Impact of assimilating humidity sounder radiances with the NICAM-LETKF system

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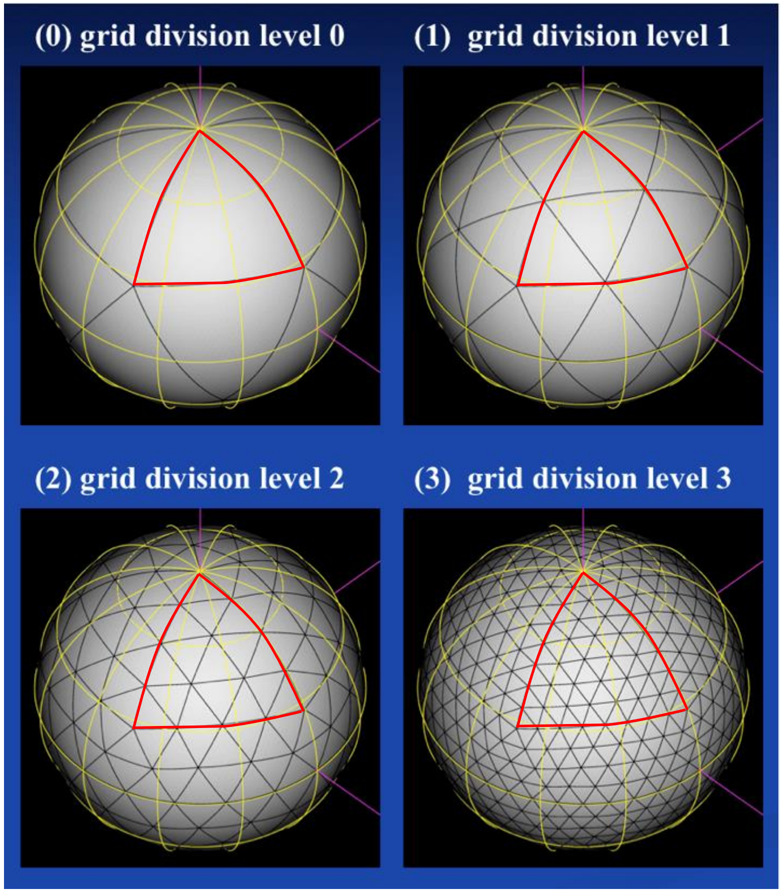
1: Indian Institute of Technology Madras

2:RIKEN, Advanced Institute for Computational Science

NICAM: Non-hydrostatic ICosahedral Atmospheric Model

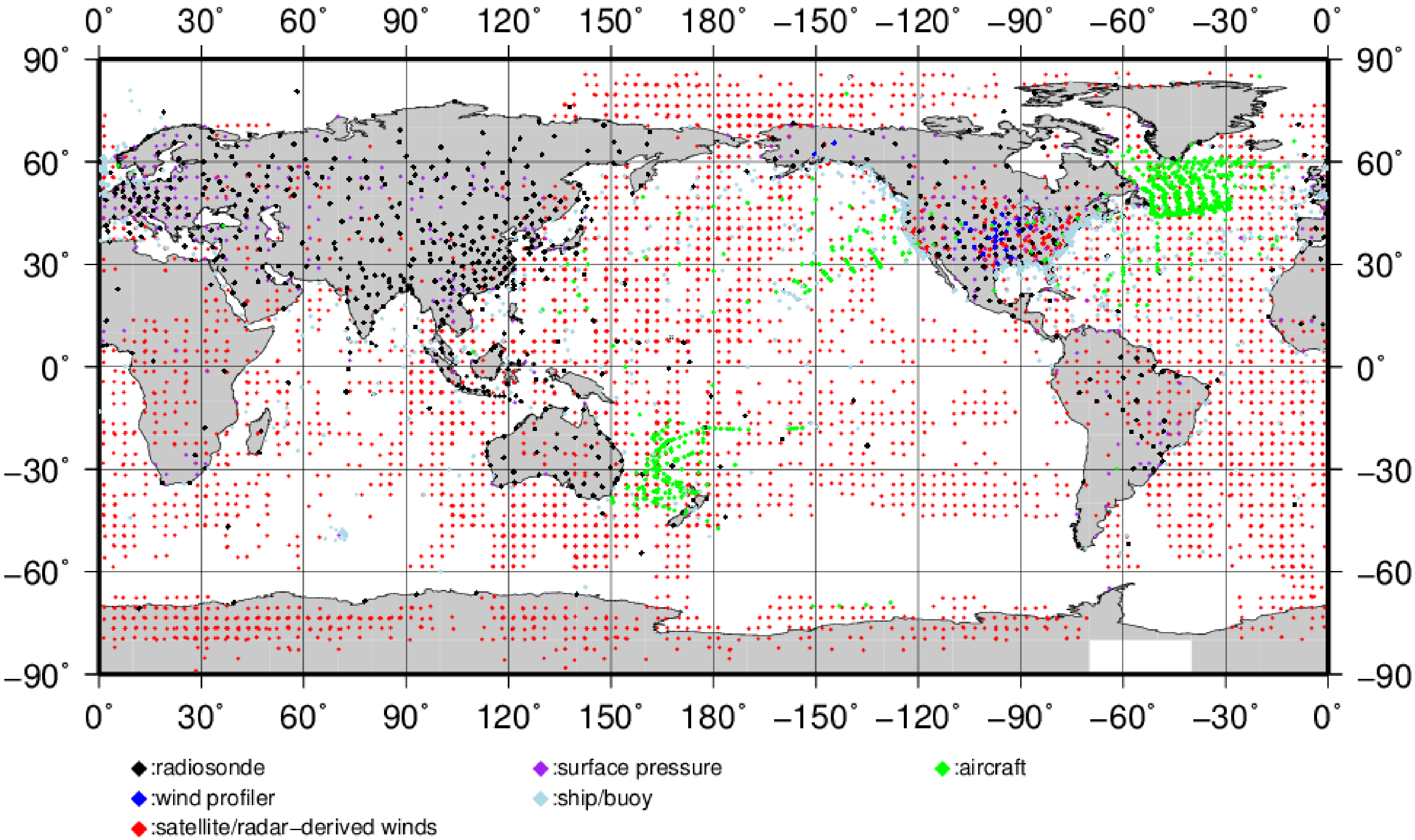
Grid division level 0 is the original Icosahedron.
The horizontal resolution can be increased by splitting one triangle into four triangles.

Grid division level	Horizontal resolution
6	112 km
7	56 km
8	28 km
9	14 km
10	7 km
11	3.5 km
12	1.7 km
13	0.87 km



Conventional observations (NCEP PREPBUFR)

6 hourly observation

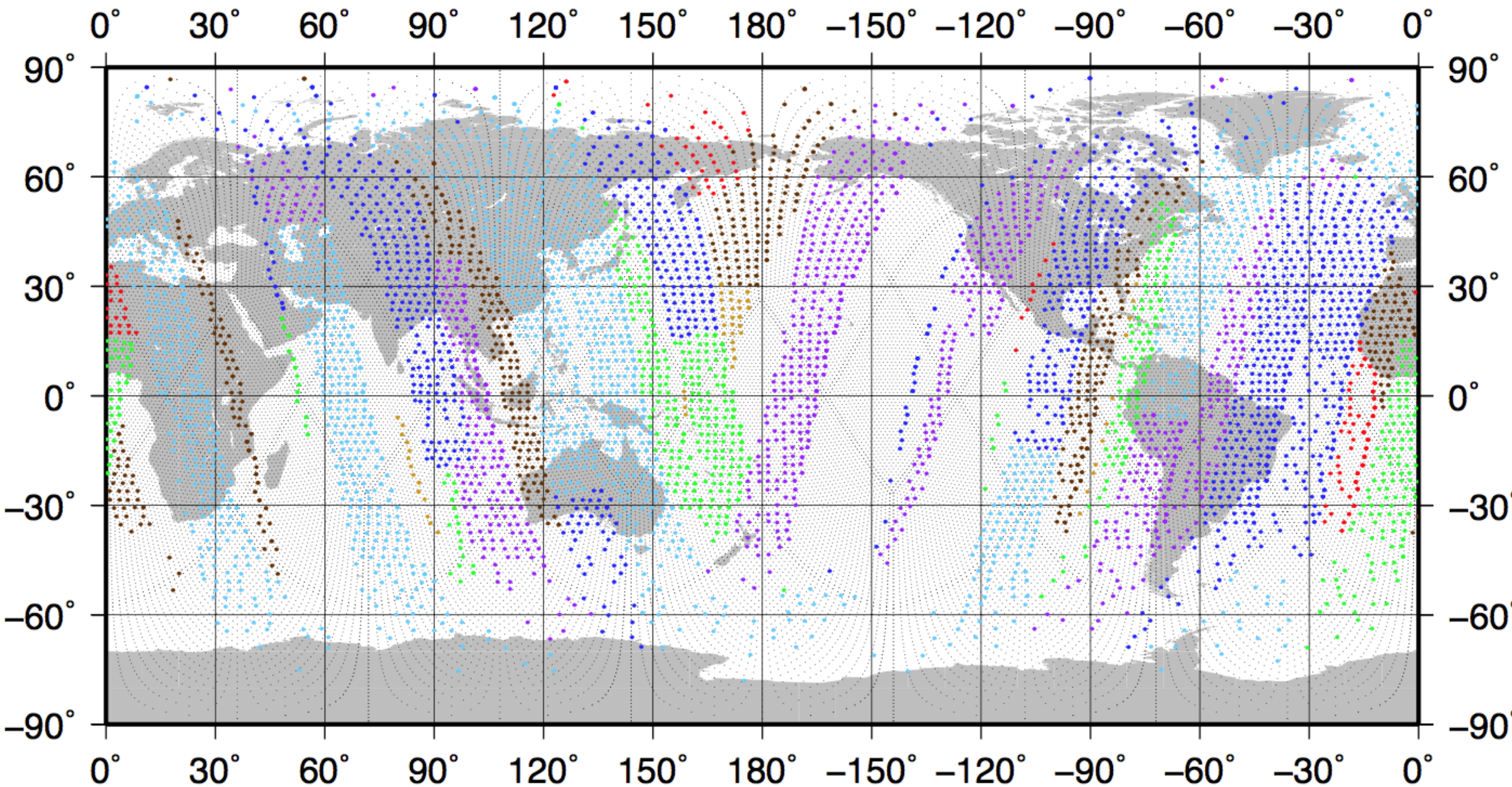


K computer

AMSU-A (after thinning)

Thinning distance: 250km

NOAA-15, 16, 18, 19
6 hourly observation



Different colors show the observations at different time slot

Bias correction

airmass bias

scan bias

$$\mathbf{y} - \mathbf{H}\mathbf{x}^f - \mathbf{p}^T\boldsymbol{\beta} - \boldsymbol{b_{scan}}$$

K computer

Estimating airmass bias

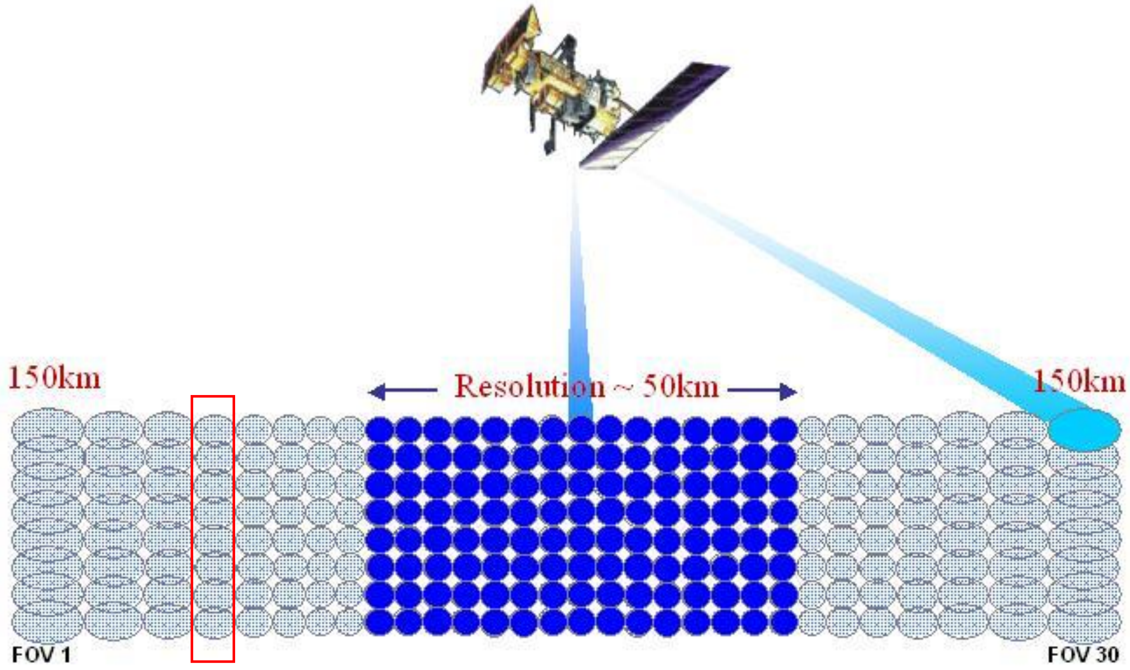
Ensemble-based variational bias correction method

$$\delta\boldsymbol{\beta} = \left(\mathbf{B}_\beta^{-1} + \mathbf{p}\mathbf{R}^{-1}\mathbf{p}^{\mathrm{T}}\right)^{-1}\mathbf{p}\mathbf{R}^{T}(\mathbf{y} - \mathbf{H}\overline{\mathbf{x}^{a}} - \mathbf{p}^{T}\boldsymbol{\beta})$$

Predictor
Integrated weighted lapse rate (1000-200 hPa)
Integrated weighted lapse rate (200-50 hPa)
Surface temperature
Satellite zenith angle

Estimating scan bias

$$b_t^{scan_{new}}(n) = \alpha b_{t-1}^{scan}(n) + (1-\alpha)\left(b_t^{scan_{est}}(n) - b_{t-1}^{scan}(n)\right)$$



AMSU Scanning Geometry and Resolution

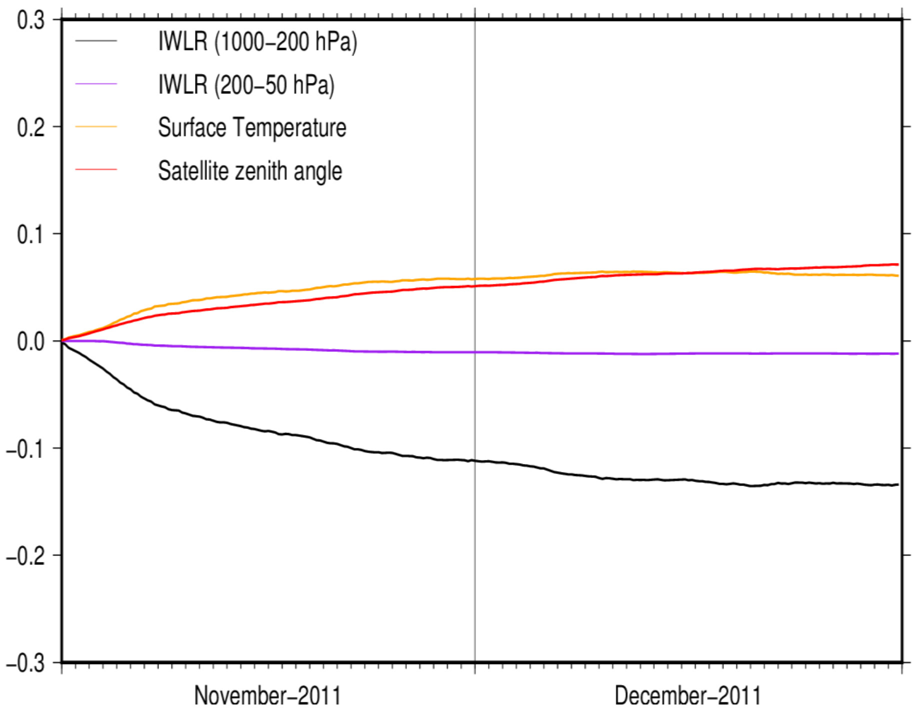
(http://tropic.ssec.wisc.edu/real-time/amsu/explanation.html)

- AMSU-A observations have different biases at each scan position
- Estimating scan bias from the innovation statistics

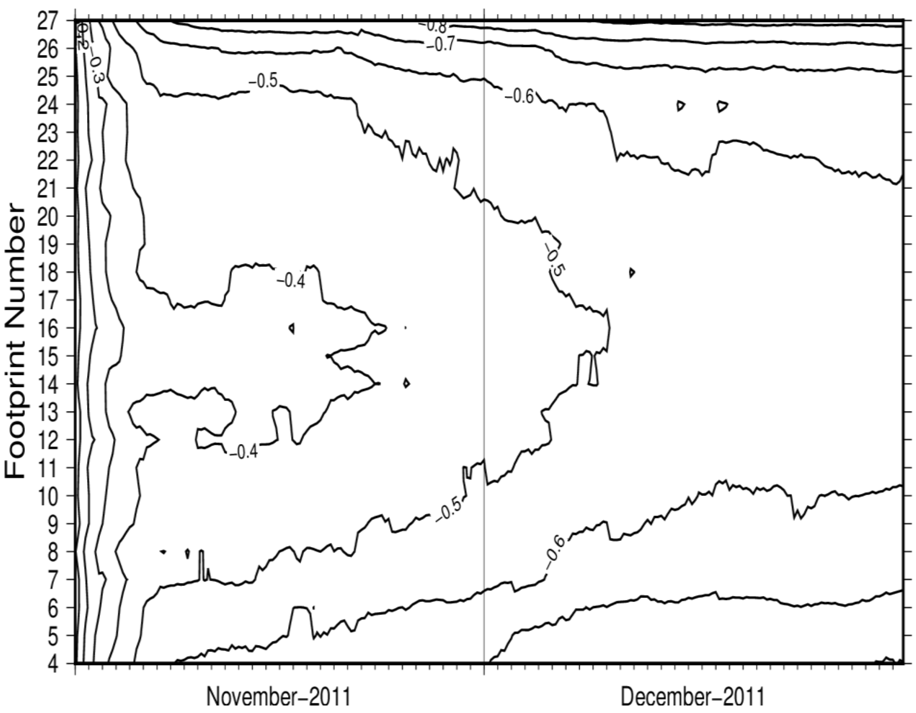
Estimated bias

Ch. 6 of NOAA-18

Coefficients of airmass bias

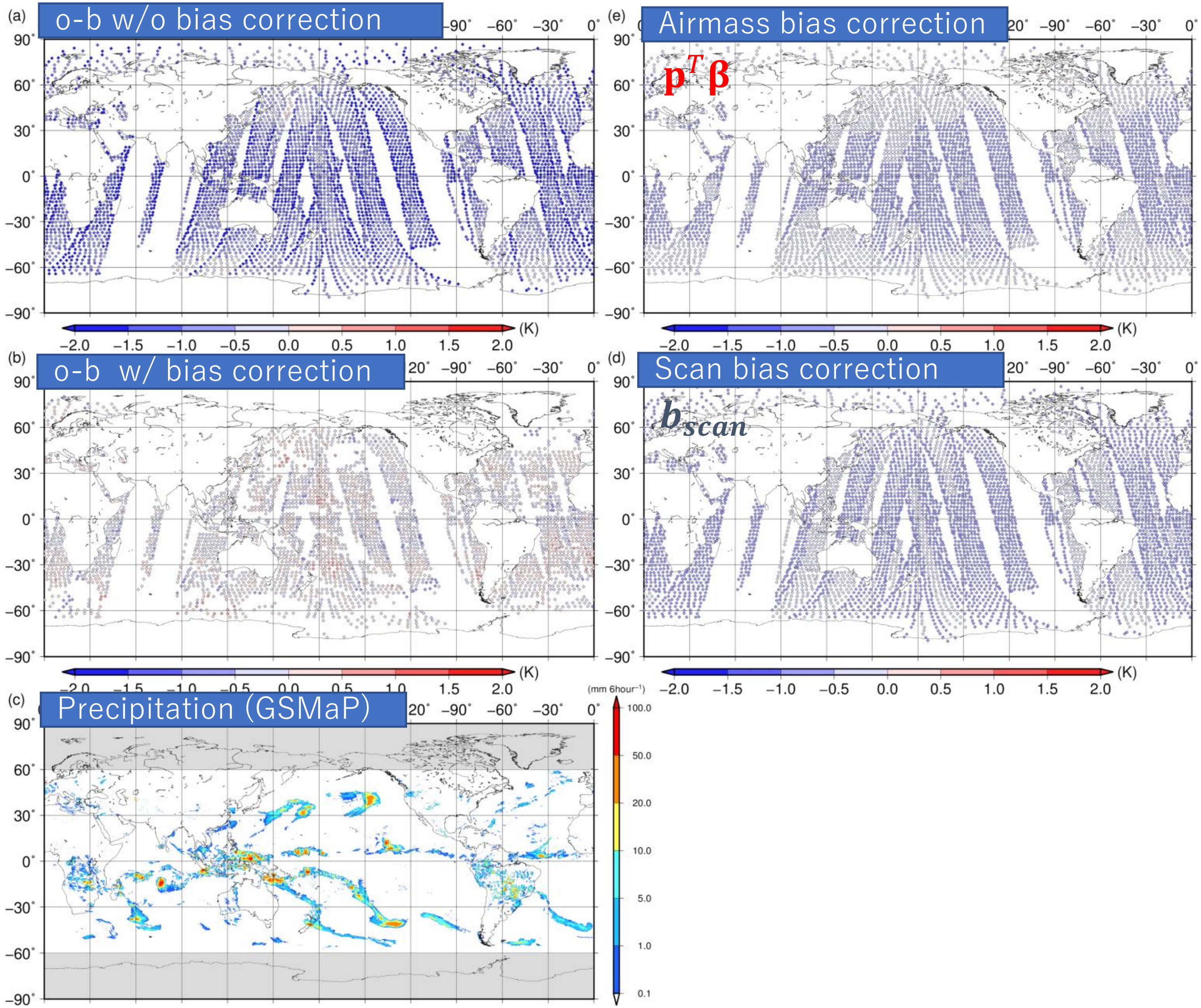


scan bias



o-b (AMSU-A)

$$\mathbf{y} - \mathbf{H}\mathbf{x}^f - \mathbf{p}^T\boldsymbol{\beta} - b_{scan}$$



K computer

Global RMSD for temperature (vs. ERA-interim)

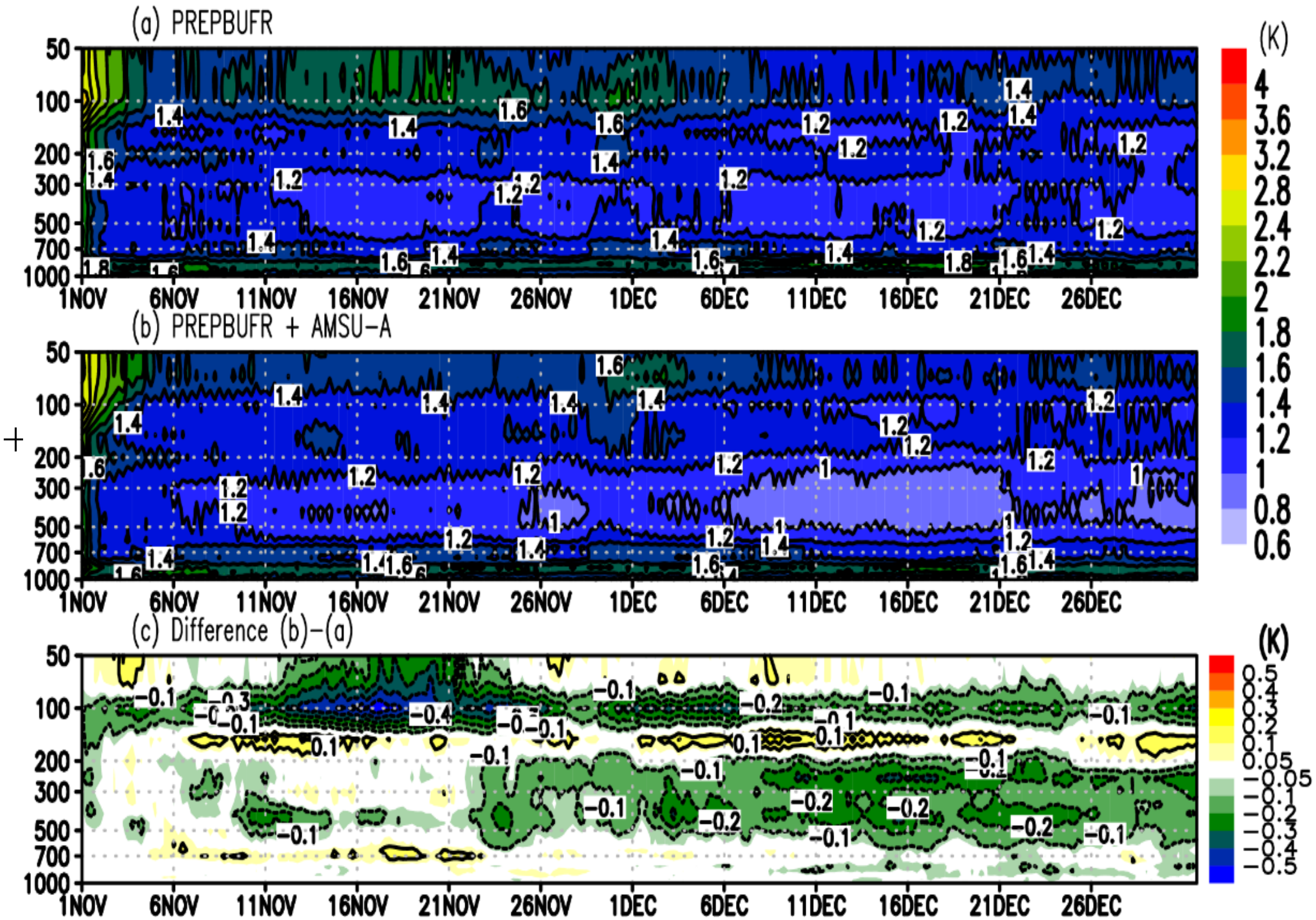
2 months (00Z 01 Nov. 2011 – 18Z 31 Dec. 2011)

Ensemble size = 40

Only PREPBUFR

PREPBUFR+ AMSU-A

Difference



better

Summary

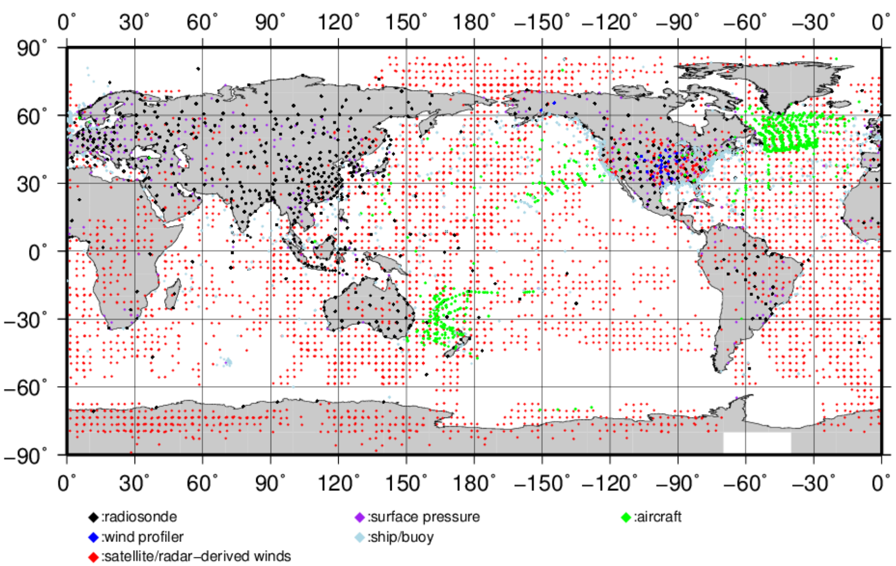
- Terasaki et al. (2015) introduced NICAM-LETKF systems
  - Assimilating only conventional observations (NCEP PREPBUFR)

- Assimilating satellite observations (AMSU-A)
  - Developing the observation operator for satellite radiances with RTTOV
  - Adaptively estimating the airmass and scan biases
  - Analysis becomes more accurate in the troposphere

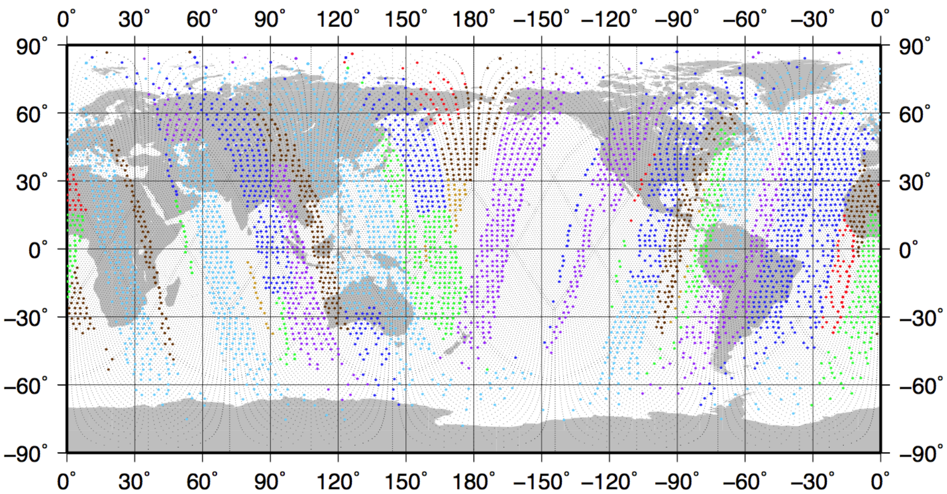
Why Humidity Sounder?

- AMSU-A radiances are sensitive to temperature.
- There are a few observations of humidity over ocean.
- It is expected to have a positive impact on the humidity analysis by assimilating humidity sounder in the NICAM-LETKF system

Conventional observations



AMSU-A



Data Assimilation Team

Impact of assimilating humidity sounder radiances with the NICAM-LETKF system

Krishnamoorthy Chandramouli

Indian Institute of Technology Madras, India.

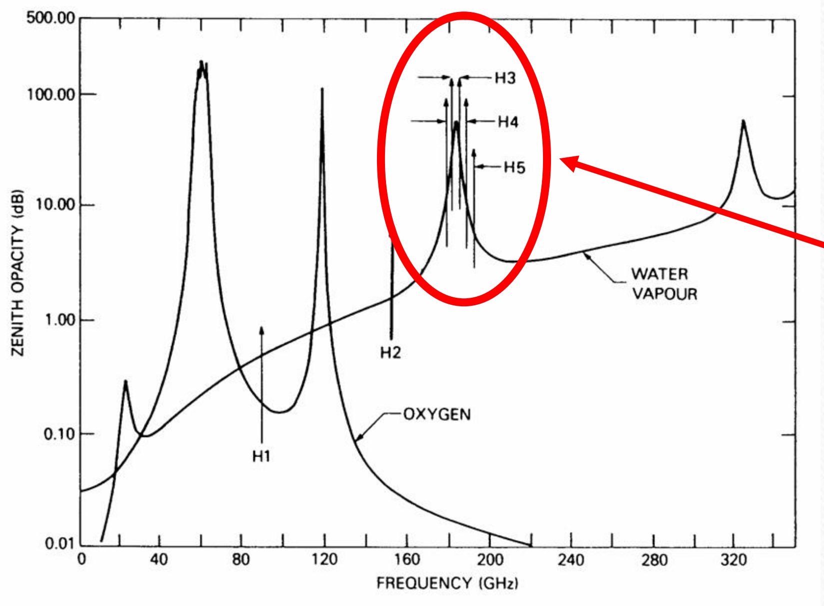
Intern supervisor : **Koji Terasaki**

AICS RIKEN, Kobe, Japan.

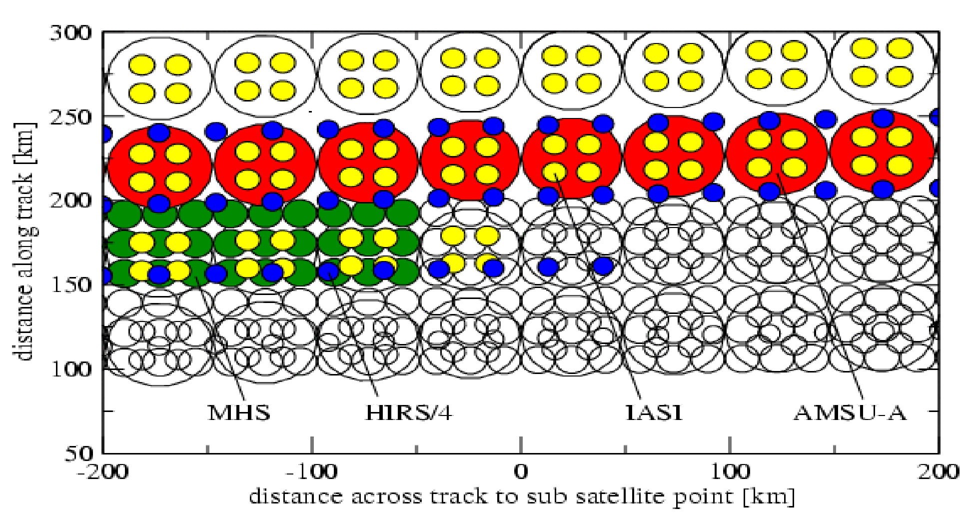
Introduction

- Miyoshi et al. (2010)
  - Compared LETKF and 4D-Var using JMA global model.
  - Developed the adaptive bias correction for satellite radiances.
  - Showed LETKF and 4D-Var have comparable performance.
- Better handling of satellite observations for operational use of LETKF
- Terasaki et al. (2015)
  - Implemented LETKF with NICAM (Assimilating only PREPBUFR data)
  - Direct use of NICAM icosahedral grid (ICO-LETKF).
  - .ICO-LETKF showed overall acceleration in computation.
- Terasaki and Miyoshi (2017)
  - Assimilated AMSUA radiances with the NICAM-LETKF system.
  - Online estimation of scan and air-mass bias for radiance observations.
  - Showed considerable improvement in the analysis.
- Goal : To assimilate MHS radiances with the NICAM – LETKF system

MHS Characteristics



Instrument	IFOV type	IFOV size	Sampling interval (across-track)	IFOV size (nadir)	Samples per scan line	Scan separation	Swath width
		(deg)	(deg)	(km)		(km)	(km)
AMSU-A	circular	3.3	3.33	47.63	30	52.69	±1026.31
MHS	circular	1.1	1.11	15.88	90	17.56	±1077.68



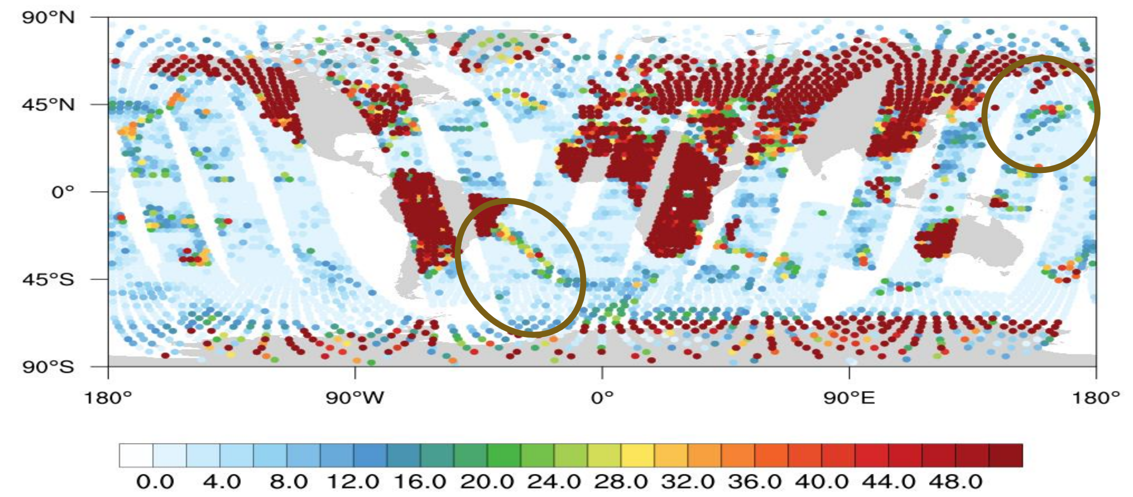
Courtesy: EUMETSAT

- 3 Channels centered around the water vapor line (183.31 GHz)
- 2 window channels (H1 and H2)
- Possible to get the humidity signatures from H3, H4 and H5

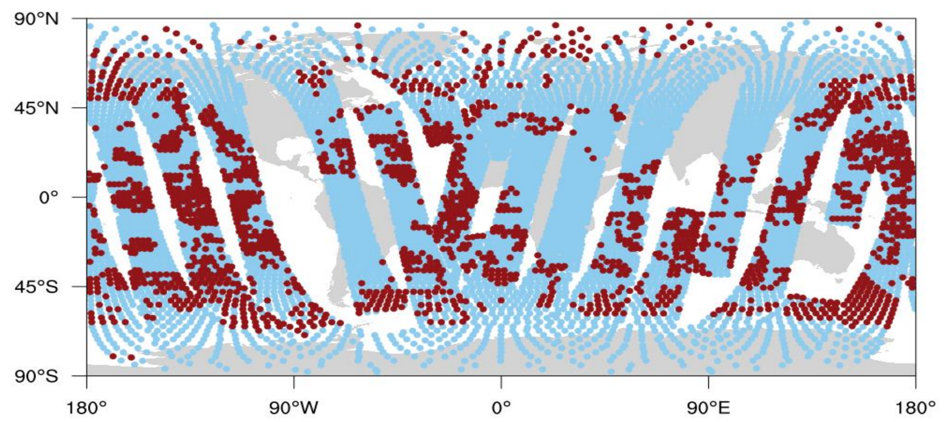
Quality control of MHS radiances

- RTTOV model as forward operator
- QC of MHS radiances is similar to the operational scheme used for GSI
  - Step 1: Calculation of **Liquid Water Path (LWP)$_{index}$** and **Total Precipitable Water (TPW)$_{index}$** (**$LWP_{Index} = F(Ch1_{o-b}, Ch2_{o-b})$**)
  - Step 2: Remove : **$TPW_{index} > 1$**
  - Step 3: Remove pixels with ***$abs(O-B)_i > 3e_i$***
- Observations from 1-15 and 75-90 FOVs are not considered
- Horizontal thinning distance is set to 140 km (Refer to Terasaki (2015) and Terasaki (2017) for more details on horizontal thinning)
- Superobing of MHS over 3x3 grid box (Only 20 FOVs)

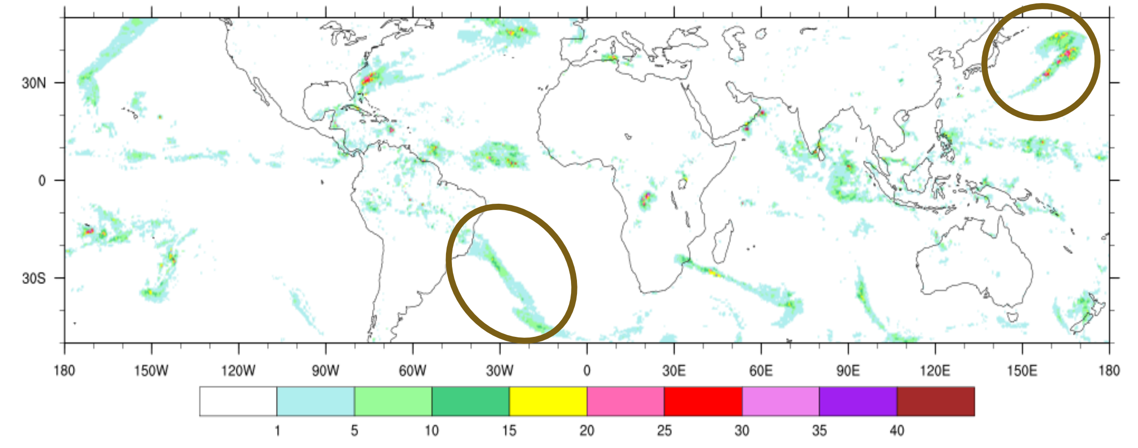
TPW index



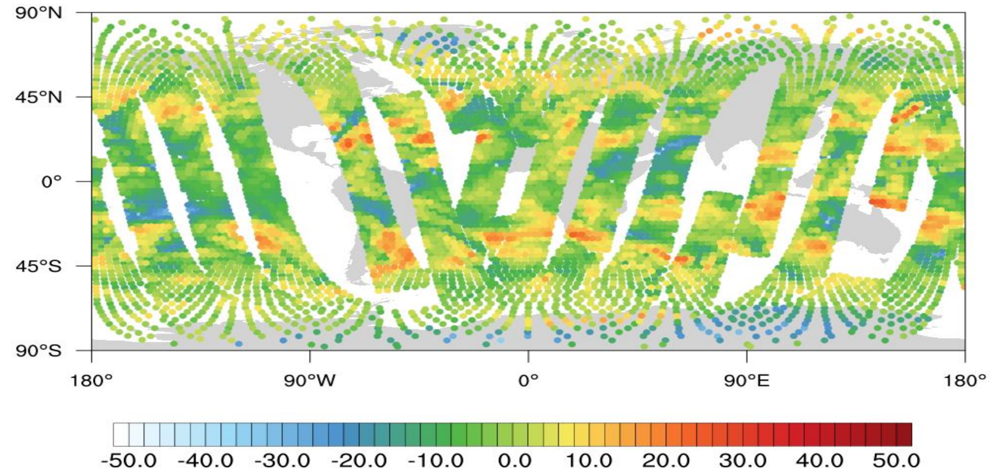
QC Flag



TRMM 3B42



O-B Ch4



Bias predictors for MHS

Miyoshi et al. (2010)

1. IWLR
2. Surface Temperature
3. 1/cos θ
4. constant

Kazumori (2014) (JMA)

1. 2 - IWLR
2. Surface Temperature
3. 1/cos θ

ECMWF

1. 1000 - 300 hPa thickness
2. 200 - 50 hPa thickness
3. 10 - 1 hPa thickness
4. 50 - 5 hPa thickness

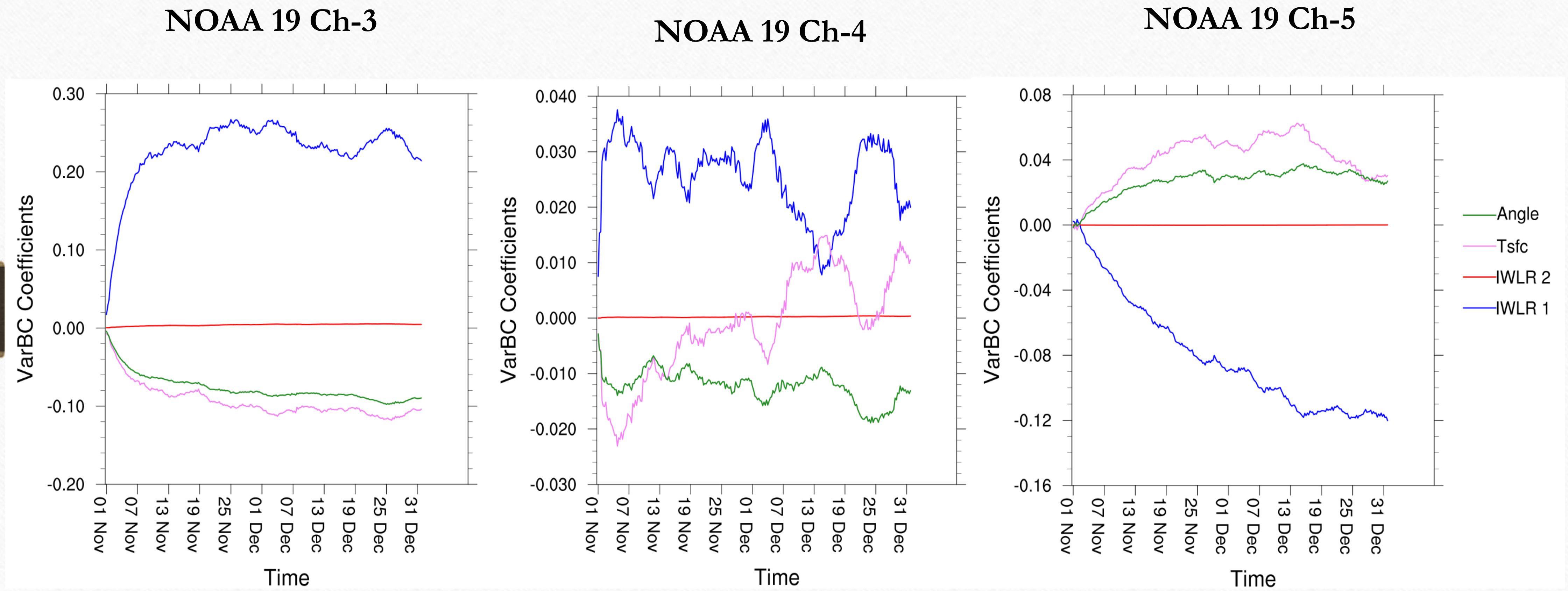
NCEP GSI

1. 2 - IWLR
2. Surface Temperature
3. 1/cos θ
4. TCWV

Present study

- Exp 1 – 4 Predictors
- Exp 2 – 3 Predictors
- Exp 3 – 2 Predictors

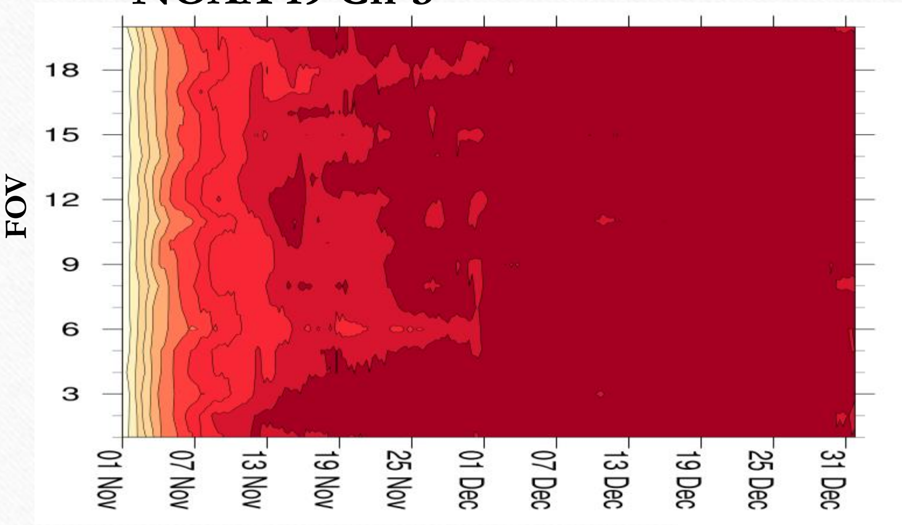
4 Predictors for VarBC



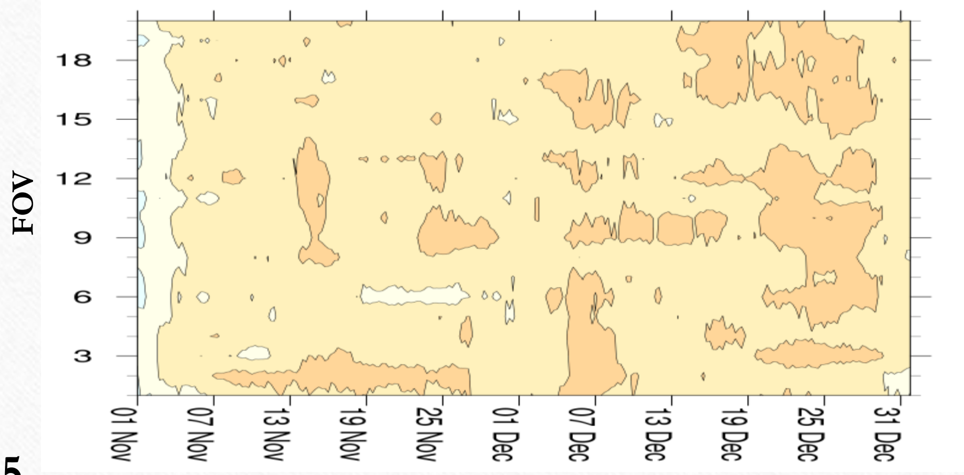
Time history of bias predictor coefficients

4 Predictors for VarBC

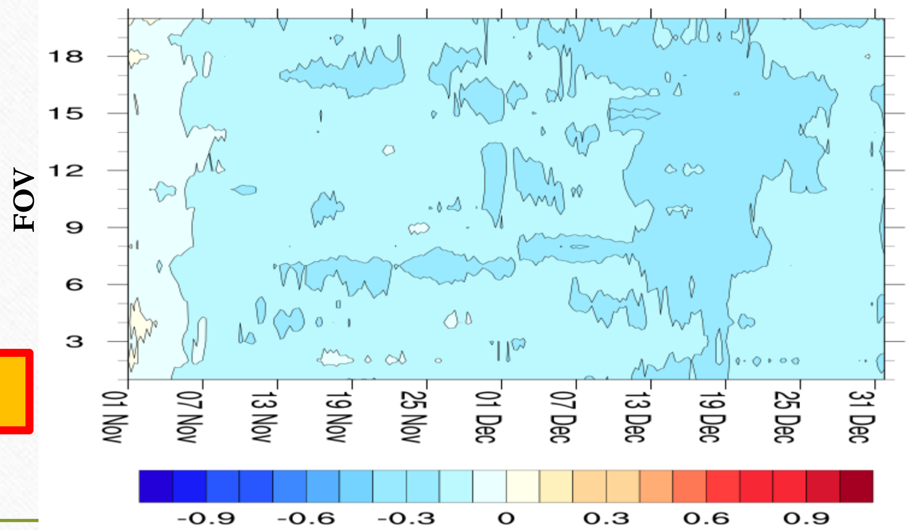
NOAA 19 Ch-3



NOAA 19 Ch-4

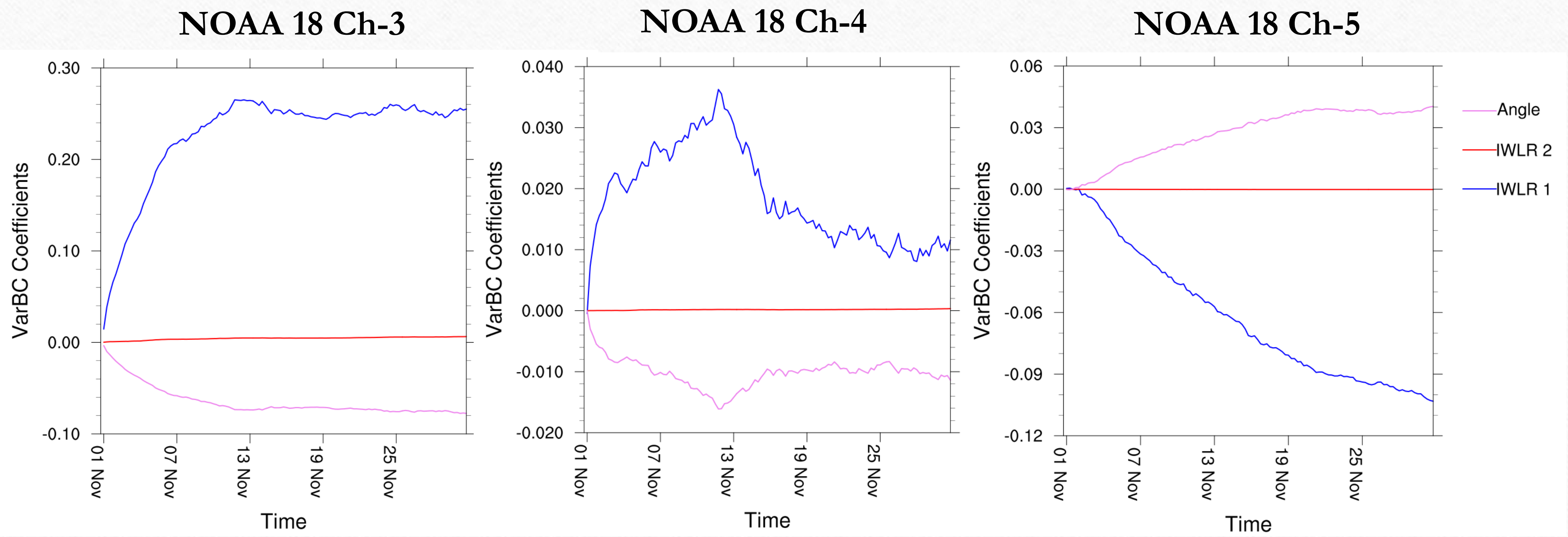


NOAA 19 Ch-5



Time history of scan bias values

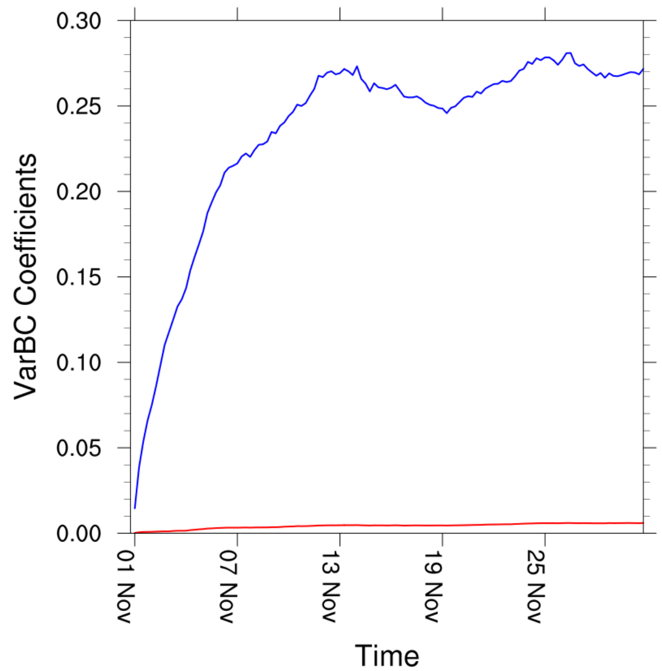
3 Predictors for VarBC



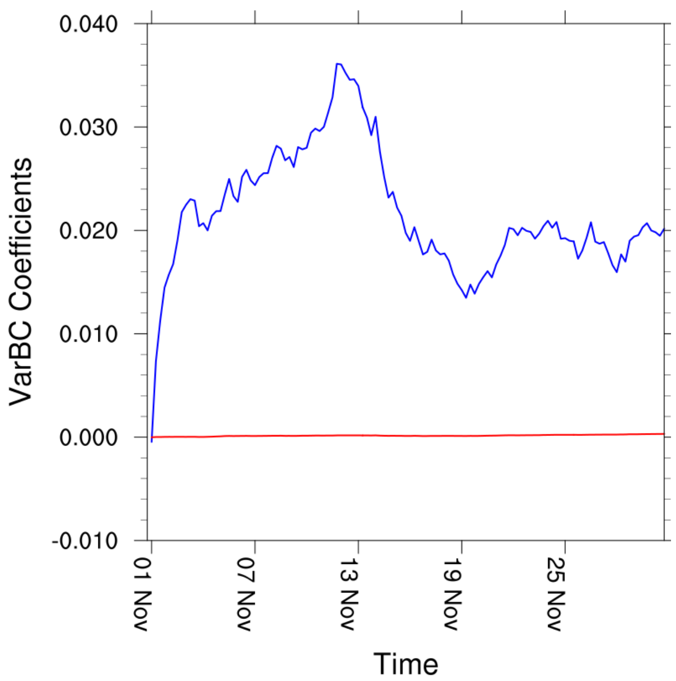
Time history of bias predictor coefficients

2 Predictors for VarBC

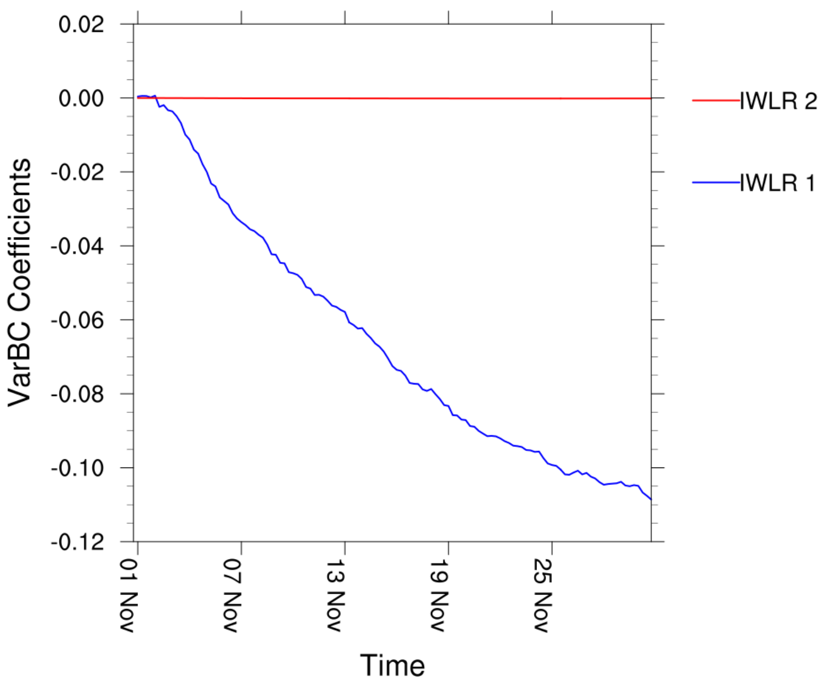
NOAA 18 Ch-3



NOAA 18 Ch-4



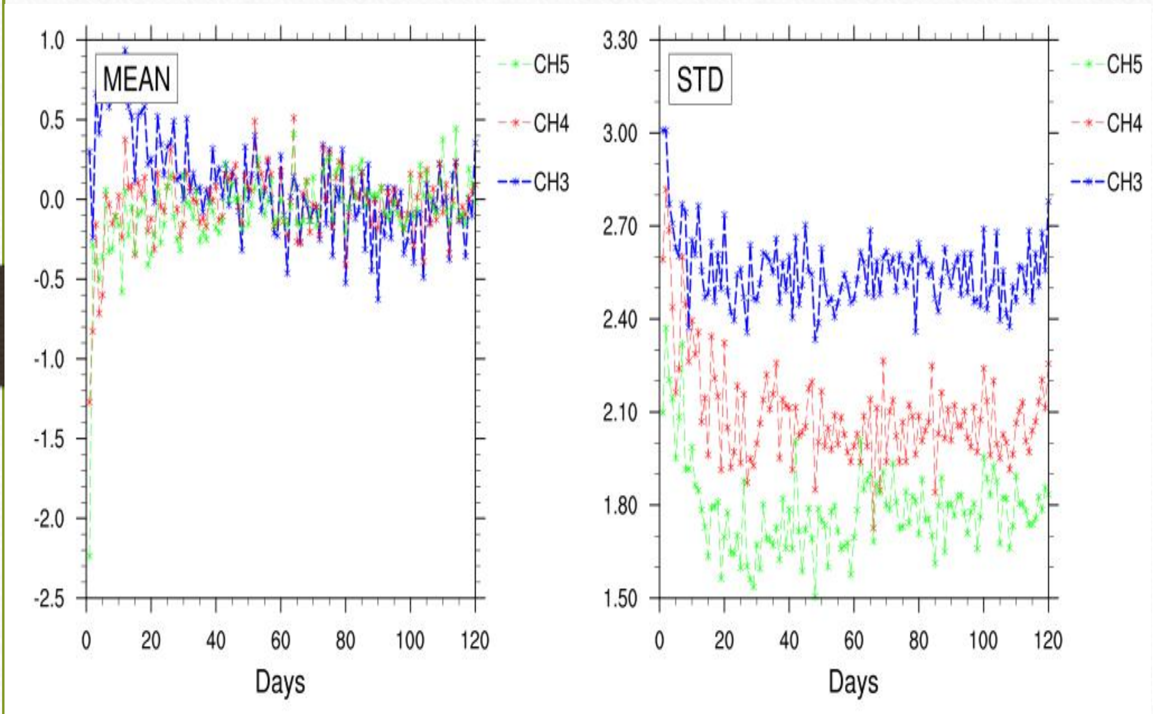
NOAA 18 Ch-5



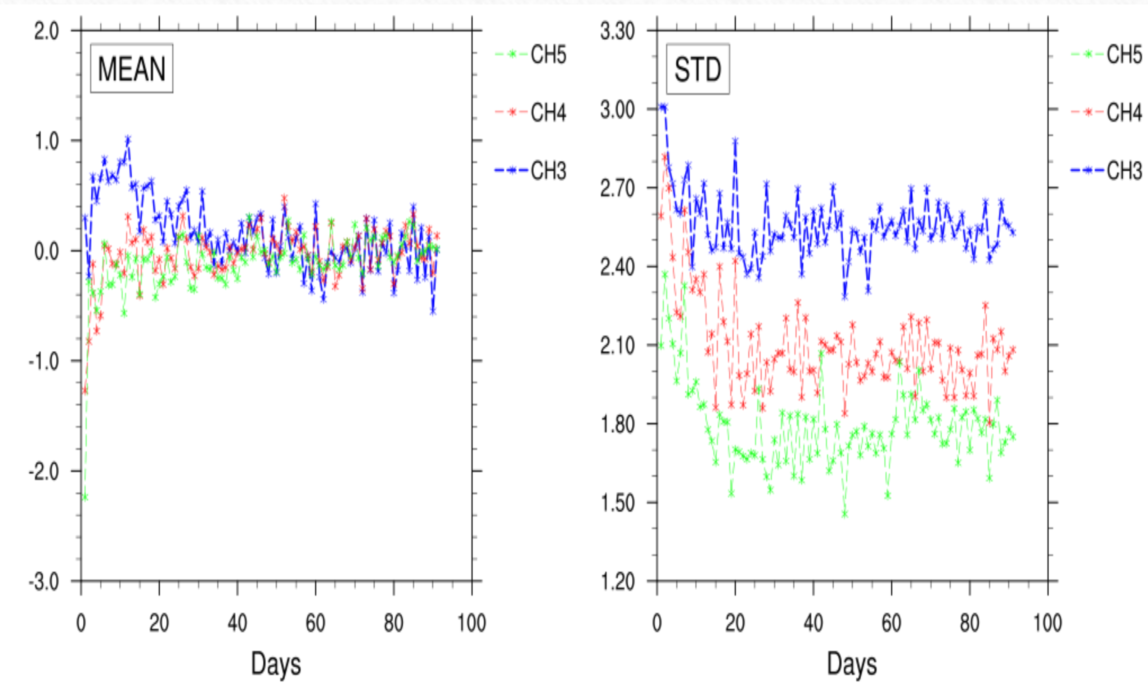
Time history of bias predictor coefficients

O-B Statistics

3 Predictors

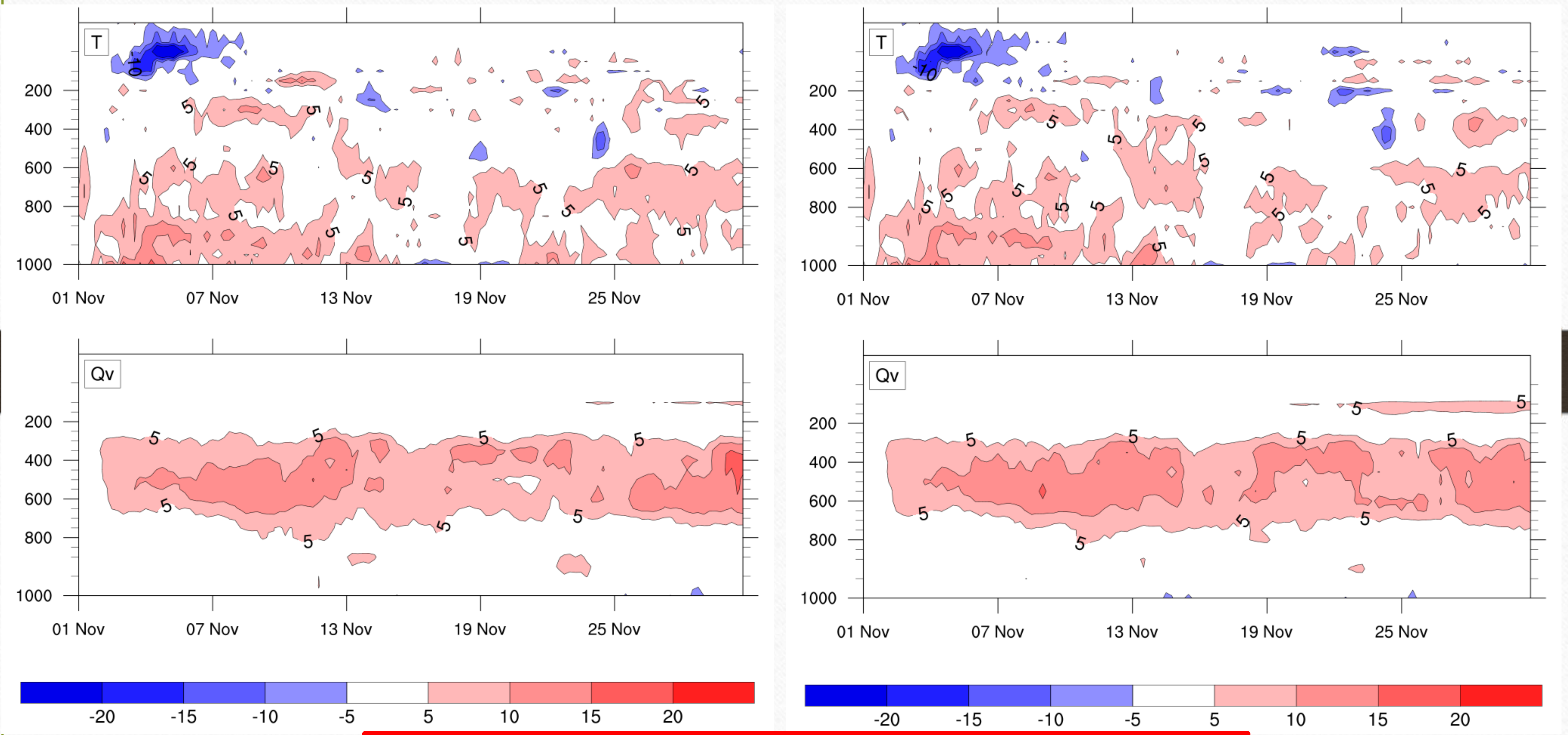


2 Predictors



Time history of O-B mean and standard deviation

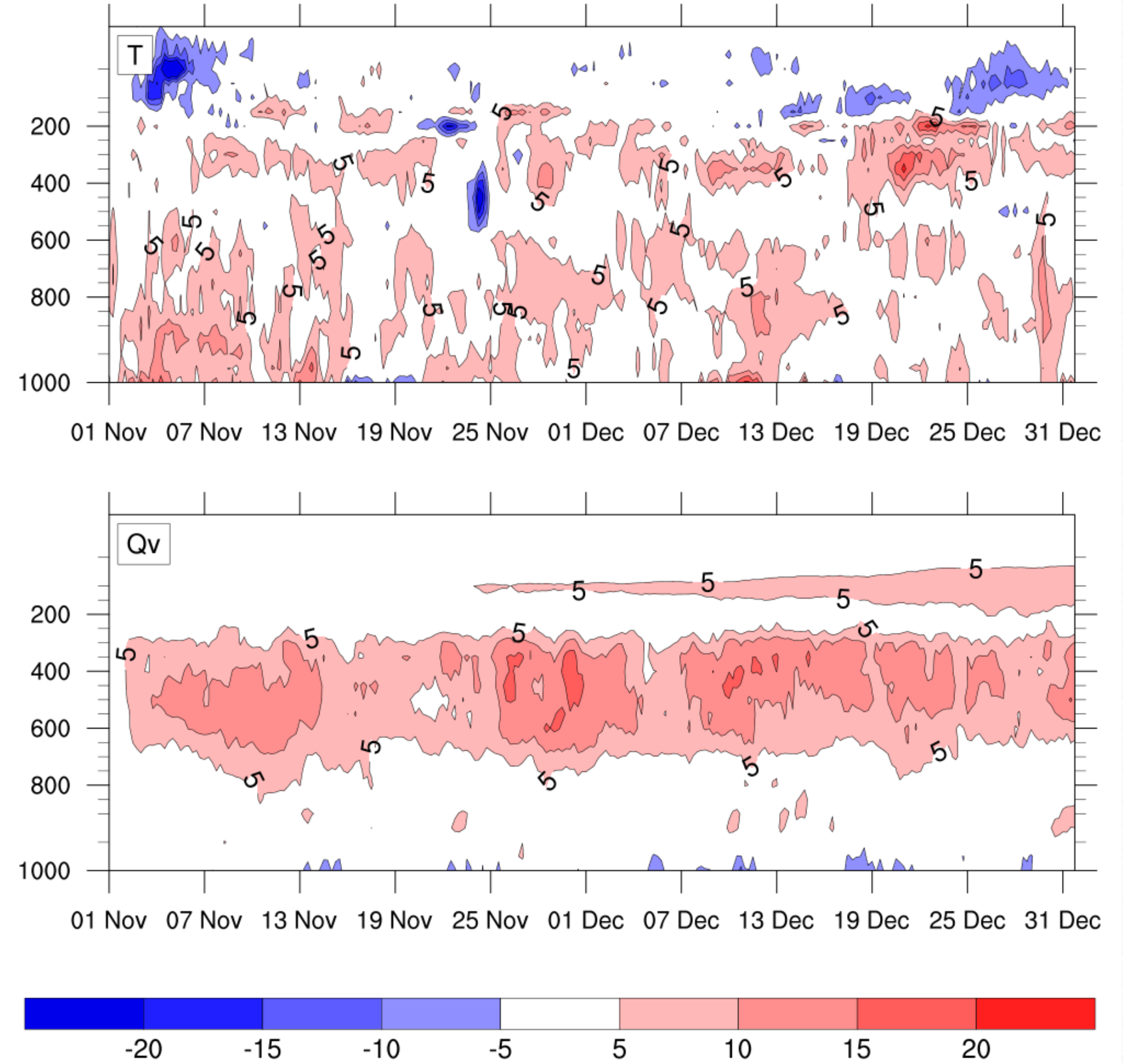
2 Predictors 3 Predictors



Percentage improvement based on RMSE (MHS vs AMSUA)

- In all the three cases there is a considerable improvement in the analysis after assimilating MHS radiances.
- The humidity bias between 600 – 400 hPa layer has reduced considerably.
- Fast convergence of bias predictor coefficients for channel 3 and 4.
- Further experiments on assimilating MHS radiances, use only 2 predictors for air-mass bias correction (ECMWF)
    - IWLR (1000 – 300 hPa)
    - IWLR (200 – 50 hPa)

4 Predictors

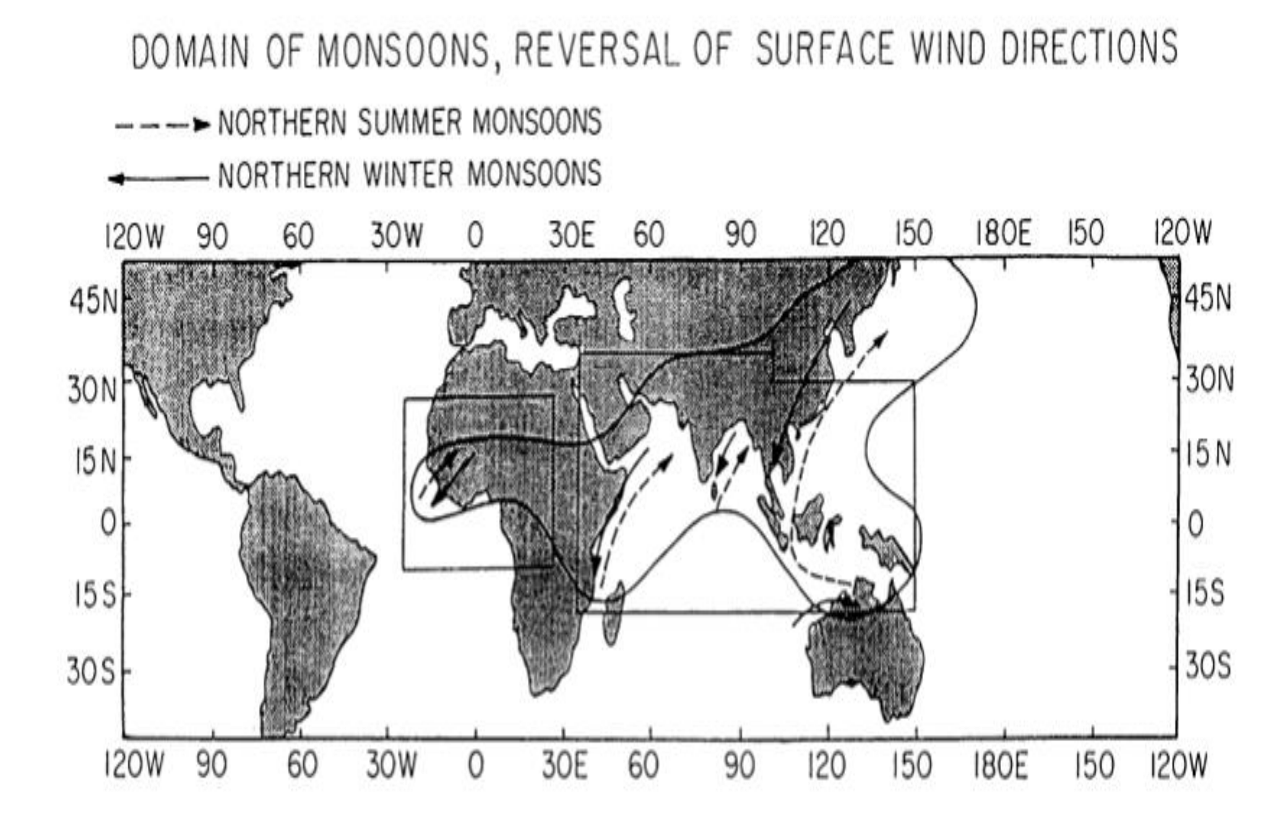


Percentage improvement based on RMSE (MHS vs AMSUA)

A Case Study

Indian Summer Monsoon

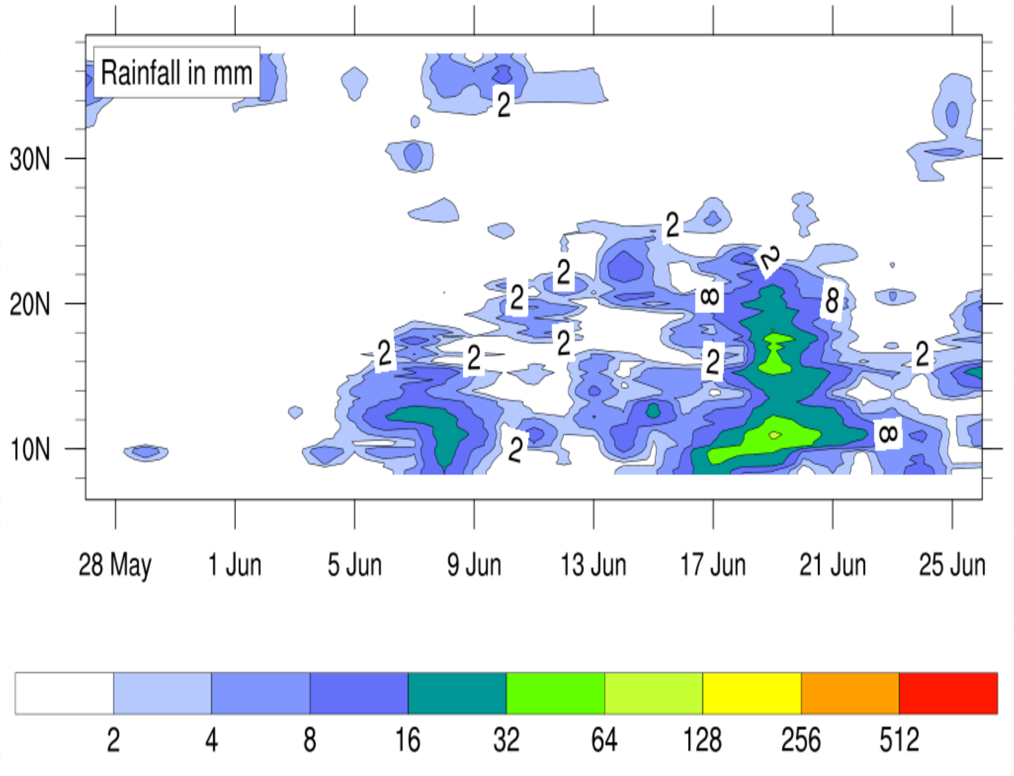
- Monsoon – surface wind reversal
- The onset of ISM denotes the beginning of primary rainy season in India
- Up to 70% of Indian rainfall from ISM (June to September)
- Indian monsoon tied to the socio-economic life



From Tropical Meteorology by T. N. Krishnamurthi

The case of Indian Summer Monsoon Onset

IMD observed rainfall in mm
Avg. over 70-80E



- Test case: Indian monsoon onset – 2012
- Actual onset on 5th June 2012 (IMD monsoon report)
- ISM onset date declared by IMD using subjective methods.
- Various onset indices have been developed in the recent times
- Here in this study we report the onset using the ISM index developed by Wang et al. (2009)

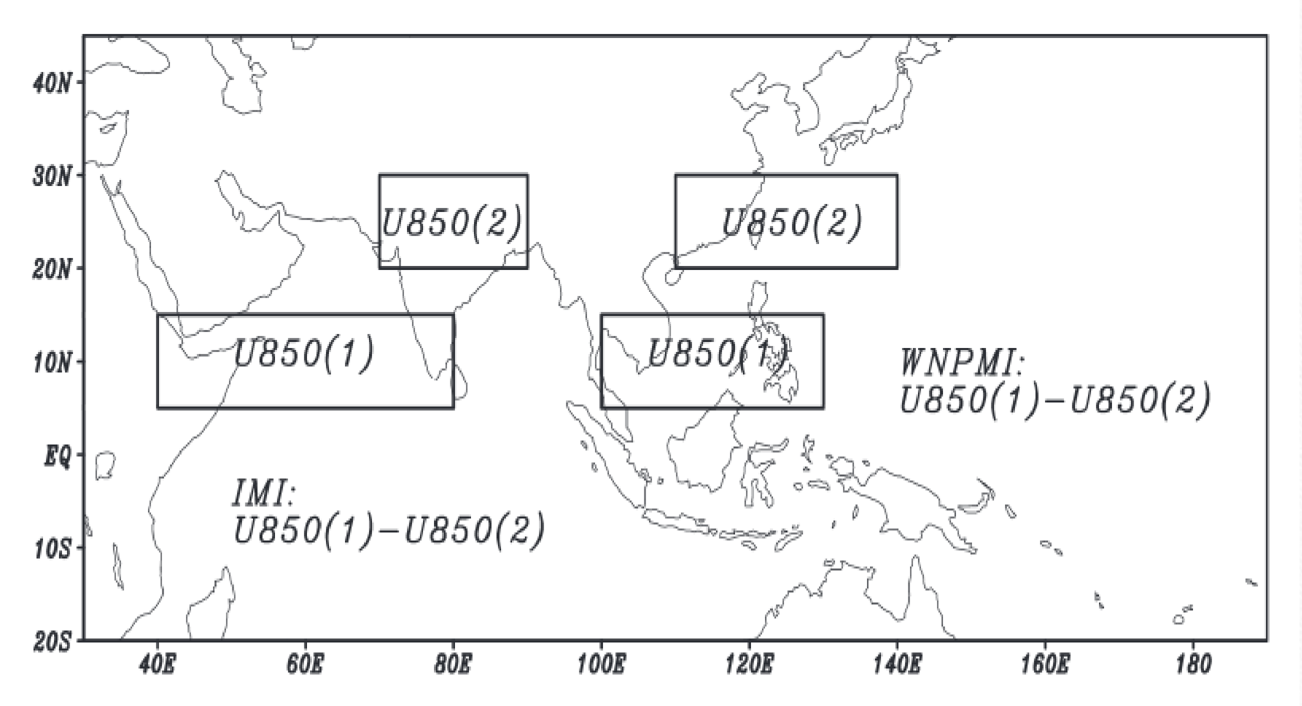
Indices for monsoon onset

ISM index : U850(1) – U850(2)

Onset Circulation Index (OCI):

Average 850hPa 'U' wind over lat-lon box : 5–15N, 40–80E

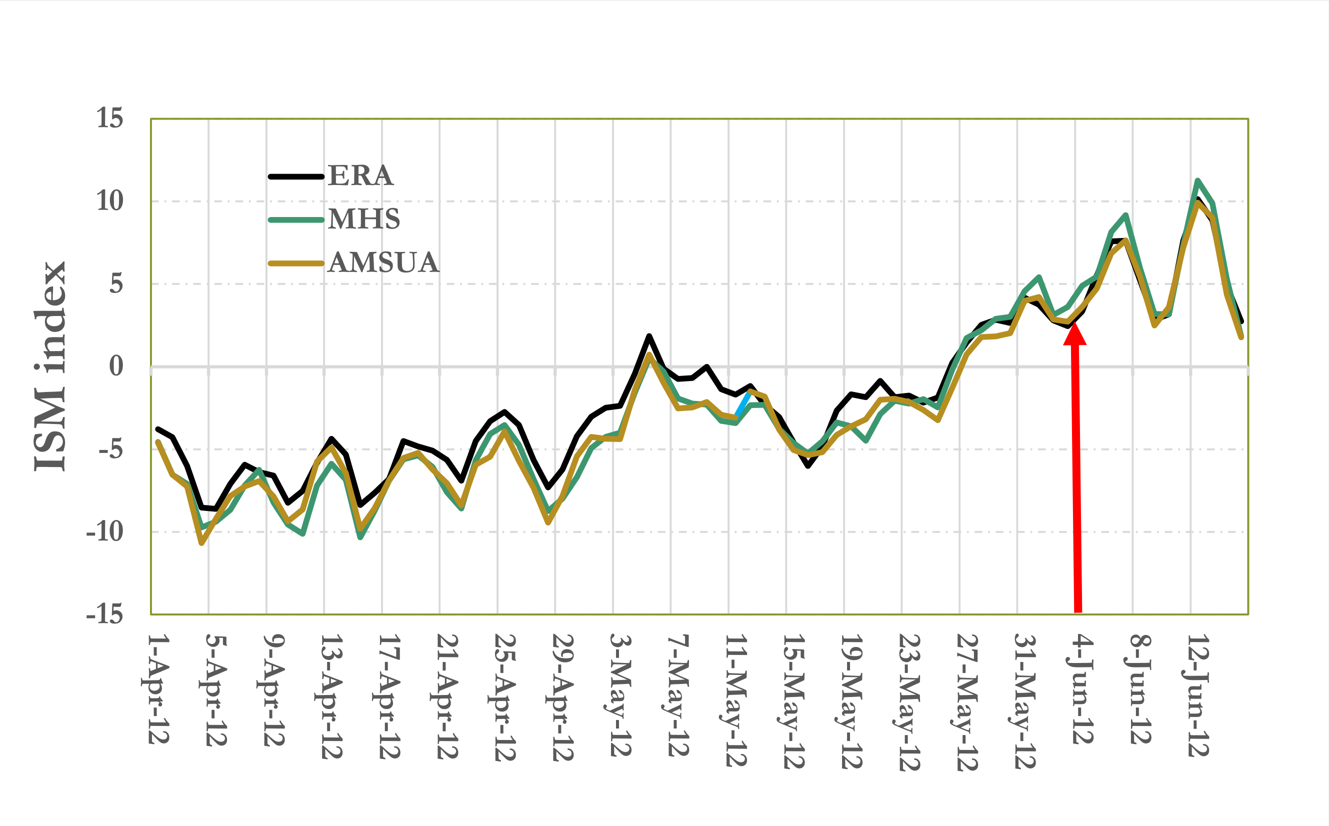
"The date of onset is defined as the first day when OCI exceeds 6.2 m/s , with the provision that the OCI in the ensuing consecutive 6 days also exceeds 6.2 m/s" – Wang et al. 2009



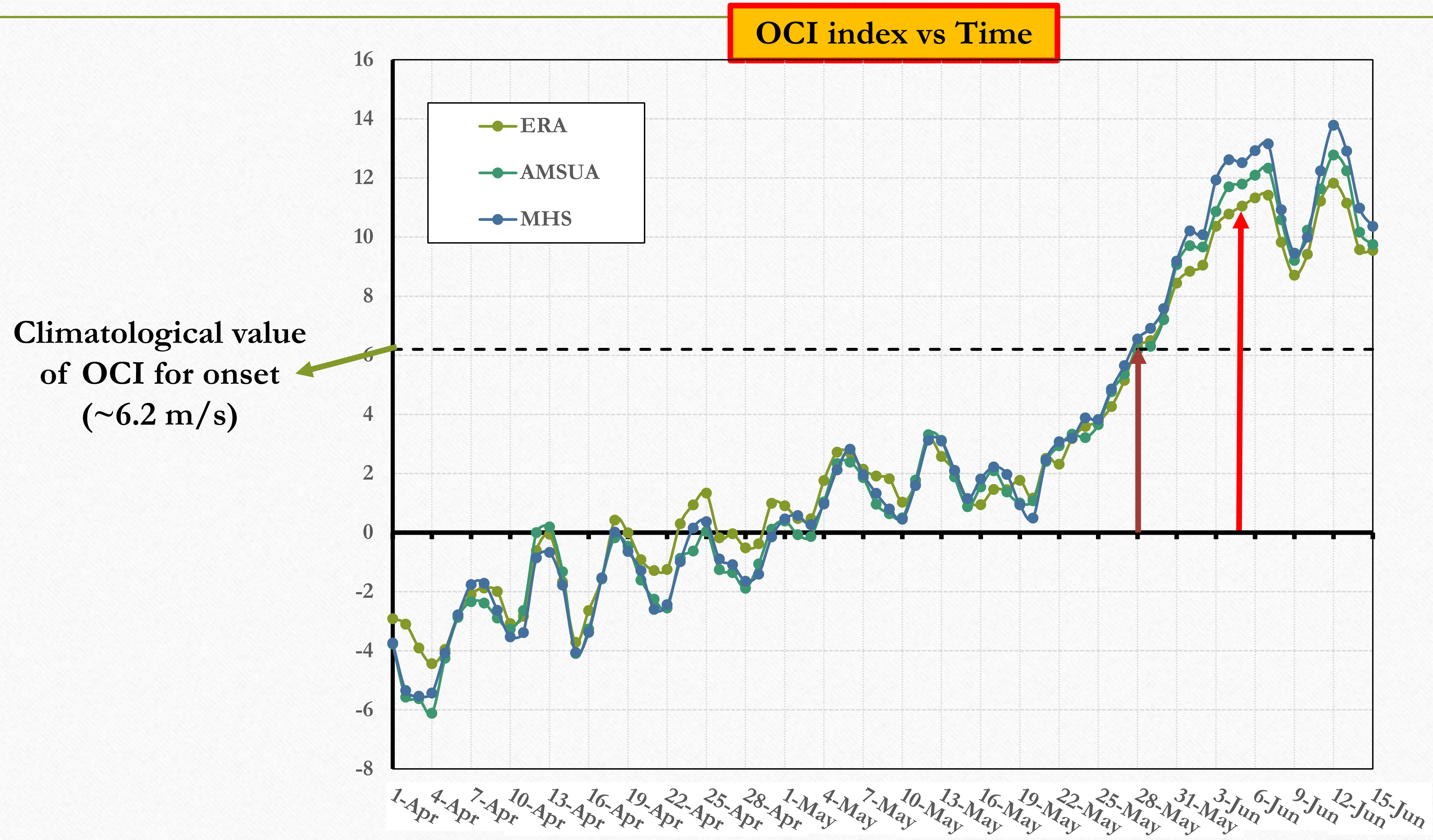
From Wang et al. (2009)

NICAM-LETKF Analysis experiments

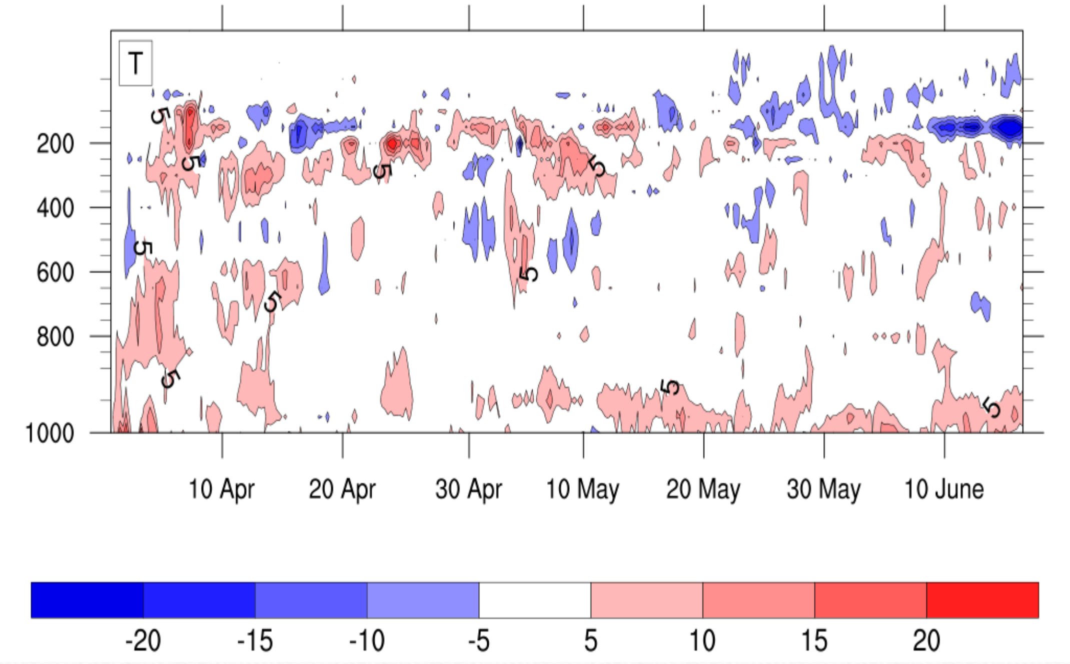
- 3 months analysis with AMSUA and MHS radiances
- Forecast experiments with NICAM
- ISM index calculated for the above analysis experiment and validated with the ERA Interim data
- Both MHS and AMSUA analysis captures the ISM index variation

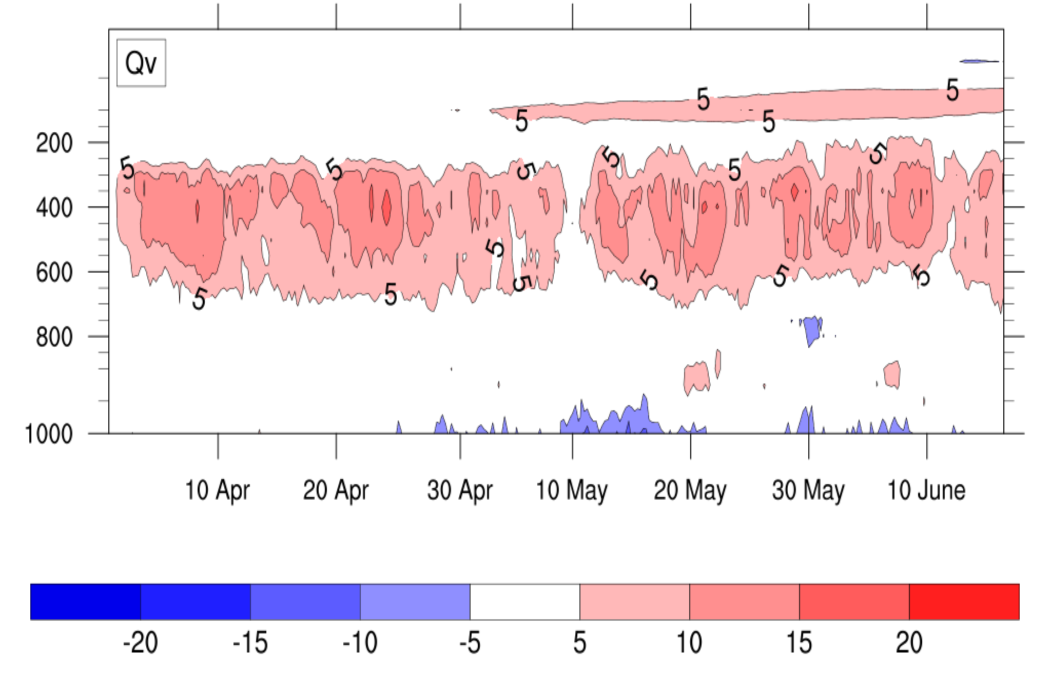


ISM index vs Time


OCI index vs Time
ERA
AMSUA
MHS
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
1-Apr
4-Apr
7-Apr
10-Apr
13-Apr
16-Apr
19-Apr
22-Apr
25-Apr
28-Apr
1-May
4-May
7-May
10-May
13-May
16-May
19-May
22-May
25-May
28-May
31-May
3-Jun
6-Jun
9-Jun
12-Jun
15-Jun
Climatological value
of OCI for onset
(~6.2 m/s)

NICAM-LETKF Analysis experiments





% improvement for 2012 case

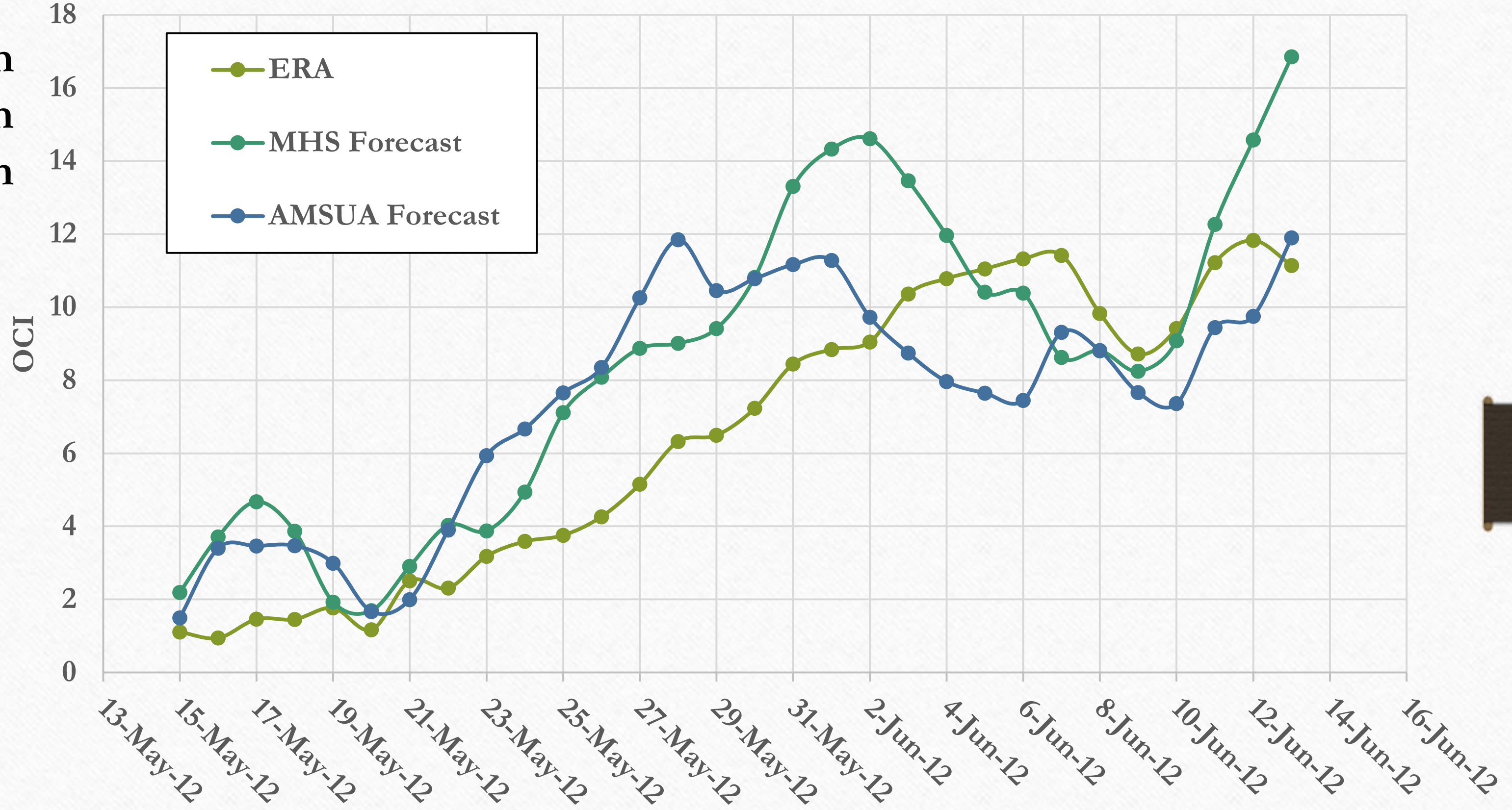
NICAM forecast experiments

NICAM forecast initialized from 15 May 2012 using analysis from MHS and AMSUA assimilation cycles

Onset date:

IMD : 05 Jun 2012
ERA : 28 May 2012
MHS : 25 May 2012
AMSUA : 24 May 2012

OCI – Onset Circulation Index
Average 850hPa 'U' wind over lat-lon box : 5–15N, 40–80E



NICAM forecast experiments

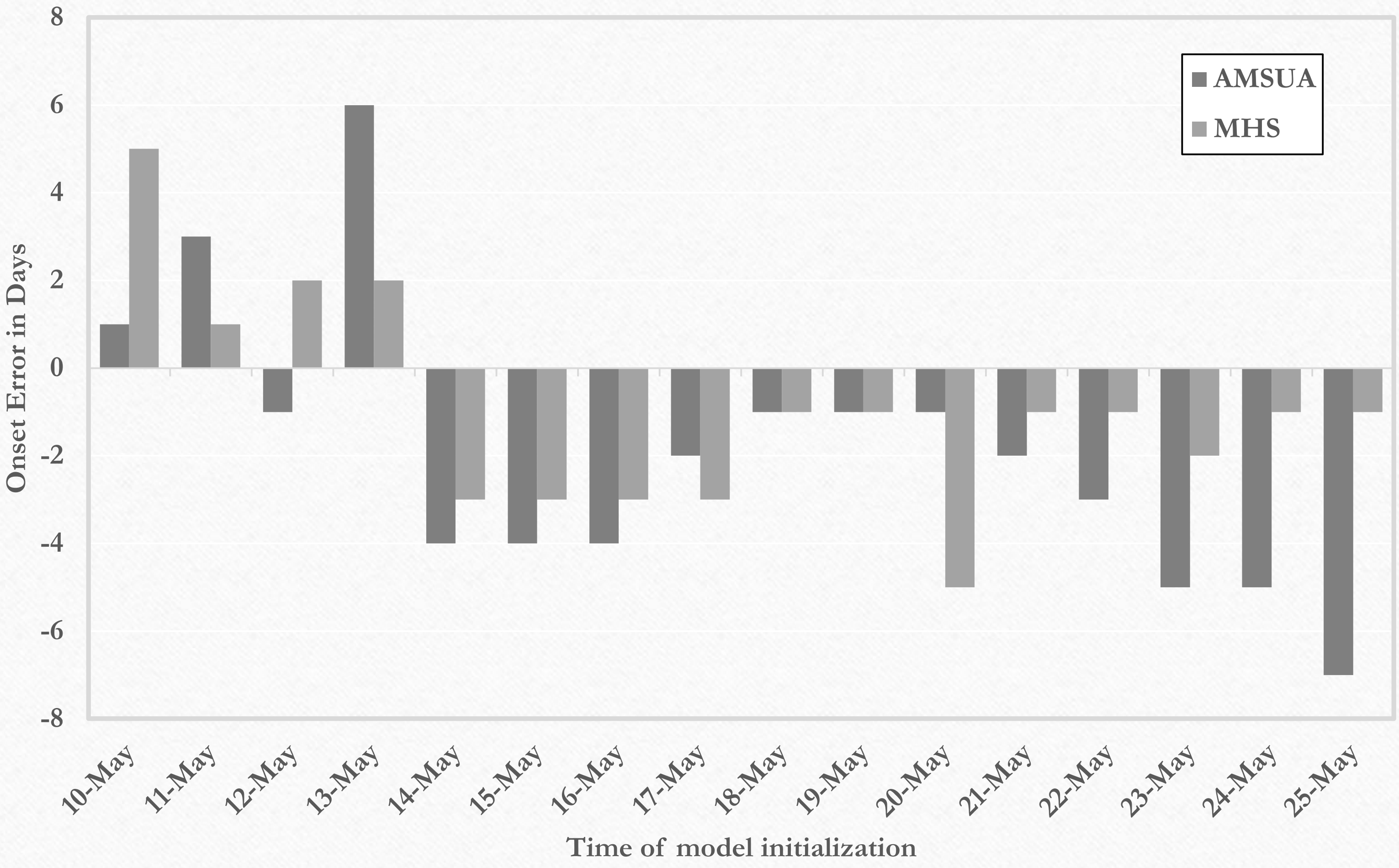
Error in the onset date (in Days) from NICAM model forecast when compared with the onset date from ERA using OCI

+ve -> Late onset

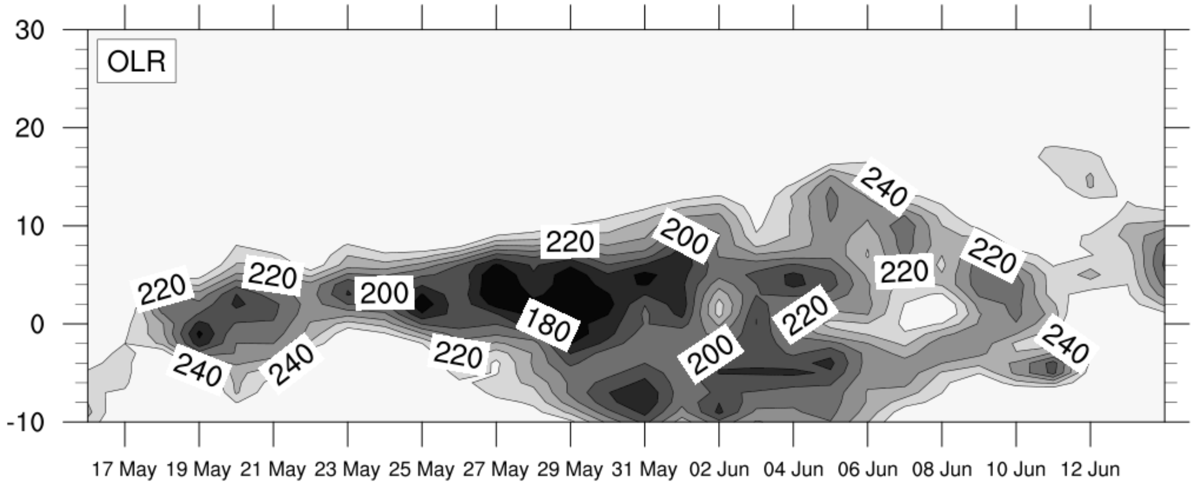
-ve -> Early Onset

ERA Onset date using OCI : 28 May 2012

Avg Error (15-25May):
AMSUA : ~3.1 Days
MHS : ~1.9 Days

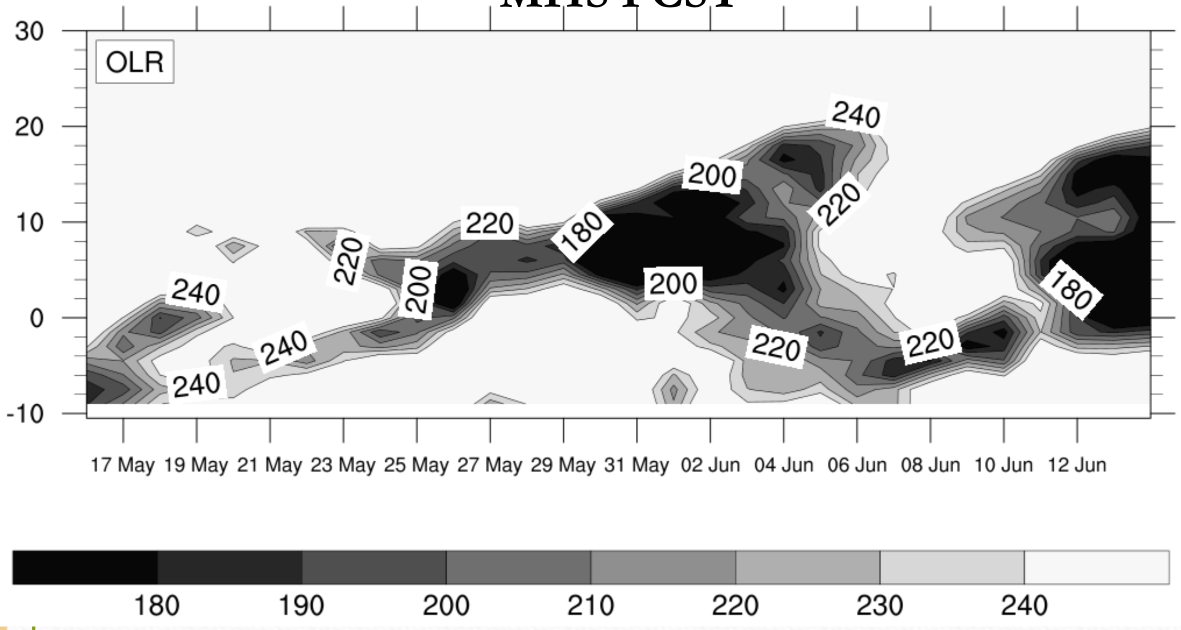


NOAA OBS

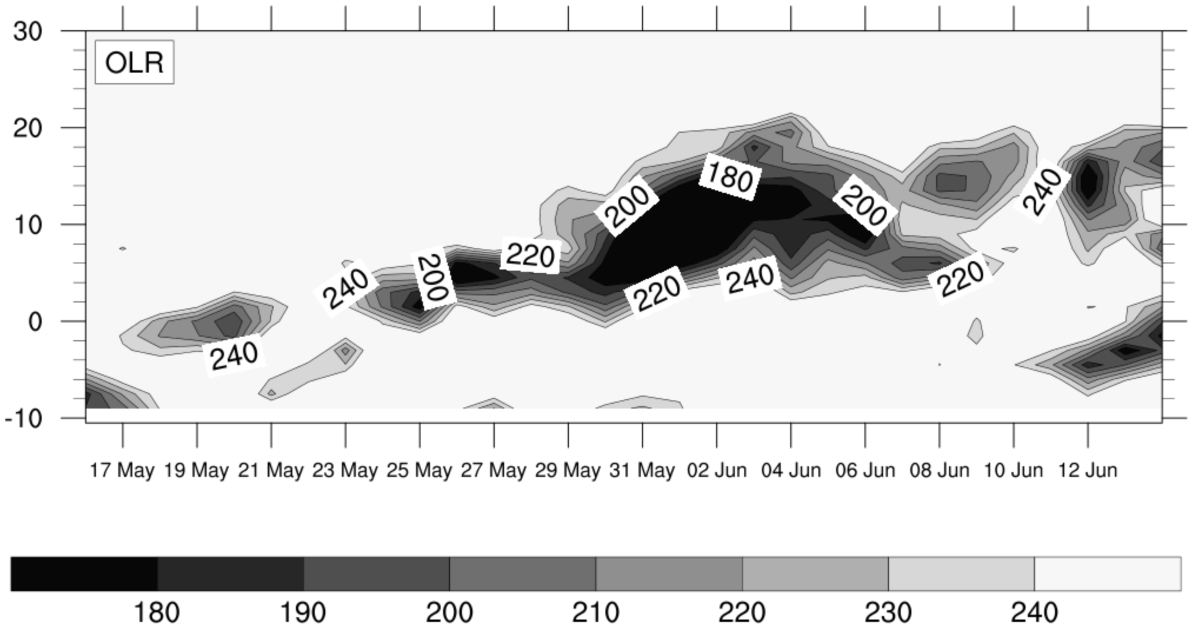


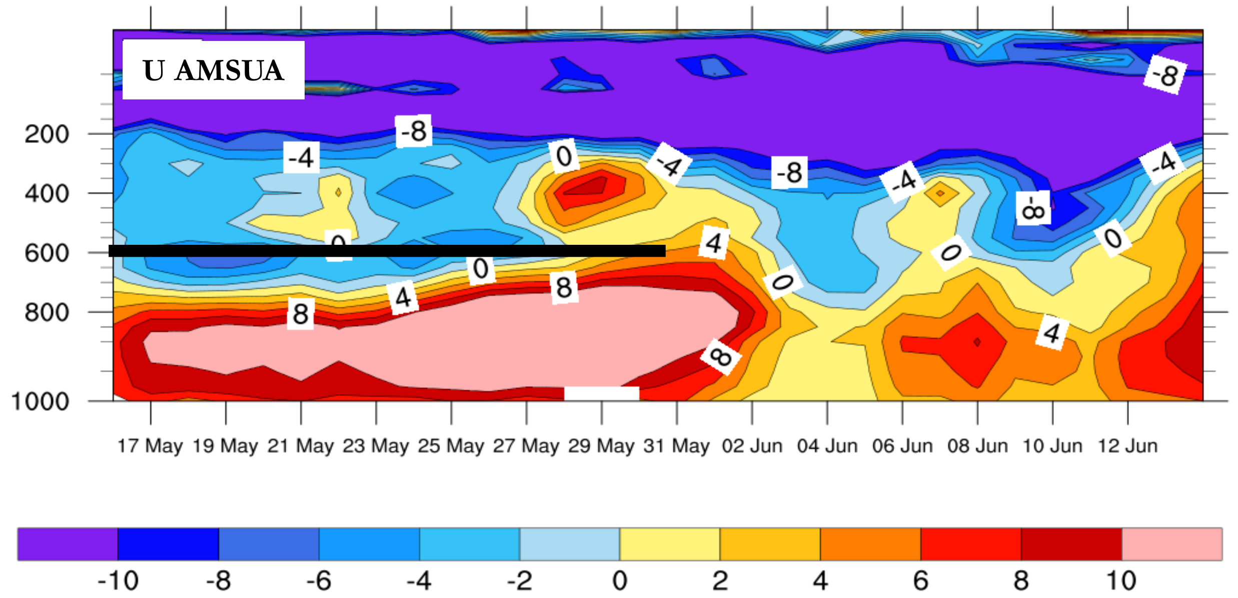
OLR in W/m^2
(Averaged over 60E to 80E)

MHS FCST

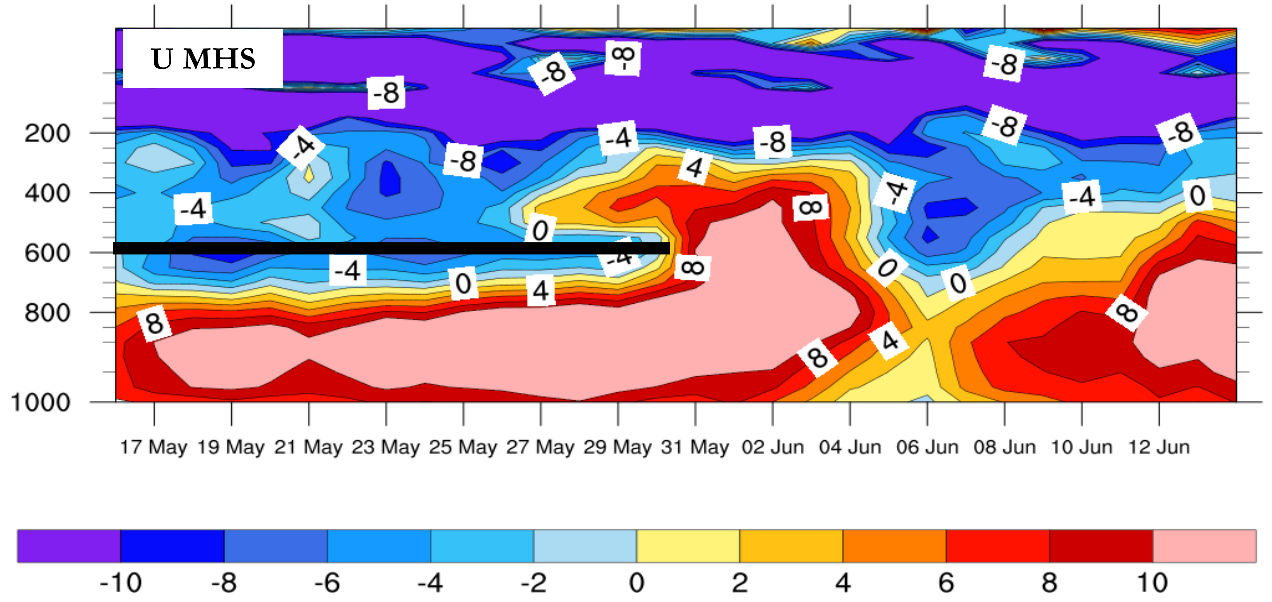


AMSUA FCST





MHS forecast produce strong westerlies which is indicator of ISM onset



Conclusions

- The addition of MHS radiance to the existing NICAM-LETKF system improves the humidity analysis fields especially in the middle troposphere.
- Several set of predictors for MHS radiance bias correction were tested and for the case study only 2 predictors were used.
- ISM onset index based on the analysis from MHS and AMSUA assimilation compares well with the ERA Interim data
- The analysis of the NICAM model forecast of ISM onset is underway.
- Comparison of the forecast initialized with MHS and AMSUA analysis is being done.

Limitations:

- Only MHS pixels over ocean is assimilated
- Objective definition of Indian Monsoon Onset based on the model OLR values
- Owing to the resolution of NICAM model , precipitation values were not compared for the Monsoon experiments

Thank you for your attention !