

# Combination on Normal Equation Level of monthly GRACE GPS- and SWARM gravity fields

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**GGHS**

Thessaloniki

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- EGSiem combination service
- Processing standards and strategy
- Relative weighting
- Formal and true errors of monthly gravity fields
- Contribution analysis
- Validation

# Motivation

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- The EGSiEM combination service provides monthly GRACE K-band gravity fields combined on Normal Equation (NEQ) Level.
- To ensure consistency, a set of common standards for reference frame, Earth rotation, force model and satellite geometry were defined.
- EGSiEM lately was extended to also include SLR and GPS-only NEQs.
- GRACE (GPS) + SWARM serves for demonstration.

# EGSIEM Standards

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- Reference frame: reprocessed GPS-constellations and high-rate clock corrections.
- Earth rotation: IERS 2010
- Force model:
  - relativistic corrections (Schwarzschild, Lense-Thirring, de Sitter)
  - Sun and all planets as point masses
- Satellite geometry: common antenna reference points



# Force Model and Processing Strategy

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- Not fixed, but for this study consistent (Celestial Mechanics Approach of AIUB):
  - AIUB-GRACE-03S (static part only) up to degree 90
  - EOT11A up to degree 100, including admittances
  - AOD1B-RL05 up to degree 100
  - Earth and pole tides according to IERS 2010
  - constrained stochastic accelerations every 15 minutes in radial (R), along-track (S), cross-track (W)
  - daily constant accelerations in R, S, W
  - 1/rev-accelerations in R, S, W (GRACE only).

# Relative weighting

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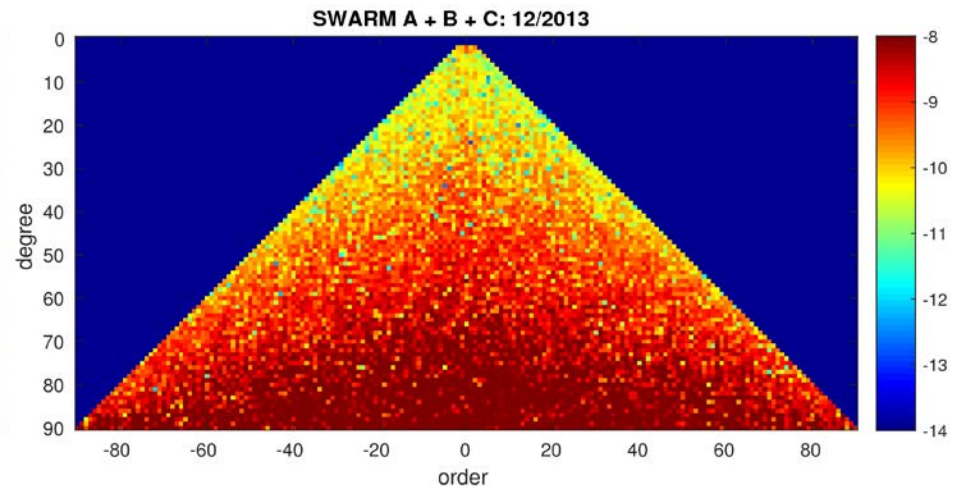
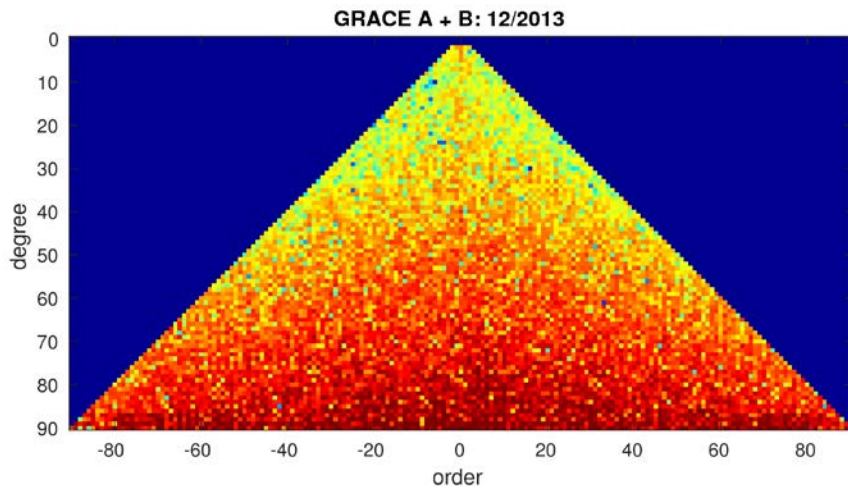
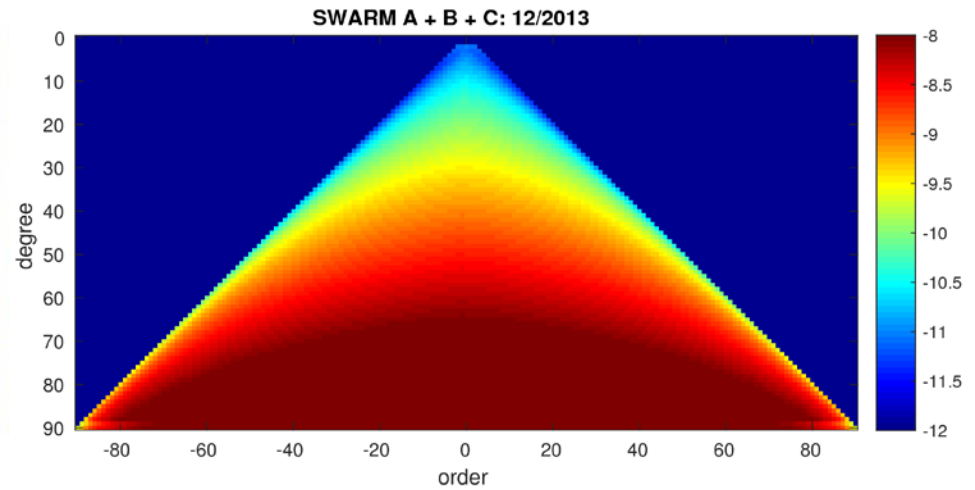
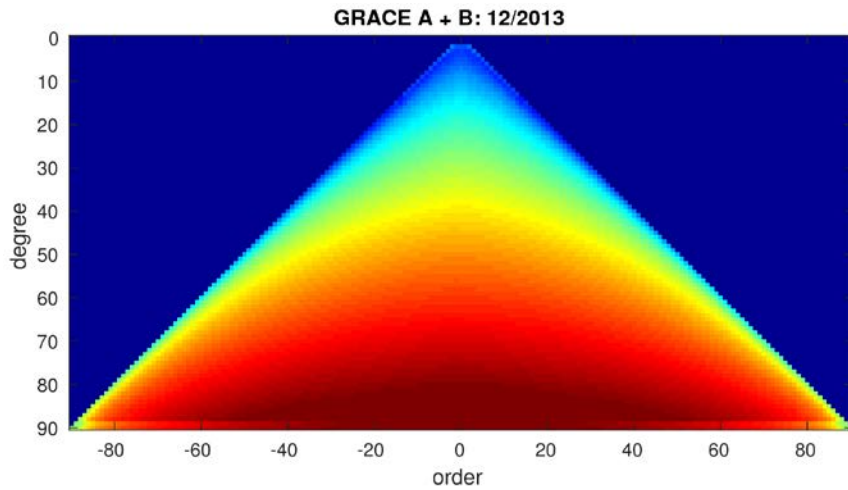
- For this study all satellites were processed using the same observation type:
    - kinematic positions (10s-sampling)
  - same type of noise model:
    - observations are considered as uncorrelated in time
    - constrained stochastic accelerations absorb model deficiencies
- ⇒ Generally easy to combine
- ⇒ But: different sampling rate of SWARM (1s from July 2014 on) leads to over-weighting of SWARM.

Variance factors for relative weighting:

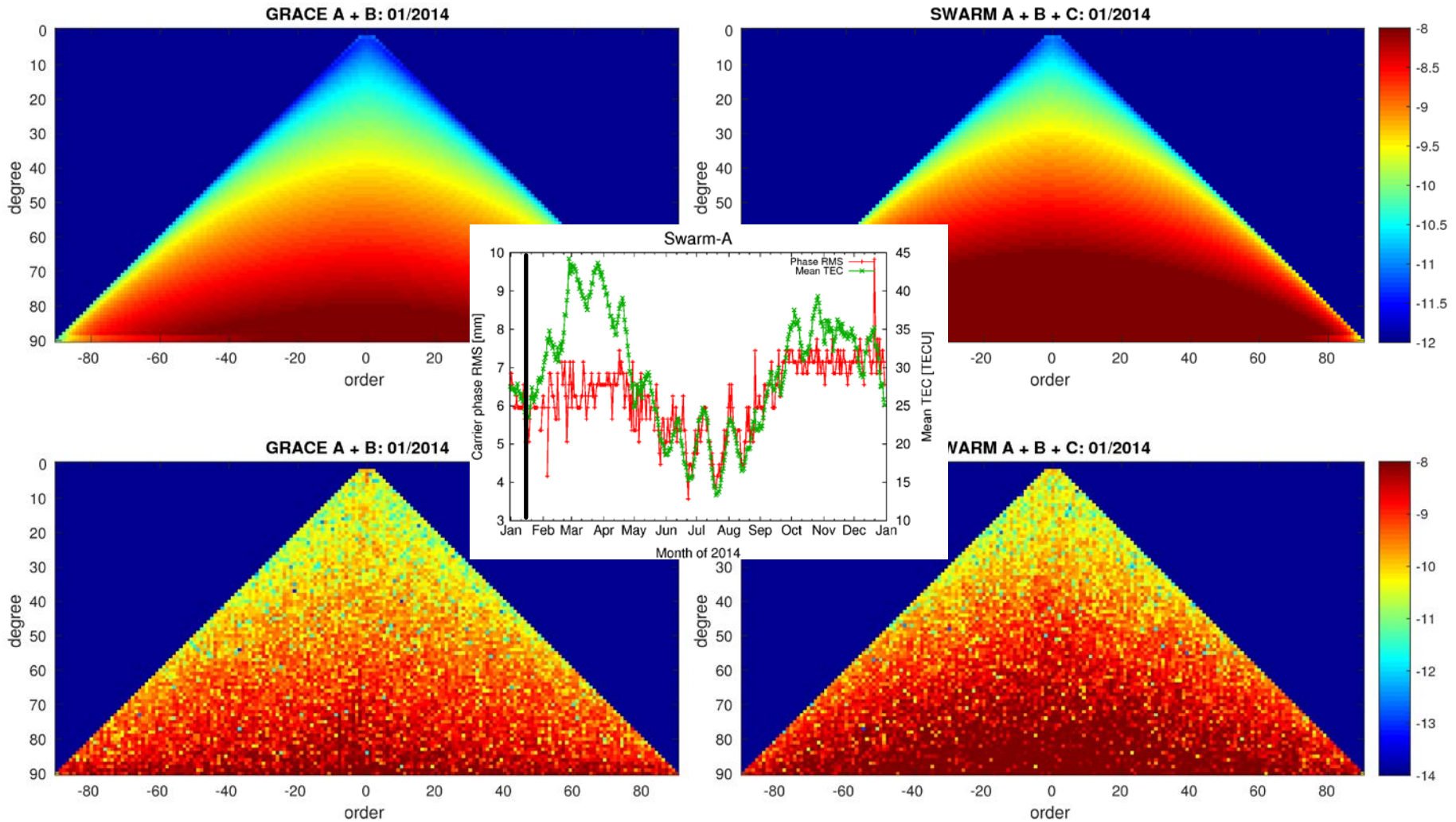
$$W = S_0^2 * \text{DOF} / v^T P v$$

$S_0 = 0.001 \text{ m}$  ; DOF = Degree Of Freedom

# Individual Combinations

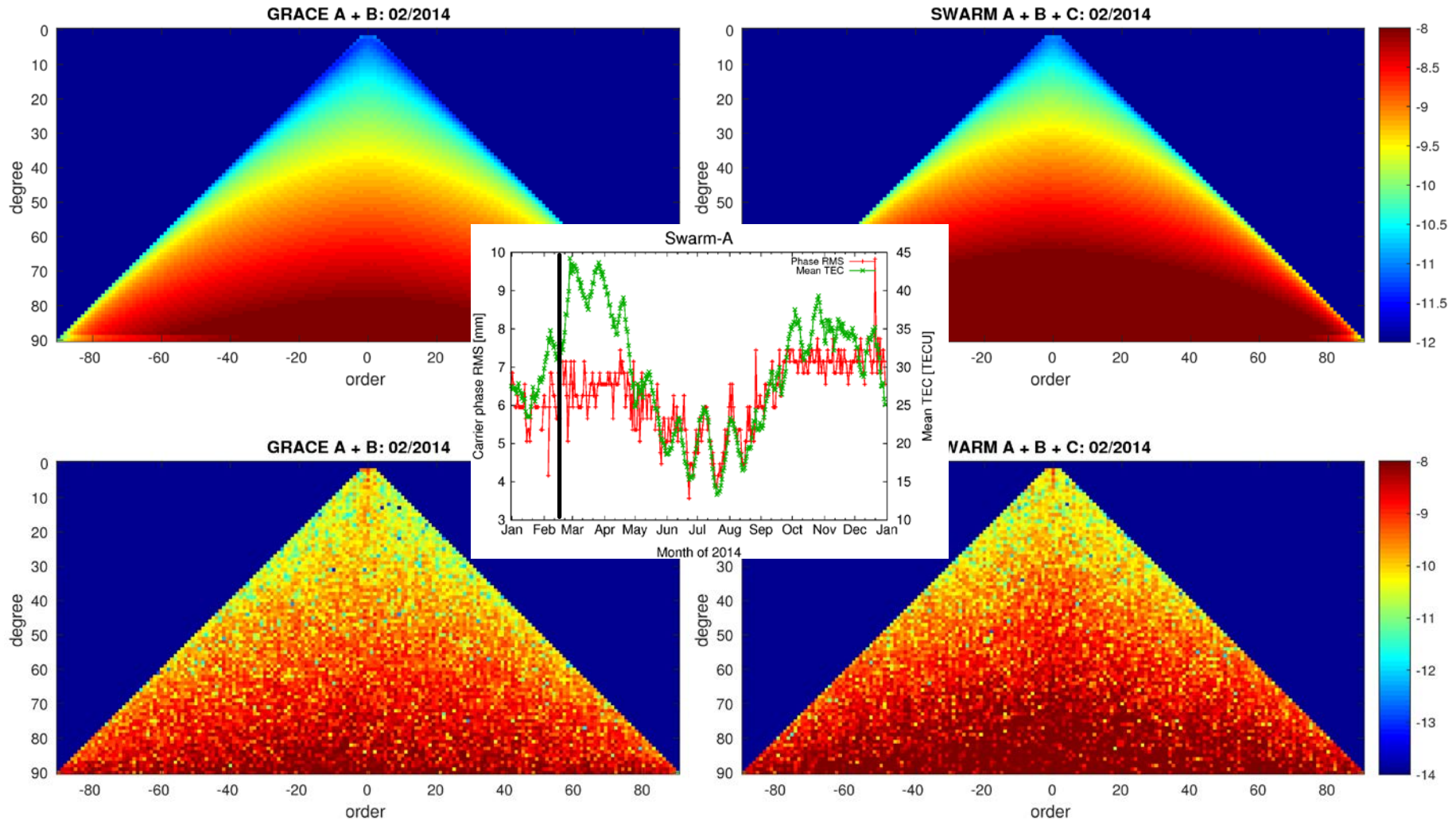


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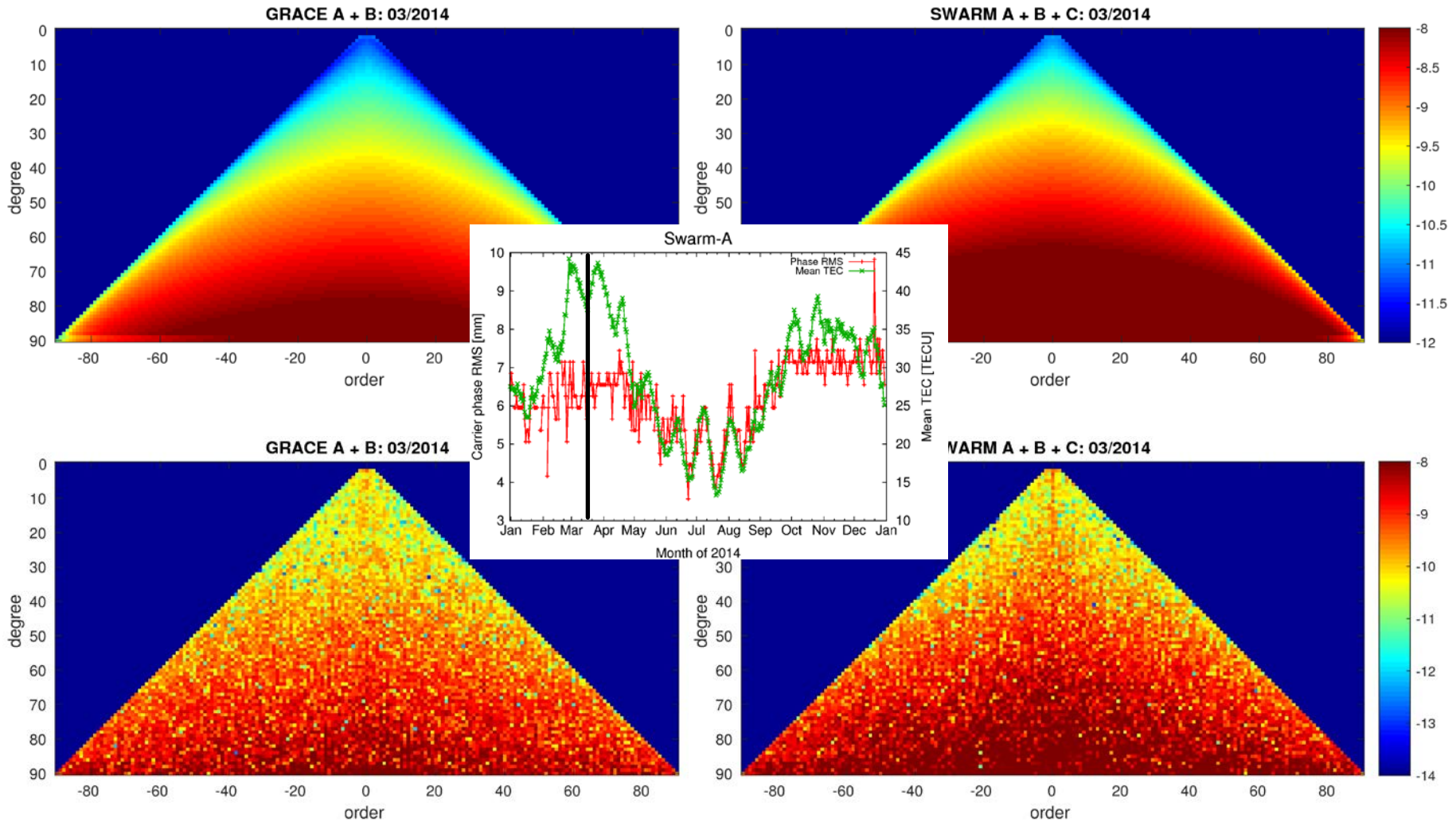




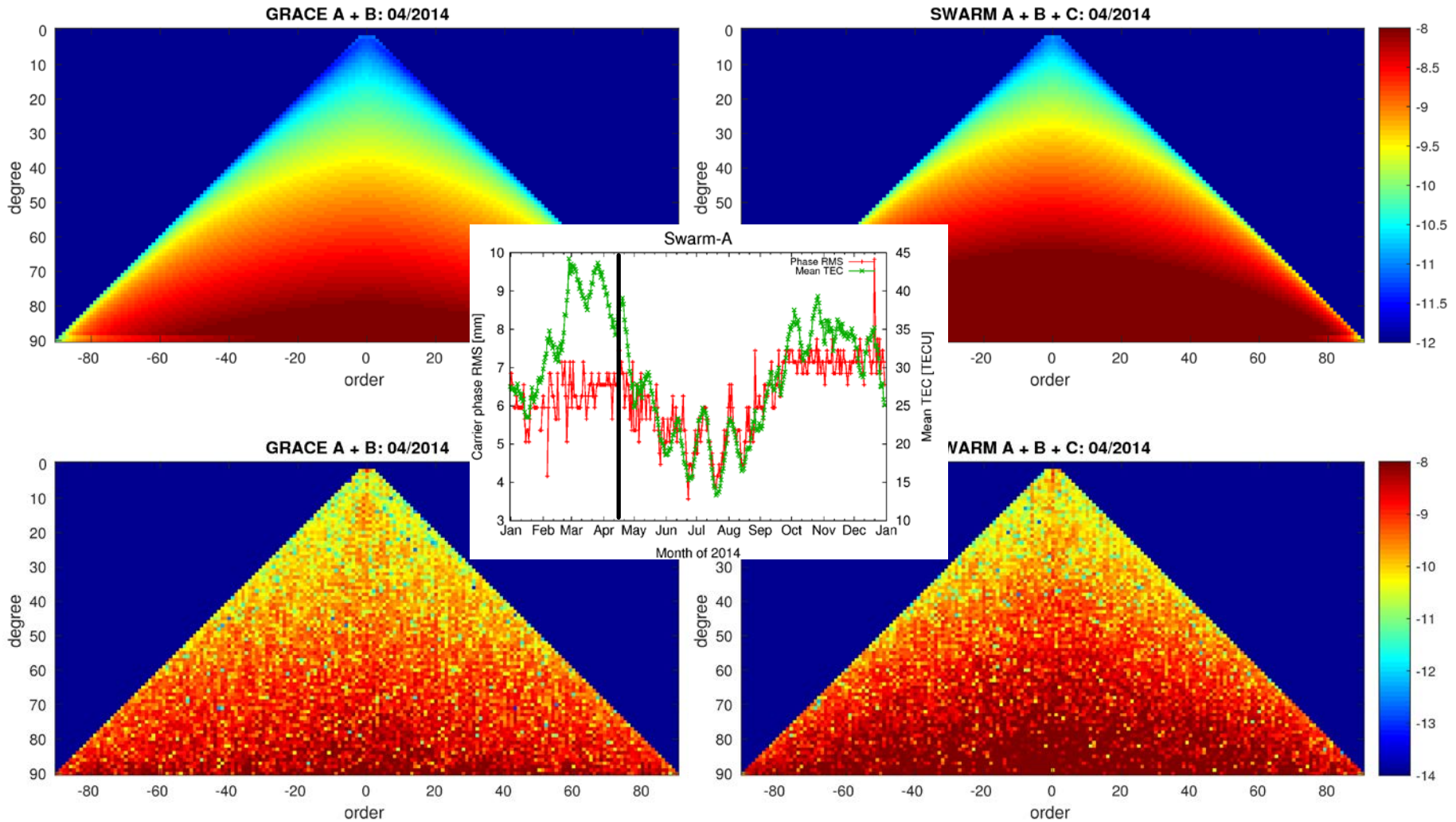
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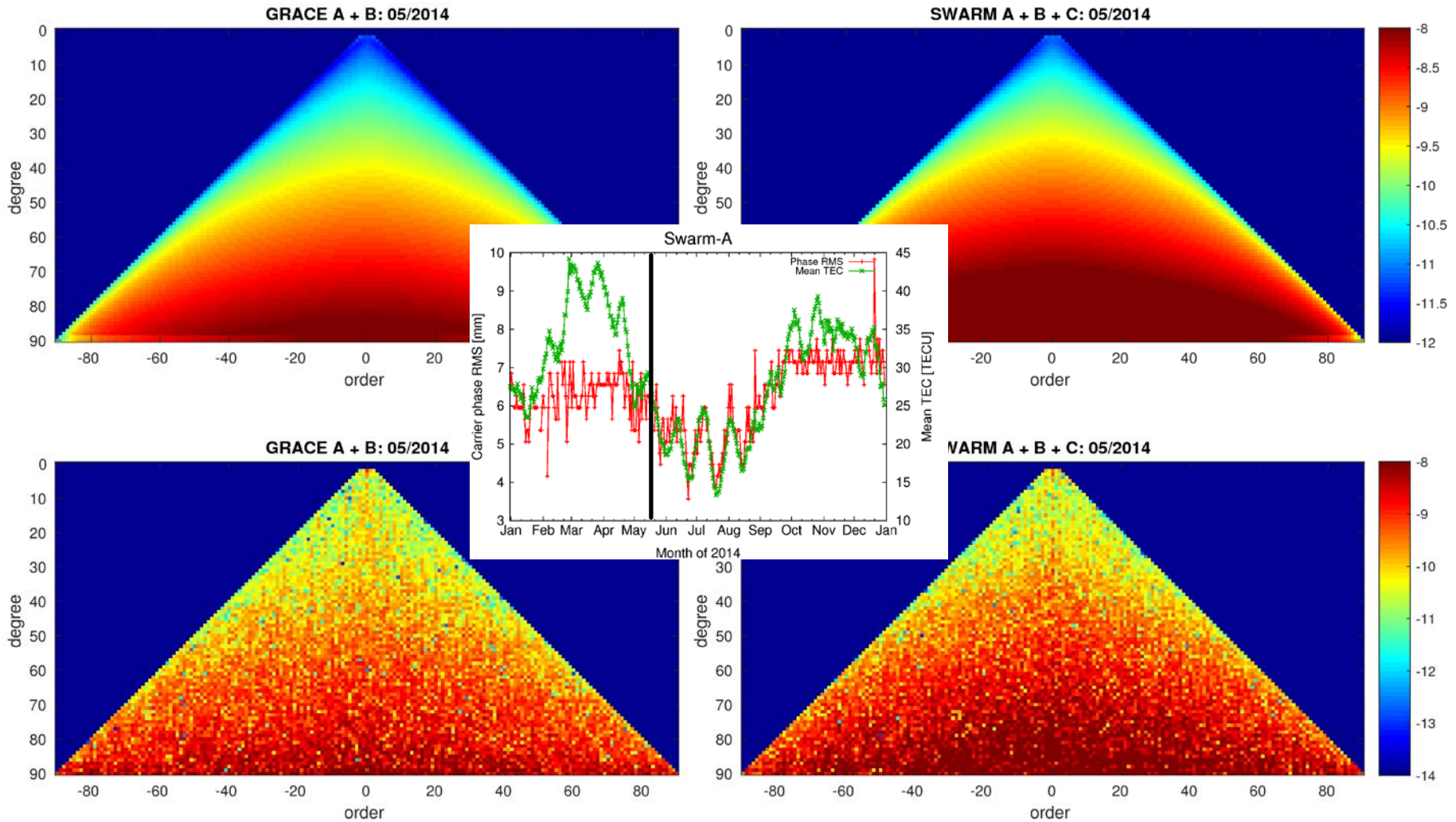


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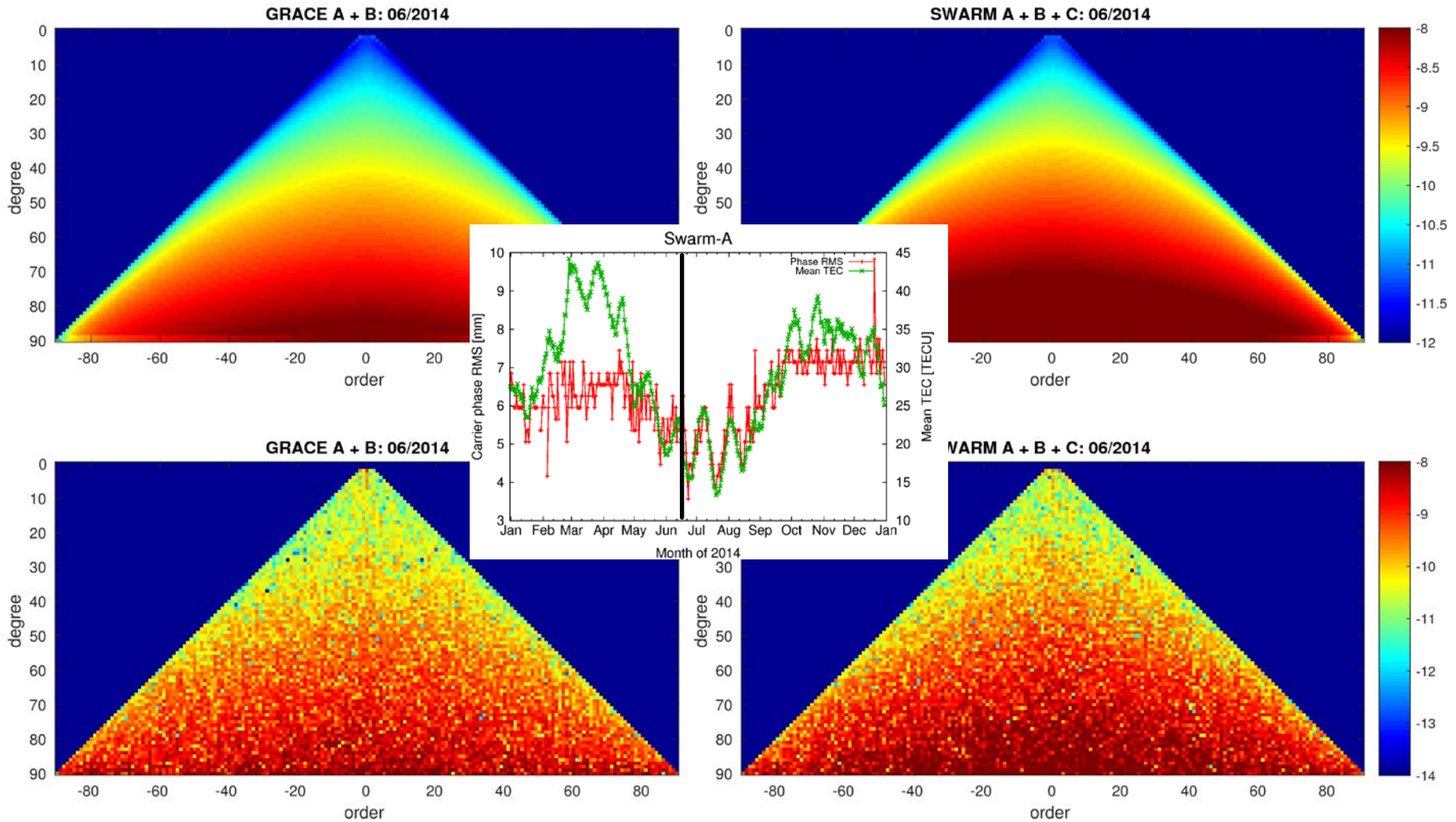


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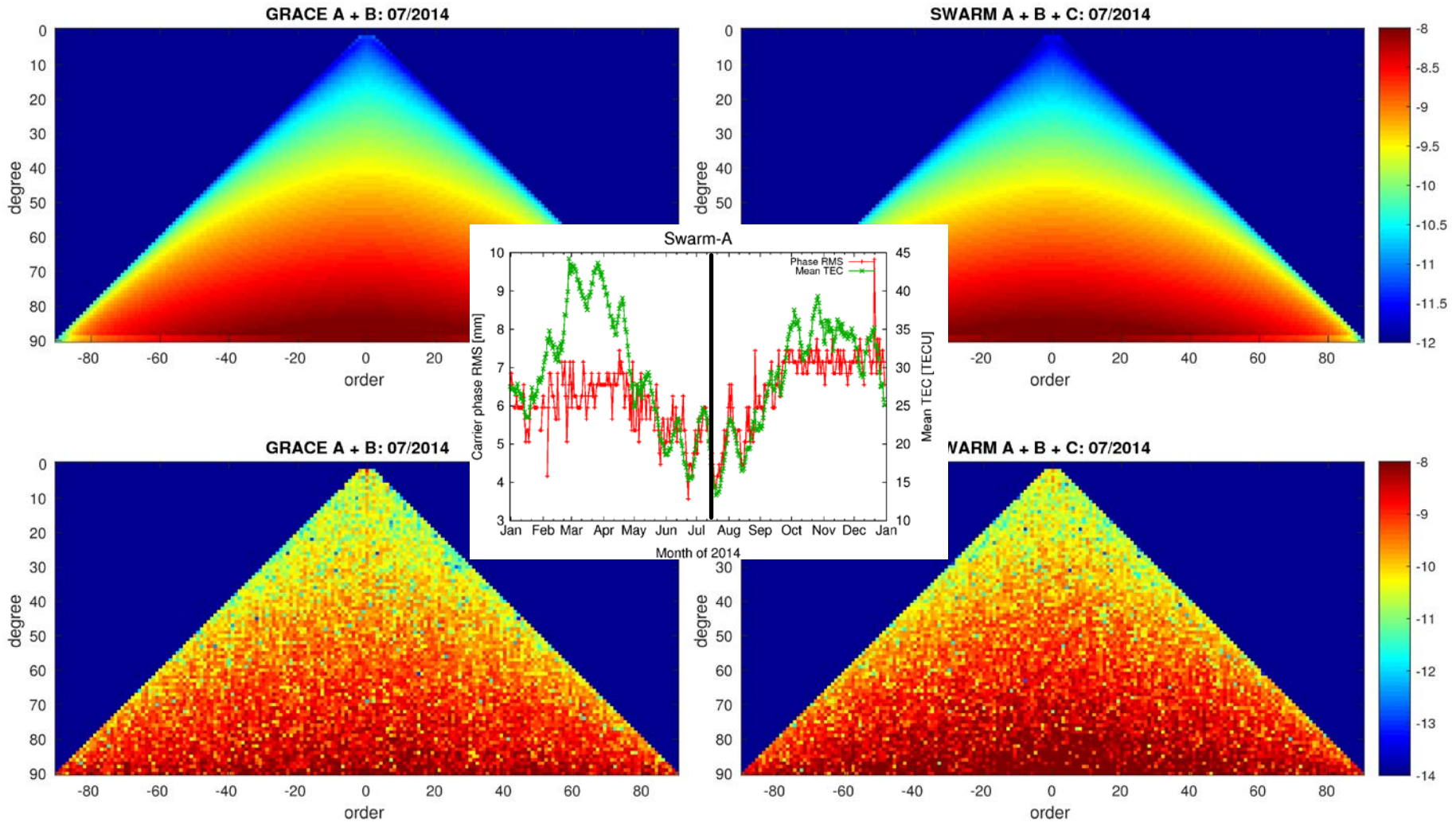




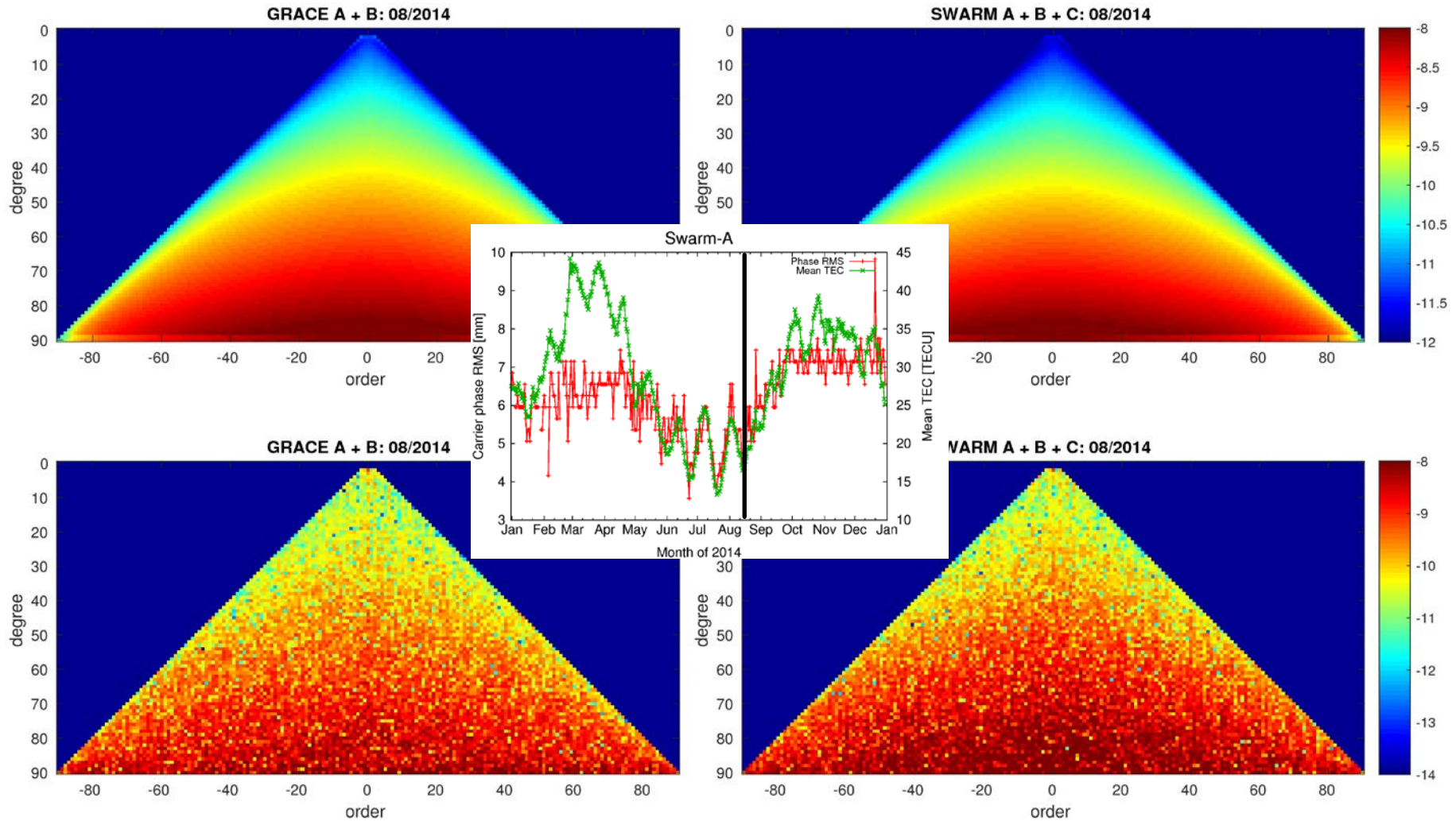
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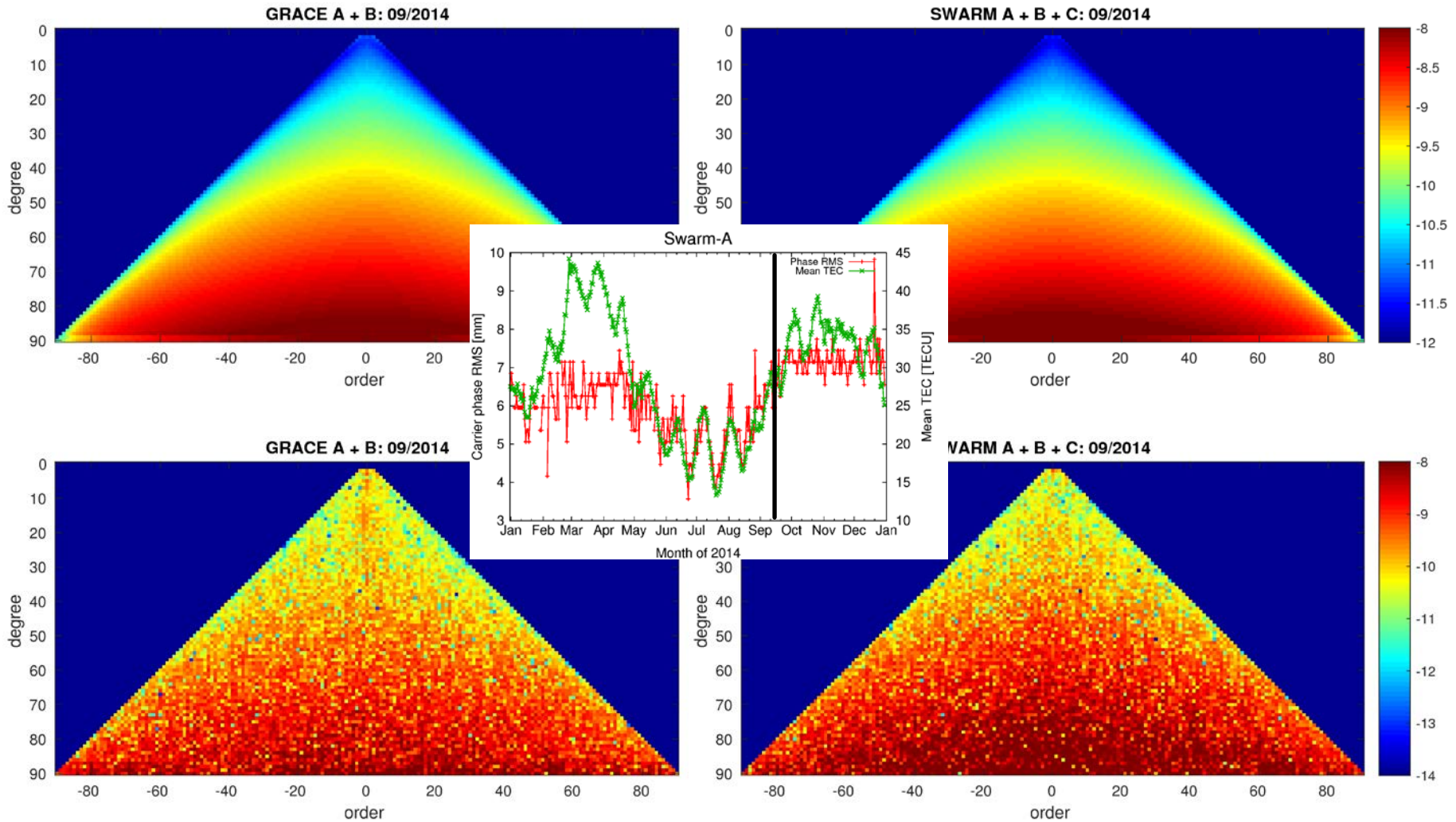


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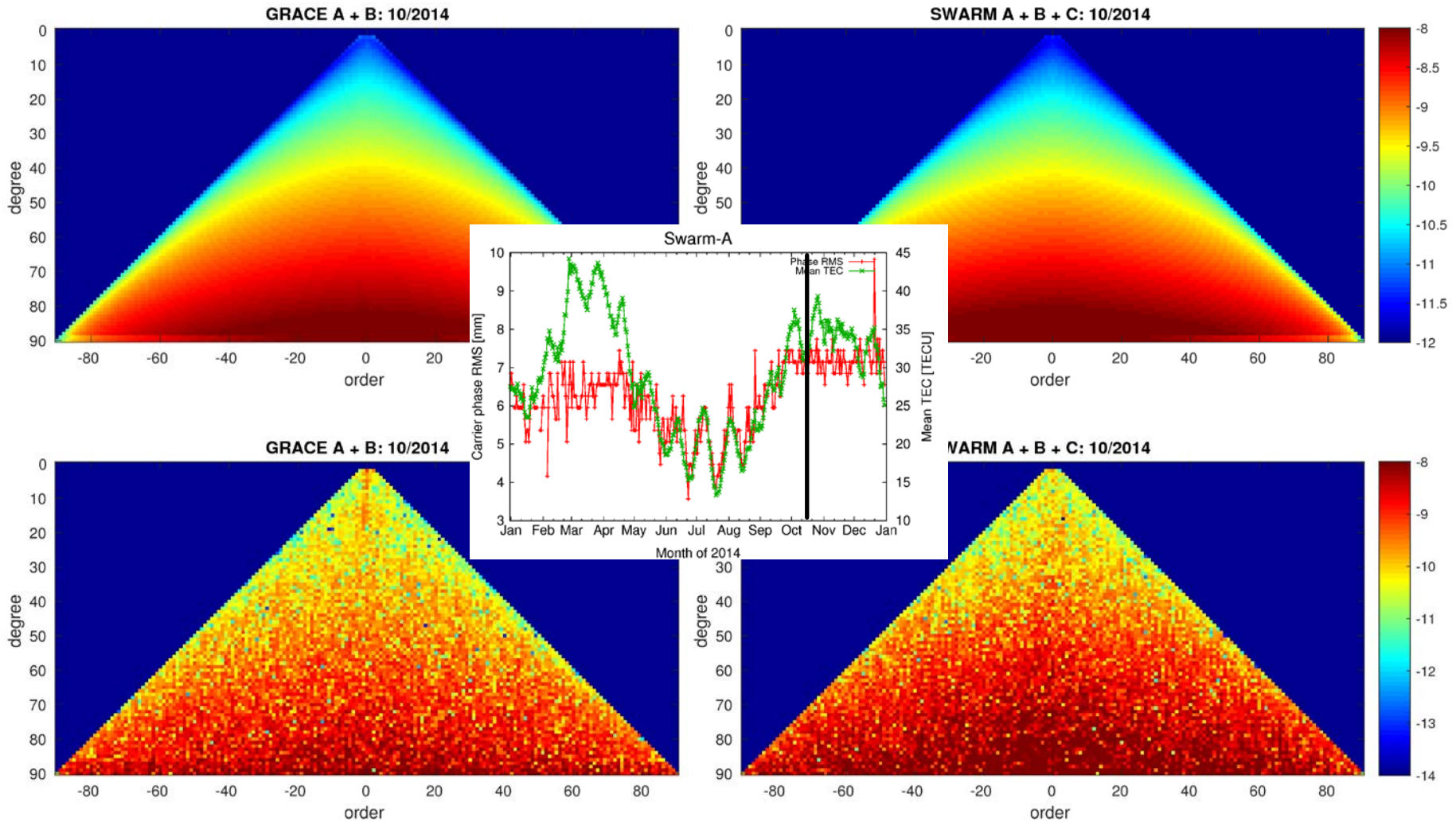




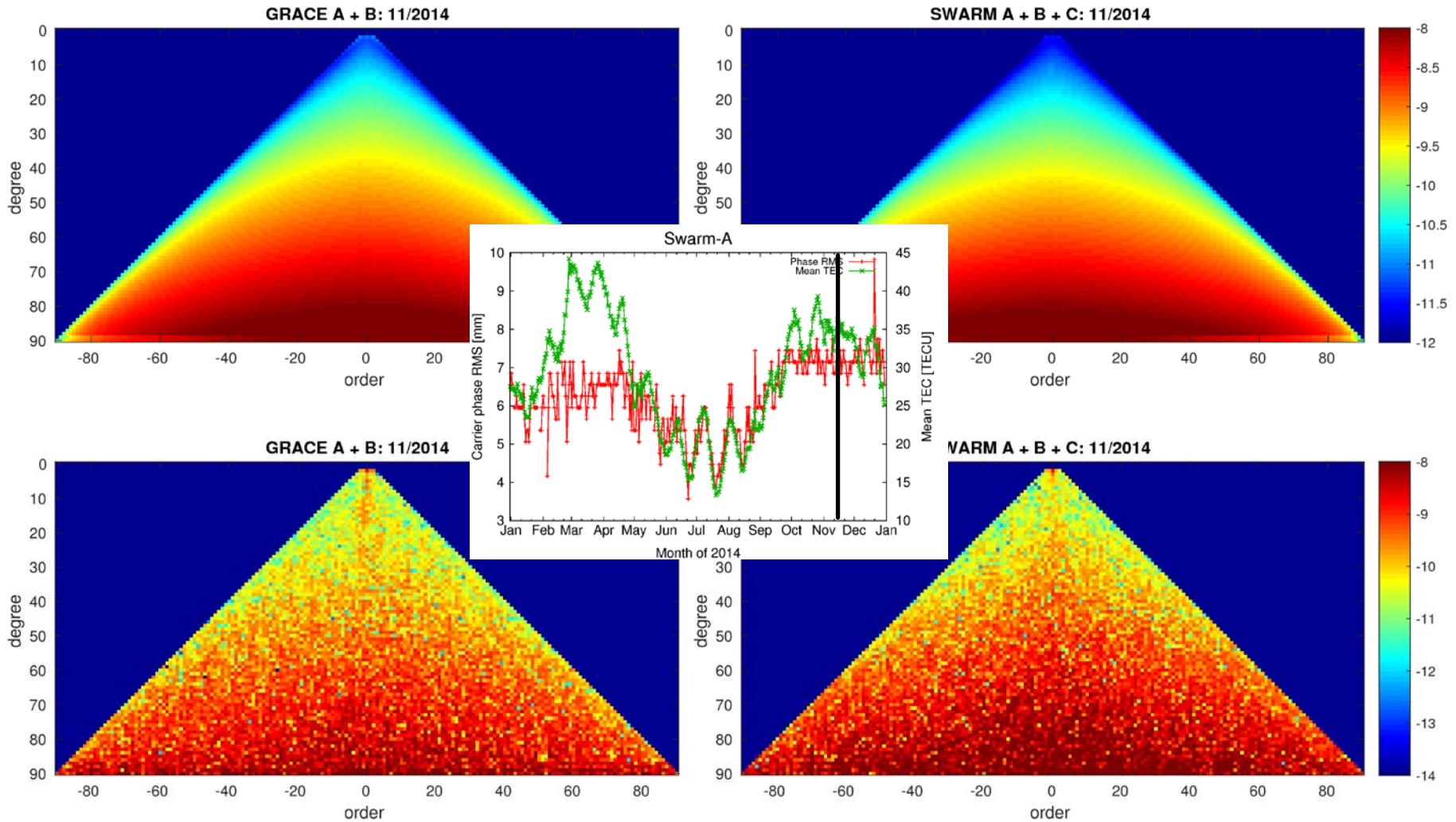
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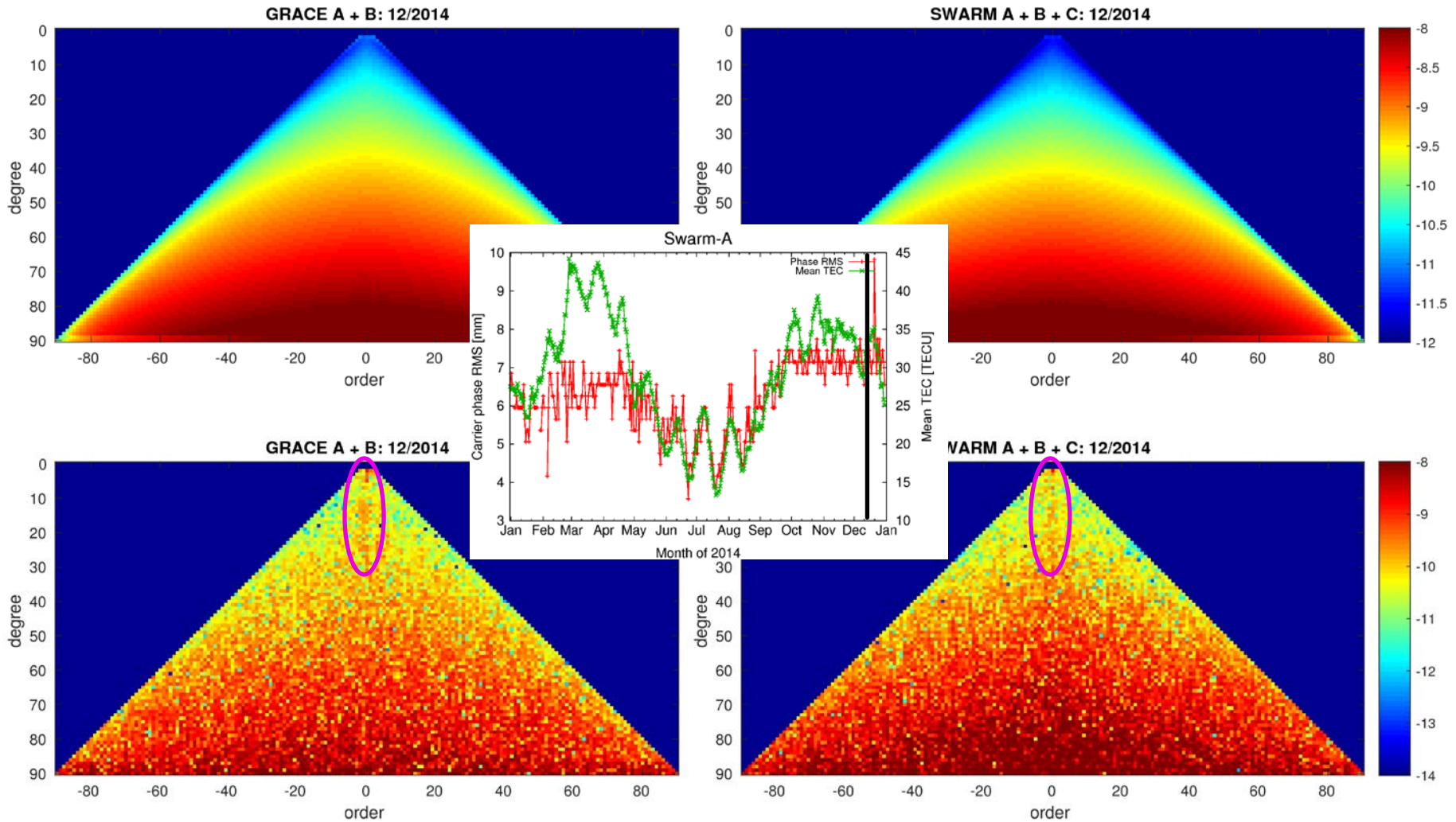


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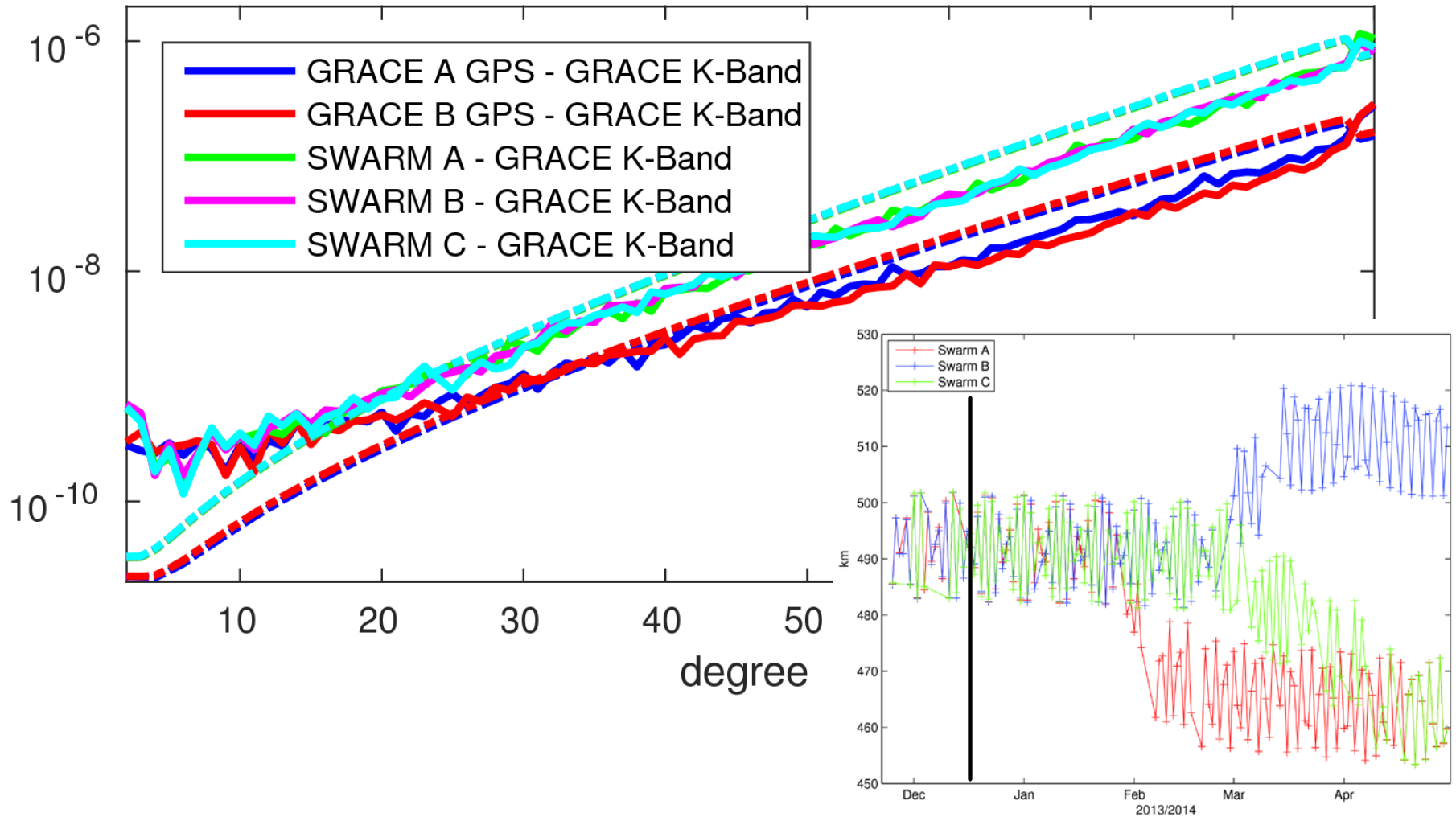


# Individual Combinations



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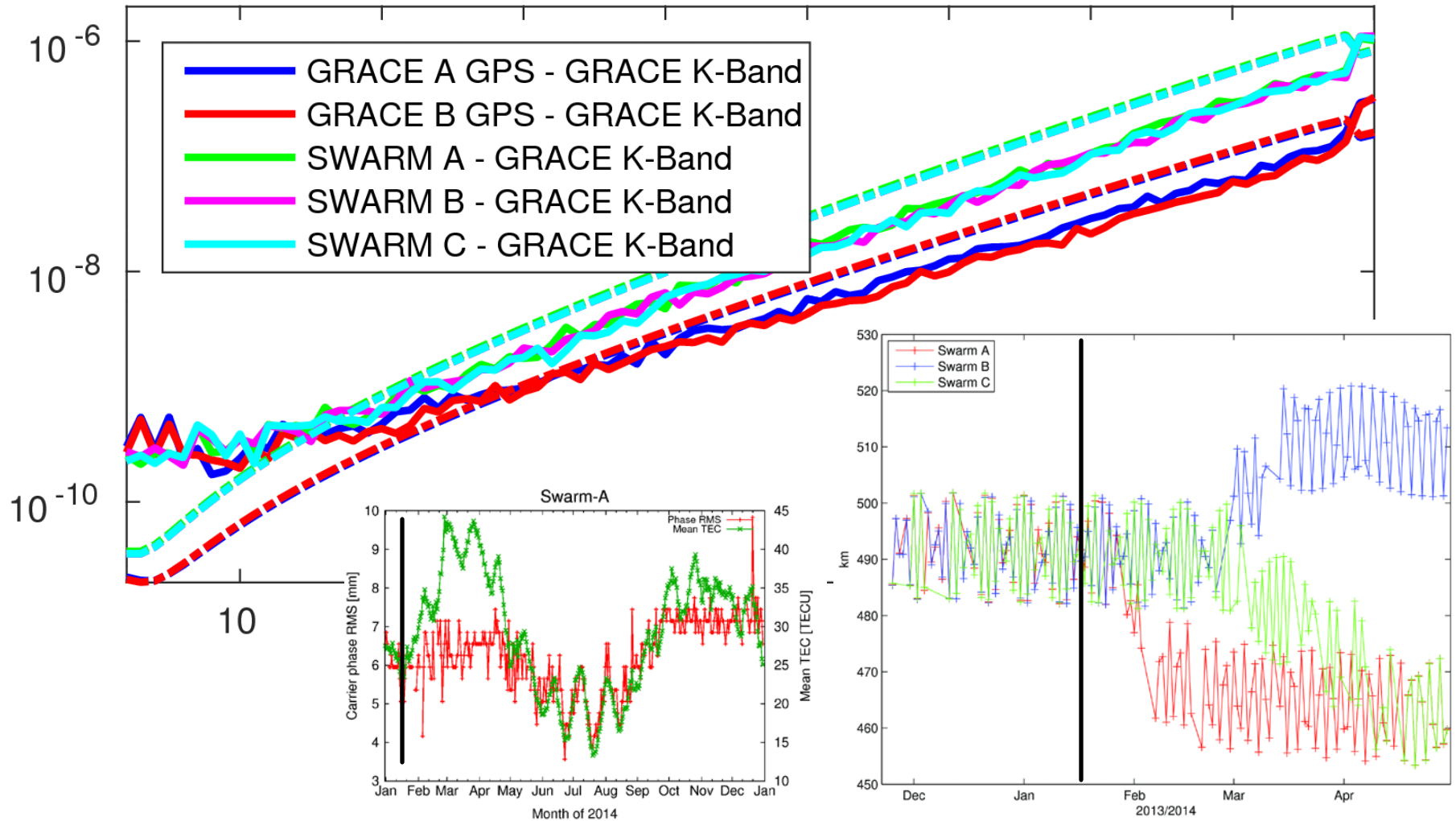
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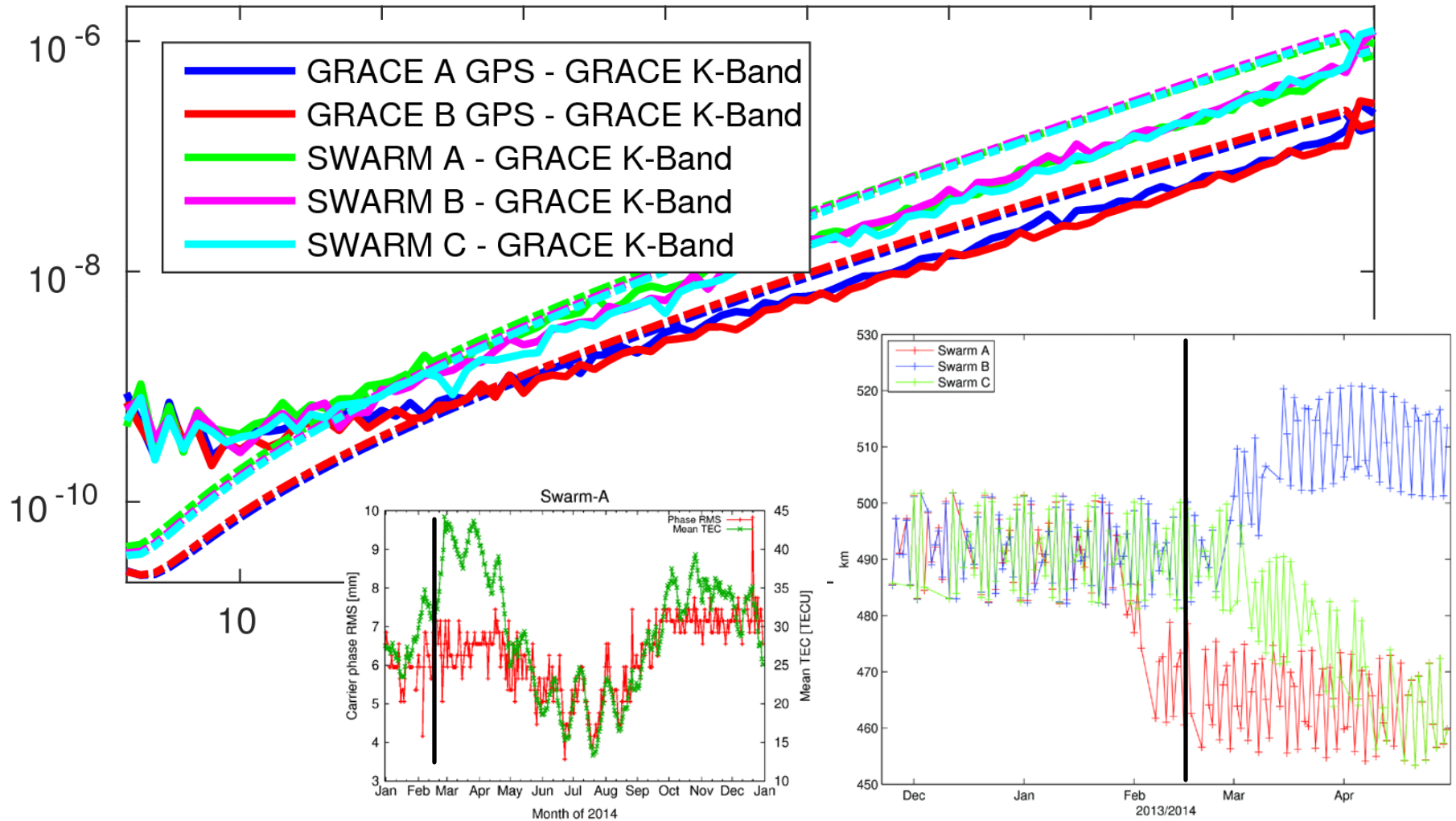
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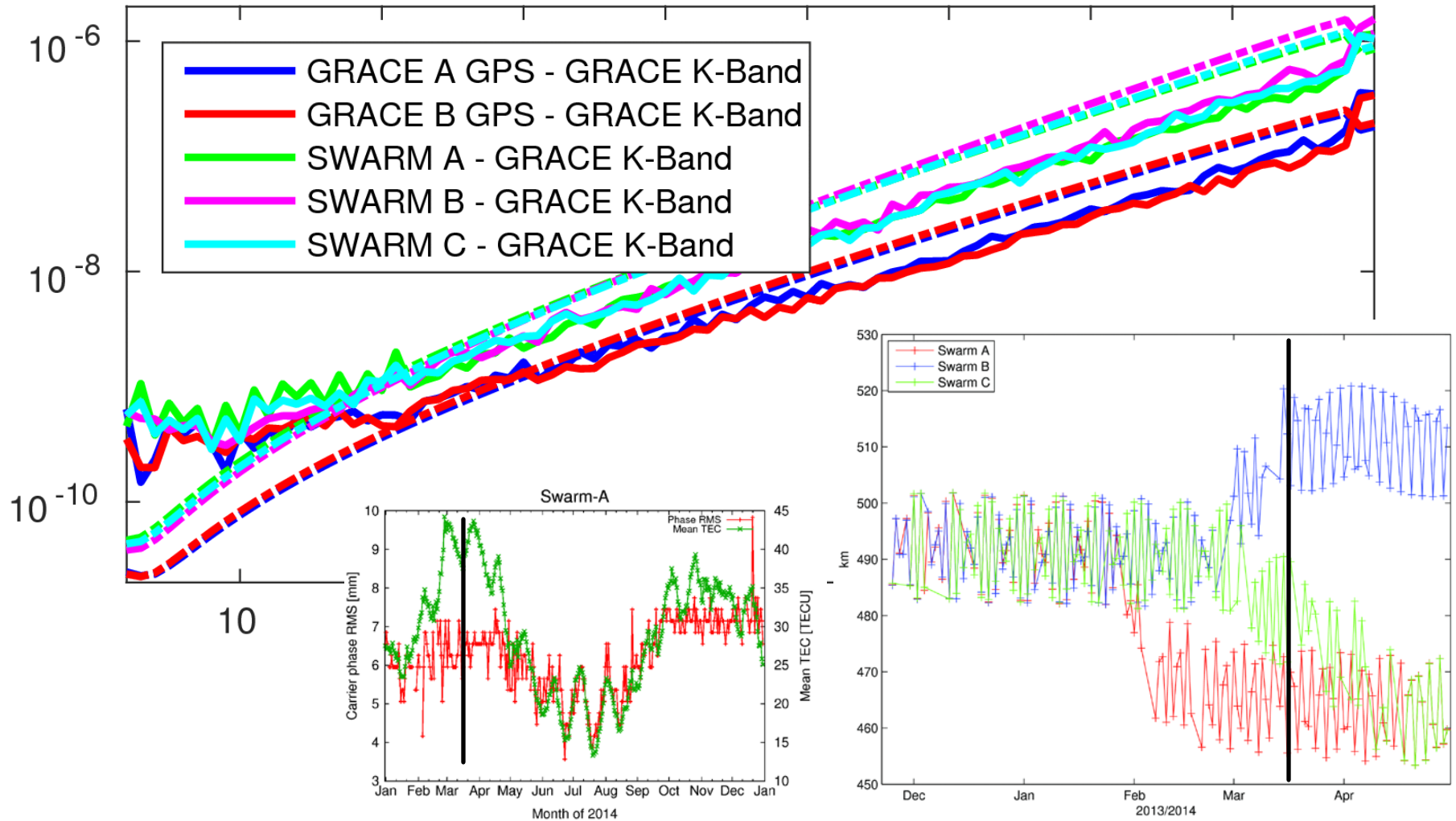
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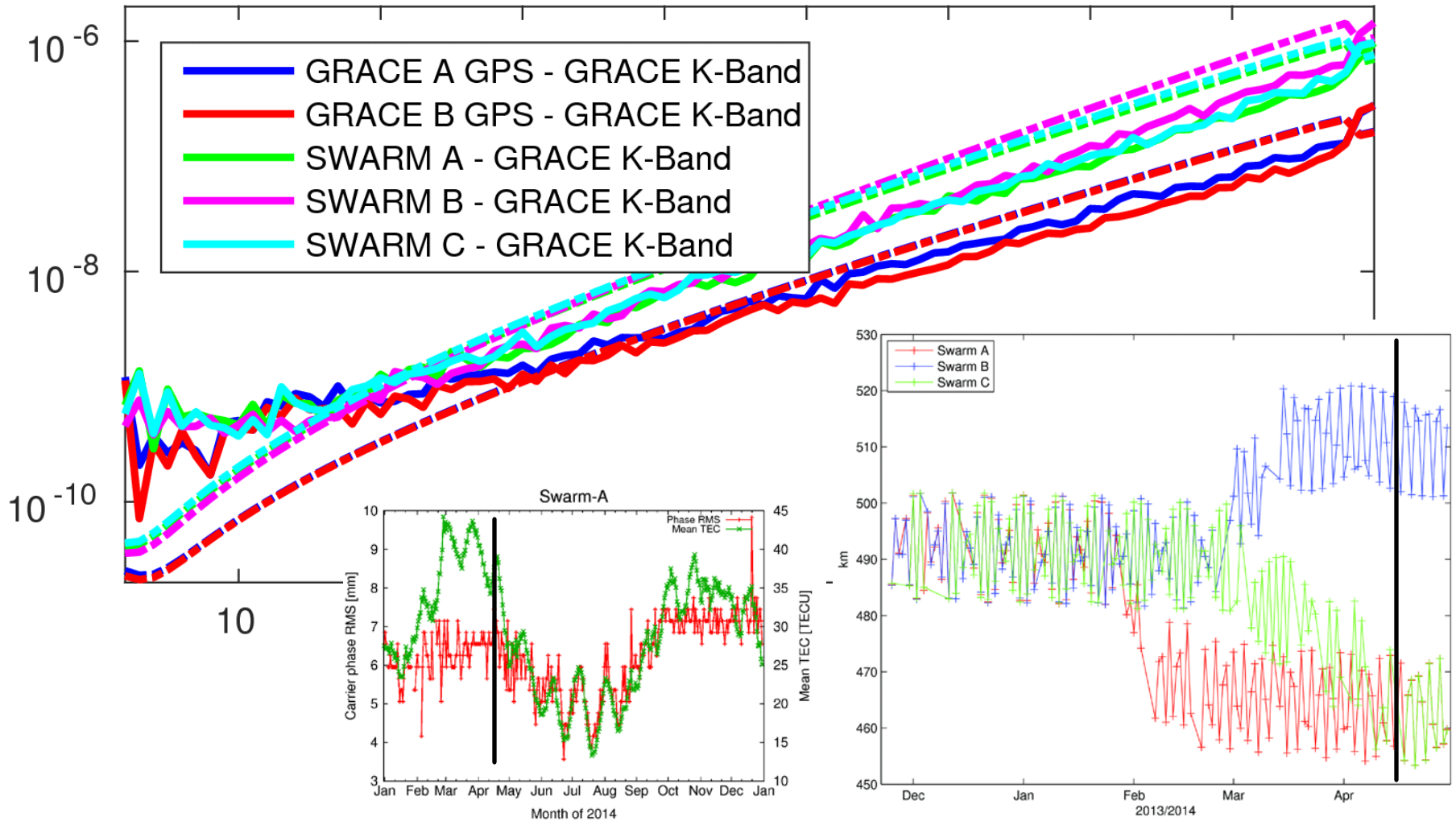
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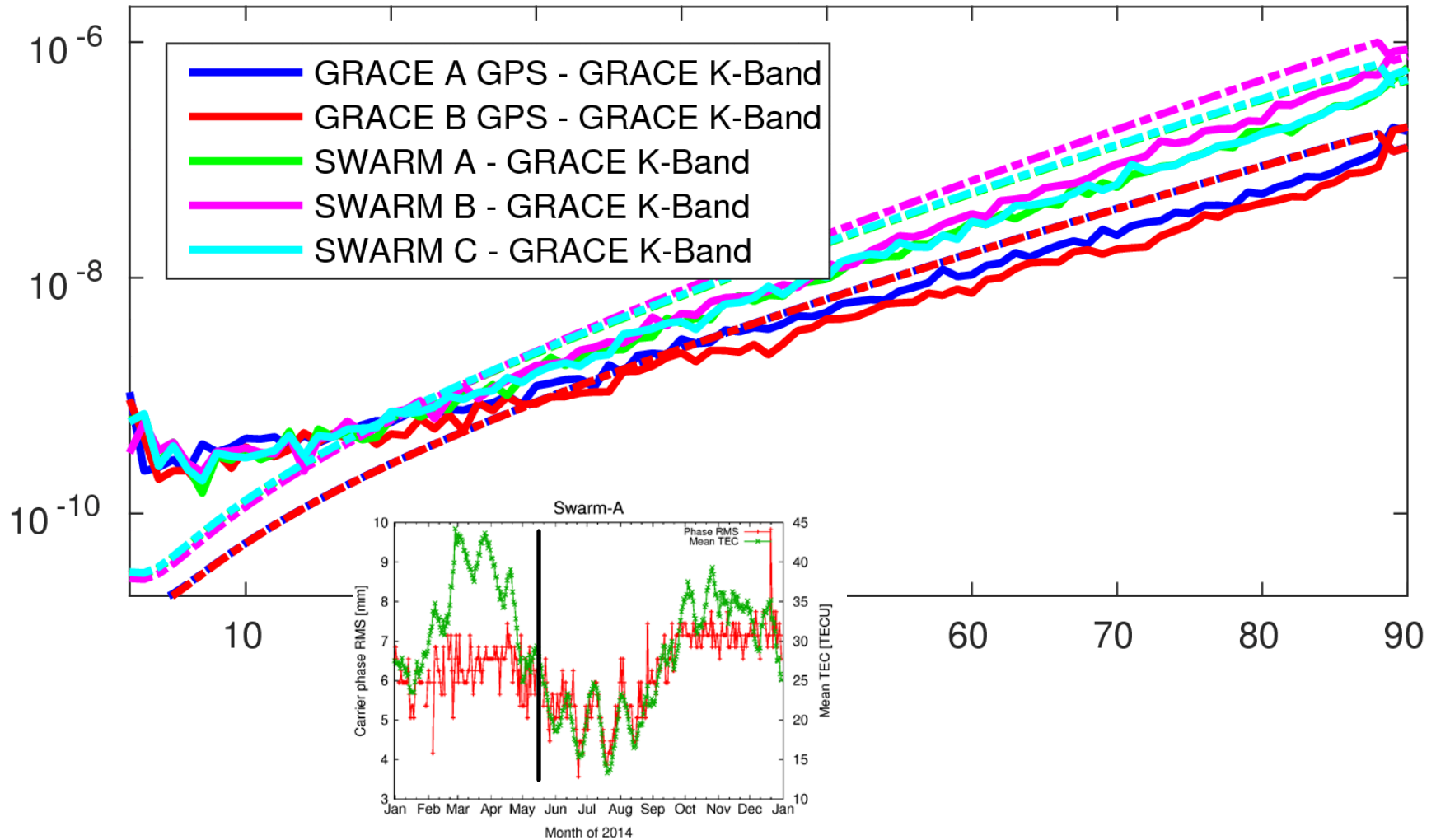
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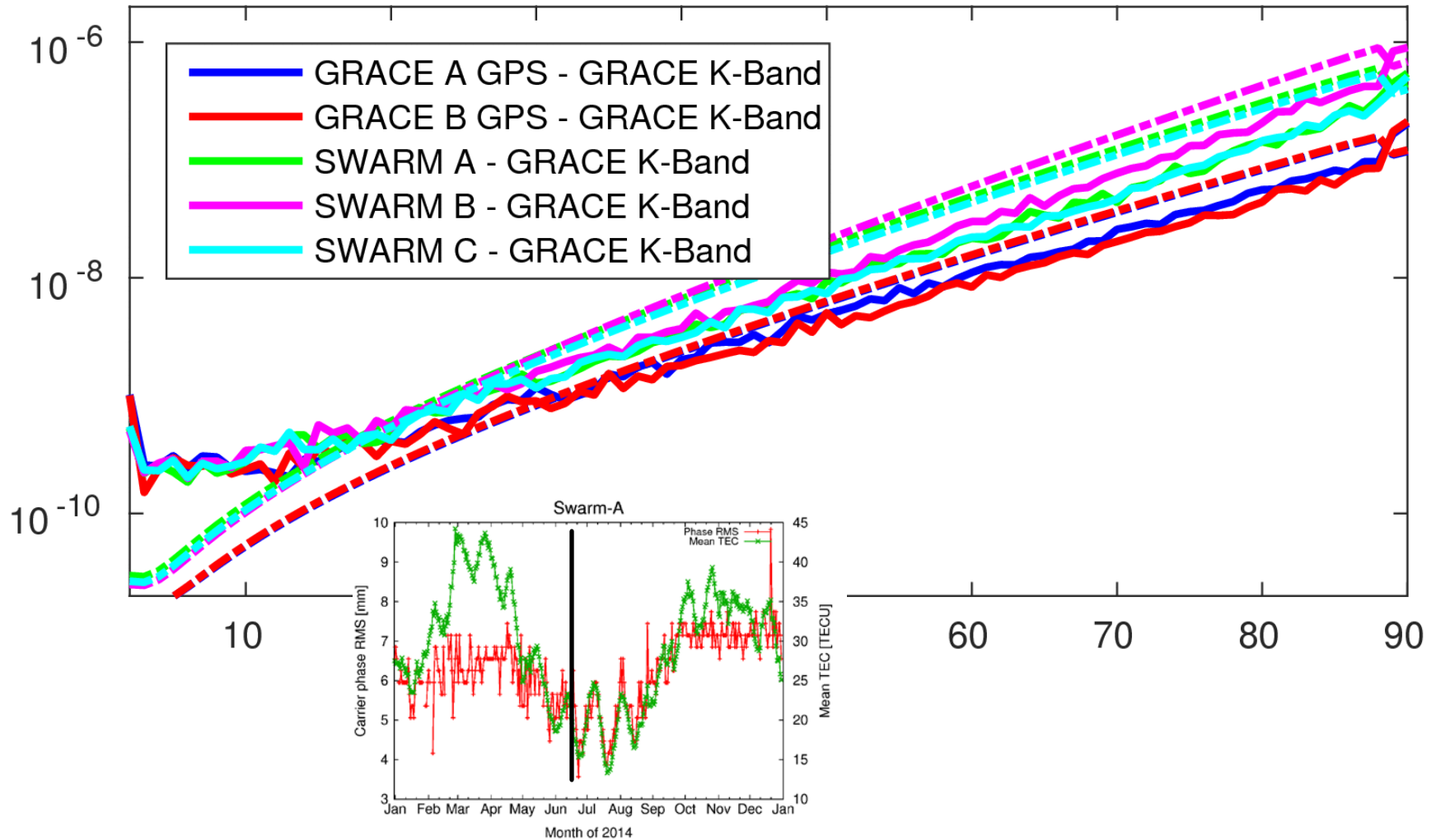
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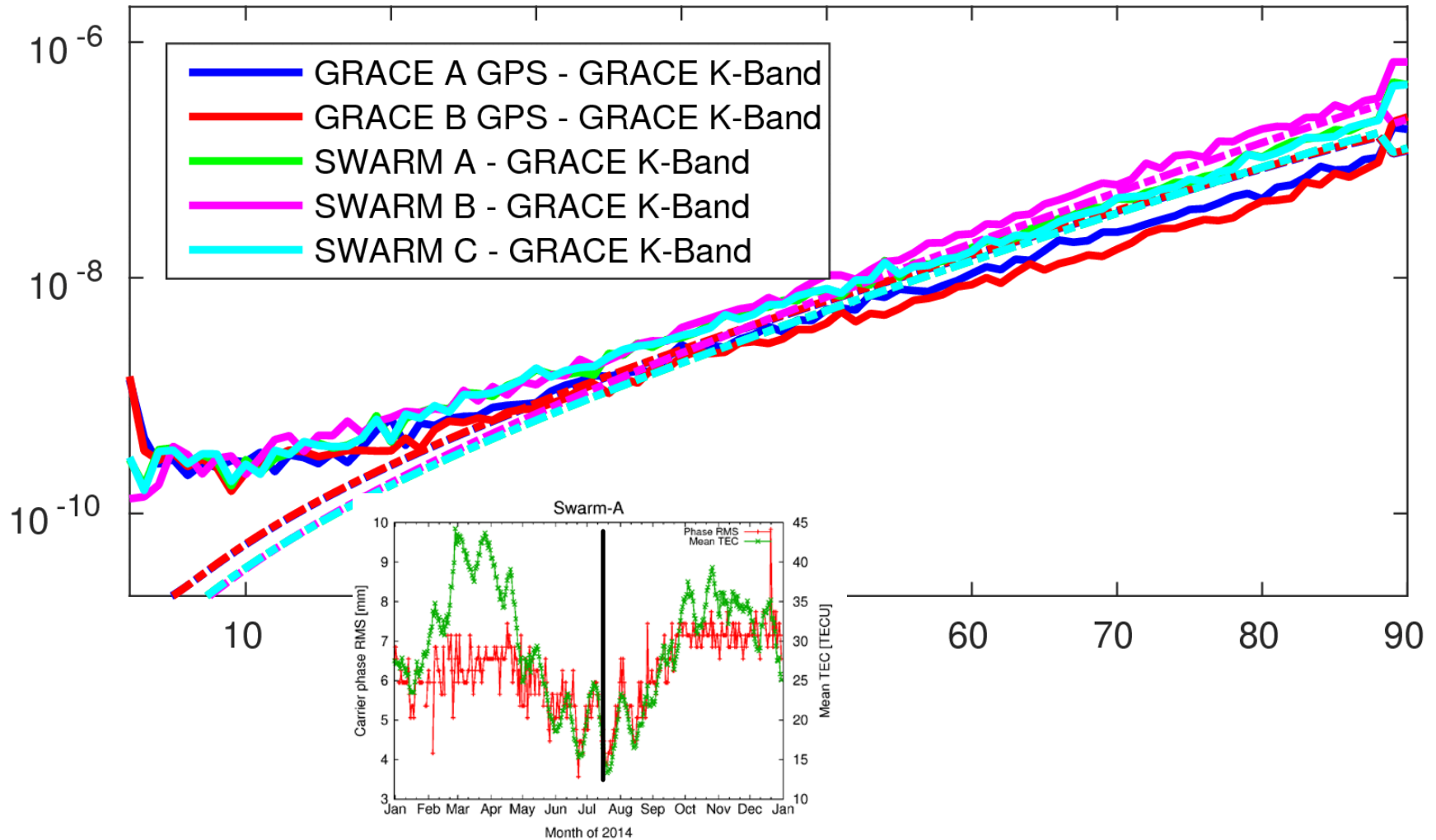
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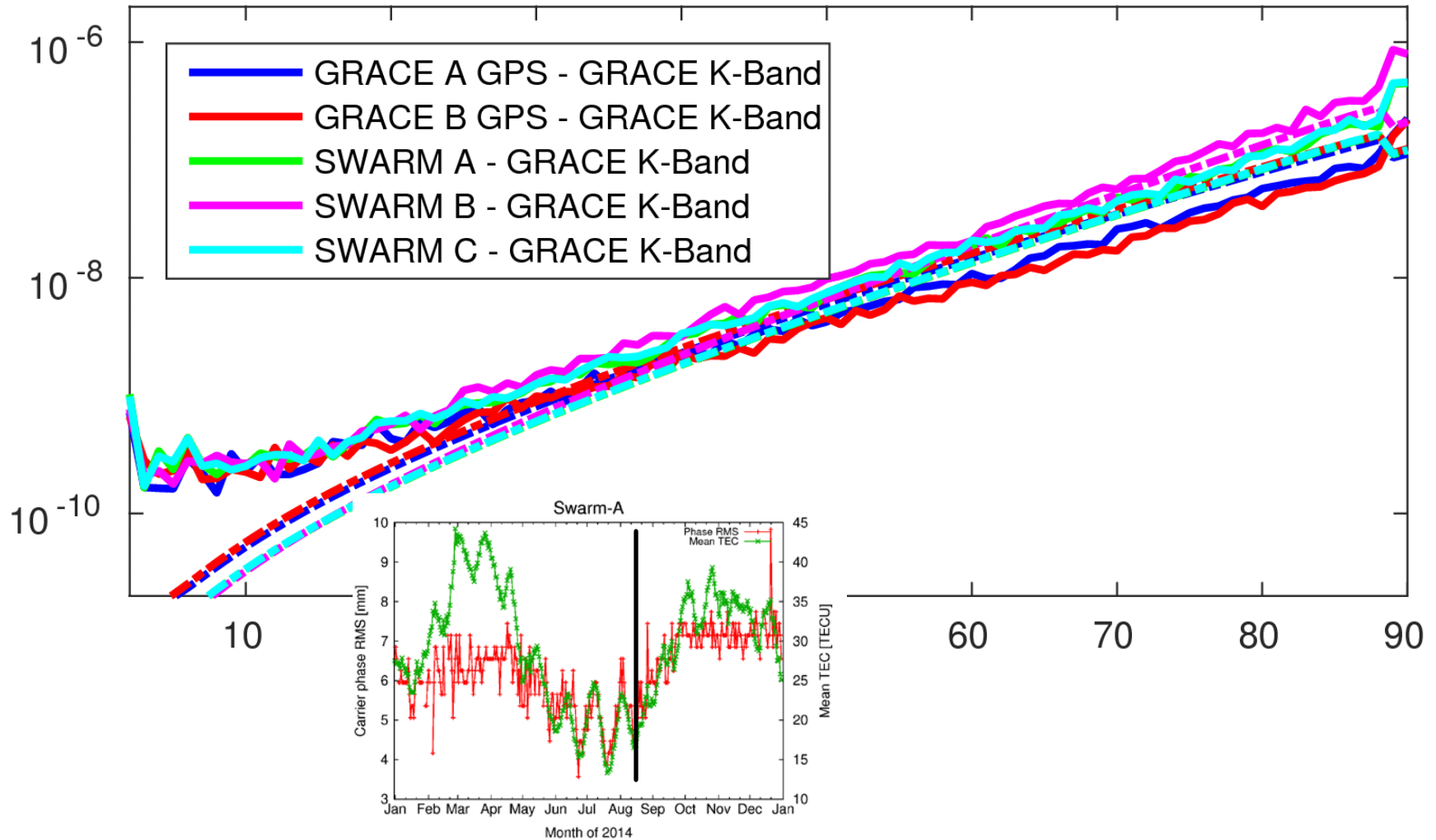
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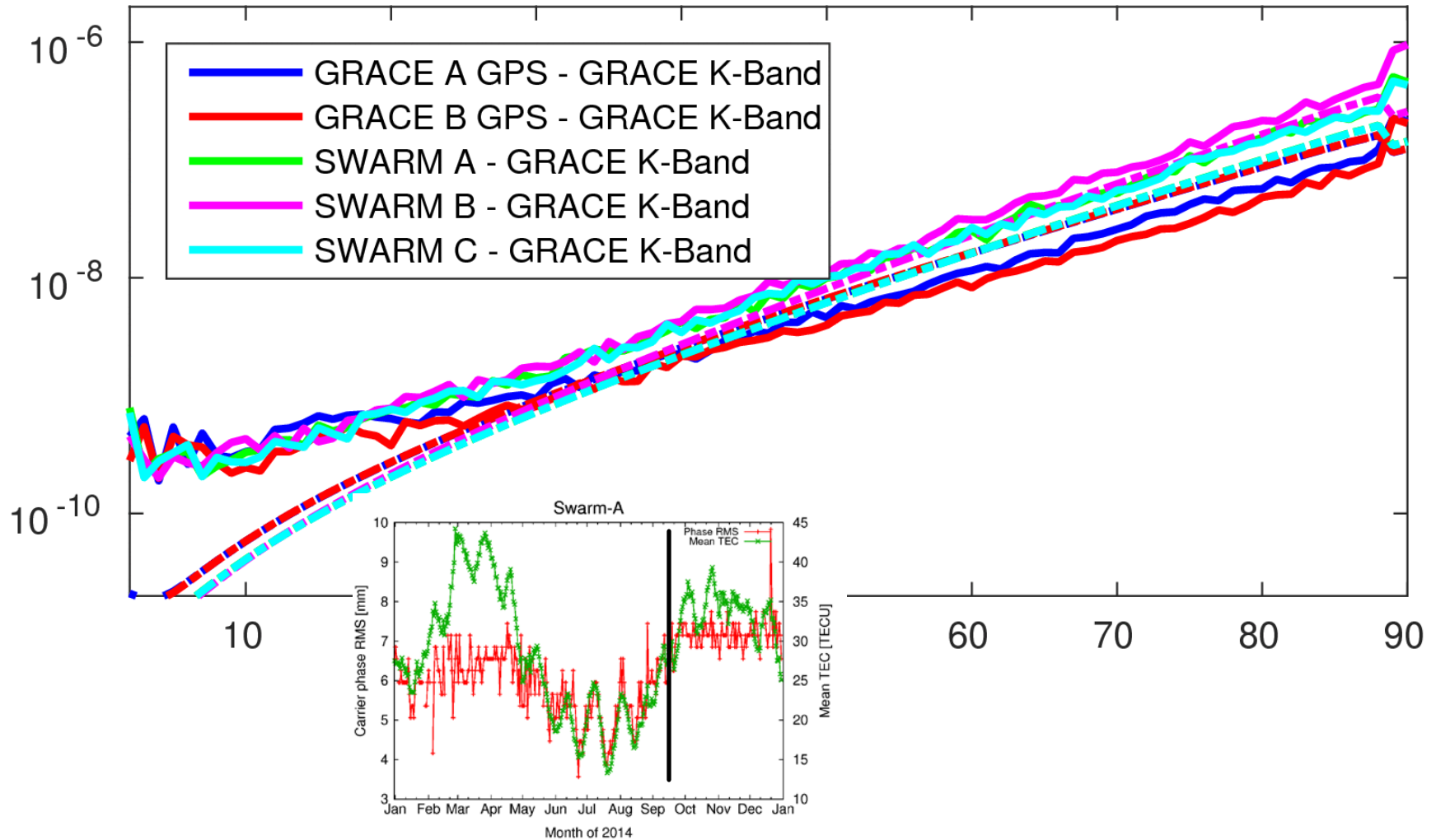
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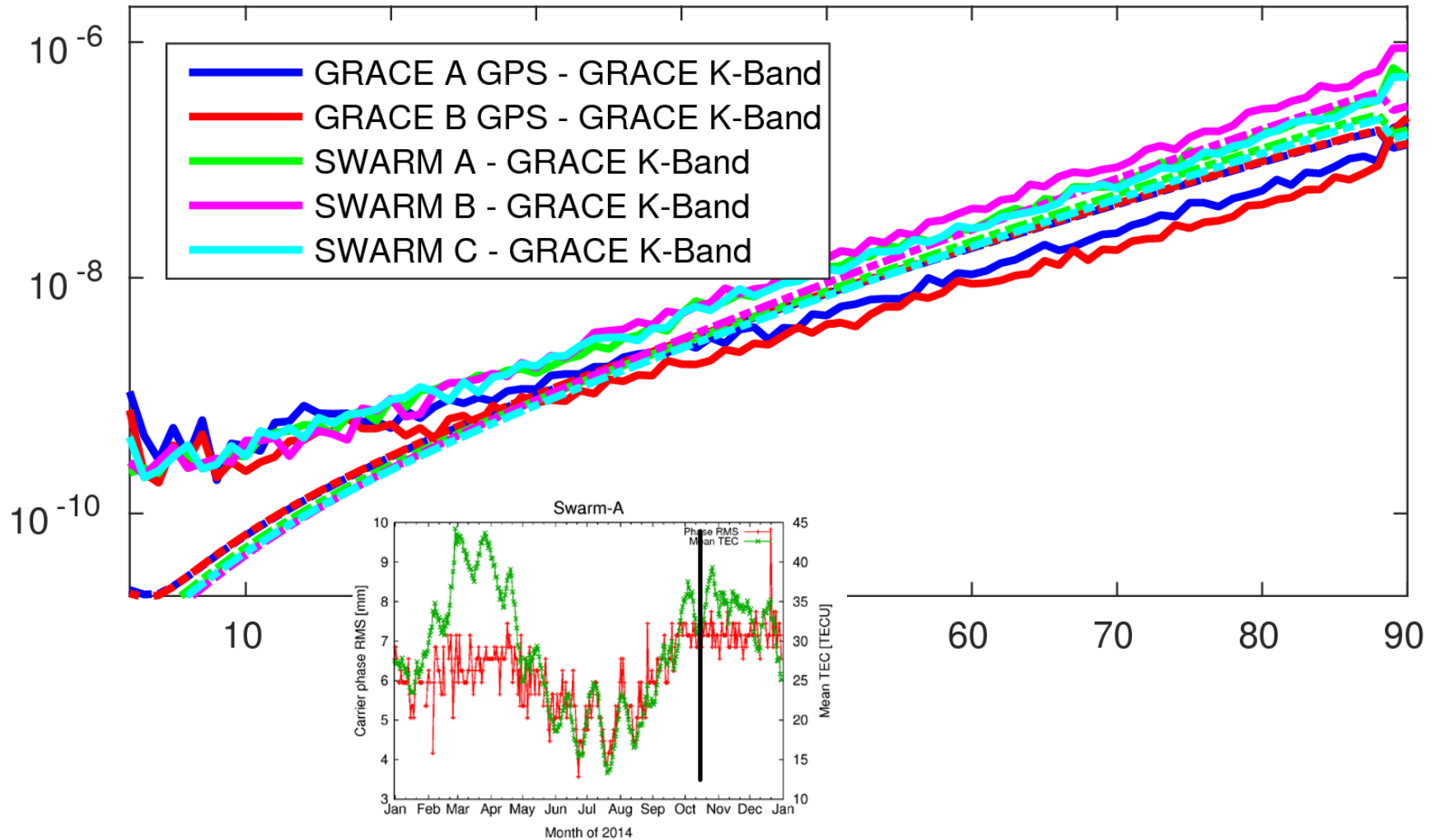
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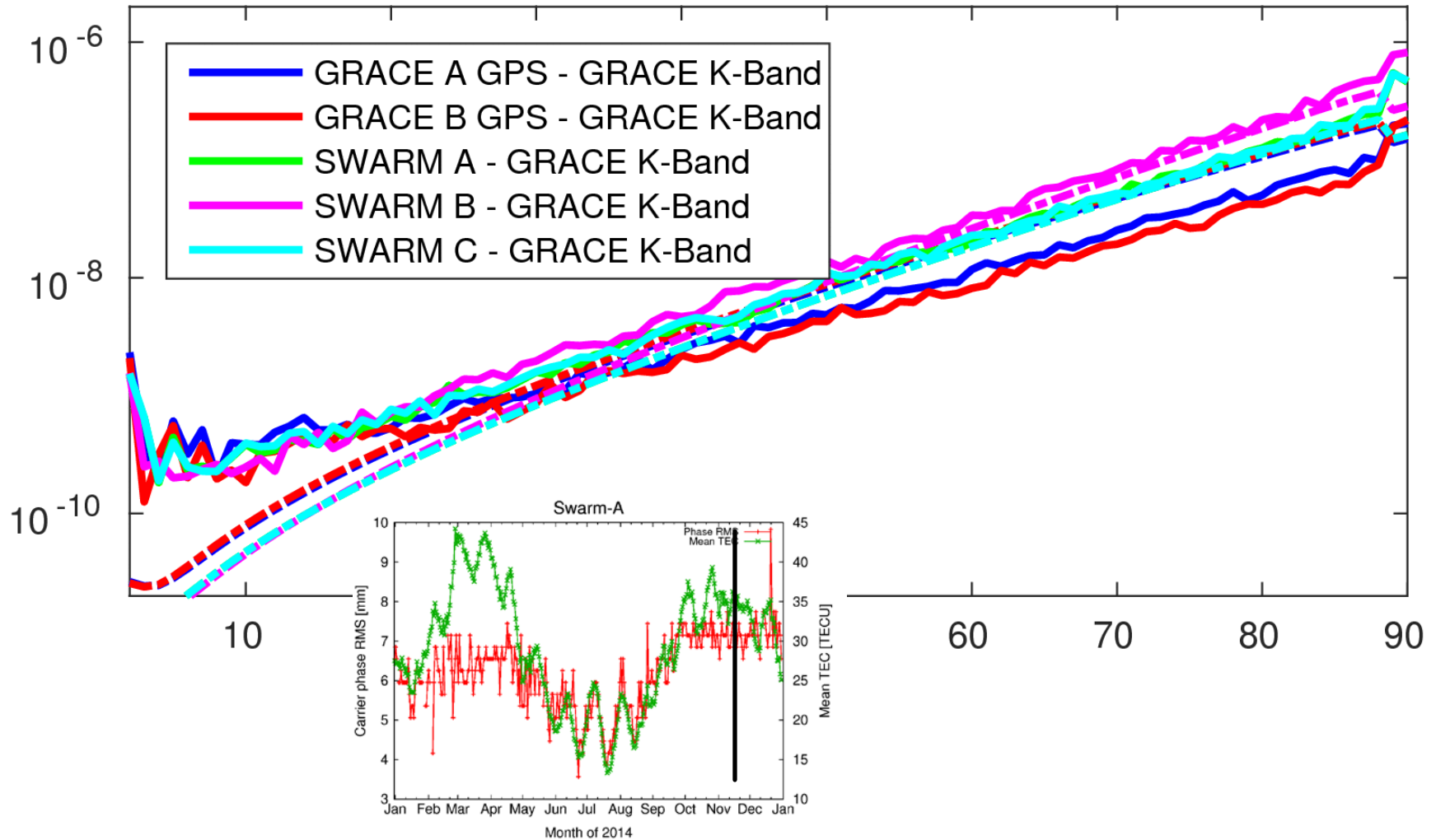
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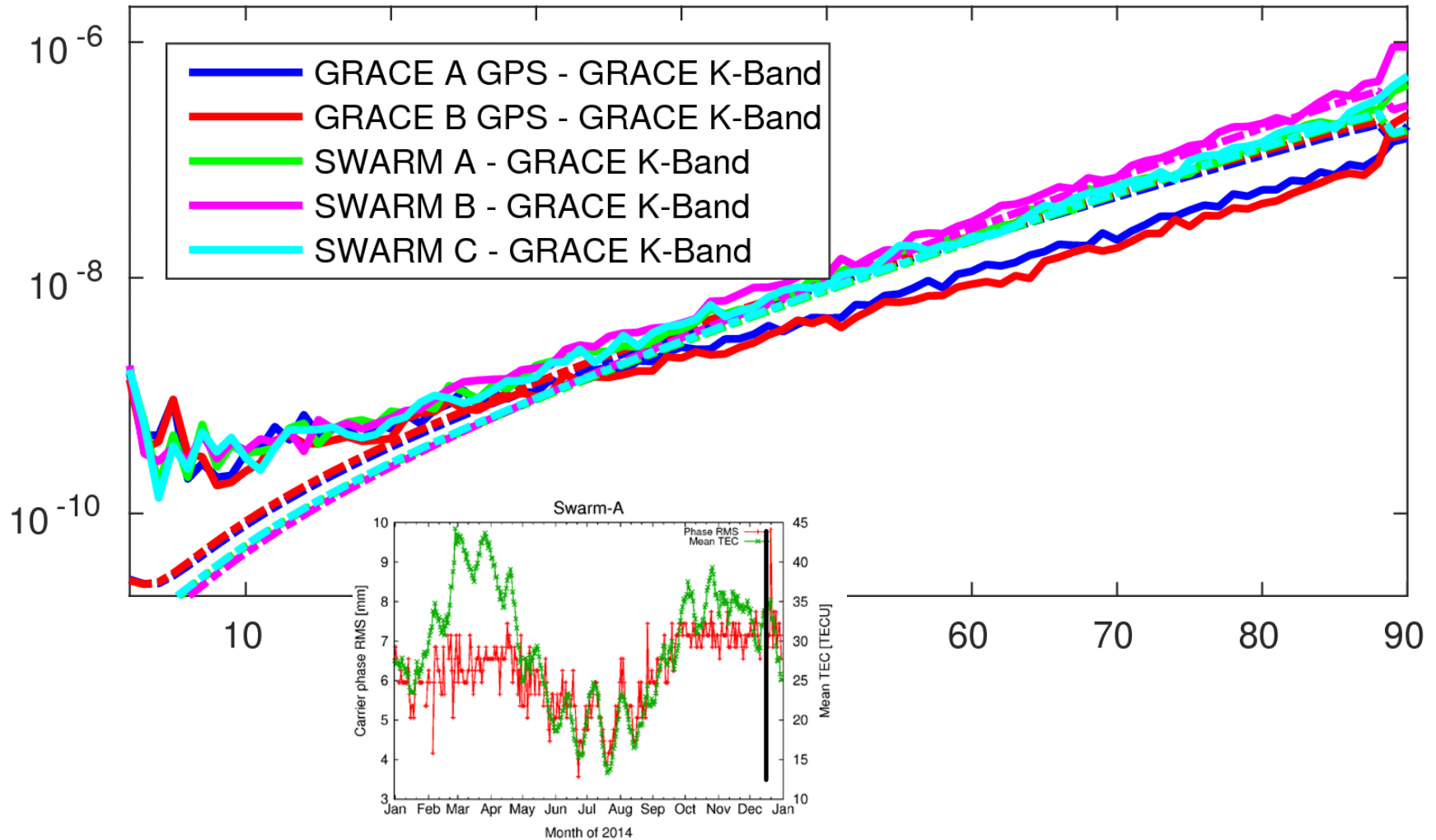
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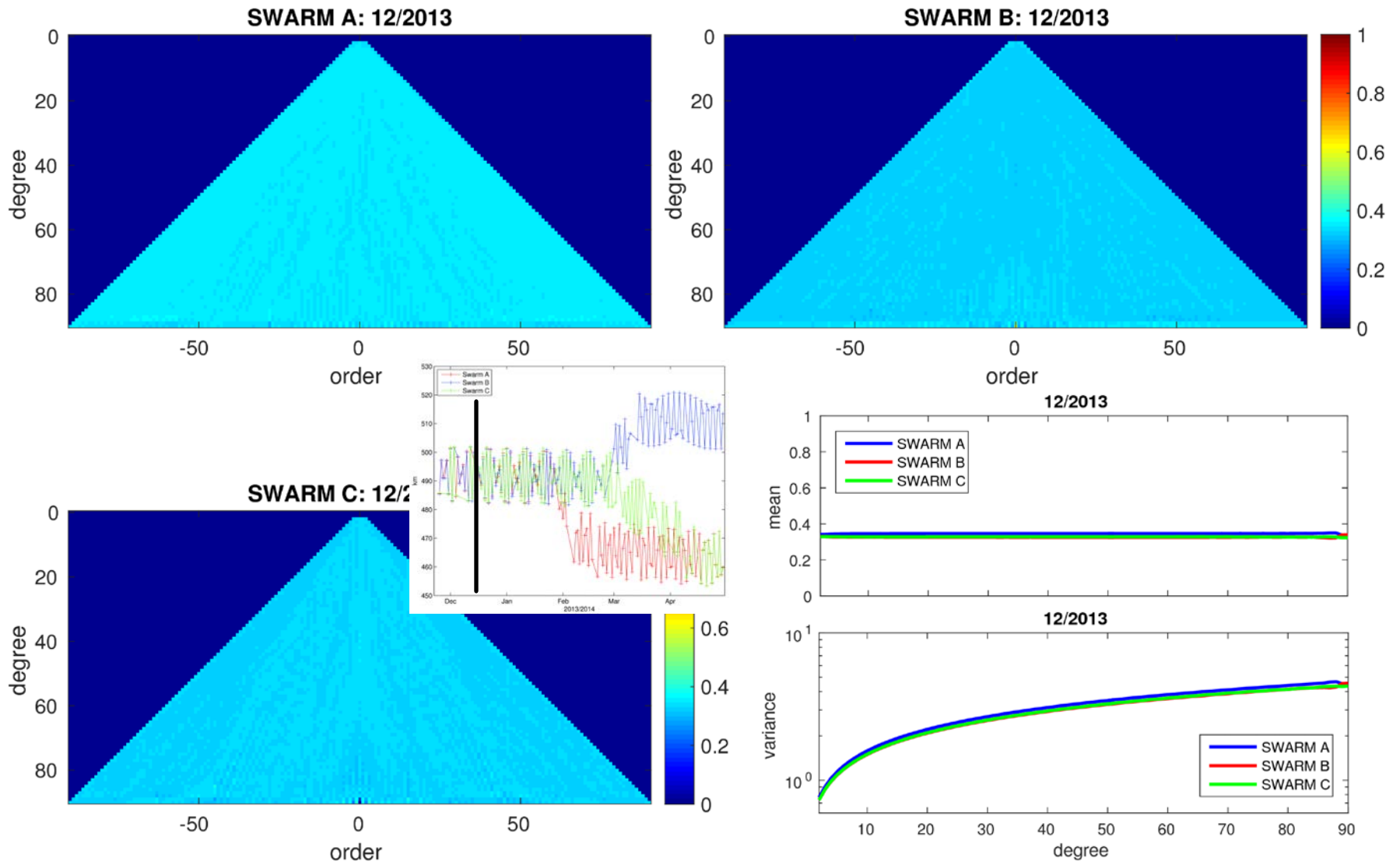


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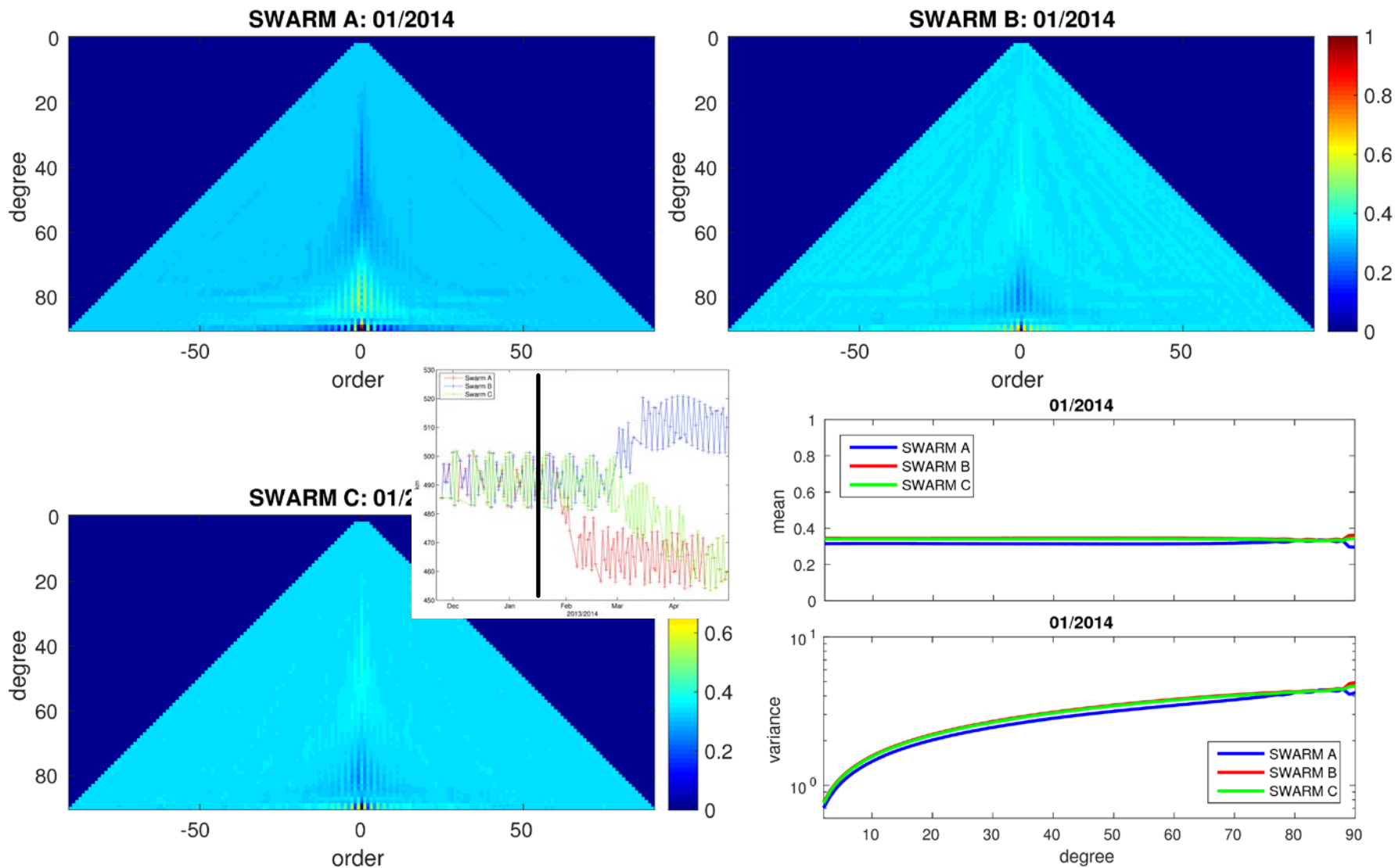
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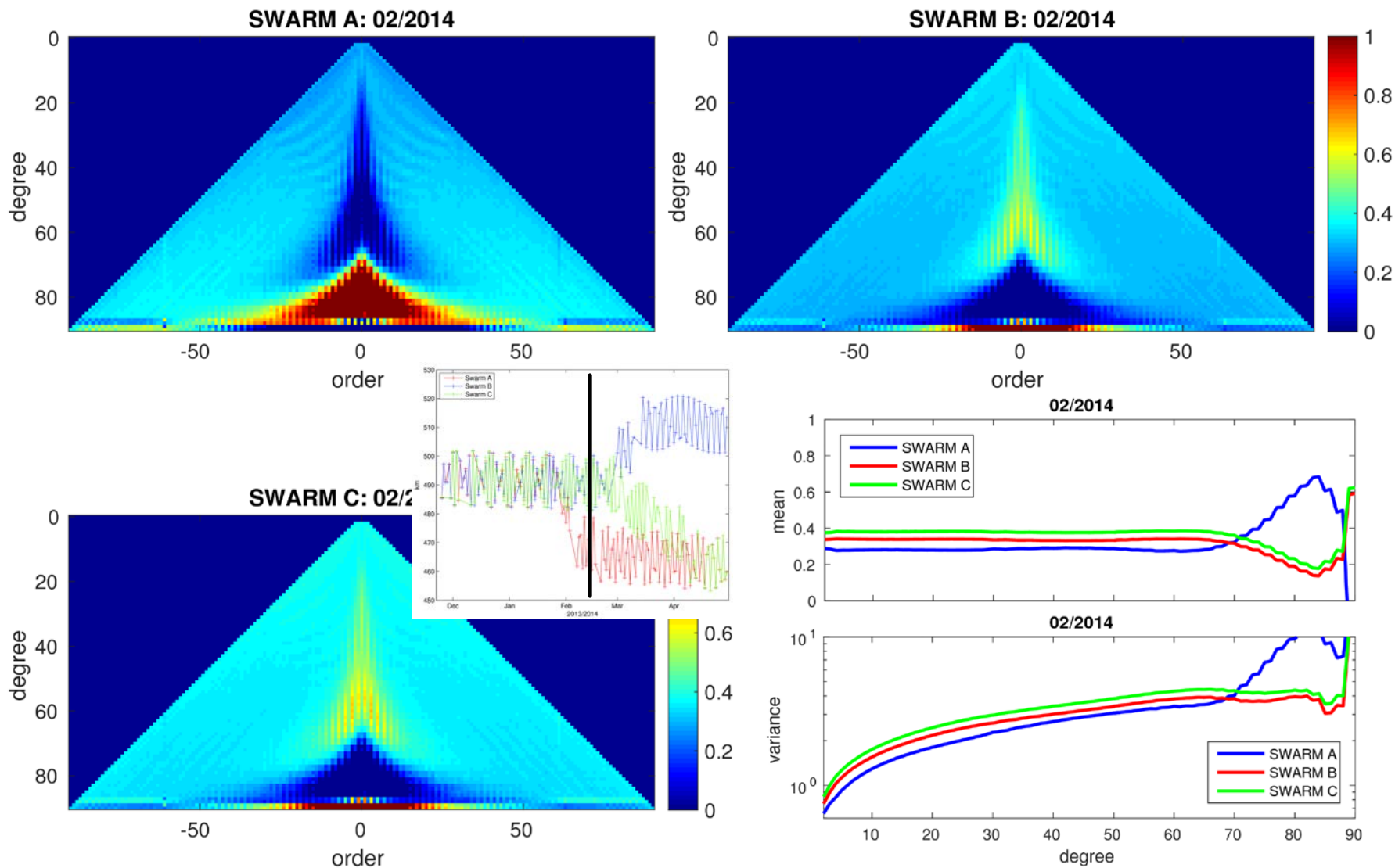
# GRACE + SWARM: contribution analysis



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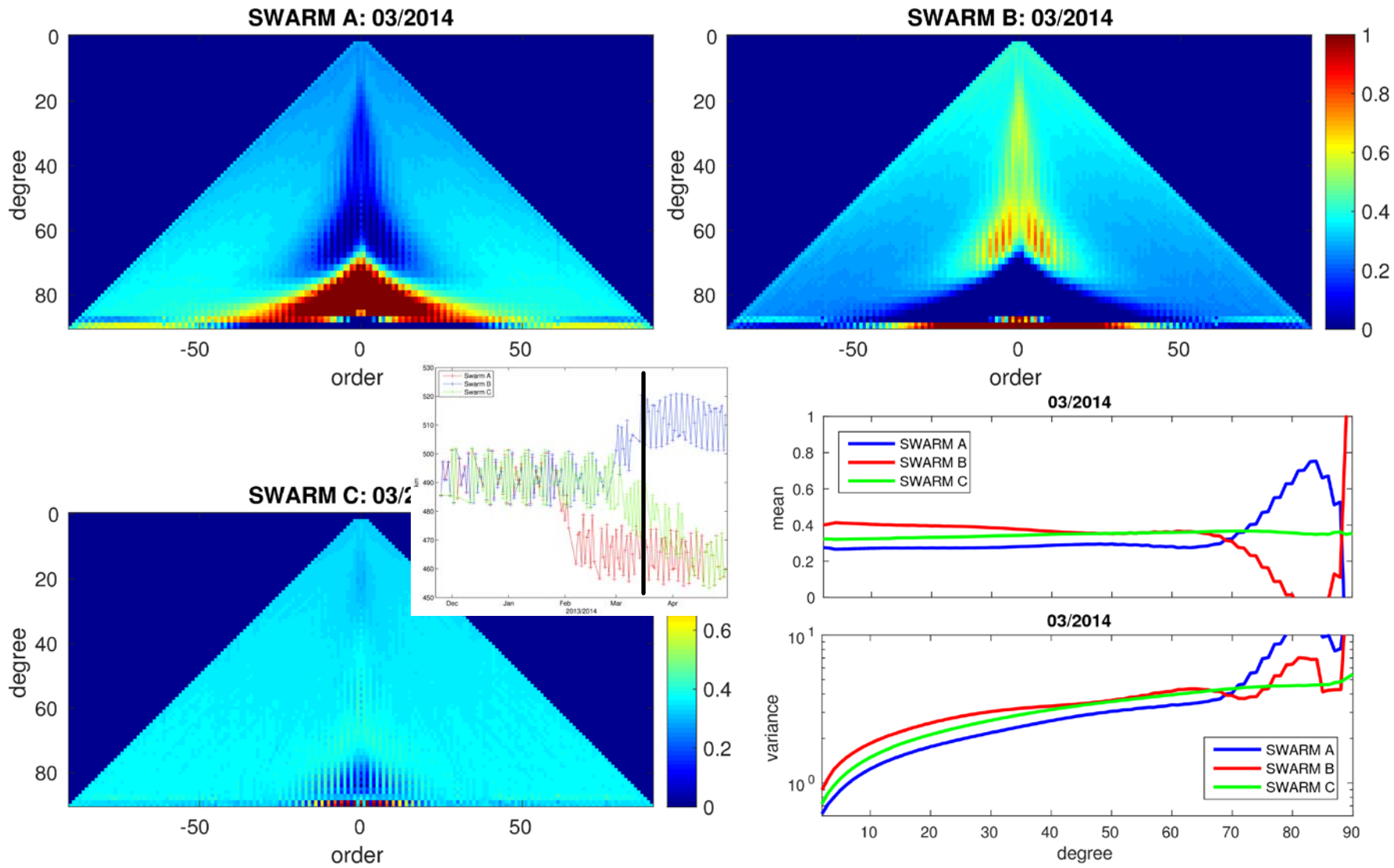


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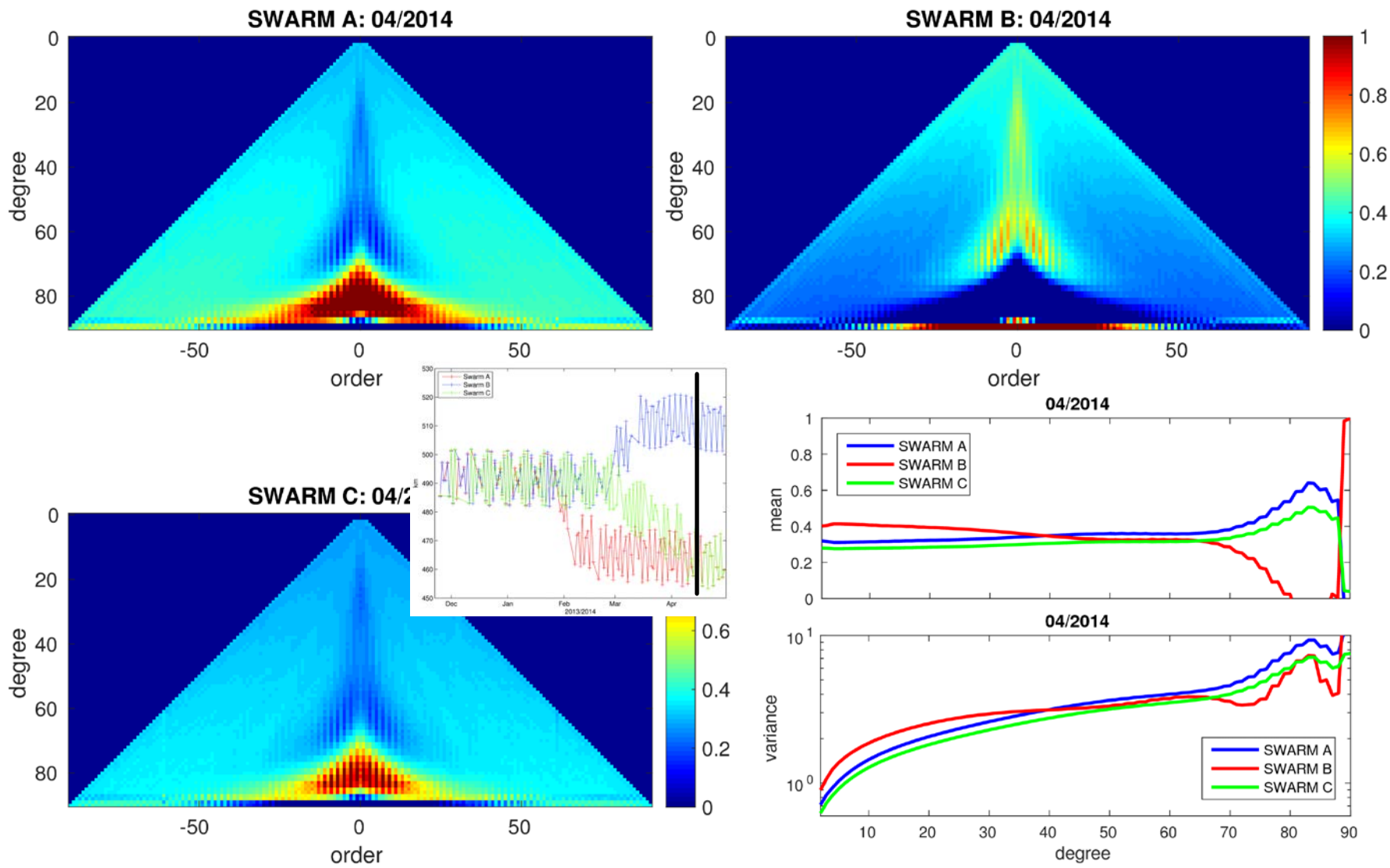


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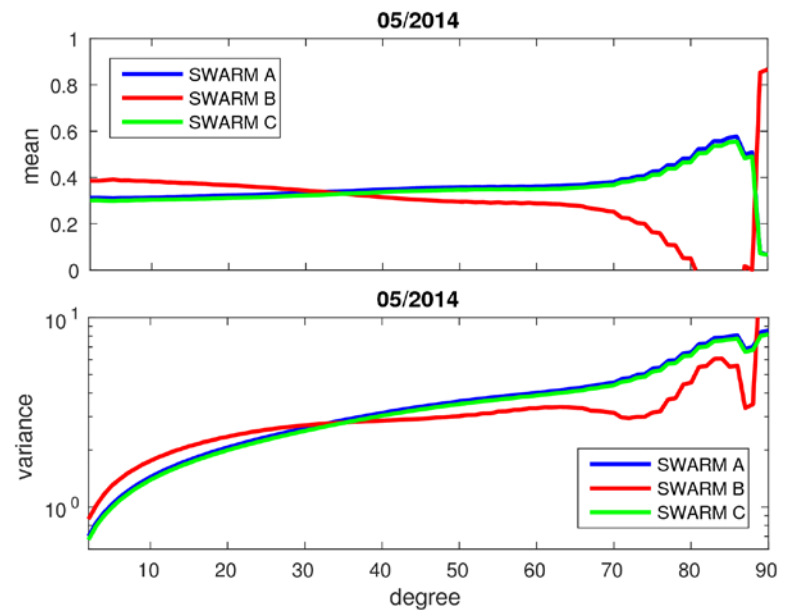
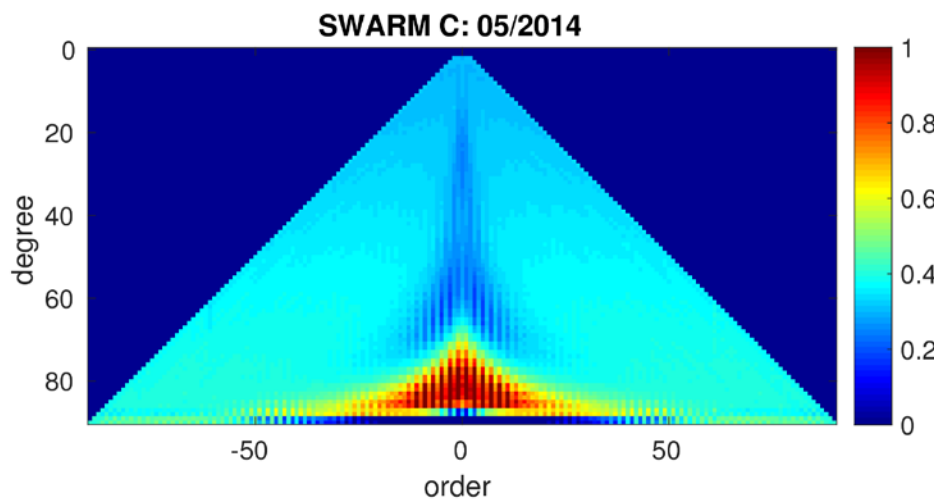
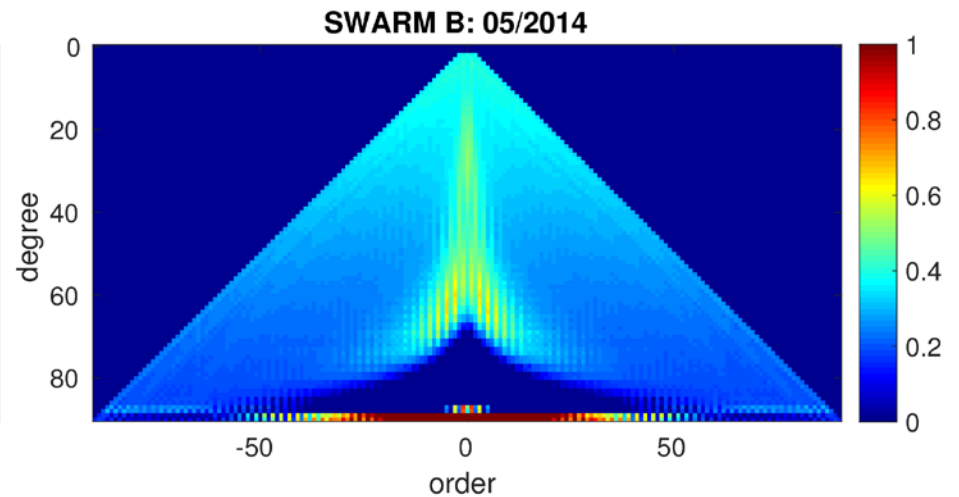
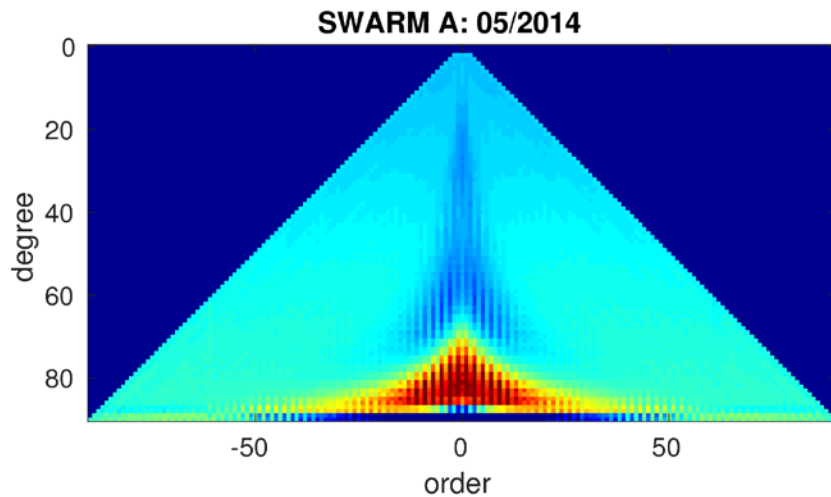




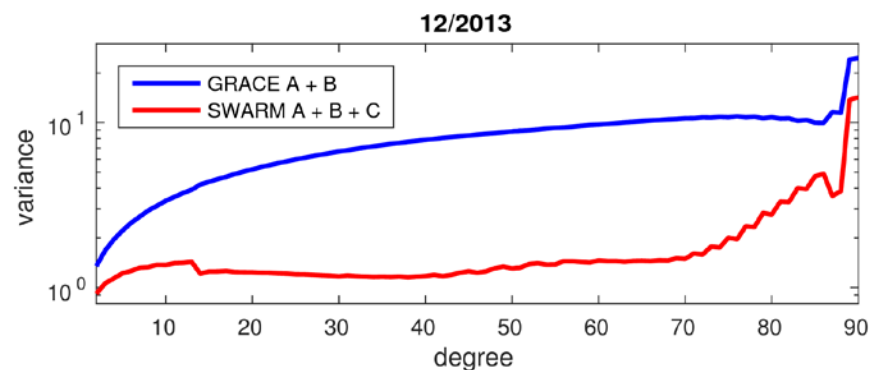
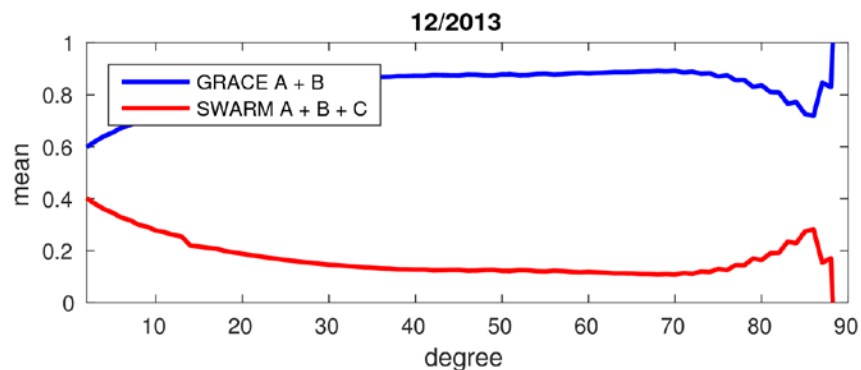
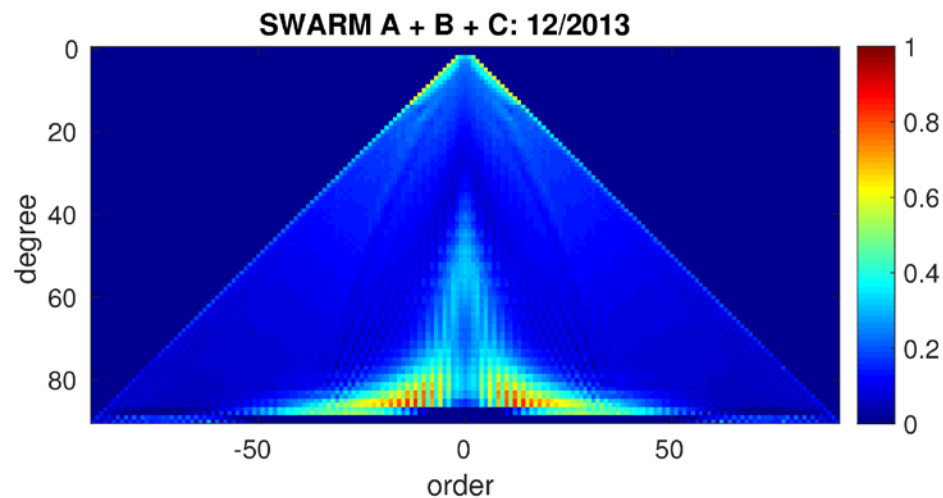
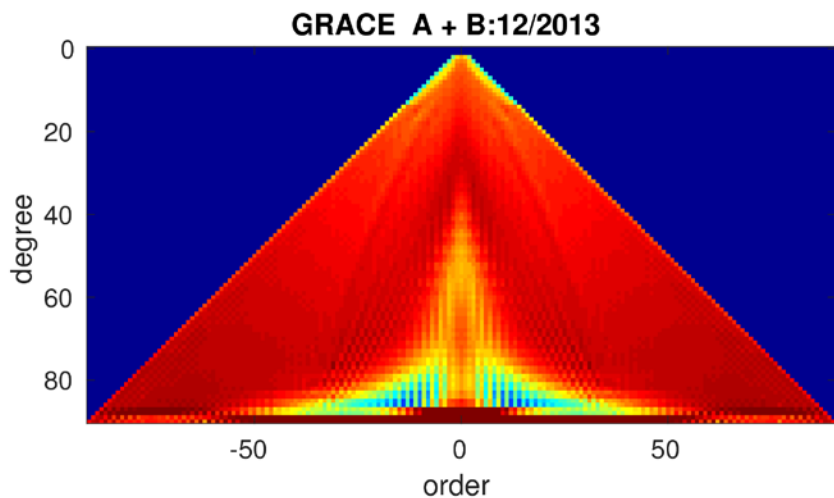
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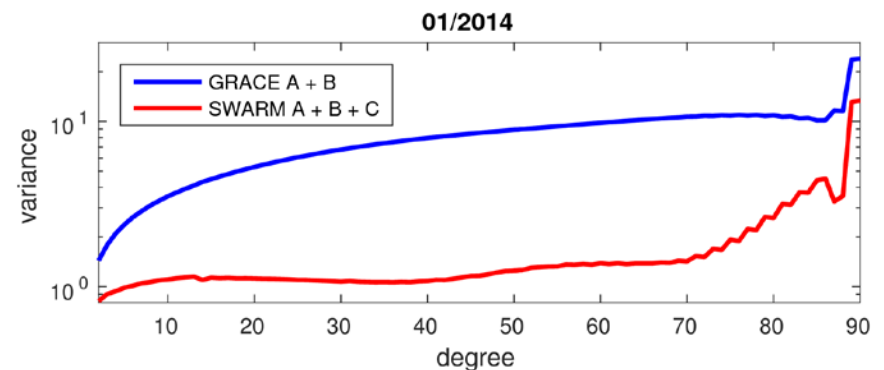
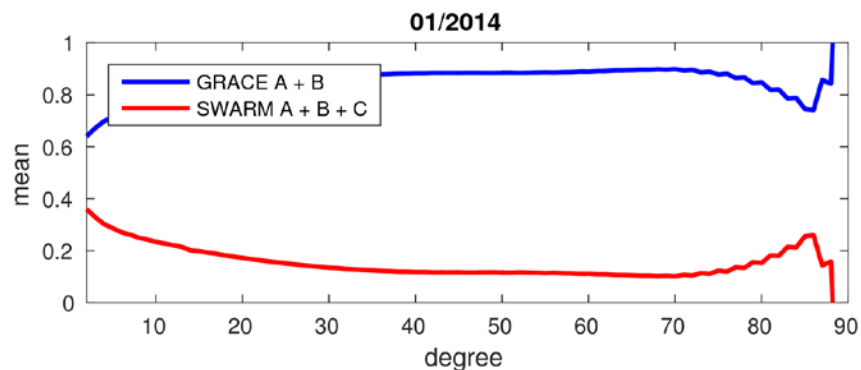
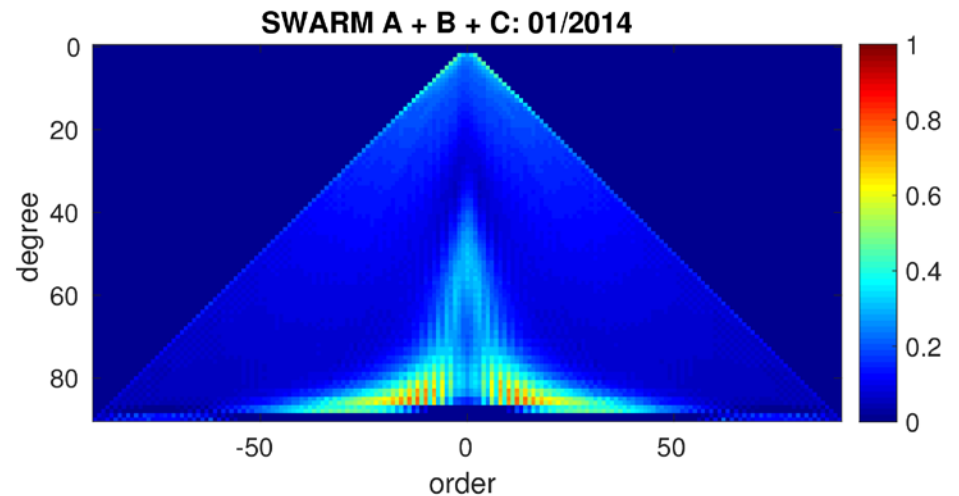
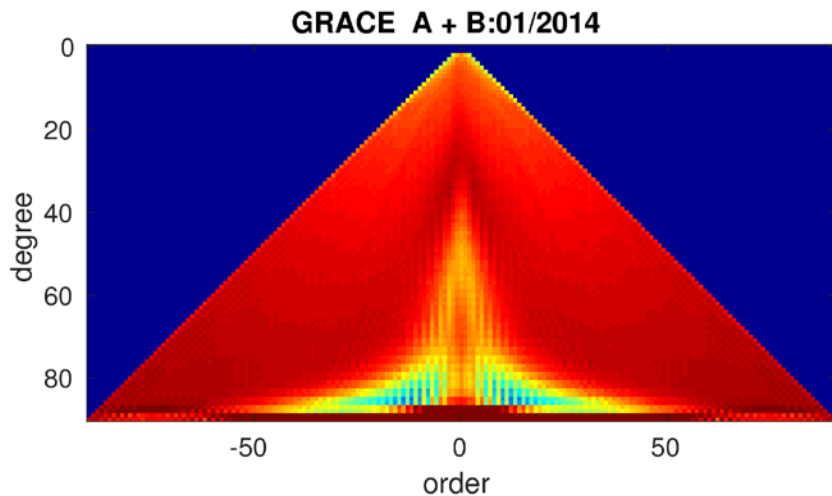
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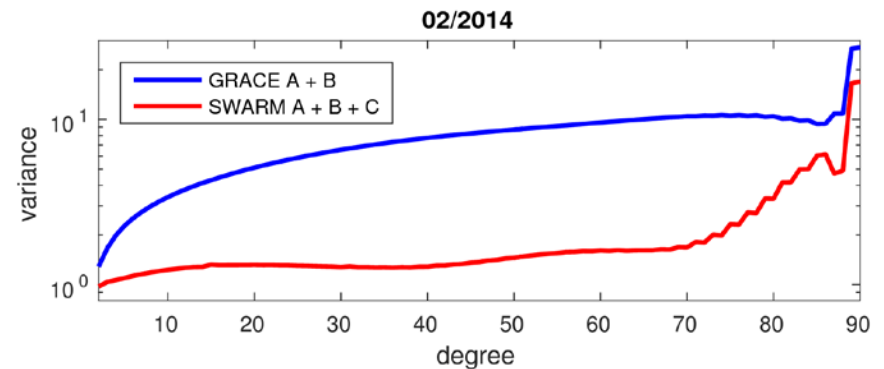
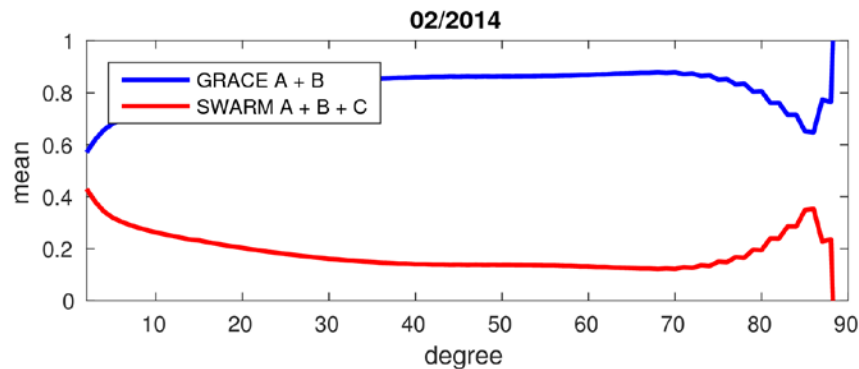
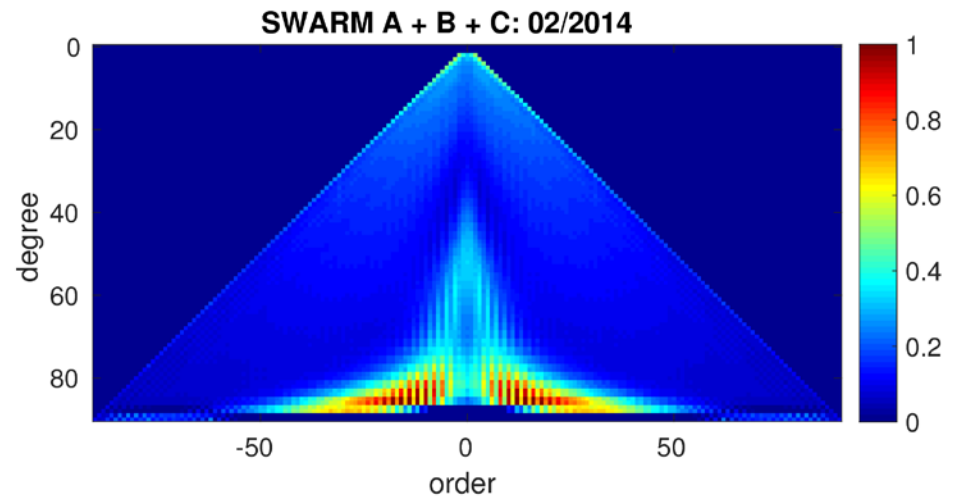
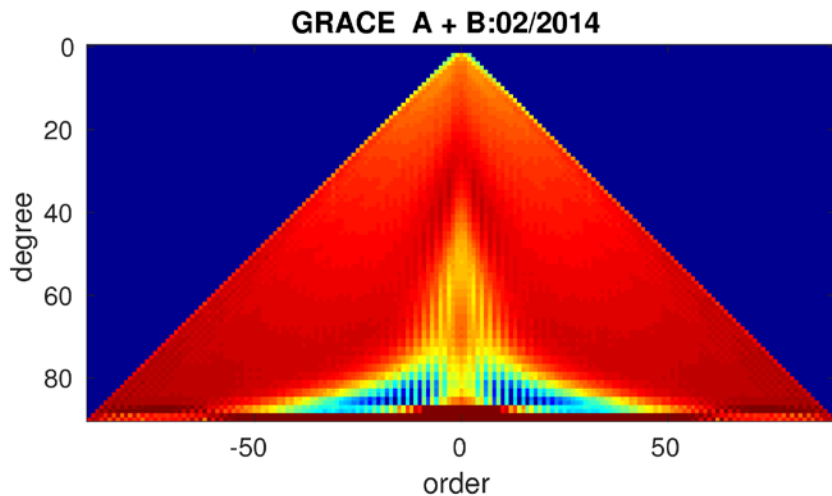
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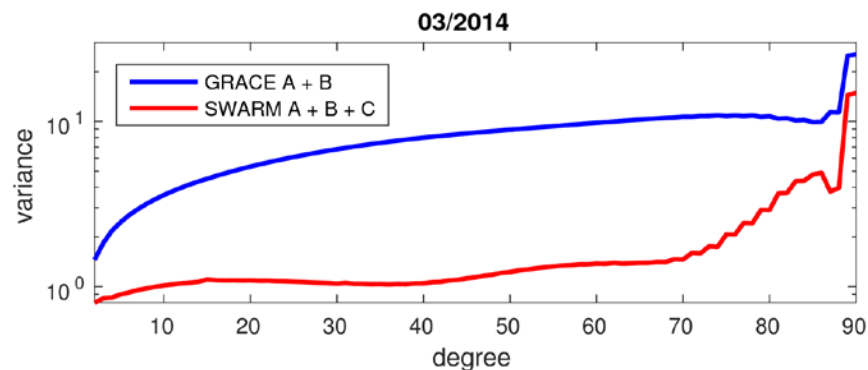
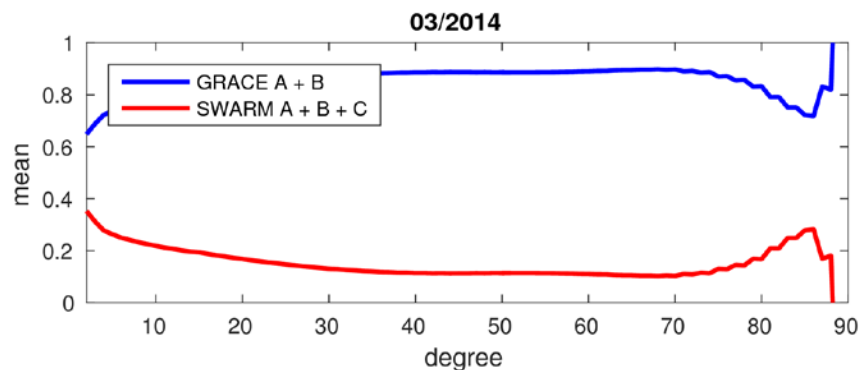
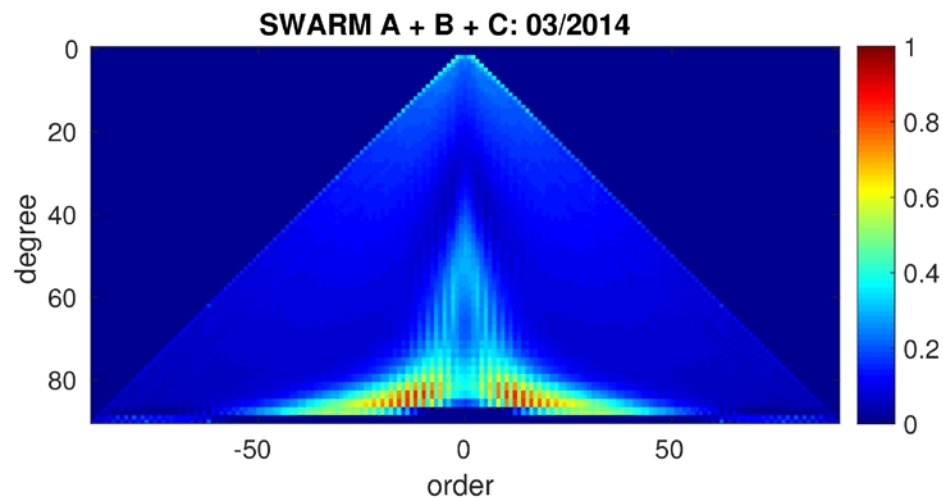
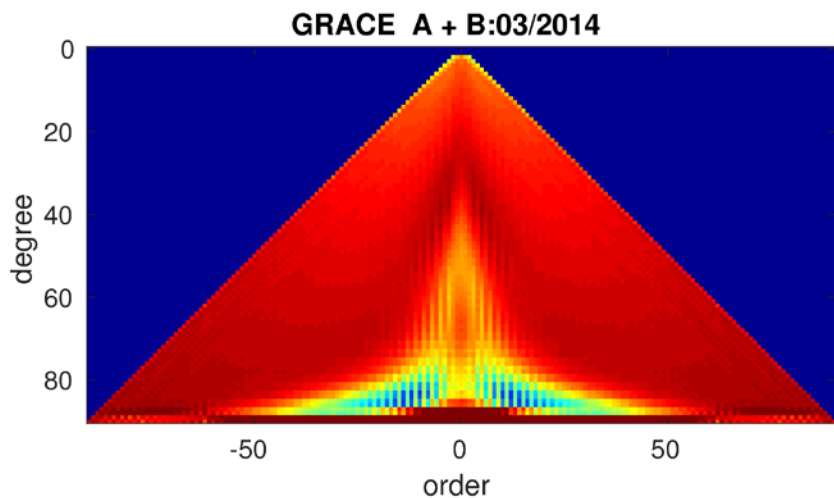


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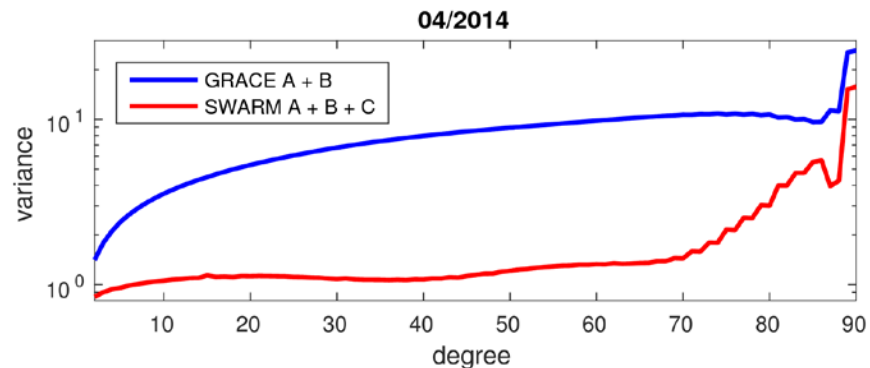
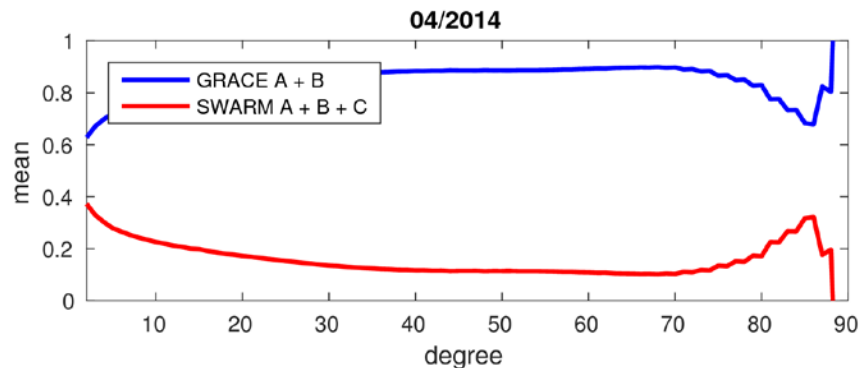
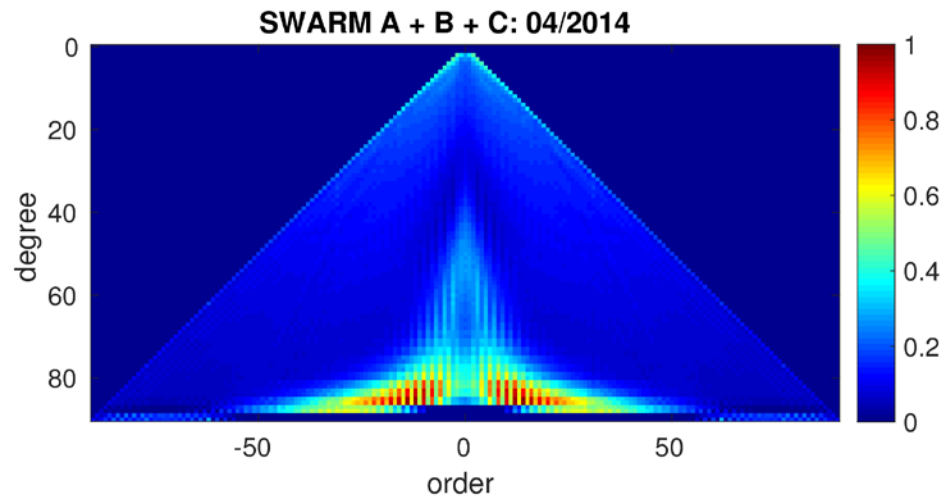
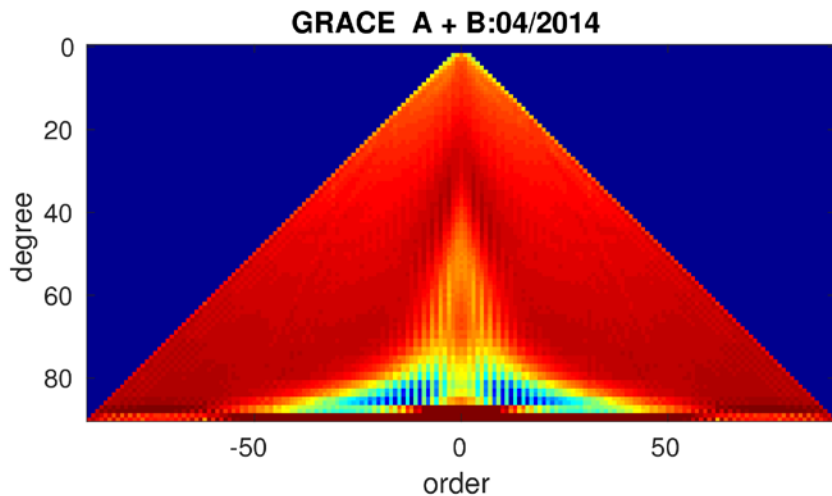




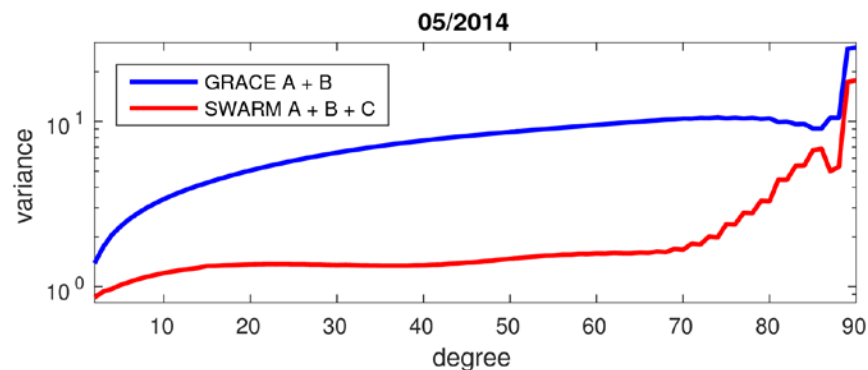
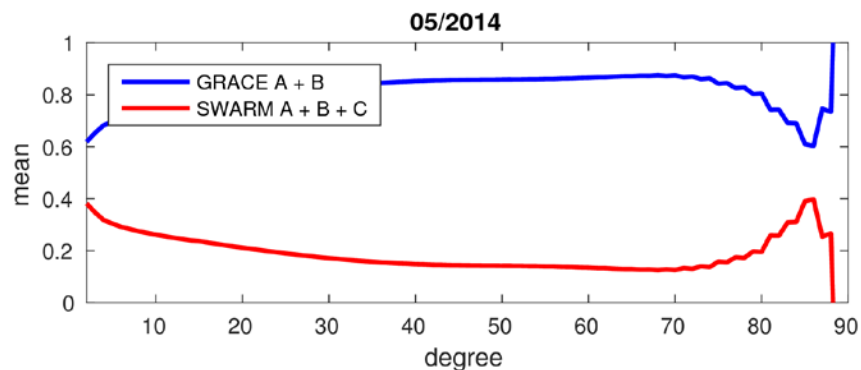
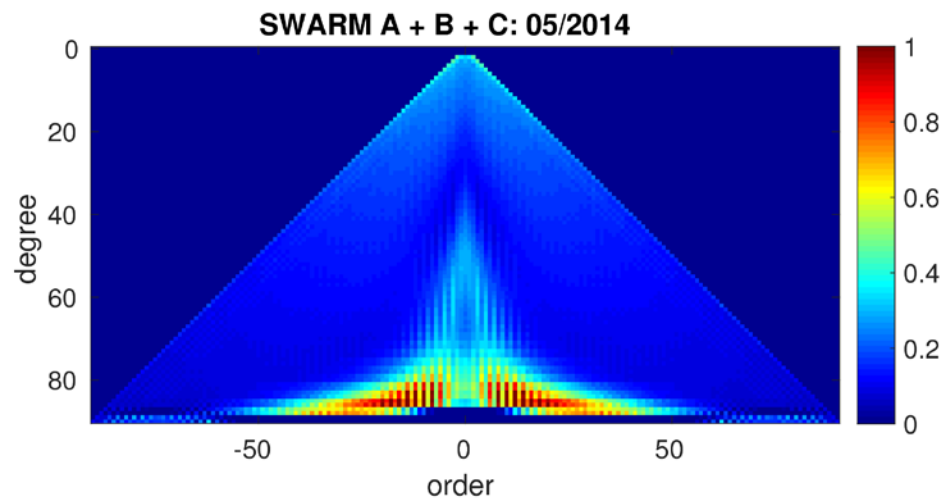
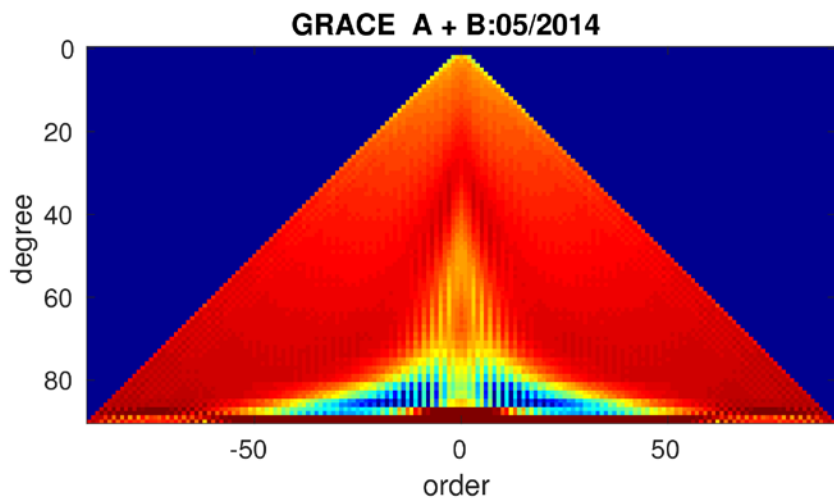
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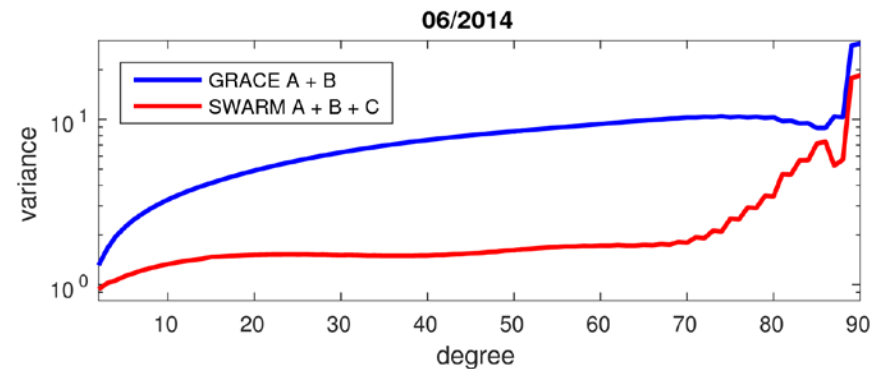
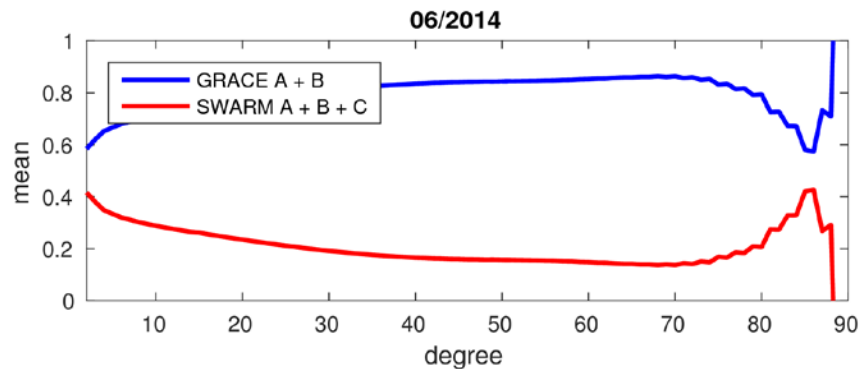
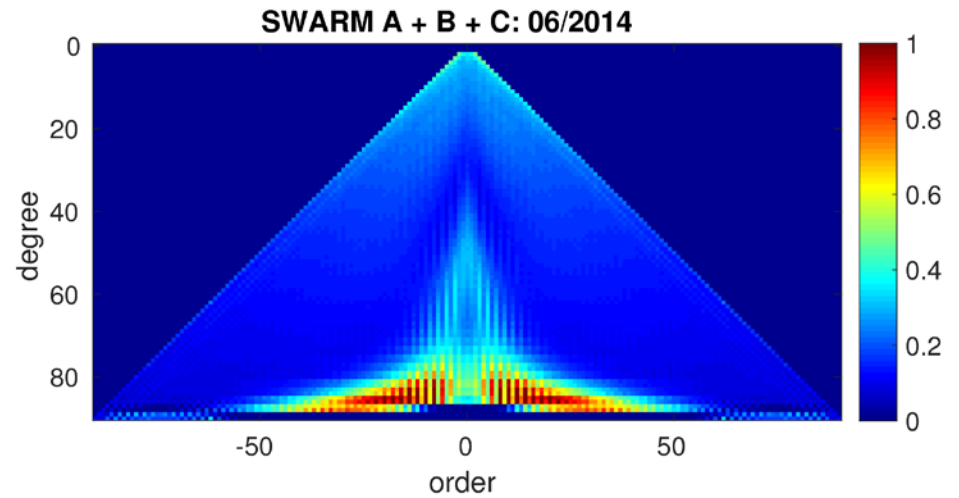
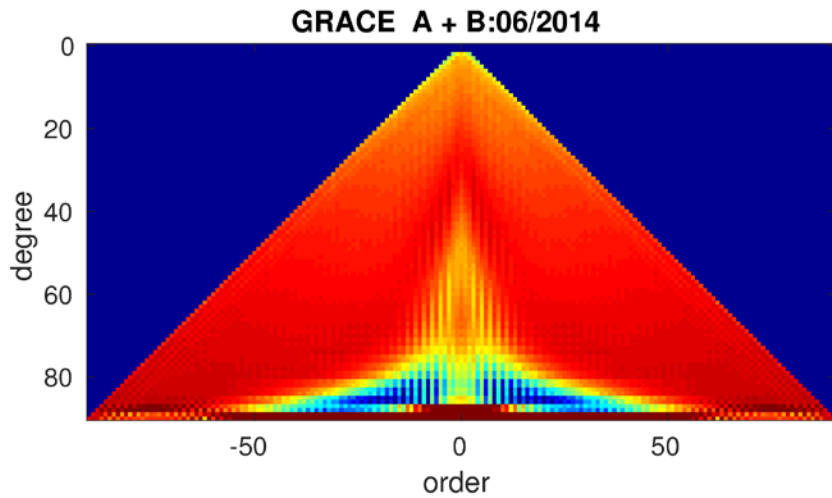
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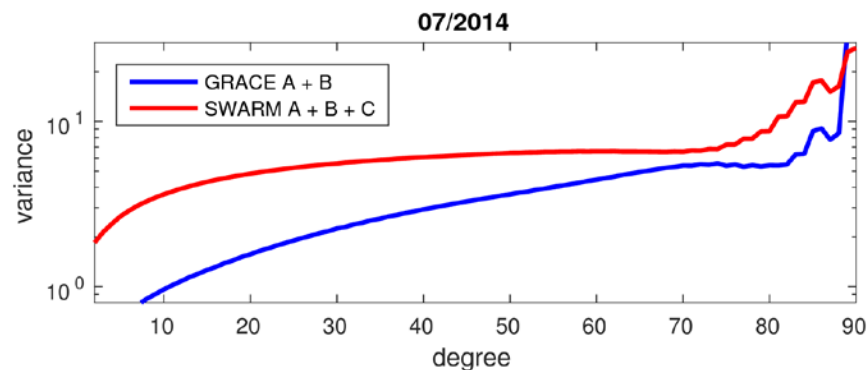
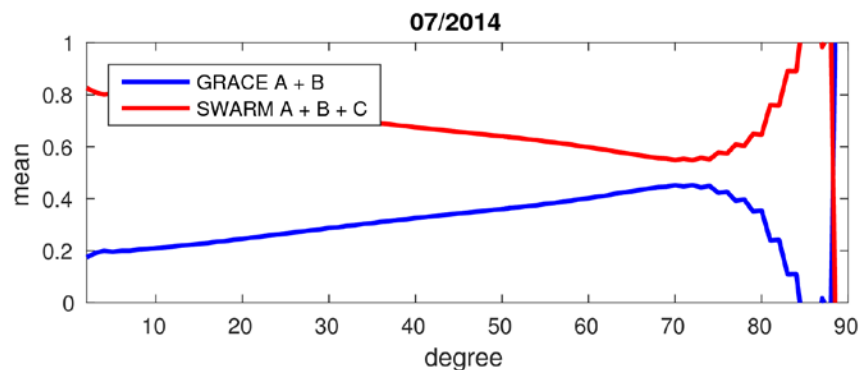
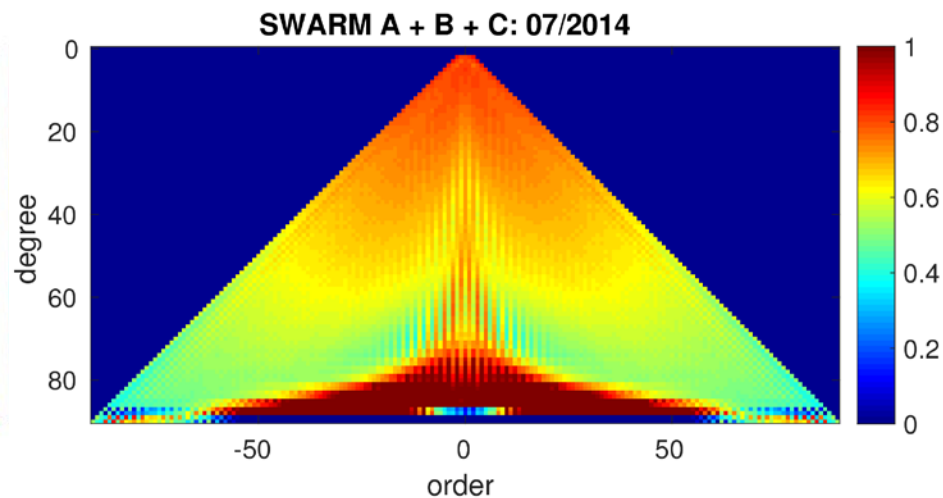
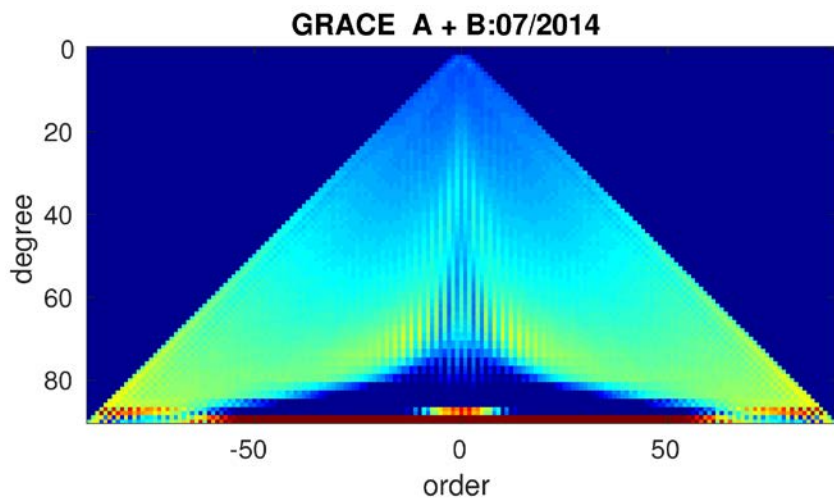
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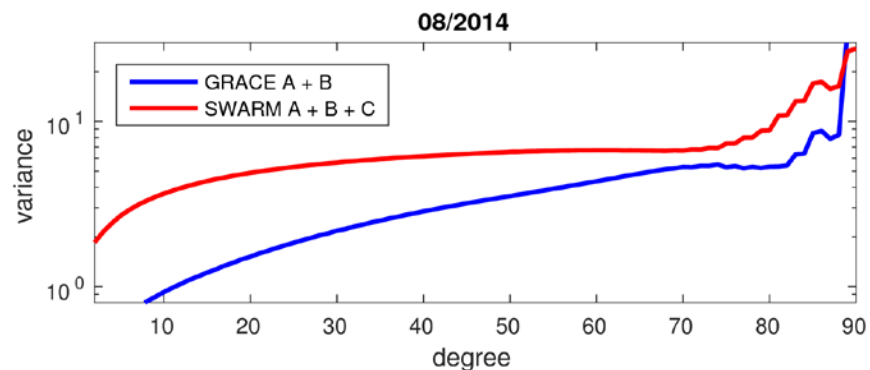
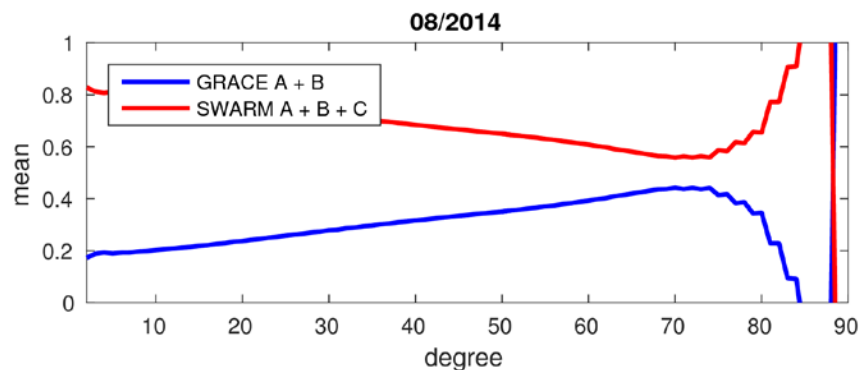
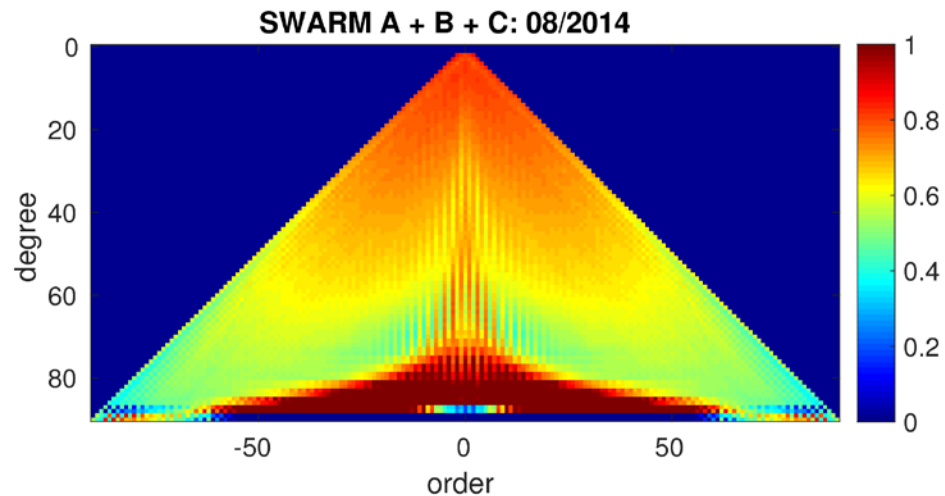
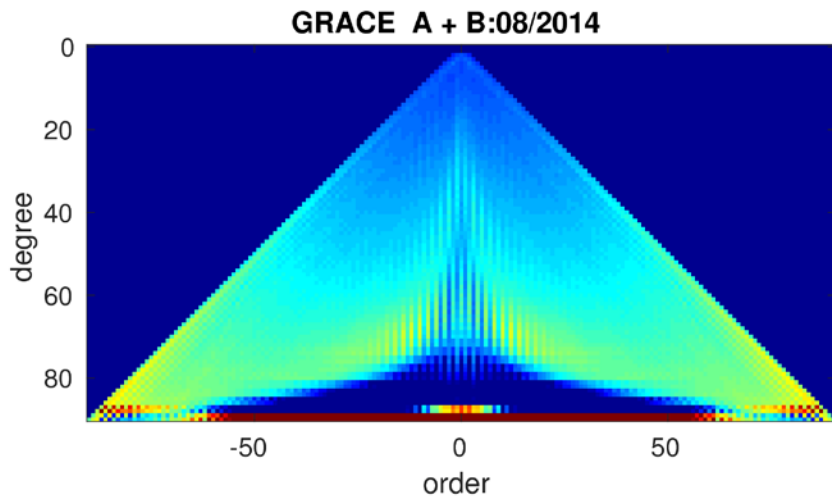


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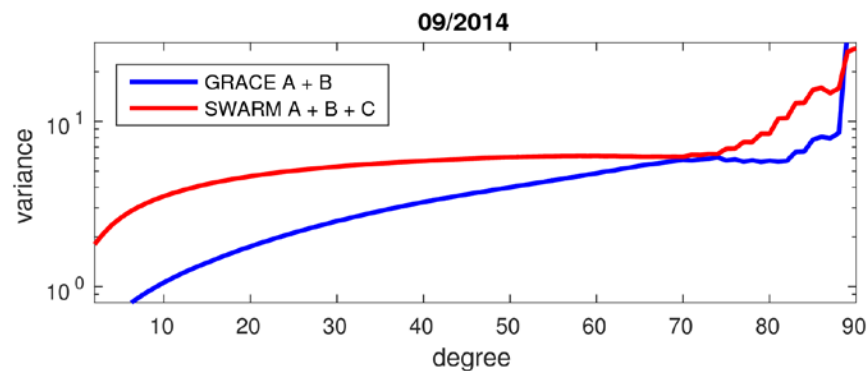
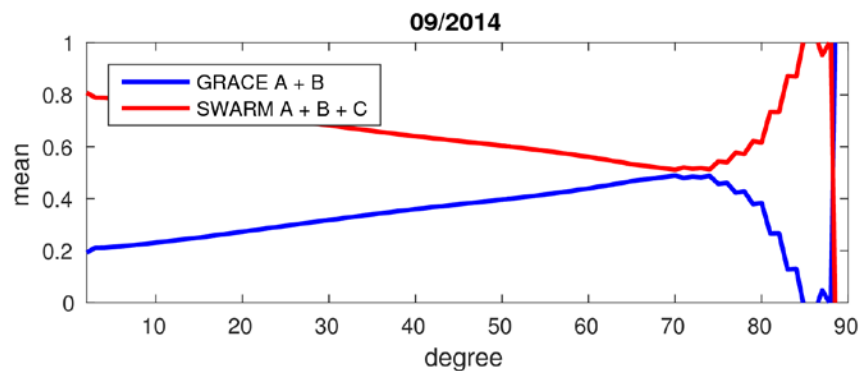
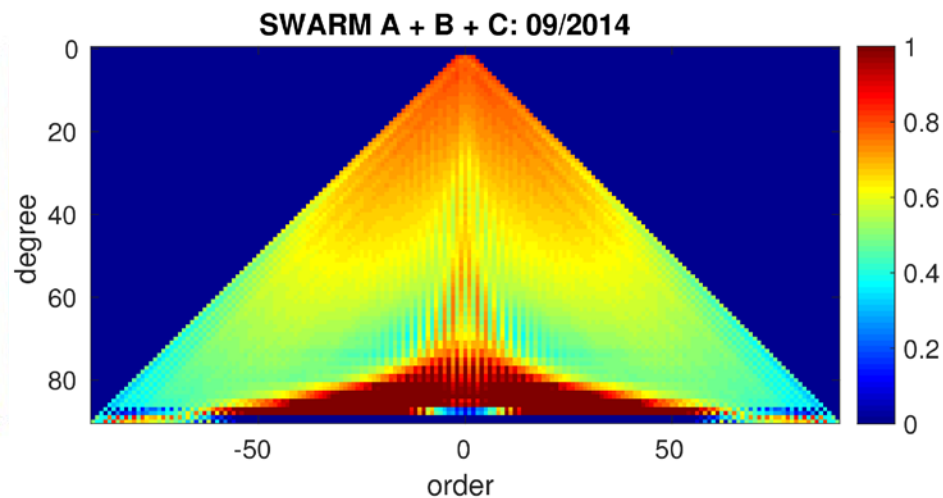
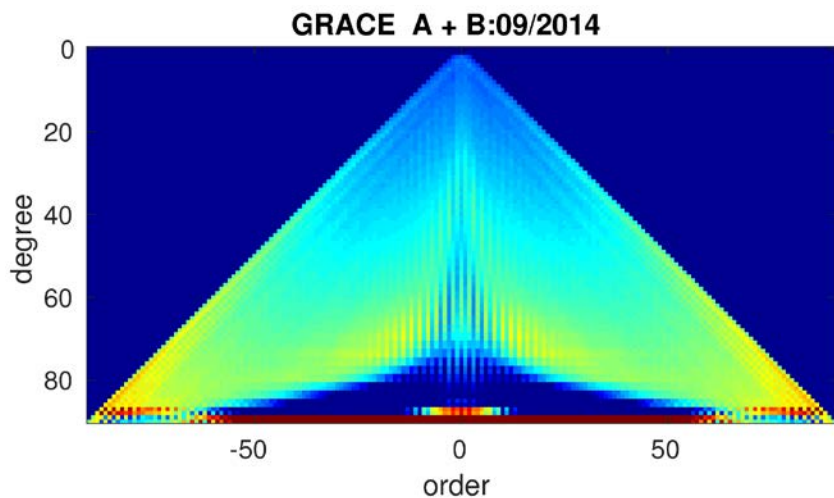




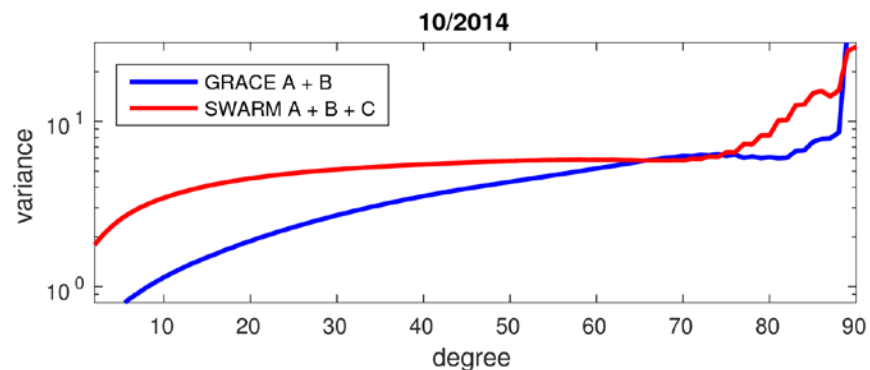
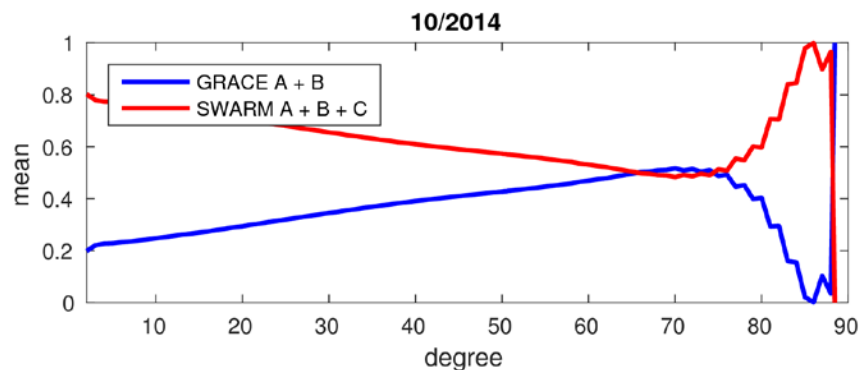
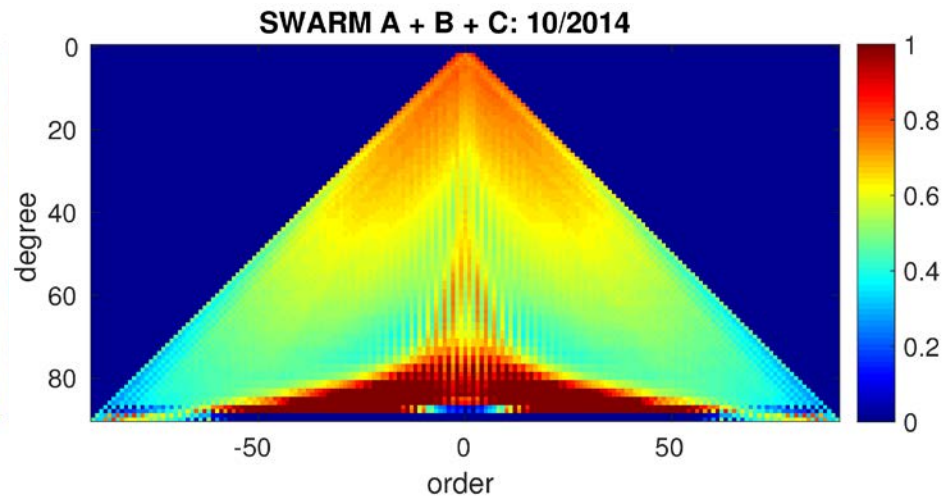
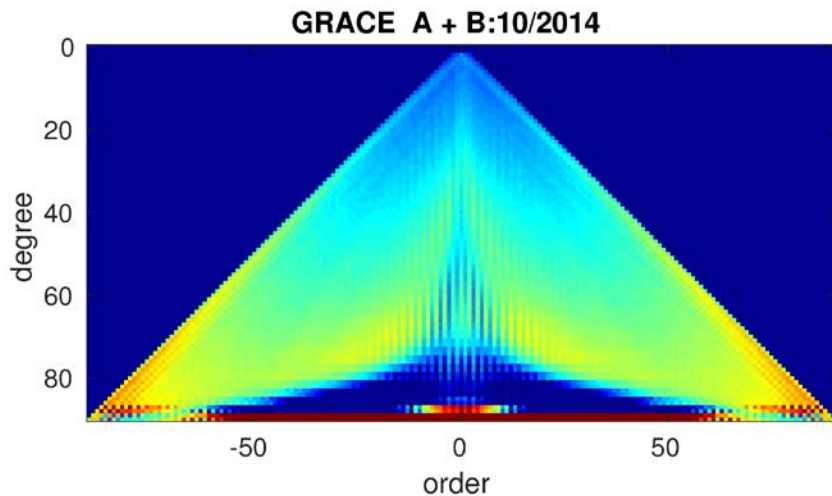
# GRACE + SWARM: contribution analysis



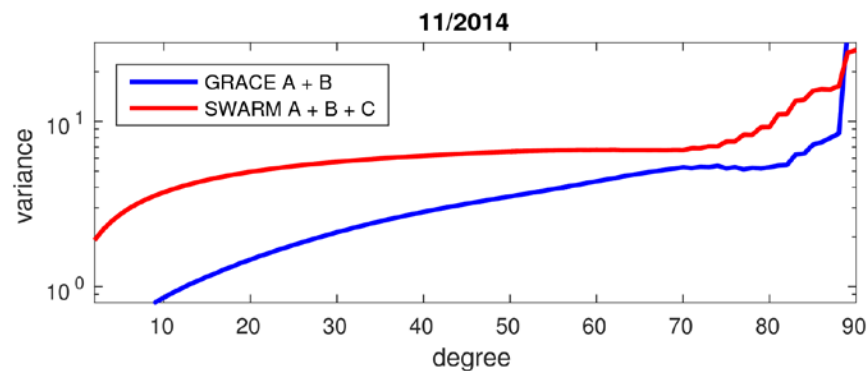
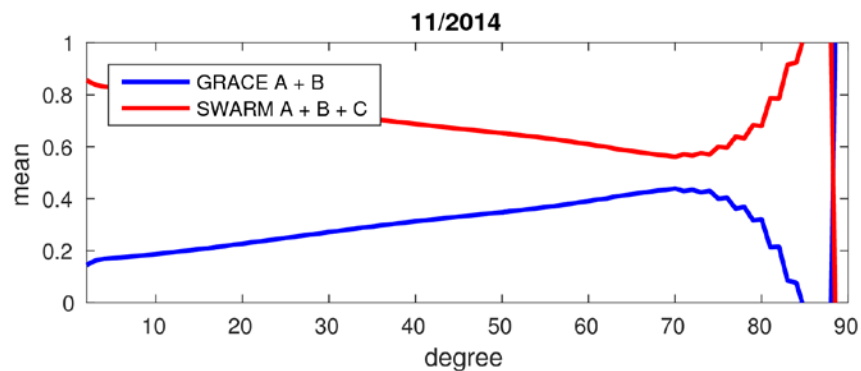
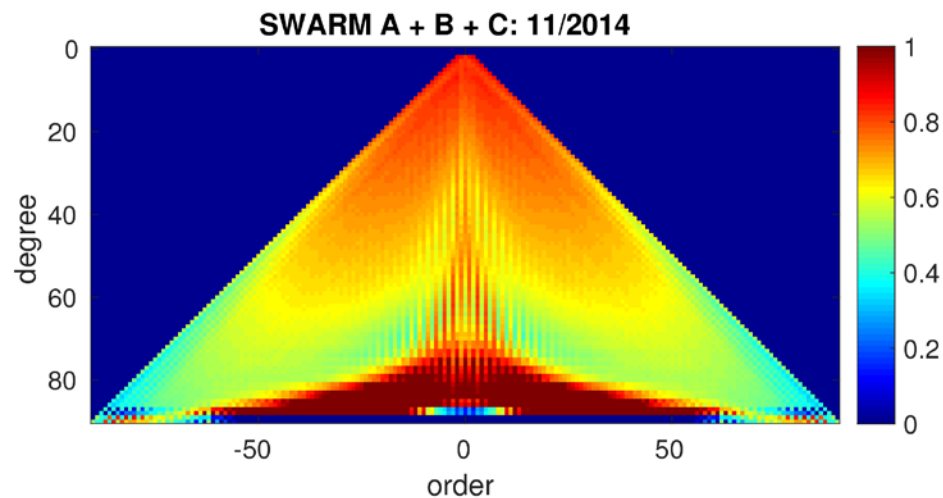
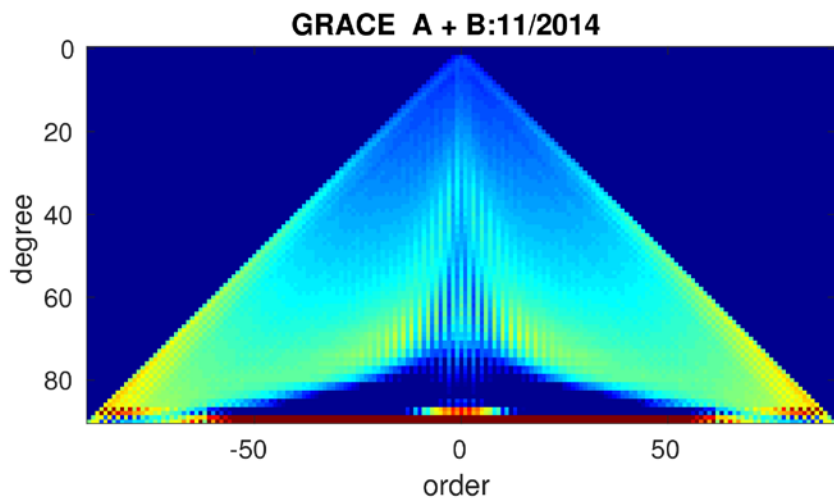
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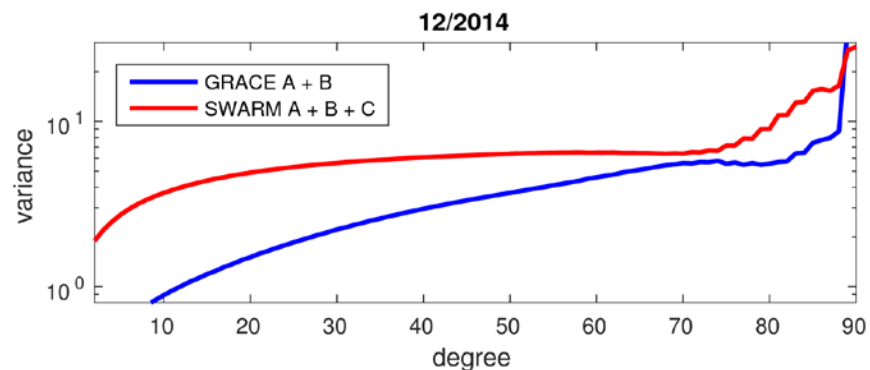
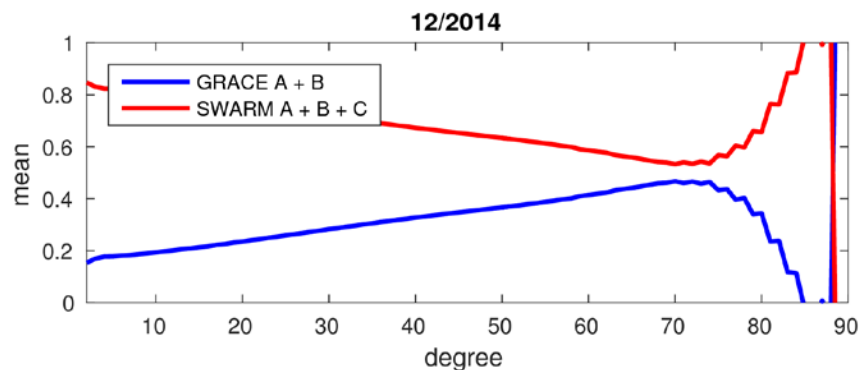
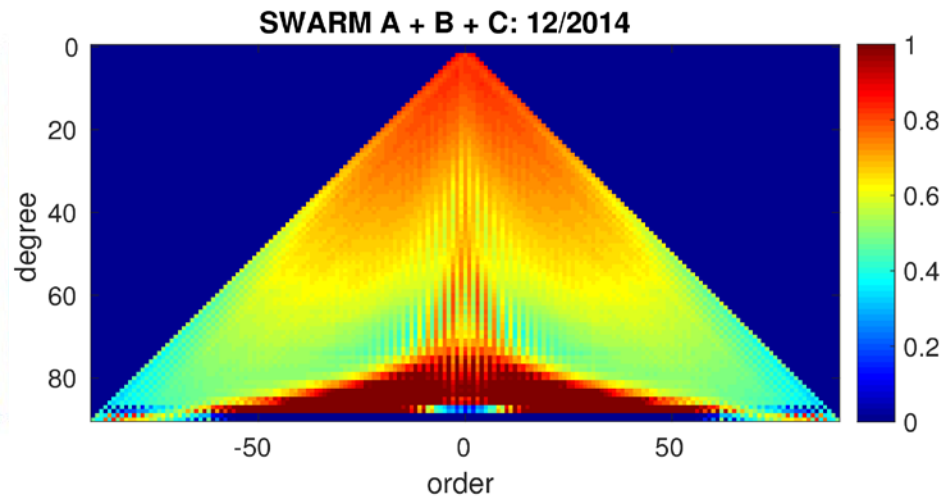
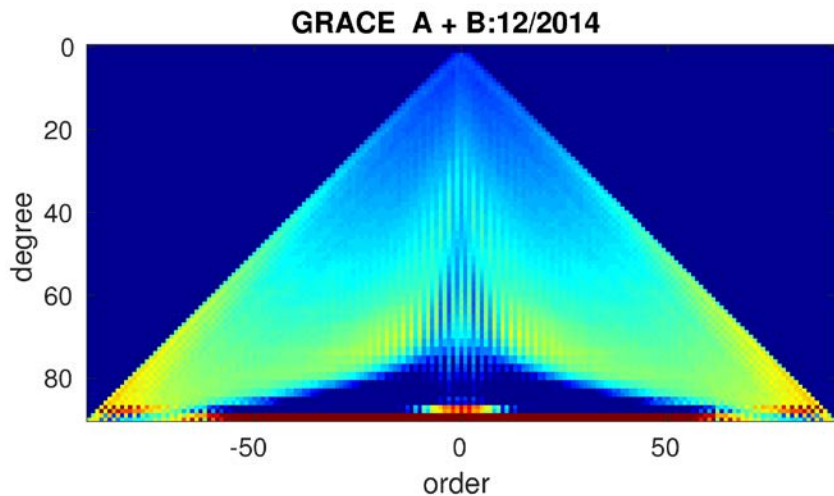
# GRACE + SWARM: contribution analysis



# GRACE + SWARM: contribution analysis

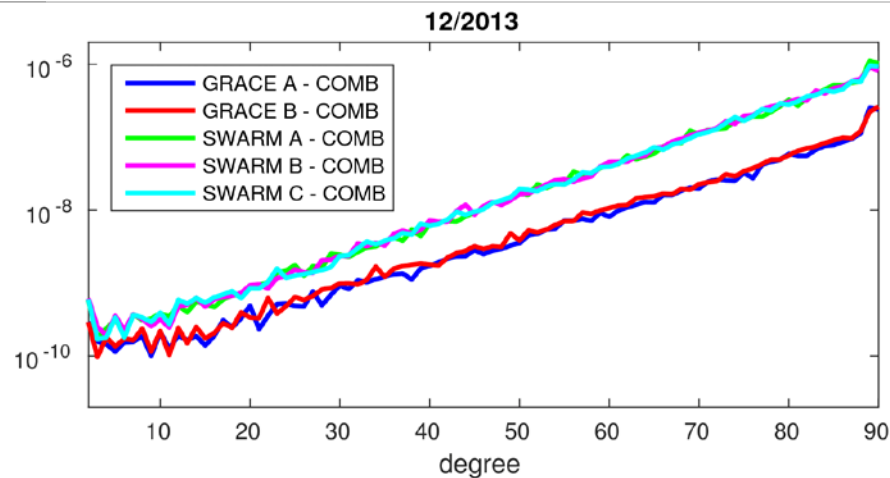
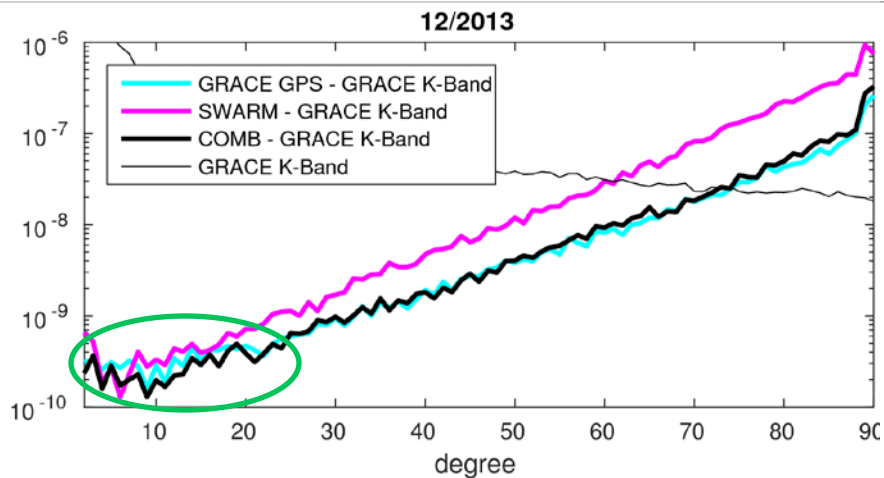
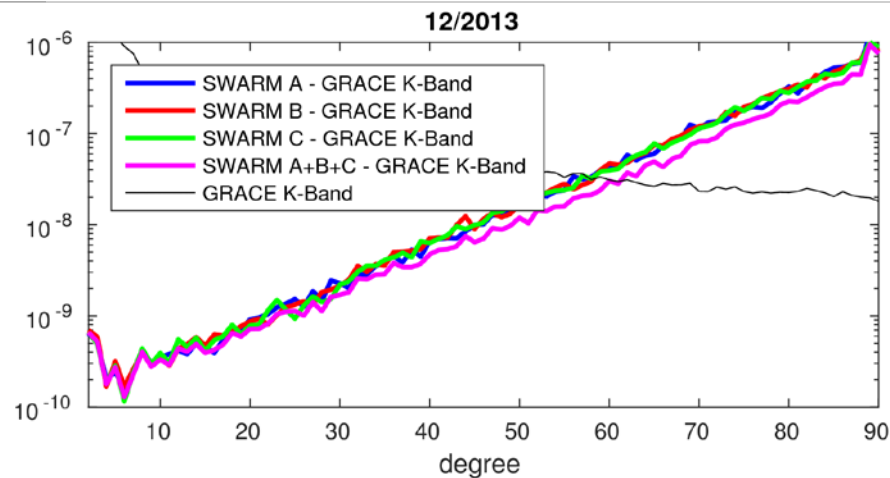
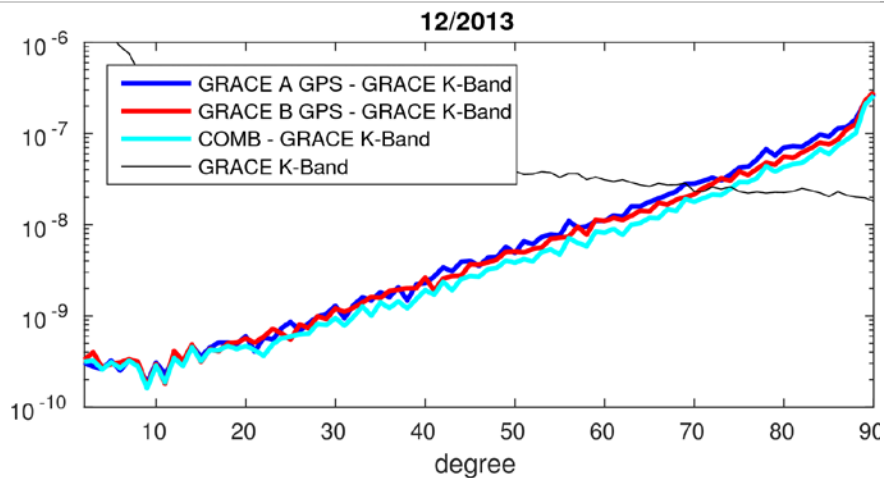


# GRACE + SWARM: contribution analysis

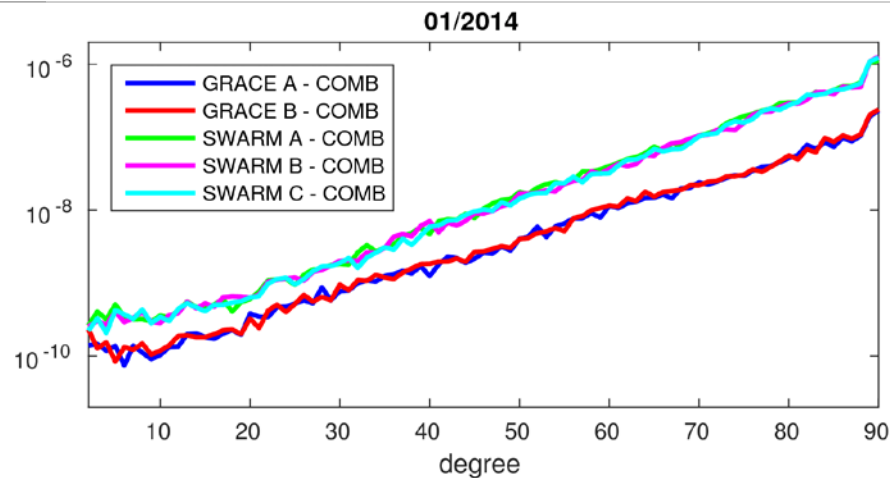
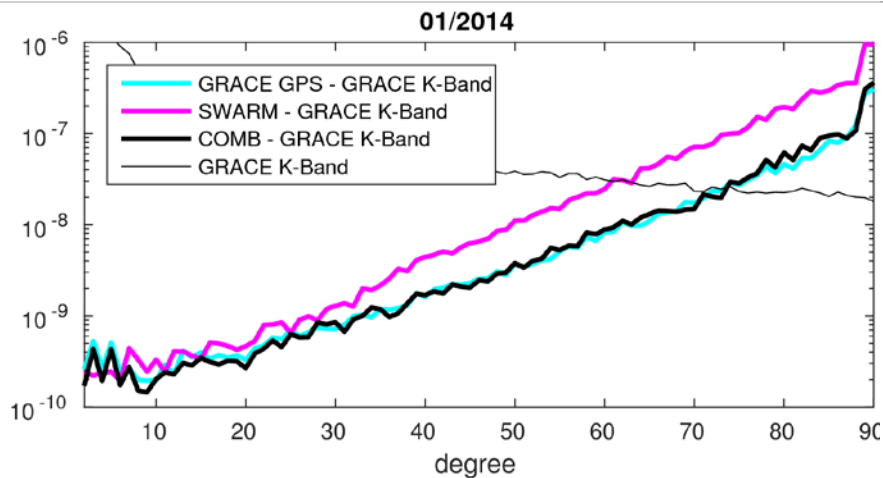
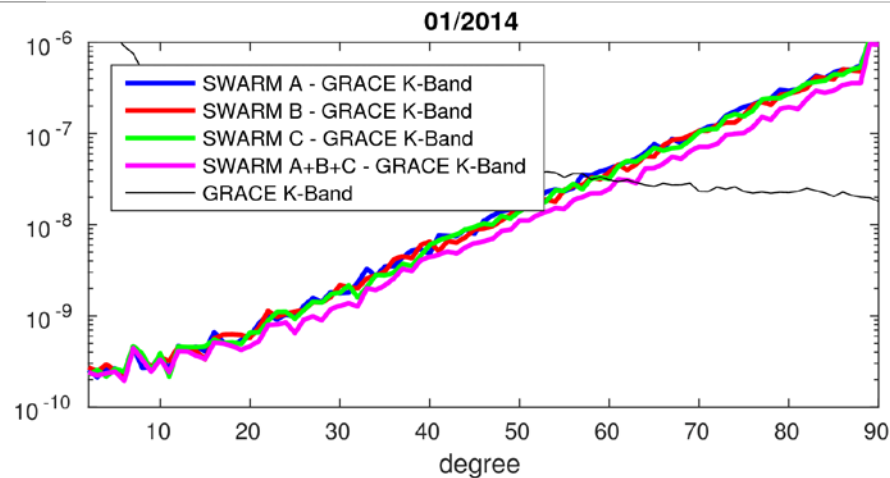
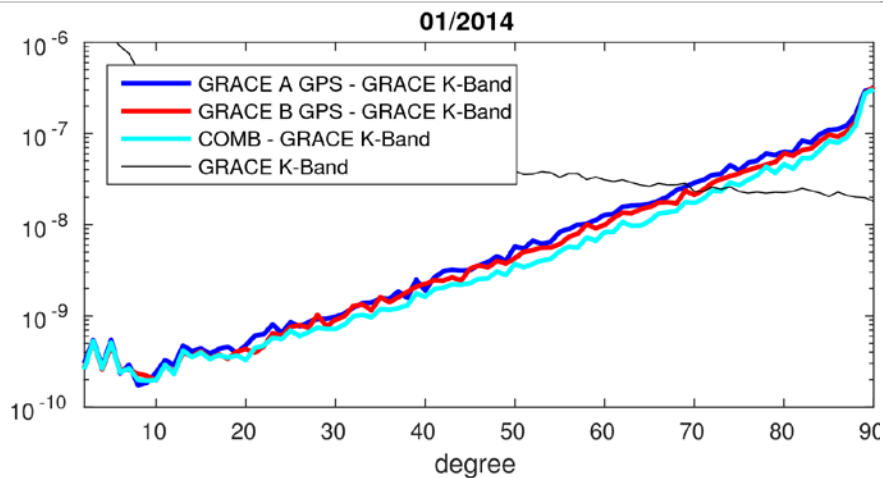




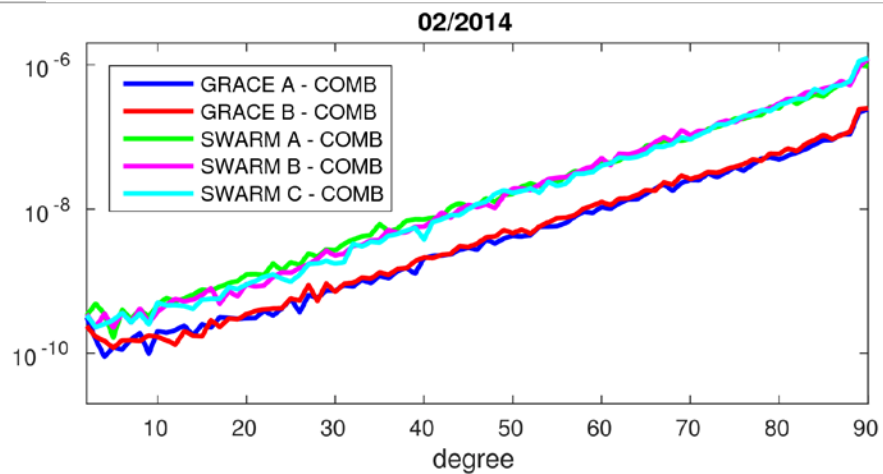
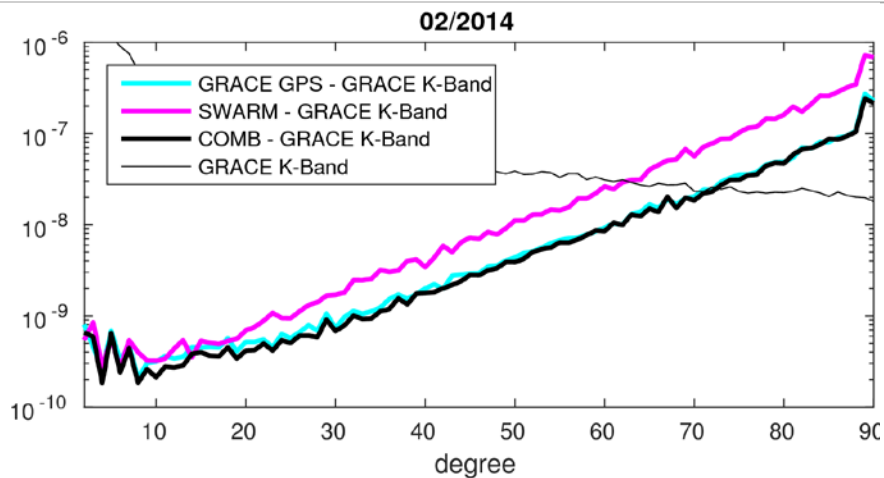
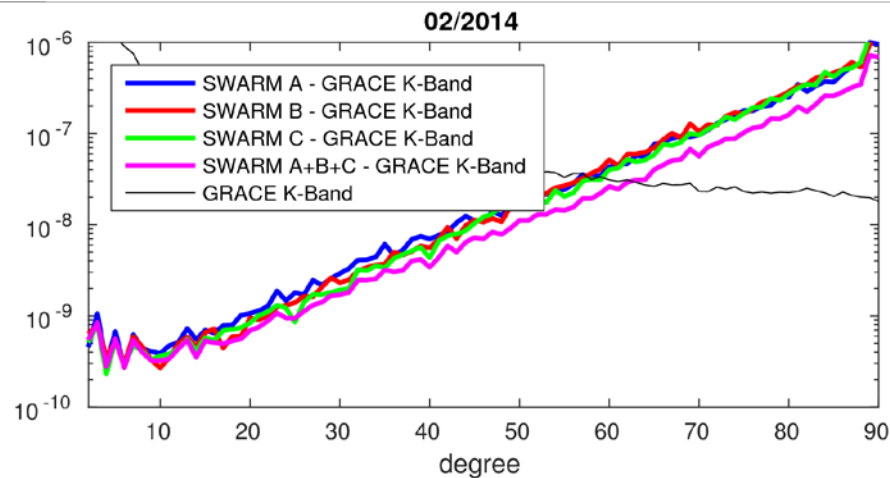
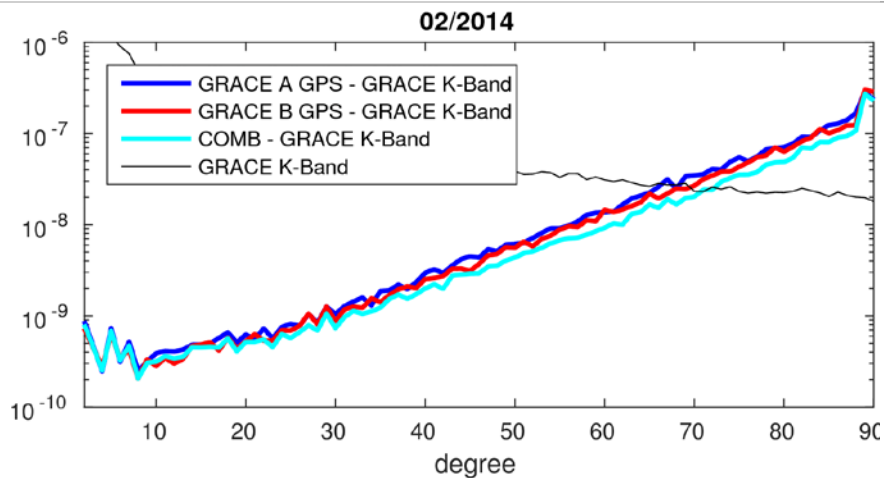
# Validation against GRACE K-band



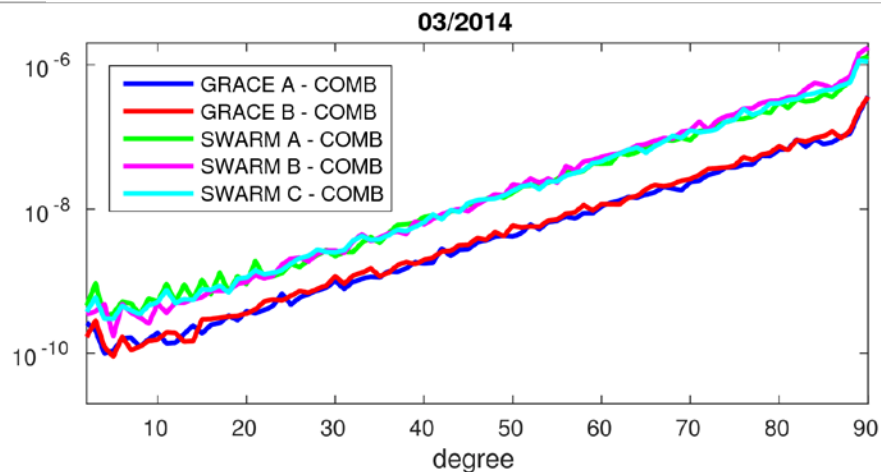
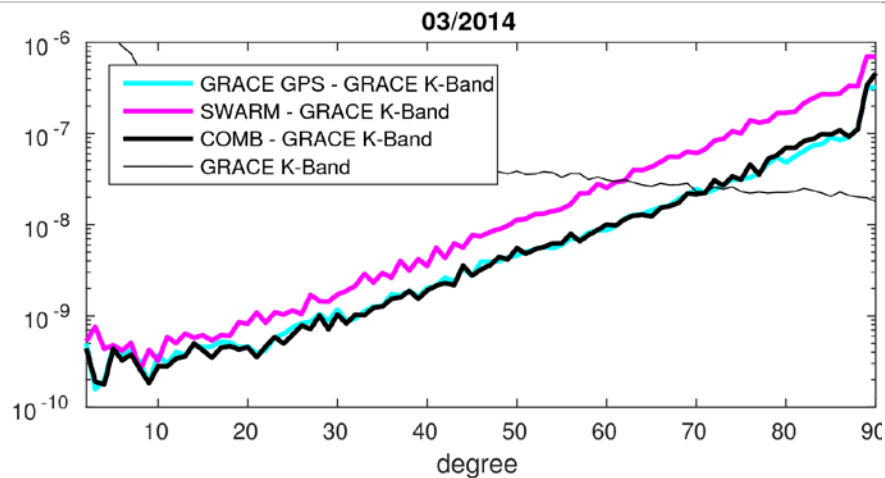
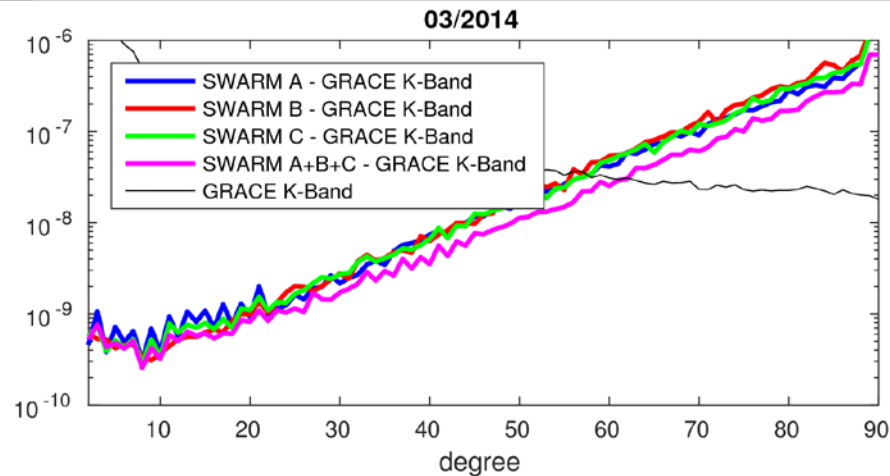
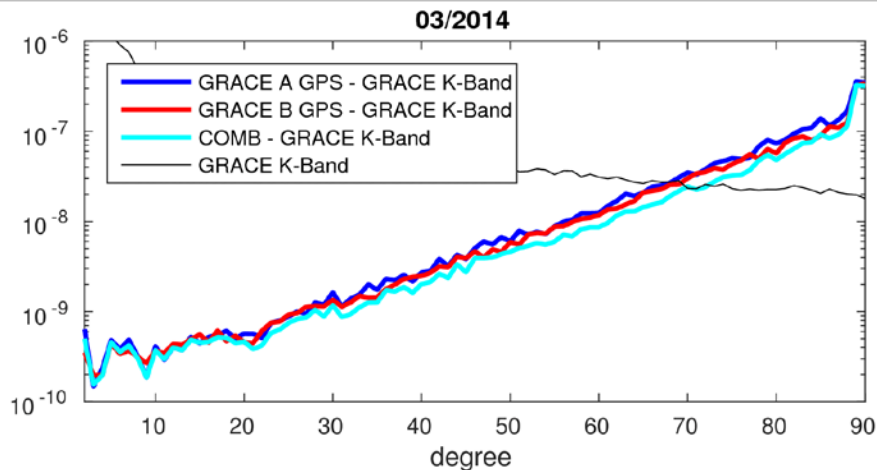
# Validation against GRACE K-band



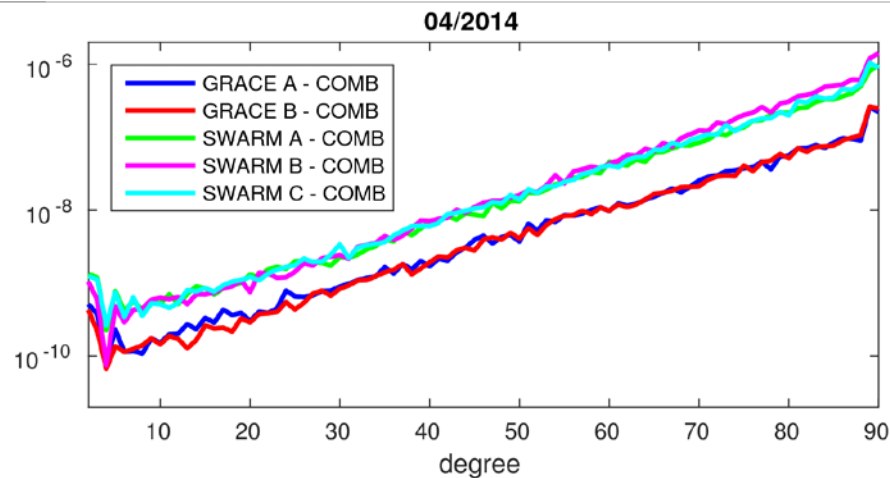
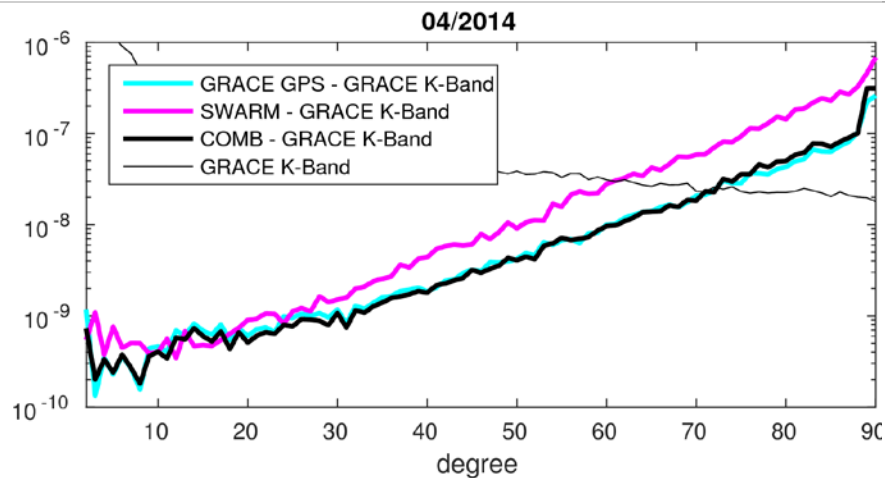
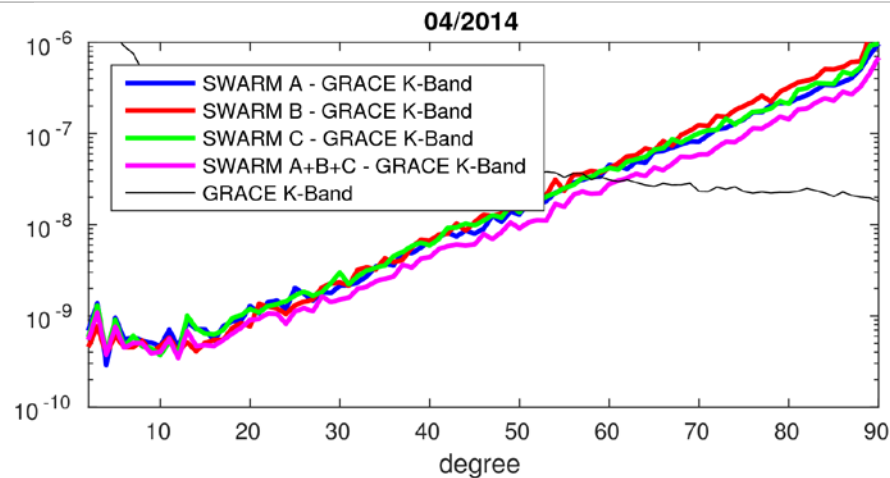
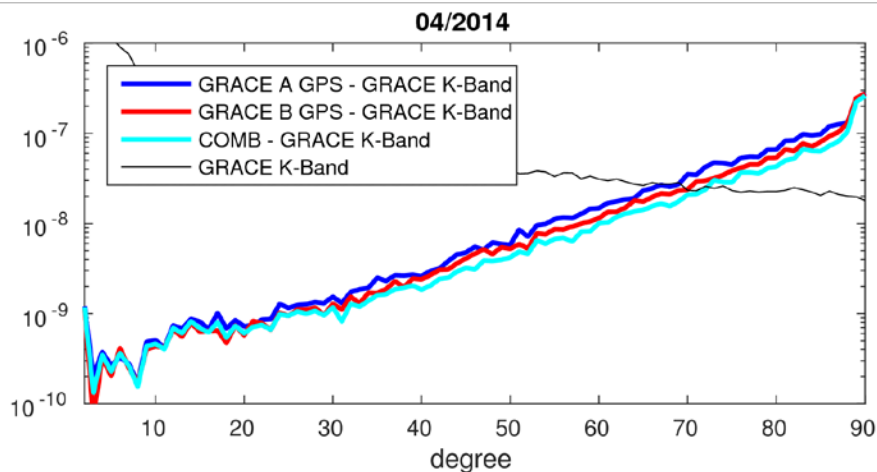
# Validation against GRACE K-band



# Validation against GRACE K-band

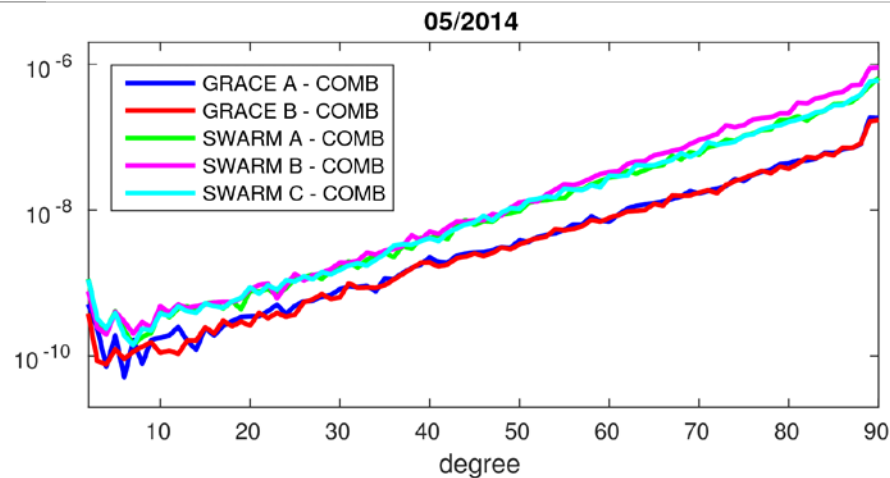
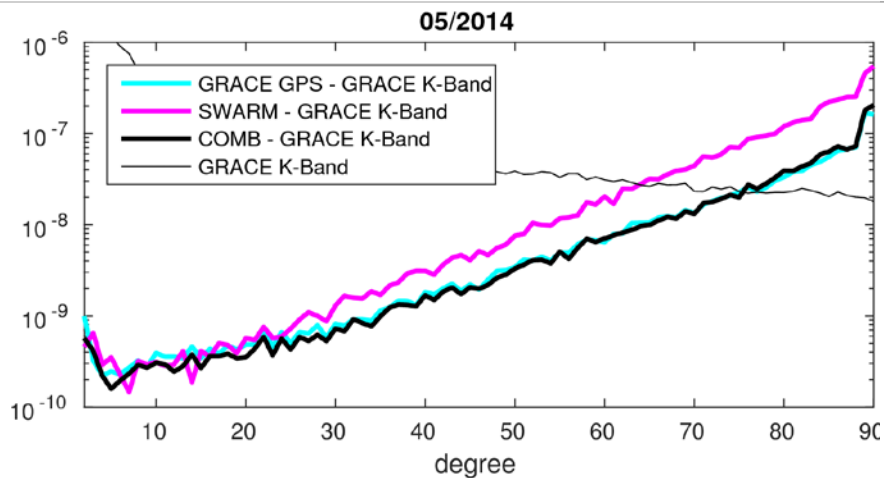
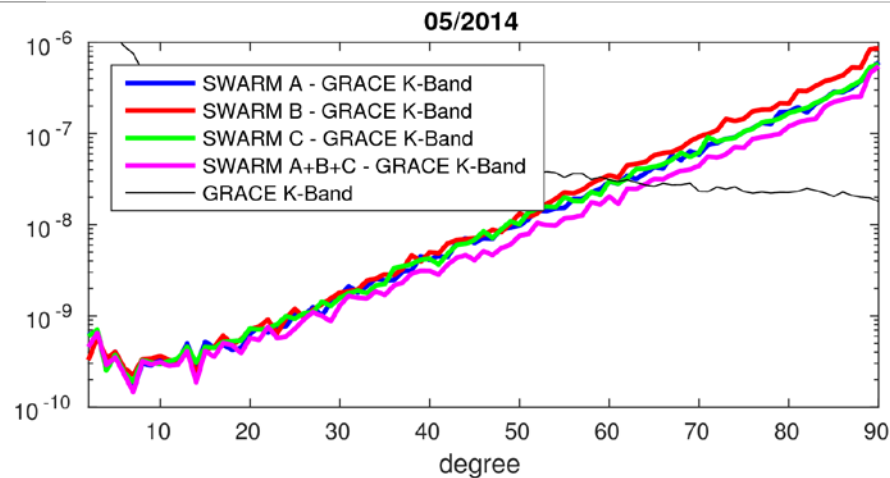
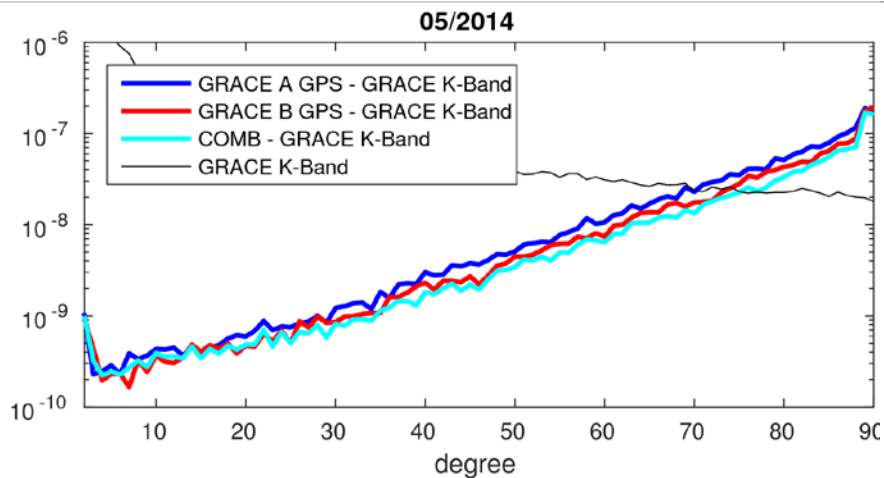


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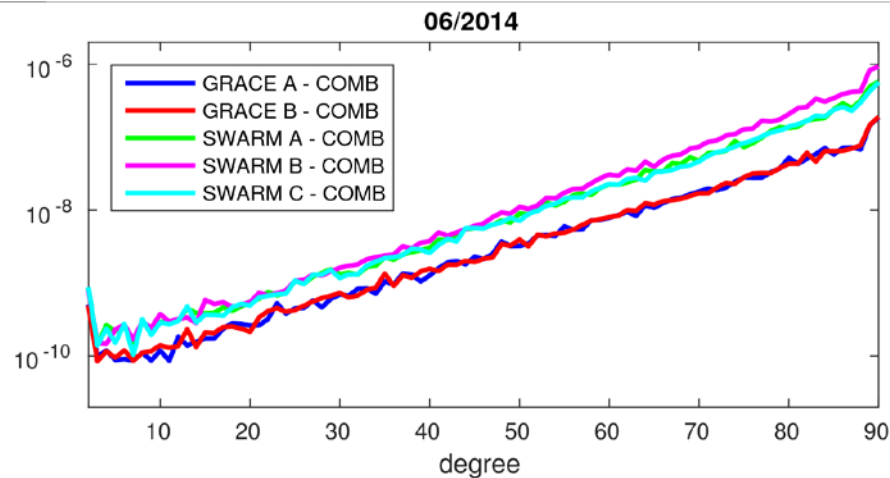
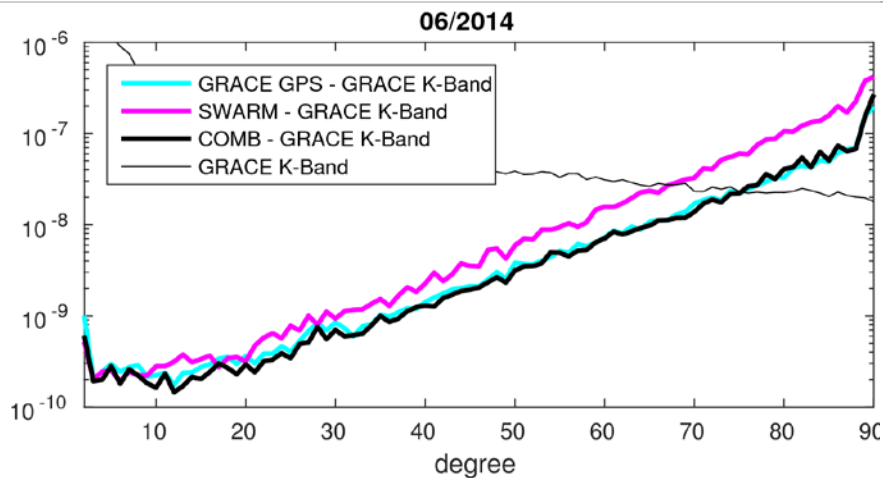
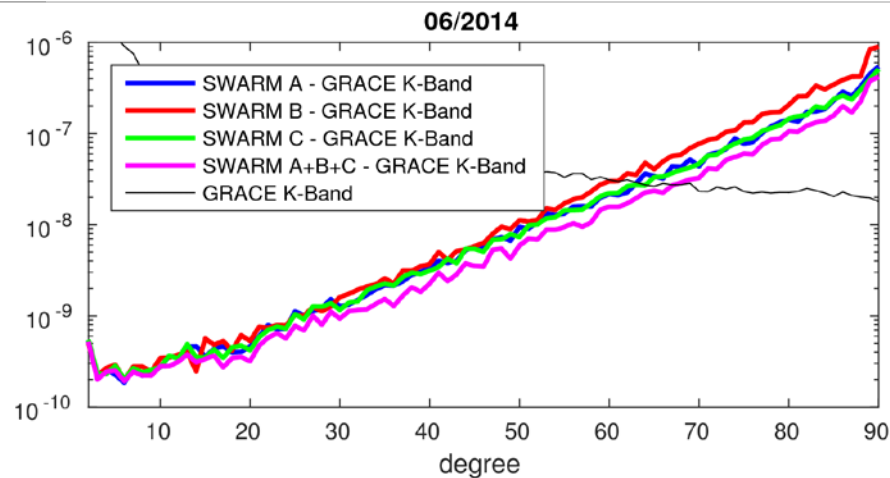
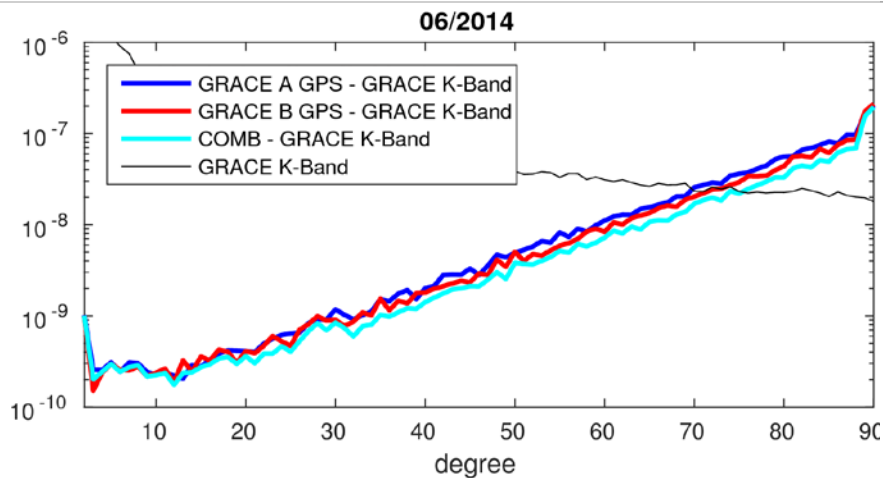




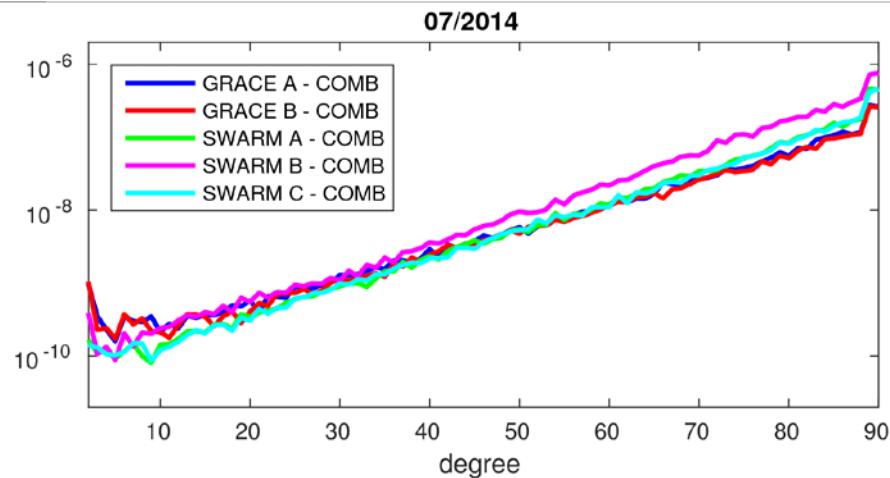
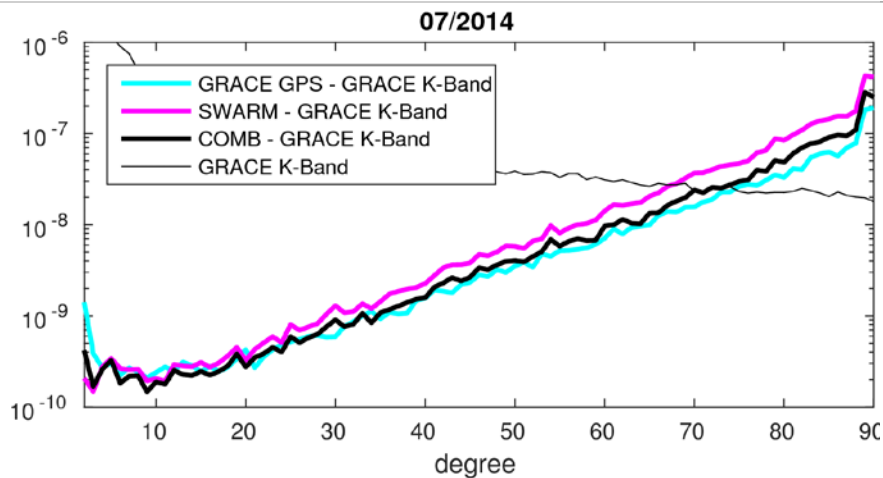
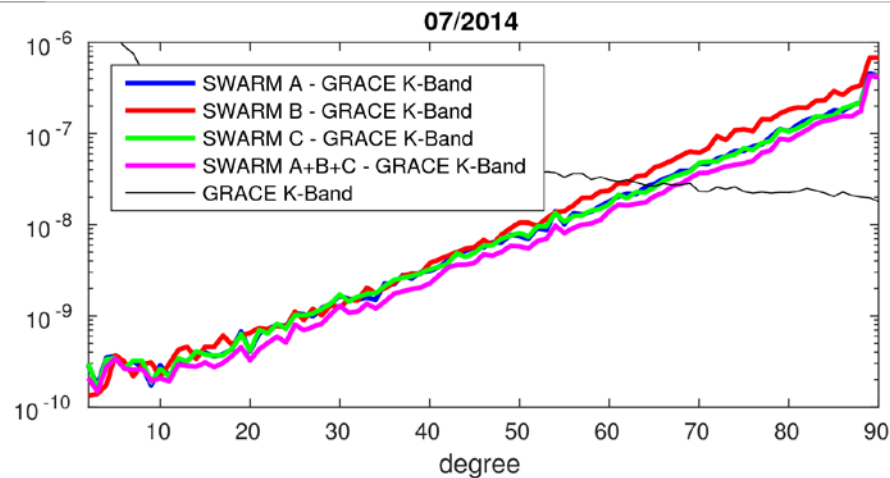
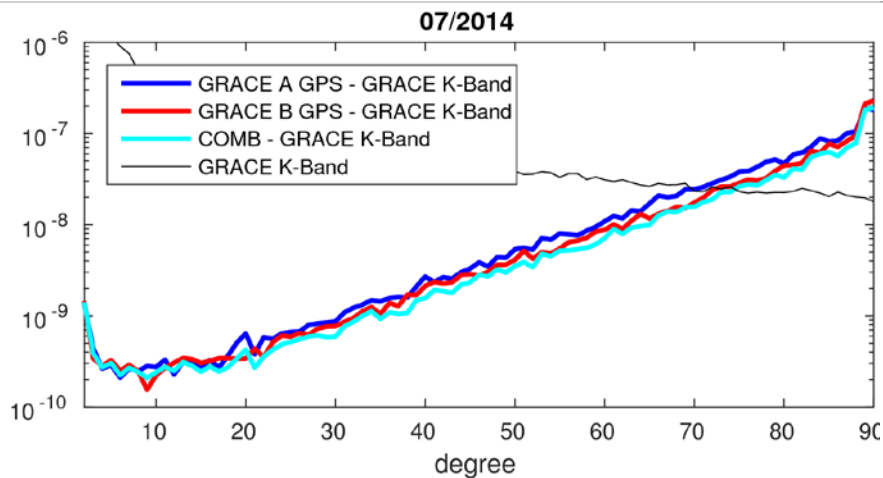
# Validation against GRACE K-band



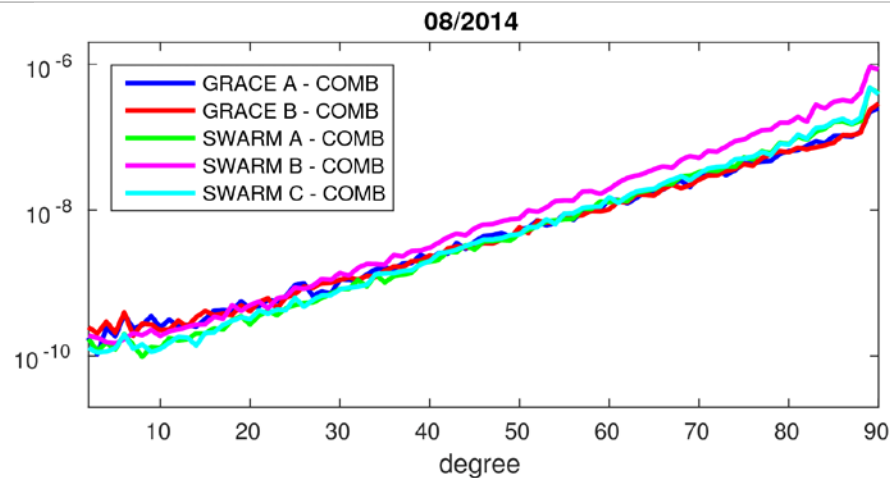
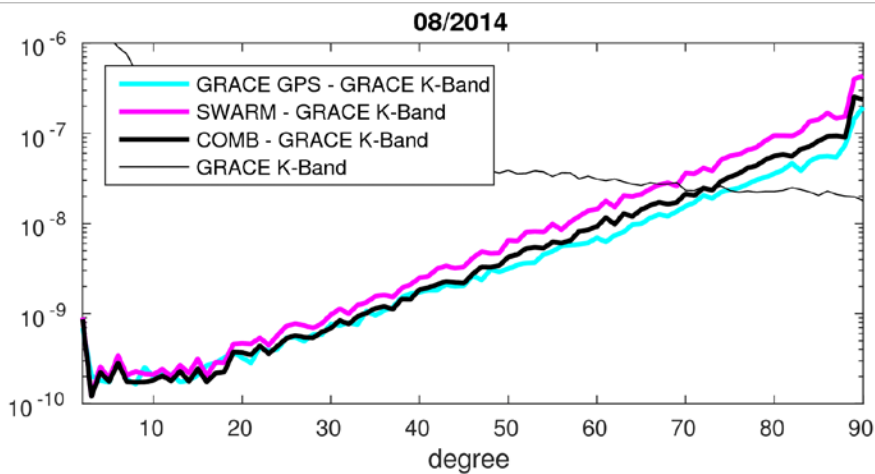
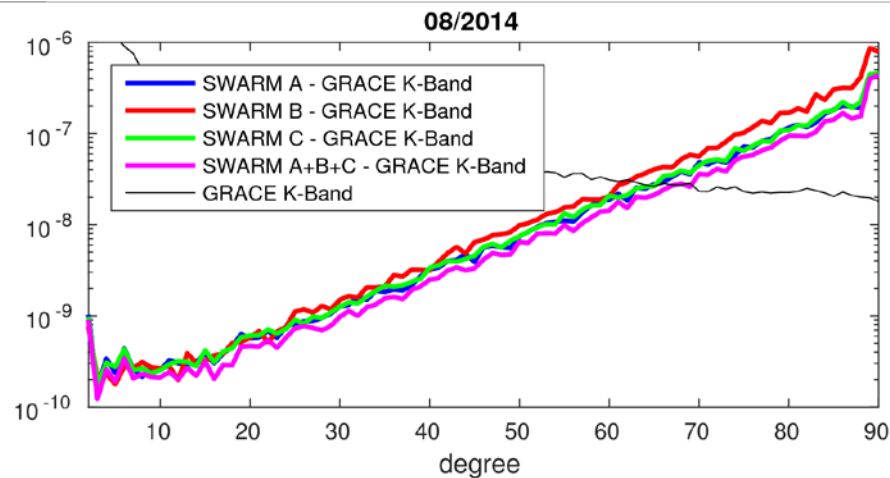
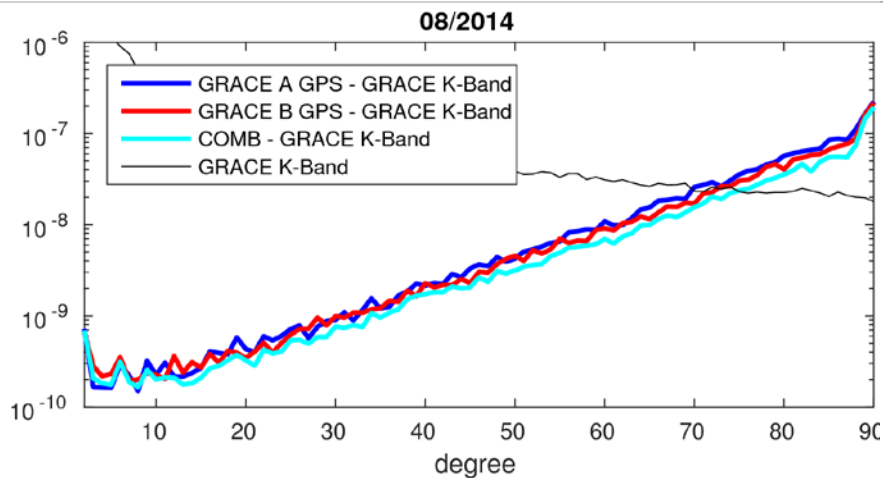
# Validation against GRACE K-band



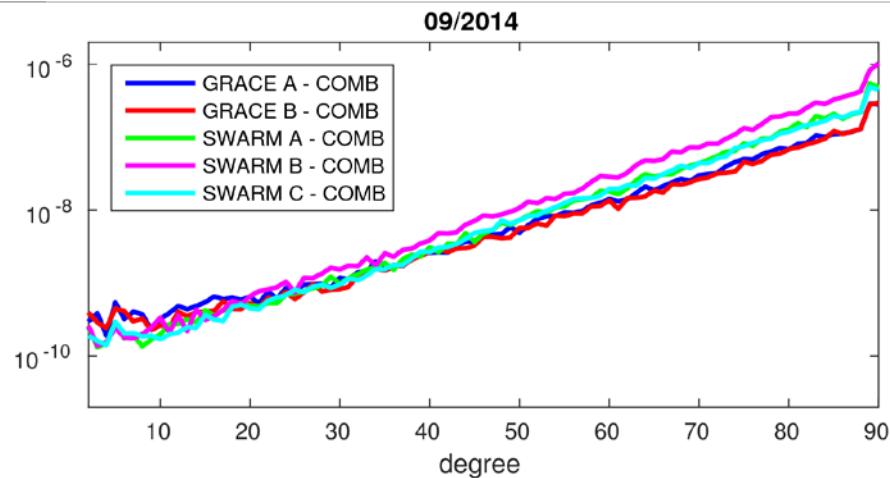
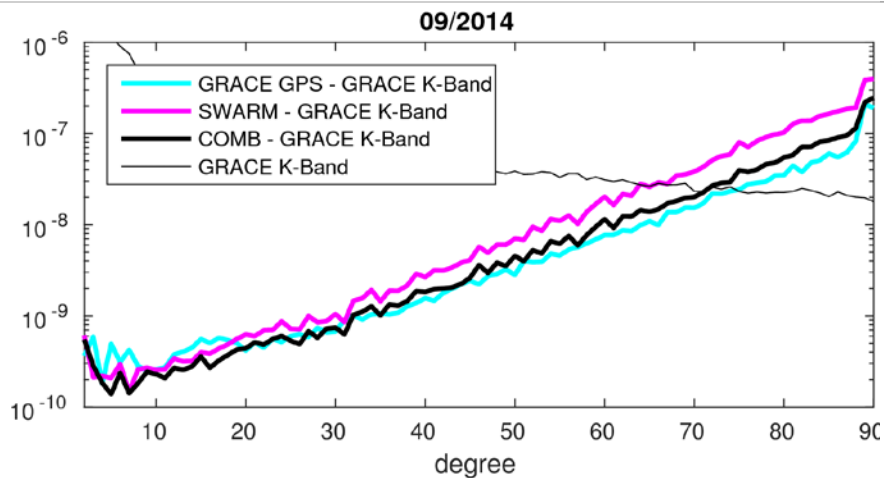
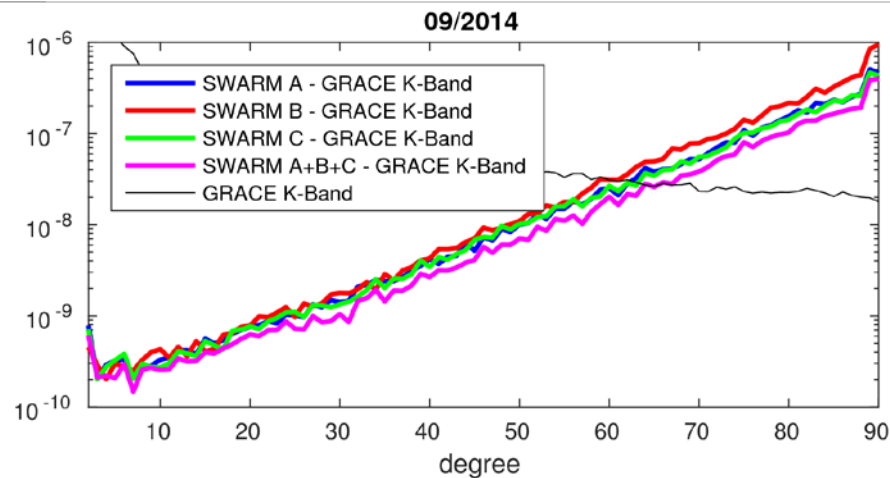
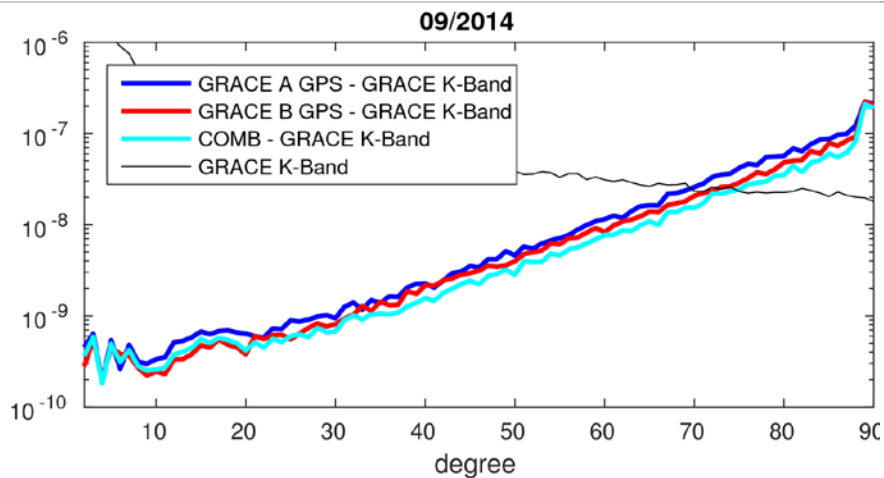
# Validation against GRACE K-band



# Validation against GRACE K-band

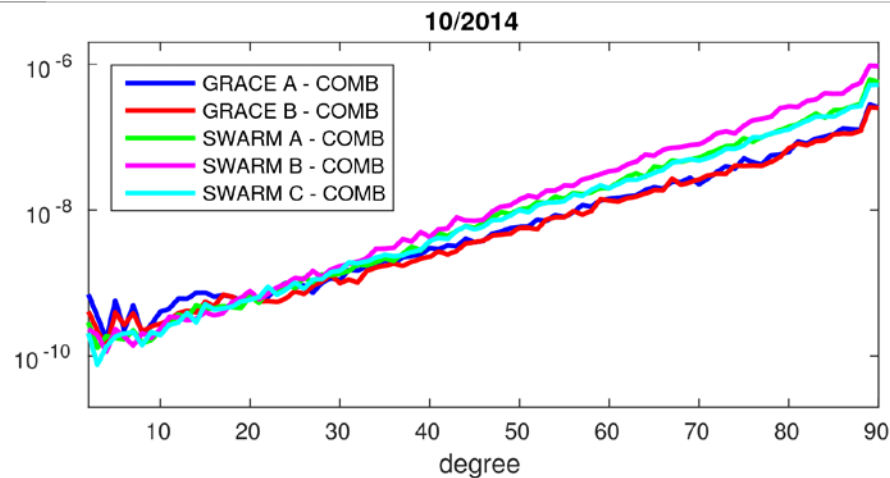
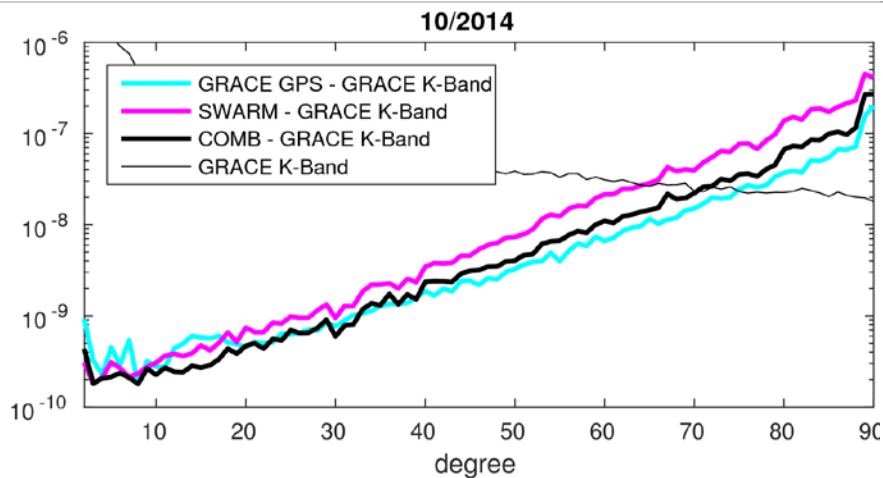
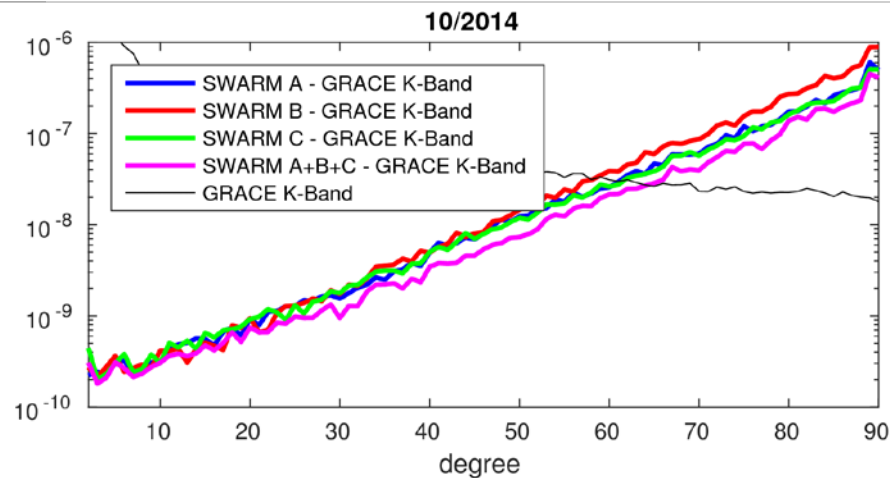
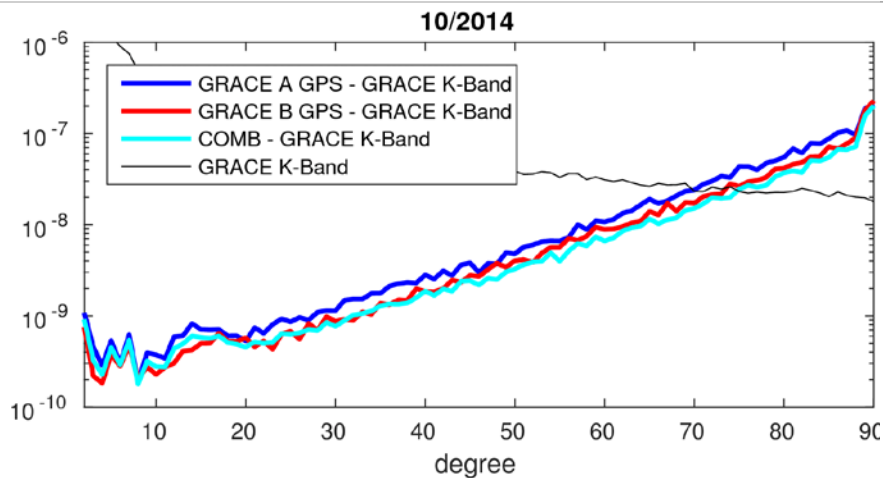


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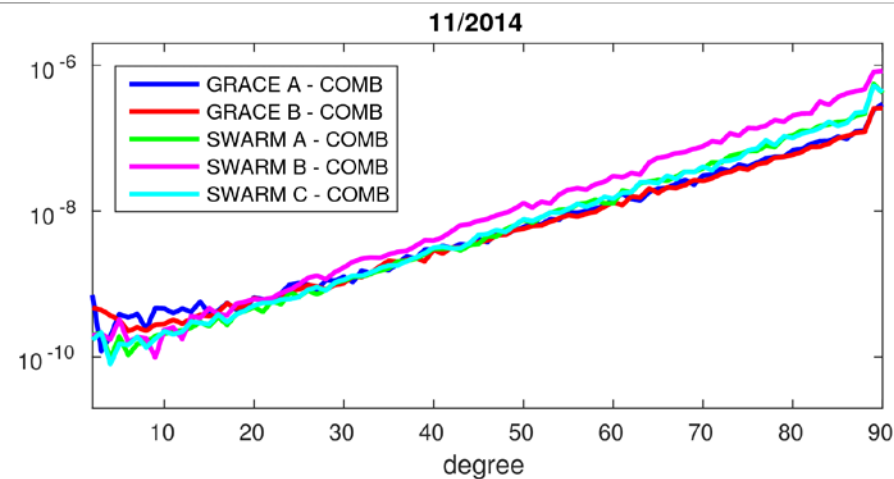
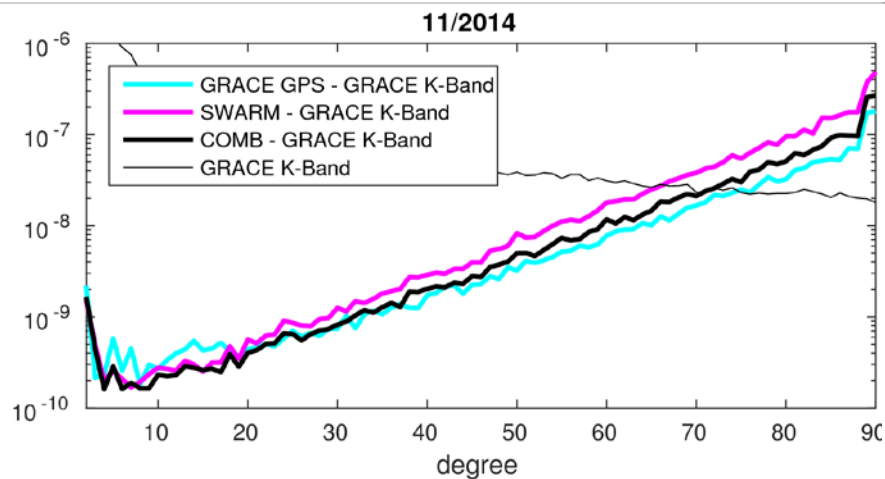
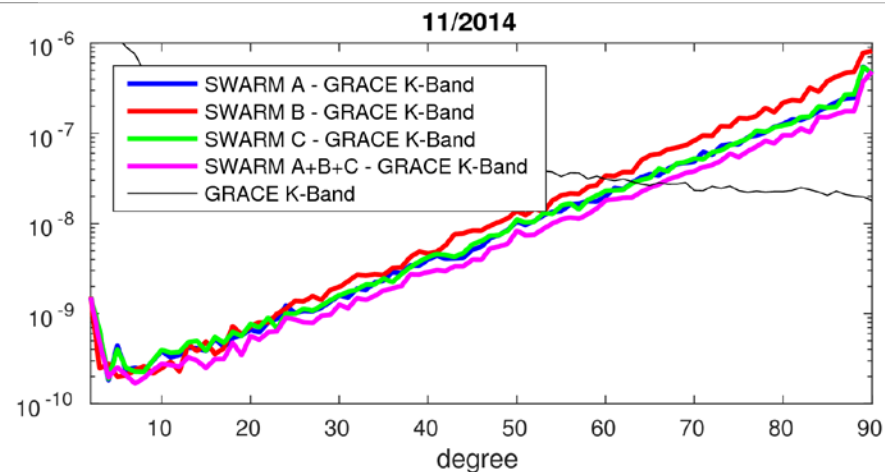
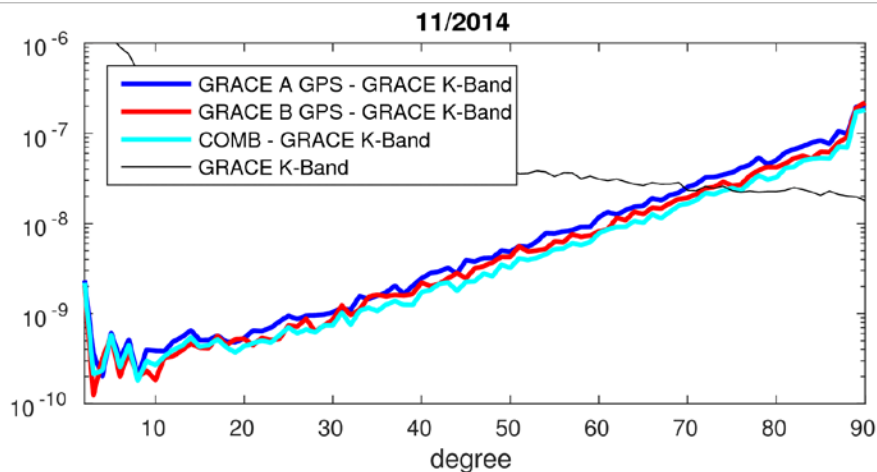




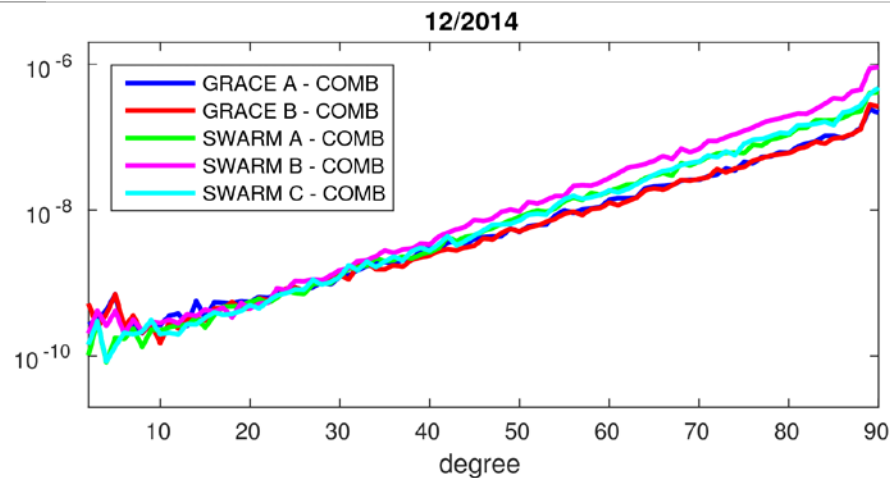
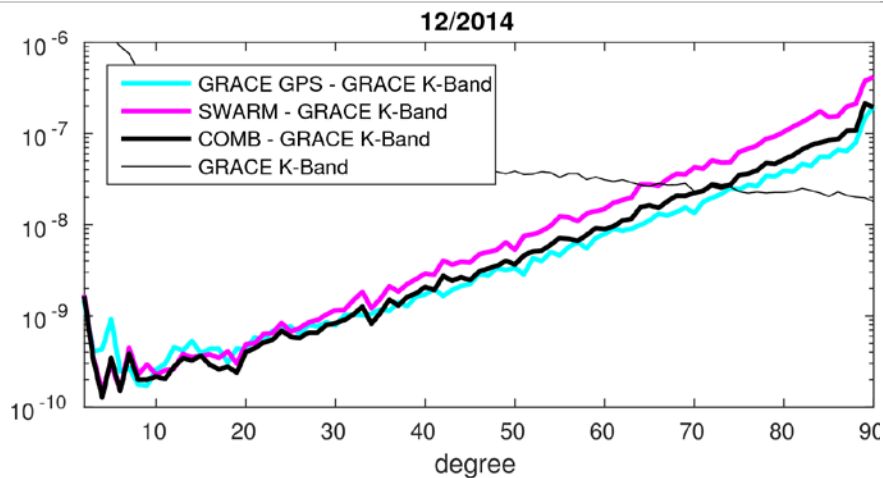
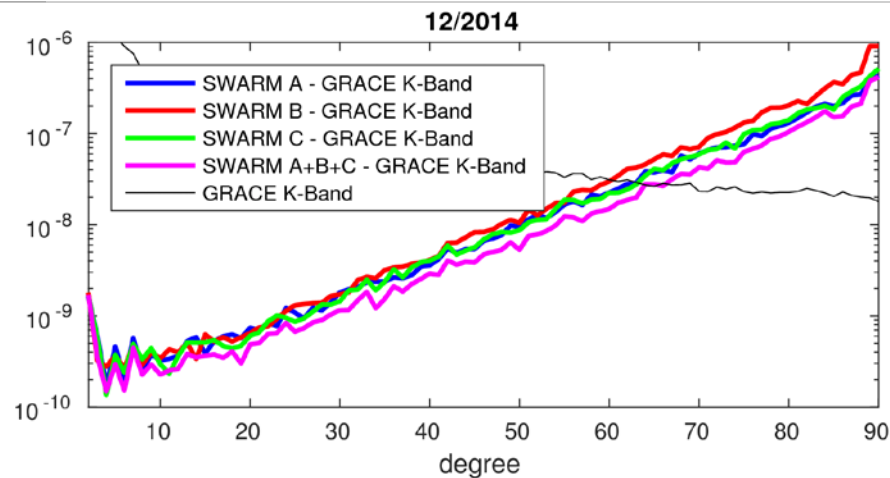
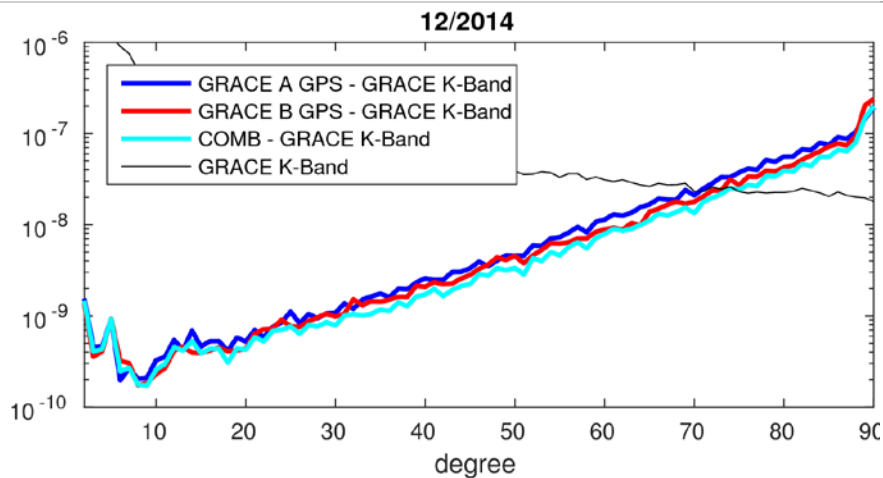
# Validation against GRACE K-band



# Validation against GRACE K-band

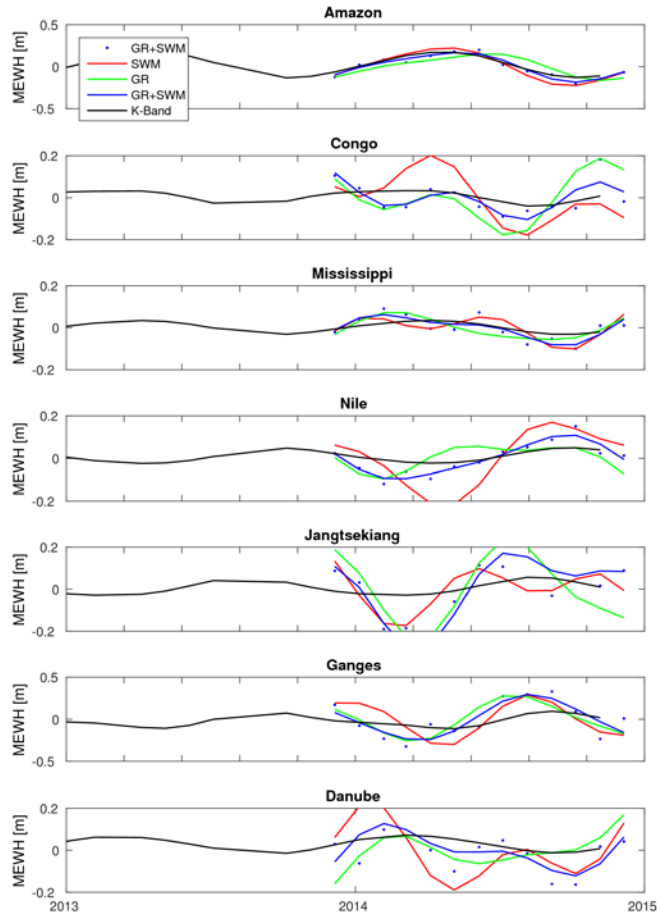


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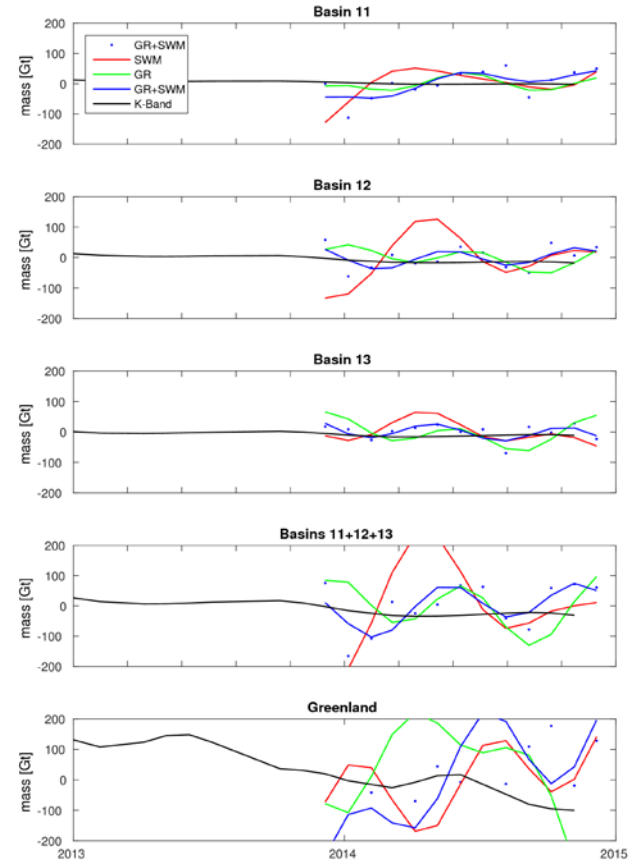


# Evaluation

## Seasonal variations in river basins



## Ice mass loss in polar regions



# Conclusions

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- GRACE and SWARM NEQs can be combined „just like that“ till 06/2014.
  - Low degree coefficients profit from the combination, while high degree coefficients are determined by the lower flying GRACE satellites.
  - After 06/2014 the change in sampling rate of the SWARM satellites leads to over-weighting of SWARM.
  - Combination of NEQs from different processing centers (with different noise models) will make an advanced relative weighting necessary.
- => Watch out for future EGSIEM presentations!