Ocean surface waves in an ice-free Arctic Ocean

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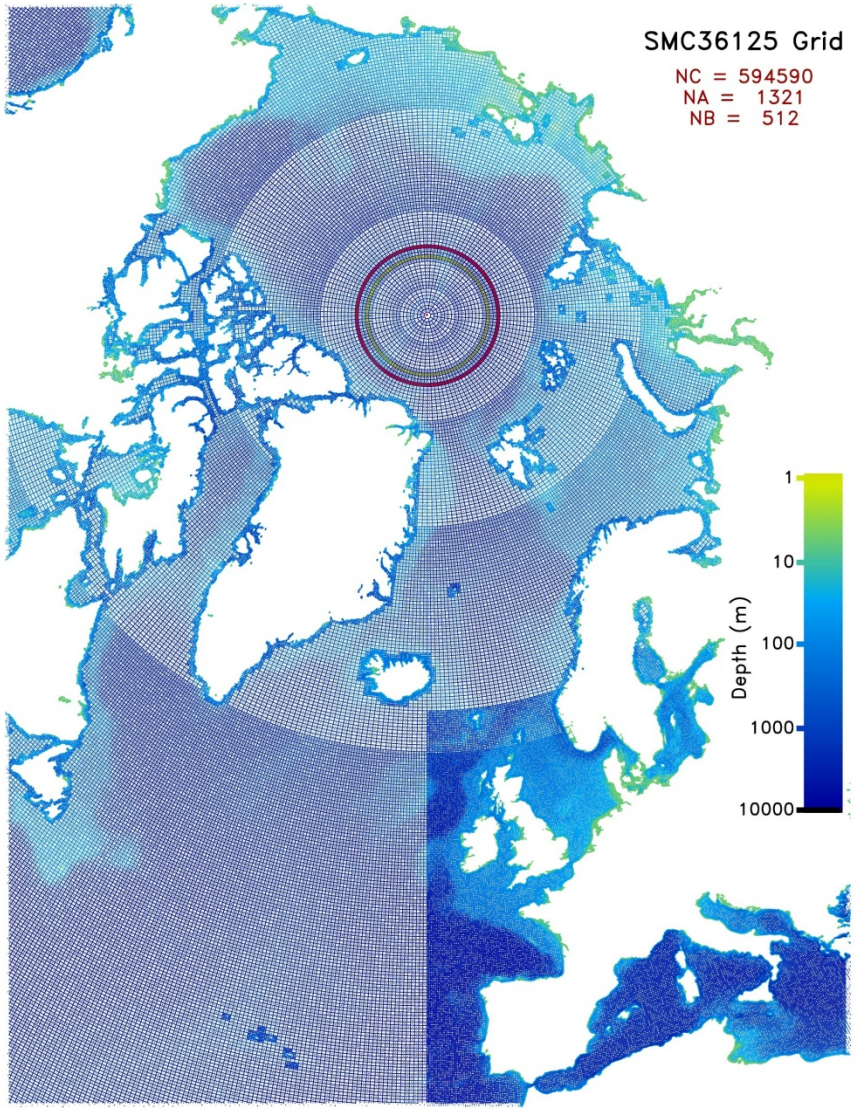
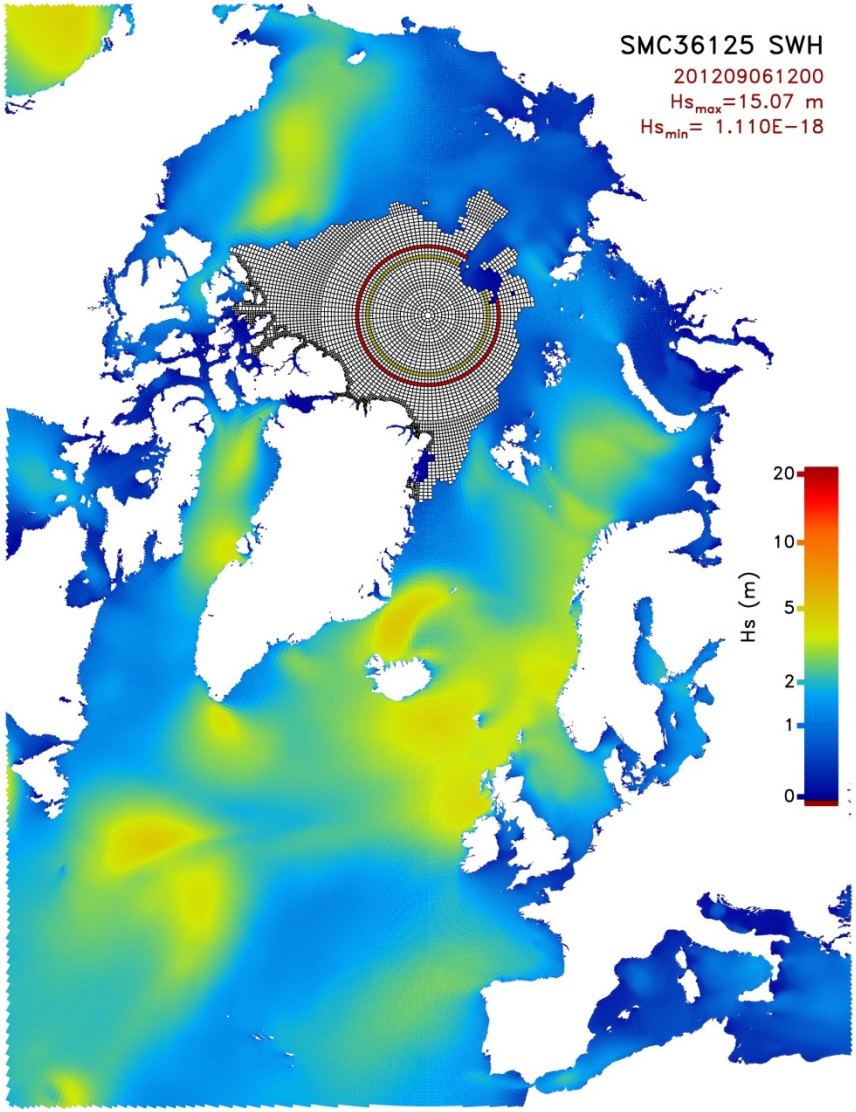
Motivation for Arctic wave model





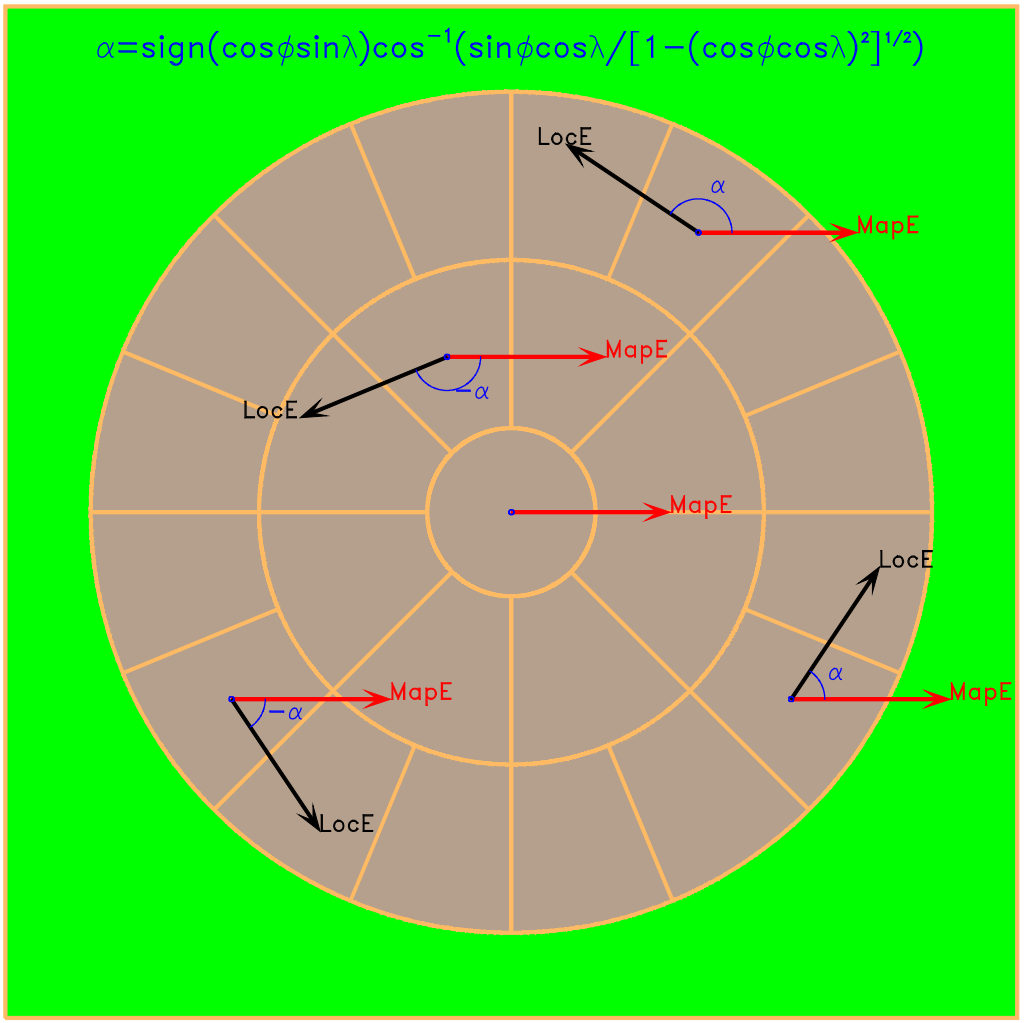
Conclusions

- Using a fixed direction (map-east) to define wave spectra at high latitudes reduces the scalar-assumption errors in Arctic.
- The map-east method works fine within the Arctic part and is consistent with the conventional local east method in an overlapping zone, 65º-85ºN.
- Validations with satellite SWH and buoy spectra confirm that the Spherical Multiple-Cell (SMC) grid with the map-east system in the Arctic allows the whole Arctic to be included in a global wave model for wave forecasts or climate applications.

1. Methodology

- Use a fixed direction (map-east) to define wave spectra at high latitudes or in the Arctic part.
- Expand Arctic part (from 85ºN to 65ºN for satellite data validation.
- Simulation of waves in ice-free Arctic Ocean.
- Compare expand Arctic part with original one.
- Test in SMC 3-6-12-25 km global wave model.

Map-east reference direction



- SMC grid uses merged cells at high latitudes to relax CFL limit on time step.
- Introduce a round polar cell to avoid polar blocking and singularity.
- Define wave spectral component with fixed reference direction --- the map-east, instead of the rapidly changing local east at high latitudes.
- Keep map-east system in *Arctic part* from the local east in *global part*.

Wave model terms in the Arctic part on SMC grid

All source terms are unchanged except for that the wind (and current) velocity is rotated into the map-east system.

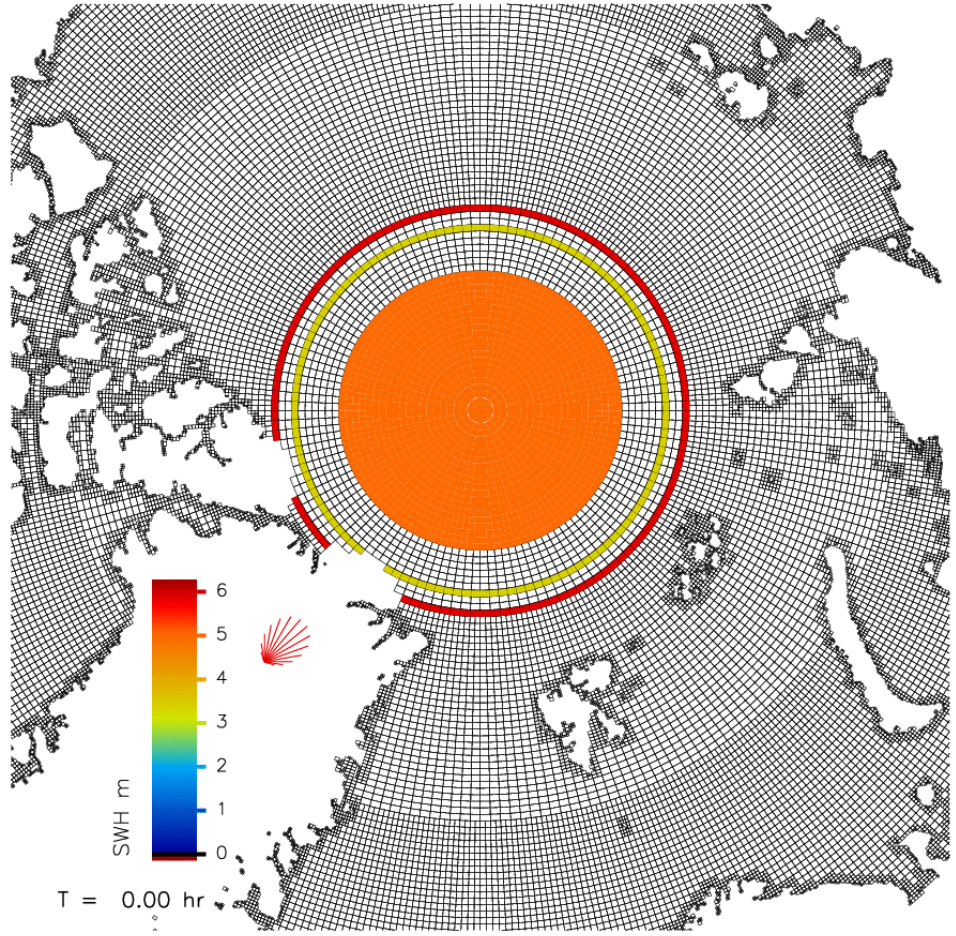
$$\begin{pmatrix} u' \\ v' \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix}, \qquad \begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} u' \\ v' \end{pmatrix}$$

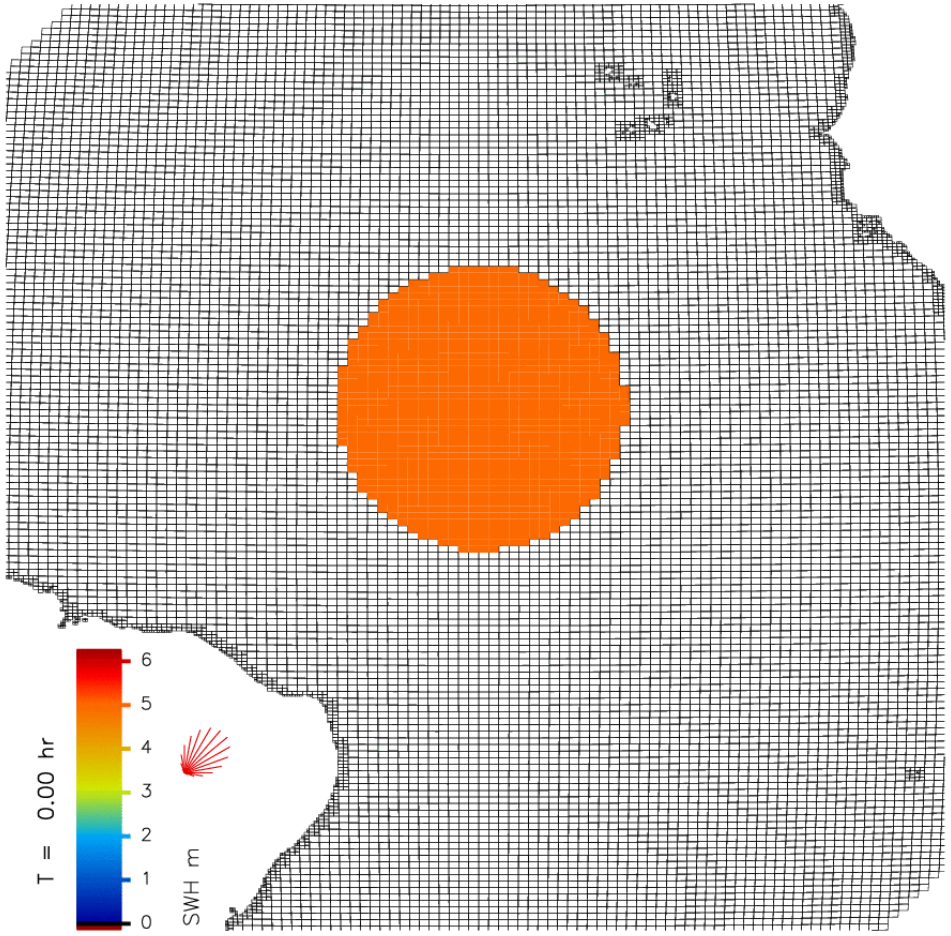
$$\cos\alpha = \frac{\cos\lambda\sin\varphi}{\sqrt{1-(\cos\lambda\cos\varphi)^2}}, \qquad \sin\alpha = \frac{\sin\lambda}{\sqrt{1-(\cos\lambda\cos\varphi)^2}},$$

Propagation on the SMC grid is unified for the two parts with wave speed in the Arctic part given by:

$$c_{gx} = c_g \cos(\theta' - \alpha), \qquad c_{gy} = c_g \sin(\theta' - \alpha)$$

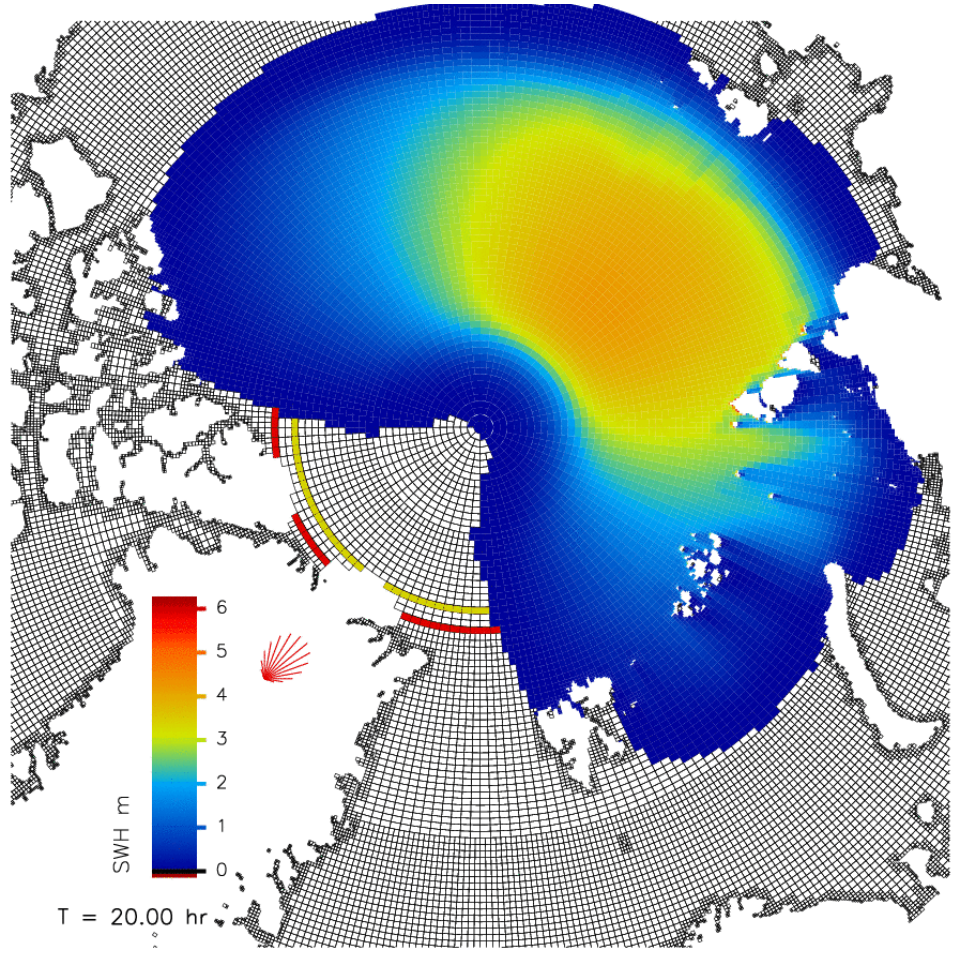
Wave transport on 6-25 SMC grid --- Arctic via Atlantic

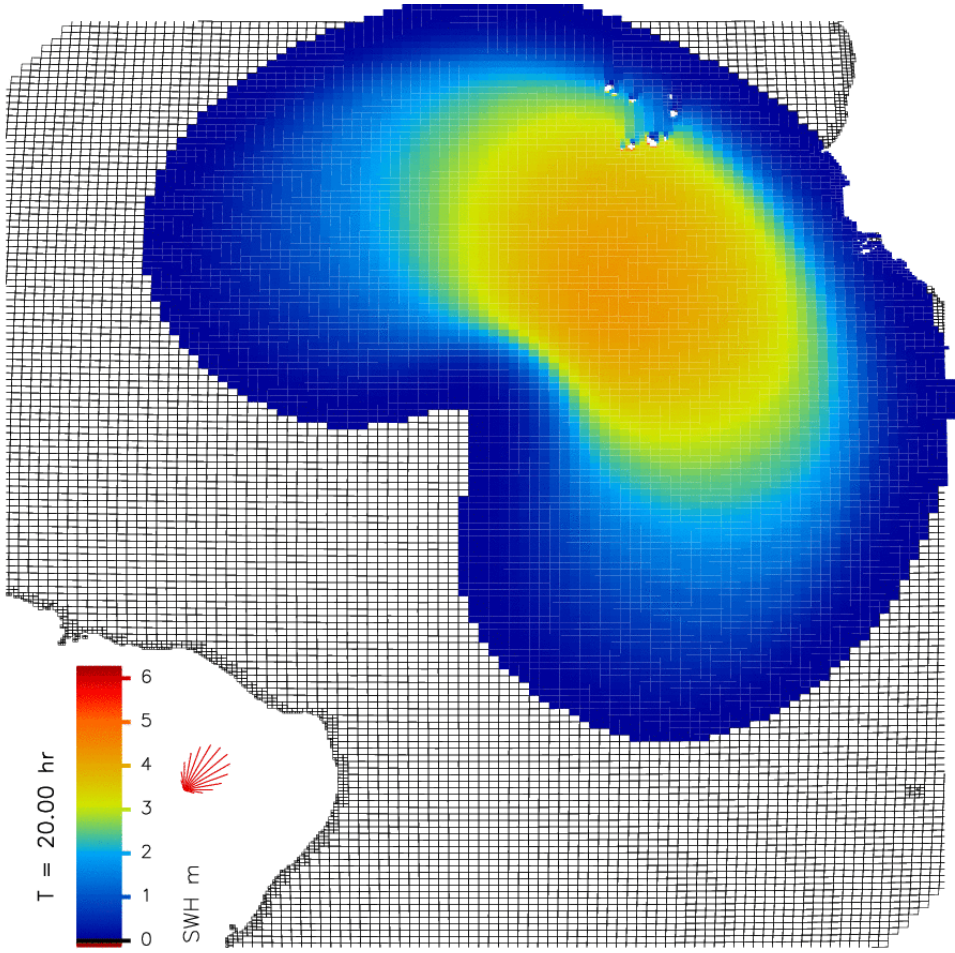




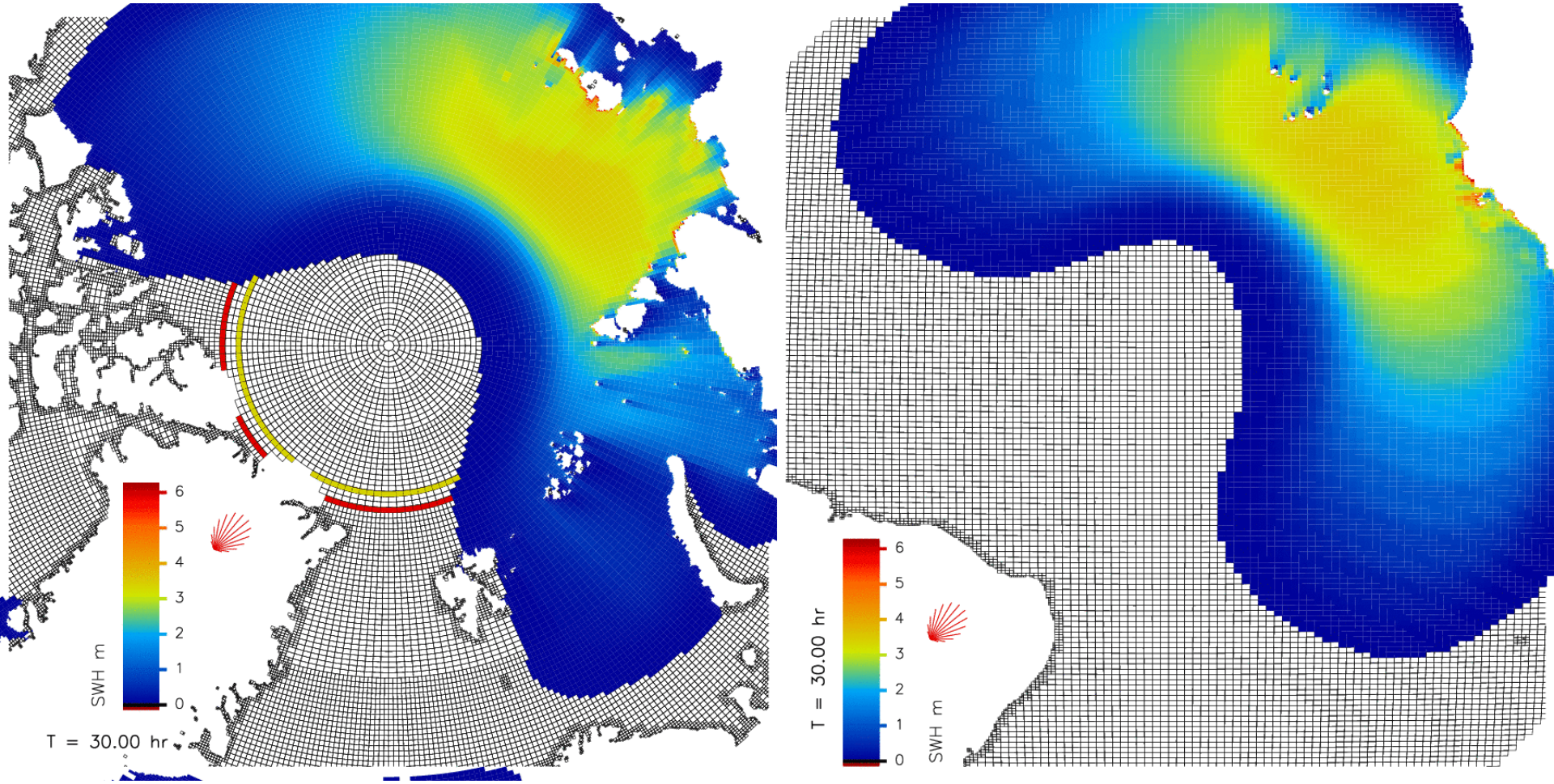
Li, J.G. 2012: Propagation of ocean surface waves on a SMC grid. *J. Comput. Phys*. **231**, 8262-8277

Wave transport on 6-25 SMC grid --- Arctic via Atlantic

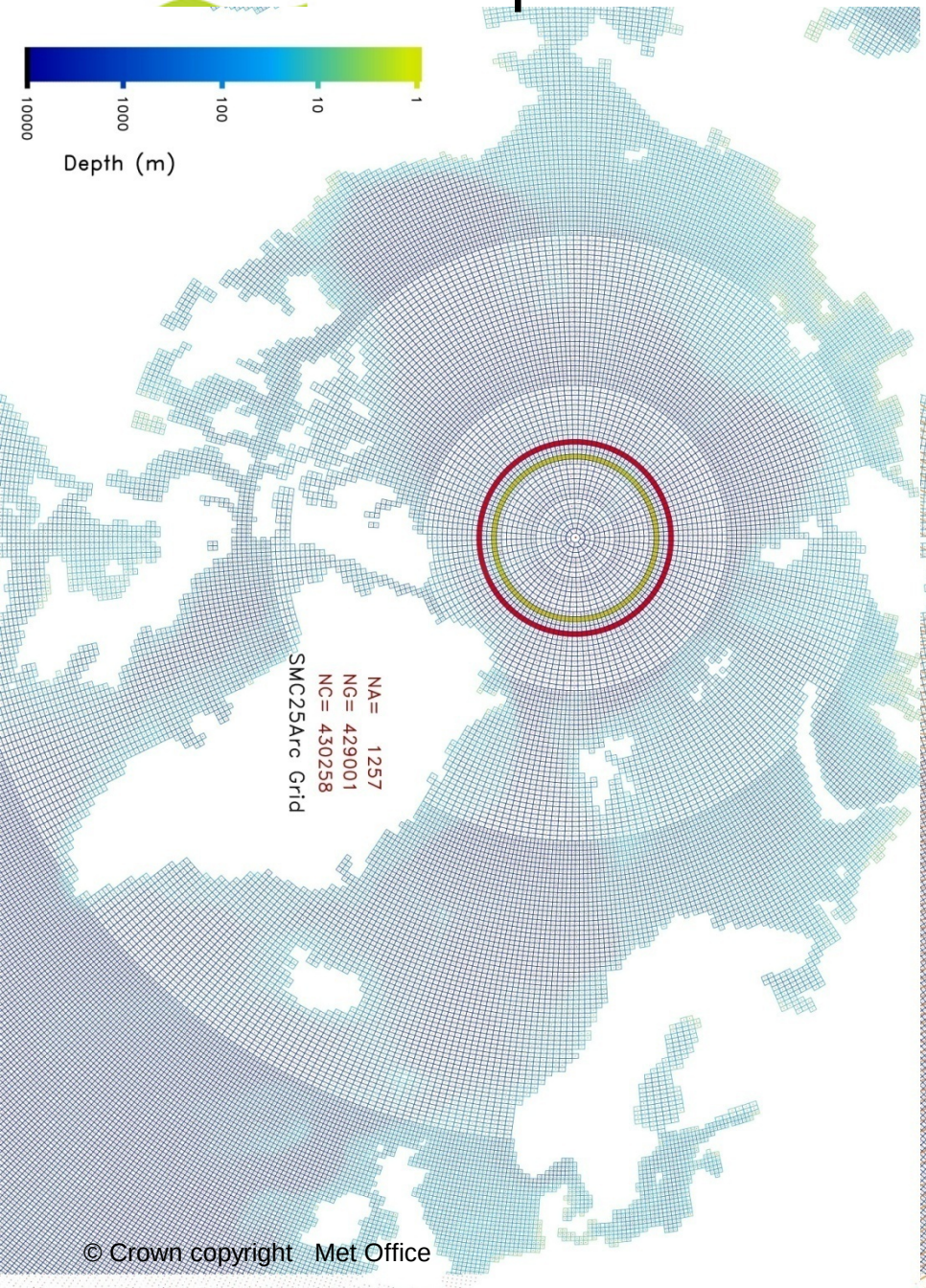


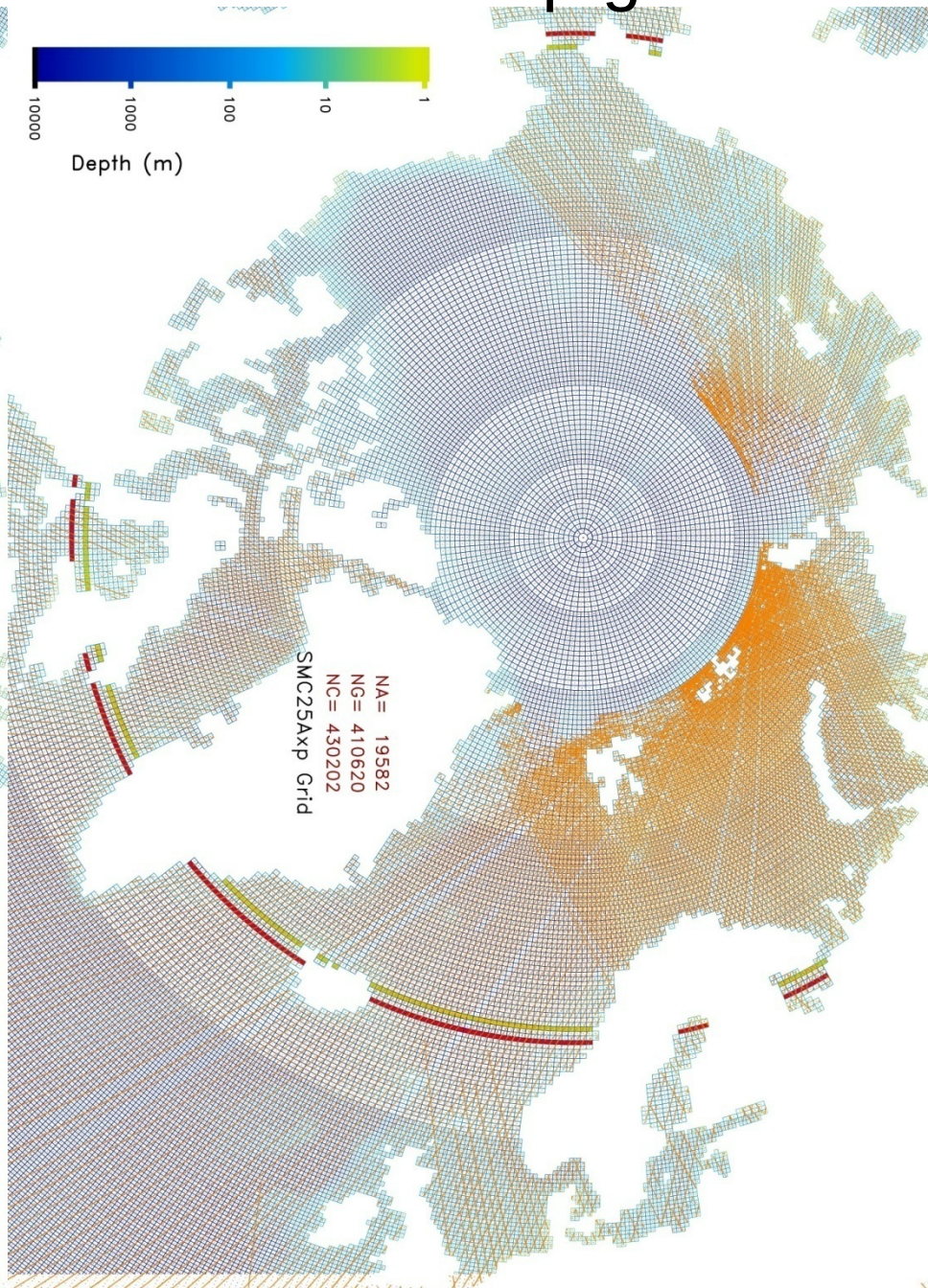


Wave transport on 6-25 SMC grid --- Arctic via Atlantic

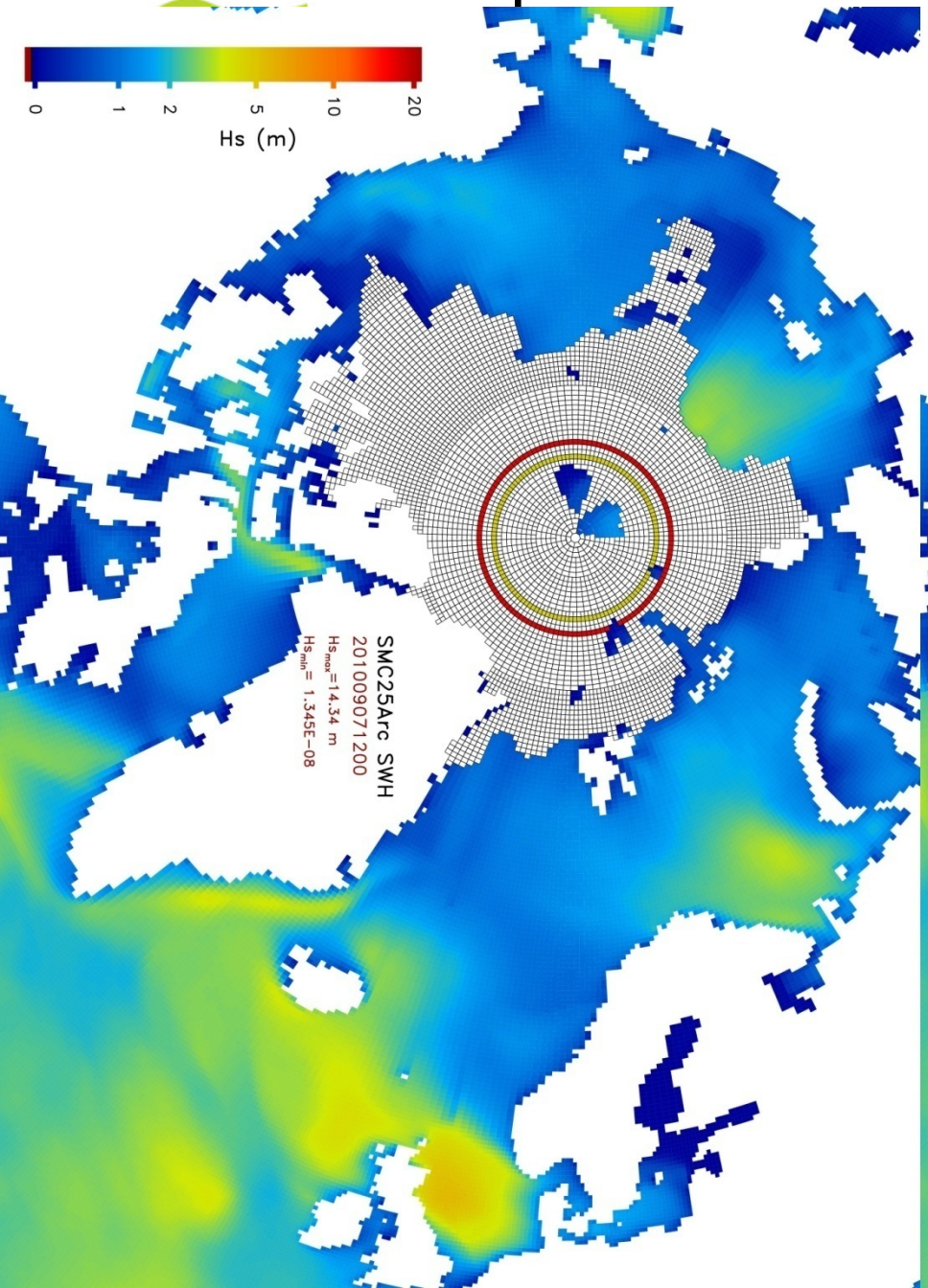


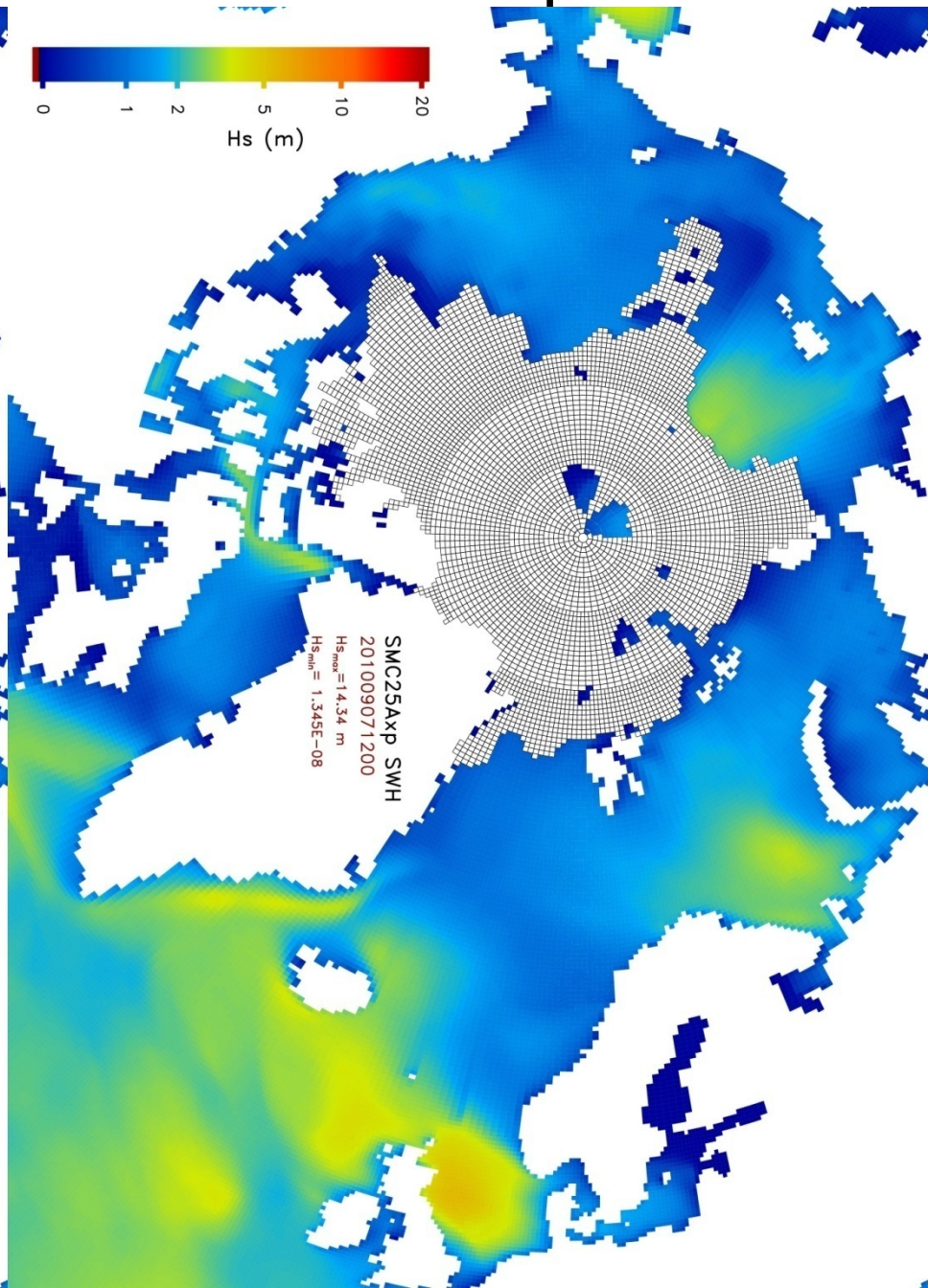
Comparison of SMC25 Arc and Axp grid



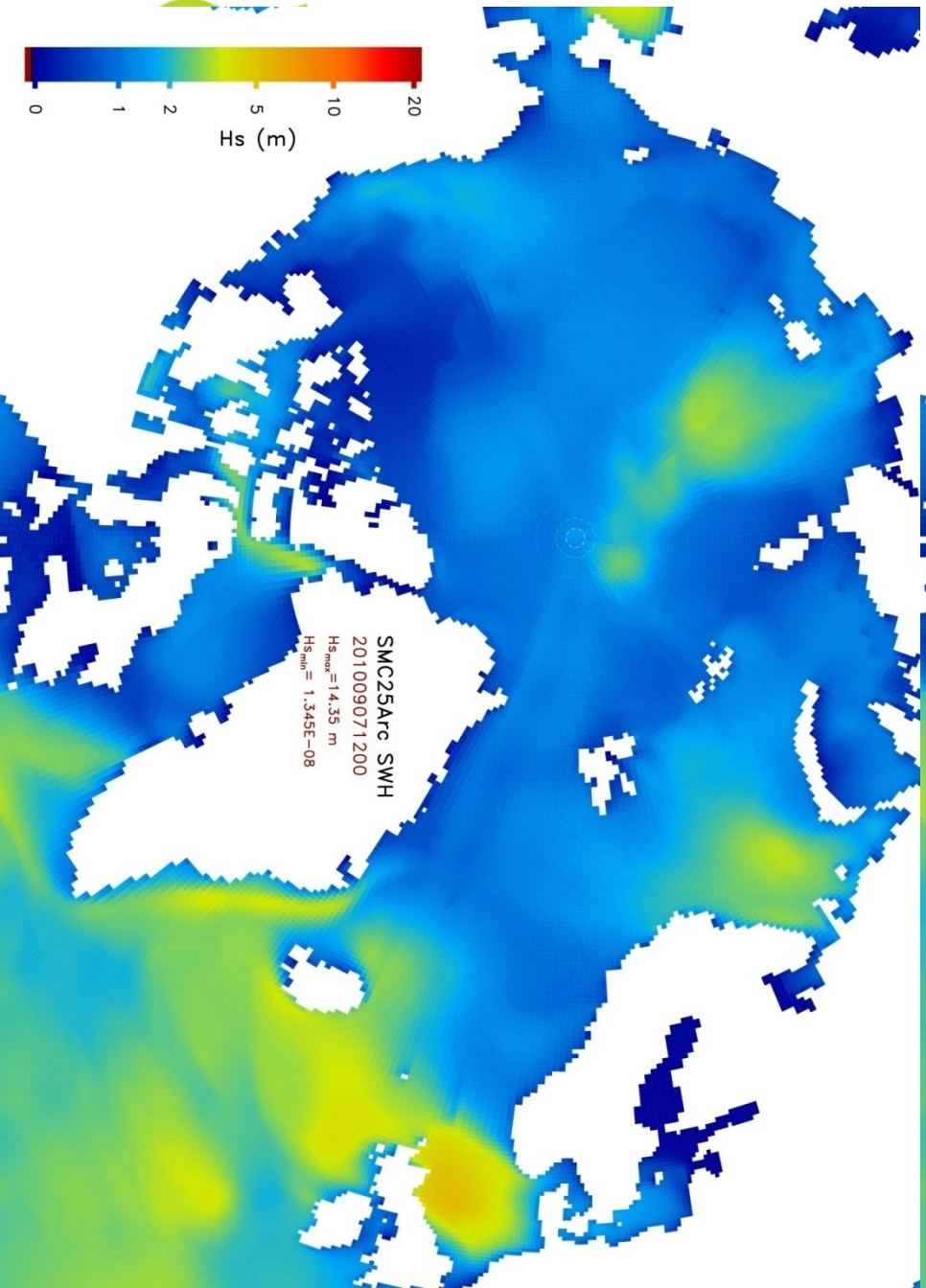


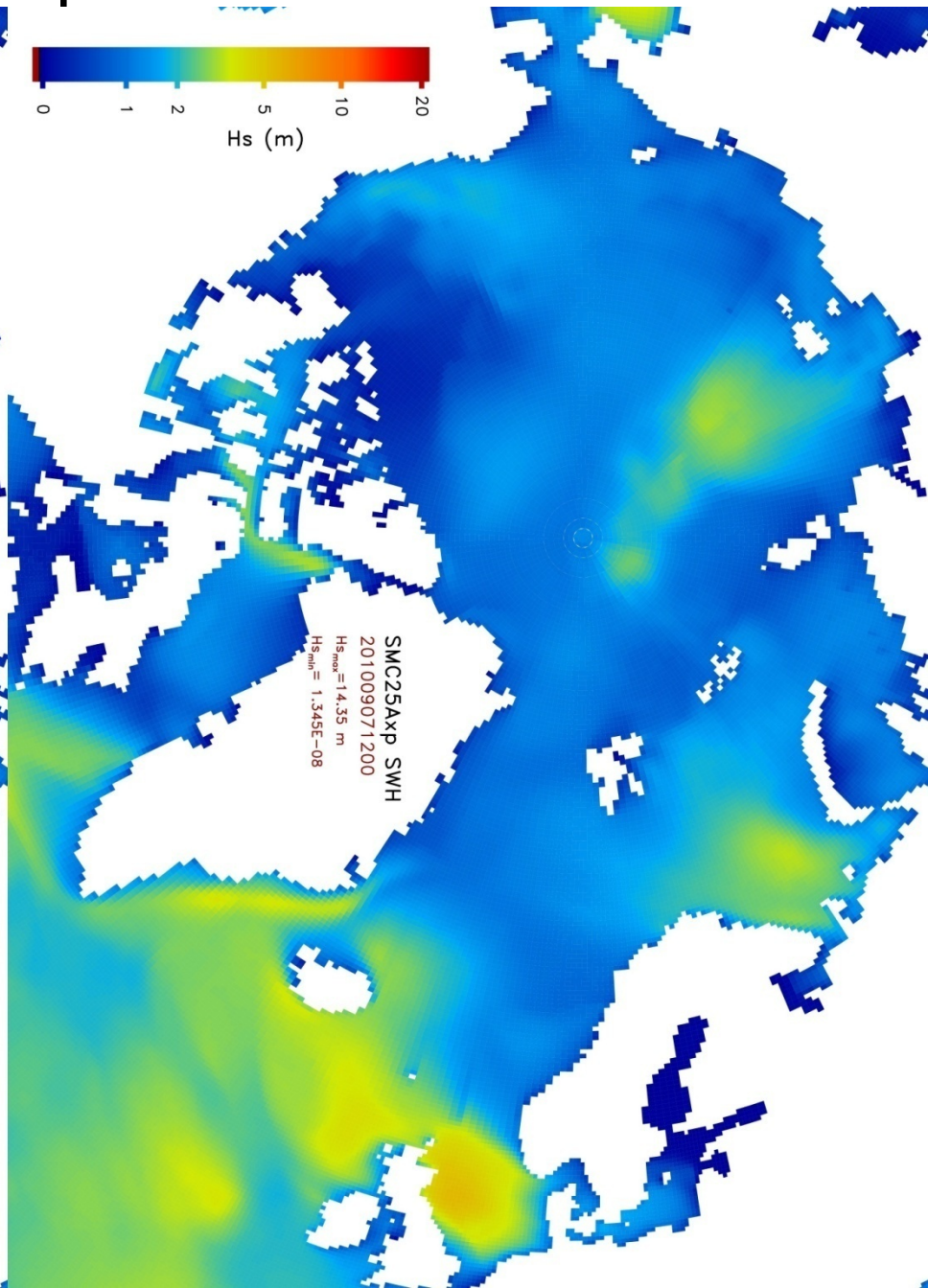
Comparison of SMC25 Arc and Axp SWH



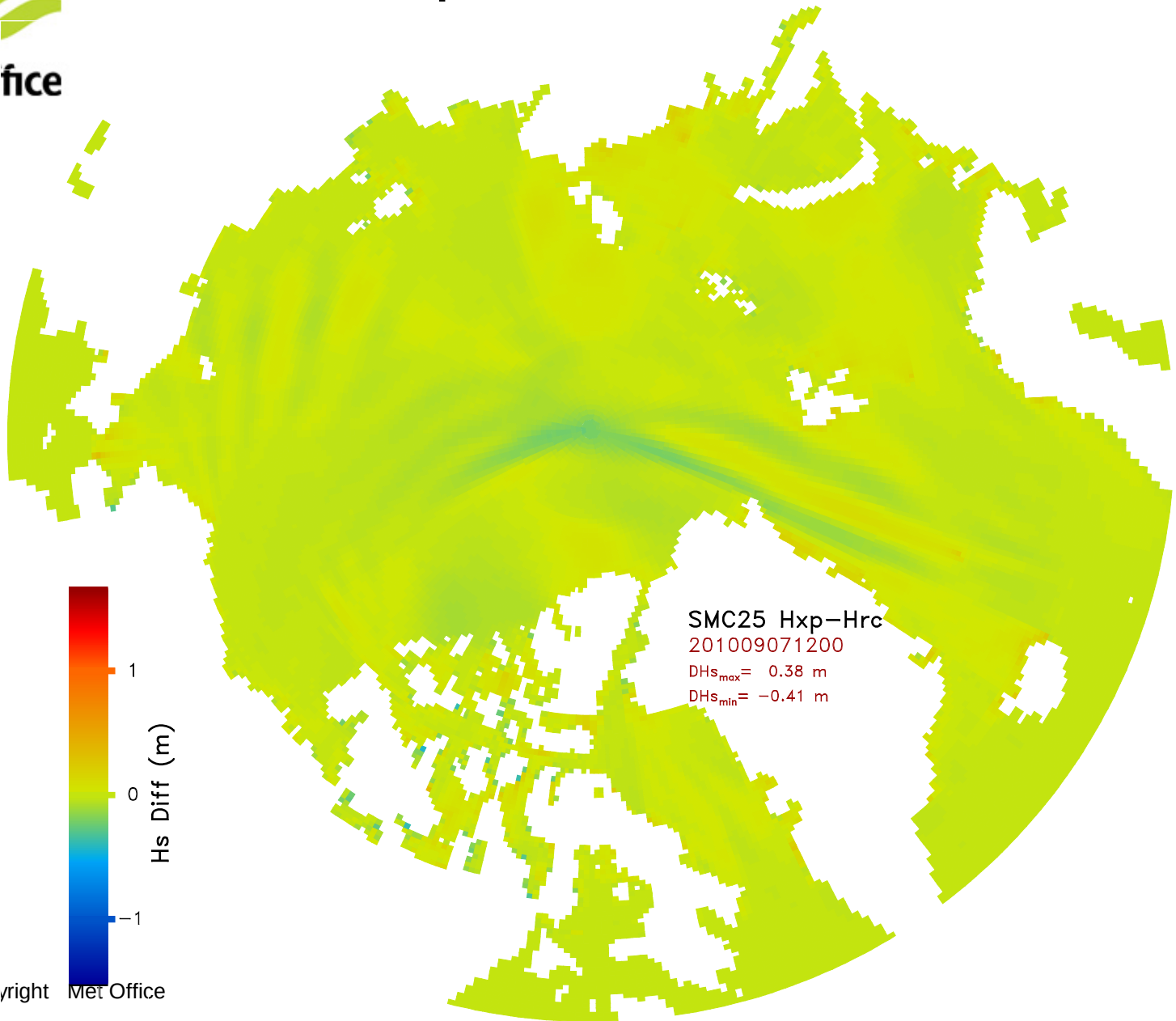


SMC25 Arc and Axp SWH – Ice-free case

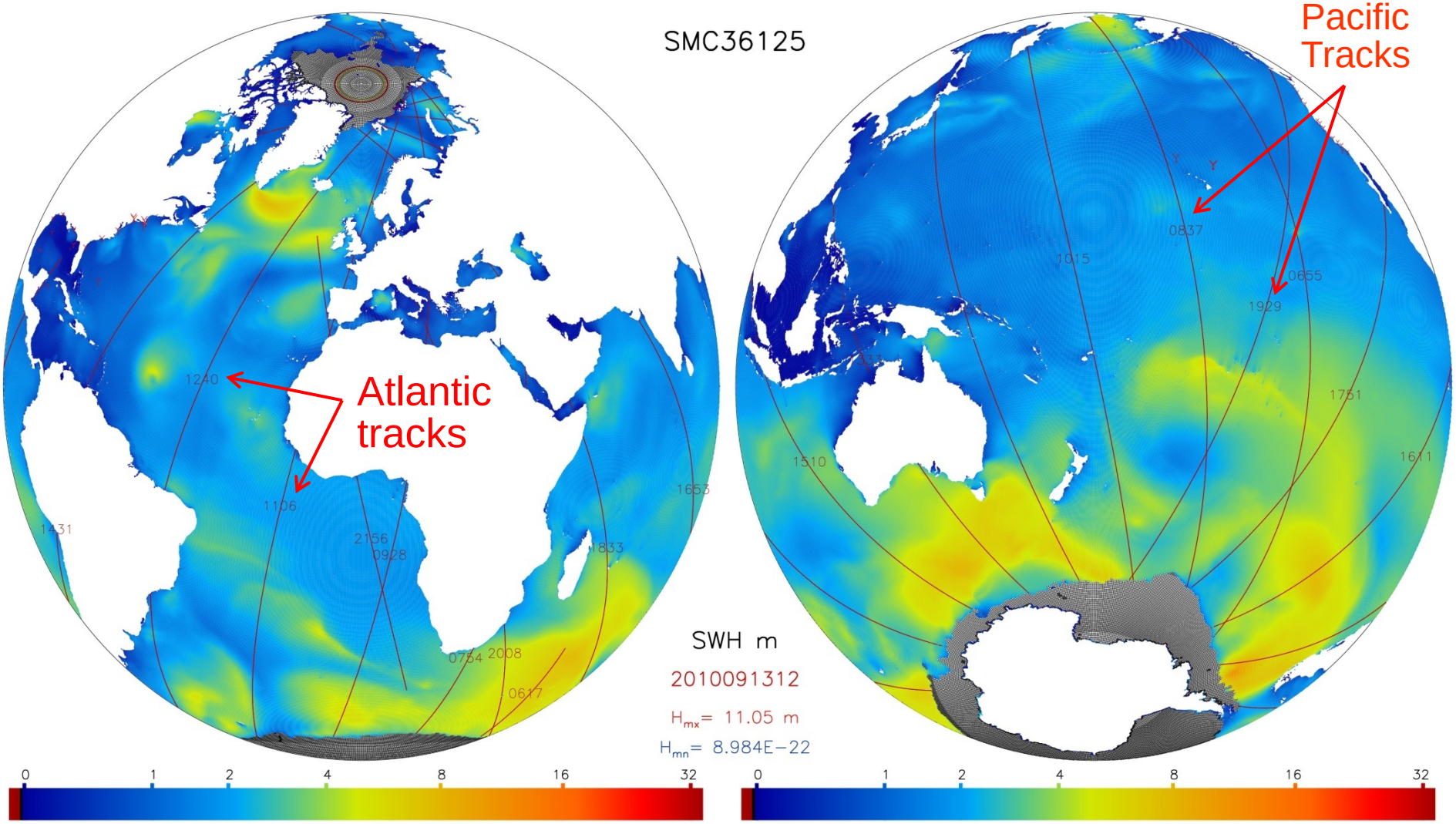




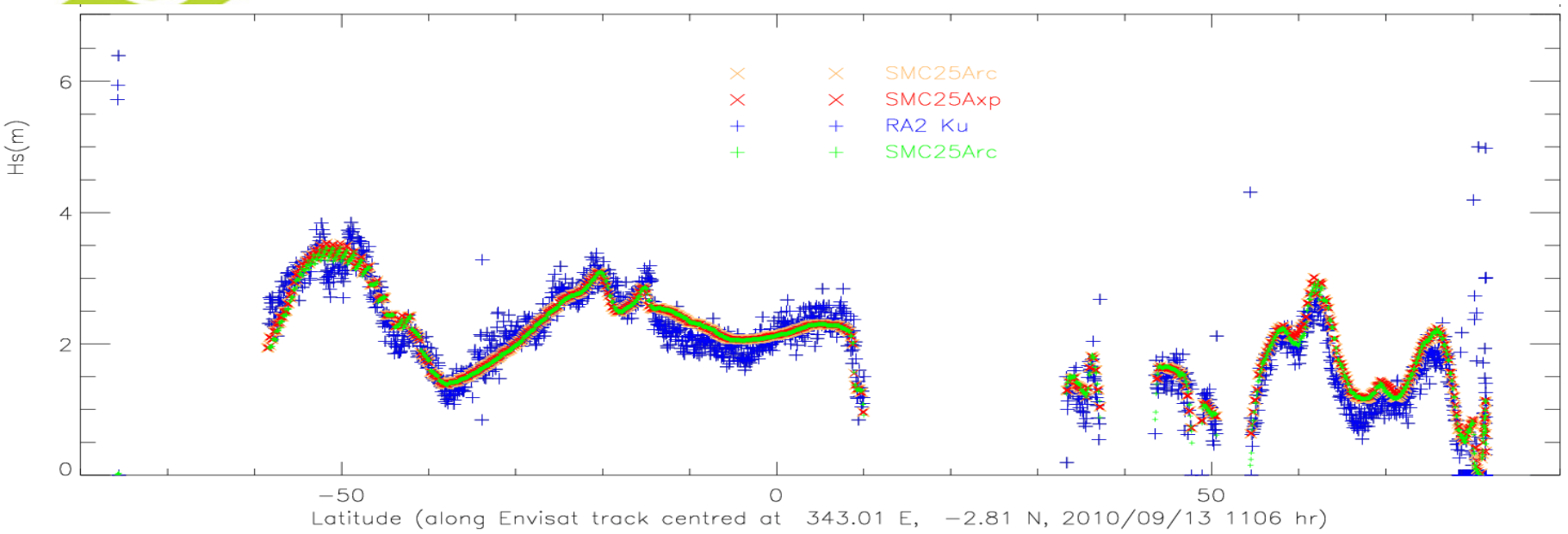
SMC25 Axp – Arc SWH > 60ºN

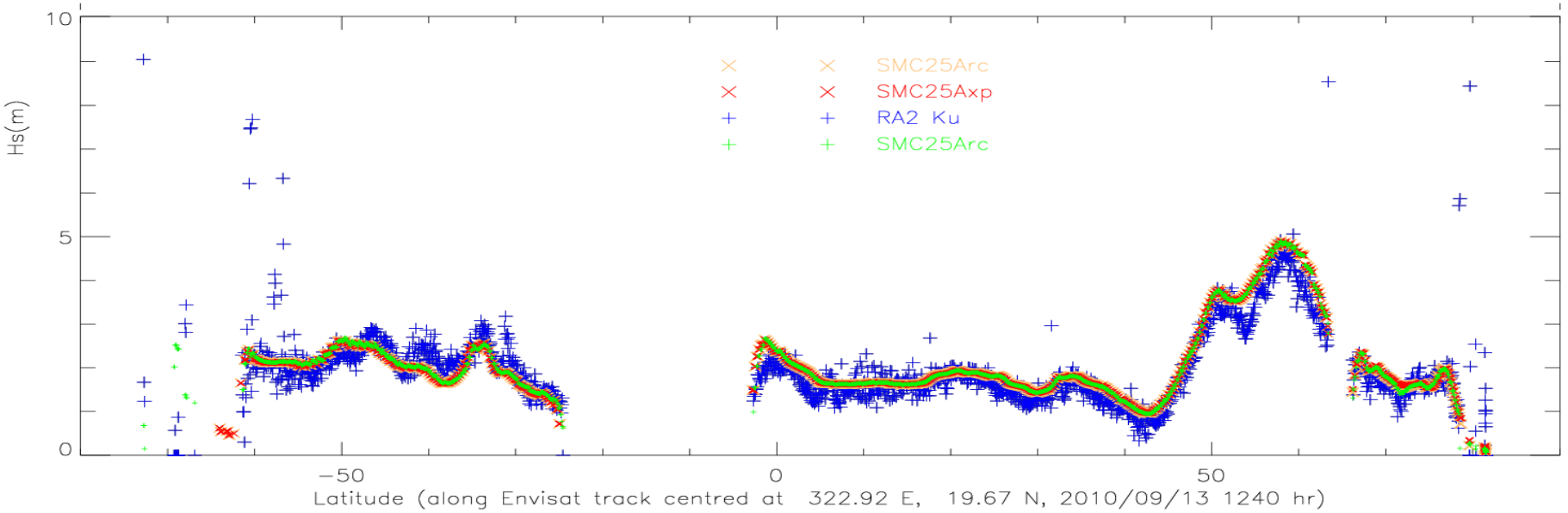


Comparison with satellite and buoys

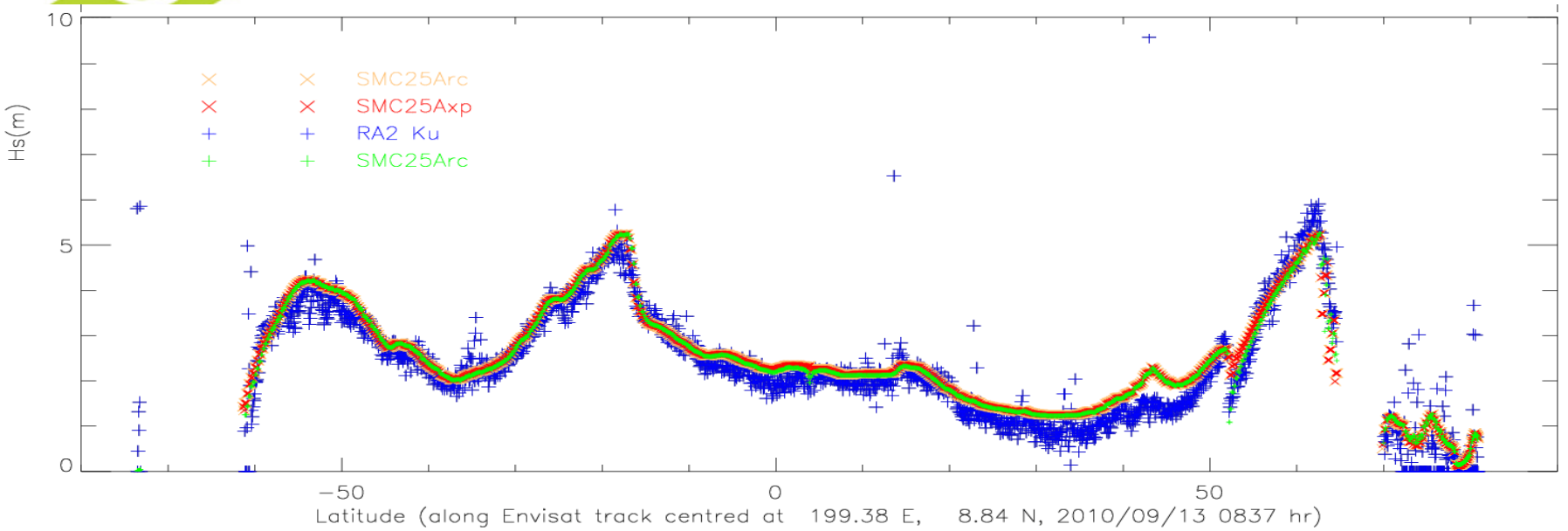


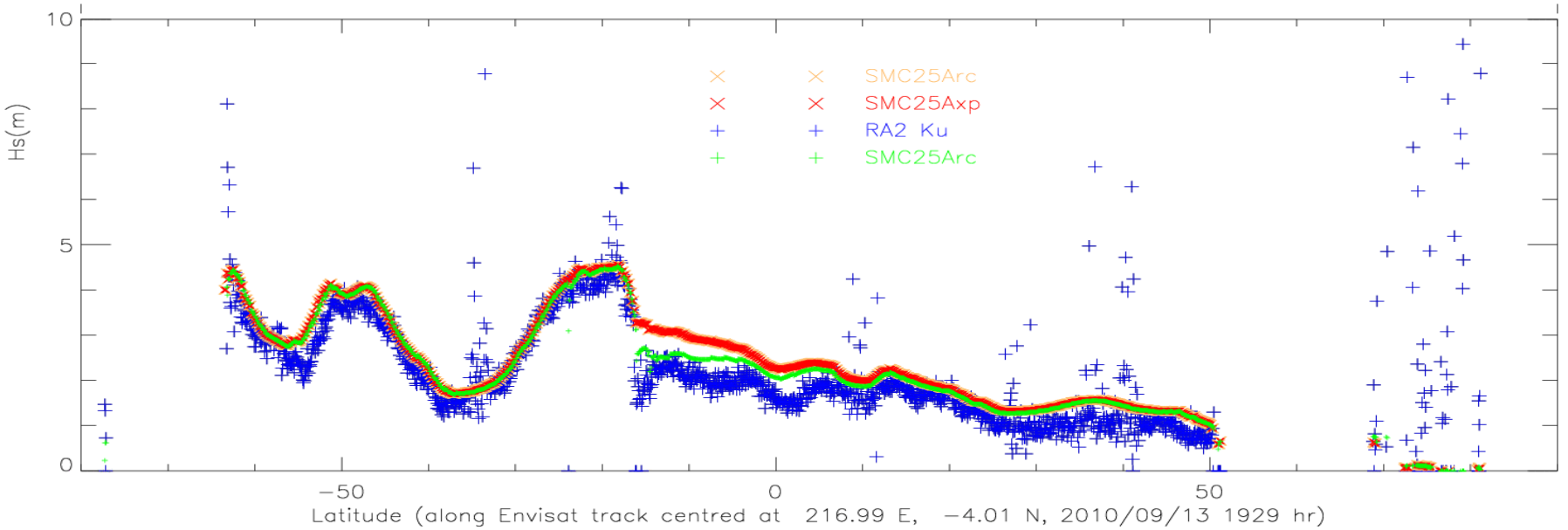
Along satellite tracks in Atlantic



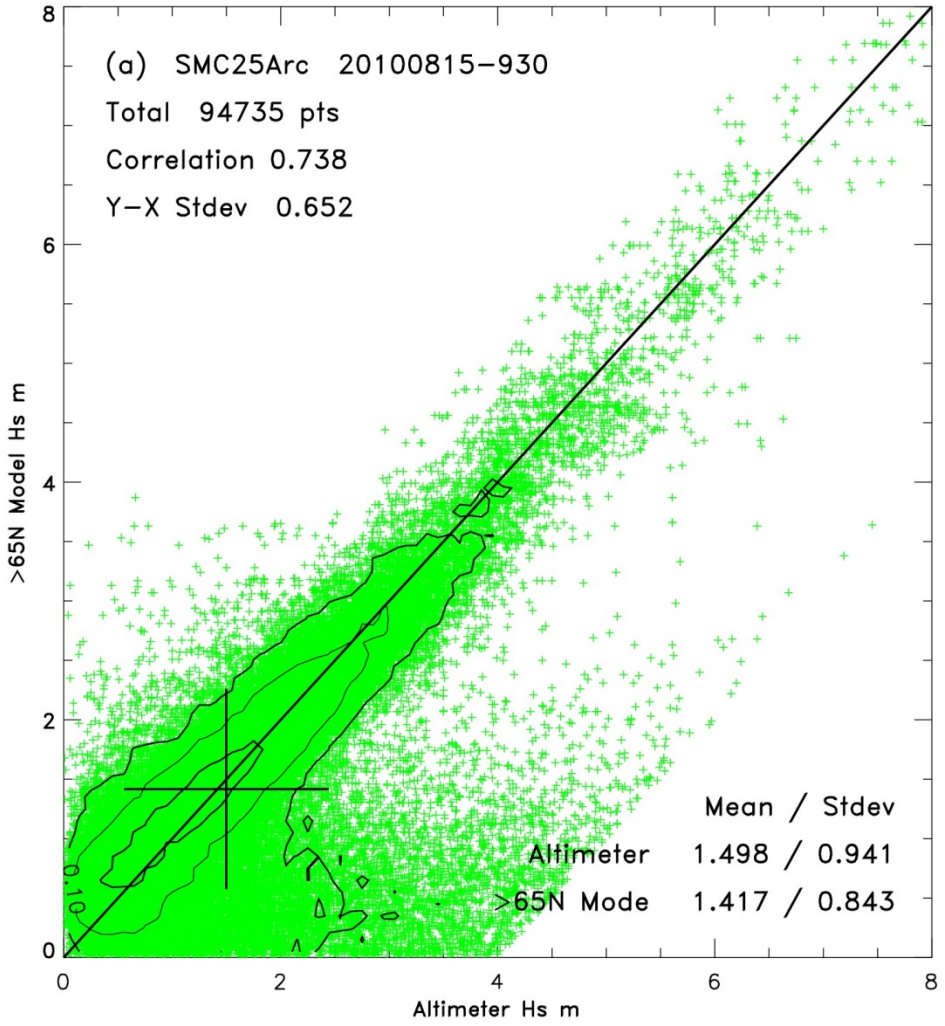


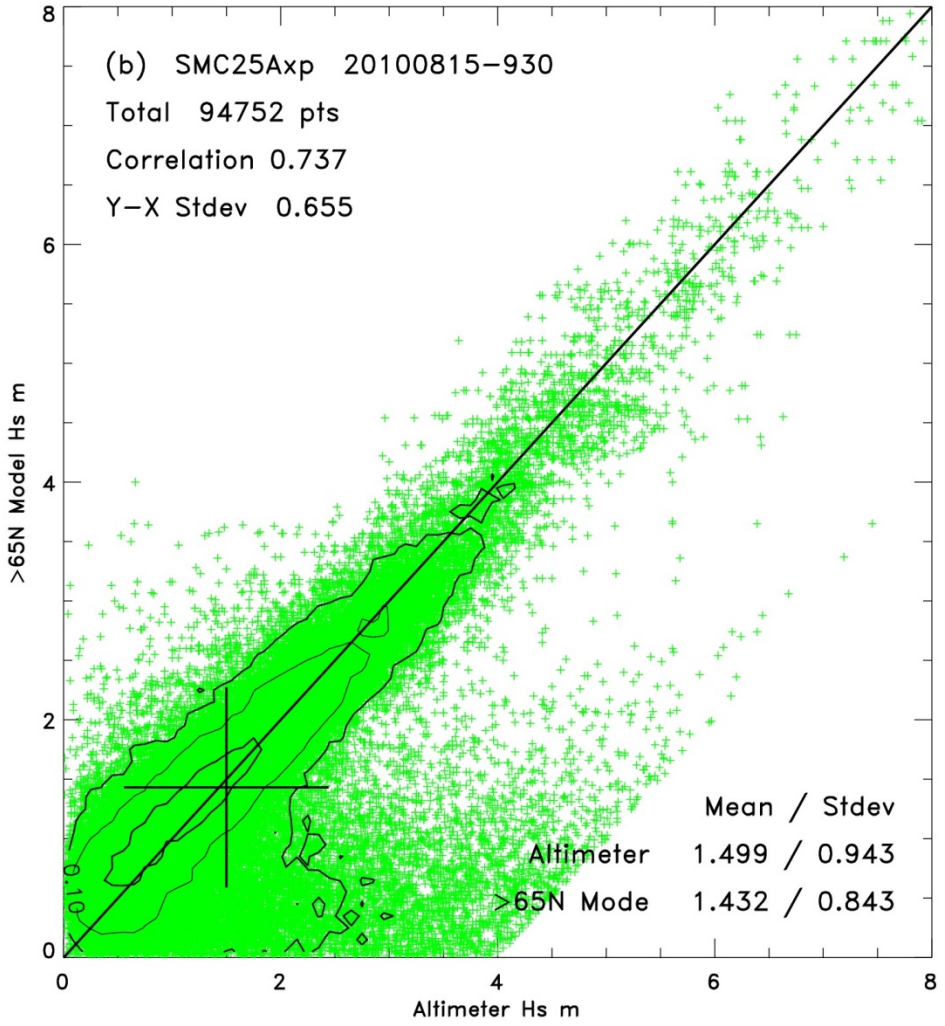
Along satellite tracks in Pacific



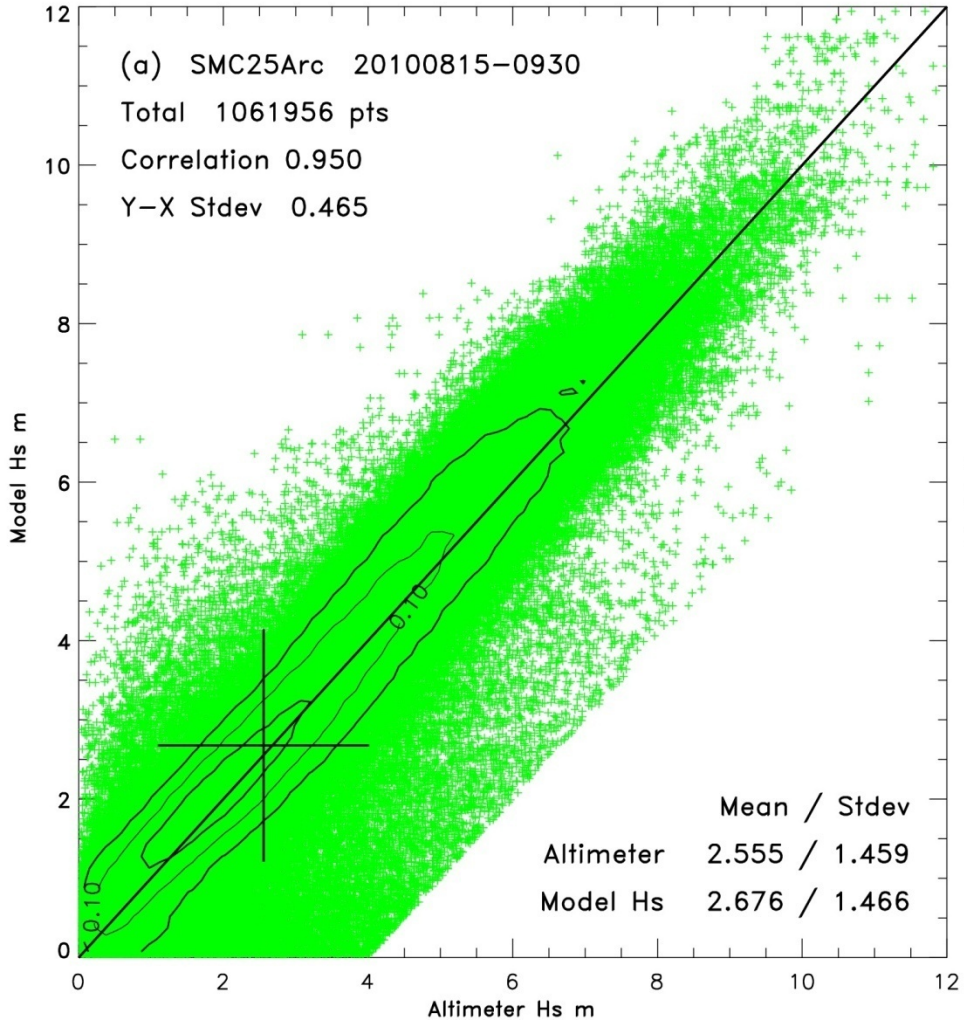


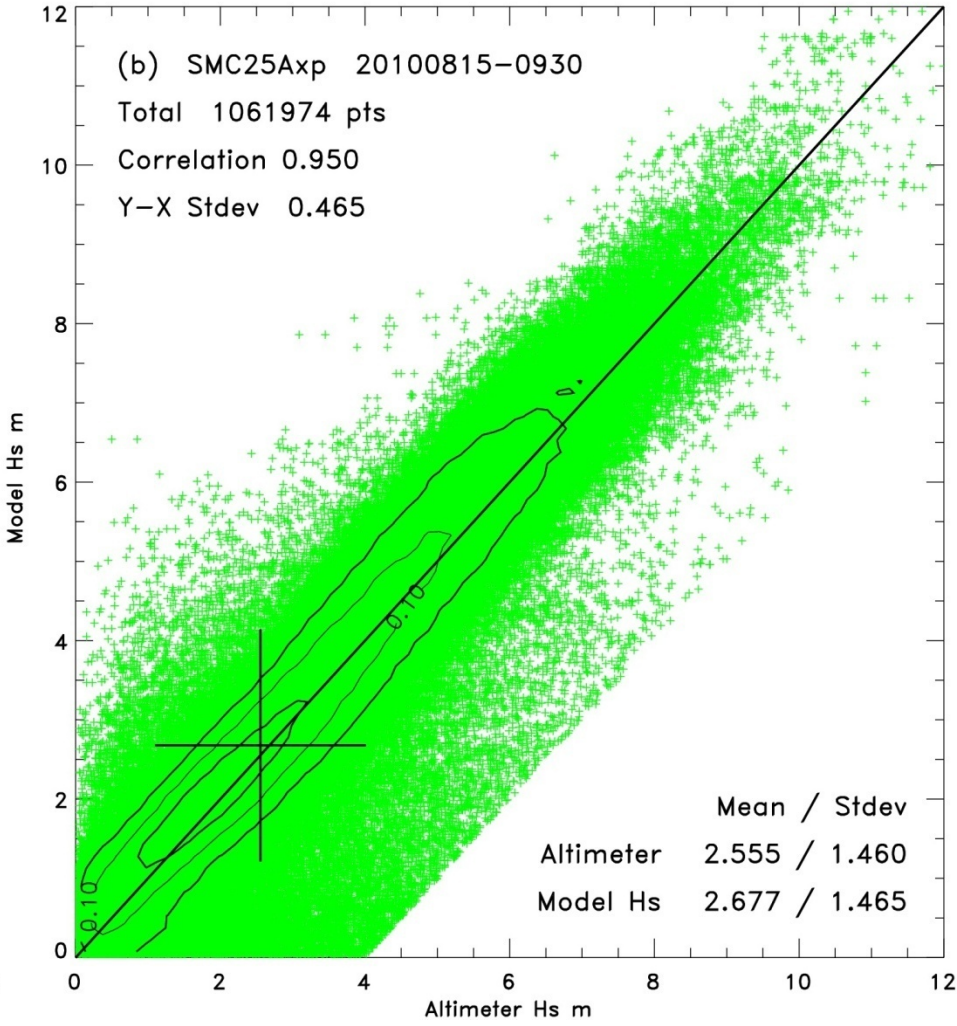
Satellite scatter plot 46 days >65ºN





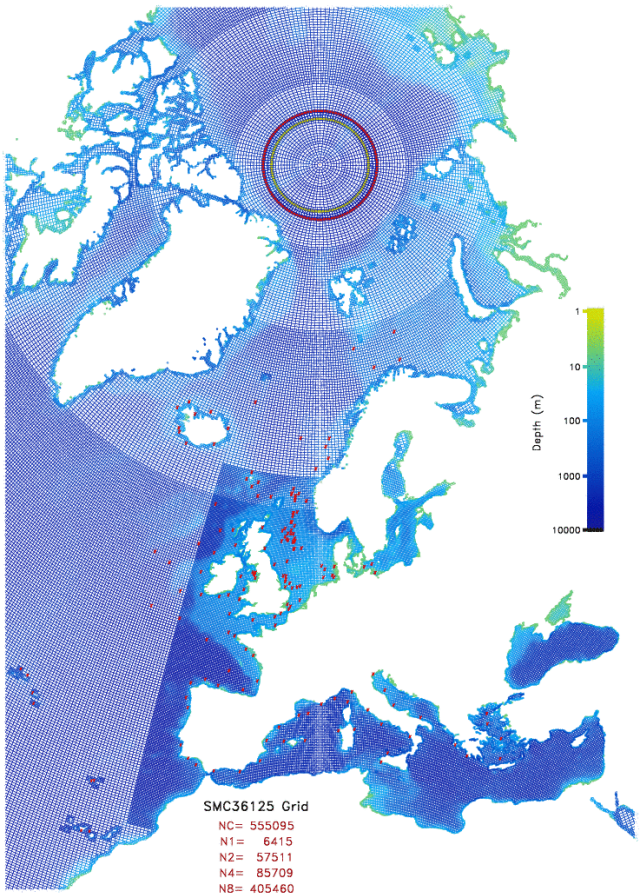
Satellite scatter plot global 46 days

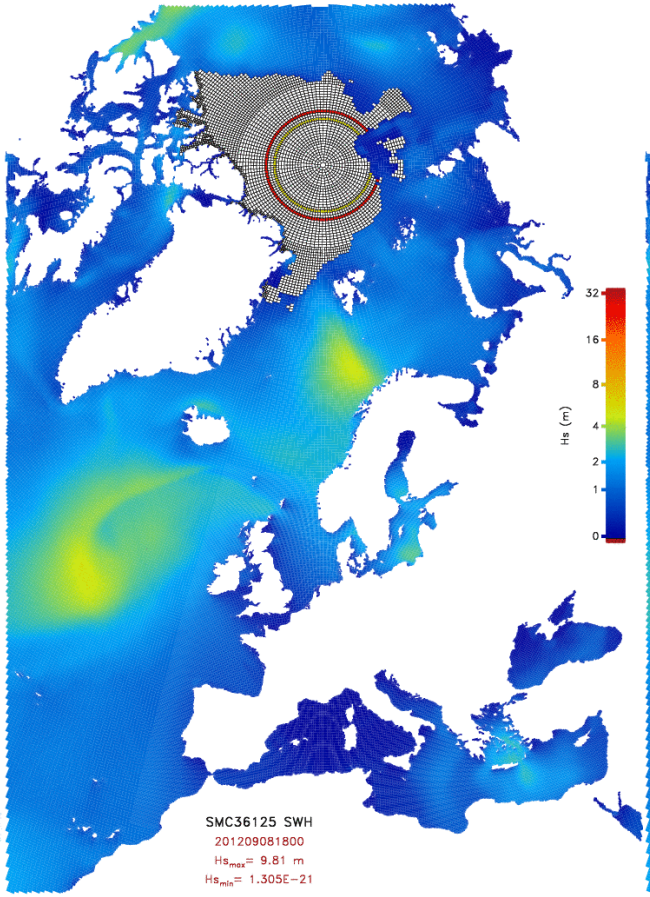


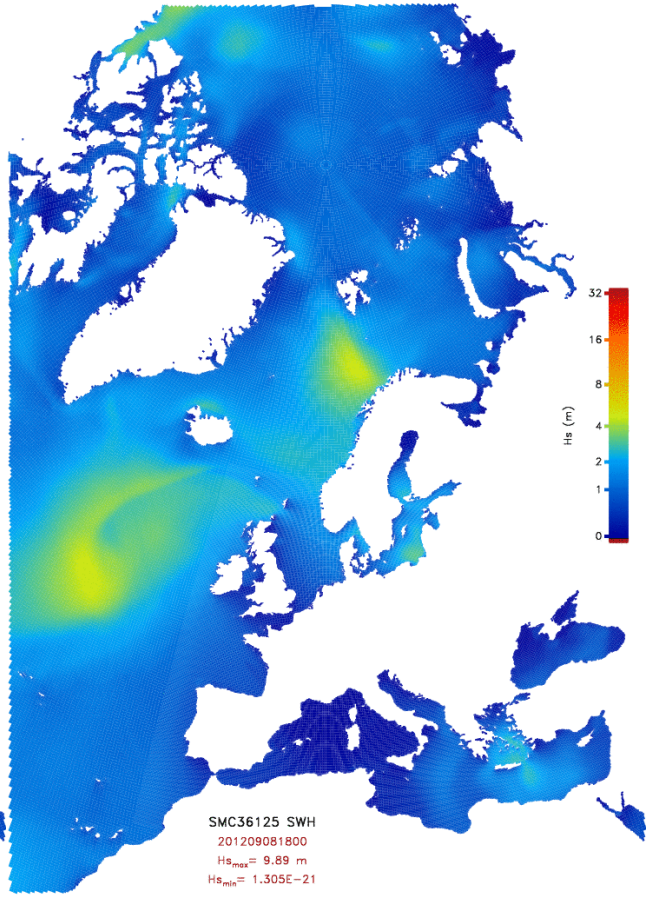


Comparison SMC36125 Arctic and European SWH with/out Ice

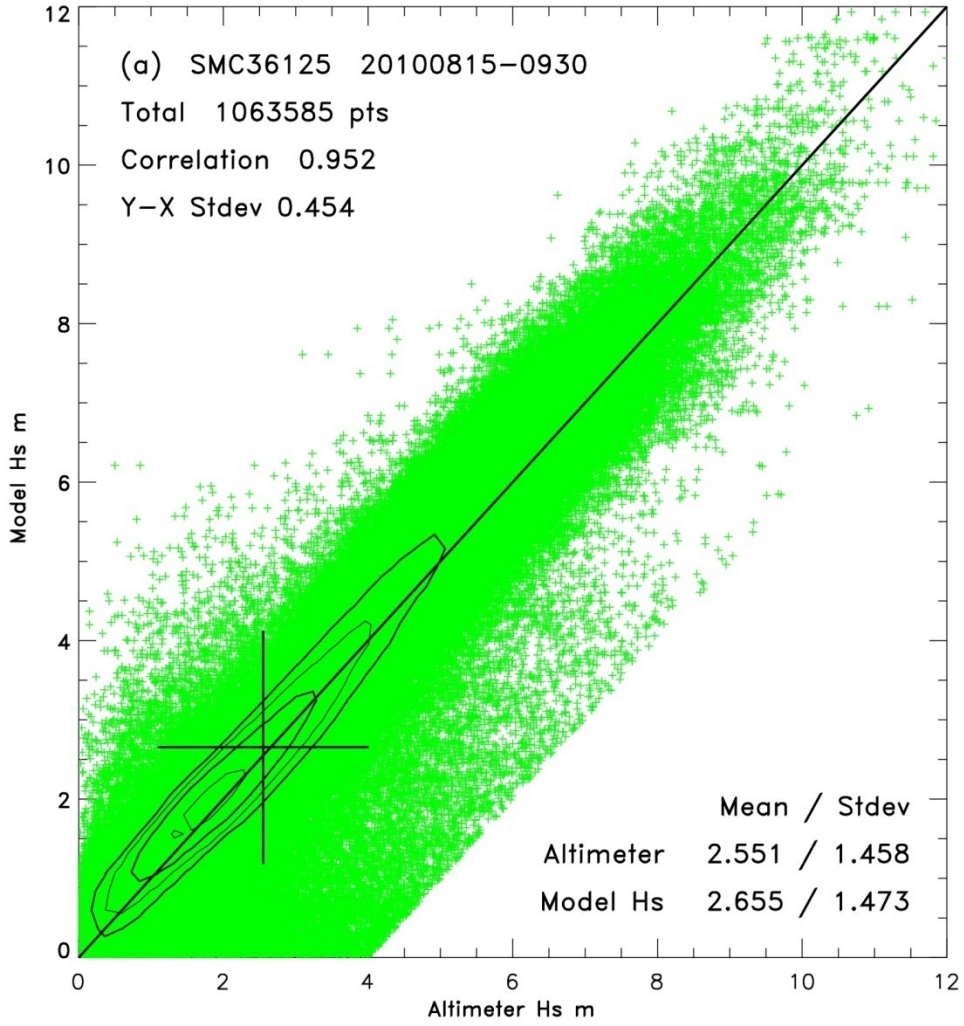
Arctic part is activated for both ice and ice-free cases.

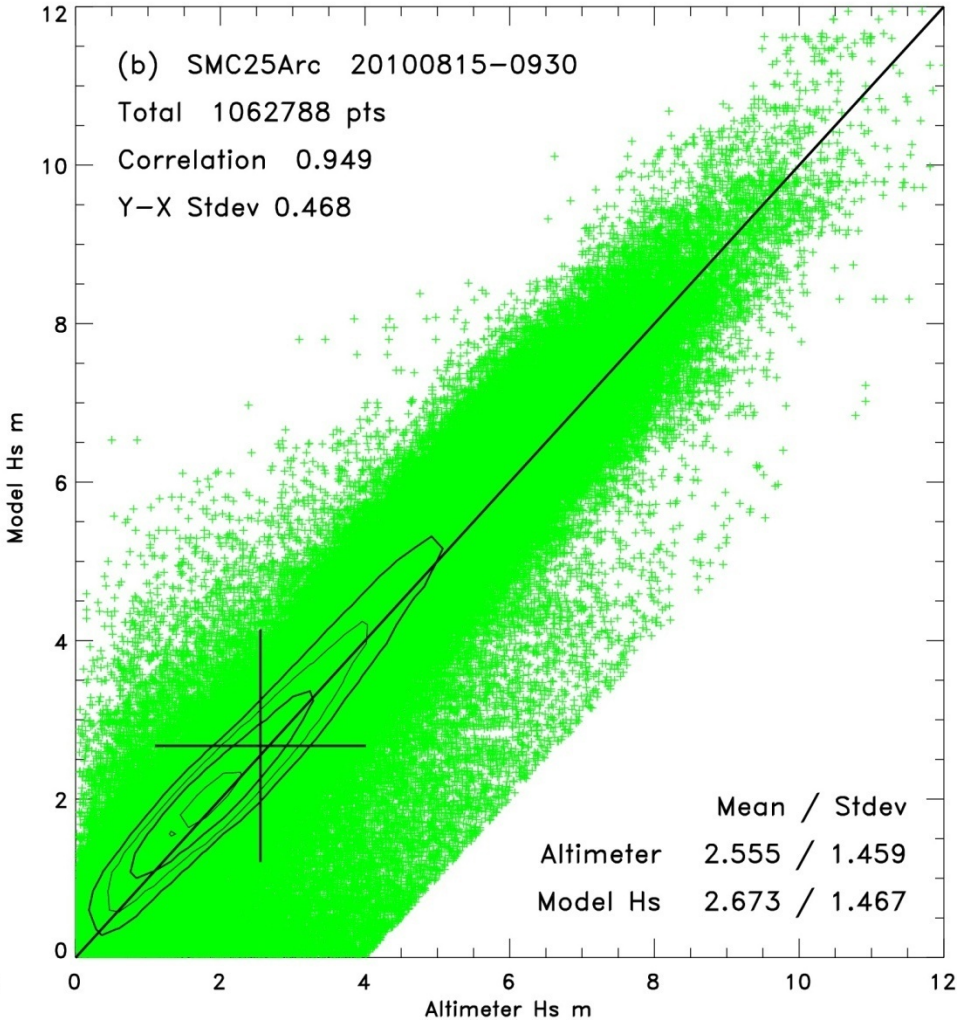




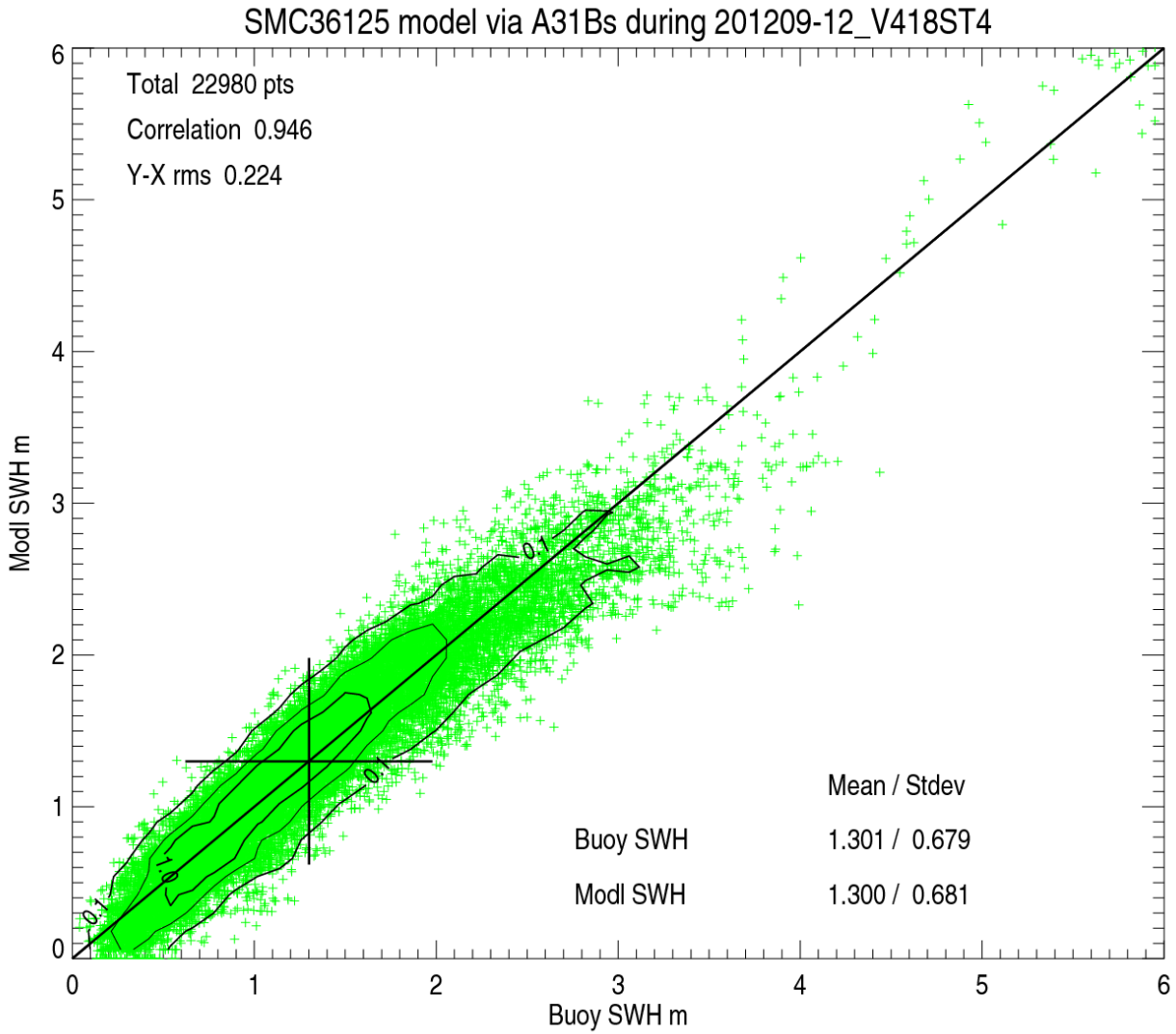


SMC36125 - SMC25Arc global 46 days





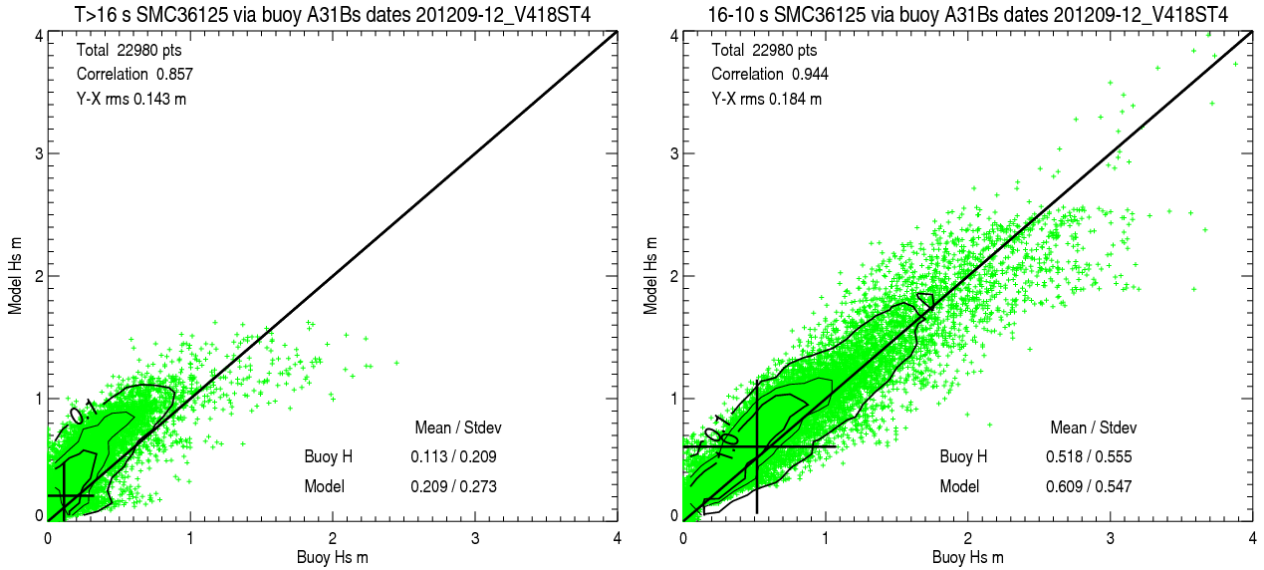
Comparison SMC36125-ST4 via Buoy SWH 201209-12

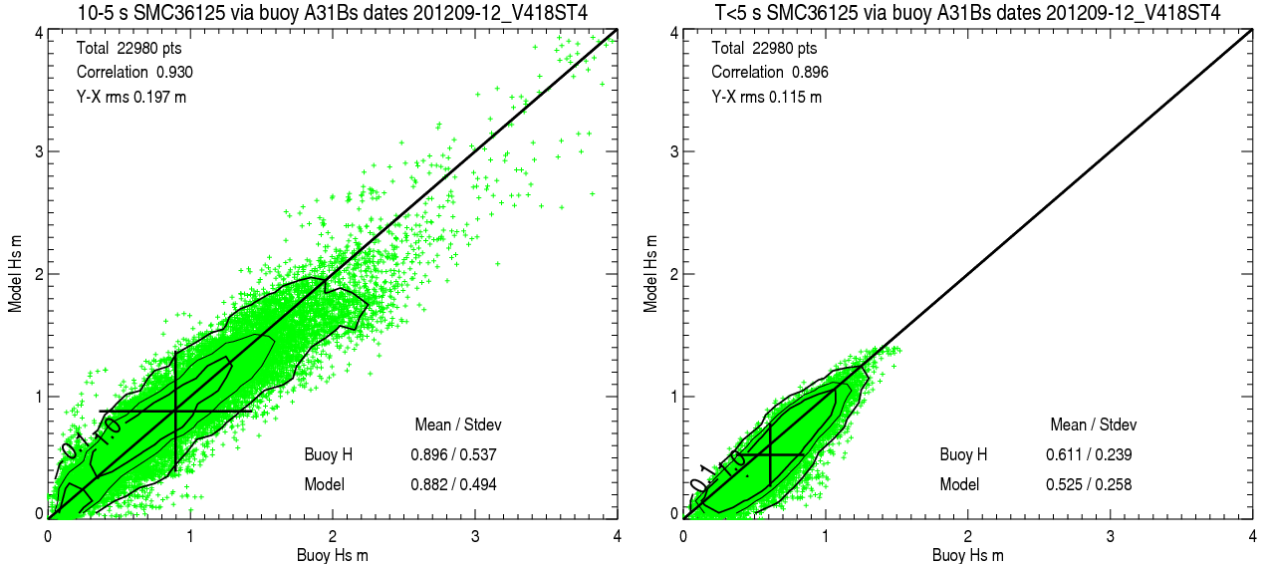


WW3 V4.18 retuned ST4 source term

32 spectral buoys from NDBC.

Comparison SMC36125-ST4 with Buoy 4-bin SRWH





First two bins for swell, model is slightly higher than buoy;

Last two bins for windsea, model is slightly lower;

So retuned ST4 source term is balanced over the full spectral range.

Summary and conclusions

- Using a fixed direction (map-east) to define wave spectra at high latitudes reduces the scalar-assumption errors in Arctic.
- An expanded Arctic part is used to validate the map-east method directly against satellite data.
- The map-east method works fine within the Arctic part and is consistent with the conventional local east method in an overlapping zone, 65º-85ºN.
- Switch on the Arctic part (ARC option) in the global SMC grid allows the whole Arctic to be included in the wave model, WAVEWATCH III, for climate applications and wave forecasts.

Questions?