Direct Assimilation of Satellite SST Radiances

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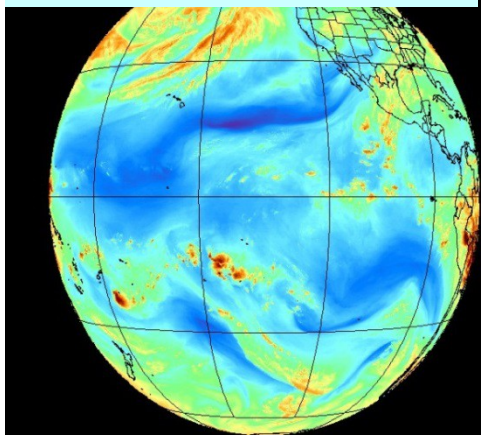
GHRSST XIV Science Team Meeting
Woods Hole Oceanographic Institution
17-21 June 2013

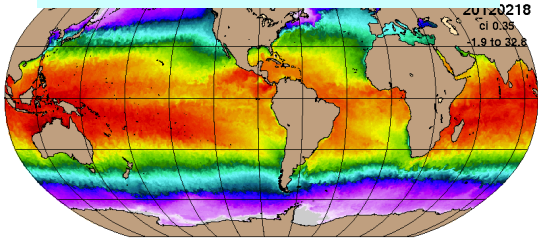
SST Radiance Assimilation: Objectives

- **develop method for direct assimilation of satellite SST radiances using radiative transfer modeling:**
  - incorporate impact of real atmosphere above SST field
  - remove atmospheric signals in SST radiance data
- **incremental approach – requires prior information on variables known to affect satellite SST radiances:**
  - prior atmospheric information (Ta, Qa) from Navy NWP (NAVGEM, COAMPS)
  - prior SST from ocean model

GOES-15 Water Vapor



HYCOM SST Forecast



SST Radiance Assimilation: Implementation

Atmospheric Correction:

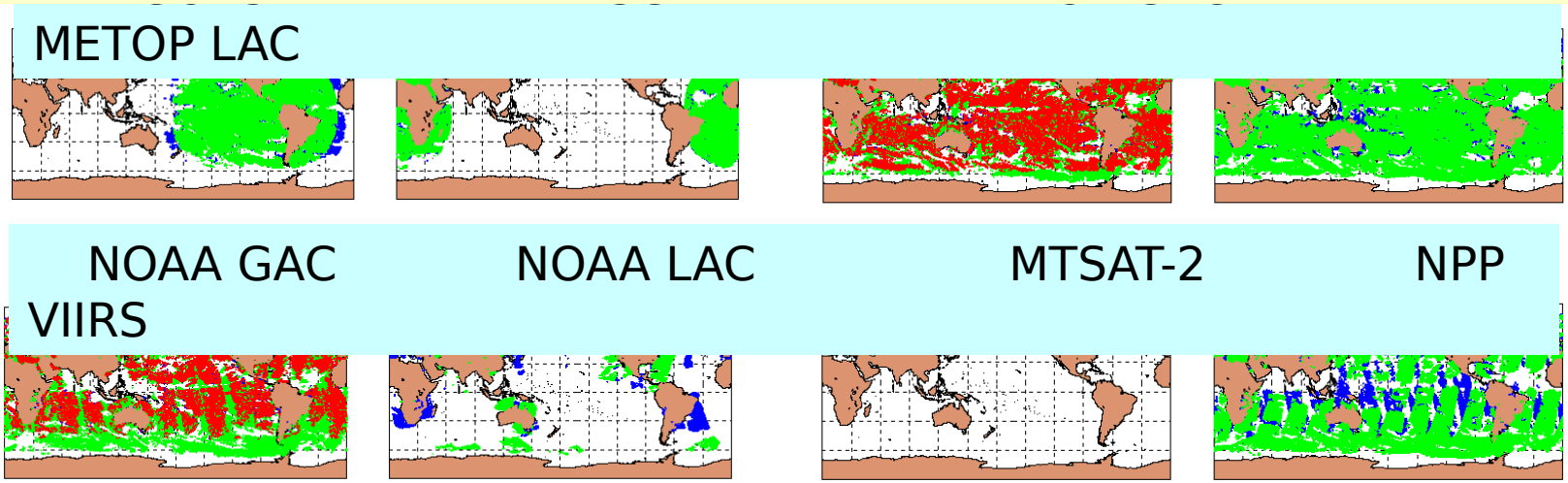
- prior SST is NAVOCEANO SST retrieval
- atmospheric priors (Ta, Qa) from Navy global NWP
- computes “atmospheric correction” to the prior SST
- correction is saved with SST and applied prior to analysis

Variational Analysis:

- prior SST from ocean model forecast (no need for empirical SST retrievals)
- atmospheric priors from NWP model (global or regional) used to force the ocean model
- ideally the NWP and ocean models have evolved in coupled mode (true coupled DA problem)

SST Radiance Assimilation: Observing Systems

Navy Global NWP Model: 13 June 2013 n = 52,411,589



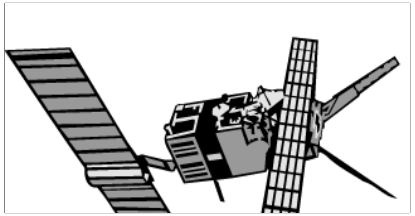
- NAVOCEANO: GOES (13,15), NOAA (18,19), METOP (A,B), NPP-VIIRS
- OSI-SAF: MSG
- NESDIS: MTSAT-2 (not used)

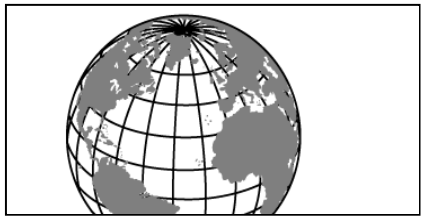
NAVOCEANO SST data include cloud cleared radiances

No radiance data available for MSG & MTSAT-2

Should radiance data be a requirement for L2P?

SST Radiance Assimilation: Observation Operator





SST Radiances (BTs)

Ocean Model SST

NWP Fields

Calibration, QC, Cloud Clearing

CRTM Forward Model: TOA-BTs

Compute Differences: δBTs

SST Radiance Monitoring

SST Inverse Model: δSST

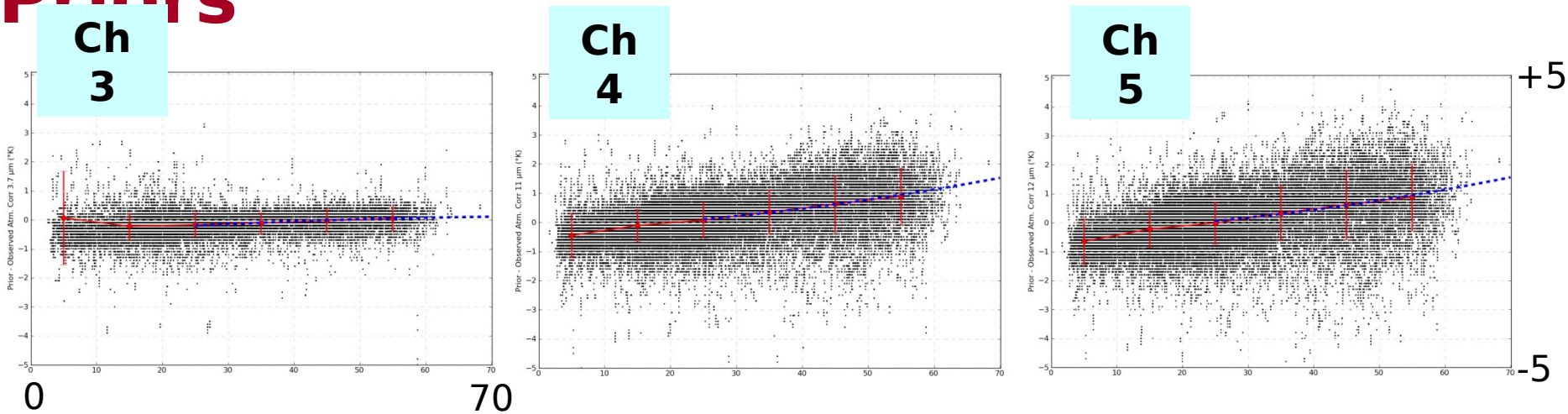
CRTM Jacobians (∂Tb/∂x)

Other Observations: T,S,U,V

3DVAR Minimization

Observation & First Guess Errors

Bias Correction: Navy NWP Priors

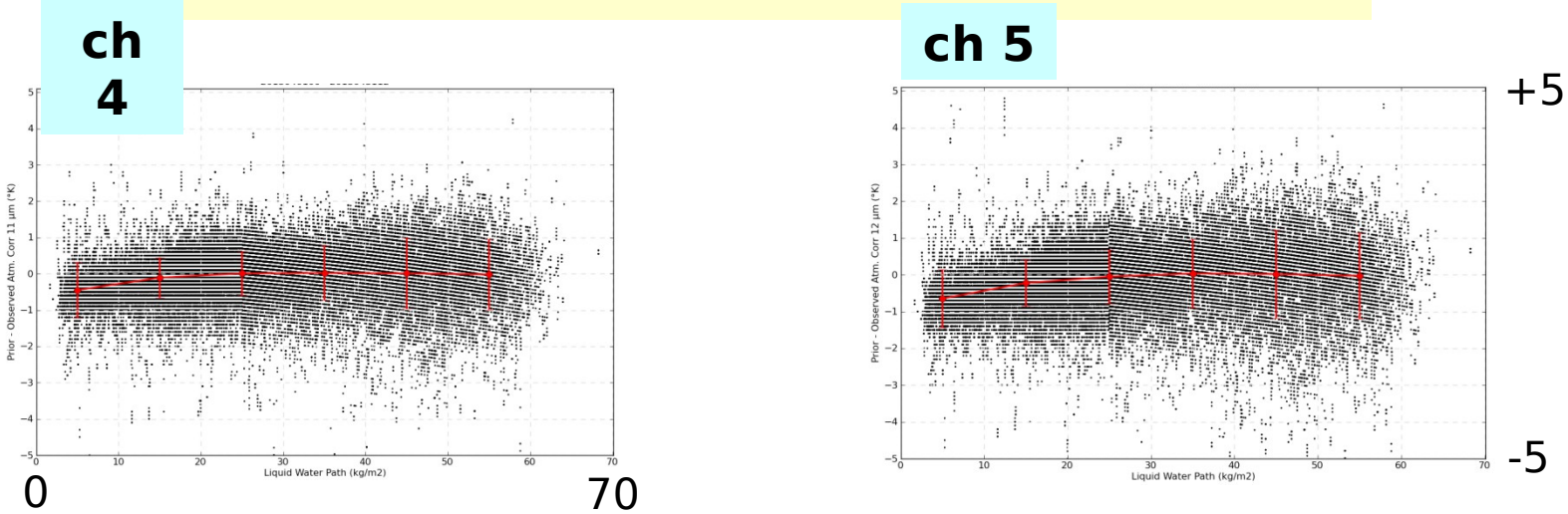


Prior minus Observed Corrections vs. NAVGEM Liquid Water Path
(NAVO_SST – CRTM_BT) - (BUOY_SST – METOP_BT)

- prior corrections are increasingly greater than observed as water vapor content increases (channel 3 not affected)
- bias a result of NWP water vapor profiles being too moist in what otherwise should be cloud free areas based on satellite data
- bias detection and corrections based on April 2013 NAVO buoy match-up database for METOP-A

Bias Correction: Navy NWP Priors

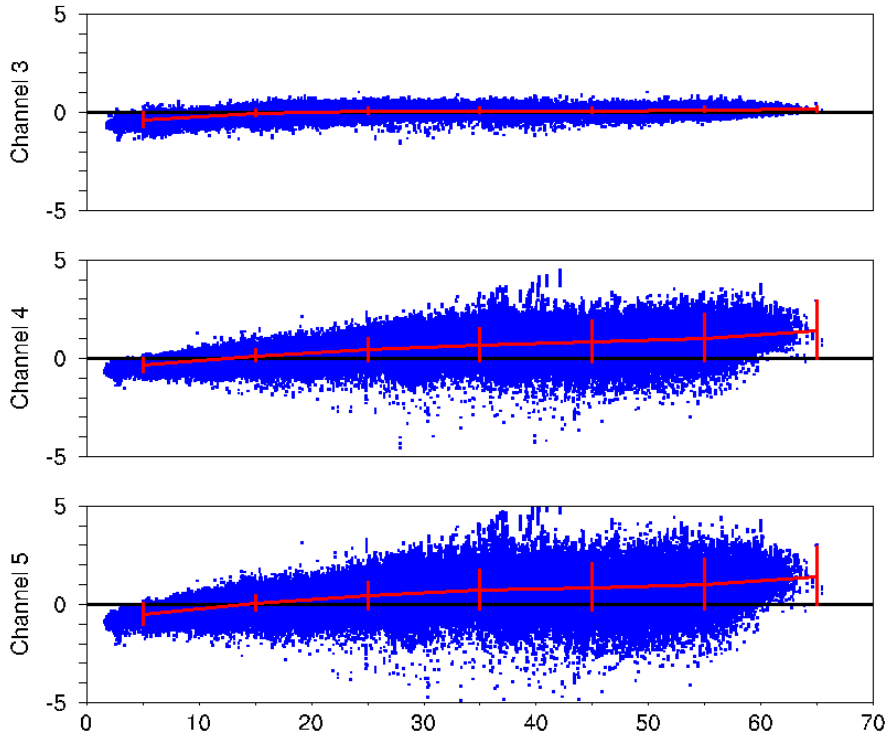
After NAVGEM water vapor bias correction

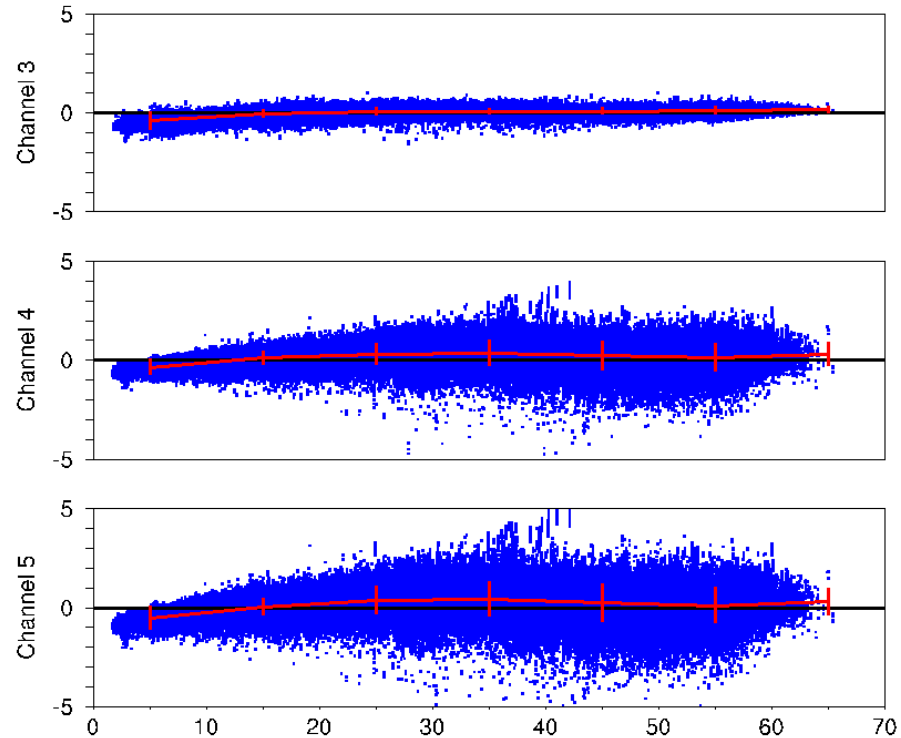


- bias correction minimizes differences across channels simultaneously
- bias parameters updated daily:
  - 30-day sliding time window of NAVO buoy match-up data
- automated updating scheme captures changes in water vapor distribution of NAVGEM model and NAVDAS 4DVAR assimilation

CRTM Forward Model: METOP-A

s Corrected Prior





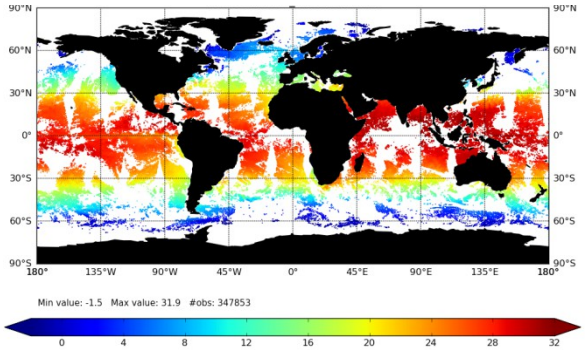
Liquid Water Path kg/m2

Liquid Water Path kg/m2

METOP-A minus CRTM simulated TOA-BT:

δBT innovations

1 May 2013



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SST Inverse Model

Computes SST correction (δTsst) given TOA BT innovations (δBT) and CRTM Jacobians (J):

$$\begin{bmatrix} \delta BT \cdot J_{sst} \\ \delta BT \cdot J_t \\ \delta BT \cdot J_q \end{bmatrix} = \begin{bmatrix} \varepsilon_{sst} + J_{sst} \cdot J_{sst} & J_{sst} \cdot J_t & J_{sst} \cdot J_q \\ J_t \cdot J_{sst} & \varepsilon_t + J_t \cdot J_t & J_t \cdot J_q \\ J_q \cdot J_{sst} & J_q \cdot J_t & \varepsilon_q + J_q \cdot J_q \end{bmatrix} \begin{bmatrix} \delta T_{sst} \\ \delta T_a \\ \delta Q_a \end{bmatrix}$$

Requires specification of prior error statistics:

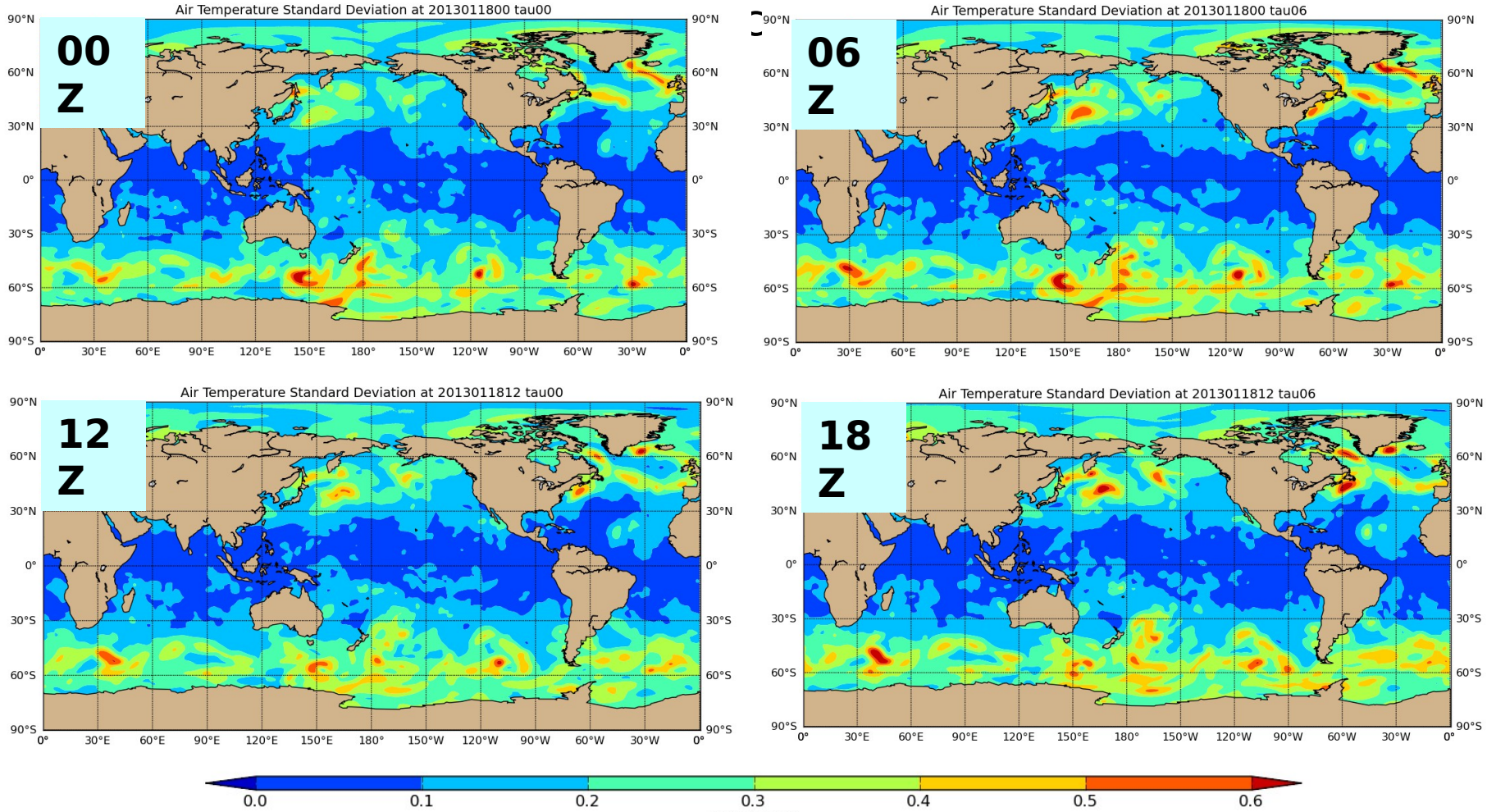
- air temperature: εt
- specific humidity: εq
- sea surface temperature: εsst
- satellite BTs + radiometric error: εbt

δBT innovations are partitioned into δTsst , δTa , δQa corrections based on the error statistics

SST Inverse Model: Prior Errors

NOGAPS Ensemble: Air Temperature 18 Jan 2013

Situation Dependent Uncertainty of

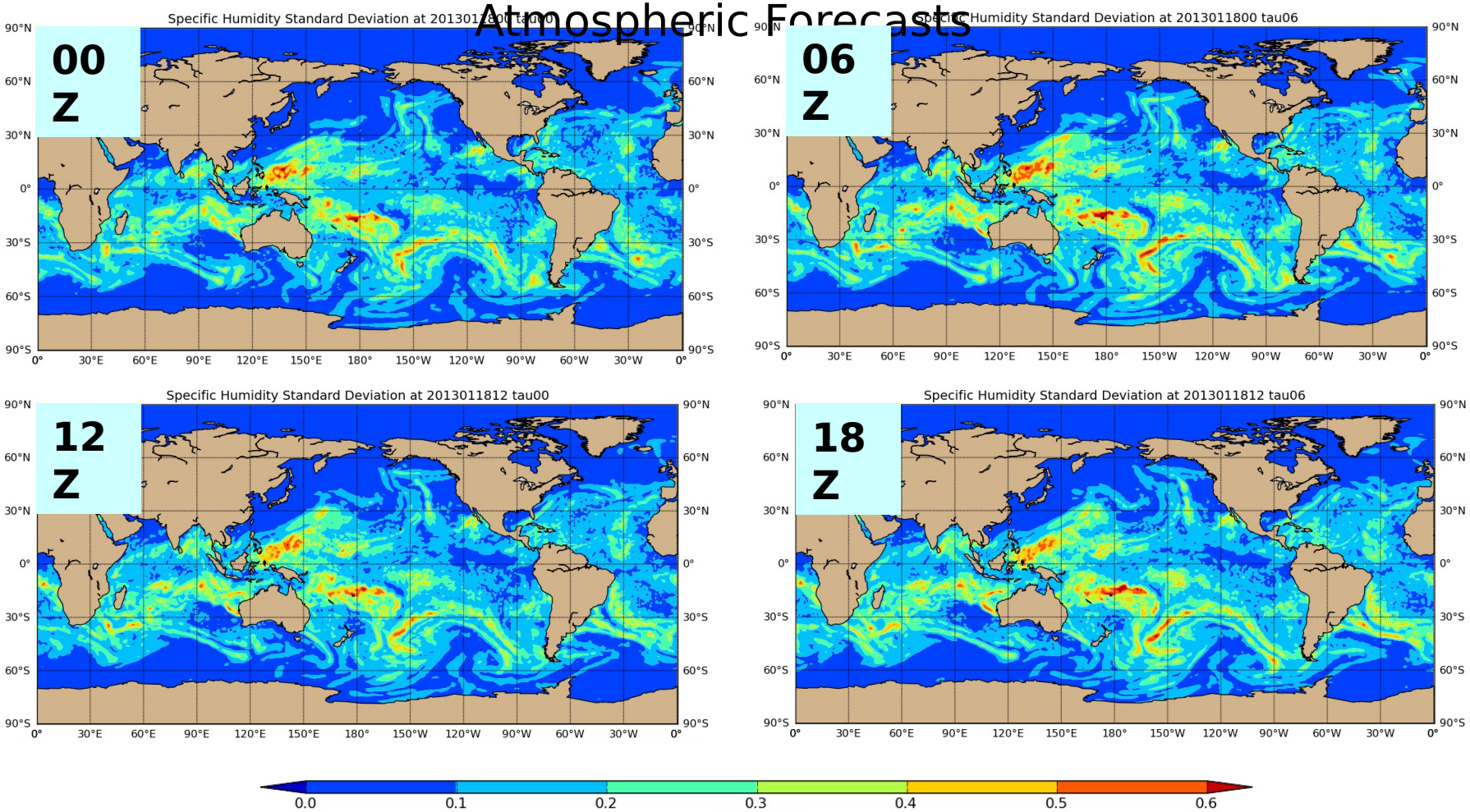


Standard Deviation

SST Inverse Model: Prior Errors

NOGAPS Ensemble: Specific Humidity 18 Jan 2013

Situation Dependent Uncertainty of Atmospheric Forecasts

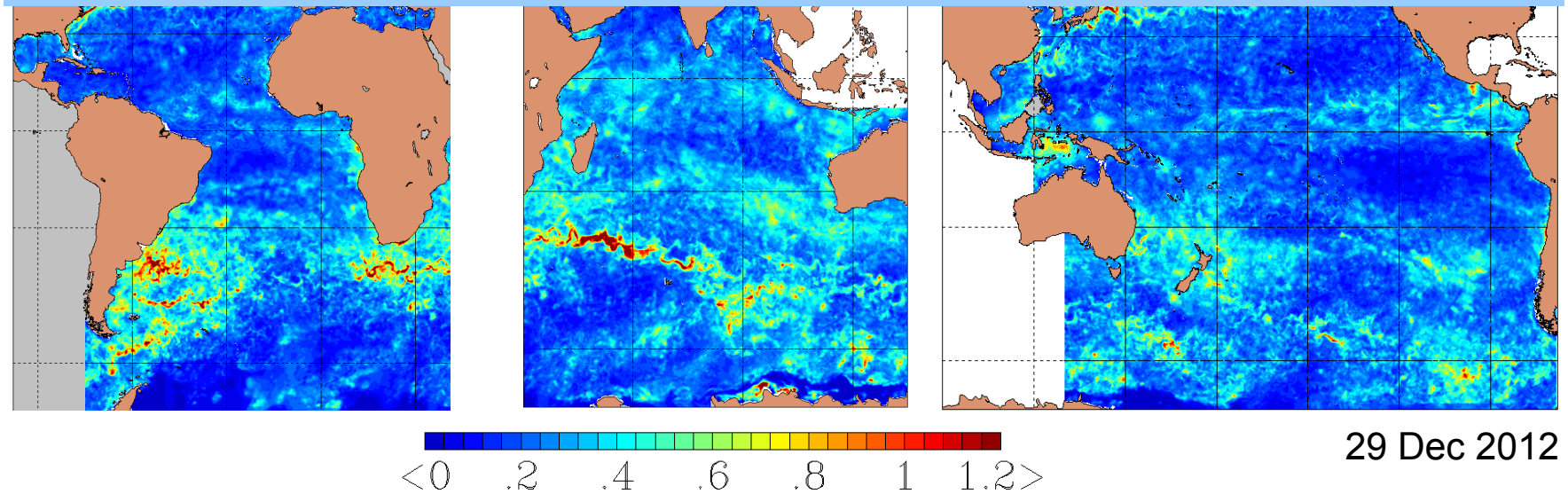


SST Inverse Model: SST Errors

Atm Correction Option: SST Errors from Buoy Matchups

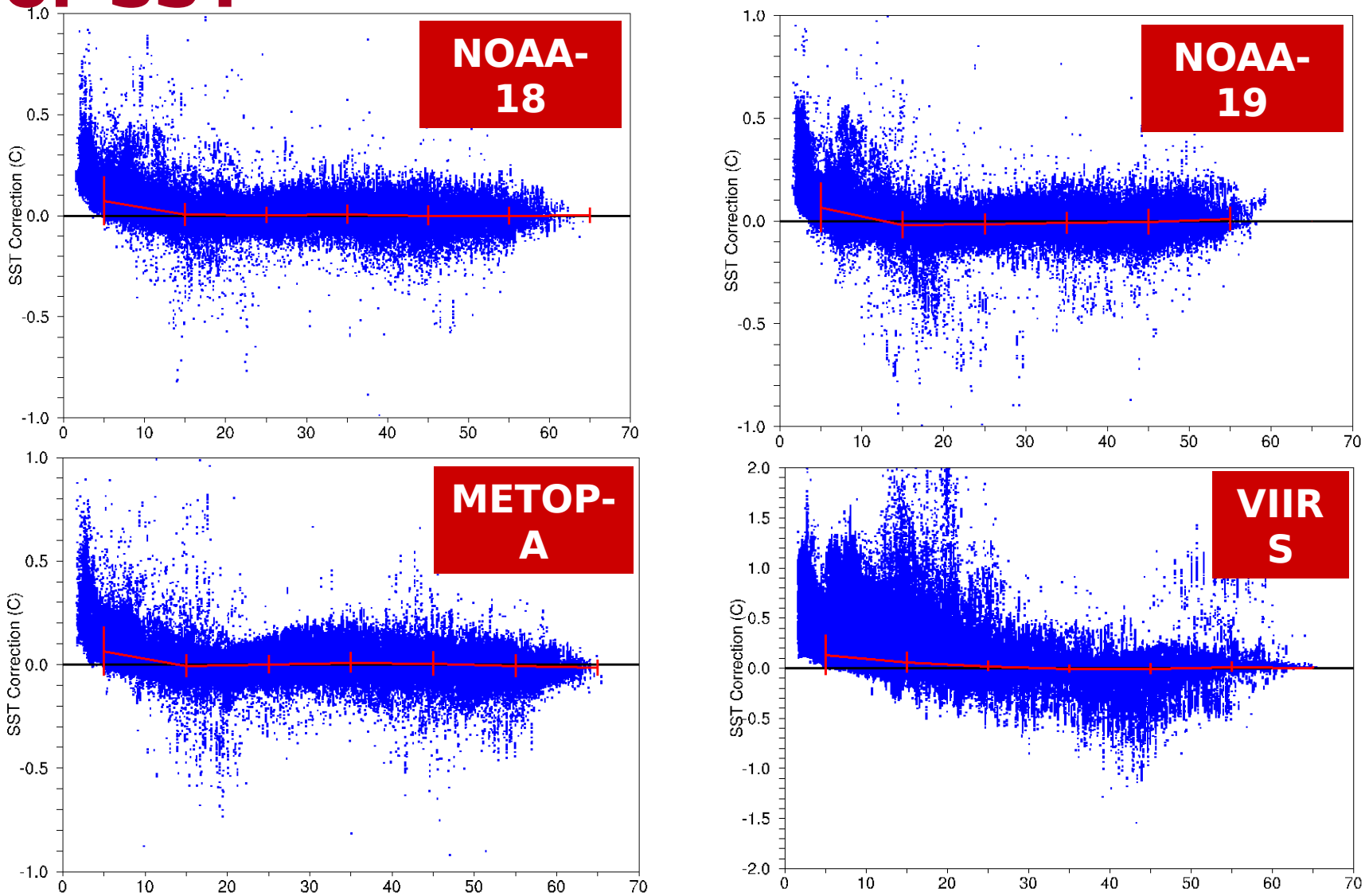
	NOAA-18	NOAA-19	METOP-A	GOES-13	GOES-15	VIIRS
Day	0.416	0.461	0.433	0.989	0.612	0.522
Night	0.440	0.411	0.395	0.587	0.544	0.405
Rlx	0.494	0.463	0.459	-	-	-

3DVAR Option: SST Errors from HYCOM Forecast



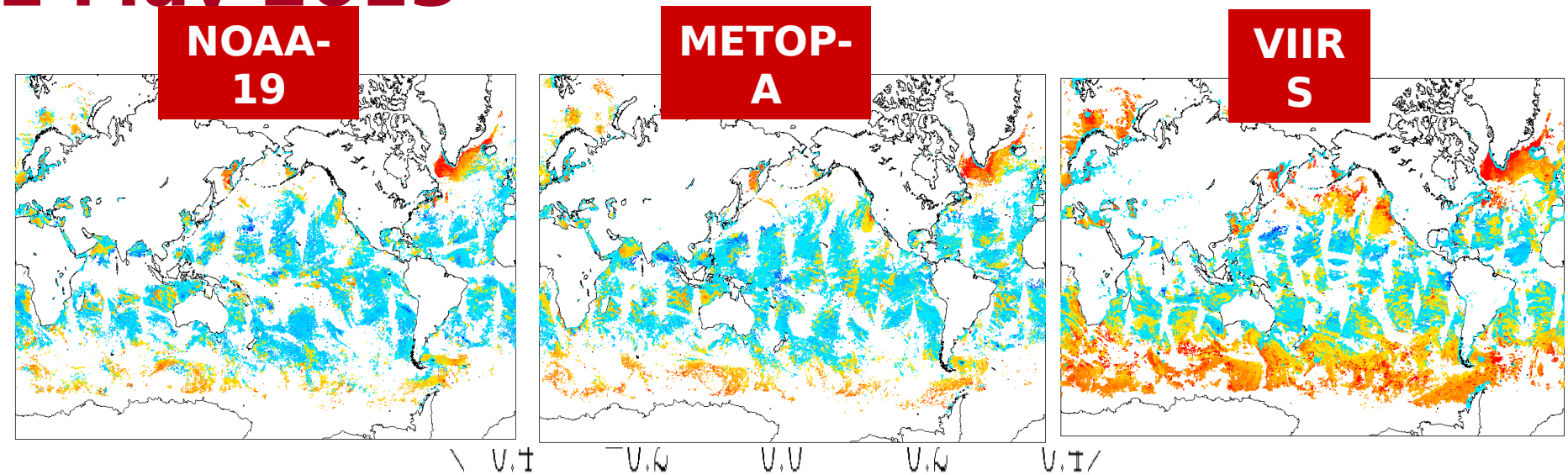
29 Dec 2012

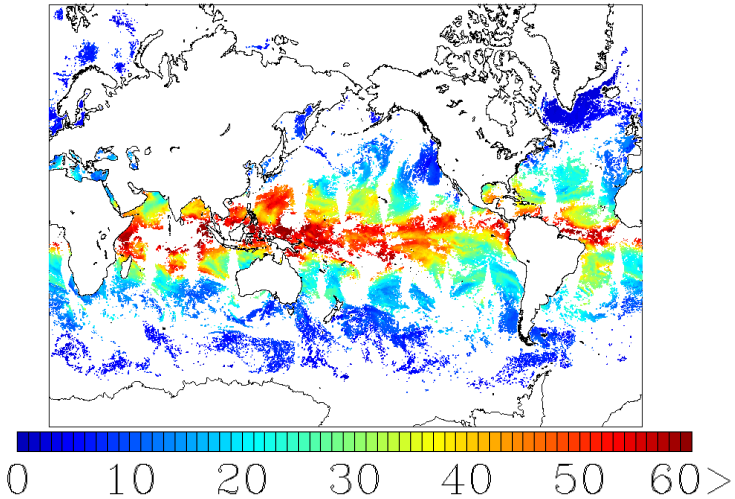
SST Corrections: NAVO prior SST



δTsst vs. Liquid Water Path — 1 May 2013

SST Corrections: NAVO prior SST - 1 May 2013





NAVGEM Water Vapor at METOP-A Locations

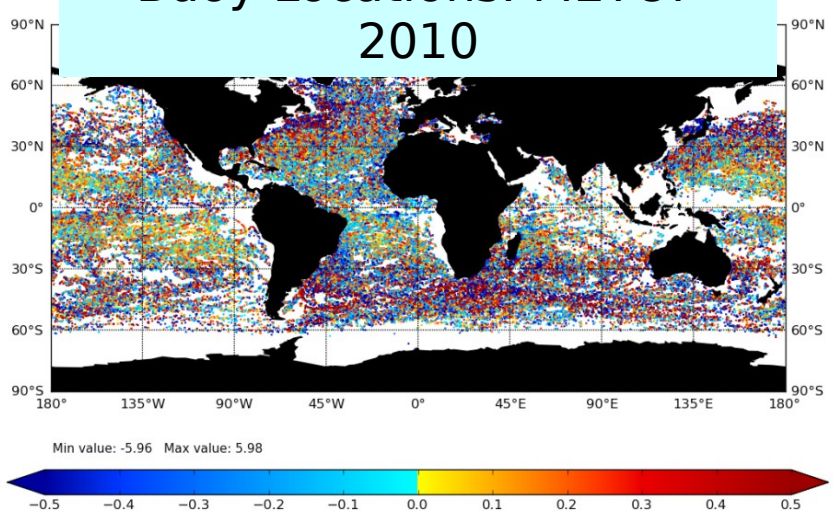
- large positive SST corrections at high latitudes where atmosphere is dry
- globally defined NAVO SST empirical retrieval algorithm is biased in certain regimes of application
  - drifting buoy network limited at high latitudes

SST Radiance Verification: ESA CCI

Mean Error of Prior and Corrected SST vs. Drifting Buoys

- METOP radiances
- NWP priors from ECMWF (Ta, Qa)
- SST prior from UKMO

Buoy Locations: METOP 2010



Month	Count	Prior Error	Correct Error
Jan	12,074	-0.030	-0.004
Feb	11,577	-0.023	0.001
Mar	12,218	0.064	0.031
Apr*	12,218	-0.003	0.021
May	13,354	-0.028	-0.002
Jun	12,269	-0.058	-0.032
Jul	14,016	-0.048	-0.024
Aug	13,401	-0.048	-0.025
Sep*	13,237	-0.009	0.013
Oct	11,986	-0.021	0.004
Nov	11,547	-0.052	-0.025
Dec	11,941	-0.058	-0.031

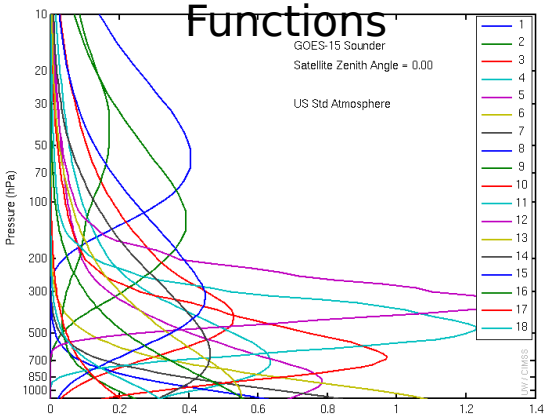
*error corrected SST > error prior SST

METOP 2010 Data Count	Error Prior SST	Error Corrected SST	Per Cent Improvement
149,383	-0.0314	-0.0062	80.2%

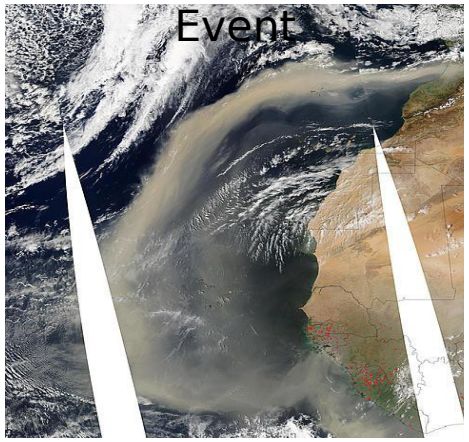
SST Radiance Assimilation: Future Capabilities

- **Improve Navy NWP lower boundary condition:**
  - atmosphere correction removes temporal inconsistencies in NAVO SST retrievals
  - allows use of surface sensitive sounding channels in atmospheric 4DVAR
- **Extend method to MW sensors and ice covered seas:**
  - corrections for both sea surface and ice surface temperatures
  - some progress using VIIRS IST EDR as prior
- **Include NAAPS aerosols as prior information in forward and inverse models:**
  - dust is optically active in infrared - creates cold bias when present

GOES-15 Channel Weighting Functions



Saharan Dust Event



Questions?