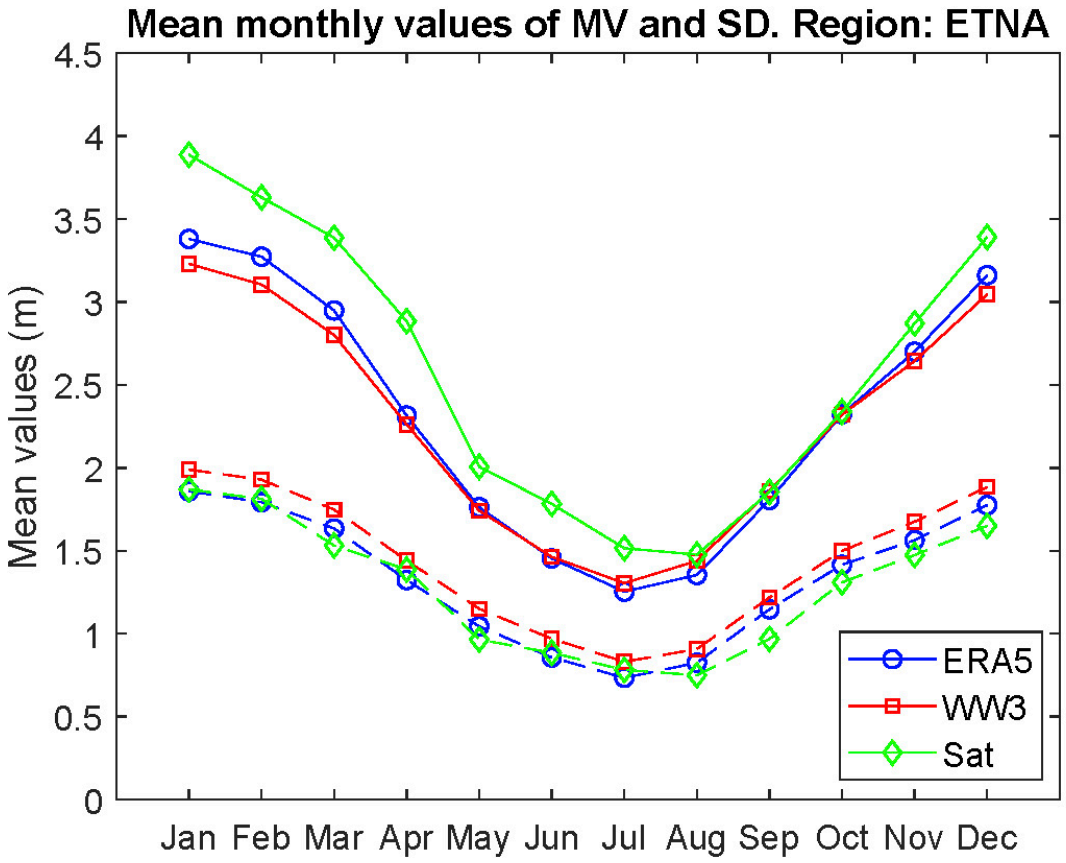
Regional seasonality (availability, ETNA)



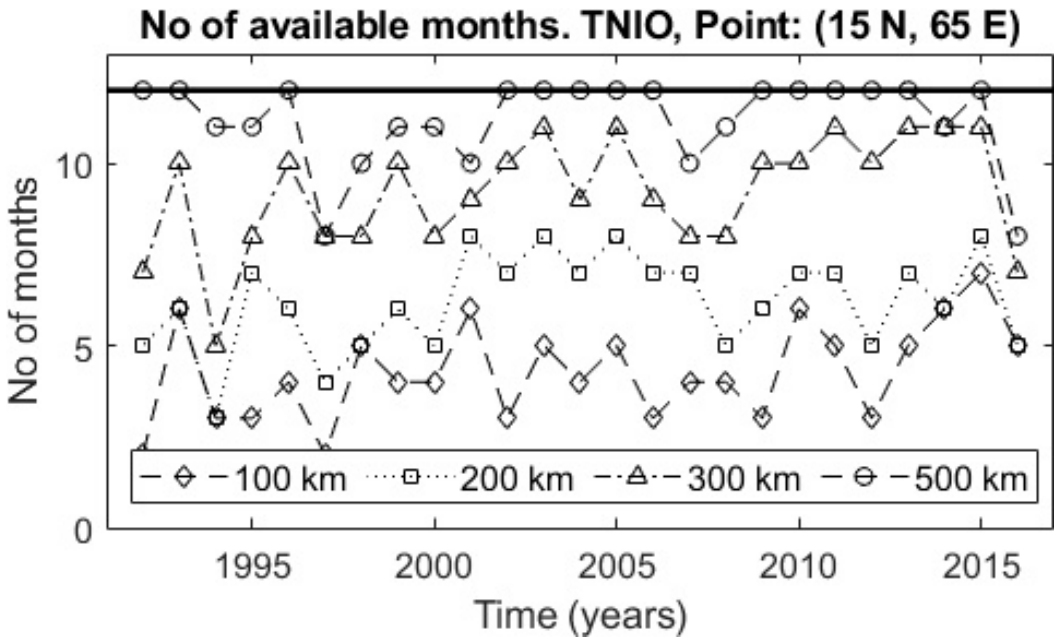


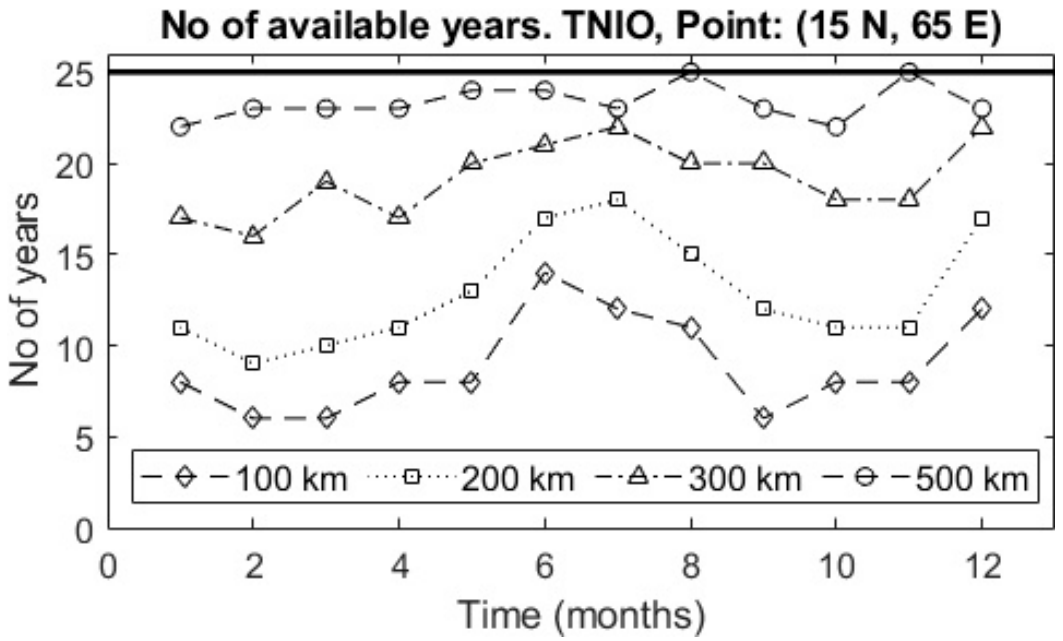
Regional seasonality (points, ETNA)



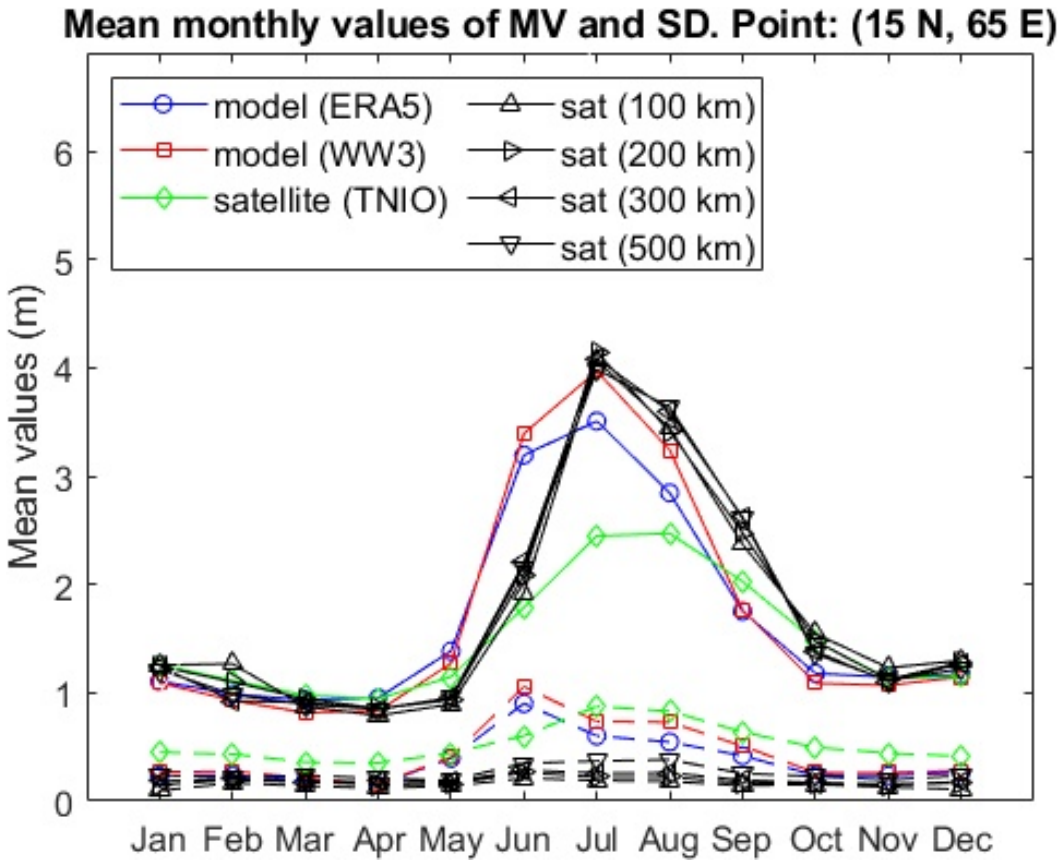


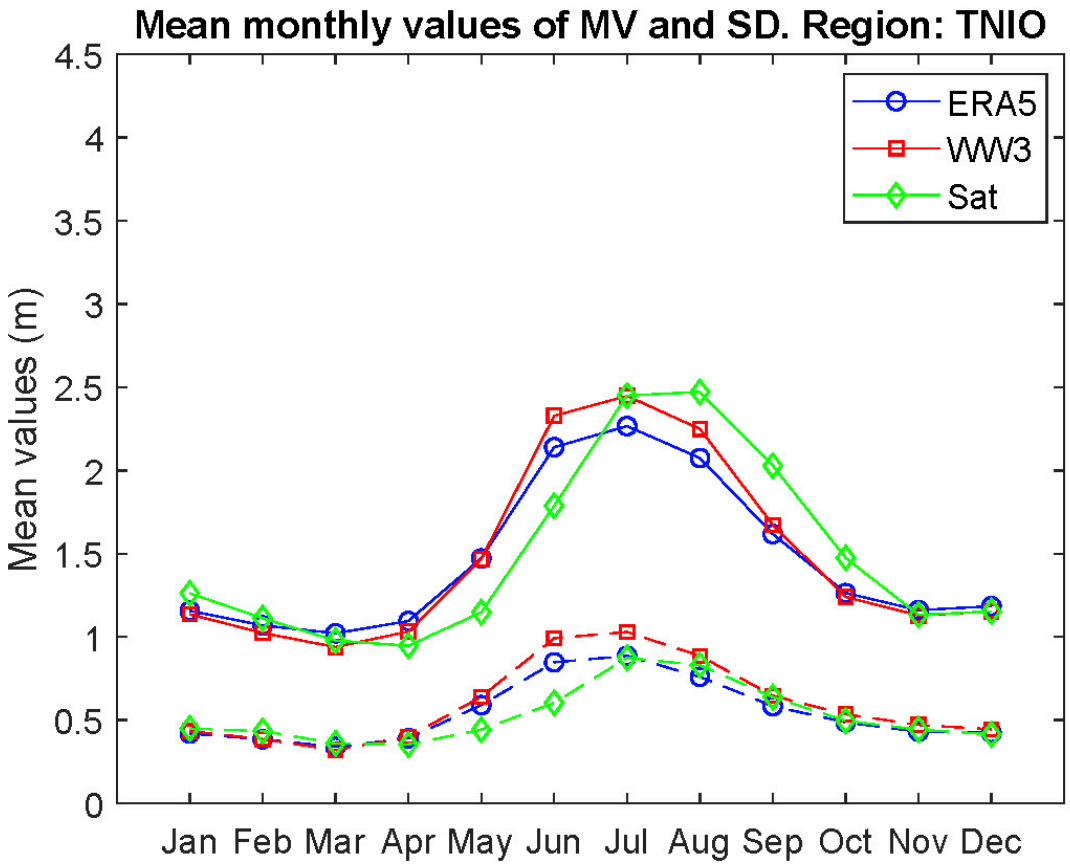
Regional seasonality (availability, TNIO)



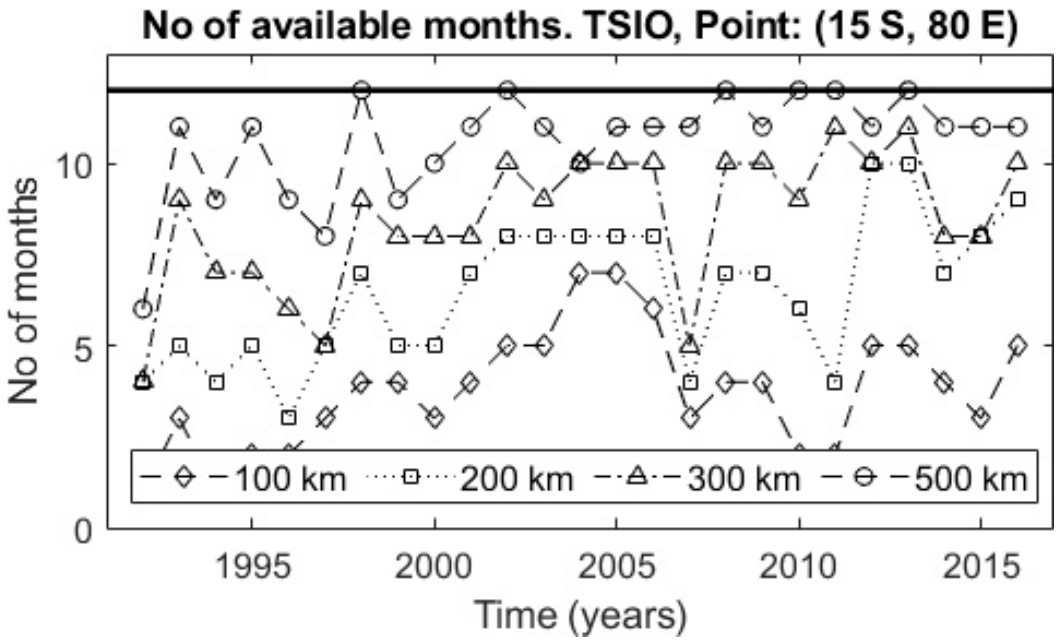


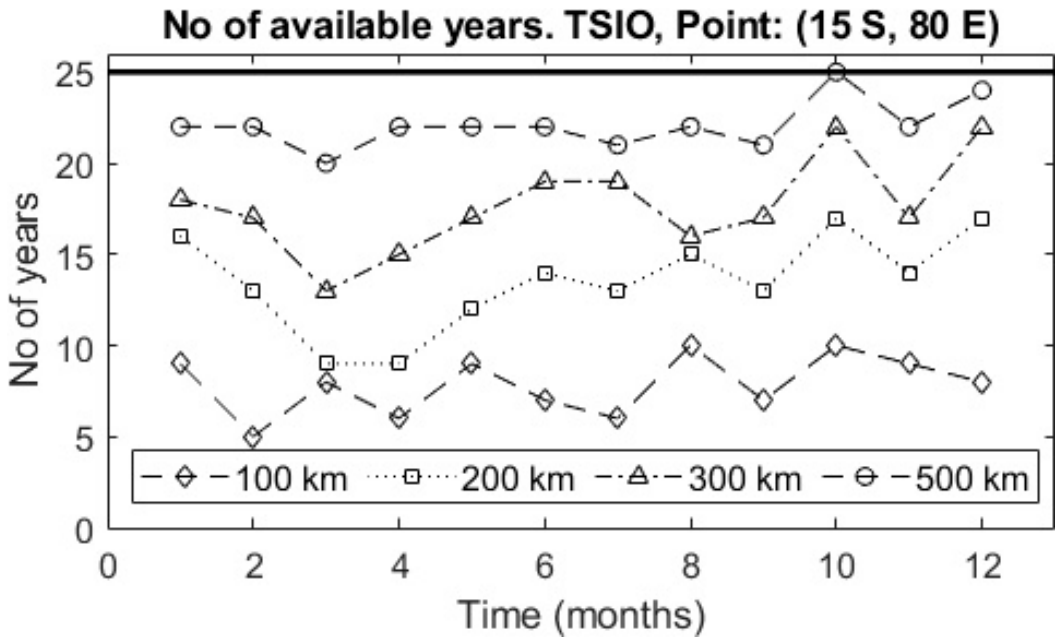
Regional seasonality (points, TNIO)



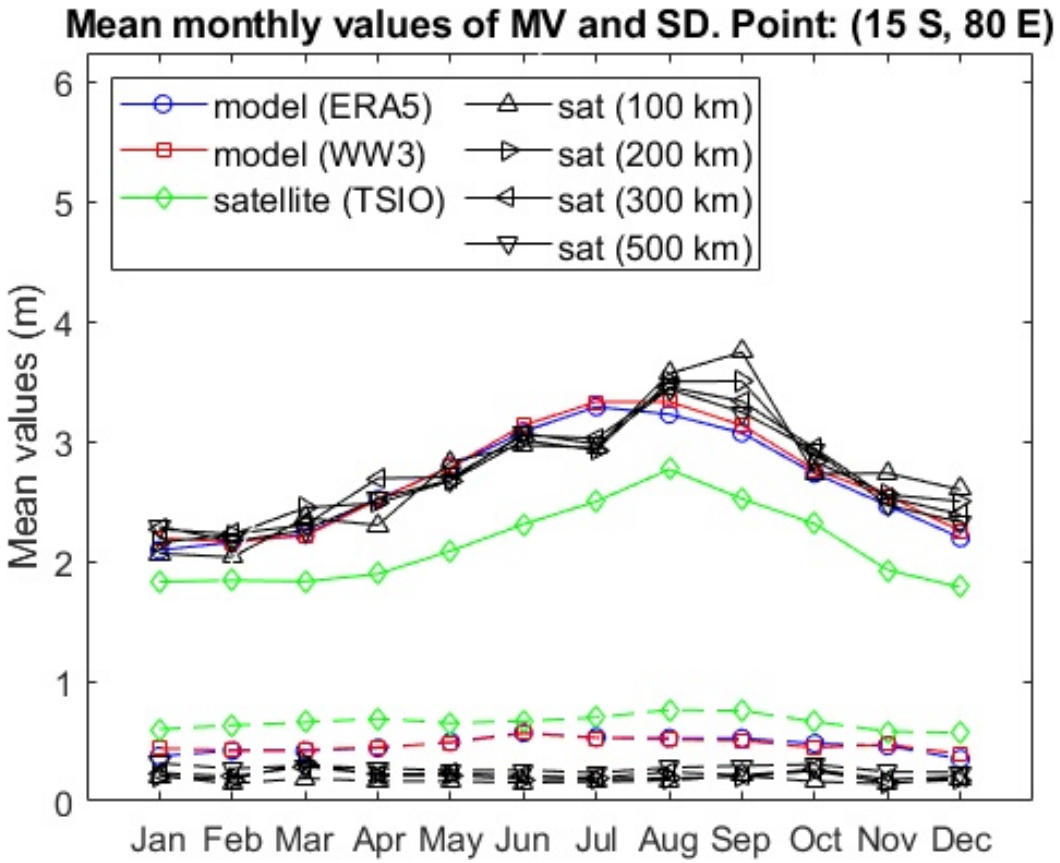


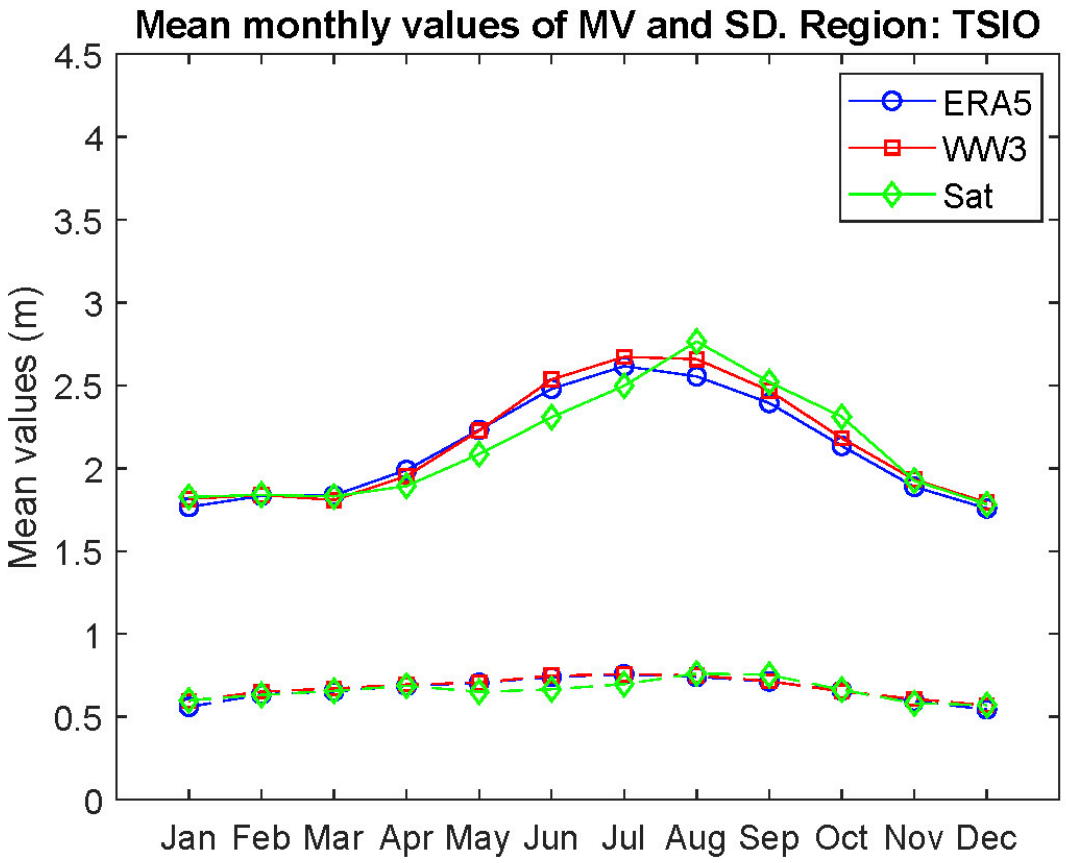
Regional seasonality (availability, TSIO)





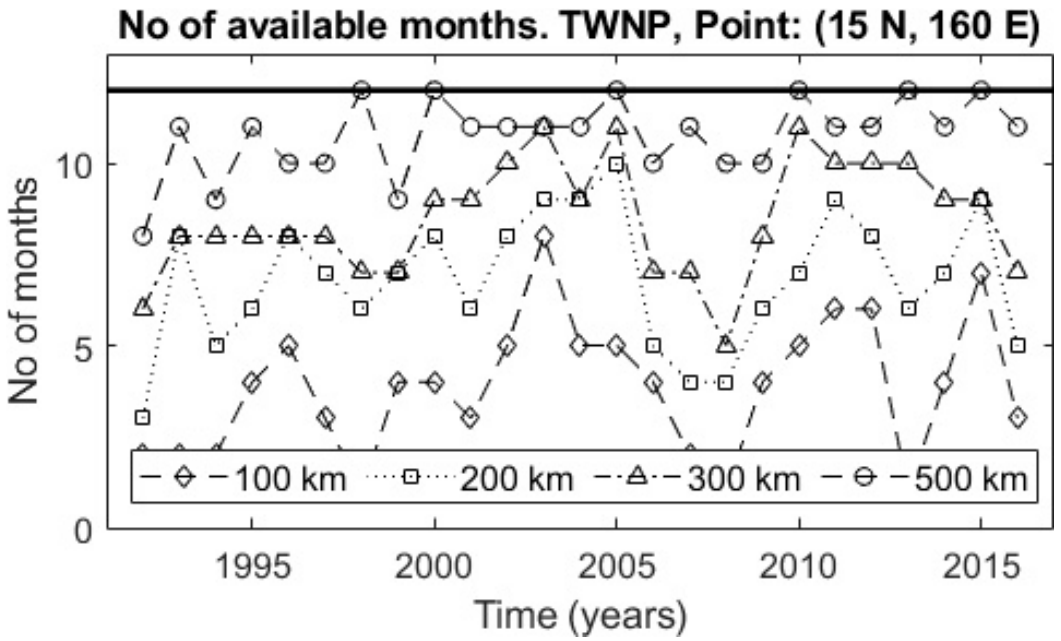
Regional seasonality (points, TSIO)

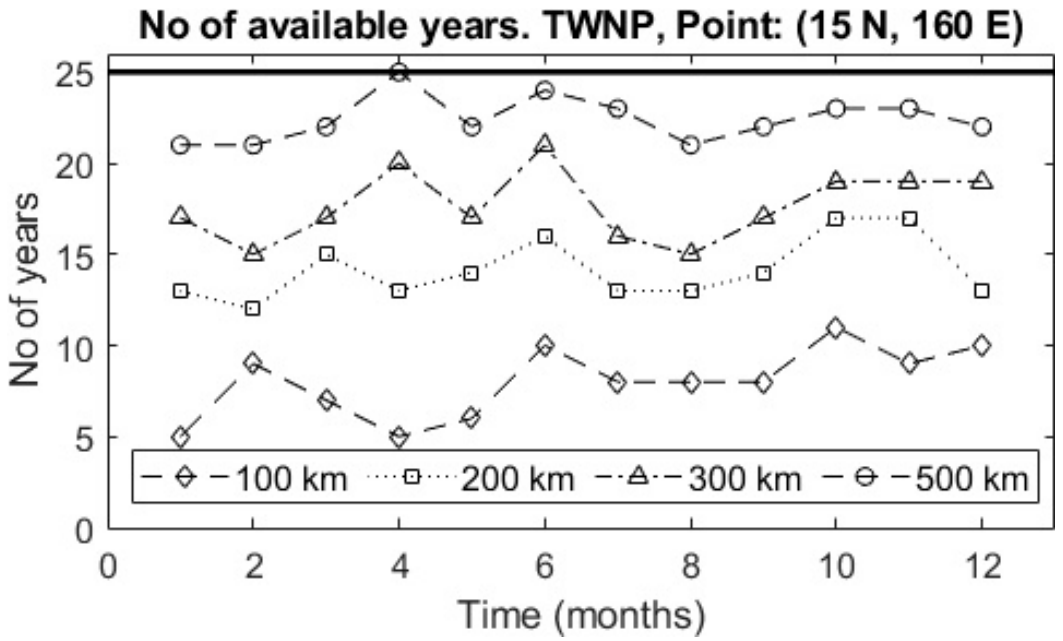




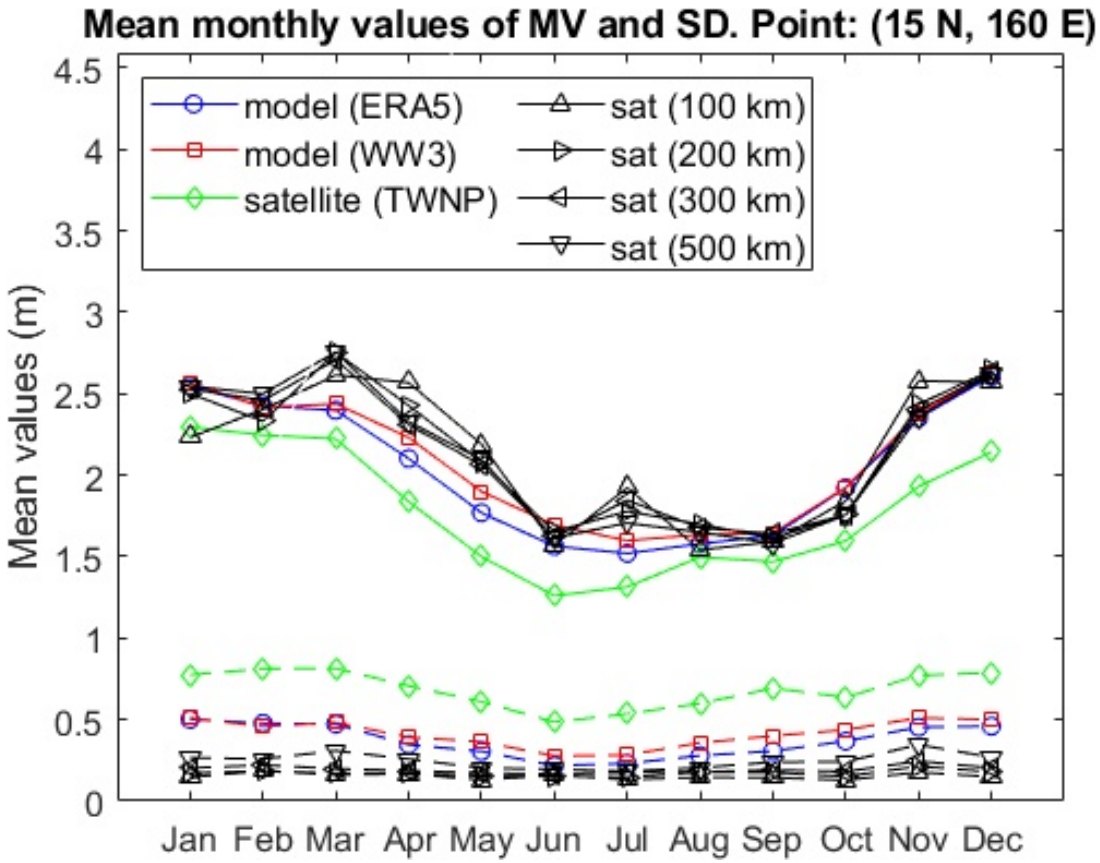
SINTEF

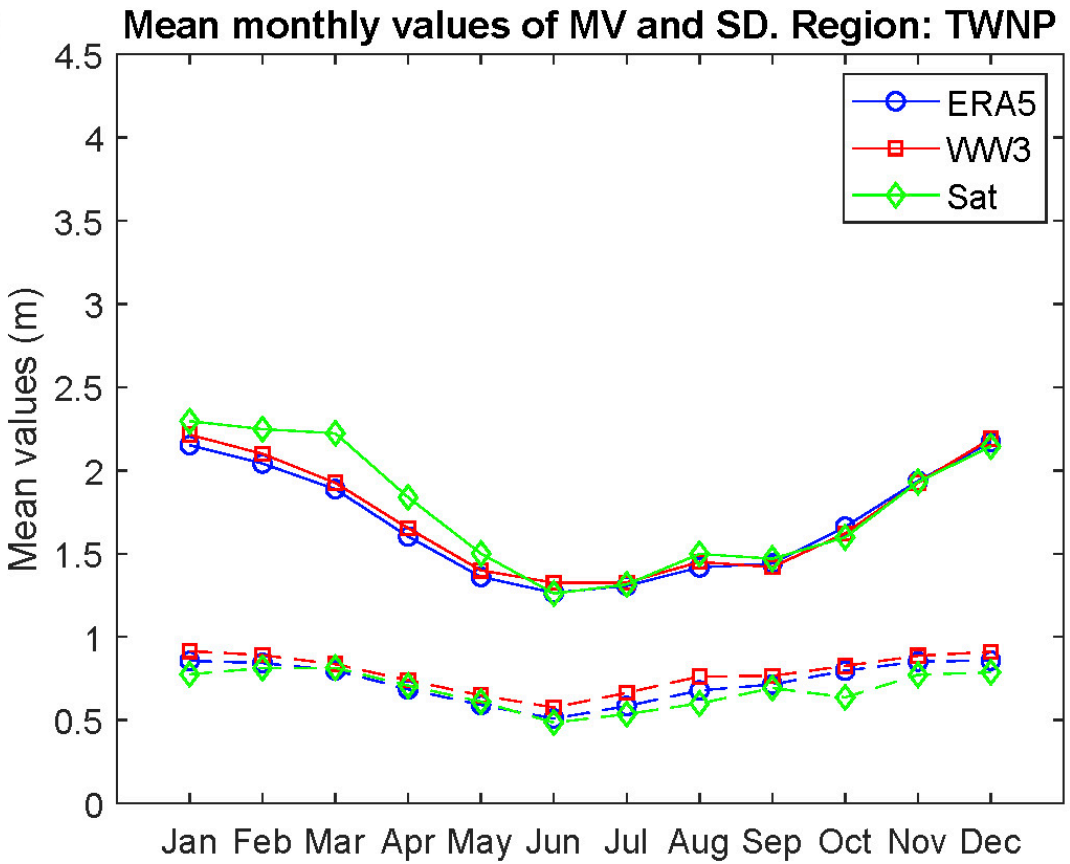
Regional seasonality (availability, TWNP)



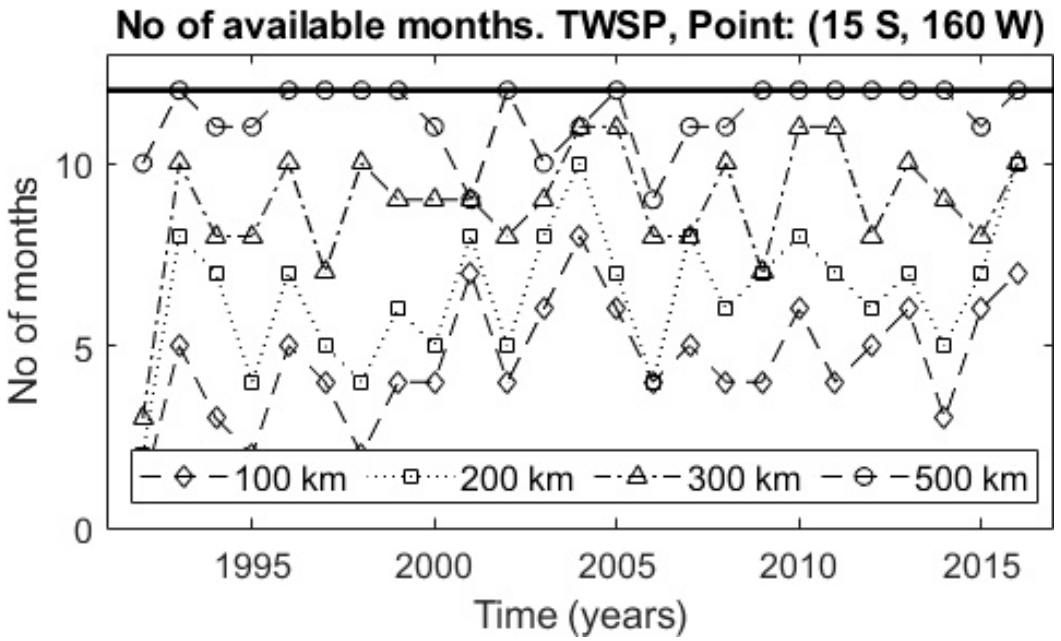


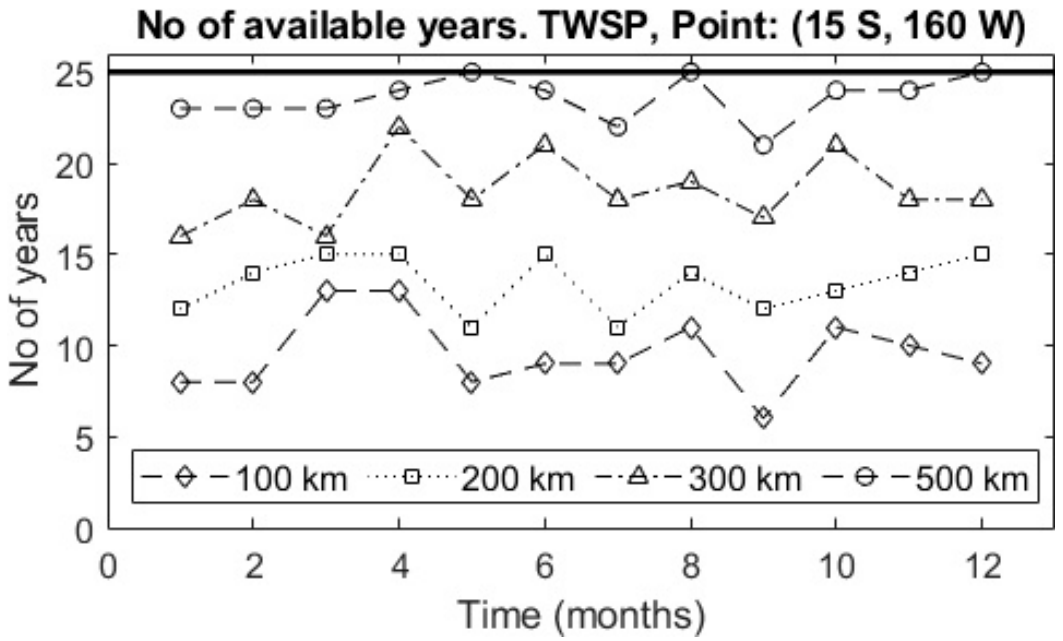
Regional seasonality (points, TWNP)



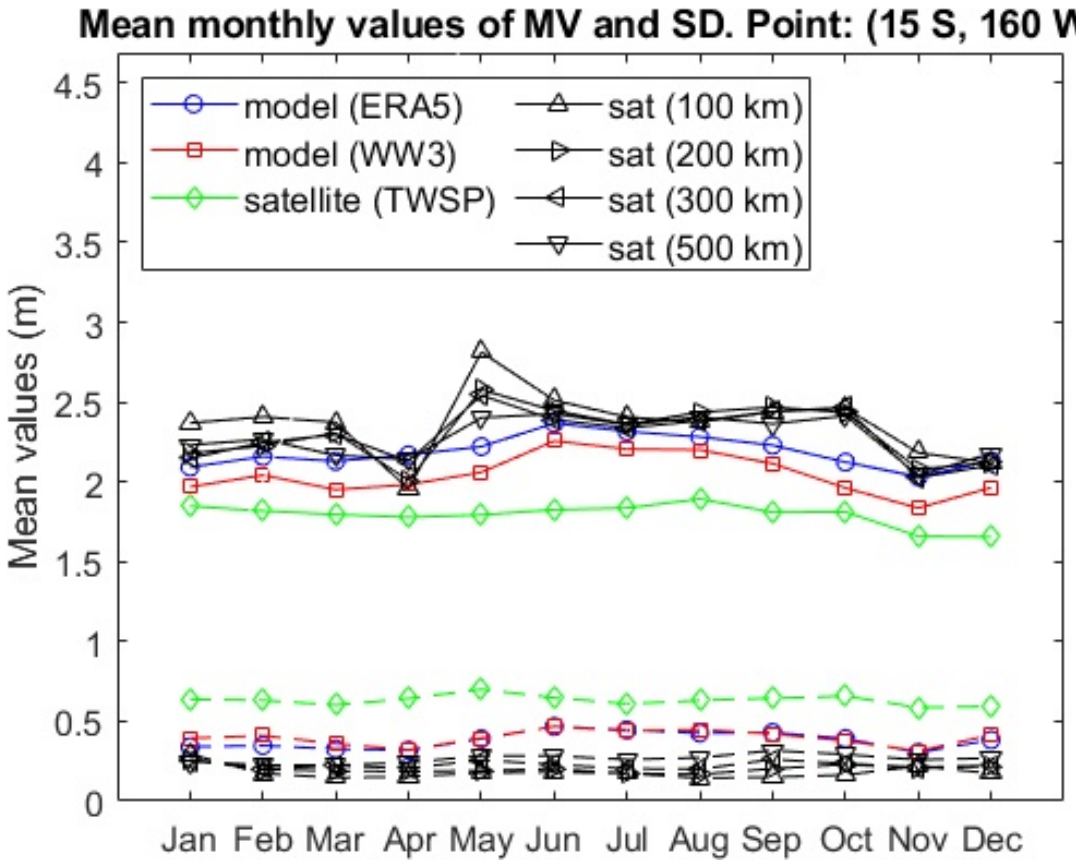


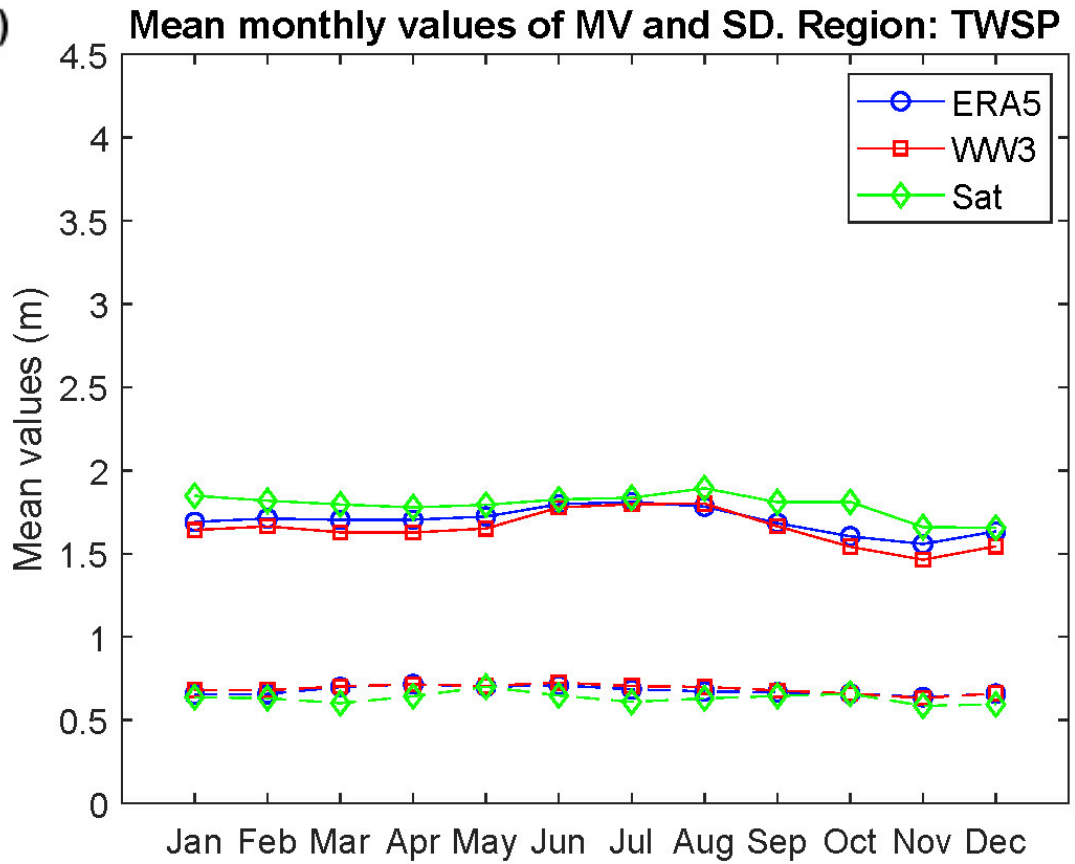
Regional seasonality (availability, TWSP)



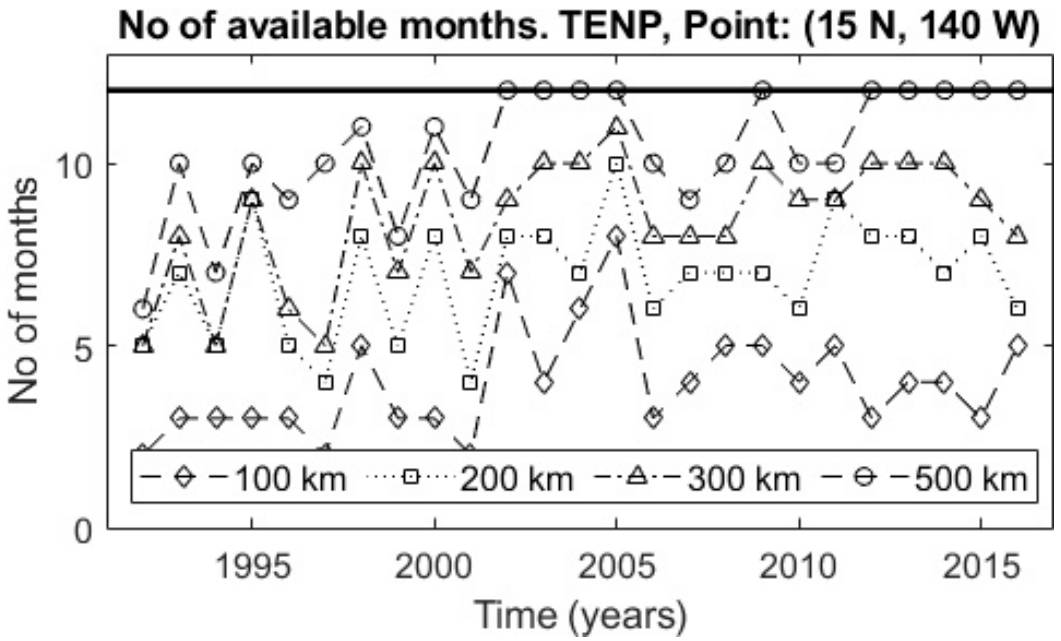


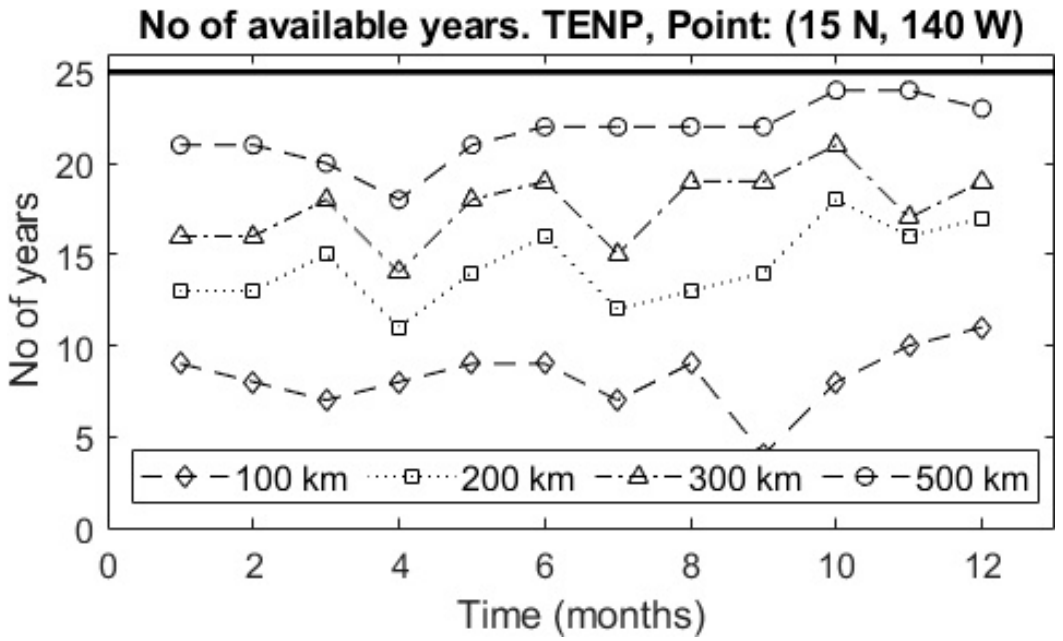
Regional seasonality (points, TWSP)



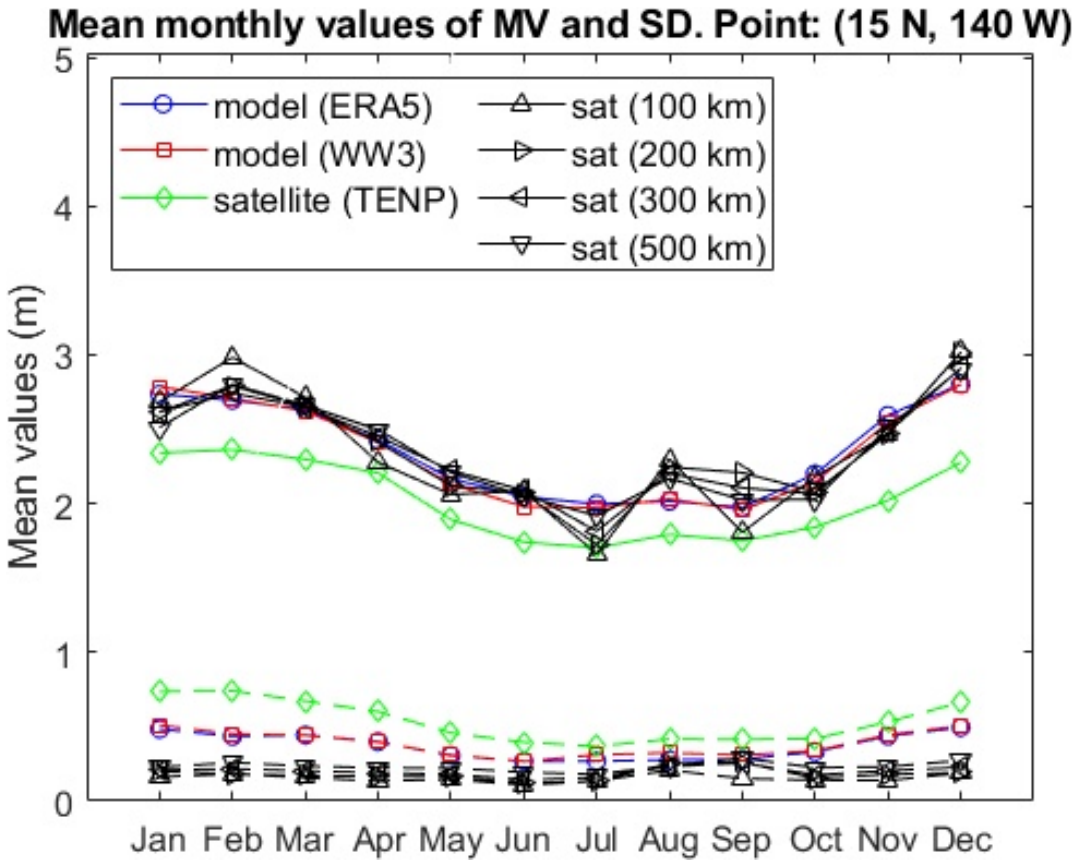


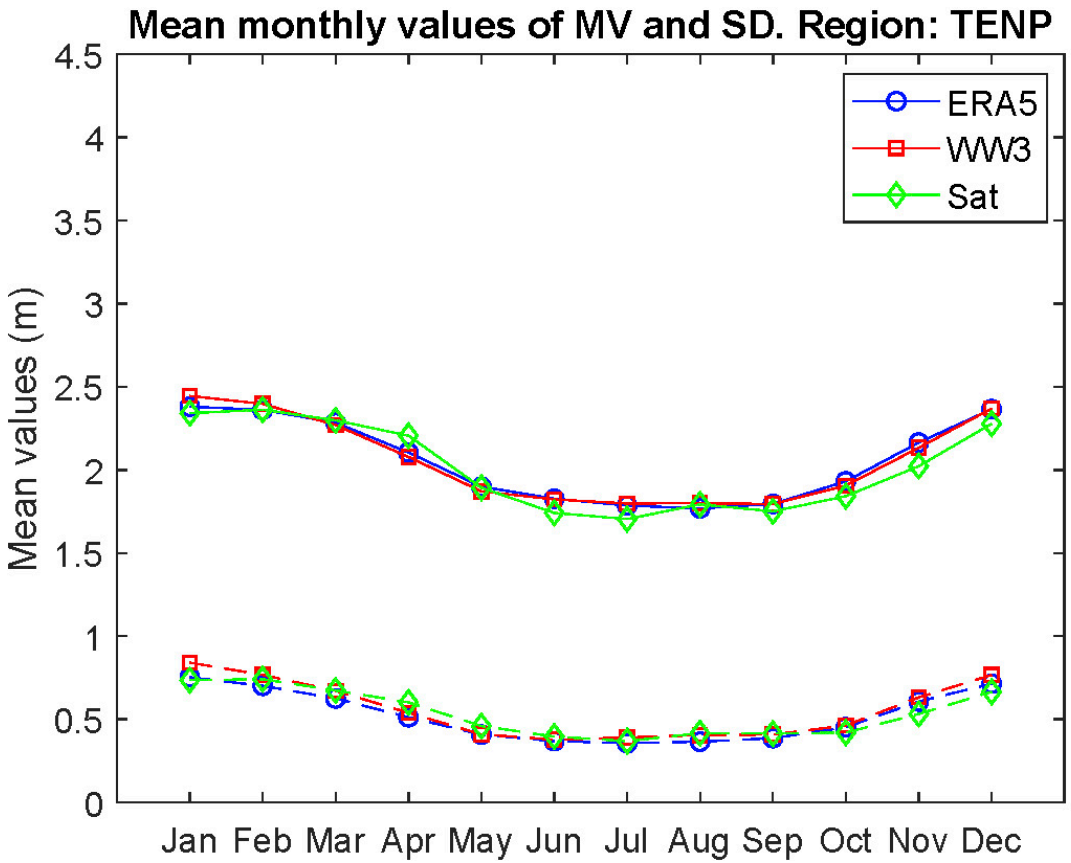
Regional seasonality (availability, TENP)



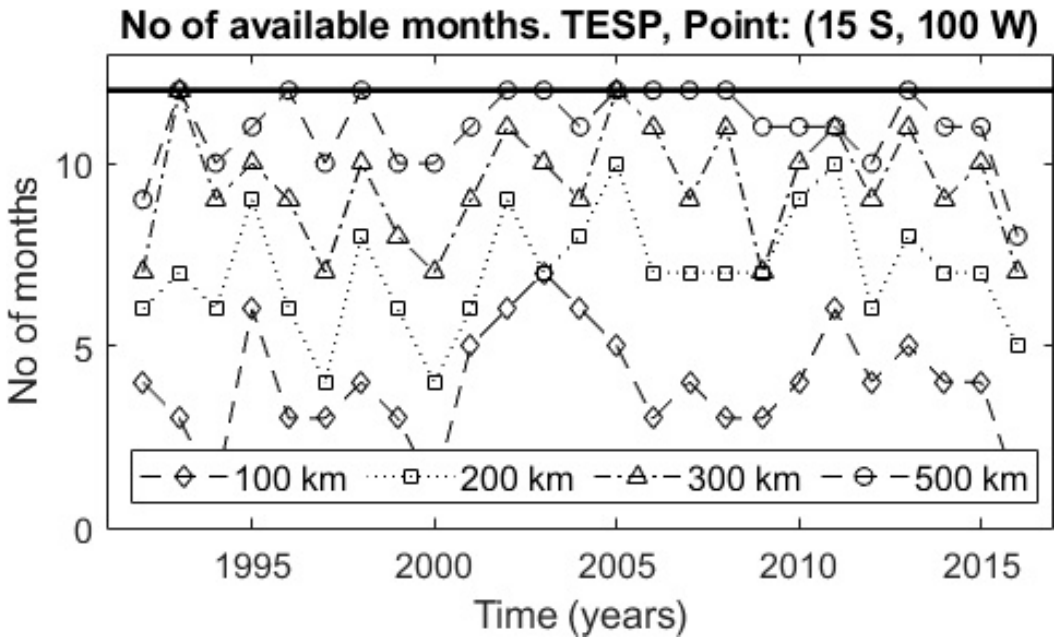


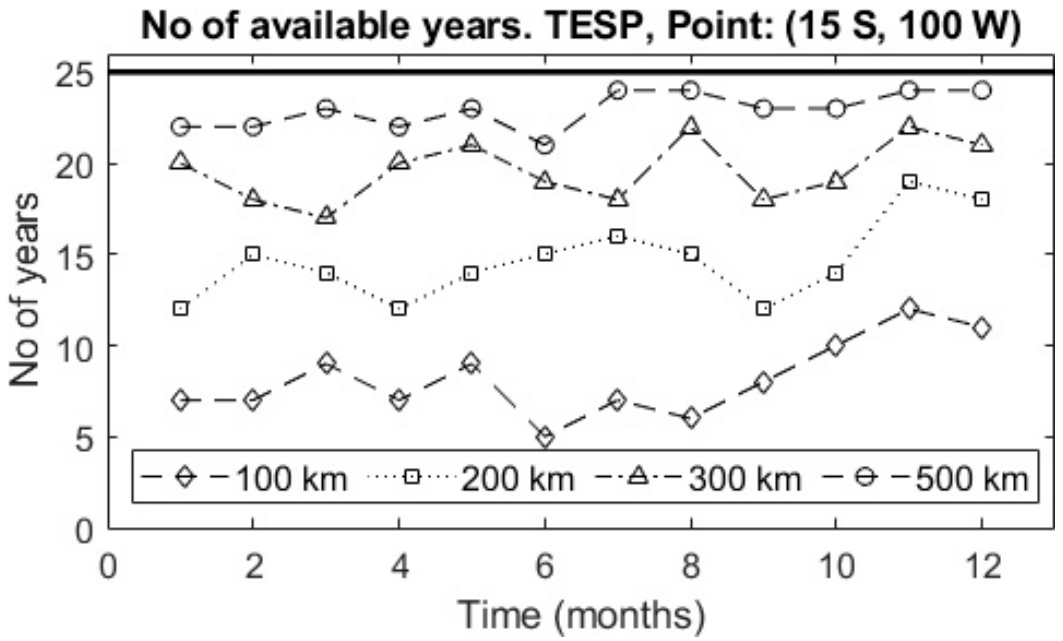
Regional seasonality (points, TENP)



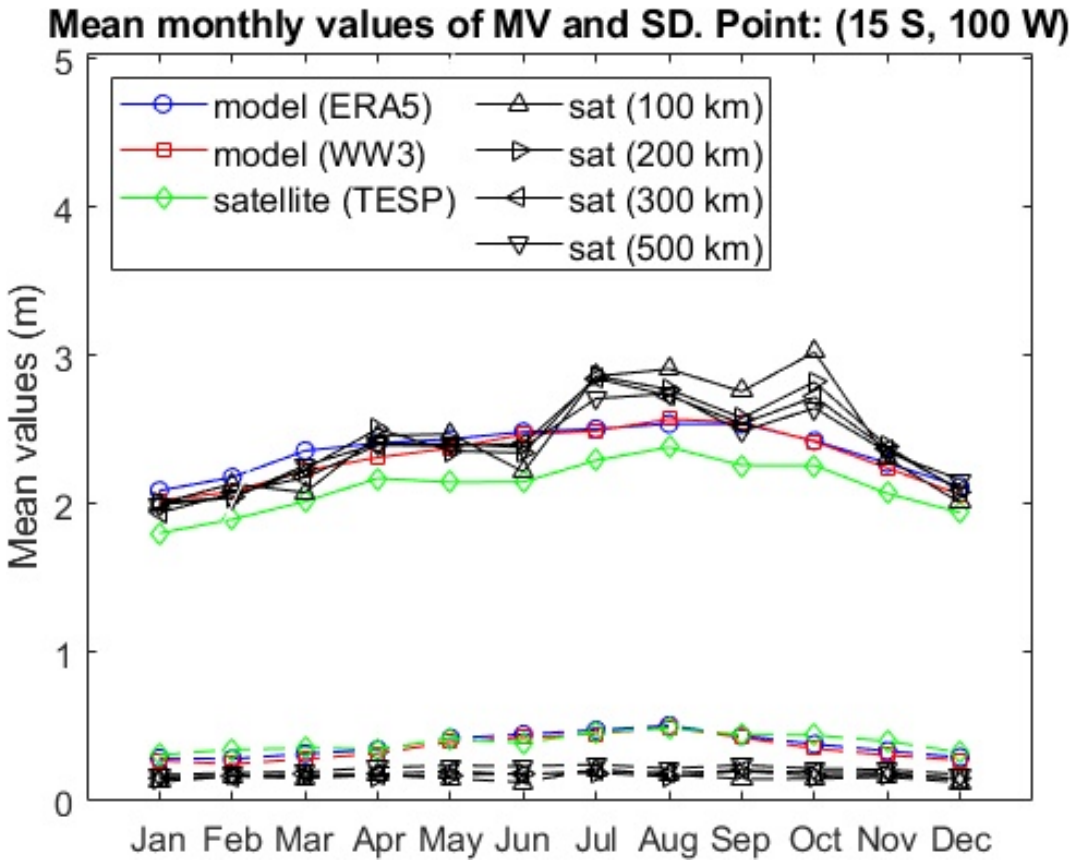


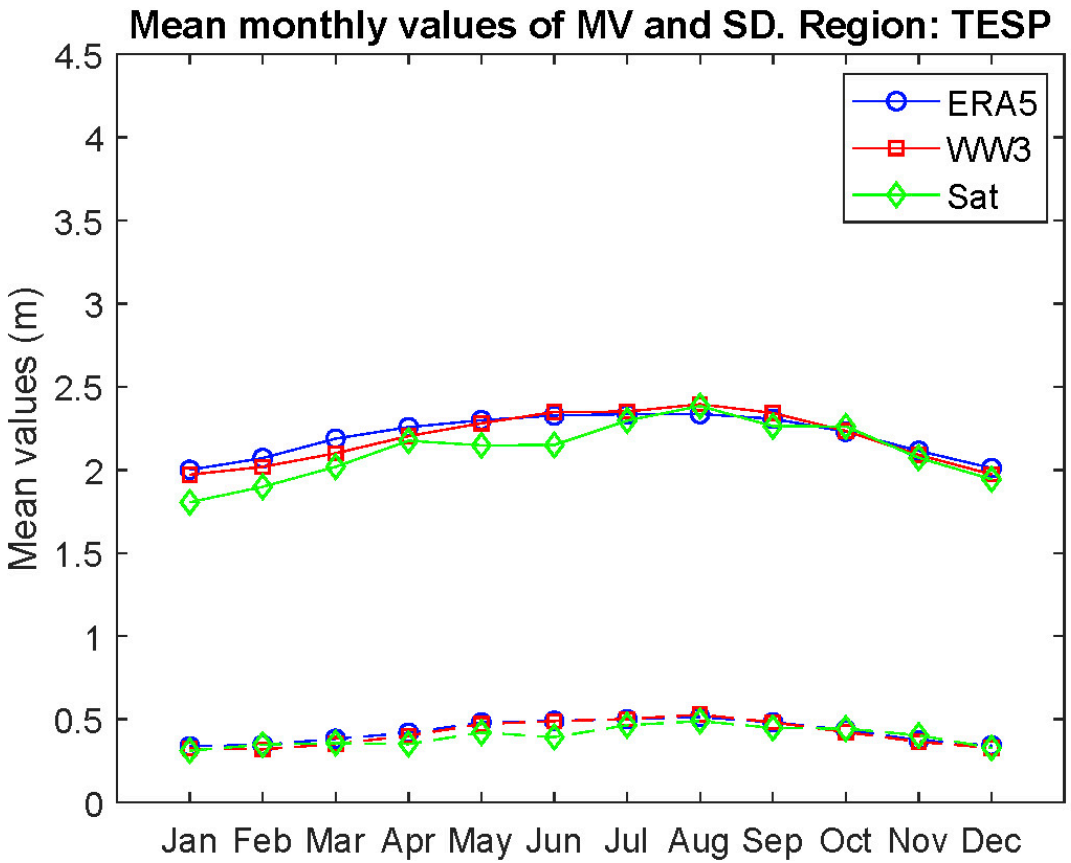
Regional seasonality (availability, TESP)





Regional seasonality (points, TESP)





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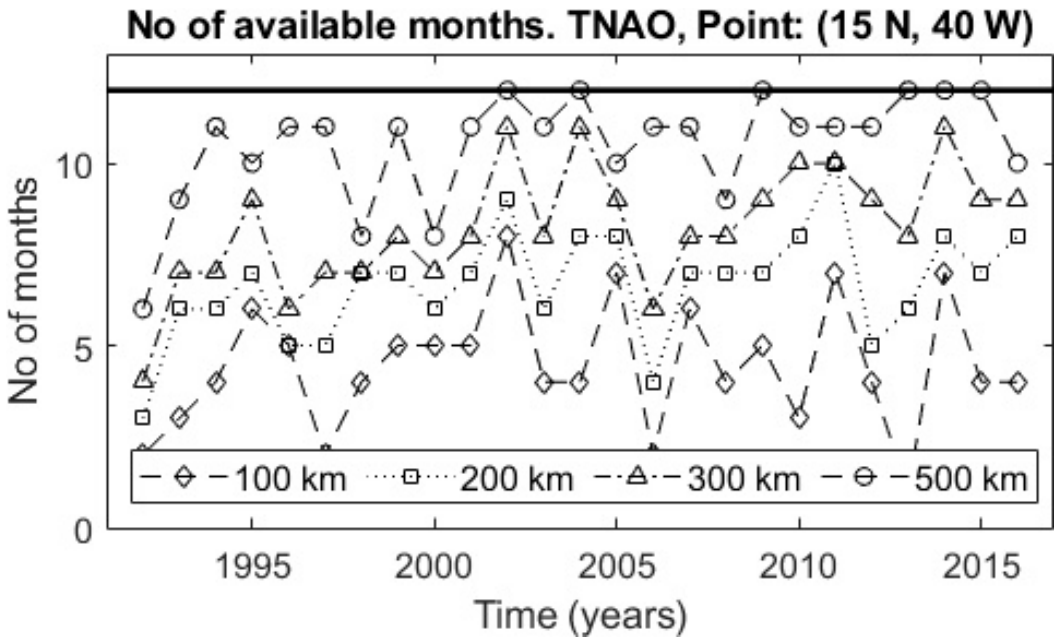
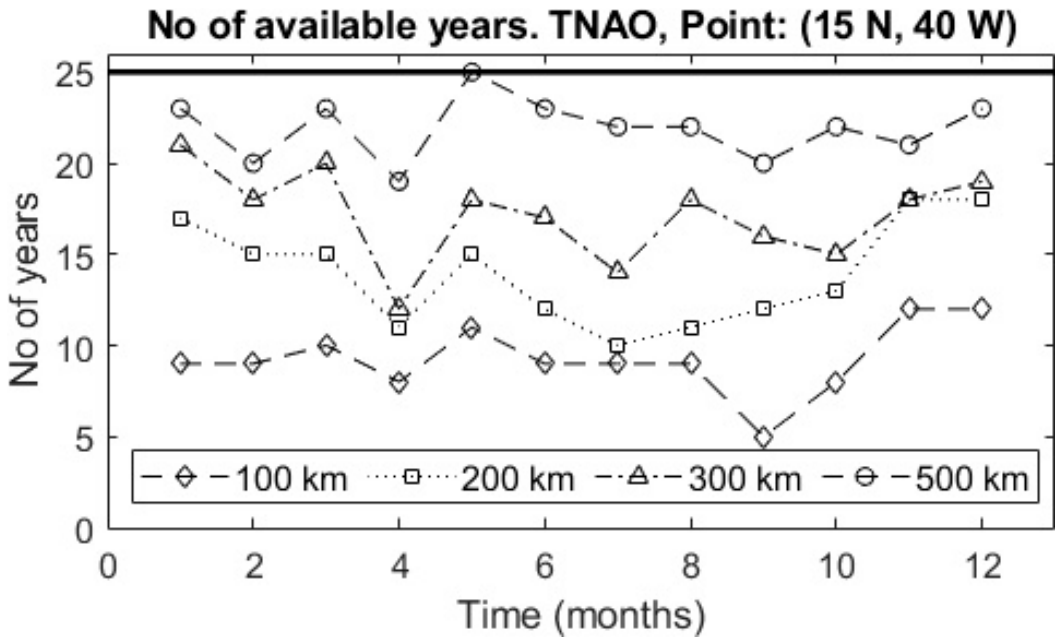
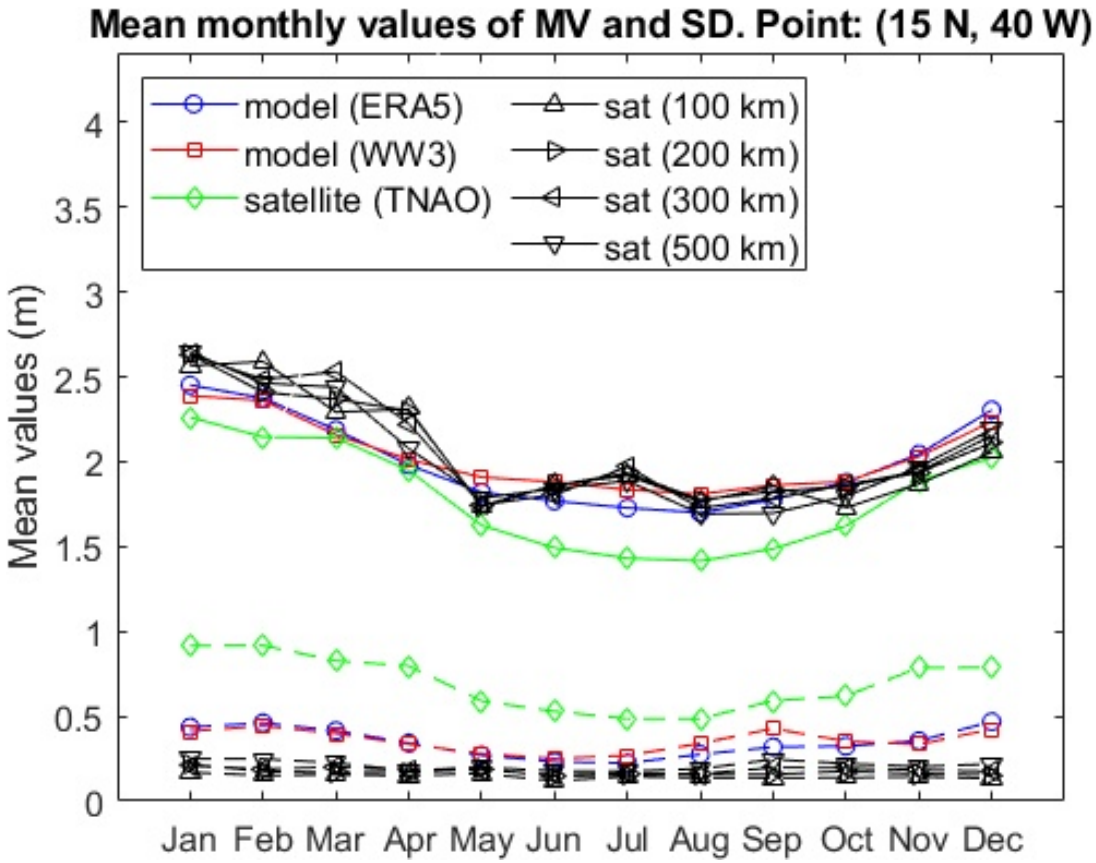
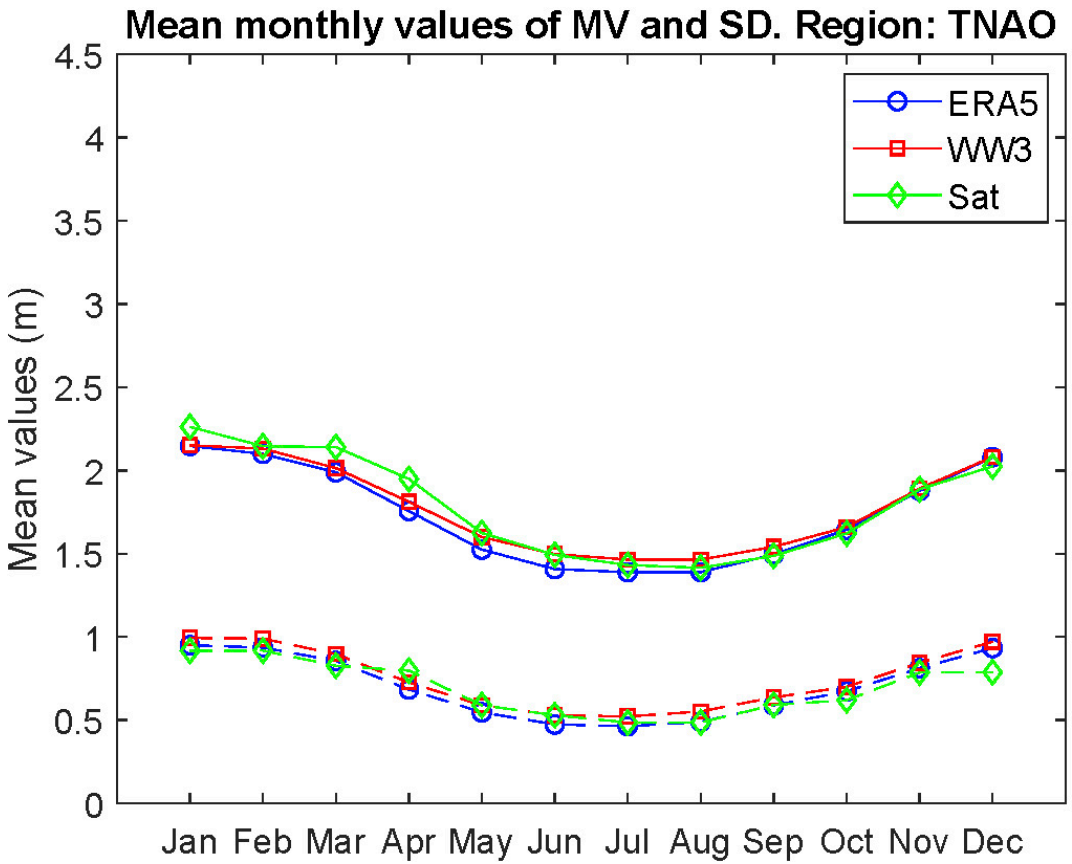
Regional seasonality (availability, TNAO)





Regional seasonality (points, TNAO)





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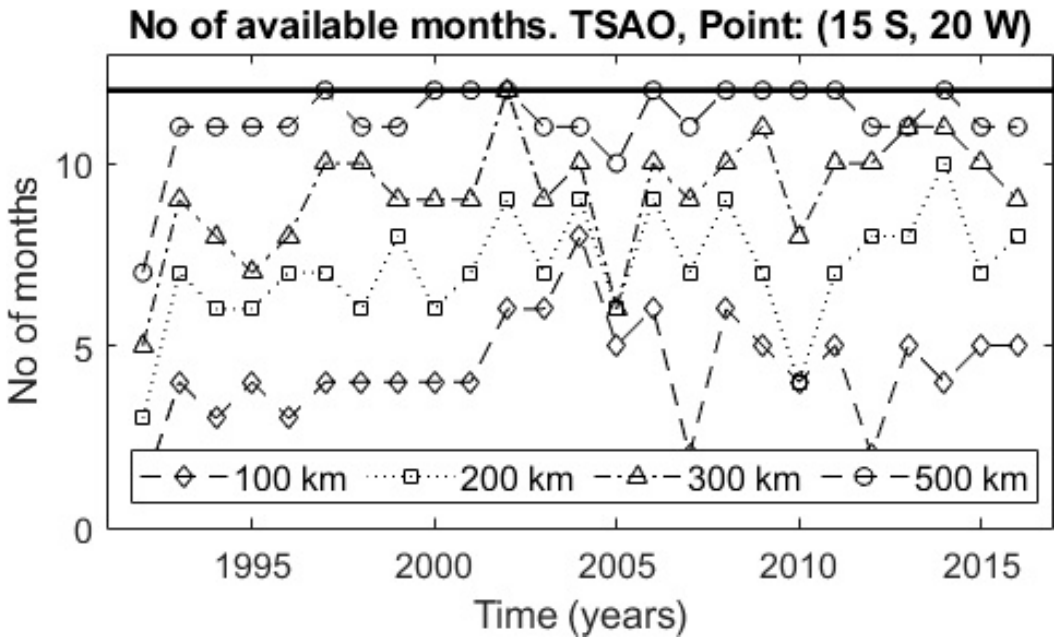
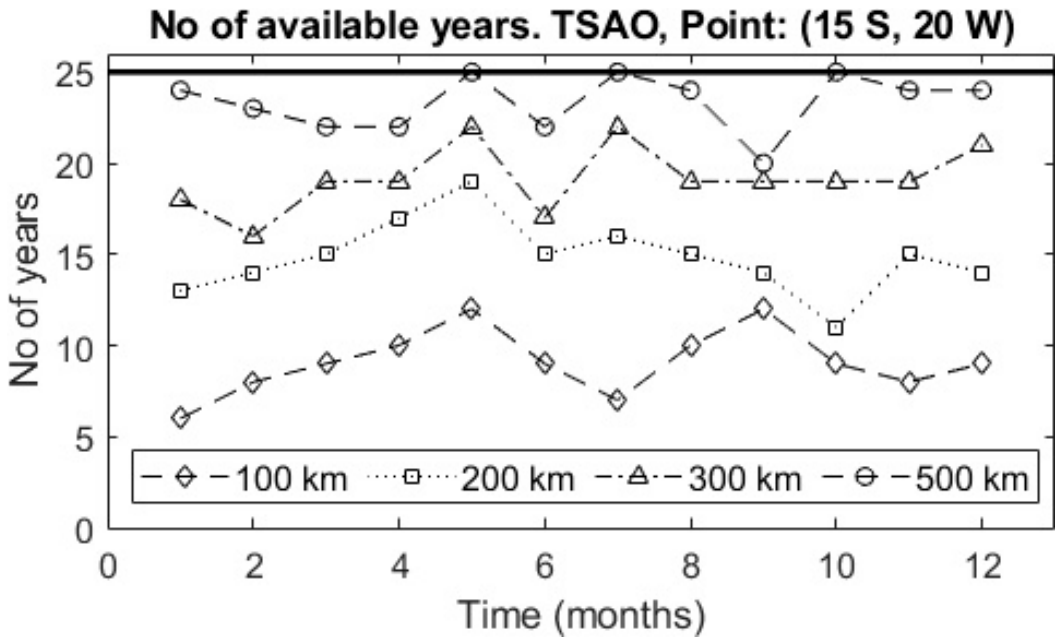
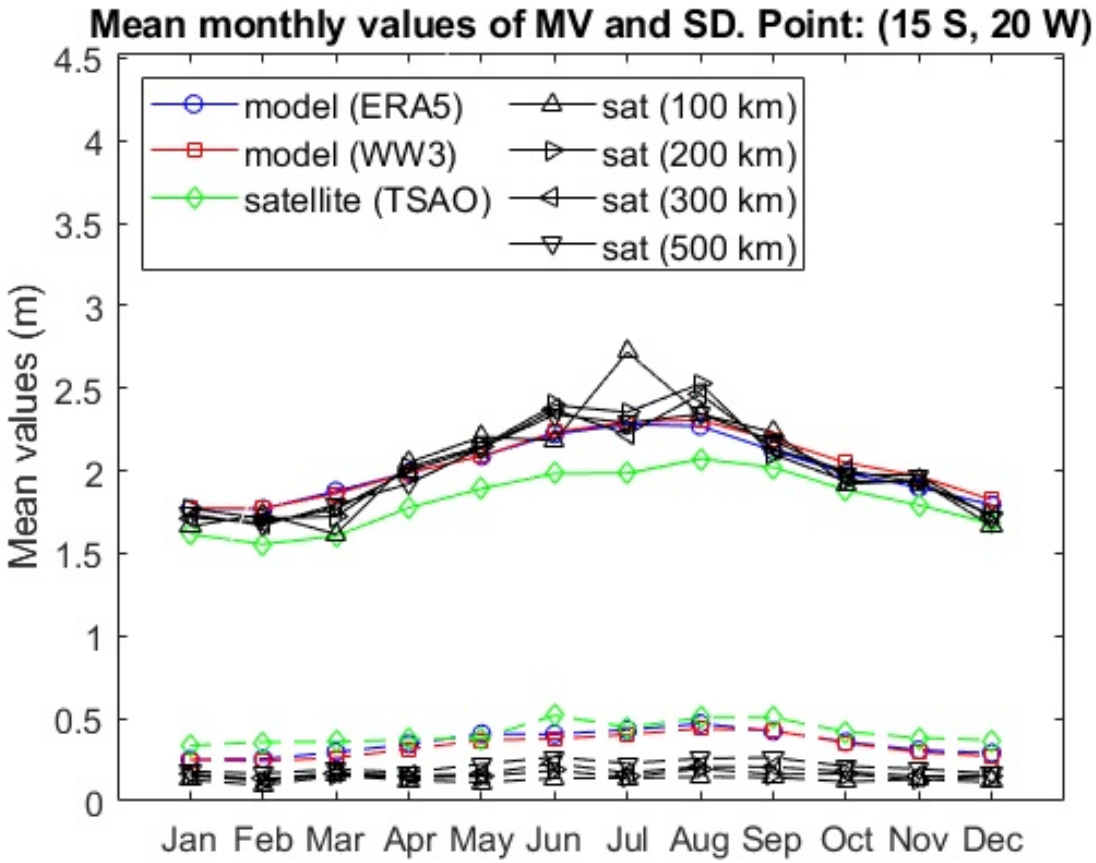
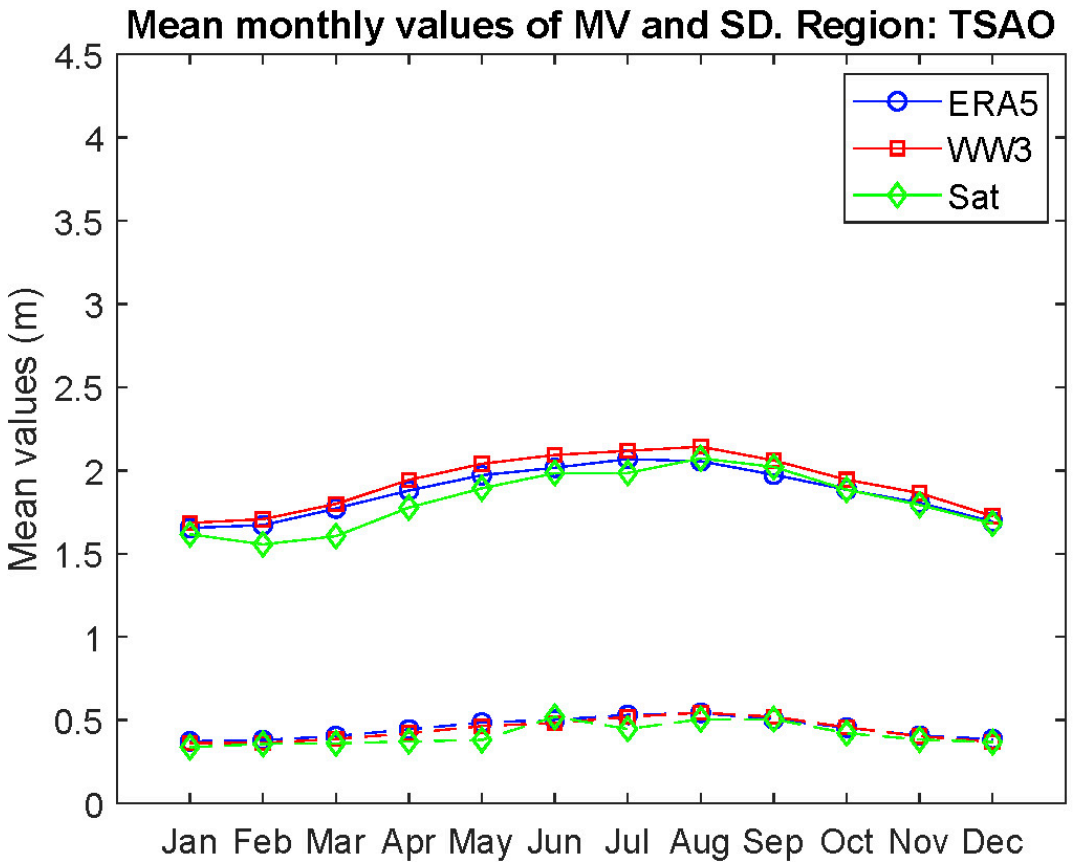
Regional seasonality (availability, TSAO)



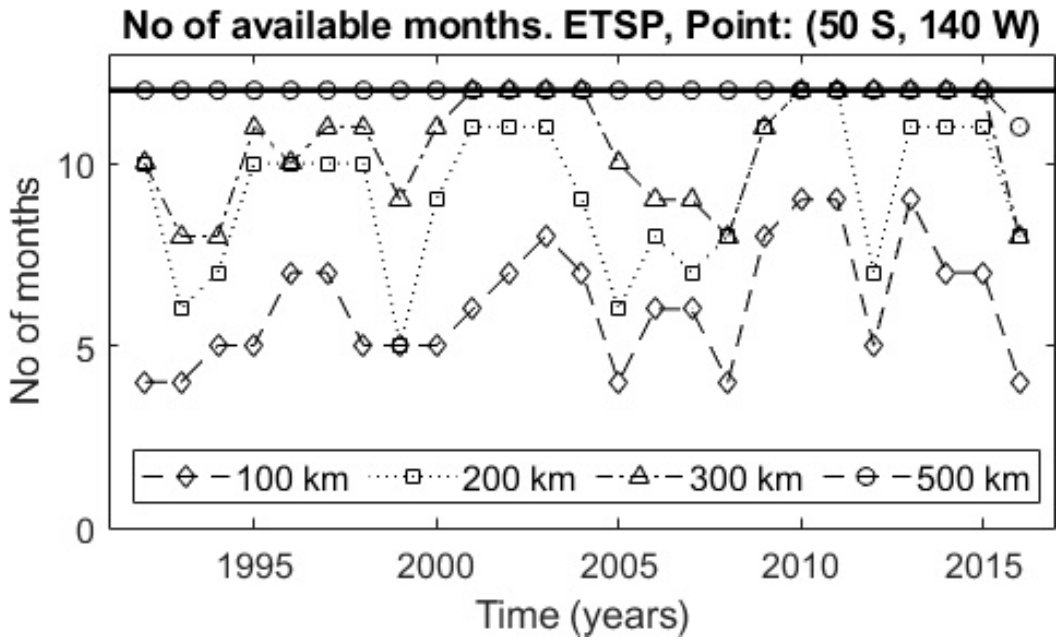


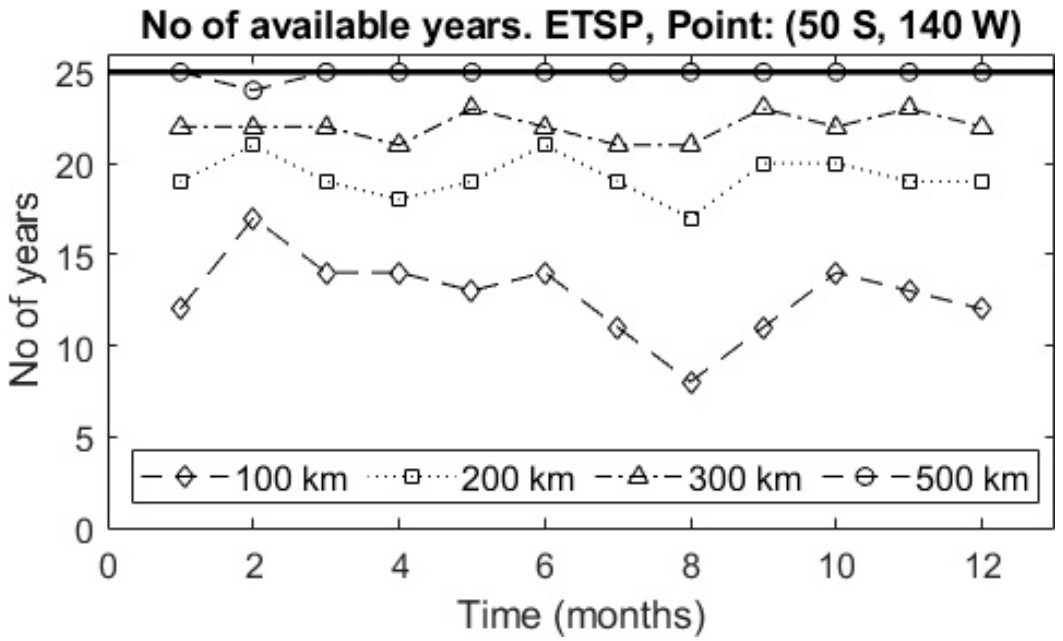
Regional seasonality (points, TSAO)



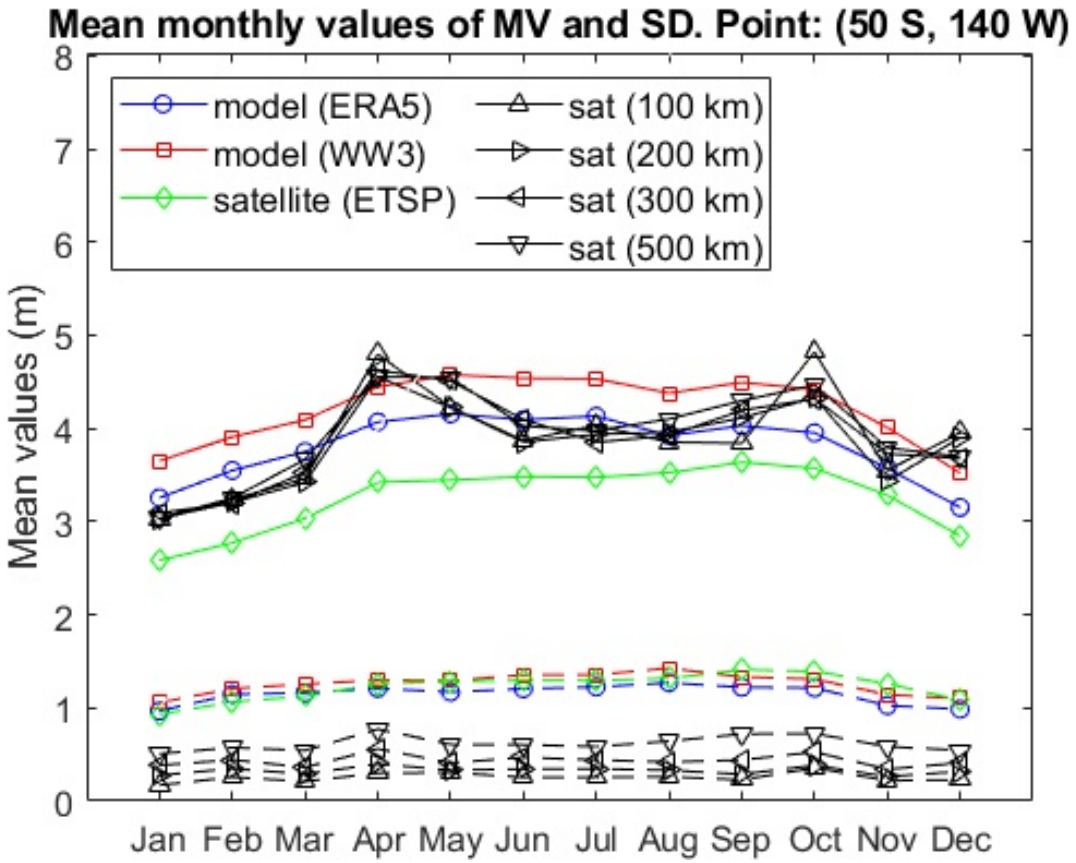


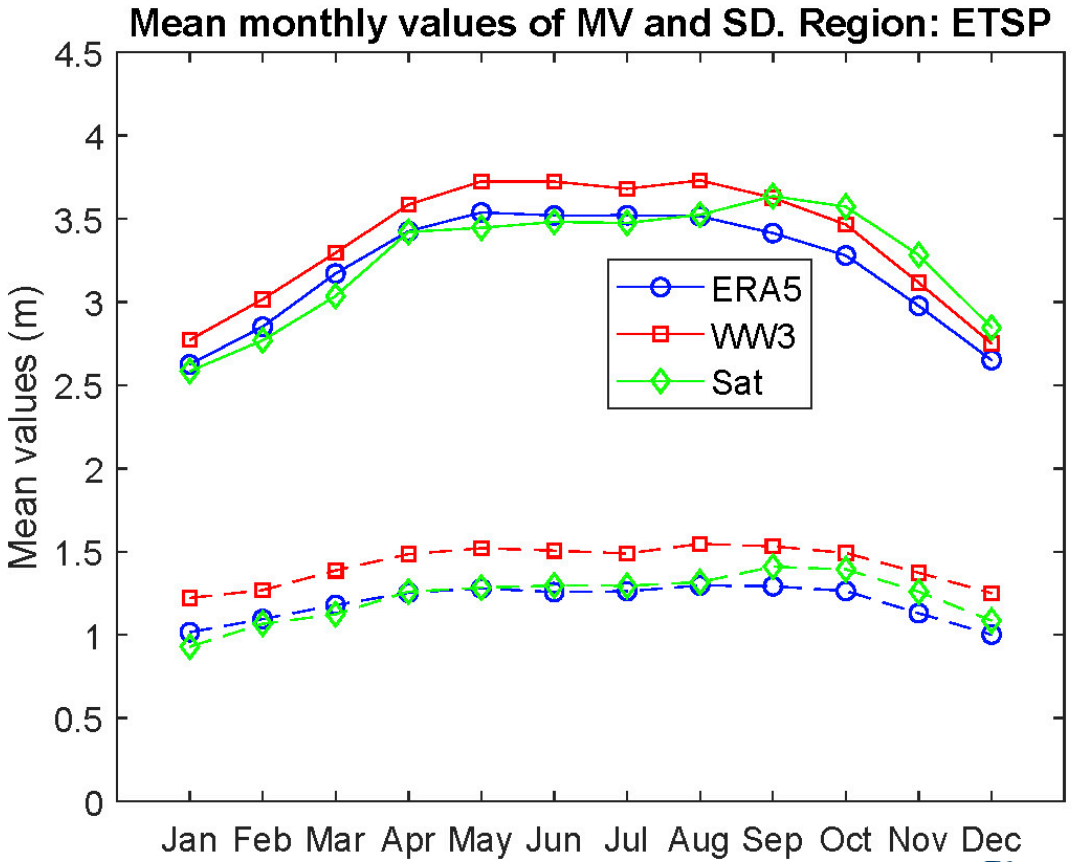
Regional seasonality (availability, ETSP)



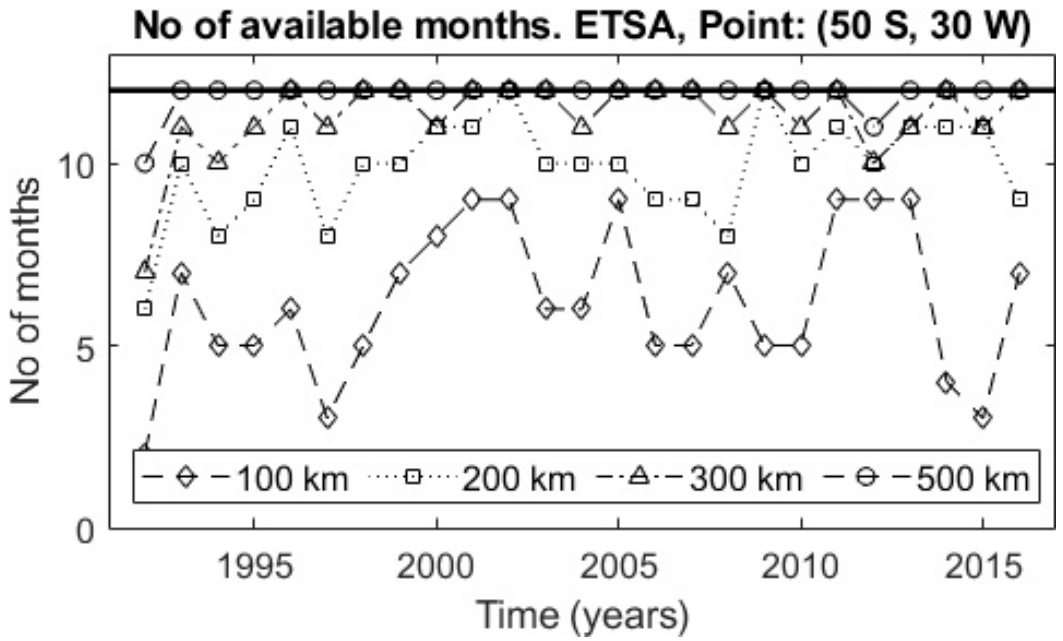


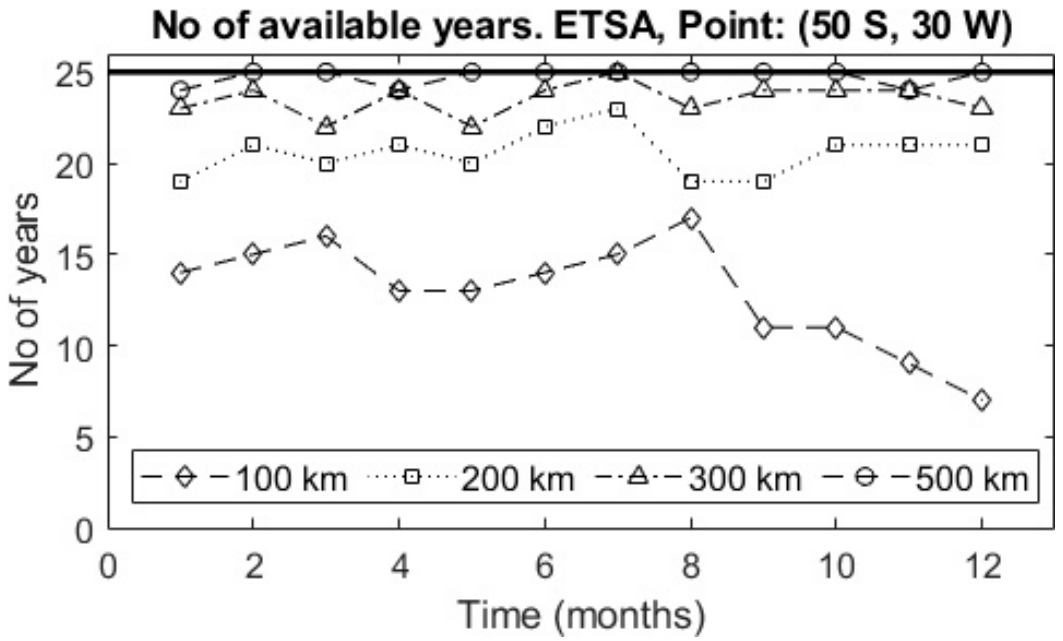
Regional seasonality (points, ETSP)



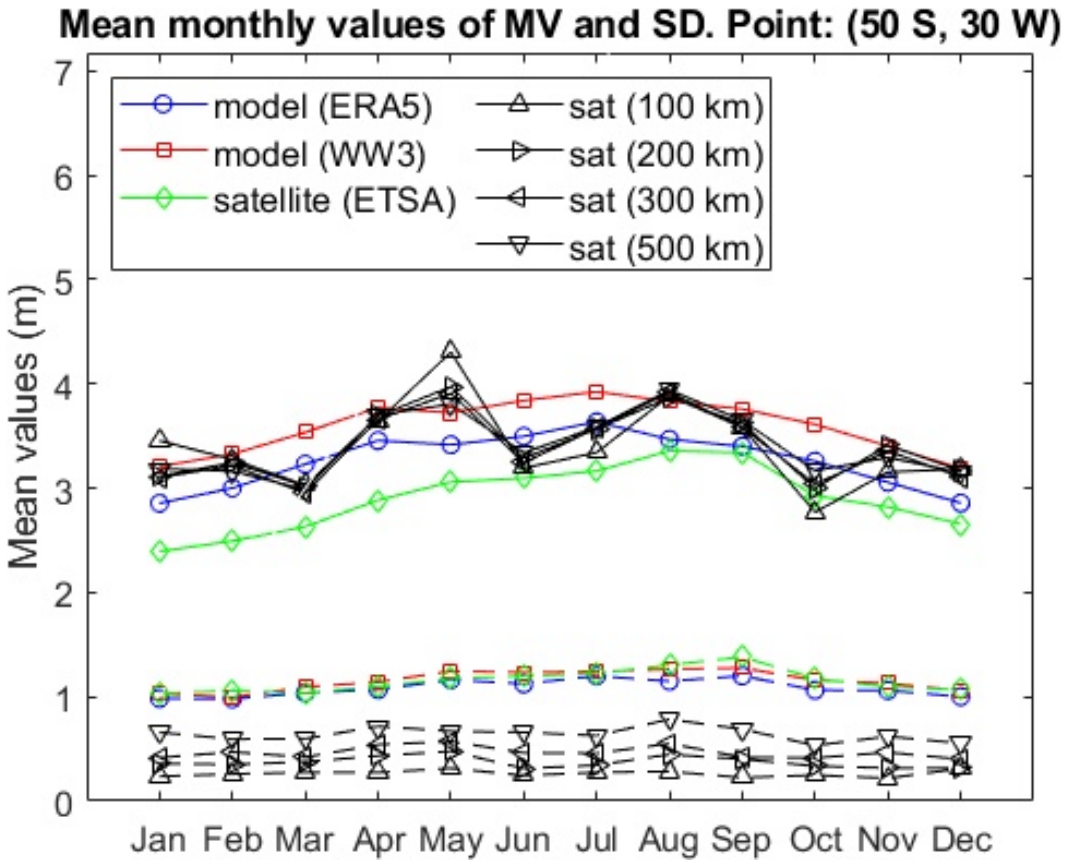


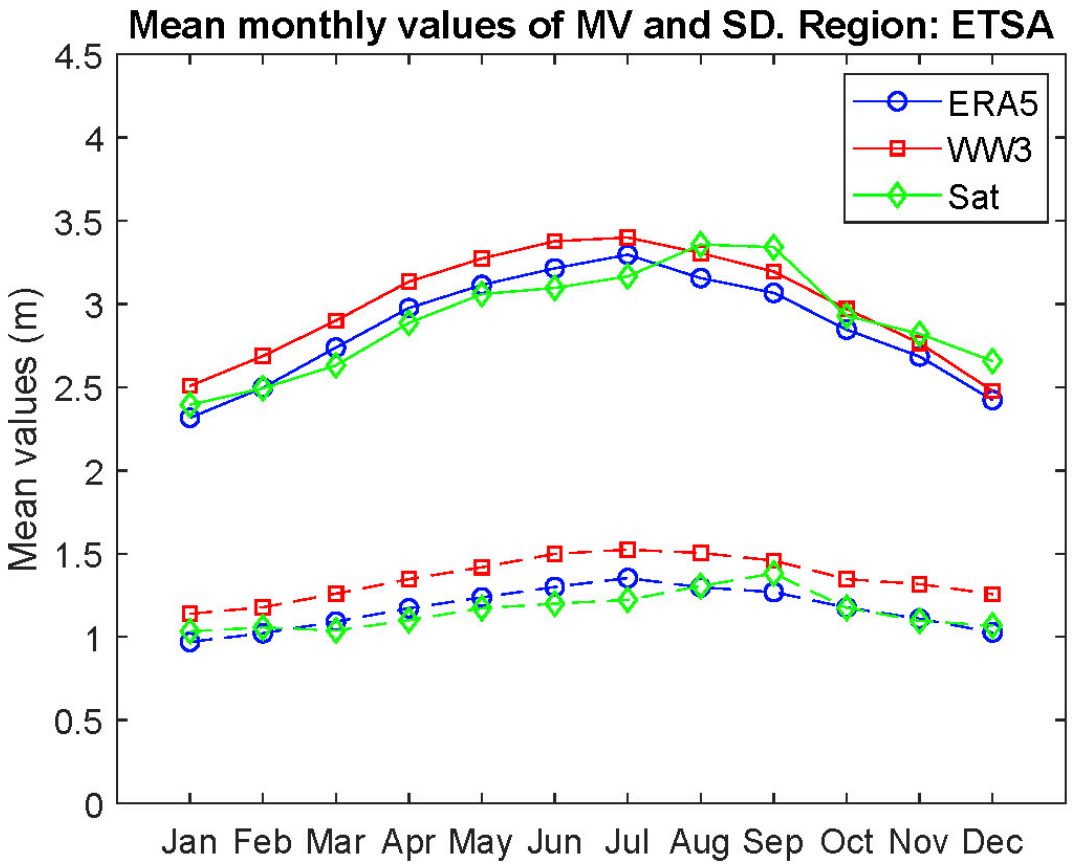
Regional seasonality (availability, ETSA)





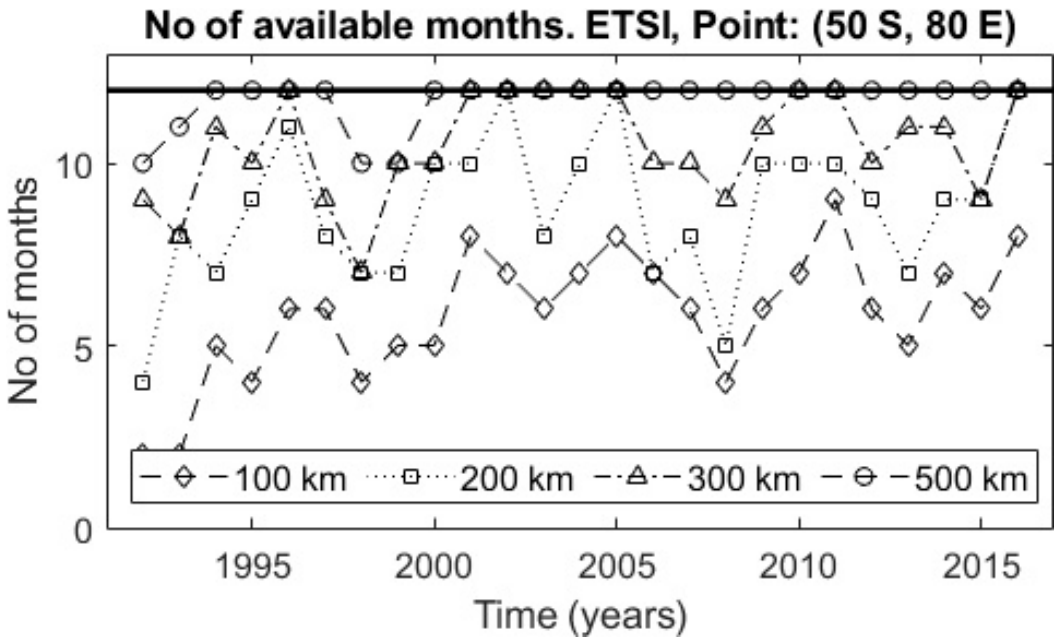
Regional seasonality (points, ETSA)

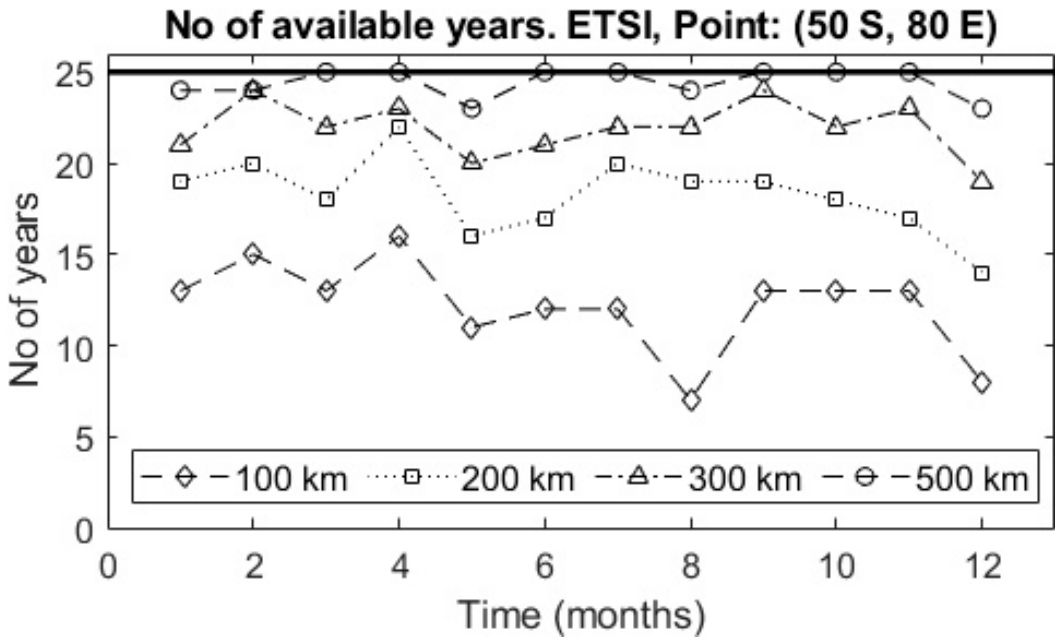




SINTEF

Regional seasonality (availability, ETSI)





Regional seasonality (points, ETSI)