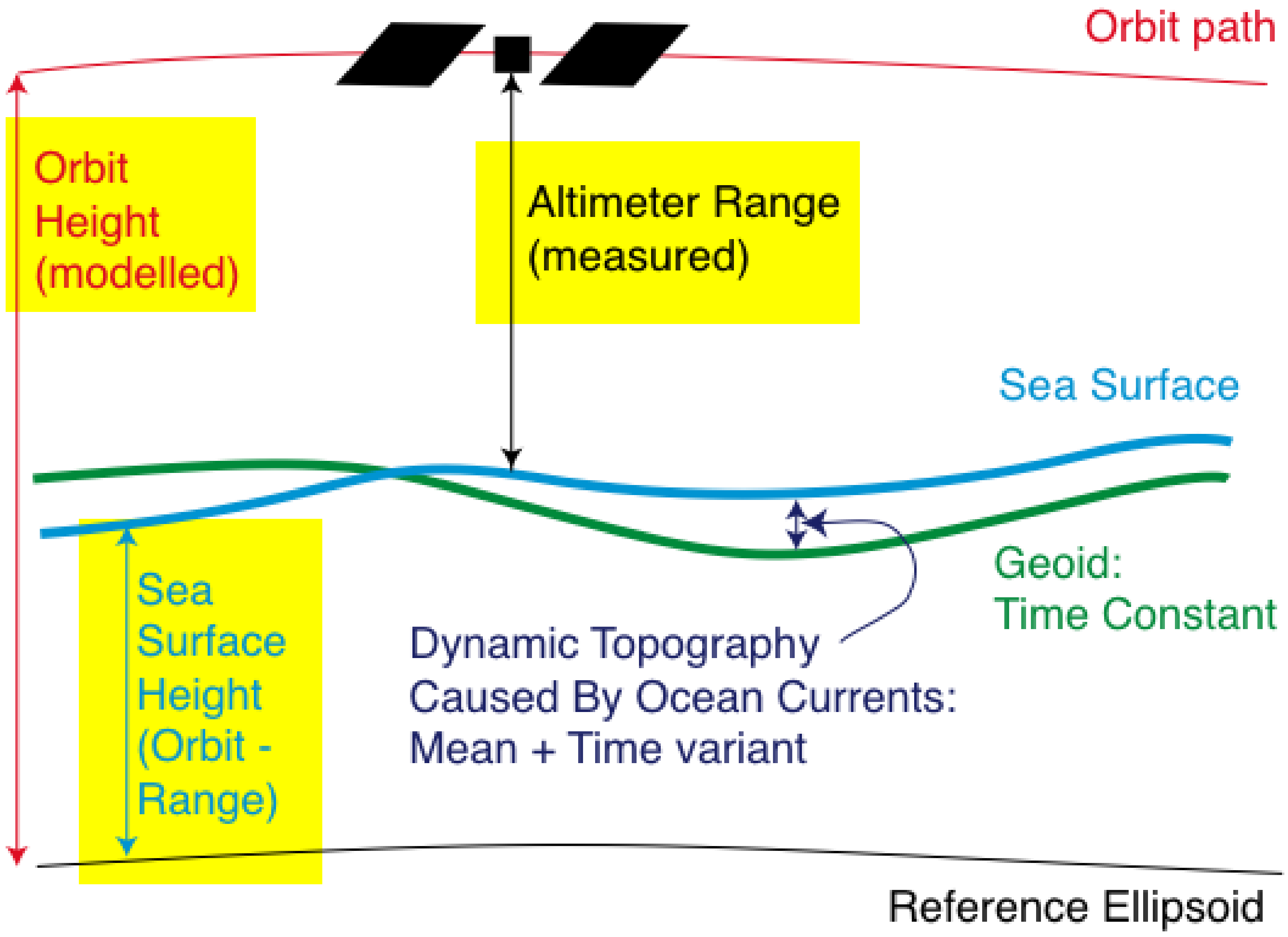
P. Cipollini, H. Snaith - A short course on Altimetry

Altimetry 3 - Altimetry and Oceanography (measuring ocean processes)

All the processing seen so far is to get a good SSH=orbit-range



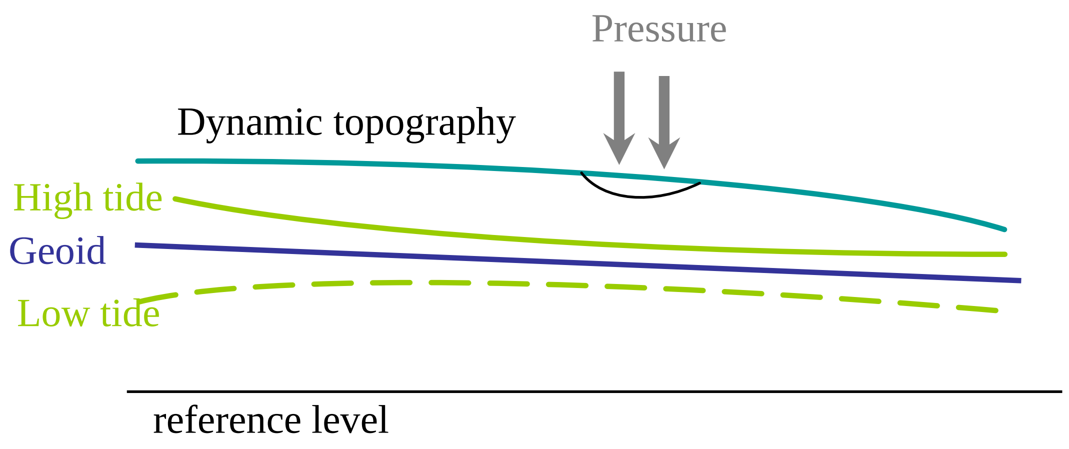
Interpreting Ocean Surface Topography

Geoid (~100 m)

- Time invariant
- Not known to sufficient accuracy
- To be measured independently (gravity survey)

Tides (~1-2 m)

- Apply a tidal prediction
- New tidal models derived from altimetry
- Choose orbit to avoid tidal aliasing



Atmospheric pressure (~0.5 m)

- Apply inverse barometer correction (1mbar ~ 1 cm)

Dynamic topography (~1 m)

- The intended measurement

Some of these we want to correct for – or not, depending on the application!!!

Atmospheric pressure (the "Inverse Barometer" Correction)

- When air pressure changes the ocean acts like a barometer (in reverse). High air pressure depresses the sea surface, low air pressure raises it.
- 1 mbar (hPa) change in air pressure is approximately equal to a 1cm change in the sea surface
- Good in mid and high latitudes not in Tropics
- Also, not very accurate in enclosed basins (like the Mediterranean)

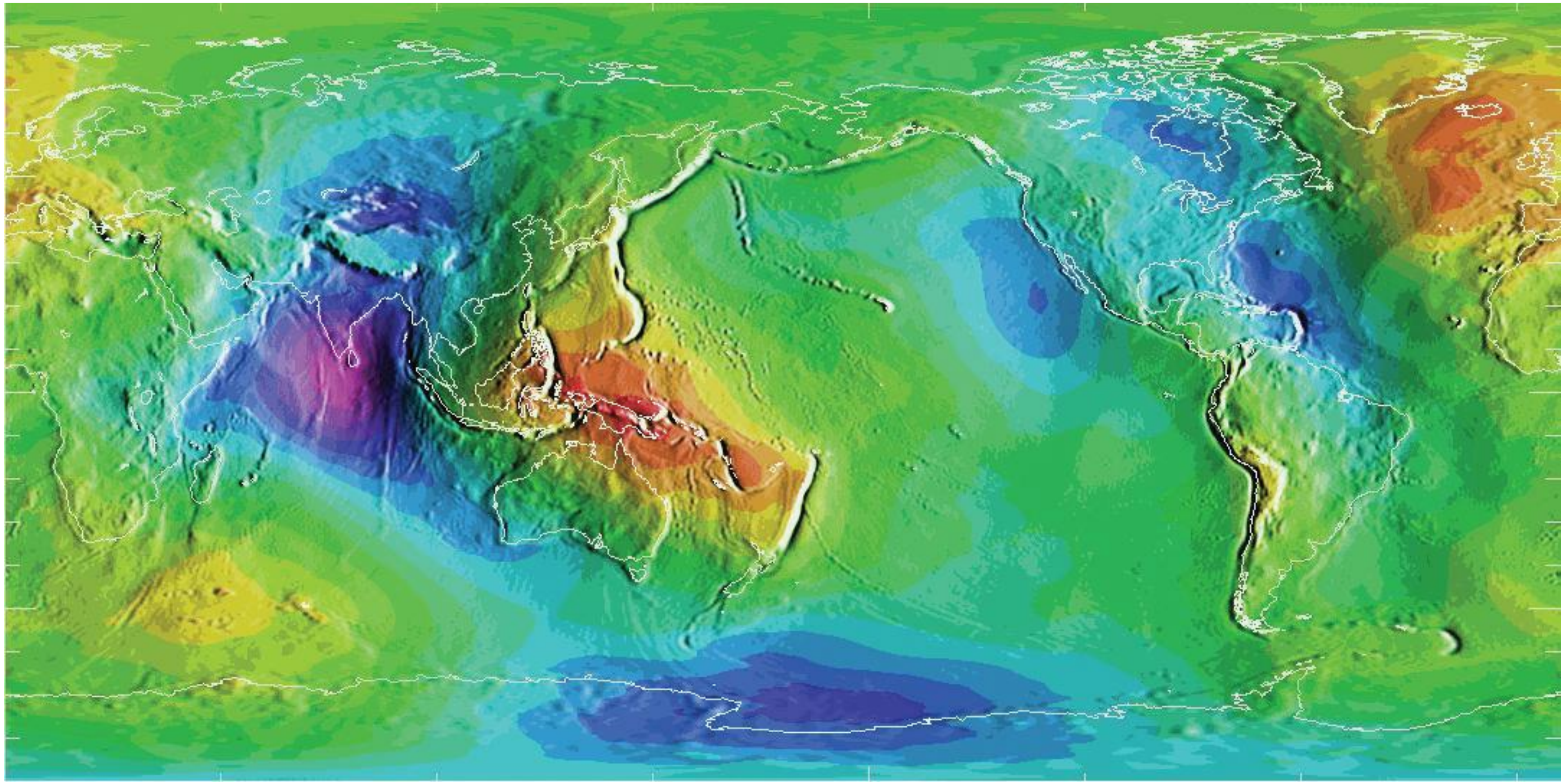
Barotropic Models

- An alternative to an IB correction is to use a correction from a barotropic model of the ocean
- Barotropic (non-depth dependent) motions move very quickly and can be aliased by the altimeter ground tracks
- Barotropic models are quick to run but have proved hard to validate

The problem of the Geoid

- The geoid is the surface of equal gravity potential on the Earth's surface (the shape of the Earth)
- The ellipsoid is an approximation to the shape of the Earth
- We know the ellipsoid - we do not know the geoid with the accuracy we would like!!!

The Geoid



Scale: magenta (-107 m) to red (84.5 m)

The Geoid

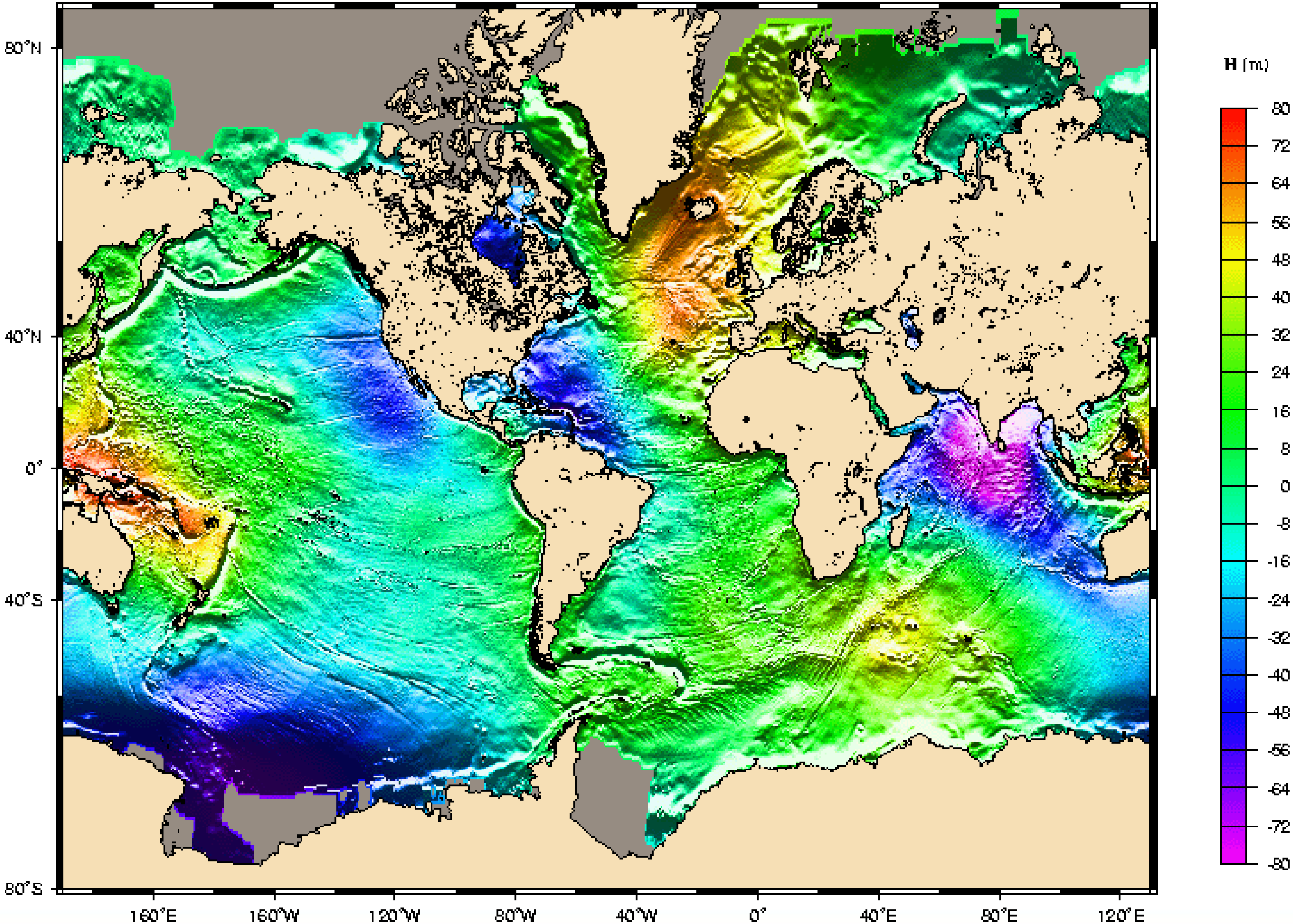
- The geoid is usually expressed in terms of spherical harmonics (sine curves on the sphere). These have degree and order
  - Degree and order 360 is a resolution of approx. 1˚
- Sea surface pressure and hence geostrophic currents are in terms of sea surface height relative to the geoid
- We measure sea surface height (and hence slopes) relative to the ellipsoid.

Removing the Geoid

- The geoid is time invariant (approximately)
- So if we subtract a mean sea surface we will remove the geoid
- But we lose ...

... the mean circulation

Mean sea surface



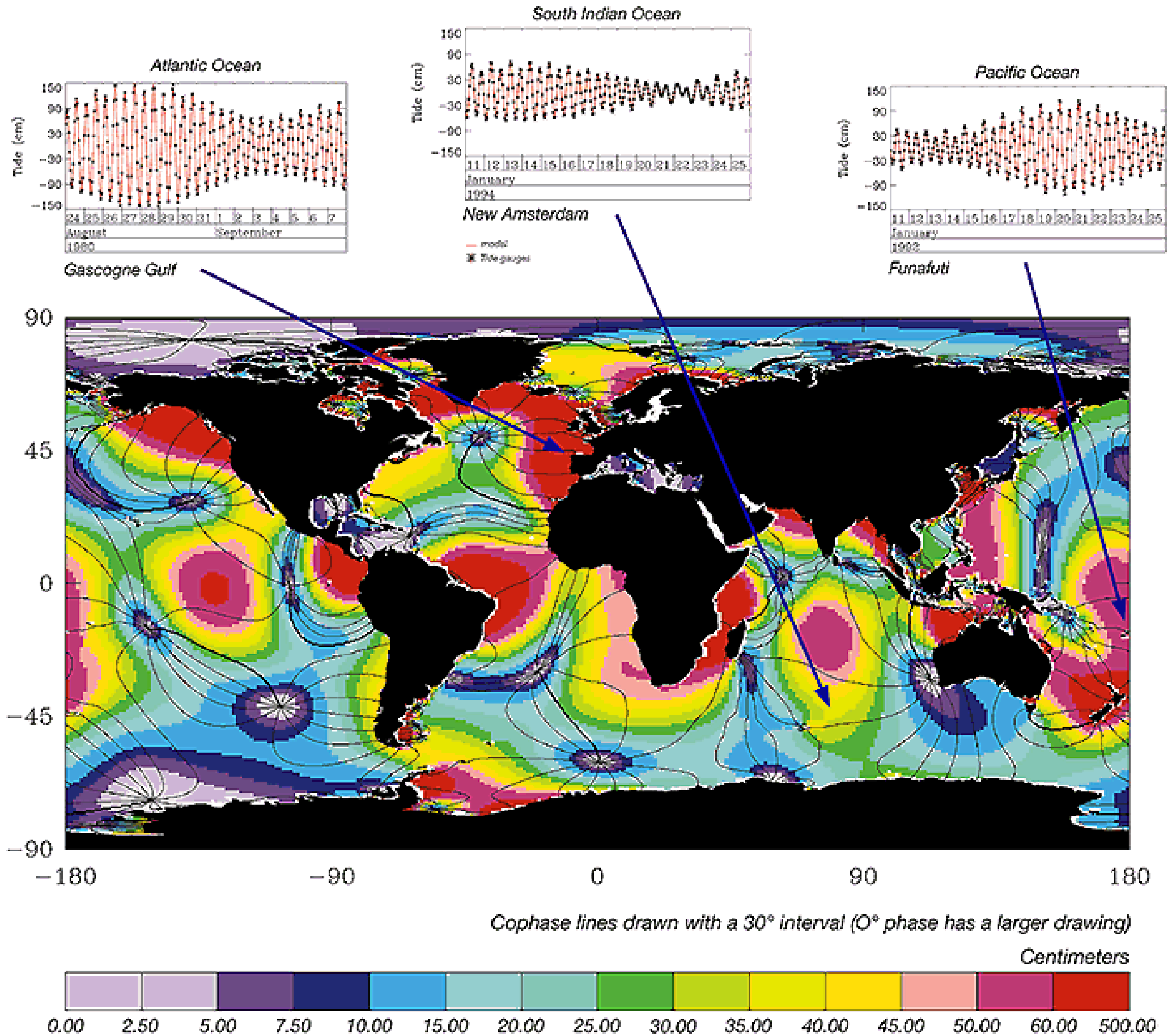
SSH residuals

- The sea surface height residual (or Sea Surface Height Anomaly - SSHA) is what remains after removing the mean in each location (Mean Sea Surface)
- Any constant dynamic topography (from steady currents) will have been removed!
- Contains only the **time-varying** dynamic topography
- May still contain time varying errors
  - Un-removed tidal or barometric signal
  - Orbit error
- With new independent accurate geoid models (from GRACE and the new ESA GOCE mission) we are starting to be able to subtract the geoid and work with **absolute dynamic topography** (much better for oceanographers!)

Tides

- If we are going to use altimetry for oceanographic purposes we need to remove the effect of the tides
- Alternatively we could use the altimeter to estimate the tides - tidal models have improved dramatically since the advent of altimetry!
- In general we use global tidal models to make predictions and subtract them from the signal

The up and down of the ocean tides



Source : IMG/LEGI, Grenoble 1995

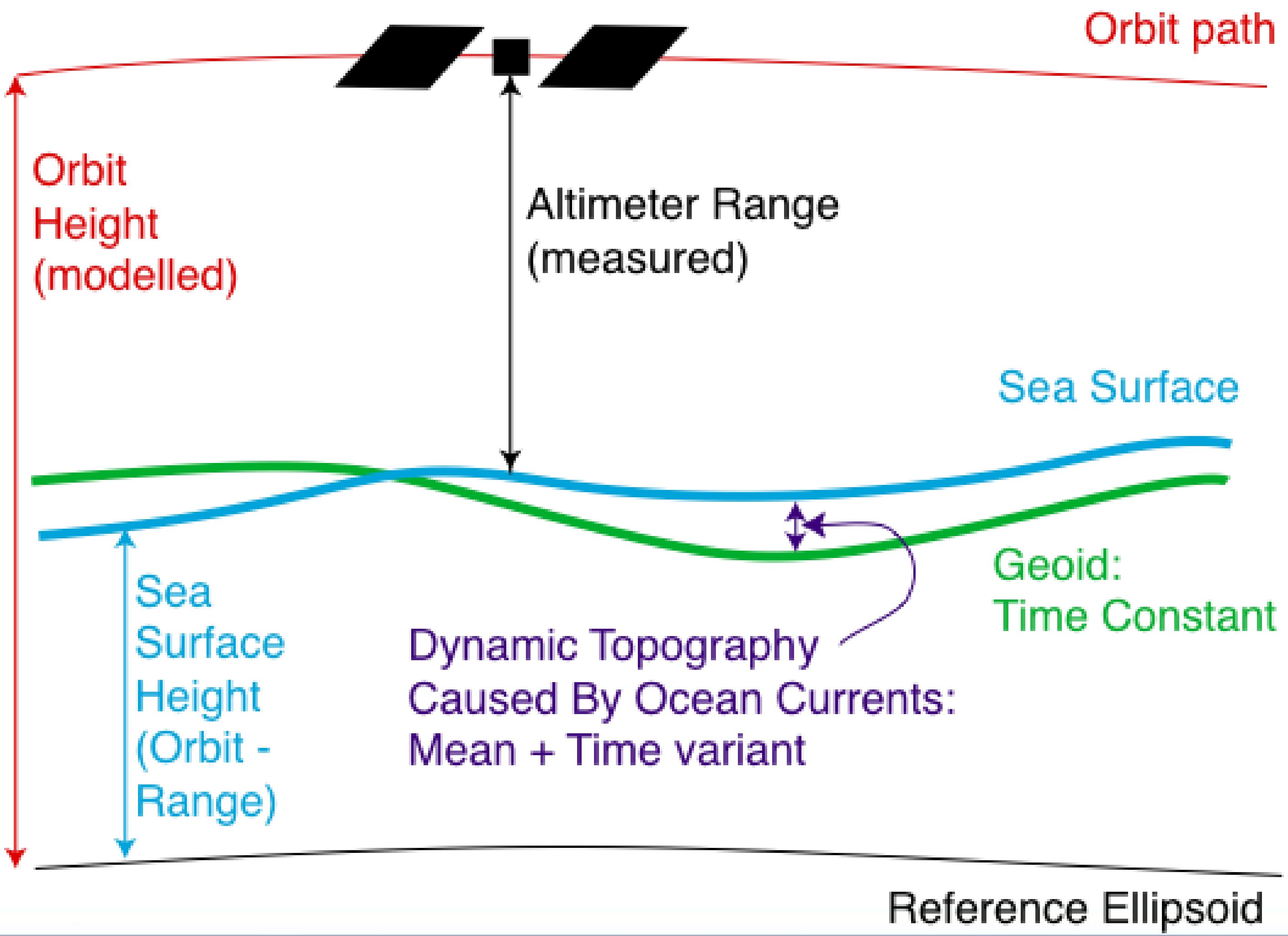
More tides!

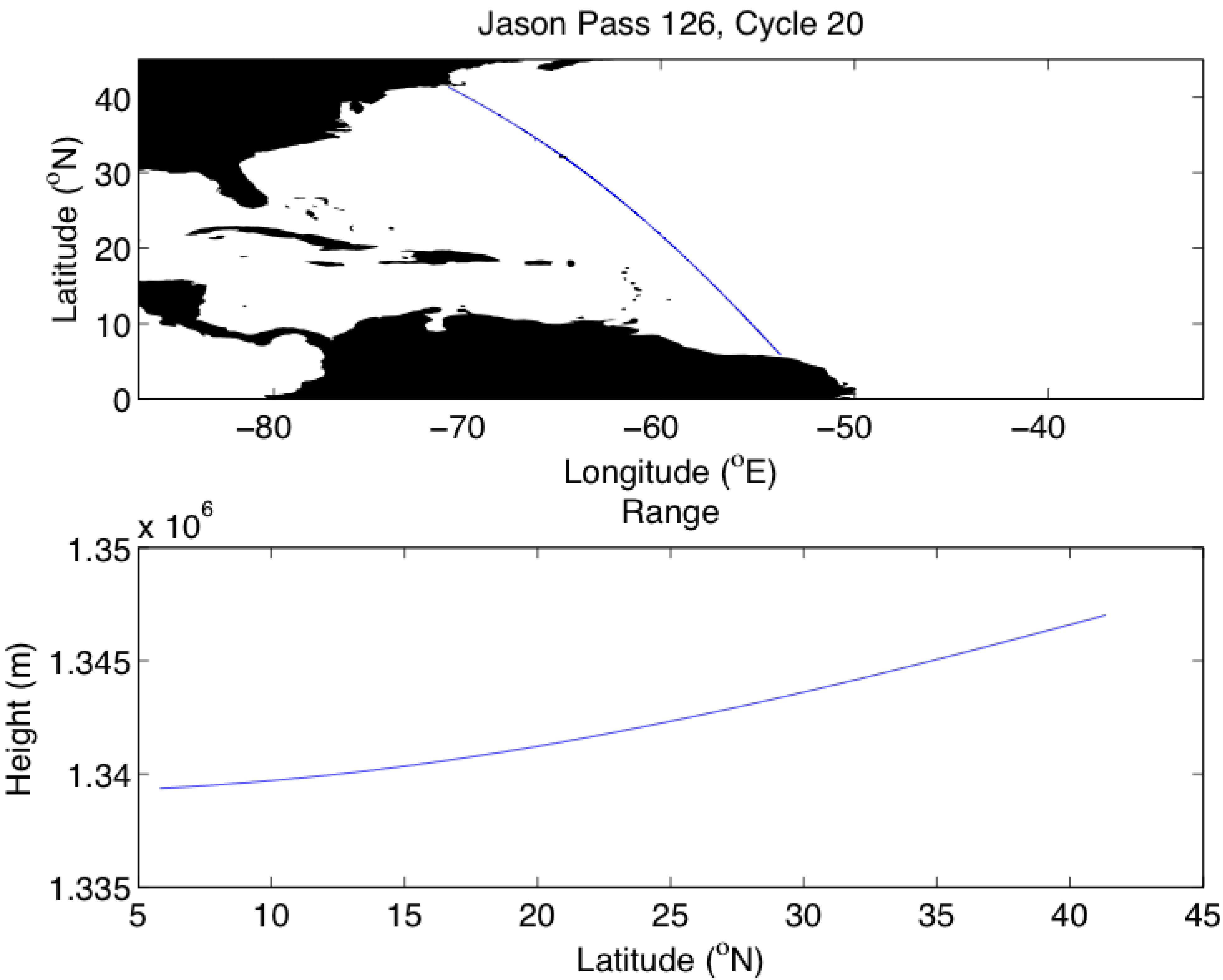
- As well as the ocean tide we have to consider
  - the loading tide (the effect of the weight of water). This is sometimes included in the ocean tide
  - the solid earth tide
  - the polar tide
- On continental shelves the global models are not very accurate and local models are needed
- Any residual tidal error is going to be aliased by the sampling pattern of the altimeter

Aliasing Periods

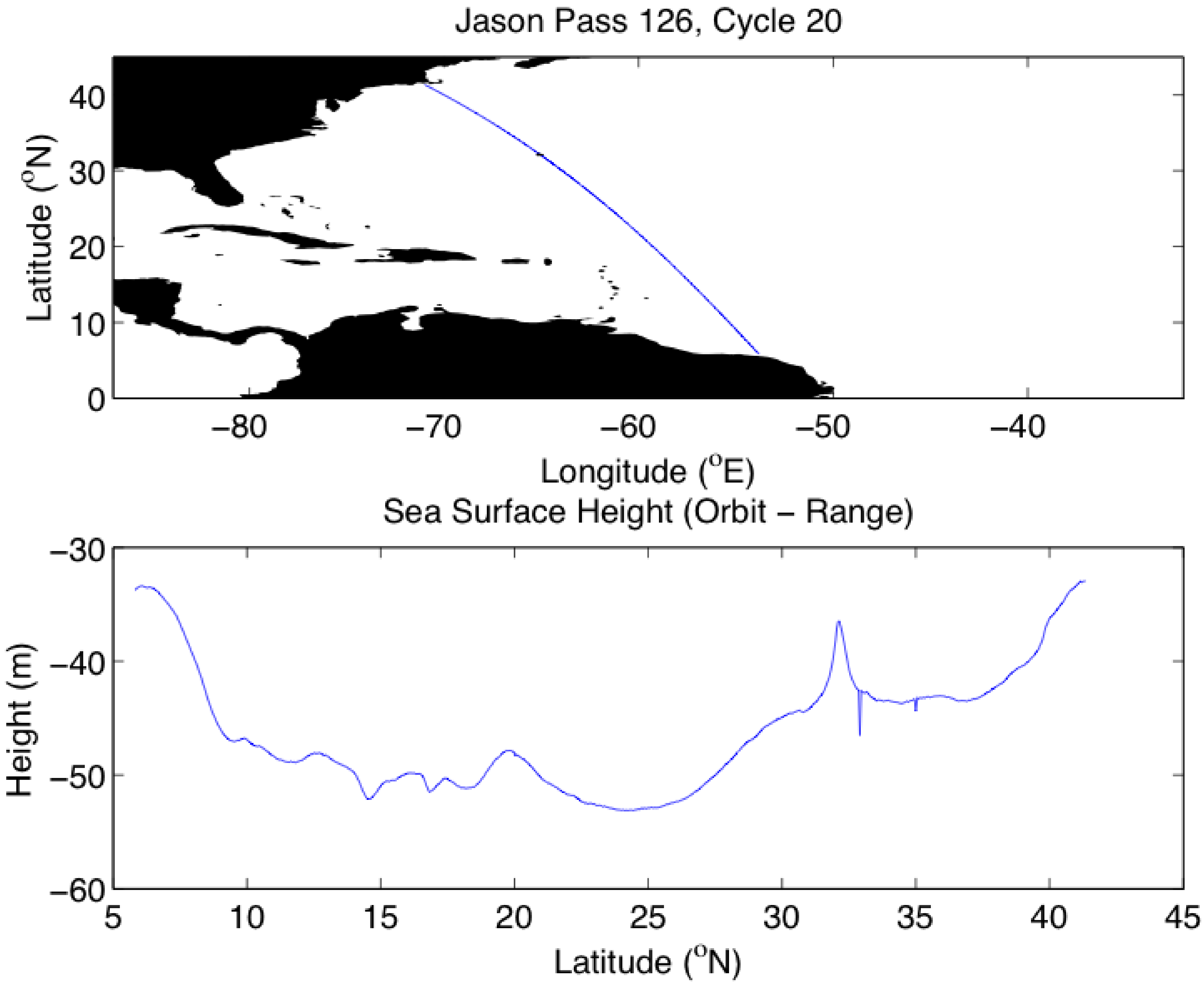
		T/P		ERS	
Tide	Period (h)	Alias (days)	wave length (°)	Alias (days)	wave length (°)
M2	12.42	62	9E	95	9E
S2	12	59	180W	0	∞
N2	12.65	50	9W	97	4W
K1	23.93	173	360W	365	360E
O1	25.82	46	9.23E	75	9E
P1	24.07	89	360W	365	360W

Example over a pass

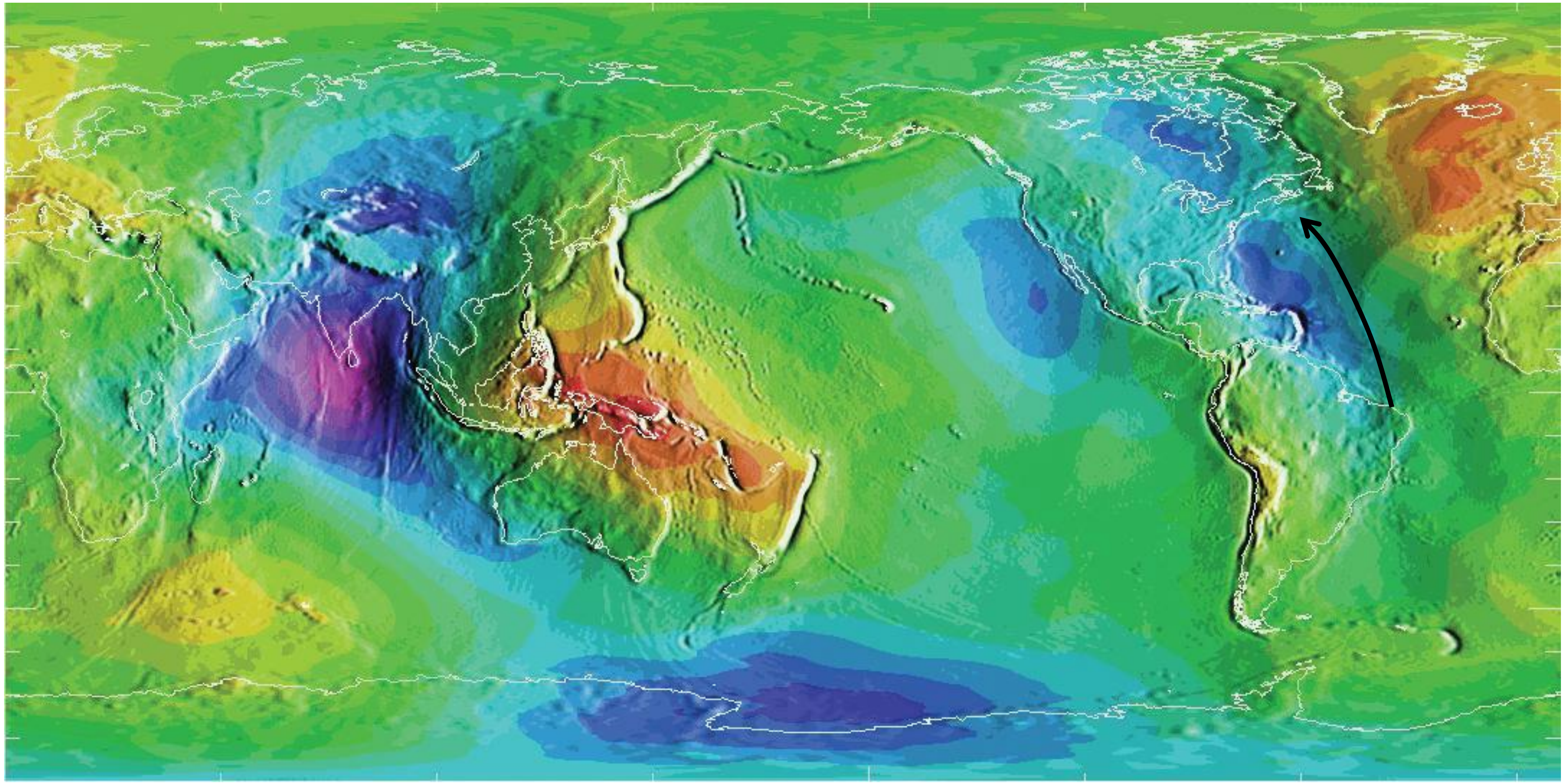




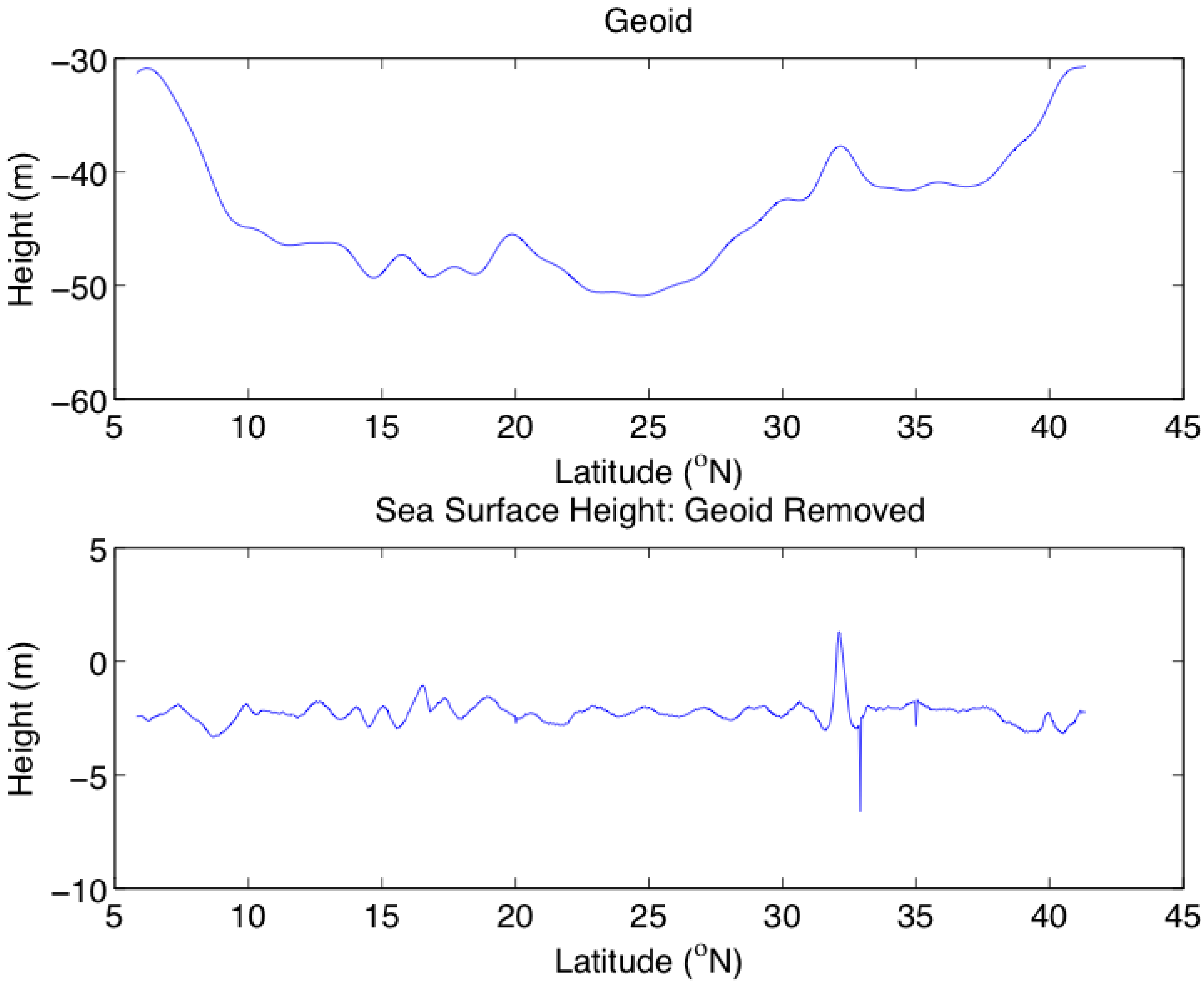
Jason Pass 126, Cycle 20
Latitude (°N)
40
30
20
10
0
−80
−70
−60
−50
−40
Longitude (°E)
Range
x 10^6
1.35
1.345
1.34
1.335
Height (m)
5
10
15
20
25
30
35
40
45
Latitude (°N)


Jason Pass 126, Cycle 20
Latitude (°N)
Longitude (°E)
Sea Surface Height (Orbit – Range)
Height (m)
Latitude (°N)

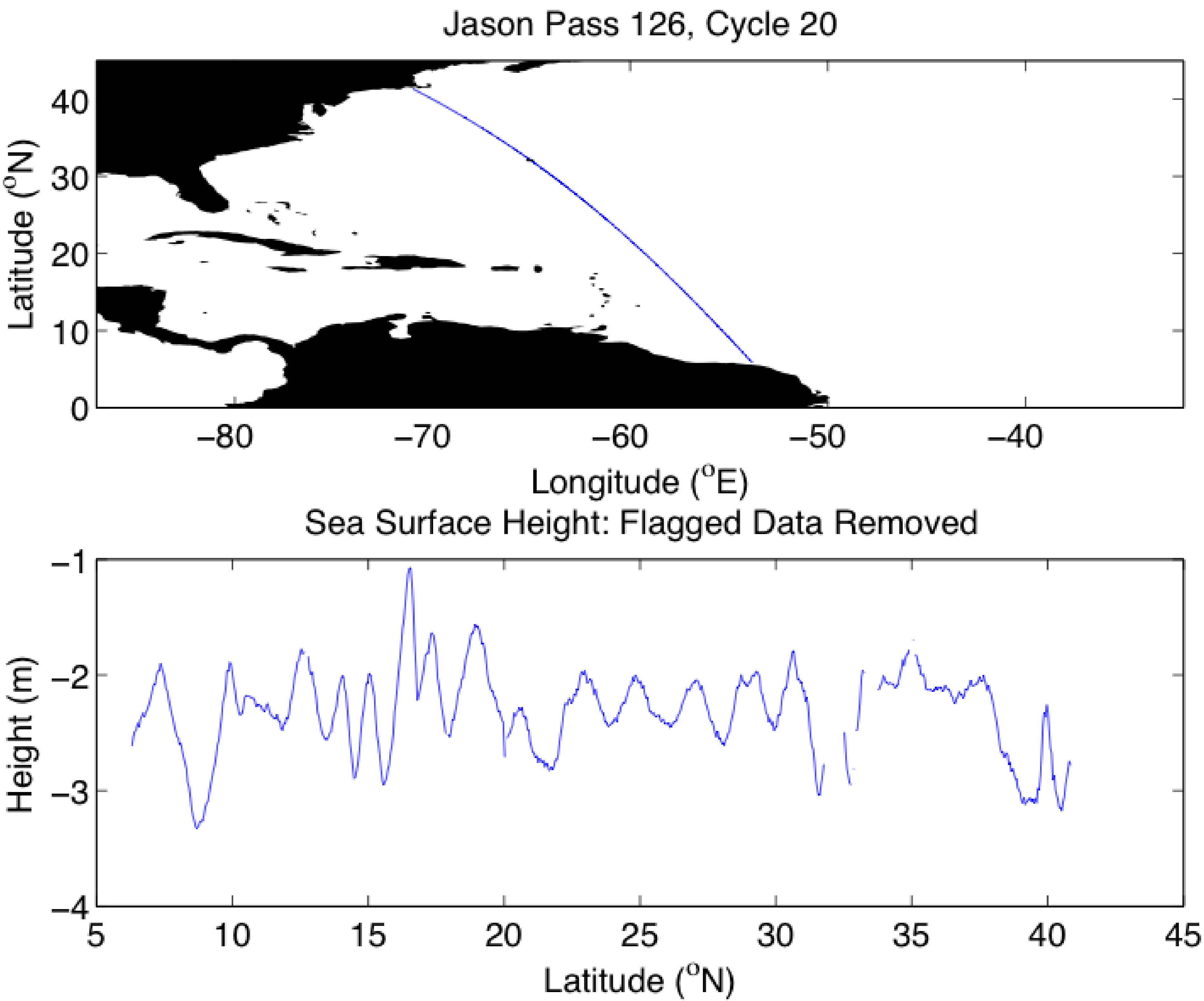
The Geoid

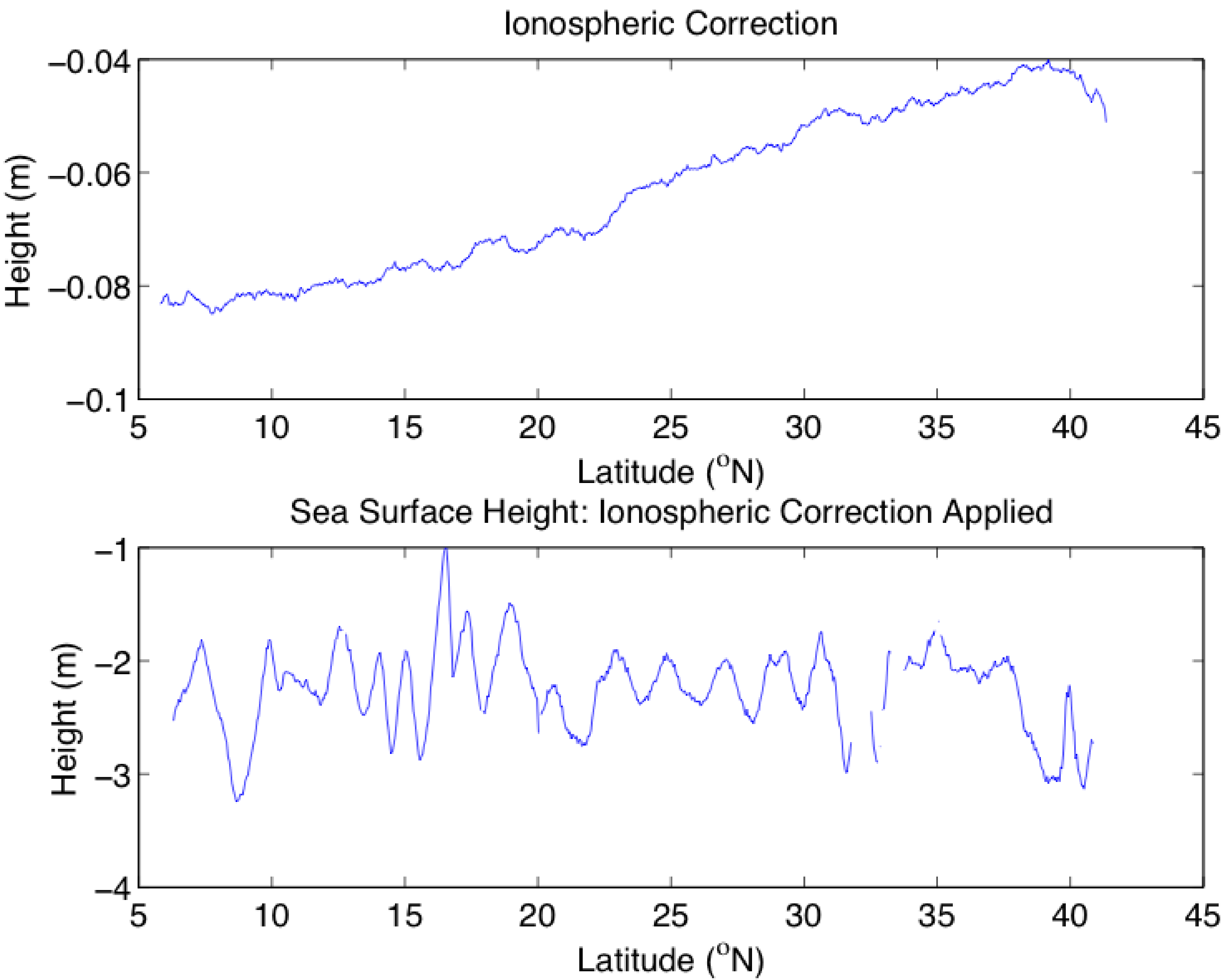


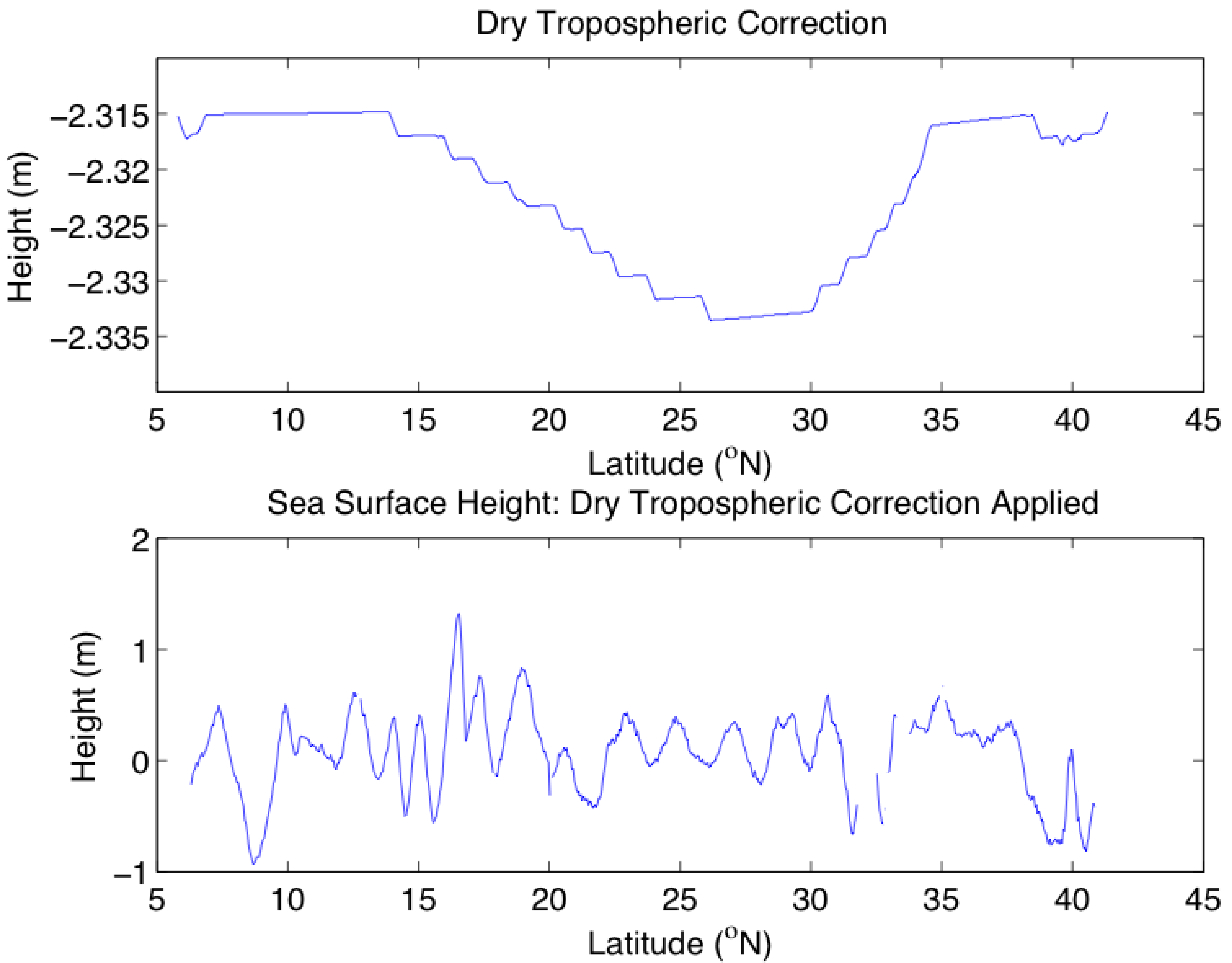
Scale: magenta (-107m) to red (84.5m)



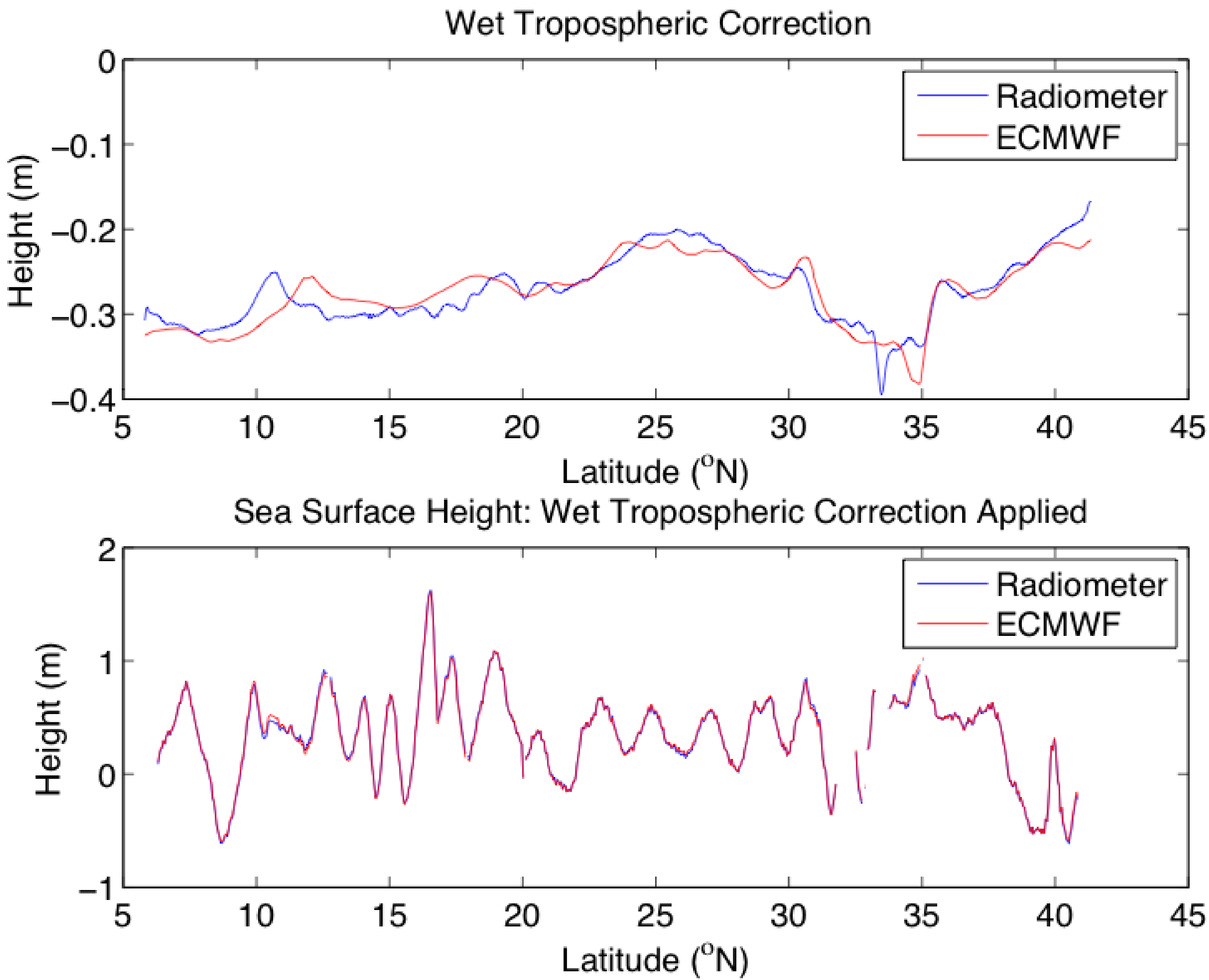
Geoid
Height (m)
−30
−40
−50
−60
5
10
15
20
25
30
35
40
45
Latitude (°N)
Sea Surface Height: Geoid Removed
Height (m)
5
0
−5
−10
5
10
15
20
25
30
35
40
45
Latitude (°N)


Jason Pass 126, Cycle 20
Latitude (°N)
Longitude (°E)
Sea Surface Height: Flagged Data Removed
Height (m)
Latitude (°N)

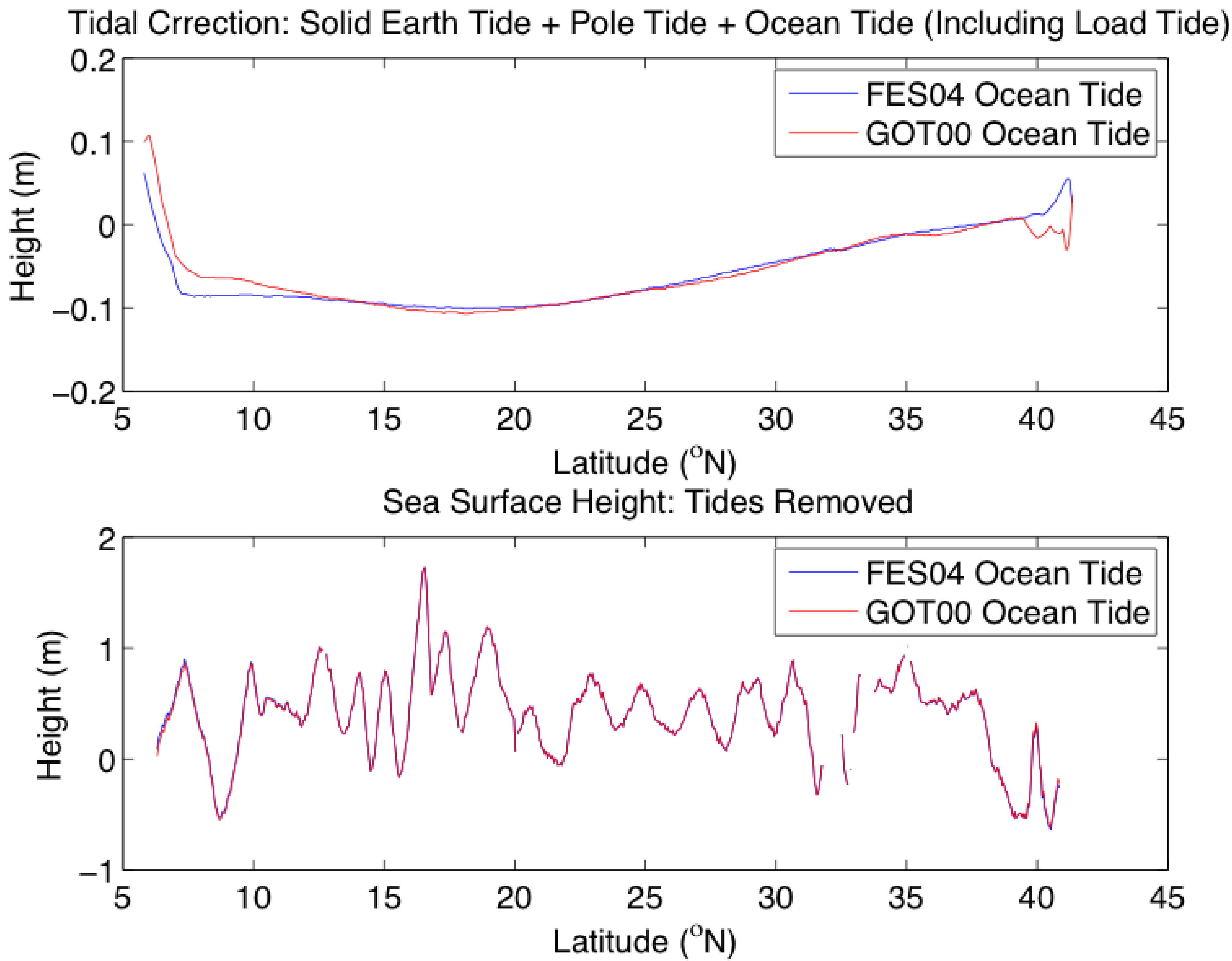

Ionospheric Correction
Height (m)
−0.04
−0.06
−0.08
−0.1
5
10
15
20
25
30
35
40
45
Latitude (°N)
Sea Surface Height: Ionospheric Correction Applied
Height (m)
−1
−2
−3
−4
5
10
15
20
25
30
35
40
45
Latitude (°N)

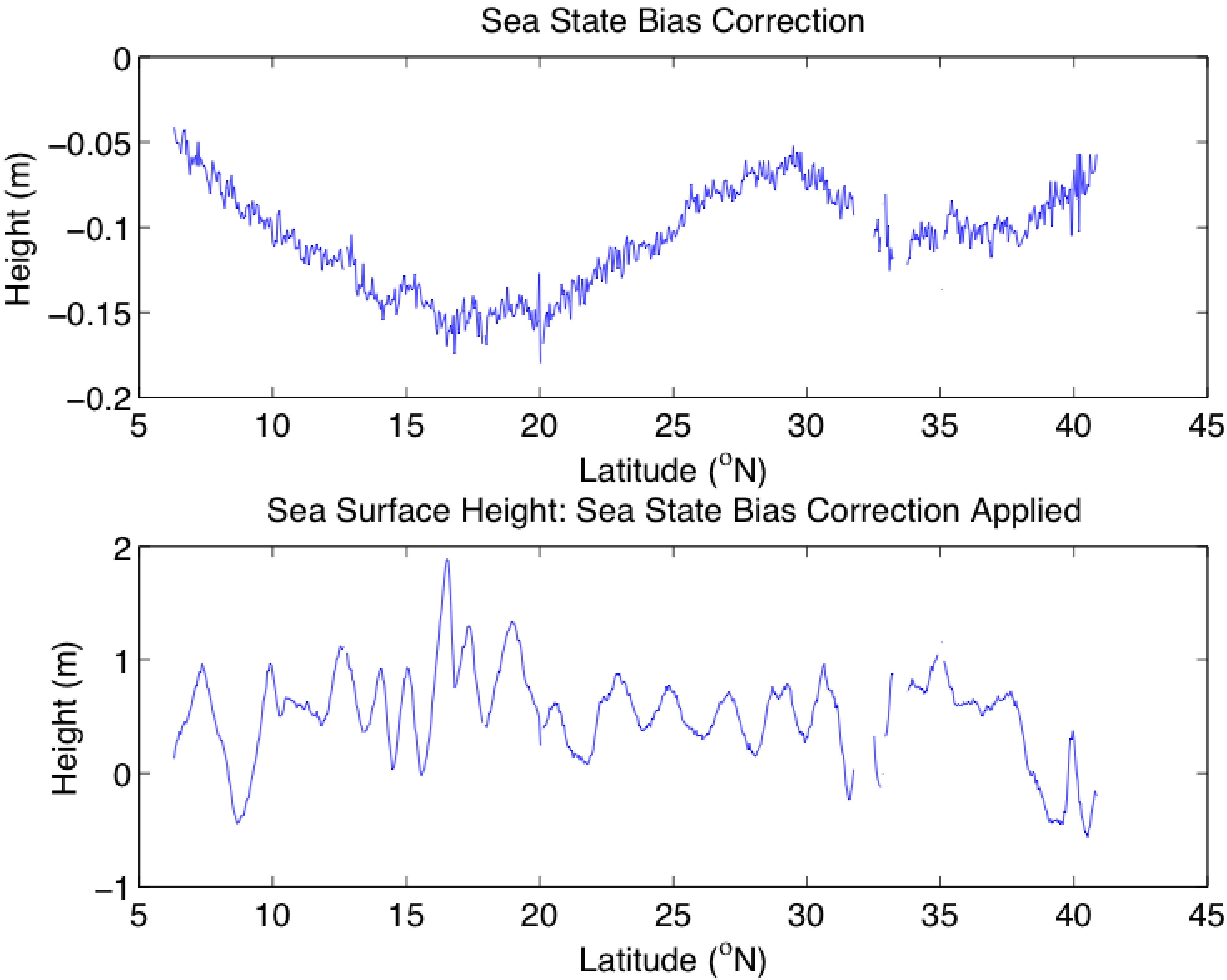


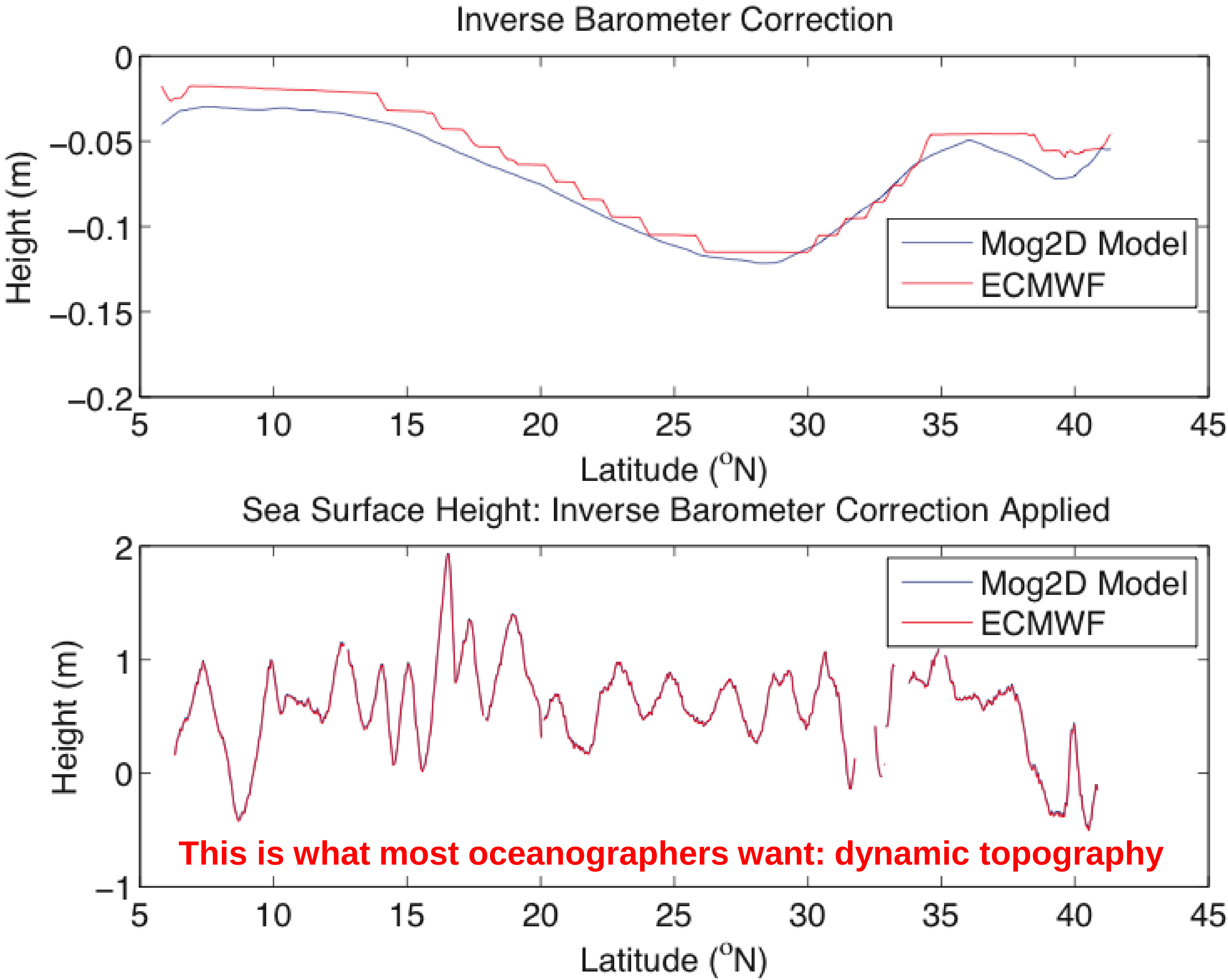
Dry Tropospheric Correction
Height (m)
−2.315
−2.32
−2.325
−2.33
−2.335
5
10
15
20
25
30
35
40
45
Latitude (°N)
Sea Surface Height: Dry Tropospheric Correction Applied
Height (m)
2
1
0
−1
5
10
15
20
25
30
35
40
45
Latitude (°N)

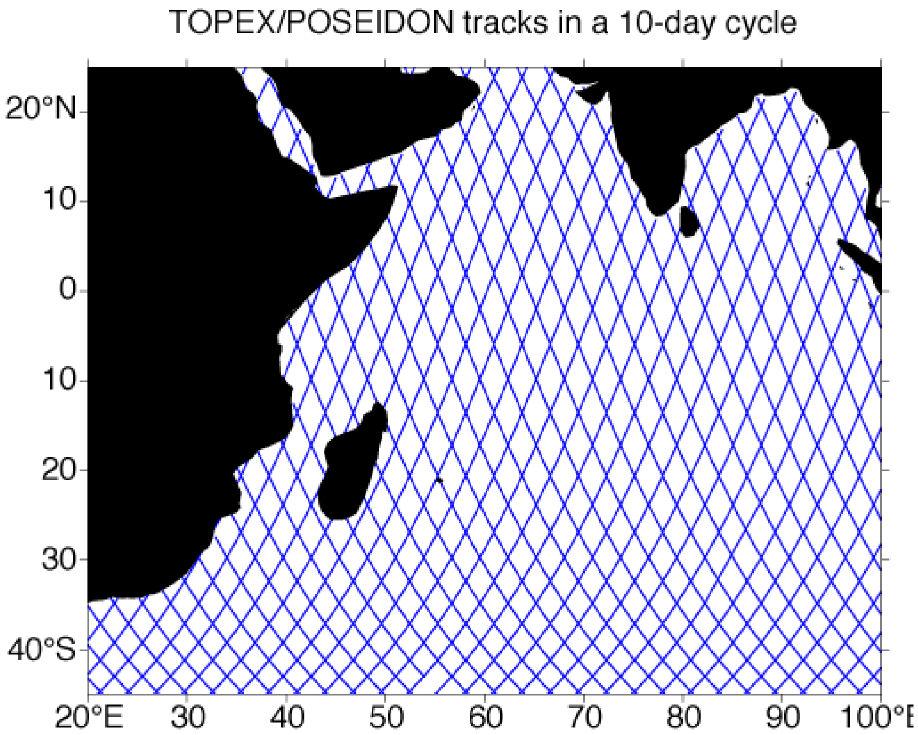


Wet Tropospheric Correction
Radiometer
ECMWF
Height (m)
0
−0.1
−0.2
−0.3
−0.4
5
10
15
20
25
30
35
40
45
Latitude (°N)
Sea Surface Height: Wet Tropospheric Correction Applied
Radiometer
ECMWF
Height (m)
2
1
0
−1
5
10
15
20
25
30
35
40
45
Latitude (°N)

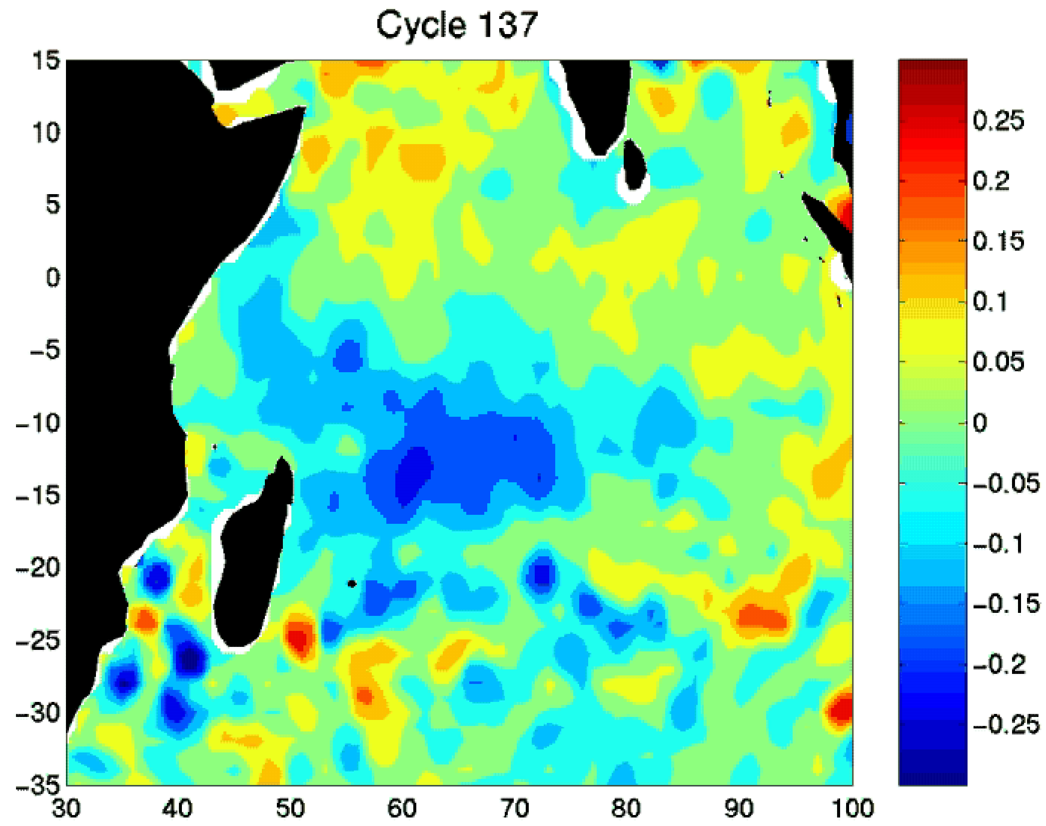

Tidal Crrection: Solid Earth Tide + Pole Tide + Ocean Tide (Including Load Tide)
FES04 Ocean Tide
GOT00 Ocean Tide
Height (m)
0.2
0.1
0
−0.1
−0.2
5
10
15
20
25
30
35
40
45
Latitude (°N)
Sea Surface Height: Tides Removed
FES04 Ocean Tide
GOT00 Ocean Tide
Height (m)
2
1
0
−1
5
10
15
20
25
30
35
40
45
Latitude (°N)


Sea State Bias Correction
Height (m)
0
−0.05
−0.1
−0.15
−0.2
5
10
15
20
25
30
35
40
45
Latitude (°N)
Sea Surface Height: Sea State Bias Correction Applied
Height (m)
2
1
0
−1
5
10
15
20
25
30
35
40
45
Latitude (°N)


Inverse Barometer Correction
Height (m)
0
−0.05
−0.1
−0.15
−0.2
5
10
15
20
25
30
35
40
45
Latitude (°N)
Mog2D Model
ECMWF
Sea Surface Height: Inverse Barometer Correction Applied
Height (m)
2
1
0
−1
Mog2D Model
ECMWF
This is what most oceanographers want: dynamic topography
5
10
15
20
25
30
35
40
45
Latitude (°N)



"Interpolation"
"Gridding"



Example of interpolated data and data in space and time