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AQUARIUS/SAC-D

Aquarius Salinity Algorithm and Simulations

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Remote Sensing Systems

Aquarius/SAC-D Science Workshop
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Objectives

Forward Model

Construct a comprehensive and accurate computer simulation of Aquarius' operation on orbit

Ocean scenes (salinity + other variables) ➔ Radiometer Counts

Inverse Model

Use this Aquarius Simulator to develop retrieval algorithms and verify performance

Radiometer Counts ➔ Salinity

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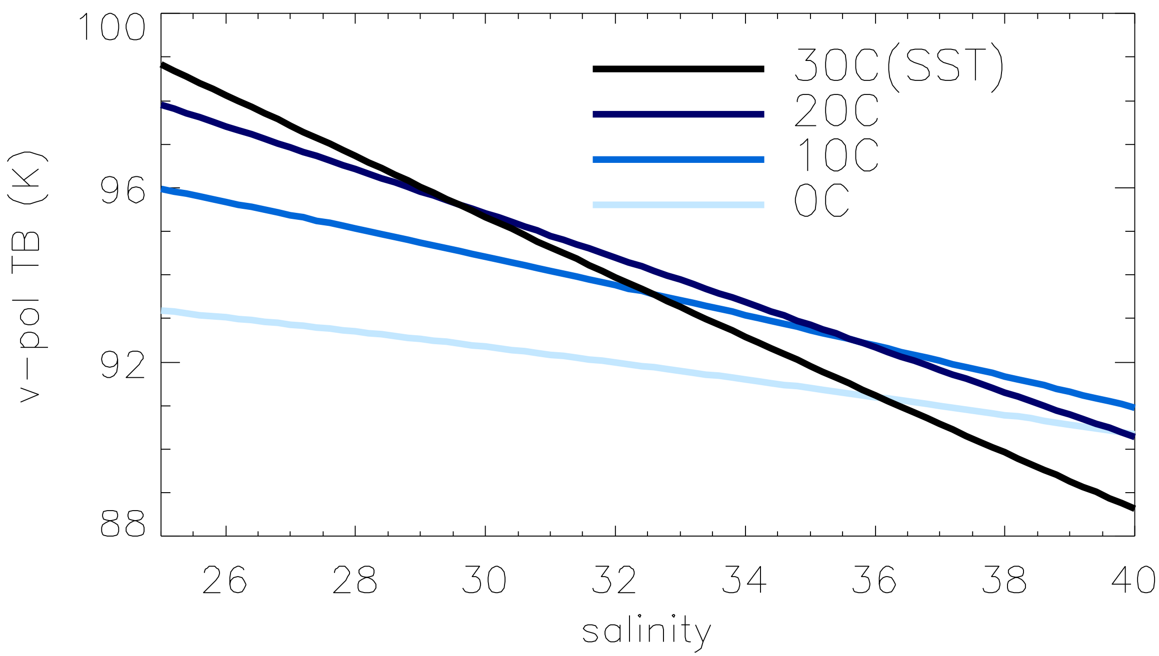
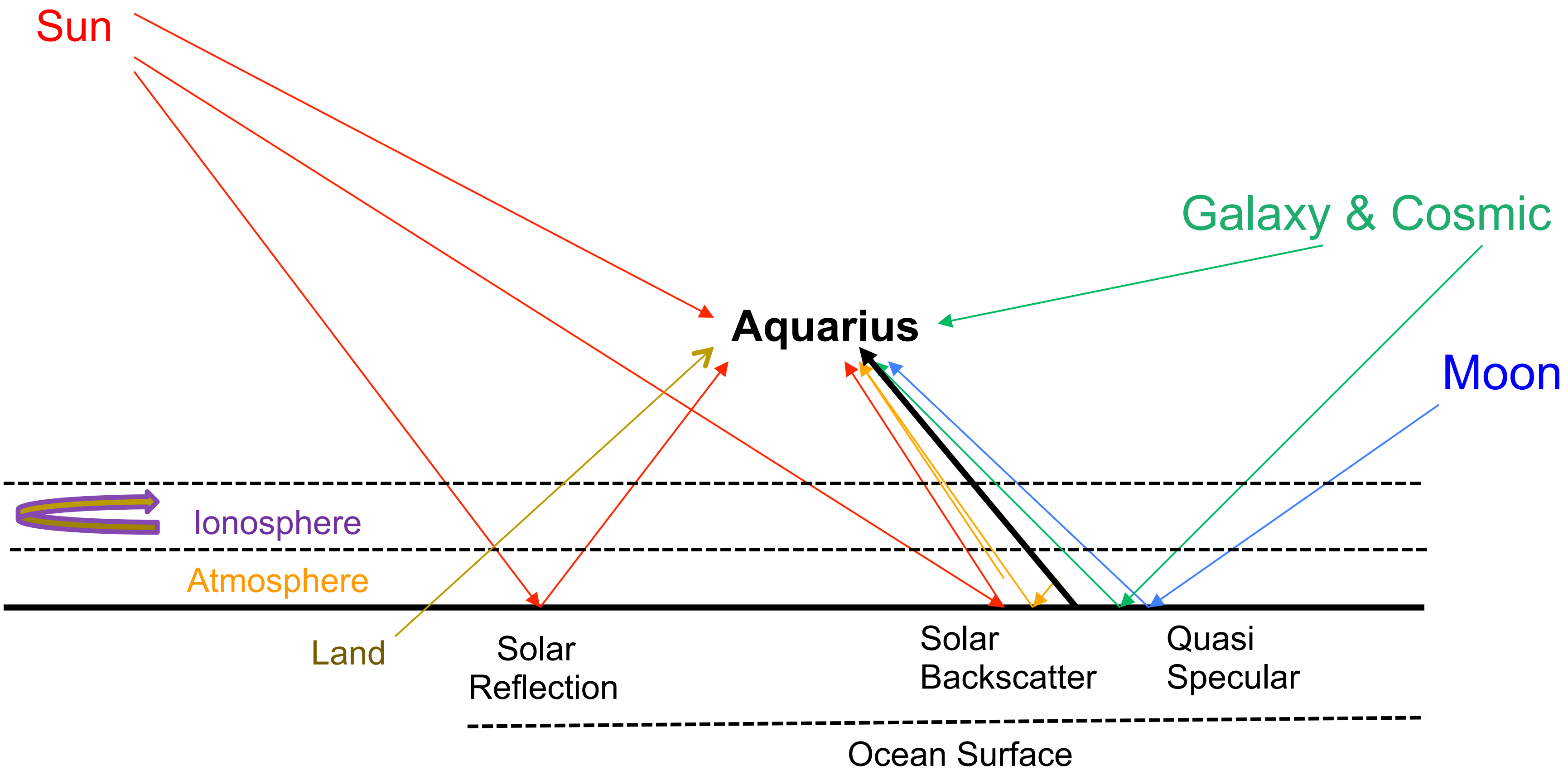
Principle

NaCl → dielectric constant of sea water → emissivity



Signals Receive by Aquarius



Components of Aquarius On-orbit Simulator

1. Direct, reflected, and backscattered solar radiation
2. Cosmic and galactic radiation
3. Faraday rotation in the ionosphere
4. Full slant-path integration through NCEP atmospheres
5. Surface emissivity from NCEP wind fields, Reynolds SST fields, & HYCOM salinity model.
6. Land emissivity and temperature model
7. Sea Ice emissivity model
8. Complete integration of the 4-Stokes parameters over the complete 4 pi steradians
9. Intensive numerics with integration error < 0.01 K
10. Realistic NEDT

The Antenna Temperature Equation

$$\mathbf{T}_A = \begin{bmatrix} T_{Amea,V} + T_{Amea,H} \\ T_{Amea,V} - T_{Amea,H} \\ T_{Amea,+45} - T_{Amea,-45} \\ T_{Amea,left} - T_{Amea,right} \end{bmatrix}$$

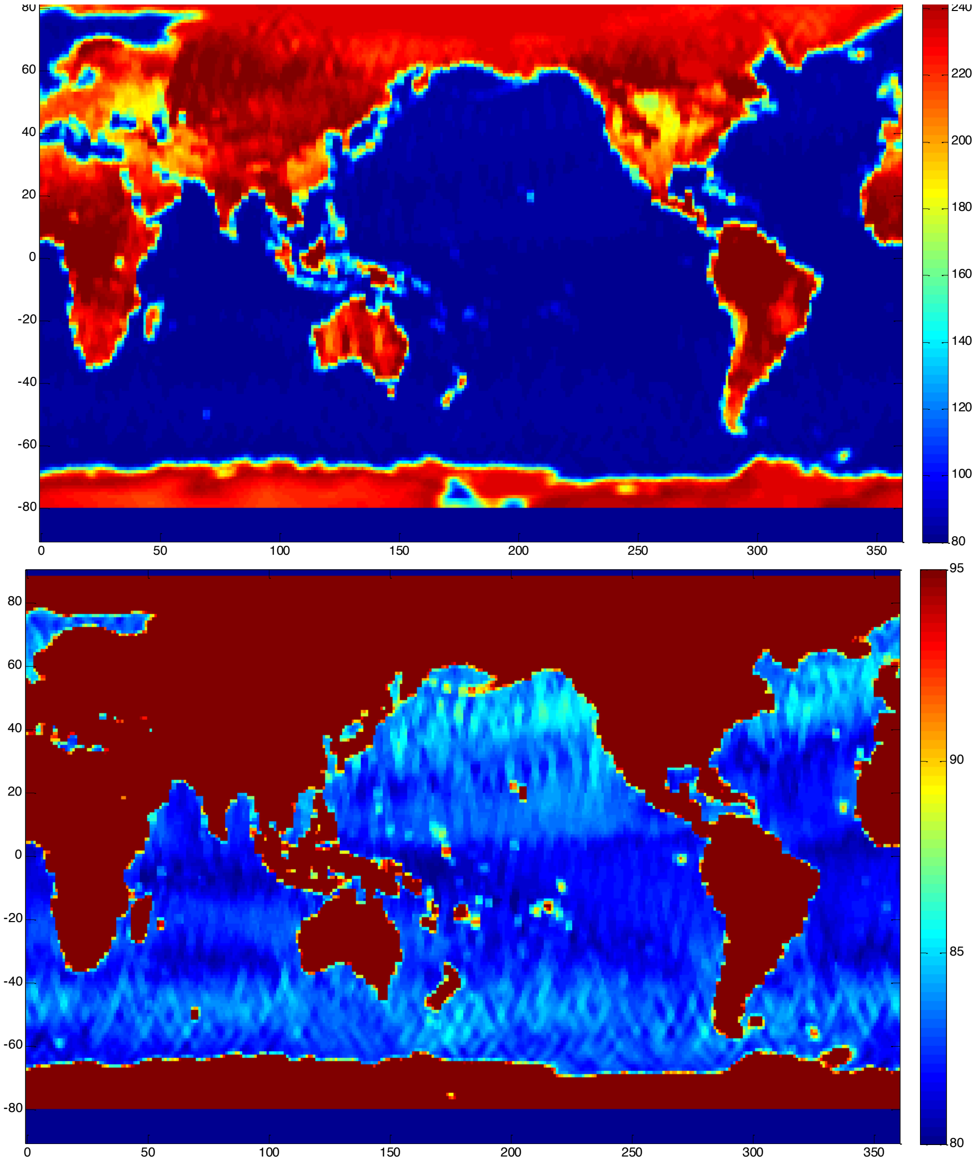
$$\mathbf{T_A} = \frac{1}{4\pi}\int_{Earth} \mathbf{G}(\mathbf{b})\mathbf{R}(\phi)\mathbf{T_B}(\theta_i)\frac{\partial\Omega}{\partial A}dA \;+\; \frac{1}{4\pi}\int_{Space} \mathbf{G}(\mathbf{b})\mathbf{T}_{\mathbf{B},space}d\Omega$$

Direct solar radiation included in $T_{B,Space}$. Reflected and backscattered solar radiation included in T_B(□)

$$\mathbf{R}(\phi) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2(\phi+\phi_f) & -\sin 2(\phi+\phi_f) & 0 \\ 0 & \sin 2(\phi+\phi_f) & \cos 2(\phi+\phi_f) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\frac{\partial\Omega}{\partial A} = f_{lat}\frac{\cos\theta_i}{R^2}$$

Weekly TA Map from On-orbit Simulator



Middle horn, h-pol
80 K to 240 K

Middle horn, h-pol
80 K to 95 K

L1a to L2 Aquarius Processor

1. Compute geolocation variables
2. Convert radiometer counts to antenna temperature
3. Ingest ancillary products for radiometer footprint
4. Compute top-of-the-atmosphere brightness temperature
5. Compute surface brightness temperature
6. Estimate salinity given surface TB and wind
7. Compute expected antenna temperature

Geolocation Variables

iflag_sun= 1 if sun is visible from spacecraft (usual case), otherwise it = 0
zang= intra-orbit angle. it is zero at the south pole, 90 deg at the equator ascending node, etc.
sclat= geodetic latitude of the spacecraft earth nadir point (deg)
sclon= east longitude of the spacecraft earth nadir point (deg)
scalt= spacecraft altitude, nadir point to spacecraft (meters)
sund= earth-to-sun unit vector in eci coordinates
sunr= unit vector from spacecraft to sun reflection point on earth in eci coordinates
moond= earth-to-moon unit vector in eci coordinates
bore_sight= unit vector from the spacecraft to the center of the observation cell
cellat= geodetic latitude (deg)
cellon= east longitude (deg)
celtht= boresight earth incidence angle (deg)
celphi= boresight earth-projection relative to clockwise from north (deg), boresight points towards earth
suntht= sun vector earth incidence angle (deg)
sunphi= sun vector earth_projection relative to clockwise from north (deg), sun vector points away from earth
sunglt= sun glint angle: angle between the specular reflected boresight vector and the sun vector (deg)
mooonglt= moon glint angle: angle between the specular reflected boresight vector and the moon vector (deg)
glxlat= j2k declination latitude from where the specular galactic radiation originated (deg)
glxlon= j2k ascension from where the specular galactic radiation originated (deg)
cellat_corners= geodetic latitudes of the four corners of the 3-db footprint
cellon_corners= east longitudes of the four corners of the 3-db footprint

Software for geolocation is based on standard methods with accuracy <= 100 meters
Oblate Spheroid Earth Model: WGS-84 RE=6378.137D3, RP=6356.752D3
Values calculated every 1.44 seconds at mid-point of count averaging.

Converting Radiometer Counts to Antenna Temperature (T_A)

- ATBD by Jeff Piepmeier and computer code by Thomas Meissner
- Each 1.44 sec cycle has 60 earth counts
- Assortment of calibration counts
- 85 thermistors readings
- Contains all updates recommended at March Santa Rosa Meeting
- Earth counts are averaged with and without an RFI filter provide by Chris Ruff
- Option to use either with-RFI -filter or without-RFI-filter for subsequent processing
- Algorithm verified by doing closure runs: count ➔ TA ➔ count
- False detection of RFI is currently occurring at coast lines.

Required Ancillary Data: NCEP GDAS

2D (lon, lat) Fields

GRIB No.	GRIB Name	Description
Ocean Reflectivity		
247.1	UGRD:10 m above ground:anl	u component of surface wind
247.2	VGRD:10 m above ground:anl	v component of surface wind
Land Reflectivity		
230	TMP:surface:anl	surface land/ocean temperature
231	SOILW:0-.1 m below ground:anl	top layer soil moisture
T_{bup}, T_{bdown}, and		
195	PRES:surface:anl	surface air pressure
246	RH:2 m above ground:anl	surface relative humidity
211	HGT:surface:anl	surface height
242	TMP:2 m above ground:anl	surface air temperature
196	PWAT:entire atmosphere:anl	columnar water vapor
222	CWAT:entire atmosphere:anl	columnar cloud water

3D (lon, lat, height) Fields

T_{bup}, T_{bdown}, and

	CLWMR:xxx mb:anl	layer cloud water
	TMP:xxx mb:anl	layer air temperature
	RH:xxx mb:anl	layer relative humidity
	HGT:xxx:anl	layer height

Preprocessor **Mk_Atmos_Tables** generates 2D Fields of T_{bup}, T_{bdown}, and .

3-D Interpolation of tables in latitude, longitude, and time used to get value at Aquarius footprint

Required Ancillary Data: SSS, SST, Sea Ice, TEC

SSS - Salinity Reference Field: Yi Chao adaptation of HYCOM

SST - NOAA's daily, 0.25 degrees OI SST product

Sea Ice – NOAA's daily 1/12 degree fractional sea ice product

Solar Flux - NOAA, Space Weather Prediction Center, daily 1.4 GHz measurements at four sites

Total Electron Content - University of Berne Global 2-Hour Ionosphere Maps

Preprocessor **Prep_Ice_Map** averages 1/12 degree sea ice product to Aquarius footprint resolution

3-D Interpolation of tables in latitude, longitude, and time used to get value at Aquarius footprint

Required Ancillary Data: Simulator Pre-Computed Products

Land Fraction in 3 db footprint:	**(nlon=2160, nzang=2881 , 0.12 deg)**
Land Fraction over entire gain pattern:	**(nlon=2160, nzang=2881 , 0.12 deg)**
Direct and Reflected TA Sun Tables:	**(nomega=1441, nzang=1441, 0.25 deg)**
Direct and Reflected TA Galaxy Tables[1]:	**(nomega=1441, nzang=1441, 0.25 deg, nwind=5)**

Note 1: Correction made to reflected TA galaxy tables to account for actual SST and SSS.

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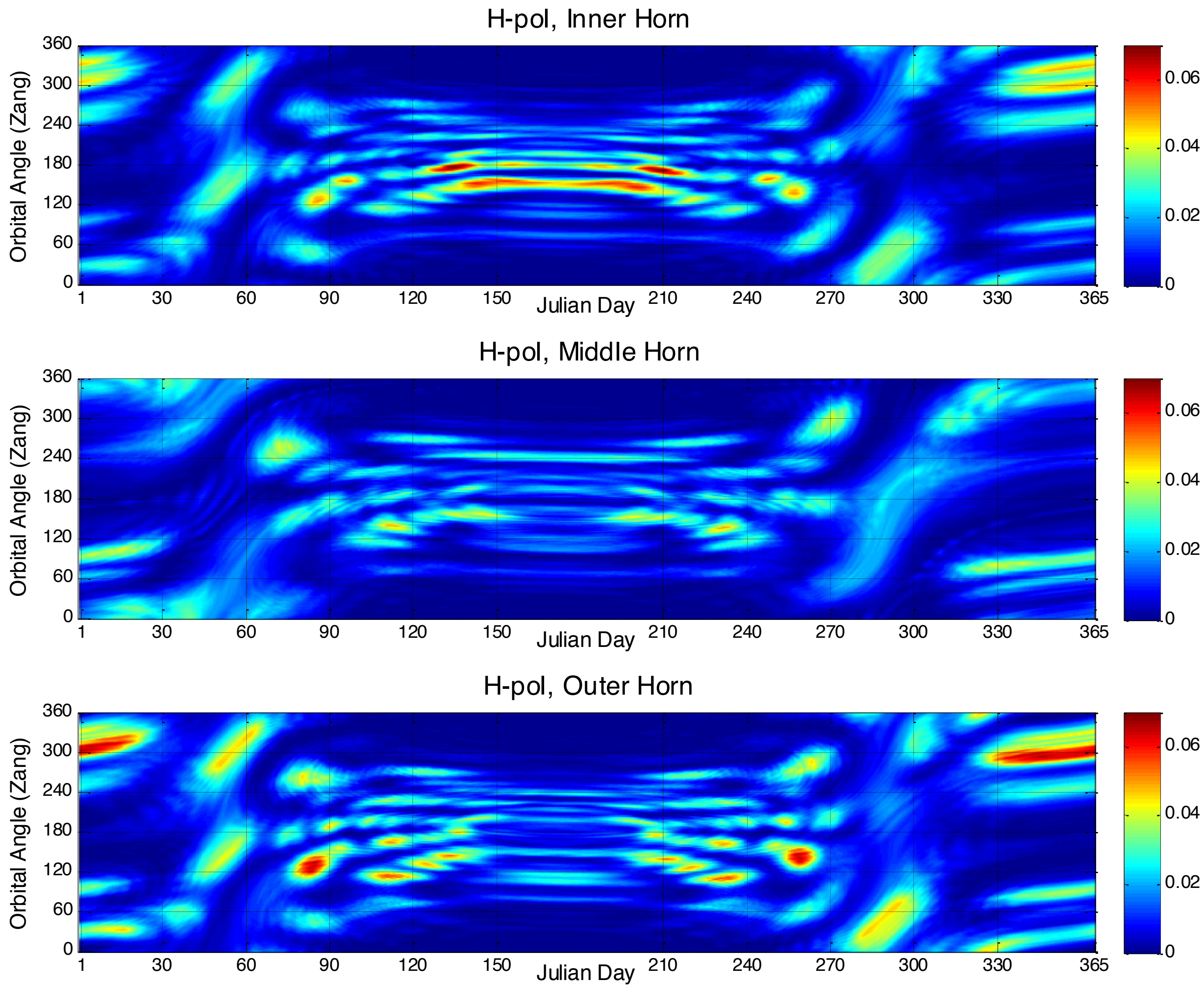
Direct Solar



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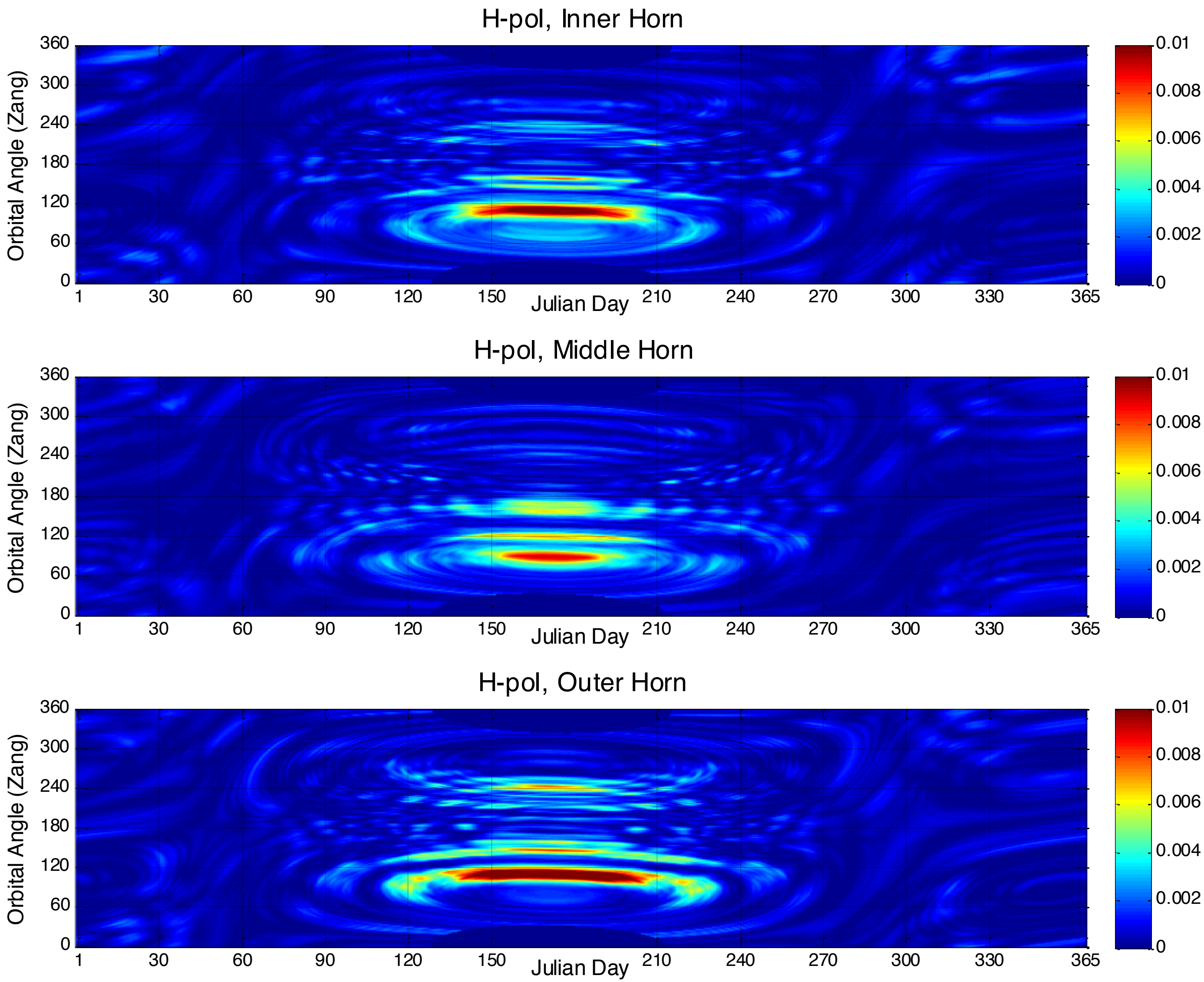
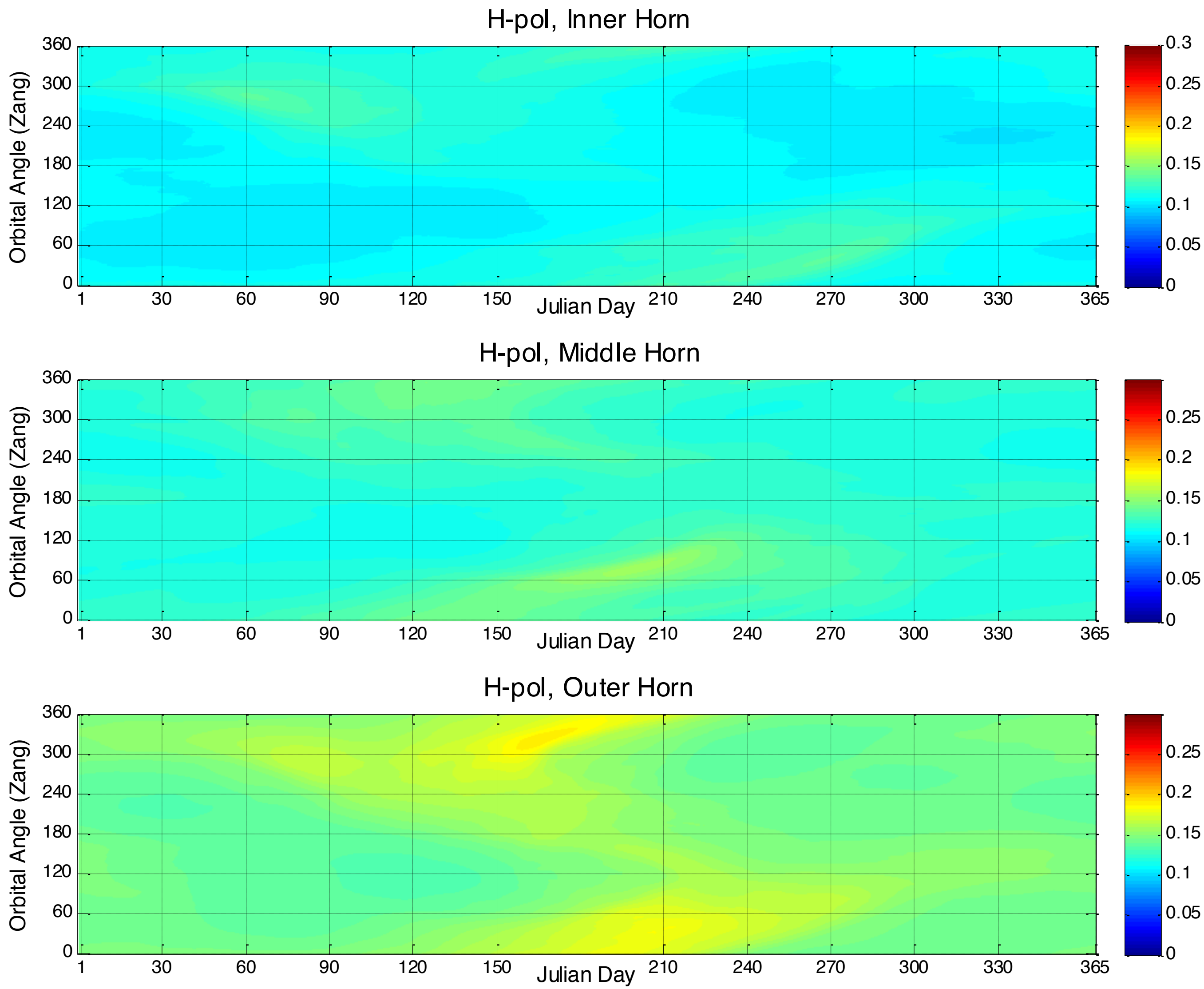
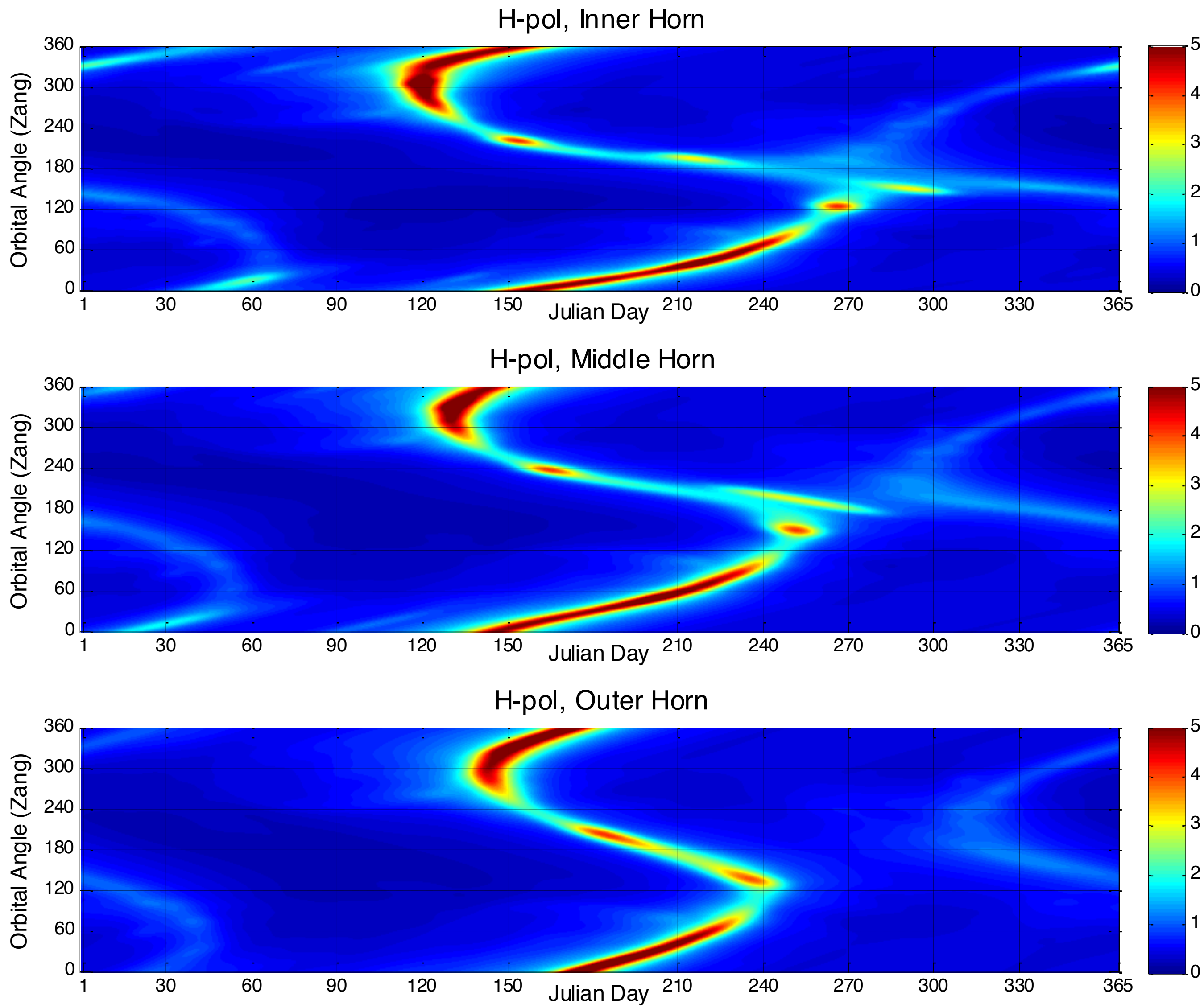
Reflected Solar



Direct Galaxy



Reflected Galaxy (wind=0)



Compute Top-of-Atmosphere T_B

Subtract contributions from sun and galaxy

$$\mathbf{T}_{\mathbf{A},earth} = \mathbf{T}_{\mathbf{A},mea} - \mathbf{T}_{\mathbf{A},sun\_direct} - \mathbf{T}_{\mathbf{A},sun\_refl} - \mathbf{T}_{\mathbf{A},galaxy\_direct} - \mathbf{T}_{\mathbf{A},galaxy\_refl}$$

Disentangle polarization and de-bias incidence angle effects (i.e., the ‘antenna pattern correction ‘)

$$\mathbf{T}_{\mathbf{B,toi}} = \mathbf{A}\mathbf{T}_{\mathbf{A},earth}$$

Where $\mathbf{T}_{\mathbf{B,toi}}$ and $\mathbf{T}_{\mathbf{A}}$ are 3 element vectors and $\mathbf{A}$ is the 3 by 3 APC matrix.

Remove Faraday rotation

$$T_{B,toa}(1) = T_{B,toi}(1)$$

$$T_{B,toa}(2) = \sqrt{T_{B,toi}^2(2) + T_{B,toi}^2(3)}$$

Convert to conventional polarization

$$T_{BV} = \frac{T_{B,toa}(1) + T_{B,toa}(2)}{2}$$

$$T_{BH} = \frac{T_{B,toa}(1) - T_{B,toa}(2)}{2}$$

Compute Surface Brightness Temperature

Remove atmospheric contribution to T_B using NCEP profiles of pressure, temperature, and water
Remove backscattered sun and specularly reflected moon

$$T_{B,sur\downarrow} = T_{B,dw} + \tau T_{B,cosmic}$$

$$T_{B,toa} = T_{B,up} + \tau \left[\varepsilon T_s + (1-\varepsilon) T_{B,sur\downarrow} + \tau T_{B,sun\_scat} + \tau T_{B,moon\_refl} \right]$$

$$\varepsilon = \frac{\dfrac{T_{B,toa} - T_{B,up}}{\tau} - T_{B,sur\downarrow} - \tau T_{B,sun\_scat} - \tau T_{B,moon\_refl}}{T_s - T_{B,sur\downarrow}}$$

$$T_{B,sur} \equiv \varepsilon T_s \qquad \textit{Valid for all surfaces}$$

Remove wind direction effects

$$T_{B,sur,isotropic} = T_{B,sur} - \left[a_1(\theta_i)\cos\phi_r + a_2(\theta_i)\cos 2\phi \right] W$$

Estimation of Sea Surface Salinity (SSS)

$$T_{BP,sur} \equiv T_s E\left(S, T_s, W, \theta_i\right)$$

Regression algorithm trained with simulated data
(Possibly more terms will be added to account for non-linearities)

$$S = a_0\left(T_S, \theta_i\right) + a_1\left(T_S, \theta_i\right) T_{Bv,sur} + a_2\left(T_S, \theta_i\right) T_{Bh,sur} + a_3\left(T_S, \theta_i\right) W$$

- SST and Wind come from best available sources
- Inc. angle knowledge is critical

See: Salinity Error due to Surface Roughness Effects
RSS Memorandum 121504

Compute Expected Antenna Temperature

The only unknown in the retrieval process is salinity.

- Surface brightness temperature is computed using reference salinity
- TOA brightness temperature is computed by adding atmosphere back in
- TOI brightness temperature is computed by applying Faraday rotation
- Earth Antenna temperature is computed by apply the inverse APC (A^{-1})
- Total Antenna temperature is computed by adding in sun and galaxy.

Work to be Done

1. Get Live Simulation Up and Running. August 16

2. Delivery Update L2 code to ADPS. August 30

3. Work on Land Correction Tables and Galaxy Reflection from rough ocean surface.

Backup Slide on Algorithm Performance

SSS Retrieval Performance for 2007 Simulations

The next 4 slides show:
1. Yearly mean salinity field used for the 2007 simulation (truth)
2. Yearly mean difference of retrieved salinity minus true salinity
3. Standard deviation of retrieved weekly salinity minus true weekly salinity
4.Standard deviation of retrieved monthly salinity minus true monthly salinity

Noise added:
1.Realistic NEDT noise added to observations
2.Wind noise is 1 m/s (stddev) and SST noise is 0.5 C (stddev). Both wind and SST noise are correlated over ten 1.44 sec cycles and have a decorrelation length around 50 km. Previous results assume wind noise and SST noise uncorrelated from 1.44 sec cycle to the next. This meant wind and SST noise averaged close to zero on 100 km space scales. The current decorrelation length of 50 km is still probably too short, but it is a step in the right direction of realism.

Color codes:
White is sea ice. It represents the maximum sea ice extent
Light gray denotes land contamination exceeding 0.2%
Dark gray denotes land contamination exceeding 5%.

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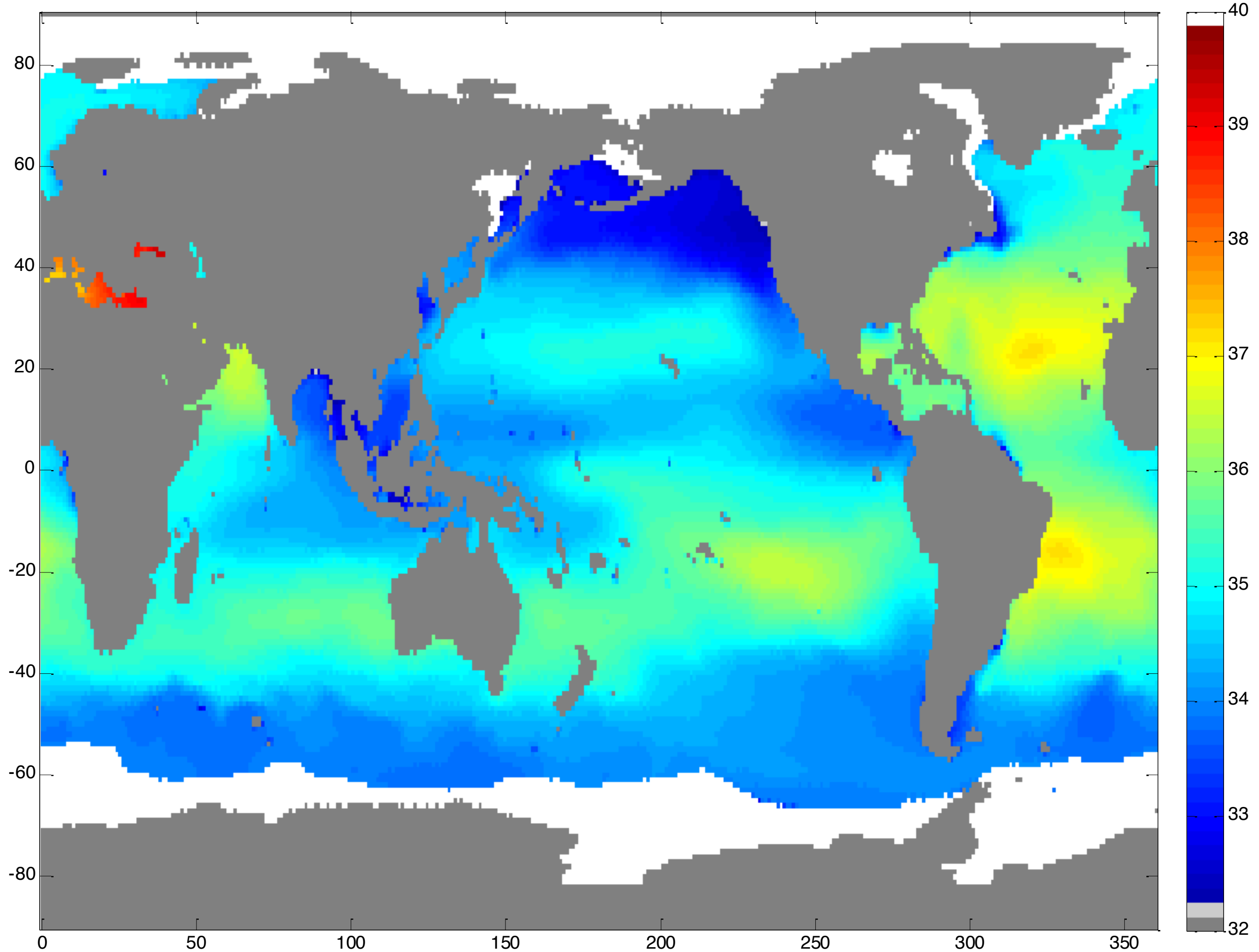

Yearly Mean Salinity Field (truth)

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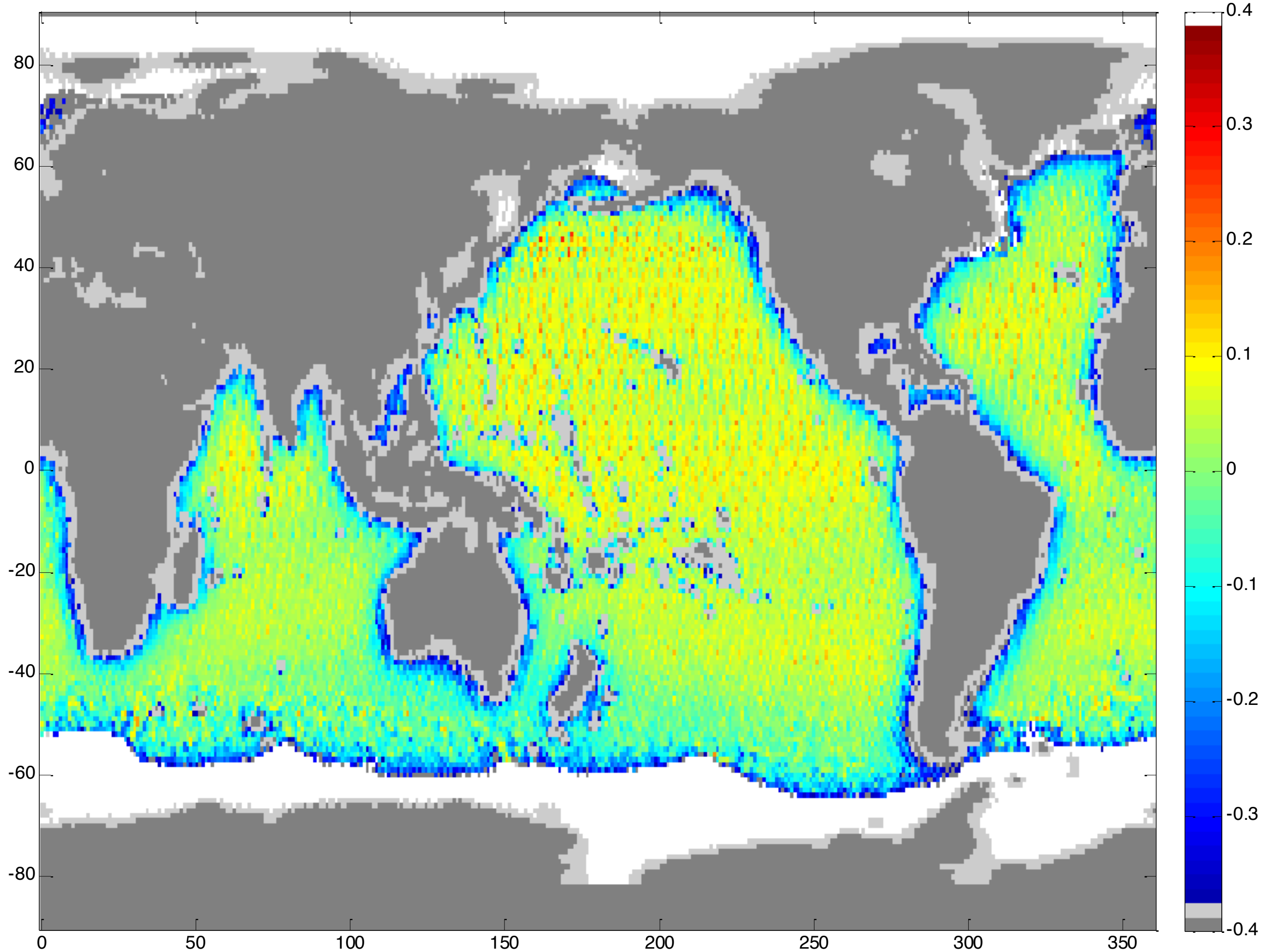
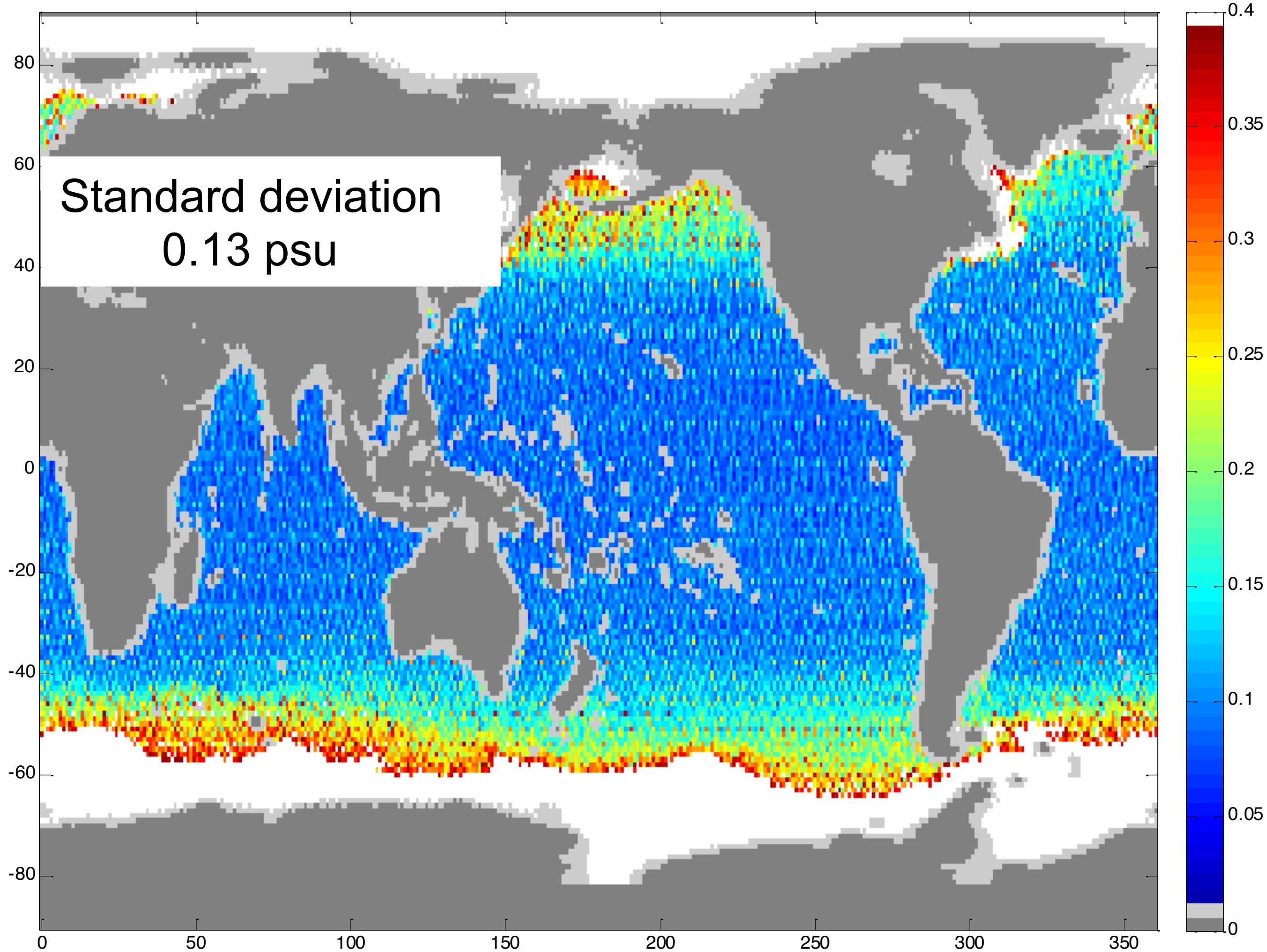


Yearly Mean Difference of Retrieved Minus True Salinity



Standard deviation of retrieved weekly salinity minus true weekly salinity

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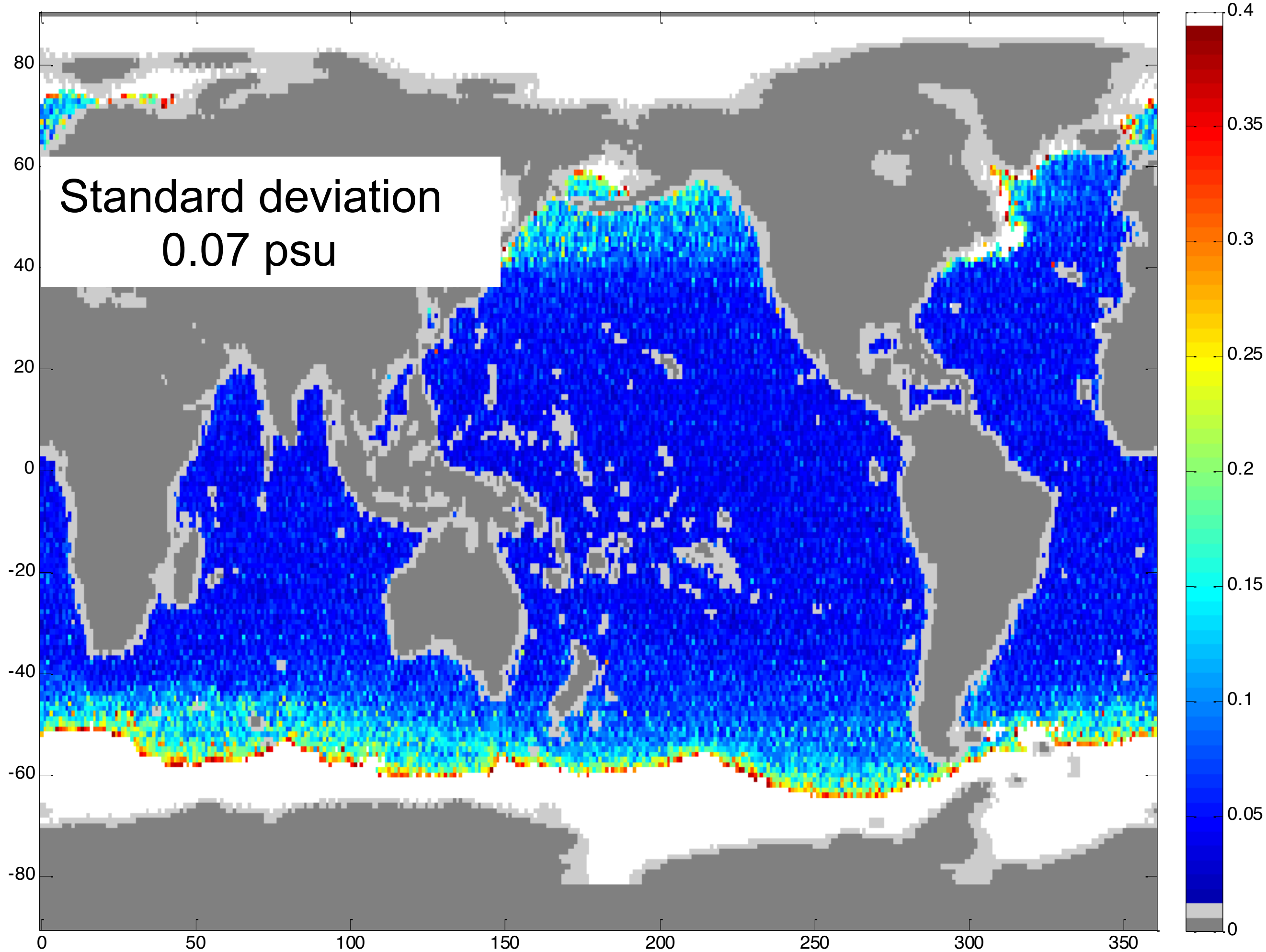

Standard deviation of retrieved monthly salinity minus true monthly salinity

Conclusions

SSS retrieval error reduces from 0.13 to 0.07 psu going from weekly to monthly averages

Simulations verify algorithm performance:

1. Computer Code

2. Given exact knowledge of antenna pattern, APC and Faraday correction work well

3. Given a perfect wind-roughness model (Wise model) and no rain, the algorithm is working well.

4. Land contamination starts at F=0.1%. Fact that standard deviation near land is small suggest that land correction is feasible

Caveats:

- Perfectly calibrated radiometer
- Perfect knowledge of antenna pattern
- No modeling of roughness effect on galactic reflection.
- Perfect geophysical model.
- Optimistic wind error (too random)
- Perfect modeling of rain