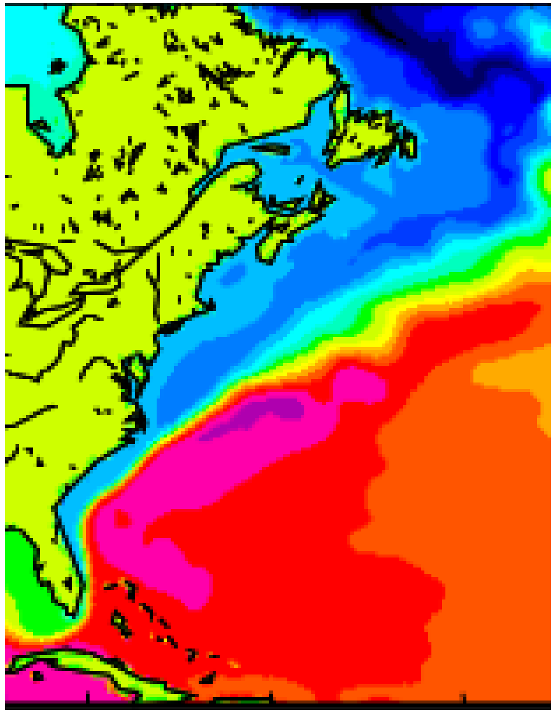
Small-Scale Signal in Mean Dynamic Topographies Applying Combined Geoid Models



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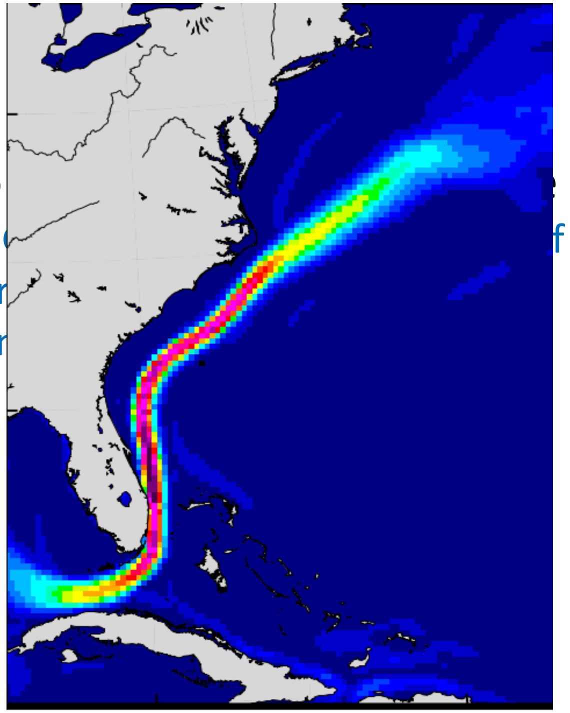


Small-Scale Signal in Mean Dynamic Topographies Applying Combined Geoid Models

- Computation of geodetic MDT (new globalization methodology for MSS)
- Comparison of ‘geodetic’ geostrophic surface currents with near/surface drifter data for 6 test cases
- Small scale signal content : regional test for Gulf Stream and Kuroshio

Computation of geodetic Mean Dynamic Topography (MDT)

- Geoid model *N* is synthesized up to selected max. d/o d_{max}
- Mean Sea Surface (MSS) is globalized and synthesized up to d_{max}
- MDT=MSS-N

  following Bingham et al. (2008)

- The MDT is filtered applying a truncated Gaussian kernel with filter scale *r* (truncated at 3**r*)

The MDT depends on three parameters:

- the geoid model *N* (GOCO05c, EGM2008, Eigen6c4, GECO, UGM)
- the cutoff d/o d_{max} (250, 300, 360, 420, 480, 540, 600, 720, 840, 960)
- the filter scale *r* [0°, 0.1°, 0.2°,…, 1°]

The (ocean) MSS applied is DTU15MSS (*Andersen et al., 2016*)

Computation of geodetic Mean Dynamic Topography (MDT)

New methodology for globalizing the MSS

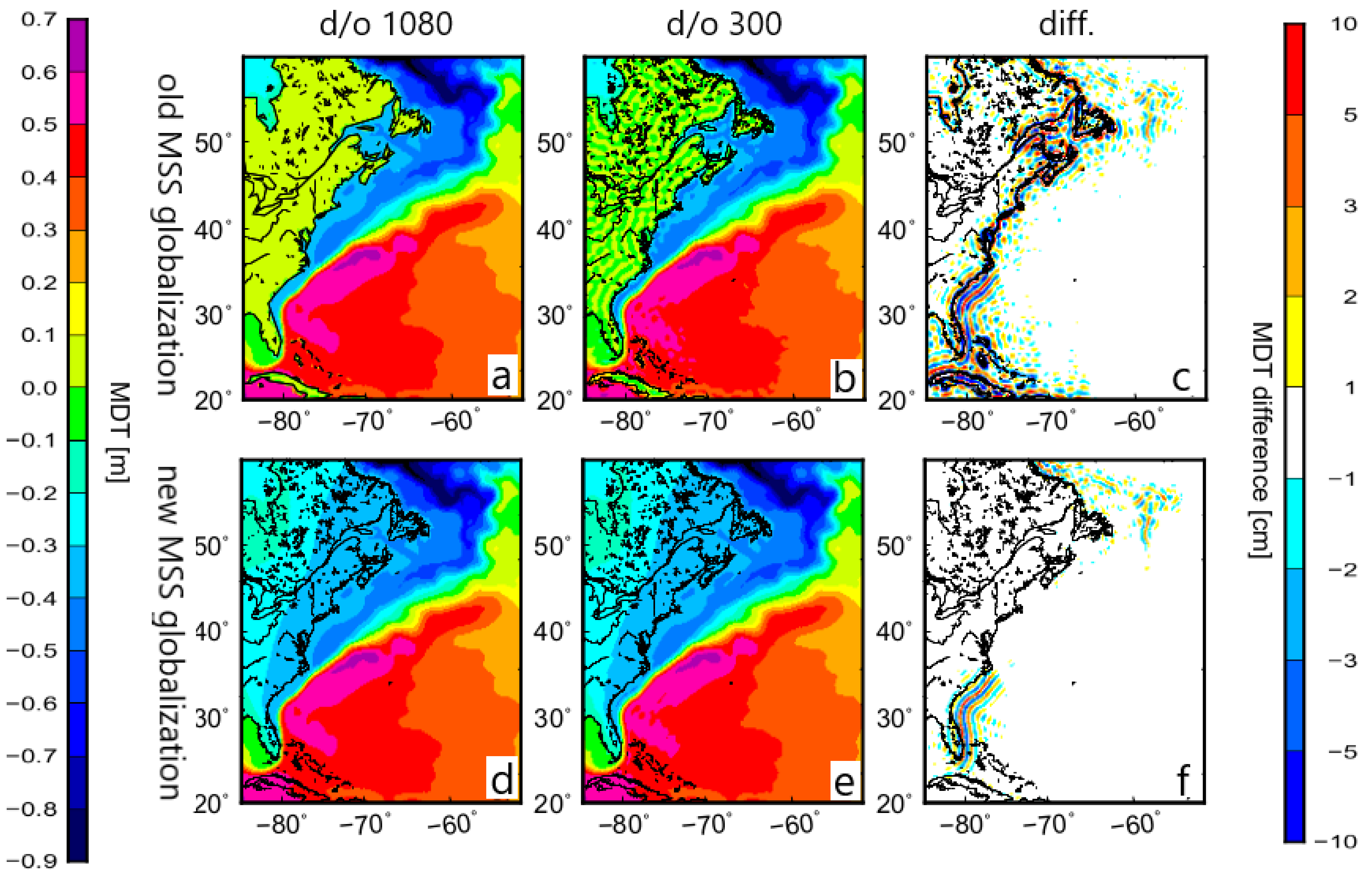
Conventional approach:

- A geoid model is used as fill-in (means MDT=0 over land), which causes a land-sea step in MDT=MSS-N and Gibbs effects when decreasing spectral resolution to selected max. d/o

New approach (Siegismund, 2020):

- MSS includes MDT information over land:
  - A Coastal MDT is estimated as difference of the MSS and a high resolution geoid model
  - A smooth MDT is defined over land by solving the Laplace equation with the coastal MDT as boundary condition (source-free heat equation)

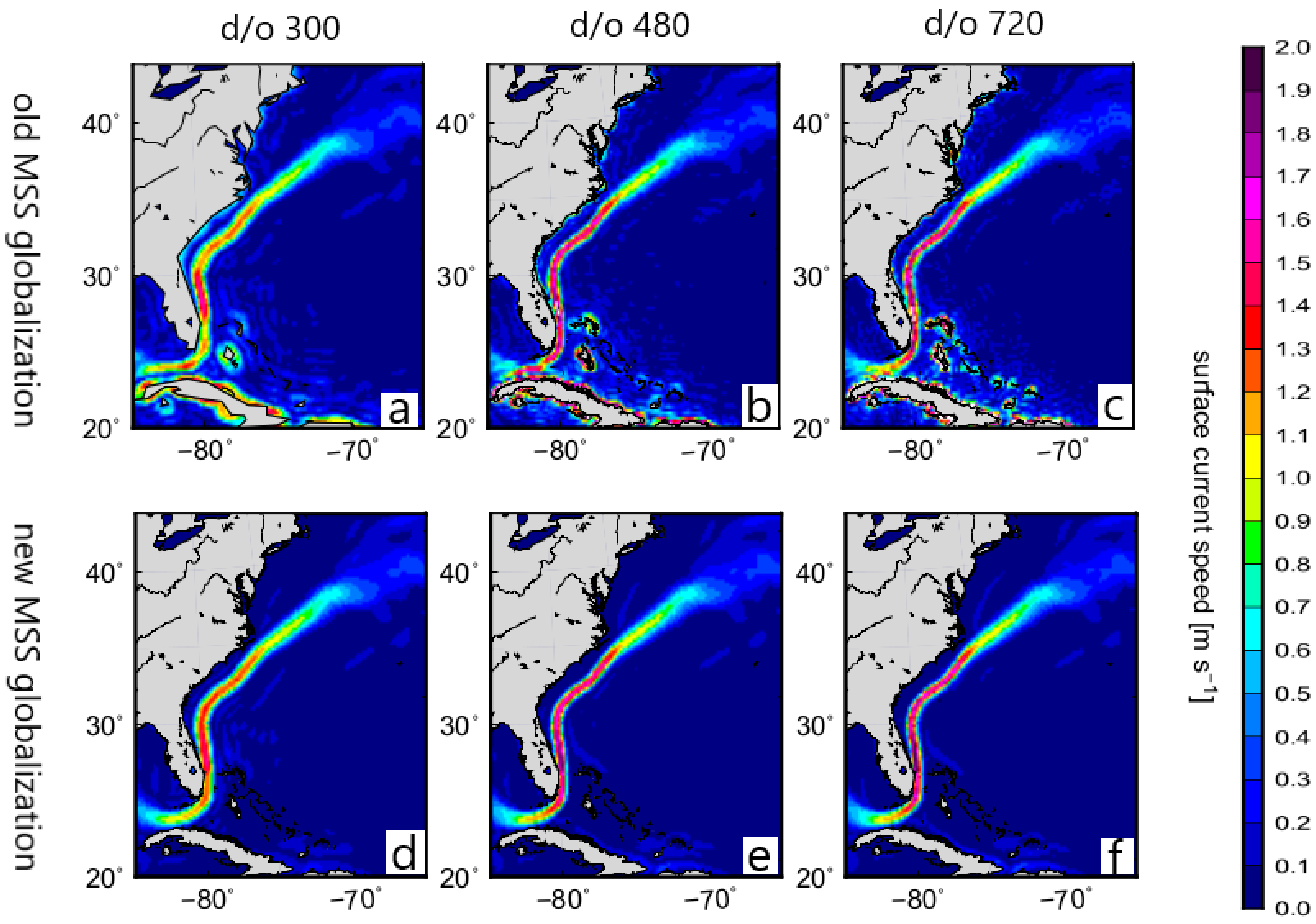
New methodology for globalizing the MSS



Idealized example for proposed MSS globalization:

- A high resolution North Atlantic hydrodynamic model (MITgcm; Biri et al., 2016) is interpolated to a 10'x10' grid (equivalent to d/o 1080).
- Grid points over land and outside-model domain are set
  - either to 0 (panel **a**; conventional method: MDT=0)
  - or filled by solving Laplace's equation (panel **d**; new method: smooth MDT over land, no land-sea step)
- Spherical harmonic cut-off at d/o 300 is performed for both methods:
  - panel **b**: conventional method,
  - panel **e**: new method
- The differences (d/o 300 – d/o 1080) show
  - reduced Gibbs effects in the new method (panel **f**)
  - compared to the conventional method (panel **c**).

New methodology for globalizing the MSS



The proposed smooth MSS globalization has especially strong effects on the surface geostrophic currents computed from the MDTs at different cut-off d/o.

Combined geoid models applied:

Model	data	degree	Reference
GOCO05c	A,G,S	720	Fecher et al. (2017)
SGG-UGM-1	EGM2008, S(Goce)	2159	Liang et al. (2018)
GECO	EGM2008, S(Goce)	2190	Gilardoni et al. (2016)
EIGEN6C4	A,G,S(Goce),S(Grace),S(Lageos)	2190	Frst et al. (2014)
EGM2008	A,G,S(GRACE)	2190	Pavlis et al. (2012)

Comparison of surface geostrophic currents from geodetic MDTs with drifter data

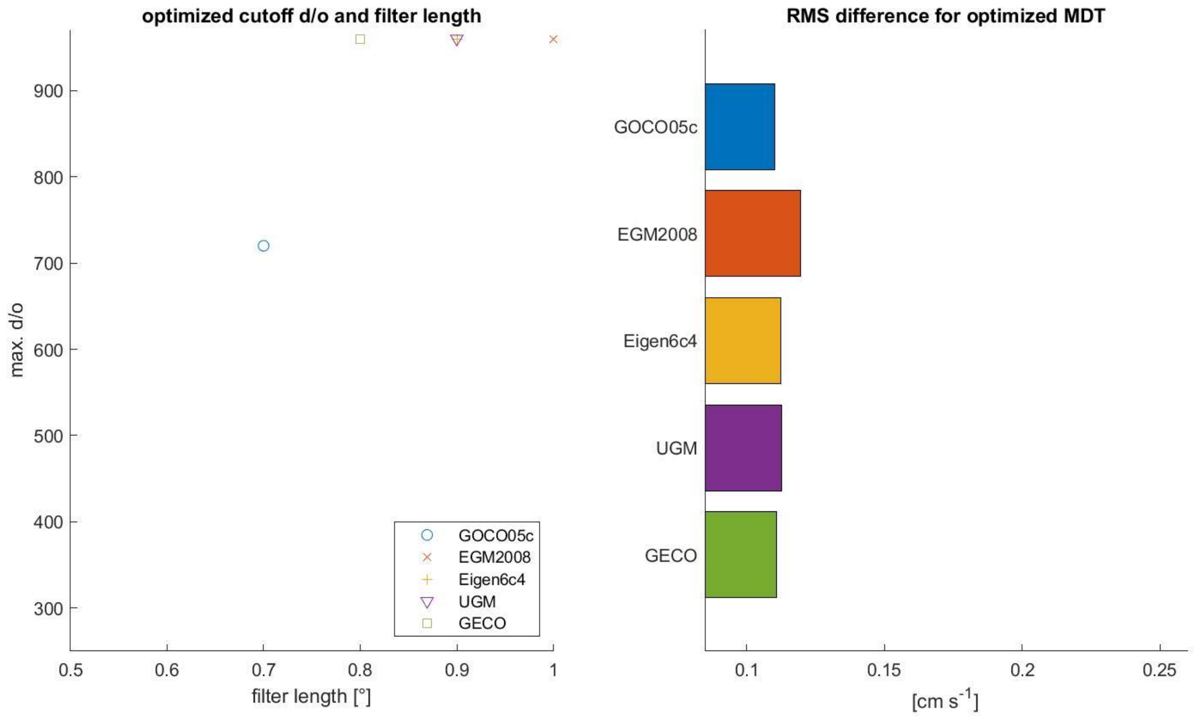
The 6h near-surface drifter velocities (GDP; Lampkin and Centurioni, 2019) are geostrophically corrected independent from any MDT model (Siegismund, 2020).

RMS differences to geostrophic surface currents from geodetic MDTs are calculated for the following test regions:

1. Global (65°S-65°N)
2. Without coastal area (more than 100 km offshore)
3. Only coastal area (not more than 100 km offshore)
4. Reference velocity > 30 cm s^{-1} and more than 100 km offshore
5. Reference velocity < 2 cm s^{-1} and more than 100 km offshore

Reference velocities are obtained from MDT CNES-CLS18 (Rio et al., 2018)

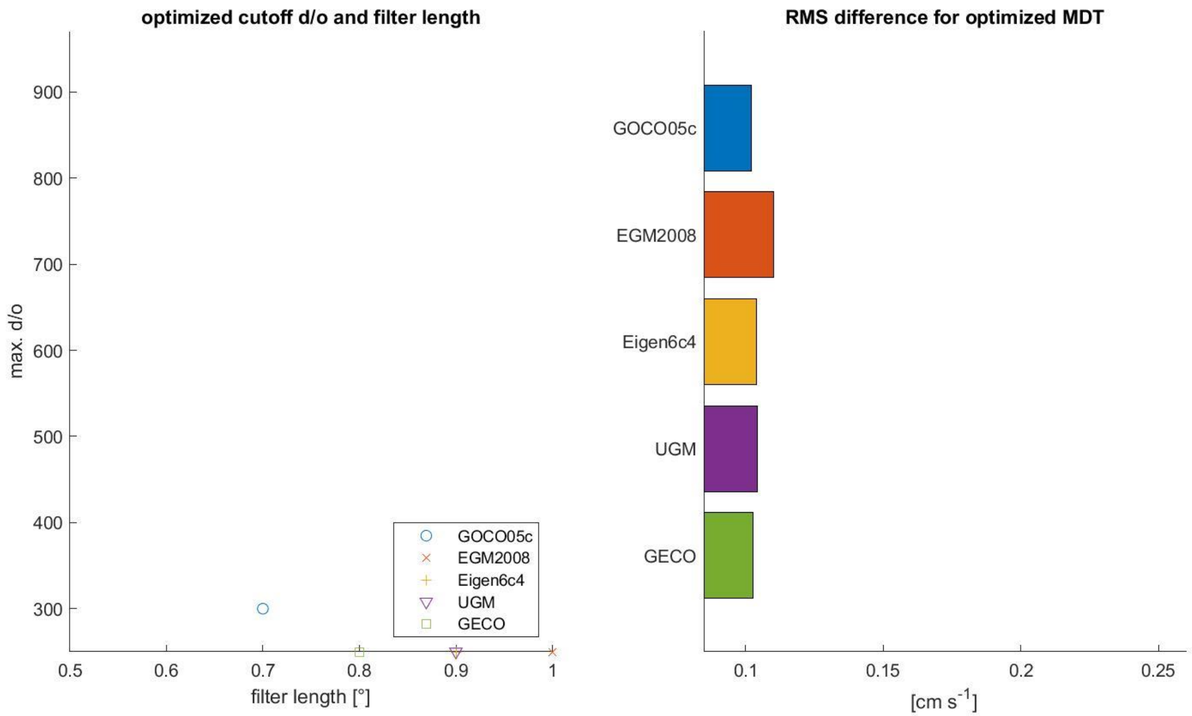
Test region 1: Global (65°S-65°N)



Each MDT model is optimized with respect to max. d/o and scale of the spatial filter to minimize RMS difference to geostrophically corrected near-surface drifter data.

For all geoid models highest spectral resolution is optimal (GOCO05c comes with max. d/o 720), but the optimum spatial filter (with $r \geq 0.7°$) kills large part of the small scale information.

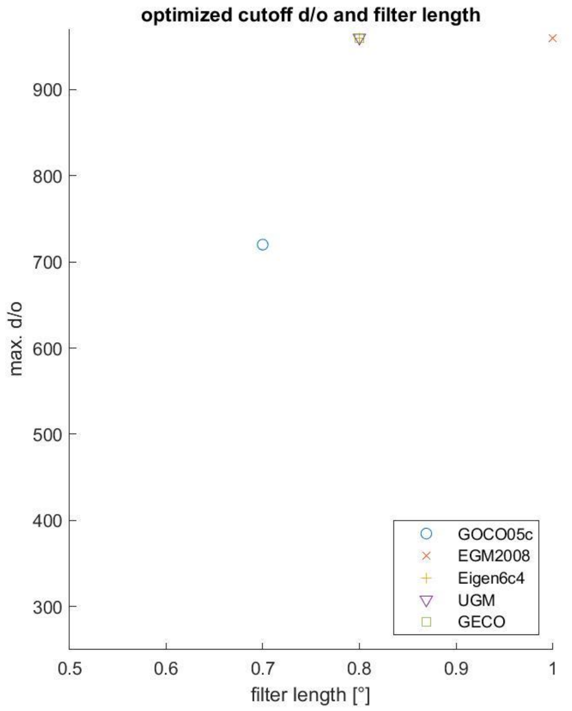
Test region 2: Without coastal area (more than 100 km offshore)

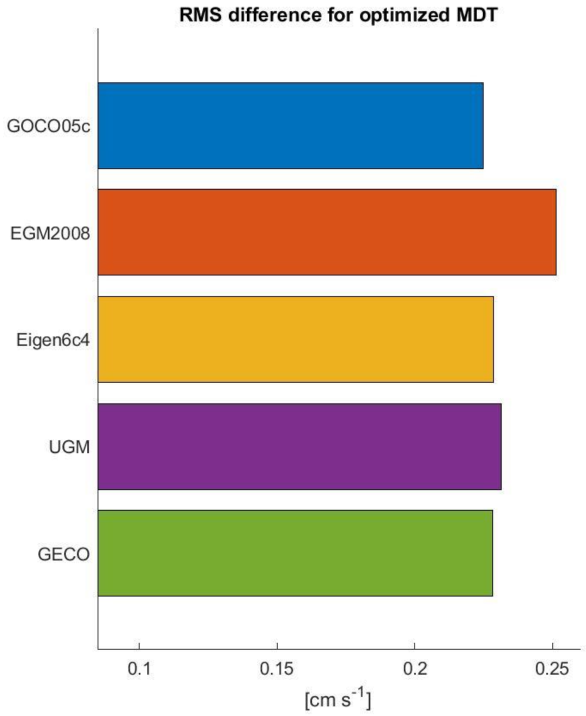


Each MDT model is optimized with respect to max. d/o and scale of the spatial filter to minimize RMS difference to geostrophically corrected near-surface drifter data.

Without the coastal area best MDT models come with d/o 250 (EGM2008, Eigen6c4, UGM, GECO) or d/o 300 (GOCO05c) while filter scale is unchanged compared to the global case.
Probably this is especially due to (erroneous) strong MSS gradients near the coast, causing Gibbs effects when cutting-off small scales (there are no strong gradients/ steps at the coast and over land due to the new MSS globalization approach!)

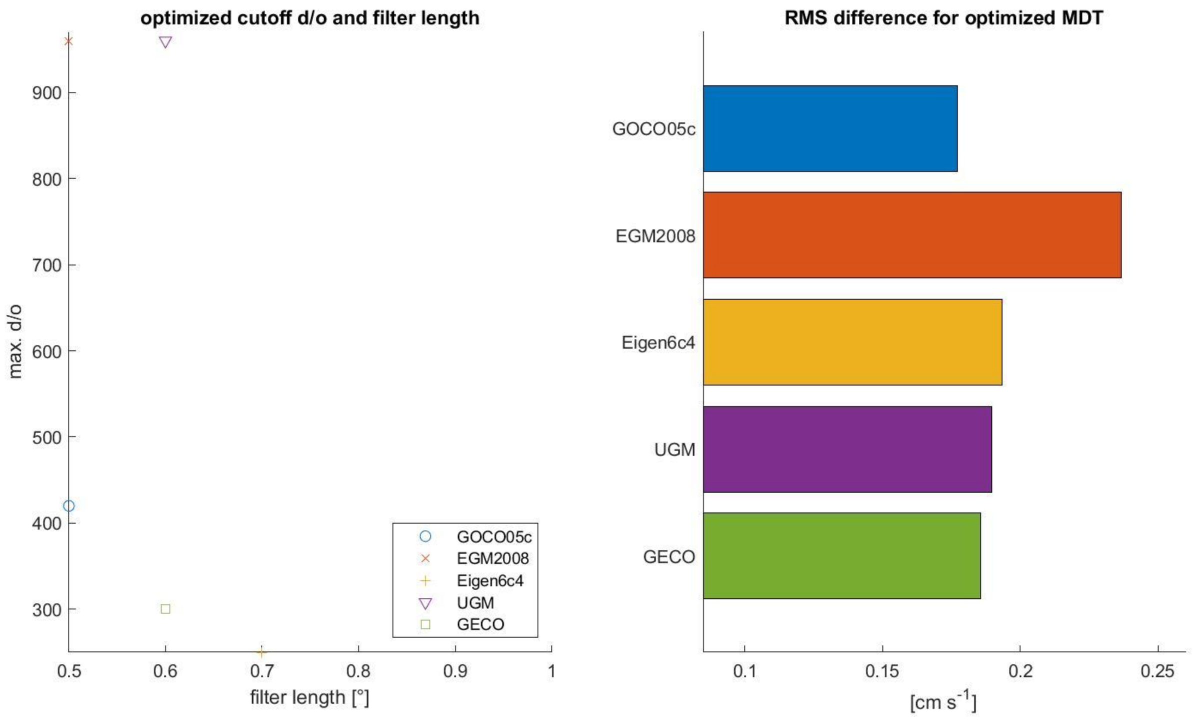
Test region 3: Only coastal area (not more than 100 km offshore)





As expected, if only the coastal area is considered, highest spectral resolution is optimal.

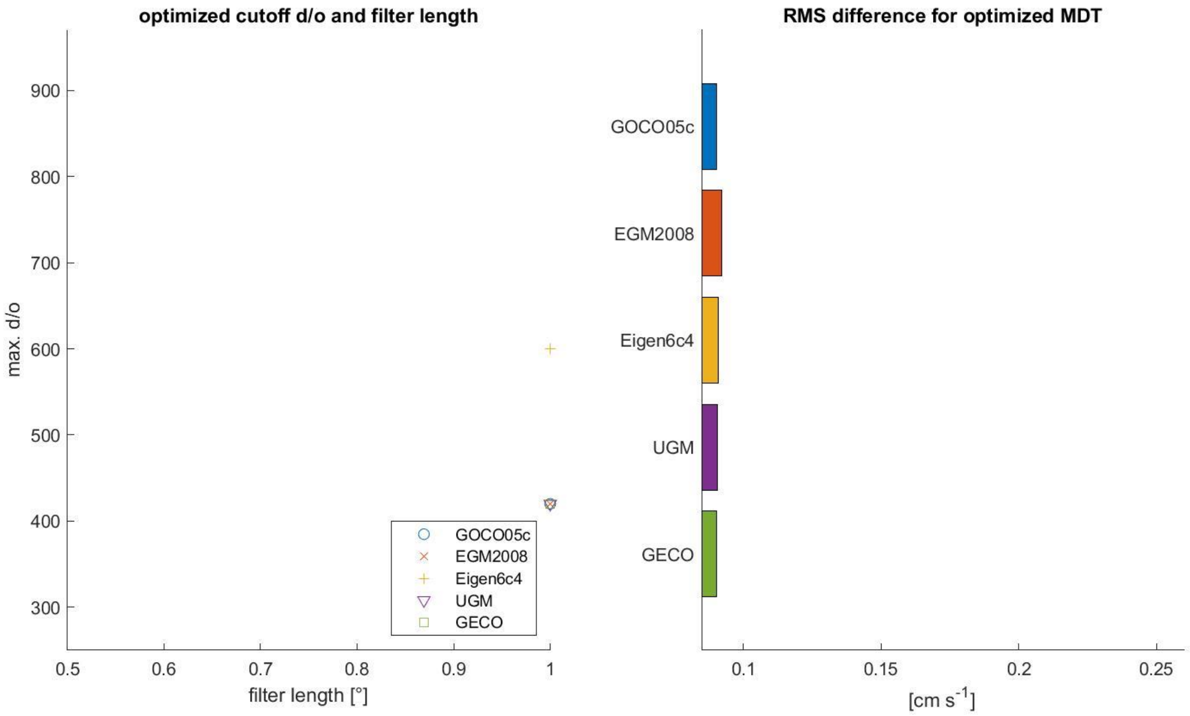
Test region 4: Reference velocity > 30 cm s-1 and more than 100 km offshore

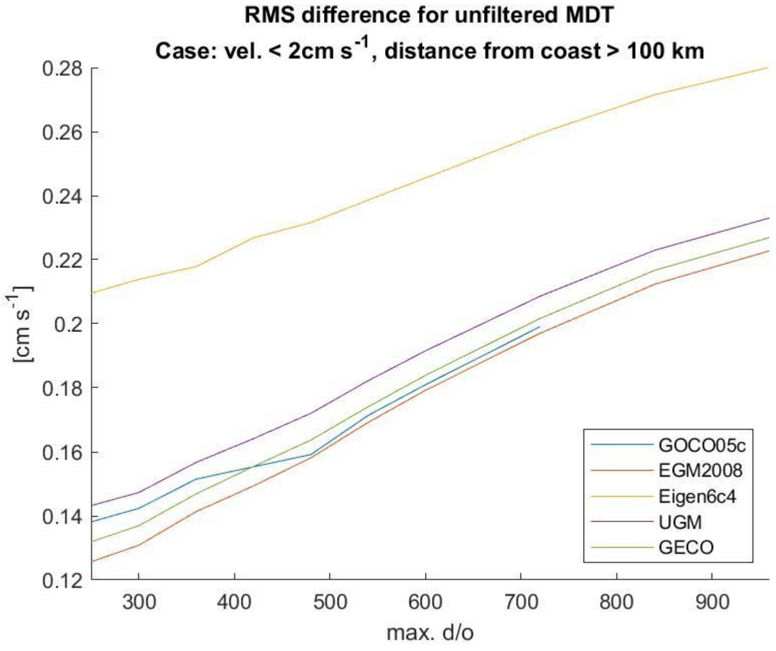


- This case includes strong small scale currents where signal content on small scales is needed to reduce the omission error
- For GOCO05c, Eigen6c and GECO optimum spectral resolution, however is only 420, 250 and 300, respectively.
- For EGM2008 and UGM, though optimum d/o is 960, RMS hardly changes for cut-off d/o beyond 300 (changes are below 0.1 mm s^{-1} for both models, not shown)

Small scale signal content further discussed in detail for Gulf Stream and Kuroshio.

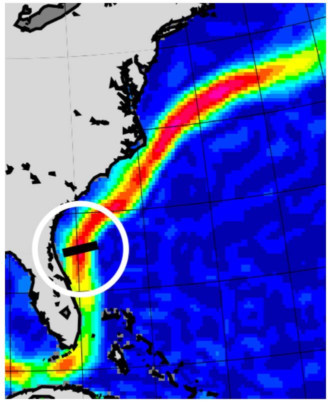
Test region 5: Reference velocity < 2 cm s-1 and more than 100 km offshore

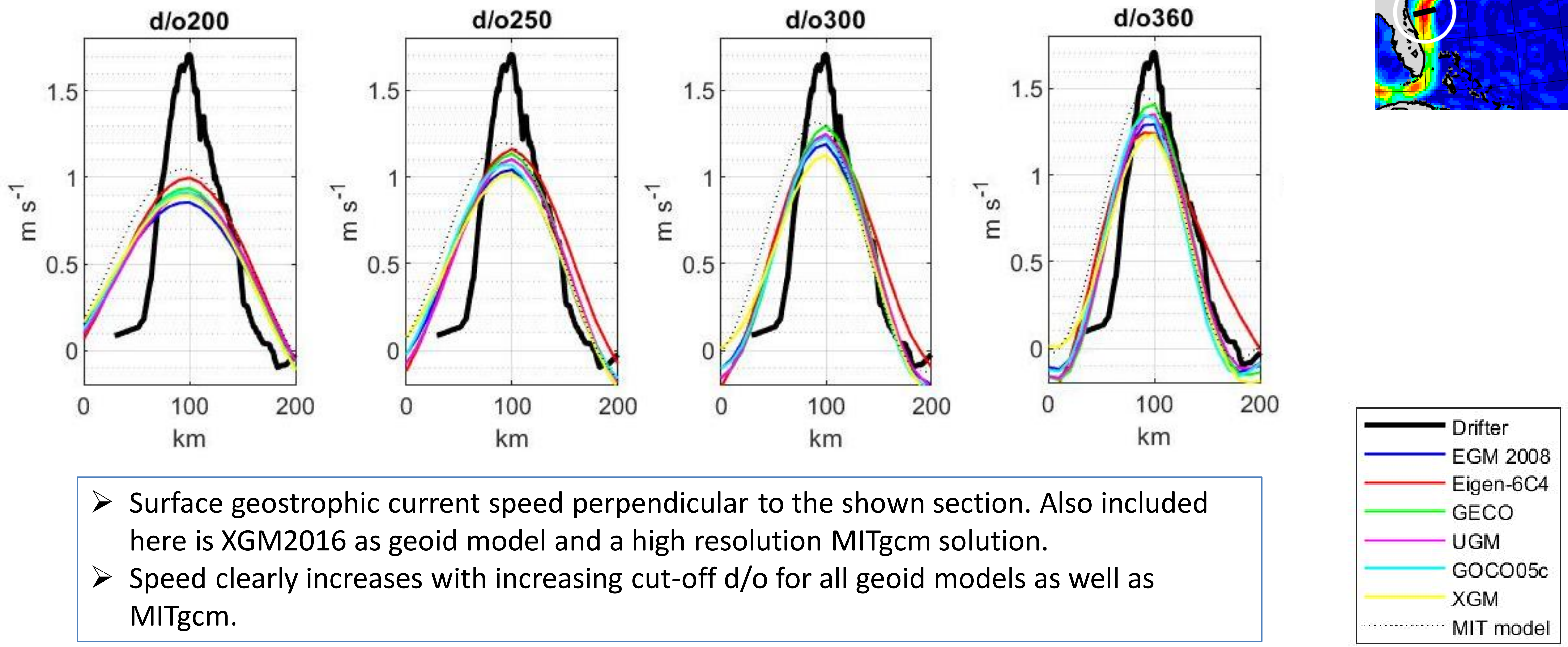




Probably, optimum filter length > 1° for all geoid models (not tested). Since expected signal is small, this case is suitable to test (relative) commission error of the MDT models depending on d/o (right panel). The commission error increases with max. d/o and is significantly higher for Eigen6c4 than for all other geoid models.

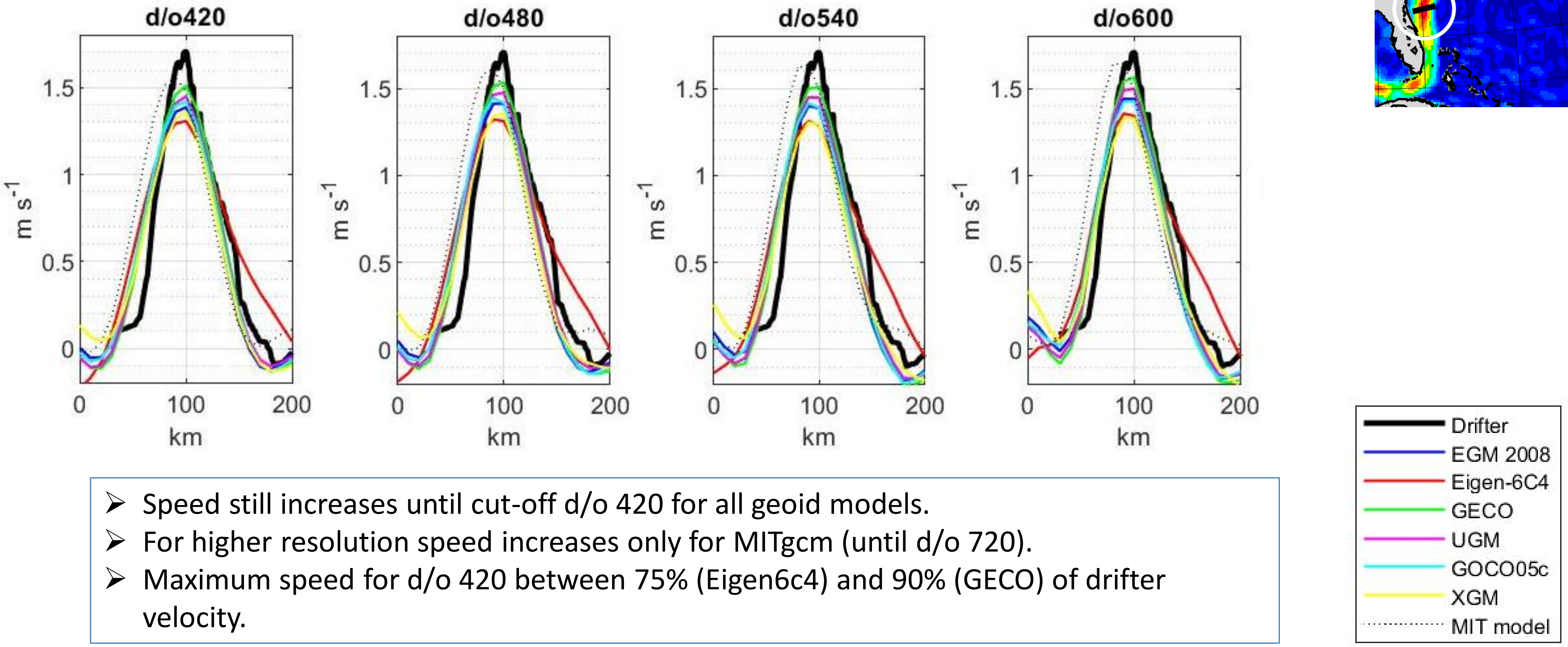
Gulf Stream: Signal content depending on spectral resolution

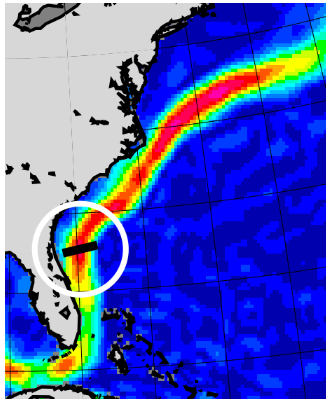




- Surface geostrophic current speed perpendicular to the shown section. Also included here is XGM2016 as geoid model and a high resolution MITgcm solution.
- Speed clearly increases with increasing cut-off d/o for all geoid models as well as MITgcm.

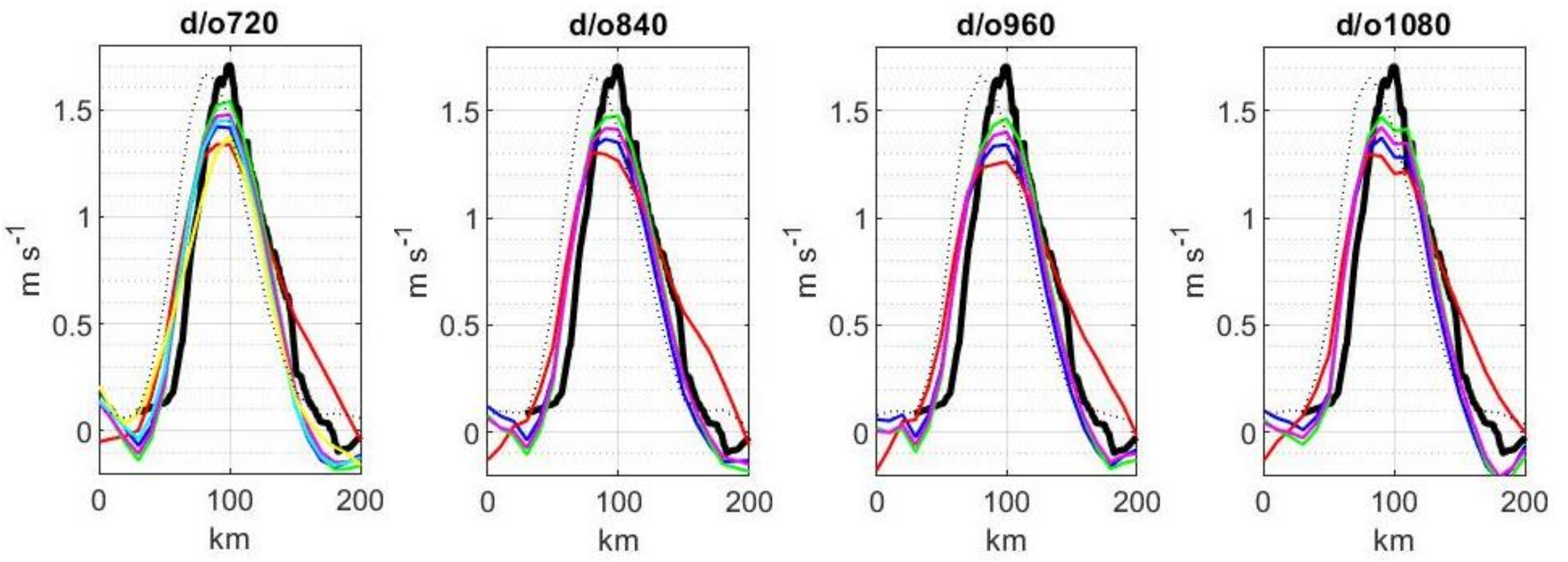
Gulf Stream: Signal content depending on spectral resolution

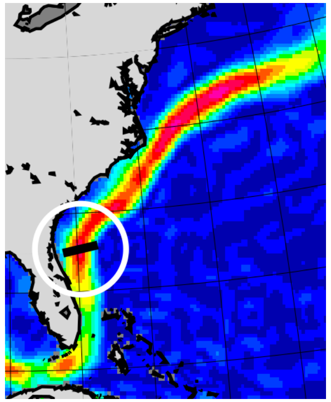


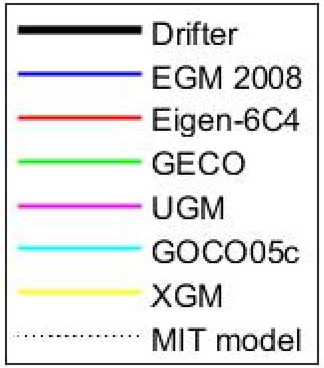


- Speed still increases until cut-off d/o 420 for all geoid models.
- For higher resolution speed increases only for MITgcm (until d/o 720).
- Maximum speed for d/o 420 between 75% (Eigen6c4) and 90% (GECO) of drifter velocity.

Gulf Stream: Signal content depending on spectral resolution

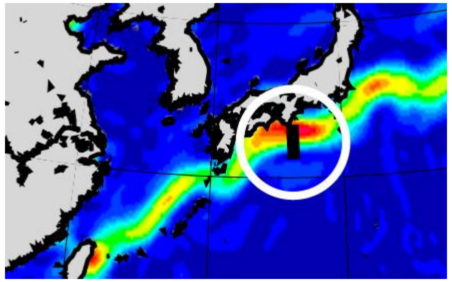


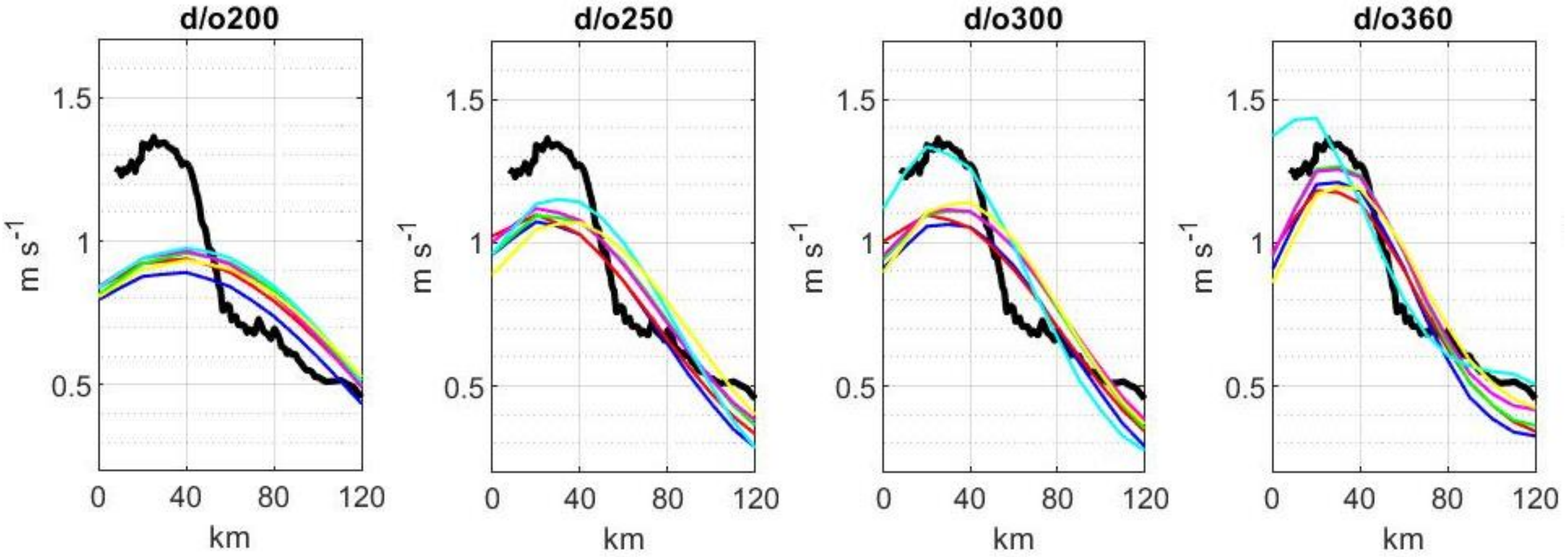


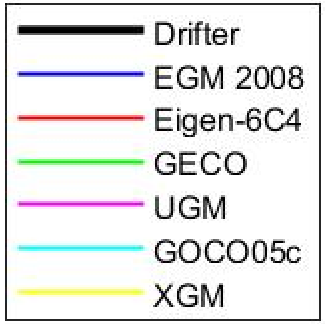


- ➢ Speed still increases until cut-off d/o 420 for all geoid models.
- ➢ For higher resolution speed increases only for MITgcm (until d/o 720).
- ➢ Maximum speed for d/o 420 between 75% (Eigen6c4) and 90% (GECO) of drifter velocity.

Kuroshio: Signal content depending on spectral resolution

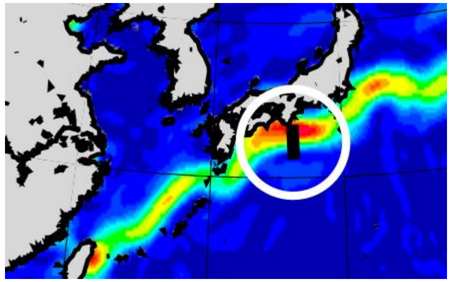


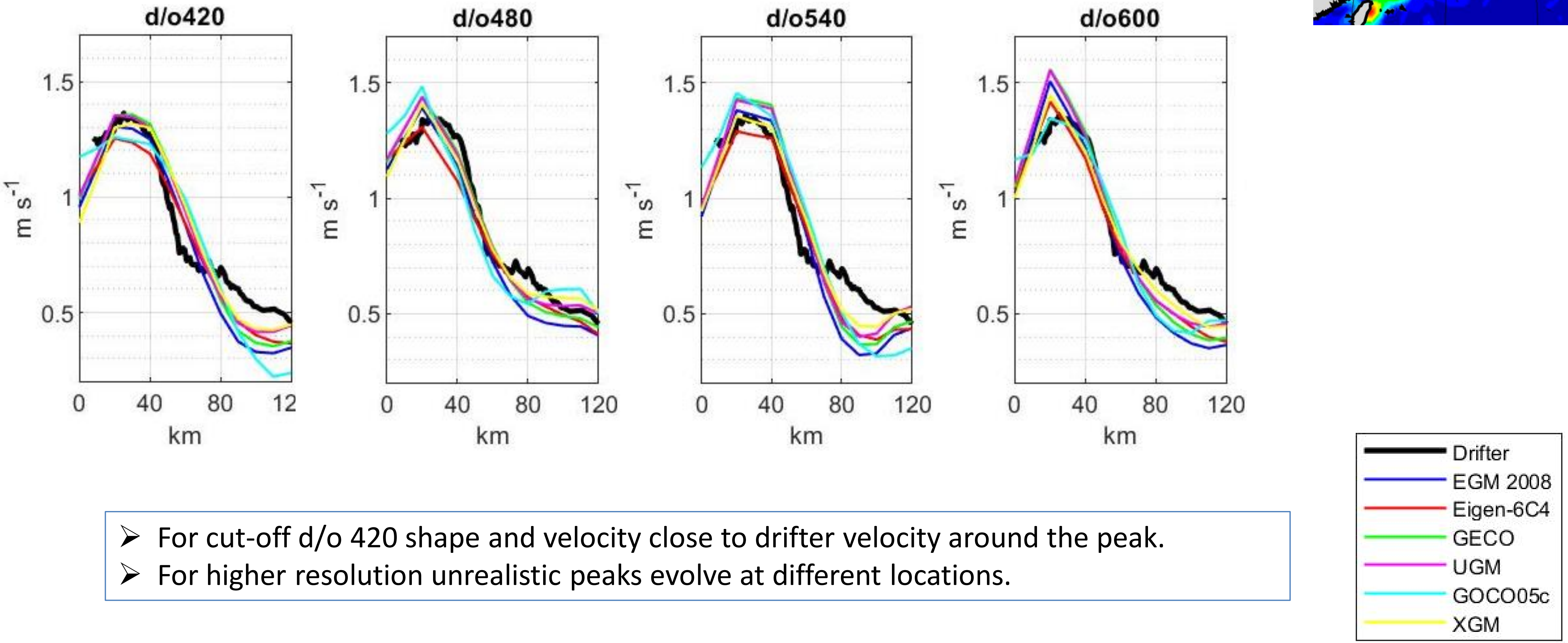




- Surface geostrophic current speed perpendicular to the shown section. Also included is here XGM2016 as geoid model.
- Speed clearly increases with increasing cut-off d/o for all geoid models (though GOCO05c overshoots).

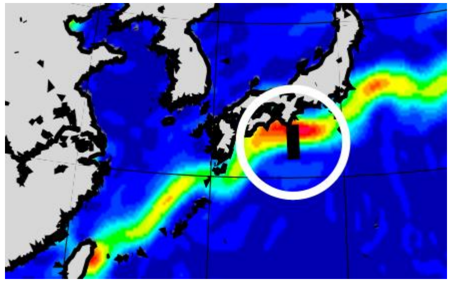
Kuroshio: Signal content depending on spectral resolution

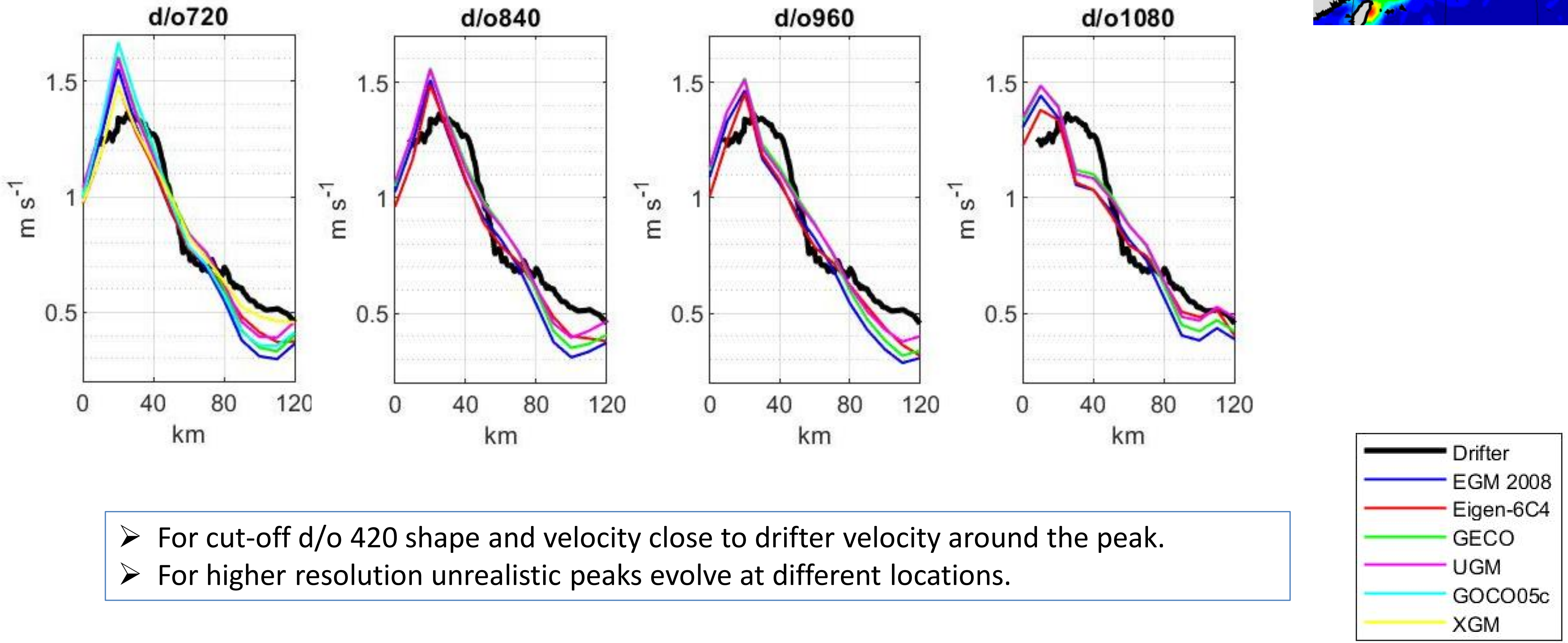




- For cut-off d/o 420 shape and velocity close to drifter velocity around the peak.
- For higher resolution unrealistic peaks evolve at different locations.

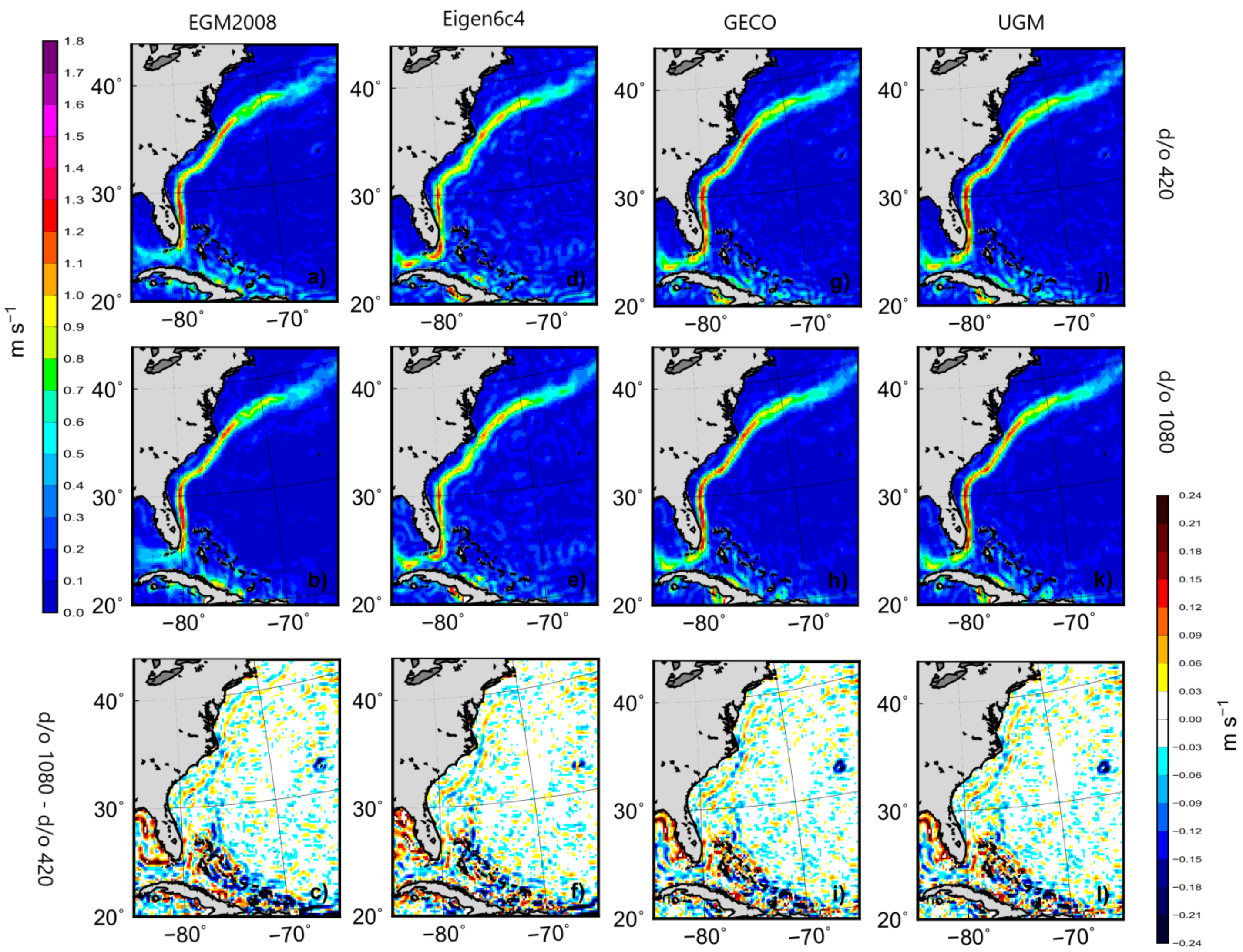
Kuroshio: Signal content depending on spectral resolution





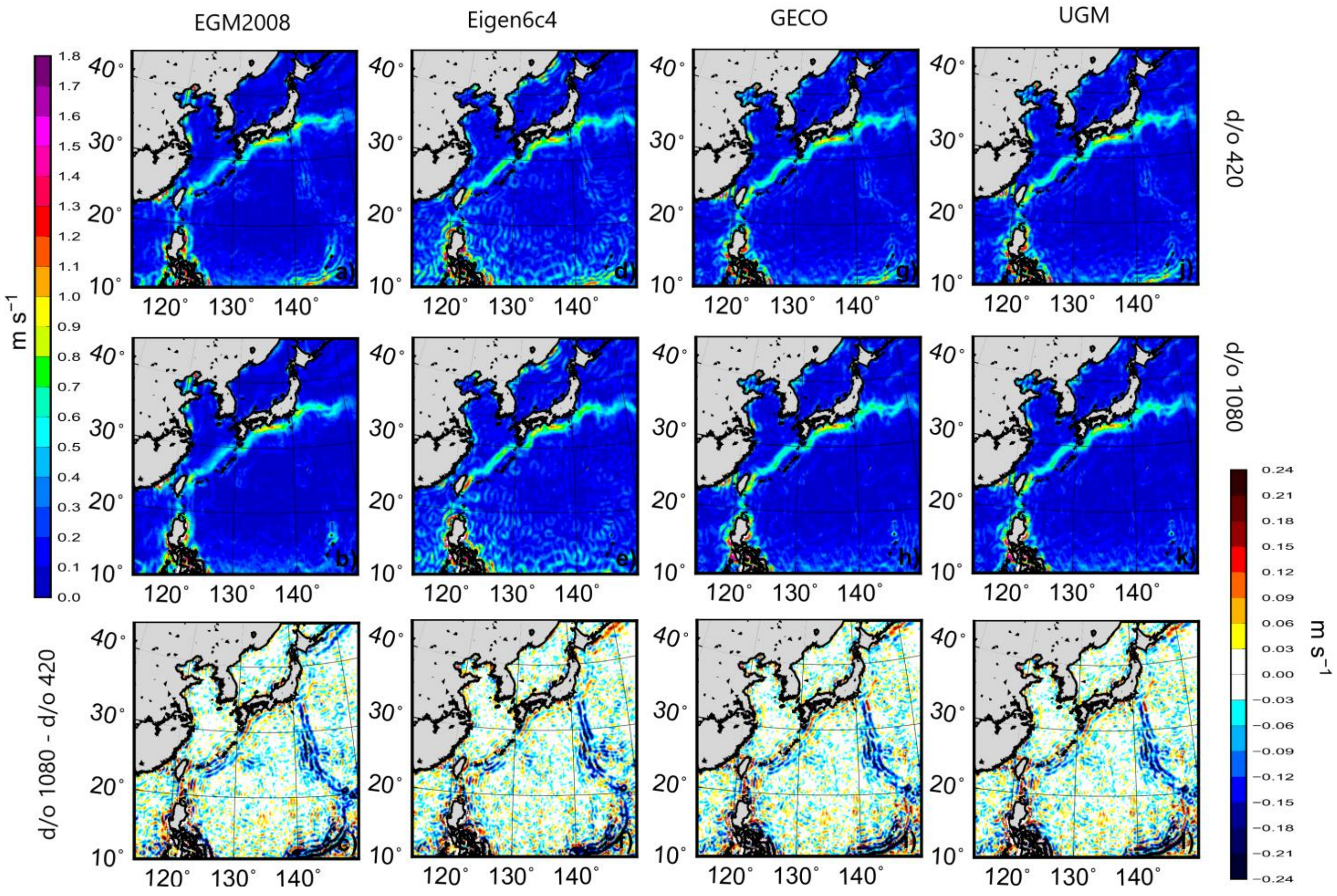
- For cut-off d/o 420 shape and velocity close to drifter velocity around the peak.
- For higher resolution unrealistic peaks evolve at different locations.

Gulf Stream: Signal content depending on spectral resolution



- Shown are geostrophic surface currents obtained from the geodetic MDTs. All MDTs are filtered with *r*=0.2°
- The difference (d/o 1080 – d/o 420) shows a pattern along the U.S. east coast.
- This pattern, however, does not follow the Gulf Stream, but might reflect strong geoid gradients in that area.
- As for the specific section shown before, also for the whole Gulf Stream/ North Atlantic Current shown, no additional MDT signal is visible for d/o 1080 compared to d/o 420.

Kuroshio: Signal content depending on spectral resolution



- Shown are geostrophic surface currents obtained from the geodetic MDTs. All MDTs are filtered with r=0.2°
- The difference (d/o 1080 – d/o 420) shows a pattern of stripes.
- This pattern, however, does not follow the Kuroshio, but the strong geoid gradients along the margins of the Philippine Plate.
- As for the Gulf Stream, no additional MDT signal is visible for d/o 1080 compared to d/o 420.

Small-Scale Signal in Mean Dynamic Topographies Applying Combined Geoid Models

Conclusions

- Geostrophic surface currents from geodetic MDTs that apply new combined geoid models (GOCO05c, Eigen6c4, GECO, UGM) are slightly closer to near-surface drifter velocities than those that use EGM2008 for all regions tested.
- From analysing geostrophic surface currents for the Gulf Stream and the Kuroshio no signal is detectable above d/o 420 for any of the tested geoid models.
- Though MDT signal beyond d/o 420 cannot be detected and higher spectral resolution increases the commission error of the MDT, higher resolution reduces Gibbs effects probably caused by strong (and erroneous) MSS gradients near the coast.
- Away from the coast, no significant improvements (in terms of smaller RMS differences to drifter velocities) are detectable beyond d/o 420.
- However, d/o 420 is well above the resolution obtained from satellite-only geoid models.

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