5. 生态系统过程模型的简要叙述。

面对众多的生态系统过程模型(Process-based ecosystem model), 按照模型的应用领域和研发背景进行分类比较实用(Shugart, 1990; Hutt *et al.*, 1998; Mäkelä *et al.*, 2000; Landsberg, 2003; Morales *et al.*, 2005).

(Ⅰ) 强调植物生理的作物生产模型

用计算机模拟光合作用、蒸腾作用等, 最先出现在人工的农田生态系统, 而非自然生态系统(de Wit, 1965; Breman *et al.*, 1970). 在集成电路计算机发展起来之前, 计算机模型就开始被用于模拟作物生产(Bouman *et al.*, 1996). 随着计算机技术的进步, 作物生产模拟的工作逐渐成为一个热点内容(de Wit, 1978). 即使时至今日, 这个领域仍旧保持着旺盛的生命力(Yin and van Laar, 2005; Long *et al.*, 2006). 我国的王天铎, 高亮之, 黄耀等人及其团队在这方面做了很多有影响力的工作(高亮之等, 1994; Yu and Wang, 1998; Huang *et al.*, 2009).

(Ⅱ) 基于个体的生态学模型簇

JABOWA 模型的出现, 开启了基于个体生态学模型簇(Individual-Based Model, IBM)的新时代(Botkin *et al.*, 1972; DeAngelis and Grimm, 2014). 之所以称之为模型簇, 主要是因为这类模型数量比较多, 比如 Grimm *et al.*, (1999)简单回顾了过去十年的 IBM 模型, 竟有 50 个之多. Le Roux *et al.*, (2001)举出 27 个例子,这些只是冰山一角. 这一类模型在生态学领域流行很广(Liu and Ashton, 1995; Pacala *et al.*, 1995; Pacala *et al.*, 1996), 并一直在不断的进展(Fyllas *et al.*, 2014). 葛剑平(1996)在其专著中, 对这部分模型有阶段性的总结.

(III) 陆面过程模式

陆面过程模型主要是用来给大气模型提供陆面参数化结果, 代表性的有 SiB (Simple Biosphere model, Sellers *et al.*, 1986), BATS (Biosphere-Atmosphere Transfer Scheme, Dickinson *et al.*, 1993), LSX (Land-surface-transfer scheme, Pollard and Thompson, 1995), LSM (Land surface model, Bonan *et al.*, 1996)等. Wang *et al.*, (2002)认为陆面模式可以分为三个世代, 呈递进式演进.

(Ⅳ) 植物生理生态与微气象类过程模型

1980s, 光合作用的生化模型和气孔导度模型相继问世(Farquhar *et al.*, 1980; Jarvis, 1976; Ball *et al.*, 1987), 使叶片过程可以相对准确的被模拟, 进而促使探求从叶片到冠层的尺度扩展成为热点(Kim and Verma, 1991; Leuning *et al.*, 1995; Lloyd *et al.*, 1995). 尺度扩展的方案常用的有三种(有些归为两种): 大叶模型(Big-leaf), 双叶模型(Sun-shade)和多层模型

(Multi-layer) (De Pury and Farquhar, 1997). 经比较, 双叶模型被认为是精确性和简洁度结合较好的方案(Wang and Leuning, 1998). 基于植物生理生态学的生态系统过程模型比较多, 比如MAESTRA (Wang and Jarvis, 1990), SPA (Soil plant atmosphere continuum, Williams *et al.*, 1996), Sinclair *et al.*, (1976), 罗毅等(2001)的工作.

值得一提的是, 1950s~60s微气象学领域发展迅速, 湍流物质传输的核心理论得以成功构建, 跟植被遥感紧密联系的冠层辐射传输也进展飞速, 催生了一些新模型. 比如, Cupid (Norman *et al.*, 1982; Jarvis *et al.*, 1985)以及Waggoner and Reifsnyder (1968)的工作等.

(Ⅴ) 生物地球化学模型

可以归并到生物地球化学类的生态系统过程模型很多, 比如CENTRURY (Parton *et al.*, 1987), Biome-BGC (前Forest-BGC, Running and Coughlan, 1988), TEM (Terrestrial Ecosystem Model, Raich *et al.*, 1991; Melillo *et al.*, 1993), PnET (Aber *et al.*, 1992); FinnFor (Kellomäki *et al.*, 1993), DNDC (Li *et al.*, 1994); CEVSA (Cao and Woodward, 1998); CenW (Kirschbaum *et al.*, 1999), BEPS (Liu *et al.*, 1997; Chen *et al.*, 1999), EPPML (张娜等, 2001), Sim-CYCLE (Ito *et al.*, 2002), TECO (Weng and Luo, 2008)等.

(Ⅵ) 生物地理模型

生物地理模型是在全球植被气候关系工作的基础上发展起来的(Holdridge, 1967; Lieth, 1972; Woodward, 1987), BIOME系列模型对生物地理模型的推动很大(Prentice *et al.*, 1992; Haxeltine and Prentice, 1996), CASA模型则跟遥感结合得很好(Potter *et al.*, 1993). Ji *et al.*, (1995)的AVIM模型, 在中国比较常用. 这类模型与陆面模式以及生物地球化学模型进一步的融合, 最终形成了动态植被模型(Woodward *et al.*, 1995).

(Ⅶ) 动态植被模型

动态植被模型(Dynamic global vegetation model, DGVM)是在IGBP计划的框架下推动(VEMAP Members, 1995), 在前面几种模型的基础上发展起来的. DGVM模型较多, 使用比较多的有IBIS (Integrated Biosphere Simulator, Foley *et al.*, 1996), ORCHIDEE (ORganizing Carbon and Hydrology In Dynamic EcosystEms, Krinner *et al.*, 2005), LPJ (Lund-Potsdam-Jena, Sitch *et al.*, 2003), JULES (Joint UK Land Environment Simulator, Best *et al.*, 2011), JeDi-DGVM (The Jena Diversity-Dynamic Global Vegetation Model, Pavlick *et al.*, 2013). 近年来, 在动态植被模型基础上发展起来的植被种群模型(Vegetation dymography model)越来越受重视, 或可能是将来过程模型发展的方向之一(Fisher *et al.*, 2018).

(Ⅷ) 混合模型

不同类别模型之间相互交融，形成混合模型(Hybrid model). 事实上，以上模型的分类是相对的，不同模型之间常常有交集. 差异比较大的模型，二者边界明显，交集很少. 研究人员为了发挥差异比较大的不同类别模型各自的优点，通过跨类别的融合，进而形成了混合模型. 其中典型的有 Hybrid (Friend *et al.*, 1997), 3-PG (Physiological Principles in Predicting Growth, Landsberg and Waring, 1997), TRIPLEX (Peng *et al.*, 2002), ED (Ecosystem demography model, Moorcroft *et al.*, 2001; Medvigy *et al.*, 2009). 事实上，ED 也是植被种群模型的一种.

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