Seasonal forecast skill over the Greater Horn of Africa: a verification atlas of System 4 and SEAS5. Part 1: Precipitation.

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ABSTRACT

Presenting a comparison of seasonal forecasts over the Greater Horn of Africa (GHA) from System 4 and SEAS5. Results are presented for three-month forecasts of the three major seasons of the region, March-May, July-September and October-December, at all available lead times. Also included is the verification for single month targets of these seasons.
Part 1 contains verification of precipitation (verification of 2m air temperature follows in part 2). Mean climate, biases and ensemble mean correlations are shown, and the final section contains maps of the Relative Operating Characteristic area under curve, measuring model ability to discriminate events across a range of percentile threshold exceedance events (namely, 10, 20, 25, 33, 50, 67, 75, 80, 90%ile exceedance).

Contents

Acknowledgements

This work was supported by the NERC/DfID project ForPAc: Toward Forecast-based Preparedness Action (funded under the SHEAR programme; see www.forpac.org for more details). Thanks to ECMWF for provision of seasonal hindcast and reanalysis data, and to the Climate Hazards Group of UCSB for provision of the CHIRPS rainfall dataset.

1 Introduction

The Greater Horn of Africa (GHA) experiences rainfall seasons related to the large scale latitudinal movement of the tropical rain belt (note that the concept of the Inter-Tropical Convergence Zone is problematic over Africa and 'tropical rain belt' is seen to be more scientifically accurate Nicholson (2018)). Broadly speaking, there are three main seasons across the region. During March to May (hereafter MAM) the tropical rain belt moves northward and countries including Kenya experience the 'long' rains. As the rain belt reaches its maximum northward extent, Ethiopia, South Sudan and Sudan experience their main rain season, from July to September (hereafter JAS), concurrent with the West African Monsoon. Finally as the belt returns southward the equatorial region experiences a second rainfall season, the 'short' rains occurring from October to December (hereafter OND). Subsequently the rain belt moves to southern Africa before returning in boreal spring of the following year. For a comprehensive review of GHA climate science and predictability, see Nicholson (2017).

The seasonal predictability of these three seasons is considered here. Note that all locations within the GHA will not necessarily experience clear rainfall seasons following this pattern, with variations in timing, length and intensity, related to latitude, proximity to the coast, topography and other local factors. This is even the case within a single country; for instance semi-arid North East Kenya experiences two short seasons, with the long rains starting some time later than 1-Mar, whilst some parts of the wet highlands in the west experience continuous rainfall between the short and long rains, without a distinct 'dry' season between. However for the purposes of sketching out the broad patterns of seasonal predictability over the region, the seasons of MAM, JAS and OND are adequate. For more detail on reader is referred to Dunning et al. (2016), in which the spatial and interannual variability of onset and cessation has been mapped across the entire African continent. In addition MacLeod

(2018) has assessed the ability of the ECMWF extended-range and seasonal prediction systems to provide early warnings of anomalous onset and cessation.

Here, validation of seasonal forecasts of precipitation is shown here for the three seasonal of GHA; both for the current operational seasonal forecast system SEAS5 (operational from November 2017) and its predecessor, System 4 (operational since November 2011). The purpose of this report is to provide an atlas outlining the performance of SEAS5 for GHA and where improvements are seen from System 4. A detailed description of all figures is not provided, beyond a brief summary of key points.

The following short section contains details of the data and methods and a summary of key results. Subsequently the collection of verification maps is provided for precipitation.

2 Data and methods

2.1 Seasonal forecasting systems

System 4 and SEAS5 are evaluated here and there are several differences between the systems. Both use different cycles of the atmosphere IFS model (CY36R4 and CY43R1), representing six years of IFS developments in terms of physics, new Earth system components and initialization methods. Atmospheric resolution is increased, moving from TL255 (80km) to TCo319 (36km). A newer version of the ocean model NEMO is used in SEAS5, at higher resolution than System 4 (moving from 1° to 0.25°). An overview of System 4 is provided in ECMWF technical memorandum number 656 Molteni et al. (2011), whilst full details of the differences between the systems are outlined in an article in the ECMWF Winter 2018 newsletter Stockdale et al. (2018).

Both systems are initialized once per month and verification metrics here are calculated for both across the hindcast 1981-2017. SEAS5 has a 25 ensemble member hindcast, whilst System 4 has 25 members for the start dates February, May, August and November, with 15 for the rest. All available members are considered for each lead time.

2.2 Reference data and verification methods

Precipitation is compared with the Climate Hazards Infra-Red with Stations (CHIRPS) merged satellite-gauge dataset Funk et al. (2015). CHIRPS is a blend of station and satellite information, providing daily precipitation estimates at 0.05° spatial resolution from 1981 to the present. All fields are interpolated to a 1° grid before analysis. Gridpoints are masked where the climatological mean of observations is low (nominally $< 10mm$).

Maps over GHA are presented showing climatologial mean, bias, ensemble mean correlation and Relative Operating Characteristic Area Under Curve (hereafter ROC AUC). Ensemble mean correlation is calculated using Pearson's correlation coefficient, with 95% significance levels calculated based on a two-tailed t-test. ROC AUC measures the ability of a forecast to discriminate the occurrence or non-occurrence of an event. The events considered here are based the crossing of the percentile thresholds 20%, 33%, 50%, 67% and 80%, with definitions of percentiles calculated pointwise and separately for the model and reference datasets. ROC AUC for these percentiles indicate the forecast system to anticipate a lowest quintile, lower tercile, above/below median, upper tercile and highest quintile season/month. A ROC AUC of 0.5 indicates the system is no better than climatology, whilst 0.9 indicates perfect discrimination. Statistical significance of the ROC AUC depends on both the hindcast length and the frequency of the event under consideration, and 95% significance values have been calculated here by comparison with a Mann-Whitney U test (see Mason and Graham (2002) for details and further discussion of the ROC AUC).

For each metric in turn, results are presented each season in turn, both for three-month seasonal averages (e.g. MAM) but also for individual months (e.g. March). Assessment of predictability characteristics over GHA indicate that the traditional three-month seasons are not necessarily coherent and that more information may be present in individual monthly averages. A consistent figure layout is followed throughout, with upper and lower rows showing System 4 and SEAS5 results. Longest lead forecasts are shown on the far left column (in the case of seasonal average, lead 4-6), with shorter lead forecasts shown in subsequent columns, ending in the shortest, zero lead forecast (lead 0-2) on the far right. In all cases the precise initialization date of the forecast is indicated in the subfigure.

2.3 How to search the atlas

Given the large number of figures, a unique code has been added to each figure in order to quickly navigate. This code is in the format *MetricTarget*. Options for '*Metric*' are:

- Clim (climatology plots)
- Bias (model bias against reference data)
- Corr (ensemble mean correlation)
- ROCxx (ROC AUC, where xx indicates the percentile corresponding to the event: 20, 33, 50, 67, 80 for lowest quintile, lower tercile, above/below median, upper tercile and highest quintle respectively),

and options for '*Target*' are three letter codes referring to either the three-month season or the monthly target (i.e. MAM, JAS, OND, Mar, Apr, May, Jul, Aug, Sep, Oct, Nov, and Dec)

By searching this document for a specific code one can navigate directly to the analysis of interest. For example, searching for ROC20May will navigate to the page containing the plot of ROC AUC of lowest quintile precipitation for May.

3 Summary of results

- Both systems underestimate MAM and overestimate OND rainfall (figures 9 and 10). There is some improvement in the bias over Western Kenya during MAM and over Tanzania during OND at short leads. For OND SEAS5 has a dry bias near the Kenyan coast, where System 4 had a wet bias.
- Predictability of the OND is much higher than MAM, with significant skill at long leads (figures 17 and 18). The skill of MAM forecasts issued 1-Feb and before is low, whilst there is higher skill for the 1-Mar MAM forecast. This is consistent with previous work on the ECMWF operational system Dutra et al. (2013); Mwangi et al. (2014) and with understanding of GHA predictability, where ENSO and the Indian Ocean Dipole exert strong forcing on the short rains but not the long Nicholson (2017).
- There are some improvements in ensemble mean correlation with SEAS5. Most notably, the long lead forecasts for December precipitation is much improved (figure 24): over Kenya ensemble mean correlations from 1-Aug forecasts increase from less than 0.3 in System 4 to over 0.6 in SEAS5. This may be related to improvements seen for El Niño forecasts Stockdale et al. (2018), as there is a strong ENSO teleconnection at this time of the year. There is also some improvement seen for May forecasts in SEAS5 (figure 21), over northern Kenya and Somalia. Note that long lead May prediction is potentially skillful, whilst long lead MAM is not.
- The broad pattern of skill for discriminating wet and dry years (ROC AUC) follows that for ensemble mean correlation. However the discrimination of upper quintile wet OND years over Kenya (figure 34) during is higher than discrimination of lower quintile years (figure 30). This may be related to the asymmetry in teleconnections reported by Nicholson (2015), where observational analysis indicated that short rains over equatorial east Africa are on average more strongly linked to large-scale drivers. The converse is observed over Tanzania, where ROC AUC for 20%ile events is much higher at longer leads than 80%ile events.

4 Results: Precipitation

4.1 Climatology and bias

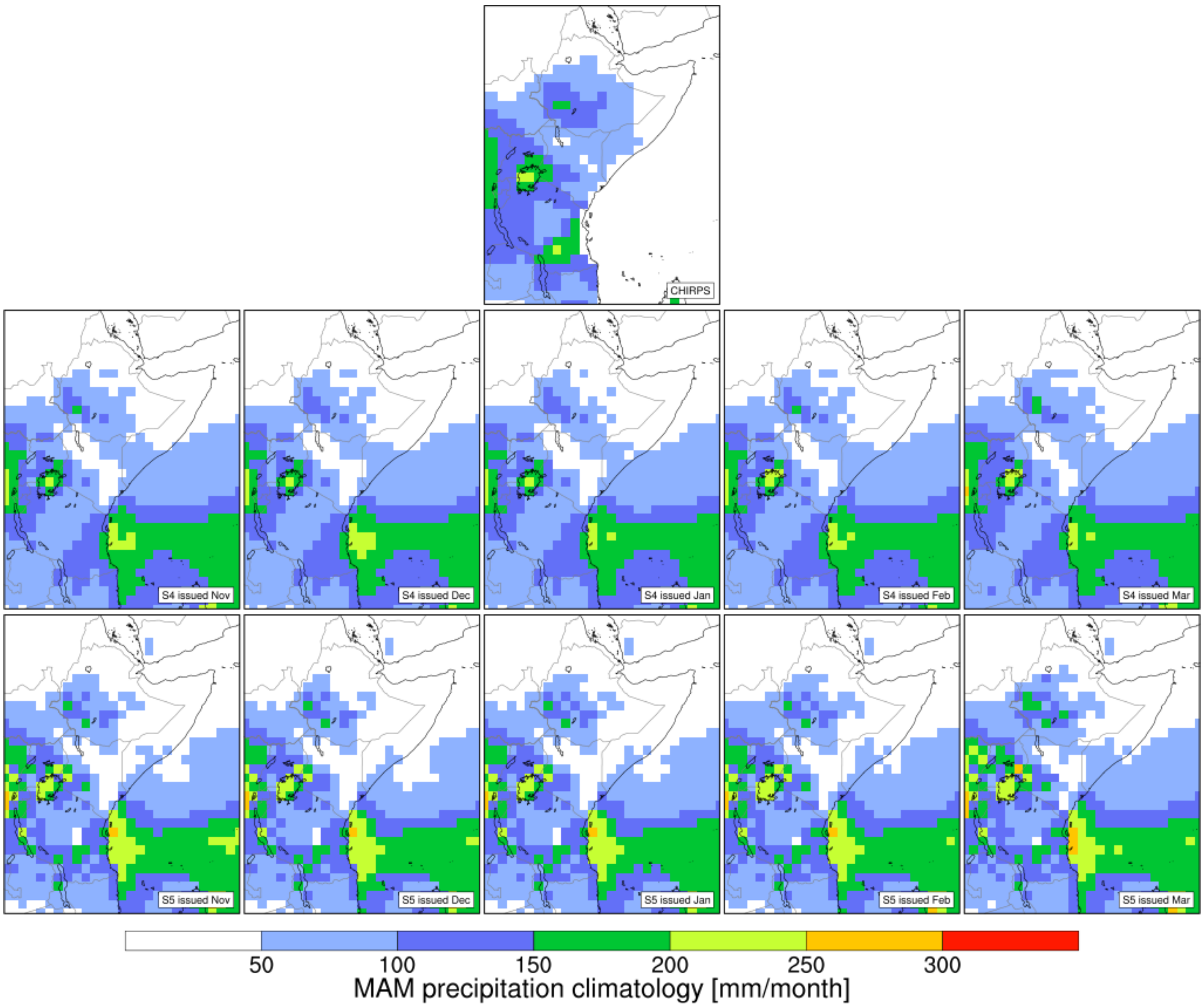

Figure 1. [ClimMAM] Precipitation climatology for MAM: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

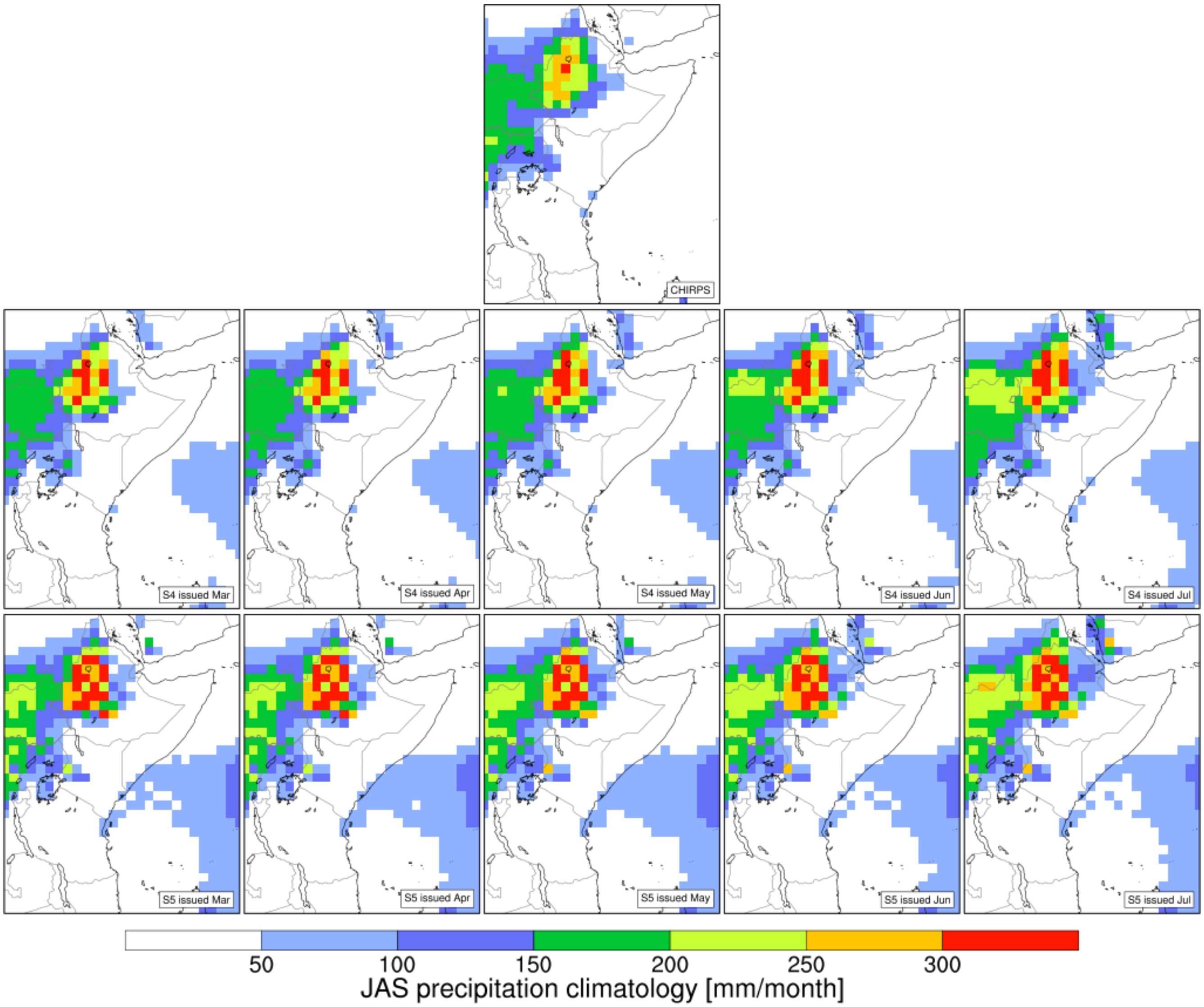

Figure 2. [ClimJAS] Precipitation climatology for JAS: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

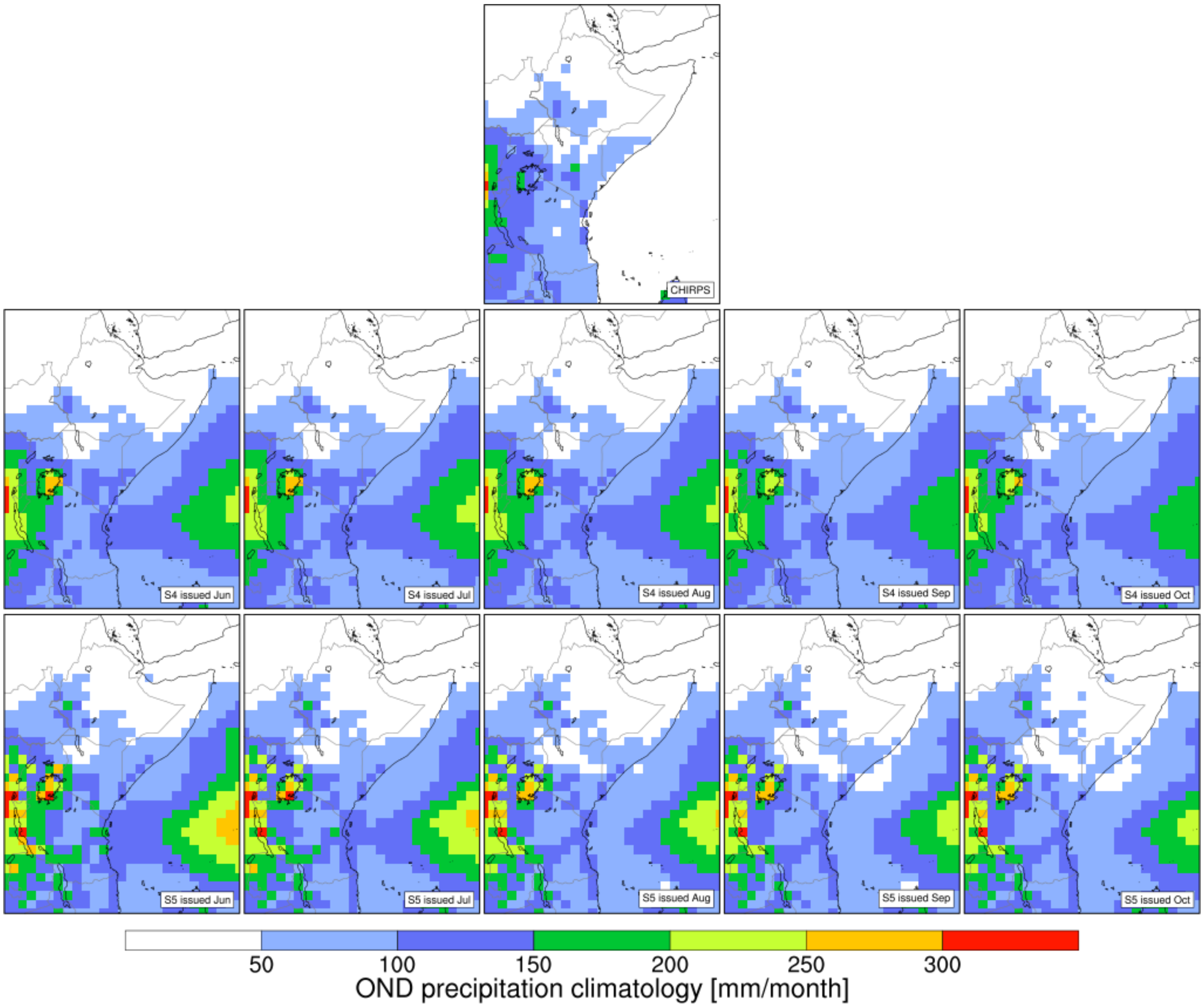

Figure 3. [ClimOND] Precipitation climatology for OND: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

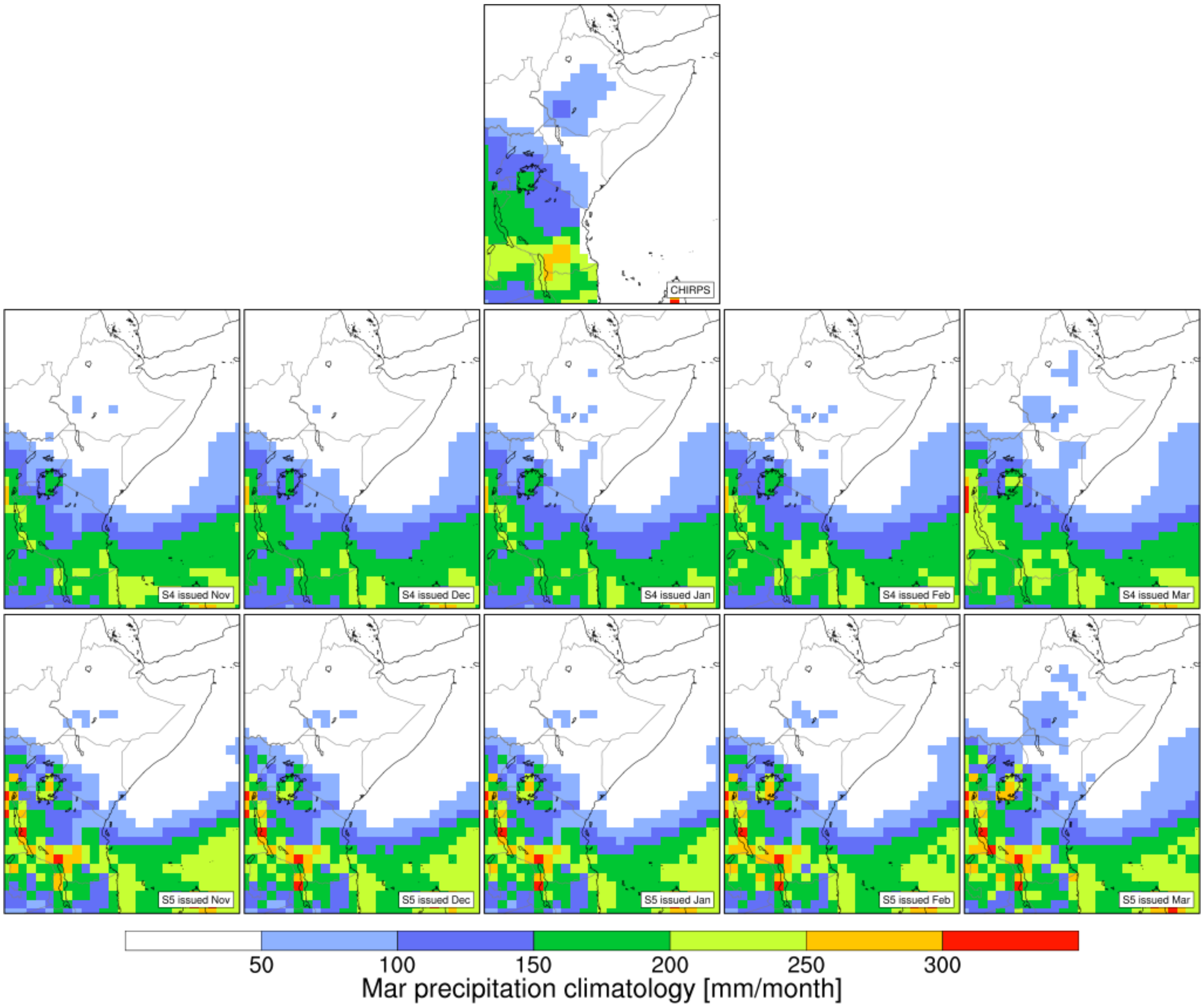

Figure 4. [ClimMar] Precipitation climatology for Mar: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

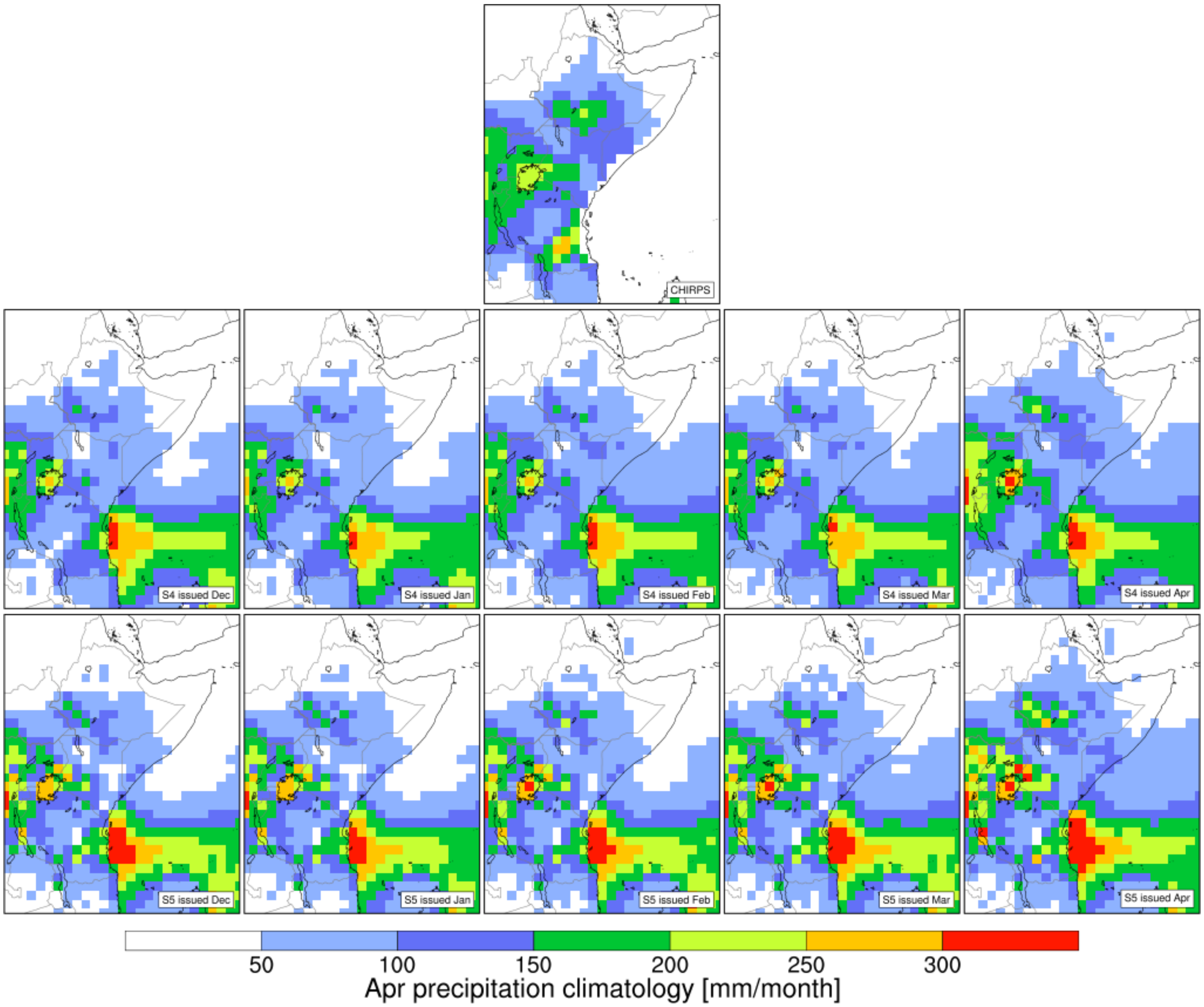

Figure 5. [ClimApr] Precipitation climatology for Apr: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

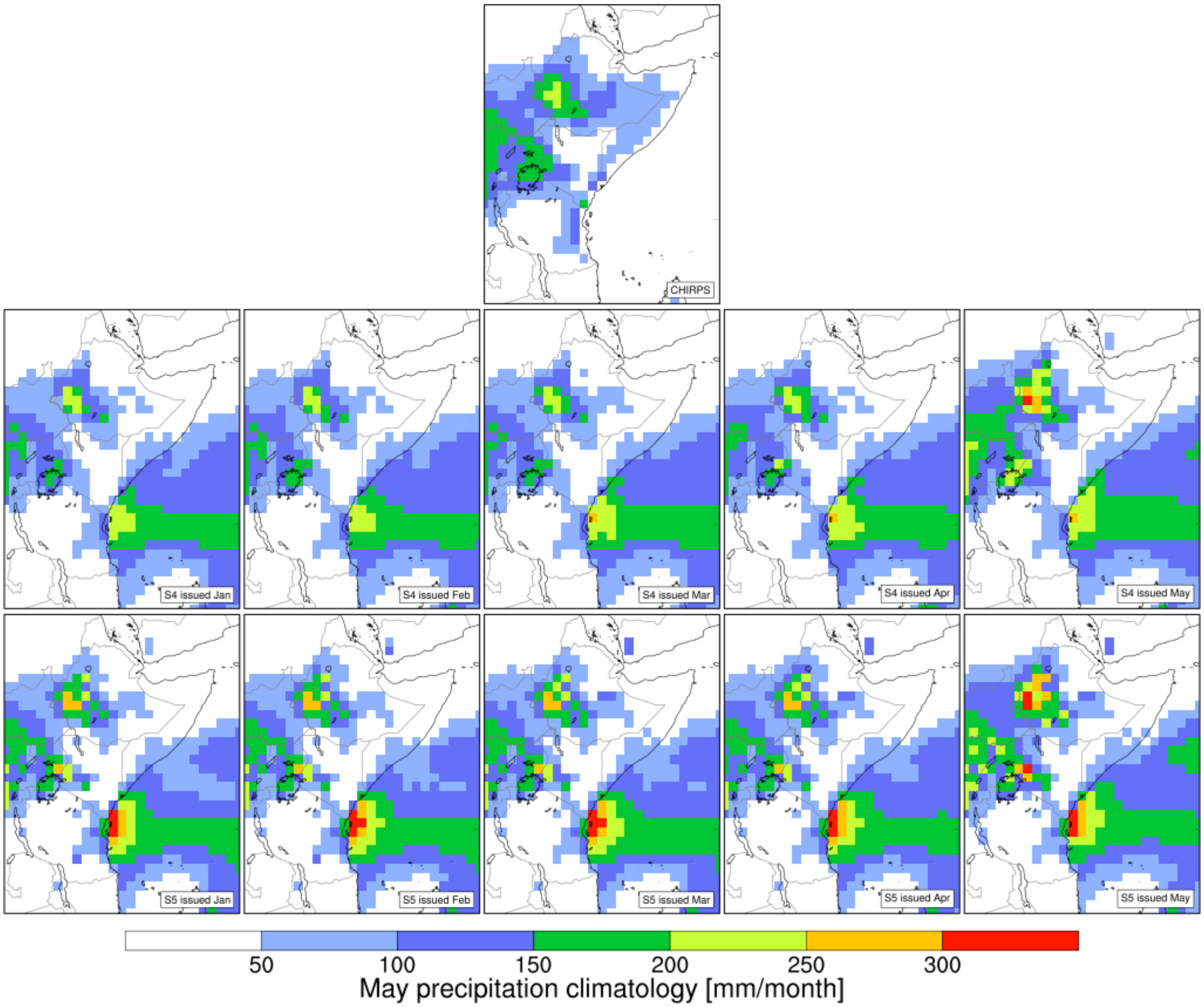

Figure 6. [ClimMay] Precipitation climatology for May: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

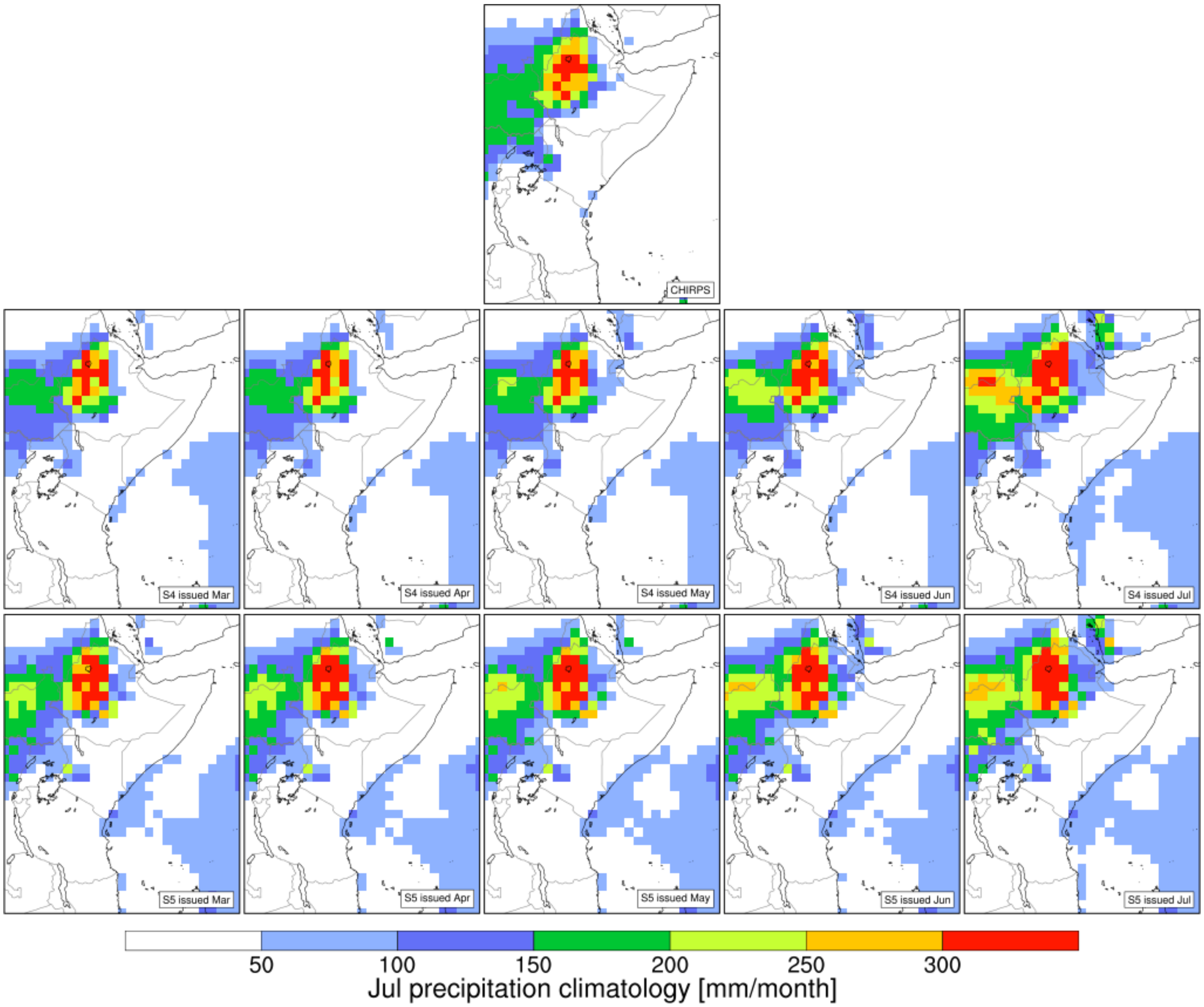

Figure 7. [ClimJul] Precipitation climatology for Jul: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

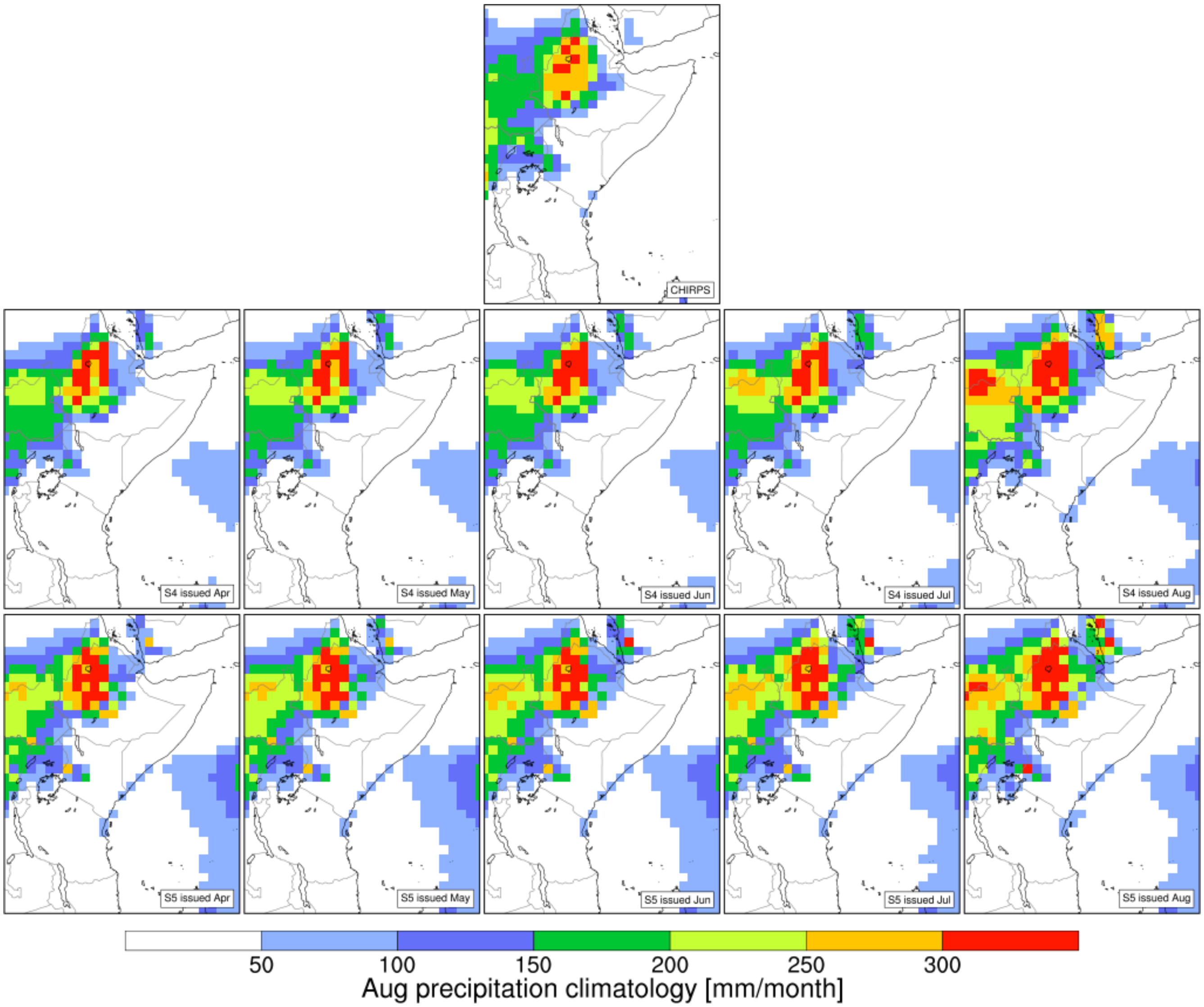

Figure 8. [ClimAug] Precipitation climatology for Aug: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

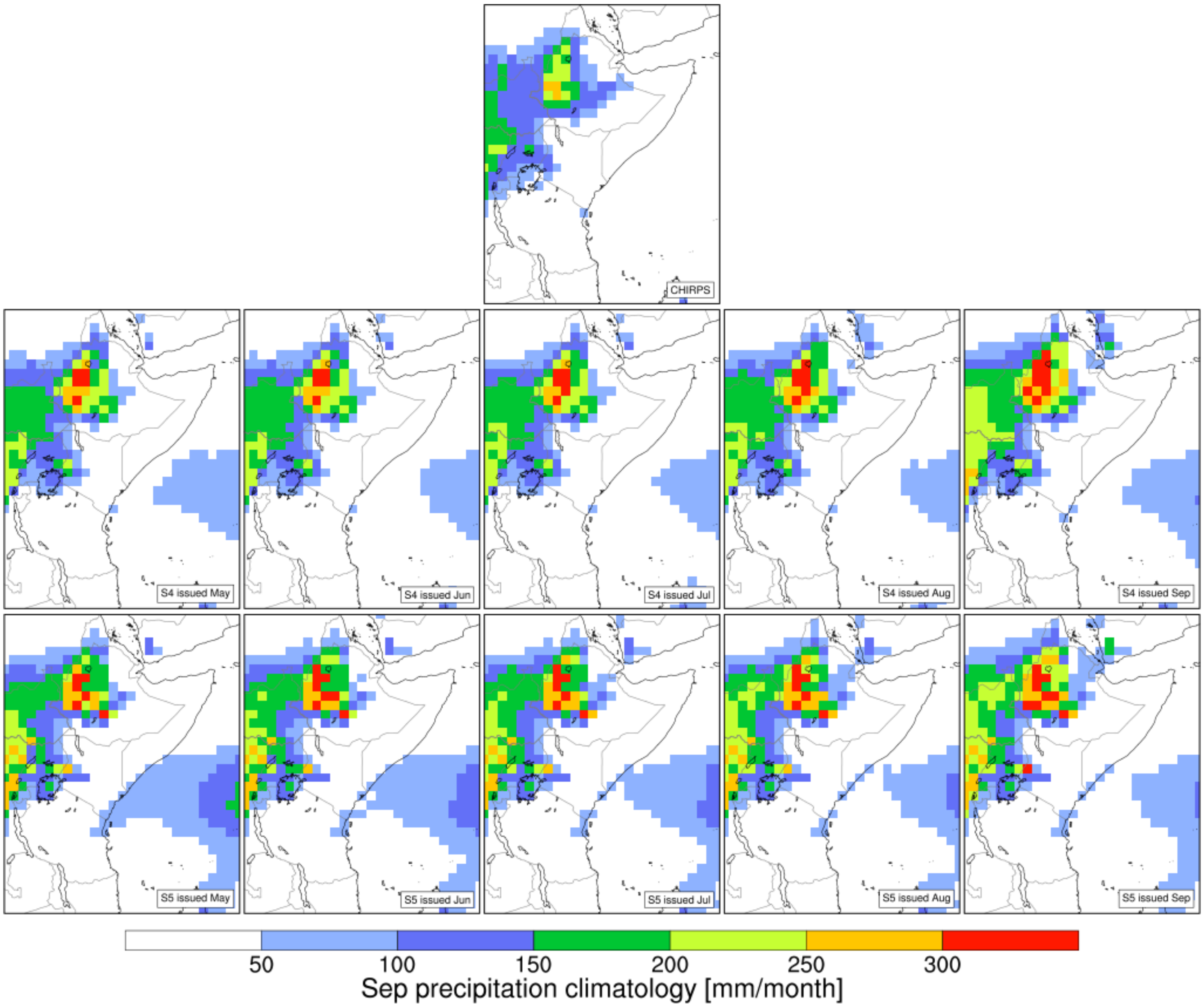

Figure 9. [ClimSep] Precipitation climatology for Sep: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

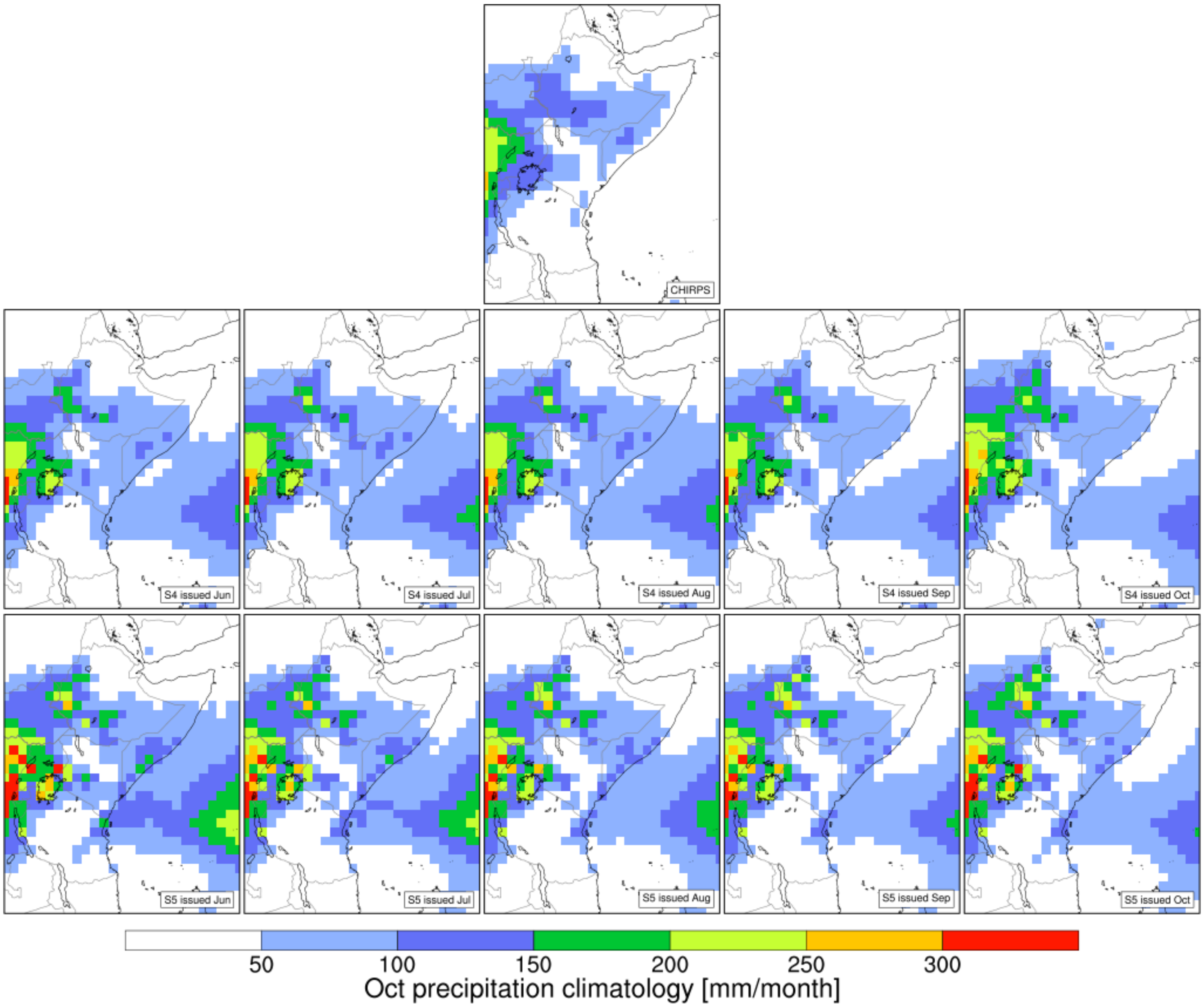

Figure 10. [ClimOct] Precipitation climatology for Oct: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

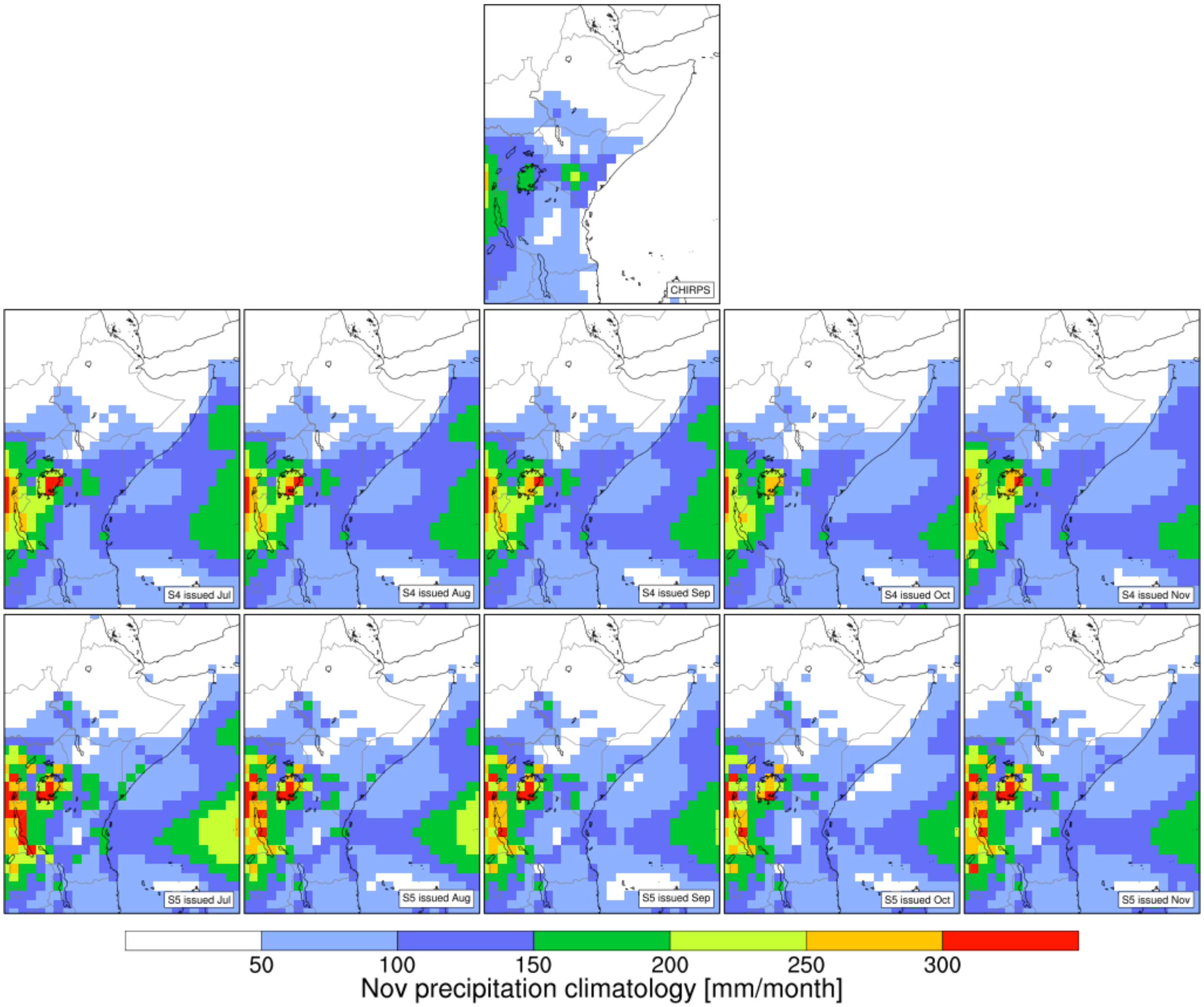

Figure 11. [ClimNov] Precipitation climatology for Nov: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

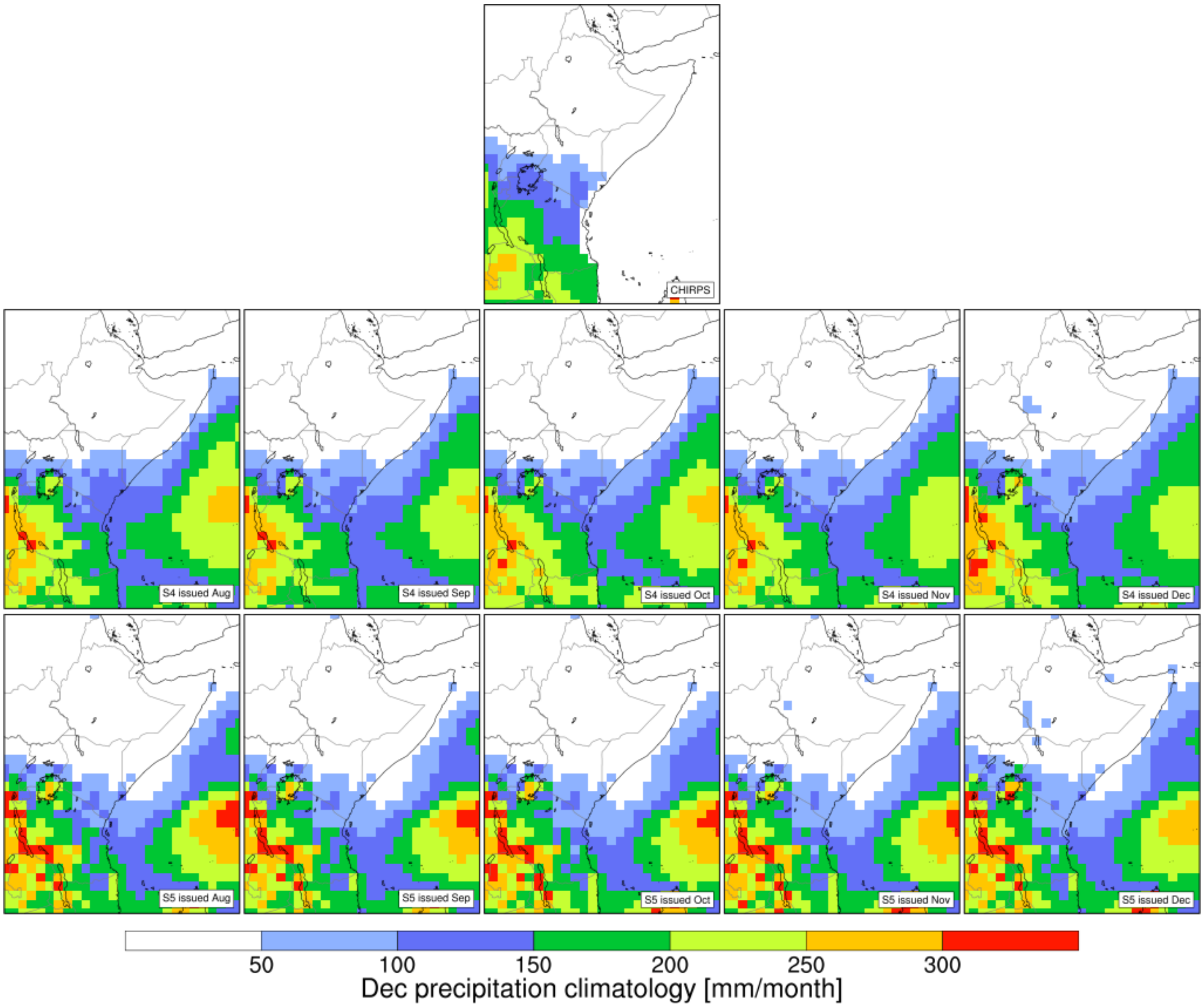

Figure 12. [ClimDec] Precipitation climatology for Dec: CHIRPS (top) and ensemble mean System 4 (middle) and SEAS5 (bottom)

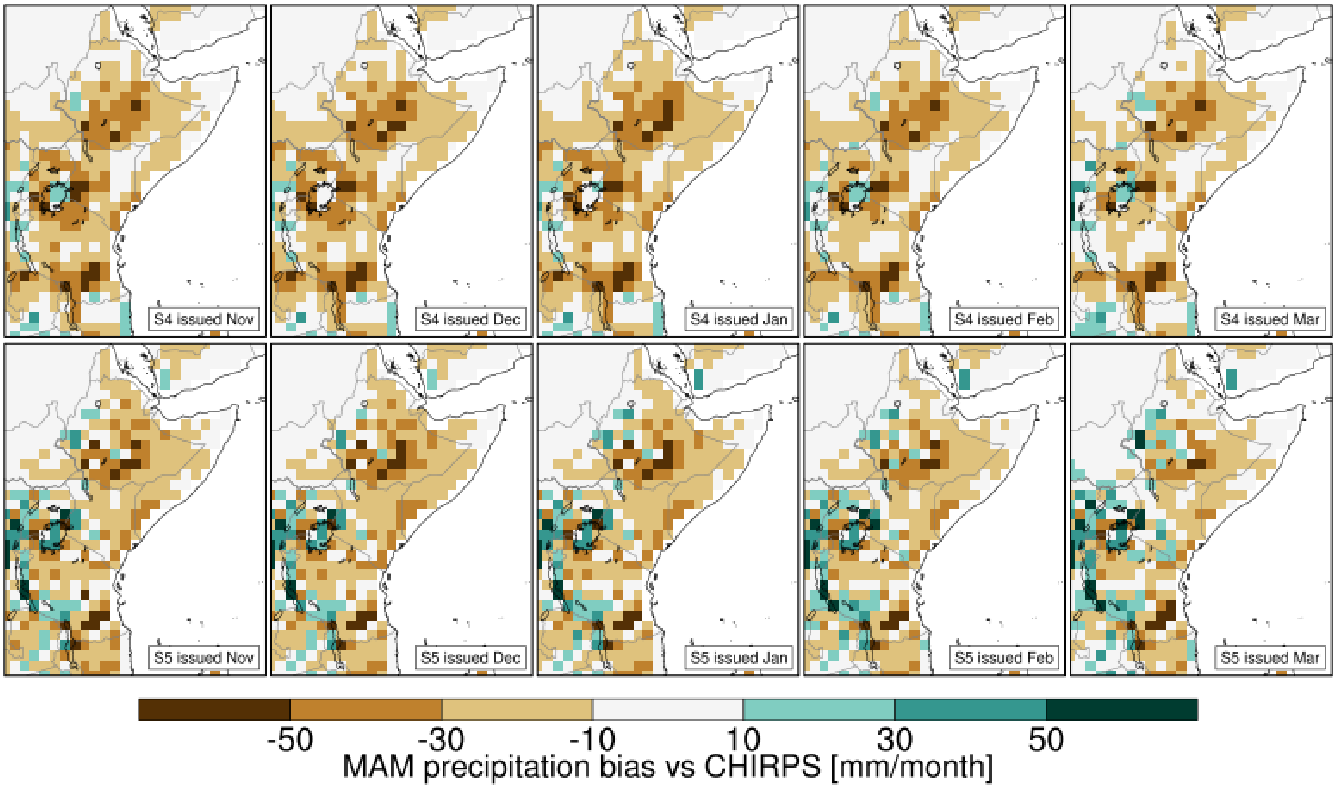

Figure 13. [BiasMAM] Precipitation ensemble mean bias MAM, System 4 (top) and SEAS5 (bottom) vs CHIRPS

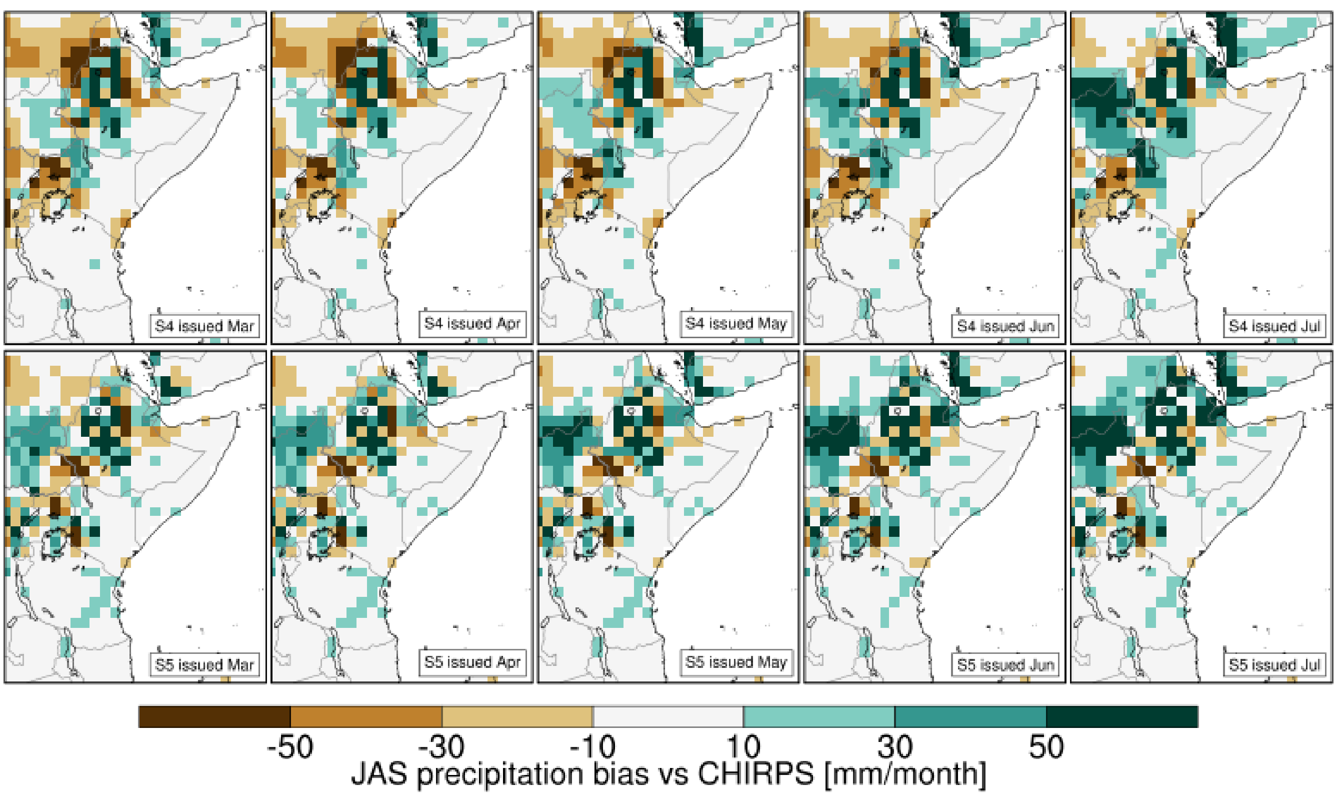

Figure 14. [BiasJAS] Precipitation ensemble mean bias JAS, System 4 (top) and SEAS5 (bottom) vs CHIRPS

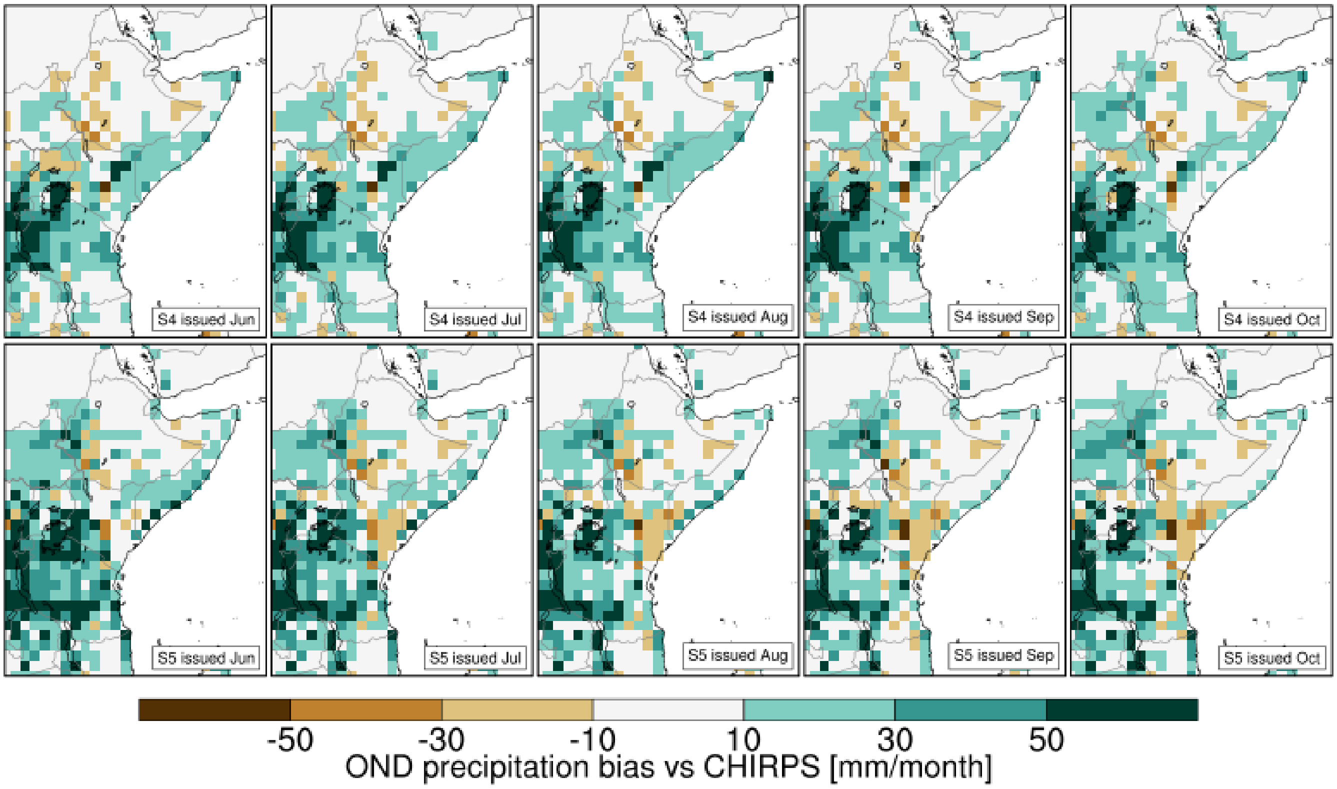

Figure 15. [BiasOND] Precipitation ensemble mean bias OND, System 4 (top) and SEAS5 (bottom) vs CHIRPS

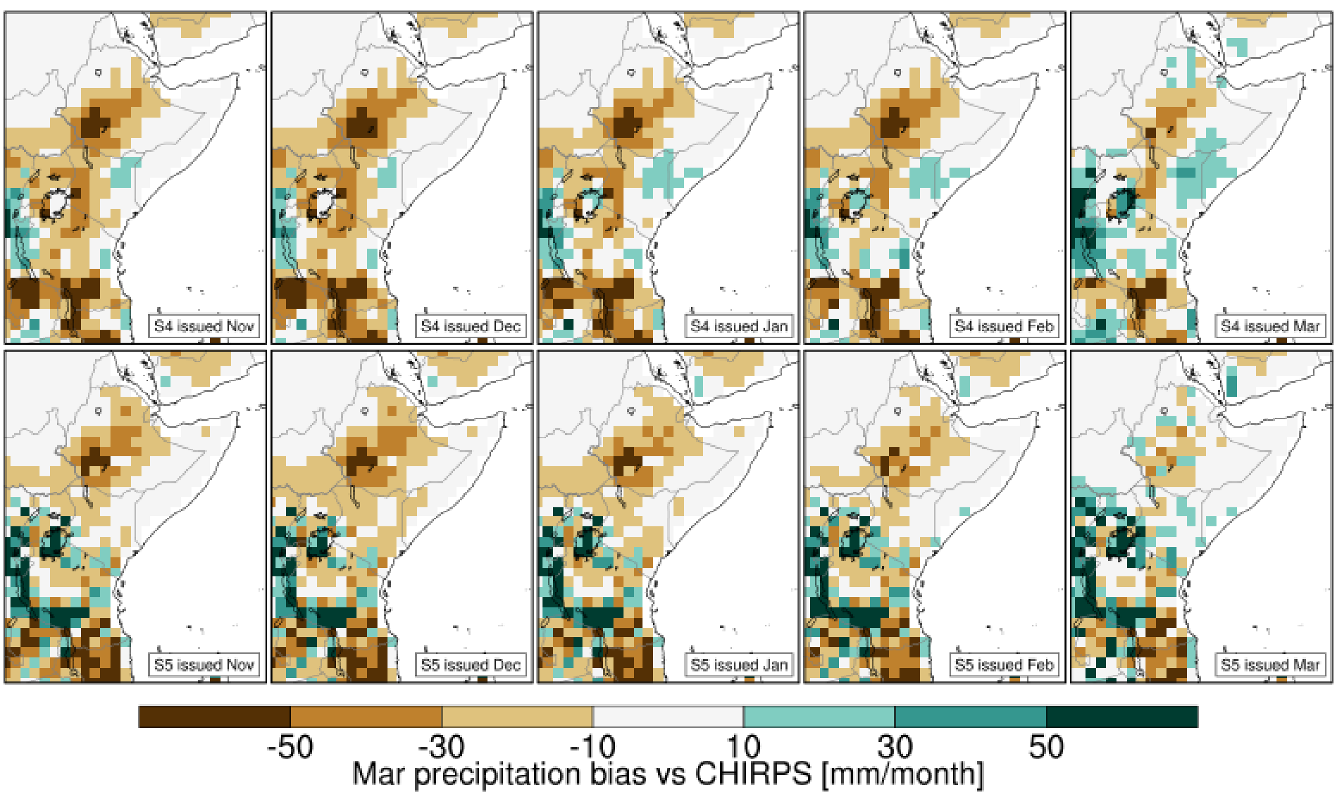

Figure 16. [BiasMar] Precipitation ensemble mean bias Mar, System 4 (top) and SEAS5 (bottom) vs CHIRPS

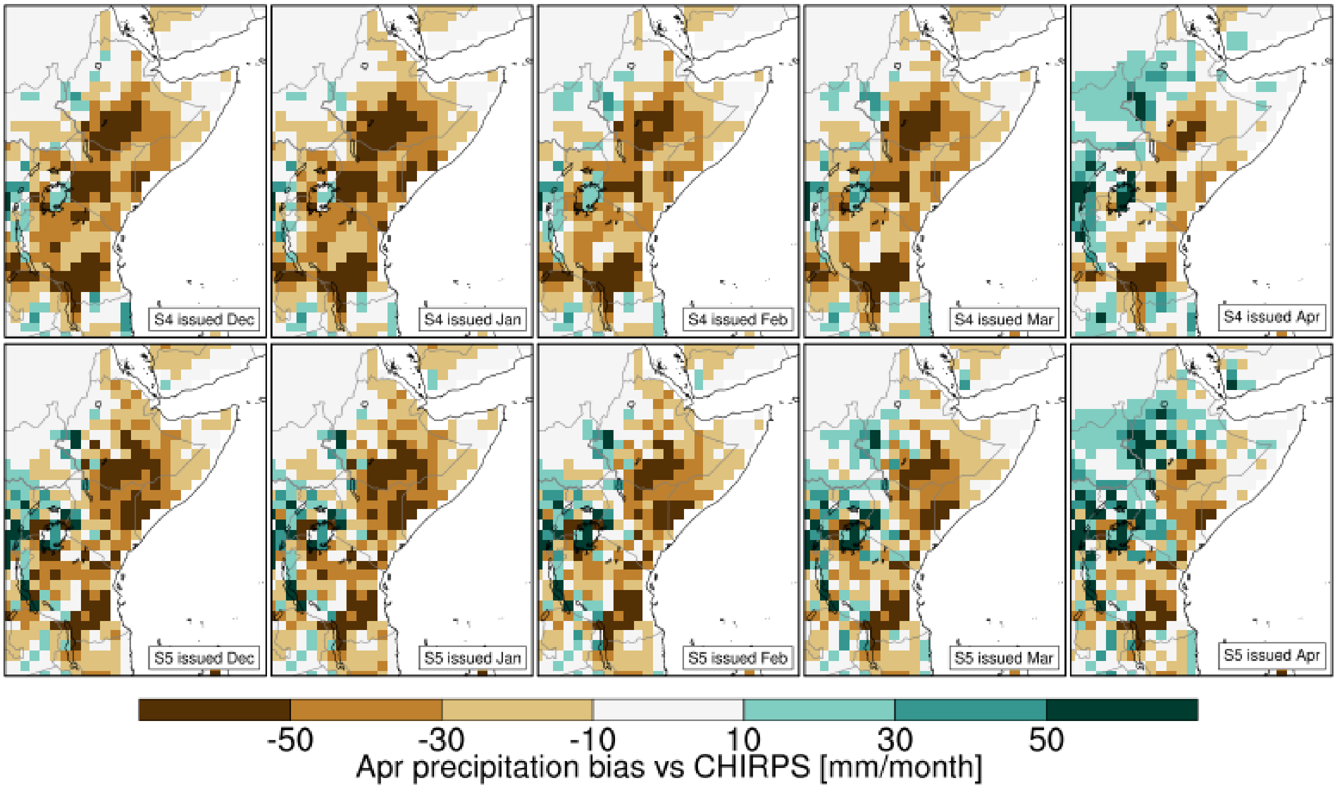

Figure 17. [BiasApr] Precipitation ensemble mean bias Apr, System 4 (top) and SEAS5 (bottom) vs CHIRPS

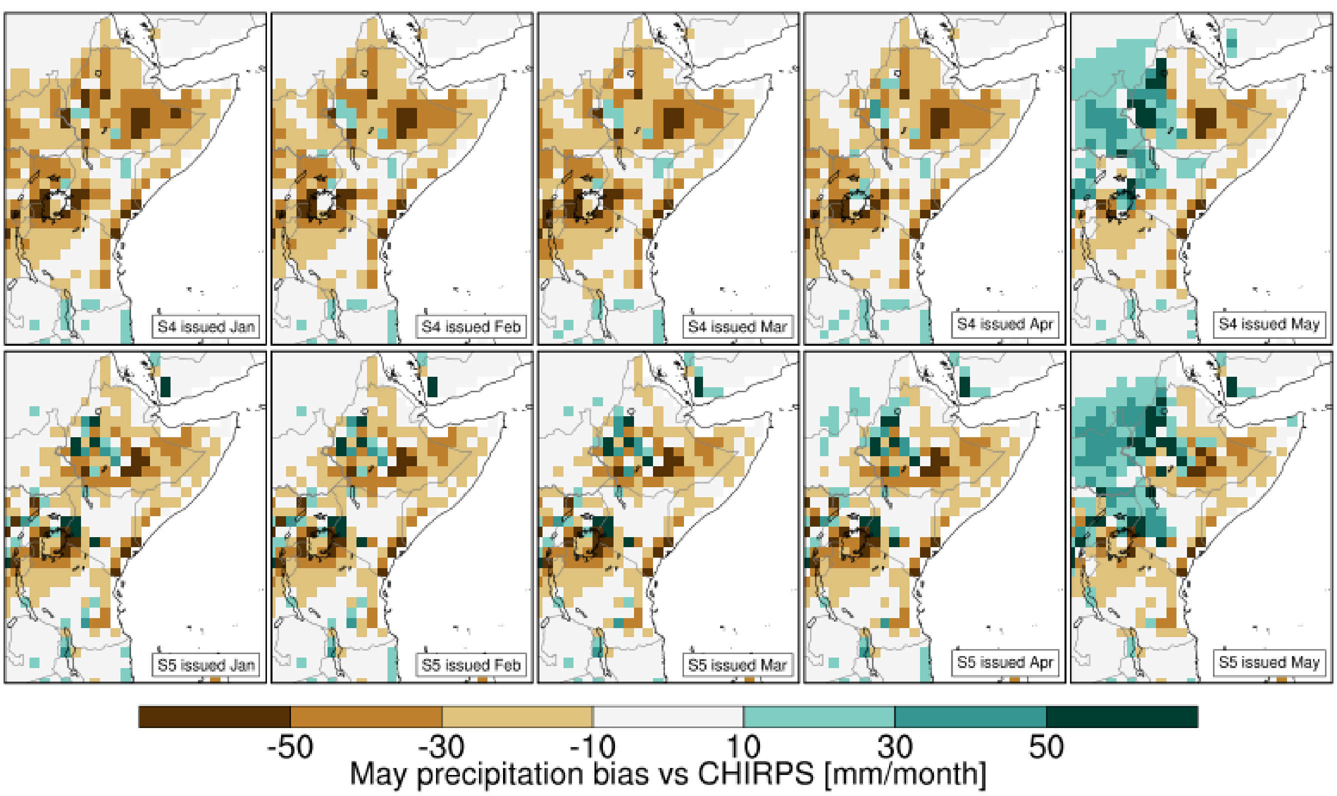

Figure 18. [BiasMay] Precipitation ensemble mean bias May, System 4 (top) and SEAS5 (bottom) vs CHIRPS

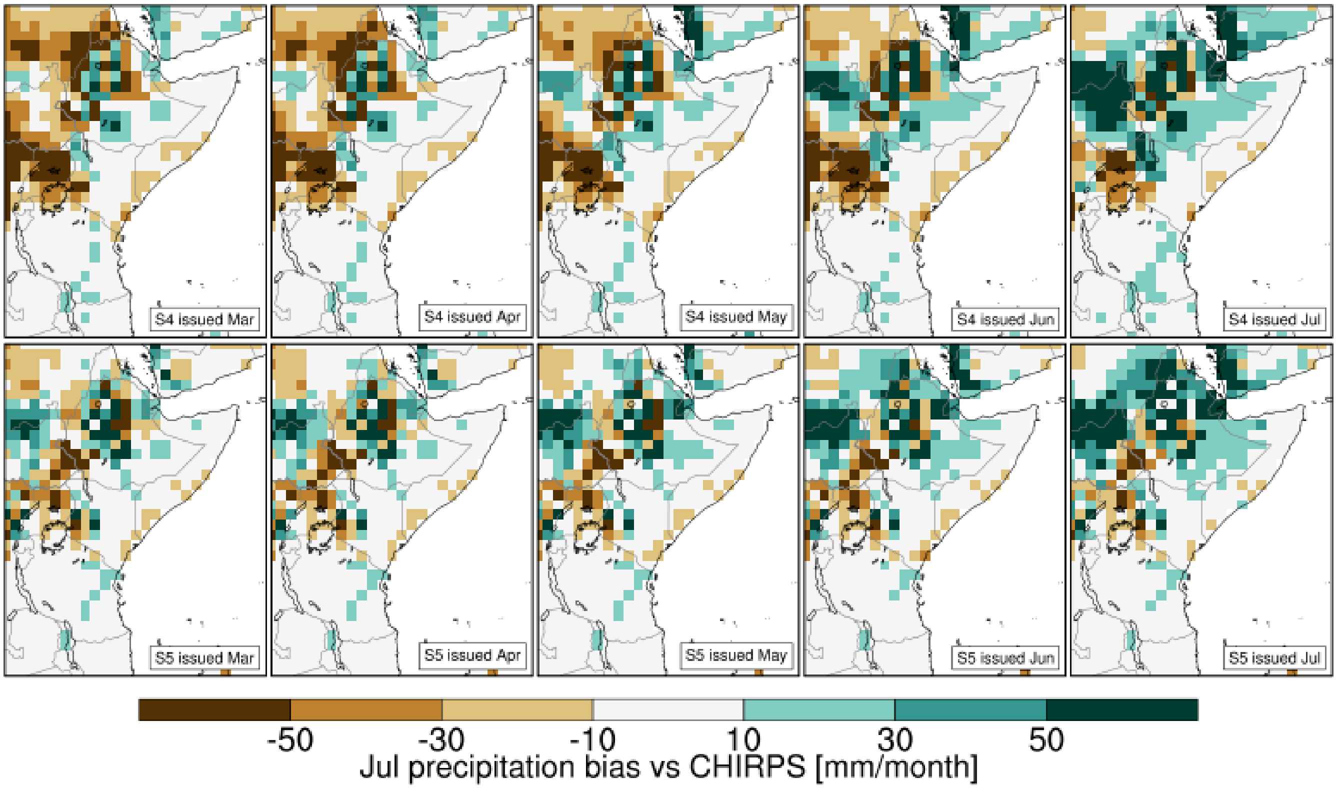

Figure 19. [BiasJul] Precipitation ensemble mean bias Jul, System 4 (top) and SEAS5 (bottom) vs CHIRPS

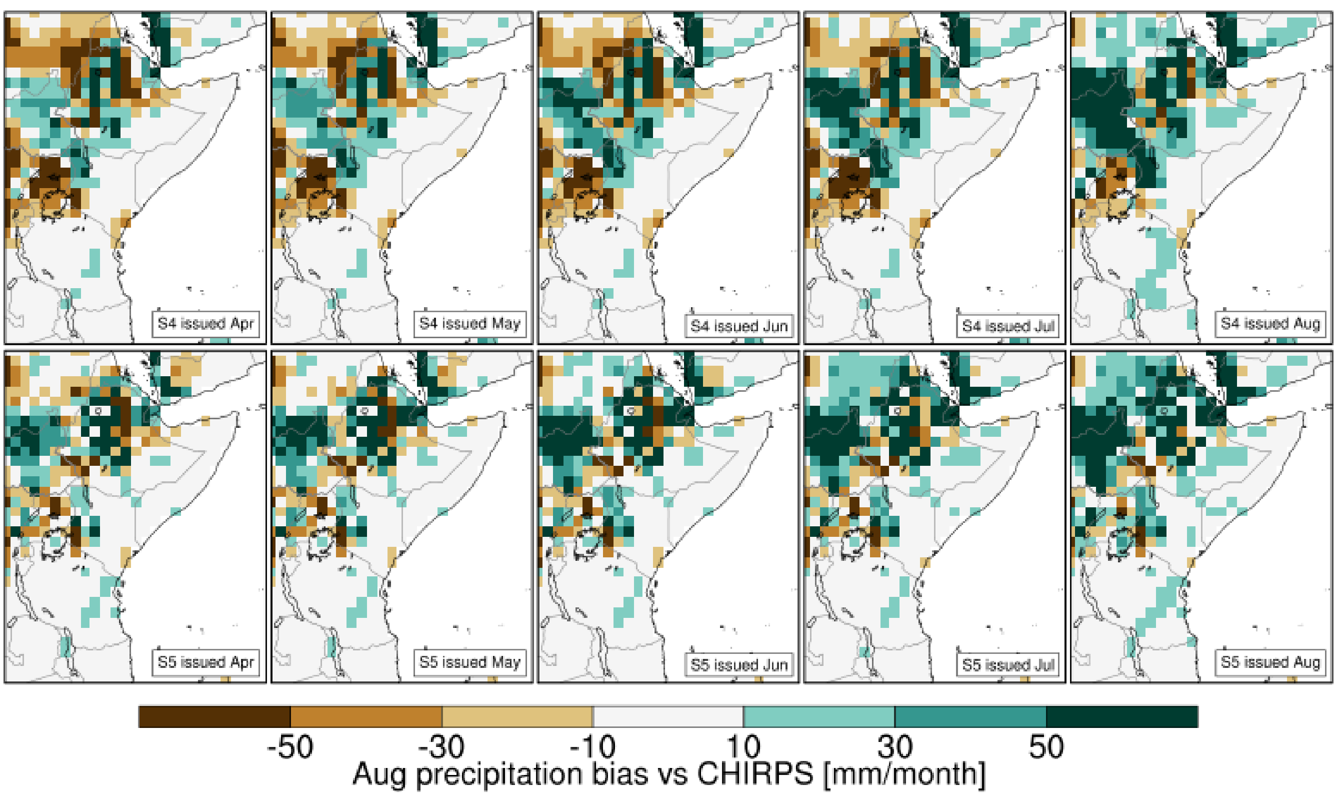

Figure 20. [BiasAug] Precipitation ensemble mean bias Aug, System 4 (top) and SEAS5 (bottom) vs CHIRPS

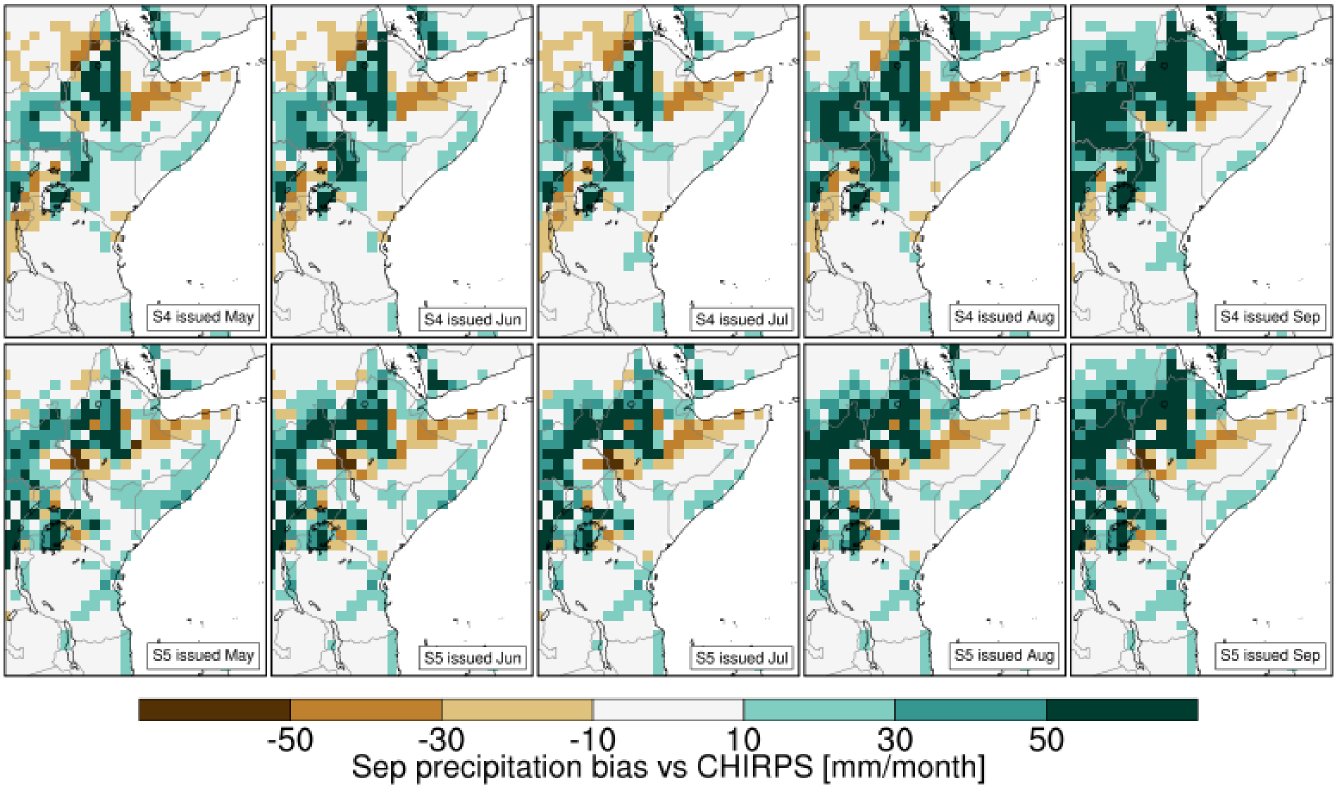

Figure 21. [BiasSep] Precipitation ensemble mean bias Sep, System 4 (top) and SEAS5 (bottom) vs CHIRPS

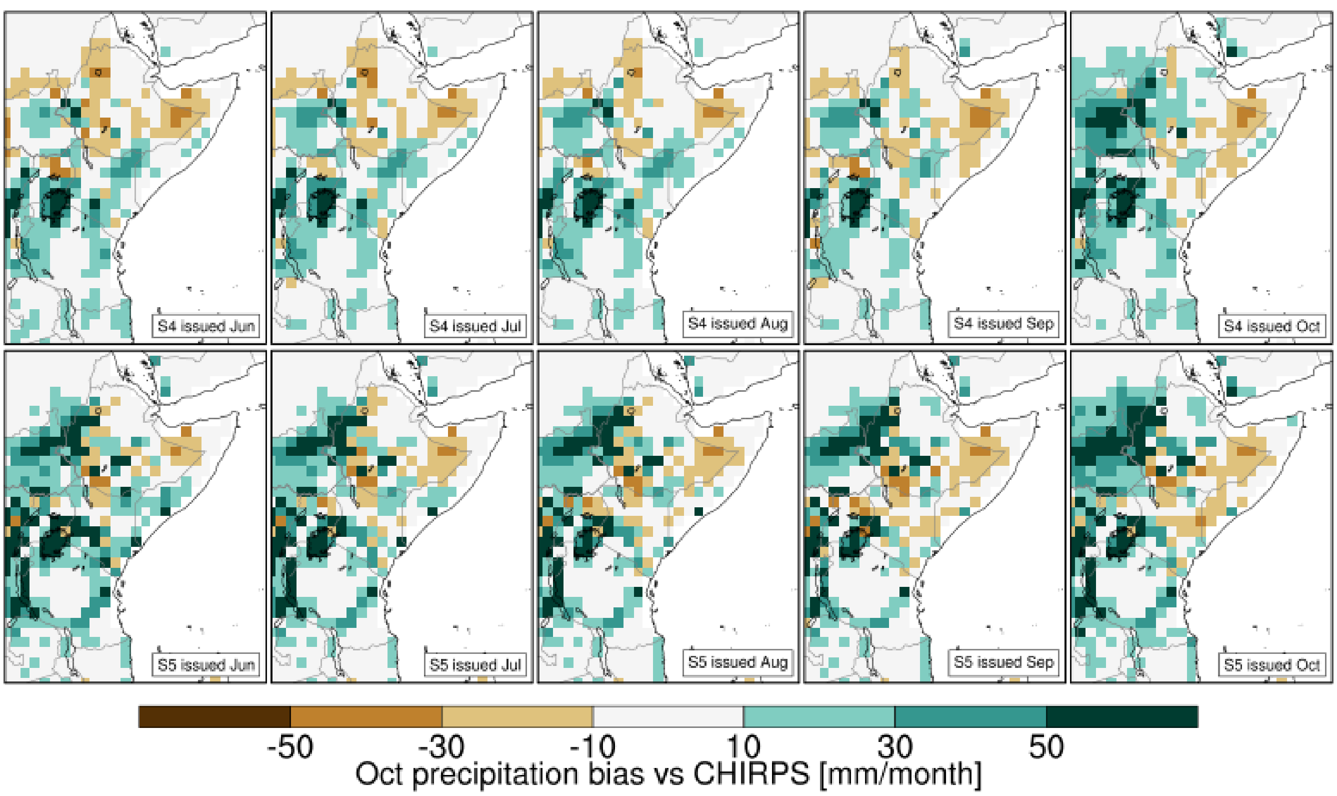

Figure 22. [BiasOct] Precipitation ensemble mean bias Oct, System 4 (top) and SEAS5 (bottom) vs CHIRPS

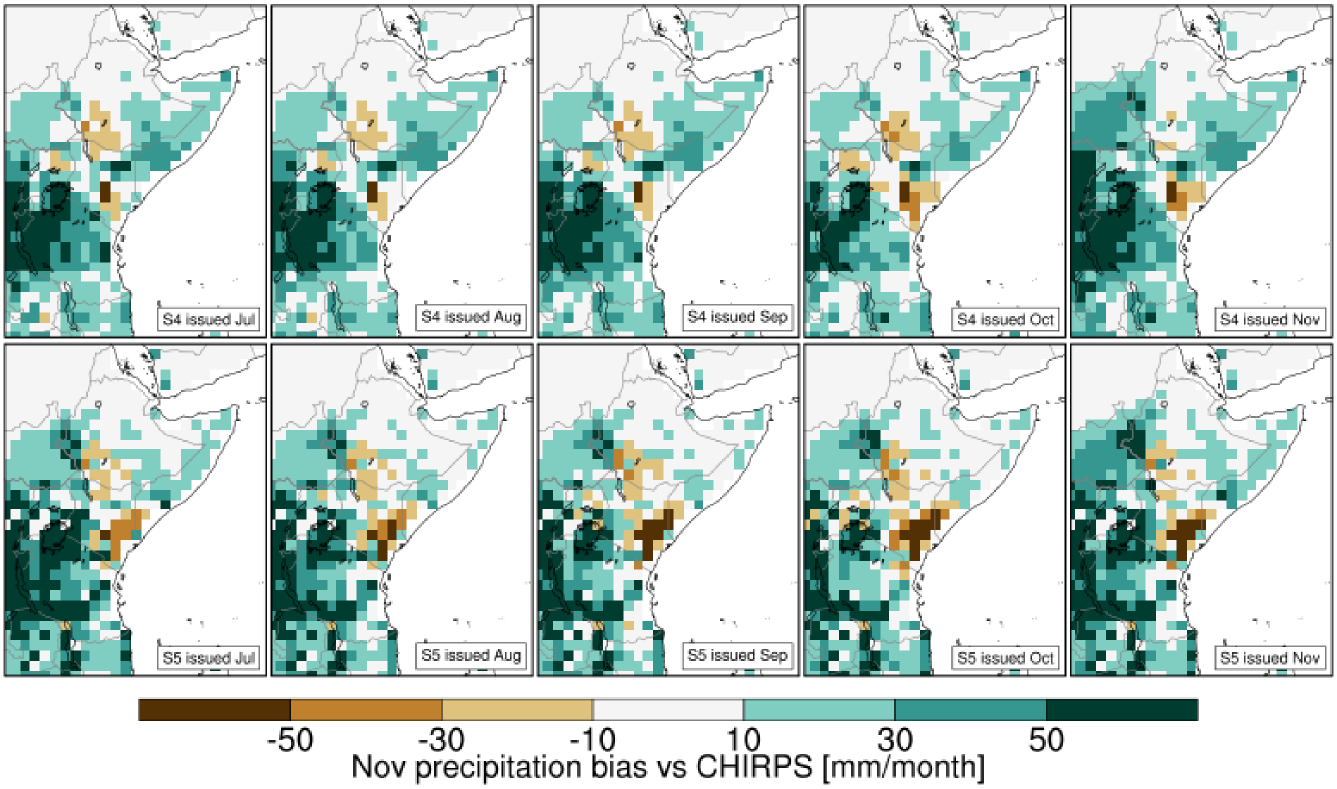

Figure 23. [BiasNov] Precipitation ensemble mean bias Nov, System 4 (top) and SEAS5 (bottom) vs CHIRPS

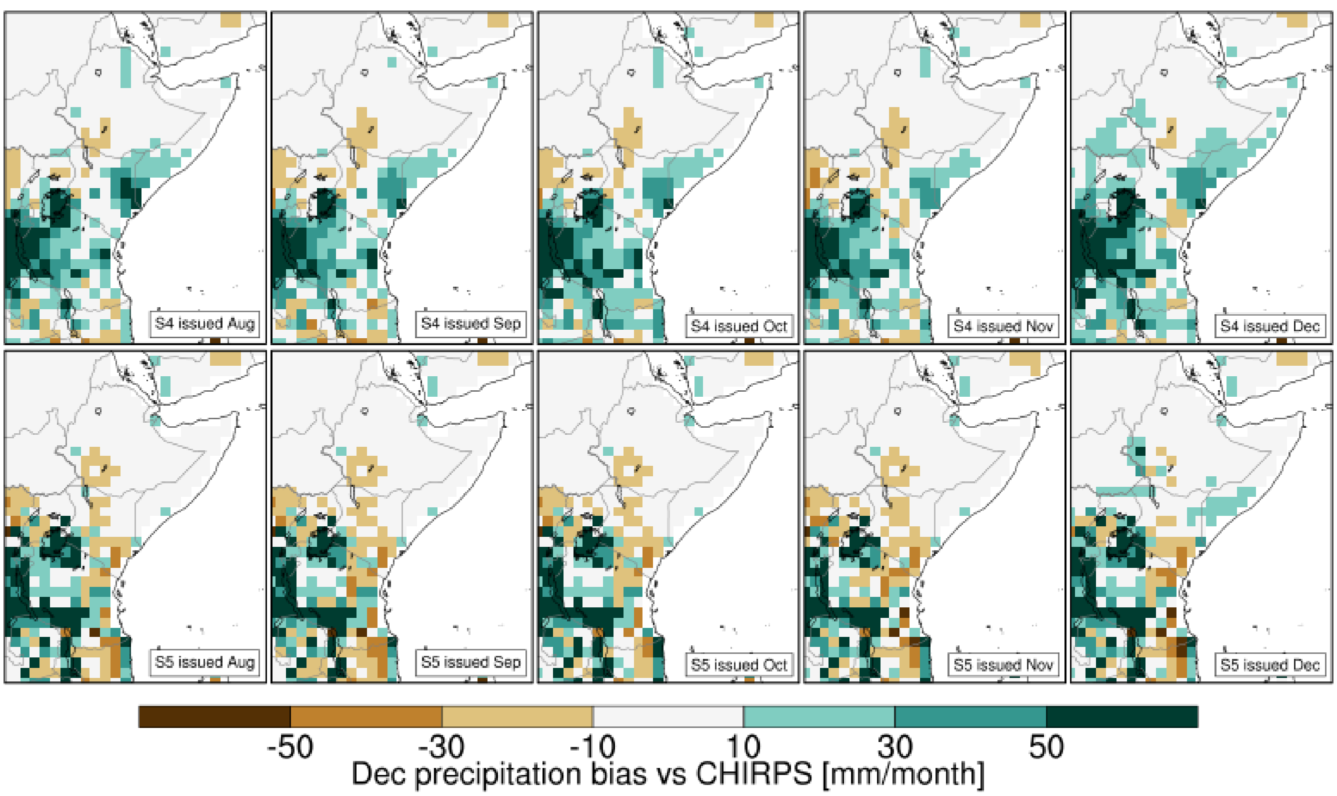

Figure 24. [BiasDec] Precipitation ensemble mean bias Dec, System 4 (top) and SEAS5 (bottom) vs CHIRPS

4.2 Ensemble mean correlation

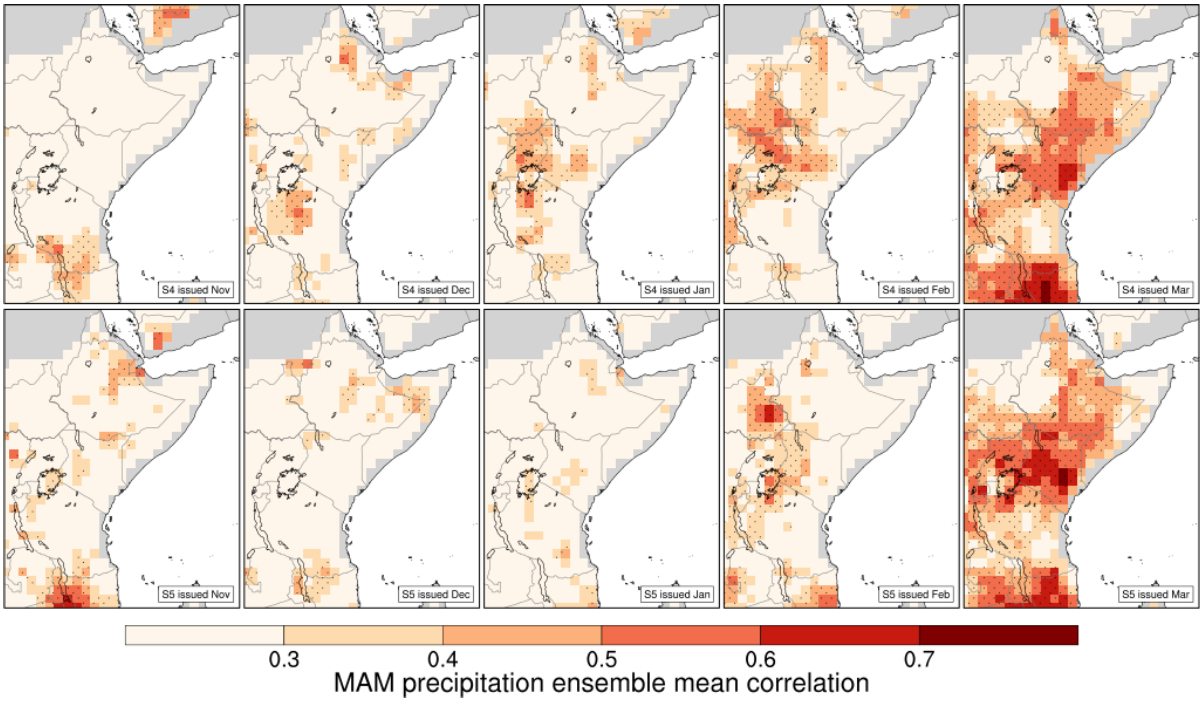

Figure 25. [CorrMAM] Pearson's correlation coefficient for MAM, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

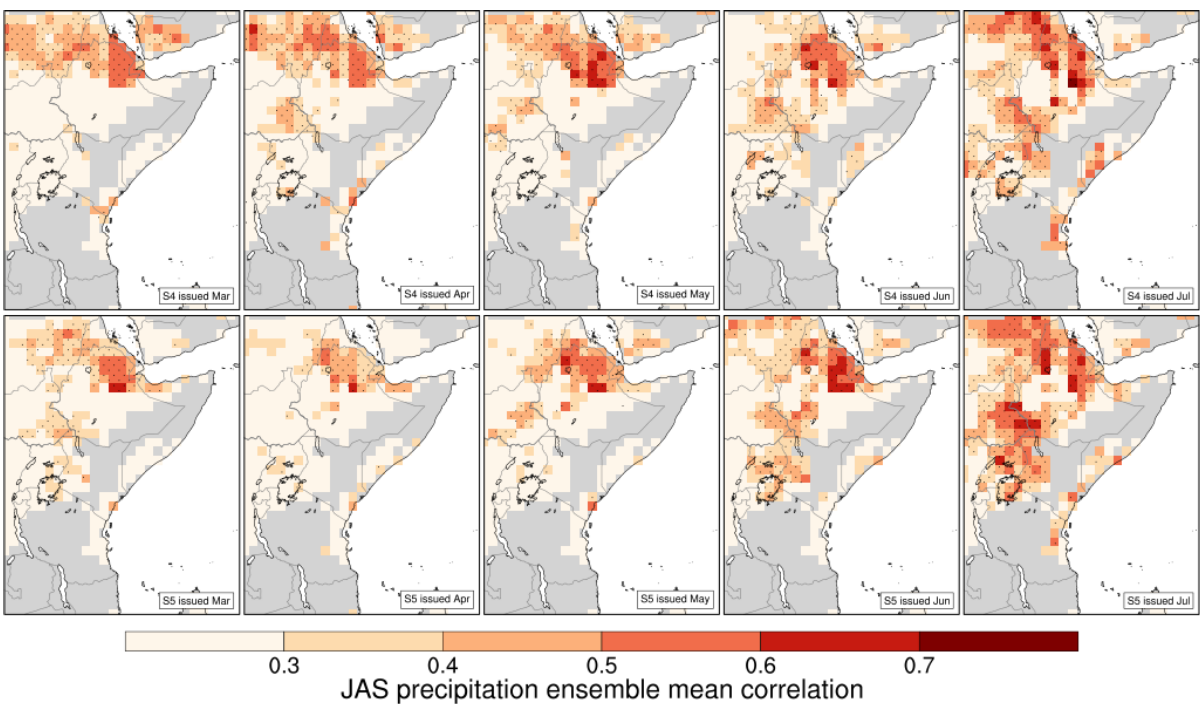

Figure 26. [CorrJAS] Pearson's correlation coefficient for JAS, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

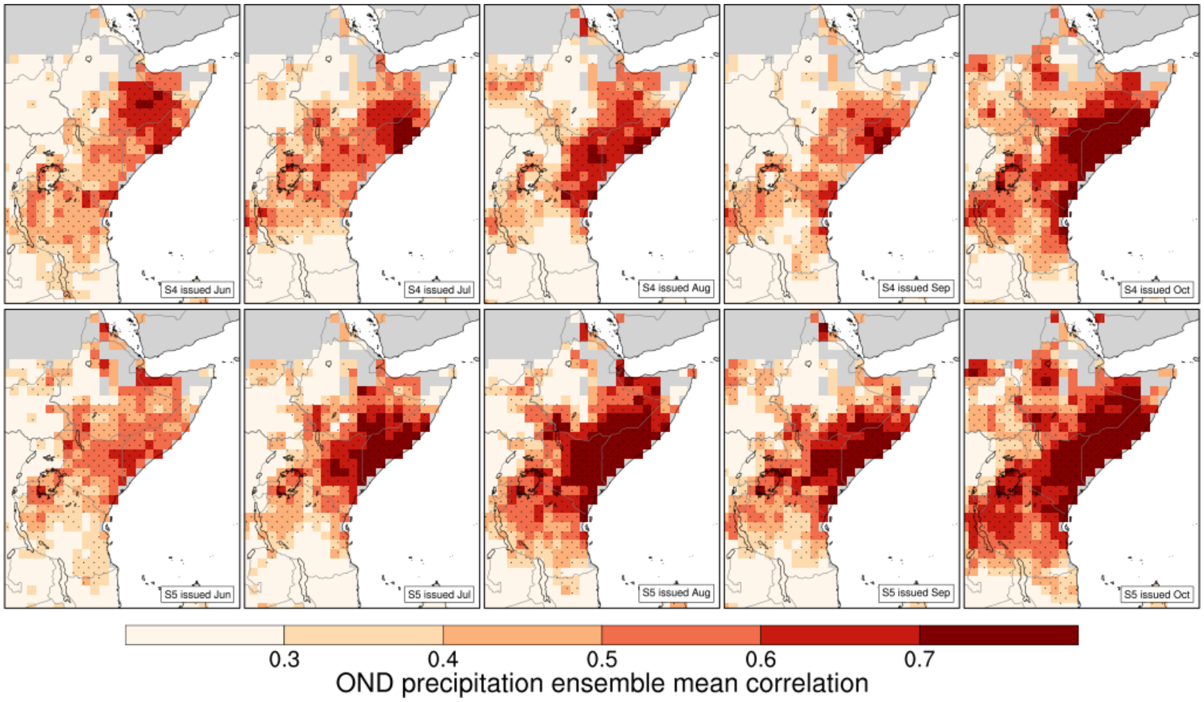

Figure 27. [CorrOND] Pearson's correlation coefficient for OND, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

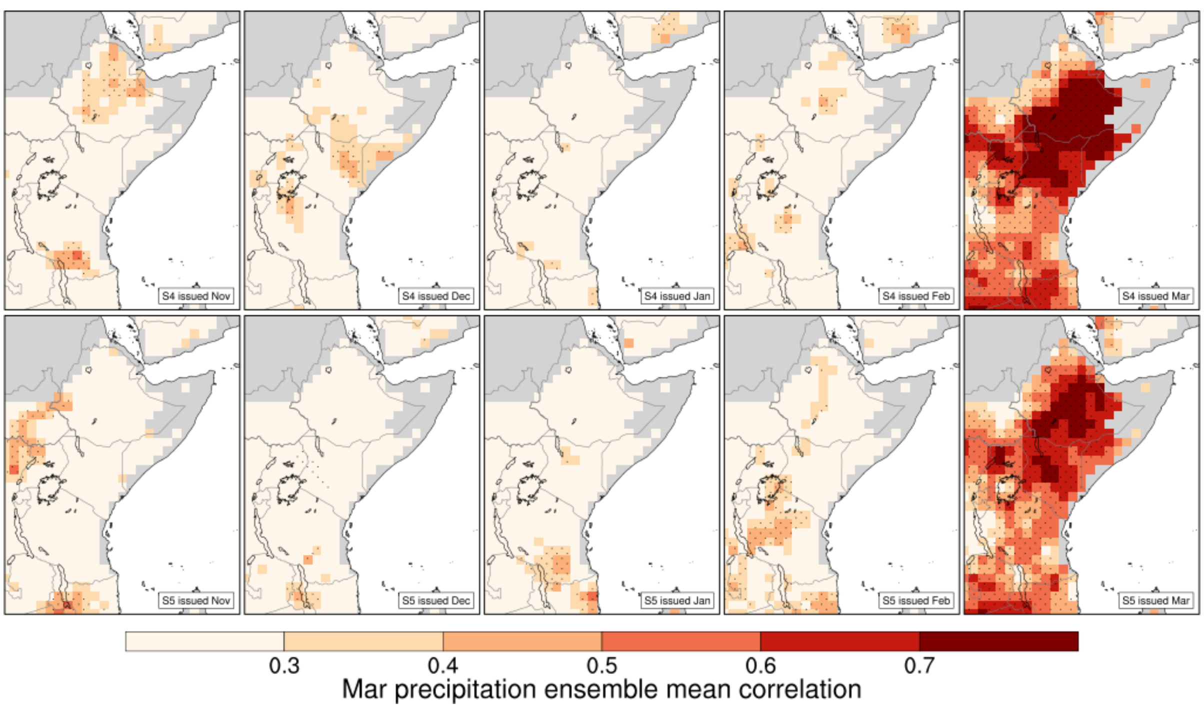

Figure 28. [CorrMar] Pearson's correlation coefficient for Mar, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

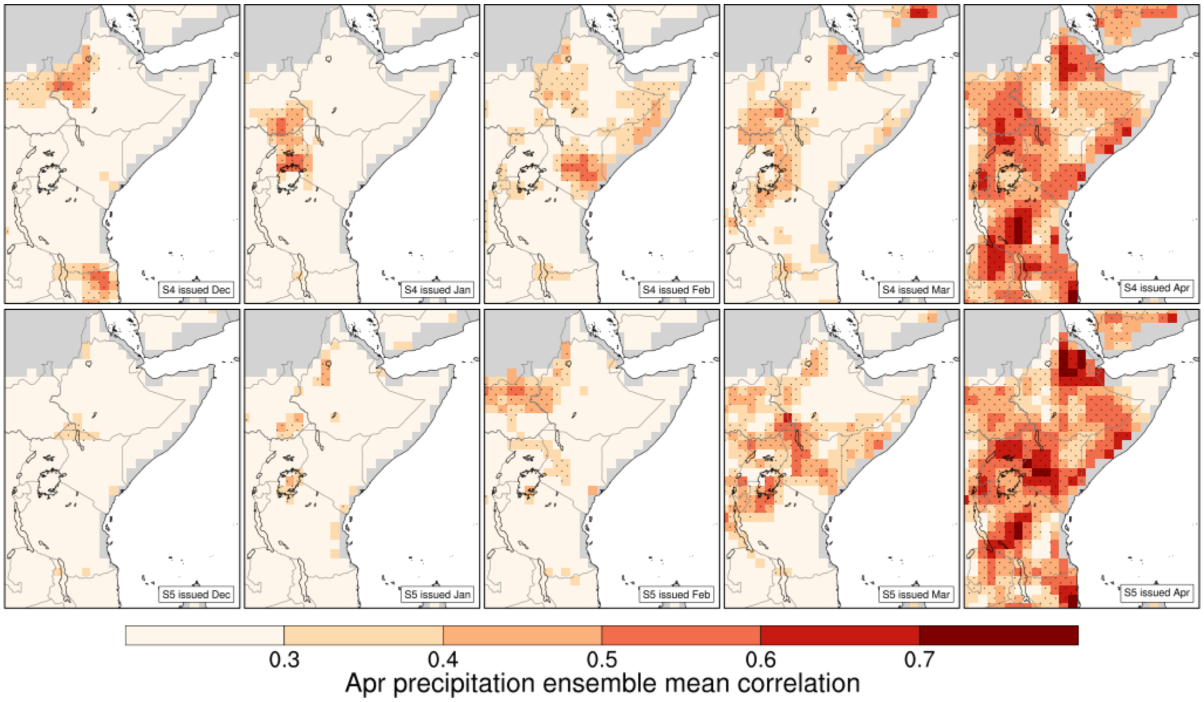

Figure 29. [CorrApr] Pearson's correlation coefficient for Apr, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

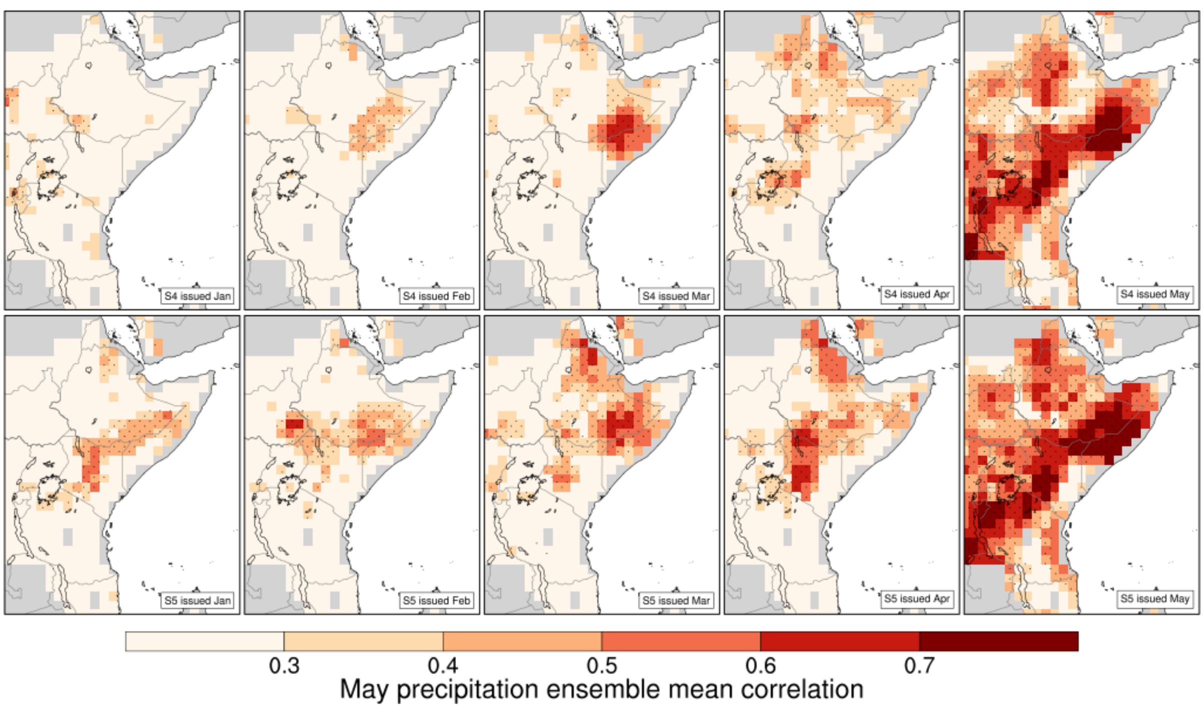

Figure 30. [CorrMay] Pearson's correlation coefficient for May, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

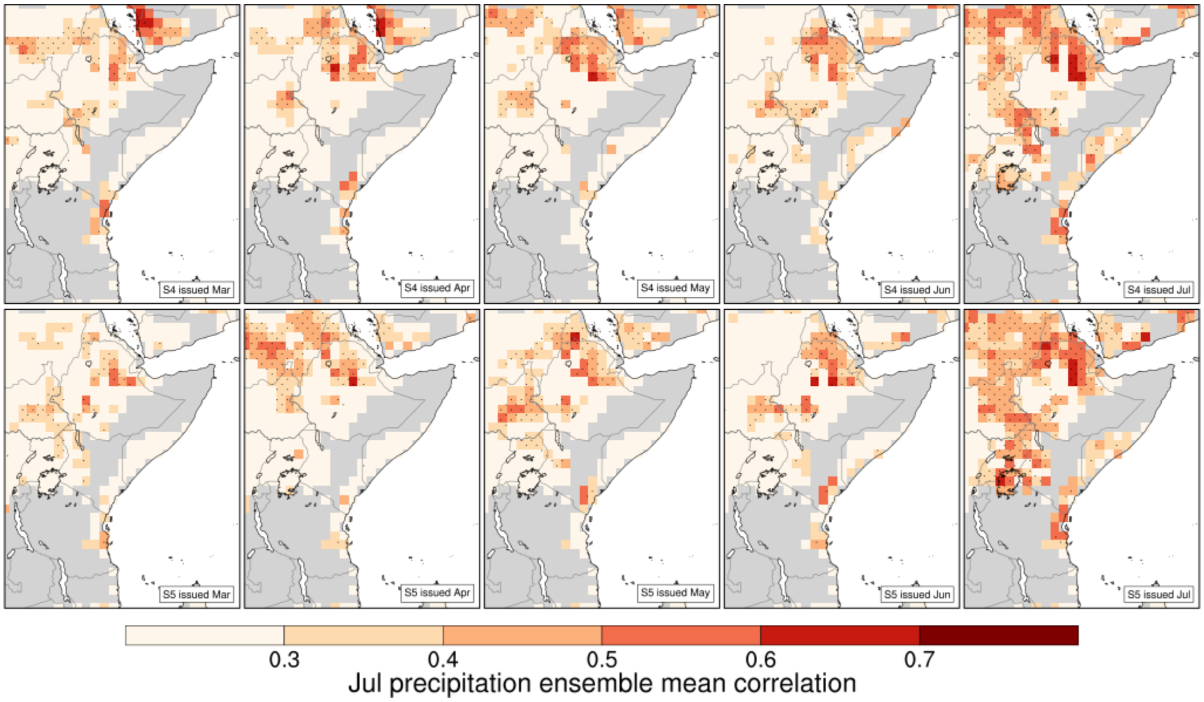

Figure 31. [CorrJul] Pearson's correlation coefficient for Jul, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

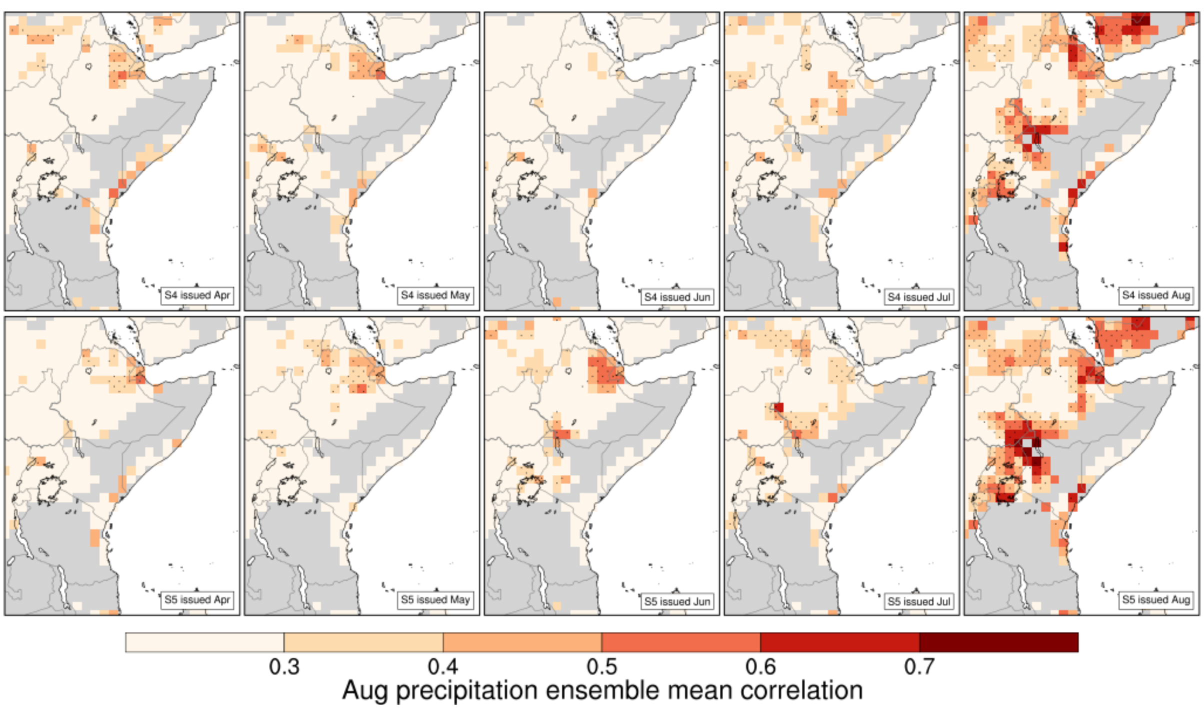

Figure 32. [CorrAug] Pearson's correlation coefficient for Aug, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

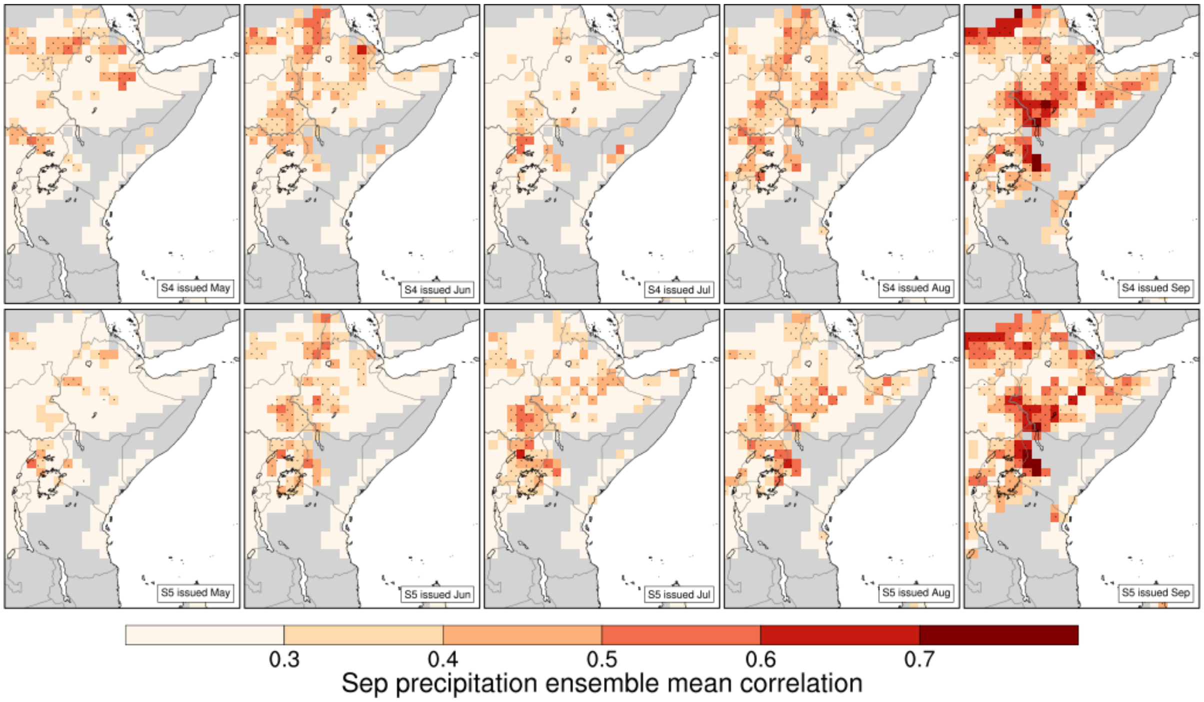

Figure 33. [CorrSep] Pearson's correlation coefficient for Sep, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

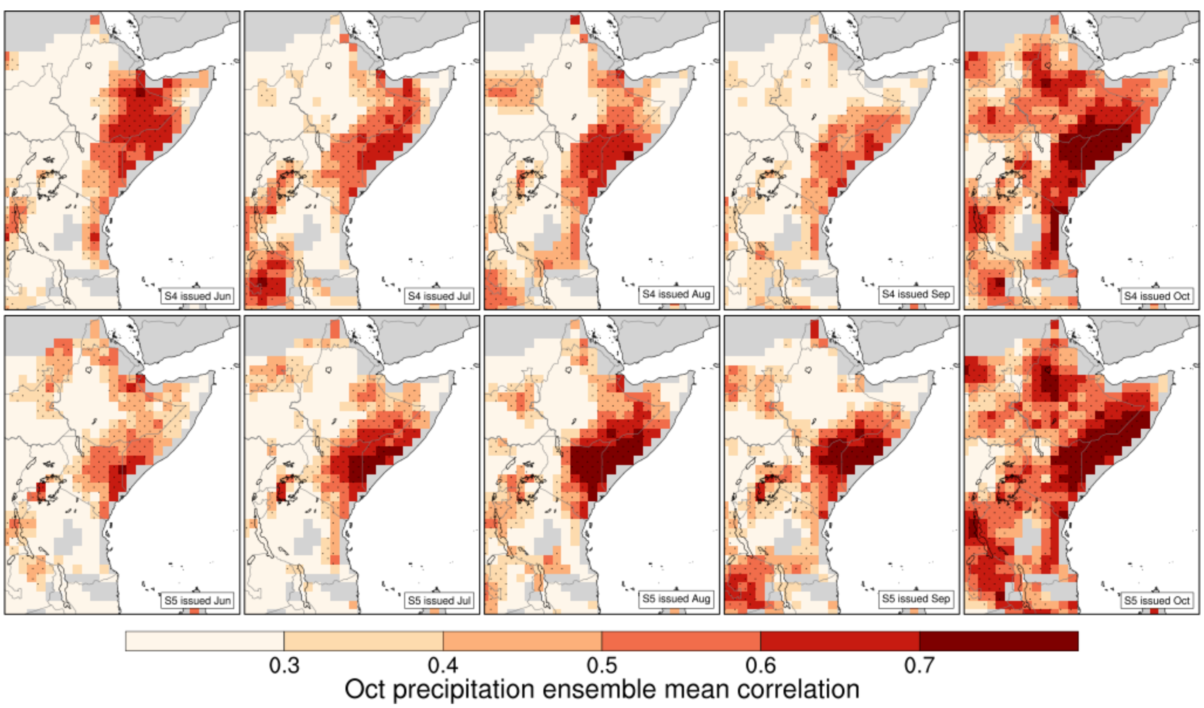

Figure 34. [CorrOct] Pearson's correlation coefficient for Oct, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

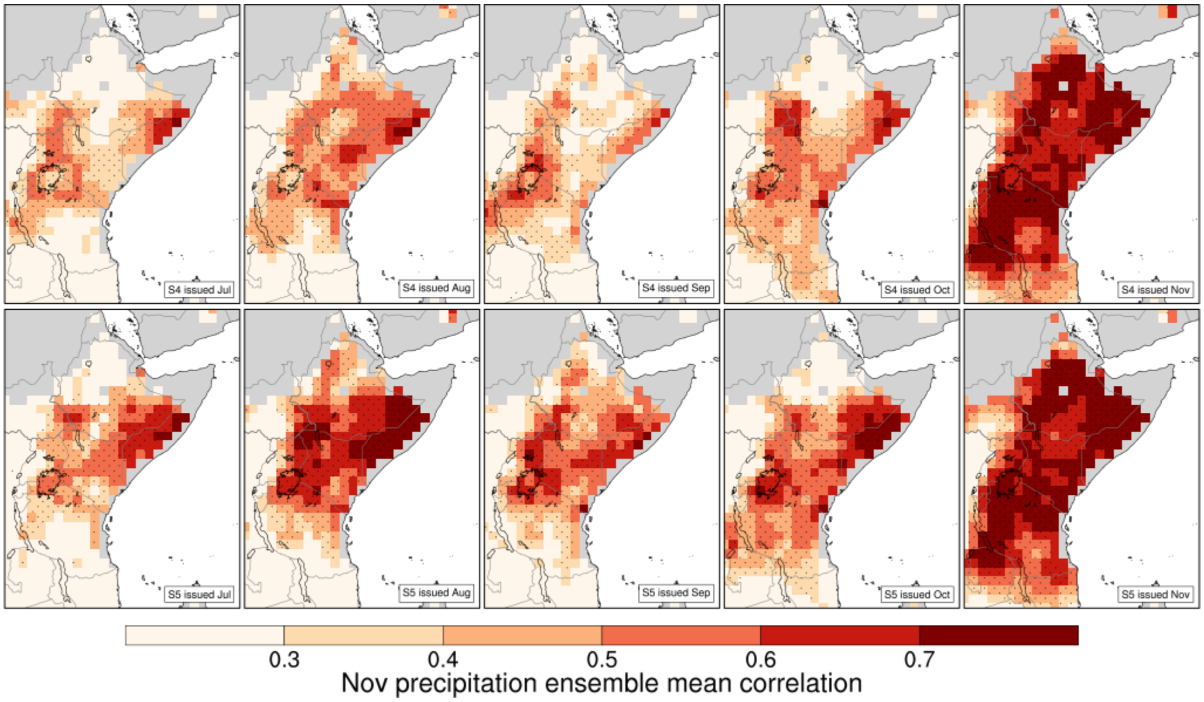

Figure 35. [CorrNov] Pearson's correlation coefficient for Nov, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

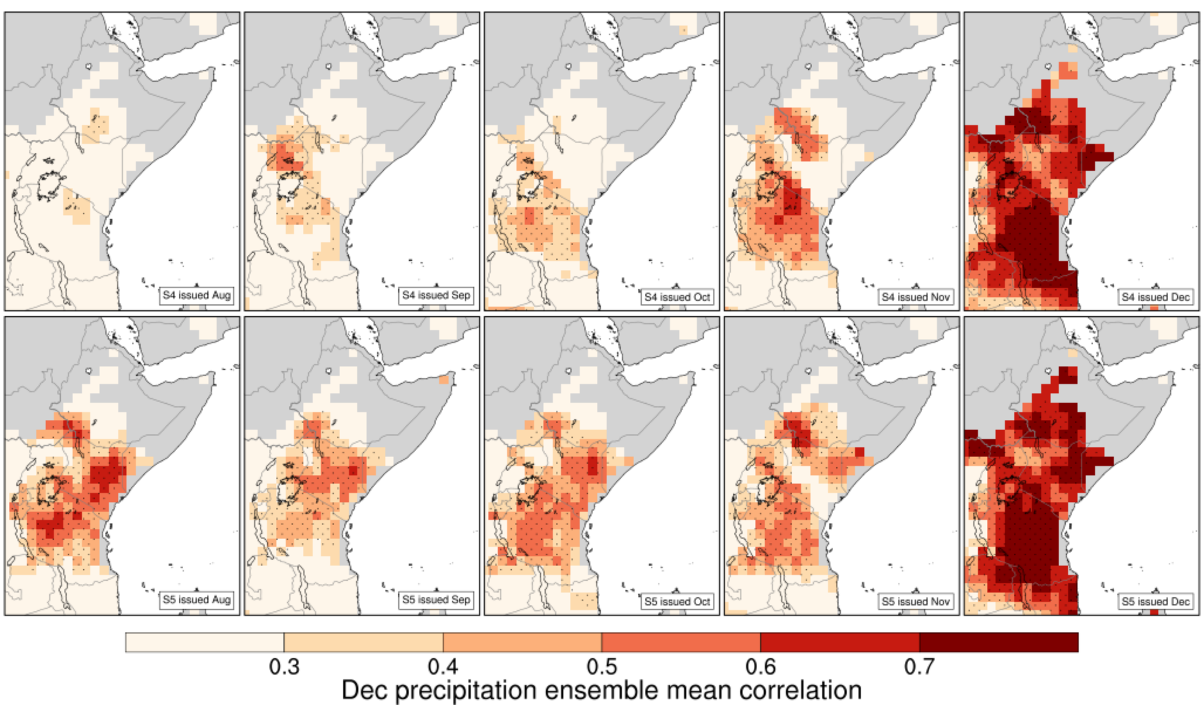

Figure 36. [CorrDec] Pearson's correlation coefficient for Dec, ensemble mean precipitation System 4 (top) and SEAS5 (bottom) vs CHIRPS. Stippling indicates correlations significantly different from zero at the 95% significance level.

4.3 Relative Operating Characteristic AUC

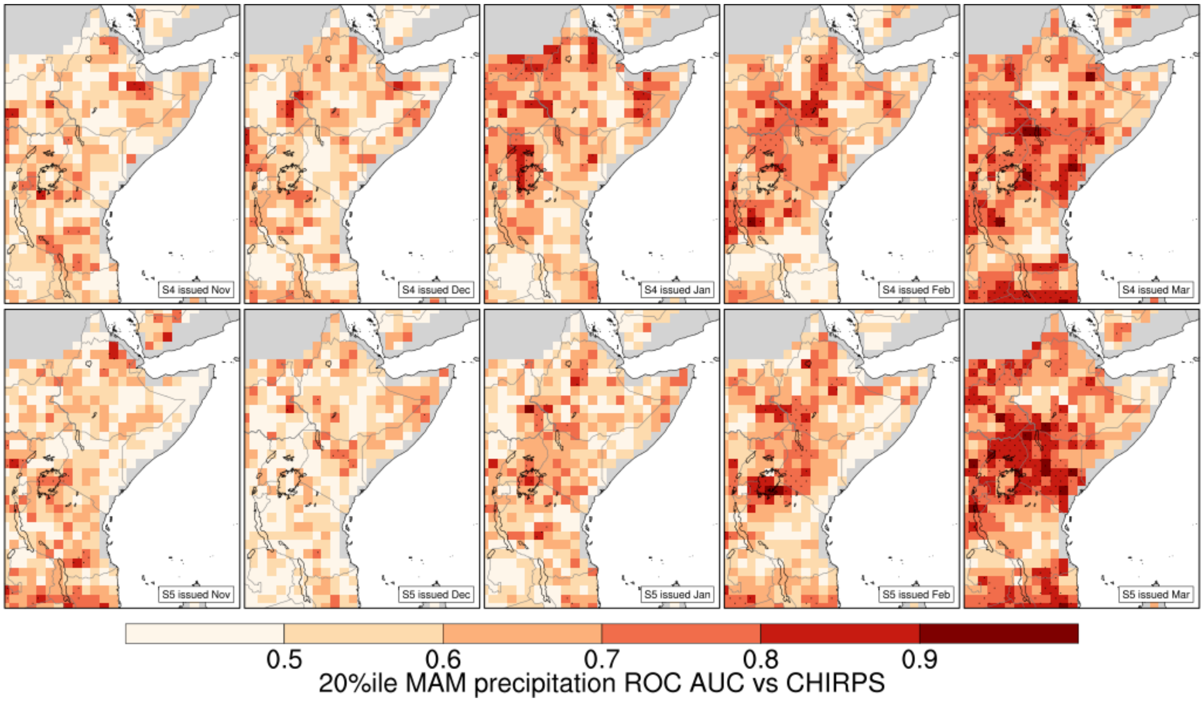

Figure 37. [ROC20MAM] ROC Area under curve for MAM: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

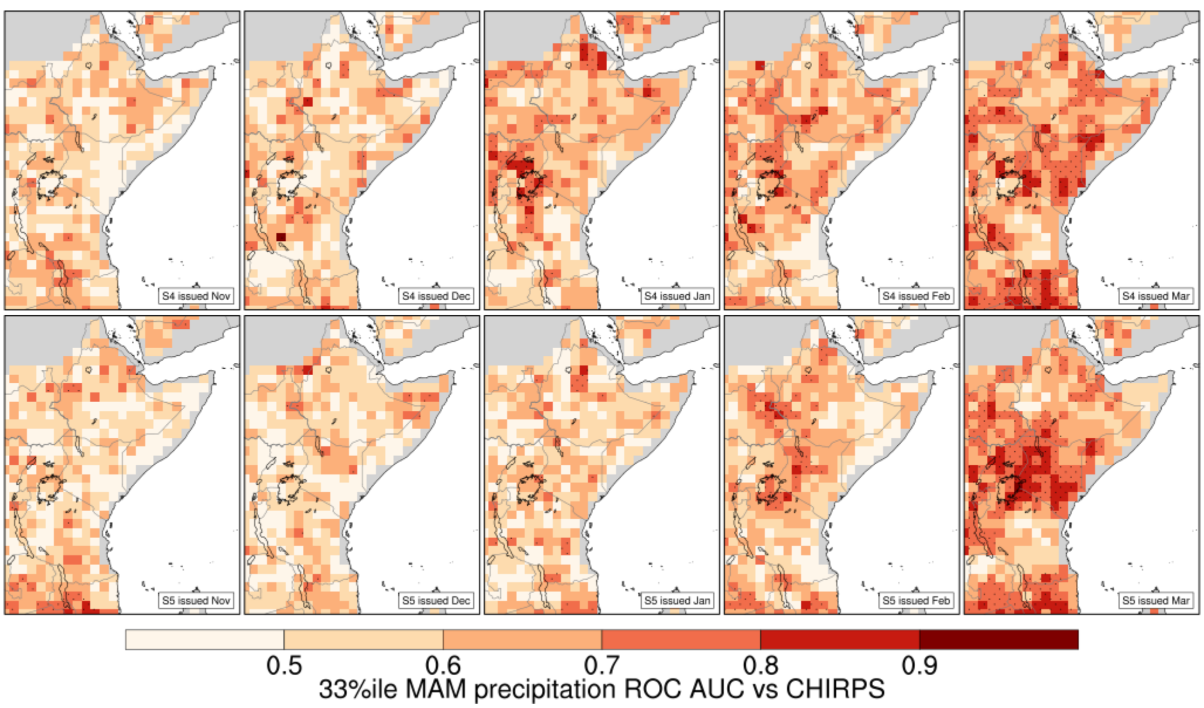

Figure 38. [ROC33MAM] ROC Area under curve for MAM: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

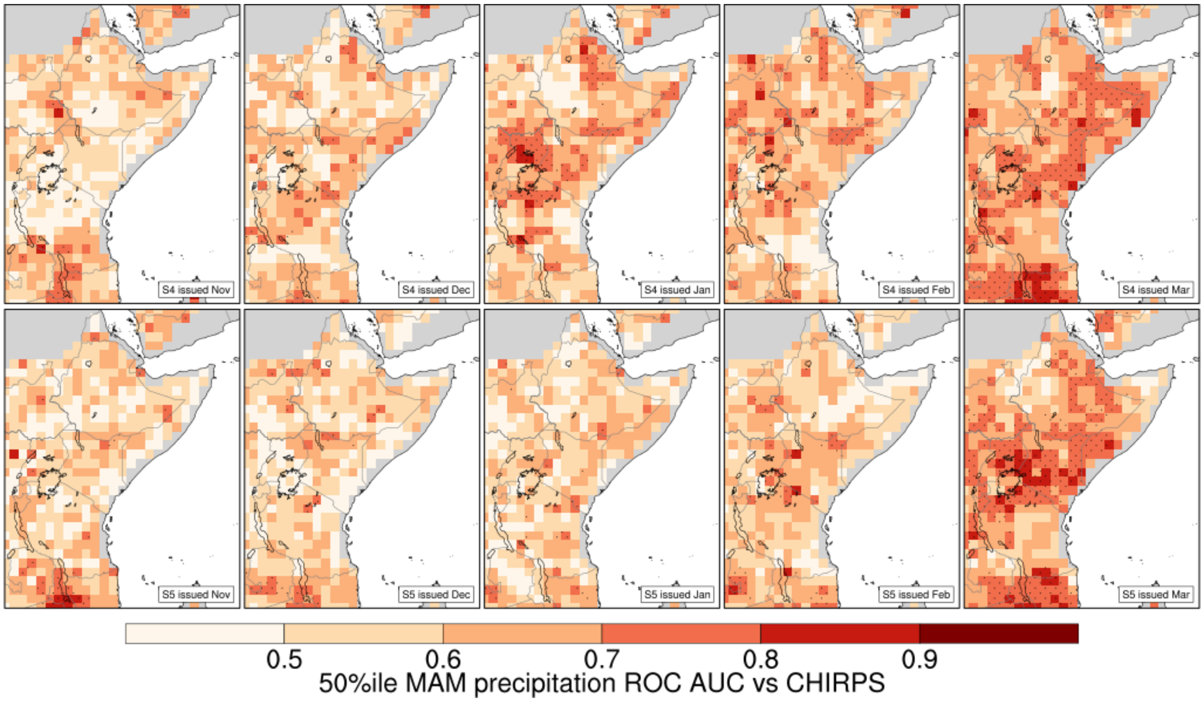

Figure 39. [ROC50MAM] ROC Area under curve for MAM: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

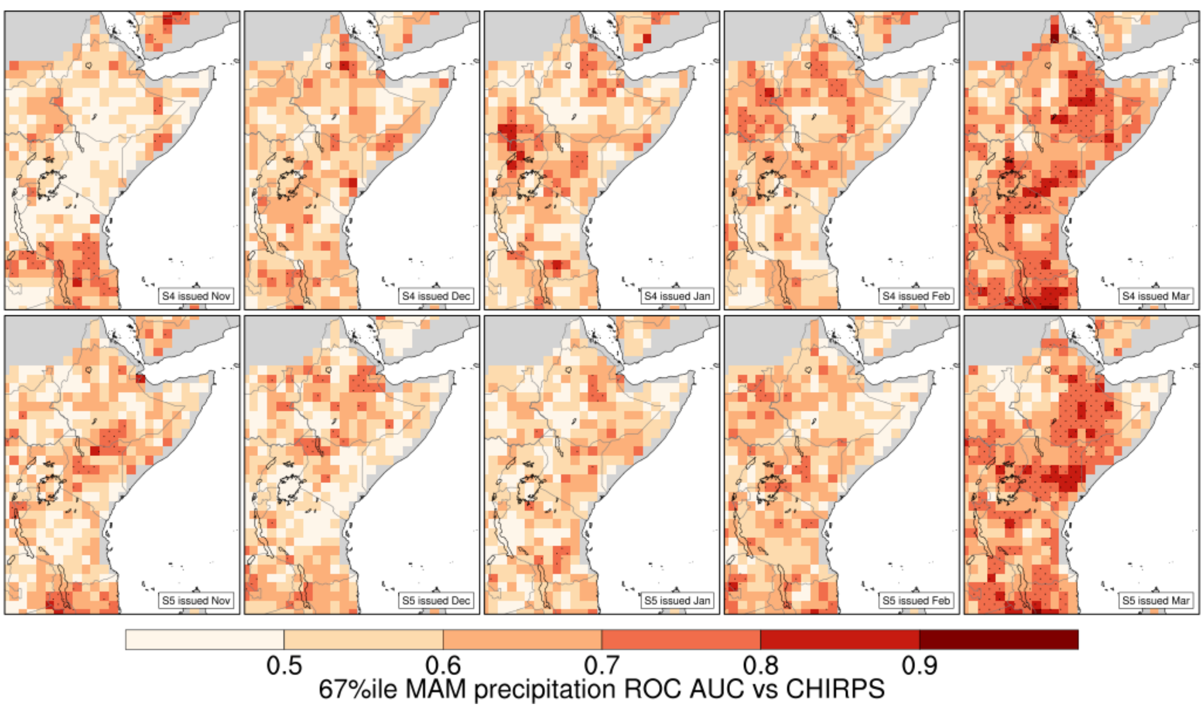

Figure 40. [ROC67MAM] ROC Area under curve for MAM: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

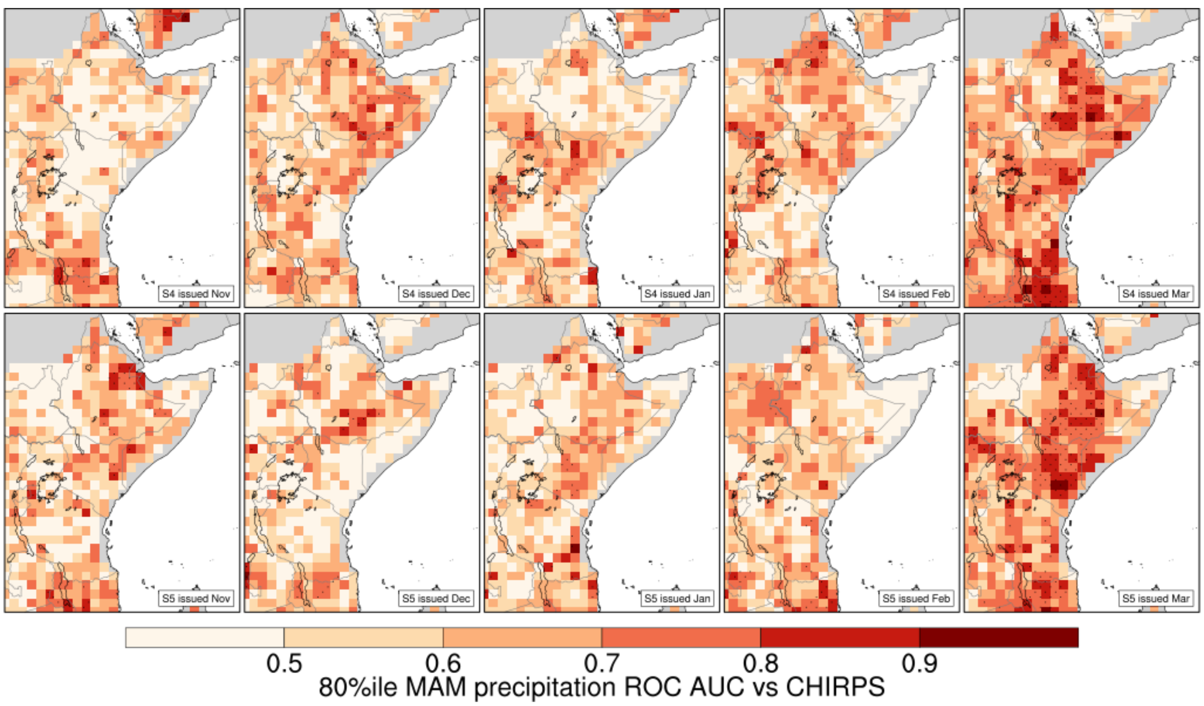

Figure 41. [ROC80MAM] ROC Area under curve for MAM: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

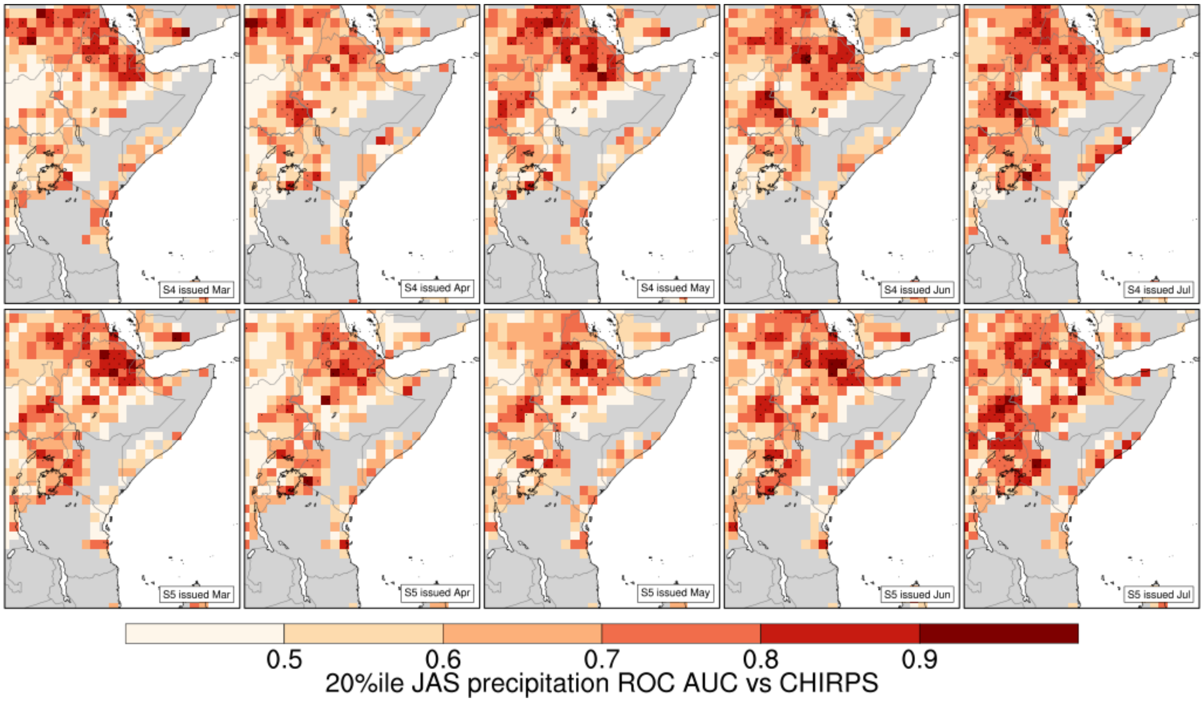

Figure 42. [ROC20JAS] ROC Area under curve for JAS: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

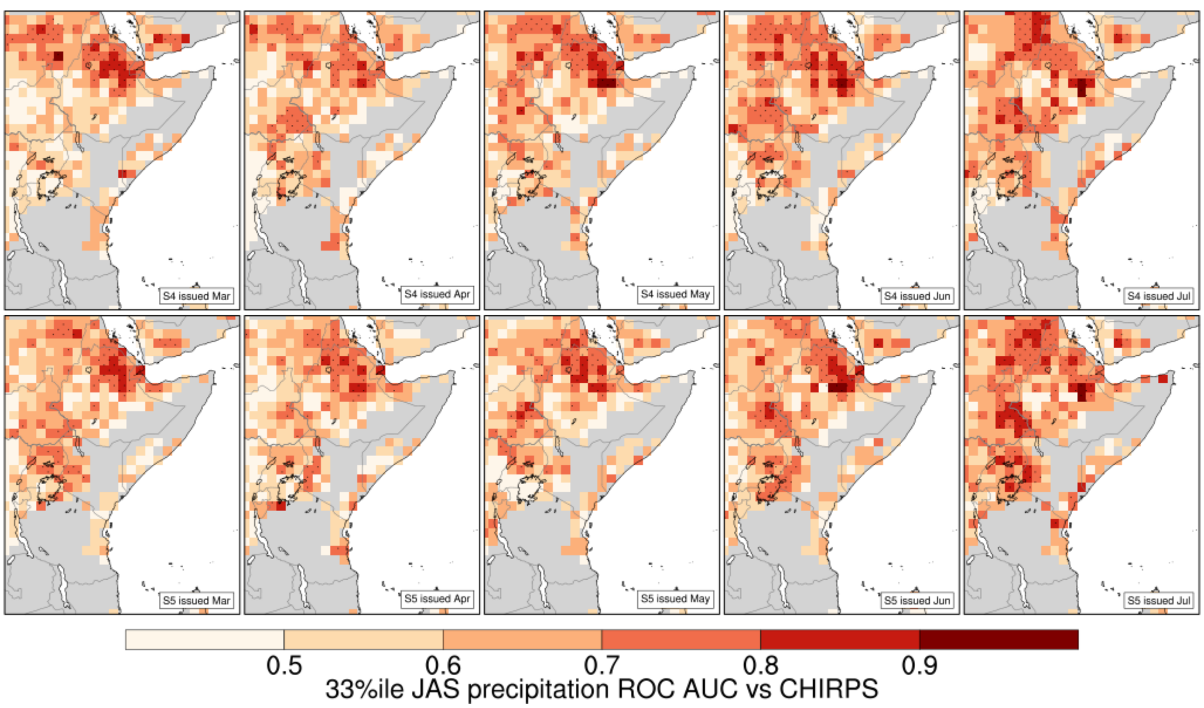

Figure 43. [ROC33JAS] ROC Area under curve for JAS: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

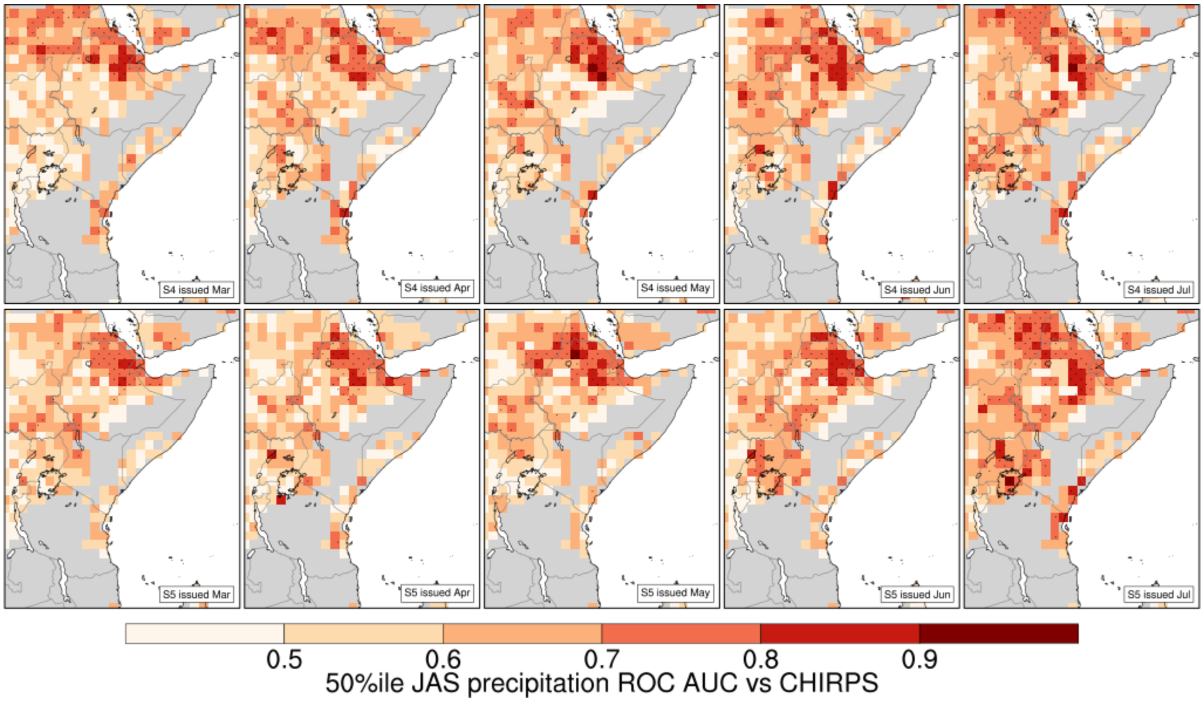

Figure 44. [ROC50JAS] ROC Area under curve for JAS: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

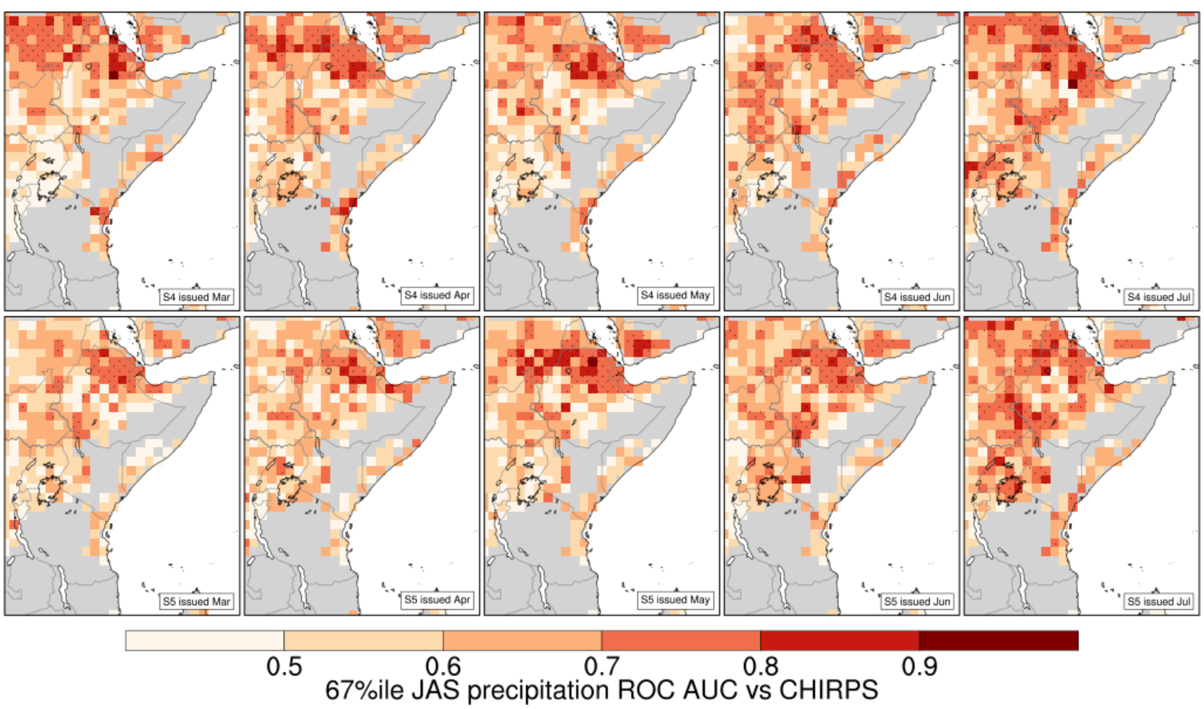

Figure 45. [ROC67JAS] ROC Area under curve for JAS: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

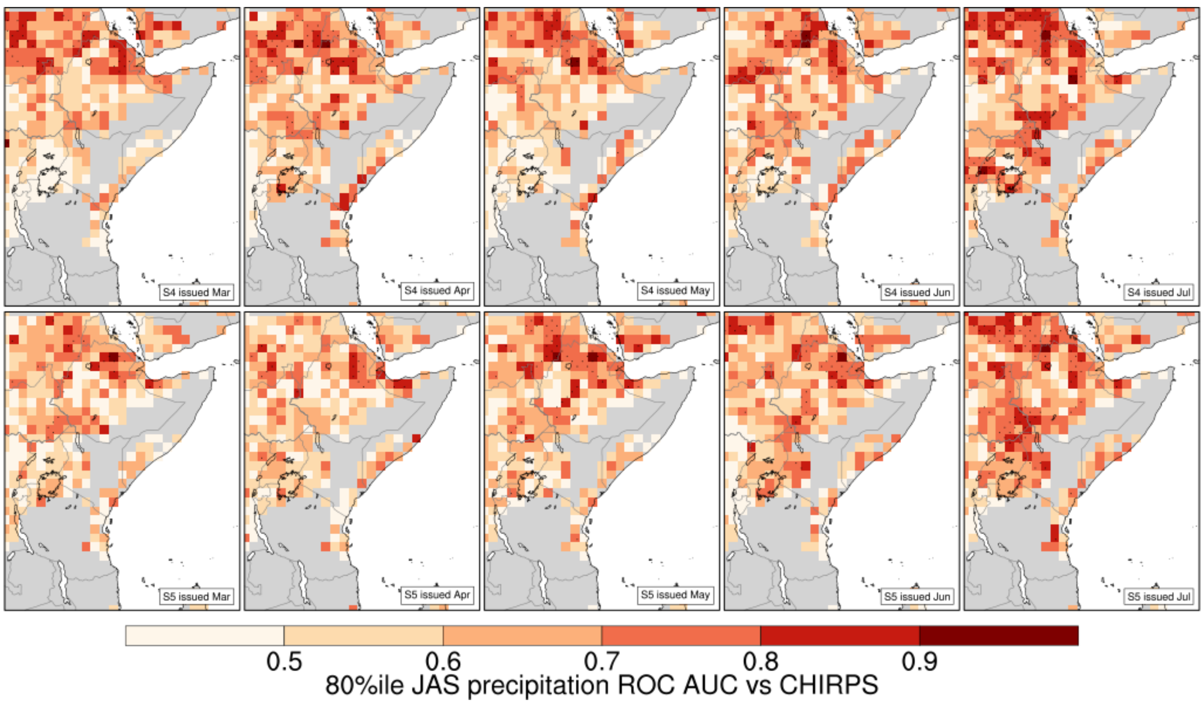

Figure 46. [ROC80JAS] ROC Area under curve for JAS: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

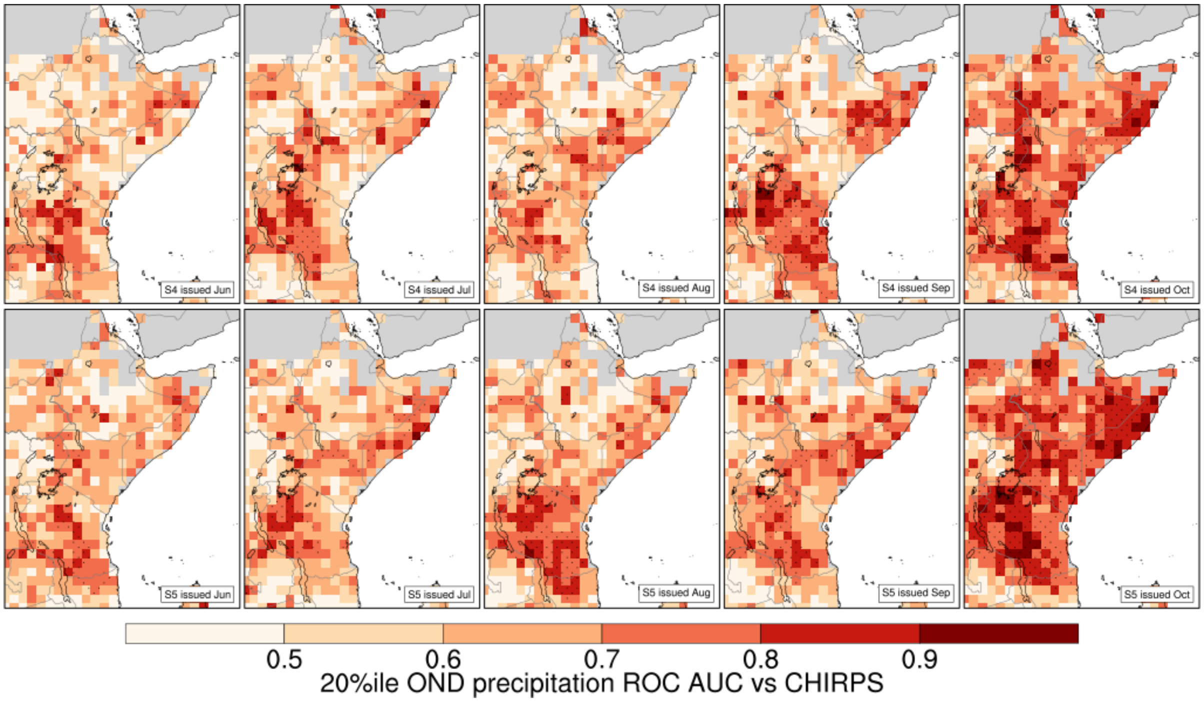

Figure 47. [ROC20OND] ROC Area under curve for OND: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

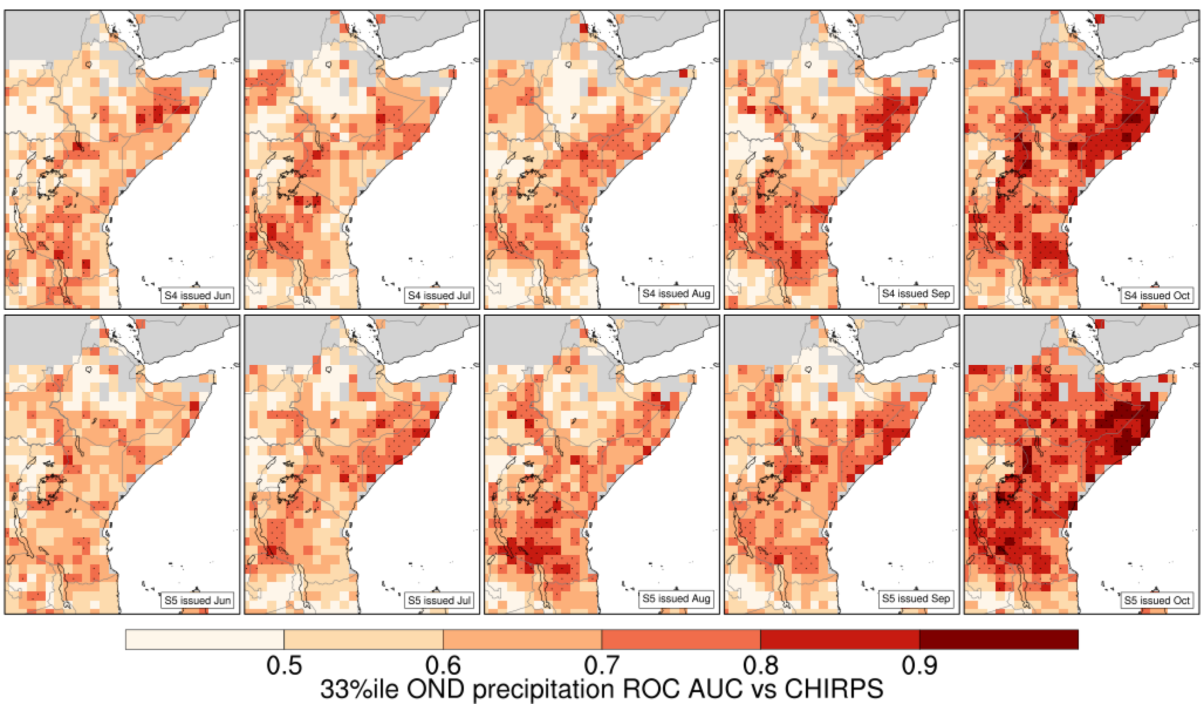

Figure 48. [ROC33OND] ROC Area under curve for OND: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

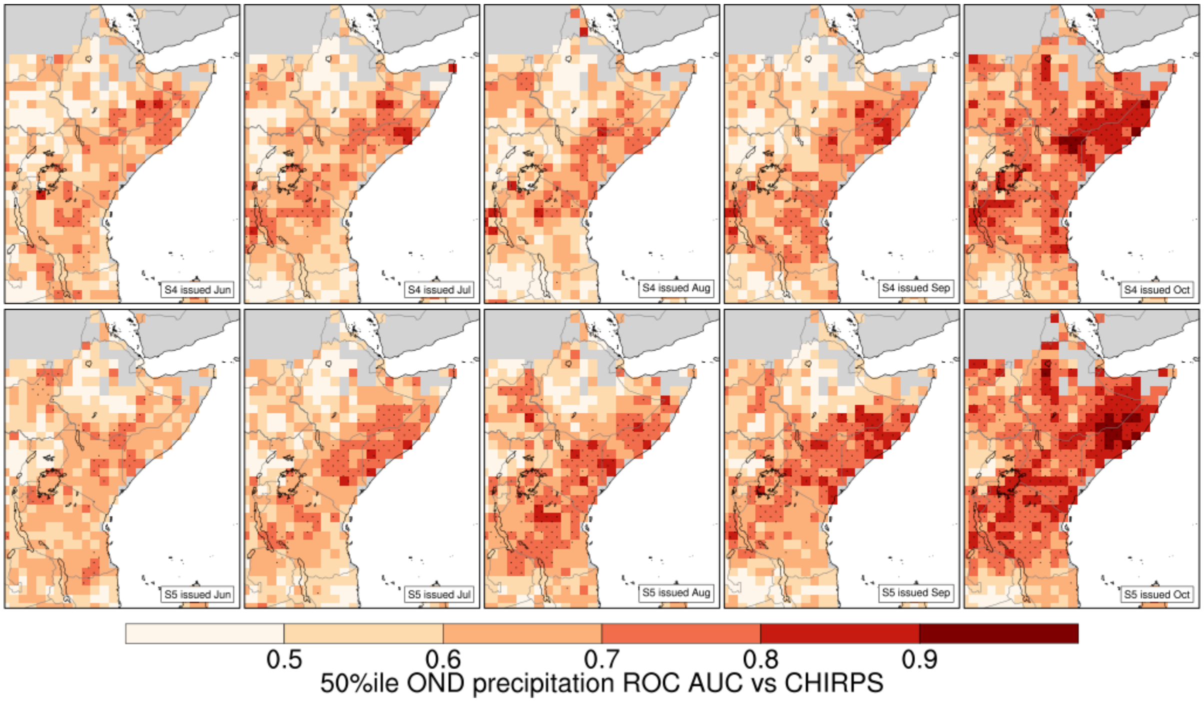

Figure 49. [ROC50OND] ROC Area under curve for OND: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

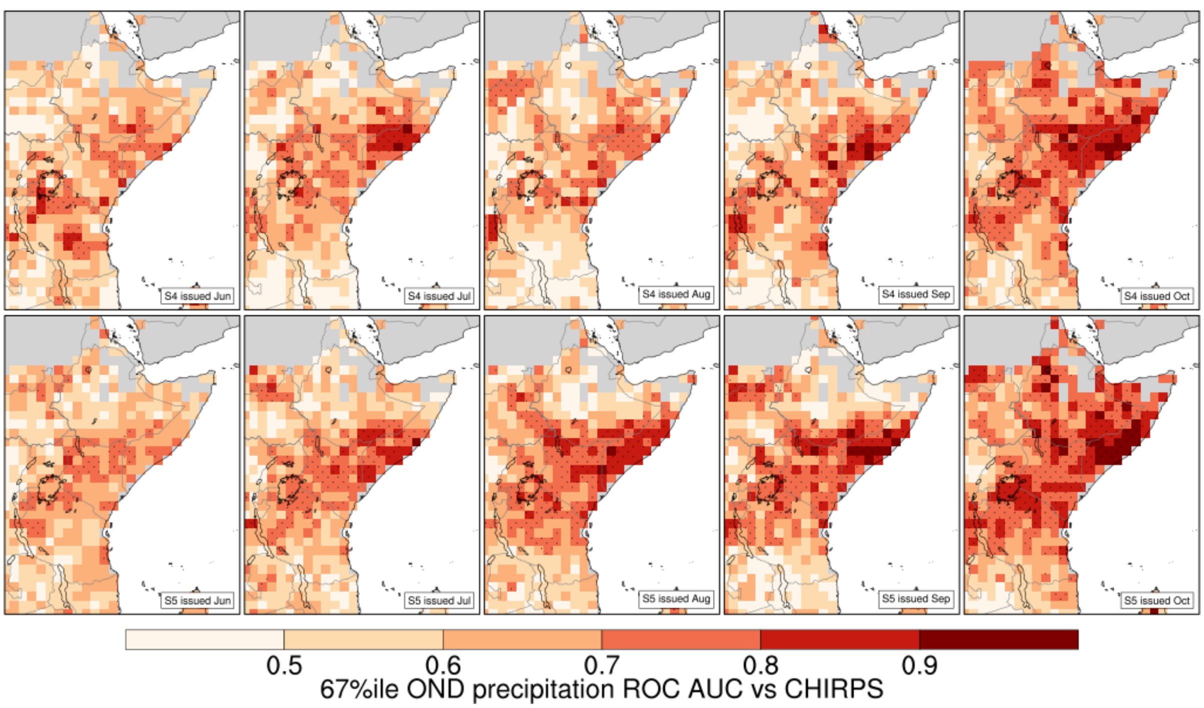

Figure 50. [ROC67OND] ROC Area under curve for OND: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

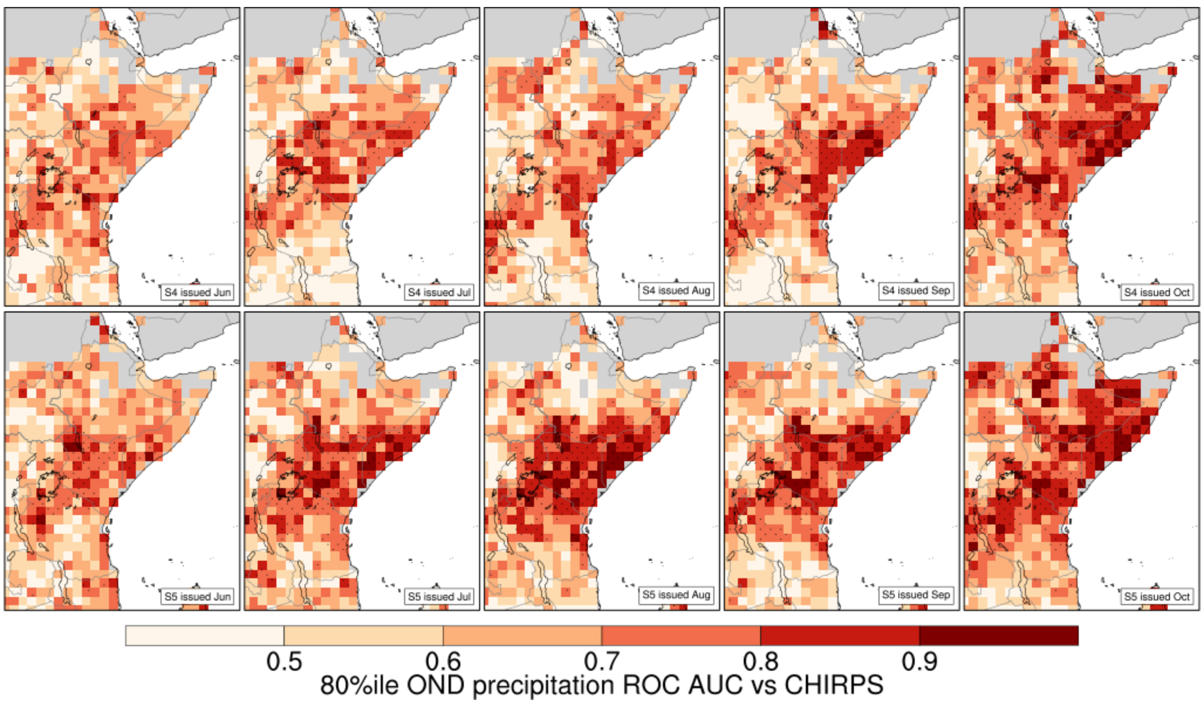

Figure 51. [ROC80OND] ROC Area under curve for OND: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

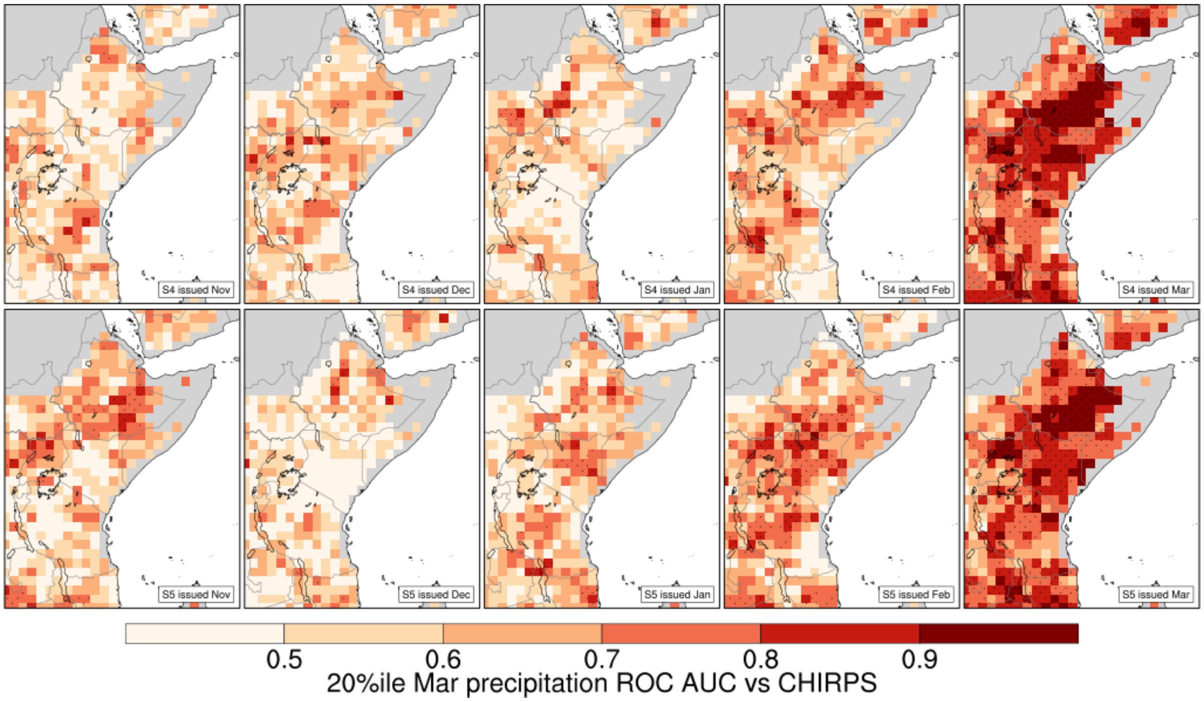

Figure 52. [ROC20Mar] ROC Area under curve for Mar: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

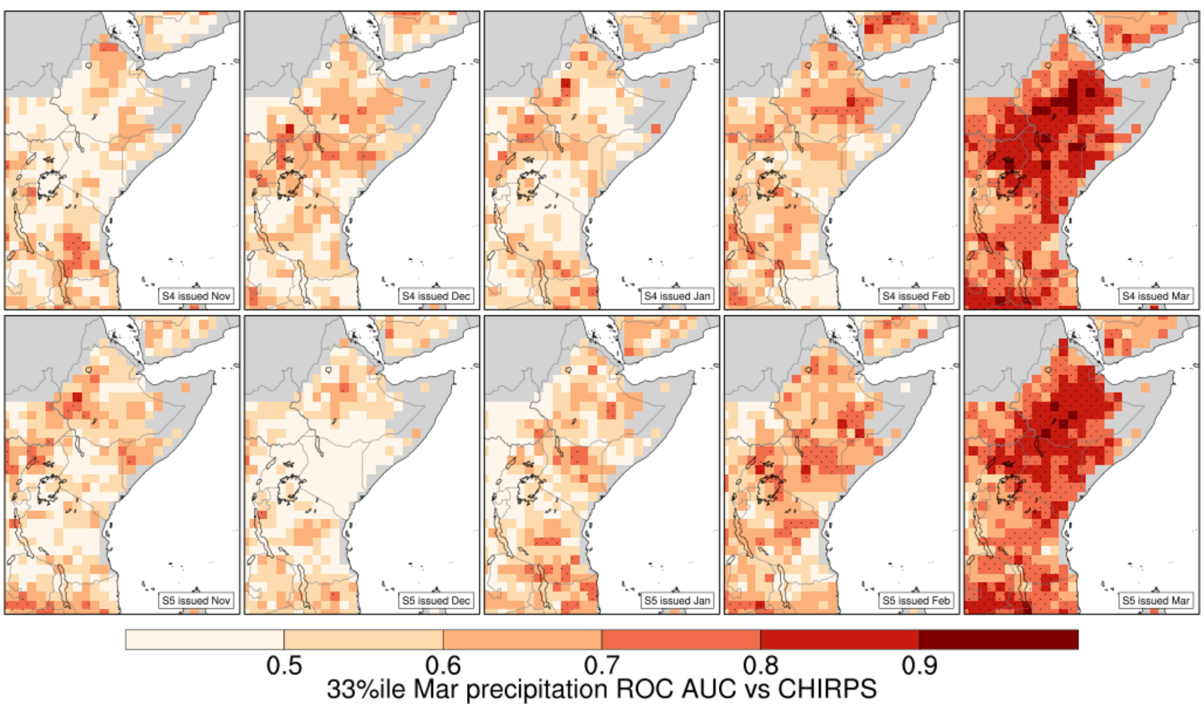

Figure 53. [ROC33Mar] ROC Area under curve for Mar: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

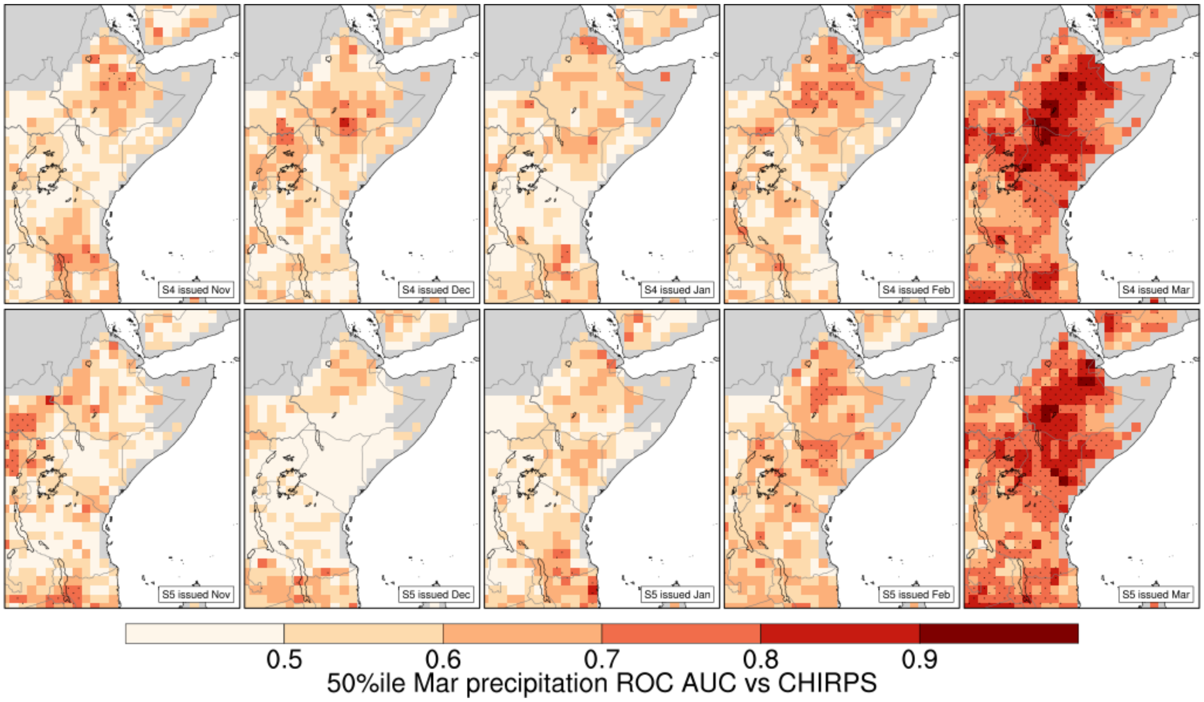

Figure 54. [ROC50Mar] ROC Area under curve for Mar: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

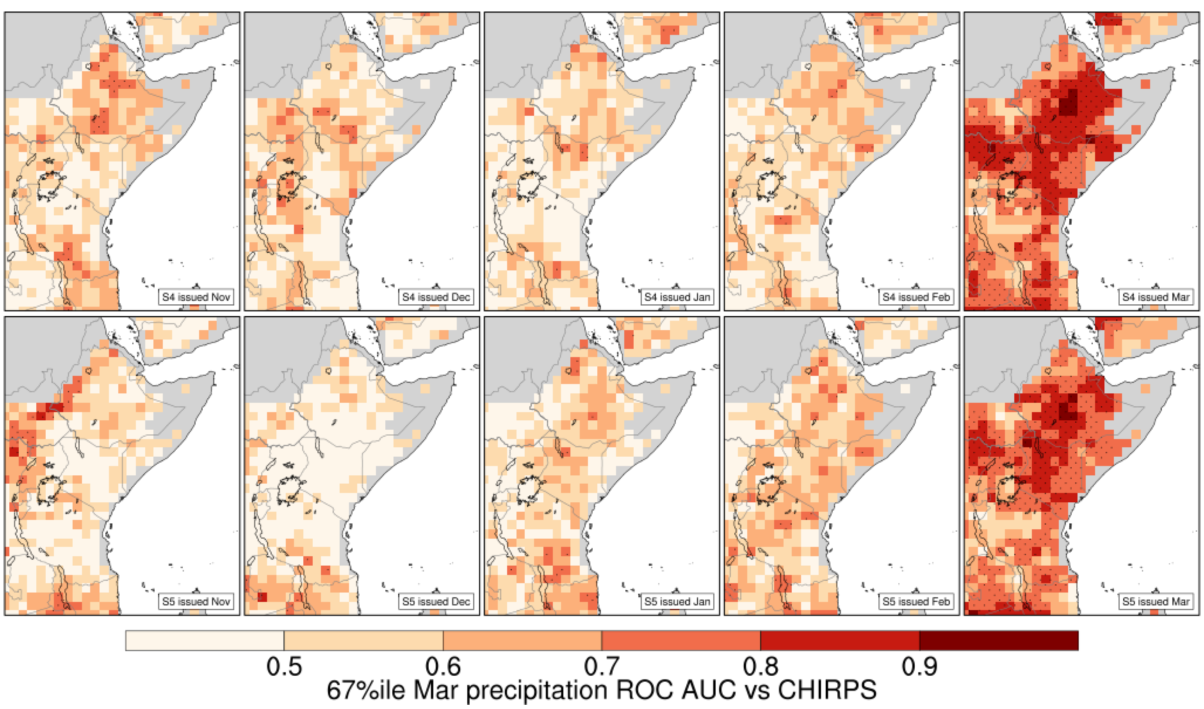

Figure 55. [ROC67Mar] ROC Area under curve for Mar: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

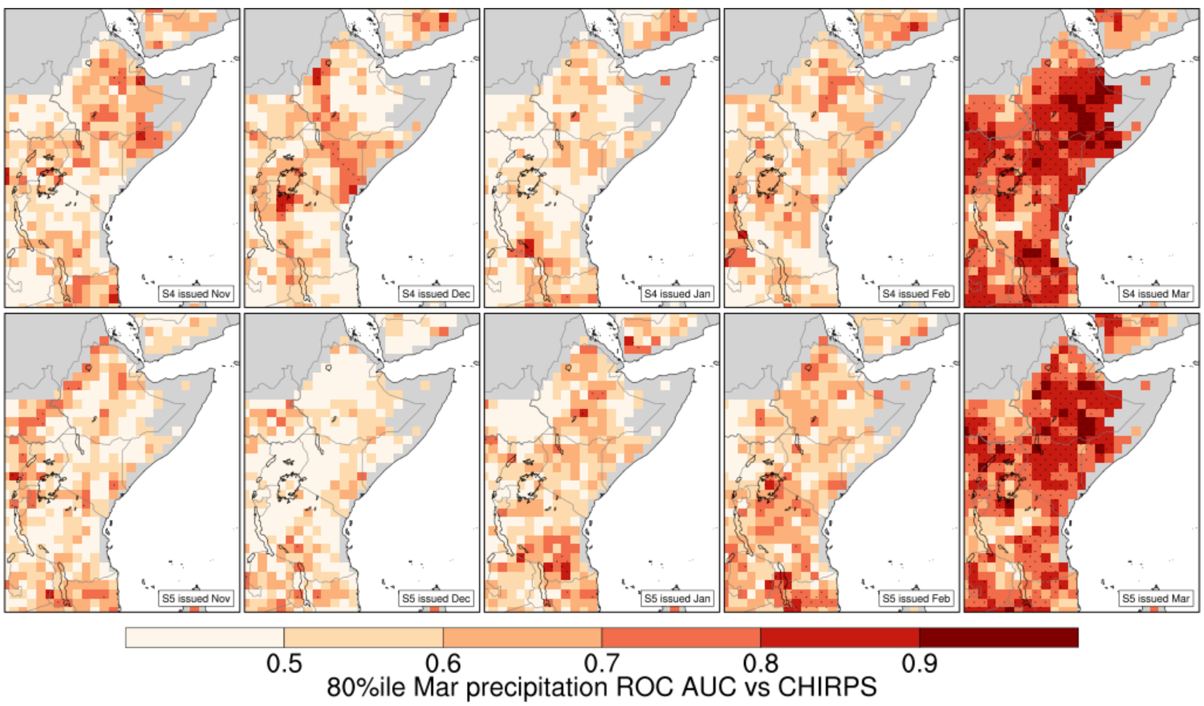

Figure 56. [ROC80Mar] ROC Area under curve for Mar: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

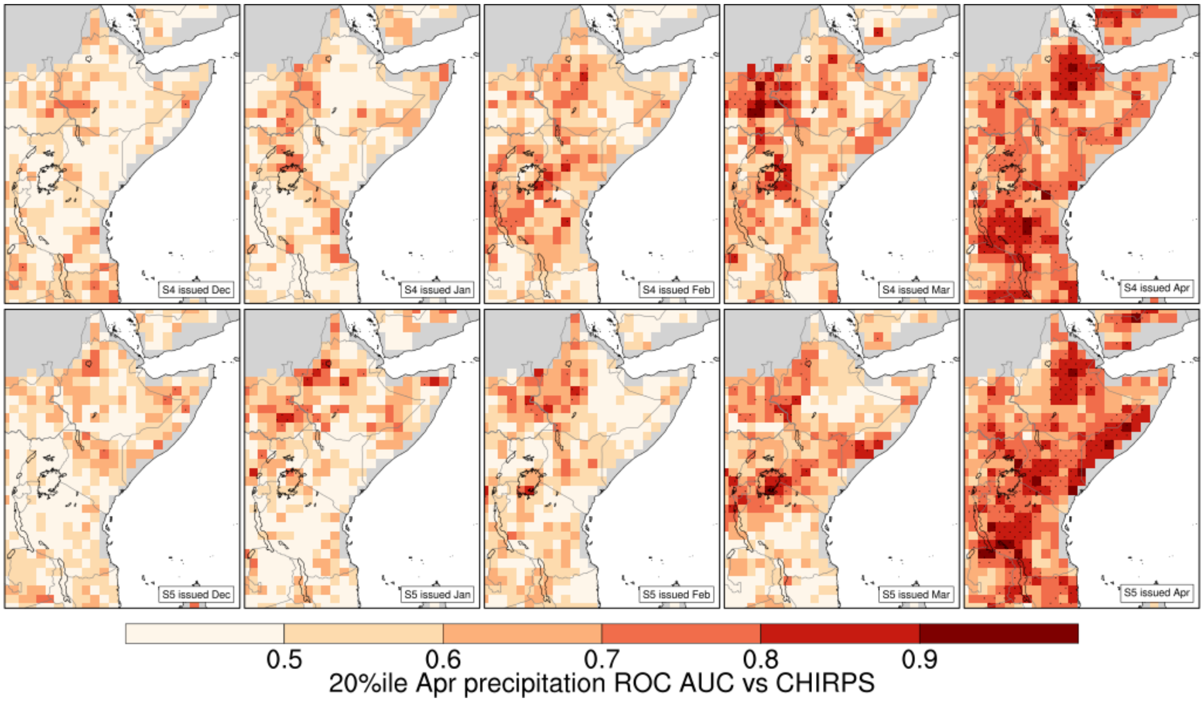

Figure 57. [ROC20Apr] ROC Area under curve for Apr: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

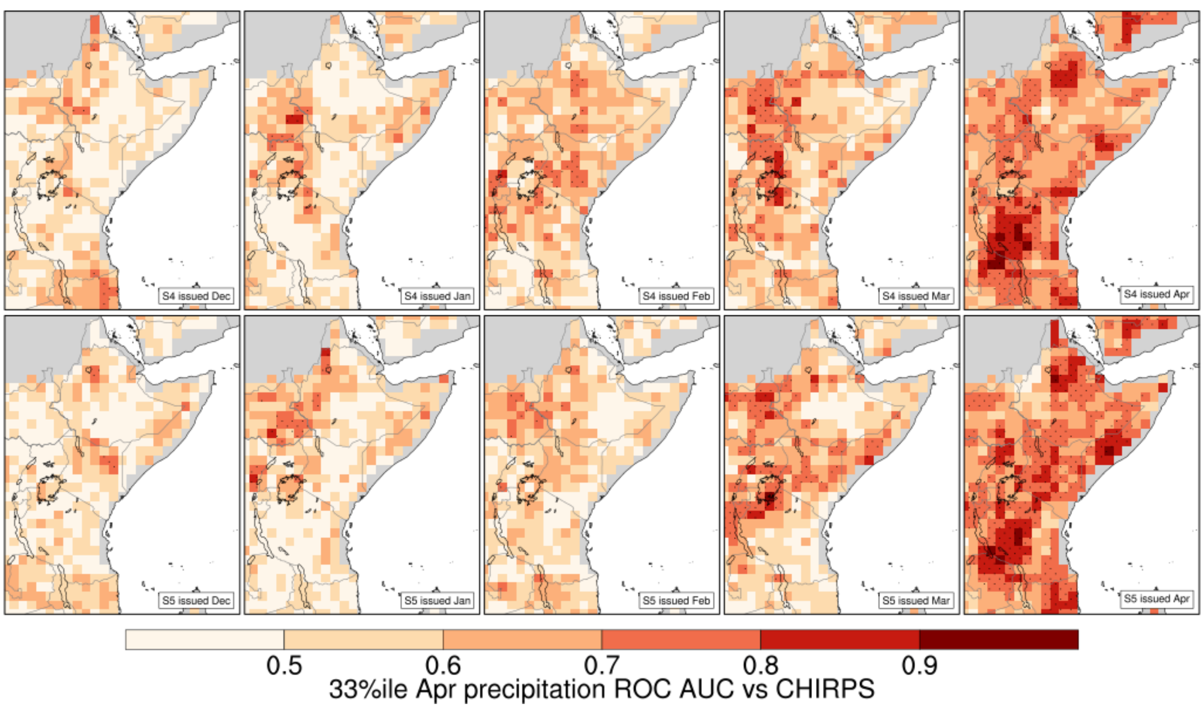

Figure 58. [ROC33Apr] ROC Area under curve for Apr: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

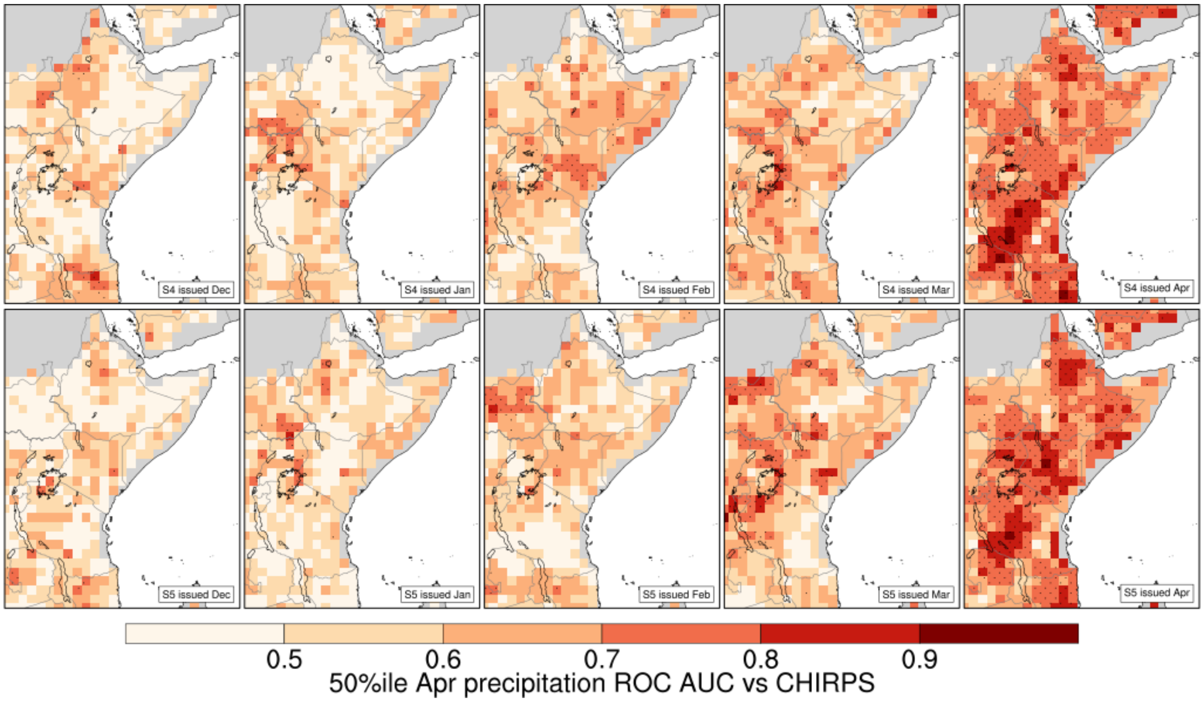

Figure 59. [ROC50Apr] ROC Area under curve for Apr: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

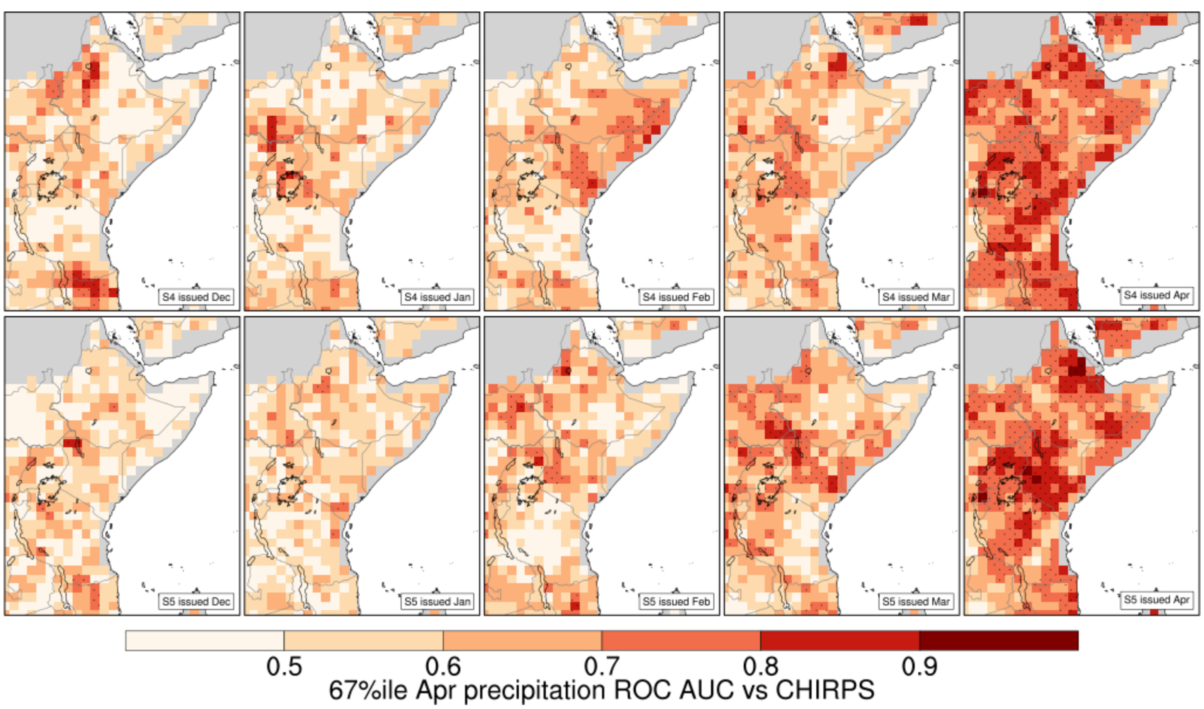

Figure 60. [ROC67Apr] ROC Area under curve for Apr: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

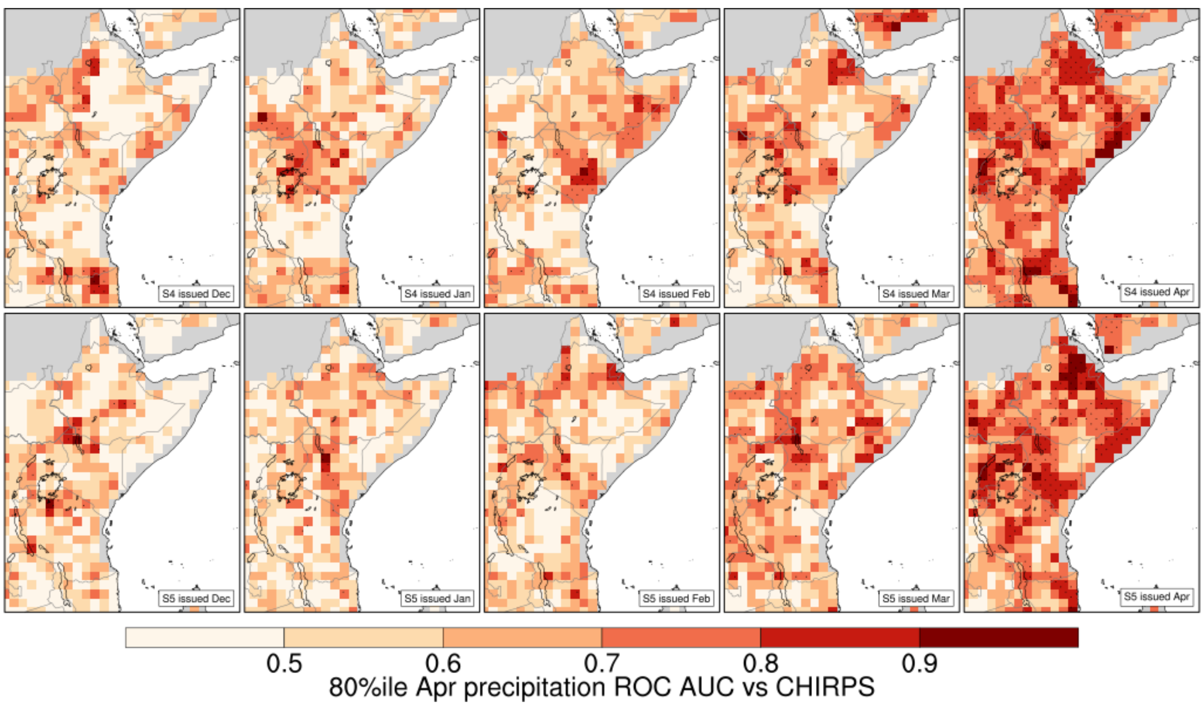

Figure 61. [ROC80Apr] ROC Area under curve for Apr: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

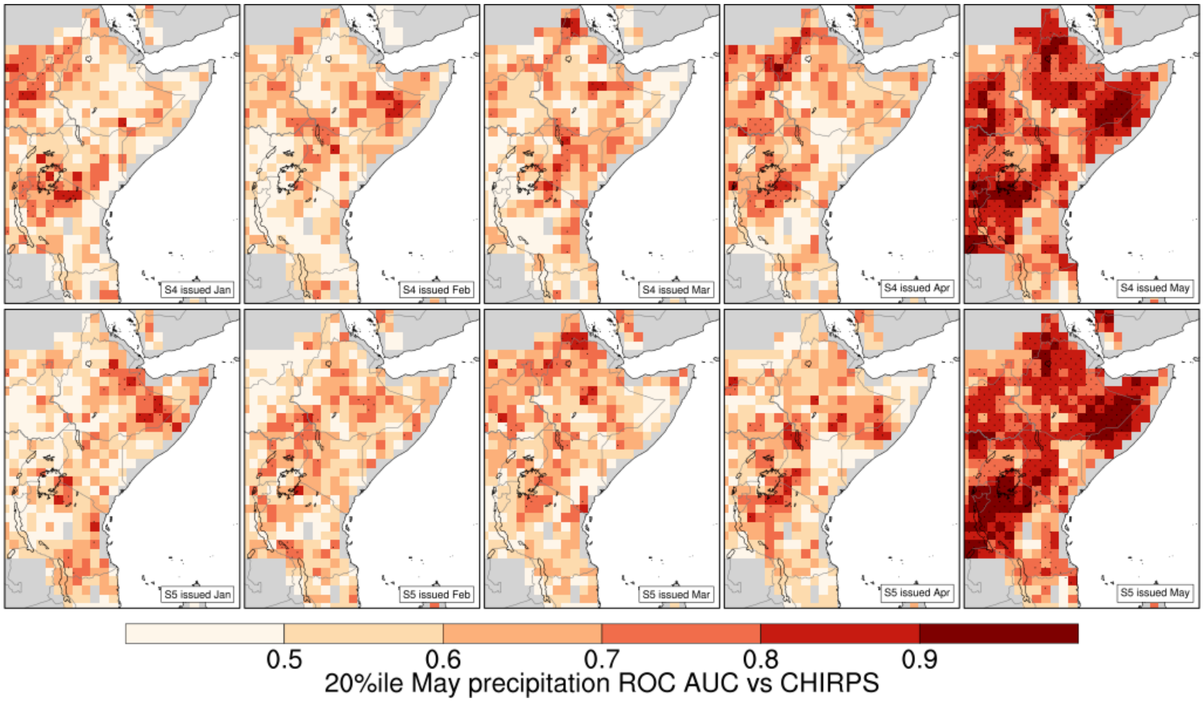

Figure 62. [ROC20May] ROC Area under curve for May: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

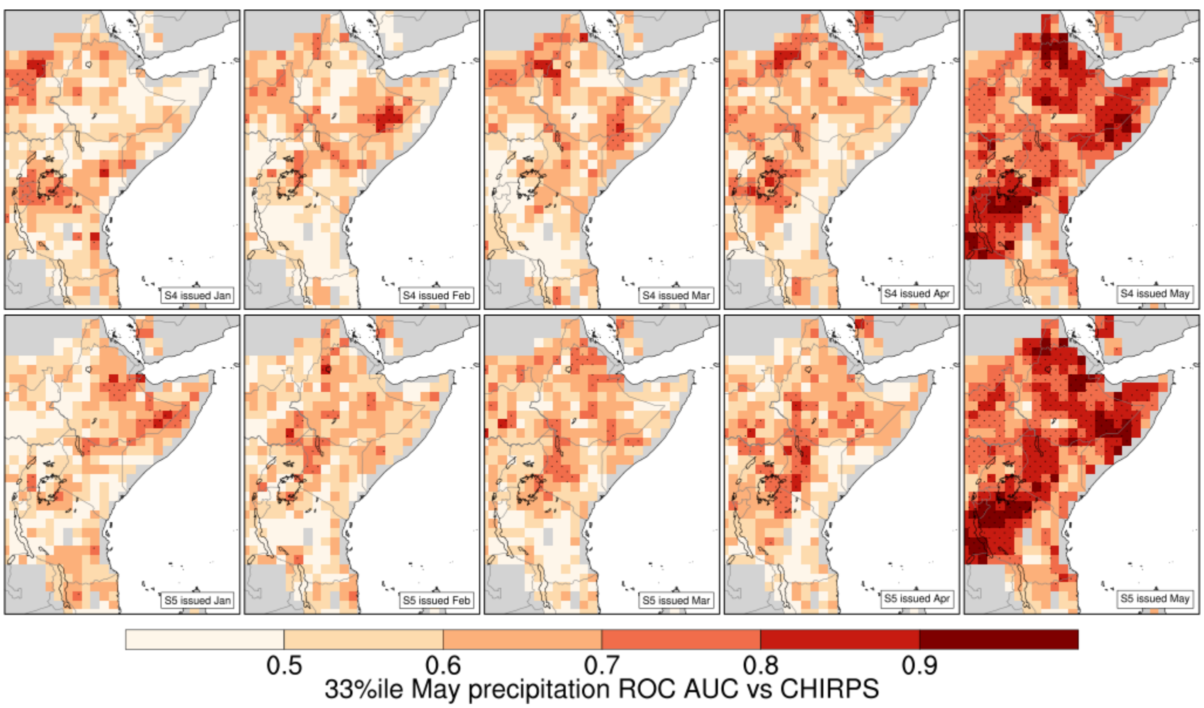

Figure 63. [ROC33May] ROC Area under curve for May: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

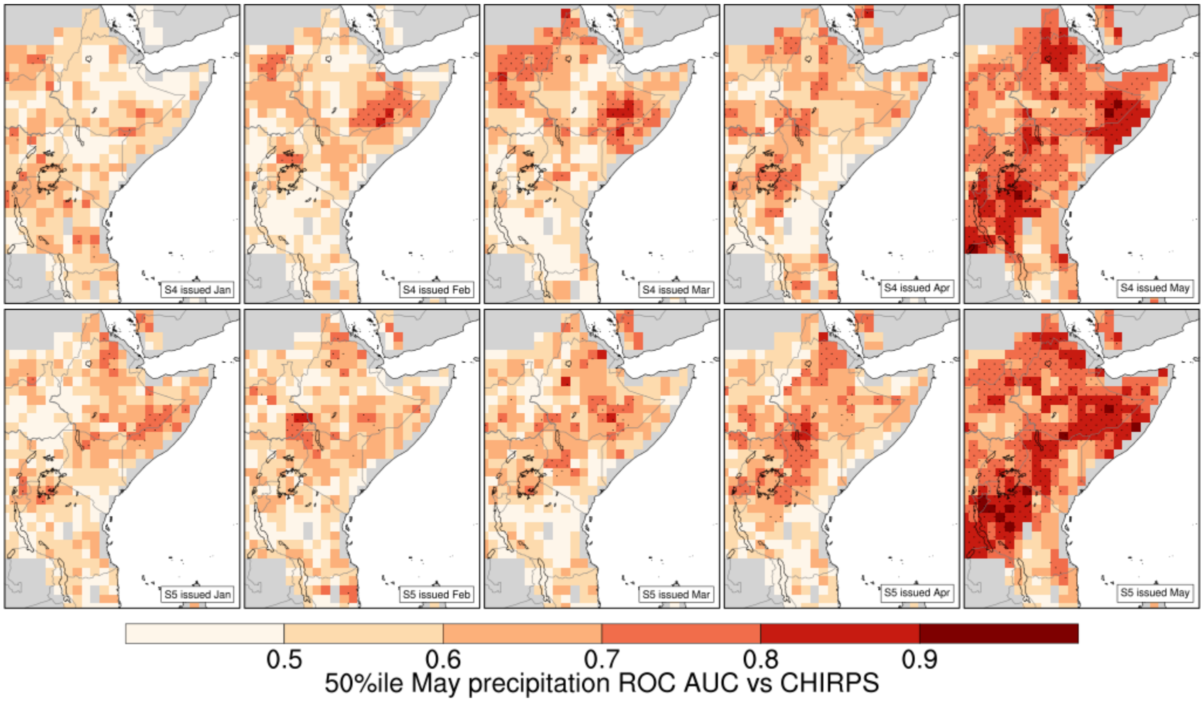

Figure 64. [ROC50May] ROC Area under curve for May: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

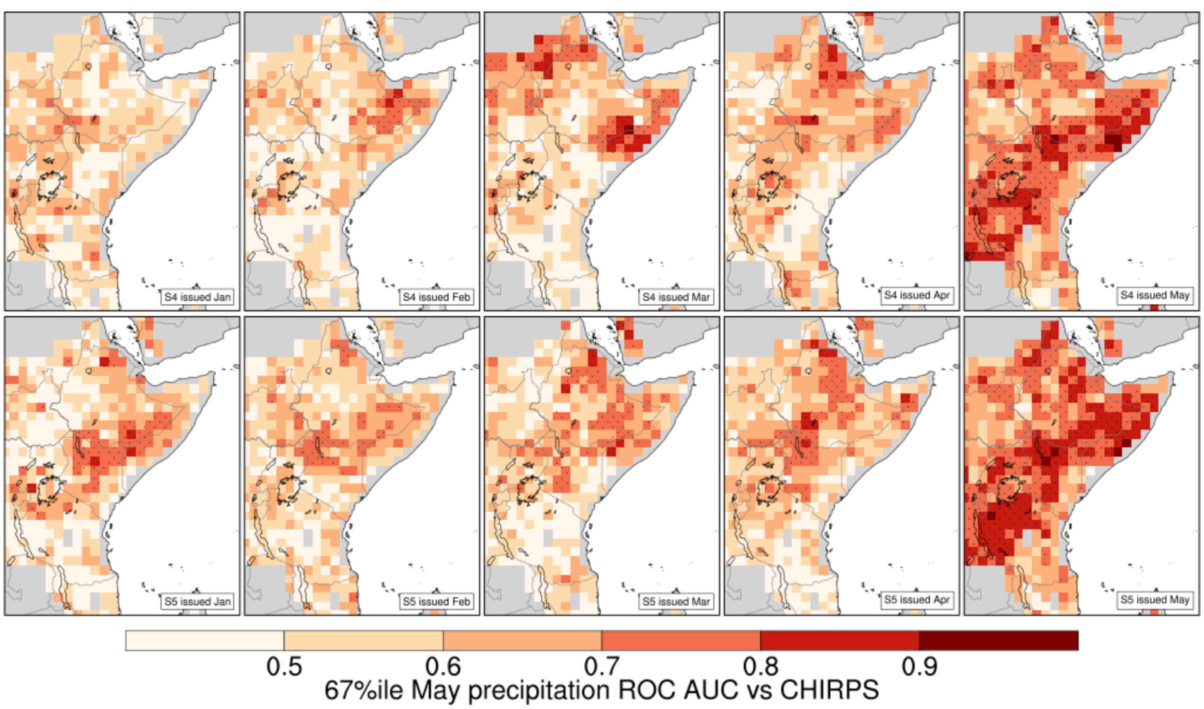

Figure 65. [ROC67May] ROC Area under curve for May: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

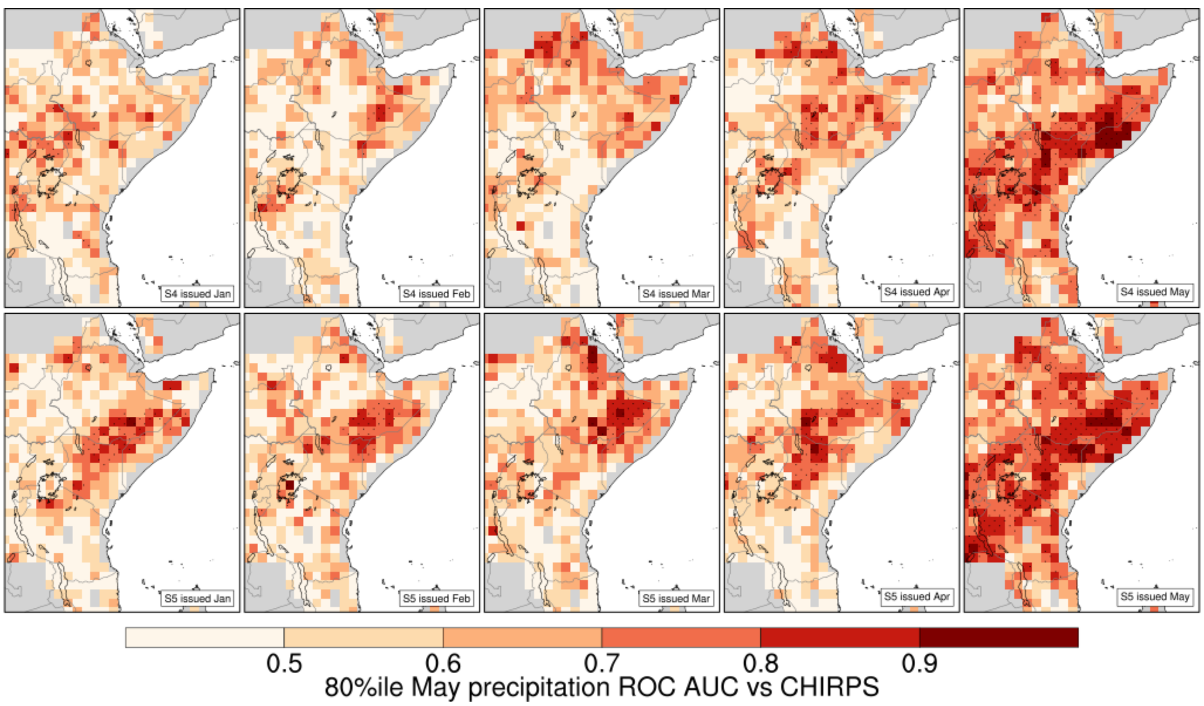

Figure 66. [ROC80May] ROC Area under curve for May: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

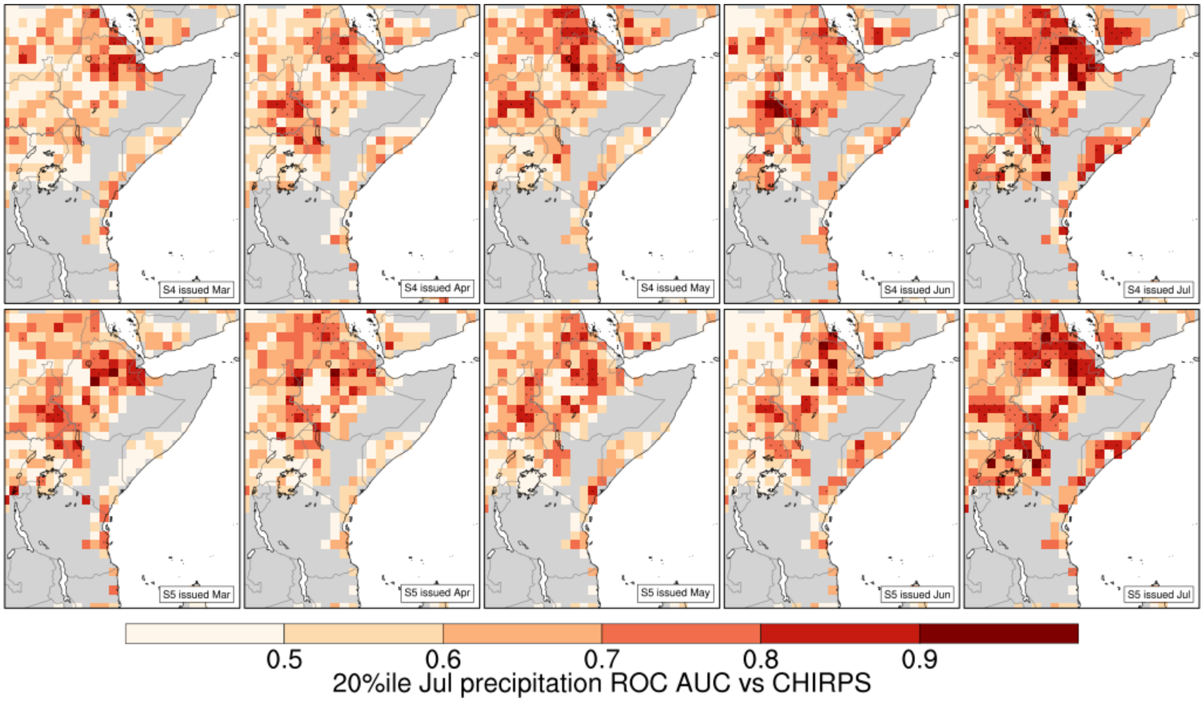

Figure 67. [ROC20Jul] ROC Area under curve for Jul: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

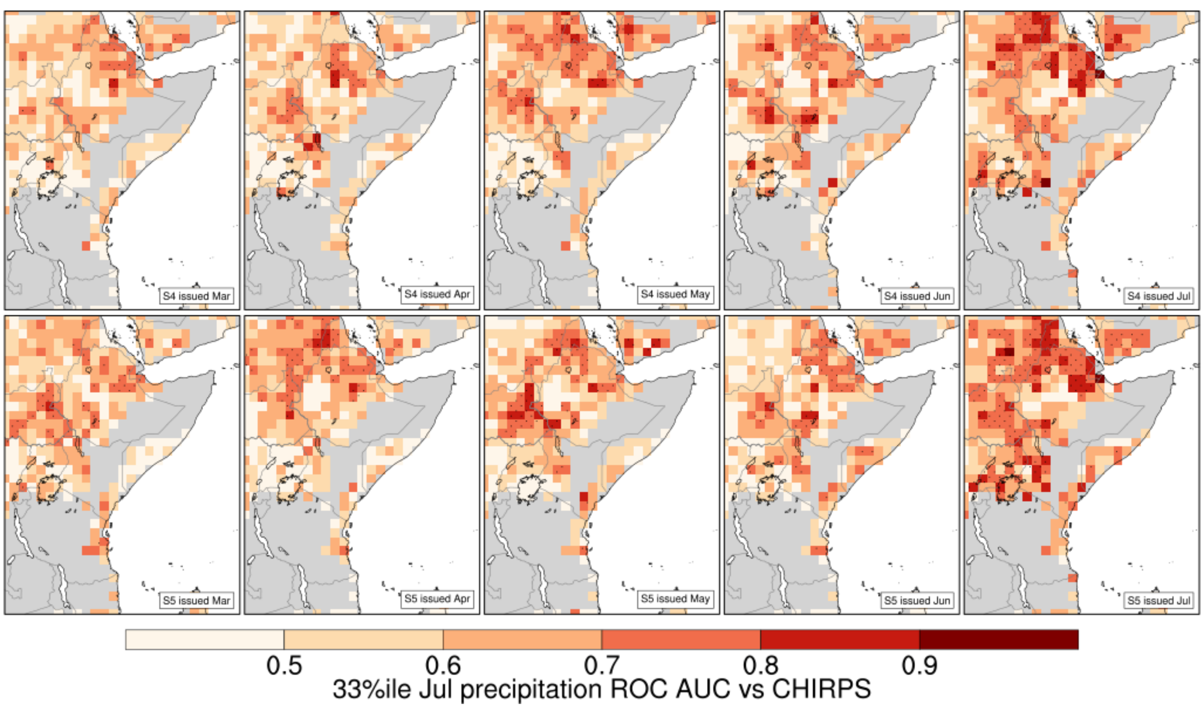

Figure 68. [ROC33Jul] ROC Area under curve for Jul: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

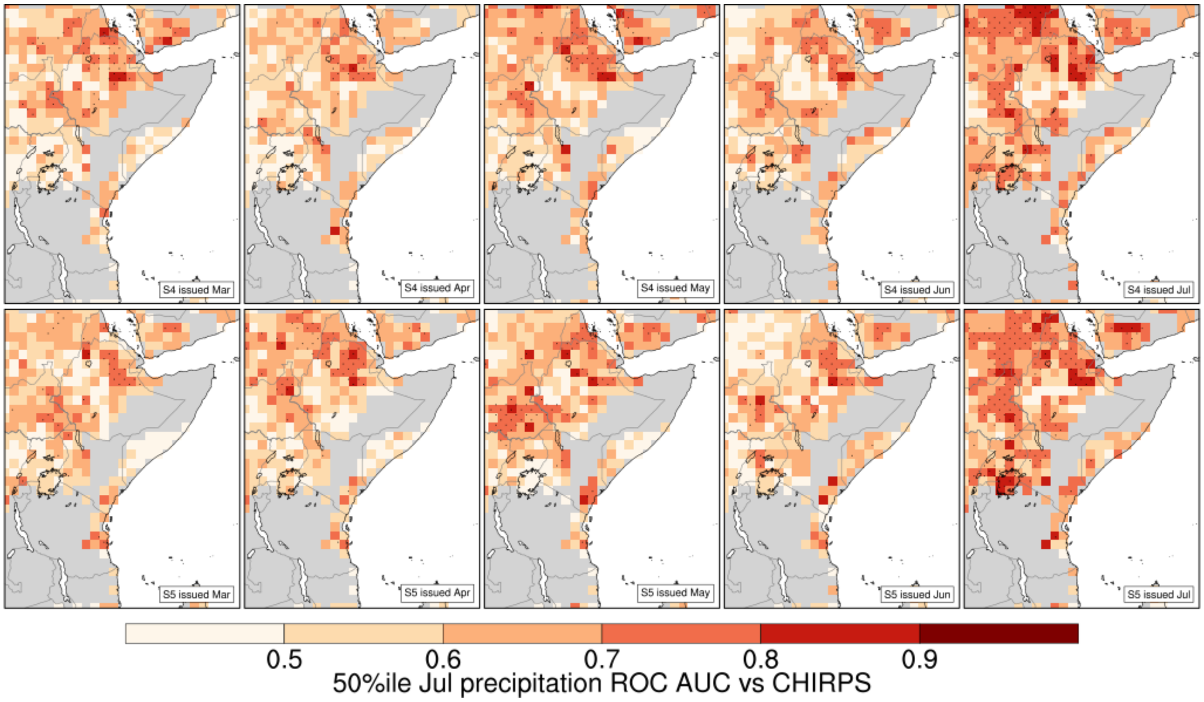

Figure 69. [ROC50Jul] ROC Area under curve for Jul: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

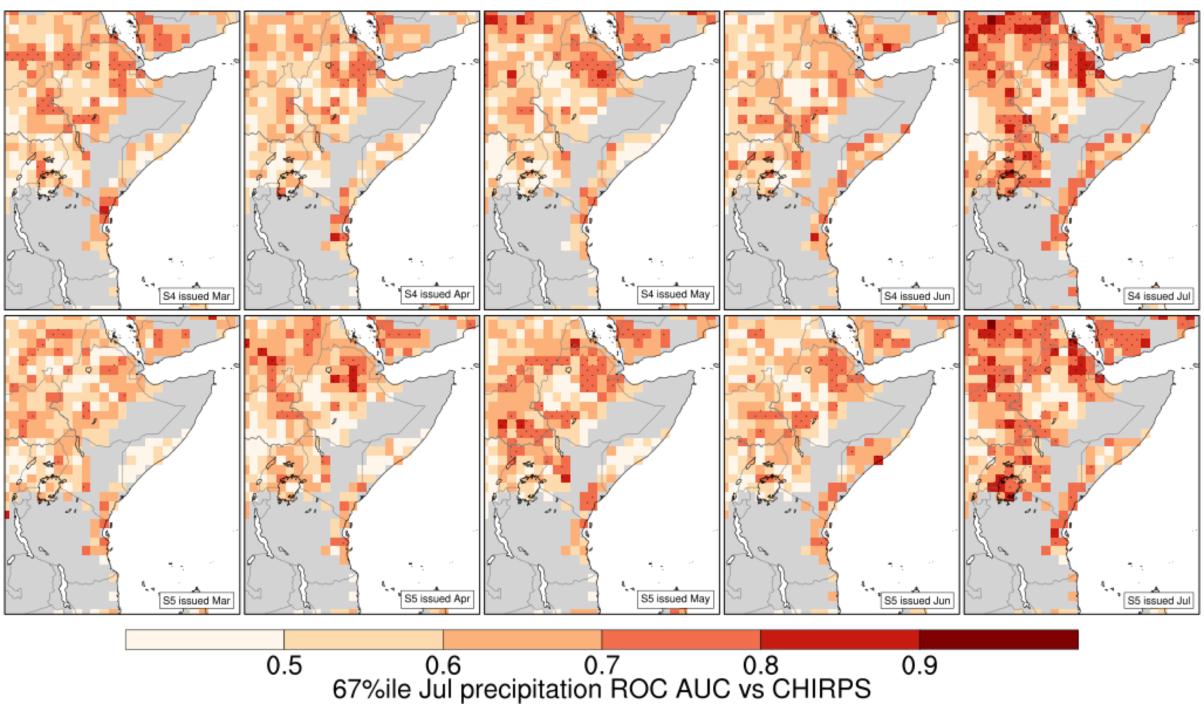

Figure 70. [ROC67Jul] ROC Area under curve for Jul: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

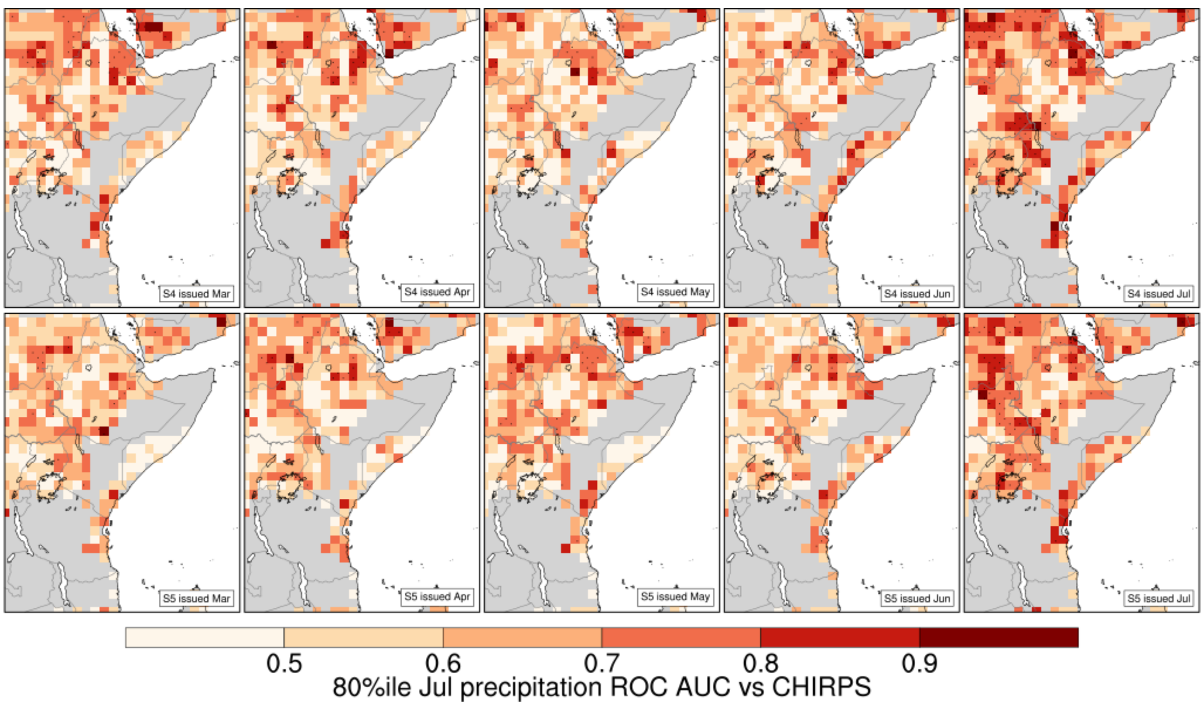

Figure 71. [ROC80Jul] ROC Area under curve for Jul: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

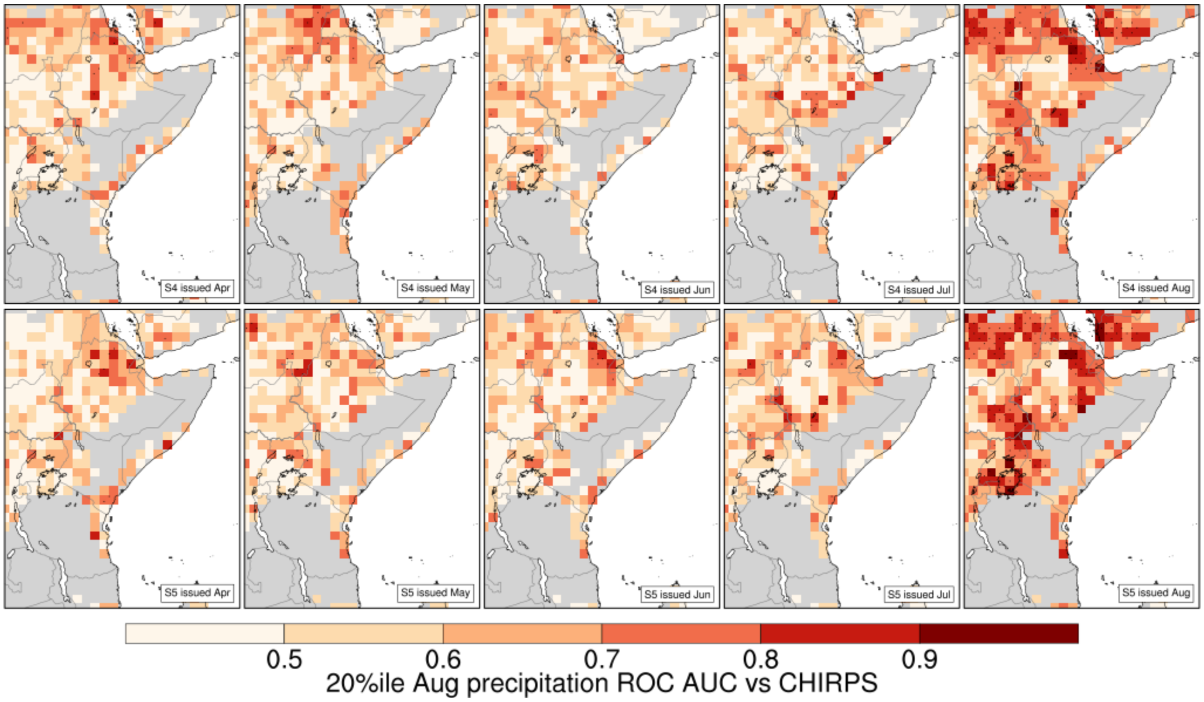

Figure 72. [ROC20Aug] ROC Area under curve for Aug: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

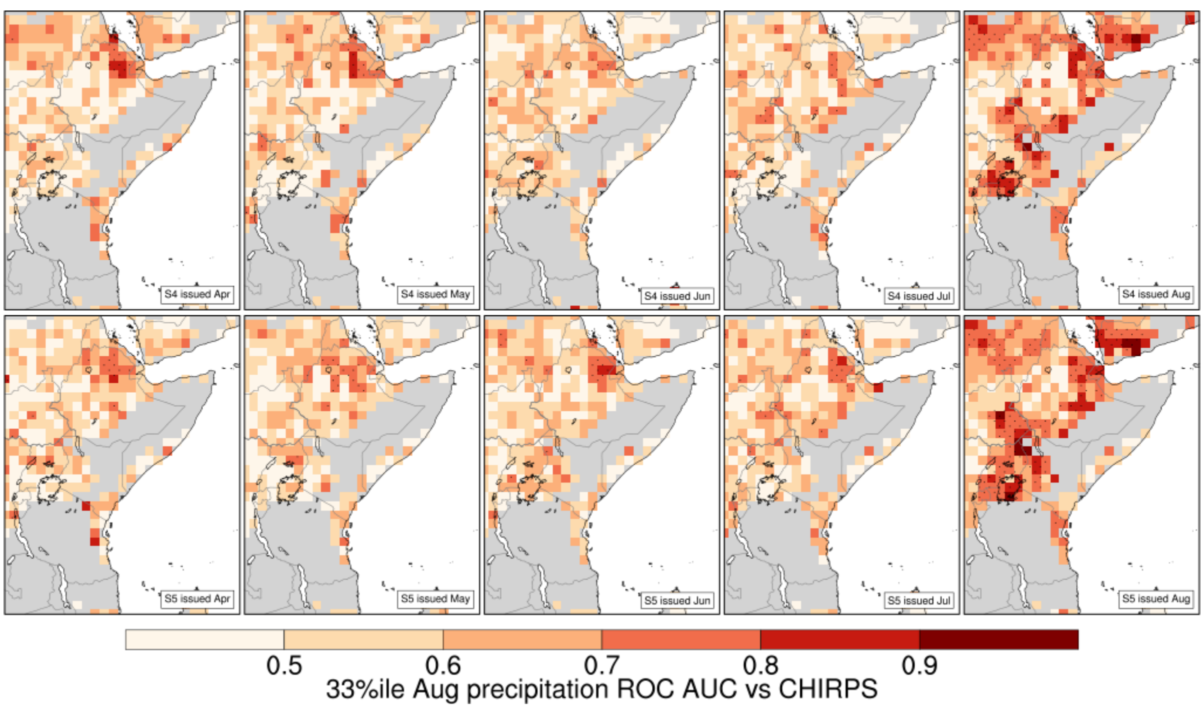

Figure 73. [ROC33Aug] ROC Area under curve for Aug: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

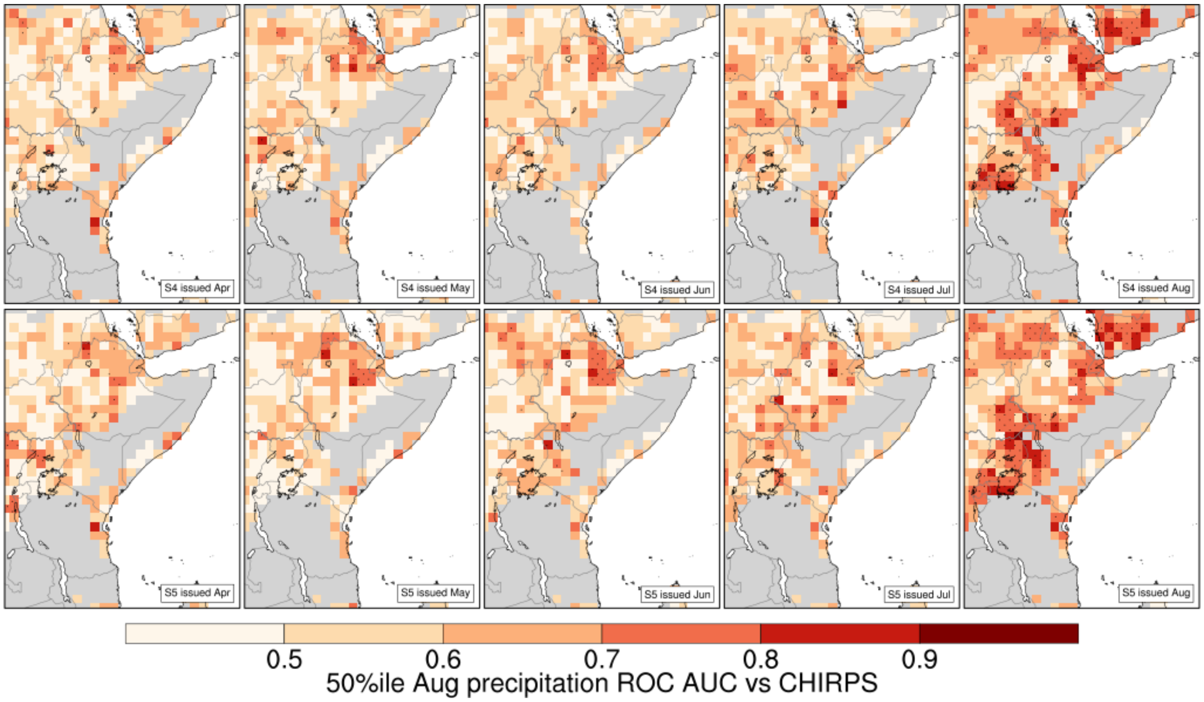

Figure 74. [ROC50Aug] ROC Area under curve for Aug: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

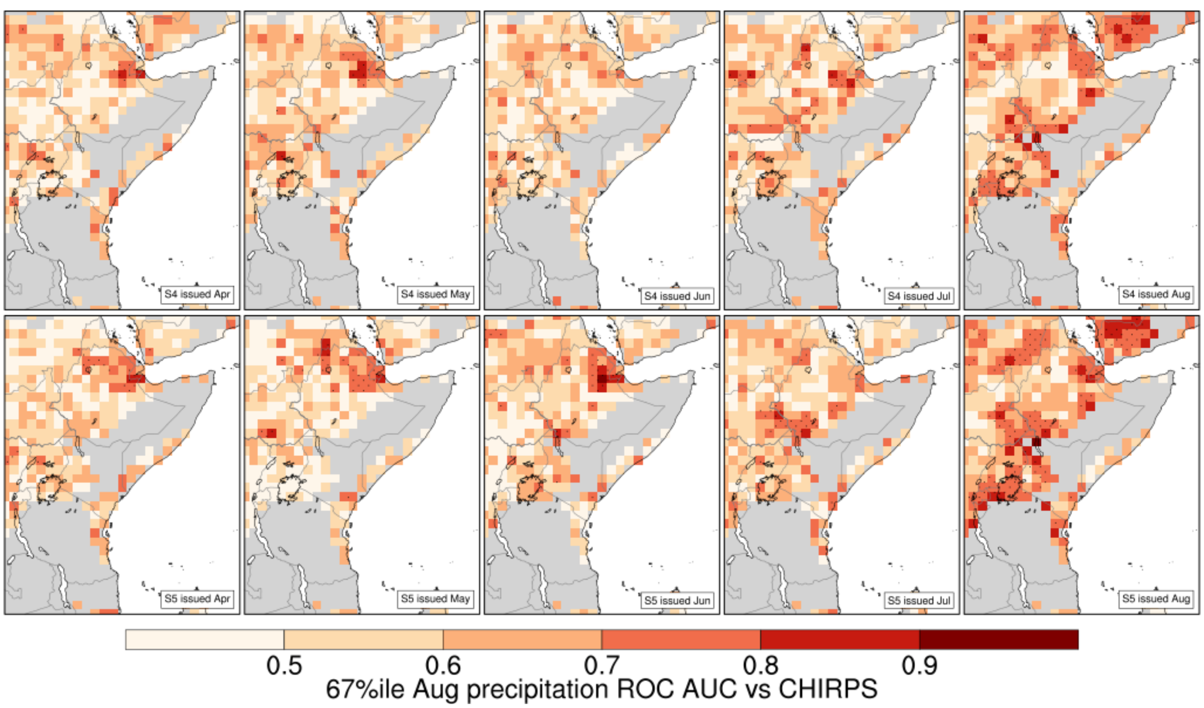

Figure 75. [ROC67Aug] ROC Area under curve for Aug: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

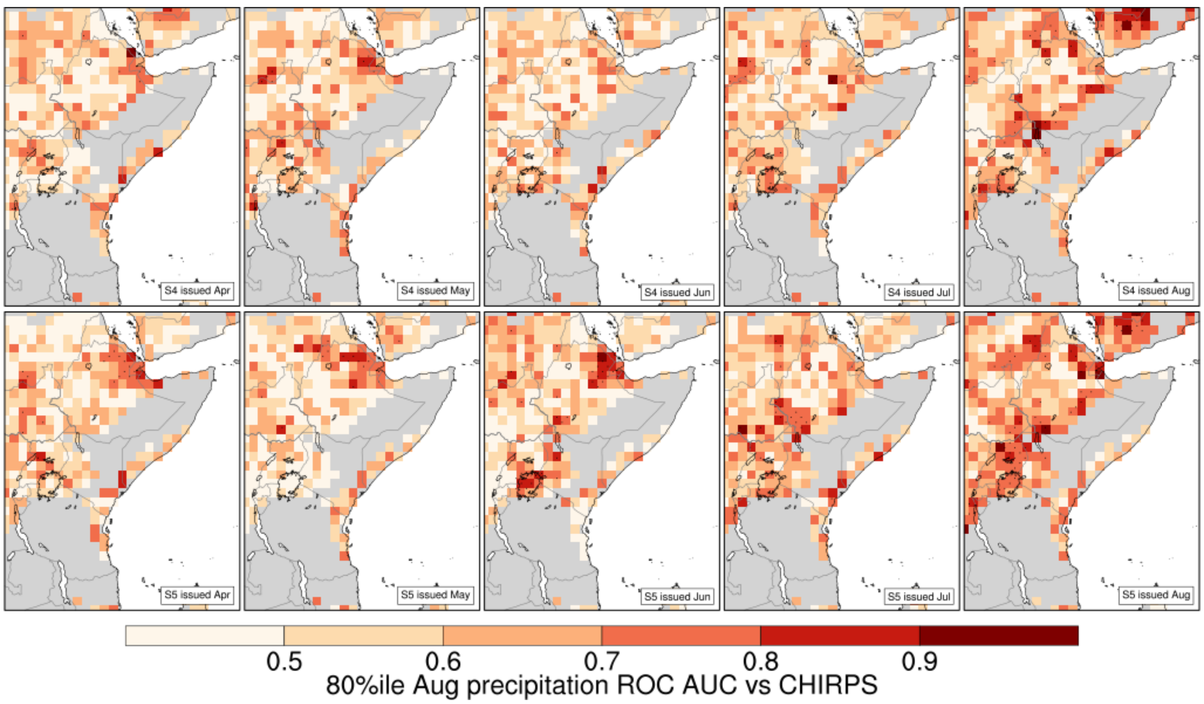

Figure 76. [ROC80Aug] ROC Area under curve for Aug: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

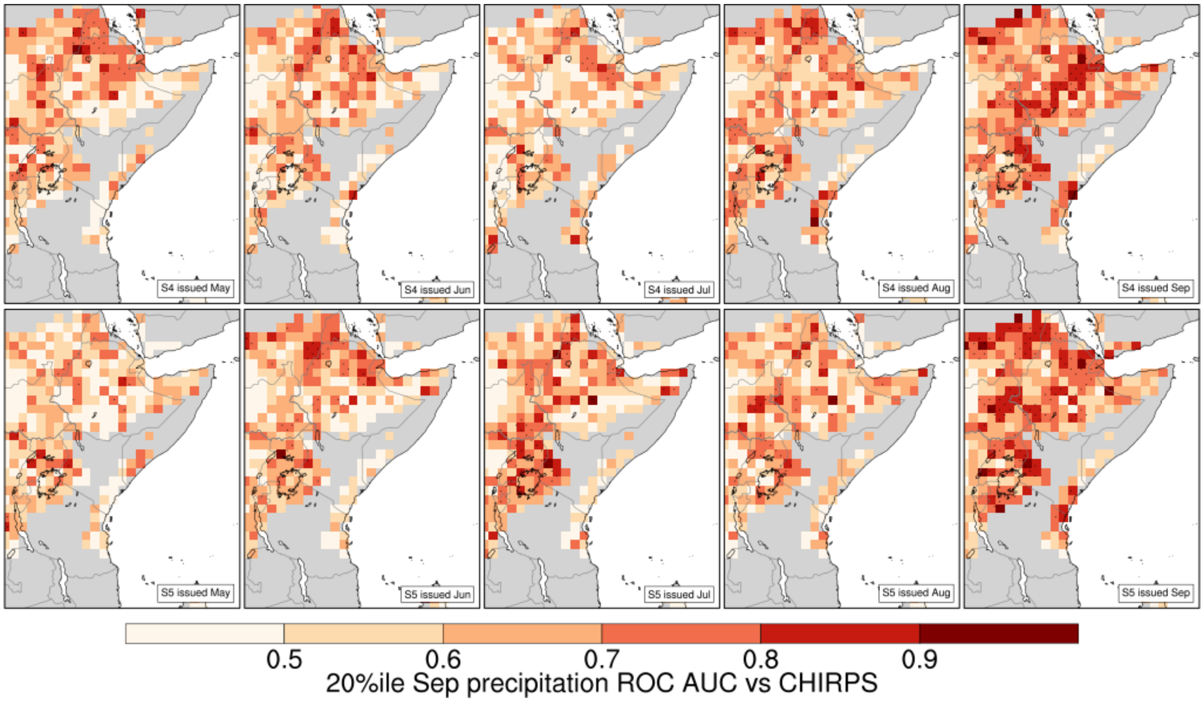

Figure 77. [ROC20Sep] ROC Area under curve for Sep: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

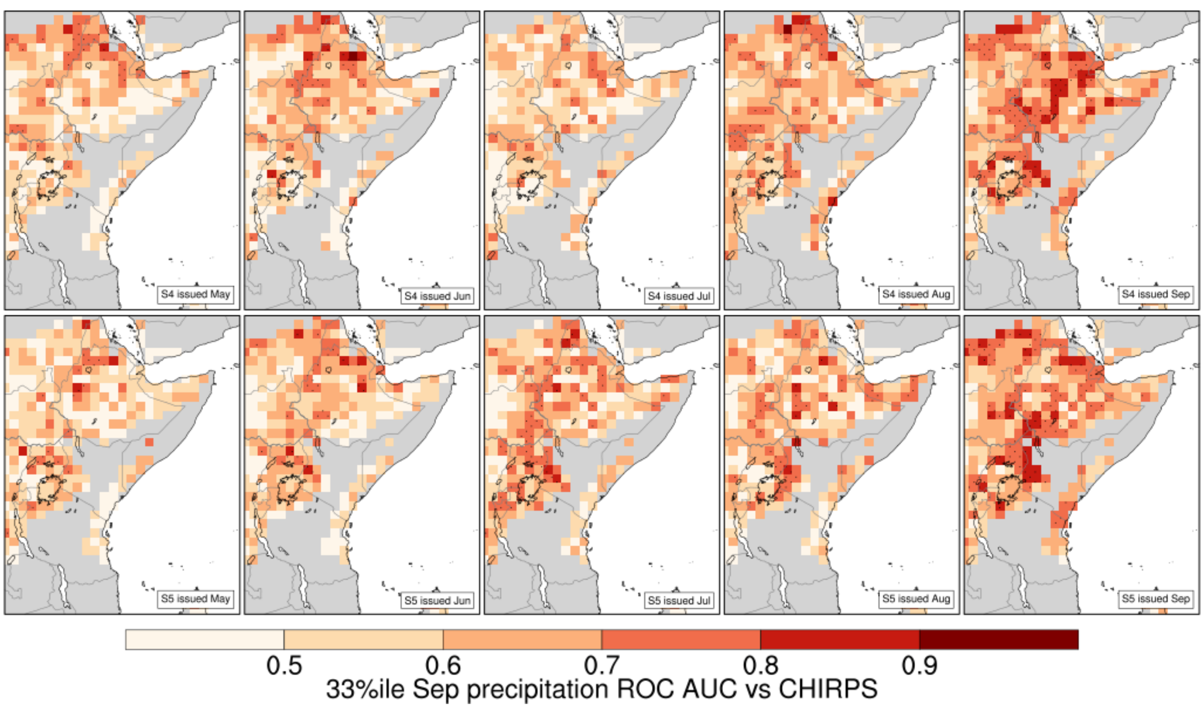

Figure 78. [ROC33Sep] ROC Area under curve for Sep: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

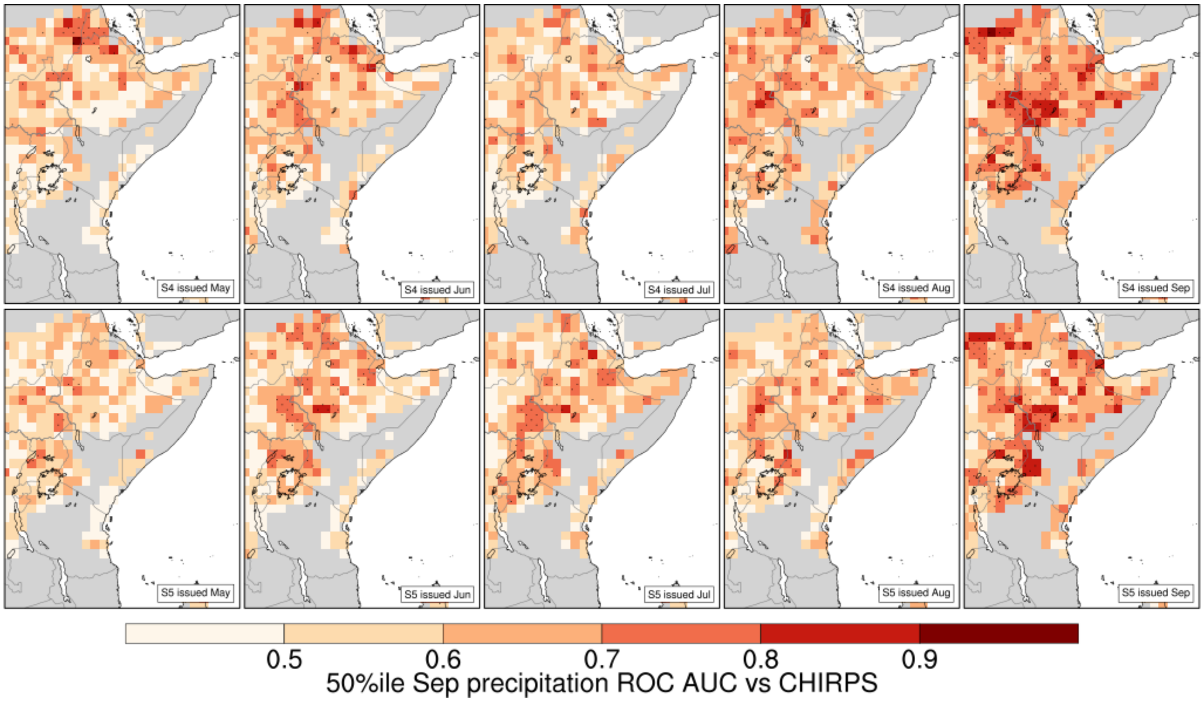

Figure 79. [ROC50Sep] ROC Area under curve for Sep: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

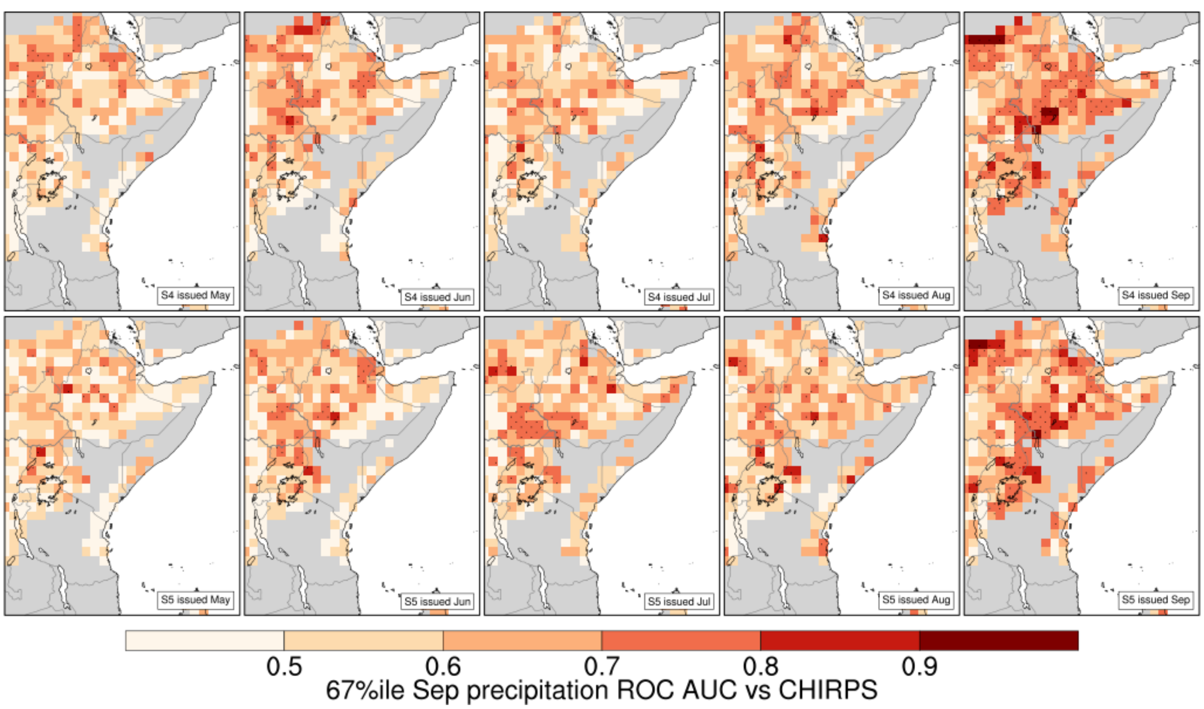

Figure 80. [ROC67Sep] ROC Area under curve for Sep: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

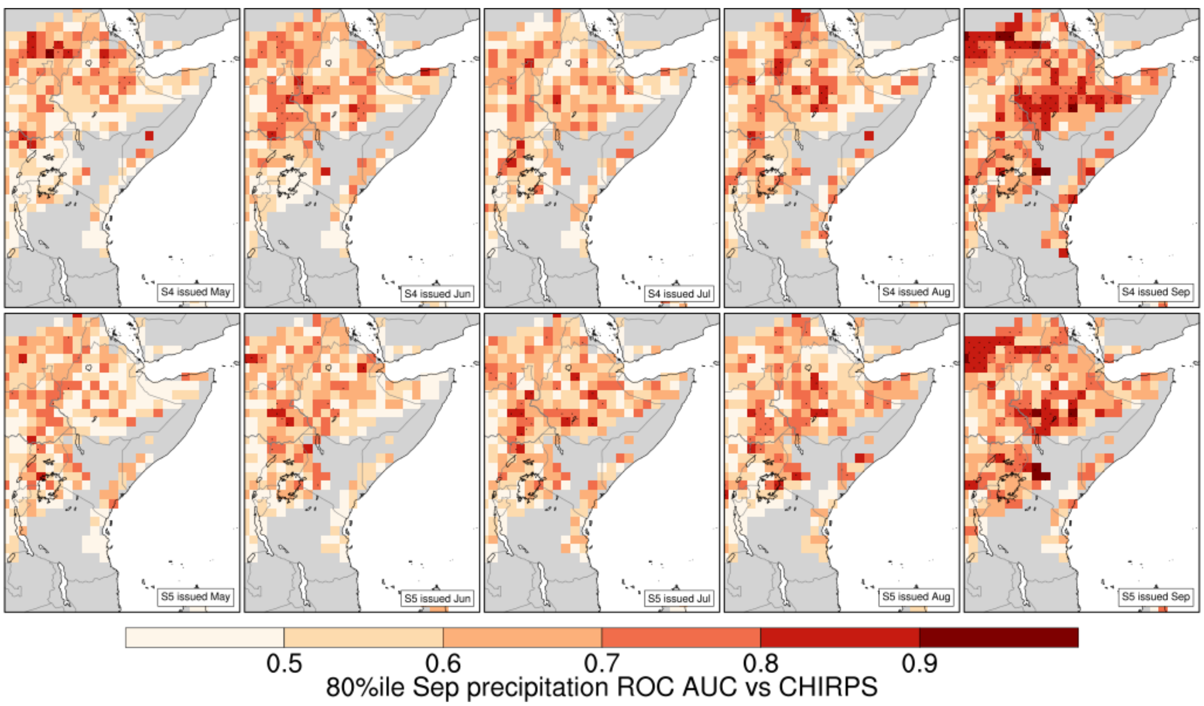

Figure 81. [ROC80Sep] ROC Area under curve for Sep: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

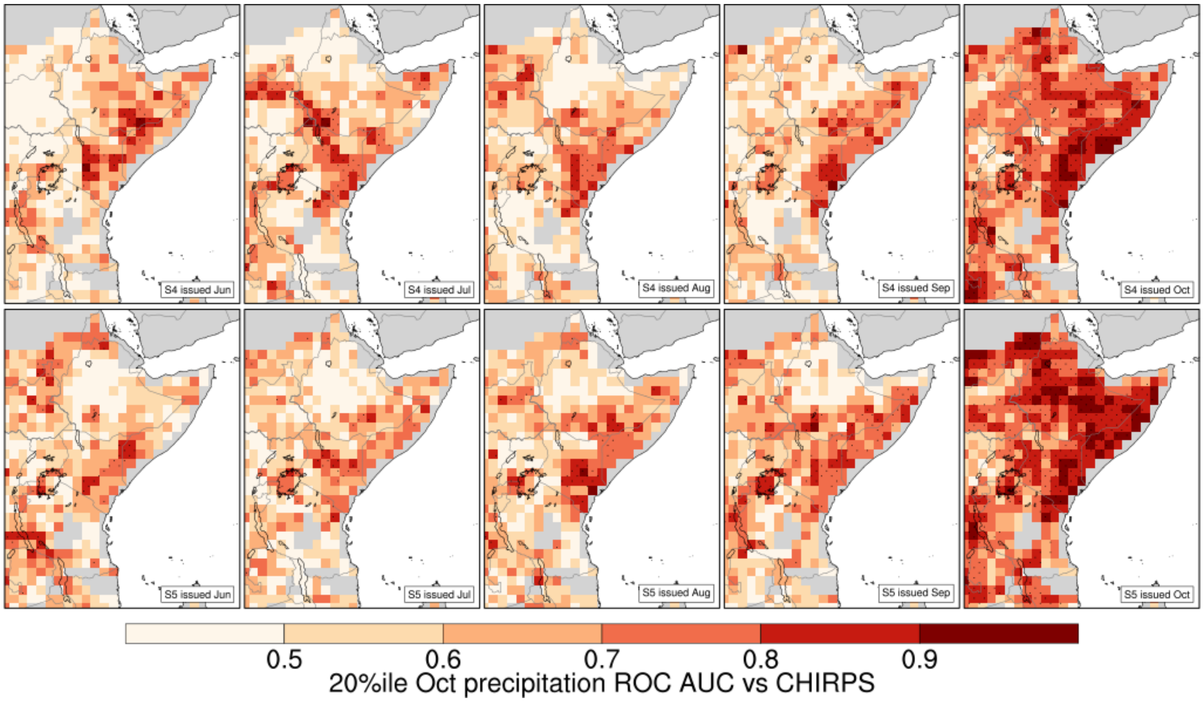

Figure 82. [ROC20Oct] ROC Area under curve for Oct: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

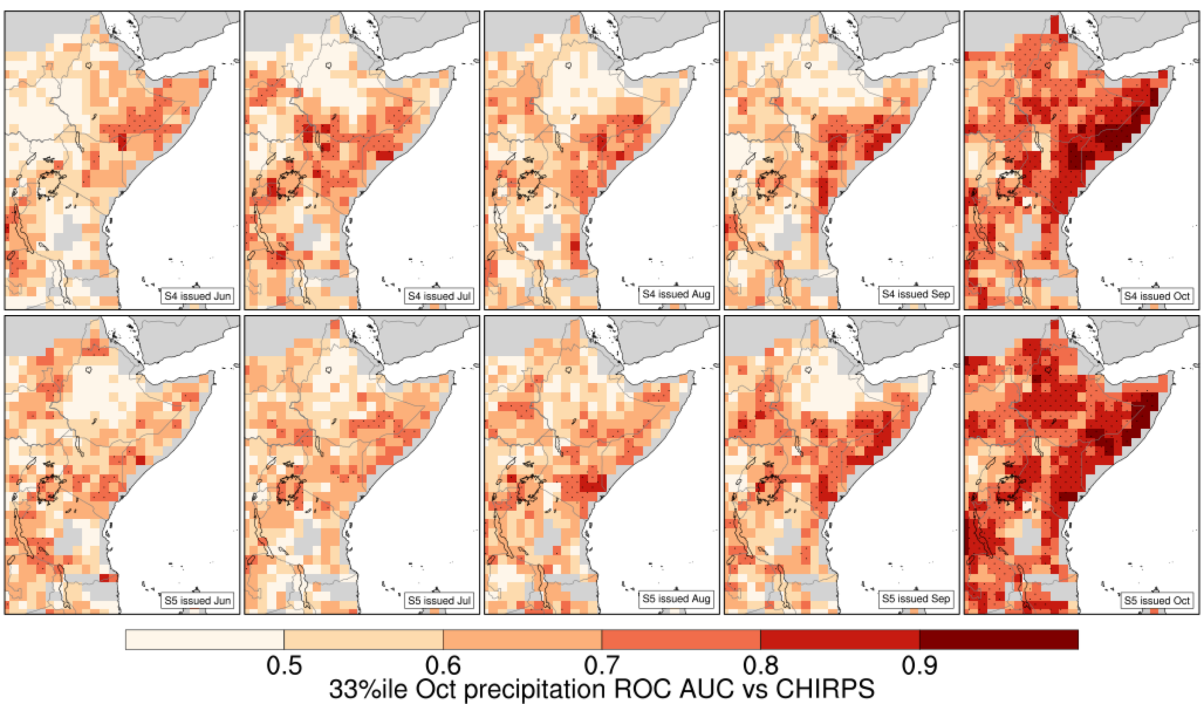

Figure 83. [ROC33Oct] ROC Area under curve for Oct: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

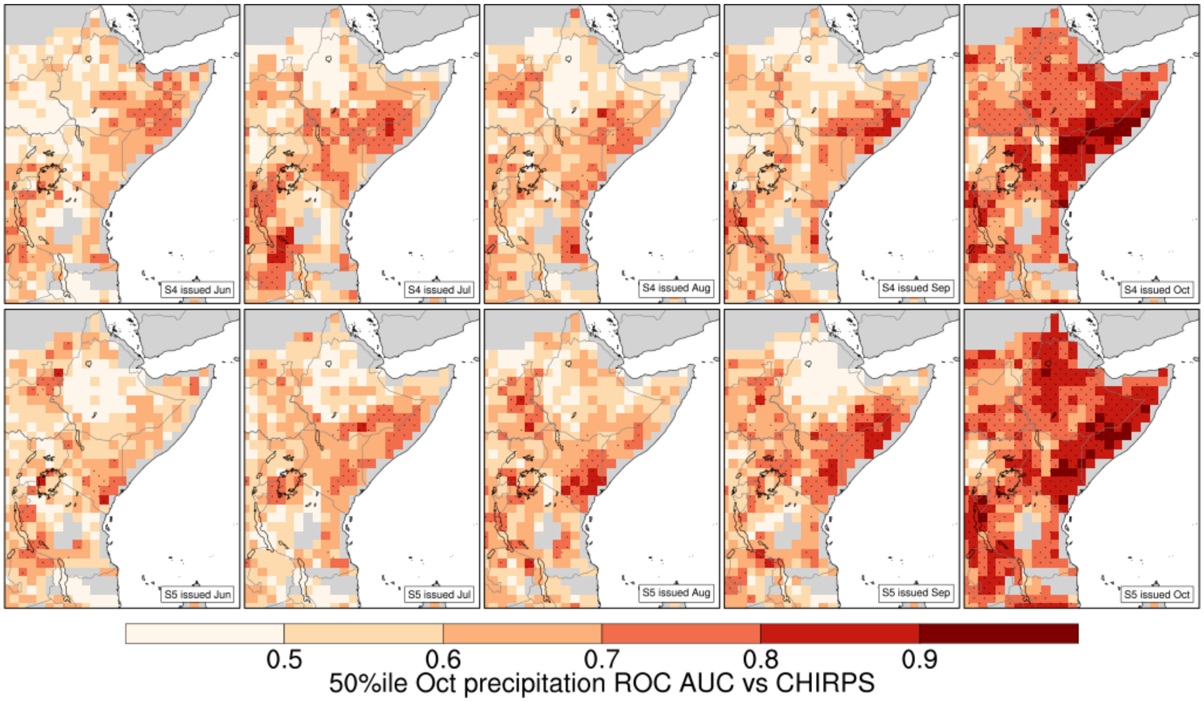

Figure 84. [ROC50Oct] ROC Area under curve for Oct: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

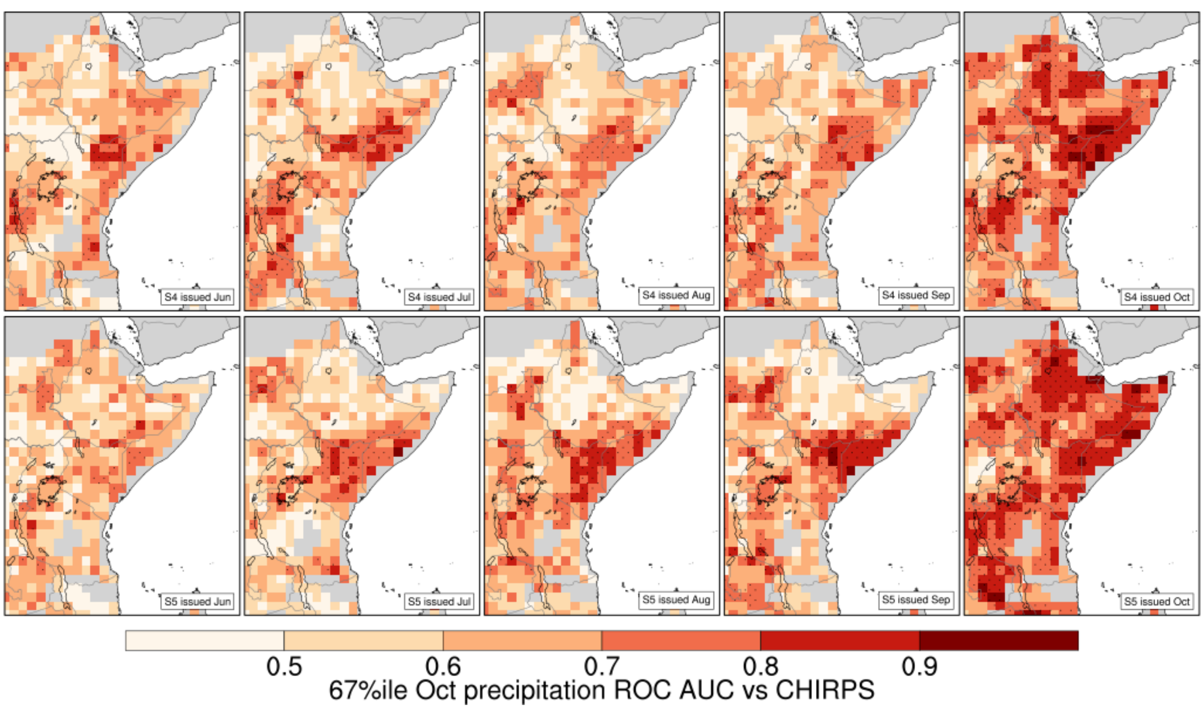

Figure 85. [ROC67Oct] ROC Area under curve for Oct: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

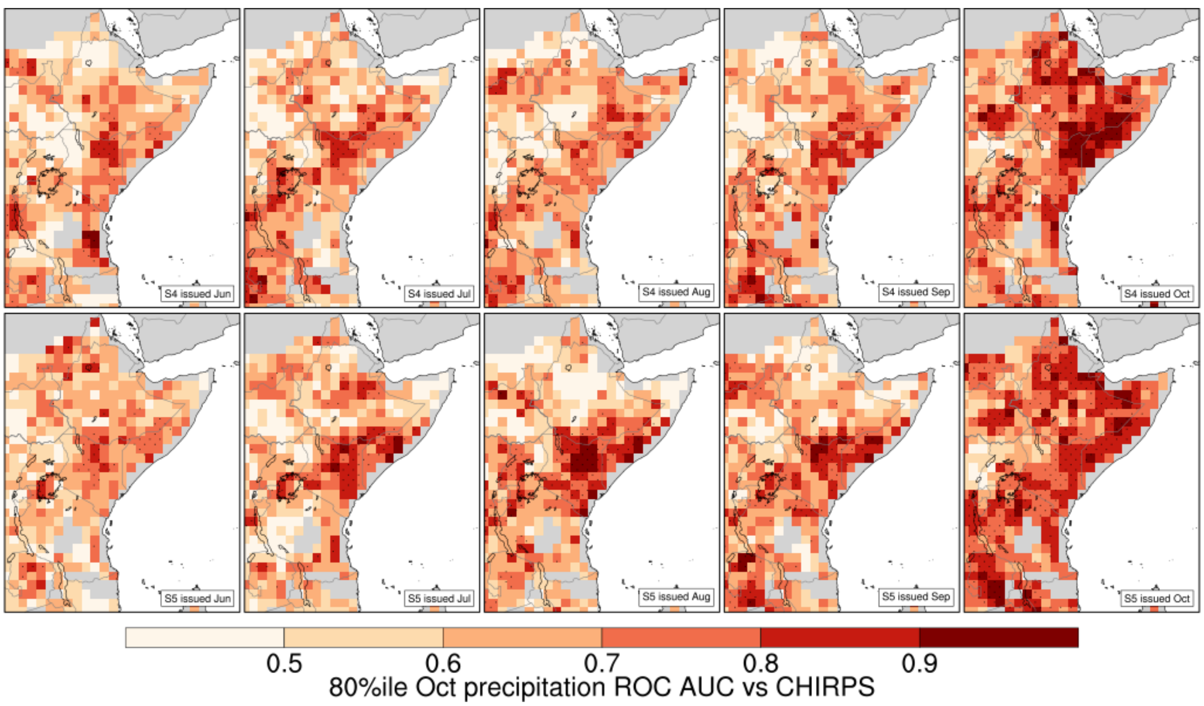

Figure 86. [ROC80Oct] ROC Area under curve for Oct: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

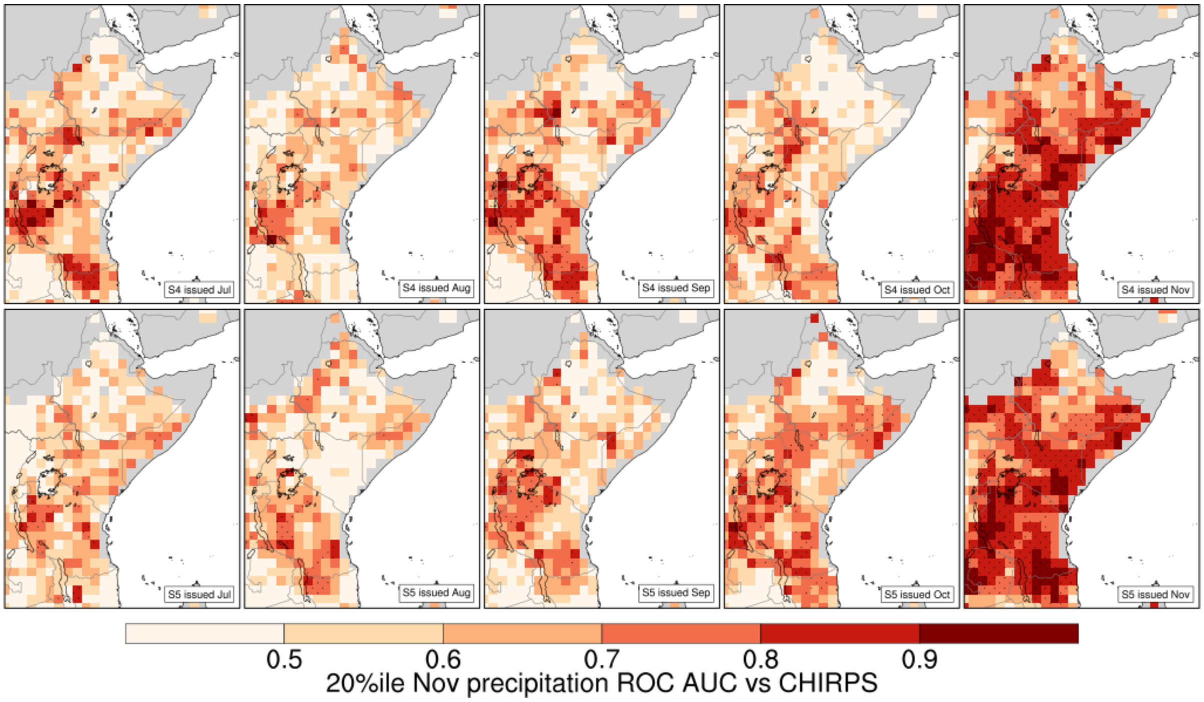

Figure 87. [ROC20Nov] ROC Area under curve for Nov: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

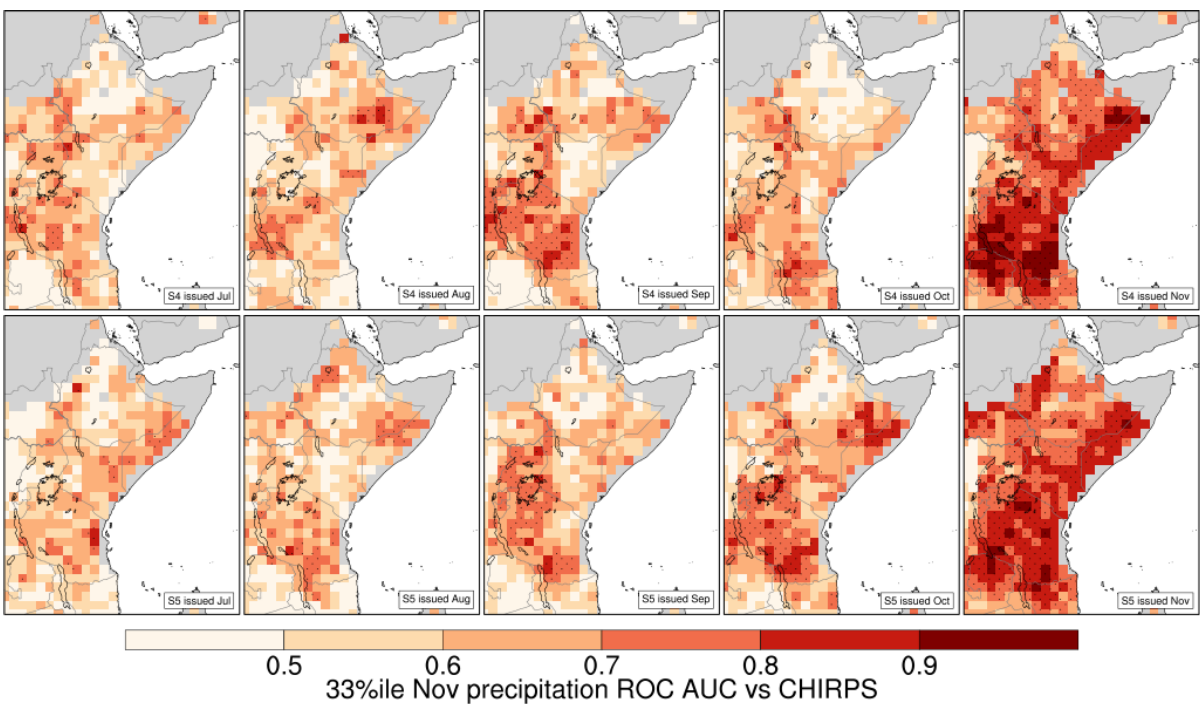

Figure 88. [ROC33Nov] ROC Area under curve for Nov: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

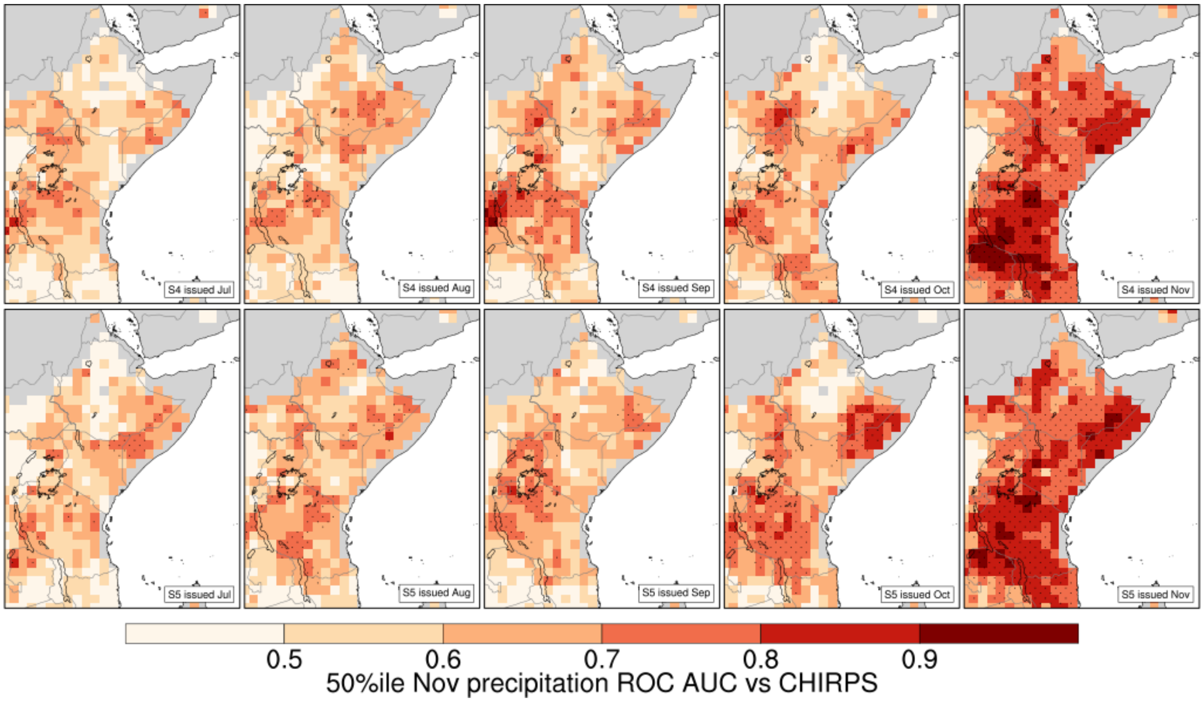

Figure 89. [ROC50Nov] ROC Area under curve for Nov: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

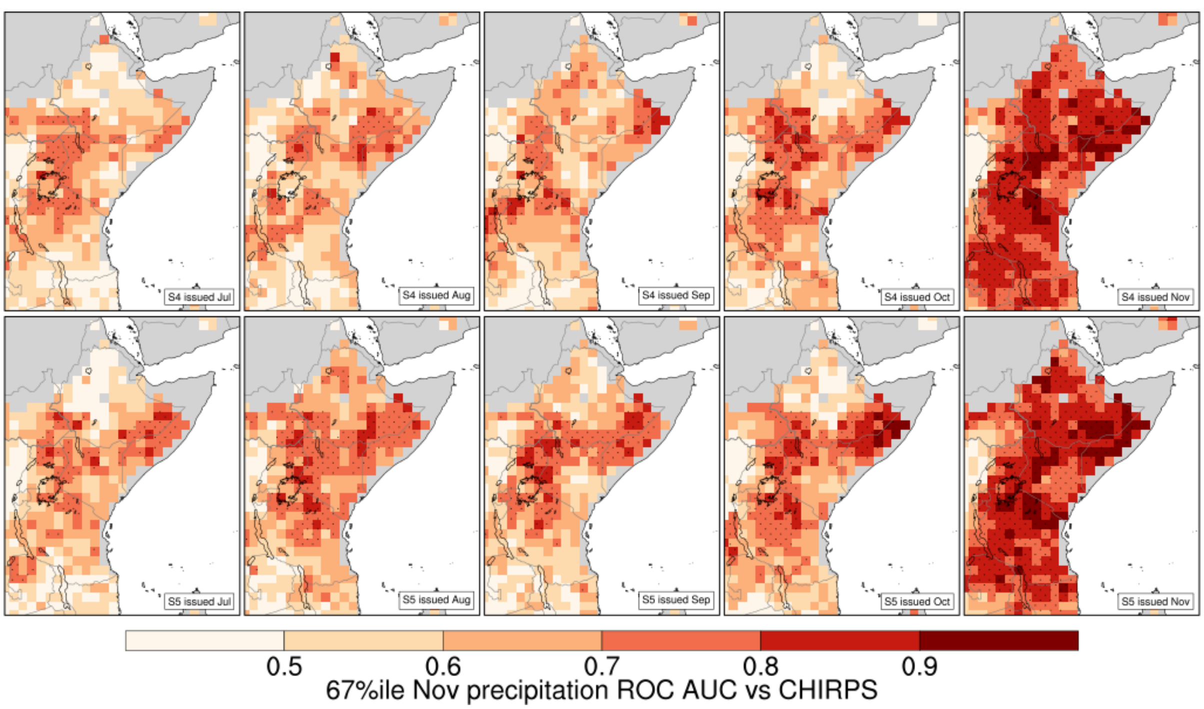

Figure 90. [ROC67Nov] ROC Area under curve for Nov: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

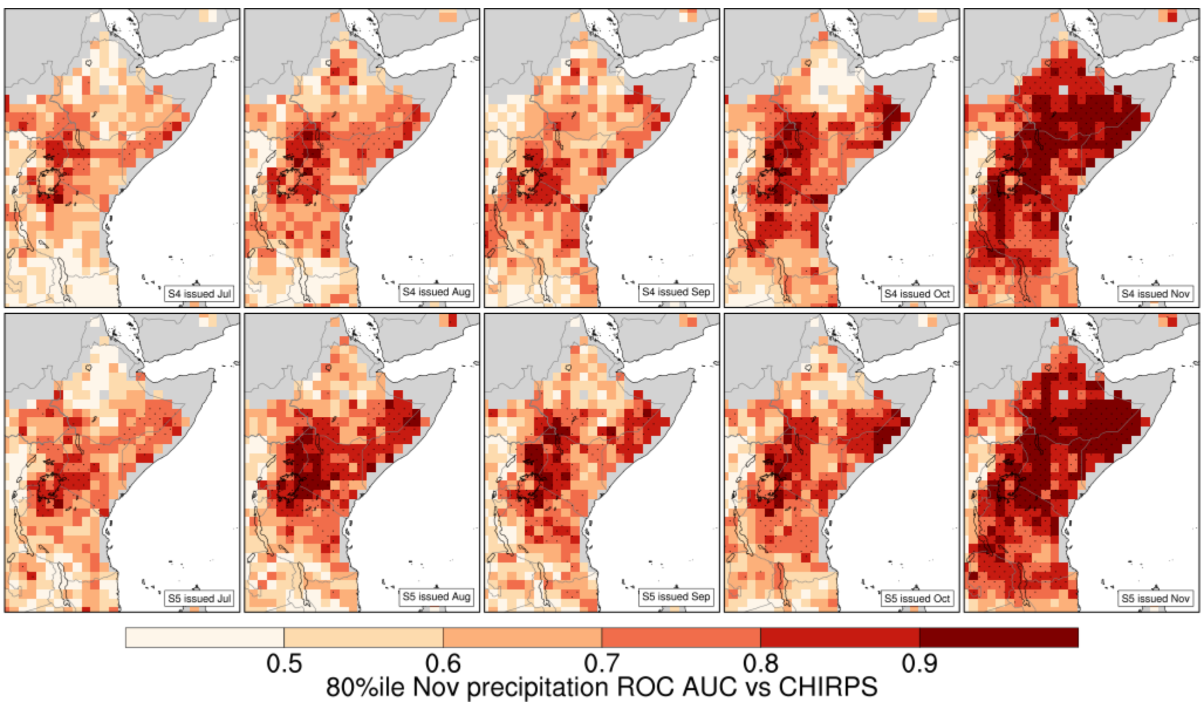

Figure 91. [ROC80Nov] ROC Area under curve for Nov: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

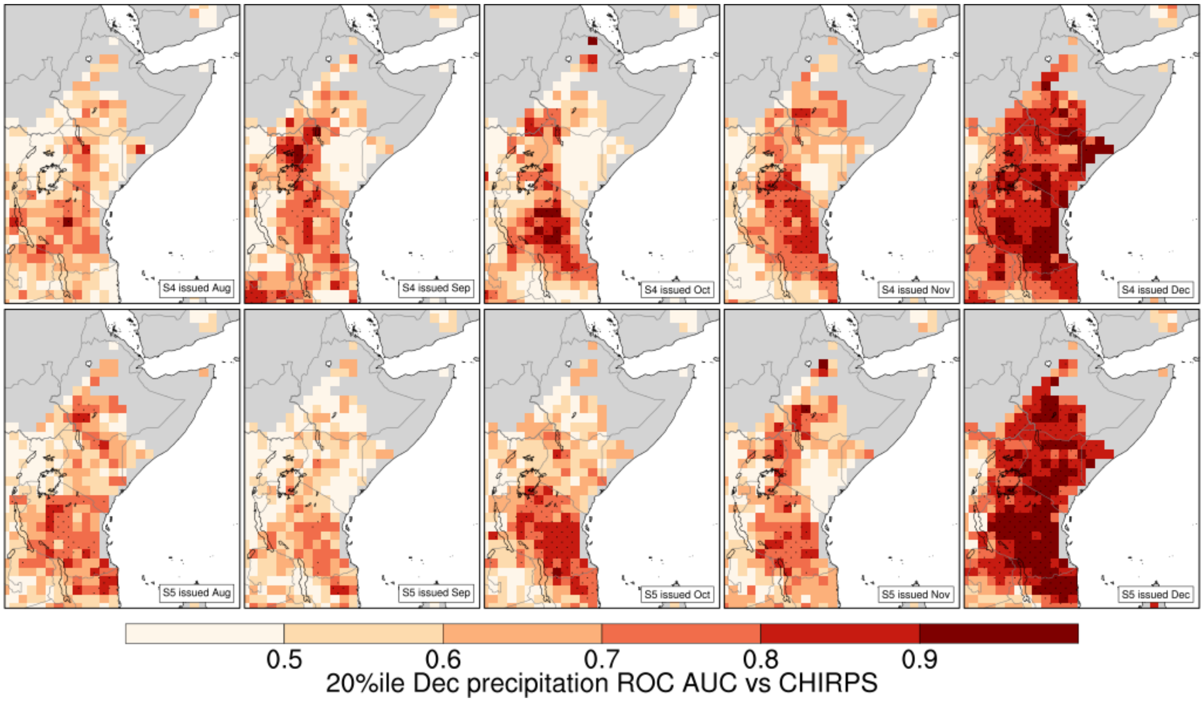

Figure 92. [ROC20Dec] ROC Area under curve for Dec: exceedance of 20%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

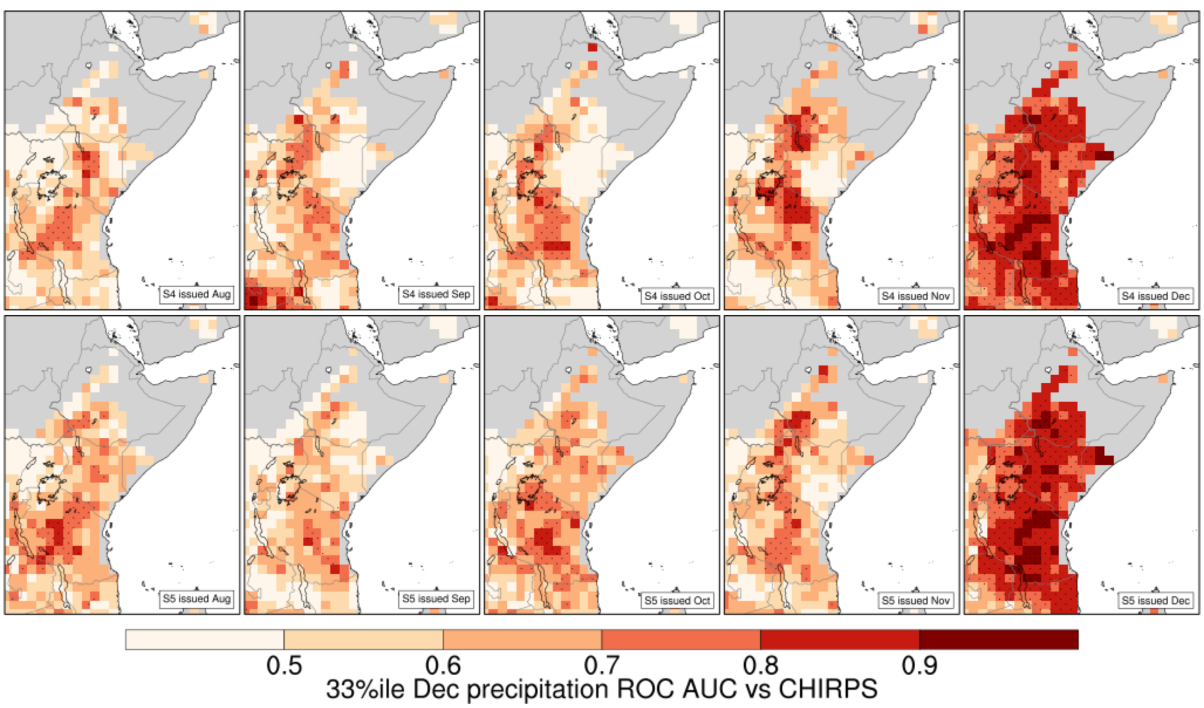

Figure 93. [ROC33Dec] ROC Area under curve for Dec: exceedance of 33%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

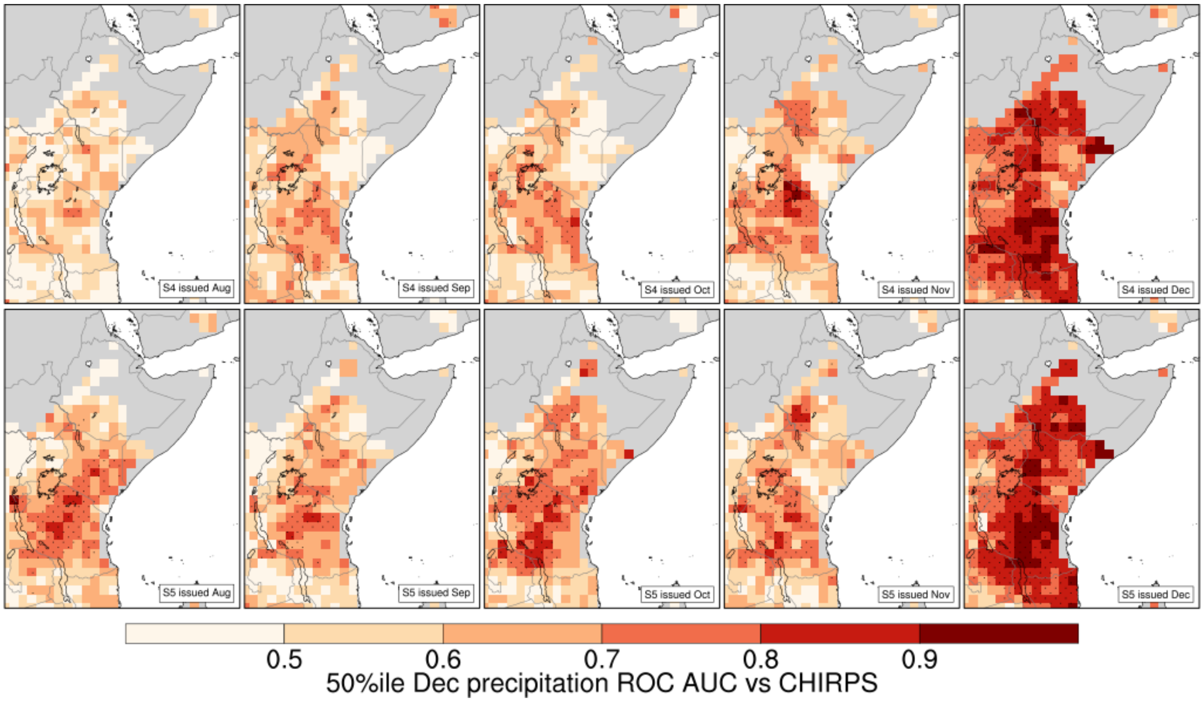

Figure 94. [ROC50Dec] ROC Area under curve for Dec: exceedance of 50%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

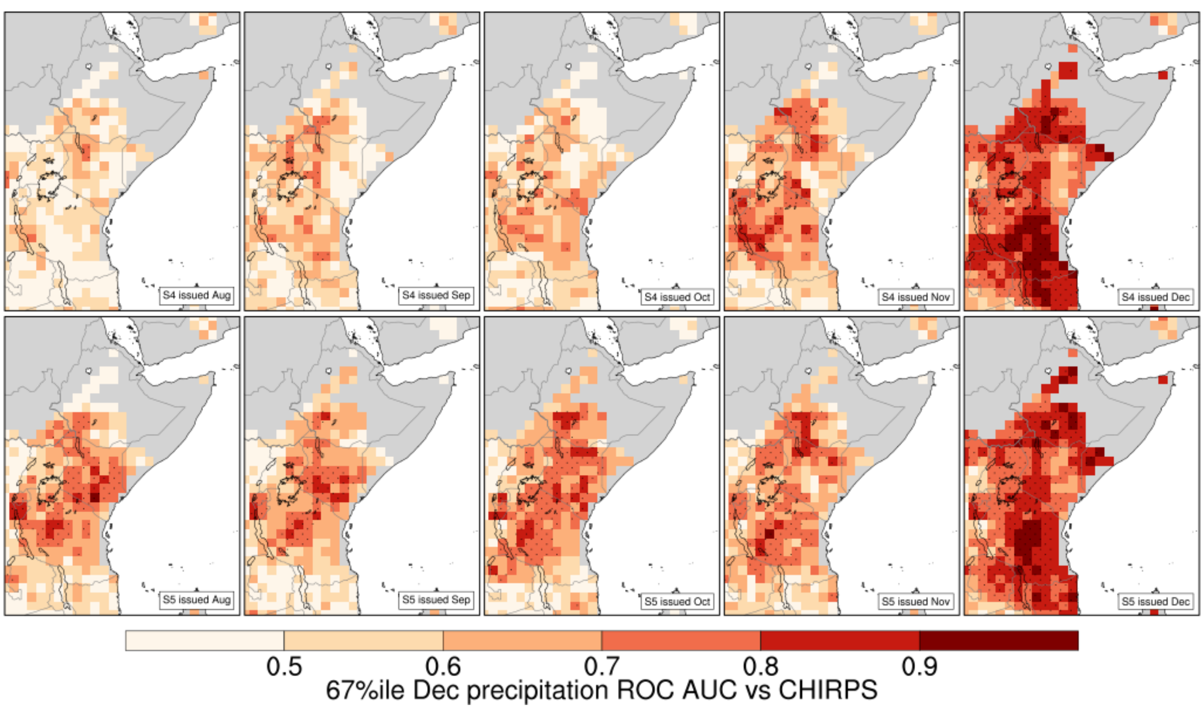

Figure 95. [ROC67Dec] ROC Area under curve for Dec: exceedance of 67%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

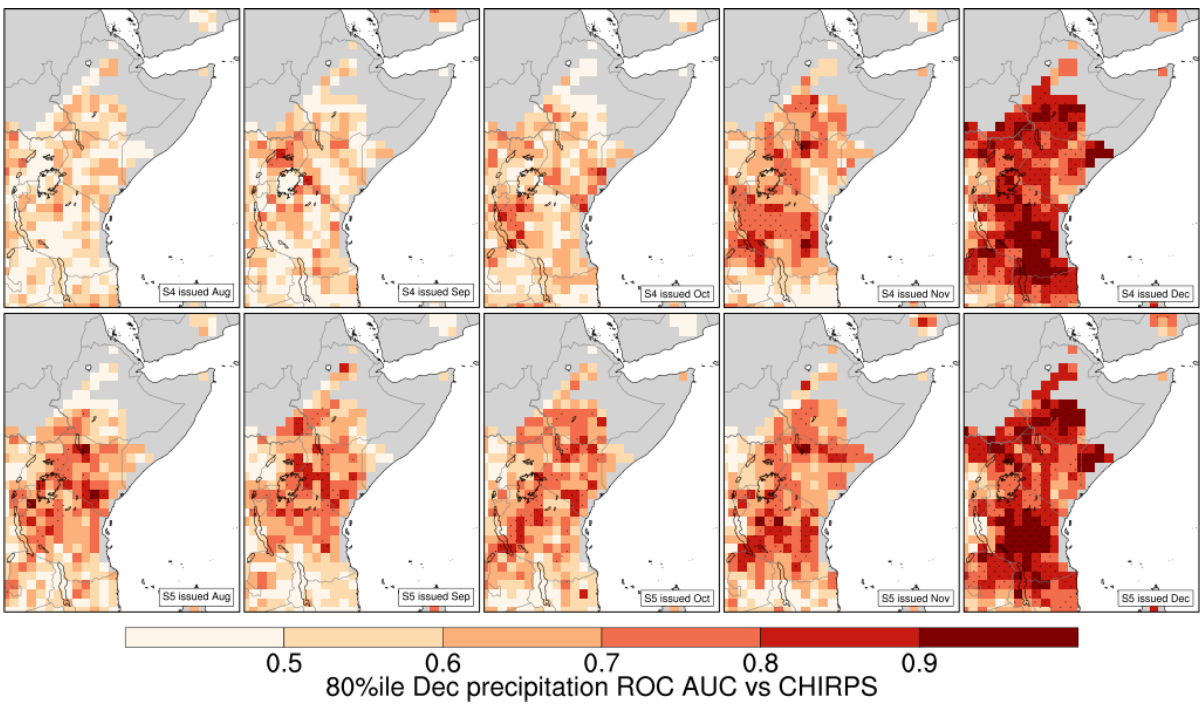

Figure 96. [ROC80Dec] ROC Area under curve for Dec: exceedance of 80%ile, for System 4 (top) and SEAS5 (bottom) precipitation vs CHIRPS. Stippling indicates correlations significant at the 95% level.

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