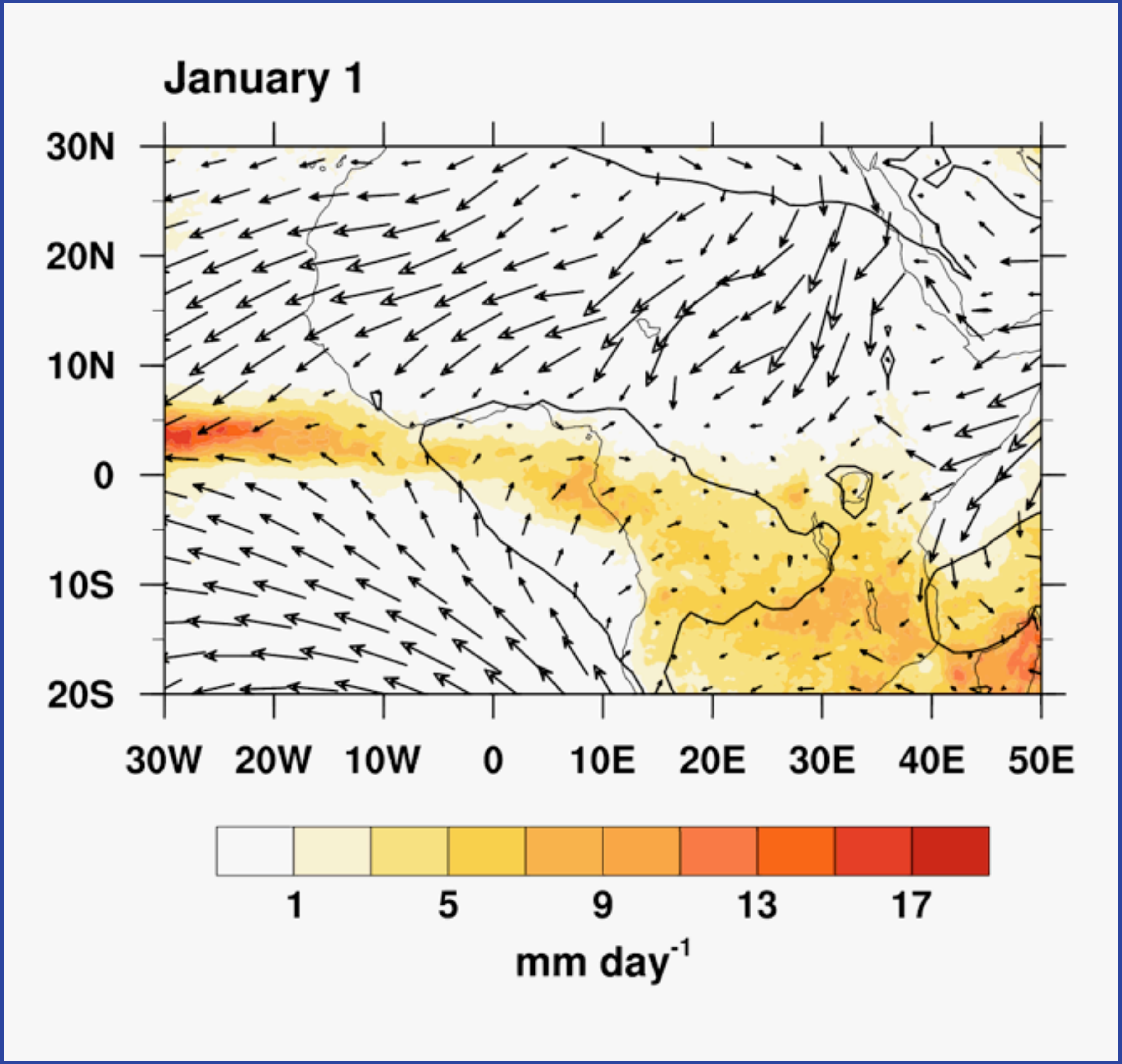
The West African Monsoon - Insights from the MMF

Rachel R. McCrary
David A. Randall
Cristina Stan

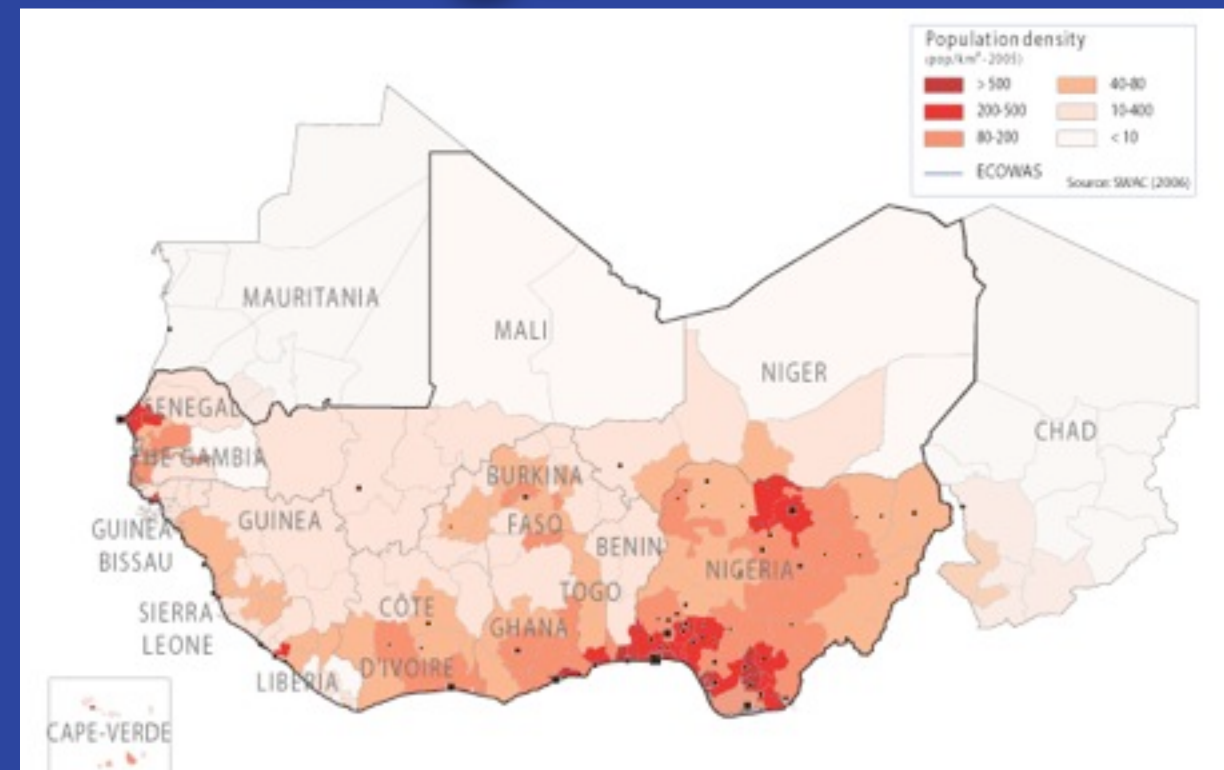
CMMAP Team Meeting August 7, 2012

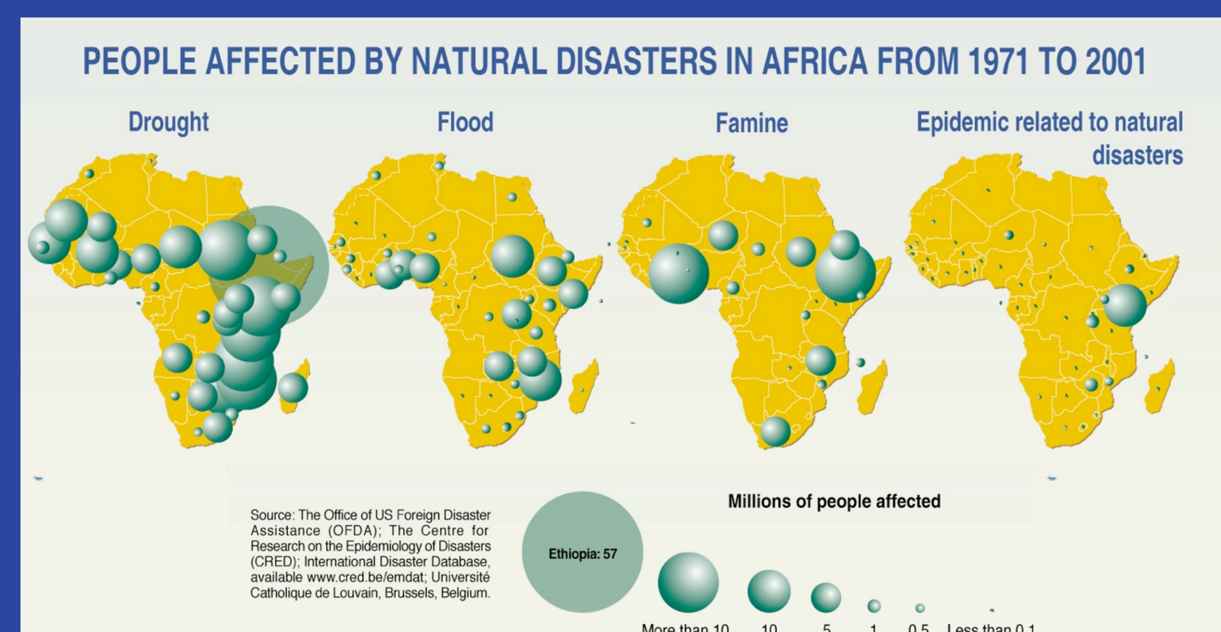
Mean Annual Cycle of Rainfall



Populations in West Africa are vulnerable to climate variability and change.

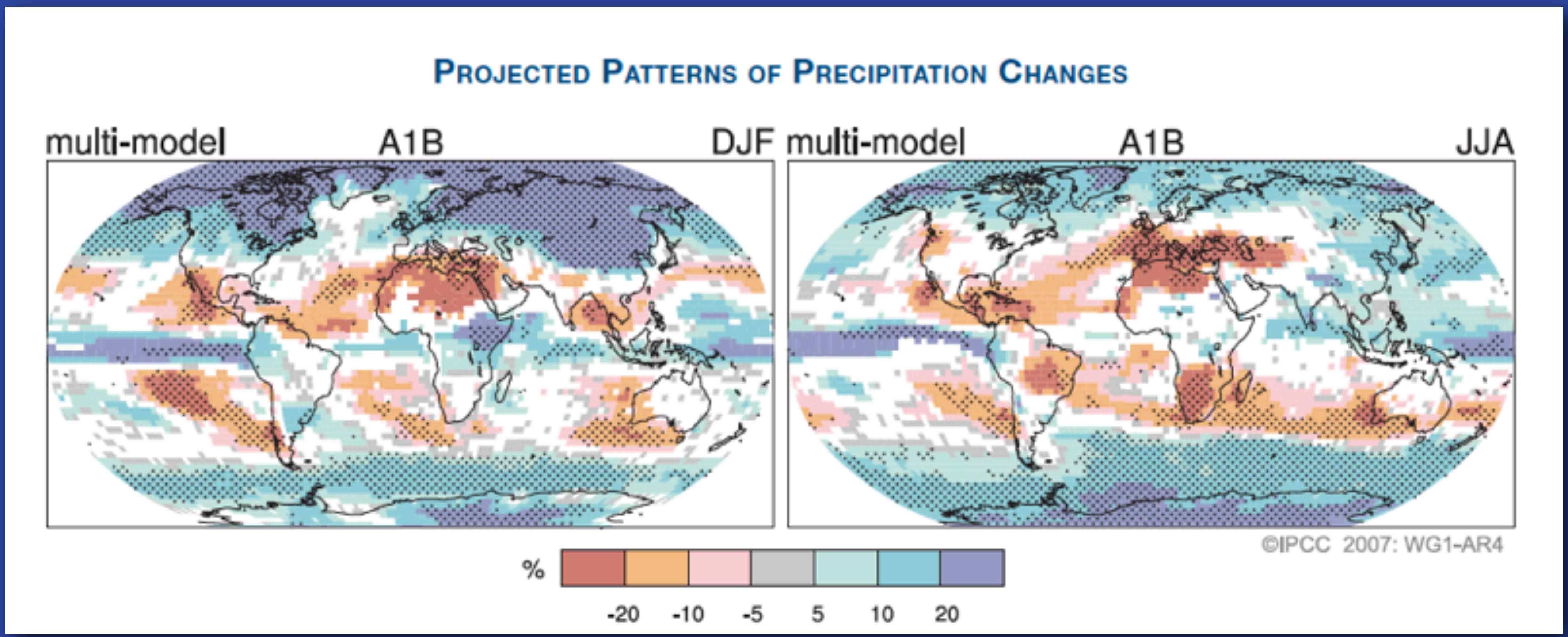
- West Africa is home to ~317 million people.
- The communities in Sub-Saharan Africa depend strongly on rainfall where 65% of the labor force and 95% of the land use is devoted to agriculture.
- Large-scale irrigation infrastructures do not exist in this region i.e. no safeguards against drought.



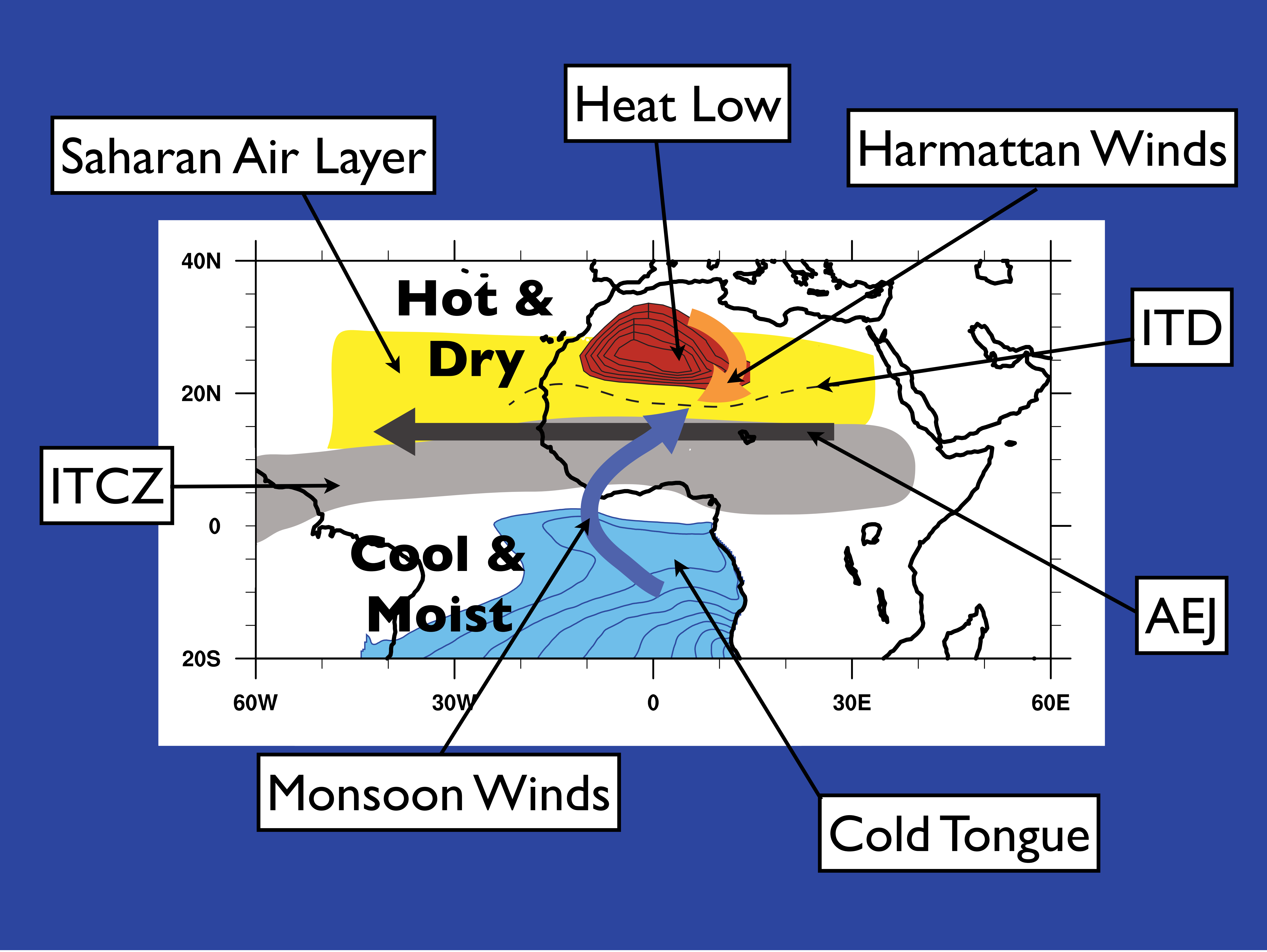


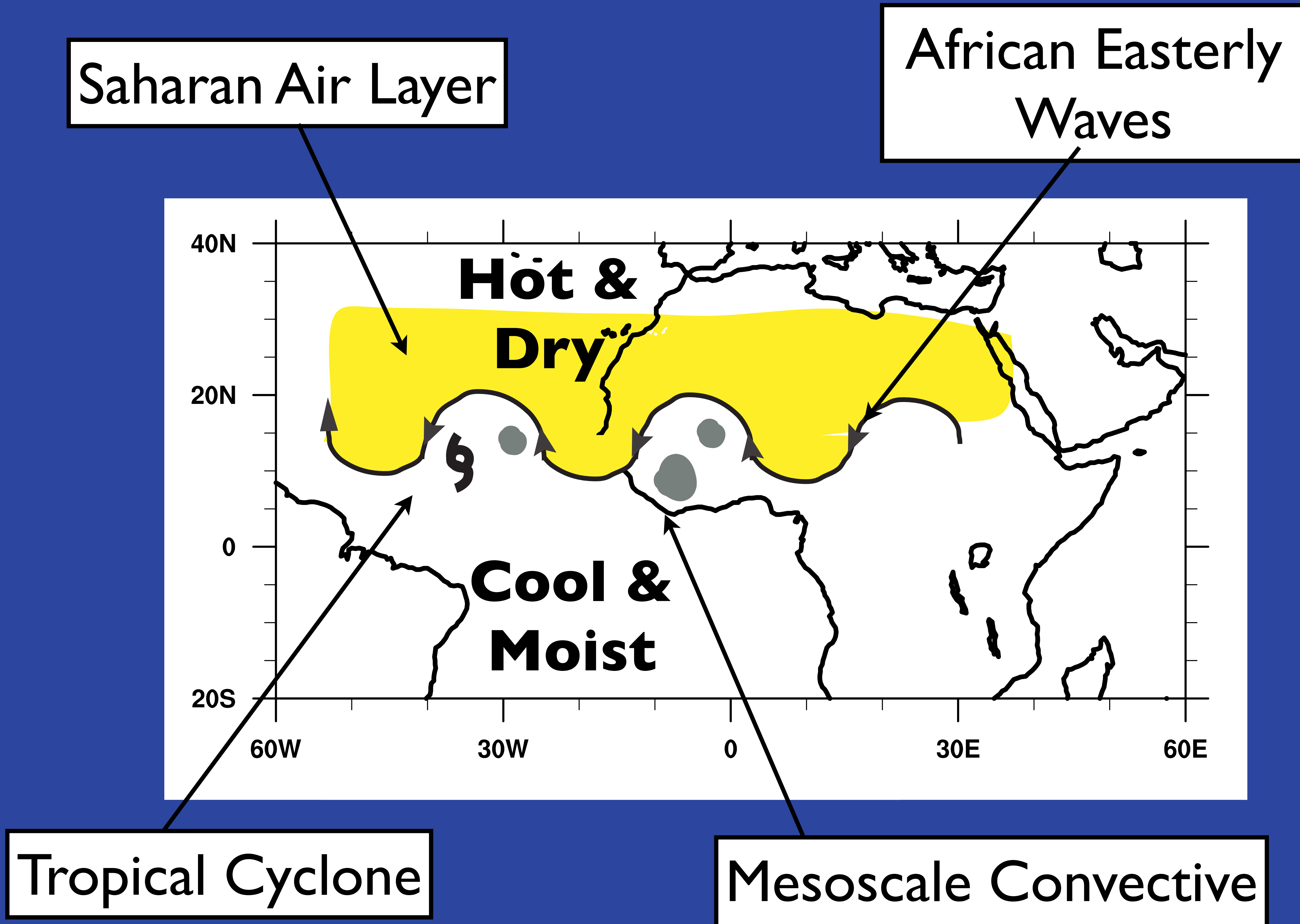
Credit: Phillippe Rekacewicz, UNEP/GRID-Arndal

There is no consensus about how precipitation will change over West Africa in a warming climate.

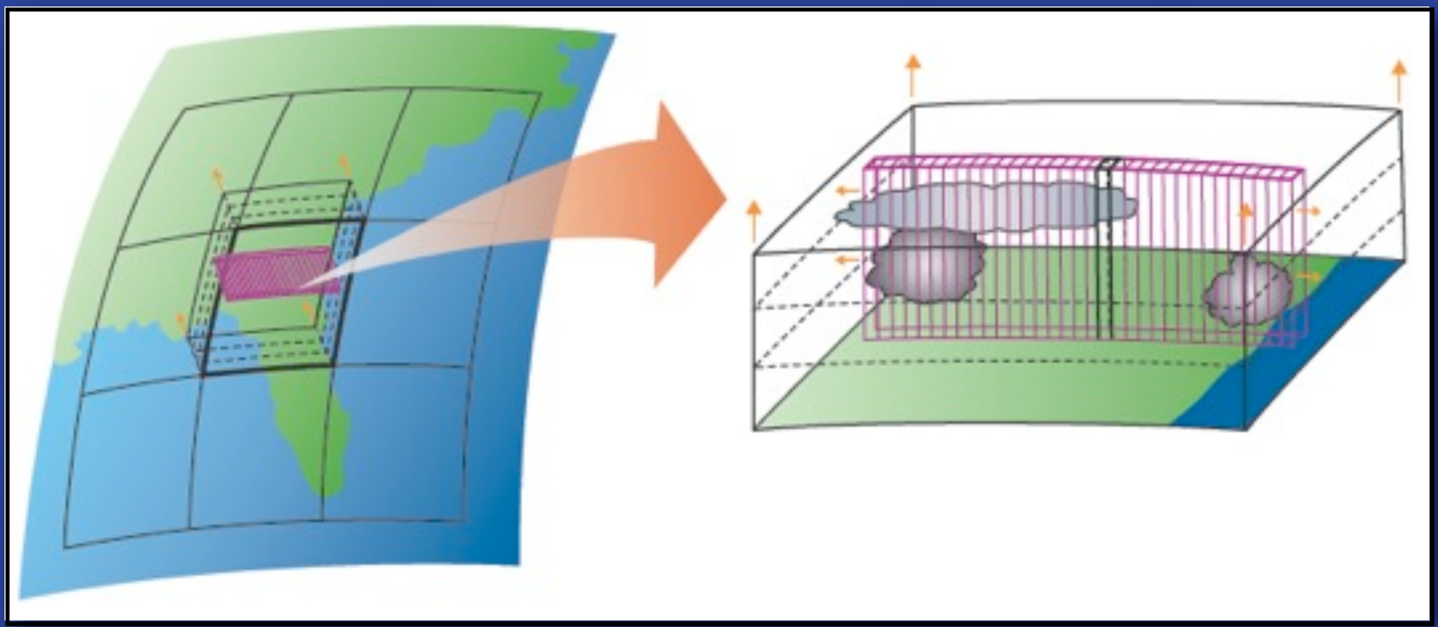


- Less than 66% of the global models agree on the sign of the change in precipitation over West Africa.
- More than 1/3 of these models do not represent the monsoon. The models that that do typically misrepresent the spatial patterns and intensity of monsoon precipitation (Cook and Vizy 2006).


Heat Low
Saharan Air Layer
Harmattan Winds
ITD
Hot &
Dry
ITCZ
Cool &
Moist
AEJ
40N
20N
0
20S
60W
30W
0
30E
60E
Monsoon Winds
Cold Tongue


Saharan Air Layer
African Easterly Waves
Hot &
Dry
Cool &
Moist
40N
20N
0
20S
60W
30W
0
30E
60E
Tropical Cyclone
Mesoscale Convective Systems

Why the Super-parameterization?



Traditional convective parameterizations are replaced by embedding a two dimensional cloud resolving model in each grid box.

Grabowski, 2001
Khairoutdinov and Randall, 2011

Like a public opinion poll, the superparemterization represents a sampling of the cloud scale processes that can be expected in each gridbox.

- The superparameterization or “SP” improves the representation of:
  - The MJO (Benedict and Randall, 2009)
  - The Asian Monsoon (DeMott et al., 2011)
  - The Diurnal Cycle (Pritchard and Somerville, 2009)

Key Questions

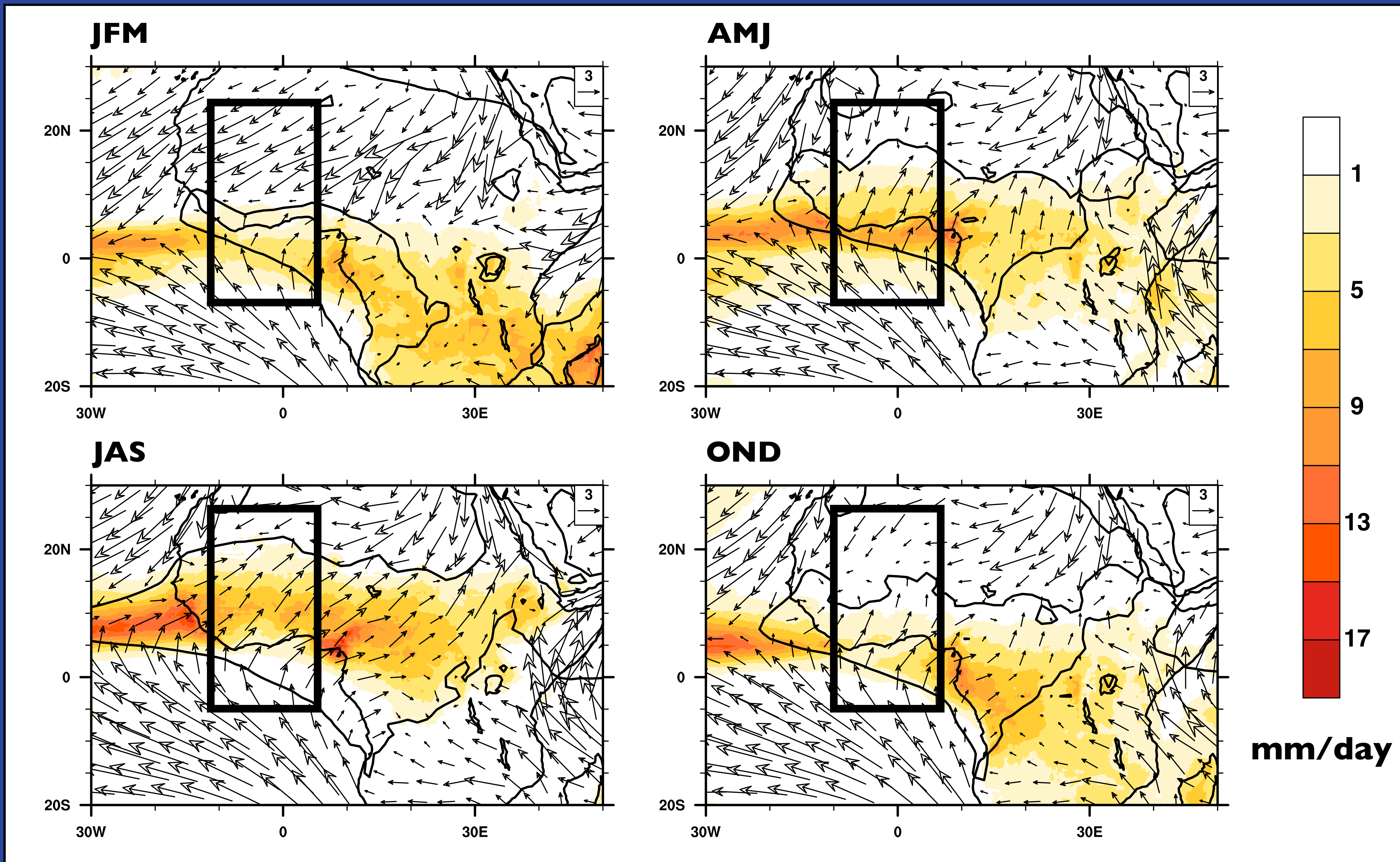
- How does the Superparameterization influence rainfall over West Africa?
- Does the SP-CCSM represent African easterly waves?
- How does the horizontal and vertical structure of the simulated waves compare with observations?

Models & Data sets

- **CCSM3.0** - “control”
- **SP-CCSM3.0** - Christina Stan at COLA/George Mason Univ.
  - 25 years of daily output
  - 5 months of 3hrly output (summer)
  - T42 resolution (~2.8°lat/lon), 26/30 levels

- **TRMM - 3B42 (precipitation)**
  - 1997-2010, daily mean precipitation 0.25°x0.25° resolution
- **NOAA Interpolated OLR**
  - 1979-2010, daily mean, 2.5°x2.5°
- **ERA-I - (dynamical fields)**
  - 1979-2010, daily mean, 1.5°x1.5°

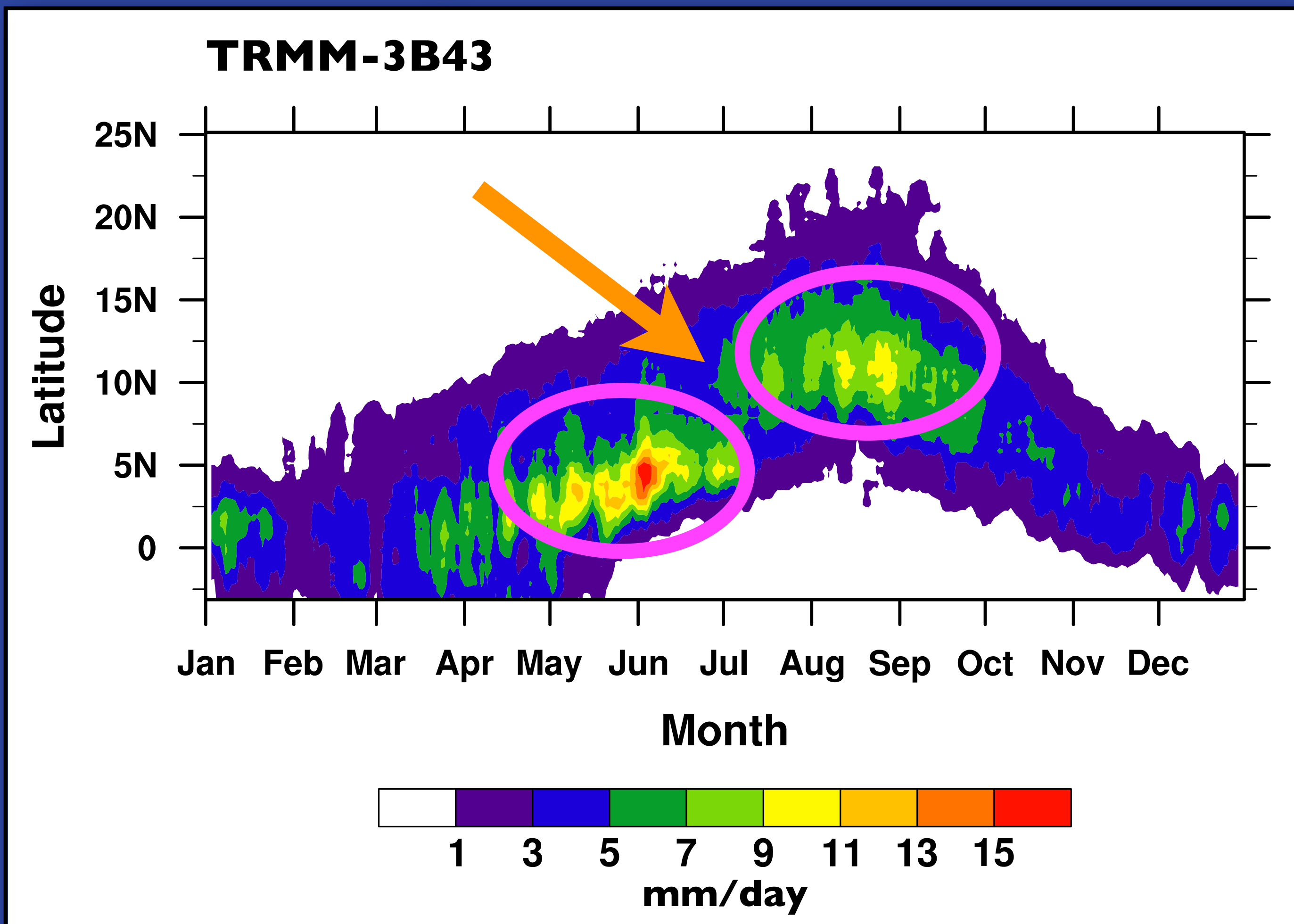
Observed Monsoon Rains



TRMM -3B42 precipitation (1997-2010)
ERA-I 925 hPa winds (1997-2010)

Observed Monsoon Rains

TRMM -3B43 precipitation (1997-2010)
Averaged between 10ºW - 5ºE

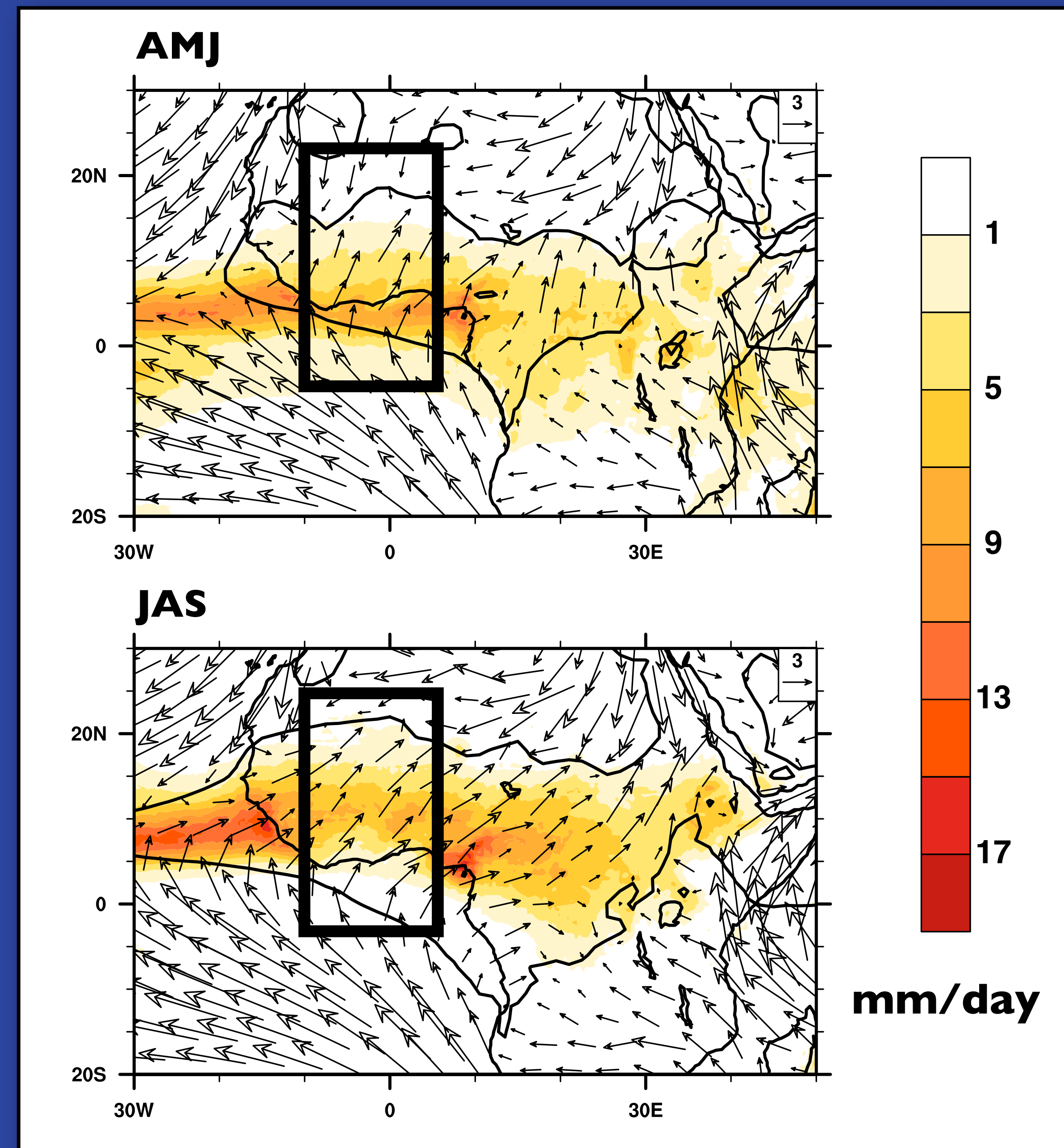


5 day running mean

Two precipitation maxima

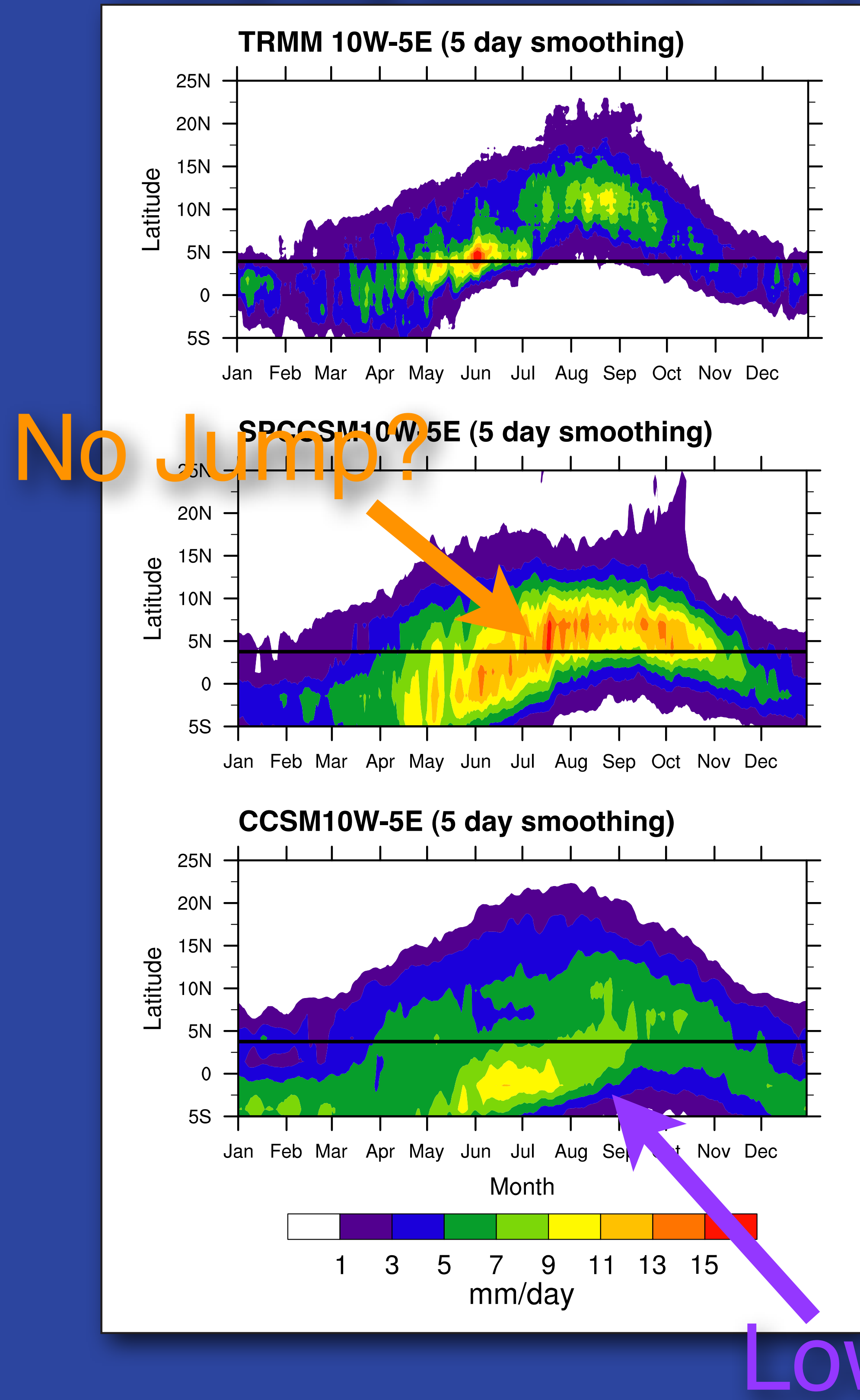
Monsoon Jump

TRMM -3B43 precipitation (1997-2010)
ERA-I 925 hPa winds (1997-2010)

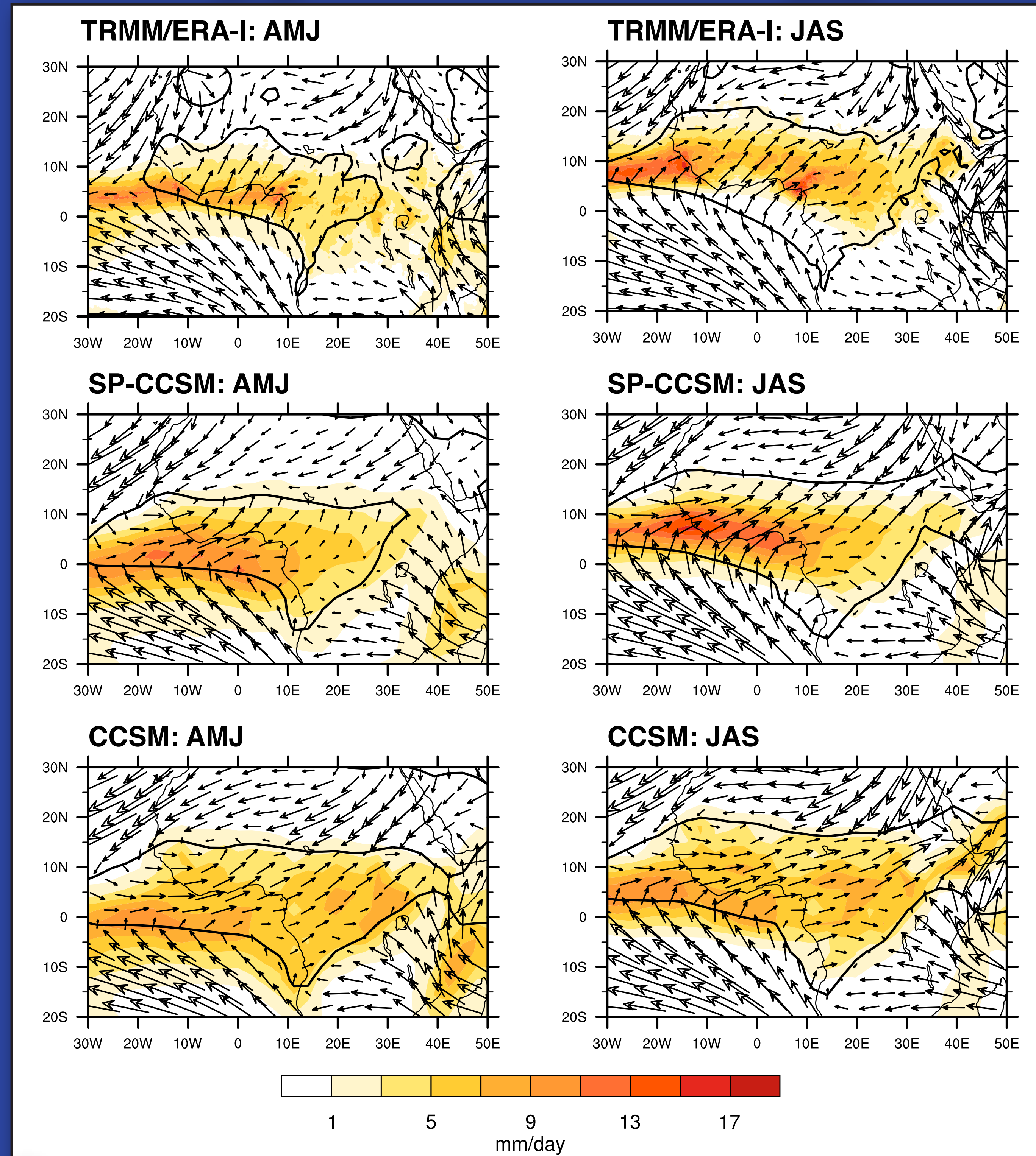


Seasonal Cycle of Rain

Precip. Avg. between 10ºW-5ºE

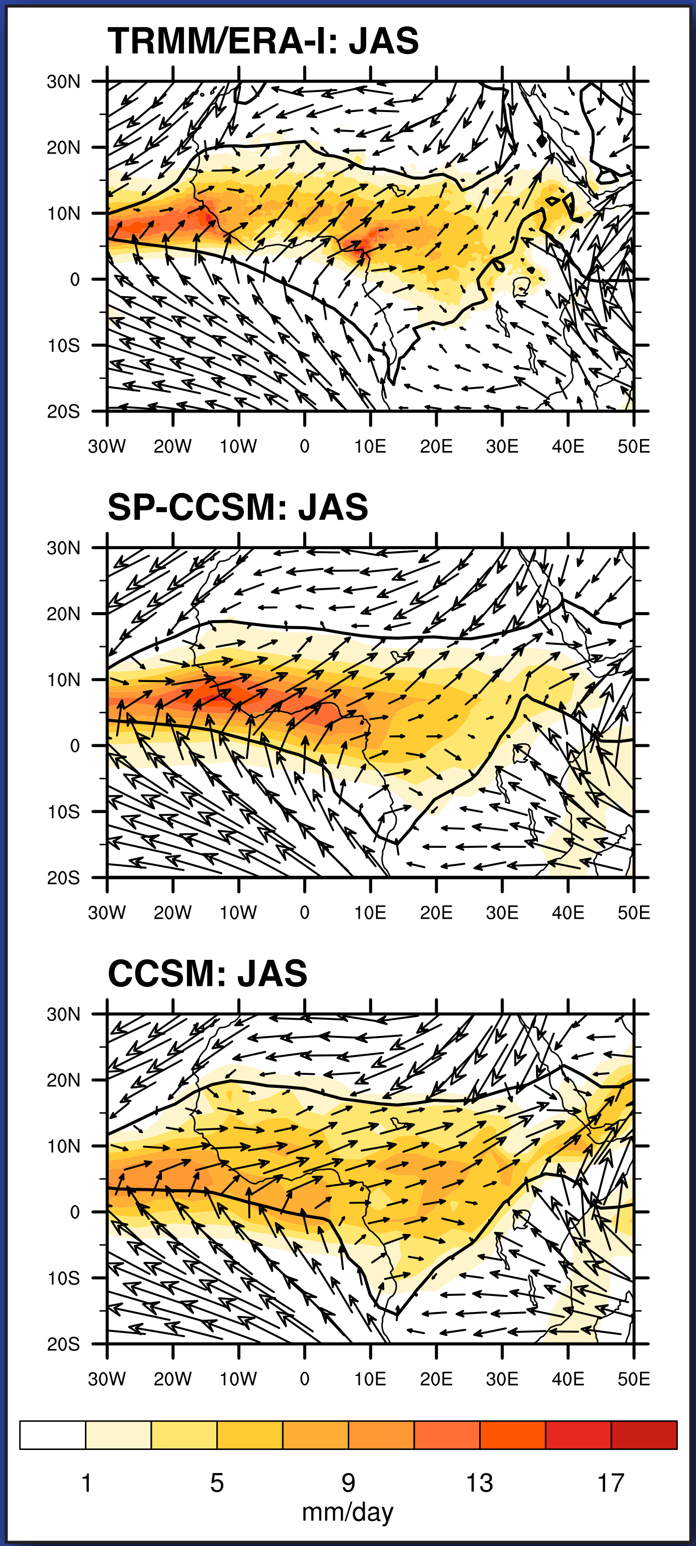


JFM JAS

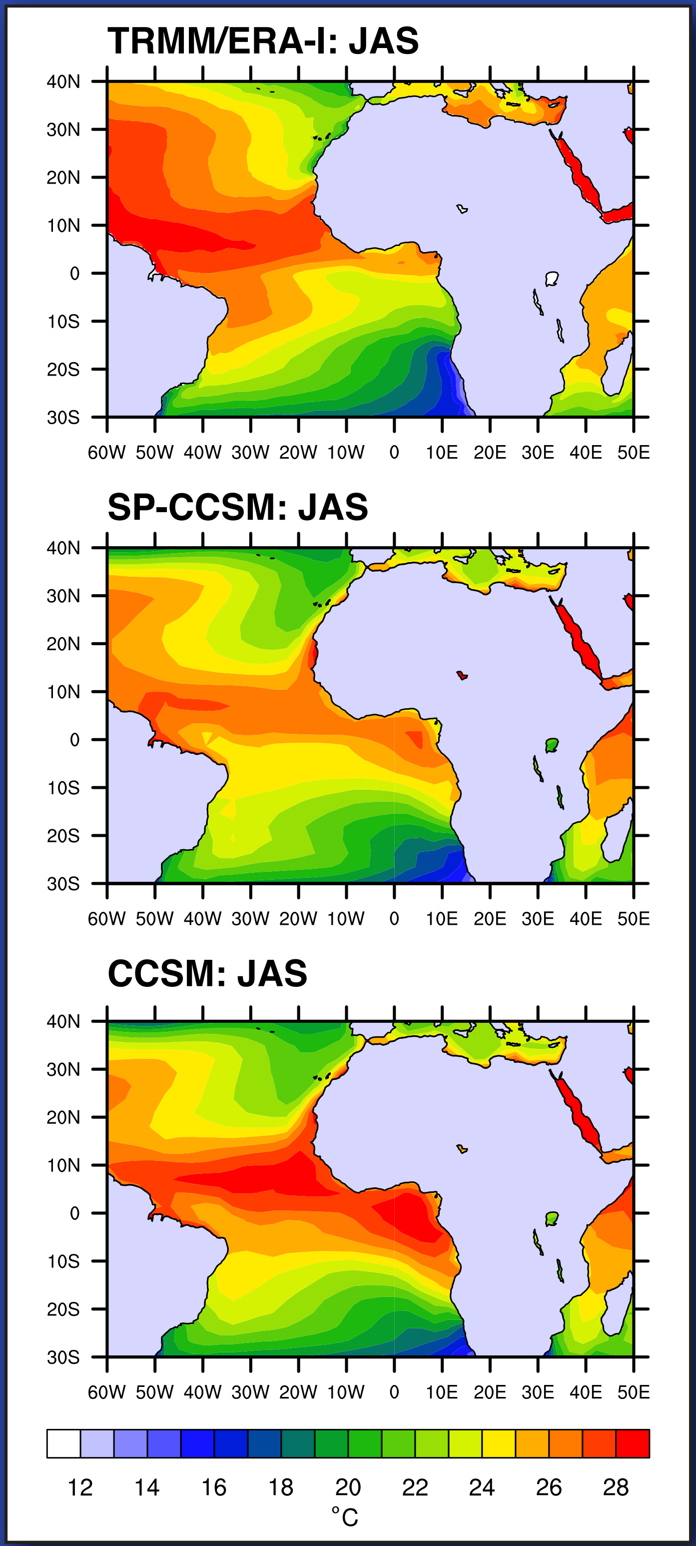


The Atlantic Cold Tongue

JAS Precipitation & Winds

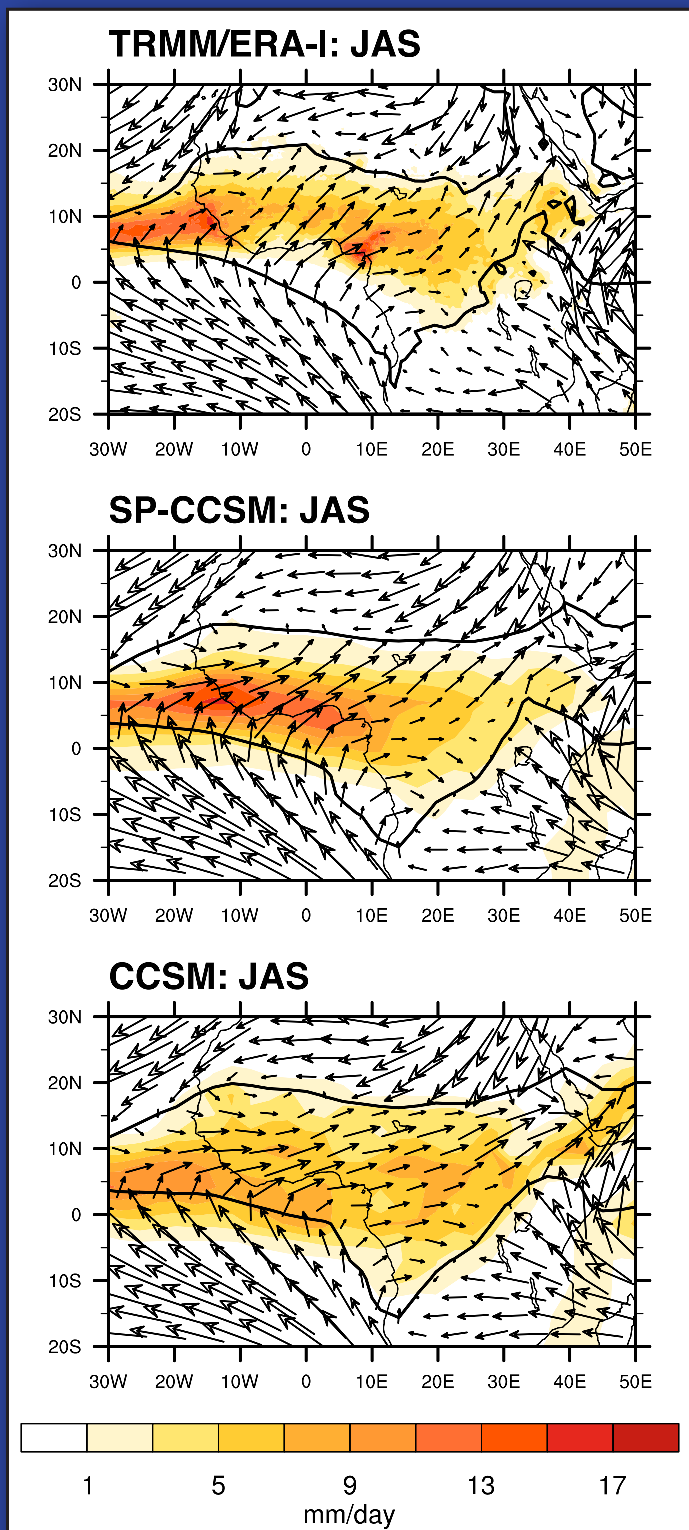


JAS SSTs

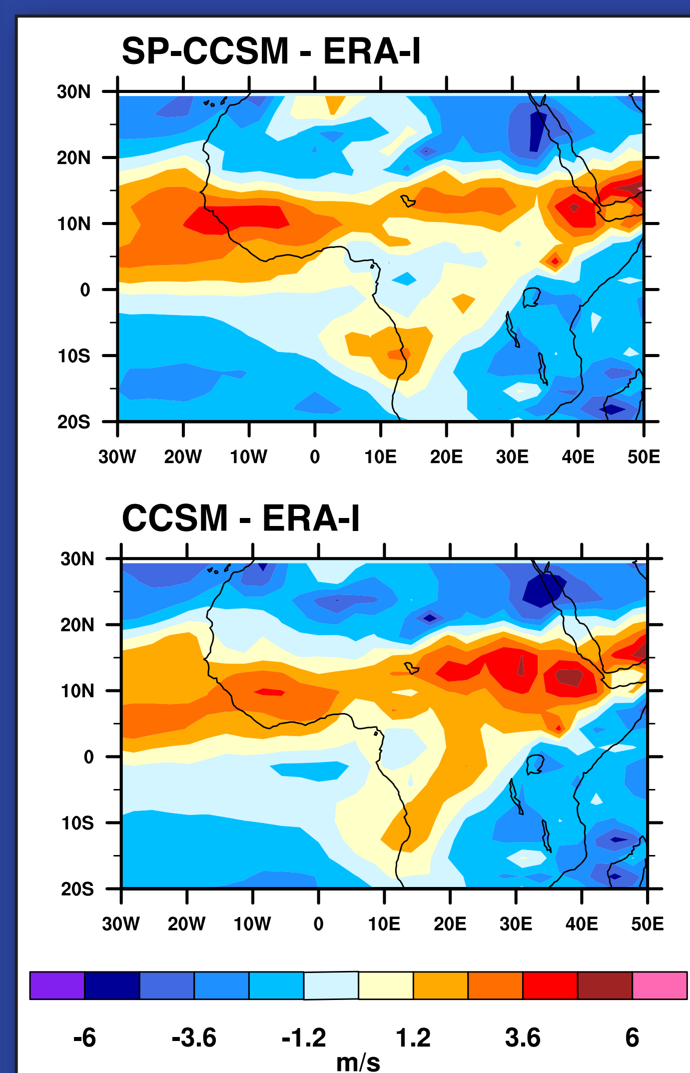


Zonal and Meridional Wind Biases

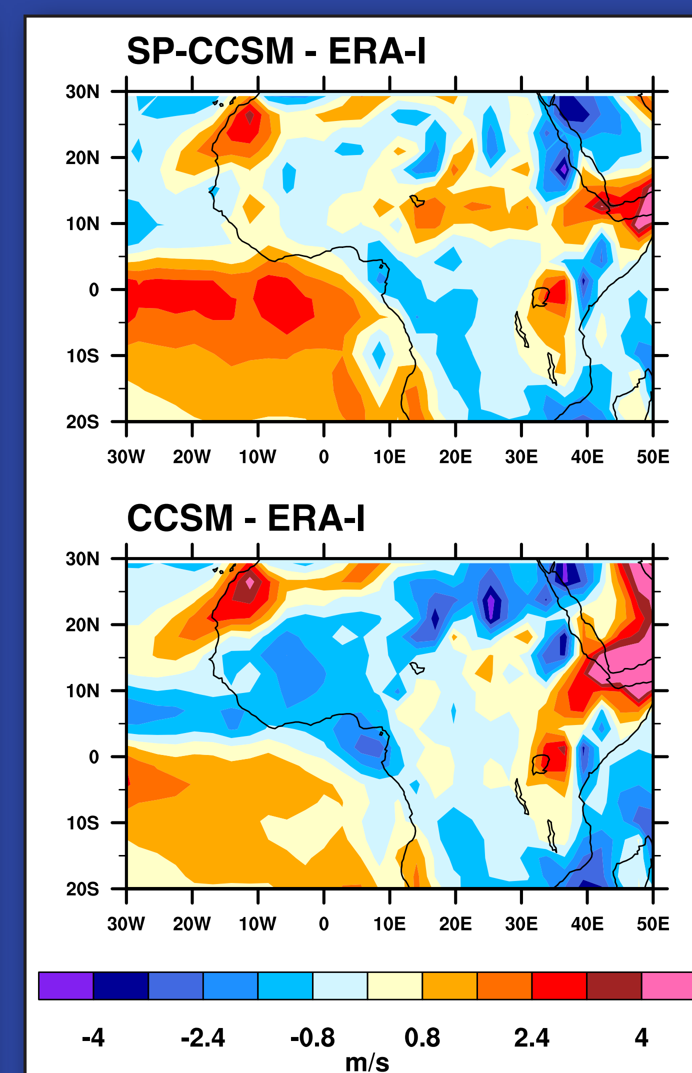
JAS Precipitation & Winds



JAS Zonal Wind Model - Observations

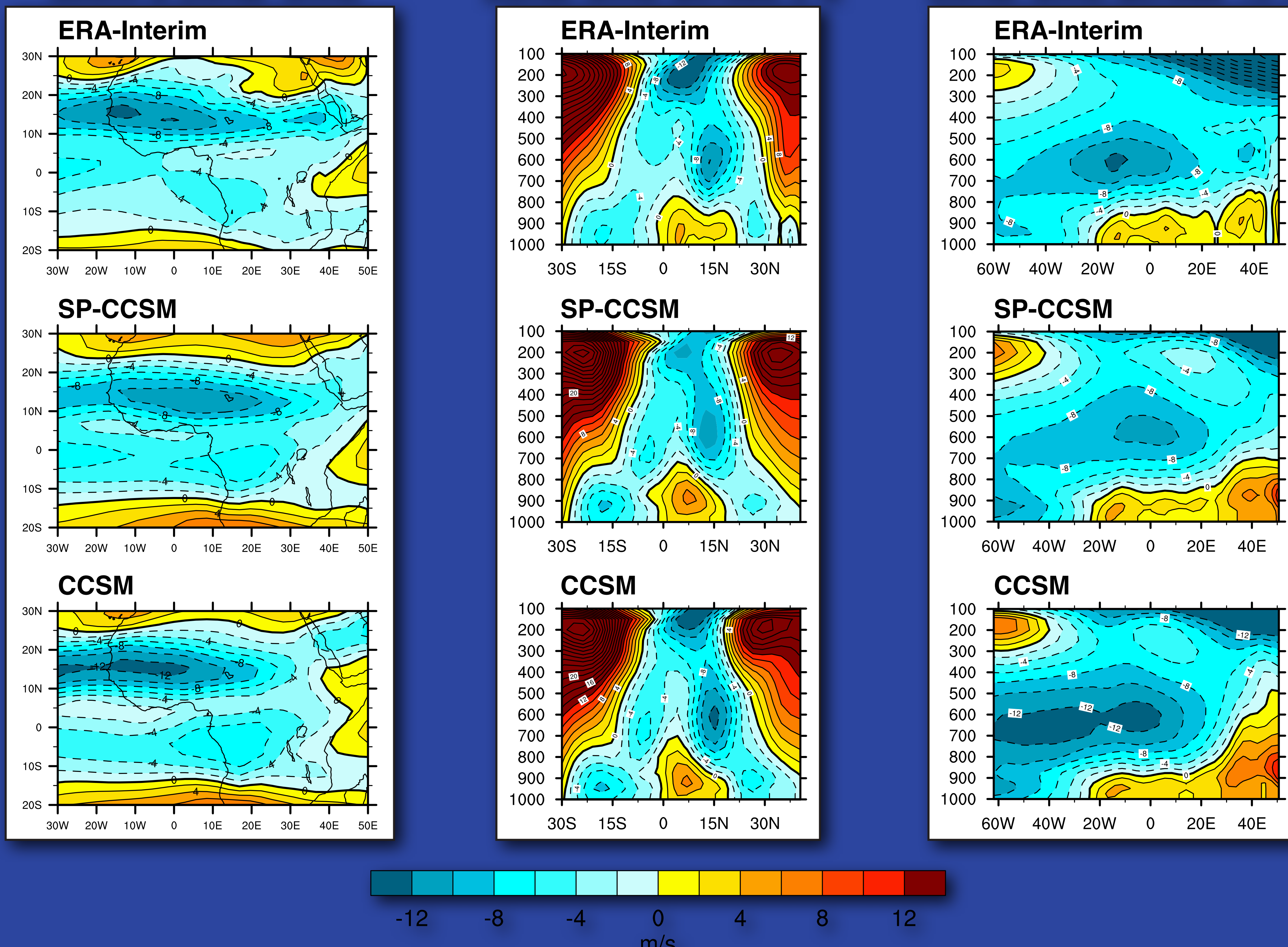


JAS Meridional Wind Model - Observations



African Easterly Jet

600hPa Zonal Wind | Zonal wind across 0ºE | Zonal wind across 15ºN



Thursday, August 9, 12

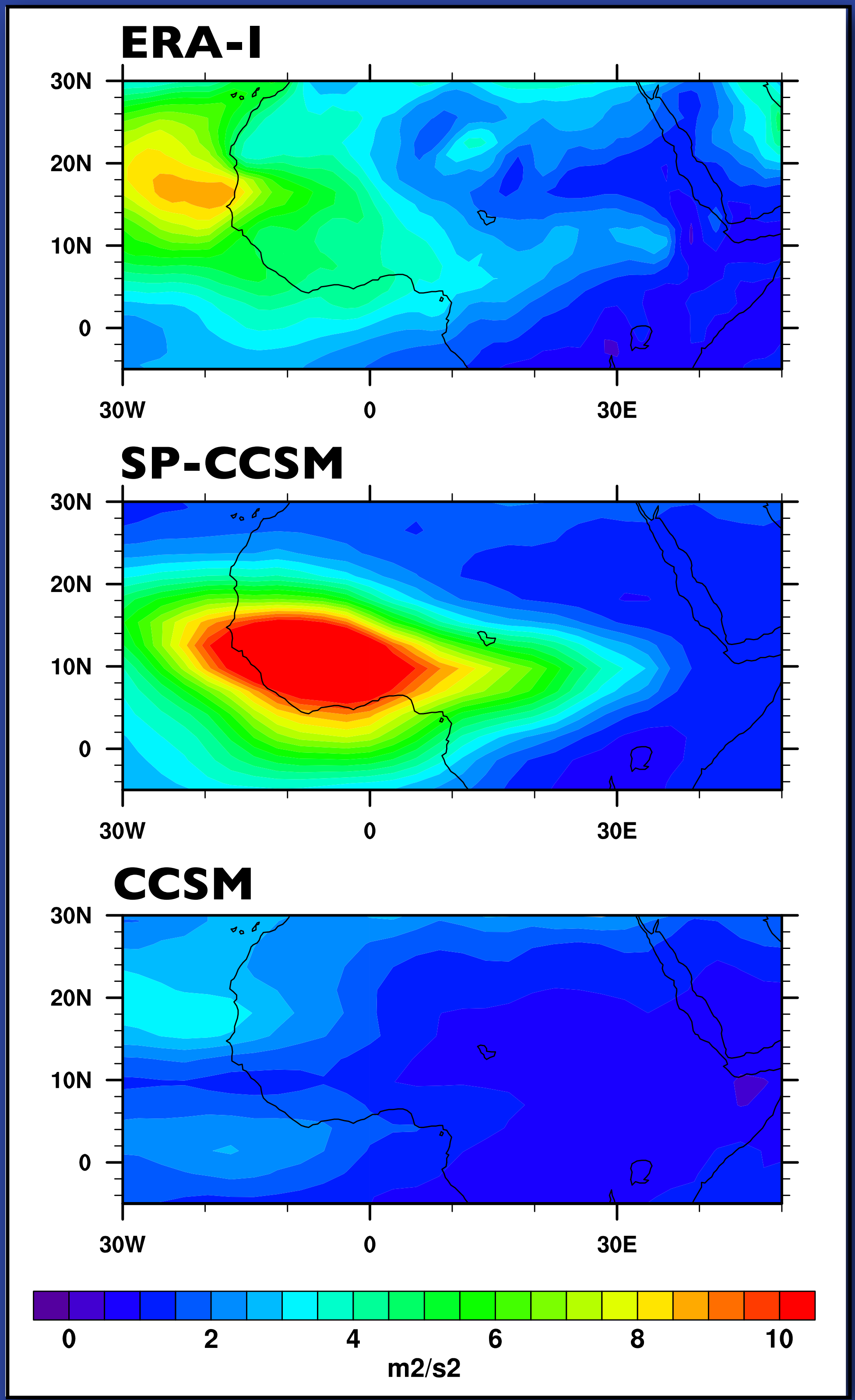
African Easterly Waves (AEWs)

- Barotropic-Baroclinic westward propagating disturbances with a period of 3-6 days and wavelengths of 2000-5000 km.
- Major source of atmospheric variability over West Africa.
- Organize precipitation on synoptic timescales.
- Coupling between convection and AEWs is not well understood.
- Often act to initiate hurricanes in the Atlantic.

Hurricane Ivan

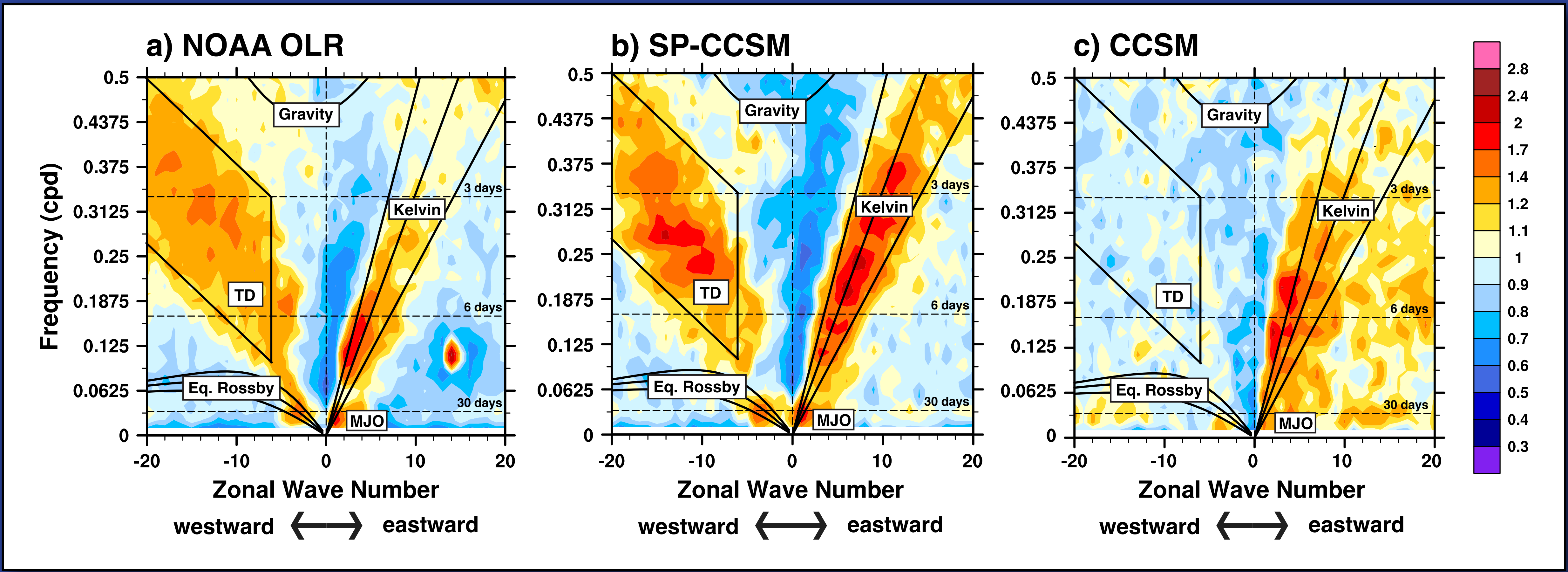
African Easterly Waves

Composite JAS variance of V-wind



- 2-6 day band-pass filtered variance of V-wind.
- SP-CCSM - overestimates AEW variability
- CCSM - no apparently AEW activity

Tropical convection is organized on similar time and spatial scales to observations.

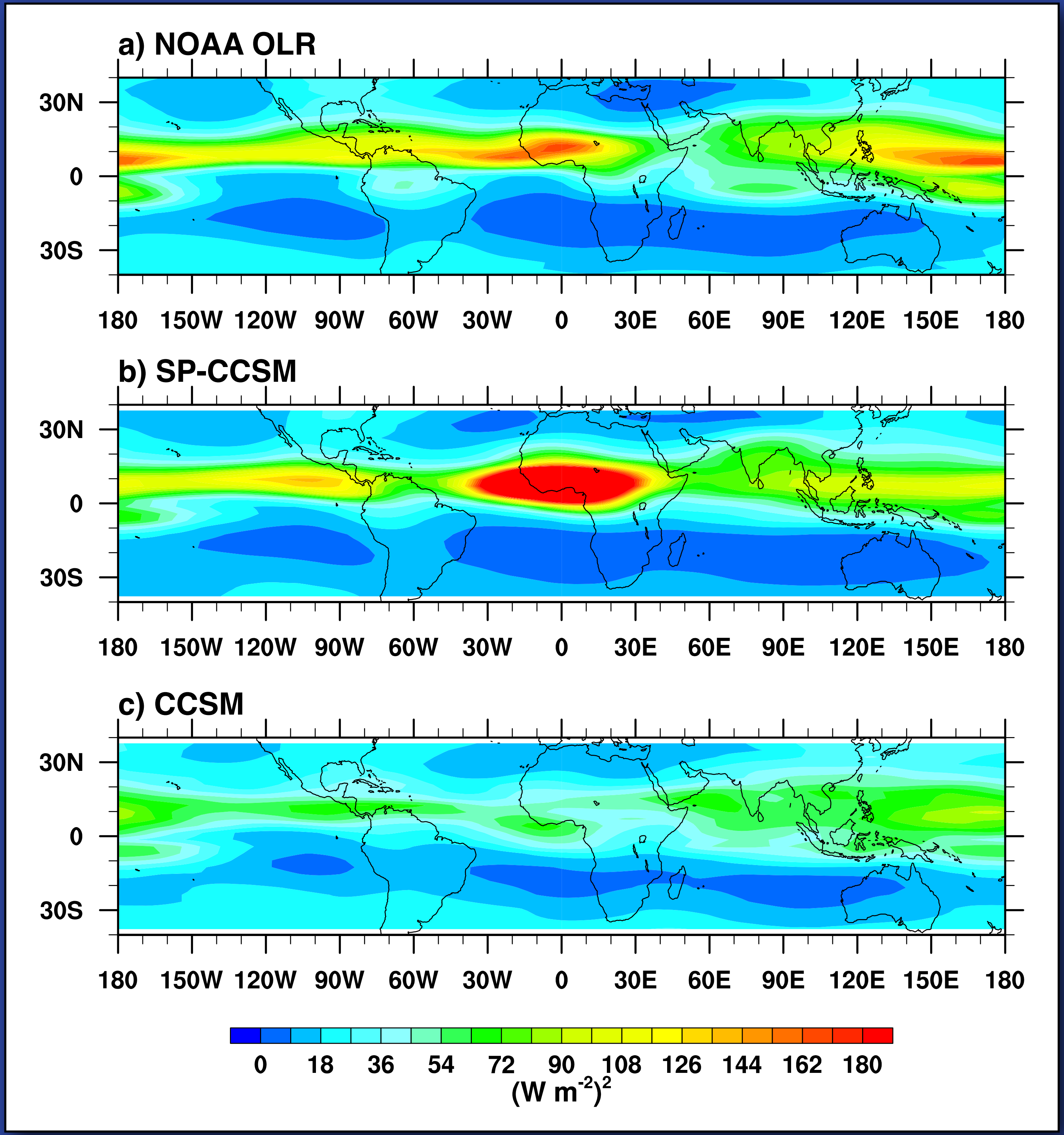


JJAS OLR symmetric signal-to-noise space time power spectra.

Calculated between 15ºN and 15ºS

JJAS Variance of TD Filtered OLR

SP-CCSM overestimates easterly wave activity over West Africa.



Variance of TD filtered OLR/ Total variance

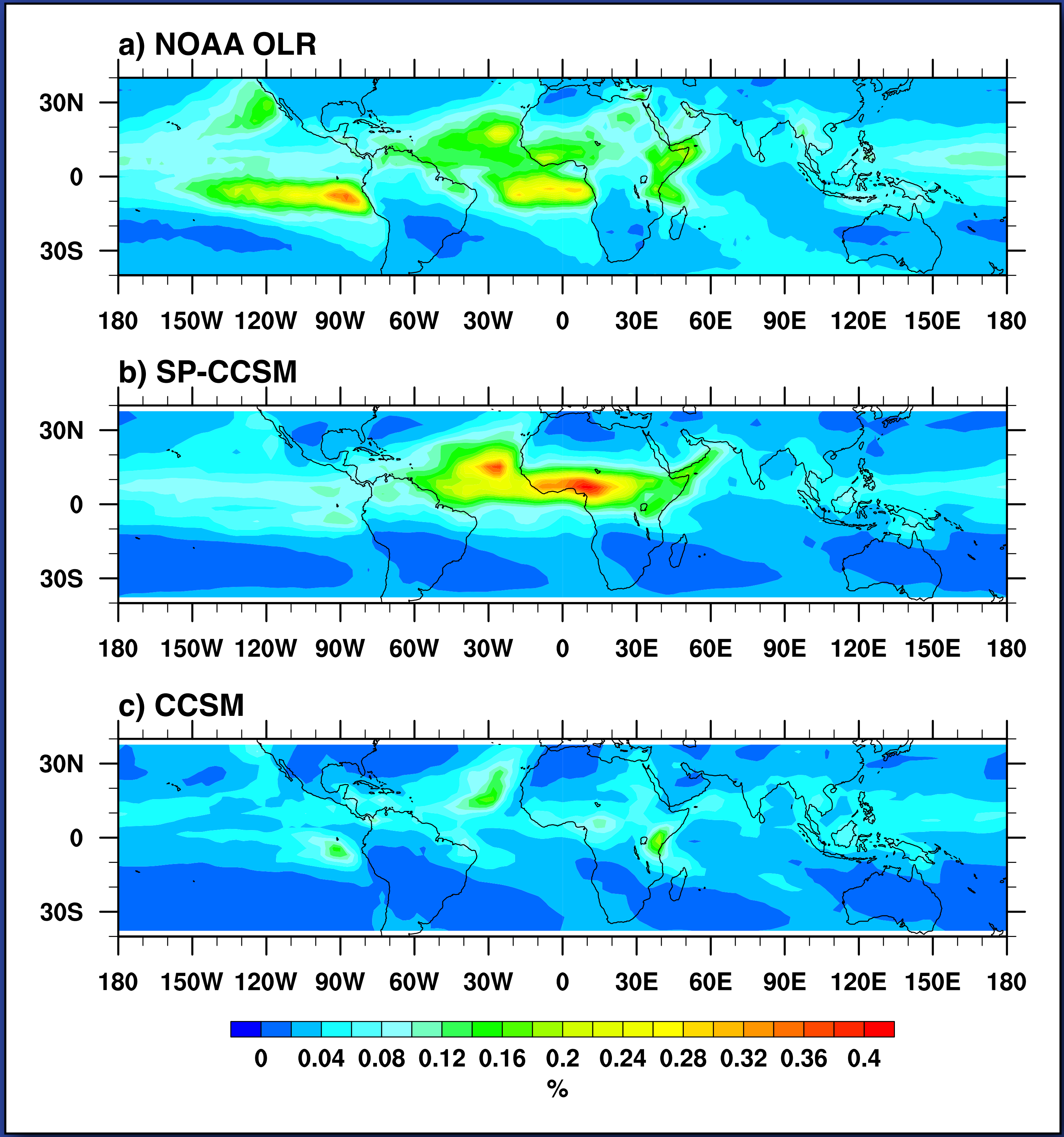
SP-CCSM overestimates easterly wave activity over West Africa.

TD filtered OLR describes:

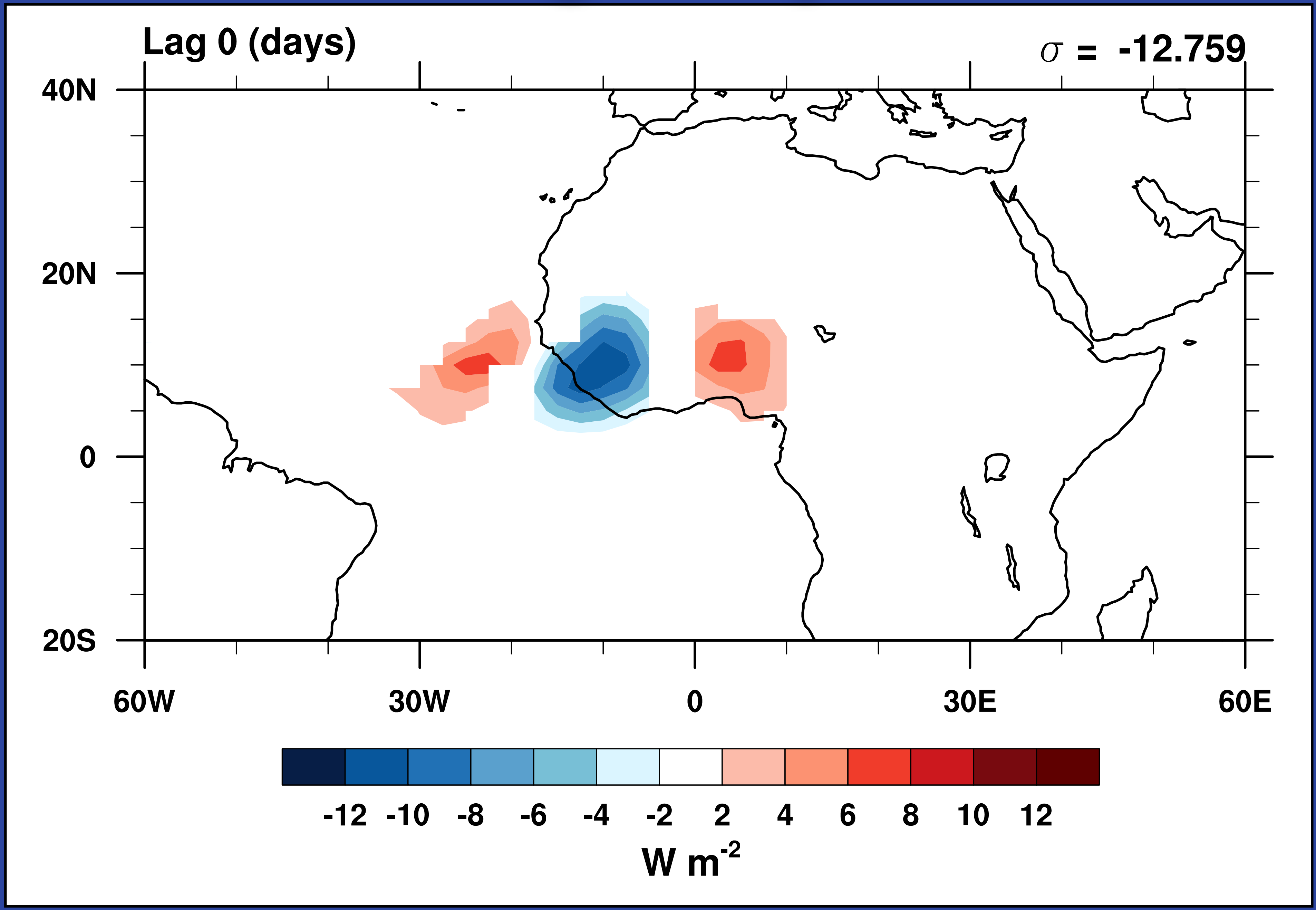
20-30% of total variance in observed OLR.

50-60% of total variance in SP-CCSM.

Less than 10% of the total variance in CCSM.



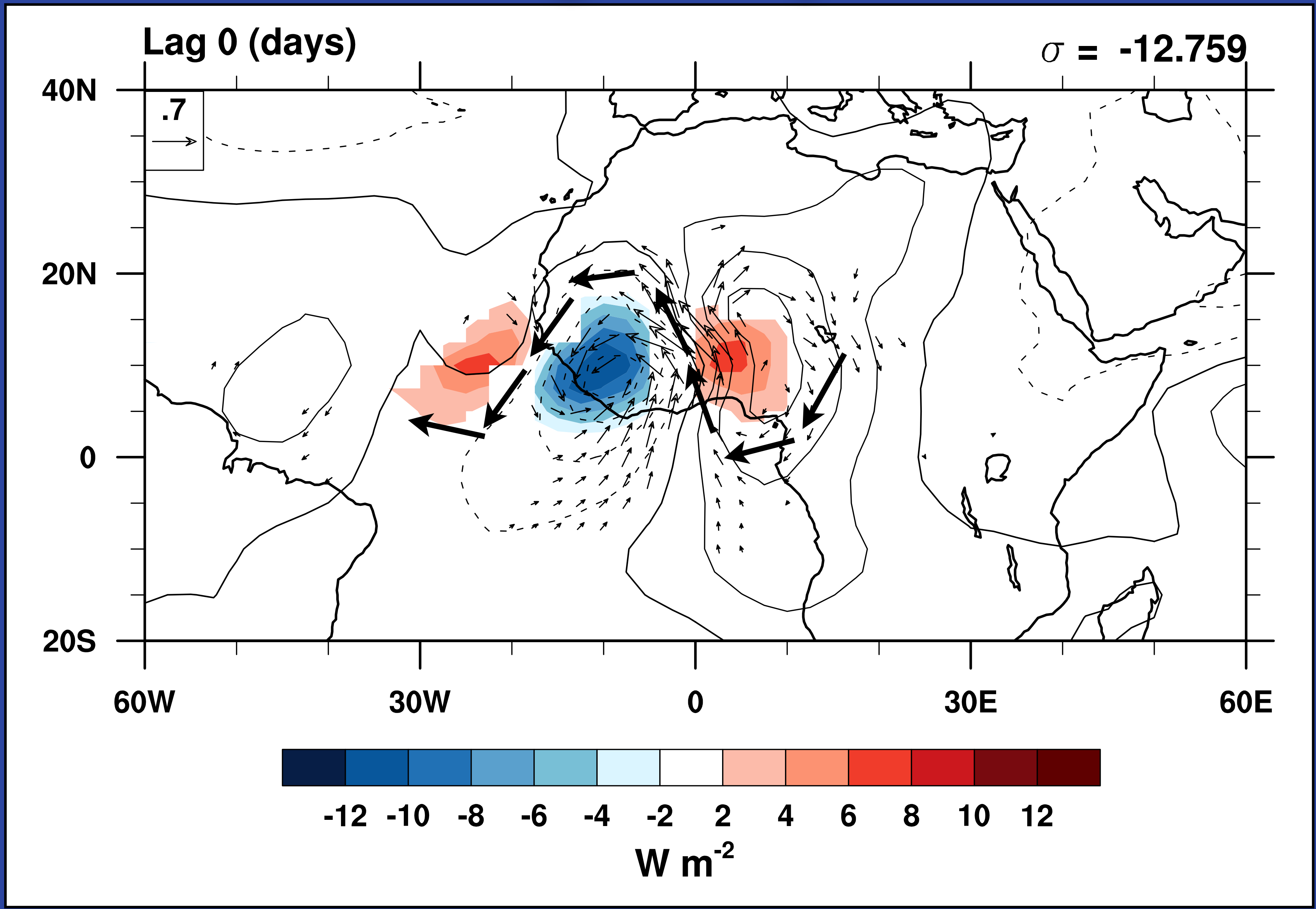
Horizontal Structure of AEWs
Lag 0 days



OLR anomalies regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

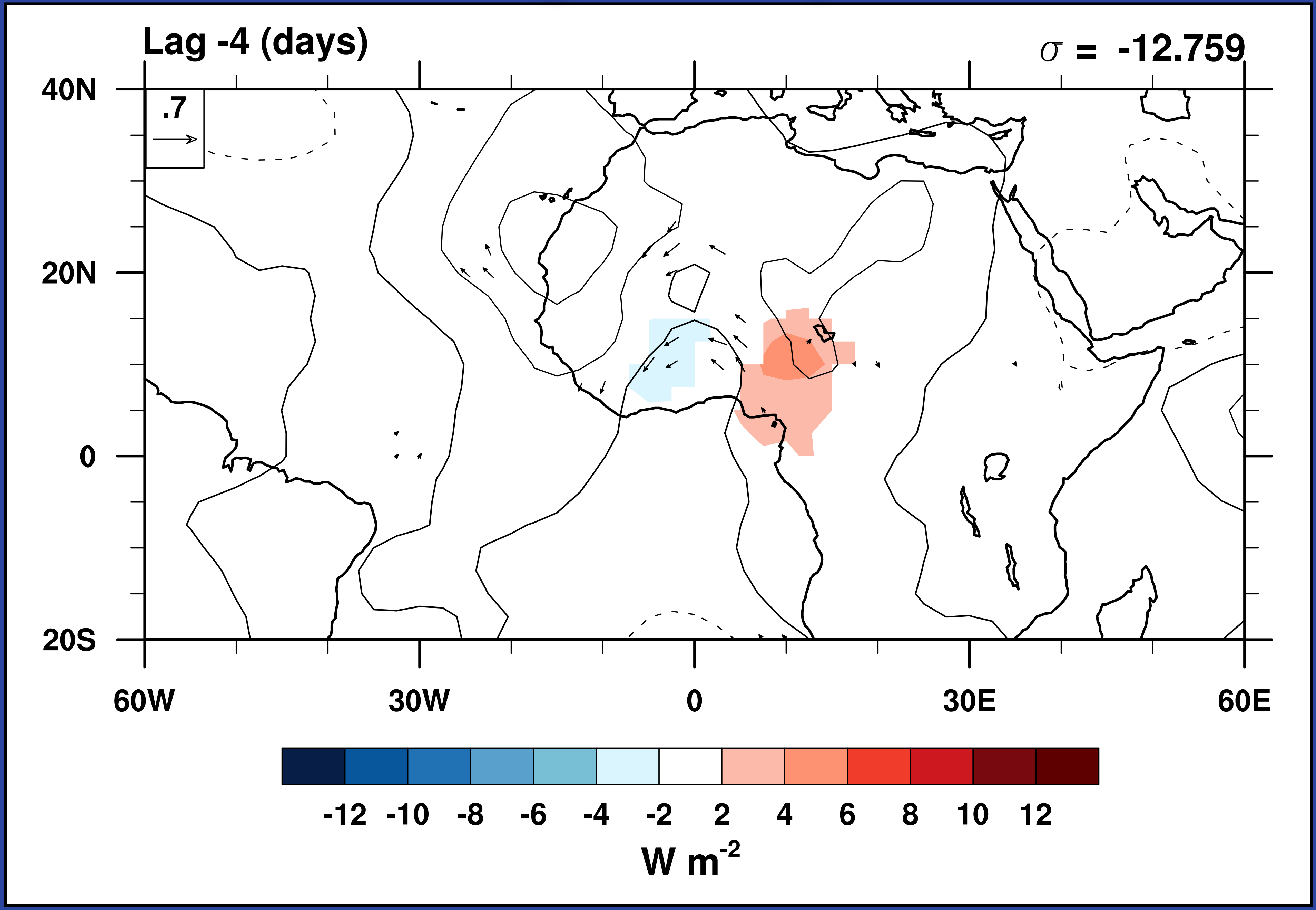
Horizontal Structure of AEWs
Lag 0 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

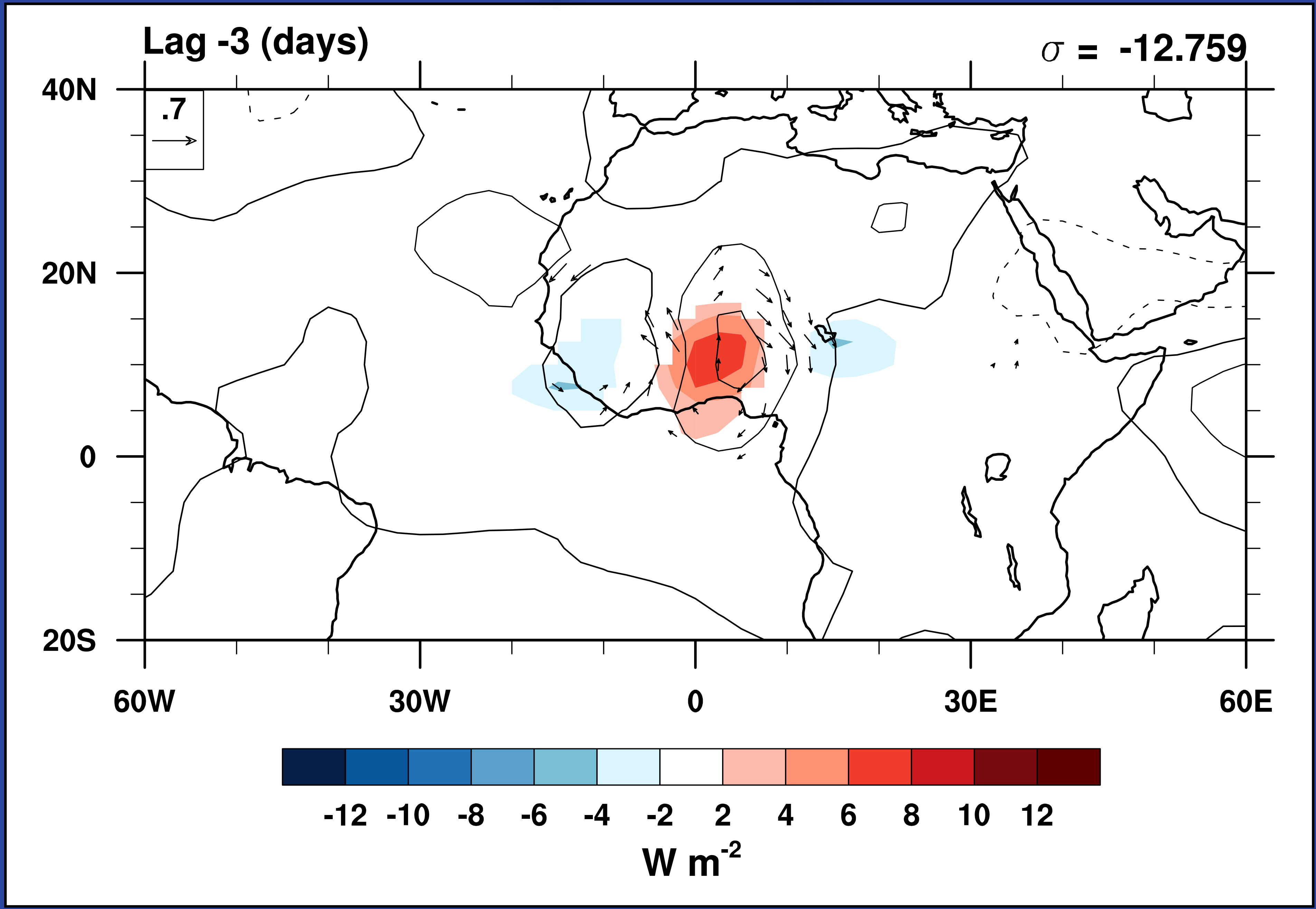
Horizontal Structure of AEWs
Lag -4 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

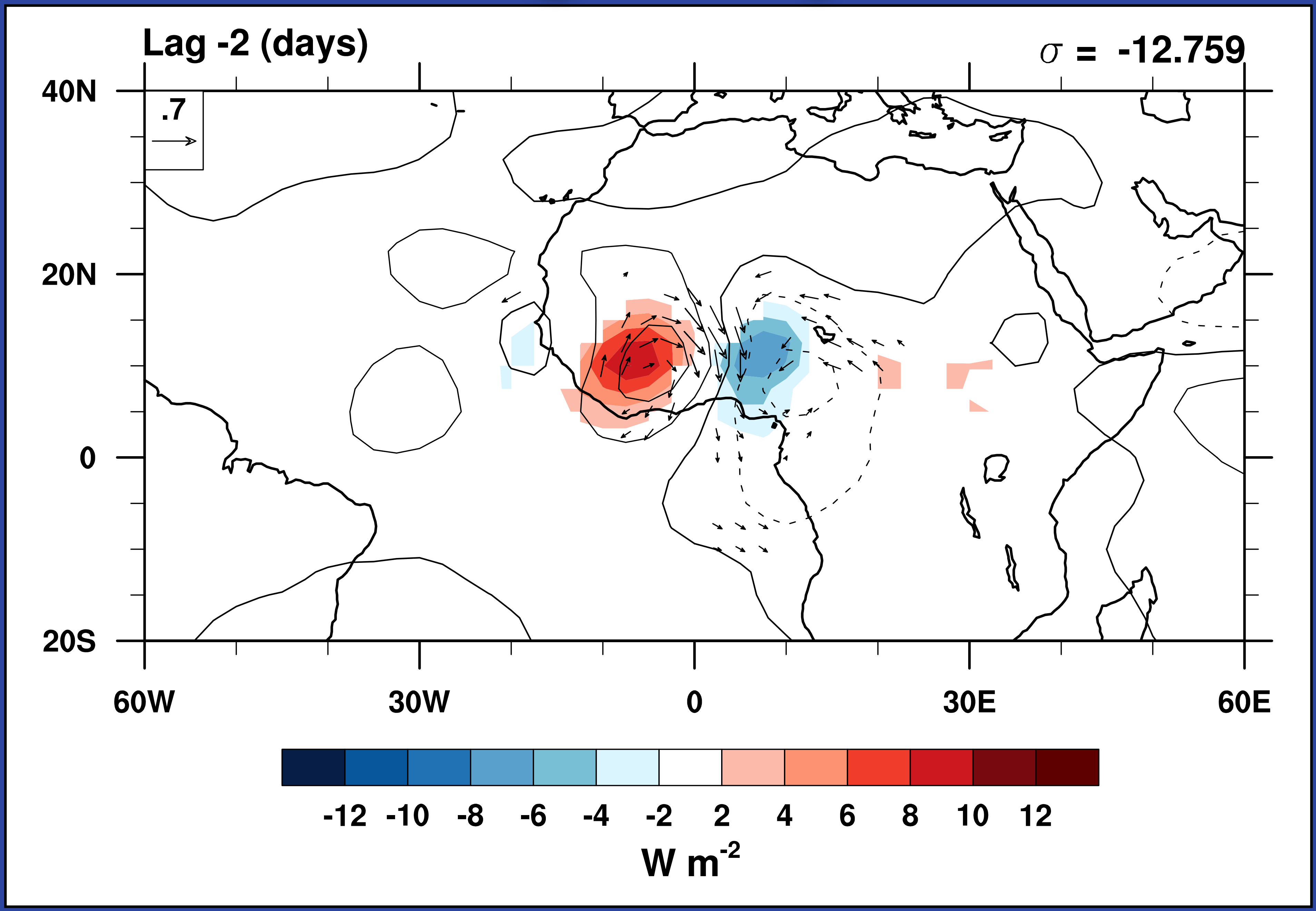
Horizontal Structure of AEWs
Lag -3 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

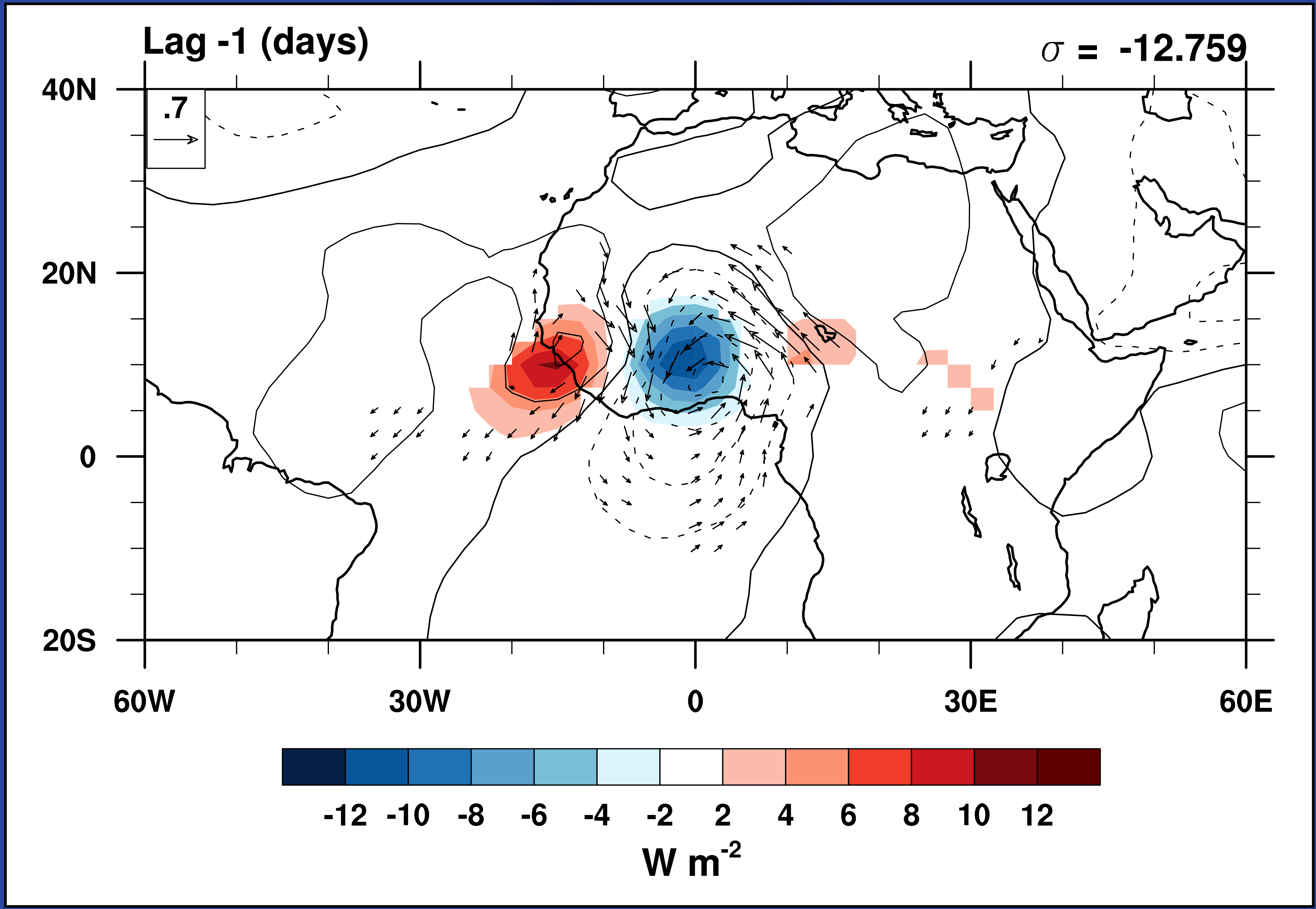
Horizontal Structure of AEWs
Lag -2 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

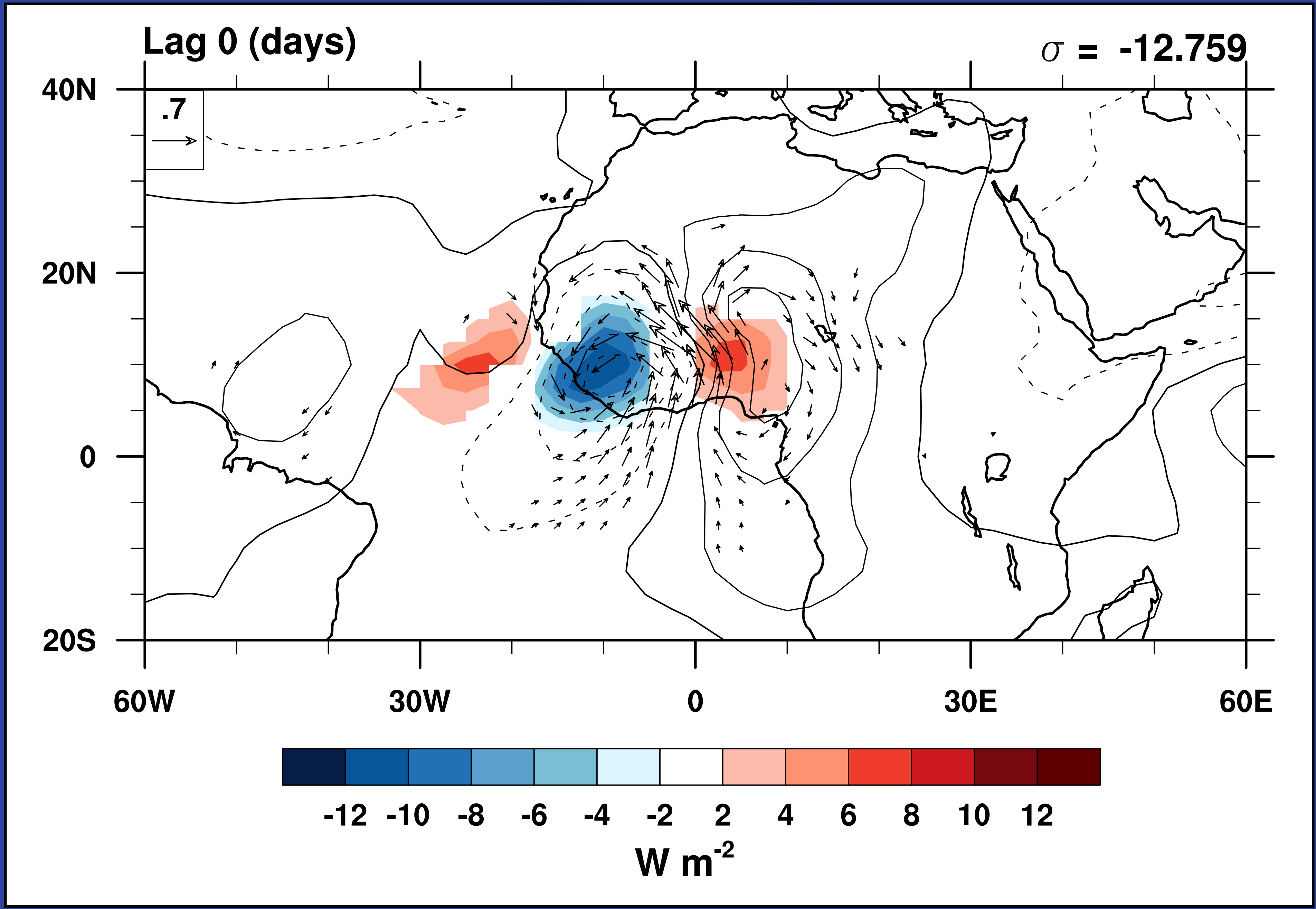
Horizontal Structure of AEWs
Lag -1 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

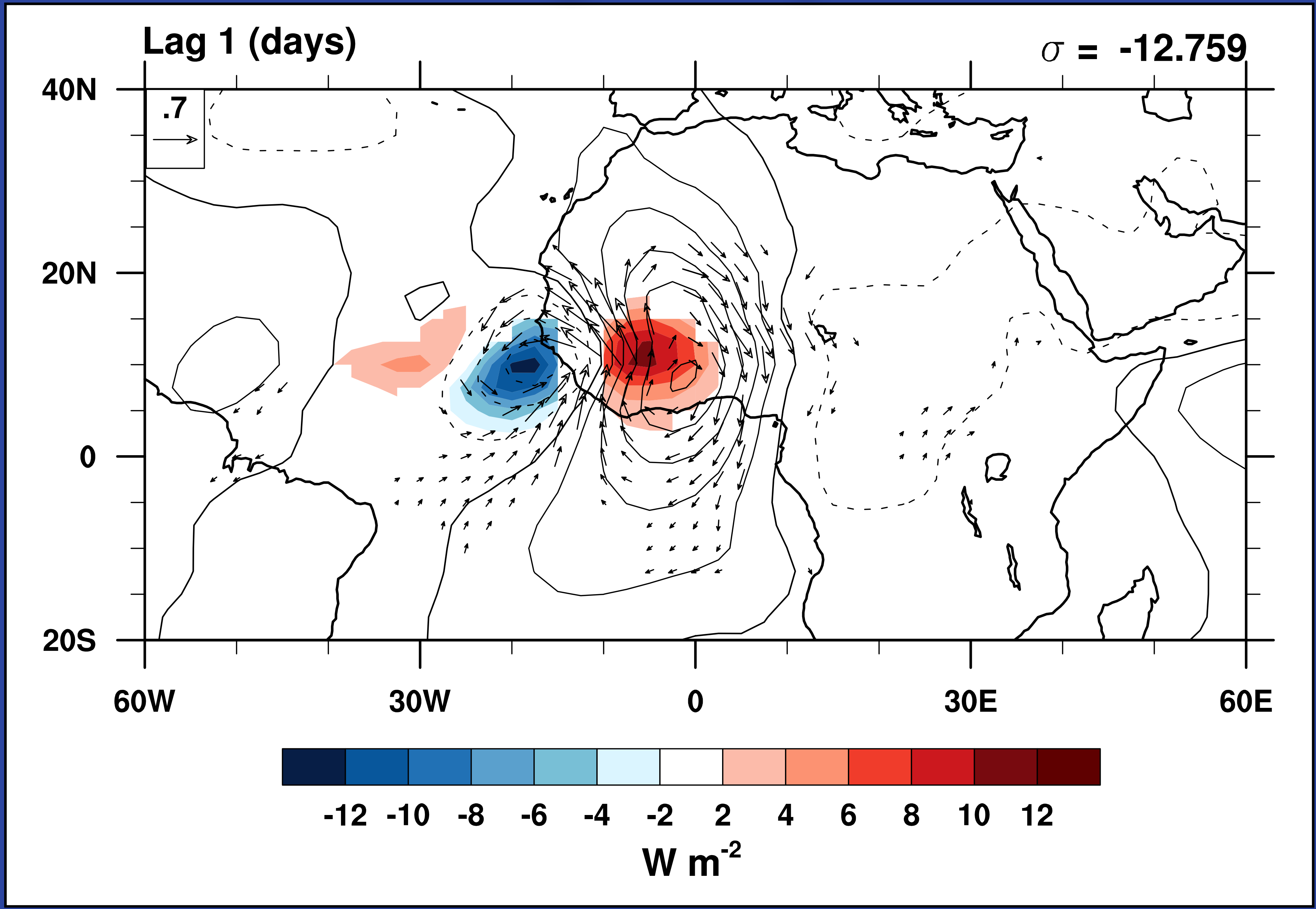
Horizontal Structure of AEWs
Lag 0 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

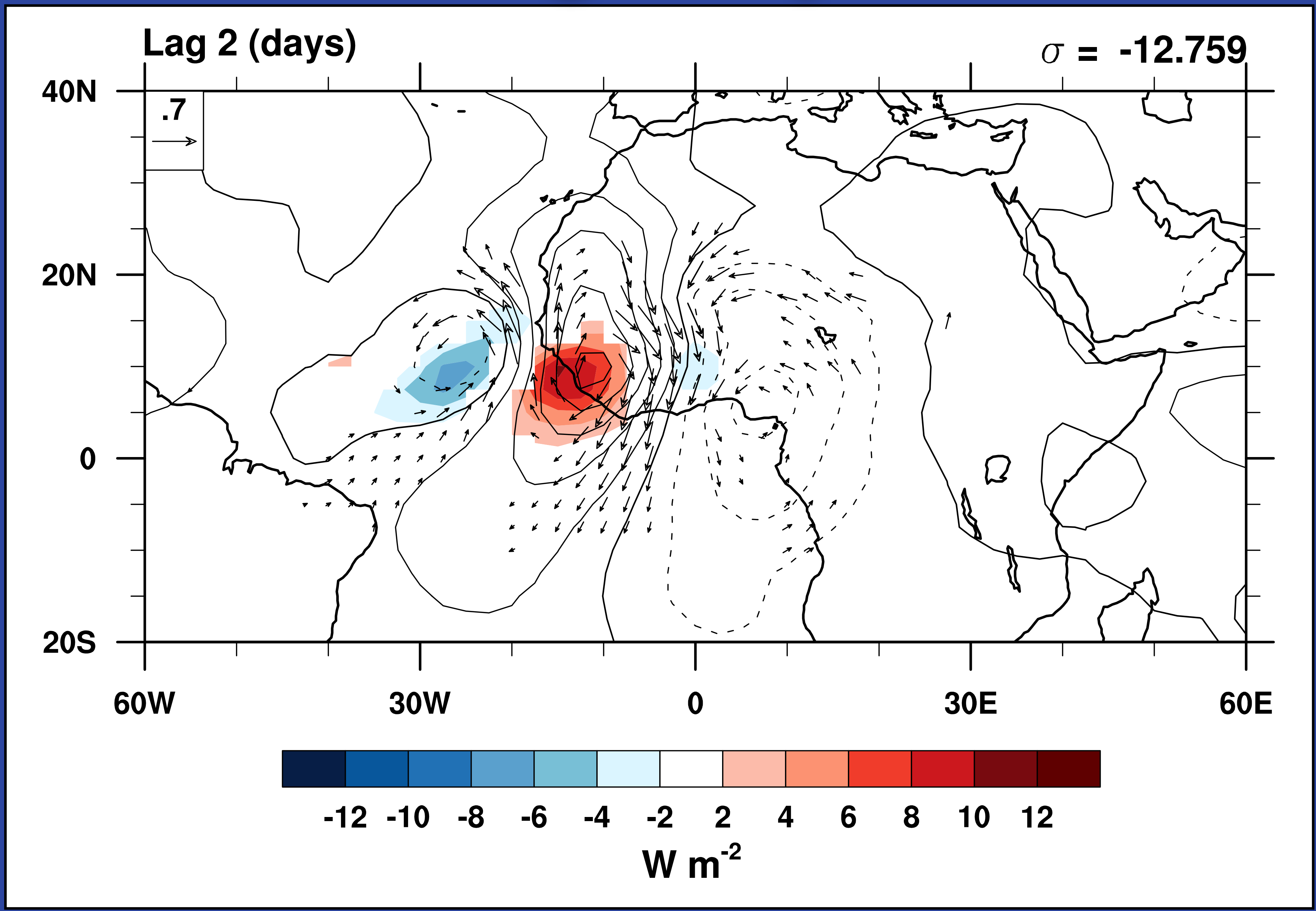
Horizontal Structure of AEWs
Lag 1 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

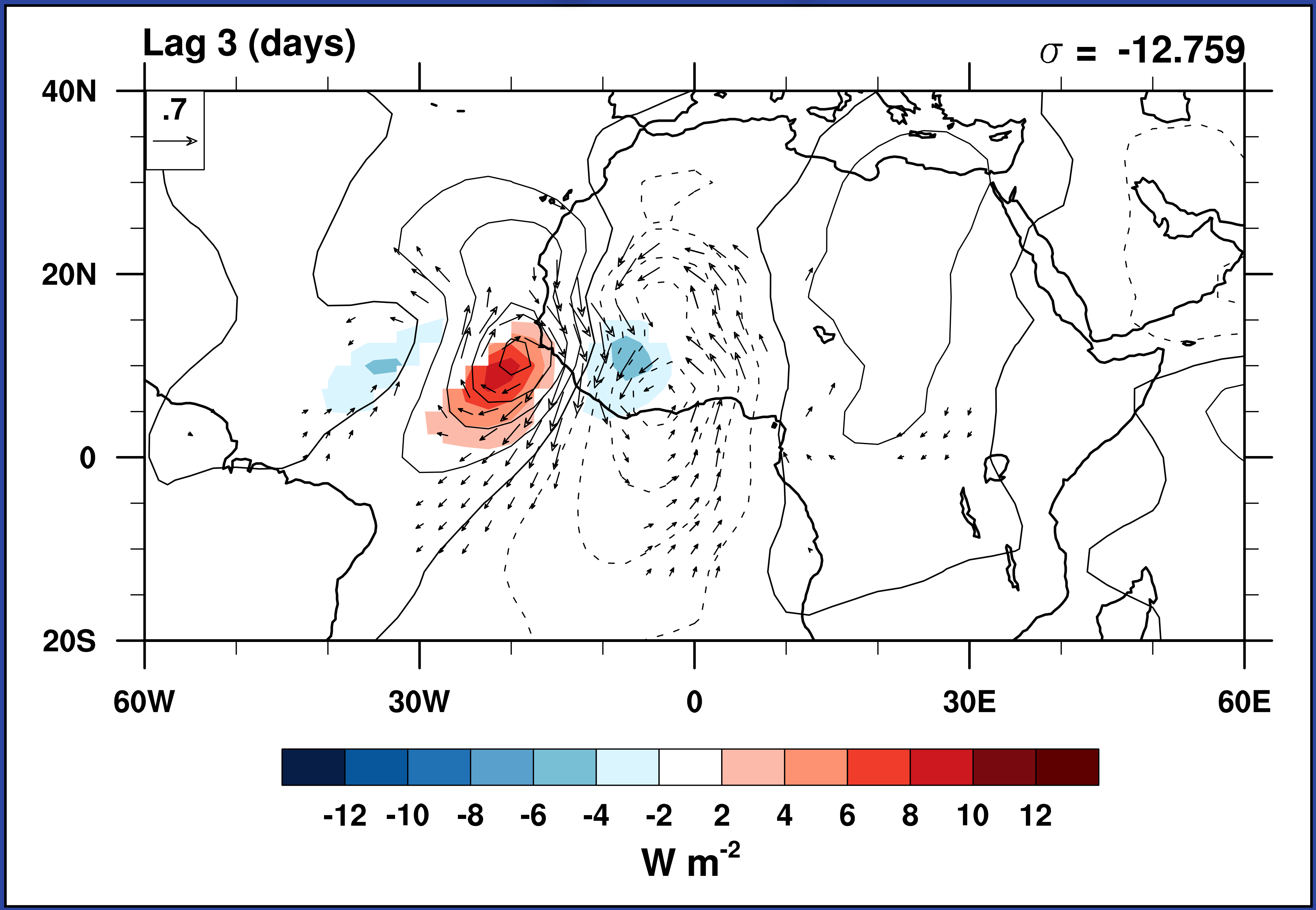
Horizontal Structure of AEWs
Lag 2 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

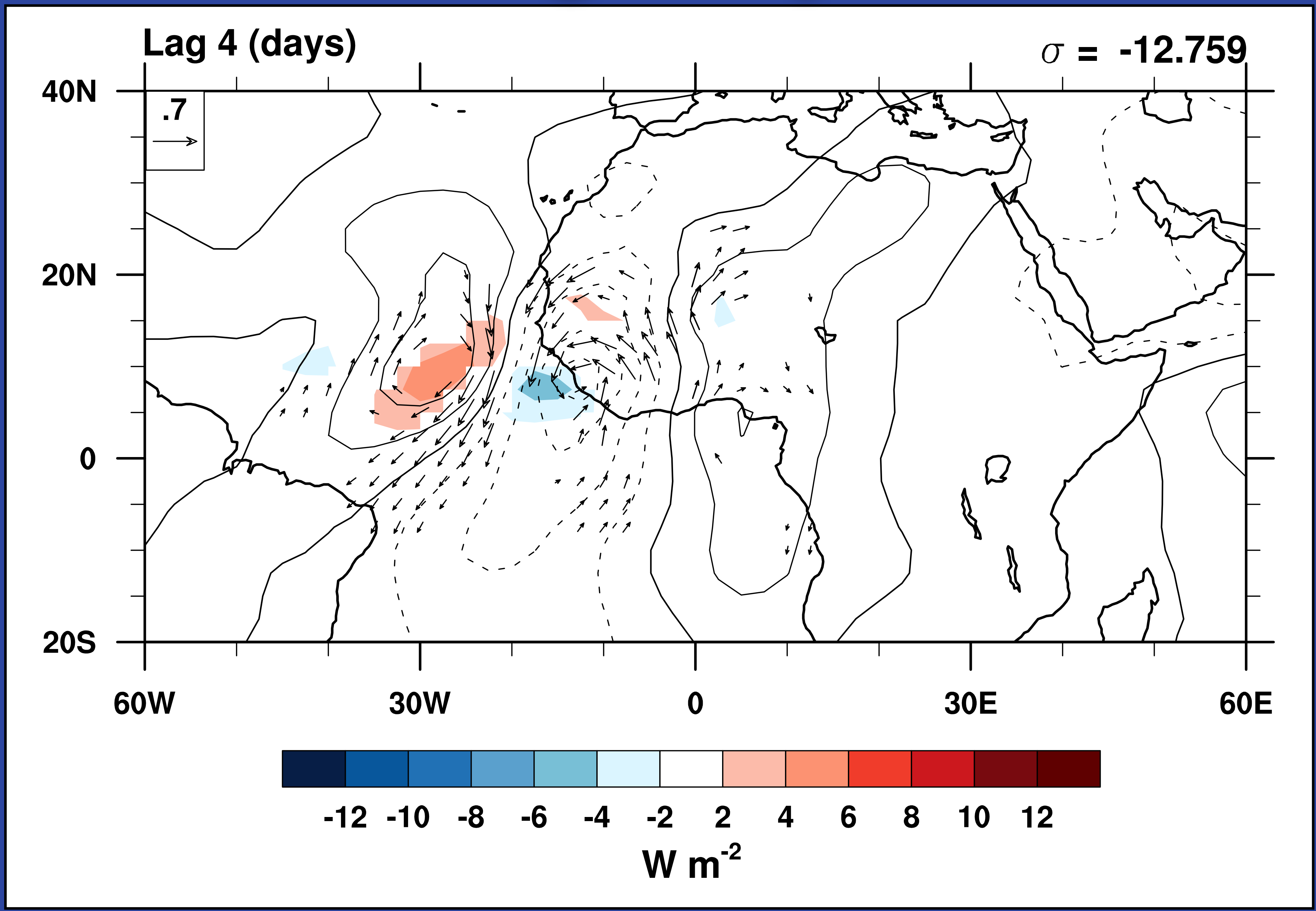
Horizontal Structure of AEWs
Lag 3 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

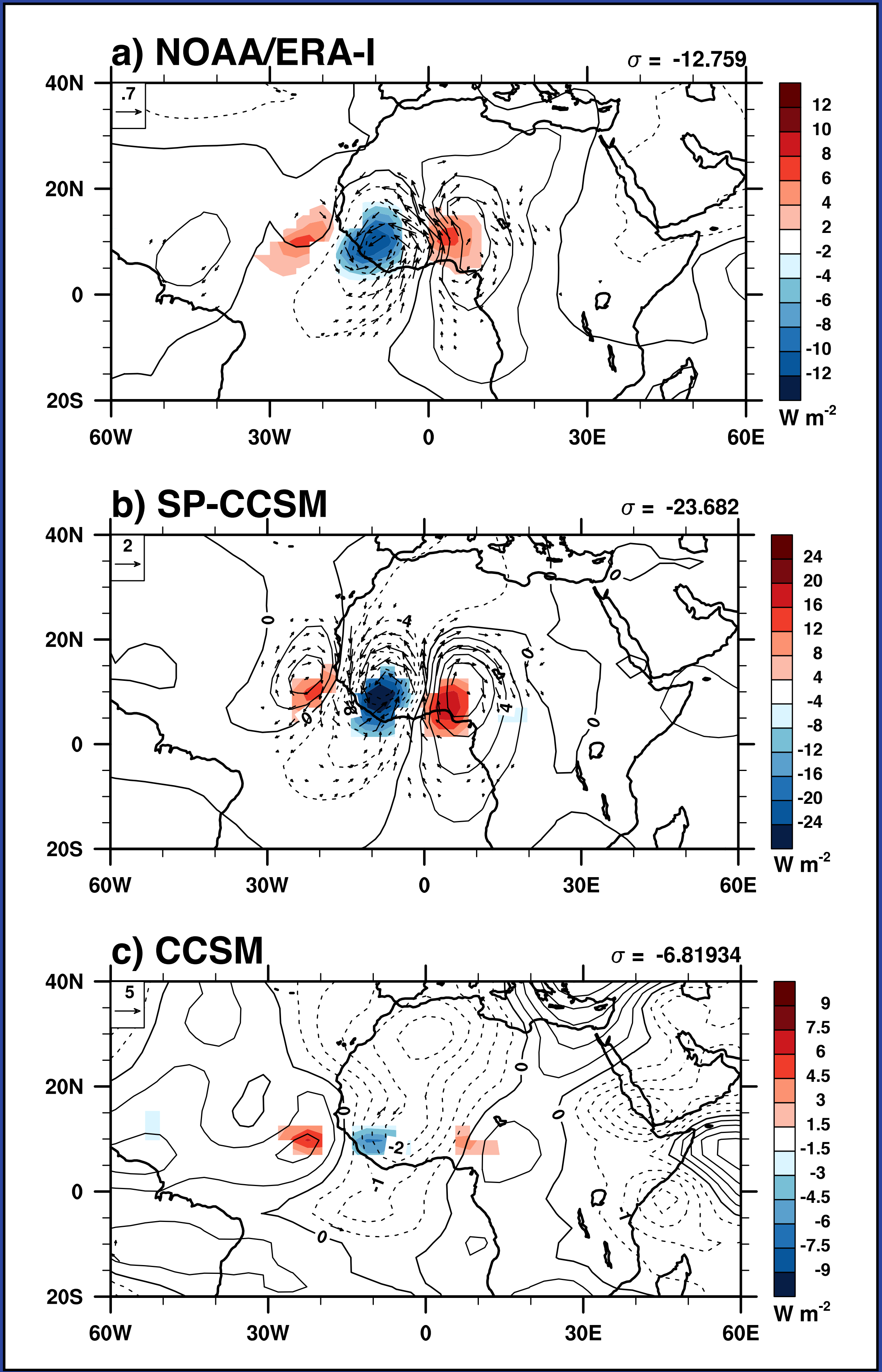
Horizontal Structure of AEWs
Lag 4 days



OLR and 850hPa circulation regressed against the TD filtered OLR time series (scaled by 1 sigma) at 10ºN, 10ºW for JJAS.

Methods similar to Kiladis et al. 2006

Horizontal Structure of AEWs Lag 0 days



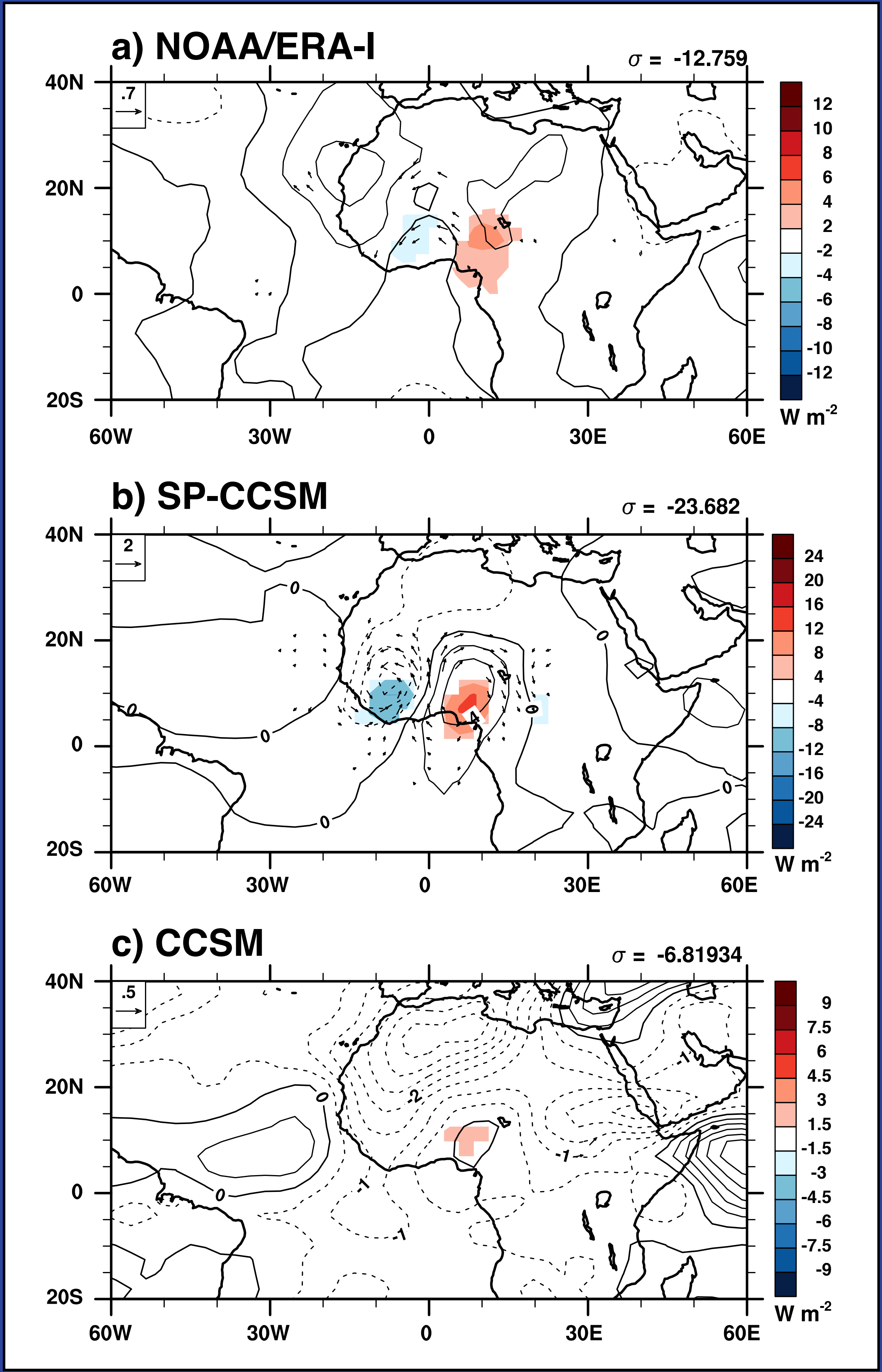
** Change in scale for each figure**

Only the statistically significant relationships (95% confidence) for OLR and vector winds are shown.

No statistically significant circulation patterns found in CCSM

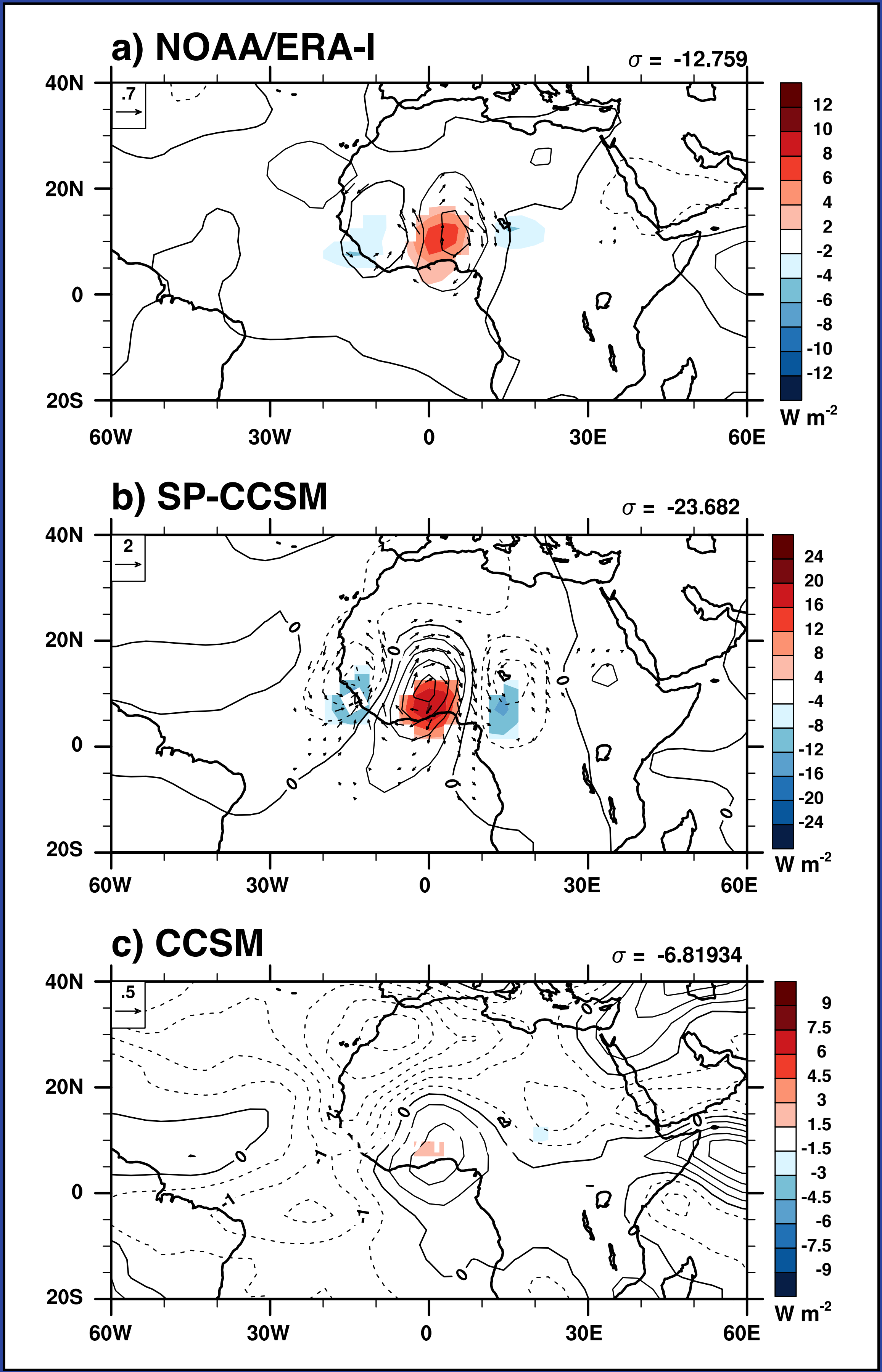
Methods similar to Kiladis et al. 2006

Horizontal Structure of AEWs
Lag -4 days



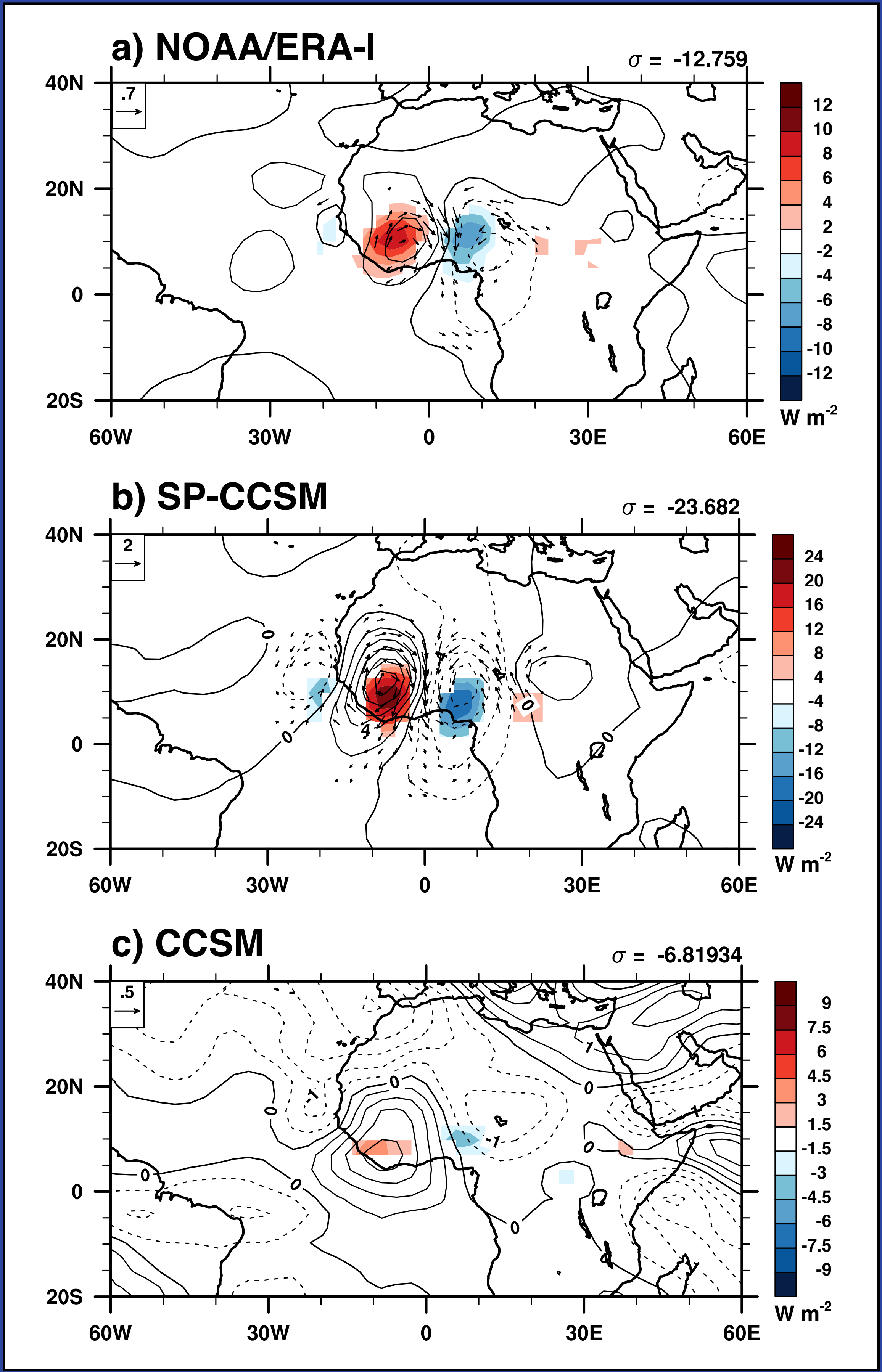
** Change in scale for each figure**

Horizontal Structure of AEWs Lag -3 days



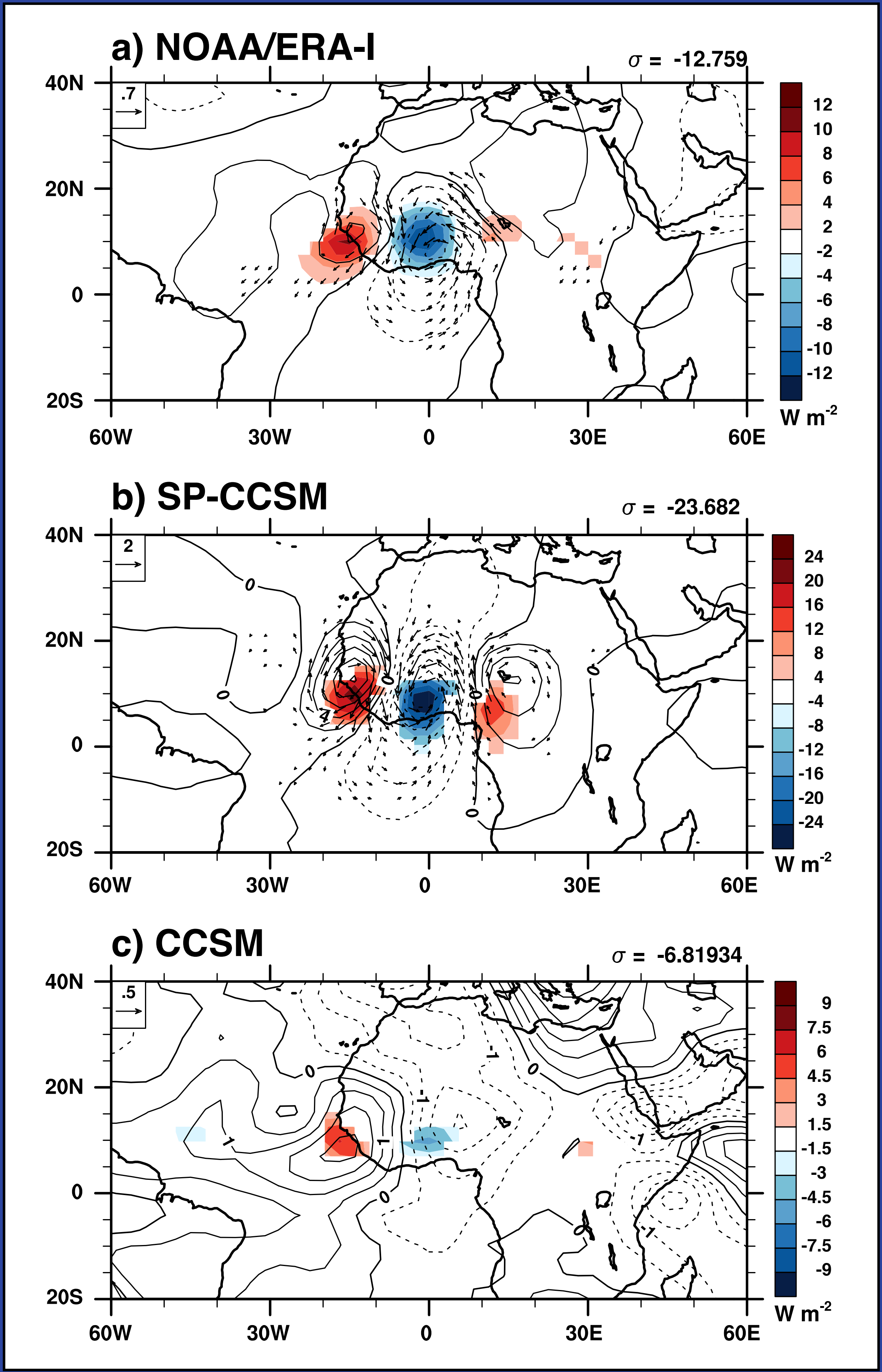
** Change in scale for each figure**

Horizontal Structure of AEWs Lag -2 days



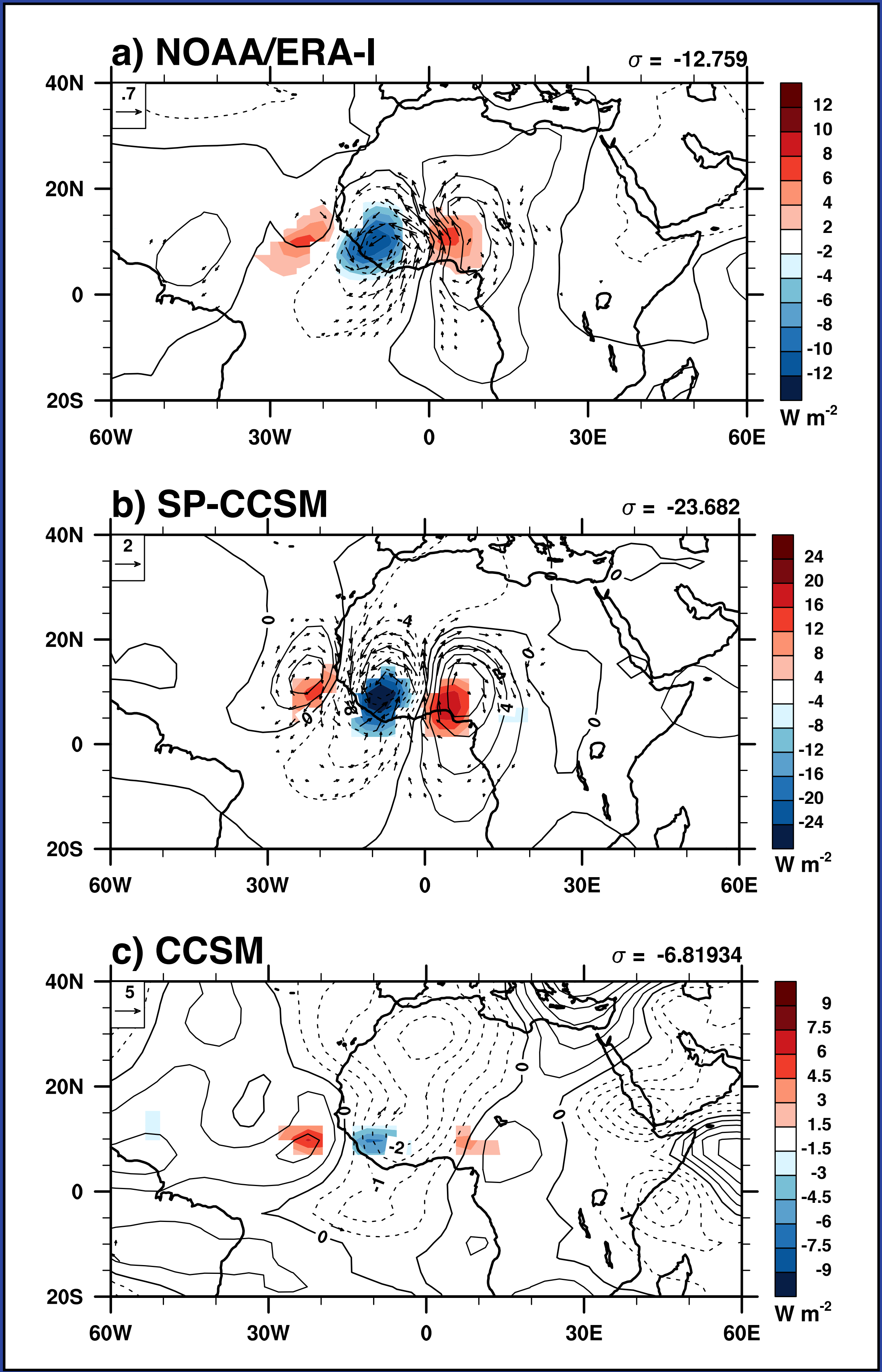
** Change in scale for each figure**

Horizontal Structure of AEWs Lag -1 days



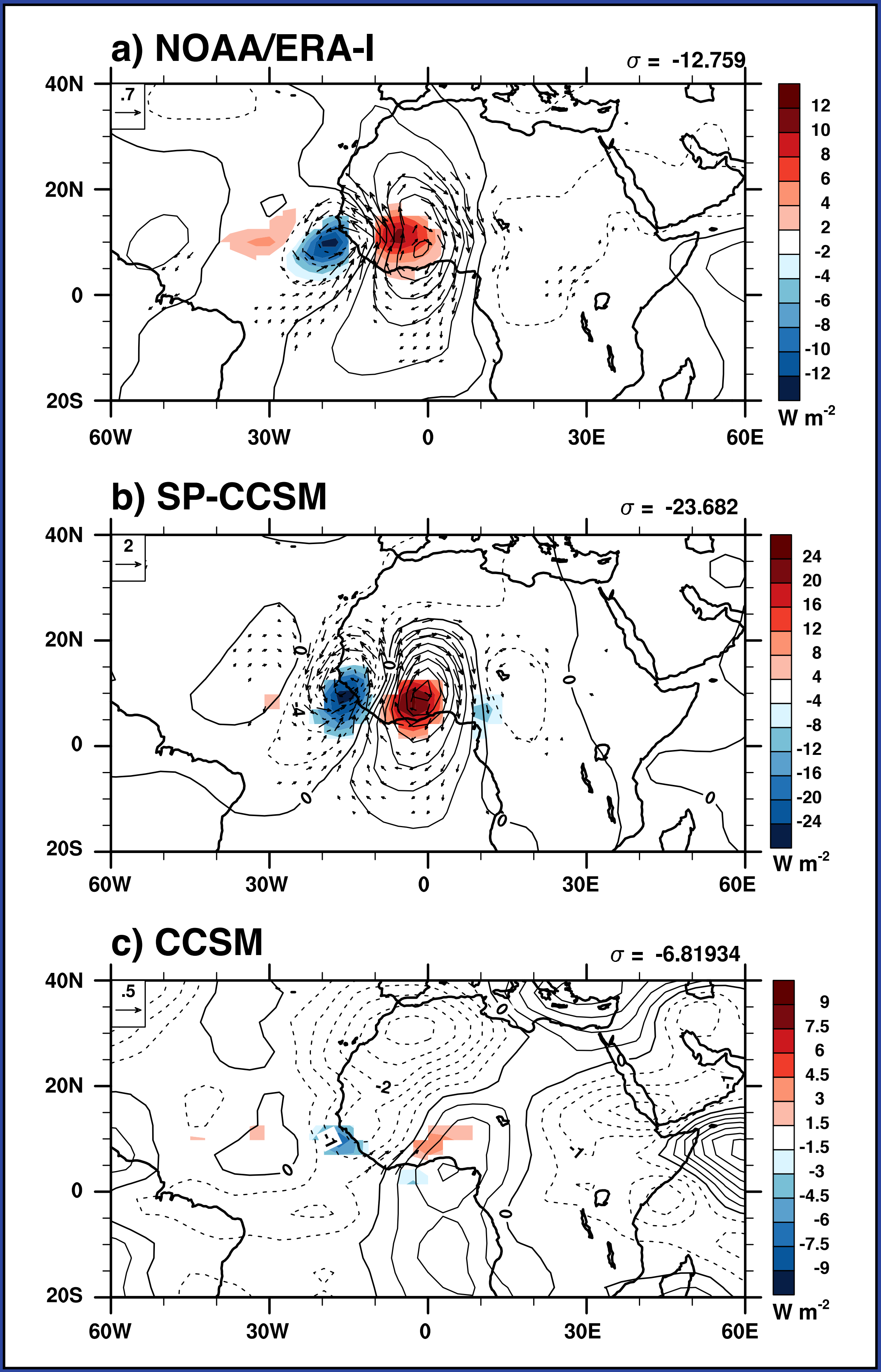
** Change in scale for each figure**

Horizontal Structure of AEWs
Lag 0 days



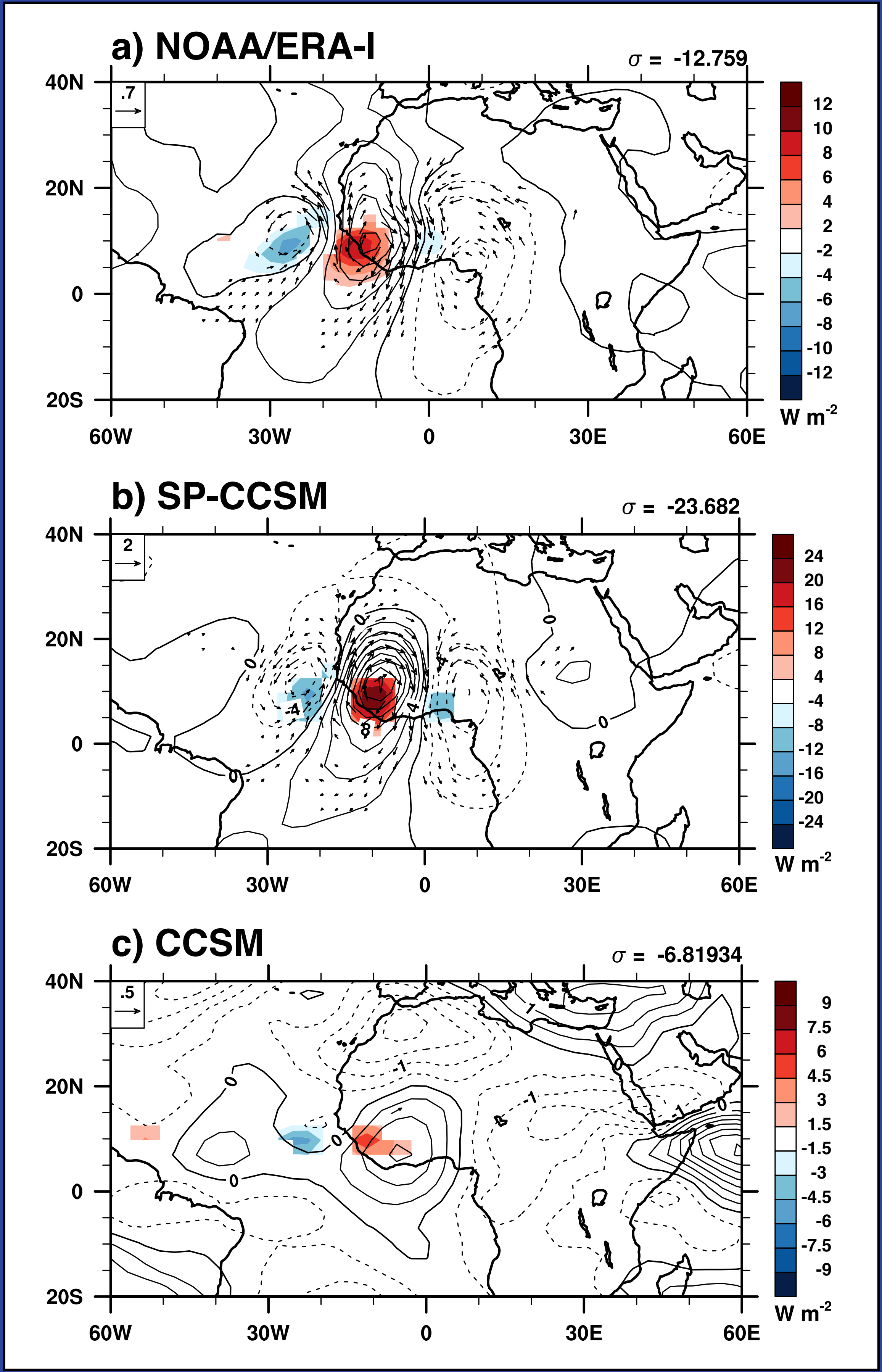
** Change in scale for each figure**

Horizontal Structure of AEWs Lag 1 days



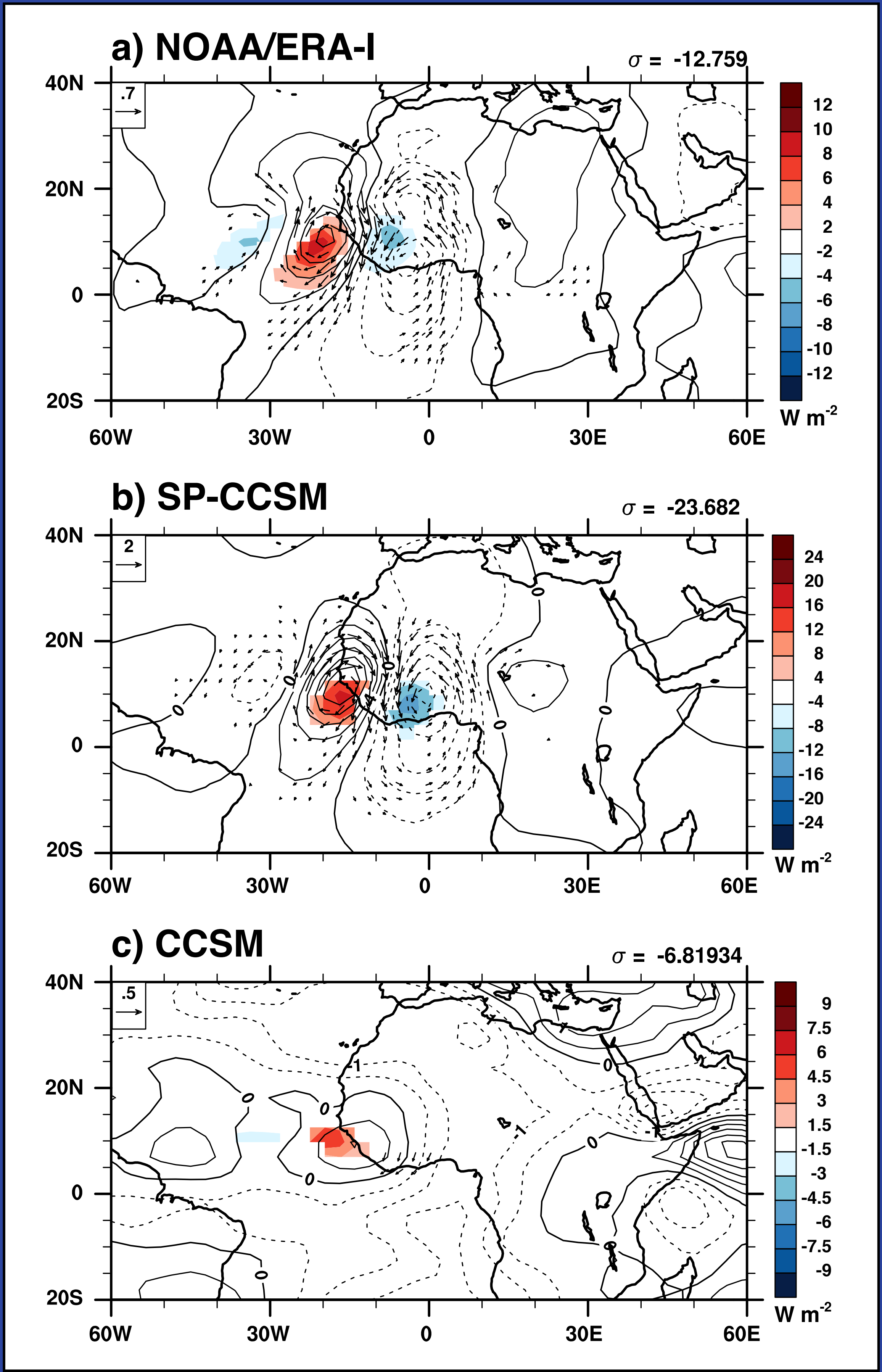
** Change in scale for each figure**

Horizontal Structure of AEWs Lag 2 days



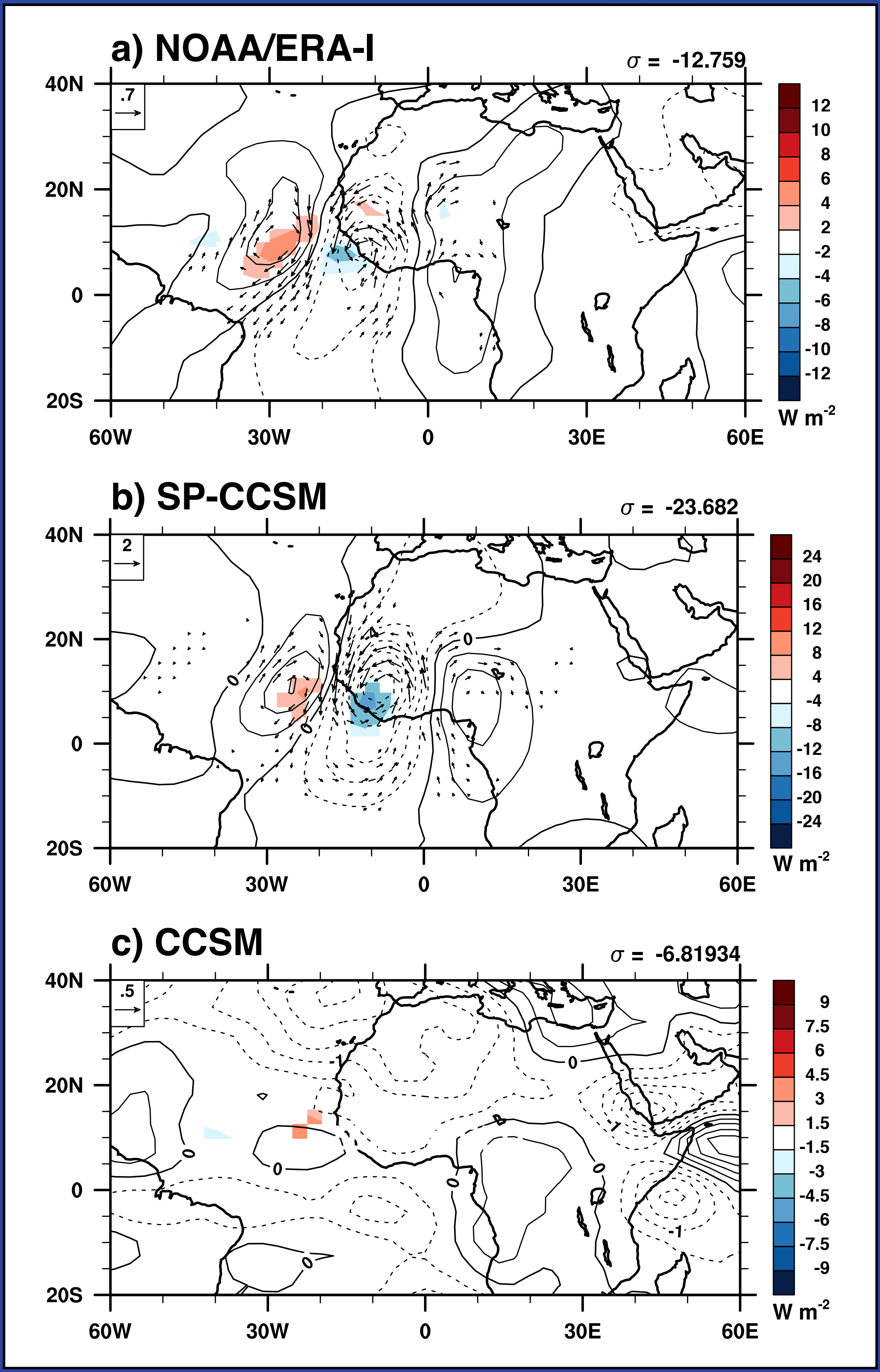
** Change in scale for each figure**

Horizontal Structure of AEWs Lag 3 days



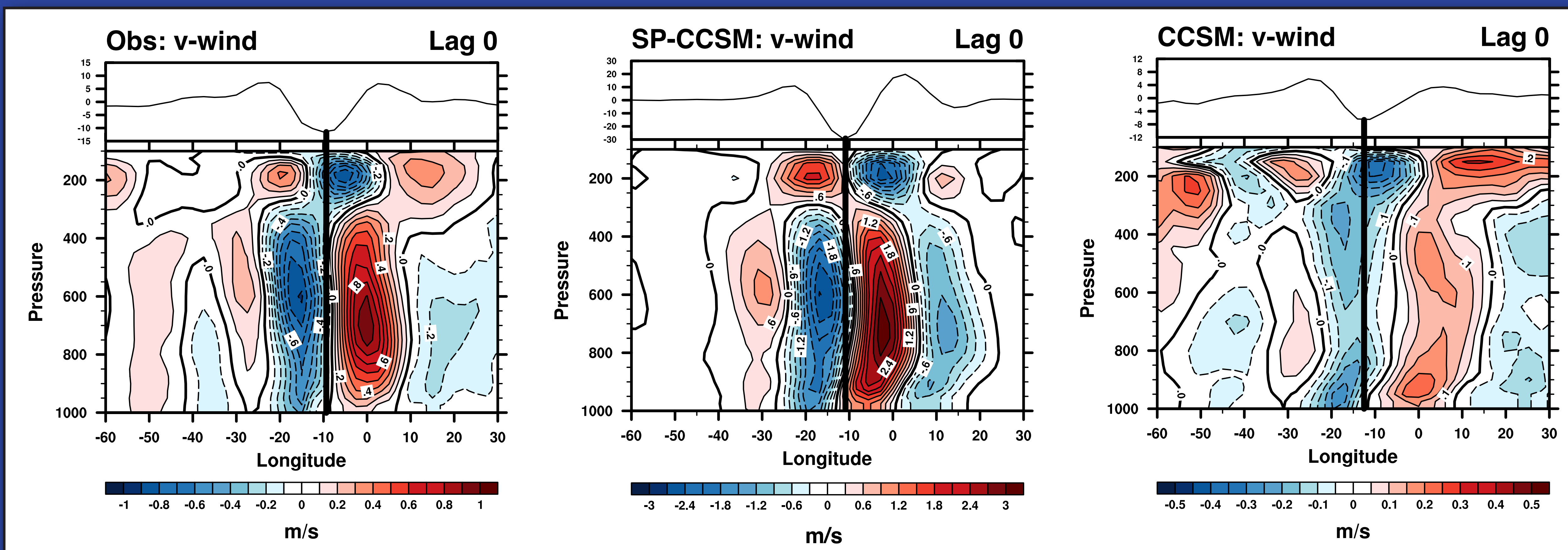
** Change in scale for each figure**

Horizontal Structure of AEWs Lag 4 days



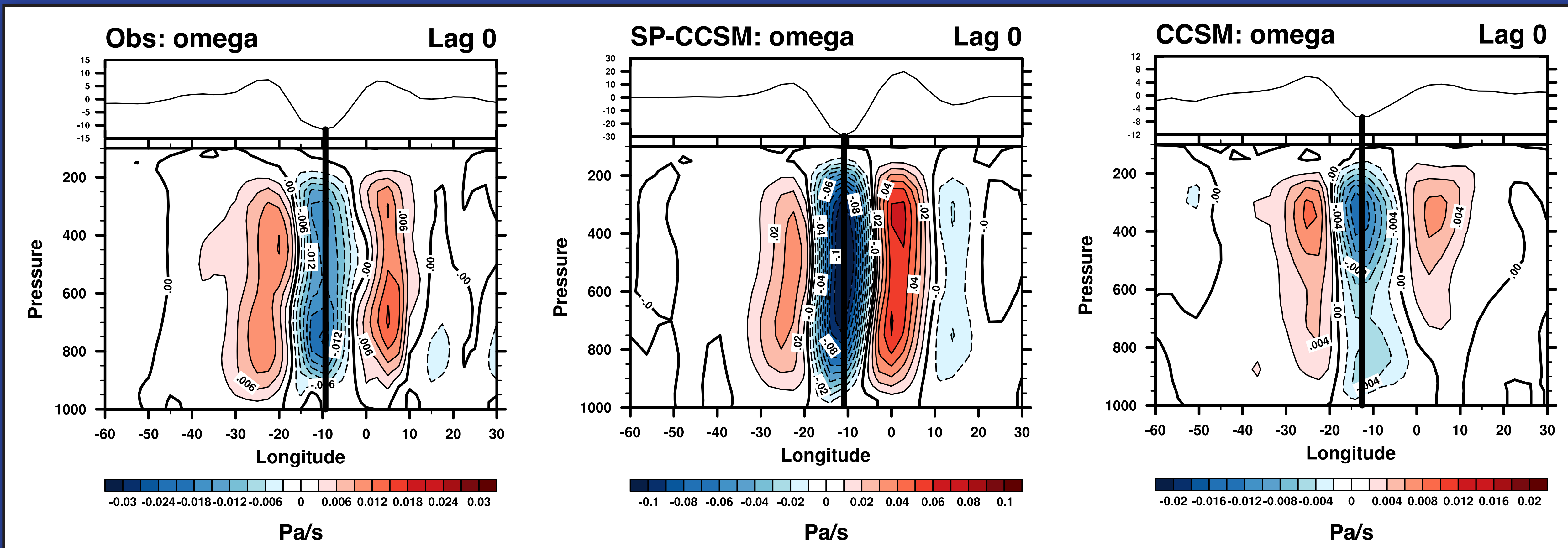
** Change in scale for each figure**

Vertical Structure of AEWs: Meridional Wind Lag 0 days



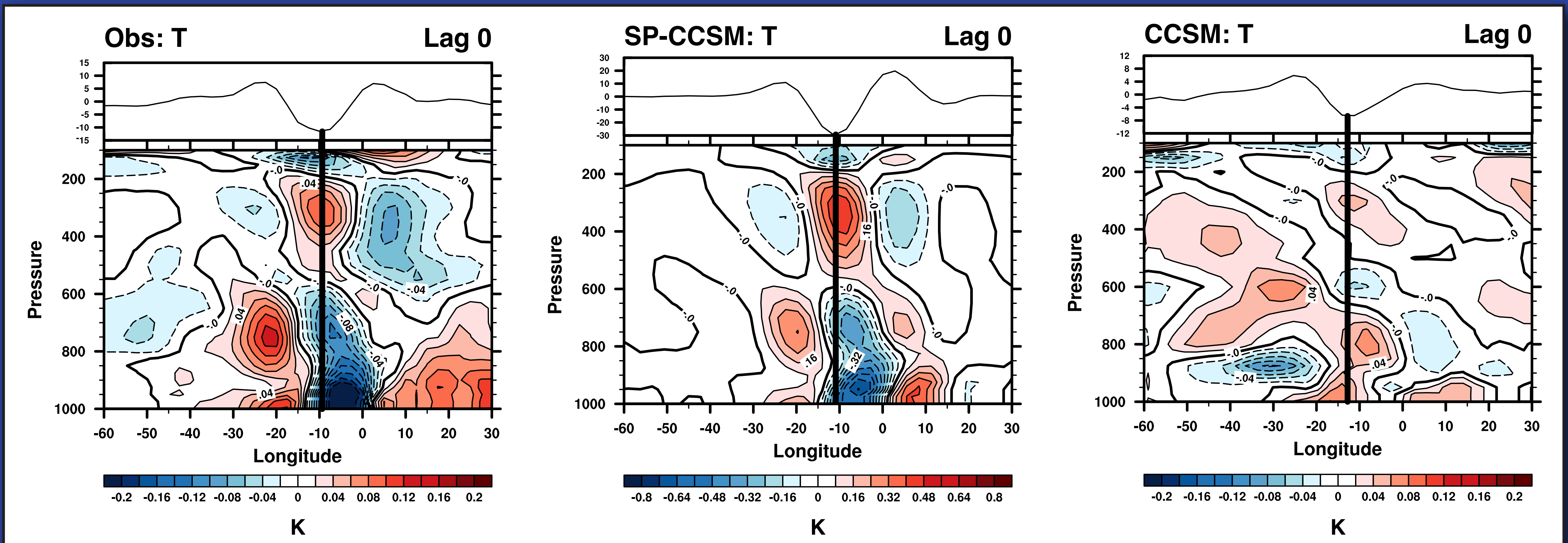
Meridional wind anomalies along 10ºN regressed onto the TD filtered time series of OLR from the basepoint 10ºN, 10ºW.

Vertical Structure of AEWs: Omega Lag 0 days



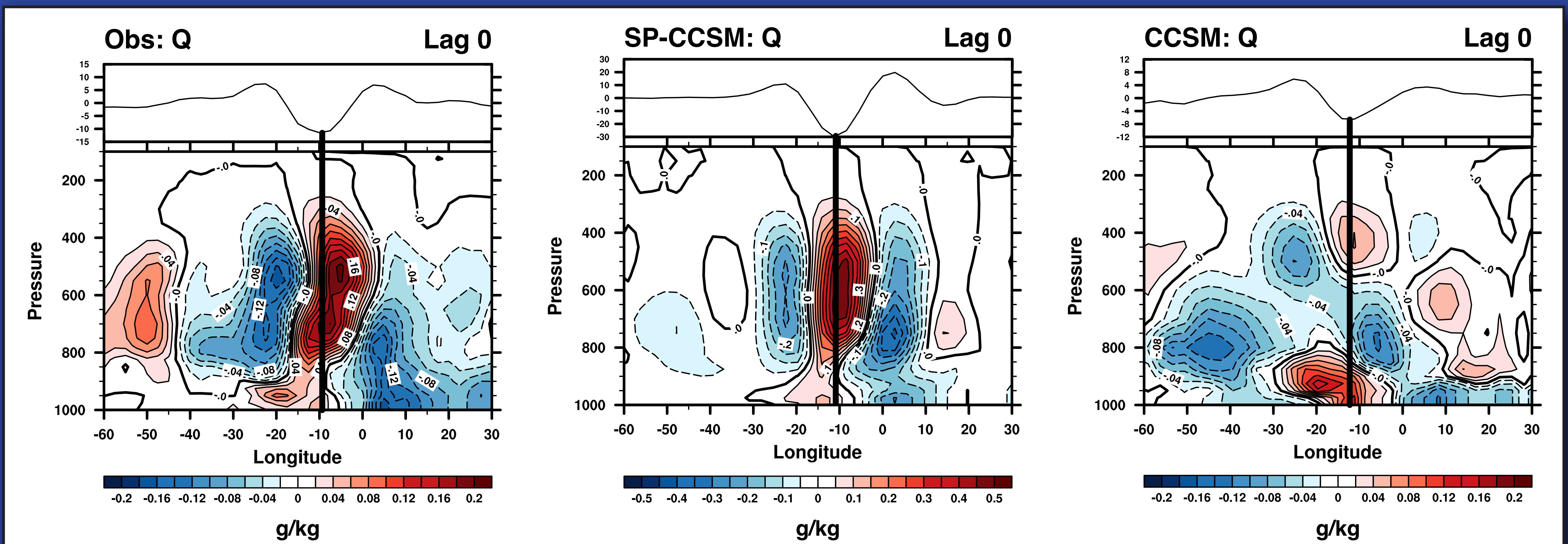
Omega anomalies along 10ºN regressed onto the TD filtered time series of OLR from the basepoint 10ºN, 10ºW.

Vertical Structure of AEWs: Temperature Lag 0 days



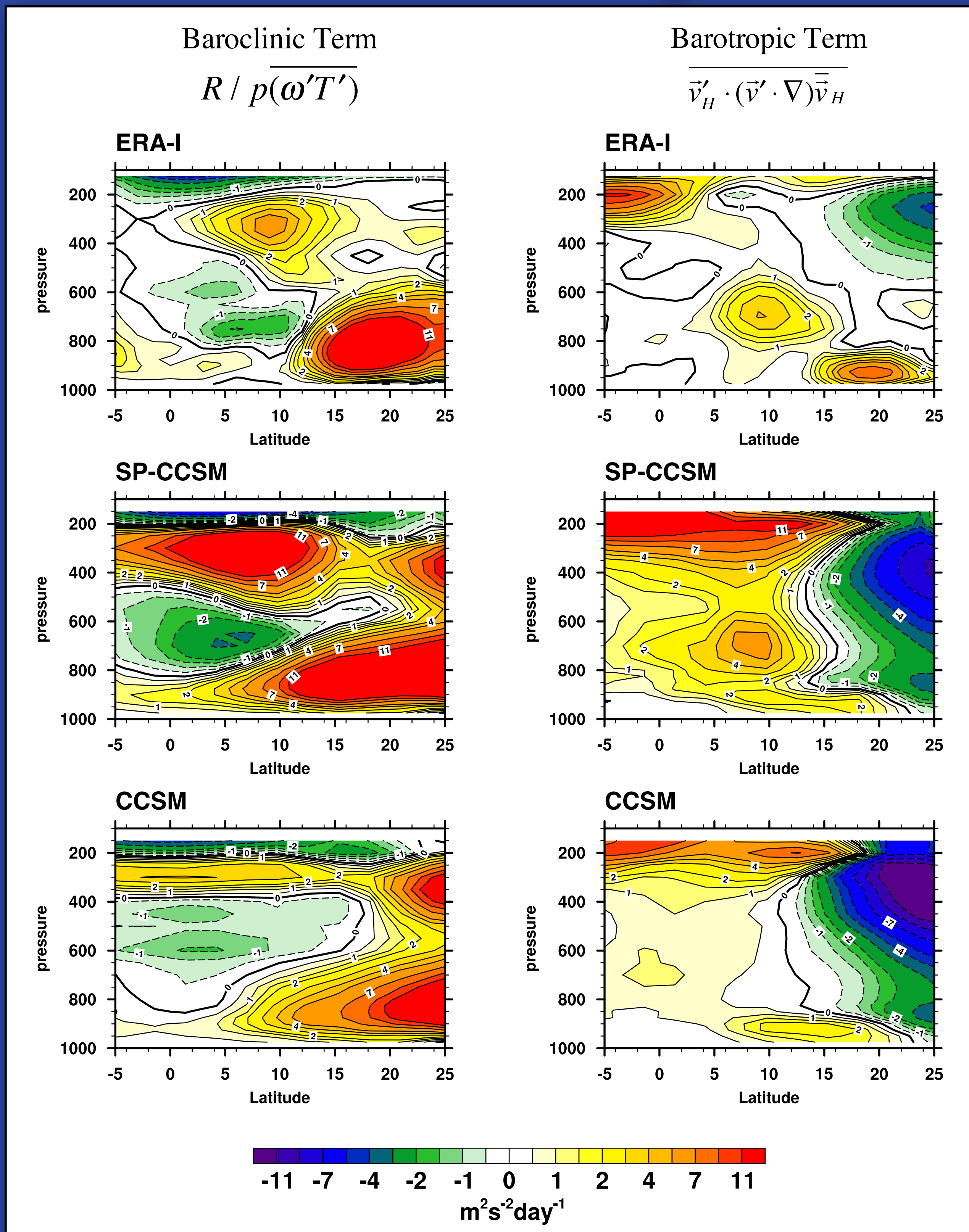
Temperature anomalies along 10ºN regressed onto the TD filtered time series of OLR from the basepoint 10ºN, 10ºW.

Vertical Structure of AEWs: Specific Humidity Lag 0 days



Specific humidity anomalies along 10ºN regressed onto the TD filtered time series of OLR from the basepoint 10ºN, 10ºW.

Barotropic and Baroclinic conversions to Eddy Kinetic Energy



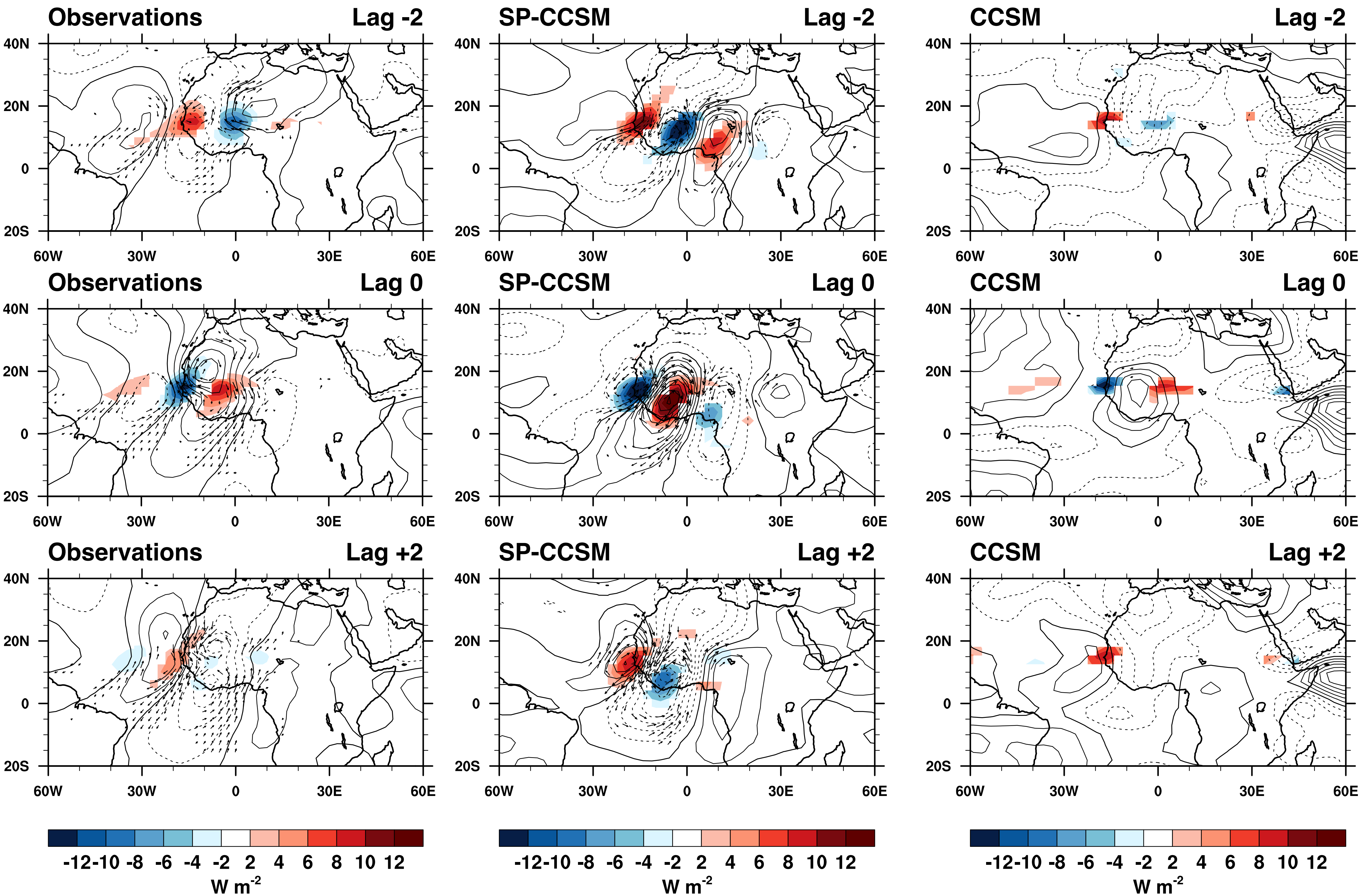
- Baroclinic term - conversion of eddy available potential energy to eddy kinetic energy due to rising motion in warm anomalies and sinking motion in cold anomalies.
- Barotropic term - conversion of mean energy to eddy kinetic energy. Waves extract energy from the wind shears associated

The implementation of the super-parameterization into the CCSM:

- Improves the representation of monsoon precipitation over West Africa.
- Enhances AEW variability over the region .
- The horizontal and vertical structure of simulated waves are comparable to observations

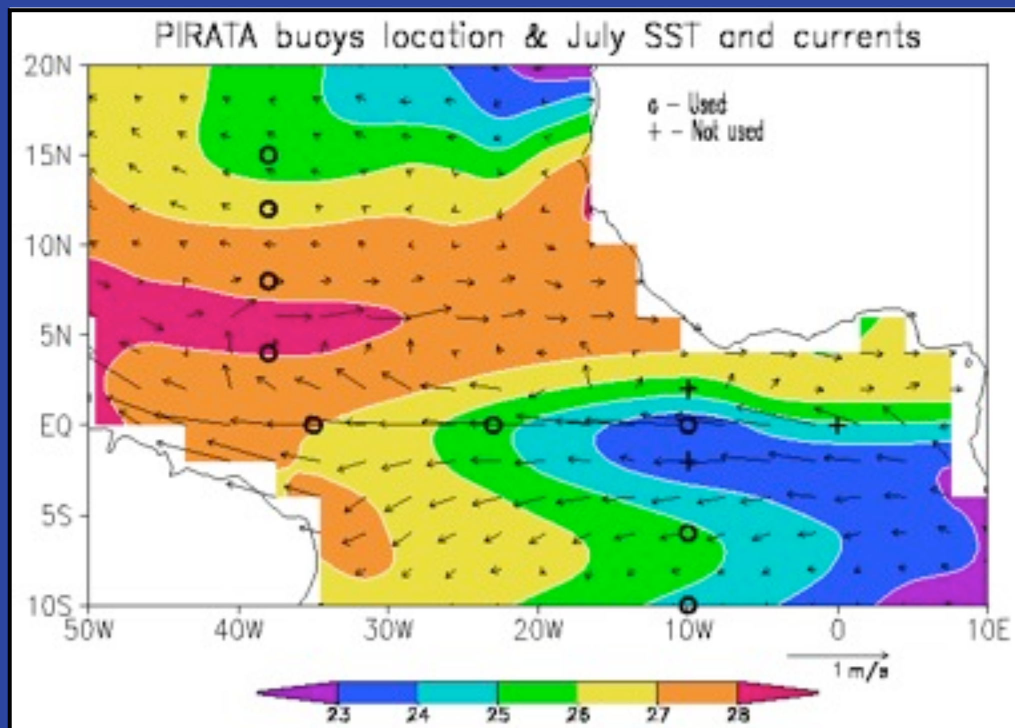
Currently working on...

- Using the methods to identify systematic errors first used by ECMWF

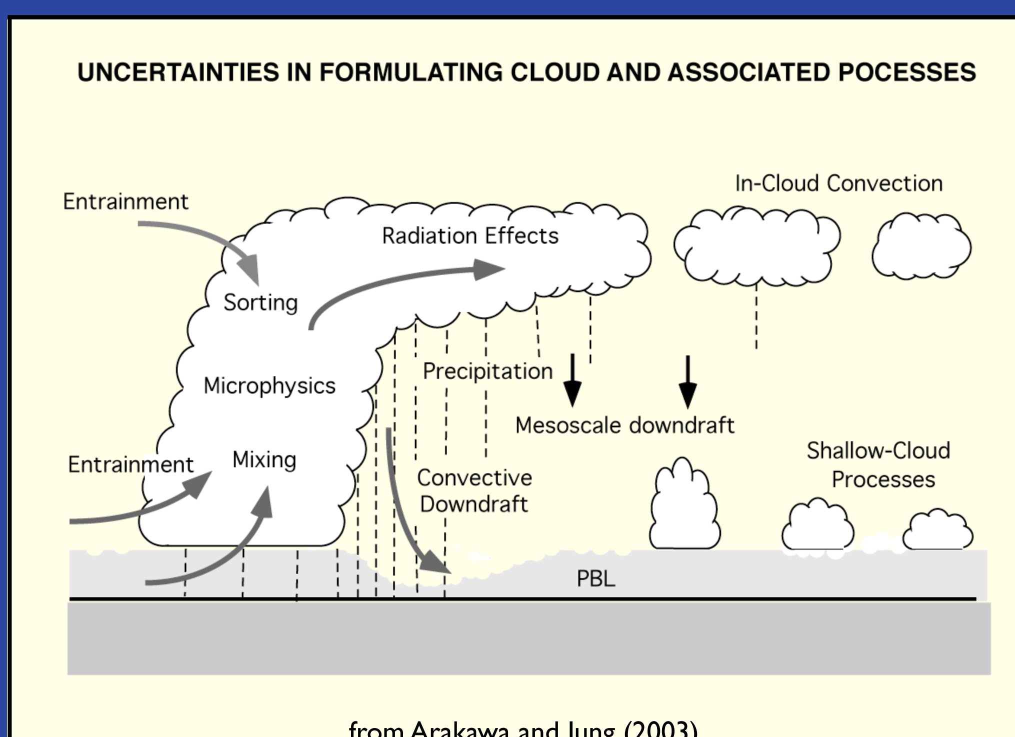

Observations
Lag -2
SP-CCSM
Lag -2
CCSM
Lag -2
Observations
Lag 0
SP-CCSM
Lag 0
CCSM
Lag 0
Observations
Lag +2
SP-CCSM
Lag +2
CCSM
Lag +2
40N
20N
0
20S
60W
30W
0
30E
60E
-12 -10 -8 -6 -4 -2 2 4 6 8 10 12
W m-2

Why do the models misrepresent monsoon rains over West Africa?

Atlantic Cold Tongue



Convective Parameterizations



Topography