Growin: Modeling Ionospheric Instability Growth Rates During Solar Minimum and Giving Away the Code

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Abstract

Growin is a module that calculates the flux-tube-integrated linear Rayleigh-Taylor instability (grow)th rate of (i)o(n)ospheric irregularities is often used in the study of equatorial spread F(ESF). The Rayleigh-Taylor instability is often the prevailing explanation for the growth of plasma irregularities in the bottomside into plumes of depleted plasma, therefore a computation of its growth rate is valuable. This package includes many common approximations used in the computation of the Rayleigh-Taylor growth rate. Although not the focus of this discussion, Kelvin-Helmholtz instabilitiesfrom neutral wind shear below the bottomside F region are another source of plasma instability in the bottomside F region intended to be included in this package eventually.

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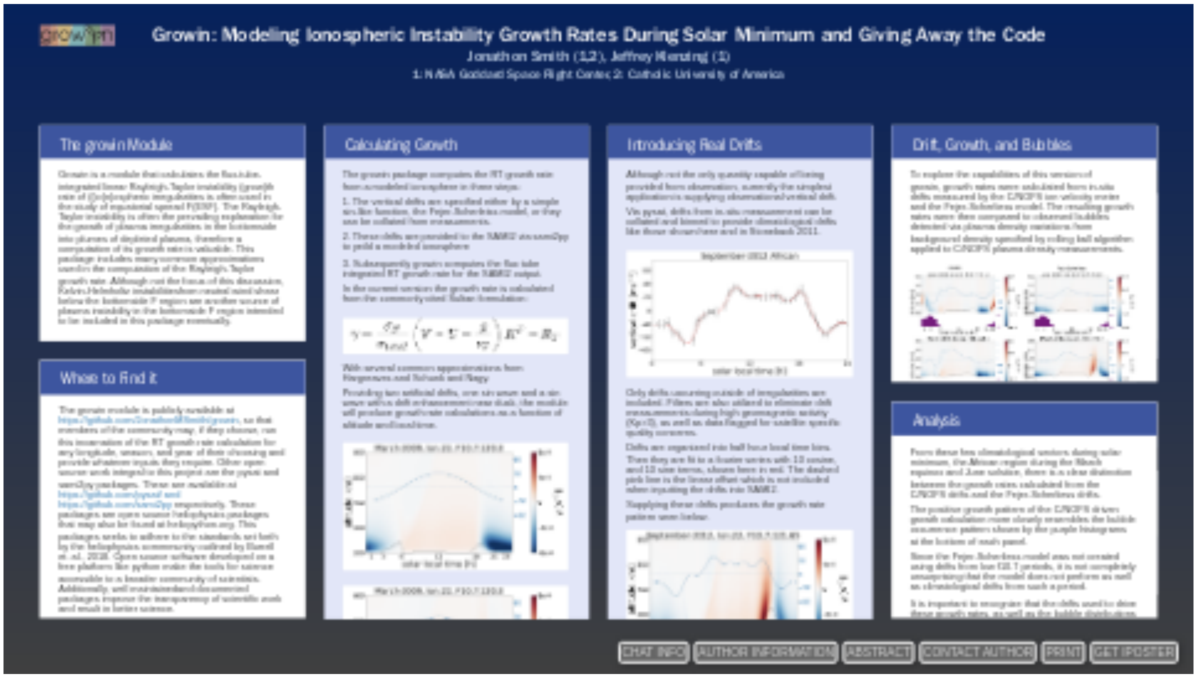

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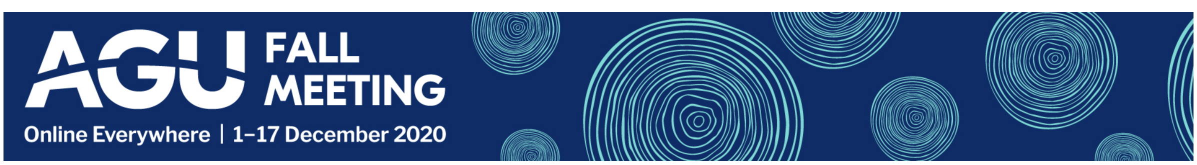


THE GROWIN MODULE

Growin is a module that calculates the flux-tube-integrated linear Rayleigh-Taylor instability (grow)th rate of (i)o(n)ospheric irregularities is often used in the study of equatorial spread F(ESF). The Rayleigh-Taylor instability is often the prevailing explanation for the growth of plasma irregularities in the bottomside into plumes of depleted plasma, therefore a computation of its growth rate is valuable. This package includes many common approximations used in the computation of the Rayleigh-Taylor growth rate. Although not the focus of this discussion, Kelvin-Helmholtz instabilitiesfrom neutral wind shear below the bottomside F region are another source of plasma instability in the bottomside F region intended to be included in this package eventually.

WHERE TO FIND IT

The growin module is publicly available at https://github.com/JonathonMSmith/growin (https://github.com/JonathonMSmith/growin), so that members of the community may, if they choose, run this incarnation of the RT growth rate calculation for any longitude, season, and year of their choosing and provide whatever inputs they require. Other open source work integral to this project are the pysat and sami2py packages. These are available at https://github.com/pysat/ and https://github.com/sami2py (https://github.com/pysat/ and https://github.com/sami2py/) respectively. These packages are open source heliophysics packages that may also be found at heliopython.org. This packages seeks to adhere to the standards set forth by the heliophysics commmunity outlined by Burrell et. al., 2018. Open source software developed on a free platform like python make the tools for science accessible to a broader community of scientists. Additionally, well maintainedand documented packages improve the transparency of scientific work and result in better science.

DOI 10.5281/zenodo.3678866 | coverage unknown | maintainability C | docs passing

CALCULATING GROWTH

The growin package computes the RT growth rate from a modeled ionosphere in three steps:

1. The vertical drifts are specified either by a simple sin-like function, the Fejer-Scherleiss model, or they can be collated from measurments.

2. These drifts are provided to the SAMI2 via sami2py to yeild a modeled ionosphere

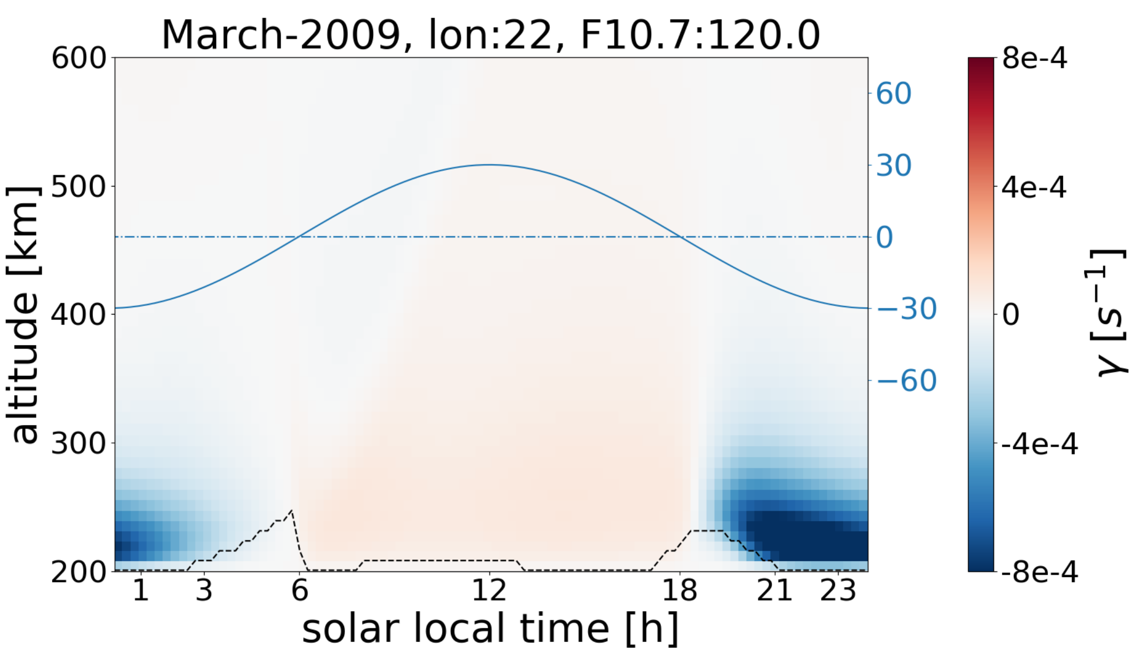
3. Subsequently growin computes the flux tube integrated RT growth rate for the SAMI2 output.

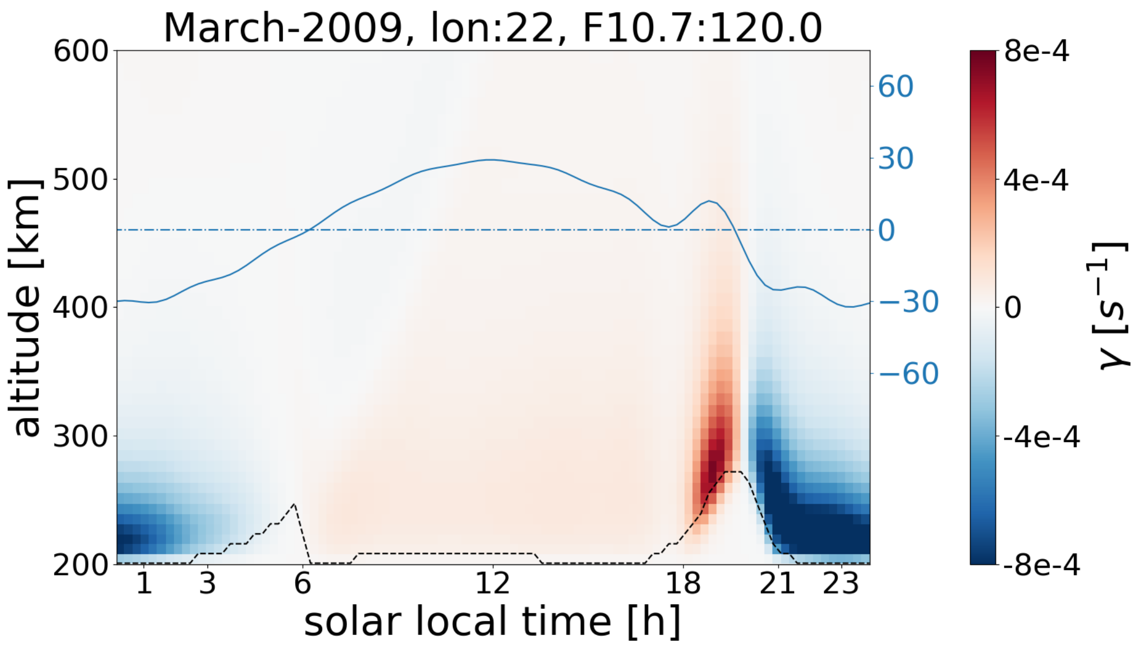
In the current version the growth rate is calculated from the commonly cited Sultan formulation:

$$\gamma = \frac{\sigma_F}{\sigma_{total}} \left(V - U - \frac{g}{\nu_F} \right) K^F - R_T$$

With several common approximations from Hargreaves and Schunk and Nagy.

Providing two artificial drifts, one sin wave and a sin wave with a drift enhancement near dusk, the module will produce growth rate calculations as a function of altitude and local time.





In these growth rate plots red indicates positive growth rates, or places where a seed perturbation is most likely to lead to a runaway RT instability. And blue indicates negative growth, or places where a seed perturbation is least likely to lead to a runaway RT instability.

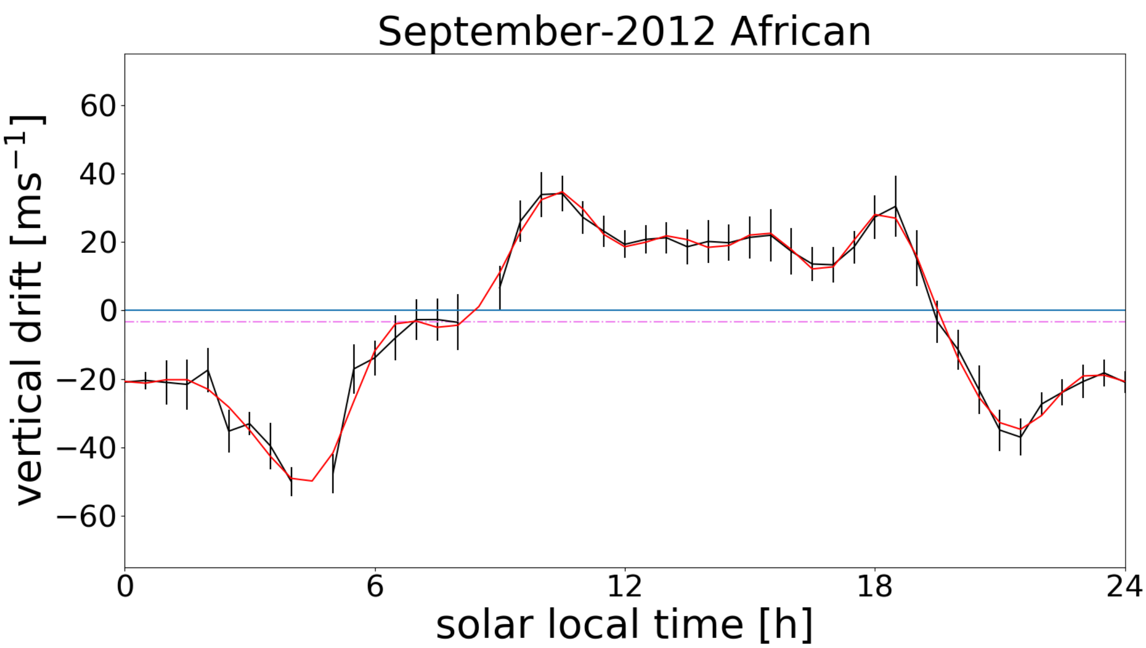
The blue horizontal line shows 0 m/s, and the blue curve is the vertical drift (axis labeled in blue in m/s).

Finally the dashed black line indicates an approximation of the bottomside F region by marking, for each local time, the maximum altitude gradient of the flux tube integrated electron density taken from SAMI2.

INTRODUCING REAL DRIFTS

Although not the only quantity capable of being provided from observation, currently the simplest application is supplying observational vertical drift.

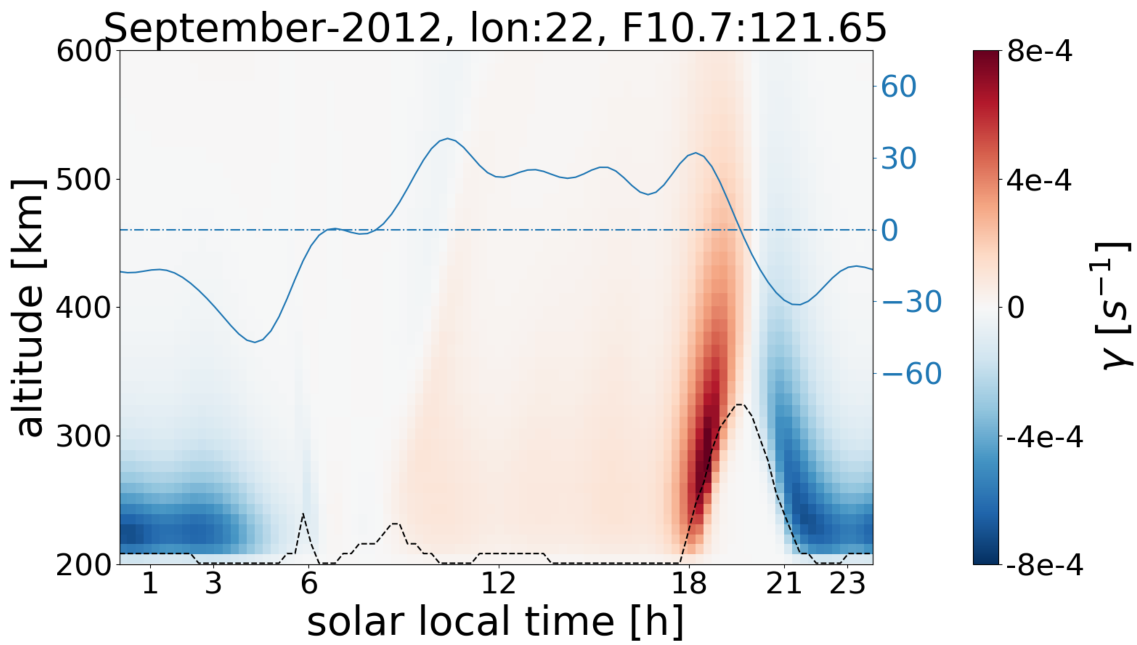
Via pysat, drifts from in-situ measurement can be collated and binned to provide climatological drifts like those shown here and in Stoneback 2011.



Only drifts uccurring outside of irregularities are included. Filters are also utilized to eliminate drift measurements during high geomagnetic activity (Kp>3), as well as data flagged for satellite specific quality concerns.

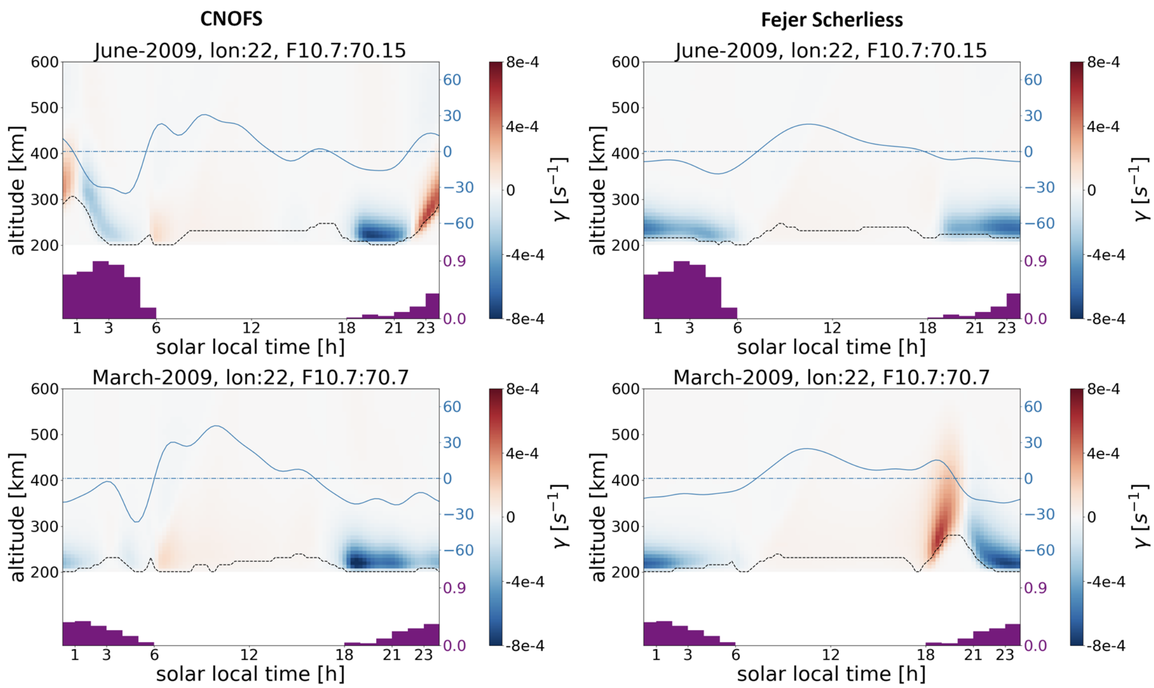
Drifts are organized into half hour local time bins. Then they are fit to a fourier series with 10 cosine, and 10 sine terms, shown here in red. The dashed pink line is the linear offset which is not included when inputting the drifts into SAMI2.

Supplying these drifts produces the growth rate pattern seen below.


September-2012, lon:22, F10.7:121.65
altitude [km]
600
500
400
300
200
solar local time [h]
1
3
6
12
18
21
23
60
30
0
−30
−60
8e-4
4e-4
0
-4e-4
-8e-4
γ [s^-1]

DRIFT, GROWTH, AND BUBBLES

To explore the capabilities of this version of growin, growth rates were calculated from in-situ drifts measured by the C/NOFS ion velocity meter and the Fejer-Scherliess model. The resulting growth rates were then compared to observed bubbles detected via plasma density variations from background density specified by rolling ball algorithm applied to C/NOFS plasma density measurements.



ANALYSIS

From these few climatological sectors during solar minimum, the African region during the March equinox and June solstice, there is a clear distinction between the growth rates calculated from the C/NOFS drifts and the Fejer-Scherliess drifts.

The positive growth pattern of the C/NOFS driven growth calculation more closely resembles the bubble occurrence pattern shown by the purple histograms at the bottom of each panel.

Since the Fejer-Scherliess model was not created using drifts from low f10.7 periods, it is not completely unsurprising that the model does not perform as well as climatological drifts from such a period.

It is important to recognize that the drifts used to drive these growth rates, as well as the bubble distributions are climatological, and so we cannot discern from these relationships alone that bubbles formed under the exact circumstances shown in one of these panels.

Bubbles also may develop slowly under the influence of small growth rates near dusk and rise slowly to the satellite altitude. However, a large growth rate does indicate an Ionospheric environment accommodating to plasma bubble development.

A more in depth exploration of the differences between these drifts and the performance of the growin module is currently in progress to be re-submitted for publication shortly.

AUTHOR INFORMATION

Jonathon Smith, Jeffrey Klenzing

ABSTRACT

A seasonal and zonal climatology of Rayleigh-Taylor growth rates during solar minimum and solar moderate conditions as a function of local time and altitude has been developed using open source data and software.
The *growin* python module utilizes other Heliophysics python modules to collate and process vertical plasma drift to drive the SAMI2 model and subsequently calculate the flux tube integrated Rayleigh-Taylor growth rate.
The process is repeated for two different types of drift inputs: the Fejer-Scherliess model and measured drifts from C/NOFS.
These growth rates are compared to bubble occurrence frequencies obtained from a dataset of bubbles detected by the C/NOFS satellite.
There is agreement between periods of strong positive instability growth and high frequencies of bubble occurrence in both low and moderate solar activity conditions when using C/NOFS drifts.
Fejer drifts are only in agreement with bubble occurrence frequencies during moderate solar activity conditions.
Bubble occurrence frequencies are often above 25% even when growth rates in the bottomside F region are negative.
The climatological nature of the growth rates discussed here begs further study into the day-to-day variability of the growth rate and its drivers.